AC-LGAD Progress Report

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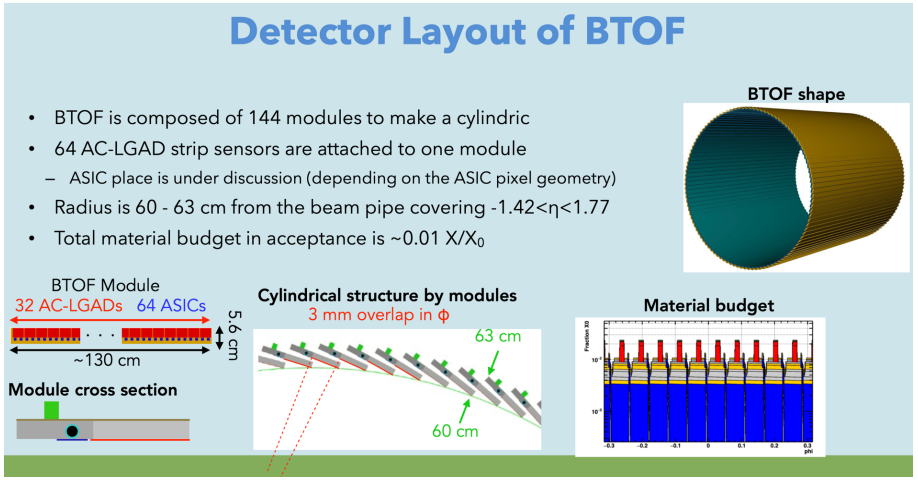
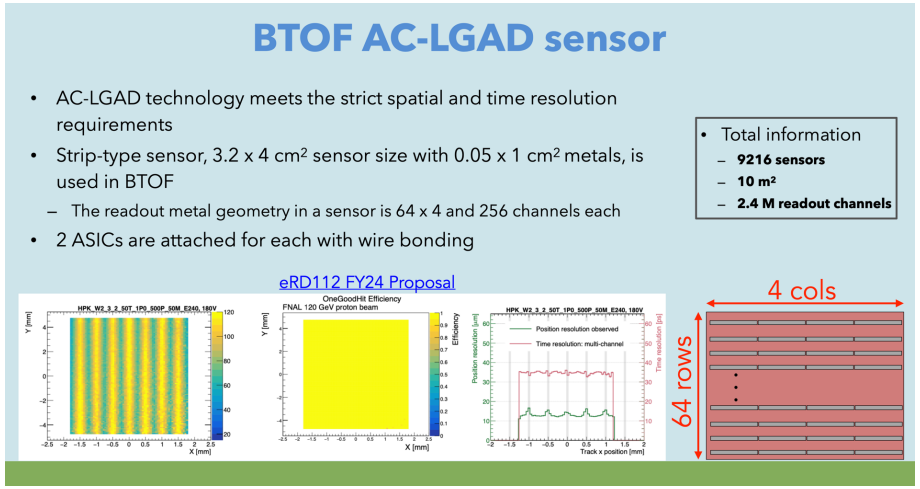
Motivation

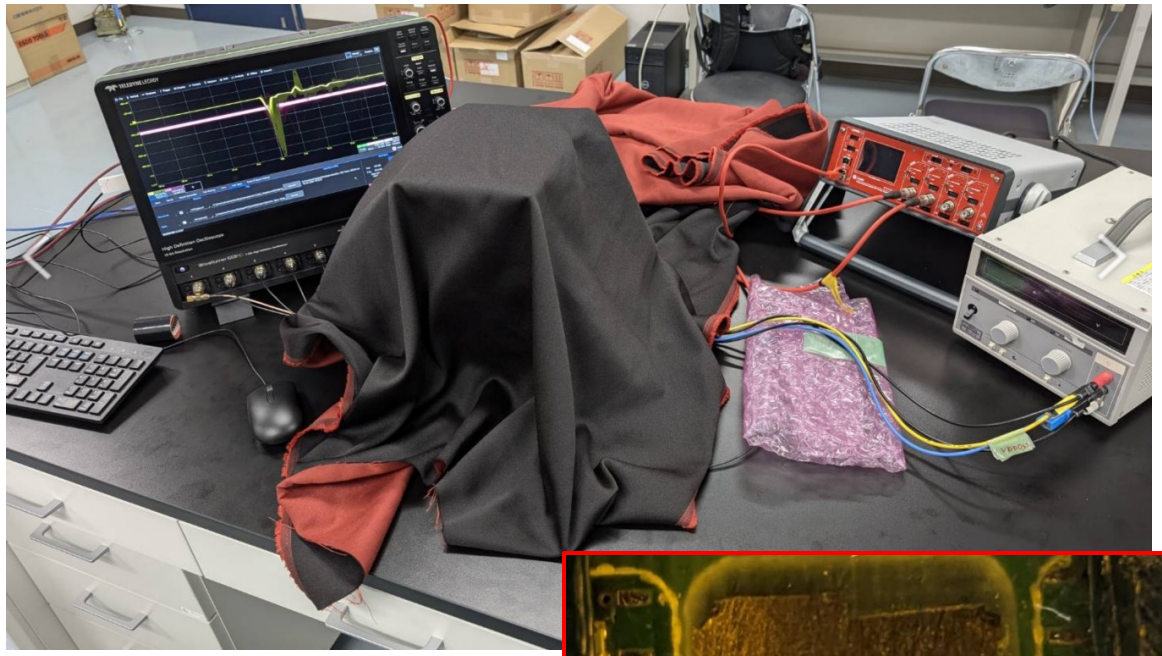
- Development for installation in ePIC experimental TOF detector
  - ✓ Achieve ~30 ps timing resolution and ~30 μm spatial resolution
  - ✓ Study the temperature dependence of sensor performance
    - ➢ A change of 1℃ results in a change of 1V
  - ✓ To enable accurate performance evaluation in a laboratory system

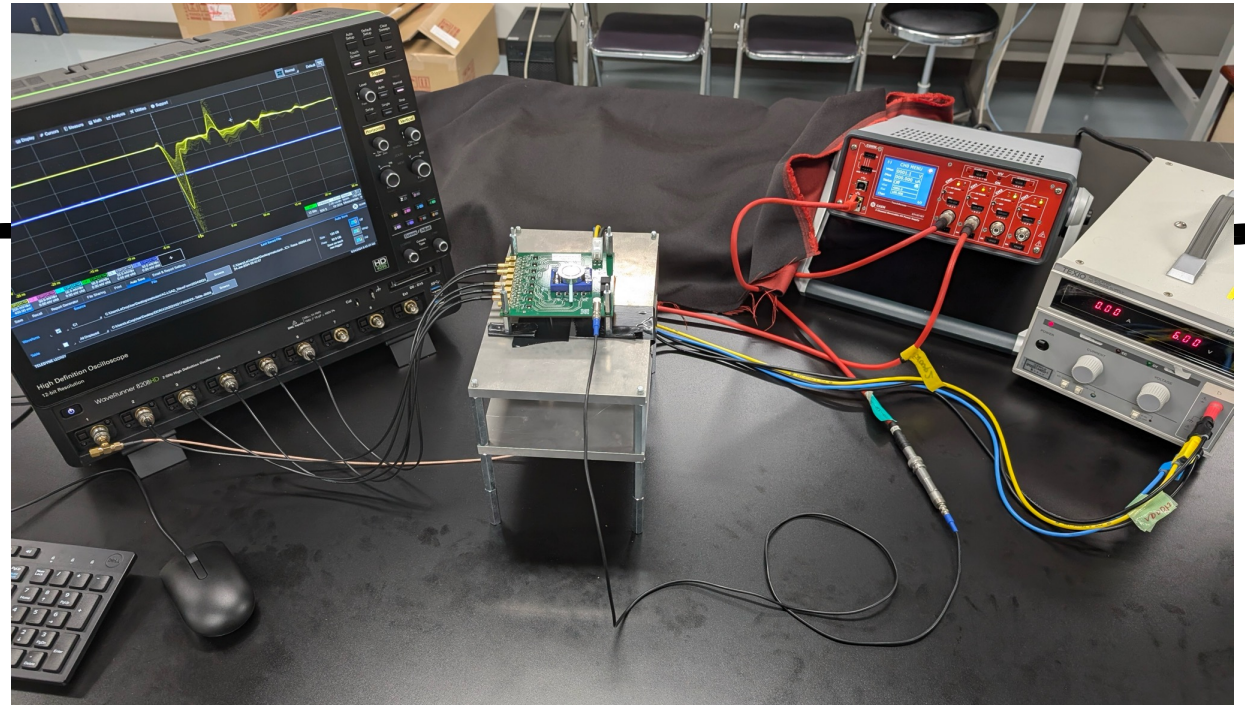


← Yano-san's slide →
(2024/06/24 EIC-asia meeting)

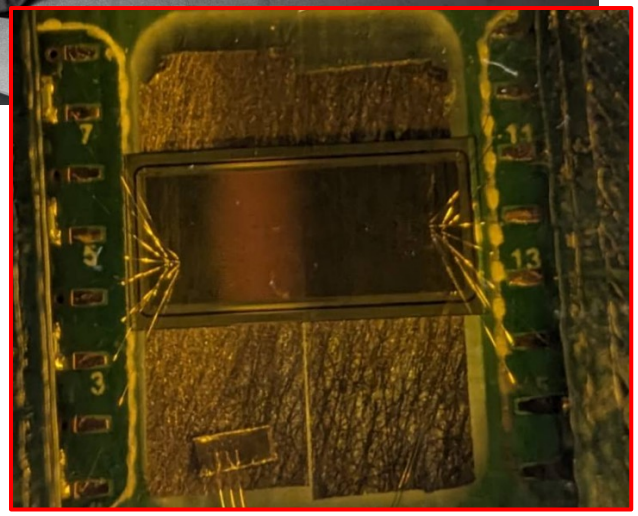


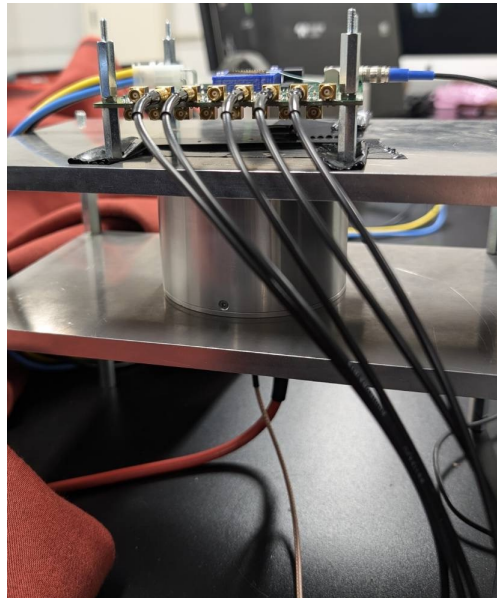
Testbench

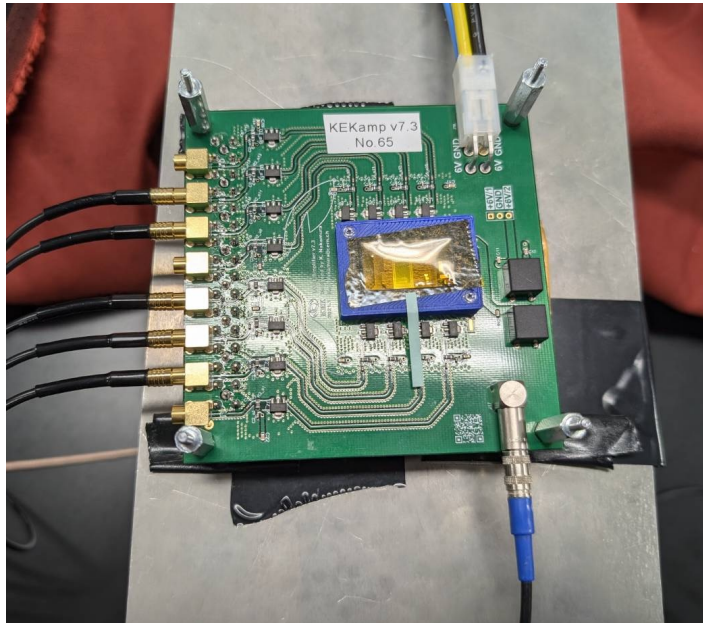




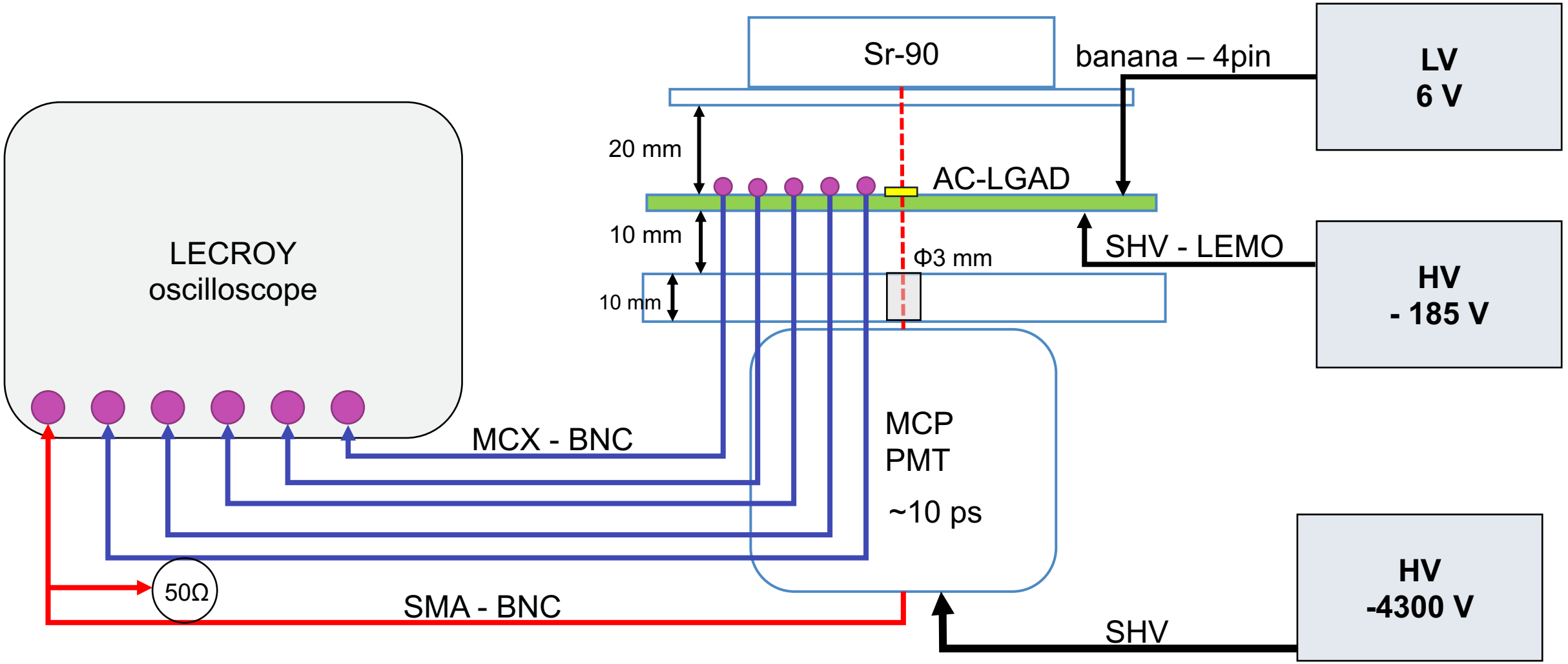
Stripe-type AC-LGAD
from KEK(HPK) →



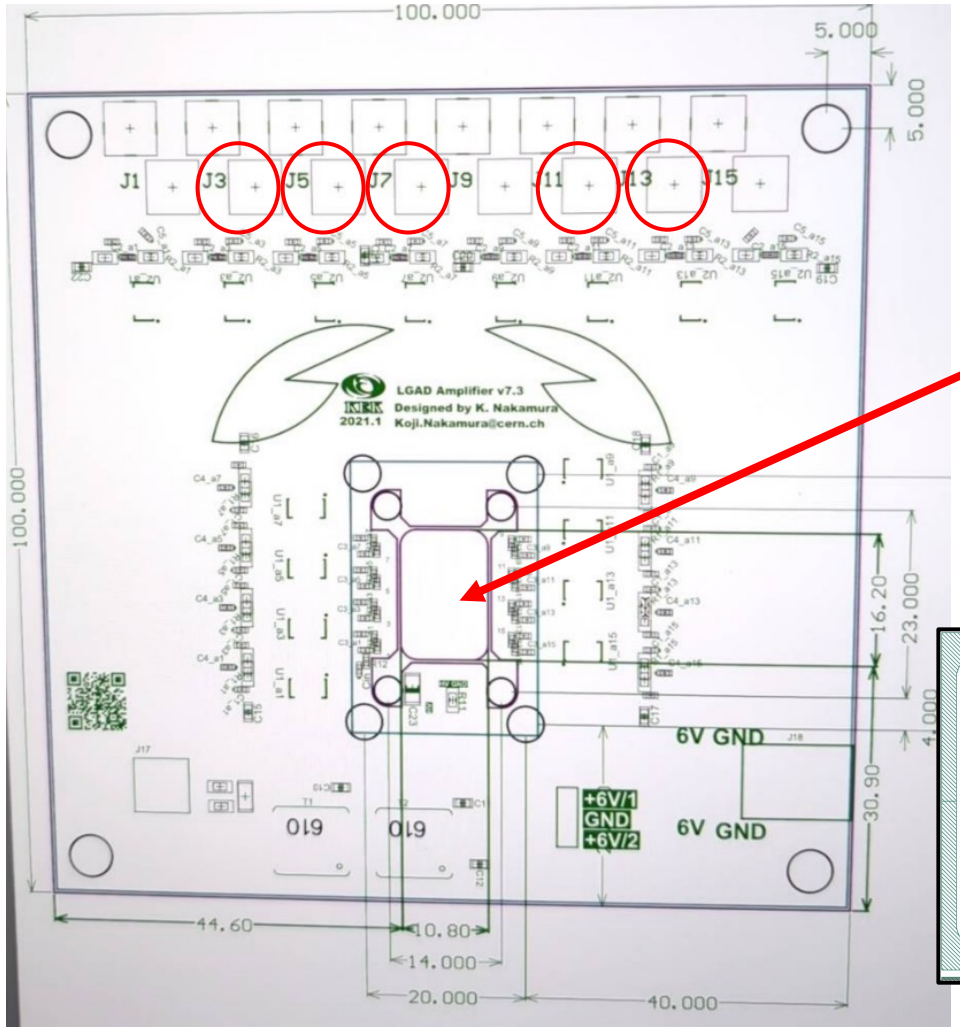




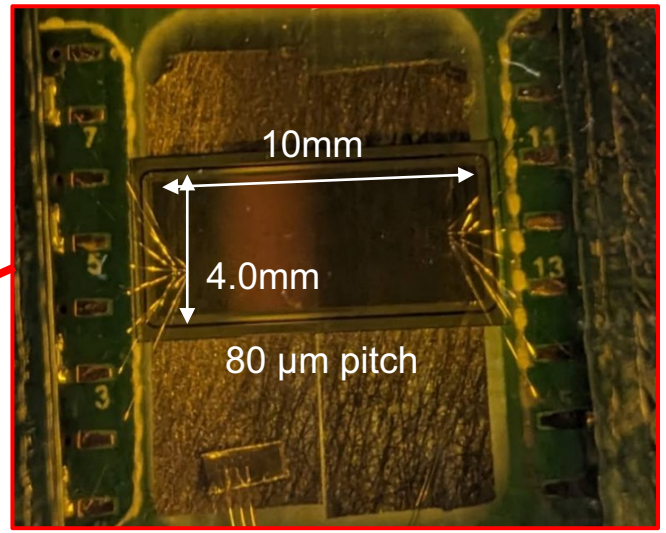
Experiment Setup

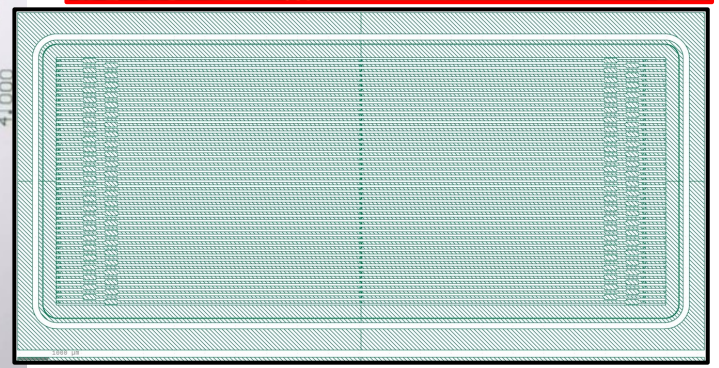


Select AC-LGAD channel

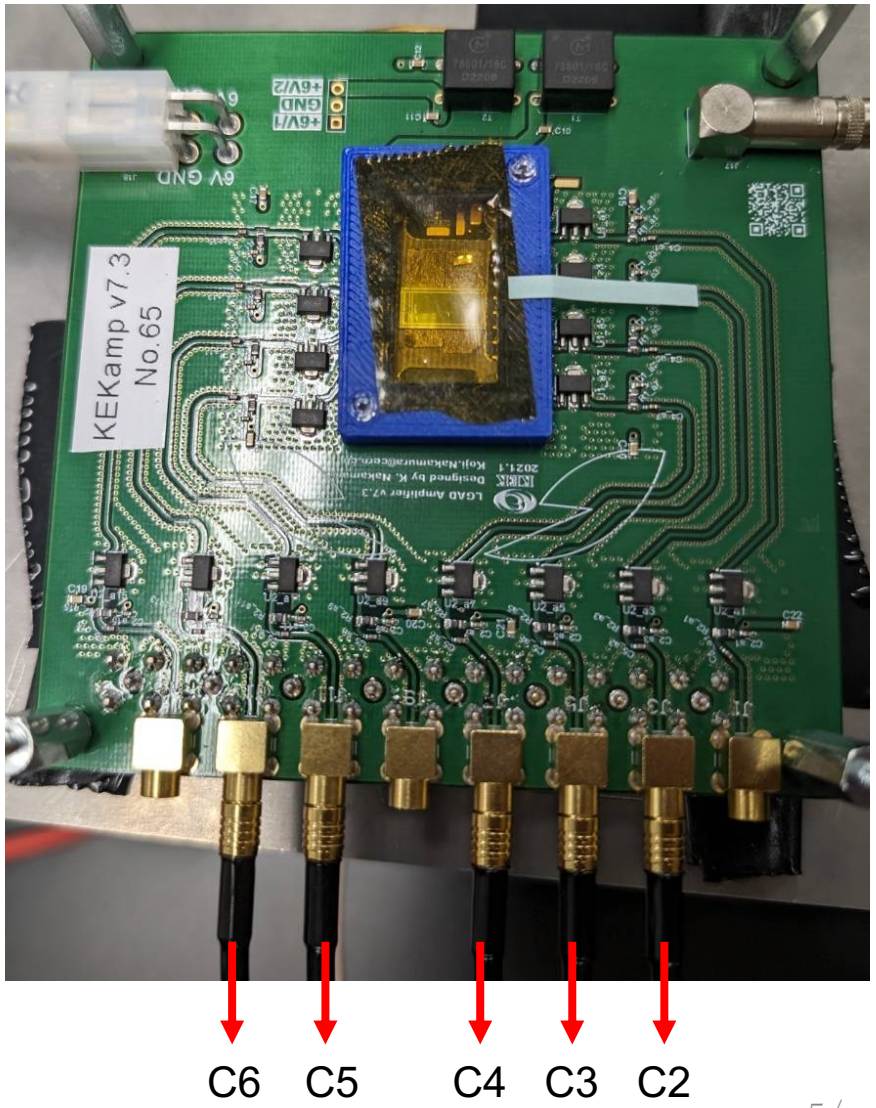


Wire-bonded AC-LGAD





50 stripes, 16 wire-bonded



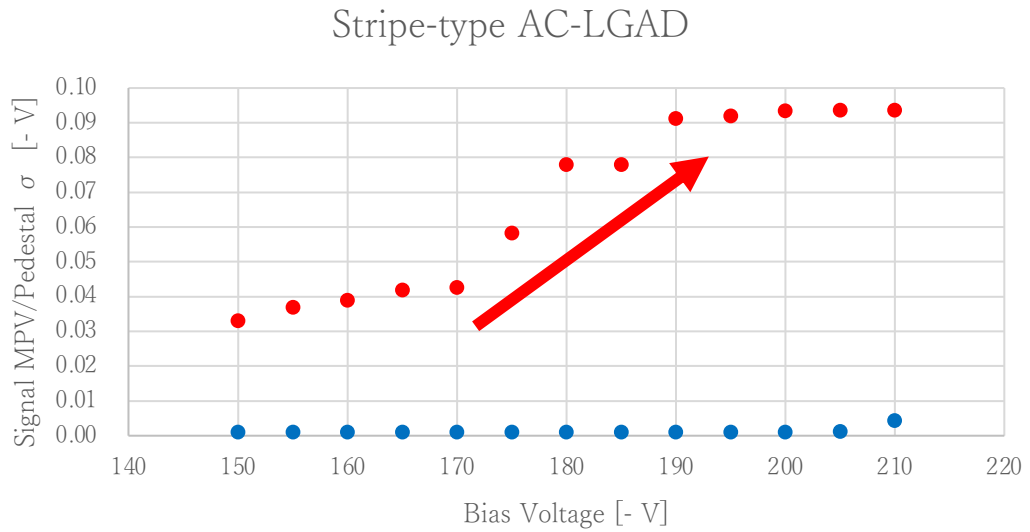
Current Result

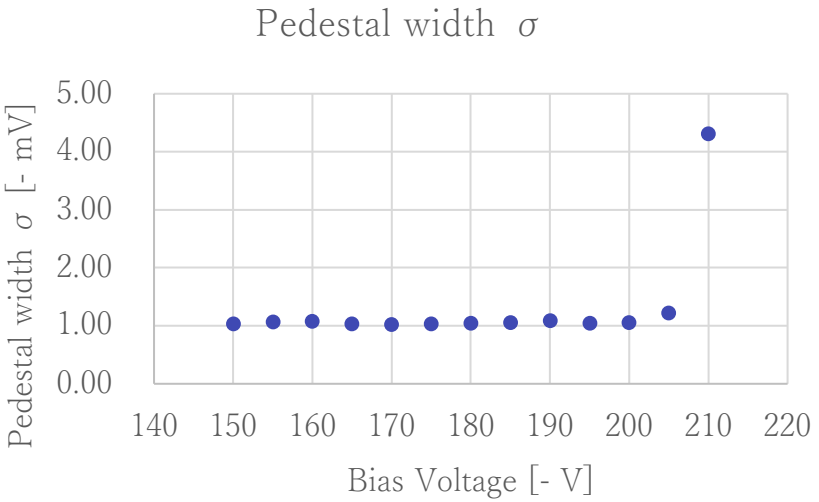
- Bias Voltage dependence
- V-I Correlation
- Checking each channel signal waveform
- Pulse Height Distribution
- Observation of charge sharing
- Discovery of feature of HPK AC-LGAD (Amp board of KEK)

Bias Voltage dependence

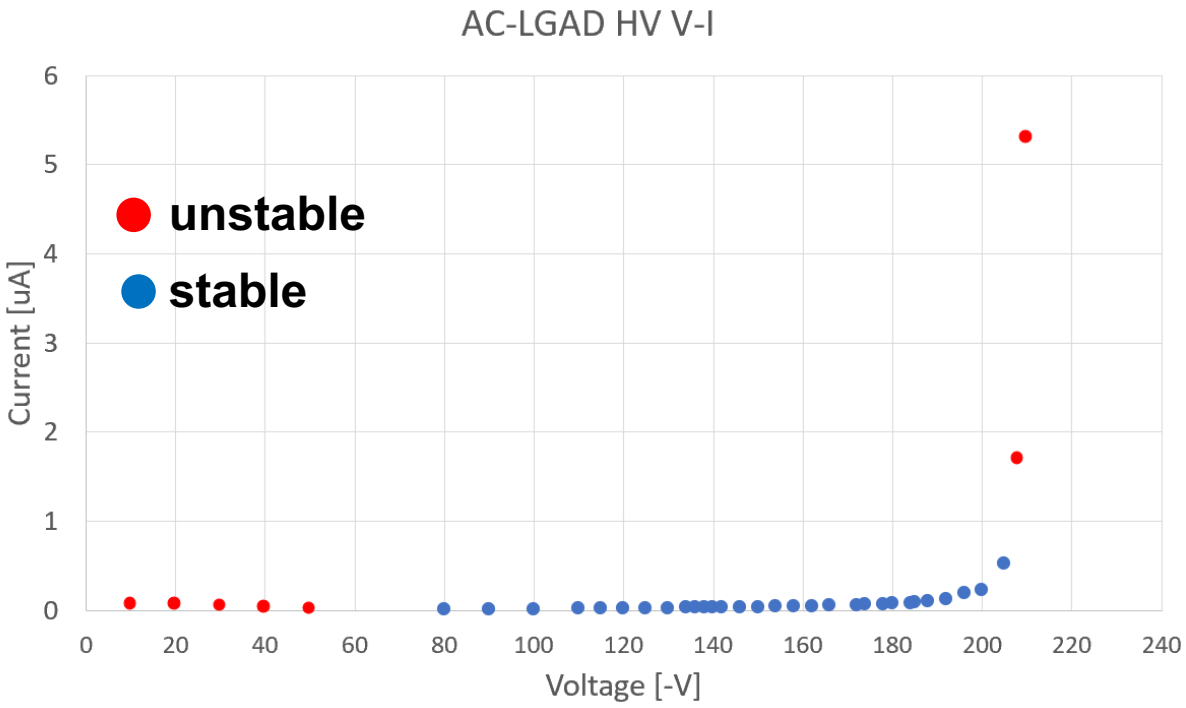
- Maximum Point Voltage
  - ✓ -170V -> -190V for large voltage increase
  - ✓ -190 V and thereafter almost constant value
- Pedestal width σ
  - ✓ Basically settled around -1.0 mV
  - ✓ Started to increase from -205V, and suddenly became greatly blurred at -210V

Other status
LV: 5.56V, 0.44A
Trigger: C2, -5.0 mV

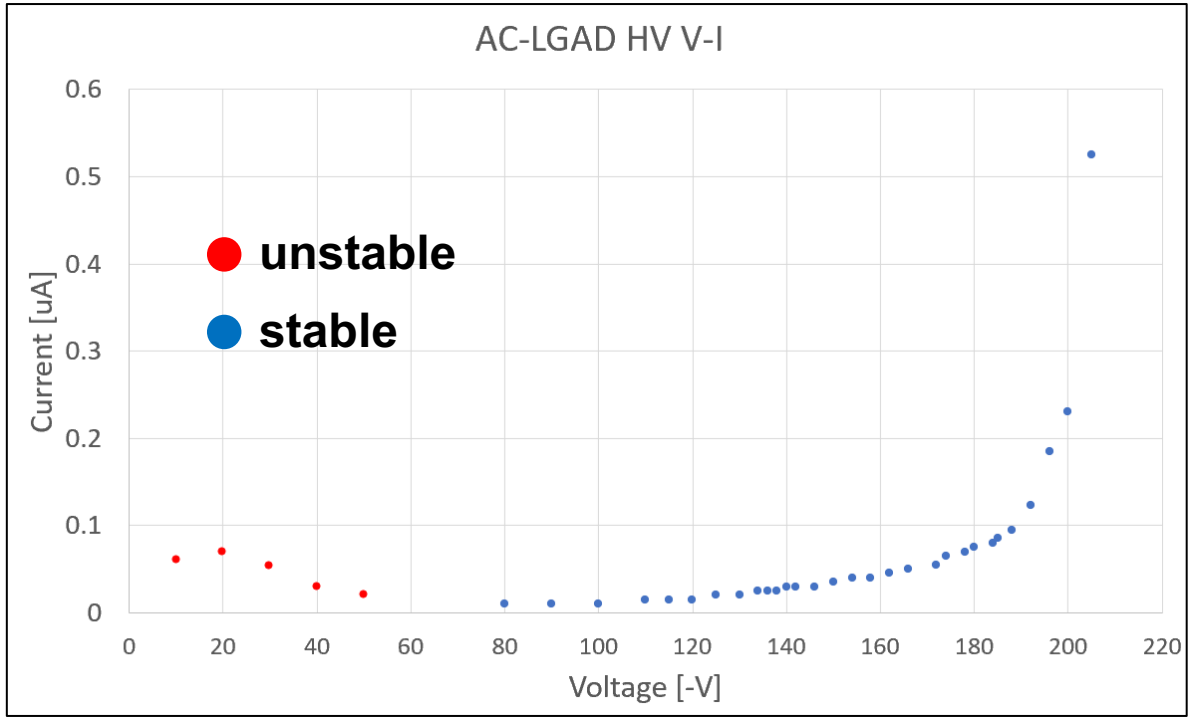




V-I Correlation



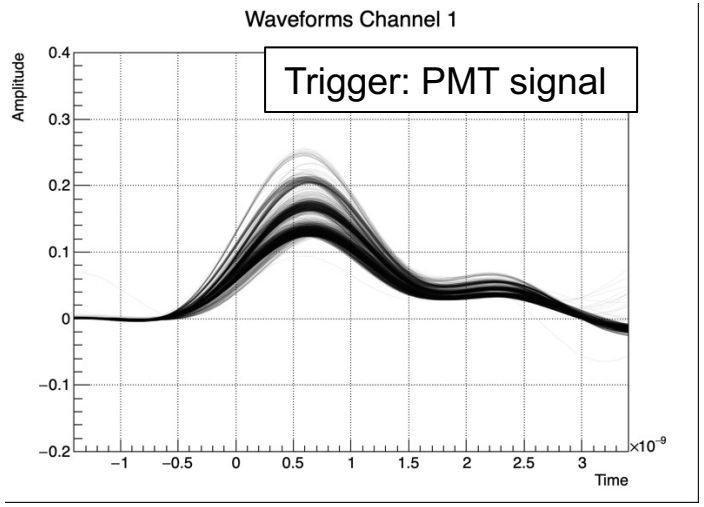
Zoom (0V -> -205V)

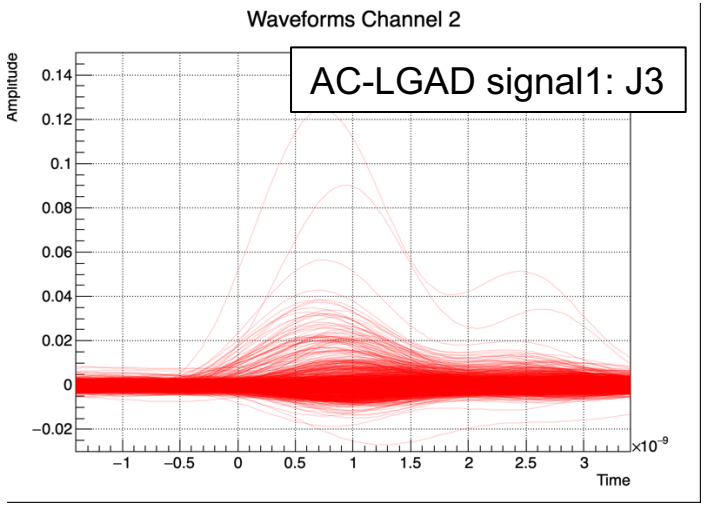


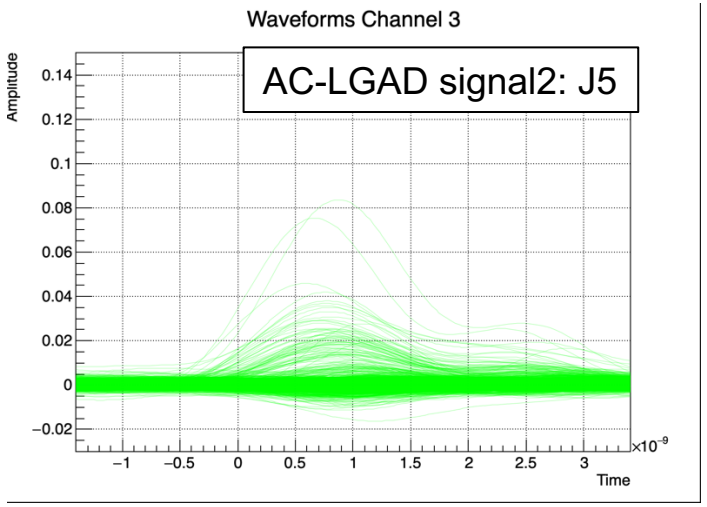
- Sharply increasing trend after -185V

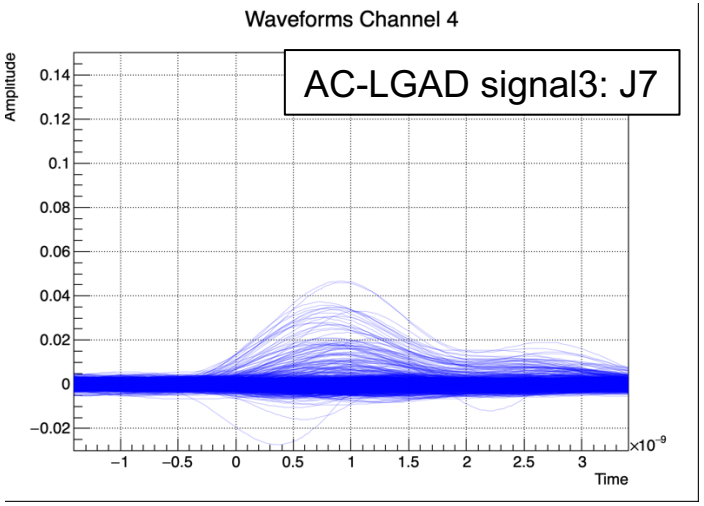
HV optimum value is determined to be -185 V

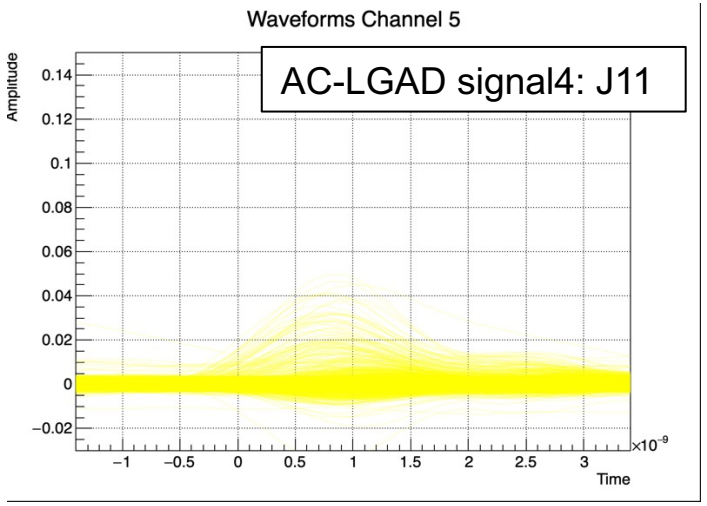
Each cannel waveform HV:-185V, 23°C

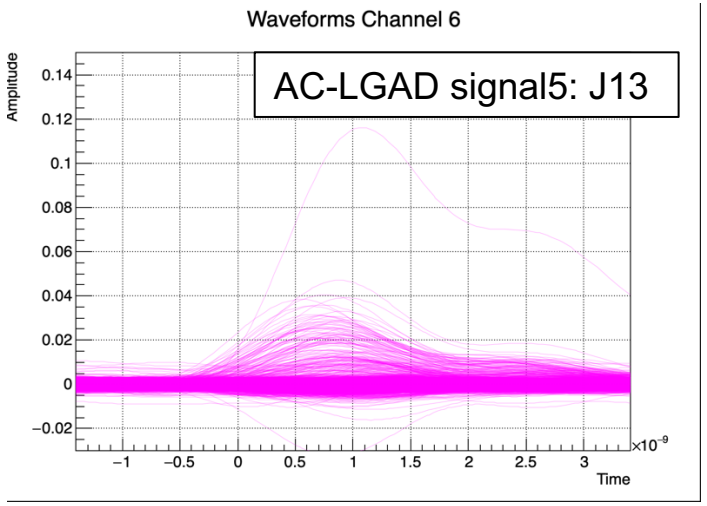




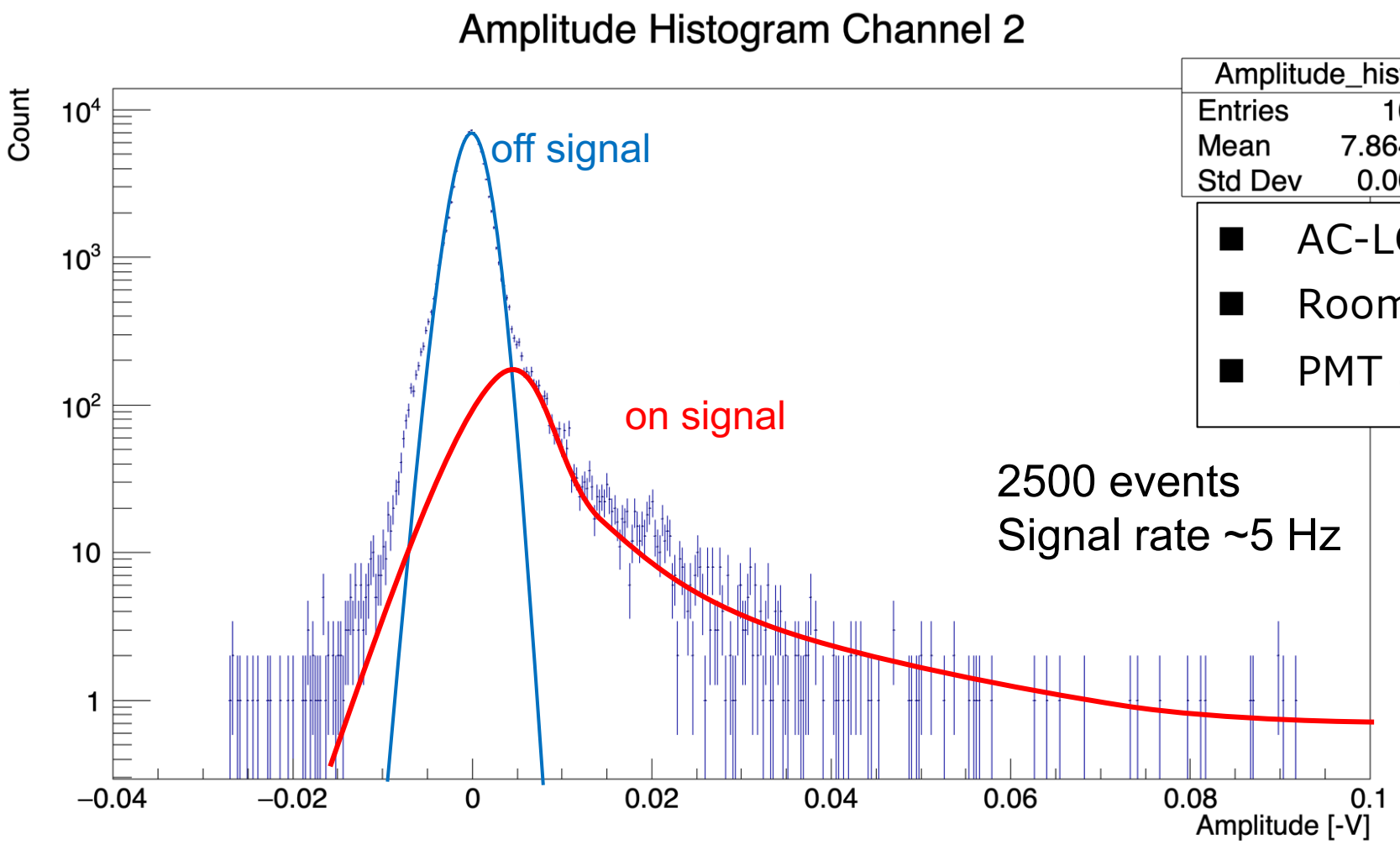




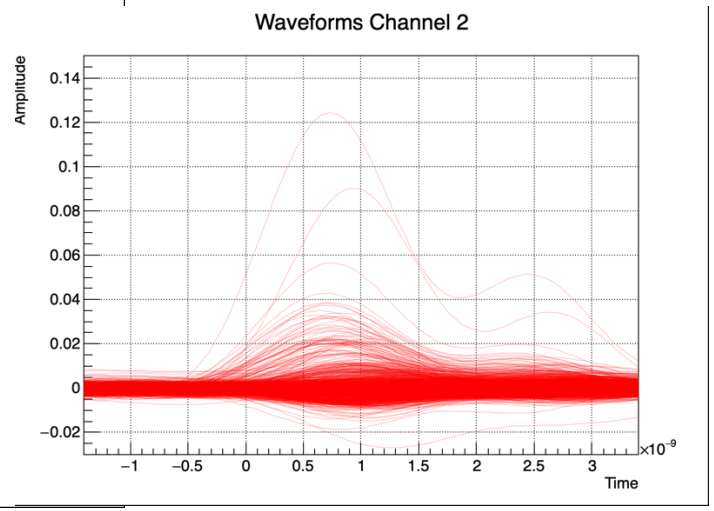




Pulse Height Distribution

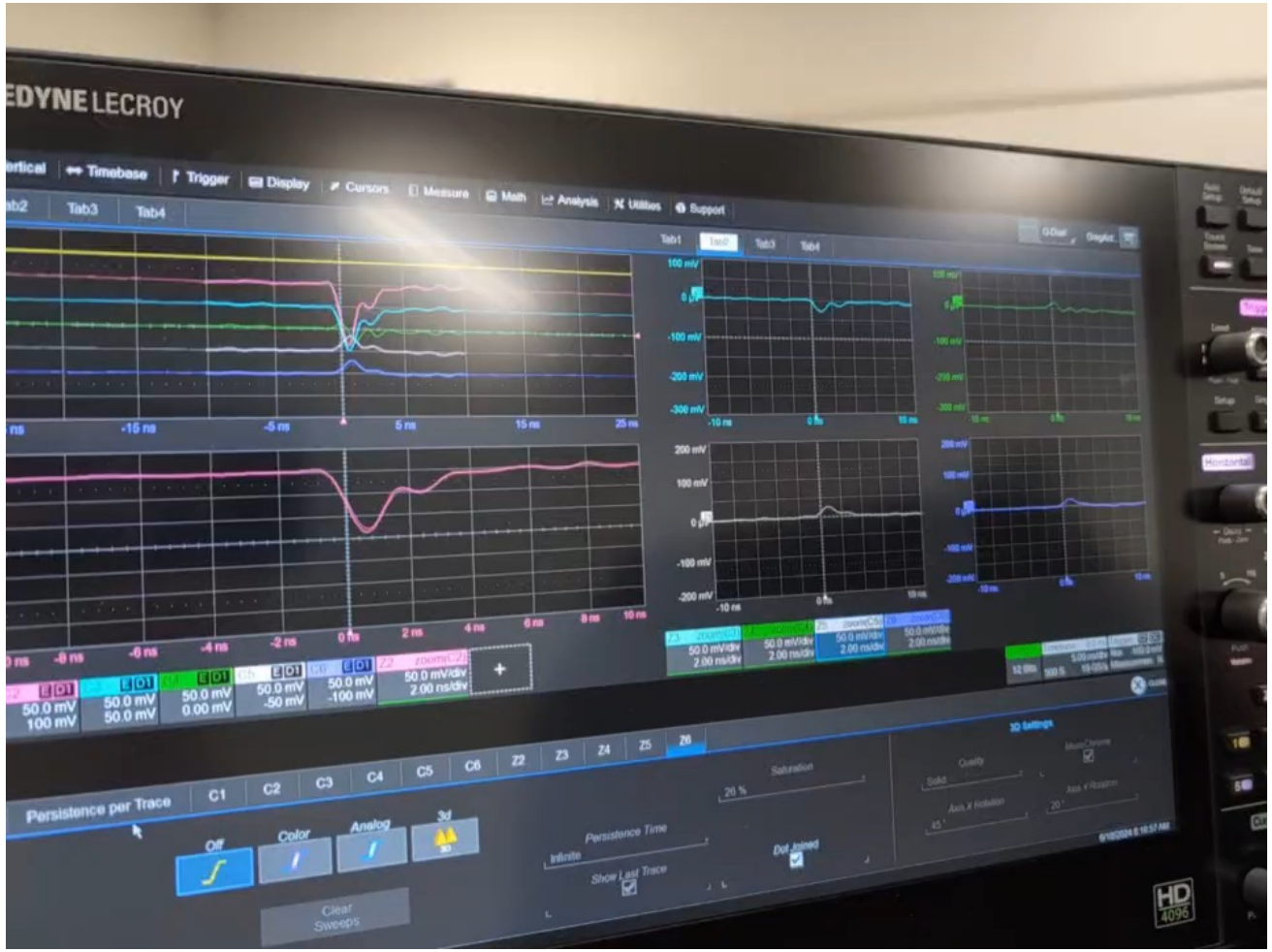


- AC-LGAD HV:-185V
- Room temperature: 23℃
- PMT signal threshold: -100 mV



Observation of charge sharing

Movie (trigger: C2 signal)



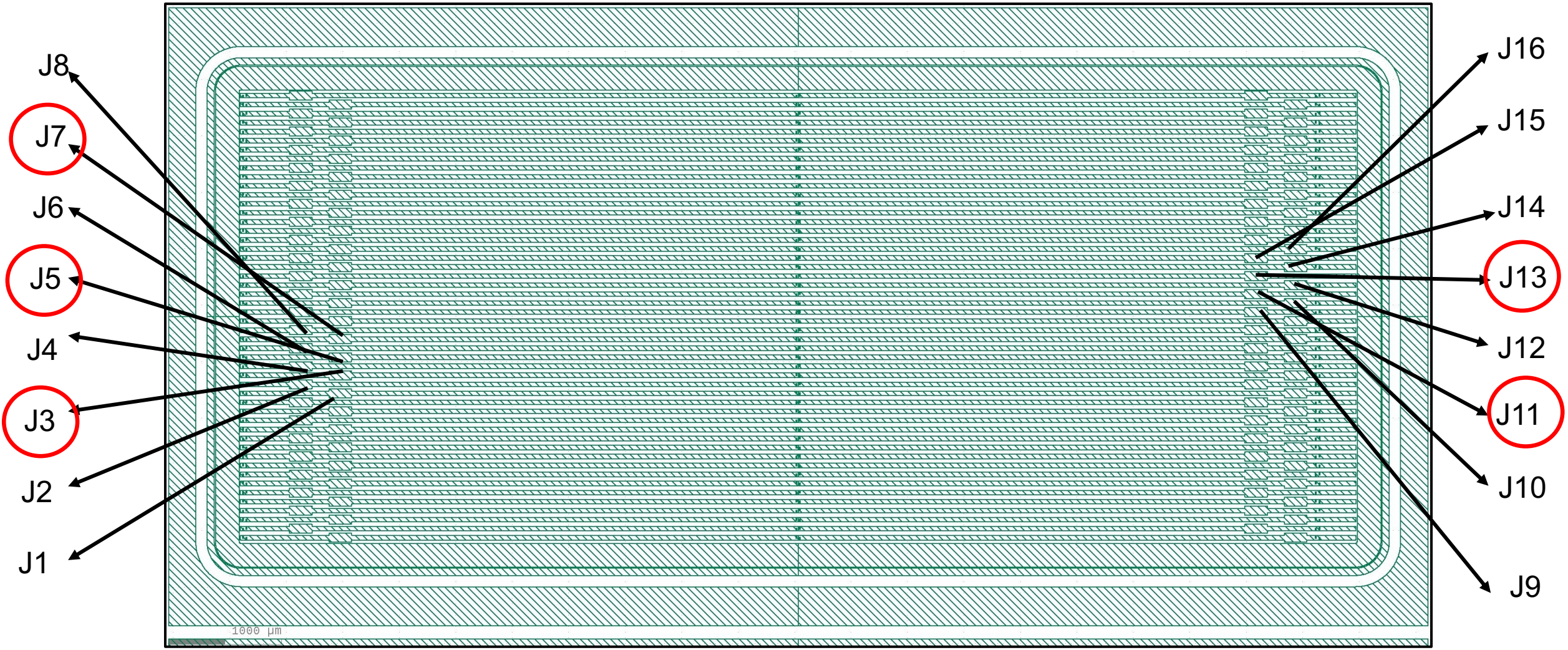
Trigger signal (PMT)

Trigger signal (PMT)

Weirdness of Waveforms

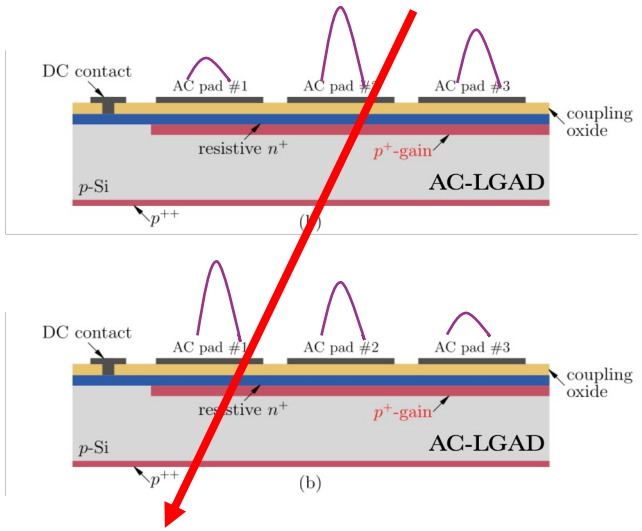
- The waveform of the channel that is wire-bonded on the opposite side to the trigger channel tends to be reserved.
- The reason for this is under investigation

Wire-bonded sensor



Next plan

- Signal Waveform Analysis
  - ✓ Calculate time resolution by reading values
- Measurement of temperature dependence
  - ✓ 1V change at 1°C (AC-LGAD HV)
- Trigger dependence
  - ✓ -100mV or -150 mV on PMT signal
- 10-20 BNL AC-LGADs will arrive
  - ✓ We can measure path length of decay electron



Summary

- Hiroshima Univ. started evaluating the performance of the strip AC-LGAD (from HPK) using a radioactive source.
  - ✓ 0.4x10 mm^2 strips with 80 μm pitch
- The dependence on bias voltage was evaluated
  - ✓ **The optimum HV is -185V**
- The signals(P/N) are different for each channel (but correlated)
- HU will evaluate the **temperature dependence** and **gain uniformity** of full-size sensor

Reference of this research

- arXiv:2207.07355
- https://tchou.tomonaga.tsukuba.ac.jp/events/20/201130/06.pdf
- R&D of 4D Detectors with EICROC and AC-LGAD at EIC consolidating a US-Japan Consortium

Backup

Time resolution

$$\sigma_t^2 = \sigma_{tw}^2 + \sigma_j^2 + \sigma_L^2$$

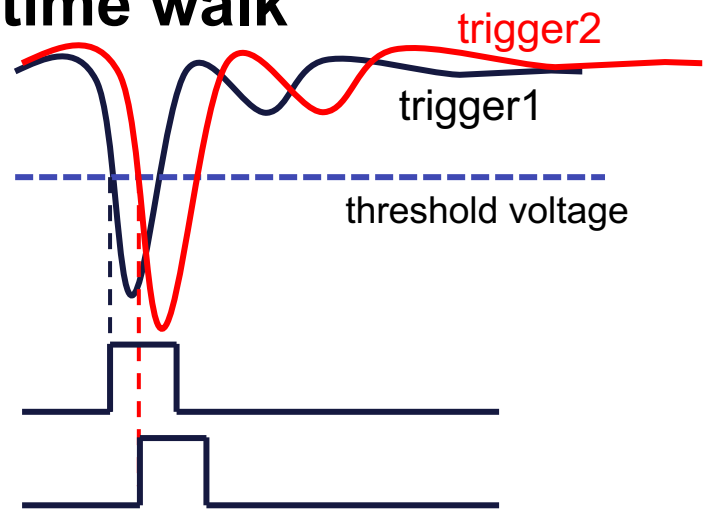
σ_t: $time\ resolution$

σ_{tw}: $time\ walk$

σ_j: $time\ jitter$

σ_L: $Landau\ noise$

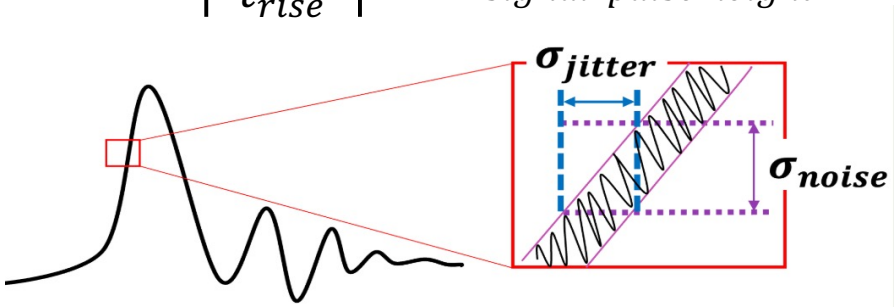
time walk



time jitter

$$\sigma_j = \frac{\sigma_{noise}}{\left|\frac{signal}{t_{rise}}\right|}$$

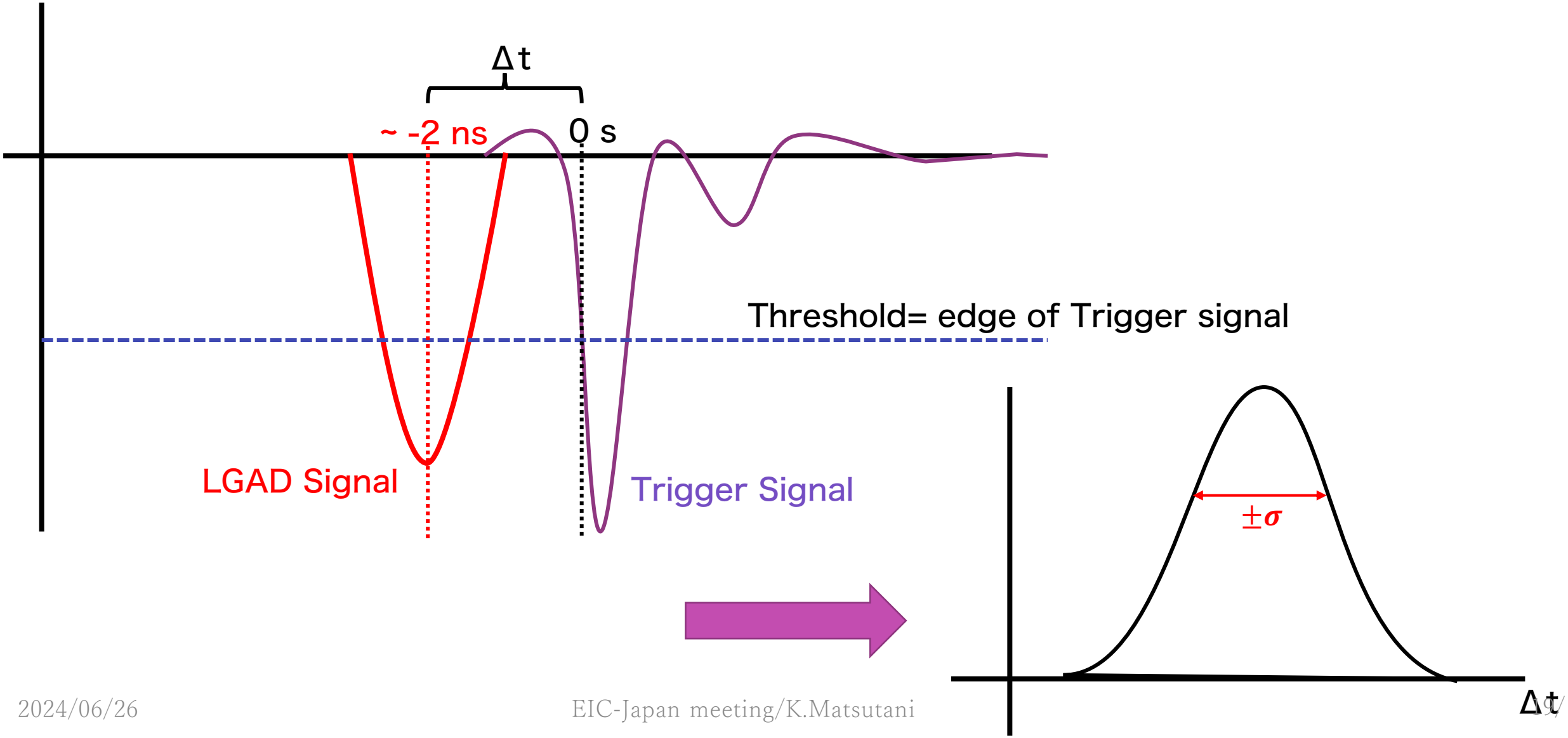
σ_{noise}: $noise\ width$
t_{rise}: $rise\ time$
$signal$: $palse\ height$



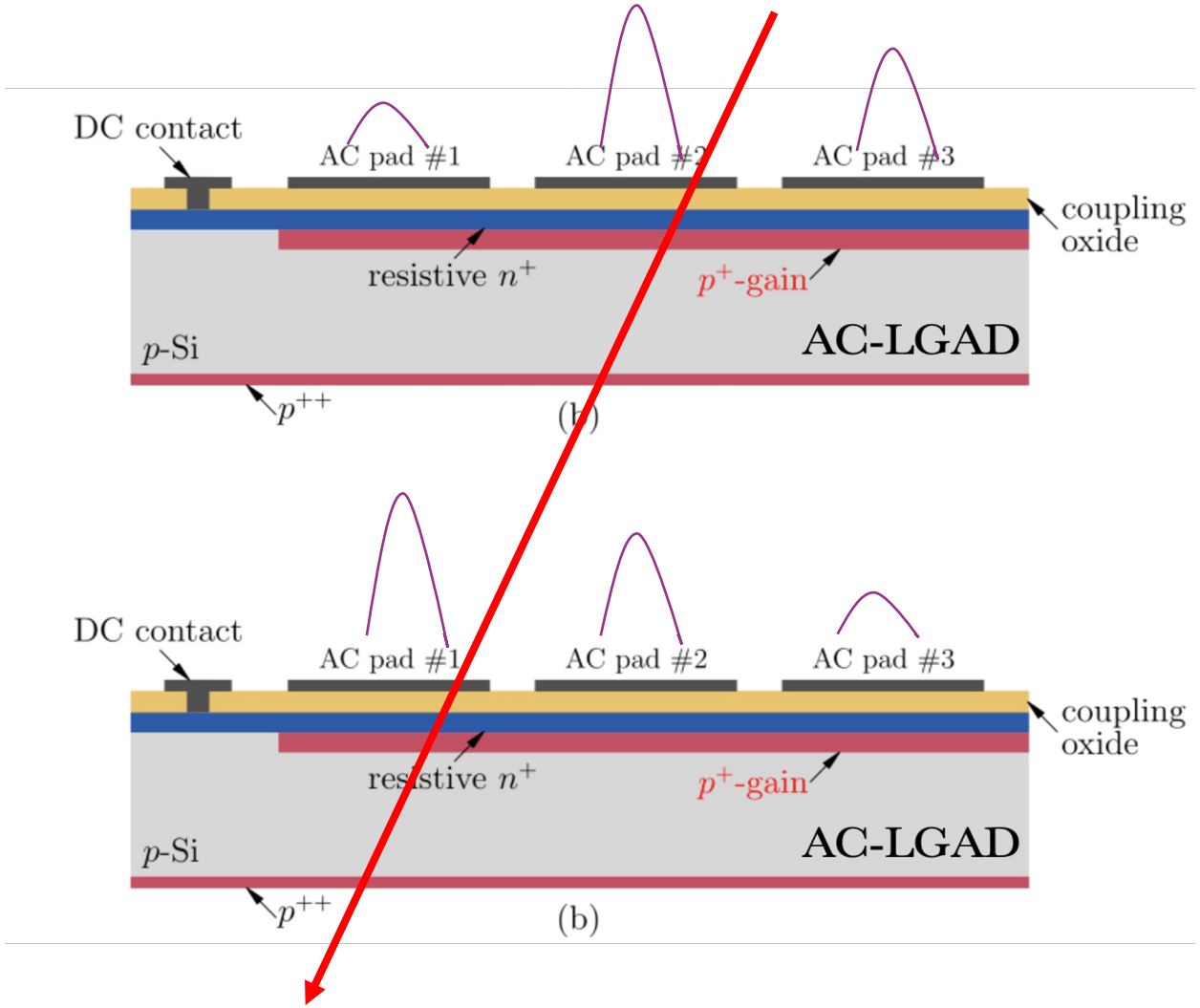
Landau noise

Noise due to statistical distribution in energy deposition by incident electrons.

Time resolution σ measurement

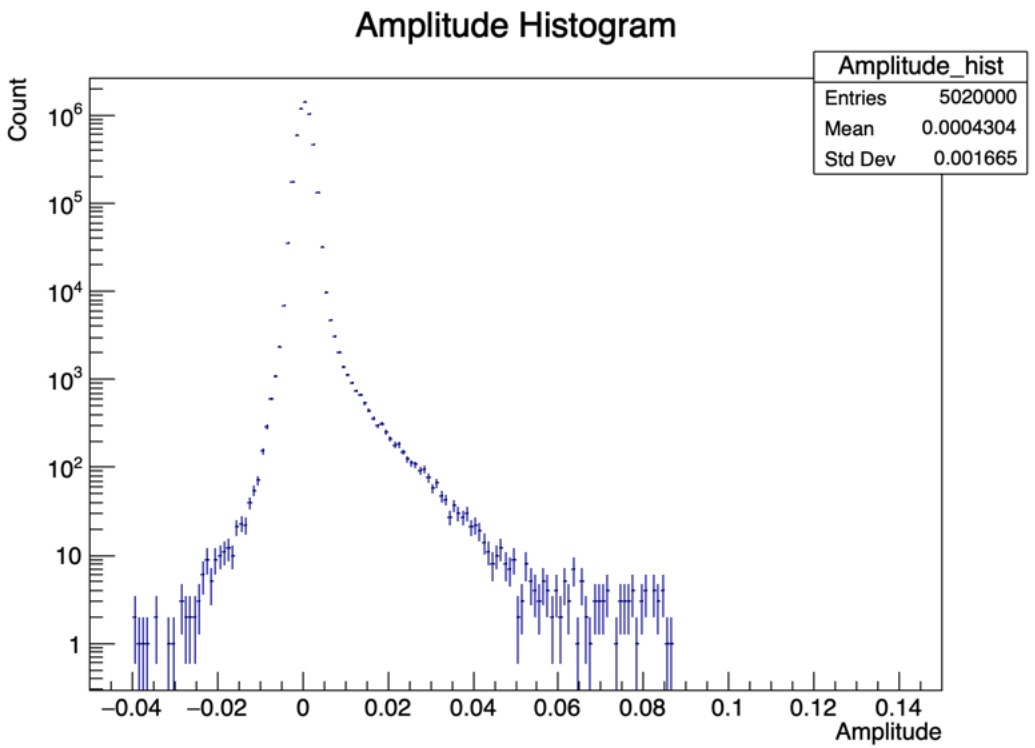


Path length using multi AC-LGADs

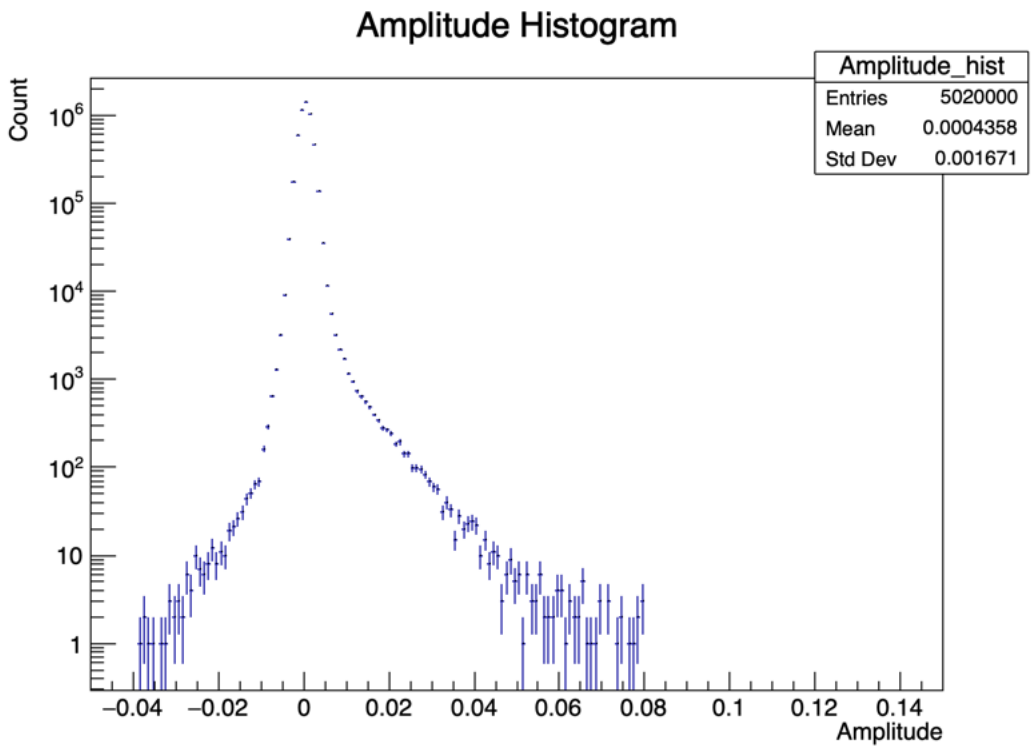


Trigger dependence; Bias Voltage: -185 V

Trigger:-40mV PMT signal

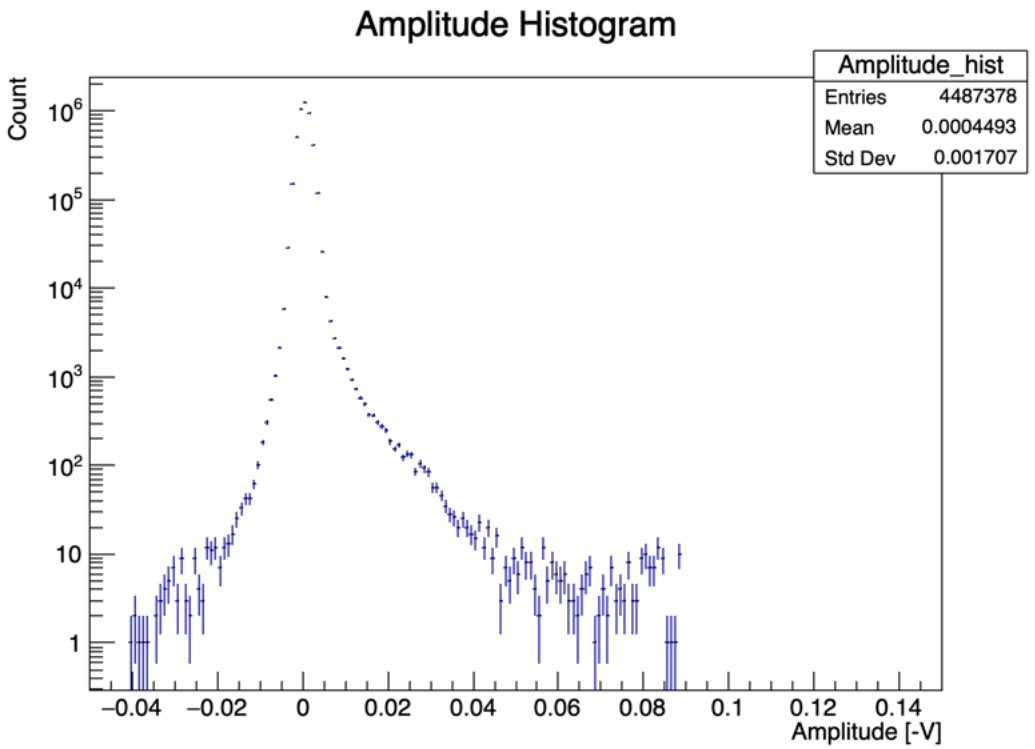


Trigger: -80mV PMT signal

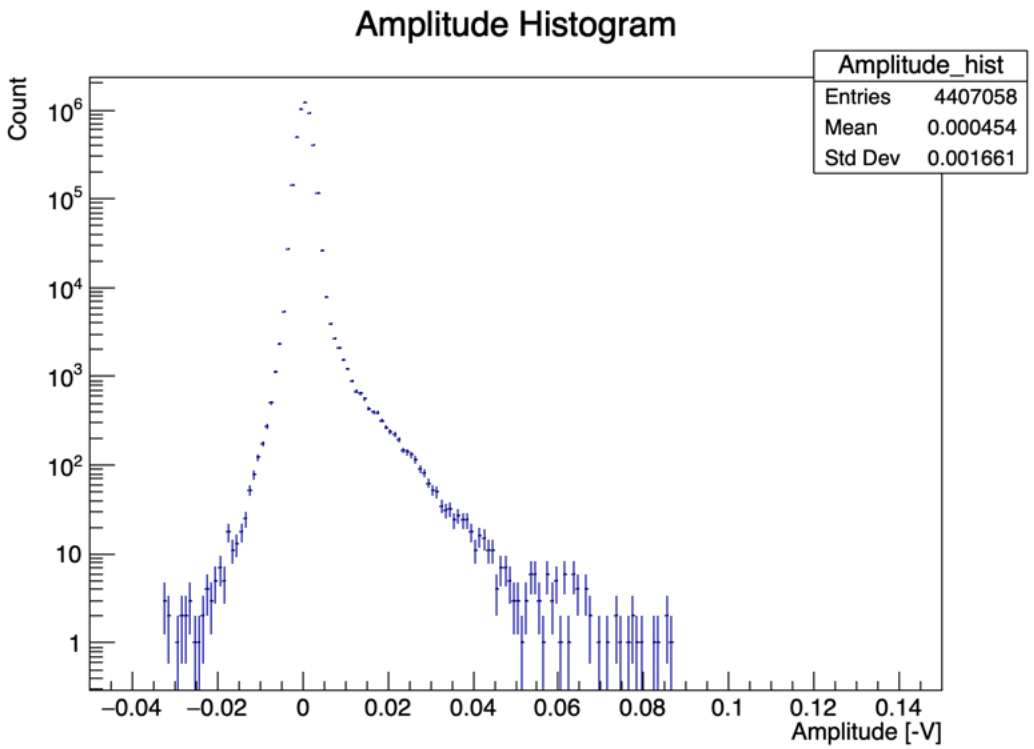


Trigger dependence; Bias Voltage: -185V

Trigger: -100mV PMT signal

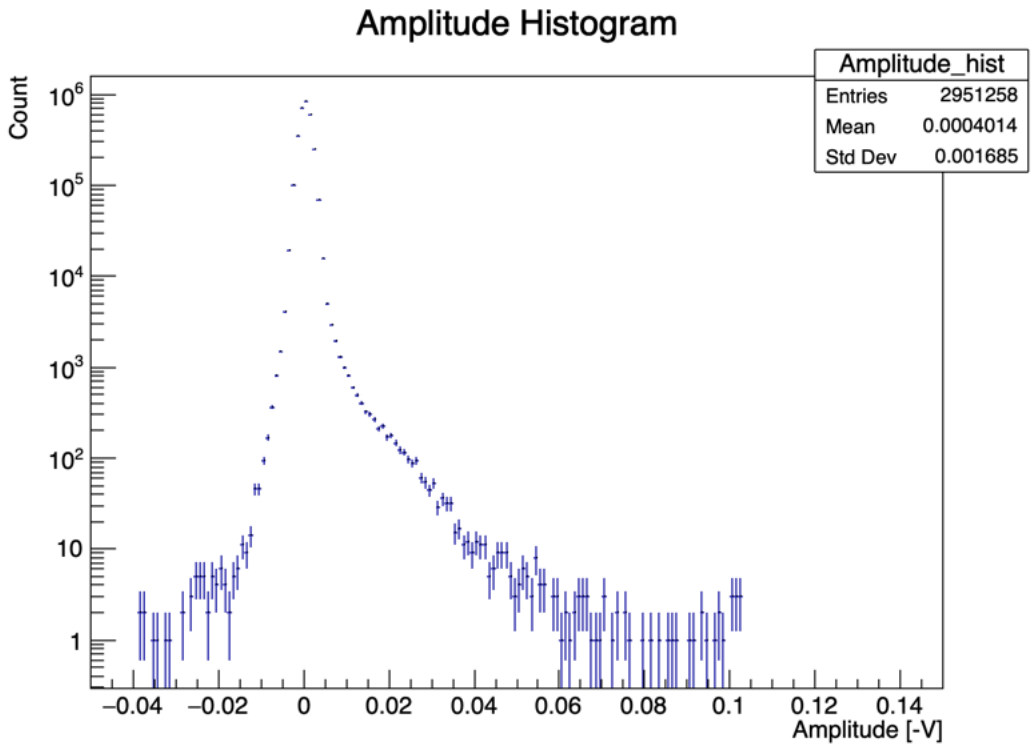


Trigger: -150mV PMT signal

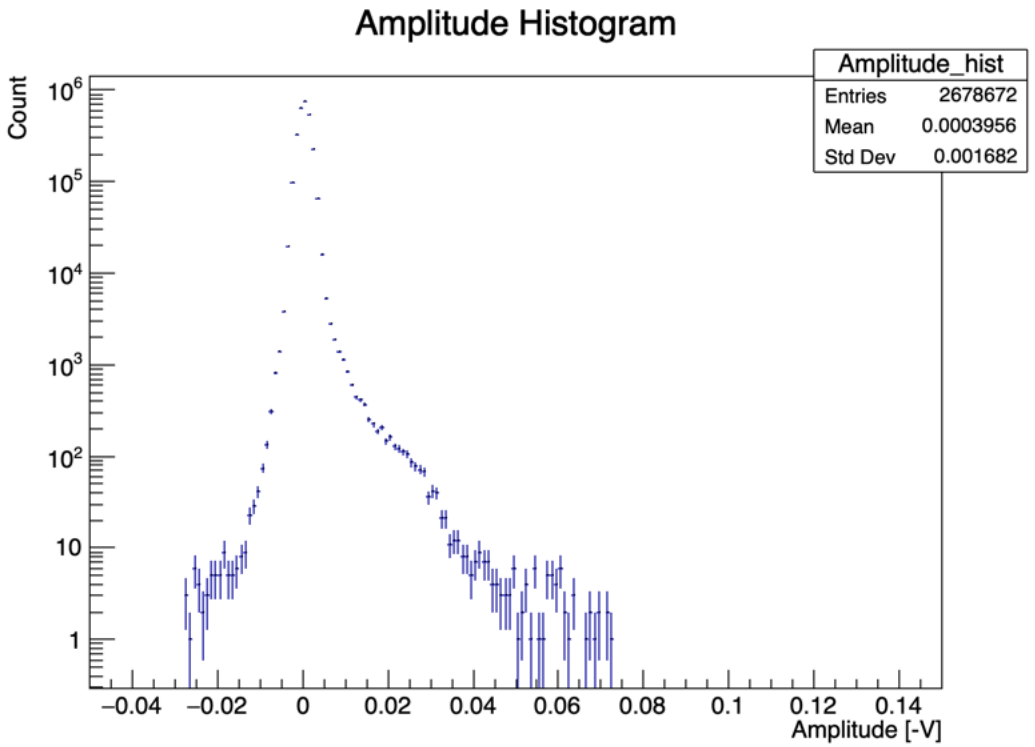


Trigger dependence; Bias Voltage: -185V

Trigger: -200mV PMT signal

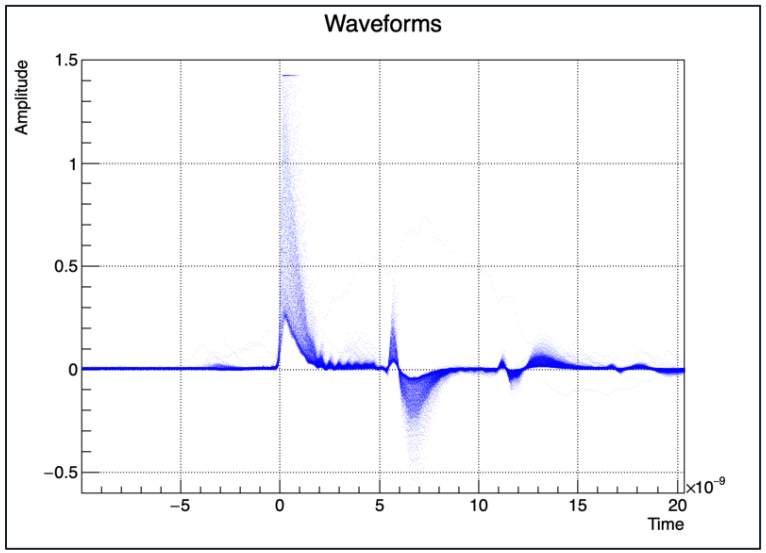


Triger: -250mV PMT signal



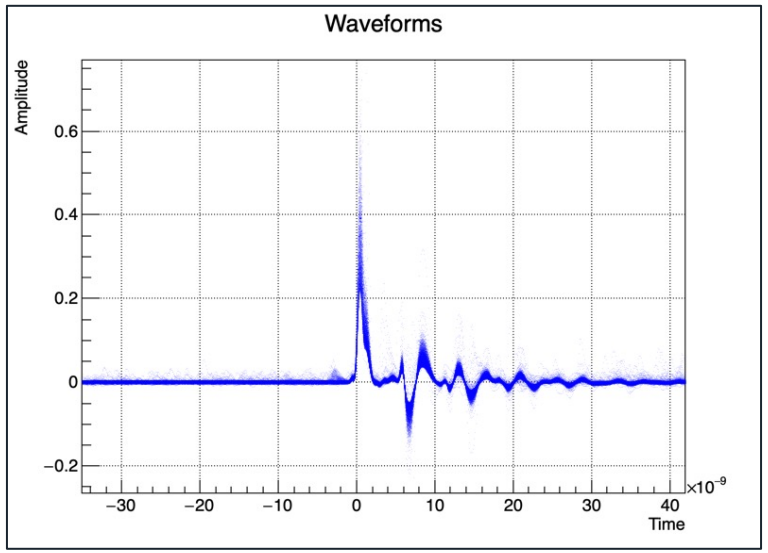
6/11　-4300V Trigger:-150mV

none



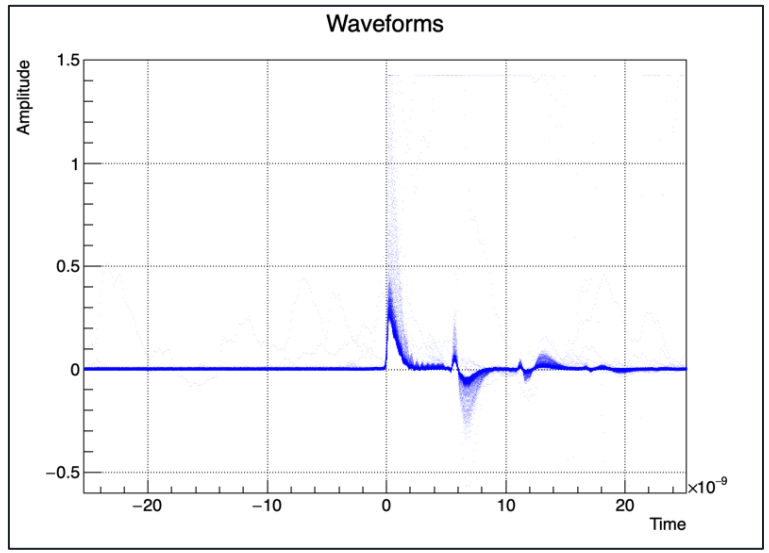
900 events, 4329s
0.2 Hz

Sr-90 only



1024 events, 54s
19 Hz

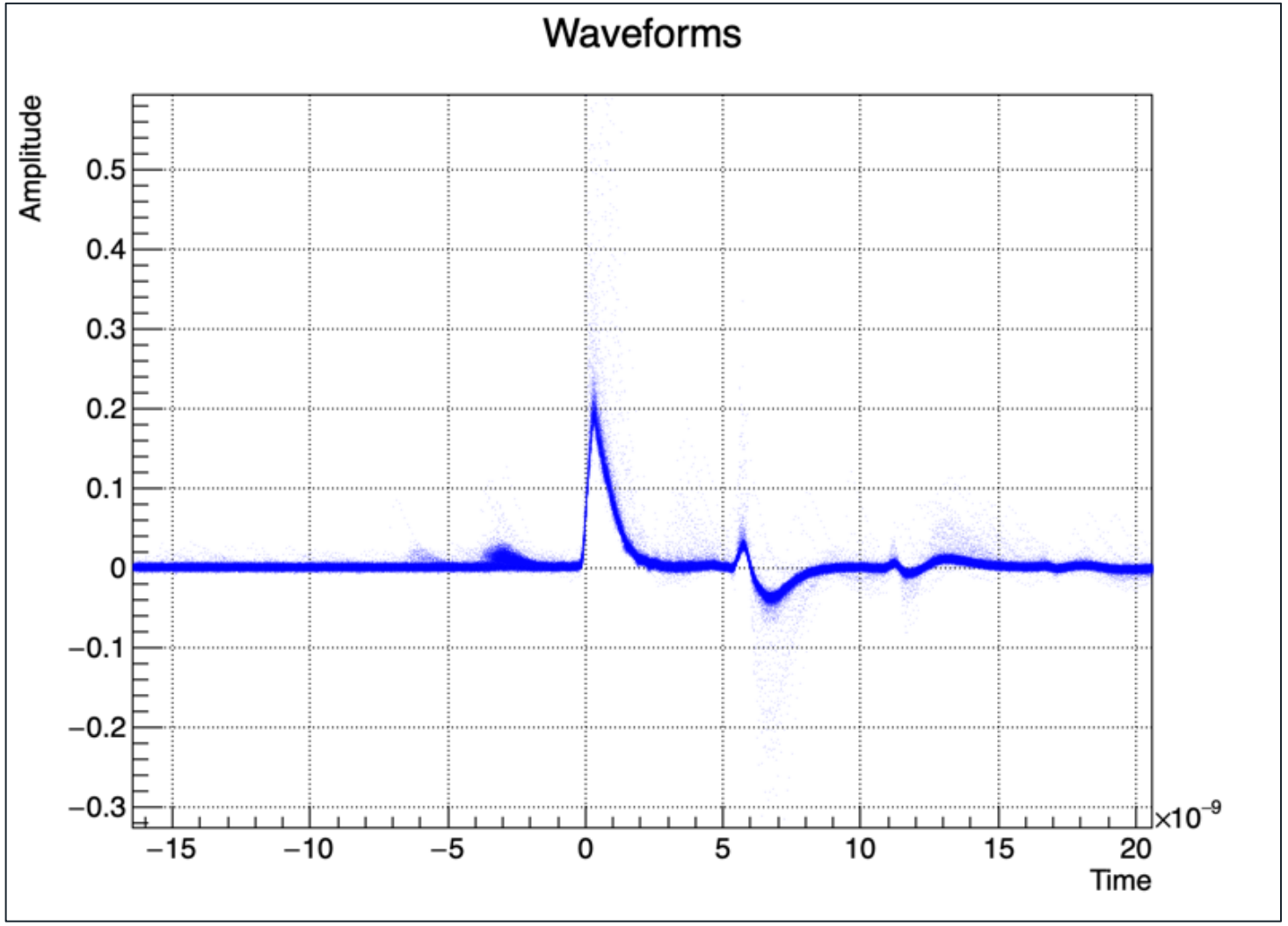
Sr-90 + AC-LGAD



1005 events, 813s
1.2 Hz

Threshold : Signalの50%が-150mVを超えた時を0sとする
→そもそものSignalが-300mV以上でないと反応しない
→検出回数が少ない原因？

6/11 -4300V Trigger: -75 mV



Sr-90 + AC-LGAD

1138 events, 195s
5.8 Hz

やはり(当たり前だが) Triggerが低いと検出効率は上がる

AC-LGADのSignalを見て，どちらも逃がさないかつNoiseの少ないtriggerを探す

オシロスコープでできたこと

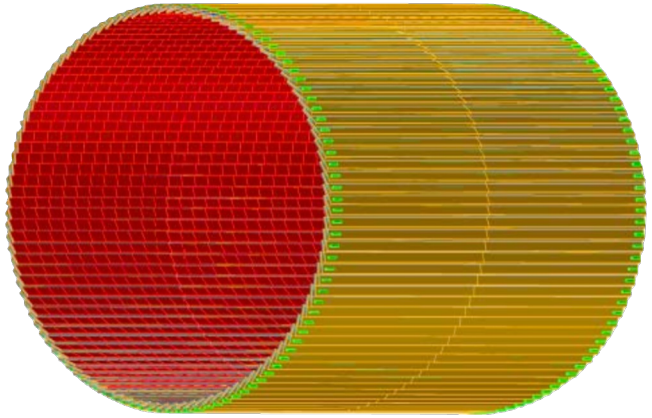
- Waveformの拡大
  - ✓ 見たいところ，測定したいところを細かく見る
- MeasureモードでAmpl., Rise time, jitterの計算などをみる
  - ✓ それぞれの平均最大最小σなどいろいろ見ることができる
  - ✓ 計算は四則演算，逆数など簡単なもの（組み合わせ可)
- ThresholdをTime walkの影響をなくす50% Trigger Signalに設定
  - ✓ 信号のブレがあきらかに減った
- 統計を貯めてHist表示
  - ✓ 例えば，Rise timeの時間分布，ampl.のブレを見たりできる。

- PMTとAC-LGADの信号の到達時間差を計算してヒスト表示もできそう

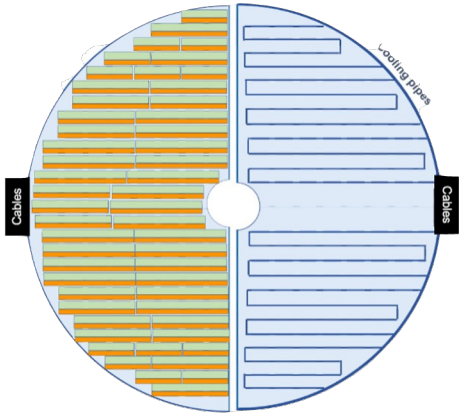
Background: AC-LGAD application at EIC

Improve spatial, similar time resolution to previous incarnation (AC-LGAD) various applications at EIC

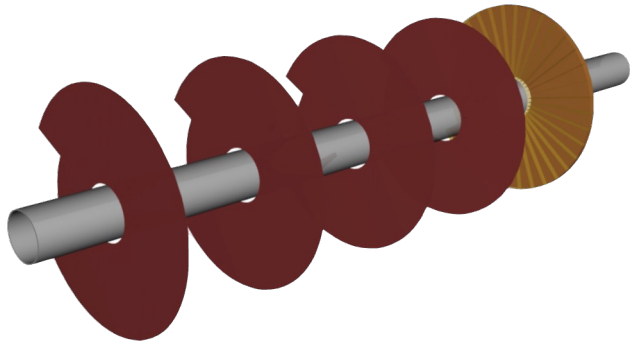
Barrel TOF (strips)



Forward TOF (pixel)



B0 tracker (pixel)



Roman/OMD (pixel)

	Area (m^2)	Channel size (mm^2)	# of Channels	Timing Resolution	Spatial resolution	Material budget
Barrel TOF	10	0.5*10	2.4M	30 ps	30 μm in $r \cdot \varphi$	0.01 X0
Forward TOF	2	0.5*0.5	8.8M	25 ps	30 μm in x and y	0.05 X0
B0 tracker	0.07	0.5*0.5	0.28M	30 ps	20 μm in x and y	0.01 X0
RPs/OMD	0.14/0.08	0.5*0.5	0.56M/0.32M	30 ps	140 μm in x and y	no strict req.

AC-LGAD devices has the potential to enhance EIC detectors' capabilities in a significant way, with eRD112 and eRD109 groups spearheading the R&D of this technology

Open areas for generic R&D: ASIC compatibility of long-strip sensor, large area sensor production