LGAD/PSD development

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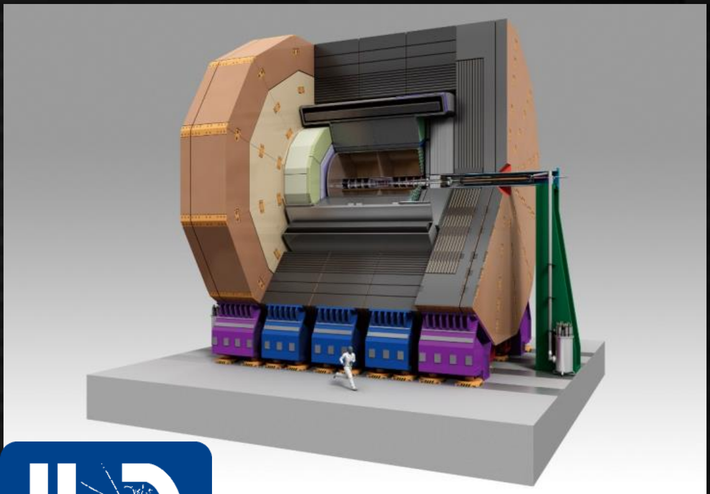
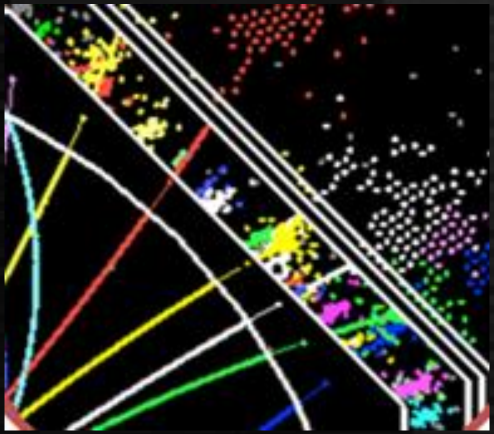
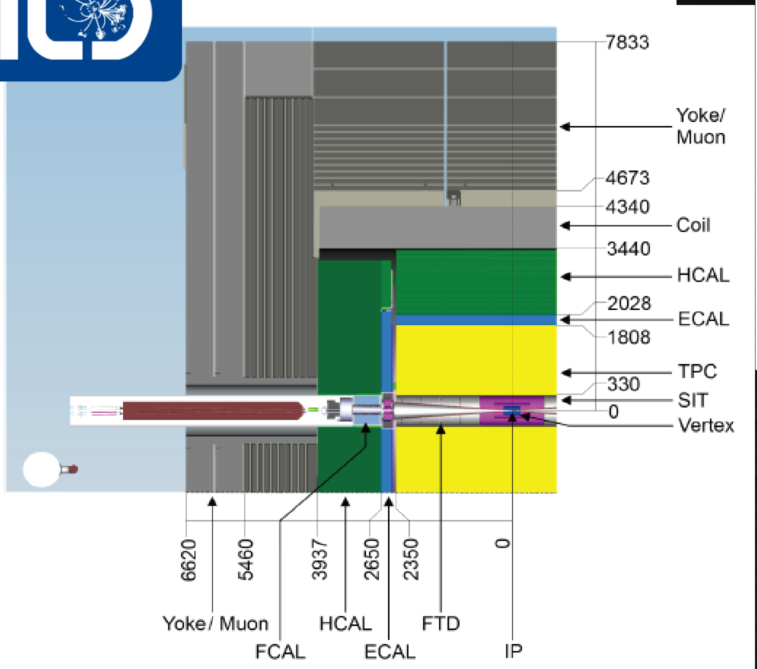
(Kyushu University)

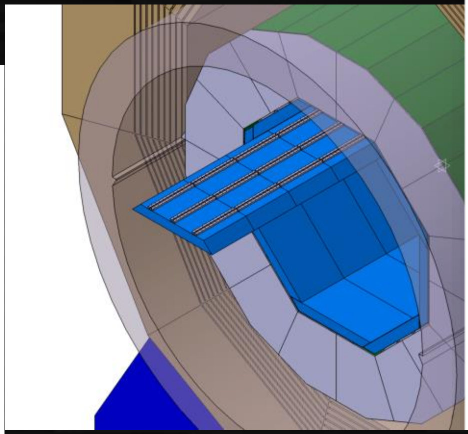
English version of ELPH proposal and material for discussion to HPK

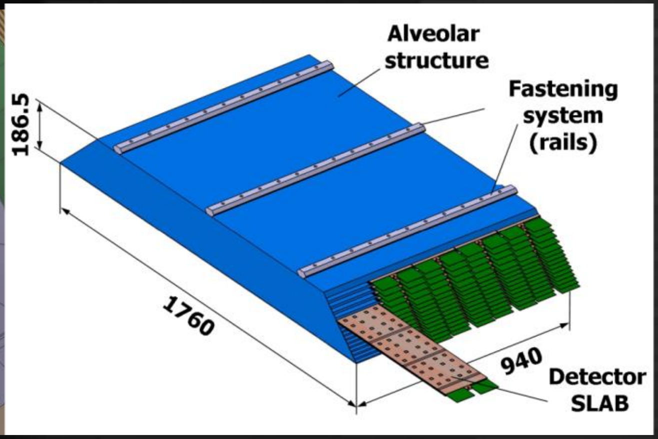
ILD and SiW ECAL







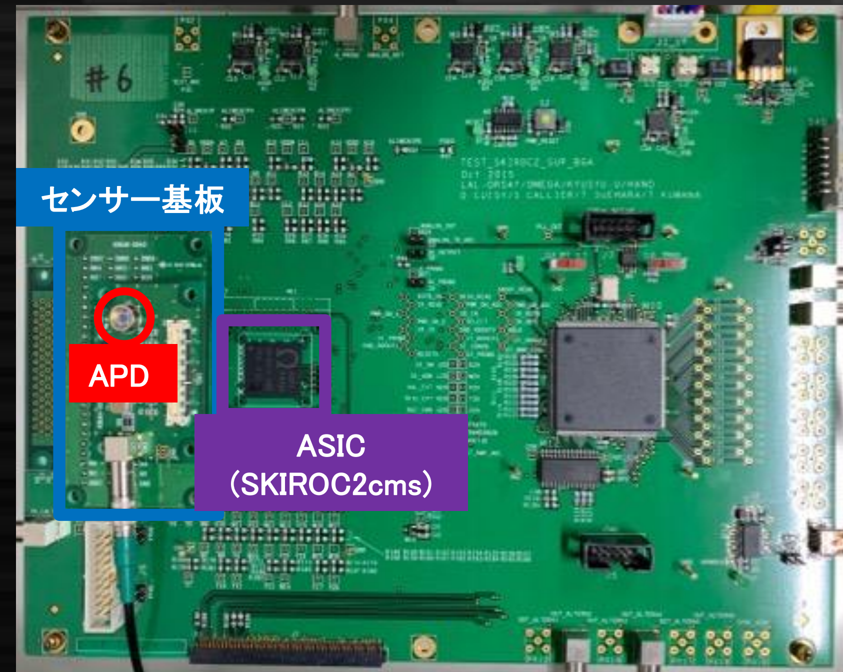




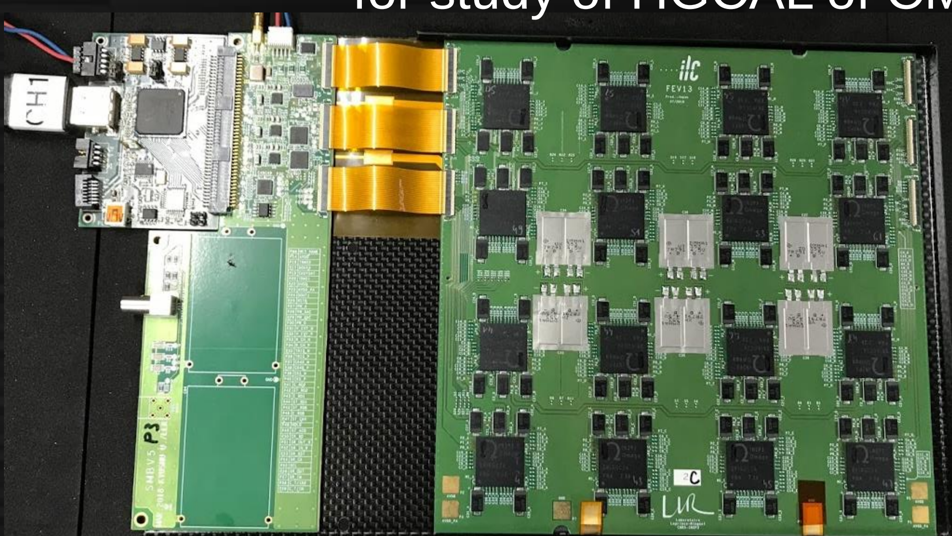
Silicon-tungsten ECAL
30-layer sandwich calorimeter
5 mm cell 100 M ch, 0.4 M sensors
LLR, LAL, LPNHE, Kyushu, KEK etc.

Readout ASIC and PCBs

SKIROCシリーズ
(2A/CMS) by OMEGA
64 ch readout
Preamp + 2 gain (1/10)
slow shaper + fast
shaper for triggering
SKIROC2CMS: good TDC
+ 13 cell 40 MHz digitizer
for study of HGCAL of CMS

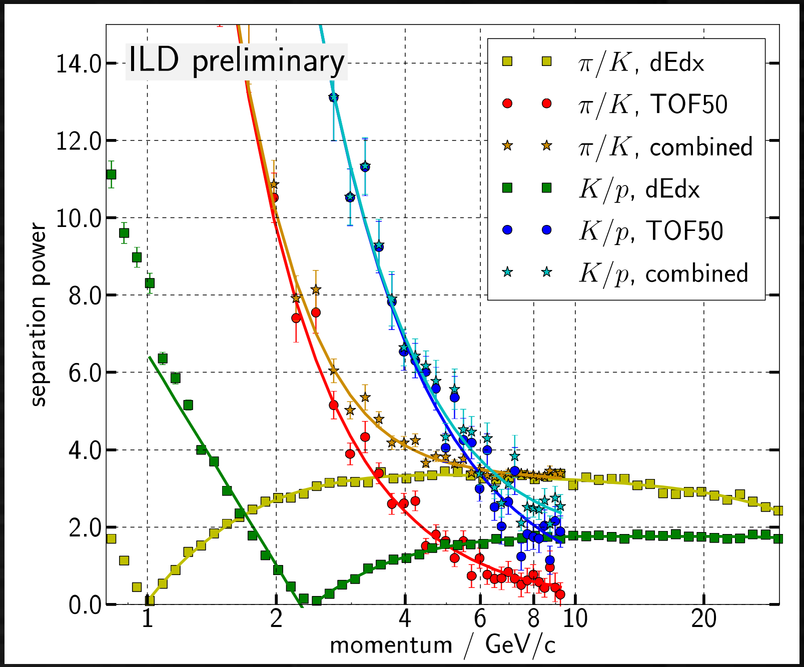


↑ SKIROC2 evaluation board
A daughter board is connected
with a PCB connector to use this
board for readout of various sensors

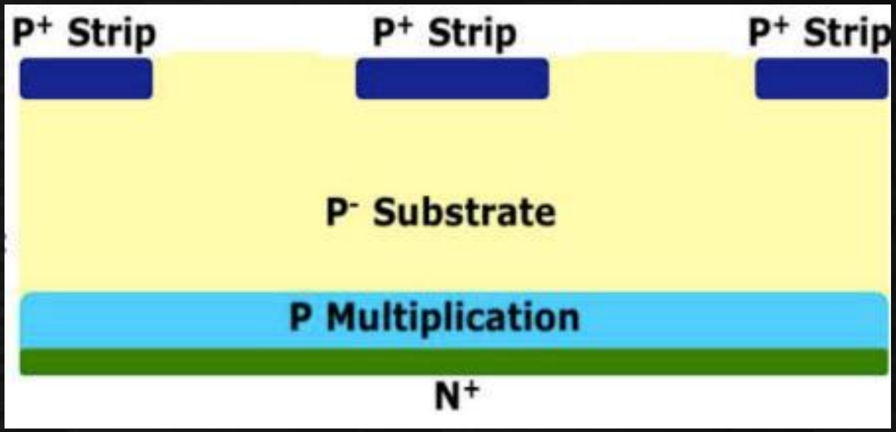


← FEV13
Developed as a technological proto-
type for SiW-ECAL: usable for sensor
studies with pads at the back side

LGAD and timing resolution



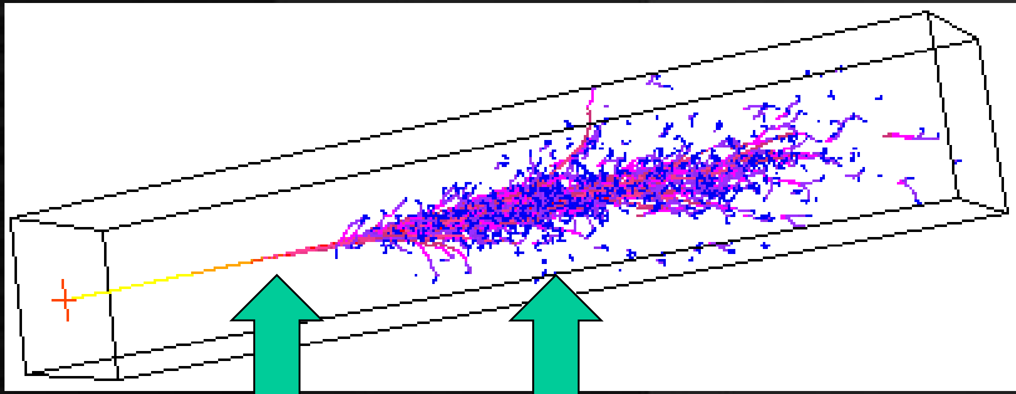
Possible to separate π/K/p up to 3-5 GeV by 50 psec ToF with dE/dx at TPC



LGAD (Low Gain Avalanche Detector) is a silicon sensor with avalanche gain.
~20 psec timing resolution is demonstrated at ATLAS
gain flatness may be concerned

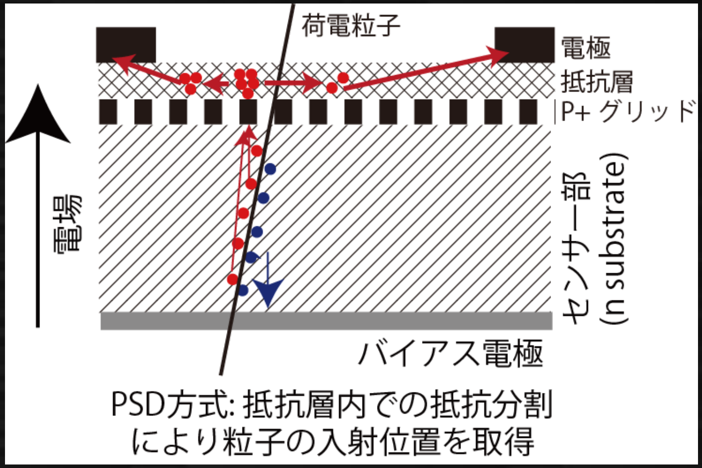
PSD and position of photons

Better position (direction) resolution of photons can be used for π^0 reconstruction and photon-related BSM search



Position resolution is important at beginning of showers ~2 mm with standard pads

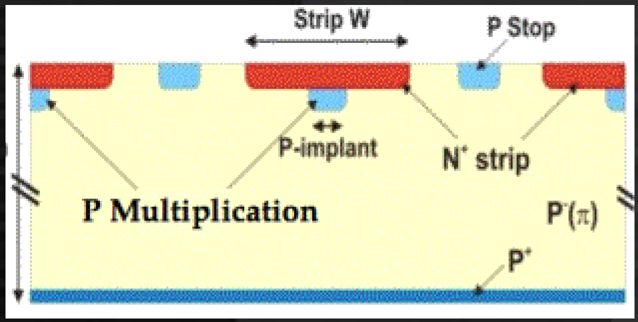
Around Shower-max it is determined with Moriere radius and number of hits ~0.3 mm in ILD



PSD uses resistive division to identify gravity center with multiple electrodes without significantly changing number of readout channels

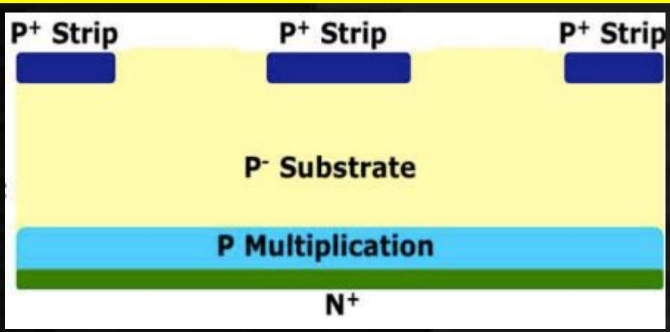
LGAD (APD) sensors to test

Bigger sensors will be tested this year because we got difficulty on efficiency and position dependence as well as timing resolution mainly because of lower rates

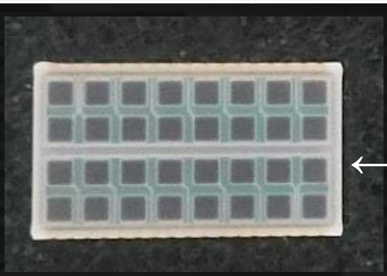


Reach-through: performance demonstrated but multiplication only at the P-implant

Spec no	type	VBR[V]	size [mm]
S8664	Inverse	400	3ϕ, 5ϕ, 5 x 5 mm
S5344/5345	Inverse	150	3ϕ, 5ϕ
S2384/2385	RS	150	3ϕ, 5ϕ
S6045	RS	200	3ϕ, 5ϕ
S8550-02	Inverse	400	Array (32ch, 1.6 mm sq)
FBK sensor	RS	?	Array (92ch, 1 x 3 mm)



Inverse: Good for calorimeter because of better gain flatness but need to investigate



Multi-cell LGAD

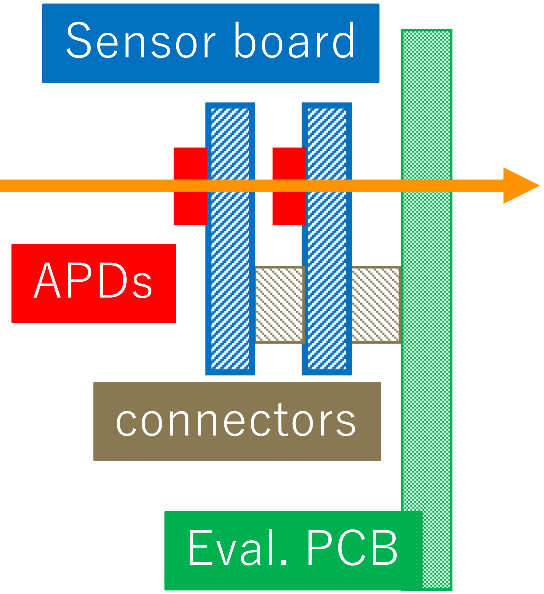
←Hamamatsu

FBK→

Positron beam irradiation (11/18~22)

- Test Beam @ELPH(Tohoku)
  Positron beam, 500 MeV

Measurements of timing resolution

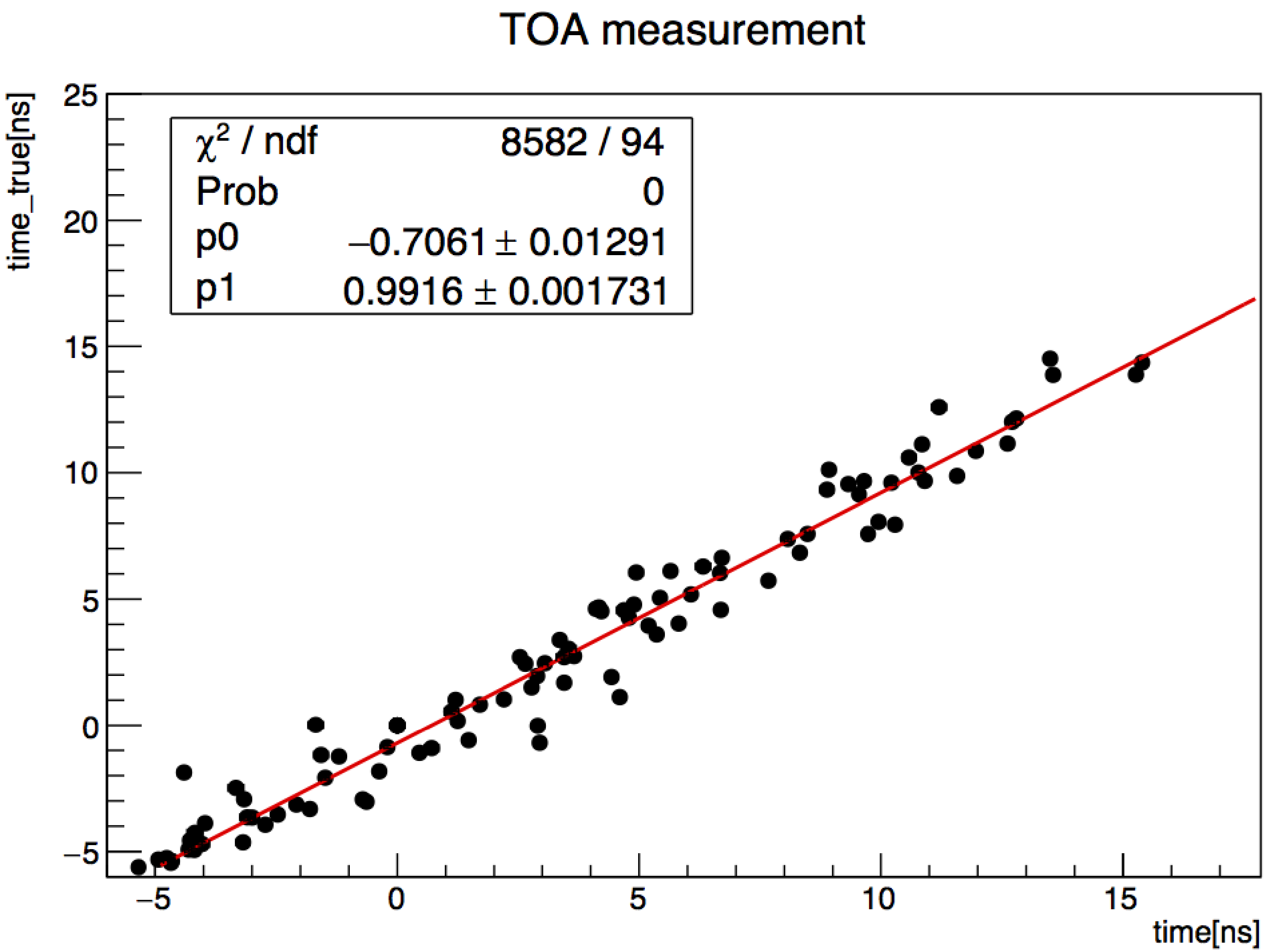


S2384

Penetrating events with identical APDs

Timing resolution from timing correlation

Measurement result

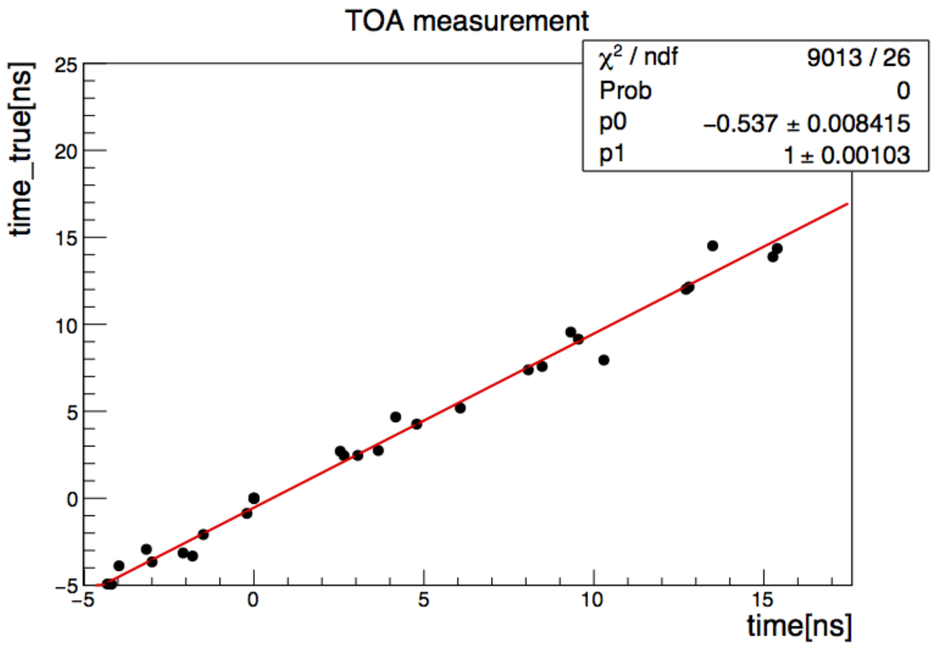


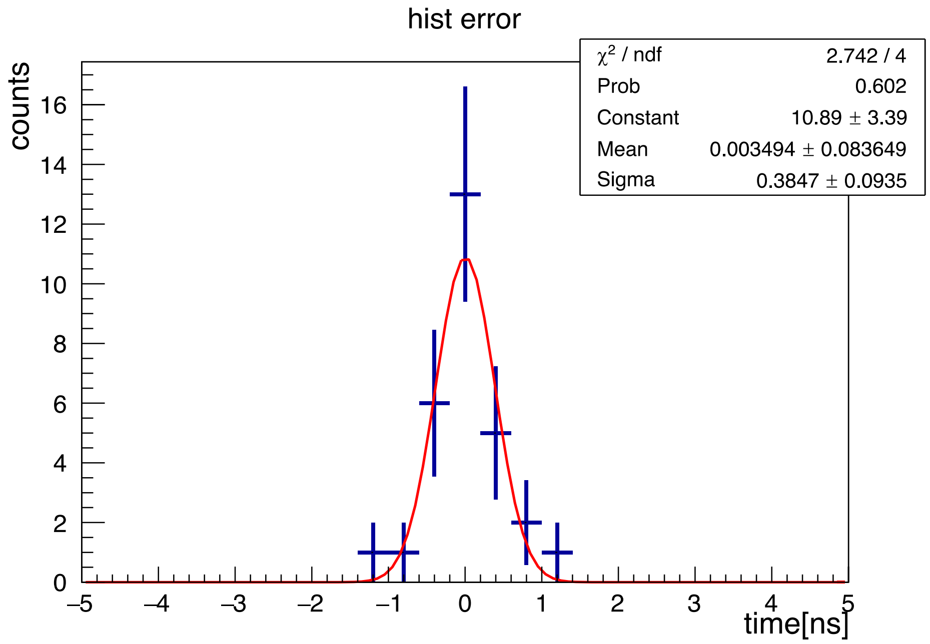
※Timewalk corrected

Measurement result

➢ Only with > 100 fC

- Smaller timewalk effect
- Smaller jitter
- Should have better resolution because of steeper voltage-rise





Timing resolution (> 100 fC) : 385 ± 94 ps

With Jitter of 50 ps at 100 fC… $\sqrt{385^2 - 50^2} \cong 382$ ps

CHEF2019@Kyushu

Proceedings:

arXiv:2002.06780 (LGAD)
arXiv:2002.06534 (PSD)

Wednesday, 27 November

17:20 **Study of silicon sensors for precise timing measurement** 20m
Speaker: Yuto Deguchi (Kyushu University)
CHEF2019.pdf

17:40 **Study of Position Sensitive Silicon Detector (PSD) for SiW-ECAL at ILC** 20m
Speakers: Mr Yuto Uesugi (Kyushu University), hep kyushu
CHEF2019_uesugi.p...

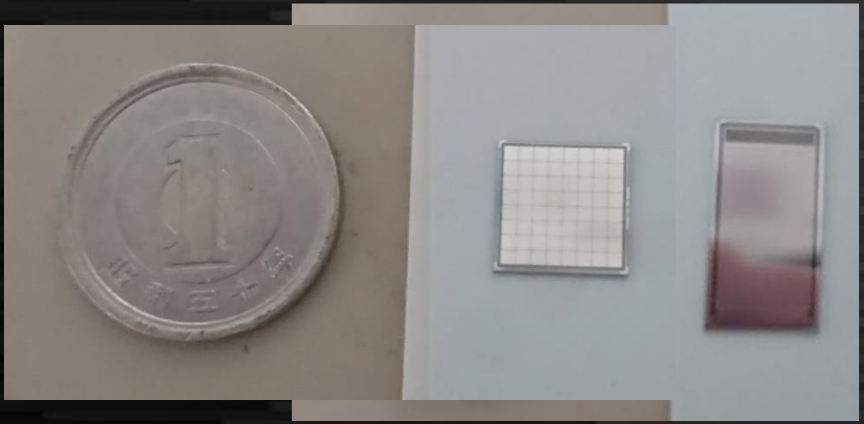
Issues at last year

APD serial No.	APD-1 イベント数	APD-2 イベント数	同期イベント数	検出効率
S12023-10A	1002	965	147	14.9 %
S8664-10K	613	298	4	0.9 %
S2384	4355	5796	1136	22.4 %
S8664-20K	368	185	2	0.7 %
S8664-55	3060	2327	96	3.6 %

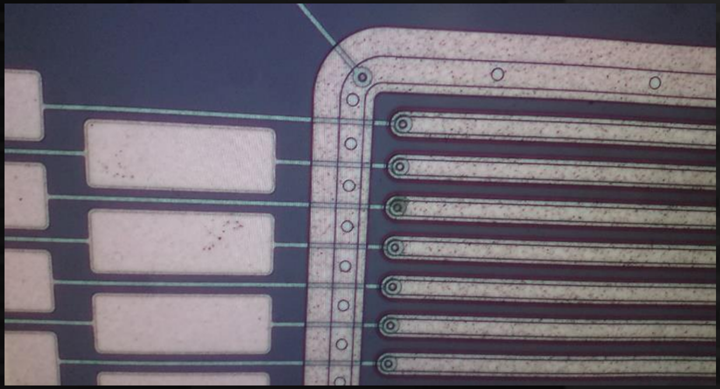
- Lower double-hit rate
  - Esp. with inverse type
  - Low efficiency?
  - Different gain by position?
    → Tracking detector at front and back side should help
  - Measurement of 3 sensors (2 in previous due to tech. reason)
- Lower statistics
  - Using bigger sensors, short distance, better DAQ etc.
- Bad timing resoultion
  - Correction (timewalk, ch-dep of TDC) is not working?
  - More statistics and 3-sensor measurement should help to investigate more

Tracking sensors

- Silicon pad with 1 mm cells
  - 8 x 8 mm (16 x 16 mm covered with 4 sensors)
  - Measuring beam profile
  - Used for trigger
- Silicon-strip sensors
  - 50 μm pitch, 128 ch (256ch with 2 direction)
  - Precise measurement of position dependence
- 256ch readout with FEV13
  - Using an adapter board (wire bonding for strips)



1mm-cell sensor (left)
strip sensor (right)



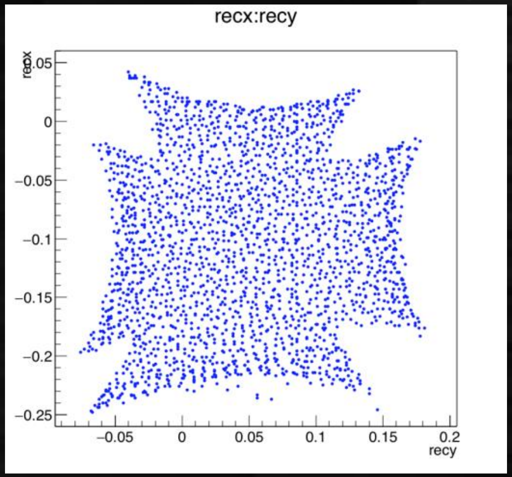
Edge of strip sensor

Purpose and program at ELPH (LGAD)

1. Timing resolution and efficiency LGAD
   - Place 1 mm sensors at front and back side to ensure the positrons hit the center of LGADs
   - Place 3 LGADs with minimal distance
     Measurement of timing resolution and efficiency
   - Sensors with 4 types and 2 sizes, with several bias voltages
2. Position dependence with multi-cell LGADs (16hrs)
   - Place strip sensors at front and back side for precise positions
   - Evaluate difference of efficiency and timing resolution by position

PSD sensors

1st gen (2016)



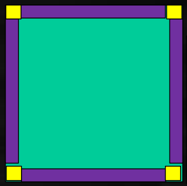
Result of laser scan

Parasitic production with g-2 sensors
7 mm cell, single, 320 μm thickness
Position reconstruction with laser

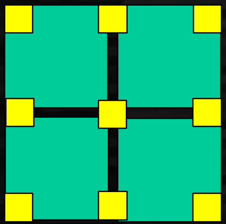
Low dynamic range of ~20%
→ need improvements

2nd gen (2018)

Dedicated for PSD
4 x 4 cells, 5.5 mm cell size,
650 μm thick, resistive split
with two methods of
P+ mesh and dedicated
resistive layers tried



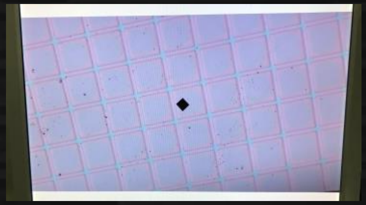
Low-R edge

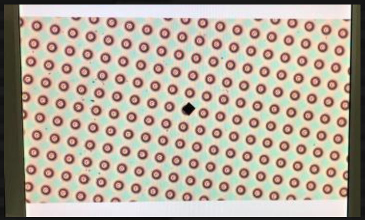


Sharing pads

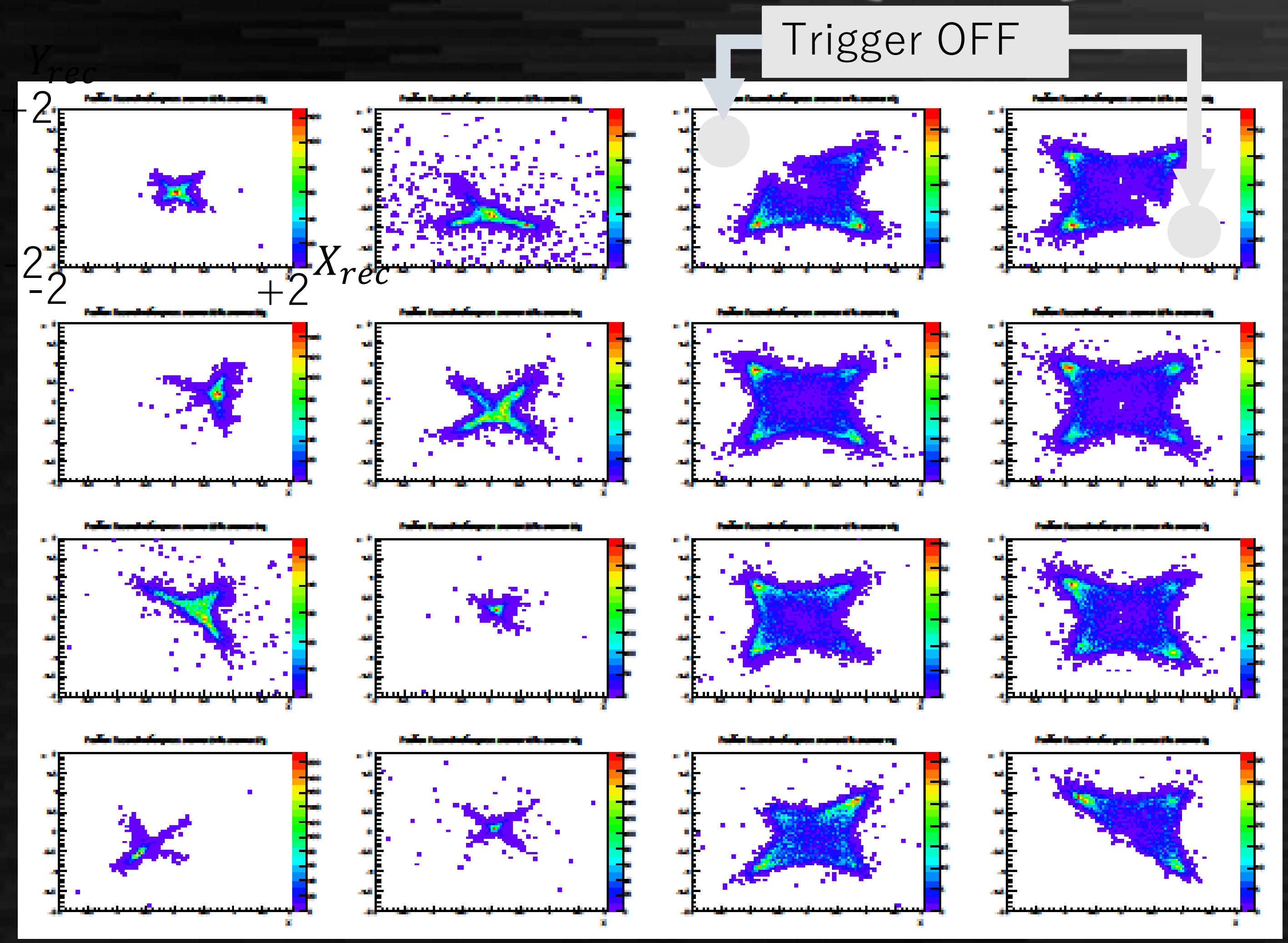
Measurements in 2019 (^{90}Sr)

PSD (normal)
P+ mesh (left)
R layer (right)





R layer has 10x resistivity to P+ mesh



Good dynamic range confirmed with R layer

Beam test at 2019 for PSD

- Measurements with SKIROC2A testboard prepared
  → Failure at half-month before the testbeam
  → Substituted with SKIROC2CMS testboard
    - Higher noise (SKIROC2CMS not aimed for MIP self trigger)
    - Threshold tuning is too rough
    - Seen RI signal at lab in Kyushu
- MIP is not seen because of higher noise at beam line
  - Measured with triggering with scintillator
  - Too high noise for realistic investigation
  - (Priority put on LGAD which was somewhat working)
- Will do again this FY with improved setup

Improvements of setup

- Tracking sensors (common to LGAD)
  - 1 x 1 mm cell sensors (to ensure particle passing PSD)
  - Strip sensors (for position resolution studies)
- FEV13 will be used instead of testboard
  - Many demonstration for SiW-ECAL (S/N ~ 20)
    - Issued on some channels exist with testboard of SKIROC2A
  - Measuring multiple PSD at once
    - 256 ch readout by 4 ASICs (for 4 PSDs)
- Noise reduction (shielding)
  - Will use shield box covering sensor and electronics

Purpose and program at ELPH (PSD)

1. Measurement of position resolution
   - 1 mm cell sensors and PSDs to confirm position reconstruction
   - Strip sensors and PSDs to measure detailed position resolution
   - PSDs with 3-types, 10 parameters

Due to limited availability of ELPH,
we have only approved with 12 hrs x 2 shifts this year
shared with ALICE SiECAL team (Tsukuba)

Beam time is expected in February 2021

Things to do before TB

- Preparing FEV13 for sensor connection
  - First assembly with 1 ASIC done, not tested yet
- Preparing adapter PCBs
  - Design ongoing
- Assembly, wire-bonding for strips (Oct. – Nov.)
  - Mainly plan to use anisotropic conductor sheets
  - Wire bonding at Kyushu
- Test with RI and laser (Nov. – Dec.)
- Mechanical structure (Oct.-Dec.)
- Preparation for beam test analysis (Dec.-Feb.)
  - Have to be prepared for instant analysis in short beam time

Development schedule

Microsoft Excel

ƒ[ƒNƒV[ƒg

Schedule for sensor production

- 2020
  - 8 inch sensors (small production or test sample)
- 2021
  - 8 inch sensors (small production)
  - LGAD (production ①)
  - PSD (compatible with prototype)
- 2022
  - 8 inch sensors (quasi-final specification) ~100
  - PSD (quasi-final specification) ~10
- 2023
  - 8 inch sensors (repeat) ~1000, PSD (repeat) ~100枚
  - LGAD (quasi-final specification)

Schedule at construction

<table>
<tr><th></th><th colspan="4">Y1</th><th colspan="4">Y2</th><th colspan="4">Y3</th><th colspan="4">Y4</th><th colspan="4">Y5</th><th colspan="4">Y6</th><th colspan="4">Y7</th><th colspan="4">Y8</th><th colspan="4">Y9</th></tr>
<tr><td></td><td>Q1</td><td>Q2</td><td>Q3</td><td>Q4</td><td>Q1</td><td>Q2</td><td>Q3</td><td>Q4</td><td>Q1</td><td>Q2</td><td>Q3</td><td>Q4</td><td>Q1</td><td>Q2</td><td>Q3</td><td>Q4</td><td>Q1</td><td>Q2</td><td>Q3</td><td>Q4</td><td>Q1</td><td>Q2</td><td>Q3</td><td>Q4</td><td>Q1</td><td>Q2</td><td>Q3</td><td>Q4</td><td>Q1</td><td>Q2</td><td>Q3</td><td>Q4</td><td>Q1</td><td>Q2</td><td>Q3</td><td>Q4</td></tr>
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<tr><td>budget (M$)</td><td colspan="4">49.61</td><td colspan="4">28.02</td><td colspan="4">23.59</td><td colspan="4">12.78</td><td colspan="4">2.87</td><td colspan="4">0.02</td><td colspan="4"></td><td colspan="4"></td><td colspan="4"></td></tr>
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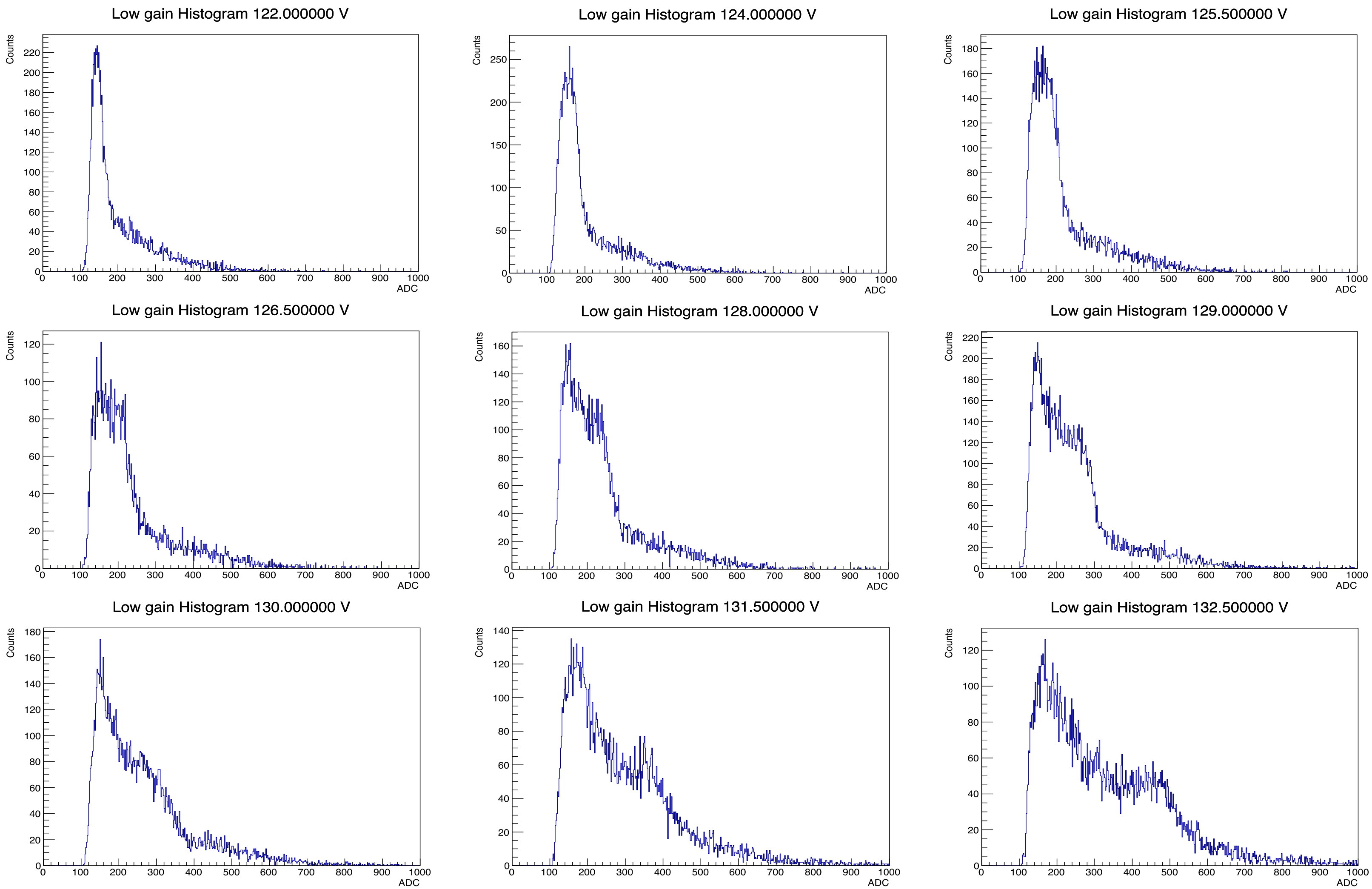
- Y1~Y4 for sensor production
  - 2026-28 assuming construction start at 2026
  - Silicon pad: ~2000 m^2
  - LGAD (if approved): 100-300 m^2
  - PSD (if approved): 100-300 m^2

Backup

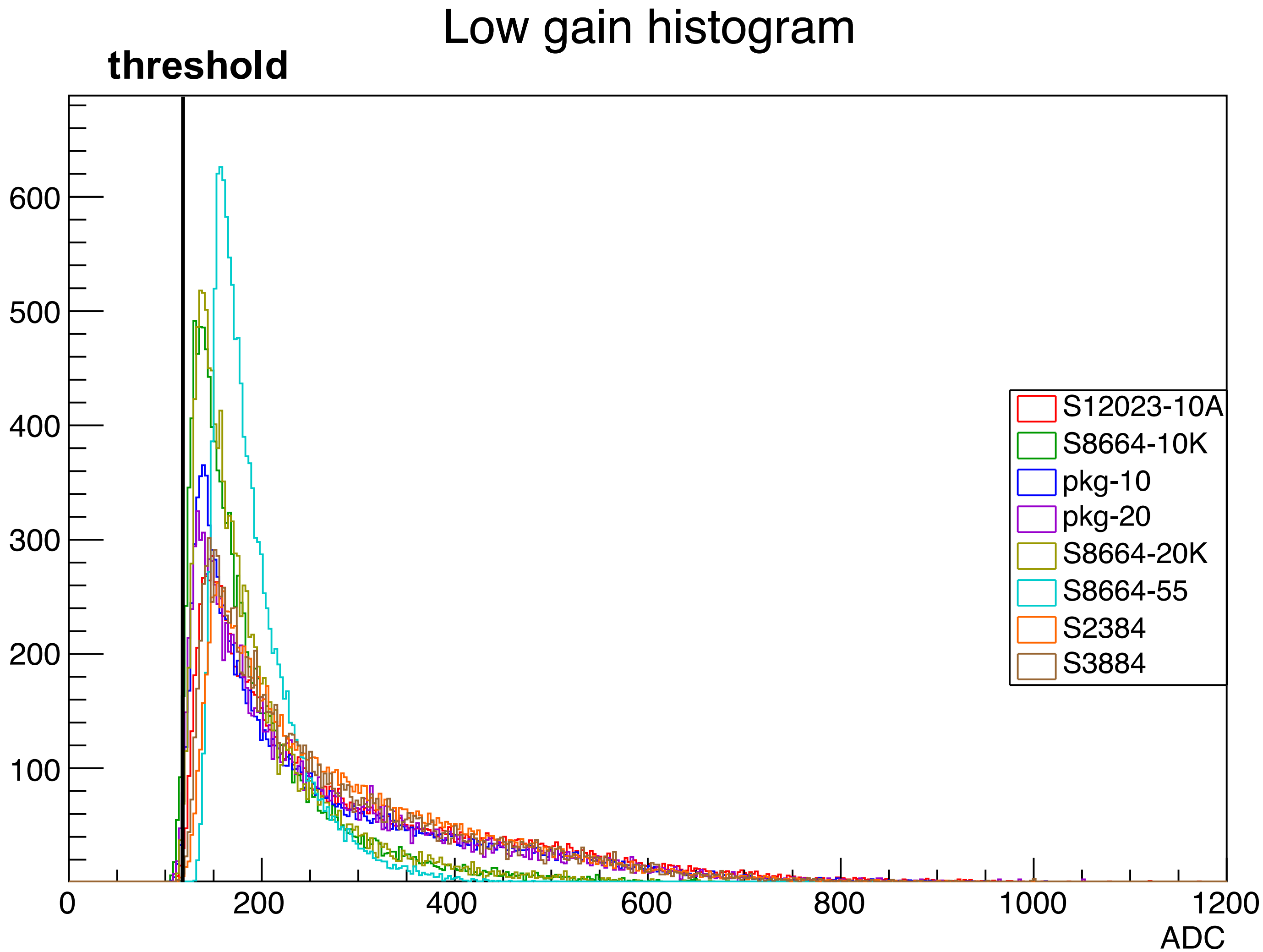
放射線源を用いた測定

➤ ガンマ線でのGain測定

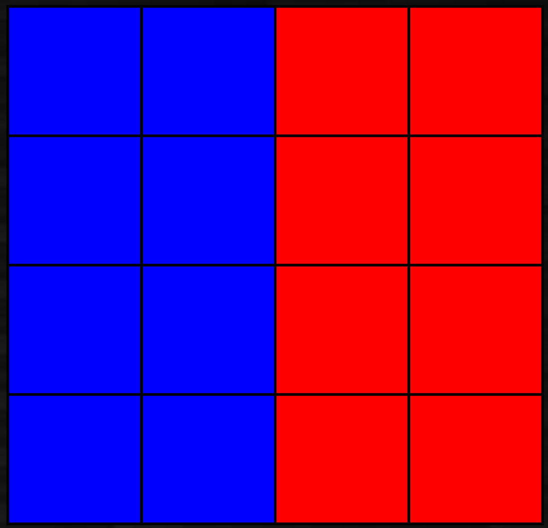


放射線源を用いた測定

➢ 各APDのADC分布 (Low gain)

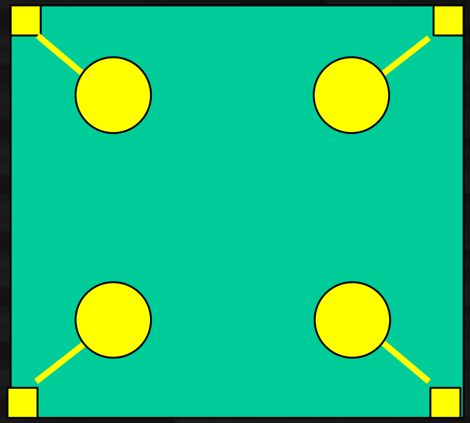


PSD: 仕様1-1



通常の(透明?)抵抗体ベタ
(またはグリッド)による分割

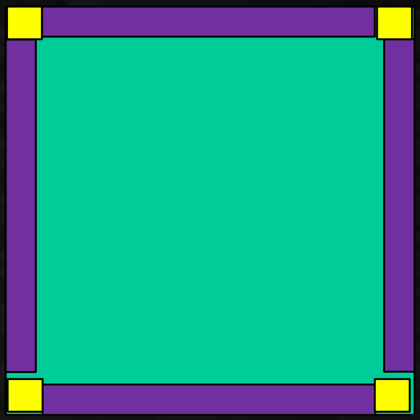
青部分: 抵抗値小(前回P+ gridと同程度)
赤部分: 抵抗値大(青の10/20/30倍程度)



読み出しパッド: 端部に最小の電極を設け
接続用パッドにつなぐ
接続用パッド: 0.5 mm φ, 辺から1mm程度
の位置 (端部でのdistortionを測るため)
パッドは0.5 mm□でも可

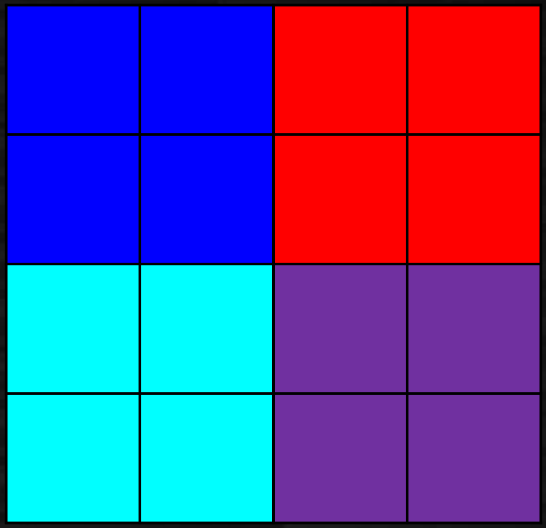
P+ pitch: 100 or 50 μm

PSD: 仕様1-2



面部は1-1と同じ
端部に低抵抗のラインを設置

中心に入射した場合の$R_{surface}$とR_{edge}の比が
青, 赤: 2程度
水色, 紫: 5程度



合計抵抗が
青, 水色: 前回P+ gridと同程度
赤, 紫: 上記より高め(可能であれば10倍)

その他の仕様は1-1と同じ

PSD: 仕様2-1

- 2-1: 1-2と同様
  低抵抗部分とパッドは
  隣のセルと共有
  - パッドは端部でOK
  - 1-2の青, 水色仕様
    を半々で