Study of a New Liquid Scintillator Array for Neutron Scattering Cross Section Measurements at NCSR “Demokritos”

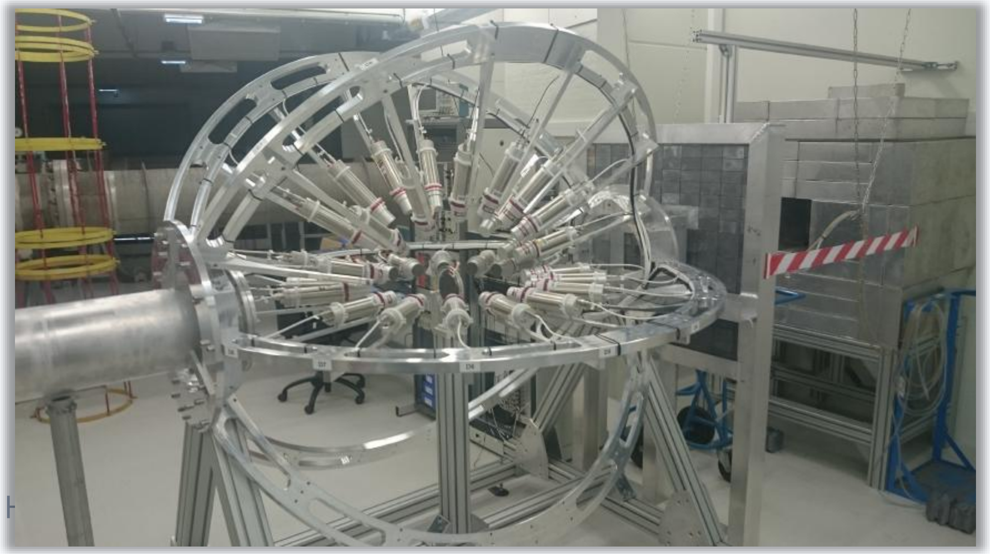
L. Amanatidis[1], T. Zafeiris[1], I. Mitropoulos[1], M. Diakaki[1], M. Kokkoris[1], V. Michalopoulou[1], K. Kaperoni[1], R. Vlastou[1], I. Tsormpatzoglou[1], A. Lagogiannis[2], M. Axiotis[2]

1) Department of Physics, National Technical University of Athens, 157 80 Athens, Greece

2) Tandem Accelerator Laboratory, Institute of Nuclear Physics, N.C.S.R. “Demokritos”, Aghia Paraskevi, 15310 Athens, Greece

Motivation

- Neutron elastic scattering cross-section data are fundamental in nuclear physics, with important applications in nuclear reactor technology, astrophysics, medicine and material science.
- Lack of experimental data in the neutron elastic scattering cross-section in medium mass nuclei
- A complementary setup to the ELISA at GELINA JRC, started to be developed at NCSR "Demokritos"



Experimental Challenges

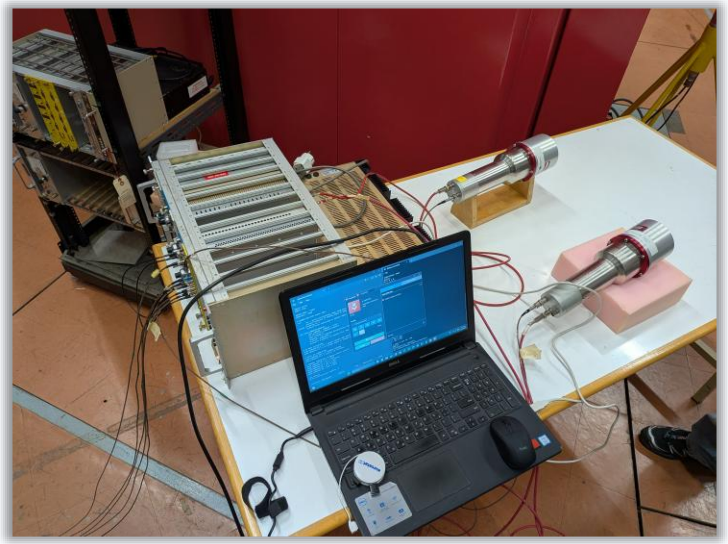
The experimental study of neutron elastic scattering presents four major challenges:

1. Detection through secondary particles.
2. The angular dependence of neutron scattering
3. High-purity and isotopically enriched samples are required
4. Background interference

Neutron Detection

In this work, four organic liquid scintillators were studied: one 2″x2″ BC501A detector and three brand new 3″x3″ EJ309 detectors.

These detectors are particularly suitable for neutron detection due to their excellent neutron–gamma discrimination capabilities.



Properties	BC501A	EJ309
Basic Solvent	C_8H_{10}	$C_{16}H_{20}$
Light Output, %Anthracene	78	80
Ratio H:C Atoms	1.212	1.25
Wavelength of Maximum Emission (nm)	425	424
No. of Electros per cc ($x10^{23}$)	2.87	3.17

Neutron detection

Neutron beam experiments always involve mixed fields (n-γ)

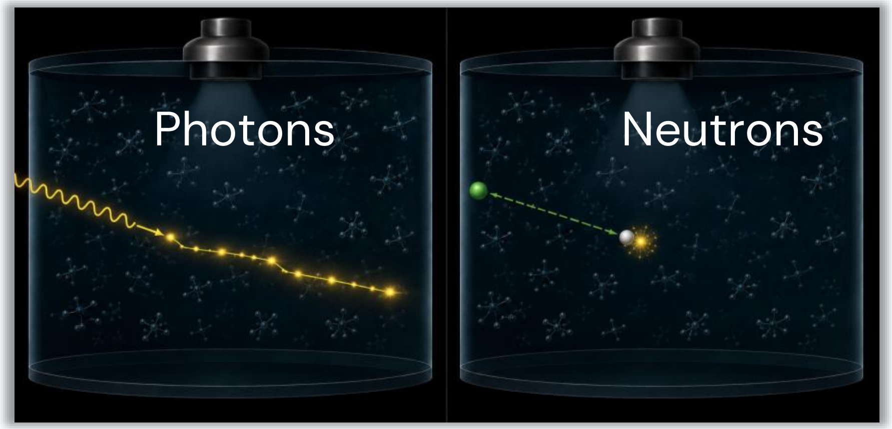
Liquid scintillators are sensitive to both gamma rays and neutron.

Gamma rays → Compton electron
Neutrons → proton + carbon recoils
} Create excited molecules

The excitation molecular energy released:

- Thermal quenching
- Fluorescent light emission near UV

(light output)



Neutron detection

Neutron beam experiments always involve mixed fields (n–γ)

Liquid scintillators are sensitive to both gar

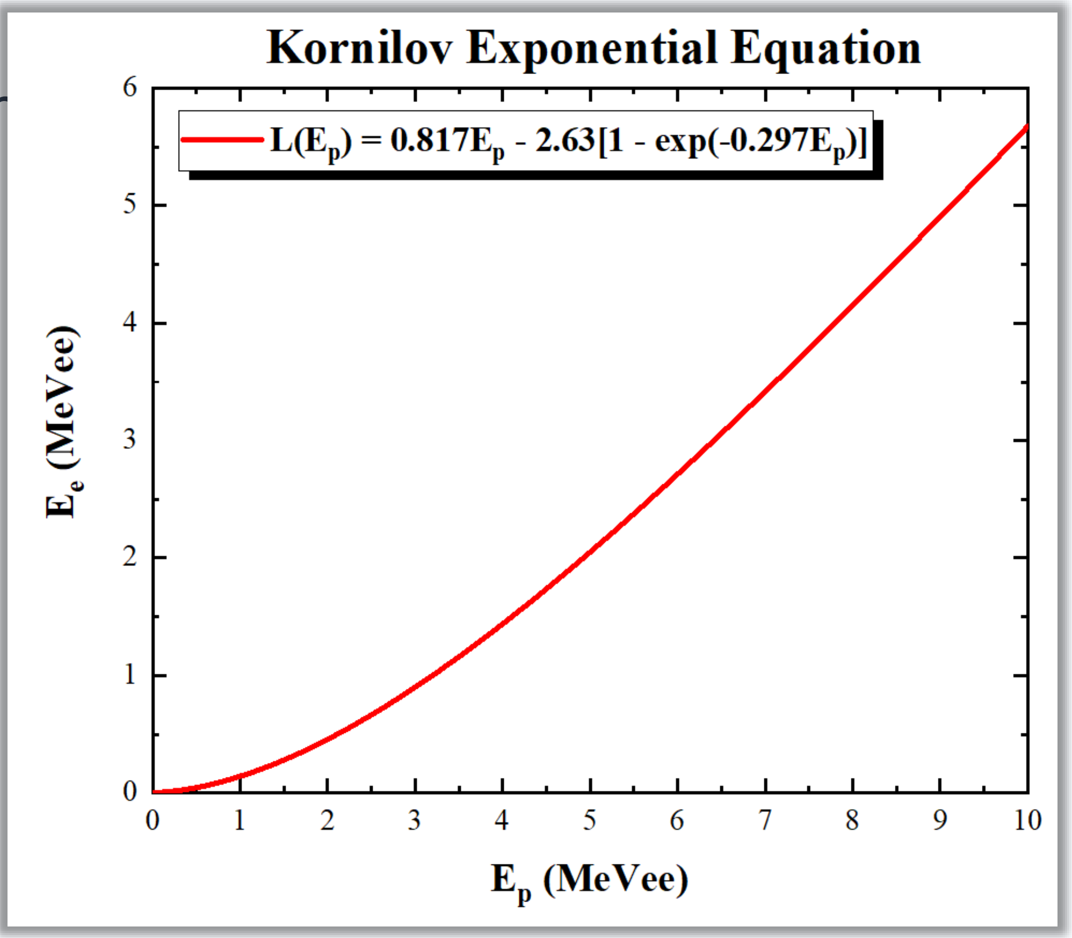
Gamma rays → Compton electron

Neutrons → proton + carbon recoils

The excitation molecular energy released:

- Thermal quenching
- Fluorescent light emission near UV

(light output)



Pulse Shape Analysis

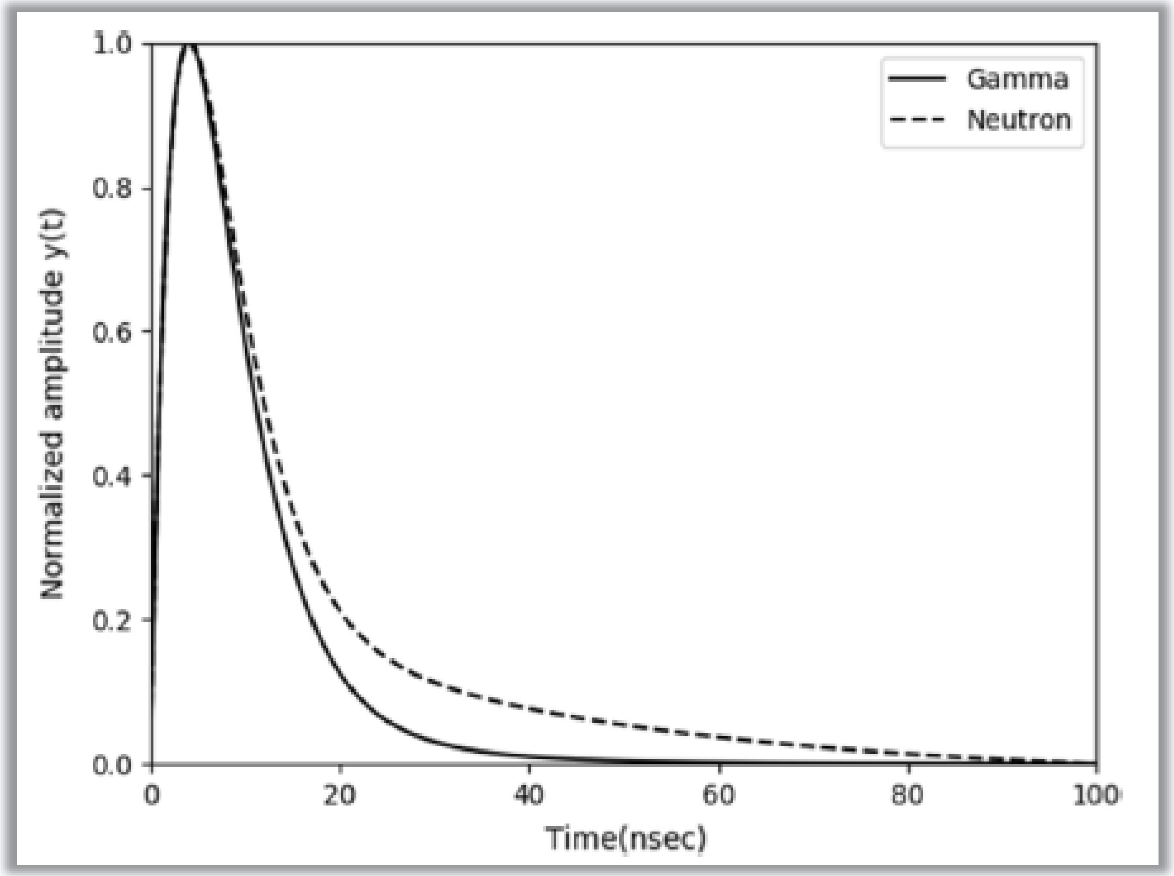
Light pulses:

- Fast rising time (few ns)
- Slow decay constant (20 – 200 ns)

Pulse shape analysis is used to discriminate this time difference and identify the particle

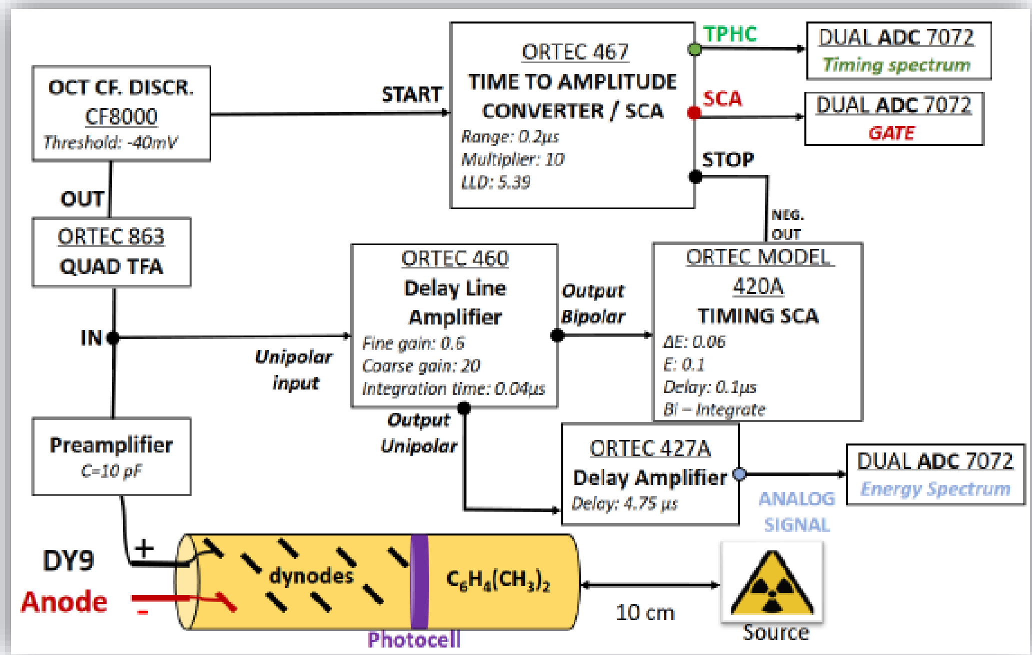
Two PSA techniques were investigated:

- Analog electronics circuit
- Semi – Analog Mesytec (MPD-4) unit

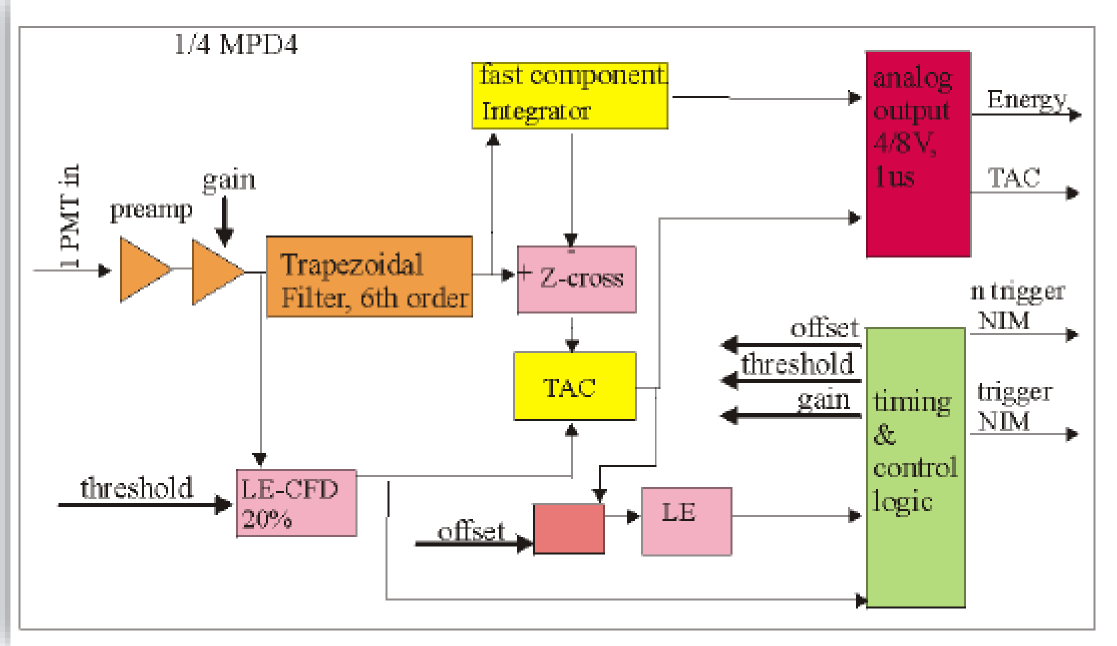


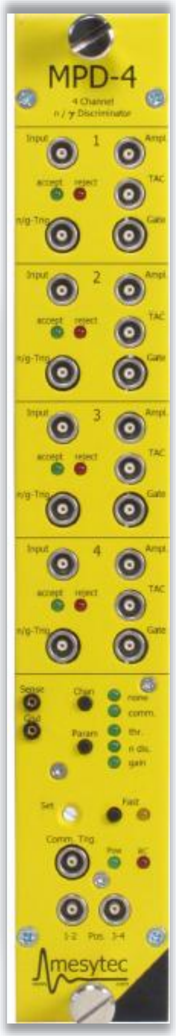
PSA - Electronics

Analog:



Mesytec MPD-4:

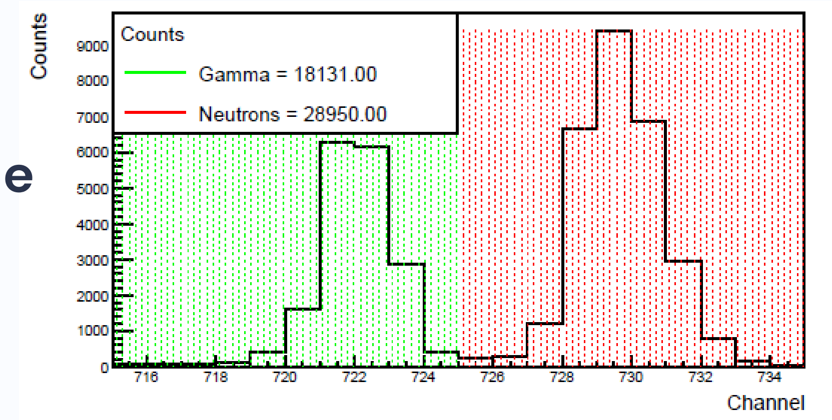




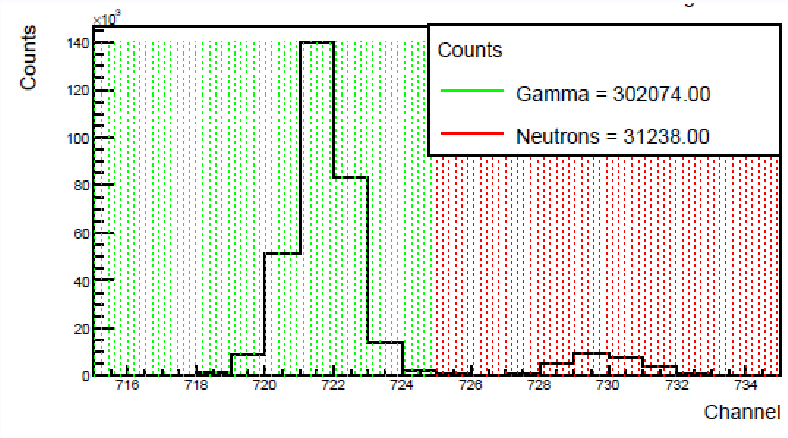
Time spectrum – TAC output

Analog circuit:

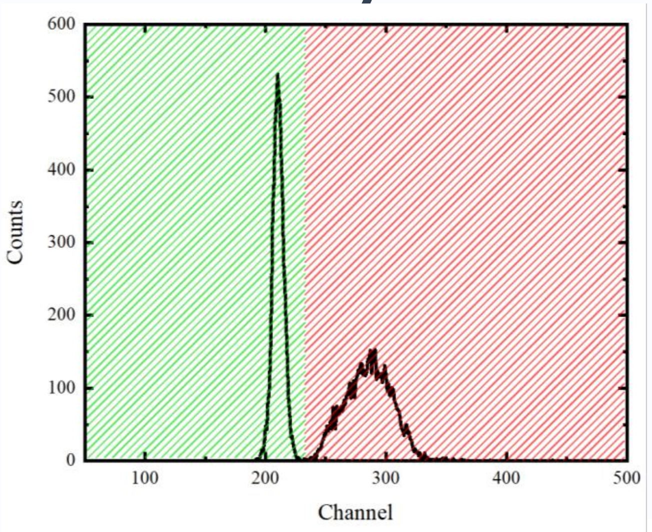
AmBe source



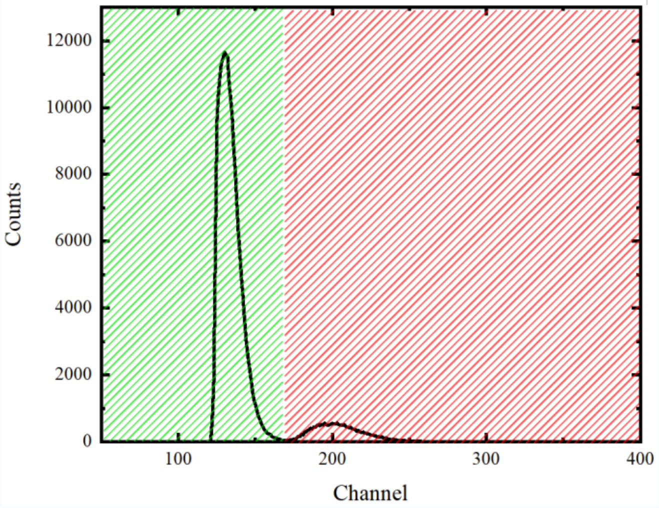
AmBe + ^{137}Cs source



Mesytec:



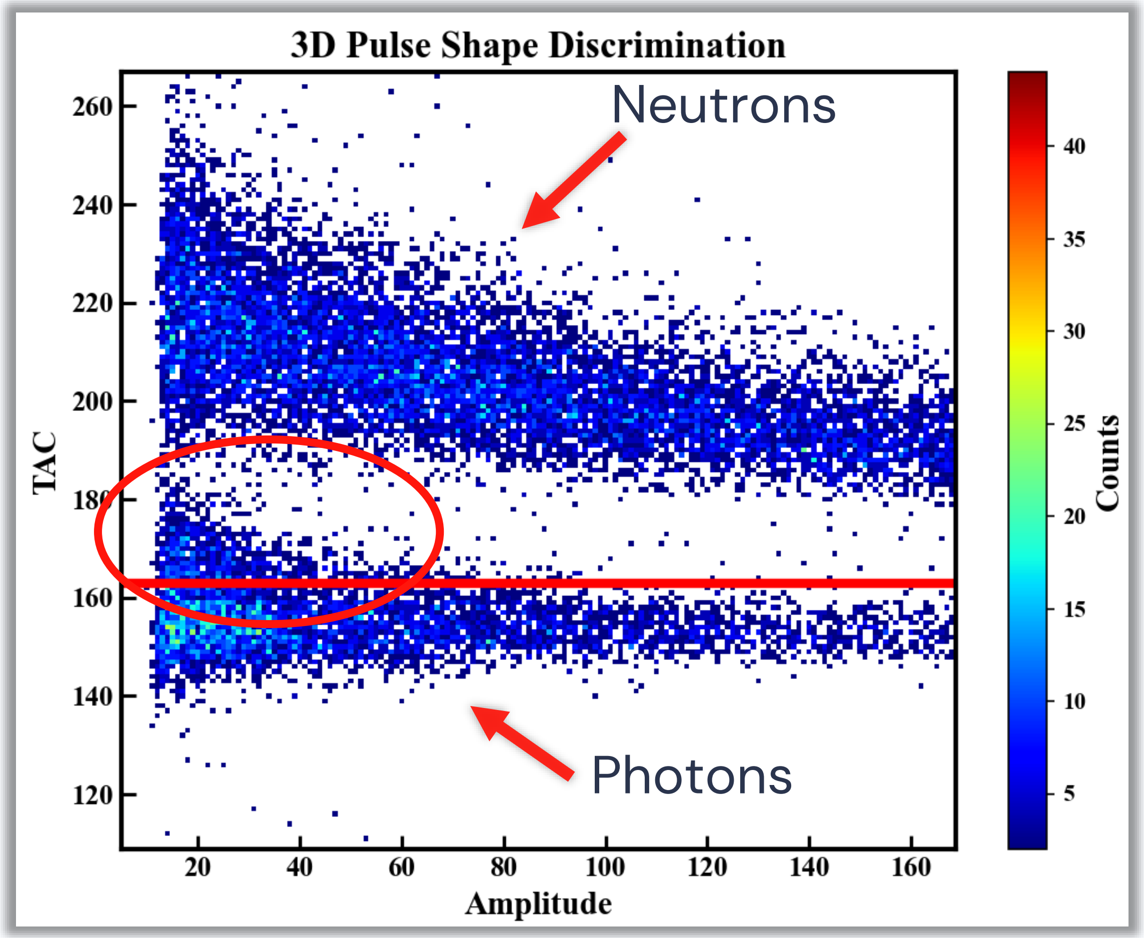
AmBe source



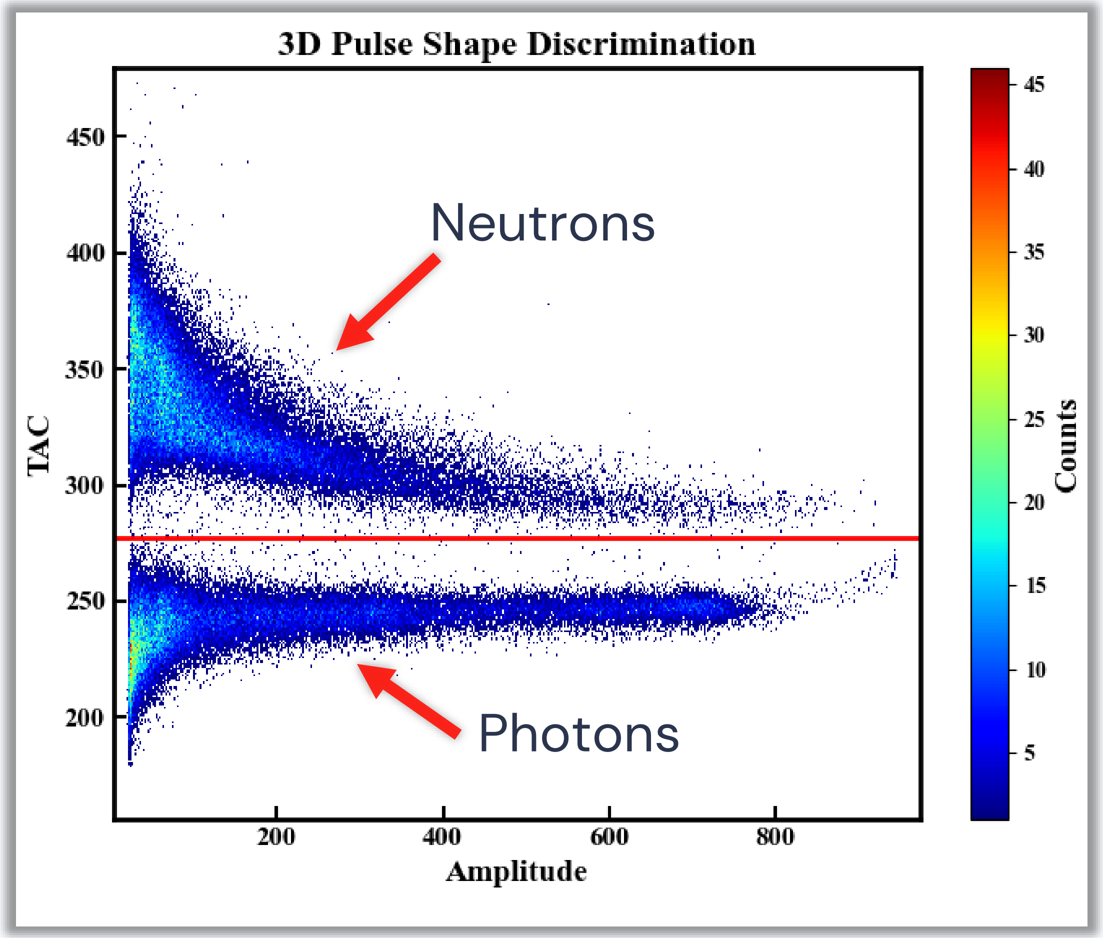
AmBe + ^{137}Cs + ^{60}Co source

3D - PSA

Before optimization



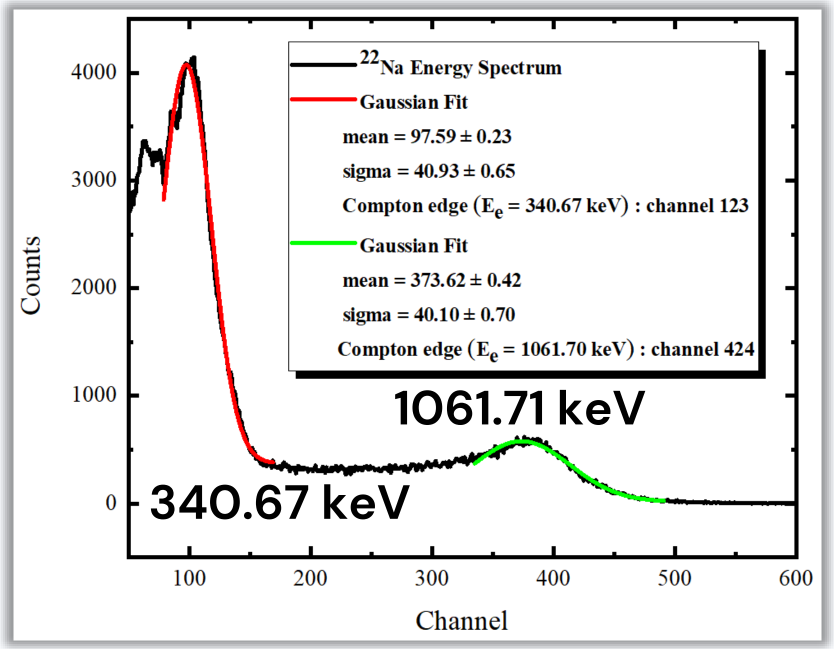
After optimization



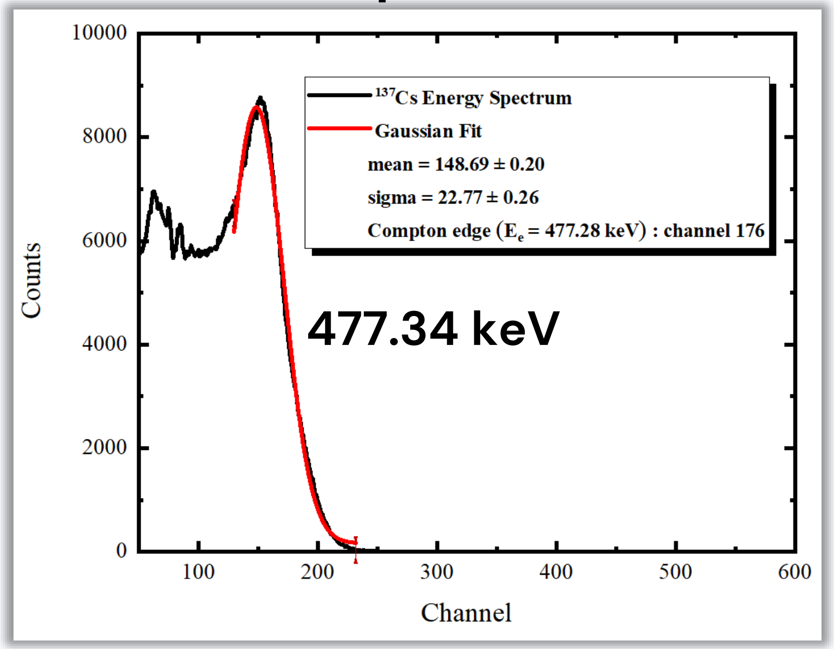
Energy Calibration

Using the MPD-4 unit for fixed gain ^{22}Na, ^{137}Cs and ^{54}Mn energy spectrum was taken for energy calibration

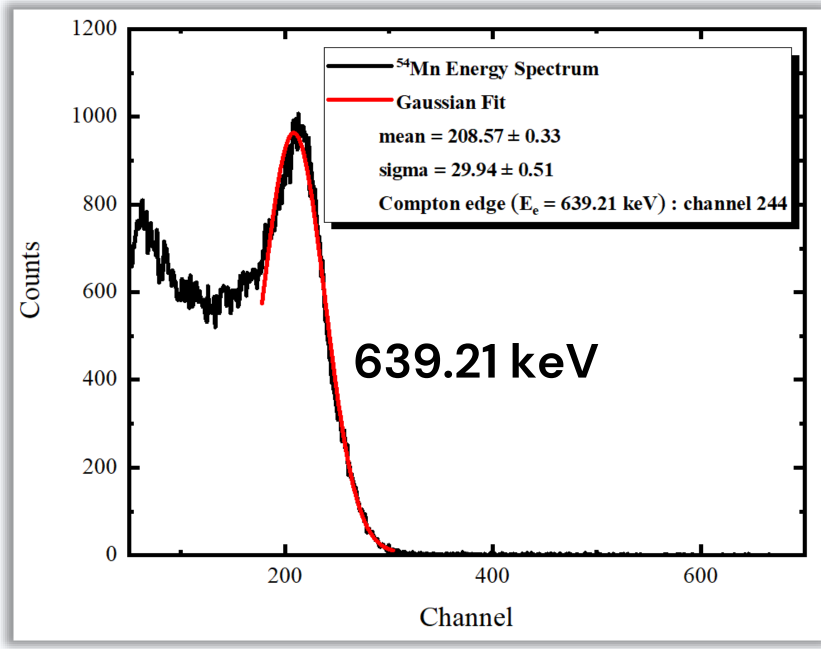
^{22}Na spectrum



^{137}Cs spectrum



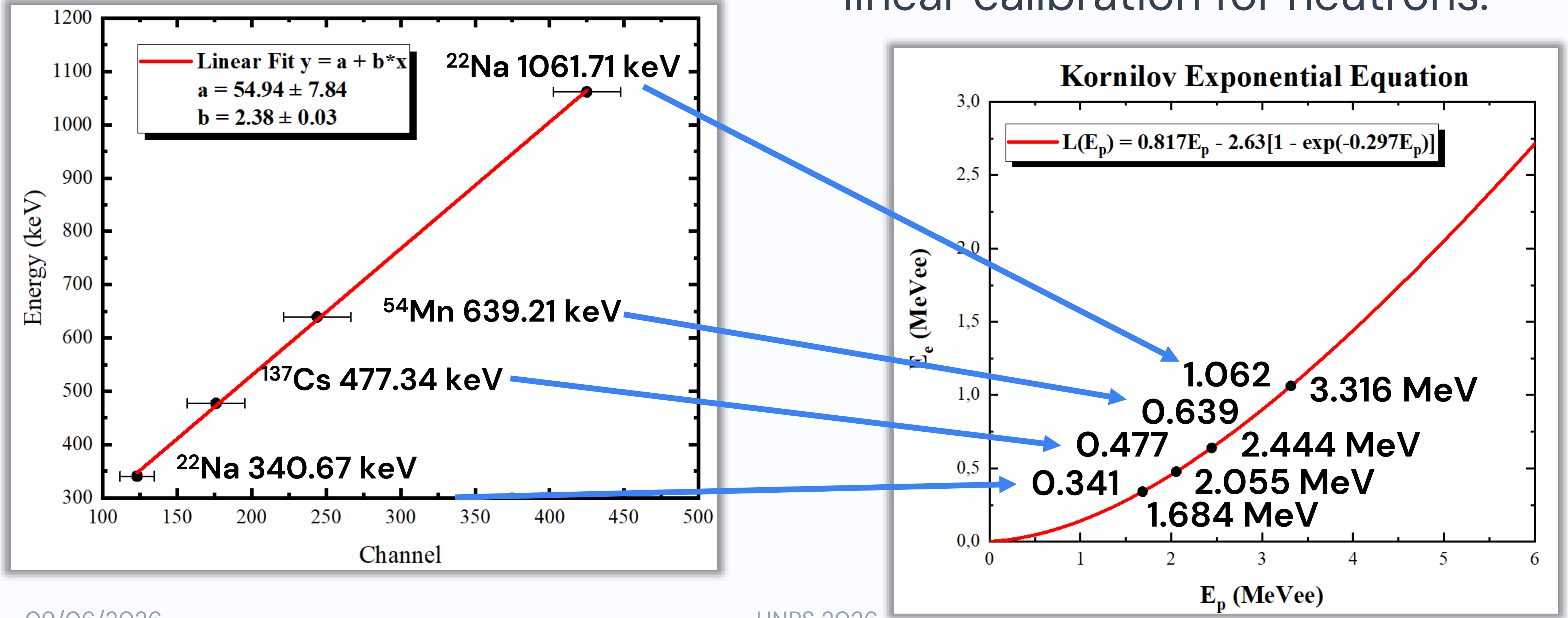
^{54}Mn spectrum



Energy Calibration

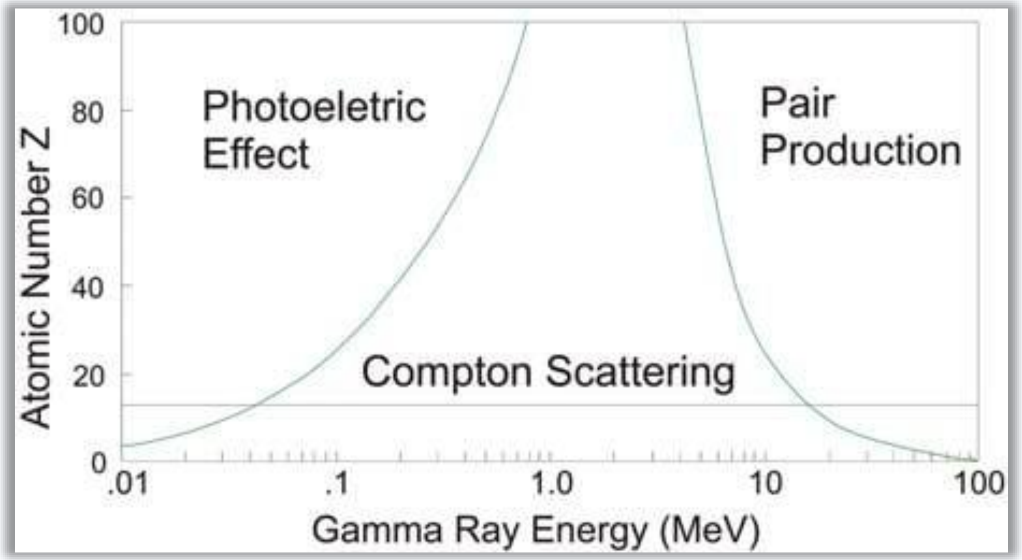
The energy calibration was determined through a linear fit.

Appling the Kornilov equation to calibrate neutron energies. Non linear calibration for neutrons.



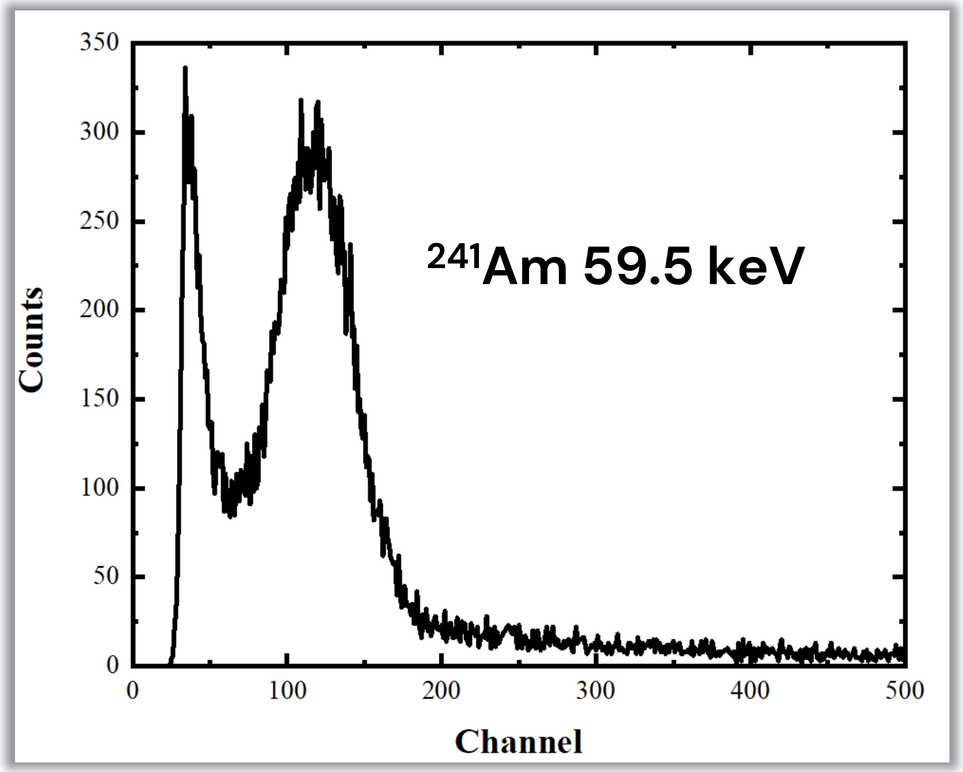
Lowest neutron energy detection

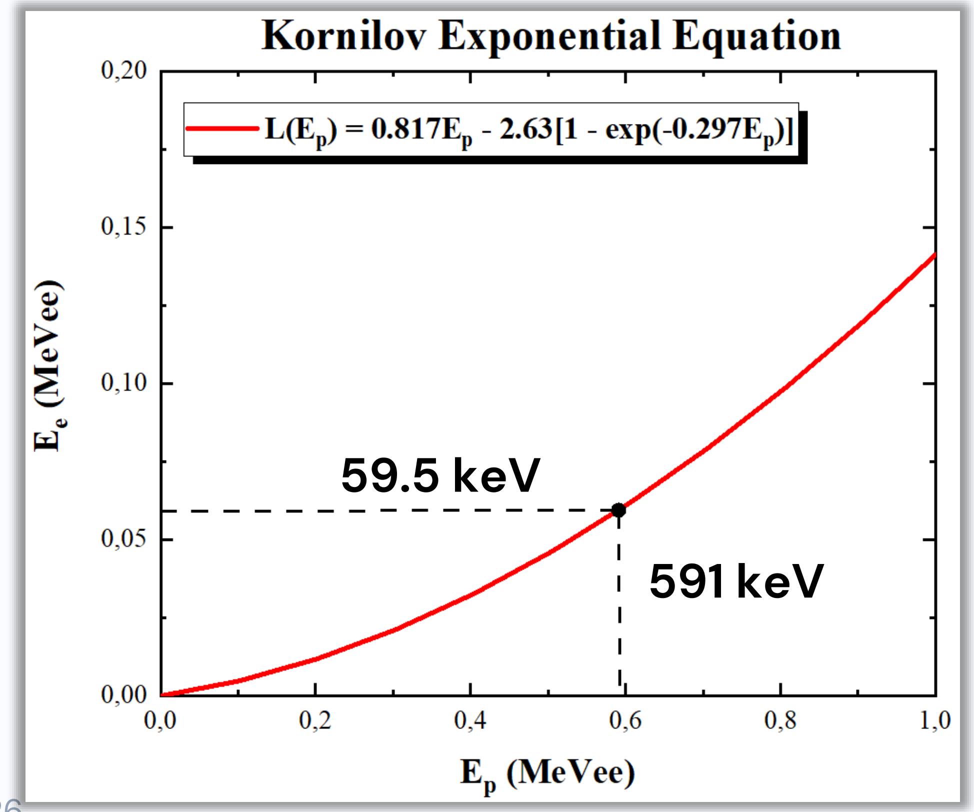
With high gain the photopeak of ^{241}**Am** is visible in the EJ309.
The minimum neutron energy that can be detected is **591 keV**



Lowest neutron energy detection

With high gain the photopeak of ^{241}**Am** is visible in the EJ309.
The minimum neutron energy that can be detected is **591 keV**

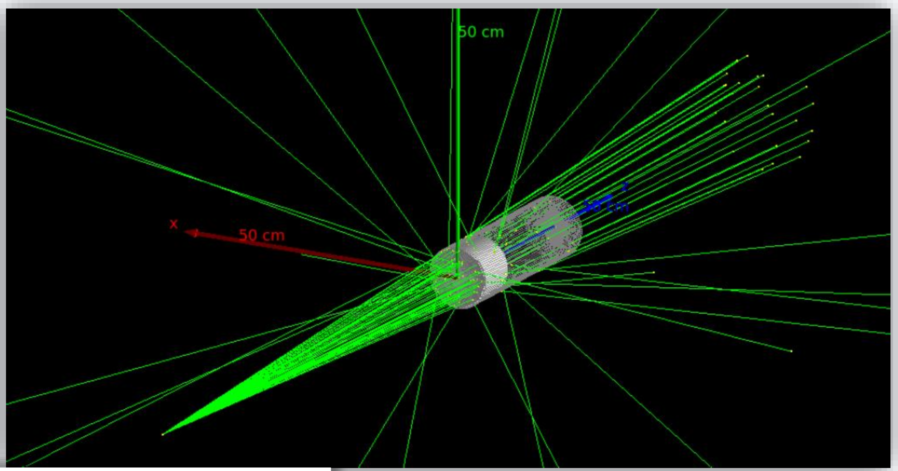


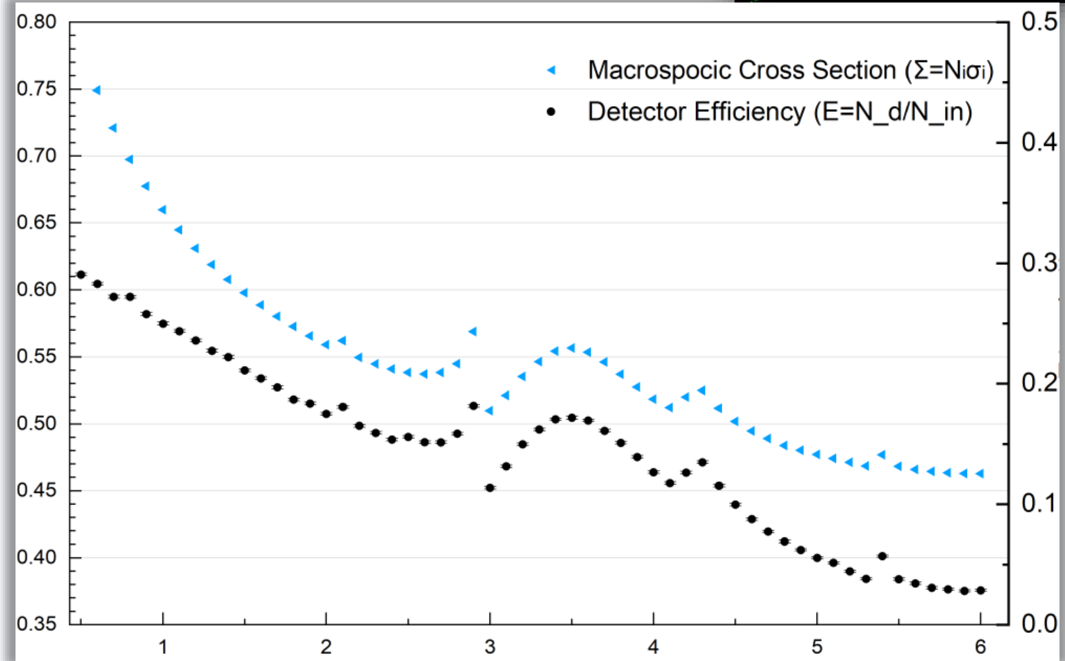


Intrinsic Efficiency of EJ-309

Simulation of the detector was performed via Geant4.

- Monoenergetic, isotropic and point neutron beam
- Scoring Volume the active volume of the detector
- Calculated the intrinsic efficiency of the Detector $\frac{\#Detected}{\#In}$

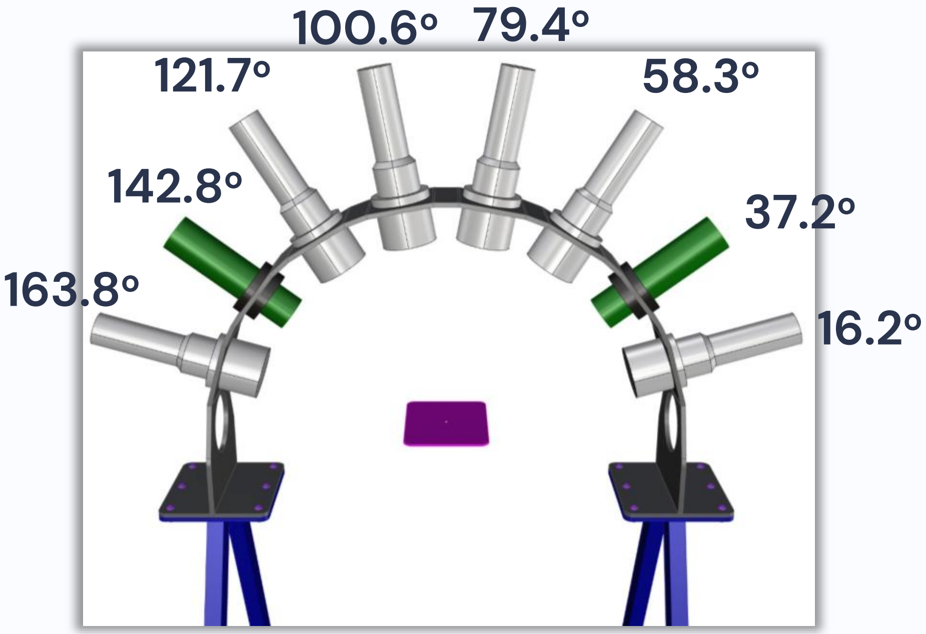




Calculation of σ using Gauss-Legendre quadrature

The detection angles have been chosen, so that their corresponding cosines match the zeros of the Gauss-Legendre quadrature polynomial of the 8th order.

$$\sigma(E) = 2\pi \sum_{i=1}^{8} w_i \frac{d\sigma}{d\Omega}(E, cos\theta_i)$$

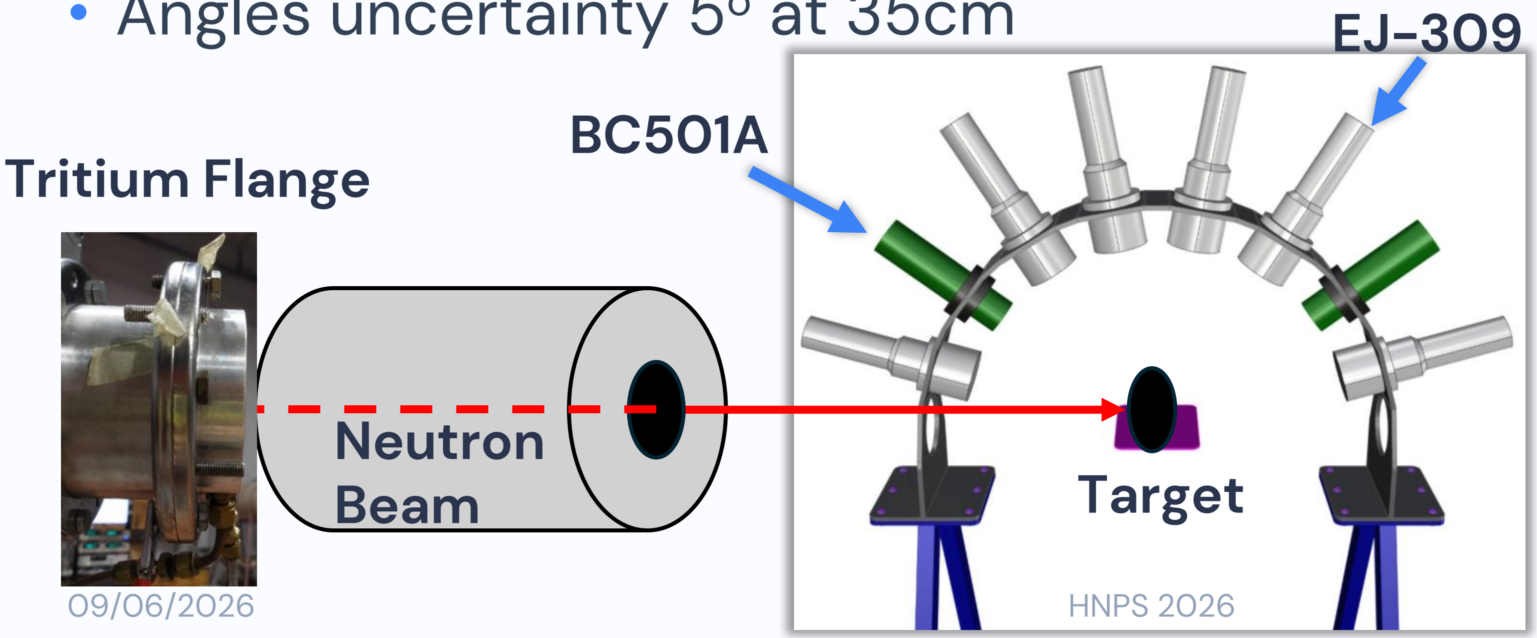


θ_i (o)	$cos\theta_i$	w_i
16.2	0.9603	0.1012
37.2	0.7967	0.2224
58.3	0.5255	0.3137
79.4	0.1834	0.3627
100.6	-0.1834	0.3627
121.7	-0.5255	0.3137
142.8	-0.7967	0.2224
163.8	-0.9603	0.1012

Design of the new experimental setup

After considering the requirements of the NCSR “Demokritos”, by using the $^{3}H(p,n)$ reaction the ideal experimental setup is:

- Distance from the Tritium target 100cm
- Diameter target 10cm
- Angles uncertainty 5º at 35cm



Conclusion – Future Perspectives

Conclusion:

- Successful neutron–gamma discrimination was achieved using the three EJ309 liquid scintillators and the BC501A detector.
- Detector intrinsic efficiency calculated using GEANT4.
- A new experimental setup was designed to meet the requirements of NCSR "Demokritos".

Future Perspectives:

- Calculate the actual efficiency of the detectors, adding the light output function and energy threshold in the GEANT4 code
- Once the detector support structure is completed, the validation of the entire setup will be performed using neutron elastic scattering on ^{12}C
- Measurements with medium-mass nuclei will be carried out.

Thank you for your attention