Evaluation of LFS continuous scintillation crystals for PET

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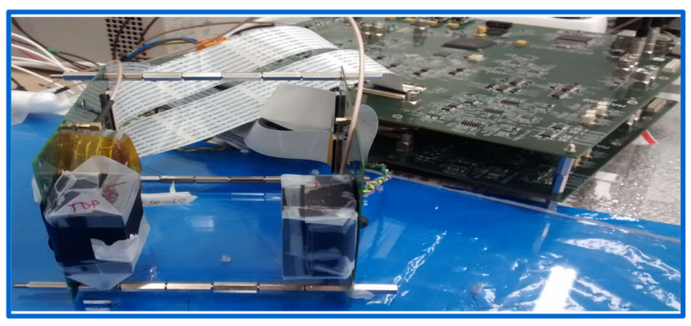
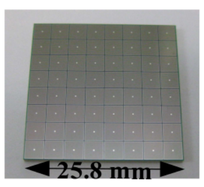
Introduction

- The suitability of monolithic **Lutetium Fine Silicate** (LFS) continuous scintillation crystals for PET **(Positron Emission Tomography)** has been investigated.
- **Three crystal types**, measuring 25.8x25.8x15 mm³, were tested:
  - LYSO white coating
  - LFS white coating (LFS-W)
  - LFS specular coating (LFS-S).
- **Test measurements**:
  - Crystal characterisation. LYSO and LFS crystals in coincidence with another LYSO crystal (white coating, 1x1x10mm³) coupled to a 1-channel SiPM, with a ^{22}Na source.
  - ^{22}Na position reconstruction. Two head detectors of each crystal type in time coincidence, have also been carried out with a point-like ^{22}Na source.
- Two different **light distribution models** for the interaction position estimation were tested [1].
- A **ML-MLEM image reconstruction** code developed within the group was used to reconstruct the data.

Detector components

- ***SiPM-TSV*** (64-channel array - S13361-3050AE-08 - Hamamatsu Photonics – 25.8x25.8 mm²).
- ***SiPM-pixel*** (C13365-1350SA - Hamamatsu Photonics – 1.3x1.3 mm²).
- The ***readout system*** is a custom-made data acquisition board based on the 64-channel VATA64HDR16 ASIC from IDEAS.

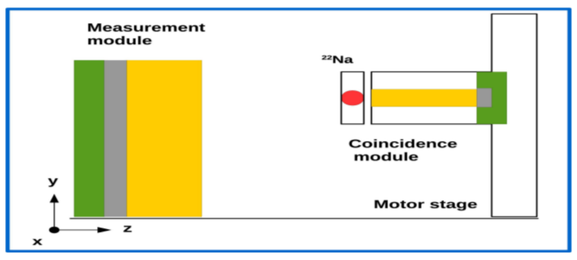




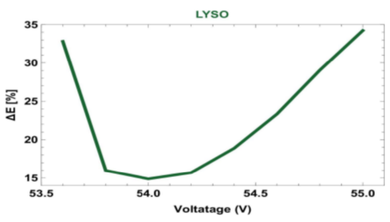
- ***LYSO-W*** (LYSO crystal - 25.8x25.8x15 mm³ - white coating – EPIC).
- ***LFS-W*** (LFS crystal - 25.8x25.8x15 mm³ - white coating – ZECOTEK).
- ***LFS-S*** (LFS crystal - 25.8x25.8x15 mm³ - specular coating – ZECOTEK).
- ***LYSO-pixel*** (LYSO crystal - 1x1x10 mm³).

Decay constant: LYSO ~ 41 ns | LFS < 33 ns [2,3,4].

Crystal characterisation



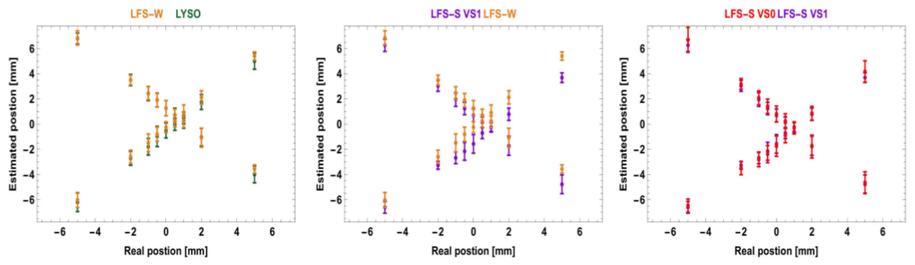
- ^{22}Na source electronically collimated operating the module in coincidence with a small crystal. Measurements in different positions.
- For each crystal, position measurements were taken with the voltage giving the optimum energy resolution.
- Interaction position estimation models
  - VS0: reflections in the crystal sides not considered
  - VS1: reflections in the crystal sides considered.
- LYSO and LFS-W → VS0 models.
- LFS-S → VS0 and VS1 models.

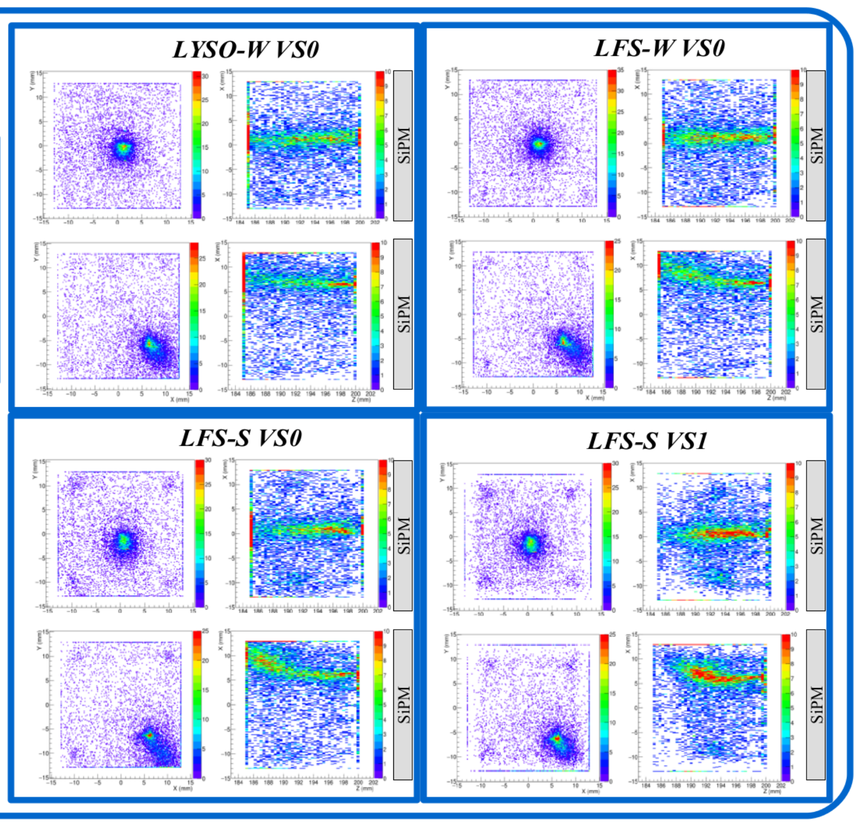


Mean energy resolution *for the three crystal types*

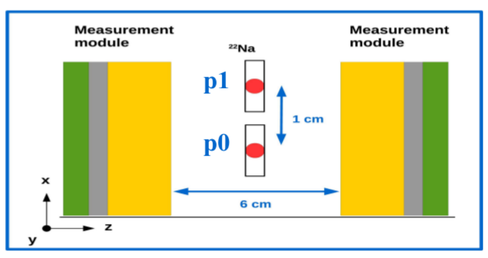
	LYSO	LFS-W	LFS-S
VOLT	54 V	54.2 V	54.2 V
ΔE	14%	19%	17%

at center	LYSO	LFS-W	LFS-S VS0	LFS-S VS1
FWHM x-axis	1.4 [mm]	1.4 [mm]	1.5 [mm]	1.2 [mm]
FWHM y-axis	1.4 [mm]	1.0 [mm]	1.9 [mm]	1.7 [mm]

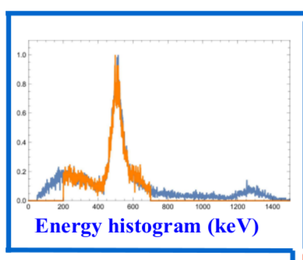


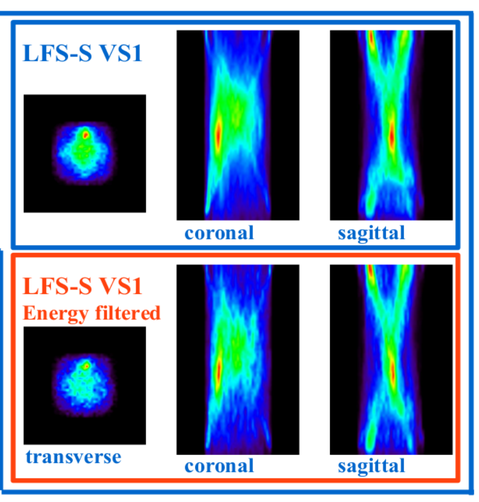


^{22}Na position reconstruction



- Timing coincidence:
  - overlapping of output signals
  - output signals of 6 ns.
- Data energy filtered offline.
- LYSO and LFS-W → VS0 models.
- LFS-S → VS0 and VS1 models.



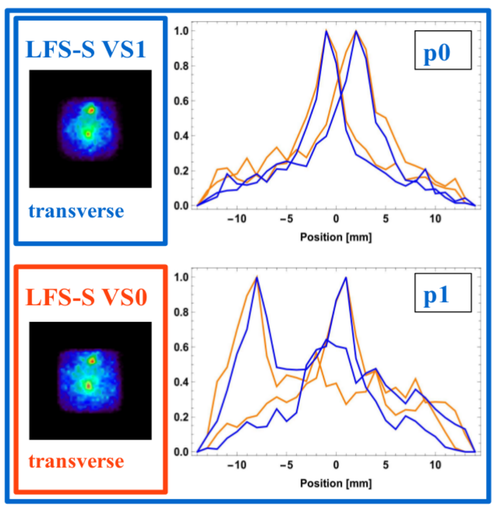


Images are obtained employing an iterative List-Mode Maximum Likelihood Expectation Maximization (LM-MLEM) algorithm:

$$\lambda_v^{(n+1)} = \frac{\lambda_v^{(n)}}{s_v} \sum_{i=1}^{M} \frac{t_{iv}}{\sum_k t_{ik} \lambda_k^{(n)}}$$

M = measured events, t_{iv} = system matrix, $\lambda^{(n)}$ = image at iteration n.

Slightly better resolution for VS1



Fit results for positions p0 and p1 for the following crystal type and model combinations:
LYSO-VS0, LFS-W-VS0 and LFS-S-VS1.

The reconstructed position was **fitted to a gaussian function**.

		x-axis μ [mm]	x-axis σ [mm]	y-axis μ [mm]	y-axis σ [mm]
LYSO VS0	p0	1.5	2.2	-0.3	2.8
	p1	-9.0	1.5	0.8	2.6
LFS-W VS0	p0	2.2	2.0	-0.1	2.0
	p1	-9.0	1.5	0.9	2.3
LFS-S VS1	p0	2.0	2.1	-0.8	1.7
	p1	-8.3	1.1	0.1	2.4

- Position is reconstructed correctly within errors.
- Reconstruction when using crystals with specular coating are successfully reconstructed.
- LFS σ-values for both coating types are of the same order.
- LFS and LYSO σ-values are of the same order.

Conclusions

- **Interaction position estimation models with (VS1) and without (VS0) reflections have been sucessfully tested for experimental data.**
- **Position estimation models with reflections appear to result in slightly better resolutions than without.**
- **LFS has slightly worse energy resolution than LYSO, although their reconstructed spatial resolutions appear to be of the same order.**
- **Taking into account that LYSO and LFS present similar performance level (and considering that LFS has better timing resolution than LYSO) we conclude that LFS is a valid substitute for LYSO.**

References

[1] Etxebeste, A. et al., “3D position determination in monolithic crystals coupled to SiPMs for PET”, Physics in Medicine and Biology (2016)
[2] Grodzicka, M., et al. "Characterization of LFS-3 scintillator in comparison with LSO." Nucl. Instrum. and Methods in Phys. Res. A, 226-230 (2011)
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[4] Ota, R., et al. “Evaluation of a Sub-Millimeter Resolution PET Detector With a 1.2 mm Pitch TSV-MPPC Array One-to-One Coupled to LFS Scintillator Crystals and Inter-Crystal Scatter Studies With Individual Signal Readout”, IEEE Transactions on Radiation and Plasma Medical Sciences, vol. 1, no 1, p. 15-22 (2017)

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