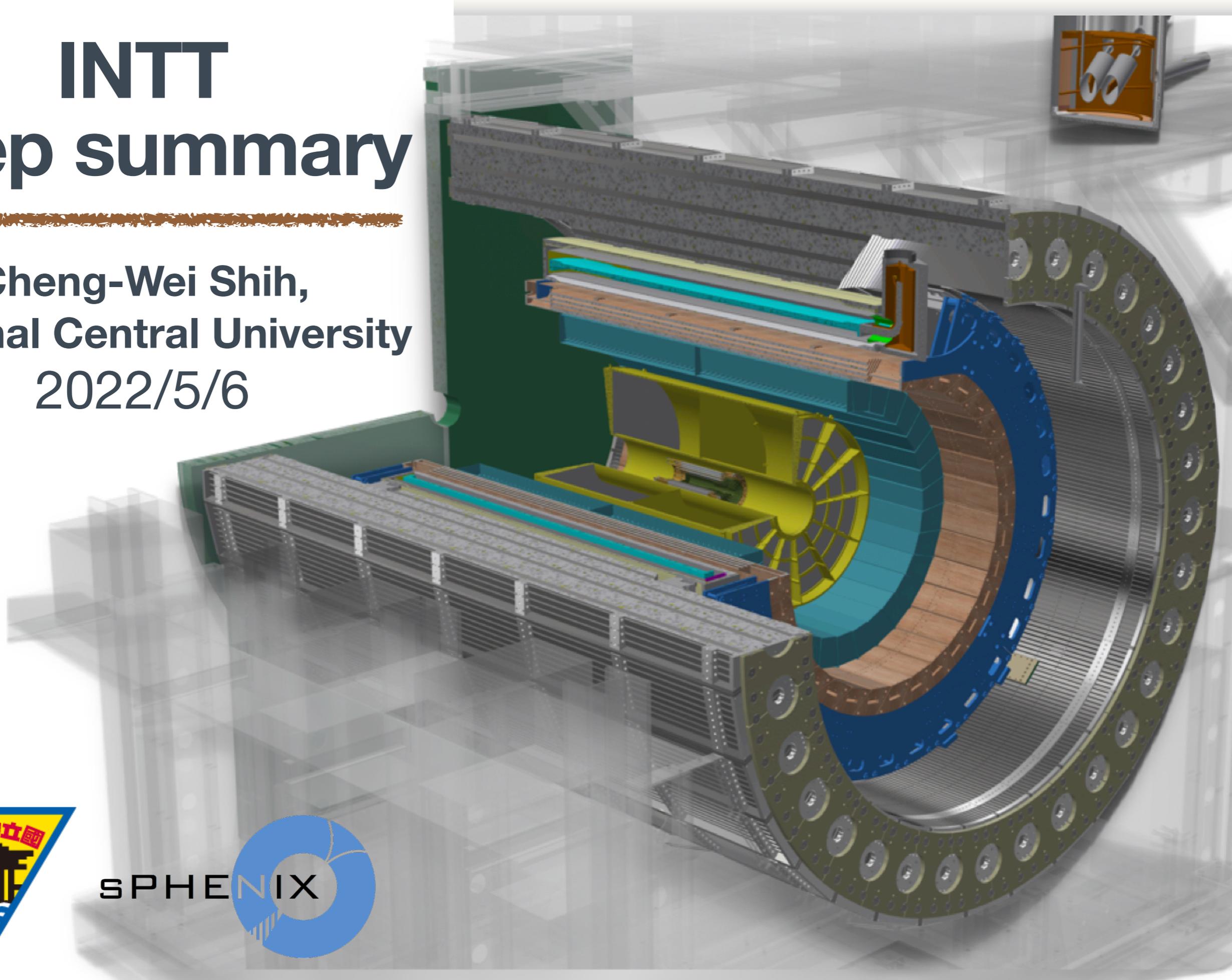


INTT edep summary

Cheng-Wei Shih,
National Central University
2022/5/6



// DAC scan

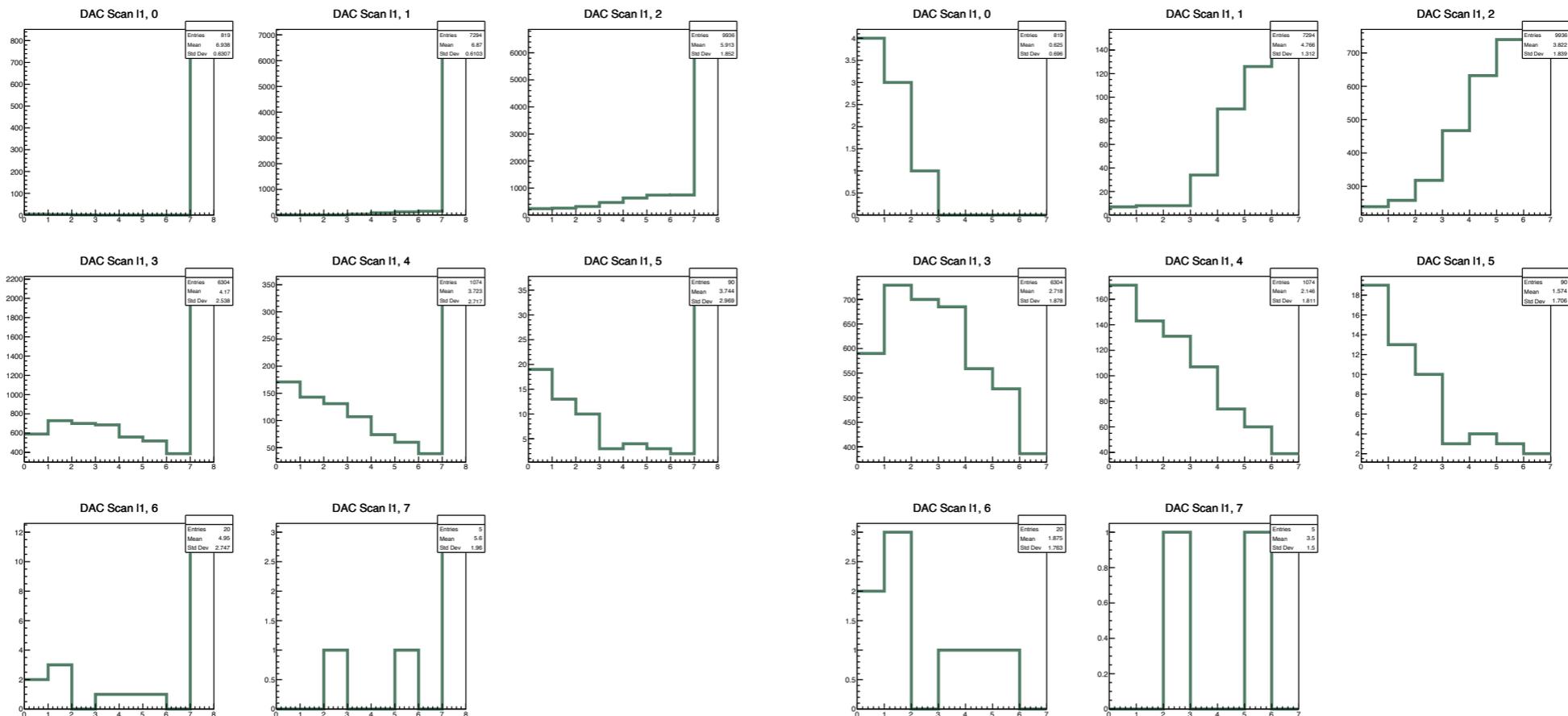
- Event profile has to be 111
- single hit for each layer only
- Clone groups in one INTT trigger event are deleted

- Algorithm is same as Testbeam2019 :
 - 6th, 7th bins : histogram **matching**
 - 8th bin : overflow, neglect
- Criteria :
 - Event profile has to be 111
 - single hit for each layer only

run1	run2	run3	run4	run5	run6	run7	run8
8	28	48	68	88	108	128	148
12	32	52	72	92	112	132	152
16	36	56	76	96	116	136	156
20	40	60	80	100	120	140	160
24	44	64	84	104	124	144	164
28	48	68	88	108	128	148	168
32	52	72	92	112	132	152	172
36	56	76	96	116	136	156	176
40	60	80	100	120	140	160	180

With 8th bin, L0

Without 8th bin, L0

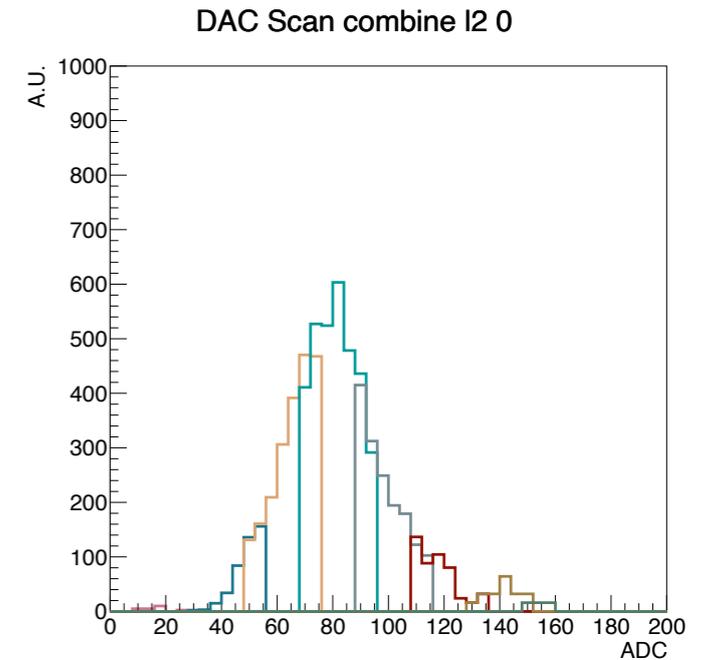
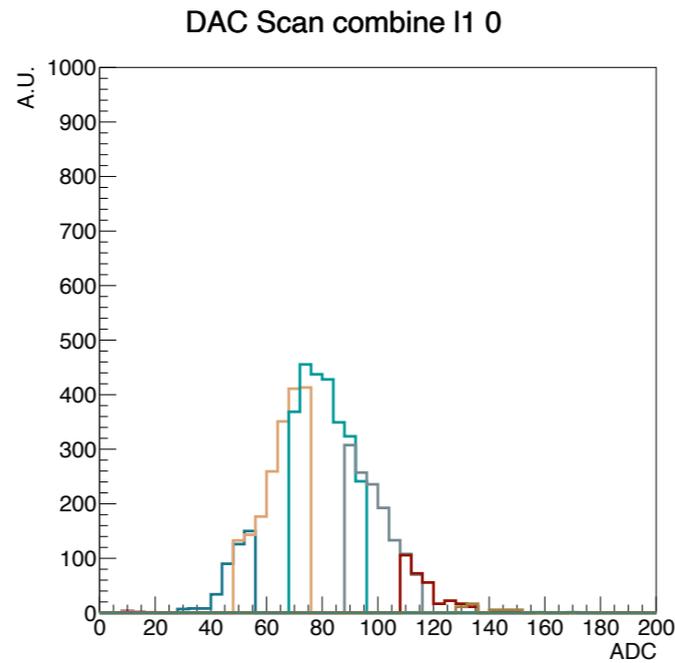
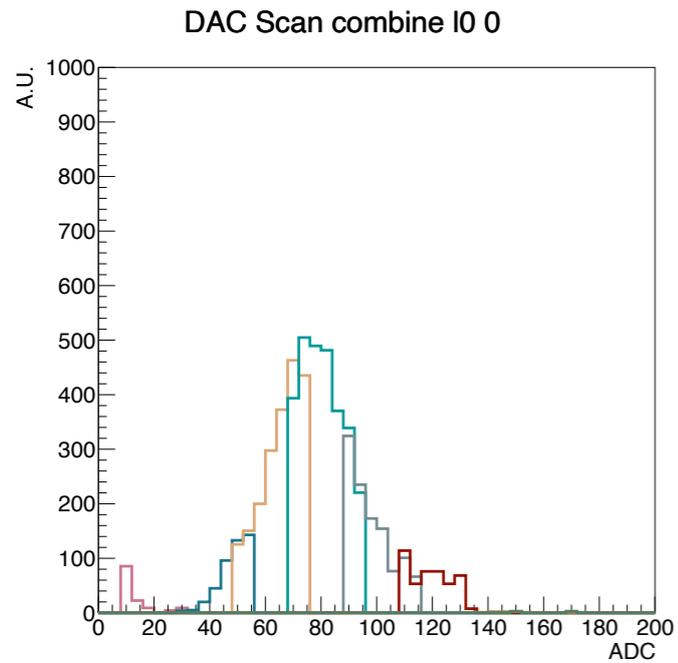


Testbeam2021, bias voltage 50 V

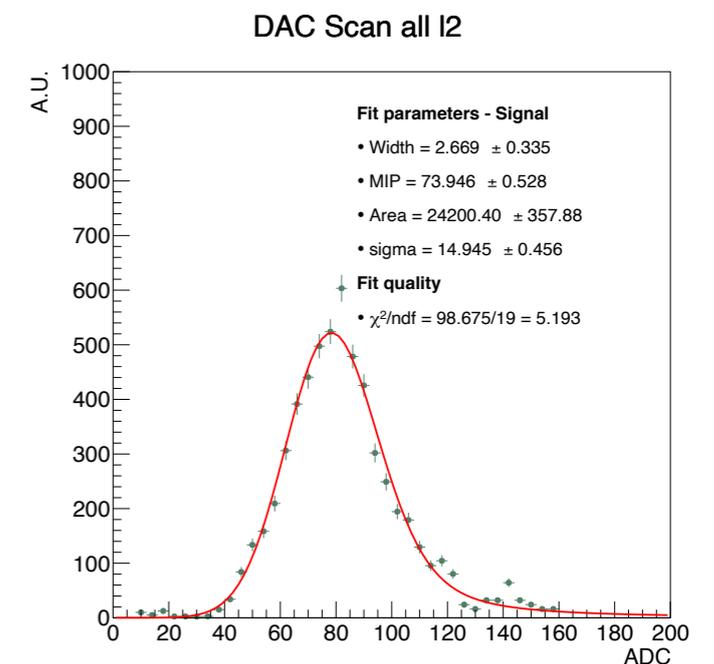
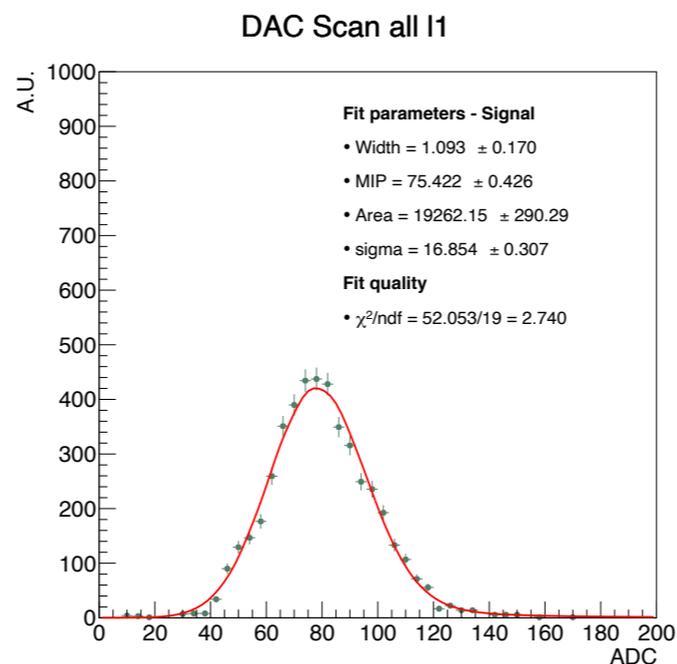
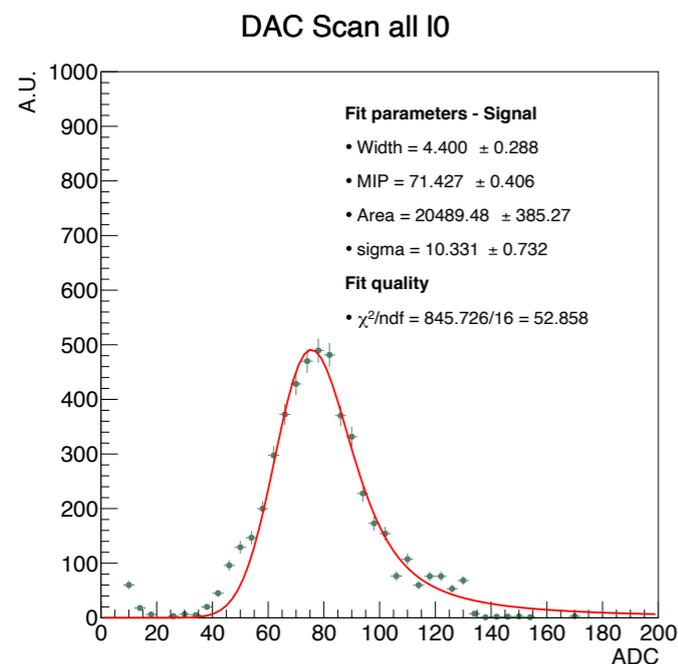
// DAC scan

- Event profile has to be 111
- single hit for each layer only
- Clone groups in one INTT trigger event are deleted

Histogram matching



Fitting function : Landau convolute with Gaussian

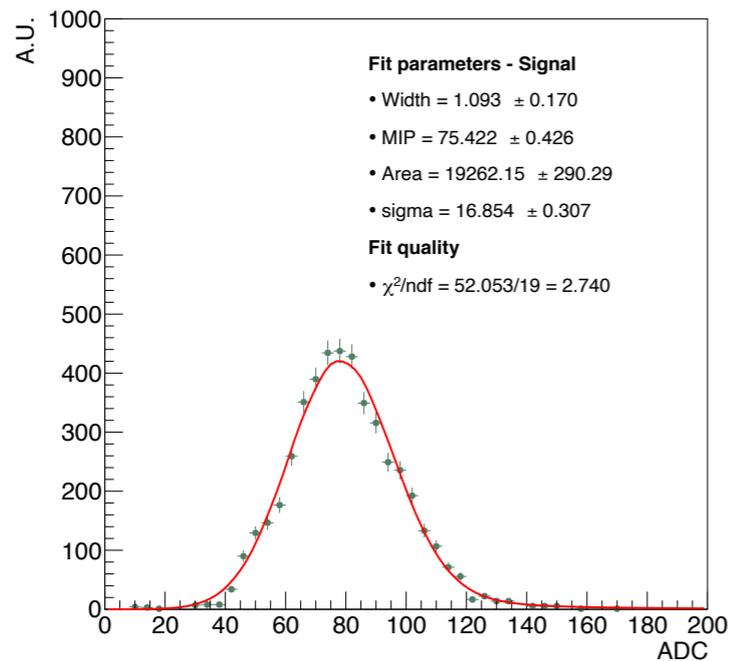


Testbeam2021, bias voltage 50 V

// DAC scan comparison

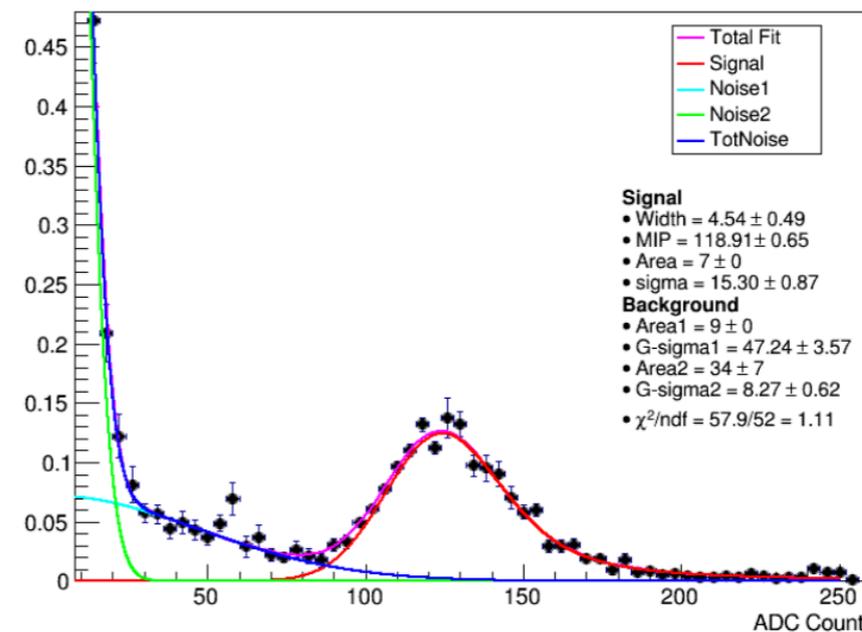
Testbeam2021, 50 V
Positron beam, 1 GeV

DAC Scan all I1



Testbeam2019, 100 V
Proton beam, 120 GeV

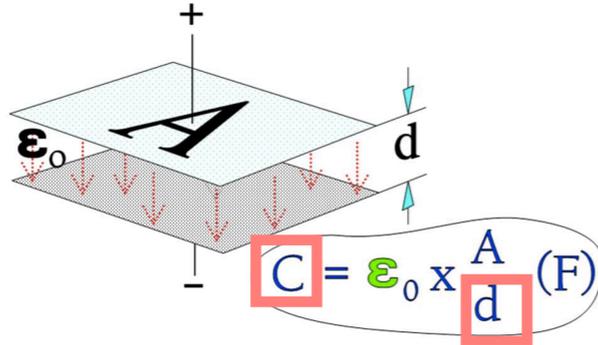
ifem=1 chip=45



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

// Capacitance - relation

Based on the materials I found



Based on the theory :

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

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

$$C = \sqrt{\frac{\epsilon_0 \epsilon_r}{2\mu\rho|V|}} \cdot A$$

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

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

Signal

// Capacitance - bias voltage

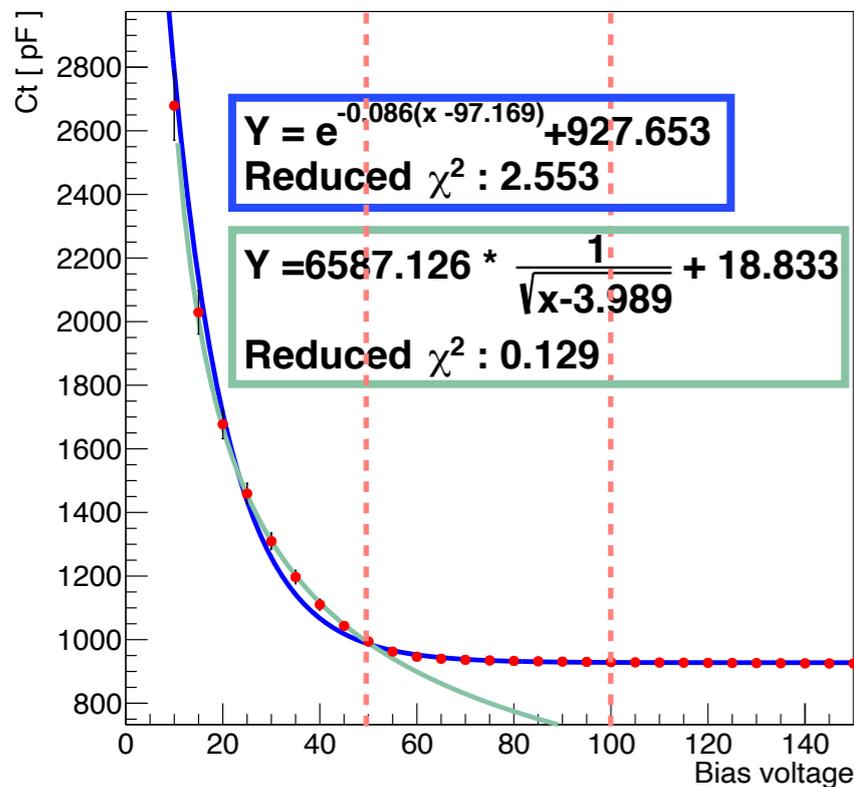
Based on the theory :

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

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

Verify **capacitance vs voltage**

INTT Type-A sensor, CV curve



	@24.35 V	@ 50 V	@ 100 V
Type A, Ct [pF]	1495.45	994.149	929.325

$$\frac{1}{\sqrt{50}} / \frac{1}{\sqrt{24.35}} = \boxed{0.697}$$

$$\frac{C@50V}{C@24.35V} = \frac{994.149}{1495.45} = \boxed{0.665}$$



$$\frac{1}{\sqrt{100}} / \frac{1}{\sqrt{50}} = \boxed{0.707}$$

$$\frac{C@100V}{C@50V} = \frac{929.325}{994.149} = \boxed{0.934}$$



For the case of INTT, $C \propto \frac{1}{\sqrt{V}}$ seems to be suitable to describe the data only for the **range 0 V to 50 V**

// Capacitance - bias voltage

Based on the theory :

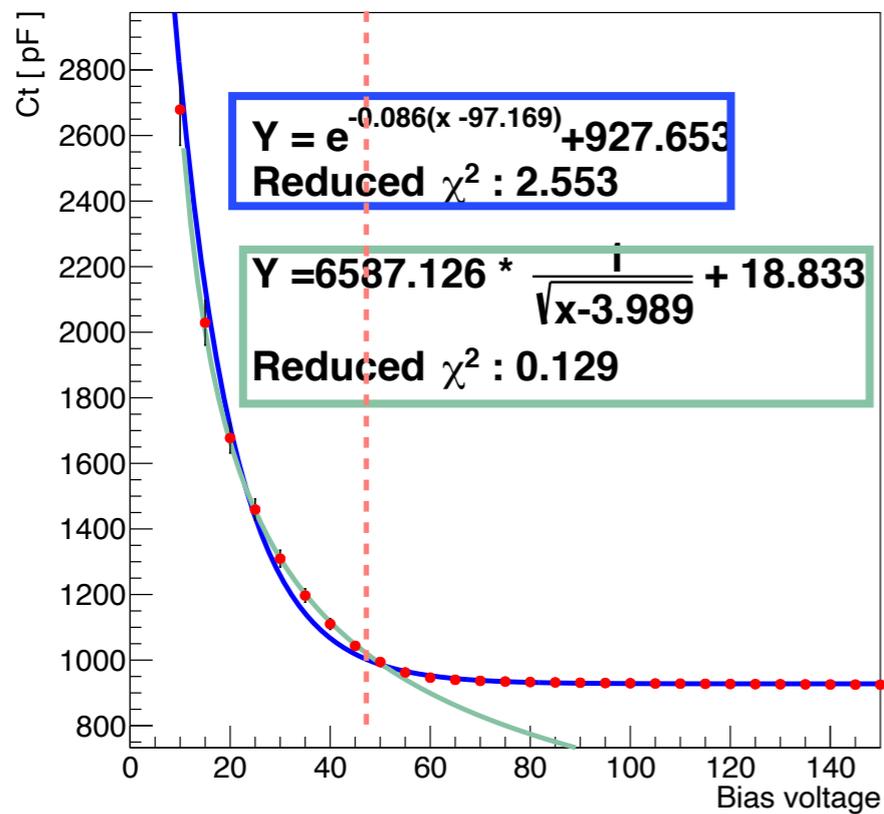
$$C \propto \frac{1}{d} \propto \frac{1}{\sqrt{V}} \propto \frac{1}{\text{signal}}$$

Paper link

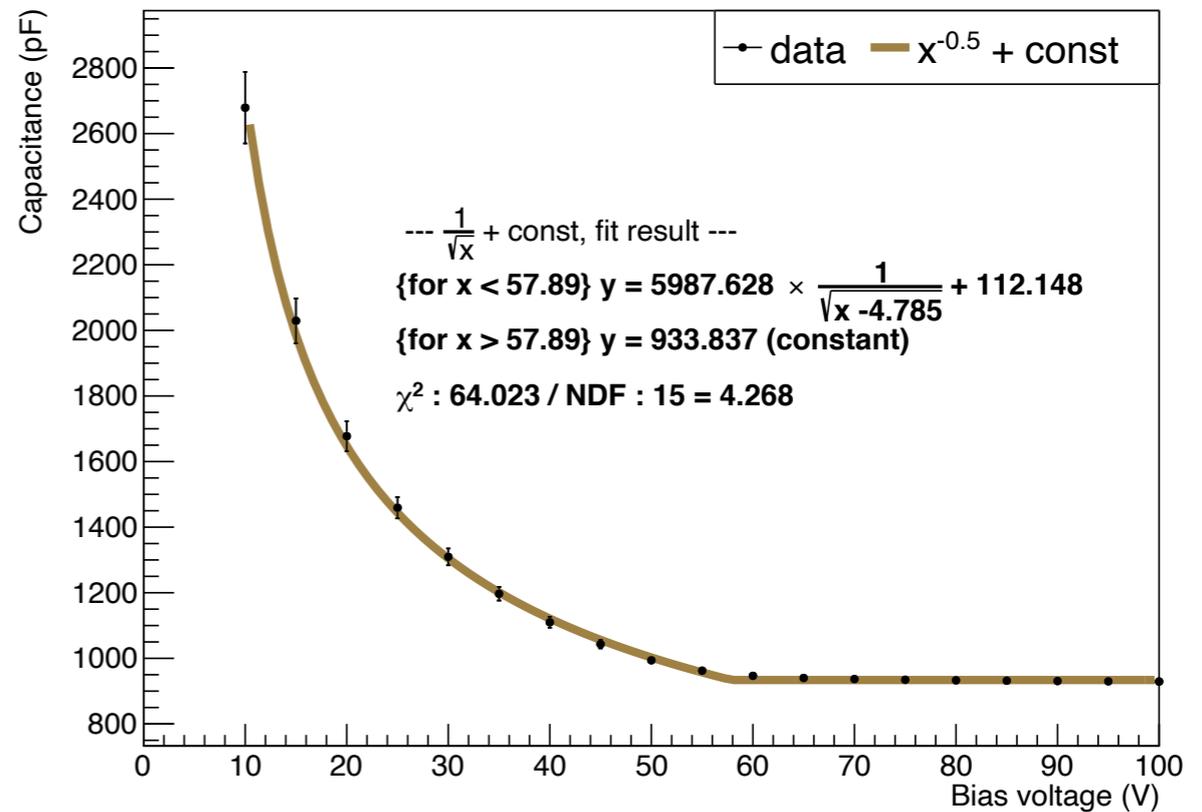
Thus, the capacitance of a planar diode exhibits a $V_{\text{Bias}}^{-1/2}$ behavior before the bias voltage reaches the depletion voltage V_{D0} . For $V_{\text{Bias}} > V_{\text{D0}}$, the body capacitance per unit length is:

$$c_0 = \epsilon \frac{p}{d} = \text{const.} \quad (3)$$

INTT Type-A sensor, CV curve



Capacitance - Bias voltage



INTT sensor, full depletion voltage

Measurements from Hamamatsu

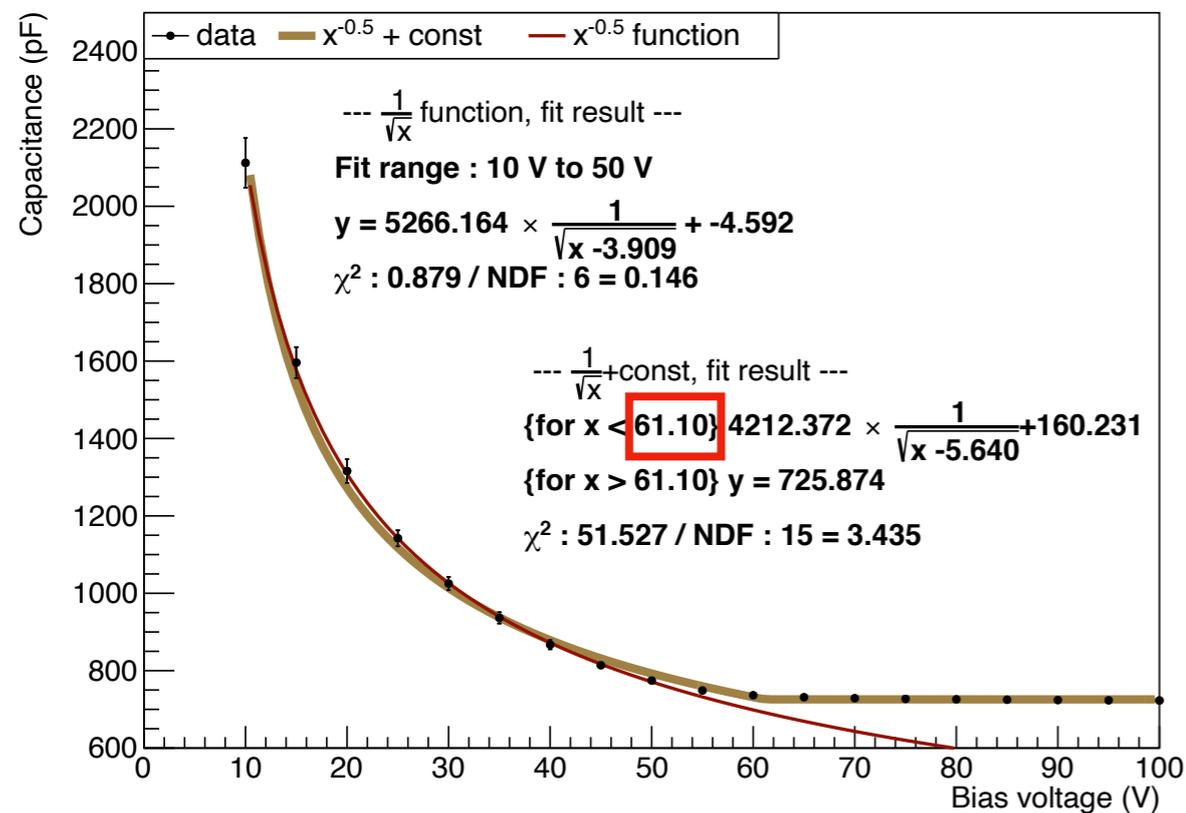
220 V	68.4	919.5	68.2	920.0	67.8	920.3	69.2
225 V	68.5	919.5	68.2	920.0	67.8	920.1	69.5
230 V	68.7	919.3	69.0	919.9	68.0	920.0	69.8
235 V	68.9	919.2	69.1	919.7	68.4	919.8	70.1
240 V	69.1	919.0	73.9	919.6	69.1	919.7	70.8
245 V	69.4	918.9	74.2	919.4	72.0	919.6	73.5
250 V	70.1	918.8	72.7	919.3	73.9	919.5	75.8
Vfd [V]	65	65	65				
NG Strip	Nothing	Nothing	Nothing				

Paper link

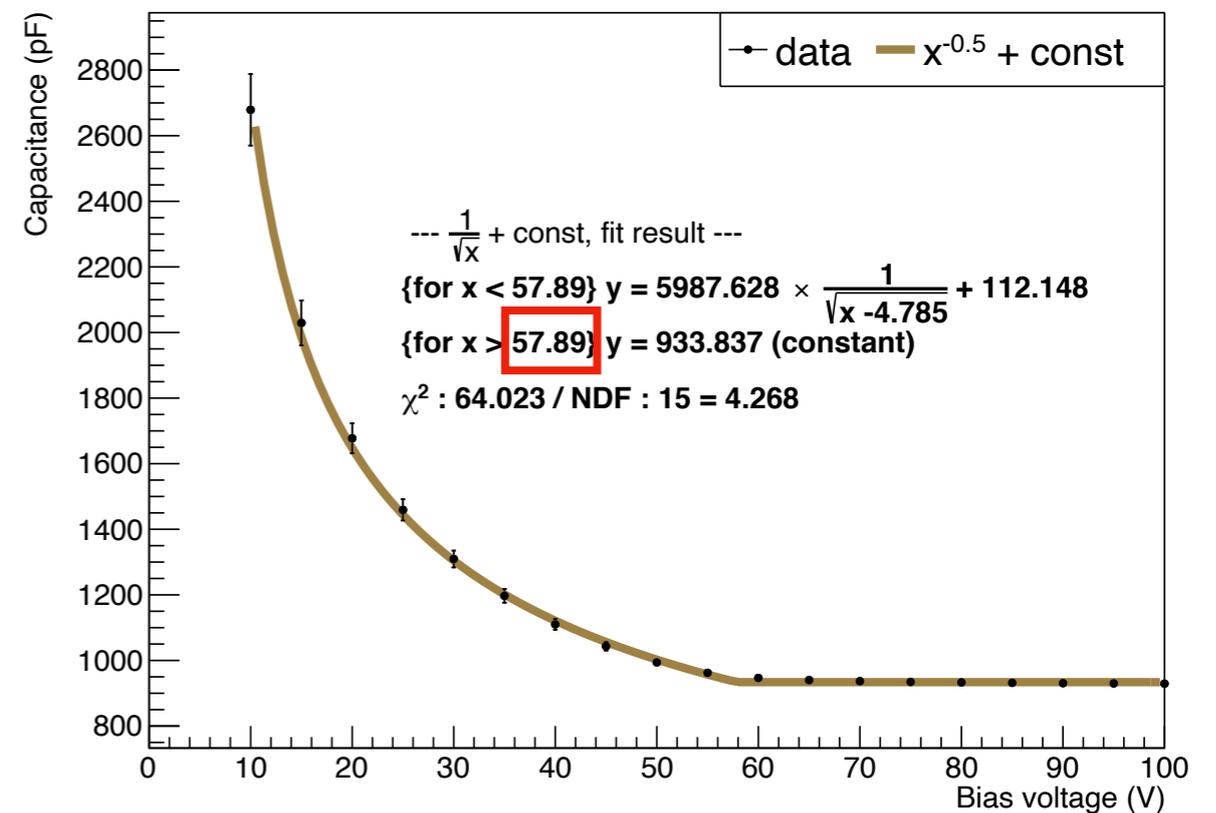
Thus, the capacitance of a planar diode exhibits a $V_{\text{Bias}}^{-1/2}$ behavior before the bias voltage reaches the depletion voltage V_{D0} . For $V_{\text{Bias}} > V_{\text{D0}}$, the body capacitance per unit length is:

$$c_0 = \epsilon \frac{p}{d} = \text{const.} \quad (3)$$

Capacitance - Bias voltage (type B)



Capacitance - Bias voltage (Type A)



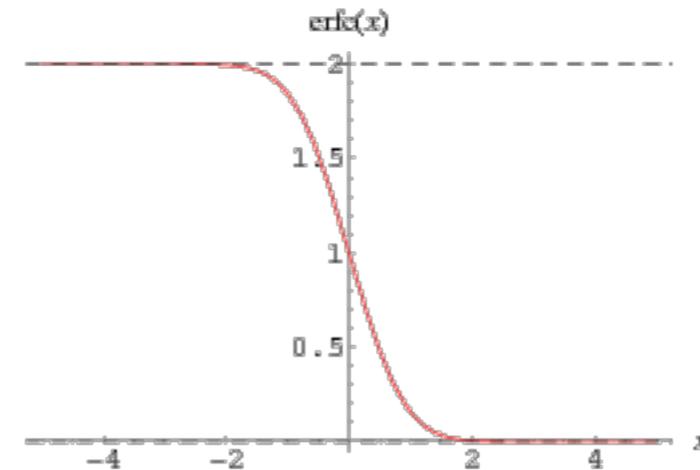
Full depletion voltage 61 ~ 65 V

// Capacitance - bias voltage

Complementary error function as a factor

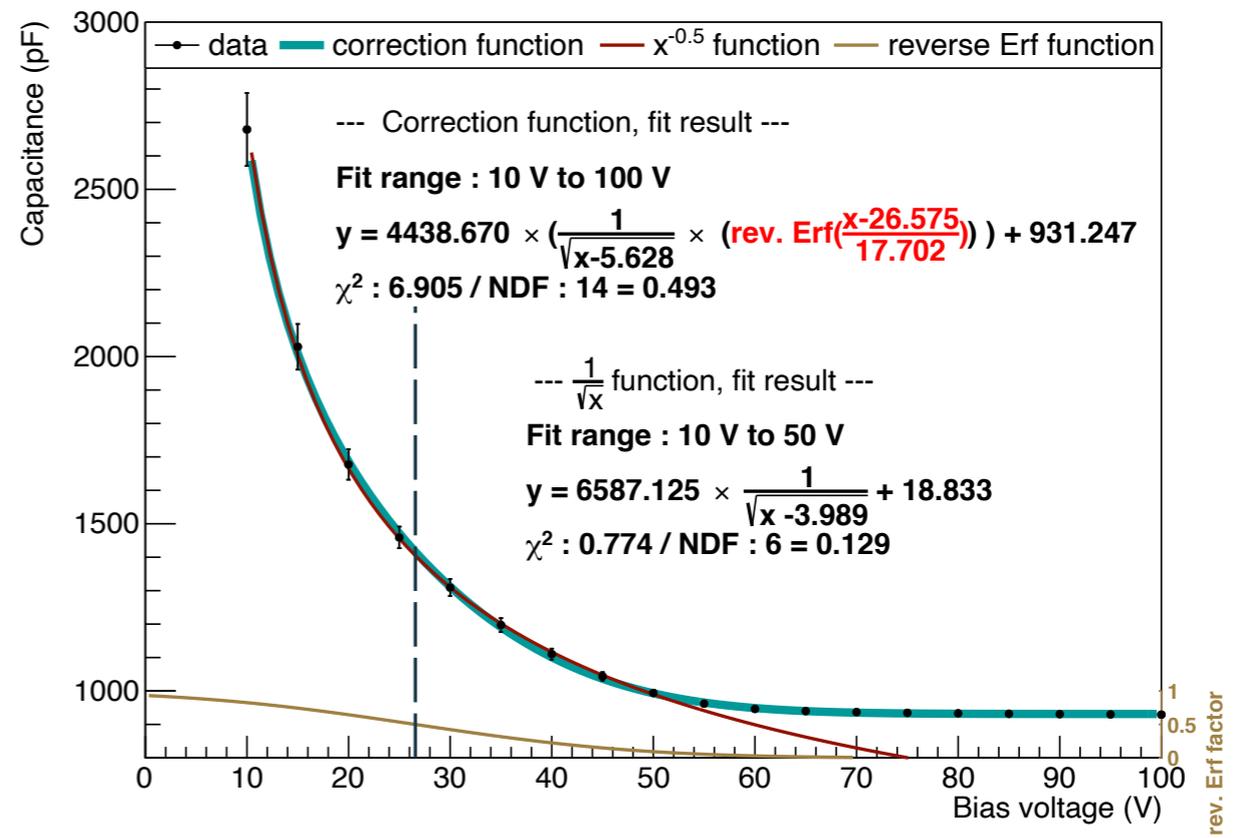
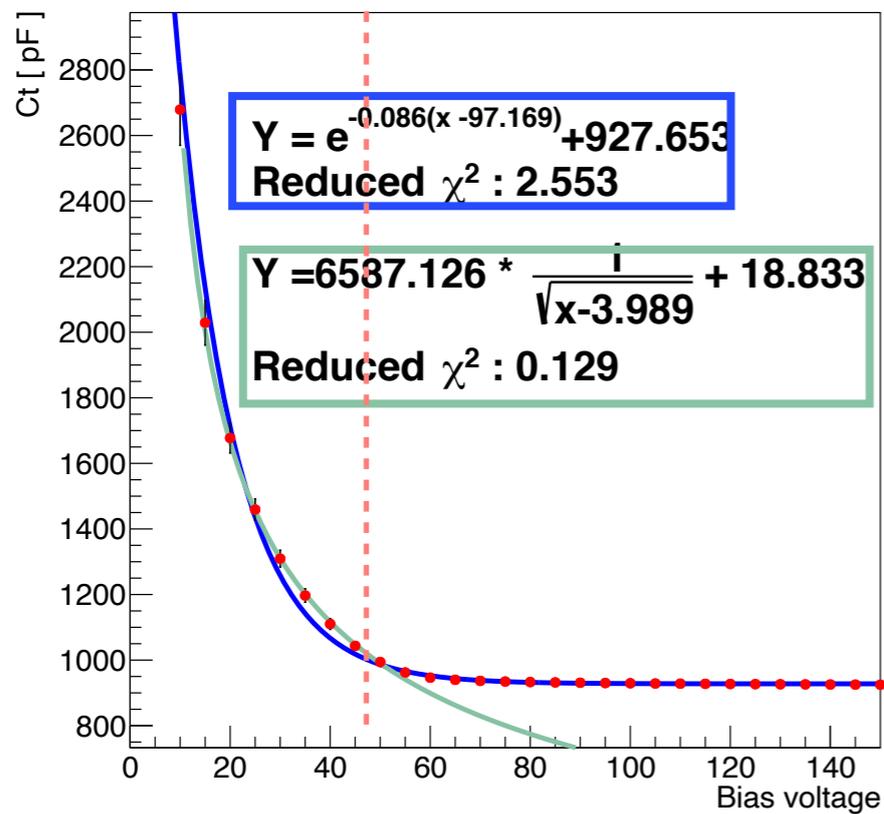
Based on the theory :

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



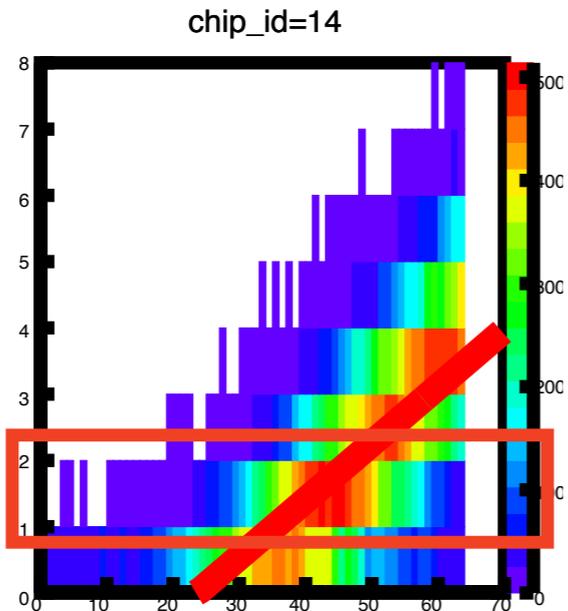
Capacitance - Bias voltage

INTT Type-A sensor, CV curve

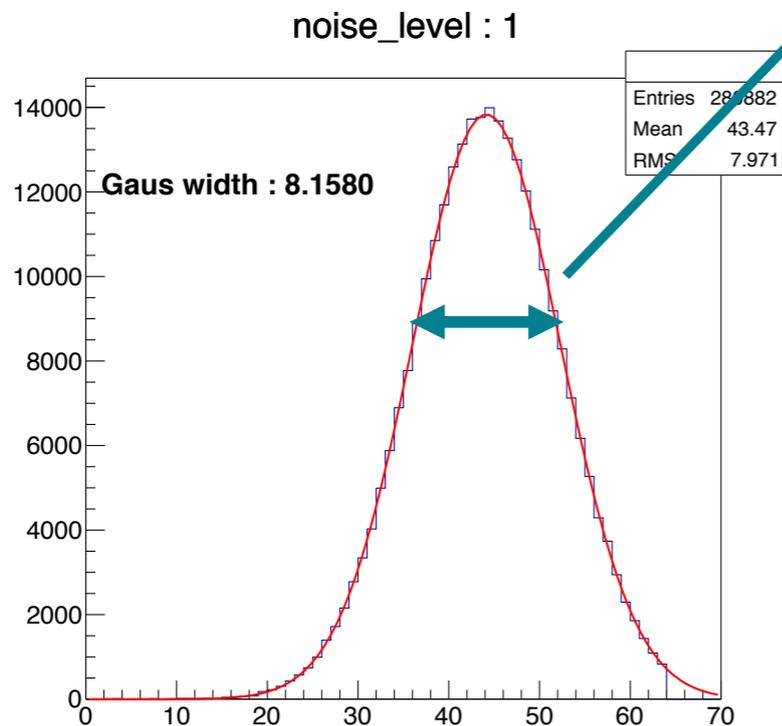
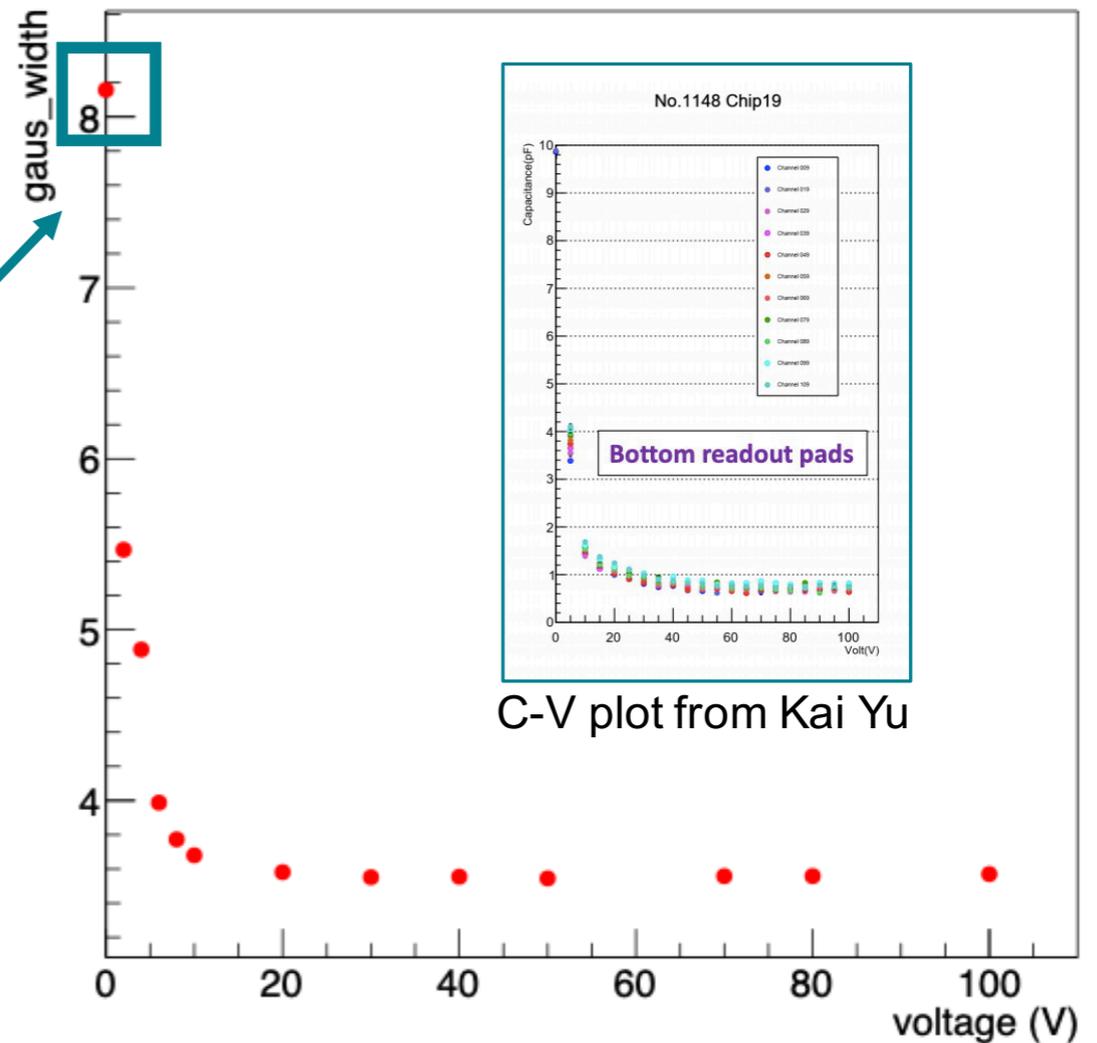


// Supply voltage vs noise level

Previous results, 2020/06/19



pre-Production-002, gaus_width to V



The difference can barely be found for the runs with bias voltage larger than 25 V

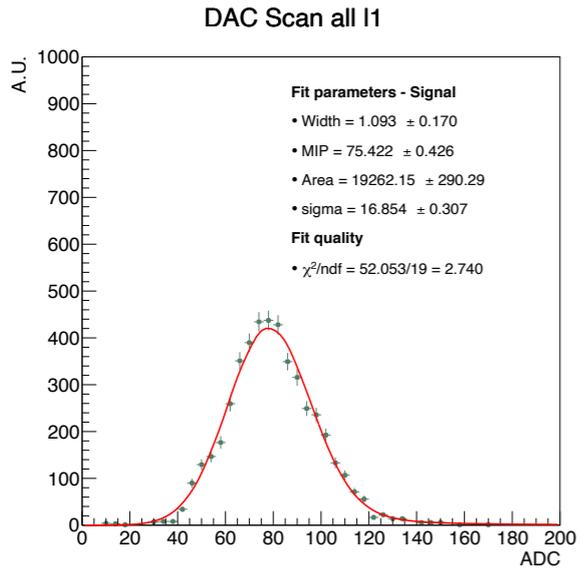
// DAC scan comparison

Based on the theory :

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

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

Verify edep vs voltage (V) and capacitance (C)



Compare $\frac{1}{\sqrt{V}}$ and $\frac{1}{\text{signal}}$ →

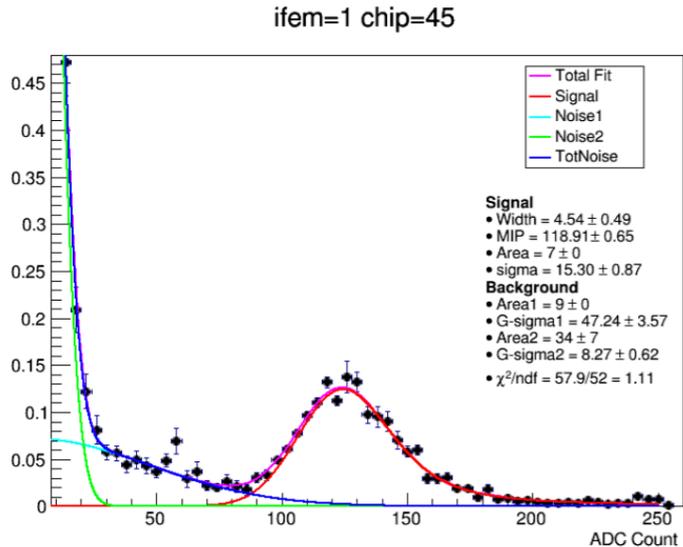
$$\frac{\frac{1}{\sqrt{100}}}{\frac{1}{\sqrt{50}}} = 0.707$$

$$\frac{\left(\frac{1}{\text{edep@100}}\right)}{\left(\frac{1}{\text{edep@50}}\right)} = 0.634$$


Compare "C" and $\frac{1}{\text{signal}}$ →

$$\frac{C@100V}{C@50V} = \frac{929.325}{994.149} = 0.934$$

$$\frac{\left(\frac{1}{\text{edep@100}}\right)}{\left(\frac{1}{\text{edep@50}}\right)} = 0.634$$

Conclusion : we should not use the voltage for the comparison, we should use capacitance.

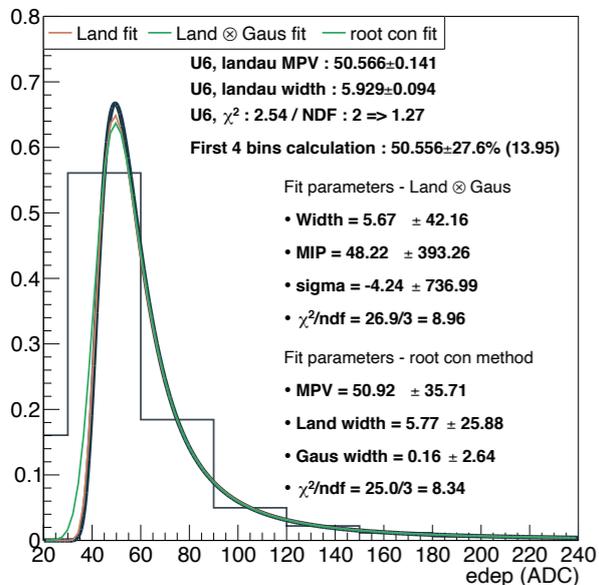
But the capacitance ratio doesn't match to the edep ratio

// Source test, different supply voltage

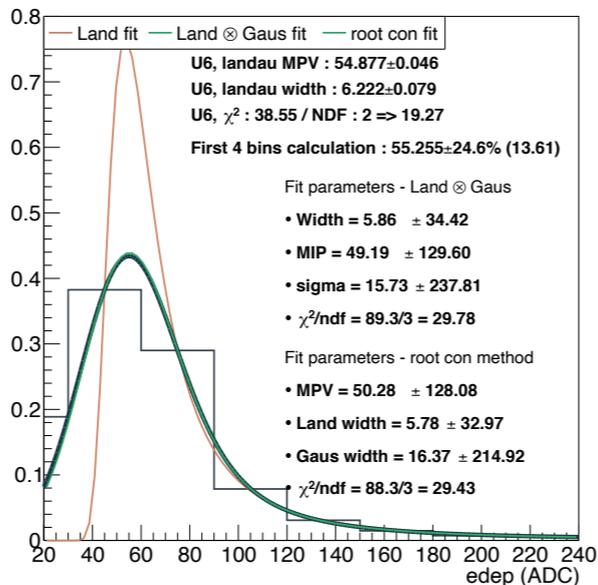
A further approach, the source test with different supply voltage. From 25 V to 100 V

Sr-90, self-trigger, threshold 20 ADC, adc setting : 20, 30, 60, 90, 120, 150, 180, 210

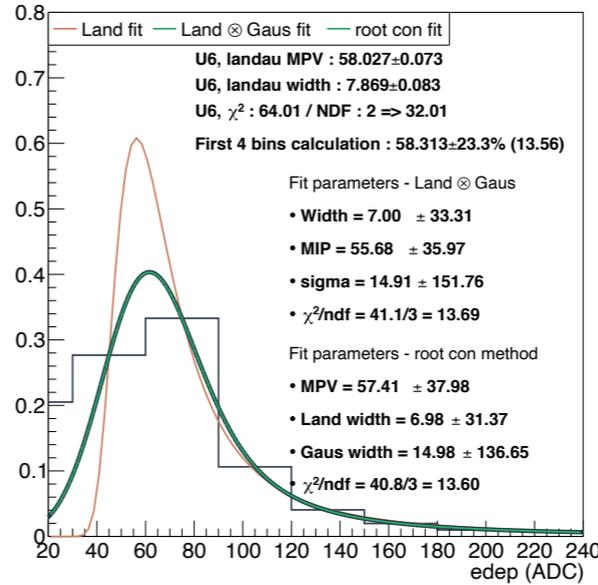
chip id : 6, voltage : 25



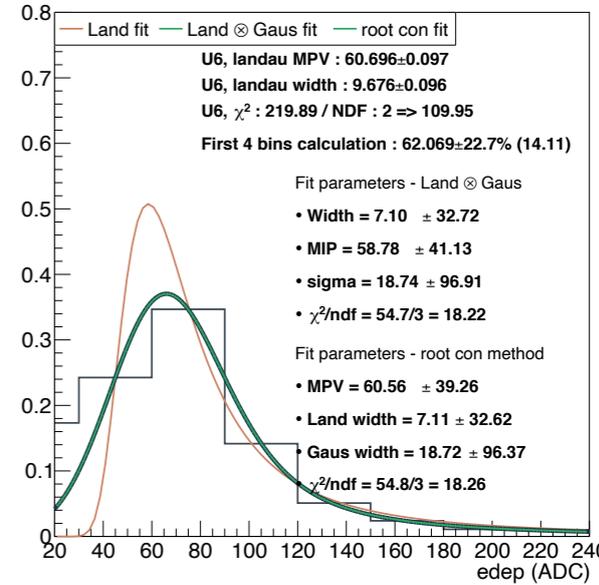
chip id : 6, voltage : 35



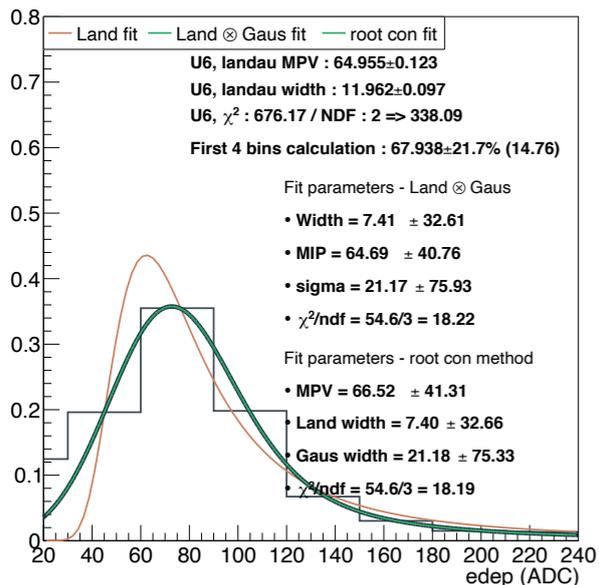
chip id : 6, voltage : 43



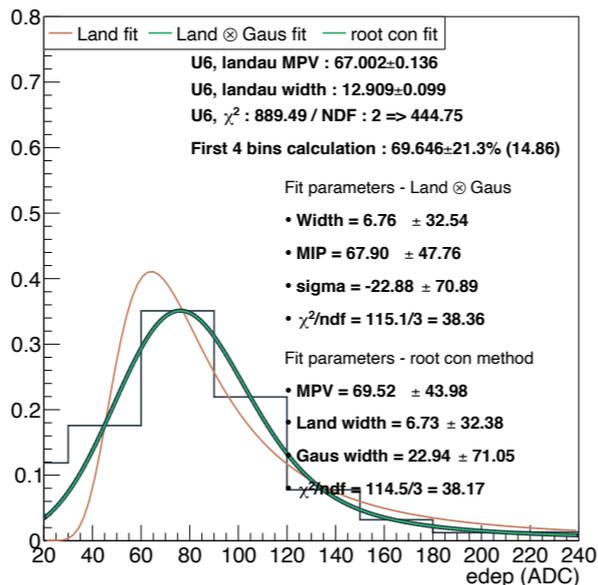
chip id : 6, voltage : 50



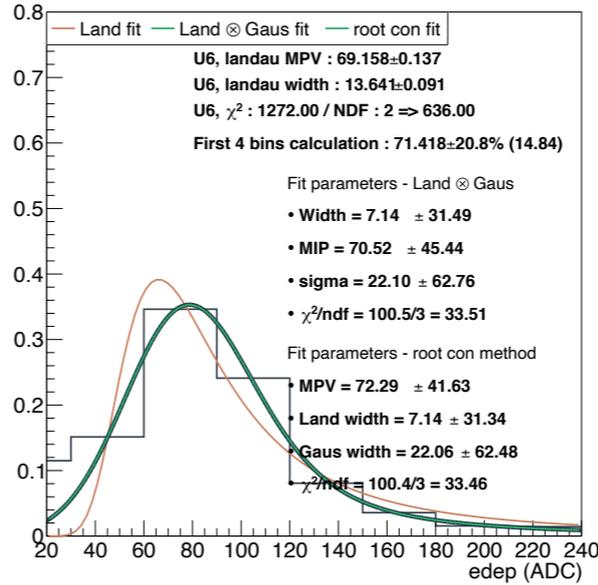
chip id : 6, voltage : 60



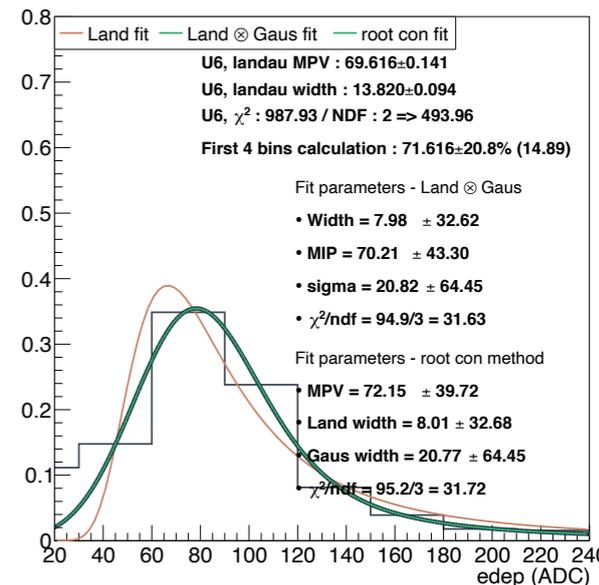
chip id : 6, voltage : 70



chip id : 6, voltage : 85



chip id : 6, voltage : 100

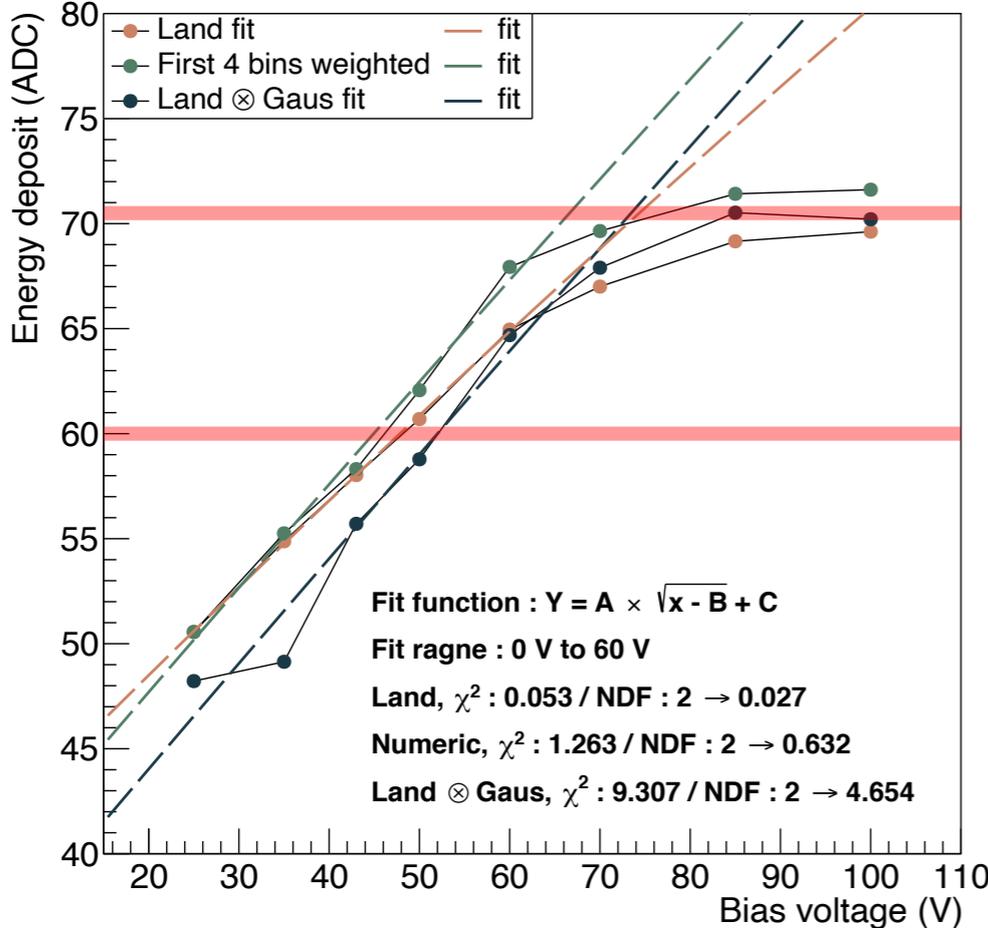


I used the root official convolution fit as well. but the return of the MPV is not true MPV

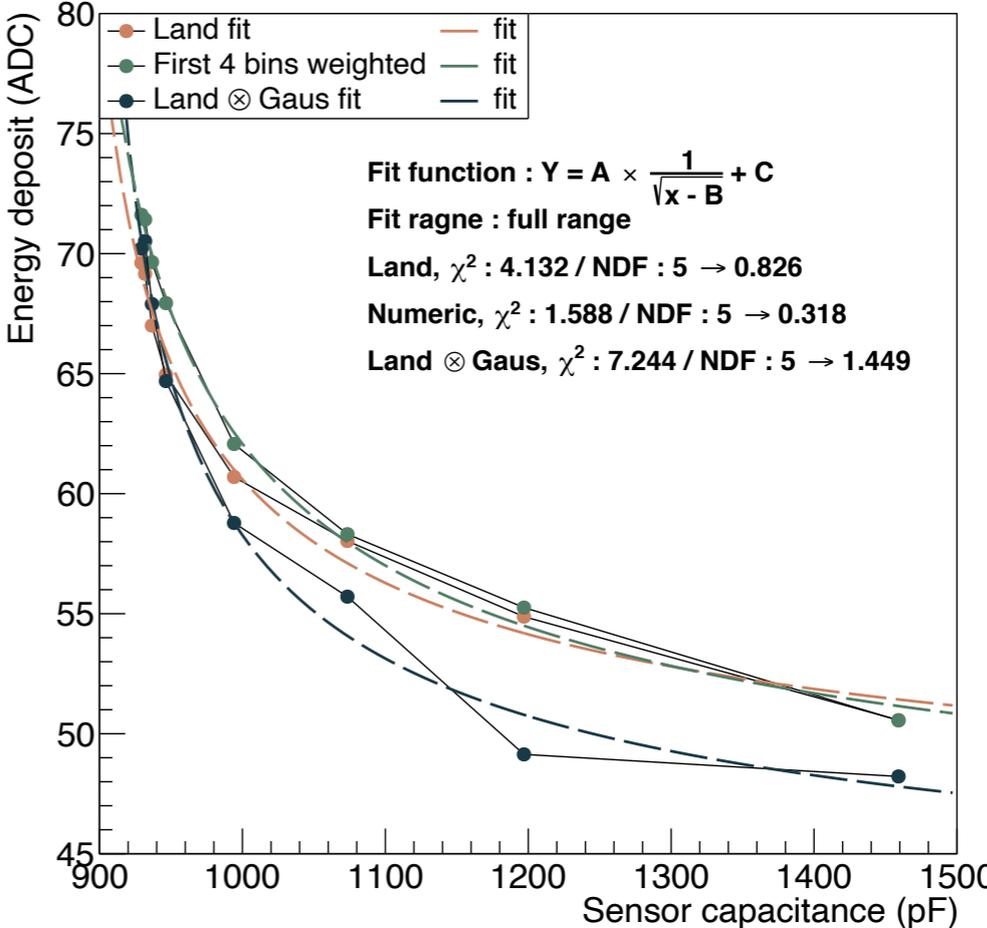
Source test, different supply voltage

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

Energy deposit v.s. Bias voltage



Energy deposit v.s. Sensor capacitance



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

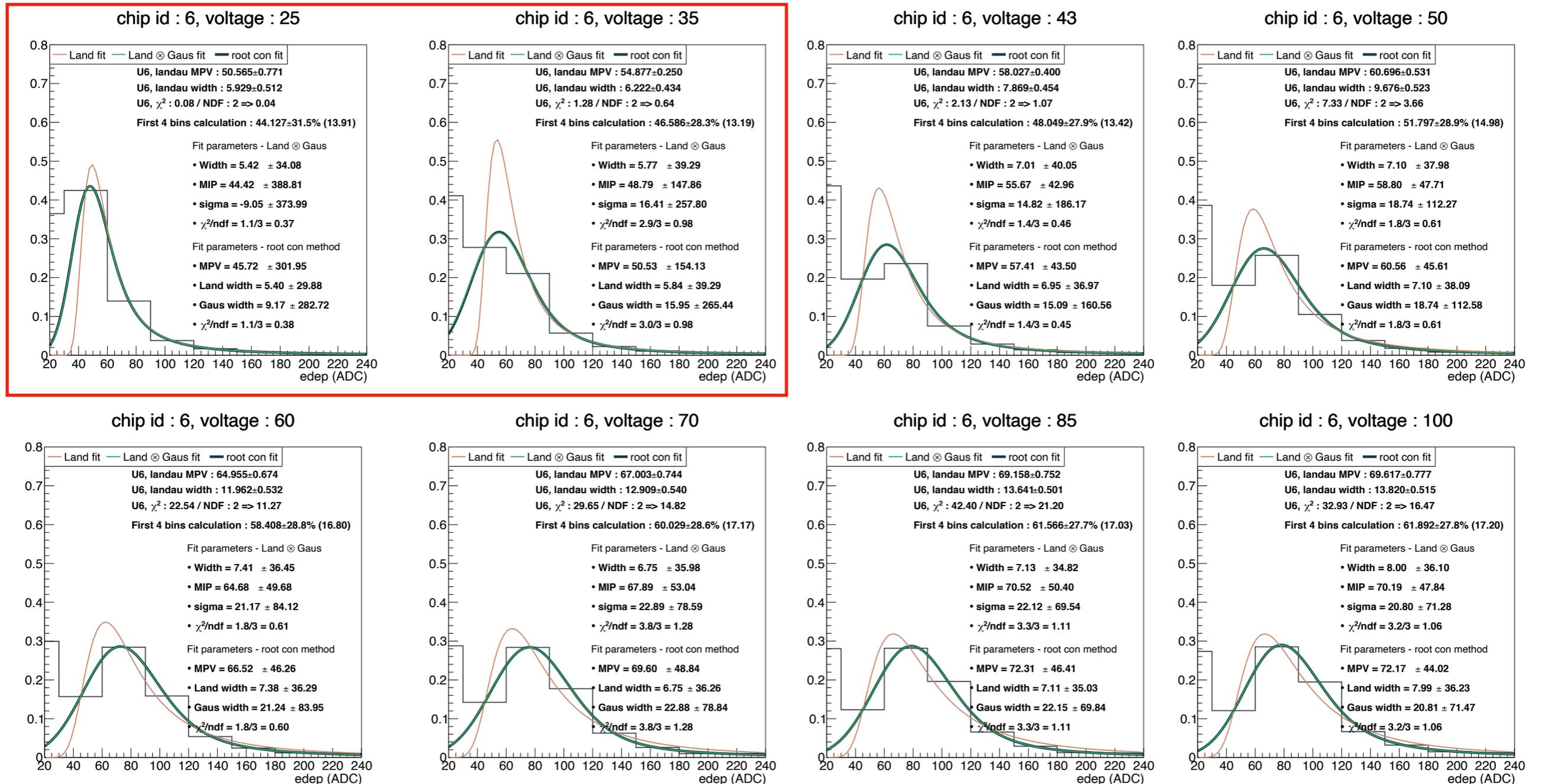
For the case of capacitance, it is reasonable. The full range is considered for the fitting.

// Source test, different supply voltage

Sr-90, self-trigger, threshold 20 ADC, adc setting : 20, 30, 60, 90, 120, 150, 180, 210

The entry of each bin is divided by the bin width

The signal overlaps with the noise too much.

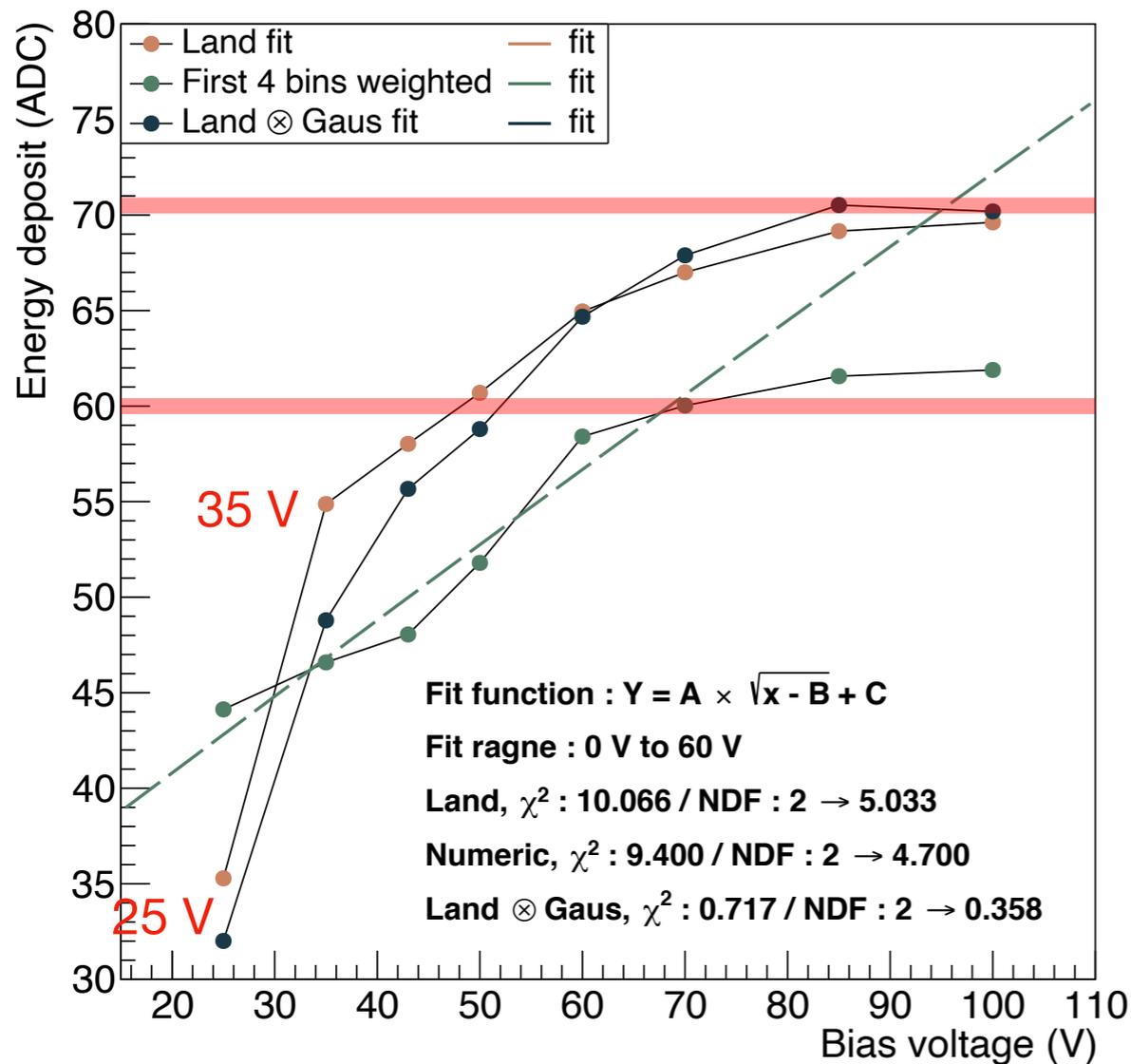


// Source test, different supply voltage

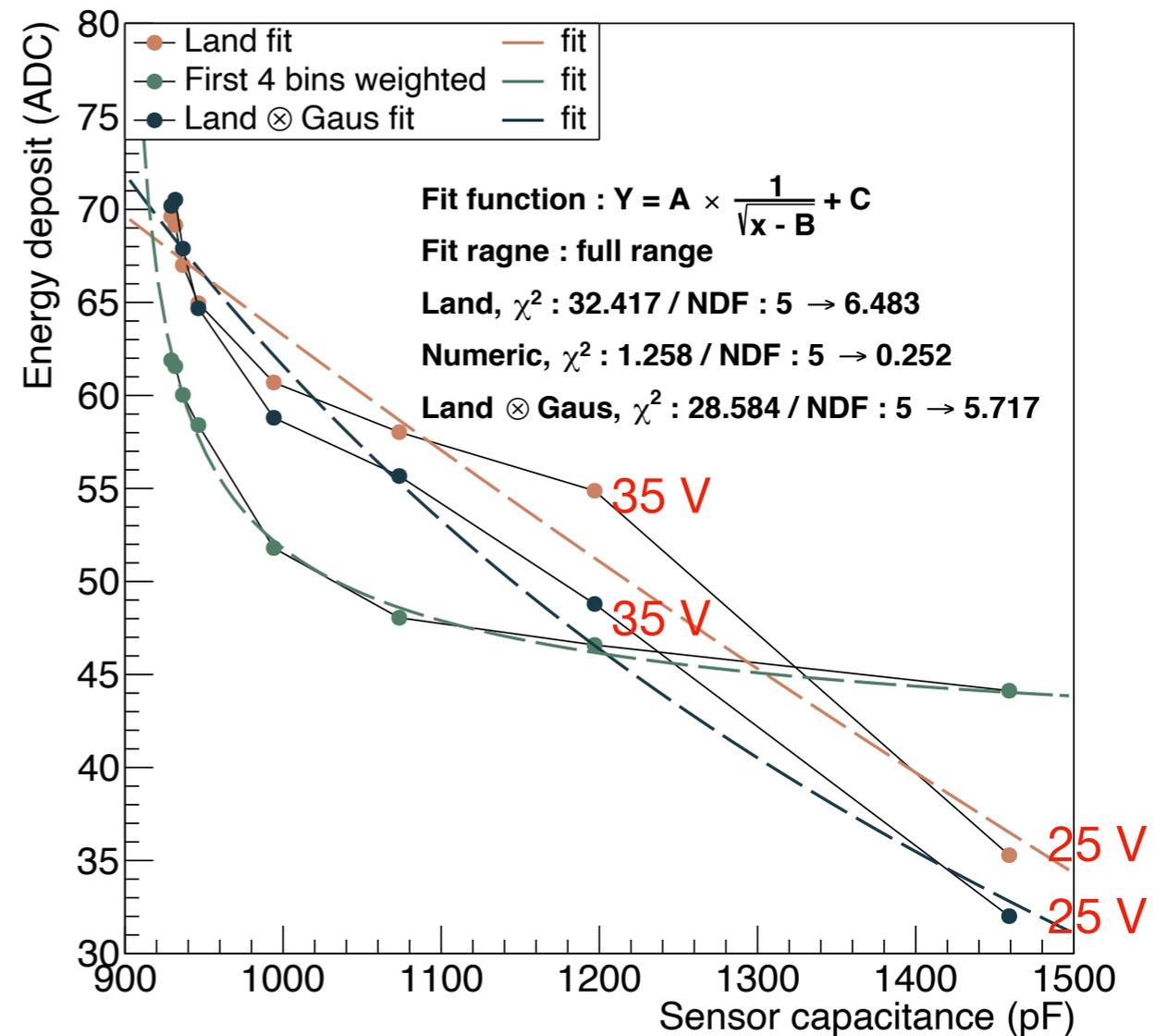
Sr-90, self-trigger, threshold 20 ADC, adc setting : 20, 30, 60, 90, 120, 150, 180, 210

The entry of each bin is divided by the bin width

Energy deposit v.s. Bias voltage



Energy deposit v.s. Sensor capacitance



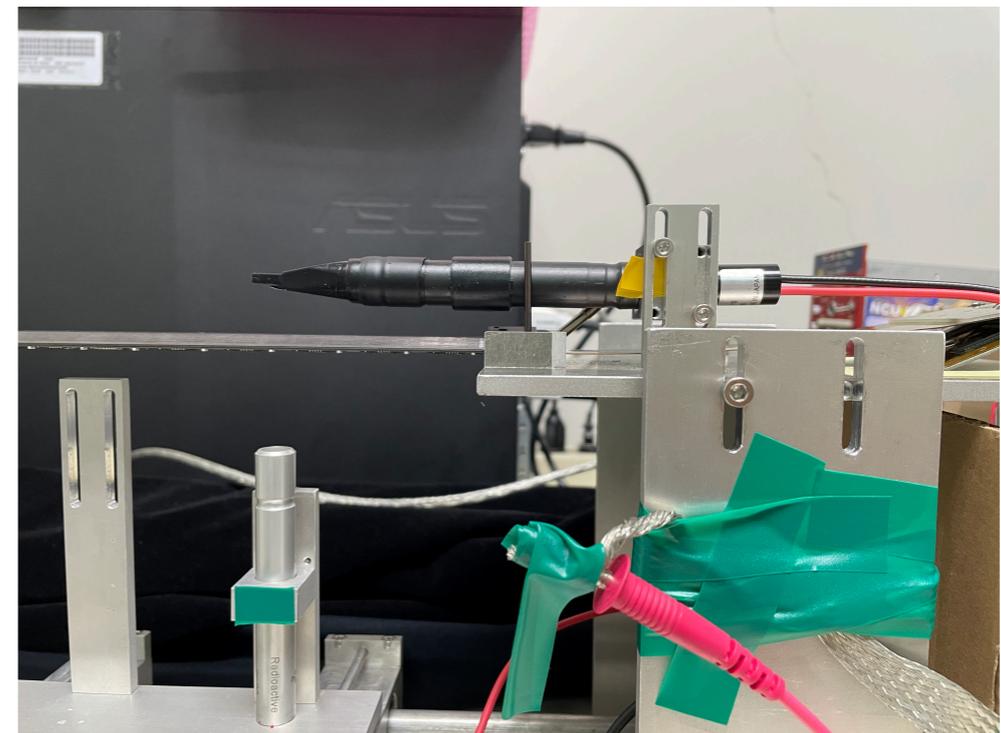
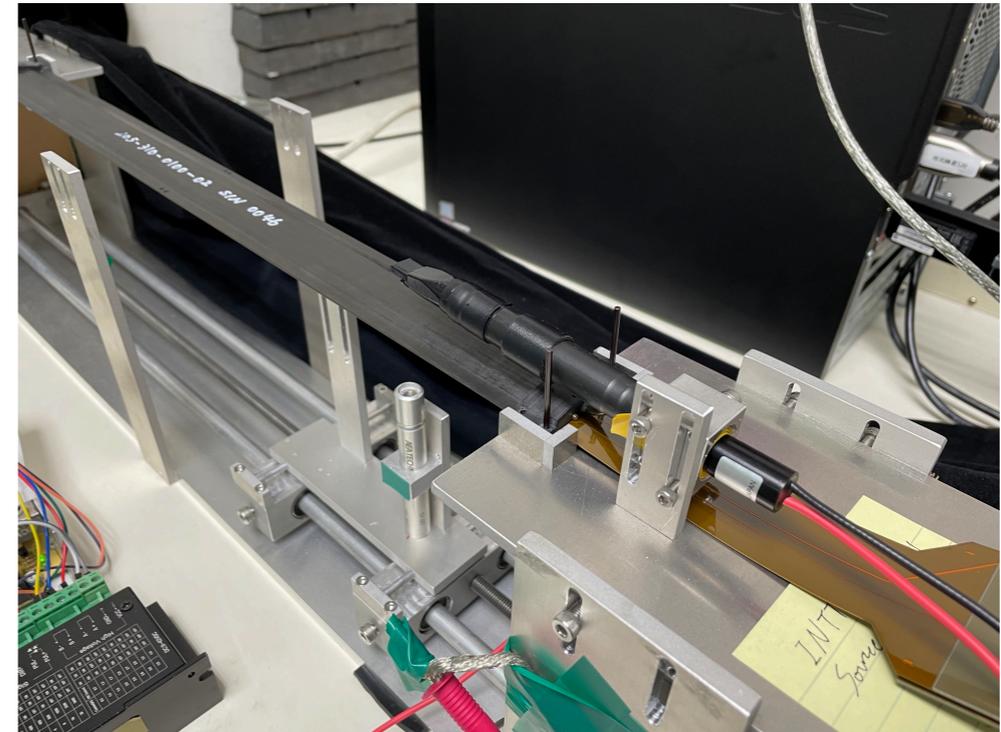
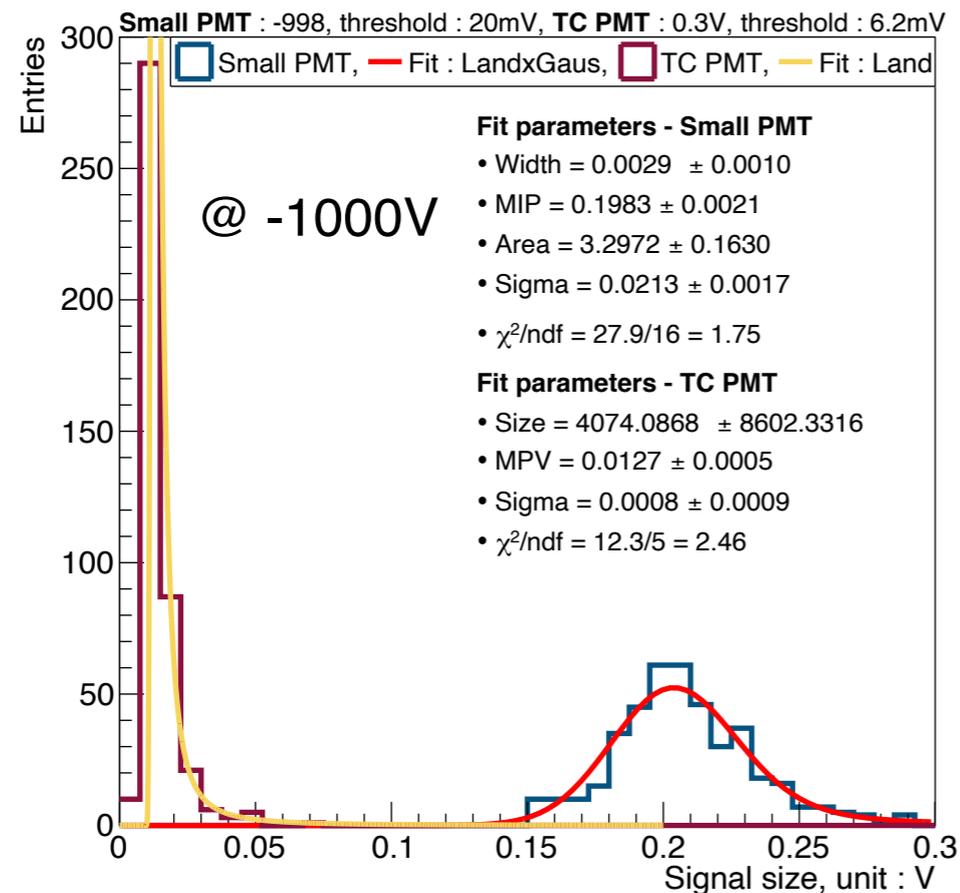
The MPVs of run 25 V and run 35 V are not accurate due to large overlap of signal and noise

// Source test, different supply voltage

The experiment was re-performed

Upgrade : add the scintillator, more data points & customized adc setting for different run

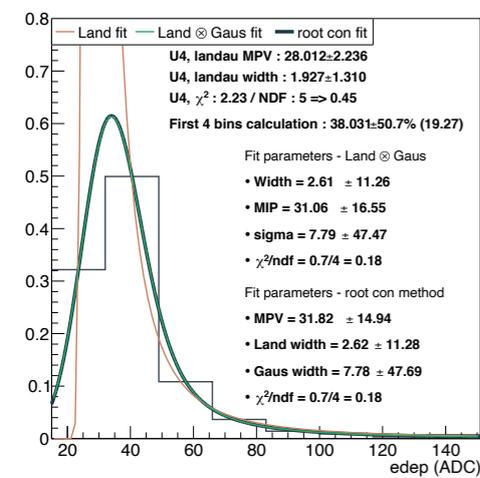
Trigger scintillator edep distribution
Signal size



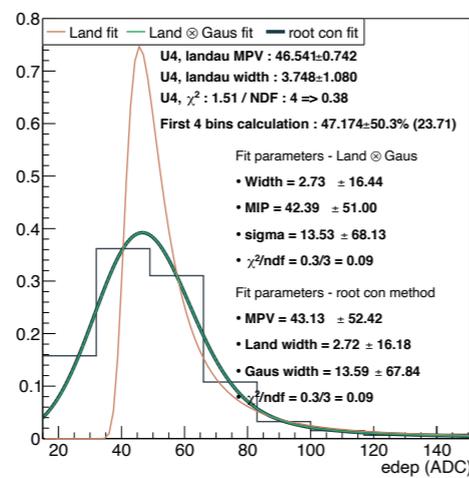
// Source test, different supply voltage

Upgrade : add the scintillator, more data points & customized adc setting for different run

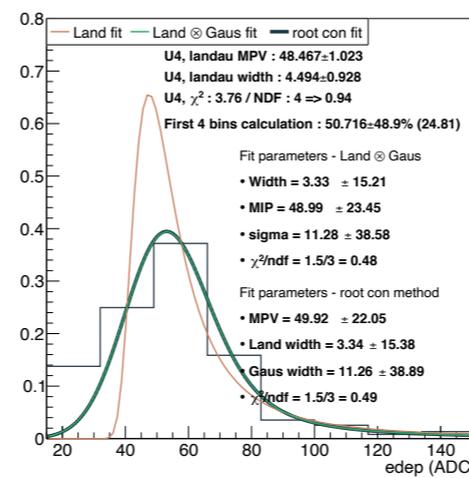
With Sci., chip id : 4, voltage : 15



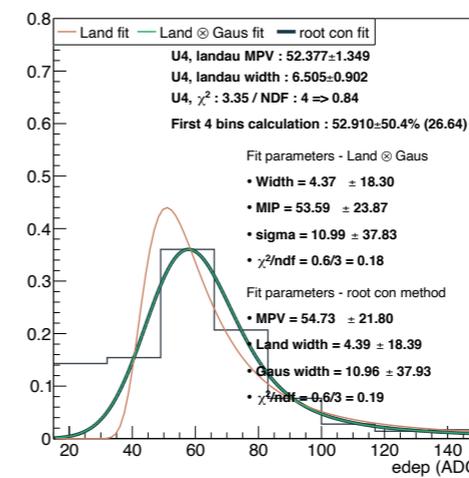
With Sci., chip id : 4, voltage : 25



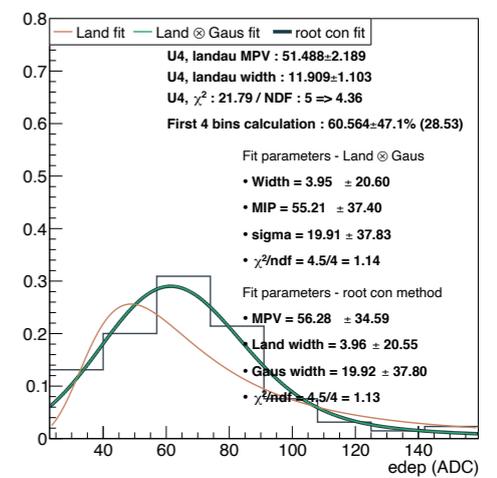
With Sci., chip id : 4, voltage : 30



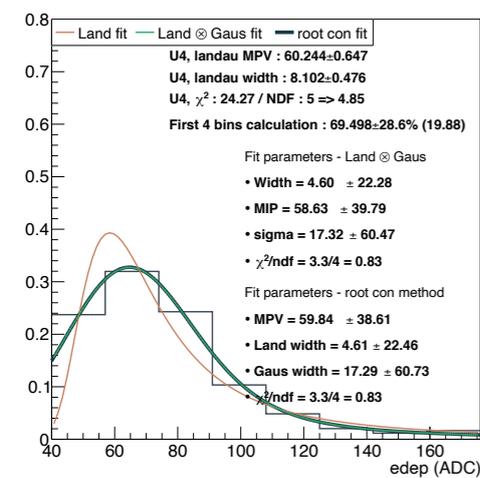
With Sci., chip id : 4, voltage : 35



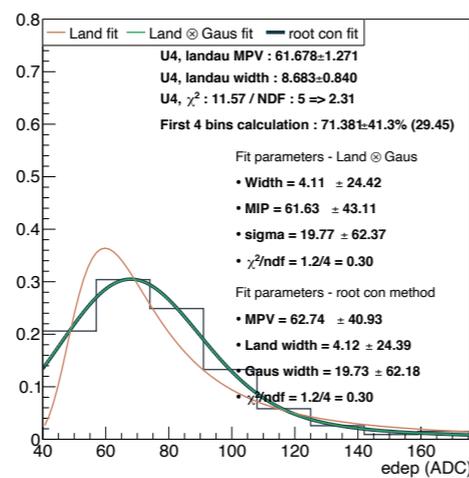
With Sci., chip id : 4, voltage : 43



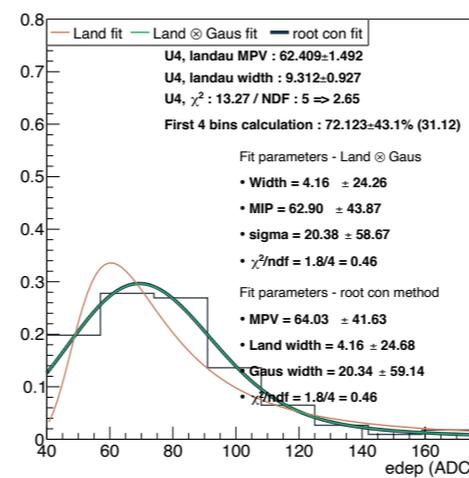
With Sci., chip id : 4, voltage : 50



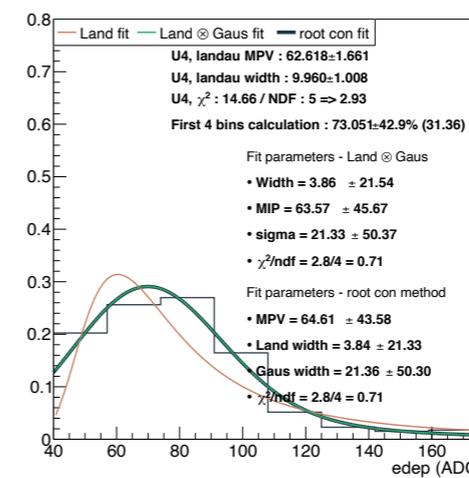
With Sci., chip id : 4, voltage : 55



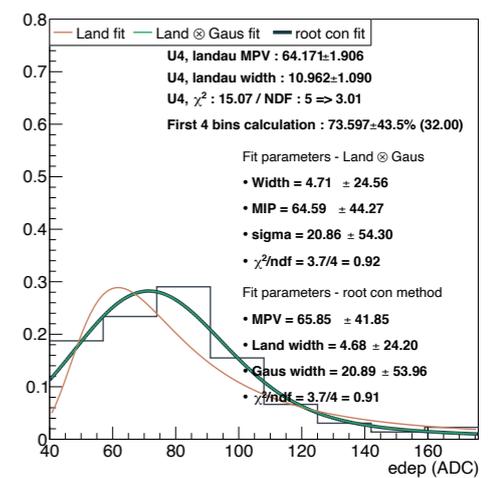
With Sci., chip id : 4, voltage : 65



With Sci., chip id : 4, voltage : 85



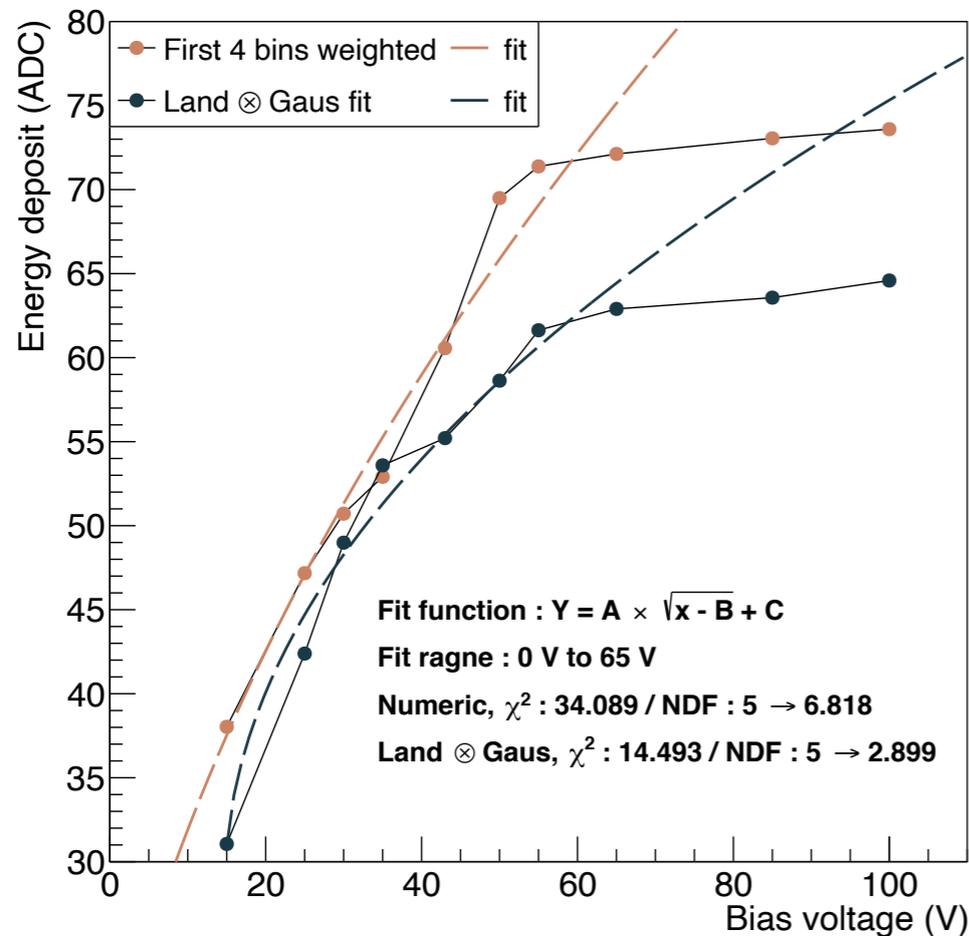
With Sci., chip id : 4, voltage : 100



// Source test, different supply voltage

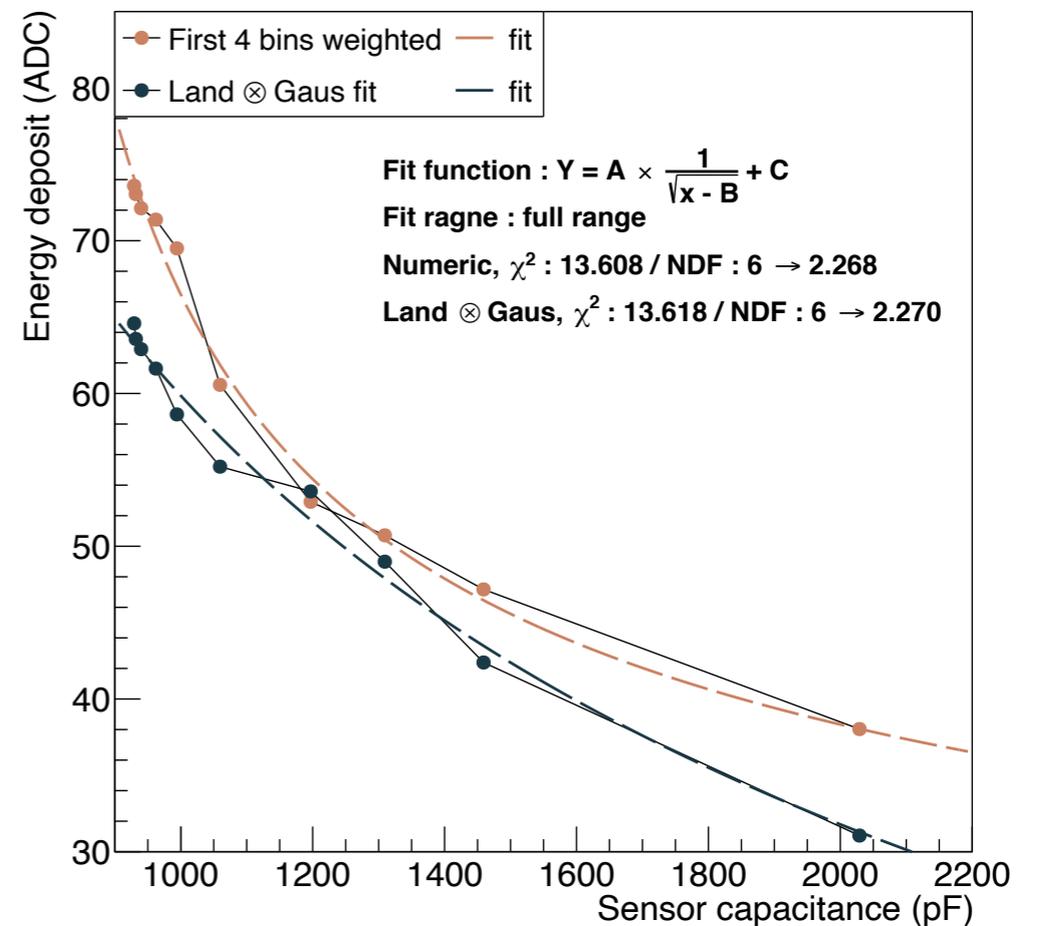
Upgrade : add the scintillator, more data points & customized adc setting for different run

Energy deposit v.s. Bias voltage



The result fits to our expectation, the discrepancy increases as the bias voltage is larger than 60 V. Because it gradually reaches to the limit of the depletion region

Energy deposit v.s. Sensor capacitance



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

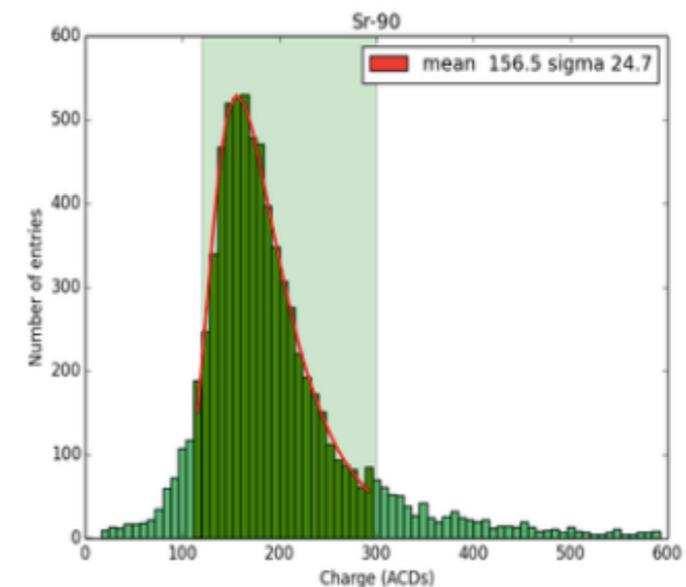
// Energy deposit of Sr-90 (Y-90) in thin silicon

Paper link

3.2. Passage of particles through matter

The signal formation in the silicon sensor is due to the ionizing energy loss of the incident particles. One can study the charge deposition of a mip using a Sr90 β source. The system allows the reconstruction of the

Sensor thickness : 300 μm

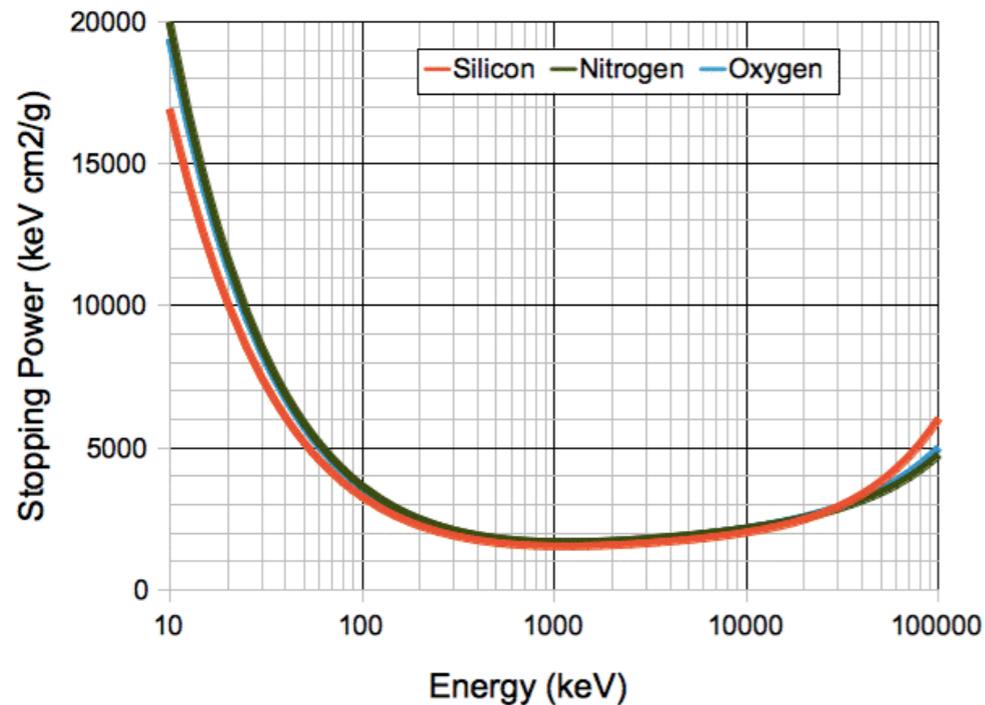


Charge deposition of a mip (Sr-90 β source)

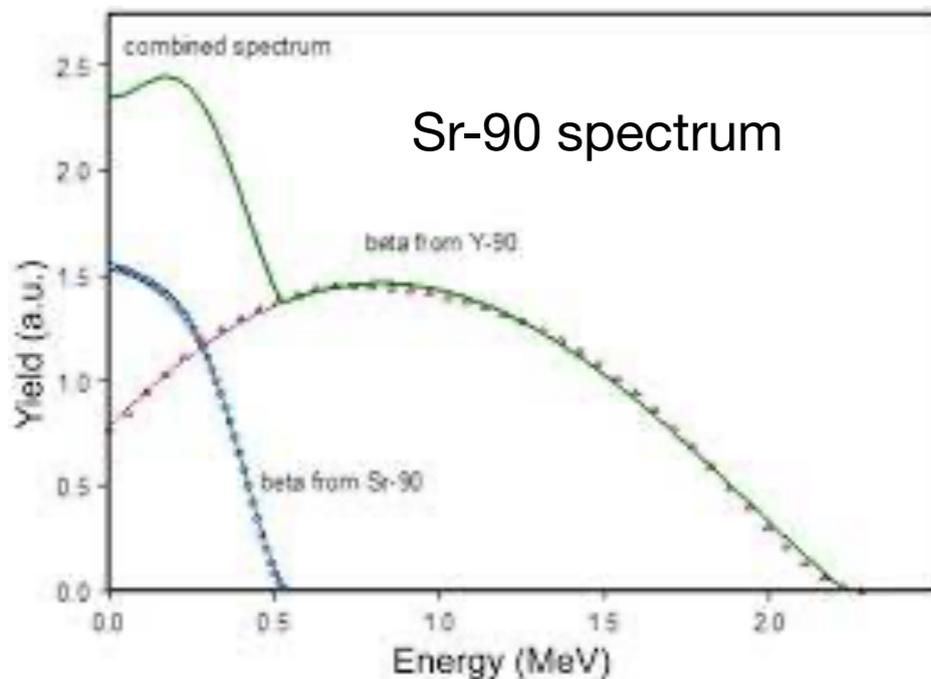
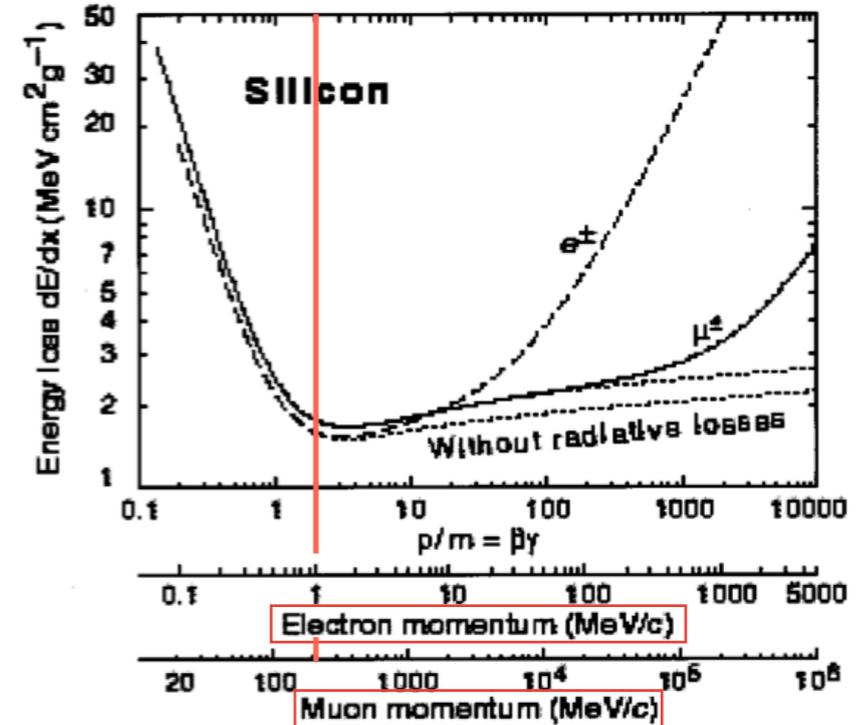
Electrons from the Sr-90 seem to be the MIP particles

// Energy deposit of Sr-90 (Y-90) in thin silicon

Electron stopping power



Paper link



Electron stopping power @ 1 MeV Calculated by [web](#)

(required) Kinetic Energy (MeV)	Stopping Power (MeV cm ² /g)			Density Effect Parameter
	Collision	Radiative	Total	
1.000E+00	1.507E+00	2.360E-02	1.531E+00	3.424E-01

$$\frac{1.531 \text{ (MeV cm}^2\text{/g)} \times 2.33 \text{ (g/cm}^3\text{)} \times 320 \text{ (}\mu\text{m)}}{10^4} = 0.114 \text{ MeV}$$

From [paper](#) : minimum ionization energy of muon in silicon : 1.664 MeV cm²/g

// Another approach - G4 test

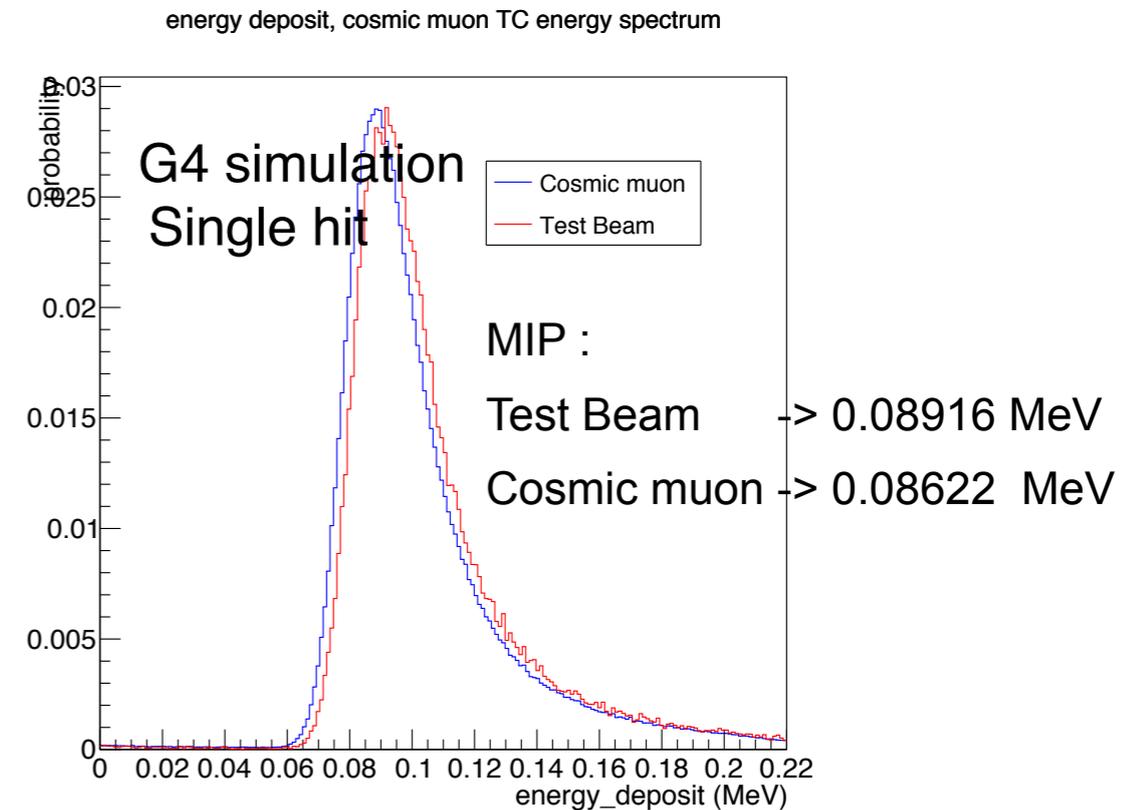
Conversion function :

$$\text{mV} = \text{DAC} * 4 + 210$$

$$\text{mV} = \frac{E_{\text{dep}} * 10^6 [\text{eV}] * 1.6 * 10^{-4} [\text{fC}] * G}{3.6 \text{eV}} + O$$

G : 100 [mV/fC], O : 280 [mV]

Based on NWU's sophisticated study, the offset should be 200



$$\frac{0.089 \text{ MeV} * 10^6 * 1.6 * 10^{-4} * (\text{Gain} : 100)}{3.68 \text{ eV}} + (\text{Offset} : 200) = 586.956$$

$$(586.956 - 210) / 4. = 94.239 \text{ ADC}$$

// edep summary table

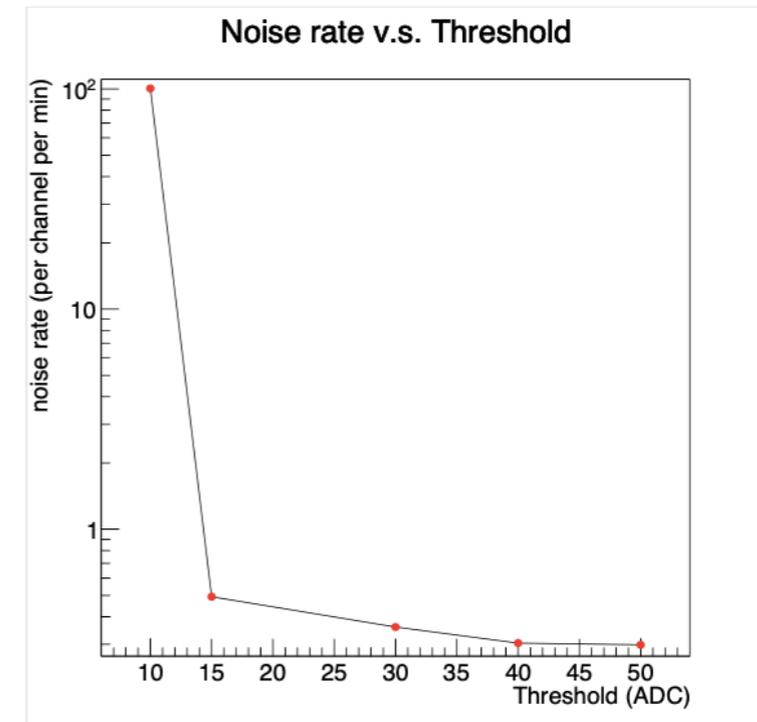
Item	Peak position Land x Gaus	Peak position pure land	setting	note
Testbeam2021, 3 layer average	73.598		DAC scan	50 V
Testbeam2019	118.91		DAC scan	100 V
Source test	58.80	60.696	8 bins, self-trigger, threshold 20 adc (with sci.)	50 V
	70.19 (76.09)	69.62 (64.13)		100 V
	58.63	60.244	8 bins, with sci., customized adc setting (w/o first bin in fitting)	50 V
	64.59 (72.2)	64.171 (75.36)		100 V
		74.039	8 bins, threshold 40 adc	100 V
Cosmic test	82.11	73.626	8 bins, threshold 15 adc	100V, 2 scis

*thre 40, source test is from : NCU_fphx_raw_module_44_20211214-1935_0

Noise study

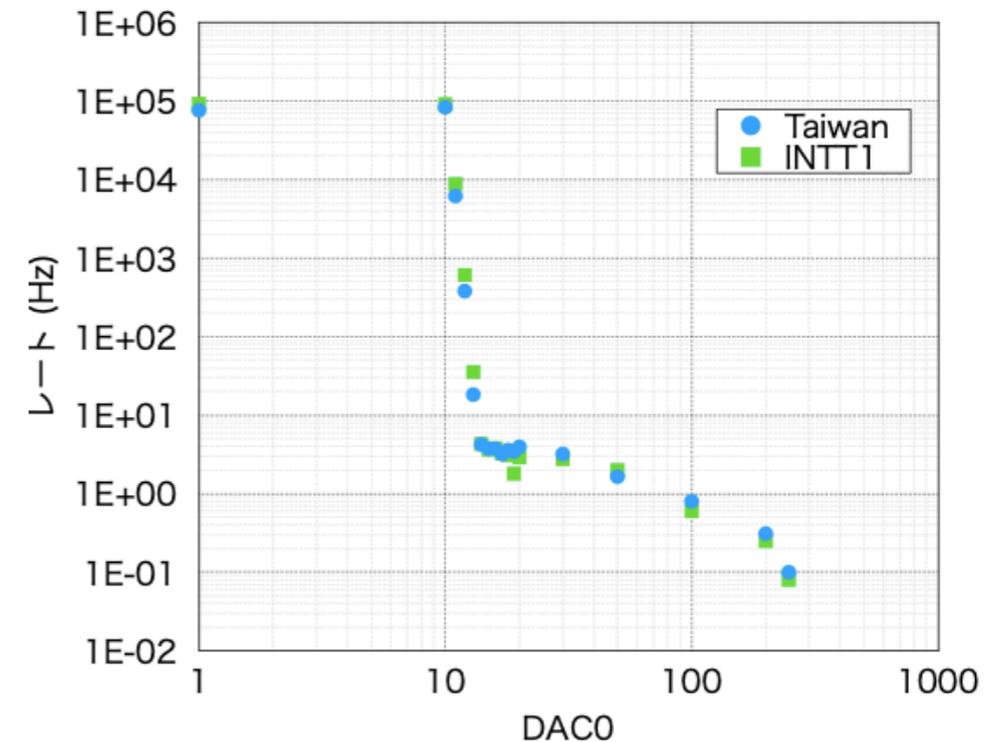
// Noise rate v.s. Threshold

Threshold (ADC)	rate (per channel per min)	
10	100.515	± 0.086
15	0.493	± 0.0065
30	0.359	± 0.0045
40	0.304	± 0.0042
50	0.298	± 0.004



DAC0 を変えたときのセルフトリガーレート

	unit : adc	Ratio of noise rate
Genki	@30 / @15	0.753
	@50 / @15	0.548
CW	@30 / @15	0.728
	@50 / @15	0.604



The results are consistent !

// Noise rate - voltage

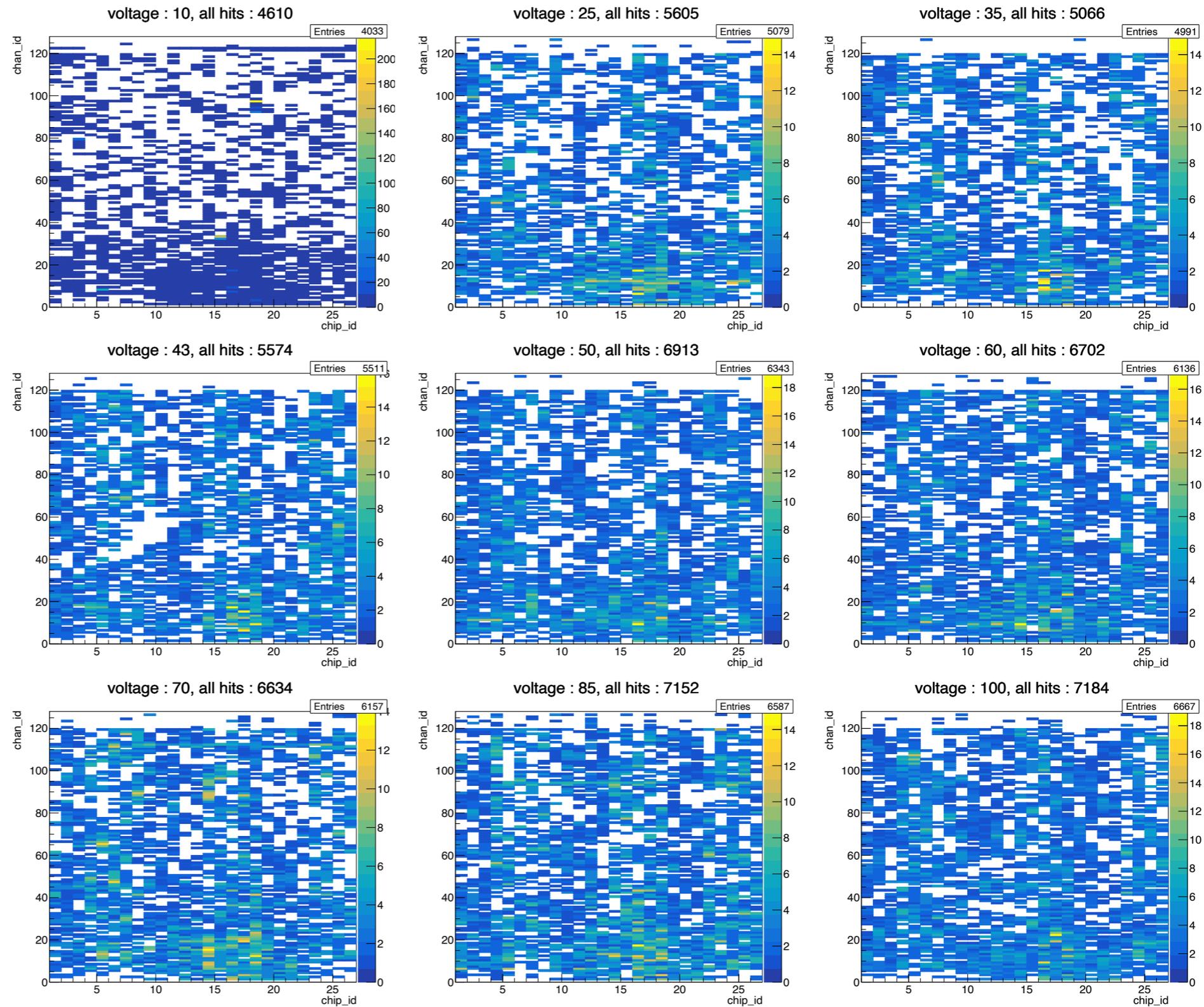
Voltage range : 10 V ~ 100 V

Chan mask : 0 ~ 5 & 120 ~ 127

Threshold : 20 adc

Running time : 5 mins

Average total hits : 6160



// Noise rate - voltage

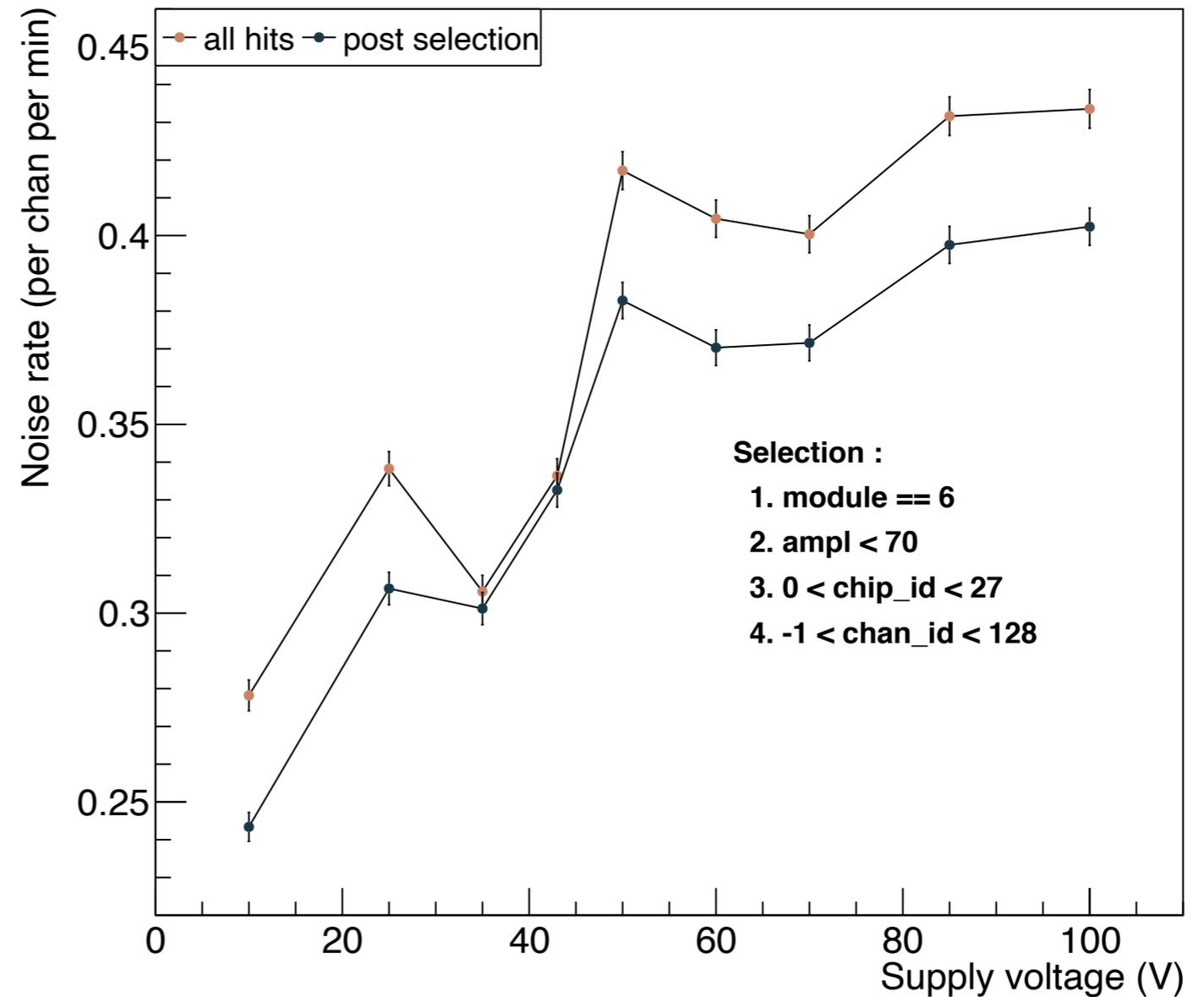
Voltage range : 10 V ~ 100 V

Chan mask : 0 ~ 5 & 120 ~ 127

Threshold : 20 adc

Running time : 5 mins

Average total hits : 6160



Capacitance study

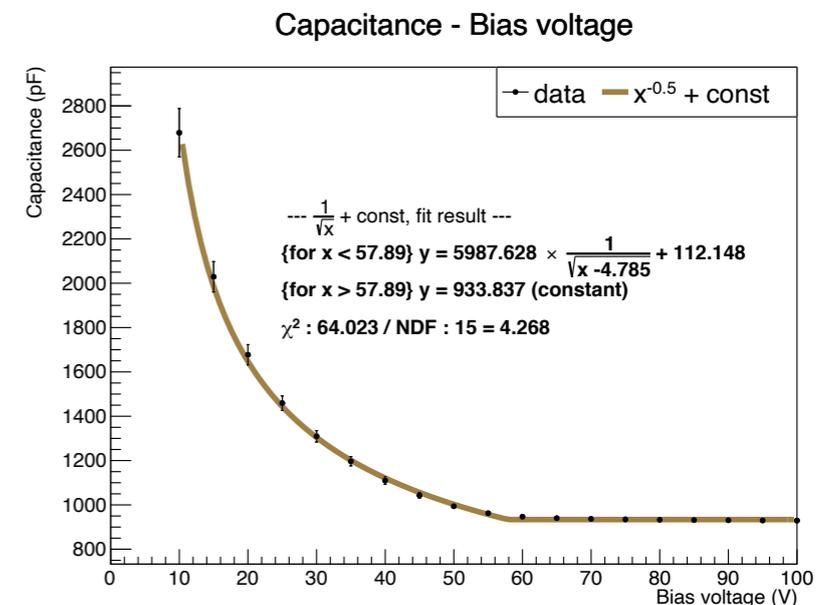
// Capacitance - original goal

- Estimate the depletion length of INTT sensor @ 50 V
 - In order to correct the G4 model, aid the gain & offset study

In a planar device the thickness of the depleted region is

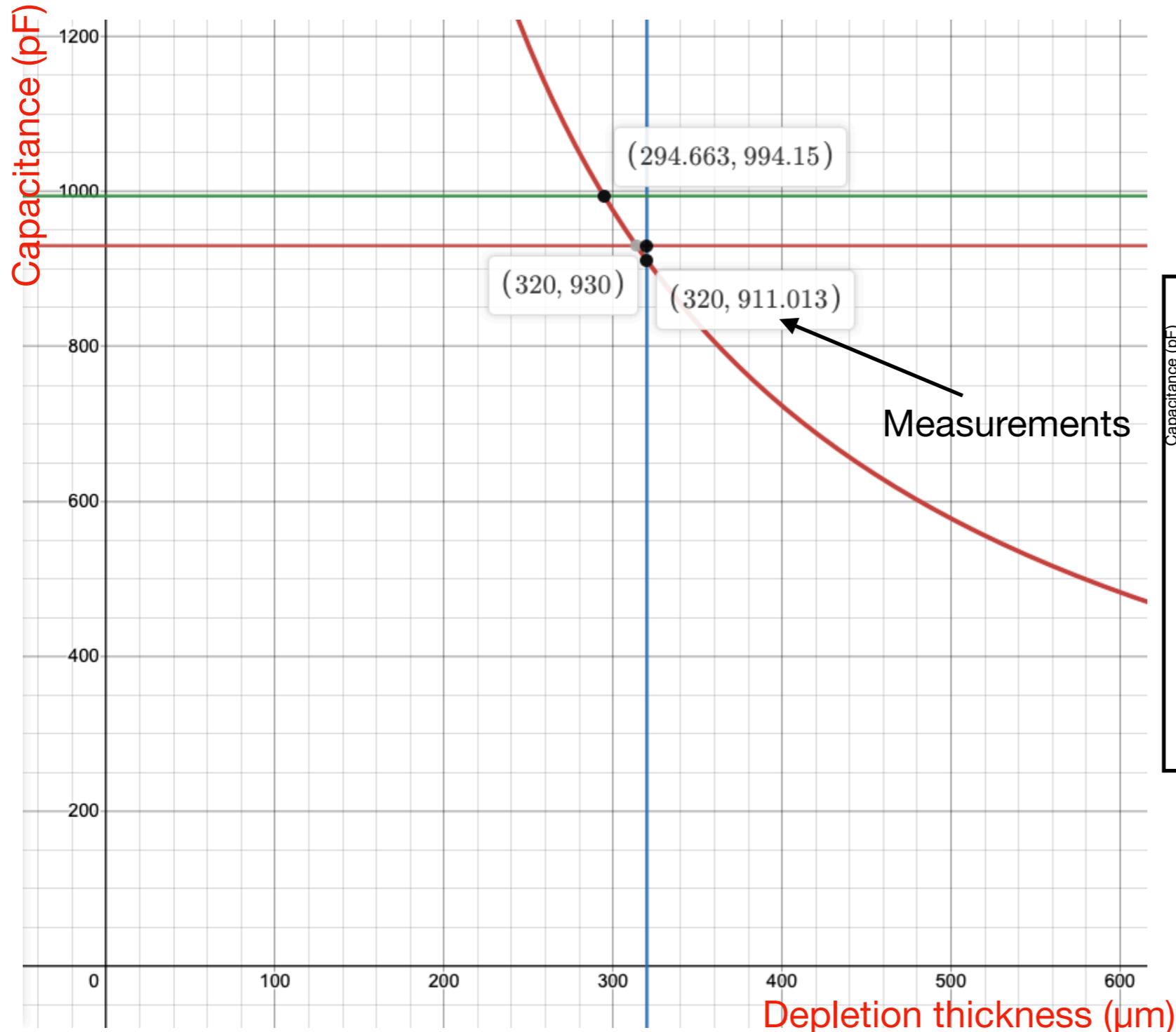
$$W = \sqrt{2\epsilon(V + V_{bi})/Ne} = \sqrt{2\rho\mu\epsilon(V + V_{bi})} = K\sqrt{V + V_{bi}}$$

- $V_{bi} = 0.5V$, $K = 2\rho\mu\epsilon = \text{constant}$
- Assumption : @ 58 V, depletion length = 320 μm
 - $K = 320/\sqrt{58.5} : 41.838$
- Next : try to substitute V with W . $V = W^2/K^2$

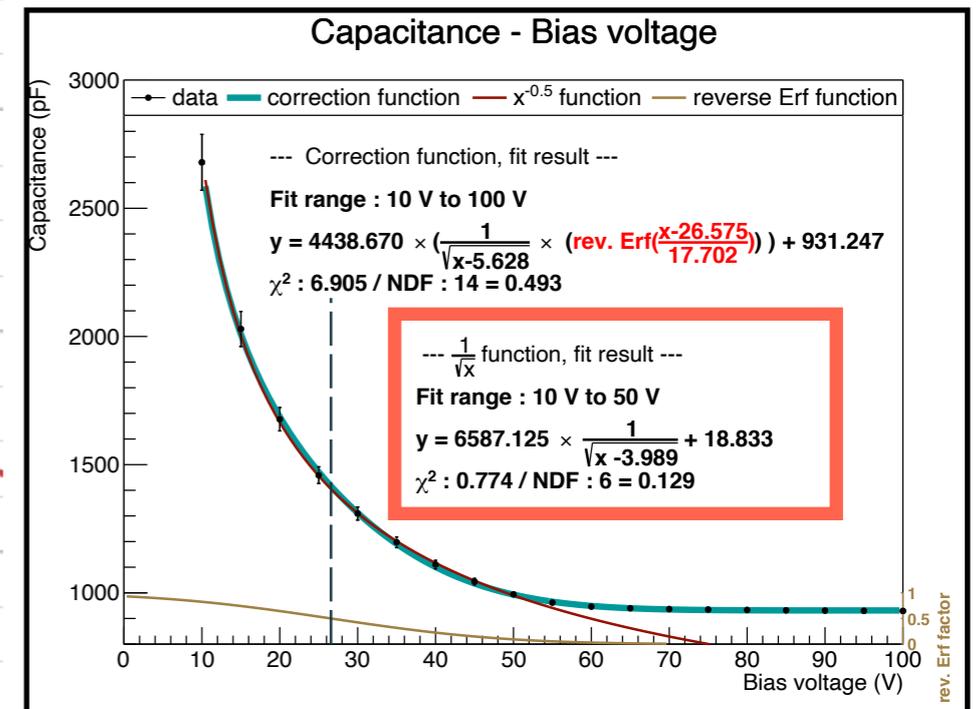


// Capacitance - original goal

- Next : try to substitute V with W . $V = W^2 / K^2$

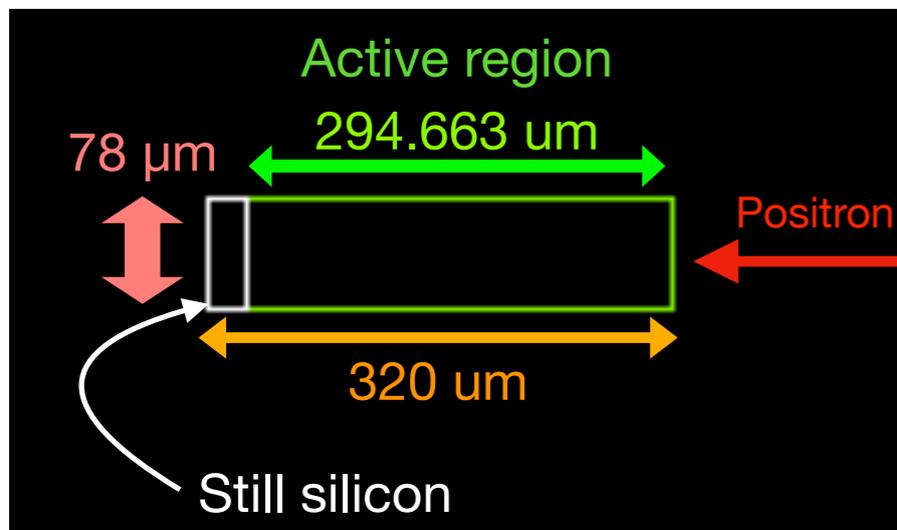


Capacitance @ 50 V : 994.149 pF
 Estimated thickness : 294.663 μm

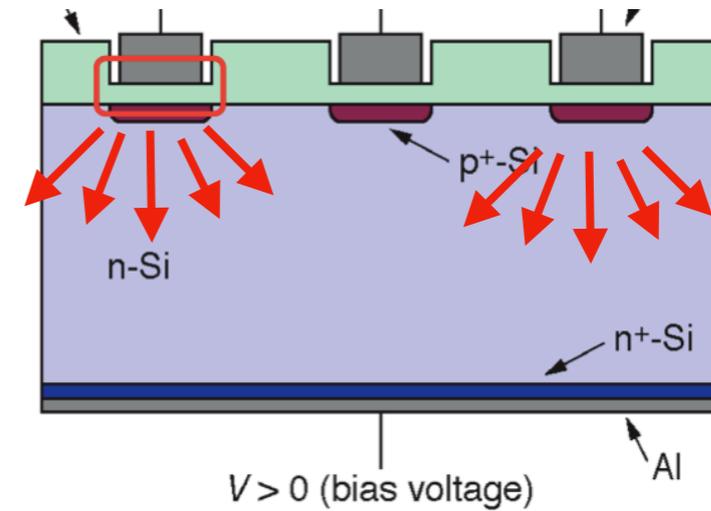


// Edep comparison - Simple G4 simulation

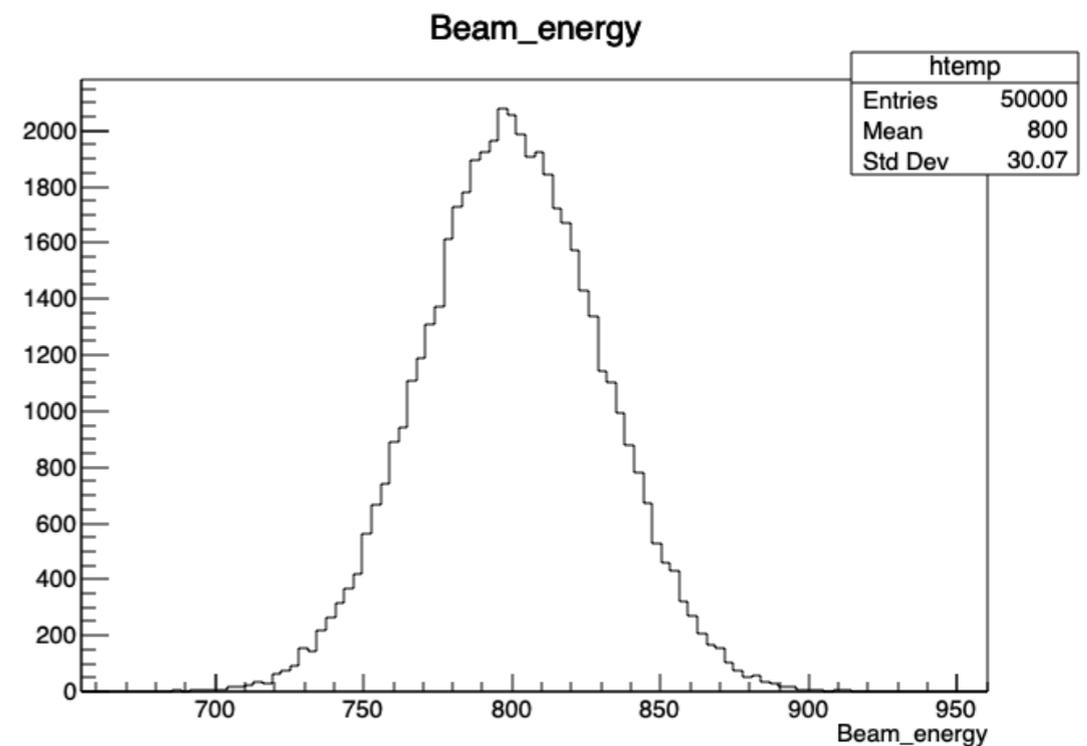
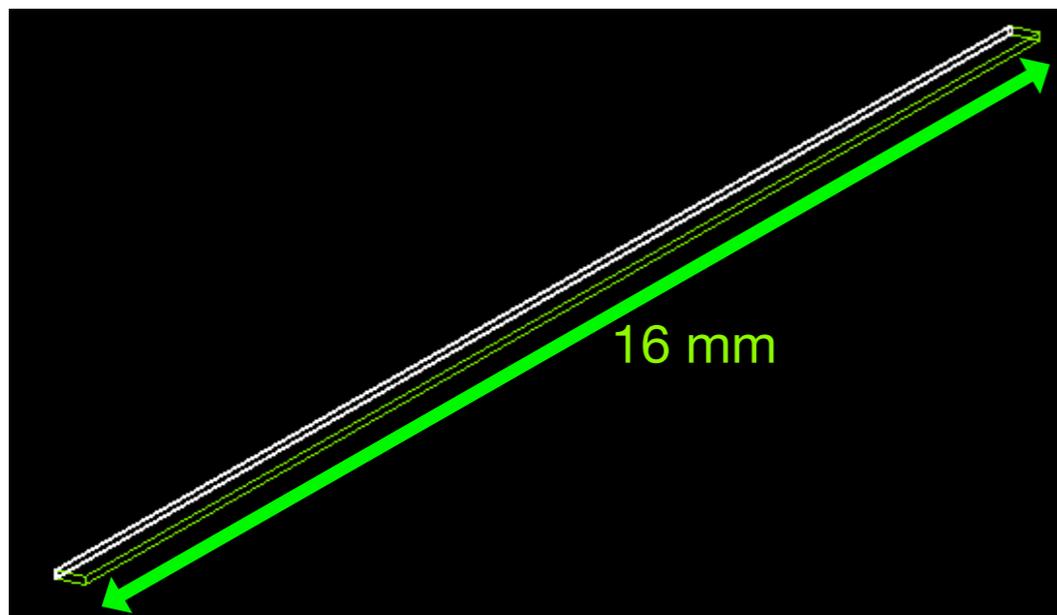
Single strip simulation



Depletion region growth direction



Position Beam energy
peak : 800 MeV, Width : 30 MeV



// Edep comparison - 294.66 μm

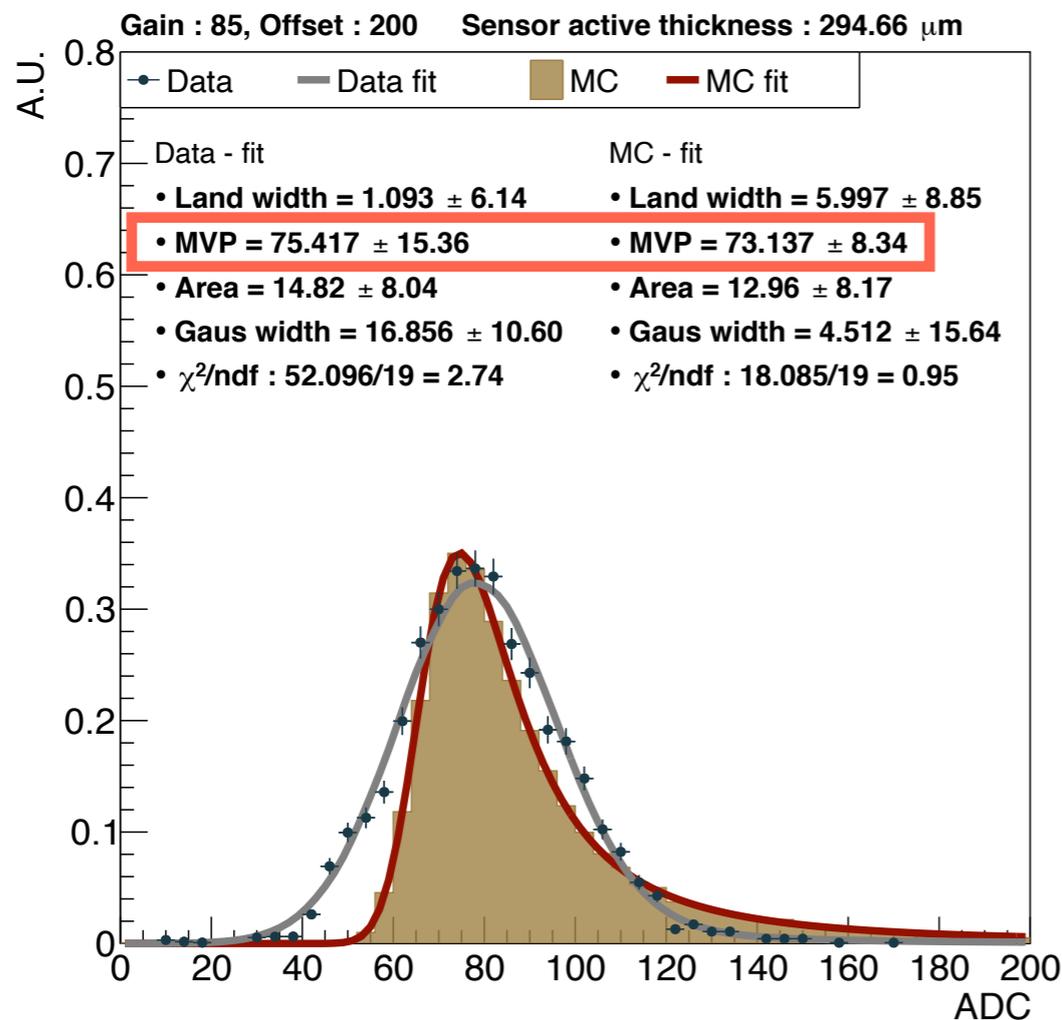
Effective Channel gain: 46, 50, 60, 67, 85, 100, 150, or 200 mV/fC

Conversion function

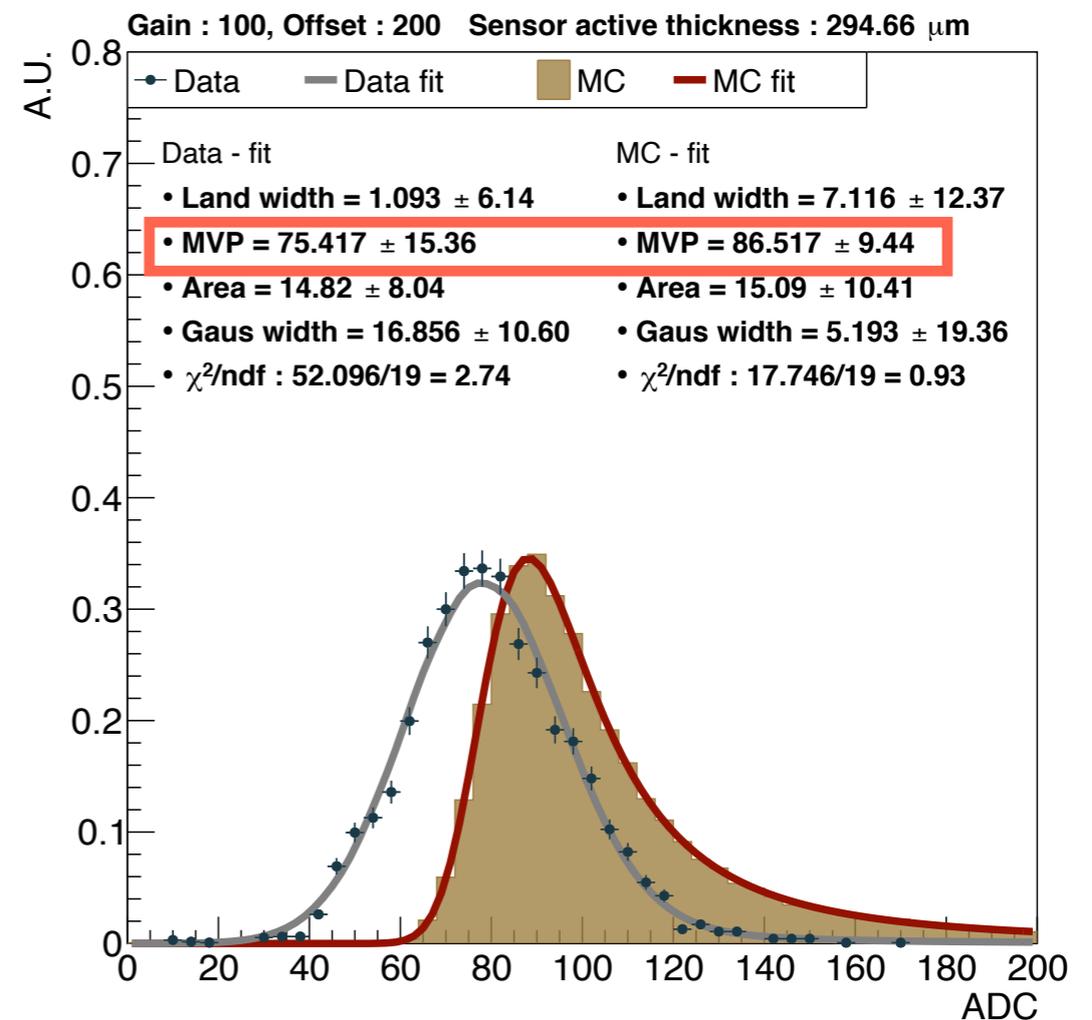
$$mV = DAC * 4 + 210 \quad mV = \frac{Edep * 10^6[eV] * 1.6 * 10^{-4}[fC] * G}{3.6eV} + O$$

Sensor active thickness : 294.663 μm

Gain 85, Offset 200



Gain 100, Offset 200



// Edep comparison - 320 μm

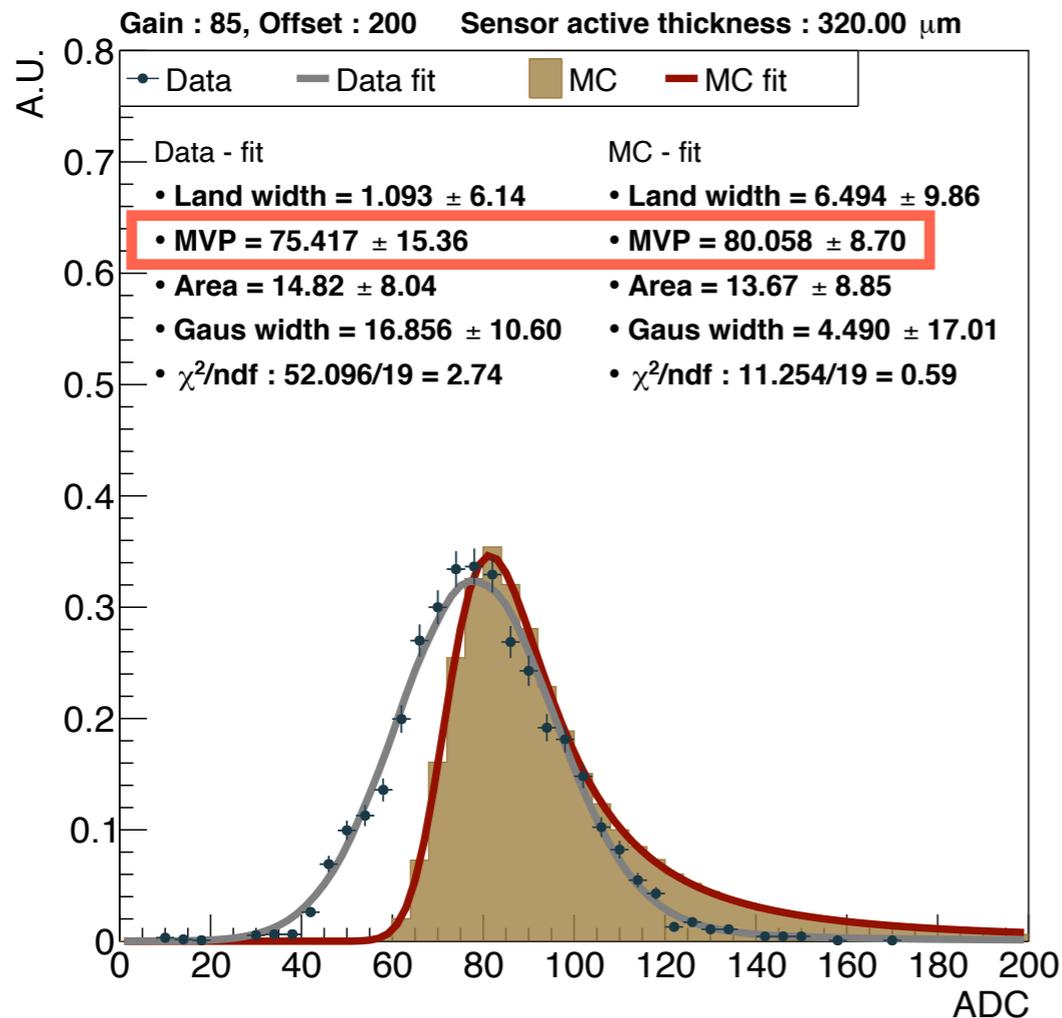
Effective Channel gain: 46, 50, 60, 67, 85, 100, 150, or 200 mV/fC

Conversion function

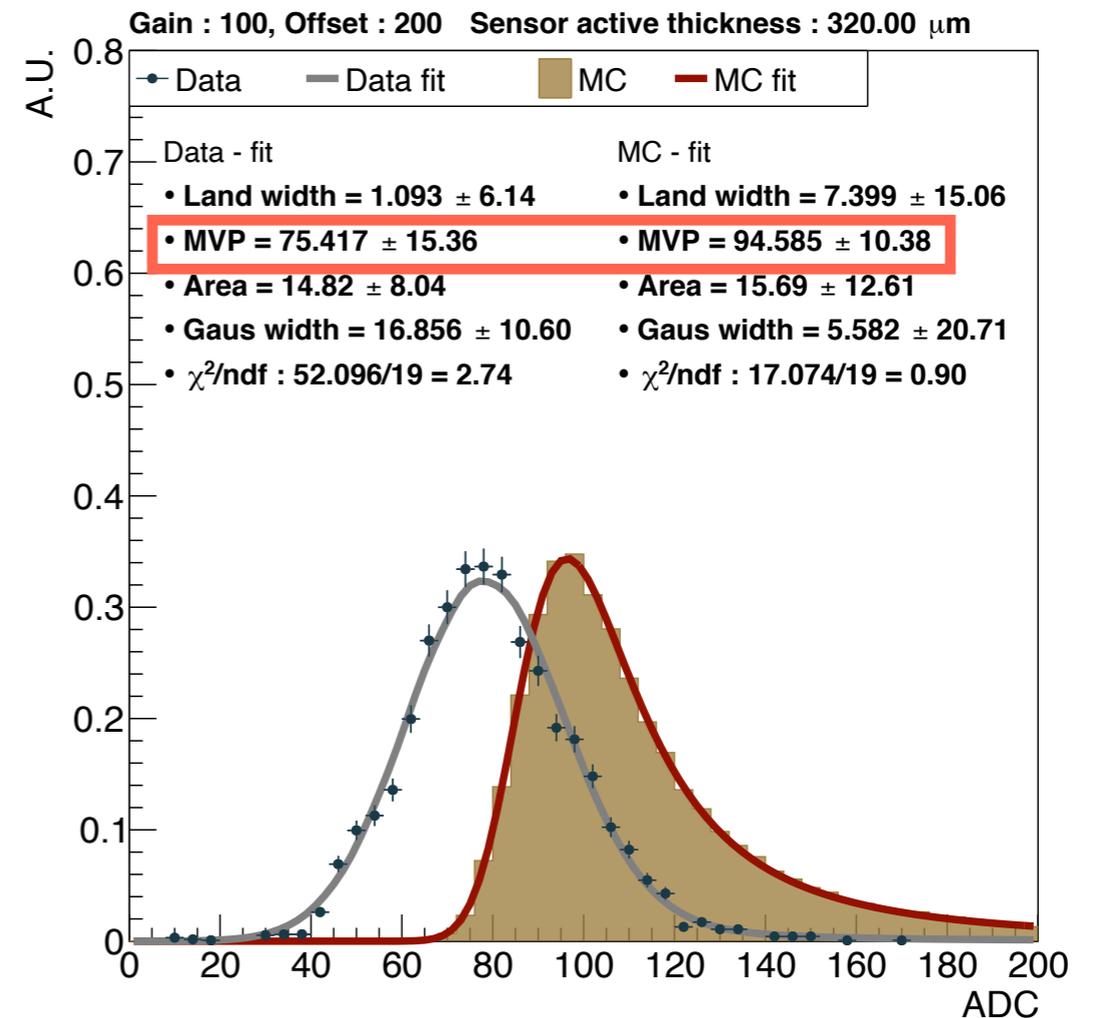
$$mV = DAC * 4 + 210 \quad mV = \frac{Edep * 10^6[eV] * 1.6 * 10^{-4}[fC] * G}{3.6eV} + O$$

Sensor active thickness : 320 μm

Gain 85, Offset 200



Gain 100, Offset 200



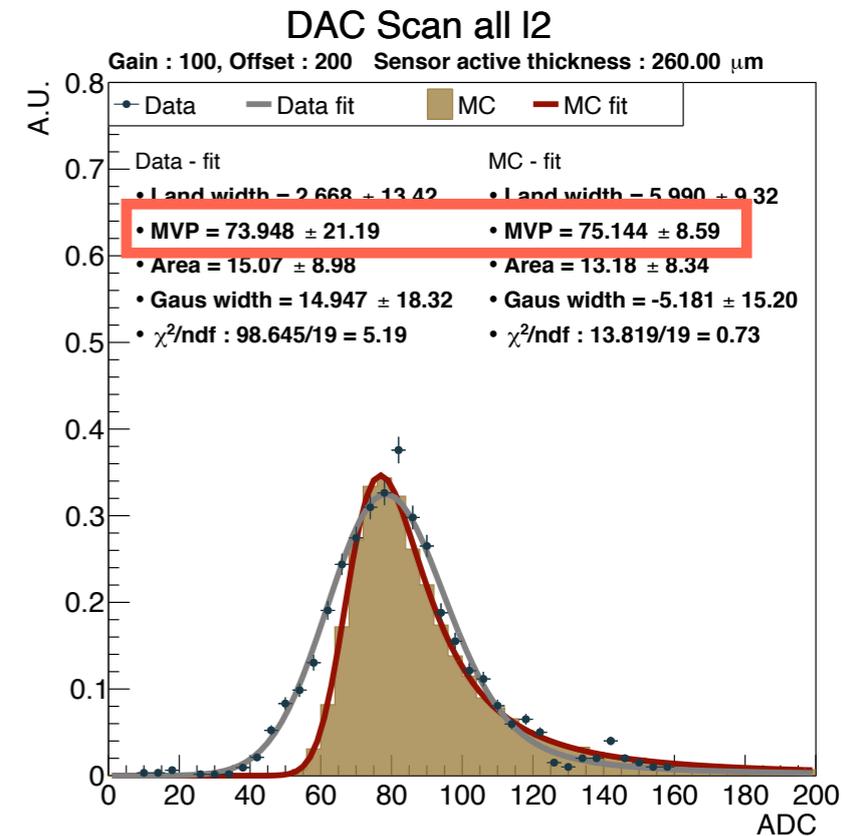
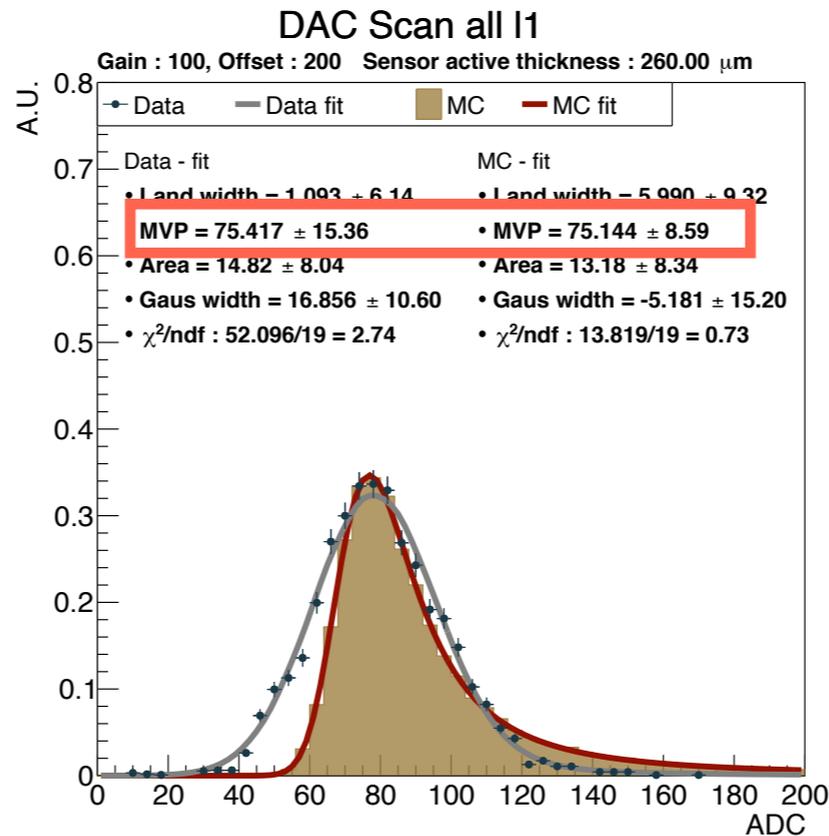
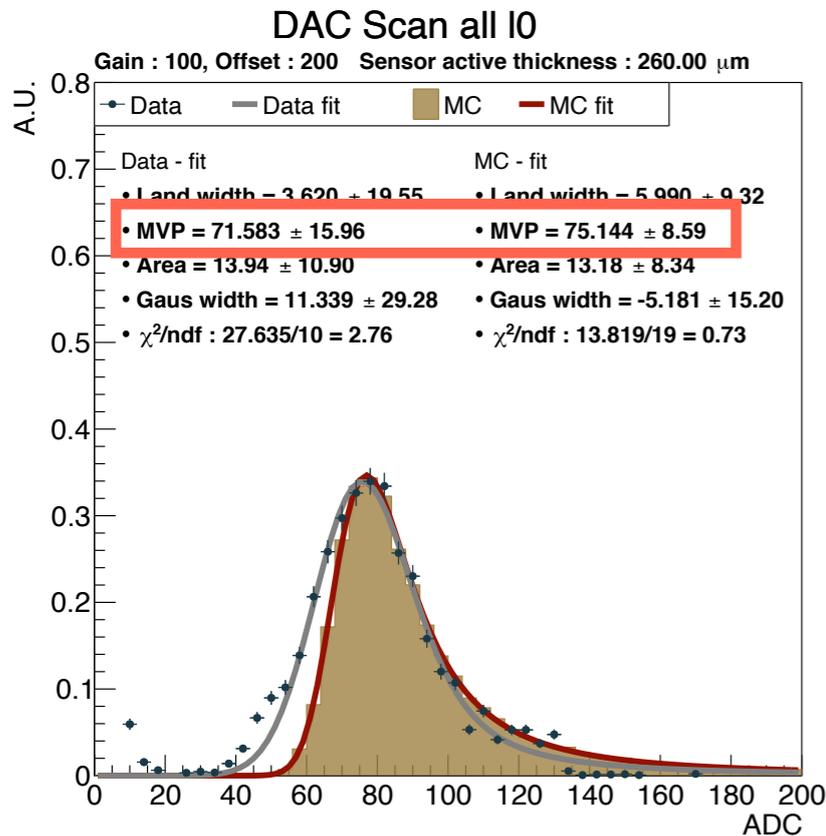
// Edep comparison - 260 μm

Effective Channel gain: 46, 50, 60, 67, 85, 100, 150, or 200 mV/fC

Conversion function

$$mV = DAC * 4 + 210 \quad mV = \frac{Edep * 10^6[eV] * 1.6 * 10^{-4}[fC] * G}{3.6eV} + O$$

Sensor active thickness : 260 μm Gain 100, Offset 200



// Conclusion - 1

- The DAC scan experiments were performed in both Testbeam 2019 (Fermilab) and Testbeam 2021 (ELPH).
 - The peaks of the distributions have non-negligible discrepancy.
- For the INTT sensor, $C \propto 1/\sqrt{V}$ can describe the data from 0 V to 50 V.
- The capacitance ratio doesn't match to the edep ratio.
- The experiment of the source test with different supply voltage was performed to Confirmation the relations.
 - Signal $\propto \sqrt{V}$ (0 ~ 60 V),
 - Signal $\propto 1/\sqrt{C}$ (full range).
- The electrons from Sr-90 seem to be the MIP particles.

// Conclusion - 2

- Testbeam2021 vs source test
 - Testbeam (DAC scan, 50 V) : 73.598 adc
 - Source test (8 bins, 50 V) : 58.63 adc
 - Discrepancy : 20.3 % → reasonable
- Based on all studies, the edep @ 100 V should not be that high (~120 ADC)
 - Reason : Different readout system ? Gain ?
- The noise rate increases as the supply voltage increases.
- The estimated depletion thickness @ 50 V : 294.663 μm .
 - A discrepancy between MC and data is observed.
- For the case of 260 μm active thickness, Gain 100 and Offset 200, the peaks of MC and data are similar.

// More important questions to be answered

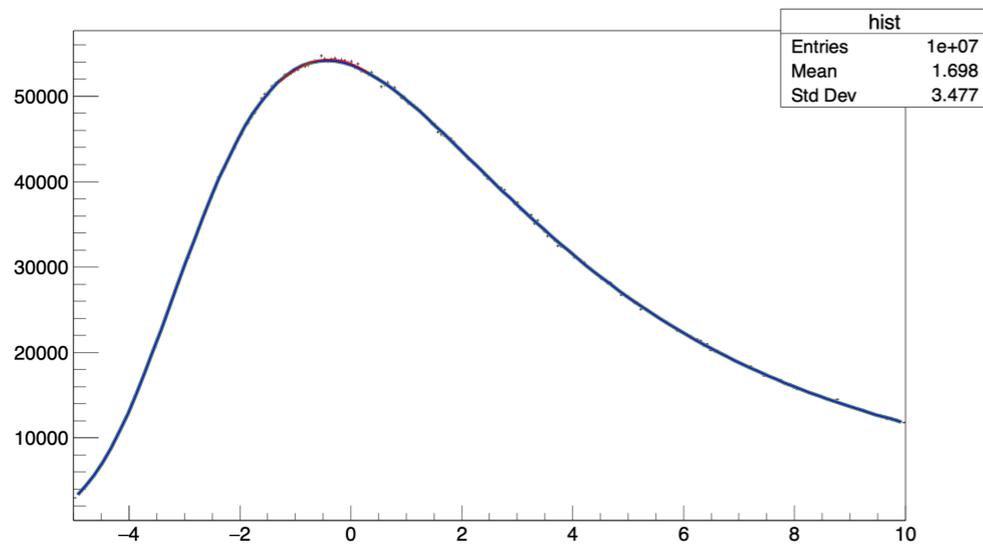
- The best threshold setting ? A : 15 adc
 - It contains all the signal edep distribution and little noise.
 - Confirmation with the Testbeam efficiency results.
- Can the bias voltage be lower ? A : Yes
 - Full depletion voltage : 61 ~ 65 V.
- What is the Gain & Offset value we are using now ?
 - A : Seems to be Gain 100, Offset 200
- The consistency of the ADC distribution, FEM & Felix board.
 - Should be identical, need to be confirmed.

Back up

// root land test

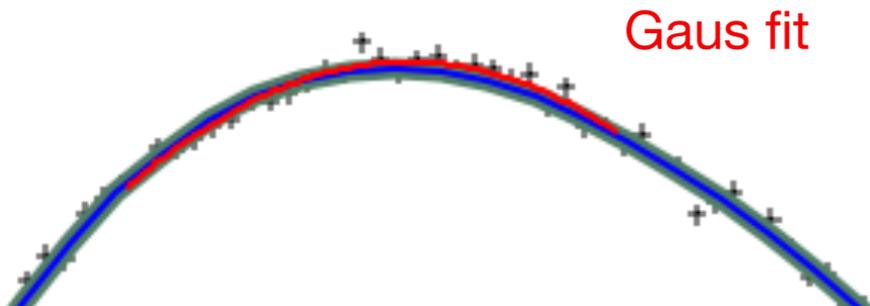
- The TMath::Landau() returns the mean (approximate MPV) instead of the true MPV.

Set TRandom::Landau(0,2)



```

FCN=114.775 FROM MIGRAD STATUS=CONVERGED 134 CALLS 135 TOTAL
EDM=7.70732e-10 STRATEGY= 1 ERROR MATRIX UNCERTAINTY 1
EXT PARAMETER STEP FIRST
NO. NAME VALUE ERROR SIZE DERIVATIVE
1 Constant 2.99973e+05 1.51832e+07 2.76422e-01 1.72006e-07
2 MPV 8.54684e-04 1.71525e-02 1.01404e-01 2.10312e-02
3 Sigma 2.00067e+00 1.06030e-05 1.01404e-01 2.10312e-01
ERR DEF= 0.5
FCN=7.79843 FROM MIGRAD STATUS=CONVERGED 215 CALLS 216 TOTAL
EDM=2.28092e-08 STRATEGY= 1 ERROR MATRIX ACCURATE
EXT PARAMETER STEP FIRST
NO. NAME VALUE ERROR SIZE DERIVATIVE
1 Constant 5.43241e+04 6.73763e+01 0.45101e-05 0.00729e-06
2 Mean -3.82575e-01 1.79977e-02 6.21652e-05 3.13724e-03
3 Sigma 2.87006e+00 1.11157e-01 6.21652e-05 3.13724e-03
ERR DEF= 0.5
FCN=114.775 FROM MIGRAD STATUS=CONVERGED 234 CALLS 235 TOTAL
EDM=9.70497e-09 STRATEGY= 1 ERROR MATRIX UNCERTAINTY 1
EXT PARAMETER STEP FIRST
NO. NAME VALUE ERROR SIZE DERIVATIVE
1 land width 2.00067e+00 1.06826e-03 5.32e-01
2 land MPV -4.44860e-01 1.55756e-03 4.99e-02
3 Area 6.00148e+05 2.36867e+02 -1.26323e-01 -4.23427e-07
4 Gaus_width 1.73999e-06 1.14030e-01 -1.99428e-04 1.34481e-04
    
```



TMath::Landau() fit

TMath::Gaus() fit

TMath::Hooa() fit

Generate a random number following a Landau distribution with location parameter mu and scale parameter sigma: Landau((x-mu)/sigma) Note that mu is not the mpv(most probable value) of the Landau distribution and sigma is not the standard deviation of the distribution which is not defined.

For mu =0 and sigma=1, the mpv = -0.22278

// 1 GeV positron beam vs 120 GeV proton beam

- Could the discrepancy is caused by some different physical process, because of different beam used ?
 - Seems to be NO. The paper : <https://iopscience.iop.org/article/10.1088/1748-0221/6/06/P06013/pdf>
- The paper used 100 MeV electron and 12 GeV proton

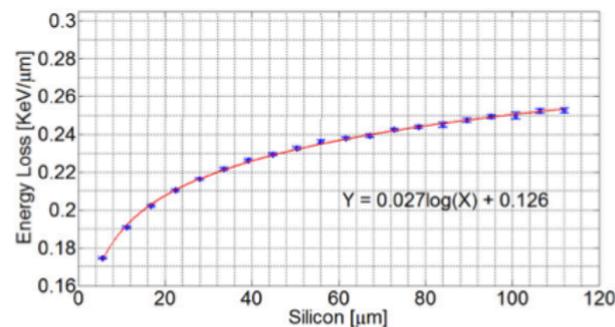


Figure 11. Energy loss for 12GeV protons passing through several silicon thickness.

The energy loss is similar

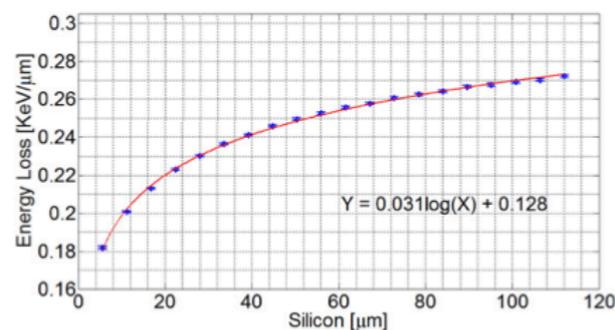
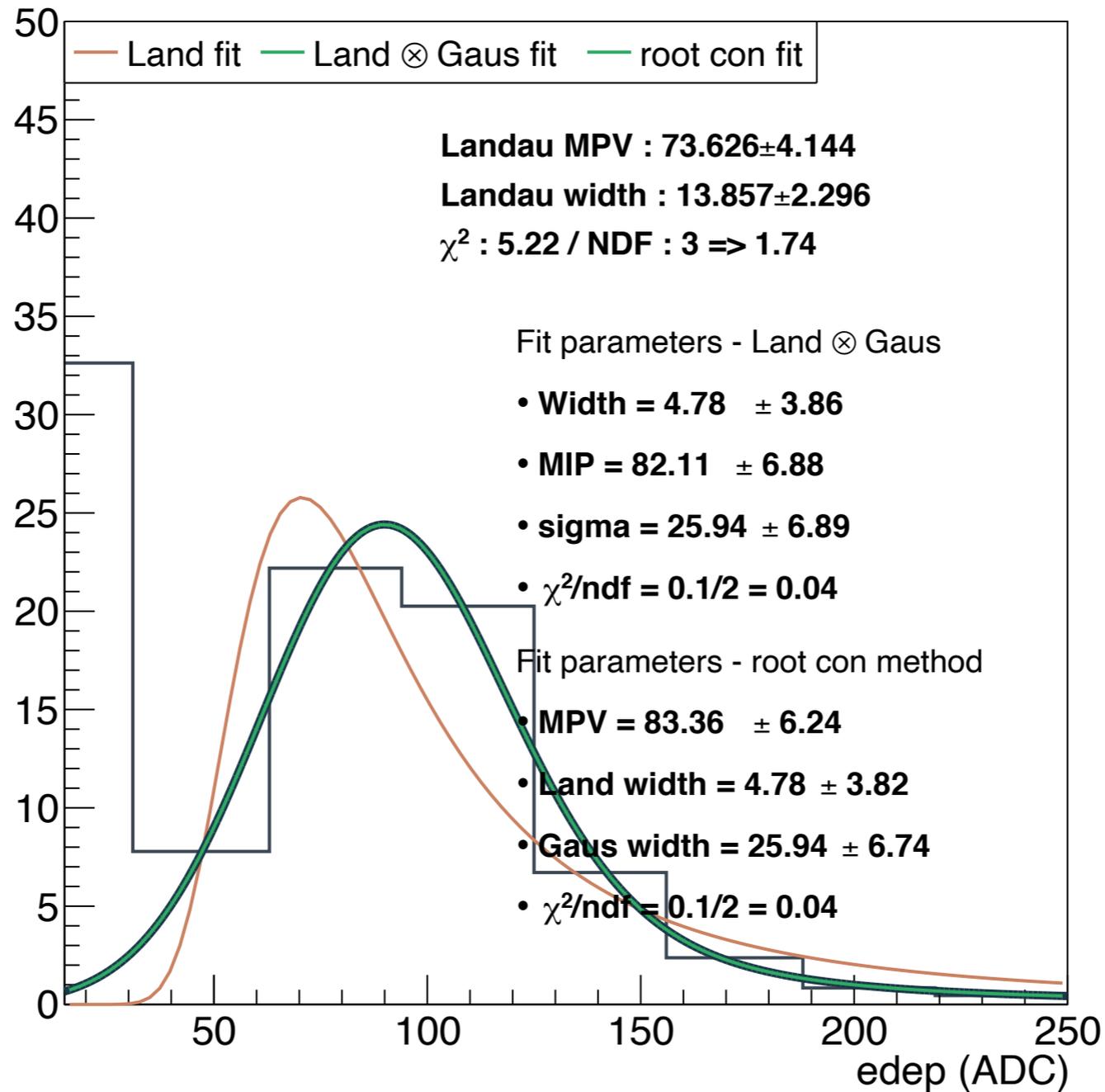


Figure 12. Energy loss for 100MeV electrons passing through several silicon thickness.

// Cosmic results

Cosmic ray, 2 scintillators & CC, 100 V

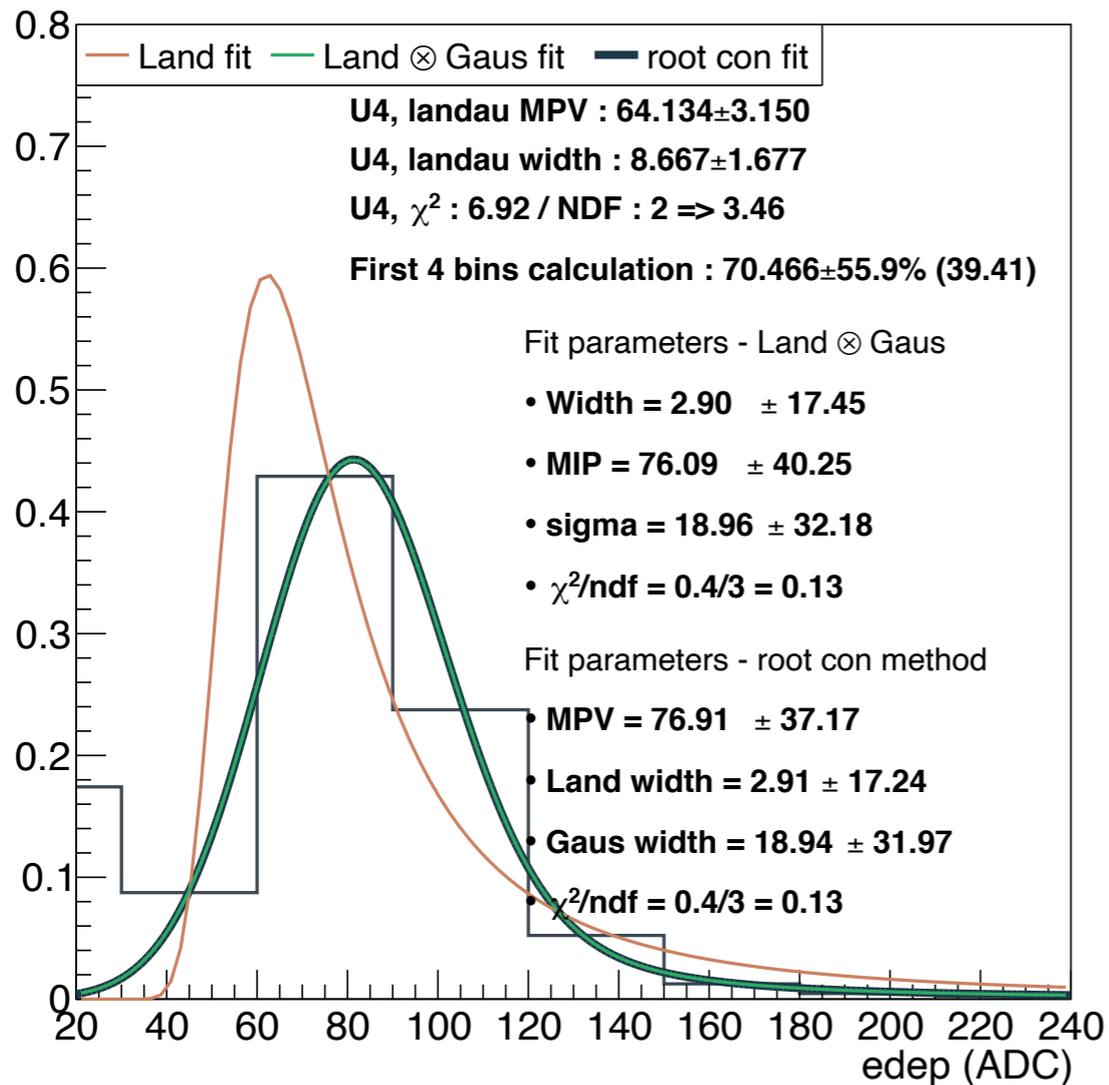


adc setting : 15,31,63,94,125,156,188,219,250

// Source test

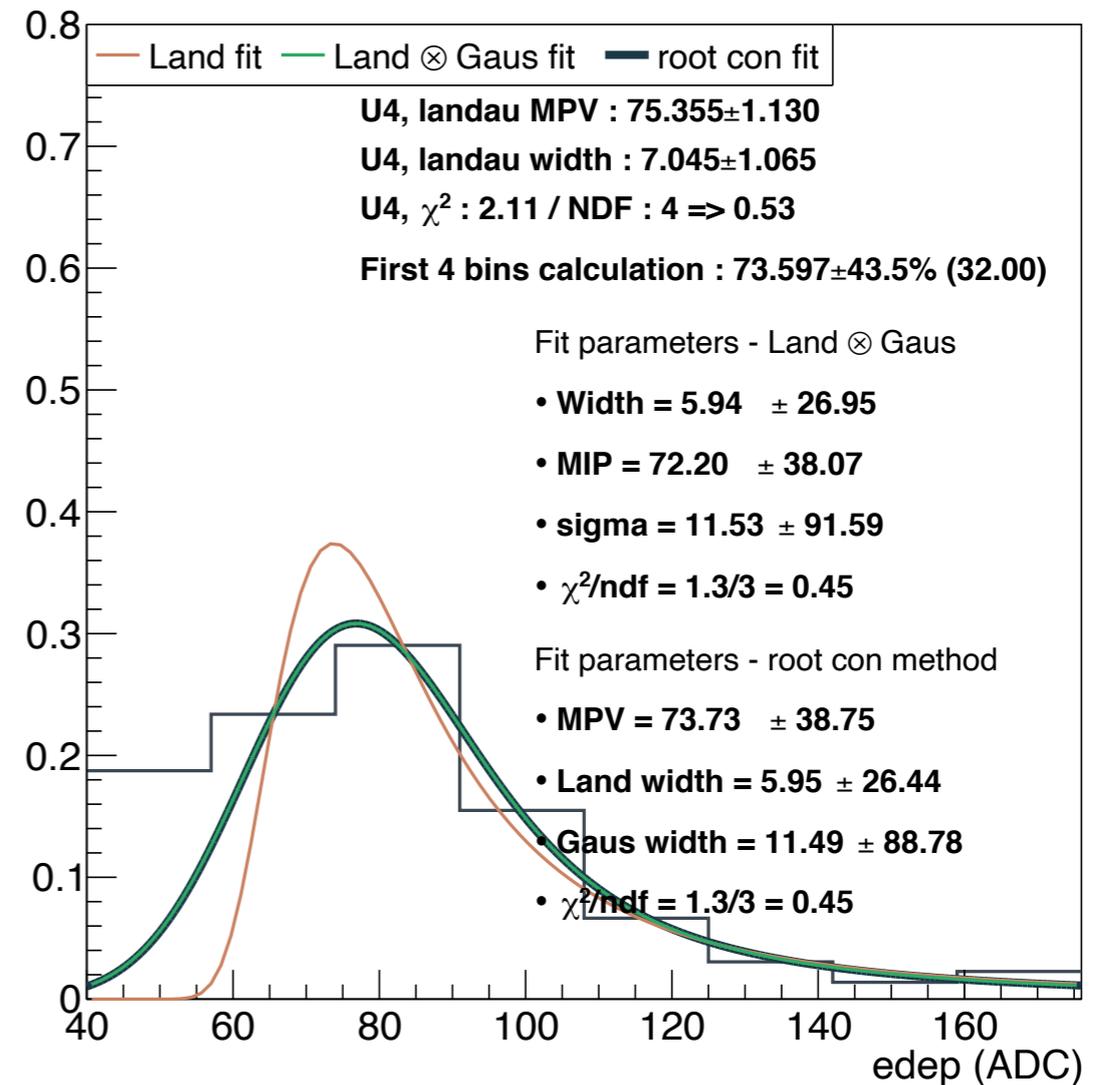
100 V
with sci
adc setting : 20, 30, 60, 90, 120, 150, 180, 210

With Sci., chip id : 4, voltage : 100



100 V
with sci
adc setting : 40, 57, 74, 91, 108, 125, 142, 159
Fitting without the consideration of the first bin

With Sci., chip id : 4, voltage : 100



// conversion function

Conversion function :

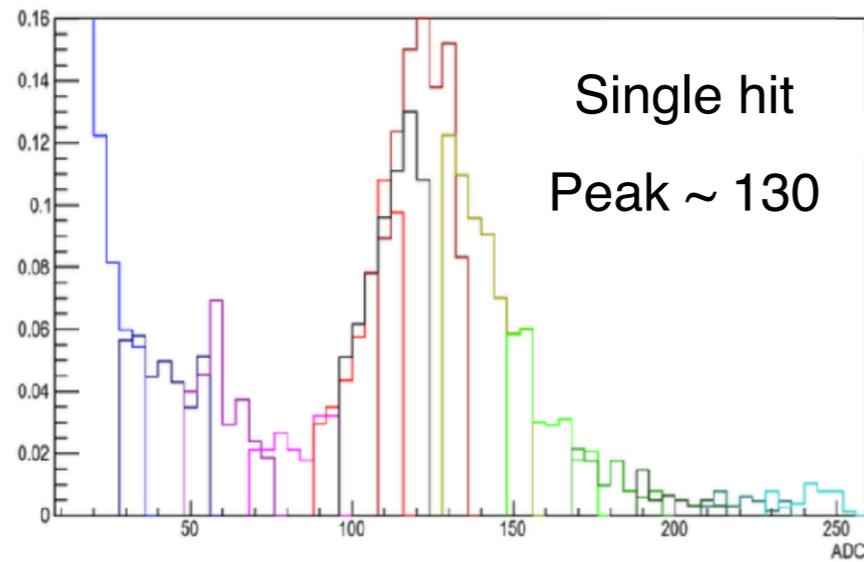
$$\text{mV} = \text{DAC} * 4 + 210$$

$$\text{mV} = \frac{E_{\text{dep}} * 10^6[\text{eV}] * 1.6 * 10^{-4}[\text{fC}] * G}{3.6\text{eV}} + O$$

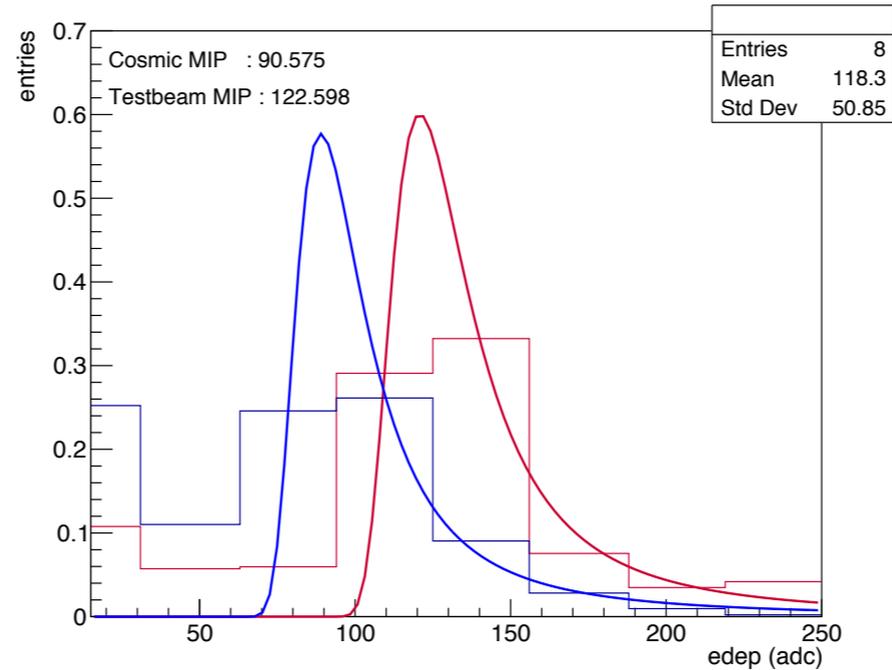
G : 100 [mV/fC], O : 280 [mV]

// DAC scan - comparison

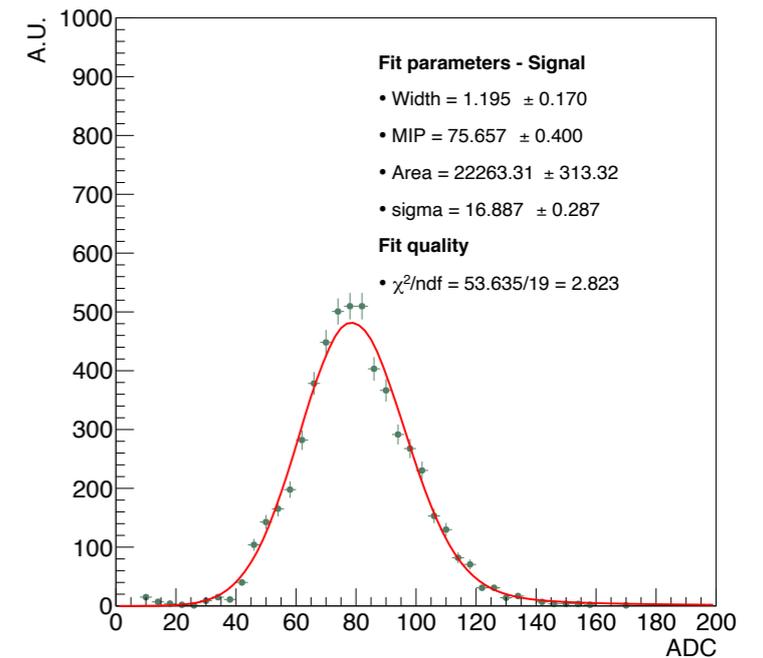
TestBeam2019



— Cosmic
— Testbeam2019



DAC Scan all I1

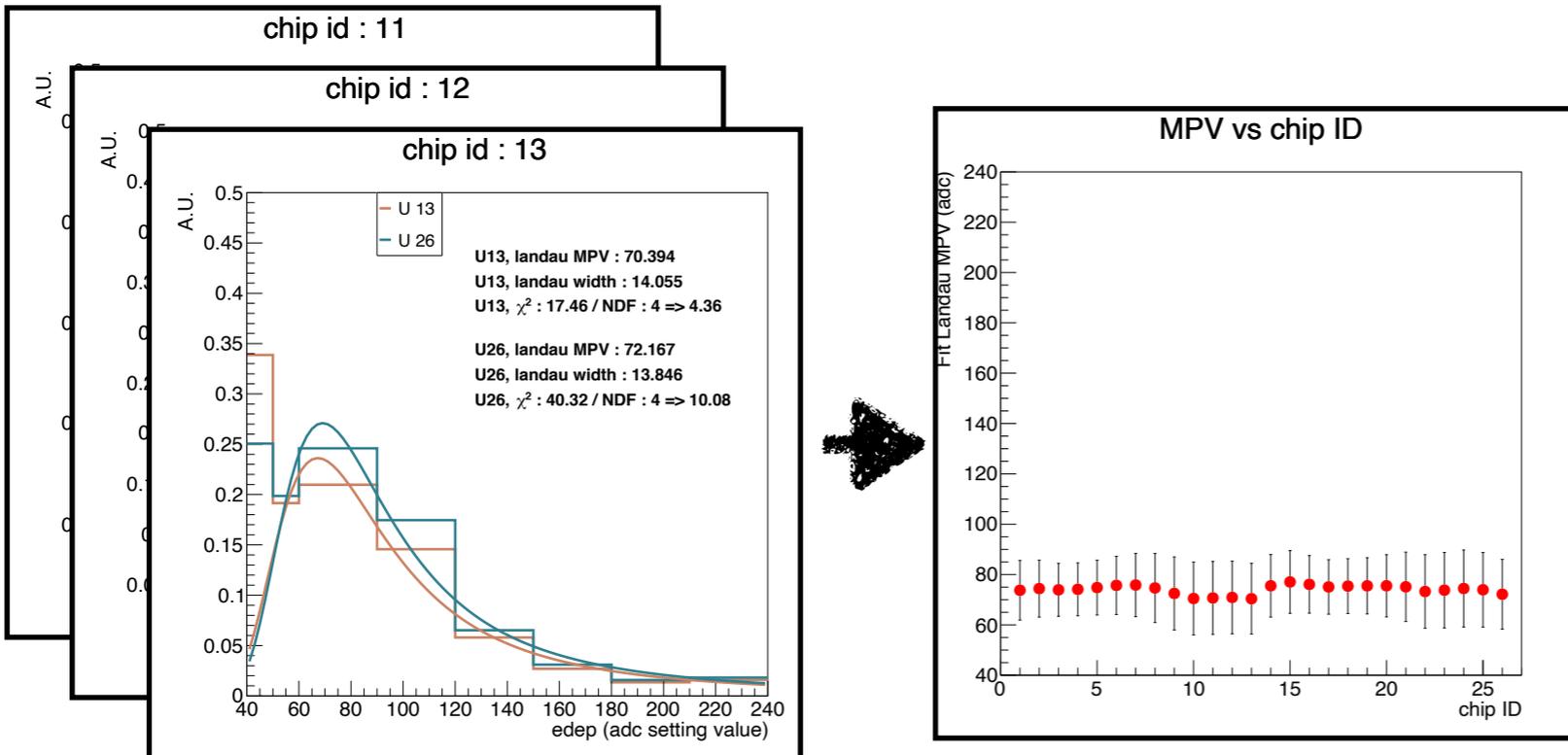


Cosmic MPV : 90.58
Testbeam : 122.598

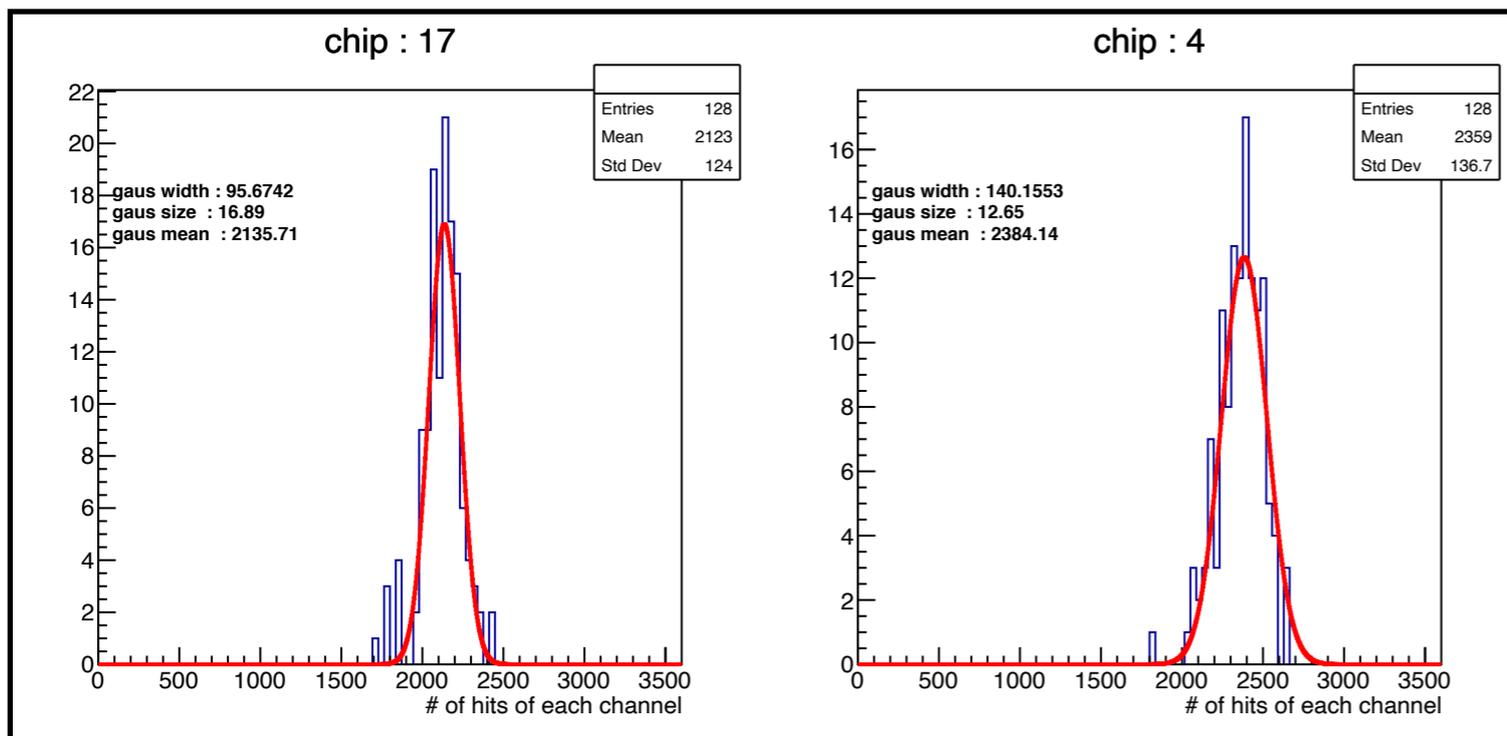
Bias voltage : 50V
MPV : 75.7

// Source test results, threshold 40 adc

- 5 ladders were tested with the source



- Criteria 1 : entry < 5 sigma of the distribution
- Criteria 2 : entry < 5 sigma of the distribution and entry < 900

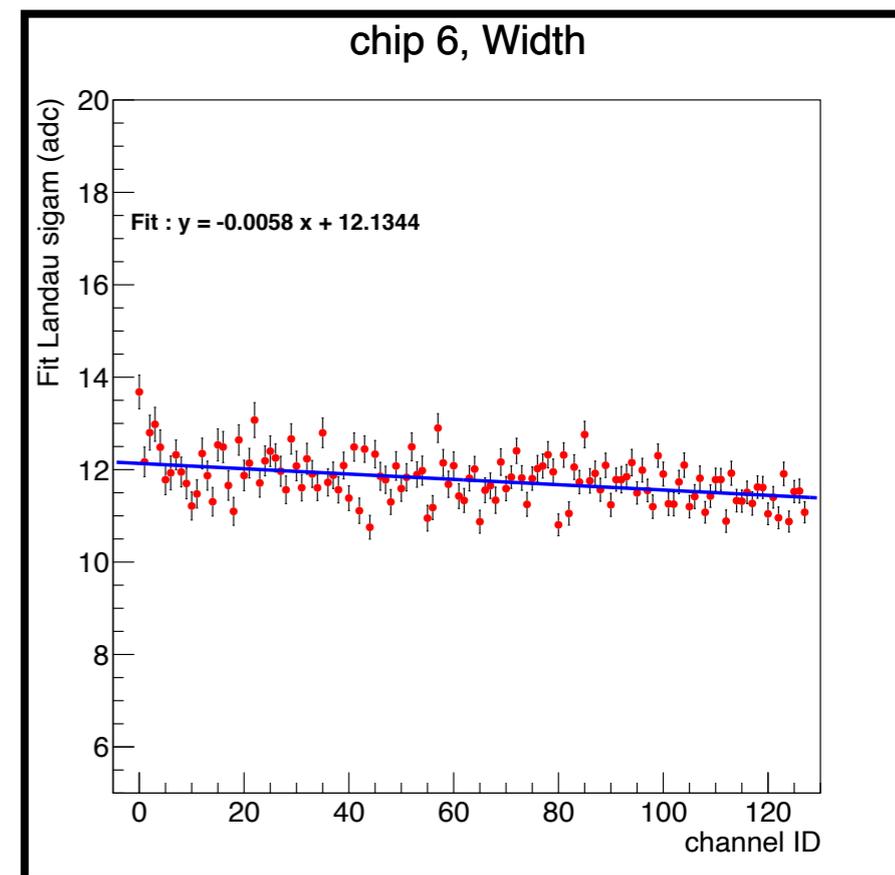
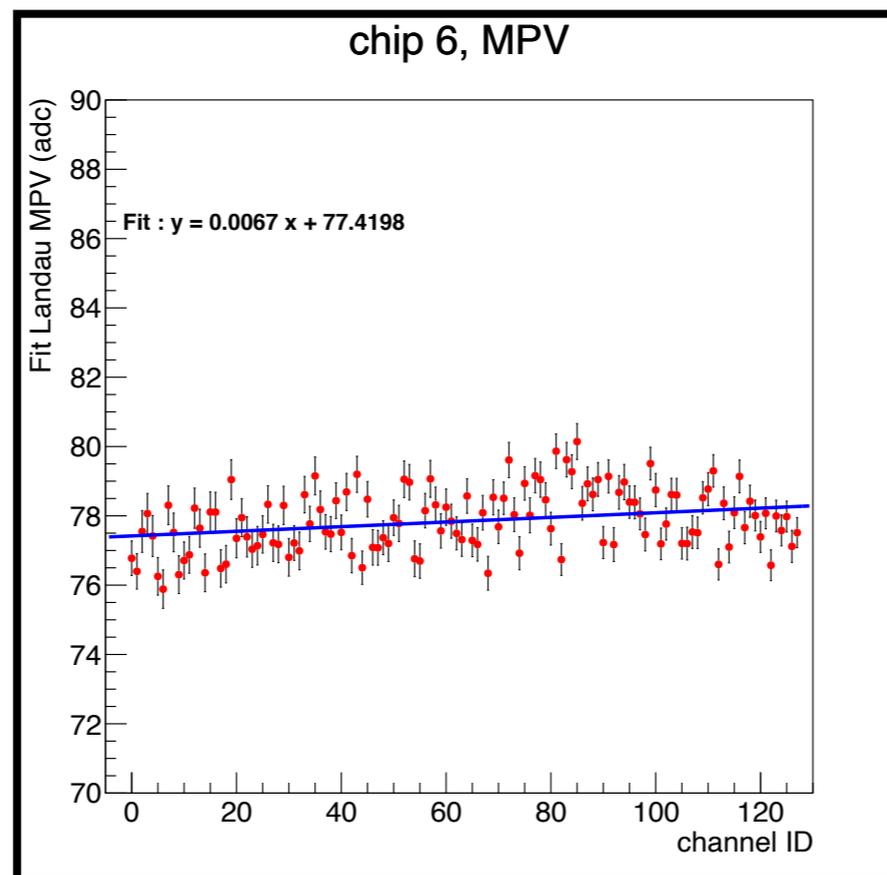
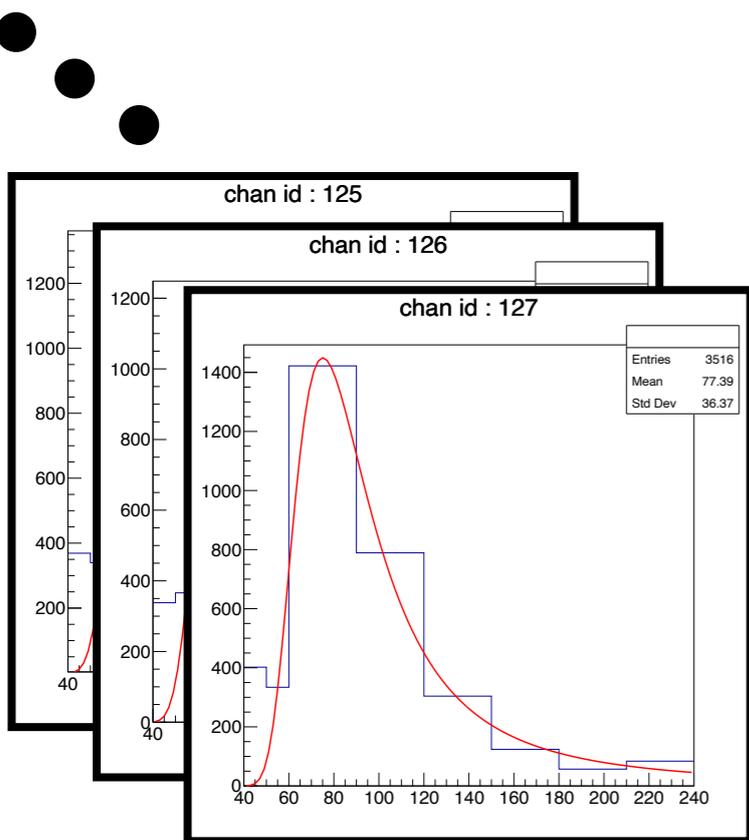
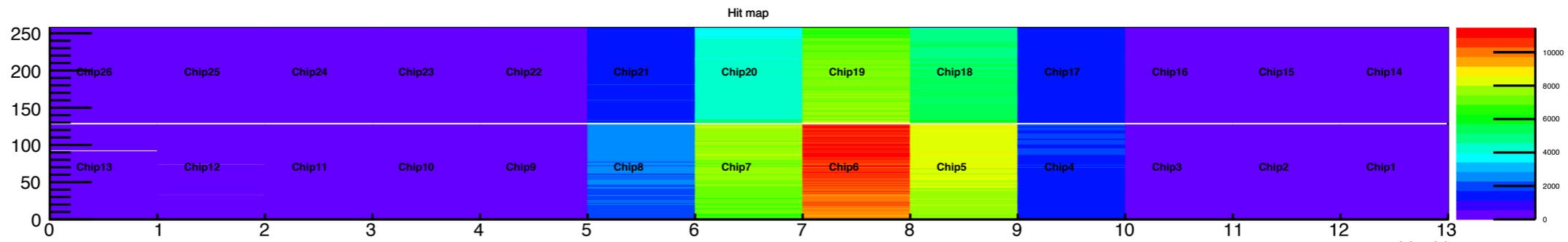


of bad channel

	Criteria 1	Criteria 2
02-0077	7	0
02-0046	2	1
02-0013	3	0
02-0016	5	1
02-0028	19	2

// Source test, channel consistency, threshold 40 adc

- Self-trigger mode
- Threshold : 40
- With Sr-90
- Fixed at U6
- 30 mins run



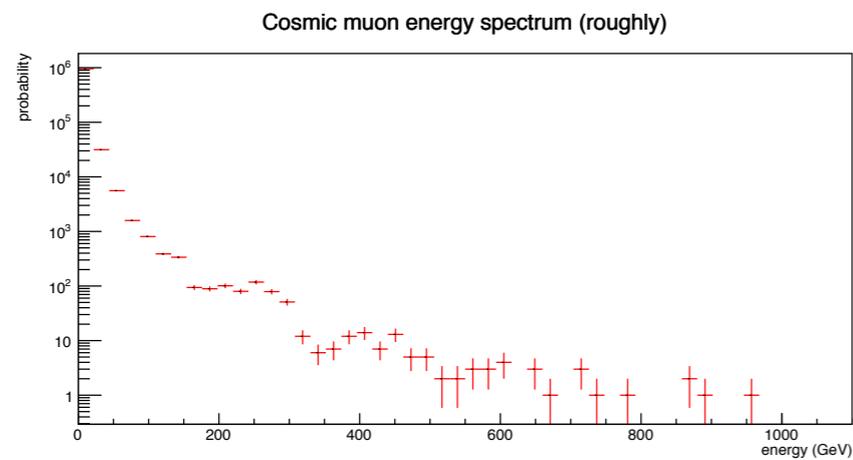
Cosmic test, comparison



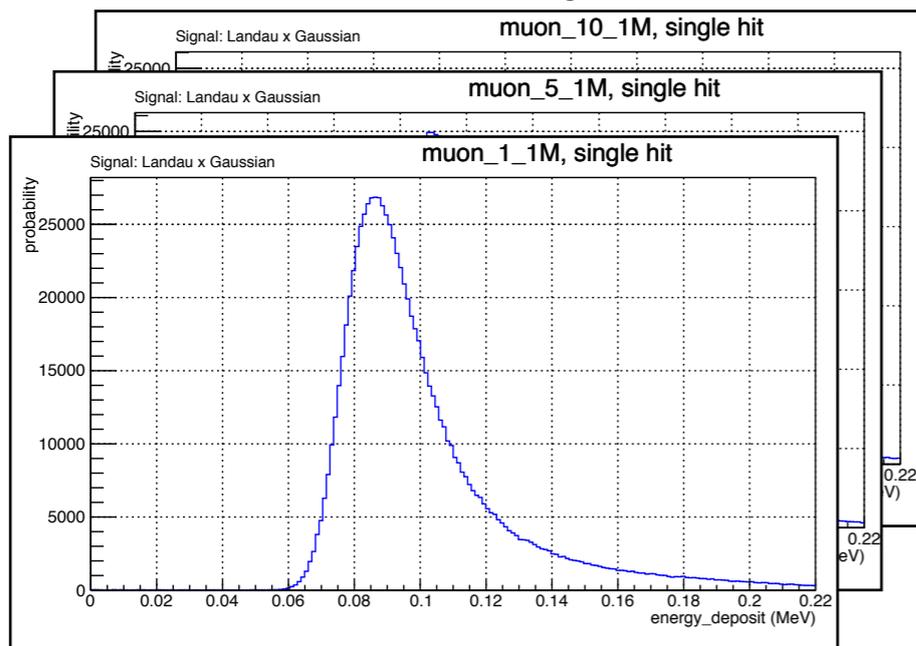
Beam information :

Test Beam : 120 GeV proton

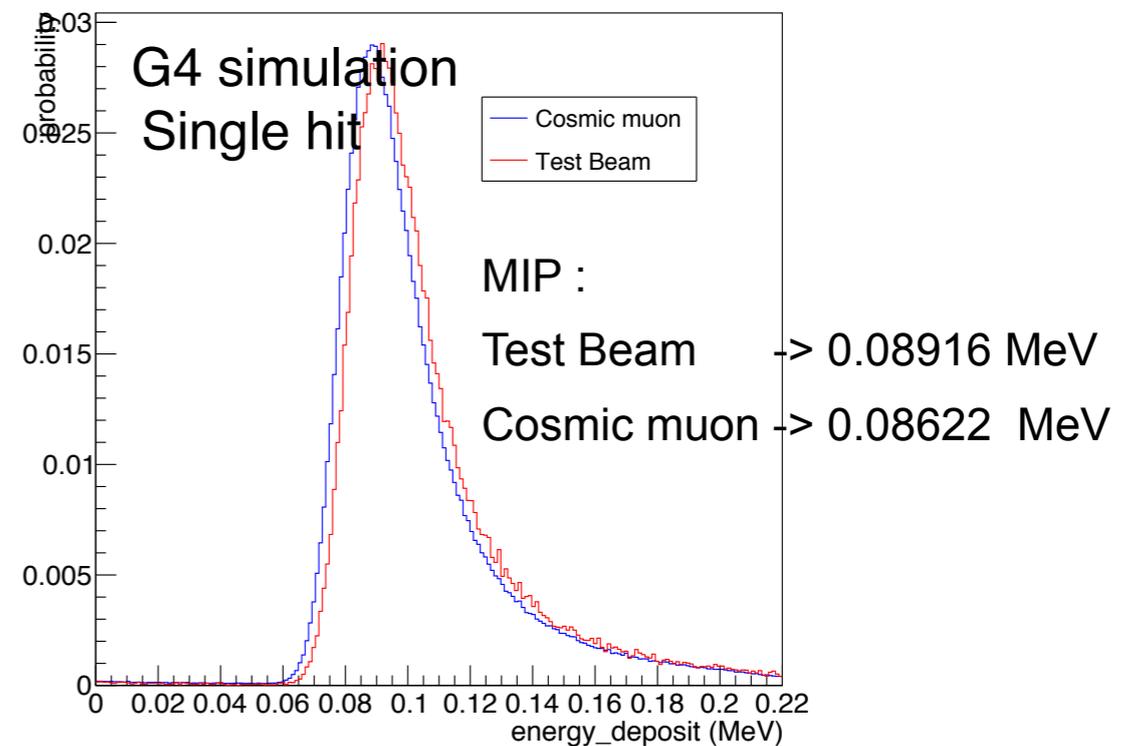
cosmic muon : roughly energy spectrum



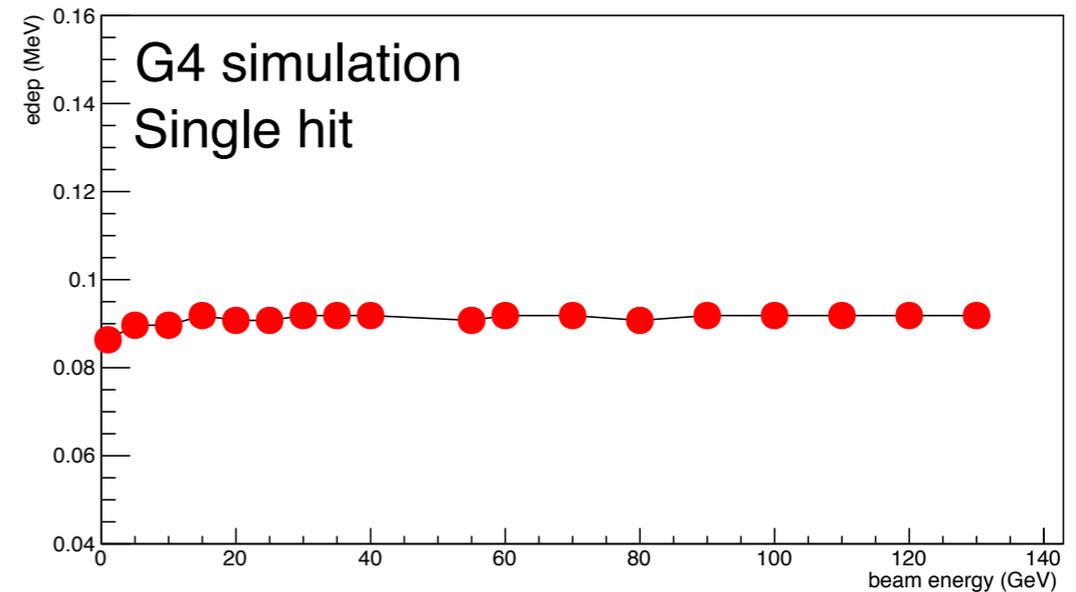
• • • 1 to 130 GeV



energy deposit, cosmic muon TC energy spectrum



Muon edep scan, 1 GeV to 130 GeV



Noise study

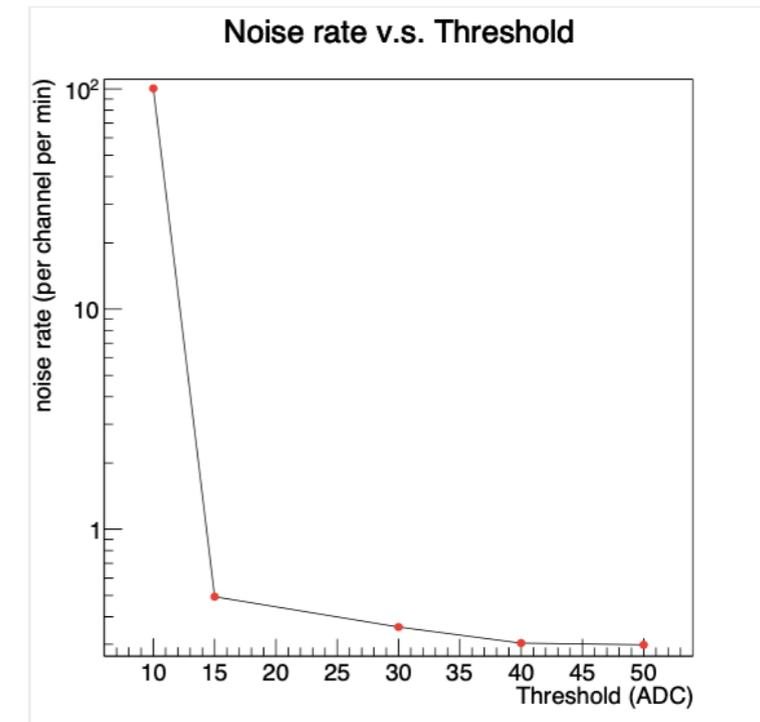
// Source test, system noise

Self-trigger, no source

Threshold (adc)	Operation time (min)	total event	rate (per min per channel)
15	15.5	20873	0.404 ± 0.0028
40	1282	926089	0.217 ± 0.00022

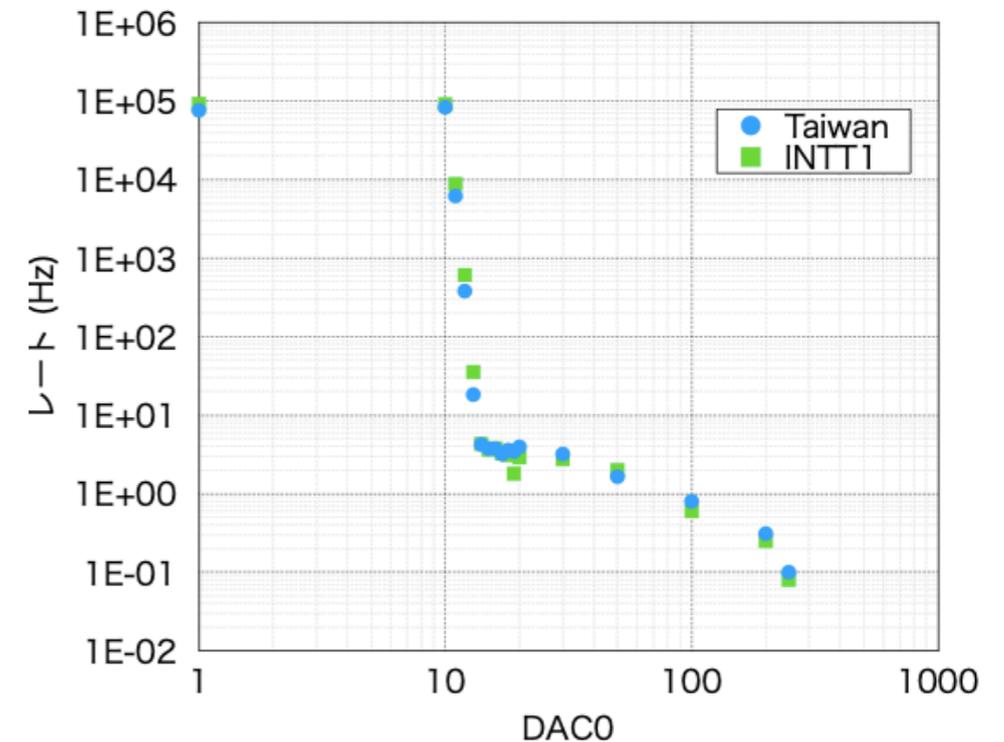
// Noise rate v.s. Threshold

Threshold (ADC)	rate (per channel per min)	
10	100.515	± 0.086
15	0.493	± 0.0065
30	0.359	± 0.0045
40	0.304	± 0.0042
50	0.298	± 0.004



DAC0 を変えたときのセルフトリガーレート

	unit : adc	Ratio of noise rate
Genki	@30 / @15	0.753
	@50 / @15	0.548
CW	@30 / @15	0.728
	@50 / @15	0.604

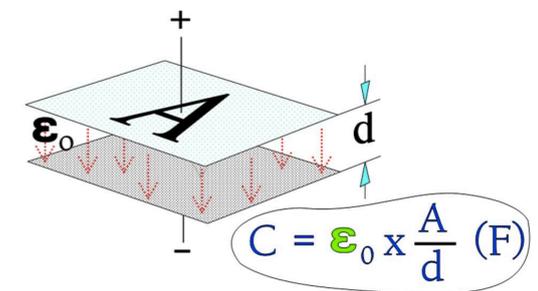
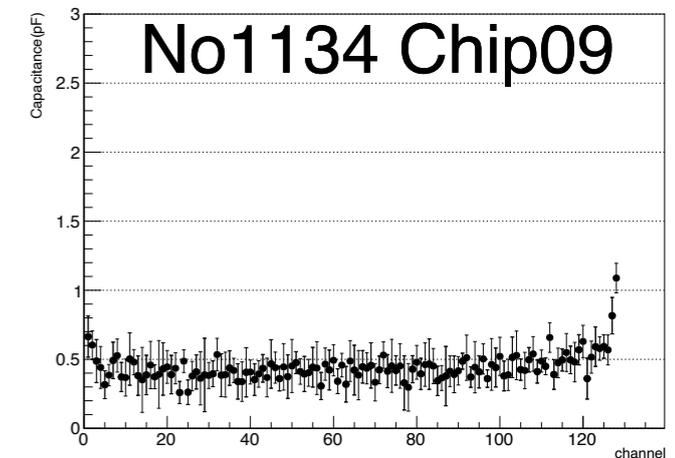


The results are consistent !

Capacitance study

// Capacitance - check

- Total capacitance of type-A @ 100 V : 929.3248 pF (Hamamatsu)
- Capacitance of each channel ~ 0.5 pF (NCU)
 - $0.5 * 16 * 128 = 1024$ pF -> reasonable.
- $\epsilon_0 = 8.854 * 10^{-12}$ (unit : F/m)
- Area of type-A sensor = $128 * 16 * 0.016 * 0.000078$
 - -> 0.00255 m²
- $(8.854 * 10^{-12}) * (0.00255) / 0.00032 = 70.71$ pF
- $(8.854 * 10^{-12}) * (0.00255) / 0.0000245 = 923.6$ pF
- 0.0000245 m = 24.5 μ m



// Capacitance - check

- Confirmation the equation :
 - Area of type-A sensor = $128 * 16 * 0.016 * 0.000078$
 - $\rightarrow 0.00255 \text{ m}^2$
 - Area of type-B sensor = $128 * 10 * 0.020 * 0.000078$
 - $\rightarrow 0.00199 \text{ m}^2$
 - $C_A / C_B : A_A / A_B = 929.32/723.02 : 0.00255/0.00199$
 - $\rightarrow 1.285 : 1.281$
- Assumption : a correction facto $f = 13.14$
- $$C = \frac{\epsilon_0 A}{d} \times f$$
- Assume C @ full depletion (320 um) @ 100 V = 929.3248 pF
- Depletion thickness @ 50 V (C = 994.1497 pF) : 299.107 um

// Capacitance, another confirmation

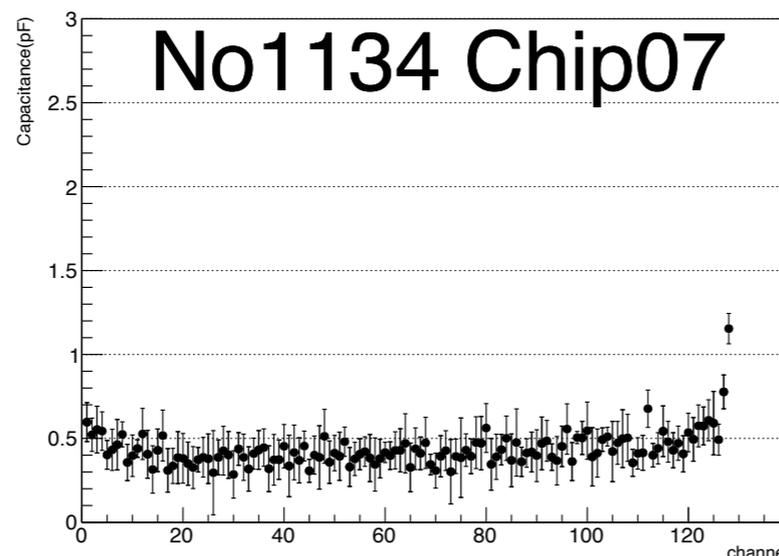
- $1.5 \text{ pF cm}^{-1} \times 0.032 \text{ cm} = 0.048 \text{ pF}$

The conductive p and n regions together with the depleted volume form a capacitor with the capacitance per unit area

$$C = \epsilon/W \approx 1 \text{ [pF/cm]} /W \text{ in Si.} \quad (34.21)$$

In strip and pixel detectors the capacitance is dominated by the fringing capacitance to neighboring electrodes. For example, the strip-to-strip Si fringing capacitance is $\sim 1\text{--}1.5 \text{ pF cm}^{-1}$ of strip length at a strip pitch of $25\text{--}50 \text{ }\mu\text{m}$.

No area information involved



Measurement $\sim 0.5 \text{ pF}$

// Capacitance, reference

In a planar device the thickness of the depleted region is

$$W = \sqrt{2\epsilon(V + V_{bi})/Ne} = \sqrt{2\rho\mu\epsilon(V + V_{bi})} \quad (34.20)$$

where V = external bias voltage

V_{bi} = “built-in” voltage (≈ 0.5 V for resistivities typically used in Si detectors)

N = doping concentration

e = electronic charge

ϵ = dielectric constant = $11.9 \epsilon_0 \approx 1$ pF/cm in Si

ρ = resistivity (typically 1–10 k Ω cm in Si)

μ = charge carrier mobility

= 1350 cm² V⁻¹ s⁻¹ for electrons in Si

= 450 cm² V⁻¹ s⁻¹ for holes in Si

In Si

$W = 0.5[\mu\text{m}\sqrt{\Omega\text{-cm} \cdot V}] \times \sqrt{\rho(V + V_{bi})}$ for n -type Si, and

$W = 0.3[\mu\text{m}\sqrt{\Omega\text{-cm} \cdot V}] \times \sqrt{\rho(V + V_{bi})}$ for p -type Si.

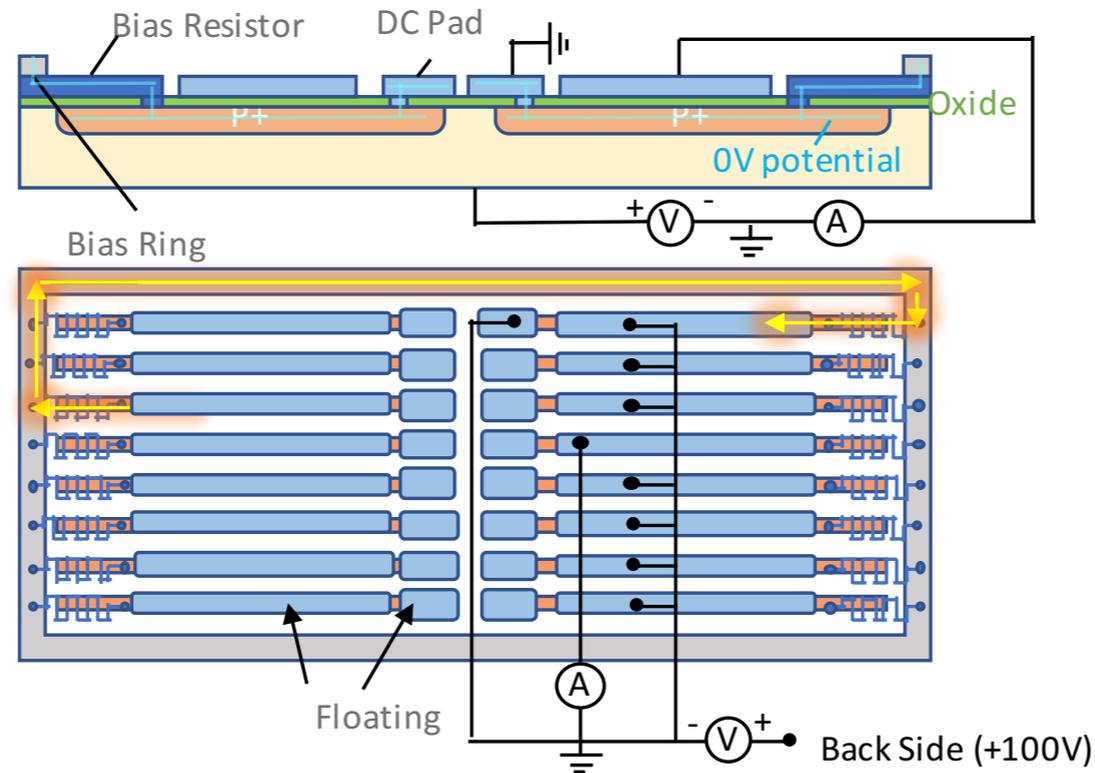
The conductive p and n regions together with the depleted volume form a capacitor with the capacitance per unit area

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In strip and pixel detectors the capacitance is dominated by the fringing capacitance to neighboring electrodes. For example, the strip-to-strip Si fringing capacitance is $\sim 1\text{--}1.5$ pF cm⁻¹ of strip length at a strip pitch of 25–50 μm .

// INTT sensor

- n-type sensor, 底部是正電壓。
- 這可以從給的電壓和位置知道 因為是加逆偏壓 就會知道哪端是N 哪端是P
- n-type : detector bulk is n-type



// Edep comparison - Gain setting

- **GSel<2:0>**: determines integrator feedback capacitance $C_{fb} = 25\text{fF} + [(8.6\text{fF})(\text{GSel}<0>) + (25\text{fF})(\text{GSel}<1>) + (50\text{fF})(\text{GSel}<2>)]$. Default = 010.
- With a fixed shaper **gain** of about 5, the nominal system transfer **gain** can then be set to approximately 46, 50, 60, 67, 85, 100, 150, or 200 mV/fC.

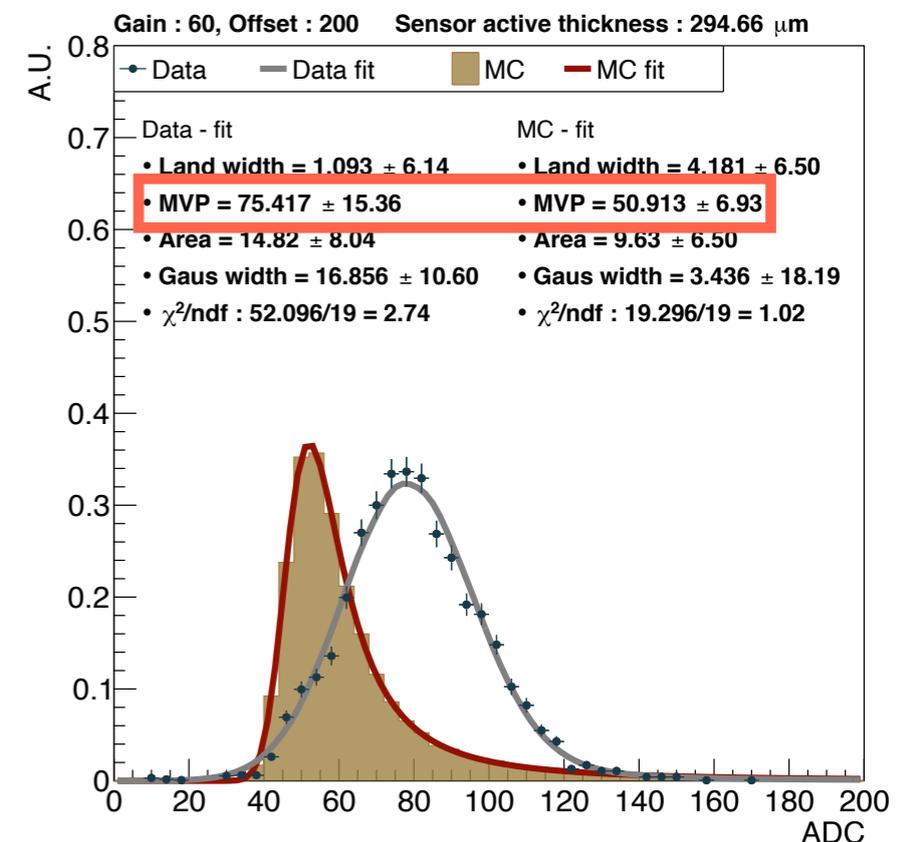
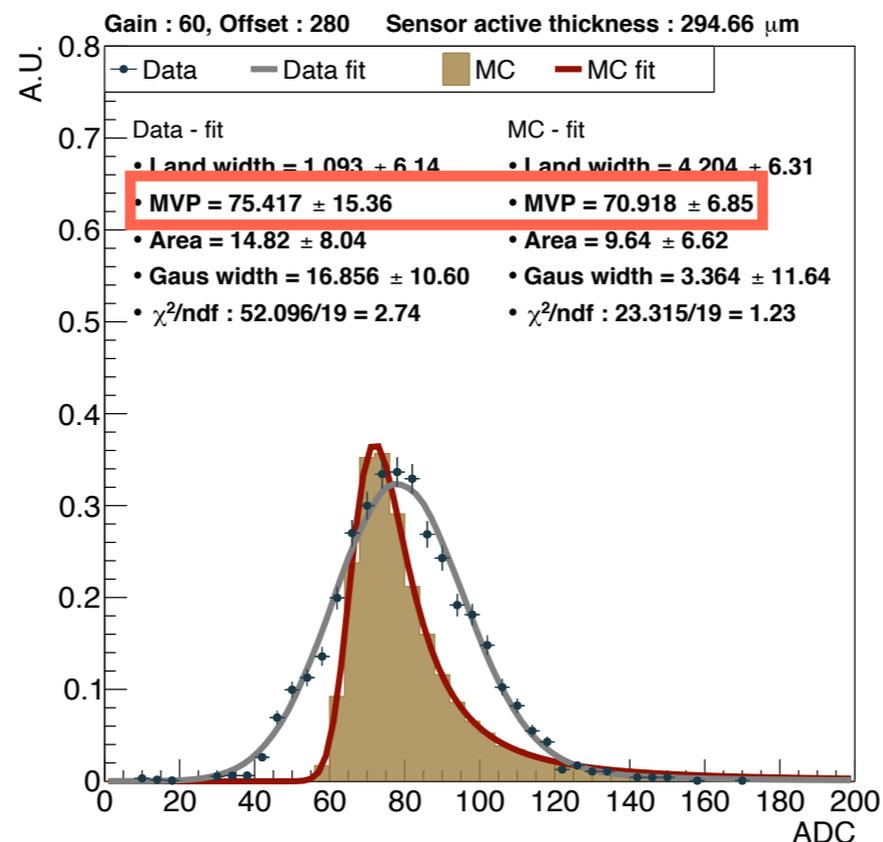
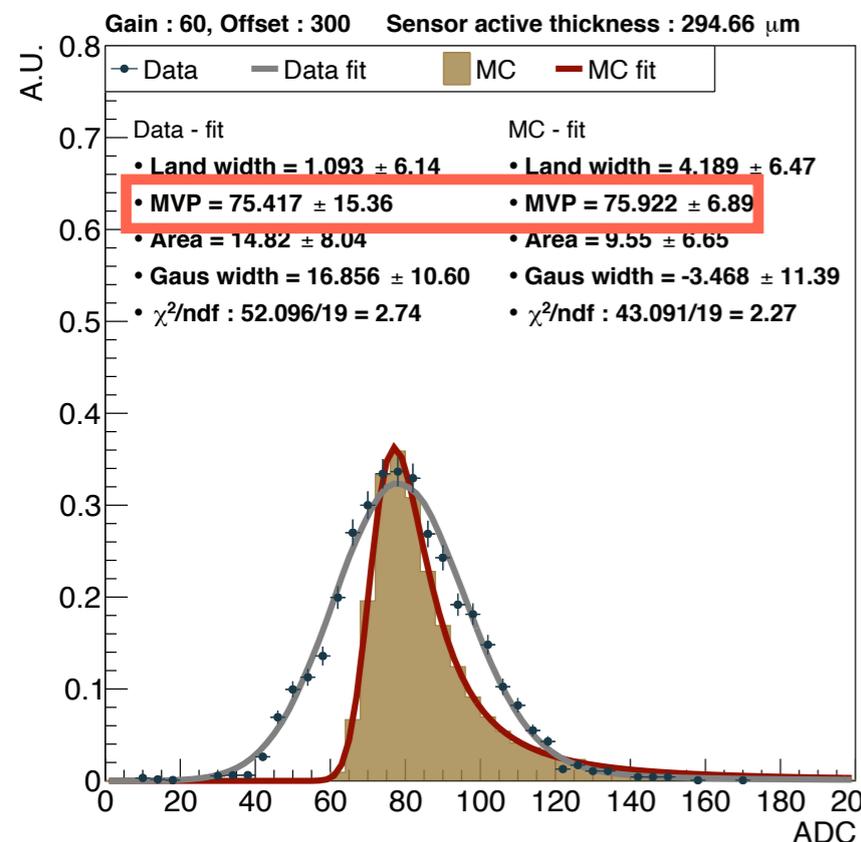
13	FB1Sel <3:0>	4	Read	Write	Set	Reset	Default
	LeakSel <7:4>	0					
14	P3Sel <1:0>	0	Read	Write	Set	Reset	Default
	P2Sel <7:4>	4					
15	GSel <2:0>	2	Read	Write	Set	Reset	Default
	BWSel <7:3>	8					

The Gain setting : 100 mV/fC

Gain 60, Offset 300

Gain 60, Offset 280

Gain 60, Offset 200



// Summary

- Testbeam2021 vs source test
 - Testbeam (DAC scan, 50 V) : 73.598 adc
 - Source test (8 bins, 50 V) : 58.63 adc
 - Discrepancy : 20.3 % → reasonable
 - The supply voltage in Testbeam2021 seems to be confirmed to be 50 V.
- Source test vs cosmic test (100 V)
 - Source test (8 bins, threshold 20 adc) : 69.617
 - Cosmic test (8 bins, threshold 15 adc) : 73.626
 - Discrepancy : 5.4 % → reasonable
- Another approach, G4 : 94.239 ADC → contradicts with the Testbeam2019
- Based on the plots on slide 10, the edep @ 100 V should be ~ 80 adc → contradicts with the Testbeam2019.
 - Reason : Different readout system ? Gain ?