Optimizing the Performance of a $LaBr_3$:Ce, Sr Based Neutron and Gamma Dual Detector

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Introduction

$LaBr_3$:Ce scintillators, when co-doped with a small amount of strontium and other aliovalent elements, are shown to have significantly improved light output and energy resolution [1, 2]. Our previous study shows strontium and calcium co-doping also enhances the crystal's ability to discriminate between heavy charged particles and gamma radiations via pulse shape discrimination (PSD). Complete suppression of internal alpha radiation background can be achieved in Ca or Sr co-doped $LaBr_3$:Ce [3]. Moreover, the enhanced alpha-gamma PSD makes it possible to use the co-doped $LaBr_3$:Ce crystal for dual neutron-gamma detection when coupled with a neutron convertor such as ^{6}LiF, which is also an excellent reflector.

Pulse Shape Discrimination

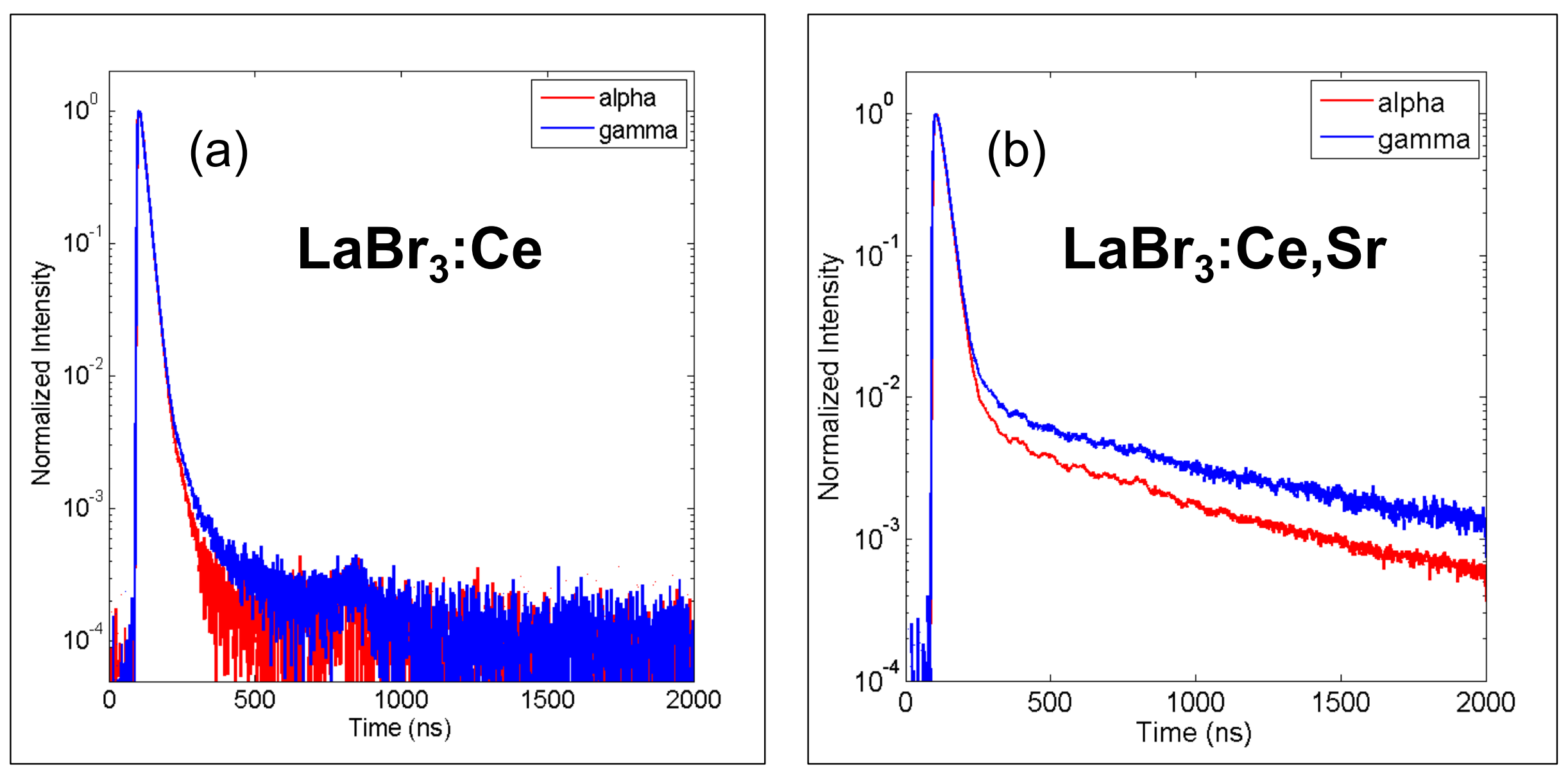

Fig. 1 Averaged PMT pulses of (a) Ce only and (b) Sr co-doped $LaBr_3$:Ce when excited by α particles or γ-rays

- **Sr co-doped $LaBr_3$:Ce shows more prominent pulse shape differences between gamma and alpha pulses than standard Ce only $LaBr_3$.**

Detector Configuration

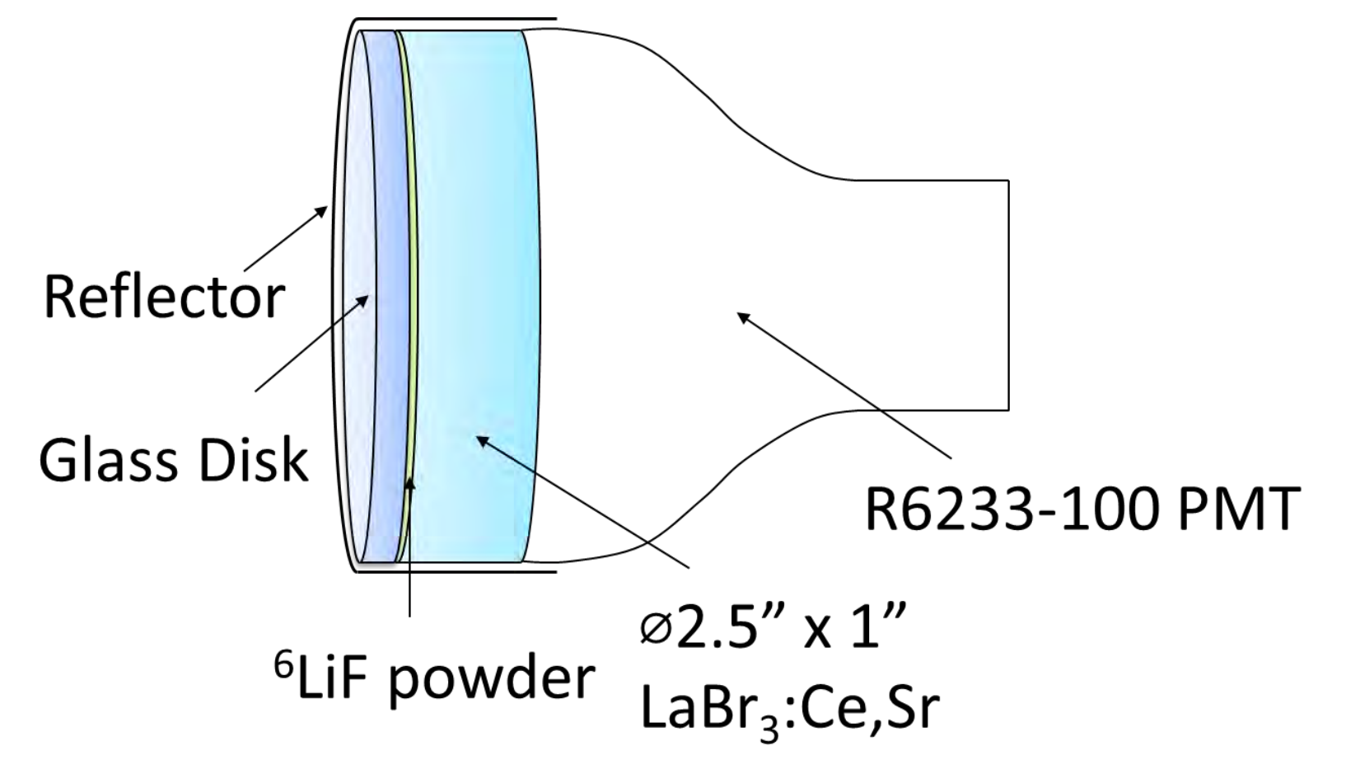

Fig. 2 Schematic drawing of the prototype detector

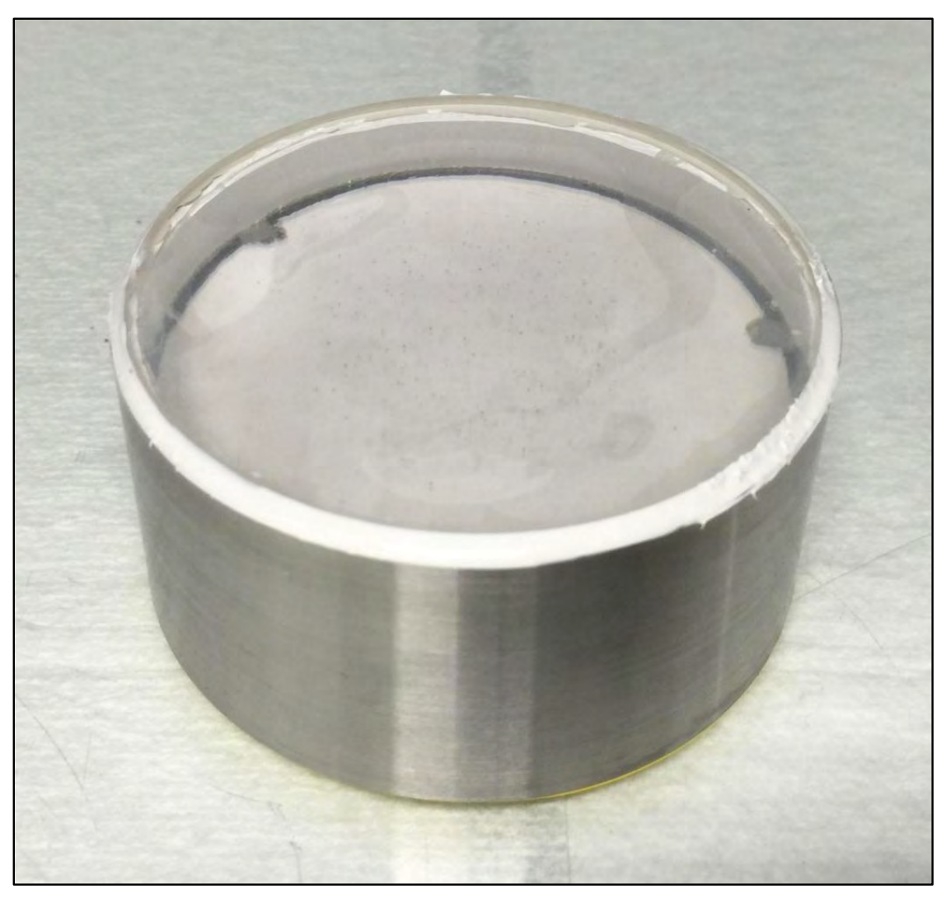

Fig.3 Photo of the assembled detector (w/o PMT)

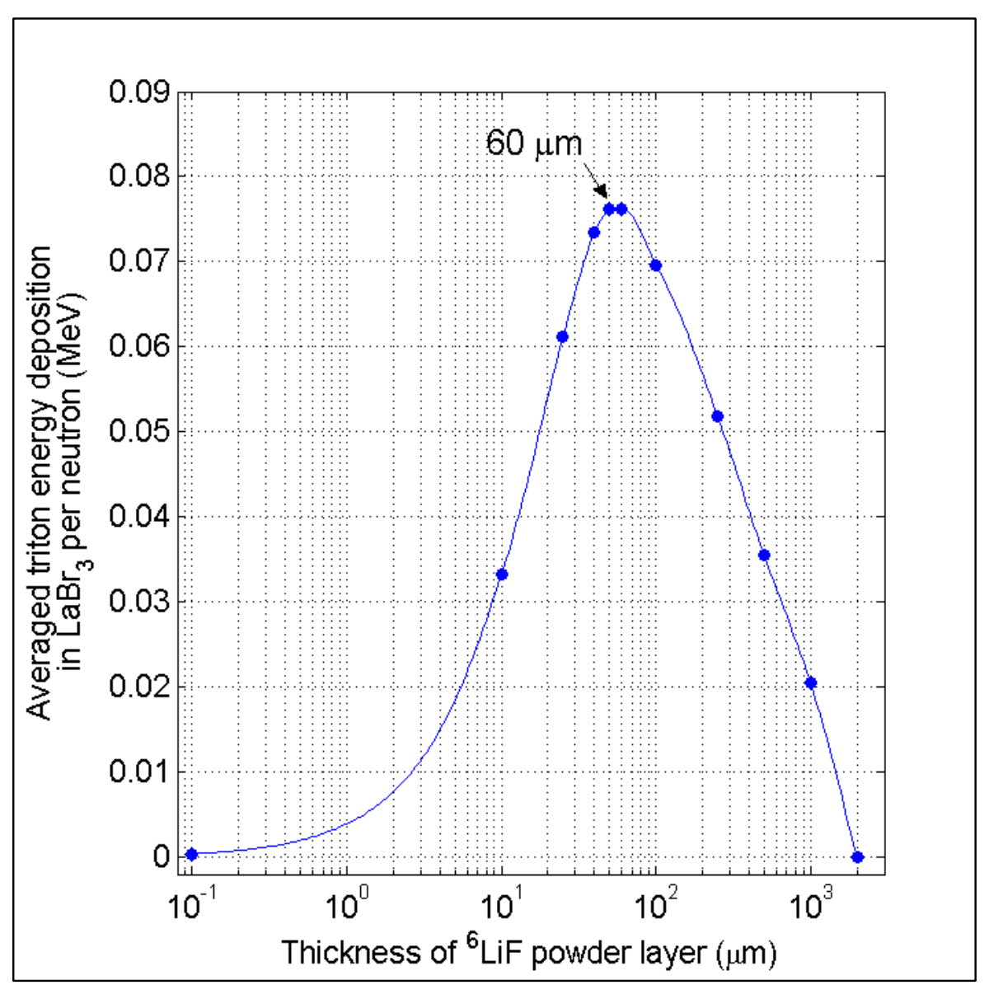

Fig. 4 Averaged neutron energy deposition per incident neutron (simulated)

$$n + {}^6Li \rightarrow t\ (2.75\ MeV) + \alpha\ (2.05\ MeV)$$

- **93.5% enriched ^{6}LiF powder is used as thermal neutron converter.**
- **Tritons (2.75 MeV) from ^{6}Li(n,t)α reaction are used as the signal for neutron detection.**
- **MCNPX simulations suggest the optimal ^{6}LiF layer thickness is 60 μm.**
- **Detectors with different ^{6}LiF thickness (30 μm, 60 μm, 100 μm, and 200 μm) were tested.**

Thermal Neutron Detection

Experimental Setup A ^{252}Cf source (12.8 ng) was placed 5" from the detector. The source was shielded with 2.25" thick Pb and 2" thick high density polyethylene (HDPE) to attenuate the gammas and moderate the neutrons, respectively. Thermal neutron flux through the detector was determined by MCNPX.

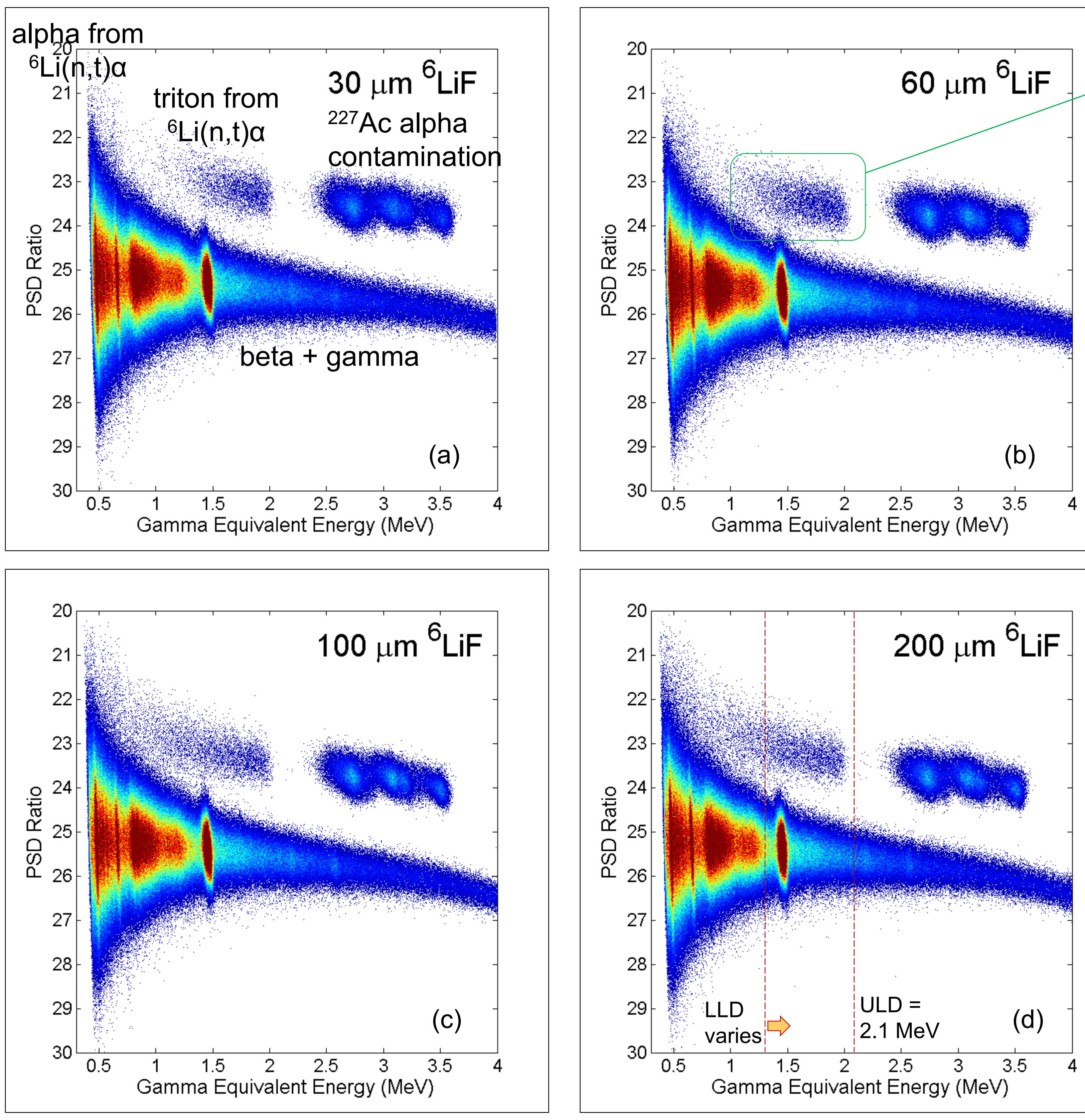

Fig. 5 Gamma-neutron PSD scatter intensity plot of $LaBr_3$:Ce, Sr with (a) 30 μm (b) 60 μm (c) 100 μm (d) 200 μm thick ^{6}LiF conversion layer

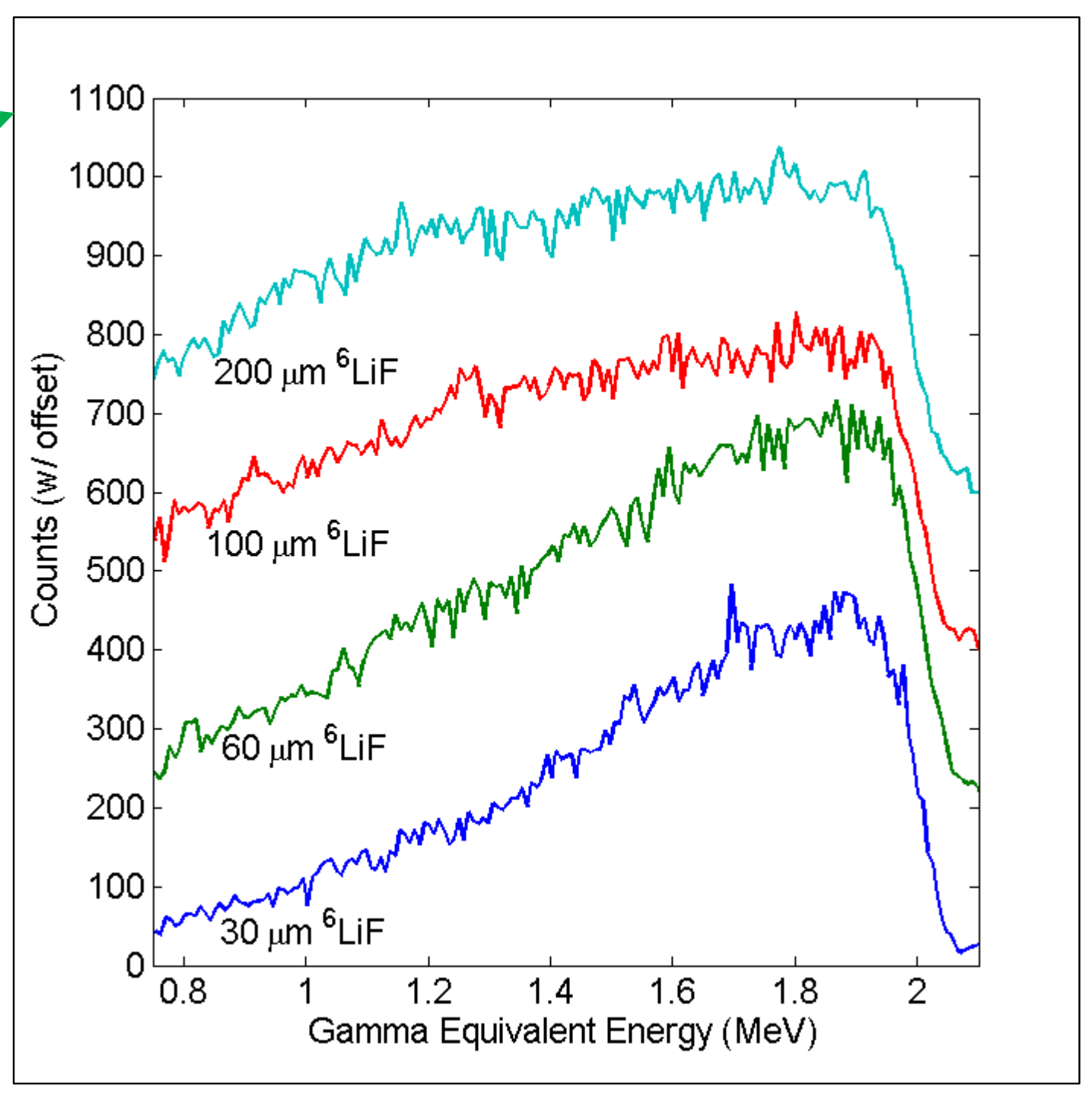

Fig. 6 Pulse height spectra for tritons from ^{6}Li(n,t)α reaction, Showing increasing straggling with ^{6}LiF thickness

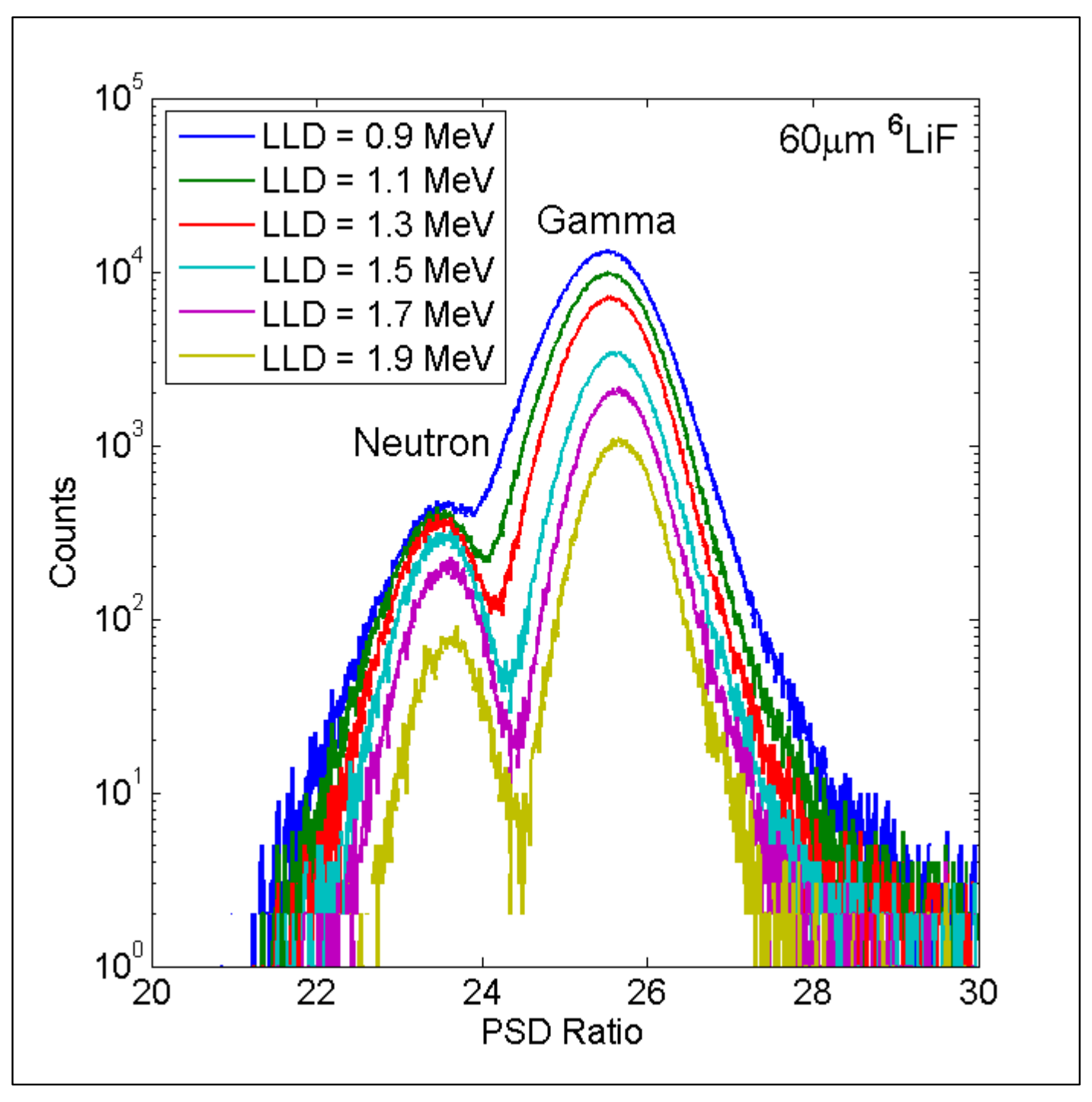

Fig. 7 Pulse shape spectra of 60 μm ^{6}LiF coated detector at different lower energy thresholds

- **Reducing ^{6}LiF thickness reduces energy straggling of tritons in ^{6}LiF.**
- **Minimal change in triton energy spectrum if ^{6}LiF thickness > 100 μm.**
- **Good PSD when lower energy threshold > 1.5 MeV.**

Table I Neutron detection properties of ^{6}LiF surrounded $LaBr_3$:Ce,Sr detectors (LLD = 1.5 MeV)

^{6}LiF Thickness	Thermal Neutron Detection (E_n < 0.2 eV)			PSD FoM	Gamma Rejection Ratio*
	Capture Rate	Detection Efficiency	Det. Eff. per unit area		
30 μm	8.1%	2.9%	0.60% /layer*inch^2	1.19	$5.2 * 10^{-5}$
60 μm	**15.2%**	**3.1%**	**0.63% /layer*inch^2**	**1.17**	**$7.8 * 10^{-5}$**
100 μm	23.3%	2.8%	0.56% /layer*inch^2	1.23	$2.2 * 10^{-6}$
200 μm	39.8%	2.7%	0.55% /layer*inch^2	1.23	$1.9 * 10^{-6}$

* Assuming 95% of neutrons are counted

- **As expected, thermal neutron detection efficiency is highest when the thickness of ^{6}LiF is 60 μm.**
- **A fraction of captured neutrons generate detectable signals depending on the thickness of ^{6}LiF.**
- **Further increasing the thickness of ^{6}LiF will not increase neutron detection efficiency.**

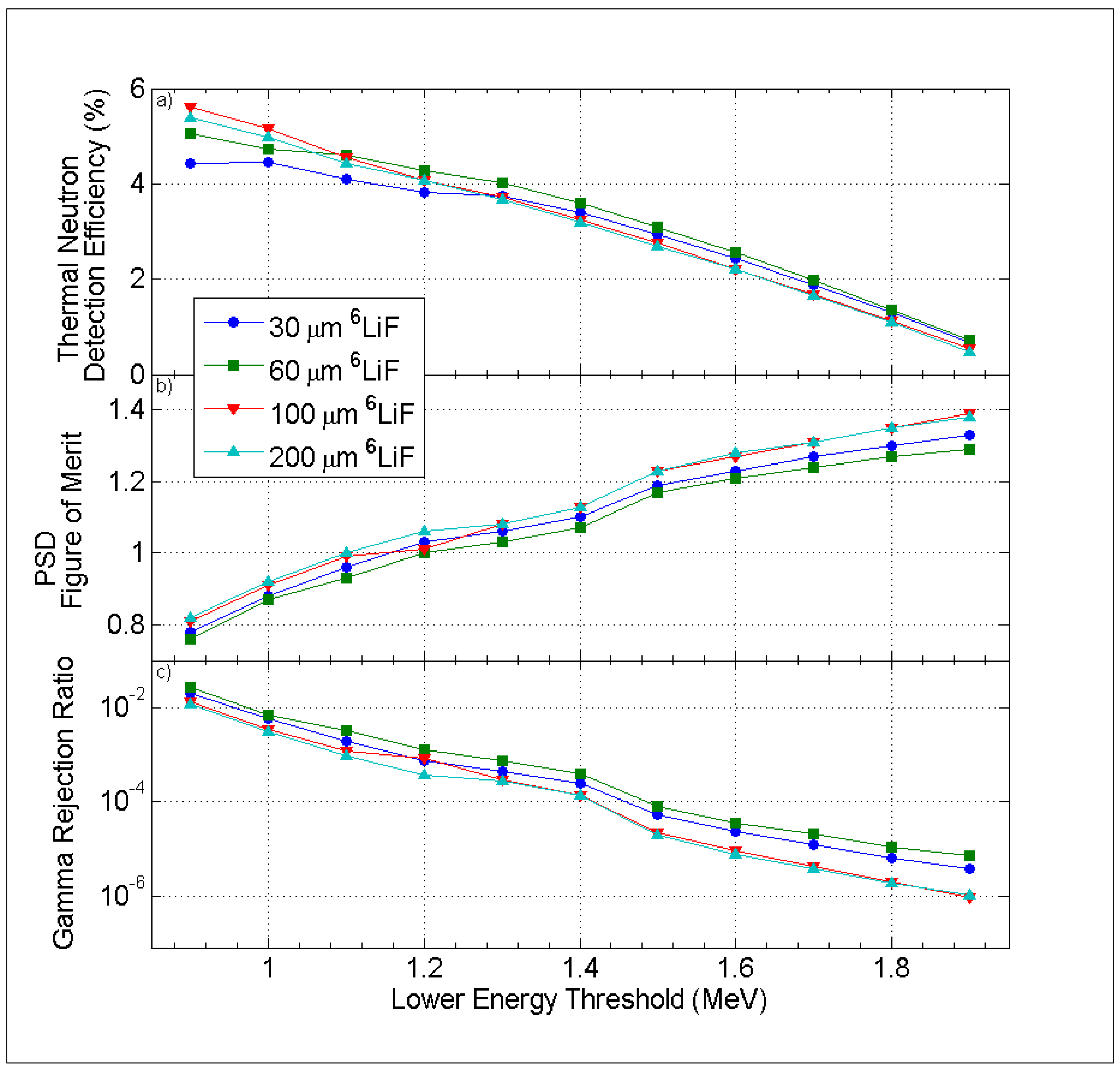

Fig. 8 a) Thermal neutron detection efficiencies (E_n < 0.2 eV), b) PSD Figure of Merit, and c) gamma rejection ratio at different lower energy thresholds

Summary and Outlook

- **A dual gamma-neutron detector can be created by surrounding a Sr co-doped $LaBr_3$:Ce crystal with ^{6}LiF powder.**
- **A fast PMT is not required to realize good PSD in Sr co-doped $LaBr_3$:Ce. Main pulse shape differences are in the slow decay component.**
- **Multiple ^{6}LiF layers or large surface-area-to-volume ratio are desired for efficient neutron detection.**
- **Replacing the usual reflector with ^{6}LiF powder can add neutron detection capability to $LaBr_3$:Ce,Sr detectors.**

REFERENCES
[1] K. Yang, P.R. Menge, J. Buzniak, V. Ouspenski, 2012 IEEE-NSS-MIC Conference record, N1-135, pp. 308-311 (2012).
[2] M. S. Alekhin, J. T. M. de Haas, I. V. Khodyuk, K. W. Krämer, P. R. Menge, V. Ouspenski and P. Dorenbos, Appl. Phys. Lett. 102, 161915 (2013).
[3] K. Yang, P.R.Menge, V. Ouspenski, 2014 IEEE-NSS-MIC Conference record, N39-2 (2014)

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