Project submitted for the base funding of Artem Alikhanyan National Scientific Laboratory (ANSL)

Principal investigator Hamlet Mkrtchyan

TITLE: Study of the Structure of Hadrons, their Production and Electromagnetic Interaction Properties with High Energy Electrons and Photons.

Division/group: Experimental Physics Division/Laboratories #121, 122 &126.
(In collaboration with Jefferson Laboratory, in a framework of Memorandum of Understanding between ANSL (former YerPhI) and TJNAF).

DURATION: 2011-2013

Estimated Project Costs (± 20%)

Estimated total cost of the project (US $)	~450,000

Including:

Payments to Individual Participants	(100k/year) ➔ 300 k
Equipment	**-**
Materials	**-**
Other Direct Costs	(~3.3 k/year) ➔ 10 k
Travel	(~47 k/year) ➔ 140 k

PROBLEM:

The fundamental nature of matter in terms of elementary particles and their interactions is central topic in subatomic physics. Our understanding of the substructure of the matter has evolved considerably over the last hundred years. The incremental improvements in experimental design, coupled with progressively more sophisticated theoretical formalisms have led to our present-day understanding that all matter is constructed from combination of six quarks and six leptons. The electromagnetic interaction has proved to be very successful in probing the structure of the nucleon in a quest to understand the strong interactions between quarks and gluons.

Since 1990, in the framework of Memorandum of Understanding (MOU) between the JLab and ANSL (former YerPhI), our group (based on laboratories #121, 122 and 126) carried out series of experiments using electron and photon beams of CEBAF accelerator and equipments in JLab experimental Halls A, B and C. ANSL group made valuable contribution in the construction and development of series of detectors at JLab, proposed and carried out several experiments, and played key role in nearly all the major experiments conducted at CEBAF. In the framework of this proposal, in 2011-2013 the ANSL group will continue collaboration with JLab. We will take part in the series of upcoming experiments using up to 6 GeV energy electron and photon beams (including polarized beams & polarized targets), and experimental apparatus in Halls A, B and C, and will work on development of new physics projects and experimental apparatus related with JLab 12 GeV upgrade.

OBJECTIVES:

A wide range of frontier physics studies, development analysis technique, design and construction of particle detectors for JLab experiments beyond 2012 will be conducted by Yerevan group in 2011–2013 in collaboration with Jefferson Lab. Below we will summarize only most important areas of our activities.

TASK 1: Search for exotic mesons in the final state $\pi^o\eta$ and $\pi^o\eta'$

- *Analysis of coherent meson photoproduction on ^{4}He using data from experiment [1.1].* The experiment is aimed to search for $J^{PC}=1^{-+}$ states in the coherent photoproduction of $\pi^0\eta$ and $\pi^0\eta'$ off ^{4}He. The data have been collected in 2009 using CLAS detector as a part of eg6 experiment in Hall B. The background from associated baryon resonances is suppressed in the coherent production on the nuclear target. In the data analysis, scattered electron kinematics is deduced from missing momentum analysis and is selected in the quasi-real photoproduction region. Scattering on a spin and isospin zero target, ^{4}He, simplifies the Partial-Wave Analysis.

Task description and main milestones	Participating institutions
Task 1.1 Calibration and event selection Task 1.2 Data analysis, MC simulations Task 1.3 Determination of physics quantities Results: presentations and discussions in meetings, 1-2 articles	JLab, ANSL and Hall B CLAS Collaboration

TASK 2: Search for a new physics beyond the Standard Model

- *Qweak experiment [2.1] in Hall C* will measure the proton weak charge via parity violating elastic *ep* scattering at Q^2 = 0.026 (GeV/c)^2, and provide ≈0.3% accuracy measurement of $\sin^2\theta_W$. A

deviation from prediction of Standard Model will give a hint of new physics. The experiment employs ~180 μA beam of ~85% polarized, 1.2 GeV electrons on a 2.5 kW power, 35 cm LH2 target, an 8 segment toroidal magnet, 8 Quartz Čerenkov detectors, beam-line and polarimeter.

- *APEX* experiment [2.2] in Hall A will search for a new Vector Boson *A'* decaying to e^+e^-. A' is a thought source of various effects revealed in the dark matter search experiments. The Boson will be produced by electron radiation of high-Z target. It will be searched in 65–550 MeV mass range, as a weak narrow resonance in the invariant mass spectrum of decay e^+e^- pairs. The experiment will use 80 μA CEBAF CW electron beam, a Tungsten wire mesh target, a combination of septa magnet with High Resolution Spectrometers in order to detect e^+e^- pairs at very forward angles. A test run for APEX was performed in Hall A in July 2010, the first results are expected from data analysis included in this Project.

Task description and main milestones	Participating institutions
Task 2.1 Calibration & optimization of Qweak experimental setup Task 2.2 Qweak experimental data taking and on-line analysis Task 2.3 APEX test run data analysis Task 2.4 Preparation of APEX experimental apparatus & software Results: presentations, discussions in meetings, 1-2 articles	JLab, ANSL and Hall C QWeak Collaboration JLab, ANSL and Hall A Collaboration

TASK 3: Study of the nucleon structure

- *The Neutron Electric Form Factor* G_E^n *at* Q^2*=1.2 (GeV/c)*^{2} will be extracted from the collected data in Hall A experiment [3.1]. In this experiment quasi-elastic cross section asymmetry from the semi-inclusive reaction $^3\vec{H}e(\vec{e},e'n)pp$ was measured at Q^2=1.3, 1.7, 2.4, and 3.5 (GeV/c)^2. The experiment used 75% polarized electron beam and 40% polarized $^3\vec{H}e$ target. The scattered electrons were detected in BigBite spectrometer, recoil neutrons were detected in BigHAND. The results from the experiment on the three highest Q^2 kinematic points have been reported recently. The analysis of the Q^2*=1.2 (GeV/c)*^{2} data point is underway and will be completed in this project.
- *Extraction of GPDs* from the analysis of data on Time-like Compton scattering (TCS) [3.2], based on Hall B CLAS e1-6 and e1f data sets. In TCS, the real part of the Compton amplitude can be accessed via measuring an asymmetry arising from exchange of l^+ and l^- momenta. The real part of the Compton amplitude is proportional to the integral of GPDs over the Bjorken *x*, and provides important information for the GPDs. The analyzed process is quasi-real photoproduction of (e^+e^-) pairs at Q^2 >1.1 (GeV/c)^2 in the reaction $\boldsymbol{ep \rightarrow e^+e^-p'e'}$. The kinematics of the scattered electron is deduced from missing momentum analysis.

Task description and main milestones	Participating institutions
Task 3.1 Determination of neutron G_E^n at Q^2=1.2 (GeV/c)^2 Task 3.2 Extraction of GPDs from the analysis of TCS data Task 3.3 Comparison of experimental results with theory Models Results: presentations, discussions in meetings, 1-2 articles …	JLab, ANSL and Hall B CLAS collaboration

TASK 4: Nucleon-Nucleon short range correlations

- *A-dependence of the scaling effect of the ratio of inclusive electron scattering cross sections for heavier nuclei and deuterium in the region x* > 1 *and* Q^2 > 1.5 *(GeV/c)*^{2}. In the previously published works by Yerevan group, the relative per-nucleon probability of 2-nucleon Short Range Correlations (SRC), $a_2(A)$, was extracted based on theoretical calculations and measurements from

CLAS *e*2 [4.1] and other experiments. This proposal is to refine and further SRC investigations by using data on (*e*, *e*') inclusive scattering from CLAS *eg*2 run period [4.2]. The goal is to study scaling with Bjorken *x* of the ratio of cross sections from heavier targets to that from deuteron at *x* > 1.5, and extract $a_2(A)$ for ^{12}C, ^{27}Al, ^{56}F, and ^{208}Pb nuclei. The Q^2 dependence of *r* will be investigated.

- *Structure of bound nucleon, search for nucleon modification in nucleus* will be conducted using CLAS electro-production data on Deuterium from *e6* experiment [4.3]. The main goal is to extract information on the modification of a bound nucleon. For investigation the simplest nucleus of Deuterium has been chosen. We will look for possible changes of nucleon properties in the SRC relative to QF by examining the ratio of cross sections of electron scattered on nucleon in the SRC and QF as a function of Q^2. We will use exclusive $d(e,e'p)n$ reaction, with neutrons from SRC selected within reconstructed momentum range > 275 MeV/c, and QF events at x= 1, and inclusive scattering $d(e,e')$ in the range $1.5 < x < 2$ for $Q^2 > 1.5$ (GeV/c)^2, where SRC dominates.

Task description and main milistones	Participating institutions
Task 4.1 Estimation of acceptance and Faraday cup corrections; determination of cross section ratios of heavy nuclei to Deuteron, hence probabilities of 2NN SRCs. Result: – article.	JLab, ANSL and Hall B CLAS collaboration
Task 4.2 Study of properties of nucleons in SRCs, i.e determination of their form factors. Result: – thesis of a member of Yerevan group.	JLab, ANSL and Hall B CLAS collaboration
Task 4.3 Comparison of obtained results with theory models. Results: presentations and discussions in meetings, 1-2 articles	JLab, ANSL and Hall B CLAS collaboration

TASK 5: Development of Physics projects & apparatus for experiments at CEBAF 12 GeV

- *The neutron electromagnetic Form Factor ratio* G_E^n / G_M^n at Q^2 = 5.0, 6.8, and 10.2 (GeV/c)^2 will be measured in Hall A [5.1] at 12 GeV energy by measuring the transverse asymmetry $A_\perp$ in double polarized semi-exclusive $^3\overrightarrow{He}(\vec{e},e'n)pp$ scattering. This quantity will be used to extract the electric form factor, G_E^n, as more precise data for G_M^n at high Q^2 becomes available. The accuracy $\Delta G_E^n = 3\times10^{-4}$ at Q^2 =10 (GeV/c)^2 will be reached.
- *Proton Form Factor Ratio at Q^2 = 13 & 15 (GeV/c)^2* will be measured via Recoil Polarimetry in Hall A [5.2], using recoil polarization technique. The new data will give access to a region of Q^2 in which G_E^p is completely unknown. The experiment will utilize 75 μA current, 11 GeV energy electron beam with 85% polarization on a 40 cm LH2 target. Scattered electrons will be detected in the highly segmented calorimeter BigCal. The recoil proton will be detected in SuperBigBite, which will include a dipole magnet, polarimeter with GEM trackers, and a hadron calorimeter.
- *The first measurement of the ratio $R = \sigma_L/\sigma_T$ in SIDIS* in a wide kinematic range of *z*, *x*, Q^2 and P_t^2 will be performed in Hall C experiment [5.3]. These measurements will allow study of the inclusive-exclusive connection in pion electroproduction, a process where duality has been shown to be valid, and are necessary for the interpretation of flavor decomposition by SIDIS at 12-GeV JLab. We will detect $\pi^\pm$ pions in SHMS in coincidence with scattered electrons in HMS from LH2 and LD2 targets at beam energies 6.6-11.0 GeV.
- *Transverse Momentum Dependence of Semi-inclusive Pion Production* will be studied in experiment [5.4] with 11 GeV CEBAF beam in Hall C. We will map the P_t dependence for semi-inclusive electroproduction of $\pi^\pm$ from proton and deuterom 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/c. The experiment will use HMS-SHMS spectrometers.

- *Design and construction of calorimeter for SHMS spectrometer (in Hall C); pre-shower calorimeter for CLAS12 detector (in Hall B). Design and construction of detectors for Super BigBite Spectrometer, and upgrade of BigBite Spectormeter (in Hall A).*

Task description and main milistones	Participating institutions
Task 5.1 Test of the BigBite and HRS spectrometer detectors**.** Development of calibration methods for BigBite calorimeter and drift chambers. Construction of detectors for SuperBigBite.	JLab, ANSL and Hall A Collaboration
Task 5.2 MC simulations and development of analysis technique for $R = \sigma_L/\sigma_T$ ratio and P_t-dependence studies in SIDIS at 12 GeV	JLab, ANSL and Hall C Collaboration
Task 5.3 Construction of calorimeter and aerogel detector for SHMS, and preshower for CLAS12, and detectors for SuperBigBite.	JLab, ANSL and Hall A, Hall B and Hall C Collaborations
Results: presentations and discussions, 1-2 Tech.Nots, 1-2 articles	

IMPACT:

- *Search for exotic mesons in the final state $\pi^o\eta$ and $\pi^o\eta'$ (Hall B experiment E07-009):* During the past 15 years, a number of different experiments have provided tantalizing evidence for 1^{-+} exotics $\pi_1(1400)$, $\pi_1(1600)$, and $\pi_1(2000)$. If each of these states was verified, this would result in an overpopulation of the 1^{-+} hybrid nonet where there should be only one π_1 state. Most of the searches for exotics have used hadronic production reactions, i.e. πN and *pp(n),* characteristically yielding high statistics. J/ψ decays have been studied as well, but with considerably lower statistics. So far two states below 1.8 GeV have been identified as $J^{PC} = 1^{-+}$ exotics at masses around 1.4 GeV and 1.6 GeV. It is not clear if these are hybrids or four-quark states, and there is a controversy in the amplitude analysis. For clarification, more experiments in different production and/or decay modes, with high statistics and robust amplitude analyses are needed. The mass range of the lowest lying exotic hybrid is accessible at current CEBAF energies. The CLAS detector is an ideal tool for studying multi-particle final states.
- *Measurement of the proton weak charge (E02-020 Qweak experiment):* The proposed measurement of Q_W^p will be performed with significant smaller errors and has a much cleaner theoretical interpretation than existing low Q^2 data (neutrino-nucleus scattering, NuTeV and atomic parity violation, APV). It is complementary to a Moller scattering experiment E-158 at SLAC which will determine $\sin^2\theta_W$ at low Q^2, but will be carried out to higher precision. Any significant deviation of $\sin^2\theta_W$ from the Standard Model prediction at low Q^2 would be a signal of new physics. If LHC observes a new neutral boson with mass Λ, Qweak results could help identify it by constraining the magnitude and sign of the coupling-to-mass ratio g_{e-p}/Λ.
- *Search for a new Vector Boson A' (*E12-10-009 APEX Experiment):* This experiment is particularly timely in light of a series of recent anomalies from terrestrial, balloon-borne, and satellite experiments that suggest that dark matter interacts with Standard Model particles. Much of this data sharply hints that dark matter is directly charged under a new force mediated by an *A*' and not described by the Standard Model. Theoretical, as well as phenomenological expectations suggest an *A*' mass $m_{A'} \leq 1$ GeV. Much of this region will be explored with the proposed experiment. The experiment will achieve very good sensitivity because the statistics of e^-e^+ pairs will be ≈10,000 times larger in the explored mass range than any previous search for the *A'* boson

has acquired. The importance for fundamental physics of discovering new forces near the GeV scale cannot be overstated.

- *Neutron Electric Form Factor G_E^n at Q^2 = 1.2 (GeV/c)^2 (analysis of Hall A experiment E02-013):* The neutron electric form factor is one of the fundamental quantities in the nuclear physics. It is particularly difficult to measure because of the charge neutrality of the particle. E02-013 is part of a series of experiments at JLab devoted to the neutron form factor measurement. It has extended the Q^2 range of experimental data more than twice. The lowest Q^2 point will require more detailed studies of inelastic backgrounds and sources of errors in determination of detector efficiencies at high rates. This is important for next generation experiments at 12 GeV.

- *GPDs from Timelike Compton Scattering:* Up to date GPDs were experimentally investigated only through the Deeply Virtual Compton Scattering $\gamma^* p \to \gamma p$, where γ* has large spacelike virtuality while outgoing photon is on shell. The Timelike Compton Scattering process $\gamma p \to \gamma^* (\to l^+ l^-) p$ offers a new way to access the real part of the Compton amplitude, through the angular asymmetry of $l^- l^+$ pairs. This study deals with experimental data on TCS collected for the first time in the kinematic region of total center mass energy s=7.8 GeV and the heavy photon virtuality of Q^2=1.34 (GeV/c)^2. Also, for the first time the study will yield comparison of the data with GPD based models.

- *Short – range correlations (SRCs):* For many decades, directly observing SRCs was considered an important, though elusive, task of nuclear physics. During the last few years Yerevan group at Jlab, using CLAS measured ratio of the cross-sections for electrons scattering with large momentum transfer off medium and light nuclei in the kinematic region that is forbidden for scattering off low momentum nucleons. Steps in the value of this ratio appeared to be the first direct observation of SRCs of two and three nucleons in nuclei. Discovery of strong short range correlations in nuclei with strong dominance of I=0 SRC, proves validity of the strategy of using high momentum transfer processes for probing SRCs. It provides a solid basis for future experimental studies. As outlined above, this project furthers studies on SRCs in order to better understand the nature of the phenomenon.
- *The Neutron Electromagnetic Form Factor Ratio G_E^n / G_M^n at High Q^2 (Hall A proposal P12-09-016).* Knowledge of the neutron electromagnetic form factors, G_E^n and G_M^n, are essential for understanding of nucleon structure. Data for G_E^n at high Q^2 are necessary, in particular, to constrain spin-flip GPDs at high momentum transfer. In the last ten years, a variety of double polarization experiments measuring G_E^n have been performed at different facilities: MIT-Bates, NIKHEF, MAMI, and JLAB Halls A and C. This experiment is a natural continuation of the previous E02-013 experiment in JLab Hall A, with significant extension of the Q^2-range of experimental data.
- *Proton Form Factor Ratio Measurements at 13 & 15 (GeV/c)^2 via Recoil Polarimetry (Hall A experiment E12-07-109).* Current theoretical models describe proton data well up to $Q^2 \approx 5$ (GeV/c)^2, and diverge strongly at higher Q^2 where there are no precision data to constrain the calculations. Conditions at JLab are recognized as unique for such kind of measurements, and this experiment is optimized to rich the needed quality of data.
- *Measurement of $R = \sigma_L/\sigma_T$ in Semi-Inclusive DIS (E12-06-104 proposal):* Essentially no information exists on the value of R in SIDIS. In DIS, at fixed x the ratio R asymptotically scales like Q^2. For SIDIS R is assumed to be similar to that of DIS. This assumption has never been thoroughly checked. For the first time the assumption $R_{SIDIS} = R_{DIS}$ will be checked, and, since we plan to measure Semi-Inclusive π^+ and π^- electroproduction on both hydrogen and deuterium targets, also we will check whether $R_{SIDIS}^{\pi^+} = R_{SIDIS}^{\pi^-} = R_{SIDIS}^{H} = R_{SIDIS}^{D}$.

- *Transverse Momentum Dependence of Semi-inclusive Pion Production (PR-09-017 proposal):* Very little is known about the dependence of the *up* and *down* parton distribution functions on their transverse momentum k_t. The proposed measurements will constrain the initial transverse widths of *up* and *down* quarks, and the transverse momentum widths of favored and unfavored fragmentation functions.

Brief survey of the worldwide researches made on the project topics, the competitiveness of the project, and achievements of the group

The two 6 GeV experiments mentioned above, E02-020 (Q_{weak}) and E12-10-009 (A' search) are related to the Modern Physics. As such, their role is hard to overestimate. Q_{weak}, a major experiment at JLab, searches for hints of physics beyond the Standard Model effectively on a TeV energy scale. A' search, if succeeded, will discover a new particle related to the Dark Matter. Yerevan group was actively involved in the preparations to both experiments and will continue with data taking and analysis. It is anticipated that both experiments will present results in the leading refereed journals.

Among the data analyses, data mining of experiment E07-009 is aimed at detection of an exotic meson configuration not seen before. E02-013 (G_E^n at $Q^2 = 1.2$ GeV^2) and the GPDs from Hall B data TCS analyses, are to clarify structure of hadrons. E05-115, the two SRC analyses are to further understanding of the structure of nuclear medium. Note that in 5 cases (E07-009, E02-013, GPDs from TCS analysis, and SRC analyses) ANSL group is the leader. Note also that ANSL group is among the initiators of Short Range Correlations experiments at JLab. Obtained results on SRCs were cited as one of the most significant results of Jefferson Lab in studying structure of nuclei and made twice in CERN Courier, in November 2005 and January 2009. Results from analyses will be published in the refereed journals.

Traditionally, ANSL group has a strong commitment to hardware development at JLab. Among detectors constructed with leading contribution from the group are 1744 channel lead-glass calorimeter BigCal, CLAS electromagnetic calorimeter, HMS/SOS lead glass calorimeters and HMS aerogel detector. Now the group actively participates in design and construction of SBS spectrometer in Hall A, CLAS12 Pre-shower calorimeter in Hall B, and took responsibility for construction of SHMS lead glass calorimeter in Hall C. Those works are valuable contributions into the CEBAF 12 GeV Upgrade Program. Intermediate results on constructive methodology will be described in JLab Notes, and complete constructions in the refereed journals.

References:

1.1 "Meson spectroscopy in the Coherent Production on ^{4}He with CLAS". JLab experiment E07-009, **I. Aznauryan** and S. Stepanyan spokespersons.

2.1 "QWeak- A Precision Test of the Standard Model and Determination of the Weak Charges of the Quarks Through Parity Violating Electron Scattering". JLab Experiment E02-020 (E08-016), R. Carlini, S. Kowalski, S. Page spokespersons.

2.2 "Search for a New Vector Boson A' Decaying to e^+e^-". JLab experiment E-12-10-009, R.Essig, P.Schuster, N.Toro, B.Wojtsekhowski spokepersons.

3.1 "Measurement of the Neutron Electric Form Factor Gen at high Q^2". JLab Experiment E02-013, G. Cates, N. Liyanage, B. Wojtsekhowski spokespersons.

3.2 CAA for Time-like Compton Scattering, http://www.jlab.org/~stepanya/tcs/caa_tcs_e1_6f.pdf

4.1 "Study of Short-Range Properties of Nuclear Matter in Electron-Nucleus and Photon-Nucleus Interactions with Backward Particle Production Using the CLAS Detector", JLab experiment E89-036. **K. Egiyan** spokesperson.

4.2 "Quark Propagation through Cold QCD Matter", JLab Experiment 02-104. W. Brooks spokesperson.

4.3 "Electron Scattering from a High Momentum Nucleon in Deuterium". JLab Experiment E94-102 K. Griffioen and S. Kuhn spokespersons.

5.1 " Measurement of the Neutron Electromagnetic Form Factor Ratio G_{En}/G_{Mn} at High Q^2 ". JLab Proposal E12-09-016, G. Cates, S. Riordan and B. Wojtsekhowski spokespersons.

5.2 "Large Acceptance Proton Form Factor Ratio Measurements at 13 and 15 (GeV/c)2 using Recoil Polarization Method". JLab Proposal E12-07-109, C.Perdrisat, V.Punjabi, B.Wojtsekhowski, L.Pentchev, M.Khandaker and E.Cisbani spokespersons.

5.3 "Measurement of the Ratio R=sigmaL/sigmaT in Semi-Inclusive Deep-Inelastic Scattering". JLab Proposal E12-04-104, P. Bosted, R. Ent and **H. Mkrtchyan** spokespersons.

5.4 "Transverse Momentum Dependence of Semi-Inclusive Pion Production". JLab Proposal E12-09-017, P. Bosted, R. Ent and **H. Mkrtchyan** spokespersons.

Personnel Commitments:

Total number of participants in the project is 24, of which 12 are younger than 35. The commitments are summarized in the table below.

	Name	Position	Responsibility
1	H. G. Mkrtchyan	Doctor phys. Head of the project	QWeak data taking. Preparation of cosmic test setup for SHMS Preshower. MC studies of kinematics, rates and physics backgrounds for 12 GeV experiments "P_t dependence in SIDIS" and "$R=\sigma_L/\sigma_T$ in SIDIS".
2	S. S. Arutunyan	Engineer	Design of the detectors and support structures
3	V. H. Tadevosyan	Physicist	QWeak data taking. Development of SHMS Calorimeter calibration and on-line data analysis codes. MC studies of kinematics, rates and physics backgrounds for 12 GeV experiments "P_t dependence in SIDIS" and "$R=\sigma_L/\sigma_T$ in SIDIS".
4	A. R. Asaturyan	Physicist	QWeak data taking. SHMS Preshower assembling and testing.
5	A.H. Mkrtchyan	Physicist	QWeak data taking. SHMS Preshower assembling and testing.
6	S.V. Zhamkochyan	PhD Physicist	QWeak data taking. Development of SHMS Calorimeter calibration and on-line data analysis codes.
7	PhD student		Simulation and Physics analysis
8	Graduate student		Simulations and Physics analysis
9	A.H. Shahinyan	PhD Engineer, Head of Lab. 122	Preparation of detector packages for Hall A 12 GeV upgrade, specifically for SBS spectrometer, including: trigger design and preparation; design and construction of prototypes and working detectors, their testing, installation and maintenance.
10	H.A. Agababyan	Engineer	Development of fast and trigger electronics
11	H.V. Voskanian	Physicist	Assembling and testing of modules for CLAS12 Pre-shower calorimeter.
12	E.S. Ghandilyan	Technician	Analysis of existing Hall A experimental data. Development of data analysis software. MC simulations of different detector configurations.
13	S.L. Abrahamyan	Physicist	Development of data analysis software, including packages for detector calibration and online analysis. Offline data analysis, extraction of physics results. MC simulations for future experimental projects, including SBS spectrometer.
14	PhD student		Simulations and Physics analysis
15	Graduate student		Simulations and Physics analysis
16	N.B. Dashyan	PhD Phys., Head of Lab. 126	Development of GEANT model for the target and the radial time projection chamber (RTPC) used in experiment E07-009, in the framework of GEANT-

			3 simulation package for CLAS. Development of hit reconstruction algorithm for CLAS12 electromagnetic calorimeters. Extraction of physics results from CLAS *eg*2 run period on A-dependence of the scaling effect of the ratio of inclusive electron scattering cross sections, A(*e*,*e*'), for heavier nuclei and deuterium in the region $x_B>1$ and $Q^2>1.5$ GeV^2 .
17	J.L. Qocharova	Physicist	Simulations and Physics analysis
18	S.S. Mailyan	Engineer	Preparation of detector packages for Hall A 12 GeV upgrade, namely: testing and construction of prototype detectors; preparation of detectors for installation in the Hall and their maintenance during experiment.
19	N.E. Gevorkyan	Physicist	Maintenance and development of slow control software for CLAS. Development of beam line instrumentation and slow control software for Hall B 12 GeV upgrade. Extraction of physics results on nucleon modification in nucleus, using CLAS electroproduction data on deuterium from experiment E94-102.
20	K. Alanakyan	Physicst	Development and Studies of detector prototypes
21	R. Paremuzyan	PhD Physicist	Calibration of data from experiment E07-009. Extraction of physics results on Time-like Compton scattering and Generalized Parton Distributions from Hall B CLAS e1-6 and e1f data sets.
22	A. Simonyan	PhD student	Calibration of data from experiment E07-009. Development of hit reconstruction algorithm for CLAS12 electromagnetic calorimeters. Analysis of coherent meson photoproduction data on ^{4}He from experiment E07-009, search for exotic mesons in the final state $\pi\eta$ and $\pi\eta$'.
23	PhD student		Simulations and Physics analysis
24	Graduate student		Simulations and Physics analysis

Equipment:

Equipment description (*)	Cost (US $)
Total	

* The Project will use JLab equipments, CEBAF accelerator beams and Hall A, B and C apparatuses.

Materials:

Materials description (*)	Cost (US $)
Total	

* All necessary materials for the Project will be supplied by JLab.

Other Direct Costs:

Direct costs description	Cost (US $)
Personal Computers	5x 1,000
Printer	1x 500
Scanner	1x 500
Computer farm	(*)
Large disk space (~5 Terra bite)	(*)
Fast Internet connection with JLab	(*)
Access to journals or to copies of important articles	~1,500
Other expenses (office equipments, …, etc)	~2,500
Total	~10,000

* We assume this will be covered by general expenses of Physics Division

Travel costs (US $):

CIS travel	International travel	Total
Moskow-Dubna (RF)	Newport-News (USA)	
~$3,300/year *	~$40,000/year **	($43,300/year)x3 ➔ ~$130 k
	~$3,300/year ***	(~$3,300/year)x3 ➔ ~$10k

* Assuming support for CIS travel (2-3 person)/year for 5-7 days each.

** Assuming support for USA travel on the level of (2 FTE)/year for participation in collaboration activities (since the most part of travel expenses necessary for project will be covered by JLab), and International travel 1.0/year for participation in international workshops and conferences.

*** Support for International Conferences and Workshops (1-2 person/year)

Technical Approach and Methodology

1. Search for exotic mesons in the final state $\pi^o\eta$ and $\pi^o\eta'$

- *Analysis of coherent meson photoproduction on ^4He.* Will use data from Hall B experiment E07-009 which ran in September – December of 2009 as part of eg6 CLAS run period, with aim to search for $J^{PC}=1^{-+}$ states in the coherent photoproduction of $\pi^0\eta$ and $\pi^0\eta'$ off ^{4}He. The background from associated baryon resonances, one of the key issues in meson spectroscopy with photon beams at JLAB energies, is suppressed in the coherent production on the nuclear target. In order to ensure coherent production, recoil helium nuclei were detected in the specialized detector, Radial Time-projection Chamber, while full hadronic final states (decay products of produced meson) in the CLAS detector. In the data analysis, scattered electron kinematics is deduced from missing momentum analysis and is selected in the quasi-real photoproduction region. Scattering on a spin and isospin zero target, ^{4}He, simplifies the Partial-Wave Analysis. The ANSL group played key role in the installation and running of the experiment, and is leading data analysis.

  During past 15 years, a number of different experiments have provided tantalizing evidence for 1^{-+} exotics $\pi_1(1400)$, $\pi_1(1600)$, and $\pi_1(2000)$. If each of these states was verified, this would result in an overpopulation of the 1^{-+} hybrid nonet where there should be only one π_1 state. Most of the searches for exotics have used hadronic production reactions, i.e. πN and $pp(n)$, characteristically yielding high statistics. J/ψ decays have been studied as well, but with considerably lower statistics. So far two states below 1.8 GeV have been identified as $J^{PC} = 1^{-+}$ exotics at masses around 1.4 GeV and 1.6 GeV. It is not clear if these are hybrids or four-quark states, and there is a controversy in the analysis. For clarification, more experiments in different production and/or decay modes, with high statistics and robust amplitude analyses are needed.

  The mass range of the lowest lying exotic hybrid is accessible at current CEBAF energies. The CLAS detector is an ideal tool for studying multi-particle final states.

2. Search for a new physics beyond the Standard Model

- *Qweak experiment (E02-020)* will run in Hall C. This will measure the proton weak charge via parity violating elastic ep scattering at $Q^2 = 0.026$ GeV^2. *Qweak* will provide ≈0.3% accuracy measurement of $\sin^2\theta_W$, the most precise stand alone measurement of the weak mixing angle at low Q^2. A deviation from prediction of Standard Model will give a hint of new physics. The Standard Model makes a firm prediction of Q_W^p, based on the running of the weak mixing angle $\sin^2\theta_W$ from Z^o pole down to low energies. Any significant deviation of $\sin^2\theta_W$ from the Standard Model prediction at low Q^2 would be a signal of new physics. Currently there are only two off-peak measurements of $\sin^2\theta_W$ which test the running at a significant level: one from atomic parity violation (APV) and one from high energy neutrino-nucleus scattering (NuTeV). The experiment employs ~180 μA beam of up to 85% polarized, 1.2 GeV electrons on a 2.5 kW power, 35 cm liquid hydrogen target, an 8 segment toroidal magnet, 8 Quartz Čerenkov detectors, beam-line and polarimeter. The ANSL group has valuable contribution in design and construction of the Main Detector, is part of the team responsible for Region-I GEM tracker and electron beam polarimetry. In 2011-2013 we will take part in data taking and analysis.

  The proposed measurement of Q_W^p will be performed with smaller statistical and systematic errors and has a much cleaner theoretical interpretation than existing low Q^2 data. It is complementary to an SLAC experiment E-158 which will determine $\sin^2\theta_W$ from parity violation in $\vec{e}e$ (Moller) scattering at low Q^2, but will be carried out to higher precision. Qweak will place

new constrain on quark vector couplings C_{1u}, C_{1d}. If LHC observes a new neutral boson with mass Λ, Qweak could help identify it by constraining the magnitude and sign of the ratio g_{e-p}/Λ.

*Experiment APEX (*E12-10-009)* will search for a new vector boson *A'* with weak coupling $\alpha' \sim 6\times10^{-8}\alpha$ to electrons in the mass range 65 MeV < $m_{A'}$ < 550 MeV. New vector bosons with such small couplings arise naturally from a small kinetic mixing of the "dark photon" *A'* with the photon — one of the very few ways in which new forces can couple to the Standard Model — and have received considerable attention as an explanation of various dark matter related anomalies. The Boson will be produced by electron radiation of high-Z target. It will manifest itself as a weak narrow resonance in the invariant mass spectrum of decay e^+e^- pairs. The experiment can determine the mass of an *A*' to an accuracy of 1–2 MeV.

The experiment will use 80 μA CEBAF CW electron beam at energies of 1.1, 2.302, 3.3, and 4.482 GeV incident on a long (50 cm) thin tilted tungsten wire mesh target, a combination of septa magnet with High Resolution Spectrometers (HRS) in order to detect e^+e^- pairs at very forward angles. Construction of the target considerably reduces multiple scattering, hence reduces relative mass resolution to 0.5%. Both arms of the HRS will be positioned at small angles between 5.0° and 5.5° relative to the nominal target position.

In July 2010 a test run for APEX was performed in Hall A. ANSL group was involved in preparation, installation and data taking. The group members upgraded drift chambers with new amplifier cards on both spectrometers (for operation with high efficiency at a rate ~ 3-5 MHz), developed software package for data analysis and calibration. A member of the group participates in data analysis. The group will take part in preparation of apparatus for full APEX run.

This experiment will be sensitive to new gauge bosons with couplings as small as $\alpha'/\alpha \sim (6-8)\times10^{-8}$ for masses in the range 65 – 300 MeV, and $\alpha'/\alpha \sim 2\times10^{-7}$ for larger $m_{A'}$ < 525 MeV. This is about a factor of 3−35 times lower in gauge kinetic mixing ε than existing constraints, and corresponds to 10 − 1000 times smaller cross-sections. This region of mass and coupling is compatible with *A'*s explaining the annual modulation signal seen by the dark matter direct detection experiment DAMA/LIBRA, and also with dark matter annihilating into *A*'s, which explains a myriad of recent cosmic-ray and other astrophysical anomalies. In addition, the experiment would be the first to probe *A*'s of mass ~100 MeV with ε below ~10^{-3}, the range most compatible if the Standard Model hypercharge gauge group is part of a Grand Unified Theory.

3. Study of the structure of the nucleon

- *Measurement of the Neutron Electric Form Factor G_E^n at Q^2 = 1.2 (GeV/c)^2* . In experiment E02-013 the electric form factor of the neutron, G_E^n, was measured at Q^2 = 1.3, 1.7, 2.4, and 3.5 (GeV/c)^2 by measuring the helicity dependent quasi-elastic cross section asymmetry from the semi-inclusive reaction $^3\vec{H}e(\vec{e},e'n)pp$. This asymmetry is directly related to the ratio of the electric and magnetic form factors of the neutron. The experiment used 75% polarized electron beam on 40% polarized $^3\vec{H}e$ target. The scattered electrons were detected in Hall A BigBite large acceptance magnetic spectrometer, while coincident recoil neutrons were detected in a large hadron detector, BigHAND. The first results from the experiment on the three highest Q^2 kinematic points have been presented elsewhere recently. Analysis of the lowest Q^2 point, which is a duty of a researcher from NSL, has been delayed because it required more detailed studies for estimation of inelastic backgrounds, for detector calibration and determination of their efficiencies at relatively high rates. The new data point at this Q^2 overlaps with previous measurements, hence is important for check of data consistency.

The neutron electric form factor is one of the fundamental quantities in the nuclear physics. It is particularly difficult to measure because of the charge neutrality of the particle. E02-013 is part

of a series of experiments at JLab devoted to the neutron form factor measurement. It has extended the Q^2 range of experimental data more than twice. ANSL is planned to actively participate in the next generation G_E^n experiment at 12 GeV JLab.

- *Extraction of information on GPDs from analysis of data on Time-like Compton scattering (TCS) (Hall B).* This is ongoing "data mining" project based on CLAS e1-6 and e1f data sets. The aim of the study is to extract information on the real part of the Compton amplitude. Analysis is performed by a researcher from ANSL. Currently it is in very advanced stage.

  TCS is an inverse process to Deeply Virtual Compton Scattering (DVCS) and gives access to Generalized Parton Distributions (GPDs). In TCS, the real part of the Compton amplitude can be accessed via measuring an asymmetry arising from exchange of l^+ and l^- momenta. The real part of the Compton amplitude is proportional to the integral of GPDs over the internal quark loop momentum, *x*, and provides important information for modeling the GPDs, in particular on the contribution of the D-term.

  The analyzed process is quasi-real photoproduction of (e^+e^-) pairs at high virtualities, $m^2(e^+e^-) = Q^2 > 1.1$ (GeV/c)^2 in the reaction $\boldsymbol{ep \rightarrow e^+e^-p'e'}$, where ***e*** and ***e'*** are incoming (beam) and scattered electrons, ***p*** and ***p'*** are the target and recoil nucleons, and $\boldsymbol{e^+}$ and $\boldsymbol{e^-}$ are the final state lepton pairs. The detected particles are ***p'***, $\boldsymbol{e^+}$ and $\boldsymbol{e^-}$. The kinematics of the scattered electron is deduced from missing momentum analysis. In order to have photoproduction of lepton pairs, events with electrons scattered at very small angles are selected. The real part of the Compton amplitude is extracted from the azimuthal angular asymmetry between the reaction plane and the lepton plane.

  Up to date GPDs were experimentally investigated only through the process of Deeply Virtual Compton Scattering (DVCS) $\gamma^* p \rightarrow \gamma p$, where γ^* has large spacelike virtuality while outgoing photon is on shell. Basic observables in DVCS are cross-section, spin asymmetries and Beam Charge Asymmetry (BCA). Cross-section measurements and BCA give access to the real part of Compton amplitudes, and spin asymmetries give access to the imaginary part of Compton amplitudes, which are linear combinations of GPDs. The Timelike Compton Scattering process $\gamma p \rightarrow \gamma^*(\rightarrow l^- l^+)p$ offers a new way to access the real part of the Compton amplitude, through the angular asymmetry of $l^- l^+$ pairs.

  This study deals with experimental data on TCS collected for the first time in the kinematic region of total center mass energy s=7.8 GeV and the heavy photon virtuality of Q^2=1.34 (GeV/c)^2. Also, for the first time the study will yield comparison of the data with GPD based models. In the future, with upgrade of Jefferson lab machine energy to 12 GeV one can access the domain of higher photon virtualities.

4. Nucleon-Nucleon short range correlations

- *A-dependence of the scaling effect of the ratio of inclusive electron scattering cross sections for heavier nuclei and deuterium in the region x > 1 and Q^2 > 1.5 (GeV/c)^2.* In the previously published works by Yerevan group, the relative per-nucleon probability of 2-nucleon Short Range Correlations (SRC), $a_2(A)$, was extracted based on theoretical calculations and measurements from different CLAS experiments. This proposal is to refine and further SRC investigations by using data on (*e*, *e*') inclusive scattering from different targets from CLAS *eg*2 run period. The goal is to study scaling with Bjorken variable *x* of the ratio of cross sections from heavier targets to that from Deuterium, $r(A)$, at $x > 1.5$, and extract $a_2(A)$ for ^{12}C, ^{27}Al, ^{56}F, and ^{208}Pb nuclei. The Q^2 dependence of *r* will be investigated. Use of the double-set target (a key element in *eg*2 run period), when data were taken simultaneously from cryogenic and solid targets mounted in a row, will allow greatly reduce systematic uncertainties. The range of *A*-dependence will be extended up to 208. Acceptance and radiative corrections will be applied, PID cuts will be refined.

During the last few years a qualitative progress in the study of SRCs was reached based on the analysis of the high momentum transfer (*e*,*e*') Jlab data, the (*p*,2*pn*) BNL data, the (*e*,*e*'*pp*) and (*e*,*e*'*pn*) Jlab data. In particular, Yerevan group at Jlab, using CLAS measured ratio of the cross-sections for electrons scattering with large momentum transfer off medium and light nuclei in the kinematic region that is forbidden for scattering off low momentum nucleons. Steps in the value of this ratio appeared to be the first direct observation of SRCs of two and three nucleons in nuclei. Impressive experimental progress of the last few years -- discovery of strong short range correlations in nuclei with strong dominance of I=0 SRC, proves validity of the strategy of using high momentum transfer processes for probing SRCs. It provides a solid basis for future experimental studies. As outlined above, this project furthers studies on SRCs in order to better understand the nature of the phenomenon.

- *Structure of bound nucleon, search for nucleon modification in nucleus.* This analysis will be conducted using CLAS electro-production data on Deuterium target from *e6* experiment (E94-102). The main goal of the study is to extract information on the modification of a bound nucleon which is important for full understanding of the structure of nucleons as a whole. For this investigation the simplest nucleus of Deuterium, with well known wave function, has been chosen. The two nucleons in the Deuteron can be in two phases: quasi free (QF), when nucleons are apart with average distance of 1.7 fm and their interaction is well described by mean field momentum distribution, and Short Range Correlations (SRC), when nucleons approaching to each other up to 1 fm and partially overlap. The study will look for possible changes of nucleon properties in the SRC relative to QF by examining the ratio of cross sections of electron scattered on nucleon in the SRC and QF as a function of photon virtuality Q^2.

  The analysis will proceed in two ways: use of exclusive $d(e,e'p)n$ reaction, with neutrons from SRC selected within reconstructed momentum range > 275 MeV/c, and QF events at $X_{bj} = 1$; and use of inclusive scattering $d(e,e')$, when SRC contribution to the wave function is dominated in the range $1.5 < x < 2$ for $Q^2 > 1.5$ (GeV/c)^2. The feasibility of the study is checked by testing resolution of reconstruction of x in CLAS, and estimation of contribution from inelastic events. For the latest, calculations in Light Cone Dynamics model from M.Sargsyan (FSU) is used. Different theoretical models will be tested in comparison with obtained experimental data.

5. Development of physics projects & apparatus for experiments at CEBAF 12GeV

- *The Neutron Electromagnetic Form Factor Ratio G_E^n/G_M^n at High Q^2 (Hall A proposal P12-09-016).* The goal of the proposed experiment is measurement of the electromagnetic form factor ratio of the neutron, G_E^n/G_M^n, at high four–momentum transfer squared values of Q^2 = 5.0, 6.8, and 10.2 (GeV/c)^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 then be used to quickly extract the electric form factor, G_E^n, as more precise data for G_M^n at high Q^2 becomes available. The electrons will be detected in the BigBite spectrometer with a new GEM based tracker and the neutrons in an array of scintillators. Separation of recoiling protons and neutrons will be performed magnetically.

  ANSL group will participate in testing and calibration of both electron and hadron side detectors in testing facilities, and will be responsible for development and implementation of detector electronics. A group member will play key role in installation and maintenance of detectors on floor, and will also have a significant contribution into data analysis.

  Knowledge of the neutron electromagnetic form factors, G_E^n and G_M^n, are essential for understanding of nucleon structure, as they are related to the Fourier transforms of the electric

charge and magnetic moment distributions. The recently developed approach for calculations of exclusive reactions in the Q^2-range between 1 and 10 $(\mathrm{GeV/c})^2$ using generalized parton distributions (GPDs) relates these elastic form factors and the results from deep inelastic scattering and deeply virtual Compton scattering. Data for G_E^n at high Q^2 are necessary, in particular, to constrain spin-flip GPDs at high momentum transfer.

In the last ten years, a variety of double polarization experiments measuring G_E^n have been performed at different facilities: MIT-Bates, NIKHEF, MAMI, and JLAB Halls A and C. This experiment is a natural continuation of the previous E02-013 experiment in JLab Hall A, with significant extension of the Q^2-range of experimental data. With accurate measurements of G_M^n, the accuracy $\Delta G_E^n = 3\times10^{-4}$ for the highest Q^2 point from this experiment can be reached. Such a measurement would significantly increase knowledge about a fundamental property of the neutron in a region where no data are available.

- *Proton Form Factor Ratio Measurements at Q^2 = 13 & 15 $(\mathrm{GeV/c})^2$ via Recoil Polarimetry (Hall A experiment E12-07-109).* This experiment will measure the ratio of the proton elastic form factors, G_E^p and G_M^p, to Q^2 = 15 $(\mathrm{GeV/c})^2$, using recoil polarization technique. The new data will give access to a region of Q^2 in which G_E^p is completely unknown; it corresponds to very short distances inside the proton, a kinematical region most critical for the testing of QCD based models of the nucleon.

  The experiment will utilize 75 μA current, 11 GeV energy electron beam with 85% polarization on a 40 cm long LH2 target. Scattered electrons will be detected in the highly segmented electromagnetic calorimeter BigCal. To obtain sufficient statistics for such large momentum transfer the recoil proton will be detected in a new detector SuperBigBite, which will include a single dipole magnet, a polarimeter with three GEM trackers, and a hadron calorimeter.

  Yerevan group will have a significant contribution in the preparation and installation of experimental setup for proposed experiment. The group members will play key role in preparing and testing electronics for both electron and proton arm detection systems, and organization of triggers. Significant part of work of installation of experimental setup in the hall and maintenance during the experiment running will be covered by Yerevan collaborators. Group members will also participate in data analysis.

  An entirely new picture of the structure of the proton has emerged after two experiments in Hall A at JLab showed that the ratio G_E^p / G_M^p was in fact not constant, and decreased by a factor of 3.7 over the Q^2 range 1 to 5.6 $(\mathrm{GeV/c})^2$. The new data stimulated theoretical activity. Current theoretical models describe proton data well up to $Q^2 \approx 5$ $(\mathrm{GeV/c})^2$, and diverge strongly at higher Q^2 where there are no precision data to constrain the calculations.

  Conditions at JLab are recognized as unique for such kind of measurements. The ratio method to be used minimizes systematic errors, for cross section measurement, and analyzing power of polarimeter and beam polarization cancel out. Huge background will be to large extent eliminated by detecting recoil proton in SBS in coincidence with scattered electron in BigBite, with high thresholds posed on signals from the both calorimeters. Large solid angle and momentum acceptances, high luminosity and small angle capabilities, good angular, vertex and momentum resolutions give SBS big advantage compared to other devices for form factor measurements.

- *The Measurement of the ratio $R = \sigma_L/\sigma_T$ in Semi-Inclusive Deep-Inelastic Scattering (Hall C proposal E12-06-104).* The goal of this CEBAF-12 GeV experiment (proposed by ANSL group and JLab) is measurement of the ratio $R=\sigma_L/\sigma_T$ in Semi-Inclusive Deep-Inelastic Scattering (SIDIS) in a wide kinematic range of z, x, Q^2 and P_t^2. These measurements will allow to study the inclusive-exclusive connection in pion electroproduction, a process where duality has been shown to be valid, and are necessary for the interpretation of flavor decomposition by SIDIS at 12-GeV

JLab. Essentially no information exists on the value of R in SIDIS. In DIS, at fixed Bjorken x the ratio R asymptotically scales like Q^2. For SIDIS R is assumed to be similar to that of DIS. This assumption has never been thoroughly checked. For the first time the assumption $R_{SIDIS} = R_{DIS}$ will be checked, and, since we plan to measure Semi-Inclusive π^+ and π^- electroproduction on both hydrogen and deuterium targets, also we will check whether $R_{SIDIS}^{\pi^+} = R_{SIDIS}^{\pi^-} = R_{SIDIS}^{H} = R_{SIDIS}^{D}$. Many Semi-Inclusive DIS experiments at 12 GeV JLab require knowledge on R.

Proposed experiment will detect $\pi^{\pm}$ in coincidence with scattered electrons from LH2 and LD2 targets at CEBAF beam energies 6.6, 8.8 and 11.0 GeV and currents of 50 μA. The Hall C HMS spectrometer and the projected SHMS will be used for electron and meson detection. ANSL group will play leading role in development and preparation of particle detection and identification systems, including construction of new electromagnetic calorimeter and aerogel Cherenkov detectors for SHMS. We will be responsible collaborator during data taking and analysis. Only unique quality JLab CW electron beam after 12 GeV upgrade and Hall C HMS & SHMS magnetic spectrometer pair will allow carry out such measurements.

- *Transverse Momentum Dependence of Semi-inclusive Pion Production (Hall C proposal PR-09-017).* The experiment E00-108, proposed and lead by ANSL group, for the first time verified that low-energy factorization for semi-Inclusive pion electroproduction holds down to the nucleon resonances region. Hall C at CEBAF 12 GeV energies will give new opportunities to continue our semi-inclusive pion electroproduction program. 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. 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/c)^2, $0.3 < z < 0.5$, and $P_t < 0.5$ GeV/c.

  The experiment will use electron beam with energies 6.6, 8.8 and 11 GeV, and Hall C HMS-SHMS magnetic spectrometer coincidence pair. ANSL group, as before, will play leading role in development and preparation of particle detection and identification systems, electronics and analysis tools. We will be responsible for data taking and analysis.

  A central question in the understanding of nucleon structure is the orbital motion of partons. Much is known about the x and Q^2 dependences of the *up* and *down* parton distribution functions in the nucleon. In contrast, very little is known about the dependence of these functions on their transverse momentum k_t. Increasingly precise studies of the spin sum rule strongly suggest that the net spin carried by quarks and gluons is relatively small, and therefore the net orbital angular momentum must be significant. This in turn implies significant transverse momentum of quarks.

  Similar to the proposed experiment (E00-108) has been performed in Hall C using 5.5 GeV energy electrons. We have found that the fragmentation widths μ+ and μ- are correlated, and a larger k_t width for *d* quark than for *u* quark. But all these results can be only considered as suggestive at best due to the limited kinematic range covered. Proposed measurements will constrain the initial transverse momentum widths of *up* and *down* quarks, and the transverse momentum widths of favored and unfavored fragmentation functions. The highly-focusing HMS & SHMS spectrometers and CEBAF 12 GeV energies will allow best determination of the P_t dependence of the cross section ratios of π^+/π^- for hydrogen and deuterium targets.

6. Development and construction of experimental apparatus for CEBAF 12 GeV

- *Design and construction of calorimeter for Hall C SHMS spectrometer.* The segmented lead glass calorimeter is designed of 2 parts: Preshower and Shower. The 10 cm thick Preshower is to be assembled from 28 TF-1 type lead glass blocks from the retired Hall C SOS spectrometer. The Shower, 50 cm long, will be assembled from 224 blocks from HERMES spectrometer (F-101 type lead glass). Significant work is done already by ANSL group on testing the modules, the future assembling and studies of the detector will be completed in this project .

- *Design and construction of a pre-shower calorimeter for CLAS12, Hall B.* Simulations performed by Yerevan group members have shown significant deterioration in the resolution of existing CLAS electromagnetic calorimeter above 5 GeV. Neither can it effectively distinguish the two photons from π^0 decay above 5.5 GeV. The newly built pre-shower calorimeter will effectively address these problems. Currently the detector is under construction. All the major components are received. ANSL group leads efforts in preparation of stacking of lead-scintillator layers by performing light yield and attenuation measurements of scintillator strips, and quality checks for wavelength shifting fibers. The group will lead assembly and testing of each calorimeter module. The first module is expected to be assembled in February of 2011. All six modules must be ready for installation in 2013.
- *Design and construction of SBS (Super BigBite Spectrometer) for Hall A.* SBS will serve as hadron spectrometer in the experiment E12-09-018. It will utilize GEM-based tracking in order to accommodate high rates. It will consist of a dipole, a high resolution tracker, a Ring Imaging Čerenkov counter, and a segmented calorimeter as a trigger. ANSL group will participate in design and construction of the hadron calorimeter, will work on GEM trackers and RICH detector (in part of testing of electronics).
- *Upgrade of BigBite spectrometer in Hall A.* The spectrometer will serve as an electron arm in a number of 12 GeV experiments aimed at proton and neutron form-factor measurements. Its detector package will be modified in order to accommodate increased count rates at the higher energies. ANSL group is planned to take part in the modification of gas Čerenkov counter.

7. List of ANSL group journal publications in the last three years

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Personnel Commitments:

List of Alikhanian NSL group members involved in project 2011-2013

	Name	Position	Participation	Responsibility	Comments
1	H. G. Mkrtchyan	Doctor phys. Head of the project			
2	S. S. Arutunyan	Engineer	0.5		
3	V. H. Tadevosyan	Physicist	1.0		
4	A. R. Asaturyan	Physicist	1.0		
5	A.H. Mkrtchyan	Physicist	1.0		
6	S.V. Zhamkochyan	PhD Physicist	1.0		
7	PhD student		0.5		
8	Graduate student		0.5		
9	A.H. Shahinyan	PhD Engineer, Head Lab. 122	1.0		
10	H.A. Agababyan	Engineer	0.5		
11	H.V. Voskanian	Physicist	1.0		
12	E.S. Ghandilyan	Technician	0.5		
13	S.L. Abrahamyan	Physicist	1.0		
14	PhD student		0.5		
15	Graduate student		0.5		
16	N.B. Dashyan	PhD Phys., Head Lab. 126	1.0		
17	J.L. Qocharova	Physicist	0.5		
18	S.S. Mailyan	Engineer	1.0		
19	N.E. Gevorkyan	Physicist	1.0		
20	K. Alanakyan	Physicst	1.0		
21	R. Paremuzyan	PhD Physicist	1.0		
22	A. Simonyan	PhD student	1.0		
23	PhD student		0.5		
24	Graduate student		0.5		

Number of participants ------ 24
Required positions ---------- 17

** Assuming average salary on the level of ~$500/month ➔(~$100 k/year for 17 positions).