Towards large calorimeters based on Lanthanum Bromide or LYSO crystals coupled to silicon photomultipliers: A first direct comparison for future precision physics

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The $LaBr_3$(:Ce) and LYSO Properties compared to other scintillators

Very attractive media due to:

- Ultra high light yield [**LaBr(Ce)**]: **63 000 ph/MeV** (1.65 x NaI)
- Fast response [**LaBr(Ce)**]: **16 ns** (0.6 x YAP)
- High density [**LYSO**]: **7.1 g/cm³** (2.46 x LXe)

for a compact calorimeter able to provide simultaneously very high energy and timing performances

Figure of Merit, F.o.M = $\sqrt{(\frac{\rho \cdot LY}{\tau})}$

Scintillator	Density ρ(g/cm³)	Light Yield LY(ph/keV)	Decay time τ (ns)	F.o.M. $\sqrt{(\rho \cdot LY)/\tau)}$
$LaBr_3$(Ce)	5.08	63	16	4.55
LYSO	7.1	27	41	2.17
YAP	5.35	22	26	2.13
LXe	2.89	40	45	1.61
NaI(Tl)	3.67	38	250	0.75
BGO	7.13	9	300	0.46

$LaBr_3$(:Ce) and LYSO Detectors: Status and Prospects

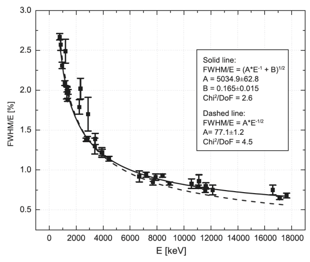
Status:

- Well established low energy gamma calorimetry with detector sizes of (Diameter x Length): 1”x1”, 2”x2” and 3”x3”
- In rapid development for PET applications

Prospects for high energy gamma calorimetry ***O*(50 MeV)**:

- Challenge: **Large size crystals**
  Desired: 5” x 8-10”, recently commercially available: 3.5” x 8” (Saint Gobain), under test: 3.5” x 9”
- Photosensors: multi-pixel photon counter/silicon photomultiplier (**MPPC/SiPM**)
- **For the first time** a large crystal coupled to MPPC to fully exploit the detector performances at high gamma energy

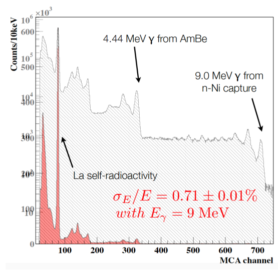
i.e. 2” x 2”
M. Ciemała et al.
NIMA 608 (2009) 76–79



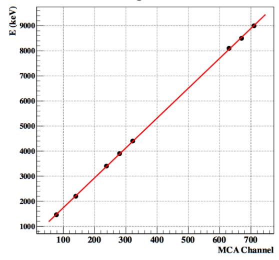
i.e. 3” x 3”
L. Galli et al.
NIMA 718 (2013) 48-51
A. Papa et al.
Nucl. Phys. B 248-250 (2014) 115-117

Detector:
3” x 3” $LaBr_3$(:Ce) coupled to a Photomultiplier PM XP53A2B

Energy spectra



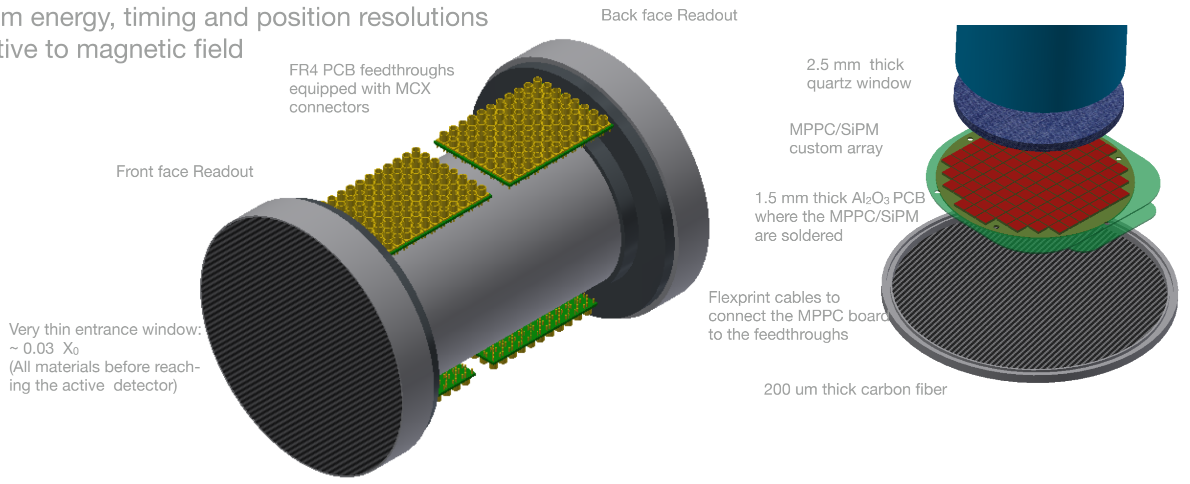
Energy response Linearity



Detector Layout

The first large crystal assembly for high energy gamma detection O(50) MeV with a MPPC double readout scheme for:

- Maximal photosensor coverage area
- Optimal geometrical acceptance
- Very high photosensor granularity
- High rate sustainability
- Optimum energy, timing and position resolutions
- Insensitive to magnetic field



The photosensors: MPPC/SiPM

- The high LY and the short X_0 point towards relative small pixel size (< 50 um)
- The comprise between granularity and number of DAQ channels is achieved with relative medium sensor size (active area: 6x6 mm²) for a number of photosensors of O(400)
- Two candidates: Hamamatsu S13360-6025PE and sensL MicroFJ-60035TSV

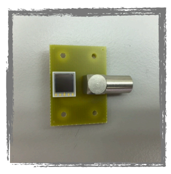
	Package [mm2]	Active area [mm2]	No. Of pixels	Fill factor [%]	PDE [%]	PCB cov. [%]	F.o.M
Hamamatsu	7.35 x 6.85	6.0 x 6.0	57600	47	18-20	69	4.5E+03
sensL	6.13 x 6.13	6.07 x 6.07	22292	75	33-43	91	4.1E+03

F.o.M. = No pixel x PDE x PCB cov. / price

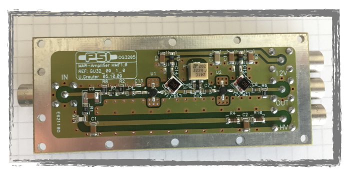
The electronics: Preamplifier, shaping, trigger and DAQ

- Low noise amplifiers (< 5 mV peak-to-peak) based on the Mini-Circuits MAR-6 gain block device (factor gain: up to 100, with pole-zero cancellation and adjustable shaping) (phase I)
- Data acquisition system: A waveform digitiser based on the DRS chip. The DRS evaluation board with a frequency sampling up to 5 GSample/s (phase I). The WaveDREAM (up to 5GSample/s) that will include also the preamplification station with adjustable gain (x1-100)

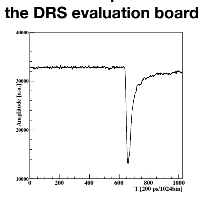
Hamamatsu MPPC S13360-6050CS



PSI standalone MPPC pre-amplifier

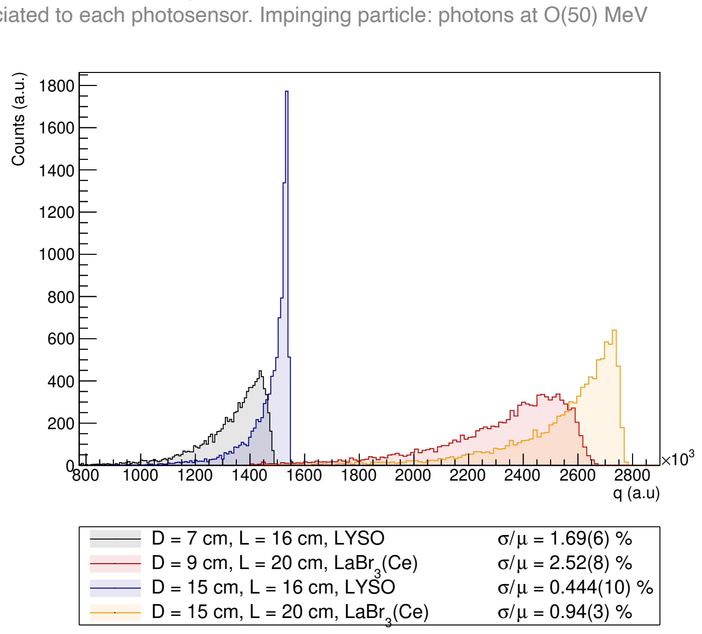


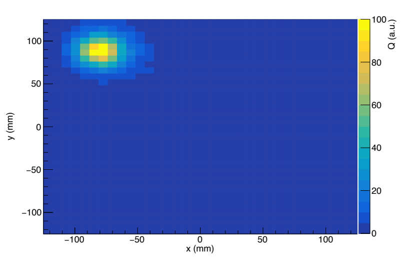
MPPC S13360-6050CS Waveform acquired with the DRS evaluation board



Energy Resolution

The results are obtained via Monte Carlo simulations based on GEANT 4 and a custom code that includes the MPPC/SiPM response, the electronics and the reconstruction algorithms. The analysis is based on the waveforms associated to each photosensor. Impinging particle: photons at O(50) MeV

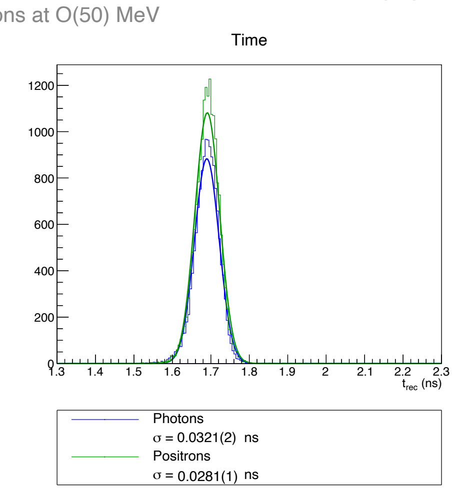


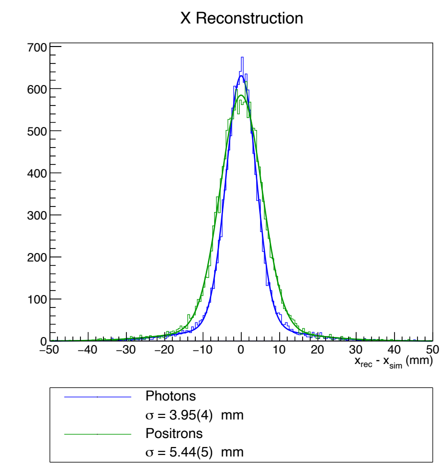


Photons detected per SiPM on the inner surface of a crystal

Time & Position Resolution

Typical time and position distributions for impinging photons and positrons at O(50) MeV





Summary and Outlook

The challenges for new calorimetry for incoming experiments at intensity frontiers is to provide detectors with ultra-precise time resolution and supreme energy resolution.

Two very promising materials on the market are LaBr3 (Ce) and LYSO, supported by recent developments aiming at providing new relative large crystals.

The well established MPPC/SiPM technology open the road to geometrical configurations never considered before (i.e.multiple readout scheme, with sensors along the path of the incident radiation, high granularity, geometrical cut for the best detector acceptance etc.) allowing to fully exploit the scintillation crystal characteristics [i.e. for LaBr(Ce) - R = 4.5 cm, L = 20 cm - the energy resolution for single readout (back), single readout (front) and double readout are respectively: 7.8(2)%, 5.6(1)% and 2.25(7)%]

Detailed Monte Carlo simulations including the ideal case of a single big crystals, the largest one available in the market and array 4 x 4 and 3 x 3 made of available crystals as well as more complex configurations with big crystals have been studied.

Due to the shorter radiation length and smaller Moliere radius a LYSO crystal of the available size (R = 3.5 cm, L = 16 cm) performs better in terms of energy deposit compared to the currently available larger crystal made of LaBr3(Ce). An energy resolution of $\sigma_E/E \sim 1.7(1)\%$ can be obtained, and that can be further improved using bigger crystals (R = 6.5 cm, L = 25 cm, $\sigma_E/E \sim 0.74(1)\%$). Energy resolution approaching $\sigma_E/E \sim 0.3(1)\%$ can be addressed for both crystals with ultimate sizes (R = 20-23 cm, L = 17-32 cm). A timing resolution $\sigma_t \sim O(30)$ ps and position resolutions O(few mm) can be obtained in all cases.

A first large LYSO detector prototype coupled to MPPC for high energy gamma calorimetry is currently under construction.

Grants:
SNF n. 200020_172706, MIUR Montalcini D.M. 2014 n. 975