Ա. Ի. ԱԼԻԽԱՆՅԱՆԻ ԱՆՎԱՆ ԱԶԳԱՅԻՆ ԳԻՏԱԿԱՆ ԼԱԲՈՐԱՏՈՐԻԱ
(ԵՐԵՎԱՆԻ ՖԻԶԻԿԱՅԻ ԻՆՍՏԻՏՈՒՏ)

Խաչատրյան Վաչիկ Հրաչյայի

ԹԹՎԱԾՆԱՅԻՆ ԱԿՏԻՎ ԹԻՐԱԽ ՑԱԾՐ ԷՆԵՐԳԻԱԿԱՆ ՄԻՋՈՒԿԱՅԻՆ ՌԵԱԿՑԻԱՆԵՐԻ ՈՒՍՈՒՄՆԱՍԻՐՈՒԹՅԱՆ ՀԱՄԱՐ

Ա.04.16 - «Միջուկի, տարրական մասնիկների և տիեզերական ճառագայթների ֆիզիկա» մասնագիտությամբ ֆիզիկամաթեմատիկական գիտությունների թեկնածուի գիտական աստիճանի հայցման ատենախոսության

ՍԵՂՄԱԳԻՐ

ԵՐԵՎԱՆ – 2019

A. I. ALIKHANYAN NATIONAL SCIENCE LABORATORY
(YEREVAN PHYSICS INSTITUTE)

Vachik Khachatryan

AN OXYGEN ACTIVE TARGET FOR LOW ENERGY NUCLEAR REACTION STUDIES

SYNOPSYS

of Dissertation in 01.04.16 - nuclear, elementary particles, and cosmic ray physics presented for the degree of candidate of physical and mathematical sciences

YEREVAN-2019

Ատենախոսության թեման հաստատվել է Ա. Ալիխանյանի անվան Ազգային Գիտական Լաբորատորիայի (ԵրՖԻ) գիտական խորհրդում:

Գիտական ղեկավար՝
Ֆիզ.-մաթ. գիտ. թեկնածու Ամուր Մարգարյան (ԱԱԳԼ)

Պաշտոնական ընդդիմախոսներ՝

Ֆիզ.-մաթ գիտ. դոկտոր Ա.Դանագուլյան (ԵՊՀ)
Ֆիզ.-մաթ գիտ. թեկնածու Հ.Գուլքանյան (ԱԱԳԼ)

Առաջատար կազմակերպություն՝ Երևանի Պետական Համալսարան (ԵՊՀ):
Պաշտպանությունը կայանալու է 2019 թ հուլիսի 2 ին ժամը 16 ին, ԱԱԳԼ-ում գործող ԲՈՀ-ի «Ֆիզիկայի» 024 մասնագիտական խորհրդում (Երևան - 0036, Ալիխանյան եղբայրների փ. 2):
Ատենախոսությանը կարելի է ծանոթանալ ԱԱԳԼ-ի գրադարանում:
Սեղմագիրն առաքված է 2019 թ. մայիսի 22-ին:
Մասնագիտական խորհրդի գիտական քարտուղար՝

Ֆիզ.-մաթ գիտ. դոկտոր Հ. Մարուկյան

The subject of the dissertation is approved by the scientific council of the A. Alikhanyan National Science Laboratory (YerPhI)

Scientific advisor:
Candidate of ph-math sciences Amur Margaryan (AANL).

Official opponents:
Doctor of ph-math sciences A.Danagulyan (YSU)
Candidate of ph-math sciences H.Gulkanyan (AANL)

Defense takes place on 2nd of July 2019 at 16:00 on the meeting of the special council of the Higher Attestation Commission of RA 024 ”Physics”, acting in A.Alikhanyan National Science Laboratory (Yerevan-0036, St. Alikhanyan Brothers 2).
The dissertation can be found at the AANL library.
The synopsis is sent out on 22th of May 2019.
Scientific secretary of the special council:
Doctor of ph-math sciences H. Marukyan

Physics motivation

Thermonuclear burning in stars is responsible for the synthesis of most chemical elements heavier than helium in the universe. The $^4He(\alpha\alpha, \gamma)^{12}C$ and $^{12}C(\alpha, \gamma)^{16}O$ reactions are two of the most important fusion processes in astrophysics. These reactions essentially govern the helium burning phase, and their rates determine the ratio of ^{12}C:^{16}O (C/O) in the "ashes" of the helium burning process. Consequently, these reactions strongly influence the subsequent nucleosynthesis processes for massive stars and their final nucleosynthesis yields. Stellar evolution models in which nuclear reaction networks are implemented in detail do not yield consistent results yet, and the $^{12}C(\alpha, \gamma)^{16}O$ cross-section is one of the most important nuclear physics uncertainties still to be resolved.

The Hoyle state, the 0_2^+ state at excitation energy (E_x) 7.654 MeV in ^{12}C, is considered archetypal of a state that exhibits α-particle structure, with one possible configuration being a 3-α gas-like structure similar to a Bose-Einstein condensate, consisting of three α particles all occupying the lowest 0S state. It is expected that equivalent Hoyle-like states should also exist in heavier α-conjugate nuclei such as ^{16}O and ^{20}Ne. A measurement of the $^{12}C(^4He,^8Be)^8Be$ excitation function indicated that a series of 2^+ to 6^+ resonances were populated in the E_x = 16–21 MeV energy range.

The photodisintegration of ^{16}O at ~8.0 MeV produces ^4He and ^{12}C with energies about 675 and 225 keV, respectively, flying back-to-back, which aids the positive identification of this channel. The detection of such low-energy nuclear fragments are challenging, so the main problem we tried to solve during this dissertation is to come up with a new detector system called Low-Pressure Multi-Wire Proportional Chamber (LPMWPC) active target to register low-energy, highly-ionizing particles.

Aim of the dissertation

The dissertation is devoted to the development and testing of an oxygen-active target for low energy nuclear reaction studies. It is a position and time-sensitive detector system based on the low-pressure MWPC technique and Si detectors. The few Torr pressure of methylal ($(OCH_3)_2CH_2$) serves as working gas for the MWPC operation, and in addition, the oxygen atoms of the methylal molecules serve as an experimental target. The main advantage of this new target-detector system is a high sensitivity to the low-energy, highly ionizing particles, produced after photodisintegration of ^{16}O, and insensitivity to γ-rays and minimum ionizing particles, thus allowing us to detect only the products of the nuclear reaction of interest. The threshold energy for the detection of α particles and ^{12}C nuclei are about 50 keV and 100 keV, respectively. Timing and position resolution of low-pressure MWPC modules were investigated using an α-particle source and fission fragments in laboratory conditions, as well as, using bremsstrahlung photon beam from 20 MeV electron beam.
The aim was to:

- Design and develop LPMWPC capable of registering low-energy highly-ionizing particle, and simultaneously be insensitive for minimum-ionizing high energy particles and gamma-rays.
- Test in the laboratory conditions, find optimal parameters for the detector to obtain acceptable timing and position resolution to investigate reactions which are important for nuclear astrophysics.
- Proof that the detector system is capable of operating in high-intensity beams.
- Implement new methods for signal registration, data collection, and analysis.

- Measure the ionization loses of alpha particles in the methylal gas.

Practical value

The developed active target detector system is proposed to use to:

- Study of the cluster states in ^{16}O using proton beams from the Yerevan proton cyclotron and laser Compton backscattered photon beams at the ELI-NP facility.
- Measure the $^{16}O(\gamma,\alpha)^{12}C$ cross section at HIγS (High-Intensity Gamma-Ray Source) with a Low-Pressure MWPC based Active Target.
- Study of the decay pion spectroscopy of light hypernuclei at electron and proton-beam facilities, using the recoil distance technique for separation of produced hypernuclei and a magnetic spectrometer for precise measurement of the decay pion momentum.
- Measure the ionization energy losses of low-energy alpha particles for different gases.

The novelty of the results

The main parameters of LPMWPC are:

- High rate capabilities (few. MHz)
- Low registration efficiency ($<10^{-4}$ for single MWPC unit) against the minimum ionizing particles
- Good time resolution ~450 psec
- Good coordinate resolution ~1mm
- High registration efficiency (~100%) for low-energy nuclear fragments
- Minor effect on the fragment energy (fragment moves approximately with a constant speed inside the detector)

There are currently two experimental approaches under consideration for measurement of the inverse $^{16}O(\gamma, \alpha)^{12}C$ reaction, which is more accessible than the direct $^{12}C(\alpha, \gamma)^{16}O$ reaction. One is based on the bubble chamber technique and a bremsstrahlung photon beam; the other employs an Optical Time Projection Chamber (O-TPC) and a Laser Compton Backscattered (LCB) γ-ray beam. Both methods are very sensitive to the background.

The proposed method is based on two technologies: an active target based on low-pressure MWPCs, and a gamma-ray beam from backscattering of laser photons from several hundred MeV electrons. The latter produces an intense monochromatic gamma-ray beam with small angular divergence ($<2 \times 10^{-4}$ rad). Methylal ($(OCH_3)_2CH_2$) and hexane (C_6H_{14}), at a pressure of a few Torr, serve as the filling gases for the operation of the MWPCs. Operation with hexane is intended for evaluation of the background from carbon nuclei in methylal. The proposed active-target system employs a gas pressure of 3–9 Torr to detect low-energy nuclear fragments and determine their trajectories and velocities. The low pressure renders it very insensitive to minimum ionizing particles and γ-rays, but the disadvantage of this is low luminosity due to the small density of the target. Laser backscattering delivers a highly-directed, pencil-like photon beam so that this drawback can be mitigated by using a multimodular active-target system with sufficient total length to provide the necessary luminosity for the experiment. For example, at ELI-NP, the angular divergence of the LCB γ-ray beam is expected to be less than 2×10^{-4} rad, which means that over a

10 m distance the transverse size of the beam will increase by only 2 mm. Therefore, the active-target system could, in principle, consist of a stack of some hundreds of modules with a total length equal to 10 m.

Structure of the dissertation:

The dissertation consists of an introduction, five chapters, conclusion, and the table of content

Content

INTRODUCTION

In this section, a brief history of nuclear astrophysics is discussed. A process of the synthesis and evolution of chemical elements is presented. We also discuss the mystery of Hoyle state, how it helped to solve the problem of Carbon production out of 3 Helium nuclei and how it is important for life as we know it. Moreover, we give a short review of various models that can explain the true nature of Hoyle excitation energy. Namely, the review of the first solely theoretical calculations of Hoyle state performed by E. Epelbaum using Lattice Monte Carlo simulation and Weinberg's approach - the quark-gluon theory - for nuclear interaction, was presented. Also, a short description of ongoing experiments is presented.

Nuclear reaction rates play a critical role in the understanding of stellar evolution and explosions. However, in many cases, nuclear reaction rates still carry large uncertainties due to the paucity of experimental data and incomplete theoretical understanding of the underlying reaction mechanisms. New experimental methods and techniques, combined with the development of new theoretical tools, have exposed fresh avenues to pursue nuclear reactions of significance for nucleosynthesis at, or near, the actual temperatures of stellar burning. Nuclear astrophysics has entered a period characterized by unprecedented demands for new information and for improved accuracy. This challenge is being driven by the quality and breadth of current observational data, a direct consequence of impressive advances in observational technology.

This thesis provides an overview of the most critical nuclear reactions for a number of nucleosynthesis environments and suggests some new methods to overcome the difficulties from an experimental point of view.

CHAPTER 1

In this chapter, we present the overall overview of gaseous detectors, proportional chambers and low-pressure Multi-Wire Proportional Chambers (MWPCs). The LPMWPC is a proportional counter with three electrodes (two cathodes and one anode) having parallel-plane symmetry. The operational mechanism of the LPMWPC combines the principles of a regular multiwire proportional chamber (MWPC) and a parallel-plate avalanche counter (PPAC). MWPCs that operate at normal gas is not suitable for time measuring, because their time resolutions are typically on the order of several tens of nanoseconds. This is due to the long drift time of electrons, released in the sensitive volume towards the sense wire, where amplification occurs. The first measurements at low pressure (P =3 Torr) have shown that a time resolution of about 2.5 ns (FWHM) could be reached with 5.5 MeV α-particles. This result was simply attributed to a faster drift time at higher reduced fields. Further investigations have clearly shown that the amplification mechanism at low pressure is entirely different.

The LPMWPC modules were designed, prepared and developed in AANL and Yerevan Telecommunication Research Institute. The detector module consists of two wired-cathode and three wired-anode plates stacked on top of each other. The electrodes are made of G10 (epoxy) with a thickness of 3 mm, which is also the plane spacing.

All planes have a wire spacing of 1mm. The anode plane used 20 μm diameter gold-plated tungsten wire, while the cathode and guard planes used 40 μm diameter copper-beryllium wires (the schematic view is in Fig.2).

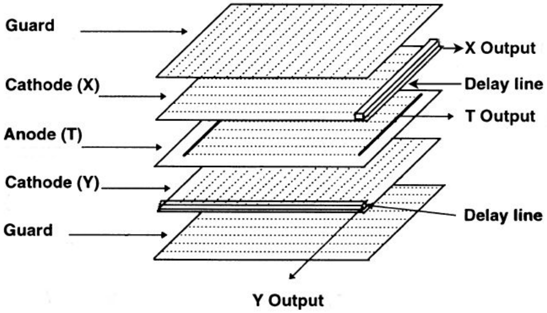

Fig. 2: Schematic diagram of the single unit of MWPC.

Groups of three cathode wires are connected to tapped delay lines (2 ns/tap) to provide position information using the method of time difference. This readout provides ~1 mm position resolution. Tap by tap readout would allow position reconstruction with sub 100μm precision. However, we used the time difference between the anode pulse and induced cathode pulse propagating towards the end of a delay line because ~1 mm resolution satisfies the requirements of the planned experiments.

The positive signals induced on the cathodes are used for the position (x, y) read-out, one coordinate from each plane. The two outer wire planes function as guard planes against electrons from ionization taking place outside of the chamber region, and as additional electrodes to provide double step amplification.

A test experimental setup was developed in order to investigate the operational modes of the LPMWPC units and to measure the timing and position characteristics using a 0.14 mg/cm^2 thick, 30×30 mm^2 Pu-239 α-particle source, which has three lines: 11% - 5.099, 20% - 5.137 and 69% - 5.150 MeV. It consists of two MWPC1 and MWPC2 units, mounted at 5.5 cm distance from each other. Mylar absorbers with a 1 mm diameter hole in the center were used to collimate the α particles(see Fig. 3). Using this setup the time and position resolutions and dE/dx distributions in the MWPCs were studied. The geometry of the test setup is shown in Fig. 3.

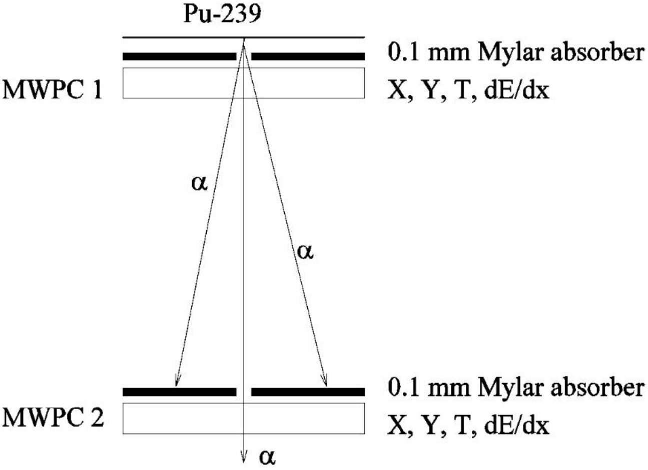

Fig.3. Schematic representation of the test setup.

The MWPCs and SSDs are mounted in a rectangular vacuum chamber, which has windows for beam entrance and exit. Lemo connectors, fastened on the walls of the vacuum chamber, provide access to electronics outside the vacuum chamber. The chamber can operate from 2-10 Torr of methylal vapor. For amplification of the resulting signals with a high ratio of the signal by the noise four types of high-frequency transimpedance amplifiers with different magnification, factors have been designed and manufactured. To ensure a wide spectrum of frequencies, the "Texas Instruments" high-band and super-low noise operational amplifier chips were used. In addition, these amplifiers differ in input and output signals.

CHAPTER 2

Chapter 2 is devoted to the testing of experimental technique in the lab and beam conditions.

The low-pressure MWPC system can operate in the so-called single-step and double-step model. In the case of single step the typical potentials applied to the anode, cathode, and guard planes are U_a = +400, U_c = -100 and U_g = 0 V respectively and the resulting signals from the α-particles have a few 10's of mV amplitudes. In the case of a double step, the typical potentials are U_a = +300, U_c = 0 and U_g = -300 V respectively and amplitudes of the resulting signals increased by an order of magnitude, compared to the single-step case. The typical signals from anode and cathode planes generated by α-particles in MWPC1 (double-step operational mode) and registered by 500 MHz oscilloscope. The diagram of the signal readout and data acquisition electronics is shown in Fig. 4.

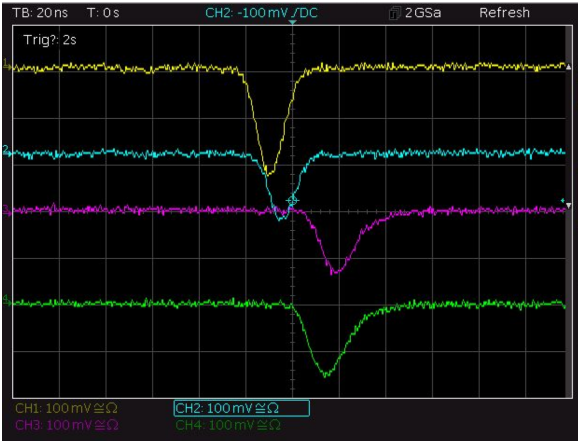

Fig 4. Typical signals from anode and cathode planes after amplification for operating conditions: Methylal 3.3 Torr, +300 V on the anode, 0 V on the cathodes and -300 V on the guard planes. Trace 1 (yellow), 2 (cyan): signals from anode planes of the top and bottom MWPC units. Trace 3 (magenta), 4 (green): signals from two cathode planes of the top MWPC unit. The time scale is 20 ns/division and an amplitude scale of 100 mV/division.

The signals are connected to the Analog to Digital Converters (ADC) and Time to Digital Converters(TDC). Two start signals, Start1 and Start2 are formed by using coincidences of anode signals from MWPC1 and MWPC2, where the timing of the Start1 and Start2 signals is determined by the MWPC1 and MWPC2 anode signals, respectively. These start signals are used for measuring the time difference between the two anode planes (time-of-flight (TOF) timing resolution) and between the anode and corresponding cathode planes (position measurement resolution) of the MWPC1 and MWPC2 units. A copy of the Start1 signal is also used to generate an ADC Gate signal for digitizing of both anode signals. From the TDC data, the time difference distribution of the particle flying from one module to another is being reconstructed. This can be normalized to build the velocity spectrum of particle. In the other hand, the signals from ADC can be used to reconstruct the energy losses left by the particle in the detector's volume(dE/dx). A LabView software has been written to read and write the data into files for later analysis and simultaneously recreates the histogram of all channels.

For the data analysis, the ROOT package with C++ language and Python analytics tools have been used. In Fig. 6 the TOF distribution is shown. From this distribution, we can determine the time resolution of the MWPC units, which is equal to $638/2^{1/2} \approx 450$ ps.

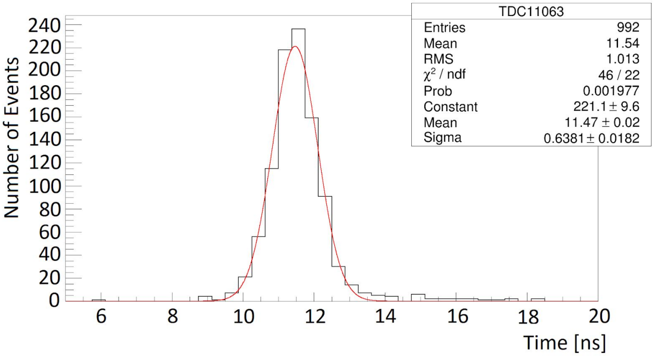

Fig. 6. Time difference between signals from the anode planes of MWPC1 and MWPC2.

In Fig. 7 the time-difference spectrum between the anode and one cathode plane of MWPC1 is presented. The sigma of this distribution is about 1 ns, which results in a 1.5 mm position resolution.

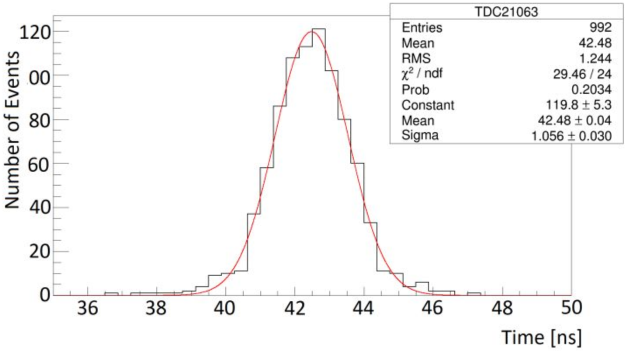

Fig. 7. Time difference between the anode and one cathode plane of MWPC1.

The typical measured spectrum of amplitudes of the MWPC1 anode signals, which are proportional to the ionization energy losses dE/dx of charged particles, is presented in Fig. 8.

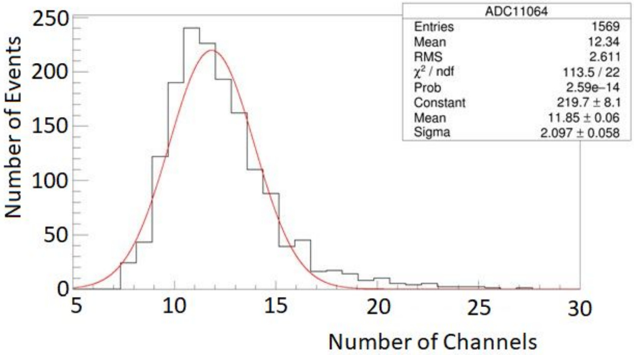

Fig. 8. Distribution of the amplitudes of MWPC1 anode signals.

The time resolution of the MWPC unit, as a function of methylal vapor pressure was constructed. It shows that a pressure range of 2-3 Torr is optimal for the best time resolution.

We also test LPMWPC and four types of amplifiers using bremsstrahlung photon beam from c MeV Electron beam. This is a proof of concept experiment that the MWPC modules can operate with gamma beam, producing high enough signals distinguishable from large background. The test detector is schematically depicted in Fig. 9. It mainly consists of 2 MWPC chambers which are placed in the vacuum chamber.

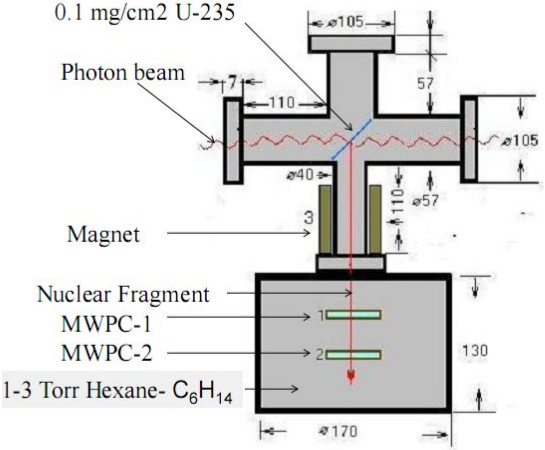

Fig 9. The schematic view of the detector.

The interaction of the 50 Hz, 1 msec, 40 nA electron beam with the radiator having 0.01 radiation length creates a photonic beam. The signals produced from the fission fragments and the beam "halo" that are produced when the photon beam interacts with the U-235 foil and hexane vapor molecules inside the detector are registered via digital scope are depicted in Fig. 10, 11. The following two important conclusions can be drawn from this picture. First, the LPMWPC have over 1 MHz rate capability.

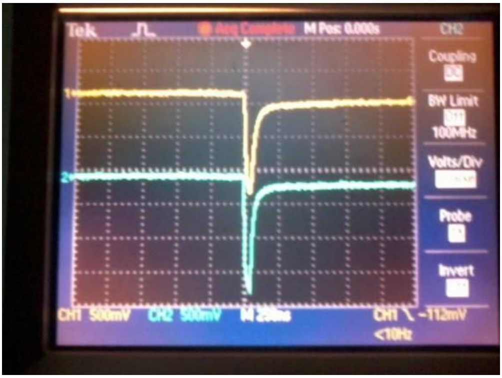

Fig. 10. The typical signals of fission fragments produced from the interaction of the photon beam and ^{235}U

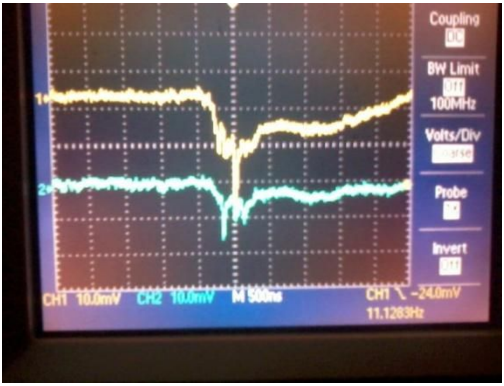

Fig. 11 The typical signals of alpha particles produced from the interaction of the photon beam with hexane vapor.

Secondly, with the CW beam, they can operate in about 10,000 times more intense photon beams. It opens up new possibilities for performing experiments of astrophysical interest in low energy domains, such as the study of the photodisintegration of the oxygen into an alpha particle and carbon nuclei reaction.

CHAPTER 3

In this chapter, we consider the application of the active ^{16}O target for The possibility of measuring the $^{16}O(\gamma, \alpha)^{12}C$ cross-section in the 8–10 MeV energy region by using a LCB γ-ray beam.

We are planning to measure the inverse reaction because it is about ~60 times more than direct reaction. The photodisintegration of ^{16}O at 8.0 MeV produces ^{4}He and ^{12}C with energies 675 and 225 keV, respectively, flying back-to-back, which aids the positive identification of this channel.

A schematic drawing of the prototype, active-target module is shown in Fig 12 left. It consists of four low-pressure chamber units (1, 2, 3 and 4), which form two symmetric arms. The MWPC units are windowless in order to present the minimum amount of material to the incident, low-energy nuclear fragments. The geometrical acceptance of the active target depends on the L1, L2 and L3 dimensions, where the optimal sizes will be determined in future Monte Carlo and experimental studies. In the present study, we used prototype MWPC units with an active area of 30 × 30 mm^2.

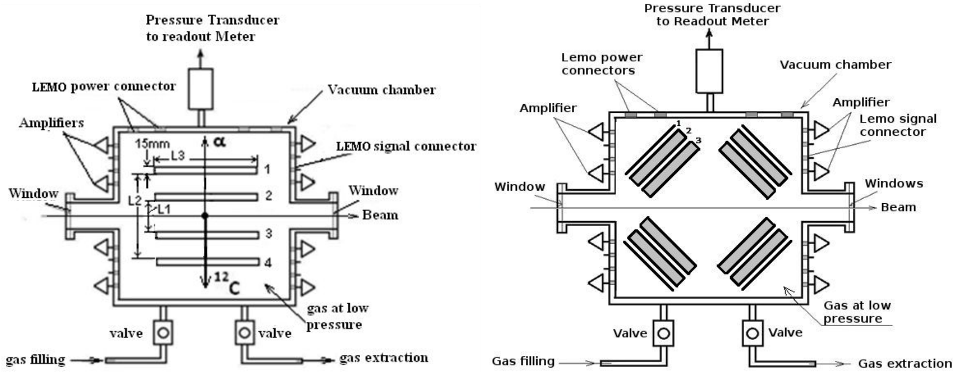

Fig. 12. Schematic of the active target: Multi Wire Proportional Chamber (MWPC) units 1, 2, 3, 4.

The methylal gas serves as an ionization medium for MWPC operation, and in addition, the oxygen atoms of the methylal molecules serve as an experimental ^{16}O target. The number of oxygen atoms in the target is about $N_O = 6*10^{17}$ atoms/cm^2.

The other possible implication of active target is to investigate the Hoyle states at ^{16}O in the 15–20 MeV energy range, excited with the help of the proton and monochromatic polarized photon beam.

The Hoyle state in ^{16}O is expected at 15.1 MeV. This state decays mainly through the following two channels:

1) $^{16}O(15.1\ MeV) \text{->} \alpha + {}^{12}C(0_1^+)$
2) $^{16}O(15.1\ MeV) \text{->} \alpha + {}^{12}C(2_1^+) \text{->} \alpha + {}^{12}C(0_1^+) + \gamma$

The neighboring 2^+ resonance has a decay channel $^{16}O(2^+) \text{->} p + {}^{15}N(1/2^-)$. Detecting decay protons, α-particles, ^{12}C and ^{15}N nuclei from resonance states at *Ex* ≈ 15 MeV, produced by means of different type incident particles (proton, photon, etc.), requires a high resolution and large-acceptance experimental setup. This is crucial for identifying the Hoyle like state in ^{16}O and studying its structure. The resonance states in ^{16}O at Ex ~ 15 MeV cannot decay strongly into the 4α channel. There are, however, a number of resonances at 16-21 MeV energy range that decay to the ^{8}Be+^{8}Be or ^{12}C(Hoyle)+alpha final-states. It is worthy to mention that even experimental study the decay of the 15.1 MeV state into two ^{8}Be's (i.e. into four low-energy α-particles) may be a very rewarding subject in order to elucidate further it's α cluster structure. For this experiment we suggest slight modification of active target detector that consists of eight modules of MWPC to register each alpha particle out of four, in different pair of modules(Fig. 12 right)

Using a multi-module active-target system consisting of some hundreds of modules, the number of oxygen atoms can be increased by over two orders of magnitude.
To be detected, low-energy decay particles require enough energy to pass through the module, i.e., they are required to have a range of at least 5.5 cm to generate signals in both MWPC units. The ranges for He and C ions in methylal, simulated by means of the SRIM are displayed in Fig. 13, it can be seen that an active-target detector system filled with 3 Torr methylal is capable of detecting alpha particles with energies above 50 keV and ^{12}C nuclei with energies higher than 100 keV.

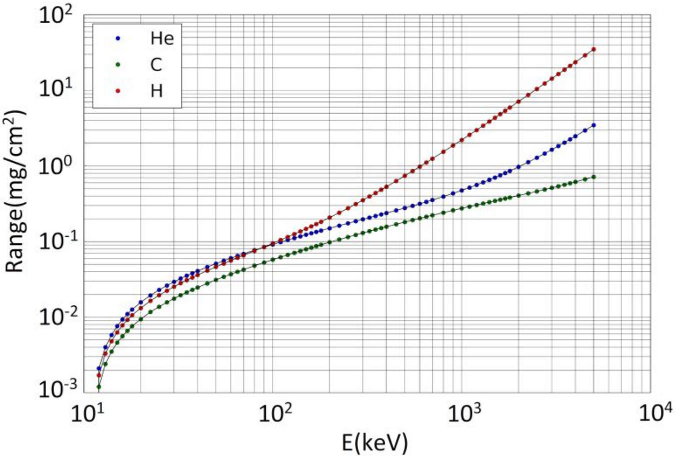

Fig. 13. The ranges of H(line 1), He(line 2), C(line 3), ions in methylal vs energy.

We also propose to carry out an exploratory experiment at HiγS starting with a check on the in-beam background conditions for the ^{16}O(γ,α)^{12}C reaction at photon energy around 8 MeV, where the reaction cross section is very small. This will be followed by a measurement of this reaction cross section at photon energy around 9.5 MeV, where the cross section is ~10^{4} larger and then a measurement of the ^{12}C(γ, 3α) reaction cross section in the energy region 9.5-15.5 MeV. These exploratory measurements will be carried out using an experimental setup based on the prototype chamber, which is similar to that displayed in Fig. 12, but with a converter (C) and target (T) added. The converter will be used to produce electron-positron pairs, mimicking the type of background conditions which are expected for the real experiment. The target will be a 1 μm thick Mylar (Polyethylene terephthalate: $(C_{10}H_8O_4)_n$) or Polyethylene $(C_2H_4)_n$ film angled at ~20 deg, with respect to the beam direction, which increases the effective thickness presented to the beam by a factor ~3.

CHAPTER 4

In this section we discuss the application of MWPC in decay pion spectroscopy of light hypernuclei at electron-and proton-beam facilities, using the recoil distance technique for separation of produced hypernuclei and a magnetic spectrometer for precise measurement of the decay pion momentum. By using the present proposed approach the rate of the detected hypernuclei can be increased by one-to-two orders of magnitude compared to recent experiments carried out at the MAMI electron accelerator in Mainz. The possibility of realizing a high luminosity decay pion spectroscopy experiment with proton beams is also discussed.

Here, we propose a new experiment for decay pion spectroscopy of light hypernuclei, which would be suitable both for electron- and proton-beam facilities. Identification of produced hypernuclei is realized by detecting the low-energy recoils and using the recoil distance technique. The general layout of the experimental setup is shown in Fig. 14. The incident electron (or proton) beam hits the 2 mg/cm^2 target and produces a hyperfragment, which exits the target and decays after ~ 200 ps outside the target, resulting in a decay pion and recoil nucleus. The flight distance from the primary interaction point is estimated to be ~ 1 mm. Decay pions are detected in the high-resolution magnetic spectrometer - $H\pi S$ located at ~90 degrees. In this case, the hyperfragment decays outside of the target, and as a result, the monochromatic spectrum of produced pions is broadened by kinematics. The recoil nucleus is detected by means of the recoil detector, which is located at the opposite side of the beam to the $H\pi S$.

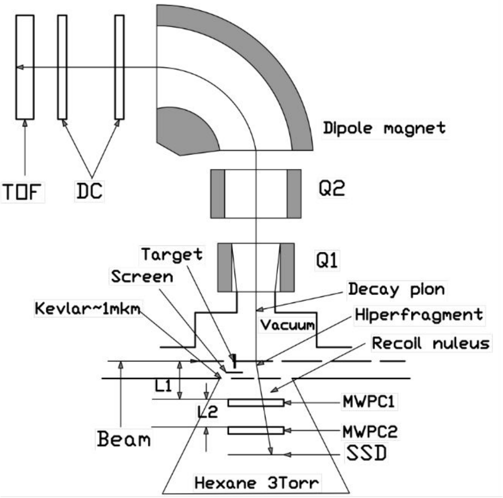

Fig 14. Schematic view of the proposed experiment consisting of the high-resolution pion spectrometer ($H\pi S$) and the low-energy recoil detector for detection of the recoiling nuclei in coincidence with the decayed pions.

The target is a thin foil of thickness ~2mg/cm^2 so that most produced hyperfragments exit and decay outside of the target. The RD is screened from the central beam- on-target region, to enhance the signal for hyperfragments produced outside of the target and separated from the accelerator vacuum by a 1-2 μm Mylar or Kevlar foil. In Fig. 14 the recoiling nuclei are detected by MWPC1, MWPC2, and the SSD, while decay π^- mesons are detected by the magnetic spectrometer HπS. In principle, the RD can operate without an SSD. In that case, the energy of the recoiling nucleus would be determined by its velocity with its type determined from the decay pion momentum.

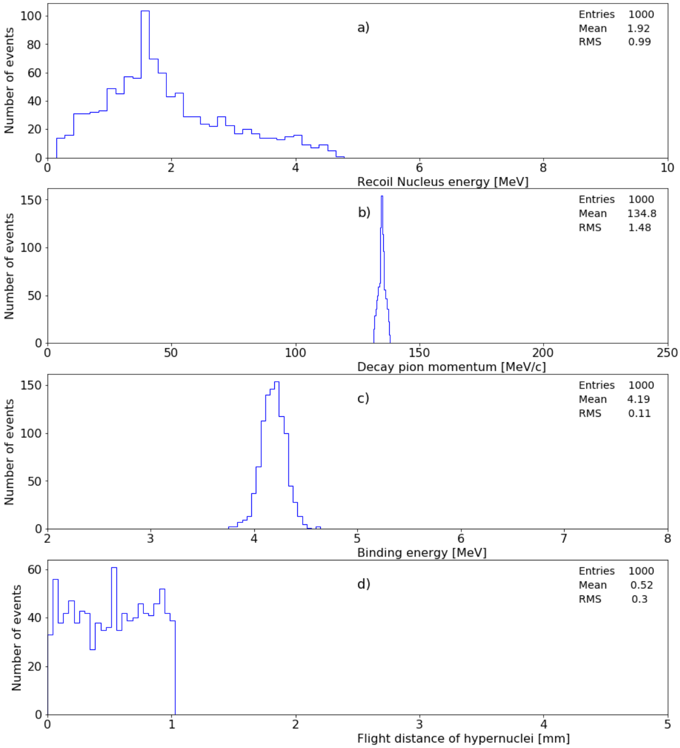

Fig. 15. Simulated distributions for ${}^{6}_{\Lambda}H$ decay into a pion and ${}^{6}He$ nuclei: energy of ${}^{6}He$ (a), decay pion momentum (b), binding energy (c), and flight distance of ${}^{6}_{\Lambda}H$ hypernuclide (d).

The Monte Carlo simulation has been conducted to simulate the experiment. For the decays, we assume the Λ binding energy for Λ6H to be 4.18 MeV which is the Λ binding energy of the hypernucleus. The resulting distributions are shown in Fig. 15.

For experiments with electron beams, a simple analysis estimates that the expected yields of detected hyperfragments will be one-to-two orders of magnitude higher than was observed in previous experiments carried out at MAMI. Two-body π^- decay spectroscopy of $\Lambda 3H$ and $\Lambda 4H$ hyperfragments using an RF structured electron beam and RF PMT based time-of-flight detectors will provide ultra-precise values of the binding energies of Λ-particles to $\Lambda 3H$ and $\Lambda 4H$ hyperfragments. These can be used to check theoretical predictions and as a reference for other hyperfragments. Experiments with proton beams will have a very high yield compared to electron experiments. They can be used to extend the study of light hypernuclei to the exotic $\Lambda 2n$ and $\Lambda 3n$ hypernuclei and to the heavy hyperhydrogens $\Lambda 6H$ and $\Lambda 8H$. In all cases, for a realistic estimation of expected hyperfragment yields, test studies are needed to determine the maximum intensity of the incident electron/photon or proton beams at which the recoil detector will operate smoothly.

CHAPTER 5

In this section, we present the measurements of ionization energy losses of alpha particles in Methylal gas and compared with the Stopping and Range of Ions in Matter SRIM-2013 simulation. The alpha particle energy losses have been experimentally determined for ^{239}Pu α-particle source using a dedicated experimental setup based on low-pressure multi-wire proportional chambers(LPMWPC); such losses are observed to deviate significantly from the calculated ones. The deviations suggested that in the low (≤ 1 MeV) energy region the stopping powers given by SRIM-2013 might be overestimated of about 5-10%. The geometry of the setup is shown in Fig. 16.

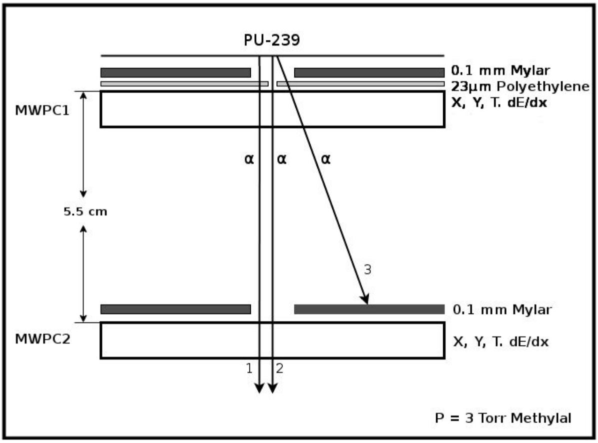

Fig. 16. The schematic view of the experimental setup. 1- alphas that pass through 23 μm Polyethylene and 5.5 cm 3 Torr Methylal, 2 - alphas that pass through Methylal, 3 - alphas that are absorbed.

The distribution of the TOF was divided into small chunks and for each chunk, ADC distribution was generated. The mean of the ADC distribution was picked. Consequently for every energy the *dE/dx* was determined and calibrated to match the energy loss value corresponding to 5.15 MeV (Fig. 17).

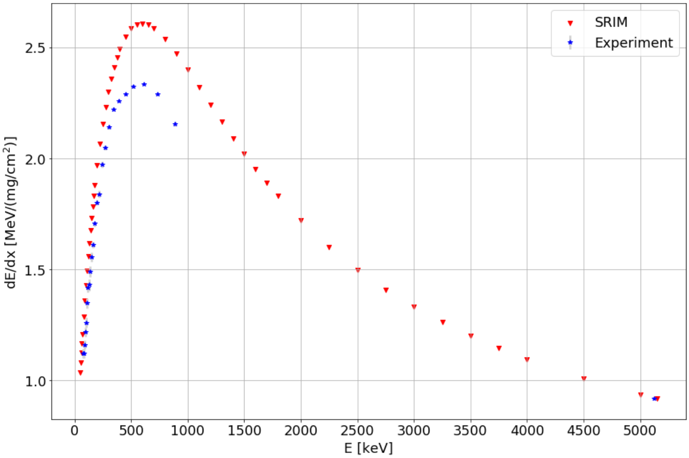

Fig 17. The energy loss of the alpha particles in methylal. Red-triangle is the SRIM data and the blue-star is the experimental data

The results of the experimental data show that the SRIM dataset in low energy regions has inaccuracy and shows about 5-10% more than those in the experiment. This means that alpha particles have higher ranges than it is estimated in SRIM dataset.

In **Conclusion,** the main results are discussed

Complete **Bibliography** is presented in the thesis.

Publication List

1. **Khachatryan, V.H.** Ionization Energy Losses of Low-Energy Alpha Particles in Methylal. Armenian Journal of Physics, v. 12 (1), 2019, pp. 124-130.
2. R. Ajvazyan, **V.Khachatryan** et al. Active Oxygen Target for Studies in Nuclear Astrophysics with Laser Compton Backscattered γ-ray Beams, MDPI particles, v. 1(1), 2018, pp. 126-137.
3. A. Margaryan, **V.Khachatryan** et al., Active target for α-particle condensation studies in 16O, J. Contemp. Phys., v. 54, no.2, 2019, pp. 117–125.
4. A. Margaryan, **V. Khachatryan** et al., Decay pion spectroscopy: a new approach, Nucl. Instrum. Methods A, v. 935, 2019, pp. 40-50.

Рузюме
Кислородная активная мишень для исследований низкоэнергетические ядерных реакций

Диссертация посвящена разработке и испытанию кислородно-активной мишени для исследований низкоэнергетических ядерных реакций. Это система детекторов, чувствительное к положению и времени частиц, которая основана на МПКНД (Мульти-проволочной Пропорциональной Камере Низкого Давления) и кремниевом детекторе. Рабочим газом для МПКНД служит метилаль ($(OCH_3)\ _2CH_2$) при давлении несколько торр, а атомы кислорода в молекуле метилаля служат в качестве экспериментальной мишени. Основным преимуществом этой новой системы мишени-детектора является высокая чувствительность к низкоэнергетическим сильно ионизирующим частицам, образующимся после фоторасщепления ^{16}O, и невосприимчивость к γ-лучам и слабо ионизирующим частицам, что позволяет регистрировать только продукты представляющей интерес ядерной реакции. Пороговые энергии обнаружения α-частиц и ядер ^{12}C составляют около 50 кэВ и 100 кэВ соответственно. Основные результаты которые мы получили для МПКНД:

- Высокая производительность и скорость (~ МГц)
- Низкая эффективность регистрации ($<10^{-6}$) фона гамма-лучей и релятивистских частиц
- Хорошее разрешение по времени ~ 450 пс
- Хорошее координатное разрешение ~ 1 мм
- Высокая эффективность (~ 100%) для регистрации ядерных фрагментов
- Незначительное влияние на энергию фрагмента (фрагмент движется с постоянной скоростью внутри детектора)

В рамках диссертации была проведена следующая работа:

- Детектор был испытан в лабораторных условиях, были найдены оптимальные параметры (для получения оптимальное временное и координатное разрешение для исследования реакций, важных для ядерной астрофизики).
- Детекторная система также была проверена на ускорителе, доказывая что детекторная система способна работать в пучках высокой интенсивности и нечувствительна к низкоионизирующих частиц
- Были измерены ионизационные потери альфа-частиц в метилальном газе.
- Было исследовано кластерная состояние в ^{16}O с энергией 15,1 МэВ с использованием протонных пучков на Ереванском протонном циклотроне и лазерных комптоновских пучков обратного рассеяния на ELI-NP.
- Было предложено измерить поперечное сечение $^{16}O(\gamma,\ \alpha)^{12}C$ на HIγS (источник гамма-излучения высокой интенсивности).
- А также была предложено исследование спектроскопии распадающихся пионов легких гиперядер на электронных и протонных пучках с использованием метода расстояния отдачи для разделения образующихся гиперядер и магнитного спектрометра для точного измерения импульса распадающегося пиона.

- Новые методы были реализованы для регистрации сигналов, сбора и анализа данных.

Недостатком детектора является низкая светимость из-за малой плотности атомов-мишеней. Лазерное обратное рассеяние дает высоко направленный пучок фотонов, так что этот недостаток можно уменьшить, используя многомодульную систему с активной мишенью с достаточной общей длиной, чтобы обеспечить необходимую светимость для эксперимента..

Թթվածնային ակտիվ թիրախ ցածր էներգիական միջուկային ռեակցիաների ուսումնասիրության համար

Ամփոփում

Ատենախոսությունը նվիրված է ցածր էներգիայի միջուկային ռեակցիաների ուսումնասիրության համար պատրաստված թթվածնի ակտիվ թիրախի մշակմանը, փորձարկմանը և կիրառություններին: Ակտիվ թիրախը դետեկտորային համակարգ է, որը հնարավորություն է տալիս չափել անցնող մասնիկի կորդինատը եւ ժամանակի: Այն հիմնված է ՑՃԲՀԽ-ների (Ցածր Ճնշման Բազմալար Համեմատական Խցիկ) եւ սիլիկոնային դետեկտորի վրա: ՑՃԲՀԽ-ն համար որպես աշխատանքային գազ է ծառայում մեթիլալ $((OCH_3)_2CH_2)$ գազը, որը գտնվում է մի քանի Տորր ճնշման տակ, իսկ մեթիլալի մոլեկուլում գտնվող թթվածնի ատոմները ծառայում են որպես փորձարառական թիրախ: Այս նոր դետեկտոր-թիրախային համակարգի հիմնական առավելությունն այն է, որ այն կարող է գրանցել ցածր էներգիաների բարձր իոնիզացիա ունեցող մասնիկներին, որոնք առաջանալու են թթվածնի ֆոտոճեղքման ռեակցիայից: Այն նաև չափազանց անզգայուն է գամմա ճառագայթների և մինիմում իոնիզացնող մասնիկների նկատմամբ, որը թույլ կտա գրանցել անմիջապես միջուկային ռեակցիայի արգասիքները: α- մասնիկների եւ ^{12}C միջուկների գրանցման շեմային էներգիաները, համապատասխանաբար, կազմում են 50 կէՎ եւ 100 կէՎ: ՑՃԲՀԽ-ի համար ստացված հիմնական արդյունքներն են՝

- Բարձր արագագործություն (~ ՄՀց)
- Գամմա ճառագայթների եւ ռելատիվիստական մասնիկների ֆոնի նկատմամբ ցածր գրանցման էֆեկտիվություն $(<10^{-6})$
- Լավ ժամանակային լուծունակություն ~450 պկվ
- Լավ կոորդինատային լուծունակություն ~1 մմ
- Բարձր արդյունավետություն (~100%) միջուկային ֆրագմենտների գրանցման համար
- Փոքր ազդեցություն մասնիկի էներգիայի վրա (մասնիկը շարժվում է գրեթե անփոփոխ արագությամբ դետեկտորի ներսում)

Ատենախոսության ընթացքում կատարվել են հետեւյալ աշխատանքները՝

- Դետեկտորը փորձարկվել է լաբորատոր պայմաններում, գտնվել են օպտիմալ պարամետրերը (ժամանակ եւ կոորդինատի լուծունակության ընդունելի արժեքներ՝ միջուկային աստղաֆիզիկայում կարևոր ռեակցիաներ ուսումնասիրելու համար):

- Դետեկտոր-համակարգը նույնպես փորձարկվել է Երևանի Ֆիզիկայի Ինստիտուտում գտնվող ինժեկտորային արագացուցչի վրա՝ ապացուցելով, որ այն կարող է գործել բարձր ինտենսիվությամբ փնջի տակ: Ցույց է տրվել որ այն անզգայուն է փնջի ֆոնի մասնիկների նկատմամբ:
- Կիրառվել են նորագույն մեթոդներ տվյալների հավաքման և մշակման համար:
- Կատրավել է մեթիլային գազի մեջ ալֆա մասնիկների իոնացման կորուստների չափում:
- Առաջարկվել է ուսումնասիվել ^{16}O միջուկի կլաստերային վիճակերը 15.1 ՄէՎ էներգիական տիրույթում՝ օգտագործելով Երևանի պրոտոնային ցիկլտրոնի փունջը եւ ELI-NP-ի հետցրված լազերային կոմպտոնային փունջը:
- Առաջարկվել է չափել $^{16}O(\gamma, \alpha)^{12}C$ ռեակցիայի կտրվածքը HIγS- ում (բարձր ինտենսիվության գամմա ճառագային փունջ):
- Ինչպես նաև առաջրակվել է իրականացնել թեթև հիպերմիջուկների համար տրոհված պիոնների սպեկտրոսկոպիա, էլեկտրոնային և պրոտոնային փնջերի վրա՝ օգտագործելով հետցրված մասնիկների հեռավորության չափելու տեխնիկան՝ առաջացած հիպերմիջուկներին առանձնացելու համար, և մագնիսական սպեկտրոմետր՝ տրոհված պիոնի ճշգրիտ իմպուլսի որոշման համար:
- Կիրառվել են նորագույն մեթոդներ տվյալների հավաքման և մշակման համար:

Գրանցիչ համակարգի հիմնական թերությունը դա ցածր լուսատվությունն է՝ պայմանավորված թիրախաի ատոմների ցածր խտությամբ: Լազերային հետցրված փունջը տալիս է բարձր ուղղորդվածության ֆոտոնային փունջ, հետեւաբար, այս թերությունը կարող է կոմպենսացվել՝ օգտագործելով ակտիվ թիրախի բազմամոդուլար համակարգ բավարար ընդհանուր երկարությամբ՝ փորձի համար անհրաժեշտ լուսատվությունը ապահովելու համար: