Studies with position-sensitive SiPM and MPT readout chip

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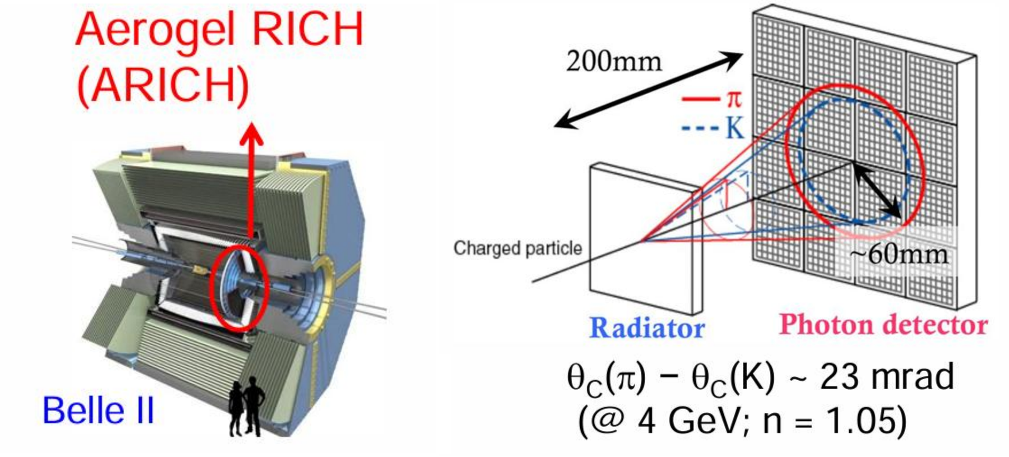
Outline

- Introduction
- Study of SiPM-Array for Cherenkov light
- Study of position-sensitive SiPM (PSS)
- Performance of MPT2321 Chip
- Summary

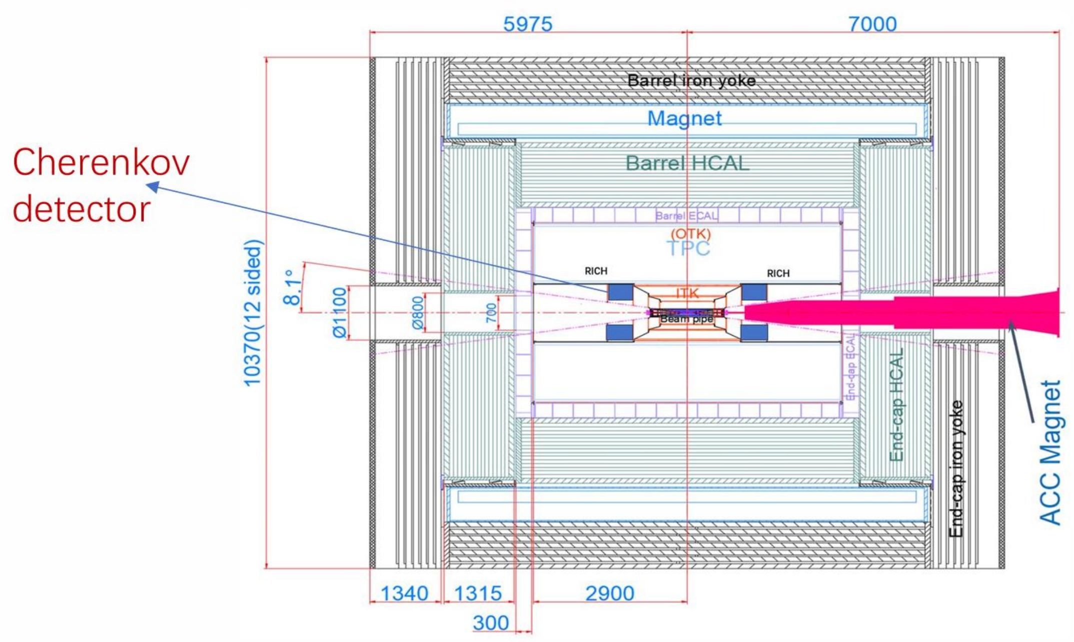
Introduction



By Shohei Nishida， 2022 CEPC workshop

	HAPD	MPPC (SiPM)
Pad / Position	4.9mm × 4.9mm	3.0mm × 3.0mm
PDE	~20% (QE ~ 30%)	~40%
Gain	7×10^4	6×10^6
Wavelength	200-600 nm	320-900 nm
Dark Count	~0	~0.5 MHz
Operation voltage	−8kV HV + 350V bias	60V
Radiation damage	Tolerable at Belle II	Weak

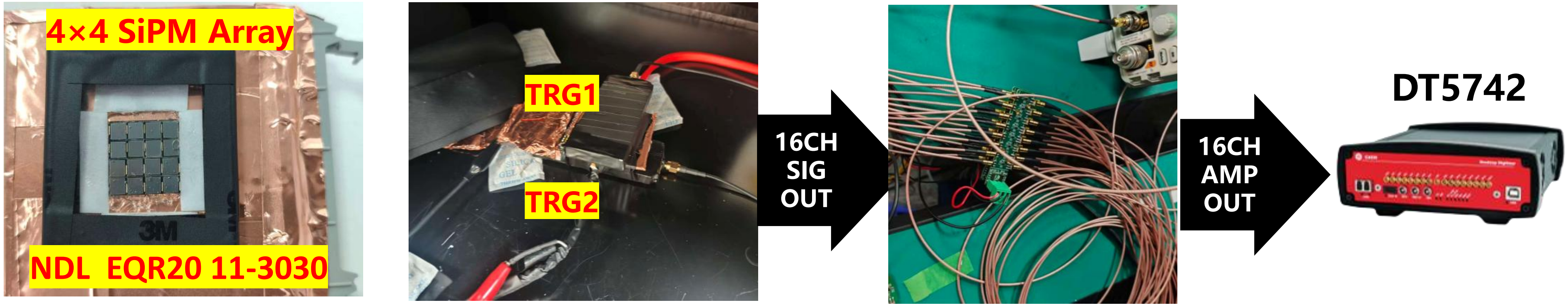
Possible Cherenkov detector at CEPC



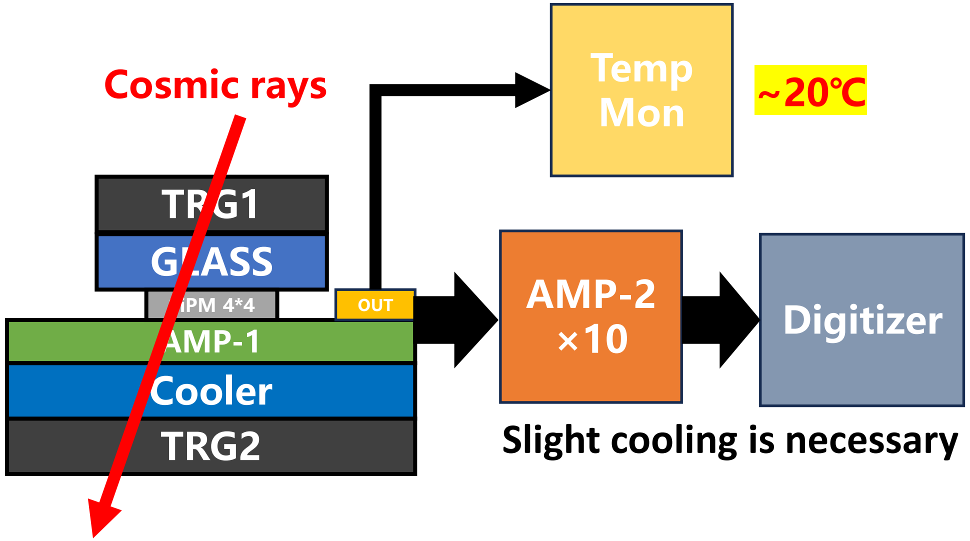
SiPM has good performance, but radiation tolerance and dark counts is an issue.

Standalone SiPM-Array Test

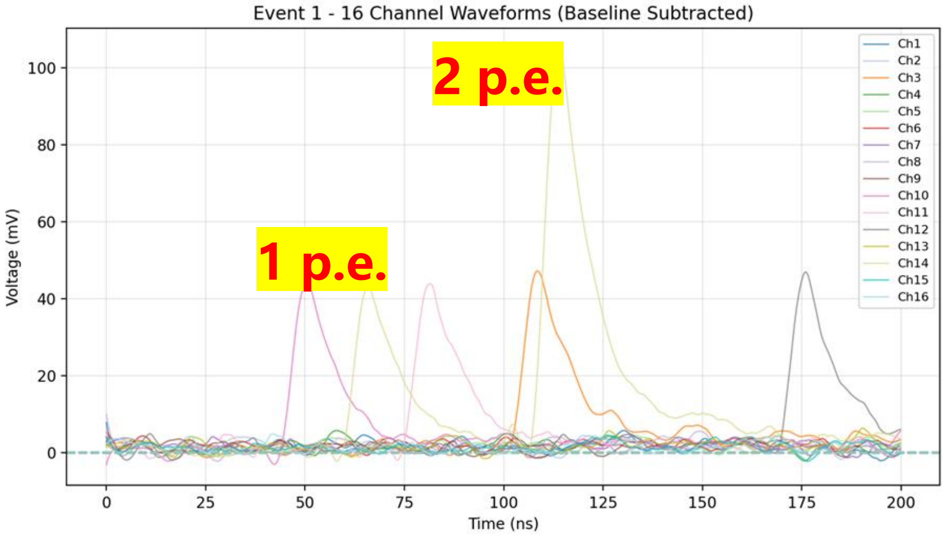
To evaluate the impact of dark counts. we used a SiPM array to detect Cherenkov light of cosmic rays.



Two-stage amplifier is used to get a high SNR

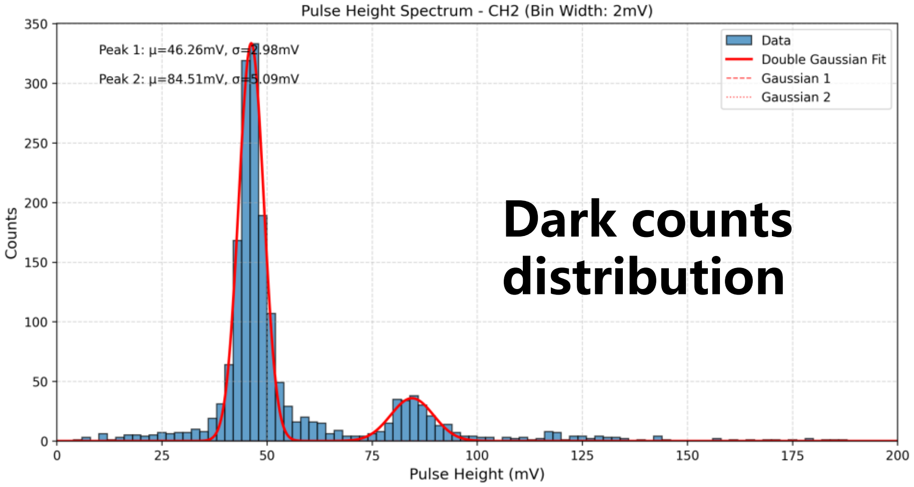


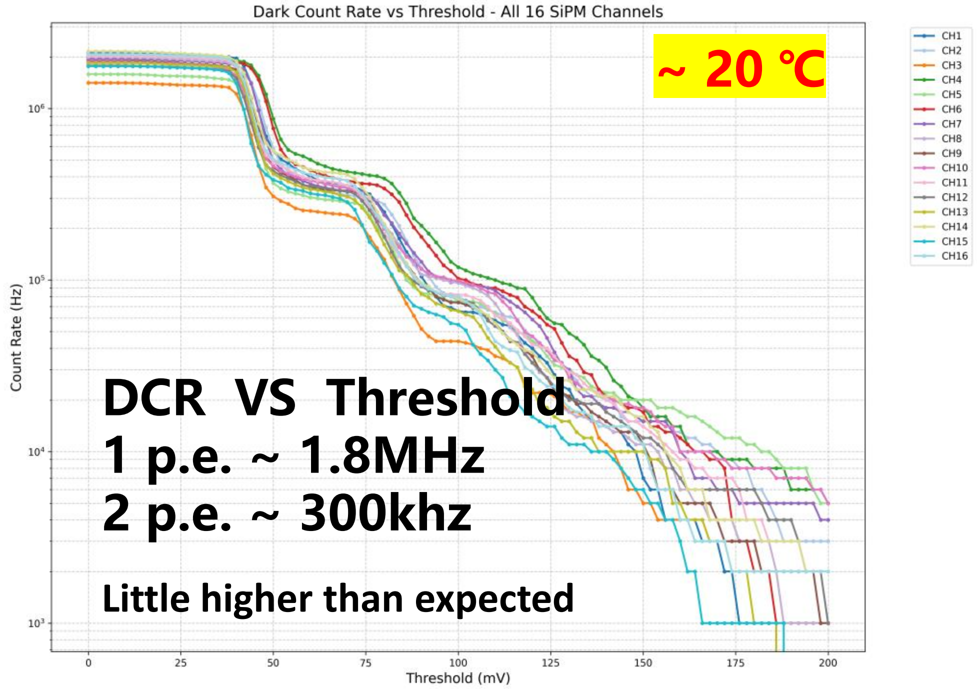
Slight cooling is necessary



Typical waveform of dark counts

Calibration of SiPM SPE





SPE = Mean (peak1) - Mean (peak2)

SNR = SPE / sigma (pedestal) > 25

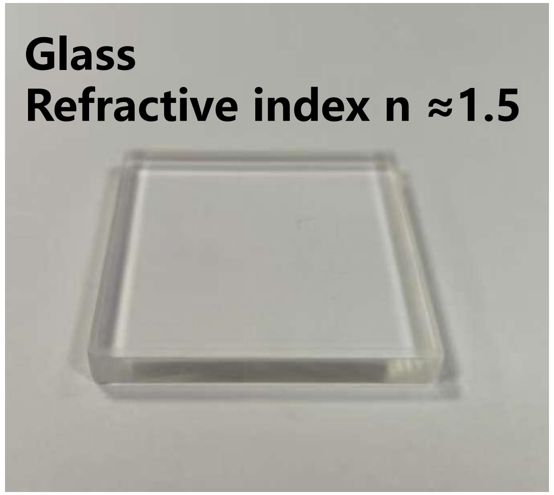
Crosstalk = Area(peak2) / Area(peak1)

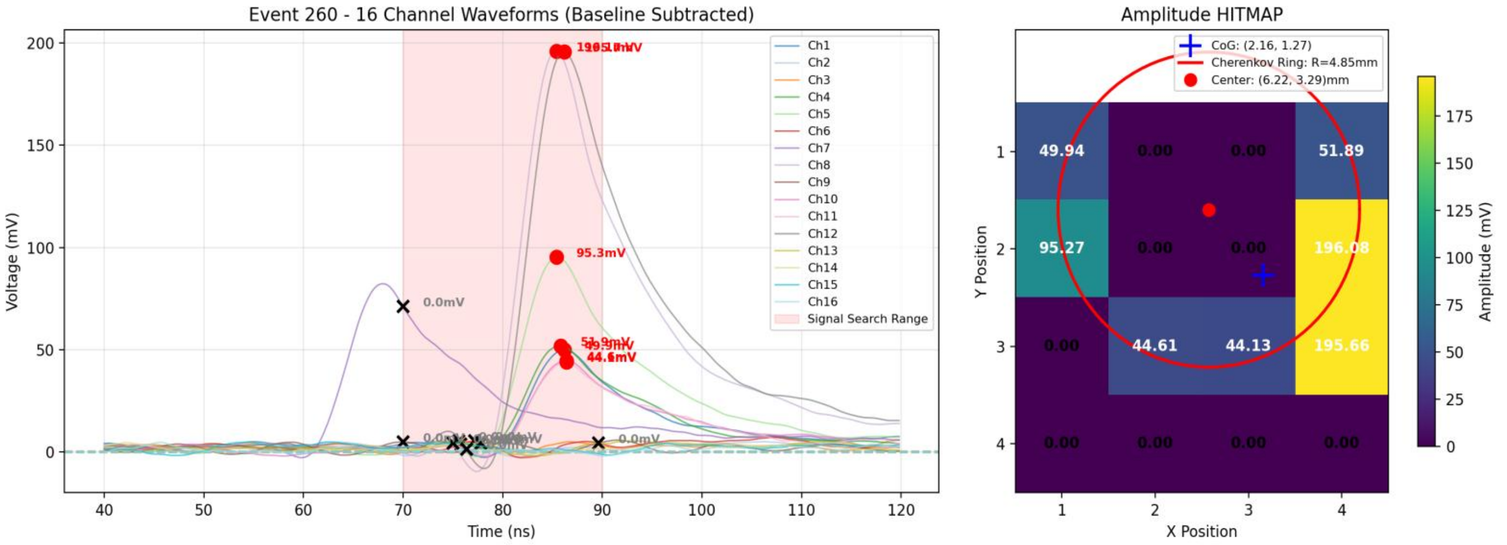
N.O.	SPE(mV)	Crosstalk	N.O.	SPE(mV)	Crosstalk
1	36.8	7.4%	9	35.2	9.4%
2	38.3	10.5%	10	33.7	8.5%
3	35.4	8.5%	11	34.1	9.1%
4	38.4	10.5%	12	35.5	11.1%
5	35.5	9.9%	13	34.1	8.0%
6	38.4	8.7%	14	34.3	10.0%
7	36.4	7.1%	15	33.3	8.2%
8	35.6	8.0%	16	34.6	9.0%

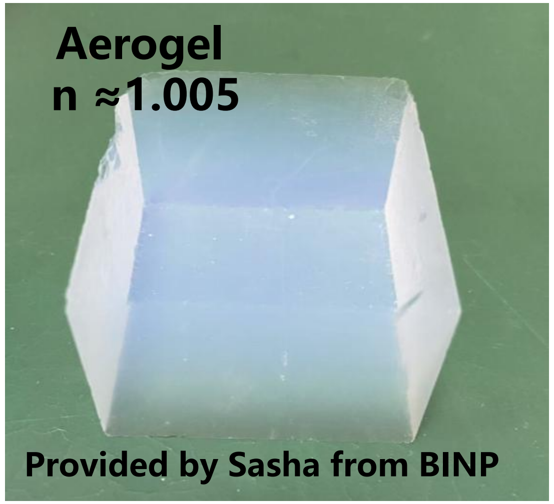
Set Threshold：0.5 p.e. → detect single photon

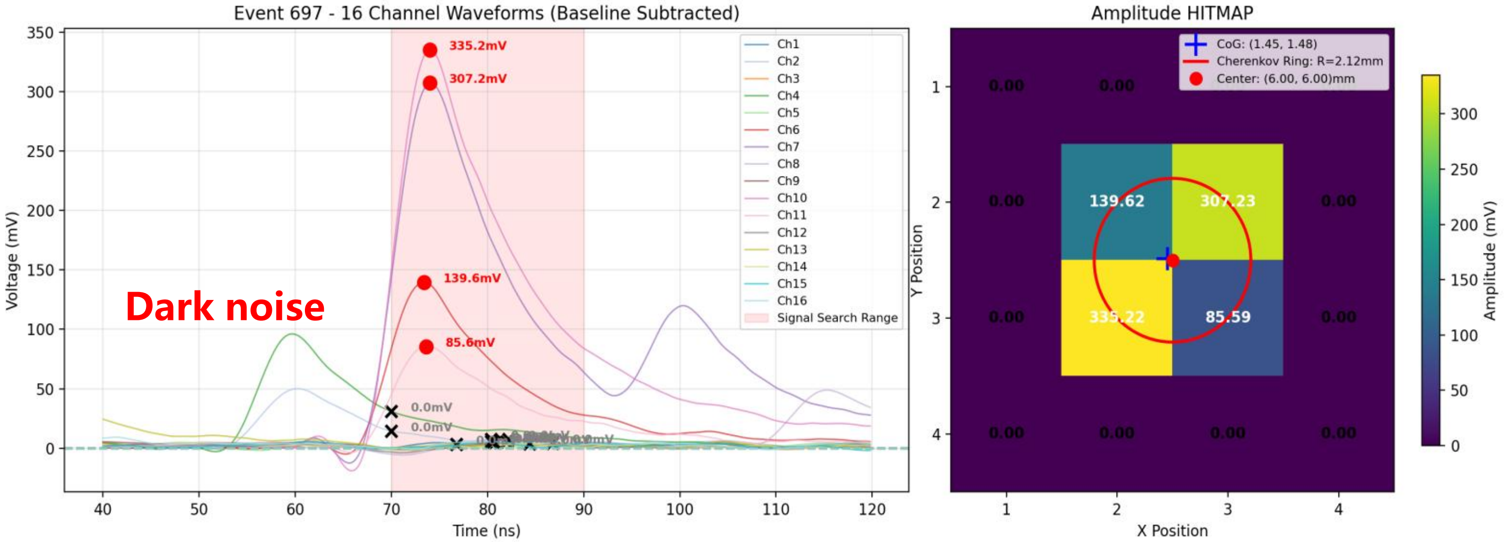
Search Peak Window：20ns → reduce impact of DCR

Cerenkov signals from Glass / Aerogel









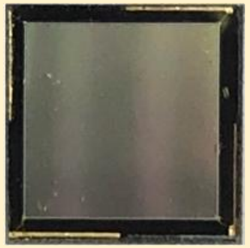
With slight cooling and applying a narrow window, single-photon detection using SiPMs is feasible.

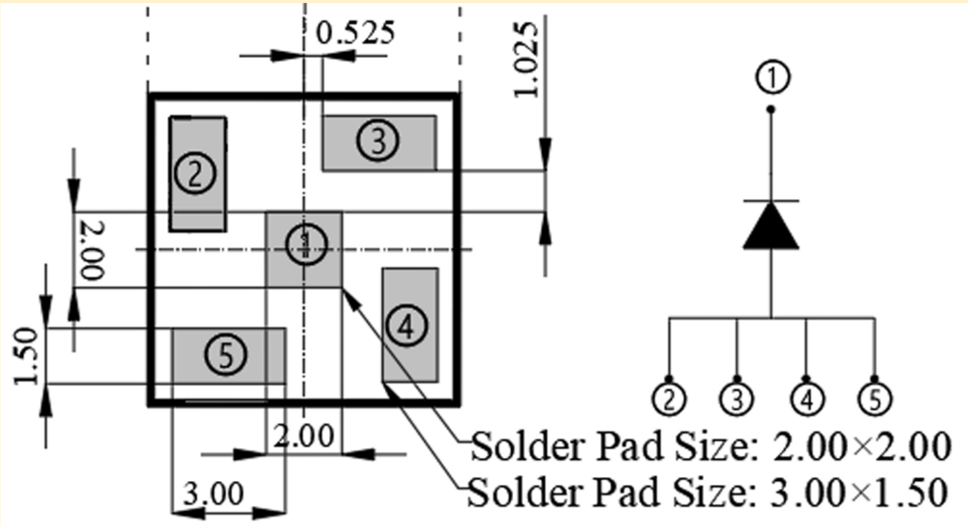
PS-SiPM TEST SET-UP

The position resolution of a standalone SiPM is limited by its size.
To achieve higher position resolution, position-sensitive SiPM（PS-SiPM） is a good choice.

NDL PSS 11-6060-S

Pitch: 20um
Active Area: 6.24×6.24 mm^2
DCR: 150 kHz/mm^2





The charge is distributed via the four pads

➢ Position Algorithm

$$x_c = \frac{L}{2} \cdot k \cdot \frac{(Q_2 + Q_3) - (Q_1 + Q_4)}{(Q_1 + Q_2 + Q_3 + Q_4)}$$

$$y_c = \frac{L}{2} \cdot k \cdot \frac{(Q_3 + Q_4) - (Q_1 + Q_2)}{(Q_1 + Q_2 + Q_3 + Q_4)}$$

➢ Readout board for PS-SiPM

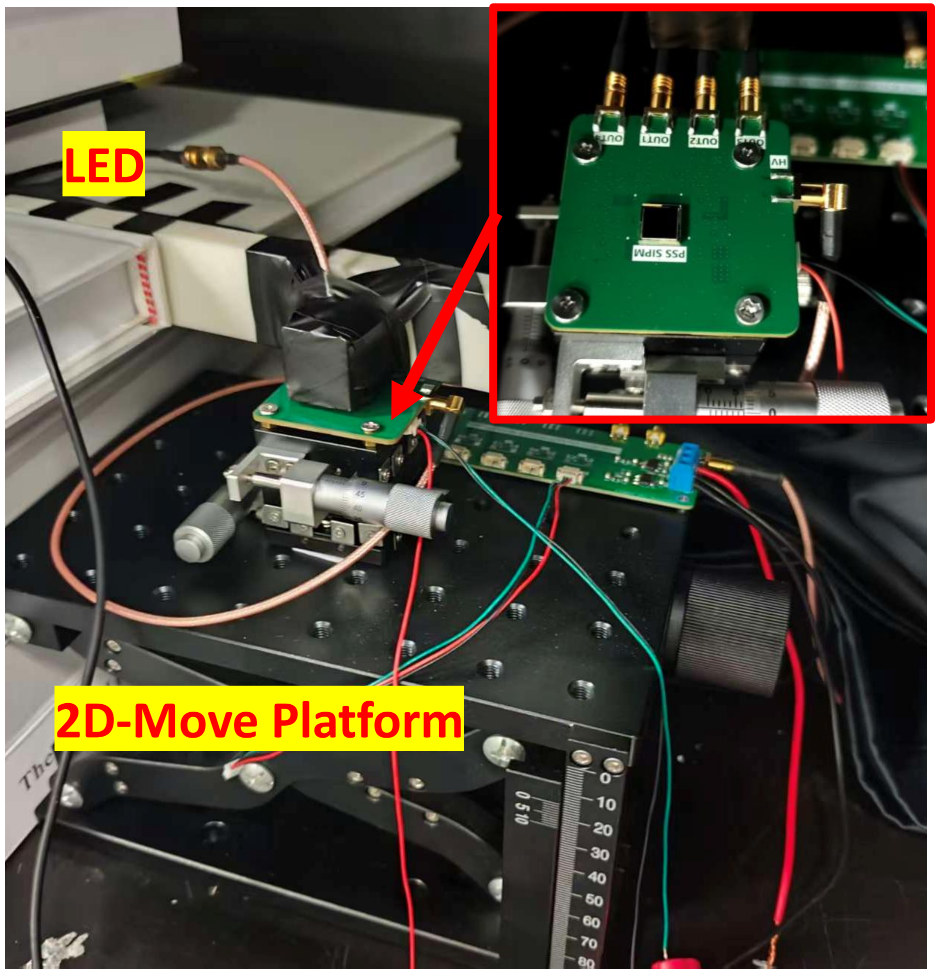
Gain： +20 V/V

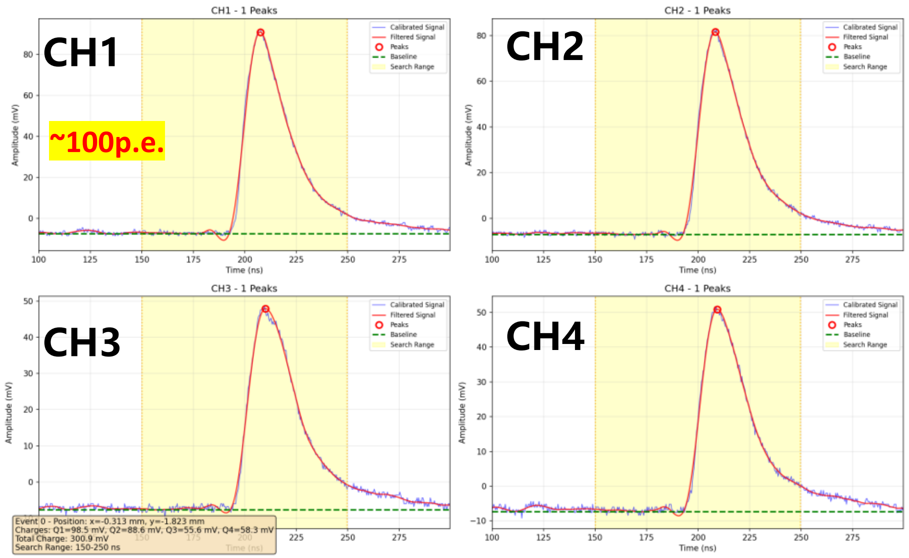
Bandwidth(-3dB)： 400 MHz

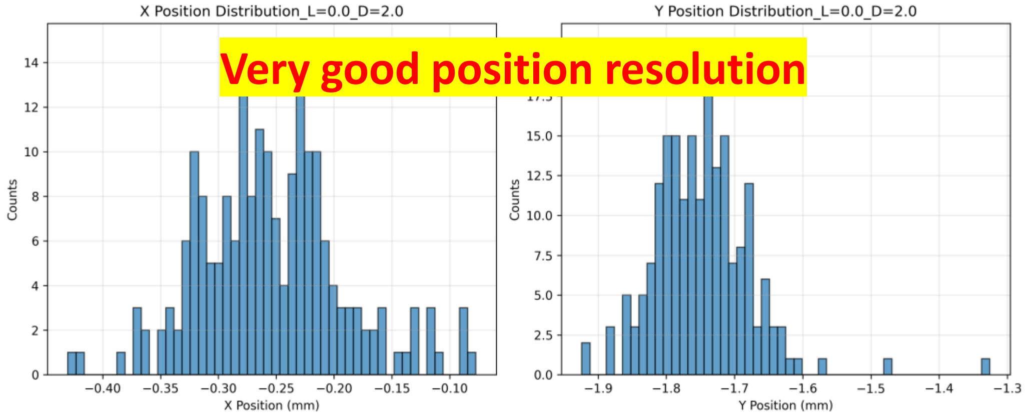
Baseline noise(RMS): 300uV

Input impedance: 50Ω

Preliminary Test of PS-SiPM





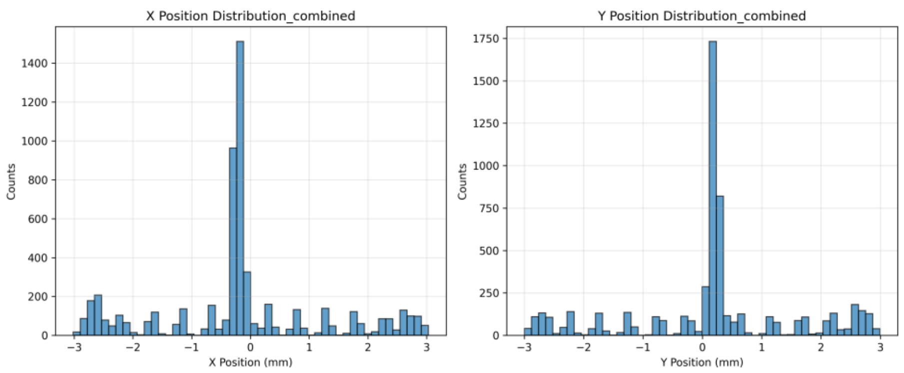


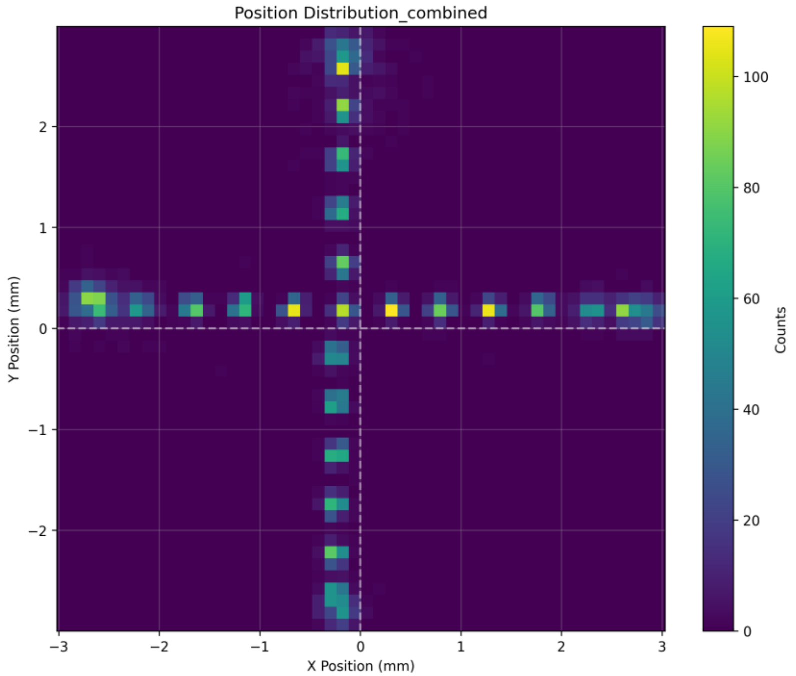
The resolution is related to light spot size.

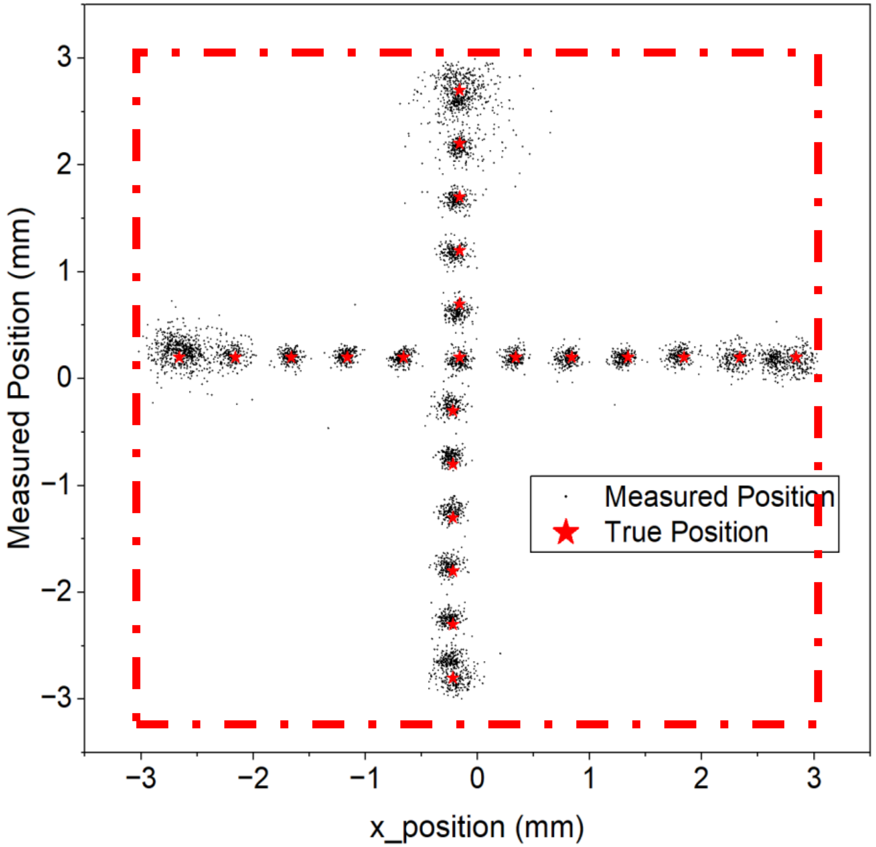
σ(x) = 0.062mm **σ(y) = 0.074mm**

Reconstruction of different regions

Response of the PS-SiPM at different region.







The reconstruction is poor near the edge position.

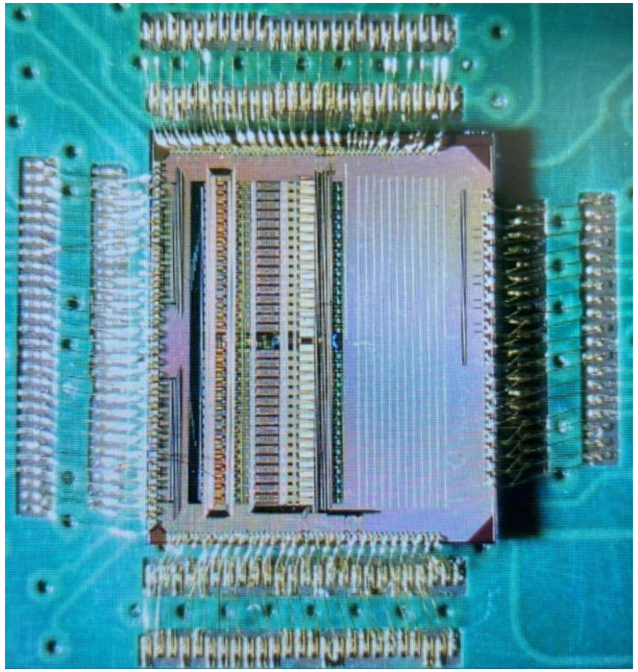
1. **Number of photons collected decreases at edge.**
2. **Charge sharing among four pads has huge different.**

Introduction of MPT2321

The MPT2321 chip is a SiPM signal processing SoC chip designed for high-precision time-of-flight signal processing.

Features

- **32 input channels**
- Automatically select the range of measurement signals
- **50ps precision 20-bit TDC**
- **12bit ADC**
- Complete on-chip signal processing
- Standard IIC Bus Control
- 8b10b encoding transmission
- Multichannel LVDS data transmission
- 12 M cps transmission event rate
- High integration, low power consumption
- 200M data transmission rate
- The maximum charge measurement dynamic range is **4 nC**
- Minimum detectable signal range **4fC**



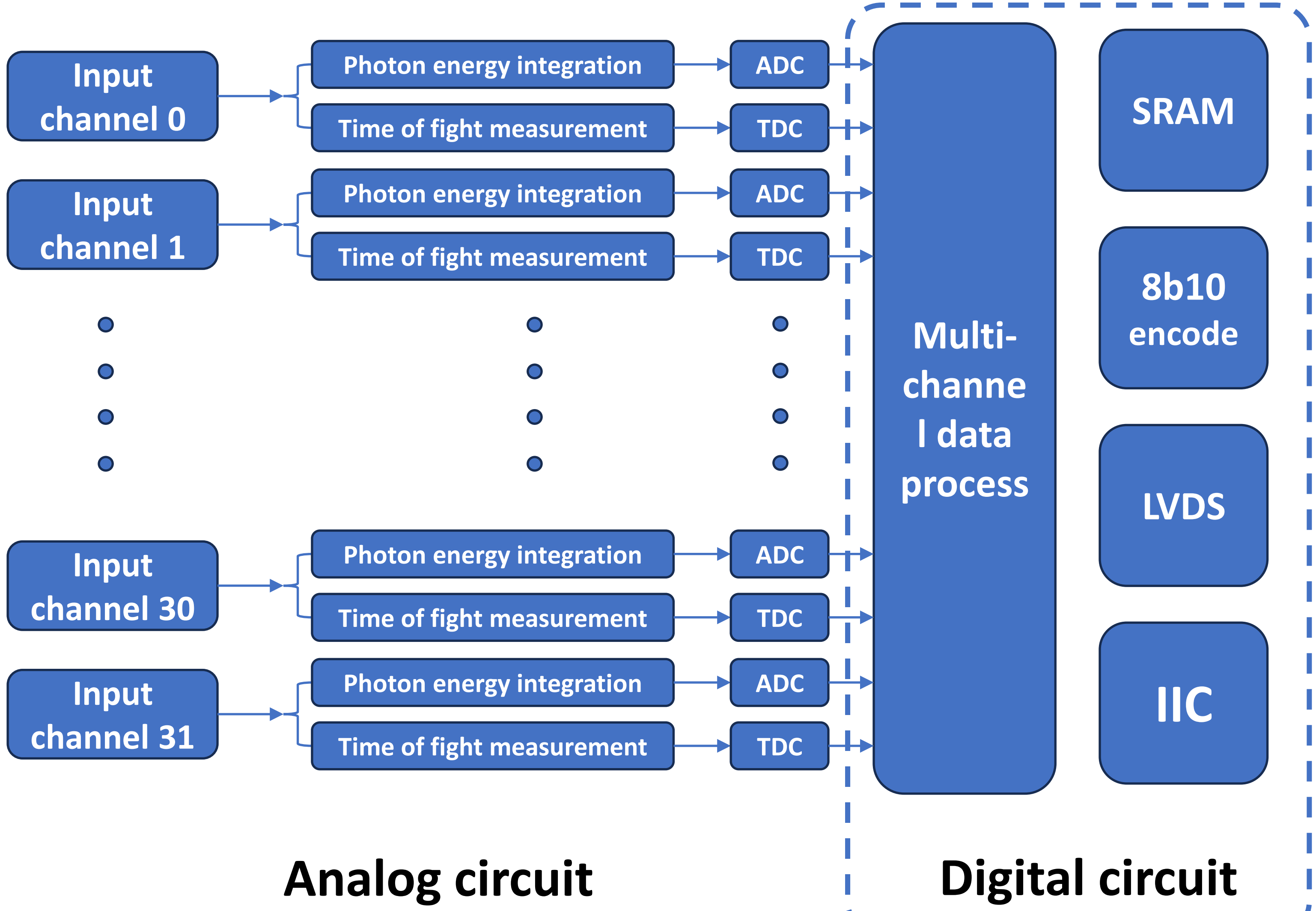
MPT2321 chip

宇称电子
MICROPARITY
Sensor and Science

Structure of MPT2321 chip

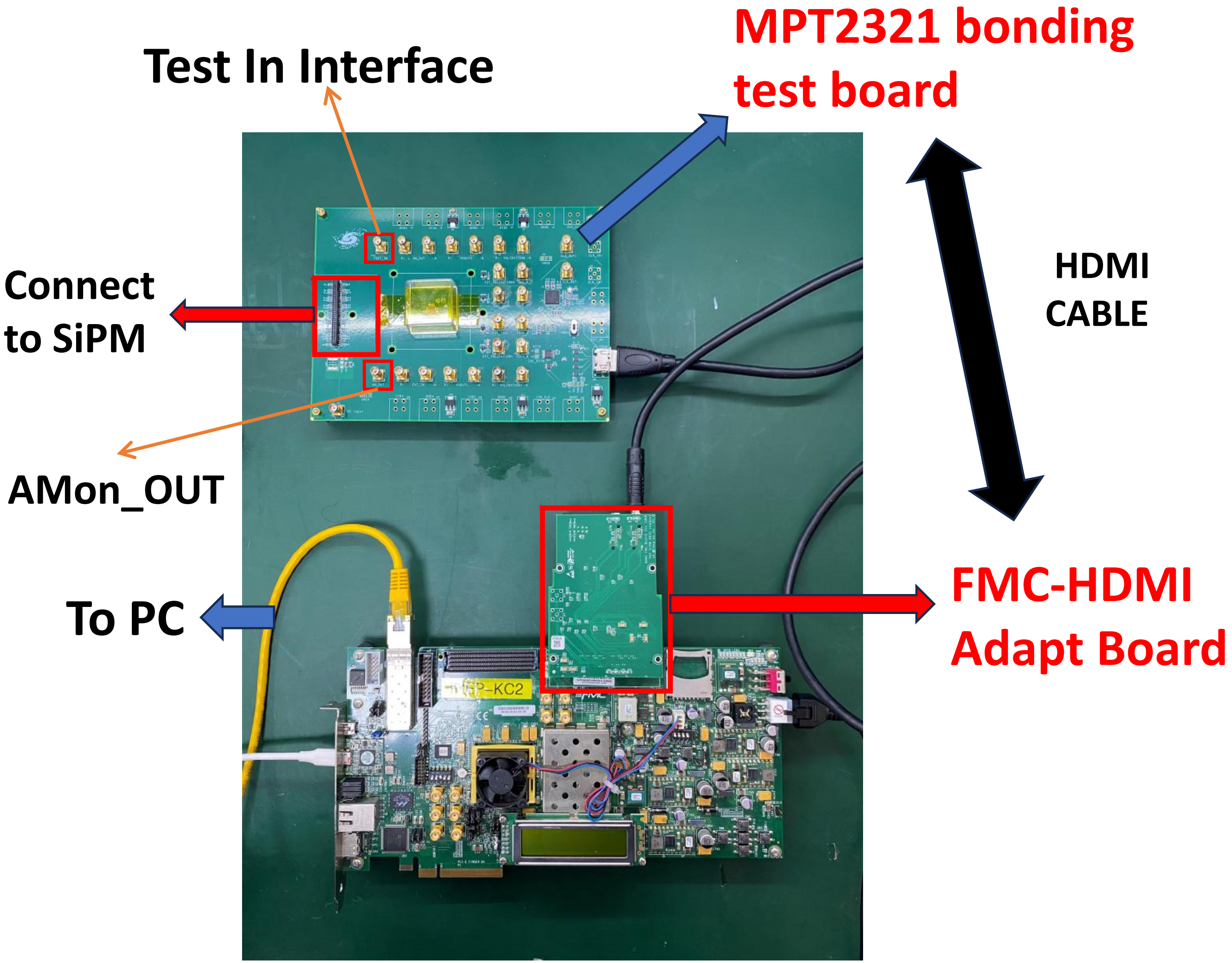
- **Analog circuit**
  - 12bits ADC module
  - 50ps precision TDC

- **Digital circuit**
  - Control of chip status
  - Data processing, compression and output



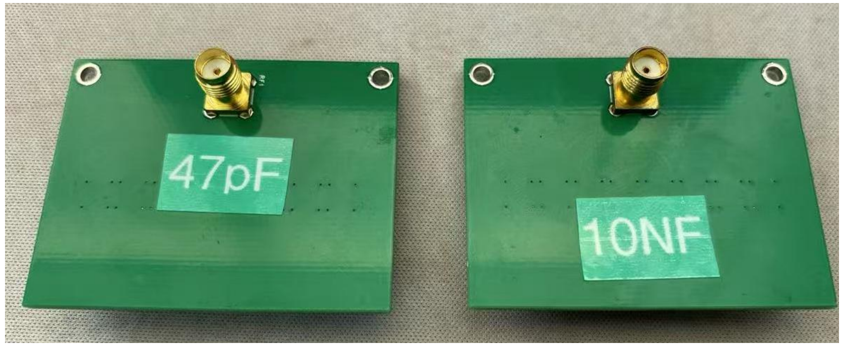
Test platform for MPT2321

- **FPGA Board: KC705 of Xilinx**
- Signal input to MPT2321
  - ➢ Female Header
  - ➢ Test In interface
- MPT2321 to FPGA
  - ➢ HDMI
  - ➢ FMC-HDMI Converter
- FPGA to PC
  - ➢ RJ45-SFP converter
  - ➢ USB-JTAG to program FPGA

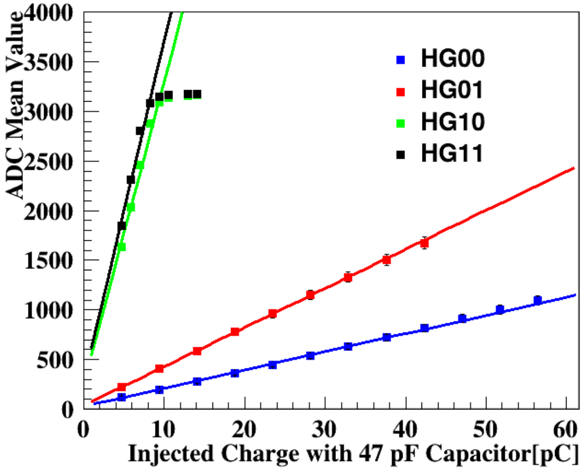


Test Results – Charge dynamic range

- Measurement Method
  - ➢ Inject Pulse through Charge inject board
- **Injected Charge: $Q = \Delta V \times C$**
- Capacitor of Charge inject board
  - ➢ High-Gain mode: 47 pF
  - ➢ Low-Gain mode: 1 nF

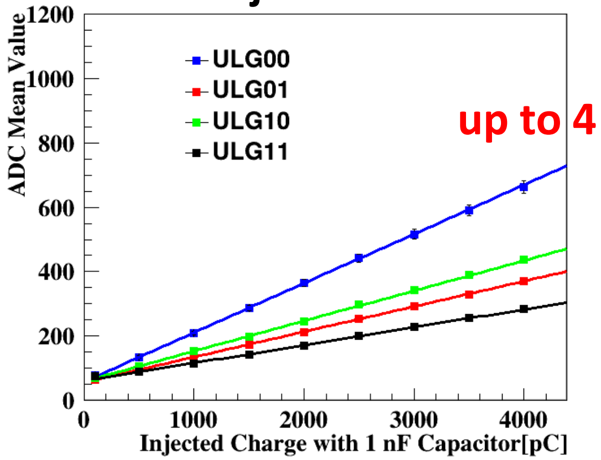


Charge Injection Board



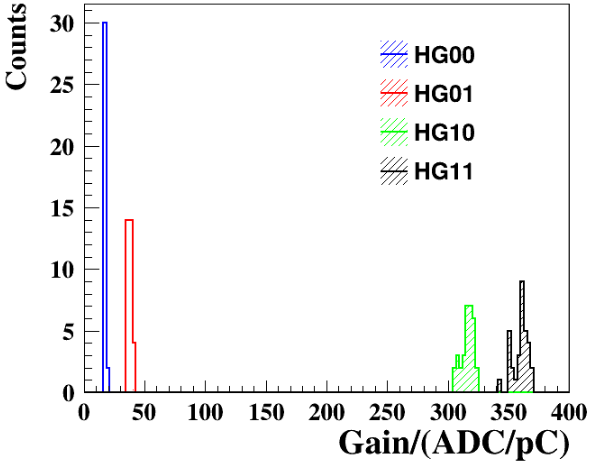
High-Gain mode

four adjustable levels

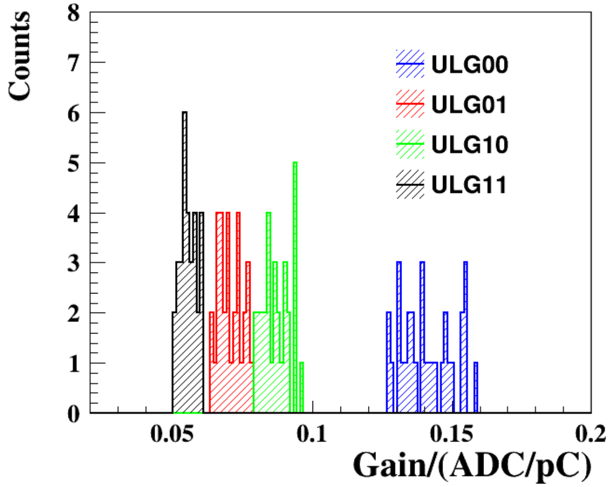


up to 4 nC.

Low-Gain mode



High-Gain mode

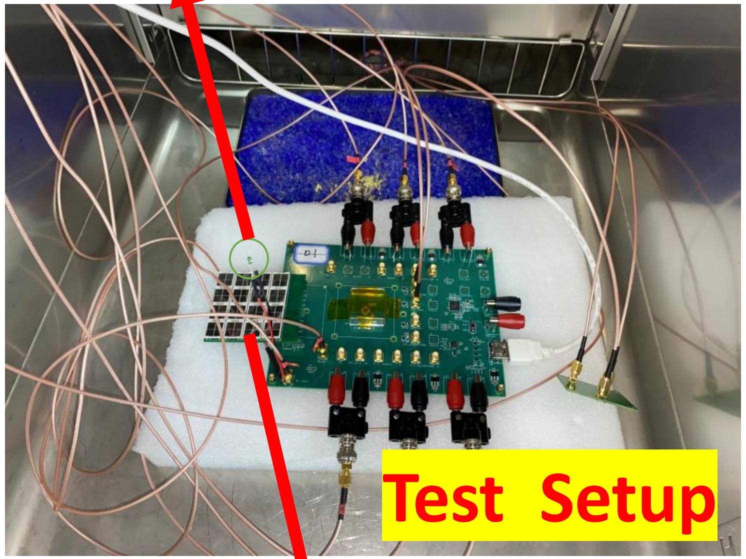


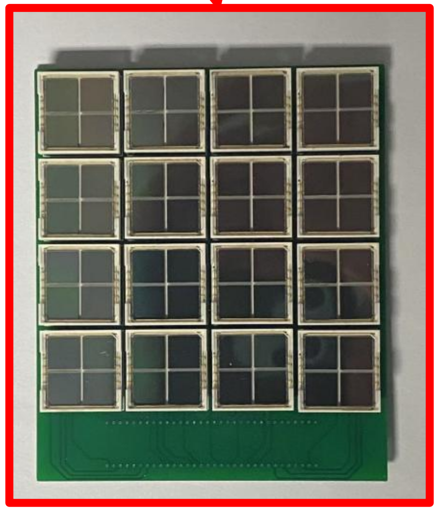
Low-Gain mode

Test Results – Connect to SiPM Array

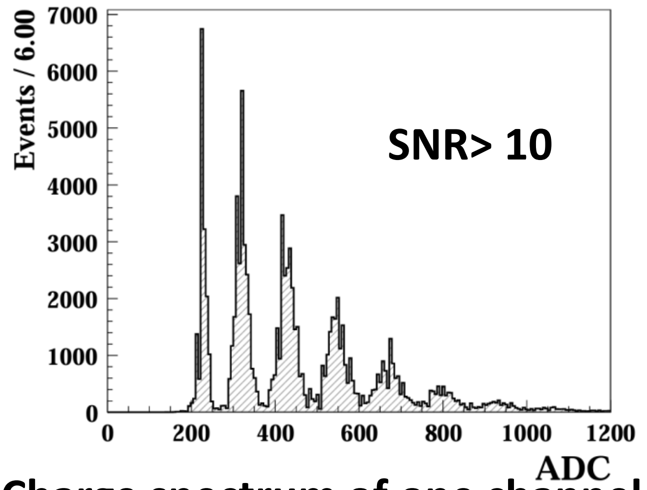
- SiPM Type:
  - **S13371-6050CQ-02 (Hamamatsu)**
- Measurement Method
  - **Green LED** drove by pulse signal
  - Pulse signal
    - Width: 10 ns
    - Amplitude: 1.070 V
  - Using **external trigger mode**
    - Same frequency with LED driver pulse

Green LED

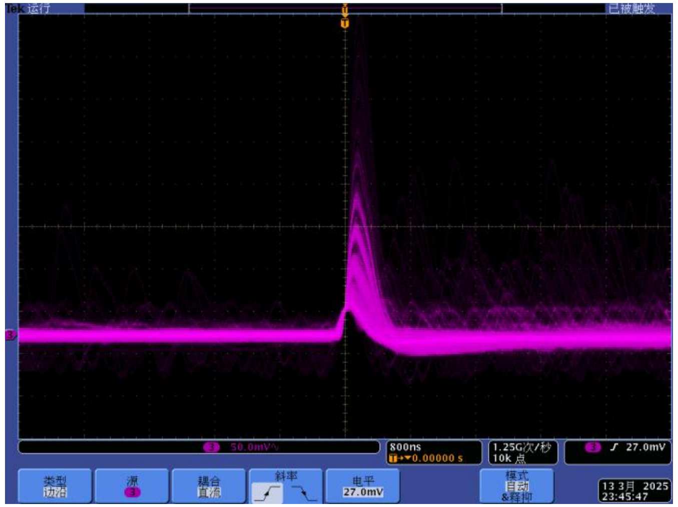




8x8 SiPM array



Charge spectrum of one channel

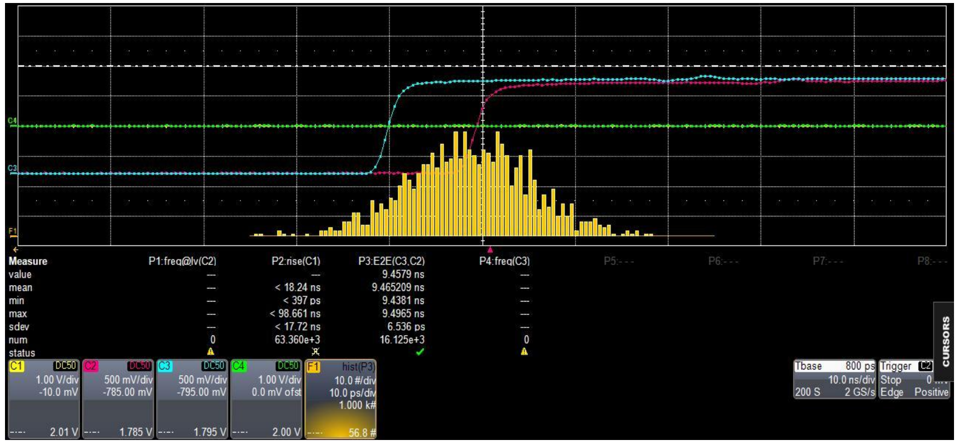


Waveform from AM_OUT

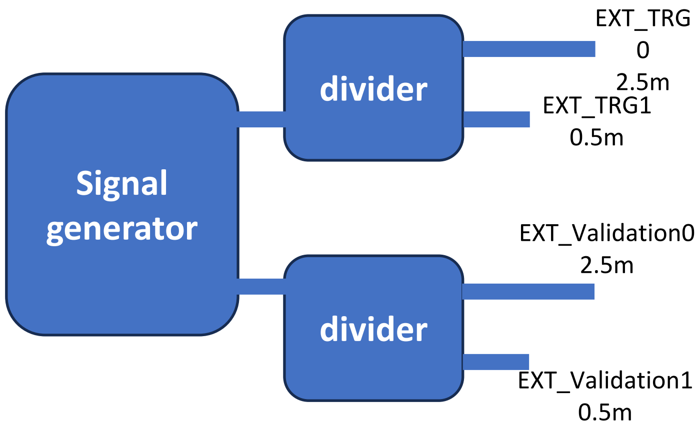
Test Results – TDC performance

- **Cable delay method**
  - The difference of the length of two cable is 2m
  - Time difference
    - oscilloscope: 9.47 ns
    - MPT2321: 9.33 ns
- **Time resolution: ~150 ps**
- **Frequency of TDC clock: 80 MHz**

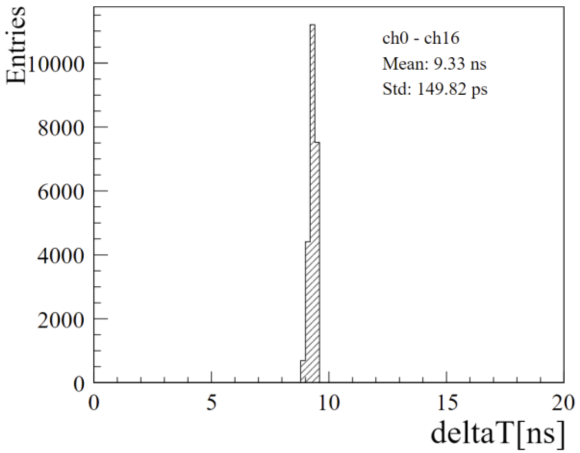
Higher TDC clock frequency can improve the time resolution, but it will also increase power consumption.



Cable delay measured by oscilloscope



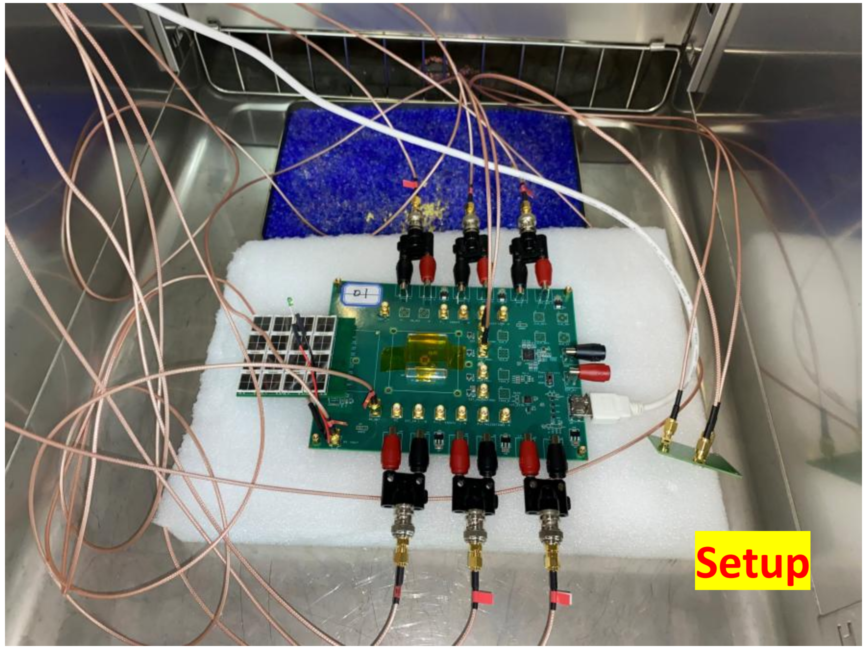
Test Setup

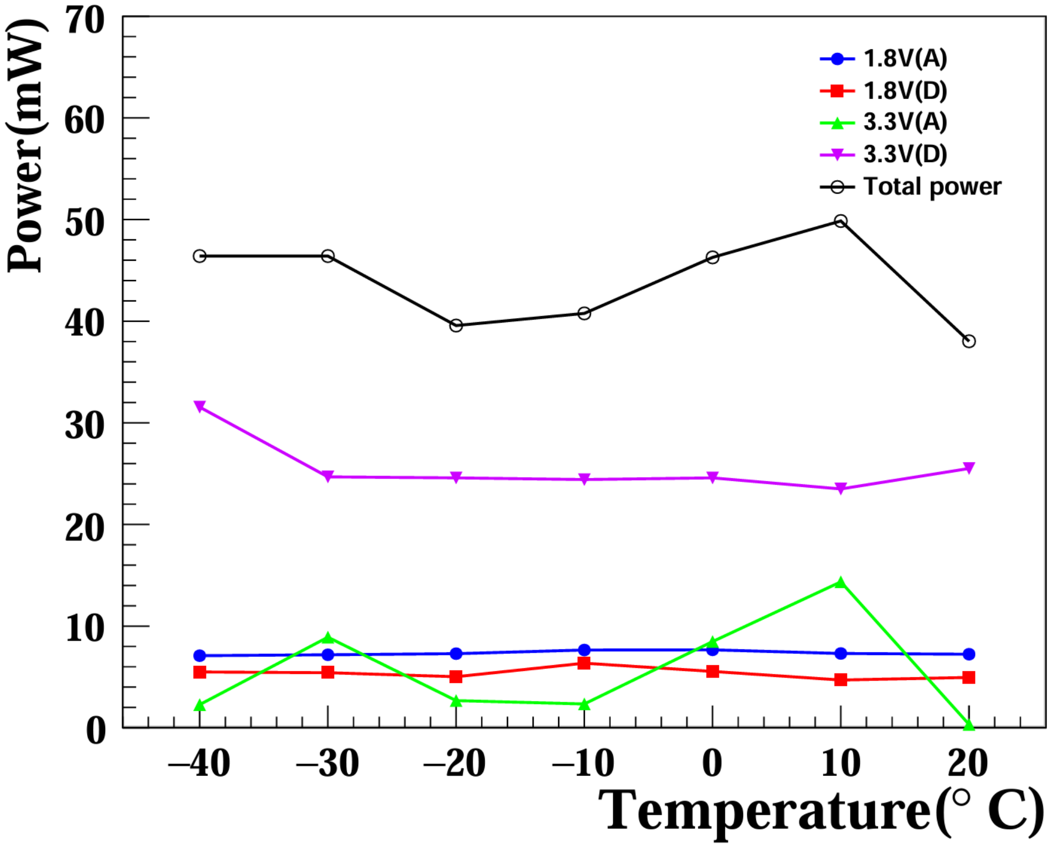


Cable delay measured by MPT2321

Test Results – Power consumption

- Measurement method
  - The test board is set in a thermostat
  - Monitor the current of power supply interface
- **The Power consumption is stable at -40 ℃ ~ 20 ℃**





Power consumption vs Temperature

Meets the requirements for future low-temperature operation.

Summary

- Slight cooling and a narrow coincidence window can achieve single-photon detection by effectively reduce the impact of SiPM dark counts.
- PS-SiPM demonstrate a superior position resolution of better than 100 μm.
- The MPT2321 ASIC exhibits excellent performance in both time and SPE resolution.

Next Steps:

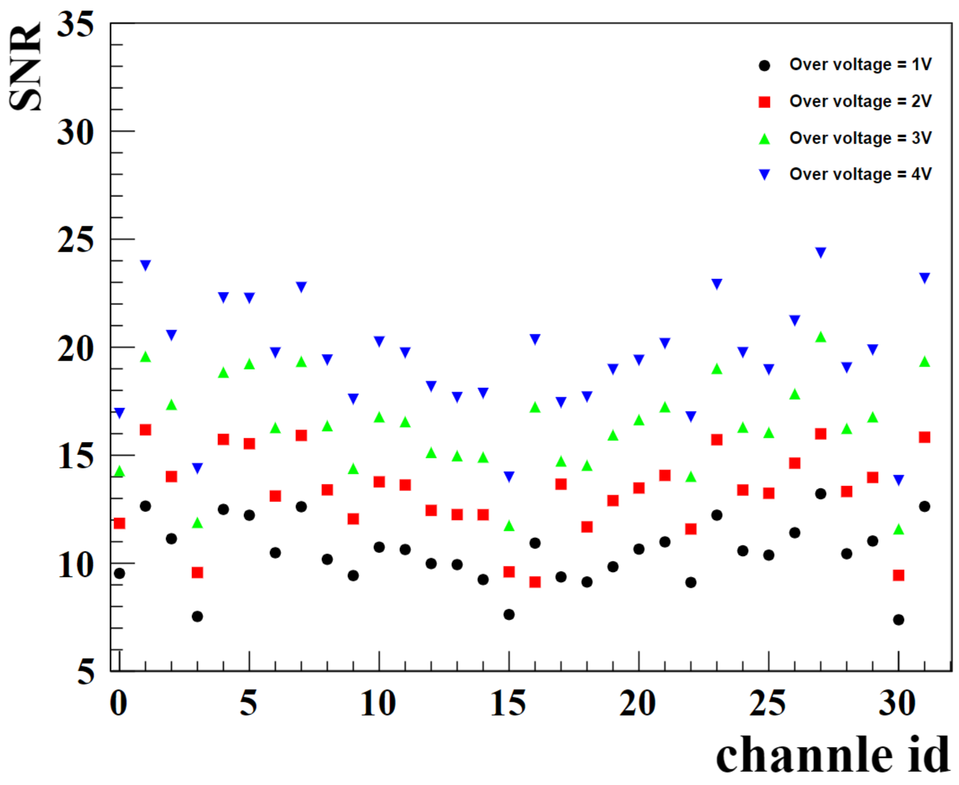
A PS-SiPM array prototype is under construction for further test.

THANKS !

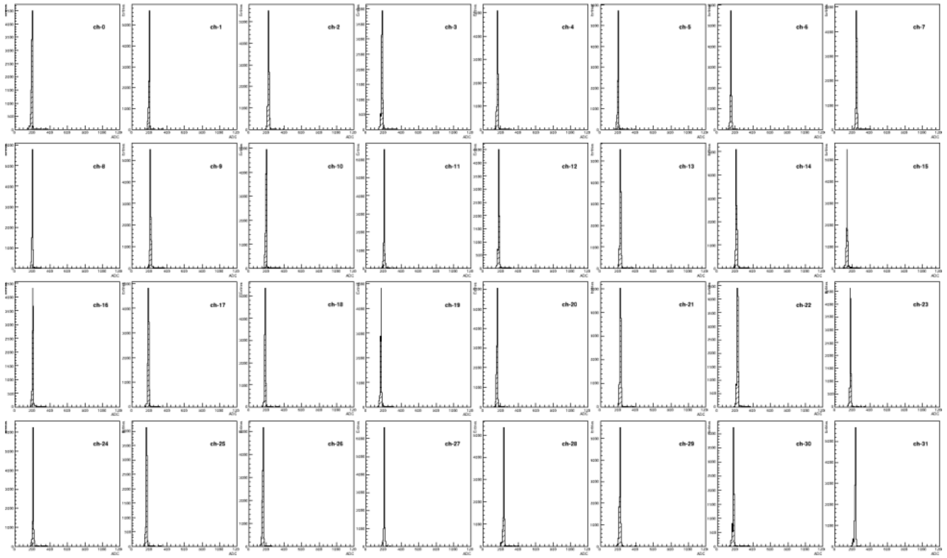
back up

Test Results – Signal-to-noise ratio (SNR)

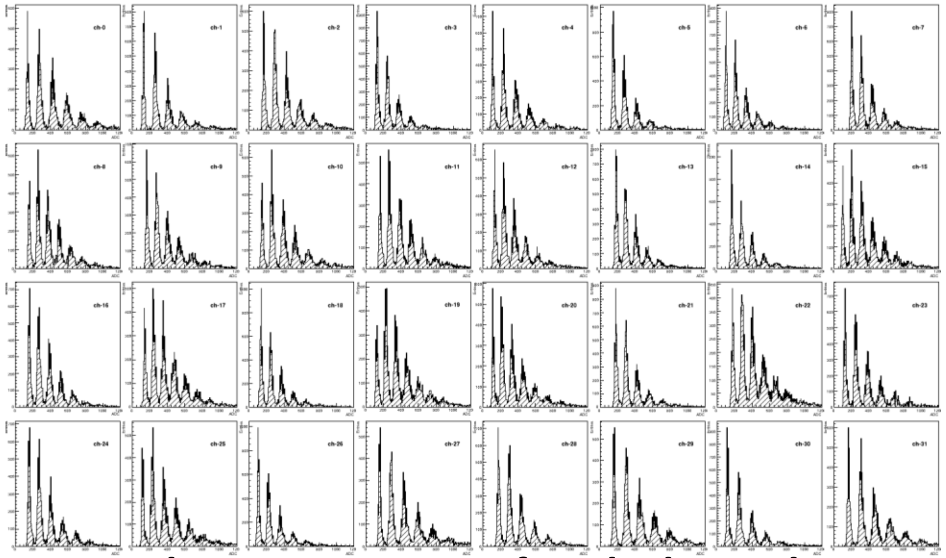
- Signal-to-noise ratio
  - Ratio of the gain and the STD of the pedestal



SNR of each channel



Distribution of pedestal of each channel



Charge spectrum of each channel