Development of innovative PET Module with Depth of Interaction and Timing capabilities

G. Stringhini [1,2], M.Pizzichemi[1], A.Polesel[1,2], Tahereh Niknejad[3], M. Paganoni[2], S. Tavernier [4], E. Auffray[1]

gianluca.stringhini@cern.ch

1 - CERN, Geneve, Switzerland. 2 - University of Milano-Bicocca, Milan, Italy. 3 - LIP, Lisbon, Portugal. 4 - Vrije Universiteit Brussel, Brussels, Belgium.

Why the Depth Of Interaction?

- Avoid the **parallax error** in small animals and organ dedicated PET scanner.
- Improve the timing performances by correcting the **time jitter** of the photon propagation in whole body PET detectors.

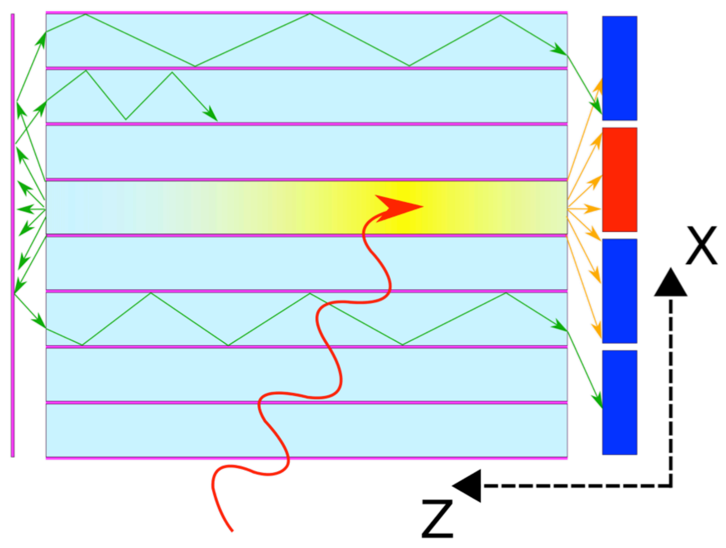
A new approach to the DOI

Standard approaches:

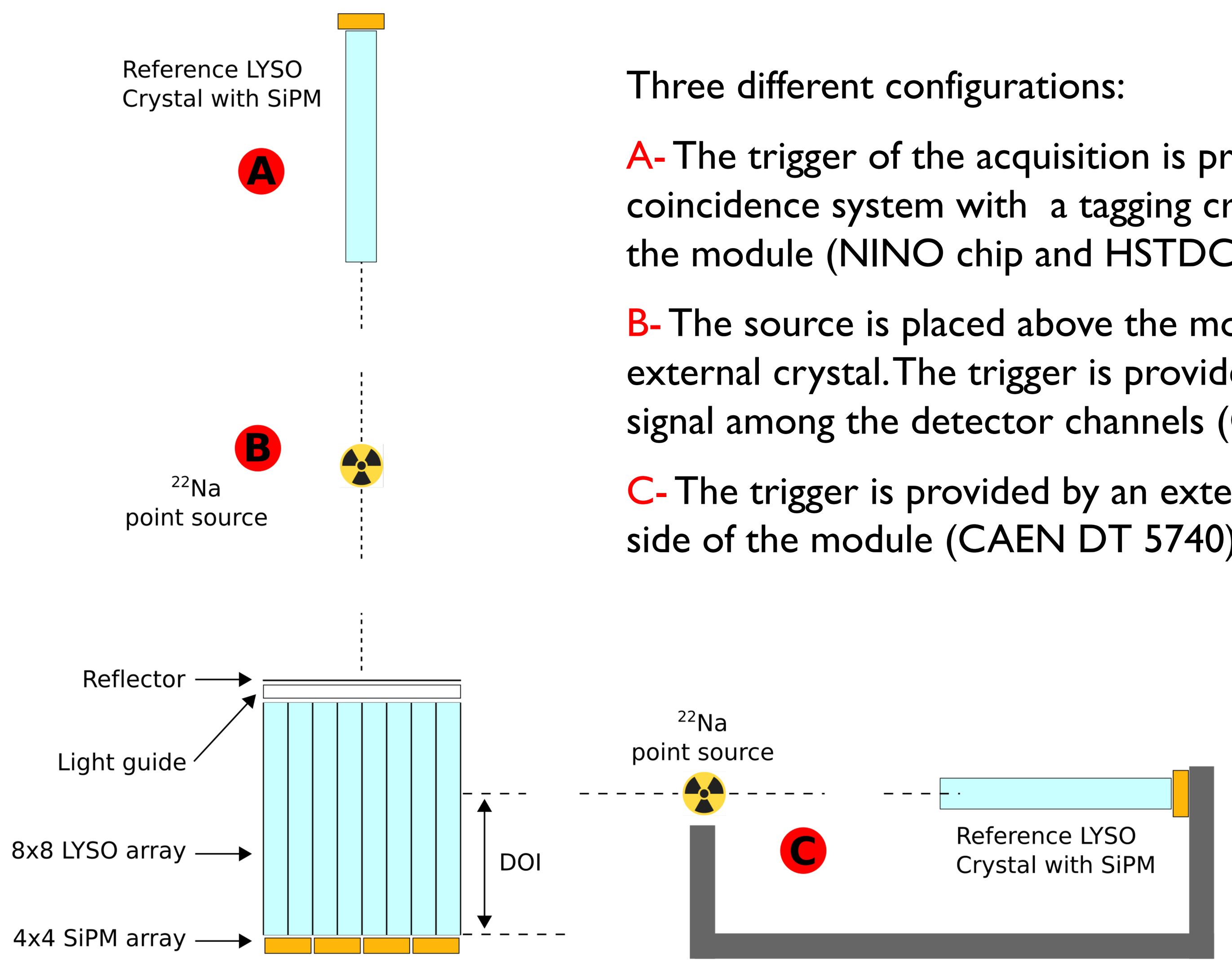
- Each scintillator is read from both sides by a detector obtaining the DOI exploiting the asymmetry of the light collected.
- Layers of scintillators with different pulse profile and identification of the hit layer by a pulse shape discriminator.

Innovative approach:

Single side readout [1]. The light that, due to the single side readout, would escape from the matrix is recirculated again in the matrix by using a glass light guide and a reflector (ESR). The DOI information is extracted from the light that is shared among the scintillators.



The experimental setup



Three different configurations:

A- The trigger of the acquisition is provided by a coincidence system with a tagging crystal on the top of the module (NINO chip and HSTDC).

B- The source is placed above the module and there is no external crystal. The trigger is provided by the highest signal among the detector channels (CAEN DT 5740).

C- The trigger is provided by an external crystal on the side of the module (CAEN DT 5740).

Method

Identification of the **(x,y,z)** impact point by using a set of coordinates **(u,v,w)** that are combination of the charge collected. U and v are a weighted average of the position of the detectors while w is defined as follow:

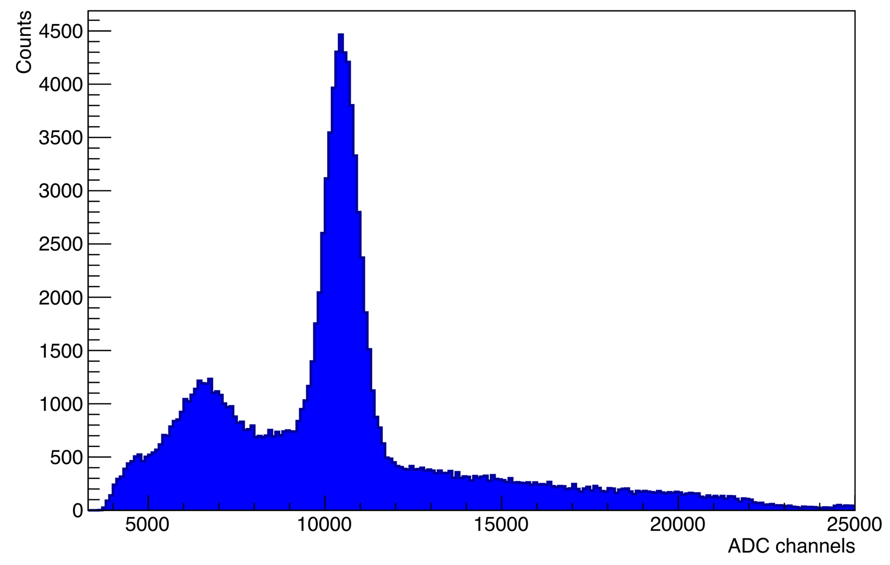
$$w = \frac{p_{max}}{P}$$

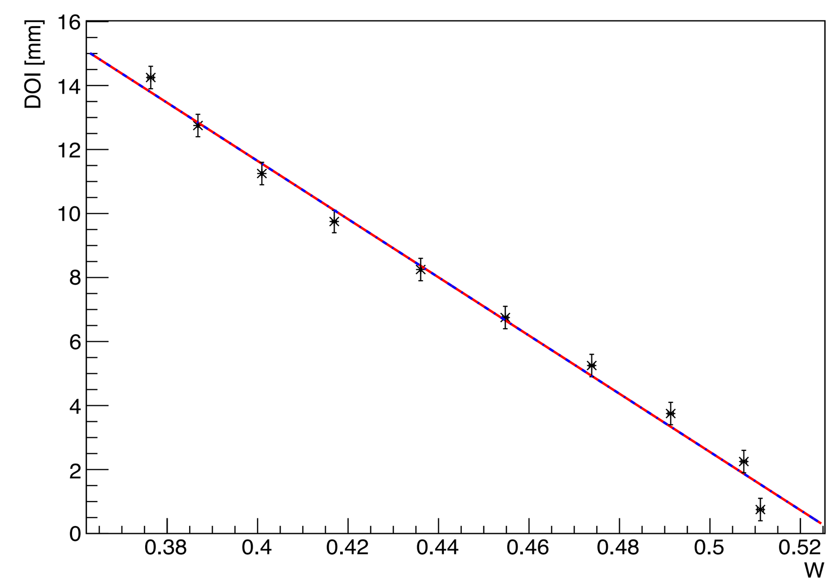
where p_{max} is the maximum of the charge collected among the cells of photodetector and P the sum of all the charges. The arrival time of the photons can be corrected by the DOI information ($\delta_i(h)$) of the illuminated crystal or using a weighted average of the timestamps of the nearby crystals.

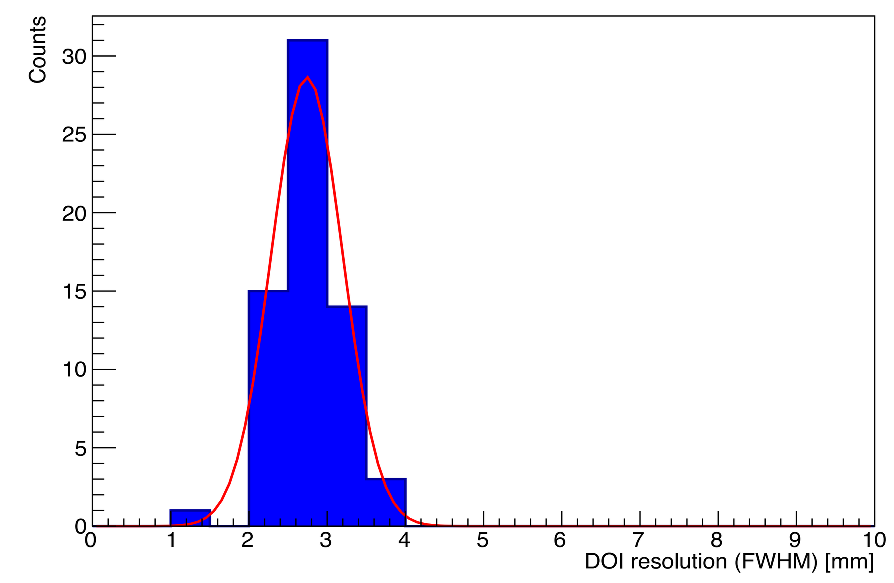
$$\hat{t} = \frac{\sum_{i=1}^{n}\left[(t_i(h) - \delta_i(h)) \cdot \frac{1}{\sigma_i^2(h)}\right]}{\sum_{i=1}^{n}\frac{1}{\sigma_i^2(h)}}$$

Energy and DOI Characterization

With the B setup, the events in the **(u,v,w)** space accumulate in 64 clusters corresponding to the 64 crystals. The spectrum of each crystal can be obtained and the average energy resolution of the entire module is **10% FWHM.** With the C setup, it is possible to establish a direct correlation between the w coordinate and the DOI and calculate the DOI resolution of the module that is **2.7 mm FWHM.**

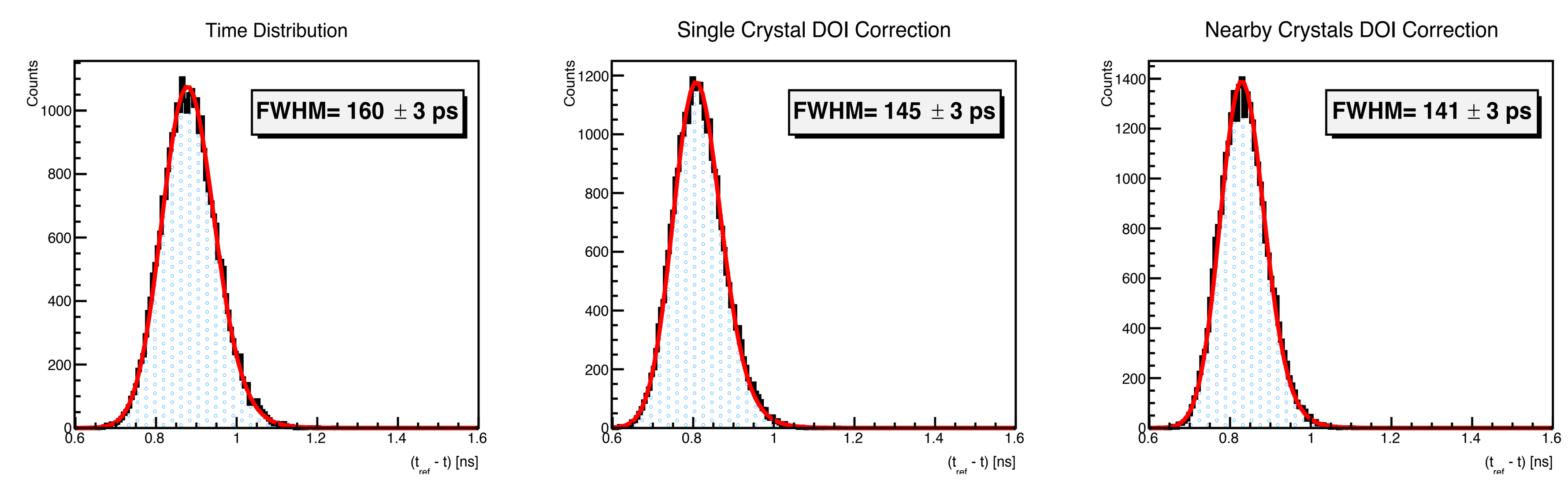




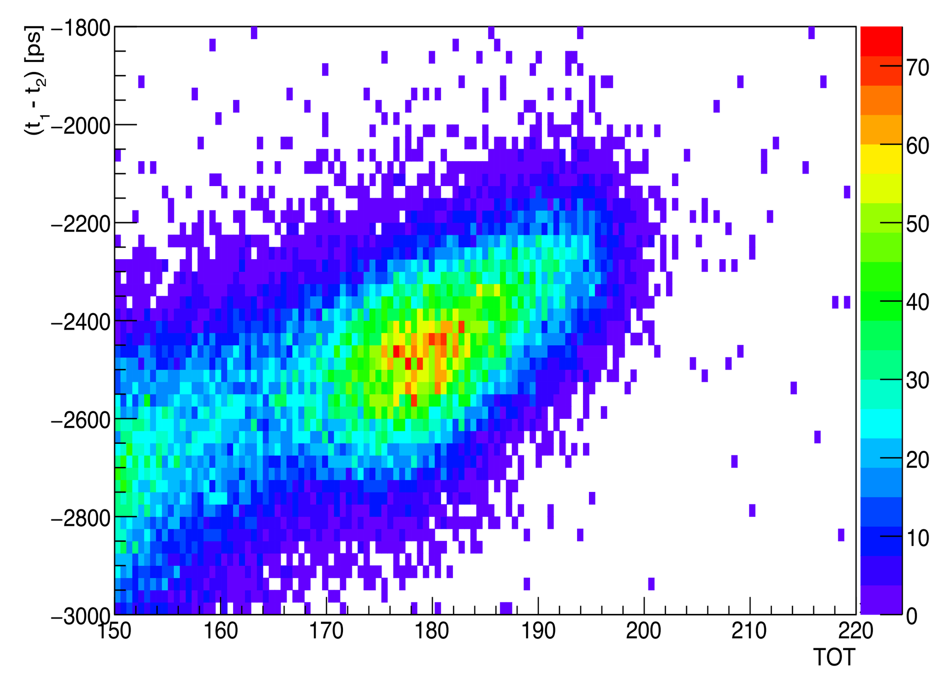


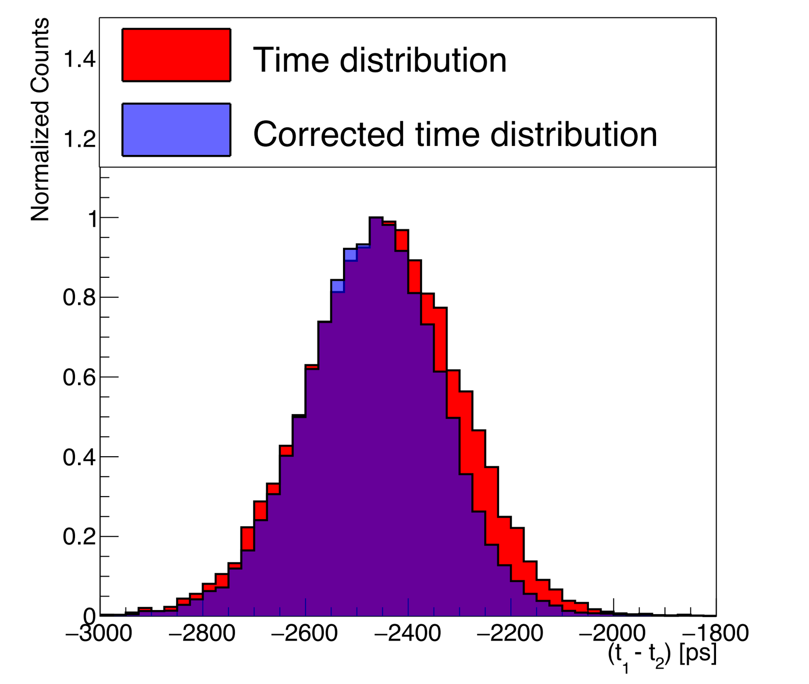
Timing Characterization

GEANT4 simulations show that the timing performances improve if it takes into account the DOI information. The FWHM of the arrival time distribution improves from **(160±3) ps** to **(145±3) ps** if the DOI information of the illuminated crystal is exploited. The FWHM reaches a value of **(141±3) ps** if the correction involves all the nearby crystals averaging among all the timestamps.



Using the A setup, it is not possible to perform the correction using all the nearby channels due to the fact that we can obtain the time stamps of the photon and the time over threshold of just the tagging crystal and one photodetector channel of the module. The only feasible correction is the one that exploits the DOI of the illuminated channel. The plot shows a clear correlation between the CTR and the TOT of the hit crystal due to a correlation between the DOI and the TOT of the signal. By correcting for this effect, the CTR improves from **(349 ±6) ps FWHM** to **(299 ±6) FWHM ps**.





Conclusion

A complete characterization of our innovative PET shows excellent energy resolution (10%), good DOI resolution (2.7 mm FWHM) and promising timing performances (CTR of 299 FWHM ps) making it a suitable candidate for an organ dedicated or whole body PET scanner.

[1] M. Pizzichemi et al., *A new method for Depth of Interaction determination in PET detectors*, Phys. Med. Biol. **61** (2016) 4679

[2] G. Stringhini et al., *Development and evaluation of a practical method to measure the Depth of Interaction function for a single side readout PET detector*, 2016 *JINST* **11** P11014.

This work was carried out in the frame of Crystal Clear and supported by CERN KT Project "New ClearPEM module", CERN KT Project "Detector module development for Whole BodyPET" and ASCIMAT project.