Innovative PET detector concept based on SiPMs and continuous crystals

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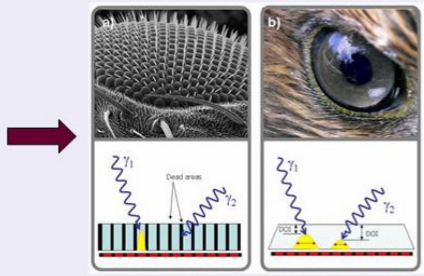
Motivation

Positron Emission Tomography (PET) is mainly being pushed by physicians to deliver high image spatial resolution together with an improvement of the sensitivity in order to better and earlier detect small lesions. Conventional whole-body PET systems, even those enabling the Time of Flight (FOF) determination, can hardly reach a spatial resolution below 5 mm. Moreover, it has been pointed out the convenience of simultaneously obtain PET and Magnetic Resonance (MR) images, specially in order to obtain such simultaneous but also dynamical sequences of images.



Pixellated and continuous crystals

Monolithic crystals solve several drawbacks present in crystals arrays

- Depth of Interaction (DOI) determination without extra detector sensor components, parallax error correction.
- Higher sensitivity since there is not dead areas.
- Mainly only limited by positron range and reconstruction effects.

SiPM sensors are suitable for working in the presence of magnetic fields.

- Enable Time of Flight measurements in contrast to APDs.
- Dark counts reduces with active area.
- Relatively easy to manufactured when compared with PMTs.

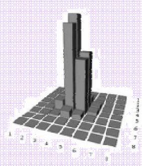
	MR compatible	*TOF*
PMT	No	Yes
APD	Yes	No
SiPM	Yes	Yes

Crystal thickness *vs.* border effects

Although monolithic crystals present several advantages when compared with pixellated technology, there is a important drawback that has to be controlled, the so-called border effect. In our design, the *X*, *Y* and *Z* photon impact coordinates are calculated through a modified resistor network. *X* and *Y* are mainly obtained by means of applying the Anger logic.

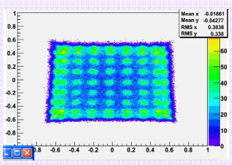
$$X = \frac{PMT^{up}_{right} + PMT^{down}_{right} - PMT^{up}_{left} - PMT^{down}_{left}}{PMT^{up}_{left} + PMT^{up}_{right} + PMT^{down}_{left} + PMT^{down}_{right}}$$

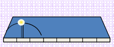
$$Y = \frac{PMT^{up}_{right} + PMT^{up}_{left} - PMT^{down}_{right} - PMT^{down}_{left}}{PMT^{up}_{left} + PMT^{up}_{right} + PMT^{down}_{left} + PMT^{down}_{right}},$$



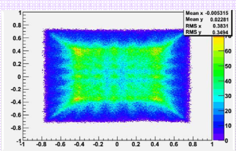
Whereas the *Z* or DOI relates to the light spread and, therefore, it is mandatory to preserve always the light distribution.

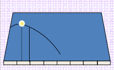
As it is shown in the example above, our crystal design have a pyramidal truncated shape. This shape reduces the border effect, specially with crystals of up to 10 mm thickness. However, us the purpose of this work is to increase the sensitivity, we intend to use crystals with thickness reaching 25 mm. This causes an increase of the border effect which translates into a poorer determination of the exact *X* and *Y* coordinates.





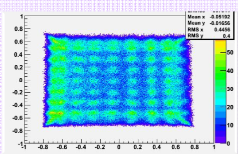
10 mm thickness.
9x9 ^{22}Na sources

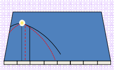




21 mm thickness.
9x9 ^{22}Na sources

One of the solution to reduce this effect is to also reduce the sensor acceptance light angle, this can be achieved by using a non-sequential (Crystal-Coupling-Photosensor) refractive index coupling media or by means of special light guides. A variety of faceplates (FP) offer the chance of restricting the acceptance angles accordingly to their core/cladding refraction index relation (Numerical Aperture, NA) and to the surrounded indexes.





15 mm thickness.
9x9 ^{22}Na sources

FP with NA=1
Acceptance Angle ~ 34º

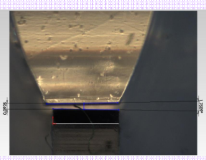
Thus, it will be necessary to use light systems preserving as more as possible the light distribution reducing the acceptance angle to the photosensor.

Coupling to SiPM arrays

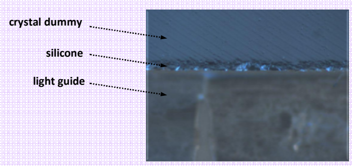
Small area SiPMs reduce dark counts and also their prices becomes very competitive. Moreover, in addition to the need of using light systems to reduce the acceptance angle, we have decided to use the smallest available detectors of just 1 mm^2 active area in combination with light concentrators.

It is important to collect as much light as possible into de small detection areas of every SiPM without losing light distribution information. Thus, we have designed specific light concentrators. Every device manages to transmit about 70% of the light with a very small cross-talk contribution with neighboring devices.

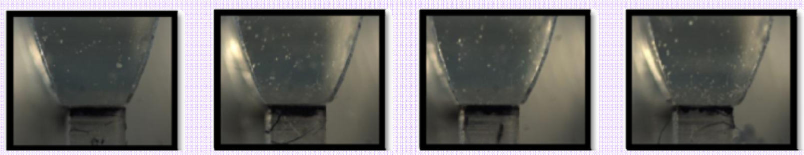
Coupling between light guides and detectors must be almost perfect in order to reduce transmission looses. Herein, both guide lights and sensor must ensure a good parallelism. Initial test showed an angular misalignment as well as a center to center shift.



Tilt misalignment between light guides and SiPM dummy.

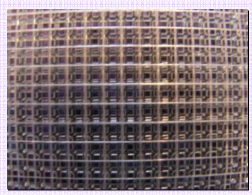


Coupling thickness below 100 microns



Good alignment between light guides and SiPM dummy.

In order to perform sequential tests, the coupling media was based on silicones which provide the system with good mechanical robustness at the time that allow one to perfom repetitive tests. As seen in the side photograph, a relative good alignment between light guides and SiPM dummies was achieved, also seen in the previous row of pictures. Shifts below 0.1 mm are expected.



Conclusions

- Thick continuous crystals in combination with small active area SiPMs seem to have a huge potential in order to increase both scanner sensitivity and spatial resolution.
- Moreover, the use of this type of photosensors allows one to run them into magnetic field environments and, so, to construct hybrid PET-MT systems with the consequent chance of simultaneously acquire dynamical PET-MR images.
- Crystal thickness increases detector sensitivity but at the cost of larger border effects.
- Some available light guides could reduce border effects by decreasing the acceptance angle of the light distribution.
- Alignment between such guides and detectors is crucial in order to transfer as more light as possible. First tests showed good matching between guides and sensors.
- Future works are now concentrated on the first running of the PCB which contains an array of SiPM. A modified resistor network will allow for X, Y and Z impact position determination.

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