Enhanced α-γ Discrimination in Co-doped $LaBr_3$:Ce

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Outline

- Introduction
  - Co-doped $LaBr_3$:Ce
  - Radiation background in $LaBr_3$:Ce
- Radiation background in co-doped $LaBr_3$:Ce
- Pulse shape analysis
- Potential applications

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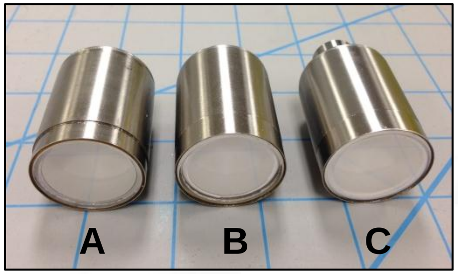
Co-doped $LaBr_3$:Ce

Ca and Sr co-doped $LaBr_3$:Ce

- Better light output and energy resolution[1-3]
- Better proportionality[1-3]
- Mechanical properties not affected[4]
- Additional longer decay component[1,2]

Samples for this research



Ruggedized hermetic package
sapphire window

Sample	Dopant	Size	Relative L.O.	ΔE/E @ 662keV
A	5% Ce	⌀1” X 1”	100%	3.4%
B	5% Ce + 0.5% Ca	⌀1” X 1”	137%	2.9%
C	5% Ce + 0.5% Sr	⌀1” X 1”	129%	2.8%

[1] M. S. Alekhin, D. A. Biner, K. W. Krämer, and Dorenbos, P., Journal of Applied Physics, 113, 224904 (2013)
[2] M. S. Alekhin, J. T. M. de Haas, I. V. Khodyuk, K. W. Krämer, P.R. Menge, V. Ouspenski, and P. Dorenbos, Applied Physics Letters, 102, 161915 (2013)
[3] K. Yang, P.R. Menge, J.J. Buzniak, V. Ouspenski, NSS/MIC, 2012 IEEE , vol., no., pp.308,311, Oct. 27-Nov. 3 (2012)
[4] A. Benedetto, S. Valladeau, D. Richaud, V. Ouspenski, R. Gy, poster 094, SORMA XV (2014)

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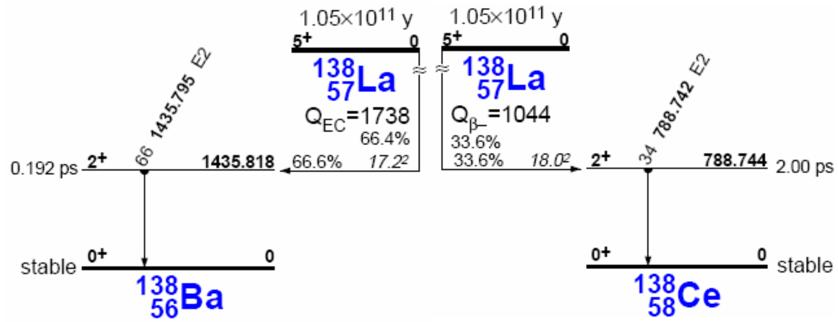
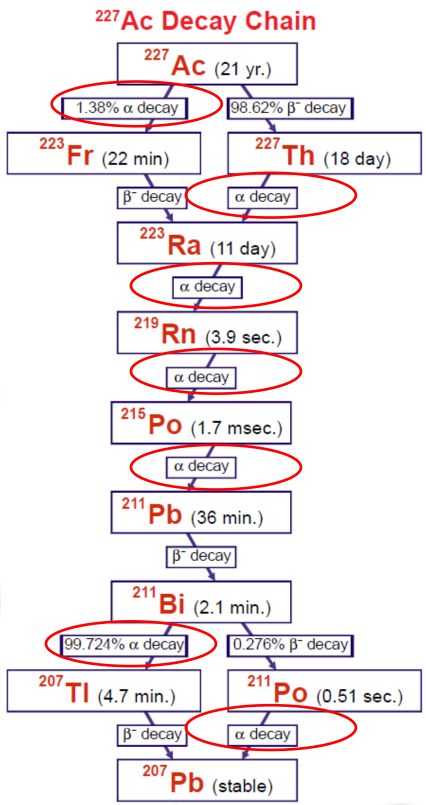
Radiation Background in $LaBr_3$:Ce

^{138}La: γ (1436 keV + 789 keV) + β



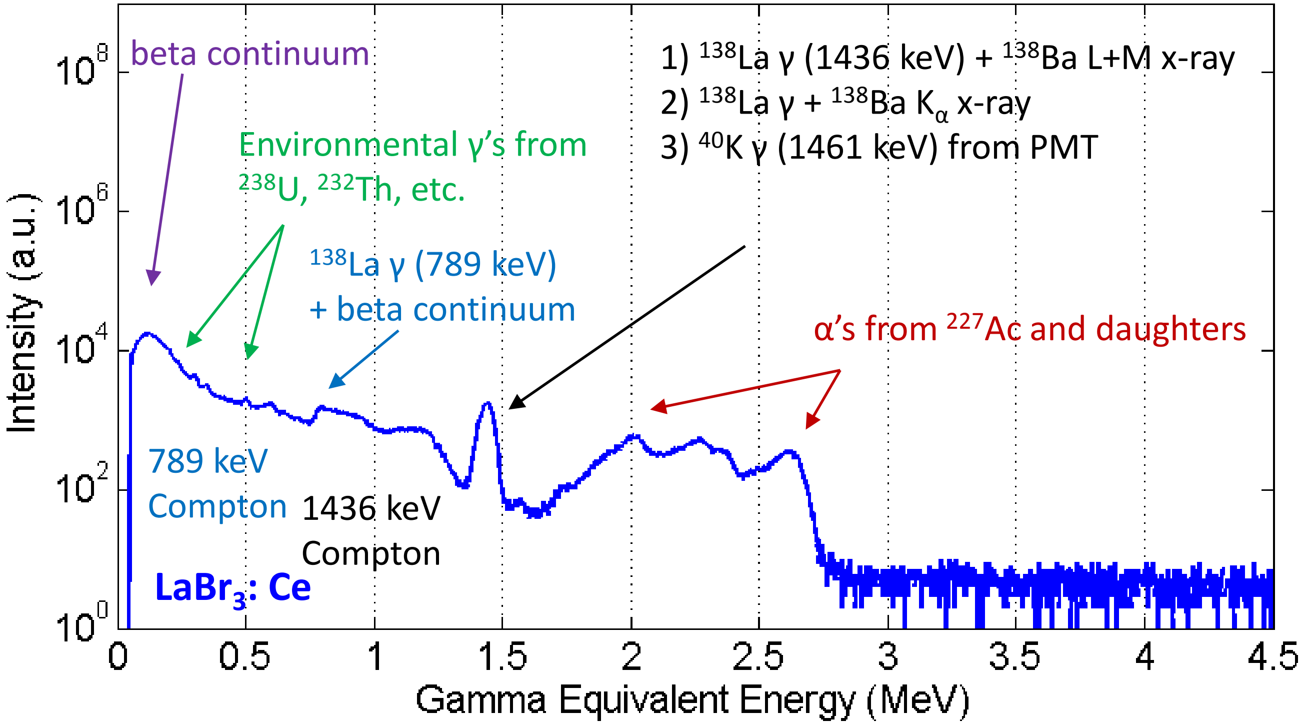
^{227}Ac: mainly α (5.0 – 7.4 MeV)



L.P. Ekström and R.B. Firestone, WWW Table of Radioactive Isotopes, database version 2/28/99 , http://ie.lbl.gov/toi/index.htm

Gamma-ray spectrum catalogue, Ge and Si Detector Spectra 4th Edition, Idaho National Engineering & Environmental Laboratory, 1999

Radiation Background in $LaBr_3$:Ce



Doping	G.E.E. (α)
Ce	1.7 – 2.7 MeV

B.D. Milbrath, R.C. Runkle, T.W. Hossbach, W.R. Kaye, E.A. Lepel,B.S. McDonald, L.E. Smith, NIM-A 547 (2005) 504-510
F.G.A. Quarati et. al, Nuclear InstrumentsandMethodsinPhysicsResearchA683(2012)46–52
"BriLanCe Performance Summary" , Saint-Gobain Crystals, http://www.crystals.saint-gobain.com/

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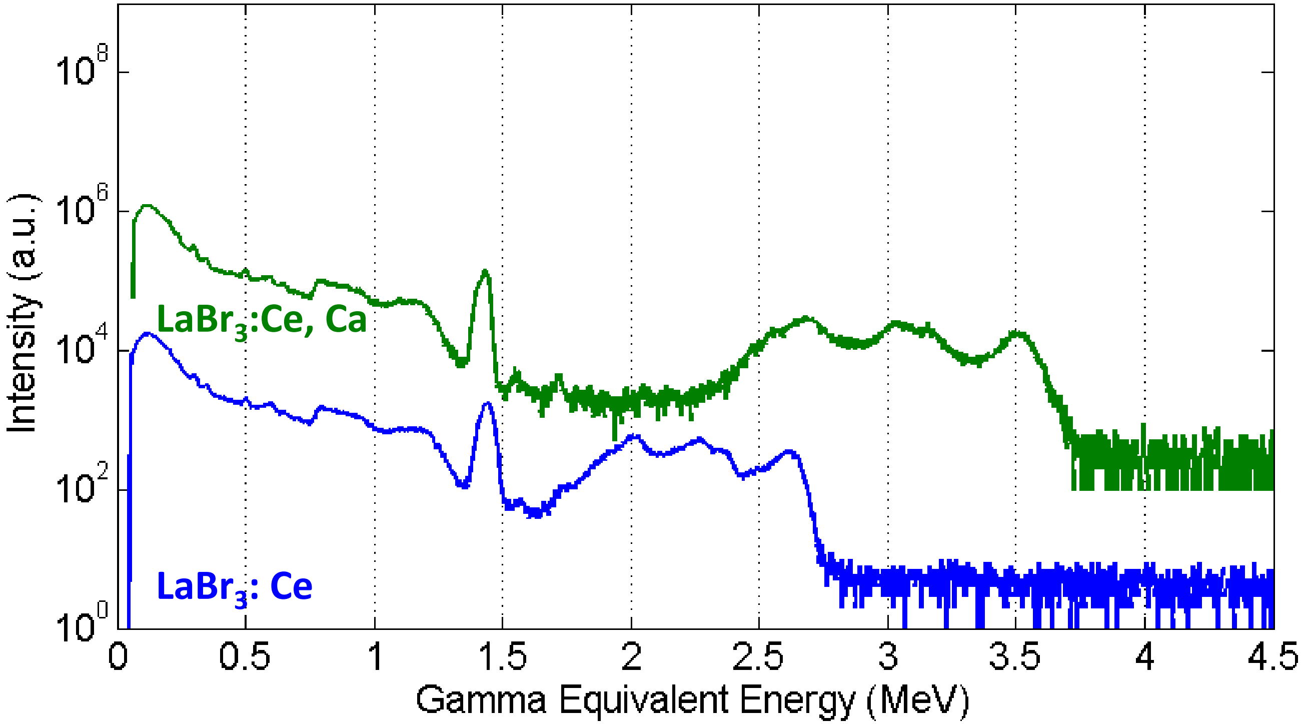
Radiation Background in Co-doped $LaBr_3$:Ce



Doping	G.E.E. (α)
Ce + **Ca**	2.3 - 3.6 MeV
Ce	1.7 – 2.7 MeV

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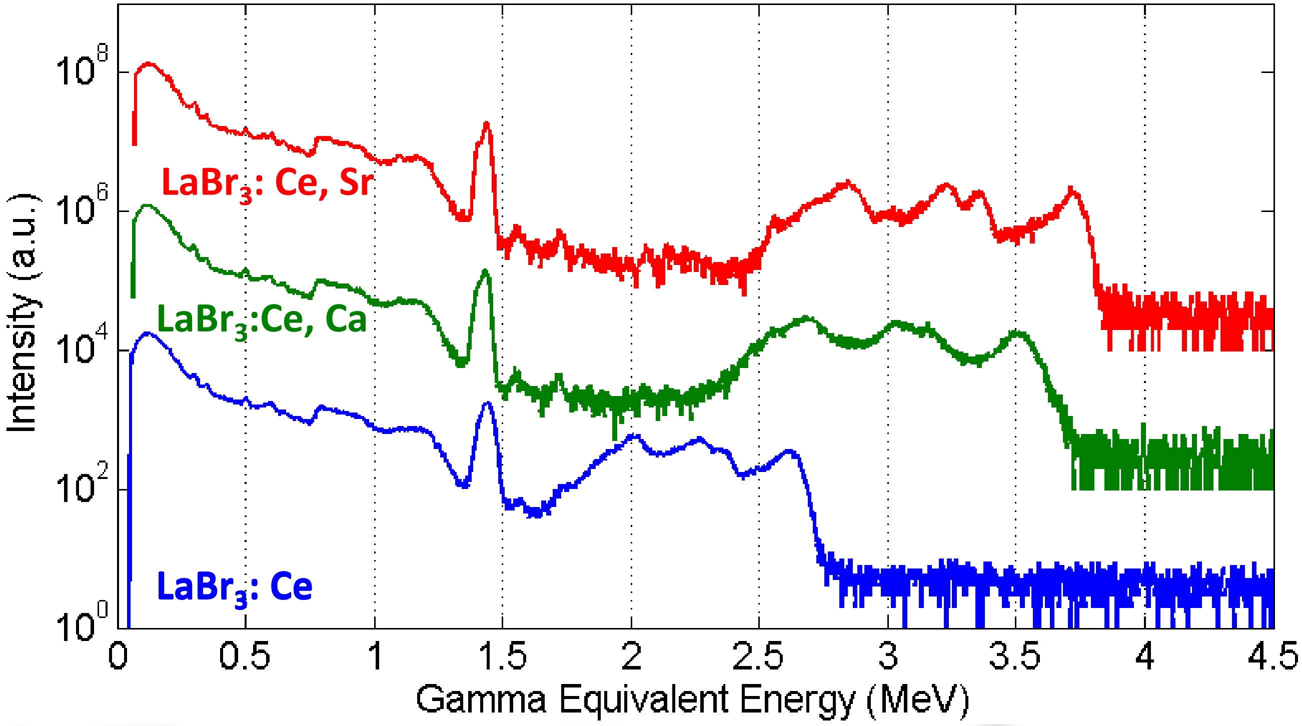
Radiation Background in Co-doped $LaBr_3$:Ce



Doping	G.E.E. (α)
Ce + **Sr**	2.5 - 3.8 MeV
Ce + **Ca**	2.3 - 3.6 MeV
Ce	1.7 – 2.7 MeV

- **Gamma Equivalent Energy of α increases significantly.**

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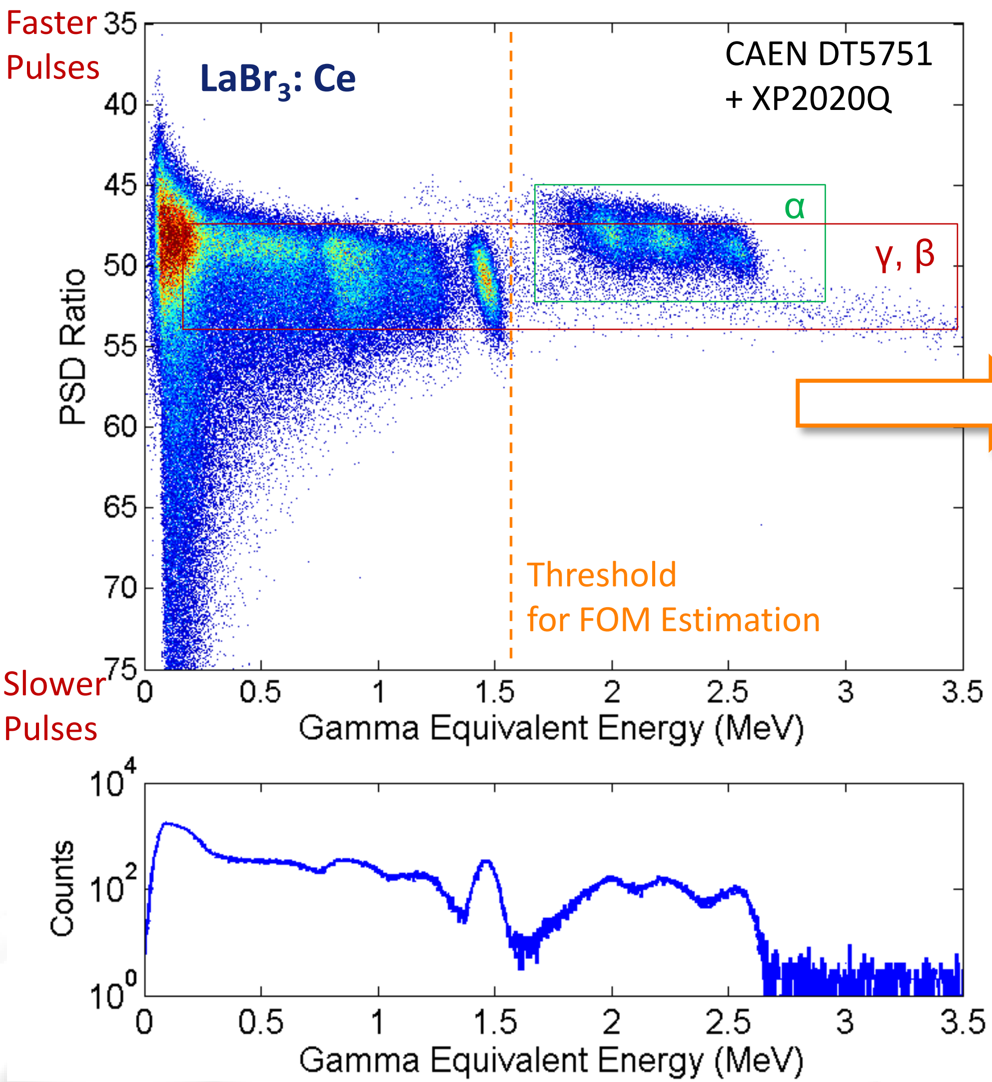
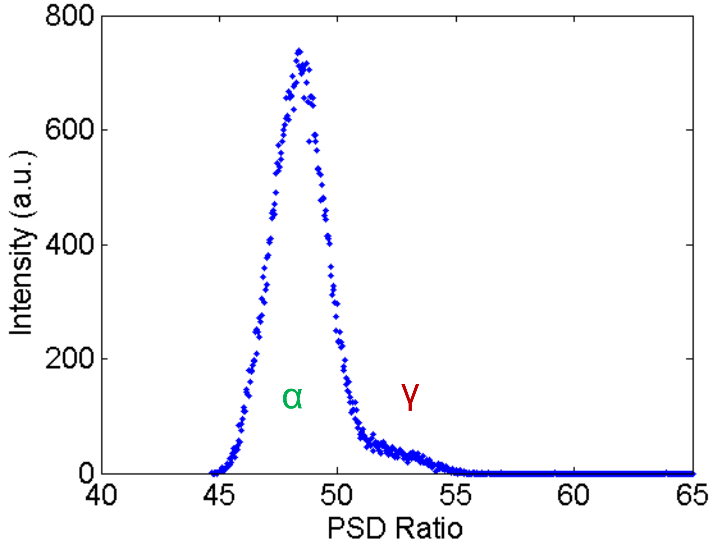
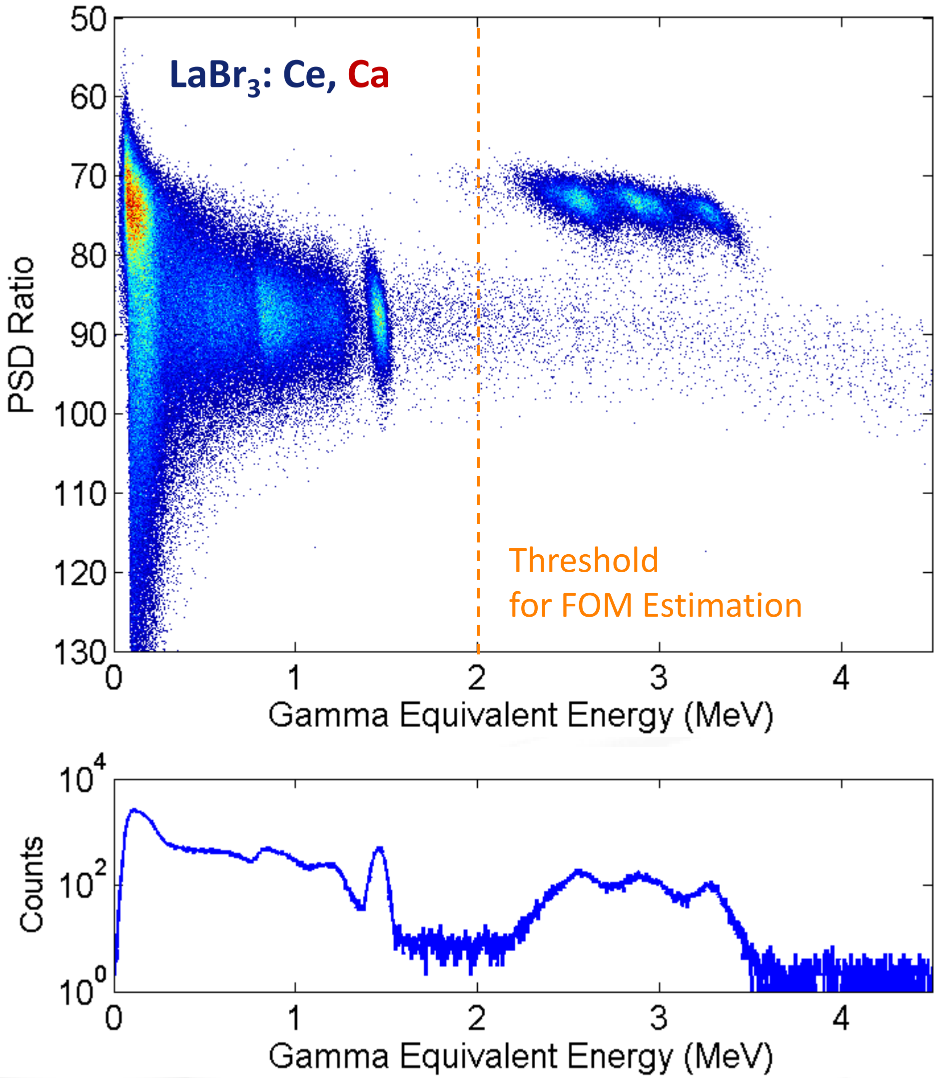
Pulse Shape Discrimination

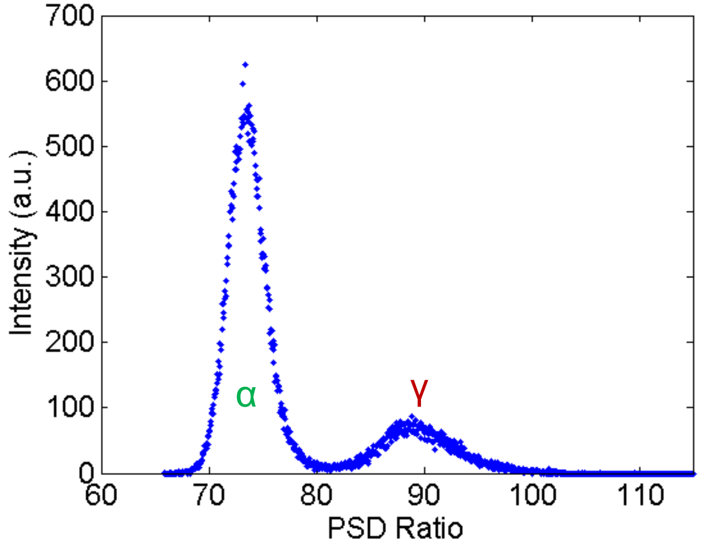




- **PSD Figure of Merit = 0.73**

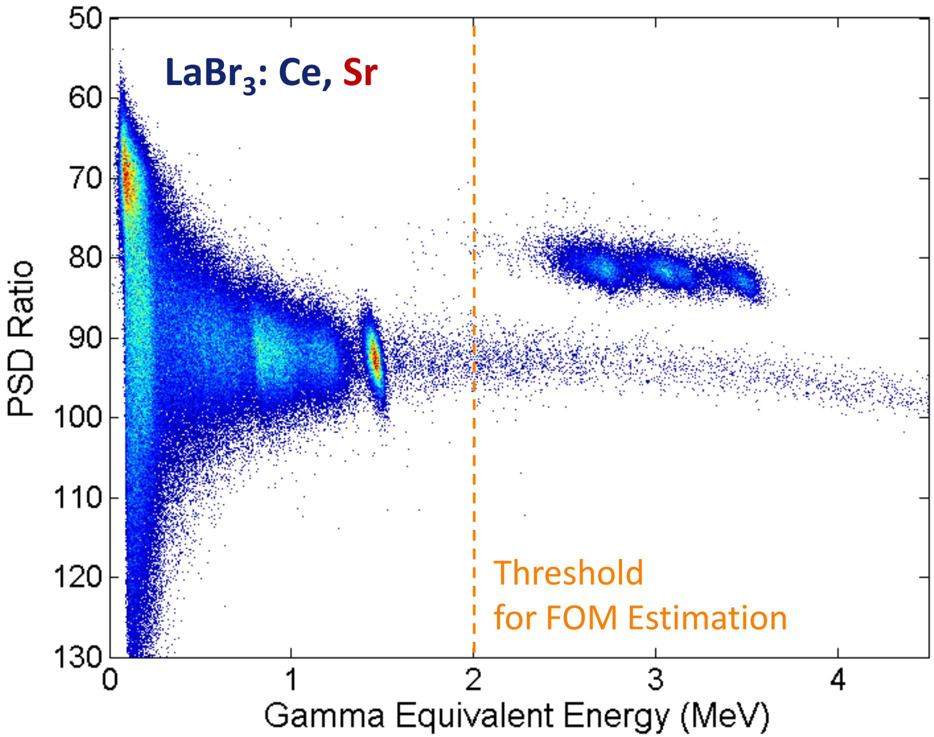
Pulse Shape Discrimination

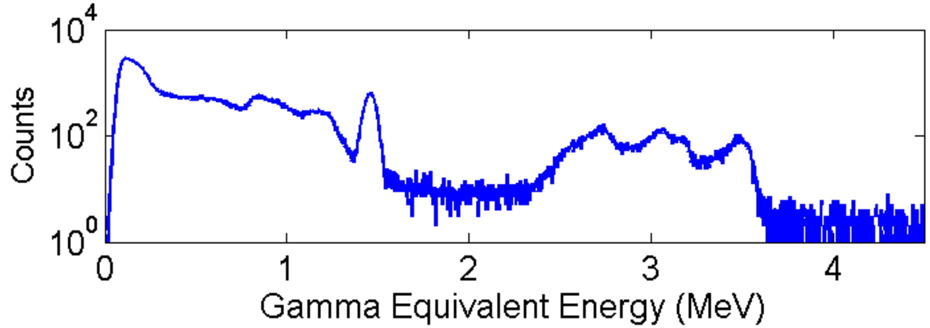


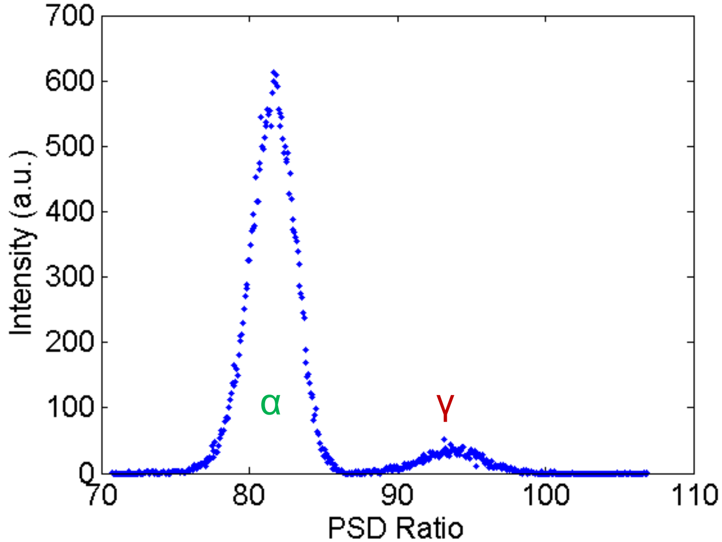


- **PSD Figure of Merit = 1.25**
- **Significantly enhanced PSD**

Pulse Shape Discrimination

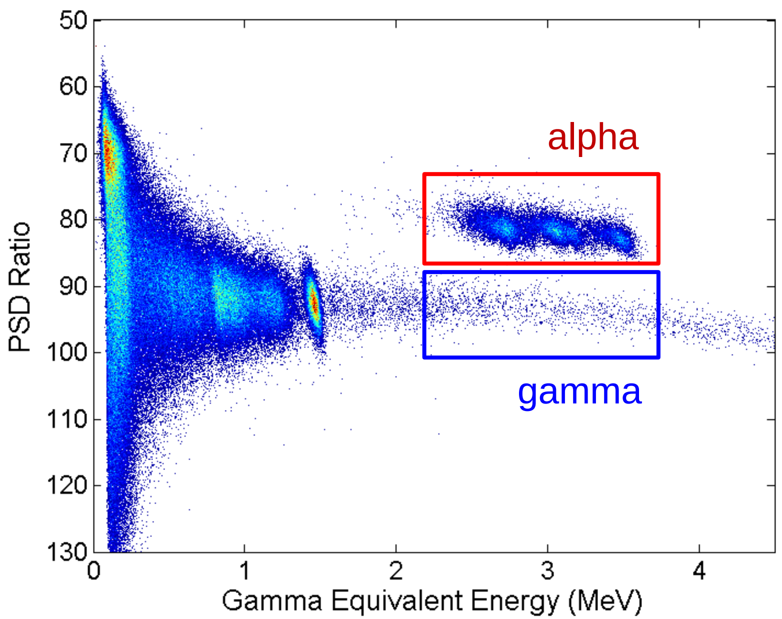




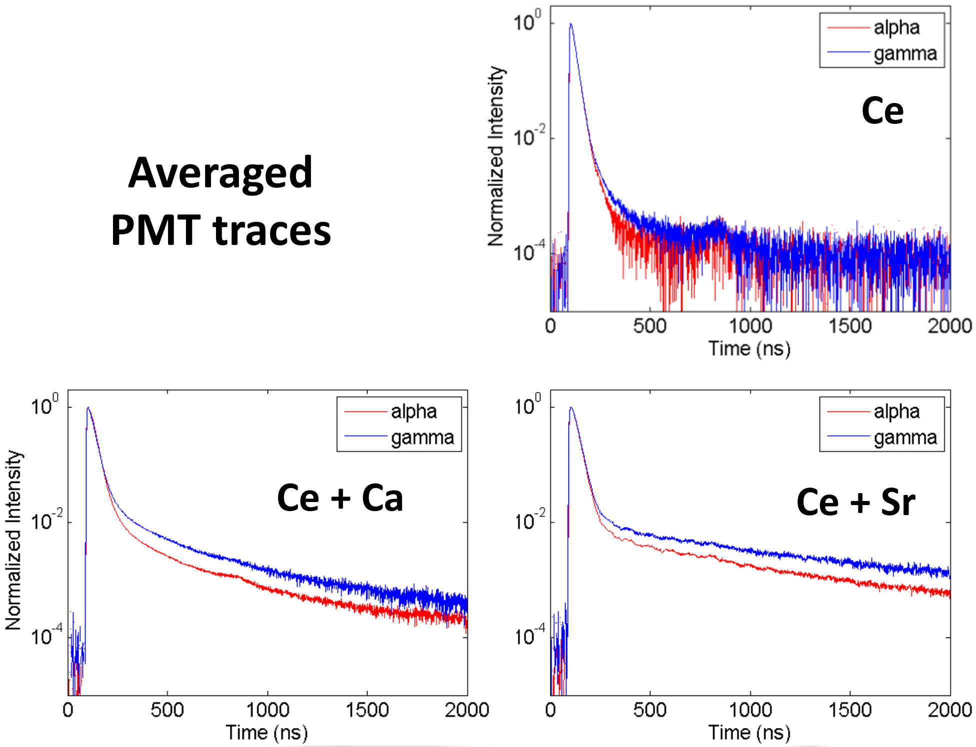


- **PSD Figure of Merit = 1.57**

Change in Pulse Shapes



Averaged PMT traces



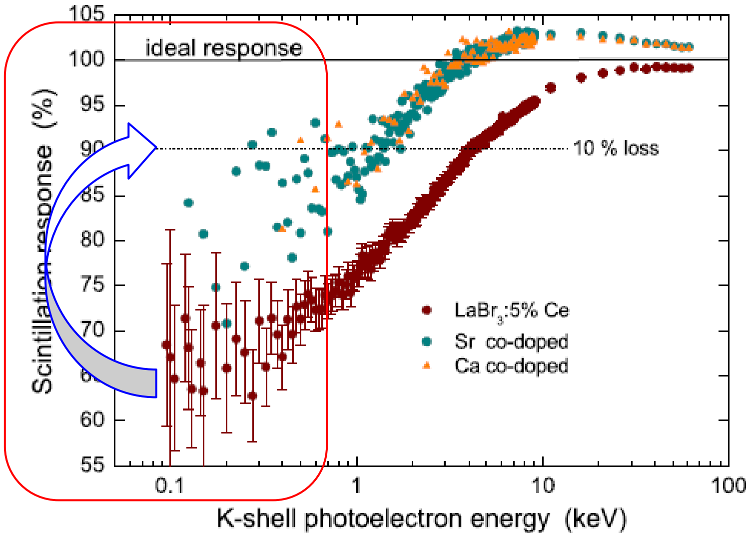
Percentage of light in secondary decay components

	Ce	Ce + Ca	Ce + Sr
α	1.2%	6.3%	9.5%
γ	2.1%	12.7%	15.1%

- **Alpha pulses have less secondary decay components than gamma pulses.**
- **Basis for enhanced PSD**

Possible Explanation

- **Increased α GEE**
  - **Compared to gamma and beta, charged particles produce more low energy charge carriers with higher excitation density (*dE/dx*).**
  - **Both Ca and Sr co-doping increase the relative light yield of $LaBr_3$:Ce for low energy electrons**
  - **Higher light yield for charged particles**



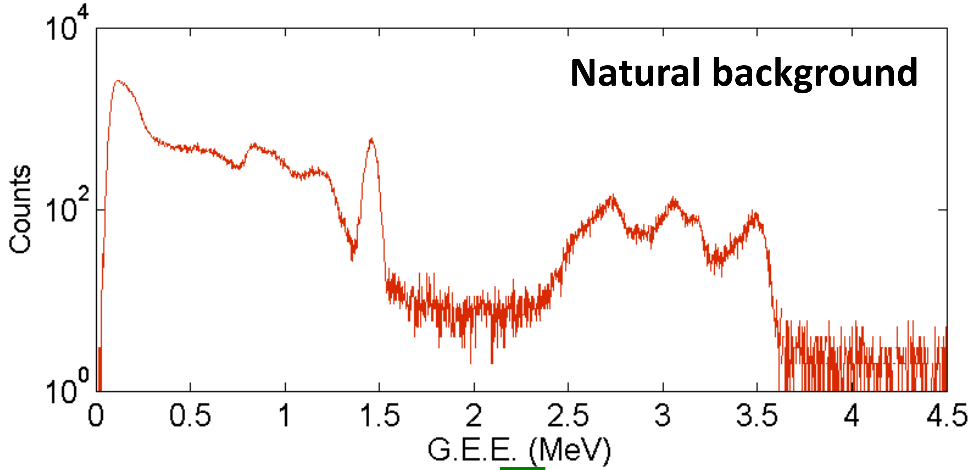
M. S. Alekhin, J. T. M. de Haas, I. V. Khodyuk, K. W. Krämer, P.R. Menge, V. Ouspenski, and P. Dorenbos, Applied Physics Letters, 102, 161915 (2013)

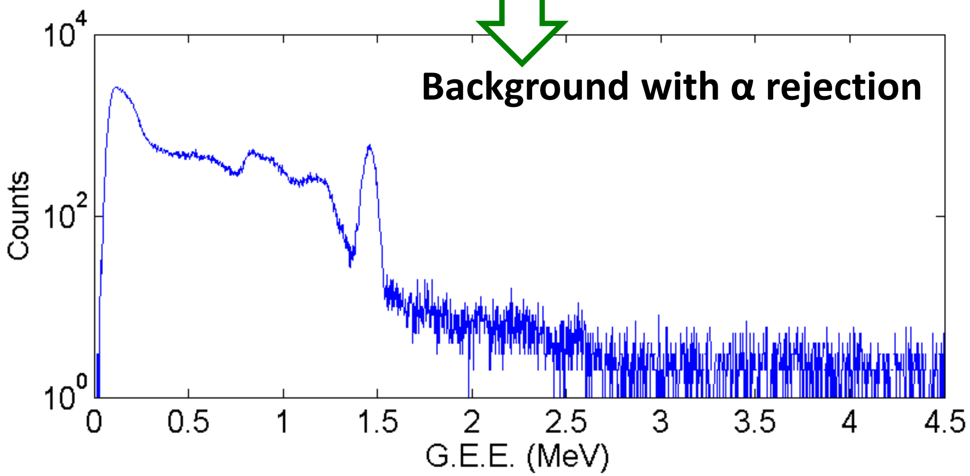
- **Enhanced α-γ PSD**

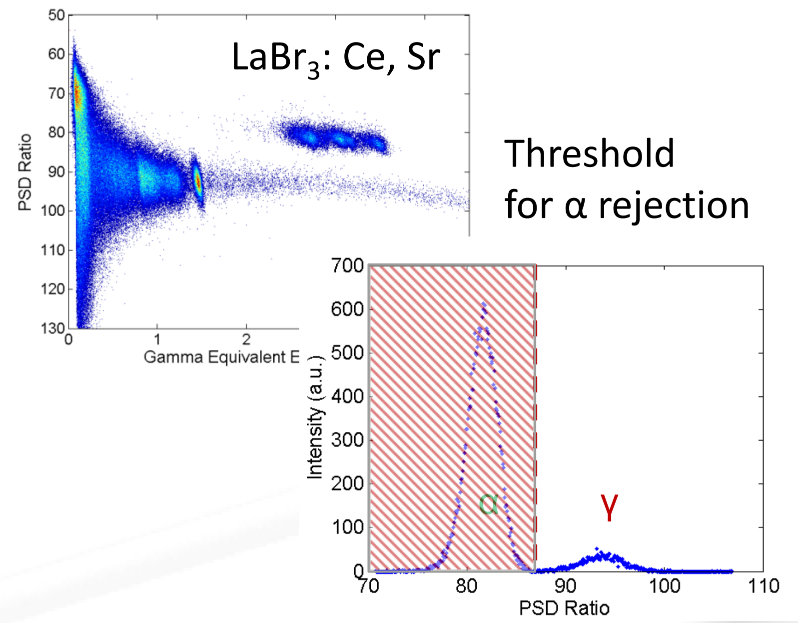
R.T. Williams, J.Q. Grim, Q. Li, K.B.Ucer and W.W. Moses, Phys. Status Solidi B 248, No. 2, 426–438 (2011)

  - **Higher light yield: PSD Resolution** $\propto \frac{1}{\sqrt{N}}$
  - **New information: Ca and Sr co-doping may change the branching ratio for different quenching routes in $LaBr_3$:Ce. The excitation-density-sensitive exciton-exciton annihilation (bi-molecular decay) could be enhanced.**

Alpha Background Suppression







- **α-γ PSD FOM = 1.57**
- **Rejection ratio 10^{-8}**
- **No background above 1.5 MeV**

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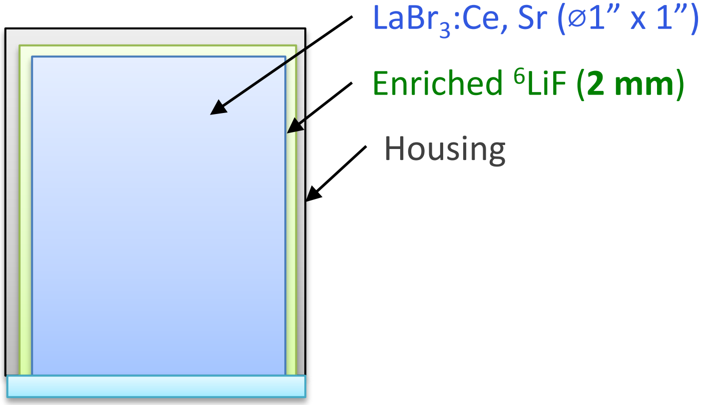
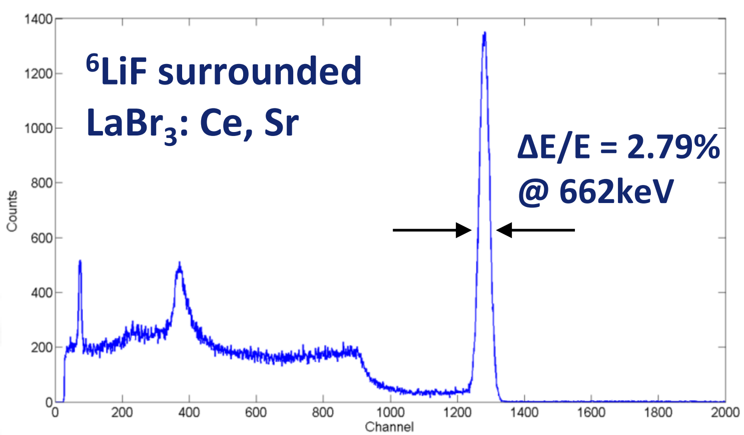
^{6}LiF-$LaBr_3$(Ce, Sr) Neutron Detector



Proof-of-Concept Detector

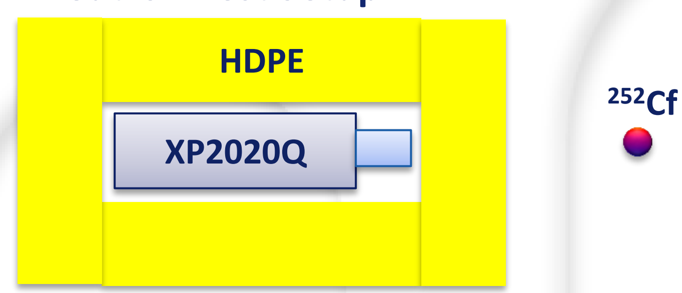
n + ^{6}Li → t (2.75 MeV) + α (2.05 MeV)

- **$LaBr_3$ surrounded with ^{6}LiF as a neutron conversion layer and light reflector**
- **Range of α in LiF = 6.6 μm;**
- **Range of t in LiF = 28.1 μm**
- **Thickness of LiF layer is not optimized.**

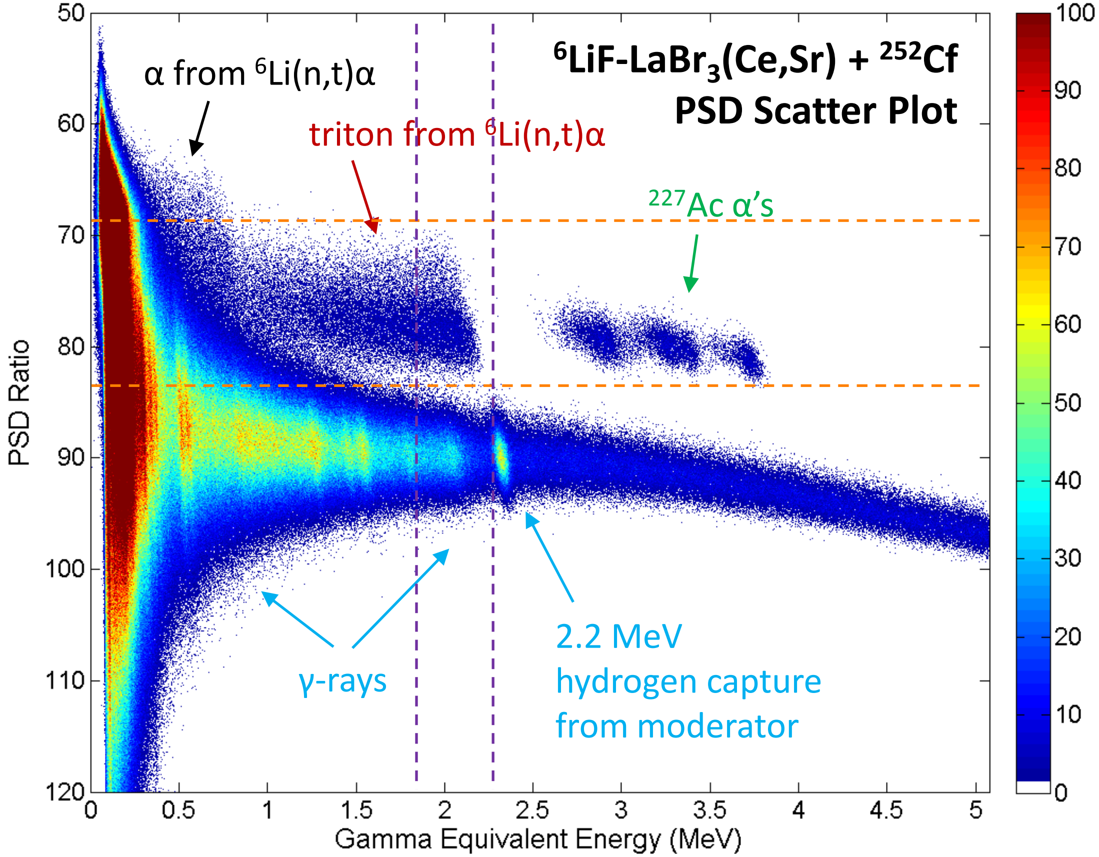


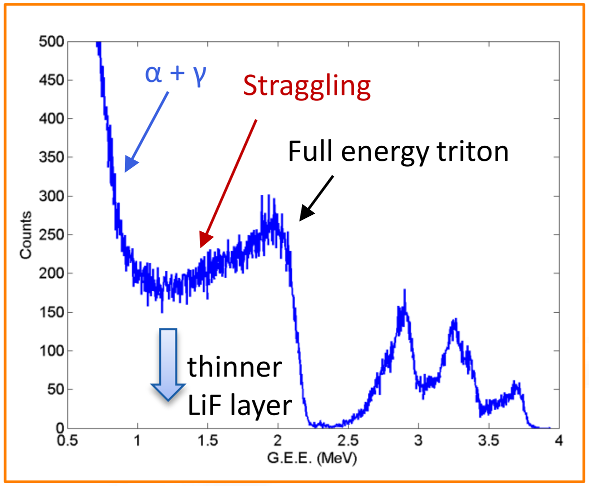
No change in gamma response

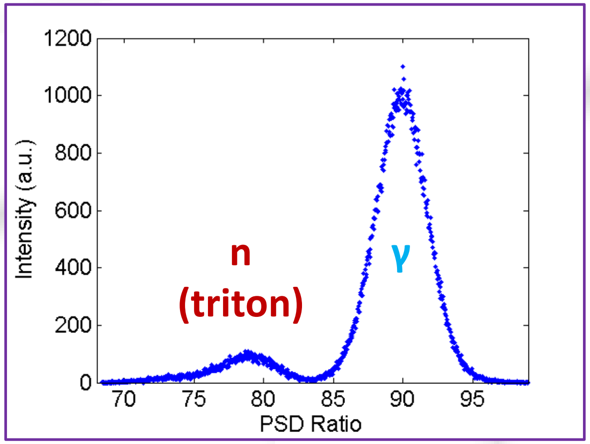
Neutron Test Setup



Neutron Response







- **Clear separation between neutron and gamma**
- **Triton is much less quenched than alpha.**
- **n-γ PSD FOM = 1.22 (rejection ratio ~ 10^{-5})**

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Summary and Outlook

- Both Ca and Sr co-doped $LaBr_3$:Ce shows **significantly increased GEE for charged particles** and **enhanced α-γ PSD**.
- α background in co-doped $LaBr_3$:Ce can now be completely eliminated by PSD (FOM > 1.5).
- With a ^{6}LiF conversion layer, Sr co-doped $LaBr_3$:Ce can be used as a high-performance detector for both neutron and gamma.
- Thickness of ^{6}LiF and geometry of $LaBr_3$:Ce will be further optimized to improve detection efficiency and reduce energy straggling.

Thank you for your attention.