INSIDE Project

Innovative Solutions for In-beam DosimEtry in Hadrontherapy

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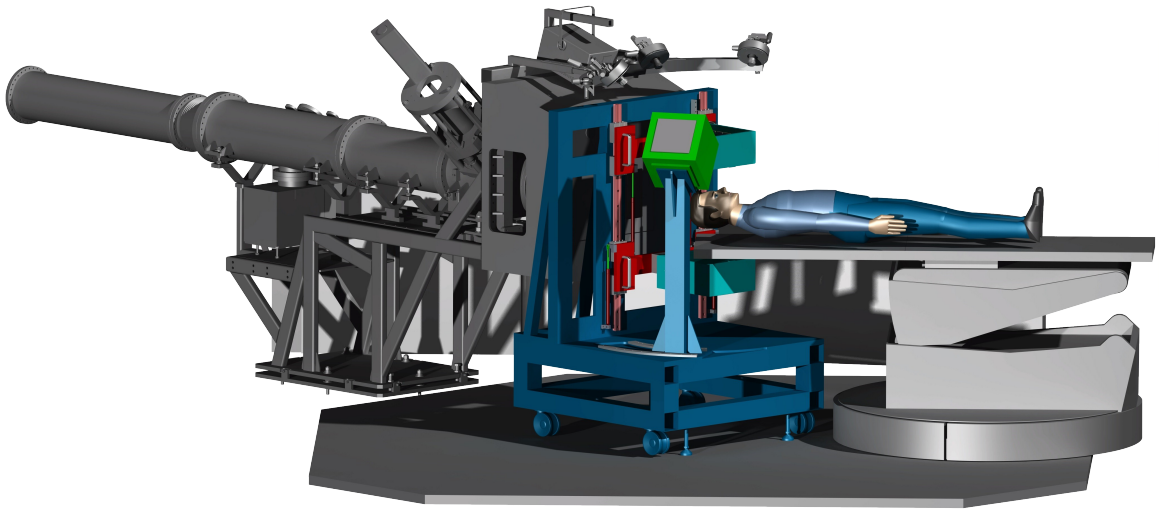

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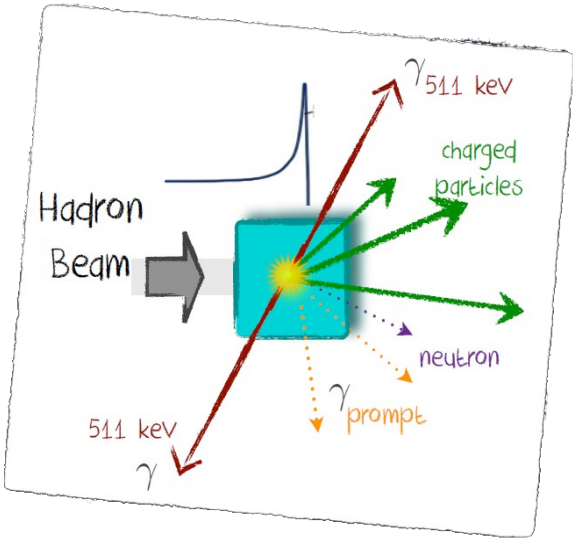
The INSIDE project

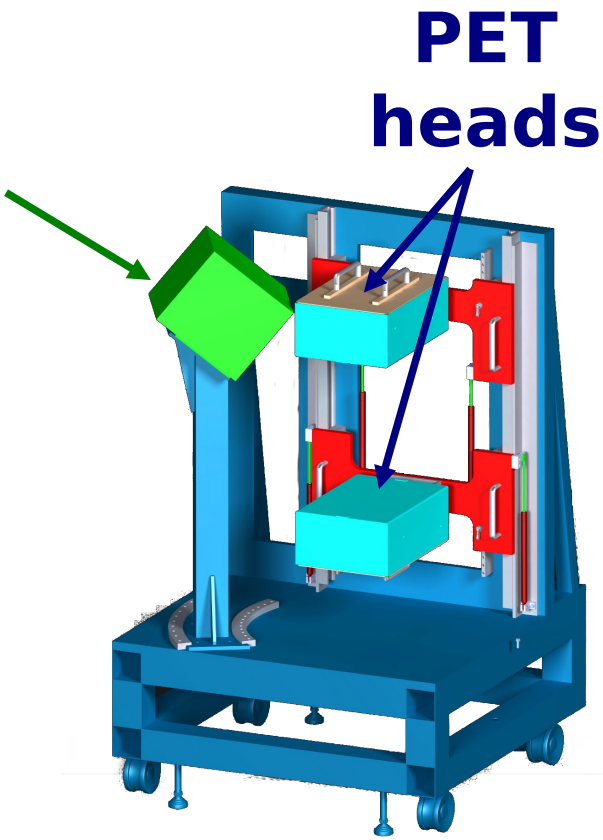
- It is under the national research program PRIN MIUR 2010-2011 – 2010P98A75

- It is part of the “Dose Monitoring for Hadrontherapy” working package of the RDH project

- It is a collaboration of:
  - Politecnico di Bari and INFN Bari
  - INFN (Milano, LNS, LNF)
  - University of Pisa and INFN Pisa
  - University of Roma La Sapienza and INFN Roma1
  - University of Torino and INFN Torino

The INSIDE monitoring system





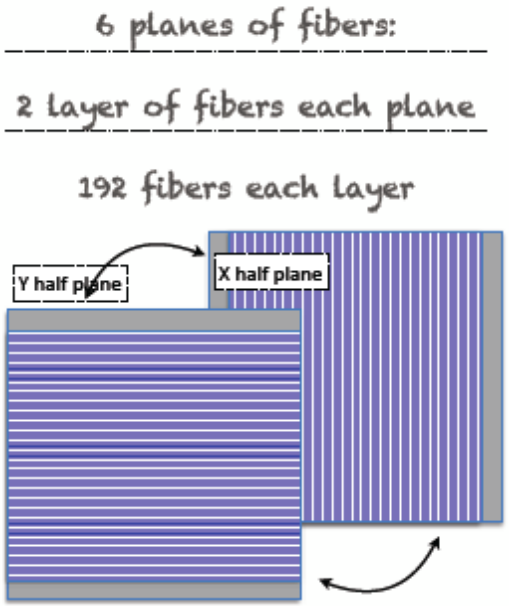
- The monitoring system developed by the INSIDE project will be based on a PET system and a Dose Profiler
- It will make use of both the β^+ emitters created during the irradiation and the prompt radiation
- The monitoring system will be installed at the CNAO hadrontherapy facility

fondazione CNAO
Centro Nazionale di Adroterapia Oncologica per il trattamento dei tumori

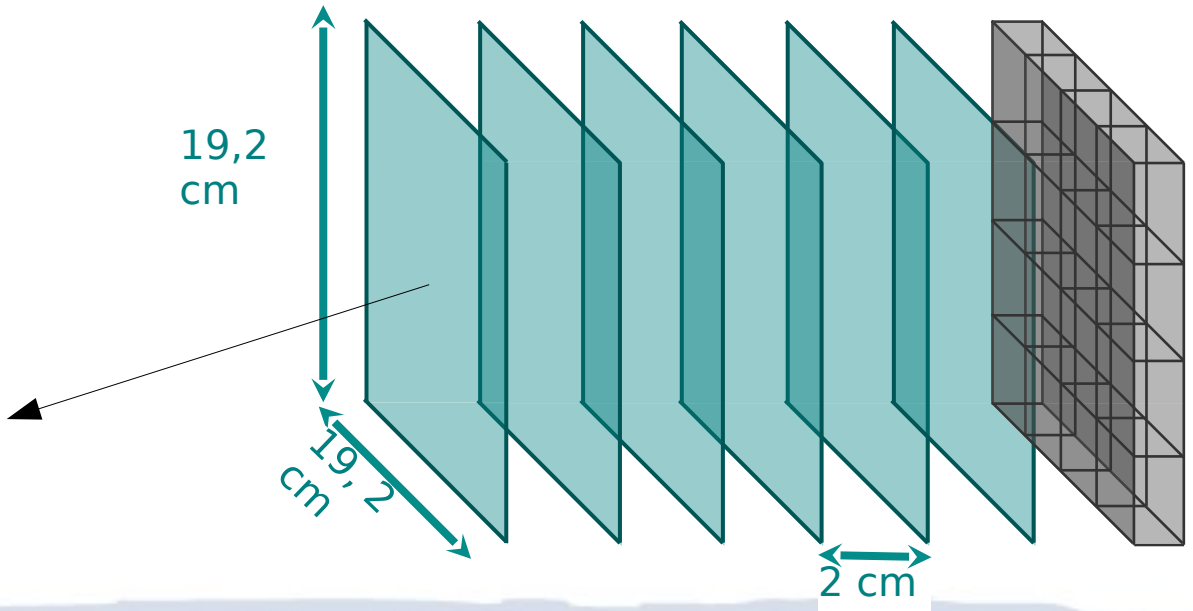
The Dose Profiler

(V. Patera, Roma)

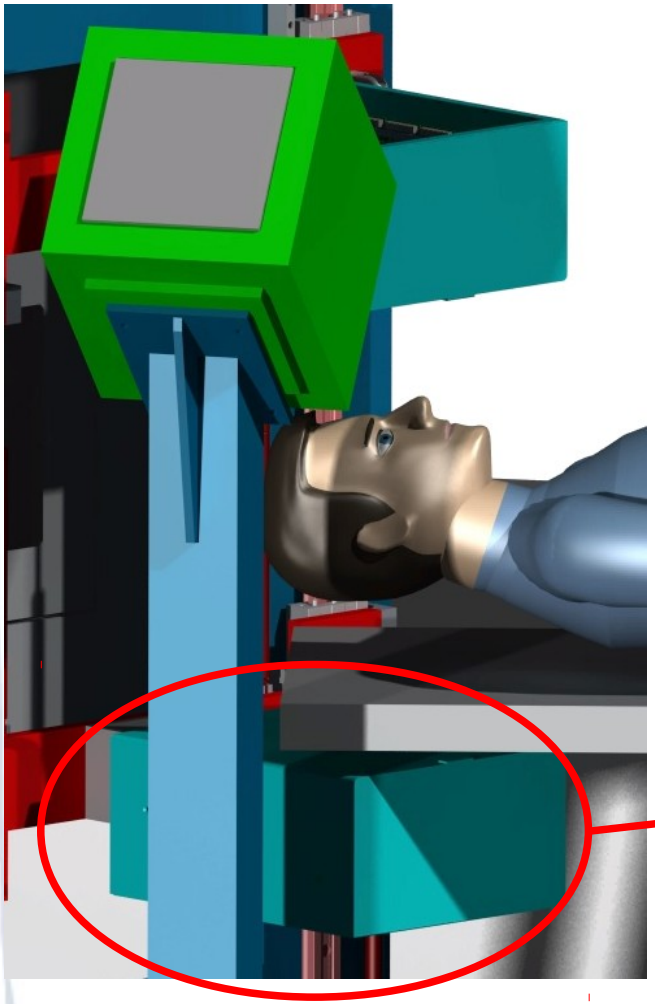
- **6 XY planes with 2 cm spacing**
- **Each plane made of 2 stereo layers of 192 0.5x0.5 mm^2 square scintillating fibers**
- **2x0.5 mm squared fibers read out by Hamamatsu 1mm^2 SiPM : S12571-050P**
- **32 SiPM feed a 32 channels ASIC BASIC32**



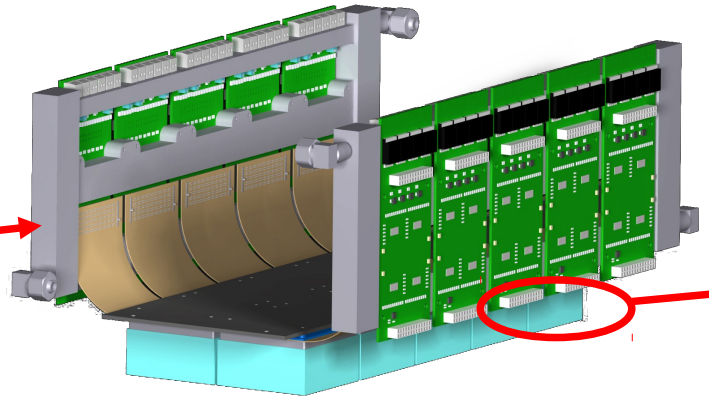
(M. Marafini, Roma)

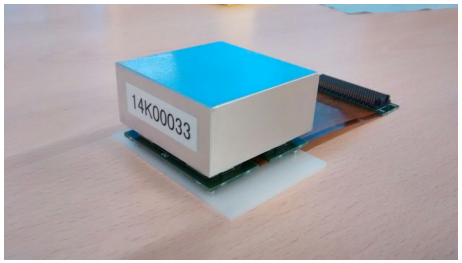


PET heads



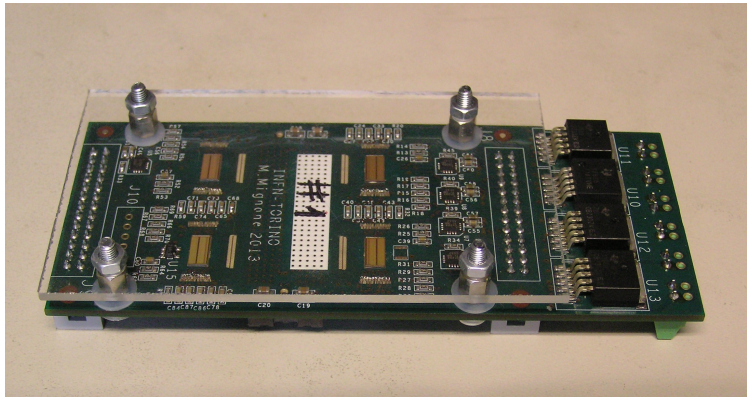
- Two planar heads, each 10 cm (axially) x 25 cm (transaxially) with a gantry aperture of 55 cm
- 2 x 5 LFS scintillator matrices of 5 x 5 cm^2, with 16 x 16 pixels (3 x 3 x 20 mm^3) of 3.2 mm picth
- 16 x 16 Multi-Pixel Photon Counters (MPPC) arrays from Hamamatsu
- 4 custom-design 64 channels TOF-PET ASIC



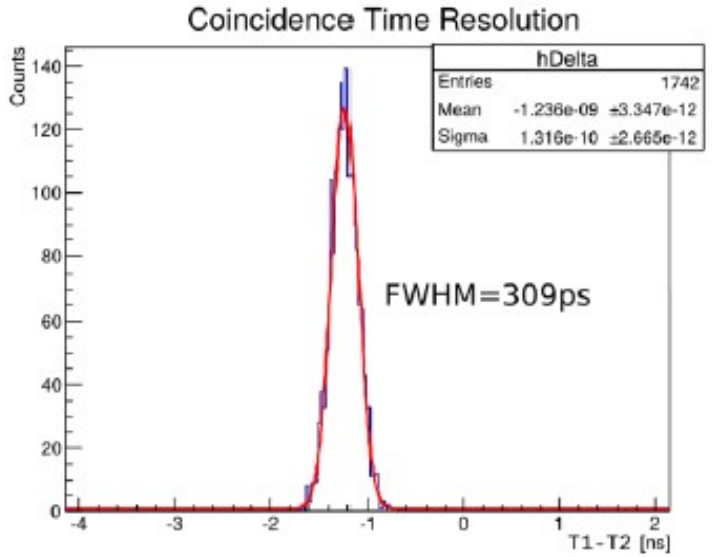


Front-end ASIC TOF PET

Parameter	Value
Number of channels	64
Clock frequency	80 – 160 MHz
Dynamic range of input charge	300 pC
SNR (Q_{in} = 100 fC)	> 20-25 dB
Amplifier noise (in total jitter)	< 25 ps (FWHM)
TDC time binning	50 ps
Coarse gain	G_0, $G_0/2$, $G_0/4$
Max. channel hit rate	100 kHz
Max. output data rate	320 Mb/s (640 w/ DDR)
Channel masking	programmable
SiPM fine gain adjustment	500 mV (5 bits)
SiPM	up to 320pF term. cap., 2MHz DCR
Calibration BIST	internal gen. pulse, 6-bit prog. amplitude
Power	< 10 mW per channel



FE Board w 4 TOFPET ASICs
R. Wheadon INFN Torino



Tofpet performances

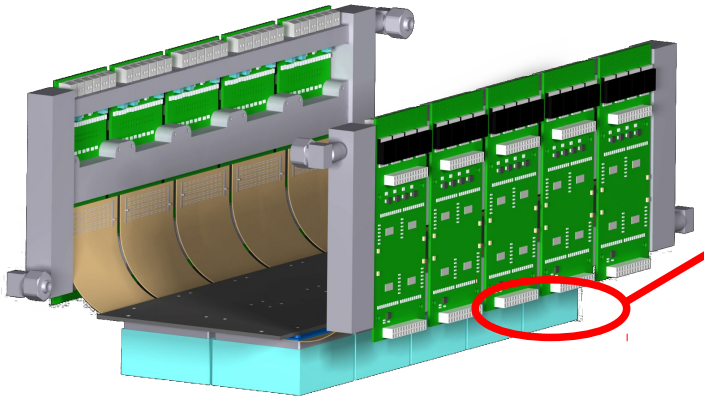
MPPC discrete TSV 4x4 arrays (3 x 3 mm2 pixels)

Crystal 4x4 matrix on each array (3.5 x 3.5 x 15 mm3)

Crystal-SiPM matching 73 %

Courtesy of M. Rolo, LIP and ENDOTOFPET EU project

Test of the TOF PET ASICS



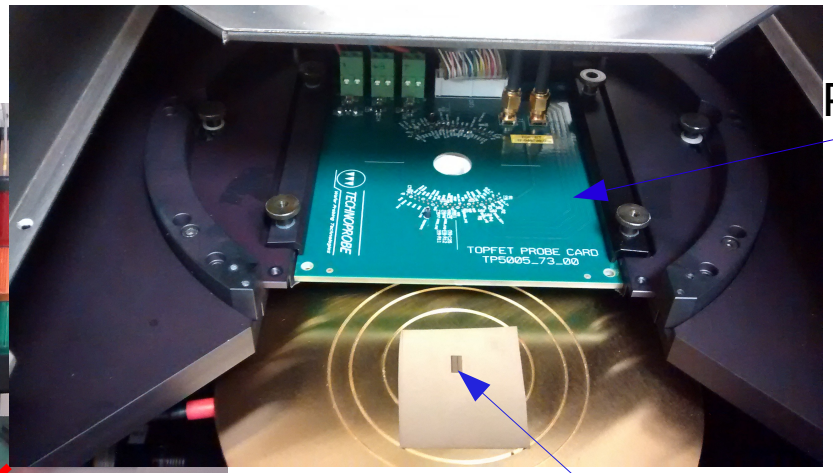
- 16x16 SiPM matrix
- 4 TOF PET chips needed

- Each PET head needs 40 TOF PET chips
- Each TOF PET chip must be tested

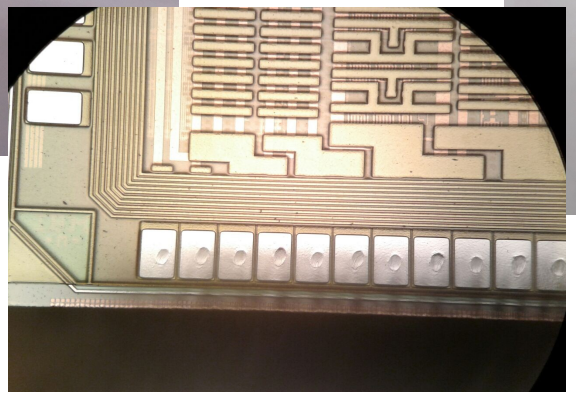
Test of the TOF PET ASICS: experimental set up

(A. Lodola, N. Marino, M. Morrocchi, M.A. Piliero, G. Pirrone, Pisa)

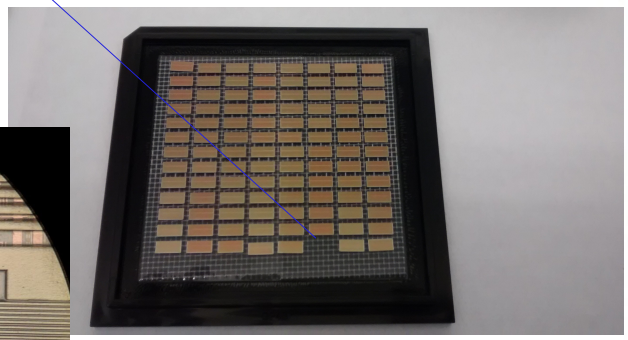
Probe station at the clean room, INFN Pisa



Probe card

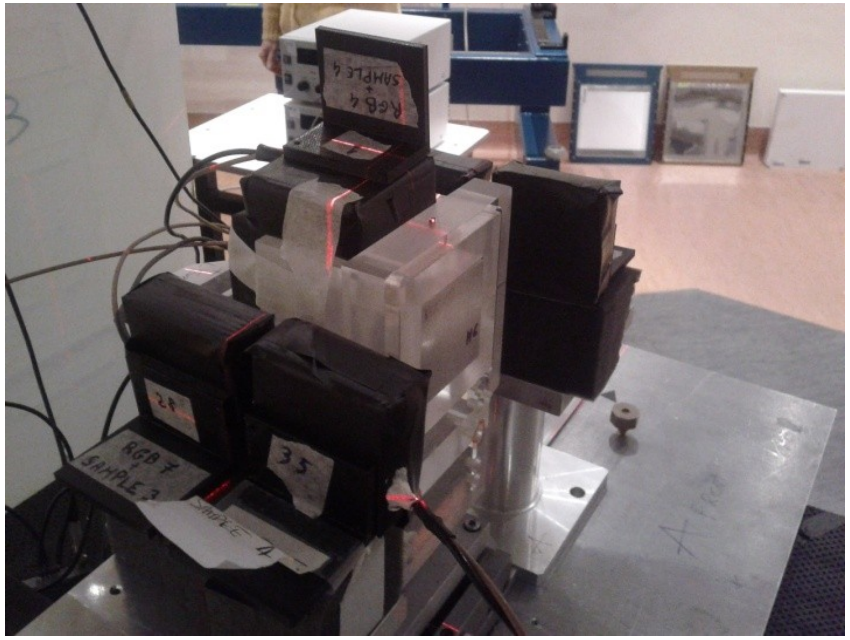


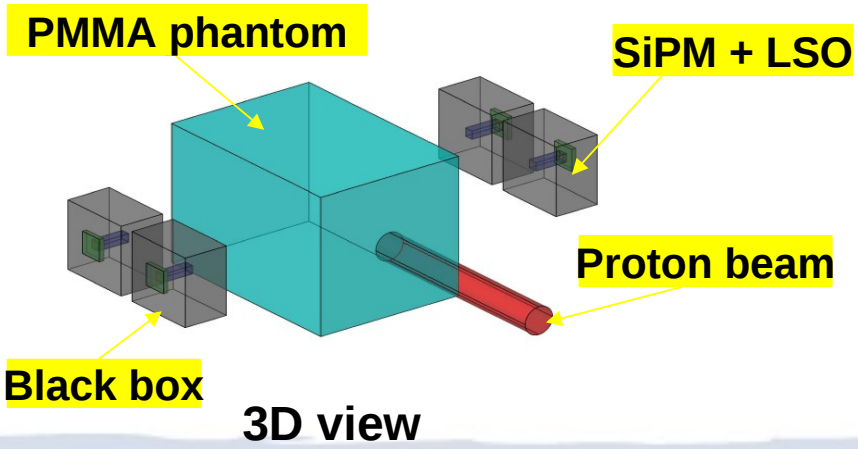
Tracks left by the probe card needles on the TOF PET pads



TOF PET chips

PET system: first experimental set up

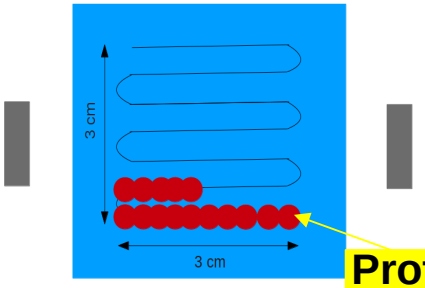




3D view

- PMMA phantom: 5 x 5 x 7 cm^3
- RGB SiPM from AdvanSid 3 x 3 mm^2
- LYSO crystal 3 x 3 x 10 mm^3
- TOFPET ASIC read out
- 4DMPET acquisition board
- Acquisition software developed in LabView code, at INFN sez. Torino

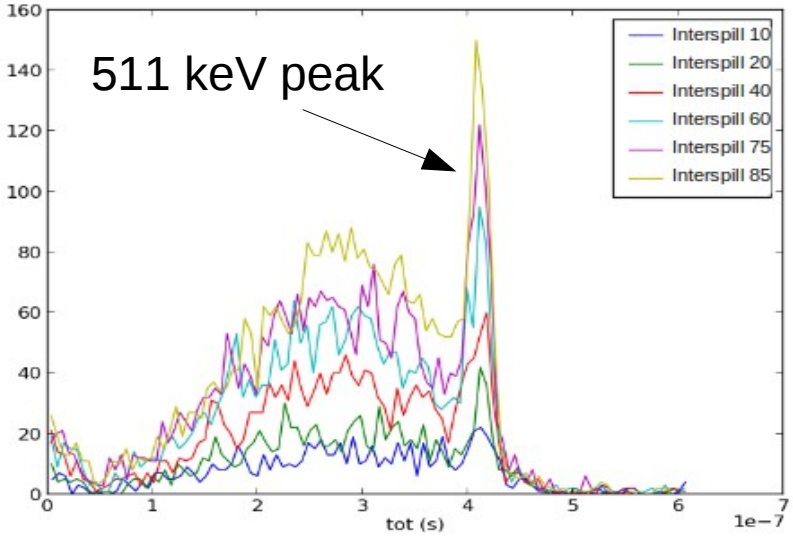
PET system: first experimental results



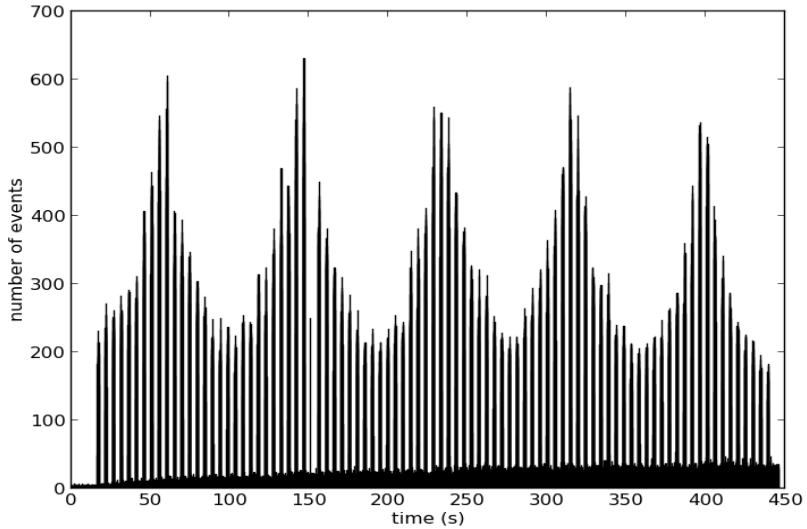
Front view

Proton beam spot

- Proton beam energy: 95 MeV
- Pulsed beam: 10^9 protons per spill, 1 s beam on (spill) , 4 s beam off (interspill)
- Proton beam scanning an area of 3x3 cm^2
- 88 spills

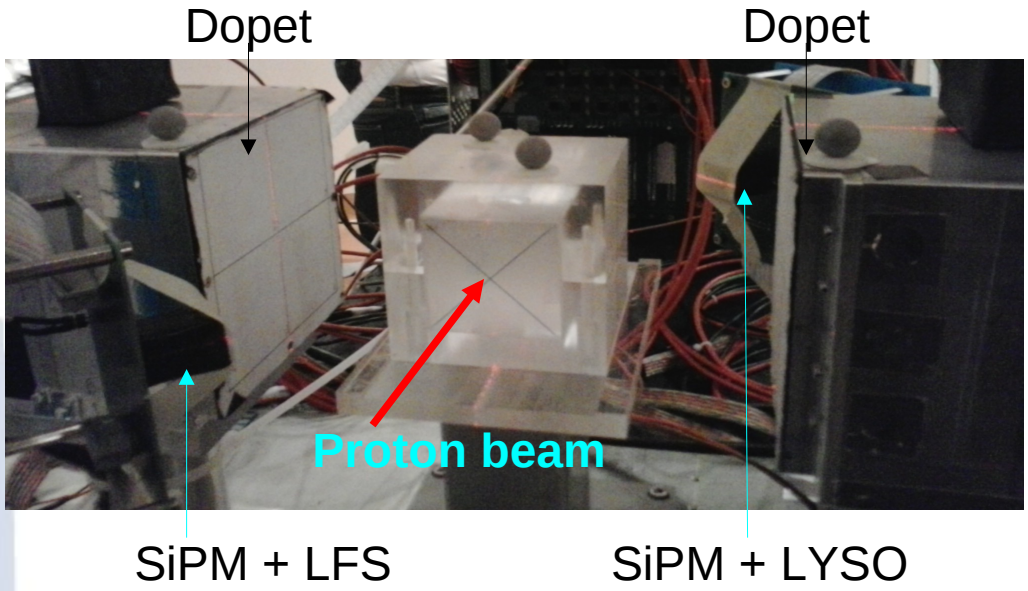


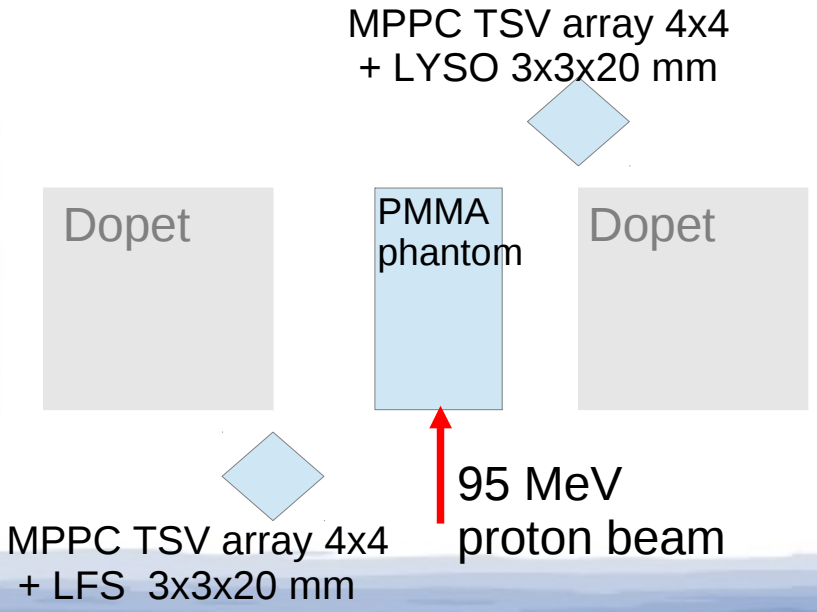
- The response of the detection system is stable with time during the irradiation



- The detection system can clearly reproduce the pulsed time pattern of the radiation beam.
- The number of events oscillates because of the movement of the beam spot.

PET system: second experimental set up



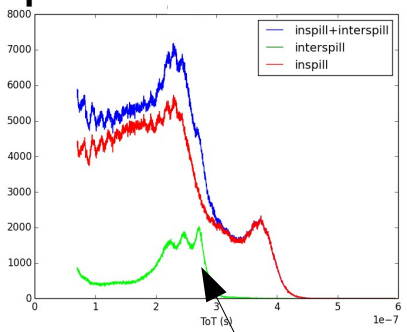


- PMMA phantom: 5 x 5 x 7 cm^3
- TOFPET ASIC read out
- 4DMPET acquisition board
- Acquisition software developed in LabView code, at INFN sez. Torino

- Proton beam energy: 95 MeV
- Pulsed beam: 10^9 protons per spill, 1 s beam on (spill) , 4 s beam off (interspill)
- 20 min continuous irradiation, about 330 spills

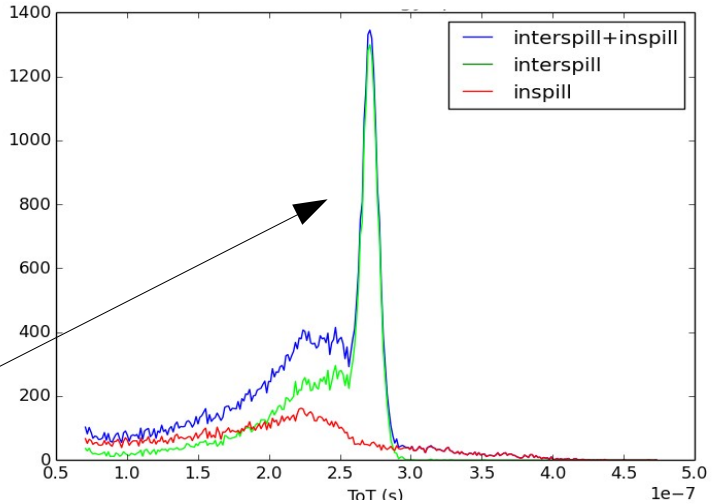
PET system: experimental results

Single matrix energy spectrum

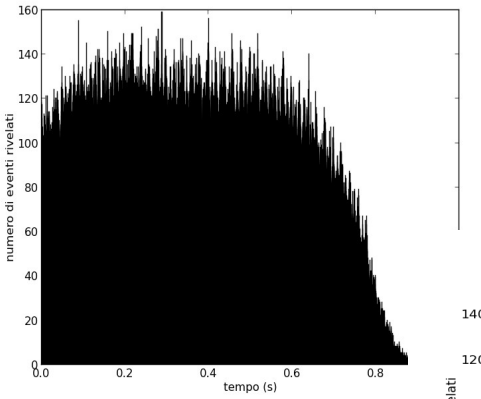


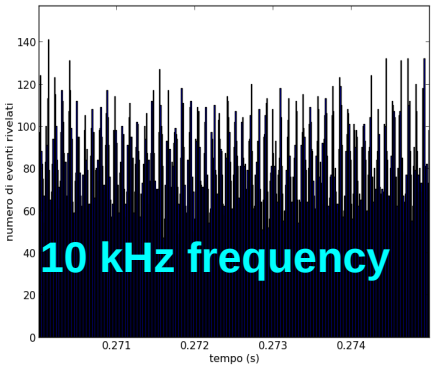
511 keV peak

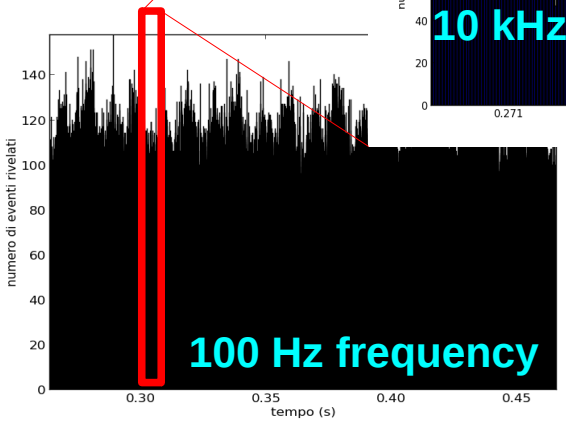
Coincidence energy spectrum



- **The 511 keV peak can be easily reconstructed from the coincidence events in the interspill data**
- **The inspill data is more influenced by multiple coincidences because of the prompt radiation**

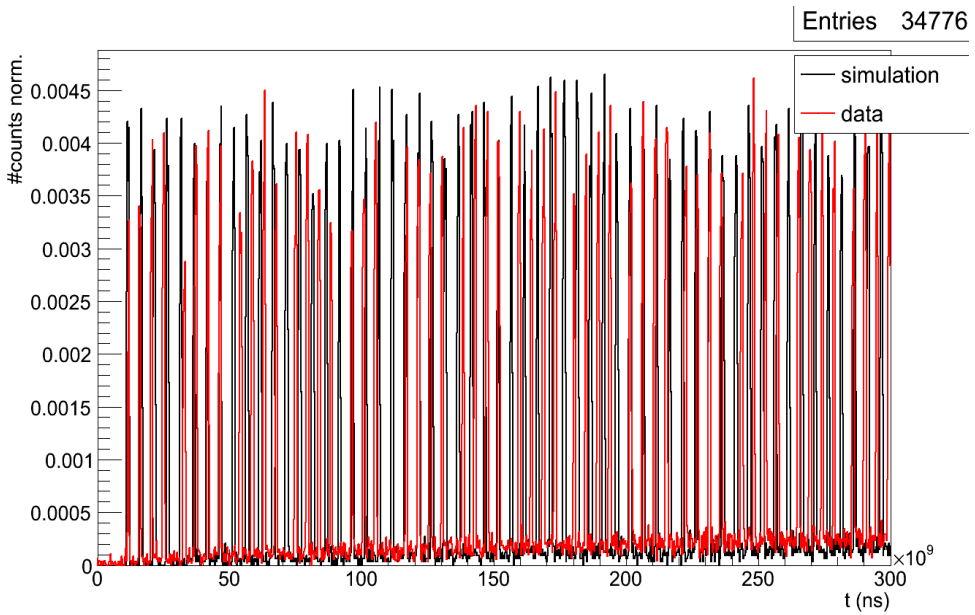


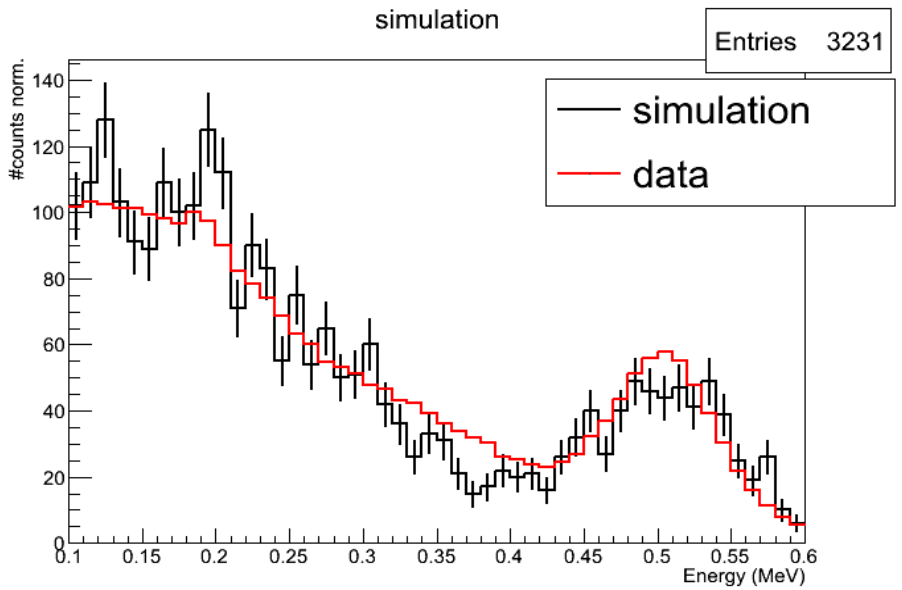




- **10 kHz is the frequency of the protons extraction within the bunch (spill).**

FLUKA MC code validation





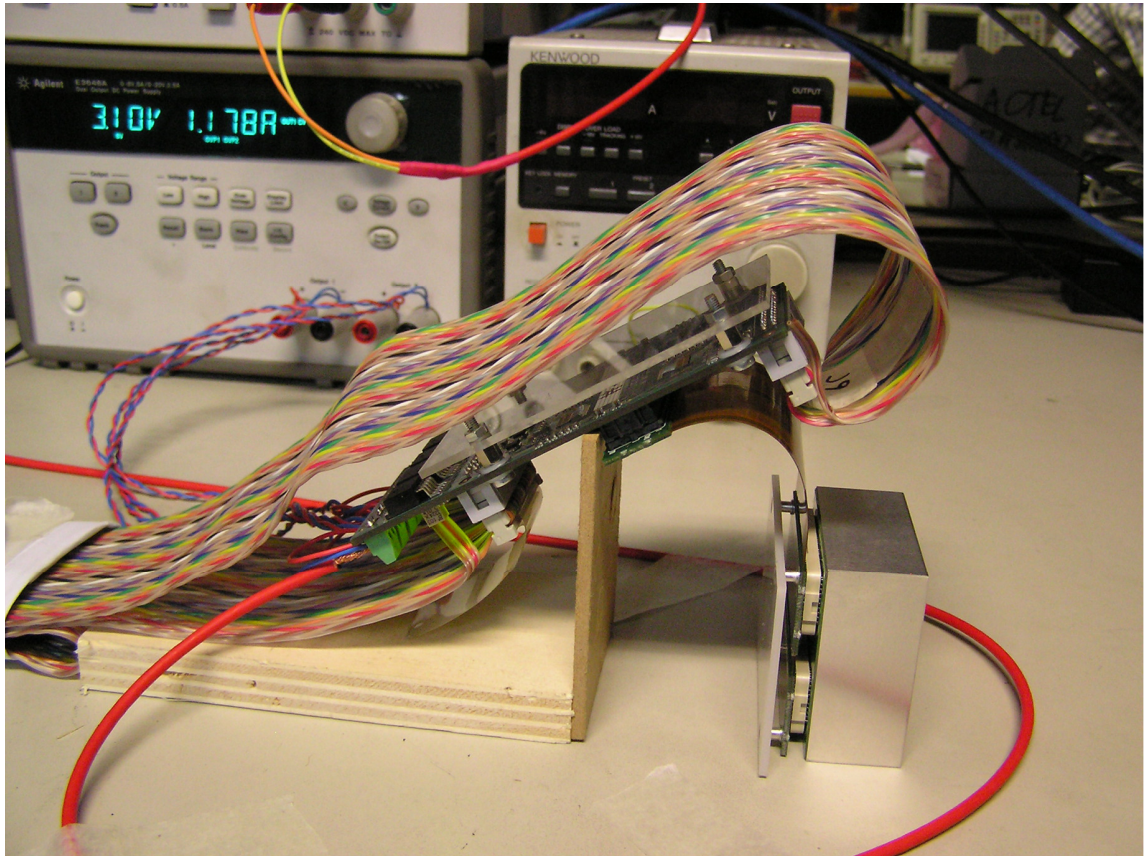
- $2 \cdot 10^9$ pps (protons), 300 s, ~ 60 spills
- 95 MeV protons, PMMA phantom
- 12 runs, $1 \cdot 10^8$ primaries each
- Custom FLUKA routine to extract data
- Validation of the single-channel acquisition rate:
  - same trend in inter-spill (β^+activity rising) and in-spill (prompt signal)
  - limitations due to irregular beam repetition (only in the case of test beams)

(F.Pennazio, Torino)

Conclusions

- Very promising results from CNAO test beam of the PET system prototypes
- The response of the detection and read-out system is stable during the irradiation
- The PET system prototypes were capable of handling the event rates either inspill and interspill
- The 511 keV peak was easily reconstructed from the interspill coincidence data
- Good agreement between the MC and the experimental data

INSIDE PET detector: FE board + module



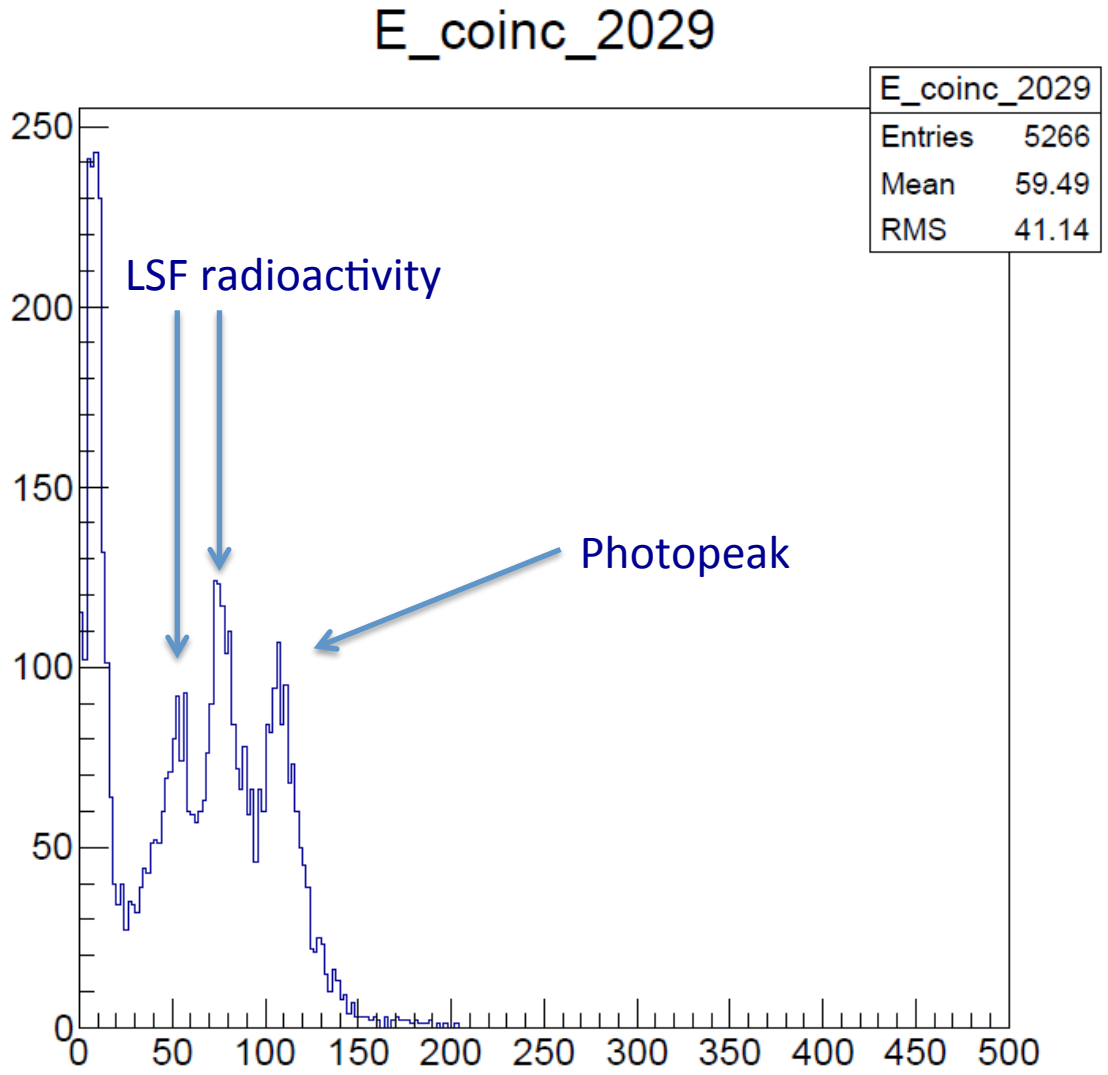
Electronic lab @ INFN Torino

very low activity Na22 source

2 modules in coincidence

no photopeak seen without coincidence

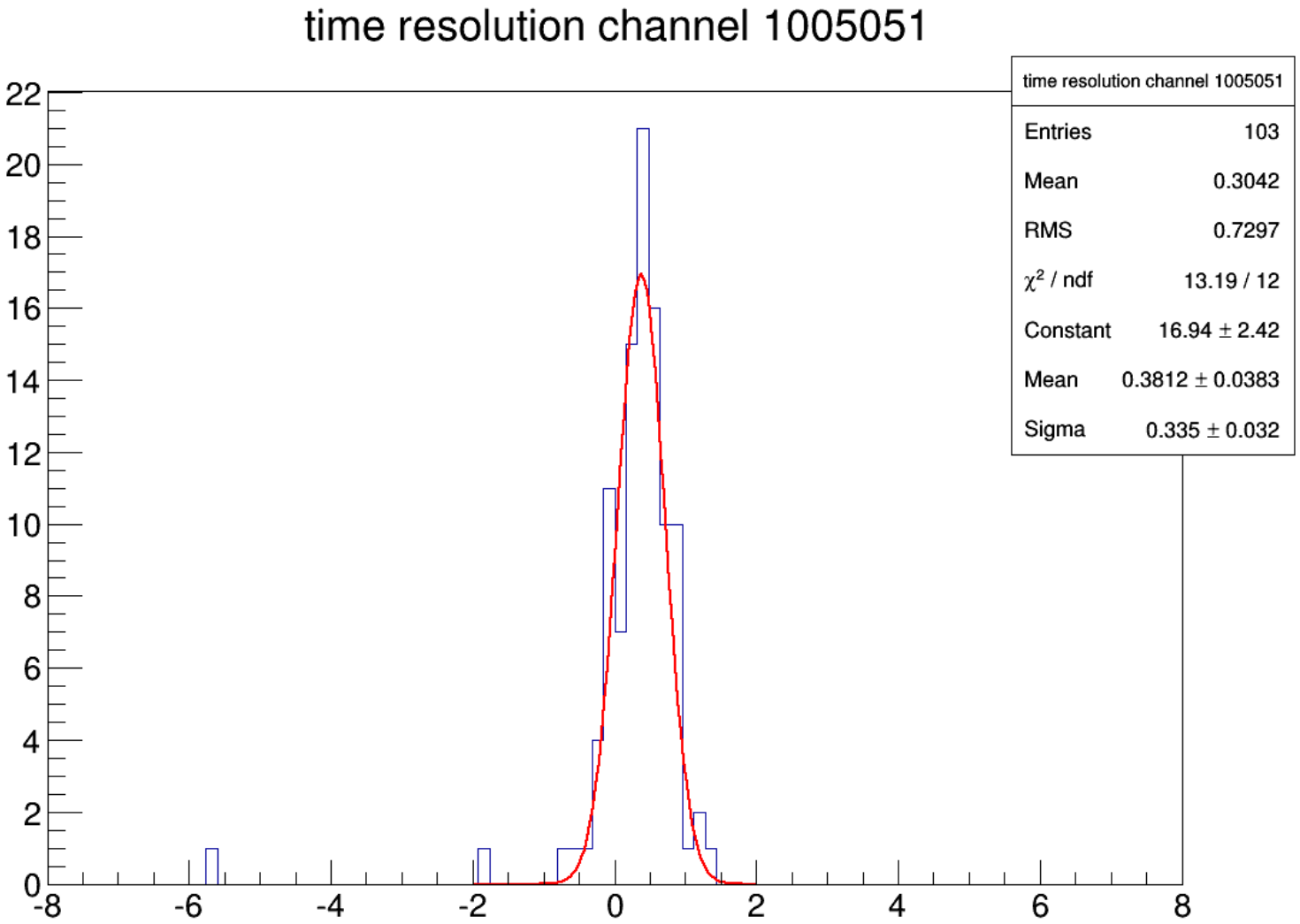
INSIDE PET detector: 2 modules



Energy resolution: ~ 11%

Any channel in module 1 vs. module 2

INSIDE PET detector: 2 modules



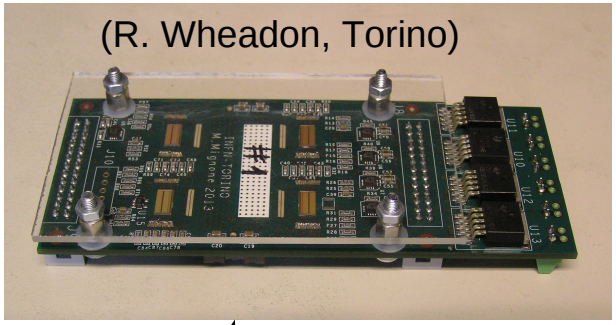
Time resolution: ~ 330 ps @ T ~ 50 C

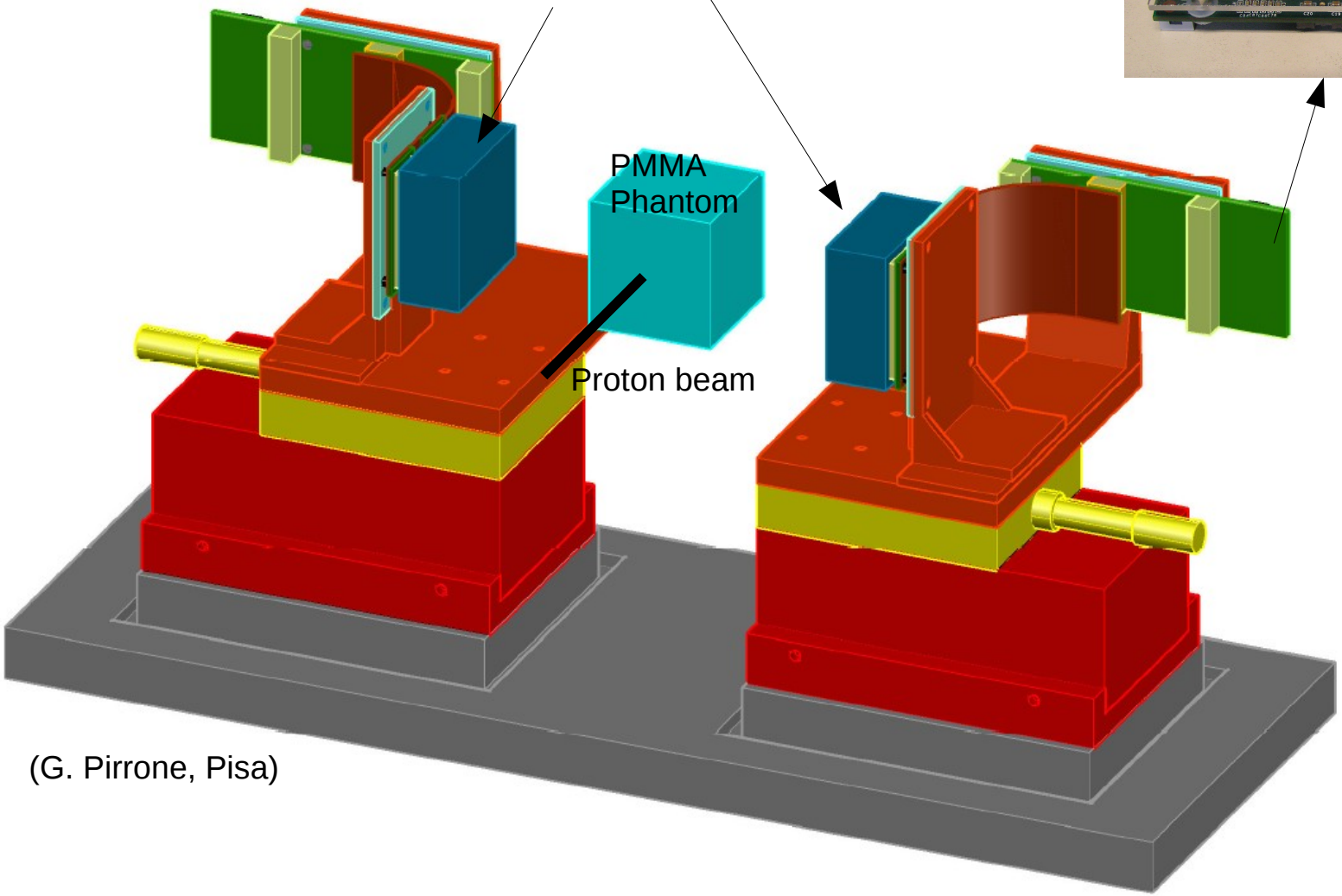
Most populated channel pair in module 1 vs. module 2

Next beam test

LSF + Hamamatsu SiPM matrix

(R. Wheadon, Torino)





(G. Pirrone, Pisa)

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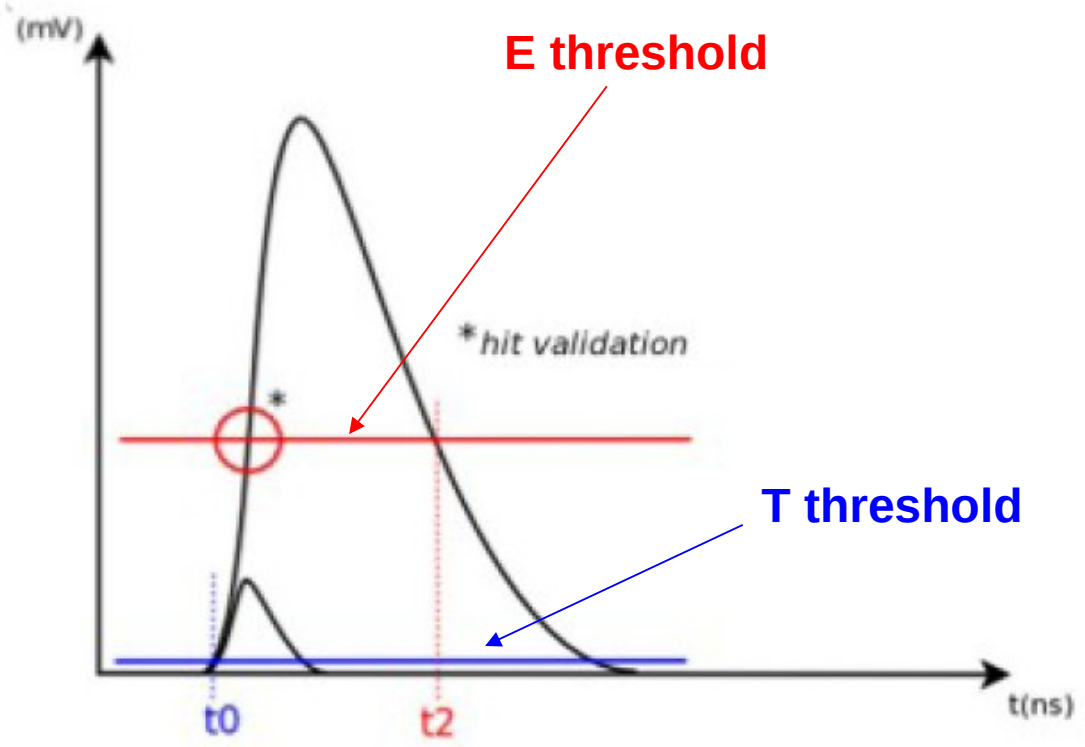
TOF-PET working principles



ToT (energy meas) = t2 - t0

- Energy measurement through the Time-Over-Threshold technique
- Energy proportional to ToT: non-linear dependence

Rolo, M. D., et al. "TOFPET ASIC for PET applications." Journal of Instrumentation 8.02 (2013).