Tests of PET modules with Silicon Photomultipliers

R. Pestotnik[1], S.Korpar[2,1], H. Chagani[1], R. Dolenec[1],
P.Križan[3,1],R. Verheyden[1], A.Stanovnik[4,1]

[1] *Jožef Stefan Institute, Ljubljana*
[2] *Faculty of Mathematics and Physics, University of Ljubljana*
[3] *Faculty of Chemistry and Chemical Engeeniring, University of Maribor*
[4] *Faculty of Electrical Engeeniring, University of Ljubljana*

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Outline:

Motivation
- Surface sensitivity
- Timing resolution
- Studies of two SiPM modules
- Conclusions

Motivation - Silicon photomultipliers

SiPM: array of APDs operating in Geiger mode.

A lot of advantages:

Low operation voltage~ 10-100 V

Gain ~ 10^6

peak PDE up to 65%(@400nm)

PDE = QE x ε_{geiger} x ε_{geo}

ε_{geo} – dead space between the cells

Timing resolution ~ 100ps

Work in the magnetic field

Dark counts ~ several 100kHz/mm^2

Application for PET:

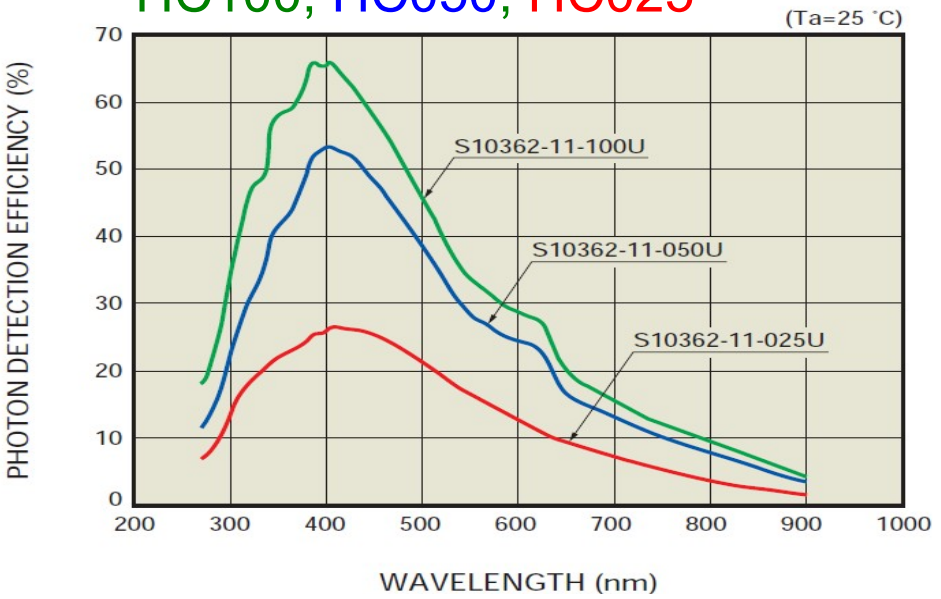
Detection of several photons

- above noise threshold

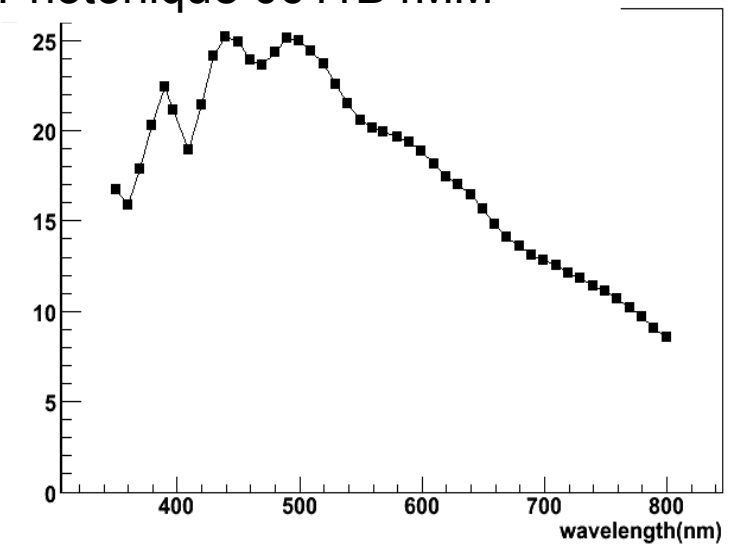
Dual modality with MRI

Hamamatsu:

HC100, HC050, HC025

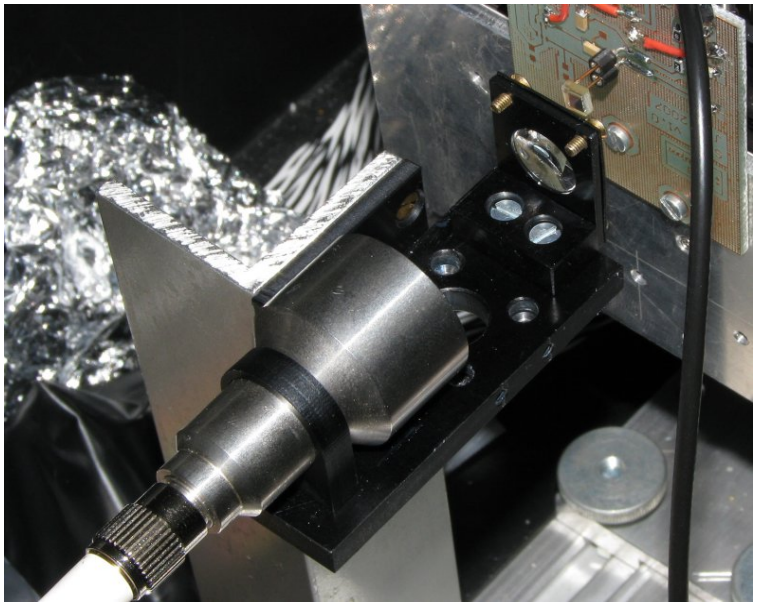


Photonique 0611B4MM

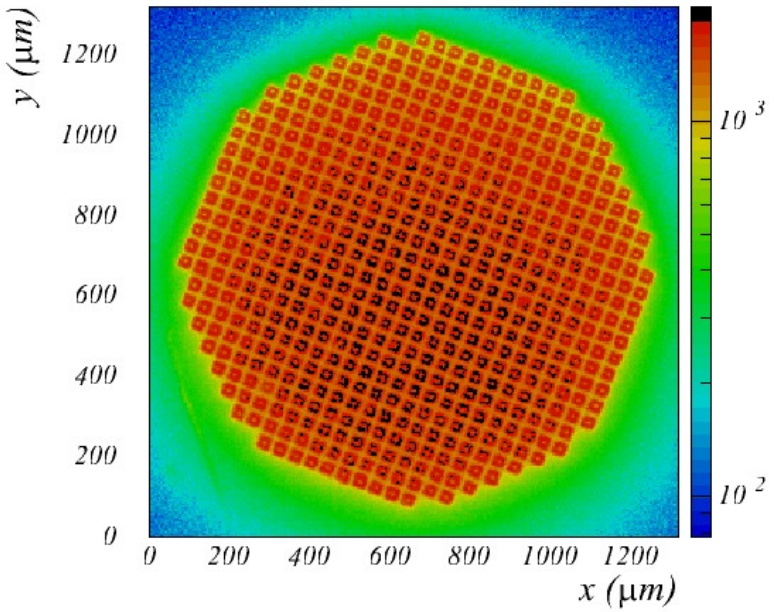


Surface sensitivity for single photons

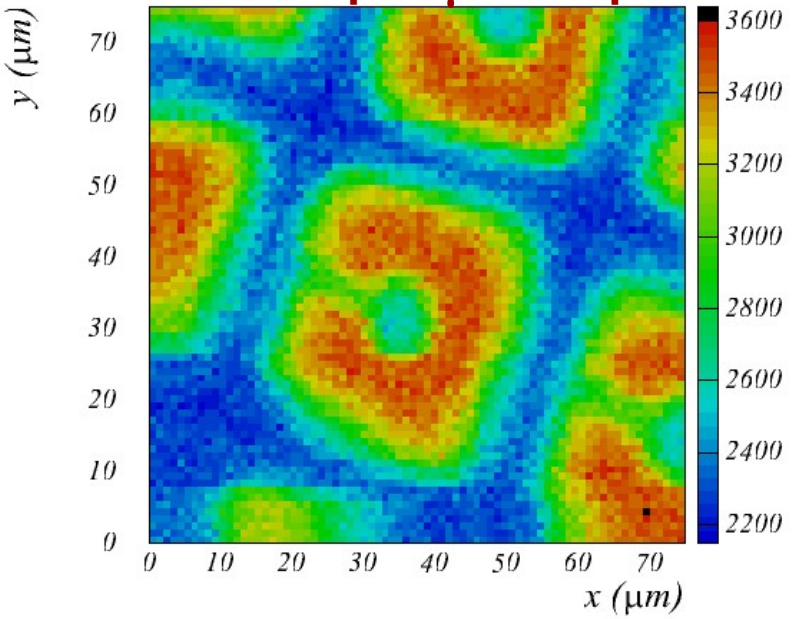
2d scan in the focal plane of the laser beam
($\sigma \approx 5$ µm)
intensity: on average << 1 photon
→ single photons
selection: single pixel pulse height,
in 10 ns TDC window



S137 (CPTA/Photonique)
5 µm step size



Close up: 1 µm step size



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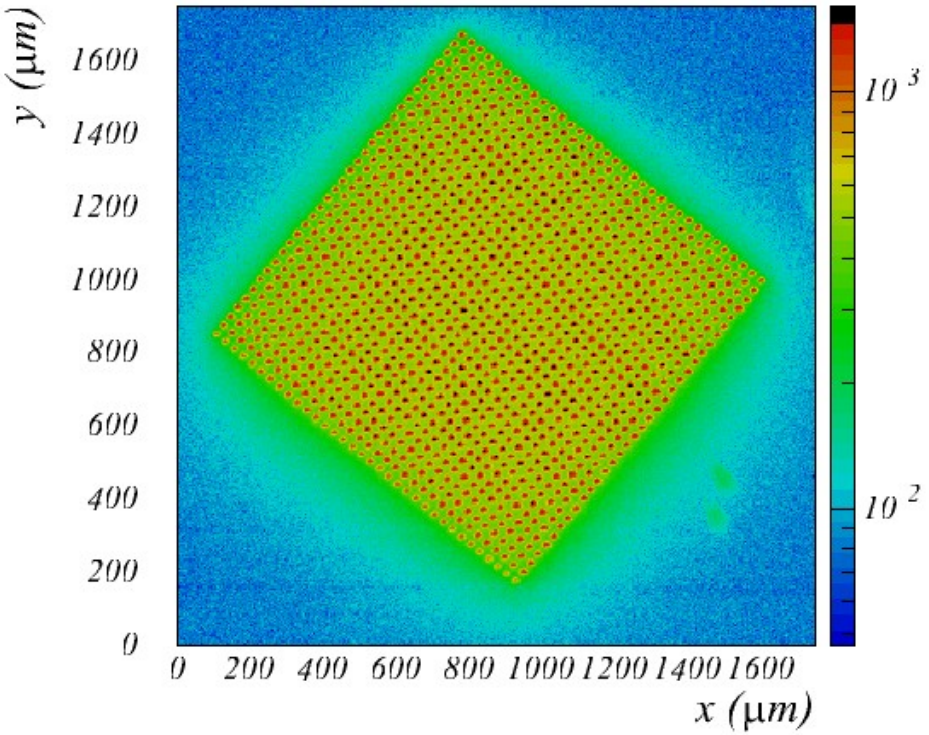
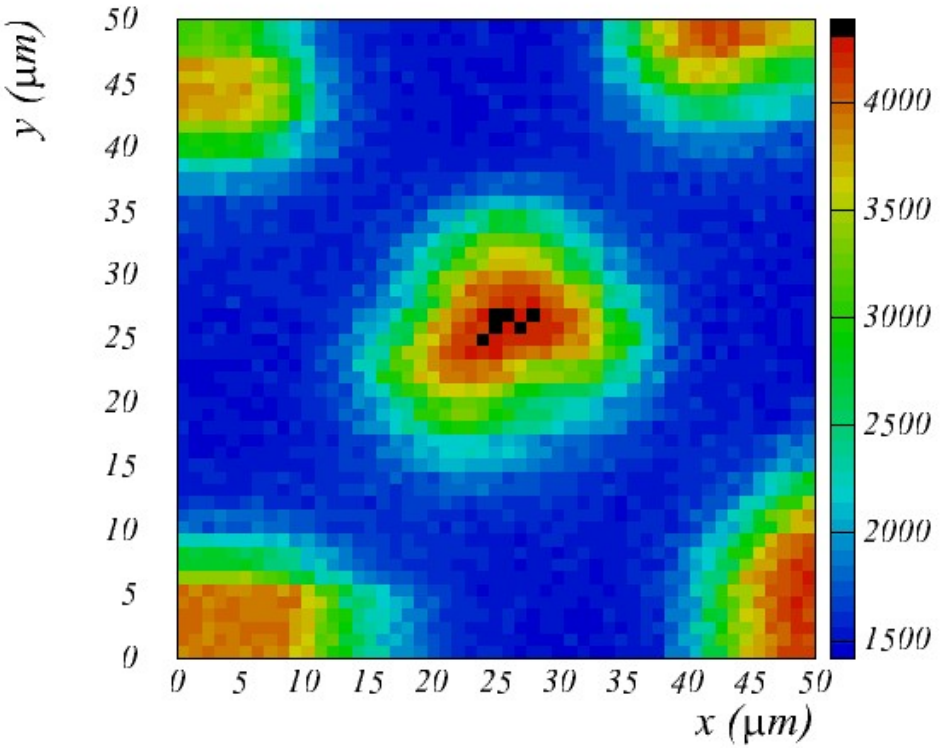
Surface sensitivity for single photons 2

E407 (Pulsar/MEPHI)



5 μm step size

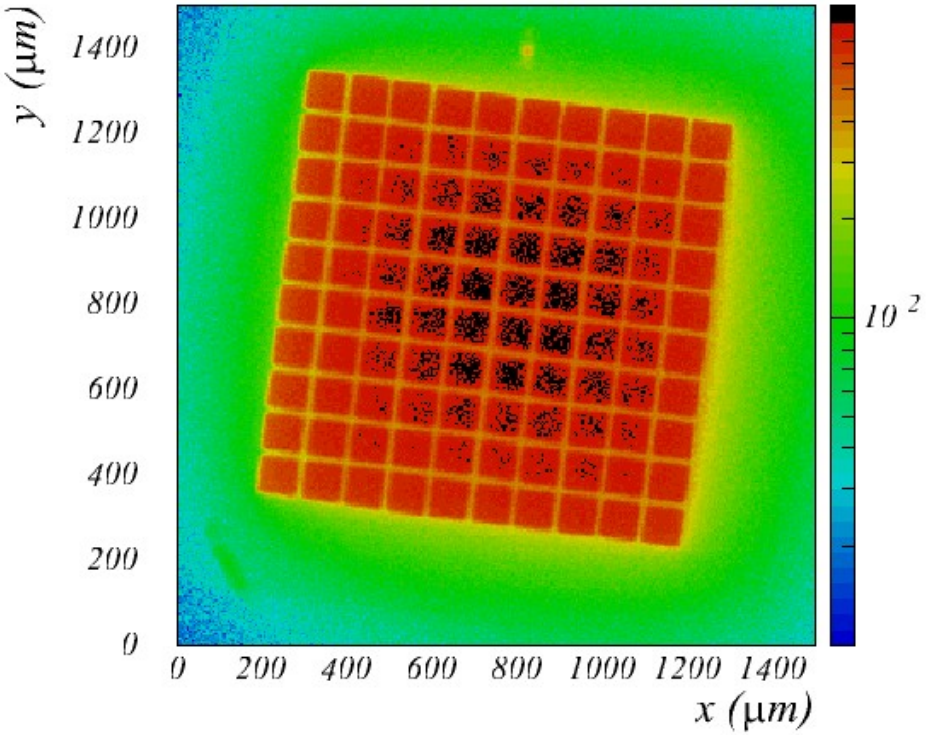


Close up: 1 μm step size

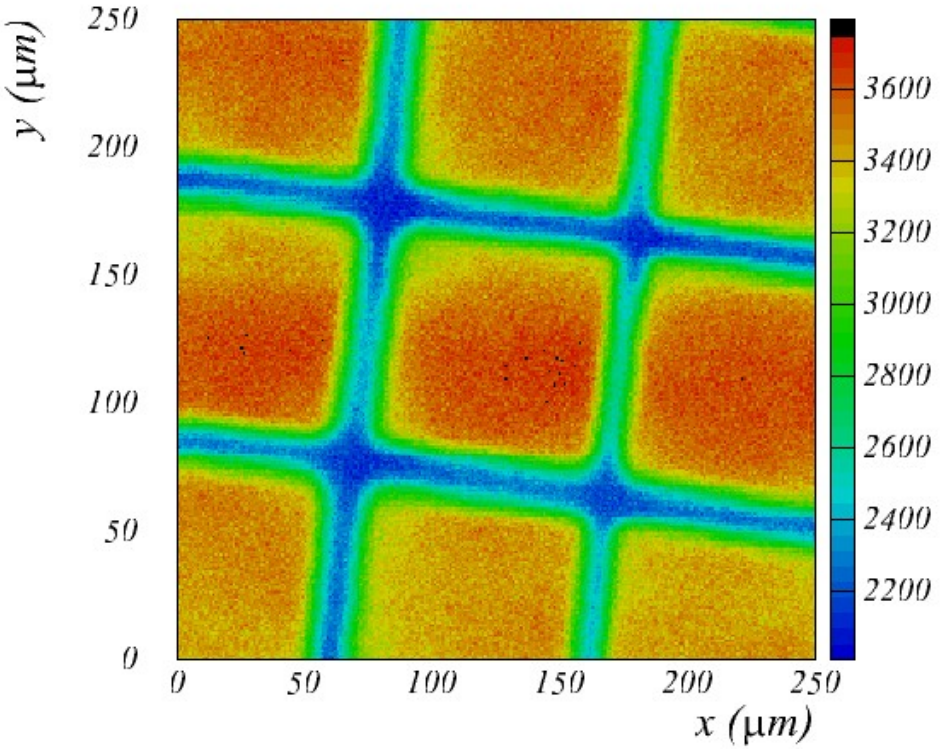
Surface sensitivity for single photons 3

Hamamatsu MPPCs 1x1 mm^2

H100C



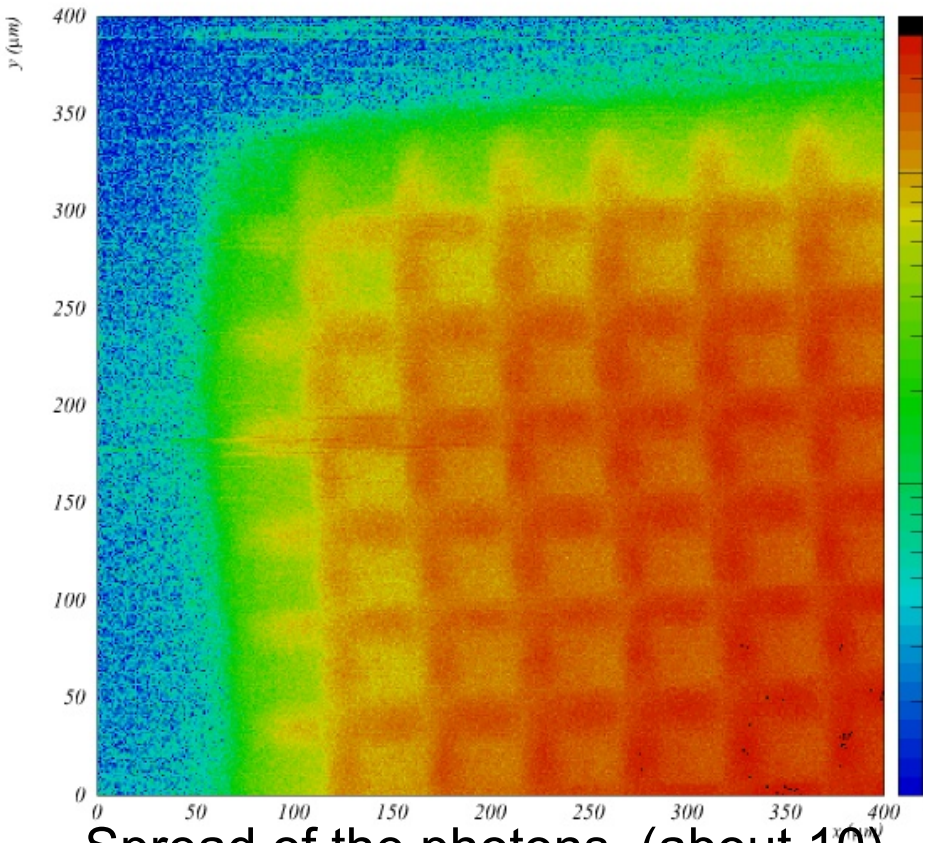
5 μm step size



Close up: 1 μm step size

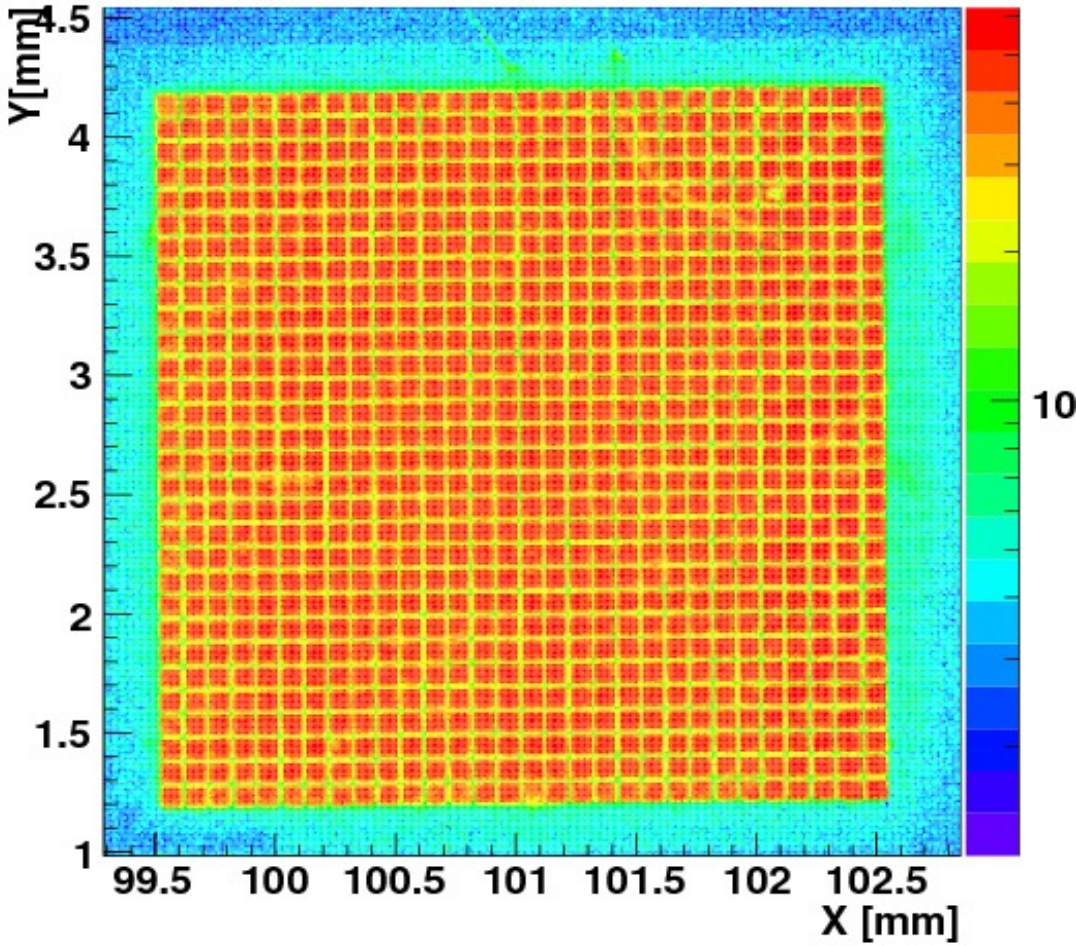
Surface sensitivity for larger devices

Photonique 0611



Spread of the photons (about 10) between 2(3,4) cells

Hamamatsu MPPC 3x3 mm^2



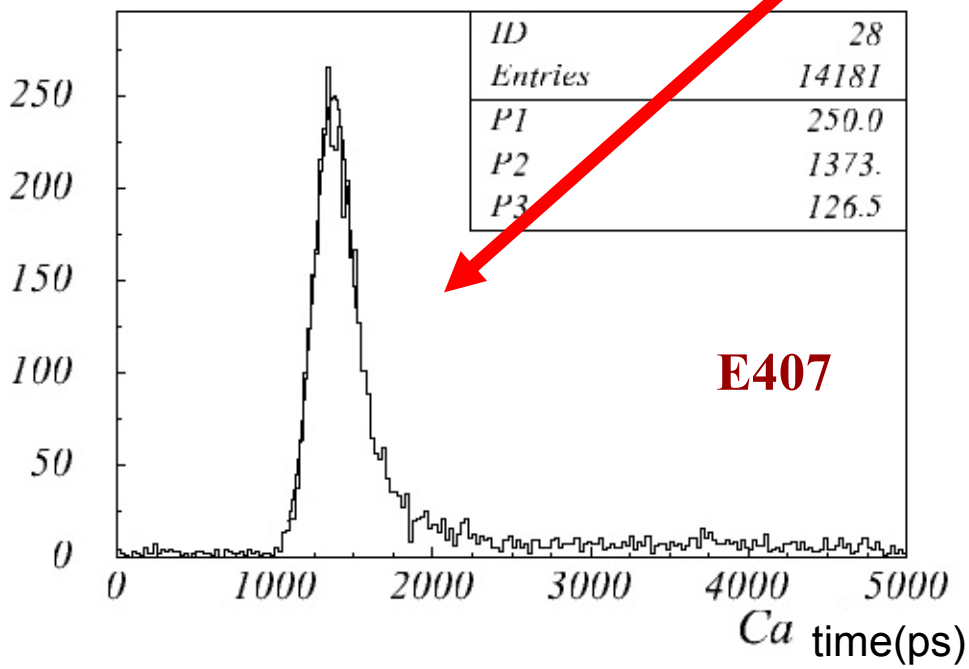
Sensitivity to single photons

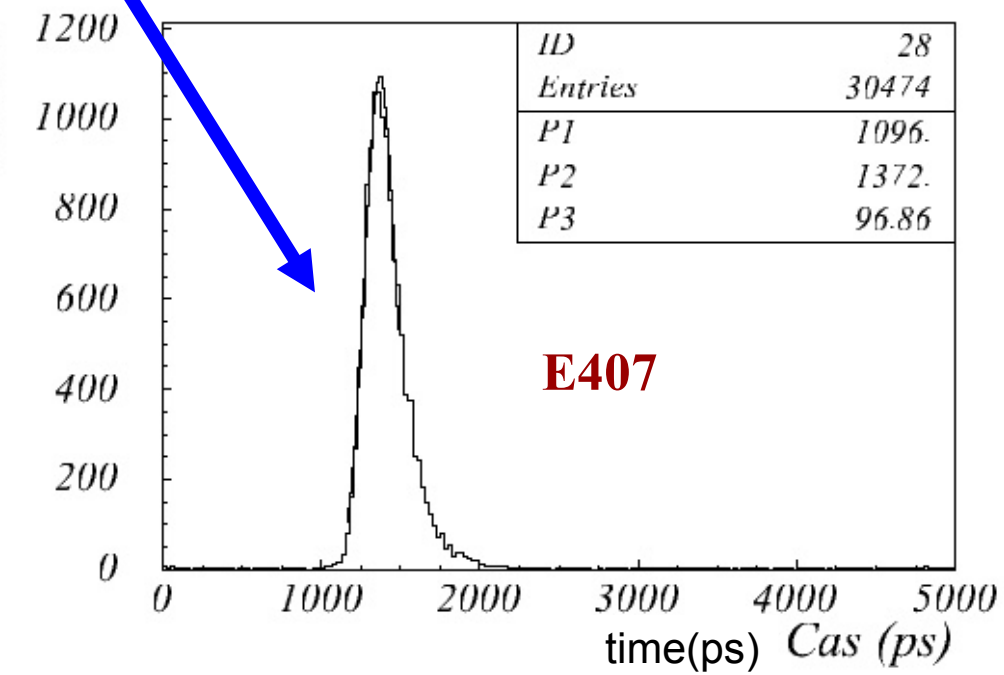
- **5 μm step size**
- **–laser beam ($\sigma \approx 5$ μm)**

Time resolution after time walk correction

Response of the silicon photomultiplier to a light pulses fromPILAS laser
no scintillator attached – pure SiPM
Larger pixels – better timing

red* vs *blue





1mm² SiPMs	E407	S137	H100C	H050C
σ_{red} (ps)	**127**	**182**	**145**	**212**
σ_{blue} (ps)	**97**	**151**	**136**	**358**

$\sigma \approx$ 100-200 ps

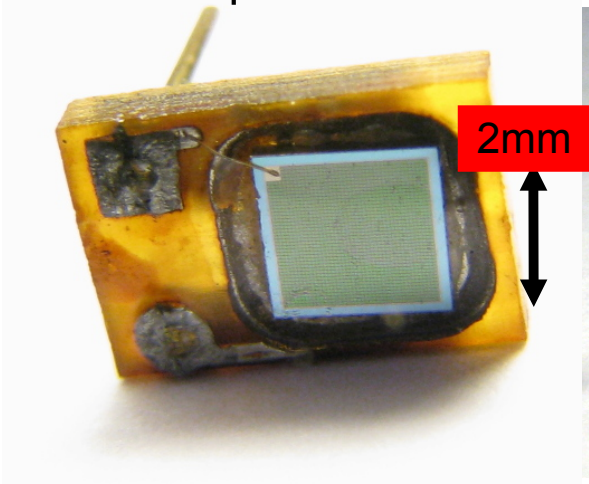
For larger devices
•larger capacitance → slower signals

PET module

2.1x2.1 mm^2

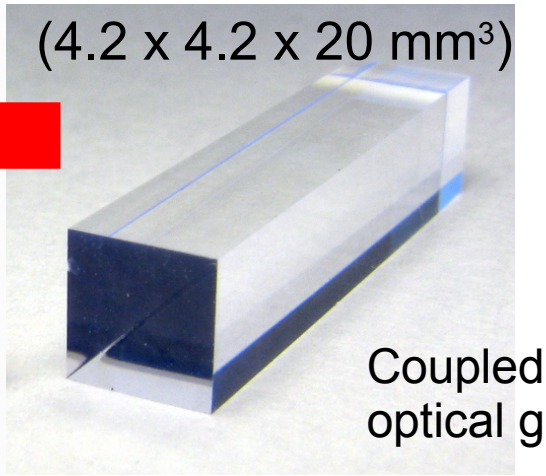
1700 pixels

Photonique 0611B4MM

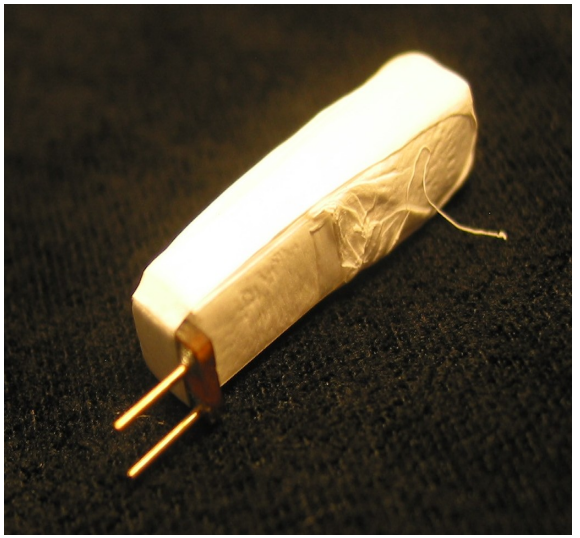


Sinocera LYSO crystal

(4.2 x 4.2 x 20 mm^3)

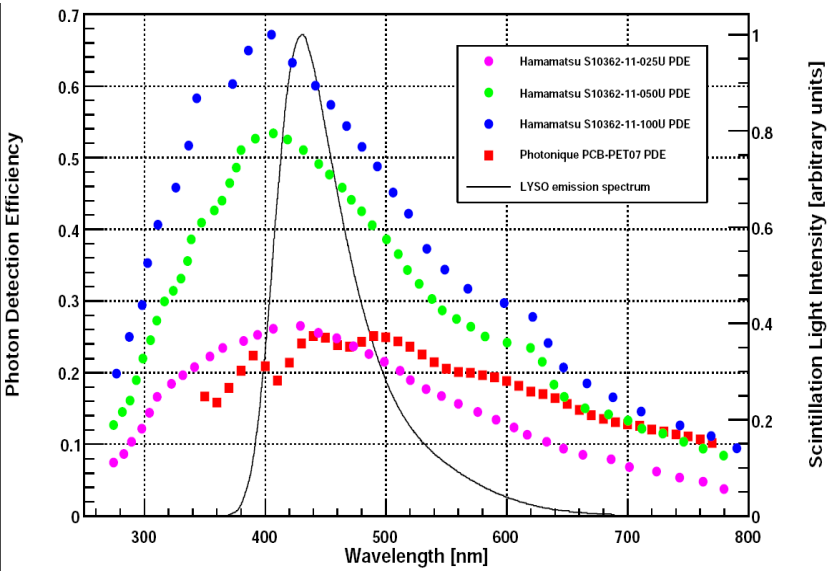


Coupled with optical grease

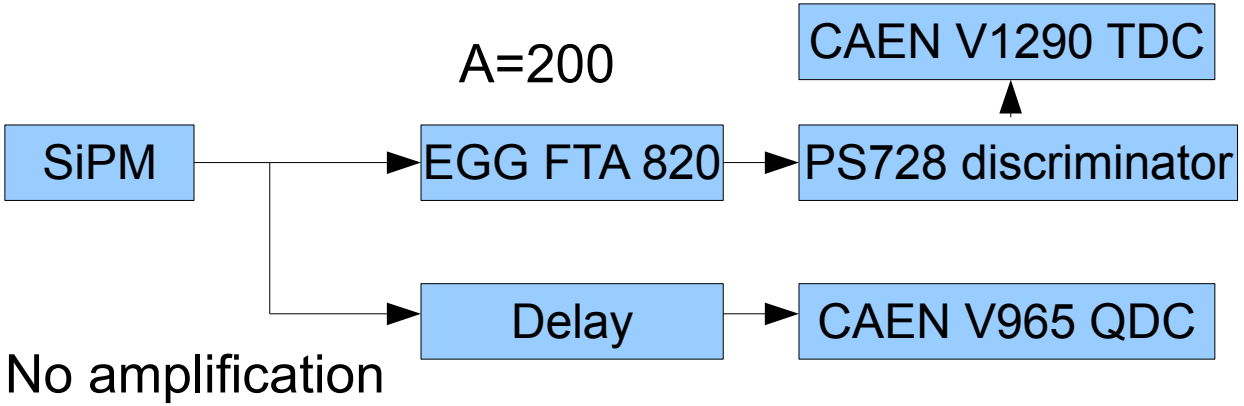


Teflon wrapping

PDE and the LYSO emmision spectrum well matched



Data Acquisition:

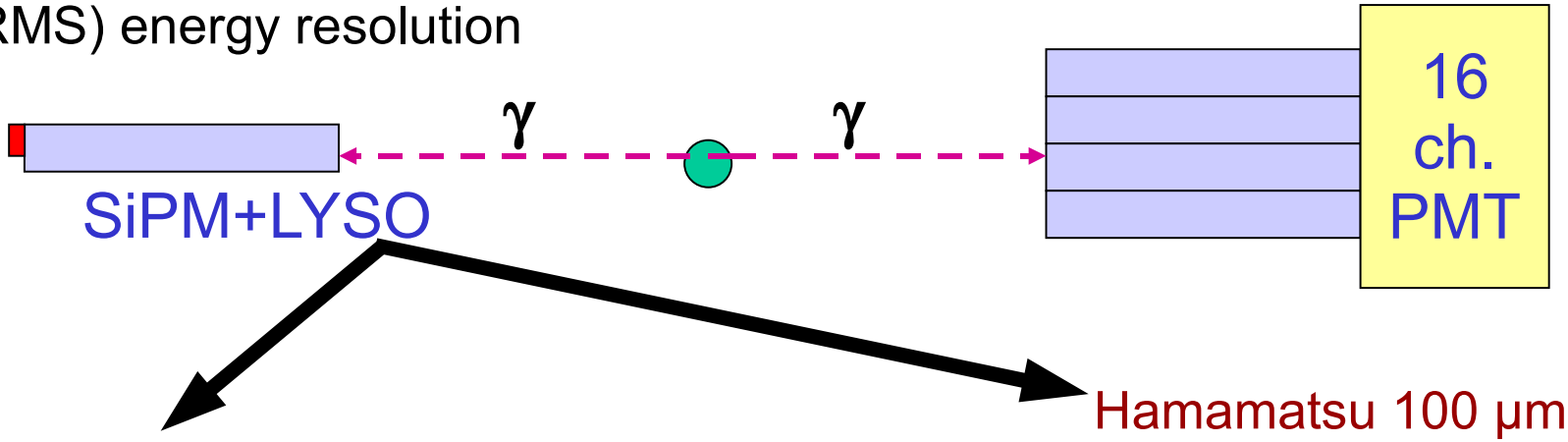


No amplification

Studies of a PET module 2

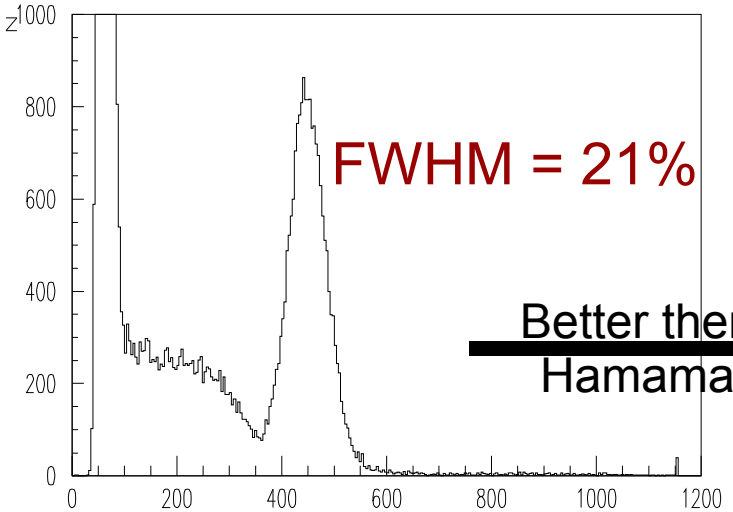
LYSO+SiPM tests with ^{22}Na in coincidence with a 4x4 LYSO + MAPMT (Hamamatsu R5900) module

~9% (RMS) energy resolution

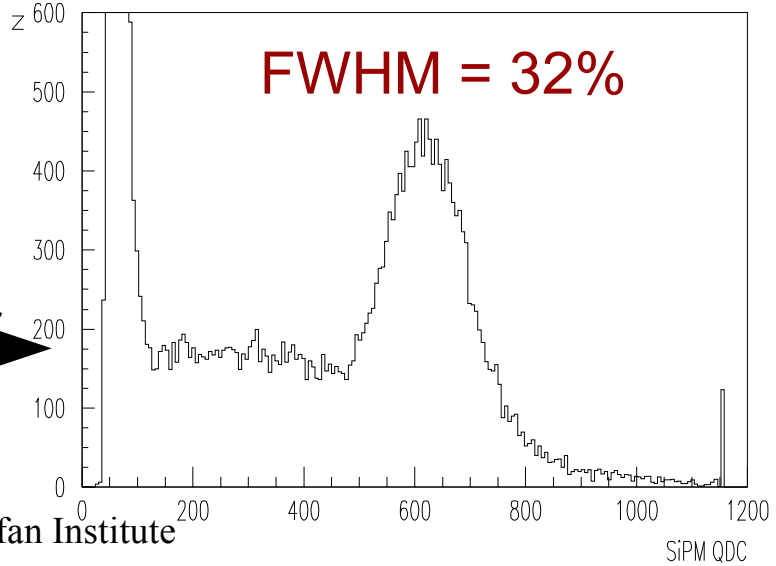


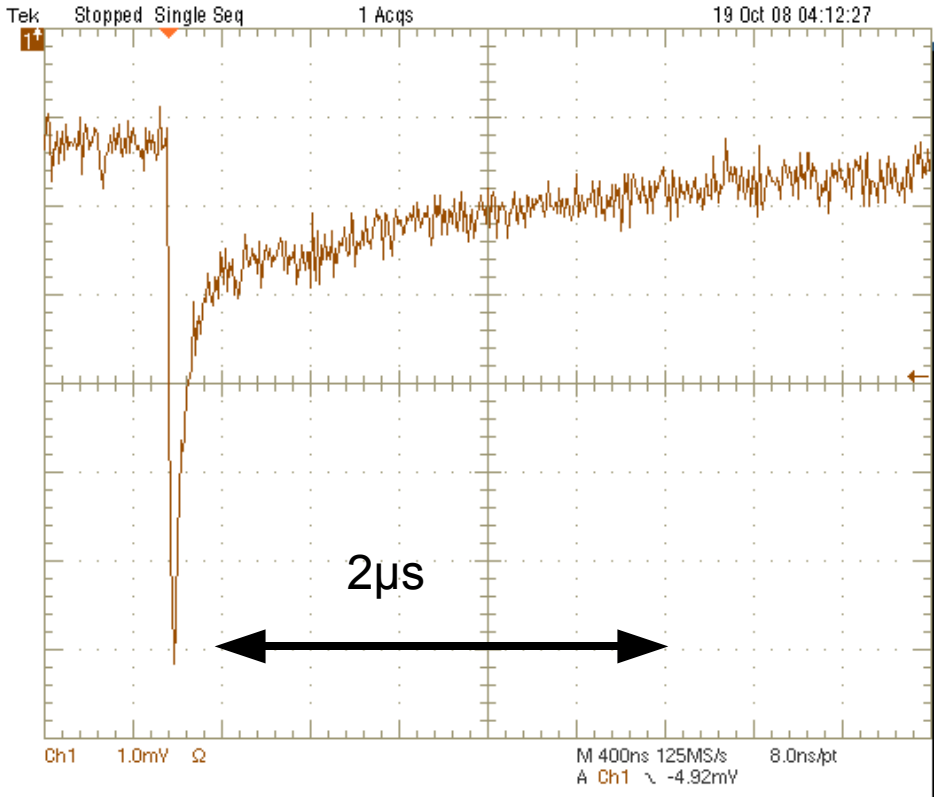
Photonique 0611B4MM

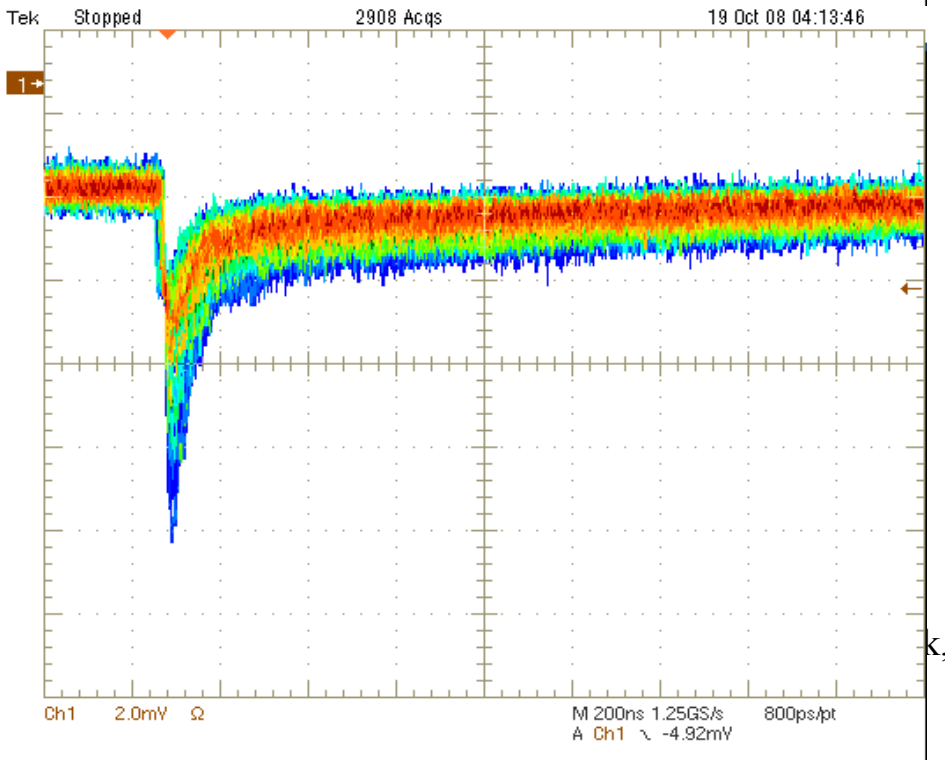
Hamamatsu 100 μm
1x1mm^2
ceramic package



Better then 4x smaller Hamamatsu sample





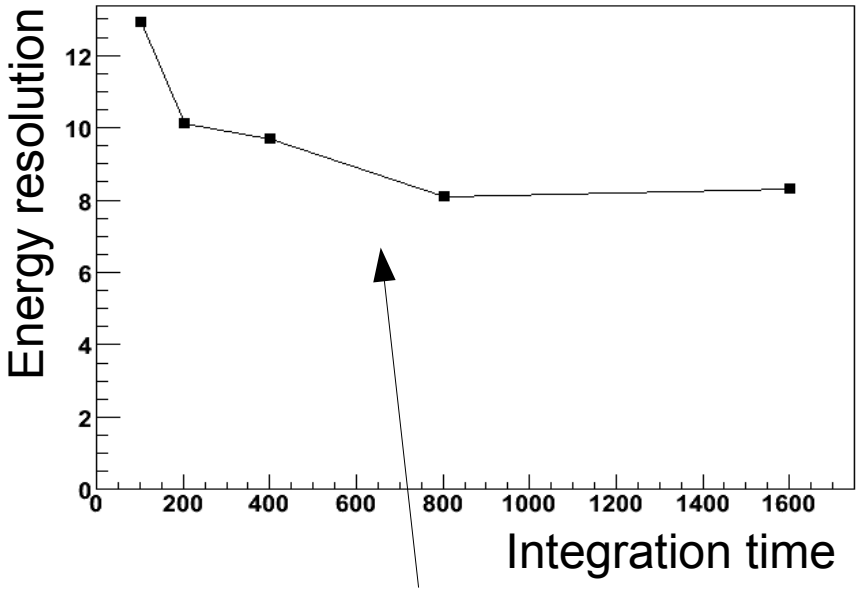


Pulse shape

2 characteristic decay times

1st very short ~50ns

2nd ~ 1µs

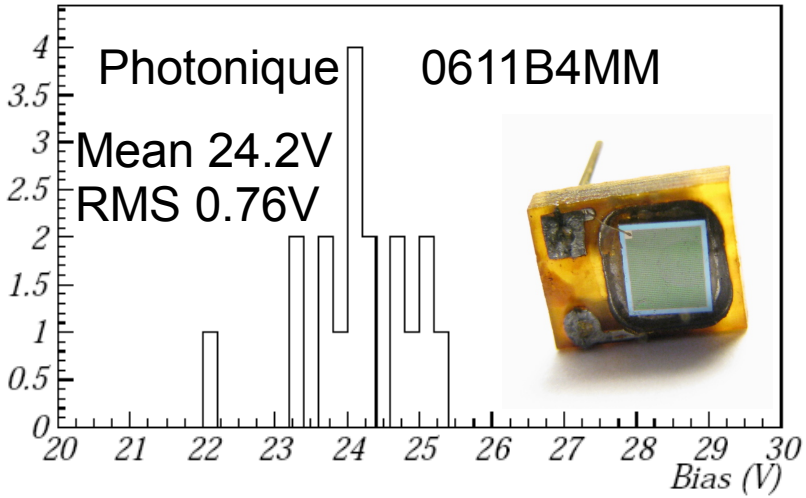


Integration time set to 800 ns

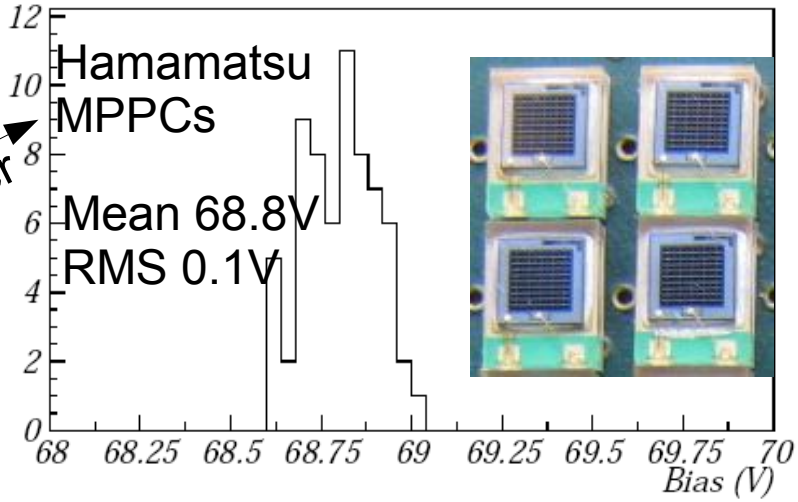
Studies of a SiPM – LYSO PET module

4x4 module (4.5mm pitch) constructed out of 16 SiPMs coupled with optical grease to LYSO crystal array

Bias voltage variation: Resistor network on the PCB

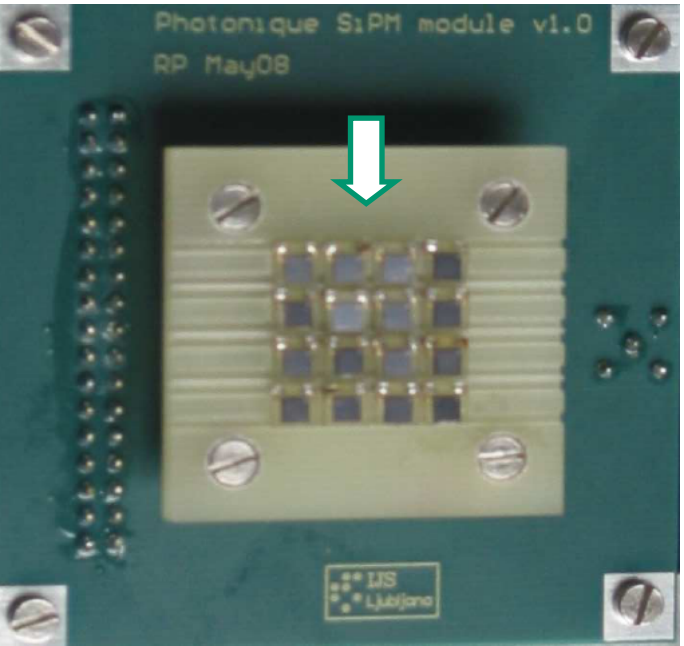


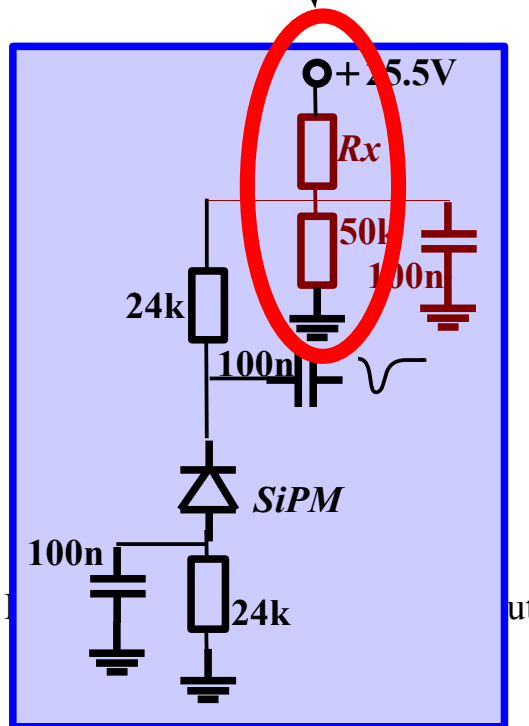
Uniformity much better

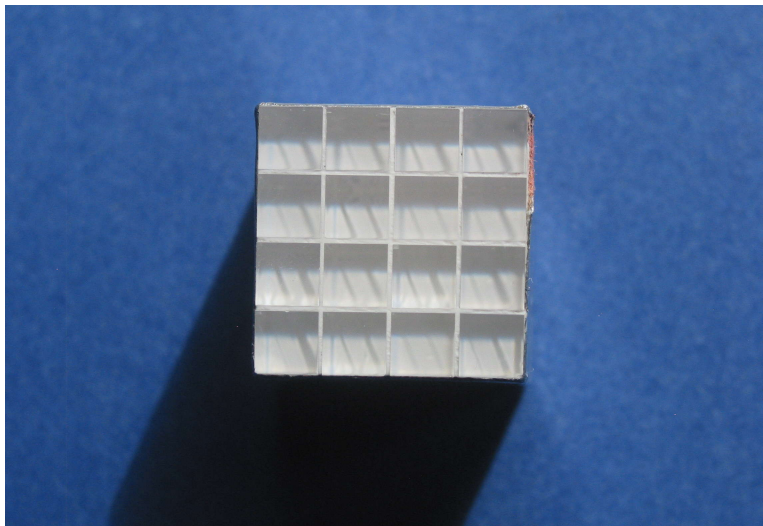


4x4 array of LYSO crystals ($4.5 \times 4.5 \times 20\ mm^3$)

$BaSO_4$ reflector wrapped around LYSO matrix





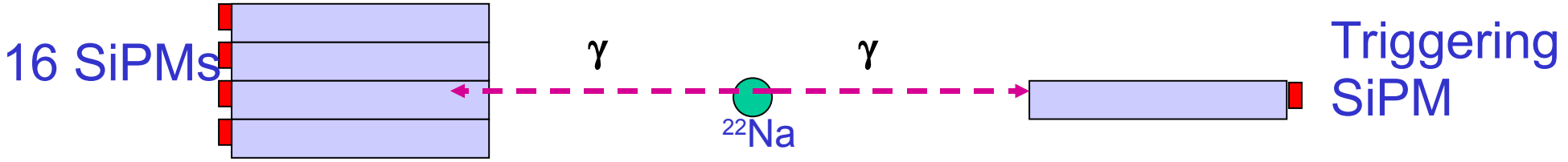


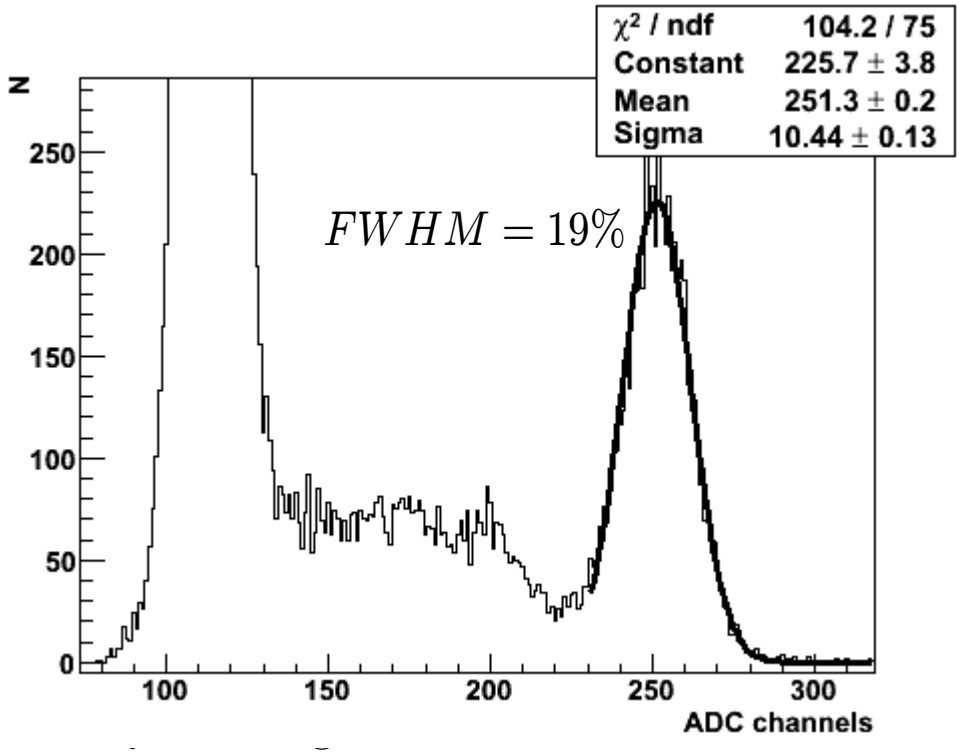
First studies of a PET module

Testing a PET module with:

4x4 array of LYSO crystals (4.5 x 4.5 x 20(30) mm^3)

16 SiPMs (Photonique 0611B4MM - 2.1x2.1 mm^2)





Energy spectrum

- Big variation in the position of the photopeak:
  - 16% RMS for different channels
- Small light yield
- Problematic coupling of the module to the LYSO scintillator array

Long tails in the pulse shapes

Test different SiPMs

SiPM specifications

Factory data

Producer	Photonique	Hamamatsu
SiPM type	0607	S10931-100P
Package type	PCB with pins	SMD
Size (mm^2)	2.2 x 2.2	3 x 3
Operating Voltage(V)	25	70
Gain	$7.5\ 10^5$	$2.4\ 10^6$
Terminal capacitance (pF)	160	320
Number of pixels	1700	900
Pixel size (μm)	40	100
Peak PDE	0.25	0.75

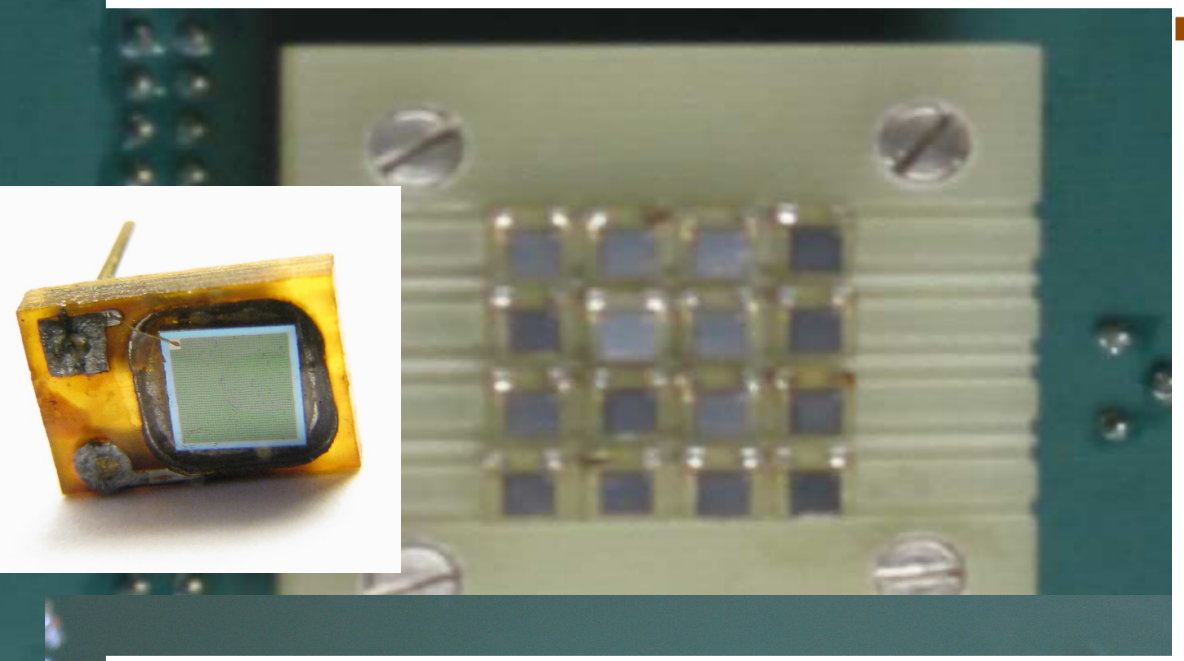
PRO:

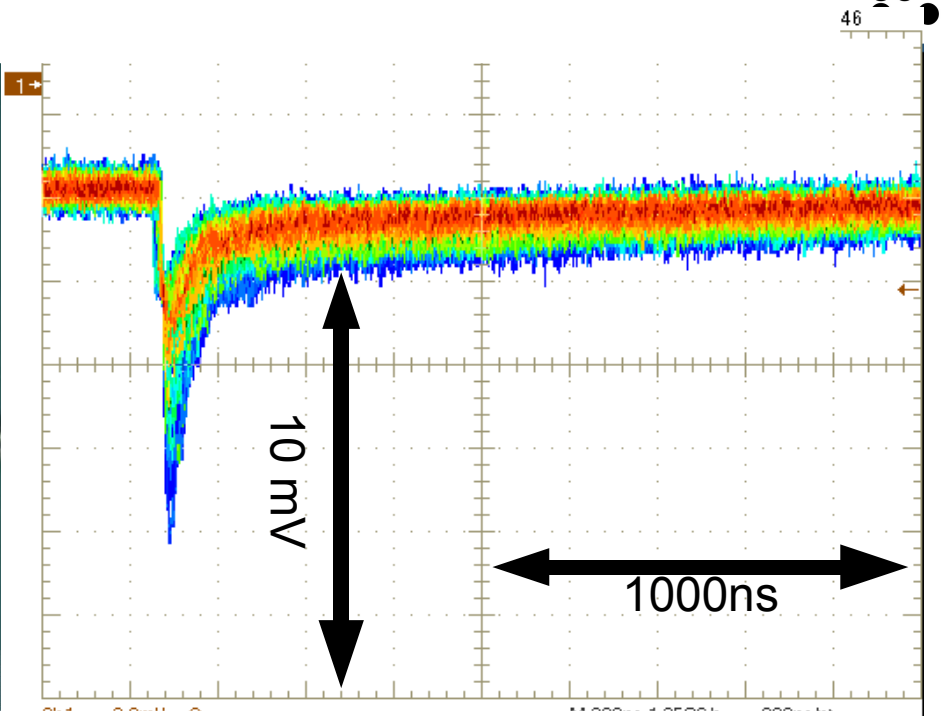
•Package more suitable for construction of larger modules and coupling of the crystals
•Larger
•Higher Gain
•Higher peak PDE

CON:

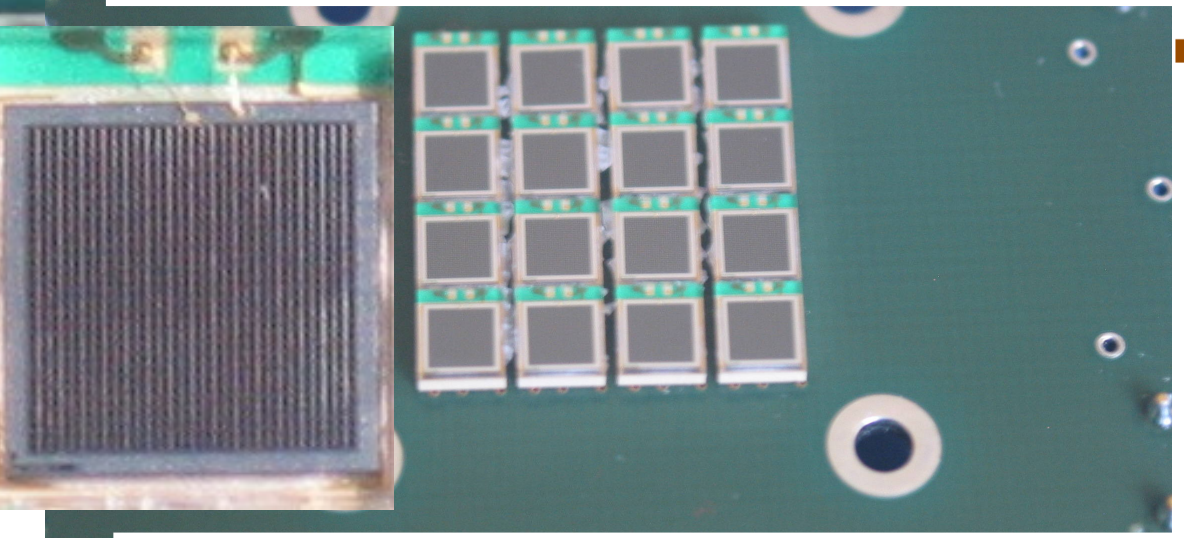
•Larger capacitance – worse timing
•Larger pixels - nonlinearity

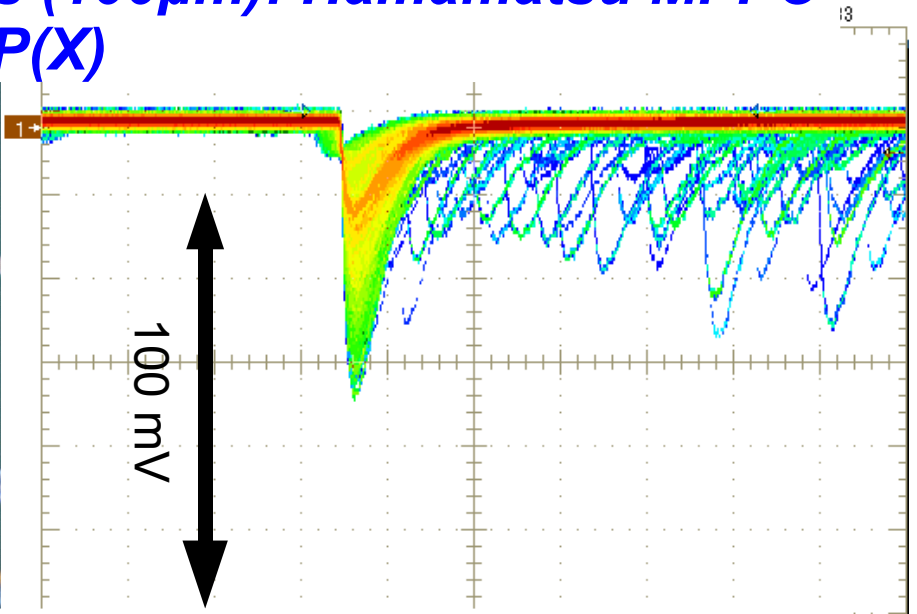
Standard package with pins,1700 pixels (50µm)- Photonique PCB-PET07





SMD package, 3mm x 3mm, 900 pixels (100µm): Hamamatsu MPPC S10931-100P(X)

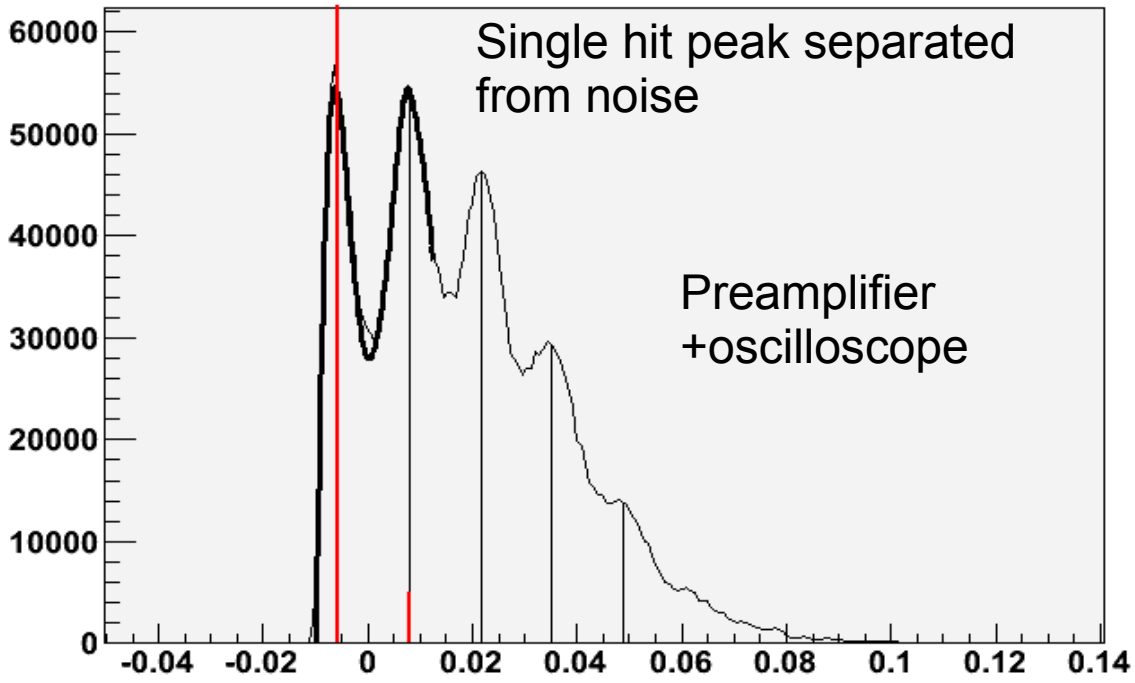




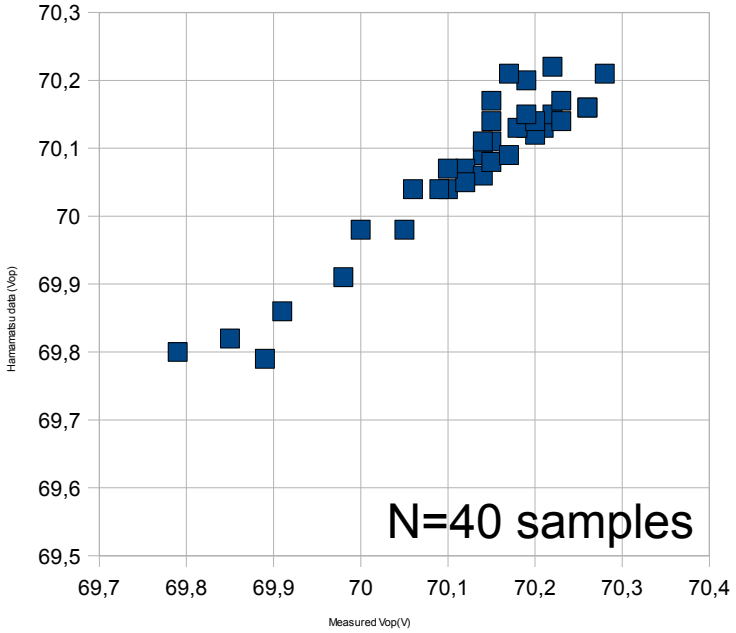
Better surface control,
larger signal, no tails in the signal shape ->expected better timing

Hamamatsu MPPC : Operating voltage

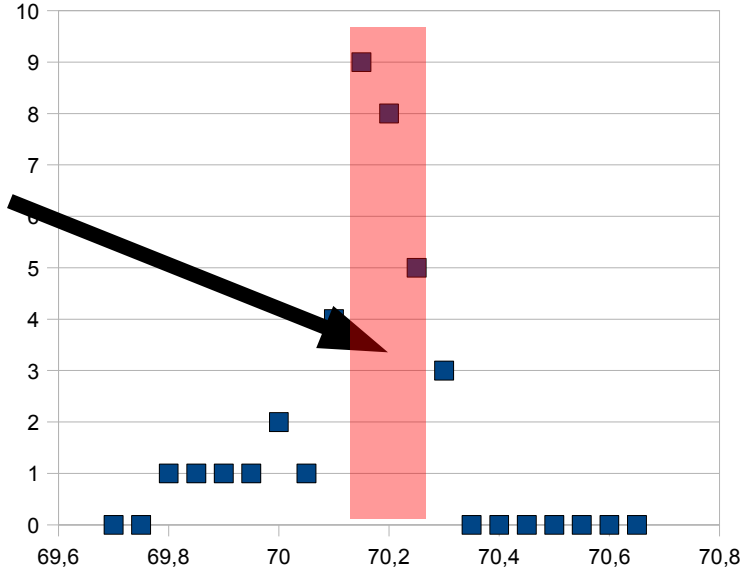
All the samples tested:
Gain vs bias voltage
Determined the operating voltage



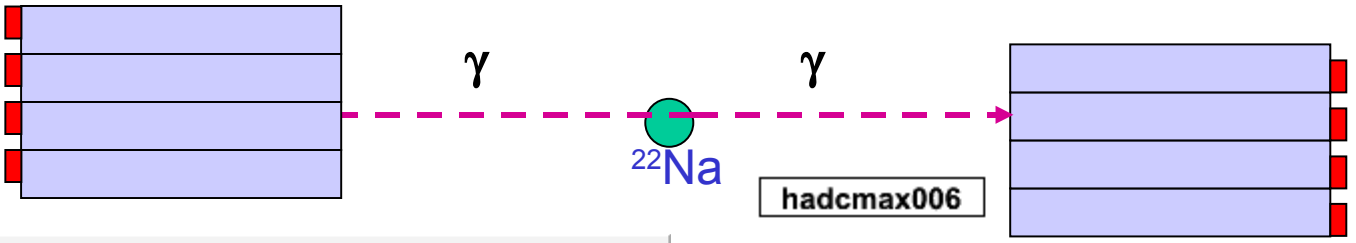
Correlation between the manufacter recommended V and our working V



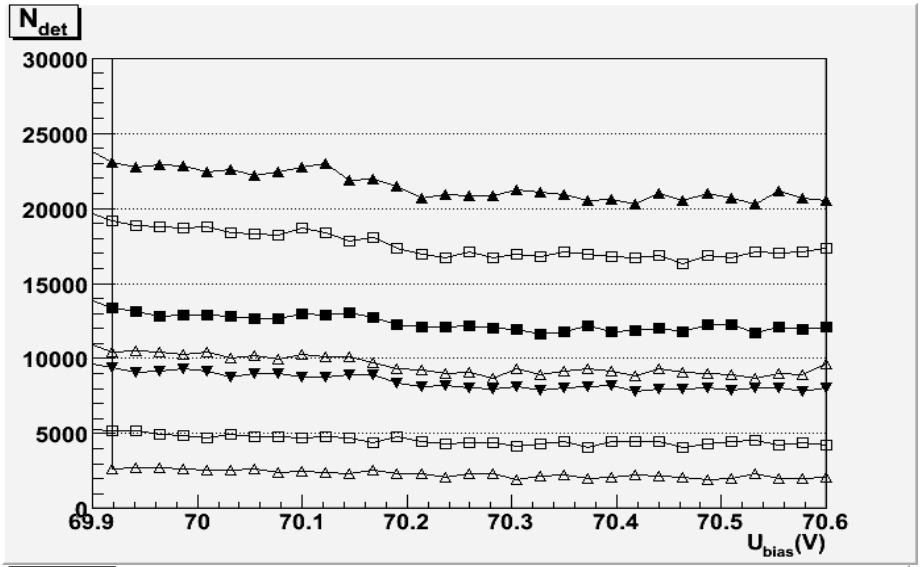
Selection of samples with similar operating voltage.

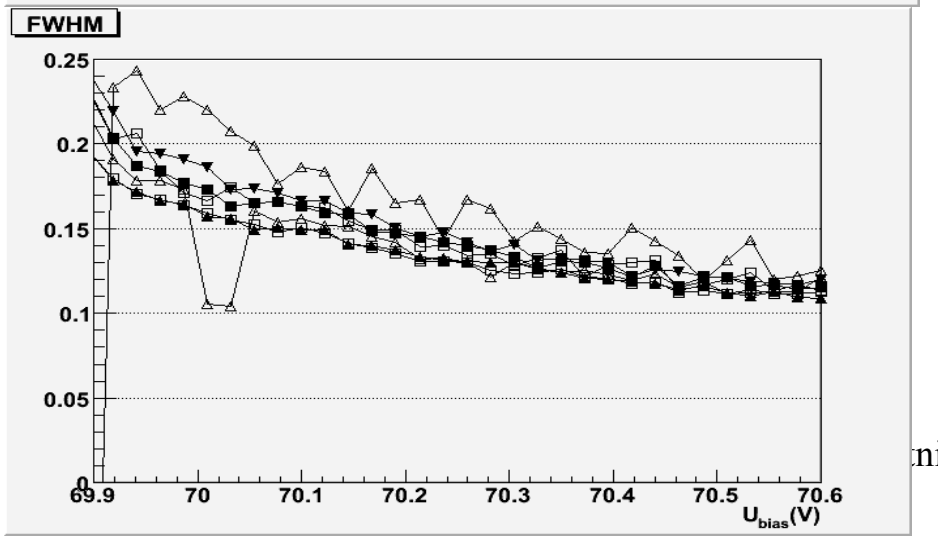


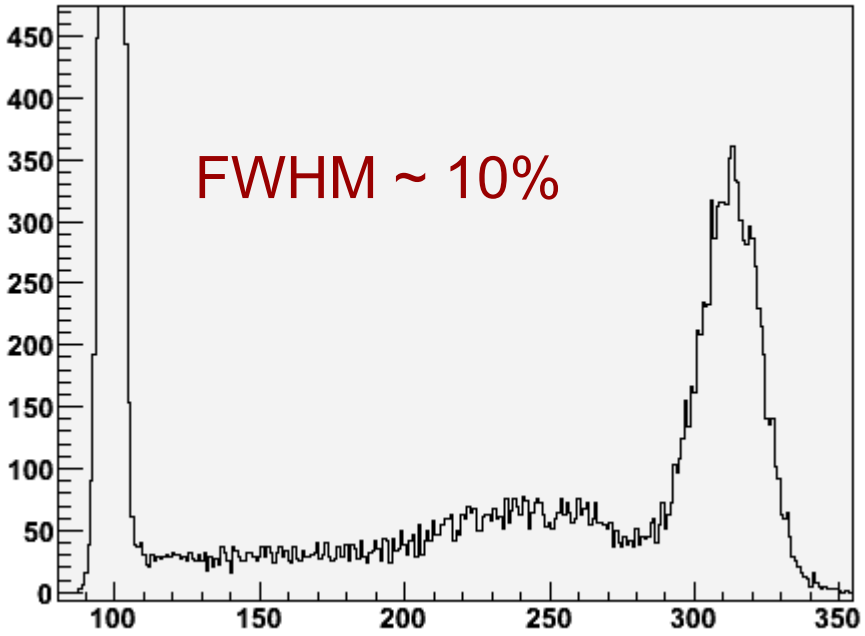
Hamamatsu MPPC -Energy resolution



One channel used as a trigger

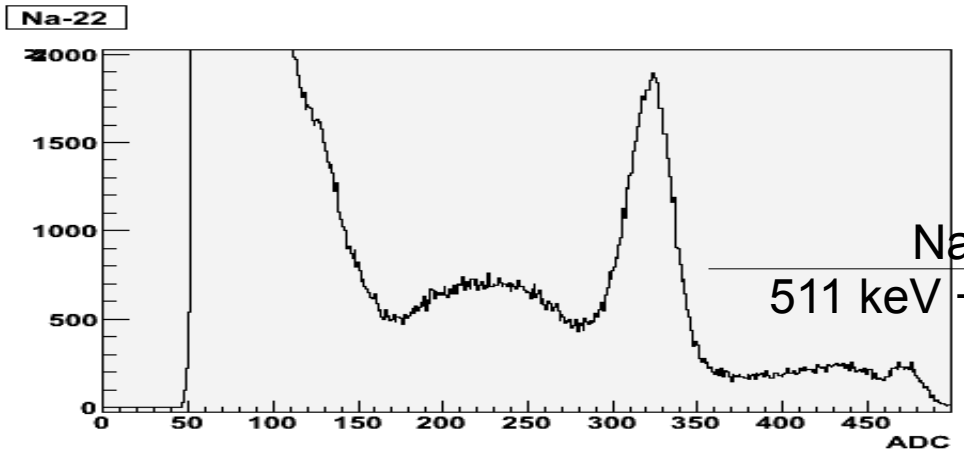


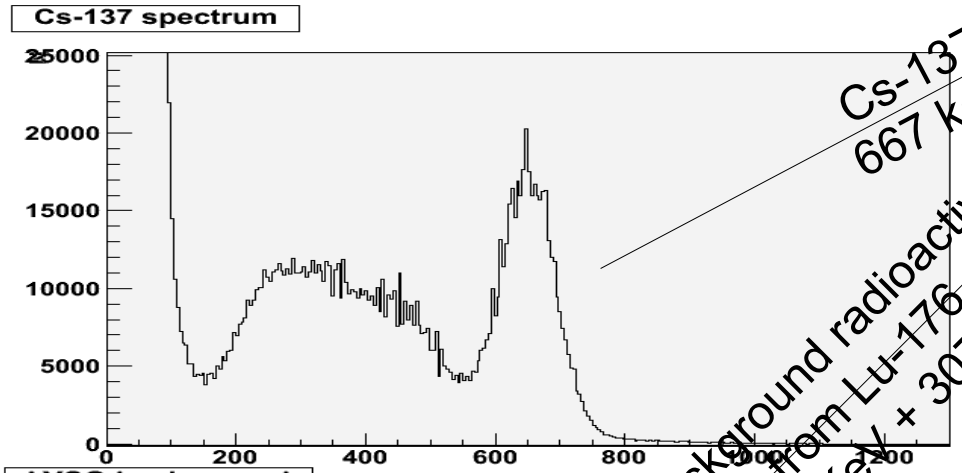


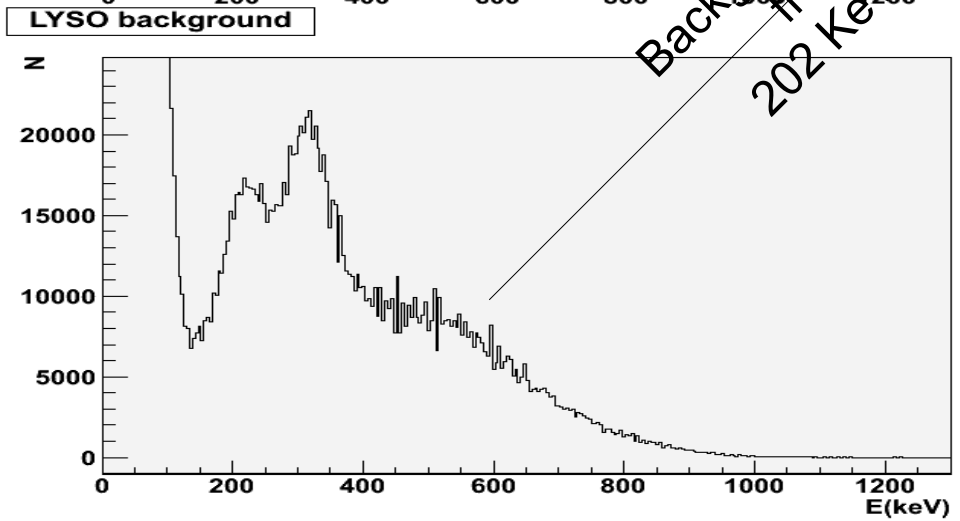


FWHM ~ 10%

Hamamatsu MPPS: Response to different radioactive sources







Na-22
511 keV + 1230keV

Cs-137
667 keV

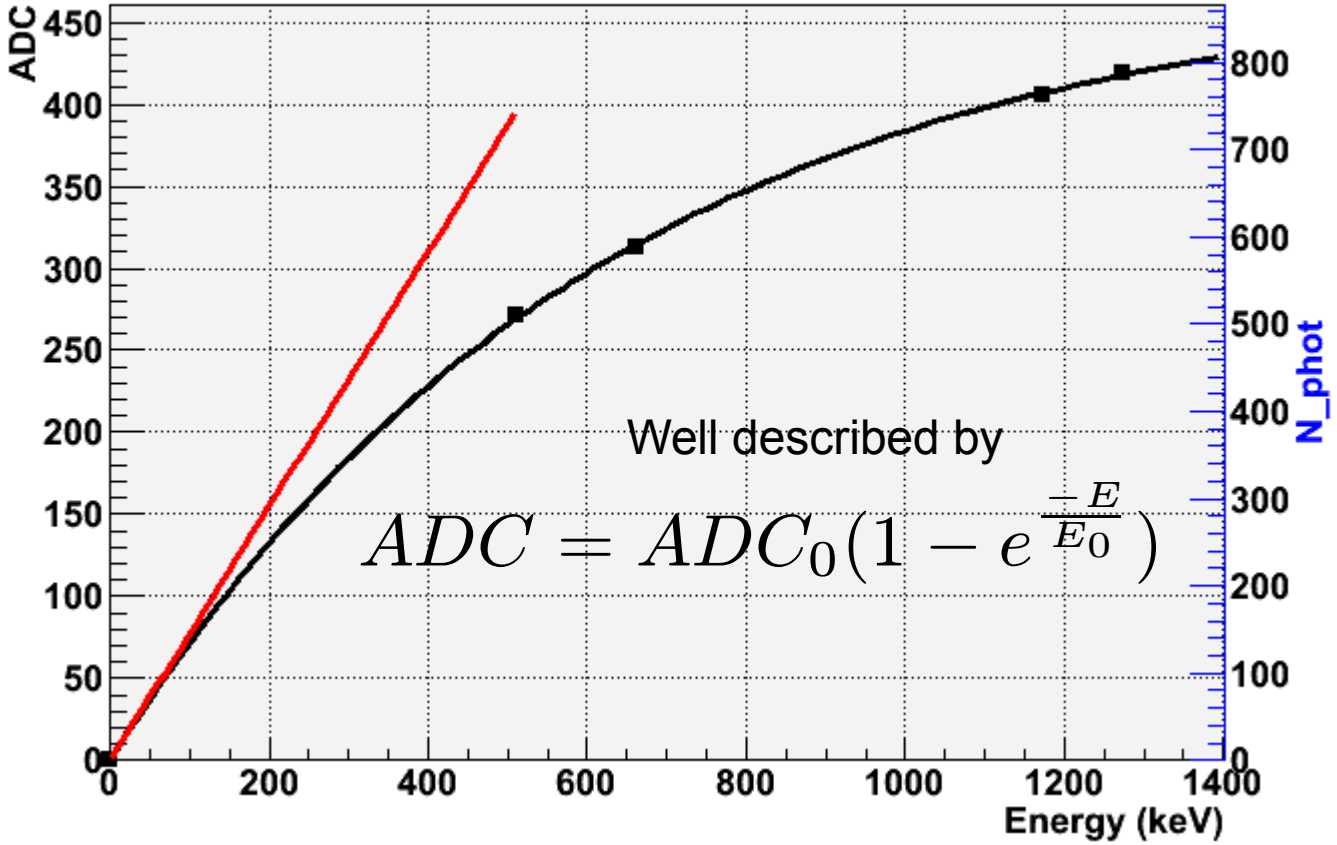
Background radioactivity
from Lu-176
202 KeV + 307 keV

Response of the SiPMs is not linear
Saturation - 900 pixels

Different radioactive sources can be used to calibrate the energy response.

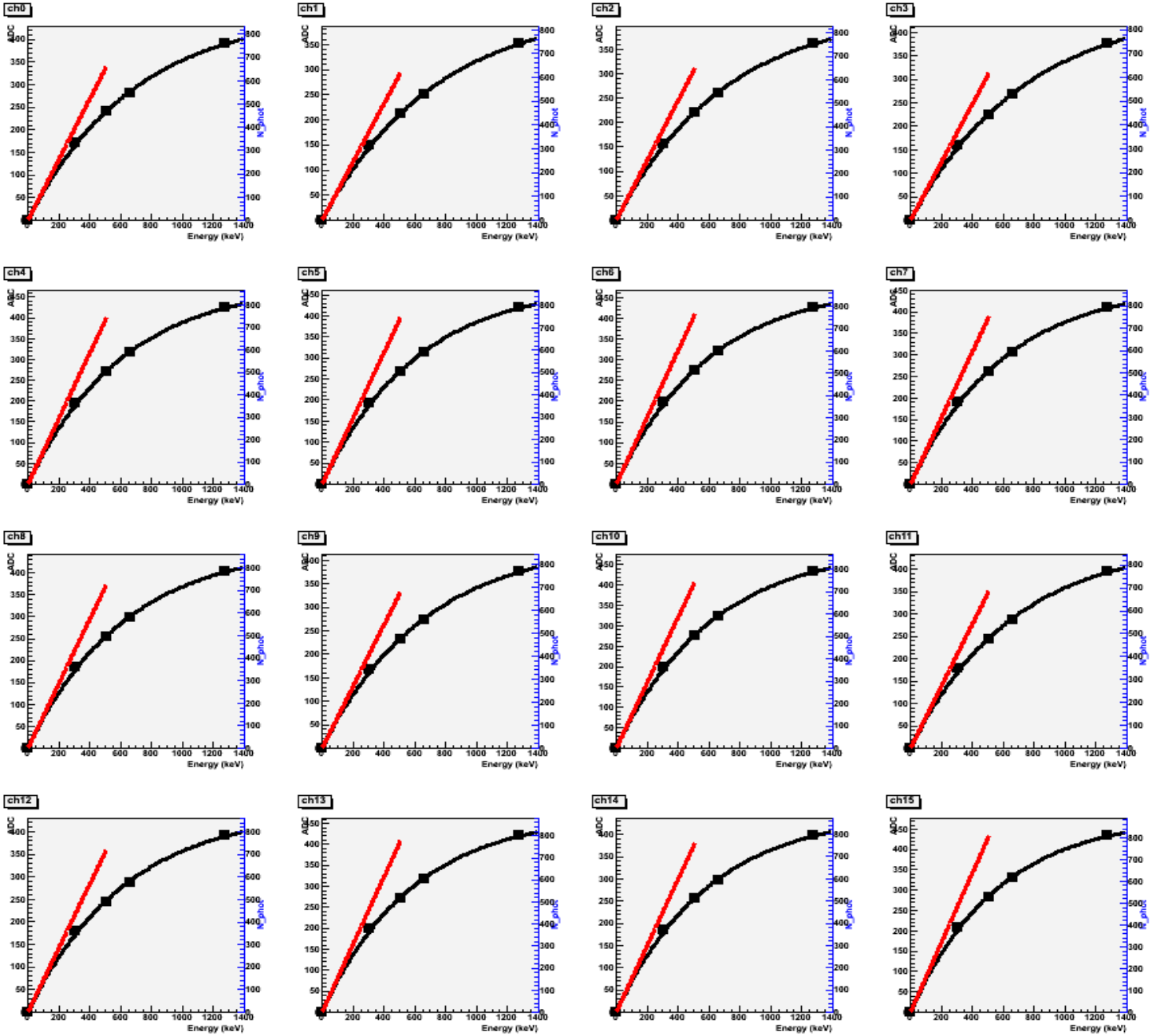
Energy – ADC relation

ADC of the peaks with well known energy fitted to determine ADC_0 end E_0

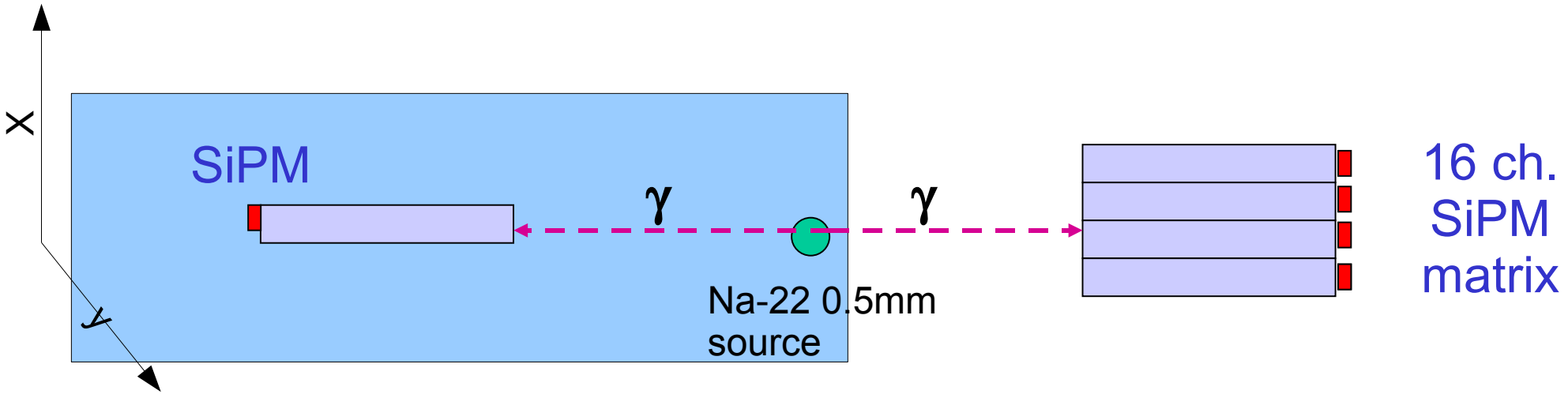


Around 750 photons detected for the anihillation 511keV gamma

Similar response found in all channels
Difference in the response (pulse height of the peak) 4% RMS



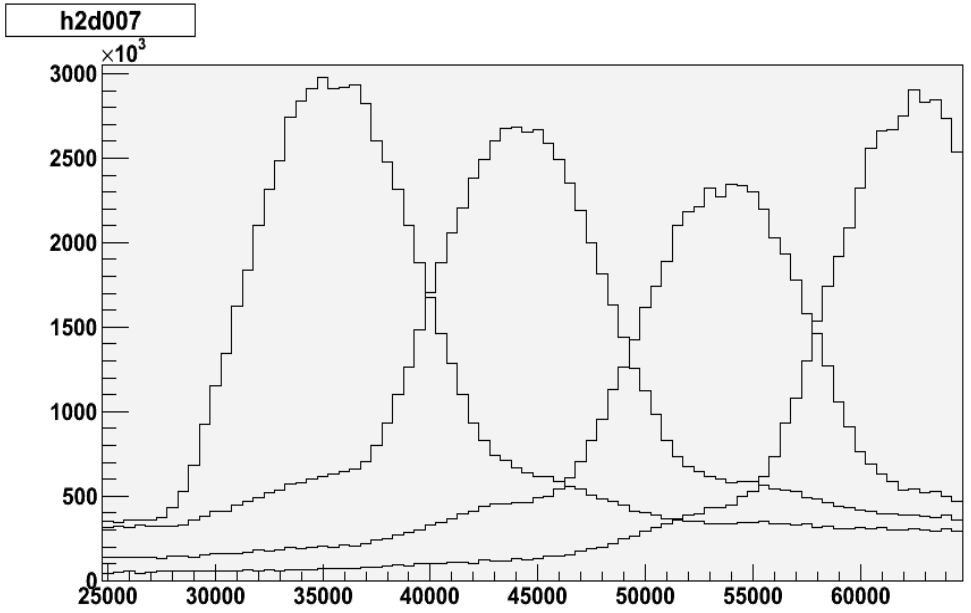
Na-22 Source position scan



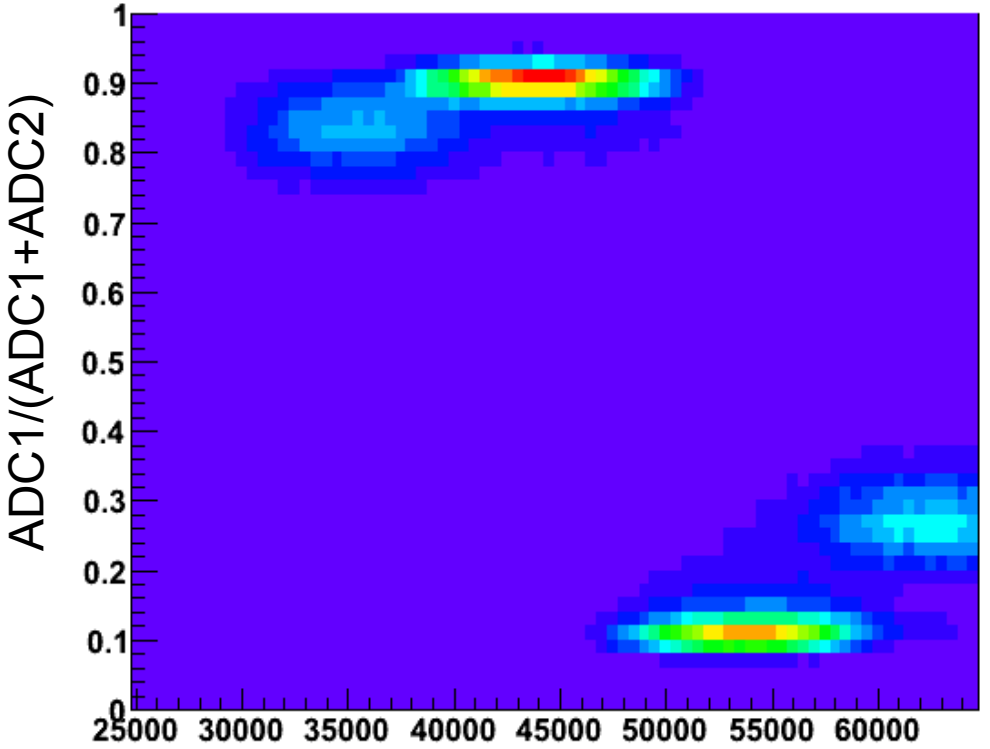
Na-22 source and SiPM (single crystal -left) fixed on the same support

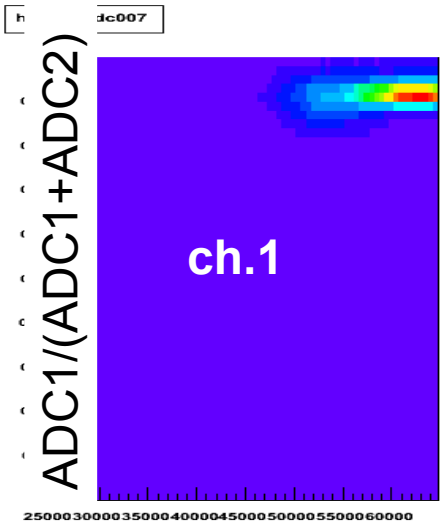
Scanned across the 4x4 LYSO+SiPM module

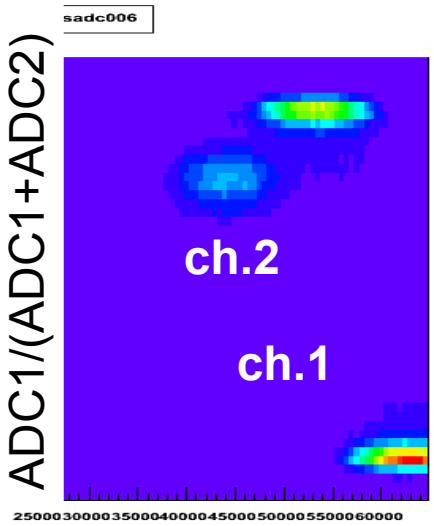
Light distribution

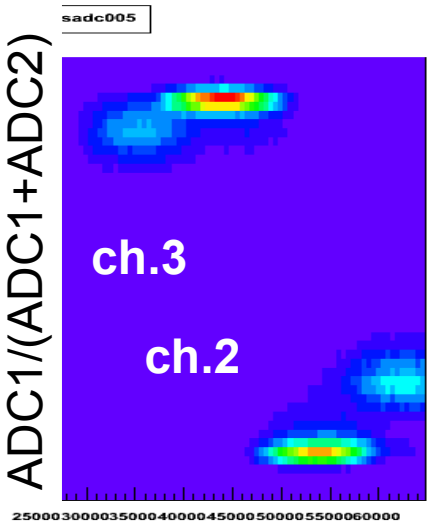


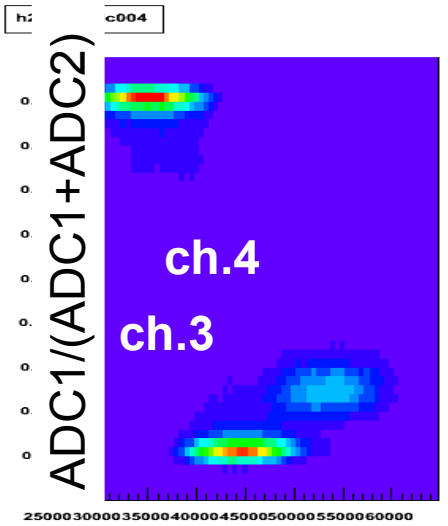
Position of the source



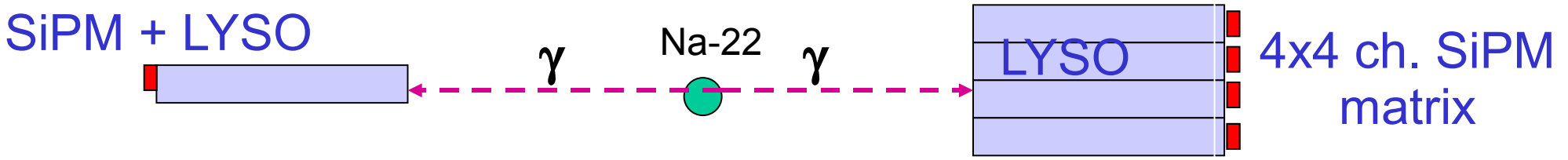




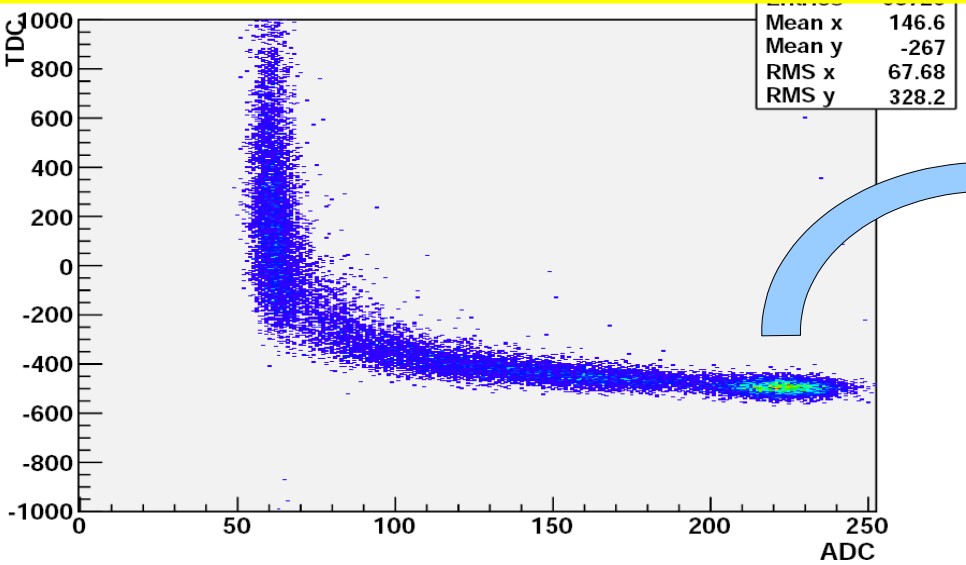


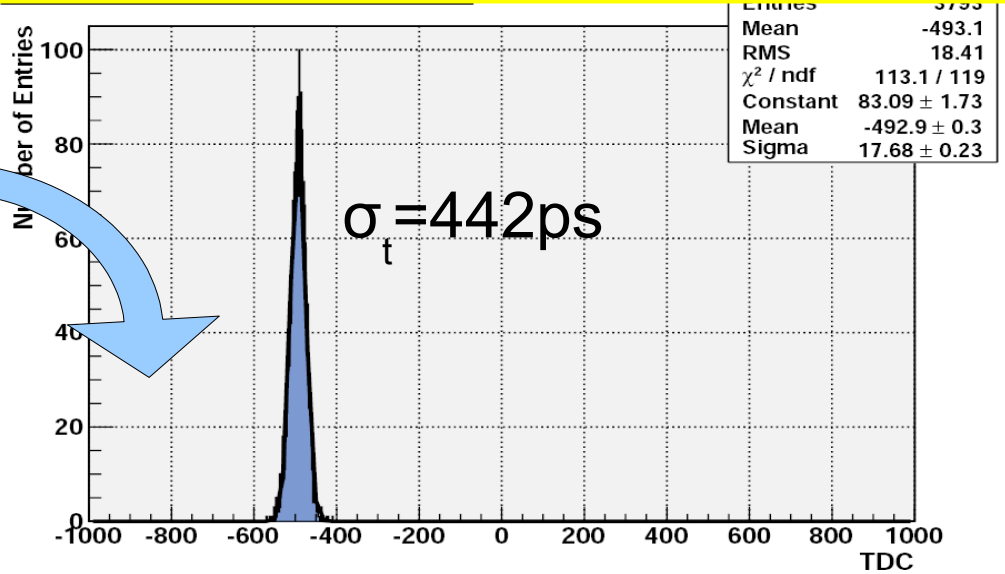


Timing for annihilation gamma's



Time difference between the coincident γ's





- Expected width much smaller: 200*√2 ~ 300 ps
  - Reason:
    - Analog signals connected to fast amplifier Ortec FTA820 and discriminated
    - discriminator threshold at ~10 photons

★ Solution:

Fast preamplifier which would allow to discriminate at the single photon level

Conclusions

We have studied the SiPMs to be used as a photon detector for PET.

Position sensitivity for single photons was measured for different SiPMs.
Timing resolution: ~100-200 ps for single photons for 1mm^2 devices.

Two PET modules of 4x4 SiPMs + 4x4 2 cm long LYSO crystals were constructed:
- PCB with 2-pins package - 2.1 mm x 2.1mm - Photonique 0611B4MM
- SMD package 3mm x 3mm Hamamatsu MPPC S10931-100P(X)

Energy resolution FWHM 10% (Hamamatsu) and FWHM 21% (Photonique) was obtained.

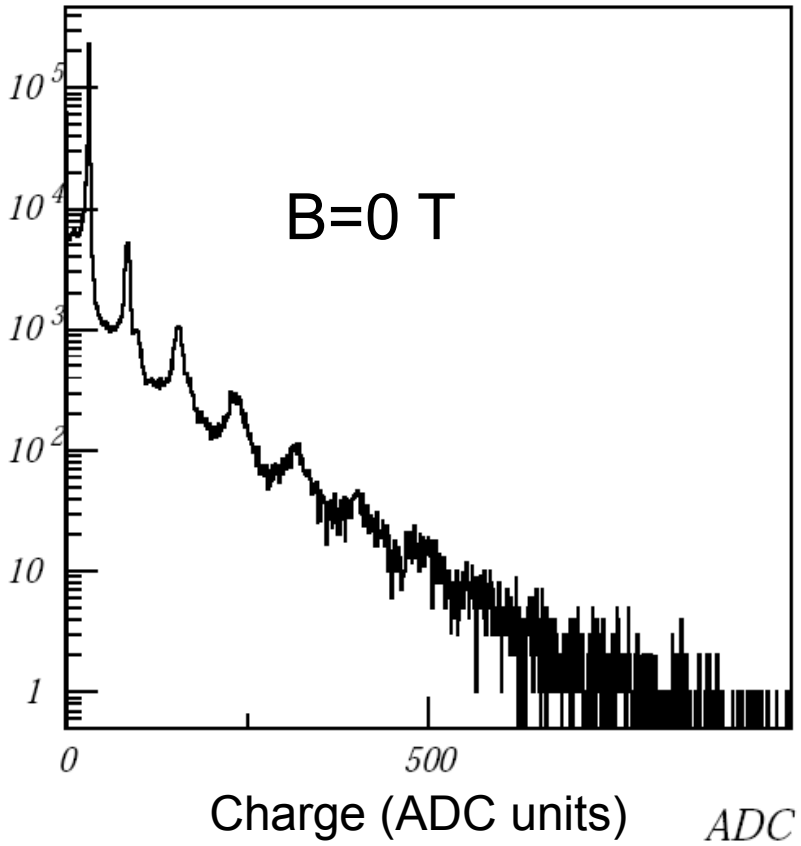
Due to saturation the energy response is not linear.
LYSO scintillation signal is on average 10x higher for Hamamatsu (larger pixels)
The SiPMs can be used as an efficent detector of scintillation photons in PET applications

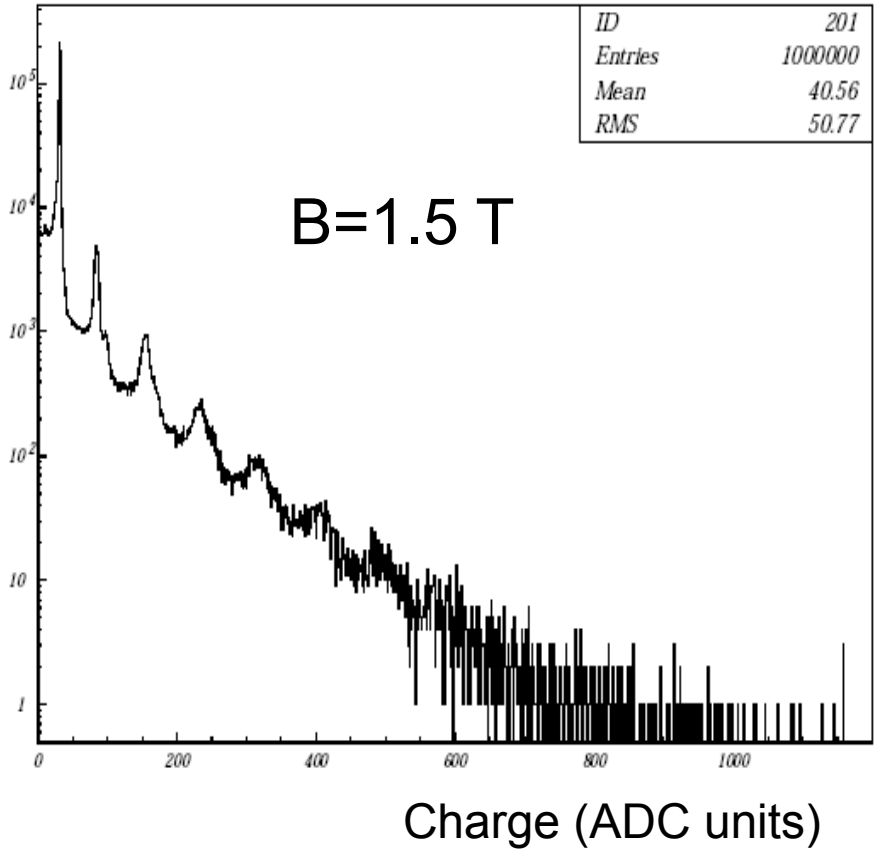
Next steps:
- Design PA electronics
  - Improve timing
- Improve coupling of the scintillator crystals
- Design of the demonstrator

Magnetic field sensitivity

Response of the Hamamtsu MPPC (1mm x1mm -100 mm) to a 635 nm light pulses.

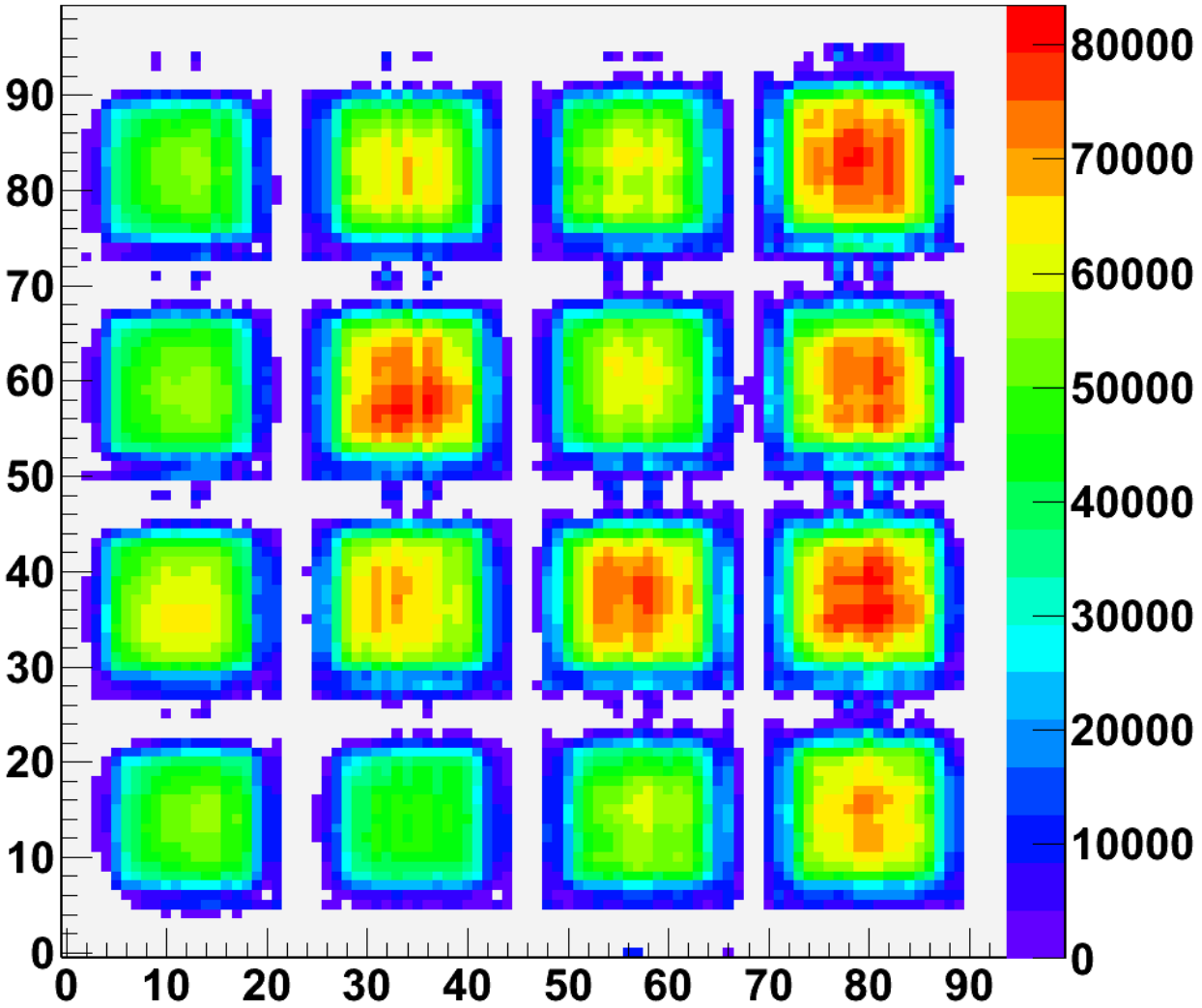
Confirmed: No observable degradation in the magnetic field





Surface sensitivity to the 635nm laser light

(beam size $\sigma \approx 0.2$ mm) step size 0.25 mm

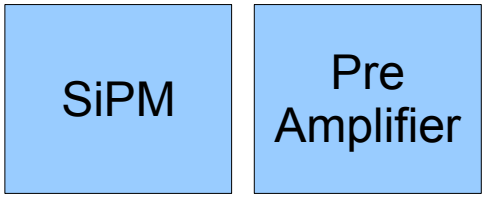


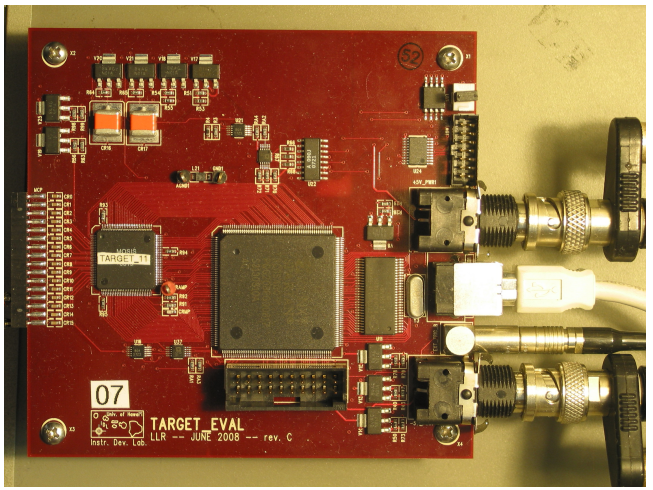
Readout for SiPM modules

The large analog bandwidth recorder and digitizer with buffered readout – TARGET ASIC

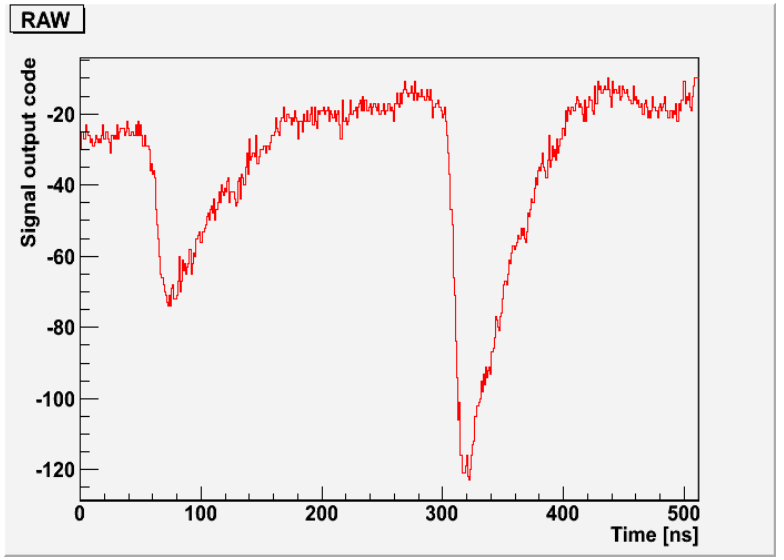
G.Varner et al NIMA 591 (2008) 534.

Signals from SiPMs





Signals from SiPMs



- 2.5 GHz sampling chip
- 16 channels/ chip