HAMAMATSU
PHOTON IS OUR BUSINESS

Scientific contribution and Industrial applications of Photon detectors on Hamamatsu Photonics

HAMAMATSU PHOTONICS K.K.
Solid State Division
Koei Yamamoto

38th ICHEP August 2016 Chicago

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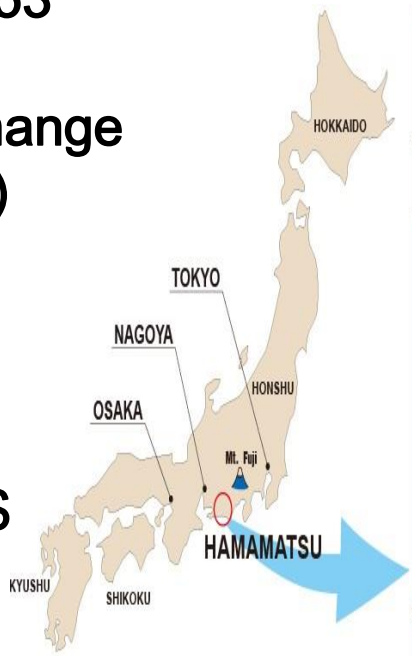
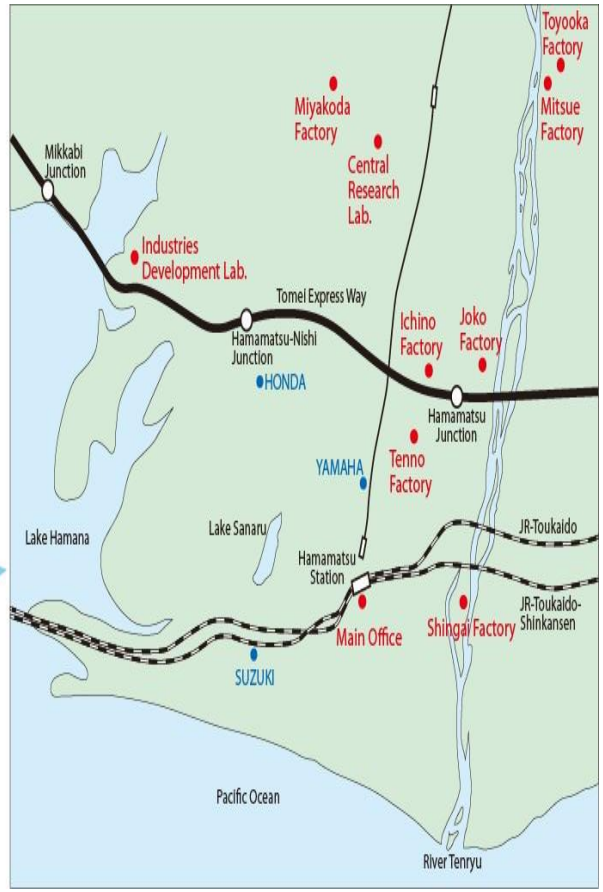
Company Information: Hamamatsu Photonics K.K.

- Established: September 29, 1953
- Stock listing: Tokyo Stock Exchange
  (1st Section, ID number: 6965)
- Capital : 35 Billion YEN
- Turnover FY15:
120 Bio Yen net sales / 1 Bio US$
- Number of employees : > 4400

Where is Hamamatsu





Hamamatsu Photonics K.K. - Divisions:

Photomultiplier Tubes, Light Sources, Fiber Optics Plates, Image Sensors, X-ray Products, etc.

Photodiodes, Photo ICs, Image Sensors, Infrared Sensors, X-ray Sensors, Solid State Emitters, etc.

Imaging & Measurement Instruments in the diverse fields such as biological/ medical/pharmaceutical fields, semi-conductor, spectroscopy and industry

High Power LD, CW LD, QCL, etc.

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Optical Sensors (Photomultiplier Tubes)

Over 90% PMT share of the world market.

Electron Tube Division

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Optical Sensors(Head-on PMT)

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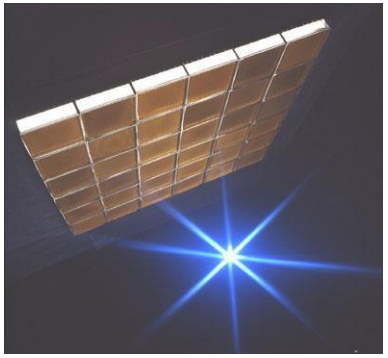
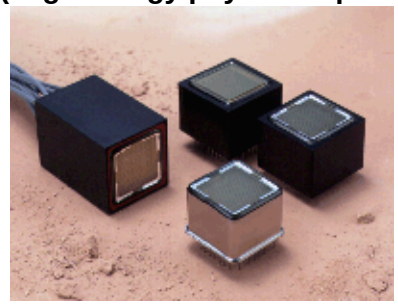
- The No.1 choice in academic research fields including high energy physics.
- Striving to develop new sensors by merging the features of semiconductors and electron tubes.
- Makes the world's most sensitive and responsive optical sensors in the near infrared range.

Flat panel PMT



Metal package PMT

(high energy physics experiments)



Near infrared PMT

(biological function measurement)

Whole-body PET

Super-Kamiokande

Here, a total of 11,200 of 20-inch dia. PMTs are used to catch neutrinos and monitor proton decay.

Electron Tube Division

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Optical Sensors (microPMT)

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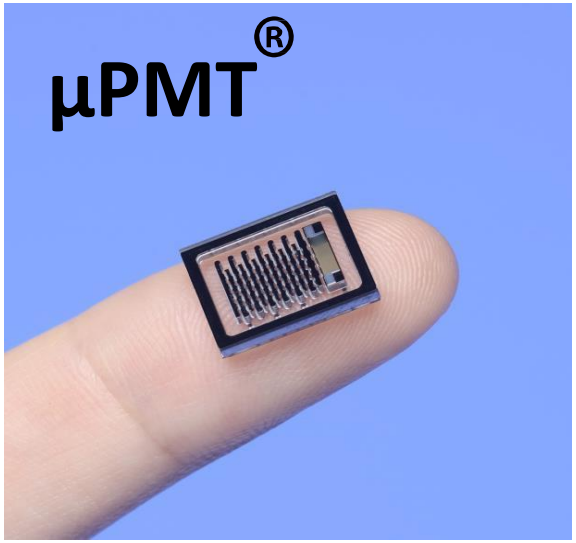

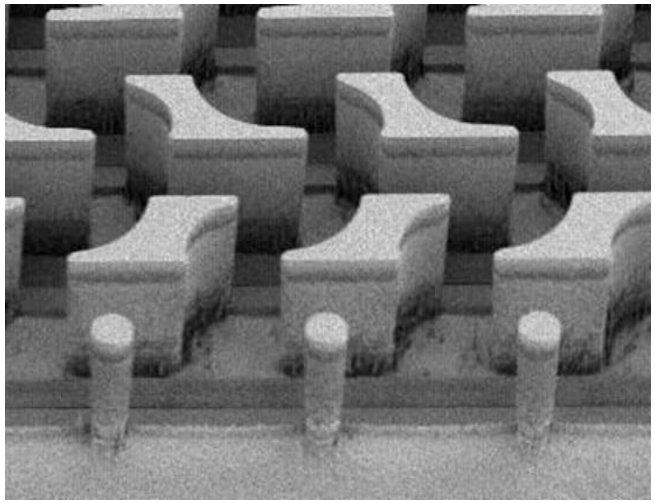

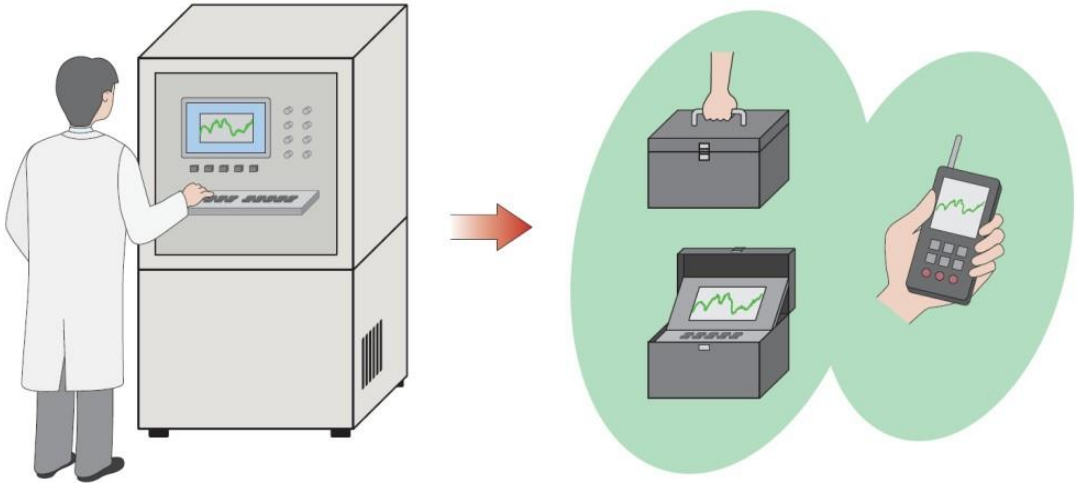

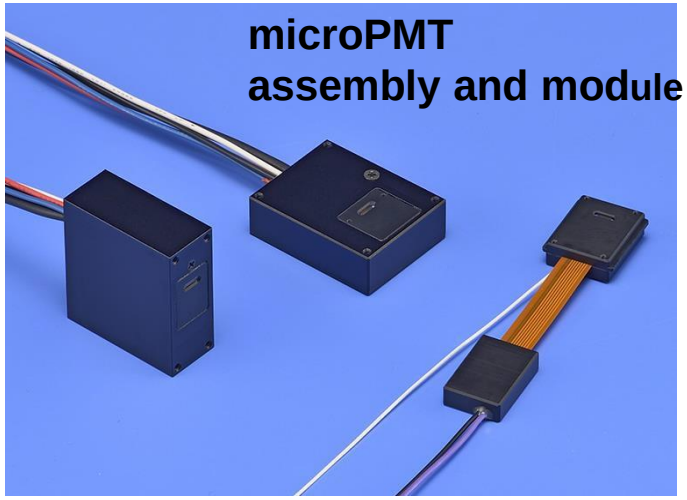

Extremely miniaturize with keeping the high performance.
Practicable for miniaturizing the instrument, hand held measuring instruments.

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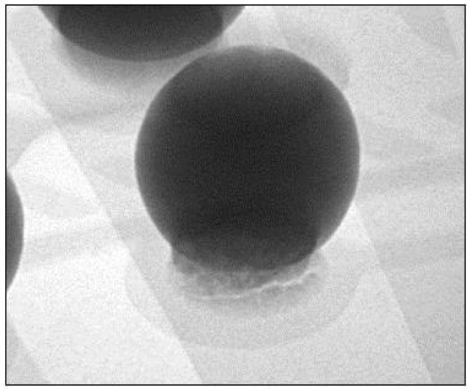
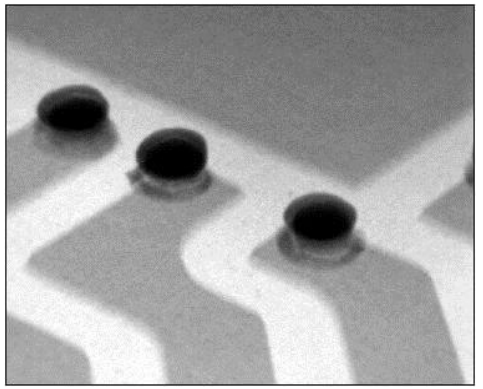
X-Ray Related Products

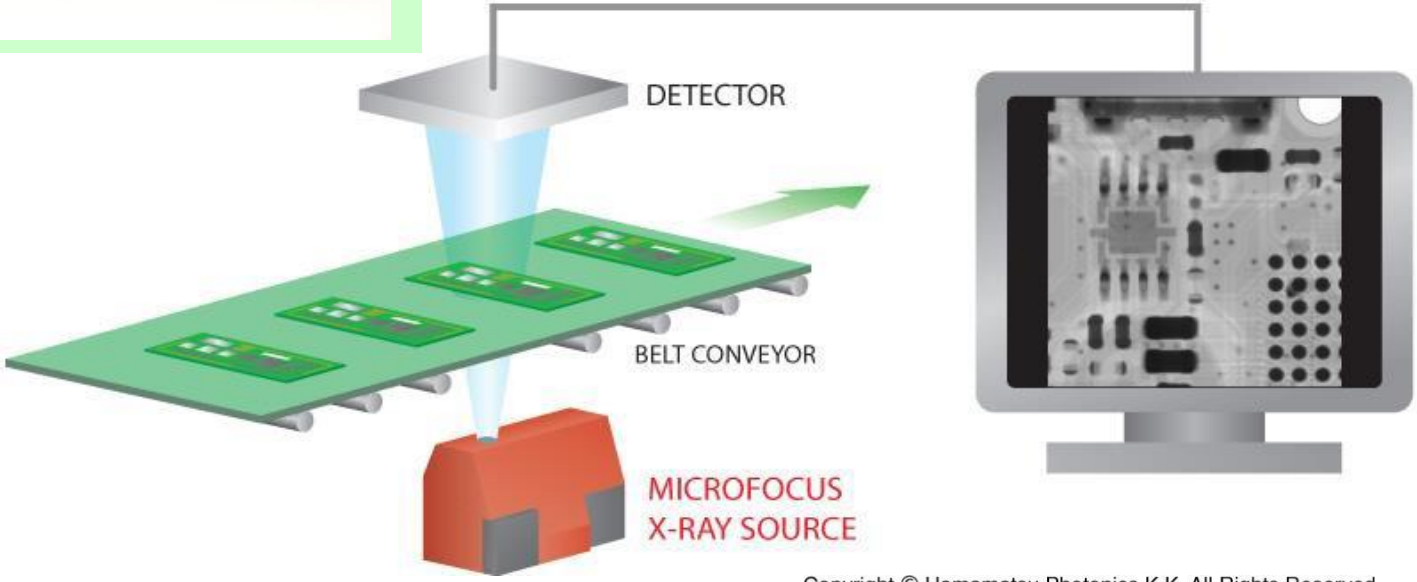
Microfocus X-ray source
(non-destructive X-ray inspection)



BGA joint



IC bumps (50μm)



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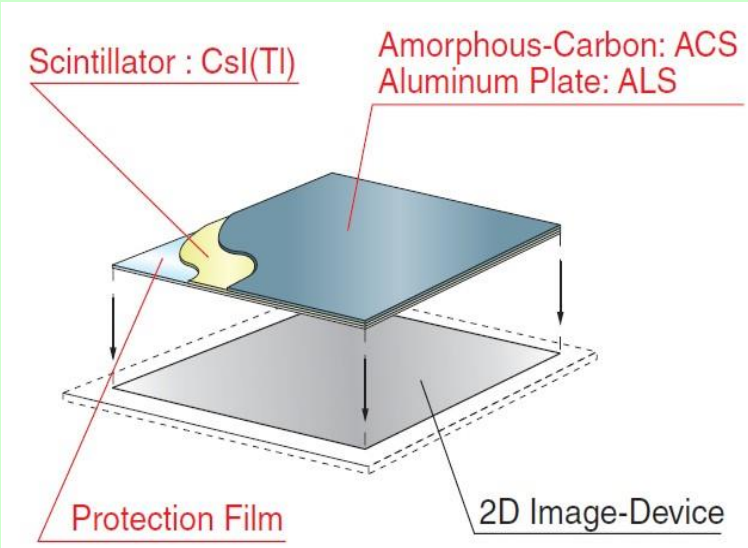
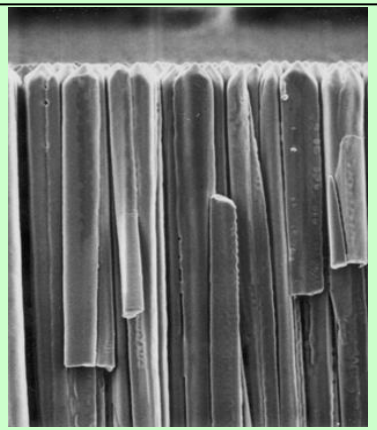
X-Ray Related Products

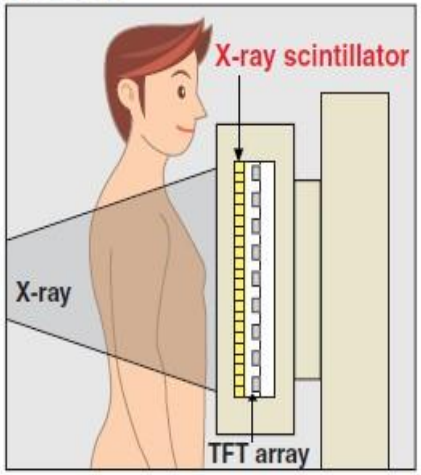
Scintillator



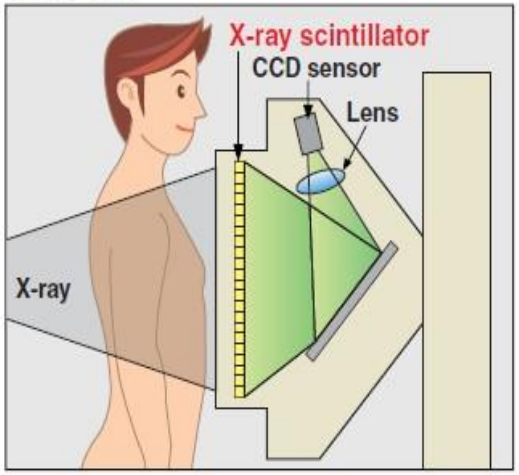


FOS (Fiber Optics Plate with CsI scintillator)
ACS (Amorphous-carbon plate with CsI scintillator)
GPXS (Greap Performance X-ray CsI scintillator)
ALS (Aluminum plate with CsI scintillator)

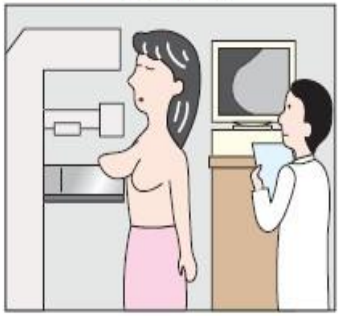
Chest examination
FPD-DR



CCD-DR



Mammography



Dental examination

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Low Light Cameras for Life Science

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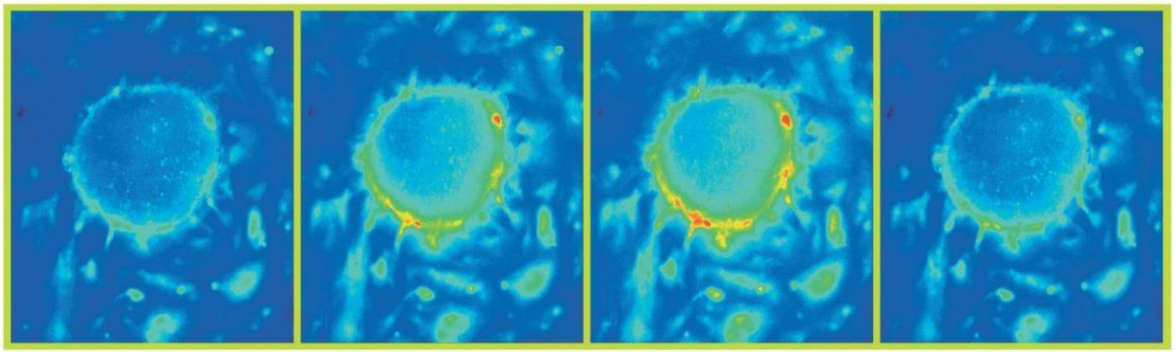
Systems Division

Scientific CMOS Camera ORCA-Flash 4.0 V2

ORCA-Flash 4.0 V2 is the new generation camera featured by low noise, high speed and high resolution.

ORCA-Flash4.0 V2



High-speed Ca2+ imaging of cardiomyocyte derived from human iPS cell stained with Fluo8-AM. Sequential images were obtained every 10 ms.

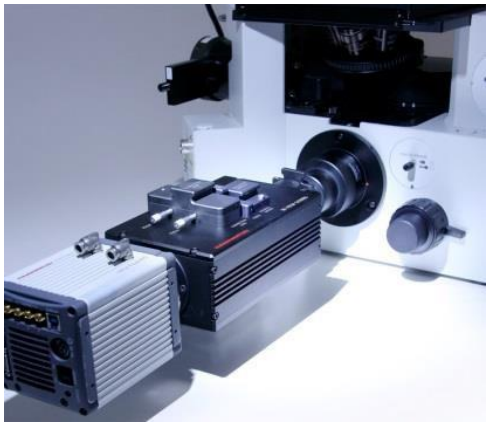
Electron Multiplying CCD camera

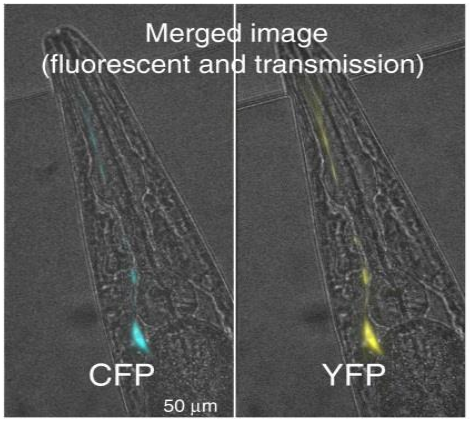
ImagEM is ideal for bio-medical imaging require very high speed and high sensitivity.

ImagEM X2

Time Image Splitting Optics W-VIEW GEMINI

Simultaneous dual wavelength imaging by a single camera.





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Pharmaceutical & Medical Research

Systems Division

Kinetic plate reader for HTS and assay development

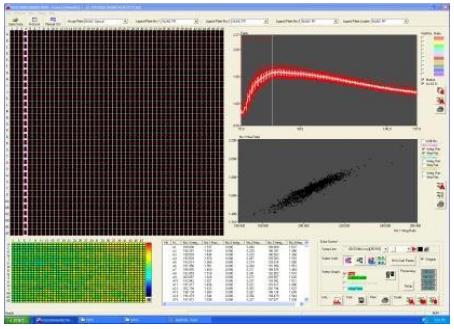
. Hamamatsu Photonics assists developing new drugs synthesizing large amounts of chemical compounds using new technical breakthroughs by offering high-speed, cell-based assay screening systems as well as functional analysis and screening systems..

▪ Kinetic Plate Reader for Cell-based Assay Screening

FDSS /uCELL

▪ Cell-based Assay System corresponding High Throughput

Analysis of kinetic response



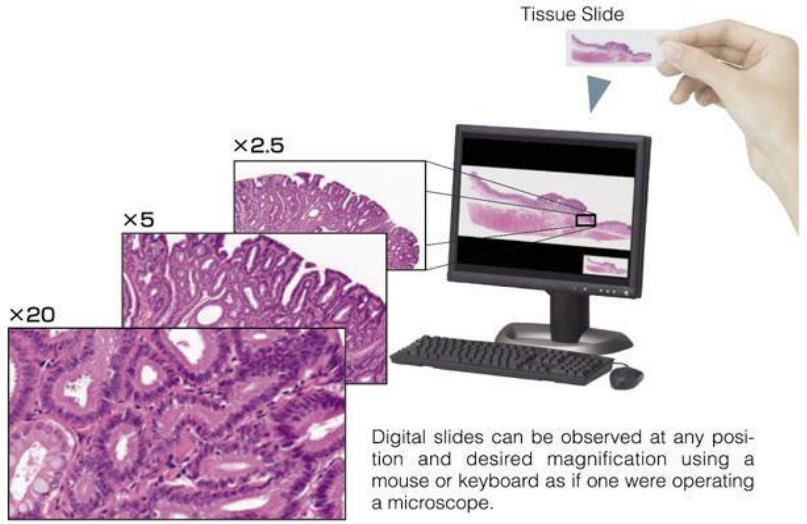
FDSS7000EX

Digital slide scanner for pathology and cytology

The NanoZoomer 2.0 converts glass slides into the digital form

NanoZoomer-XR
(Process up to 320 slides automatically)

NanoZoomer-SQ (Desktop and light weight)



Digital slides can be observed at any position and desired magnification using a mouse or keyboard as if one were operating a microscope.

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Semiconductor QC and Process

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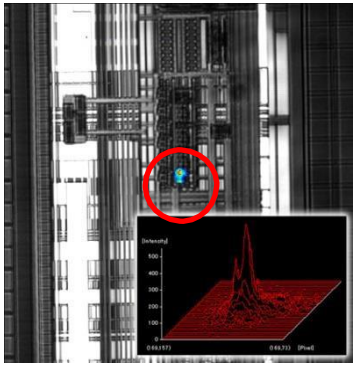
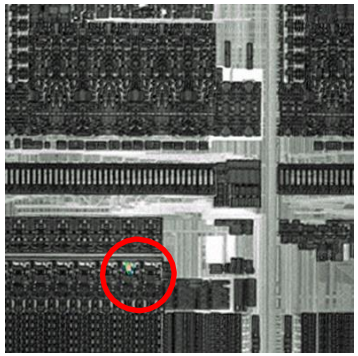
Failure detection and analysis

This system locates, visualizes and analyzes failures inside semiconductor devices by detecting weak light emissions, heat emissions or electrical changes caused from the failures.

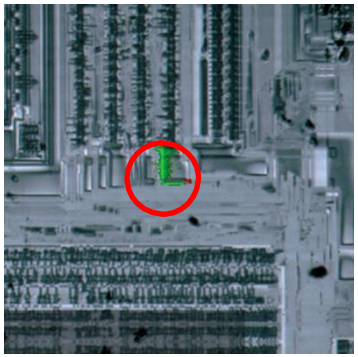
PHEMOS series



ESD damage localization



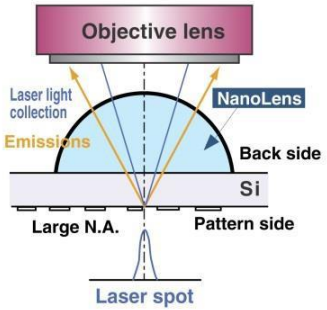
FET rush current caused by a short or open circuit

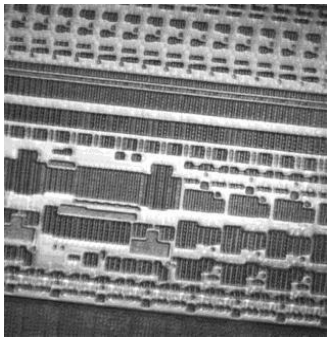


Metal wiring defect analysis using the IR-OBIRCH method

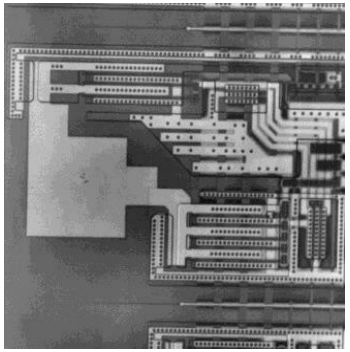
High resolution and lhigh ight collection efficiency

NanoLens (solid immersion lens)

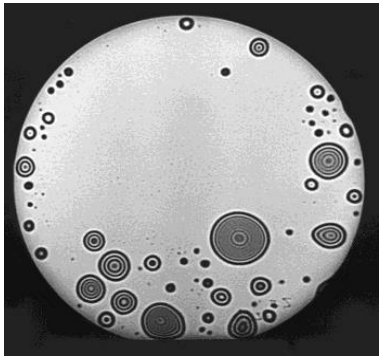




IR imaging of internal structures



Imaging of Chip internal



Imaging of SOI wafer Void

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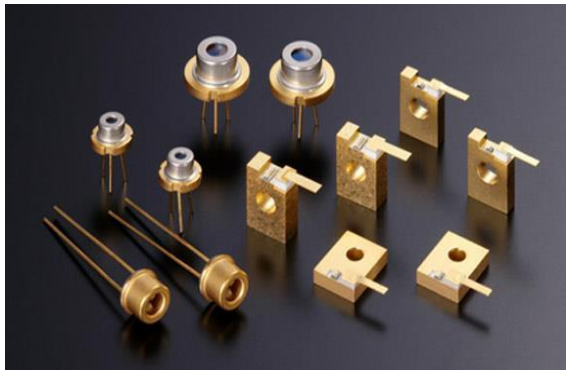
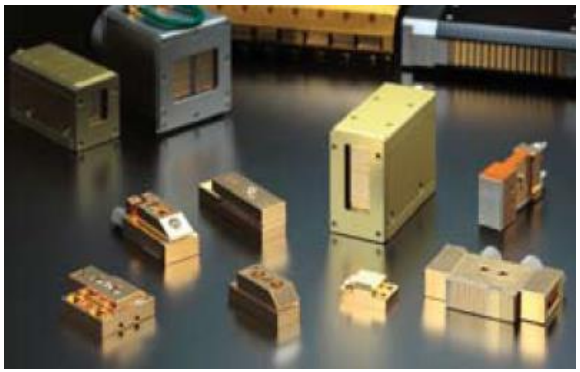
Products of laser group

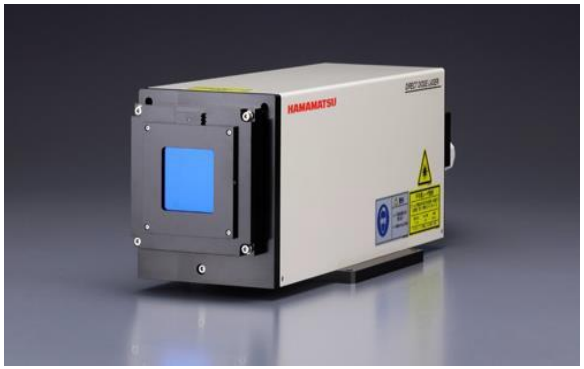
We develop every part of our semiconductor lasers ourselves, from epitaxial growth to chip assembly to drivers. The finished products offer high reliability for many applications.



■ Laser diodes



■ High power laser diode bar modules



■ Direct diode laser（DDL）

■ Fiber output laser diode（FOLD）

■ Quantum cascade lasers（QCL）

■ LD irradiation light source（SPOLD）

Development Headquarter

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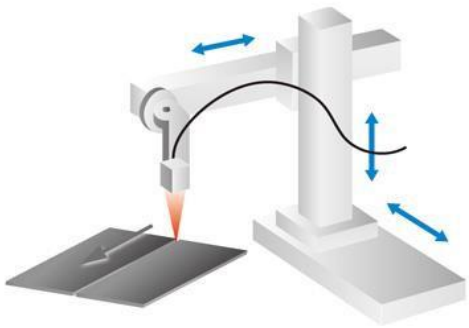
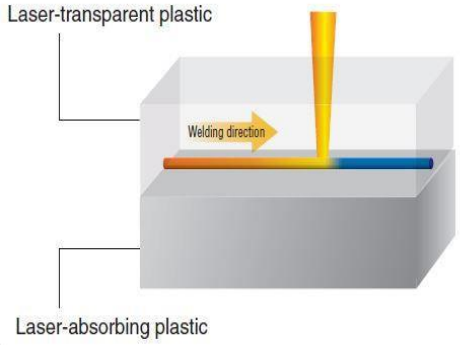
Applications of laser diodes

Processing



1D(line) welding

3D welding



Plastic welding

Soldering

Range measuring

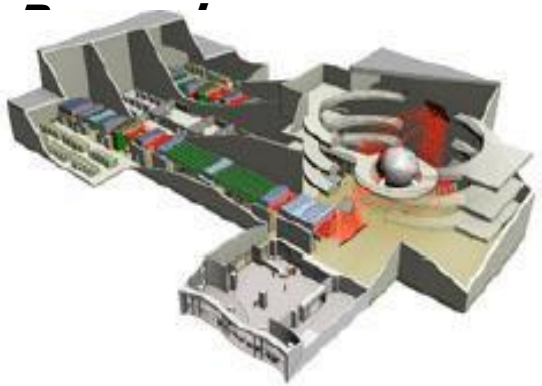
Distance meter

Anti-collision

Medica

OCT(Optical coherence tomography)

Academic



Laser fusion research

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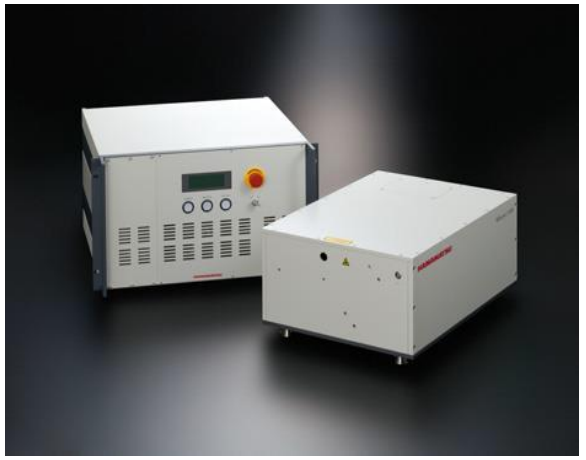
Products of integral optics

Solid-state laser



- Microchip laser
- Ultrashort pulsed laser “MOIL-ps L11590”

Laser analysis equipment

- Tera-Hz spectrophotometer
- Portable Raman spectrometer module

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Industries development laboratory

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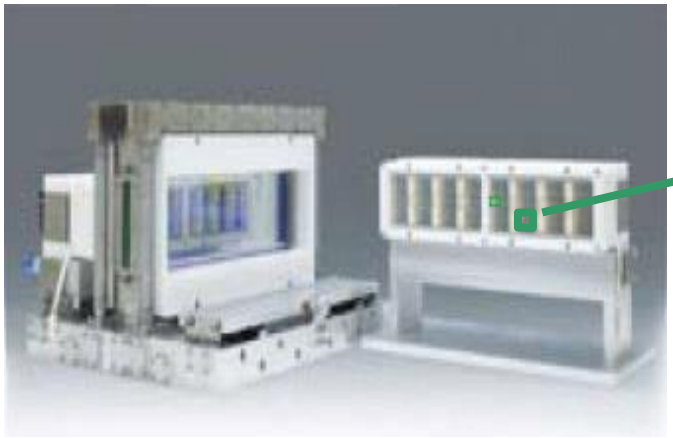
Working to achieve laser fusion generation

Promoting high-power semiconductor laser (LD) research and bringing applications for high-power output lasers to the industrial front

Laser irradiation building for research

High-intensity femtosecond lasers



A 50-stack high-power LD module

Solid-state laser driver excited by high-power LDs

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Development Headquarter

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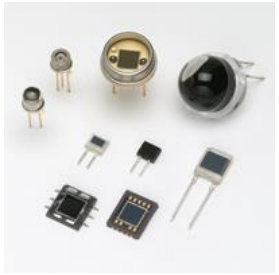
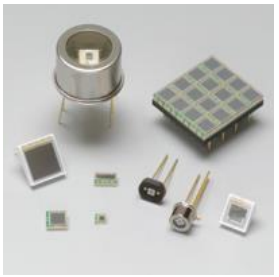
Products of Solid State Division



Si photodiodes



APD/ MPPC

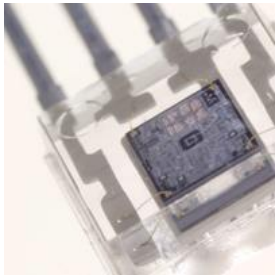
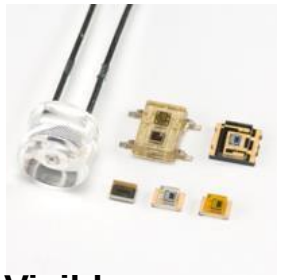


Photo ICs

Image sensors

PSD

Infrared LED/detectors

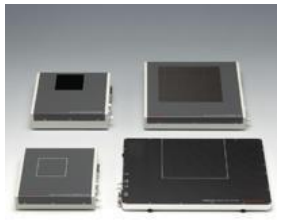


Visible sensors

Color sensors

LED

Optical communication



Flat panel sensors

spectrometers

Opto- Modules

Automotive devices

LCOS-SLM

Solid State Division

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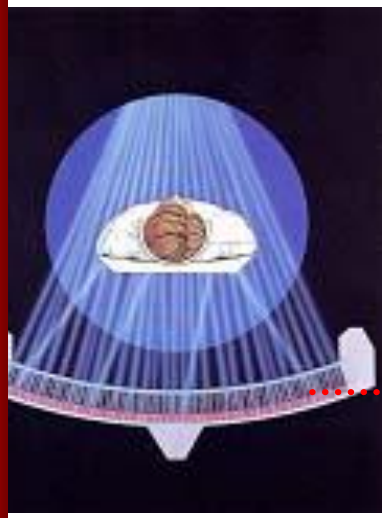
X-ray detector for medical CT

Multi Slice(ID to 2D)



Si PD Array

Solid State Division

X-ray Baggage Inspection

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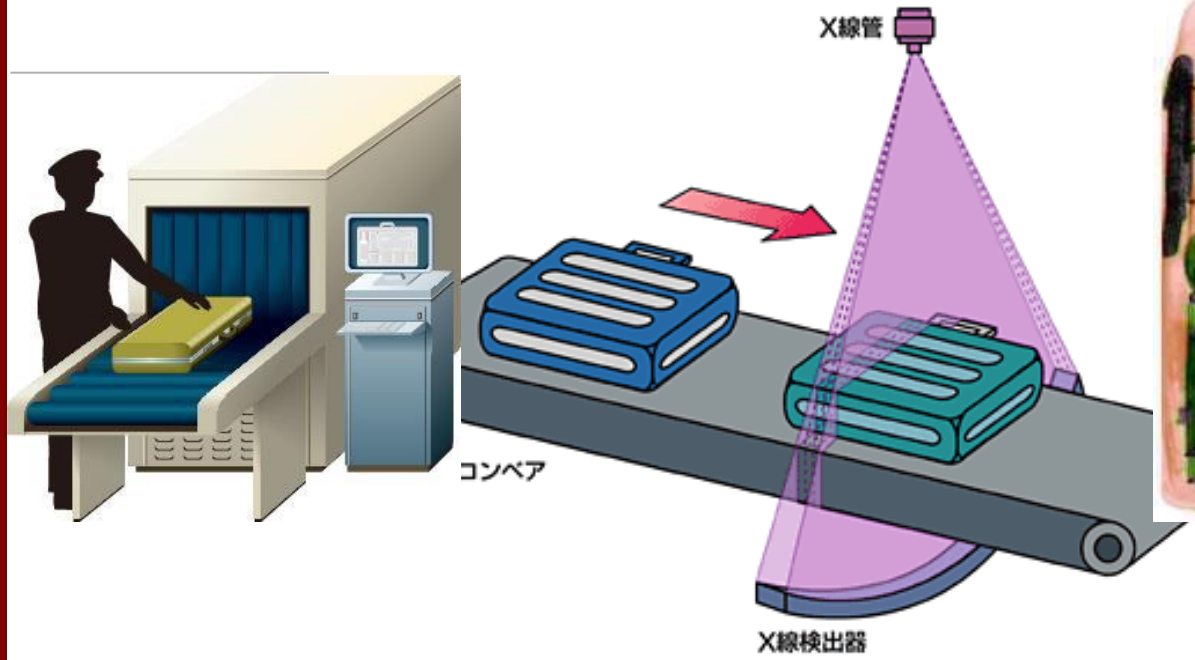
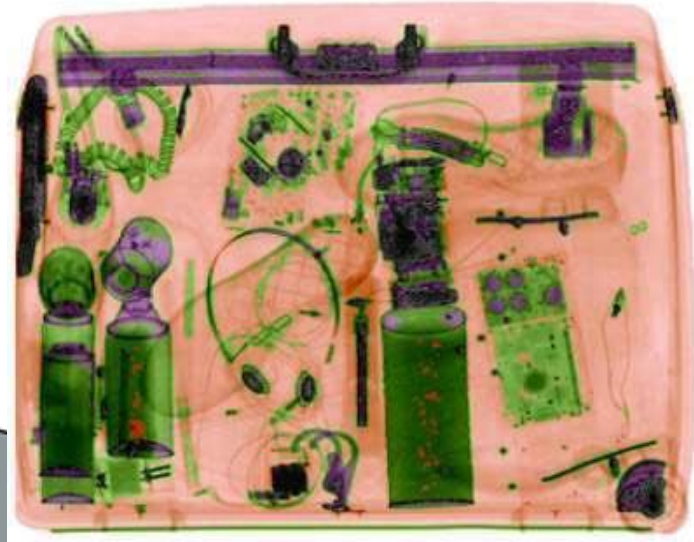
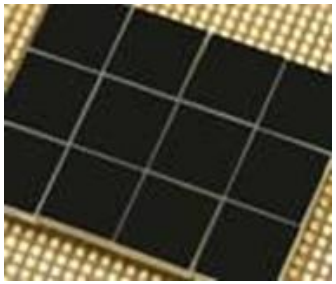


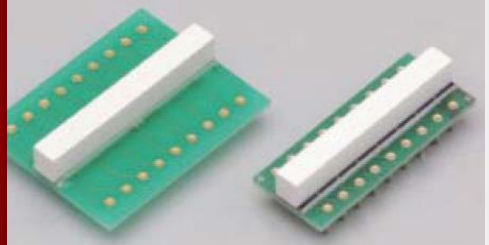


Si photodiode array with scintillator

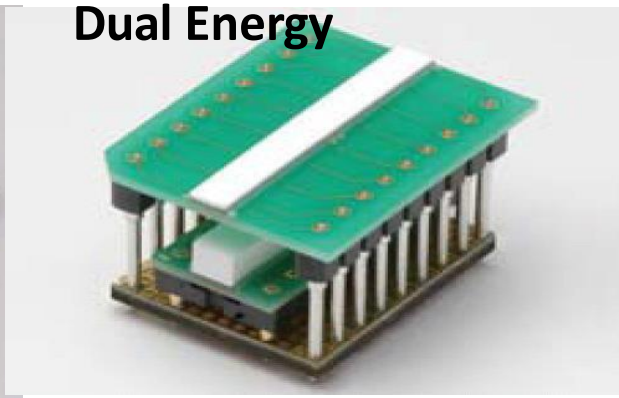


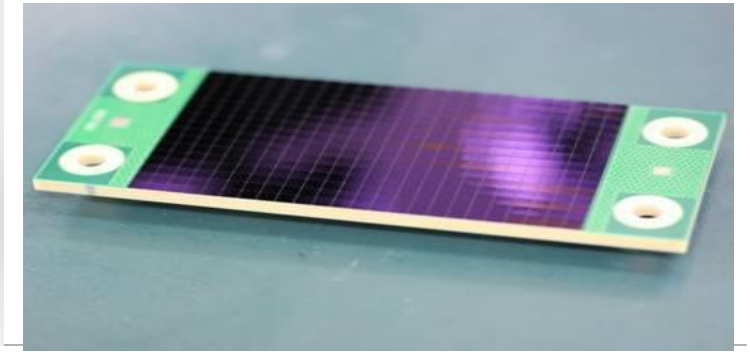
2D BT-PD array

Single Energy



Dual Energy





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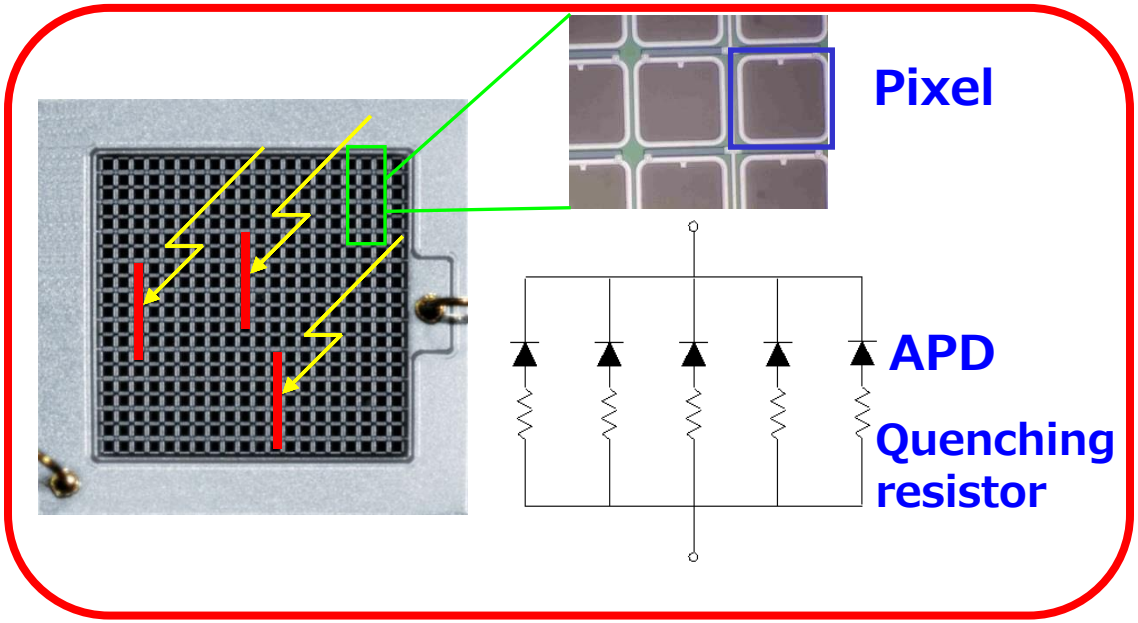
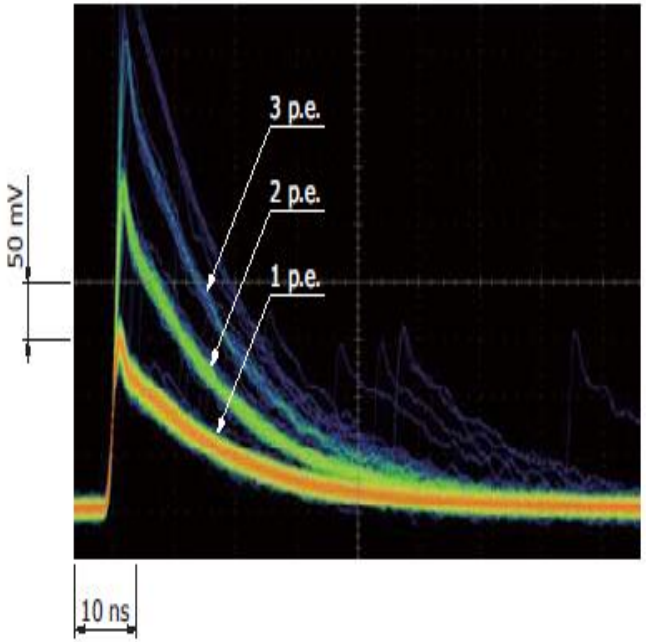
Solid State Division

Principle of Operation

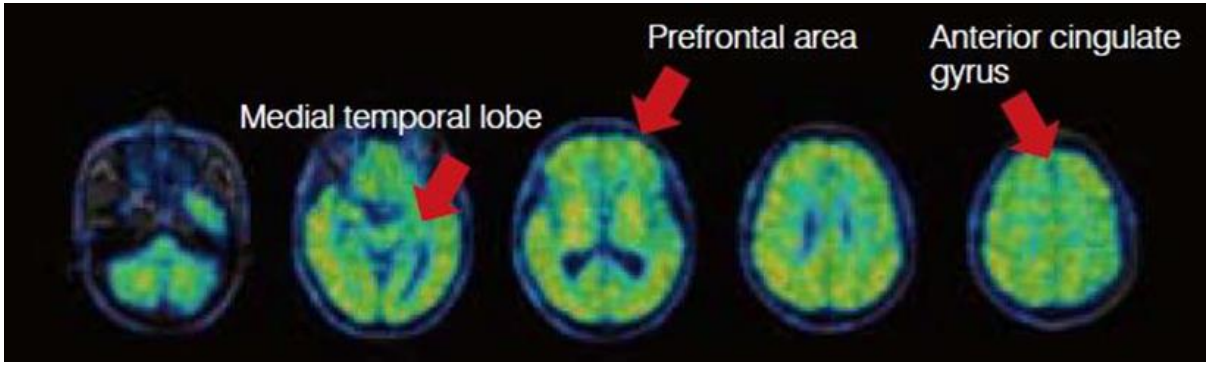


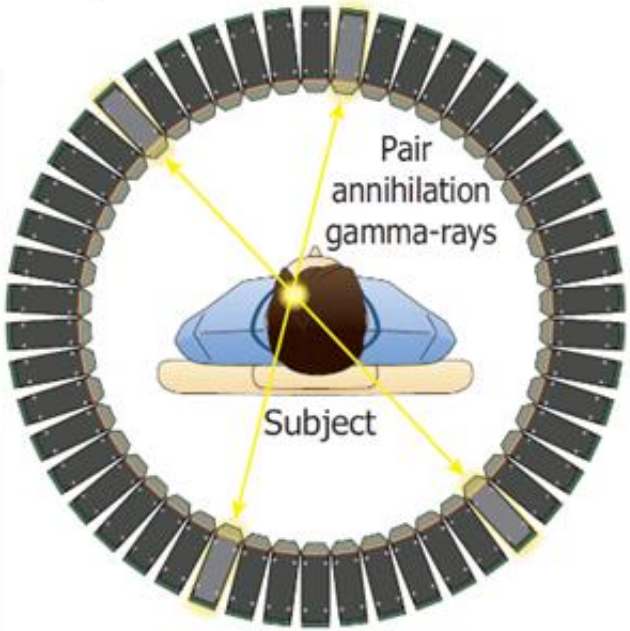


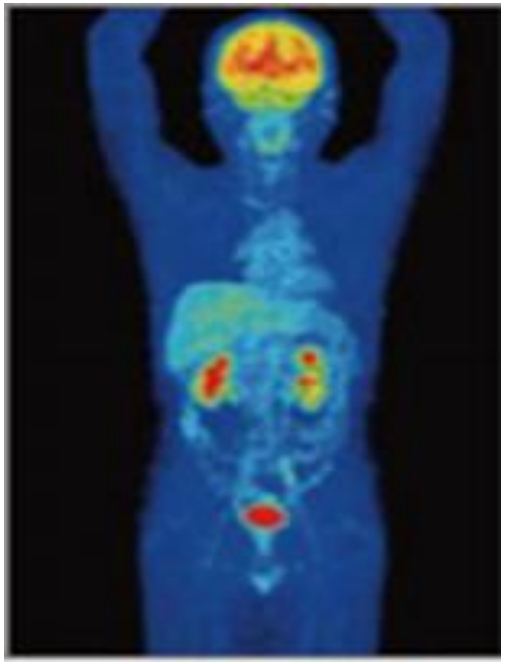
● Basic Operation

- ✓ Each pixel operates separately in Geiger-mode
- ✓ Each pixel outputs a same amplitude pulse
- ✓ Pulse generated by multiple pixels are output while superimposed onto each other (detected at the same time)
- ✓ No position information

MPPC Module for PET Application

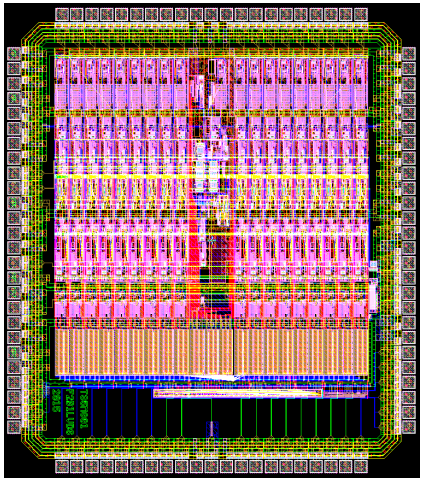






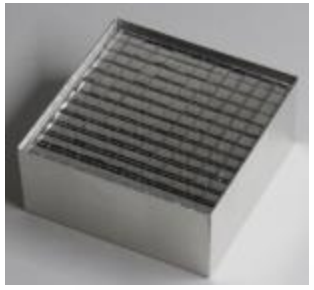
TOF PET Module

Specifications	
CRT	280 ps
Energy resolution	<15 %
Crystal material	LFS (Lutetium Fine Silicate)
Crystal dimensions	4.14×4.14×20 mm 12×12 array
MPPC type	LCT type
Detector dimensions	4.0×4.0 mm 12×12 Array
Pixel size	75 μm
Operating voltage	24V Require Local Power Supply
Consumption power	5 W
Interface	High Speed Serial

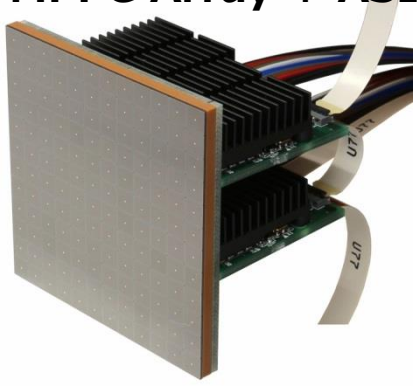


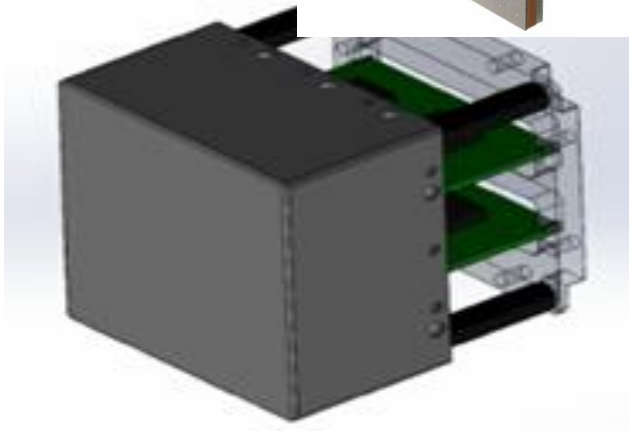
	New (2016)
Power Consumption	3mW/ch
Timing Resolution	~200ps
Process	0.18 CMOS

12×12 LFS Array



MPPC Array + ASIC





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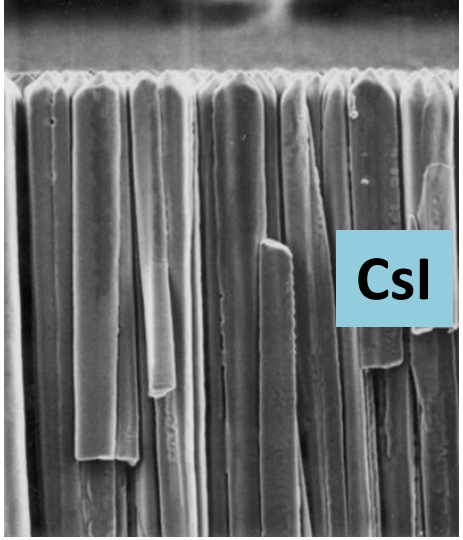
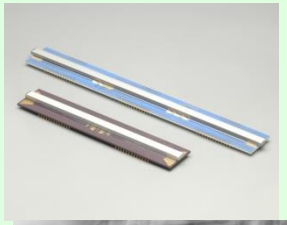
Dental Application

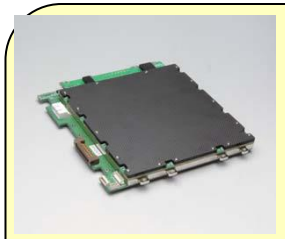


Intra-Oral

Pan/Ceph



CT



Solid State Division

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Scientific Contribution

HAMAMATSU PHOTONICS K.K.

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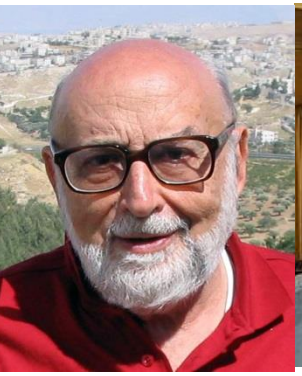
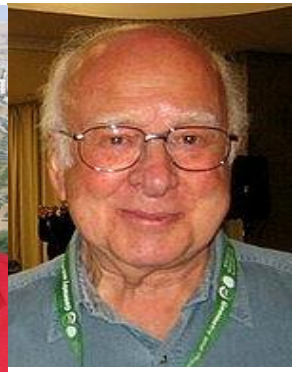
Contribution to Nobel Prize

2002 **Masatoshi Koshiba, professor emeritus of University of Tokyo, was awarded the Nobel Prize in physics, as a result of research conducted at the Kamiokande using Hamamatsu 20”PMT**





2013 **Professors emeriti François Englert and Peter Higgs won the Nobel Prize in Physics. (Our SSDs, APDs, and PMTs helped to detect the Higgs boson)**

2015 **T akaaki Kajita, professor of University of Tokyo, was awarded the Nobel Prize in physics, as a result of research conducted at the Super-Kamiokande facility using 20” PMT from Hamamatsu Photonics.**

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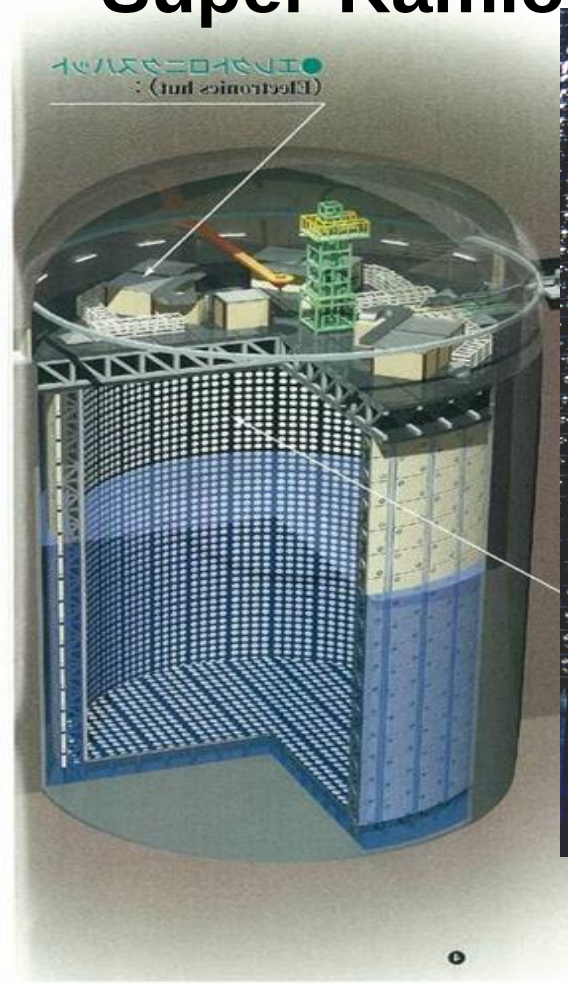
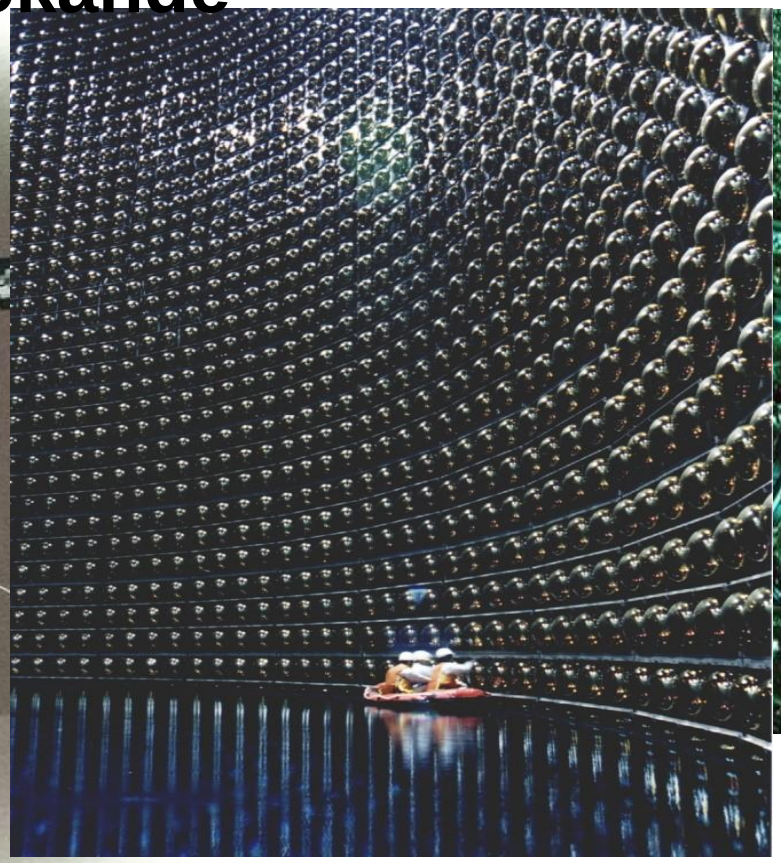
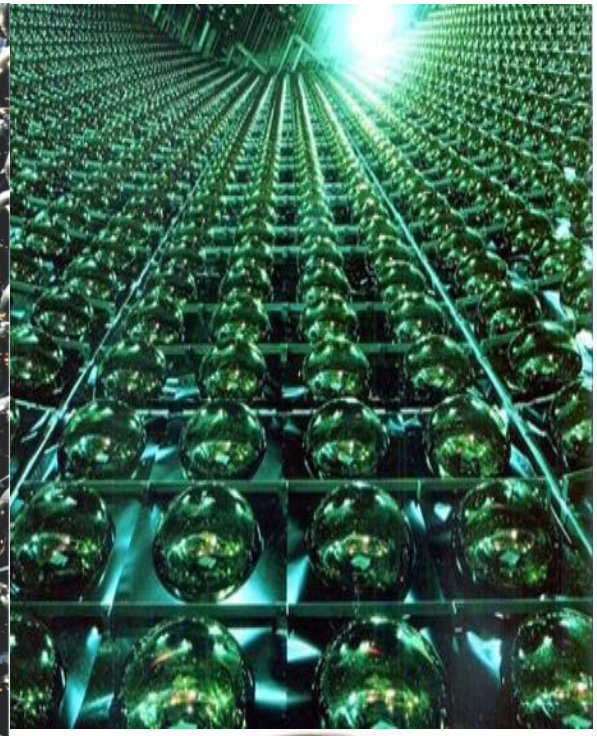
Neutrino Detection

- Super-Kamiokande -







20” PMT

“Super Kamiokande” There are 11,200 PMT with 50cm diameter Inside

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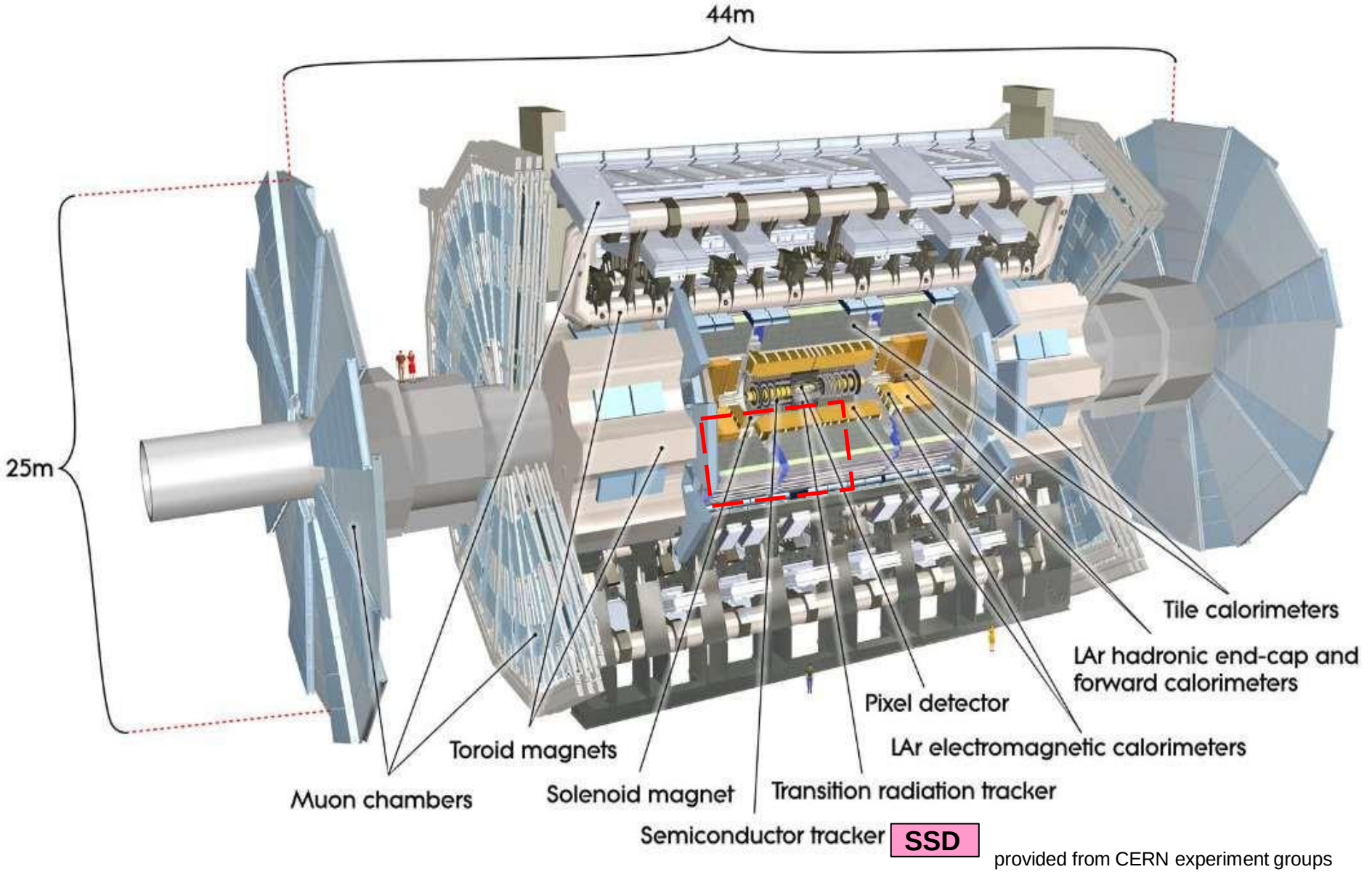
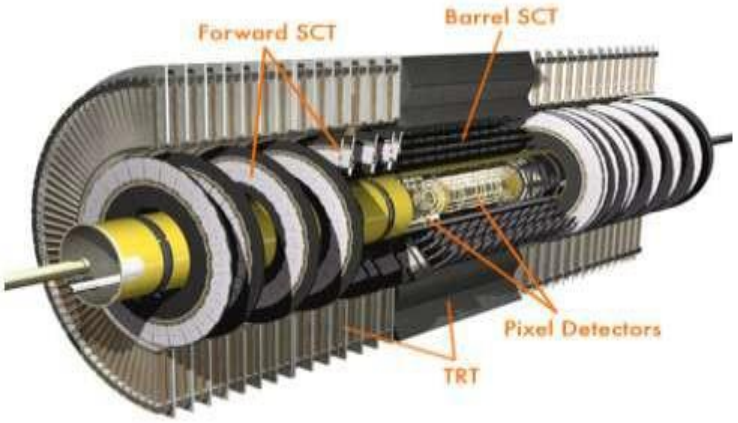
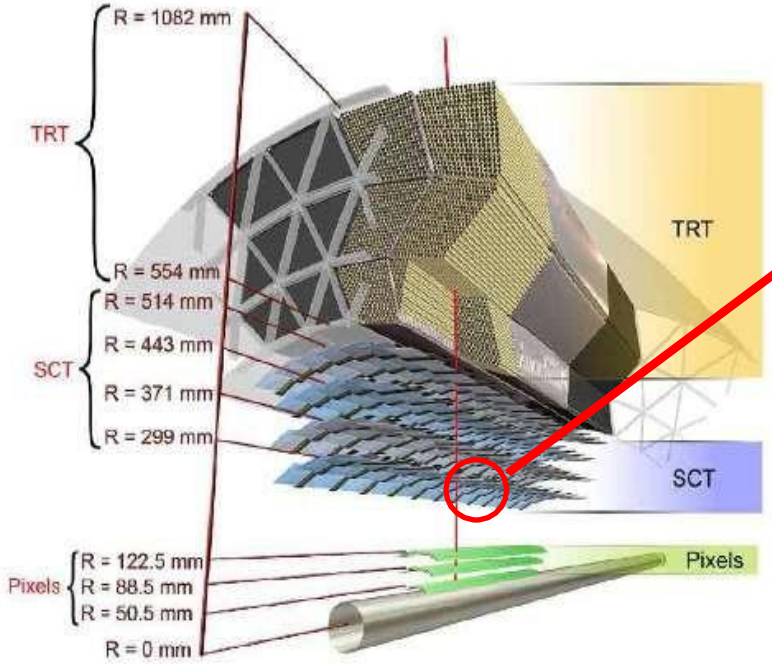
ATLAS - SSD

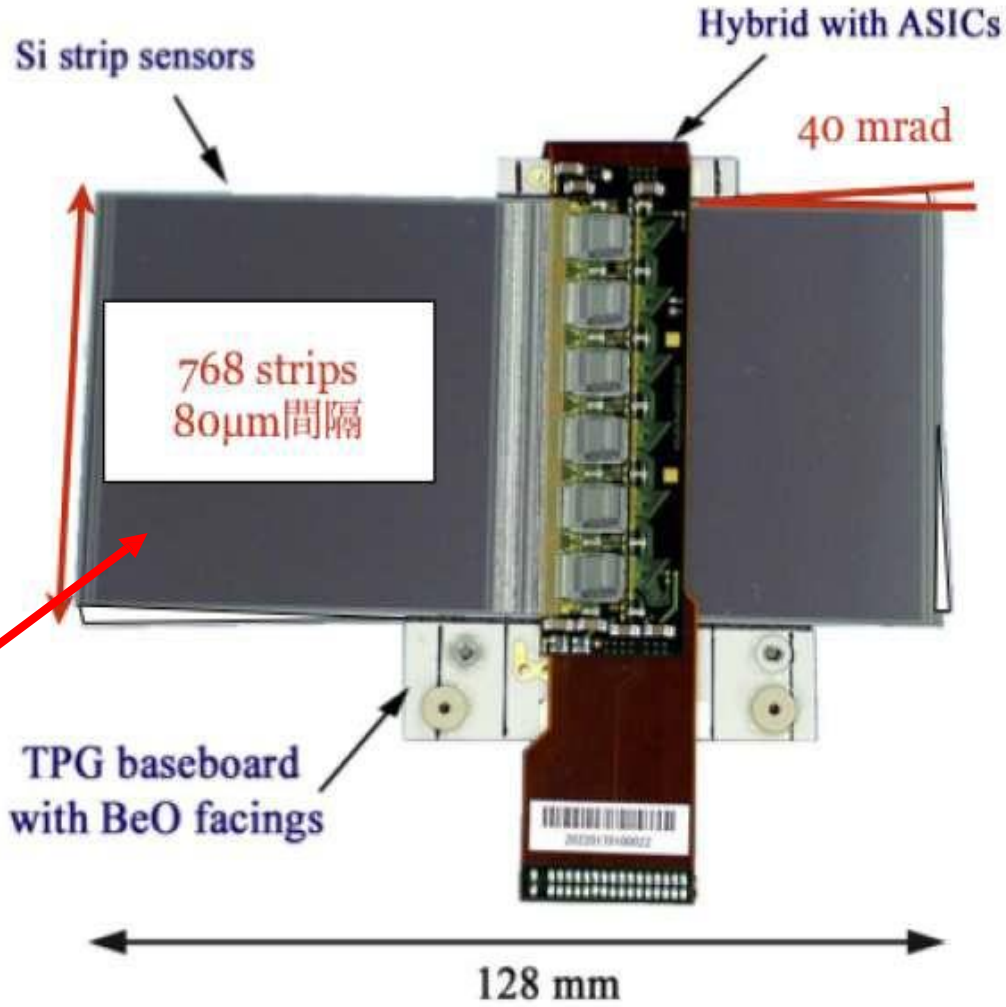


provided from CERN experiment groups

ATLAS
Central tracking detectors & SCT module







provided from CERN experiment groups

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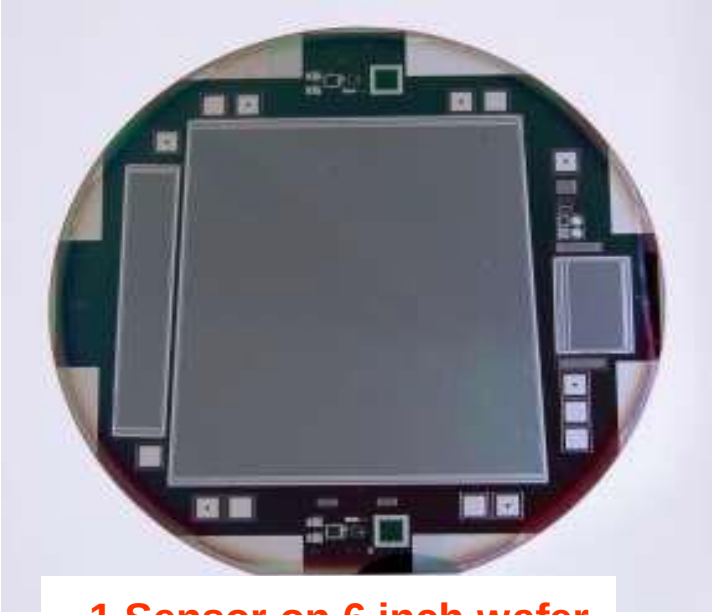
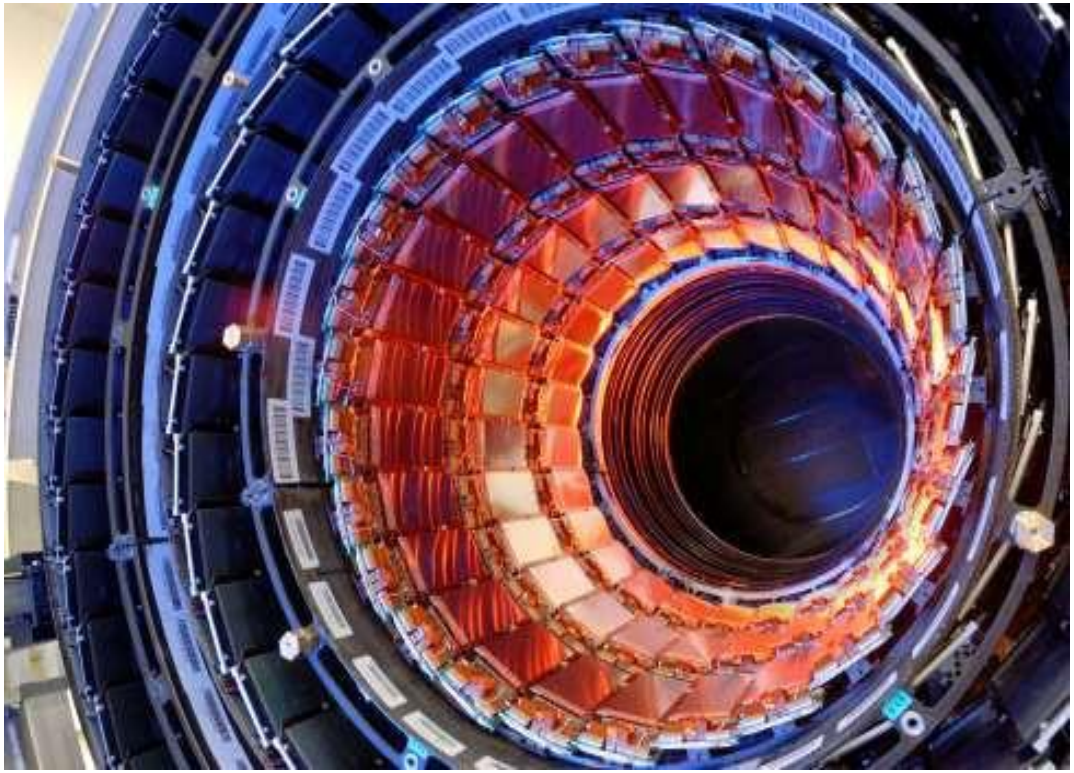
CMS
Si tracker and SSD

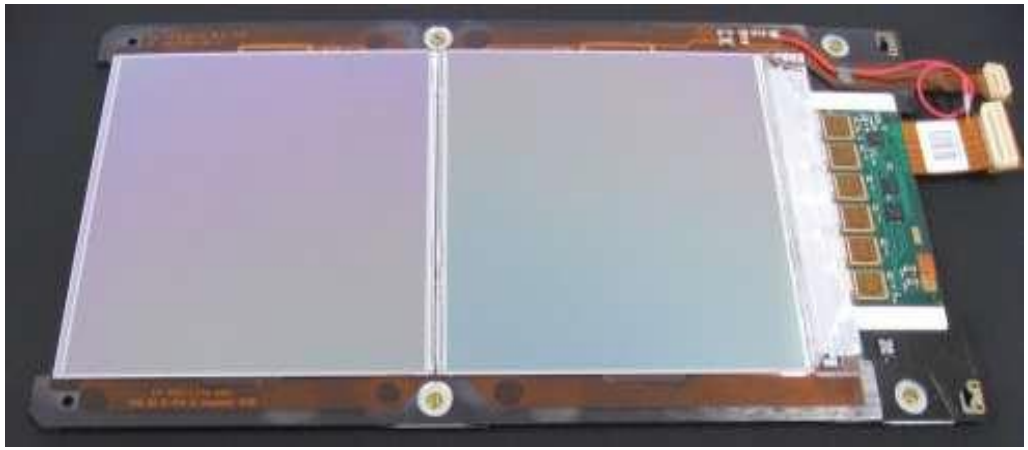


1 Sensor on 6 inch wafer

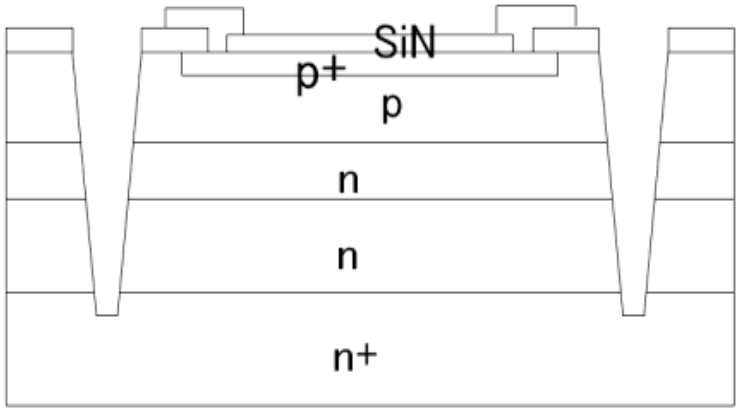


provided from CERN experiment groups

S9153, S9154 series



CMS
Specifications and Structure of APD



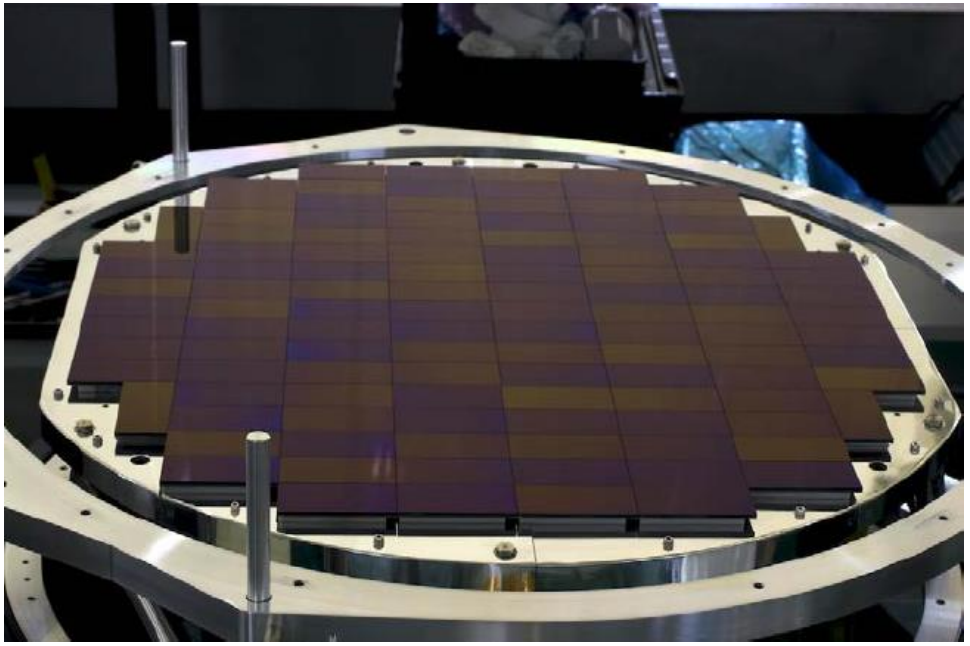
- **Blue sensitivity improved by SiN-AR coating**
- **low-capacity by spreading the depletion layer into the N side**
- **V-Groove for less increase of surface leakage current due to the irradiation damage.**

Spec.(Ta = 25℃)

STD No	S8148
active area	5 x 5 mm2
breakdown voltage (VB)	> 325 V
Operating Voltage (VR)	300 - 450 V
Difference VB-VR	> 25 V
Dark current at VR	< 50 nA
Capacitance at VR	65 - 85 pF
Quantum efficiency at VR, 430nm	75 ± 5%
Passivation layer	SiN
Protective coating	Epoxy Resin

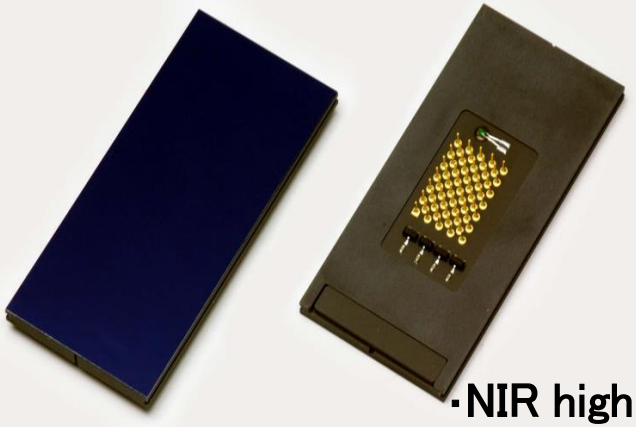
Fully depleted back illuminated CCD

SUBARU observatory at Hawai



116pcs 3x6cm 4side buttable CCD

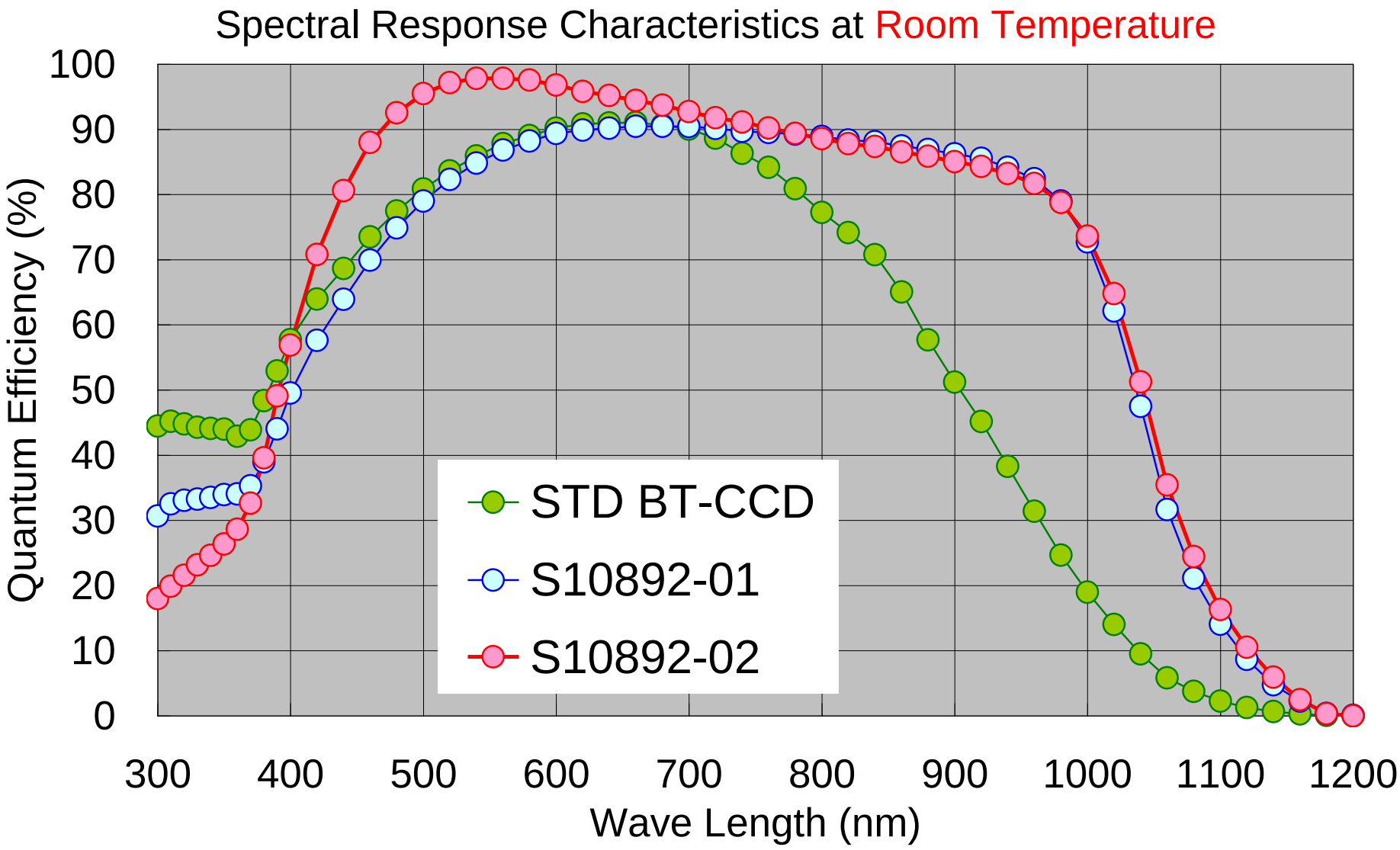
Observation of outer galactic space



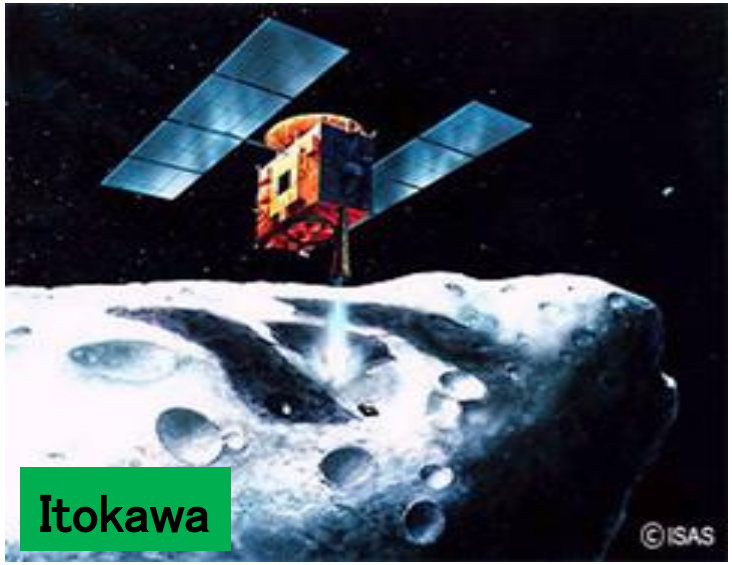
・NIR high sensitivity

・Low noise (4erms@133kHz)

Quantum Efficiency



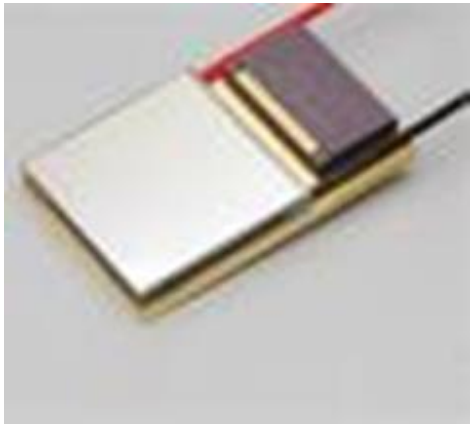
Astronomical Application



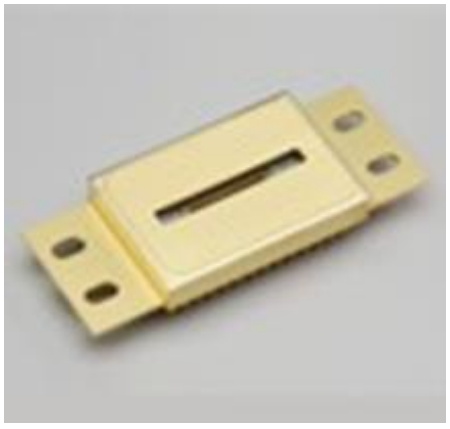
HAYABUSA brought back Itokawa's sample after 7 years long and traveling about 2 billion kilometers journey.

HAYABUSA had two of detectors on board developed by Hamamatsu to observe the surface materials of Itokawa. One was CCD for fluorescence X-ray spectrometer and other was Infrared Spectrometer.

CCD image sensor



InGaAs image sensor



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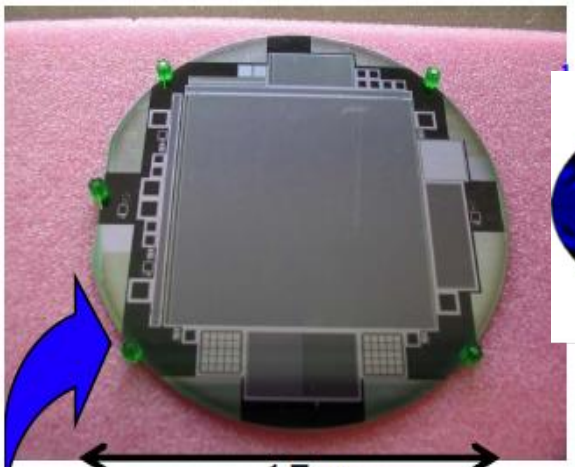
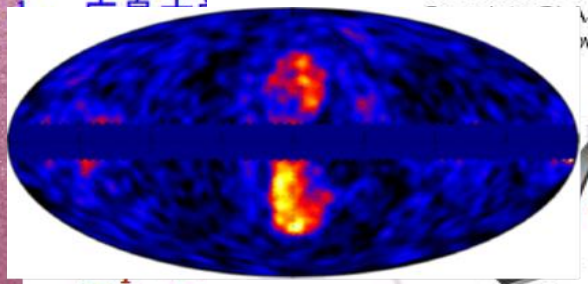
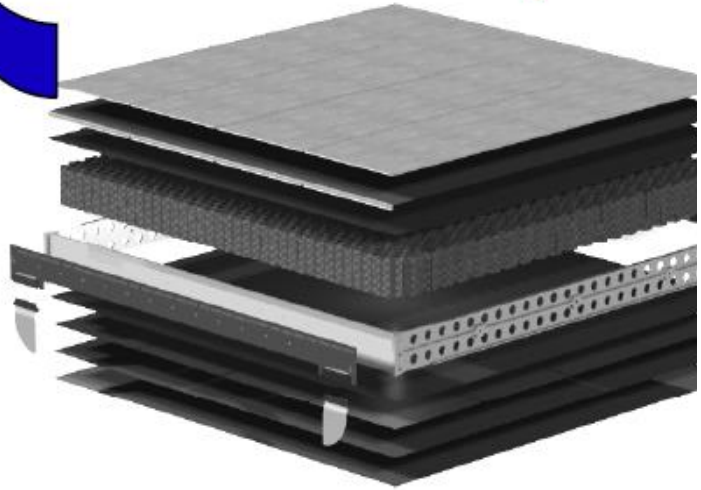
Gamma-ray Large Area Space Telescope(GLAST)





(X)



Total strip detectors:11,000pcs
Each strip are: 8.95x8.95 mm
228µm pitch

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New Developments

HAMAMATSU PHOTONICS K.K.

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Recent Development for HEP

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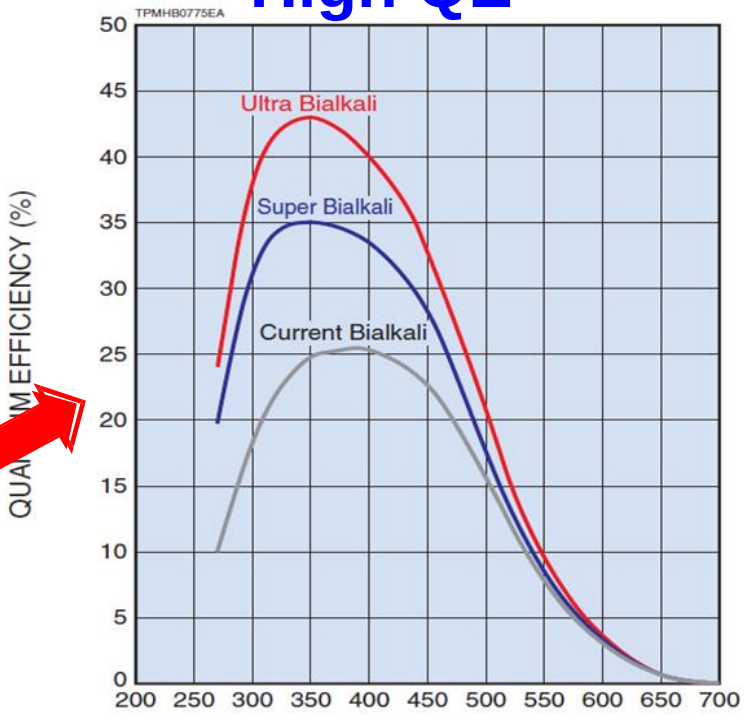
Large Size

PMT

Fast Time Respons

Low Temp. & Low R.I.

High QE



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Future Experiments for PMT (1/2)

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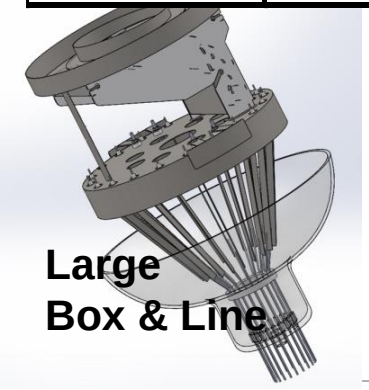
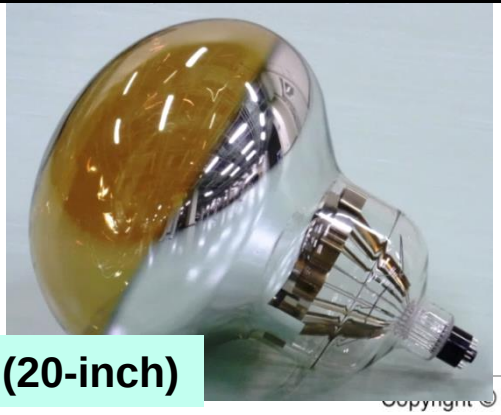
Category	Experiment	Experimental Site	Delivery	Type of PMT
Neutrino	Hyper-Kamiokande	Kamioka/Japan	2018~	R12860 (20-inch) ASSY
				R5912 (8-inch) ASSY
	NuPRISM	J-Parc/Japan	2020~	R12199 (3-inch)
	KamLand2-Zen	Kamioka/Japan	2018~	R12860 (20-inch) ASSY
	JUNO	Jiangmen/China	2016~	R12860 (20-inch)
			2017~	R12199 (3-inch)
	KM3NeT	Mediterranean Sea	2014~	R12199 (3-inch)
	Baikal-GVD	Lake Baikal	2015~	R7081-100 (10-inch)
	PINGU/IceCube	the South Pole	2018~	R12199 (3-inch)





R12860 (20-inch)

R12199 (3-inch)

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Future Experiments for PMT (2/2)

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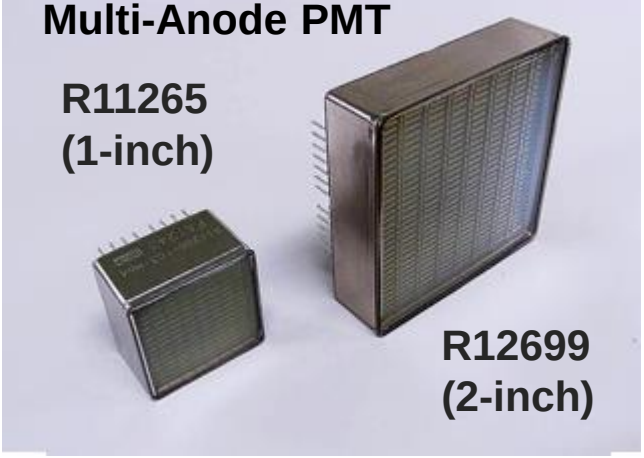
Category	Experiment	Experimental Site	Delivery	Type of PMT
Collision Experiment	RICH/LHC-B	CERN	2015~	1-inch Square MA-PMT
				2-inch Square MA-PMT
	RICH/CBM	GSI/Germany	2015~	2-inch Square MA-PMT
Dark Matter	LZ7	SURF/USA	2016~	3-inch Metal Bulb PMT
	XENON-1T/-nT	Gran-Sasso/Italy	2015~	3-inch Metal Bulb PMT
Gamma-ray Telescope	CTA	North-La Palma South-Chile	2015~	R12992 (1.5-inch)

Multi-Anode PMT



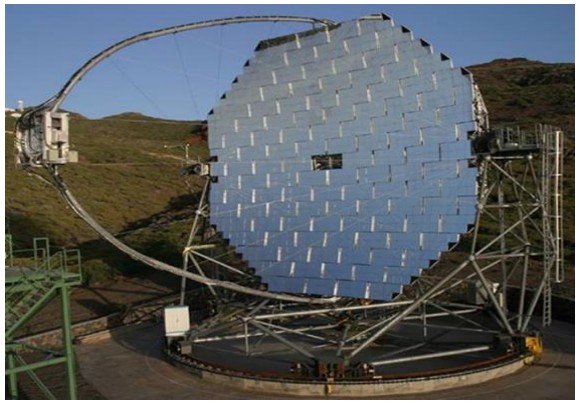
High QE and Low Noise

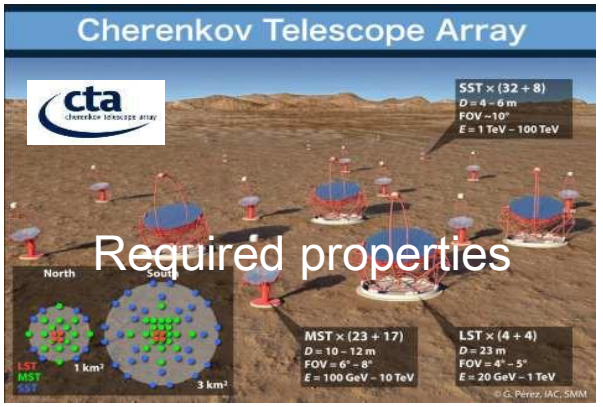
Metal Bulb PMT

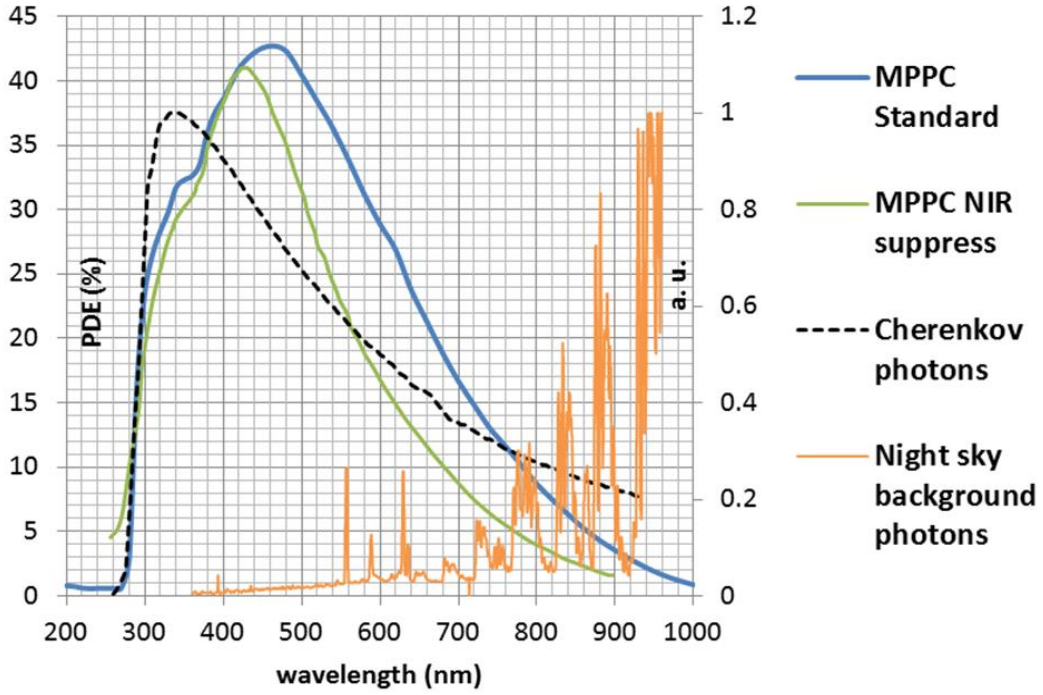
MPPC for Cherenkov Telescope Array

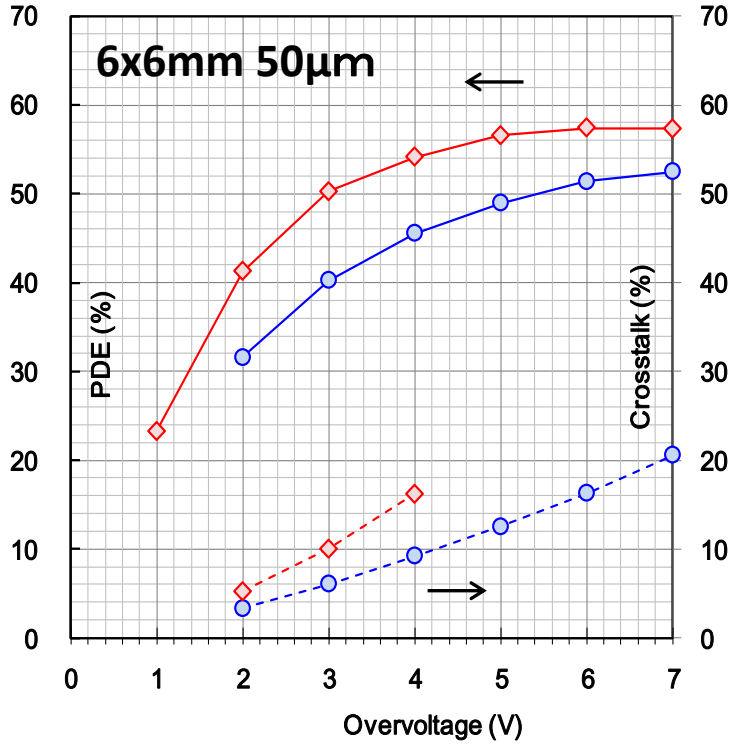
Required Properties

- High PDE @350nm
- High Gain
- Low cross talk
- Low dark count
- Large sensitive area
- Less sensitivitv in visible









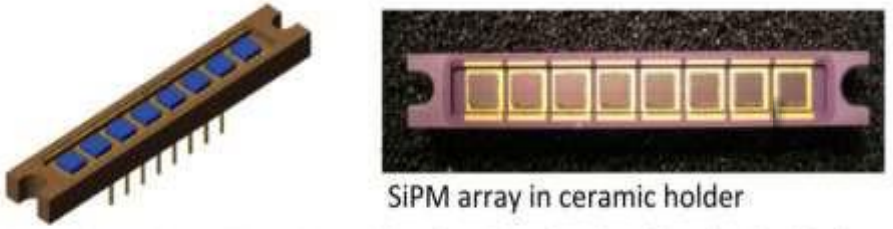
MPPC for CMS HCAL upgrade (HB/HE)

Compact Muon Solenoid experiment at CERN's LHC

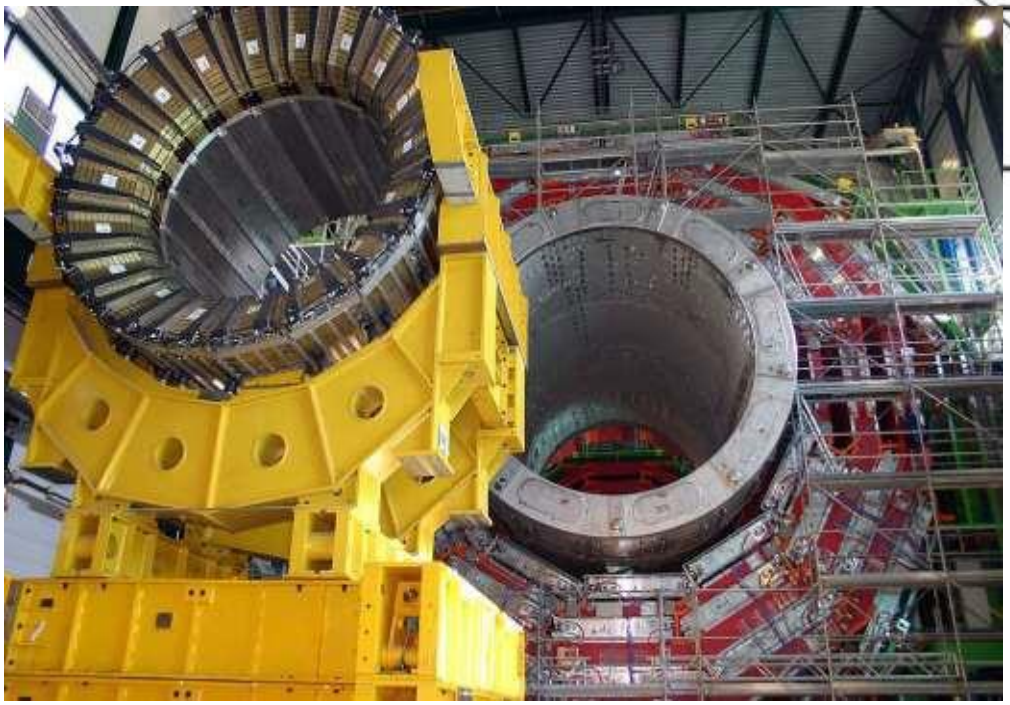
Required properties

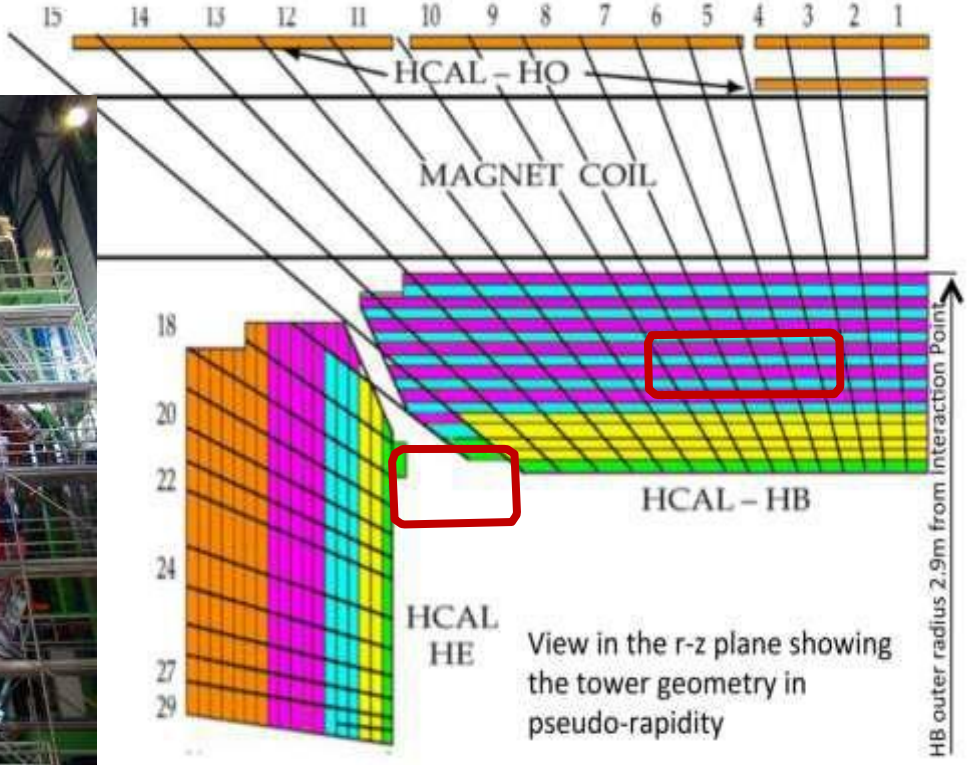
- Low dark count
- Radiation hardness
- High PDE
- Wide dynamic range

Sensitive area: ϕ3.3mmx8ch 15μm pitch



SiPM array in ceramic holder



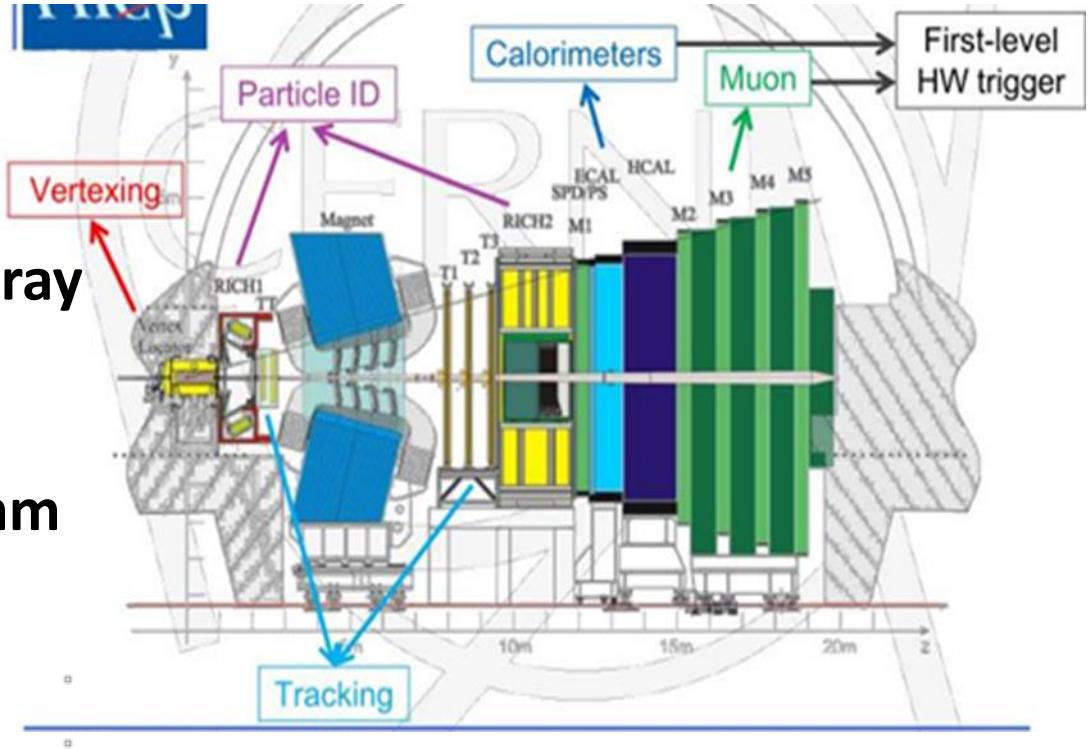


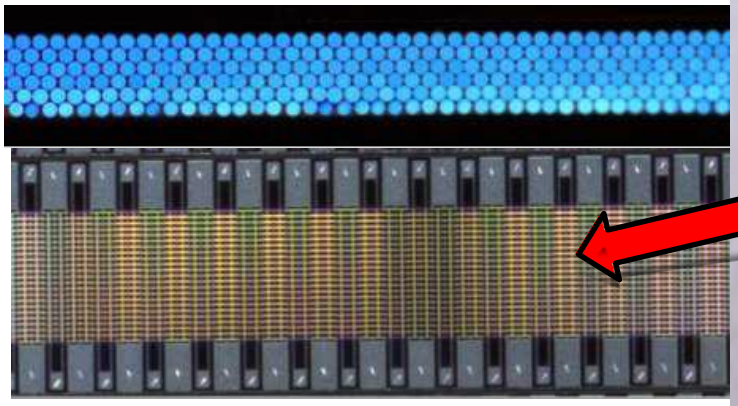
View in the r-z plane showing the tower geometry in pseudo-rapidity

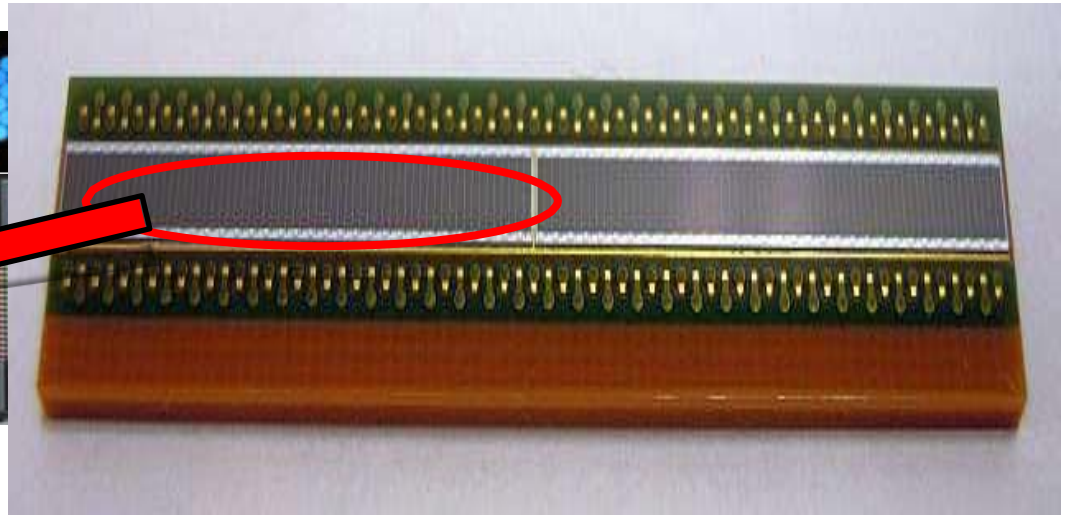
MPPC for LHCb SciFi Tracker

Required Properties

- Coupled with SciFi matrix
- 64x2ch fine pitch MPPC array
- High position accuracy
- High PDE @400nm
- Area: 0.23x1.5mm p0.25mm



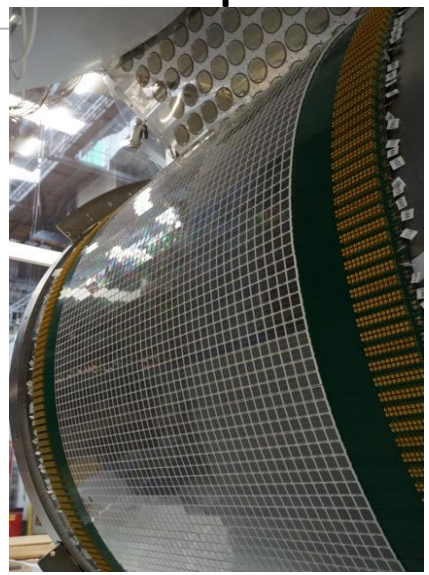




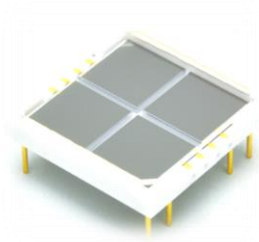
MPPC for VUV detection

1. Search for the $\mu^+ \rightarrow e^+ +$ gamma decay

MEG experiment



- MEG experiment
  - 6mm sq. – 2x2ch. x 6,000pcs
  - LXe (178nm) sensitivity & Low temperature resistive PKG

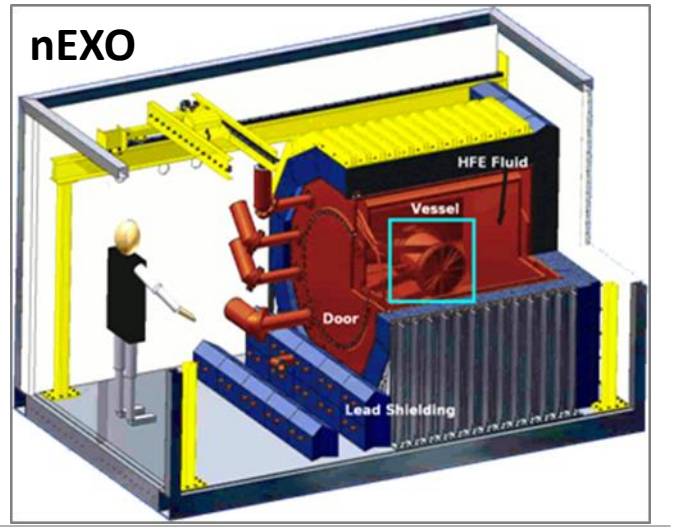


2. Dark matter search

- DARWIN ・LAr or LXe sensitivity
- ANKOK ・LAr (128nm) sensitivity
- ArDM ・LAr sensitivity or WLS

3.Precise neutrino experiment

- DUNE
- nEXO ・LXe direct detection, Low RI PKG
- NEXT ・WLS, Low RI PKG



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MPPC : VUV Detection

ICHEP 2016, ID: 450

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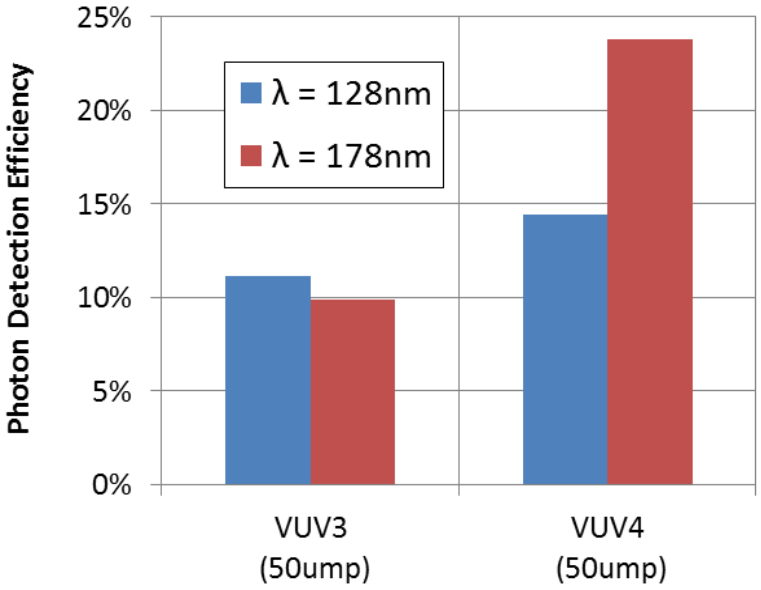
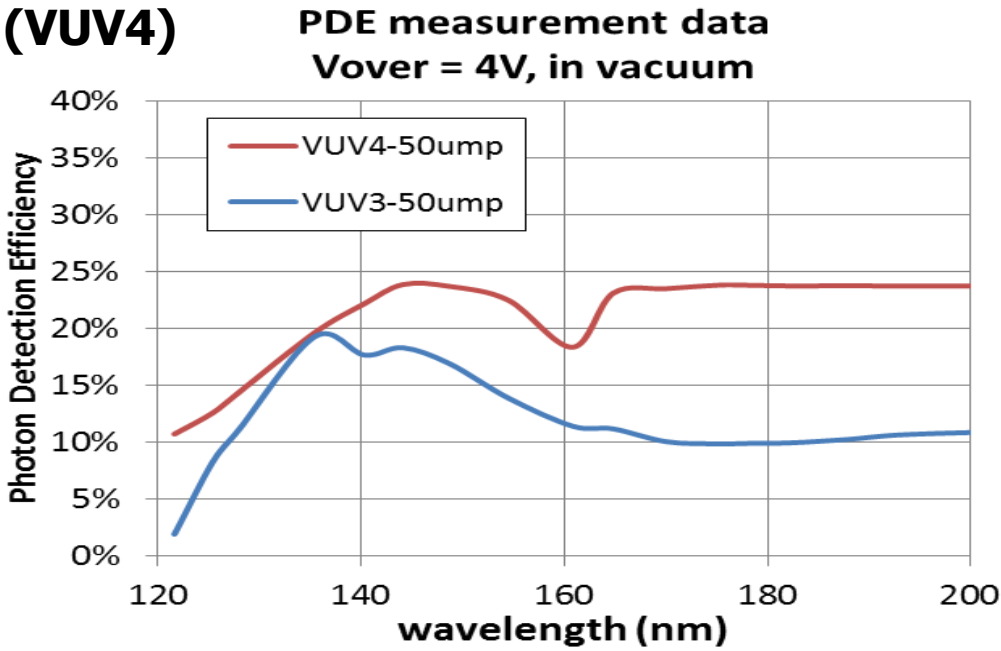
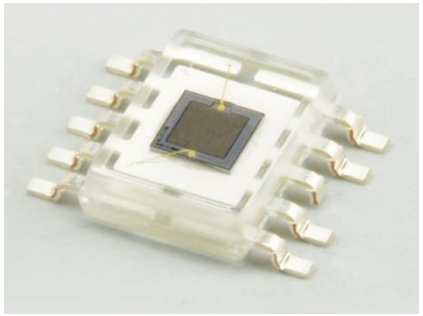
New improvements to a specialized Multi-Pixel Photon Counter (MPPC) for neutrino less double-beta decay and dark matter search experiments

➢ Improvement for VUV sensitivity (VUV4)

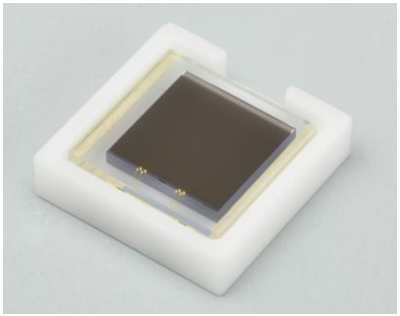




➢ Packaging technology for physics experiment with liquid scintillator



➢**Ultralow-RI for indirect VUV detection**



➢**Ultralow-RI for direct VUV detection**

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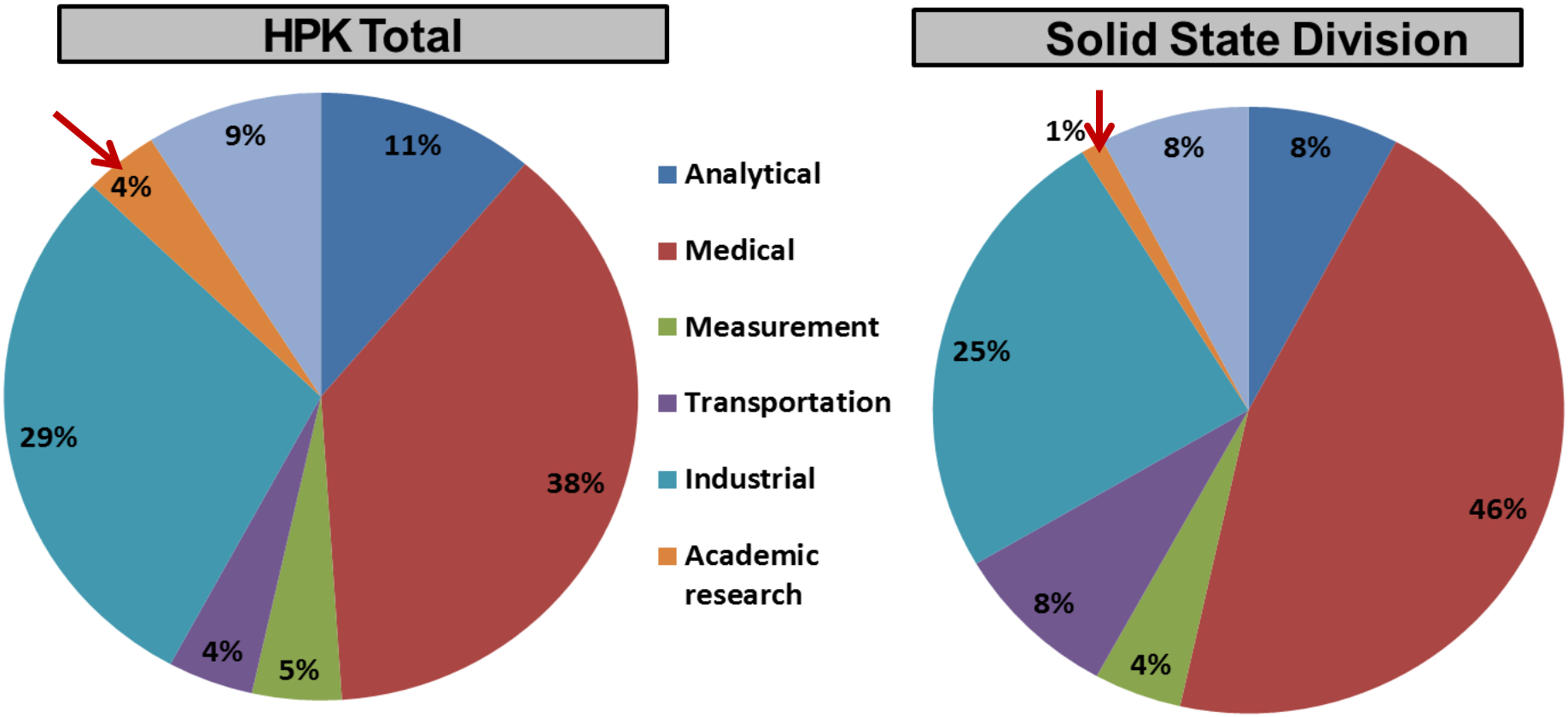
Sales by Application

Sales share in major application



Thank for Your attention

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