Current status of Hamamatsu Si detectors for ILC Experiment

HAMAMATSU PHOTONICS K.K.

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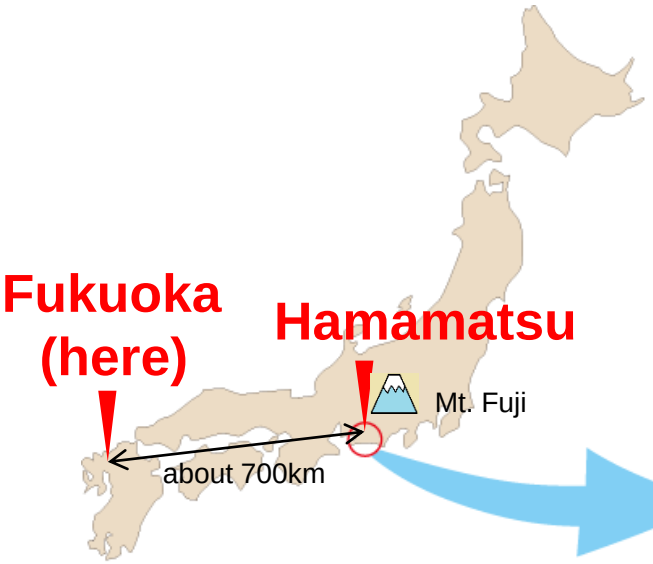
HAMAMATSU PHOTONICS K.K.
Solid State Division

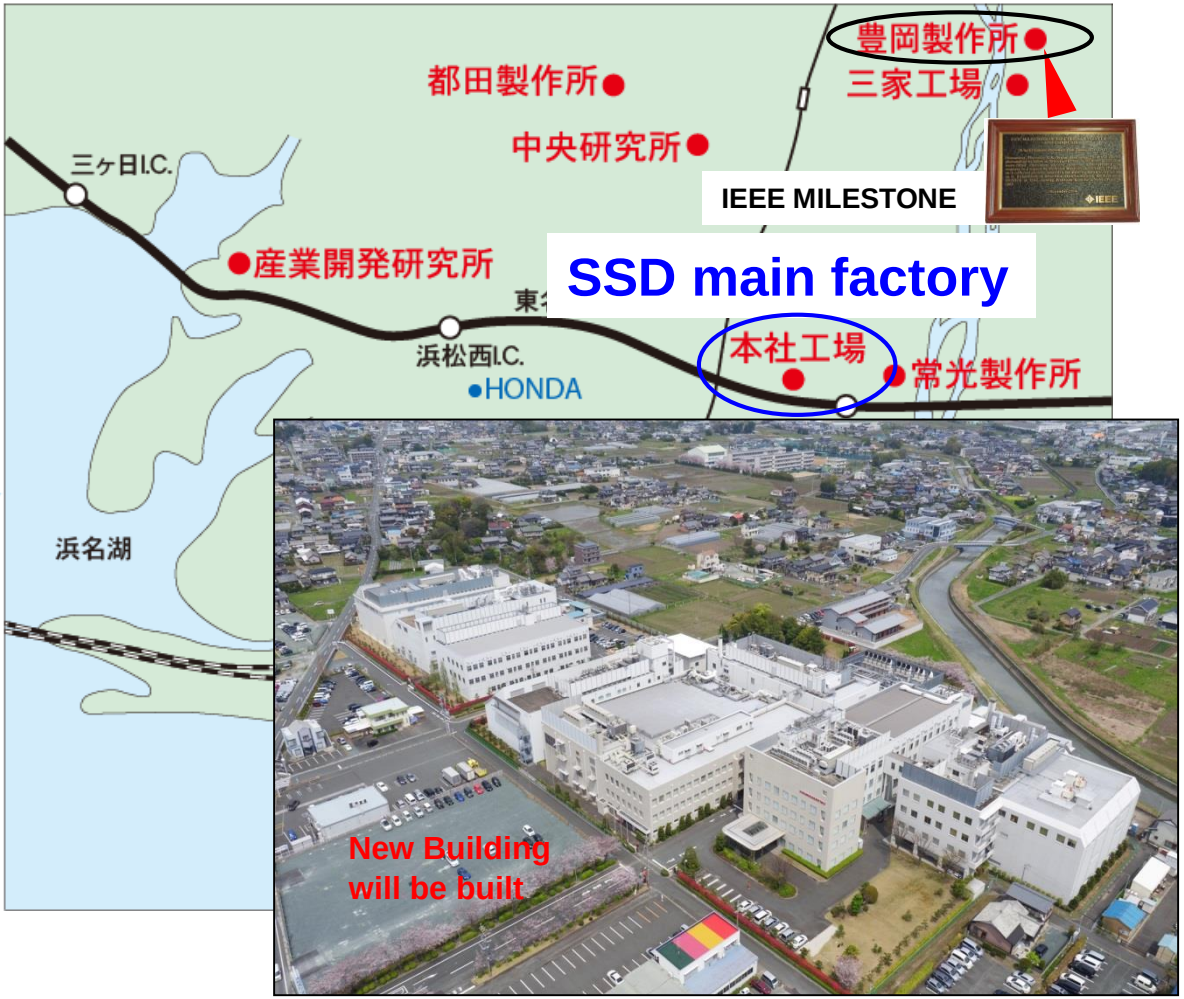
Outline

1. HPK's Si detector is used various HEP experiments
2. Si-PAD for ILD E-cal
3. Development of large area PAD detector
4. MPPC® (Multi Pixel Photon Counter) for HEP application

1. **HPK's Si detector is used various HEP experiments**
2. Si-PAD for ILD E-cal
3. Development of large area PAD detector
4. MPPC® (Multi Pixel Photon Counter) for HEP application

Where is Hamamatsu?

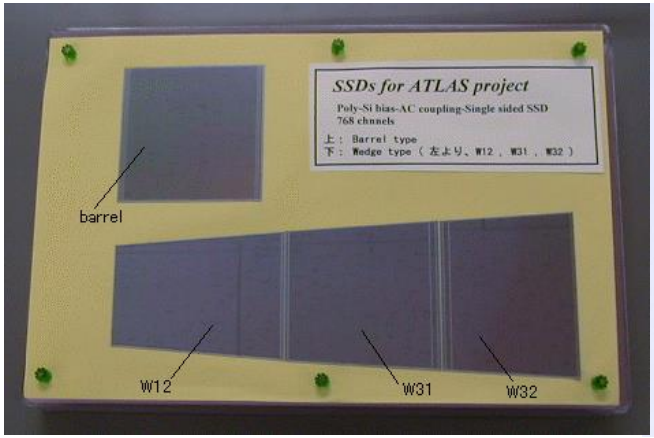




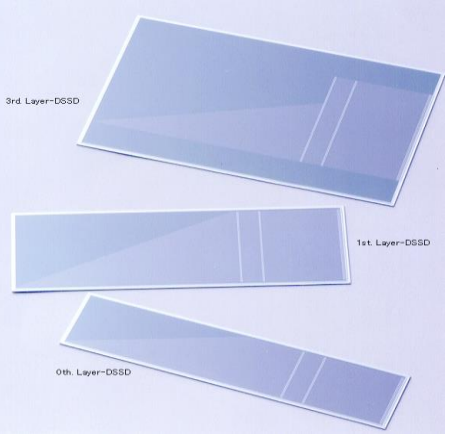
Hamamatsu Si detectors for HEP

Particle detection

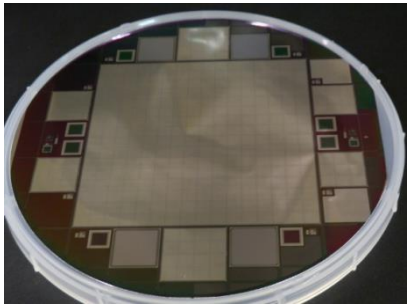
Silicon Strip Detector(SSD)
Silicon Pixel Detector
Silicon PAD Detector



SSSD(for tracker)
（e.g. ATLAS,CMS)



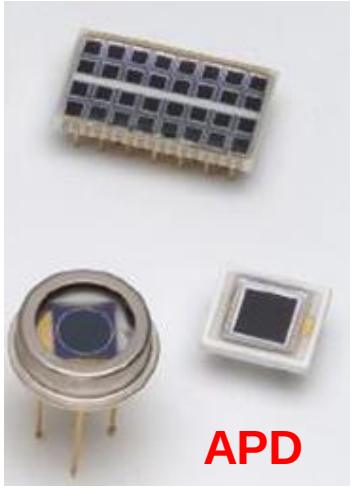
DSSD(for tracker)
(e.g. BELLE)



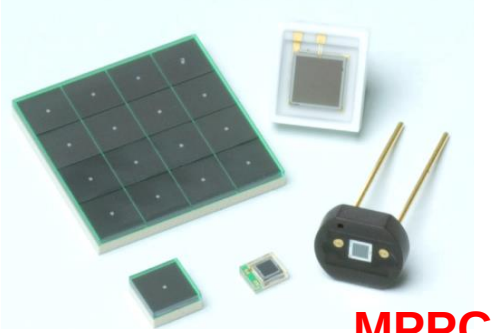
PAD
(for calorimeter)

Photo detection

Silicon Photo Diode(PD)
Silicon Avalanche Diode(APD)
Multi Pixel Photon Counter(MPPC®)



APD



MPPC

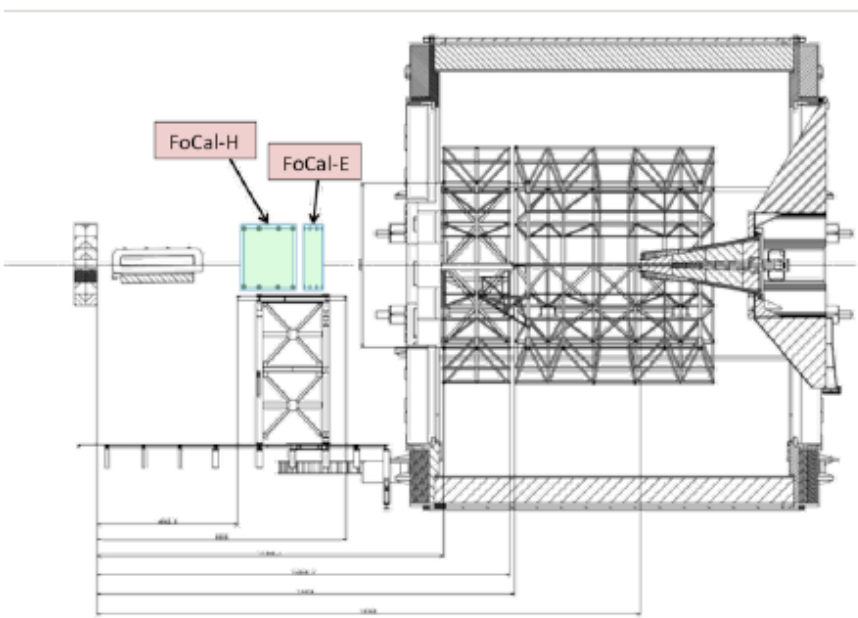
Review of Si-strips and Si-PADs produced by Hamamatsu

PROJECT	DETECTOR TYPE	size	QTY.	period
ATLAS	AC-SSSD 6type , poly-Si	1chip/4inch	16000	2001～2003
GLAST	AC-SSSD , poly-Si	1chip/6inch	11500	2001～2003
CMS	AC-SSSD 14type , poly-Si	1chip/6inch	24000	2003～2006
LHC-b	AC-SSSD , poly-Si	1chip/6inch	560	2005～2006
ALICE	AC-SSSD 2type , poly-Si	1chip/6inch	106	2005～2006
Phenix	Strippixel , DML	3chip/6inch	600	2007
PP2PP	AC-SSSD 2type , poly-Si	1chip/6inch	120	2003～2007
FVTX	AC-SSSD 2type , poly-Si	3chip/6inch	450	2009～2010
ASTRO-H	DC-DSSD , DC-PAD , Bridge DML	3chip/6inch	260	2007～2011
STAR-HFT	AC	2chip/6inch	216	2012
HALL-B	AC	1chip/6inch	434	2012
BELLE-II	AC	1chip/6inch	265	2011～2014
DAMPE	AC-SSSD , poly-Si	1chip/6inch	768	2014
ALICE-FoCal(mini)	DC-PAD	1chip/6inch	61	2017

-Topics-
2018.4.26
the First collision!

Recently, HPK has shipped(pick up shortly today).

Forward Calorimeter (FoCal) in ALICE



- Electromagnetic calorimeter for γ and π^0 measurements, with Hadron Calorimeter.

- At z ≈ 8m (outside magnet) $3.3 < \eta < 5.3$

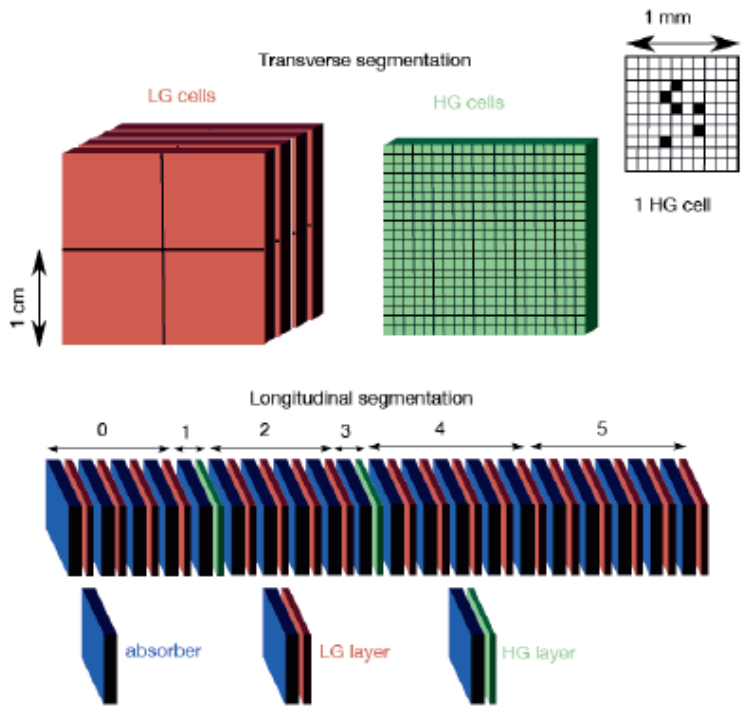
- **Proposed schedule:**
  - mini-FoCal: 2018- (after LS2)
  - full FoCal: 2023- (after LS3)

Main challenge: **separate γ/π^0** at high energy
- Need small Molière radius, high-granularity read-out
- Si-W calorimeter, granularity ≈ $1 mm^2$

*This slide is provision by Dr.Tatsuya.Cyujo/University of Tsukuba

FoCal-E Strawman Design

ALICE



- **Si/W** sandwich calorimeter layer structure:
  - W absorbers (thickness $1X_0$)+ Si sensors
- Longitudinal segmentation:
  - 4 segments low granularity (LGL)
  - 2 segments high granularity (HGL)

- **LGL segments (PAD)**
  - 4 (or 5) layers of Si/W
  - Si-PAD with analog readout
  - cell size 1 x 1 cm^2
  - 8 x 8 = 64 PADs per layer
  - signal are longitudinally summed

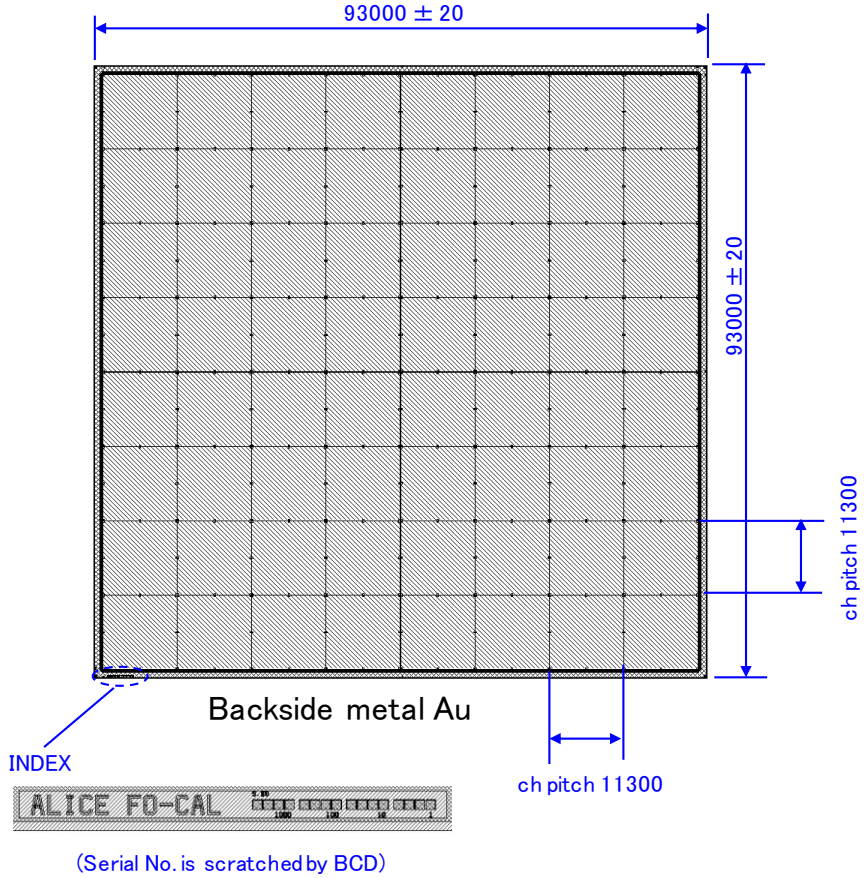
- **HGL segments (MAPS)**
  - single layer with W.
  - CMOS-pixel (MAPS*).
  - pixel size ≈ 25 x 25 μm^2
  - digitally summed in 1mm^2 cells

MAPS = Monolithic Active Pixel Sensor

*This slide is provision by Dr.Tatsuya.Cyujo/University of Tsukuba

Specification of Si-PAD for Alice-FoCal

Chip overall



HAMAMATSU

Si Photo Diode
S10938-6475

■ General ratings

Parameter	Rating	Unit
Detector type:	PIN-PD array	
Orientation of crystal:	<100>	
thickness:	320 ± 15	μm
Dead thickness at backside	20	μm
Chip size	93 x 93 ± 0.02	mm
Number of ch	64 (8 x 8)	ch
PAD pitch(X):	11300	μm
PAD pitch(Y):	11300	μm
Single ch P+ size:	11250 x 11250	μm
Single ch Al size:	11280 x 11280	μm
Readout PAD size:	200 x 200	μm

-Rough result-

Id(typ) <1nA/ch @200V
Ct(typ) 47pF/ch@200V
Vfd 45V

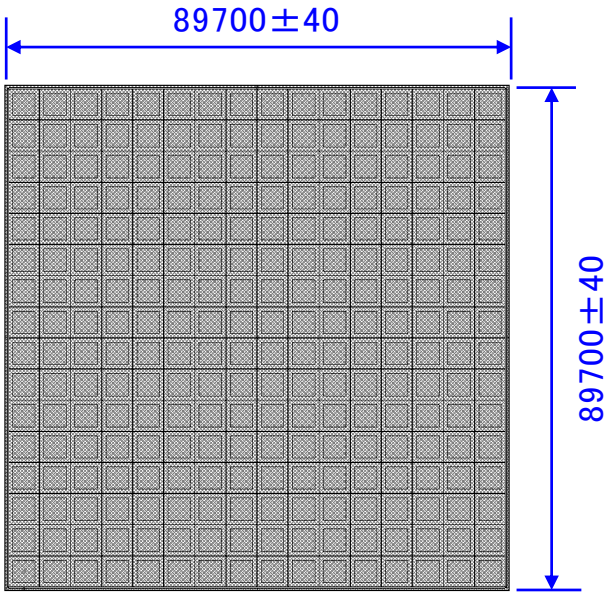
1. HPK's Si detector is used various HEP experiments

2. **Si-PAD for ILD E-cal**

3. Development of large area PAD detector

4. MPPC® (Multi Pixel Photon Counter) for HEP application

Specification of Si-PAD for ILD E-cal (thicker ver./Shipped 2018.3)



active area
88480 x 88480

Back Side:
Common Cathode(All metalization/pure Al)

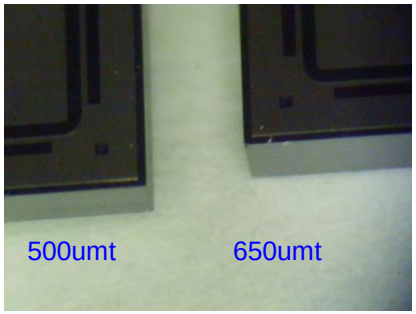
■General Ratings

Current ver.

Parameter	Rating	Unit
Device type	P+ PIXEL on N substrate	
Chip size	89700 ± 40 x 89700 ± 40	μm
Active area	88480 x 88480	μm
Chip thickness	320±15 or 500±15	μm
Number of PIXELs	256(16 x 16)	ch
PIXEL pitch	5530 x 5530	μm
PIXEL GAP	10	μm

Thicker ver.

Parameter	Rating	Unit
Device type	P+ PIXEL on N substrate	
Chip size	89700 ± 40 x 89700 ± 40	μm
Active area	88480 x 88480	μm
Chip thickness	650±15	μm
Number of PIXELs	256(16 x 16)	ch
PIXEL pitch	5530 x 5530	μm
PIXEL GAP	10	μm



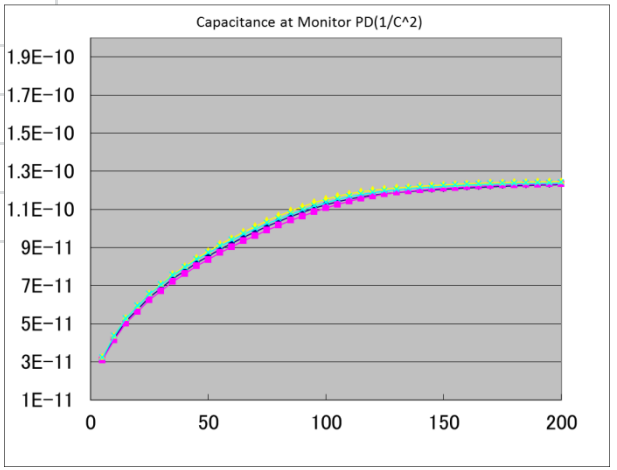
Inspection result of Si-PAD for ILD E-cal (thicker ver./Shipped 2018.3)

chipNo. 1
200V

Leakage current[nA] Id TOTAL 238 [nA]

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1	4.0	1.9	1.7	1.7	1.5	1.6	1.4	1.5	1.5	1.4	1.6	1.5	1.6	1.6	2.1	3.9
2	2.2	0.6	0.6	0.5	0.5	0.5	0.5	0.5	0.7	0.6	0.7	0.5	0.9	0.8	0.6	1.9
3	1.7	0.6	0.9	1.6	0.5	0.5	0.5	0.5	0.6	0.6	0.5	0.8	0.5	1.2	0.6	1.7
4	1.9	0.6	0.6	0.8	0.5	0.5	0.5	0.5	0.9	0.6	0.5	0.5	0.5	0.6	0.7	1.6
5	1.5	0.6	0.6	0.5	0.6	0.5	0.5	0.6	0.8	0.6	0.6	0.6	0.5	0.9	0.7	1.5
6	1.6	0.5	1.6	1.0	0.6	0.5	0.8	0.7	0.6	0.6	0.8	0.7	0.6	0.6	0.6	1.6
7	1.6	1.3	0.5	0.9	0.5	0.5	0.8	0.9	0.6	0.7	0.7	0.7	0.6	0.7	0.6	1.8
8	1.9	0.5	0.9	0.6	0.5	0.5	0.7	0.6	0.8	0.9	0.8	0.7	0.6	0.6	0.6	1.9
9	1.6	0.6	0.5	0.5	0.6	0.5	0.6	0.6	0.7	0.6	0.9	0.7	0.8	0.7	1.3	1.8
10	1.7	0.5	0.7	0.5	0.8	0.6	0.7	0.5	0.6	0.7	0.6	0.6	0.6	0.6	0.6	2.1
11	1.7	0.5	0.5	0.6	0.5	0.5	0.5	0.5	0.6	0.5	0.5	0.7	0.6	0.8	0.8	1.7
12	1.5	0.6	0.8	0.5	0.6	0.5	0.5	0.5	0.5	0.6	0.8	0.8	0.6	0.7	0.7	1.7
13	2.0	0.8	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.6	0.8	0.5	1.0	0.6	0.7	1.8
14	1.9	0.6	0.7	0.9	0.7	0.5	0.5	0.5	0.5	0.5	0.5	0.6	0.6	0.9	0.7	1.8
15	2.0	0.7	0.6	0.6	1.2	0.5	0.5	0.8	0.7	0.5	0.8	0.5	0.6	0.6	0.7	2.3
16	3.7	1.9	1.7	1.6	1.6	2.2	1.6	1.5	1.5	1.7	1.6	1.6	1.7	2.1	1.9	3.7

12	13	14	15	16
1.5	1.6	1.6	2.1	3.9
0.5	0.9	0.8	0.6	1.9
0.8	0.5	1.2	0.6	1.7
0.5	0.5	0.6	0.7	1.6
0.6	0.5	0.9	0.7	1.5



- **Very low leakage current typ:0.5nA/ch @200V25℃ (at inner ch, typically a few nA at outer ch)**
- **No NGch**
- **Vfd:90V**

Now in checking(by customer side) and assembling at Kyushu university.

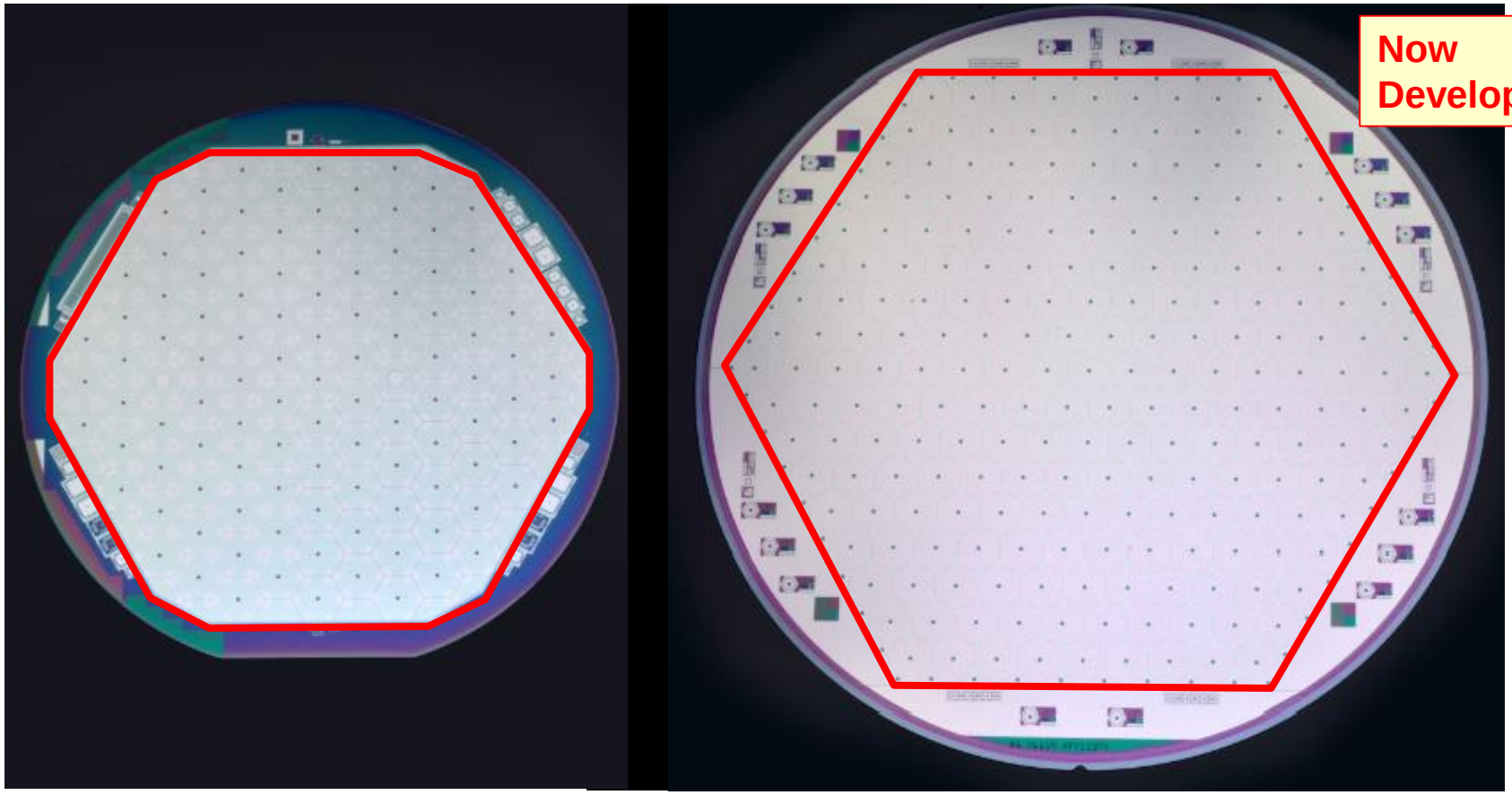
1. HPK's Si detector is used various HEP experiments

2. Si-PAD for ILD E-cal

3. **Development of large area PAD detector**

4. MPPC® (Multi Pixel Photon Counter) for HEP application

Development of 8inch-PAD detector



6inch-PAD detector

- 12 Polygon shape chip
- 109 x Hexagonal PADs + α

8inch-PAD detector

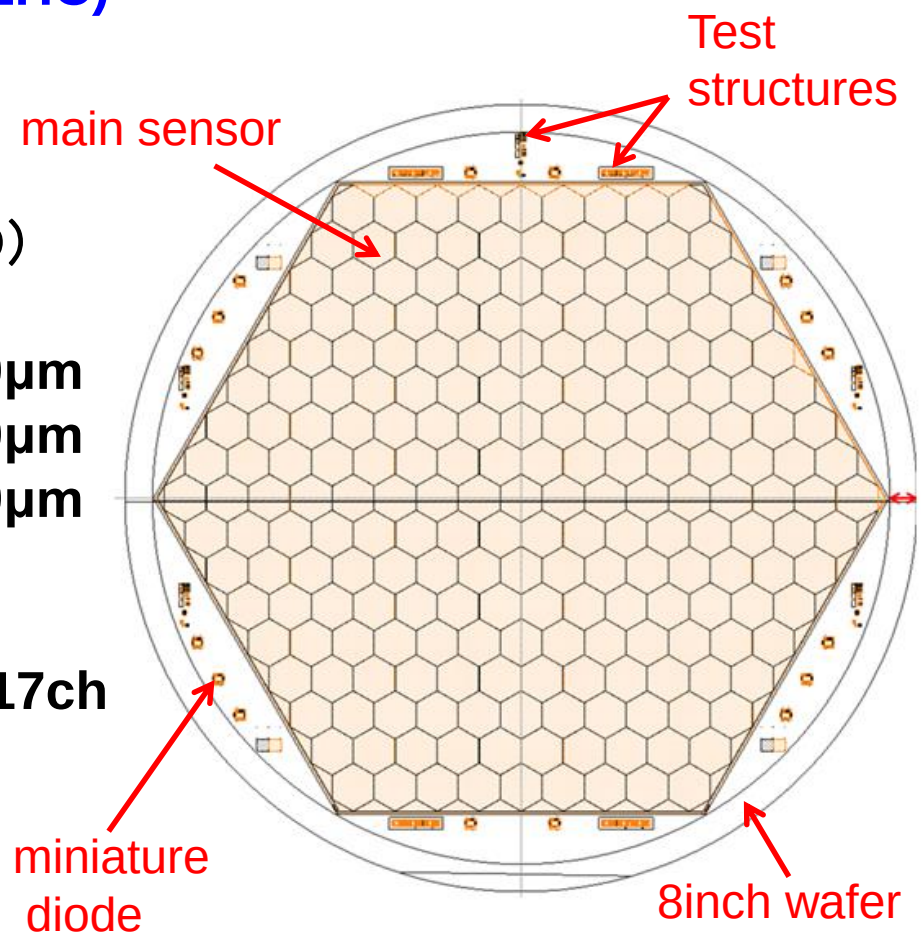
- Hexagonal shape chip
- 217 x Hexagonal PADs + α

Development of 8inch-PAD detector

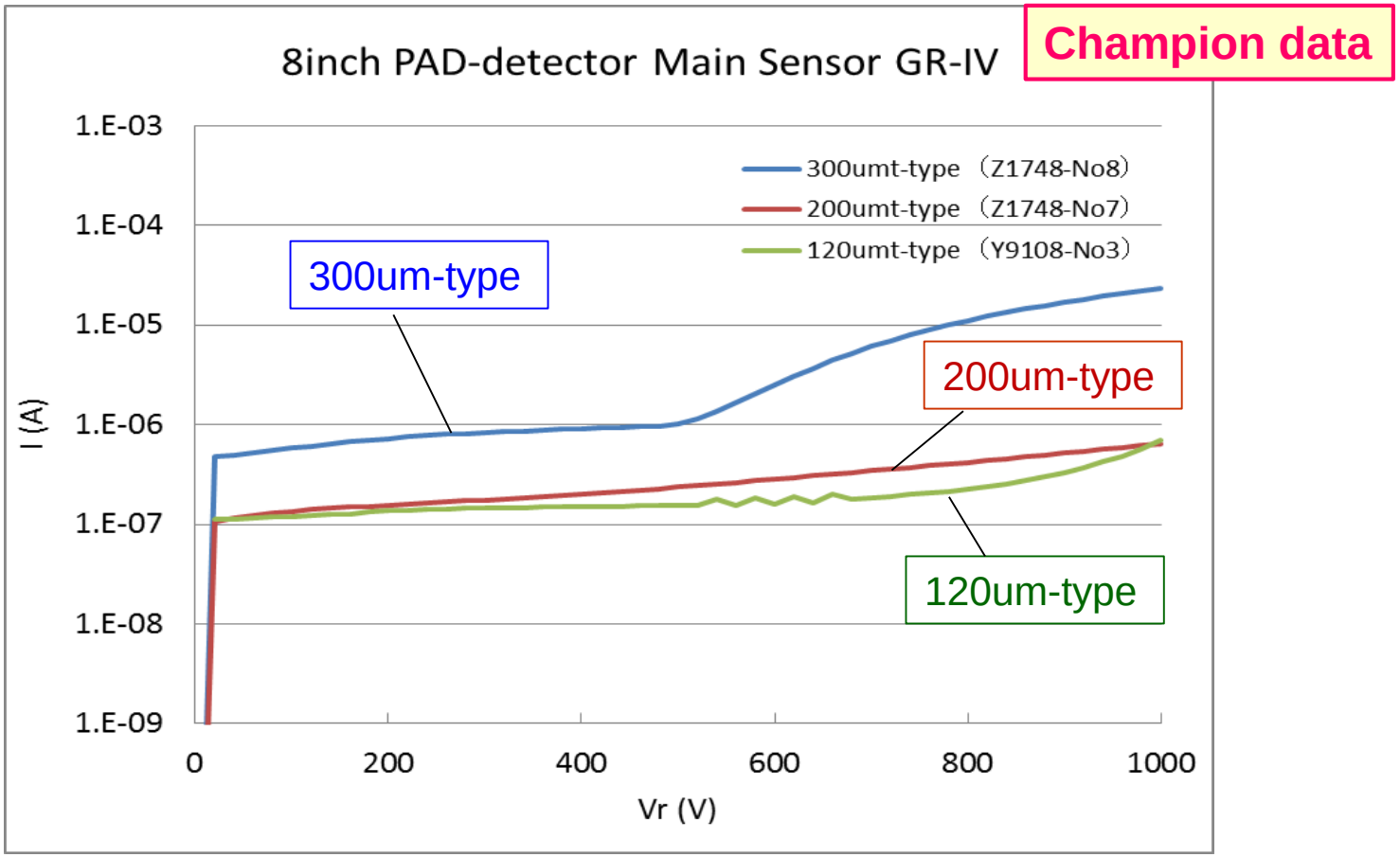
■ Our 1st Proto-type
（target for CMS-HGCAL HL-LHC)

- Size : 8 inch
- Type : N+ in p
  （P-substrate and N-PAD）
- Thickness : 3types
  - ・Active 300μm、Physical 300μm
  - ・Active 200μm、Physical 200μm
  - ・Active 120μm、Physical 300μm

- Size of PAD :~ 1cm2
- Number of Hexagonal PAD : 217ch



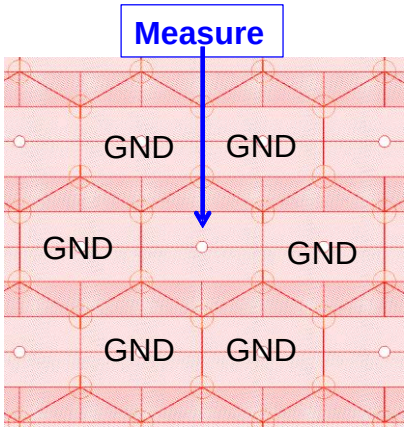
Result-1
Guard-Ring I-V of Main Sensor



Enough low dark current and high voltage tolerance

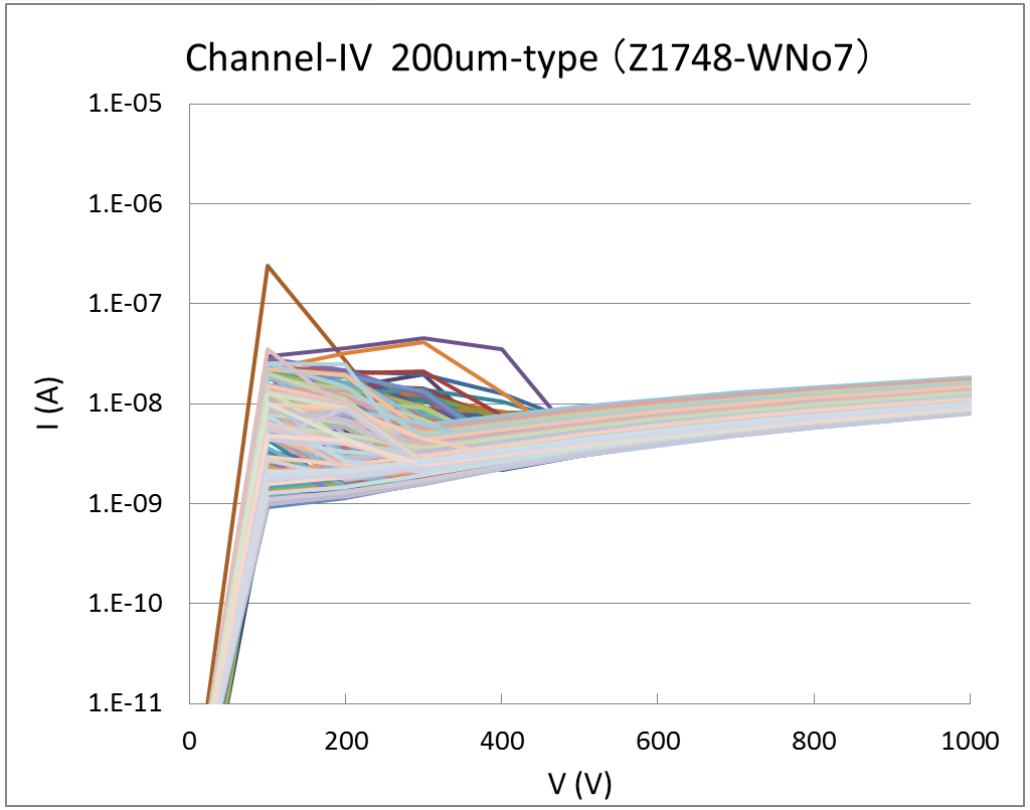
Result-2
Channel I-V of Main Sensor

■ **We measured IV curve of every channels with surrounded channels GND.**



Champion data

200μm type



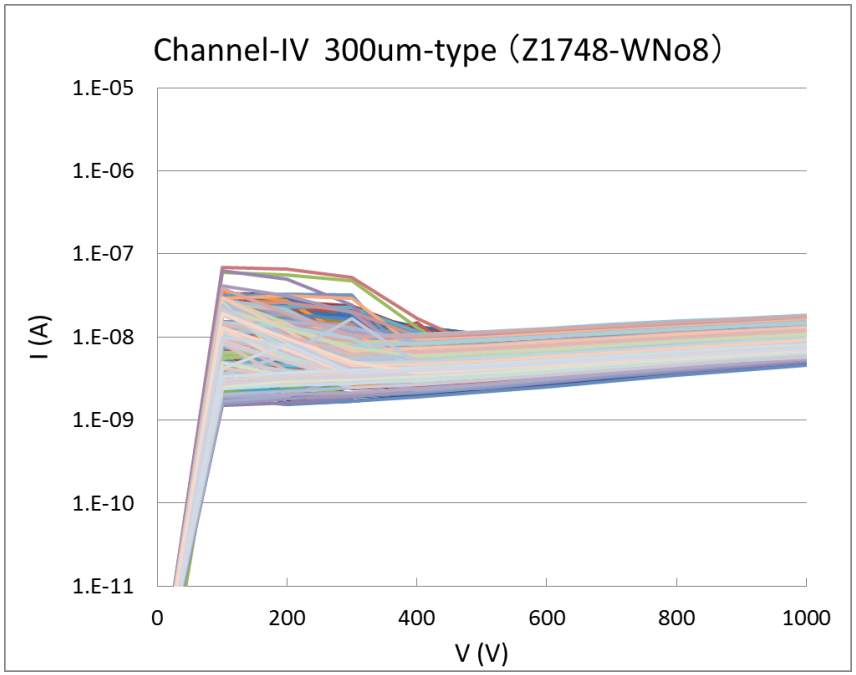
As well as GR-IV results,
We got good results.

Result-2
Channel I-V of Main Sensor

■ **We measured IV curve of every channels with surrounded channels GND.**

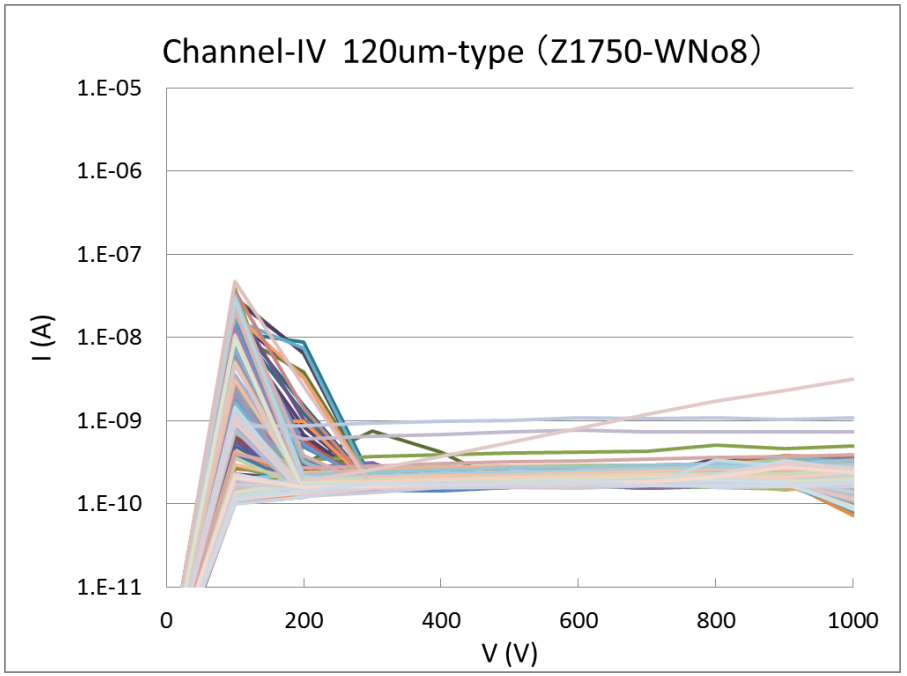
Champion data

300μm type



Similar result as 200um type

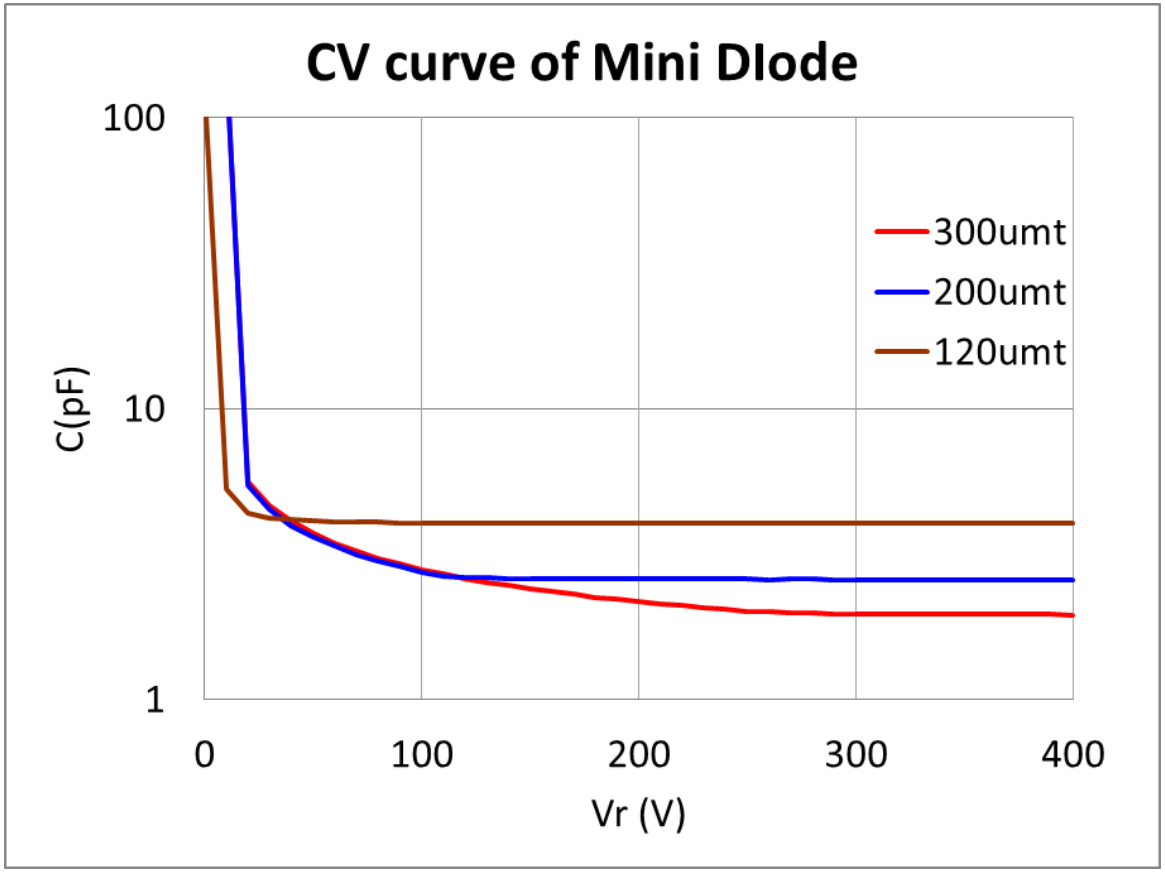
120μm type

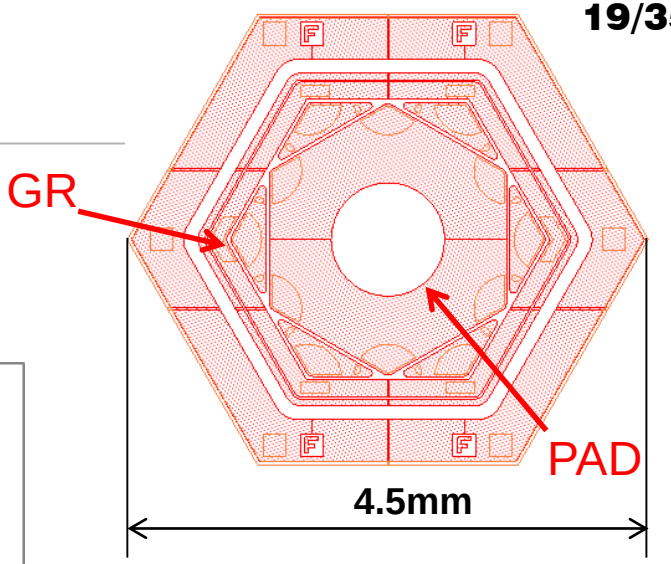


Lower leakage current than Other types

Result-3
C-V curve of Mini Diode

■ **We measured CV curve of Mini Diode and estimated the full depletion voltage.**





Full depletion voltage

300μm type : ~280V
200μm type : ~130V
120μm type : ~ 30V

Future prospect of 8inch wafer production

○DC-type : PAD-detector, PIXEL

- Development stage ～2019
- will be available 2020～

○AC-type : AC coupled SSD

- Development stage 2020～2022
- will be available 2023～

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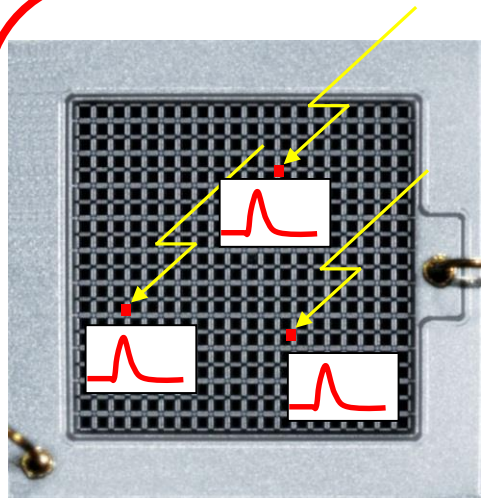
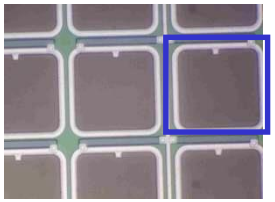
3. Development of large area PAD detector
4. **MPPC® (Multi Pixel Photon Counter) for HEP application**

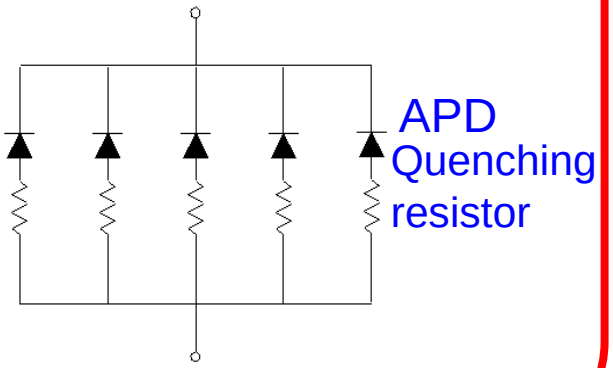
MPPC® Technology Overview

➢What is an MPPC®?

- **M**ulti-**P**ixel **P**hoton **C**ounter
  a new type of photon-counting device made up of multiple APD pixels operated in Geiger mode (=SiPM)



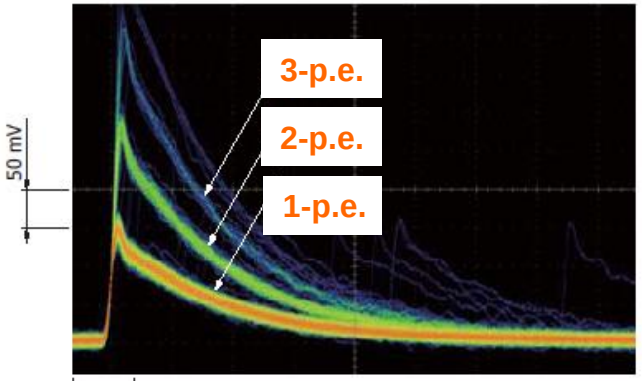




Output is summation of all pixel output

➢Features

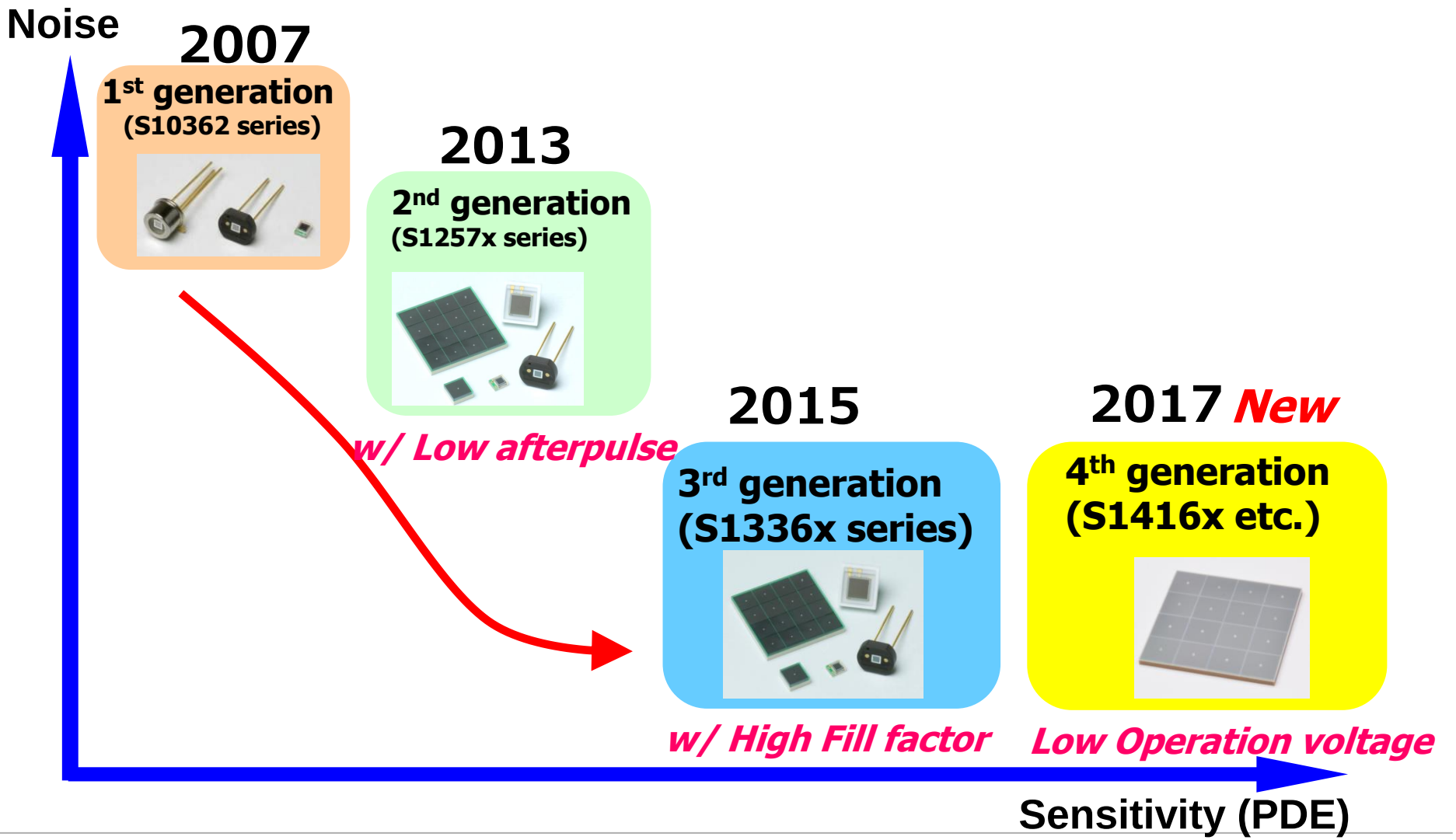
- Small size / light weight
- Room temperature operation
- Low bias operation : 40~70V
- High gain: 10^5 to 10^6
- Excellent timing resolution
- Insensitive to magnetic fields
- Simple readout circuit operation



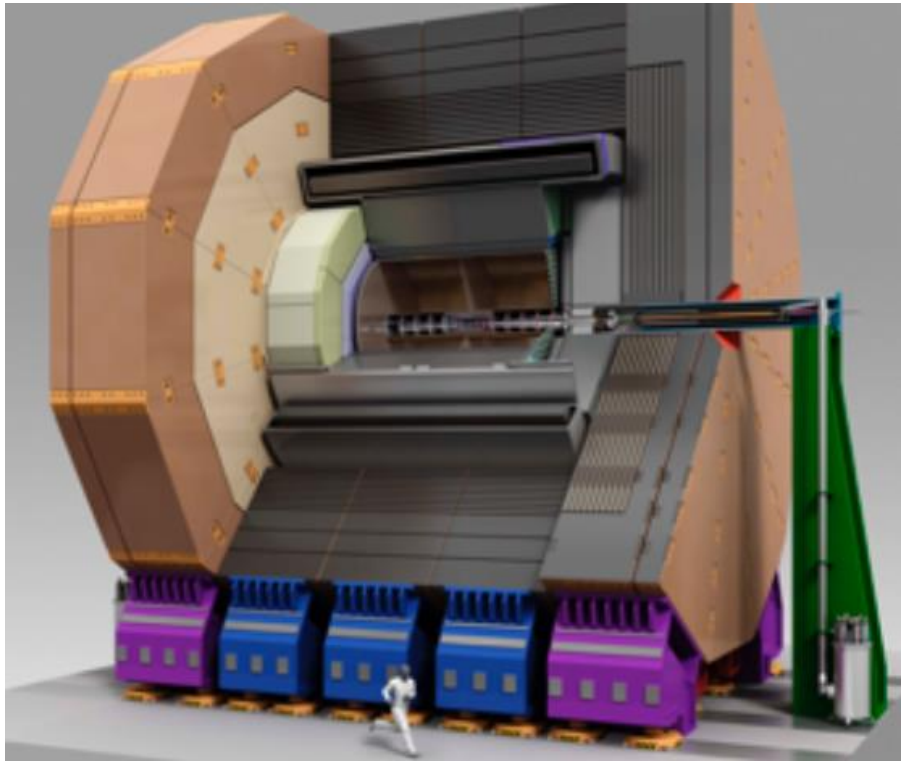
$$Q_{out} = N_{fired} \times C_{pixel} \times (V_{op} - V_{BR})$$

$$N_{fired} = PDE \times N_{photon}$$

History of MPPC®s



MPPC in Accelerator



- Accelerator is consisted by some detector which is designed for detecting timing, position and energy.

- MPPC has been used in any type of detectors.
  - Tracker
  - Timing detector
  - Calorimeter
  - Muon detector

- Most especially, calorimeter is suitable detector for MPPC.

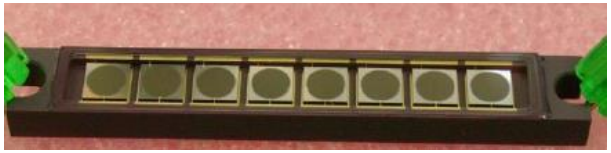
MPPC in calorimeter

- Determine particle energy by scintillator (λp= 350-550nm)
  - *A) Coupled directly (bar or fiber; LYSO, CsI, plastic, etc.)*
  - *B) Coupled with wavelength shifter(WLS) fiber*

Both are match to MPPC's sensitivity peak

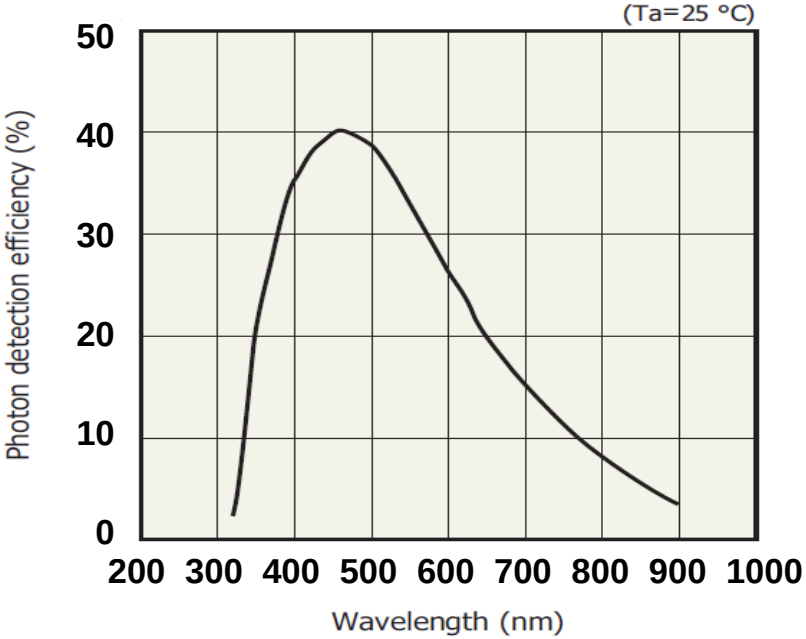
- ***MPPC in calorimeters***

  CMS/LHC, mu2e, NICA etc.
  (& ILC !?)



MPPC for CMS/LHC

- ***Request***
  - **Dynamic range**
  - **High sensitivity**
  - **Radiation hardness**

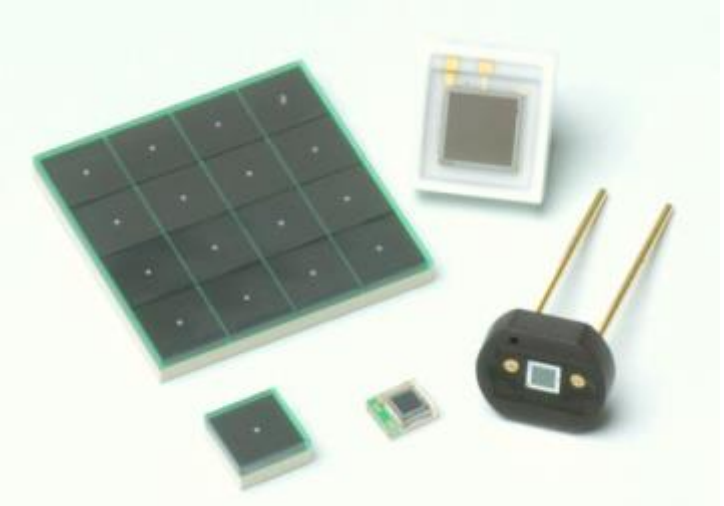


MPPC for general propose

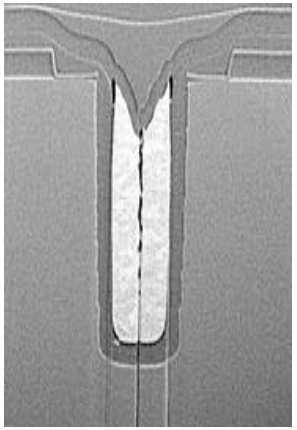
S13360 series

- **Low noise (dark count, cross-talk)**
- **High count rate (fast recharging)**
- **Excellent timing resolution**
- **High blue light sensitivity**
  → ***match to scintillator emission***
- **Single & TSV array lineup**

➢ ***Suitable for any application***



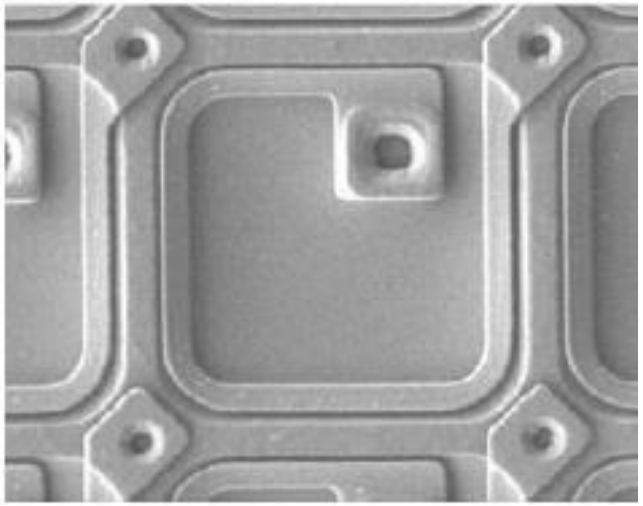
Trench isolation
(between pixel to pixel)

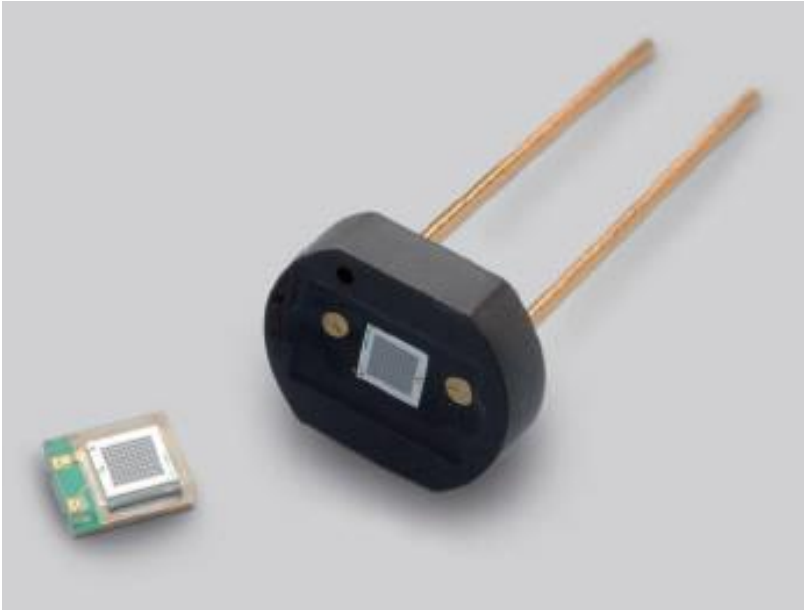


High dynamic range type

S12571/S12572-010, -015C/P

- **High-dense pixels (10/15μmp) & high dynamic range**
- **High PDE (maximized fill factor)**
- **S1257x-015 is known as a good radiation hardness device.**
  - ***Suitable for calorimeter.***



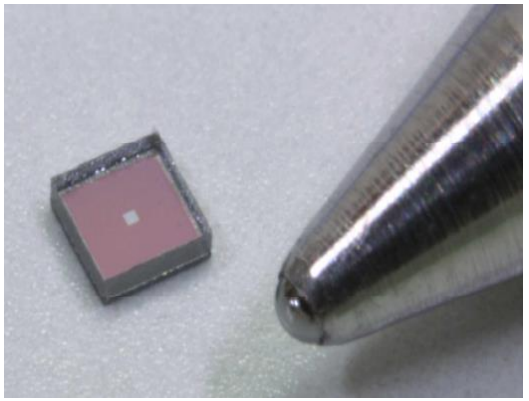


Wafer Level Chip Size Package (WLCSP)

S13190 & S13615 Series

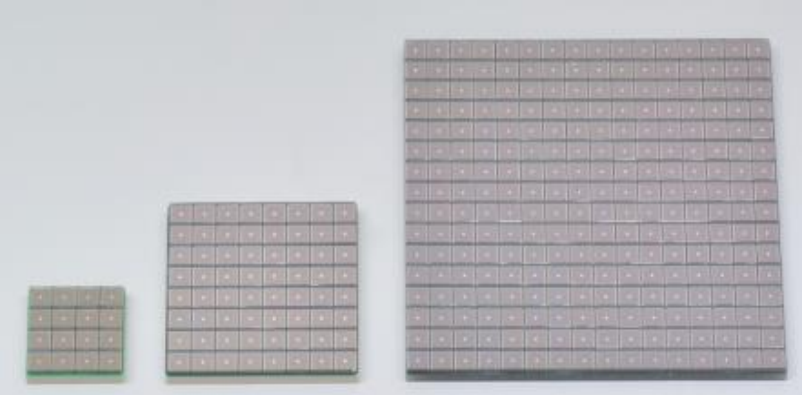
- **1x1mm² TSV with support glass**
- **Small and compact**

  Package size: 1.13mm SQ.
  (Active area : 1.0mm SQ.)
- **4-side tillable & high density assembly**

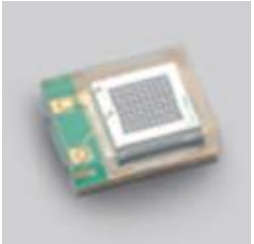


***S13190: High dynamic range type**

S13615: Low noise type



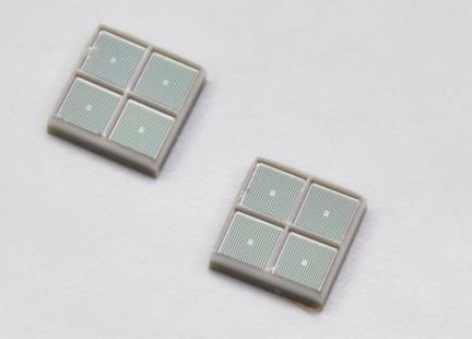
MPPC for ILC



【H-CAL】

S13360-1325PE (low noise type)

S13615-custom
(1mm^2-2x2ch.-25ump, 4 ch. parallel connected)



【EM-CAL】

S12571-015P, -010P

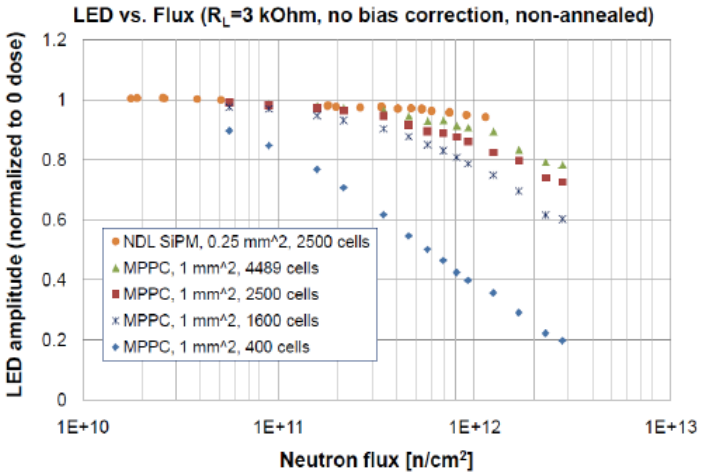
(high dynamic range type)

Radiation hardness

Bulk damage:

- Irradiated particle create the defect in MPPC and affect some characteristics (noise, PDE, gain).
- Maximum permissible irradiation:

  ~10^12 (1MeV neq/cm^2)

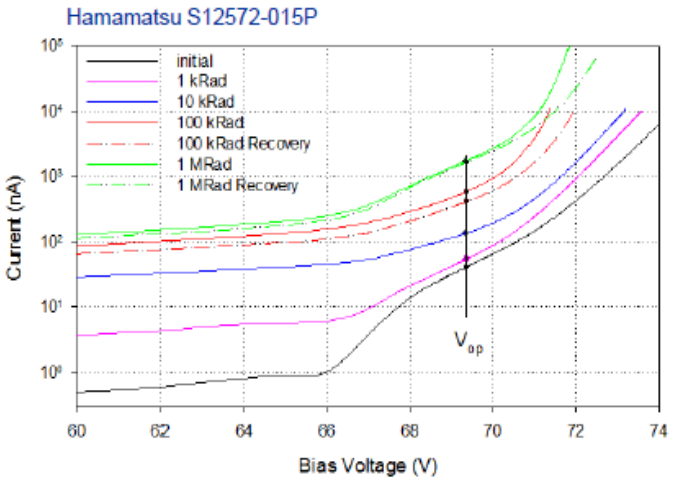


Y. Musienko, SiPM workshop, 2011

Surface damage:

- Low energy X-rays can produce surface damage affecting the passivation layer.
- Ionizing particles can produce charging up effects affecting the internal fields inside MPPC.
- Maximum permissible irradiation:

  Depend on the particle and energy.
  (ex. 60Co-1Mrad: Id ~ 100 times)



C. Woody, CPAD Workshop, 2016

Smaller pixel sizes show less damage.

Development for NEXT

Motibation

- **High dynamic range**
  - → ***Smaller pixel***
- **Good energy resolution**
  - → ***High PDE & Noise suppression***
- **Anti-electric noise**
  - → ***High gain***
- **Radiation Hardness**
  - → ***Lower overvoltage operation(= low noise)***

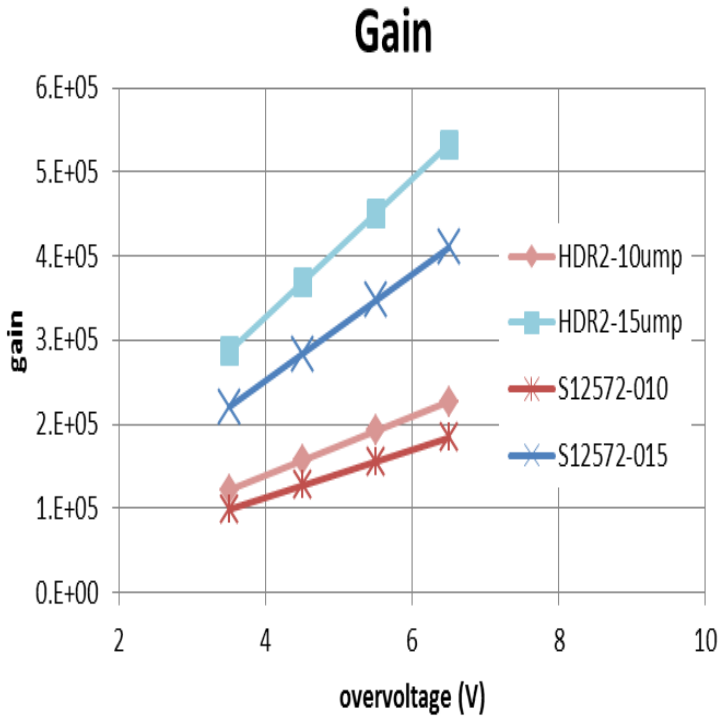
HDR2(High dynamic range 2) is under development!

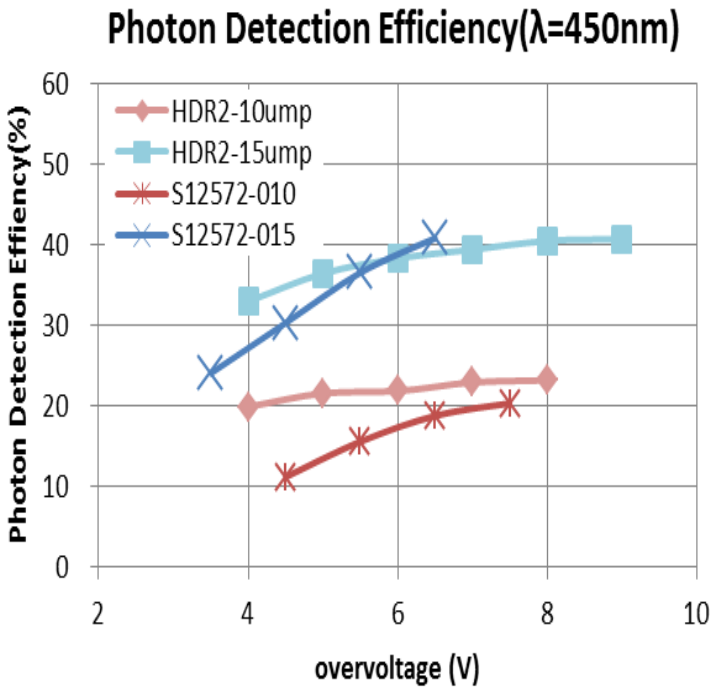
MPPC-HDR2 (Under development)

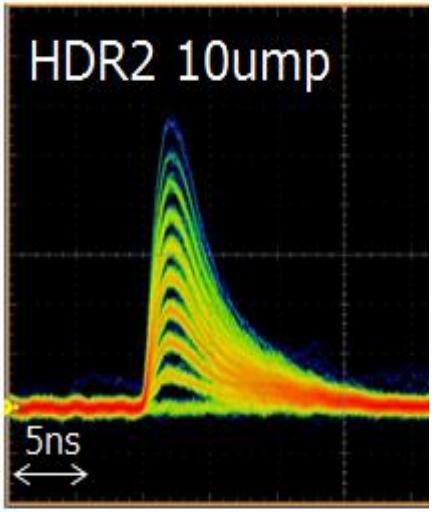
4th generation MPPC family; High dynamic range type

- **Low bias operation: Vbr~40V (*S1257x: Vbr~65V)**
- **High gain & high PDE even low overvoltage**

[Preliminary results]







MPPC-HDR2 (Under development)

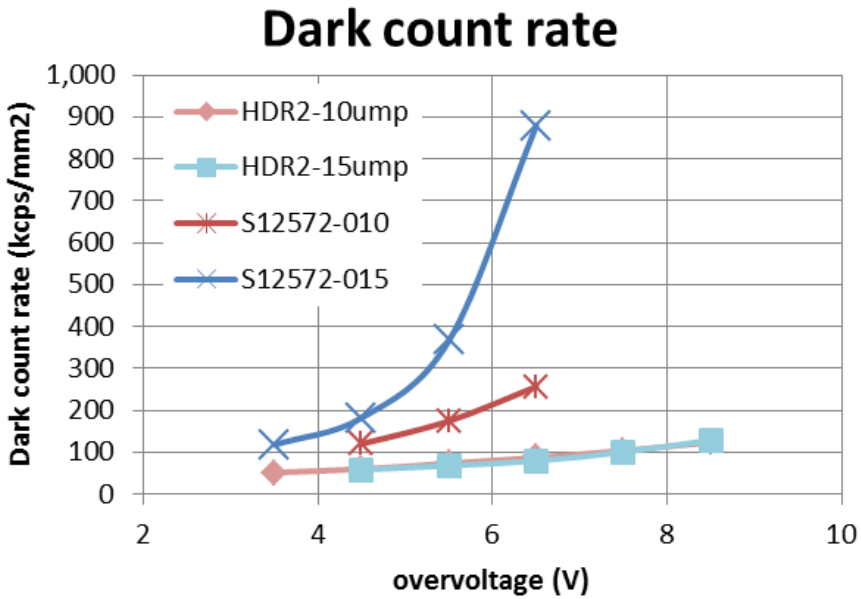
Noise characteristics

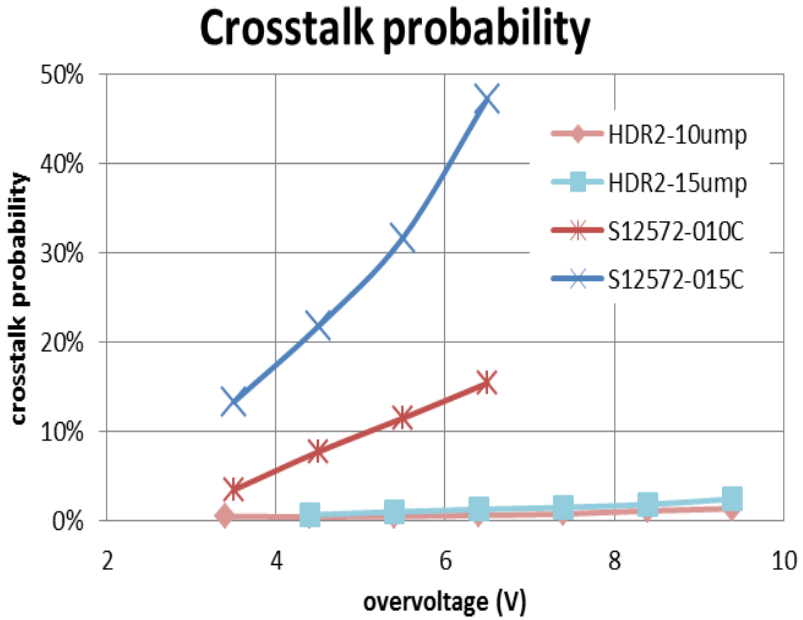
- Dark count rate and crosstalk probability is suppressed by trench isolation technology.

➡ S/N ratio and energy resolution will be improved!

(Now checking reliability and radiation hardness)

[Preliminary results]





Summary

1. The Hamamatsu SSDs and PADs sensors have been used various HEP experiments.

2. Also, We are now developing for ILC.

3. In parallel, We are now developing 8-inch PAD detector, and we have obtained several trial results.

3. We have developed and delivered MPPC ® s for HEP experiments as well as PADs.

4. New high dynamic range MPPC® (MPPC-HDR2) is under development. High PDE, low noise and high dynamic range characteristics will contribute to the calorimeter's improvement.

Closing

We Hamamatsu are proud that our Si-detectors are used for many physical experiments.
We continually make efforts to provide a better sensor, and contributes to the development of physics.

Photo of Ichino factory with beautiful cherry blossom

Awards received from the LHC experimental groups

Thank you for your attention.

jp.hamamatsu.com