Development of SiPM based detectors for dedicated PET applications

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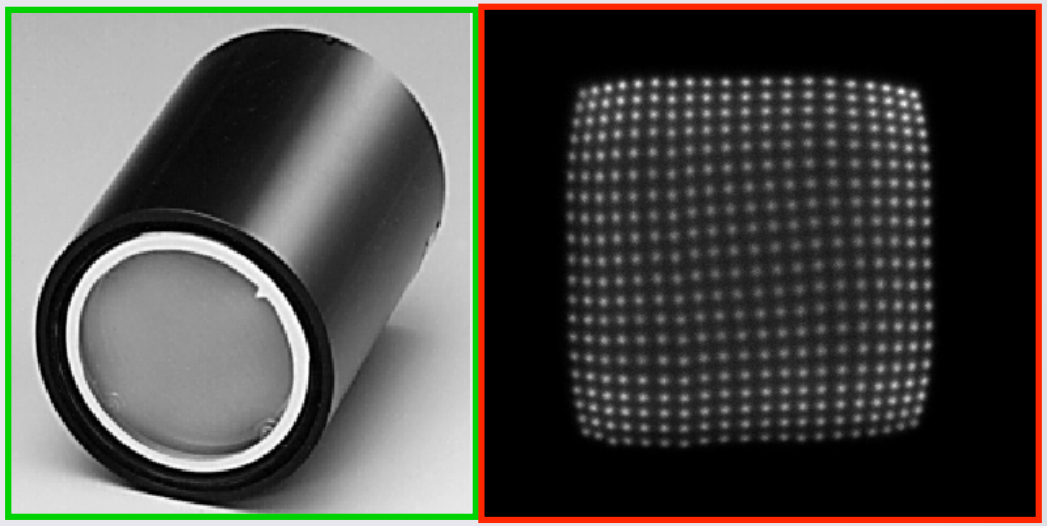
Dedicated PET applications at University of Pisa: pre-clinical systems

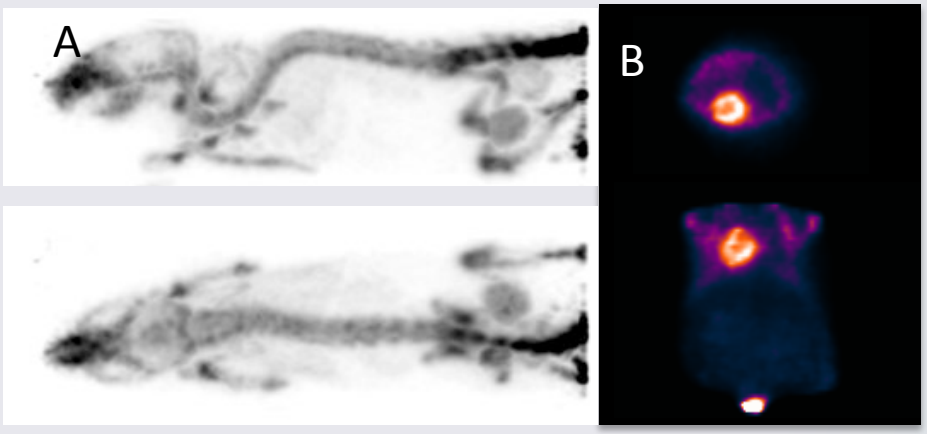
- YAP-(S)PET: an integrated PET/SPECT system with rotating heads



- PSPMT: Hamamatsu R2486
- Scintillator: YAP(Ce)

Dedicated PET applications at University of Pisa: small animals

- YAP-(S)PET: an integrated PET/SPECT system with rotating heads

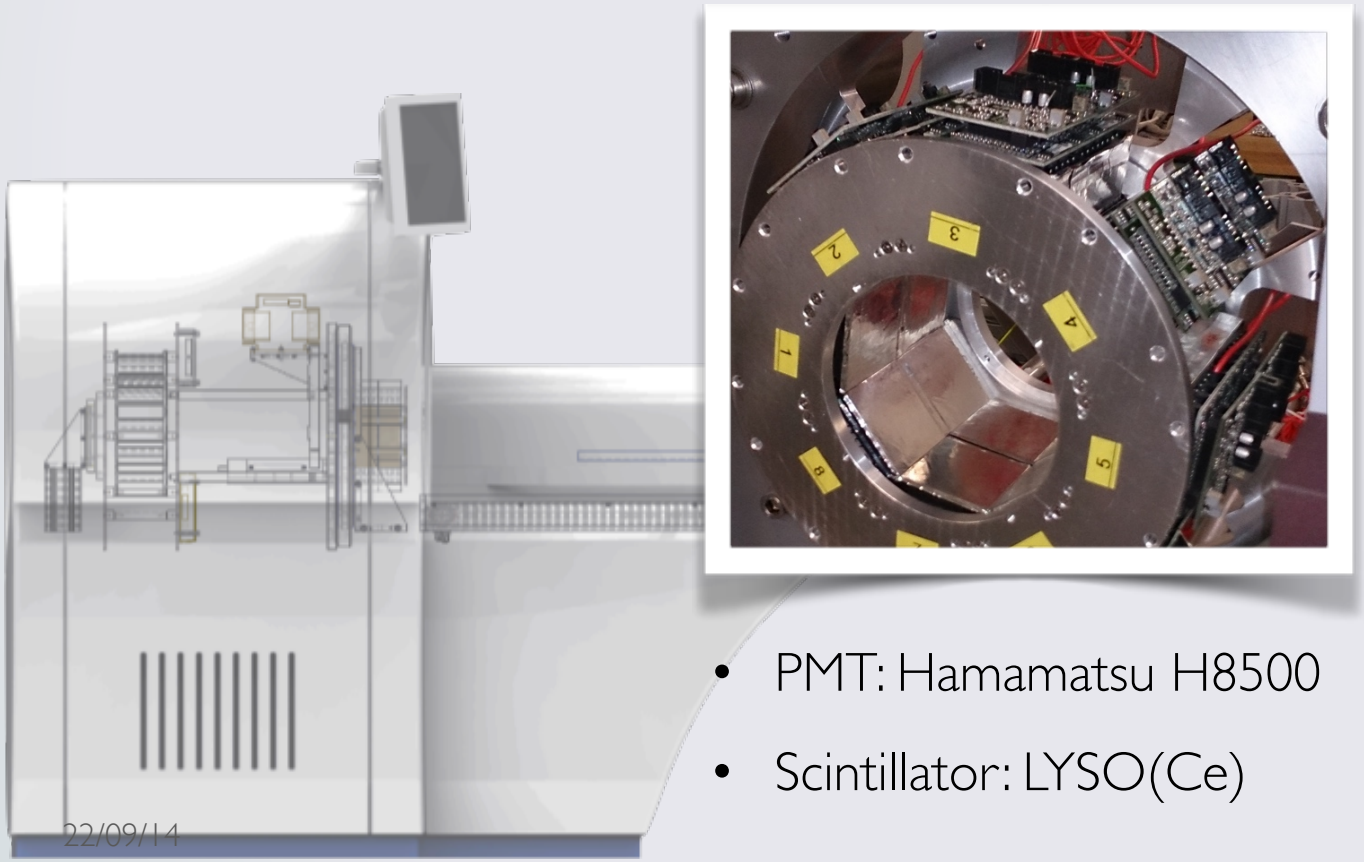


A) MIP image of a mouse injected with $^{18}F^{-}$ solution

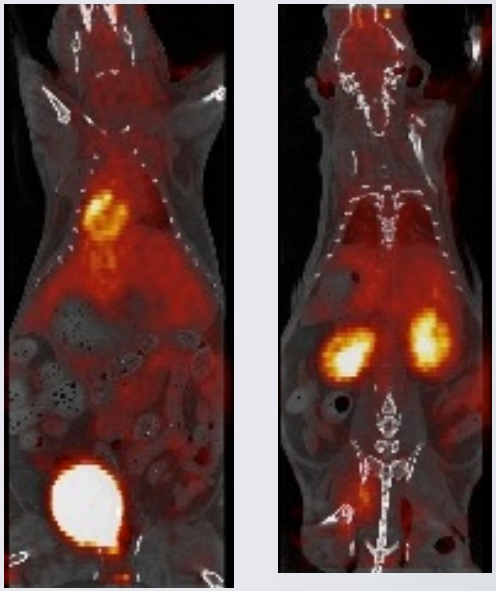
B) Image of the miocardium of a mouse injected with ^{18}F-FDG

Dedicated PET applications at University of Pisa: pre-clinical systems

- IRIS PET/CT: PET/CT system with 16 detectors

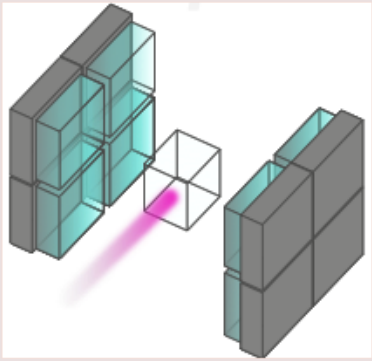


- PMT: Hamamatsu H8500
- Scintillator: LYSO(Ce)



PET/CT in-vivo imaging of a mouse

Dedicated PET applications at University of Pisa: hadrontherapy

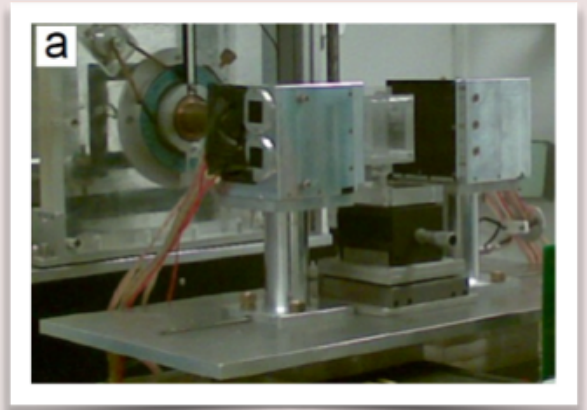


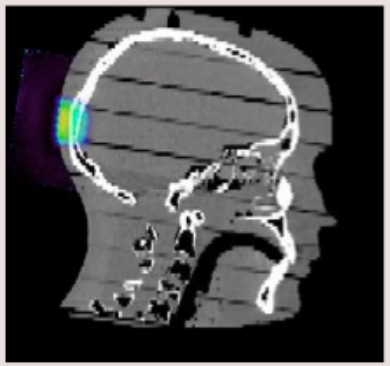
Present design with 4 + 4 detectors

DoPET:

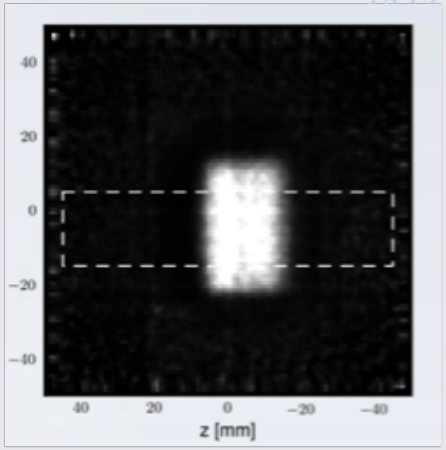
Dual-head PET system for proton range monitoring in HT

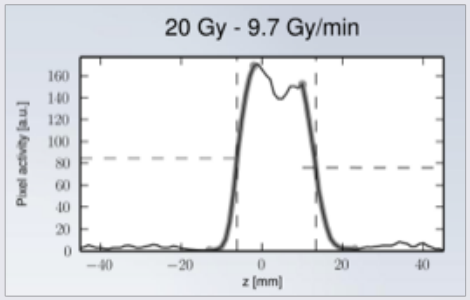
- beam-on measurement capability
- 1 mm FWHM precision on activity distal fall off position determination





Installation at the CATANA beamline in Italy and image of a irradiated RANDO phantom





Sample image and beam z-profile of PMMA irradiated at 20 Gy (62 MeV protons)

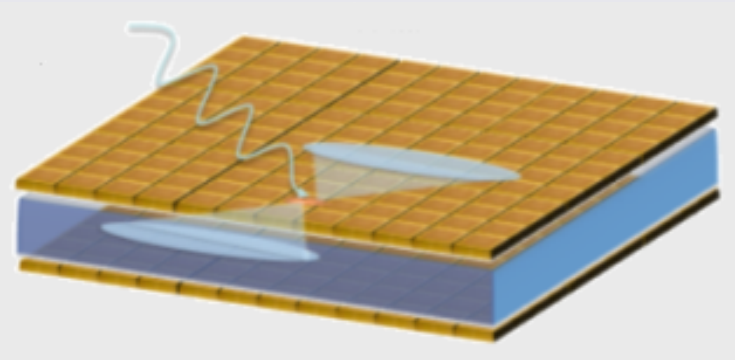
Acquisition:
2 min. beam on
+ 1 min. beam off

SiPM applications to dedicated PET: motivations

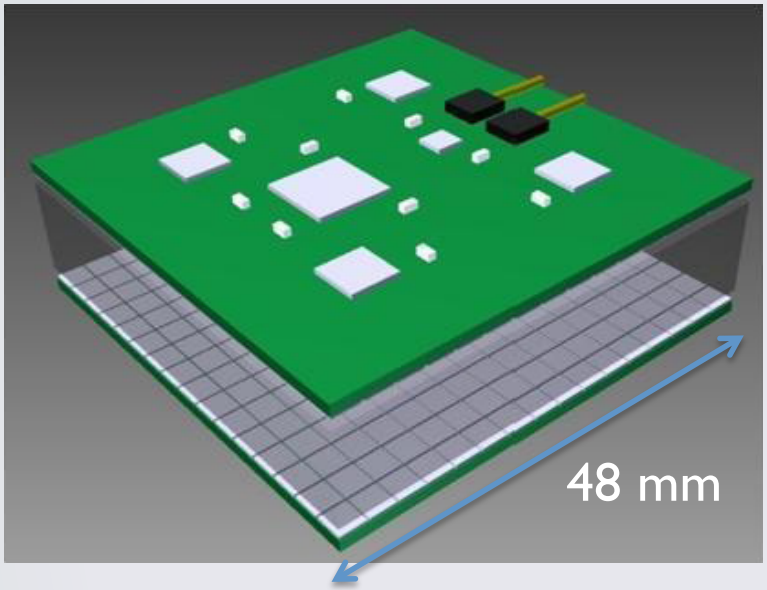
- *High granularity*
  - High resolution applications
  - Low dead time applications
- *High speed*
  - TOF applications
- *Insensitive to magnetic fields*
  - MR compatible (PET/MR systems)
- *Compactness*
  - Application with space constraints

Exploit one of more of these features to overcome the limitations of PMT-based dedicated PET systems

4DM-PET: a PET detector module with depth of interaction capability



4DM-PET module



- Continuous LYSO scintillating crystal coupled to both sides with SiPMs arrays.

- Matrices of 16 x 16 single pixels of 3 x 3 mm^2

- High resolution in X – Y directions:

1 mm FWHM.

- DOI estimation capability (comparing the informations in the two matrices).

2 mm FWHM.

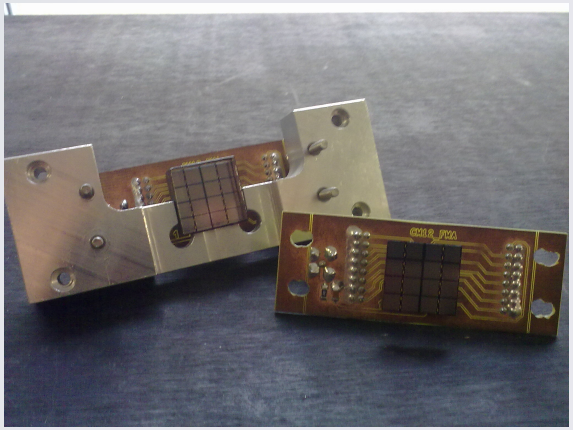
- Time resolution compatible with Time Of Flight requirements.

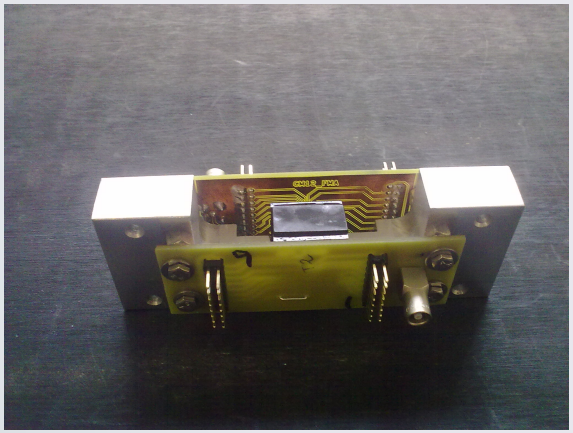
200 ps FWHM

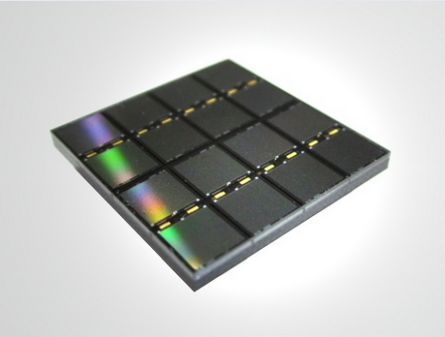
- Insensitivity to magnetic field for hybrid PET-MR applications.

First tests

First prototype module composed of two matrices coupled to LYSO crystal of total dimensions of about 20 x 20 x 10 mm^3 and with SiPMs of 4 x 4 mm^2 active area.





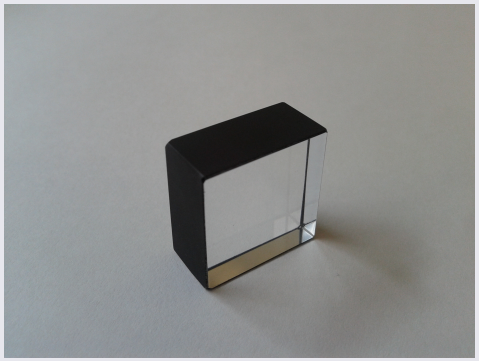


Matrix FBK-Irst: ASD-SiPM4S-P-4×4T-50

Dark Counts: $4.5 \cdot 10^7$ - $8 \cdot 10^7$

Cells number: 6400

Cells size: 50 μm x 50 μm



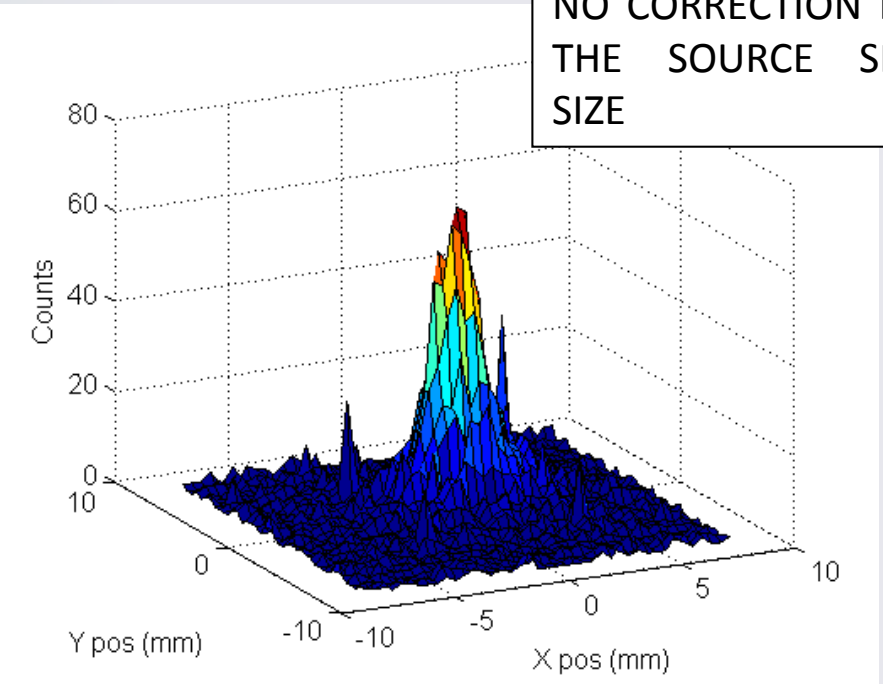
LYSO monolithic crystal

Dimensions: 20 x 20 x 10 mm^3

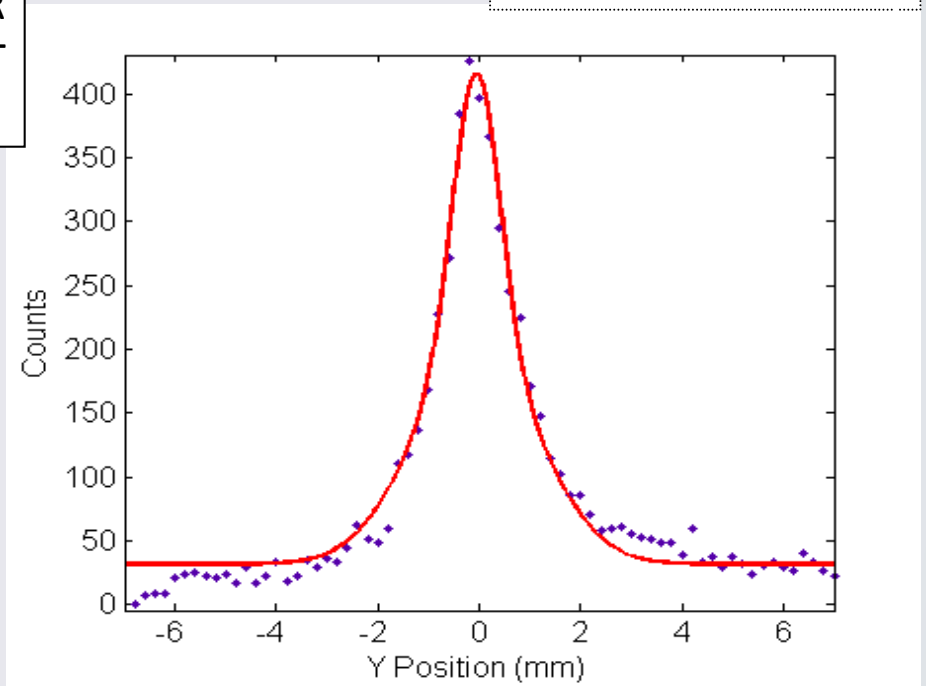
Black painted lateral faces in order to avoid reflection.

First tests: spatial resolution

NO CORRECTION FOR THE SOURCE SPOT SIZE

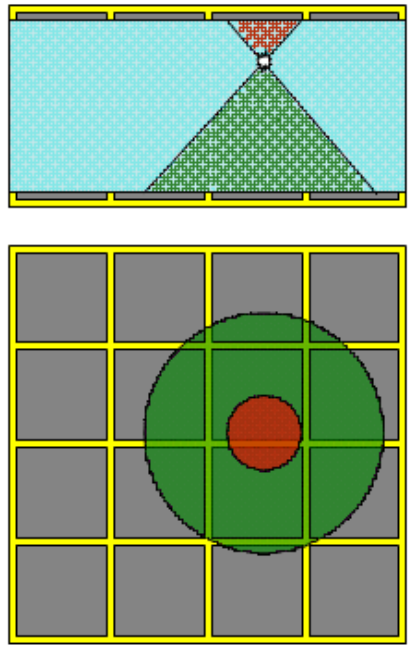


FWHM = 1,76 mm



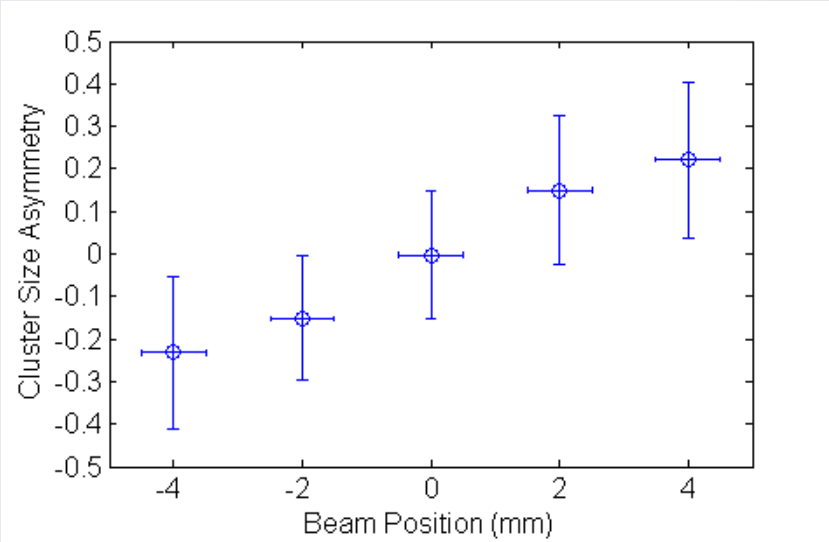
Courtesy of Matteo Morrocchi, INFN Pisa

First tests: DOI performance



$$DOI \propto \frac{CSize_A - CSize_B}{CSize_A + CSize_B}$$

DOI can be estimated with the asymmetry of the Cluster Size in the two tiles.



DOI resolution: 2.4 mm FWHM:

too few pixels are involved in the cluster!

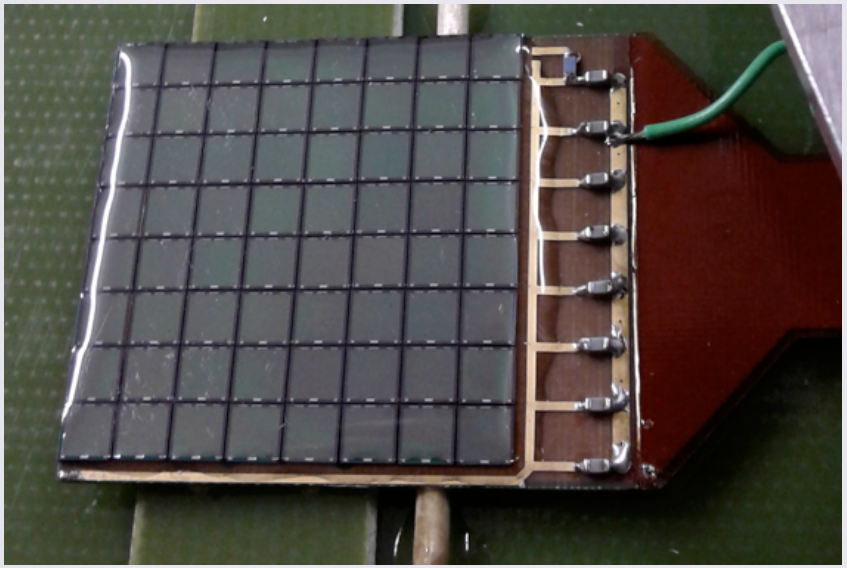
DOI can be estimated also using the asymmetry of the energy deposited in the pixel with the higher amplitude

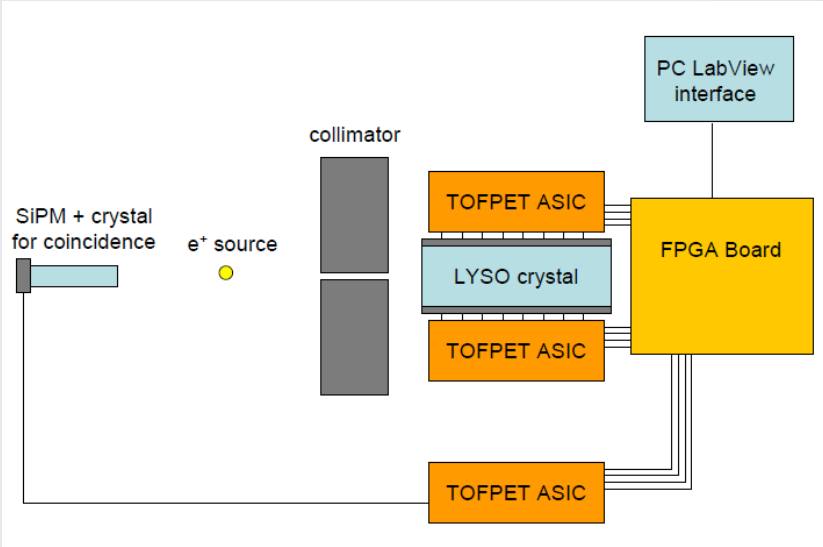
$$DOI \propto \frac{MAX_A - MAX_B}{MAX_A + MAX_B}$$

Courtesy of Matteo Morrocchi, INFN Pisa

Second prototype

- 8x8 SiPM from AdvanSiD (RBG type)
- ASIC TOFPET from ENDOTOFPET FP7 project

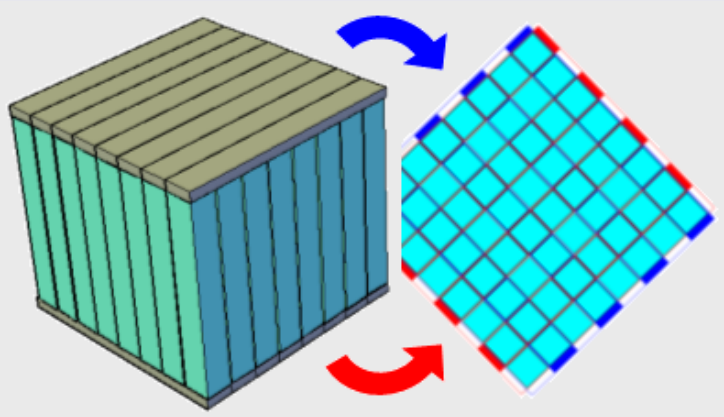




$$DOI \propto \frac{MAX_A - MAX_B}{MAX_A + MAX_B}$$

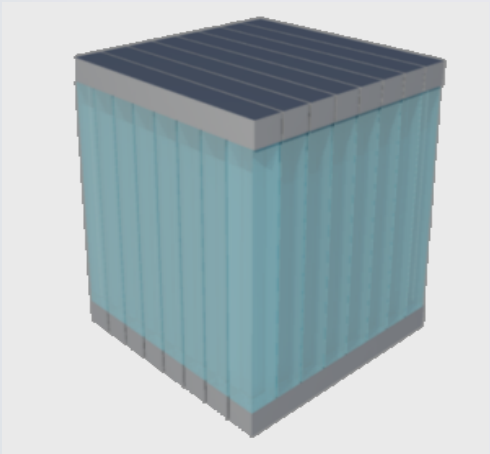
First measurements indicate the targed DOI of <u>less than 2 mm</u> FWHM.

A Detector Module Composed of Pixellated Crystals Coupled to SiPM Strips



Strip design: A Two Side Read-Out

Readout of a pixellated LYSO matrices using rectangular SiPMs on both sides of the crystal:



$N_{crystals} = 64$

Pitch = 1.5 x 1.5 mm^2

Thickness = 10 mm

Area = 12 x 12 mm^2

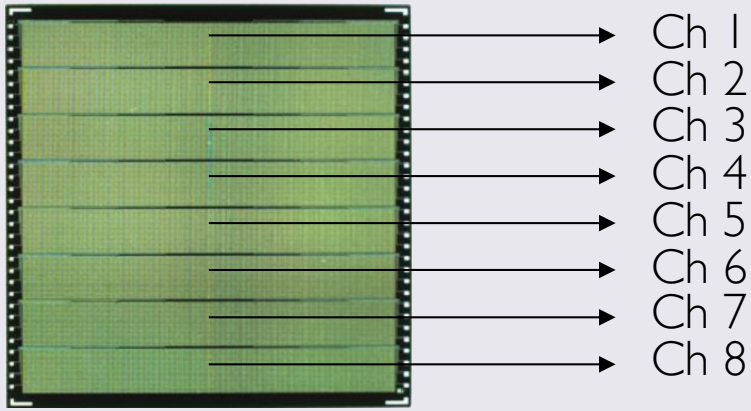
16 analog channels

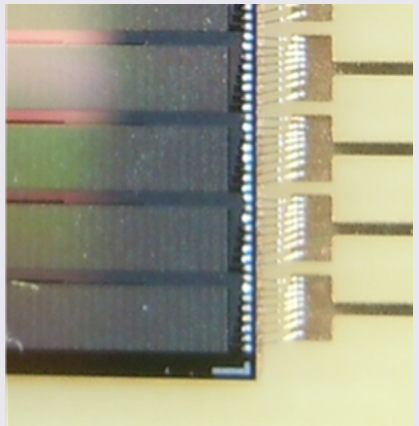
Front Side: X information

Back side: Y information

FBK-IRST monolithic 64-channels matrices

The 8 channels of the same line have been connected in parallel to the same analog input:

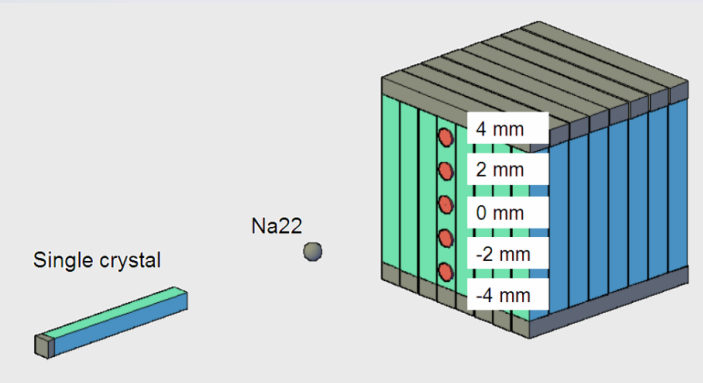


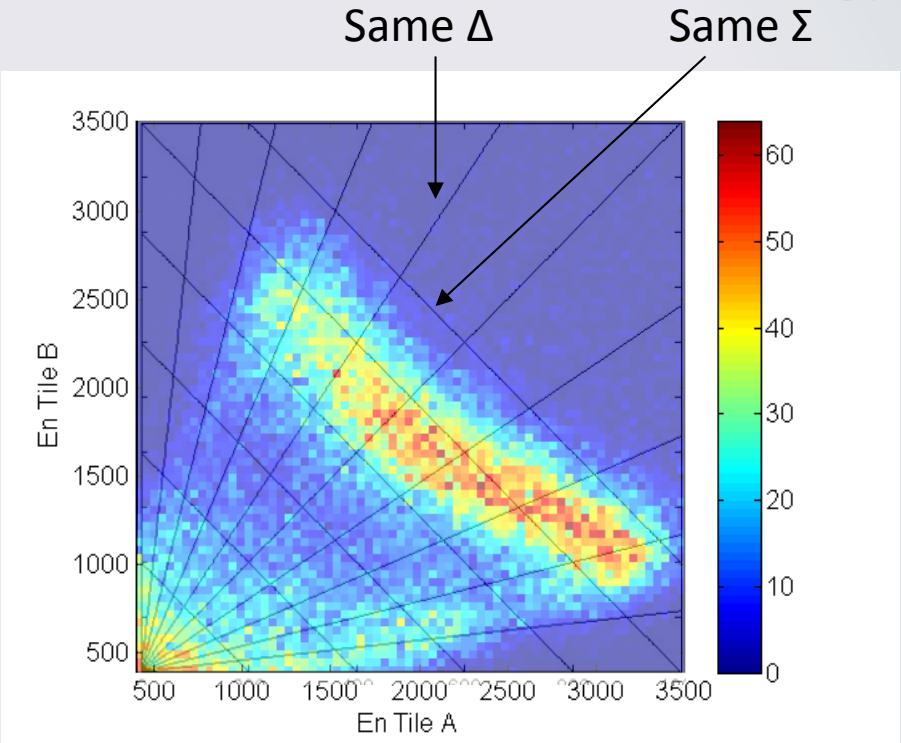


Total surface of each strip is comparable to a 4 x 4 mm^2 SiPM

Courtesy of Matteo Morrocchi, INFN Pisa

DOI Dependence of Collected Energy





En Tile A = Sum of signals in the front-side

En Tile B = Sum of signals in the back-side

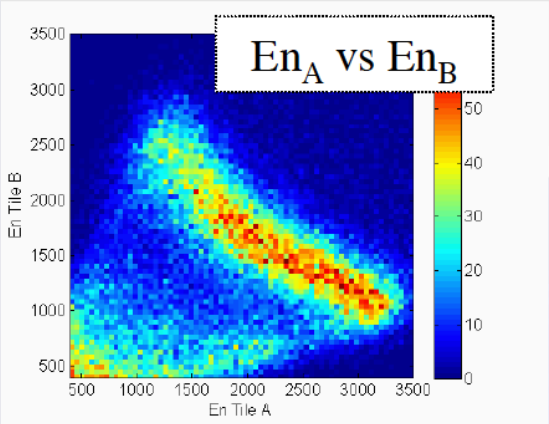
The energy of the event is related to the total collected energy, while the DOI is related to the asymmetry of the distribution of the energy in the two faces.

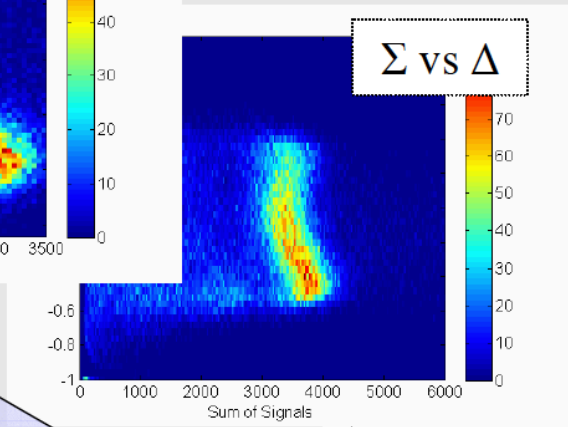
$$\Delta = \frac{En_A - En_B}{En_A + En_B}$$

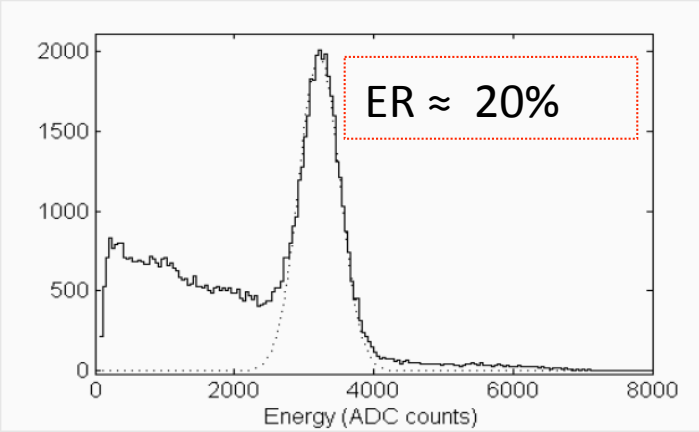
$$\Sigma = En_A + En_B$$

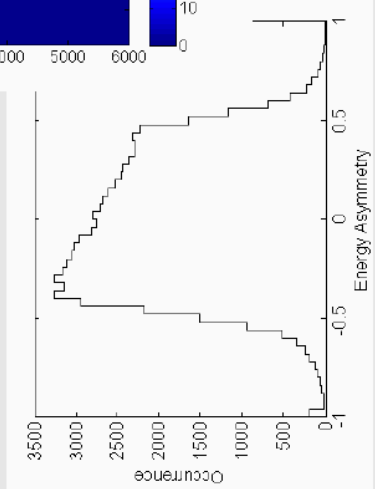
Courtesy of Matteo Morrocchi, INFN Pisa

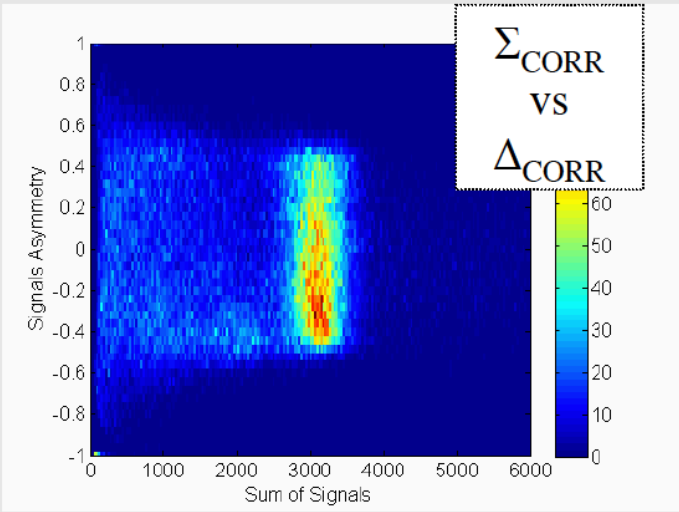
Strip design: Performance

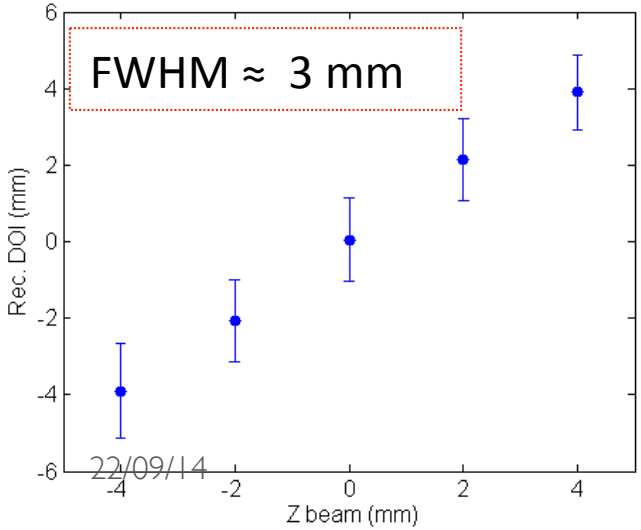








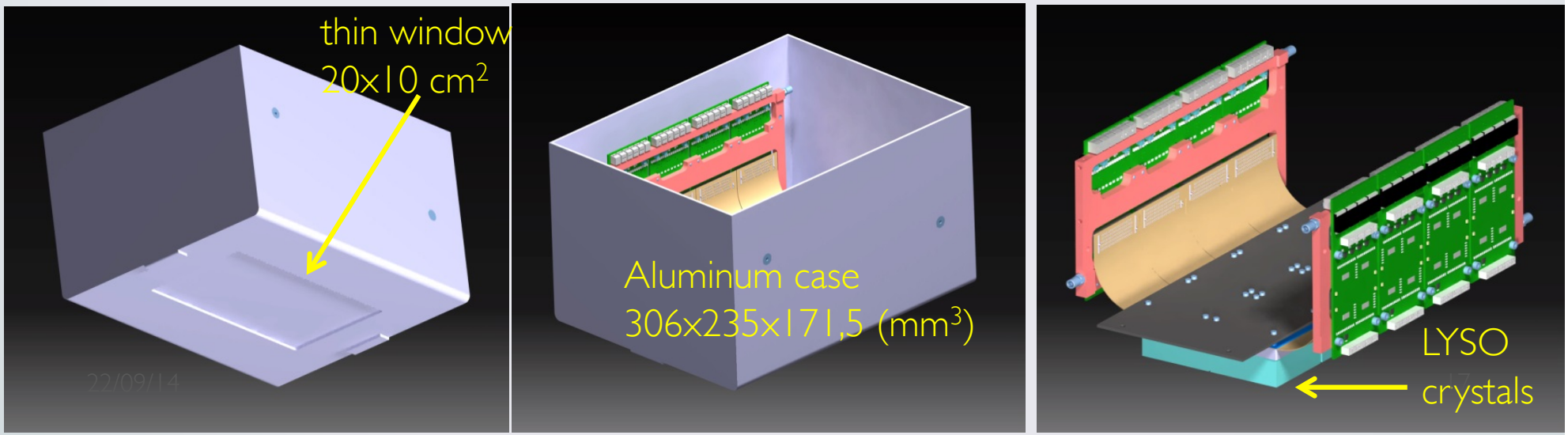




Courtesy of Matteo Morrocchi, INFN Pisa

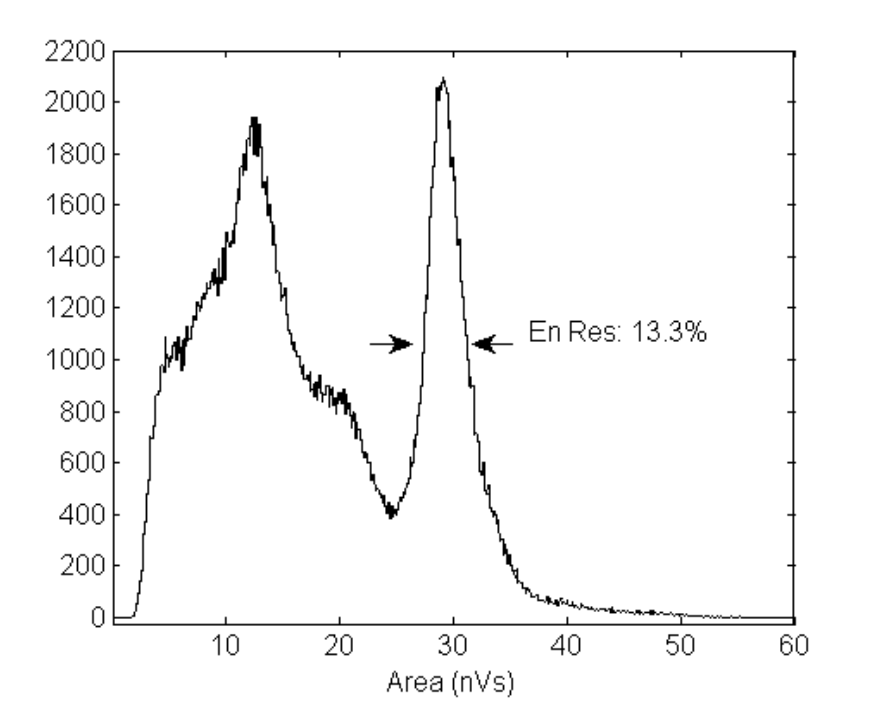
The INSIDE PET detectors

- DAQ sustains annihilation and prompt photon rates during the beam irradiation – TOF as a plus to reduce distortion
- Two planar panels each 10 cm x 20 cm^2 wide. Each panel will be made by 2 x 4 detection modules
- Each module is composed of a pixelated LYSO scintillator matrix 16 x 16 pixels, 3x3 for a total sensitive area of 5x5 cm^2
- One SiPM array (16x16 pixels, by Hamamatsu) is coupled one-to-one to LYSO crystals

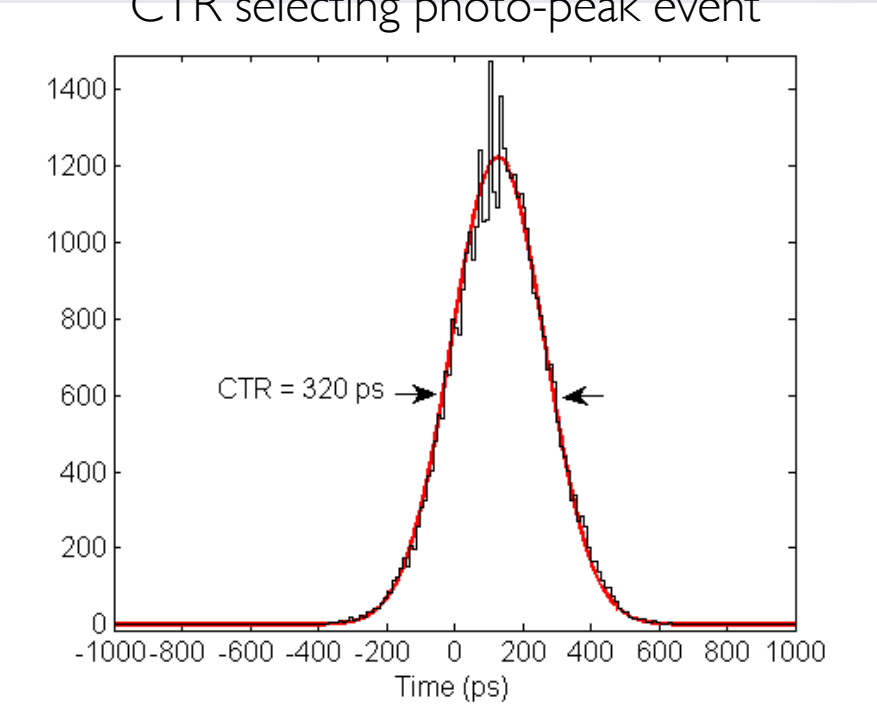


Preliminary timing measurements

HAMAMATSU SiPM + 3 x 3 x 20 LYSO crystal COUPLED TO A PREAMPLIFIER



CTR selecting photo-peak event



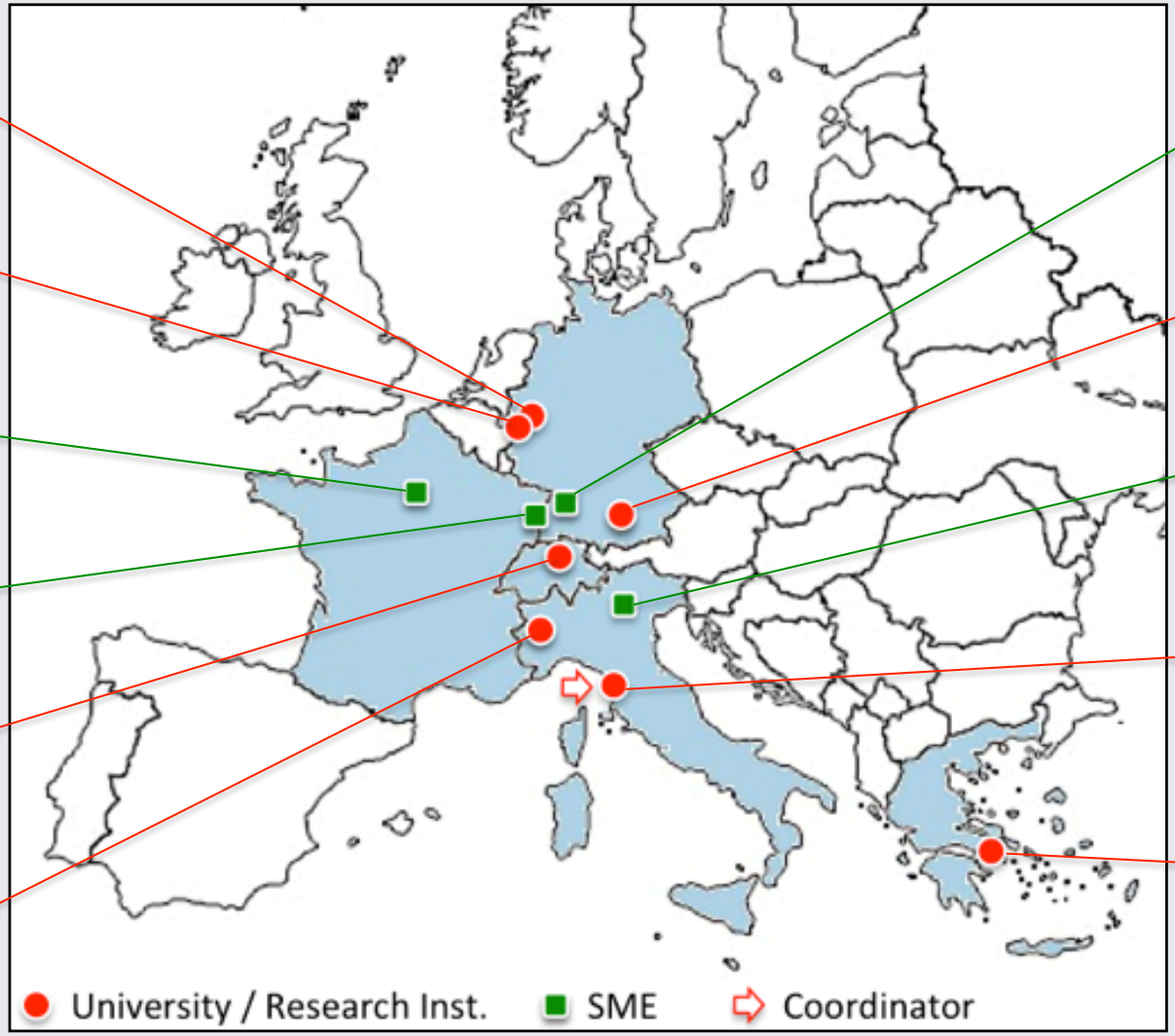
TRIMAGE OBJECTIVES

TRIMAGE: an optimized TRImodality (PET/MR/EEG) imaging tool for schizophrenia

- *TRIMAGE aims to create a trimodal, cost effective imaging tool consisting of **PET/MR/EEG** using cutting edge technology with performance beyond the state of the art.*

- *The tool is intended for broad distribution and will enable effective early diagnosys of schizophrenia and possibly other mental health disorders.*

TRIMAGE CONSORTIUM

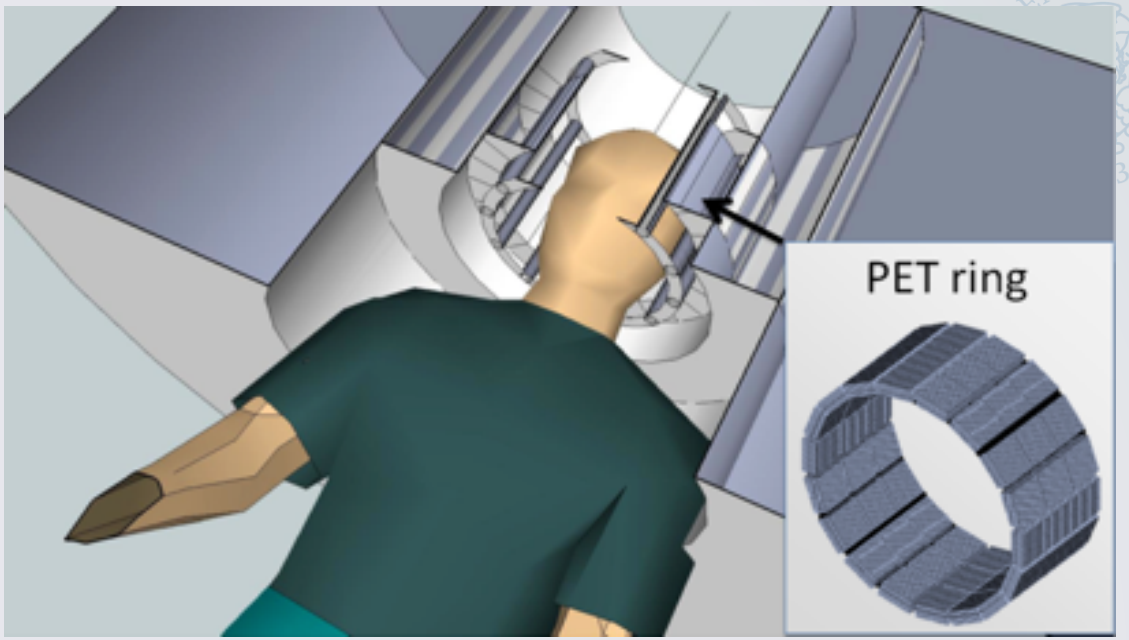


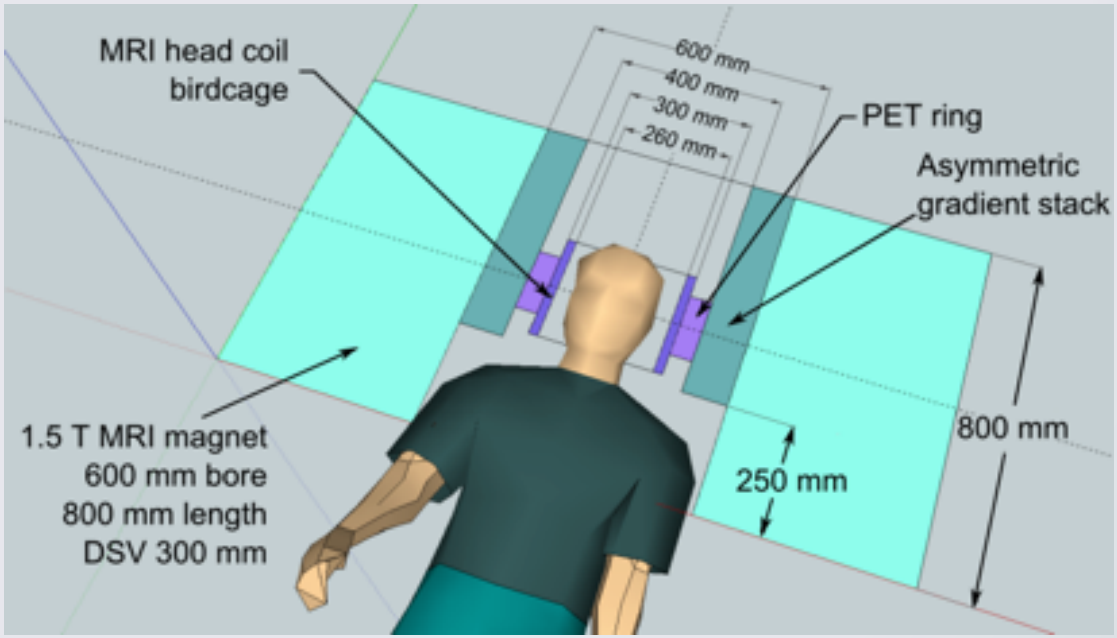
WP3 Objective

Design and construction of a PET system capable to:

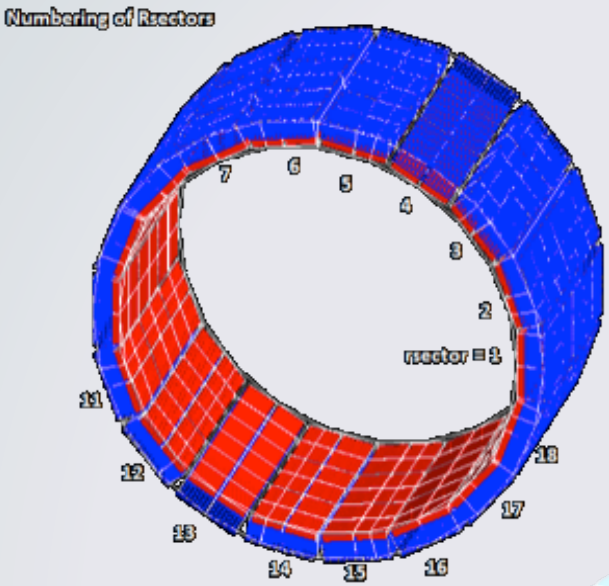
- Image the brain with a image quality beyond the state-of-the-art

- Work inside a 1.5 T MRI

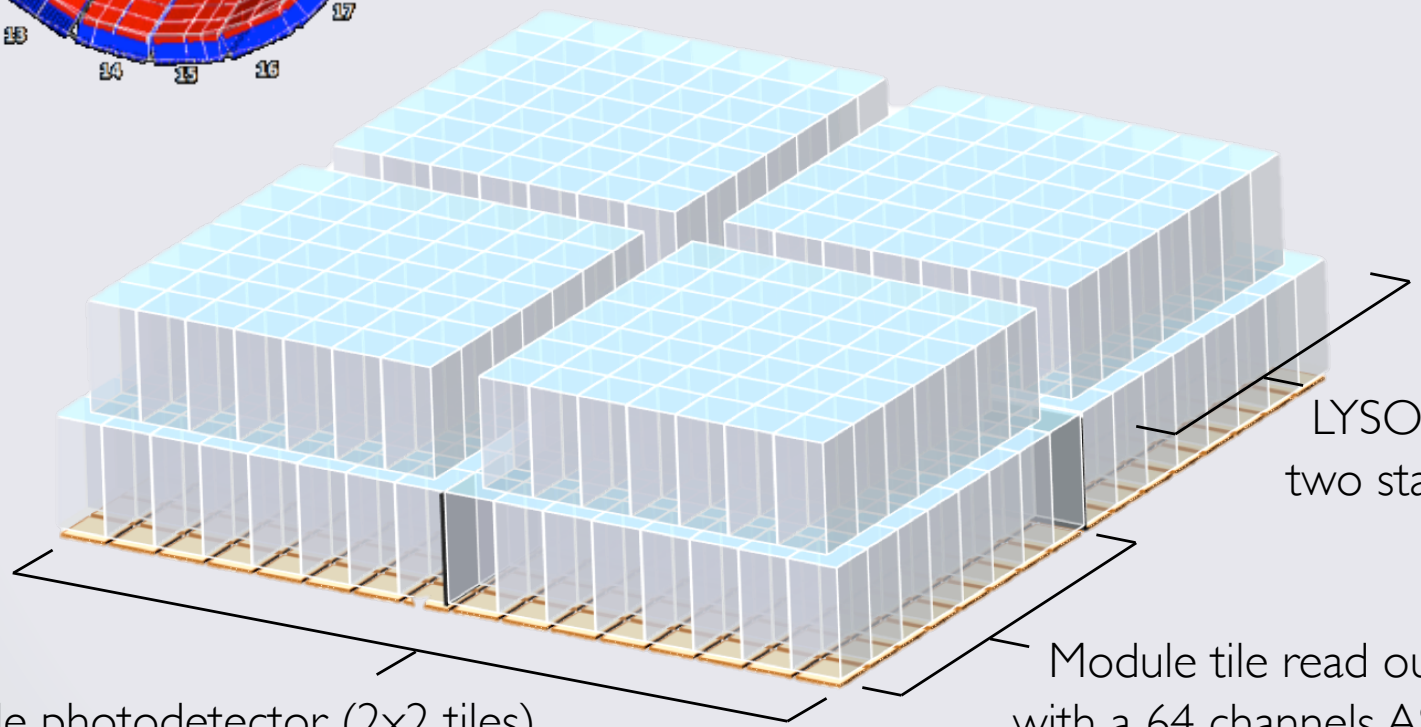




THE MODULE

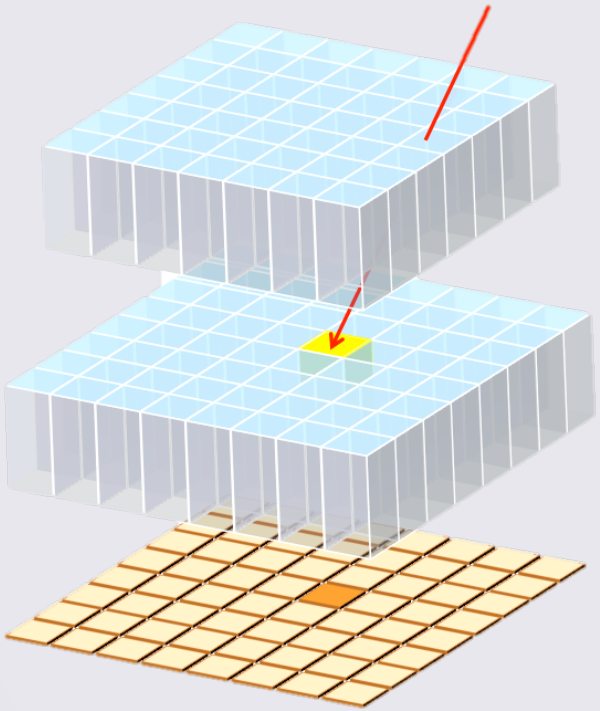


The PET ring comprises 18 sectors each of which is made of three modules



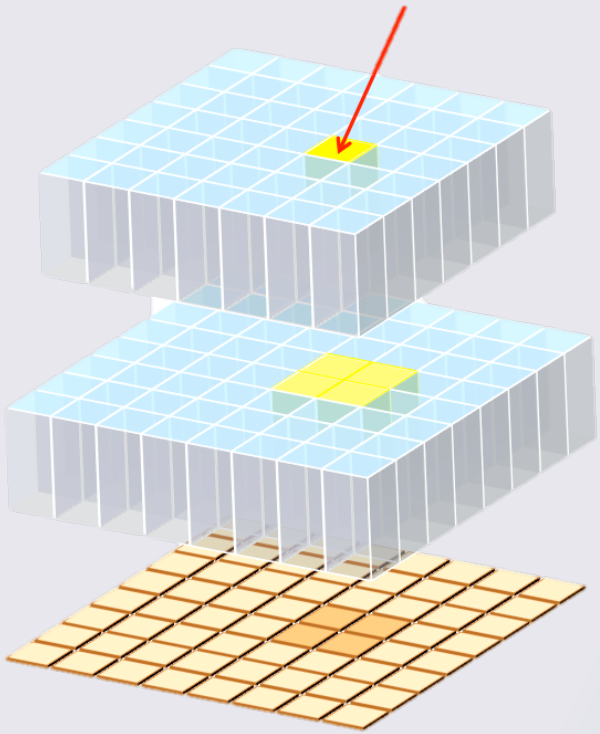
Pixel identification concept

Interaction in the bottom layer



"only one" SiPM is fired

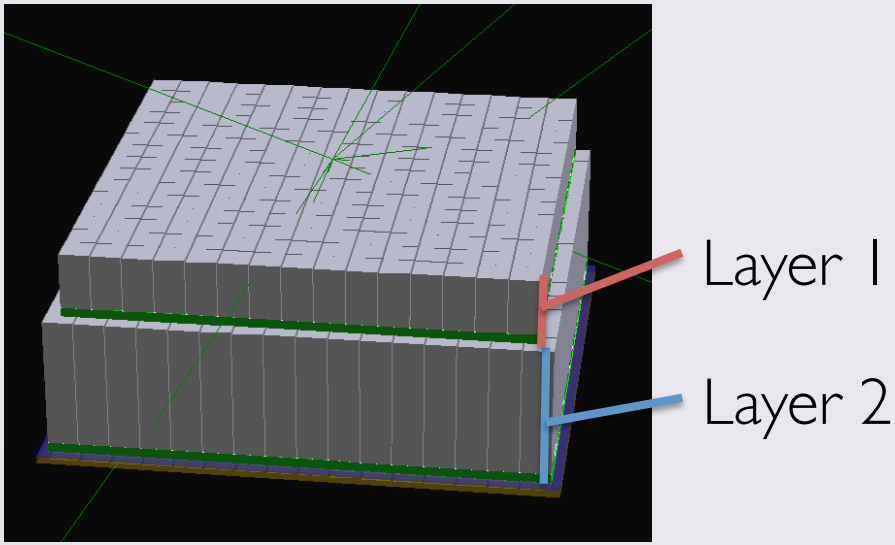
Interaction in the top layer

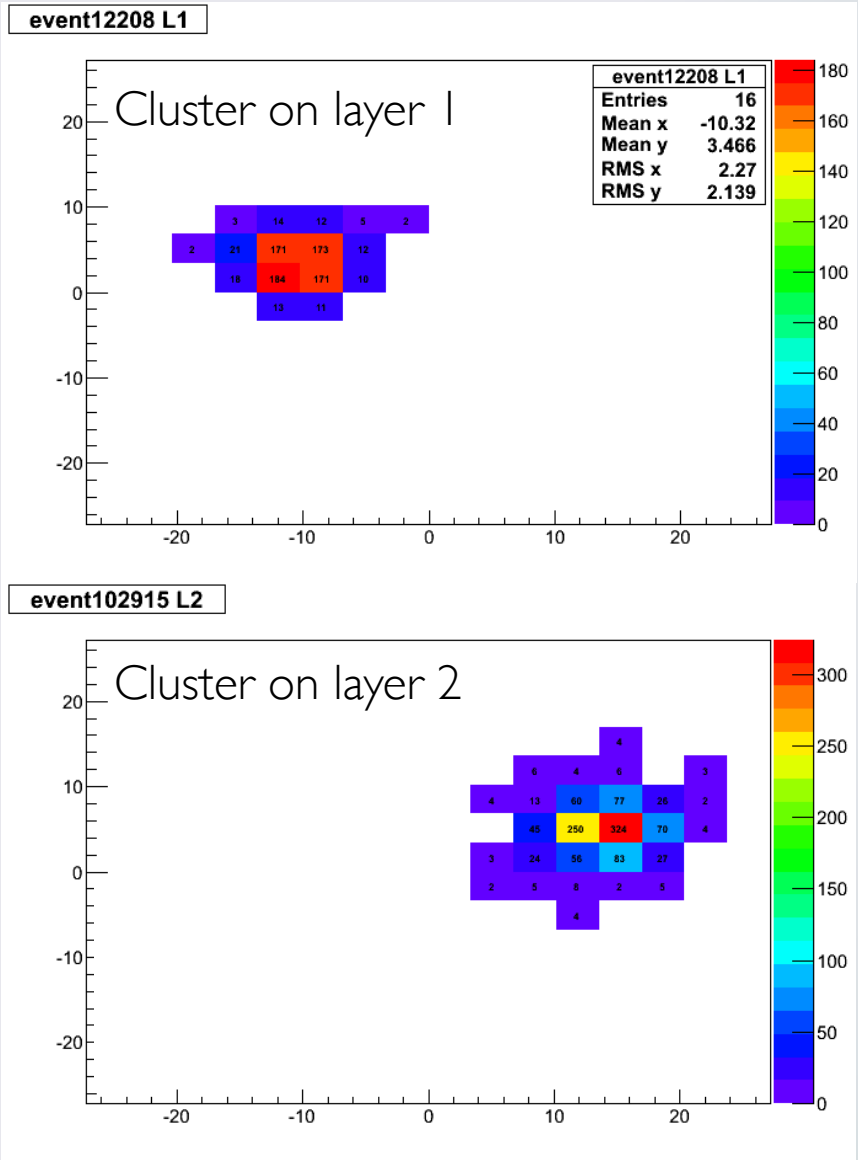


"four" SiPMs are fired

Monte Carlo simulation of the module

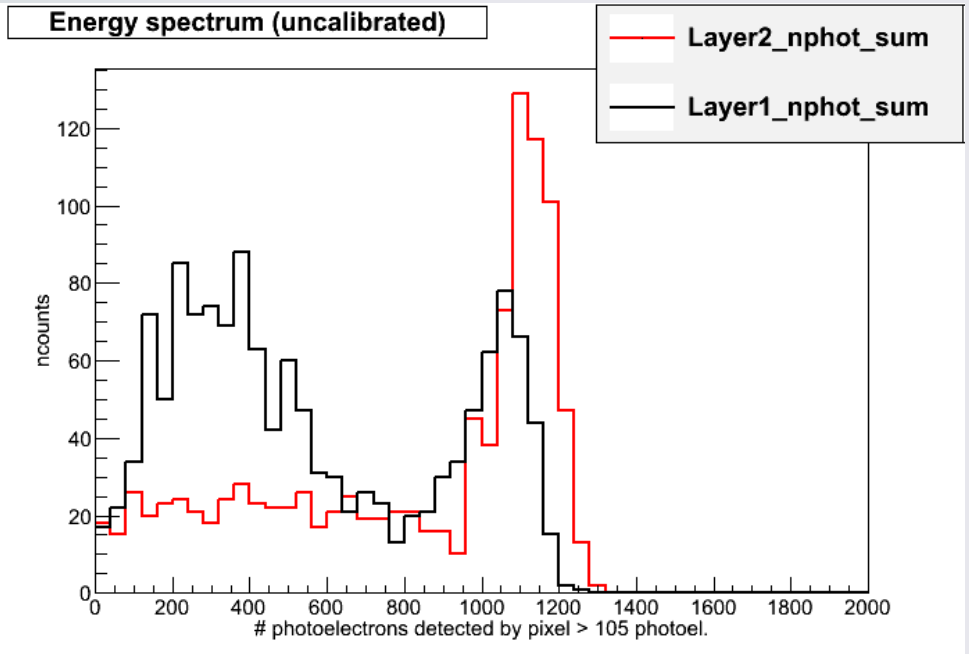
GAMOS 4.0.0 based on GEANT4.9.5.p02
w/UNIFIED optical model

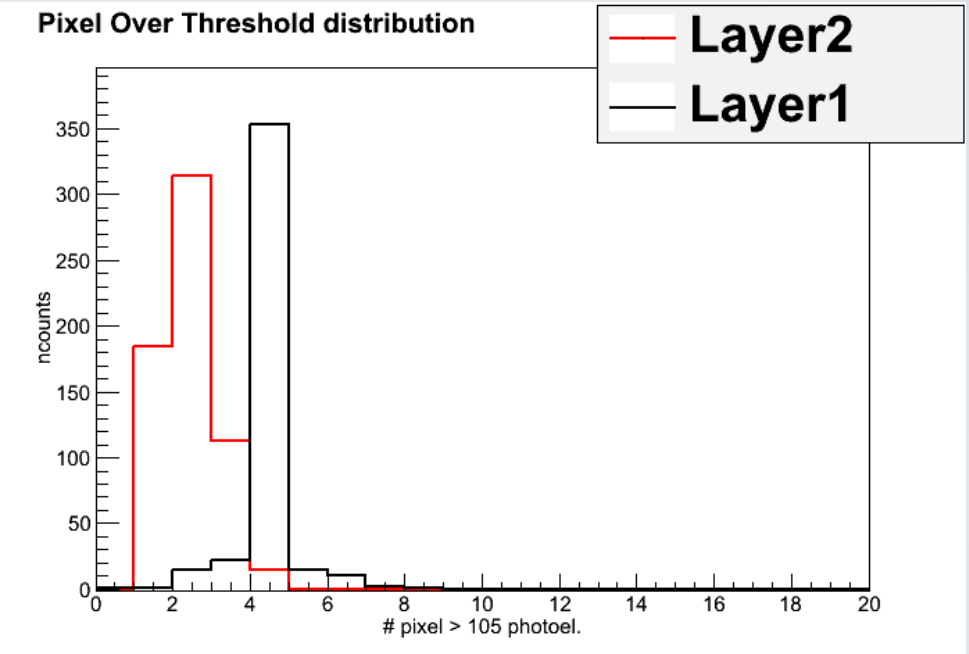




Courtesy of Francesco Pennazio, INFN Torino

Layer identification





Energy distribution on layer 1 (black) and 2 (red)

Courtesy of Francesco Pennazio, INFN Torino

Layer identification:

- Measuring the number of pixel (SiPM) with an energy deposition > than a fixed theshold
- E.g., with a thershold of 105 phoelectrons
- 95 % of layer identification

Conclusion

We are exploiting different features of SiPM to design dedicated PET systems with different requirements:

Project	High granularity	Speed	Magnetic compatibility	Application	Compactness
4DM-PET	★ To achieve high spatial resolution	★	★	Pre-clinical imaging (demonstrator)	★ To minimize the attenuation of the top "layer"
Strip readout	★		★	(demonstrator)	★ To minimize the attenuation of the top "layer"
INSIDE	★ To sustain high count rates	★		In-beam PET dose monitoring in hadrontherapy	
TRIMAGE	★ One-to-one coupling		★	Brain PET/MR	★ To fit in a very compact system

Acknowledgement

- The presented material arises from the work by researchers of the groups involved in:
  - 4DM-PET INFN project
  - INSIDE project collaboration
  - RDH INFN experiment collaboration
  - TRIMAGE project collaboration