HAMAMATSU

PHOTON IS OUR BUSINESS

Hamamatsu Photonics K.K.

Symposium University of Tokyo – ETH Zurich – University of Zurich
17 October, 2023

Outline

- About HAMAMATSU — Yuji Hotta (ETD)
- Product introduction for PMTs — Kensuke Suzuki (ETD)
- Product introduction for MPPCs — Kota Kobayashi (SSD)

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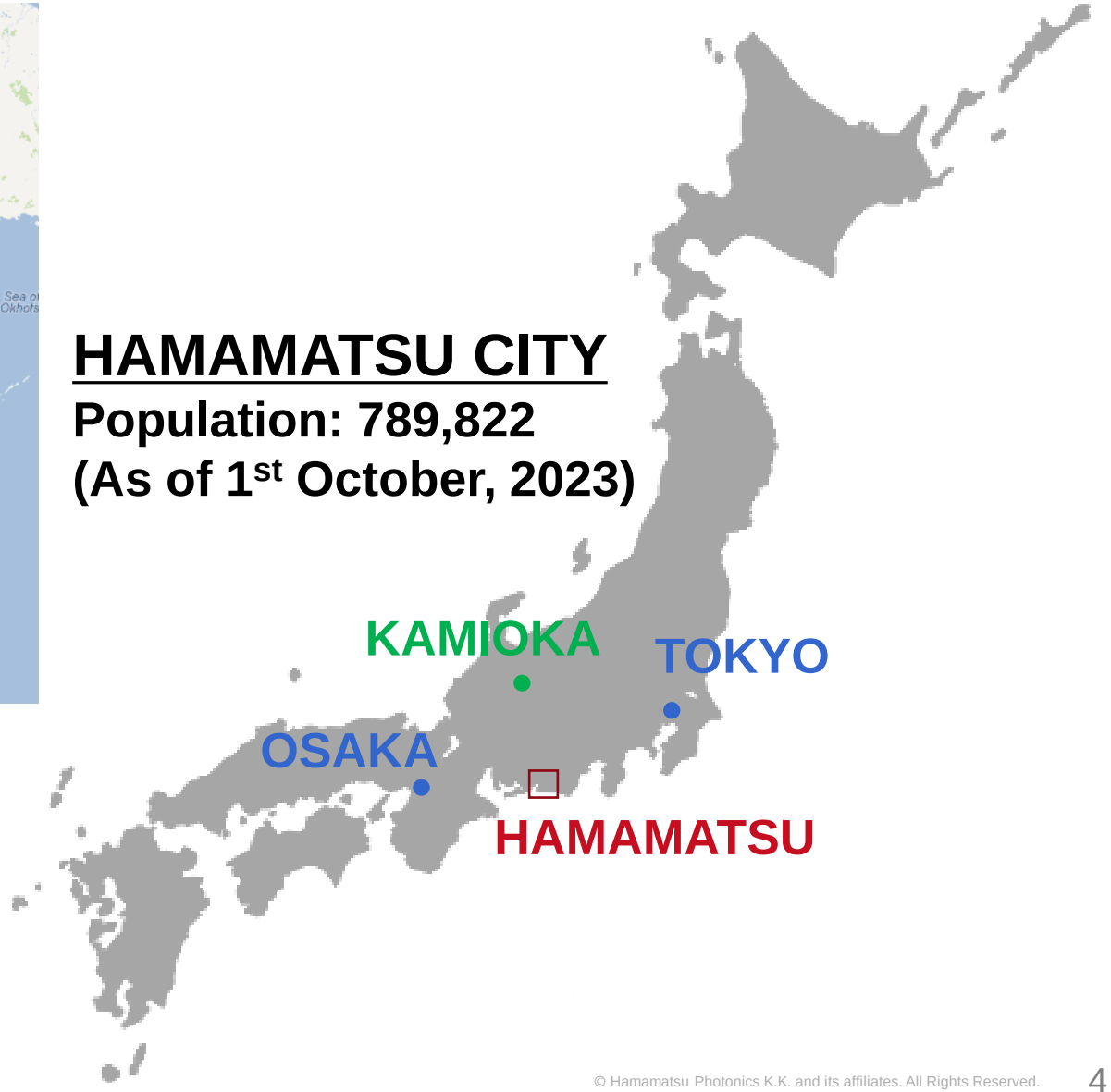
About HAMAMATSU

Location

HAMAMATSU CITY

Population: 789,822
(As of 1st October, 2023)



Eel (Unagi)

Dumpling (Gyoza)

Location

HAMAMATSU
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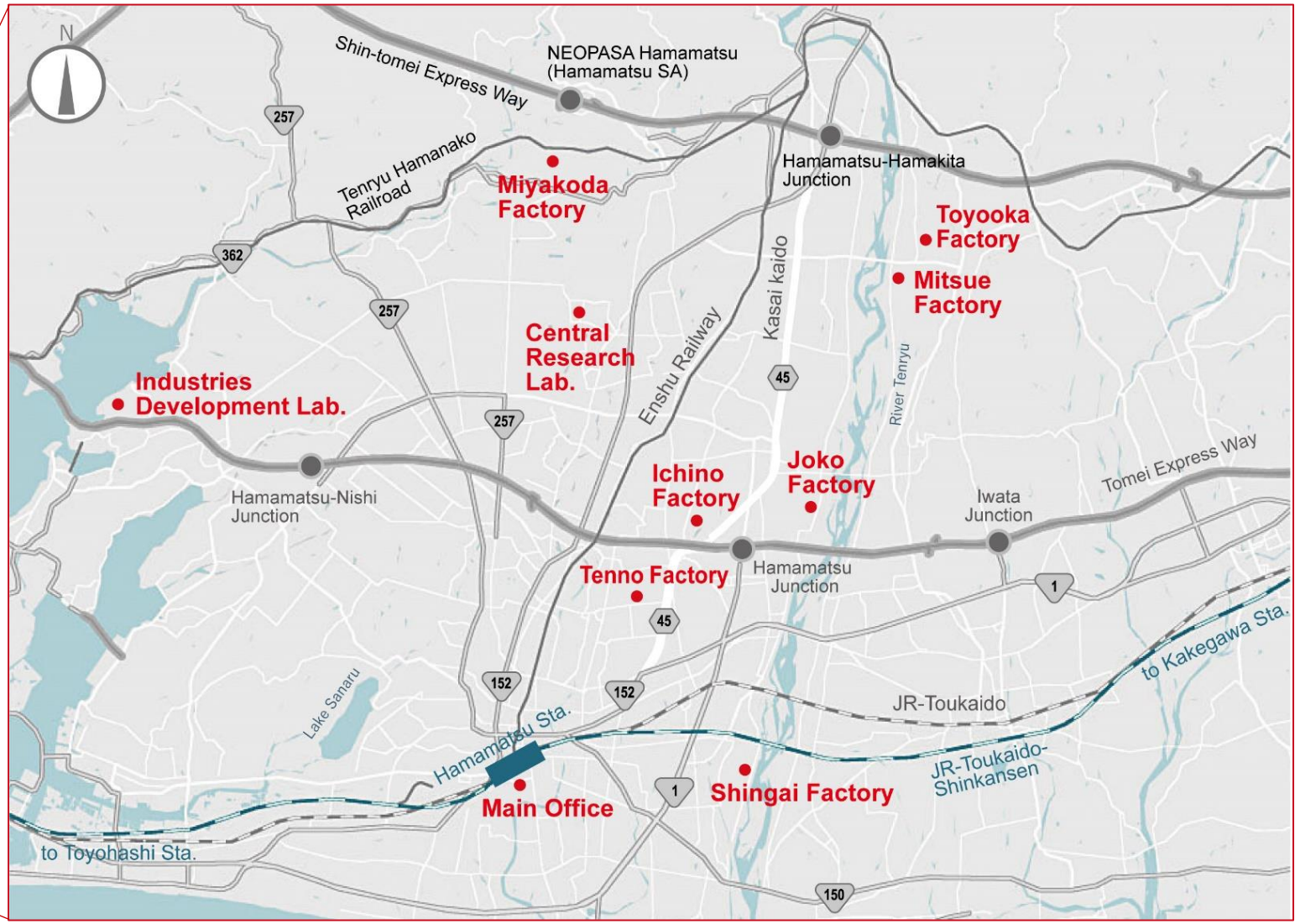
HAMAMATSU CITY
Population: 789,822
(As of 1st October, 2023)


Eel


Dumpling



Corporate Data

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Company Name	HAMAMATSU PHOTONICS K.K.
Established	September 29, 1953
Capital	35,048 million yen
Stock listing	Tokyo Stock Exchange, Prime Market
Main Product Lines	・Photomultiplier Tubes ・Imaging Devices ・Light Sources ・Opto-semiconductors ・Imaging and Analyzing Systems

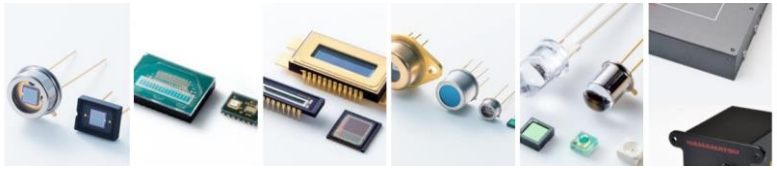
As of September 30, 2022

Division

Factories

Electron Tube Division

Solid State Division

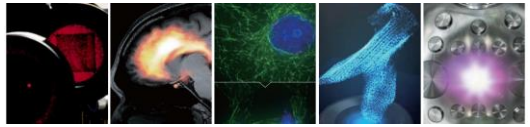


Systems Division

Laser Promotion Division

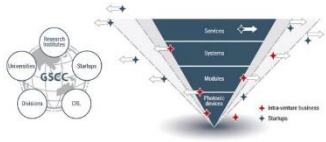
Laboratories

Central Research Laboratory



Other

Global Strategic Challenge Center (GSCC)



Subsidiary

ENERGETIQ TECHNOLOGY, INC.

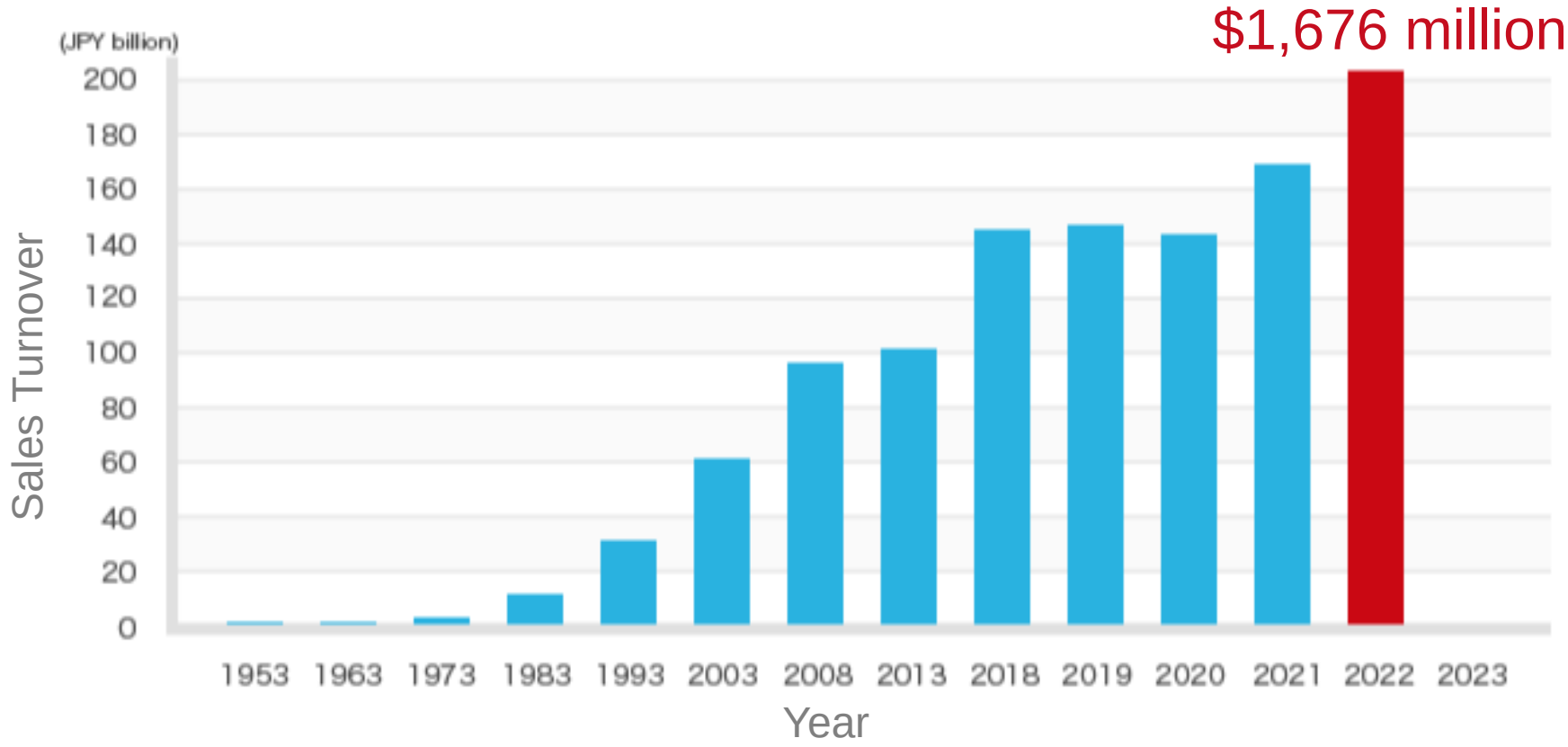
Number of employees (Japan)

Total	3,973 people

Business Divisions	Business Sites	Number of people
Electronic Tube Division	Toyooka Factory & Tenno Glass Factory	1,244 people
Solid State Division	Ichino Factory, Mitsue Factory & Shingai Factory	1,429 people
System Division	Joko Factory	444 people
Laser Promotion Division, Compound semiconductor Fab. Center	Miyakoda Factory & Central Research Laboratory	252 people
Global Strategic Challenge Center	Central Research Laboratories & Main Office	80 people
Central Research Laboratory	Central Research Laboratory	208 people
Administration & Managing Office	Main Office (front of Hamamatsu station)	316 people

As of January 1, 2023

Sales Turnover



We develop and sell various products using optical technology.
In September 2022, consolidated sales reached $1,676 million.
(Converted at an exchange rate of 124.55 yen to the U.S. dollar.)

Sales Distribution by Region

* As of September 2022, consolidated

Today, our products are used in over 100 countries.

Percentage of Net Sales

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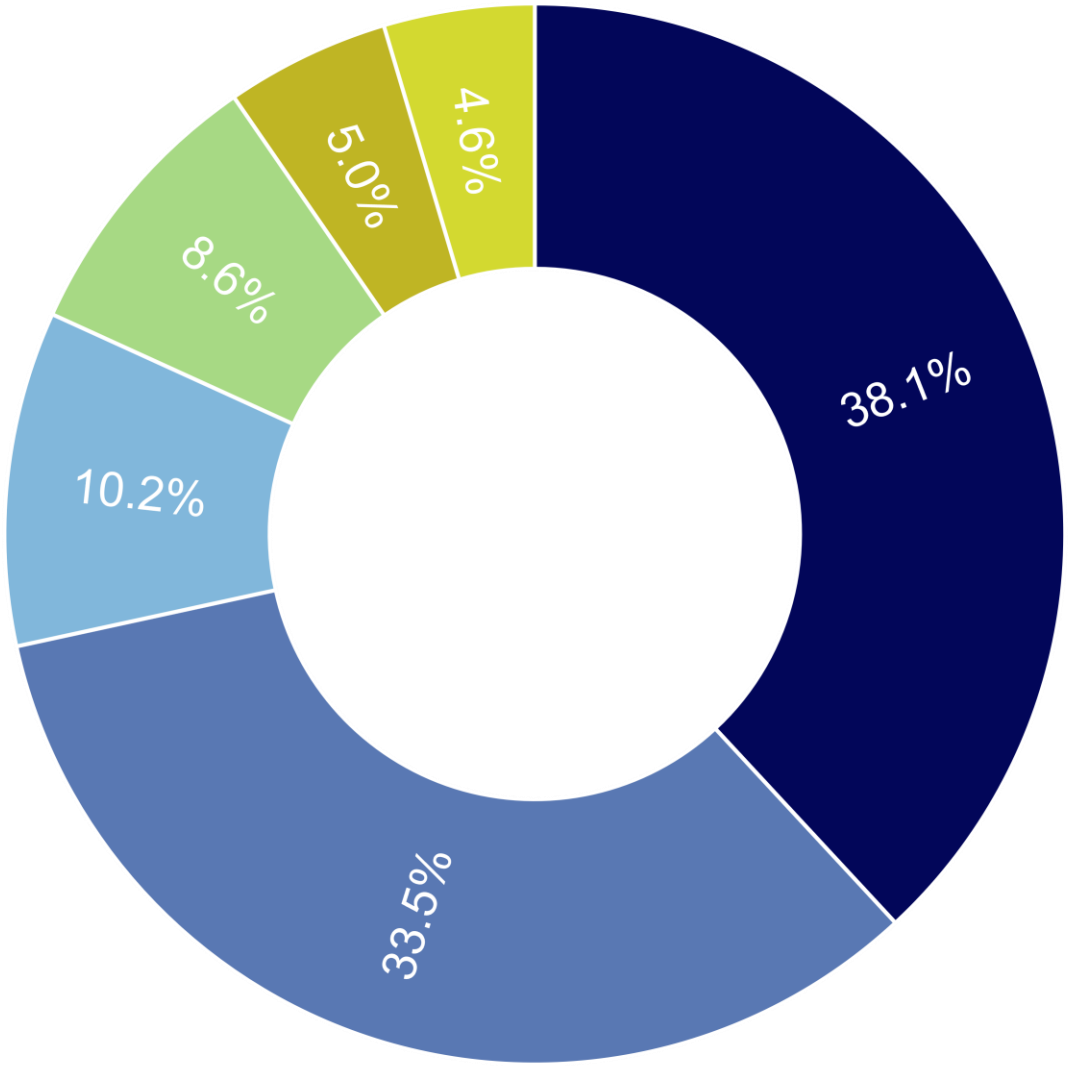
Measuring instruments : 4.6%

Academic research : 5.0%

Other : 8.6%

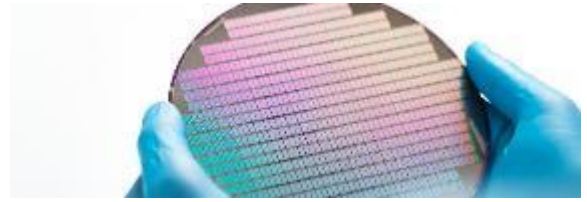
Analytical instruments : 10.2%



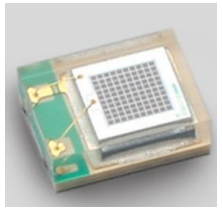
(Fiscal year ended September 2022)

Medical-Bio instruments : 38.1%

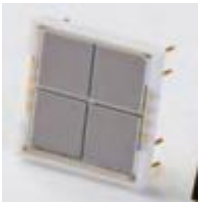
Industrial instruments : 33.5%



Shipping Record



Experiment Name	Product	QTY
Super Kamiokande/ID	20" PMT	11,200
Super Kamiokande/OD	8" PMT	1,900
T2K/ND280/FDG	MPPC	120,000
MEG	2" PMT	850
MEG-II	MPPC	4,100
XENONnT	3" PMT	500



https://www.hamamatsu.com/jp/ja.html

https://www.hamamatsu.com/eu/en.html

PHOTON FAIR 2023

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70th Anniversary

PHOTON FAIR 2023

光で何ができるか

2023.11.16(木) 17(金) 18(土) 10:00 - 18:00
(最終日 18 日のみ 9:00 - 12:00)

アクトシティ浜松 展示イベントホール
JR 浜松駅北口から徒歩約 10 分

完全事前登録制（入場無料） 事前登録受付中！

www.photonfair.jp

https://www.photonfair.jp/

創立70周年を迎えて開催する光の総合展示会

PHOTON FAIR（フォトンフェア）は、浜松ホトニクスが主催する光の総合展示会で、「光で何ができるか」をテーマに5年に一度開催しています。
PHOTON FAIR 2023では浜松ホトニクスの技術や製品を「くらし」「健康」「脳」「地球」「宇宙」「量子」の6つの展示テーマと弊社のコア・テクノロジーに沿って展示します。そのほか、著名なゲストによる特別講演や弊社エンジニア、研究者そして社外講師による30セッション以上のセミナーも開催します。

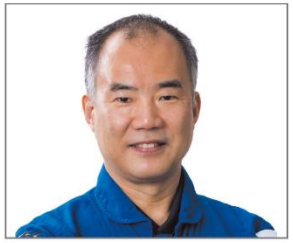
◀PHOTON FAIR 2018の会場風景

講演会

浜松ホトニクス株式会社
代表取締役社長
丸野 正
光技術による社会貢献と高付加価値化への挑戦

ブリュッセル自由大学（VUB）
副学長 兼 教授
ヒューゴ・ティエンポン 氏
光技術が切り拓く新たな世界：ブリュッセル・フォトニクス研究チームの視点

東京大学カブリ数物連携宇宙研究機構
特別教授・浜松プロフェッサー
村山 斉 氏
ダークマターとダークエネルギー



宇宙飛行士
野口 聡一 氏
宇宙の魅力や宇宙産業・宇宙技術開発の現状と今後の発展

浜松ホトニクス株式会社 フォトンフェア事務局
〒 430-8587 静岡県浜松市中区砂山町325-6 日本生命浜松駅前ビル E-mail：photonfair@hq.hpk.co.jp

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Product introduction for PMTs

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Agenda

- Fast Time Response PMT R13xxx series and R16768-100
- Hemisphere PMT R14374(3” PMT), R14688(8” PMT)
- R12699-406-M4(2” FP-PMT)
- R9880 Series (TO-8 PMT)

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Agenda

- Fast Time Response PMT R13xxx series and R16768-100
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- R9880 Series (TO-8 PMT)

Fast Time Response PMT R13xxx Series (1)

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- Fast Time Response PMT R13xxx Series Spec. Comparison

Type Name		R13478	R13449	R13408	R13089	R15608
Size		1"	1-1/8"	1-1/2"	2"	3"
Effective Area Min.[mm]		Φ 22	Φ 25	Φ 34	Φ 46	Φ 65
Spectral Response	Range [nm]	300 - 650				
	Peak Wavelength [nm]	420				
Photocathode Material		BA				
Window Material		K				
Dynode Structure / Stages		L/8	L/8	L/8	L/8	L/10
Cathode Characteristics	Luminous Typ. [uA/lm]	95	95	95	95	85
	Blue Sensitivity Index. Typ.	10	10	10	10	9.5
Anode Characteristics	Luminous Typ. [A/lm]	50				
	Gain Typ.	5.3E+05	5.3E+05	5.3E+05	3.2E+05	9.4E+06
	Dark Current (After 30 min.) Typ. [nA]	3	3	3	10	15
	Dark Current (After 30 min.) Max. [nA]	30	30	30	50	100
	Rise Time Typ. [ns]	0.9	0.9	1.2	2	1.9
	T.T.S. (FWHM) Typ. [ps]	130	170	190	230	400
Pulse Linearity	2 % Deviation [mA]	10	10	20	30	30

・Main Feature
・Fast Time Response
・High Time Resolution

Mainly Used for TOF experiment, radiation monitoring.

Fast Time Response PMT R13xxx Series (2)

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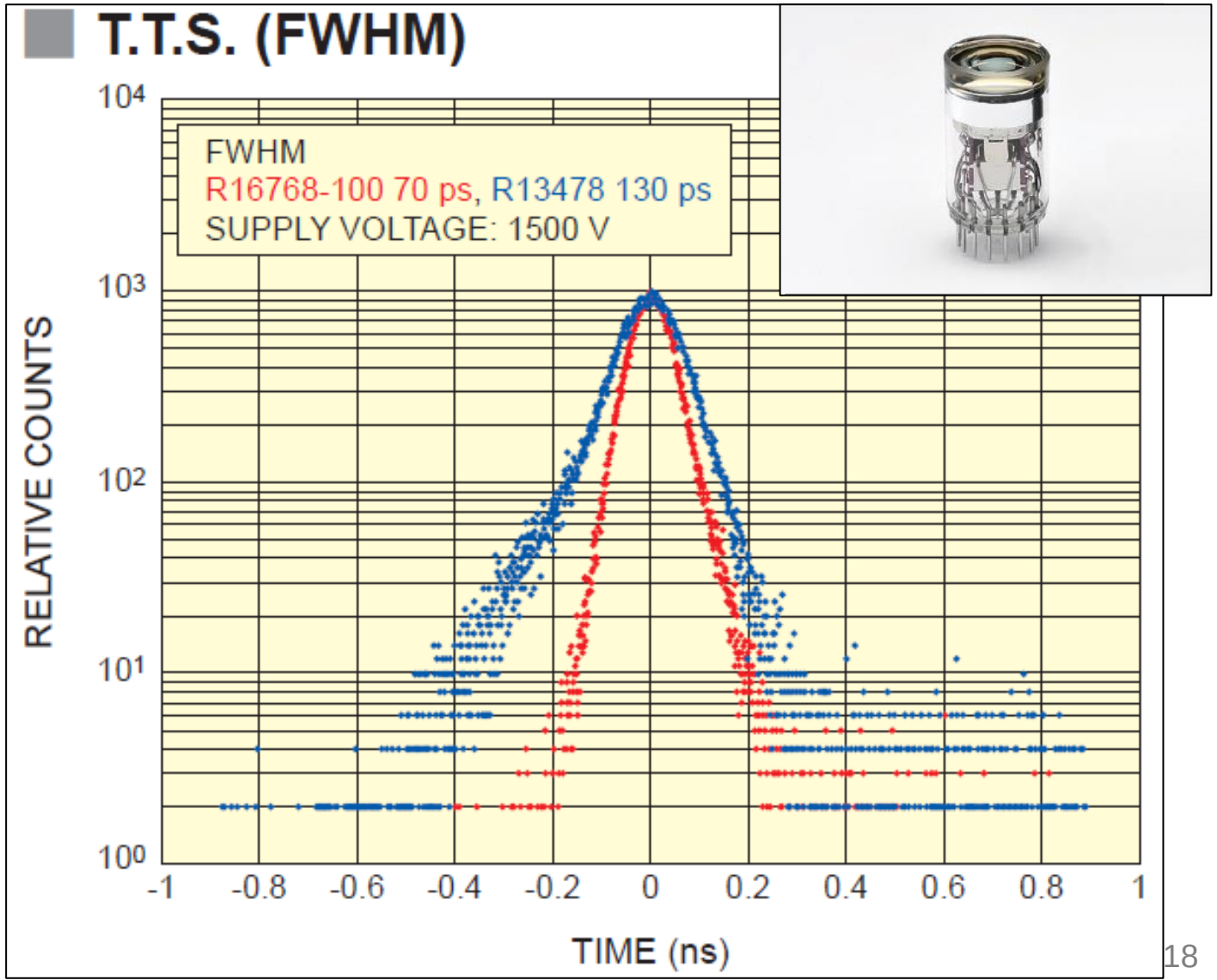
- R13478 & R16768-100 Spec. Comp.

Type Name		R13478	R16768-100
Size		1"	1"
Effective Area Min.[mm]		Φ 22	Φ 12
Spectral Response	Range [nm]	300 - 650	160 - 650
	Peak Wavelength [nm]	420	350
Photocathode Material		BA	SBA
Window Material		K	Q
Dynode Structure / Stages		L/8	L/8
Cathode Characteristics	Luminous Typ. [uA/lm]	95	120
	Blue Sensitivity Index. Typ.	10	12.5
Anode Characteristics	Luminous Typ. [A/lm]	50	180
	Gain Typ.	5.3E+05	1.5E+06
	Dark Current (After 30 min.) Typ. [nA]	3	3
	Dark Current (After 30 min.) Max. [nA]	30	30
	Rise Time Typ. [ns]	0.9	0.9
	T.T.S. (FWHM) Typ. [ps]	130	70
Pulse Linearity	2 % Deviation [mA]	10	10

- R13478 & R16768-100 TTS Data Comparison



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Agenda

- Fast Time Response PMT R13xxx series and R16768-100
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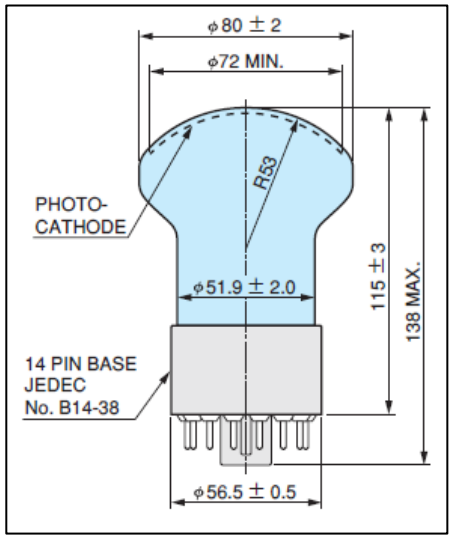
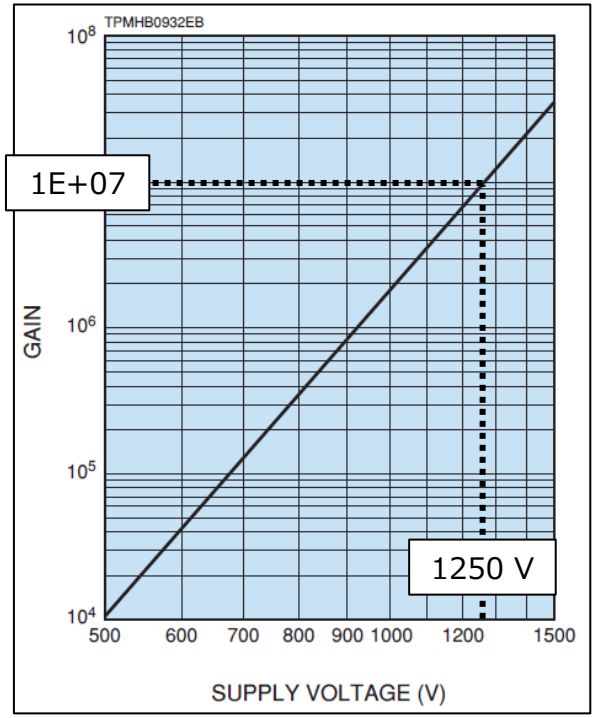
- R9880 Series (TO-8 PMT)

Hemisphere 3” PMT R14374 Series

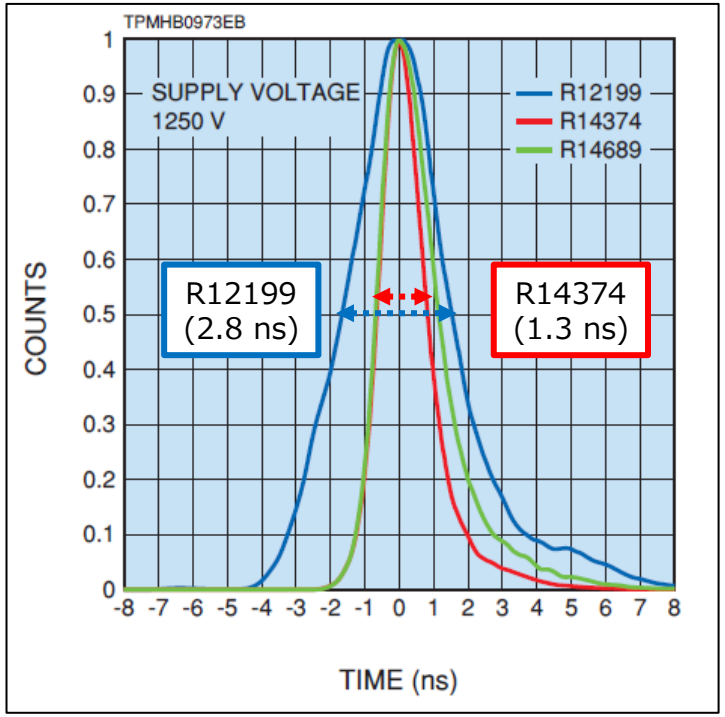
● R14374



● V-Gain



● TTS Comparison Data



● R12199/R14374 Spec. Comparison

Type Name		R12199	R14374
Size		3"	
Effective Area Min. [mm]		Φ 72	
Spectral response	Range [nm]	300 to 650	
	Peak Wavelength [nm]	420	
Photocathode material		BA	
Window material		K	
Dynode structure / Stages		C&LF / 10	
Cathode characteristics	Luminous Typ. [uA/lm]	90	
	Blue sensitivity index Typ.	11	
Anode characteristics	Luminous Typ. [A/lm]	900	
	Gain Typ.	1.0E+07	
	Dark current (After 30 min) Typ. [nA]	50	
	Rise Time Typ. [ns]	3	2.9
	Transit Time Typ. [ns]	35	35
	T.T.S. (FWHM) Typ. [ns]	2.8	**1.3**

- **Main Feature**
- **High Gain**
- High Time Resolution

Mainly Used for HEP experiment

Hemisphere 8” PMT R14688 Series (1)

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R5912

R14688

● R5912 & R14688 Specification Comparison

Parameter	R5912	R14688	Unit
Diameter	202 dia.		mm
Effective area (Min.)	190 dia.		mm
Spectral response	300 to 650		nm
Photocathode	BA/SBA		-
Gain	1.0×10^7		-
Applied voltage for gain of 1.0×10^7	1500	1750	V
Rise time	3.6	2.2	ns
Electron transit time	54	37	ns
T.T.S. (FWHM)	2.4	1.0	ns

Main Feature
・High Gain
・Large Size with High Time Resolution

Mainly Used for HEP Experiment

Hemisphere 8” PMT R14688 Series (2)

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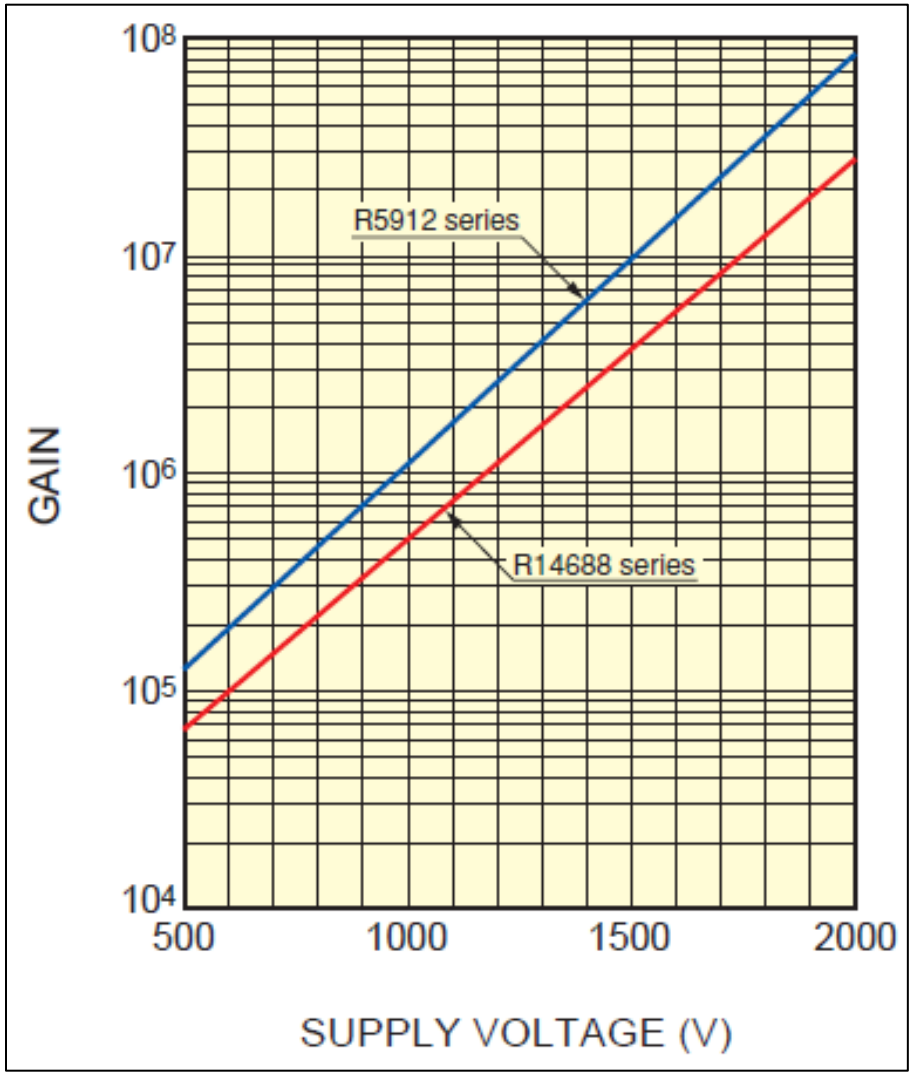
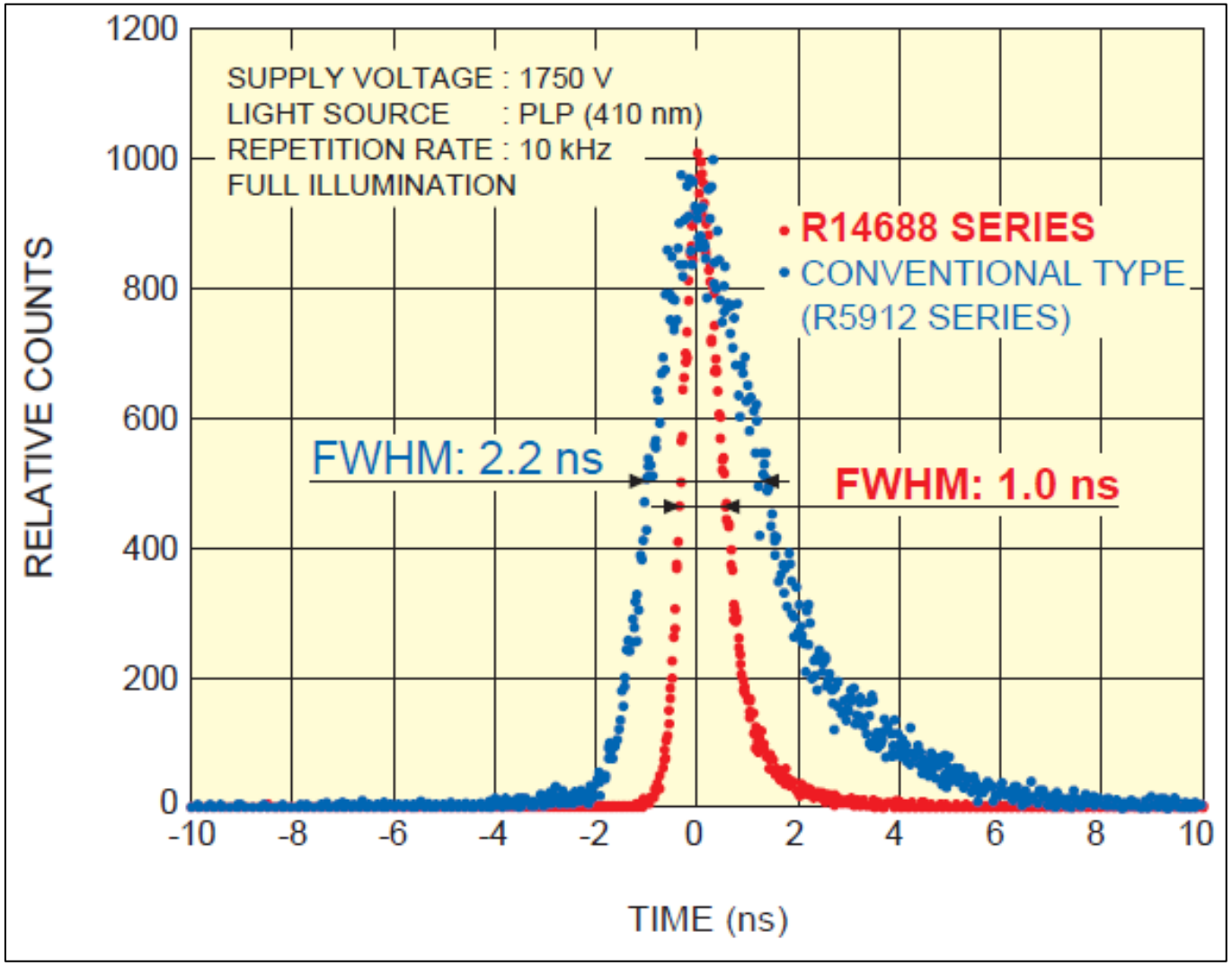
- R5912 & R14688 Gain Comparison Data



- R5912 & R14688 TTS Comparison Data



Agenda

- Fast Time Response PMT R13xxx series and R16768-100
- Hemisphere PMT R14374(3” PMT), R14688(8” PMT)
- R12699-406-M4(2” FP-PMT)
- R9880 Series (TO-8 PMT)

2” Square Flat-Panel-PMT R12699-406-M4(1)

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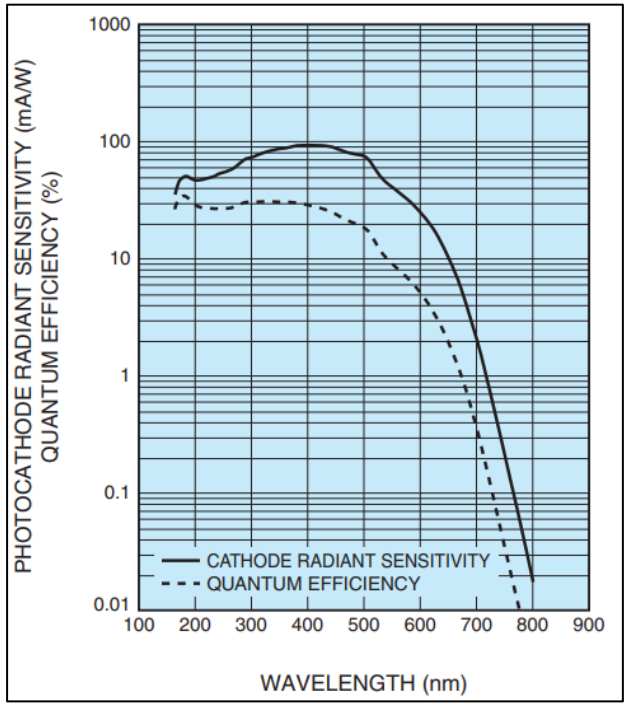
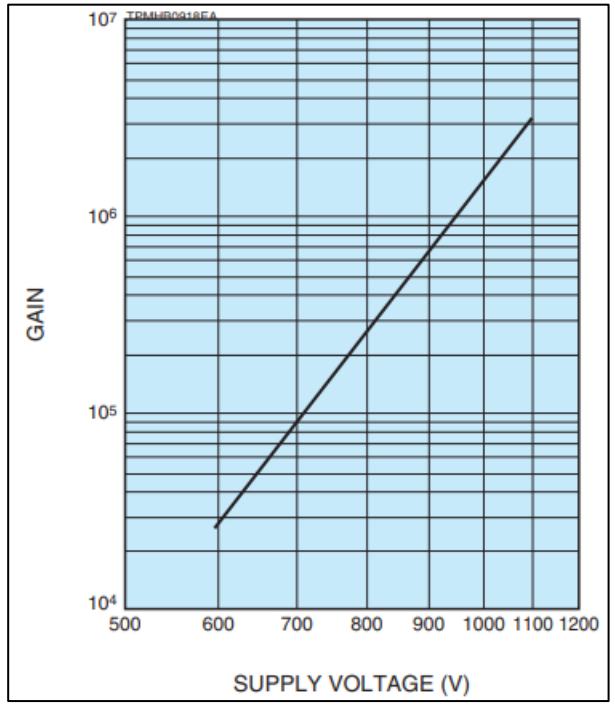
●Specification

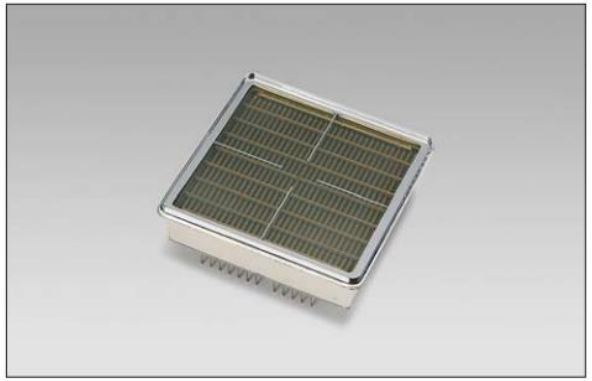
Type Name		R12699-406-M4
Size		2" □
Effective Area Min. [mm]		48.5 × 48.5
Spectral response	Range [nm]	160 to 650
	Peak Wavelength [nm]	400
Photocathode material		BA
Window material		Q
Cathode characteristics	Luminous Typ. [uA/lm]	95
	Blue sensitivity index Typ.	10
Anode characteristics	Luminous Typ. [A/lm]	140
	Gain Typ.	1.5E+06
	Dark current per channel Typ. [nA]	1.5
	Dark current in total Typ. [nA]	6
	Rise Time Typ. [ns]	1.2
	T.T.S. (FWHM) Typ. [ns]	0.41
Pulse Linearity	2 % deviation [mA]	8
Storage temperature [℃]		-110 to +50
Operating ambient temperature [℃]		-110 to +50

●QE Curve



●Gain Curve





Main Feature:

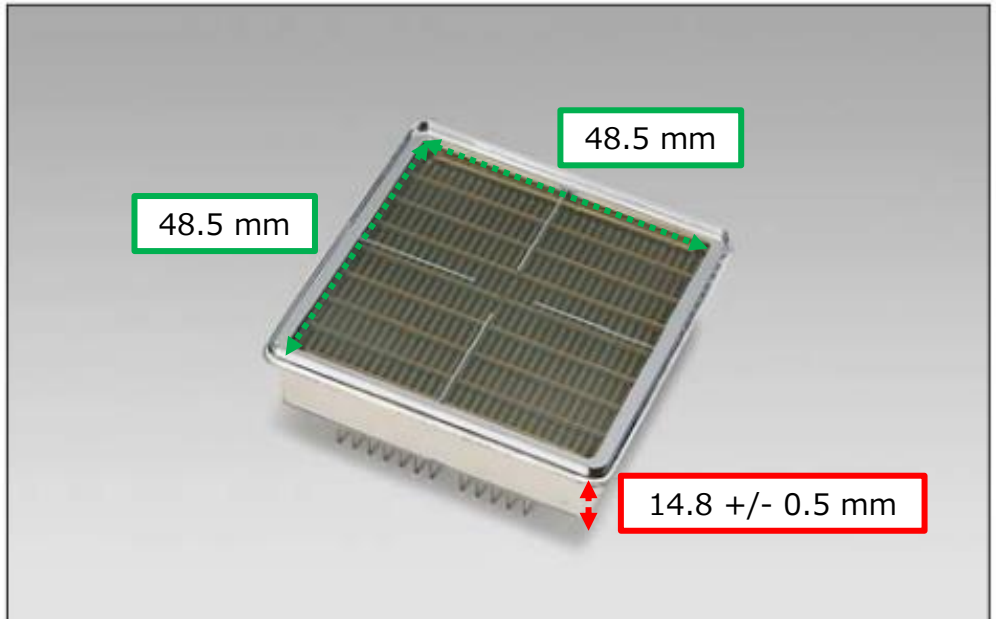
Operable at Cryogenic temperature down to -110℃

Low Radioactivity, Small height

Wide Effective area

Mainly Used for dark matter experiment

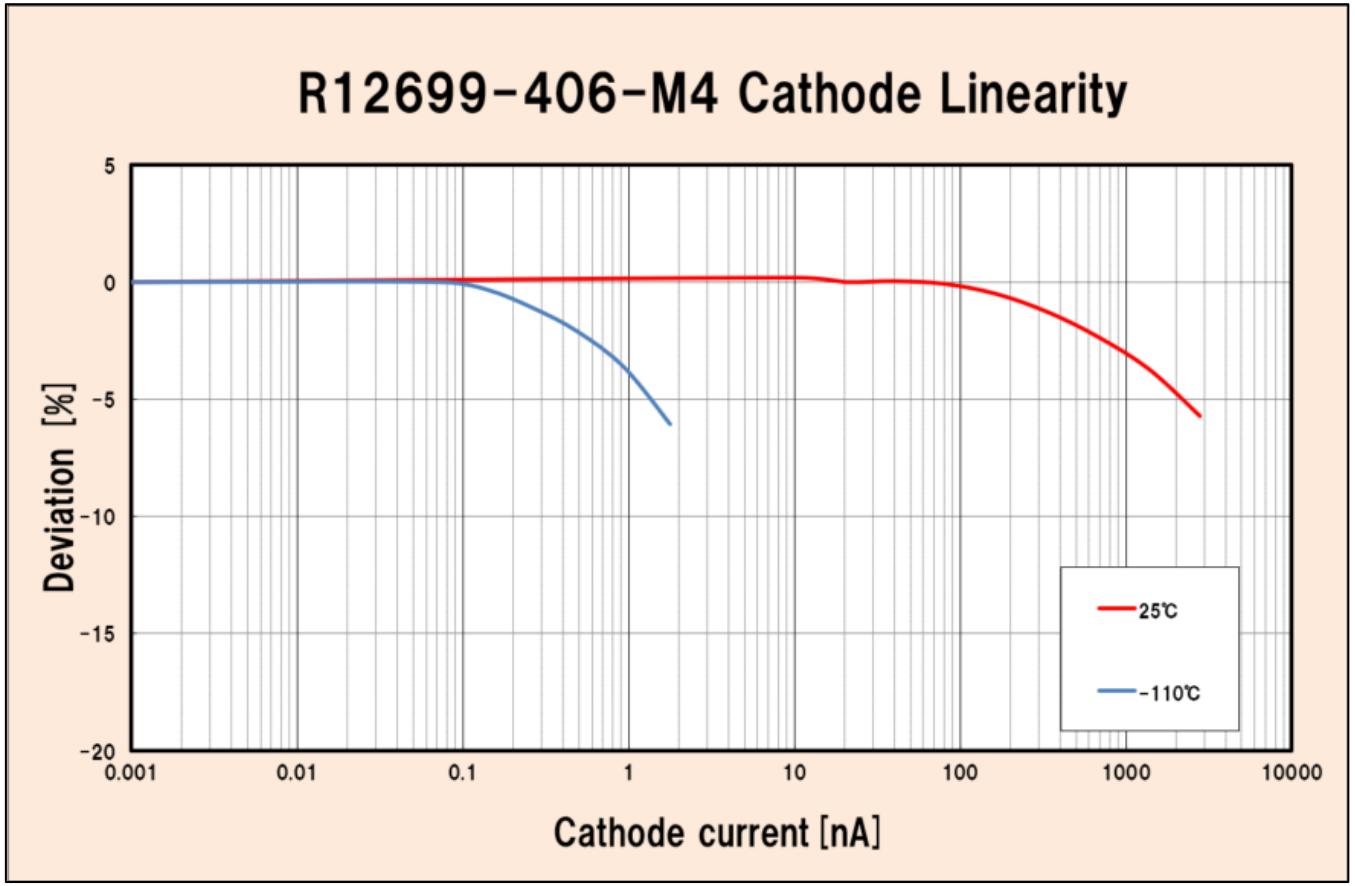
2” Square Flat-Panel-PMT R12699-406-M4(2)



	K-40 [mBq/sample]	U [mBq/sample]	Th [mBq/sample]	60Co [mBq/sample]	total [mBq/sample]
R12699-406-M4	20.0	0.0	0.0	0.0	20.0
Minimum detectable value	-	5~23	2~6	2~3	-

・The value “0.0” shows that we could not measure the radioactive component correctly because of detection limit.

● R12699-406-M4 Cathode Linearity at low temperature



Agenda

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TO-8 PMT R9880 Series (1)

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●Specification

Parameter				Value								Unit
Suffix				-09	-116	-113	-110	-210	-04	-01	-20	—
Dynode	Structure			Metal channel								—
	Stages			10								—
Maximum ratings	Supply voltage between anode and cathode			1100								V
	Average anode output current in total ②			0.01	0.1							mA
Cathode	Luminous		Min.	—	80				100		350	μA/lm
			Typ.	—	105			135	200		500	
	Blue sensitivity index		Typ.	—	13.5			15.5	—			—
	Red / White ratio		Typ.	—					0.2		0.45	—
	Radiant sensitivity ③		Typ.	35	110			130	77		78	mA/W
Anode ④	Luminous		Min.	—	80				100		350	A/lm
			Typ.	—	210			270	400		1000	
	Gain		Typ.	2.0×10^6								—
	Dark current ⑤		Typ.	0.1	1						10	nA
			Max.	1	10						100	
	Time response	Rise time	Typ.	0.57								ns
		Transit time	Typ.	2.7								
		T.T.S.	Typ.	0.2								
Operating ambient temperature				-30 to +50								°C
Storage temperature				-30 to +50								°C

Main Feature
・Small and compact
・Fast time response, high gain

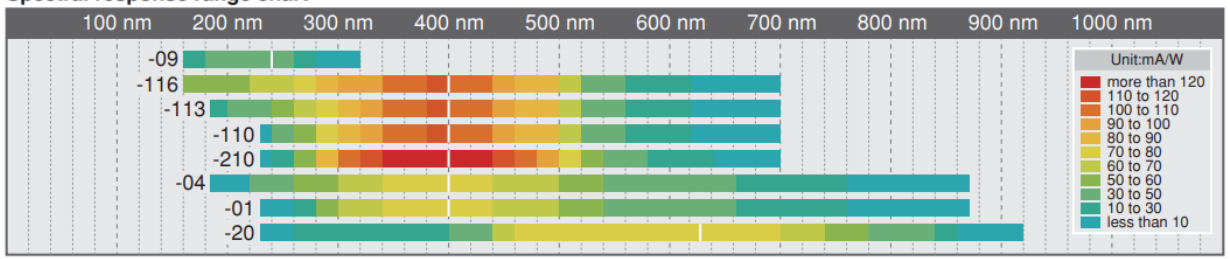
Mainly used for fluorescence observation, radiation monitoring etc..

●Spectral response range chart

Type No.		-09	-116	-113	-110	-210	-04	-01	-20	Unit
Photocathode ①		Cs-Te	SBA			UBA	MA		ERMA	—
Spectral response	Range	160 to 320	160 to 700	185 to 700	230 to 700		185 to 870	230 to 870	230 to 920	nm
	Peak	240	400						630	nm
Window material		Quartz		UV	K		UV	K		—

NOTE: ① Photocathode materials
SBA: Super bialkali, **UBA**: Ultra bialkali, **MA**: Multialkali, **ERMA**: Extended red multialkali

Spectral response range chart



Extended green photocathode type of R9880 is under development and will be released in 2024.

We have a variety in accessories for R9880, like E10679 series, E13643(D-type), C16138(DA-type) and PMT modules.

TO-8 PMT R9880 Series (2)

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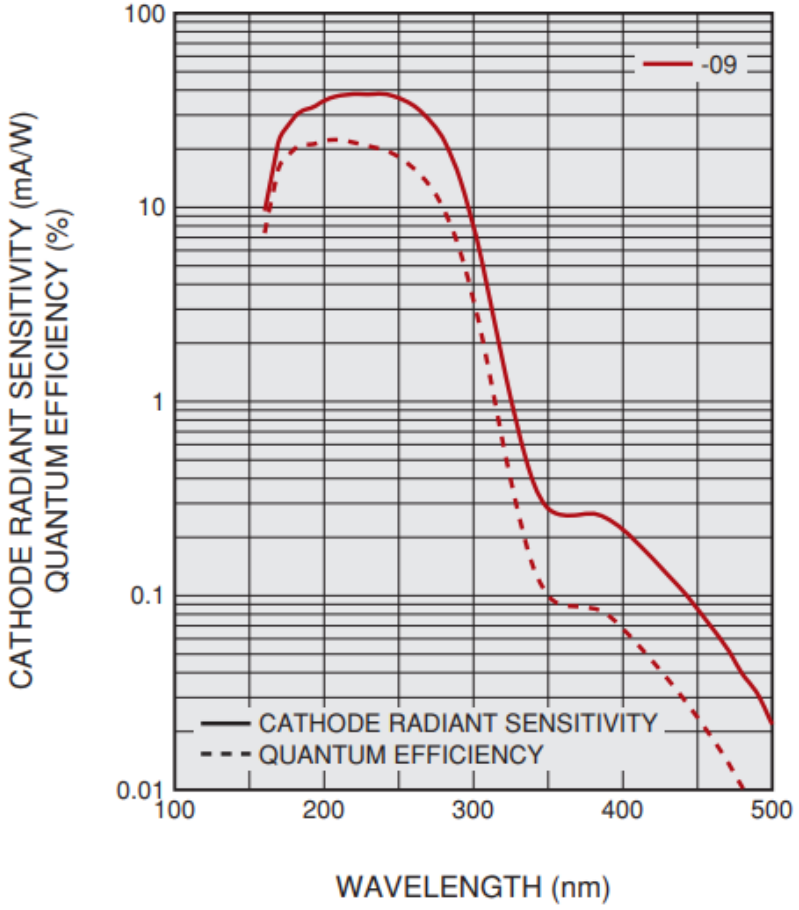
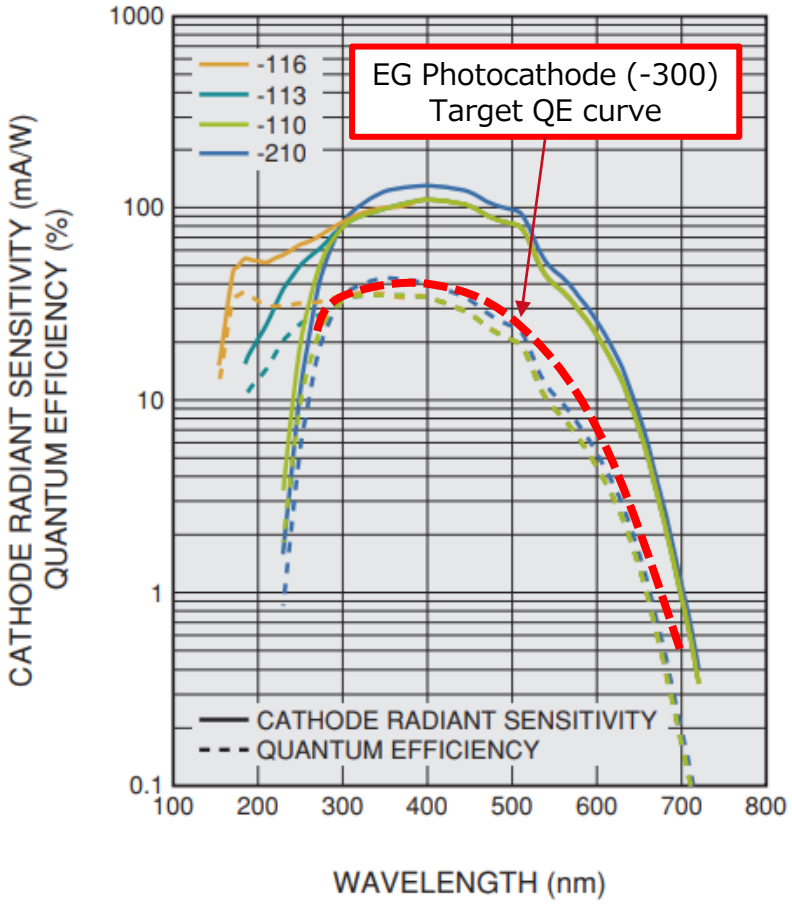
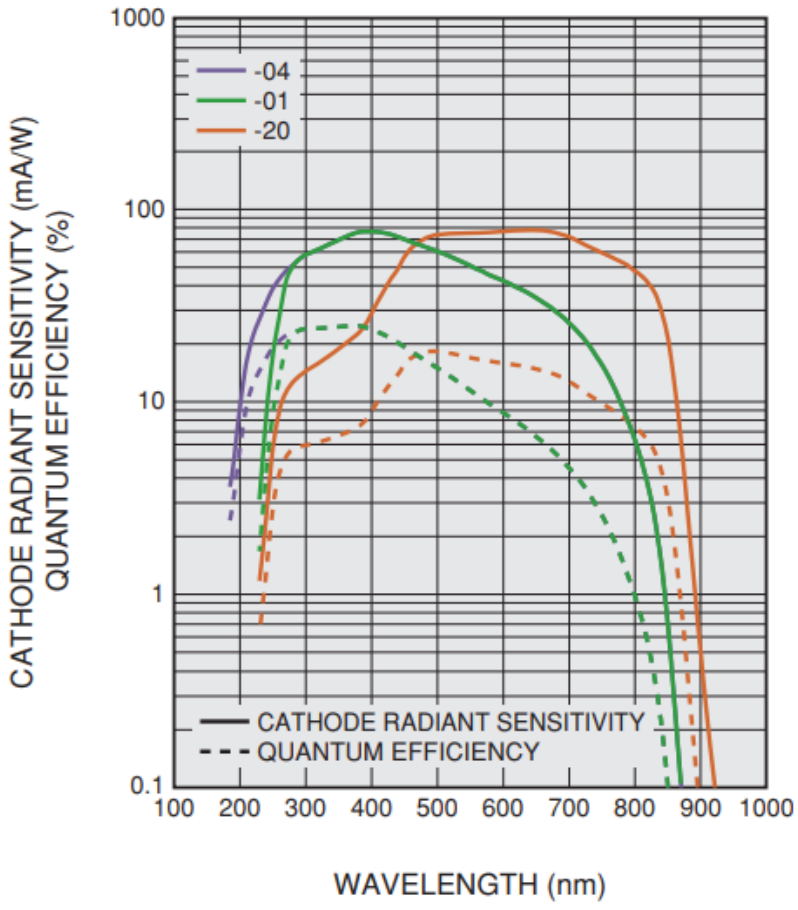
●CsTe Spectral response



●SBA/UBA Spectral response



●MA/ERMA Spectral response



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Product introduction for MPPCs

MPPC Introduction

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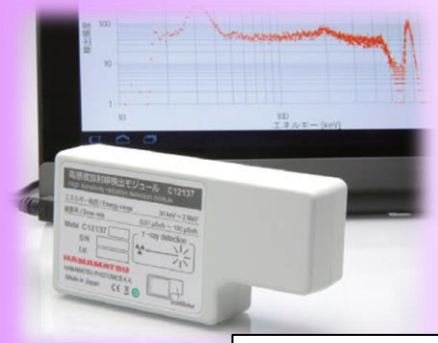
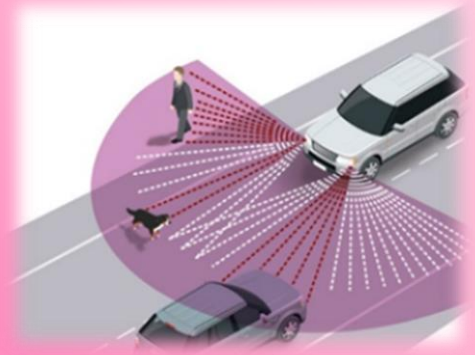
Radiation detection



Medical

MPPC (SiPM)

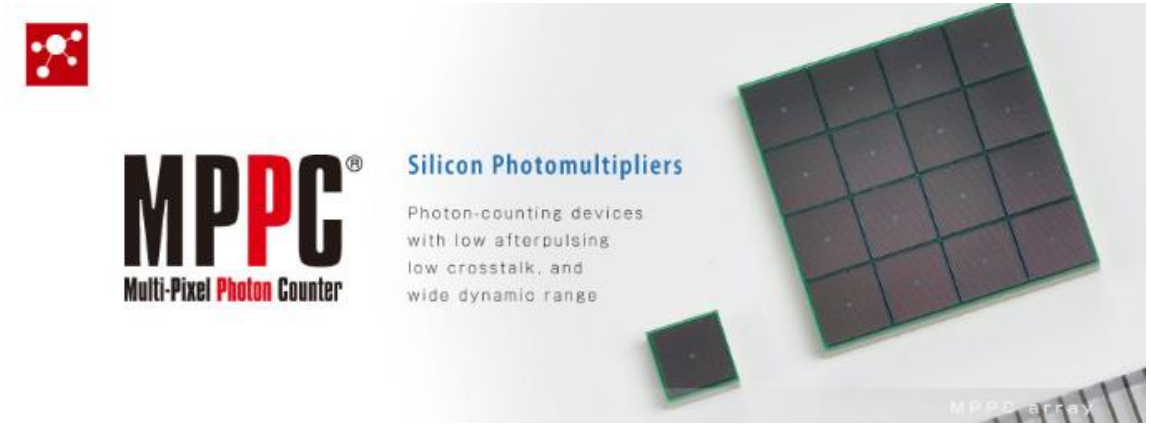
LiDAR



https://www.nidec-copal-electronics.com/j/featuring/lidar-polygon/vs_galvo/

Academic

http://ndip.in2p3.fr/ndip08/Presentations/4Wednesday/A-Midi/39-Yokoyama.pdf



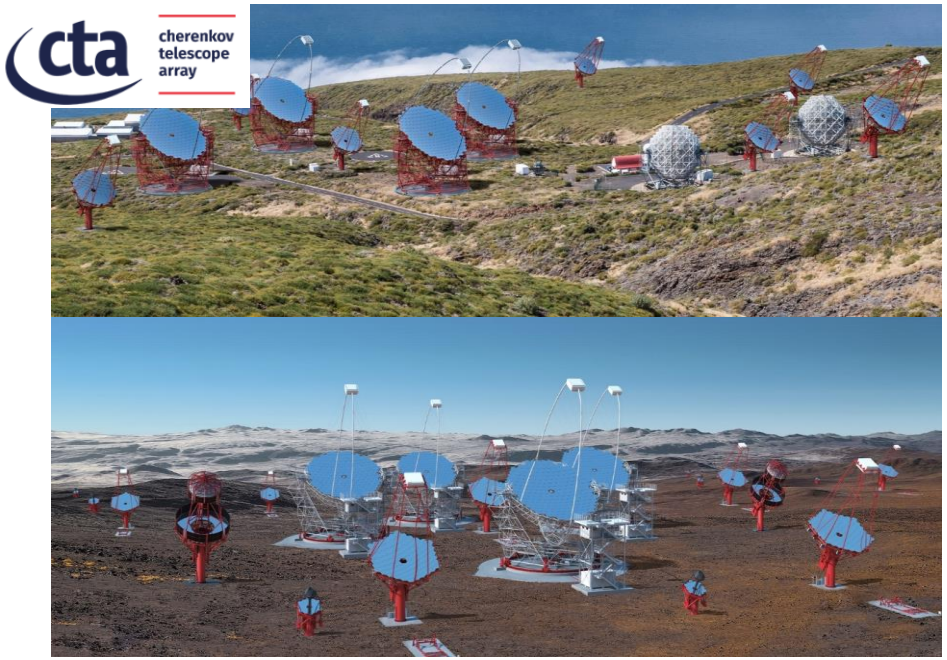
→ Focus on in this presentation

- **NUV Sensitivity MPPC**
- **VUV Sensitivity MPPC**

NUV sensitivity MPPC

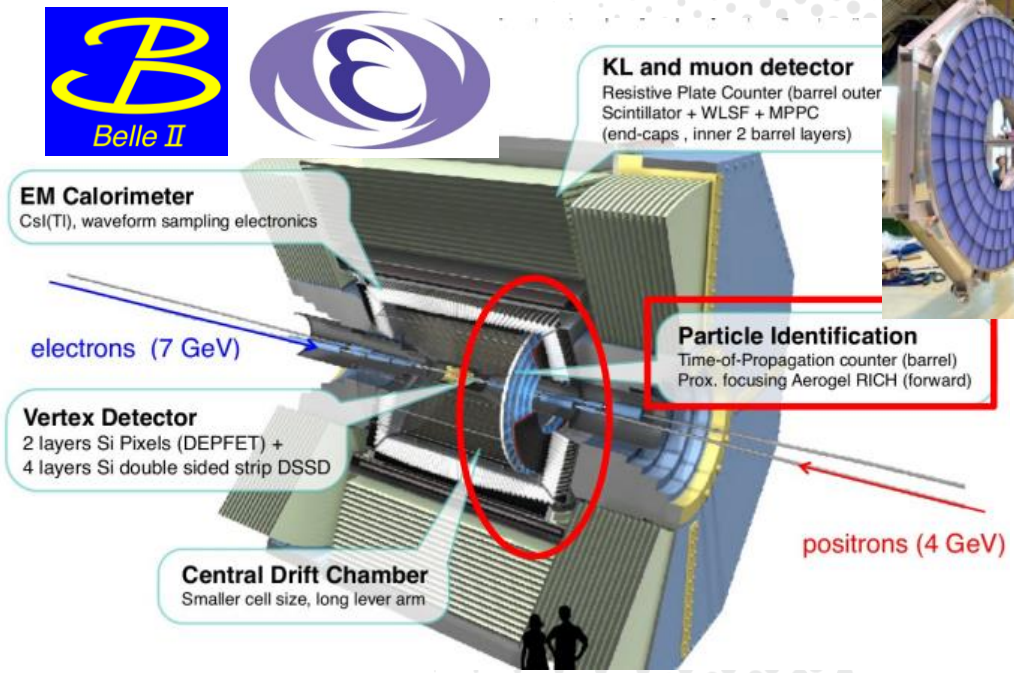
For Cherenkov light detection

Atmospheric Cherenkov light detection



https://www.cta-observatory.org/about/how-cta-works/

Silica aerogel Cherenkov radiators

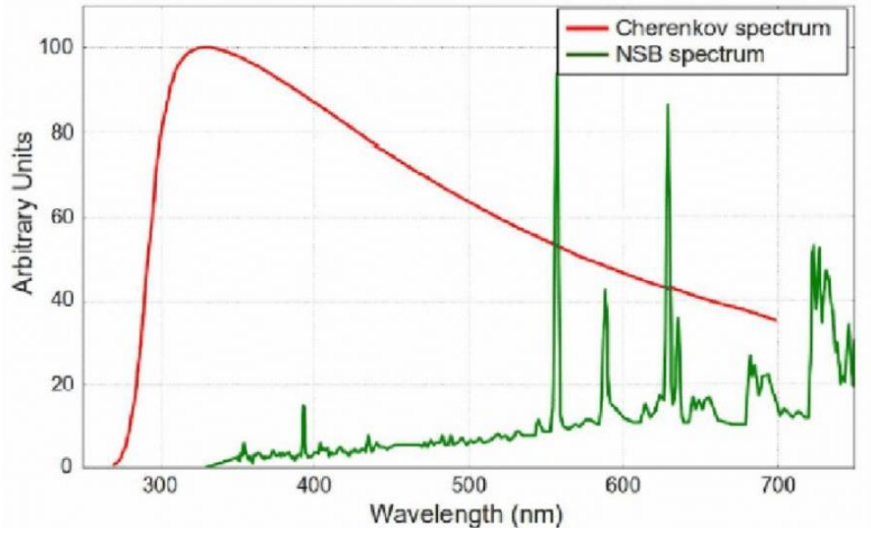


https://indico.inp.nsk.su/event/20/contributions/958/attachments/554/639/INSTR20_Belle2ARICH.pdf

NUV sensitivity MPPC: development themes

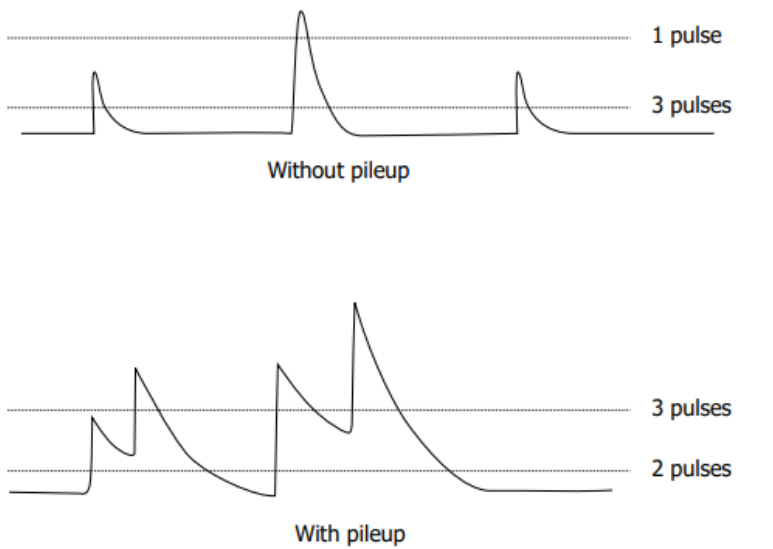
1. High NUV sensitivity
2. Pile-up suppression
3. Large active area and small dead space with NUV transmissive window

Cherenkov spectrum in atmosphere



C. R. Benn and S. L. Ellison, New Astron.Rev.,42,503 (1998).

Pile-up phenomenon



*photon equivalent

High NUV sensitivity for Cherenkov light detection

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Purpose

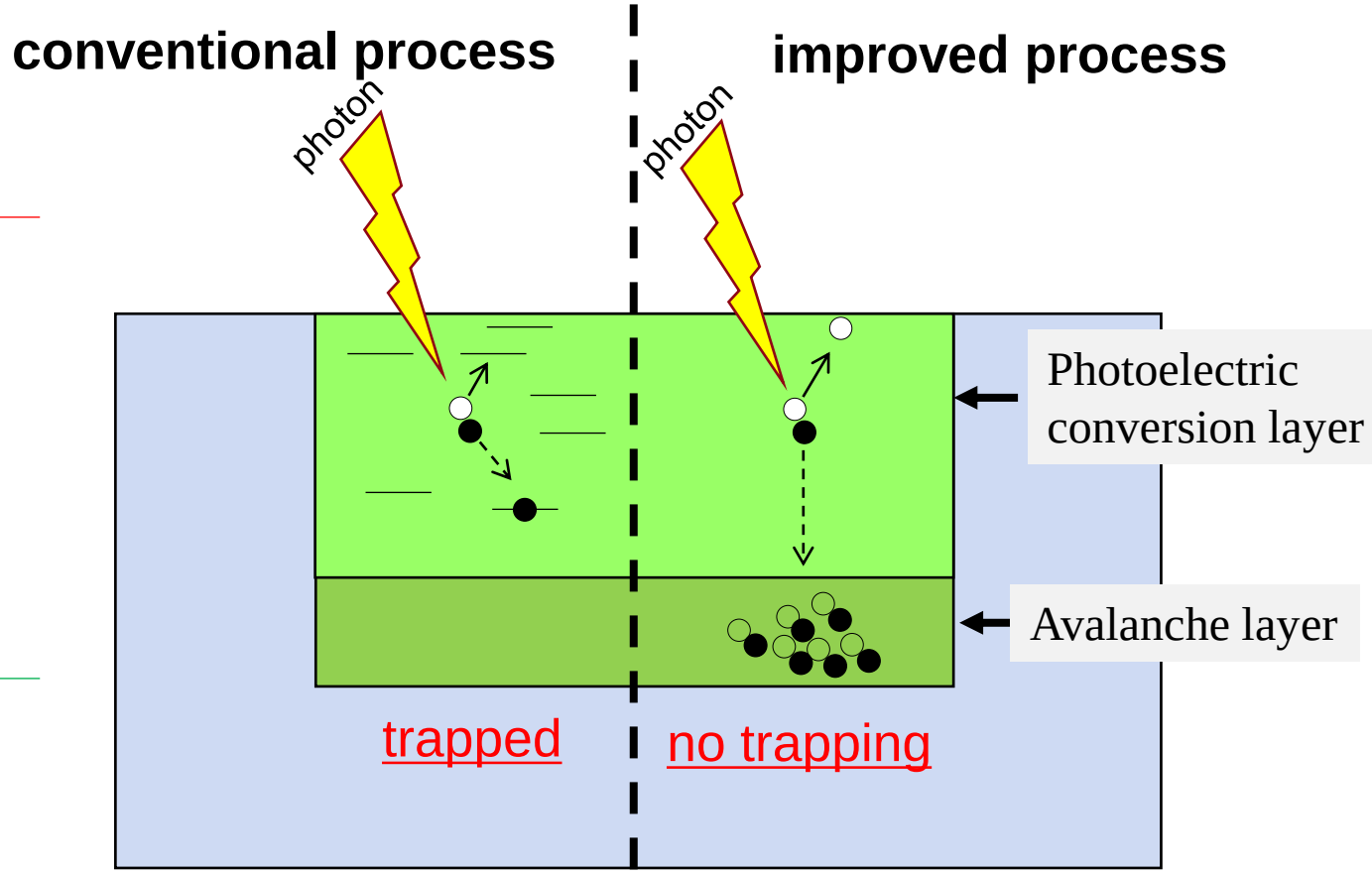
improvement of NUV sensitivity

Approach

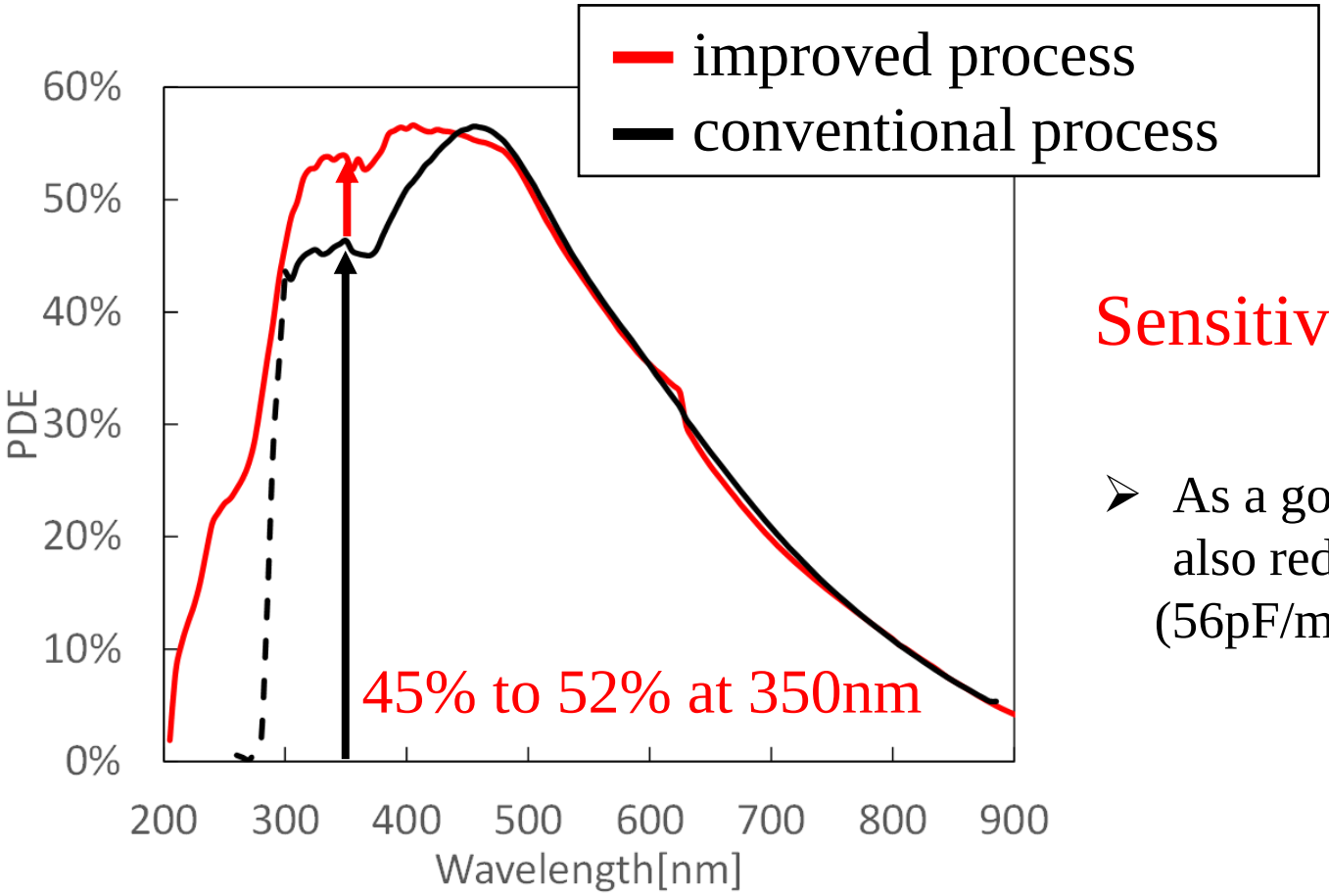
improving wafer processing
for lattice defects reduction
in the photoelectric conversion layer

Effect

increase number of carriers
which reaches to the avalanche layer



High NUV sensitivity for Cherenkov light detection



Sensitivity at 350 nm improved by 1.16 times

- As a good side effect, the improved process also reduced terminal capacitance (56pF/mm^2→36pF/mm^2)

2 Pile-up Suppression for Cherenkov light detection

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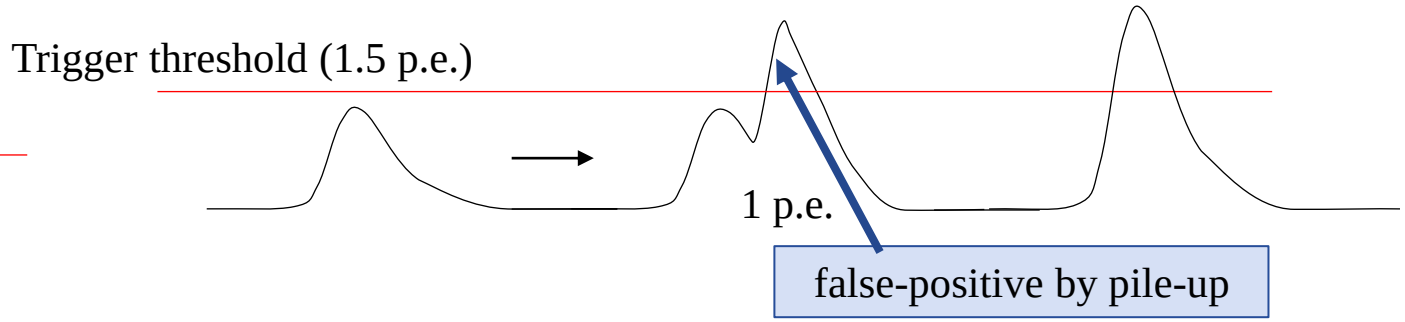
Purpose

suppression of output pile-up

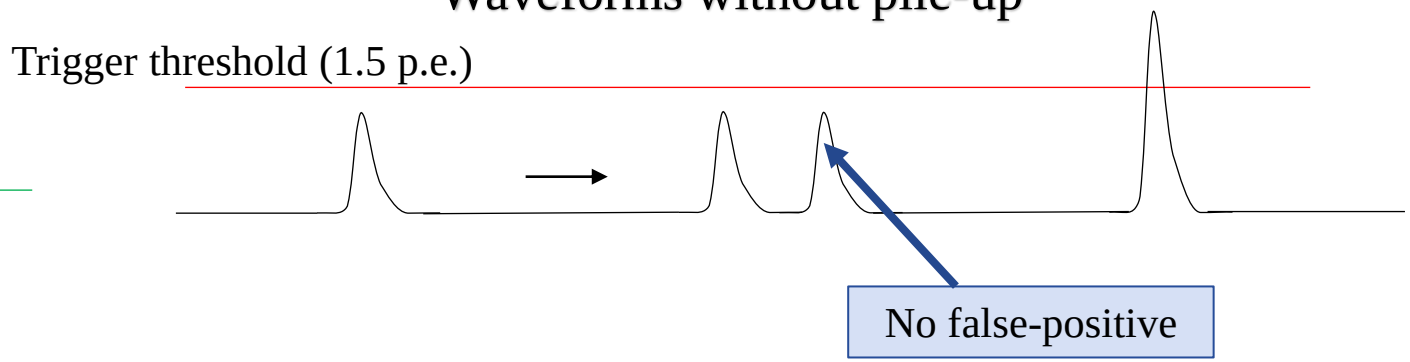
Approach

making the waveform sharper by
adjusting quenching resistor and
reducing terminal capacitance

Waveforms with pile-up



Waveforms without pile-up



Effect

a lower trigger threshold can be used
to take weaker Cherenkov light events
(=event derived from lower energy particles can be observed)

2 Pile-up Suppression for Cherenkov light detection

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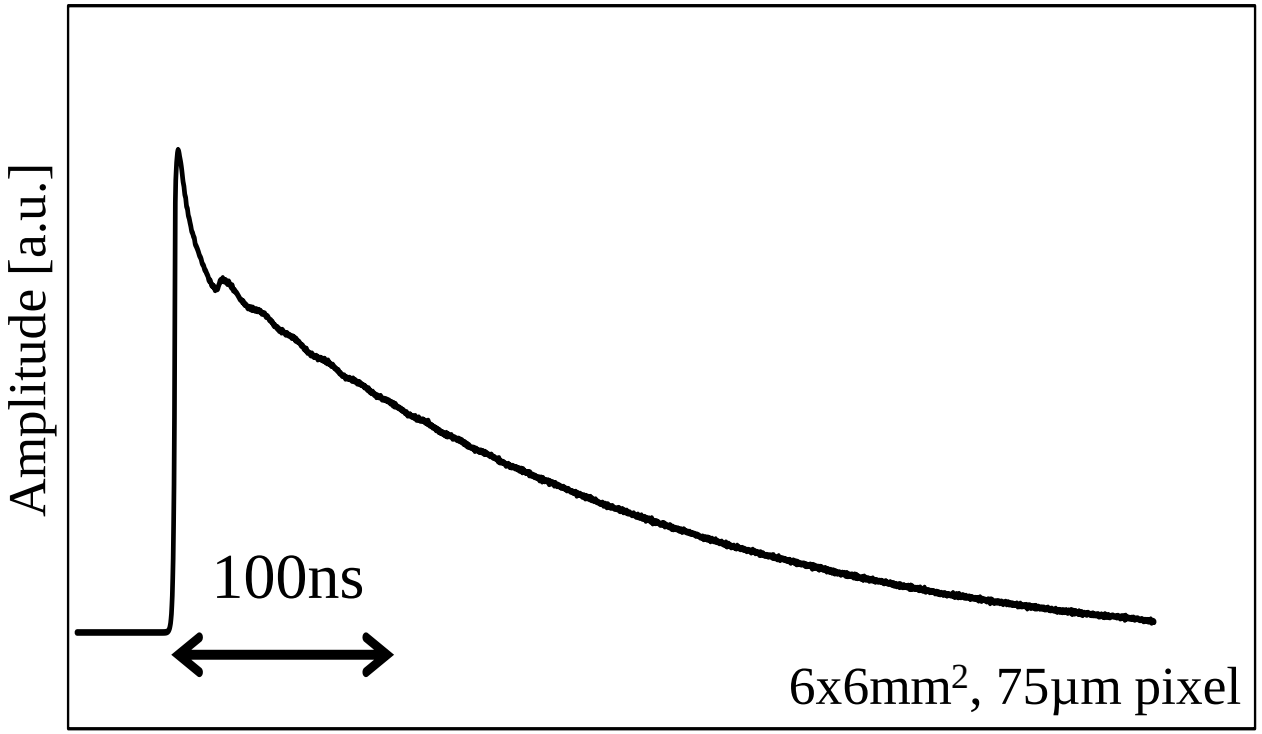
Conventional MPPC

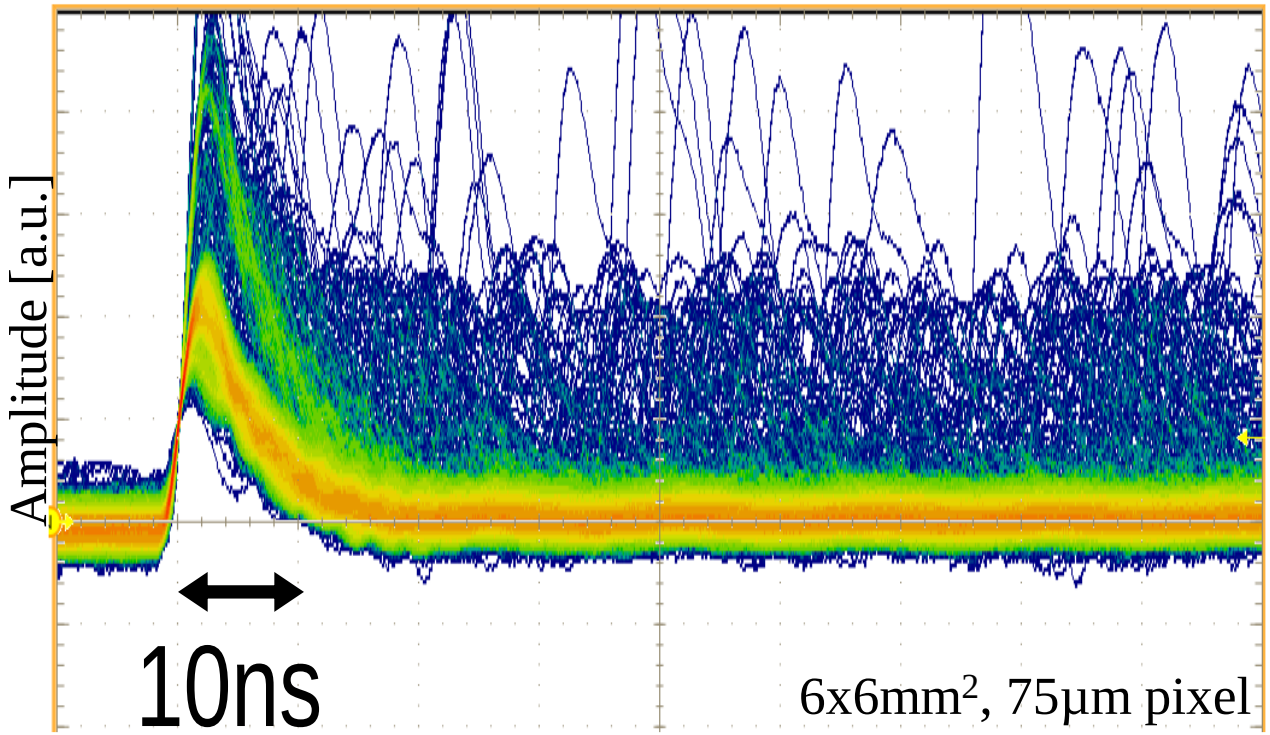
FWHM: about 90ns



(average waveform)

MPPC with R_q and C_t optimization

FWHM: about 7ns



(measurement result)

3 Large active area and small dead space with NUV transmissive window

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Purpose

Realizing large photosensitive area coverage with small dead space

Approach

Applying Through Silicon Via (TSV) technology to eliminate the dead space

To protect device surface without compromising NUV sensitivity,
attach quartz window on MPPC using NUV transmissive resin

Effect

Minimize light detection loss caused by dead space

3 Large active area and small dead space with NUV transmissive window

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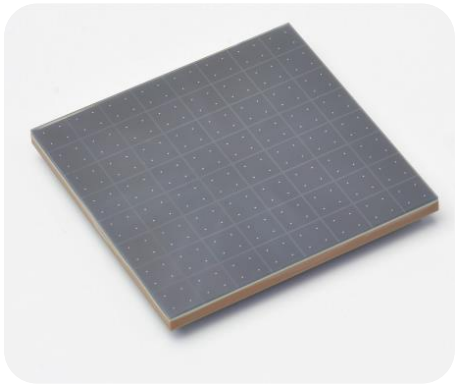
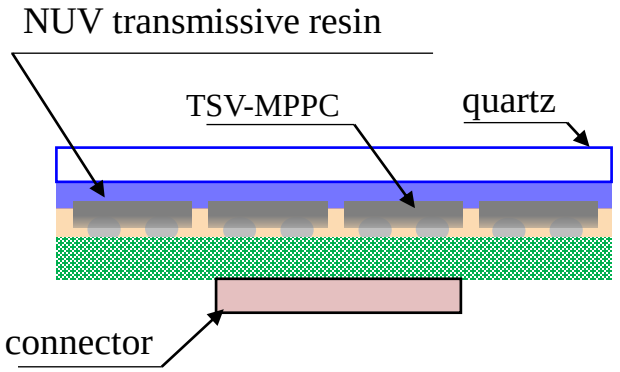
TYEP 1

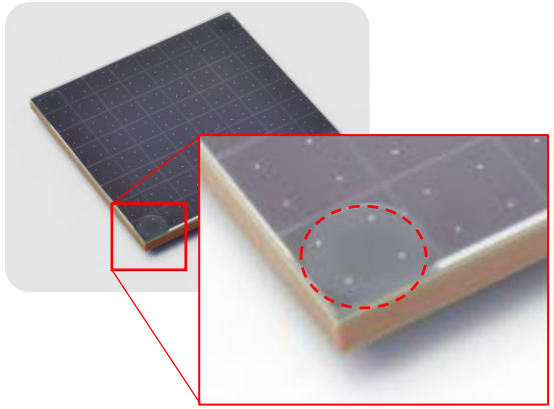


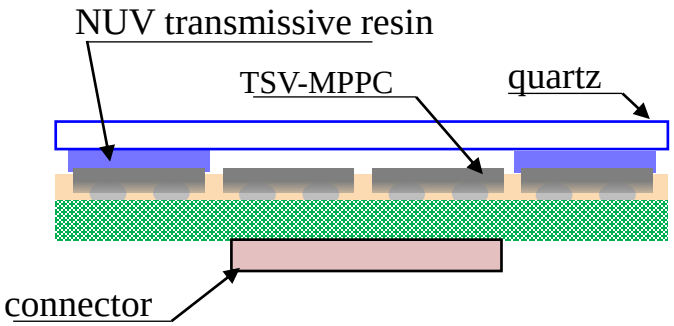


✓ **Quartz is attached by resin over the entire surface**

➢ Robust structure

TYEP 2





✓ **Quartz is attached by resin only on four corners of the surface**

➢ Low crosstalk & high PDE

Summary of MPPCs for NUV detection

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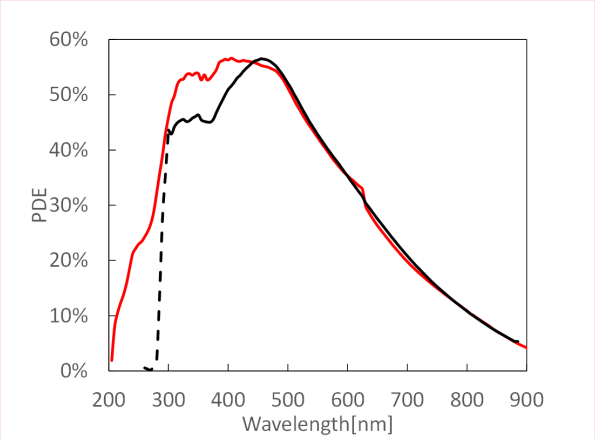
1 High NUV sensitivity



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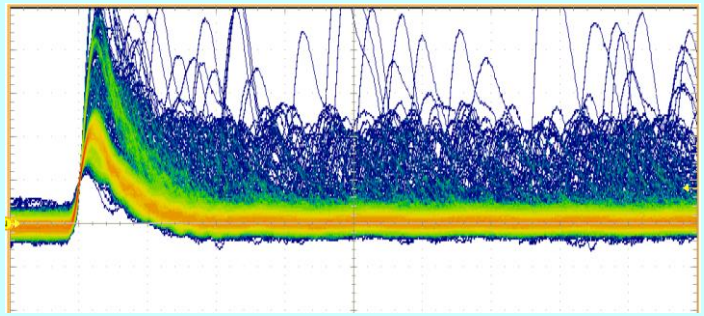
2 Pile-up suppression



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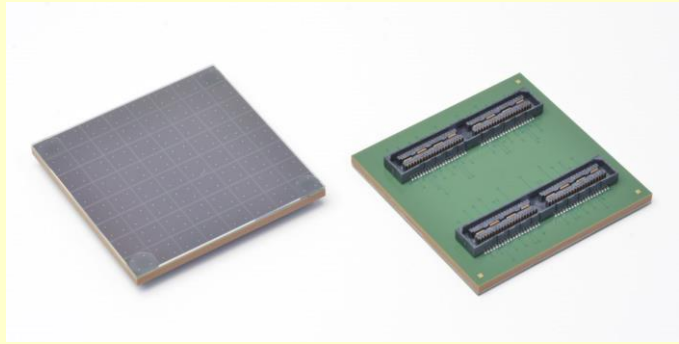
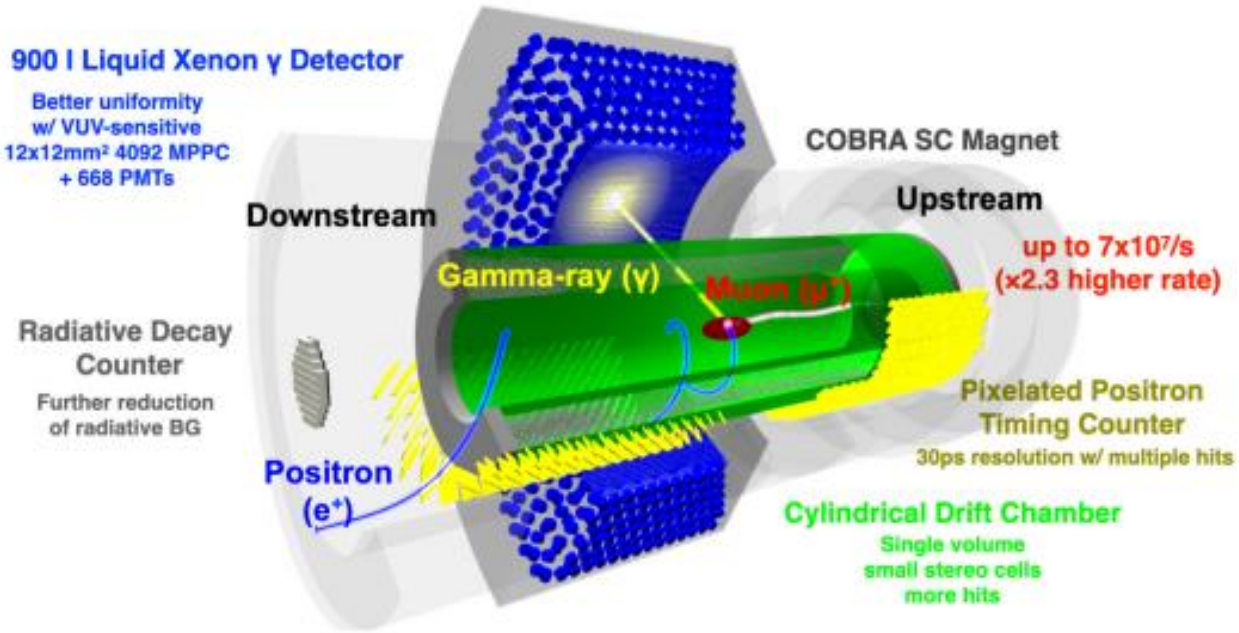
3 Large area with small dead space



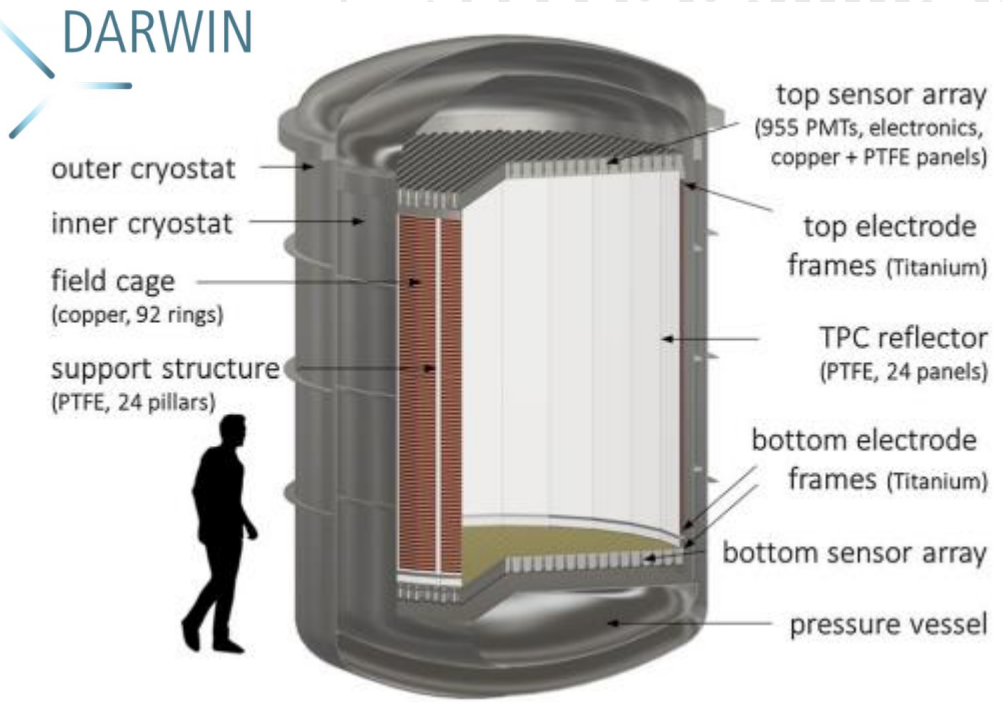
Hamamatsu produces
high NUV sensitive, low pile-up, and large area array MPPC
for Cherenkov light detection applications.

VUV sensitivity MPPC

for experiments utilizing liquid Xe as scintillation material



"The liquid xenon detector for the MEG II experiment to detect 52.8 MeV gamma-ray with large area VUV-sensitive MPPCs",
NIM A 1046 (2023) 167720
https://doi.org/10.1016/j.nima.2022.167720



"Sensitivity of the DARWIN observatory to the neutrinoless double beta decay of 136Xe",
Eur. Phys. J. C (2020) 80:808
https://doi.org/10.1140/epjc/s10052-020-8196-z

VUV sensitivity MPPC: development themes

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1 Tolerance for humidity (suppress degradation of sensitivity)

The humidity tolerance should be high for long term reliability

2 Product packaging with low RI contamination

reduce false events by undesired RIs in product material

3 Low Dark Count Rate (DCR) at liquid Xe temperature

lower DCR leads to lower event threshold −> more event collection

Improvement of humidity tolerance for LXe experiments

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Purpose

VUV-MPPC has no protection layer for moisture protection

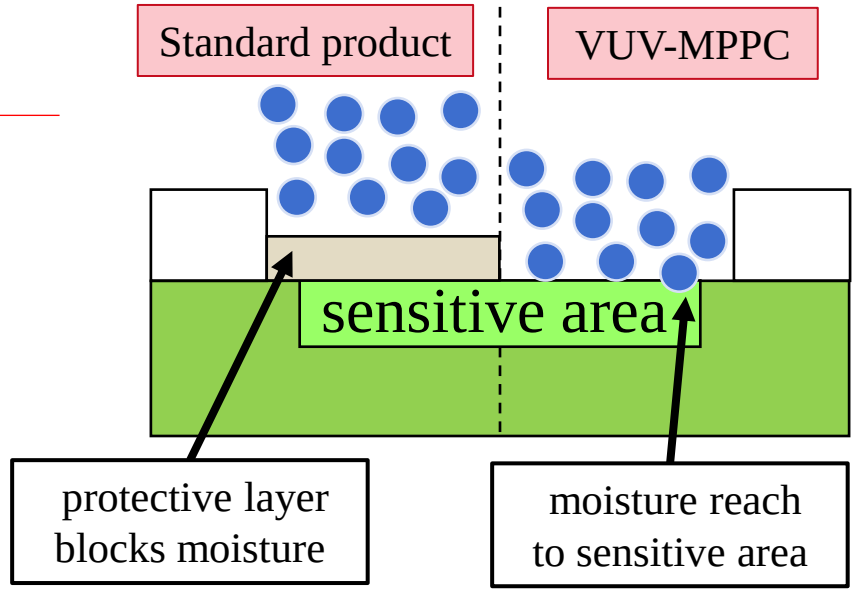
- ➢ after long-term storage, sensitivity degradation is observed

Construction of detectors for physical experiments takes 1+ years

- ➢ humidity tolerance of MPPC itself is important

Approach

Reduction of defects on Si surface
by improving the Si processing



Effect

Sensitivity degradation is suppressed.

Improvement of humidity tolerance for LXe experiments

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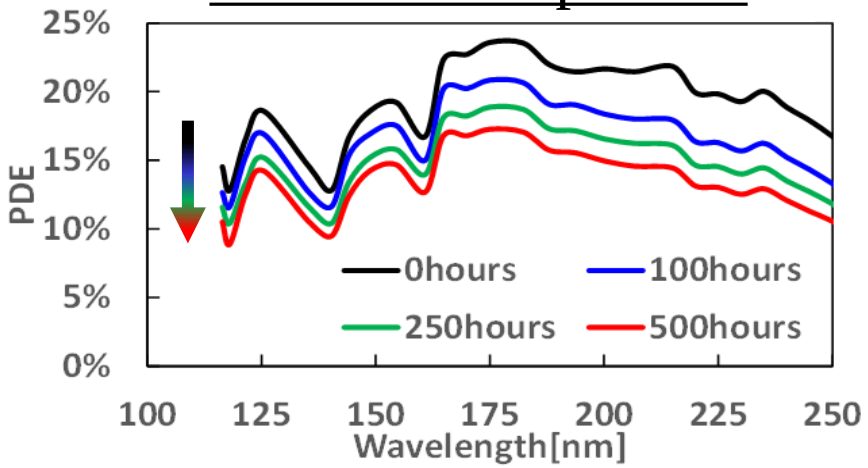
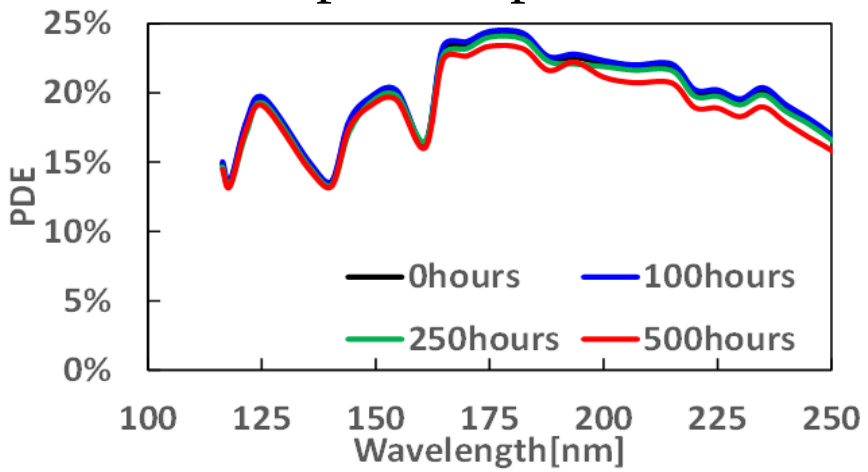
conventional process



Improved process



High Temperature/High humidity test

- Temperature : 60degC
- Humidity : 90%
- Improved process keeps sensitivity to 1000hours

Tolerance to 1000hurs @ 60degC, 90%
corresponds to 10years @ 25degC, 60%
(Vapor pressure accelerating model, confidence level :60%)

Achieve required tolerance for whole construction/operation period in physics experiments!

Development of low RI MPPC for LXe experiments

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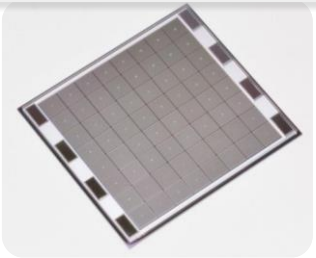
Past Prototype : Si substrate package



Pros : Low RI characteristics

Cons : Too high cost and handling difficulty

Current product : Chip on Film (CoF) package

Pros : Low cost and design flexibility

Cons : Not so great RI purity compared to Si substrate

2 CoF (Chip on film) package

CONFIDENTIAL

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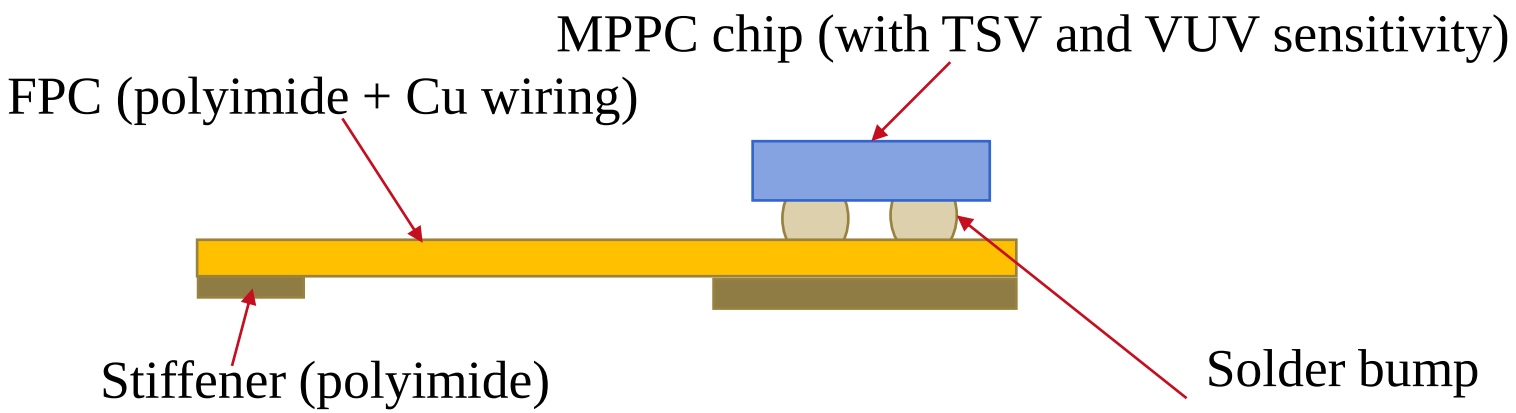
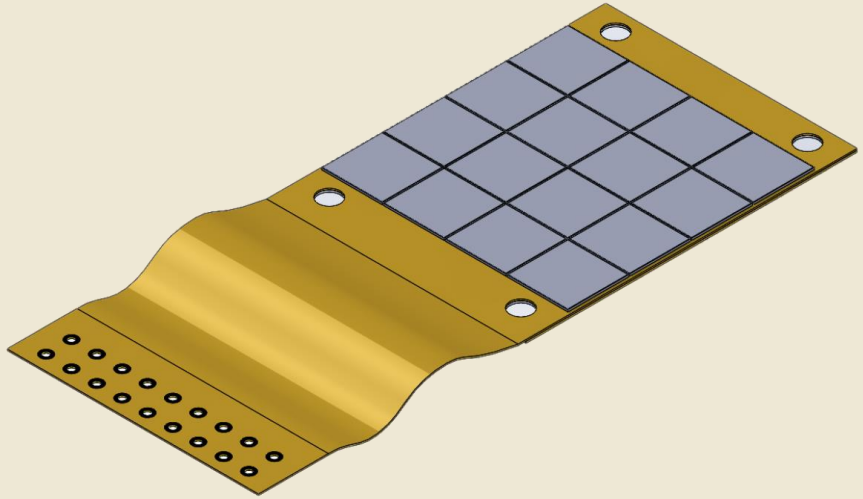
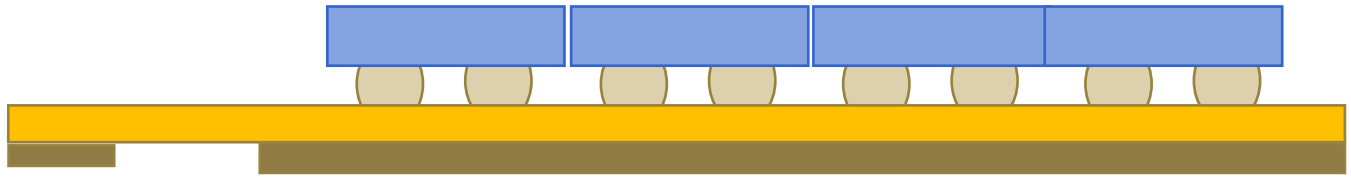
Prototype : Single channel



Under development : Large size array





3 Low Dark Count Rate for LXe experiments

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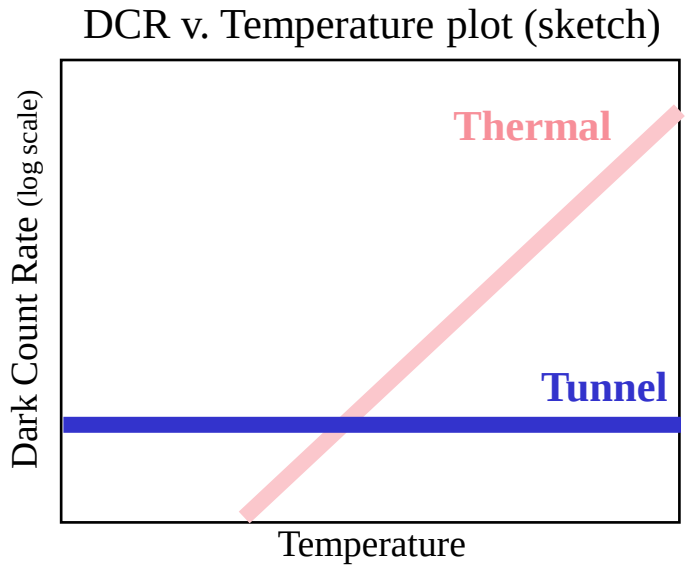
Development target of Dark Count Rate (DCR):

below 0.01 cps/mm^2 at liquid Xe temperature (160-165K)
(comparable to Photomultiplier Tube's DCR)



Two Components of DCR:

- ✓ **Thermally excited electrons**
  - Higher rate for higher temperature
  - Dominant at ambient temperature

- ✓ **Electrons traversing depletion layer by quantum tunnelling**
  - ✓ Invariant to temperature changes
  - ✓ **Dominant at liquid Xe temperature**

3 Low Dark Count Rate for LXe experiments

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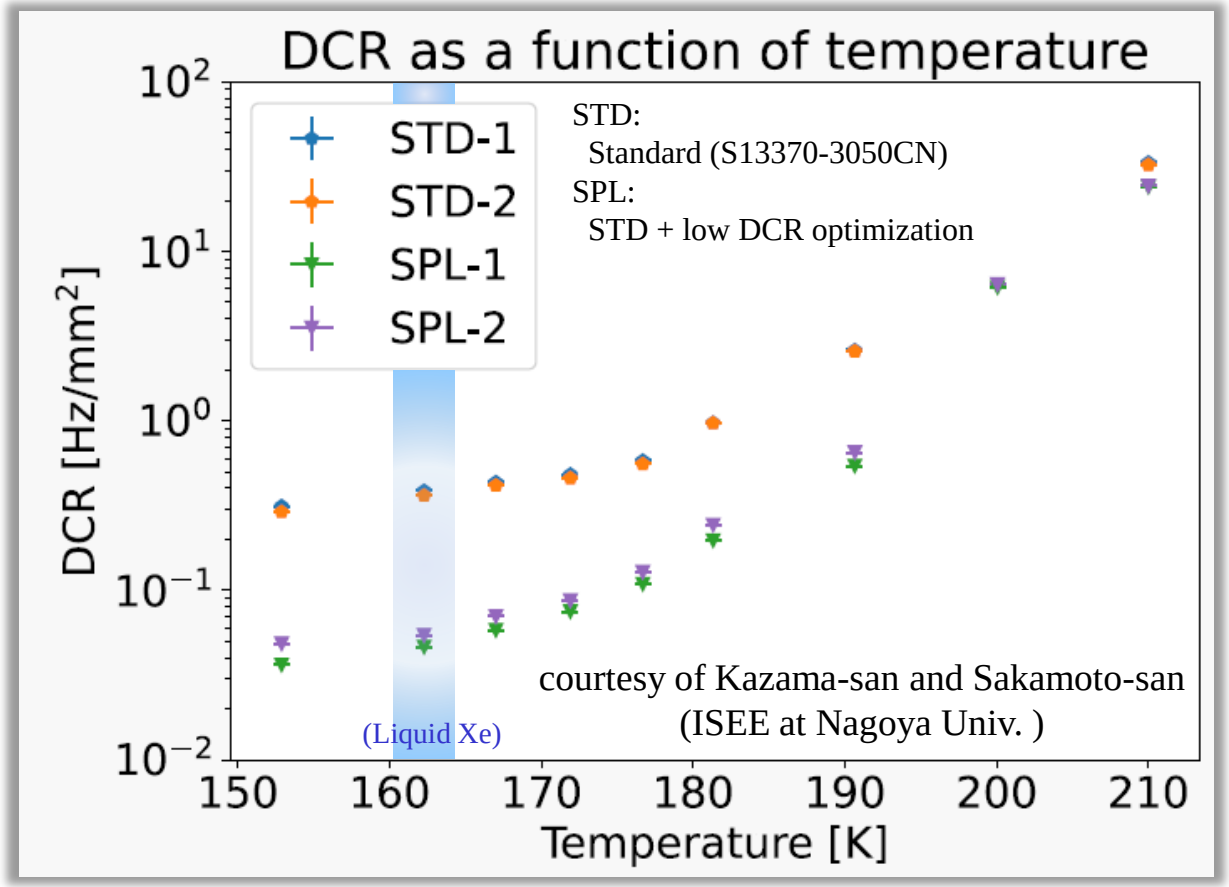
Difference from Standard VUV-MPPC:
optimization of wafer processing

- Aim to reduce E field in depletion layer

<u>DCR is reduced to 1/10</u>
from Standard VUV-MPPC
at liquid Xe temperature.

About <u>0.05cps/mm^2</u> is achieved.

Standard / low DCR prototype VUV-MPPC comparison



Summary of MPPCs for VUV detection

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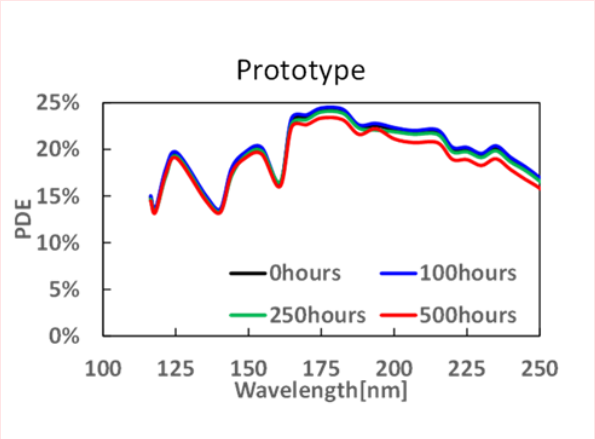
1 Improvement of humidity tolerance

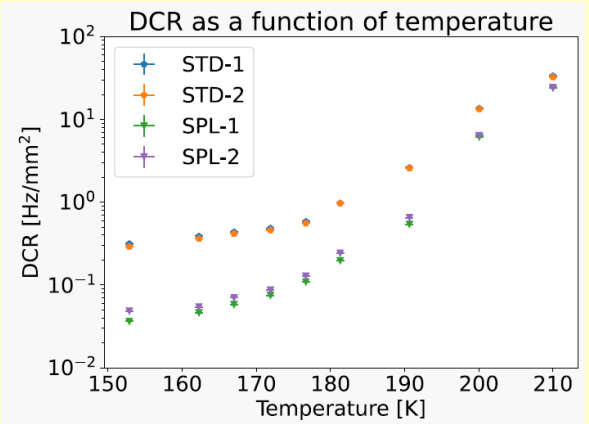


+

2 low RI PKG

+

3 low DCR at low Temperature



Hamamatsu produces humidity tolerant, low RI, and low DCR at low Temp. MPPC for experiments utilizing liquid Xe as scintillation material.

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