Program of scientific activity Experimental Physics Division (EPD) for period 2013-2017

a) **Scientific and Technical Contractual (Thematic) Activity Application for State Budget Funding - 2013**

1) Search for rare channels of the fission of heavy nuclei
2) Very High Energy Gamma-Ray Astrophysics with IACT

b) Research directions of division

The main scientific activity of EPD and its research profile:

- High energy experimental physics- collaboration with CERN-LHC (ATLAS, ALICE, CMS)
- Structure of hadrons and electromagnetic interaction properties with high energy electrons and photons - collaboration with JLab (Halls A, B , C, D)
- Fission and fragmentation of nuclei with real and virtual photon beams - collaboration with MAX-lab
- Hadron physics based on HERMES and H1 data , OLYMPUS experiment - collaboration with DESY
- Fragmentation mechanisms in high energy nuclear interactions collaboration with JINR (BECQUEREL)
- Search of rare processes in underground laboratory of Avan salt
- Very high energy gamma ray astrophysics - collaboration with HESS , CTA
- Low energy nuclear physics research on the base of ANSL's accelerator complex (electron linac, synchrotron) - cluster structure of excited states of light nuclei (He, Li, Be) and photonuclear reactions including ^{12}C into three alpha
- Investigation of two-cluster (quasi- deuteron) nuclear structure in medium weight and heavy nuclei in photonuclear reactions at energies up to 70 MeV
- Low energy proton-nucleus interactions using the external beam of the Cyclone-18
- Methodic studies: plastic scintillator, substrates for nuclear targets, NaJ(Tl), neutrons detector, microstripsilicone detectors, RF phototube, low-pressure MWPC
- Synthesis, research and application of new derivatives of chitosan

Head of EPD A.Sirunyan

Two thematic financing research themes of Armenian State Committee of Science :

1) **Search for rare channels of the fission of heavy nuclei**
2) **Very High Energy Gamma-Ray Astrophysics with IACT**

The budget theme **N10-27/4 "Search for rare channels of the fission of heavy nuclei"**

1.1. The abstract and the work content

It is foreseen to perform first investigations of the energy spectrum of γ-radiation in the relatively high-energy region (E_γ> 2.5 MeV) caused by the spontaneous fission of the ^{238}U nucleus. The search for narrow structures in that region allows one to estimate the yields (or their upper limits) of light unstable nuclei – the products of unobserved earlier forms of the ^{238}U natural radioactivity, namely, the ternary fission or the cluster radioactivity. Similar measurements will be also performed for the delayed γ-radioactivity caused by the production of unstable light nuclei in the proton-induced fission of ^{209}Bi at18 MeV. The measurements will be performed with the help of a low-background setup located in the Avan salt mine.

1.2.The work content

a) Study of the γ-radiation caused by the spontaneous fission of ^{238}U

As it is known, all nuclides with atomic number greater than Z=83 (corresponding to bismuth) are unstable. The overwhelming fraction of them isα-radioactive. Heavier nuclei, starting from thorium (^{232}Th, Z=90) can also, with a much smaller probability, disintegrate spontaneously into two heavy fragments of compatible masses (binary fission) or, yet rarely, into two heavy and one light fragments (ternary fission). An intermediate position between α- decay and spontaneous binary fission is occupied by another seldom disintegration mode- the cluster radioactivity (or cluster decay) when the disintegration of the parent nucleus is very asymmetric, resulting in a heavy fragment and a light nucleus (cluster) heavier than α-particle but lighter than a typical binary fission fragment.
All said disintegration processes induce γ- radiation. For the α-decay chain, the energy of associated gammas is rather restricted; for example, for the parent ^{238}U nucleus, E_γ does not exceed 2.5 MeV. On the other hand, the energy spectrum caused by the fission of ^{238}U is much wider. The only measurements of this spectrum are performed [1] for the range of $8 < E_\gamma < 20$ MeV (revealing an exponentially falling behaviour), while the more interesting range of $2.5 < E_\gamma < 8$ MeV is not yet explored. This range is mainly contributed by delayed gammas associated with the decay of β-unstable daughter nuclei, including light nuclei from the ternary fission or very asymmetric binary fission. These β-radioactive light nuclei can be identified by the associated inherent γ-radiation.
Presently, the cluster radioactivity (i.e. very asymmetric binary fission) is observed for several isotopes of elements with Z=87-96 (i.e. from francium to curium) and for following kinds of the cluster radioactivity corresponding to the emission of ten light nuclei: ^{14}C, ^{20}O, ^{23}F, ^{22}Ne, ^{24}Ne, ^{26}Ne, ^{28}Mg, ^{30}Mg, ^{32}Si and ^{34}Si (see references in [2]).
Hitherto no cluster radioactivity or ternary fission is observed for ^{238}U. Moreover, the lightest nucleus registered in the spontaneous fission of ^{238}U is the ^{83}Kr nucleus, with the ejection probability of $(7\pm2)\cdot10^{-4}$ per fission [3]. In this Project as it described below, a compatible or better sensitivity **(**about $10^{-3} \div 10^{-4}$ per fission**)** will be achieved in search for several β-unstable light nuclei with associated γ-radiation in the region of E_γ> 2.5 MeV, where no γ-radiation from the α-decay chain is expected. These nuclei-candidates to a new kind of cluster radioactivity or to the light product of the ternary fission of the ^{238}U nucleus are listed in Table1, along with the

half-life of their β-decay, as well as the energy of the associated high-energy (E_γ> 2.5 MeV) γ-quanta.A reliable registration of any of the listed γ-lines will mean the establishment of a new kind of the cluster radioactivity or the ternary fission of the ^{238}U nucleus. Otherwise, the upper limits for the emission probabilities for the each light cluster will be extracted from the measured γ- spectrum.

Table 1. The β-unstable light products of the ^{238}U fission, the half-life of β-decay and the energy of associated γ-quanta with comparatively large emission probability.

The fission product	Half-life	E_γ (KeV)
^{16}N	7.1 s	6129
^{22}O	2.2 s	3710; 3199
^{24}Na	15 h	2757
^{37}S	5.1 m	3103
^{49}Ca	8.7 m	3084

b) Study of the γ- radiation caused by induced fission of ^{209}Bi

The mass and charge distributions of the products of heavy nuclei fission (both spontaneous and induced) are main observables which reflect the underlying nuclear effects and mechanisms governing this process. For the case of induced fission, the relative importance of different mechanisms varies with the projectile energy $E_{p.}$ This leads to a significant E_p- dependence of the fragment mass and charge distributions (see e.g. [4,5,6,7]). For a deeper insight into the complex nature of the induced fission processes, detailed data are needed in as wide as possible E_p- range (including energies around the Coulomb barrier). These data are also necessary for improvement of various simulation codes related to different applications, such as the radiation protection, nuclear vast utilization and so on (see [8] and references therein).
We propose to include in this Project the exploration of he induced fission of the ^{209}Bi nucleus, as a part of systematical investigations of proton-induced heavy-nuclei fission processes at near- (and sub-) Coulomb barrier energies below 18 MeV – the energy region where the data on the proton-induced fission are rather scarce (see [8] for data compilation). We choose the ^{208}Bi nucleus to start said systematical investigations for the following reasons: i) ^{209}Bi is the heaviest stable nuclei in the Nature; ii) the absence of its natural radioactivity make easer the identification of gammas (at E_γ> 500 KeV) associated with the proton-induced fission; iii) there are no available data concerning the proton-induced fission at E_γ< 30 MeV.
The experiment will be performed at several energies below 18 MeV. The spectrum of the delayed gammas from the proton-irradiated bismuth target will be measured and the γ- lines corresponding to the β- radioactive products (with a half-life exceeding several hours) of the ^{209}Bi disintegration will be looked for, including the fission products already observed at higher energies (E_p = 30÷160 MeV) [9,10], such as ^{95}Zr, ^{95}Nb, ^{110m}Ag, ^{123}Te, ^{134}Cs, as well as light products (with A < 50), such as ^{24}Ne, ^{28}Mg, ^{42}K, ^{47}Ca, ^{46}Sc, ^{48}V, not yet observed in proton-bismuth interactions and being candidates to the cluster decay or to the ternary fission of the compound ^{210}Po nucleus (resulting from the proton capture by ^{209}Bi). The associated γ- radiation energies for these light nuclei are collected in Table 2.

Table 2.The β-unstable light products of the of the proton-induced ^{209}Bi fission, the half-life of the β-decay and the energy of associated γ-quanta with comparatively large emission probability.

The fission product	Half-life	E_γ (KeV)
^{24}Na	15 h	1369; 2754
^{28}Mg	20.9 h	1342

^{42}K	12.4 h	1524
^{46}Sc	83.8 d	889; 1120
^{47}Ca	4.5 d	1297
^{48}V	16 d	983; 1312

1.3.The work character and anticipated results

For the realization of both tasks, mentioned in sections 1 and 2, we'll use the low background setup of the underground experimental hall which is placed in the Avan salt mine on the depth of 660 m w.e. For now this setup consist of two low-background Ge detectors (each of about 0.6 kg) surrounded by passive and active shielding to suppress the background caused by environmental rock and cosmic muons. The resolution of both detectors is about 6 keV for the 2615 keV gammas. This allows to perform a reliable identification of γ-radioactive isotopes.
For the investigation of the gamma-radiation caused by spontaneous fission of the ^{238}U nucleus it's supposed to place uranium sample close to the detectors' system. The previous experimental estimations of the registration efficiency ξ (which includes both averaged acceptance and probability of full absorption in detector) for 662 KeV^{137}Cs gamma peak is about 0.01. Taking into account this value as well as a detection system geometry, we anticipate for Eγ ~ 4 MeV the efficiency ξ = 0.001. This value is used for the further estimations given in section 4. Detailed measurements of efficiencies for different Eγ (and source positions) we are going to perform in the nearest future. Search for fragments listed in Table 1 requires long-term measurements because of a low values both of the expected partial yields, probability for spontaneous ^{238}U fission, registration efficiencies of gammas with the listed energies.
Searching for light products of the fission of ^{209}Bi nuclei induced by protons will be performed by the same setup after irradiation of bismuth target by cyclotron protons. Thetransportation time of bismuth sample from the cyclotron house to the underground laboratory is about 2-3 hours. So, we can investigate all the fragments listed in Table 2.
It's supposed to perform complementary measurements for investigation of the γ-radiation caused by the spontaneous fission of ^{238}U nuclei in a wide energy region using large NaI(Tl) detector but much better than for liquid scintillator which was used in earlier measurements. The possibility of an implementation of our NaI(Tl) detector depends on its level of internal radioactivity that will be investigated by us experimentally in the low background conditions.
It should be mentioned that our team has an experience in the low-background experiments. We have performed in YerPhI underground laboratory together with ITEP (Moscow) the experiment in which the first (in the world) observation of two-neutrino double beta decay of ^{76}Ge was made, and the most stringent limit on half-life of neutrinoless double beta-decay in this germanium isotope was set [11]. We participated also in others low-background experiments (such as IGEX, and GEMMA).
It is foreseen, that the experimental data on the uranium spontaneous fission (SF) will be collected using a sample containing one kg of ^{238}U. With the ^{238}U half-life $T_{1/2} = 4.468\cdot10^9$ yand SF probability W(SF) = $5.5\cdot10^{-7}$, one expects about $2.2\cdot10^8$ SF/y. With this one-year statistics, a scan of the associated γ-spectrum will be performed, searching for narrow lines quoted in Table 1. If the yield of a light nucleus listed in Table 1 is around $5\cdot10^{-4}$ per fission (i.e. slightly less than for the lightest fragment ^{83}Kr hitherto observed in the SF of ^{238}U), then taking into account the setup efficiency (see Section 3), the intensity of the associated gammas registered in the high resolution Ge detector will be 220/y. For comparison, the preliminary measurements shows that the background count in Ge detector for the region of (3÷7) MeV doesn't exceed 5/y/10 KeV. The implementation also of the NaI(Tl) detector (if successful) will significantly (by 1÷ 2 order of magnitude) improve the quoted statistics.
Let us now consider the proton-induced fission reaction ^{209}Bi(p,f). According to the experimental data (available for the region of E_p> 30 MeV) [8], the cross section of this reaction in the energy

interval of a few tens of MeV strongly depends on E_p, decreasing from $\sigma(p,f) \sim 2 \cdot 10^{-26}$ cm^2 at $E_p = 50$ MeV to about $2 \cdot 10^{-27}$ cm^2 at $E_p = 30$ MeV. One can expect, that at energies $E_p < 18$ MeV the cross section σ(p,f) will be much (by a few orders of magnitude) smaller, probably being around10^{-31} cm^2. With this cross section, a large statistics of fission reaction is expected owing to the high intensity (100μA) of the C-18 proton beam. For example, with the 100μm thick Bi target, the number of expected fissions is equal to 16000 per second or, after a 5 hours of exposition, to about $3 \cdot 10^8$. This will provide a sensitivity of about 10^{-4} /fission for registration, with the help of the Ge detector, the γ-radioactive products of the ^{209}Bi induced fission.
Summarizing, the fulfillment of this Project will allow one to extract first estimations on the yields (or their upper limits) of several radioactive light nuclei produced in rare processes of the spontaneous fission of ^{238}U and near-barrier proton-induced fission of ^{209}Bi, such as the ternary or very asymmetric binary fission. The obtained data could be useful for testing the relevant theoretical models concerning heavy nuclei fission.

References

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1.4.Work schedule

1.4.1. Determination of the efficiency of the germanium detector
Date: 01.07.2013 -31.12.2013

1.4.2. Construction of the low-background setup on the base of NaI(Te) crystal
Date: 01.07.2013 -31.12.2013

1.4.3. Study of general characteristics of γ-radiation of ^{238}U with the help of low-background setups
Date: 01.01.2014 -31.12.2014

1.4.4. Searching for and study of specific spectral lines in the γ-radiation spectrum of ^{238}U
Date: 01.01.2015 -31.06.2015

1.4.5. Study of heavy nuclei fission processes induced by proton beams from the C-18 cyclotron with the help of low-background setups

Date: 01.01.2015 -31.06.2015

Performers: A.Alexanyan, H.Gulkanyan, L.Poghosyan, V.Pogosov, T.Kotandgyan

The budget theme **N13-1C 001"Very high energy Gamma-Ray astrophysics with IACT"**

2.1.The abstract and the work content

The purpose of the Project is participation in the program for investigation of astrophysical sources of Very High Energy gamma rays, using the H.E.S.S. (High Energy Stereoscopic System) Imaging Atmospheric Cherenkov Telescopes and participation in the CTA (Cherenkov Telescope Array) project. Within the framework of the HESS

Collaboration, we envisage participation in the experimental observations, analysis and interpretation of the data and explorationfor new mathematical methods for the analysis of the data obtained with H.E.S.S. II. Within the CTA, we are going to develop a Monte-Carlo program for the determination of telescopes response functions (i.e. the ray-tracing program for SST, MST and LST with different constructions) in order to create the full Monte-Carlo program including the simulation of air shower development and Cherenkov light production (MOCCA), the detection of Cherenkov light and data analysis. The response functions and the basic parameters, such as the collection areas, detection rates, energy thresholds of telescopes of different constructions will be determined. The peculiarities of the Cherenkov image parameters will be studied as well.

2.2. P r o p o s a l

The aim of the project is to continue our participation in the realization of the research programs of the H.E.S.S. (High Energy Stereoscopic System) collaboration and CTA (Cherenkov Telescope Array) consortium in the field of Very High Energy (VHE, E≥ 100 GeV) gamma ray astrophysics (A.I. Alikhanyan National Science Laboratory (Yerevan Physics Institute) is one of the founder members of the mentioned collaborations).
The basic physics goal of the VHE gamma ray astrophysics is to explore the production and propagation of high-energy particles in the Universe - i.e. to explore the Non-thermal Universe. The main achievements of the field have been reached by using Imaging Atmospheric Cherenkov Telescopes (IACT) and systems of such telescopes for registration of primary gamma-rays. The VHE astrophysics started to rapidly develop in the 1990-ies with the detection of TeV gamma rays from the Crab nebula by the Whipple collaboration [1]. Later the result was conformed on other experiments, such as HEGRA, CELESTE, CANGAROO, H.E.S.S. MAGIC and VERITAS (Fig.1 [2]). The detection of TeV gamma rays from Crab nebula started a research field in an energy domain which is essentially accessible by ground based instruments.

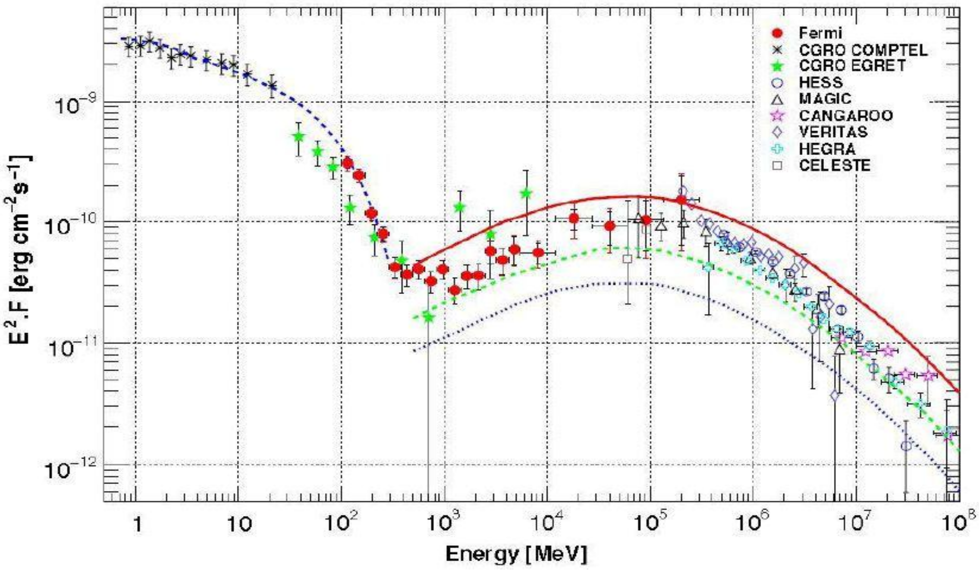

Fig.1 The Crab Nebula spectrum [2].

The use of a stereoscopic approach in the VHE gamma ray astrophysics based on simultaneous detection of air showers by a few IACTs (stereoscopy) was a fundamental approach, which allows precise reconstruction of the shower parameters, superior rejection of hadronic showers and effective rejection of the background light of different origin. The first to use this registration technique was the HEGRA (High Energy Gamma Ray Astronomy) experiment (1998-2002), in which the Yerevan Physics Institute also took their part. Gamma-ray fluxes from astrophysical sources of different classes have been registered by the HEGRA experiment. The

experimental data have been interpreted as well. However, another significant result of the HEGRA experiment was the experimentally proven high efficiency of stereoscopic approach, and nowadays this technique is the basis for the development and realization of new instruments/projects in the field of ground-based gamma ray astrophysics experiments. As a result of that – all the presently active experiments in the field, H.E.S.S., MAGIC, VERITAS as well as the planned CTA project, have adopted the method of registration of atmospheric showers simultaneously by several telescopes.
An evidence for the high effectiveness of imaging atmospheric Cherenkov technique is the fact that there have already been registered gamma-ray fluxes from more than 140 astrophysical sources of different classes, their differential energy spectra reconstructed and, based on that, the gamma-rays production mechanisms studied. Since 2004, when H.E.S.S., MAGIC and VERITAS telescopes with low energy threshold and high detection efficiency had been put into operation, there have been discovered more and more sources (Fig.2 [3]).

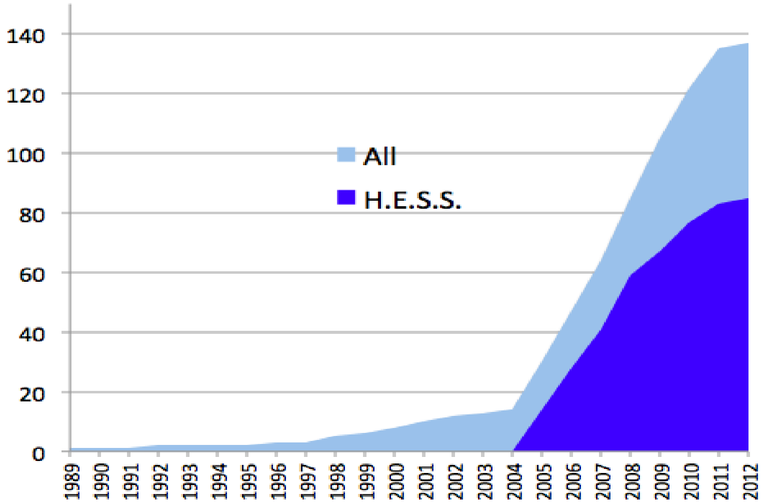

Fig.2 The number of discovered VHE gamma-ray sources by years (TeVCat data [3]). The gamma-ray sources announced at the end of 2012 are not shown.

For example, the energy threshold of the H.E.S.S. system is 70-100 GeV, allowing for one hour of observations to detect the flux of gamma-rays with a significance of 5σ in case of 5% of the flux from the Crab nebula type sources ($F_{Crab}(>1TeV)=2.17\cdot10^{-11}cm^{-2}sec^{-1}$), whereas, e.g. the HEGRA telescopes would detect such flux during about 100 hours. The MAGIC II telescope is in operation since 2004 and the H.E.S.S. II from 2012, which have by a factor of 2-3 higher sensitivity and a 20-30 GeV threshold. This will allow comparing the experimental data obtained with the ground based instruments (IACTs) directly with those obtained by space-based stations.From all the VHE gamma sources discovered to date, ~80% have been detected by the H.E.S.S. (see Figs 2 and 3 [3]).

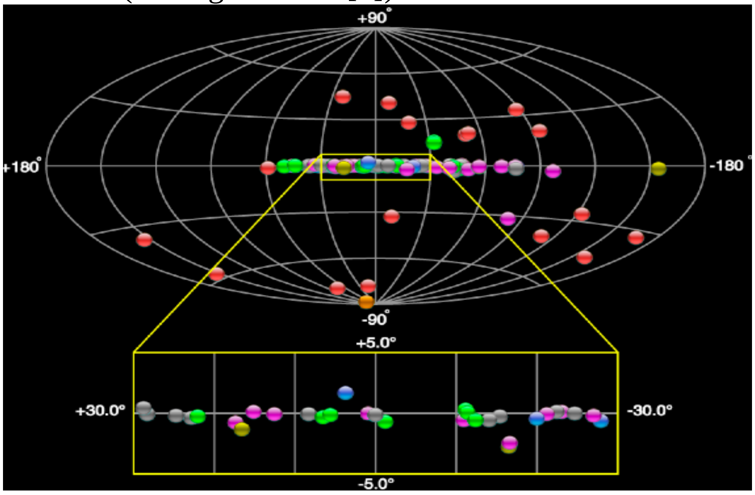

Fig.3 TeVCat sky map of H.E.S.S.-discovered gamma ray sources as of August 2012 (TeVCat data [3]). The gamma-ray sources announced at the end of 2012 are not shown.

H.E.S.S. observatory is located in the Khomas Highland of Namibia at 1800 m above sea level and started to operate on 10 December 2003. Each of the H.E.S.S. phase I identical four telescopes has the following parameters: 107 m^2 total mirror area, 15 m focal length, 13 m diameter, 0.6 m diameter mirror facets, a camera consisting of 960 photomultiplier tubes with 0.16^0 angular size, and 5^0 total field view. The energy threshold of the system is 70-10 GeV and the "working range" is from 100 GeV to 100 TeV with the energy resolution of 15-20% and arrival direction reconstruction of 0.1^o [4]. The H.E.S.S. array has been completed with the 28 m-diameter H.E.S.S. II telescope which Cherenkov light first detected on the 26^{th} of July 2012, being the largest Cherenkov telescope ever built (Fig. 4 [3]).

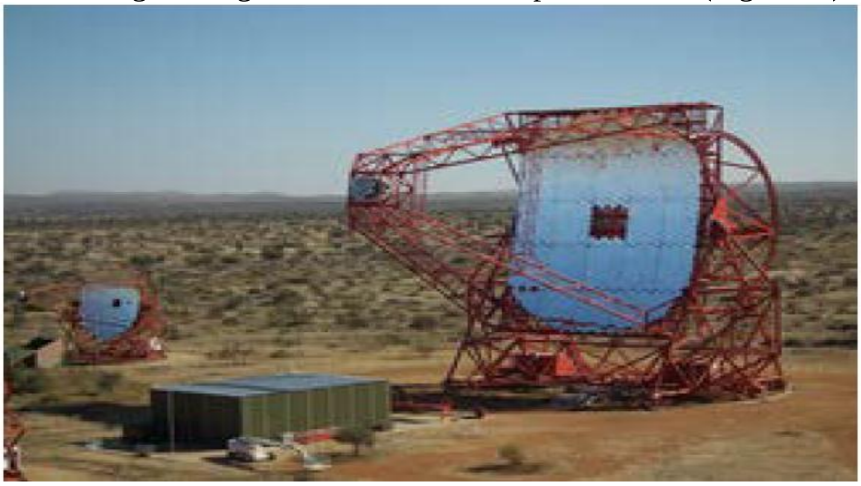

Fig.4. The H.E.S.S. II telescope.

The parameters of the H.E.S.S. II telescope are as follows: 614 m^2 total reflector area, 36 m focal length, 13 m diameter, 32.6m by 24.3m dimensions equivalent to 28 m circular dish, 875 hexagonal facets of 90 cm (flat-to-flat) size, a camera consisting of 2048 photomultiplier tubes with 0.07^o angular size, and 3.2^o total field of view. The Cherenkov image of an air shower viewd by by the H.E.S.S.-II telescope (center) and H.E.S.S.-I telescopes (sides) is shown in Fig. 5 [3].

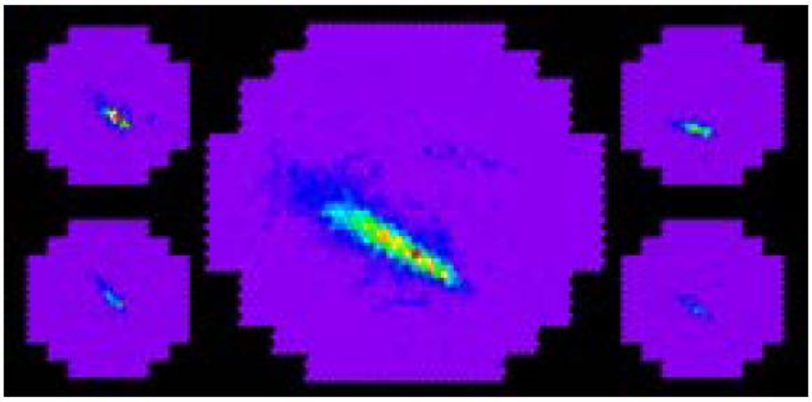

Fig.5. The image of an air shower viewed simultaneously by the H.E.S.S. II telescope (center) and by the H.E.S.S. I telescopes (sides).

H.E.S.S. has detected VHE gamma-ray fluxes from astrophysical sources of different classes, their spectra have been reonstructed and the theoretical interpretation of the experimental data given. In particular: for the first time the morphology of an astrophysical source in the TeV energy range has been investigated (SNR RX J1713.7-3946 [5], [6]); a VHE gamma-ray flux above 100 GeV has been detected from microquasar LS 5039 [7]; new TeV gamma-ray sources

– HESS J1303-631, HESS J1718−385, HESS J1809−193 and others (see, e.g. [8]) has been discovered, and 8 new VHE gamma-ray sources in the Milky-Way has been discovered (at least two of them have no known radio or x-ray counterpart) [9]; the spectrum of cosmic-ray electrons above 600 GeV has been measured [10]; VHE gamma-ray flux from Starburst Galaxy has been detected [11]; radio galaxy M87 has been studied [12]; VHE gamma-rays have been detected from supernova SN 1006 [13], Galactic globular cluster Terzan 5 [14], BL Lac object 1ES 0414+009 [15] and other sources (see Refs [16-20]).
Below are given two examples of data obtained by the H.E.S.S.

1. The spectrum of cosmic-ray TeV electrons [10]. For the first time the spectrum of cosmic-ray electrons was reconstructed, using the data obtained by the IACTs. The analysis was carried out based on the data acquired using the 4 telescope array during 2004 to 2007. The electron spectrum was reconstructed for the energy range above 600 GeV (Fig.6 [10]). The data are well described by a power-law: $dN/dE=\kappa(E/1TeV)^{-\Gamma}$, where $\kappa=(1.17\pm0.02)\times10^{-4}$ $TeV^{-1}m^{-2}sr^{-1}sec^{-1}$ and $\Gamma=3.9\pm0.1_{stat}\pm0.03_{syst}$.

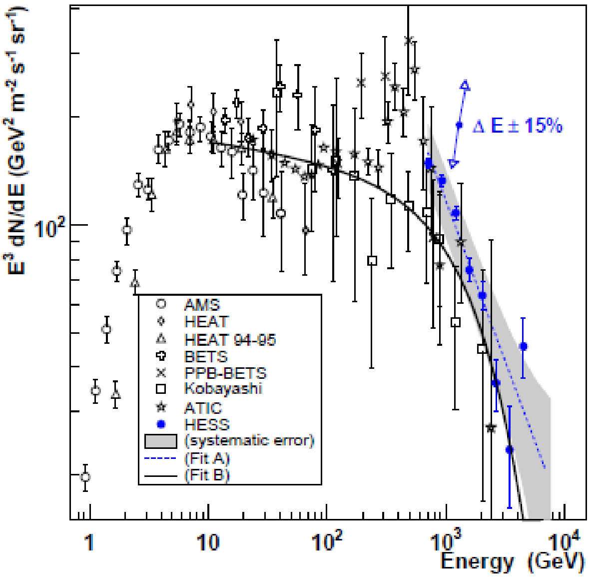

Fig.6. The energy spectrum E^3dN/dE of cosmic-ray electrons as measured by H.E.S.S. in comparison with previous measurements.

2. The data detected from Starburst Galaxy NGC 253 as compared with those obtained by Fermi-LAT [21]. The VHE ($E\geq100$ GeV) gamma-ray data from NGC 253 can be described by a power-law in energy with differential photon index $\Gamma=2.14\pm0.18_{stat}\pm0.30_{syst}$ and differential flux normalization at 1 TeV of $F_0=(9.6\pm1.5_{stat}(+5.7-2.9)_{syst})\times10^{-14}$ TeV^{-1}cm-2sec^{-1}. For high energy region, $100MeV\leq E\leq100GeV$, the differential photon index is $\Gamma=2.24\pm0.14_{stat}\pm0.03_{syst}$ and the integral flux between 0.2 GeV and 200 GeV is $F(0.2\text{-}200\ GeV)=(4.9\pm1.0_{stat}\pm0.3_{syst})\times10^{-9}cm^{-2}sec^{-1}$. The differential energy spectrum from NGC 253 is shown in Fig. 7.

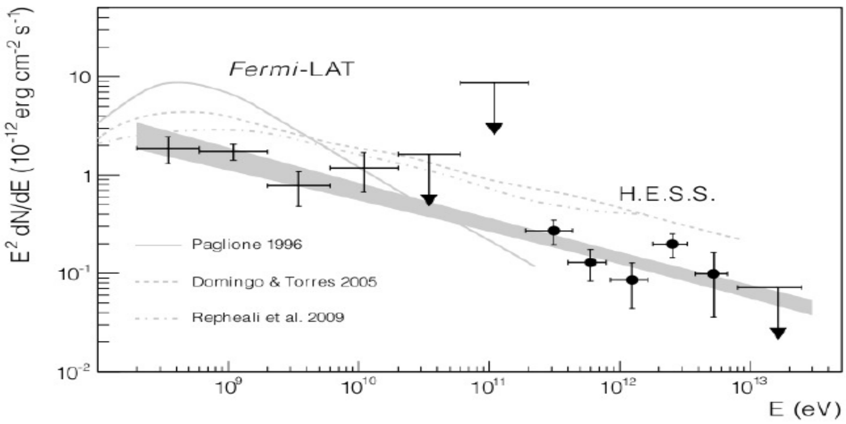

Fig. 7.The differential energy spectrum of Starburst Galaxy NGC 253 as obtained by H.E.S.S. and comparison with Fermi-LAT data.

The further development of instruments in VHE gamma-ray astrophysics is envisaged in the framework of CTA Project [22] dedicated to build two arrays with the improved sensitivity by about an order of magnitude as compared with the present instruments and the extension to energies well below 100 GeV and above 100 TeV (see Fig. 8).

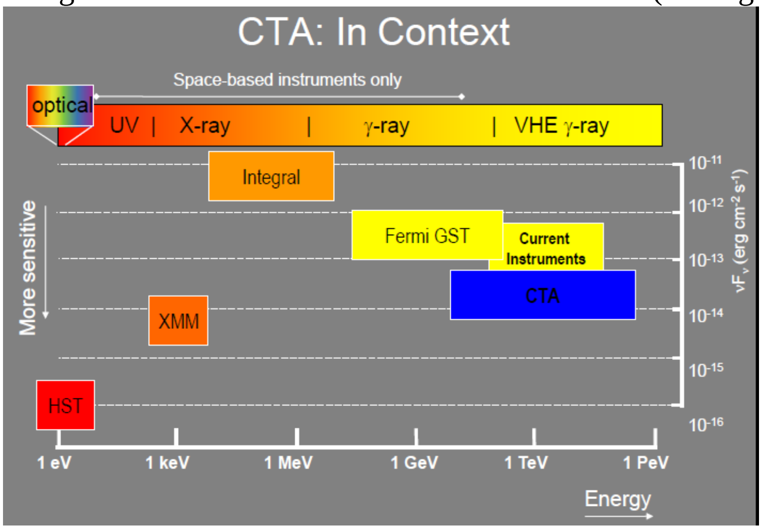

Fig. 8.CTA sensititvity as compared with other instruments.

It is envisaged to build two observatories, one in the Northern Hemisphere and the other in the Southern. The Design Report of the Project is done [22], the locations will be chosen in 2013 and the construction is planned to begin in 2014. It is designed to build telescopes of three different classes: **SST,** Small size telescopes with 4-6m diameter and 10^{o} of field of view; **MST,** Medium sizetelescopes with 10-12m diameter and $6\text{-}8^{o}$ of field of view and **LST,** Large size telescopes with 20-30m diameter and, e.g. in case of 24m diameter, $4\text{-}5^{o}$ of field of view. The shape of **SST** reflectors will be of Davis-Cotton design and that of the larger telescopes will be parabolic. By such approach there will be met the requirements imposed on the Cherenkov telescopes optical characteristics, namely, proper focusing of the Cherenkov light and low time distribution function for the photons reflected from different parts of the reflector.

The scientific objectives of the research theme are: participation in the above-mentioned collaborations, the development of a method for signal extraction efficiency and new mathematical methods for γ-events separation from experimental data for sub-50-100 GeV energy region (see below). First, the problem is that in the mentioned energy region the Cherenkov images of gamma- and background-initiated air showers become similar and the currently used mathematical methods of data analysis turn inefficient. Second, in the sub-20-30 GeV energy region, beside the cosmic-ray proton background, the contribution of the air showers induced by cosmic-ray electrons becomes significant as well [23], so that this new background component should be also taken into account for extraction of the useful signal. A primary particle energy reconstruction algorithm for sub-100 GeV energy region will be developed as well.

The achievements and expexted results.

Our research team is carrying out investigations in the field of VHE gamma-ray astrophysics since 1980-ies. In particular, starting from 1991, the group had taken part in designing and exploitation of the HEGRA Cherenkov telescope array as well as in the data analysis (the experiment was carried out from 1998 to 2002). HEGRA have studied such astrophysical objects as Crab Nebula, Mrk 421, Mrk 501, BL Lac 1ES1959+650, H1426+428, Tycho's, Giant Radio Galaxy M 87 and others. Our group has suggested a new method for the analysis of Cherenkov images and the method was used for the Crab Nebula data.

Starting from 1998, the group has taken part in designing of the H.E.S.S. telescopes and then in implementation of the research program. By the technology developed by the Yerevan Physics Institute research group, the GALAKTIKA CJSC of the National Academy of Sciences of RA manufactured the 400 mirrors ordered by the H.E.S.S. Our contribution to the construction of the H.E.S.S.-II telescope was in the form of manufacturing and shipping of 200 mirrors to the collaboration by the GALAKTIKA CJSC of the National Academy of Sciences of RA.

The H.E.S.S. array started to work in December 2003. As a result of the observations carried out to date, there have been detected gamma-ray fluxes from astrophysical sources of different classes. For instance, there is studied a number of supernova remnants, among which the morphological image of RX J1713.7-3946 in the TeV energy range has been obtained for the first time. There have been discovered 14 new γ-sources in the Galactic plane, among which there are sources with no counterparts in other ranges, meaning that the γ-rays are produced in hadronic interactions. There have been detected γ-ray fluxes from LS 5039, Vela X Nebula, BL Lac Object H2356−309, BL Lac Object PKS 0548-322, PKS 2155-304, SN 1006, Centaurus A and other sources. Besides, for the first time the spectrum of cosmic rays has been registered with IACTs and the spectrum of 13-200 TeV cosmic-ray iron nuclei restored based on the obtained data. From the H.E.S.S. data the spectrum of cosmic-ray electrons above-600 GeV has also been reconstructed, and so on.

As of August 2012, more than 80 sources of VHE gamma rays had been detected with H.E.S.S., more than 60 of which are Galactic and 19 are extragalactic sources. More than 100 research articles have been published, including articles in high-impact journals such as "Nature" and "Science". As of February 2013, according to the SAO/NASA Astrophysics Data System data, 10 articles with a high citation index published by the H.E.S.S. have been referenced a total of 2848 times. H.E.S.S. is the only VHE gamma astronomy instrument which in 2009 was included in the list of the top ten High-Impact Astronomical Observatories (see [24] and Table 1).

HIGH-IMPACT OBSERVATORIES

Rank	Facility	Citations	Participation
1	SDSS	1892	14.3%
2	Swift	1523	11.5%
3	HST	1078	8.2%
4	ESO	813	6.1%
5	Keck	572	4.3%
6	CFHT	521	3.9%
7	Spitzer	469	3.5%
8	Chandra	381	2.9%
9	Boomerang	376	2.8%
10	HESS	297	2.2%

Table 1.Top ten high-impact observatories in 2009 [24].

A Monte-Carlo program describing the IACT response is developed; this program will allow to simulate the Cherenkov telescope's "response" with account of the optical characteristics and the real arrangement of the mirror facets [25]. The program is included the MOCCA Package for description of the air showers development, as a result – the whole process, the development of air showers as well as the registration of the accompanying Cherenkov photons by the telescope have been included in the same package [26, 27]. The accuracy of the extended package has been experimentally proved by comparing the experimental data processing method with others. New mathematical methods for extraction of γ-events from the experimental data [28, 29] and the peculiarities of the Cherenkov radiation from sub-100 GeV electromagnetic air showers have been studied [23 and 30].

It has been shown that the gamma- and electron-induced air showers differ. The electron-induced showers begin to develop earlier, at higher altitudes than the gamma-induced ones, so that the induced Cherenkov light is more scattered; due to this the electron- and gamma-induced air shower images differ by both distribution and time characteristics.

During the implementation of the Research theme it is envisaged:

- to continue participation in the H.E.S.S. program – observations, experimental data processing and interpretation;
- to study the peculiarities of the Cherenkov images of cosmic-electrons-induced air showers with the H.E.S.S. II telescope;
- to develop an algorithm for the reconstruction of the primary particle energy for the H.E.S.S. II and CTA LST telescopes, taking into account that in the "working energy range" of these telescopes (E<50-10 GeV) the Cherenkov images of the gamma- and hadron-induced air showers become very similar and the contribution of the new background component – cosmic ray electrons, becomes significant;
- using numerical simulation, to compute the parameters of CTA telescopes (SST, MST and LST) of different "designs", such as the collection area, detection rate, etc;
- to investigate the possibility of using the difference of the time characteristics of Cherenkov pulses induced by γ- and hadron-induced air showers for different types of CTA telescopes, and
- to study the peculiarities of the parameters of the air-shower-induced Cherenkov light in low energy region (below tens of GeV), possibility to use new parameters, new methods for Cherenkov image cleaning ans useful signal extraction procedure.

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<u>Basic themes of Experimental Physics Division</u>

1. High energy experimental physics-collaboration with CERN-LHC (ATLAS, ALICE, CMS)

ATLAS group activity planning of ANSL (YERPHI) for 2013-2015

1.1.2013-2014

LHC and detectors in phase LS1 (Long Stop 1) after April 2013.

1. Tile Hadron Calorimeter operation and maintenance during LS1:

a. Few proposals are made and discussed: the crack scintillators(between hadronic EB and EndCap) optimal readout, activation of MBTS (Minimum Base Trigger Scintillator) system in charge integration mode as a new luminosity monitor at high collision rates, tests of Tile PMT's downdrift due to electrostatic charge accumulation, out of rate increase due to absorber radio-activation. (H.Hakobyan,F.Adamyan,G.Vardanyan)

b. Repair and maintenance of LVPS electronics infrastructure.Cosmicmuons and other tests of all systems at the end of LS1.(R.Oganezov)

2. Data analysis: High energy jet calibration for 2012 dataset, inclusive jet and dijet cross-sections for sqrt(s)=8TeV and comparison with theoretical models' predictions. Preparation of Internal notes and articles for publications. (H.Hakobyan,G.Vardanyan)

3. Monte-Carlo simulation of MBTS system.(H.Hakobyan, G.Vardanyan)
4. Grid monitoring tools development and ATLAS Tiers monitoring(L.Sargsyan)
5. Activity in ATLAS Forward Physics(MC of Cherenkov detector)(H.Hakobyan, student)
6. Study of Tile optics (H.Hakobyan, student)

1.2. 2015

Start of LHC running at sqrt(s)=13TeV

1. Tests of Tile Hadron Calorimeter performanceMBTS improvement after LS1. Measurements and checks of absolute calibration methods for MBTS system. Preparation of Internal Note on Tile and MBTS performance after LS1. (H.Hakobyan,G.Vardanyan)

2.CalorymetryOnline Shifts at ATLAS Control Room and Tile Hadron Calorimeter offline DQ shifts from home institute.(H.Hakobyan,G.Vardanyan)

Data analysis: High energy jet re-calibration for 2012 reprocessed data and start-up of 2015 data analysis, inclusive jet and dijet cross-sections for sqrt(s)=8-13TeV and comparison with theoretical models' predictions. Preparation of Internal Notes and articles for publications(H.Hakobyan,G.Vardanyan)

3.Repair and maintenance of Tile Hadron Calorimeter's LVPS. (R.Oganezov)

4.Grid monitoring of ATLAS Tiers.(L.Sargsyan)

5.Study of ATLAS Forward physics experimental method (MC) (H.Hakobyan, student)

1.3.Participants

H.Hakobyan (Group leader), F.Adamyan (scientist) R.Oganezov (electronics-engineer), L.Sargsyan (computing-engineer), G.Vardanyan(PhD student) and student (undegraduate students), if available.

Activity of ALICE team of ANSL during the years 2013-2017

The programme presented bellow has been discussed and elaborated with the participation of administration of the ALICE collaboration. It is included into general collaboration programme. The works will be carried out in the following directions:

1. Analysis and physical interpretation of experimental spectra of $\mu^+\mu^-$ pairs in low invariant mass region

1.1 Abstract

The experimental data on the production of correlated $\mu^+\mu^-$ pairs in the low mass region ($M_{\mu+\mu-}$ < 1.2 GeV/c^2) will be analysed. In this region, a large contribution is given by two-body decays of the pseudoscalar *η(547)* and vector *ρ(770)*, *ω(782)* and *φ(1020)* mesons (*η(547), ρ(770)*, *ω(782)*, *φ(1020)*)$\rightarrow\mu^+\mu^-$, as well as by Dalitz decays of *η(549), ω(782)* and pseudoscalar meson *η(958)*: (*η(549), η(958)*) $\rightarrow\mu^+\mu^-\gamma$ and *ω(782)*$\rightarrow\mu^+\mu^-\pi^0$. Besides, a considerable contribution to the spectra of correlated muon pairs is given by the semimuonic inclusive decays of charm (*c*) and beauty (*b*) mesons. The reliability of the description of the spectra of correlated muon pairs on the base of the summary contribution of the aforementioned decay processes will be investigated.

The experimental values of the differential and total cross sections of inclusive production of *ρ(770), ω(782)* and *φ(1020)* will be calculated. The software packages for the analysis of data and simulation of events will be created.

In the investigations, the data recorded in the year 2012 in *pp* collisions at 8 TeV, as well as the data to be accumulated in the years 2015-2017 will be used.

In addition, following the suggestion of the ALICE collaboration administration, the work on the upgrade of the Muon Quality Assurance central service will be carried out, with the aim to improve the evaluation of the quality of muon data.

1.2 Actuality of subject

It is expected that at early stages of the process of the collisions of lead nuclei accelerated in LHC, an extremely hot and dense state of matter consisting of free quarks and gluons - Quark-Gluon Plasma (QGP) is formed, which, expanding under high pressure, converts (due to the QCD confinement) into the state consisting of hadrons, the so-called Hadron Gas (HG).

In the experimental study of this evolution process, of special importance is the detection of muons. Produced at every stage of the hadronic collision process, muons escape the surrounding medium with negligible final state interaction and thus the observed muonic spectra contain an (almost) undistorted information about the entire history of the collision process.

Production of correlated muon pairs is basically regulated by the electromagnetic spectral function of hadrons, to which a large contribution is given by the $\rho(770)$, $\omega(782)$ and $\varphi(1020)$ light vector mesons (in the $\mu^+\mu^-$ low invariant mass region, $M_{\mu+\mu-} < 1.2$ GeV/c^2) and the families of J/ψ and Y heavy mesons (in the region $M_{\mu+\mu-} > 3.0$ GeV/c^2).

Due to small masses of light *u* and *d* quarks (5-10 MeV) the correspondent part of the QCD Langrangian possesses the property of global chiral symmetry. However, the chiral symmetry is significantly violated by the non-perturbative interaction of quarks with QCD vacuum filled by condensates. The difference between the masses of hadron chiral partners (of the order of 500 MeV) demonstrates the strength of the (spontaneous) breaking of the chiral symmetry, which is essentially due to the quark-antiquark (aka chiral) condensate.

It is expected that the condensate structure of QCD undergoes modifications at the non-zero temperature and in dense medium, resulting in the rearrangement of the hadron spectra. Indeed the numerical calculations on the lattice reveal a rapid vanishing of the chiral condensate at a temperature of T_c ~ 160-190 MeV [5] (which corresponds to the energy density of about 1 GeV/fm^3). In the hadronic word, this would be manifested as the modification of the hadron spectral functions when approaching to T_c, with eventual degeneration of the chiral partners (chiral symmetry restoration). The aforementioned phase transition from QGP to HG (or from HG to QGP) occurs just in this region of temperatures.

High energy collisions of heavy ions provide the only possibility to observe *in vivo* the modification of the hadron spectral function in the hot and dense matter. The best candidates for that are the resonances with lifetime smaller than the lifetime of the formed matter. One of them is $\rho(770)$ meson with 1.3 fm/c lifetime. According to experimental data, the evolution of hadronic matter formed in the processes of ions collisions lasts 9 –15 fm/c, i.e. during this evolution several generations $\rho(770)$ meson would be produced and would subsequently decay into the $\mu^+\mu^-$ channel. Therefore, separating contribution of the ρ-meson and studying the spectral function of this meson, one could obtain the information about the state of matter at different evolution stages.

For unambiguous interpretation of phenomena observed in heavy ion collisions it is important to ensure that these phenomena are due just to the formation of high density and hot environment. For this, it is necessary to check the existence (or absence) of these phenomena in the 'reference', proton-proton and proton-nucleus collisions where the development of collective phenomena (including QGP formation) is not expected. Investigation of the *pp, pPb* and *Pbp* collisions constitutes an important part of the ALICE research programme.

To analyse the production of muons produced at the LHC energies, the ALICE collaboration has constructed a large Muon Spectrometer, which detects muons produced in the region of polar angle from 2 to 9 degrees. Taking into account the importance of the study of dimuons produced in the low invariant mass region, the management of ALICE collaboration established a special data analysis group, which was called Low Dimuon Mass Physics Analysis Group (LmumuPAG). Members of group are ALICE teams from Cagliari (INFN, Italy), Lyon (IPNL, France) and ANSL. By the decision of the group, the ANSL team undertook the analysis of data on the *pp* collisions at 8 TeV accumulated during 2012.

1.3 Content and time schedule of the works

1.3.1 2013-2015 **Analysis of data accumulated in 2012**

Participants: *Vardanush Papikyan, Hrant Gulkanyan, Ara Grigoryan*

In 2012, only protons have been accelerated in LHC, to the energy of 4 TeV per beam, during 6 working cycles of LHC accelerator, called Periods, each of which consisted of hundreds of runs. Taking into account extremely high intensity of proton beams operated in 2012 and limited speed of data acquisition, the ALICE detector has been working in 2012 in the so-called beam-satellite mode, which has been ensuring a lower number of *pp* interactions events as compared to that in the beam-beam *pp* interactions. As a consequence, the work with data of the year 2012 needs special approaches.

The analysis of all 6 Periods is foreseen. The works will be basically carried out in the following directions:

- Classifications of Periods and runs according to trigger classes and clusters;
- Study of the ways of grouping of data accumulated in different runs;
- Study and separation of data concerning beam-gas background interactions;
- Study of the influence on data of the cuts related to the geometrical acceptance of the Muon Spectrometer detector;
- Monte Carlo simulation study of the efficiency of observation of muons in Muon Spectrometer
- Separation of correlated dimuon spectra from the observed dimuon spectra
- Description and physical interpretation of the correlated muon spectra on the base of ALIGenMuonLMR Cocktail event generator and Monte Carlo simulations;
- Development of methods of data normalization and calculation of differential and total cross sections of produced *ρ(770), ω(782)* and *φ(1020)* mesons;
- Study of the sources of systematic errors and determination of the values of these errors;

It is foreseen to prepare an Analysis Note describing the analysis of data accumulated in 8 TeV pp collisions. Analysis Note is a document in which the whole process of data analysis is presented in detail, from data selection to calculation of physical quantities. It should, in particular, include discussion of statistical and systematic errors and comparison of the obtained results with those of the other experiments. According to the ALICE collaboration rules, the Analysis Note has to be discussed and approved at the ALICE scientific meetings, after which it becomes a data analysis official document, which can be used as a reference source.

1.3.2 2014-2016 **Upgrade of the Muon Quality Assurance central service.**

The work will be done with the specialists of the responsible team (Diego Stocco, Cynthia Hadjitakis).

Participants: *Vardanush Papikyan, Ara Grigoryan, Armenuhi Abramyan, Narine Manukyan*

1.3.3 2016-2017 **Analysis of data to be accumulated in 2015-2017**

Participants: *Vardanush Papikyan, Ara Grigoryan, Hrant Gulkanyan*

2. Optimization of functionality of data handling environment of ALICE collaboration

2.1 Abstract

A work will be done to regulate the flow of files in the data handling environment of the ALICE experiment. A service of detailed monitoring of file accesses will be designed and the software of this service will be developed. Based on the monitoring data, the mathematical algorithm of the flow regulation will be created and corresponding software will be developed

Besides, the work on the upgrade of the services of AliEn Grid infrastructure, traditionally performed in our group, will be pursued.

An everyday administrative work to provide continuous functionality of the WLCG/ALICE Grid site operating in ANSL will be done.

2.2 Actuality of subject

An extremely large collection of files containing experimental, simulation and analysis data and their replicas is distributed over AliEn Grid infrastructure of ALICE collaboration. This infrastructure incorporates actually 85 high performance sites distributed over 31 countries of 4 continents. The resources of these sites are intensively exploited by more than 600 members of ALICE collaboration.

However, despite of very large storage capacities of the sites, they get quickly filled because of continuous creation of new data files, preventing thus the future accumulation of files. This means that it is necessary to develop a service, which will allow removal of the file replicas from the sites in an organized and regular manner.

Solution of this problem requires first of all a detailed monitoring of the accesses to the files, movement of the files across the AliEn sites and a proper analysis of the monitoring results.
The results of monitoring will be used to develop a mathematical algorithm of the file removal and to create an appropriate software service.

Fulfillment of this important work was suggested by the ALICE Offline project management to the members of ANSL/ALICE team.

One should note that a reliable functionality of AliEn Grid infrastructure that faces continuously increasing demands requires regular study and upgrade of its services. This work, which has been traditionally carried out by the members of ANSL/ALICE group, will also be continued by the group.

In 2010, member of ANSL/ALICE team Narine Manukyan has deployed in ANSL a WLCG site, integrating the ANSL cluster to the largest in the world Grid infrastructure of the LHC. The provision of a continuous operation of the cluster requires an everyday administrative work which will also be continued by the members of ANSL/ALICE team.

2.3 Content and time schedule of the works

2.3.1 2013-2015 **Creation of service for regulation of the file flow and removal in ALICE computing environment**

Participants: *Armenuhi Abramyan, Narine Manukyan, Ara Grigoryan.*

The work includes the following subjects:

- Creation of a service for recording the values of the file call characteristics in the Authen_ops log file of AliEn;
- Creation of a data base for the accumulation of the call characteristics;
- Creation of a service for the registration of the call characteristics in the data base;
- Development of the mathematical algorithm of the removal of files;
- Creation of a service for the removal of file replicas from the storage elements of AliEn.

2.3.2 2016-2017 **Upgrade of the software of AliEn infrastructure**

Participants: *Armenuhi Abramyan, Narine Manukyan*

2.3.3 2013-2017 **Administrative maintenance of WLCG/ANSL/ALICE site**

Participants: *Narine* Manukyan. Armenuhi Abramyan

3. Physics performance study of the Muon Forward Tracker (MFT)

3.1 Abstract

MFT detector represents an important part of the whole ALICE Upgrade project. It has been suggested by the Muon Spectrometer collaboration as a complement allowing a significant improvement of the accuracy of the reconstruction of muon tracks and of the determination of the interaction point. MFT should be integrated in the ALICE setup in 2018.
The ANSL/ALICE team has been participating in the preparation of the Letter of Intent dedicated to the demonstration of the importance of the MFT project. The works of the team will be concentrated on the Monte Carlo simulation study of the accuracy of measurement of the observed physical quantities and of the possibility of separation of physical processes contributing to the low invariant mass region of $\mu^+\mu^-$ pairs in the case of combined operation of MFT and Muon Spectrometer

3.2 Actuality of subject

Analysis of *pp, pPb, Pbp* and *PbPb* collision data accumulated by Muon Spectrometer since the beginning of LHC operations revealed a series of important results on the production of muons and dimuons at ultrarelativistic energies. In particular an increase (decrease) of the yield of the mesons of J/ψ (Y) family was observed in *PbPb* collisions, which is in agreement with what is expected in case of formation of QGP.
Meanwhile, it became evident that the actual measurement accuracy of Muon Spectrometer is not satisfactory for the study of the details of the mechanisms of the production of muons which is important for the unambiguous treatment of the obtained results. In particular, the actual setup does not provide accuracy necessary for the determination of the position of interaction point, which is due to the multiple scattering of muons in the front absorber. This limitation does not first of all allow experimental separation of the background muons, which are produced in the decays of π and K mesons. Further, unsatisfactory knowledge of the location of the interaction point prevents separation of muons produced in semimuonic decays of open charm and beauty mesons.

As a result, the actual Muon Spectrometer is not able to distinguish J/ψ mesons, which are produced in the decays of beauty mesons, from those produced at the interaction point.

Finally the distortion induced in muon tracks by multiple scattering worsens essentially the mass resolution of resonances, which decay to $\mu^+\mu^-$ pairs.

To overcome the aforementioned limitations, the Muon Spectrometer collaboration has suggested to add to the ALICE setup a new detector called Muon Forward Tracker. It represents a conical construction, incorporating 5 circular detection planes consisting of the silicon pixel microdetectors. MFT will be placed between the interaction point and front absorber.

The simulation showed that such configuration is able to provide a high accuracy of the determination of muon tracks. The main idea is that since the muon tracks observed in MFT are not distorted by the multiple scattering in the front absorber, their matching with the tracks observed in Muon Spectrometer would allow to improve significantly the accuracy of the track reconstruction, As a result, it will be possible to observe the positions of the secondary vertices of the decays of long-living mesons π, K, D and B.

Integration of MFT will significantly improve accuracy of the determination of the dimuon opening angle, which will lead to an essential increase (from 4 to 5 times) of the resolution of dimuon mass. Finally, the exploitation of MFT will provide a considerable (of one order of magnitude) increase of the signal/background ratio. The last two circumstances are of special importance for the low invariant mass region of $\mu^+\mu^-$ pairs.

By the suggestion of the Muon Spectrometer collaboration, ANSL/ALICE team will perform (on the base of Monte Carlo simulations) investigation of the consequences of MFT integration for the separation of the physical processes and for the accuracy of the measurement of the kinematical variables in the low invariant mass region of $\mu^+\mu^-$ pairs.

3.3 Content and time schedule of the works

3.3.1 2013-2014 **Study of the MFT design and software support**

Participants: *Vardanush Papikyan, Ara Grigoryan*

3.3.2 2015-2017 **Simulation studies of the physics performance of MFT in *pp* collisions**

Participants: *Vardanush Papikyan, Ara Grigoryan*

The following work will be done:

- Study of the possibility to separate the individual physical processes contributing to the spectra of correlated dimuons in the low invariant mass region in case of integration of MFT;
- Study of the accuracy of the measurement of the kinematical variables (momenta and invariant mass) in case of integration of MFT.

3Participation in the International conferences and meetings

The results of the work will regularly be presented at the meetings of the *Muon Spectrometer* collaboration, including LmumuPAG as well as *Computing in High Energy Physics (CHEP)* and other international conferences.

4. Scientific missions

Yearly scientific missions to CERN of the members of team A. Abramyan, A. Grigoryan, N. Manukyan and V. Papikyan are foreseen, every mission of 3 month duration.

It is anticipated that for each mission, the traveling, as well as living expenses and daily allowance for one month will be paid by ANSL.
The financial support for the other two months of missions will be provided by ALICE collaboration.

CMS group activity for period 2013-2016

1. **Search for Higgs boson in process VBF H→BBbar and calibration of CASTOR calorimeter in CMS experiment**

1.1 Abstract

One of the main tasks of Compact Muon Solenoid (CMS) experiment at Large Hadron Collider (LHC) is Higgs boson discovery.CMS studied five main Higgs boson decay channels, predicted by the Standard model: H->{ γγ, ZZ, WW, BBbar, ττbar).
According to the presented joint results of CMS and ATLAS experiments obtained for two channels: Higgs decays to either two photons (**H->γγ**)or to four leptons (**H->ZZ*->4l)** is found a new particle with mass of around 125-126 GeVand it is very similar to SM Higgs boson.
In the presented project we suggest to investigate in pp collision the process of Vector Boson Fusion (VBF) Higgs production, where the Higgs boson decays into a $b\bar{b}$ -pair jets. For modeling of this process PYTHIA and CMSSW(CMS Soft Ware) program packages will be used. The event selection criteria will be developed on the base of simulated data.
Is planned the analysis of experimental data of 2011 pp-collisions at 7 TeV and 2012 data at 8 TeV. We also developed the method, which allows to perform a jet energy scale calibration using W→ $q\bar{q}$ decay.
Other purpose of the project is calibration of CASTOR (Centauro And STrange Object Research) calorimeter being in the forward region of CMS detector, using from pp-collisions the experimental data with (η, ρ, ω, φ) mesons which decay into e^+e^- and γγ pairs. This task is important for research of diffraction processes in CMS experiment.
One of calibration method is reconstruction of decaying meson in di-electron channel, using HF (Hadron Forward) and CASTOR calorimeters. On the basis of Monte-Carlo calculations it is shown that using of 2013 experimental data p+Pb (√s = 2.76 TэB), where in trigger include the data of TOTEM telescope, is possible to reconstruct mesons, decayed in e^+e^-pairs. We plan to analyze these experimental data and to use them for calibration of CASTOR calorimeter.

1.2. The work content

One of the main goal of the CMS experiment at LHC is Higgs boson discovery.

The Compact Muon Solenoid (CMS) [1] experiment is one of two large general-purpose particle physics detectors built on the proton-proton Large Hadron Collider (LHC) at CERN.

4th July 2012 in a joint ATLAS and CMS seminar at CERN researchers of these experiments at the Large HadronCollider (LHC) presented their preliminaryresults on the search for the standard model(SM) Higgs boson [2] and concentrated its efforts ontwo channels: Higgs decays to either two photons or to four leptons (Fig.1). Both of these channels have excellent mass resolution; however, the two-photon channel has a modest signal over a large but measured background, and the four-lepton channel has a smaller signal but a very low background.Both channels show a statistically significant excess at about the same place: a mass ofaround 125-126 GeV.YerPhI`s physicists of ATLAS and CMS groups also have participated in the discovery of new particle, which may be the so-called Higgs boson. CMS analysed the full data sample of proton-proton collisions collected in all of 2011 and in 2012, up until June 18. These data amount to up to 5.1 fb^{-1} of integrated luminosity, at a centre-of-mass energy of 7 TeV in 2011 and up to 5.3 fb^{-1} at 8 TeV in 2012.

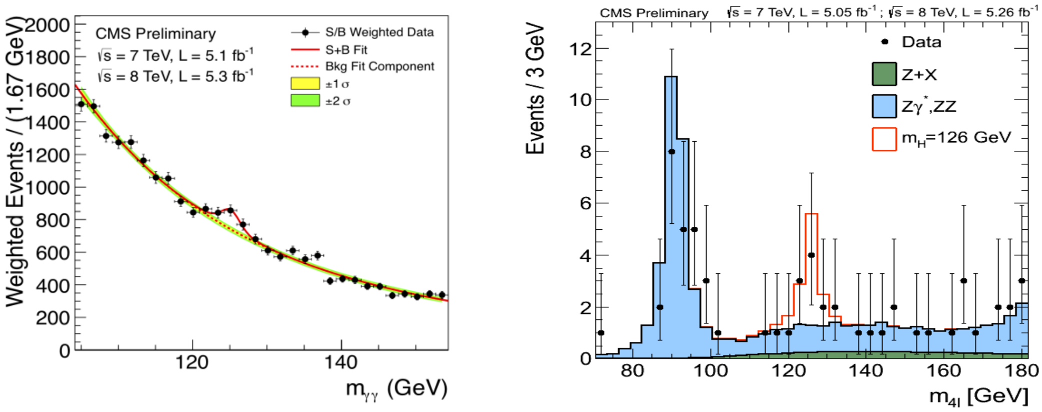
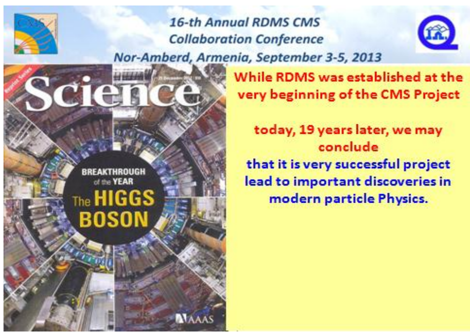


Fig.1

CMS studied five main Higgs boson decay channels. Three channels result in pairs of bosonic particles (γγ, ZZ or WW) and two channels result in pairs of fermionic particles (bb or ττ), where γ denotes a photon, Z and W denote the force carriers of the weak interaction, b denotes a bottom quark, and τ denotes a tau lepton. The γγ, ZZ and WW channels are equally sensitive in the search for a Higgs boson around 125 GeV and all are more sensitive than the bb and ττ channels.The bb channel [3] has large backgrounds from standard model processes, so the analysis searches for events in which a Higgs boson is produced in association with a W or Z, which then decays to electron(s) or muon(s). Let`s note that in bb and ττ channels no excess of events is observed and more data are required and hence ascertain whether it is indeed the SM Higgs boson or the result of new physics beyond the standard model. The LHC continues to perform extremely well. By the end of 2012, CMS expects to more than triple its total data sample, and hence to probe further the nature of this new particle.

2011 -2013 թ.թ.լրիվ տվյալները ,որոնք կազմում են 5.1 ֆբ$^{-1}$ինտեգրալ լուսատվություն 7 ՏէՎ և 19.5 ֆբ$^{-1}$ 8 ՏէՎ էներգիաներով, որտեղից երևում է , որ Ստանդարտ մոդելի Հիգգս բոզոնը սկալյար մասնիկ է (0^{+}):Այդ տվյալները տպագրվլ են SCIENCE (vol.338 p.1569) ամսագրում



In the presented Project we suggest to study in pp collision the process of Vector Boson Fusion (VBF) Higgs production, where the Higgs boson decays into a $b\bar{b}$ -pair jets (Fig.2). In the final state of this process there are also two jets from light quarks. For modeling of this process PYTHIA and CMSSW (CMS Soft Ware) program packages will be used. The event selection criteria will be developed on the base of simulated data.

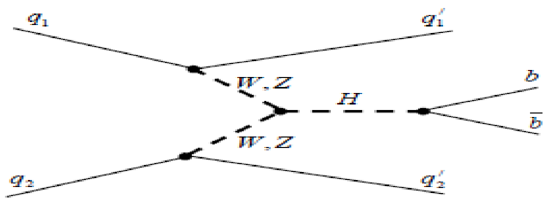


Fig.2

The cross section of this process at the energy of pp-collision 7 TeV is about 0.7 pb. Now we developed the code for generation-simulation-reconstruction of considered process.

As example, in Fig.3 is shown distribution of invariant mass of b-jets from the decay of the Higgs boson with a mass of 125 GeV. Analysis was performed for the "Particle-Flow"-jets reconstructed with anti-kt jet algorithm with a radius parameter 0.5. Shift of the average value of distribution from the Higgs boson mass caused by the fact that in the calculations the jets were taken without energy corrections.

Is planned the analysis of experimental data of 2011 pp-collisions at 7 TeV and 2012 data at 8 TeV. We also developed the method, which allows to perform a jet energy scale calibration using W$\rightarrow q\bar{q}$ decay [4].

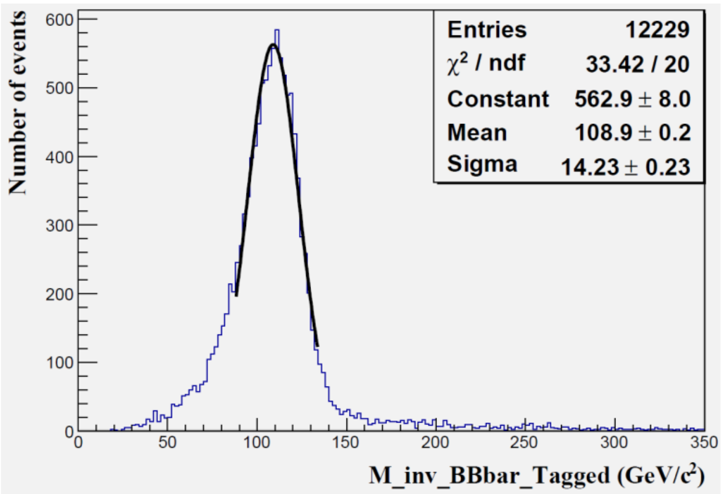


Fig.3

We perform for many years investigation of parton structure of the Pomeron in the hard diffractive processes on the forward region of CMS detector [5-7]. For analysis of these processes in pp collisions it is needed to use data of CASTOR calorimeter. In this regard is important the energy calibration of CASTOR calorimeter.

Other purpose of the project is calibration of CASTOR (Centauro And STrange Object Research) calorimeter being in the forward region of CMS detector, using from pp-collisions the experimental data with (η, ρ, ω, φ) mesons which decay into e^+e^- and γγ pairs. The CASTOR (Centauro And STrange Object Reseacrh)[8] detector is located at a distance of 14.4 m from the CMS interaction point, covering the pseudorapidity region $-6.6 < \eta < -5.2$(Fig.4).

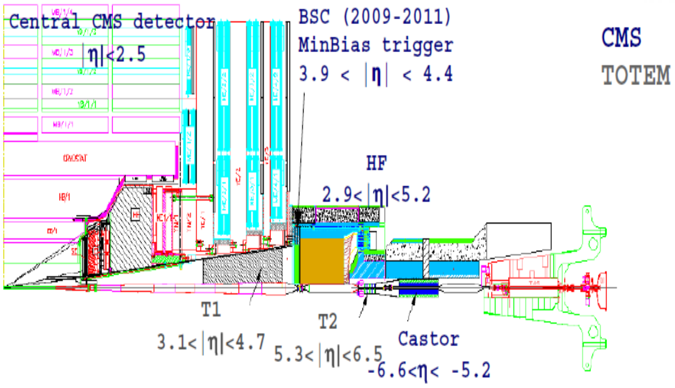


Fig.4

This is a quartz-tungsten Cerenkov sampling calorimeter. The signal in CASTOR is produced when charged shower particles pass through the quartz plates with the energy above the Cerenkov threshold (190 KeV for electrons). The CASTOR longitudinal segmentation allowsto separate electromagnetic (e,γ) and hadronic (jets) showers. In the project we will concentrate on a problem of calorimeter calibration .It is proposed to use electromagnetic decays of mesons that will allow to calibrate electromagnetic modules of CASTOR . One of the above ways of calibration is decay of different mesons (η, ρ, ω, φ) into $e^-e^+$and/or γγ pairs. Due to the their small masses, the decay angles are typically very small at large energies and therefore the final state detection using CASTOR and HF (closest to CASTOR) calorimeters. TOTEM [9] equipment can help for e / γ identification and this is important as its data give exact values of η-φ variable of trajectories.The feasibility of these mesons reconstruction in two lepton decay channel was studied by Monte Carlo method using generator of physics processes PYTHIA 6 [10] and CMSSW[11] program package.PYTHIA generated pp collisions and was developed recognition method of η meson on the base of invariant mass of gamma pairs. As showed researches because 7 TeV (2010-2011) and 2.76 TeV (2011) experimental data had systematic and statistical uncertainties the restoration of η meson is strongly suppressed by background. For calibration task is more promising the 900 GeVpp collisions data (Fig.5).

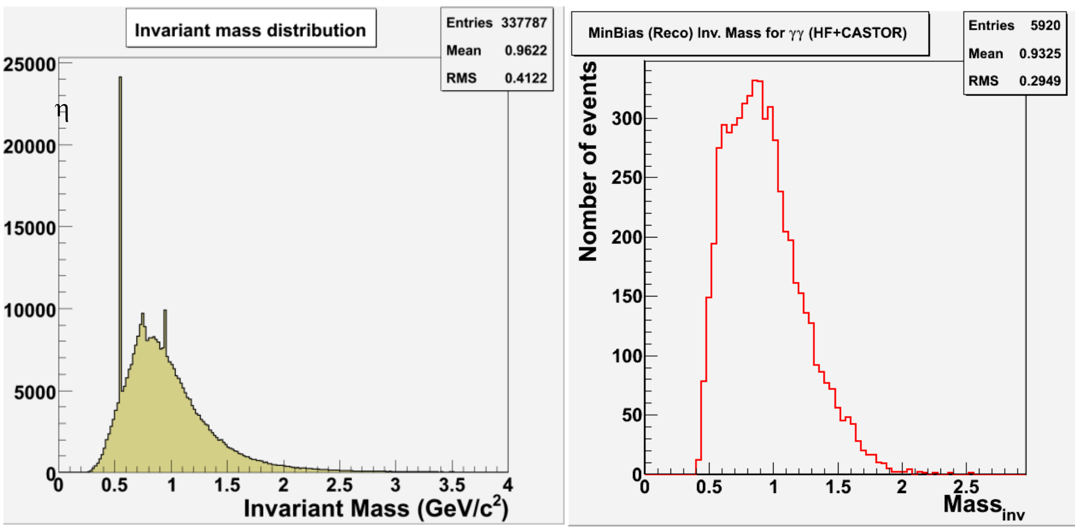


Fig.5. Invariant mass distribution of γγ pairs in HF and CASTOR detectors ($\sqrt{s}$ =900 GeV). Generator level (left) and after reconstruction.

As CMS-detector has not equipment for registration of trajectory under small angles it is necessary to combine CMS+TOTEM data, which took place in February 2013 during p+Pb data recording.Having from TOTEM data the angular parameters of charged particles trajectories and doing separation of electromagnetic/hadronic shower in CASTOR calorimeter, we can identify electrons. In early 2013 was created electromagnetic trigger for CASTOR on the base of CMS and TOTEM experimental data which can help to solve the calibration of calorimeter.Taking into account the real conditions of statistics Monte Carlo calculations have been performed for events with electronic yields in TOTEM and CASTOR calorimeters (Fig. 6).

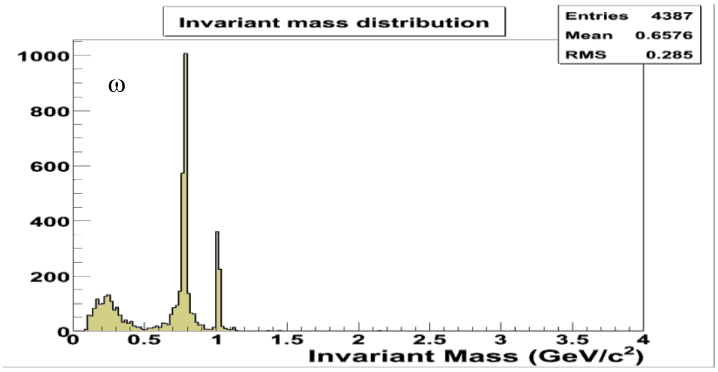


Fig.6. Invariant mass distribution of $\omega \rightarrow e^- e^+$ pairs in CASTOR and TOTEM detectors.

On the basis of Monte-Carlo calculations it is shown that using of 2013 experimental data p+Pb($\sqrt{s}$ = 2.76 TэB), where in trigger include the data of TOTEM telescope, is possible to reconstruct ω meson, decayed in e^+e^- pairs. We plan to analyze these experimental data and to use them for calibration of CASTOR calorimeter.

References

[1] S. Chatrchyan et al. The CMS experiment at the CERN LHC, CMS Collaboration JOURNAL OF INSTRUMENTATION Volume: 3 , S08004 , 2008

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[11] "CMS Software home page." https://cmsdoc.cern.ch/cms/cpt/Software/html/General/

1.5.1.3. Work schedule

2013- 2015

It is suggested to investigate study in pp collision the process of Vector Boson Fusion (VBF) Higgs production, where the Higgs boson decays into a $b\bar{b}$ -pair jets

- for Vector Boson Fusion - VBF process to perform Monte Carlo simulation using PYTHIA and CMSSW(CMS Soft Ware) program packages,
- on the base of simulated data for Vector Boson Fusion - VBF process to develop the event selection criteria ,
- to process of accumulated experimental data of 2011 at 7 TeV and 2012 data at 8 TeV in pp-collisions,
- to perform physical analysis of processed data taking into account energy calibration of hadronic jets.

Participants: S.Chatrchyan, G.Hmayakyan,V.Khachatryan,A.Sirunyan

2014- 2016

It is suggested to perform the calibration of CASTOR (Centauro And STrange Object Research) calorimeter being in the forward region of CMS detector

- (η, ρ, ω, φ)mesons decaying into $e^-e^+$and/or γγ pairs reconstruction using CASTOR and HF (closest to CASTOR) calorimeters,
- Monte Carlo calculations for CASTOR calorimeter calibration using TOTEM telescope,
- processing of 2013 p+Pb($\sqrt{s}$ = 2.76 TeV) experimental data using TOTEM telescope and CASTOR calorimeter,
- reconstruction of ω meson decaying into e+e- pairs and calibration of CASTOR calorimeter,
- data processing of recorded diffraction muon pairs in CMS experiment from pp collisions with energy of 4 TeV.

2. Structure of hadrons and electromagnetic interaction properties with high energy electrons and photons - collaboration with JLab (Halls A, B , C, D)

2.1. Abstract

ANSL (YerPhI) group made a significant contribution into design and construction of several detectors. The group proposed and carried out several experiments, took key role nearly in all experiments taken place in the Jefferson Lab. We took part in data taking and analysis. The results of our activities have been demonstrated in more than 80 publications, and presentations in International conferences and workshops.

In a framework of this project for 2013-2018 ANSL group will continue his activities in preparation and development physics program for 12 GeV beam energy and upgrade of particle detection and identification systems in experimental halls A, B, C and D at Jefferson Lab. We will design and construct detectors, will develop physics projects and software calibration and analysis, will participate in commissioning of experimental apparatus, experimental data taking and analysis.

2.1. Collaboration with HALL A at JLAB

In the framework of this proposal, in 2013-2018 the ANSL (YerPhI) group will continue collaboration with JLab Hall A. We will take part in the series of upcoming experiments using 12 GeV electron beam. Group will continue to work on design and development of new apparatus for upcoming 12 GeV experiments and upgrading existing experimental apparatus.

A1. Participation in Hall A Physics program

A1.1 E12-06-122: *"Measurement of neutron spin asymmetry A_1^n in the valence quark region using 8.8 GeV and 6.6 GeV beam energies and BigBite spectrometer in Hall A".*

This experiment proposed to perform a precision measurement of the neutron virtual photon asymmetry A_1^n in the Deep Inelastic Scattering region up to $x_{Bj} = 0.71$ using 8.8 and 6.6 GeV beam energies and the BigBite spectrometer in Hall A [1]. The proposed measurement will provide the first precision data in the valence quark region above $x_{Bj} = 0.6$ and therefore test various predictions of the relativistic constituent quark model and perturbative QCD [2].

Yerevan group will have a significant contribution in the preparation and installation of experimental setup for proposed experiment. YerPhI group members will play a key role in preparing and testing electronics for both BigBite and HRS. YerPhI collaborators will also made significant contribution into calibration of BigBite calorimeter and BigBite drift chambers.

References:

1. JLab experiment E12-06-122, G. Rosner, B. Wojtsekhowski, X. Zheng, Z.E. Meziani, N. Liyanage, et al., Measurement of neutron asymmetry A1n in the valence quark region using 8.8 GeV and 6.6 GeV beam energies and Bigbite spectrometer in Hall A.

2. E. Leader, A. V. Sviridov and D. B. Stamenov, Phys. Rev. D73, 034023 (2006)

A1.2 E12-07-109: "Large Acceptance Proton Form Factor Ratio Measurements at 13 and 15 $(GeV/c)^2$ Using Recoil Polarization Method"

The E12-07-109 experiment [1] is proposed to measure the ratio of the proton elastic form factors, G_E^p and G_M^p, to 15 GeV^2, using recoil polarization technique. An entirely new picture of the structure of the protons has emerged after two experiments in Hall A showed that the ratio G_{Ep}/G_{Mp} was in fact not constant in the Q^2 range of 1 to 5.6 GeV^2 [2-4]. These results are in contradiction with the general behavior observed from Rosenbluth separation experiments [5]. Following the unexpected results from the polarization experiments in Hall A, a measurements of the ratio G_{Ep}/G_{Mp} in the Q^2 range up to 8.5 GeV^2 have been carried out in Hall C [6]. The results from Hall C experiment confirm that the ratio G_{Ep}/G_{Mp} are decreasing with Q^2.

Yerevan group will have a significant contribution in the preparation and installation of experimental setup for proposed experiment. We will play a key role in preparing and testing electronics for both BigCal and proton arm detection system. The calibration procedure form both electron and proton arm will be done with a significant contribution of YerPhI group. Group members will be involved in preparation of trigger for both arms. Experimental setup installation in the hall and maintenance during the experiment running will be on significant part covered by Yerevan collaborators. Group members will also participate in data analysis procedure.

References:

1. JLab E12-07-109, C.F. Pedrisat, L.P. Pentchev, E. Cisbani, V. Punjabi, B. Wojtsekhowski et al., Large Acceptance Proton Form Factor Ratio Measurements at 13 and 15 $(GeV/c)^2$ Using Recoil Polarization Method.

2. O. Gayou et al., Phys Rev. Lett. 88, 092301 (2002).

3. V. Punjabi et al., Phys Rev. C71, 055202 (2005).

4. O. Gayou et al., Phys Rev. C64, 038202 (2001).

5. J. Arrington, Phys. Rev. C68, 034325 (2003).

6. A.J. Puckett et al., Phys. Rev. Lett. 104, 242301 (2010).

A1.3 PR-09-016:

"Measurement of the Neutron Electromagnetic Form Factor Ratio G_E^n/G_M^n at High Q^2"

The goal of the PR-09-016 experiment [1] to perform a measurement of the electromagnetic form factor ratio of the neutron, G_E^n/G_M^n, at Q^2 = 5.0, 6.8, and 10.2 GeV^2 in double polarized semi-exclusive $^3\overrightarrow{He}(\vec{e},e'n)pp$ scattering in quasi–elastic kinematics by measuring the transverse asymmetry, $A_\perp$, of the cross section. This quantity can be used to extract the G_E^n, as more precise high Q^2 G_M^n data becomes available. At this time, there is no accurate G_E^n data is available from double polarization measurements for Q^2 > 3.5 GeV^2.

Group members will participate in testing and calibration procedures of both electron and hadron side detector systems in testing facilities. As during E02-013 experiment YerPhI group member will play a key role in installation and maintenance of detectors in experimental hall. YerPhI group will be responsible for development and implementation of electronics for detectors, and will have a significant contribution into data analysis procedure.

References:
1. B. Wojtsekhowski, G. Cates, S. Riordan, et al., PR-09-016, Measurement of the Neutron Electromagnetic Form Factor Ratio G_E^n / G_M^n at High Q^2

<u>*A1.4 PR-09-019:*</u> *"Precision Measurement of the Neutron Magnetic Form Factor up to Q^2 = 18.0 (GeV/c)^2 by the Ratio Method"*

This experiment proposed to make a high-precision measurement of the neutron's magnetic form factor, G_M^n at Q^2 = 3.5, 4.5, 6.5, 8.5, 10.0, 12., 13.5, 16.0 and18.0 (GeV/c)^2 [1]. Little data on G_M^n exists in this kinematic range and the existing data have large systematic uncertainties.

YerPhI group members were responsible for the part of Monte-Carlo simulations needed for the proposal [2]. We will have a significant contribution in preparation and installation of the experimental apparatus in hall. Yerevan group will play a significant role in calibration, maintenance of experimental setup during experiment, and will be involved in data analysis.

References:
1. B. Quinn, B. Wojtsekhowski, R. Gilman, et al., PR-09-019, Precision Measurement of the Neutron Magnetic Form Factor up to Q^2 = 18.0 (GeV/c)^2 by the Ratio Method.
2. S. Abrahamyan, GEANT-4 simulation with saturation effect in light output.

A2. Design and development of apparatus and software

YerPhI group members will participate in upgrade, design and development of experimental apparatus and software for upcoming experiments in Hall A. Those activities are:

<u>*A2.1 Design and development of apparatus*</u>

a) Upgrade of High Resolution Spectrometers (HRS) – upgrade of VDC amplifier cards and Focal Plane Polarimeter, upgrade of front end electronics and trigger electronics
b) Design and development of high rate FASTBUS trigger system for GEp and A1n experiments, development of test setup to test FASTBUS ADC and TDC modules.
c) Design and development of front end electronics for Super BigBite and BigBite.

<u>*A2.2 Software design and development*</u>

a) Development of MC simulation software to understand efficiencies for Super BigBite and BigBite spectrometers.
b) Development of MC simulation software to estimate trigger rates for different configurations of upcoming 12 GeV experiments
c) Development of calibration software for BigBite electromagnetic calorimeter.
d) Development of DAQ software to make possible operate FASTBUS trigger system at high rate needed for GEp and A1n experiment.
e) Development of online and offline data analysis software specifically for GEn-2 experiment (as a continuation of previous work, done by group members for GEn-1).

A3. Proposed schedule of the project in Hall A for 2013-2018

Year 2013:

- HRS electronics upgrade
- MC studies of HCal for SBS and ECal for GeP-5 experiment
- Development and testing of high rate FASTBUS trigger system

Year 2014:

- HRS maintenance and commissioning for 12 GeV experiments

- Building of high rate FASTBUS trigger system.
- Monte-Carlo studies of background rates
- Participation in SBS construction

Year 2015:
- Participation in SBS construction and installation
- Online analysis and calibration software development for 12 GeV experiments

Year 2016:
- Participation in commissioning experiments
- Participation in maintenance of SBS, BigBite and HRS detector systems
- Online analysis and calibration of SBS, BigBite and HRS

Year 2017:
- Participation in 12 GeV experiments
- Data analysis and calibration software development
- Participation in maintenance of SBS, BigBiteand HRS detector systems

Year 2018:
- Participation in 12 GeV experiments
- Data analysis and calibration software development
- Participation in maintenance of SBS, BigBite and HRS detector system

2.2.Collaboration with HALL B at JLAB

The ANSL group working with Hall B at Jefferson Lab will continue to contribute in the detector development and construction for the CLAS12 detector in Hall-B, in the commissioning and calibration of apparatus, and will also perform analysis of physics data from both CLAS and future CLAS12 experiments. The group is also actively participating in the non-CLAS collaboration, HPS experiment, which will the first experiment to run in Hall B in 12 GeV era.

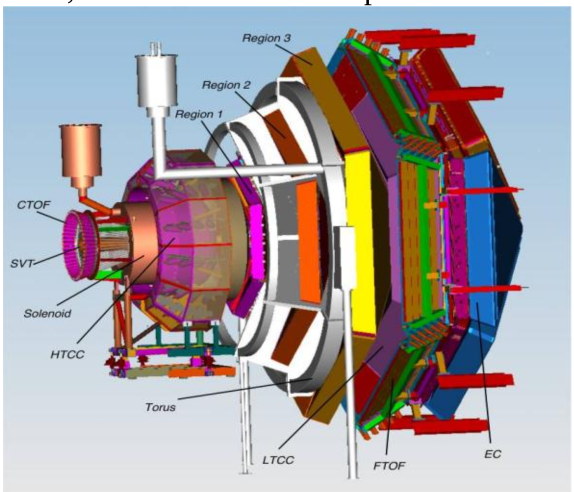

Fig.B.1: Schematic view of CLAS12 detector

B1. Hardware development projects

<u>B1.1</u>: Preshower calorimeter (PCAL)

The CLAS12 detector (Fig.B.1) is a complex detector. One of new components of CLAS12 is the preshower calorimeter. It is composed of 6 modules, each module has a triangular shape, and composed of layers of scintillator strips sandwiched with lead sheets. During 2013 the quality testing of scintillator and fibers, and the assembly of all 6 modules have been completed. The modules are tested with cosmic rays and pending for installation. We will take part in the calibration and commissioning of the detector.

<u>B1.2</u>: High threshold Čerenkov counter (HTCC) and Ring imaging Čerenkov Counter (RICH)

During 2013-2016 YerPhI group will participate in the construction, installation, calibration and commissioning of the High Threshold Čerenkov Counter (HTCC) for CLAS12 spectrometer (see Fig.B.2). We will take part in design, construction and installation of the Light weight Ellipsoidal Mirror for the future planned Ring Imaging Čerenkov Counter (RICH) which will replace Low Threshold Čerenkov Counter (LTCC). Activities for RICH mirror will start at 2016.

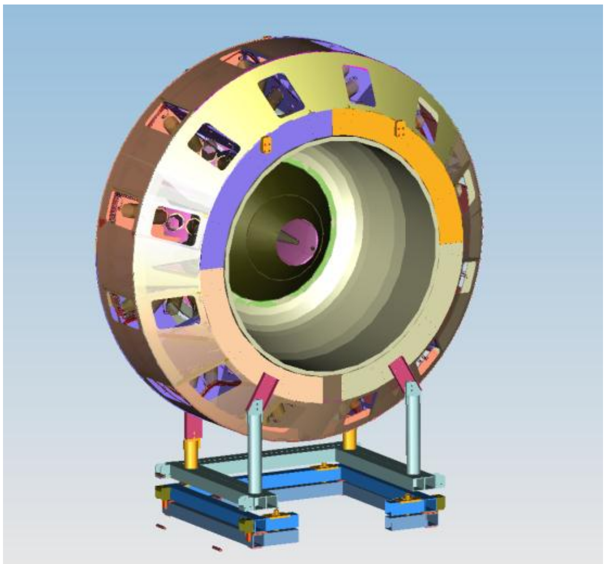

Fig.B.2 High Threshold Čerenkov Counter

B1.3: Slow controls

The group will participate in the development and commissioning of slow control system for Hall B. The main areas would be the integration of high and low voltage systems, monitoring and control of JLab developed Flash ADC, TDC and discriminator VME boards, the slow controls for HPS experiment.

B2. CLAS 6 GeV era experimental data analysis projects

B2.1: Study of inclusive A(e,e') scattering at $x_{Bj}>1$ region using eg2 data set

The analysis of early CLAS electroproduction data with nuclear targets ^{3}He, ^{4}He, ^{12}C and ^{56}Fe (e2a and e2b experiments) showed that in the region of $x_{Bj}>1$, the cross-sections ratios for different nuclei. It has been demonstrated that this scaling is due to Short Range Correlations (SRC) of nucleons in nuclei. The 2 and 3-nucleon correlations were observed in the regions $1<x_{Bj}<2$ and $2<x_{Bj}<3$, respectively. Also the scaling factors and scaling onset positions were measured. The analysis of eg2 experiment data will extend that range with data from ^{208}Pb nuclear target, and will allow direct comparison with experimental data from ^{2}H. The extension of the range will allow to verify and understand the fine structure of the scaling plateau, and its dependence of the atomic number of target nuclei.

B2.2: Search for nucleon modification on deuteron using e6 data set

The study of electron scattering on deuteron in the inclusive channel will have benefit over semi-exclusive D(e,e'p)n with higher statistics. In the proposed analysis determination of SRC states are done using measured parameters of the scattered electron. This approach with higher statistics will be more sensitive in the search of nucleon modification effects. Modification effects will be derived by comparing cross-sections of SRC states with quasi-free ones by studying its dependence on the virtuality of interacting photon (Q^2).

B2.3: Eta meson quasi-free photo-production off the deuterium

Precise data on quasi-free photoproduction of η mesons on the deuteron have been obtained at the Bonn ELSA facility [1]. The η-mesons have been detected in coincidence with recoil proton and neutron. The total cross section for quasi-free η-photoproduction of the neutron reveals, even without correction for Fermi motion, a pronounced bump-like structure around 1 GeV of incident photon energy, which is not observed for the proton. This structure is even narrower in the invariant mass spectrum of the η-neutron pairs. Strong efforts have recently been undertaken at various facilities (GRAAL in Grenoble [2], ELSA in Bonn [3] and LNS in Sendai [4]) to extract reliable results for the $\gamma n \rightarrow n\eta$ reaction at higher incident photon energies.

In this project, analysis of η-photo-production on deuterium will be performed using CLAS data taken in 2004 with up to 3.6 GeV tagged photons and 24 cm long liquid deuterium target. The dependence of the η-photoproduction cross section on the incident photon energy as well as on η-production angle will be studied. Data from two data sets of CLAS/g10 experiment carried out with high (CLAS torus field setting 3375A) and low-field (2250A) settings will be used to study the following reactions:

1. $\gamma d \rightarrow \eta(np) \rightarrow \pi^+\pi^-\pi^0(np)$,
2. $\gamma p \rightarrow \eta p(n) \rightarrow \pi^+\pi^-\pi^0 p(n)$,
3. $\gamma n \rightarrow \eta n(p) \rightarrow \pi^+\pi^-\pi^0 n(p)$,
4. $\gamma d \rightarrow \eta(np) \rightarrow \pi^+\pi^-\pi^0 d$.

The cross section on the neutron will be obtained by subtraction of $(\pi^+\pi^-\pi^0 p)$ and $(\pi^+\pi^-\pi^0 d)$ cross sections from the inclusive cross section. G10 data will not have enough statistics for the detected neutron final state at wide range of kinematics, but at few points eta photo-production cross section on the neutron will be extracted using events with detected neutron, and will be compared with extracted cross-section with inclusive measurements.

References:

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2. *V. Kuznetsov et al, Phys. Lett. B 647, 23 (2007).*
3. I. J. et al., *Phys. Rev. Lett. 100,* 252002 (2008).
4. F. M. et al., *Prog. Theor. Phys. Suppl. 168,* 90 (2007).

B2.4: *Coherent photo-production of proton and antiproton pair on deuterium target*

The main objective is to study claims of several groups on the existence of exotic states, one below the $p\bar{p}$ production threshold (1.93 GeV) and 2 above it at about 2.02 and 2.2 GeV. To measure the invariant mass spectrum of proton-antiproton pair, two coherent photo-production reactions are studied: the exclusive $d(\gamma,p\bar{p}d)$ and inclusive $d(\gamma,\bar{p}d)p$. The coherent photo-production on deuterium is chosen instead hydrogen, because there is no ambiguity about detected proton in final state. Otherwise it is not possible to distinguish target and decay protons. Coherent on the deuteron, only the t-channel production of $p\bar{p}$ is allowed. For this analysis the data set of the CLAS eg3 experiment is used, where up to 5.75 GeV bremsstrahlung tagged photon beam was incident on 40 cm long liquid deuterium target. Due to relatively high transferred momentum at these beam energies in the above reactions the deuteron is energetic enough to be detected. Other background reactions those could mimic our reactions of interest will be studied as well. These background reactions are $\gamma d \rightarrow \pi^+\pi^- d$, $\gamma d \rightarrow KKd$, $\gamma d \rightarrow pp\pi$.

B2.4: *The photo-production of ρ(770) and ω(782) mesons from deuterium*

Coherent production of ρ(770) and ω(782) mesons deuterium will be used to study meson-nucleon scattering process. The research will be done using data from the CLAS g10 experiment. This analysis will cover a photon energy range from the reaction threshold to 3.6 GeV and in a large range of transferred momentum. Final states with $\pi^+\pi^- d$ and $\pi^+\pi^-\pi^0 d$ will be used to extract cross section of coherent meson production as a function of energy and transferred momentum. The ρ(770) and ω(782) mesons will be identified in invariant mass of pions.

B3.Participation in development of Hall B physics program at CEBAF 12 (2013-2018)

<u>B3.1</u>*: Timelike Compton Scattering and J/Ψ photoproduction on the proton in e^-e^+ pair production with CLAS12 at 11 GeV(PR12-12-001). (Spokespersons: P. Nadel-Turonski, M. Guidal, T. Horn, R. Paremuzyan and S. Stepanyan)*

A significant part of approved experimental proposals in the JLab 12 GeV upgrade, are focused on the studies of Generalized Parton Distributions (GPD). Formalism of GPDs allow to obtain new kind of information that can not be accessed by elastic or Deep-Inelastic Scattering (DIS) experiments. The GPDs offer the exciting possibility of the first ever spatial imaging of the quark waves inside the proton [1–6]. The correlation of transverse spatial and longitudinal momentum information contained in the GPDs provides a new tool to evaluate the contribution of quark orbital angular momentum to the proton spin [3]. One of the possible channels to access GPDs is Time-like Compton Scattering (TCS) . As shown in [7]angular distribution of lepton pairs in TCS offers a direct access to the so called Compton Form Factors (CFF) those are defined in terms of GPDs. Main physics motivations for TCS [9] measurement are following:

- TCS measurement can be a good test of the universality of GPDs, since they should not depend on the process.
- TCS provides straightforward access to the Re/Im parts of CFF with unpolarized or circularly polarized photon beams.
- Differential cross section measurement of TCS will provide important input to global fits for extracting GPDs [8]

Measurement of J/Ψ cross-section near threshold will provide important insight to these studies, it will provide new information on the gluonic structure of the nucleon and it can potentially be one of the first CLAS12 publications. The ANSL group has a significant contribution to this proposal, and will actively participate in the preparation of the experiment, data taking, and analysis of data.

References:
1. D. Mueller, D. Robaschik, B. Geyer, F.M. Dittes, J. Horejsi. Fortsch.Phys. 42 (1994) 101, hep-ph/9812448
2.XiangdongJi, Deeply virtual Compton scattering. Phys.Rev. D55 (1997) 7114-7125, hep-ph/9609381
3.XiangdongJi, Phys.Rev.Lett. 78 (1997) 610-613, hep-ph/9603249
4.XiangdongJi, W. Melnitchouk , X. Song, Phys.Rev. D56 (1997) 5511-5523 hep-ph/9702379
5. A.V. Radyushkin, Phys.Rev. D56 (1997) 5524-5557, hep-ph/9704207
6. A.V. Radyushkin , Phys.Lett. B380 (1996) 417-425, hep-ph/9604317
7. E. R. Berger, M. Diehl, B. Pire Eur. Phys. J. C 23 (2002) 675
8. M. Guidal. Eur. Phys. J. , A37:319–332, 2008, arXiv:0807.2355 [hep-ph].
9. http://www.jlab.org/exp_prog/proposals/12/PR12-12-001.pdf

<u>B3.2:</u> *Heavy Photon Search (HPS) experiment (PR12-11-006)*

The goal of this experiment to search for new heavy vector boson(s), aka ”heavy photons” or “dark photons” or “hidden sector photons”, in the mass range of 20 MeV/c^2 to 1000 MeV/c^2. Heavy photons mix with the ordinary photon through kinetic mixing, which induces their weak coupling to electrons, where $\varepsilon \sim 10^{-3}$. Heavy photons in this mass/coupling range are expected on very general theoretical grounds, and motivated by recent astrophysical evidences, suggesting they might mediate dark matter annihilations and/or interactions with ordinary matter. Since they couple to electrons, heavy photons are radiated in electron scattering and can subsequently decay into e^+e^- which can be observed above the copious QED trident background as narrow resonances. For suitably small couplings, heavy photons travel detectable distances before decaying, providing a second signature. The HPS experiment exploits both these signatures to search for heavy photons over a wide range of couplings, $\varepsilon^2 > 10^{-10}$, and masses, using a new compact, large acceptance forward spectrometer, silicon microstrip vertex tracker, $PbWO_4$

electromagnetic calorimeter, and muon system.

B4. Proposed schedule of the project in Hall B for 2013-2018

- Year 2013:
  - Analysis of CLAS experimental data
  - Assembly, quality control and testing of PCAL modules
  - Construction of HTCC
  - Drivers for high and low voltage systems
- Year 2014:
  - Analysis of CLAS experimental data
  - Construction, installation, commissioning, calibration of HTCC
  - Finalizing the EPICS drivers for JLab developed discriminator, FADC and TDC VME boards
  - Participation in the development of slow control system for HPS experiment
  - Participation in the commissioning and data taking of HPS experiment
  - Participation in the installation, commissioning and calibration of CLAS12
- Year 2015:
  - Analysis of CLAS experimental data
  - Participation in the installation, commissioning and calibration of CLAS12
  - Participation in the maintenance of online software
- Year 2016:
  - Participation in the CLAS12 experiments
  - Analysis of CLAS & CLAS12 experimental data
  - Participation in the maintenance of online software
  - Participation in the design, construction and installation of the Lightweight Ellipsoidal Mirror for RICH
- Year 2017:
  - Participation in the CLAS12 experiments
  - Analysis of CLAS & CLAS12 experimental data
  - Participation in the maintenance of online software
  - Participation in the design, construction and installation of the Lightweight Ellipsoidal Mirror for RICH
- Year 2018:
  - Participation in the CLAS12 experiments
  - Analysis of CLAS & CLAS12 experimental data
  - Participation in the maintenance of online software
  - Participation in the design, construction and installation of the Lightweight Ellipsoidal Mirror for RICH

2.3. Collaboration with HALL C at JLAB

C1. Design, construction & commissioning of experimental apparatus in Hall C (2013-2016)

YerPhI group will design and build lead-glass electromagnetic calorimeter and aerogel Čerenkov detector for SHMS, and Neutral Particle Spectrometer based on multichannel PbWO calorimeter.

C1.1: Electromagnetic Calorimeter for Super High Momentum Spectrometer (SHMS)

With CEBAF-12 GeV upgrade Hall C will build a new SHMS spectrometer which will allow to detect particles of up to 11 GeV/c momentum at the smallest scattering angle of 5.5° [1]. Note, YerPhI group have designed and built calorimeters for HMS and SOS spectrometer [2]. It is natural now for YerPhI group to take responsibility and lead construction of calorimeter for the SHMS. To select the optimal version of the calorimeter MC simulation based on GEANT package has been performed [3, 4].

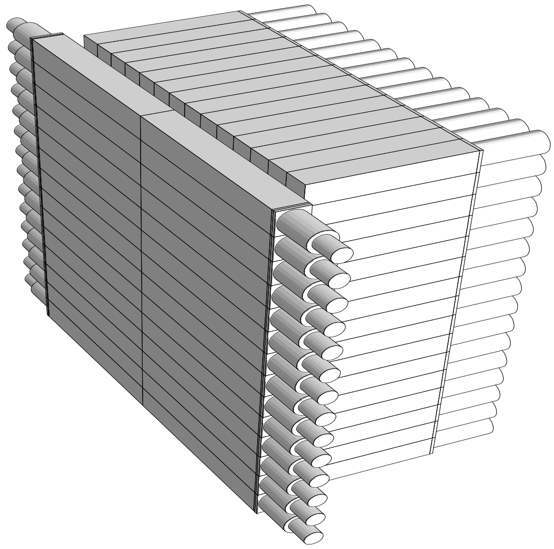


Fig.C1.1: Schematic view of SHMS calorimeter. Beam from left to right, Preshower in the front.

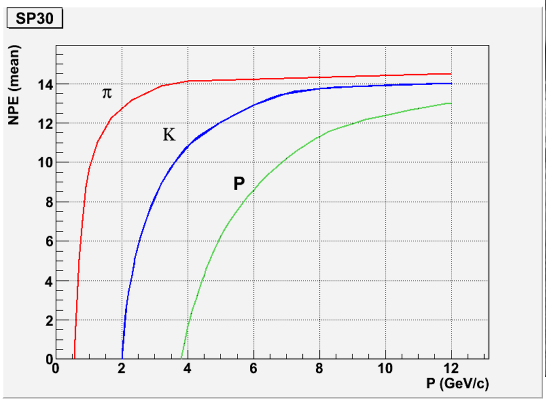
In 2013-2014 we will finish construction of Preshower and will complete revision of all blocks of Shower. Cosmic measurements will be used to equalize PMT amplitudes and to study amplitude-coordinate dependence. In 2014-2015 will develop the software and electronic read-out, and calibration codes. Installation in the SHMS are scheduled in 2015.

References:

1. *Hall-C Conceptual Design Report, Hall C 12 GeV Upgrade. JLab, Nov. 27, 2002.*
2. *The lead-glass electromagnetic calorimeters for magnetic spectrometers in Hall C at Jefferson Lab, H. Mkrtchyan et al, Nucl. Instr. Meth. A719, 85 (2013).*
3. *A. Mkrtchyan and V. Tadevosyan, Monte Carlo Simulation for SHMS Calorimeter. Part I (Version 2a-2d). JLab Tech.Note, JLAB-TN-06-035, May 2006 (12 pages).*
4. *A. Mkrtchyan, V. Tadevosyan et al., Monte Carlo Simulation for SHMS calorimeter. Part II. JLab Tech. Note, JLAB-TN-07-005, Feb 2007 (11 pages).*

<u>C1.2</u>: Construction of Aerogel Čerenkov detector for SHMS spectrometer

With CEBAF-12 GeV upgrade Hall C will build a pair of aerogel Čerenkov detectors (n=1.030 and 1.020) for the SHMS spectrometer to improve kaon identification capability, which is essential for many approved experiments at 12 GeV [1, 2]. In 2012 members of ANSL group in collaboration with CUA performed revision and studies of the PMTs and aerogel materials which was taken from the BLAST aerogel detectors, and will be use in SHMS aerogel detectors.



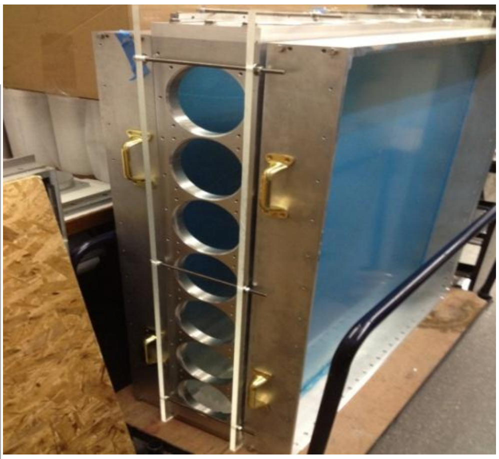


Fig.C1.2: (Left) Threshold behavior of number of photoelectrons for aerogel with n=1.030 and 10 cm thickness. (Right) Partly assembled SHMS aerogel detector's diffusion box and tray.

In the framework of this project in 2013 -2014 we will finish assembling of the aerogel detector with an index of refraction n=1.030 and will start full scale cosmic studies. Cosmic data will be used for equalization of PMT amplitudes (gains) and for the NPE-coordinate dependence studies. In 2014 -2015 will finish assembling of the aerogel detector with the lowest index of refraction (n=1.020 or n = 1.015) and will continue cosmic tests. In 2015 will develop the necessary software and electronic read-out and calibration codes. Installation and commissioning are scheduled in 2016 -2017.

References:

1. *Studies of the L-T Separated Kaon Electroproduction Cross Section from 5-11 GeV, JLab proposal E12-09-011, Spokespersons: T. Horn, G. Huber and P. Markowitz*
2. *Transverse Momentum Dependence of Semi-Inclusive Pion (Kaon) Production, JLab proposal E12-09-017, Spokespersons: R. Ent, H. Mkrtchyan and P. Bosted*
3. *The aerogel threshold Cherenkov detector for High Momentum Spectrometer in Hall C at Jefferson Lab, R. Asaturyan et al., Nucl. Instrum. Meth. A548, 364 (2005)*

<u>C1.3:</u> Design and construction of Neutral Particle Spectrometer for Hall C (2014-2017)

Newly approved experiment PR12-13-007 "Measurement of Semi-inclusive π^0 Production" [1], proposed by YerPhI group in collaboration with JLab and CUA, required coincidence detection of scattered electrons and photons from the decay of neutral pions. Electrons we will detect with existing HMS, and photons with Newtral Particle Spectrometer (NPS) [1], which based on multichannel $PbWO_4$ calorimeter. YerPhI group will design and built NPS in collaboration with JLab and CUA. This system consists of the sweeping magnet, a Neutral Particle Detector based on $PbWO_4$ blocks (as PRIMEX [2]), and a temperature controlled frame.

In 2014-2015 YerPhI group members will conduct MC studies of performance of the NPS, including background and pileup studies. In 2015-2016 we will build a prototype of the calorimeter to study radiation effects and UV curing. We will design calorimeter and its thermo-stabilization system in 2016-2017. Installation of the NPS are scheduled for 2018.

References:

1. Neutral Particle Spectrometer Facility in Hall C. Proposal to JLab PAC40, May 5, 2013

2. Performance of the Primex Electromagnetic Calorimeter, M. Kubantsev et al., arXiv:physics/0609201

C2. Participation in development of Hall C physics program at JLab 12 GeV (2013-2018)

Members of ANSL group will play active role in development of Hall C physics program at 12 GeV energies. We will perform MC studies of approved experiments proposed by ANSL group in collaboration with JLab and CUA, to optimize their kinematic and background conditions.

<u>C2.1</u>: Measurement of the ratio $R = \sigma_L/\sigma_T$ in charged pion Semi-Inclusive DIS production (JLab proposal PR12-06-104, spokespersons: Rolf Ent and Hamlet Mkrtchyan)

The experimental observation of the ratio $R = \sigma_L/\sigma_T$ in deep-inelastic scattering provided the first evidence of the spin-1/2 nature of the partons. More stringent test of the quark-parton model arises from semi-inclusive pion electroproduction. In the asymptotic limit, in the model where the electro-produced pions are the fragmentation products of the spin-1/2 partons, the ratio $R = \sigma_L/\sigma_T$ disappears like $1/Q^2$, like in the inclusive case. For the pion electroproduction, the recently developed handbag diagrams factorizing these processes into a hard-scattering process and a soft process, anticipate a behavior $R = \sigma_L/\sigma_T \sim Q^2$ at constant x, in the asymptotic limit. At large P_T is expected that $R_{SIDIS} \approx R_{DIS}$. The first experimental verification that duality and low-energy factorization for SIDIS pion electroproduction holds down to the nucleon resonances region has been obtained in E00-108 [1, 2] which was lead by YerPhI group.

It is of prime importance to map the behavior of R_{SIDIS} versus the transverse momentum P_T. YerPhI group in collaboration with JLab has initiated new proposal E12-06-104 [3] to carry out

the measurements of the ratios of longitudinal to transverse cross sections **R = σ_L/σ_T** in pion electro-production in semi-inclusive deep inelastic scattering region, with extensions into the exclusive region at 12 GeV energies.
Simultaneously we will measure inclusive (e,e'x) cross sections to determine R = σ_L/σ_T for DIS and compare with the SIDIS data. Our measurements will map: i) R as a function of z at x = 0.20 and Q^2 = 2.0 GeV^2; ii) R^H as a function of z at x = 0.40 and Q^2 = 4.0 GeV^2, and iii) R^H as a function of P_T at x = 0.30 and Q^2 = 3.0 GeV^2. The projected uncertainties for these measurements are shown in Fig.C2.1.

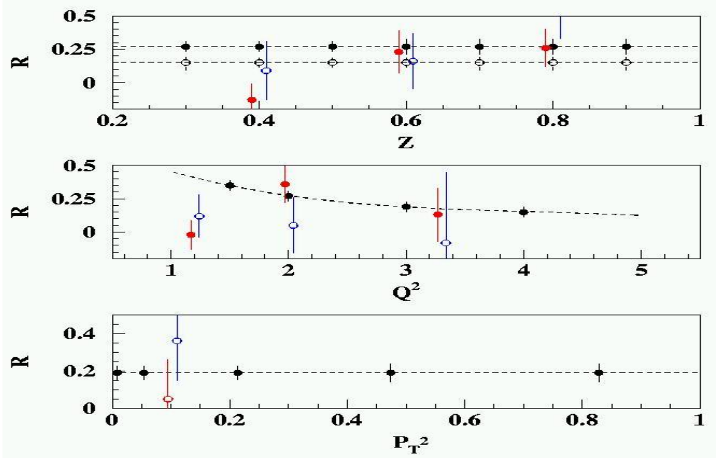


Fig.C2.1: Projected uncertainties for the proposed measurements assuming $R_{SIDIS} = R_{DIS}$.

This experiment is scheduled after 2017, when 11 GeV energy beam and detectors of the HMS and SHMS spectrometers will be commissioned and well understood. During 2014-2017 we will perform MC simulations to study background, expected systematic errors, and optimize kinematics of the measurements. We will prepare all programs for the analysis.

References:

1. *T. Navasardyan, G. Adams et al., The Onset of Quark-Hadron Duality in Pion Electroproduction, Phys. Rev. Lett.* ***98:*** *022001-(1-5), (2007); arXiv:hep-ph/0608214.*
2. *H. Mkrtchyan, P. Bosted, C. Adams et al., Traansverse Momentum Dependence of Semi-Inclusive Pion Production, Phys. Lett.* ***B 665****, 20-25 (2008); arXiv:hep-ph/709.3020 (2007).*
3. *R. Ent and H. Mkrtchyan (spokesperson), Measurement of the ratio R = σ_L/σ_T in Semi-Inclusive Deep-Inelastic Scattering, TJNAF experiment E12-06-104*

<u>C2.2</u>*: Transverse Momentum Dependence of Semi-inclusive Pion Production (PR-09-17)*
(Spokespersons Peter Bosted, Rolf Ent and Hamlet Mkrtchyan)

A central question in the understanding of nucleon structure is the orbital motion of partons. Precise studies of the spin sum rule suggest that the net spin carried by quarks and gluons is relatively small, and therefore the net orbital angular momentum must be significant.
Final transverse momentum of the pion P_t arises from convolution of the struck quark transverse momentum k_t with the transverse momentum generated during the fragmentation p_t, with the imposed condition $\vec{P}_t = z\vec{k}_t + p_t$ (see diagram in Fig.C2.2). Note, the first verification of low-energy factorization for SIDIS electroproduction of pions has been obtained in experiment E00-108 [1, 2] which was proposed and lead by YerPhI group. For the kinematic of E00-108 experiment (P_t< 0.4 GeV) we extracted the P_t^2 dependence of cross section [3] (Fig.C2.2).

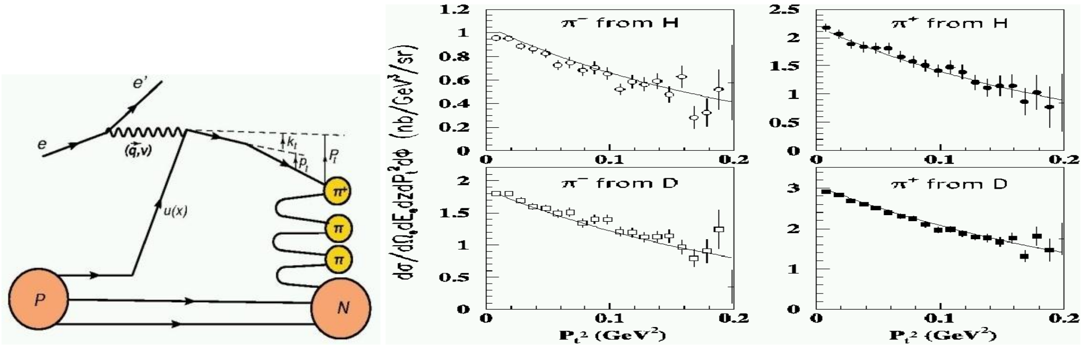


Fig.C2.2: (Left)- Schematic diagram of semi-inclusive pion electroproduction within a factorized QCD model in the lowest order of α_s. (Right)- The P_t^2 dependence of differential cross-section per nucleus for $\pi^{\pm}$ production in hydrogen and deuterium targets at $\langle z\rangle = 0.55$ and $\langle x\rangle = 0.32$.

We allow separate widths for u (μ_u) and d (μ_d) quarks, and for favored D^+ (μ_+) and un-favored D^- (μ_-) fragmentation functions. With these assumptions the fit of our data show the same p_t width for fragmentation functions, and a large k_t width for d quarks than for u quarks. In PR-09-017 we propose new sets of measurements of semi-inclusive pion electroproduction cross section and ratio of charged pions versus transverse momentum at 11 GeV energy [4]. We will map the P_t dependence for semi-inclusive electroproduction of $\pi^{\pm}$ from both proton and deuterium targets over the range 0.2 < x < 0.5, 2 < Q^2< 5 GeV^2, 0.3 < z < 0.5, and P_t< 0.5 GeV, with the Hall C HMS-SHMS magnetic spectrometer coincidence pair. The chosen setup will allow precise determination of the P_t dependence of the ratios of π^+ and π^- cross sections. This experiment will use beam energies up to 11 GeV to map out kinematic region 0.2 < x < 0.5, 0.3 < z < 0.5, 1.8 < Q^2< 4.5 GeV^2 and P_t up to 0.5 GeV/c. We will keep systematic errors for the π^+/π^- ratios < 1%. With ~10 times less statistics will do measurements for $K^{\pm}$.

In the framework of this proposal in 2013-2017 we will perform series of MC simulations to study physics backgrounds, sources of systematic errors, and to optimize kinematics of the measurements. We will prepare necessary programs for on-line and off-line analysis. The experimental measurements are scheduled after 2017, when 11 GeV energy beam, all the detectors of the HMS and SHMS spectrometers will be commissioned and well understood.

References:

1. *TJNAF Experiment E00-108, spokespersons: R. Ent, H. Mkrtchyan, G. Niculescu, 2003.*
2. *T. Navasardyan, G. Adams et al.,Phys. Rev. Lett.* ***98:*** *022001-(1-5), (2007).*
3. *H. Mkrtchyan, P. Bosted, C. Adams et al., Phys. Lett.* ***B 665****, 20-25 (2008).*
4. *TJNAF proposal PR12-09-017,spokespersons: H. Mkrtchyan, P. Bosted, R. Ent, 2009.*

<u>C2.3</u>*: Measurement of Semi-inclusive π^0 Production as validation of Factorization (Proposal PR12-13-007, spokespersons R. Ent, T. Horn, H. Mkrtchyan and V. Tadevosyan)*

The goal of the PR12-13-007 proposal [1] is to check the factorization of SIDIS cross section into quark distribution f(x) for initial nucleon and fragmentation function D(z) of final π^0. The precision of such a factorization is crucial for experimental determination of fragmentation functions and applications of QCD theory to meson production experiments. In E00-108 [2] we measured ^{1,2}H(e, e'$\pi^{\pm}$)X cross sections at x=0.3. The data showed the onset of the low-energy factorization [3, 4]. But, the partonic interpretation is only as good as the experimental validation of (x, z) factorization, which required neutral-pion cross section data to accompany anticipated charged-pion cross section data. The use of π^0 for this purpose has several advantages: absence of pion contamination generated from ρ mesons, and reduced nucleon resonance contribution.

In PR12-13-007 we will measure the SIDIS cross section of π^0 production off the proton, and map of the P_T dependence (P_T < 0.5 GeV), to validate flavor decomposition and the k_T dependence of u and d quarks. We will detect scattered electrons in HMS and photons from π^0 decay in Neutral Particle Spectrometer (NPS) [6]. The NPS is located to the left from the beam-line, while the HMS is on the right side. The NPS is envisioned as a facility in Hall C to allow for precision cross section measurements of neutral particles (γ, π^0).

In the framework of this proposal during 2013-2017 we will perform MC simulations to study physics backgrounds, systematic errors, and to optimize kinematics of measurements. We will prepare the necessary programs for the analysis. The experiment can be scheduled in 2017-2018, when NPS system will be constructed and commissioned (about NPS see section C1.3).

References:

1. *Measurement of Semi-inclusive π^0 Production as validation of Factorization, JLab proposal PR12-13-007, Spokespersons: R. Ent, T. Horn, H. Mkrtchyan and V. Tadevosyan.*
2. *TJNAF Experiment E00-108, spokespersons: R. Ent, H. Mkrtchyan, G. Niculescu.*
3. *T. Navasardyan, G. Adams et al., Phys. Rev. Lett.* ***98:*** *022001-(1-5), (2007).*
4. *H. Mkrtchyan**,** P. Bosted, C. Adams et al., Phys. Lett.* ***B 665****, 20-25 (2008).*
5. *Transverse Momentum Dependence of Semi-inclusive Pion Production ,JLab proposal PR-09-17, spokespersons P. Bosted, R. Ent and H. Mkrtchyan.*
6. *Neutral Particle Spectrometer Facility in Hall C. JLab PAC40 proposal, NPS Collaboration.*

C3. Commissioning of Hall C experimental apparatus at JLab 12 GeV energies (2016-2018)

Good candidates for commissioning experiments are experiments that require beam energies up to 11 GeV, currents in 10-80 μA, variety of liquid and solid targets (LH2 and LD2, Al, Be, B, C, …). As a good candidates for commissioning are selected following experiments:

E12-06-107 (CT): "The Search for Color Transparency at 12 GeV", spokespersons: D. Dutta and R. Ent [1]. This coincidence experiment and will measure A(e,e'p) and A(e,e'π^+) cross-sections on ^{1}H and ^{12}C with 80 μA and 8.8-11.0 GeV energies beam for Q^2 = 8, 10, 12, 14 and 16.4 GeV^2 to extract the proton and pion nuclear transparencies in the nuclear medium.

E12-10-002 (F2): "Precision measurements of the F_2 structure function at large x in the resonance region and beyond", spokespersons: S. Malace, I.Niculescu, C. Keppel[2]. This experiment will extend proton and deuteron F2 structure function precision measurements to larger x and Q^2 by measuring H(e,e') and D(e,e') cross sections in the resonance region and beyond up to Q^2~17 GeV^2 and x ~0.99., and extract F_2^p and F_2^d. This single-arm experiment will be used for commissioning optics and detectors of the SHMS and HMS spectrometers.

E12-10-003 (DED): "Deuteron Electro-Disintegration at Very High Missing Momentum", spokespersons: W. Boeglin and M. Jones [3]. High-energy, exclusive electro-disintegration of the deuteron is considered as the most effective process in probing two nucleon dynamics at short space time distances. This experiment will provide for the first time data in this kinematic regime which are of fundamental importance to the study of short range correlations in nuclei.

E12-10-008 (EMC): "Detailed studies of the nuclear dependence of F2 in light nuclei", spokespersons: A. Daniel, J. Arrington and D. Gaskell [4]. The question of the nuclear dependence of the quark structure of nuclei, as measured in DIS, has been of great interest since the EMC found significant deviation between the structure functions of heavy (iron) and light (deuterium) nuclei. The origin of EMC effect not yet well understood. The goal of E12-10-008 experiment is accumulate results for new light nuclei and extract F_{2n}/F_{2p} ratio, and expand examination of EMC-SRC correlation. It will take Q^2 scan for scaling studies. This "EMC" experiment will use inclusive electron scattering from ^{1}H, ^{2}H, ^{9}Be, ^{10}B, ^{11}B, ^{12}C and Al targets to measure C/D EMC ratio at 20°, 25° and 30°, and to look at Q^2 dependence of this ratio.

References:

1. *The Search for Color Transparency at 12 GeV, JLab proposal E12-06-107, D. Dutta and R. Ent spokespersons*
2. *Precision measurements of the F_2 structure function at large x in the resonance region and beyond, JLab proposal E12-10-002, S. Malace, I. Niculescu and C. Keppel spokespersons*
3. *Deuteron electro-disintegration at very high missing momenta, JLab proposal E12-10-003, W. Boeglin and M. Jones spokespersons.*

4. *Detailed studies of the nuclear dependence of F_2 in light nuclei, JLab proposal E12-10-008, J. Arrington, A. Daniel and D. Gaskell spokespersons*

C4: Proposed schedule of the project in Hall C for 2013-2018
Year 2013:
- Cosmic test of the SHMS Preshower
- Studies of the component, design and construction of the Aerogel detector with n=1.030
- MC studies and design of the aerogel detector with n=1.020
- Development of calibration codes for the HMS and SHMS spectrometer calorimeters

Year 2014:
- Cosmic studies of the SHMS Aerogel detector n=1.030
- Construction of the aerogel detector with n=1.020
- MC studies and design of Neutral Particle Spectrometer
- MC studies for estimation of the background conditions and corrections for charged and neutral pion electroproduction experiments SIDIS

Year 2015:
- Construction of the PbWO calorimeter prototype for studies of the radiation effects and curing
- Installation of SHMS Preshower and Shower in detector hut, cabling, electronics, cosmic tests

Year 2016:
- Participation in commissioning experiments
- Commissioning of the SHMS calorimeter

Year 2017:
- Participation in Hall C commissioning experiments
- Commissioning of the aerogel detector n=1.030
- MC studies to optimize kinematics and corrections for SIDIS $\pi^{\pm}$ and π^{0} experiments

Year 2018:
- Installation of the aerogel detector in SHMS hut and its commissioning
- Participation in Hall C commissioning experiments
- Design and beginning of construction of the NPS

2.4.Collaboration with Hall D at JLAB

The planned upgrade of CEBAF accelerator is designed to increase the maximum electron beam energy from 6 GeV to 12 GeV, and to construct a new experimental Hall D. It will house a new complex detector system called **GlueX** designed to search for exotic mesons, to perform meson spectroscopy over a range of masses up to ~3 GeV and conduct other experiments in nuclear and particle physics.
The ANSL group in Hall D has an experience in developing and maintaining the experimental control systems using **EPICS** framework, and is making a significant contribution to the development of the control and monitoring system of Hall D. In the future the group will concentrate on the commissioning of GlueX, and on calibration and analysis of the experimental data. The ANSL group will also contribute into the development of physics program in Hall D.

D1. Search for hybrid mesons and the study of light meson spectroscopy

The two flagship experiments in Hall D using GlueX detector are the E12-06-102, “Mapping the spectrum of light meson and gluonic excitations with linearly polarized photons” [1], and the E12-14-003, “An initial study of hadron decays to strange final states with GlueX in Hall D” [2], both geared towards studying in detail the spectrum of the light mesons.
Our understanding of how quarks form mesons has evolved within QCD, and we now expect a richer spectrum of mesons that takes into account not only the quark degrees of freedom but also the gluonic degrees of freedom

References:

1. *The GlueX Collaboration, "Mapping the Spectrum of Light Quark Mesons and Gluonic Excitations with Linearly Polarized Photons", GlueX-doc-1226, January (2006), http://argus.phys.uregina.ca/cgi-bin/public/DocDB/ShowDocument?docid=1226).*
2. *The GlueX Collaboration, "An initial study of hadron decays to strange final states wuthGlueX in Hall D", GlueX-doc-2198, May (2013), http://argus.phys.uregina.ca/cgi-bin/private/DocDB/ShowDocument?docid=2198*

D2. Design and development of experimental control system for Hall D (2013-2014)

D2.1: Online controls and monitoring of the electronics boards developed at JLab
The ANSL group has developed a prototype version of the EPICS support for the software for the discriminator boards which has already been tested during the beam tests in 2012. The EPICS support for the scaler readout from the JLab discriminator and the flash ADC boards is expected to be complete by October of 2014.
D2.2: Development of HV/LV system for Hall D/GlueX
The ANSL group is currently designing and developing the slow controls software for the voltage controls of FDC and CDC. This includes EPICS support, application software and a set of user graphical interface screens for the shift personnel and the detector experts. The final version of the voltage controls software needs to be completed by October of 2014 to be used during the GlueX commissioning. Some development versions of the software are needed for detector testing during the construction.
D2.3: Motion control of various devices
The GlueX experiment requires a linearly polarized photon beam which will be provided by the coherent bremsstrahlung process on an approximately 20 mm thick diamond radiator inserted into the 12-GeV primary electron beam ~100 m upstream of the GlueX target.

The ANSL group have developed prototype software for the motion of the ladders of the amorphous radiators and of the pair spectrometer converter as well as for the beam harp scans. We wil play a leading role in developing of the motorized slow controls applications for the beam-line components and the beam profile scans. The final software is expected to be ready for the beamline commissioning in the fall of 2014.

D3. Commissioning and calibration of Hall D/GlueX experimental apparatus (2014)
The group will commission the slow control system of Hall D, as well as it will take part in the commissioning and calibration of major components of the GlueX detector (BCAL, FCAL, Tagger, CDC, FDC & TOF). The detailed commissioning plan will be worked out later.

D4. Proposed schedule of the project in Hall D for 2013-2018

- Year 2013:
    - Development of HV/LV control system for Hall-D/GlueX
    - Development of motion control for Hall D beam line components
- Year 2014:
    - Finalizing the EPICS drivers for JLab developed discriminator, FADC and TDC VME boards
    - Participation in the commissioning of slow control system
    - Participation in the commissioning and calibrations of detectors
- Year 2015:
    - Participation in the detector calibration
    - Participation in the maintenance of online software
- Year 2016:
    - Participation in the data analysis
    - Participation in the maintenance of online software
- Year 2017:
    - Participation in the data analysis
    - Participation in the maintenance of online software

  - Participation in the upgrade of the GlueX with addition of planned RICH detector and Level-3 trigger system
- Year 2018:
  - Participation in the data analysis
  - Participation in the maintenance of online software

Appendix-I: List of the ANSL (YerPhI) members to carry out activities in Hall A+B+C+D

1. S. Abrahamyan - physicist, PhD
2. A. R. Asaturyan - physicist-engineer, PhD
3. N. Dashyan - physicist, PhD
4. Y. Ghandilyan - physicist, PhD Student
5. N. Gevorgyan - physicist
6. V. Kakoyan - physicist, PhD
7. G. Khachatryan - physicist, PhD Student
8. M. V. Khachatryan - PhD student
9. S. Mayilyan - engineer
10. A. H. Mkrtchyan - physicist-engineer, PhD
11. H. G. Mkrtchyan - physicist, doctor
12. K. Ohanyan - engineer
13. G. Sargsyan - engineer
14. A. Shahinyan - engineer, PhD
15. A. Simonyan - physicist, PhD Student
16. V. H. Tadevosyan - physicist
17. H. Voskanyan - physicist
18. M. Zhamkochyan - engineer
19. S. V. Zhamkochyan - physicist, PhD
20. Undergraduate students: 2-3 in 2014-2016
21. Graduate Master Students: 2-3 in 2017-2018
    Graduate PhD Students: 2-3 in 2015-2016

3. Fission and fragmentation of nuclei with real and virtual photon beams - collaboration with MAX-lab

We are proposing to perform a new study of $^{12}C(\gamma, 3\alpha)$ reaction by using tagged virtual photon beams at MAX-lab [1] and a dedicated active target system based on the low-pressure multi-wire proportional chambers (MWPCs) and Solid State Detectors (SSDs). The advantage of tagged virtual photon beam is a high intensity and monochromatic photons.

To detect the reaction events of the ^{12}C photodisintegration, we propose to use an experimental setup based on low-pressure MWPCs [2] and Si solid state detectors (SSDs). The experimental setup consists of four identical modules which form a rectangular box. The structure of an individual module is displayed schematically in Fig. 1. It consists of three layers. The first two layers are windowless MWPC planes which measure the position (x, y), hitting time (t) and ionization energy losses (dE/dx). The third layer is a Si detector which measures the kinetic energy of charged particles. The position information is used to reconstruct the trajectory of particles; timing information, dE/dx and kinetic energy - to identify charged particles and reconstruct reaction kinematics.

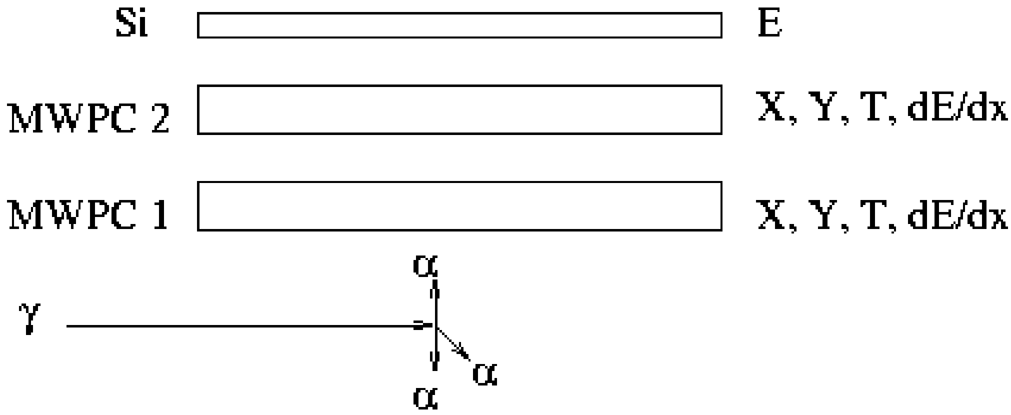


Figure 1. Schematic representation of a single detector module.

The working gas is a heptane (C_7H_{16}) with the pressure of about 3 Torr. In addition, C_7H_{16} serves as an active target. The following equations can be applied to each event:

$$E_\gamma = E_T + E_B; \qquad (2)$$

$$\Delta = (\sum \mathbf{p}_r) - \mathbf{p}_\gamma, \qquad (3)$$

where E_γ and $\mathbf{p}_\gamma$ are the energy and momentum of the γ-quantum which initiates the photodisintegration of carbon, E_T and $(\Sigma \mathbf{p}_r)$ are the total kinetic energy and momentum of the three α-particles, E_B = 7.275 MeV is the mass threshold, and Δ is the resultant momentum vector (conservation of momentum requires Δ = 0).

The energy range of $9<E_\gamma< 15$ MeV will be investigated by determination of the E_T only.

The proposed experimental setup has the following advantages.

I. Since the working gas serves as an active target, an acceptance of about 4π and detection efficiency is close to 100%.

II. MWPC planes enable one to measure the trajectories, dE/dx, and time; SSD plane - the energies of the charged particles produced in the reactions. These measurements help to distinguish different reaction events on ^{12}C from each other and from background. The effective masses of the 3α resonance states can be determined within an accuracy of about 200 keV. These measurements allow reconstructing the full kinematics of the reaction.

III. It provides information on the angular distributions of the emitted particles, which are important to determine the electromagnetic transition strengths of different multi-polarities and parities.

IV. It is possible to reconstruct the reaction point, which is important to determine the energy of produced alpha particles.

V. Since the pressure of the working gas is about 3 Torr, the detection threshold for alpha particles is about 100 keV.

1. Detector development

As a first step we are proposing to develop, produce and assemble a low-energy alpha particle detector and perform test studies of the detector at MAX-lab and Yerevan electron-photon beams.

2. Expected Rates

In the MAX-lab experiment the target will be 10 cm thick and 3 Torr pressure or ~0.125 mg/cm^2 thickness heptane gas. In addition we will have two windows each of 5 μm or total ~1.2 mg/cm^2 thickness Kevlar foil. The total radiation length, r.l., of heptane gas and two Kevlar foils will be about 4×10^{-5}. For 200 MeV and 20 nA electron current, passing through 4×10^{-5} r.l. we will have about 2×10^4 electron/s/MeV rate in the single tagging channel and $N_\gamma = 1.2\times10^7 s^{-1}MeV^{-1}$ virtual photon/s/MeV flux on target.

The expected yields are estimated from

$$Y = \sigma_{tot}^{\gamma,C} \times \Delta\Omega_{eff} \times N_\gamma \times N_C,$$

where we use $\sigma_{tot}^{\gamma,^{12}C} = 0.1\times10^{-27} cm^2$. $\Delta\Omega_{eff} = 0.25$ is the geometrical efficiency of the detector, N_c = 5.5 10^{18} is the numbers of ^{12}C nuclei in a 0.125 mg/cm^2 thickness heptane gas and we obtain $Y = 0.003$ counter/MeV/s. Consequently we will have ~200 events/MeV/100h.

References

1. E. Epelbaum et al., Phys. Rev. Lett. **109**, 252501 (2012).
2. A. Margaryan, L. Isaksson et al., Study of Carbon-12 disintegration into three alpha particles by using virtual photon tagging at MAX-lab; MAX-lab proposal 2012-01.

4. Hadron physics based on HERMES and H1 data , OLYMPUS experiment - collaboration with DESY

4.1. Abstract

The hadron physics is the most interesting area in modern high energy physics due to lack of theory of the strong interactions and ultimate necessity to check many theoretical models pretending to describe the spin and hadronization phenomena.

The planned activities during 2013-2017 are devoted to the important aspects of hadron physics. The first one is related to the problem of the nucleon spin structure via the investigation of azimuthal asymmetries in exclusive electroproduction of real photons in Deeply Virtual Compton Scattering (DVCS) reactions, as well in the reactions with exclusively electroproduced mesons. Another aspect is related to the problem of hadronization mechanism via the study of electroproduction of various identified hadrons on different nuclear targets. The experimental data associated with both aspects are extremely important to complete our knowledge and approach to the adequate theory of the strong interactions similar to Quantum Electro Dynamics (QED) for electromagnetic interactions.

Exclusive reactions are intensively investigated at different high energy laboratories like HERMES, Jlab, CERN (COMPASS). The HERMES based results together with the Jlab and COMPAS results will allow to perform a global fit to adjust the differnt GPD based structure functions and make a big step towards to the clarification of famous old problem which is called the “spin crisis”.

Also the hadronization in nuclear medium is a matter of high interest at HERMES and Jlab, the results on hadronization in nuclear medium will allow to make essential progress with the understanding of the hadronization phenomenon. The data to be analyzed are collected at HERMES experiment on HERA accelerator at DESY during more than ten years. Here we are planned also to investigate the multiplicities for electroproduction of neutral mesons like π^0 and η^0 and their ratio, which is poorly studied before.

During 2013 and 2014 we plan to perform also necessary methodic works with the Time of Flight (TOF) detector calibration and Monte Carlo simulations for a new OLYMPUS experiment at DESY on DORIS accelerator, which finished the data taking in Jan. 2013.The main goal of this experiment is the study of the cross sections asymmetry in the elastic elctron-proton and positron-proton scattering in order to check the possible contribution of the two-photon exchange diagramm in the interpretation of well known essential difference in the ratio of electric to magnetic form factors observed by using the Rosenblut separation method and measurements of the recoil proton polarization. Here the chalanging aspect is to achieve less than 1% total uncertainties in the measured cross-sections asymmetry, to solve this problem the massive Monte Carlo studies are needed, also the Yerevan group together with DESY and St. Ptsb groups will

provide independent final analysis to be compared with the results of MIT group.
4.2.Work schedule

2013 - 2014

During 2013 and 2014 we will still continue physics analysis related to the data collected by HERMES and OLYMPUS collaborations at DESY. During this period the members of our group will have regular visits to DESY to present the results for release and participate in papers drafting.

Participants: N. Akopov,G. Elbakian,H. Marukyan,G. Karyan,A. Petrosyn

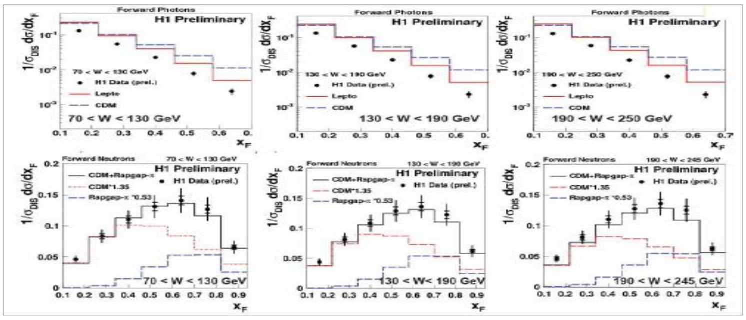
4.3. H1 experiment (group is responsible for two on-going analysis)

4.3.1. Very Forward Neutron and Photon Production in DIS at HERA

The first analysis has status T0 and now is preparing to publication.

In the analysis forward photon and neutron production cross sections are measured as a function of the energy W of the virtual photon-proton system in HCM in the kinematic range $6 < Q^2 < 100$ GeV^2 and $0.05 < y < 0.6$.

Normalised to DIS photon and neutron production cross sections as a functions of x_F in different W bins are compared to the MC predictions and to the different models the Cosmic Ray hadronic interactions.



The measured data are consistent with Feynman Scaling while CR models show W dependence.

2013-2014

Participants: A.Bunyatyan , H.Zohrabyan

4.3.2. Jet Production in DIS at Low Q^2

HERA2 data (2004-2007) with integrated luminosity ~300/pb at low photon virtuality ($5<Q^2<100$ GeV^2) and inelasticity $0.2<y<0.65$ are analysed. Single and double differential cross sections as well as frijet to dijet cross sections ratios and normalised to DIS cross section rations (at the first time) are measured for three jet algorithms (kt-, anti-kt and SISCone) usin bin-by-bin method. New data have essentially lower (~30%) systematic uncertainties compared to HERA1 data. Measured (at the first time) normalised to DIS cross sections rations let reduce correlated uncertainties, which additionally reduce total systematical uncertainties.

Data must be recalculated using unfolding method.

2013-2015

Participants: A.Baghdasaryan, S.Baghdasaryan

5. Fragmentation mechanisms in high energy nuclear interactions collaboration with JINR (BECQUEREL)

Study of nuclear fragmentation processes with photoemulsion methodics.

Abstract

It is foreseen to study the pripheral interactions of light nuclei of the 4N type (^{28}Si and ^{32}S) in photoemulsions resulting in the full or partly dissociation into α-particles, or the fission into two or more heavier fragments. The anticipated experimental data can contain valuable information about the α-cluster structure of these nuclei, as well as about the mechanisms of their bynary and ternary fission. It is foreseen to study the central collisions of 4.5 A GeV ^{28}Si nuclei with heavy nuclei in photoemulsions resulting in the fission of target nuclei. It is foreseen to study the pripheral interactions of the light nuclei beams (including radioactive ones), formed at the Dubna Nuclotron, in photoemulsions aimed at the inferring new information on the low-lying levels and the cluster structure of light nuclei (including exotic ones).

The work content

Of special interest in nuclear physics are so called 4N-type nuclei which presumably can be considered as systems composed exceptionally of α-particles. At present the α-cluster composition is, probably, proved for some excited levels of ^{12}C and ^{16}O nuclei, while for other, more complex, nuclei the experimental data are too scarce to reveal multi-alpha structure of their excited states. Two possible examples are the nuclei ^{28}Si and ^{32}S which theoretically can be considered as ensembles of, respectively, 7 and 8 α-clusters. These two nuclei will be an object of our investigations in collaboration with the Joint Institute of Nuclear Researches (JINR, Dubna, RF), in the framework of the BECQUEREL Collaboration. It is foreseen to study the peripheral interactions of 200 A GeV ^{32}S nuclei and 4.5 A GeV ^{28}Si nuclei in photoemulsions, including the full or partly dissociation of these nuclei into α-particles. The anticipated experimental data can provide deeper insight into the cluster structure of low-lying excited states of these nuclei. Besides, new data will be obtained on the binary and ternary fission of ^{32}S and ^{28}Si nuclei carrying a valuable information on possible mechanisms of these processes. At the second stage of investigations it is foreseen to obtain new data on heavy nuclei fission processes in central collisions of 4.5 A GeV ^{28}Si nuclei with heavy target nuclei of photoemulsion (Ag, Br), in particular, concerning not enough studied processes of heavy nuclei fission into two or more heavy fragments, as well as their full or almost full disintegration into a number of light fragments. The third stage of works will be devoted to the study of peripheral interactions of the light nuclei beams (including radioactive ones), formed at the Dubna Nuclotron, in photoemulsions aimed at the inferring new information on the low-lying levels and the cluster structure of light nuclei (including exotic ones). These peripheral dissociation processes correspond to inverse (multiparticle synthesis) reactions at proper energies and hence can help to infer a new information on the underlying mechanisms of the stellar nucleosynthesis. The high resolution of the energy measurement for low-lying excited states is provided by a unique spatial resolution of the track reconstruction (about 0.5 mkm) in photoemulsion.

5.1. Study of peripheral interactions of 200 A GeV ^{32}S nuclei and 4.5 A GeV ^{28}Si nuclei in photoemulsions resuling in their dissociation into a few α-particles or fission into two or three heavier fragments.

Date: 2013 – 2016

Participants: V.Sargsyan, A.Moiseenko, M.Manaseryan

5.2. Study of central interactions of 4.5 A GeV ^{28}Si nuclei with heavy nuclei of photoemulsion resuling in the full or partly disintegration of target nuclei.

Date: 2015 – 2017

Participants: V.Sargsyan, A.Moiseenko, M.Manaseryan, N.Demekhina

5.3. Study of coherent dissociation of light nuclei (including radioactive ones) in photoemulsion.

Date: 2015 – 2017

Participants: V.Sargsyan, A.Moiseenko, M.Manaseryan

6. Search of rare processes in underground laboratory of Avan salt

6.1. Preparation for experiments to search of dark matter particles (WIMPs)

The low-background laboratory of YerPhI is located at the depth of 660 m water equivalent in Yerevan salt mine. Our laboratory has such an important advantage, compared to known underground laboratories, as it is located in precincts of large city (with corresponding infrastructure and communication system) and near to the known scientific center. This circumstance is very important for realization of the mutually-advantageous international cooperation. It should be mentioned also, that the natural conditions in the mine (the humidity is about 35%, temperature 20-21 C) are very comfortable both for people and electronic devices. It's well known also, that the natural background in salt mines is exceptionally low. So it reduce a cost of required passive and active shielding technique. The only disadvantage is a relatively low depth (240 m underground). Nevertheless such a depth is sufficient for many contemporary underground physics' tasks.

There is the strong contradiction between DAMA (and then DAMA/LIBRA) experiment [(DAMA collaboration), Phys Lett. B480, 23 (2000)], which had declared the observation of a season modulation effect (and so the existence of WIMPs with masses about 60 GeV), and the null - results of other experiments (first of all, with results of CDMS collaboration [Riv. Nuovo Cim. 26N1, 1 (2003)], which is considered as the most sensitive among them). So it's very important to perform an experiment, which is able to find out the reason of this incompatibility. DAMA collaboration have used NaI(Tl) scintillation technique. We have some ideas to reduce the energy threshold of NaI detector which will substantially improve the sensitivity because of the quasi-exponentially decreasing signal rate as function of recoil energy (if an elastic WIMP - nucleus scattering is considered).

The main goal of our activity in YerPhI underground laboratory is the preparing in a frame of modest financial support the conditions for providing competitive experiments there. Now we concentrate our activity on the following questions:

1. The continuation R&D for NaI(Tl) scintillator detector technique having a goal to decrease energy threshold comparing to DAMA detectors (< 2 KeV). In the case of success we could construct the set-up for WIMPs (Relic Weakly Interacting Massive Particles - are believed to be the most plausible candidates for Cold Dark Matter) searching, which is based on the several hundreds kilograms of NaI(Tl) crystals available in Yerevan Physics Institute.

Our R&D based first of all on the following actions: increase in a light collection as much as possible by placing NaI crystal into transparent envelope and applying PMTs to each side of crystal; development of low noise electronics for performing of one- photoelectron regime; development of the pulse shape discrimination technique (if a corresponding electronics will available); development of PMTs cooling system (to reduce thermo-emission noises); development of the data acquisition system, including hardware and software.

As it was mentioned above, we have performed the test of our crystals and materials, which were supposed to be used as the parts of the detector, for the determination of a level of radio-impurities. The measurements were performed in the underground laboratory of YerPhI by means of semiconductor germanium detectors, and haven't revealed the presence of radio-impurities in our NaI crystal. For example, an upper limit for natural potassium doesn't exceed 100 ppb. Low background measurements allowed us select the materials for the detector's envelope. Data acquisition electronics for NaI(Tl), based on the CAMAC system was developed. The low-noise electronics which is necessary for performing of one photoelectron regime is in the stage of development now. The software for data acquisition and software for online control of these measurements were developed as well. We are continuing the works to improve this system.

It is prepared now the measurements of high energy neutrons (>1 MeV) background in our underground laboratory, because neutrons can imitate WIMPs scattering events.

6.2. Study of suitability of Avan salt mine for registration of astrophysical neutrinos by Askarian method

Another point of our activity was the determination of suitability of our salt mine for the detection of ultra-high energy (UHE) neutrinos through their radio Cherenkov signature (Askarian method).

The growing interest to the detection of UHE cosmic neutrinos has an astrophysical as well as particle physics motivations. All known UHE cosmic rays (except neutrinos) because of interactions with cosmic microwave background lose their initial direction and energy (charged component loses a direction due to intergalactic magnetic fields also) and so couldn't be utilized for large scale (> 100 Mpc) extragalactic astronomy. UHE neutrinos could be used also for

studying of weak interaction processes at energies unreachable by any man-made accelerator. These energies may be sufficient for revealing new physics (micro-black holes, extra dimensions, and so on).
Askarian[1962, JETP 14, 441] first proposed coherent Cherenkov mechanism for radio pulse production by charge asymmetry in electromagnetic cascades. This asymmetry arises from positrons annihilation, and leads to about 20% excess of electrons over positrons in the shower. The resulting coherent radio emission, the power of which rises quadratically with shower energy, dominates all secondary radiation processes in electromagnetic showers above 10 PeV. There are several UHE neutrinos experiments, based on this method, are planed. One of them (SalSA- collaboration) also is headed for use Askarian effect in salt rock.
There are two basic factors which determine the suitability: the size of the salt formation and the level of its transparency for radio waves. The volume of salt formation in Yerevan salt mine is large enough. We have planned to determine the attenuation lengths of radio waves in 100 – 1000 MHz frequency range. Corresponding R&D were provided, and are continuing now. First we prepared conditions for performing measurements for radio pulses at 450 MHz. To save money (because of its absence) we placed our antennas in boreholes which were drilled in salt before us, so their disposition wasn't an optimal one for correct measurements. Preliminary measurements which were carried out at 450 MHz frequency showed the significant influence of reflection processes from the surrounding walls. It is needed to drill new holes taking into account this experience.
The measurements of the propagation of radio waves in the rock of the Avan salt mine are proposed to perform for the determination of Askarian [1] method's applicability for high energy cosmic neutrino detection in Avan salt mine. It's known that an outer Galactic astrophysics in the region out of 100 Mps at the energies above 10^{16} eV could be studied by means of neutrinos only. One of the most promising approaches to the problem of detecting such neutrinos is to use Askarian method.

6.3. Works schedule

6.3.1. Works aimed to search of weak interacted heavy particles (WIMPs)

2013 – 2017

6.3.2. Study of suitability of Avan salt mine for registration of astrophysical neutrinos by Askarian method

2013 – 2014 թ.թ.

6.4.Participants: A. Aleksanyan, S. Amirkhanyan, L.Pogosyan, V.Pogosov, O. Pogosova , T.Kotandjyan

7. Low energy nuclear physics research on the base of ANSL's accelerator complex (electron linac, synchrotron) - cluster structure of excited states of light nuclei (He, Li, Be, C)

a) Study of cluster structures of excited states for the light nuclei He, Li and Be in three-body photodisintegration processes [1]

The physics of nuclear clustering is showing remarkable developments in many directions, including the nuclear-synthesis and nuclear structure/nuclear reactions and is widely discussed in special conferences and workshops since 1960 .
The few modern clustering models are recently developed, attracting the strong attention , such as: (i) novel-types of cluster structure in neutron-rich nuclei, (ii) cluster-gas-like states as states with drastically novel-type of nuclear structure, (iii) cluster condensate states (iv) coexistence of mean-field-like states and cluster states[2].
The structure of excited states for the light nuclei is in particular the subject of increasing interest and is widely discussed in the modern theoretical analyses that correspond to the existence and manifestation of cluster structures of excited states inside these nuclei [3,4].
Within the framework of a project is proposed to develop the experimental method and begin

the investigation of cluster structures of excited states for the light nuclei in three-body final states photodisintegration processes.
We propose to investigate the photo-disintegration reactions with three-body final states $\gamma+A \rightarrow 1+2+3$, where the particles (1, 2, 3) in general are the nucleons (p, n) and light nuclei (d, t, ^{3}He, ^{4}He(α)). When the targets are ^{6}Li, ^{7}Li and ^{9}Be, the particles (1, 2) are (p, d, t, ^{3}He, α), while the (3) one is the nucleon (p, n) [1].
In these conditions we can observe the following seven photo-disintegration reactions:

$$\gamma + {}^6\text{Li} \rightarrow t + d + p$$
$$\gamma + {}^6\text{Li} \rightarrow {}^3\text{He} + d + n$$
$$\gamma + {}^6\text{Li} \rightarrow \alpha + p + n$$
$$\gamma + {}^7\text{Li} \rightarrow t + t + p$$
$$\gamma + {}^7\text{Li} \rightarrow {}^3\text{He} + t + n$$
$$\gamma + {}^7\text{Li} \rightarrow \alpha + d + n$$
$$\gamma + {}^9\text{Be} \rightarrow \alpha + \alpha + n$$

There are three types of decay channels for these 7 reactions of photodisintegration:

- A statistical channel $\gamma + A \rightarrow 1+2+N$ which represents a physical background channel of the reaction (γ +A) and which can be calculated as a three-body phase-space.
- The channels of production and decay of the excited isotope states in the given reaction $\gamma + A \rightarrow 1+2+N$ and precisely in our case in the form of three two-body processes: $\gamma + A \rightarrow (12)+N$, $\gamma + A \rightarrow (1N)+2$ and $\gamma + A \rightarrow (2N)+1$ with 3 resonances' excited states, $B^*=(12)^*$, $(1N)^*$, $(2N)^*$. They are decaying in the final three-particle states.
- The channels of production and decay of the 3 particles excited states $(1+2+N)^*$.

For the study of these seven reactions $\gamma + A \rightarrow 1+2+N$, the production angles and the kinetic energy of the known particles (1, 2) will be measured in coincidence in two detectors. These measurements are able to determine: the energy (E_γ) of incident photon on the target, the parameters of excited state (x) decay products (particles 2 and 3), invariant mass or excitation energy (E_x) and width (Γ_x) of the excited state [1].
For these seven photo-disintegration reactions we present the cluster structures of 22 excited states of seven isotopes: ^{5}He, ^{6}He, ^{5}Li, ^{6}Li, ^{7}Li, ^{8}Be, ^{9}Be as well as the targets being used:

^{5}He $\rightarrow$ $(t+d)^*$, $(\alpha+n)^*$ - targets ^{6}Li, ^{7}Li, ^{9}Be
^{6}He $\rightarrow$ $(t+t)^*$, - target ^{7}Li, but differences are observed with ion-beams and π - beam experiments.
^{5}Li $\rightarrow$ $(^3\text{He}+d)^*$, $(^4\text{He}+p)^*$ - target ^{6}Li.
^{6}Li $\rightarrow$ $(^3\text{He}+t)^*$, $(^4\text{He}+d)^*$ - target ^{7}Li and $(^3\text{He}+d+n)^*$,$(t+d+p)^*$,
$(^5\text{He}^*+p)^*$, $(^5\text{Li}^*+n)^*$, $(\alpha+p+n)^*$ -target ^{6}Li.
^{7}Li $\rightarrow$ $(^6\text{He}^*+p)^*$, $(t+t+p)^*$, $(^6\text{Li}^*+n)^*$, $(\alpha+d+n)^*$, $(^5\text{He}^*+d)^*$, $(t+n+^3\text{He})^*$ - target ^{7}Li.
^{8}Be $\rightarrow$ $(\alpha+\alpha)^*$ - target ^{9}Be.
^{9}Be $\rightarrow$ $(^8\text{Be}^*+n)^*$, $(\alpha+\alpha+n)^*$, $(^5\text{He}^*+\alpha)^*$ "

The experimental results for a number of excited states presented here have been obtained with different methods [5].

At first we are plan to investigate the excited states of ^{6}He* (t + t) isotope in reaction
$\boldsymbol{\gamma + {}^7\text{Li} \rightarrow {}^6\text{He}^* + p}$ at energy up to $E\gamma$ = 75 MeV.

The results of experimental studies of two-cluster (t+t) excited states of ^{6}He* nucleus obtained so far by two various methods with ions beam ^{7}Li(^{6}Li,^{7}Be) ^{6}He [6] and π mesons ^{9}Be (π, ^{6}He) t [7] differ, concerning the number of excited states of ^{6}He*, as well as the values of the energies and widths(see Table 1).
Table 1. Excitation energy levels of ^{6}He discovered in reactions with ions [6] and π^- -mesons [7]

$^7Li + {}^6Li \rightarrow {}^7Be + ({}^6He^*(t+t))$	$\pi^- + {}^9Be \rightarrow {}^6He^*(t+t)+t$	
18,0±0.5MeV, Γ=7.7±1.1MeV	**15.8±0.6MeV, Γ=1.1±0.6MeV**	**A**
18,0±1.0MeV, Γ=9.5±1.0MeV	**20.9±0.3MeV, Γ=3.2±1.5MeV**	**B**
	31.1±1.0MeV, Γ=6.9±2.3MeV	**C**

We believe that the experimental study of the excited states of ^6He in the energy range E_x=10-60 MeV, using photons as a probe, will allow to confirm the already observed states or discover new ones and contribute in understanding of their formation mechanism.

The nuclear physics experiments will exploit the low energy (70-75 MeV) non-accelerating mode of the existing electron synchrotron, working as a stretcher. The bremsstrahlung photon beam extraction time is app. 2-3msec at repetition rate 50Hz. Detectors, together with nuclear target as well the electron-photon converter will be installed inside of the vacuum chamber, located at the internal beam of synchrotron (Fig.1). In this configuration, inspired by bremsstrahlung visible divergence, the small separation of converter from nuclear target (app. 20cm) allows the maximal photon beam intensity on the target(>10^{10} ph/s).

The silicon detector arrays will be ordered together with readout electronics at known manufacturer in Zelenograd (Russia). The existing DAQ system, CAMAC apparatus based, will be used with necessary modification of the software.

The scheme of the experimental layout is shown in Fig.1. The concept of a two-arm set-up of Si-detector telescopes [8] with a sensitive area of (100x100) mm^2 for registration of two tritons in coincidence has been chosen. Geometrically the telescopes are located at a distance of 20 cm from the target covering a solid angle of 0.25sr each. Each telescope consists of two perpendicular arrays of 50 μ thick silicon dE/dx sensors and a 1.5 mm thick E-detector with an energy resolution of app.1%, that allows to identify the particles, measure their kinetic energy in the range 4-20MeV and reconstruct the triton angles. The photon beam will be generated by the bremsstrahlung of the 75MeV electron beam of Yerevan Electron Synchrotron [9] with the intensity expected to be above 10^9 equiv.photons/s (in units of the maximal energy photons). Enriched (99%), 150 μ□ thick metallic lithium foils will be used. The beam spot size on the target is expected to be less than (10x10) mm^2. The target holder and detectors will be mounted in a vacuum chamber.

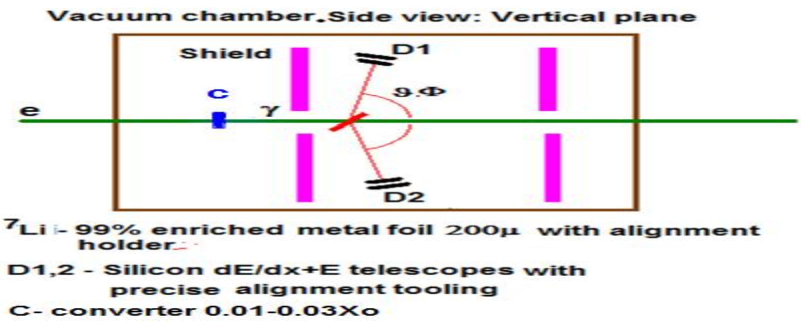


Fig.1

To work with kinematical distributions and determine the necessary requirements to the performance of the experimental set-up the Monte-Carlo simulations were carried out.

Event generation is done by a Fortran-based GENBOD code [10]. The user package also includes the beam-line and experimental setup simulation as well as the kinematical reconstruction and data analysis codes. The beam line simulation includes the bremsstrahlung energy spectrum, target simulation with photon interaction point along the target depth, geometry of the target alignment, ionisation losses and multiple coulomb scattering. The detectors simulation part contains the geometry description, the hits coordinates calculation in Si-pixels, ionisation losses, ranges, corresponding energies deposit in the telescope and their smearing due to a energy resolution. The kinematical distributions have been generated for the following processes:

- three-body disintegration process (1) - $\gamma + {}^7Li \rightarrow t + t + p$
- quasi-two-body disintegration process (2) - $\gamma + {}^7Li \rightarrow {}^6He^* + p$ with subsequent decay of excited $^6He^*$ states ($^6He^* \rightarrow t+t$), and
- quasi-two-body disintegration process (3) - $\gamma + {}^7Li \rightarrow {}^4He^* + t$ with subsequent decay of excited $^4He^*$ states ($^4He^* \rightarrow t + p$).

The detector configuration parameters: the average polar and azimuthal angles and kinetic energies of the tritons and proton are shown in Table 2.

Table 2. Setup configuration parameters

Configuration	$E_x \pm \Gamma/2$ (MeV)	$<\theta_{t1}>$ (deg)	$<\theta_{t2}>$ (deg)	$<\varphi_1-\varphi_2>$ (deg)	$<T_{t1,t2}>$ (MeV)	$<\theta_p^{cm}>$ (deg)	$<T_p>$ (MeV)
1	**20.9±1.6**	**83**	**83**	**120**	**5.7**	**82**	**15.7**
2	**31.1±3.5**	**87**	**87**	**150**	**9.9**	**76**	**8.1**

The contribution of the experimental uncertainties such as the granularity and energy resolution of detectors, beam spot size, multiple scattering and ionisation energy losses in Li target on the photon and excitation energy resolutions have been simulated and investigated separately, and the results are shown in Table 3 for the particular case of the detector setting optimized for E_x=20.9±1.6MeV.

Table 3. Contributions of experimental uncertainties on the energy resolutions for configuration “1” in Table 2

	Multiple scatterin g in target	Uncertainties of ionization losses in target	Beam spot size in target $(10x10)mm^2$	Detector granularity $(10x10)mm^2$	Detectors energy resolution	All factors together
σ_{Ex} (MeV)	0.08	0.19	0.21	0.23	0.08	0.38
$\sigma_{E\gamma}$ (MeV)	0.47	0.28	1.22	1.28	0.08	1.71

As one can see from Table 3, the main contribution to the excitation and photon energy resolution is coming from the beam spot and detector bin size and much less from the multiple scattering and variation of ionization losses. The contribution of the detector energy resolution is negligible.

Fig.2 shows the simulated invariant mass distribution of two tritons for the process $^7Li(\gamma,^6He^*)p$ for three ("A","B","C") resonance energies in the detector configuration "1", superimposed with contribution of phase-space process.

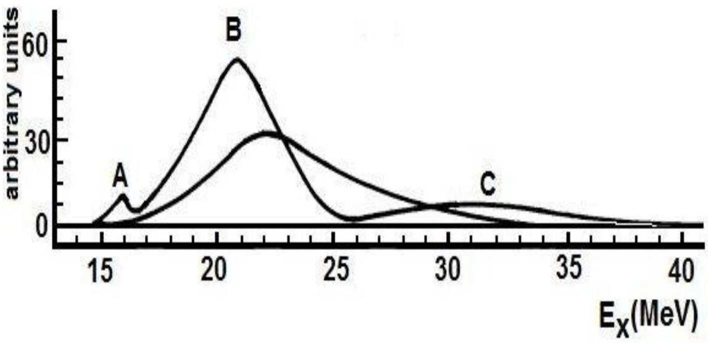


Fig.2

Fig.3 shows the spectra of photons in detector configuration "1" at the given three excitation energies (Table 1), allowing to see and evaluate the shapes of the experimental distributions for their use in the
data analysis.

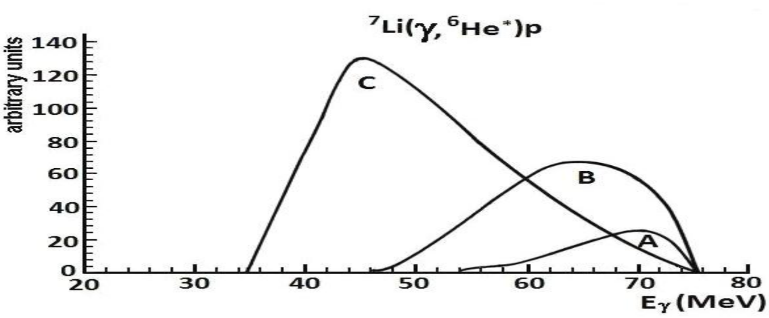


Fig.3

The expected rate of the process (2) for the ^{6}He excitation at energies E_x =15.8(A), 20.9(B) and 31.1MeV(C) have been evaluated using the experimental data on the process ^{7}Li(γ,p)^{6}He(g.s.) [11], obtained for the photon energy range of 50-120MeV and θ_p^{cm} =24-144^o, assuming the same level of the yields for the ground and excited states of ^{6}He, certainly indicated by the experimental data [12].

The yield of the process (2) can be calculated according to the standard definition

$\mathbf{N_{evt} = N_t * N_\gamma * <d\sigma/d\Omega> * \Delta\Omega * \varepsilon}$, where $<d\sigma/d\Omega>$ and $\Delta\Omega$ are the cross-section and simulated proton solid angle in the CM system, while N_t, N_γ, and ε denote the nuclei density in the target, photon intensity in the acceptance of the setup, and efficiency of registration, that accounts for the detector geometry and particle losses in the target and detector. The efficiency is defined by Monte-Carlo simulation as the ratio of the registered events to the generated ones for the selected range of excitation energy and proton CM angles. The efficiency strongly varies, depending on the excitation energy range, and detector configuration, increasing from $5*10^{-5}$ at E_x=15.8MeV to $0.7*10^{-3}$ at 20.9MeV and $6*10^{-3}$ at 31.1MeV. For the realistic values of N_t and N_γ to be in the order of $10^{21}cm^{-2}$ and 10^8s^{-1}, respectively, one can expect a maximal event rate of the order of 0.2 event/h, 7.2event/h and 32event/h for the mentioned energies, respectively.

Thus we propose to explore the three body break-up of the light nuclei using ^{6}Li, ^{7}Li and ^{9}Be targets in seven reactions of photo-disintegration with two light fragments in coincidence with the purpose of investigating two-cluster resonances excitation in an exotic light nucleus. The proposed experimental program explores an advantage of the known final state even without detection of the third particle (nucleon) that decreases the uncertainties of the physical background analysis compared to the case of undetected cluster or cluster's fragments.

As a result the feasibility of the experimental study of the reaction $\gamma + {}^7Li \rightarrow {}^6He^*(t+t) + p$ is demonstrated, both on experimental resolutions on excitation and photon energies, allowing to resolve and identify ^{6}He energy levels and on expected luminosity. According to the yield evaluations, the 250-300 hours beam time would be enough to observe and analyze the excitation of ^{6}He levels in the energy range E_x=10-40MeV. The same experimental program with minor variations might be also applied to the list of the seven photo-reactions.

For realization coincidence experiments with γ-beam in the energy range of 50-75 MeV the **new regime** of synchrotron without acceleration for the first time will be developed and used. Electron beam with pulse duration 0,7 μsec from an injector will be directed to an accelerator ring and then circulating without acceleration electrons in a mode of slow extraction provides photon beam in bremsstrahlung regime with pulse duration 2-3 msec .

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7.1.Work schedule

<u>2013-2014</u>

- Design, construction and assembling of the experimental setup, which includes special vacuum chamber for convertor, lithium target and detectors using ANSL`s mechanical workshop**.**
- Transition of electron synchrotron to a low energy stretcher mode (70-75 MeV). The extracted photon beam duration is (> 2-3 msec) at repetition rate 50 Hz.
- Design, construction and assembling of the experimental setup, which includes 6 silicone strip detectors of two types: with thickness δ= 50 µm , 1.5 mm, as well as their electronics. The detectors and readout electronics will be ordered at LHEP-JINR (semi-conductor detectors department) or taken for temporary use at LNR –JINR (collaboration with LNR JINR).
- Monte Carlo simulations and proposal preparation for the experimental study of cluster structure in the light nucleus He, Li and Be isotopes in three-body final states photodisintegration processes
- Experimental studies the excited states of ^{6}He* (t + t) isotope in reaction $\gamma + {}^7\text{Li} \rightarrow {}^6\text{He}^* + p$ at energy Eγ = 75 MeV.

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b) Study of Carbon-12 disintegration into three alpha particles

Abstract

We propose an experimental program to investigate disintegration of carbon nucleus into three alpha particles Yerevan Physics Institute. These investigations are enabled by the use of the dedicated low-energy alpha particle detector based on low-pressure MWPC technique, for determining velocities and trajectories of alpha particles and high-resolution solid state detectors, SSDs, for measuring their energies. The threshold energy for detection of alpha particles is ~100 keV. The position of the interaction point will be determined within error of about 1 mm, rms. This will allow determining the energy of the alpha particles at the interaction point, carry out identification of the produced charged particles and determining the effective masses of the 3α resonance states within error of about or less than 200 keV.
At ANSL experiment will be carried out by using 20-70 MeV electron stretcher beams. The main goal of these studies is to determine precisely photo-production cross section, mass and total width of the long-time expected and recently observed 2^+ 3α resonance states at energy range 9-10 MeV and search for 4^+ resonance state at 12-13 MeV.
These studies are important in connection with 3α reaction, which plays a crucial role in stellar helium burning as well as in cluster structure of the ^{12}C nucleus.
We define the project with three phases as follows:
Phase 1: Development, construction and test of prototype low-energy alpha particle detectors at ANSL for experimental studies with photon beams.

Phase 3: Monte Carlo simulations and development of proposals for Carbon-12 disintegration studies at ANSL electron-photon beams.

The work content

The near threshold three alpha resonance states of Carbon-12 is interesting in connection with 3α fusion process, which plays a crucial role in stellar helium burning [1-4]. In the centre of stars where the temperature is high enough, three α-particles (helium nuclei) are able to combine to form ^{12}C because of a resonant reaction leading to a nuclear excited state. Stars with masses greater than ~0.5 times that of the Sun will at some point in their lives have a central temperature high enough for this reaction to proceed. Although the reaction rate is of critical significance for determining elemental abundances in the Universe, and for determining the size of the iron core of a star just before it goes supernova, it has hitherto been insufficiently determined.

The most important resonance in ^{12}C for astrophysics is situated 7.65 MeV above the ground state, and has spin and parity 0^+ [5]. Hoyle suggested this resonance in 1953 in order to reproduce the observed abundances of ^{12}C and ^{16}O, respectively the fourth and third most abundant nuclear species in the Universe [6]. This so-called Hoyle resonance was soon discovered experimentally [7], and its properties were established [8] on the basis of a measurement of α-particles emitted in the β-decay of ^{12}B. In 1956 it was predicted [9] to have the structure of a linear chain of three α-particles, and it was further conjectured that there had to be another resonance at 9–10 MeV with spin-parity 2^+. A resonance was found soon after [10] at 10.1 MeV with a very large width of 3 MeV, but its spin-parity could only be determined as 0^+ or 2^+. The past half-century has brought little clarification to this problem, but the 2^+ resonance (at 9.1 MeV with Γ = 0.56 MeV, Γ_γ = 0.2 eV) is still included in the current NACRE (Nuclear Astrophysics Compilation of Reaction Rates) compilation of astrophysical reaction rates [4], where it enhances the $3\alpha \rightarrow {}^{12}C$ reaction rate by more than an order of magnitude for temperatures above 10^9 K. The $^{12}C^*$ states fed by the β-decay of ^{12}B and ^{12}N nuclei have been studied recently with improved methodic [11, 12]. These investigations find a dominant resonance at energy of ~11 MeV, but do not confirm the presence of a resonance at 9.1 MeV.

We are proposing to carry out a new experimental study of the $^{12}C(\gamma,3\alpha)$ reaction at ANSL by using a dedicated experimental setup-active carbon target, based on a 3 Torr heptane (C_7H_{16}, molar mass 100.21 g/mol, vapor density at 20^o C is ~4.2 10^{-3} mg/cm^3/Torr or 3.46 times of the air density, 1.205 mg/cm^3) filled MWPCs and solid state detectors [13]. The goal of this project is to develop an experimental setup which will be capable to detect alpha particles with threshold energies of about or less than 100 keV, to be able to carry out decay particle spectroscopy of the Carbon-12 excited states starting from 7.6 MeV Hoyle state.

New experimental results and precise measurements along with ab initio calculations should become a test lab for nuclear physics models.

The cross-section for the photodisintegration of $^{12}C(\gamma,3\alpha)$ has been determined for γ-ray energies up to about 70 MeV from a study of 2500 stars in nuclear emulsions [14]. The cross-section exhibits at least five resonances, situated at γ-ray energies E_γ = 17.3, 18.3, 21.9, 24.3 and 29.4 MeV (see Figure 1 and Figure 2 depicted from [14]). The integrated cross-section is 1.21 ± 0.16 MeV mb for E_γ<20.5 MeV, a further 2.8 ± 0.4 MeV mb for 20.5≤E_γ<42 MeV, and less than 0.2 MeV mb for 42≤E_γ<60 MeV.

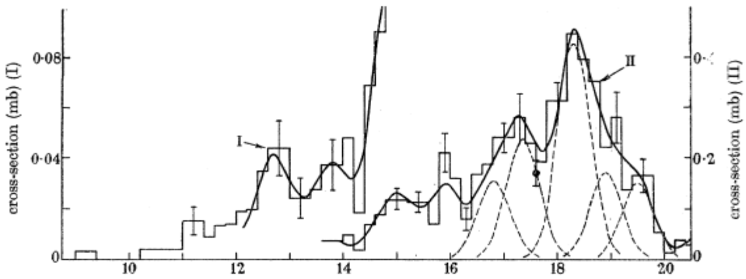

Fig. 1. $^{12}C(\gamma,3\alpha)$ cross-sections for for γ-ray energies less than 20.5 MeV ([14].

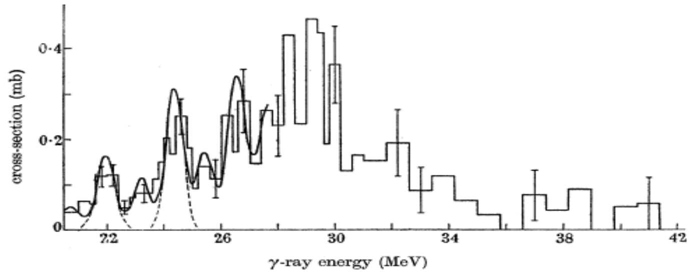

Fig. 2. $^{12}C(\gamma,3\alpha)$ cross-sections for for γ-ray energies above 20.5 MeV([14]).

Recently the photodisintegration of $^{12}C(\gamma,3\alpha)$ has been studied by using the Compton backscattered γ-ray beam [17]. Some preliminary results obtained with such a beam and mixed gas of 20% methane (CH_4) and 80% natural helium filled time projection chamber with electronic readout system are shown in Fig.4.

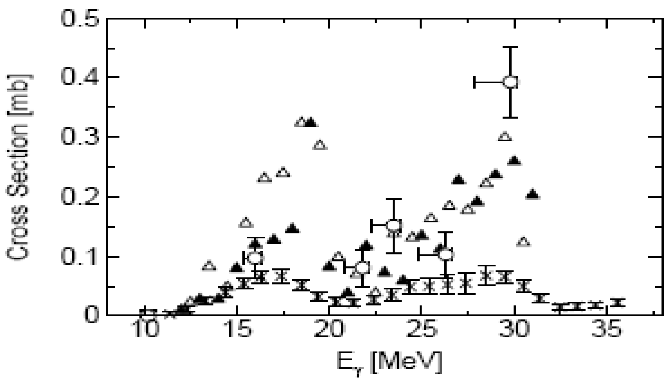

Fig. 4. The $^{12}C(\gamma, 3\alpha)$ reaction cross sections. Closed triangles; Maikov et al. [15], open triangles; Murakami et al. [16], diagonal crosses; Kotikov et al. [18], open circles; Shima [17].

The obtained total cross-section of the $^{12}C(\gamma, 3\alpha)$ reaction in the energy interval from the reaction threshold up to 40 MeV is presented in Fig. 5(a). The errors are statistic. The integral cross-section equals to 5.58 ± 0.16 MeV mb.

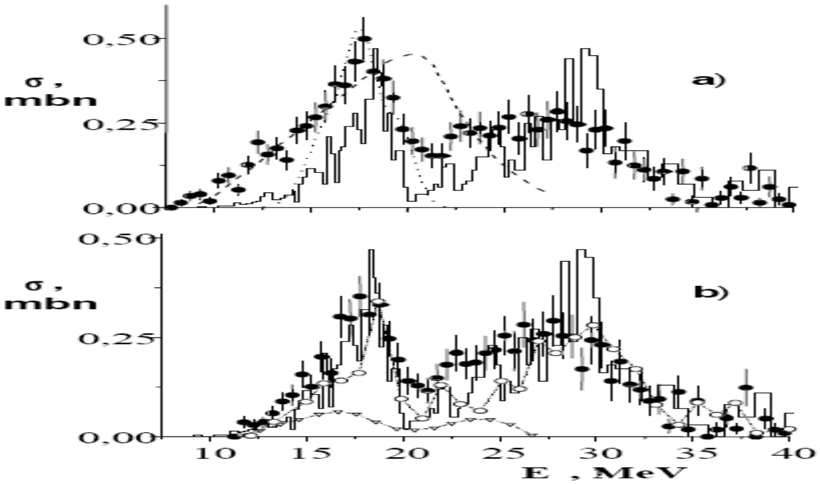

Figure 5. The total cross-section for the $^{12}C(\gamma, 3\alpha)$ reaction, histogram - [14], closed circles – [18], open circles [15].

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8.Investigation of two-cluster (quasi- deuteron) nuclear structure in medium weight and heavy nuclei in photonuclear reactions at energies up to 70 MeV

Abstract.
The object of this project is the study of nuclear structure and nuclear reaction mechanism in electromagnetic interactions at intermediate energies 20-70 MeV on targets with masses in the range 50-197 a.e.m. Study of photonuclear reactions yields with high thresholds including multi nucleon, alfa particles emission and photofission will be carried out on linear electron accelerator at maximum energy up to 70 MeV . The measurements and identification of the reaction products will be made by using activation method.
Comparison experimental results with the estimation obtained on the base of program code TALYS and modified quasideuteron Levinger model will allow to check several theoretical assumptions.
This assumes actually the course of study nuclear structures and becoming apparent in interaction with electromagnetic probes in energy range below pion production threshold.

The work content

In frames of Bohr model the cross section of reaction can be presented as product of the photo absorption probability with compound nucleus formation and followed the deexcitation process via the partial decay channels . Reactions with high threshold value ~20-30 MeV above the maximum energy of giant dipole resonance (GDR) include processes of the multi nucleon emission and the photofission of light nuclei. The cross sections of these reactions can be presented in form:

$$\sigma(E_\gamma)= \sigma_{погл.}(E_\gamma)\, P(E_\gamma) ,$$

where $\sigma_{погл.}(E_\gamma)$- photoabsorption cross section followed formation of the compound nucleus , $P(E_\gamma)$ – deexcitation probability of compound nucleus by means of above mentioned channels.In the photonuclear reactions proceeding on bremsstrahlung of the electron beam the reaction yields are measured observable as the folding reaction cross section- $\sigma(E_\gamma)$ and function describing the bremsstrahlung spectra $W(E_\gamma, E_{мах})dE$, determined as a number of photons with energy E in energy unit (1MeV) of the bremsstrahlung spectra with maximum energy E_{max}:

$$Y(E_\gamma, E_{мах}) = \int_{E_{пор}}^{E_{мах}} \sigma(E_\gamma)\, W(E_\gamma, E_{мах})dE$$

In energy range 10-40 MeV photonuclear reactions have been studied recently fifty years in detail and a number of important properties and regularities, related to the collective excitations were opened. At higher energies up to threshold of the meson production mechanism of the primary photonuclear interaction is changed . In contradiction to GDR range where photons interact with nucleus as a whole with increasing photon energy the photon wavelength become near to the dimension of two nucleons association. This fact repulses on the mechanism of the private interaction and excitation of the compound nucleus. At energies above meson photoproduction the role of the separated nucleons become dominant, this picture have been verified theoretically and experimentally.

The absorption in energy lower meson production is considered as usually in form of absorption on two nucleons correlation known as virtual quasi deuterons A most developed model in this energy range is Levinger quasi deuteron model [1,2] that based on two principals :

1. Photons absorbers mainly by two nucleons-NN pairs in nucleus
2. The reaction cross section can be presented via interaction photons with free deuterons.

In the whole the total photoabsorption cross section, revealing in the yields of the photonuclear reactions is consisted of two parts [7]:

$\sigma_{total} = \sigma_{GDR} + \sigma_{QD}$

where $-\sigma_{GDR}$ - is calculated by using microscopic nuclear model without free parameters [9]. The second part σ_{QD} is considered in frames of quasi-deuteron model. This model concerning to the dominant two nucleon photo absorption mechanism first proposed by Levinger . The idea of Levinger model is application the photoabsorbtion on free deuterons , that can be formed in nuclear matter in correlation process of the nucleons pair. The model treats the effects of the Pauli exclusion principle also in an entirely phenomenological manner. In frames of this model the excitation is transferred not to whole nucleus but separated, space correlated neutron –proton pairs [3]. In this case one proton and one neutron are excited and two particle two holes entrance states are formed . The private interaction can be followed the nucleons , alfa particles emission and fission processes or transition in most complicated configuration forms. In last case the intra nuclear cascade followed by the distribution of the excitation energy among large number of different states to excess the equilibrium. The deexcitation process is take place on the above mentioned channels [4,5].Photo-absorption cross section by Levinger model can be expressed in form:

$\sigma_{qd}(E_\gamma)= L\ (NZ)/A\ \sigma_d(E_\gamma)F(E_\gamma)$

where L-Levinger parameter, $\sigma_d(E_\gamma)$- deuteron photodisintegration cross section ; $F(E_\gamma)= e^{-D/ E\gamma}$ - Pauli blocking function . The factor NZ is total number of neutron -proton pairs inside the nucleus , which is multiplied by the reduction factor L/A to account for the fact that only correlated neutron –proton pairs can be considered to be quasi deuteron. In addition the function $F(E_\gamma)= e^{-D/ E\gamma}$ accounts for those excitations of neutron proton pair that cannot occur since the Pauli exclusion principle, where D is constant. In practice L and D are treated as free parameters to fit the photo absorption experimental data. The ambiguity in the L and D values , used by different groups ranges from L=4.9 and D=60 MeV [ ] to L=10 and D=80 MeV [ ].
The estimations of these parameters were made in [ ] on the base of analysis of the ....and consideration of the nucear level densities in frames of the Fermi gas model. Authors shown the temperature dependence of parameters for medium mass targets. The analysis development allow to authors obtain the parameters dependence on targets mass . The cross section calculations were made in frames of evaporation and exit on models and using particle –holes representation . Finally the expression for quasi deuteron absorption was following $\sigma_{qd}=(61./E_\gamma^3)(E_\gamma-2.224)^{3/2}$
and for calculation suffering effect due by Pauli blocking principle was used

In the frames of present project the experimental investigation of the photonuclear reactions in quasi deuteron absorption range on targets with masses 50-208 a m.u at maximum bremsstrahlung energy 70MeV on linear electron accelerator. The thresholds of the reactions which to be measured are located above GDR and it is proposed that GDR contribution will be not so much . It is suppose that excitation functions of the reaction yields and GDR will be not to recovering. This contribution of GDR can be evaluated by means of TALYS 1.2 programme code. The dependence of parameters of quasy deuteron model on mass and temperature of the excited nuclei will be obtain from comparison experimental data with model estimations.

Table 1. Reactions (gamma, xp yn)

Target	Reaction	Product	$T_{1/2}$	Energy γ-Transition (KeV)	%	$Q+V_{coul}$	GDR max
64Zn	γ,p2n γ,p3n	61Cu 60Cu	3.41h 23min	283 656	13 11.2	-23.84 -37.15	18.8
58Ni	γ,pn γ,p2n	56Co 55Co	78.8d 17.54h	846 1238 931 477	99.9 67 75 20.5	-21.9 -25.77	19.4
54Fe	γ,p2n	52Mn	5.59d	744 935 1434	90 94.5 100	- 23.03	19.86
92Mo	γ,p2n	89Nb	1.1hMeV	507 567	81.1 95.4	-27.6	16.64
93Nb	γ, 3n γ, 4n γ, 5n	90Nb 89Nb 88Nb	14h 2.0h 14.5 min	1129 2.9 602 1057	92.7 50 54 100		16.57
118Sn	γ, p	117In	45.2min	158 553	87 100	-20	16
112Sn	γ, p	111In	2.8d	171 245	90 94	-17.8	
74 Ge	γ,2p	72Zn	46.5h	145	83	-35.2	19
55Mn	γ,3n	52Mn		744	100	-31.2	21
181Ta	γ, pn γ,2p	179Hf 179Lu	25.1d 4.59h	455 214	66 11	-21.07 -33.87	13.3
190Pt	γ, pn γ, p2n γ, p3n	188 Ir 187Ir 186 Ir	41.5h 11h 15.8h			-22.68 -23.28 -33.28	13.02
192Pt	γ, pn	190Ir	11.78d	186 371 518 569 605	52 23 34 28 39.9	-23.15	
197Au	γ, 3n γ, 4n	194 Au 193Au	39.5h 17.55h	329;294 136;256		-23.1 -30	12.9

	γ, 5n	192Au	5h	316;296		-38.7	
209Bi	γ, p5n	203Pb	52.1h	279		-46.4	12.8

The second channel, which we planned to study the production of alfa particles.

In the range of GDR there are some measurement results concerning to the α-particles photoproduction . However the scarceness of experimental data don't allow to make some systematization and check of the mechanism. The measurements of α-particles photoproduction at energy range GDR ≤ 25 MeV have shown that the excitation function rises rapidly in near threshold range and have plateau at higher energy[ ].The other peculiarity of the (γ, α) reaction is the smallness of this reaction cross section in comparison with (n, α) and (p, α) reactions at near values of the excitation energies of compound nuclei. This discrepancy rises with growth of the target mass number. This fact is discussed as small contribution of the direct processes in (γ, α) reaction in comparison with (p, α) and (n, α) reactions. The comparison of the (γ, n) and (γ, α) reaction can give the conformation of the statistical nature of this processes. The study of these reactions at higher energies in quasy deuteron absorption range is interested as test of reaction mechanism.

Reactions (gamma, alfa)

Target					
51V	47Sc	3.349d	159	68.3	-17.19
82Se	78Ga	1.45h	277	96.4	-17.55
109Ag	105Rh	35.96h	319	19	-28.29
148Nd	144 Ce	284.6d	133.5	11	-14.12
160 Gd	156Sm	9.4h	203 165	20.6 12.7	-14.12
163Dy	159Gd	18.479h	363.5	11.4	-15.6
179Hf	175Yb	4.19d	396	6.4	-18.85
204Hf	200Pt	12.5h	243	2.49	-18.4
195Pt	191g Os	15.4d	129	29	
	191m Os	13.1h			-16.57
186W	182mHf	62min	224 344 455 506	35 42 15.5 21.6	-16.9
184W	180mHf	5.52h	215 332 443	81 94 81.9	-16.9
183W	179m Hf	25.1d	122 146 169	27 27 13.3	

In energy range above GDR are thresholds of the fission of several light nuclei A≤ 55 (Z^2/A≤12) . The increasing of fissionability of light nuclei was observed in several previous experiments [ ].Fission yields measurements by means of registration of the residuals with mass number ~ $A_{target}/2$ can give information about fission-ability of nuclei with low mass number elements.

Conclusion

In frames of presented project will be made the measurements in quasy deuteron absorption range including:

-multi nucleon emission

- α-particles emission reaction

- fission of light nuclei

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9.The Investigation of Excitation Functions of Proton Induced Reactions on ^{203}Tl, ^{nat}W, and ^{nat}Gd up to 18 MeV

Abstract

Excitation functions of the reactions ^{203}Tl(p,n)^{203}Pb, ^{152}Gd(p,n)^{152}Tb and ^{nat}W(p,xn)^{183,184}Re will be measured from their thresholds up to 18 MeV. For these nuclei experimental data or missing, or the available data are not consistent with each other and with the predictions of models. The measurements will be carried out using the stacked-foil technique and high resolution HPGe detector. Reactions induced on copper foils will be used to monitor the parameters of the proton beam. The stacks will be irradiated by proton beam on the C18/18 cyclotron. Results will be compared with theoretical predictions as well as with published experimental data.

The work content

Precise nuclear data on excitation functions for reactions induced by nucleons in the energy range up to several GeV are of great importance both for fundamental nuclear physics and for many applications. Such data are necessary to understand the mechanisms of nuclear reactions, to study the change of properties of nuclei with increasing excitation energy, and to study the effects of nuclear matter on the properties of hadrons and their interactions. Excitation functions are more sensitive to the detailed mechanisms of nuclear reactions than are double differential cross sections of emitted particles or their integrals over energy and/or angles. Therefore, excitation functions are a convenient tool to test models of nuclear reactions.

Second, and perhaps more important today, expanded nuclear data bases in this intermediate energy range are required for several important applications. Also, residual product nuclide yields in thin targets irradiated by medium- and high-energy projectiles are extensively used in cosmochemistry and cosmophysics, e.g. to interpret the production of cosmogenic nuclides in meteorites by primary galactic particles, etc.

Studies of excitation functions of charged particle induced reactions in the intermediate energy region are of considerable significance for the stellar nucleosynthesis in nuclear astrophysics for testing nuclear models as well as their practical applications. In particular, the reactions (p,n) and (p,2n) can play a significant role in the stellar nucleosinthesis of the avoided nuclei.

The proton-induced nuclear reaction cross-sectional data are very important for the nuclear data evaluation which is generally carried out on the basis of experimental data and theoretical model calculations. Nuclear reaction models are frequently needed to provide estimates of the particle-induced reaction cross-sections, especially if the experimental data are not available or unable to measure the cross-sections due to the experimental difficulty. Therefore, nuclear reaction model calculations play an important role in the nuclear data evaluation.

Besides, the new experimental data are necessary to develop theoretical models in order to explain nuclear reaction mechanisms and the properties of the excited states of nuclei in the different energy ranges.

The lack of experimental data makes it impossible to assess the predictive power of a theoretical model.

Surveying the information of excitation functions and yields of the reactions has shown that:

- published cross sections have relatively high errors, the excitation functions were measured in not enough detailed;
- the reported cross sections from different groups often showed unacceptable deviations both in the values of the cross sections and in their energy scales;
- reported calculated and/or measured thick target integral yields have significant differences.

The lack of the experimental data on these topics can be, to some extent, complemented by the considered below experiments on the 18 MeV external proton beam of the C18 cyclotron in Yerevan Physics Institute.

The aims of the work are:

1. measurements of the excitation functions of the reactions ^{203}Tl(p,n)^{203,202m}Pb, ^{nat}W(p,xn)^{182,183,184}Re, ^{nat}Gd(p,n)^{151,152,154}Tb from reactions threshold up to 18 MeV;
2. compilation and evaluation of the available cross section of the abovementioned reactions to resolve the discrepancy among the literature values;
3. perform model calculations and comparison with experimental data to check prediction capability of some computer codes.

The well-known stacked-foil activation technique and subsequent gamma spectrometry will be employed to carry out the measure of excitation functions of ^{203}Tl, ^{nat}W, ^{nat}Gd produced from their thresholds up to 18 MeV.

The detailed information concerning the three study targets is presented in Table 1.1.

Table 1.1

The list of investigated nuclei

Nuclei	Half-life	Reactions	Threshold, MeV	E_{γ}, keV	Inter
^{203}Pb	51.87 h	^{203}Tl(*p,n*)	1.75	279	
^{202m}Pb	3.53 h	^{203}Tl(*p,2n*)	8.68	422.18	
^{202}Tl	12.23 d	^{203}Tl(*p,pn*)	7.882	340.4	
^{155}Tb	5.32 d	^{155}Gd(p,n)	1.612	180	
^{154m}Tb	22.7 h	^{154}Gd(p,n)	4.37	247.9	
^{154g}Tb	21.5 h	^{154}Gd(p,n)	4.37	1274.4	
^{152m}Tb	4.2 min	^{152}Gd(p,n)	4.8	501.74	
^{152g}Tb	17.6 h	^{152}Gd(p,n)	4.8	344.4	
^{151g}Tb	17.5 h	^{152}Gd(p,2n)	12.1	287.36	
^{151m}Tb	25 s	^{152}Gd(p,2n)	12.1	99.54	
^{151}Gd	124 d	^{152}Gd(p,pn)	8.65	153.6	
^{183}Re	70 d	^{183}W(p,n)	1.35	162.32	
^{183}Re	70 d	^{184}W(p,2n)	8.797	162.32	
^{182}Re	64 h	^{183}W(p,2n)	9.827	229	
^{184g}Re	38 d	^{184}W(p,n)	2.275	163; 217	
^{184m}Re	169 d	^{184}W(p,n)	2.275	188	
^{183}Ta	5.1 d	^{186}W(p,α)	7.650	353.99	

The irradiation of Tl, W, Gd targets stacks will be performed at the external proton beam of energy of the cyclotron C18 at energy 18 MeV and current 100 nA. All channels of the reactions taking place at energies 18 MeV in the case of the natural composition of the investigated targets will be considered.

The stack will be formed by the inserting the Al and Cu foils, as the beam energy degrader and reaction monitor, respectively. The overall thickness (number of foils) of the stack was calculated so, that it reduces the beam energy to zero at the last foil. With other words, the range of the bombarding particles should be less than the thickness of the stack. The set of foils was pressed together to avoid air gaps between the foils, which could influence on the vacuum and particle stopping. The advantage of the stacked foil method is that one can get a whole excitation function curve in one single irradiation.

The schematic diagram of stacked foils for the three investigated targets is shown in Fig. 1.1.

Fig. 1.1. Schematic arrangement of the stack with Al degrader and Cu monitor foils for irradiation by protons beam.

It is suggested to perform measurements on reactions ^{203}Tl(*p,xn*)^{203}Pb by the above described stack-foils technique. For this reaction there is no experimental data at all. For reactions ^{203}Tl(p,2n)^{202}Pb, ^{203}Tl(p,3n)^{201}Pb, ^{203}Tl(p,4n)^{200}Pb, ^{205}Tl(p,2n)^{204}Pb, ^{205}Tl(p,3n)^{203}Pb and ^{205}Tl(p,4n)^{202}Pb there are only theoretical calculations by the cascade excitation, hybrid and geometry dependent hybrid, and equilibrium models (see Fig. 1.2) [1].

Contributions of equilibrium and pre-equilibrium reaction mechanisms have been investigated using different reaction model calculations. The excitation functions for pre-equilibrium calculations were newly calculated using hybrid model, geometry-dependent hybrid model and cascade-excitation model. It should be noted, that the predictions of various models differ by more than 5 times.

To determine which model more accurately describes the reaction mechanism is necessary to conduct experimental research.

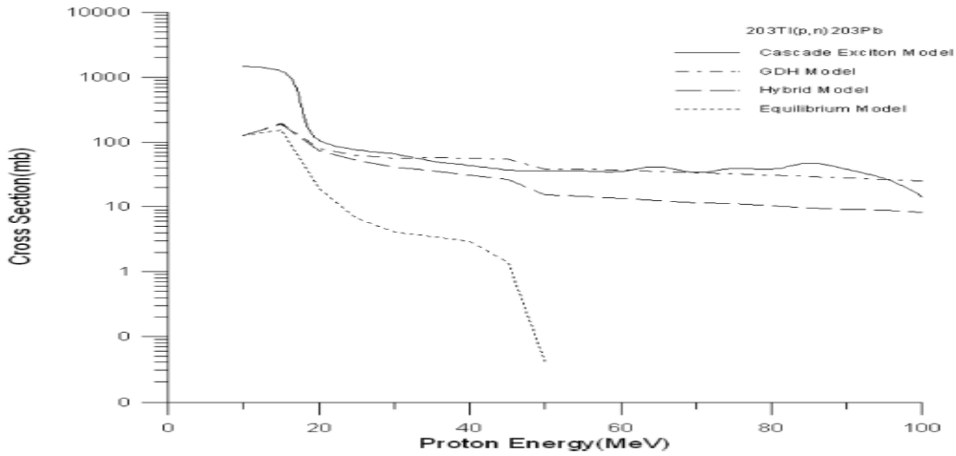

Fig. 1.2. The comparison of calculated excitation functions of ^{203}Tl(*p, n*)^{203}Pb reaction [1].

No experimental data are reported in literature.

A new data set for the production cross sections of the ^{181,182m,182g,183,184m,184g,186}Re have much importance in several fields; e.g. for the improvement of model calculations, nuclear medicine, thin layer activation process, and trace element analysis.

Only a few experimental data are available in the literature for the investigated energy region.

On the Fig. 1.3 are shown the results of the experimental data of different authors for reaction ^{nat}W(p,xn)^{183}Re [2]. In the energy range 15-17 MeV protons there are large differences between the various authors. The excitation function calculated by ALICE-IPPE code doesn’t describe satisfactorily the experimental data in the whole energy range. Excitation functions for the reaction ^{nat}W(p,xn)^{183}Re calculated by code ALICE-IPPE together with the experimental values are shown in Fig. 1.4 [3].

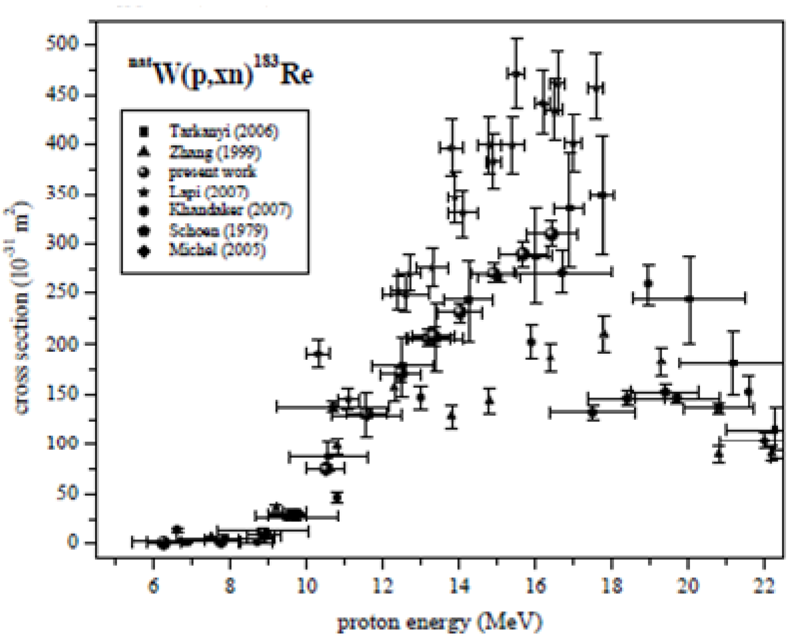

Fig. 1.3. The measured cross section of $^{nat}W(p,xn)^{183}Re$ reaction [2].

The discrepancies between the rhenium excitation function the authors explain that the used targets were the natural composition tungsten.

It is proposed to measure the cross section of the reaction on enriched target of tungsten. Our measurements of the reaction cross section for such a target will contribute to clarifying of the experimental data.

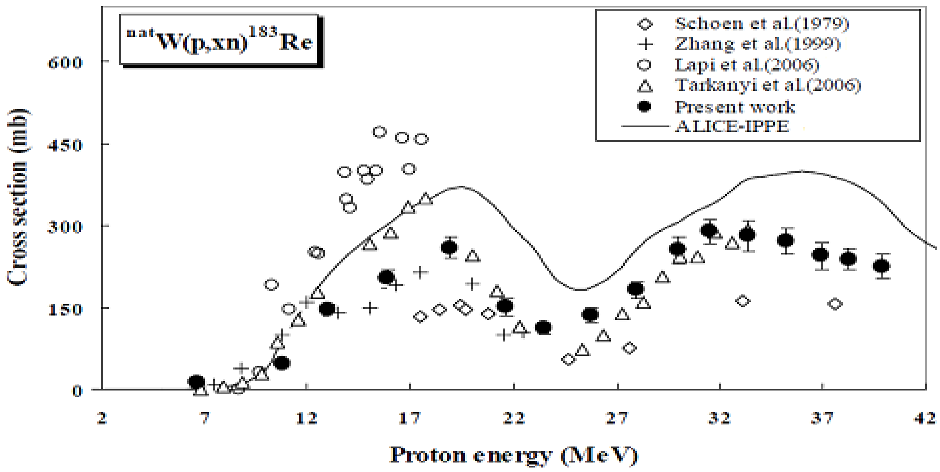

Fig. 1.4. Excitation function on the reaction $^{nat}W(p,xn)^{183}Re$ together with experimental data [3].

Measurement of cross-sections at the nucleus of gadolinium under the proton of energy up to 17 MeV was performed by only one group. The nuclear model calculation of excitation function for reaction $^{nat}Gd(p,x)^{152m+g,154m,154g}Tb$ by ALICE-91 code and EMPIRE-II code was reported in [4].
The comparisons of theoretical calculations with experimental data are shown in Fig. 1.5.

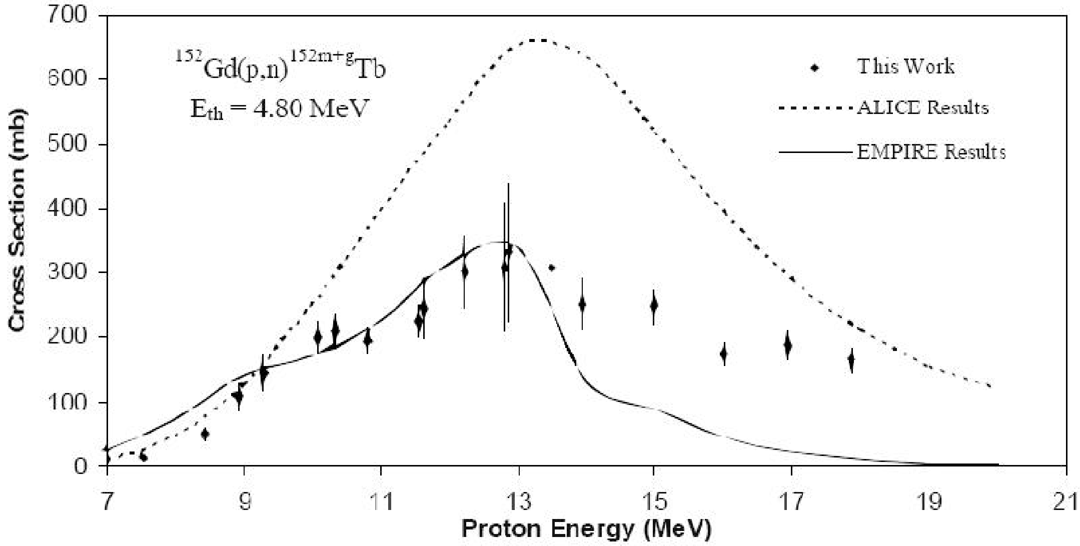

Fig. 1.5. Experimental excitation function for $^{152}Gd(p,n)^{152m+g}Tb$ together with the data obtained by theoretical calculation [4].

On the Fig. 1.5 it is observed that the measured data for the reaction $^{nat}Gd(p,x)^{154g}Tb$ are lower than the theoretical predictions obtained by the ALICE-91 code, but seem to be in agreement with the EMPIRE-II code in the energy region from threshold up to 13 MeV. At more higher energy the code EMPIRE-II doesn't describe the experimental data on reaction $^{nat}Gd(p,x)^{152m+g,}Tb$. Only at low energies up to 9 MeV there is agreement between the experimental data and theoretical calculations performed by ALICE-91 and EMPIRE-II.

The new measurements of the excitation function of the reaction $^{nat}Gd(p,x)^{152m+g,}Tb$ will contribute to experimental data and will assist the understanding the difference between theoretical calculations on ALICE and EMPIRE-II.

Also it is proposed to perform calculations on these reactions by means of the programs EMPIRE-3.1 [5], TALYS 1.4 [6] and compare the results with the available experimental data.

The activation analysis method will be applied to measure the cross sections of the isomeric pair production also.

It is suggested to study several reactions of the isomeric pair production under the proton energy up to 18 MeV at which the experimental data are rather scarce or even absent at present (see references in [7]).

Several examples are listed below

$$p + {}^{124}Sn \rightarrow {}^{124m.g}Sb+n \tag{1.1}$$

$$p + {}^{nat}Mo \rightarrow {}^{93m.g}Tc,\ {}^{94m.g}Tc,\ {}^{95m.g}Tc, \tag{1.2}$$

$$p + {}^{nat}Te \rightarrow {}^{120m.g}I \tag{1.3}$$

$$p + {}^{nat}Sn \rightarrow {}^{106m.g}Ag \tag{1.4}$$

$$p + {}^{nat}Ag \rightarrow {}^{106m.g}Ag \tag{1.5}$$

The measured cross sections of reactions (1.1-1.5) will be compared with the available data at lower and higher energies, as well as with the predictions of various theoretical models and our calculations by programs EMPIRE-3.1 [5] and TALYS 1.4 [6].

The suggested scientific program on the C18/18 cyclotron is aimed at the extraction of a large bulk of new experimental data on proton-nucleus interactions which will be useful for a better understanding of the nuclear structure and the nuclear reactions processes, as well as for optimization of various theoretical models on the low-energy nuclear reactions

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Experimental investigations of (p,γ) reactions

The stellar nucleosynthesis is a complicated multi-stage process inherent to the evolution of the Universe. One of its prominent characteristics is the abundance of chemical elements and their isotopes in various cosmic objects. The contemporary astrophysical models are not yet able to describe satisfactorily the abundances for a number of isotopes, in particular, for several isotopes of elements above iron. This concerns, first of all, 35 proton-rich (or neutron-deficient) stable nuclei which abundances are by one or two order of magnitude smaller than those for other isotopes of the same element. These isotopes are named 'avoided' or p-nuclei (the latter reflects the proton excess in them). It is established at present [1,2,3], that stellar nucleosynthesis of comparatively high-abundance isotopes, neighboring to p-nuclei, proceeds through a multi-step chain of consecutive neutron capture (n,γ) and the nuclear β-decay reactions (that is verified by a number or experimental observations), while in the synthesis of p-nuclei an essential role is played by other, so called p-processes, including first of all the (γ,p) reactions (see [4] and references therein), as well as the (γ,n), (α,p), (p,γ), (p,n), (p,2n) reactions [4,5,6,7]. Necessary conditions for p-processes can be provided in certain, so called explosive nucleosythesis stages of the evolution of stars and close-binary stellar systems. The products of the explosive nucleosynthesis, being ejected into the space, serve as a seed for the formation of the next generation stars (such as the Sun). To simulate as precisely as possible the stellar evolution (including its explosive burst stage), one needs a detailed information on a number of key quantities inferred from nuclear physics experiments, such as the nuclear masses, the β-decay half-lives and the cross sections of aformentioned reactions at the energy range corresponding to the stellar temperatures (so called 'Gamow window' for energy) [8]. It is important to stress that the explosive nucleosynthesis proceeds in very hot medium (up to temperatures of a few billions of Kelvin) and, therefore, the target-nuclei in the majority of cases are expected to be in excited states instead of the ground state. Due to this circumstance, the experimental investigation of these reactions turns out to be impossible (let alone that the most part of target-nuclei are radioactive). To illustrate the said, let us to consider an example of (γ,p) reaction which plays the major role in the stellar nucleosynthesis of avoided nuclei, for instance, the reaction $^{103}Ag^{*}(\gamma,p)^{102}Pd$ in which the avoided nucleus ^{102}Pd originates from the mother nucleus ^{103}Ag which is not only β-radioactive but, being embedded in a very hot medium, is predominantly excited to higher-level states (labeled as ^{103}Ag*). The alone source of experimental information about the ^{103}Ag*(γ,p)^{102}Pd reaction is the measurement of cross section of the inverse reaction ^{102}Pd(p,γ)^{103}Ag*, implemented with detailed equilibrium principle. The experimental data on the latter and on other (p,γ) reactions of astrophysical interest were mainly obtained in the last decade (see references in [4]), using proton beams provided by low-energy proton accelerators at the energy range of a few MeV's, being the most important range for the stellar nucleosynthesis of p-nuclei. The most part of these kind reactions are not still studied experimentally. The list of these reactions includes more than 150 (p,γ) processes on various isotopes of 45 chemical elements from germanium to mercury (see [4]). In the framework of this Project, it is suggested to foresee in the YerPhI Perspective plane the systematic and extensive investigations of several reactions from this list using the proton beam of the C-18 cyclotron. We anticipate that these investigations will enable a deeper insight into the chemical evolution of the Universe, in particular, of various systems of the Galactic.

For the majority of the A(p,γ)B type reactions under consideration, it is not mandatory to register the accompanying prompt γ-quanta, but is sufficient to detect 'delayed' gammas emitted after the β-decay of the daughter B nucleus (the so called activation method), provided that the intensity of delayed γ-quanta is sufficiently large to be disentangled from the background radiation and that the half-life $T_{1/2}$ of the daughter B nucleus is sufficiently large ($T_{1/2}$ > 1 hour) for transportation of targets (irradiated by protons) to the place foreseen for the spectrometric measuremens with the help of photodetectors.

The data on cross sections of reactions (p,γ) obtained with the activation method at a few MeV energy range of projectile protons are available for the following nuclei: ^{70}Ge [9], ^{74}Se, ^{76}Se [10], ^{84}Sr, ^{86}Sr, ^{87}Sr [11], ^{92}Mo, ^{94}Mo, ^{95}Mo,^{98}Mo [12], ^{96}Ru, ^{98}Ru, ^{99}Ru, ^{104}Ru [13], ^{102}Pd, ^{104}Pd [14], [15], ^{106}Cd, ^{108}Cd[16], ^{116}Sn[15], ^{126}Te[17]. The measurements in the said energy range, performed up to the beginning of the 2013 year (including also 'in-beam' measurements with registreation of prompt γ-quanta), involve around 30 (p,γ) reactions on various targets that composes only about 20% of reactions of astrophysical interest [4]. As for remaining 80% of reactions, the cross sections for some of them can be measured with the activation method. The list of nuclei foreseen for the first-term measurements at the YerPhI and some auxiliary information are presented in Table 2.1. The second column of Table 2.1 presents the relative abundance of the given isotope in a natural sample of the corresponding chemical element. The third and forth columns present, respectively, the daughter nucleus and its half-life. Fifth column presents the central value and the width of the Gamow window calculated with an approximate formula [8] (the temperature of the stellar medium was assumed to be 3 GK for relatively light nuclei of tin and gadolinium and 2 GK for heavier nuclei [4]).

Table 2.1

The list of target-nuclei chosen for first-term investigations of (p,γ) reaction

Target-nucleus	Relative abundance (%)	Daughter - nucleus	$T_{1/2}$	Gamow window for proton energy E_p (MeV)
^{117}Sn	7.6	^{118}Sb	5 h	3.43±1.09
^{124}Sn	6.0	^{125}Sb	2.8 y	3.43±1.09
^{152}Gd	0.2	^{153}Tb	2.34 d	4.05±1.18
^{160}Gd	21.9	^{161}Tb	6.9 d	4.05±1.18
^{174}Hf	0.16	^{175}Ta	10.5 h	3.35±0.88
^{180}W	0.12	^{181}Re	19.9 h	3.41±0.88

^{190}Pt	0.012	^{191}Au	38 h	3.53±0.90

In view of the fast rise of cross sections of (p,γ) reactions with increasing E_p, it is necessary to perform the cross section measurements at several energies around the Gamow window. To this end, it is foreseen to use a stack of several targets, which includes also auxiliary thin copper foils served for the monitoring of the proton beam intensity. Since half-life of the majority on relevant daughter-nuclei does not exceed a few days (in several cases – a few hours), it is necessary to start the simultaneous spectroscopic measurements of irradiated targets as soon as possible after the irradiation in the proton beam. In order to increase the efficiency and the confidence of measurements, two or more photodetectors are needed. It is foreseen to use in the first-term measurements high-purity germanium (HPG) detectors one of which is available in the YerPhI, while the second one is suggested to be acquired from the ORTEC Company. The works related to the determination of the optimal thicknesses of targets (including the monitoring one) and radiation durations are in progress.

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The Possibility of the Neutron Beams Formation on Base of Cyclotron C18

ABSTRACT

It is suggested to design of the Project dedicated to the investigation of the possibility of obtaining neutron beams under external proton beams of cyclotron C18. The intensity and neutron spectra of neutron beams will be investigated in the view of using for investigation of the processes in nucleosynthesis and of the radiation resistance of the electronics.

A neutron source is considered monoenergetic when the energy spectrum consists of a single line with an energy width which is much less than the energy itself. In accelerator based sources this width is mainly determined by the target thickness. In practical applications it is usually of little importance to have a narrow energy width of the line. So the "thick target yield" of a source is of interest, rather than the differential one.

Therefore the monochromaticity of a source must be viewed at with an eye on the application. Basically there are three types of applications:

a) scientific ones (physics)

b) technical ones and

c) medical ones.

In each case the demands on a monoenergetic source can differ greatly.

The yield of neutrons of the desired energy from an accelerator based monoenergetic source depends on [1]:

- the charged particle beam intensity,
- the target thickness,
- the differential cross section of the reaction
- the specific energy loss in the target material.

For instance, high-Z targets can be used to produce spallation neutrons. However, there is a recent interest in the use of a ^{7}Li target, which, when bombarded with protons, can produce a relatively high yield of quasimonoenergetic neutrons in the forward direction via the ^{7}Li(p,n) reaction. The quasimonoenergetic and broad neutron sources are needed for research in different areas in nuclear science and technology, *e.g.* Accelerator Transmutation of Waste (ATW), radiation damage studies, medical isotope production, and physics cross section experiments. In order to assess the feasibility of using lithium target to produce neutrons, accurate evaluated cross section data are needed. These data can be used to predict the neutron yield, as well as the neutron energy and angular dependencies, from both thin and thick targets. (Thin targets allow the possibility of producing quasimonoenergetic neutron sources, whereas thicker targets produce broad-spectrum neutron sources.).

Neutron production in the MeV range by the ^{7}Li(p,n)^{7}Be reaction is attractive for two reasons:

- emission of neutrons only into a narrow forward cone and
- the neutron production cross section is very high, especially at lower energies.

On the Fig. 3.1 is shown the cross section of the reaction ^{7}Li(p,n)^{7}Be in dependence of proton beam energy [2,3]. The cross section of reaction ^{7}Li(p,n)^{7}Be has the peak in the region of E_p = 5-7 MeV , the value of the peak is about 250 mb. Consequently, to obtain the high yield of neutrons on the external proton beam of cyclotron C18 necessary to use degrader for decrease proton beam energy up to 5 MeV.

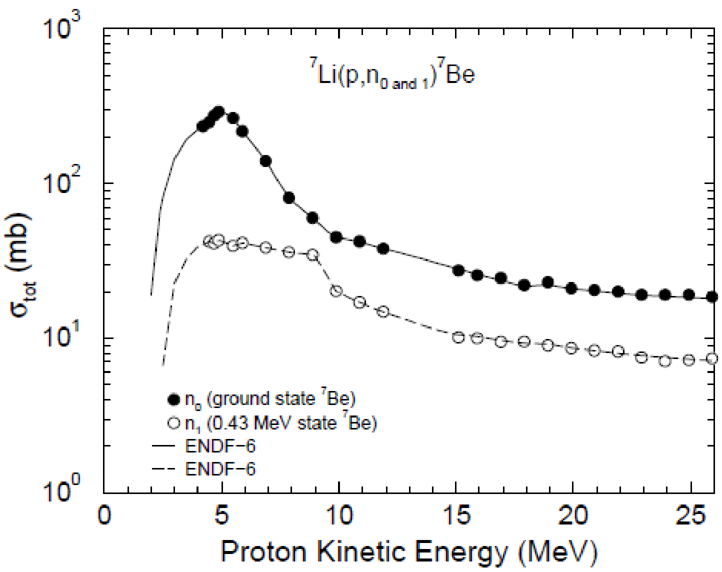

Fig. 3.1. The cross section of reaction ^{7}Li(p,n)^{7}Be in dependence of incident proton energy [2,3].

The neutron spectra in the case of incident proton energy 5 MeV calculated by code TALYS 1.4 [4] is presented on the Fig. 3.2.

Usually only neutron emission at an angle of 0° with respect to the charged particle beam is considered.

The angular distribution of emitted neutrons $^{7}Li(p,n)^{7}Be$ via neutron energy calculated by code DROSG2000 [5] is presented on the Fig. 3.3.

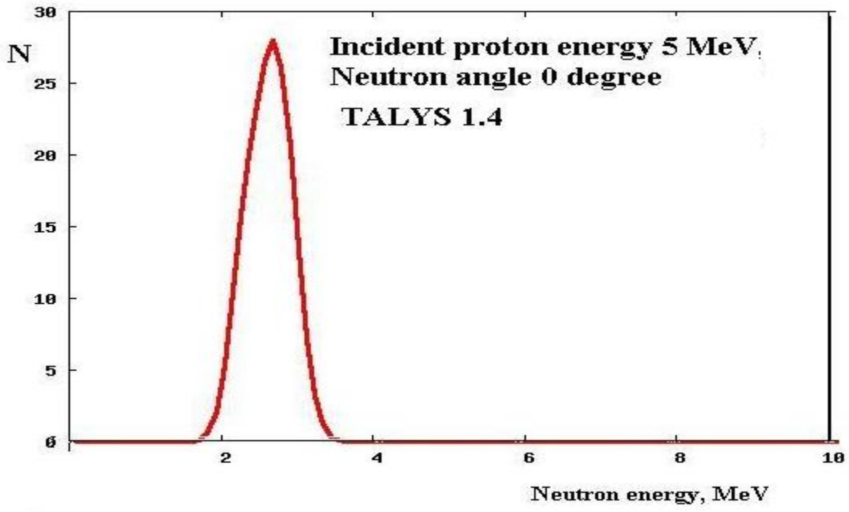

Fig. 3.2. Neutron spectra ib case of proton energy 5 MeV, neutron emitted angle 0^0 calculated by TALYS 1.4 [4].

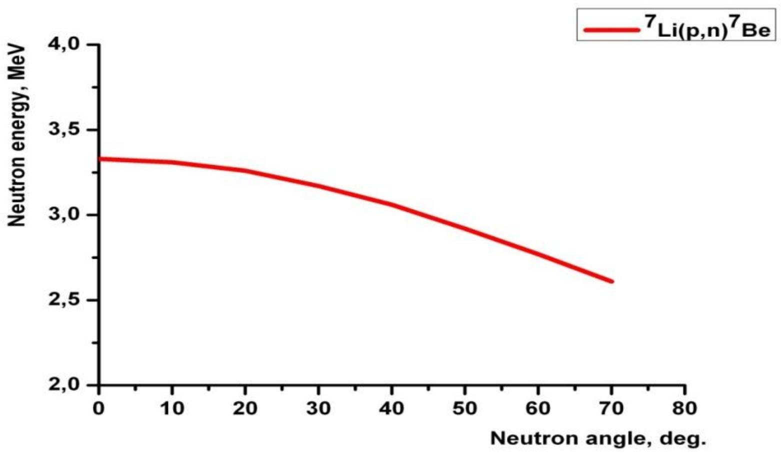

Fig. 3.3. The dependence emitted neutrons energy via neutron angle calculated by DROSG2000 [5].

From the Fig. 3.3 is seen, that placing the sample at 0° has the following advantages:

- The neutron yield is usually forward peaked.
- Neutrons emitted at 0° have the highest energy.

The yield of neutrons from reaction $^{7}Li(p,n)^{7}Be$ under protons beam in the protons energy region 2-5.5 MeV was investigated in [6]. With the increase of the energy of the incident proton, the neutron yield increases. The neutron yield behavior in dependence of the energy of the protons is shown in Fig. 3.4.

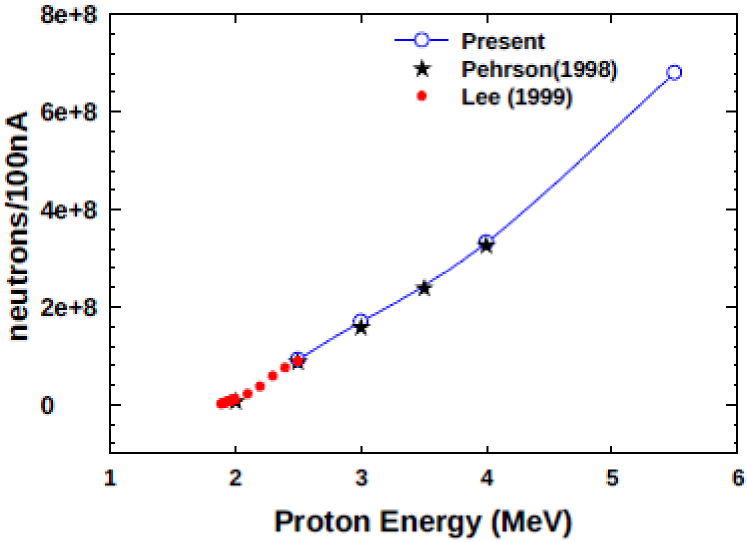

Fig. 3.4. Neutron yield from a 5mm thick natural Lithium target
for proton energies from 2.5 to 5.5 MeV [6].

The integral yield of neutrons at protons energy 5.5 MeV is $6*10^8$ n/100nA, or $6*10^9$ n/μA. In the same [6] work the angular distribution of the emitted neutrons is presented also (see 3.5). From this figure the neutrons yield in the angle region $0\text{-}20^0$ is estimated, $1.43*10^9$ n/μA.

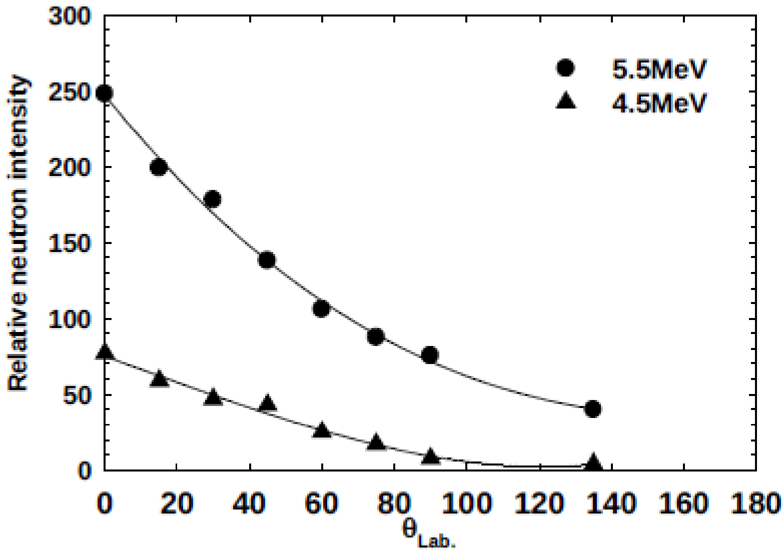

Fig. 3.5. Angular distribution of neutron yield from
thick Lithium target from 4.5 and 5.5 MeV proton energies [6].

Thus, the carried out preliminary studies show that it is possible to obtain neutron beams on the extracted proton beam of the cyclotron C18 with intensity sufficient for performing research on the study of the astrophysical reactions and application problems connected with the radiation resistance of the components of spacecraft electronics.

References (Section 3)

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10. **Synthesis, research and application of new derivatives of chitosan.**

10.1. Abstract

Interest to chitin-chitosan systems and their numerous derivatives over the years doesn't weaken, and recently considerably increased. Tens directions and a set of examples of use chitin-chitosan systems for the solution of specific applied objectives of exclusive importance are established. Chitin-chitosan systems are successfully applied in nuclear medicine, biomedicine, the nuclear industry, food and light industry, agriculture, etc. In our opinion, the great interest is represented by works on synthesis both absolutely new and not synthesized, and the well-known and already studied derivative specified systems. Works on synthesis and establishment of the main characteristics of new Schiff bases on the chitosan base come to the end with us. For the purpose of expansion of a scope of the new systems synthesized by us we plan to synthesize also water-soluble chitosan connections.

10.2.Work schedule

2013-2014

a) synthesis and establishment of the main characteristics of new Schiff bases synthesized by us on the base of chitosan.
b) research of sorption and bactericidal properties of new Schiff bases synthesized by us on the base of chitosan.
Participants- V.Gavalyan

2015-2017

a) synthesis known, and also it is perfect new water-soluble derivatives of chitosan.
b) establishment of structural features (TGA, FTIR methods) of the received water-soluble products.
c) studying of water-soluble derivatives of chitosan as antimicrobial and anti-bactericide film coverings.
Participants: V.Gavalyan, student