Study of Future 3D Calorimetry Based on LYSO or $LaBr_3$:Ce Crystals for High Precision Physics

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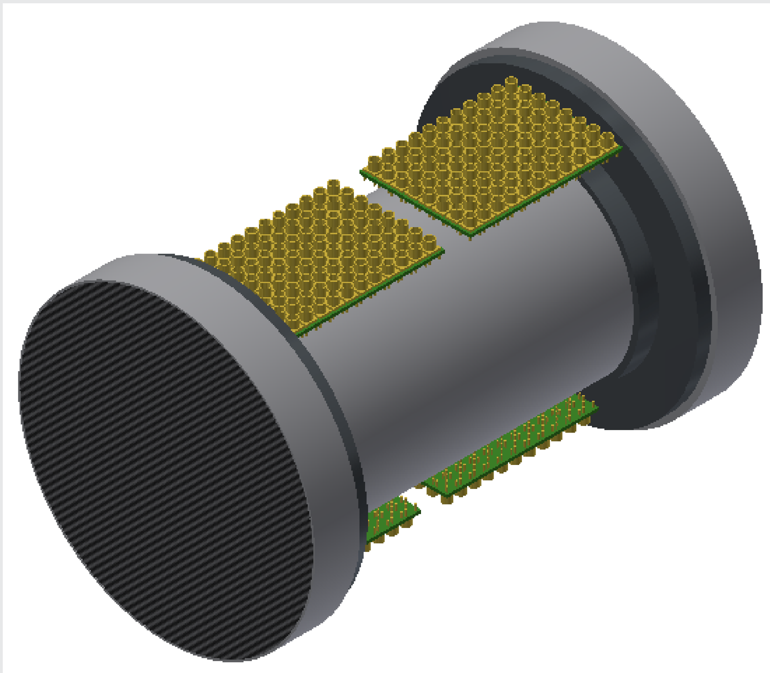
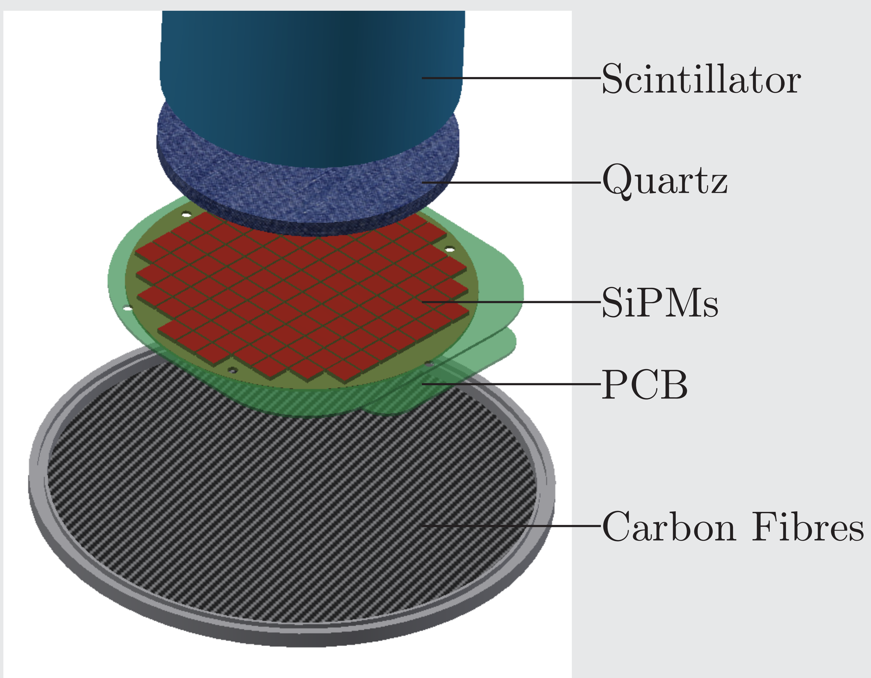
Detector Layout

Couple a scintillating crystal on both ends to SiPMs. Aim to detect $\mathcal{O}(50\,\mathrm{MeV})$ photons [1].





The small thickness of the SiPMs has hardly any impact on the impinging photon. The granular readout allows for geometrical reconstruction.

The Components

SiPM	Size (mm^2)	Active Area (mm^2)	Number of Pixels	Fill (%)	PDE (%)
Hamamatsu S13360-6025PE	7.35×6.85	6.0×6.0	57 600	47	25
sensL MicroFJ-60035TSV	6.13×6.13	6.07×6.07	22 292	75	38 to 50

Scintillator	Density ρ ($\mathrm{g/cm^3}$)	Light Yield LY (ph/keV)	Decay Time τ (ns)	Radiation Lenth X_0 (cm)
$LaBr_3$(Ce)	5.08	**63**	**16**	2.1
LYSO	**7.1**	27	41	**1.21**
NaI(Tl)	3.67	38	245	2.59
BGO	7.13	9	300	1.12

Small LYSO and $LaBr_3$(Ce) crystals are already in use for sub-MeV purposes (e.g. PET). Recent progress in the crystal growing process made a prototype for the range between 10 MeV to 100 MeV feasible.

The Simulation

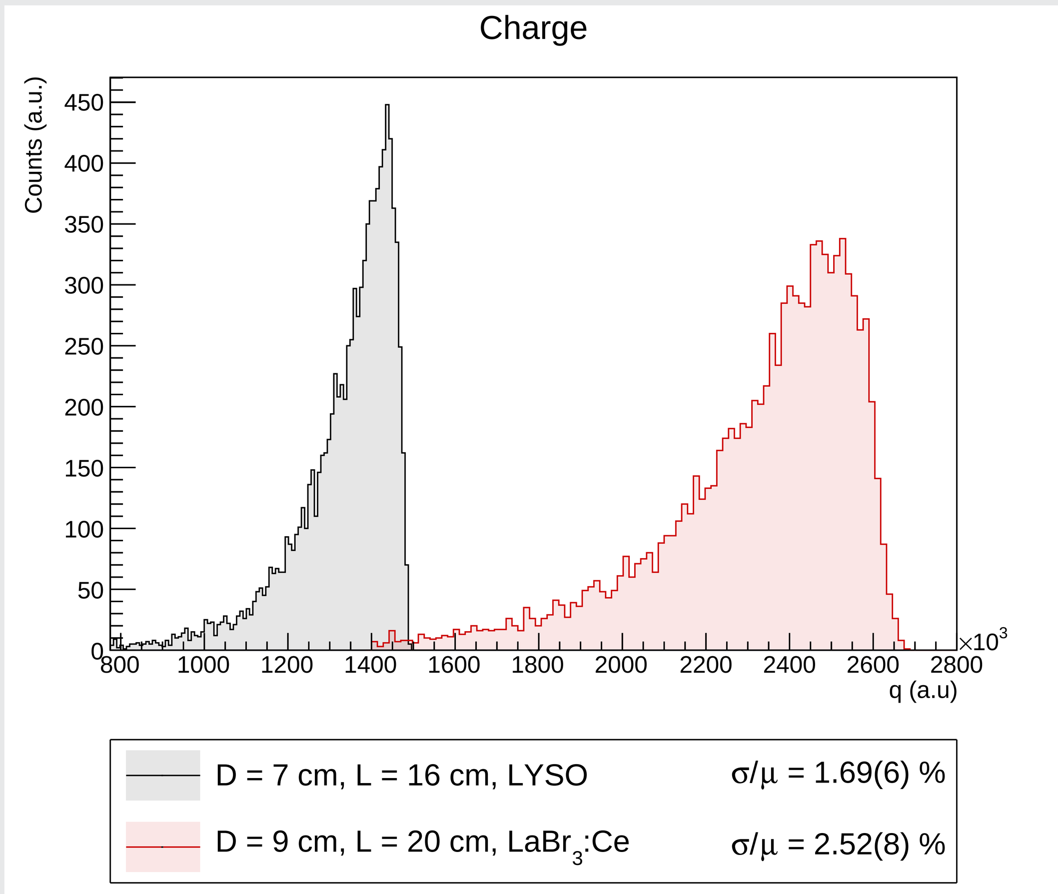
Monte Carlo simulation based on GEANT4. Custom code to take care of the SiPM responses and the reactions of the DAQ. Waveforms are generated based on data taken with SiPMs in discussion.

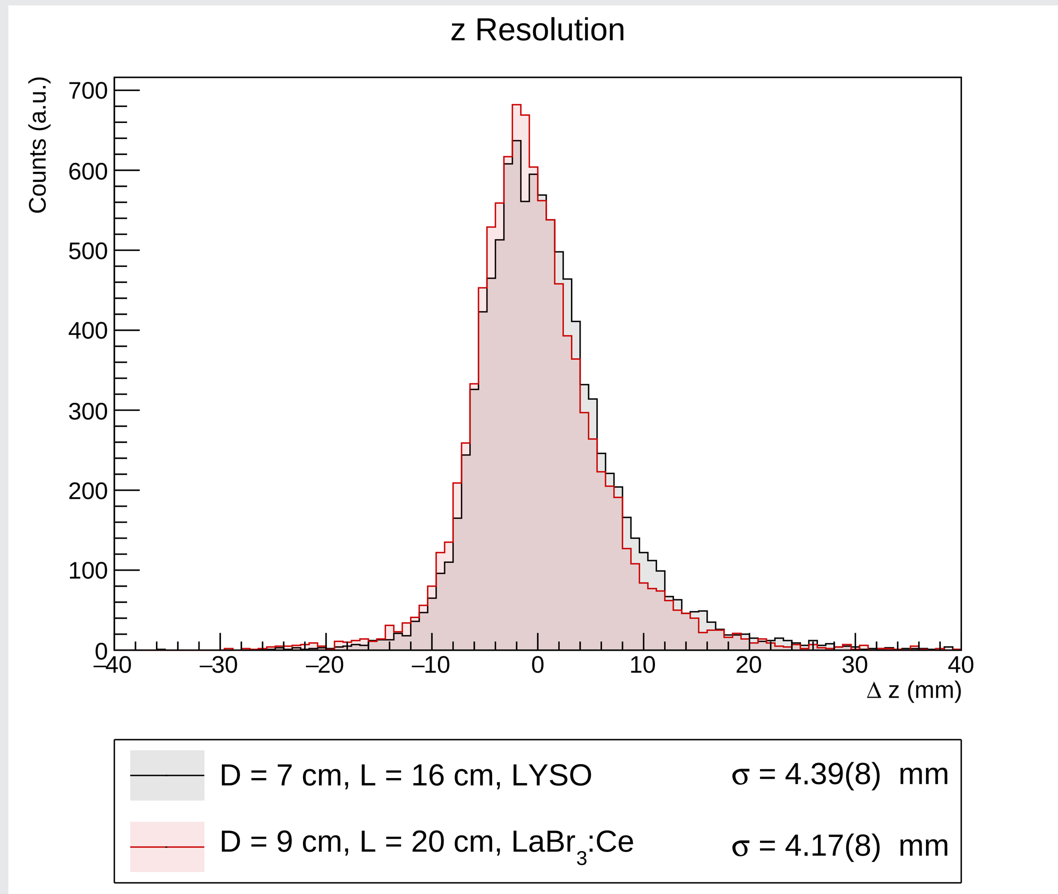
Reconstruction Algorithms:

- **Energy:** Sum the integrated charge for all waveforms.
- **Time:** Sum all waveforms on front and back respectively. Use constant fraction to estimate a time for both. Reconstruct hit time based on these two values.
- **Position perpendicular to crystal axis:** Centre of light distribution on front and back. Use linear approximation.
- **Position along crystal axis:** Use times of front and back readout along with the logarithm of the charges. Use linear approximation.

Simulations of Available Sizes

Considering hits in the central region of the crystal:



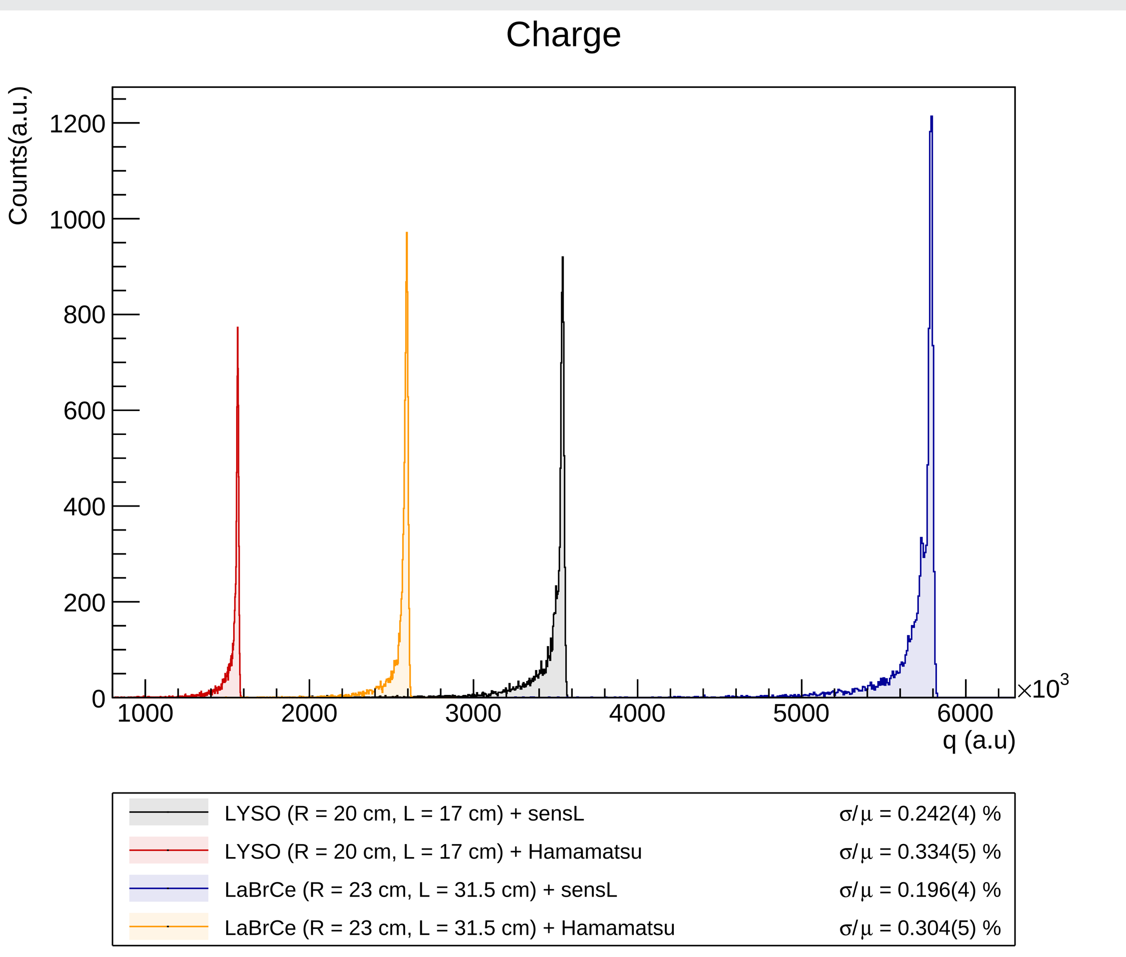


Significant differences only for charge resolution. It is limited by energy leakage through lateral sides, thus LYSO performs better due to its smaller radiation length and Molière radius.

A time resolution around 30 ps and a position resolution around 3 mm perpendicular to the crystal axis are suggested by simple fits.

Thinking Bigger

Consider LYSO and $LaBr_3$(Ce) crystals with a size of 10 Molière radii and 15 radiation lengths irradiated with 55 MeV photons.



Time resolution is estimated to $\mathcal{O}(30\,\mathrm{ps})$. Position resolution along and perpendicular to the crystal axis to $\mathcal{O}(5\,\mathrm{mm})$.

Once larger crystals get available, $LaBr_3$(Ce) can fully benefit from its higher light yield and might be the better candidate.

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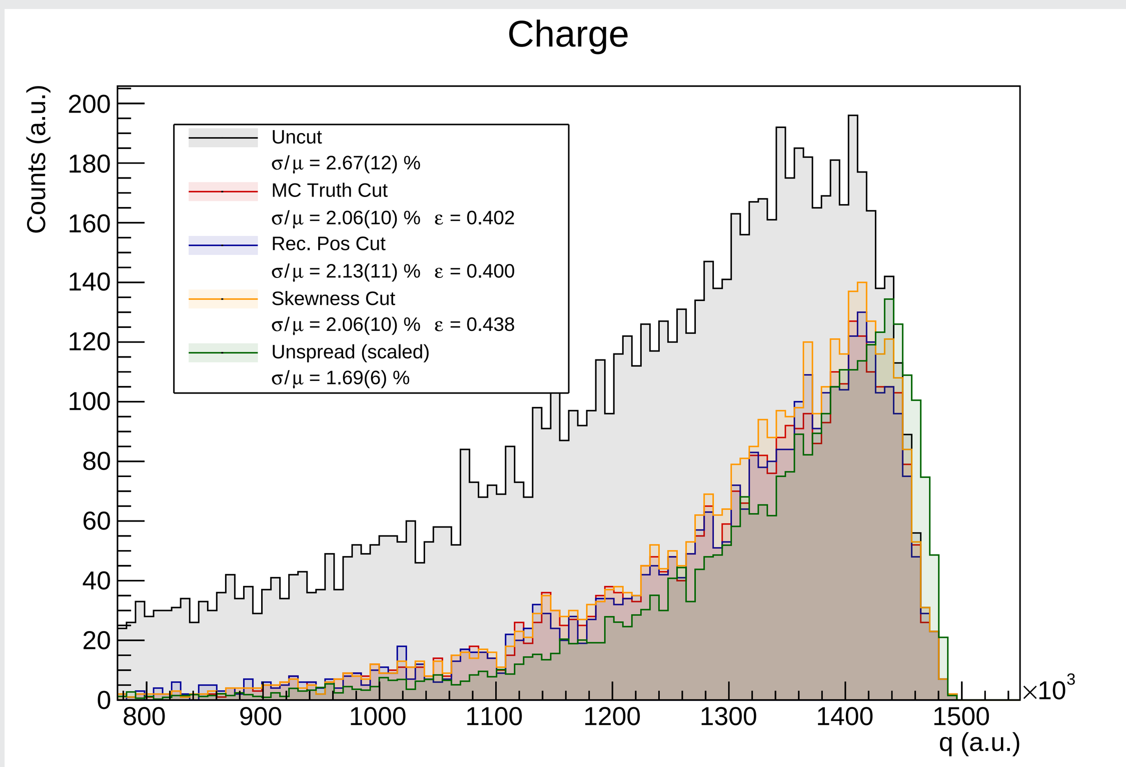
Spread Out Photons

Assume divergent photons to cover the whole front face:



Loss of charge/energy resolution is observed for the 55 MeV photons, due to events close to the lateral side. Reconstruction in the other variables is more or less unaffected.

Cuts:

- **MC Truth**: Cut events that are close to the lateral side. Used as reference.
- **Rec. Pos**: Cut events reconstructed close to the lateral side.
- **Skewness**: Cut events where most of the light is collected at large radii.

Conclusions

Simulations suggest that a calorimeter consisting of a LYSO crystal coupled to SiPMs could provide simultaneously an energy resolution below 2 %, a time resolution around 30 ps and a position resolution better than 5 mm with currently available crystals for 55 MeV photons. Such a detector would be at the precision forefront of calorimetry and has to be considered for future experiments at the precision frontier [2, 3].

The Prototype

Selection based on the simulation:

- LYSO (10 cm length, 7.5 cm diameter)
- Hamamatsu MPPC S13360-6025PE.

About to place the orders with industry. Once fully assembled and crosschecked, the prototype will be tested as auxiliary detector for the CEX calibration of the MEG II detector [4].

References

[1] A. Papa, P. Schwendimann, NIM A **936** (2018), 130

[2] A. M. Baldini et al. arXiv:1812.06540v1 [hep-ex]

[3] G. Cavoto et al. Eur. Phys. J. C **78** (2018), 37

[4] A. M. Baldini et al. (MEG II Collaboration), Eur. Phys. J. C **78** (2018), 380