Characterization of Ca co-doped LSO: Ce scintillators coupled to SiPM for PET applications

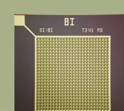
M. G. Bisogni[a,b,*], G.M. Collazuol [a,b], A. Del Guerra [a,b], S. Marcatili [a,b], C. L. Melcher [c]
a University of Pisa, Department of Physics "E. Fermi", Pisa, Italy
b Istituto Nazionale di Fisica Nucleare INFN Sezione di Pisa, Pisa, Italy
c University of Tennessee, Scintillation Materials Research Center, Knoxville, USA
* giuseppina.bisogni@pi.infn.it

Scintillators suitable for PET applications must be characterized by a high efficiency for gamma-ray detection, determined by a high density and atomic number of the crystal; a fast light signal that allows to achieve a good time resolution and to cope with high counting rates; a high light yield for a good energy and time resolution; a good linearity of the light output as a function of the energy to preserve the intrinsic energy resolution of scintillator.
Recently developed LSO:Ce scintillators, co-doped with Ca, have been produced by the University of Tennessee group. They are characterized by the improved performance of all the above mentioned characteristics. The crystals, initially tested with PMTs, showed a higher light output, faster light pulse, improved energy resolution and reduced afterglow, as compared to the standard LSO:Ce crystals. Even though the PMTs still represent the gold standard photodetectors, the recently available SiPMs are now valid candidate to replace PMTs in the next generation PET scanners thanks to their compactness, high spatial resolution performances, low bias operating voltage and, most important for combined PET/MRI systems, insensitivity to static and RF fields. In this work we present the performance of Ca co-doped LSO:Ce samples coupled to SiPMs . In particular we have assessed their performances by evaluating the energy and time resolution.

TOF-PET scanners aiming to a position resolution of the order of few centimeters require a time resolution in the 100 ps range. This can be achieved with fast scintillating crystals (LSO) and fast photodetectors

- Fast, position sensitive Photo Multipliers Tubes
  - Advantages: both coordinates and Depth Of Interaction can be determined with a small number of channels
  - Drawbacks: sensitive to magnetic fields
- Silicon Photo Multipliers (SiPM, also called MPPC)
  - Advantages: fast, compact, low bias voltage, insensitive to magnetic fields
  - Drawbacks: never been used in large systems so far

- LSO:Ce most used scintillator in PET scanners but it shows limitations as
  - Afterglow that limits the high counting rate applications
  - Non-linearity especially under 100 keV
- The newly developed LSO:Ce crystals co-doped with calcium divalent cations showed higher light output and faster light pulses
- The most recent studies also showed that co-doping of LSO:Ce with Ca substantially reduces afterglow intensity .



Material and methods

- LSO crystal samples tested

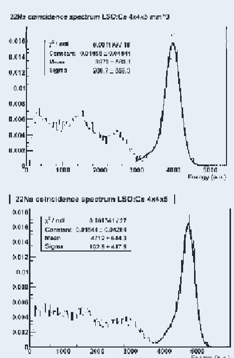
  LSO:Ce, Ca 3x3x10 mm3, 2 samples, Ca conc=0.3 %

  LSO:Ce, Ca 4x4x5 mm3, 3 samples, Ca conc=0.3 %

  LSO:Ce 2x2x10 mm3, 1 sample, Hilger Crystals

  LSO:Ce 4x4x5 mm3 , 1 sample, Hilger Crystals
- Experimental set-up
  - XP2020 Photonis and MCA Tukan used for Energy resolution measurements
  - Hamamatsu MPPC 100-C and Lecroy scope for Time resolution measurement

Energy resolution Results



scintillatore	E_res(511)fw
LSO:Ca 4x4x5	8.9%
LSO:Ca 4x4x5	8.4%
LSO:Ca 4x4x5	11.7%
LSO:Ce 4x4x5	12.1%
LSO:Ca 3x3x10	11.9%
LSO:Ca 3x3x10	11.6%
LSO:Ca 3x3x10	11.2%

Conclusions

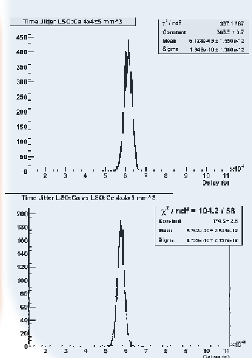
For the energy resolution, the results seems to indicate a better performance of the Ca doped crystals with respect to the standard ones for the samples 4x4x5 cm^3. For the 3x3xx10 samples we do not have a comparison with standard LSO samples.

Also for the time resolution, the performance of the Ca doped samples are superior with respect to the standard LSO sample.

In conclusions the results are encouraging, but to better understand the performances of the Ca co doped LSO crystals more statistics must be accumulated on larger samples, taking into account also different geometries and Ca doping concentration.

Finally, the time resolution must be measured with SiPM of different cell geometry (to avoid saturation problems) and also from different providers.

Time resolution results



	Cnc 15 ns FWHM (ps)	Cnc 15 ns sigma/√2 (ps)
LSO:Ca 3x3x10	357	107
LSO:Ce 2x2x10	345	104
LSO:Ca 4x4x5	427	128
LSO:Ca 4x4x5	399	120
LSO:Ce 4x4x5		143

Bibliography

L. Melcher and J. S. Schweitzer, "Cerium-doped lutetium oxyorthosilicate: A fast, efficient new scintillator," IEEE Trans. Nucl. Sci., vol. 39, no. 4, pp. 502–505, Aug. 1992.
C. L. Melcher et al, "Effects of Ca Co-Doping on the Scintillation Properties of LSO:Ce," IEEE Trans. Nucl. Sci., vol. 55, no. 3, pp. 1178–1182, Jun.2008.
C. L. Melcher et al. "Effects of calcium co-doping on charge traps in LSO:Ce," in Proc. IEEE NuclearScience Symp. Conf. Rec., Oct. 26–Nov. 3 2007, vol. 4