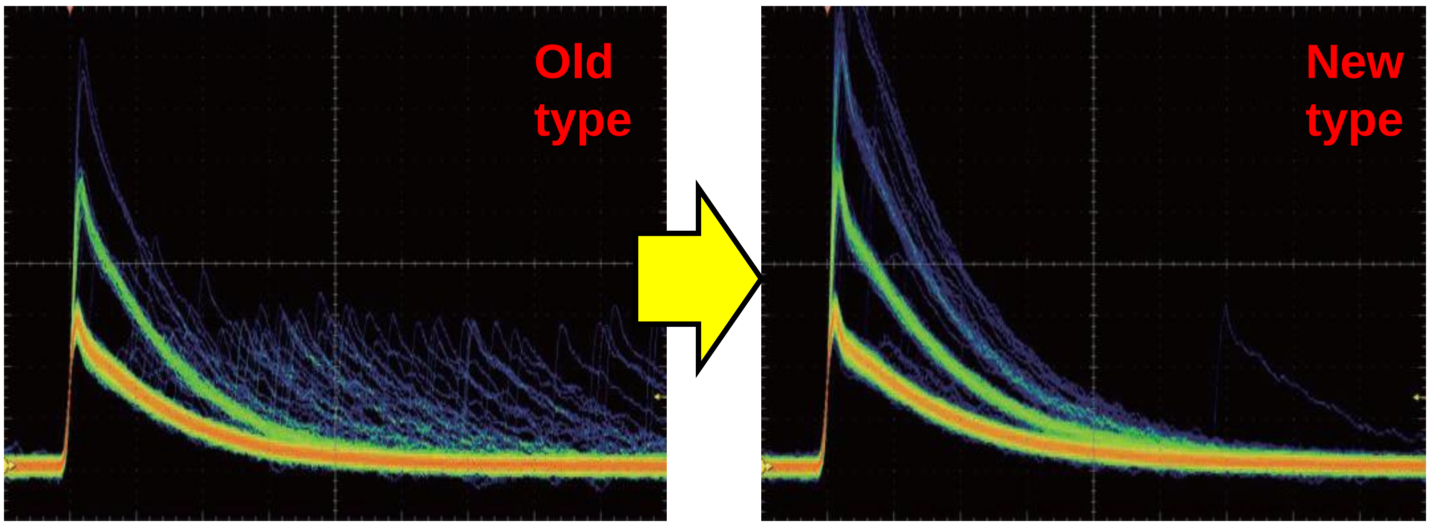
2013. Sep. 5 @HSTD9

Performance of the latest MPPCs with reduced dark counts and improved photon detection efficiency



T. Tsujikawa (Waseda Univ., JPN)

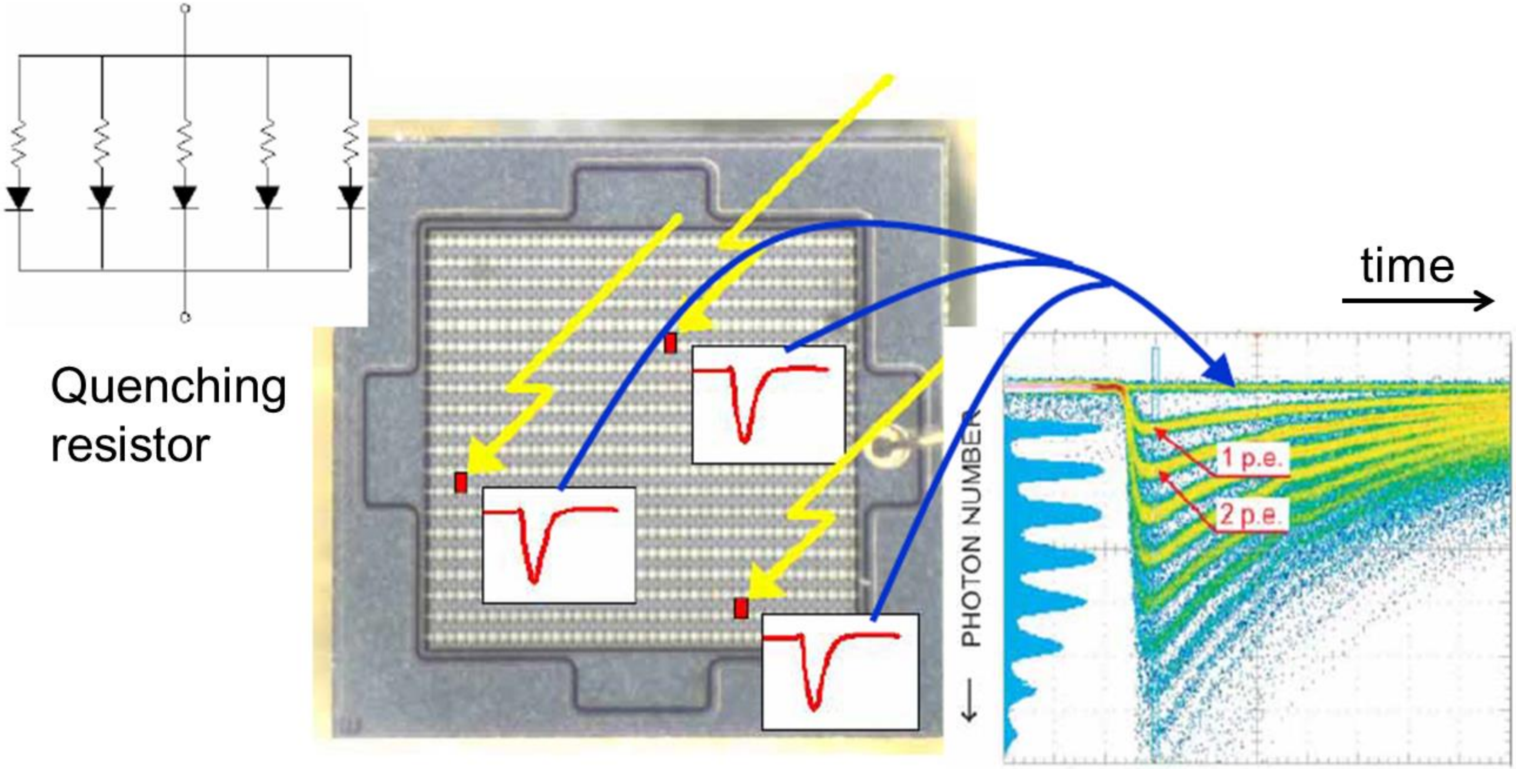
H.Funamoto, J. Kataoka, T. Fujita, T.Nishiyama, Y.Kurei (Waseda Univ.), K.Sato, K. Yamamura, S.Nakamura (Hamamatsu Photonics, K.K)

Outline

- Background
  - Light sensors in high-energy physics
  - MPPC/APD comparison
- Improved MPPC
  - Dark count, QE/PDE, linearity
  - Time response
  - Performance as a scintillation detector
- Future applications
  - Medical, Compton camera ++
- Summary

Multi-Pixel Photon Counter (MPPC)

- 2D-array of micro-APDs operated in Geiger mode
- Charges proportional to the number of fired APDs
- Low bias voltage (~ 70V)
- High gain ($10^{5\text{-}6}$)
- Insensitive to B-field ➡ *High-E phys, medical applications*

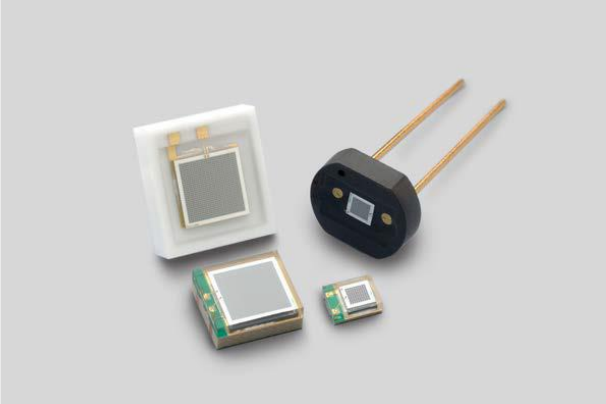


Light sensors in High-E phys.

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

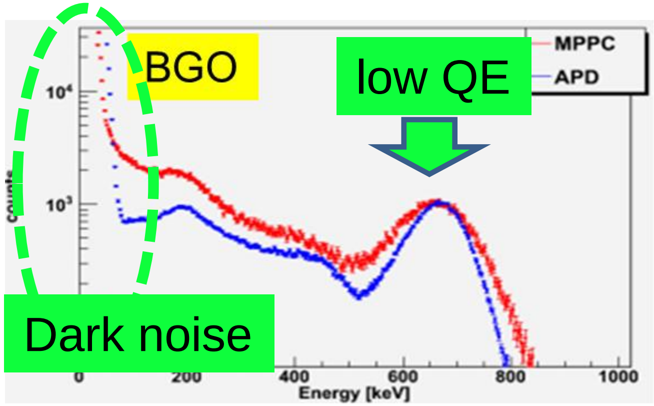
MPPC vs APD

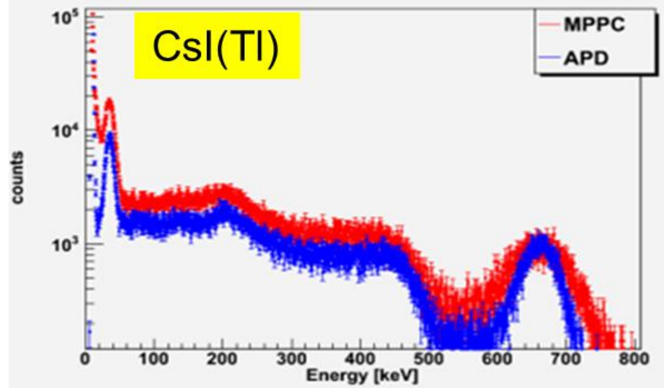
- High gain, doesn't need dedicated CSAs
  - good S/N, but dark noise …
  - good ΔT ?
- Less photon-detection efficiency (QE)
  - ΔE is generally worse
- Narrow dynamic range
  - need linearity correction

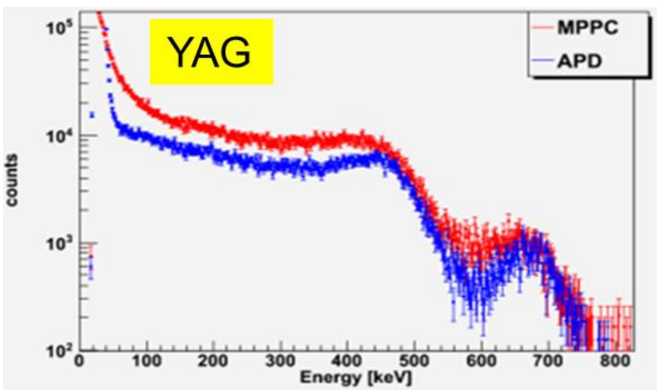


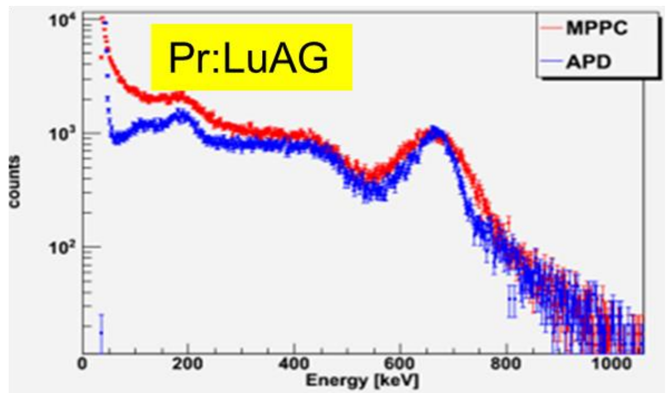
APD vs MPPC: E-resolution

Miura et al. Jinst, 2012

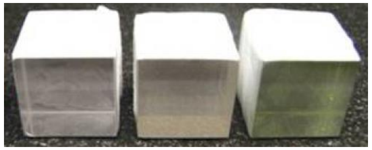




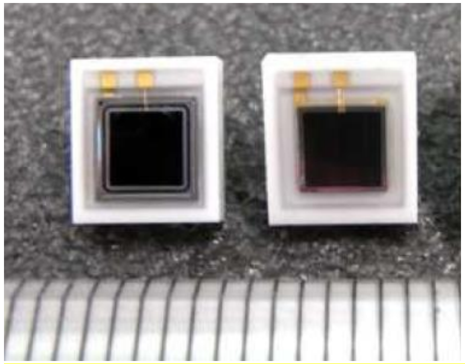




3x3x3mm crystals



+

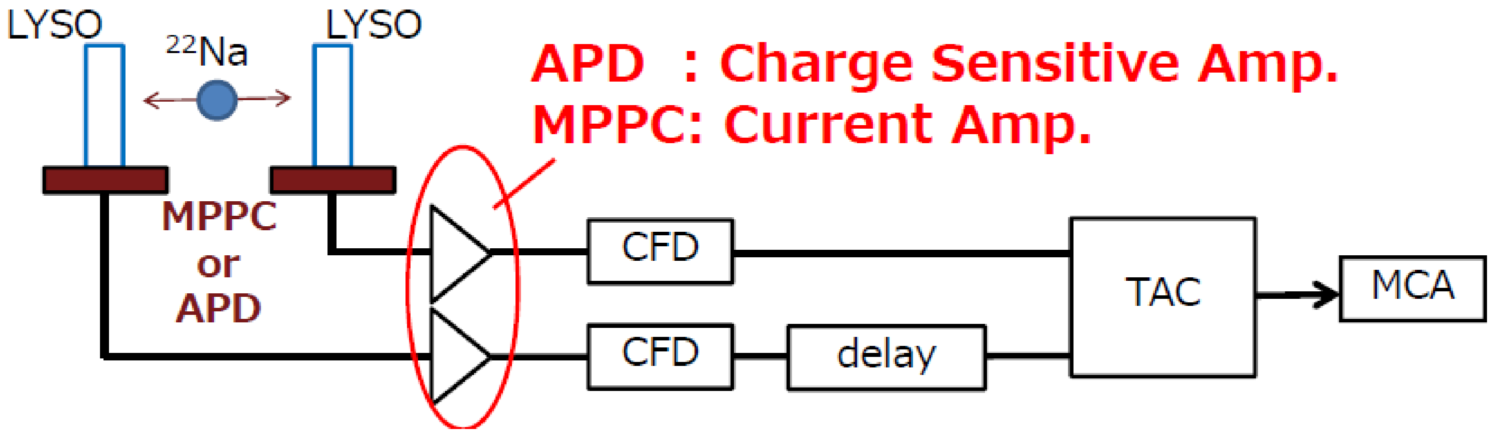


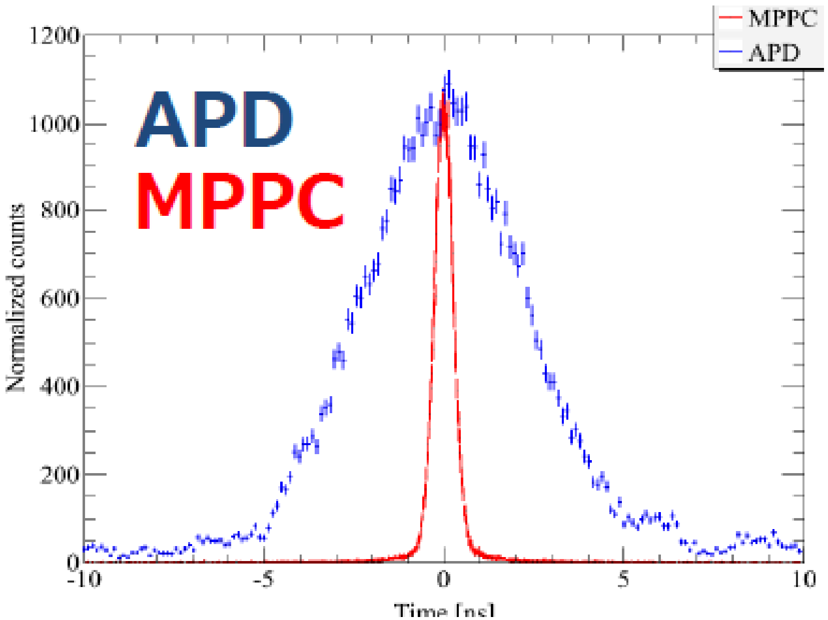
APD (3x3mm) **MPPC** (3x3mm)

- Measurements w/ APD/MPPC couple w/ small cubic scintillaotrs irradiated by 662 keV gamma-rays
- ΔE of MPPC is generally not as good as APD, due to (1) low QE and (2) contamination of dark noise…

APD vs MPPC: T-resolution

Nakamori et al. Jinst, 2012





- Back-to-back measurements of 511 keV gamma-rays

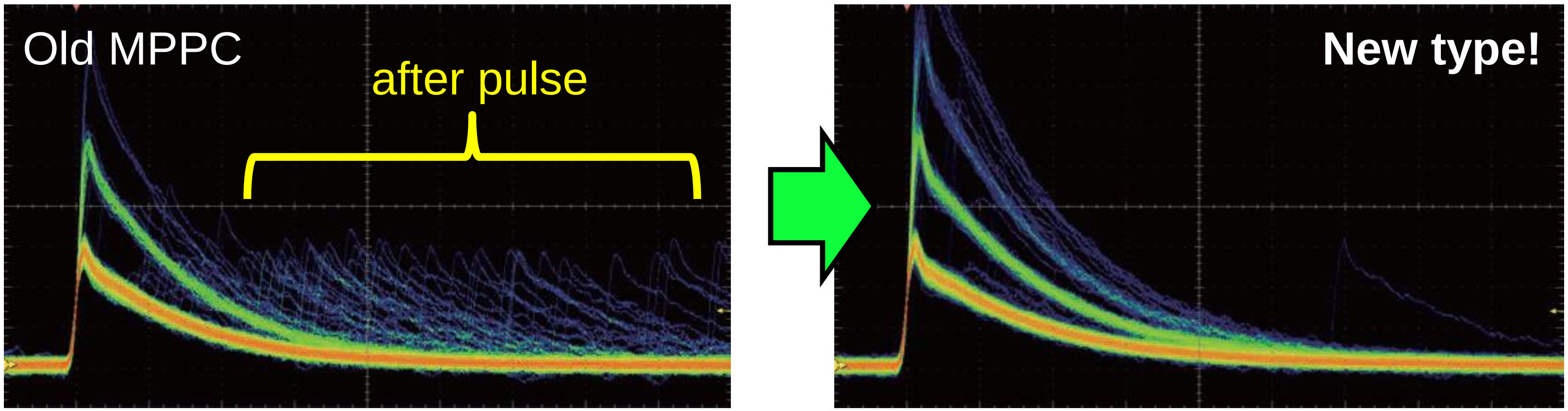
- MPPC (G = 7x10^5)
  → Δt = 624 ps (FWHM)
- APD (G = 50)
  → Δt = 5,300 ps (FWHM)

MPPC is suitable for TOF applications

New MPPC samples from HPK

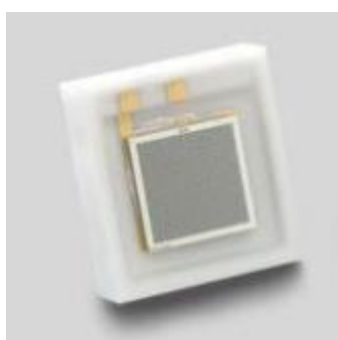
- Reduced dark, after pulse and cross-talk

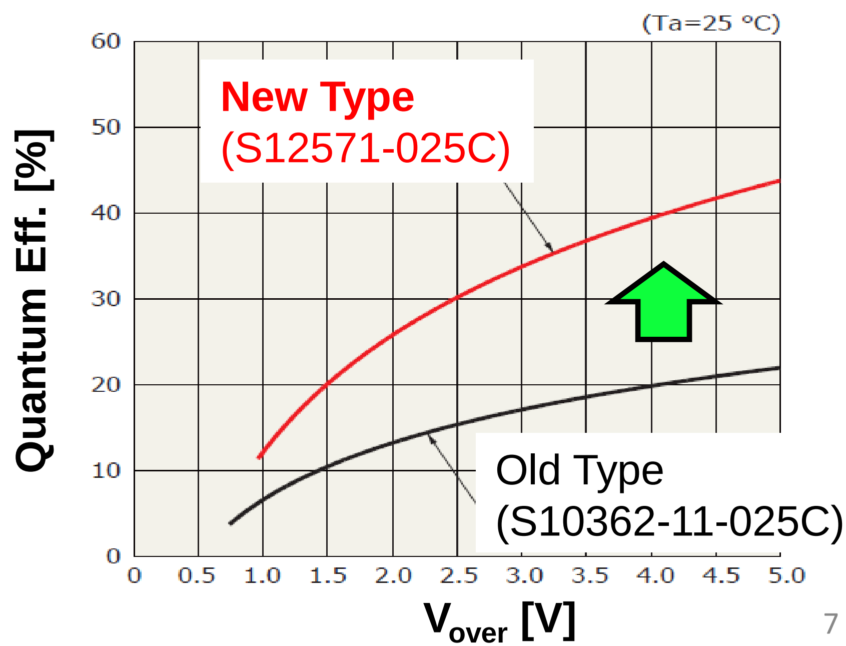
HPK 2013 catalogue



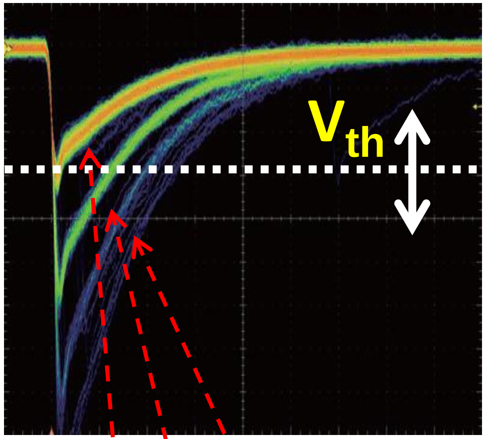
- Wide dynamic range
- Fast time response
- High QE

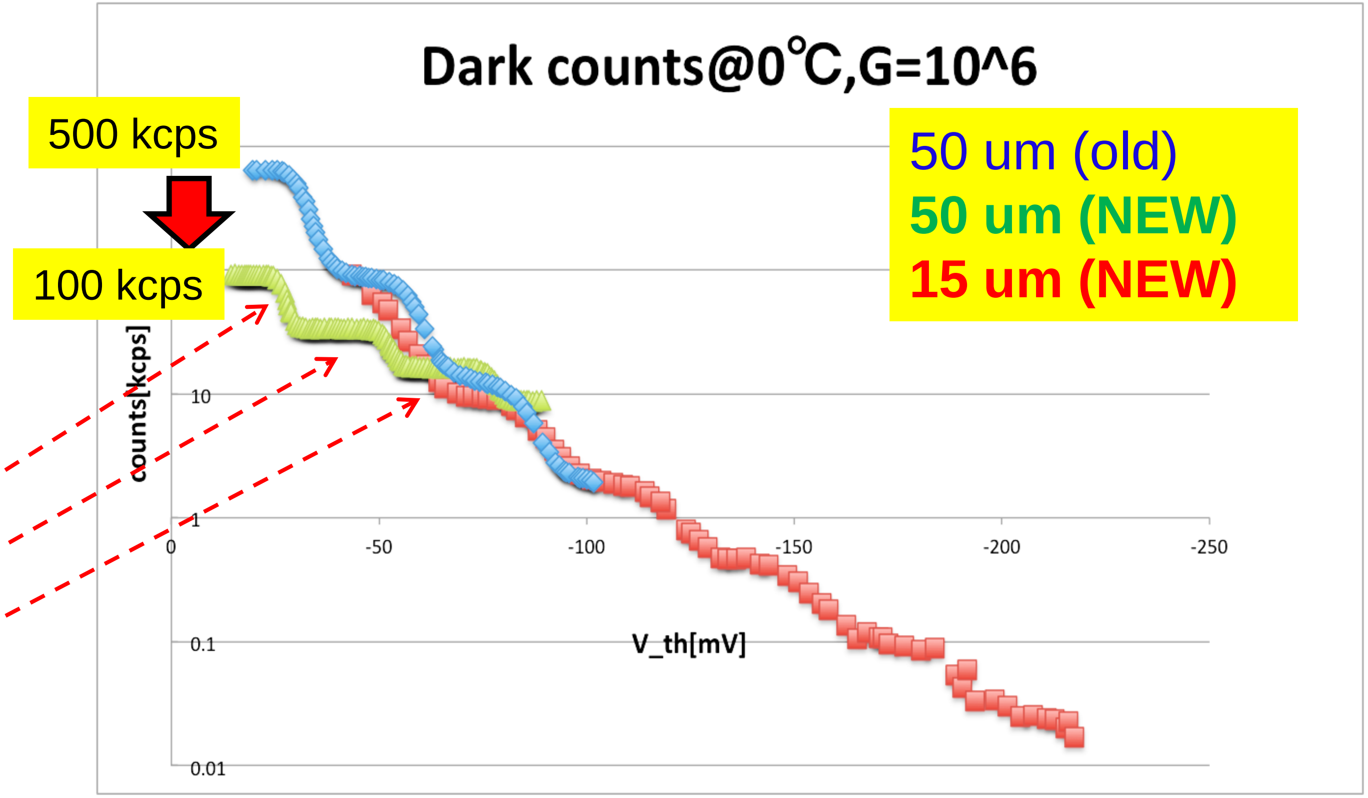
Our test sample
(ceramic 3x3 mm
15 um or 50 um)





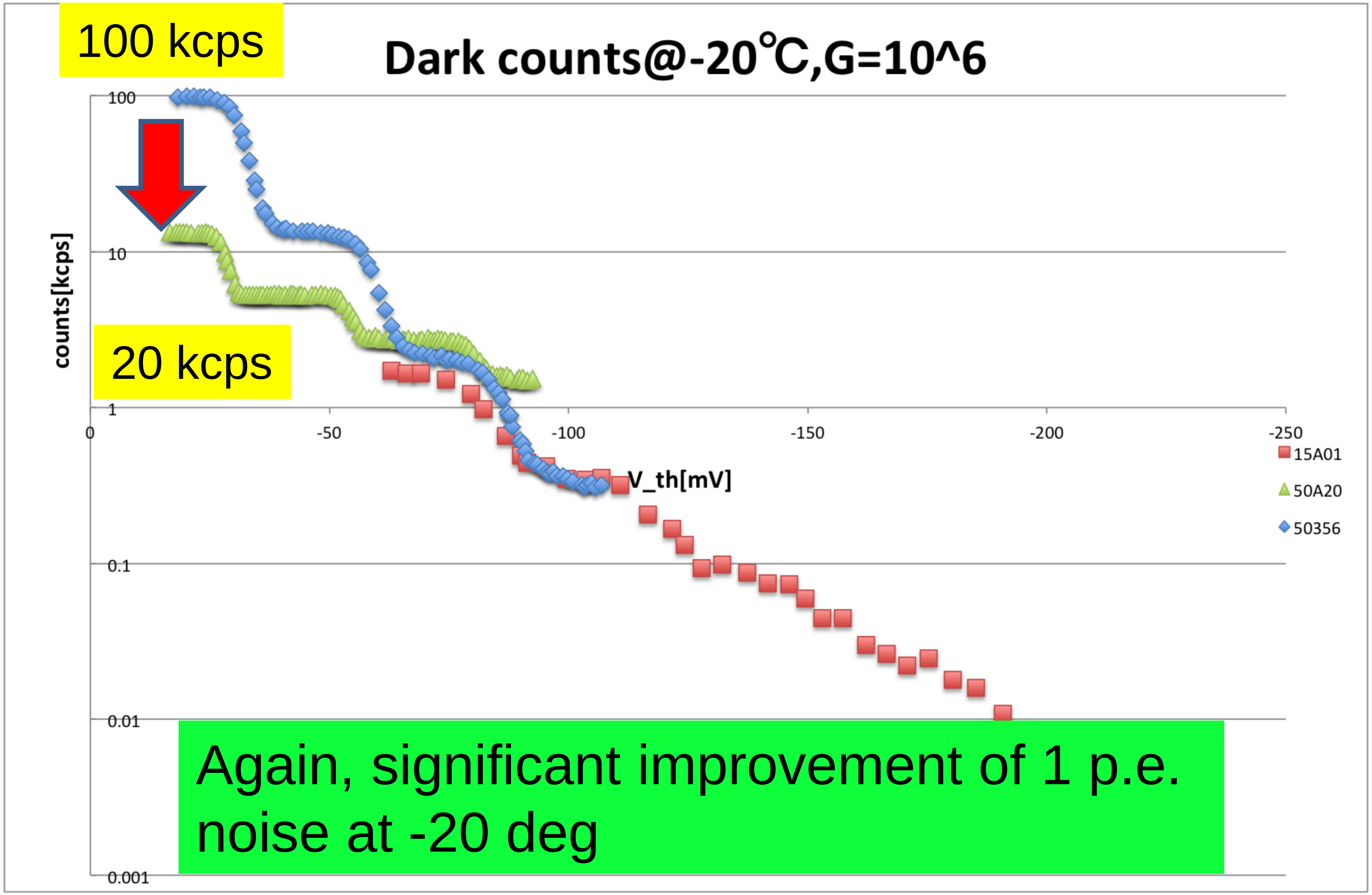
Improvement [1]: Dark counts @ 0deg



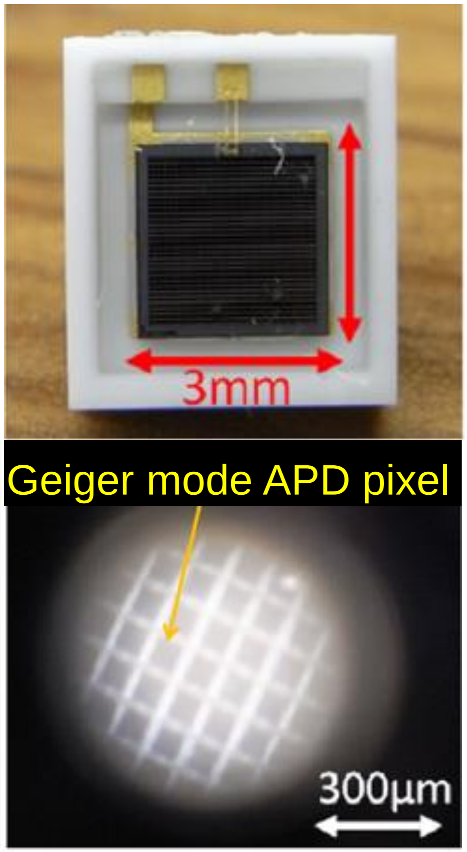


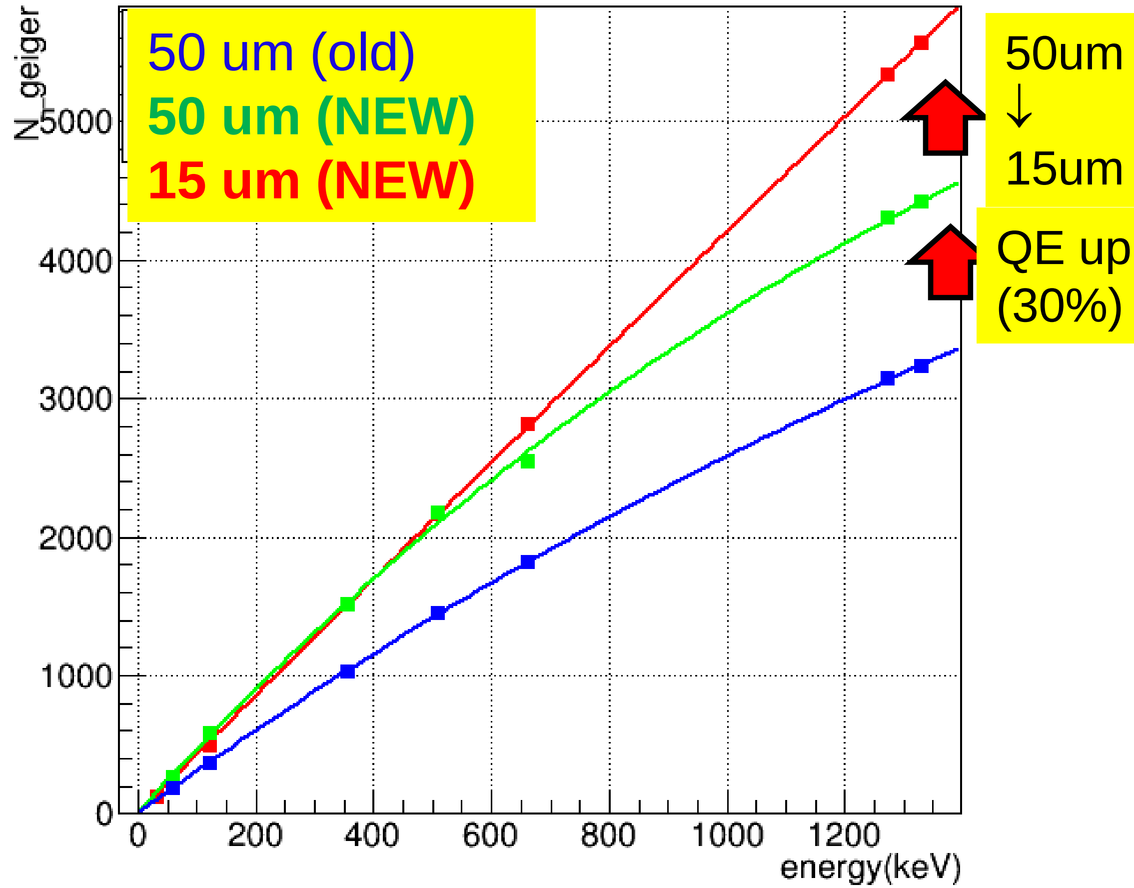
- Discontinuity of counts against threshold clearly indicates 1, 2, 3 p.e. positions of the MPPC output
- Note factor of 5 reduction of 1 p.e. dark noise (including after pulse, cross talk) as compared w/ conventional MPPCs

Improvement [2]: Dark counts @-20 deg



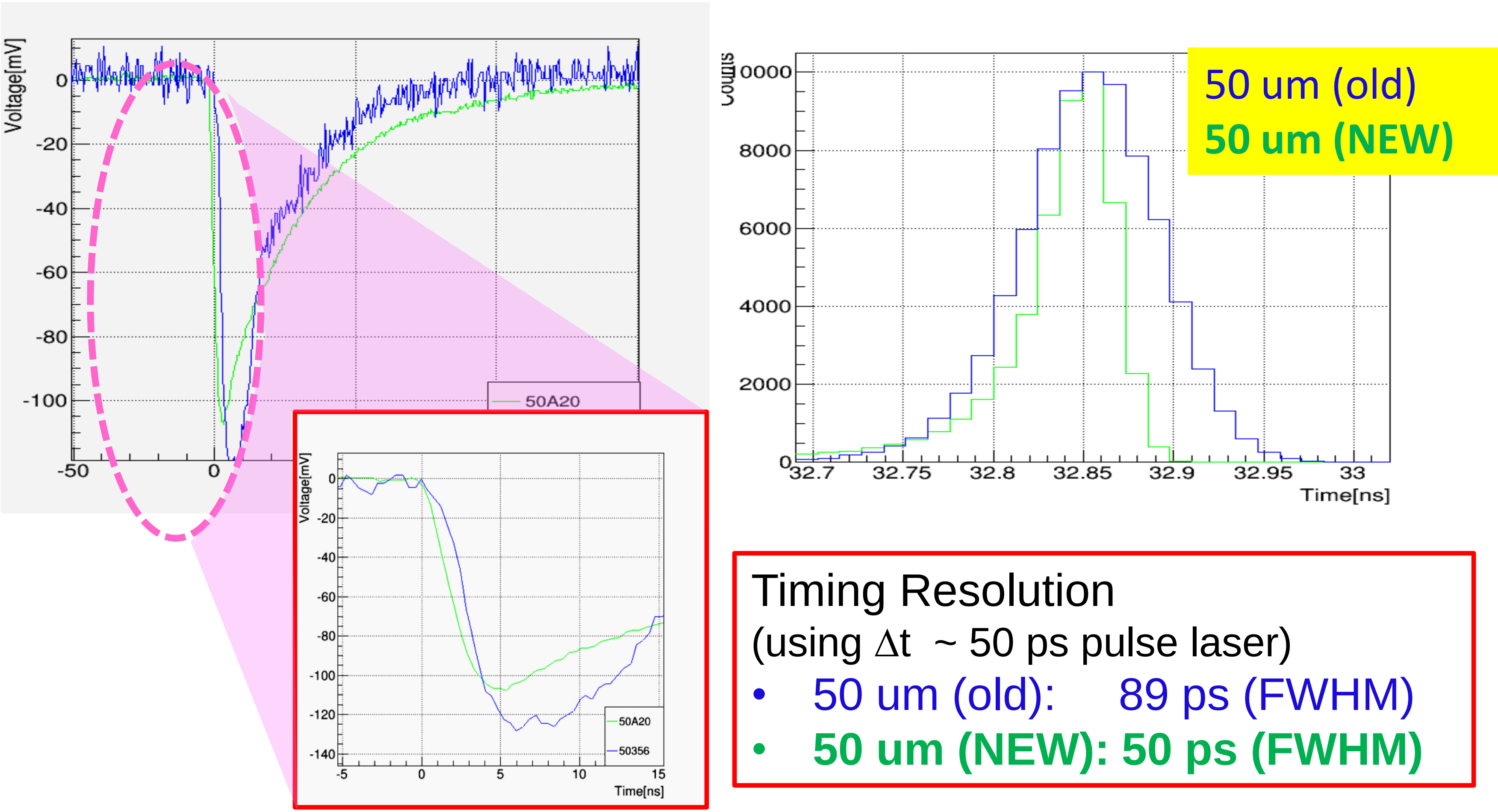
Improvement [3]: Linearity & QE





- Each MPPCs coupled with small scintillator were irradiated by various gamma ray sources to measure linearity
- Note excellent linearity of 15 um MPPC over 5,000 incident photons!

Improvement [4]: Timing Property

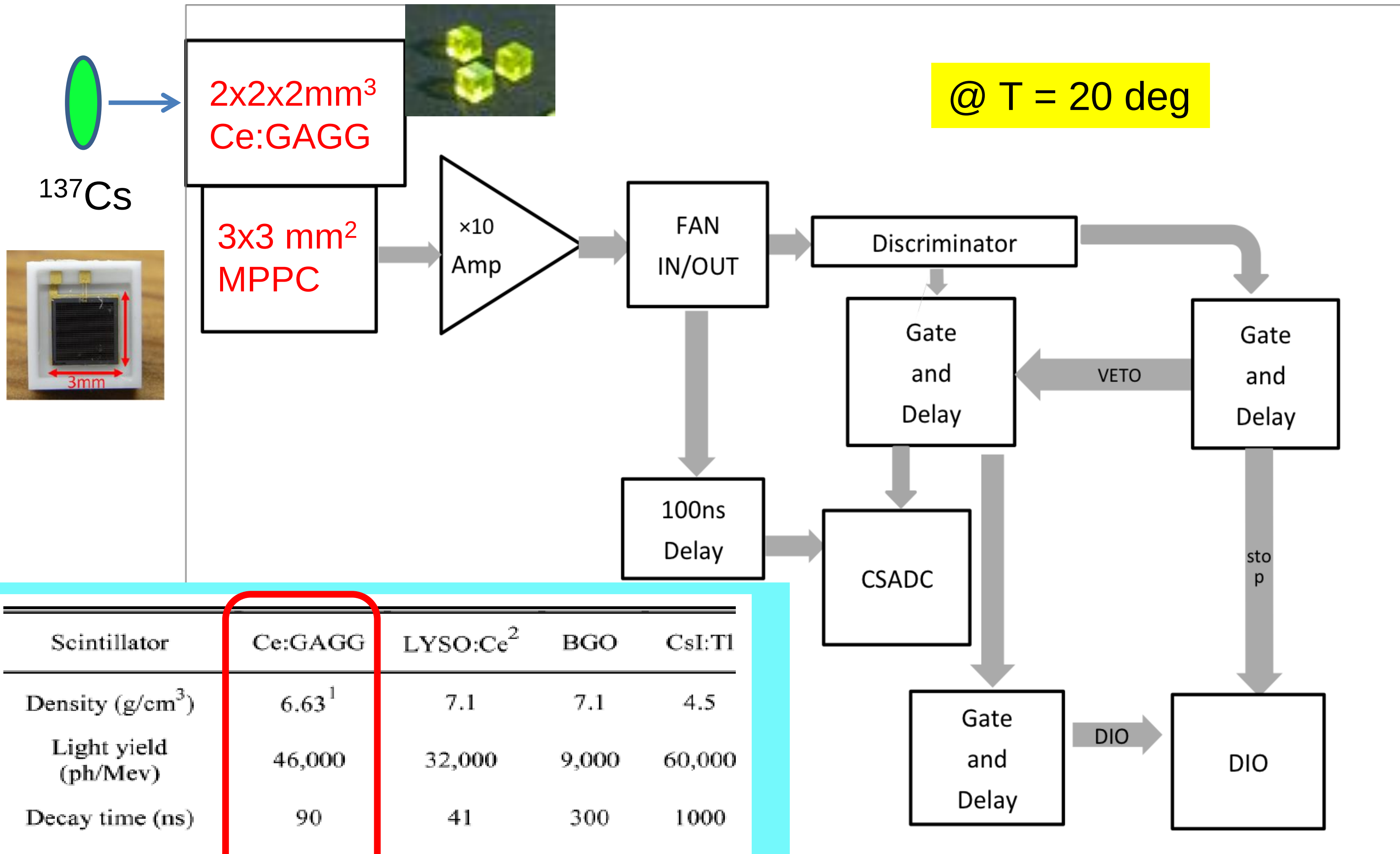


Timing Resolution
(using Δt ~ 50 ps pulse laser)

- 50 um (old): 89 ps (FWHM)
- **50 um (NEW): 50 ps (FWHM)**

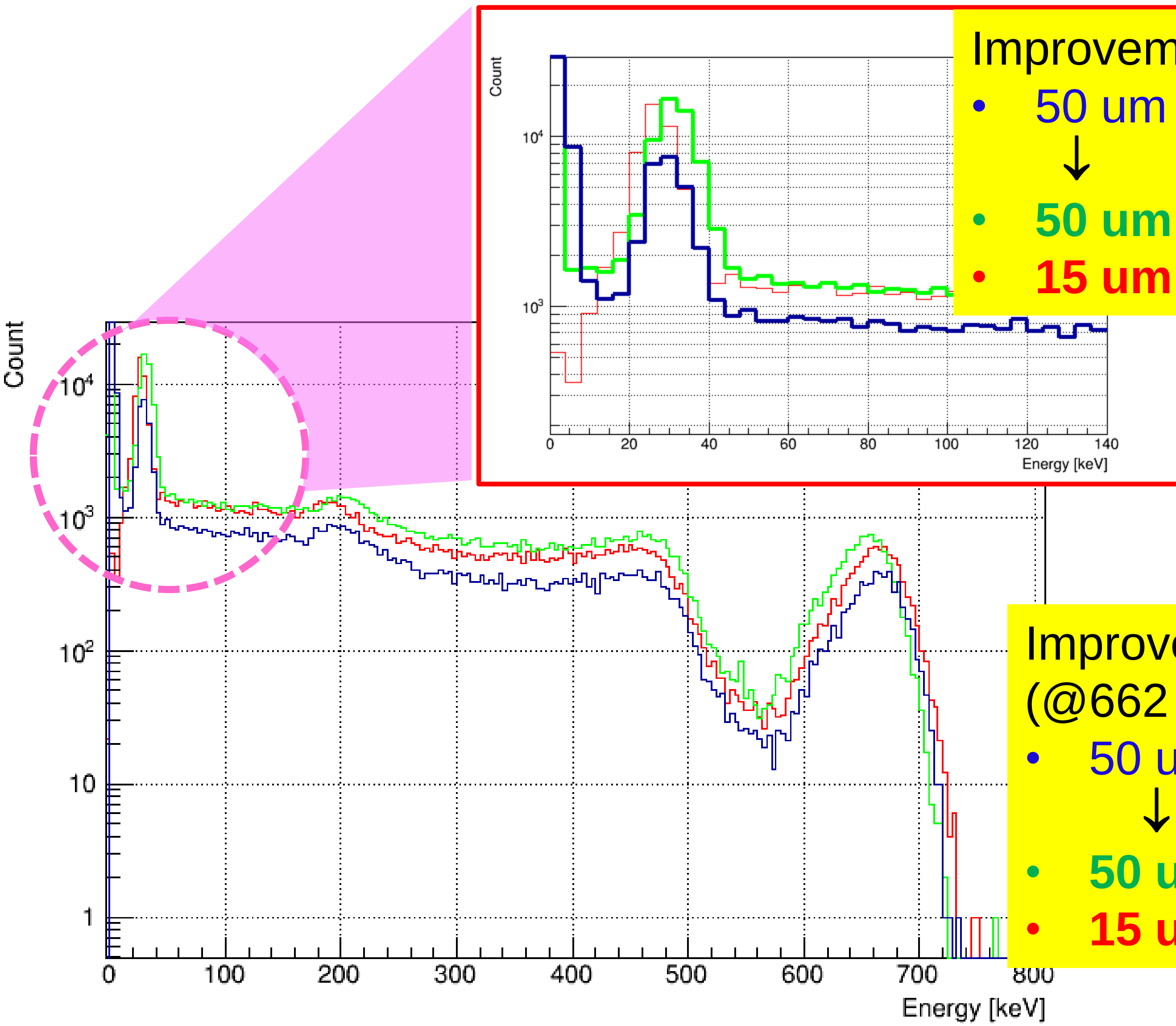
- Irradiated by high-power, pulse laser of Δt = 50 ps
- Timing response (i.e., rise time) of MPPC is improved, with sharp rise.

Performance as a Scintillation Detector (1)



Scintillator	Ce:GAGG	LYSO:Ce[2]	BGO	CsI:Tl
Density (g/cm^3)	6.63[1]	7.1	7.1	4.5
Light yield (ph/Mev)	46,000	32,000	9,000	60,000
Decay time (ns)	90	41	300	1000
Peak Emission (nm)	520	420	480	545
Energy resolution (% @ 662 keV)	4.9%	8	12	5%

Performance as a Scintillation Detector (2)



Improvement of E threshold

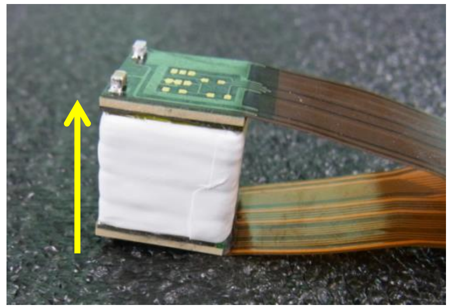
- 50 um (old) : 10 keV
  ↓
- **50 um (NEW): 4 keV**
- **15 um (NEW): <2keV !**

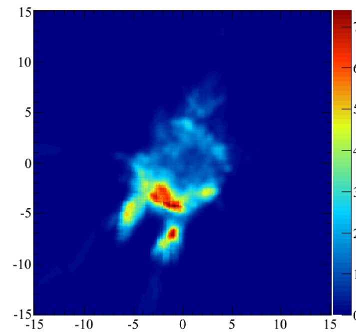
Improvement of E resolution (@662 keV, FWHM)

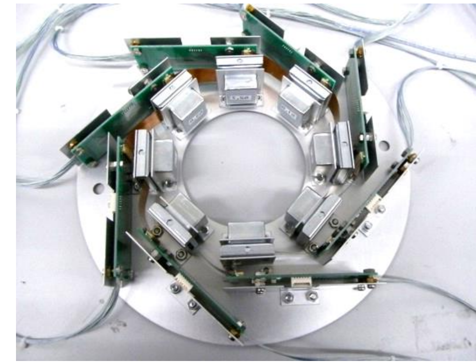
- 50 um (old) : 6.9 %
  ↓
- **50 um (NEW): 6.7 %**
- **15 um (NEW): 7.8 %**

Our Challenges w/ MPPCs!

- Next generation PET scanners





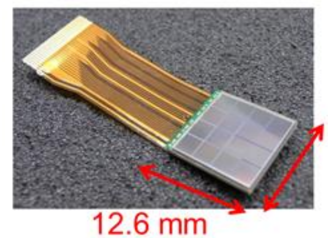


- MRI-PET
- TOF-PET
- DOI-PET

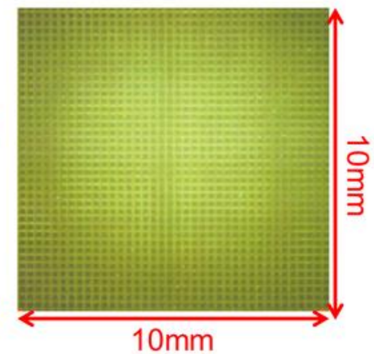
→Y.Kurei's talk this afternoon

- Fine-resolution X-ray imaging

→T.Fujita's talk this afternoon



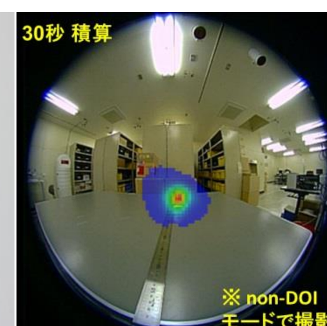
4x4 MPPC array
Ce:GAGG (0.25mm pitch)



- Handy Compton Camera

→ K.Takeuchi's talk yesterday

(see, Kataoka et al. 2013, NIM-A)



Summary

We have reported the performance of the latest Multi-Pixel Photon Counters (MPPCs; measuring 3 x 3 mm^2 in size) developed by Hamamatsu Photonics K.K

- Dark counts significantly reduced w/ improved QE (or 30% improvement of PDE)

- Linearity also improved for 15um fine-pixelized MPPC, as compared with conventional 50 um MPPCs

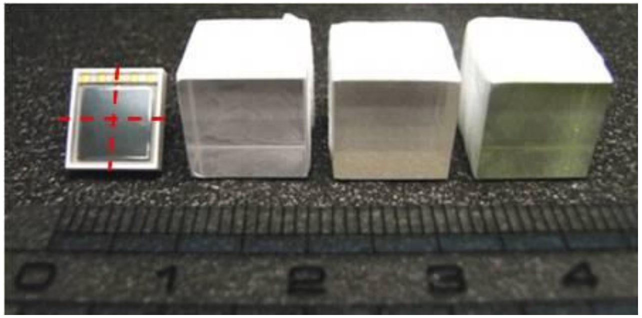
- Good E resolution of 6.7 % (FWHM) achieved for 662 keV gamma rays

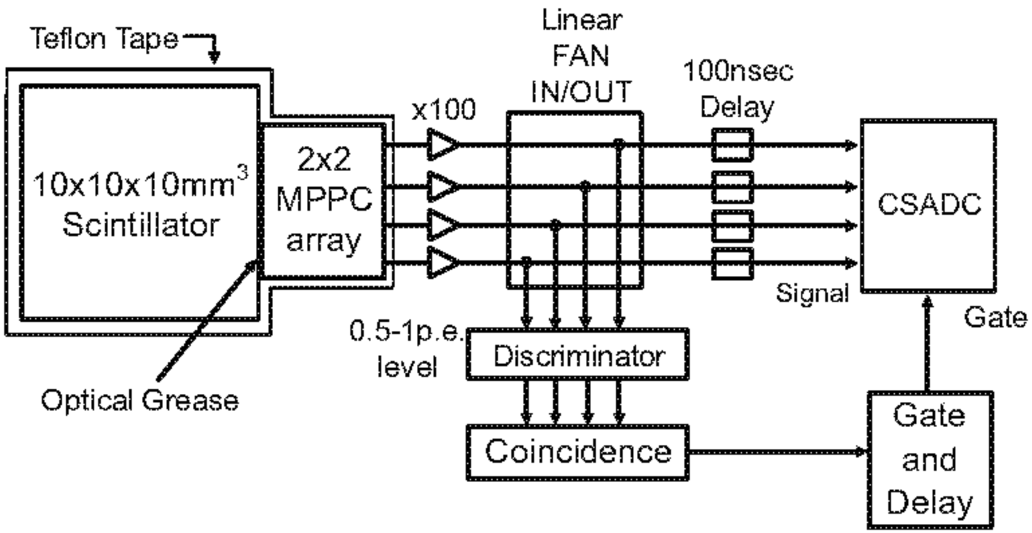
This research is partly supported by Grant in Aid for Scientific Research (S) (KAKENHI) and also by Development of Systems and Technology for Advanced Measurements and Analysis by JST (Japan Science and Technology Agency)

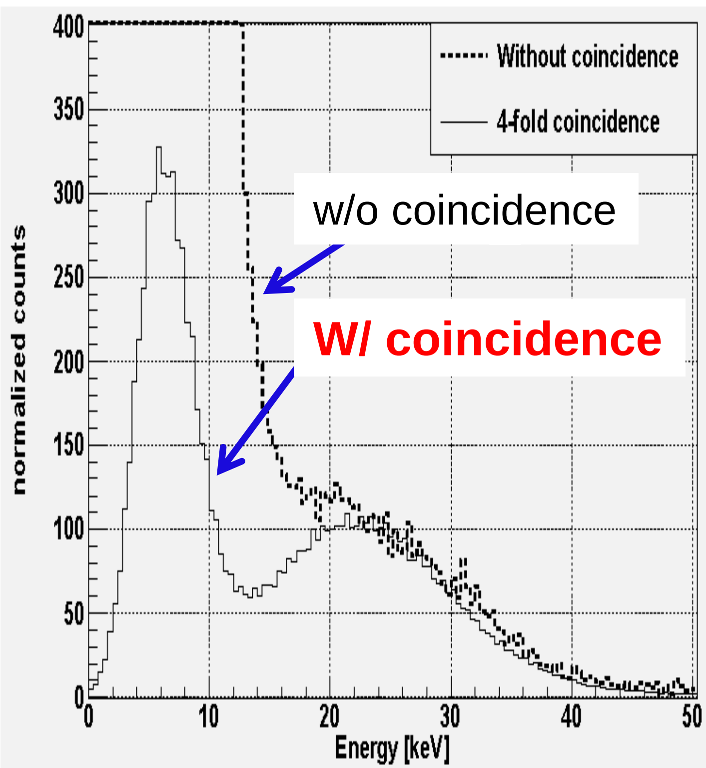
Appendix

How to reduce dark noise?

Miura et al. JSPS, 2011

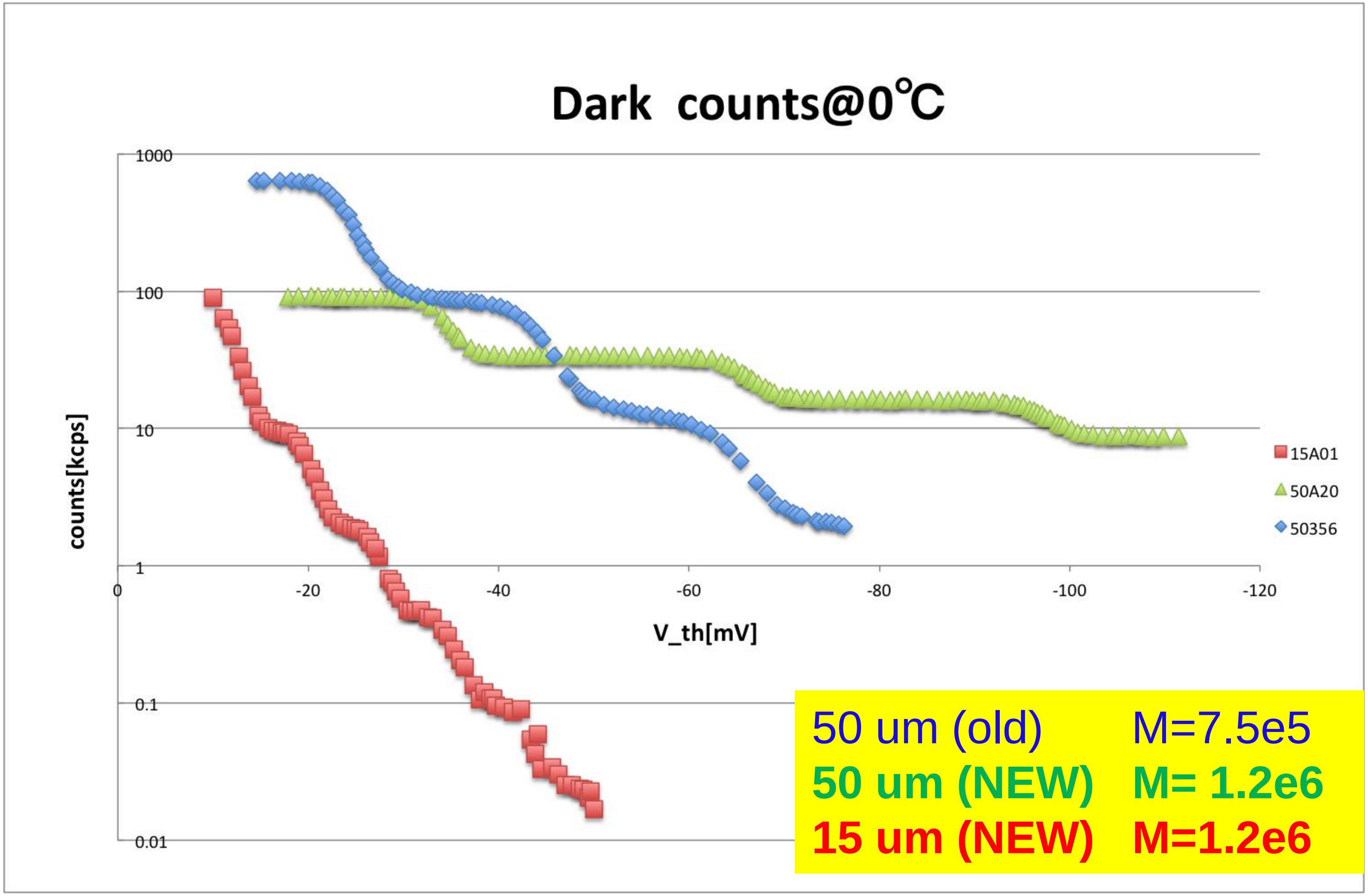






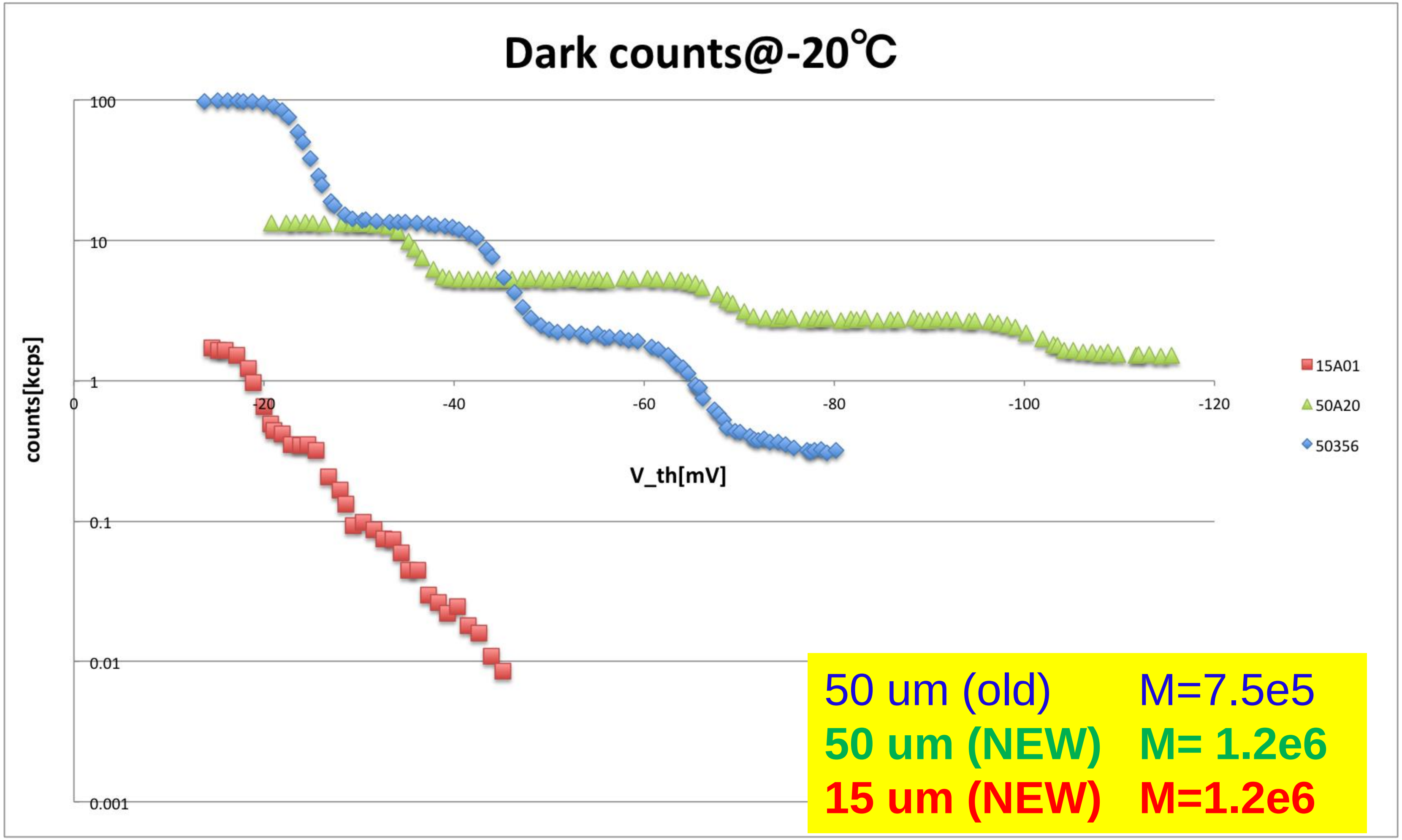
- Use 2x2 MPPC array, rather than single MPPC pixel as a read-out sensor
- By taking 4-folded coincidence of 99.8% of dark counts rejected, achieving E_{thr} of 10 keV for GSO
- But of course, such technique is redundant and increasing read-out channel

Dark Count (raw data @ 0deg)

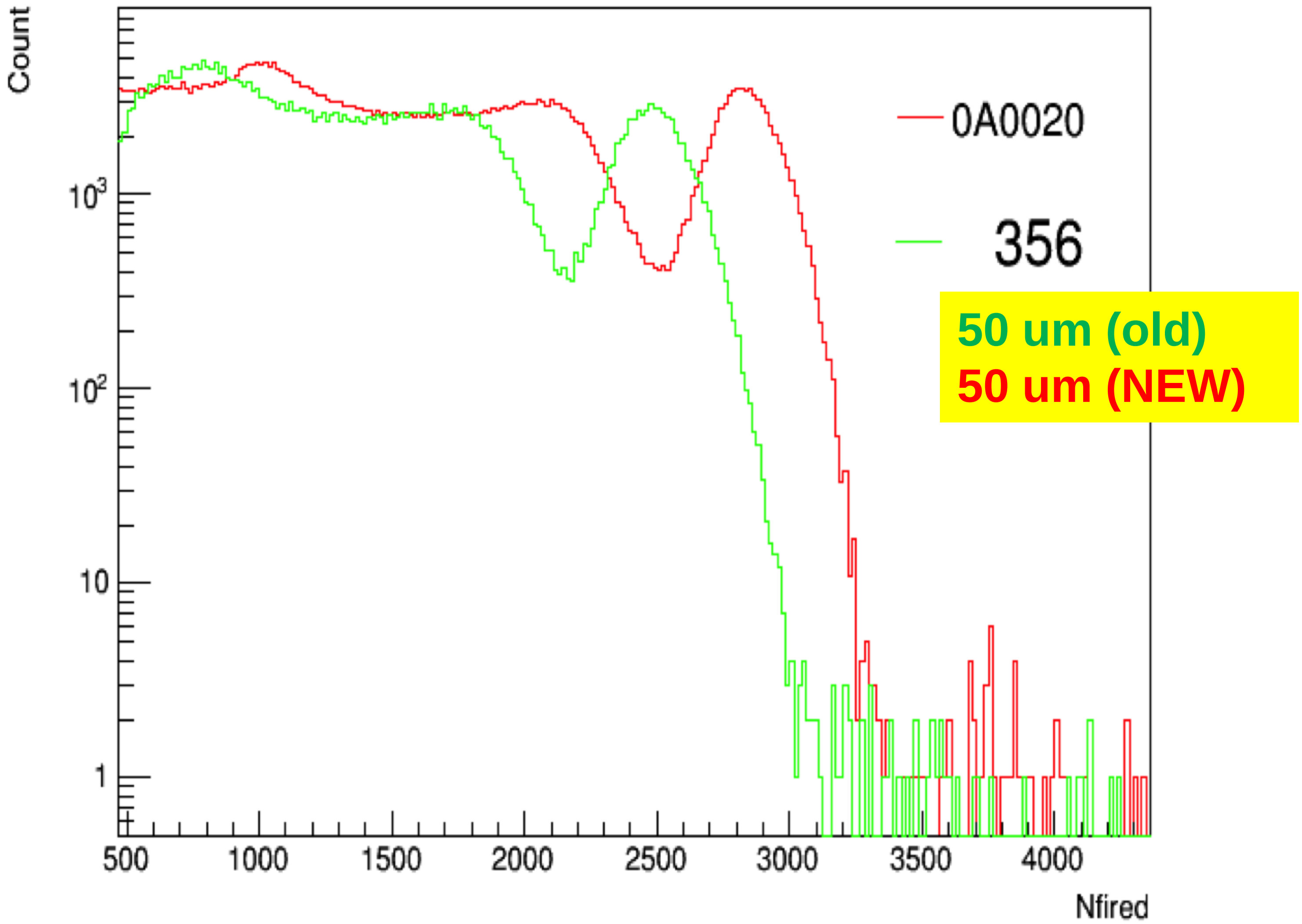


50 um (old) M=7.5e5
50 um (NEW) M= 1.2e6
15 um (NEW) M=1.2e6

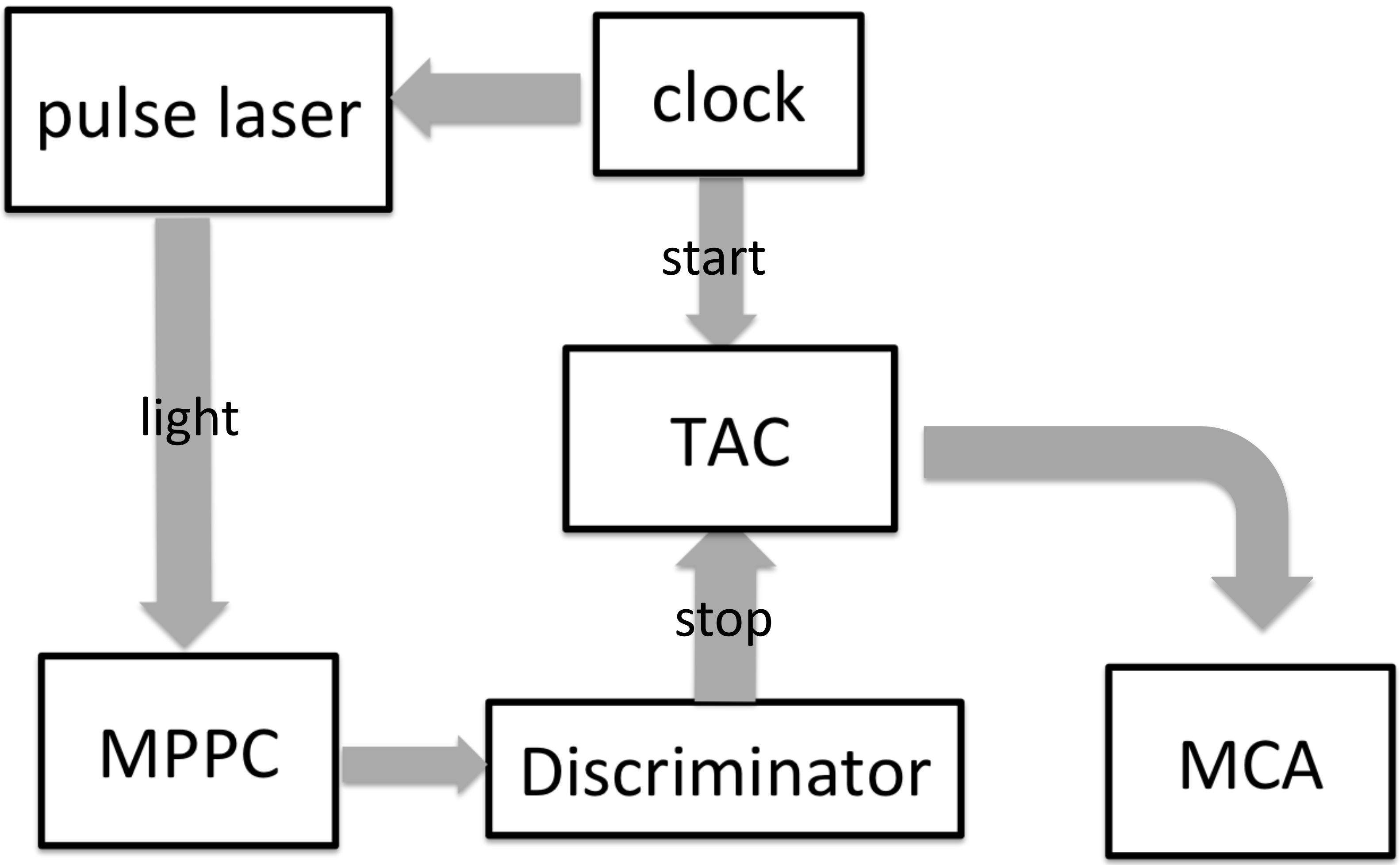
Dark Count (raw data @ 0deg)



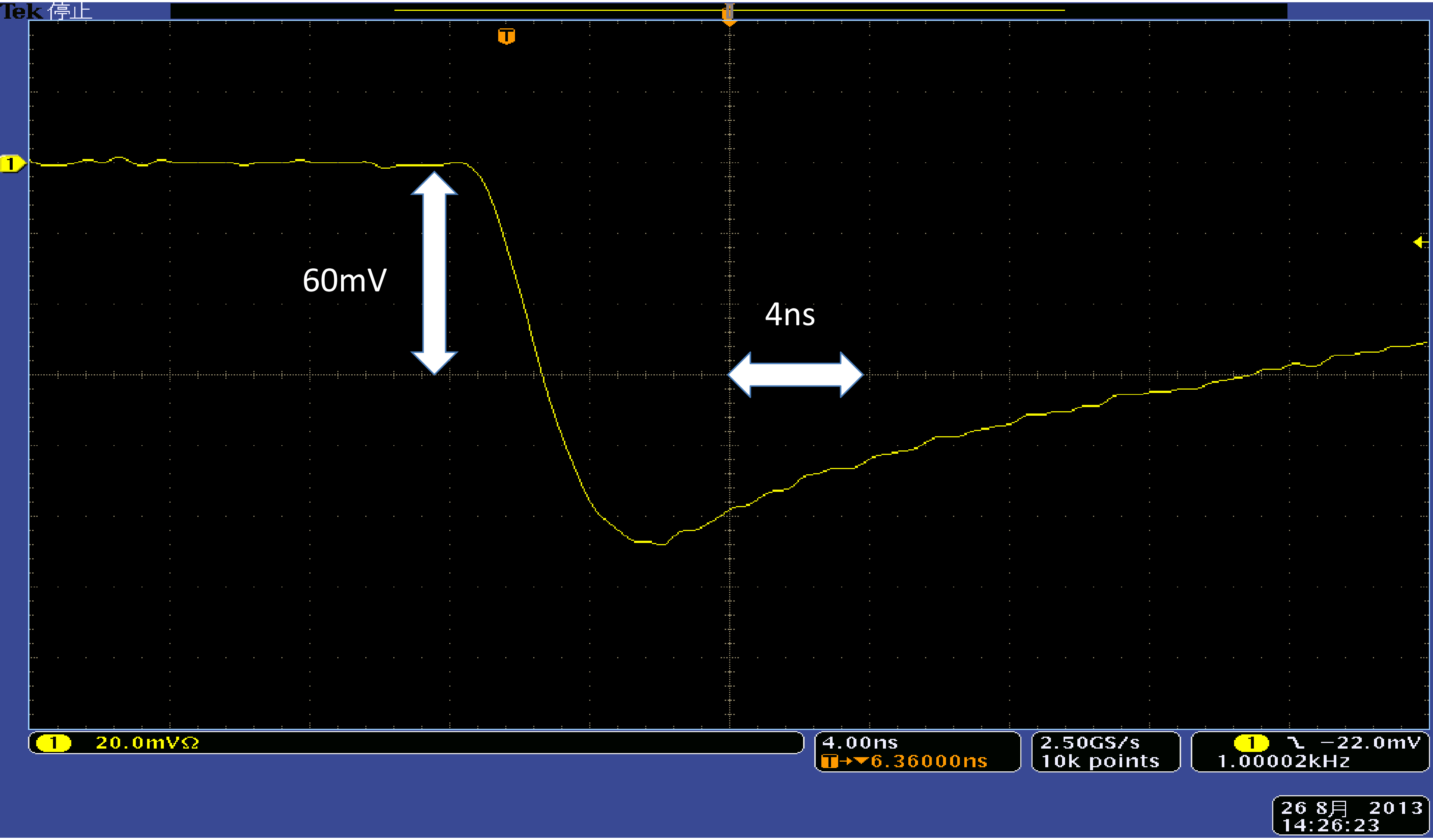
Improvement [3]: QE



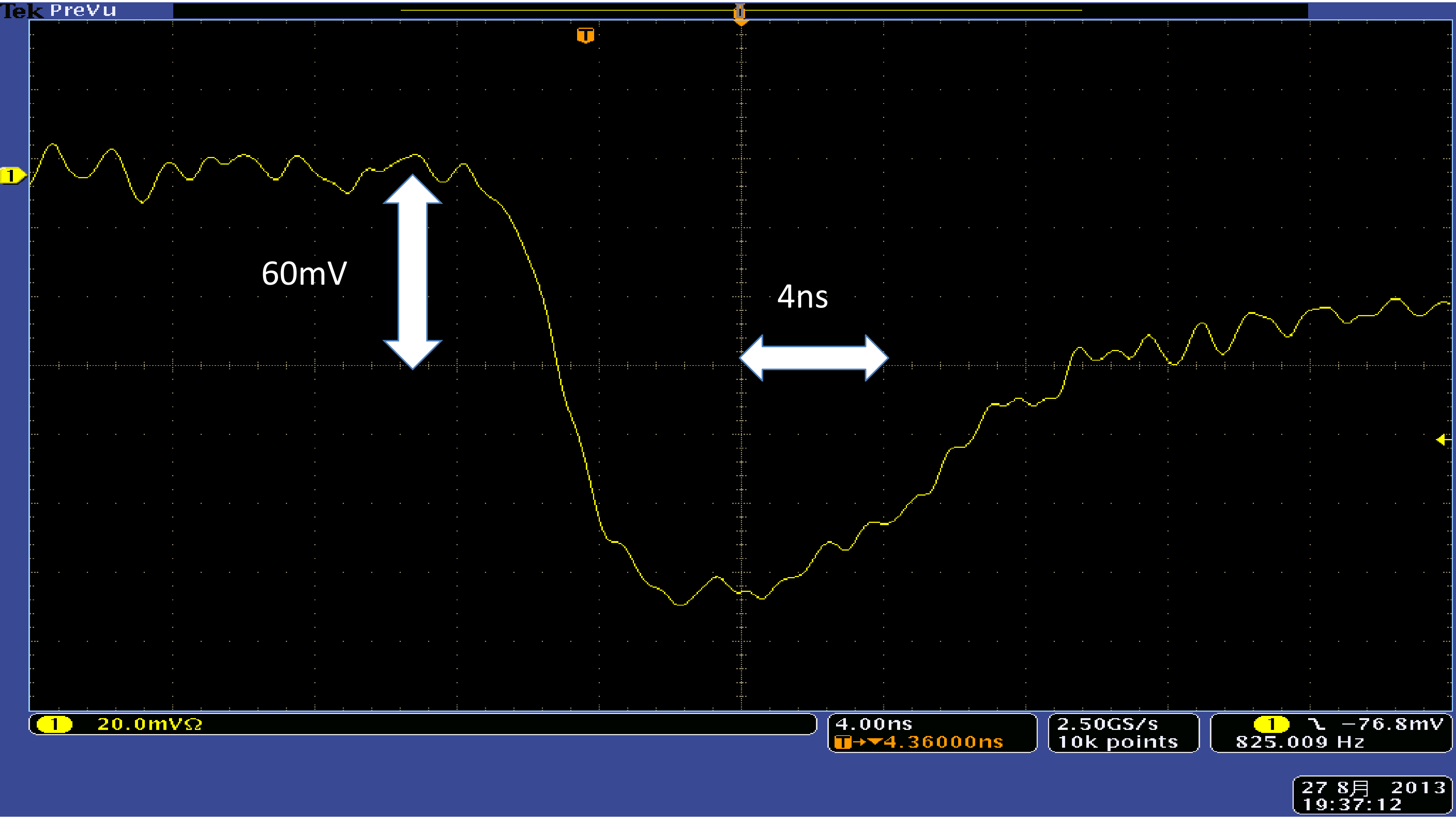
Improvement [4]: Timing Property(setup)



Waveform(raw) 50um(NEW)



Waveform(raw)   50um(old)



Details of MPPCs

@+25℃

	15 um(NEW)	50 um (NEW)	50 um (NEW)
Type No.	S12572-015C	S12572-50C	S10362-33-050C
Serial No.	A0001	0A0020	356
Vop	69.02V	68.03V	71.14V
M	2.30E+05	1.25E+06	7.50E+05
Dark(0.5thr)	570K	827K	4.74M