Monolithic crystals with SiPM read-out: optical coupling optimization

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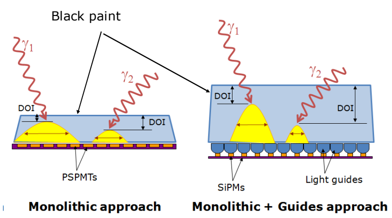
Abstract

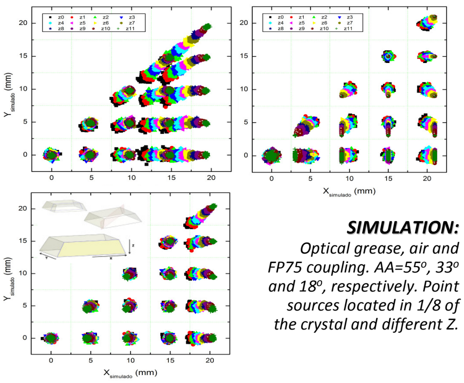
Photosensors based on Silicon Photomultipliers (SiPM) are being considered **good substitutes** of the well established Photomultiplier Tube (PMT) technology. SiPMs are very fast, have high gain and they are almost **not affected by magnetic fields**. We intend to use arrays of SiPMs for the design of Positron Emission Tomography (PET) detectors compatible with Magnetic Resonance systems. SiPMs exhibit their best performance for reduce active areas where the intrinsic dark counts are minimized. In this work we present a method to efficiently collect scintillation light at the time to reduce photosensor active area.

Continuous crystals coupled to PSPMTs

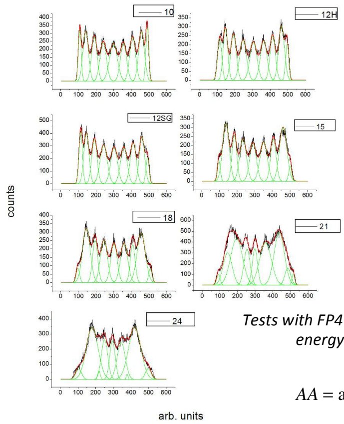
Continuous scintillation crystals preserve the spatial distribution of light, which can be reconstructed with a small number of statistical moments. However, in contrast to pixellated crystals, they account for moderate edge effects which specially depend on the crystal thickness. In order to optimize the light collection, a reduction of the acceptance angle of the scintillation photons is suggested. A compromise between small edge effects and statistically good light transmission is required. In this section we show simulated and real data for the coupling with position sensitive PMTs.

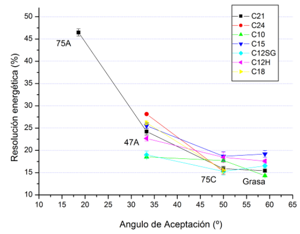


*Optical devices positioned between the scintillation crystal and the photosensor, like the so-called **faceplates** or **light guides**, make possible to reduce the acceptance angle of the incoming light. Therefore, the edge effect reduces.*



SIMULATION: *Optical grease, air and FP75 coupling. AA=55º, 33º and 18º, respectively. Point sources located in 1/8 of the crystal and different Z.*





EXPERIMENTAL: *Tests with FP47A (33º) vs. crystal thickness and results for energy resolution for various crystal thickness and coupling media*

$$AA = \arcsin\left(\frac{NA}{n}\right) \qquad NA = \sqrt{n_{core}^2 - n_{cladding}^2}$$

…coupled to SiPM using light guides

We designed a new detector concept based on small area SiPM detectors. 256 SiPMs with an active area of 1x1 mm^2 are used in this design. They are coupled to the scintillation crystal be means of light guides in order to properly concentrate such light.

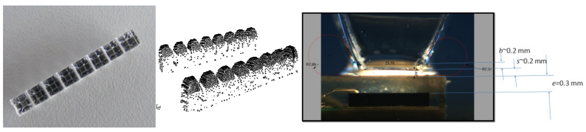


Figure. *Left, photo of the 1x8 array. Center, laser image of two units. Right, photo of the concentrator coupling to a SiPM.*

*Every concentrator has been coupled to the scintillator and to the SiPM using optical silicone cured at ambient temperature. The acceptance angle of the concentrators is of about **16 degrees**.*

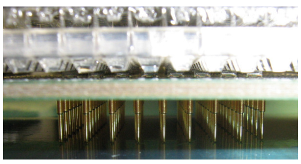
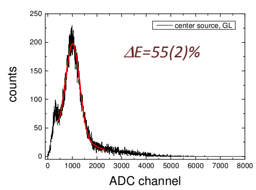


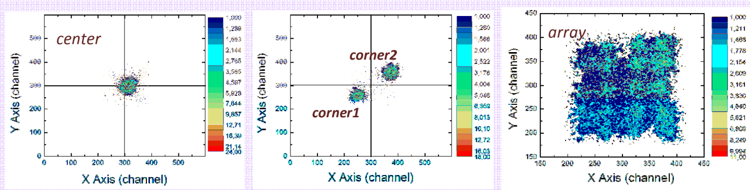
Figure. *Detail photo of the coupling to an array of 64 SiPM.*

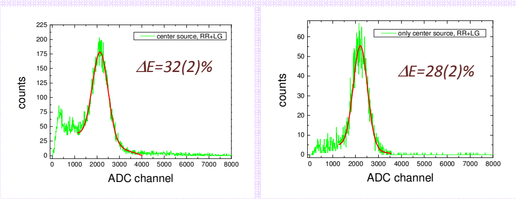
*The first tests showed a **poor light statistics** as it can be in the measured energy resolution (right), we have included retroreflector plates in the entrance face of the crystal. These devices reflect the scintillation light in the same direction, without destroying the light distribution.*



64 SiPM were used, covering a scintillation area of 24x24 mm^2. The crystal had trapezoidal dimensions of 50x50 and 40x40 mm^2 with a thickness of 12 mm. Lateral surfaces are black painted, entrance and exit faces were polished.

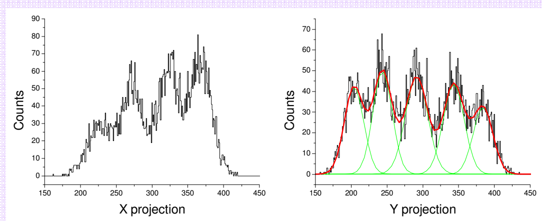
*Data were acquired for 5 minutes with a ^{22}**Na** source, 1 uCi and 1x1 mm^2. An **array** of 81 sources separated by 5 mm was also used.*





Energy Resolution at the corners:
Whole image
Corner1 (36.4 ± 2.6)%
Corner2 (30.8 ± 2.6)%
Only source
Corner1 (38.8 ± 3.2)%
Corner2 (30.0 ± 4.1)%

*The use of additional retroreflectors on the entrance face of the crystal permits to increase the light output about a factor 2 also increasing the energy resolution to about **30%** in the center of crystal.*



The ^{22}Na array served to analyzed the expected spatial resolution of the detector head.
*Out of the results obtained with these data, we estimated a detector spatial resolution of about **2.5 (0.5) mm**.*

CONCLUSIONS

Optical devices as the so called faceplates help to reduce the edge effect when using PSPMT as read-out systems.
Light guides help to concentrate scintillation light, reducing the required sensor active area but also the acceptance angle. We designed a light guide system.
We observed an almost negligible border effect when using light guides, as it was expected, at the cost of poor statistics.
Promising results showed a detector spatial resolution nearing 2.5 mm.
We still working on the coupling to increase the light collection and, thus, the energy resolution.

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