

Introduction to MPPC as a Photon Counting Device and Its Development

Yoichiro Ishikawa
Manuf.#2, Dept.#30, Solid State Division
Hamamatsu Photonics K.K.

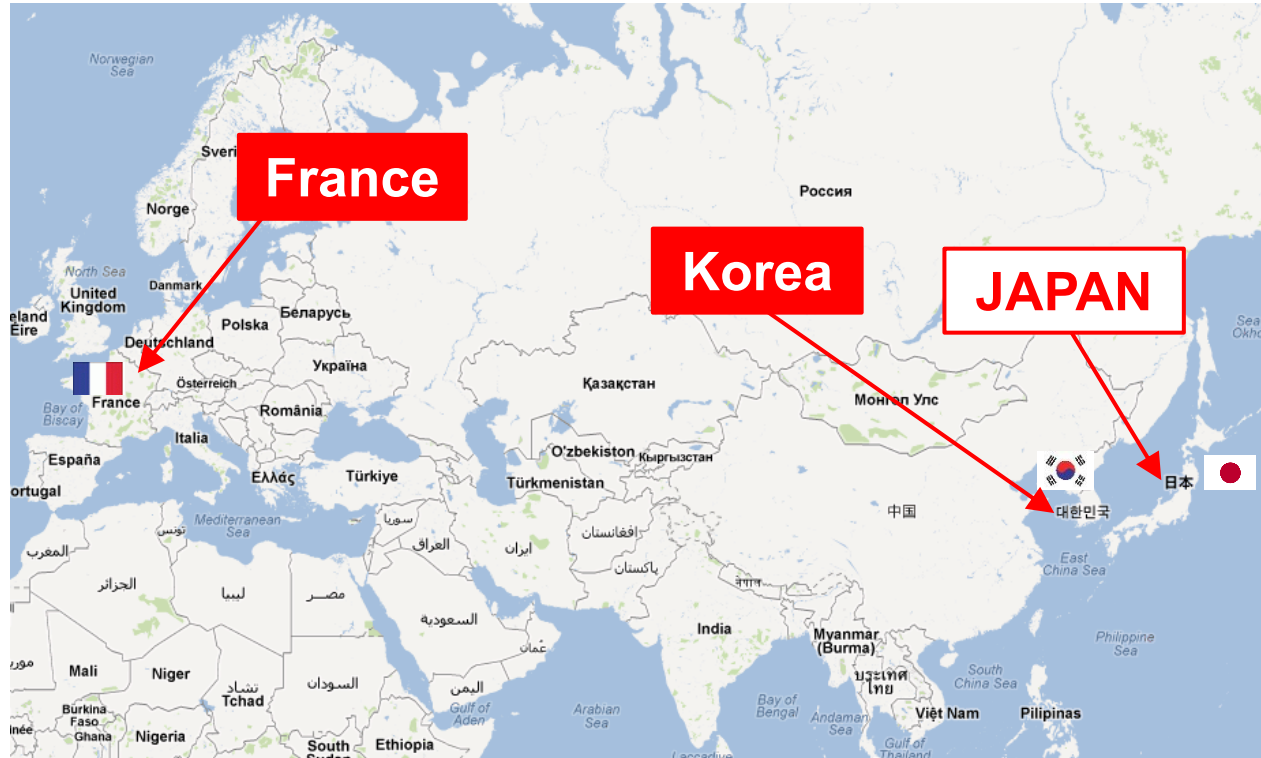
Mar.18. 2026

Index

- About HAMAMATSU
- Product introduction for MPPCs
 - Comparison of Optical Semiconductor Devices and Photomultiplier Tubes
 - Introduction for MPPCs in academic field
 - Development

About HAMAMATSU

Location



HAMAMATSU CITY
Population: 775,609
(As of 1st May, 2026)



Eel (Unagi)

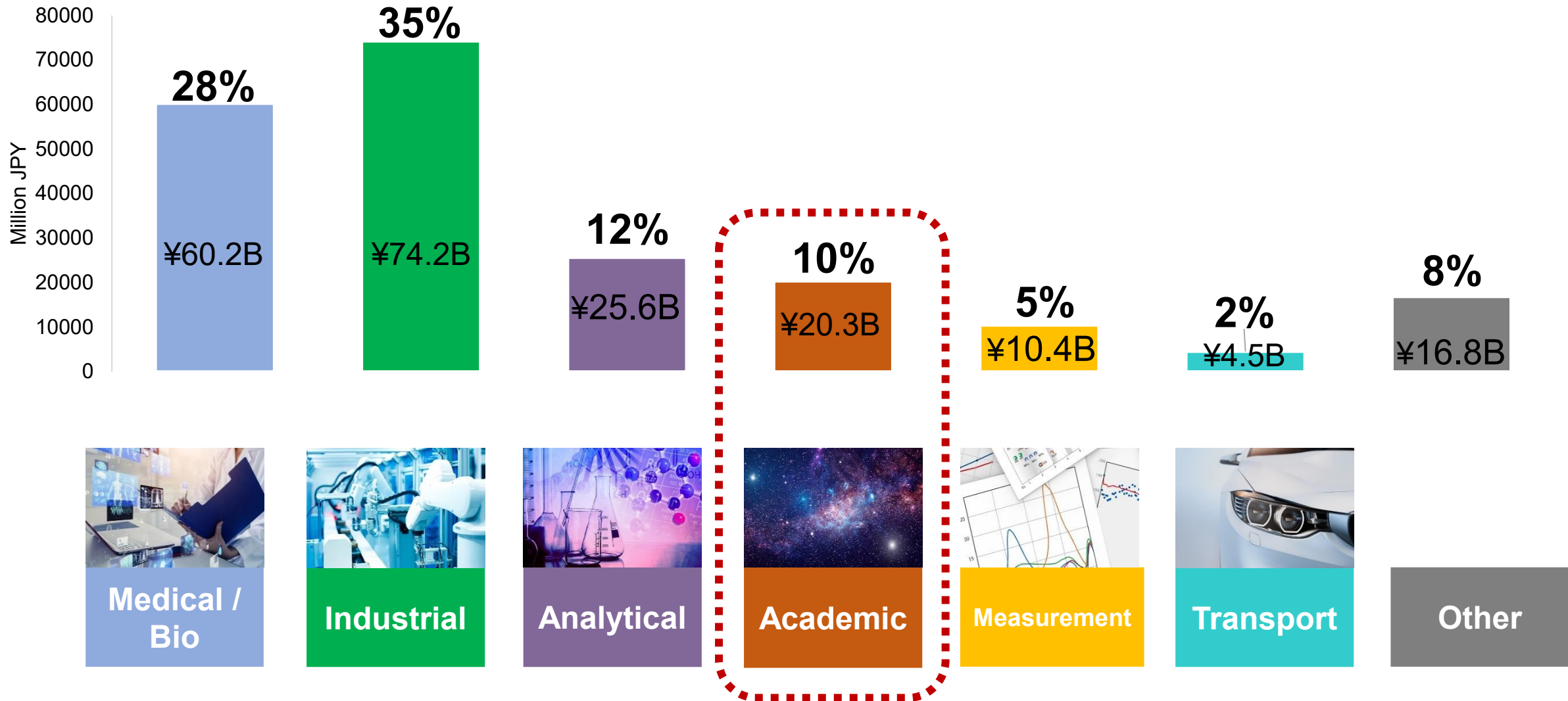


Dumpling (Gyoza)

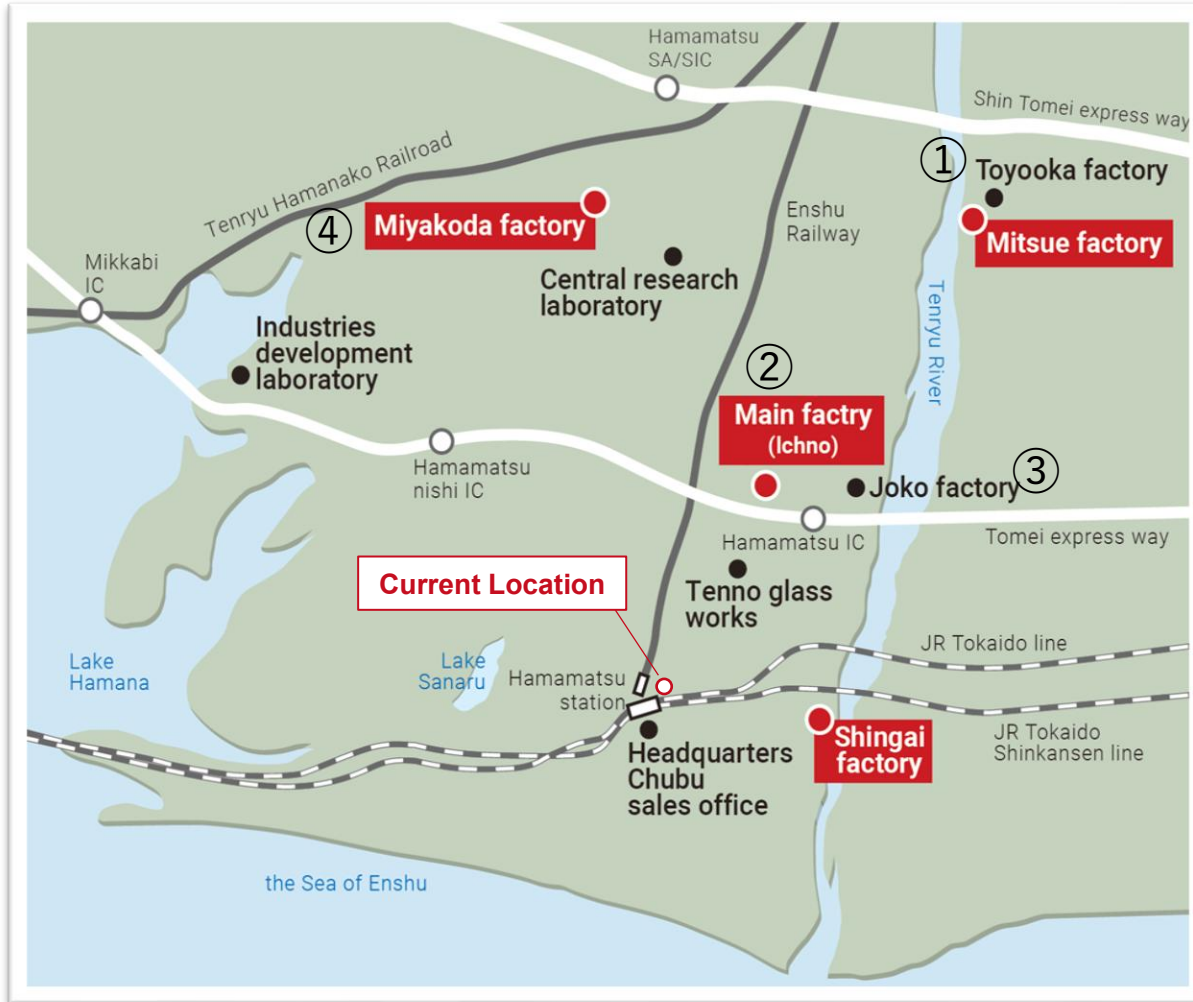
Light is possibility

Our mission is to benefit society through the development of technologies that capture, measure, and generate various types of light.

Consolidated Sales Trend by Major Applications



Factories



① Electron Tube Division (Toyooka factory)



② Solid State Division (Ichino main factory)



③ System Division (Joko factory)



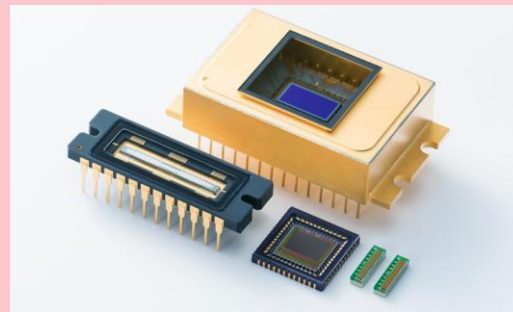
④ Laser Promotion Division (Miyakoda factory)

Four Core Divisions

- Hamamatsu designs, develops, and manufactures high-performance sensors and light sources to provide various solutions that take advantage of light.
- Each division possesses specialized technology and conducts cutting-edge research and development to evolve optical technology every day.



**Electron Tube
Division**
Photomultiplier Tube,
Lamp



**Solid State
Division**
Opto-
Semiconductor



System Division
Camera,
Image Processing
Equipment



**Laser Promotion
Division**
Laser Products

About my team!

Solid State Division Opto-Semiconductor



Si Photodiodes,
Si APDs, MPPC, SSD

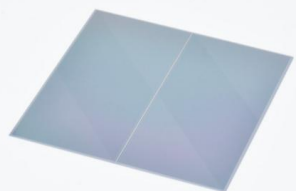
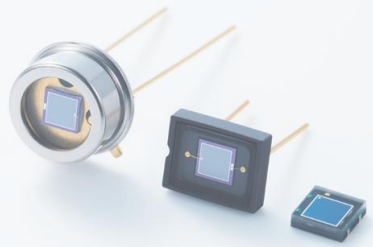


Photo ICs

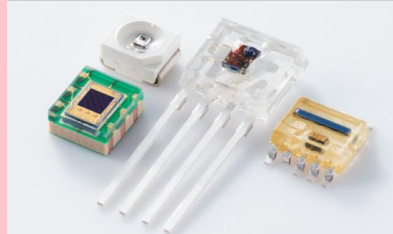


Image sensors



Infrared
detectors



Modules



Product introduction for MPPCs

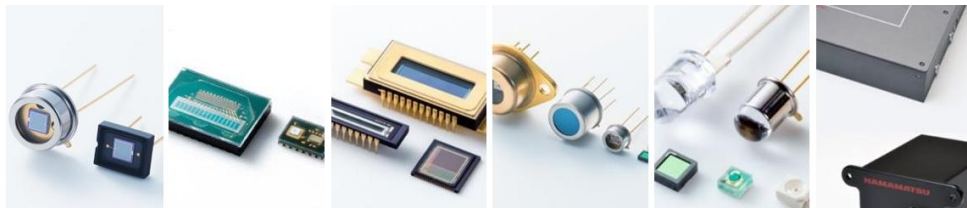
- Comparison of Optical Semiconductor Devices and Photomultiplier Tubes
- Introduction for MPPCs in academic field
- Development

Product introduction for MPPCs

- Comparison of Optical Semiconductor Devices and Photomultiplier Tubes
- Introduction for MPPCs in academic field
- Development

Hamamatsu Photonics' photon counting devices

Solid State Division



- Semiconductor photon counting device
PD, APD, SPAD, SiPM=MPPC,...etc

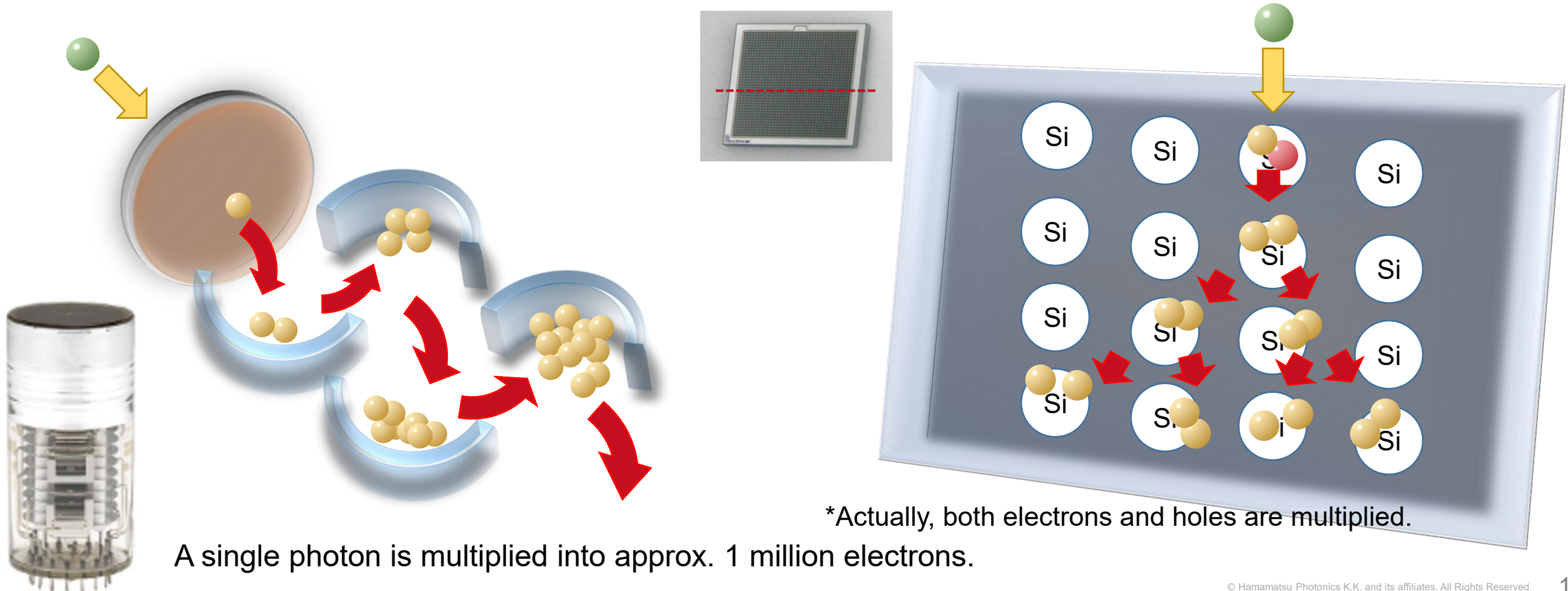
Electron Tube Division



- Photomultiplier tube

Semiconductor photon counting device

- Photomultiplier tube: Photo-electron is multiplied at dynodes.
- Semiconductor photon counting device: Hole-electron pairs are multiplied in chip.



- Photodiode : **PD**

Converting photons to hole-electron pairs (w/o multiplication)

- Avalanche photodiode : **APD**

Electrons are multiplied into 10 to 100 times by internal electrical field.
Operated under well controlled state called as leaner mode.

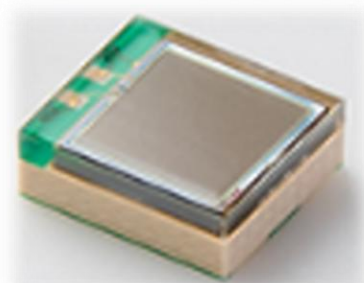
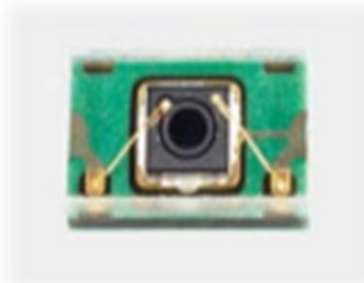
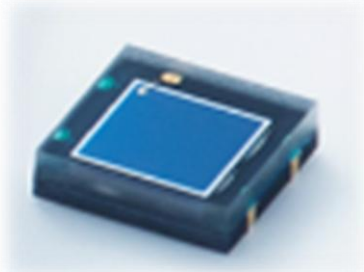
- Single photon avalanche photodiode : **SPAD**

Using APD under strong electrical field. Operated under a kind of out-of-controlled state called as Geiger-mode. A single photoelectron is multiplied into 1 million electrons.

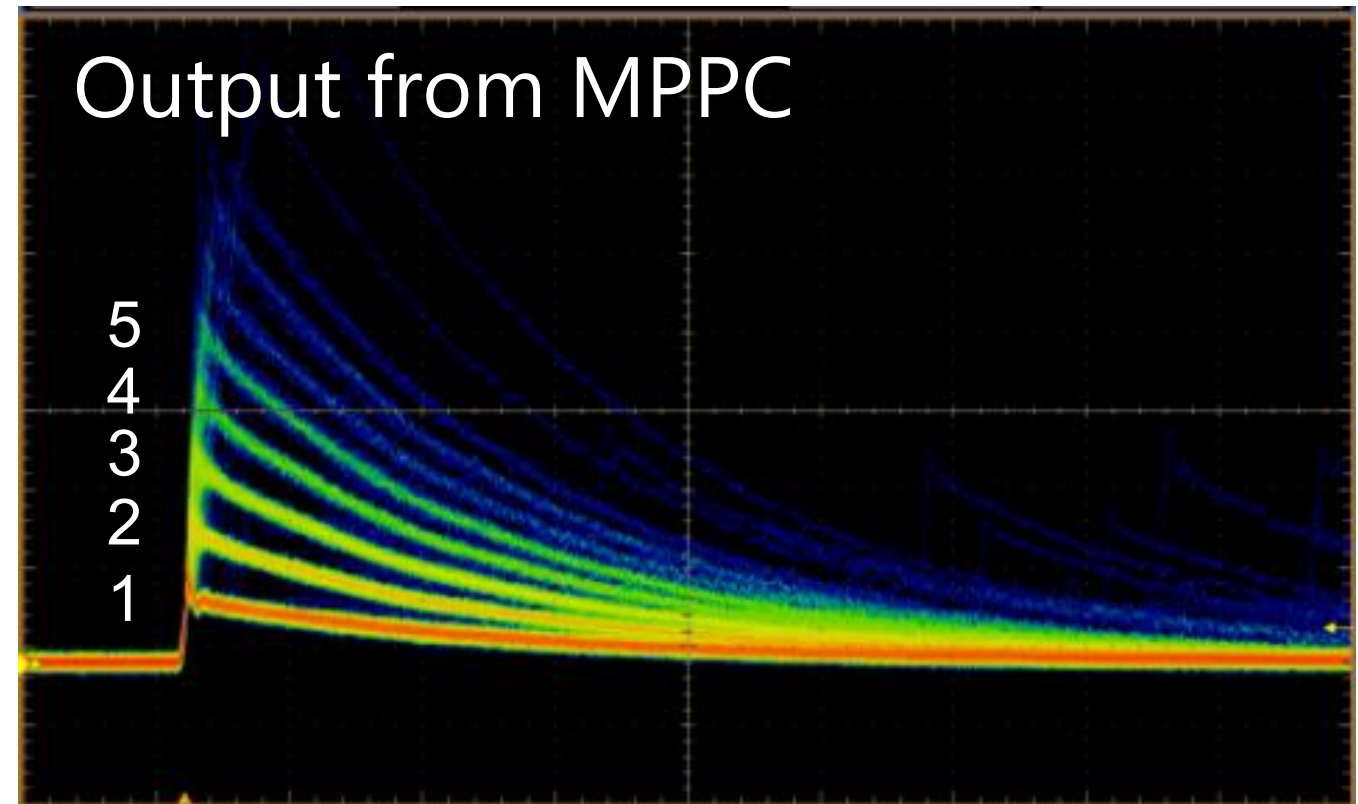
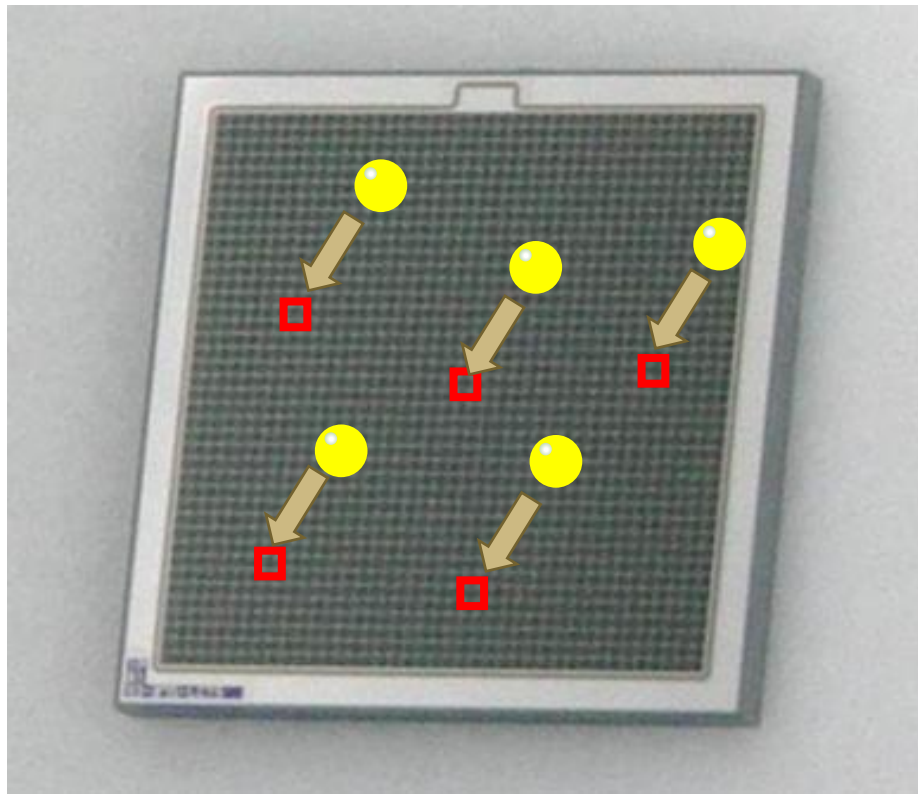
- Silicon photomultiplier : **SiPM**

= **MPPC** (Multi-pixel photon counter)

The device that a lot of SPADs are connected in parallel.
It can count number of photons at same time.



- MPPC is the device that a lot of SPADs are connected in parallel.
 - Improve the weakness of SPAD (SPAD can't count photons at same time)
 - Each SPADs are called as “pixel” or “micro cell”.



Pros

- **Small + light weight**
There is smaller product than 2 mm Sq.
- **Low voltage operation**
Operation voltage :40 – 60 V
- **High sensitivity**
PDE :50% (max.)
- **Good timing resolution**
Single photon timing resolution < 200 ps
- **Insensitive to magnetic fields**
- **Mass productizable by semiconductor production line**
- **Robust**

Cons

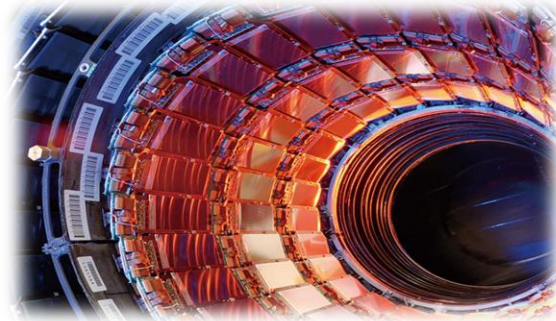
- **Difficult to make large size device**
Maximum size: 10 x 10 mm² /ch.
- **Large dark count**
Derived from the physical properties of Si.
It can be improved by cooling.
- **Limitation of dynamic range**
Number of total pixels
= Maximum countable photons at the same time
- **Long recharge time**
Several 10 ns – 100 ns
- **Temperature dependence of operation voltage**
Several 10 mV/°C. Need to the temperature compensation of applied voltage.

Product introduction for MPPCs

- Comparison of Optical Semiconductor Devices and Photomultiplier Tubes
- Introduction for MPPCs in academic field
- Development

Application of MPPC

PET scanner



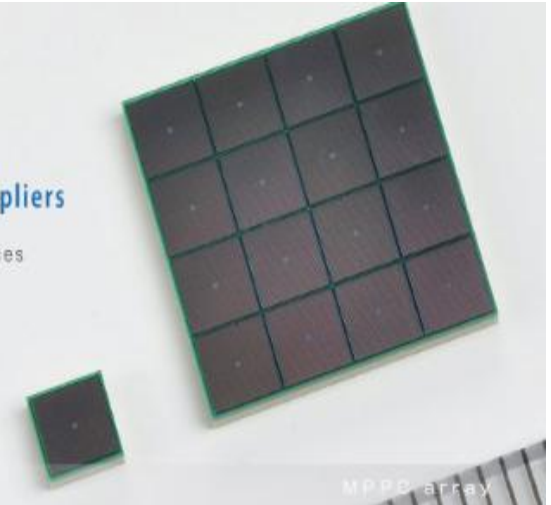
High energy physics



MPPC[®]
Multi-Pixel Photon Counter

Silicon Photomultipliers

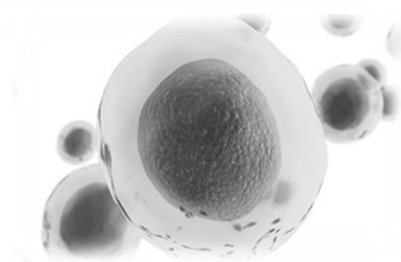
Photon-counting devices with low afterpulsing, low crosstalk, and wide dynamic range



LiDAR

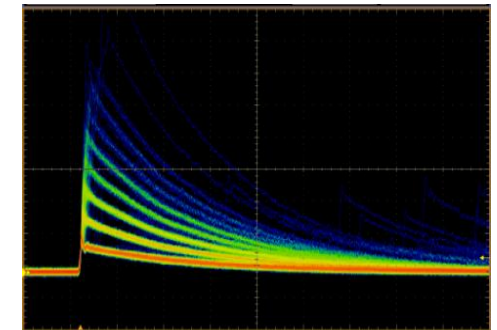


Radiation monitor



Biological measurement

- Compact / thin
- Low bias voltage
- High PDE
- No ageing degradation
- Insensitive to magnetic fields



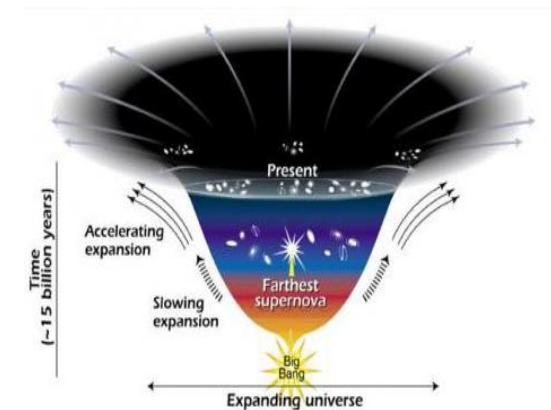
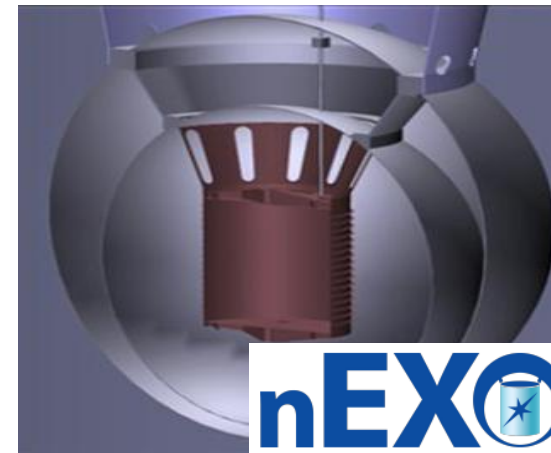
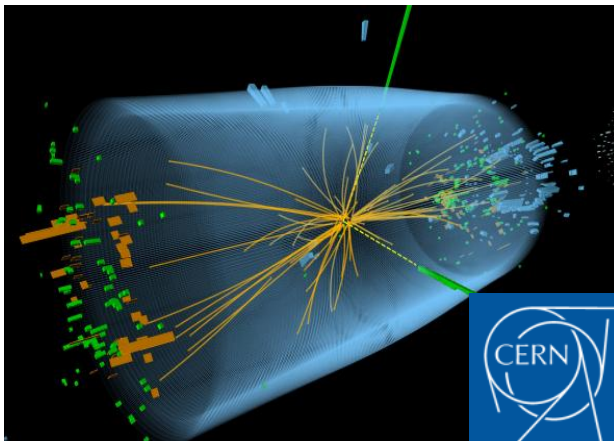
Application of MPPC

- Main field in academic

- Accelerators (especially calorimeter meters, SSD is used in tracking detectors.)
- Cherenkov light detection
- Neutrino & Dark matter search

- Academic Challenges & Requirements

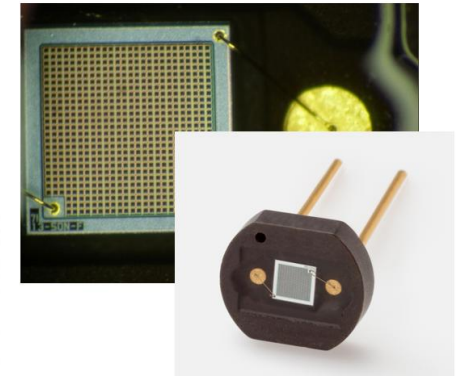
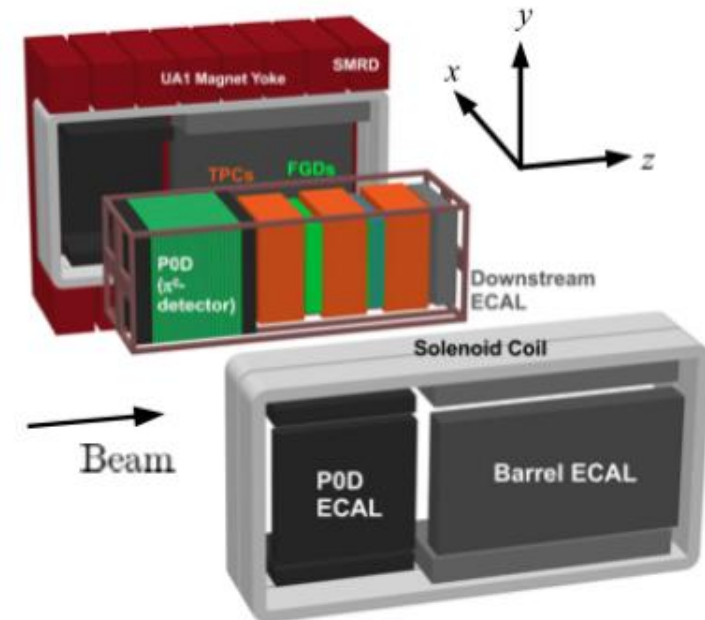
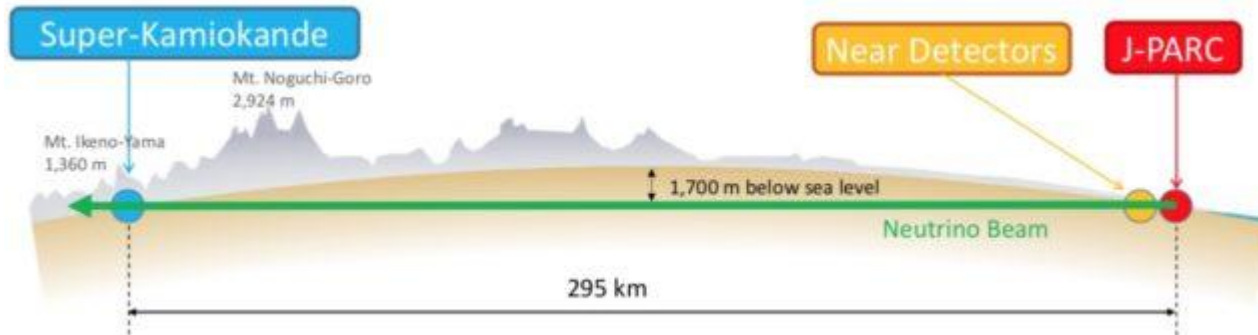
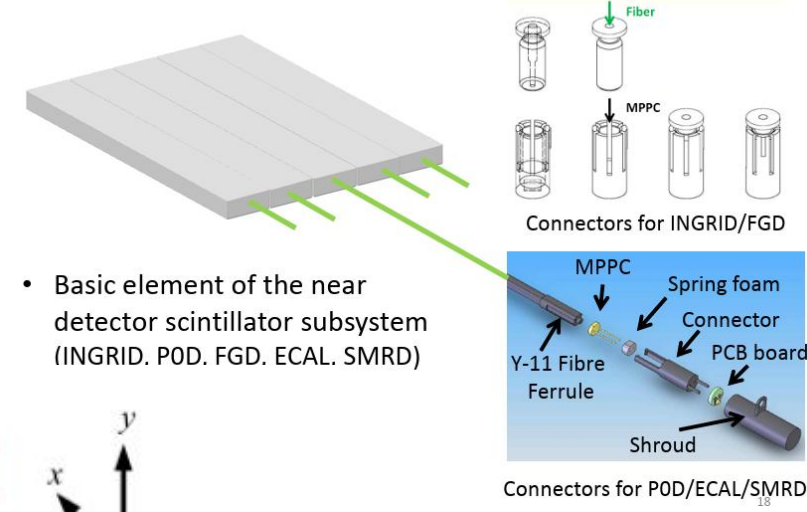
- Single-Photon sensitivity
- Magnetic field insensitivity
- High speed time resolution
- High-Density array



T2K Near Detector

- The adopted MPPC characteristics
 - Insensitive to magnetic fields: Operates in high-field environments.
 - Enables direct coupling to fiber ends within limited detector space.
 - Photon sensitive area: $1.3 \times 1.3 \text{ mm}^2$, pixels size $50\mu\text{m}$.

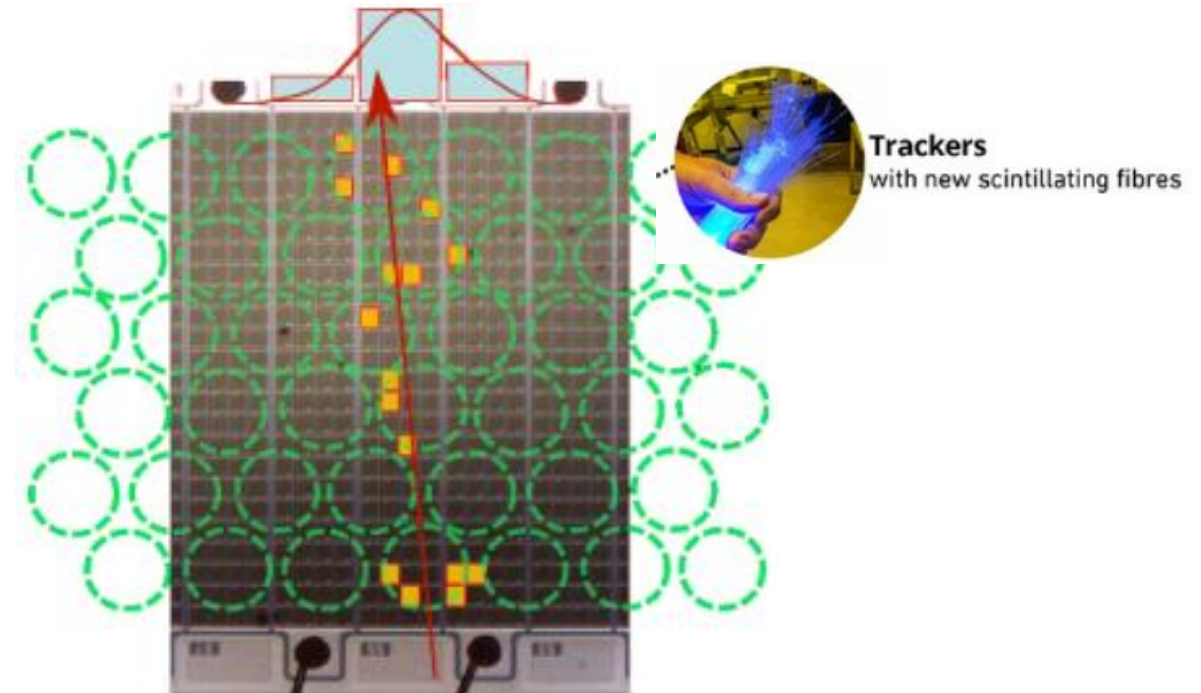
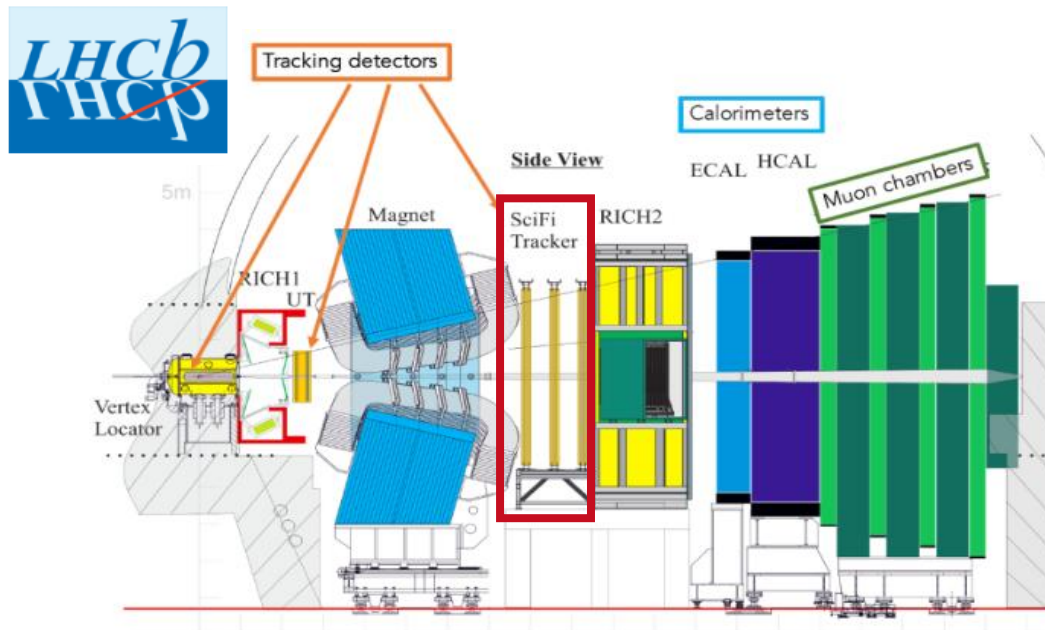
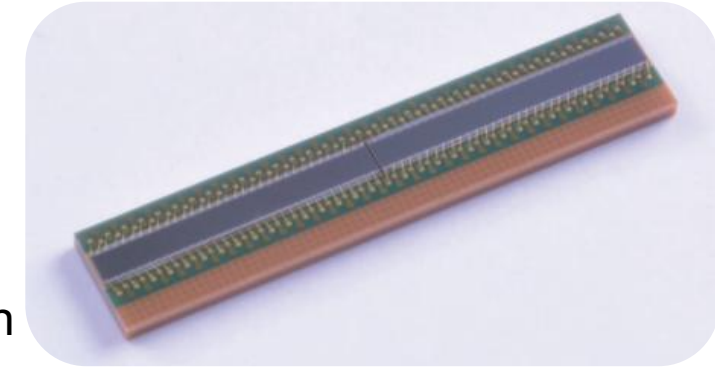
MPPC in T2K near detectors



Tracking Detectors: LHC/LHCb/Scifi Tracker

- MPPC design points

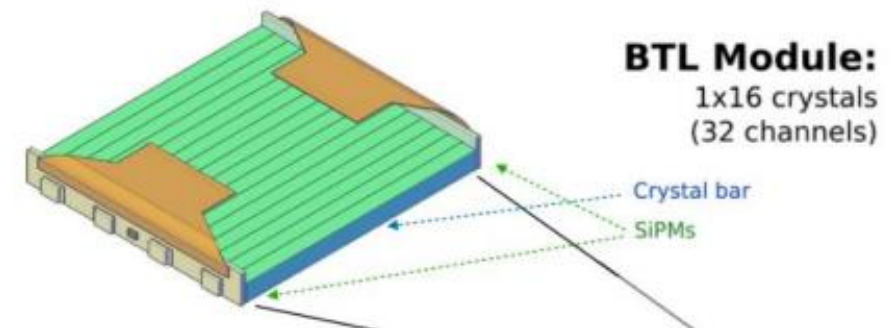
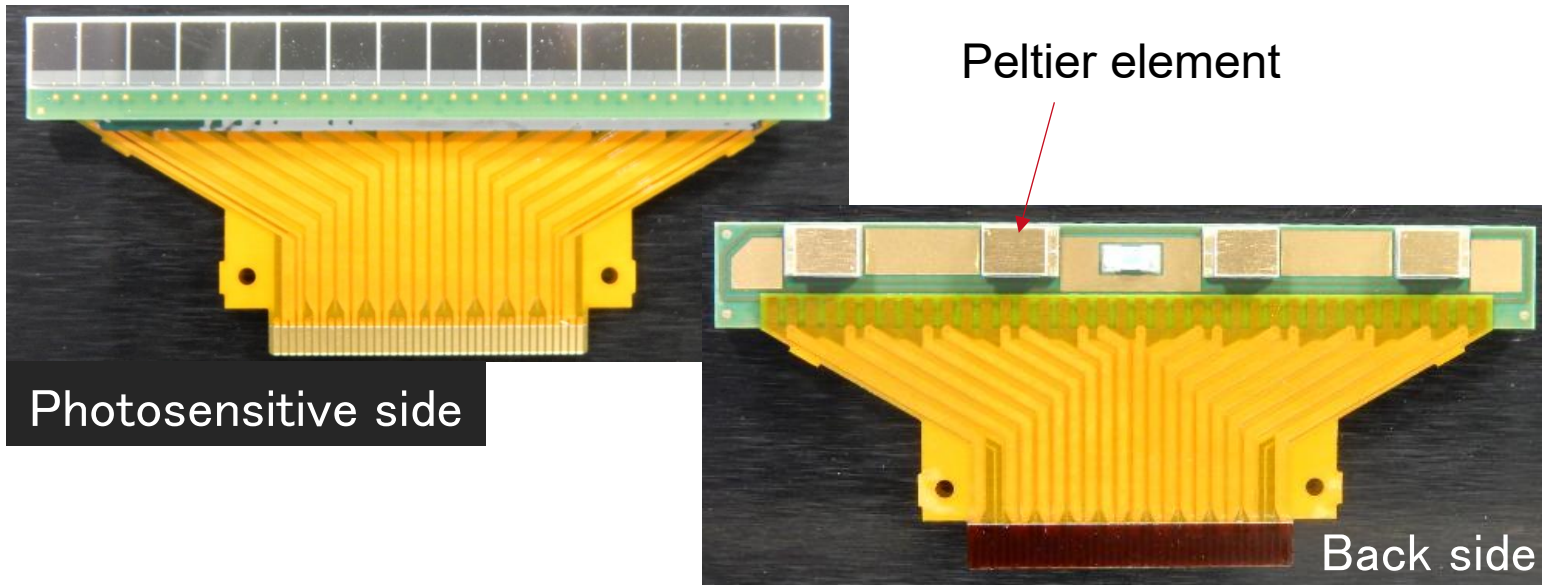
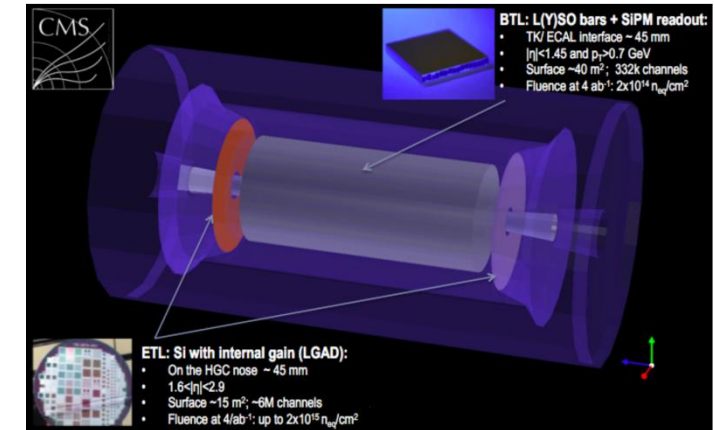
- Photon sensitive area: $0.2 \times 1.6 \text{ mm}^2$, pixels size $60\mu\text{m}$, $1 \times 128\text{ch}$ array.
- Used as a tracker in combination with optical fibers.
- R&D is also underway to develop resin-free solutions for next-generation detectors.



Timing detector: HL-LHC/CMS/BTL

● MPPC design points

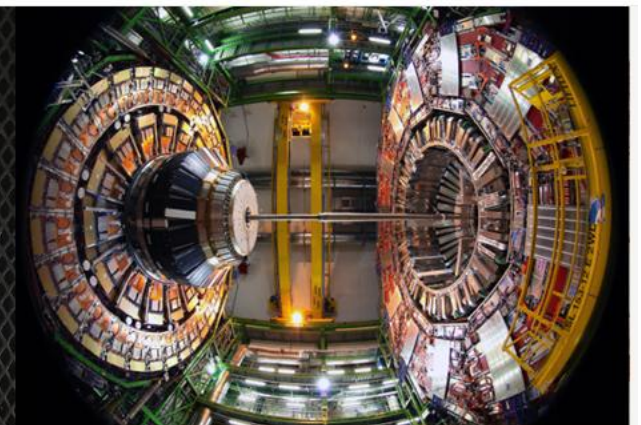
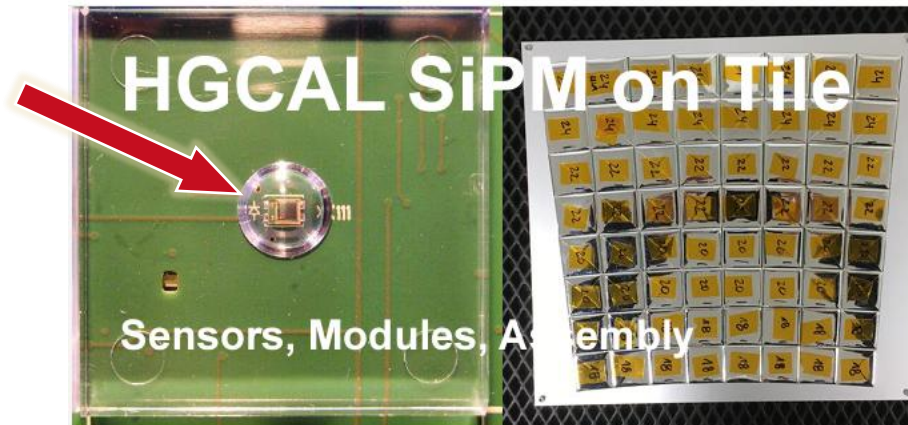
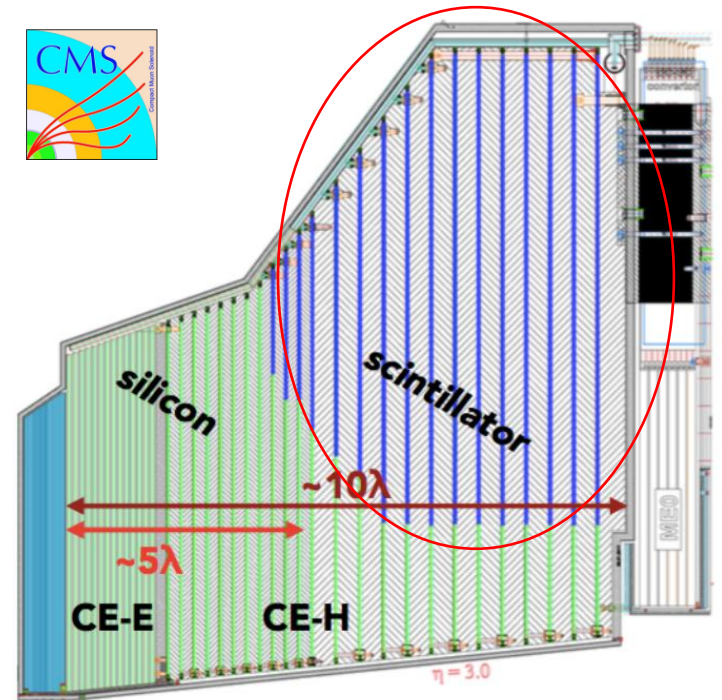
- Meets the requirement for a time resolution of <math><30\text{ ps}</math>.
- Photon sensitive area: $2.9 \times 3.8\text{ mm}^2$, pixels size $25\mu\text{m}$, $1 \times 16\text{ch}$ array.
- The radiation resistance requirement of $3 \times 10^{14}\text{ neq/cm}^2$ is met.
- Package design for use with a detector system + Peltier element cooled to -45°C .



Calorimeter: HL-LHC/CMS/HGCAL

- MPPC design points

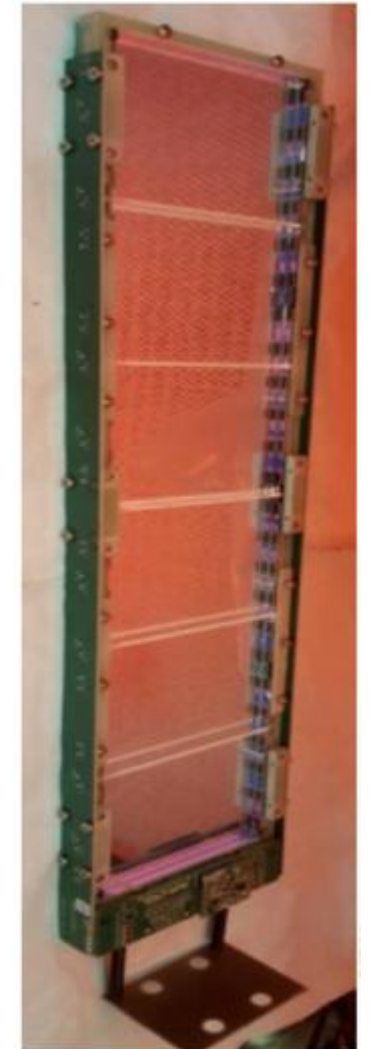
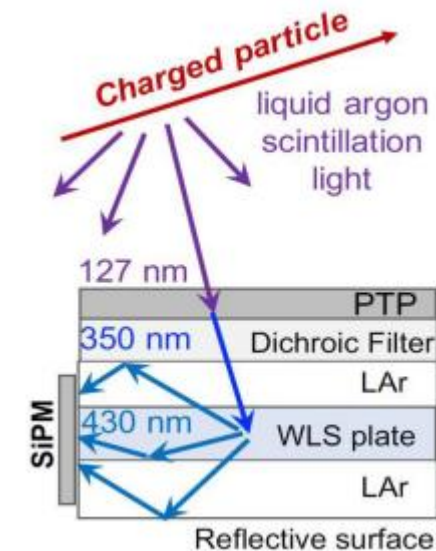
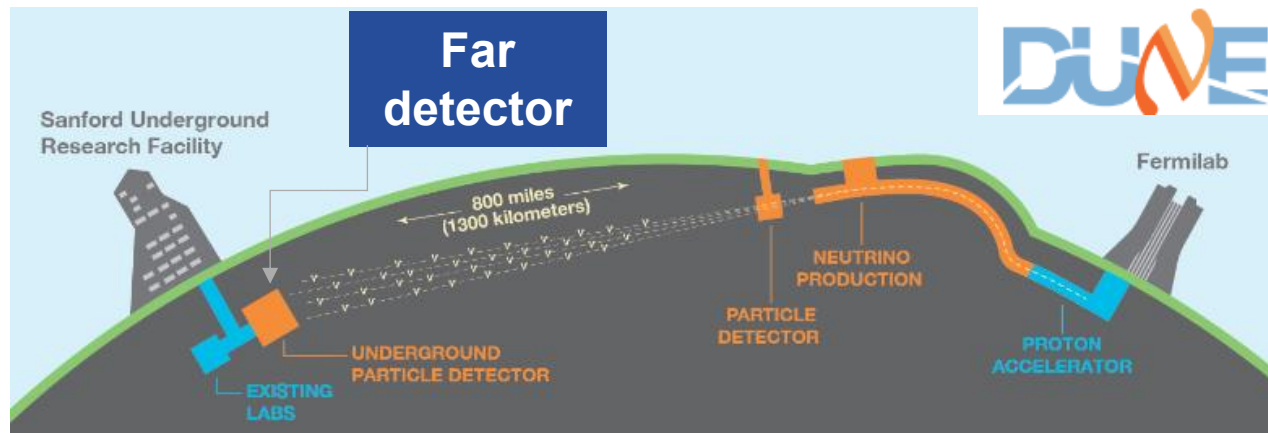
- The radiation resistance requirement of 5×10^{13} neq/cm² is met.
- Photon sensitive area: 3.0 x 3.0 mm², pixel size 15 μ m
- The detector system is used at -30°C, so a high heat-dissipation surface mount package is required.



Time Projection Chamber: DUNE/Far detector

- MPPC design points

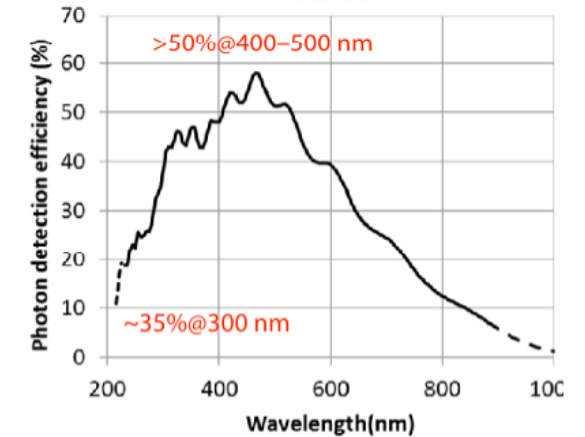
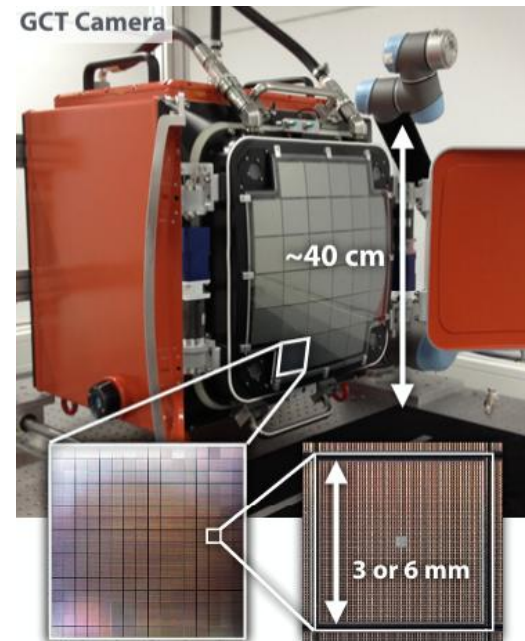
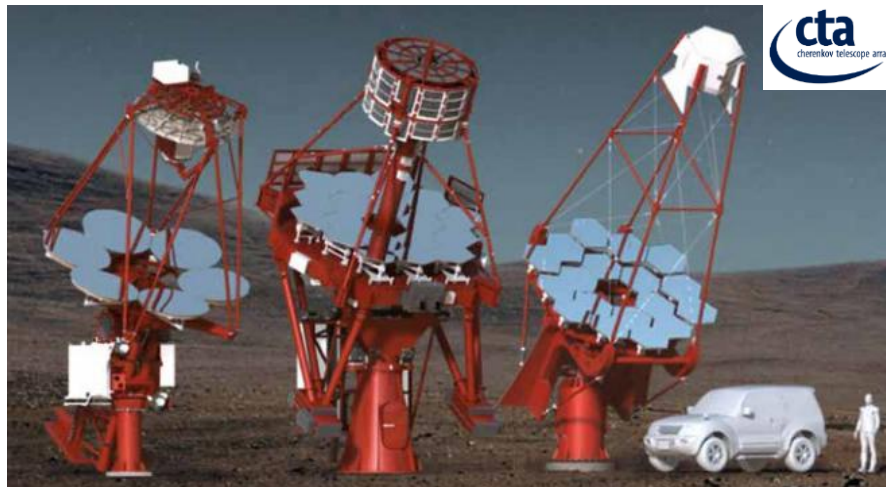
- Since it is used in Liquid Argon (LAr), it must meet the requirements for low temperature (87 K) tolerance.
- Photon sensitive area: $6.0 \times 6.0 \text{ mm}^2$, pixels size $50\mu\text{m}$, 1×6 ch array.
- Process tuning was performed to suppress afterpulses at low temperatures.
- R&D is underway for next-generation detectors.



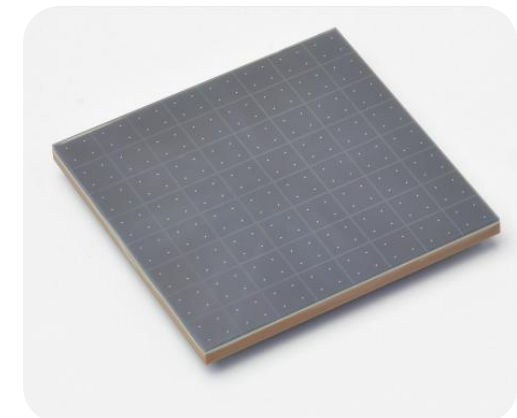
Imaging Atmospheric Cherenkov Telescopes

- MPPC design points

- Photon sensitive area: $6.0 \times 6.0 \text{ mm}^2$ (or $7.0 \times 7.0 \text{ mm}^2$), pixel size $50\mu\text{m}$, 8×8 ch array.
- Dedicated design to meet high PDE and low crosstalk characteristics.
- Robustness against night sky background and moonlight
- Low-voltage operation ($\sim 50\text{V}$)



From Hamamatsu S14521-8648 spec sheet



Product introduction for MPPCs

- Comparison of Optical Semiconductor Devices and Photomultiplier Tubes
- Introduction for MPPCs in academic field
- **Development**

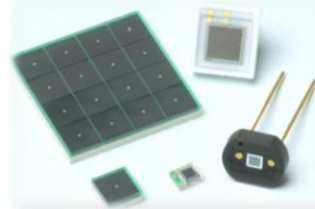
MPPC lineup history

Blue
enhanced

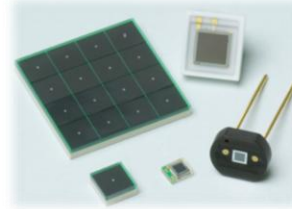
S10362 series



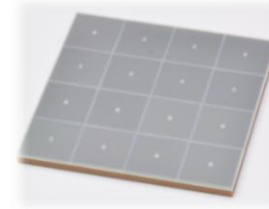
S1257x series



S1336x series

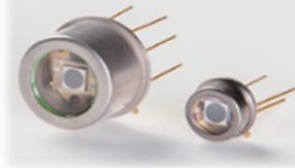


S1416x series



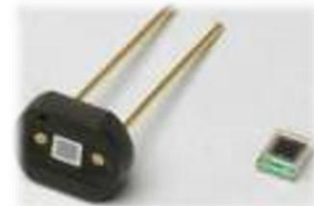
Red
enhanced

S1442x series

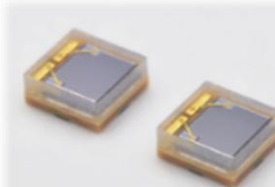


NIR
enhanced

S13720 series



S15639 series

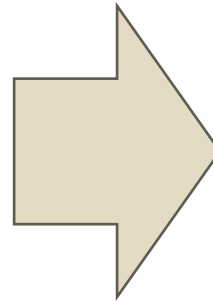
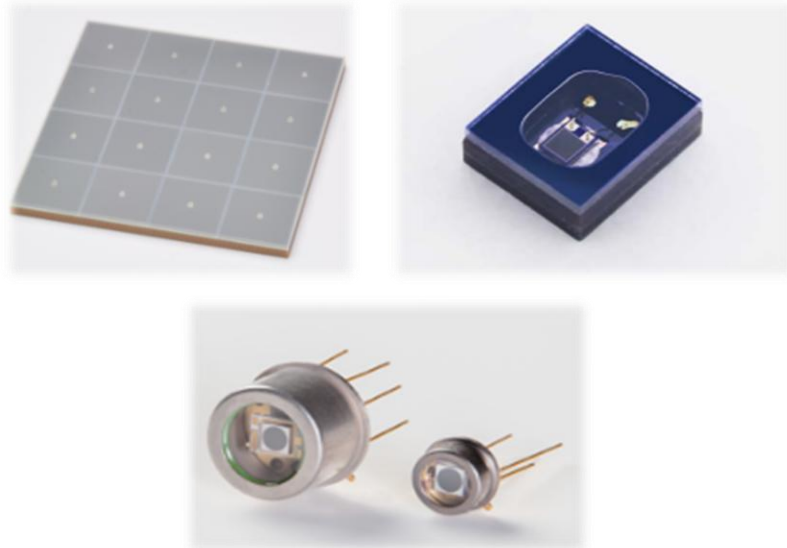
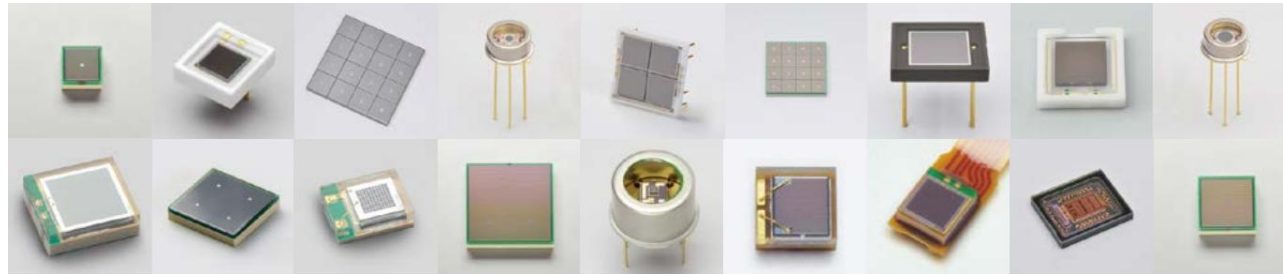


S16786 series



The MPPC have continued to evolve by improving their characteristics. Developments are underway to achieve even higher performance.

MPPC[®]
Multi-Pixel **Photon** Counter

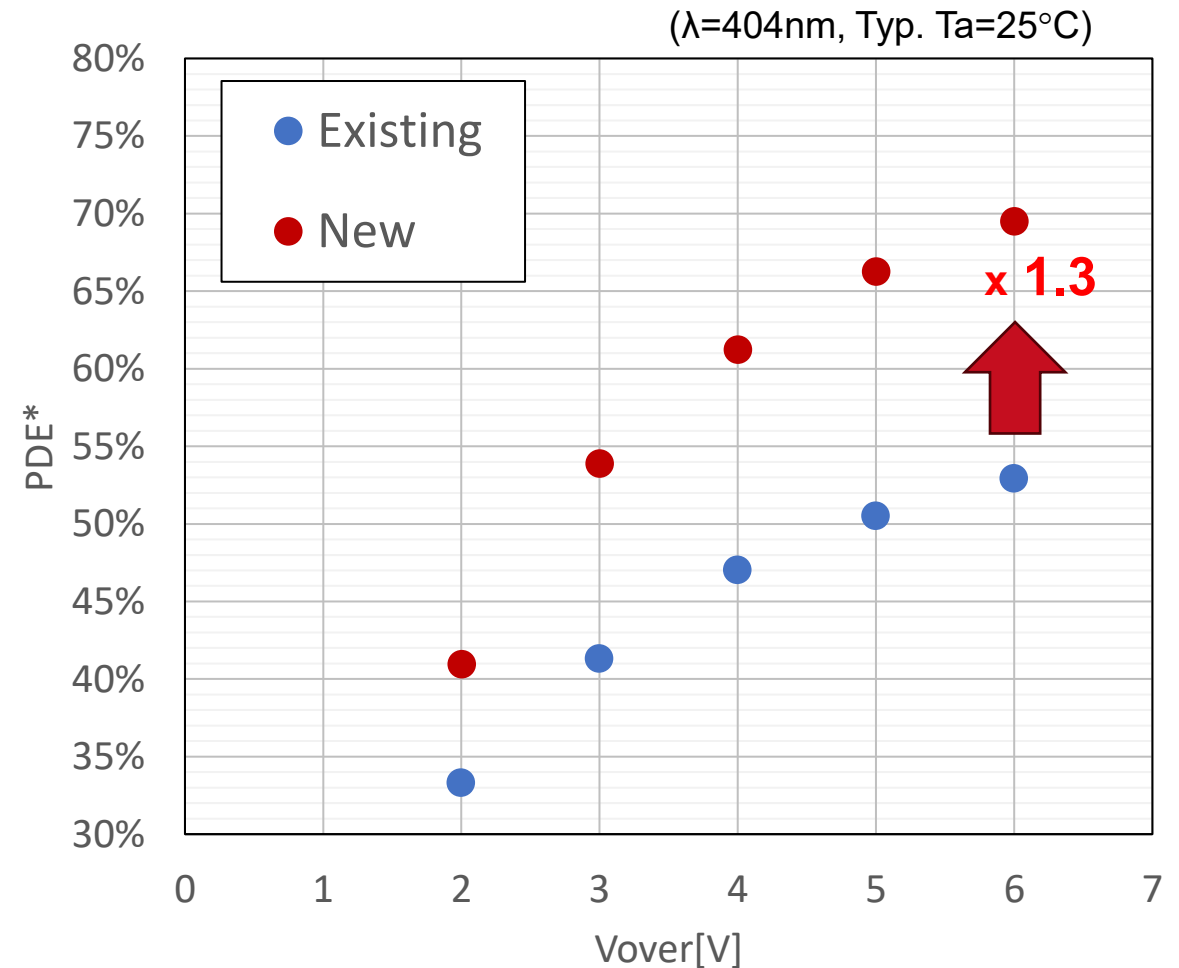
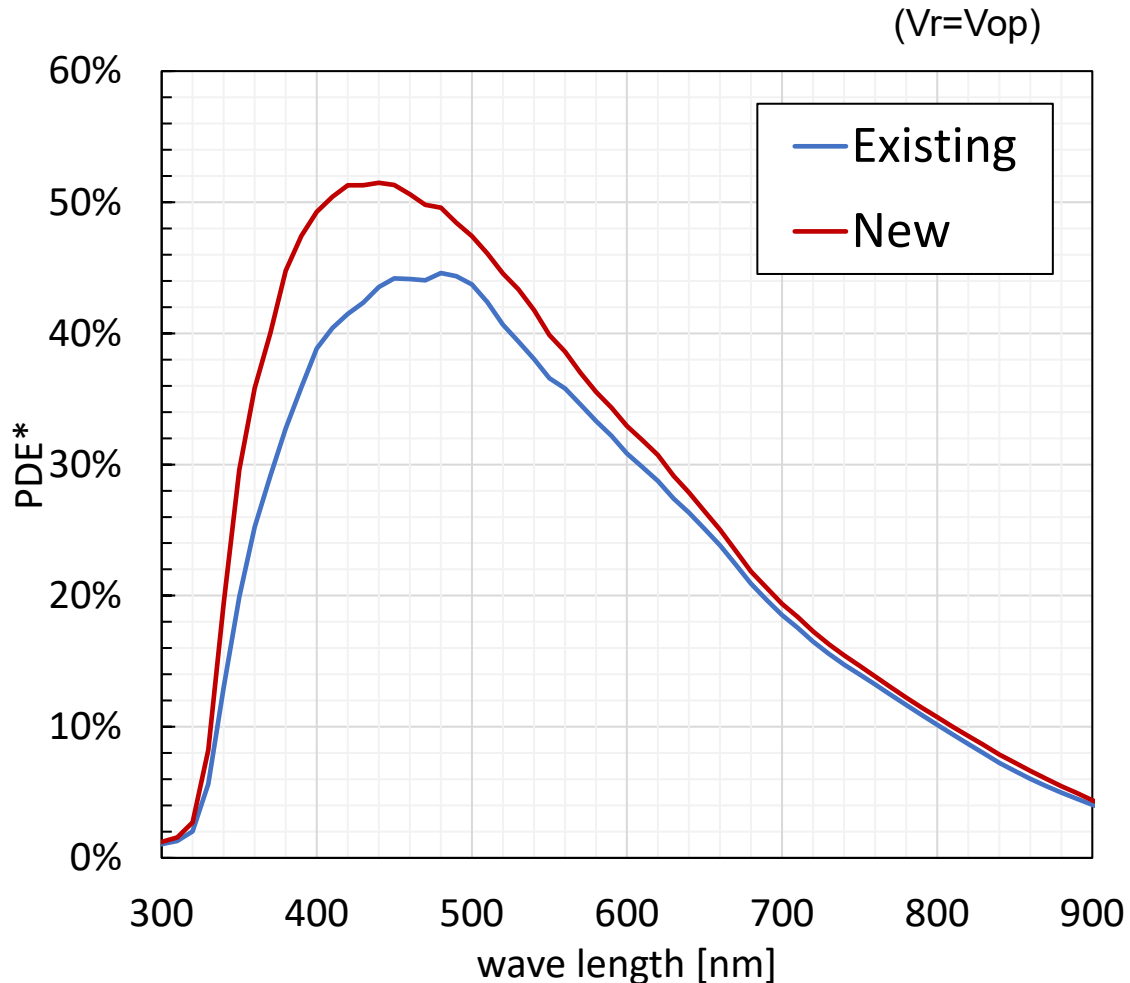


Next generation MPPC

- ✓ **Higher PDE**
- ✓ **Lower dark noise**

PDE vs. Wavelength, Over voltage

PDE is improved, particularly in the blue and visible wavelength range, and it becomes **1.3 times** higher at 404 nm. The PDE of the new MPPC can reach approx. **70 %** at $V_{over} = 6V$.

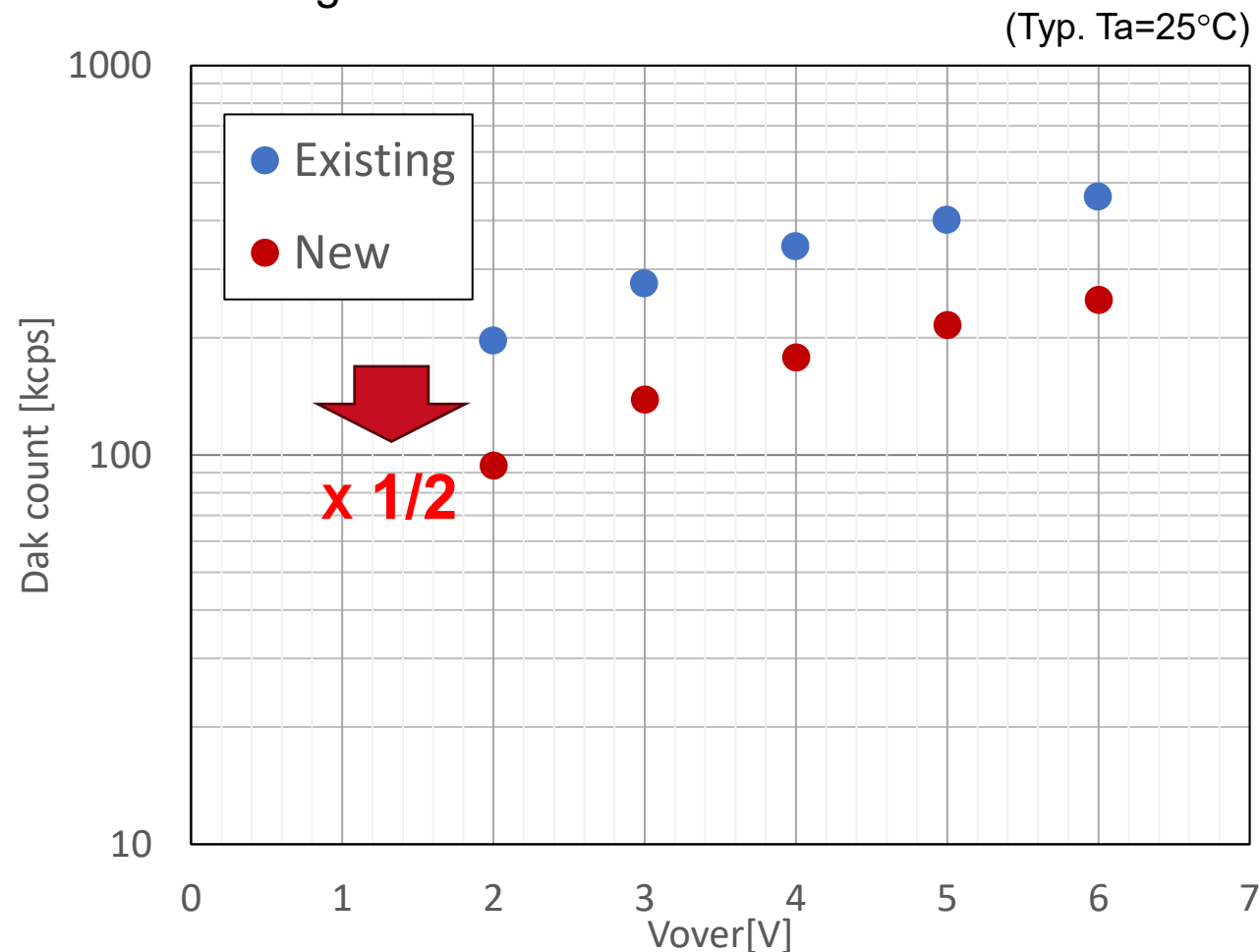


*PDE dose not include crosstalk and afterpulses

Dark count vs. Over voltage

The DCR of the new MPPC has been reduced to about **half** at the same over voltage.

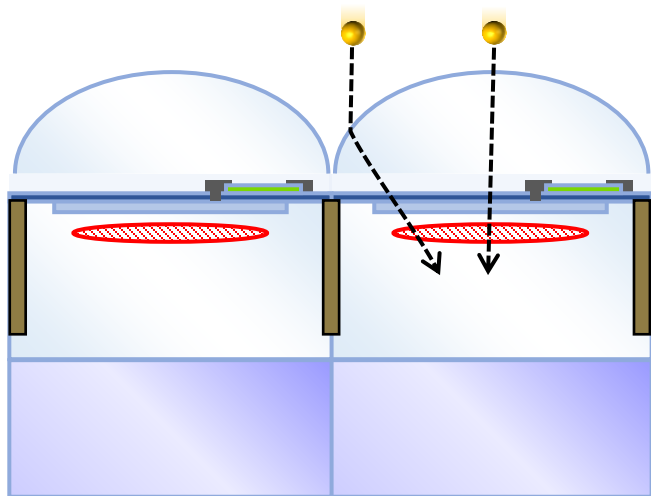
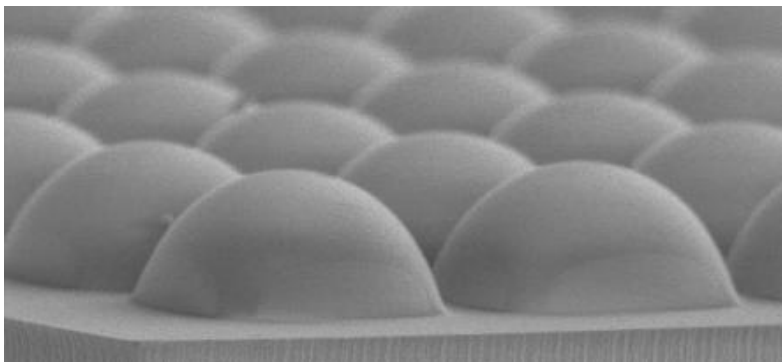
Even when a high overvoltage (~6V) is applied to the new MPPC, the DCR remains at the same level as the existing MPPC at a low overvoltage.



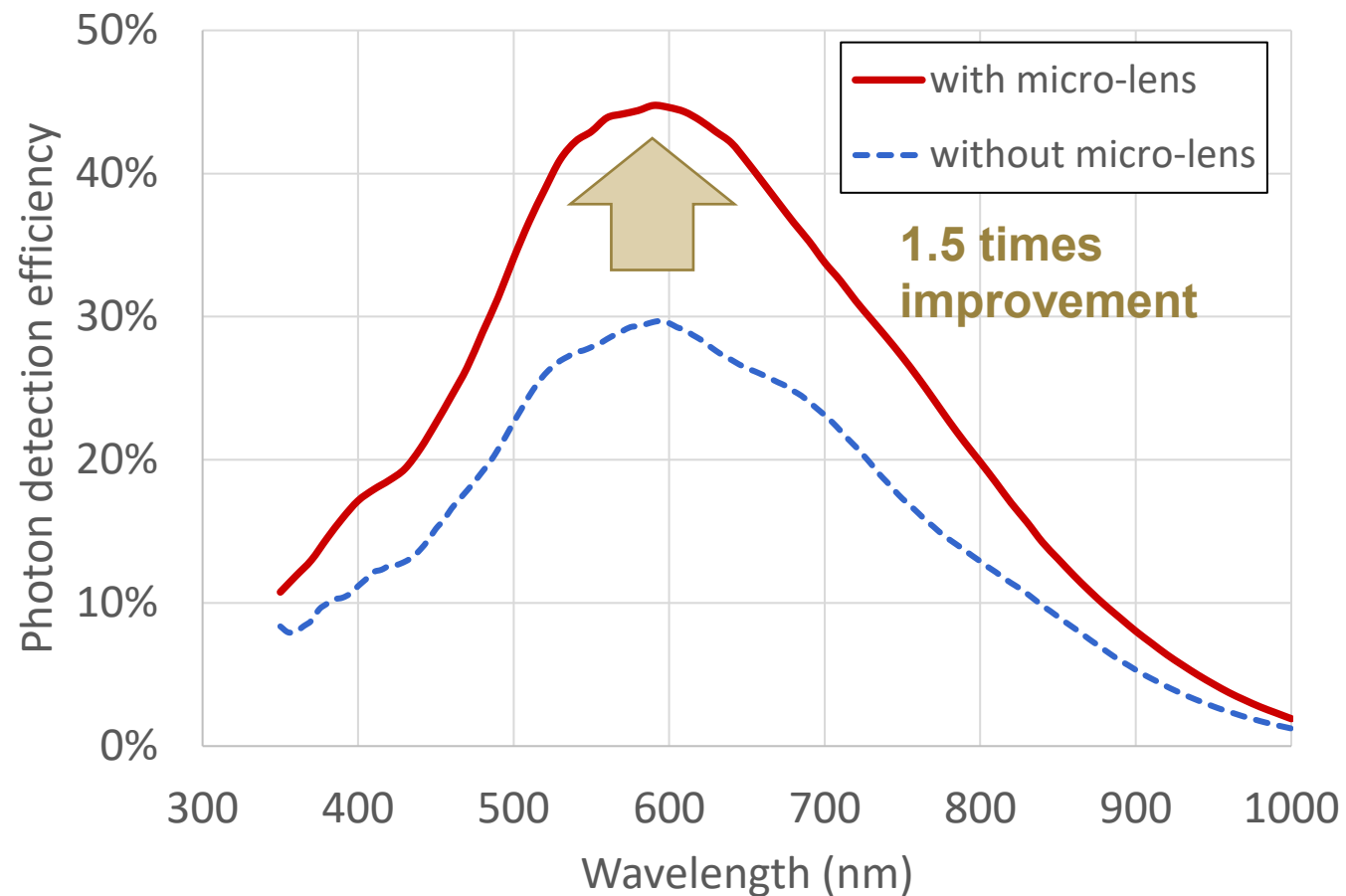
Test sample:
3 x 3 mm² – 50 μm type.

Other developments for MPPC

Micro-lens technology



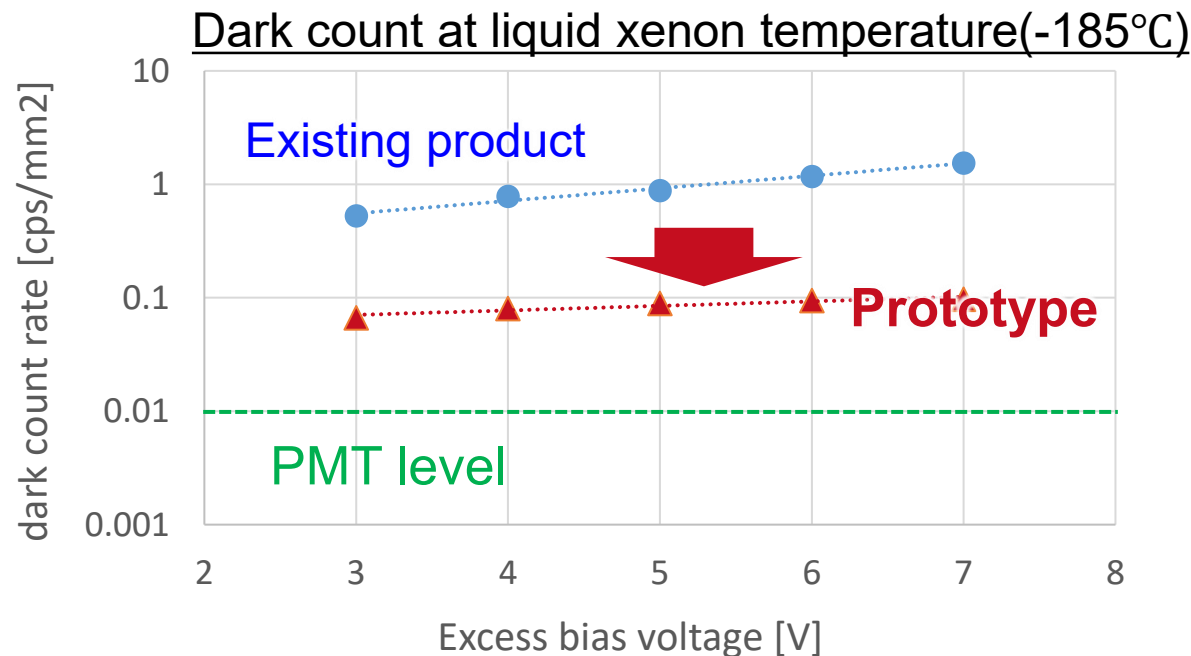
S14420-25 μ m type with or without Micro-lens



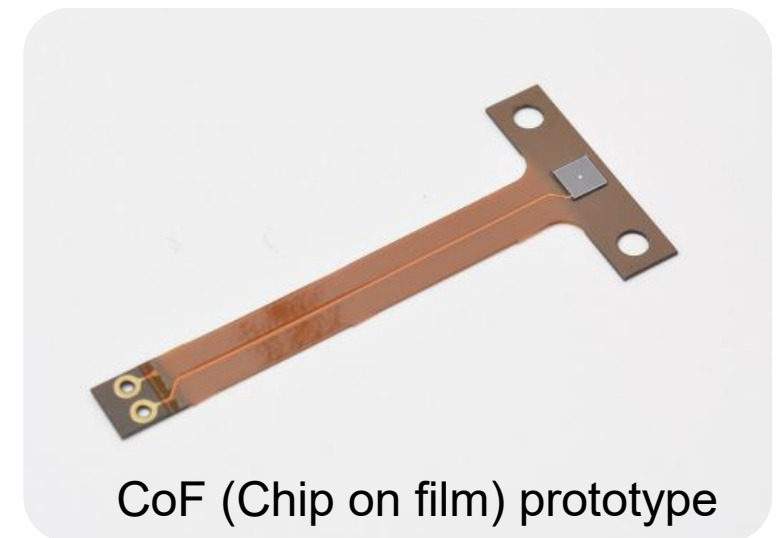
- The on-chip micro-lens(ML) can extend the effective photosensitive area and improve the PDE.
- NIR type(S16786) already has ML, and we are developing red and blue sensitive MPPCs with ML.

- MPPC design points

- Designed to be sensitive to vacuum ultraviolet (VUV, $\sim 120\text{nm}$) for photon detection from liquid xenon and liquid argon.
- Because even the slightest radiation emitted from the packaging can cause false detections, the packaging is designed to minimize radioactive materials.



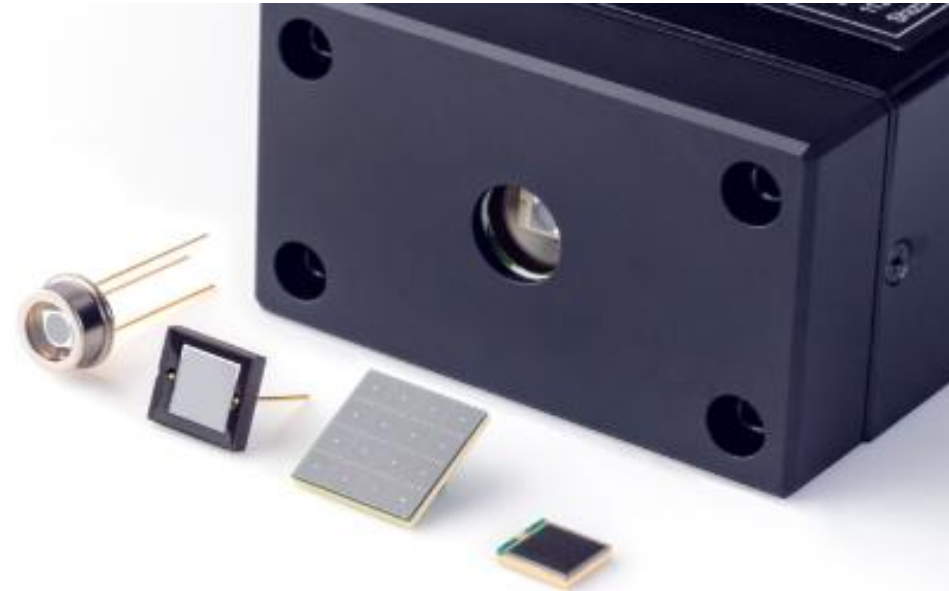
Low-radiation package



CoF (Chip on film) prototype

Summarize

- ◆ MPPCs have continued to evolve by improving their characteristics, and the developments are underway to achieve even higher performance.
- ◆ Hamamatsu is flexible and customizable to meet your requirements. Please feel free to contact us.



www.hamamatsu.com