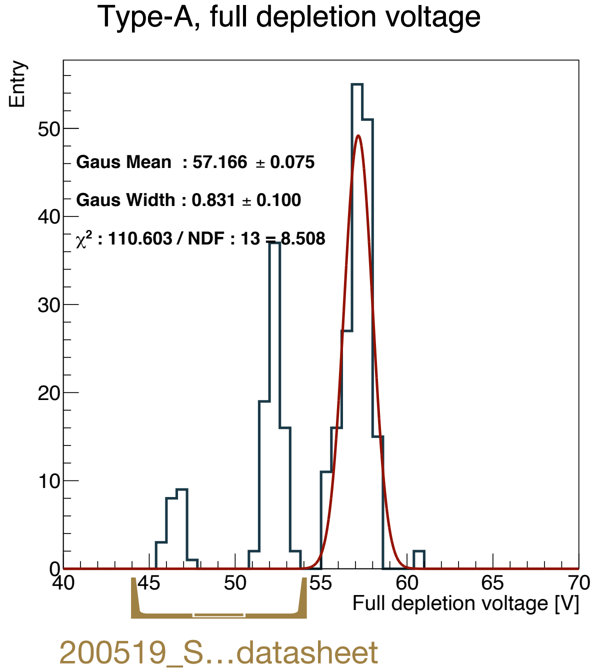
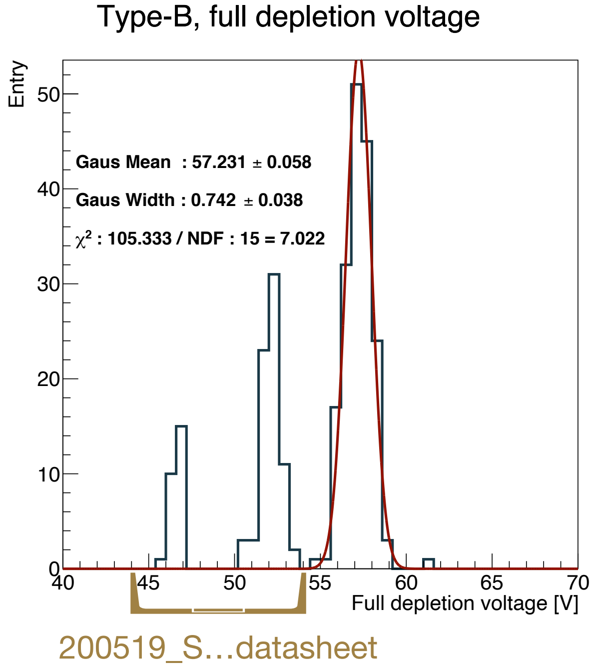
Discussion with Hamamatsu's Engineer

RIKEN/RBRC
Itaru Nakagawa

INTT sensor, full depletion voltage

274 sets of sensors are included,
file title : 190528_S…datasheet (149 sets) + 211130_S…datasheet (25 sets) + 200519_S…datasheet (100 sets)
sensor ID (A & B) : 1011 ~ 1159 + 1161 ~ 1185
1231 ~ 1330 (A) & 1223 ~ 1322 (B)





These three peaks are originated from the purity of silicon within ingots for wafers. They are known to vary by this much from one batch to another.

This is usually not an issue as long as silicons are operated high enough from the full depletion voltage, not to mention.

Hamamatsu’s insight

Cheng-Wei’s slide June 3rd, 2022

Silicon Ingot

TELESCOPE Magazine
What does technology hold in store for societies of the future?

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small stick of seed crystal hung from the end of a wire is dipped into liquid silicon. As the stick is rotated and slowly pulled up, an ingot of monocrystalline silicon is formed that has the same atomic arrangement as the seed crystal (Figure 3, top). The cylindrical ingot is then sliced into thin circular wafers, which are polished, etched, and cleaned multiple times until their surface is as shiny as a mirror (Figure 3, bottom).

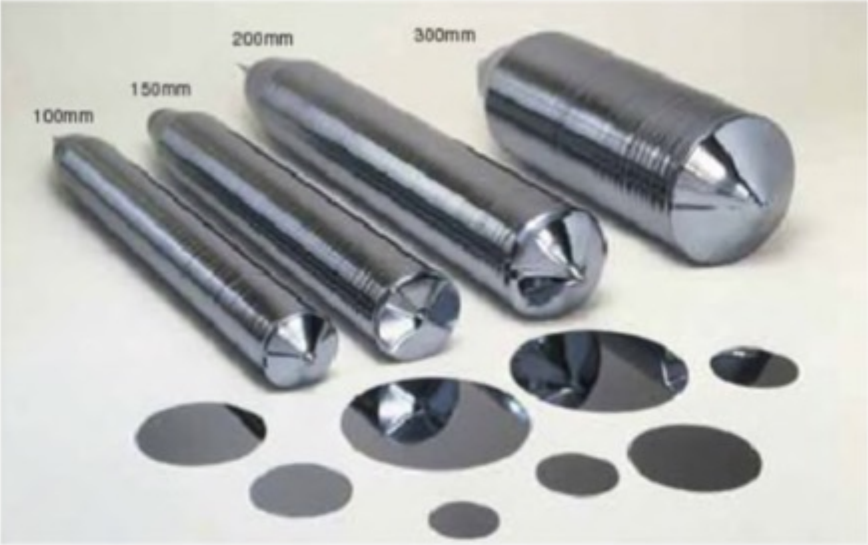


Figure 3. Silicon ingots (top) and wafers (bottom) of different diameters
Source: SUMCO

Contents

https://www.tel.com/museum/magazine/material/150430_report04_03/02.html

INTT Performance Open Questions

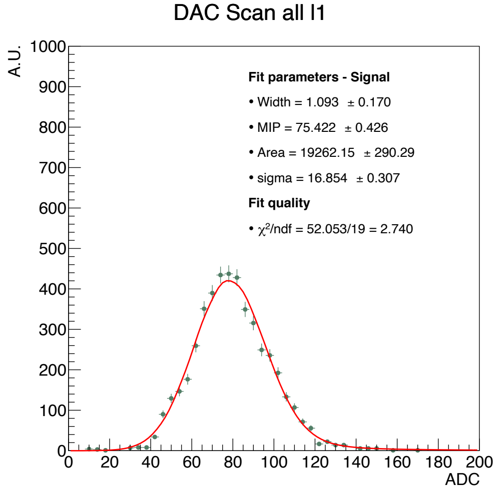
- ADC response as a function of the bias voltage
  - 100V@Fermi 2019 vs. 50V@Tohoku 2021
  - Bias scan result with source in Taiwan still doesn't explain 50V response. Sensitivity?
- Offset 200mV or 280mV is question, but this doesn't explain
  - MIP position vs single+double hit methods conflict
  - Does collimater with source helps?
  - Will be investigated by the latest NWU cosmic ray measurement with 3 ladder telescope. This study gives better angular control of trajectory compared to past single+double hit measurement.
- Thick tail of the residual distribution cannot be reproduced by MC
  - Implement accidental hit rates in MC using far side silicon area from the beam spot (Cheng-Wei)
  - Compare with low rate cosmic ray residual distribution.
  - Ultimate rate effect free efficiency evaluation with cosmic ray

Slide from the INTT meeting in May/27/2022

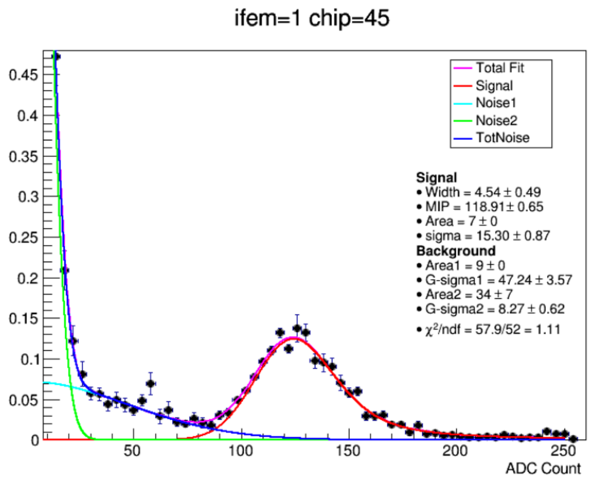
DAC scan comparison

https://indico.bnl.gov/event/15657/contributions/63079/attachments/40865/68318/INTT_energydeposit_summary.pdf

Testbeam2021, 50 V
Positron beam, 1 GeV



Testbeam2019, 100 V
Proton beam, 120 GeV



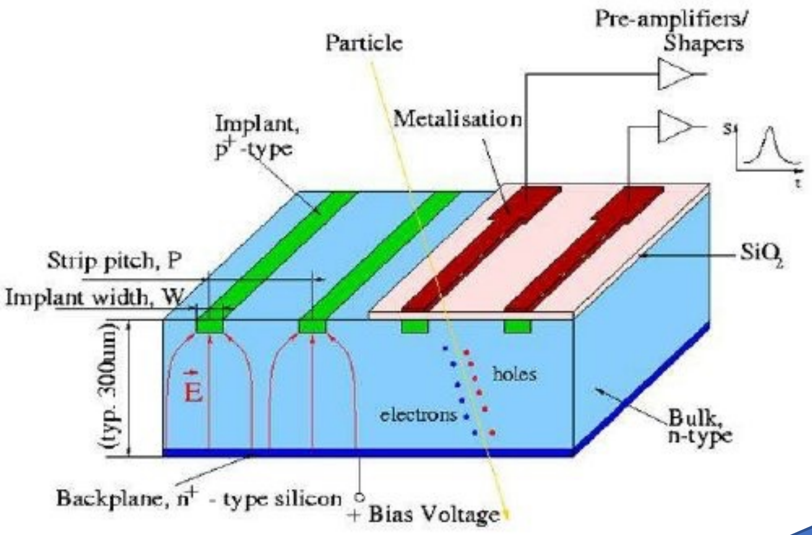
2021 Test beam was operated at 50V instead of 100V. However, observed MIP peak position (collected charge) was too low compared to what we expect from theoretical prediction.

The peaks are different
Original though : because of the difference of the supplied voltage

Capacitance - bias voltage

174 sets of sensors are included, file title : 190528_S…datasheet + 211130_S…datasheet
sensor ID : 1011 ~ 1159 + 1161 ~ 1185

Principles of operation

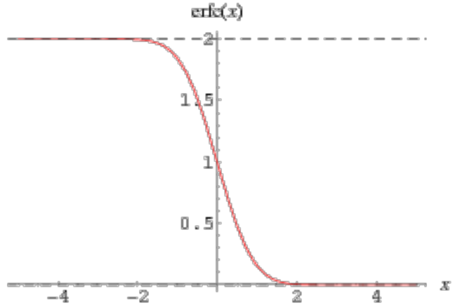


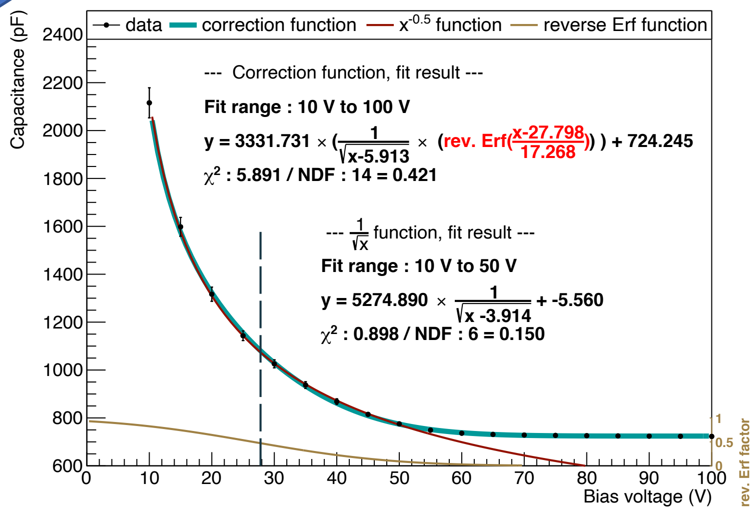
Based on the theory :

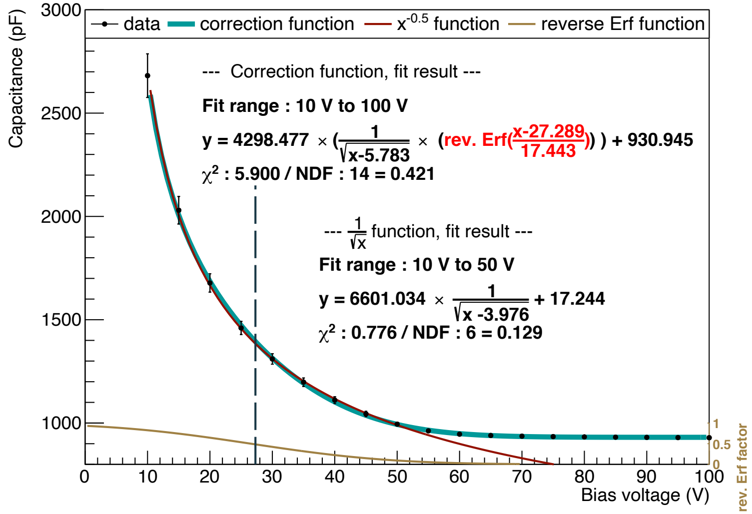
$$C \propto \frac{1}{d} \propto \frac{1}{\sqrt{V}} \propto \frac{1}{signal}$$

The theory assumes depth glows as a function of voltage

Complementary error function as a factor





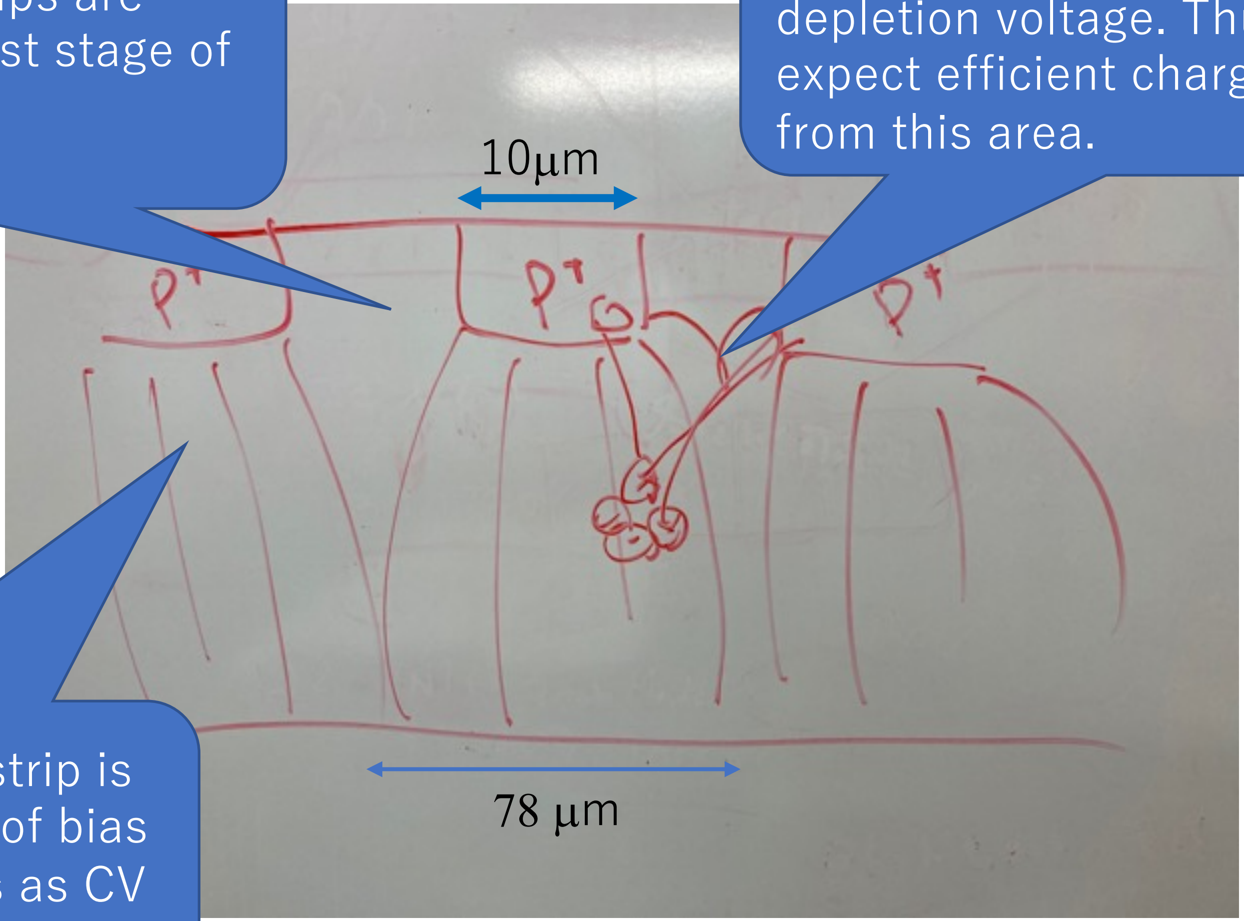


https://indico.bnl.gov/event/15909/contributions/63587/attachments/41050/68704/INTT_2022_05_20.pdf

Electric field at non-fully depleted voltage

Electric field between strips are developed towards the last stage of fully depletion voltage.

This area between strips might not be depleted even slightly below the depletion voltage. Thus we cannot expect efficient charge collection from this area.



The electric field just below strip is well developed as a function of bias voltage. This directly appears as CV response.

The best way to prove this hypothesis is to see the position dependence of the resolution within the strip width.
We'll see a dip in the efficiency distribution around the edge of a strip.

Not sure if this is doable with cosmic ray…

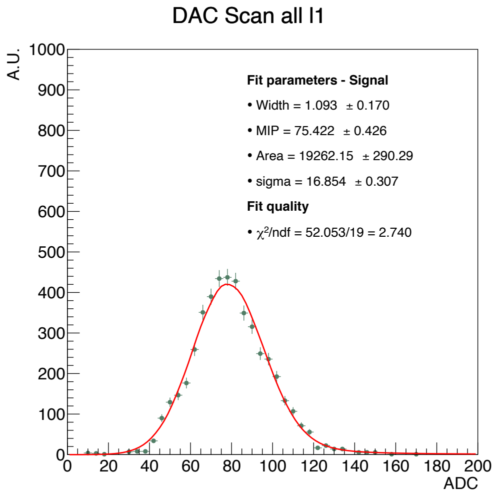
Summary

- The theoretical formula does predict expected charge collection as a function of depletion depth.
- However, the electric field is not necessarily uniform as a function of depth and thus in-efficient charge collection remains until bias voltage reaches fully depleted voltage. This is non-linear effect and depends on how strip sensors are designed.
- Unfortunately, it is difficult to predict the charge collection using ideal theoretical formula for the particular INTT sensor.

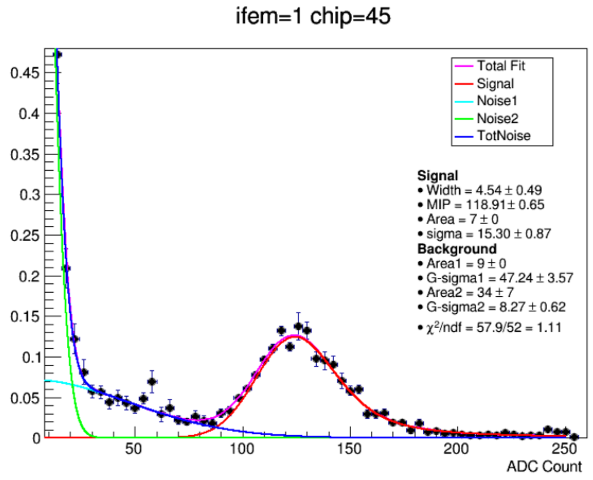
DAC scan comparison

https://indico.bnl.gov/event/15657/contributions/63079/attachments/40865/68318/INTT_energydeposit_summary.pdf

Testbeam2021, 50 V
Positron beam, 1 GeV



Testbeam2019, 100 V
Proton beam, 120 GeV



Which one is correct?
- Observation or Prediction

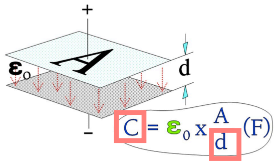
⇩

It is nice to confirm
Observation = prediction
though, it is not easy to model the electric field for our silicon strip sensor and come up with reliable prediction.

The peaks are different
Original though : because of the difference of the supplied voltage

DAC scan comparison

Based on the materials I found



$$W = \sqrt{2\epsilon\,(V + V_{bi})/Ne} = \sqrt{2\rho\mu\epsilon(V + V_{bi})}$$

d

$$C = \sqrt{\frac{\varepsilon_0 \varepsilon_r}{2\mu\rho |V|}} \cdot A$$

$$\frac{dE/dx \cdot d}{I_0} = \frac{3.87 \cdot 10^6\,\mathrm{eV/cm} \cdot 0.03\,\mathrm{cm}}{3.62\,\mathrm{eV}} \approx 3.2 \cdot 10^4\ e^- h^+ - \text{pairs}$$

Signal

Based on the theory :

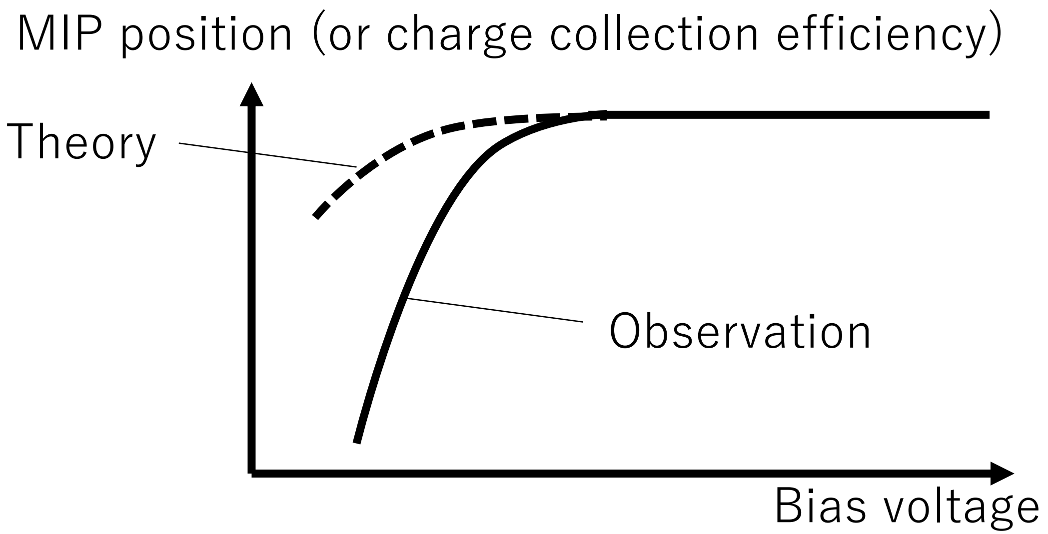
$$C \propto \frac{1}{d} \propto \frac{1}{\sqrt{V}} \propto \frac{1}{signal}$$

C : capacitance
d : the distance of the depletion region
V : supply bias voltage
signal : edep

https://indico.bnl.gov/event/15441/contributions/62374/attachments/40540/67757/INTT_energydeposit_summary.pdf

Next step?

- Give up reproducing MIP position by theoretical formula.
- However, we may want to map out the empirical charge collection as a function of bias voltage even below depletion voltage (50~60V) just to confirm safe limit of lowered bias voltage as a trade off of saving higher leakage current sensor operation.

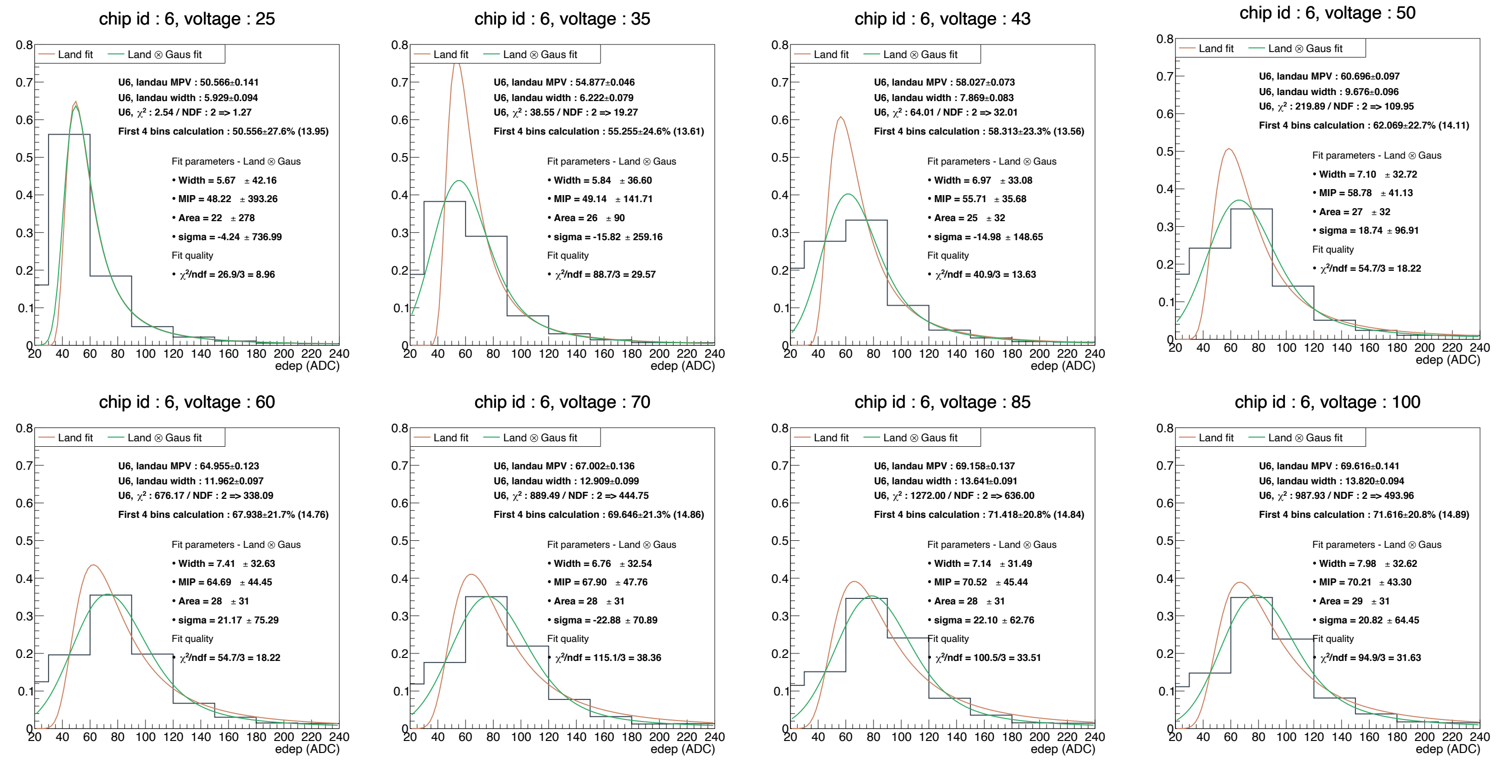


Attempted Measurement in Taiwan

Source test, different supply voltage

A further approach, the source test with different supply voltage. From 25 V to 100 V

Sr-90, self-trigger, threshold 20 ADC



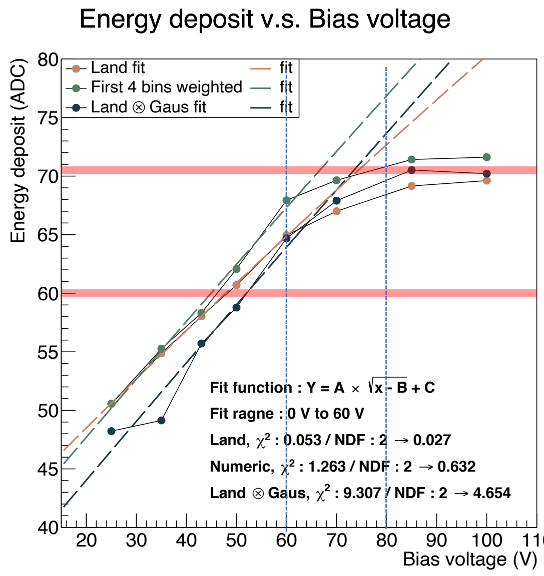
Attempted Measurement in Taiwan

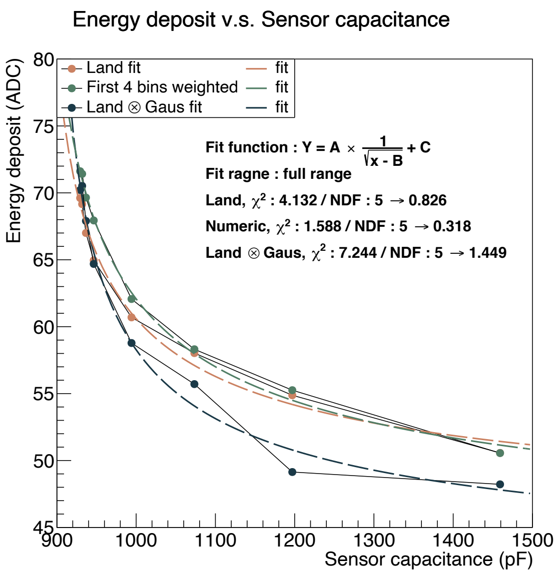
- Can we answer to the question what is the safety lowered operation bias voltage with this measurement?
- The measurement shows the collection efficiency starts dropping at 80V or so which is higher than depletion voltage 50~60V.
- Is there any idea to improve the precision of charge collection response as a function of the bias voltage?

Such a measurement should have done in one of 3 beam tests, but we have to scratch our head if we can do in test bench.

Source test, different supply voltage

Because the resolution of the energy is poor, 3 approaches to obtain the peak position : pure land, land ⊗ gaus and a numeric weighted method calculation with first 4 bins





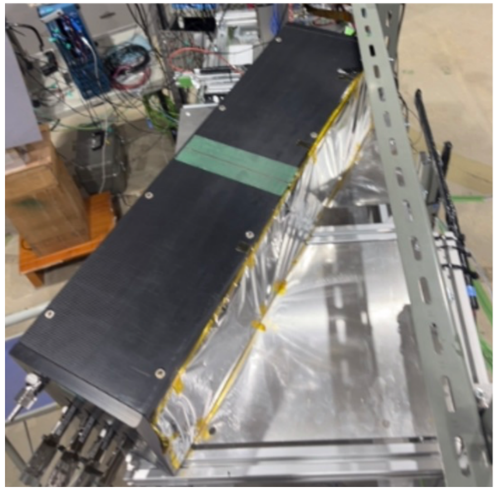
The result fits to our expectation, the discrepancy increases as the bias voltage increases. Because the it gradually reaches to the limit of the depletion region

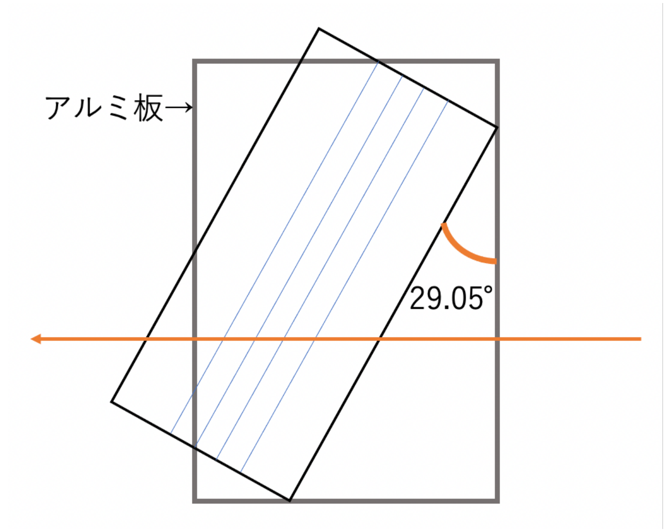
For the case of capacitance, it is reasonable as well. The full range is considered for the fitting.

sPHENIX INTT | Cheng-Wei Shih (NCUHEP, Taiwan) | 10

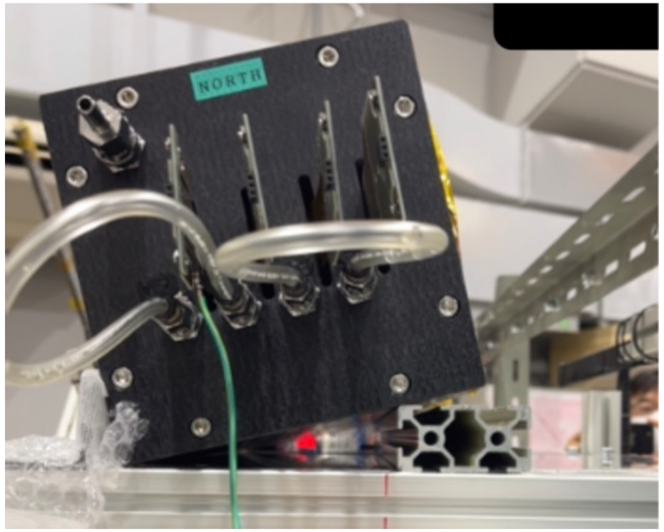
Other homework from the beam test

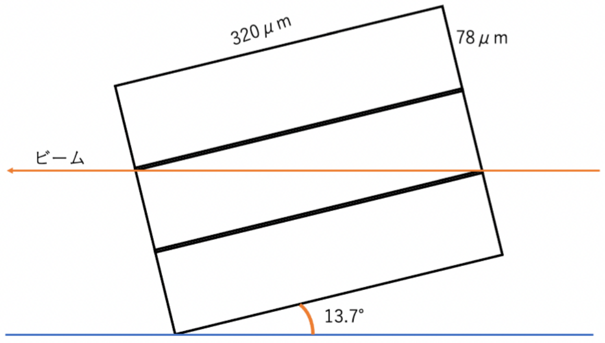
Horizontal Rotation





Vertical Rotation





Useful calibration for

- Total charge collection
- Offset value

Useful calibration for

- Charge sharing model between strips

To be implemented to INTT GEANT Model