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INFN - Pisa

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Harvard Medical School

PET applications in small animal imaging, breast cancer imaging and proton therapy

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PET scintillators

Photon detection in Functional Imaging

Small Animal Imaging:PET&CT

Breast cancer Imaging PET&SPECT

"In vivo" PET dosimetry for hadron therapy

New photodetectors: SiPM

Conclusions

Acknowledgments

- Photo-detectors are usually coupled to scintillators: the most often used was BGO (Bismuth germanate, $Bi_4Ge_3O_{12}$) and more recently is LSO (Lutetium Oxi-orto Silicate).

Material	Density [g/cm^3]	Atomic numbers	Light yield [%NaI(Tl)]	Decay time [ns]	Peak wavelength [nm]	Time resolution [ns]	Index of refraction	Comments
NaI(Tl)	3.76	11,53	100	230	410	1.5	1.85	Hygroscopic Low density
BGO	7.13	83,32,8	15	300	480	7	2.15	Low light yield Slow
LSO	7.4	71,32,8	75	40	480	1.4	1.82	Intr. background 400 cps/cm^3
GSO	6.71	64,32,8	26	600	430	-	1.85	Low light yield Slow
CsI(Tl)	4.51	55,53	45	1000	565	-	1.80	Slow
YAP:Ce	5.37	39,13,8	55	27	370	1.1	1.95	Medium Z

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PSPMT choice

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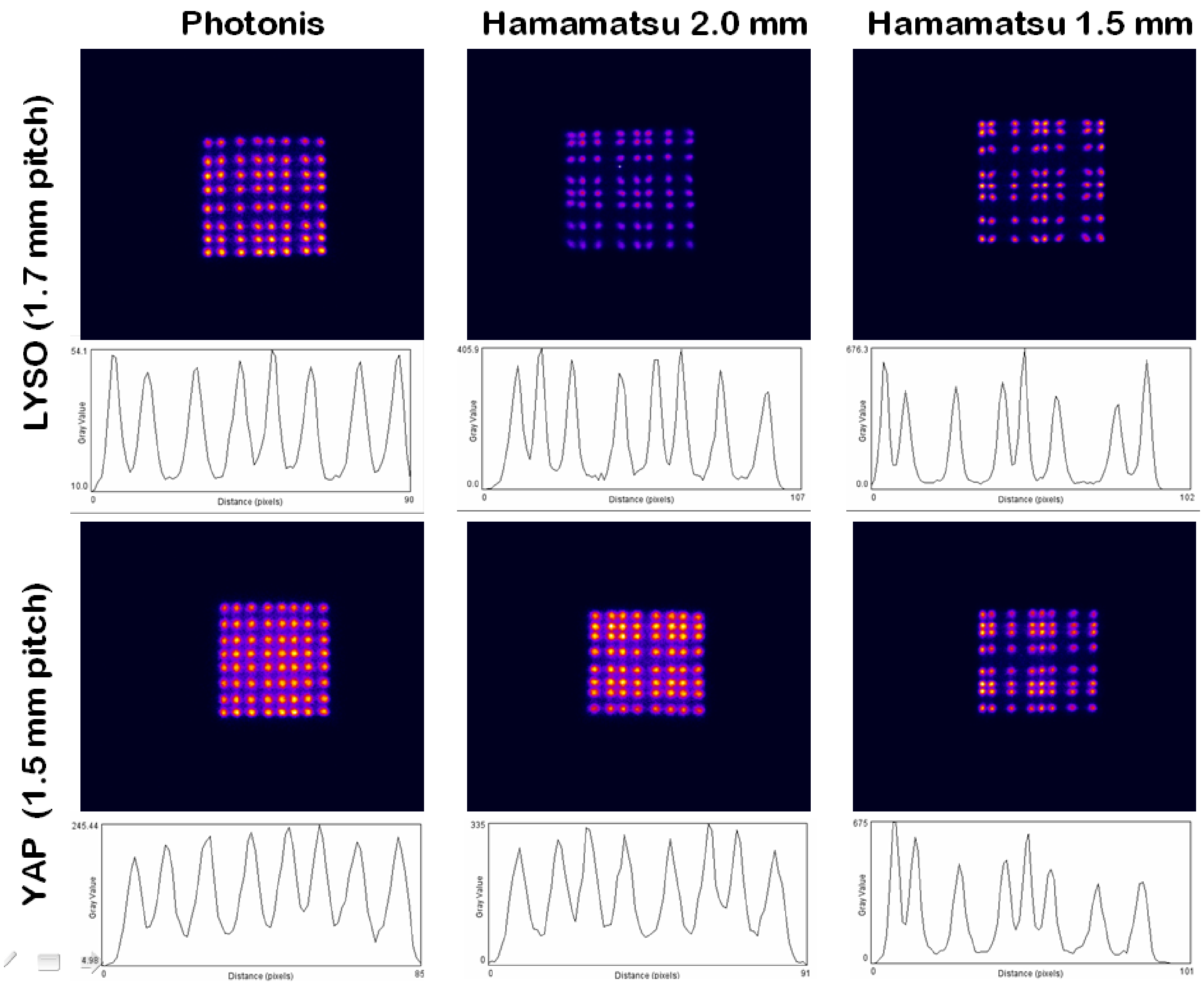

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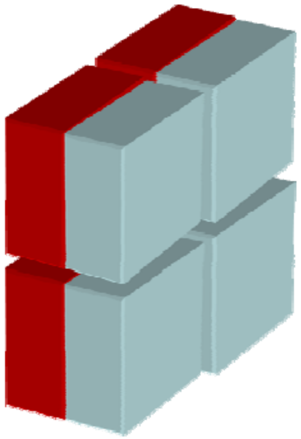
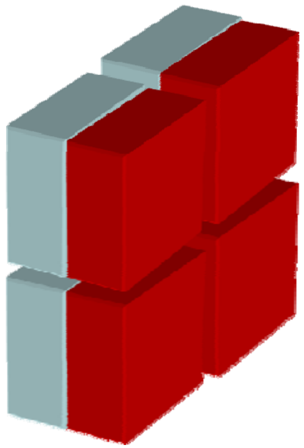
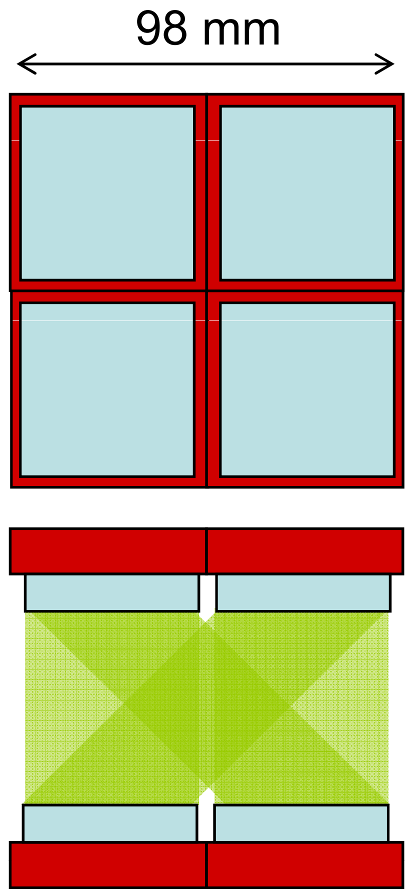
Project idea (PEM_PISA)

- Each head is made up with 4 LYSO matrices + 4 H8500
- coincidence scheme (1 vs. 4) x 4







- Matrix size : 23 x 23 cristals
- 1.9 mm side 2.0 mm pitch, 16 mm thick.

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Readout architecture

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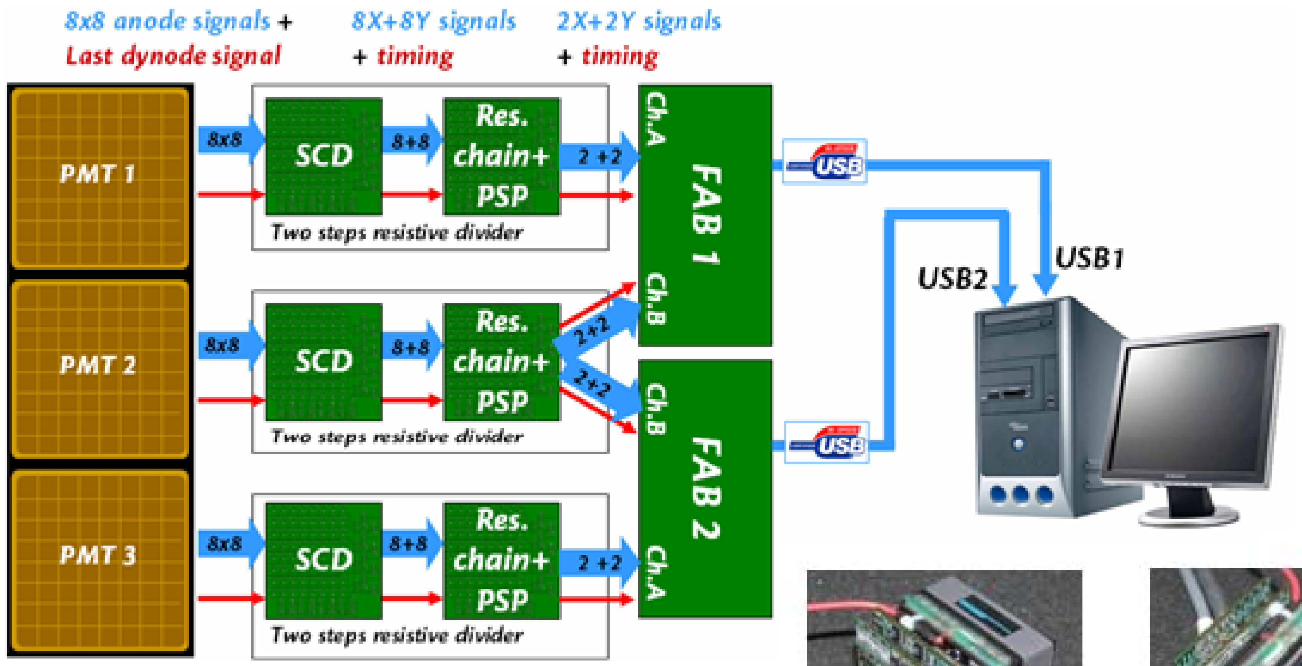
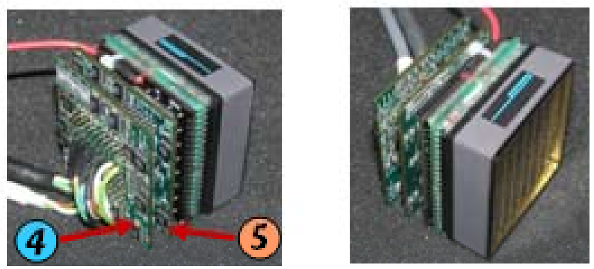


» 1 × H8500: resistive chain (4 outputs)
4 SCD (symmetric charge division)
5 + 2D chain + pre-amp (PSP)



A single H8500 module assembly with SCD + PSP

» Each det. head
1 × 3 H8500: 2 parallel DAQ boards

» PC connect.: 2 × USB 2.0

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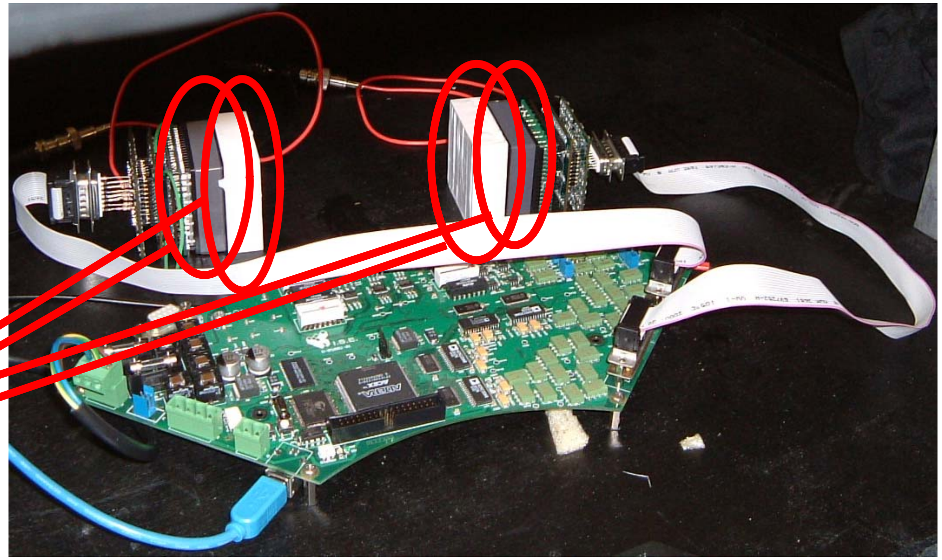
The DoPET project
(Dosimetry with Positron Emission Tomography)

The project, supported by INFN and MIUR (2006), aims to investigate the feasibility of off-line PET for millimeter range monitoring in proton-therapy.

THE PET PROTOTYPE



Square multianode photo-multiplier; Hamamatsu H8500;

Two planar heads: ℓ = 45 mm; LYSO matrix: 21x21 pixels;

Pixel area: 2.152x2.152 mm^2;

Multiplexed readout electronics: 64 in/4 out. Cristal thickness: 18 mm.

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Phantom Irradiation & Imaging

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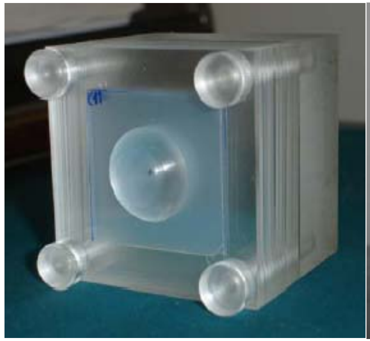
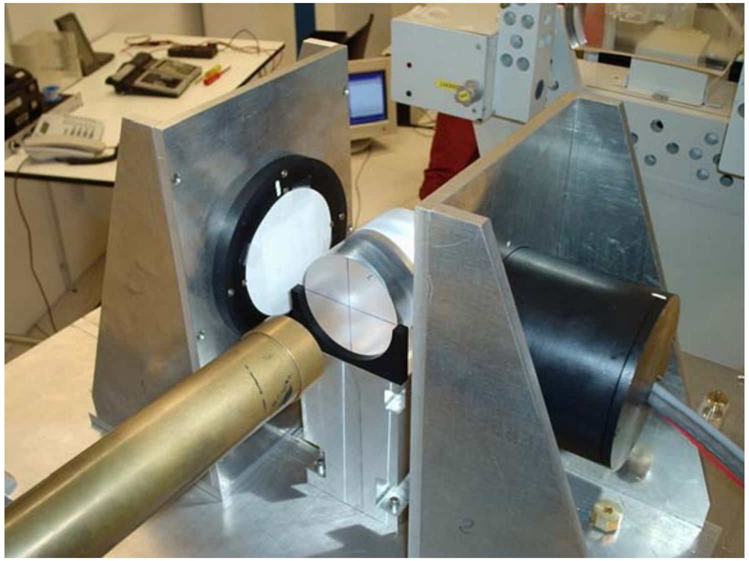
- Homogeneous cylindrical and eye phantoms of PMMA were irradiate with monoenergetic and SOBPs;
- Distance between heads: 14 cm;





- Dose delivered: 15–30 Gy within 60–240 s;
- Proton beam intensity: ~ 10^8 s^{-1};
- Final collimator: 25 mm Ø;
- PET acquisition time: 10–30 min;
- ML-EM for imaging in 3D.

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The Feasibility of PET for Range Monitoring

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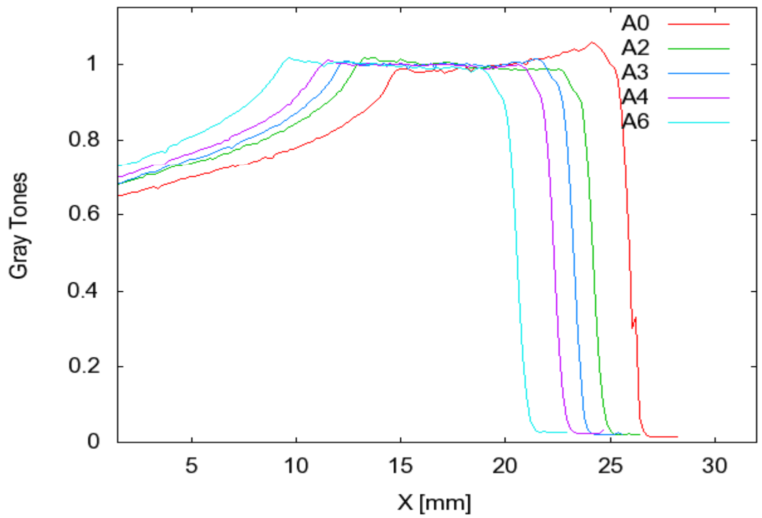
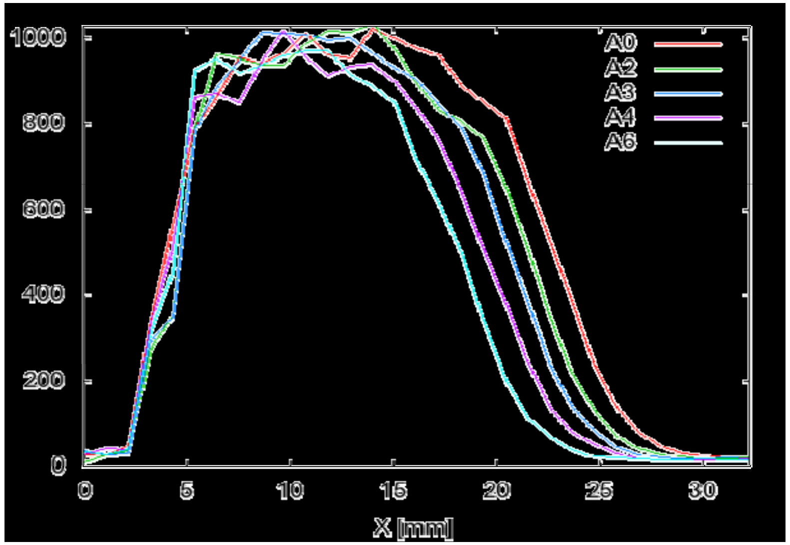
- In the ideal case of homogeneous targets we can resolve fairly well range differences of less than 2 mm.



Longitudinal ***dose*** profiles from irradiation using different range shifters and 12 mm modulator.



Longitudinal profiles of the measured ***activity*** integrated over the central slice of the PET reconstructed image.

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Testing the theoretical filters on experimental data

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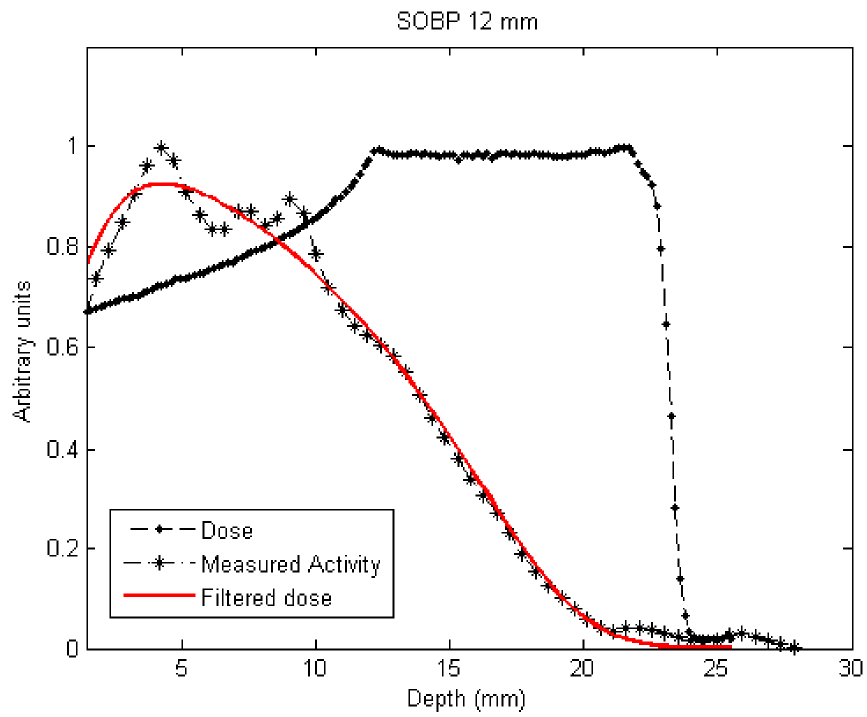
- Reconstructed activity profile in comparison with the filtered dose (SOBP of 12 mm modulation);
- T_{irr}: [0, 179] s;
- T_{scan}: [179, 2000] s;
- Transverse domain of integration: 19 mm Ø;

- Reconstructed activity profile in comparison with the filtered dose (monoenergetic Bragg curve);
- T_{irr}: [0, 138] s;
- T_{scan}: [138, 1938] s;
- Transverse domain of integration: 19 mm Ø;



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Silicon PhotoMultiplier = SiPM
Working principle

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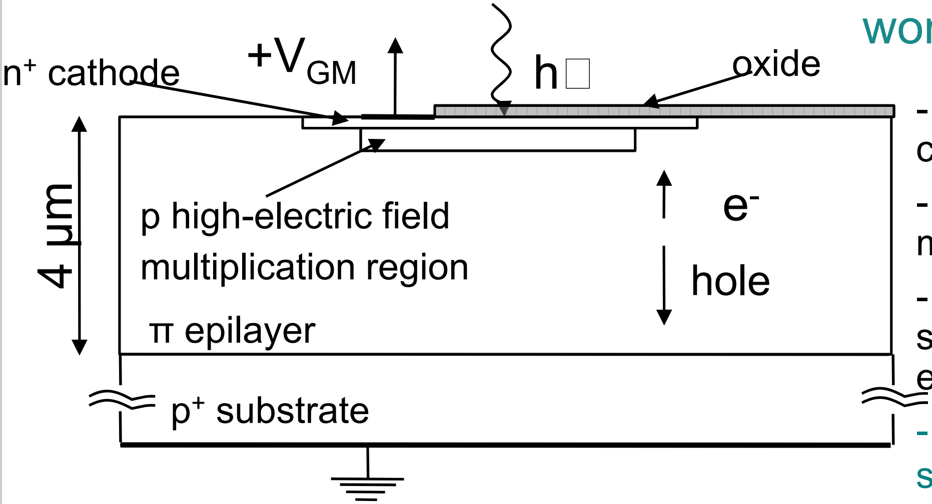
SOLID STATE PHOTODETECTOR➔ SiPM: **Multicell Avalanche Photodiode** working in limited Geiger mode



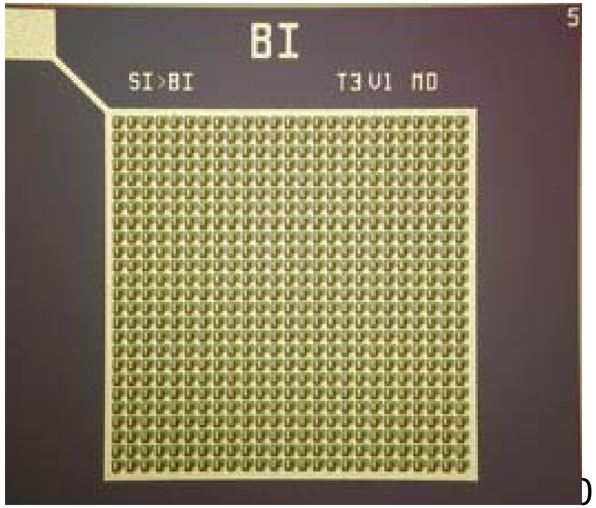
- 2D array of microcells: structures in a common bulk.
- Vbias > Vbreakdown: high field in mult. region
- Microcells work in Geiger mode: the signal is independent of the particle energy
- The SiPM output is the sum of the signals produced in all microcells fired.

-The photon is absorbed and generates an electron/hole pair

-The electron/hole diffuses or drifts to the high-electric field multiplication region

-The drifted charge undergoes impact ionization and causes an avalanche breakdown.

-Resistor in series to quench the avalanche (limited Geiger mode).



Results: energy resolution (ΔE/E)

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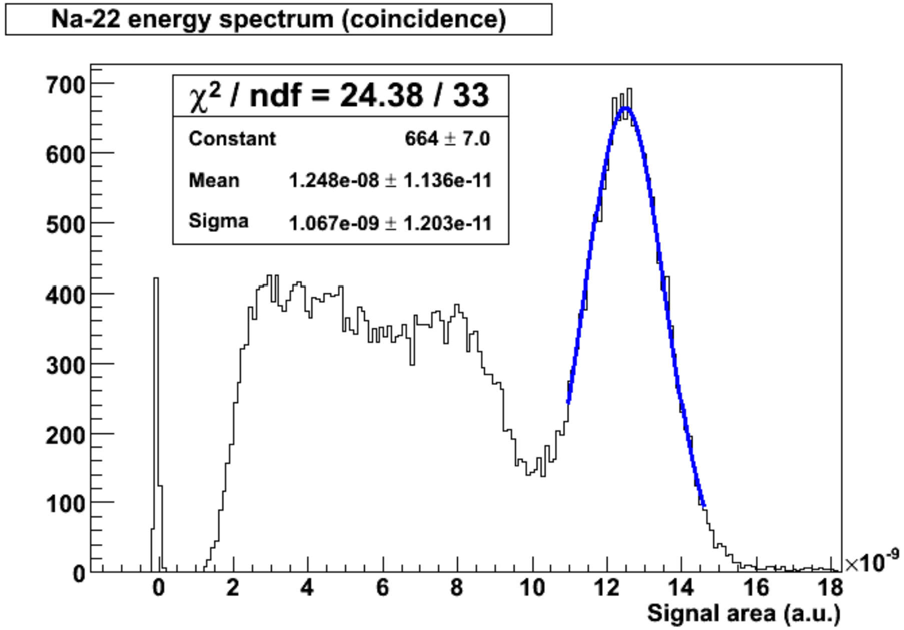
- Setup:
  - 2 LSO [1mm x 1mm x 10mm] crystals coupled to 2 SiPMs
  - Home made amplifier board.
  - Time coincidence of signals.
  - VME QDC for DAQ.
  - ^{22}Na source.

- Energy resolution in coincidence: **20% FWHM.** (best result: 17.5 %)



[G.Llosa et al, Conference Records IEEE NSS-MIC 2006, M06-88]

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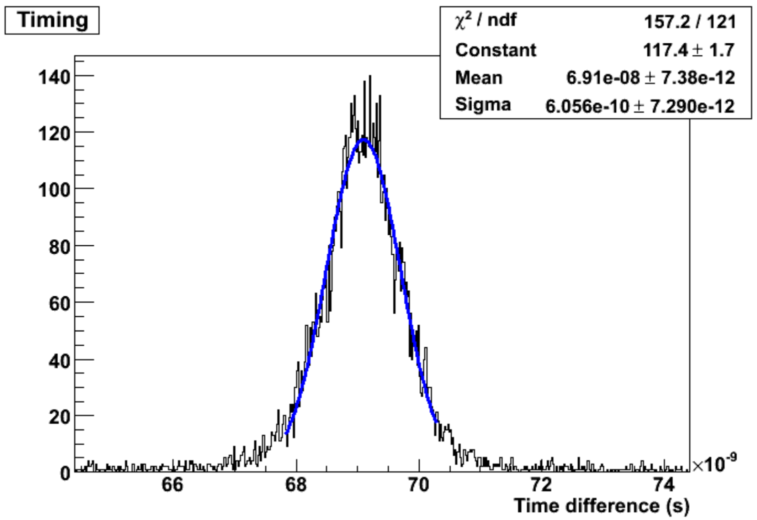
Results: coincidence timing (TOF)

- Coincidence measurement with **two LSO** crystals (1x1x10 mm^3) coupled to two SiPMs
- Theory: Post and Schiff. Phys. Rev. 80 (19501113.

$$\sigma \sim \frac{\sqrt{Q}\,\tau}{< N >}$$



Where:

<N> = average number of photons: ~ 100 photons at the photopeak

Q = Trigger level: ~1 photoelectron.

τ = Decay time of the scintillator

For two scintillators in coincidence expected : **=>** √2σ~ 630 ps .

Measured **=>** ~ 600 ps sigma.

Measurements in agreement with what we expect!!

[G.Llosa,et al. to be presented at IEEE, NSS-MIC 2007, Honolulu,USA]

Results: New detectors (May 2007)

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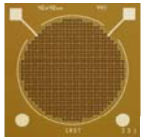
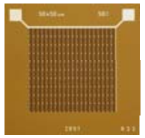
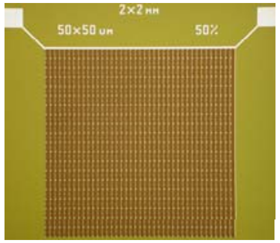
Different geometry,size,microcell size and GF.

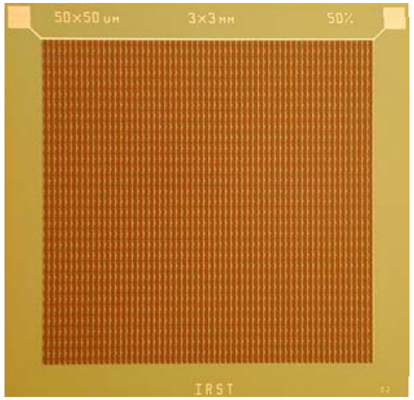
40x40μm^2 => GF 44%
50x50μm^2 => GF 50%
100x100μm^2 => GF 76%


circular (1mm diam)

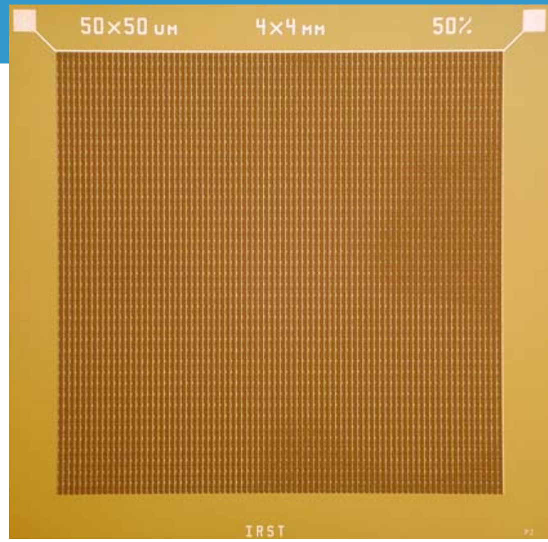

1x1mm^2



2x2mm^2



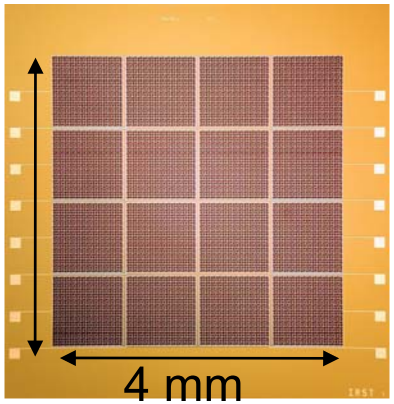
3x3mm^2 (3600 cells)



4x4mm^2 (6400 cells)

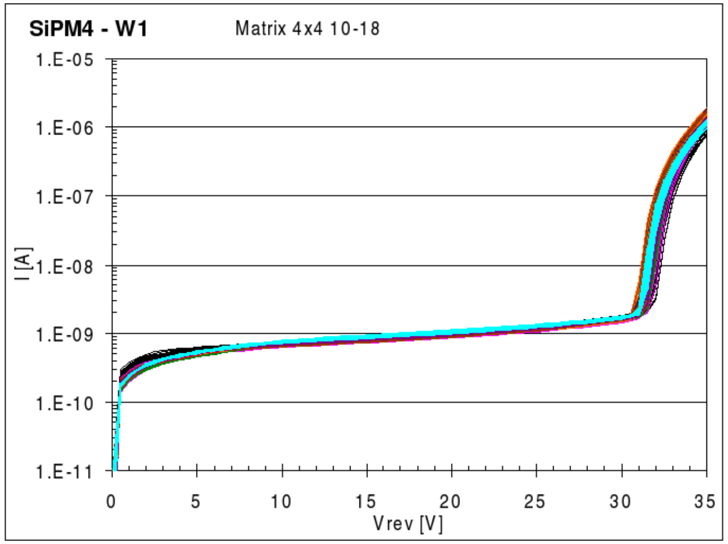
Matrices 16 elements (4x4)

4 mm



IV CURVES OF 9 MATRICES.

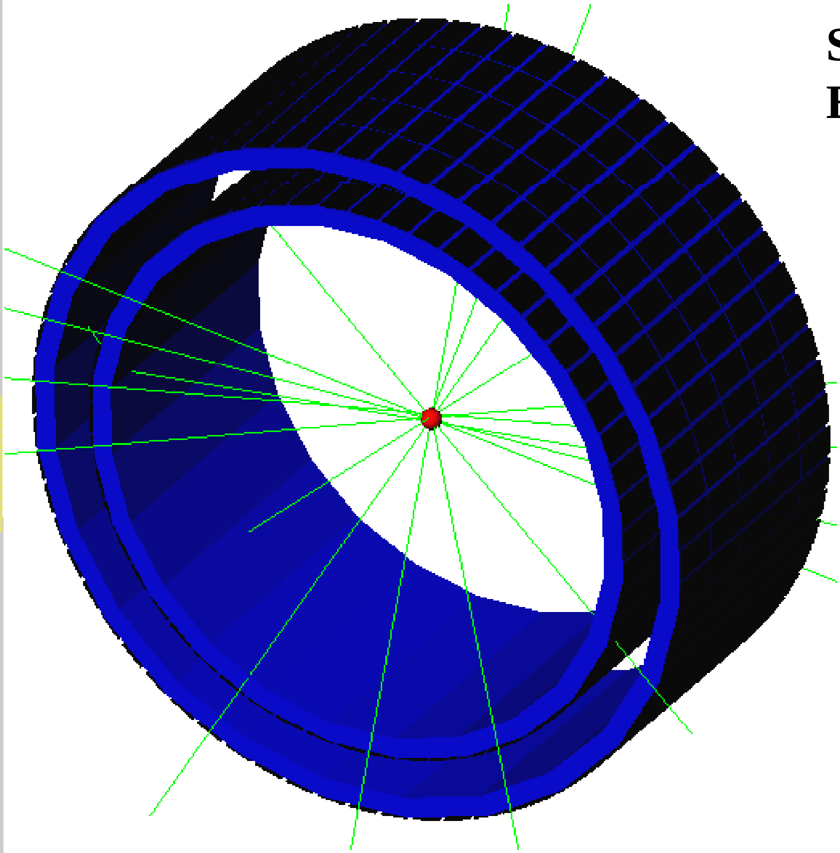
VERY UNIFORM BREAKDOWN POINT



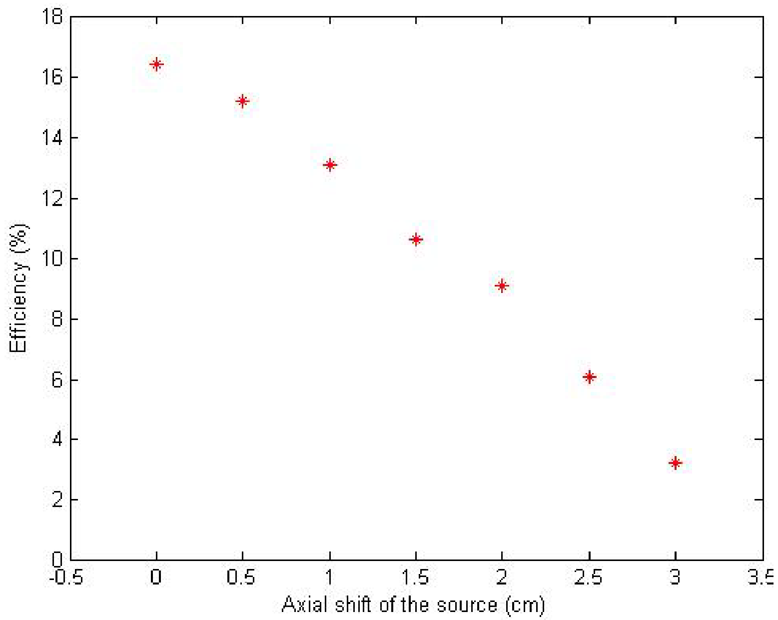
[C.Piemonte et al, Nuovo Cimento C, 2007 to be published]

The ultimate dream for small animal PET!
Design#3: Multi-annular ring

- Two coaxial continuous cylinders of LSO, each 5mm thickness and 7cm length
- 1 cm thickness for SiPM and FE readout electronics
- Inner ring inner diameter 12.5 cm; outer ring outer diameter 14.5 cm
- Number of Photodetectors ~ 60k SiPM channels total (1mm^2)



Sp Res ~0.75mm (FWHM) over FOV
Eff ~16% at the center of the FOV



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