Meet Requirements for Detectors in HEP

Jack Lin GM
Taiwan Applied Crystal
Jacklin_tac@tacrystal.com

LARGAN | TAC
大立光電集團 台灣應用晶體股份有限公司

Company Profile

- TAC was founded in 2012
- Spin-off from NSYSU in 2015
- To become a member of Largan Group in 2023.7

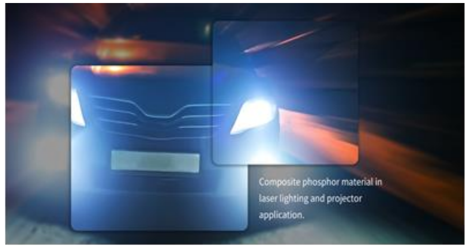
LARGAN | TAC
大立光電集團 台灣應用晶體股份有限公司

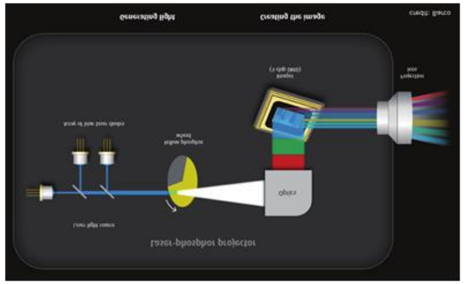
Company Profile

Advanced Medical Image and High Energy Physics

↑

Scintillator

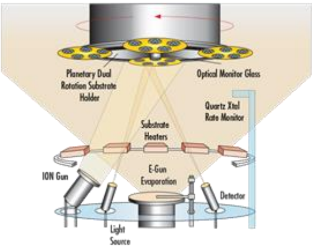


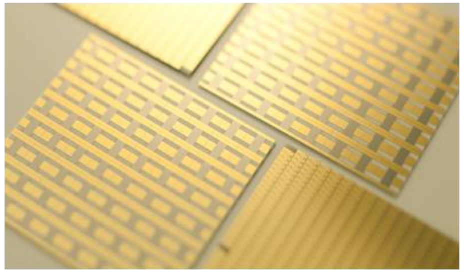


Laser Lighting
Laser Projector

↑

Crystal Phosphor





Sputtering Target
Heat Dissipation Substrate

↑

Ta_2O_5/Nb_2O_5
AlN

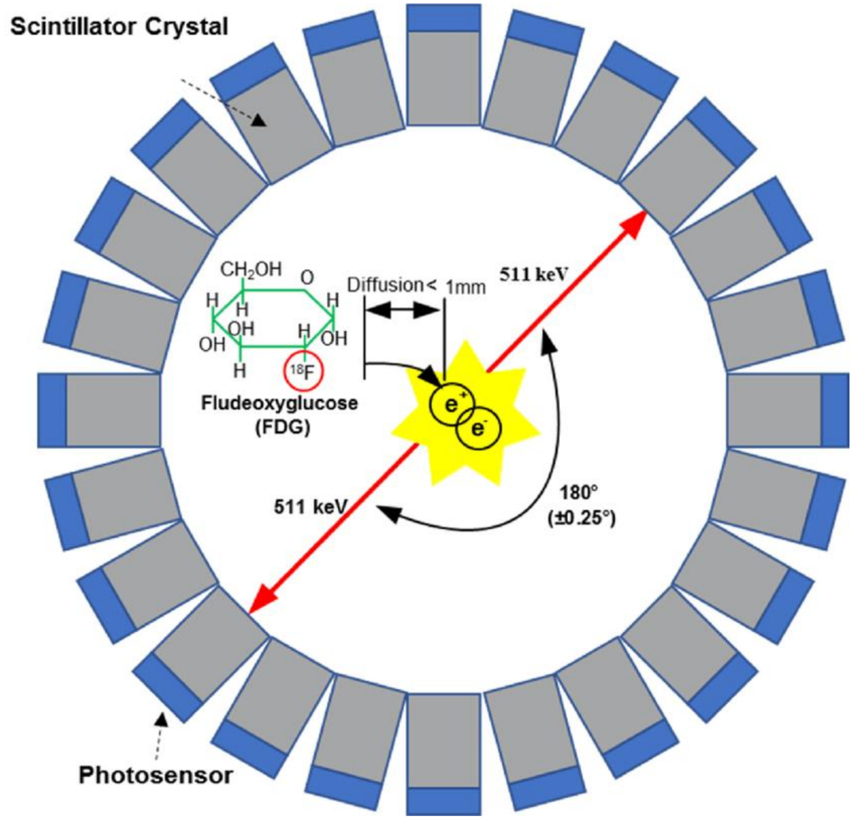
EV
Fast Charging

↑

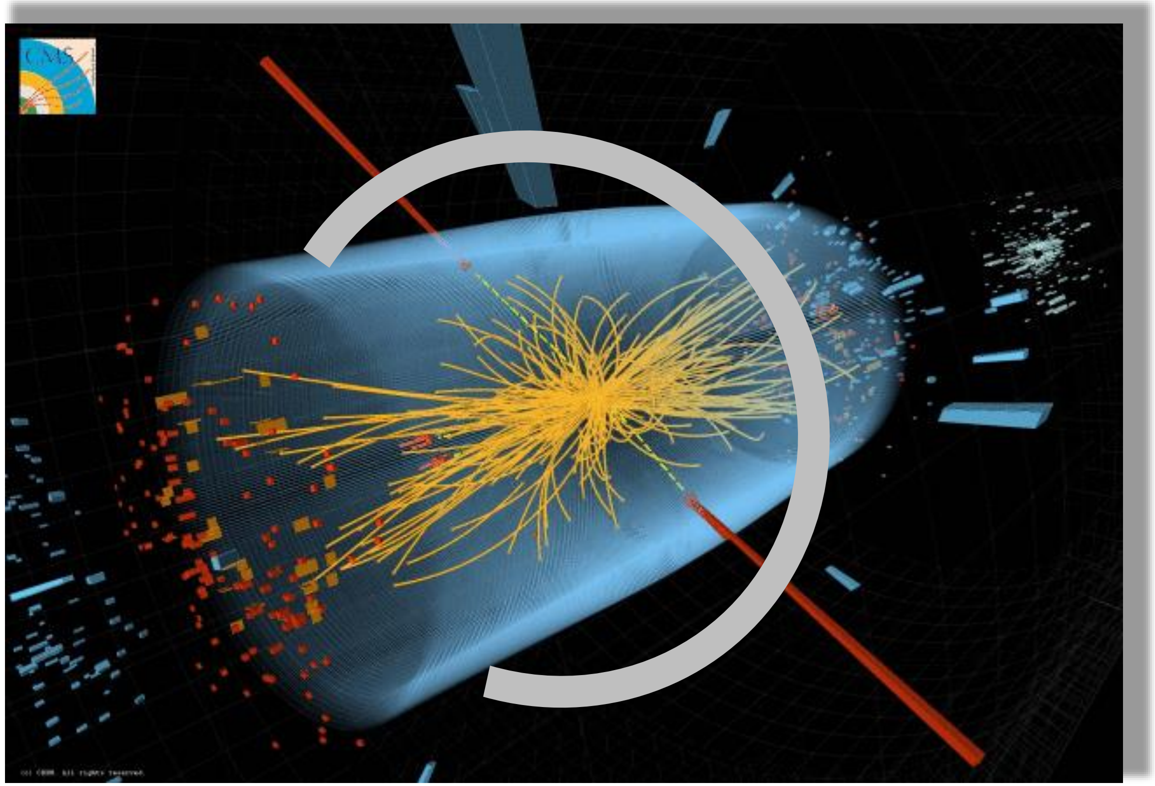
SiC

Choices of Scintillators

Medical vs. High Energy Physics

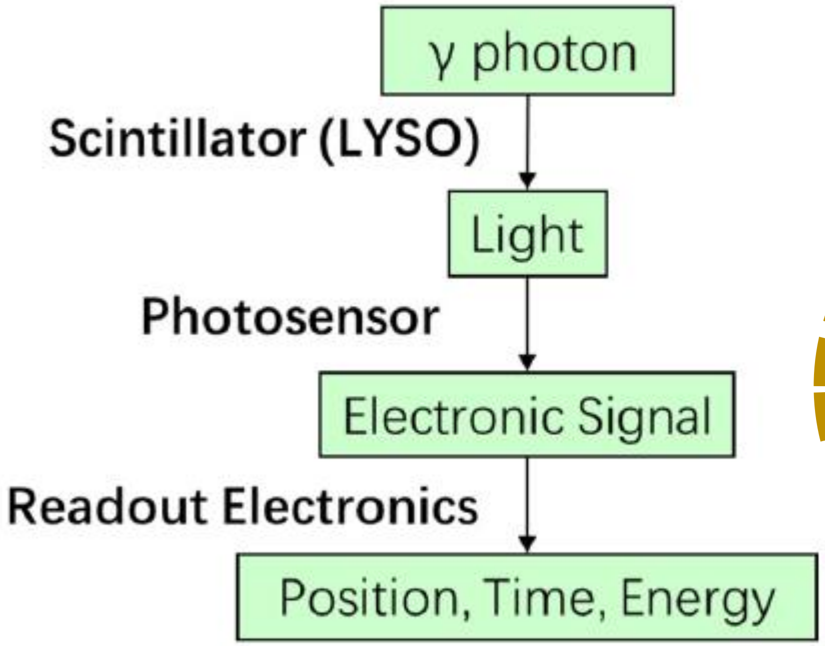


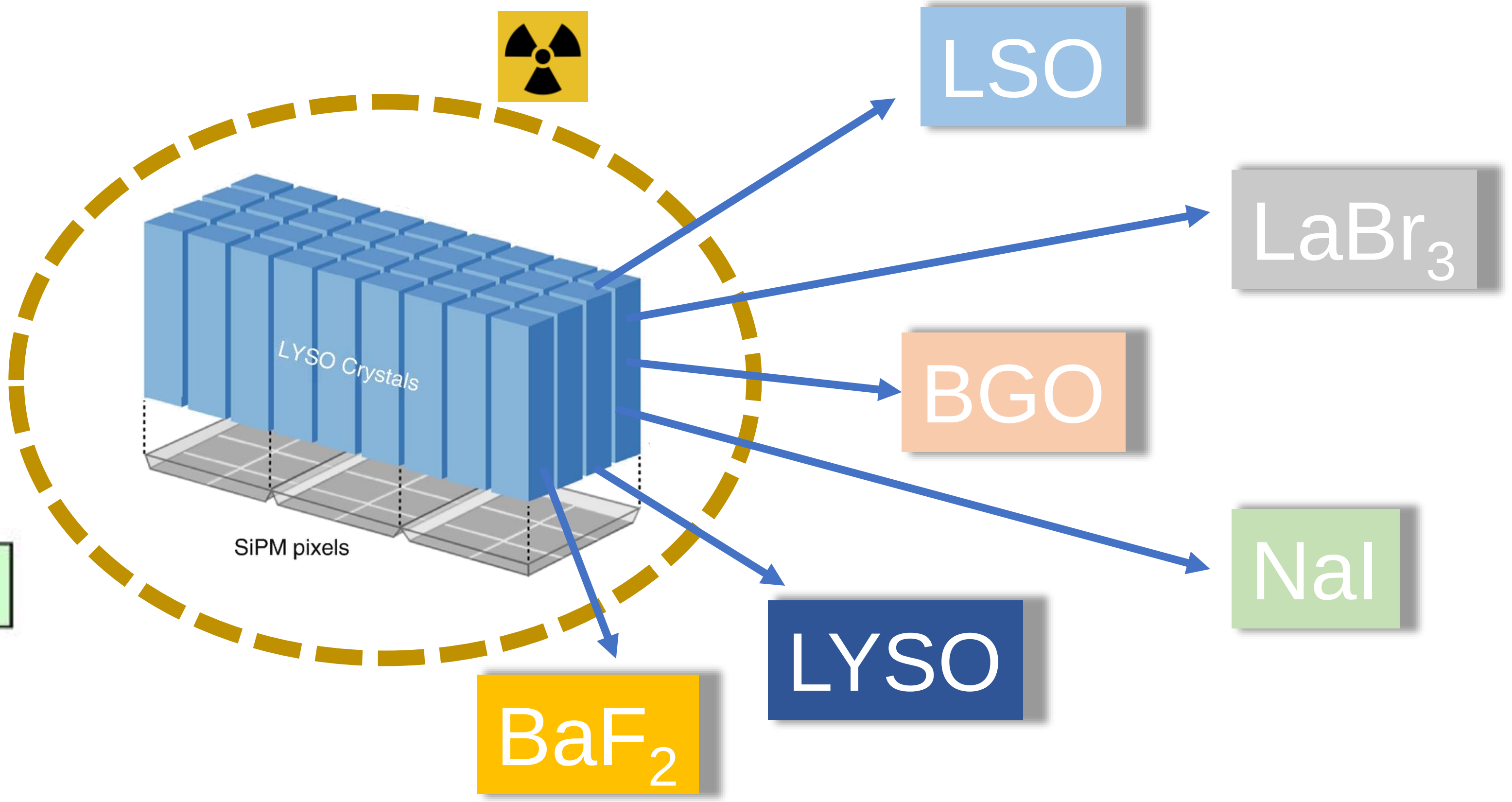
To detect photons which are created during the e^+ e^- annihilation process



To detect photons which are created during the particle collisions process

Choices of Scintillators





Choices of Scintillators

Crystal	Density [g / cm^3]	Decay time [ns]	Total light output [photons / MeV]	Energy resolution at 662 keV [%]	
BGO[a]	7.1	300	6 000	10.2 / 20	Slow timing
LYSO(Ce)	7.1	41	32 000	10.0	Lutetium is expensive
LSO(Ce)	7.4	40	32 000	10.0	
$LaBr_3$(Ce)	5.1	16	63 000	2.9	Easy to be deliquescent
NaI(Tl)[a]	3.7	230	38 000	6.6	
BaF_2	4.9	0.8	12 000	11.4	

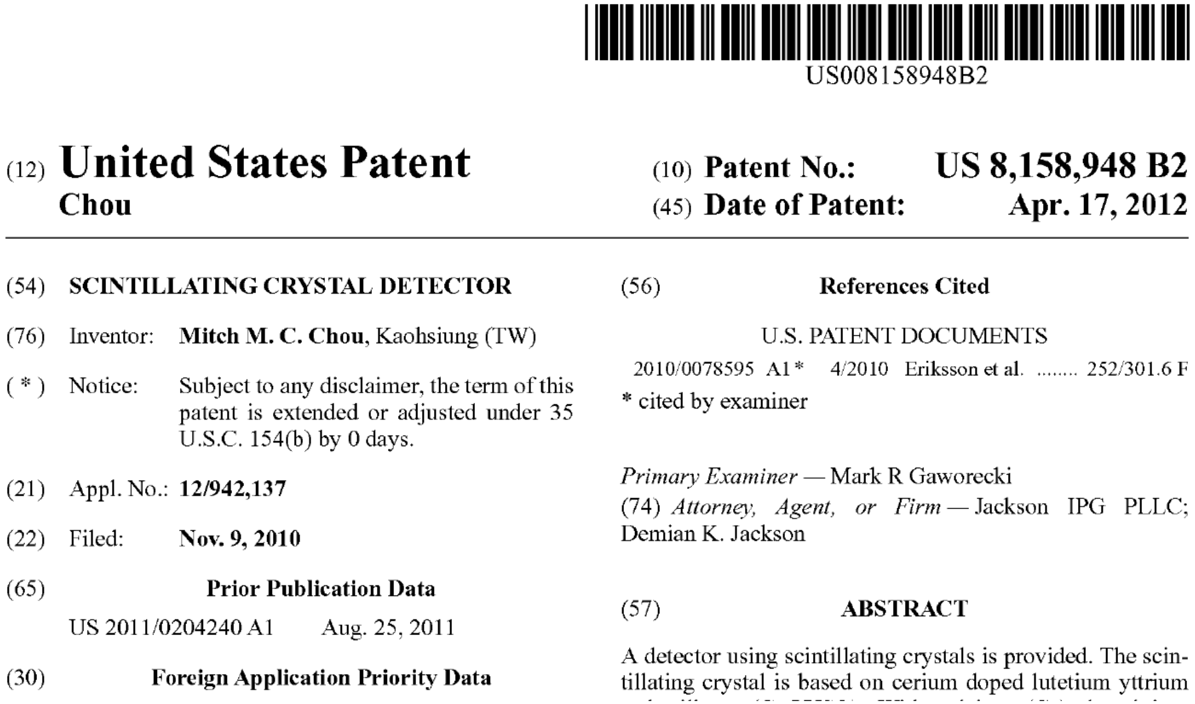
It is always a trade-off to choose a scintillator for a specific application

Balance of cost and performance

LYSO Requirement in HEP

High Light Yield Requirements

The present disclosure relates to ***doping Calcium (Ca) / Magnesium (Mg) atoms*** into cerium doped lutetium yttrium orthosilicate (Ce:LYSO) to be charge compensated with cerium (Ce) having 4 positive electrovalence (Ce^{4+}) to form Ce having 3 positive electrovalence (Ce^{3+}) for charge balance for light yield improved



US008158948B2

(12) **United States Patent**
Chou

(10) **Patent No.:** **US 8,158,948 B2**
(45) **Date of Patent:** **Apr. 17, 2012**

(54) **SCINTILLATING CRYSTAL DETECTOR**

(76) Inventor: **Mitch M. C. Chou**, Kaohsiung (TW)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

(21) Appl. No.: **12/942,137**

(22) Filed: **Nov. 9, 2010**

(65) **Prior Publication Data**

US 2011/0204240 A1 Aug. 25, 2011

(30) **Foreign Application Priority Data**

(56) **References Cited**

U.S. PATENT DOCUMENTS

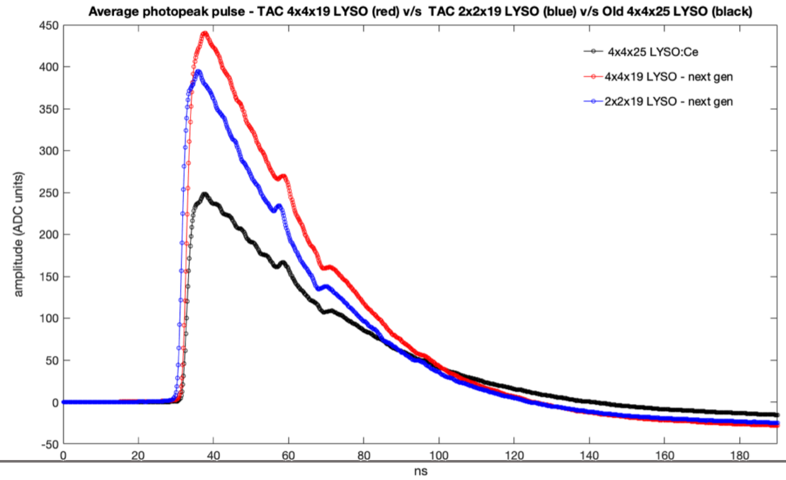
2010/0078595 A1 * 4/2010 Eriksson et al. .... 252/301.6 F

* cited by examiner

Primary Examiner — Mark R Gaworecki
(74) *Attorney, Agent, or Firm* — Jackson IPG PLLC; Demian K. Jackson

(57) **ABSTRACT**

A detector using scintillating crystals is provided. The scintillating crystal is based on cerium doped lutetium yttrium



- The measurement was performed by **Joel at Penn. Univ.**
- The light yield is superior to current one in the market

大立光電集團 台灣應用晶體股份有限公司

LYSO Requirement in HEP Towards the Limit of Special Resolution-CTR

Timing advances of commercial divalent-ion co-doped LYSO:Ce and SiPMs in sub-100 ps time-of-flight positron emission tomography

Vanessa Nadig[1], Katrin Herweg[1], Mitch M C Chou[2], Jack W C Lin[3], Edmund Chin[3], Chu-An Li[4,5], Volkmar Schulz[1,6,7,8] and Stefan Gundacker[1]

[1] Department of Physics of Molecular Imaging Systems (PMI), Institute for Experimental Molecular Imaging (ExMI), RWTH Aachen University, D-52074 Aachen, Germany
[2] National Sun Yatsen University, Kaohsiung 80424, Taiwan
[3] Taiwan Applied Crystal Co., LTD, Kaohsiung 80424, Taiwan
[4] Center of Crystal Research, National Sun Yat-sen University, Kaohsiung 80424, Taiwan
[5] Department of Materials and Optoelectronic Science, National Sun Yat-sen University, Kaohsiung 80424, Taiwan
[6] Hyperion Hybrid Imaging Systems GmbH, D-52074 Aachen, Germany
[7] Physics Institute IIIB, RWTH Aachen University, D-52074 Aachen, Germany
[8] Fraunhofer Institute for Digital Medicine MEVIS, D-52074 Aachen, Germany

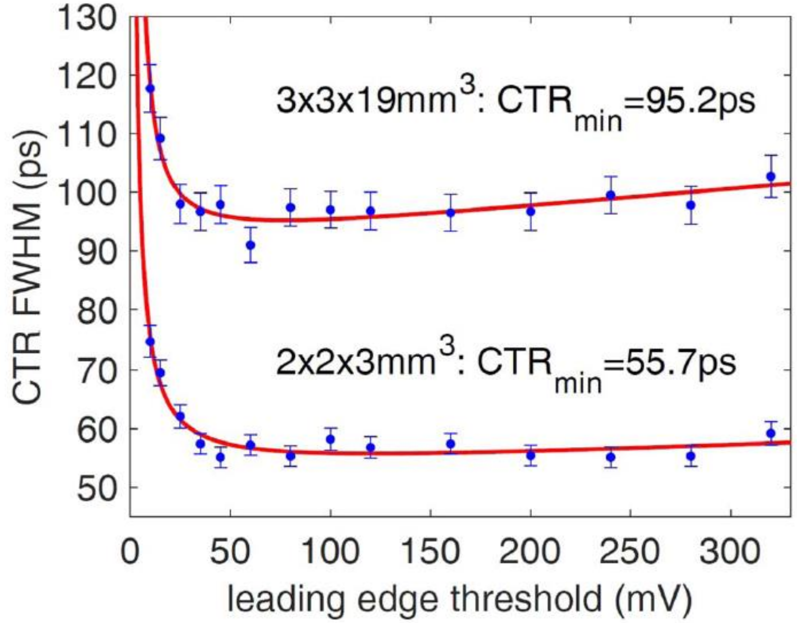


Figure 10. Optimal coincidence time resolution measured with two LYSO:Ce,Ca crystals (TAC, $2 \times 2 \times 3$ mm^3, four faces polished, and $3 \times 3 \times 19$ mm^3, six faces polished) coupled to novel Broadcom NUV-MT SiPMs (breakdown voltage 32 V) using Cargille Meltmount ($n = 1.582$). The SiPMs were read out by HF electronics and operated at a bias voltage of 50 V. The leading-edge threshold was varied.

LARGAN | TAC
大立光電集團 台灣應用晶體股份有限公司

LYSO Requirement in HEP

Tolerance of the Radiation Damage

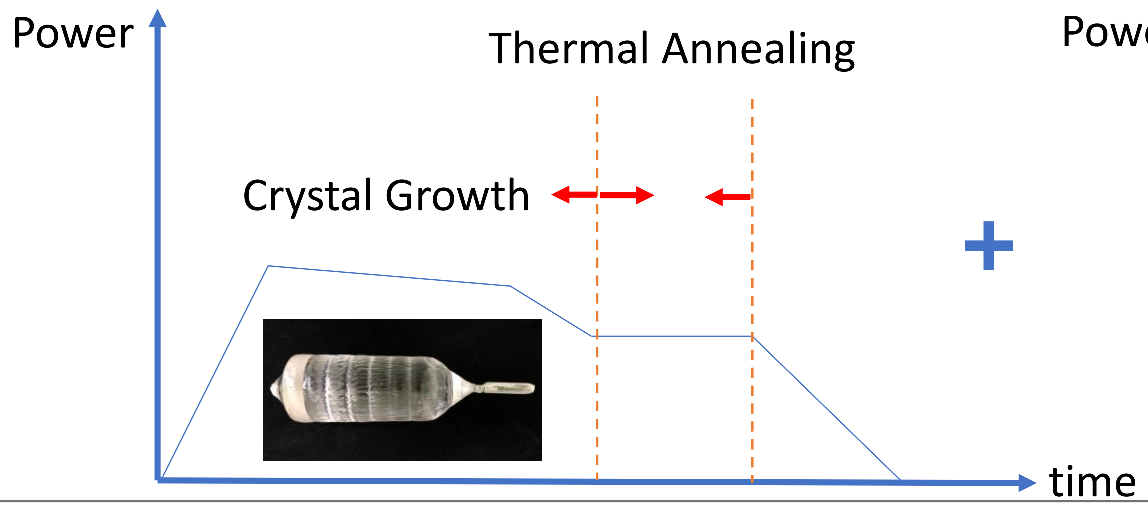
- Scintillation-mechanism damage: reduce the scintillation light yield
- Radiation-induced phosphorescence (afterglow): causes an increase of the dark current in the photodetectors, and thus an increase of the readout noise
- Radiation-induced absorption (color centers): reduce crystal’s light attenuation length (LAL), and hence the light output

Item	CsI(Tl)	CsI	BaF_2	BGO	PWO	LSO/LYSO
Scintillation mechanism	No	No	No	No	No	No
Phosphorescence (afterglow)	Yes	Yes	Yes	Yes	Yes	Yes
Absorption (color centers)	Yes	Yes	Yes	Yes	Yes	Yes

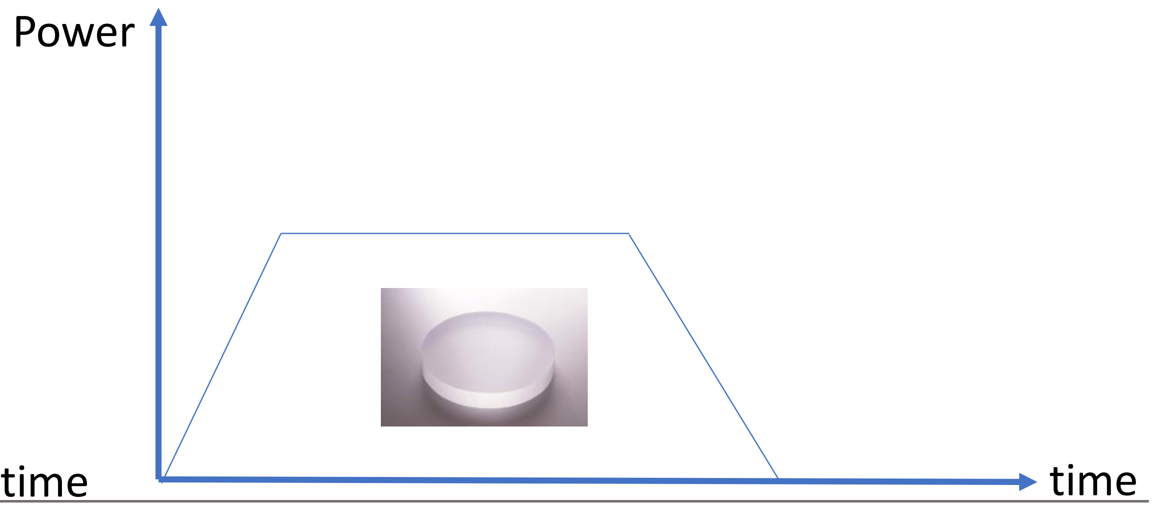
LYSO Requirement in HEP

Tolerance of the Radiation Damage

- Thermal annealing will be an effective way in eliminating color centers in the crystal from mass production perspective in factory.
- Two steps annealing during manufacturing:
  - Ingot annealing → Lengthen the time in the furnace after crystal growth finished
  - Slabs annealing



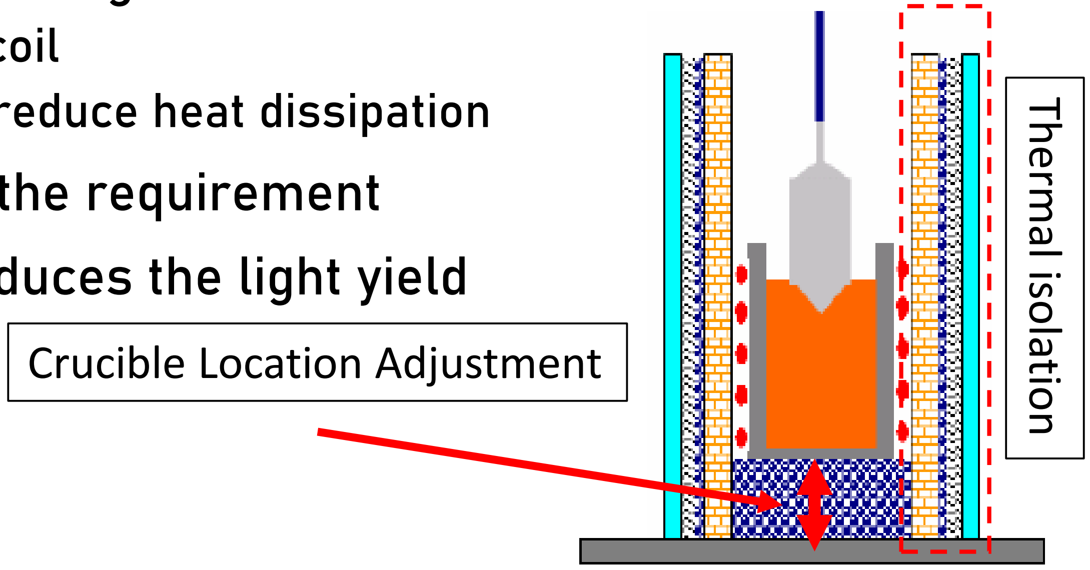
+



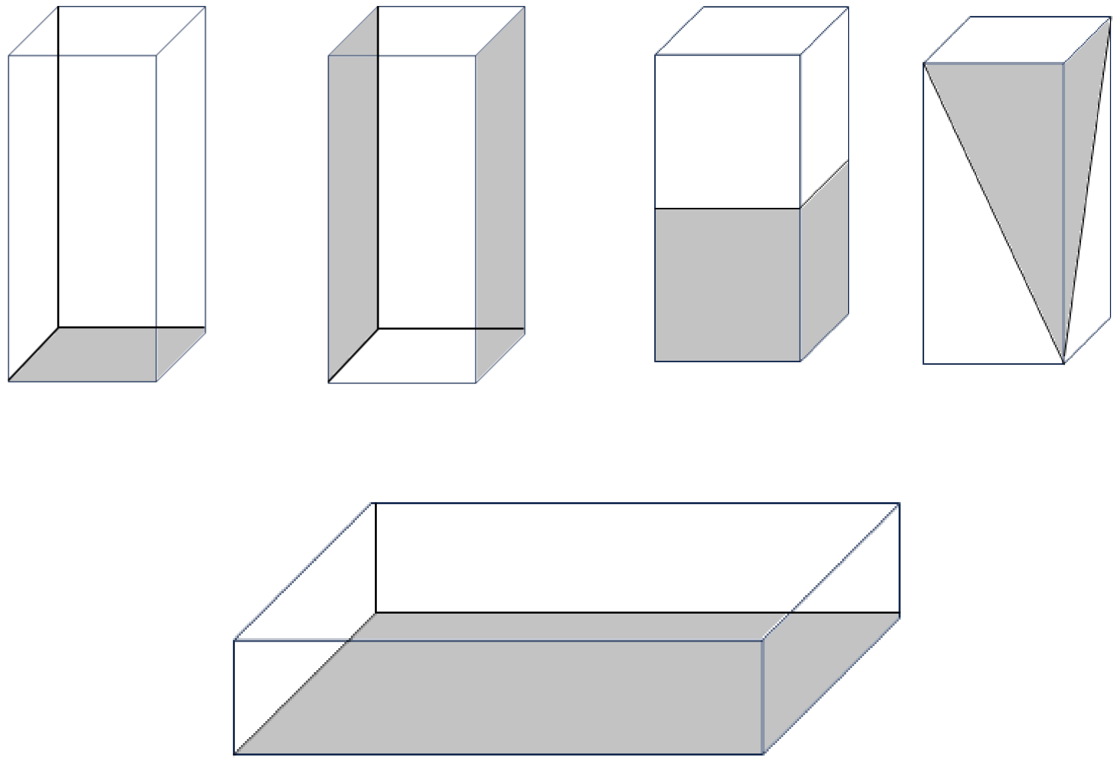
LYSO Requirement in HEP

The Uniformity of Crystal

- Due to segregation during the crystal growth，Ce distribution is not uniform from head to foot in the ingot.
- Two steps mentioned in reducing radiation-induced absorption are helpful to improve the uniformity.
- Crystal growth environment, thermal gradient in furnace is crucial.
  - Crucible location in the heating coil
  - Multilayers thermal isolation to reduce heat dissipation
- Over 95% pixels from ingot meet the requirement
- Classification of all pixels that reduces the light yield variation among the same array.

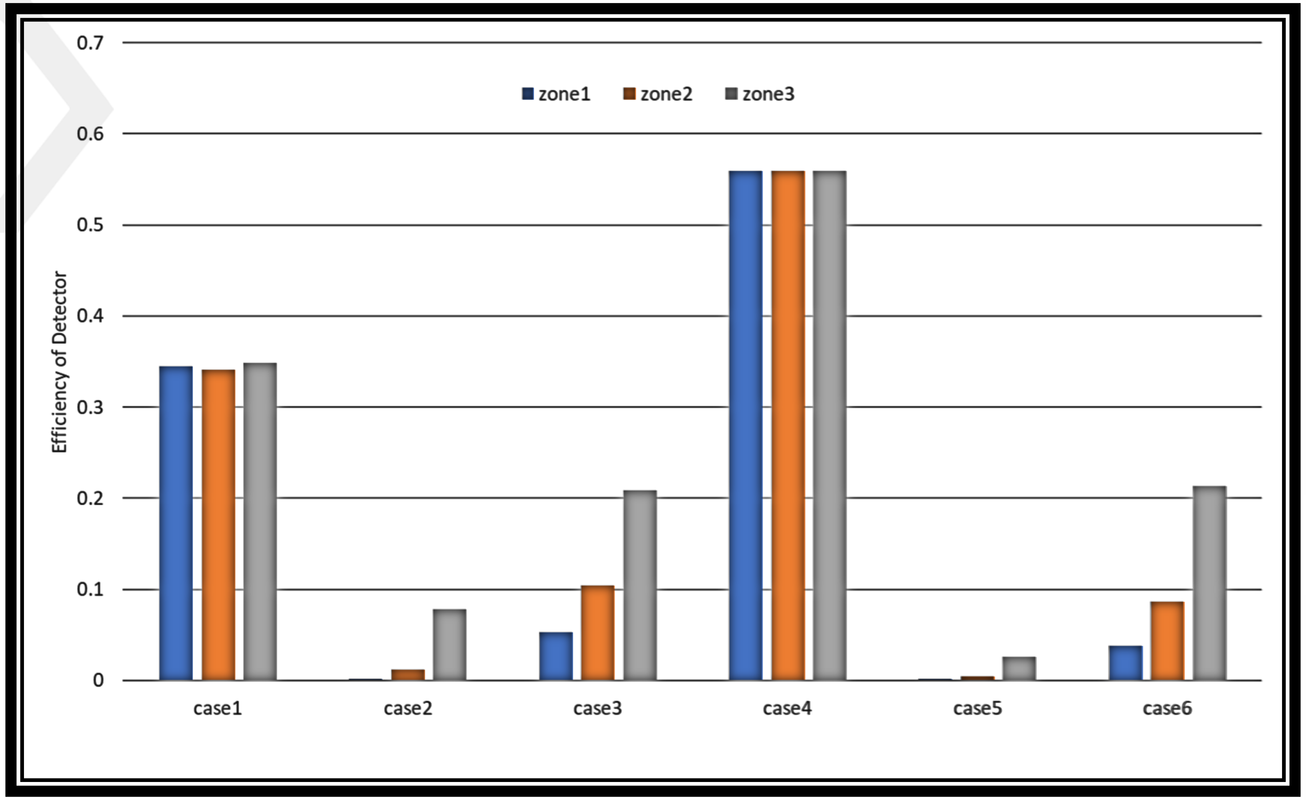


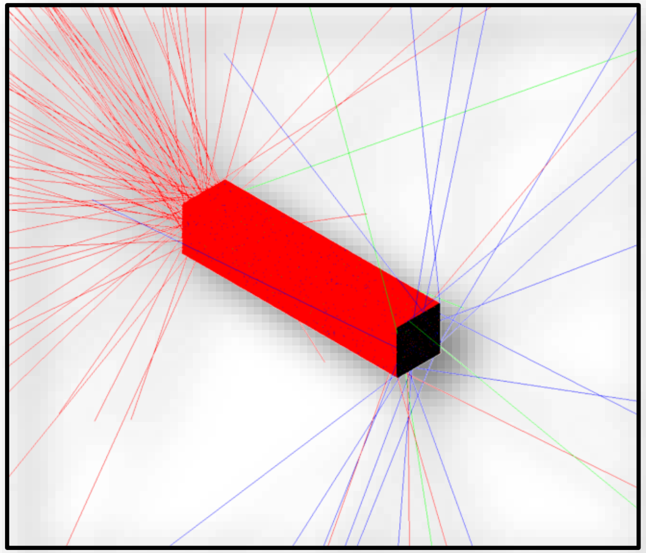
LYSO Special Treatment



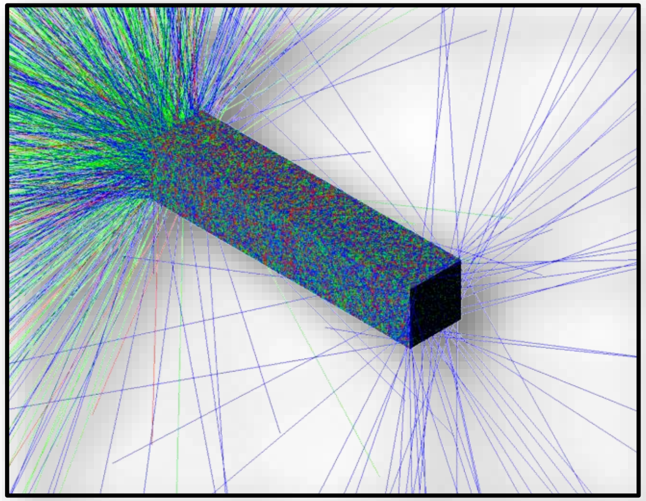
- Customized rough surface design
- To improve photon collection efficiency and lead to better CTR
- Ra value can be customized

LYSO Special Treatment

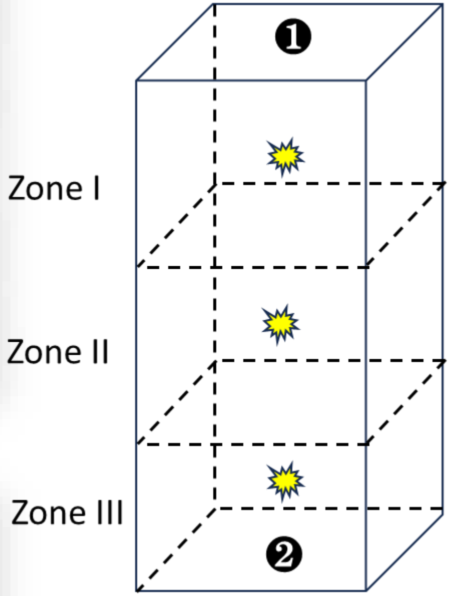




Case1



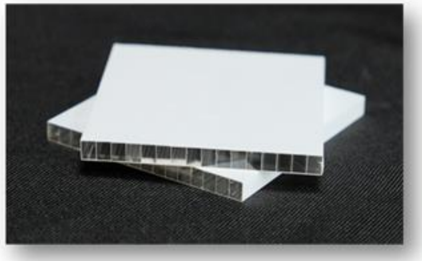
Case4

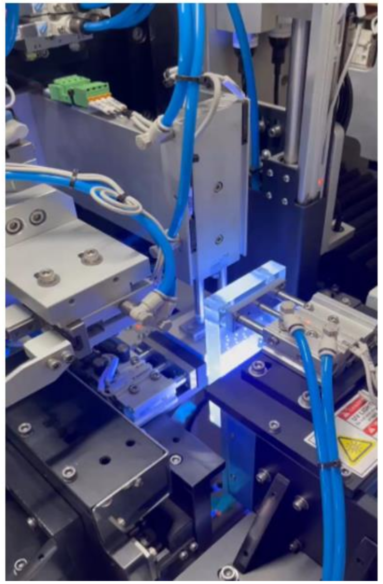


- **Case 1: 6 faces are polished and ESR at 4 lateral faces.**
- **Case 4: the same as Case1 but roughness at face 2 (conjunction with SiPM)**

LYSO Array Assembly Semi-Automation

- Semi-automation assembly to reduce manual assembly error and improve the accuracy of the array dimension.
- 3-steps to complete one dimension assembly. Load material→ line up crystal bar and reflector→ UV gluing and compress the array.
- Array coupled with SiPM through special fixture and AOI





Summary

- With the rapid development of semiconductors, the performance of SiPMs has improved, reducing the dependence on high-performance scintillation crystals.
- However, the requirements for high LY and shorter decay time still necessitate the use of high-performance scintillation crystals.
- To achieve a balance between performance and cost, enhancing the detection capabilities of Cherenkov radiation or the demand for new-generation scintillation crystals (such as meta-scintillation crystals) are important recent developments to move away from the expensive LYSO crystals.