CHEP Joint International Workshop: Detector Development for High Energy Physics and Various Applications & 7th Luminescence Materials Workshop

Scintillators For Neutron Detection

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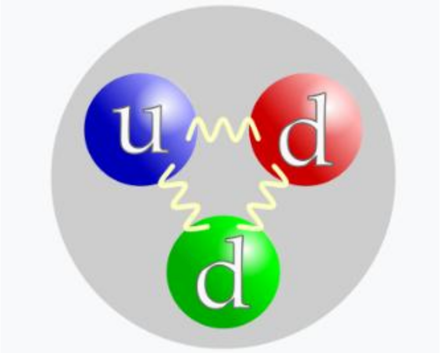
Outlines

1. Neutron Particle and It's Properties
2. Neutron Detection Principle
3. Scintillators for Thermal Neutron Detection
4. Scintillators for Fast Neutron Detection
5. Future Research

1. Neutron Particle and It's Properties

- The neutron is a subatomic particle, that has no electric charge, and a mass slightly greater than that of a proton.
- Protons and neutrons constitute the nuclei of atoms.



$$n^0 \rightarrow p^+ + e^- + \bar{\nu}_e$$

Lifetime:

- Bottle method (cold neutron): 877.75 s
- Beam method (hot neutron) : 887.7 s

Reason = unknow!

Mass	1.675×10^{-27} kg
Charge	0
Spin	1/2
Magnetic moment	$-1.913\mu_N$, ($\mu_N = 5.051 \times 10^{-27}$ JT^{-1} is the nuclear magneton)

2. Neutron detection principle

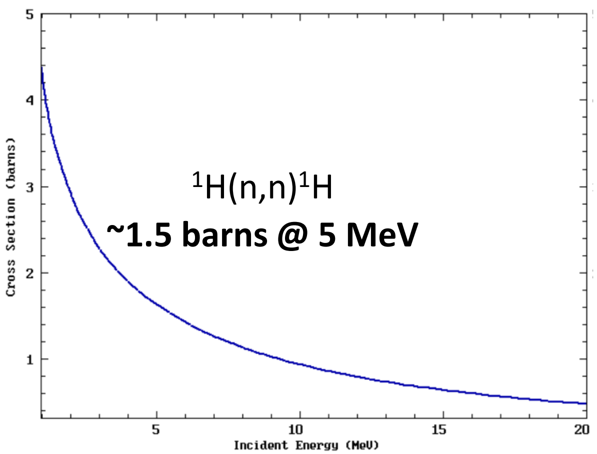
Neutral charge => Direct detection is impossible, need converter via nuclear reactions

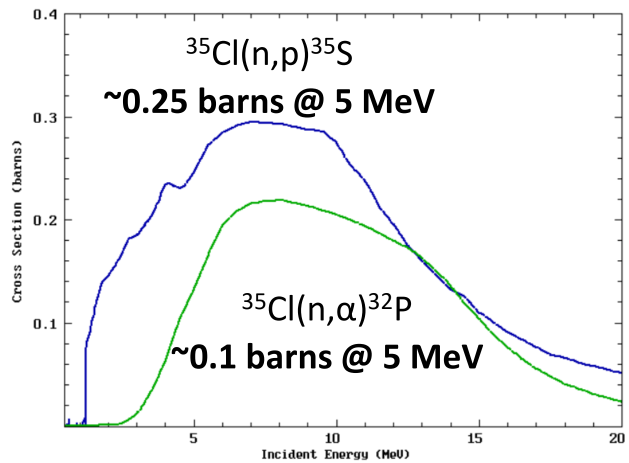
Thermal neutron detection

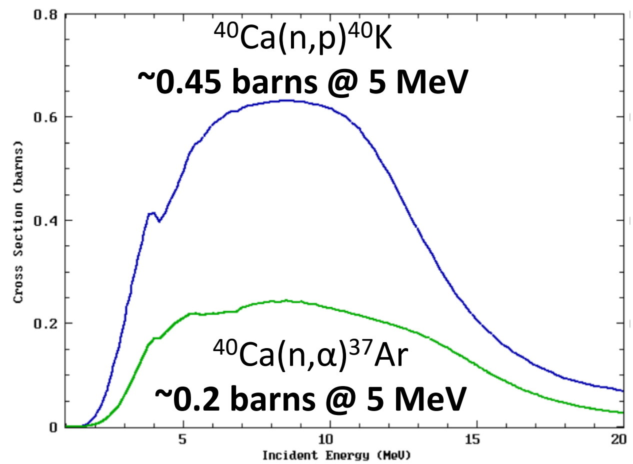
- $^{3}He(n,p)$ ~**5316** barns, natural abundance ~1.37 ppm.
- $^{6}Li(n,t)$ ~**938** barns, natural abundance ~7.6 %.
- $^{10}B(n,\alpha)$ ~**3844** barns, natural abundance ~19.8 %.
- $^{113}Cd(n,\gamma)$ ~**19960** barns, natural abundance ~12.2 %.
- ^{235}U(n, fission) ~**587** barns, natural abundance ~0.72 %.

Fast neutron detection

- ❑ ~1000 times lower detection efficiency
- ❑ Gamma rejection is typically required







3. Scintillators for thermal neutron detection

- ^{3}He(n,p) ~**5316** barns, natural abundance ~1.37 ppm.
- ^{6}Li(n,t) ~**938** barns, natural abundance ~7.6 %.
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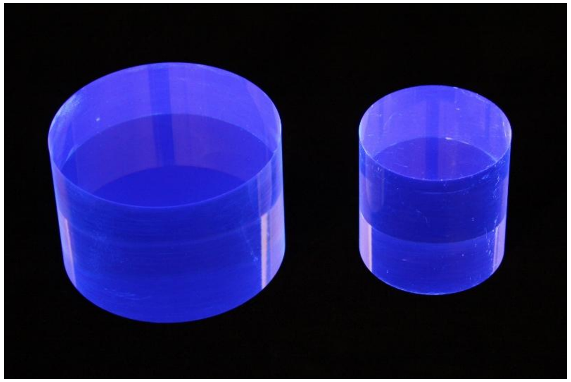
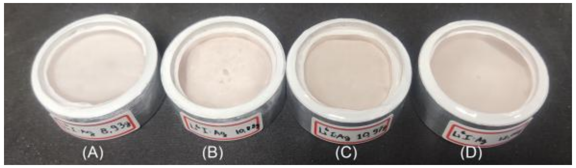
❑ ^{6}Li-based scintillators: LiF/ZnS:Ag, LiI:Ag, Cs_2LiYCl_6:Ce, $LiCaAlF_6$, NaIL, lithium-6 glass scintillators.

❑ ^{10}B-based scintillators: Borosilicate glass scintillators, B_2O_3/ZnS:Ag, boron-loaded plastic scintillators.

Li-glass SG101



Boron-loaded plastic scintillators EJ-254

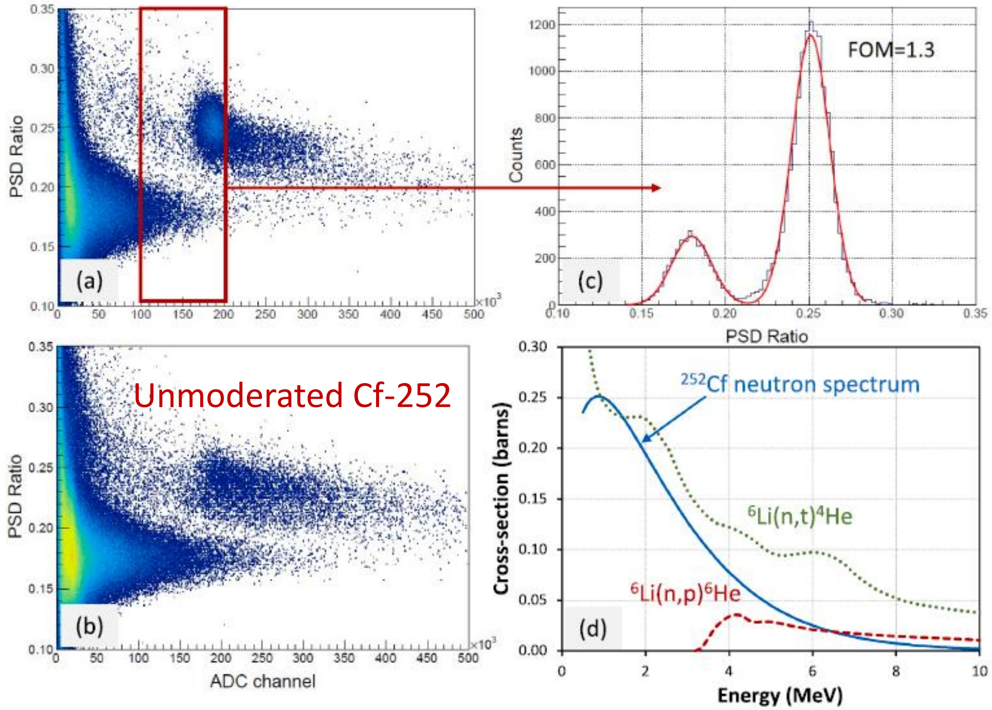


LiI:Ag

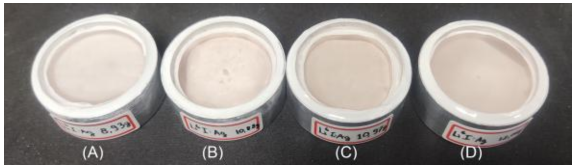
LiF/ZnS:Ag EJ-600

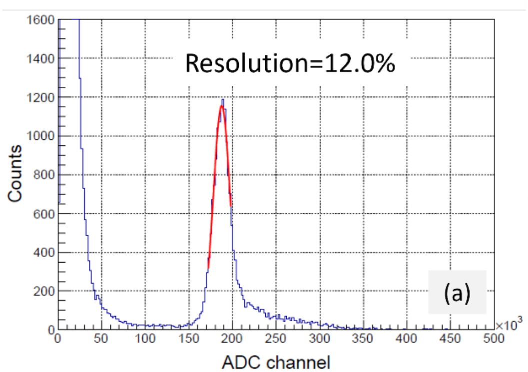
3.1 LiI:Ag

Moderated Cf-252

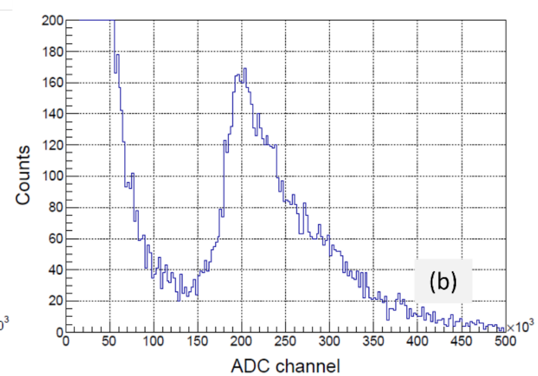


Type of particles	FOM
Gamma – neutron	1.3





Moderated Cf-252



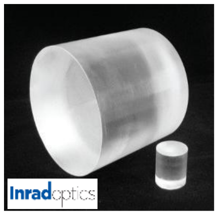
Unmoderated Cf-252

Also sensitive to epithermal and fast neutrons

https://doi.org/10.1016/j.jcrysgro.2024.127692

4. Scintillators for fast neutron detection

Stilbene ($C_{14}H_{12}$)



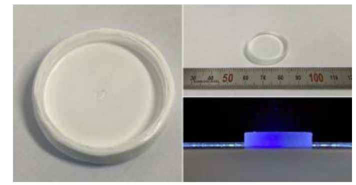
Cs_2LiYCl_6 (CLYC)

CapeScint™ Standard and Custom Radiation Detectors

$LaCl_3$

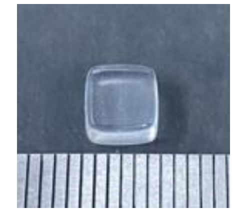
Shalom EO Crystals, optics and components

CaF_2



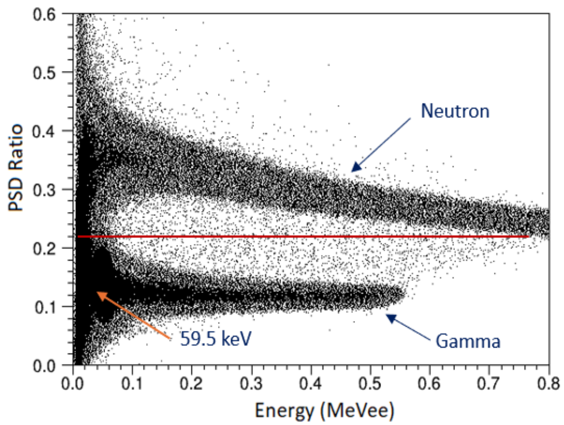
Epic Crystal

$SrCl_2$



	Stilbene ($C_{14}H_{12}$)	CLYC	$LaCl_3$	CaF_2	$SrCl_2$
Principle	$^{1}H(n,n)^{1}H$	$^{35}Cl(n,p)^{35}S$, $^{35}Cl(n,\alpha)^{32}P$	$^{35}Cl(n,p)^{35}S$, $^{35}Cl(n,\alpha)^{32}P$	$^{40}Ca(n,p)^{40}K$ $^{40}Ca(n,\alpha)^{37}Ar$	$^{35}Cl(n,p)^{35}S$, $^{35}Cl(n,\alpha)^{32}P$
Main Advantages	○ Non-hygroscopic ○ Good PSD ○ Large reaction cross-section	○ Good PSD ○ Fast/thermal neutron detection	○ Good PSD ○ Proton/alpha discrimination	○ Non-hygroscopic ○ Rel. short decay ○ Rel. large reaction cross-section	○ Rel. short decay ○ Good resolution
Main Disadvantages	▪ Fragile ▪ Unfolding required	▪ Hygroscopic ▪ Low proton/alpha discrimination	▪ Hygroscopic ▪ Long decay time	▪ Low resolution ▪ Low discrimination performance	▪ Hygroscopic ▪ Low discrimination performance

4.1 Stilbene



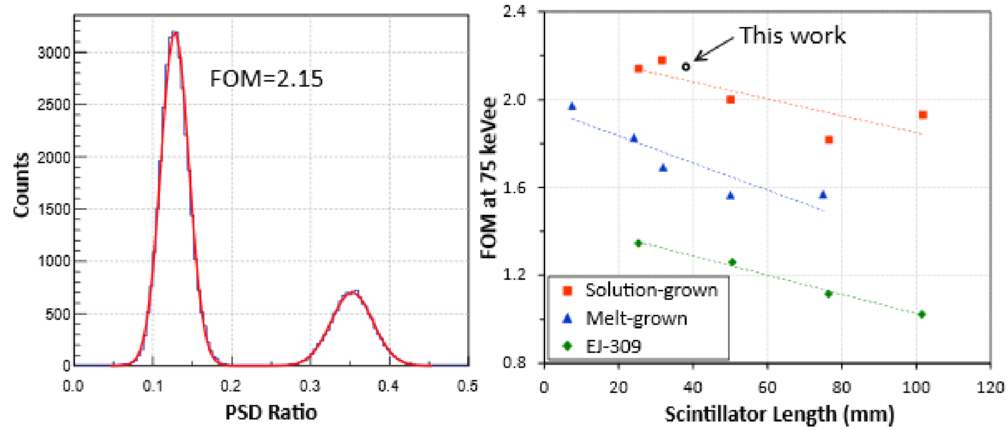
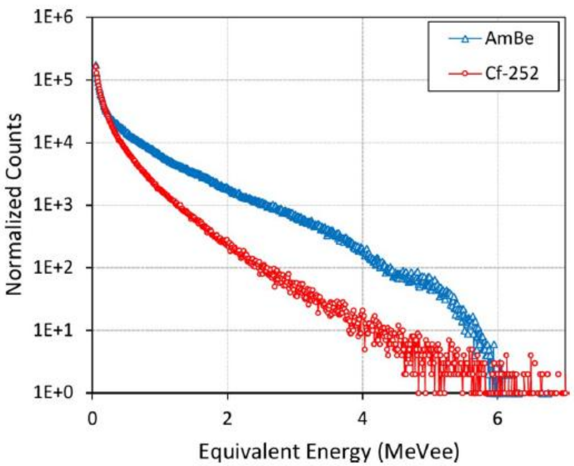
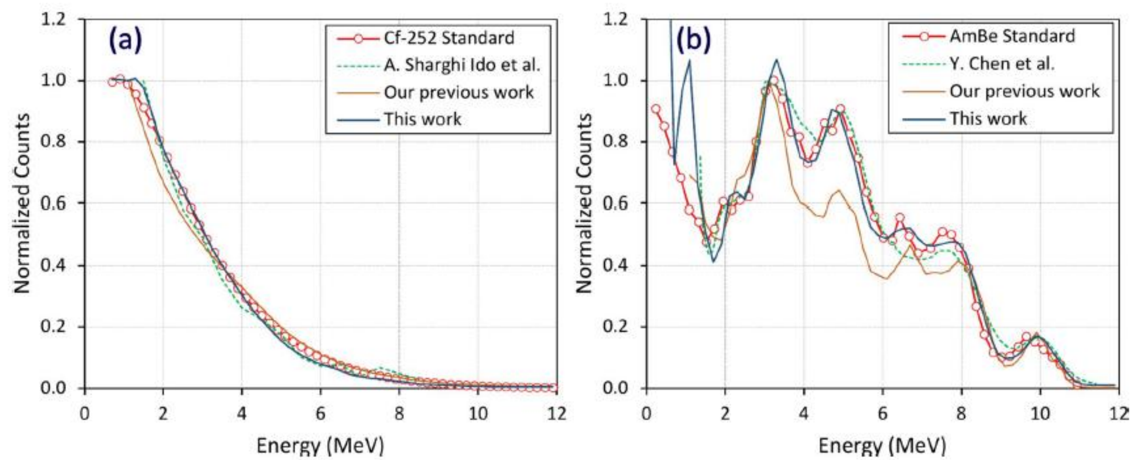


Figure 4.3: FOM value at 75 keVee in this work (left) in comparison with reported data at different scintillation lengths

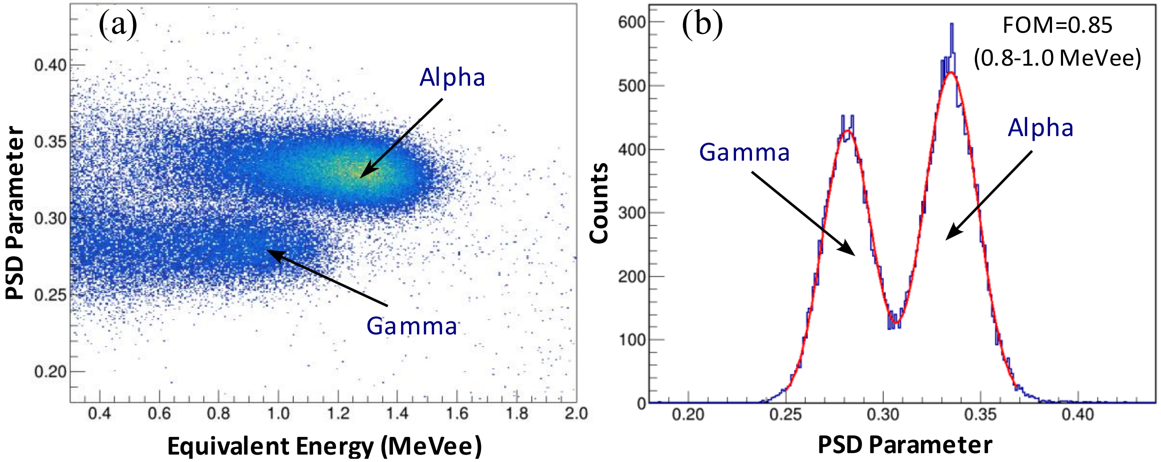


Unfolding

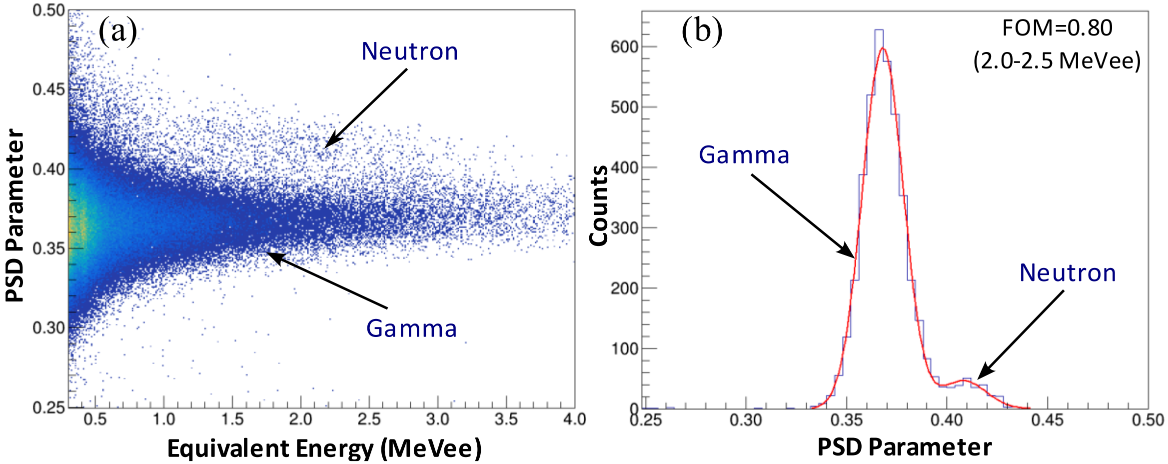


https://doi.org/10.1016/j.net.2022.10.041
https://doi.org/10.1038/s41598-024-85087-4

4.2 CaF_2



Type of particles	FOM
Gamma – Alpha	0.85

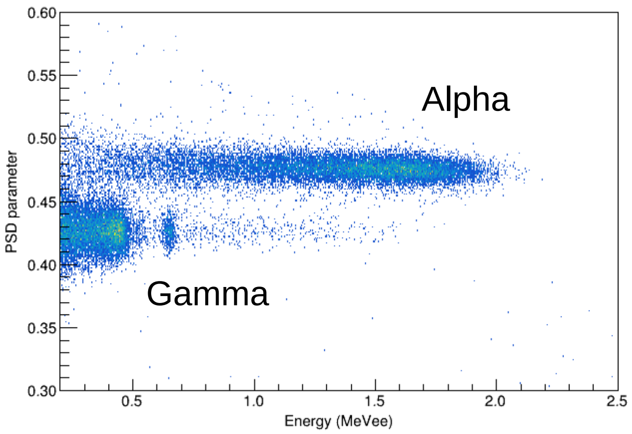


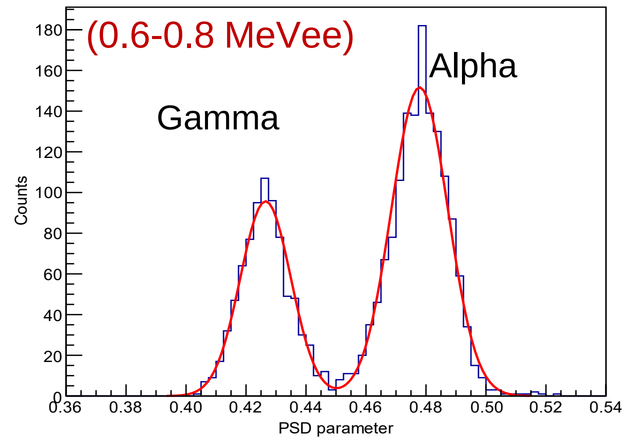
Type of particles	FOM
Gamma – Neutron	0.8

Basically from the (n,p) reaction

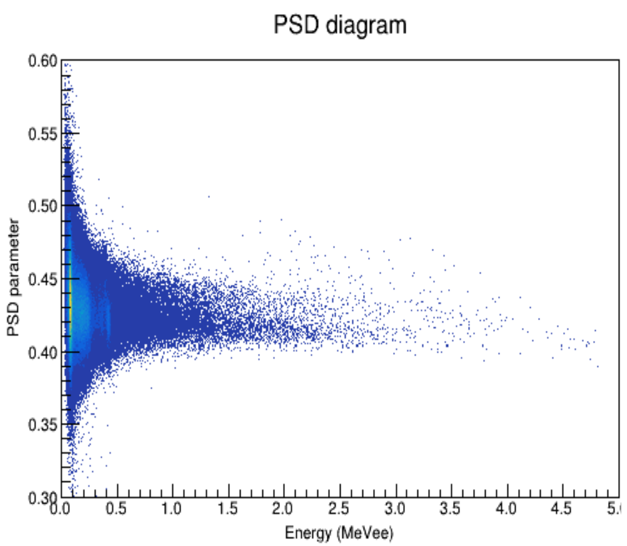
https://doi.org/10.1016/j.radphyschem.2024.111756

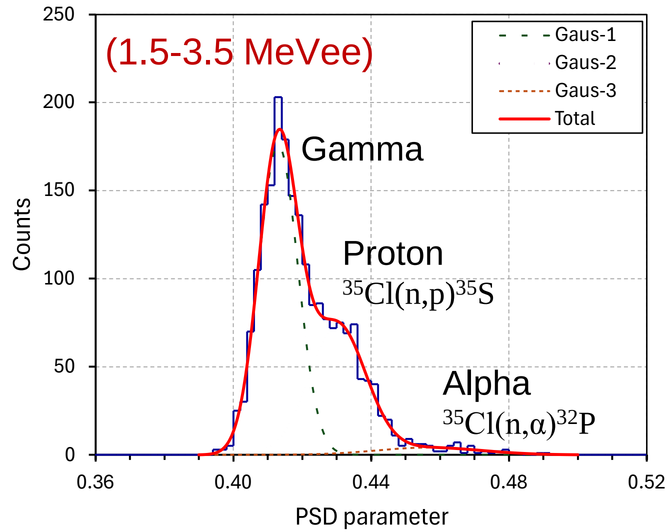
4.3 $SrCl_2$





Type of particles	FOM
Gamma – Alpha	1.23 ± 0.04





Type of particles	FOM
Gamma – Alpha	0.9 ± 0.3
Gamma – Proton	0.5 ± 0.1
Proton – Alpha	0.5 ± 0.3

5. Future Research

- Scintillation materials (Detectors and Dosimeters)
  - New Li-based scintillators
  - CaF_2: neutron detection performance at low energy
  - $LaCl_3$: Response function, spectrum unfolding
  - Stilbene and Plastic scintillators: Response function and unfolding performance
  - New Cl-based scintillators

- Detector development and Application
  - Spectrometers: neutron, muon, gamma, etc.
  - Radiography: neutron, muon, X-ray, etc.

- Physics
  - Cross-section
  - Mechanism

Thank you for your attention!