Summary of PD18

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PD18, Tokyo, Japan
29 November 2018

University of Tokyo, Japan
27-29 November 2018

- 105 Registered participants from 15 countries
- 45 Oral presentations
- 23 Posters
- Exhibitions by Industrial Partners

Main topics

SiPMs/MPPCs

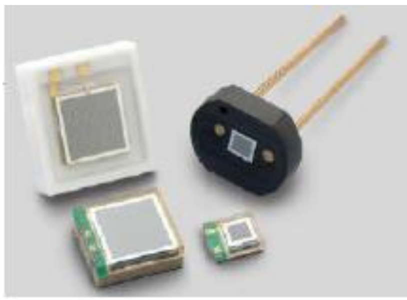
- technology
- characterization
- parameters
- various applications

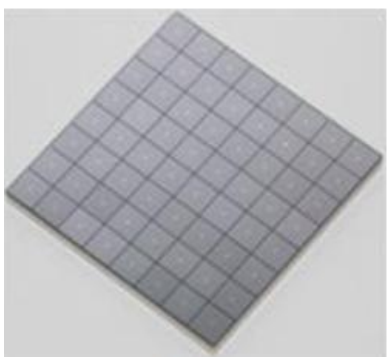
PMTs

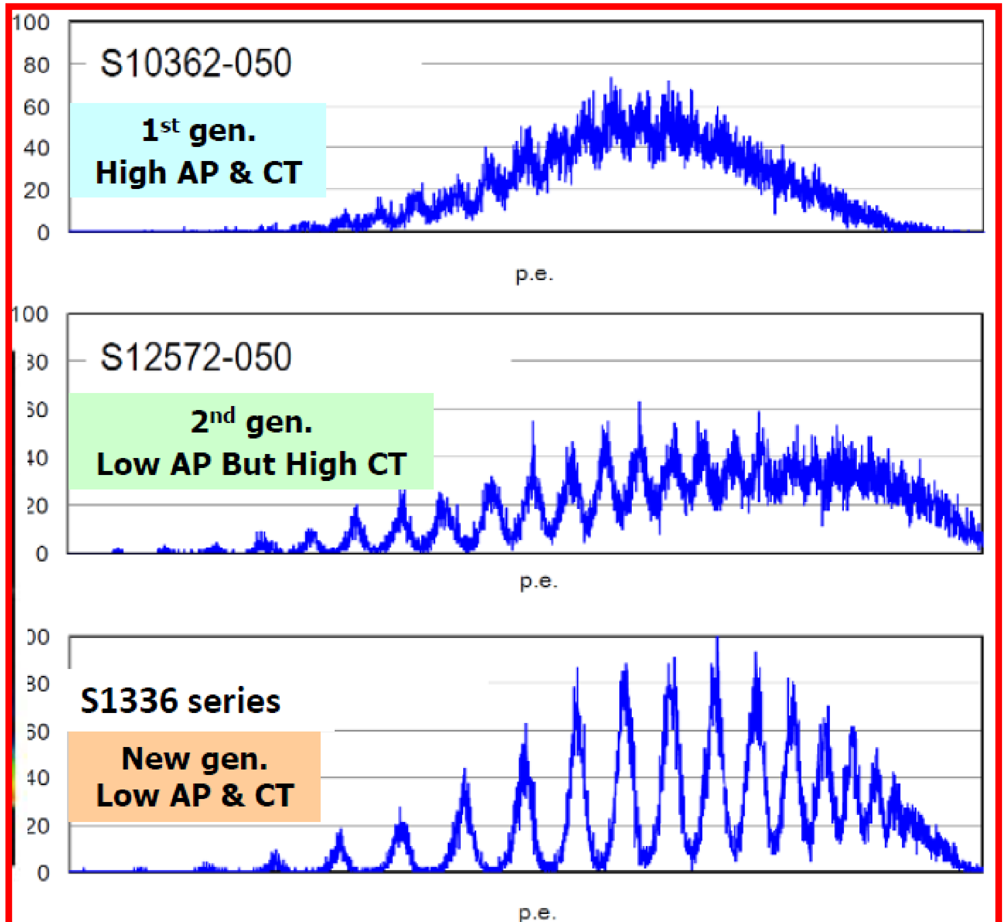
- technology
- parameters
- applications

Keynote presentation

Koei Yamamoto. Recent Development of MPPC at Hamamatsu for Photon Counting Applications







New MPPC series

<MPPC Series>	<Application>
S1337x series (VUV-MPPC)	- Liq. Xe / Ar scintillation measurement
S1452x series (CTA-MPPC)	- CTA (Cherenkov Telescope Array)
S1416x series (Small microcell: HDR-MPPC)	- Calorie meter - High Dynamic Range measurement

For scientific applications

For industrial applications

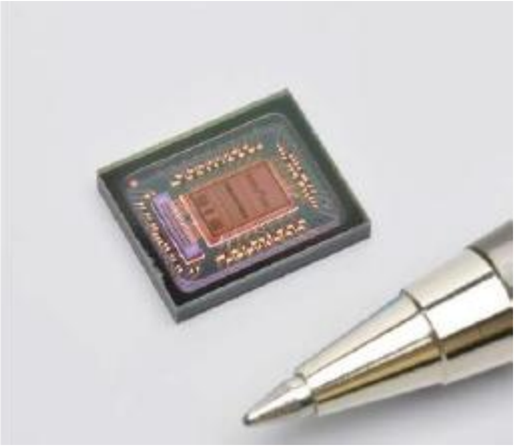
<MPPC Series>	<Application>
S1336x series (UV-VIS : General)	- General use
S1416x series (UV-VIS: Scintillation)	- PET (Positron Emission Tomography) - Radiation monitor
S1442x series (VIS-NIR: Peak shifted)	- Laser microscope - Flow cytometry - Bio-medical
S1372x series (NIR: NIR-enhanced)	- LiDAR (Light Detection and Ranging)

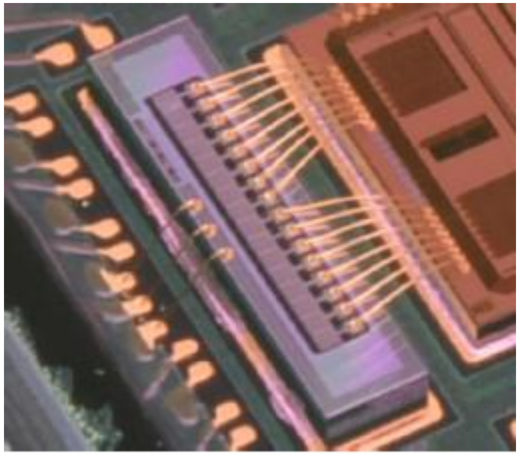
Hybrid module for LIDAR

<u>Features</u>

- Consist of 1D MPPC array and ASIC.
- It specializes in distance measurement.
- All function of ASIC are optimized for LIDAR
- Integrated Time-to-Digital Converter (TDC) and energy measurement functions

Front-end circuit	Power	180mW (+1.8V) 11mW/ch
	# of ch	1×16ch
	Energy Resolution	1 p.e.~
	Dynamic Range	>100 p.e.
TDC	LSB	0.096m(320ps)
	Range	~192m(1280ns)
Chip	Max. measure rate	250kHz
	Footprint	13.0×10.6mm

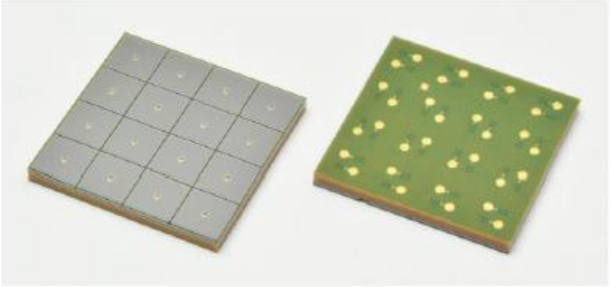


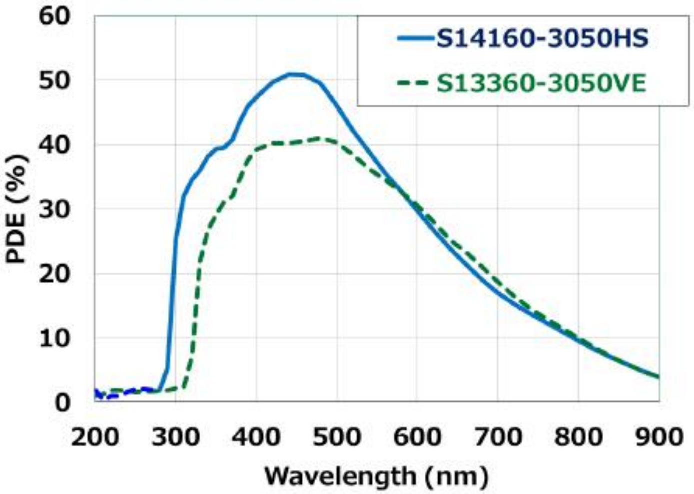


MPPCs for PET

S1416X series

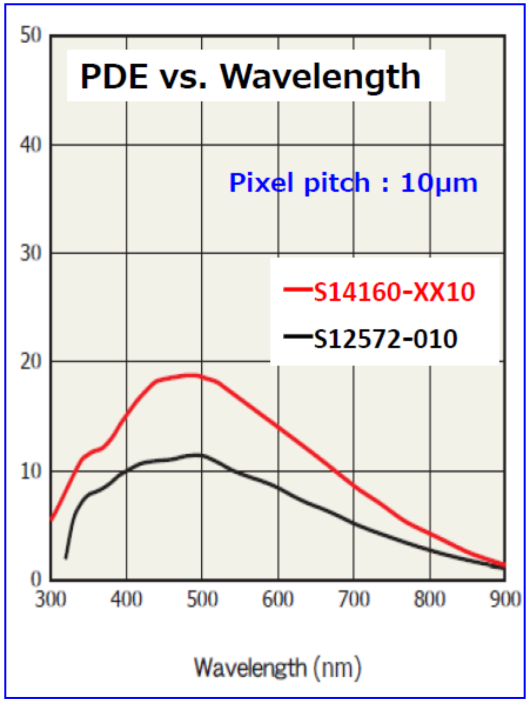
- Lower cost
- High PDE around 450nm
- Lower voltage operation
  Vbr = 37V
- Lower temp coef. of Vop
  34mV/℃
- 4 side tillable
- Active area line up :
  3x3, 4x4, 6x6 mm

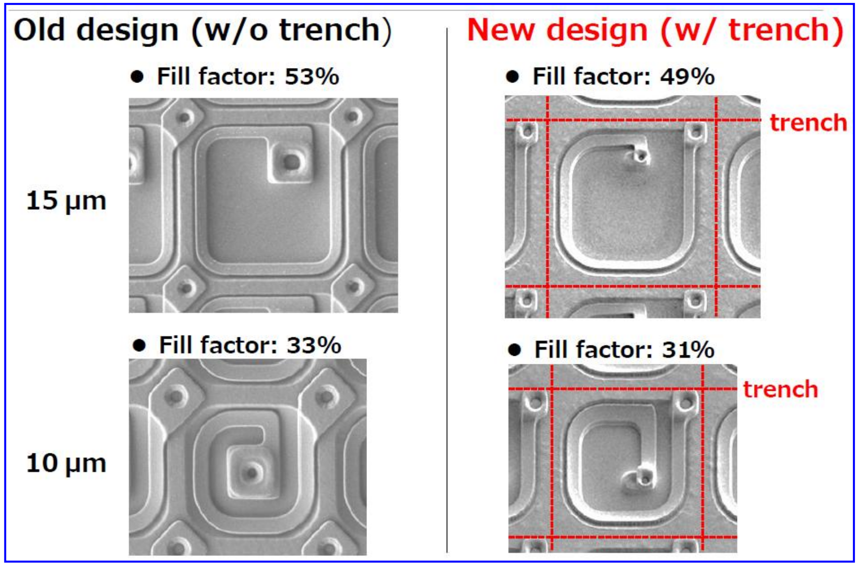


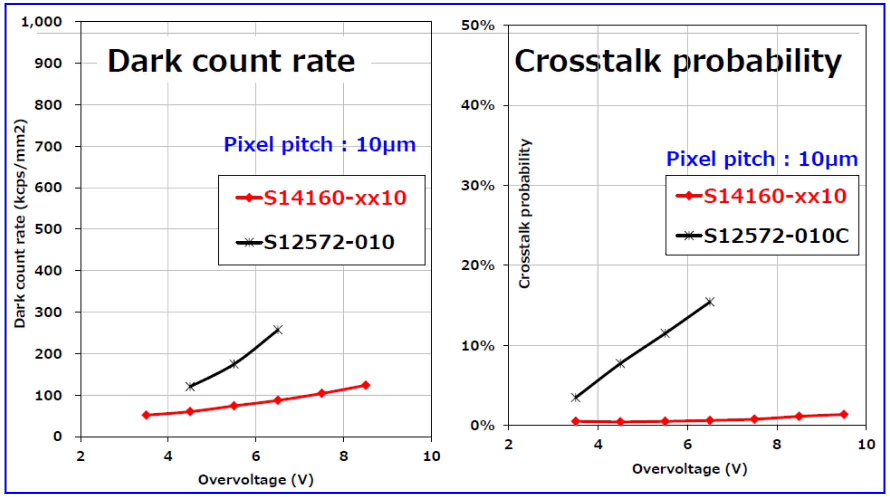


Micro cell design

	S12571	S13360	S14160 (Latest)
Breakdown voltage	65 V	53 V	38 V
Trench isolation	none	Yes	Yes
Trench width	-	~ 1 µm	~ 0.5 µm
Fill factor	10µm: 33% 15µm: 53%	10/15µm no lineup	10µm: 31% 15µm: 49%

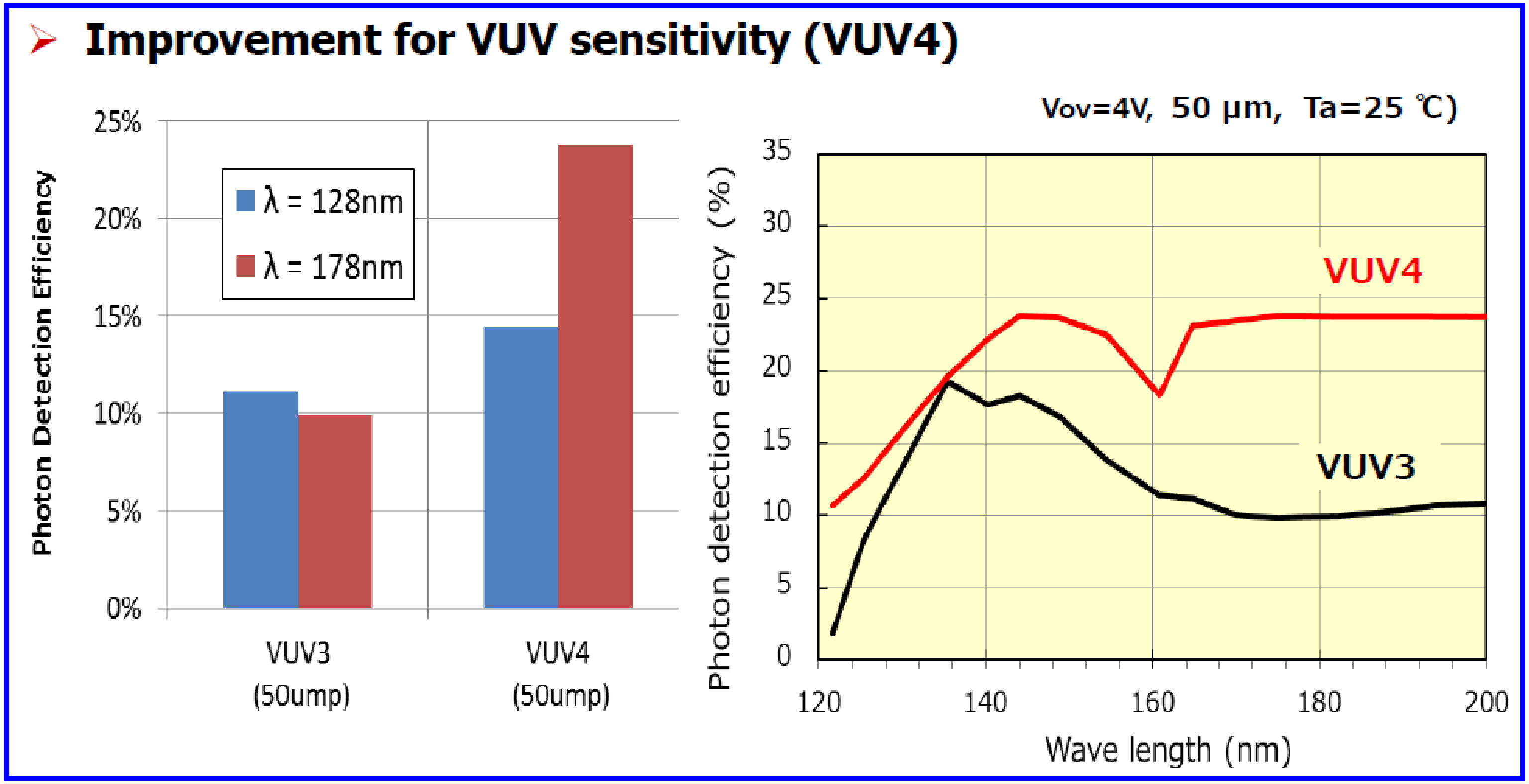




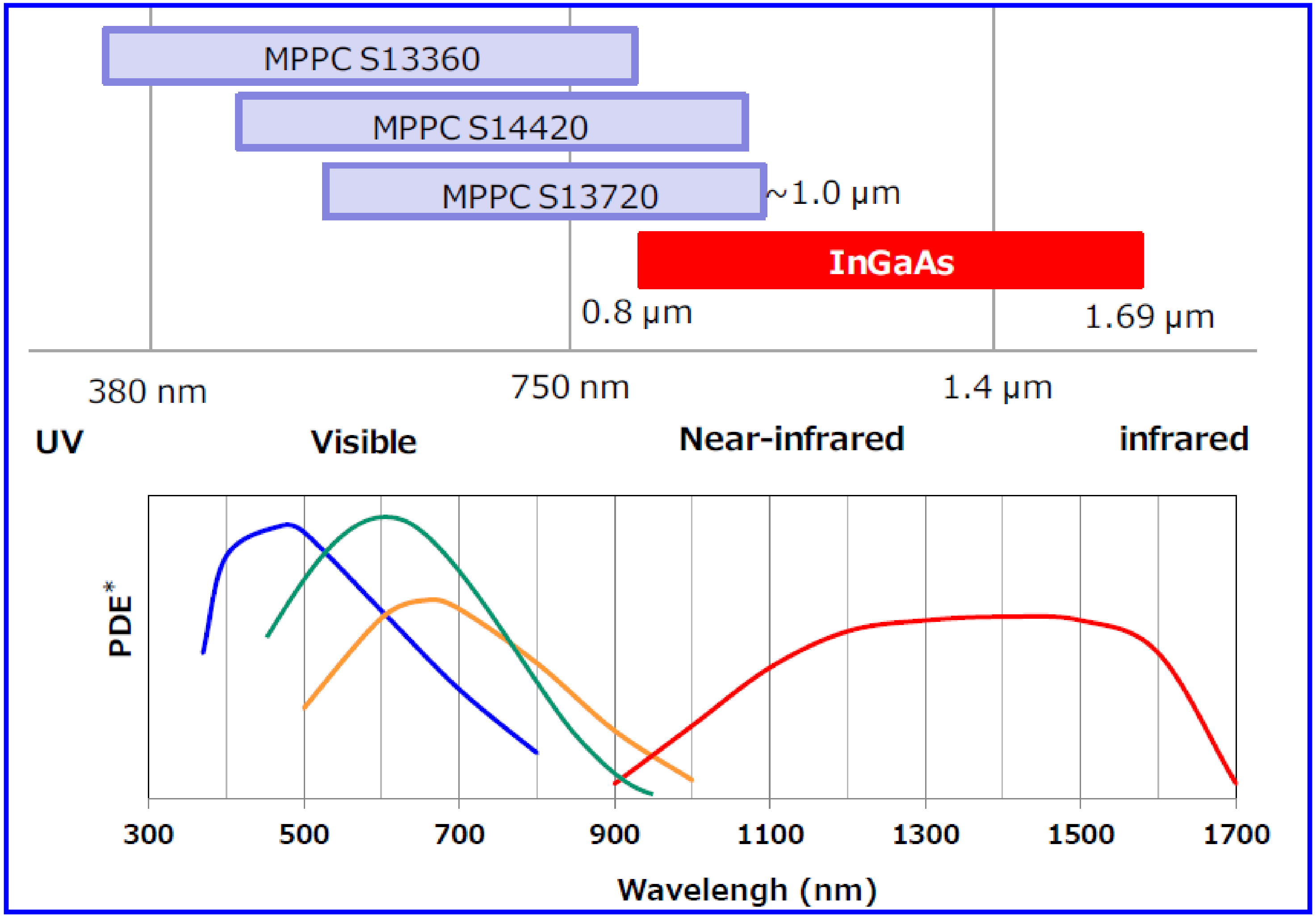


VUV detection

For LXe and LAr detectors



Si and InGaAs MPPCs



Review of SiPMs

Fabio Acerbi. SiPM overview: status and trends

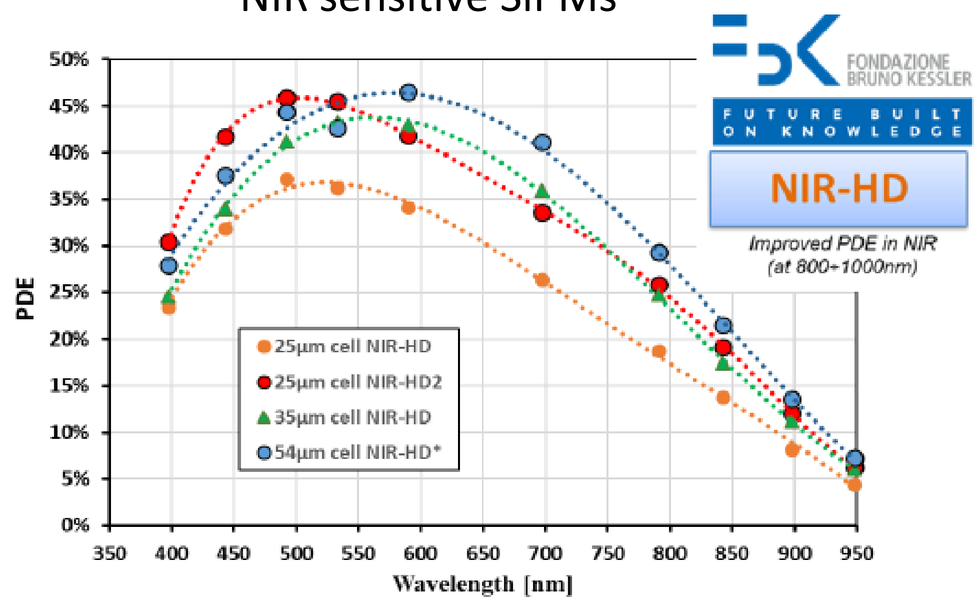
Analog SiPM, Digital SiPM

Applications:
HEP, medical imaging, life science, safety and security
NIR spectroscopy, LIDAR, low temperature (LXe, Lar) – VUV, NUV, NIR

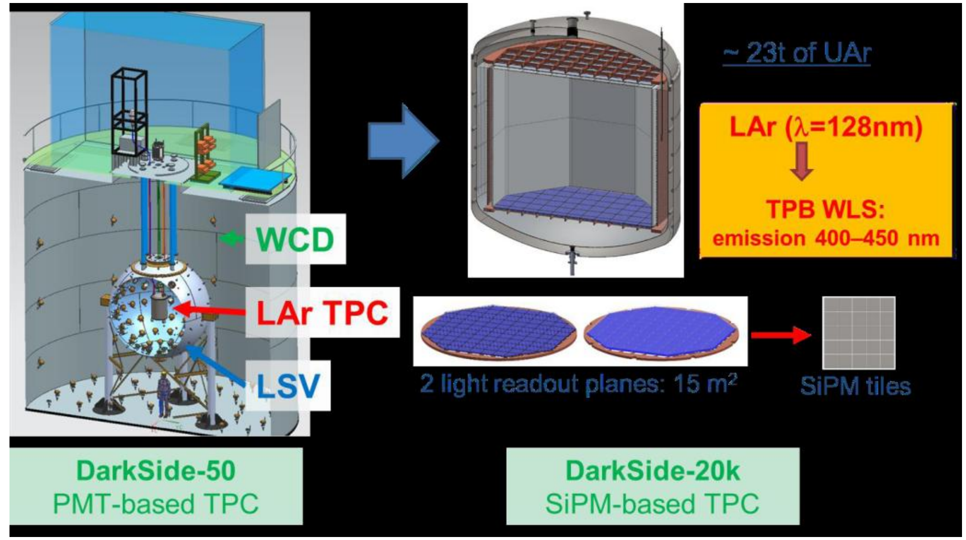
Technology,
low cost packaging

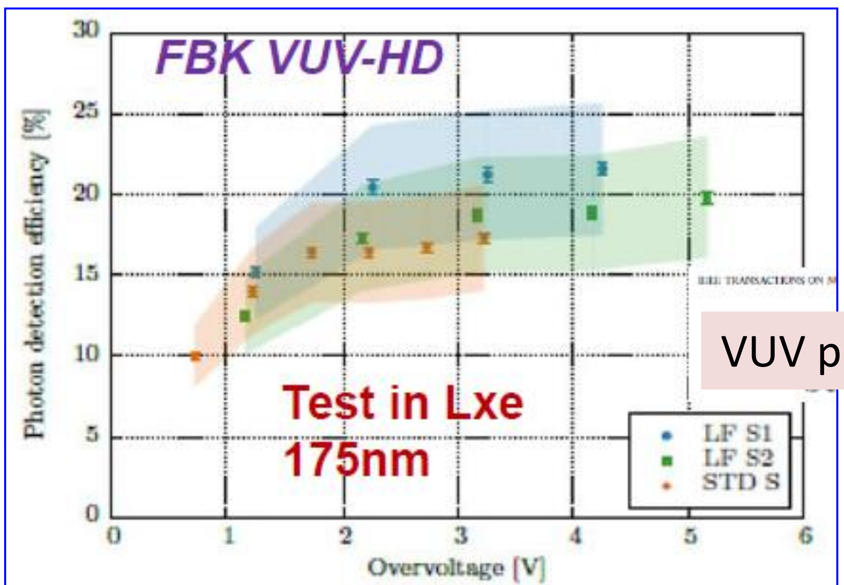
NIR sensitive SiPMs for LIDAR
InGaAsMPPC (800nm-1.6μm)

NIR sensitive SiPMs

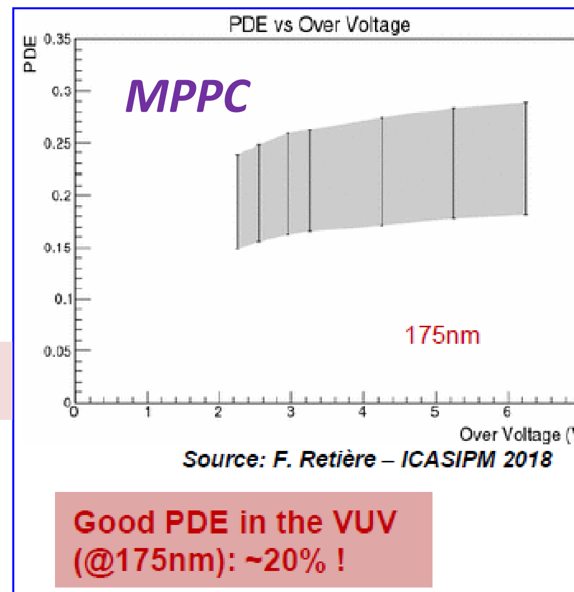


SiPMs at cryogenics temperatures
- LAr, LXe detectors





VUV performance

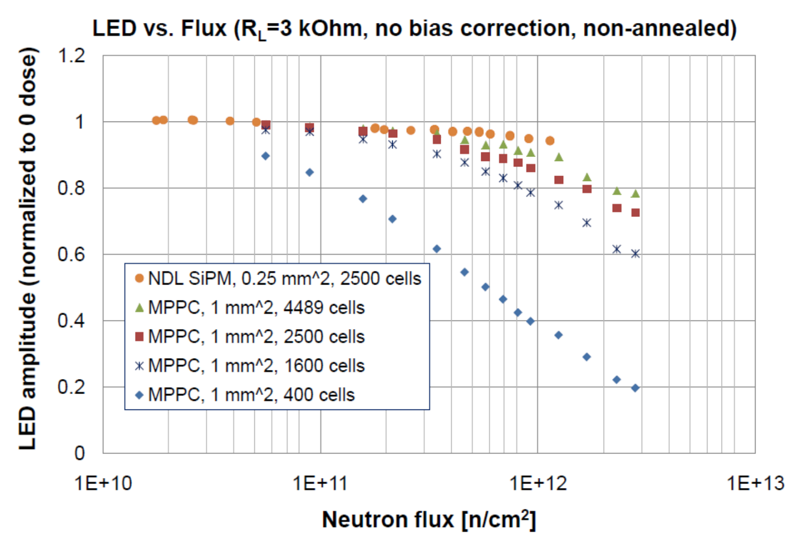


Review of radiation hardness of SiPMs

YuryMusienko et al. Radiation damage of SiPM

Results on radiation damage induced by hadrons, X-rays and gammas in SiPMs are reviewed.

Damage by neutrons



Damage by X-rays and gammas

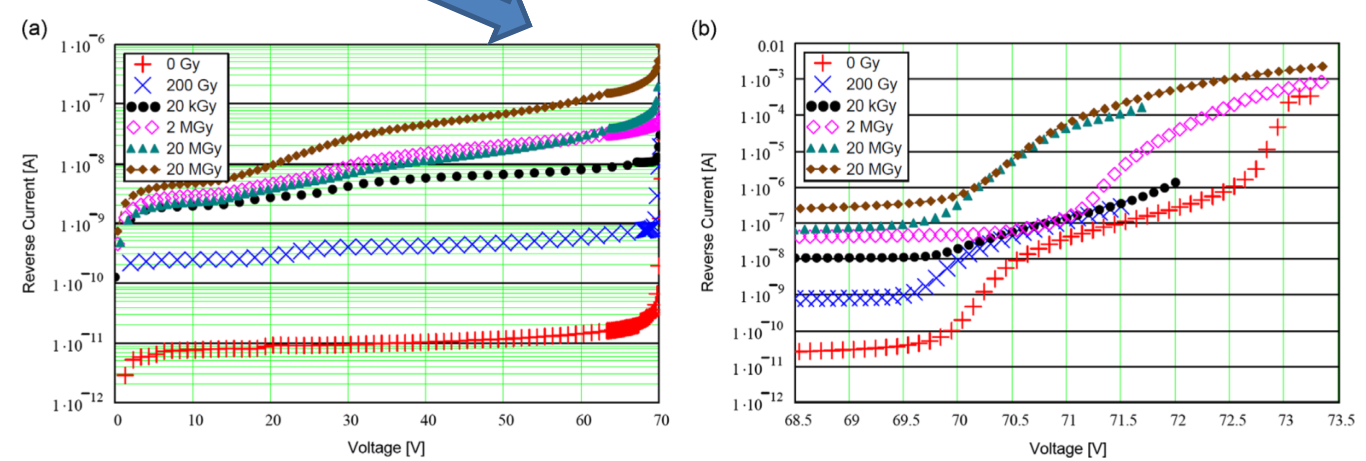
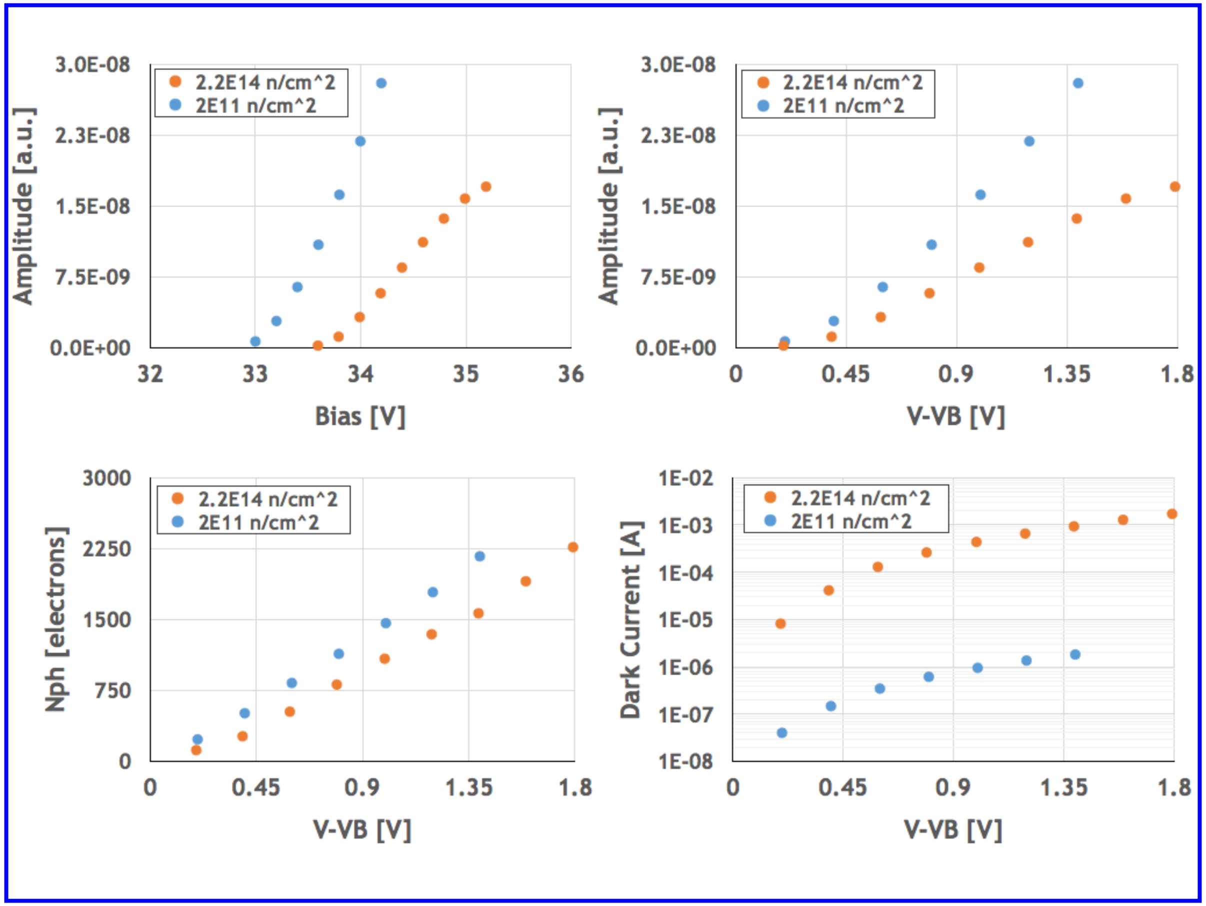


Fig. 6. Reverse currents of SiPMs as a function of voltage before, and after irradiation with X-rays to 200 Gy 20 kGy, 2 MGy, and 20 MGy (a) below the breakdown voltage, and (b) in the region of and above the breakdown voltage.

Heavily irradiated by neutrons

2.8 mm dia., 10 um cell pitch Hamamatsu MPPCs irradiated up to 2.2E14 n/cm^2

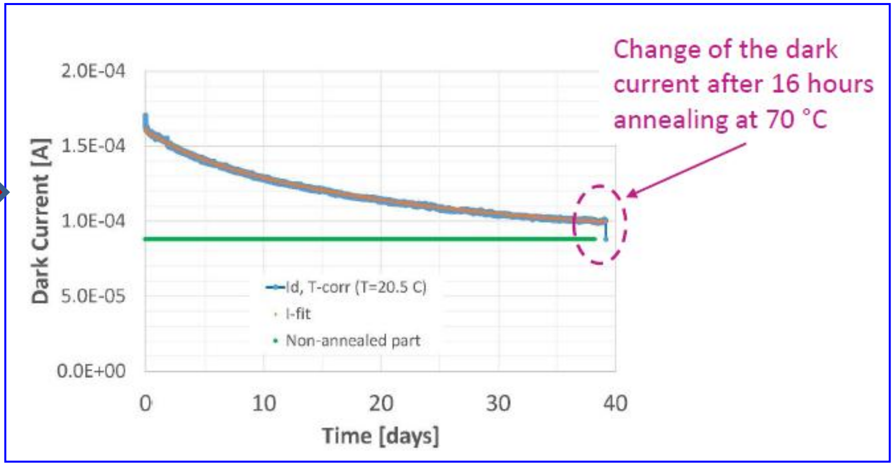
Main result:
SiPM survived this dose and can be used as a photon detector



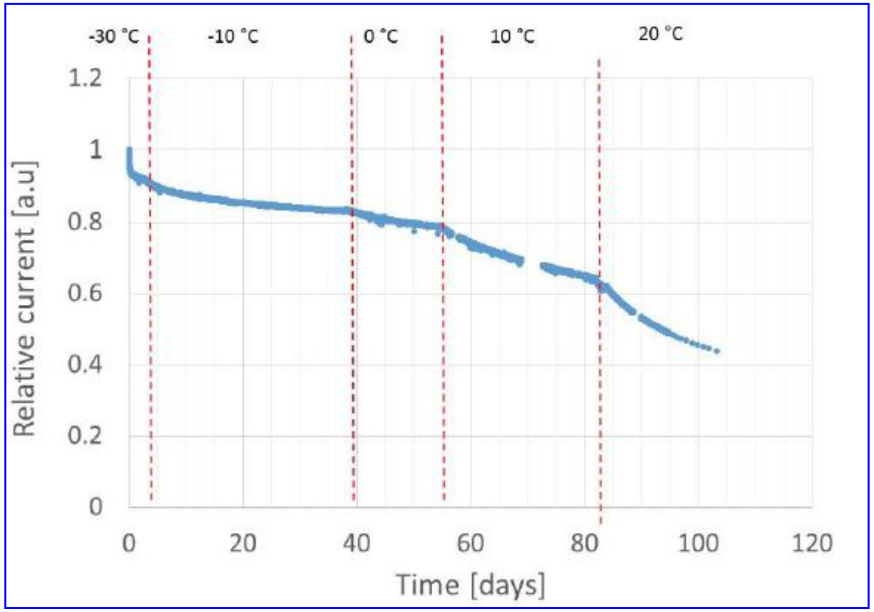
Annealing after irradiation

MPPC S10943-4732

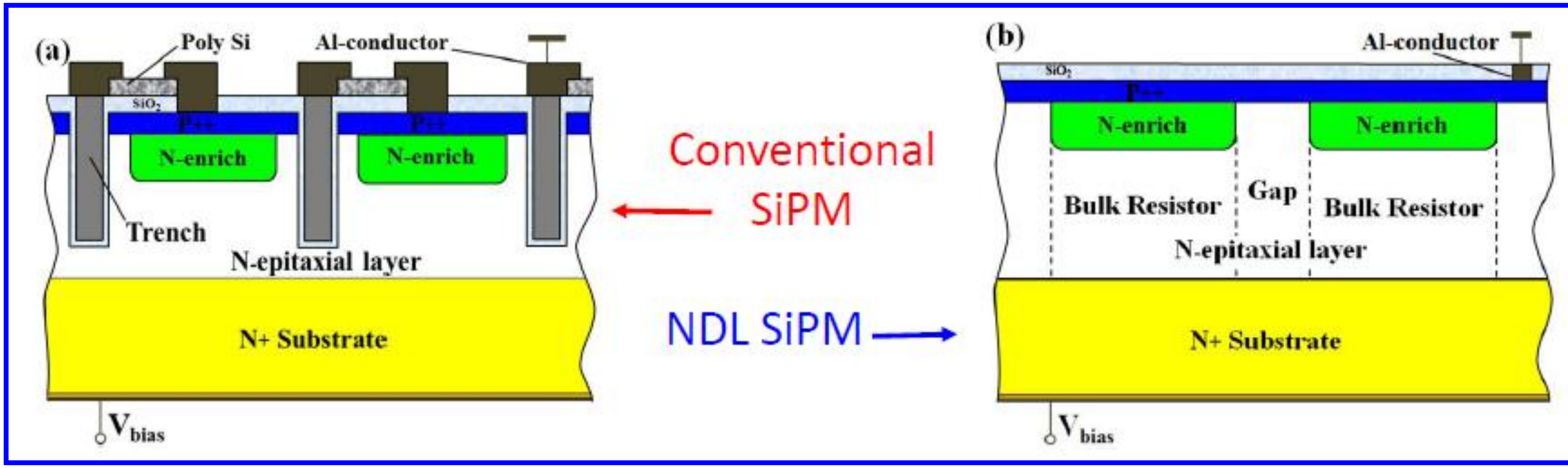
~ 40 days of annealing at T=20.5C
→ dark current reduces
from 169 mA to 100.5 mA
Additional 16 days at 70C
→ from 100.5 mA to 88 mA



Dark current reduces by 60% when temperature changes from -30C to +20C



Dejun Han. High-Density Silicon Photomultipliers with Epitaxial Quenching Resistors at NDL



- Bulk resistor under each APD cell in the epitaxial layer as quenching resistors
- Continuous cap resistive layer at the surface to connect all micro APD cells

	NDL SiPM		SensL SiPM		Hamamatsu MPPC	
Effective Active Area	11-3030 C-S/T	11-1010 C-S/T	C-30020-SMT	C-10010-SMT	S12572-010-C/P	S12571-010-C/P
	3.0×3.0 mm²	1.0×1.0 mm²	3.0×3.0 mm²	1.0×1.0 mm²	3.0×3.0 mm²	1.0×1.0 mm²
Effective Pitch	10 μm	10 μm	28 μm	18 μm	10 μm	10 μm
Micro-cell Number	90000	10000	10998	2880	90000	10000
Fill Factor	40%	40%	48%	28%	33%	33%
Breakdown Voltage (V_b)	27.5±0.4V	27.5±0.4V	24.2-24.7	24.2-24.7	65±10V	65±10V
Measurement Overvoltage (V)	5	5	2.5	2.5	4.5	4.5
Peak PDE	31%@420nm	31%@420nm	24%@420nm	14%@420nm	10%@470nm	10%@470nm
Max. Dark Count (kcps)	~6000	~500	860	96	2000	200
Gain	2×10^5	2×10^5	1×10^6	2×10^5	1.35×10^5	1.35×10^5
Temp. Coef. For V_b	25mV/℃	25mV/℃	21.5mV/℃	21.5mV/℃	60mV/℃	60mV/℃

Fabio Acerbi. **Development of High-density NIR sensitive Silicon photomultipliers at FBK**

New FBK NIR technology

Thick epitaxial layer

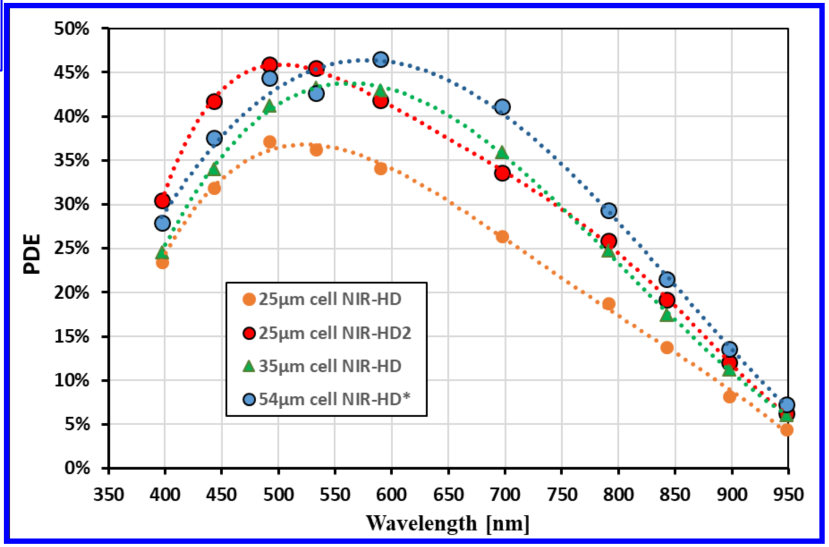
– primary DCR ~ 1Mcps/mm2

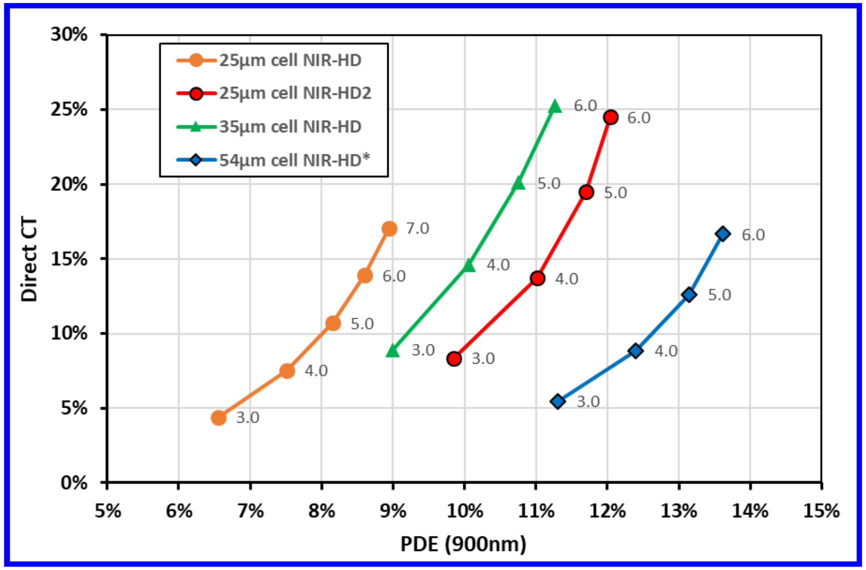
– direct cross-talk: 10÷20%

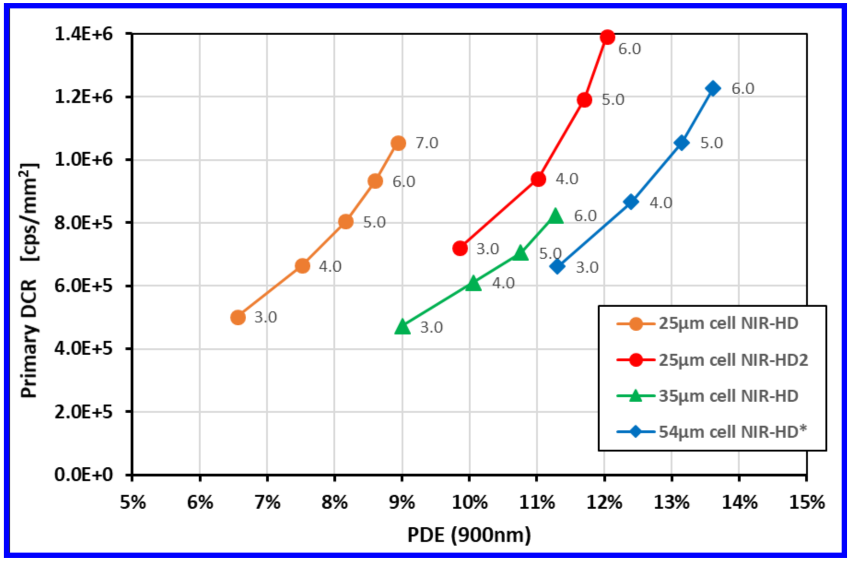
– PDE:

17% ÷20% @850nm

11% ÷13% @900nm







SiPM characterization

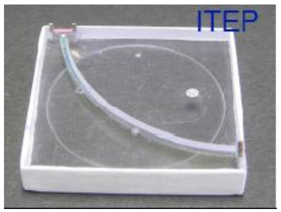
Derec Strom et al. Direct Measurement of Optical Cross-talk in Silicon Photomultipliers Using Light Emission Microscopy
- Light emission microscopy for measuring and understanding physics behind optical cross-talk, for observing device defects, avalanche morphology, etc.

Giacomo Gallina et al. Experimental SiPMs parameter characterization from avalanche triggering probabilities
- Parametrisation of PDE starting from the avalanche triggering probability. Applied for Hamamatsu VUV4 , FBK in progress.

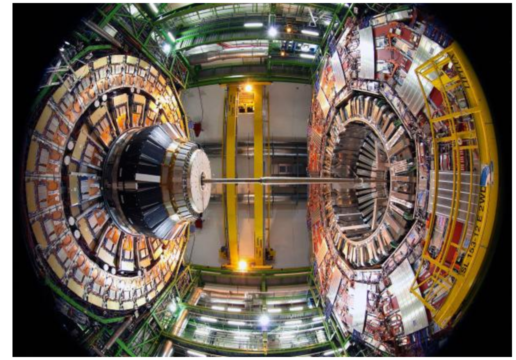
Yuki Nakamura et al. Characterization of SiPM Optical Crosstalk and its Resin Thickness Dependence
- Evaluation of a thickness dependence of neighboring-SiPMs optical cross-talk rate. Very thin coating SiPM - best solution to suppress optical cross-talk for Cherenkov telescopes

Detectors with SiPMs

Felix Sefkow. MPPCs in highly granular calorimetry - from ILC to LHC and beyond

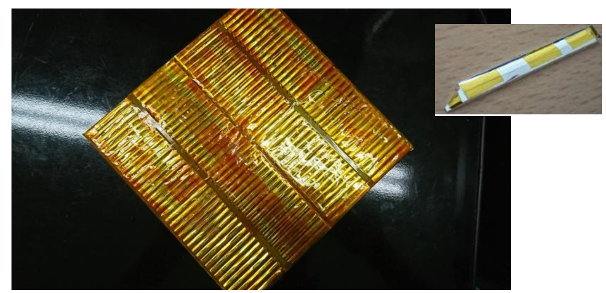


High granularity, scalable realistic detector designs with millions of channels, radiation hardness, heat dissipation and rate

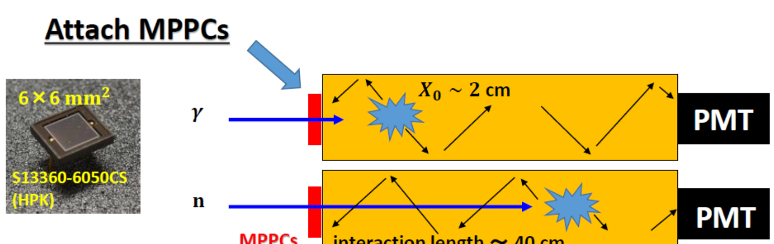


Yuya Yoshimura. Development of Scintillator Electromagnetic Calorimeter for ILD

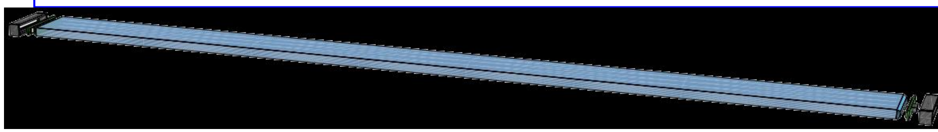
Scintillator Electromagnetic Calorimeter using tungsten, scintillators, and SiPMs

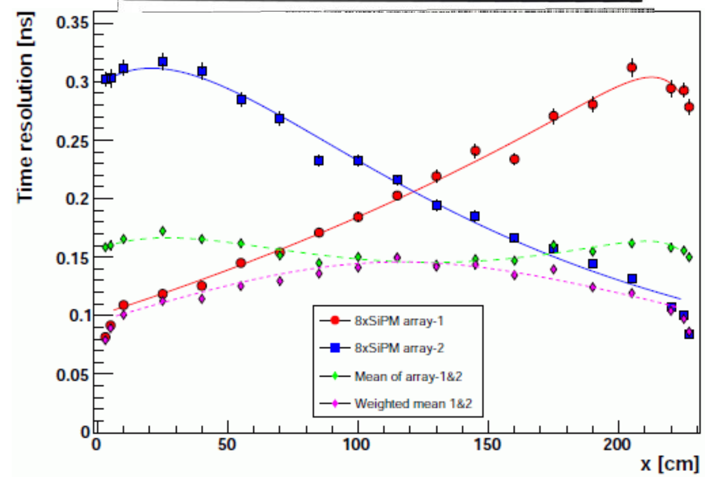


Nobuhiro Shimizu. Upgrade of the Cesium Iodide calorimeter for the KOTO experiment

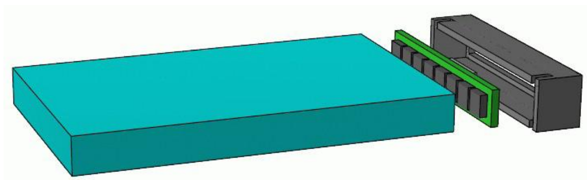


Alexander Korzenev et al. Plastic scintillator detector with the readout based on an array of large-area SiPMs for the ND280/T2K upgrade and SHiP





Array of SiPMs directly coupled to bar

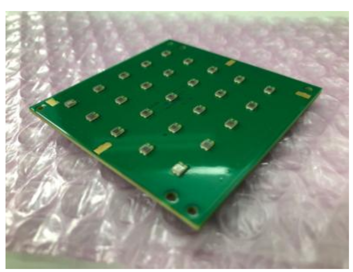


Time resolution: 80-150 ps

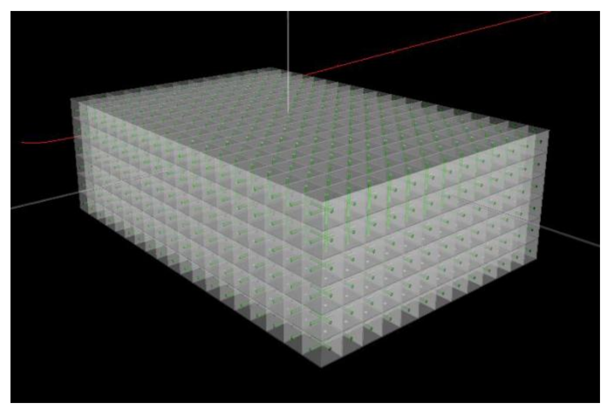
Tsunayuki Matsubara et al. Application of MPPC for T2K near detector upgrade

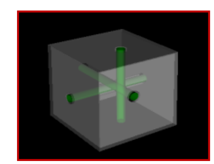
Surface-mount MPPC
S13360-1325PE
~60000 MPPC's

array 5x5



MPPC-PCB & optical interface developed



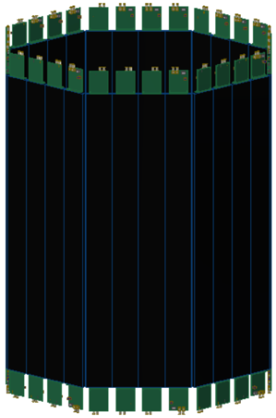


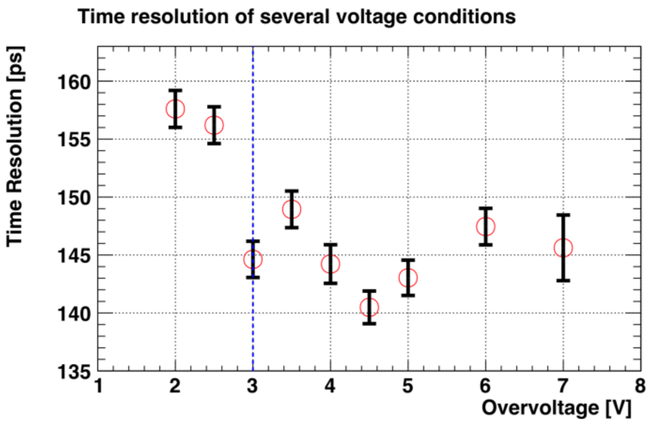
SuperFGD detector
2×10^6 cubes of $1cm^3$
3D readout with WLS fibers

Wooseung Jung et al. Development of TPC Trigger Hodoscope for J-PARC E42/E45 hadron experiment

TPV trigger hodoscope in Hyperon spectrometer a t J-PARC

80 cm long counter with 8 MPPCs at both ends

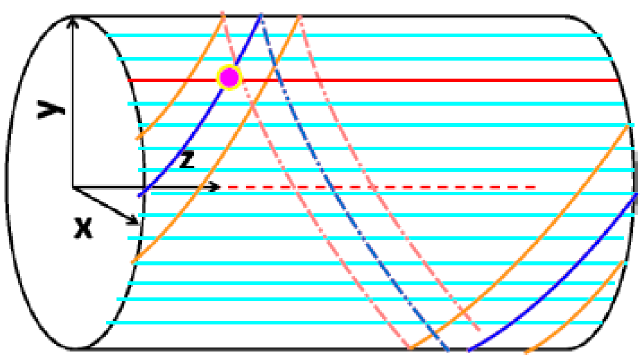


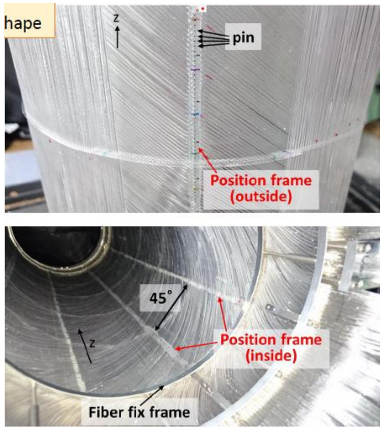


σ~140 ps

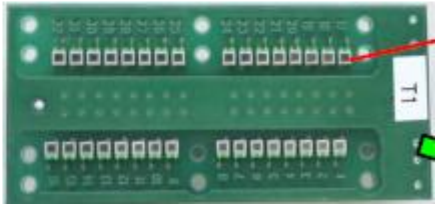
Yuya Akazawa. Operation of multi-MPPC system for cylindrical scintillation fiber tracker

∑p scattering experiment (J-PARC E40)





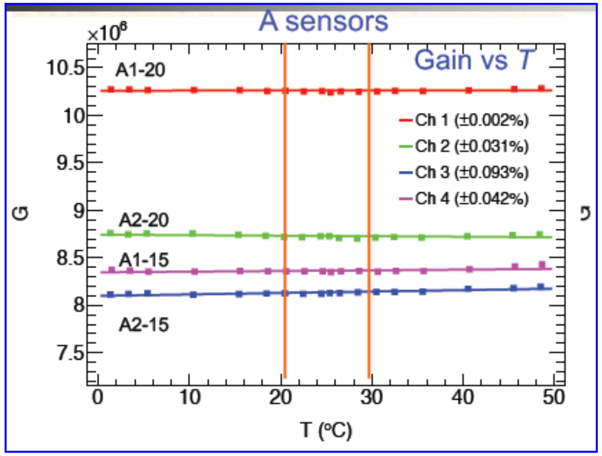
Circuit mounting 32 MPPCs

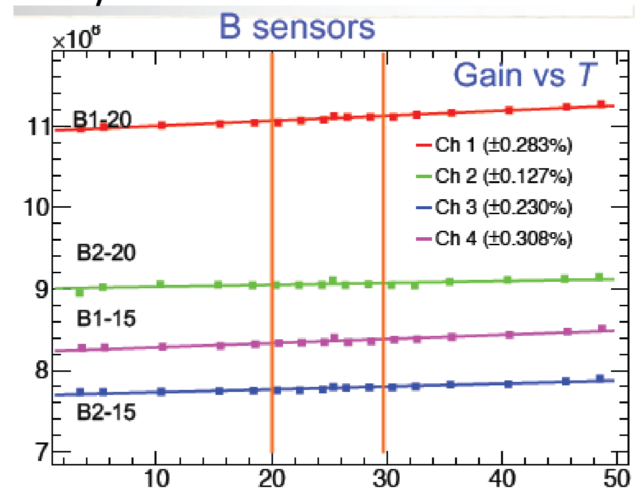


Angular resolution of CFT ･･･ $\sigma_\theta = 1.6^\circ$
Energy resolution ･･･20%(σ) @ 8~20 MeV proton
Time resolution ･･･ 2 ns(σ)

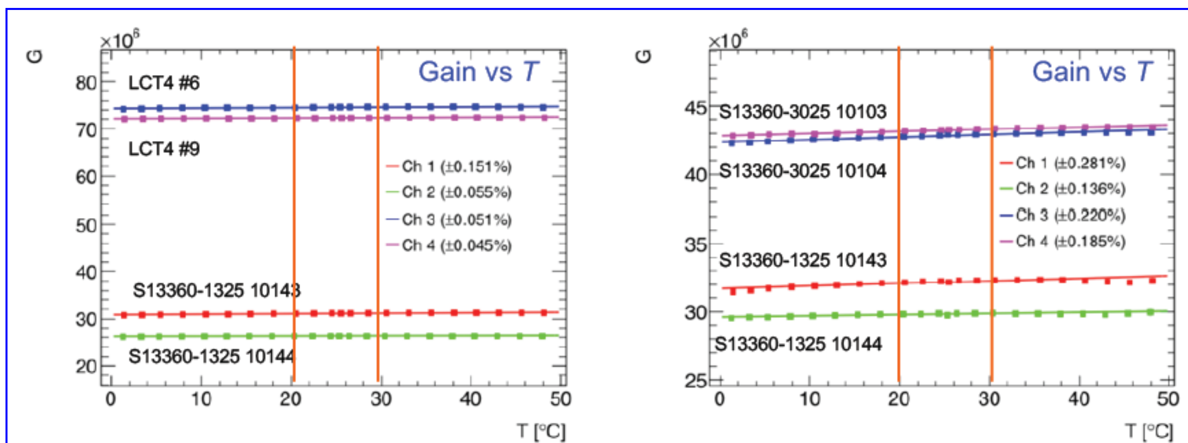
Hamamatsu MPPCs w/o trenches

Similar SiPMs can be stabilized with one dV_B/dT value





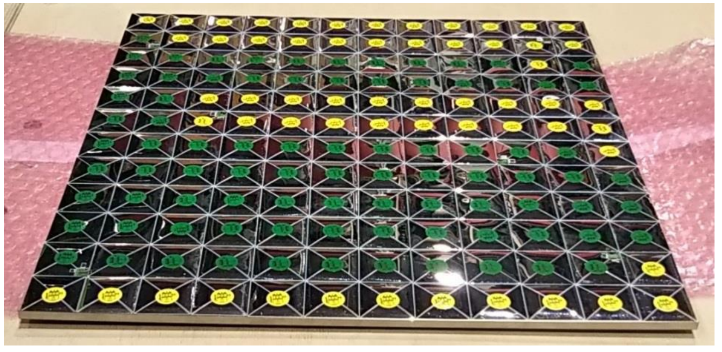
Hamamatsu MPPCs with trenches



Yuji Sudo. Characterisation and temperature stabilisation of a system with 22000 MPPCs

Analog Hadron Calorimeter for ILD

Large prototype: 38/39 active layers of 72x72cm in steel absorber, ~22000 channels, ~4λ



Excellent uniformity of MPPCs with common bias. Automatic adjustment of common V_B for temp changes: stable gain within <1%

Akira Okumura. Development of a UV-transparent Lens Array Enlarging the Effective Area of Multi-channel SiPMs

Cherenkov Telescope Array

UV transparent lens array is developed

- PDE is higher by 15%

Kento Torigoe et al. Performance study of a large CsI(Tl) scintillator with an MPPC readout for nanosatellites used to localize gamma-ray bursts

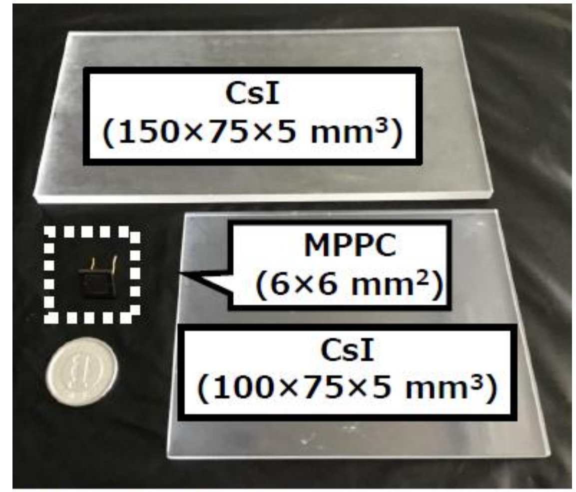
CAMELOT

CubeSats Applied for MEasuring and LOcalizing Transients

- Hungarian/Japanese collaboration project
- Measure arrival time difference with a fleet of nanosatellites

Threshold <10 keV at 25 deg is achieved

Dark current increased by 300 times at 1krad dose

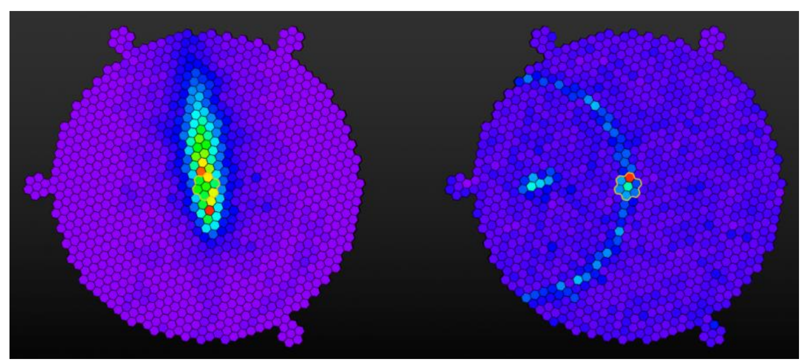


- CsI: Amcrys
- MPPC: Hamamatsu Photonics S13360-6050CS

Alexander Hahn al. Results of the Parallel Operation of Large-size SiPM Detector Modules and PMTs in IACTs

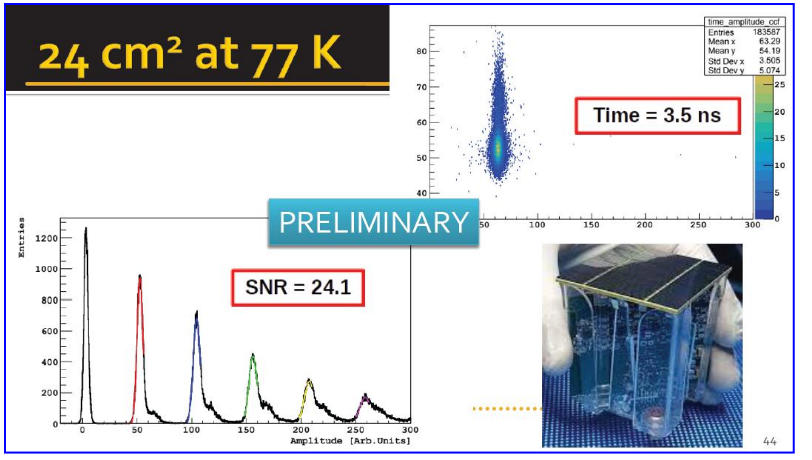
Cherenkov light

Three prototypes of different SiPMs installed in MAGIC camera

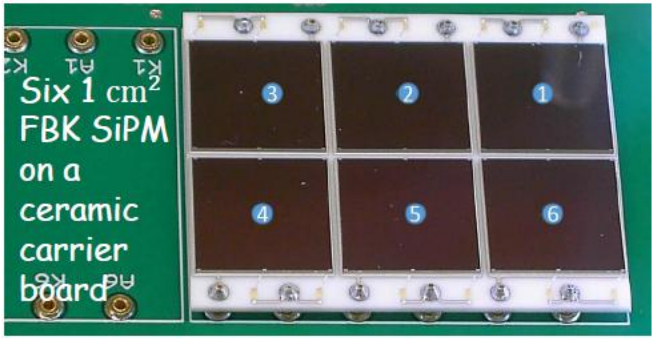


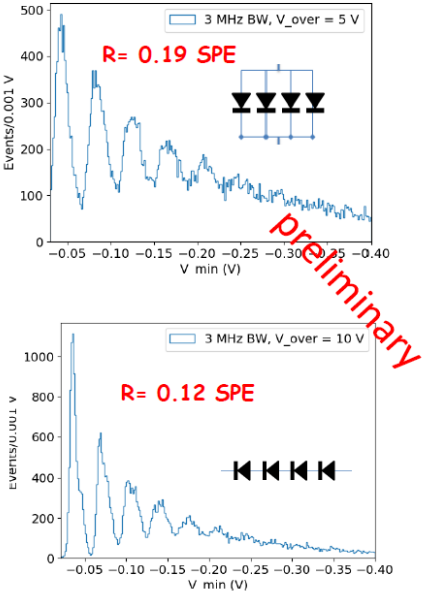
Alessandro Razeto. SiPM readout for cryogenic applications

Large SiPM arrays (~25 cm2) can be readout with good SNR and timing: SNR >20, timing ~ a few ns



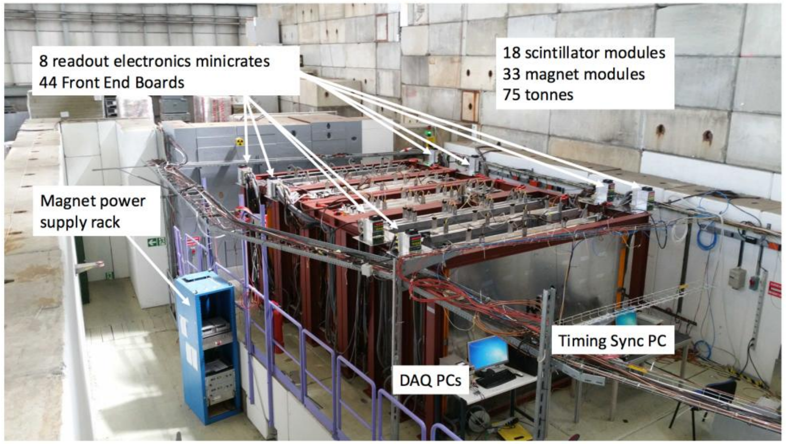
Guofu Cao. Photo-detector system with large area SiPM in nEXO





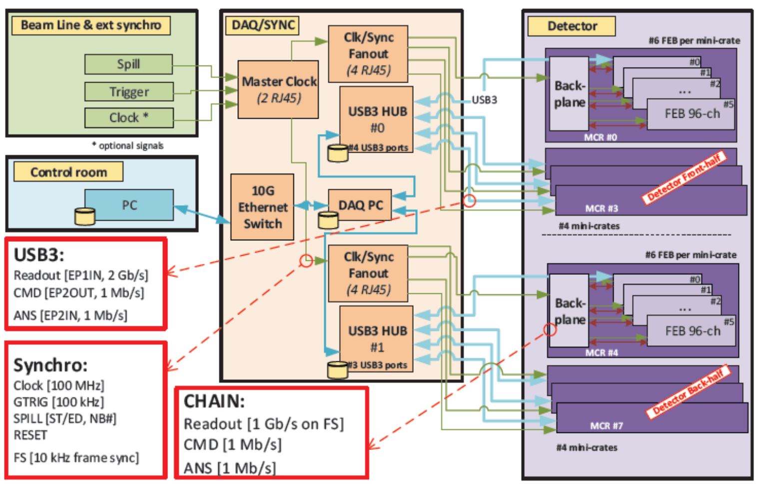
Etam Noah. Baby MIND readout electronics architecture

Baby-MIND at the CERN T9 beamline

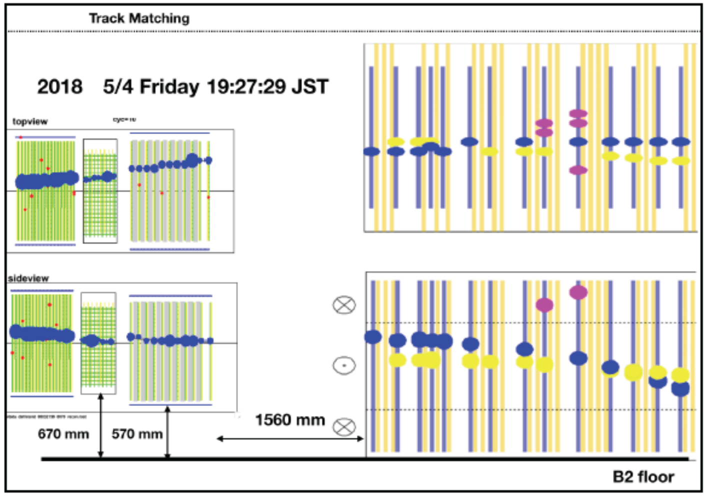


Scintillator bars with WLSfibers/MPPCs

SiPM readout chain using CITIROC chip

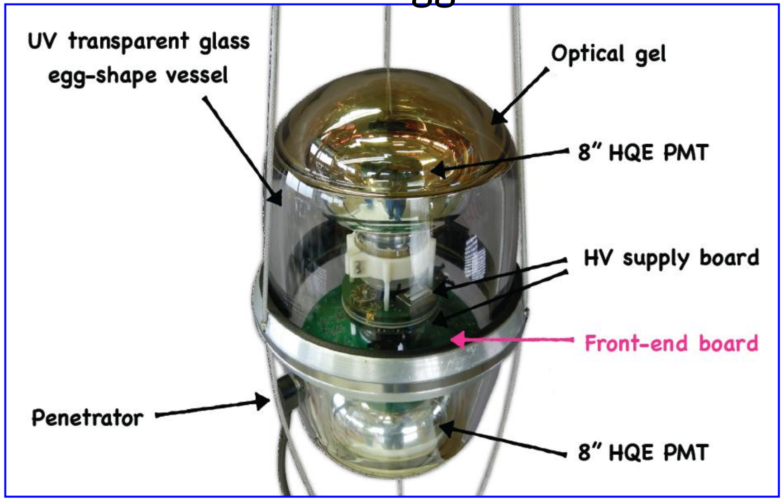


Events at J-PARC

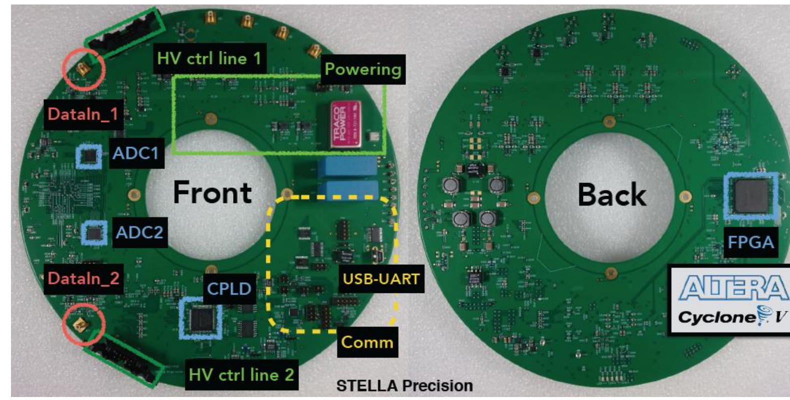


Ryo Nagai. Development of the front-end electronics for the new optical module “D-Egg” for IceCube-Gen2

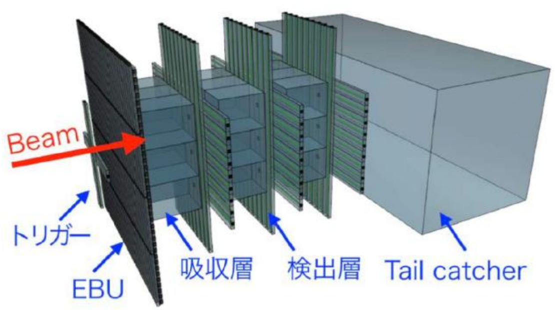
D-Egg

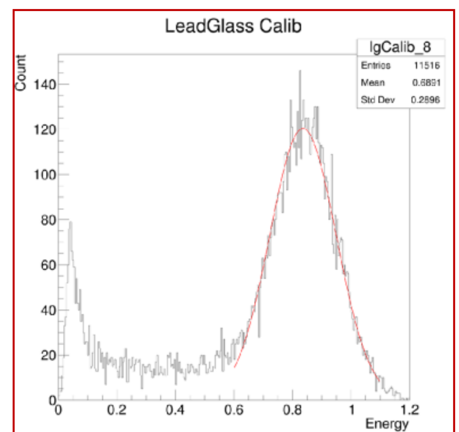


Prototype Front-End Board



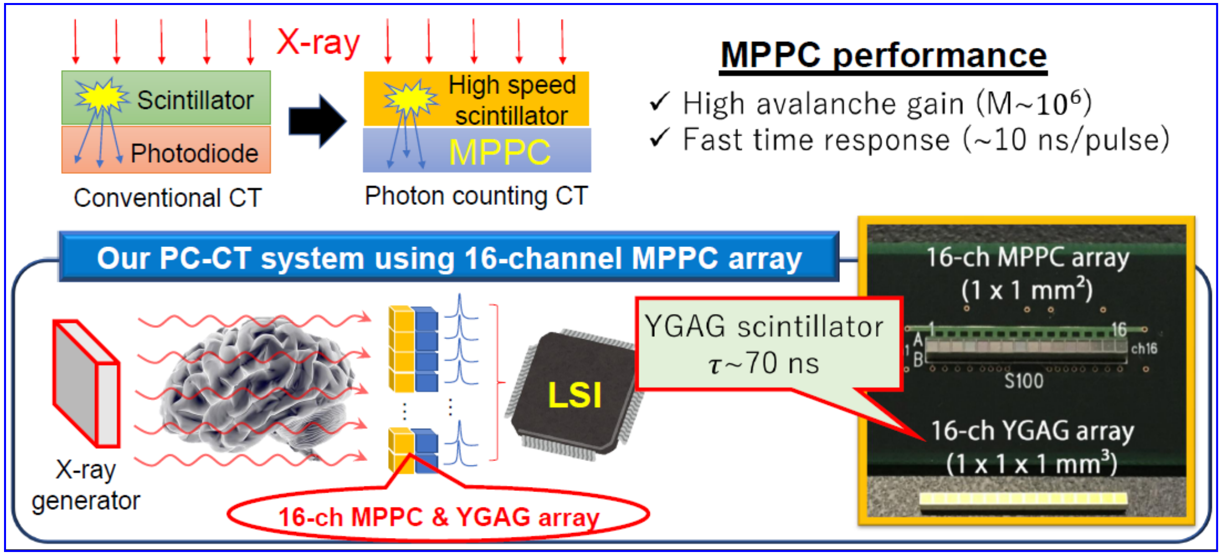
Reima Terada. Development of sampling calorimeter to use information from segmented lead glass absorber with Cherenkov light



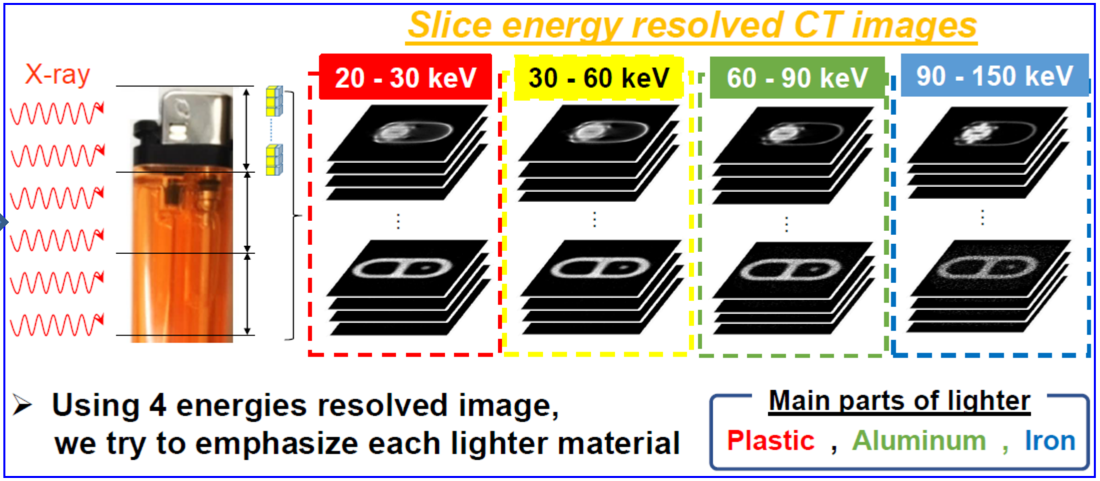


Takuya Maruhashi et al. Evaluation of a novel photon-counting CT system using a 16-channel MPPC array for multicolor 3-D imaging

MPPC in Photon Counting -CT system



Photon counting – CT:
- Multicolor image
- Material Identification

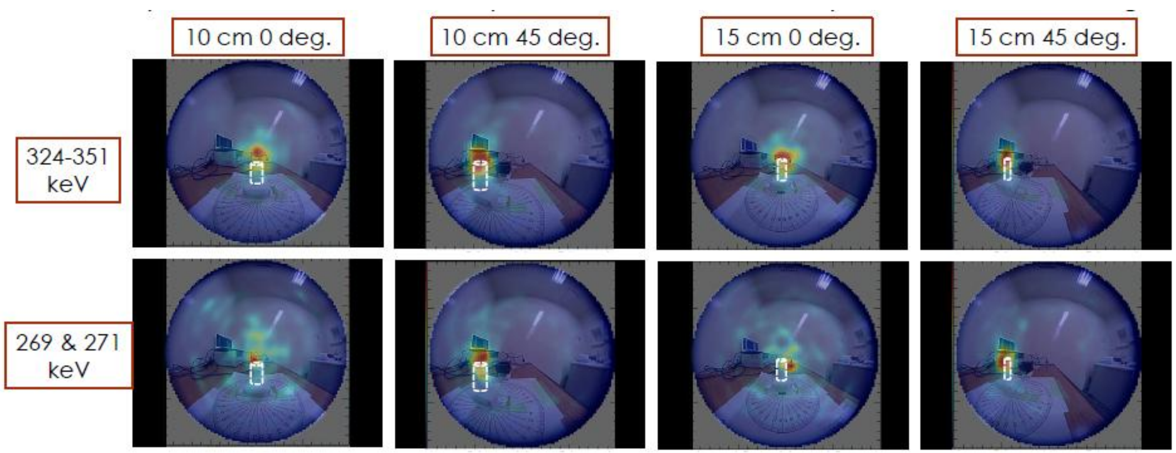


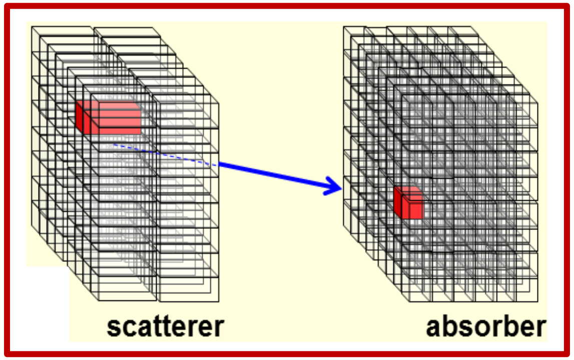
Kazuya Fujieda et al. First demonstration of portable Compton camera to visualize 223-Ra concentration for radionuclide therapy

Constitution of DOI-CC
- Scintillator: Ce:GAGG arrays (Ce-doped $Gd_3Al_2Ga_3O_{12}$)
- Photon detector: 8×8 MPPC arrays (Multi-pixel photon counter)
- Two couples of Ce:GAGG and MPPC @ scatterer
- One Ce:GAGG sandwiched with two MPPC @ absorber

	Scatterer	Absorber
Crystal size	2.0×2.0×4.0 mm^3	2.0×2.0×2.0 mm^3
Array	11 × 11 arrays 2 × 2 set	11 × 11 arrays 2 × 2 set
Layer	2	10

- A small bottle filled with Ra-223
- Reconstruct the true position of Ra-223 correctly





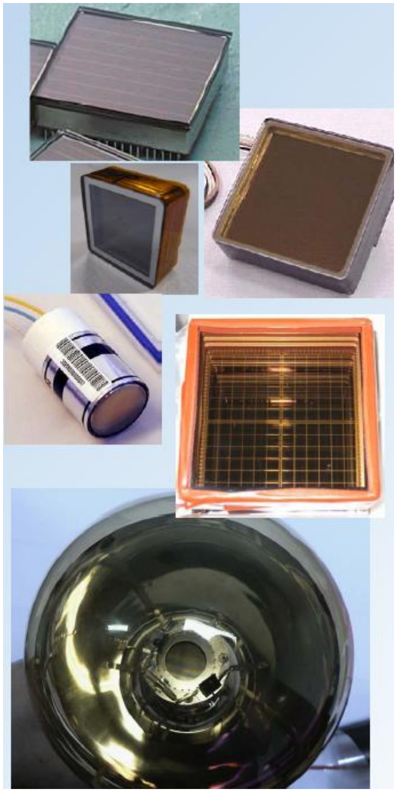
PMTs

Review of vacuum photodetectors

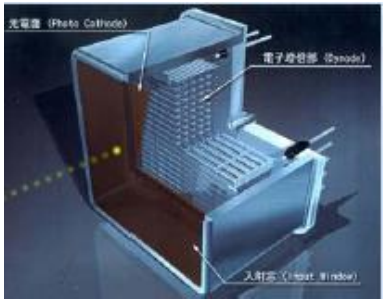
Samo Rorpar. Advanced vacuum photodetectors and their applications

Photosensors comparison table

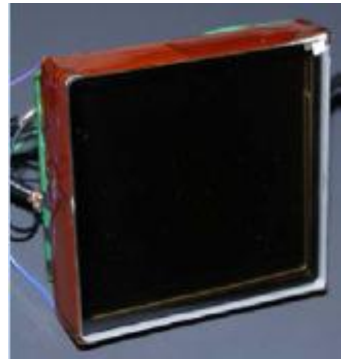
	Peak PDE	QE range	Gain	ENF	single photon?	TTS	B	Rad. Hard.	Ageing
PD	$\approx 100\%$		1	1	NO	-		OK	
APD	$\approx 80\%$	UV-IR	< 1000	> 2	NO	-	OK	OK (gain, DC noise?)	OK
SiPM	$\approx 60\%$		$\approx 10^6$	$\approx 1-1.2$	YES (dark counts?)	$\approx 50ps$			
PMT			$\approx 10^7$	$\approx 1.1-1.5$		$\approx 200ps$	$\approx 0.1\ mT$		
MA-PMT	$\approx 35\%$		$\approx 10^7$	$\approx 1.1-1.5$		$\approx 150ps$	$\approx 10\ mT$		OK
MESH-PMT			$\approx 10^6$	$\approx 1.1-2$	YES	$\approx 100ps$	$\approx 2\,T$ (axial)	HIGH (window?)	
MCP-PMT	$\approx 25\%$	UV-IR	$\approx 10^6$	$\approx 1.1-2$		$\approx 20ps$	$\approx 2\,T$ (axial)		OK? (ALD)
VPT	$\approx 25\%$		≈ 10	≈ 2	NO	-	$\approx 2\,T$ (axial)		OK
HPD	$\approx 40\%$		≈ 5000	$\approx 1-1.1$	NO	-	OK (axial)	OK	OK
HAPD	$\approx 40\%$		$\approx 10^5$	$\approx 1-1.1$	YES	$\approx 30ps$ (@high gain)		OK (DC noise?)	
CsI MWPC	$\approx 25\%$	UV	$\approx 10^5$	≈ 2	YES	$\approx 10ns$	OK	HIGH	IBF?
CsI MPGD	$\approx 20\%$	UV	$\approx 10^6$	$\approx 1.2-2$	YES	$\approx 100ps$			



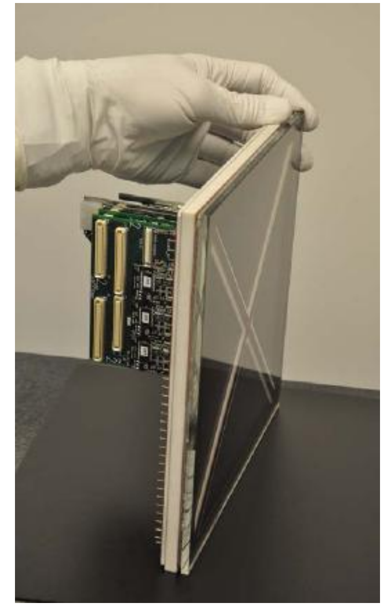
Metal channel dynode PMT



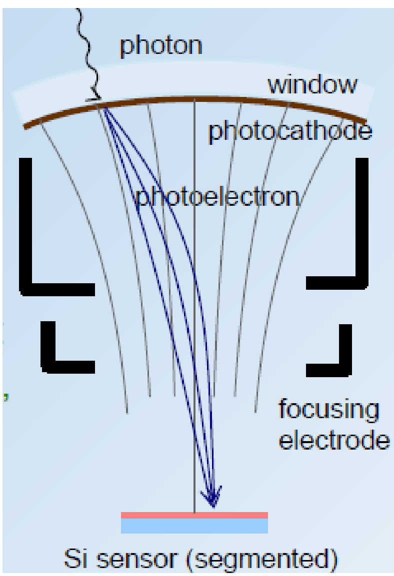
MCP- PMT



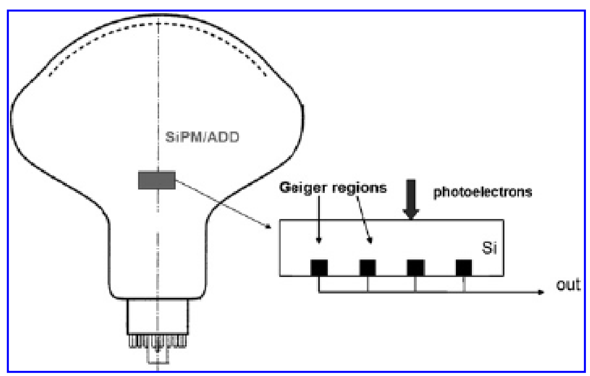
LAPPD



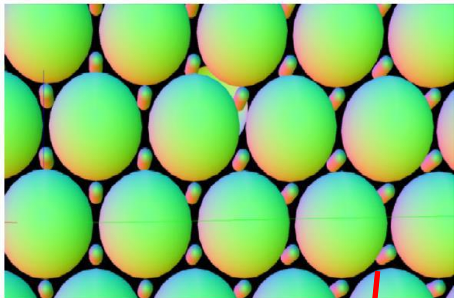
HPD, HAPD



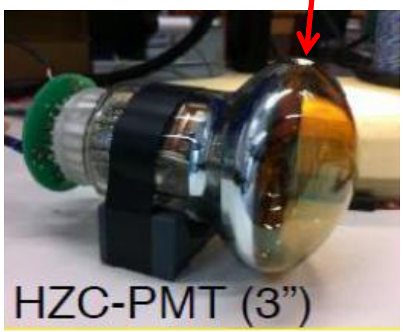
VSiPM



Reactor neutrino experiment JUNO



HZC Photonics (XP72B22)
Production rate: 2000/month
Gain (at JUNO): $3\ 10^6$
QE x CE (at 420nm): 24%
SPE Resolution: 35%
Dart Rate at ¼ PE: 1kHz
Transit Time Spread: 5ns



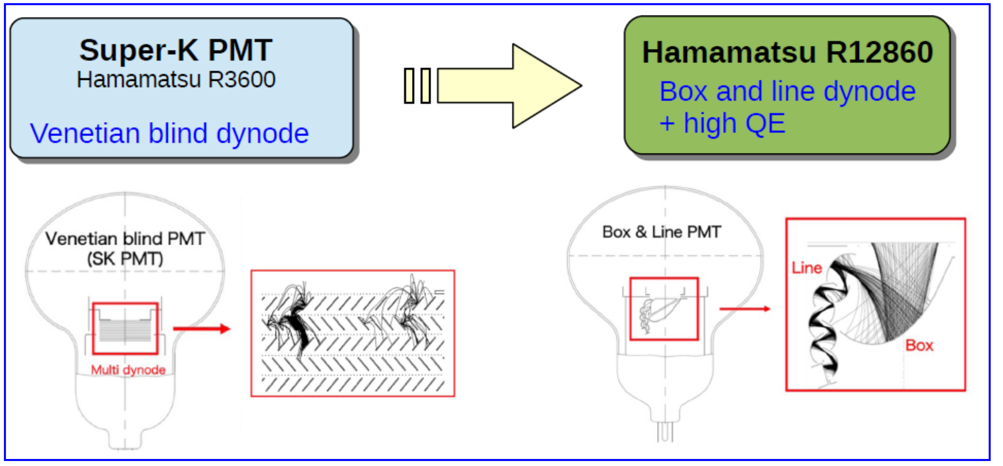
CATIROC general features
16 independent channels
Analog F.E. with **16 trigger outputs + charge and time digitization**
Autotrigger mode: all the PMTs signals above the threshold (1/3 p.e.) generate a trigger and are converted in digital data
100% trigger efficiency @ 1/3 p.e.
Dual gain front-end: HG and LG channel Charge dynamic range 0 to 400p.e. (at PMT gain 10^6)
Time stamping (resolution ~ 170 ps rms)
Each channel has a **variable gain**
One output for **DATA**
Hit rate 100 kHz/ch (all channels hit) **50 bits of data / hit channel**

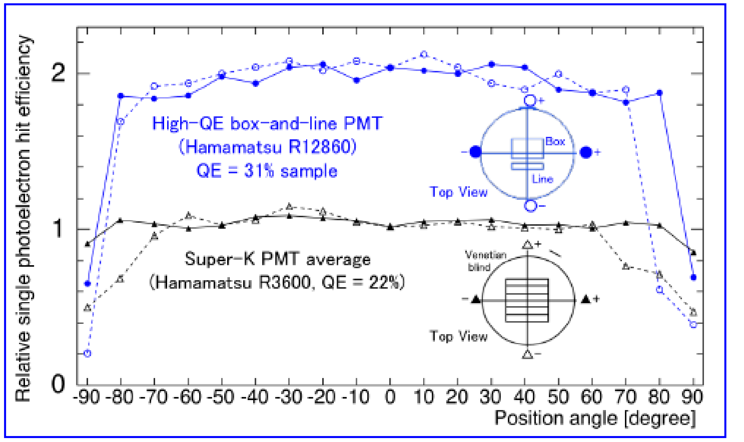
100% trigger efficiency @ **1/3 p.e.** (50 fC @ PMT gain 10^6)

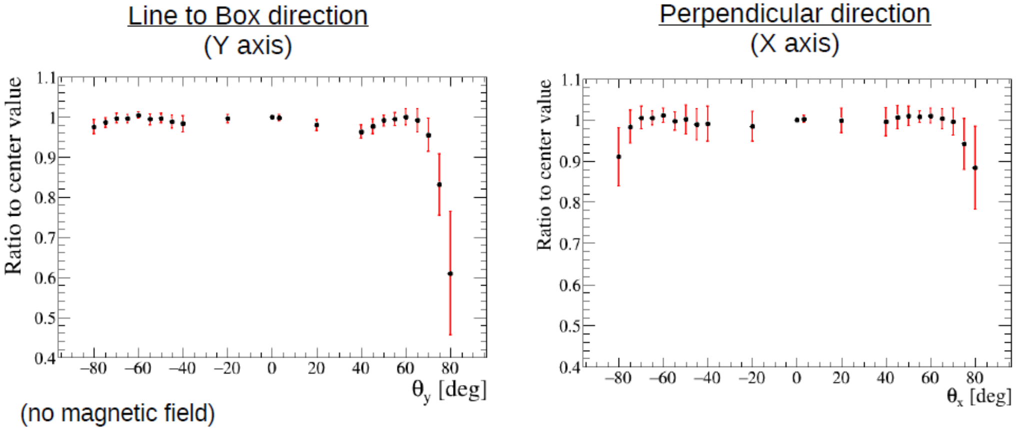
Charge resolution (**only HG used**) : 1.5 ADCu ~ **15 fC** (160fC @ PMT gain 10^6)

Time resolution= **167 ps rms**

Christophe Bronner et al. Performance of the Hyper-Kamiokande 20” PMT







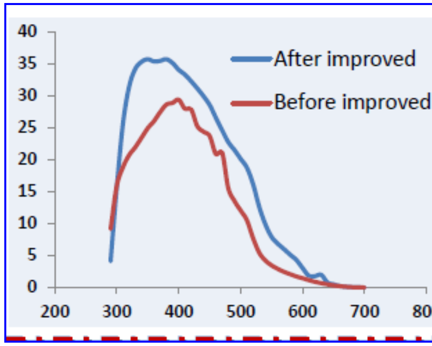
(no magnetic field)

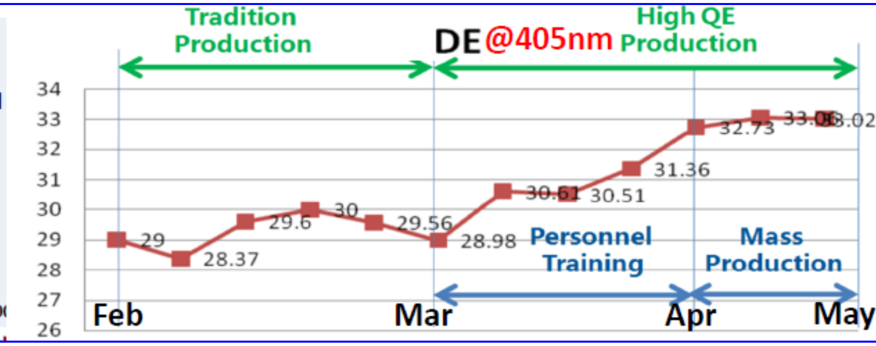
Improved performance compared to SK PMT:

- ~2x photo-detection efficiency
- TTS: 6.73 ns → 2.59 ns (FWHM)
- Charge resolution: 60.1% → 30.8%

136 of those PMTs have been installed in Super-Kamiokande
All of them passed Hyper-Kamiokande requirements in pre-installation measurements

Ling Ren. Mass Production of MCP-PMT for JUNO and Development of 20-inch MCP-PMT





>7000 PMTs delivered to JUNO

PMTs	MCP-PMT prototype	~300 MCP-PMTs	~1000 MCP-PMTs	~7392 MCP-PMTs
DE @ Gain~1E7	26%	28.9%	29.3%	30.2%
Uni-QE @ 405nm	< 10.5%	8.1%	7.8%	7.3%
Dark count rate@ 0.25 PE	30.0 kHz	33.5 kHz	36.9 kHz	38.2 kHz
Peak valley ratio	5.6	8.2	7.1	7.1
Energy resolution	41%	30.9%	33.1%	30.1%
High voltage	1930V	1780V	1767V	1747V
Rise time	1.2ns	1.4ns	1.4ns	1.4ns
After pulse rate	2.5%	1.2%	0.8%	0.6%
Linearity <10%	1000 P. E.	1175 P. E.	1160 P. E.	1308 P. E.

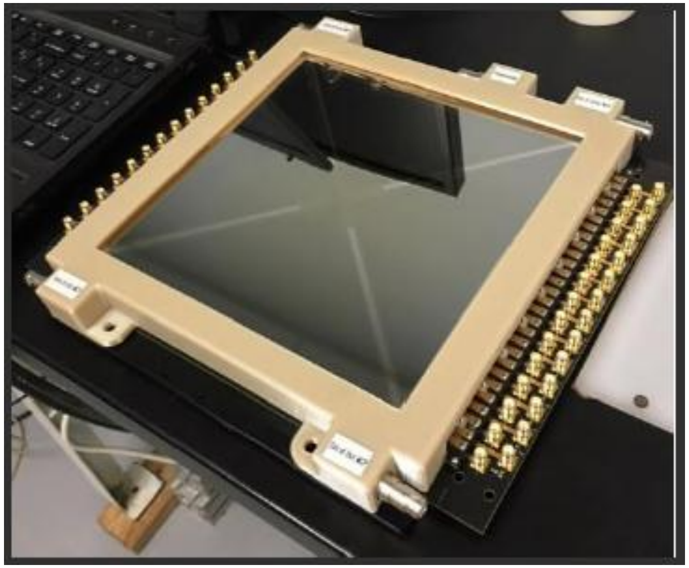
TTS improvement

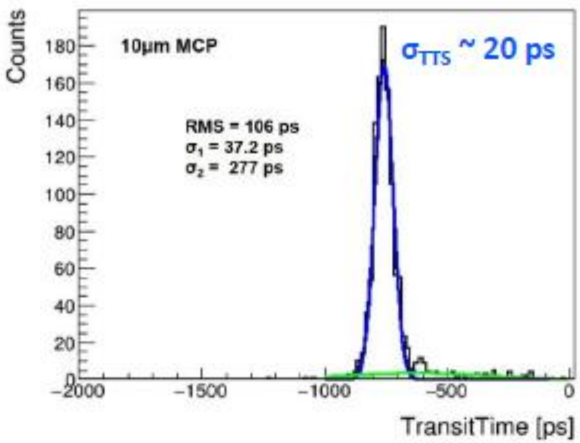
	Normal focusing electrode	Flower-like focusing electrode
QE	~30%	~30%
CE	~98%	~85%
P/V	~7	~5
TTS	~14ns	~5ns

Junqi Xie. Fast-timing microchannel plate photodetectors: design, fabrication and characterization

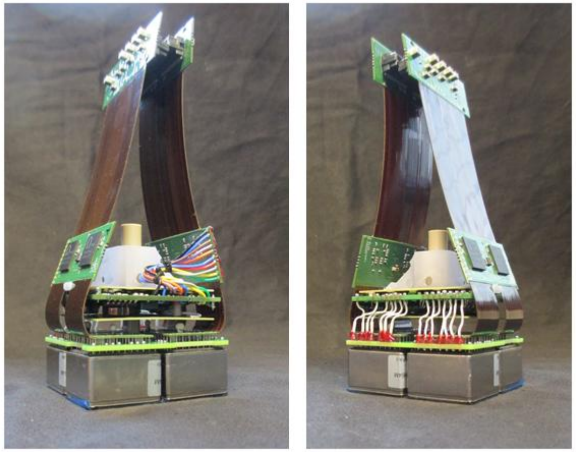
Conventional Pb-silicate glass MCP: Based on optic fiber production, chemical etching and thermal processing

"Next generation" MCPs. Break through 1: Productionof large blocks of hollow, micron-sized glass capillary arrays (GCAs) based on the use of hollow capillaries in the glass drawing process. Break through 2: Functionalization of the glass capillary arrays with atomic layer deposition (ALD) methods





Guillaume Prevot et al. A detection unit designed for the study of the UHECRs from space



Light (500g)
compact (55mm x 55mm x 55mm) detection unit:

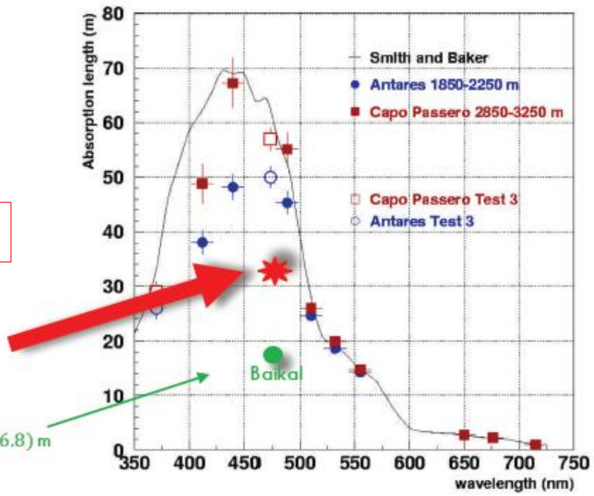
- 256 pixels
- photocounting
- GTU = 1μs
- linear from 1/3 pe to 130 pe
- consumption = about 250mW
- including HVPS & safety switches
- potted (arathane resin)
- two 100 pins output connectors

Immacolata Carmen Rea. STRAW - Strings for Absorption Length in Water

STRAW: investigation of deep-sea water optical properties (scattering length, absorptionl ength, evironmental background) feasibility studies for a large scale *Neutrino Telescope at Cascadia Basin* (2600m b.s.l.)

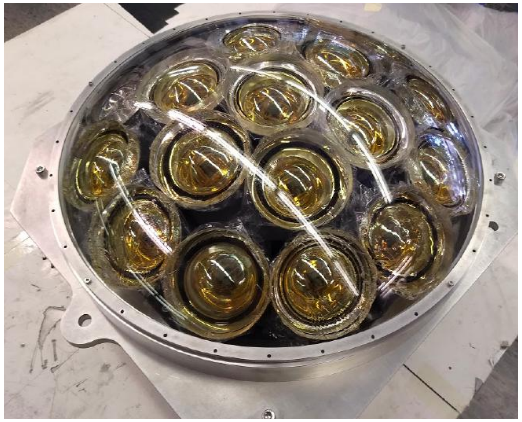
Preliminary

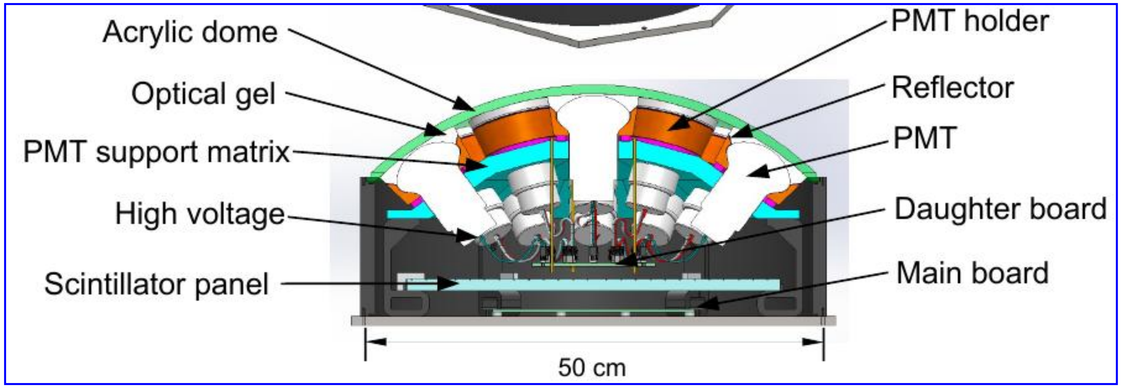
λ_{abs} (465 nm): 31.4 m ± 3.0 m (stat.) ± 5.0 m (sys.)



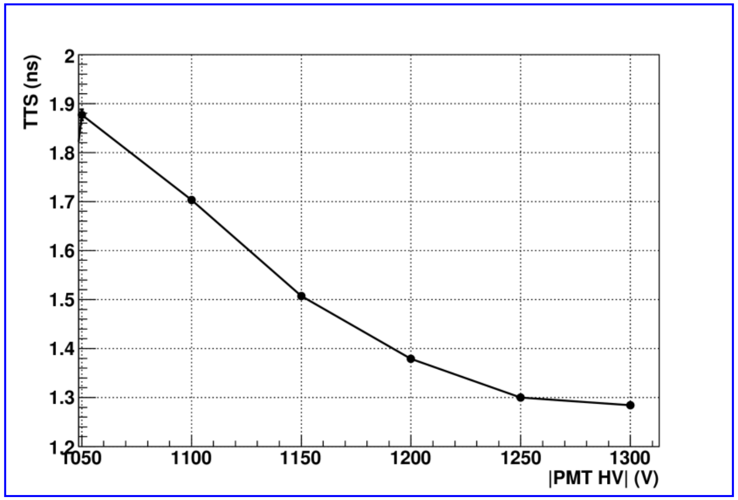
λ_{att} (470,525nm) = (17.2 ± 6.8) m

Benjamin Quilain. A multi-PMT photodetector for the Hyper-Kamiokande experiment

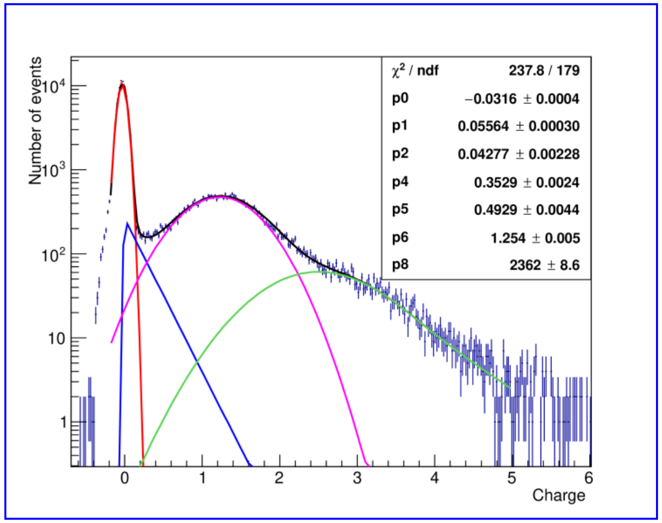




TTS < 1.5 ns



Gain = 10^7



Stephane Zsoldos. Large Area Photo-Detection System using 3-inch PMTs for the Hyper-Kamiokande Outer Detector

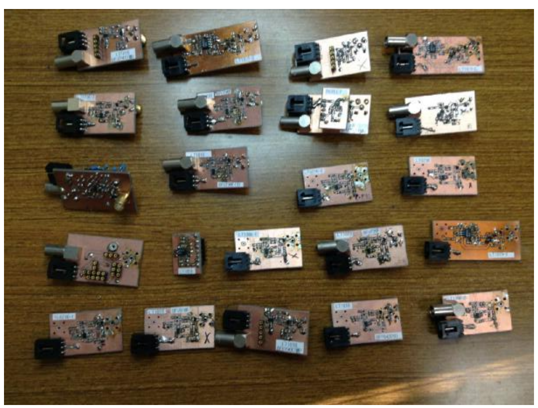
Candidates for OD

Measurements of dark rate

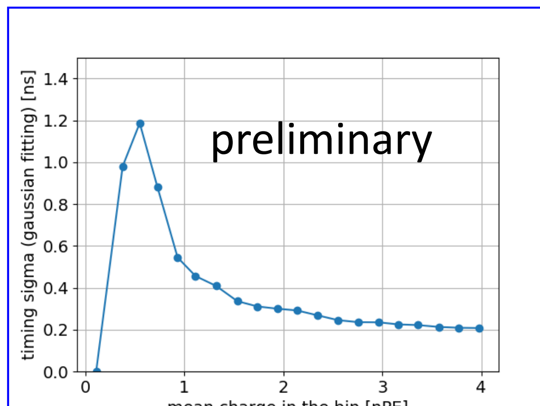
Model	Gain	Dark rates	PE Res
R14374	$2.7 \pm 0.1 \times 10^6$	210 ± 80 Hz	30%
R14374HA	$3.3 \pm 0.1 \times 10^6$	290 ± 60 Hz	21%
R14689 (3.5")	$2.8 \pm 0.1 \times 10^6$	250 ± 100 Hz	17%
R14689HA (3.5")	$2.9 \pm 0.1 \times 10^6$	240 ± 90 kHz	18%

Met requirements for dark counts in OD

Kotoyo Hoshina. Calibration and Development of preamplifier for 8-inch Hybrid Photo Detector

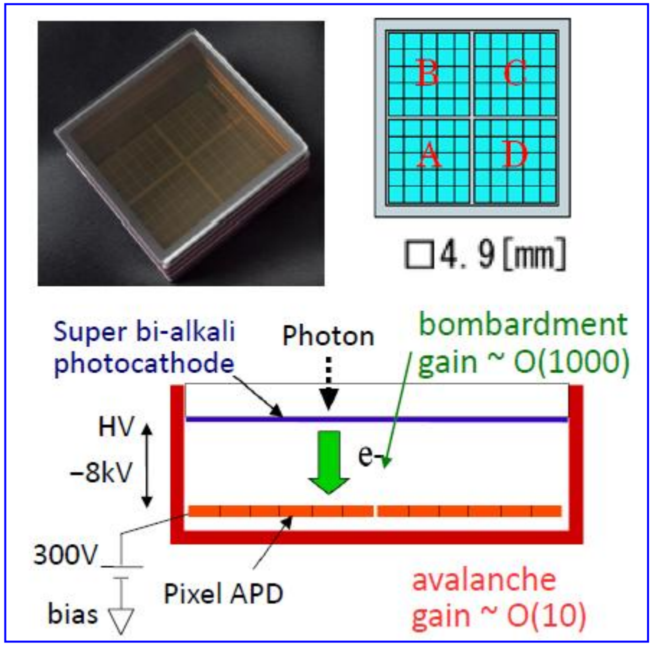


Time resolution



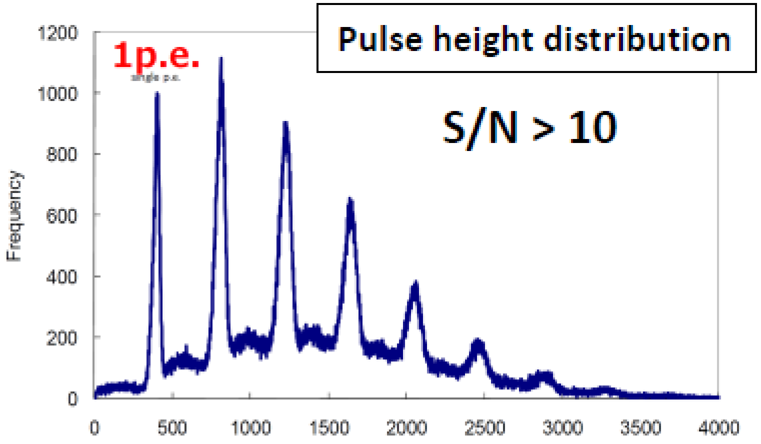
Tomoyuki Konno. Performance estimation of the Belle II Aerogel RICH counter in the first beam collision

HAPD

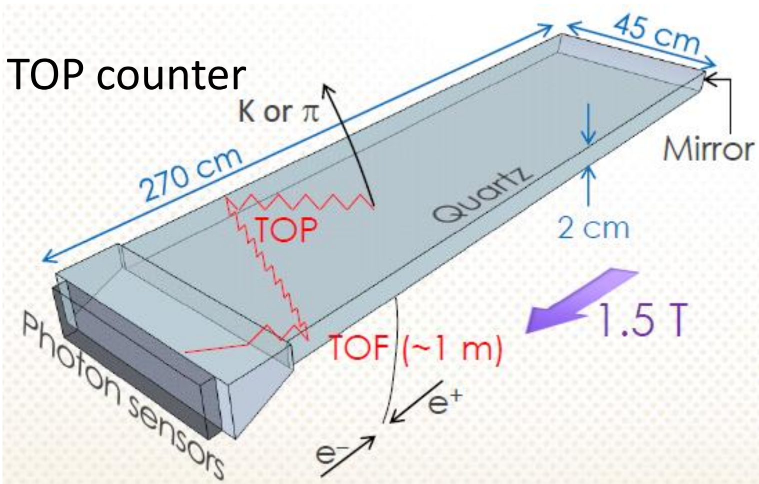


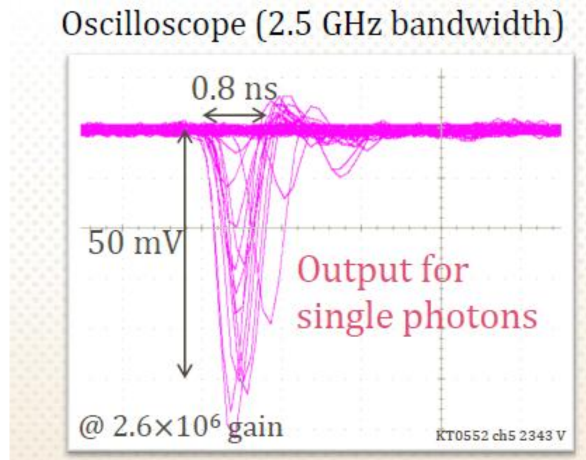
HAPD specification

Parameter	Requirements
Size	72 x 72 mm^2
# of pixels	144 ch (36 x 4 ch)
Pixel size	4.9 x 4.9 mm^2
Effective area	64 %
Peak Q.E.	28 %
Dark current	< 1 μA
HV	-8500V
Total gain	> 45000

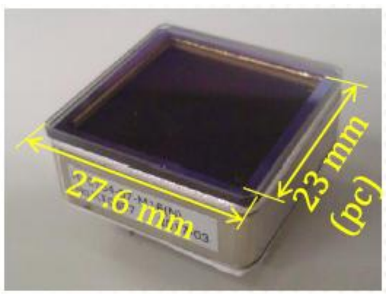


Kodai Matsuoka. Performance of the MCP-PMTs of the TOP counter in the first beam operation of the Belle II experiment





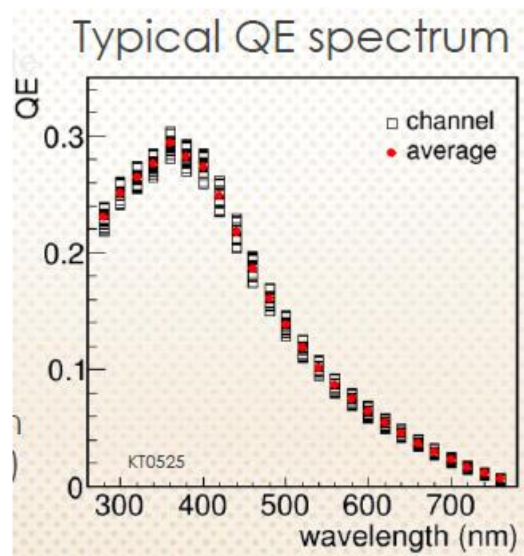
The best time resolution (σ~30 ps) of photon sensors



~34 ps TTS for every PMT

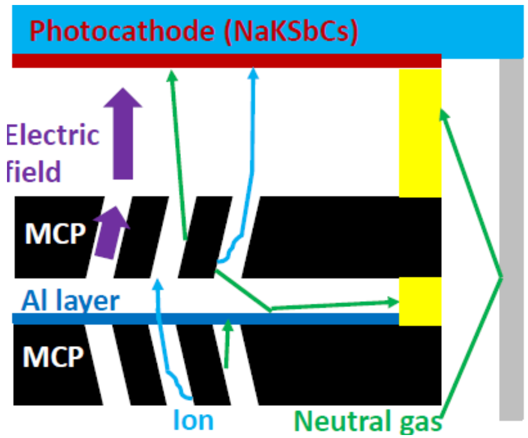
29.3% avg. QE at ~360 nm

Work in 1.5 T

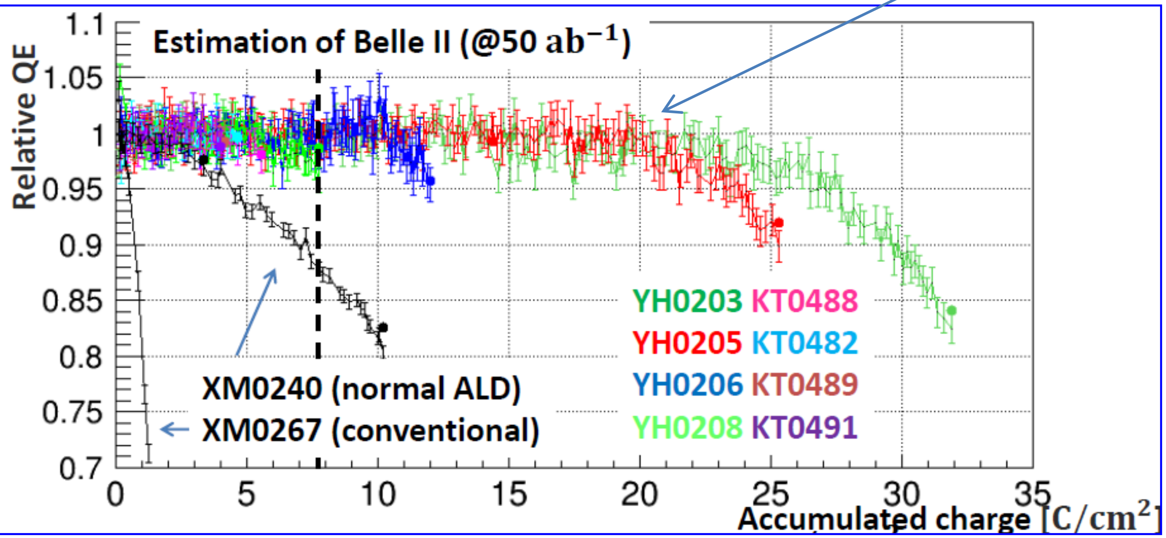


The photocathode is damaged by the neutral gases and feed backed ions emitted from MCPs.

Al coating →
Suppression of gas emission



Life extended ALD coating



For 3 years since PhotoDet15:

- great progress in Semiconductor and Vacuum Photosensors
- very active field
- new applications/ideas in physics, medicine, industry….

We sincere thank
the organizers of PD18

Wataru Ootani, Masashi Yokoyama

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A.Oya, T.Torimaru, N.Tsuji

Secretaries:
K.Kono, M. Takemoto, M. Shiota, Y.Kase

Co-organizer institutions

Supporting companies