Development of a gamma-ray imager using a large area monolithic 4x4 MPPC array for a future PET scanner

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12 September 2011
Position Sensitive Detectors 9 @ Aberystwyth

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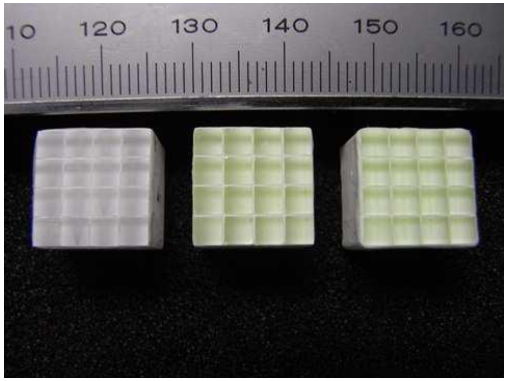
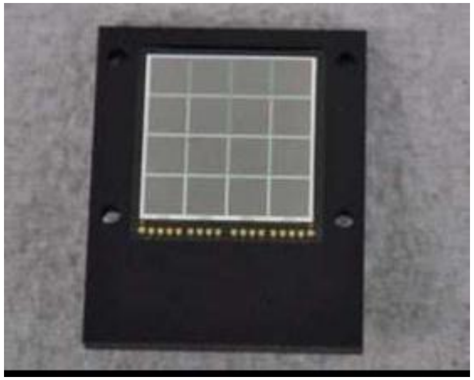
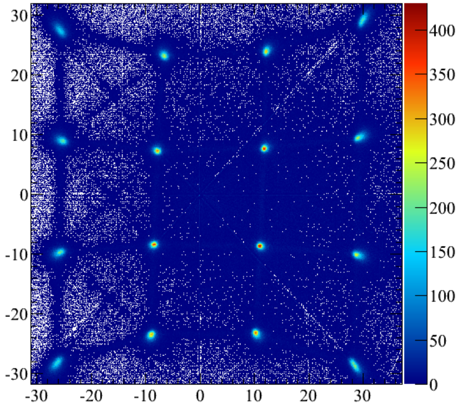






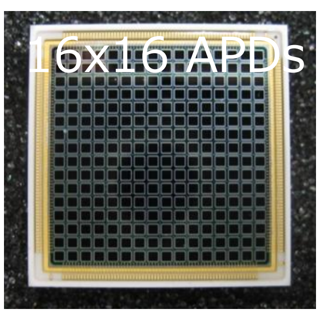
PET and our approach

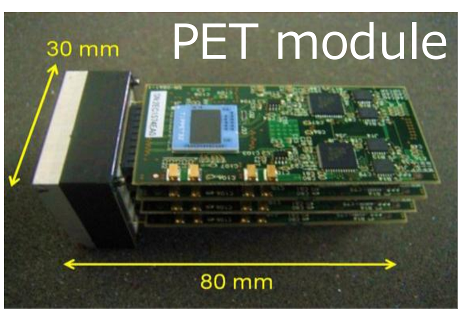
Positron Emission Tomography : $e^+e^- \rightarrow \gamma\gamma$ imaging

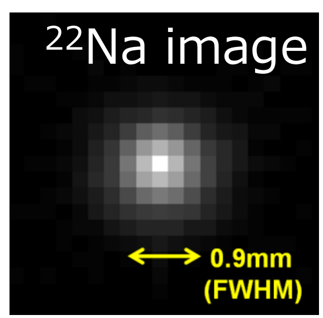
Semiconductor photosensors are promising & successful

- Compactness, low power, mass productivity, easy handling…
  - → Realized large number of channels, fine/complex configurations
  - → **"DOI-PET"**
- Insensitive to magnetic fields
  - → **"MRI-PET"**
- APD-PET project
  - → dedicated LSI (*Koizumi+10*)
  - → sub-mm resolution (*Kataoka+10*)
  - → **>a few ns time res.** (*Matsuda*)

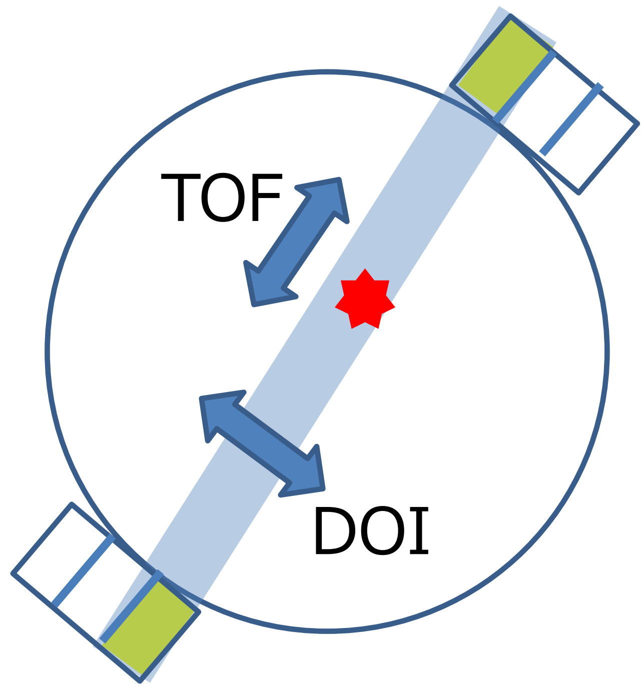
MPPC can overcome !!







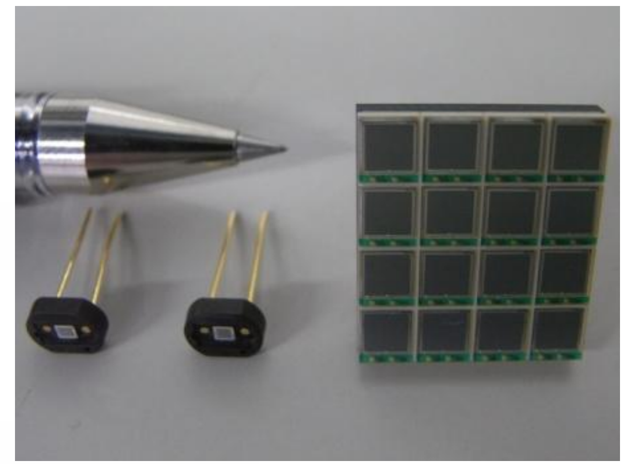
Kataoka+10

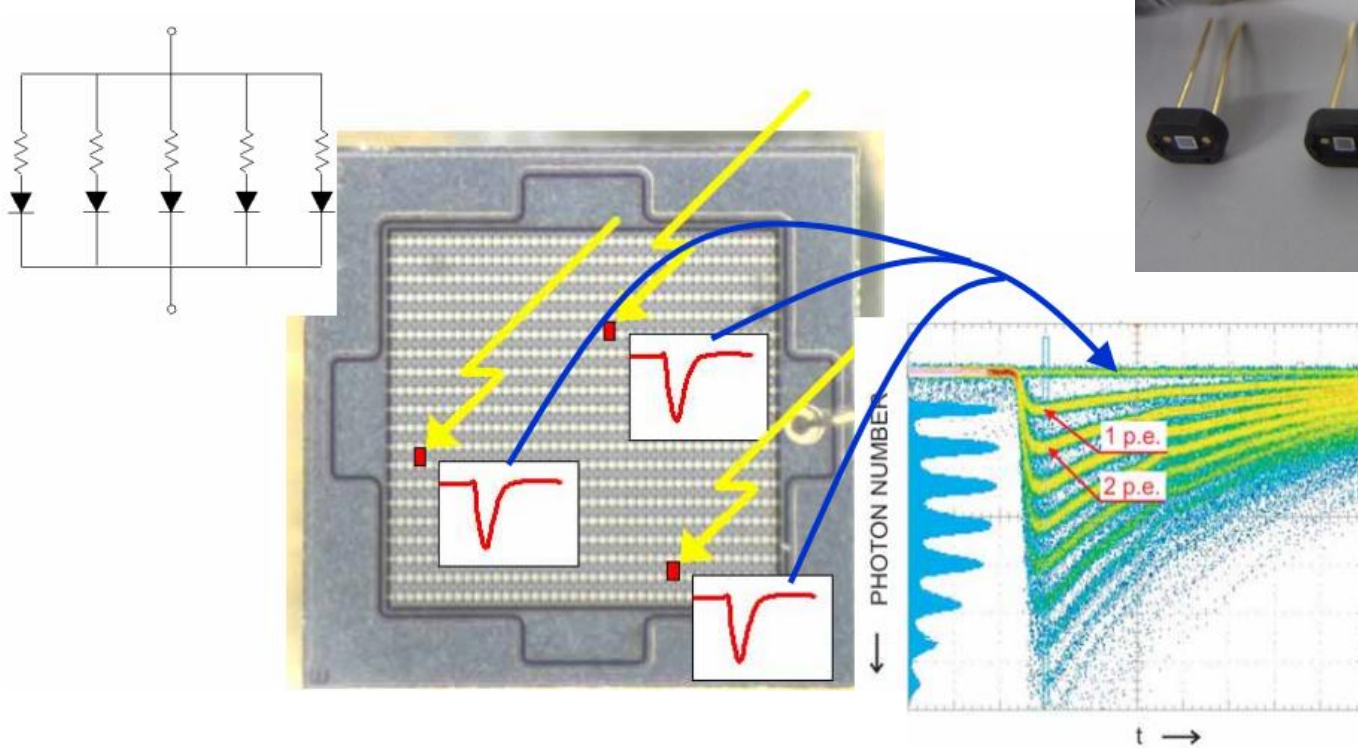


TOF & DOI information improve position accuracy

Muti-Pixel Photon Counter

- 2D-array of APDs operated in Geiger mode
- Charges proportional to the number of fired APDs
- low bias voltage (<100V)
- high gain ($10^{5\text{-}6}$)
- Insensitive to magnetic field





Characteristics summary

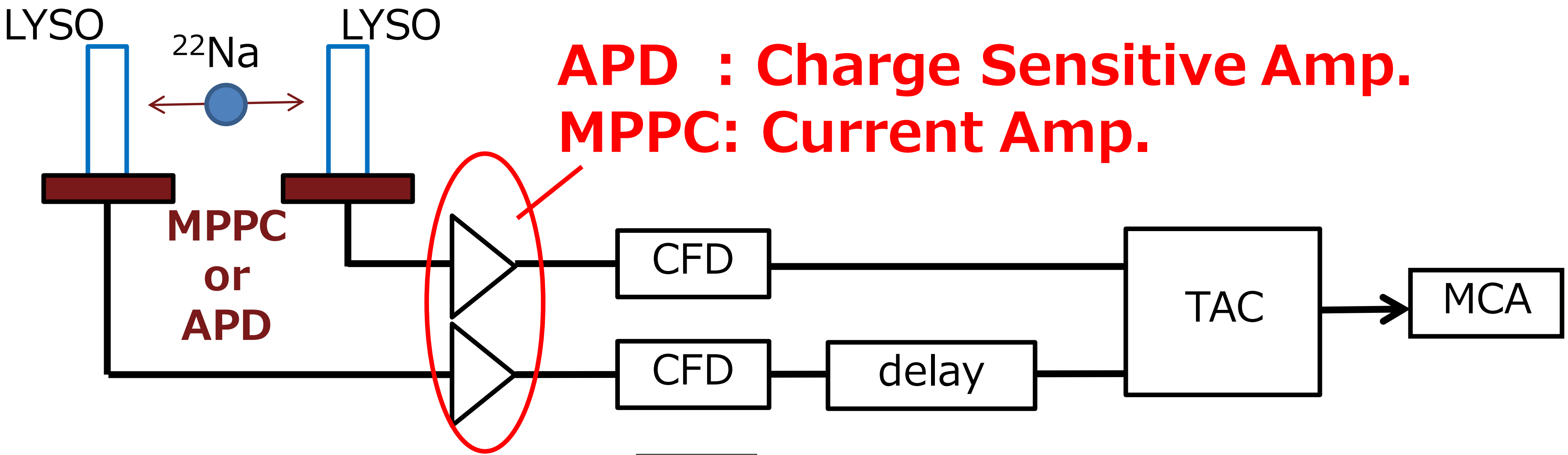
	PMT	PD	APD	MPPC
Gain	10^{5-6}	1	50-100	10^{5-6}
Q.E. (PDE)	>25	>80		>25
Volume	large	small		
Interfered by B	Yes	No		
Structure	complex	simple		
Power Consumption	high	low		

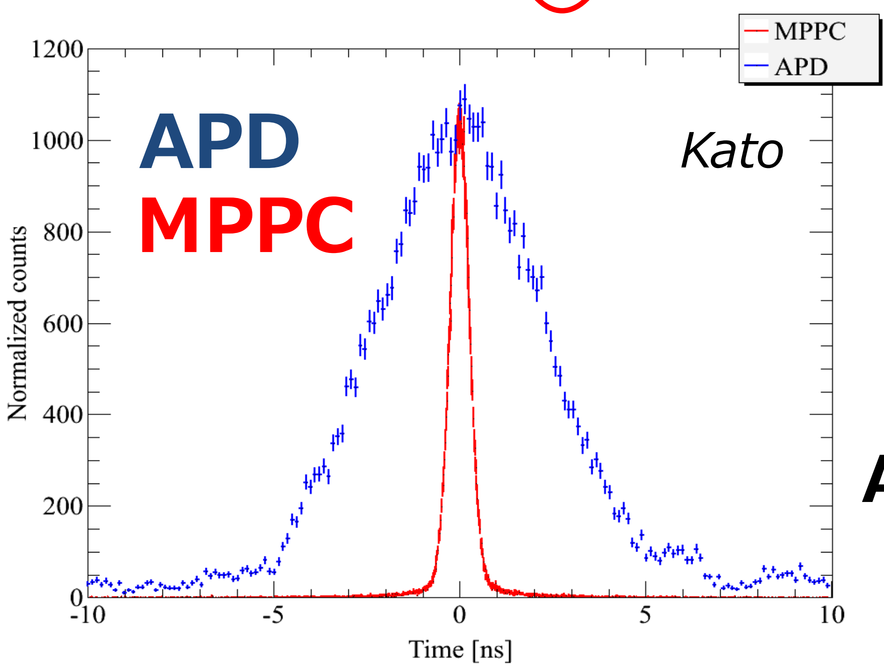
better for PET

MPPC vs APD

- higher gain, doesn't need CSAs
  - much better S/N
  - much better timing resolution (**suit for TOF-PET,** next slide)
- less photo-detection efficiency
  - worse energy resolution (*see **Poster [20] by Miura***)
- narrower dynamic range due to the limited number of pixels
  - need linearity correction

TOF Timing resolution





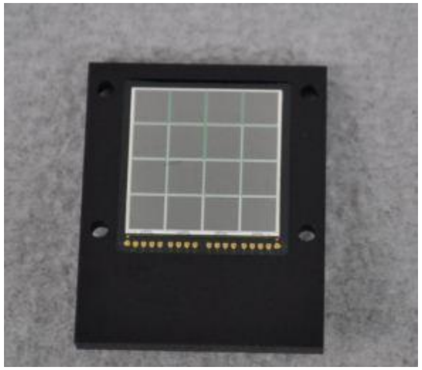
MPPC (G=9x10^5):
624ps (FWHM)

APD (G=50):
5300ps (FWHM)

APDs always require <u>CSA</u> that limits time resolution.

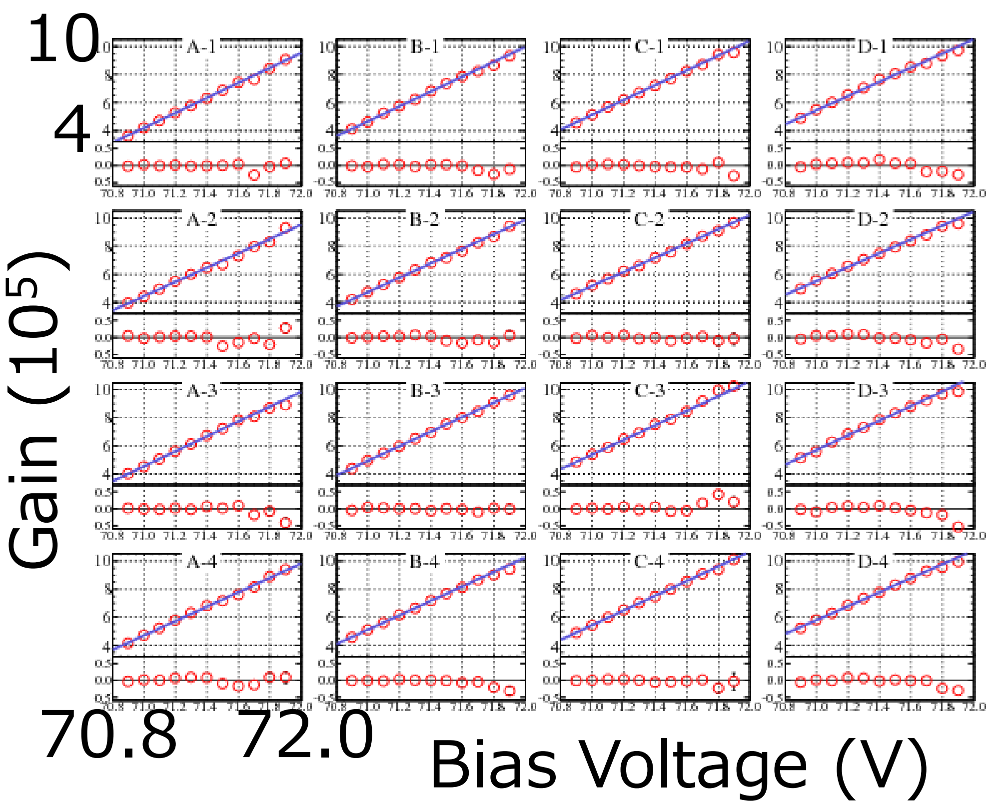
The Monolithic Array

Kato+11, NIM A

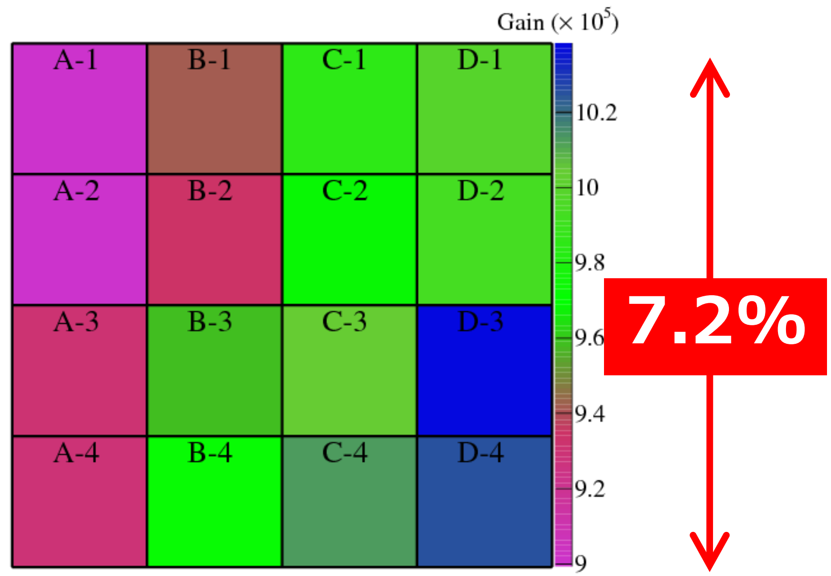


- 4x4 array with 3x3 mm2 pixel
- 0.2 mm gap
- 50 um type (3600 APDs/pixel)
- 16 anodes, common cathode
- A bit high dark count rate ~2Mcps @ 20 °C

  (this was the first prototype: ~400 kHz in recent products)



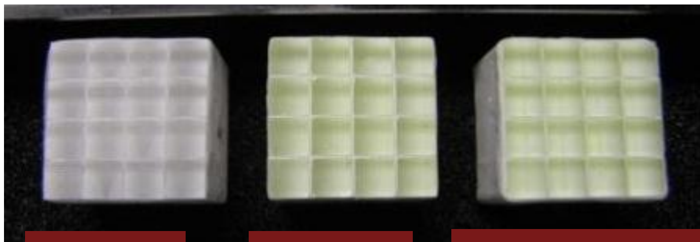
Gain map (71.9V, 0 °C)



ave. gain = 9.7x10^5

Scintillator array

LYSO	LuAG	LuAG+WLS
ρ = 7.1g/cc τ = 40ns 25 kph/MeV	ρ = 6.7g/cc τ = 20ns 20 kph/MeV	

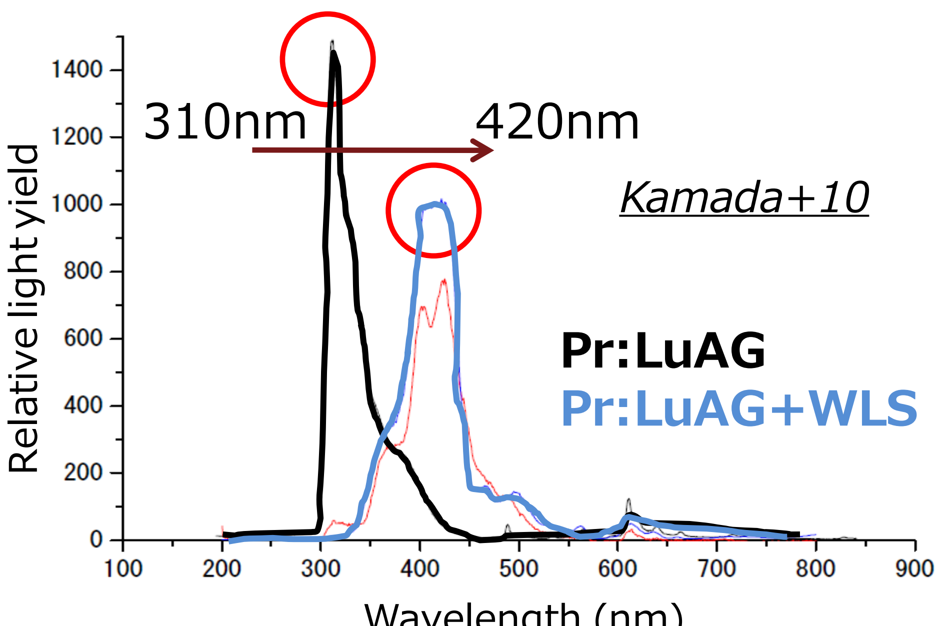


LYSO　LuAG　LuAG+WLS

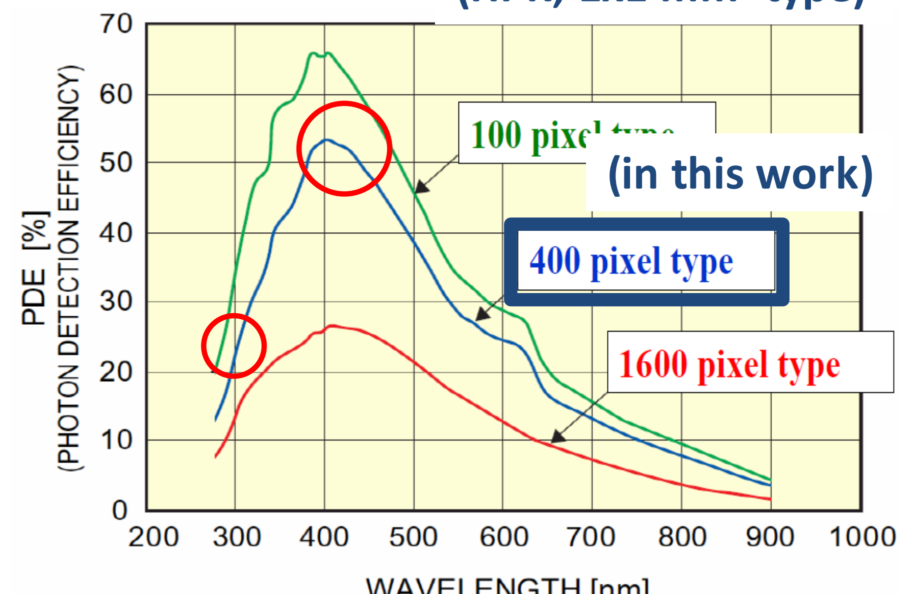
faster (better time res.)

3x3x10 mm^3 crystals
4x4 arrays
0.2 mm-thick $BaSO_4$ reflector

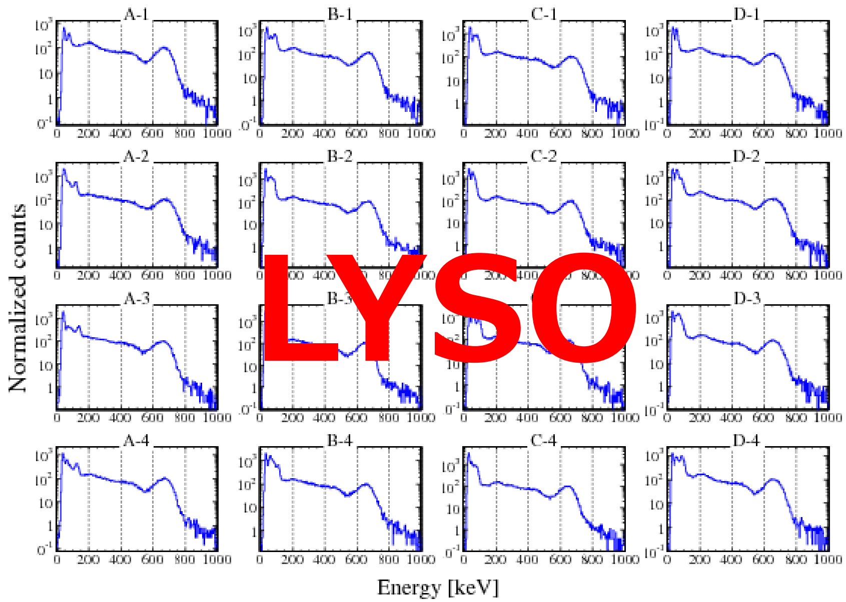
- LYSO(Ce)
- LuAG(Pr)
- LuAG(Pr) + WLS coating



(HPK; 1x1 mm^2 type)



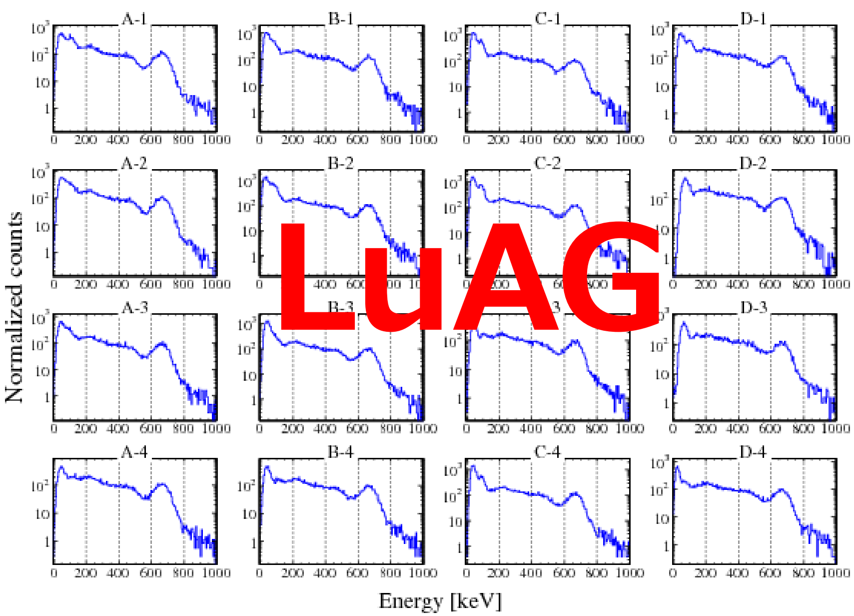
Energy spectra

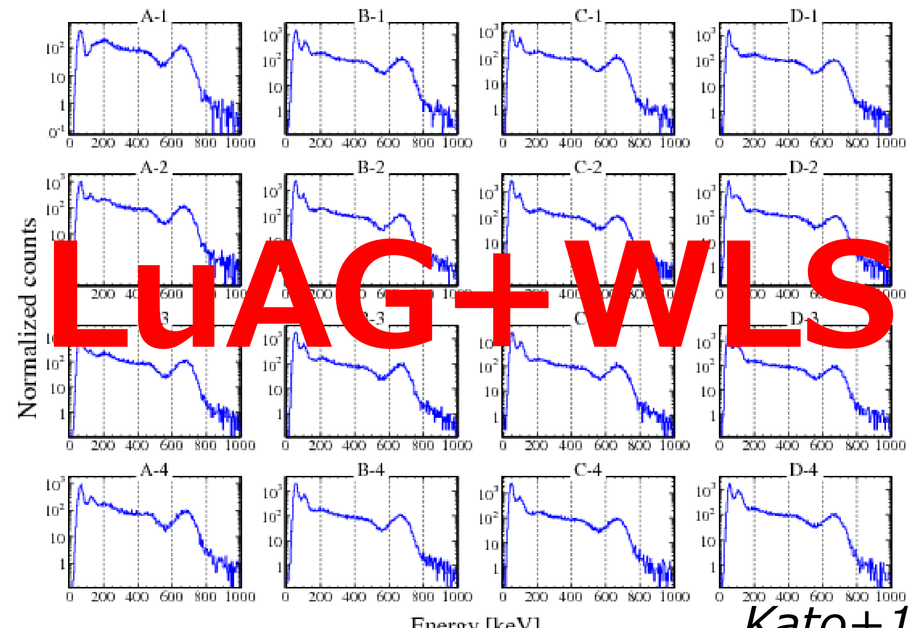


- ^{137}Cs source, 0 °C, 71.9V
- w/o current amplifier
- Linearity corrected
- Discrete readout with Q-ADC

Energy resolution for 662 keV:

LYSO	:13.8%
LuAG	:14.7%
LuAG+WLS	:14.0%

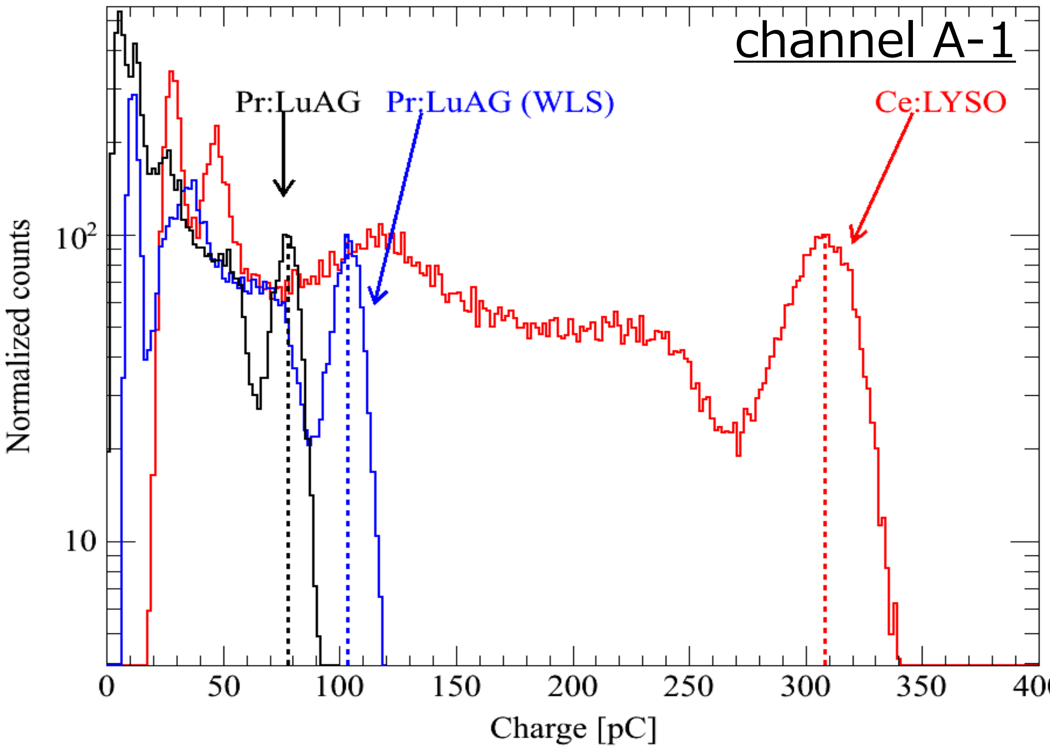




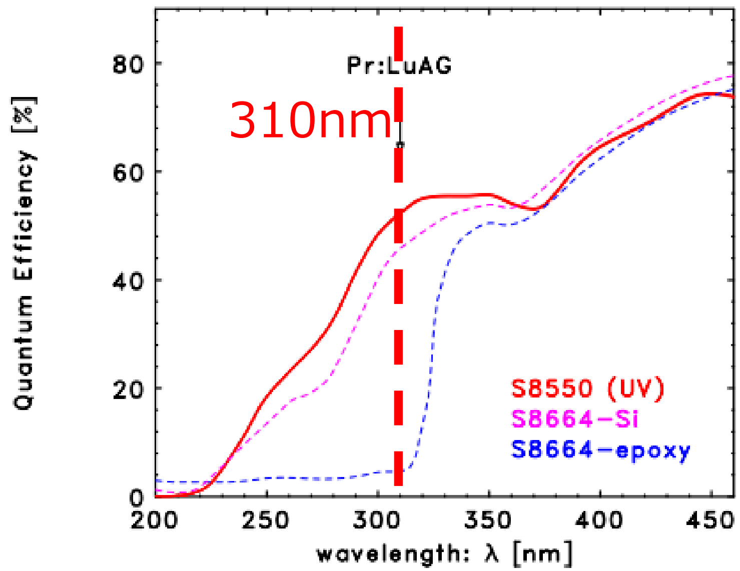
Kato+11

Charge spectra

Kato+11



Yoshino+11

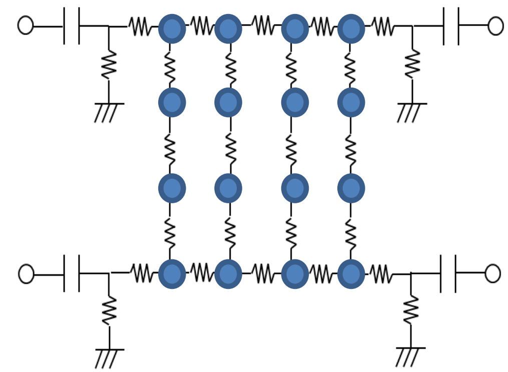


Q.E. of UV-enhanced APD

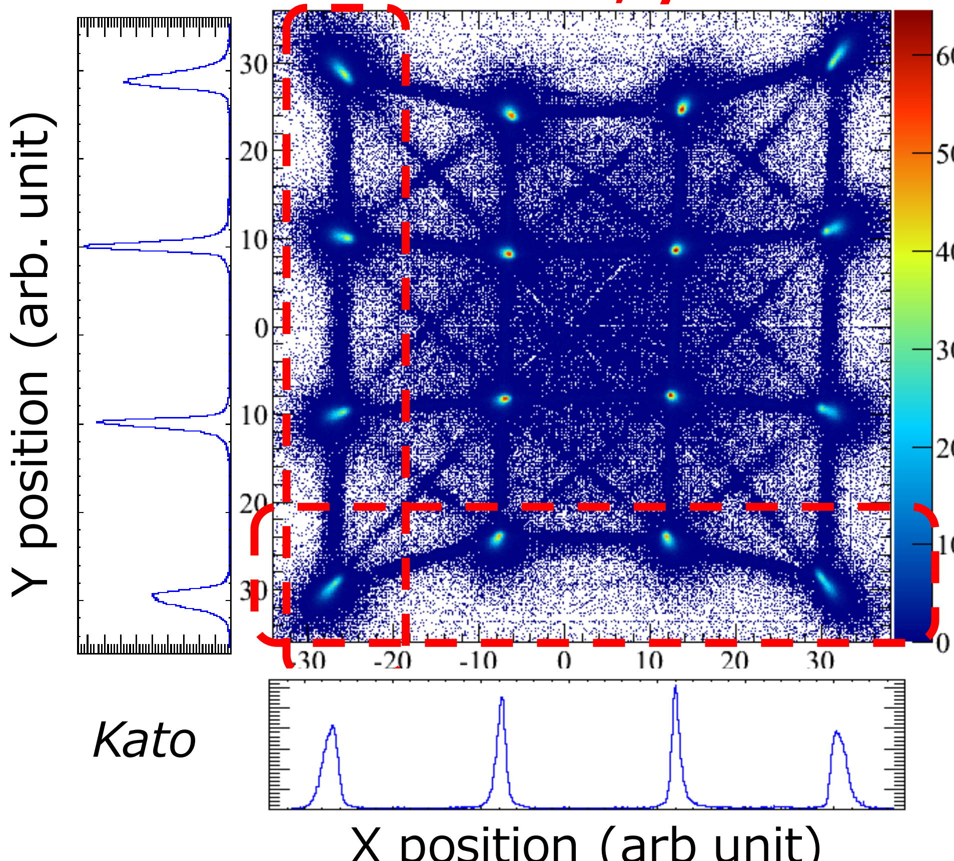
- WLS enhanced the light yields detected by ~30%
- Still much less than LYSO
- Yet we prefer LuAG for better timing resolution
- "UV-enhanced MPPC" could be a solution

Charge division readout

- Can reduce the number of read out
- Often applied for MAPMT
- 0 °C, 71.9V, LYSO array, ^{137}Cs
- Interaction positions are nicely resolved
- Spectra from each pixel extracted

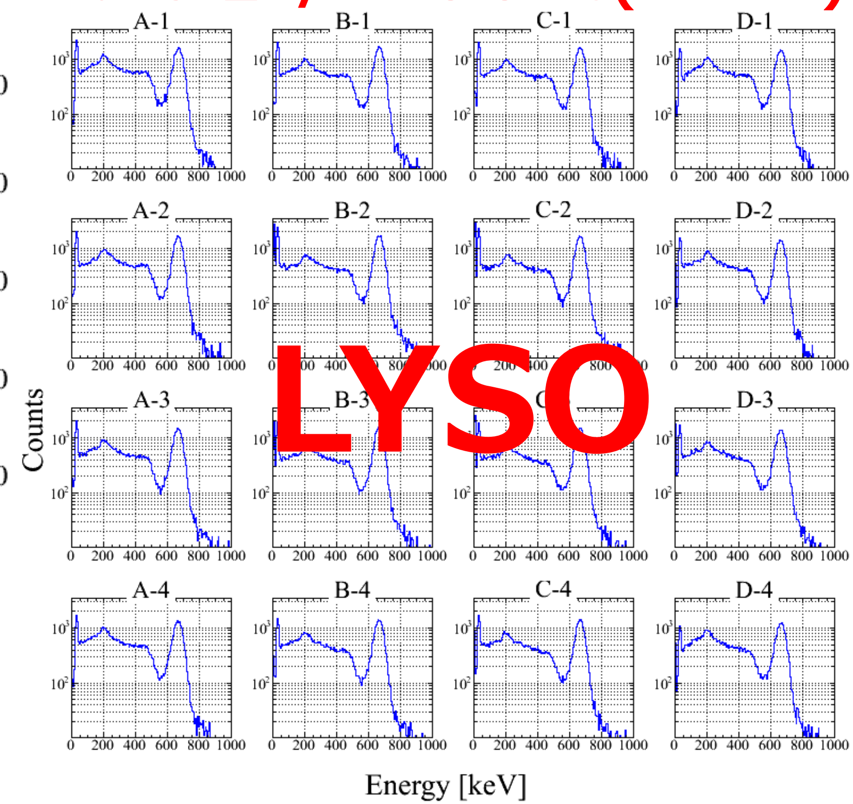


ave. FHWM ~ x:0.274, y:0.263 mm



Kato

ave. ΔE/E ~ 9.9 %(FWHM)

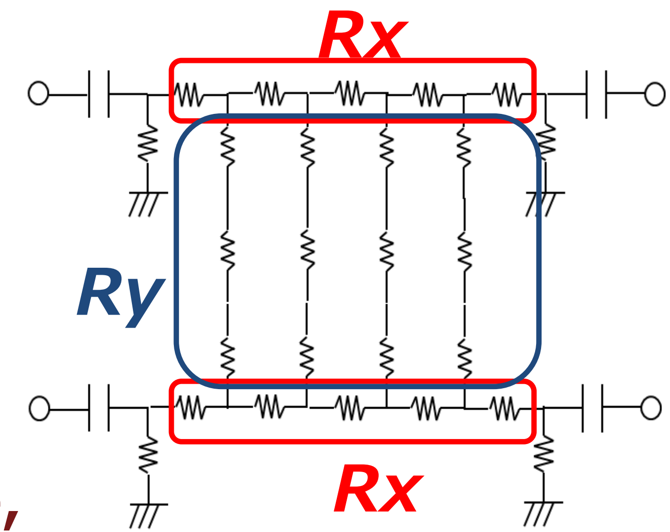


Optimization of R-chain

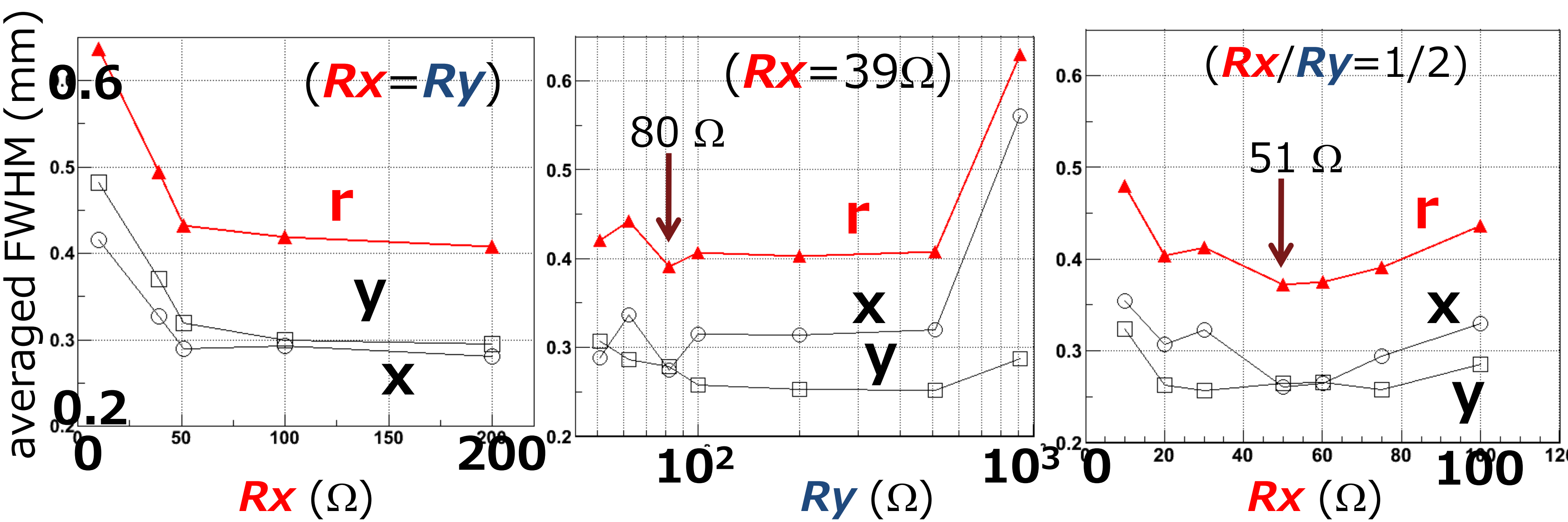
- Minimize averaged FWHM (mm) from X- and Y-projection :

$$\sigma_r = \mathrm{sqrt}(\sigma_x^2+\sigma_y^2)$$

- Too many degrees of freedom
- Just tried 3 criteria with ***Rx*** and ***Ry***



(Rx, Ry)= (51Ω, 100Ω) is the best here, but there could be better ones…



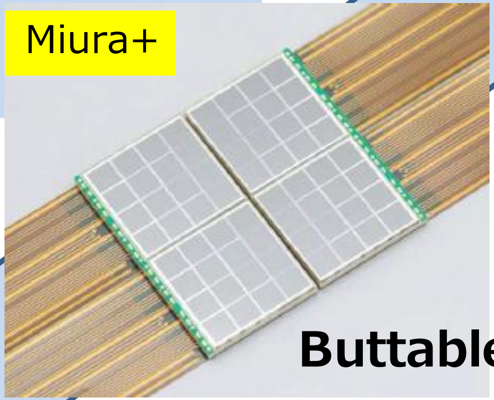
Our efforts

MPPCs development

PET application

TOF
dedicated "fast" LSI
Matsuda+11 (in prep)

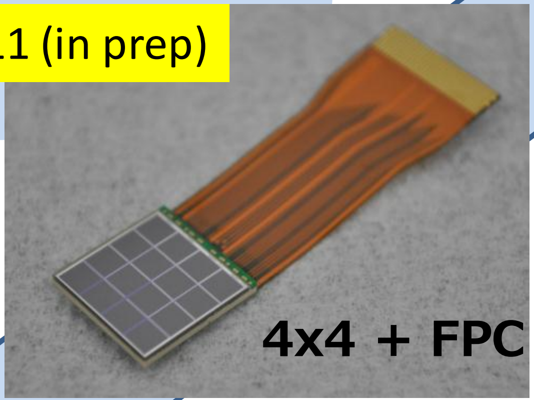
DOI
Miura+



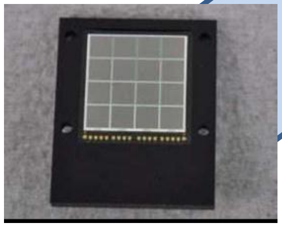
Buttable 8x8

Better pos. res.
Sub-mm LYSO array
Kato+11 (in prep)

signal precision
Waveform-DAQ



4x4 + FPC

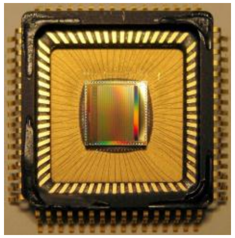


Gamma-ray measurement

BG surpression
Phoswitch counter
Miura+
Waveform-DAQ

Low threshold
Coincidence technique
Poster [20] by Miura

Waveform acquisition



(S. Ritt+)

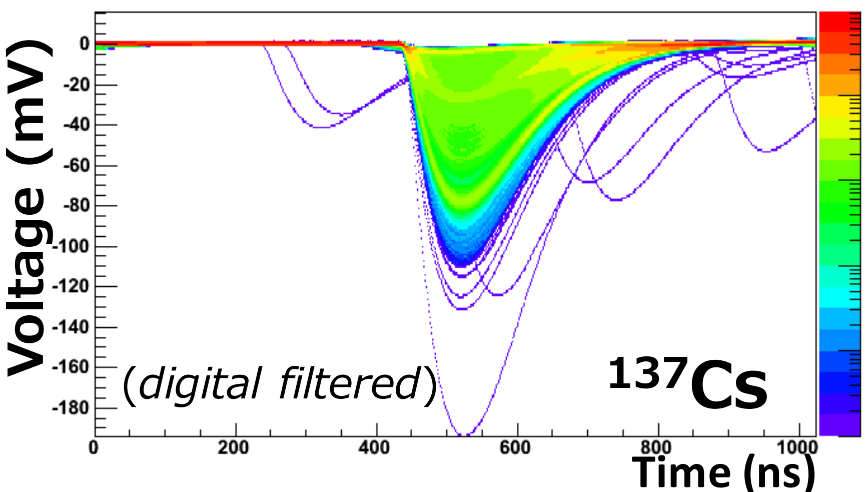
- Domino Ring Sampler 4 : Fast analog memory LSI
- developed for particle experiments (MEG, MAGIC,..)
  - Low cost, low power : 140 mW/8ch
  - fast sampling : Max 5 GHz, 1 V/12 bit

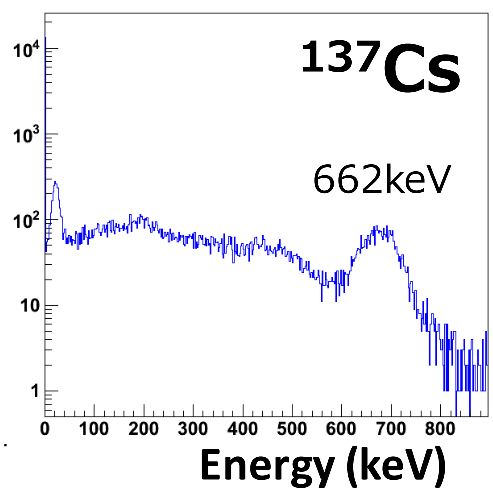
Applicable to (DOI-)PET !

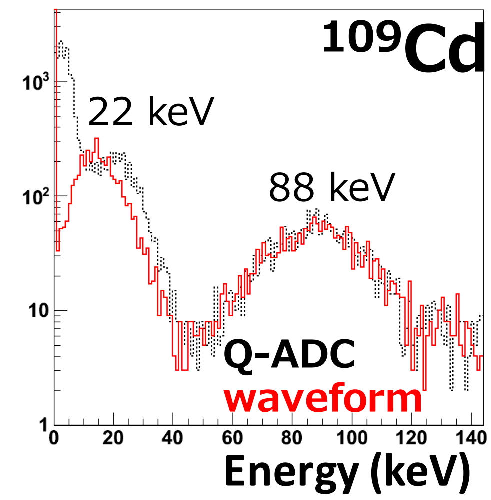
- Suit for large number of channels
- Digital filtering & noise reduction
- Capable of pulse shape discrimination
- etc··· lots of potential

Demonstration

- 3x3mm^2 MPPC + LYSO
- w/ current amp.
- 20 ^{o}C, G=7.5e5
- **Spectra obtained**
- **Noise level reduced**







Summary

- MPPC is a promising photosensor, especially for TOF-PET scanner
- We developed a monolithic 4x4 MPPC array to be applied for PET
- We showed the performance of the array as a gamma-ray detector
- LYSO(Ce) is better than LuAG(Pr) at this moment, even with the wavelength shifter
- We also demonstrated the charge division readout which works well.
- Lots of wonderful results will be published soon !