Perspectives
100-3

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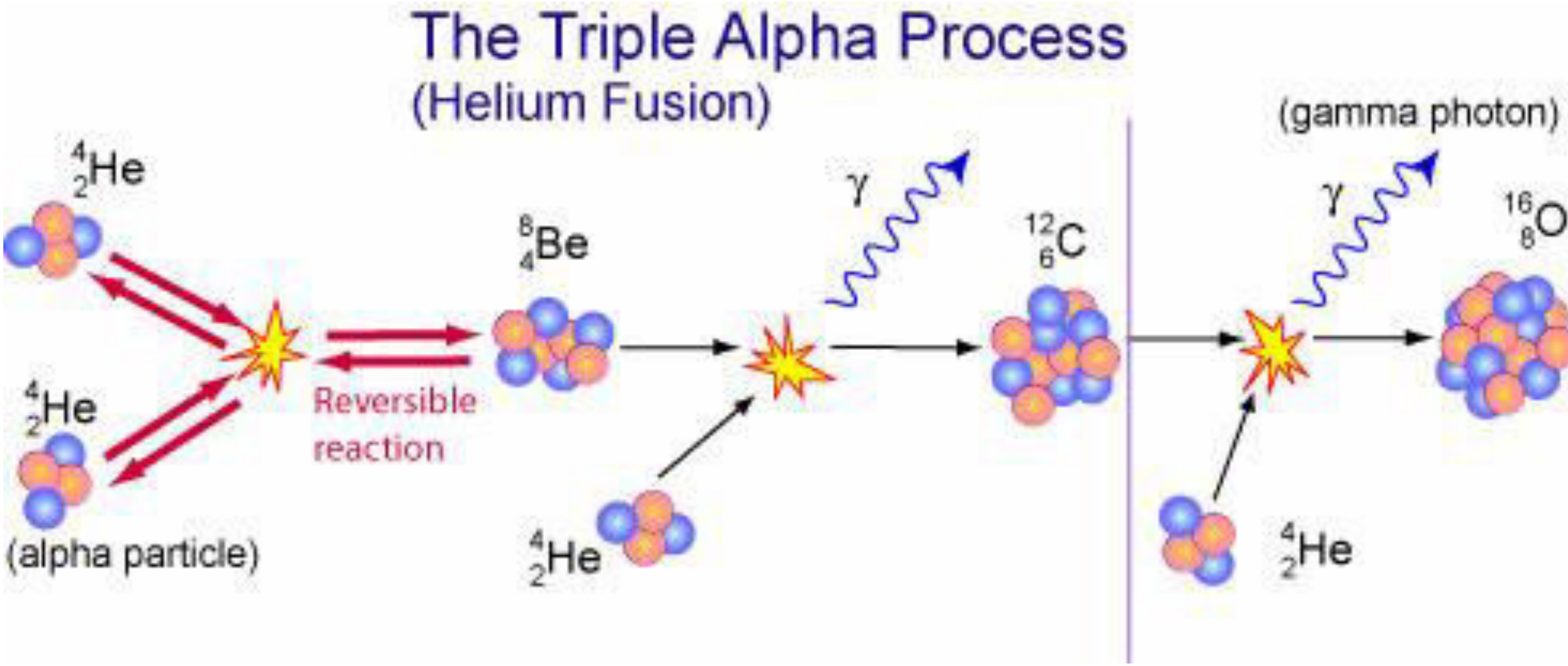
Overview

- C12→3alpha (photon, proton and neutron beams)
- Fission studies with proton and neutron beams
- Methodic studies-LPMWPC; RF-PMT; RF-Streak Camera
- Recoil detector, alpha hypercube
- Delayed pion spectroscopy
- Experiments at MAX-lab
- Nuclear medicine

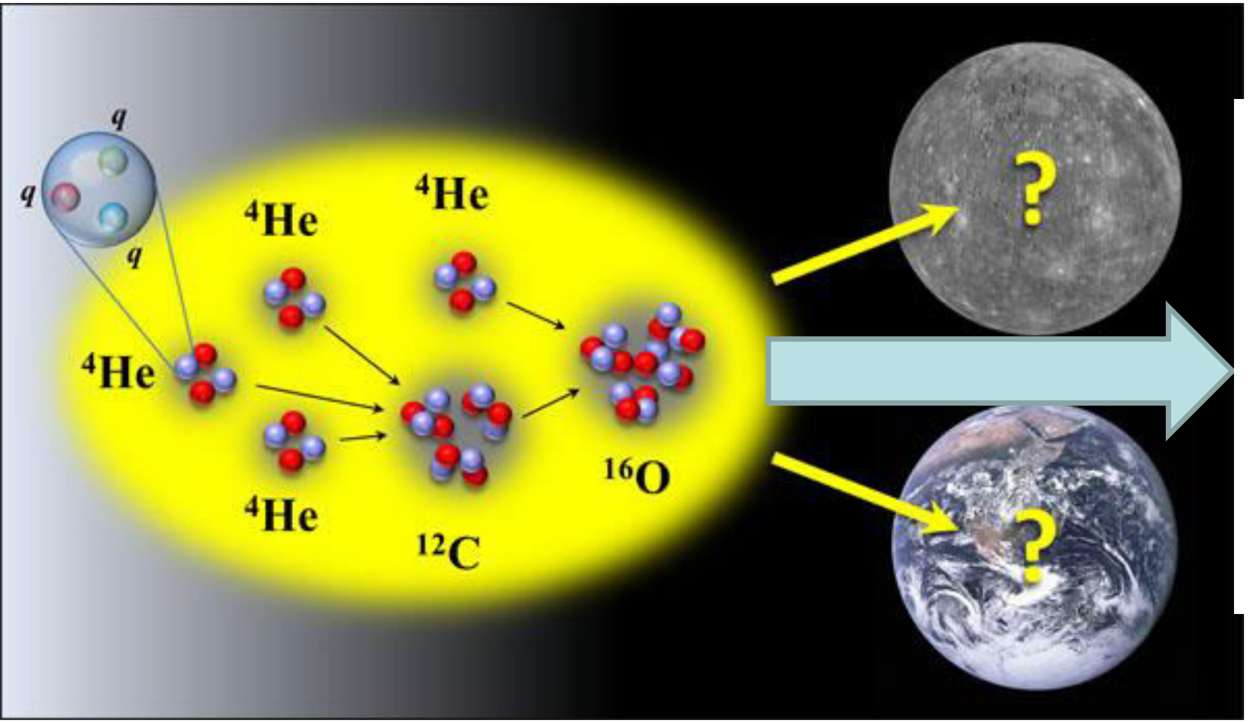
Physics Motivation-Astropysics

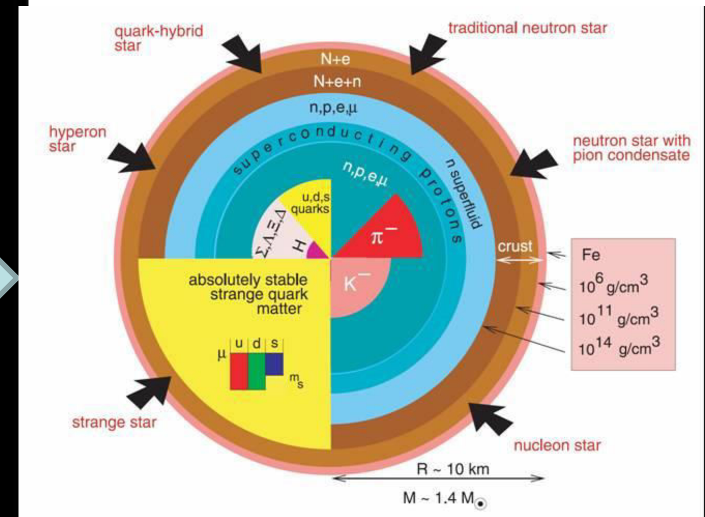


Triple alpha reaction through the Hoyle resonance plays crucial role in the stellar helium burning.

Image credit: Robert Hollow-2005

Triple alpha process in cosmos

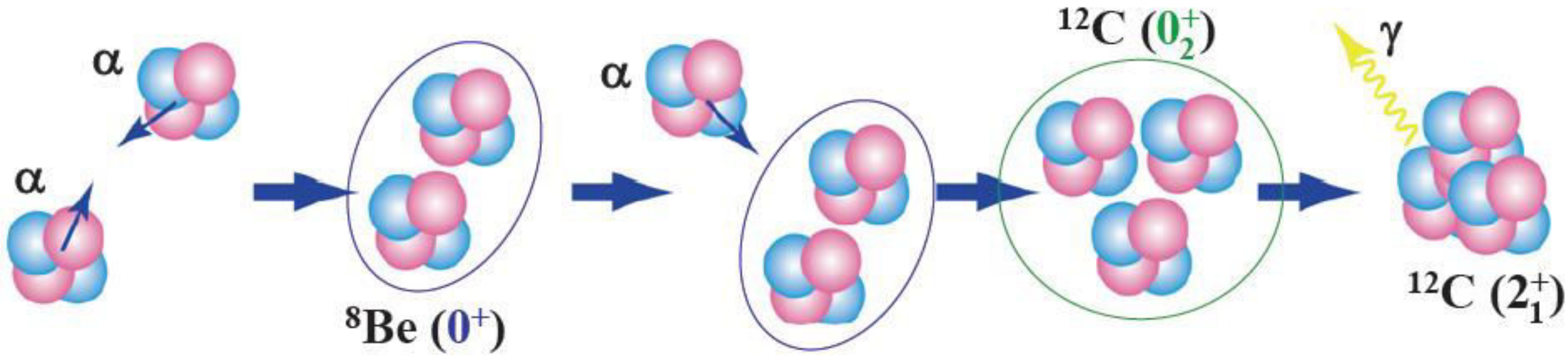




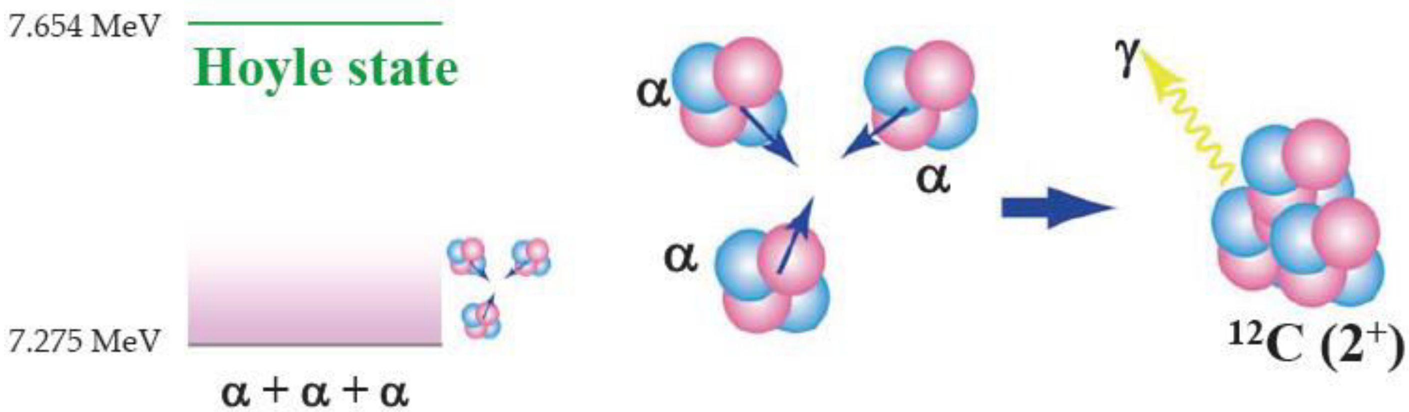
Recent ab-initio simulations predicted the energy of the Hoyle resonance-
Light quark mass and interactions determines carbon and oxygen production, the viability of carbon-based life and the dynamics of stars
Image credit: Dean Lee (modified)
Earth and Mercury images from NASA

The Resonant and Nonresonant Triple-α processes

- $T >$ a few 10^8 K: **resonant** capture



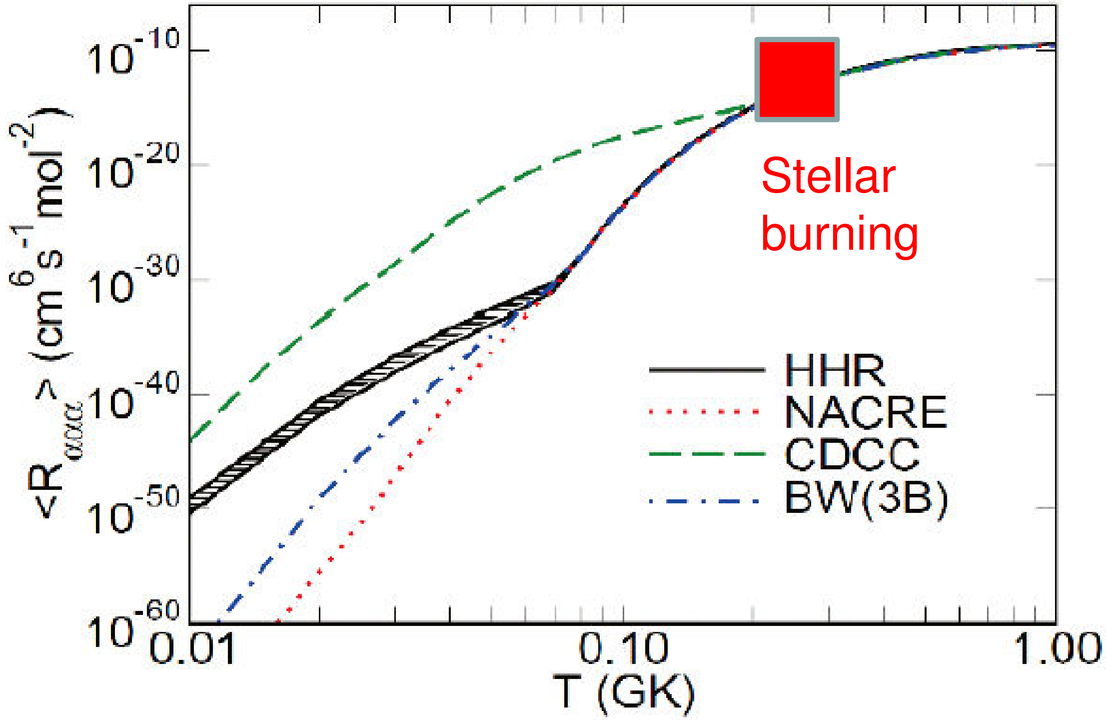
- $T < 10^8$ K: **nonresonant** capture (**T**ernary **F**usion **P**rocess)



Depicted from A. Tamii: FB20-2012

Prediction of Theoretical Models

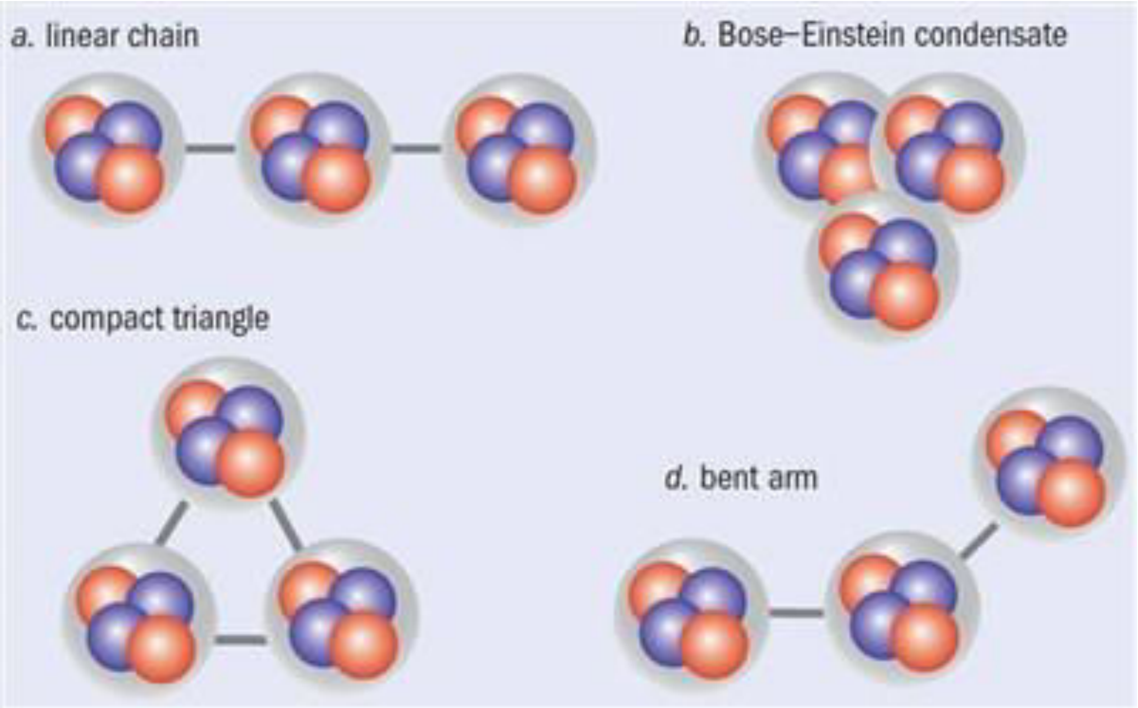
N.B. Nguyen et al., arXiv:1112.2136v1



CDCC: Continuum Discretized Coupled-Channel Method, K. Ogata et al., PTP122,1055(2009)
HHR: Faddeev Hyperspherical Harmonics with R-Matrix Expansion, N.B. Nguyen et al., arXiv:1112.2136v1
BW(EB): Phenomenological Parametrization of Photodissociation using Three-Body Breigt-Wigner Form, E. Garrido et al., EPJA47, 102(2011)
NACRE: NACRE compilation, C. Angulo et al., NPA656,3(1999), Resonance Shift Method

Depicted from A. Tamii: FB20-2012

Physics Motivation-Nuclear Physics

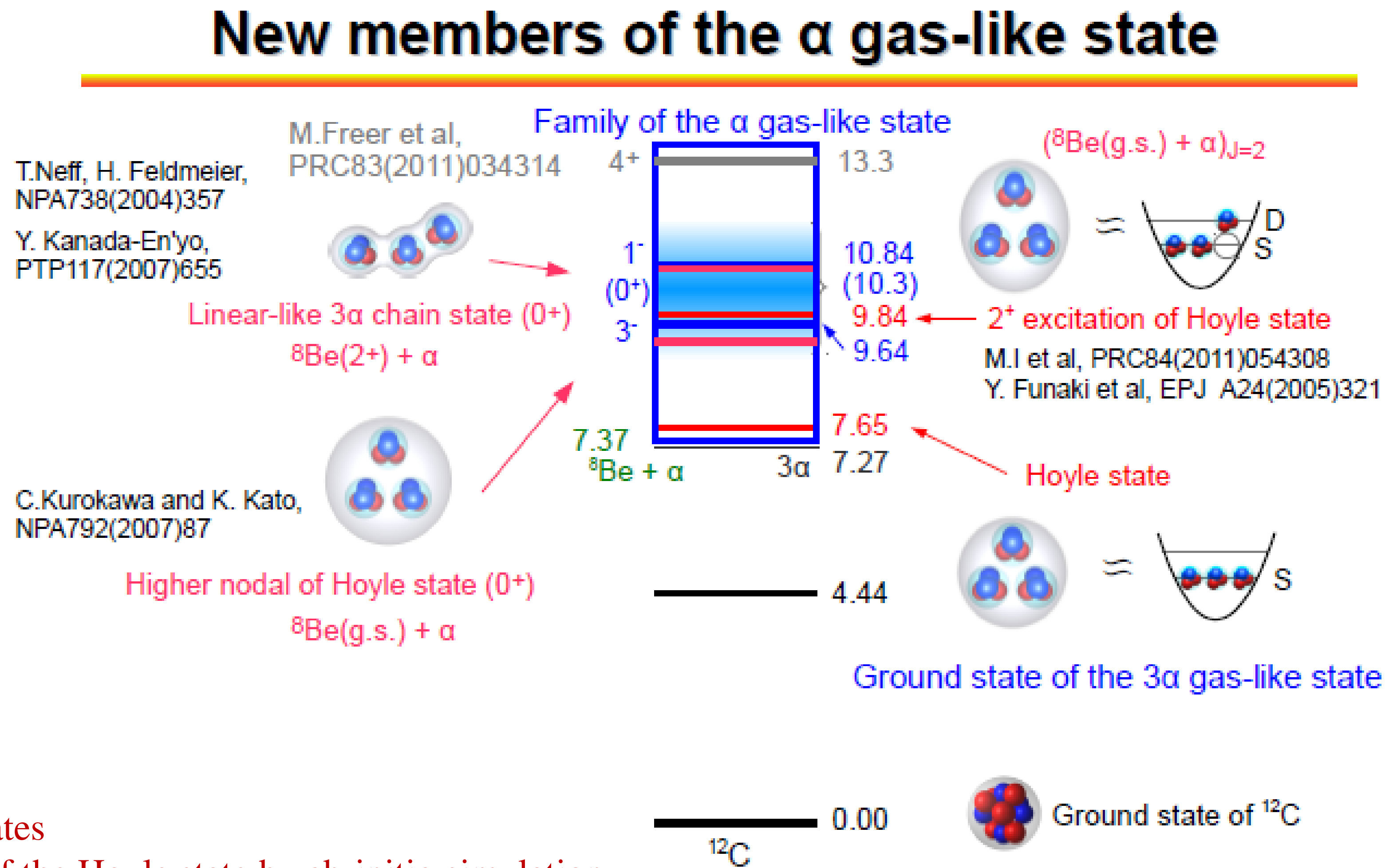


Carbon configurations

(a)The earliest model, proposed in 1956, comprises a linear chain of three alpha particles.
(b) 2001 Bose–Einstein condensate, the alpha particles are described by one single wave function.
2012 the ground state and Hoyle state of carbon-12 were calculated from first principles.
In the ground state the alpha particles were found to be arranged in a compact triangle (c)
The Hoyle state is a bent-arm configuration (d).

David Jenkins and Oliver Kirsebom 2012

Physics Motivation-Nuclear Physics



Two recent updates

a) Prediction of the Hoyle state by ab-initio simulation
   E. Epelbaum et al., *Phys. Rev. Lett.* **109**, 252501, 2012
a) Observation of long expected excited Hoyle state

Depicted from M. Itoh: Cluster-2012

Probing the Triple-α Fusion Reaction Rate at Low Temperature

Direct measurement of the triple-α reaction:

Far from experimental realization

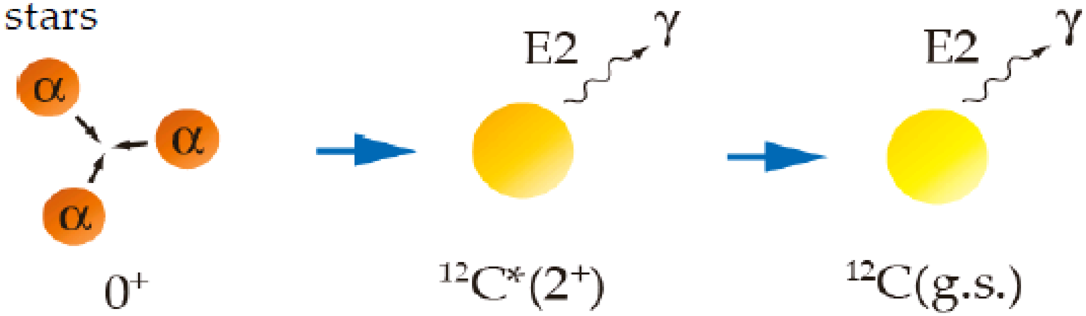
Indirect measurement

Excitation of the α-unbound continuum below 0^+_2 in ^{12}C

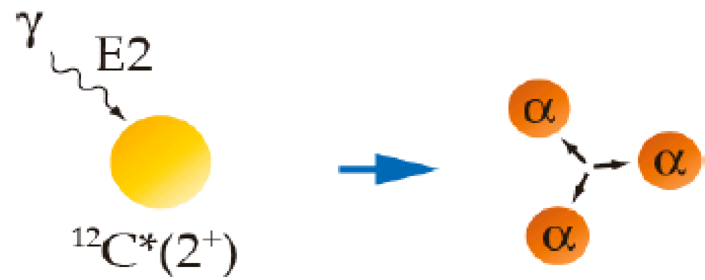
Depicted from A. Tamii: FB20-2012

Probing the Triple-α Fusion Reaction Rate at Low Temperature

Reaction in stars

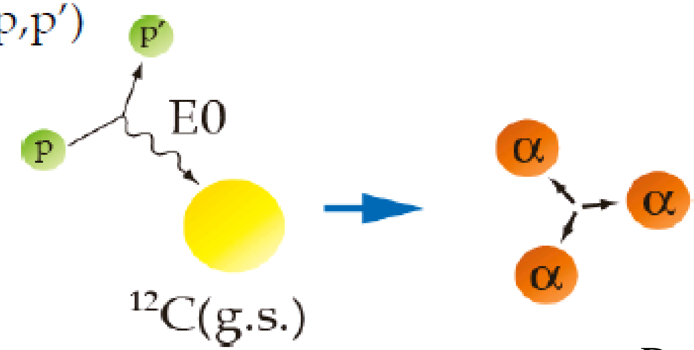


Inverse reaction



Our Measurement

by ^{13}C(p,d) or ^{12}C(p,p′)



Depicted from A. Tamii: FB20-2012

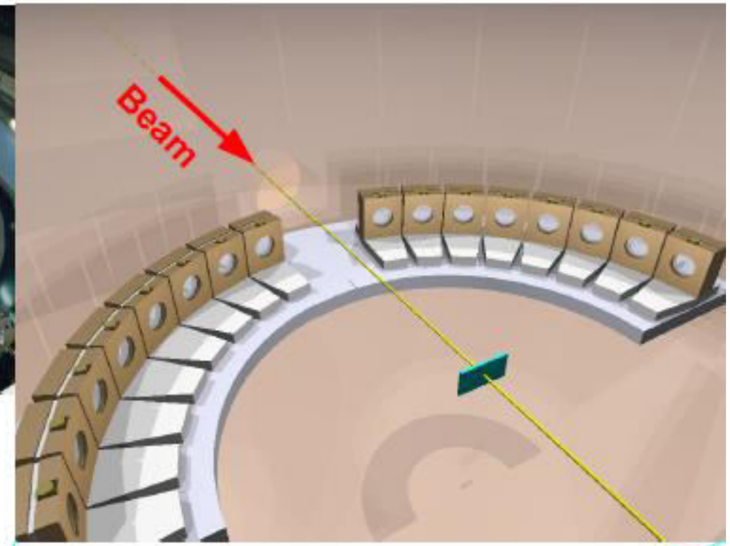
Experimental setup for the measurement of decay α particles

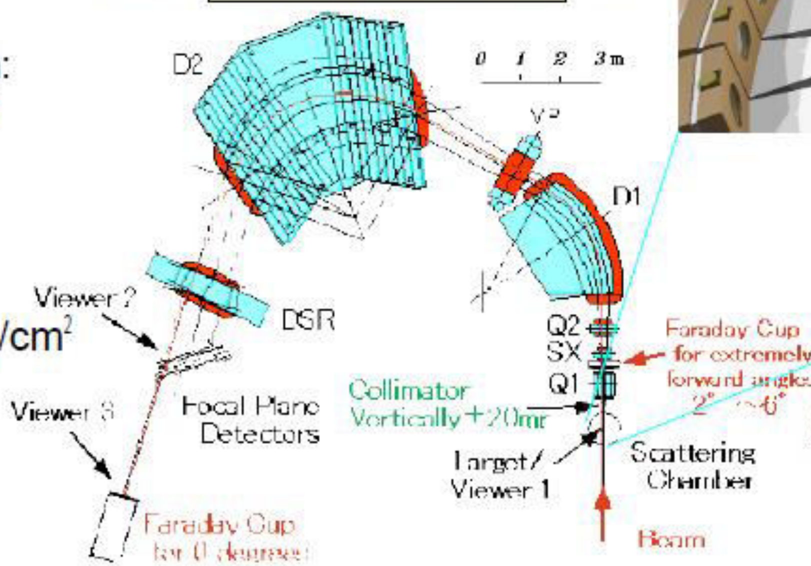
Facility:
RCNP
Osaka University

Reaction:
$^{12}C(\alpha,\alpha')^{12}C^*$
$^{12}C^* \rightarrow \alpha + ^{8}Be$

Beam:
386MeV
Resolution:
< 200keV
Angle:
0°,4°

Target:
^{12}C 100ug/cm^2

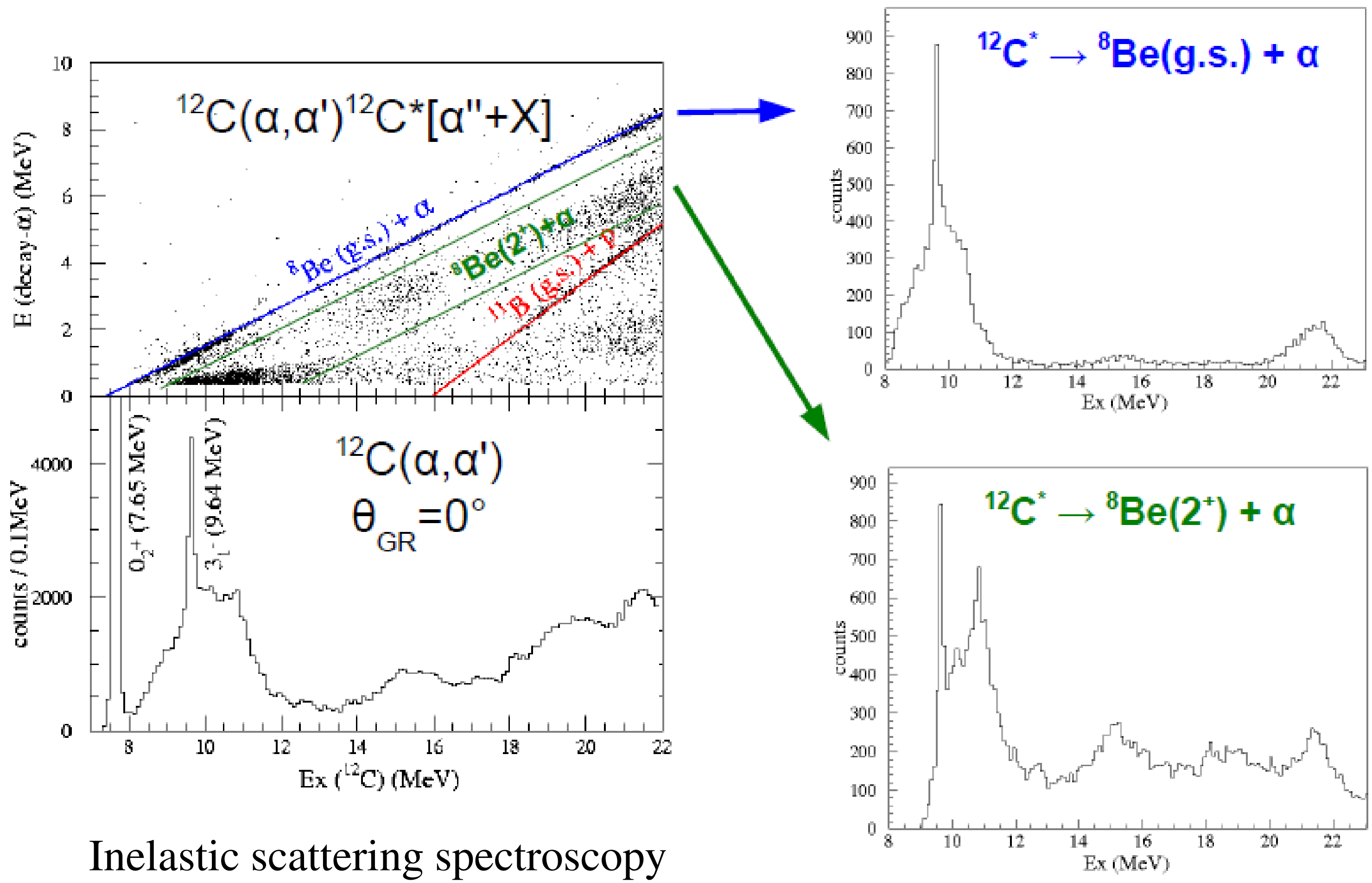




SSD : θ_{SSD} = 105°～255°
(10° step)

M. Itoh: Cluster-2012

Energy spectra for $^{12}C(\alpha,\alpha')^{12}C^*[\alpha''+^{8}Be]$ at 0°



Inelastic scattering spectroscopy

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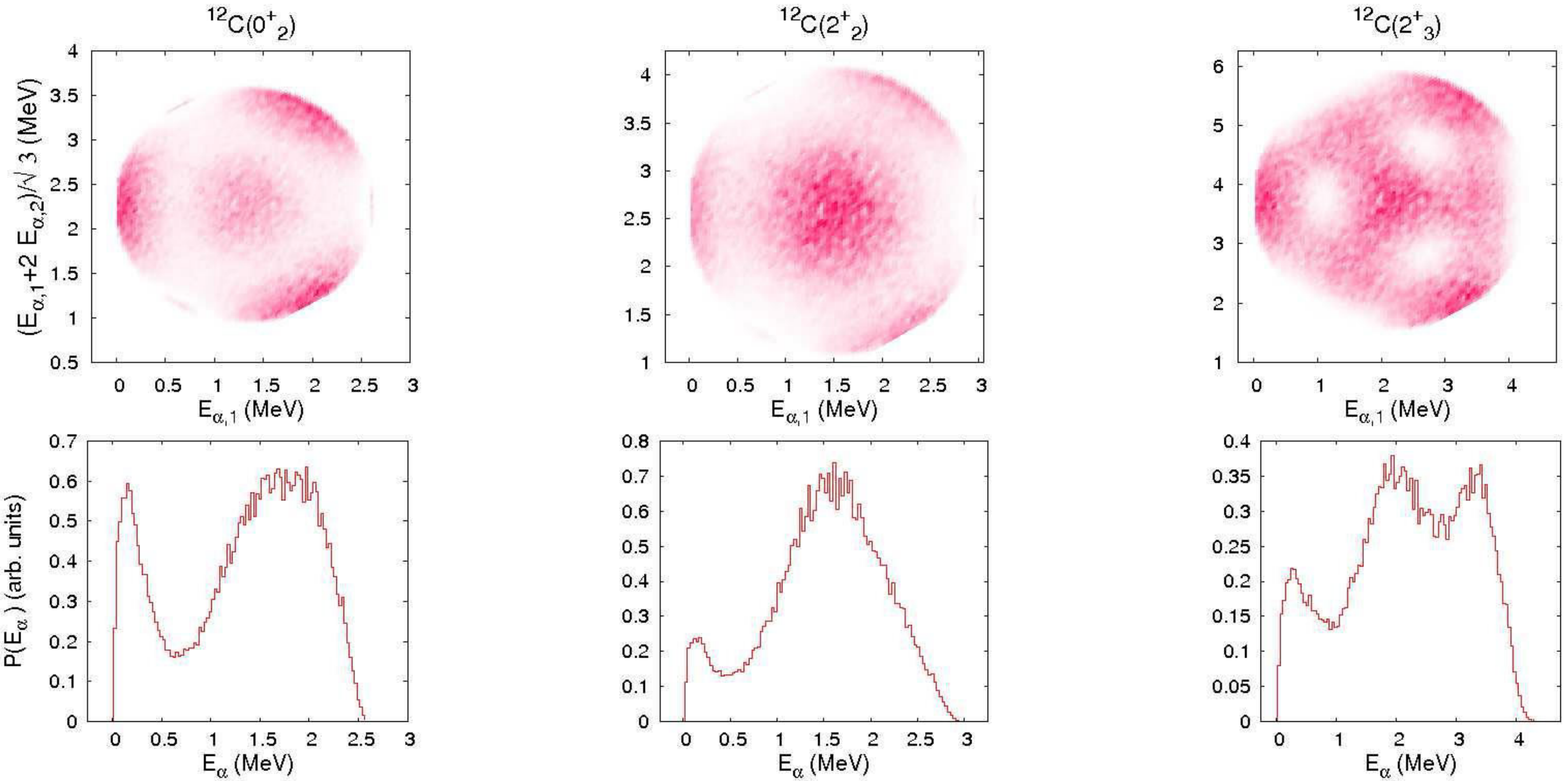
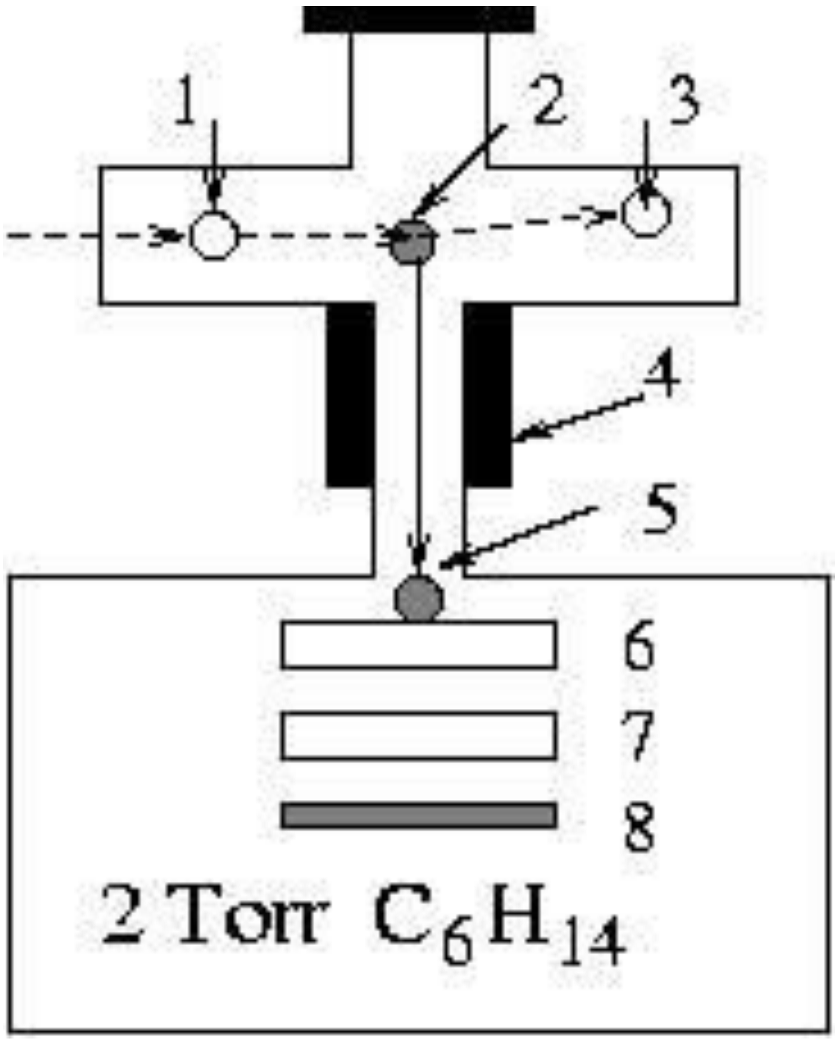
Decay particle spectroscopy

Decay Kinematics



Dalitz plot (upper part) and the alpha-particle energy distribution (lower part) for the resonances at an excitation energy of (11.22, 11.76, 13.76) MeV or (3.95, 4.48, 6.49) MeV above the 3 alpha hreshold, which is 7.275 MeV above the ground state

R. Alvarez-Rodrıguez-208



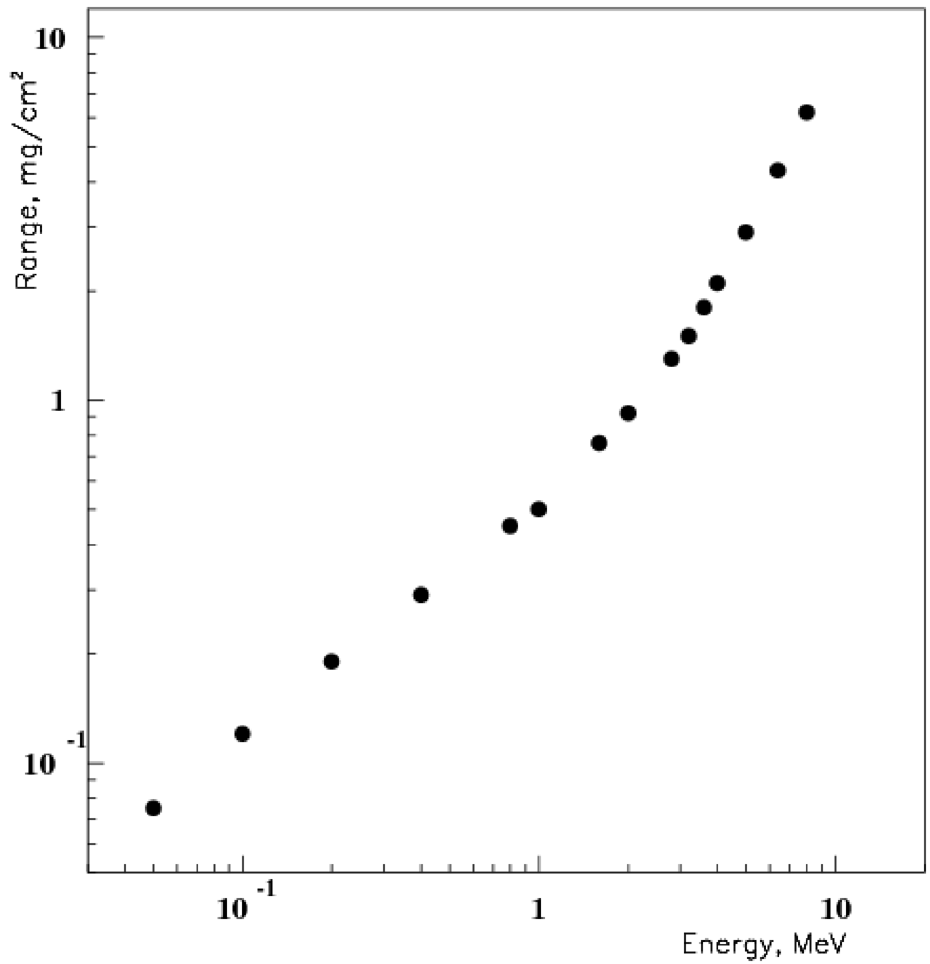
Working gas-target

Hexane- C_6H_{14} - p; C-12
CO_2- C-12; O-16
He-4
He-3
Ne
Ar

1-incident particle (proton, neutron)
2-target (p, C-12, C-13, O-16, Ne etc
3-produced particle (p, n, d, ..
4-magnet
5-recoil particle (p, α, C-12,...)
6-LPMWPC
7-LPMWPC
8-SSD

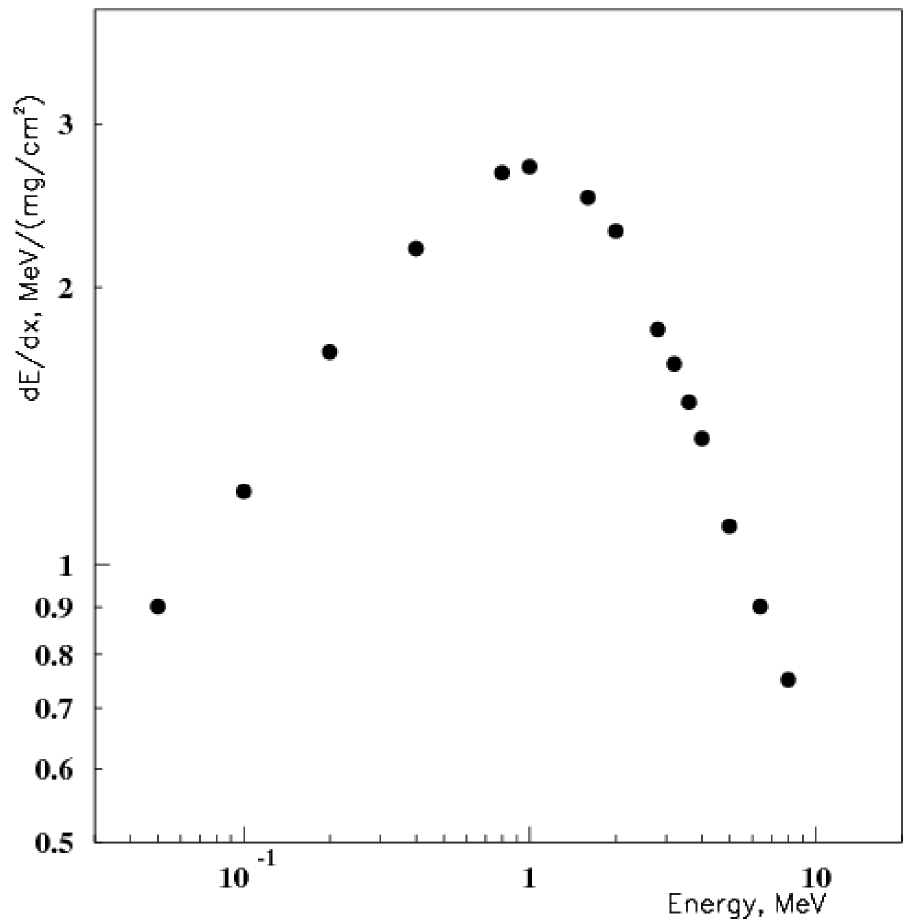
Schematic of the recoil detector

Ranges of the low-energy alpha particles



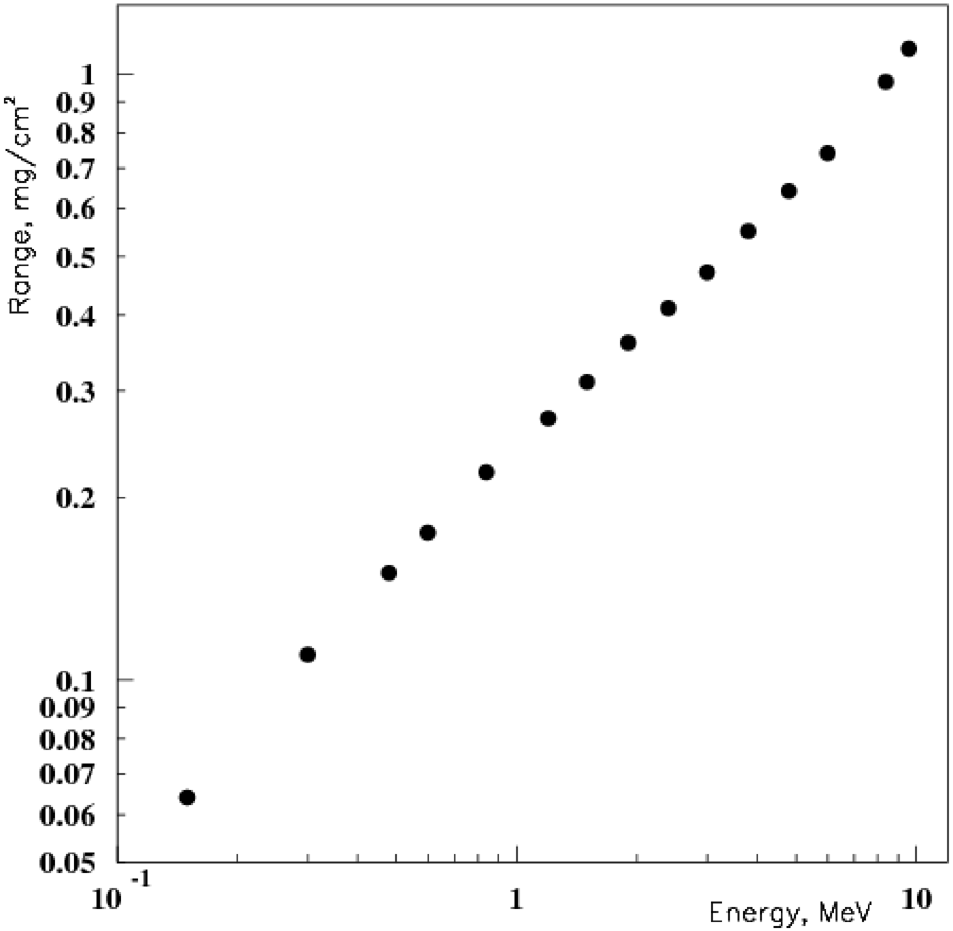
Ranges of alpha particles in $(CH_2)_n$

dE/dx of the low-energy alpha particles



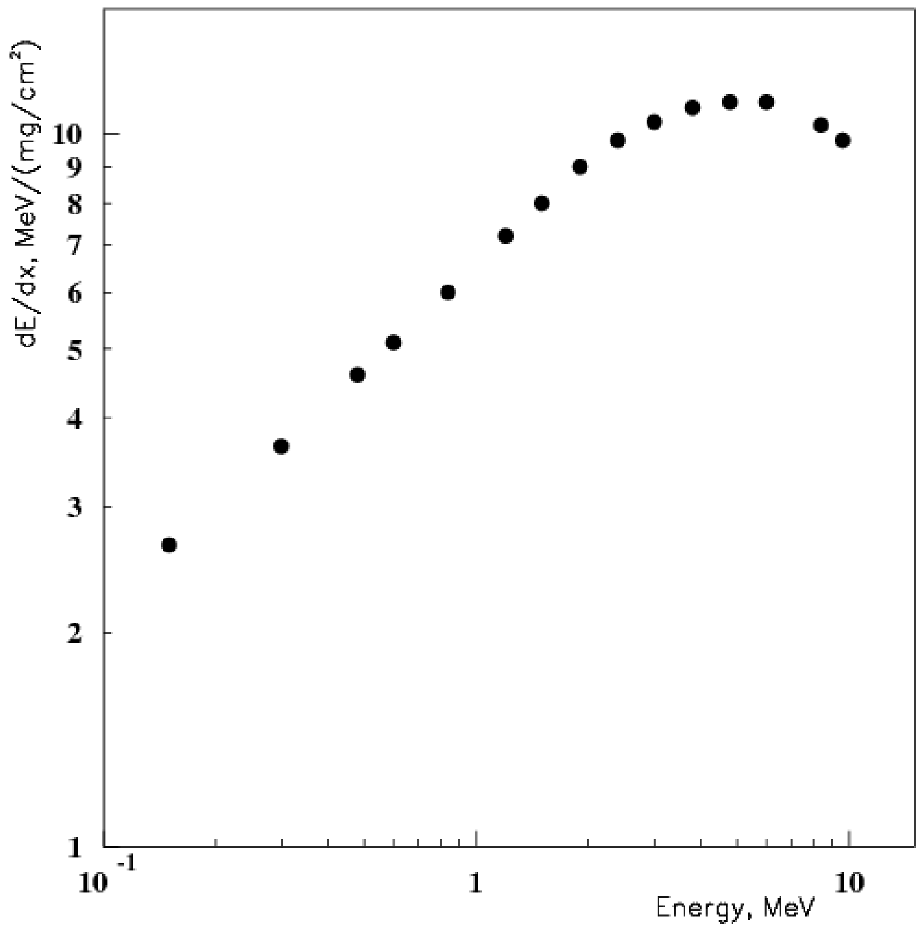
Electronic stopping power of alpha particles in $(CH_2)_n$

Ranges of the low-energy ^{12}C



Ranges of a ^{12}C in $(CH_2)_n$

dE/dx of the low-energy ^{12}C



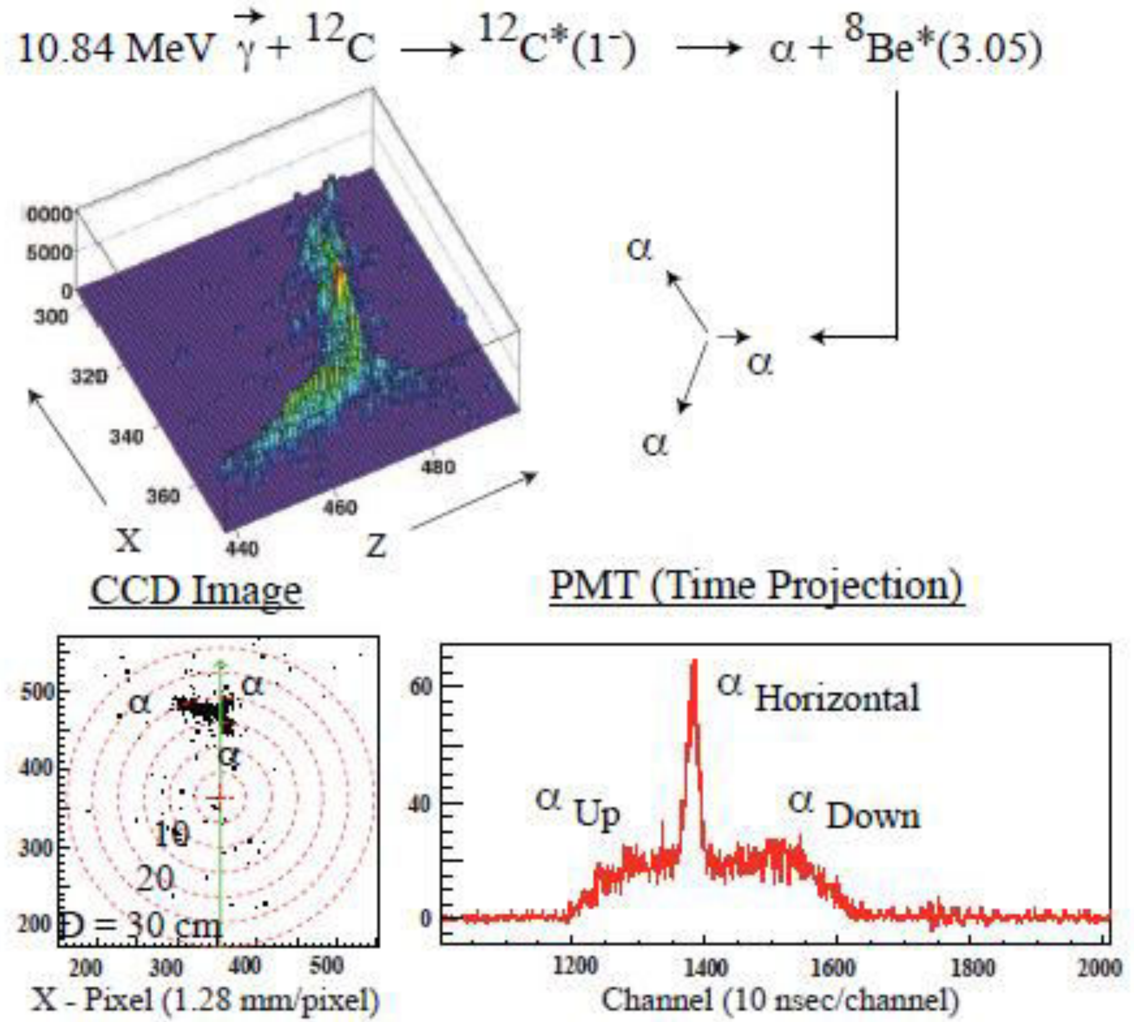
Electronic stopping power of ^{12}C in $(CH_2)_n$

Experimental Program-Bremsstrahlung Beam

- Confirmation of HIGS result
- Detail study of the $^{12}C(\gamma,3\alpha)$ near threshold
- Study of $^{12}C(\gamma,3\alpha)$ in the all available energy region
- Study of $^{16}O(\gamma,4\alpha)$; $^{20}Ne(\gamma,5\alpha)$; $^{40}Ca(\gamma,10\alpha)$
- Study of $\gamma+^{16}O \rightarrow ^{12}C+\alpha$?

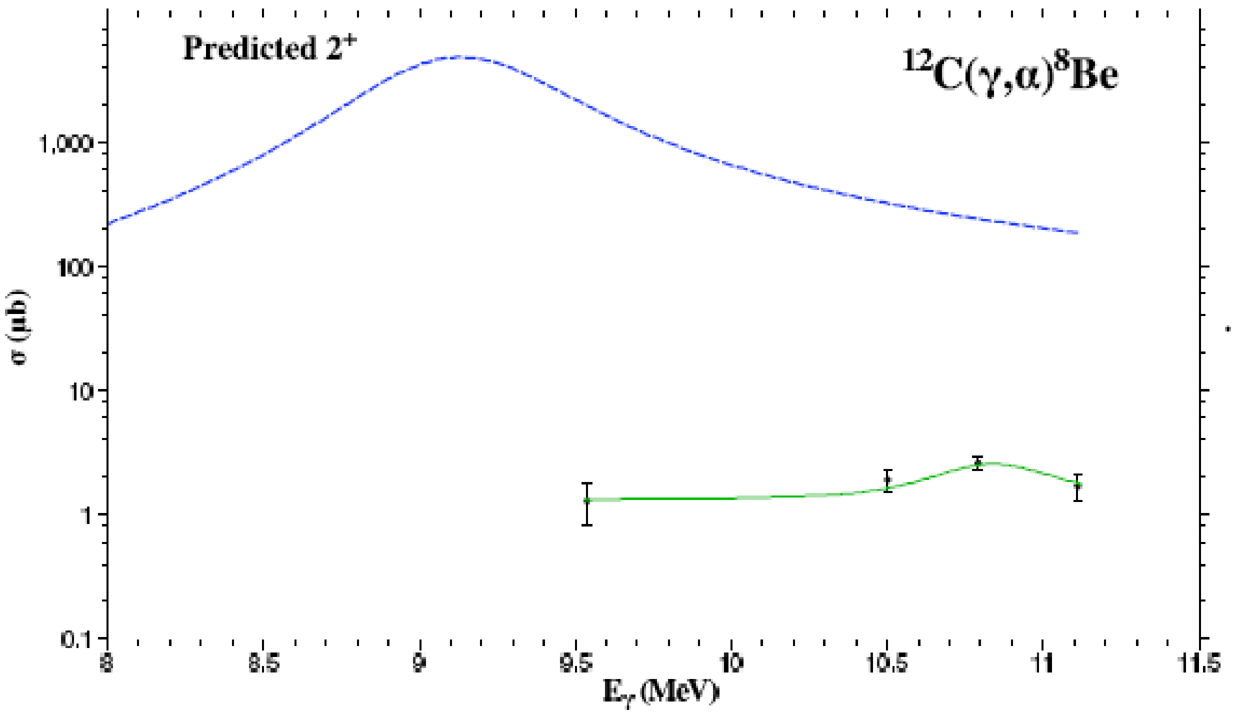
Threshold of the Hoyle state in ^{40}Ca is ~60 MeV. If it is a Bose-Einstein condensation state it has to decay into 10 few hundred keV α-particles

Experiments at HIGS with O-TPC



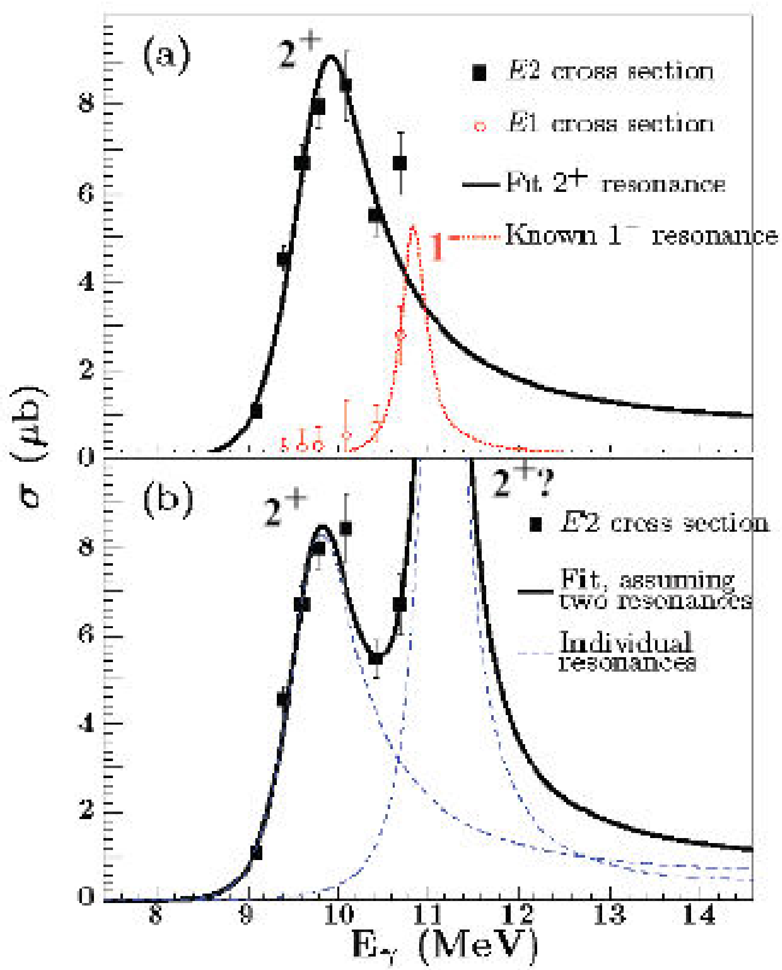
A typical 3 alpha dissociation event detected by the O-TPC

$^{12}C(\gamma,3\alpha)$-HIGS Experiment, O-TPC



The measured cross section of the $^{12}C(\gamma, 3\alpha)$ reaction compared to the cross section for the predicted 2^+ at 9.11 MeV. The line through the data points is the sum of the cross section due to the 1^- resonance at 10.84 MeV and a constant background term. M. Gai et al., 2009, LCB, O-TPC.

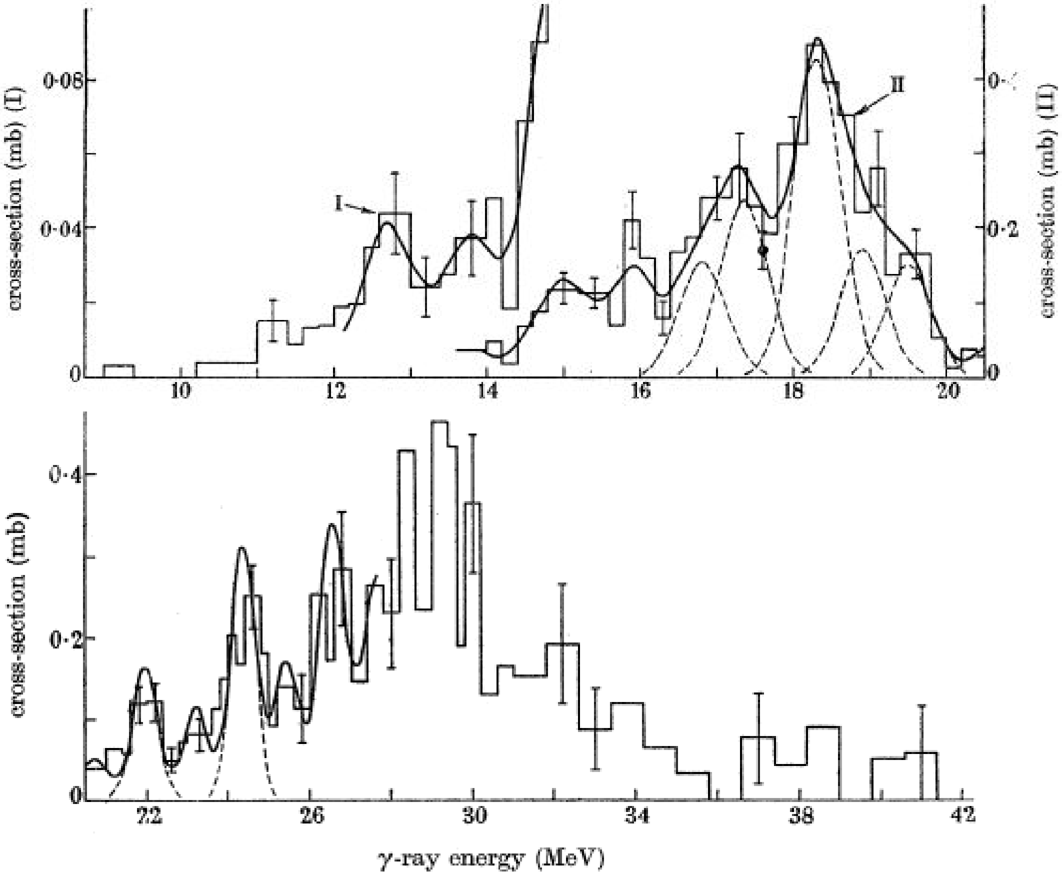
$^{12}C(\gamma,3\alpha)$-HIGS Experiment, O-TPC



The measured cross section of the $^{12}C(\gamma, 3\alpha)$ reaction (a) separated for E1 and E2 contributions and analyzed using one 2^+ state plus the known 1- state at 10.08 MeV and (b) analyzed with two 2^+ states , M. Gai et al. (20111)

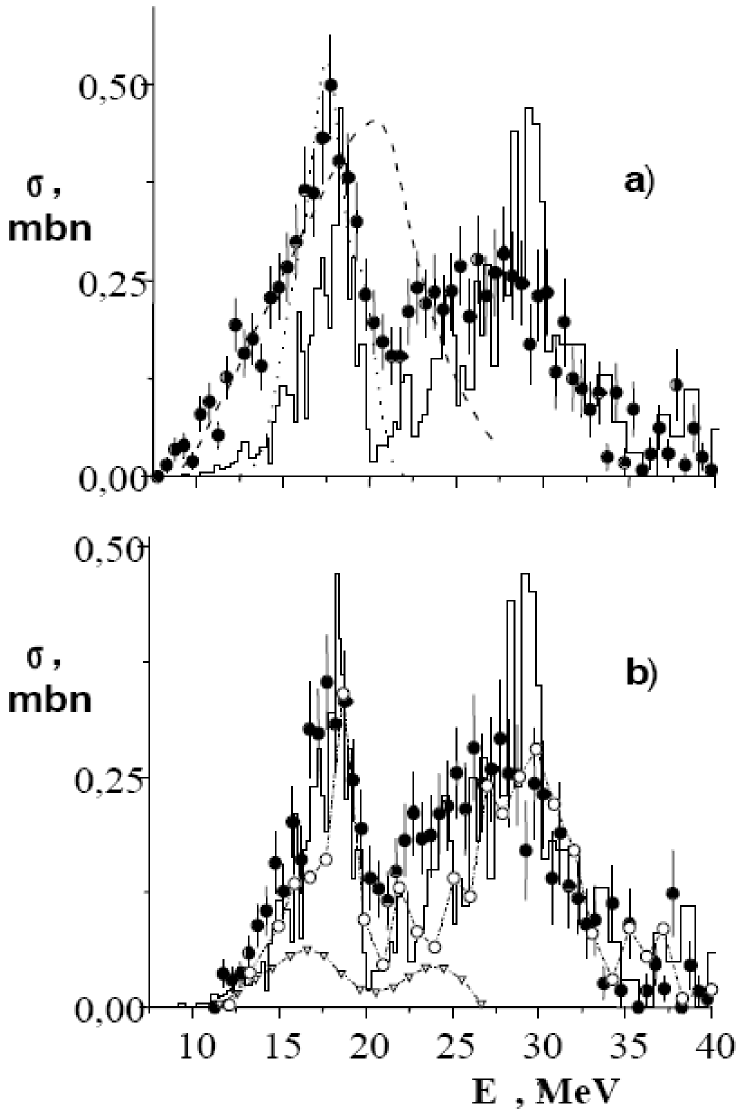
$^{12}C(\gamma,3\alpha)$-Emulsion, 1953

Bremsstrahlung or monochromatic photon beams + nuclear emulsion



$^{12}C(\gamma,3\alpha)$ cross-sections for γ-ray energies less than 20.5 MeV and above.
F.K. Goward and J.J. Wilkins, 1953.

$^{12}C(\gamma,3\alpha)$-Kharkov Experiment, Diffusion Chamber



The total cross-section for the $^{12}C(\gamma, 3\alpha)$ reaction, closed circles -Kharkov, 2004, diffusion chamber in magnetic field, methane (CH_4) and He mixture 1:7, bremsstrahlung, $E_{\gamma max}$ = 150 MeV:

a) All events;

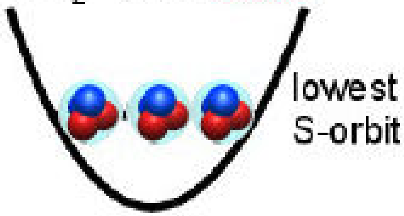
b) Events with Eα<1MeV is removed.

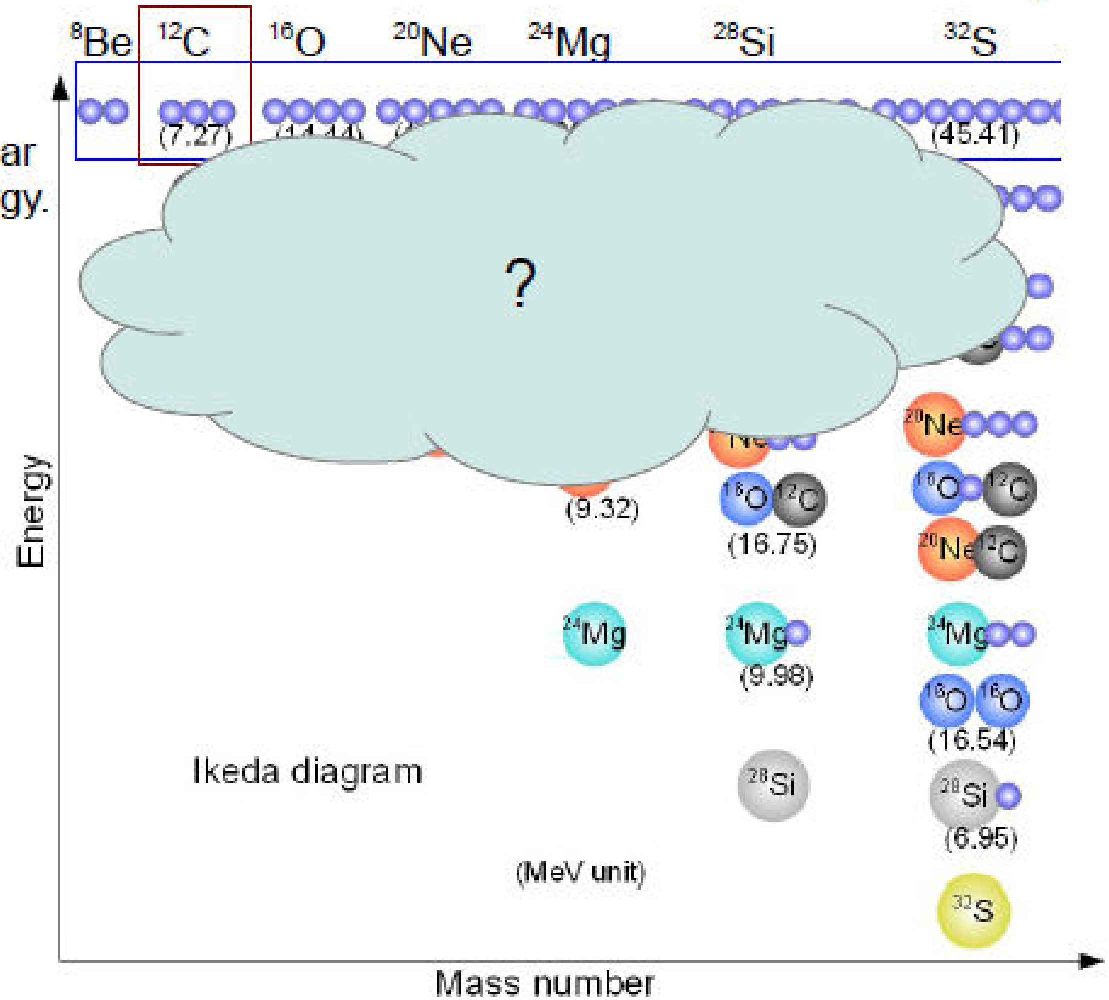
Histogram - F.K. Goward and J.J. Wilkins, 1953, open circles -Maikov et al.,1958, emulsion, bremsstrahlung; triangles -Kotikov et al., 2004, emulsion, bremsstrahlung.

Cluster structures in N=4n nuclei

- Cluster structures appear near the threshold energy.
- 0_2^+ state at 7.65 MeV: Hoyle state
  - Nucleosynthesis
  - 3α gas-like structure
- α cluster condensate
  - 3α cluster enter into the lowest S-orbit. A.Tohsaki et al, PRL87(2001)192501

^{12}C, 0_2^+ (7.65 MeV)

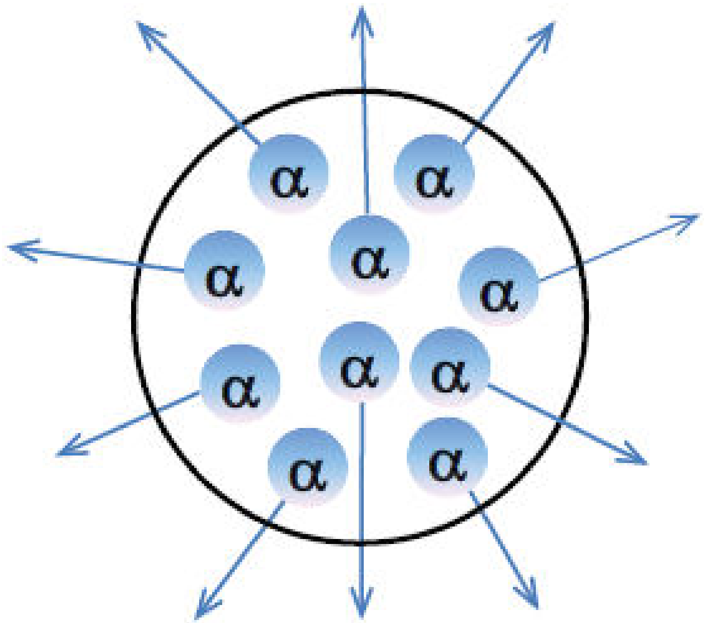




Depicted from M. Itoh: Cluster-2012

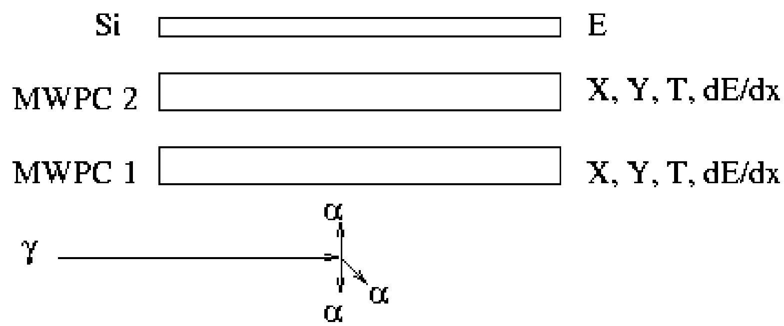
Nuclear Alpha-Particle Condensates

Low-pressure MWPC based multi-module detector is an ideal tool for detection of 10 low-energy (few 100 keV) alpha particles from Coulomb explosion of the Bose Einstein condensate state formed in Ca-40 (Hoyle state) which will be unambiguous confirmation of the existence of BEC in a nuclear matter

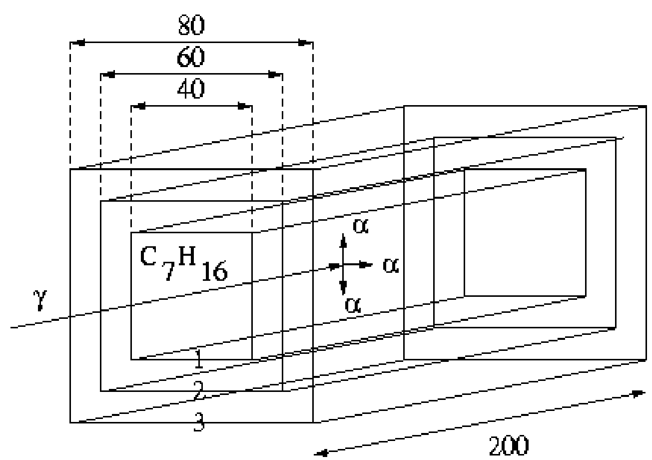


Cartoon of a Coulomb explosion of 10 alpha-particles from Ca-40 (T. Yamada et al., 2011)

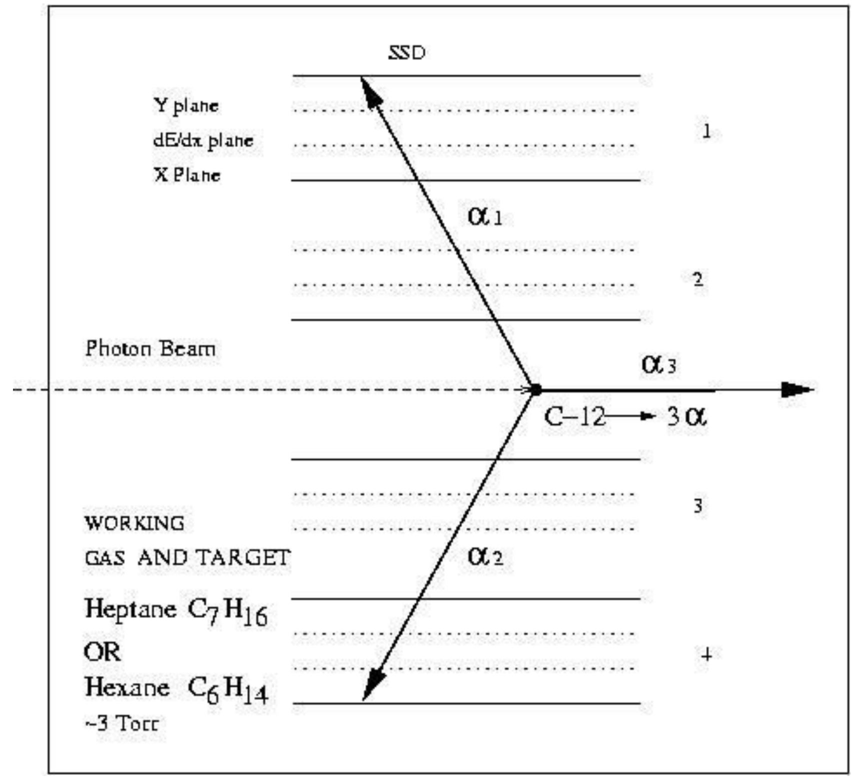
Alpha Detector-Active Target



Schematic representation of a single detector module



Schematic of the experimental setup at Yerevan



Schematic of the experimental setup at Yerevan and at MAX-lab

Proton and Neutron Beams

- $p + {}^{13}C \rightarrow d + 3\alpha$
- $p + {}^{12}C \rightarrow p' + 3\alpha$
- $n + {}^{12}C \rightarrow n' + 3\alpha$
- $p + {}^{16}O \rightarrow p' + {}^{12}C + \alpha$

1) E0 transition strength to the 3α continuum
2) Radiative branching ratio of the Hoyle state
3) Hoyle states in ${}^{12}C$
4) Hoyle state in ${}^{16}O$

Present situation of the 2_2^+ state

	Energy of 2_2^+ (MeV)	Width (MeV)	
(α,α') *1	**9.84 ± 0.06**	**1.01 ± 0.15**	Exp.
(p,p') *2	9.6±0.1	0.6±0.1	
(γ,3α) *3	~10	~1	
β decay *4	11.1±0.3	1.4±0.4	
α cond. *5	9.5	0.64	Theor.
3αOCM+ACCC+CSM *6	9.57	1.1	
3α RGM *7 *8	9.5 9.1	2 1	

Theoretical predictions with the α cluster model are consistent with experimental data.

The result of the β-decay experiment is different from others.

*1 **M.I *et al*, NPA738(2004)268, PRC84 (2011)054308**
*2 M.Freer *et al*, PRC80(2009)041303(R)
*3 M.Gai *et al*, Act.Phys.Pol.B42(2011)775
*4 S.Hyldegaard *et al*, PRC81(2010)024303
*5 Y.Funaki et al, Eur.Phys.J. A24 (2005)321
*6 C.Kurokawa and K.Kato, NPA792 (2007) 87
*7 M. Kamimura, NPA351(1981)456
*8 M.Kamimura and Y.Fukushima, Proc. INS Int. Symp., Fukuoka, 1978, p409

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M. Itoh: Cluster-2012

Experimentally determined magnitudes of various Dalitz-plot components

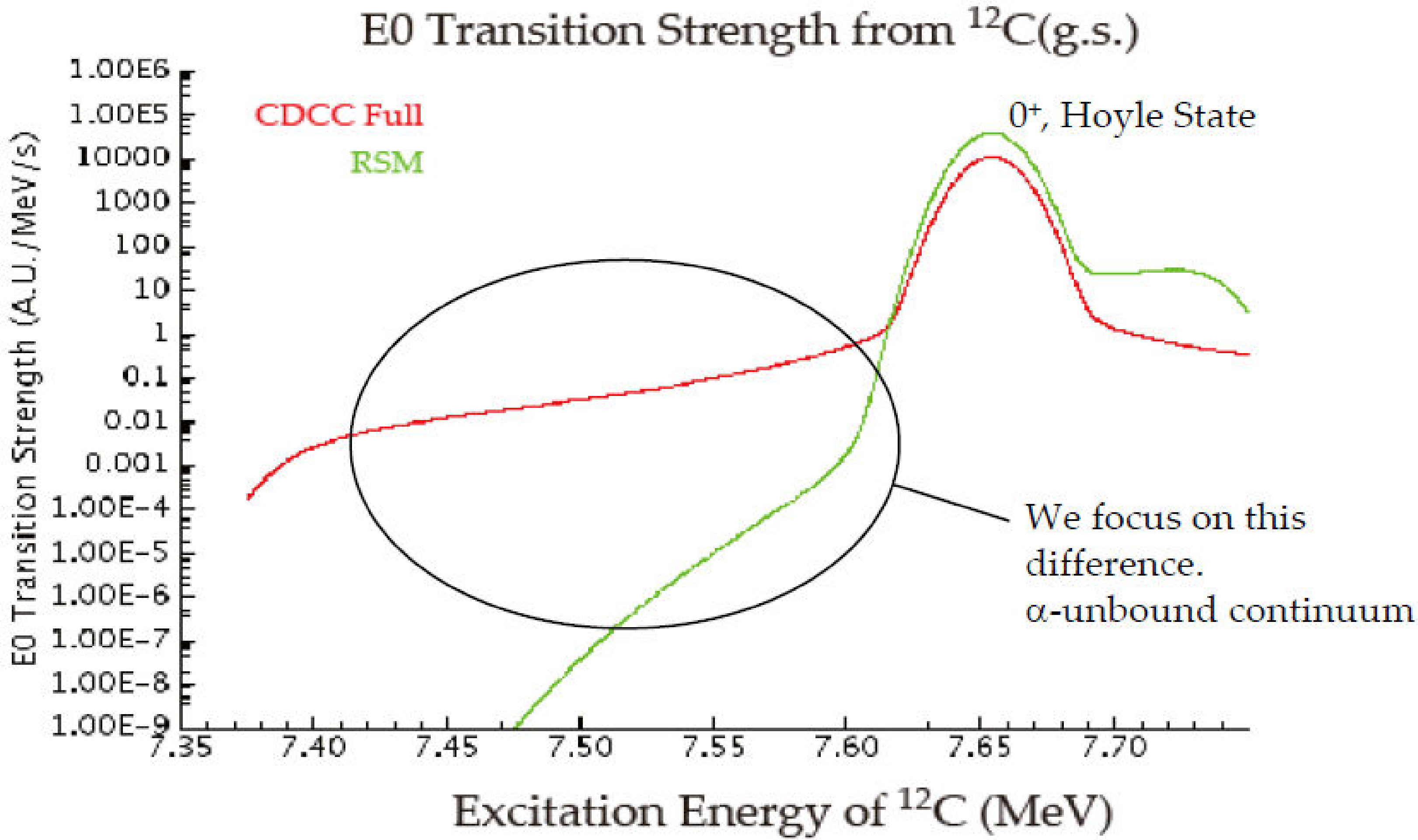
	SD	DDE	DDL	DDΦ
Freer et al	1	………..	……….	<0.03 (0.04)
Raduta et al	0.830(50)	0.075(40)	0.095(40)	……….
Manfredi et al	1	<0.003	………..	<0.003
Kirsebom et al	1	<0.0009	<0.0009	<0.005
Rana et al	0 .99	0.003(0.001)	<0.001	0.006(0.0009)

SD- sequential decay
DDE- direct decay equal energy
DDL-direct decay linear chain
DDΦ- direct decay phase-space

3α-reaction uncertainties

- At low temperature due to different theoretical estimates
- At medium temperature due to new experimental evidence for direct α-decay of the Hoyle state
- At high temperature due to possible influence of first 2^+ resonance in ^{12}C

E0 Transition Strength to the Three-α Continuum



^{12}C g.s. wave function from M. Kamimura et al.,

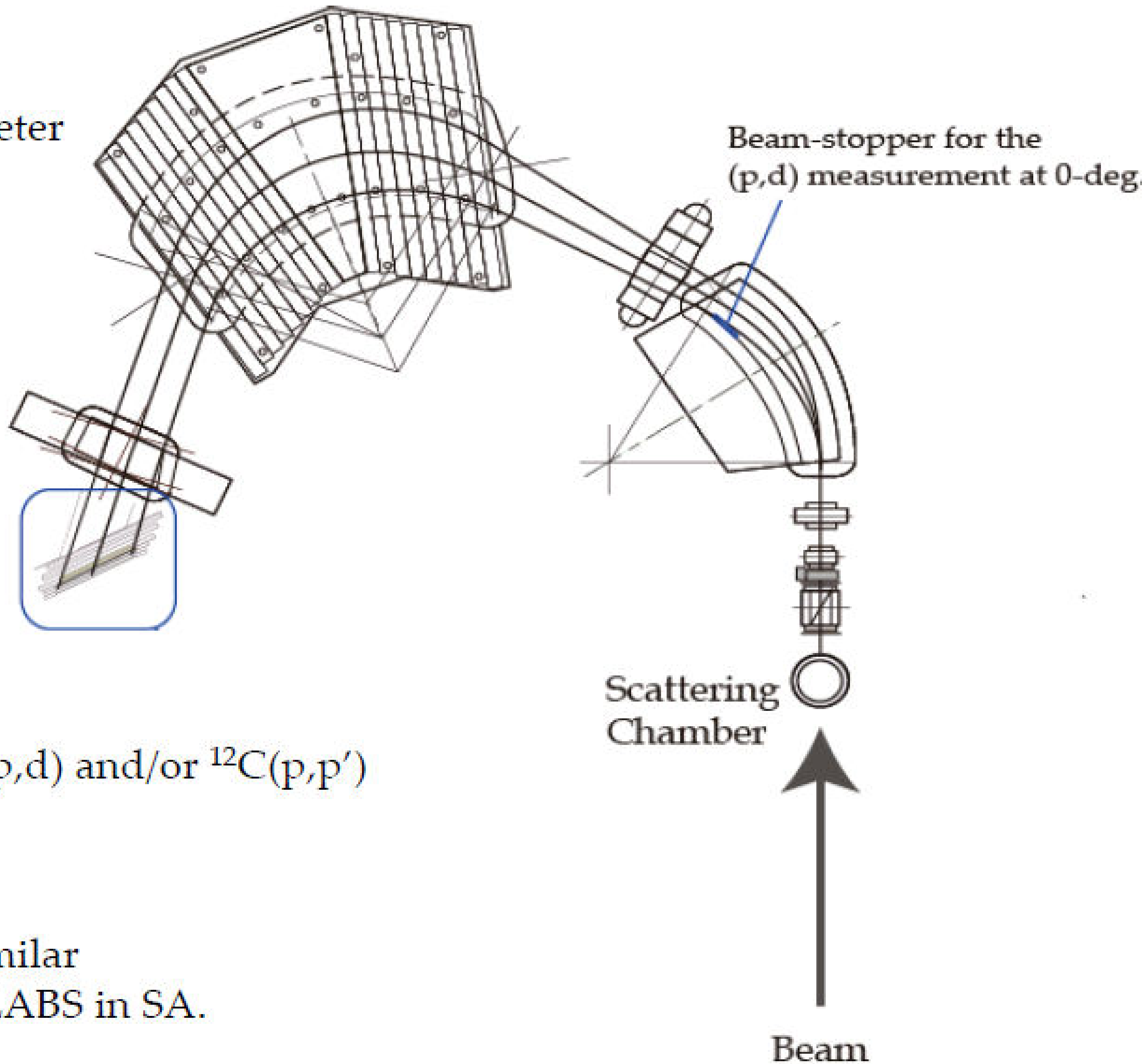
The ααα threshold is at 7.275 MeV.

Depicted from A. Tamii: FB20-2012

Experimental Setup

Grand Raiden Spectrometer
at RCNP

Proton beam at 65 MeV
Achromatic Mode,
ΔE~20 keV, 150 nA

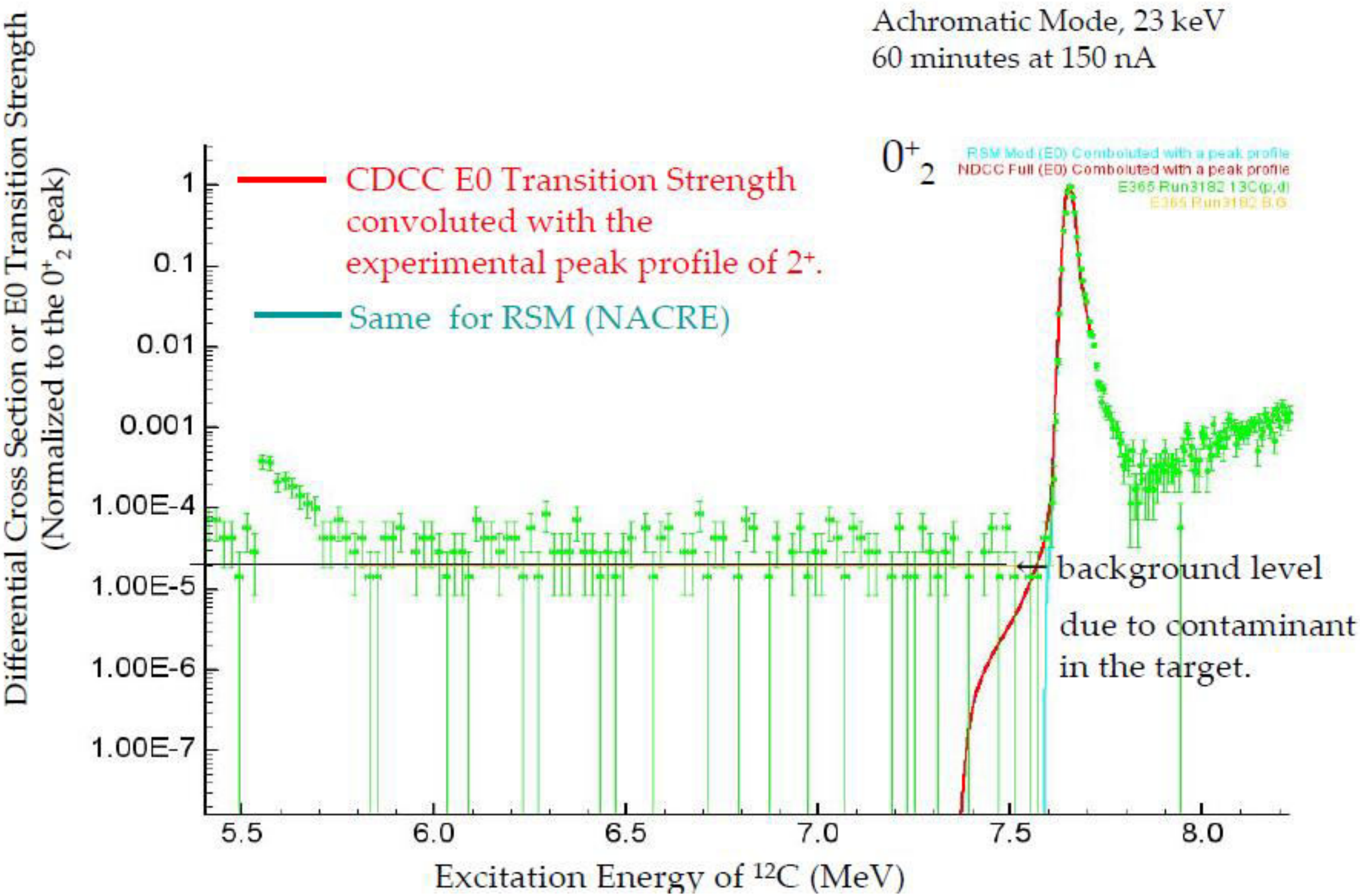


$^{13}C(p,d)$ and/or $^{12}C(p,p')$

We are also planning similar
experiment at iThembaLABS in SA.

Depicted from A. Tamii: FB20-2012

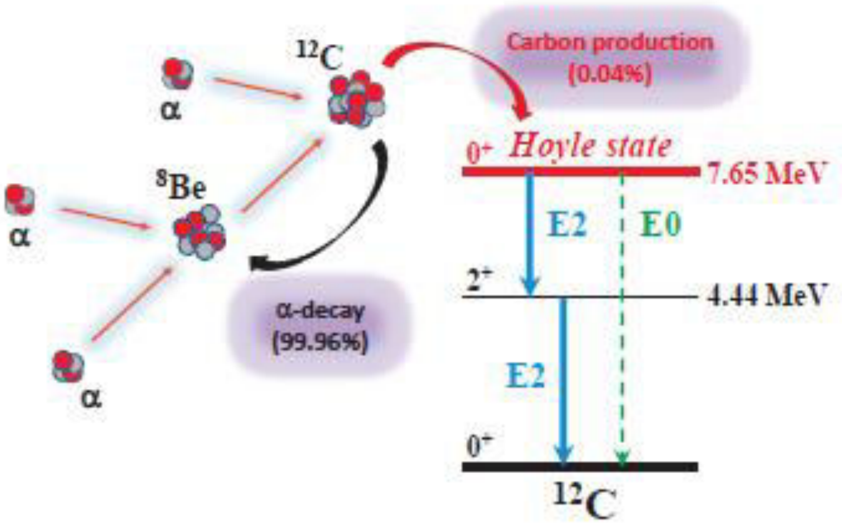
$^{13}C(p,d)$ at 0 degree



Depicted from A. Tamii: FB20-2012

Radiative Branching Ratio of the Hoyle State

3α process and the formation of ^{12}C



The rate of the triple-alpha reaction

$r_{3\alpha} \propto \Gamma_{rad} \exp(-Q_{3\alpha}/kT)$

T- is the temperature

$Q_{3\alpha}$- is the energy

released in the12C(7.65 MeV)→ 3α decay

Γ_{rad} *-is the radiative width.*

$$\Gamma_{rad.} = \Gamma_{E2} + \Gamma_{E0} + \Gamma_{E2} + \Gamma_{E0} + \Gamma_{CE} + \Gamma_{E2}$$

$$R \propto T^{-3/2} \frac{\Gamma(^{8}\mathrm{Be})}{\Gamma_{tot}} \Gamma_{rad} \exp\left(-\frac{Q_{3\alpha}}{kT}\right), \quad \Gamma_{rad} = \frac{\Gamma_{\gamma} + \Gamma_{\pi}}{\Gamma_{tot}} \times \frac{\Gamma_{tot}}{\Gamma_{\pi}} \times \Gamma_{\pi}$$

Depicted from B. Alshahrani et al: EPJ-2013

Experimental values of Γrad/Γ

Reference	Reaction and Method	Γrad/Γ × 10−4
Alburger (1961)	[10B(3He;p)12C] pγγ coinc	3.3(9)
Seeger & Kavanagh (1963)	[14N(d; α)12C] Recoiling 12C and α coinc	2.82(29)
Hall & Tanner (1964)	[10B(3He; p)12C] Recoiling 12C and p coinc	3.5(12)
Chamberlin et al. (1974)	[12C (α; α ′)12C] Recoiling 12C and α coinc	4.2(2)
Davids et al. (1975)	[12C(p; p′)12C] Recoiling 12C and p coinc	4.30(20)
Mak et al. (1975)	[13C(3He; α)12C] Recoiling 12C and α coinc	4.15(34)
Markham et al. (1976)	[12C(α; α′)12C] Recoiling 12C and α coinc	3.87(25)
Obst et al. (1976)	[12C(p; p′)12C] pγγ coinc	4.09(29)
Adopted		4.13(11)

Depicted from B. Alshahrani et al: EPJ-2013

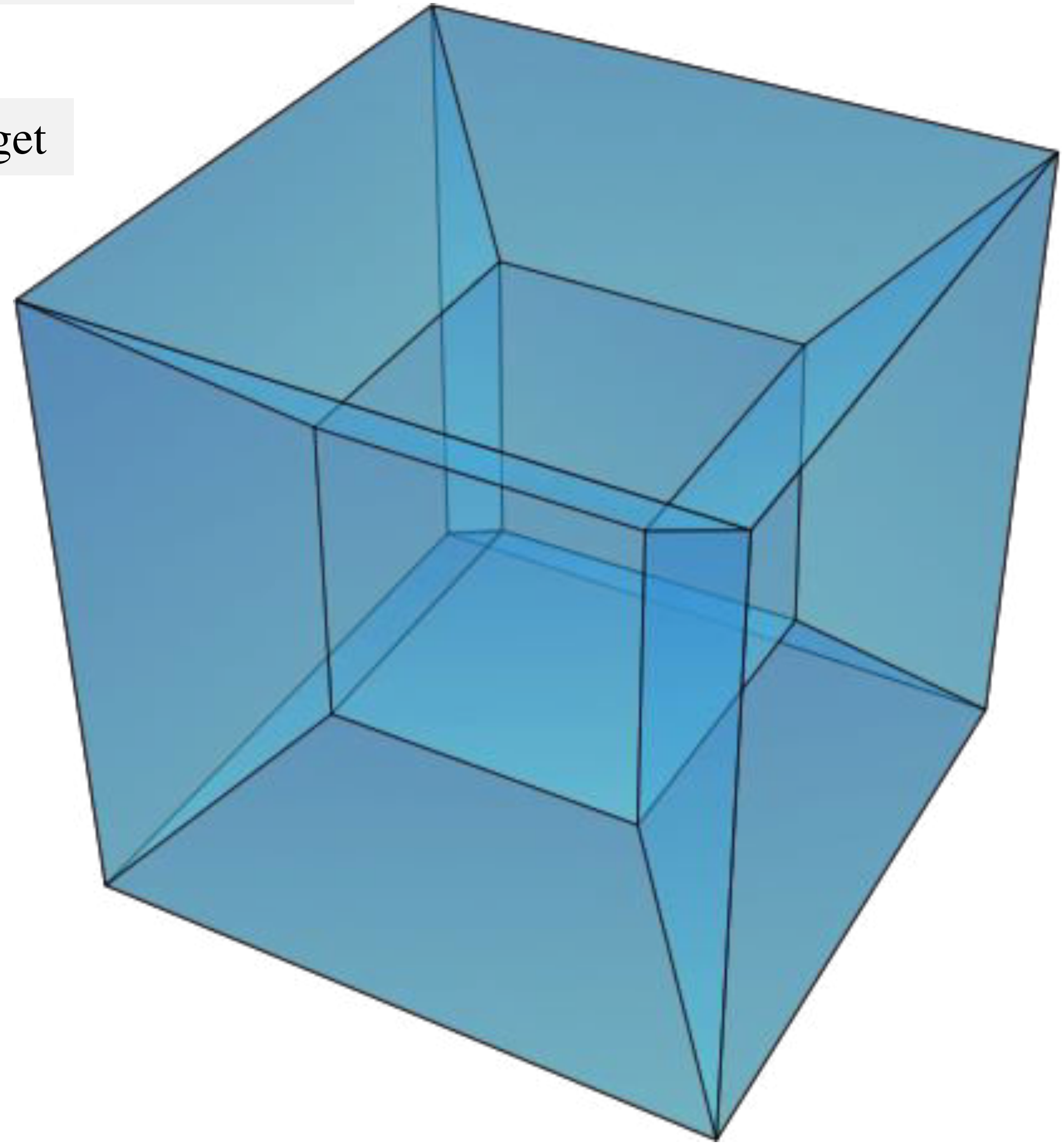
Alpha Hypercube- Unique Tool

Low-energy alpha detector-active target

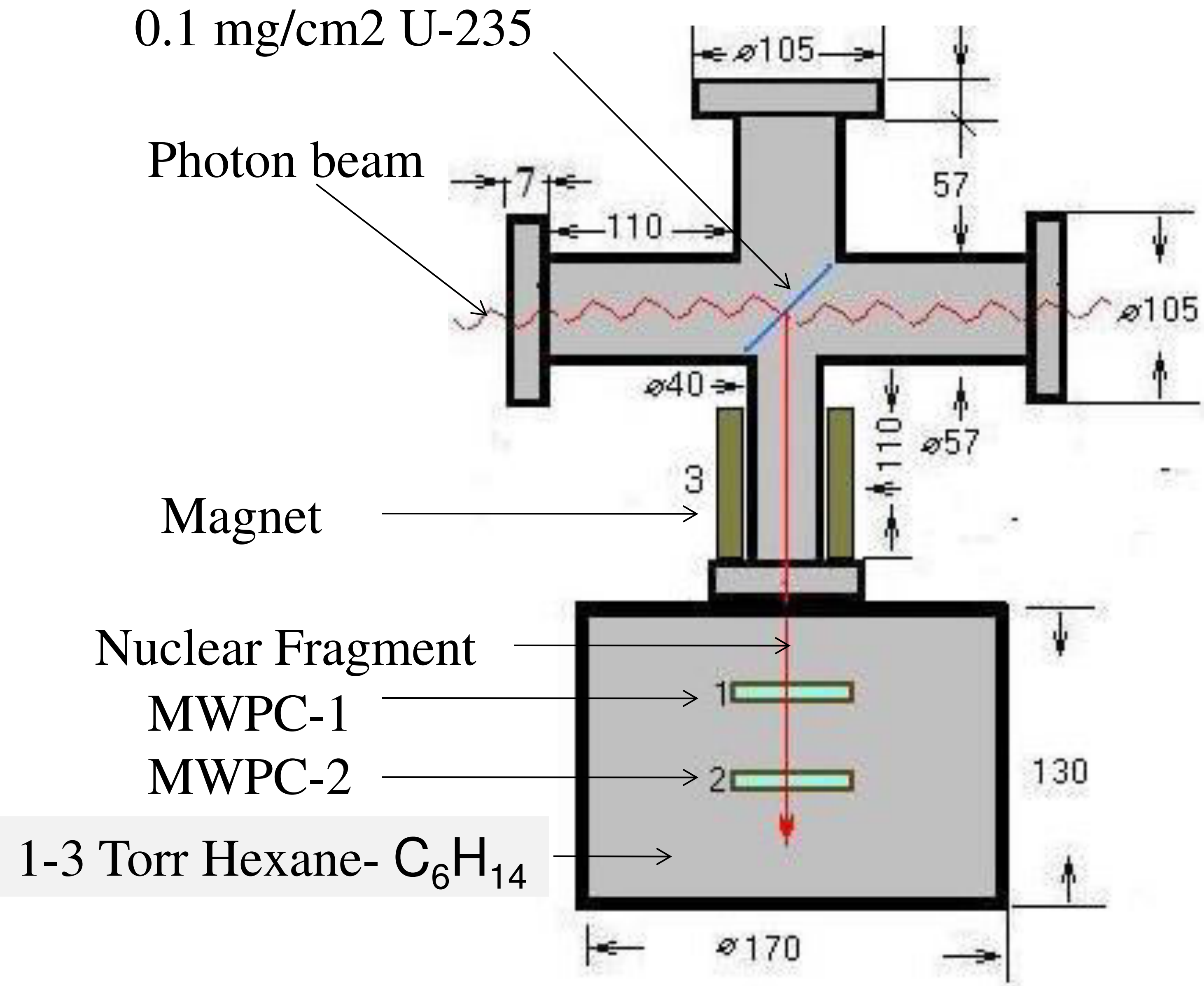
Cyclotron neutron beam

Working gas-target

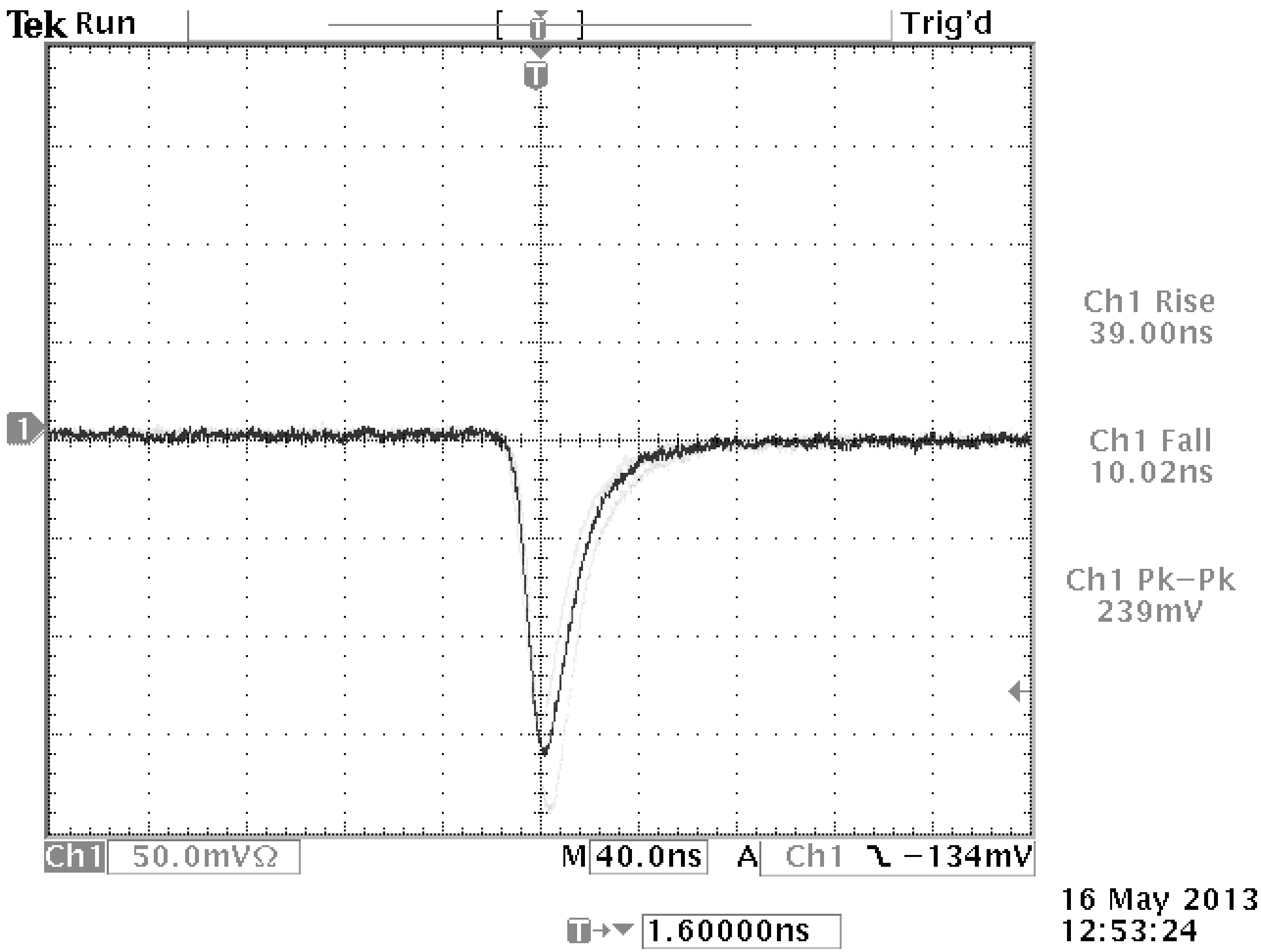
Hexane- C_6H_{14} - p; C-12
CO_2- C-12; O-16
He-4
He-3
Ne
Ar



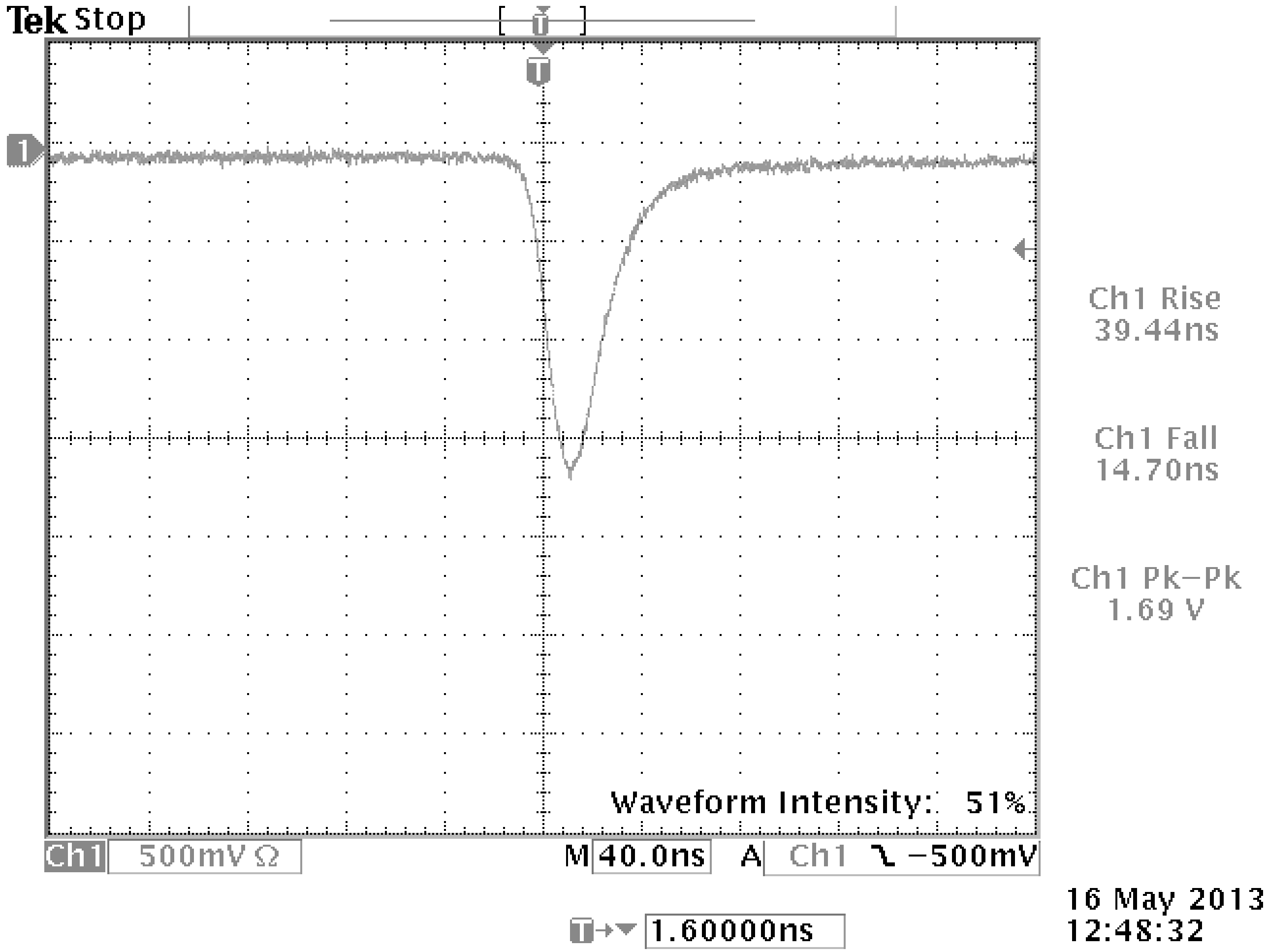
Schematic of the test setup at Yerevan



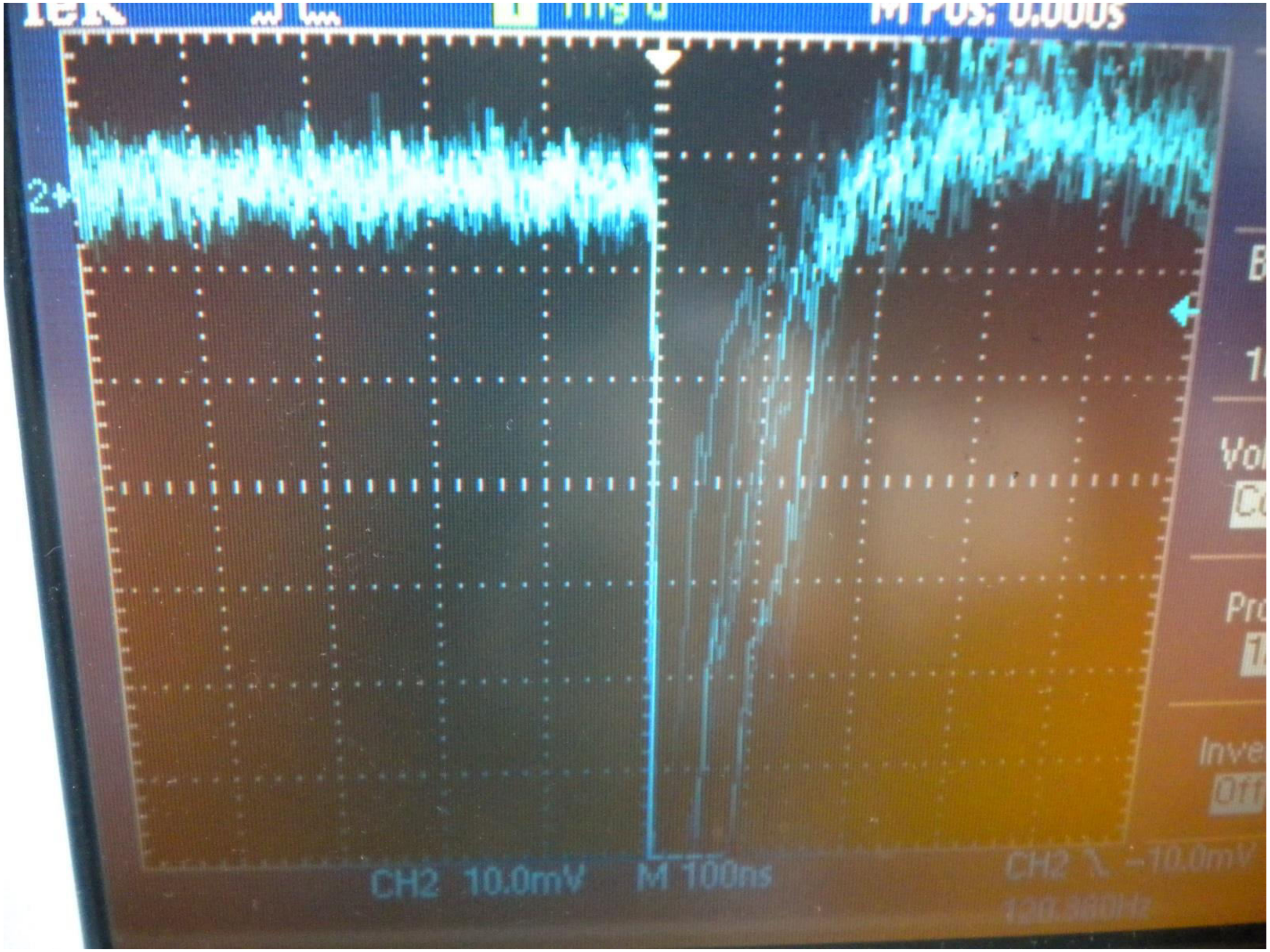
Typical signal generated by alpha particle



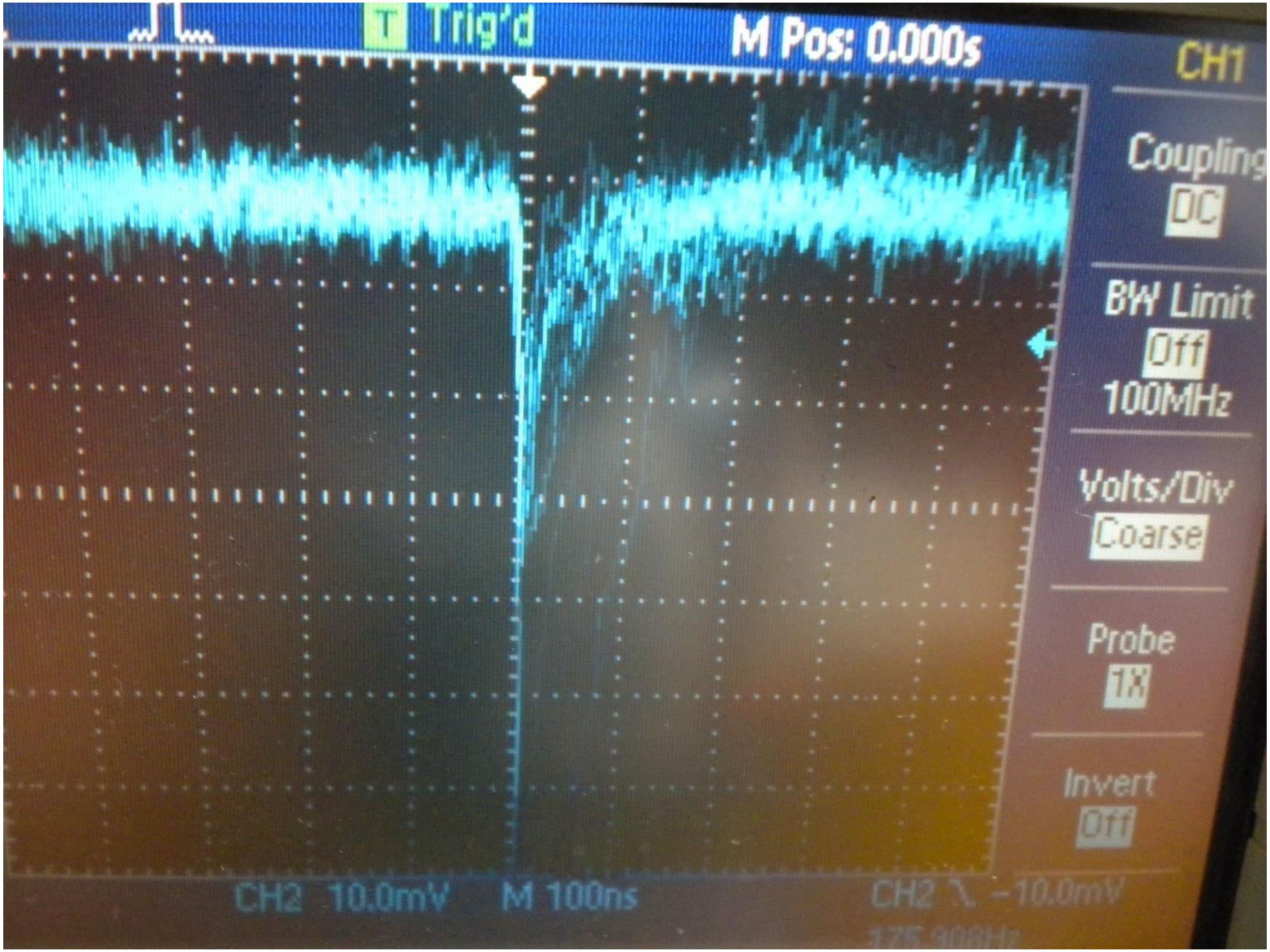
Typical signal generated by fission fragment



Typical signal generated by alpha particle



Typical signal generated by alpha particle and relativistic electrons from Sr




CH2 10.0mV
M 500ns
CH1

Fission experiments at proton cyclotron

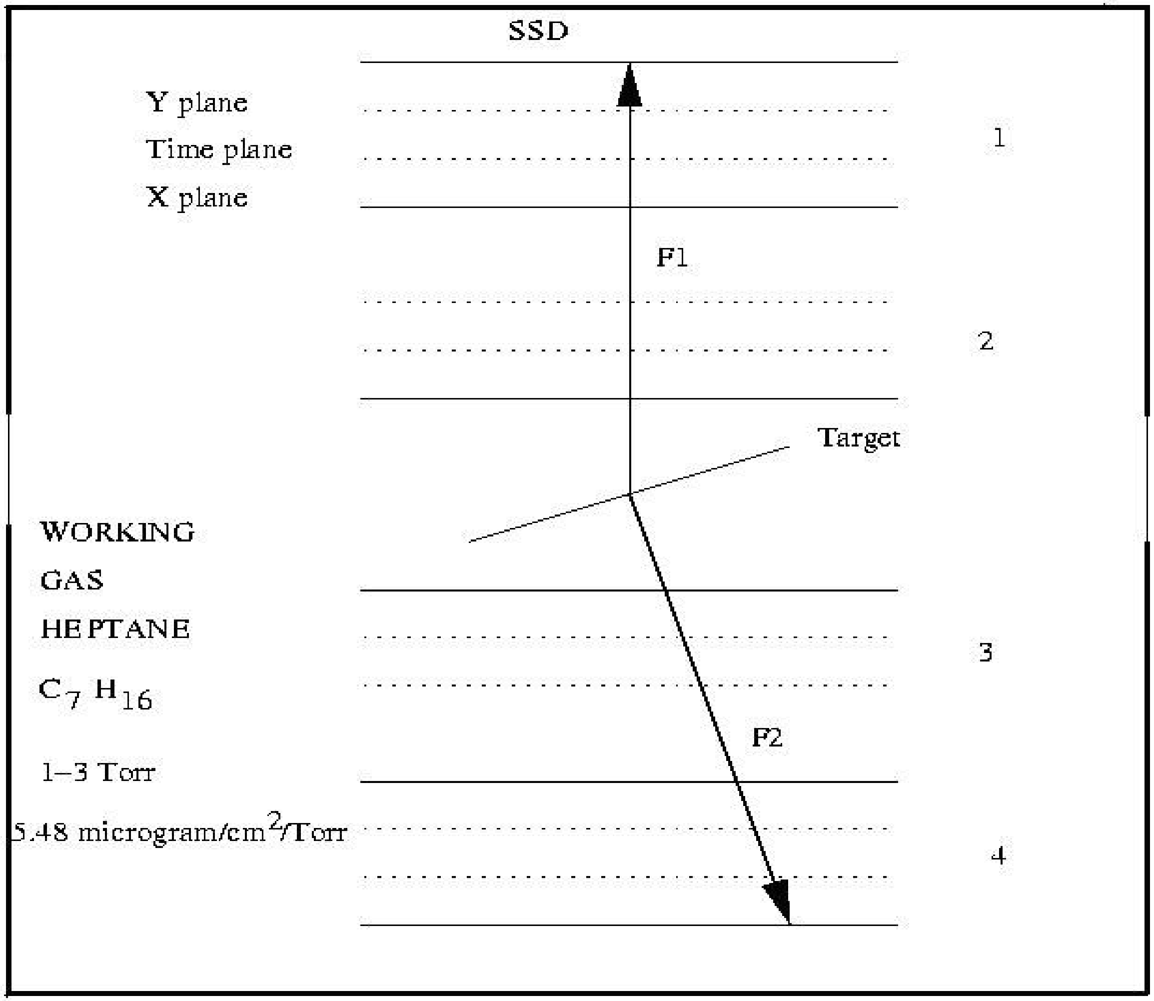
1. Collinear cluster tri-partition: it will be the most sensitive studies of this new phenomena

2. Fission cross section measurements
First time the fission cross sections of pre-actinides (Pb, Au, Th..) will be measured with 18 MeV proton beam

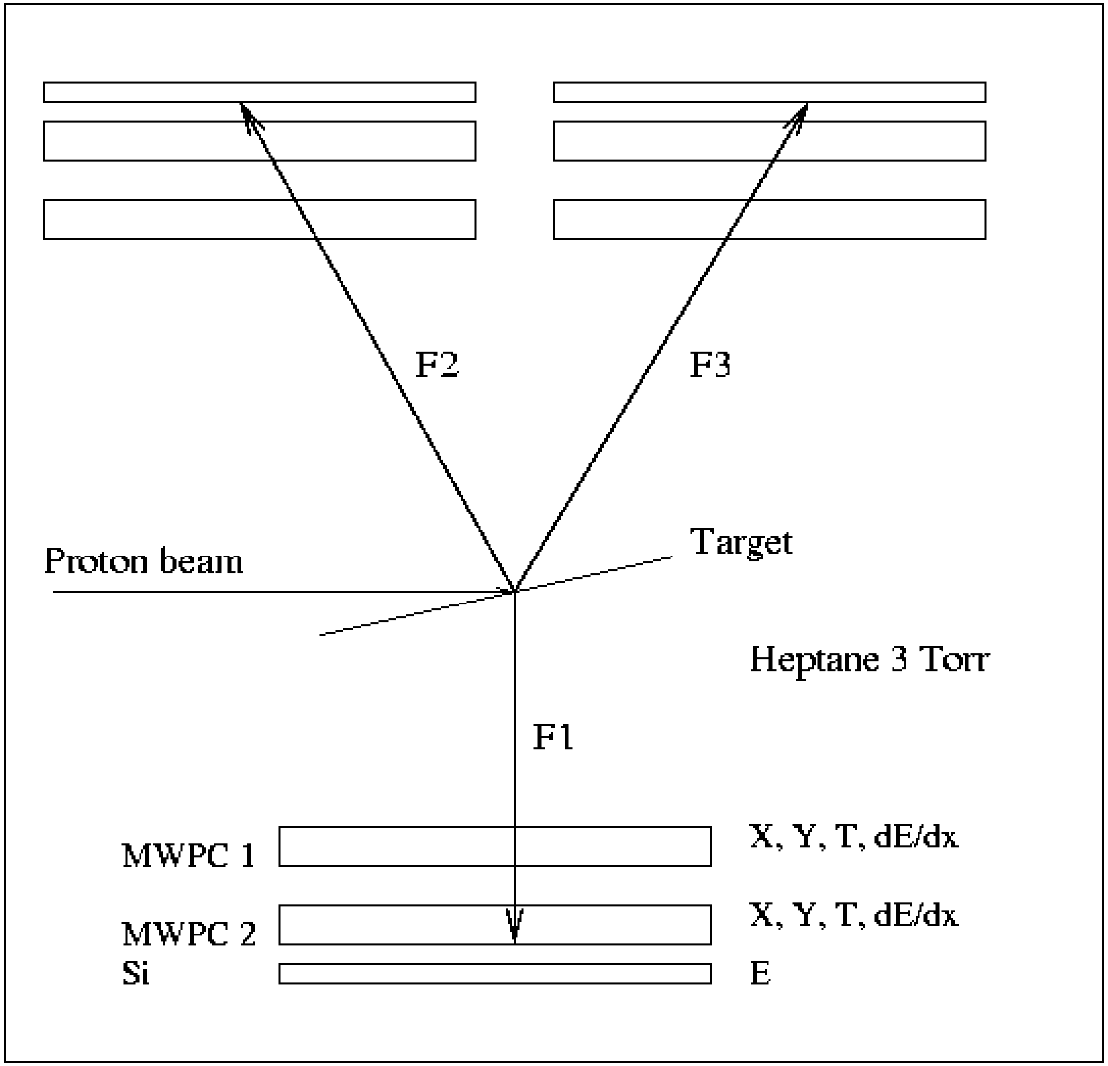
3. Studies of n+Th-232 → fission mechanisms at ~1.6 MeV

4. Studies of fission isomers with lifetimes 1-20 ns
Developed setup can determine fission fragment production time with ~200 ps resolution

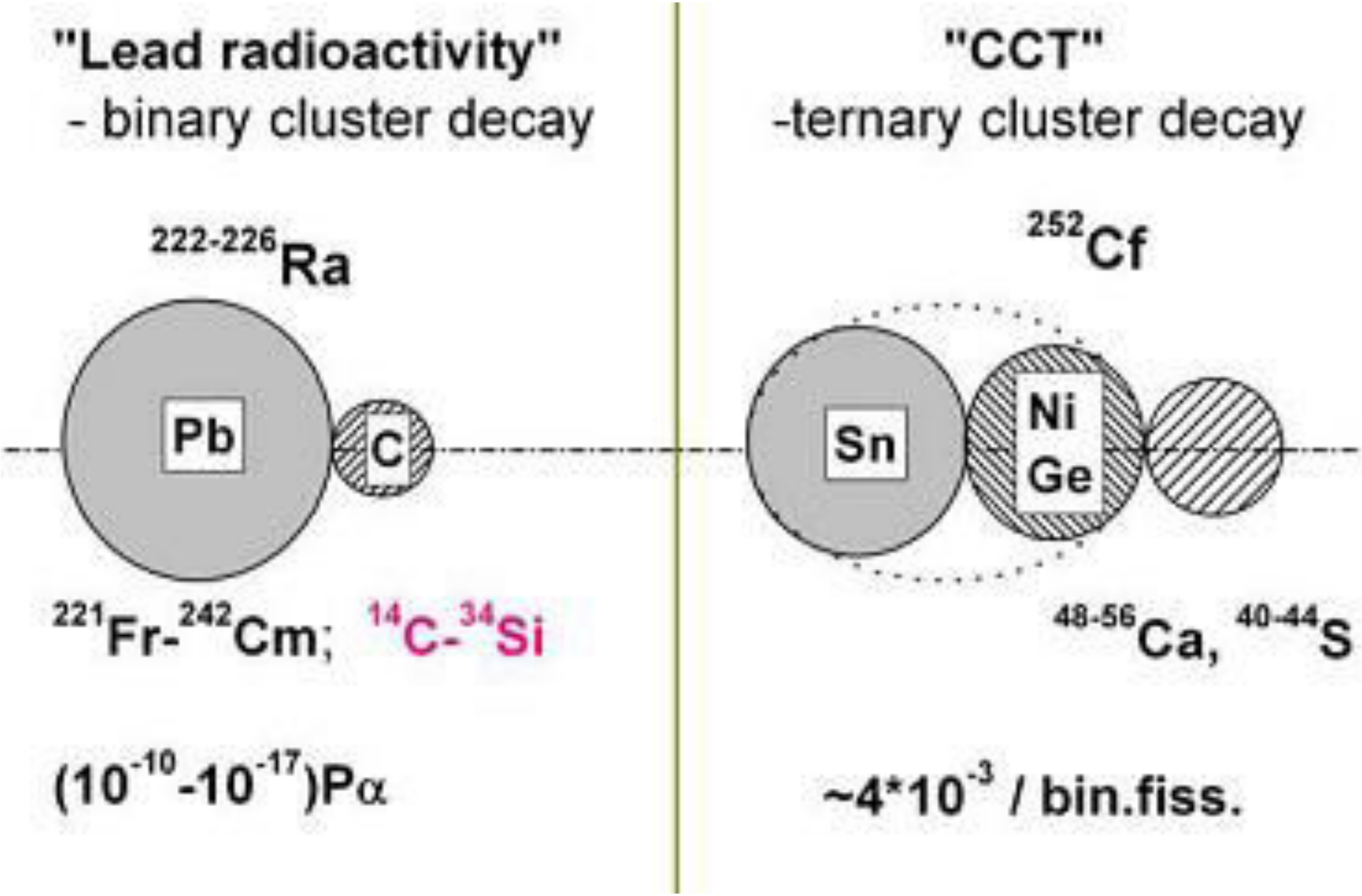
Fission Fragment Detector



Schematic of the fission fragment detector



Schematic of the ternary fission experimental setup

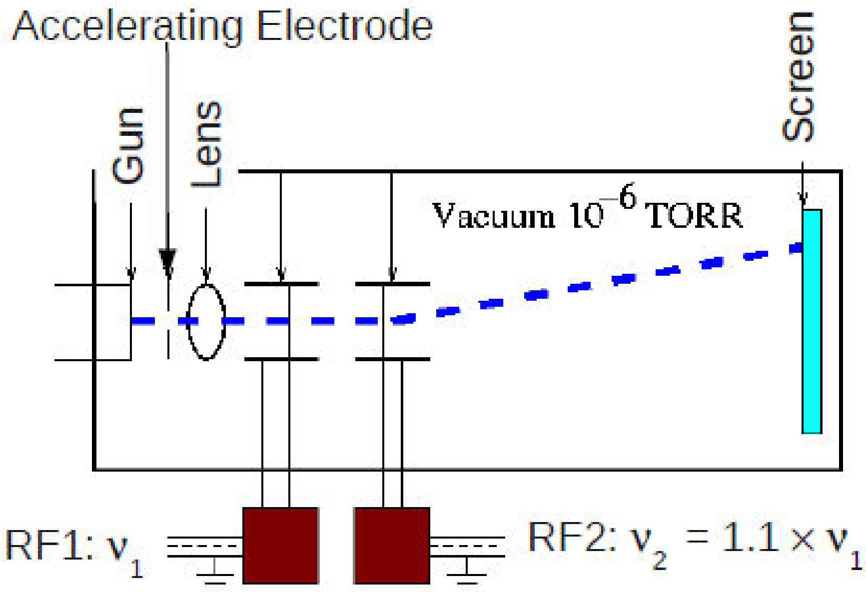


Depicted from Kamanin- 2010

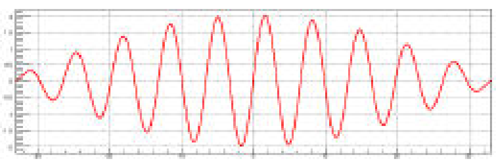
Methodic Studies

- LPMWPC, time-zero FF detector, low-energy recoil detector, alpha hypercube
- RFPMT-THz photon detector, new timing system
- RF Streak camera, spiral scanning, new timing system

Spiral scanning with two RF deflectors

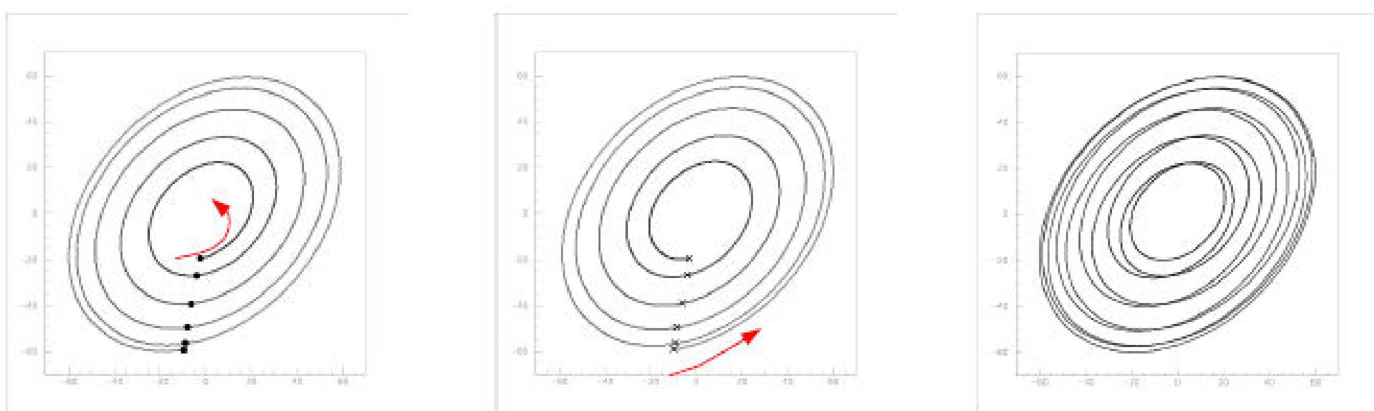


- Apply 2 RF fields, of slightly different frequency
- "Beat" in superposed response modulates radius of scanned circle



- Period of Spiral

  $\tau = 1/(\nu_2 - \nu_1) = 10\,\tau_1$
- Pixelated anode necessary



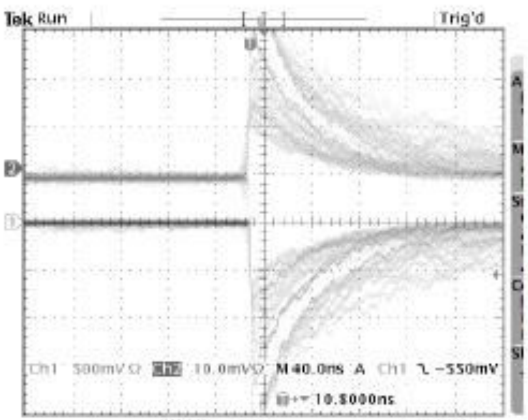
Spiral Scan Images

750 MHz Only

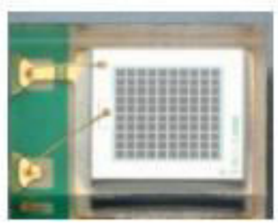
825 MHz Only

750 & 825 MHz Combined

Test with 20 mm scint.
foil + S10362 MPPC



S10362
1 mm^2

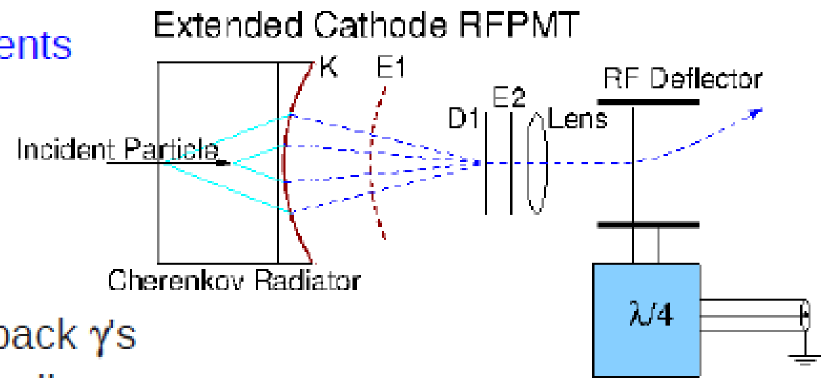


Possibilities for Pixelated Anode?

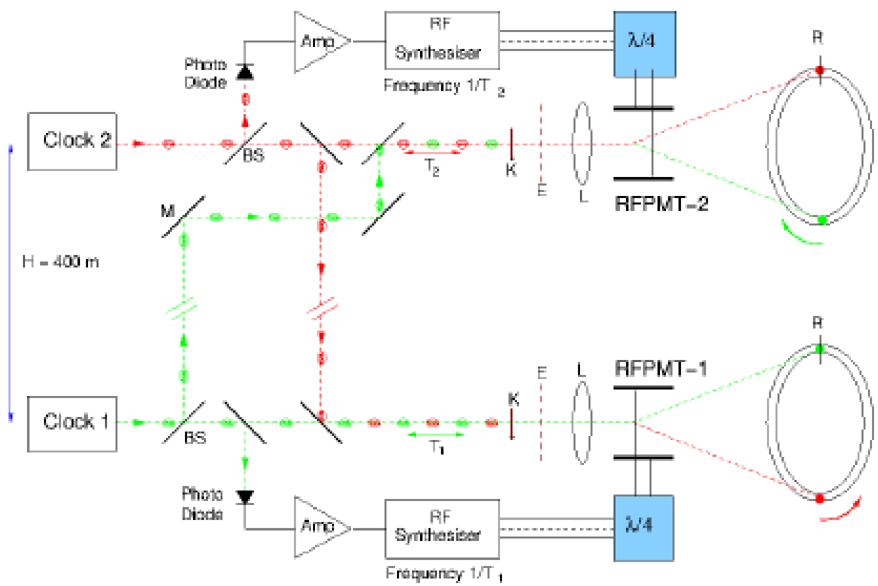
- Need large fast device
- MPPC Multiple pixel APD
- Off-the-shelf devices have
  common readout
  relatively small area
- Pulse length relatively long
  but sharp rise time
- Custom detectors available?

Potential RFPMT Applications

Nuclear Physics:
- Cherenkov Detector
- High precision time of flight measurements
- Momentum measurement, Particle ID
- Proposed use JLab (e.g. PR12-10-001 experiment)



Medical Imaging:
- Positron Emission Tomography (PET)
- Array Cherenkov detectors of back-to-back γ's
- Time of flight of back-to-back γ's → coordinate
- along line of flight of γ 's (10 ps gives ~2.5 mm)



Gravitational Red Shift

Frequency shift of identical clocks placed at different gravitational potential

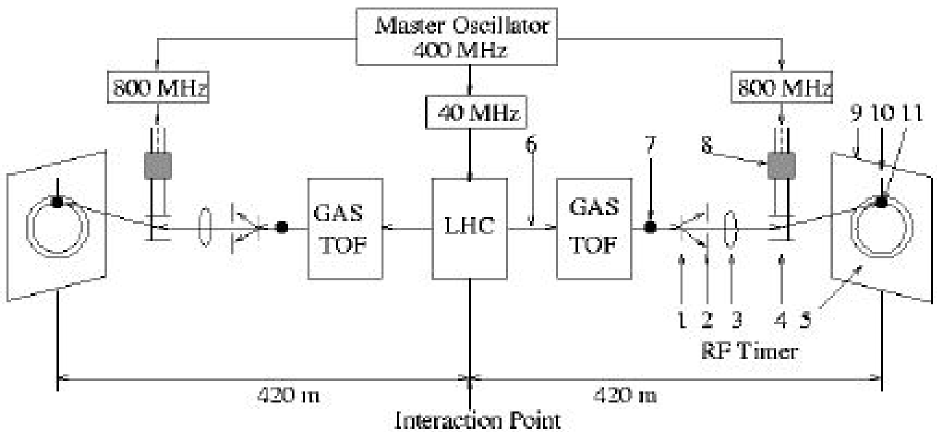
$\delta\nu/\nu \approx (1 + \alpha)\delta U/c^2$

$\alpha = 0$ if relativity holds

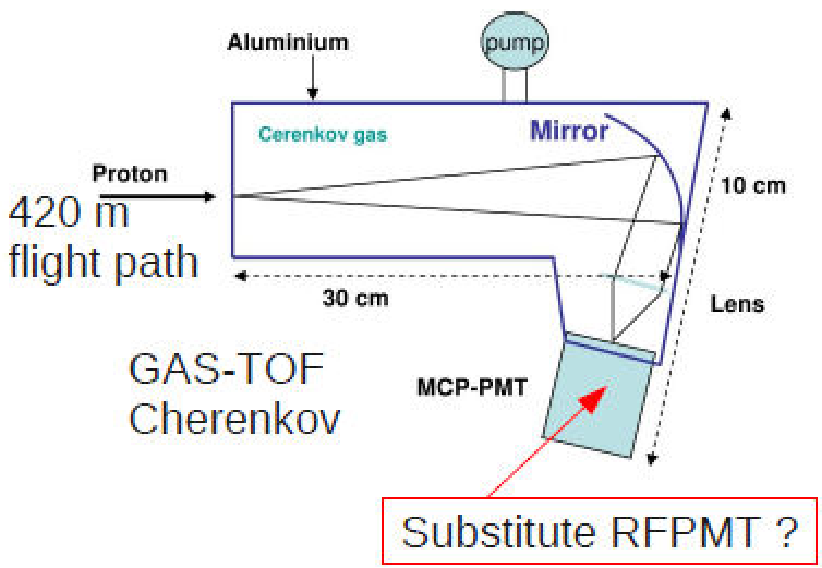
$\delta H \sim 400\text{m}, \delta U/c^2 \sim 4.4 \times 10^{-14}$

Determine upper limit on $\alpha \leq 7 \times 10^{-6}$

Possible applications at LHC



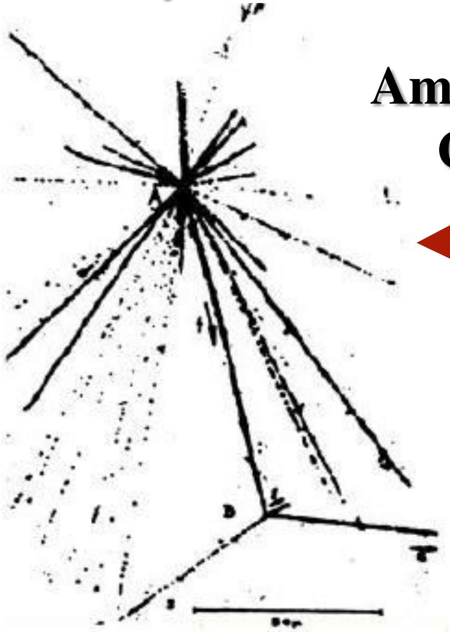
M.G. Albrow et al., arXiv:0806.0302v2 [hep-ex]



In principle RFPMT can be synchronised with the accelerator RF system:
Mainz 2.5 GHz
JLab 0.5 GHz (to each hall)

- Measure forward protons produced in collisions at ATLAS & CMS. Times T_1 & T_2
- Synchronise RF for RFPMT with LHC beam buckets
- Detect p by left/right GAS-TOF
- Background rejection from interaction point from $T_1 - T_2$
- Calibration from independent vertex measurement

Discovery of Hypernuclei
Danysz & Pniewski 1952



Neutron Star

Ambartsumyan & Saakyan 1960
Connection to compact star

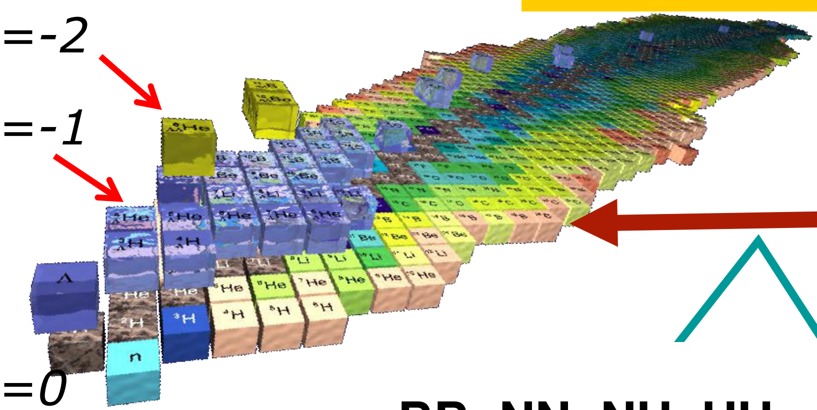
Delayed Pion Spectroscopy of Hypernuclei

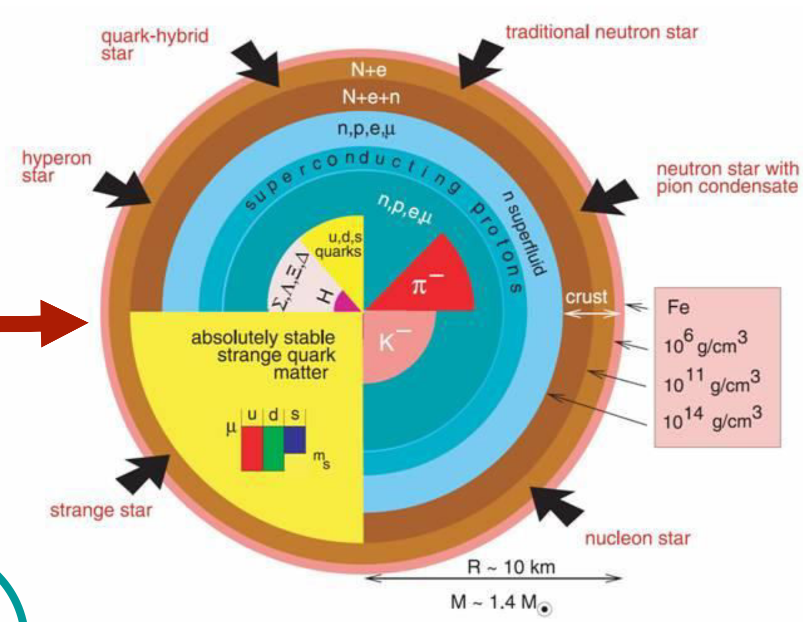
Nuclei ⟵ Baryon-Baryon Interaction ⟶ Neutron Star

~42-known, 24 as a hyperfragment
Expected number > 8000

Ambartsumyan and Saakyan 1960

~3000 - known
Expected ~8000





BB=NN+NH+HH

	n (udd)	P (uud)	Λ (uds)	Σ (uds)
n	N.R.	N.R.	S.H.	S.H.
p		N.R.	S.H.	S.H.
Λ			D.H.	D.H.
Σ				D.H.

The single and double hypernuclei are the main sources of the strange sector of baryon-baryon interaction

Hyperon Nucleon Interactions

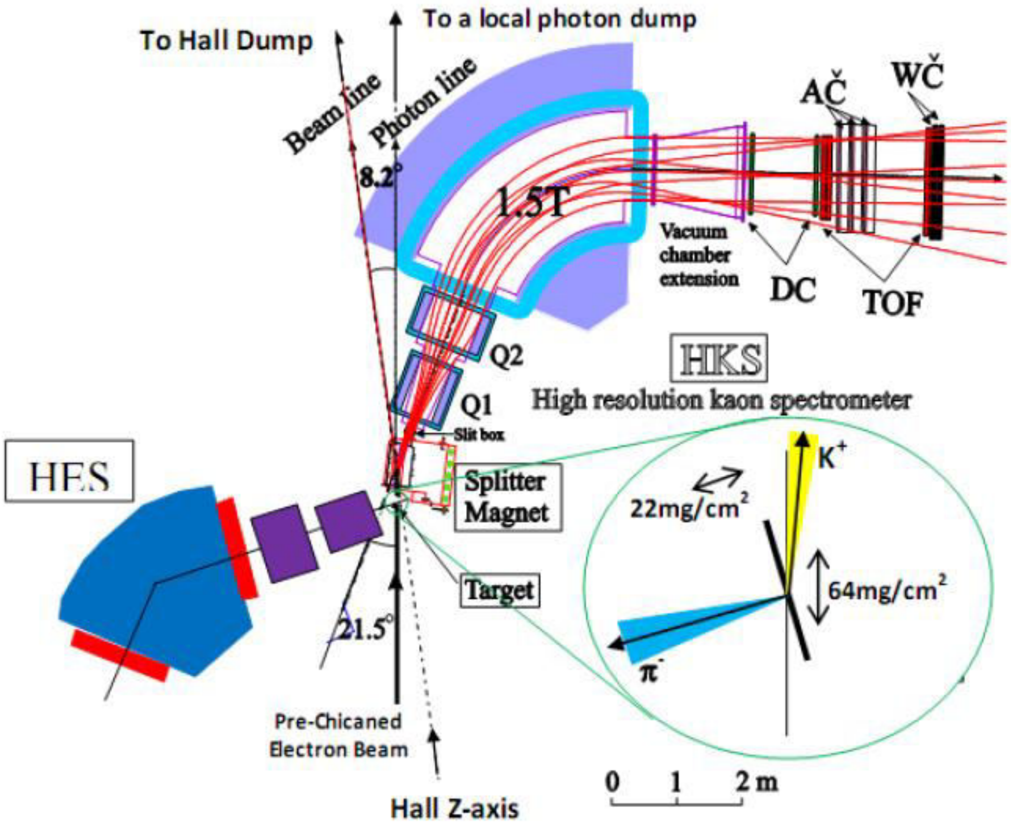
YN	$B_\Lambda(^3_\Lambda H)$	$B_\Lambda(^4_\Lambda H)$	$B_\Lambda(^4_\Lambda H^*)$	$B_\Lambda(^4_\Lambda He)$	$B_\Lambda(^4_\Lambda He^*)$	$B_\Lambda(^5_\Lambda He)$
SC97d(S)	0.01	1.67	1.2	1.62	1.17	3.17
SC97e(S)	0.10	2.06	0.92	2.02	0.90	2.75
SC97f(S)	0.18	2.16	0.63	2.11	0.62	2.10
SC89(S)	0.37	2.55	Unbound	2.47	Unbound	0.35
Experiment	0.13 ± 0.05	2.04 ± 0.04	1.00 ± 0.04	2.39 ± 0.03	1.24 ± 0.04	3.12± 0.02

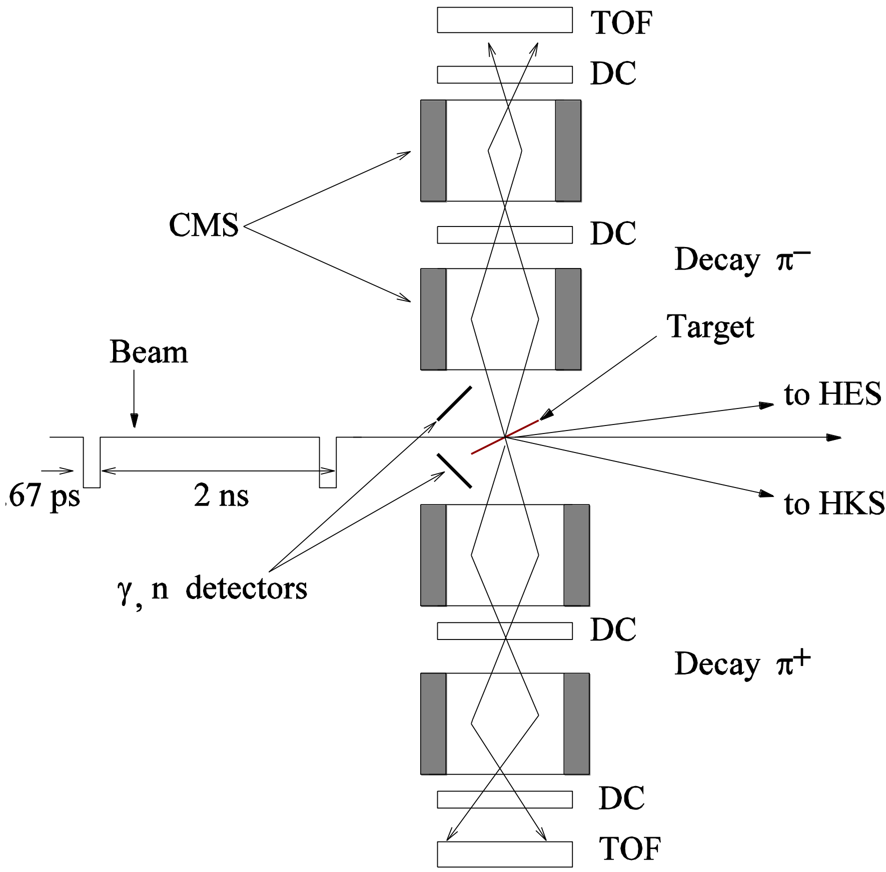
Accurate values of binding energies B_Λ of light hypernuclei is extremely important and needed for parameterization of the two body effective potential!!!

$$V_{\Lambda N}(r) = V_c(r) + V_s(r)(S_\Lambda * S_N) + V_\Lambda(r)(l_{\Lambda N} * S_\Lambda) + V_N(r)(l_{\Lambda N} * S_N) + V_T(r)S_{12}$$

High precision γ-spectroscopy has been successful for the spin dependent terms but unable to measure binding energies

Decay π Spectroscopy → Delayed π Spectroscopy





RFPMT based Cherenkov detector will open dour for delayed pion spectroscopy

HπS Calibration by TOF Measurement

From TOF concept for pions and electrons with identical flight length - L and momentum - p we have

$$t_\pi = L/(\beta_\pi c) = (L/c)\sqrt{1 + m_\pi^2 c^2 / p^2}$$

$$t_e = L/(\beta_e c) = (L/c)\sqrt{1 + m_e^2 c^2 / p^2}$$

From these two equations

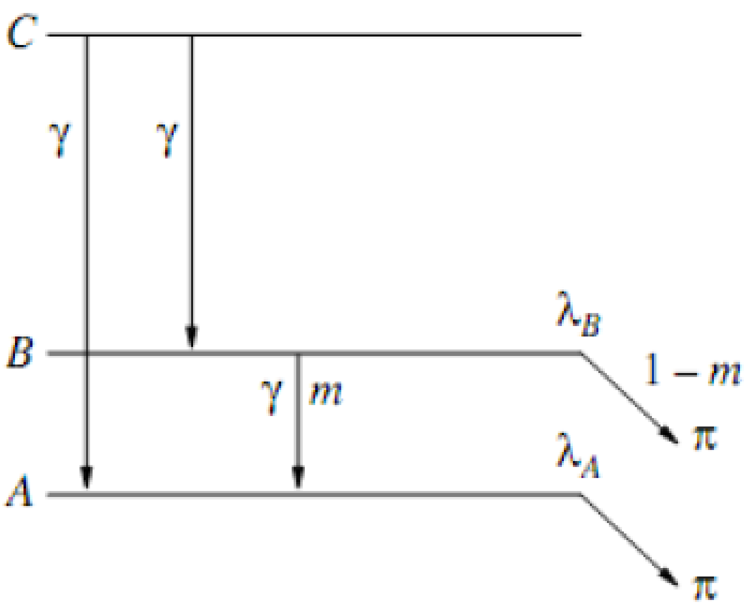
$$L/c = \sqrt{\frac{t_e^2 m_\pi^2 - t_\pi^2 m_e^2}{m_\pi^2 - m_e^2}}$$

$$p_\pi = (L/c)\frac{m_\pi c}{\sqrt{t_\pi^2 - (L/c)^2}}$$

Pion momentum can be determined by TOF measurement of pions and electrons

Tagged-Weak Pi-Method of B(E2) and B(M1) Measurement

Schematic of the Tagged-Weak Pi-Method



$$P^{B\to weak}(t) = (1-m)\lambda_B(\lambda_B^{\pi^-}/\lambda_B)N_B e^{-\lambda_B t}$$

$$P^{A\to weak}(t) = (P^{B\to A}(t) + \lambda_A N_A e^{-\lambda_A t})(\lambda_A^{\pi^-}/\lambda_A)$$

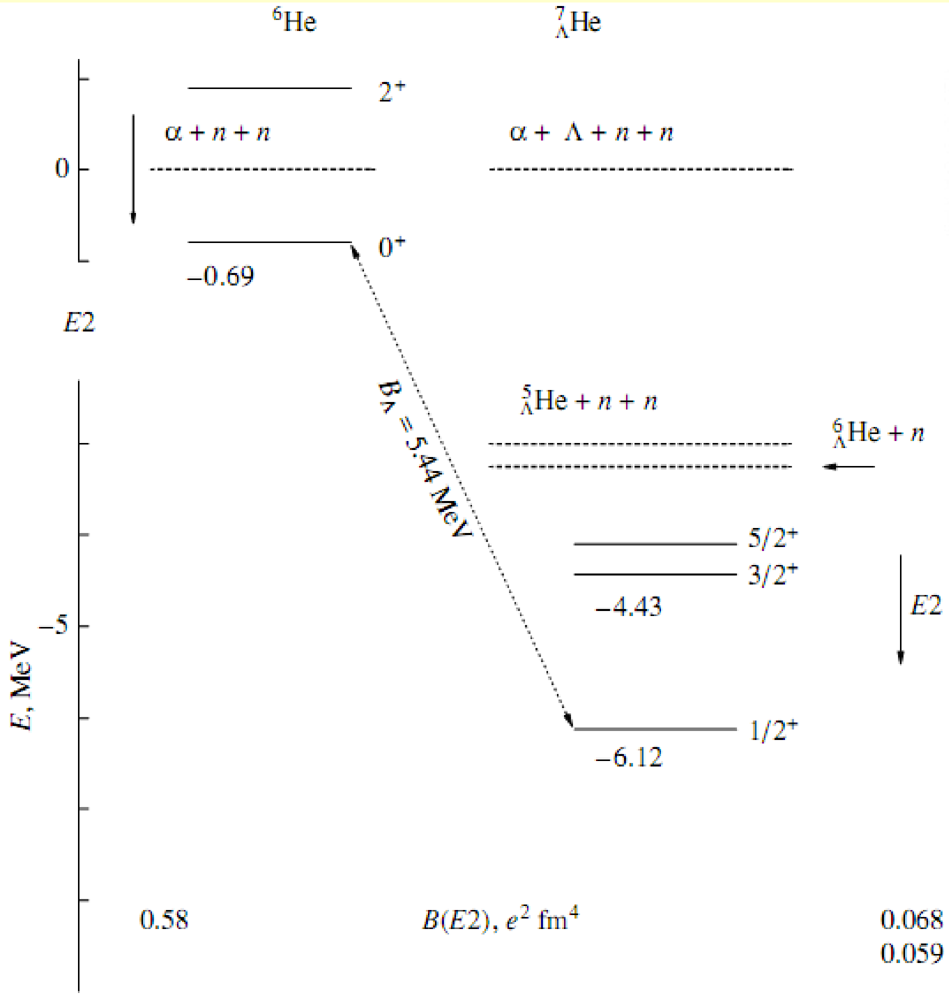
$$P^{B\to A}(t) = \frac{\lambda_A\lambda_B}{\lambda_A-\lambda_B} m N_B (e^{-\lambda_A t} - e^{-\lambda_B t})$$

$$\lambda_A = \lambda_W^A \quad \lambda_B = \lambda_W^B + \lambda_\gamma^{B\to A} \quad \lambda_W^A = \lambda_W^B \cong (200\ ps)^{-1}$$

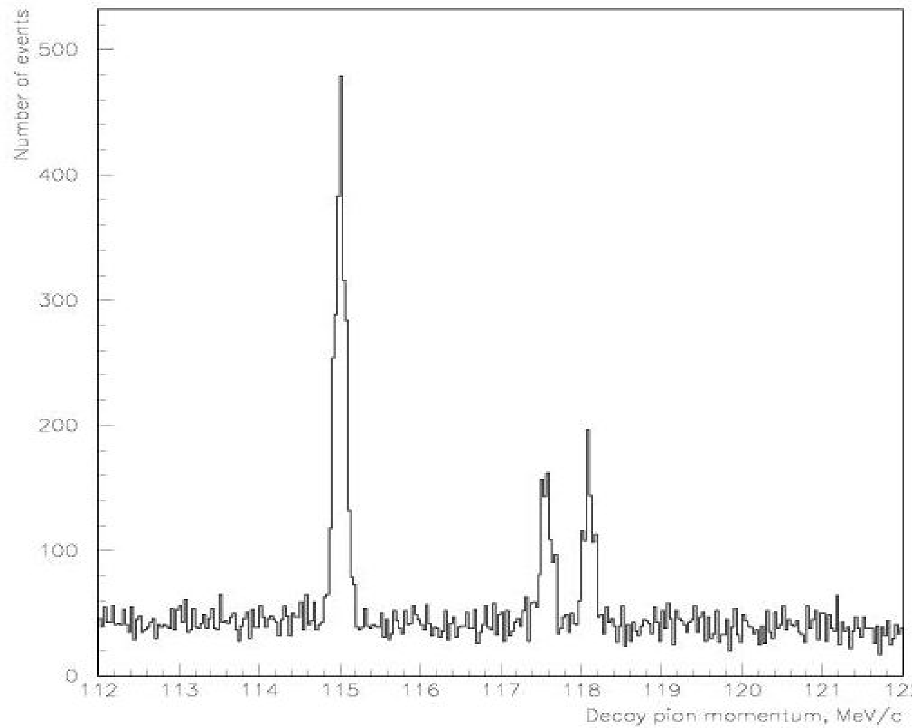
By measuring $P^{A\to weak}(t)$, $P^{B\to weak}(t)$ and fitting them together

to the equations above λ_A , λ_B and $\lambda_\gamma^{B\to A}$ can be determined

$^{7}{}_{\Lambda}He \to {}^{7}Li + \pi^{-}$: Momentum Measurement (MC simulations)

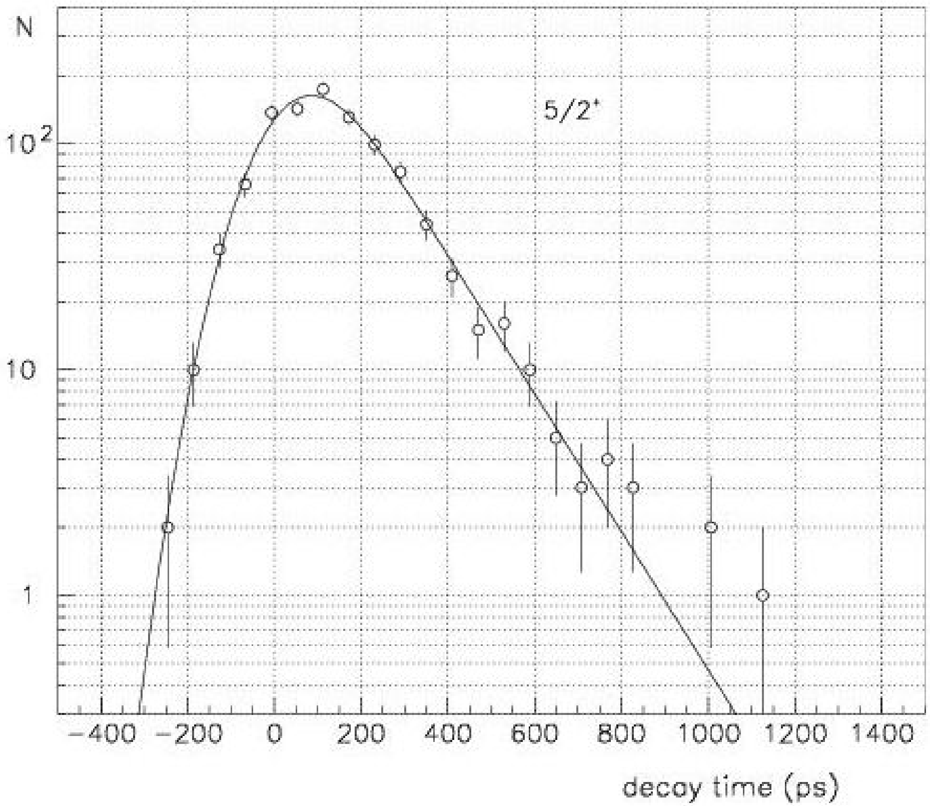


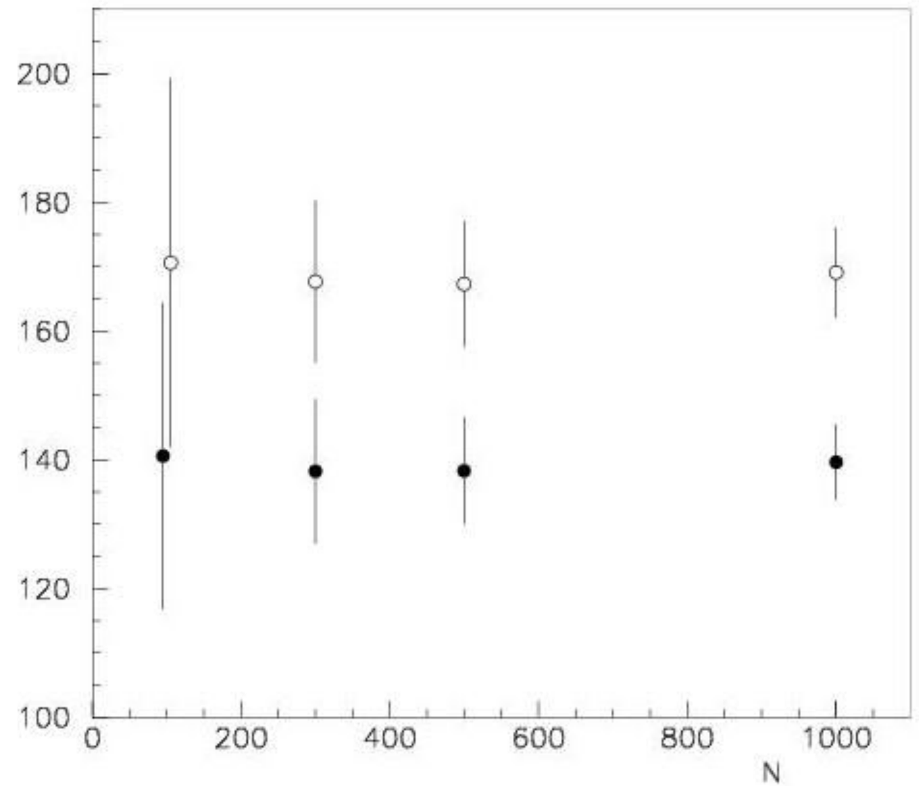
Expected level scheme of $^{7}{}_{\Lambda}He$ and $B(E2)$ calculated by Hiyama et al. with a 3-body cluster model for α+n+n and $^{5}{}_{\Lambda}$He+n+n. Phys. Rev. C59 (1999)2351.



Simulated spectrum of the decayed pions from $^{7}{}_{\Lambda}He \to {}^{7}Li + \pi^{-}$ decay (96.8% - quasi-free, 2% - 115.06 and 117.63, 118.15 MeV/*c* monochromatic lines each with 0.6% .

$^{7}_{\Lambda}He \rightarrow {}^{7}Li + \pi^{-}$: Lifetime Measurement (MC simulations)





Simulated and fitted lifetime distributions of the 5/2^{+} state. The input lifetime is 140 ps, time resolution is 100 ps, number of events is 1000.
The extracted lifetime is 139 ± 6 ps.

Sensitivity of lifetime measurement for the 5/2^{+} and 3/2^{+} states of $^{7}_{\Lambda}He \rightarrow {}^{7}Li + \pi^{-}$ case. N is the number of events.
Time resolution is 100ps.

Timing Resolution and Statistics of Lifetime Measurement

Ideal Timing Technique : timing resolution $\sigma_t = 0$

$$\sigma_\tau / \tau = 1/\sqrt{N} = 5\%$$

for N=400 events

Timing Technique with finite time resolution σ_t

MC simulations resulted:

$$\sigma_\tau / \tau \approx (\tau^2 + \sigma_t^2)^{1/2} / (\tau \times \sqrt{N})$$

For $\sigma_t = 200\,ps$ and $\tau = 20\,ps$

$$\sigma_\tau / \tau = 5\%$$

for N=40000 events

Regular Timing Technique for lifetimes $\tau \geq 10^{-10} s$

Timing Technique with RFPMT for lifetimes $\tau \geq 10^{-11} s$

Cherenkov TOF Detector with RFPMT at HπS

- Delayed pion spectroscopy → no kaon detection
- All useful virtual photon spectra is participated
- Rates is increased at least 100 times in comparison with HπS+HKS experiment
- Continuous calibration of HπS within accuracy better than 10^{-4} by TOF measurement of prompt pions and electrons
- Studies of hypernuclear states with lifetimes down to 10 ps

DREAM EXPERIMENT

2 GeV 500 MHz proton beam with similar bunch time structure and intensity will additional increase rates more than 10^4 times

Experiments at MAX-lab

- Photo-fission of heavy actinide nuclei at MAX-lab;
- Photo-fission studies of nuclei by virtual photon tagging at MAX-lab;
- Helium photodisintegration near threshold;
- Carbon photodisintegration into three alpha particles;

MAX-lab→MAX-IV   3GeV electron beam

New generation synchrotron radiation center

The European Spallation Source -ESS

Nuclear Medicine

Single photon imaging

RF PMT - new possibilities in time-domain single photon imaging

- FLIM - fluorescence lifetime imaging
- FRET - Foster resonance energy transfer
- STED - Stimulated Emission Depletion super resolution microscope
- DOI - diffuse optical imaging
- TOF-PET

FLIM is a unique and versatile tool to be used by scientists working at the multi-disciplinary interface of biology, chemistry, physics and engineering. Borst&Visser-2010