AC-LGAD sensor measurements and Simulation

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Outlook

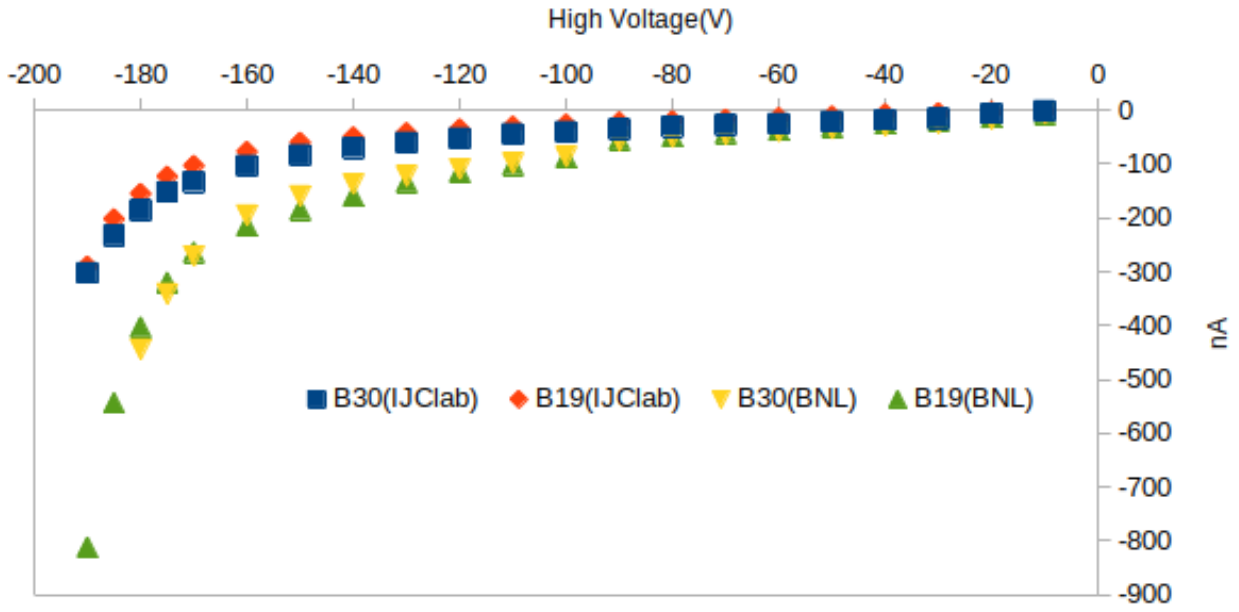
- Testboard measurements B19, 30
  - sharing
  - TDC performances
- Pixel detector simulation model study
  - to know the spatial resolution under different ADC-bit

Experimental setup

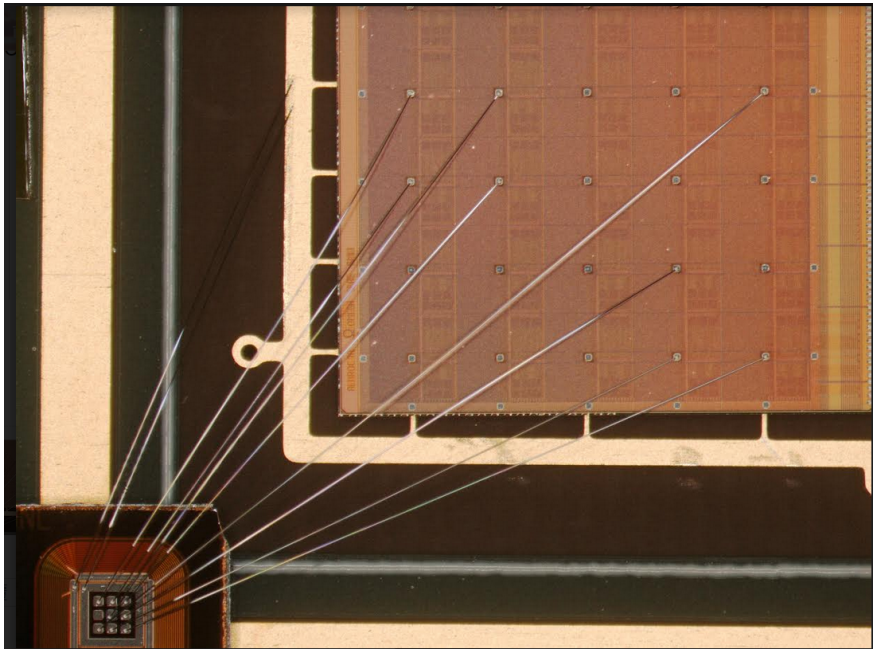
Sensor and the ASIC are in the dark box

IV curve of B19 and 30

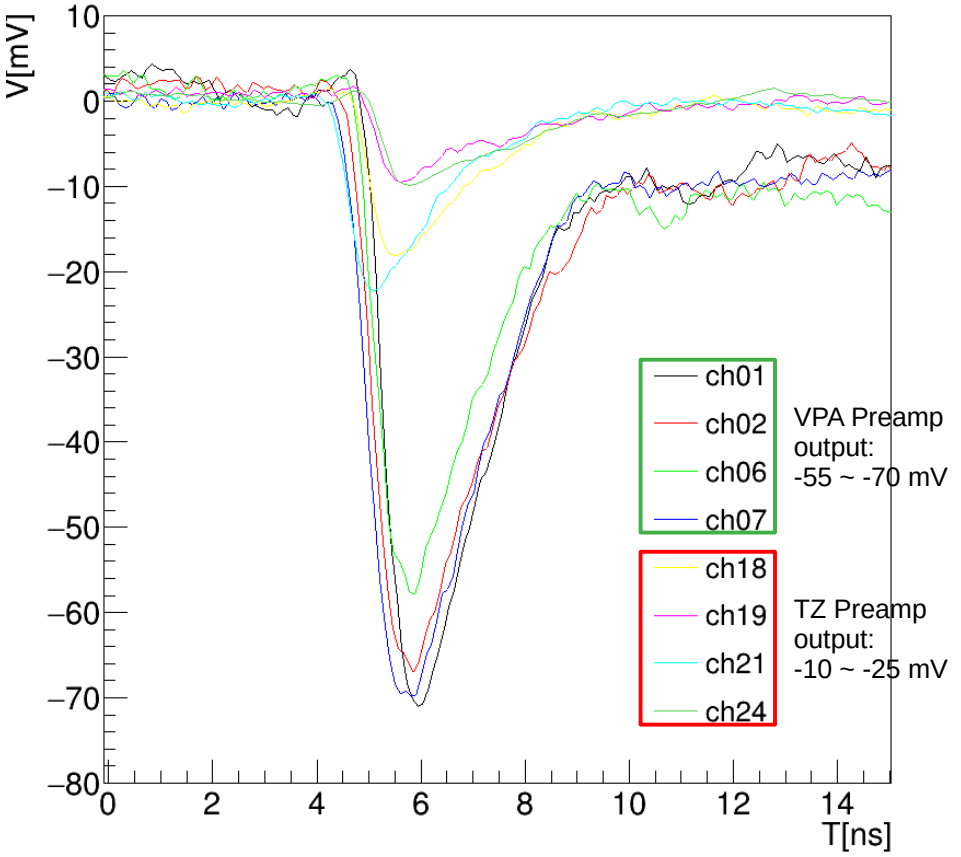
- The I-V curve comparison between IJClab and BNL
- The difference between IJClab and BNL comes from the experimental setup.



Channel sharing of B19



Probe the injected channel
turn off the other 24 channels



Preamp:VPA

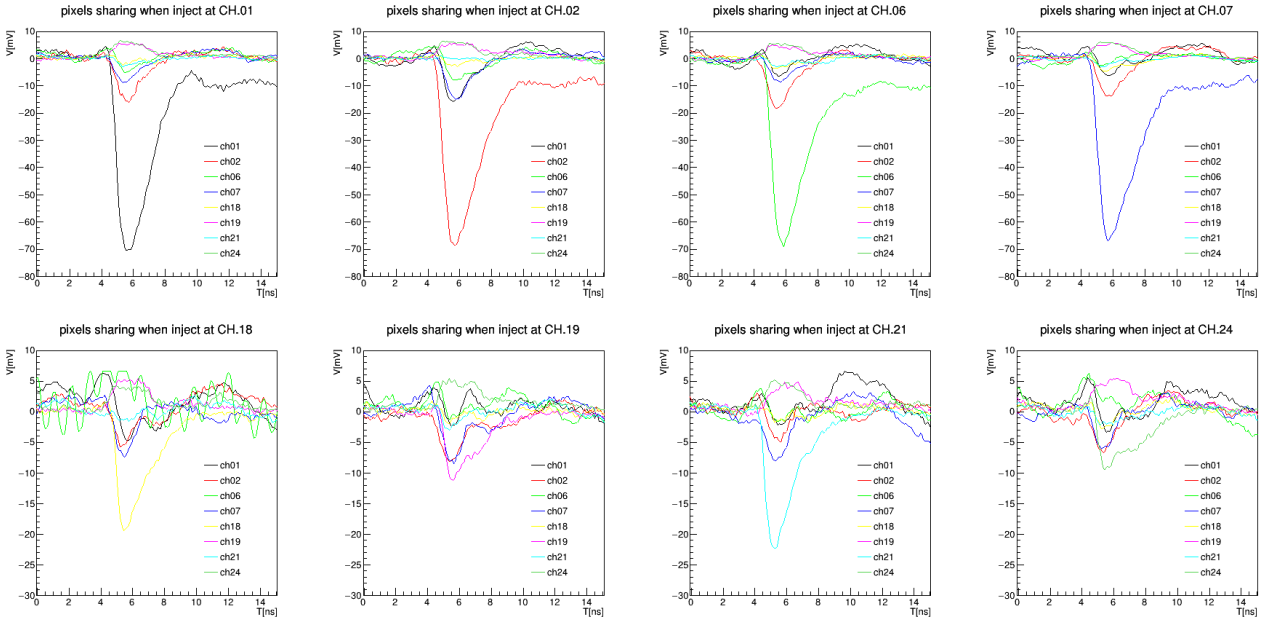
0	5	10	15	20
1	6	11	16	21
2	7	12	17	22
3	8	13	18	23
4	9	14	19	24

1	2	7
NC	6	18
21	19	24

Preamp:TZ

HV: -160V
I: ~68nA
DAC pulser: 10[~8fC]
DAC-bit[threshold]: 400

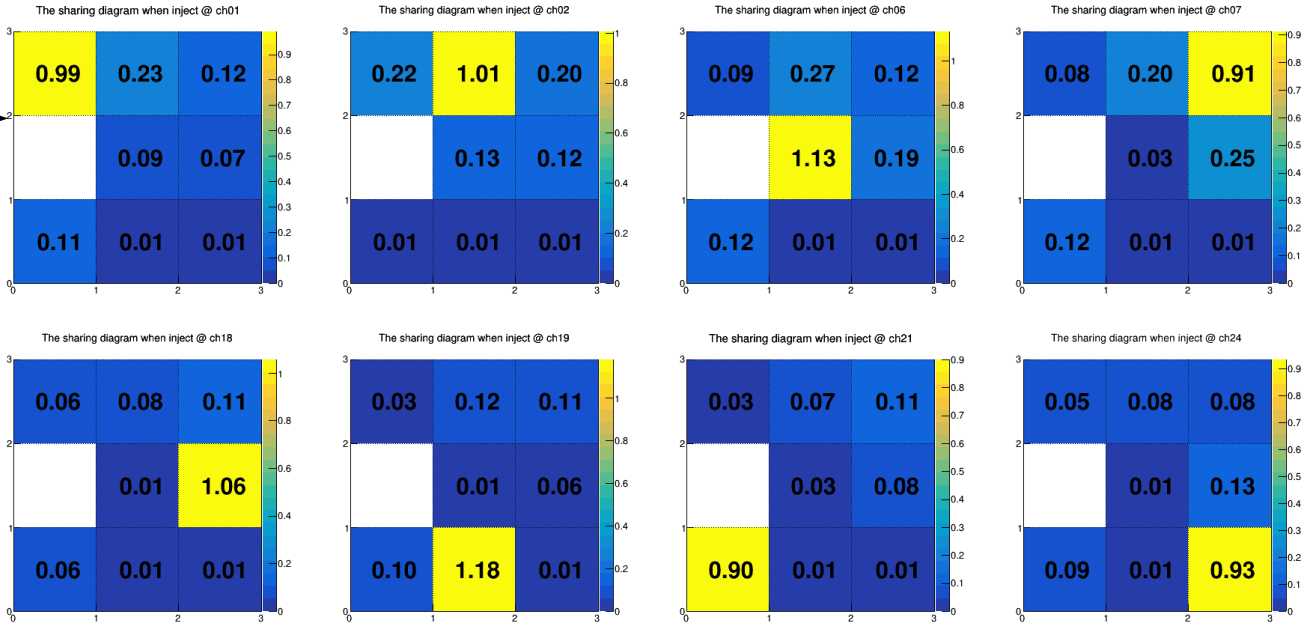
Channel sharing of B19



HV: -160V
I: ~68nA
DAC pulser: 10[~8fC]
DAC-bit[threshold]: 400

Amplitude of each channel normalized to the one when all others are OFF (previous slide)

Charge injected in one channel [yellow background]

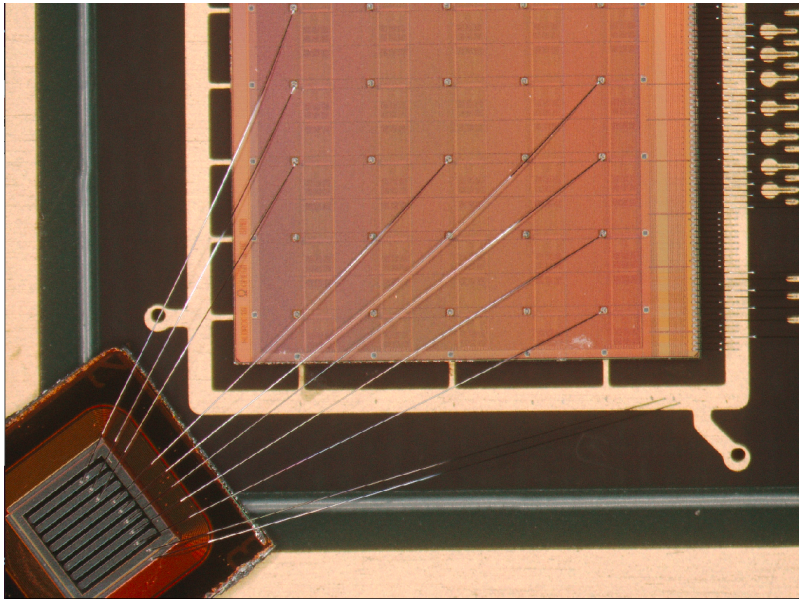


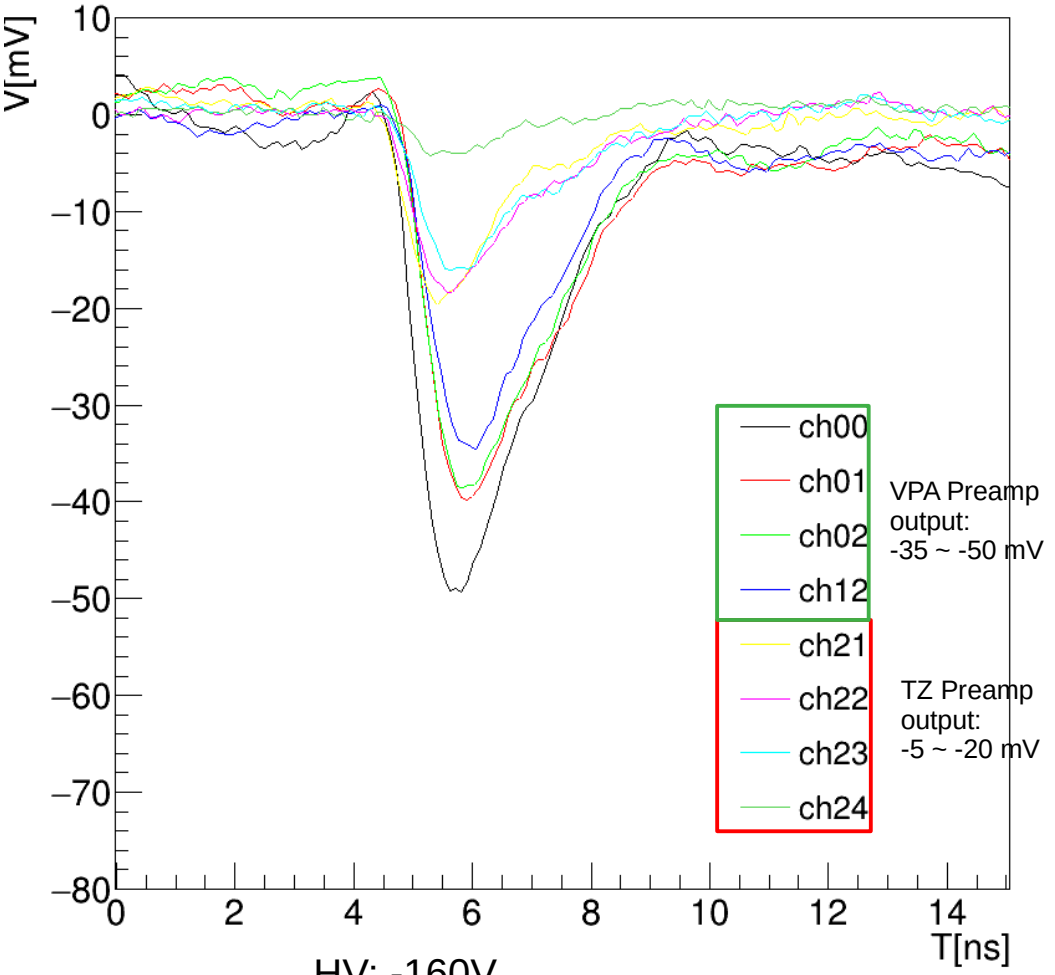
1	2	7
NC	6	18
21	19	24

Sensor to chip ID map

Channel sharing of B30

Probe the injected channel
turn off the other 24 channels





Preamp: VPA

0	5	10	15	20
1	6	11	16	21
2	7	12	17	22
3	8	13	18	23
4	9	14	19	24

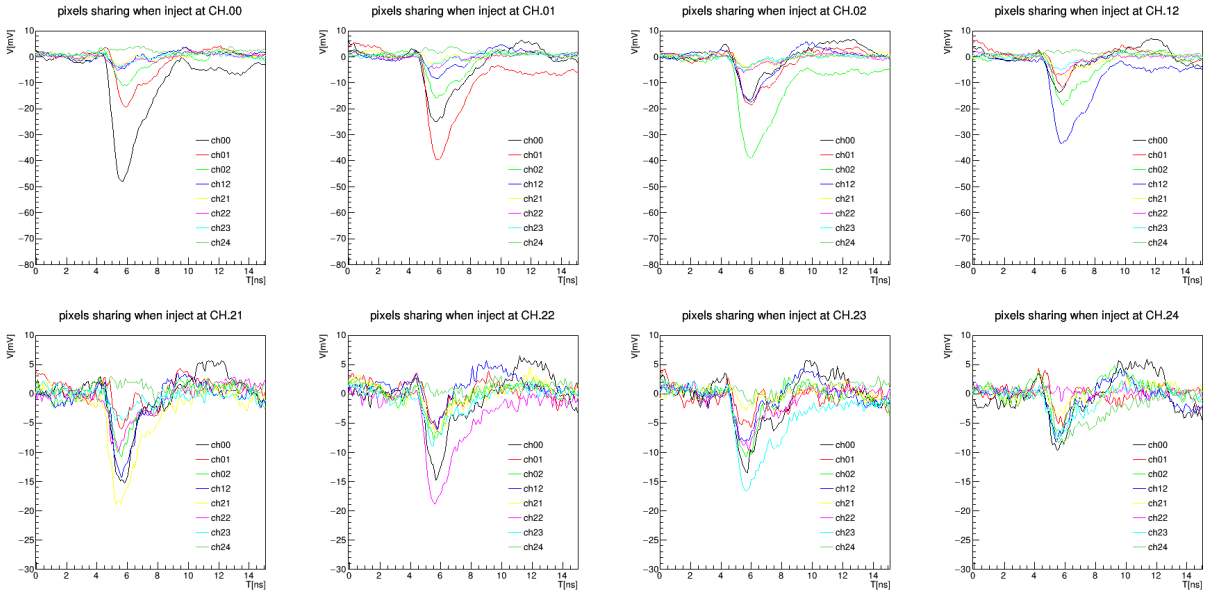
Preamp: TZ

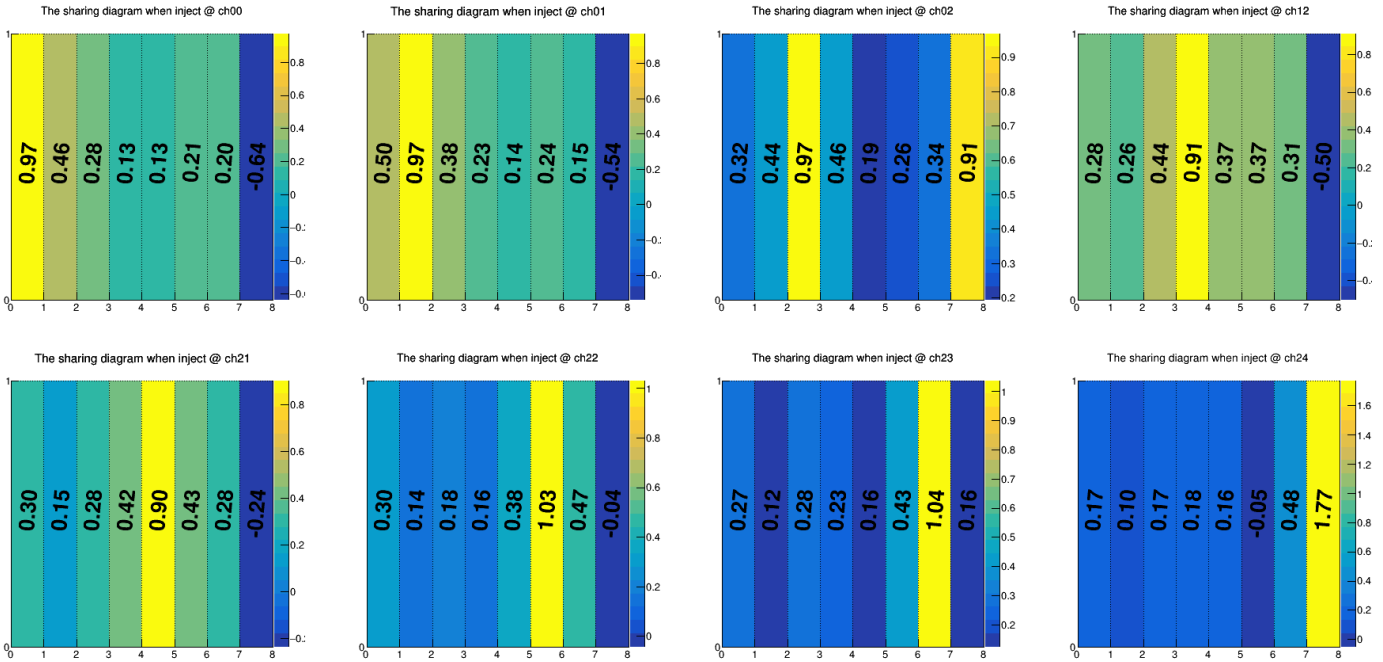
0	1	2	12	21	22	23	24

HV: -160V
I: ~85nA
DAC pulser: 10[~8fC]
DAC-bit[threshold]: 400

Pixel sharing of B30

HV: -160V
I: ~68nA
DAC pulser: 10[~8fC]
DAC-bit[threshold]: 400





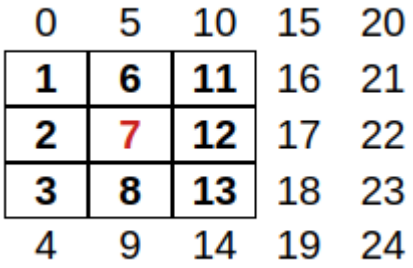
The high ratio at ch24 in the ch2 sharing would be caused from forgot to switch the probe.

0	1	2	12	21	22	23	24

Sensor to chip ID map

Sharing between connected and non-connected sensor

- Except for sensor connection, B12 is same as B19
- Inject charge ~8fC into ch.07, then probing others.



2	2.8	2
4.7	130	4.1
1.7	2	2

B12

0	0	2.3
14	68	5.2
2	2	2

B19

unit [mV]

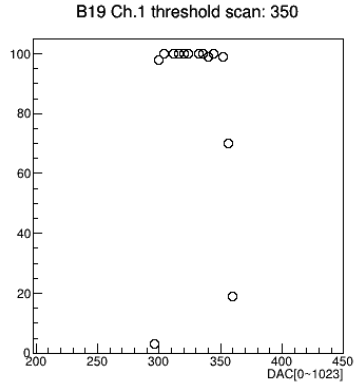
TDC measurements (B19)

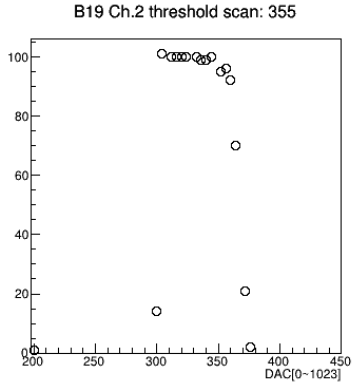
- 2 TDC => TOA & TOT
- Discriminator: const. threshold value type.
- To know the time-walk effect, jitter and determine the TOA LSB.
  - Threshold scan
  - Determine TOA LSB by Delay scan
  - Charge scan => time walk and jitter in different charge.

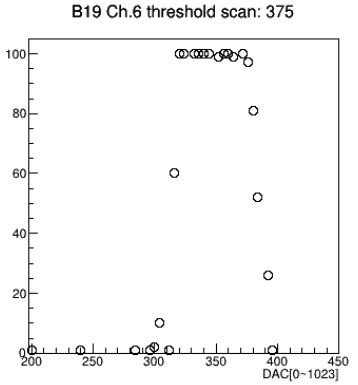
TDC measurements (B19)

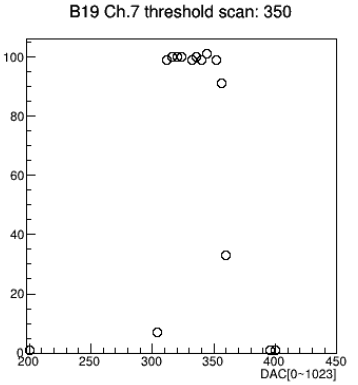
- **Threshold scan**
  Q = 3 (2.5fC) for 8 channels
- Know the proper threshold value for each channels

#TOA [Yaxis]



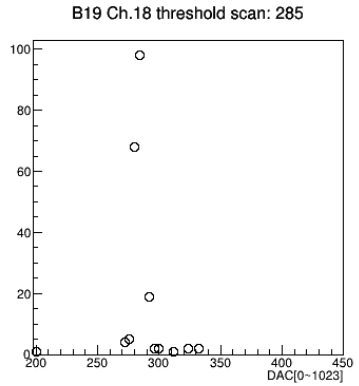


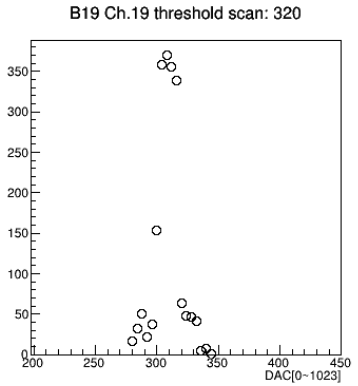


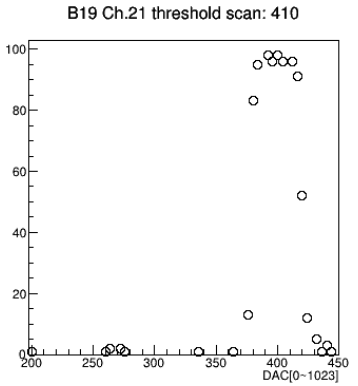


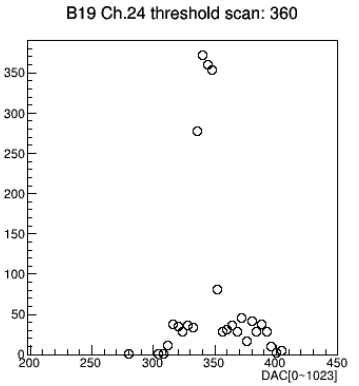
VPA

#TOA [Yaxis]







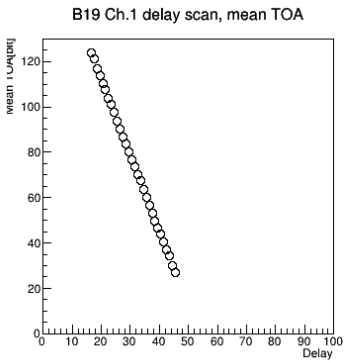


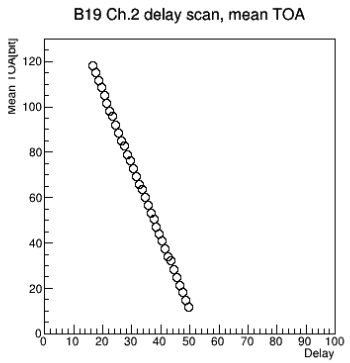
TZ

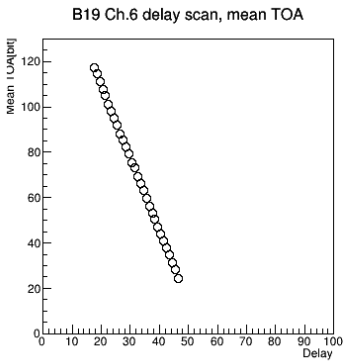
TDC measurements (B19)

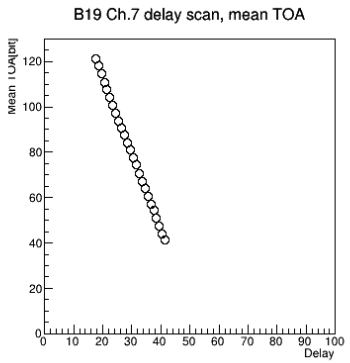
- **Delay scan**
  Q = 30[25fC] for all channels
- each delay bit[10ps], using slope and delay bit to determine TOA LSB

mean TOA [Yaxis]

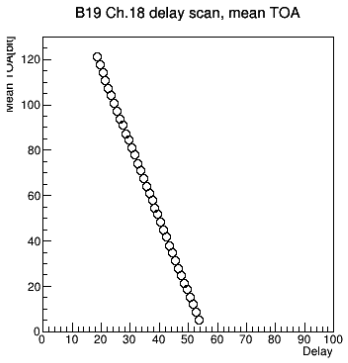


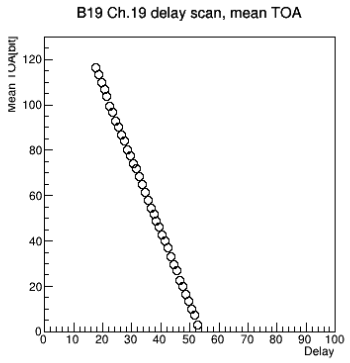


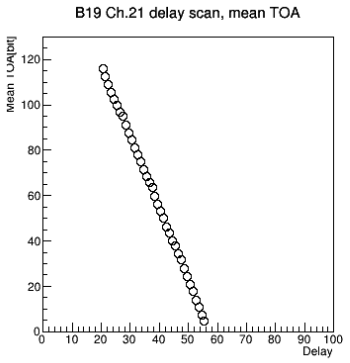


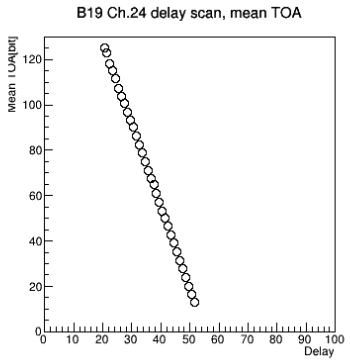


mean TOA [Yaxis]







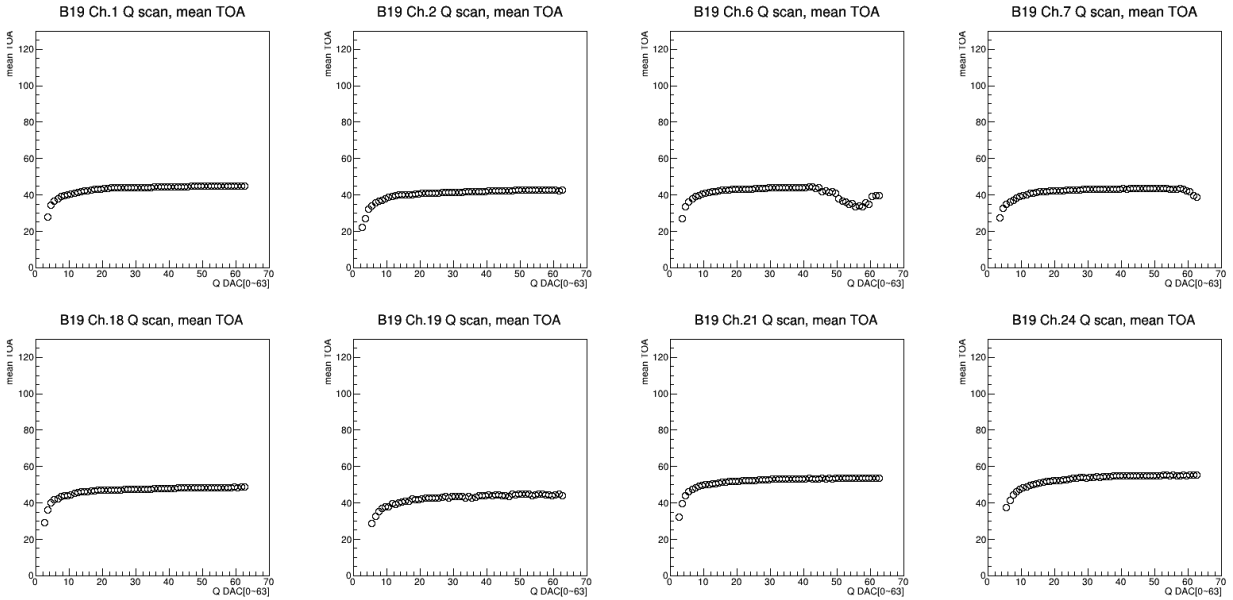


CHID	01	02	06	07	18	19	21	24
Corrected LSB[ps]	28.59	29.79	30.02	28.65	28.98	29.9	30.32	26.32

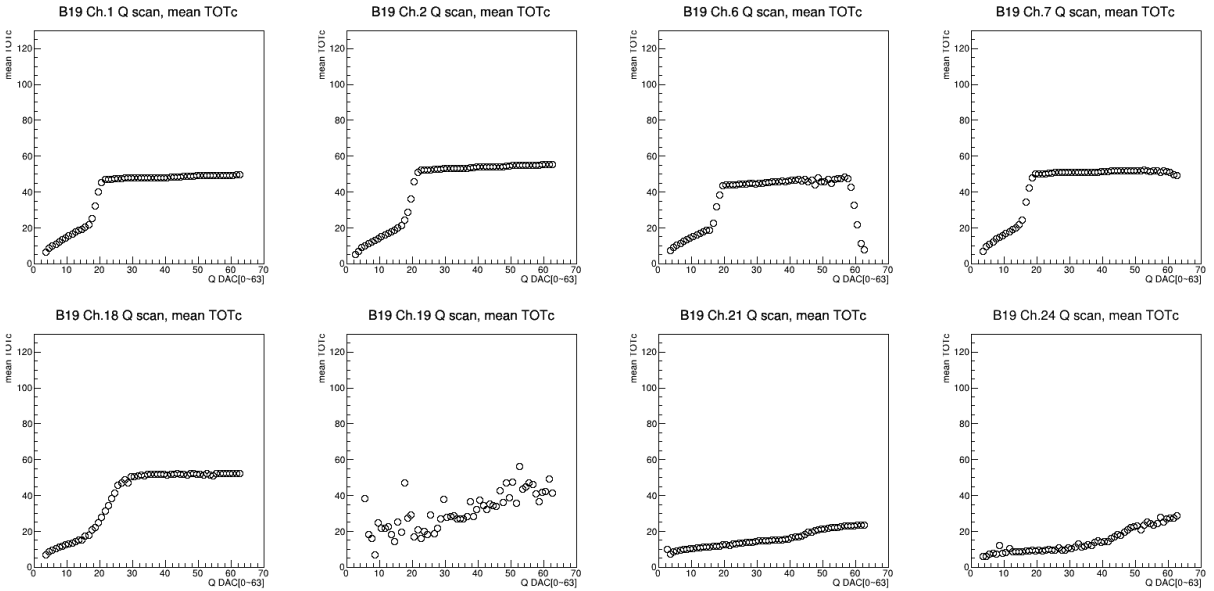
TDC measurements (B19)

Charge scan

Mean TOA[bit] v.s. Q
time walk effect



Mean TOT[bit] v.s. Q
The saturation start
~ Q = 25bit(21fC)

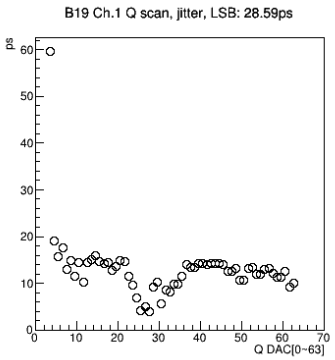


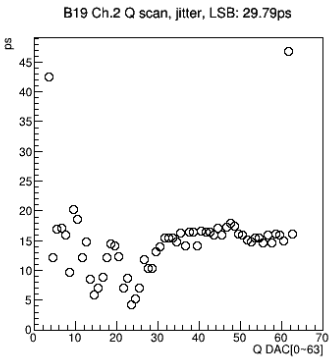
TDC measurement (B19)

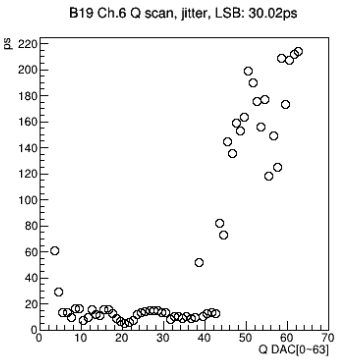
Charge scan

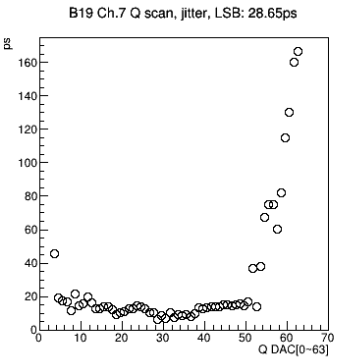
jitter[ps] v.s. Q

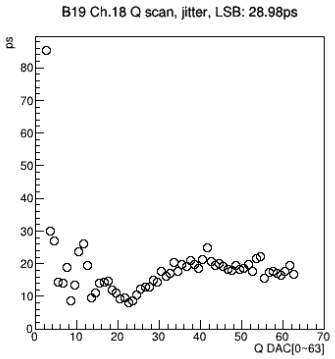
jitter: 15~20 ps
Calculated from
determined LSB[~30ps]

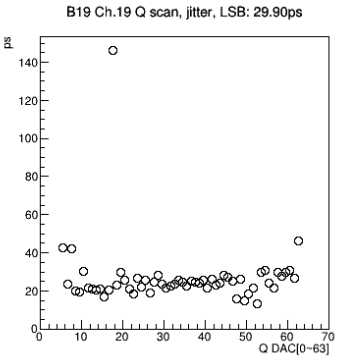


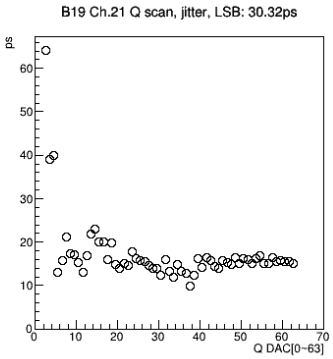


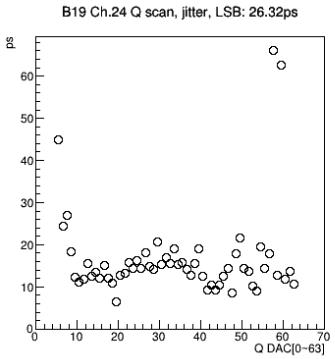












conclusion

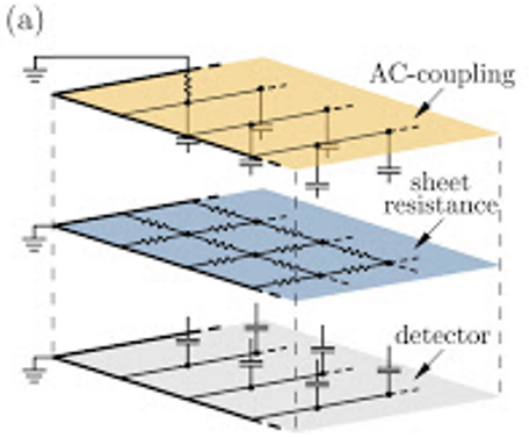
- The determined LSB value for each TDC is ~30ps.
- Most channel have saturated issue, as Q>21, shown in the charge scan
- The average jitter for each channel is 15~20ps. All these 8 TDC performance are uniform
- Measure the signal by TOA & TOT
- B30 has problem on TOA measurements, still investigated.
- Beta source and infrared laser measurement will conducted in future.

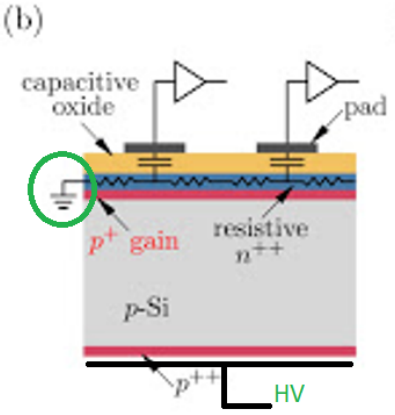
Simulation of pixel sensor

- Maxime build a electronics model about 5x6 pixel sensor
- Simulate the preamp(TZ) output with different inject points
- To know the spatial resolution difference between ADC 8 & 10 bit

y pos						
5	24	25	26	27	28	29
4	18	19	20	21	22	23
3	12	13	14	15	16	17
2	6	7	8	9	10	11
1	0	1	2	3	4	5
	1	2	3	4	5	6 x pos

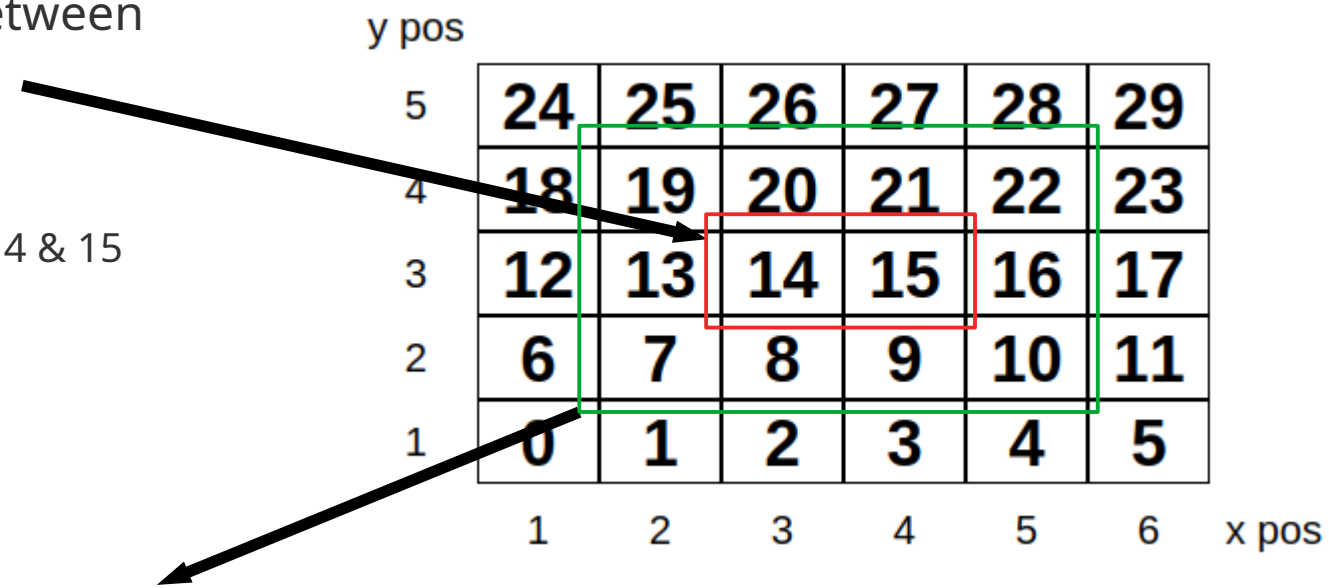
Inject E(19fC) between ch.14 & 15





Simulation of pixel sensor

- 30 pixels in single pad
- Extract the data(voltage) from excel(Maxime) and draw them in 2D plot
- Each pixel connect each other with resistor
  Rsheet: 100Ω, 1kΩ, 2kΩ, 5kΩ, 10kΩ
- E injection point between pixel 14 & 15, and
  ratio: 0 -> totally on 14
  ratio: 1 -> totally on 15
  ratio: 0~1 -> between 14 & 15

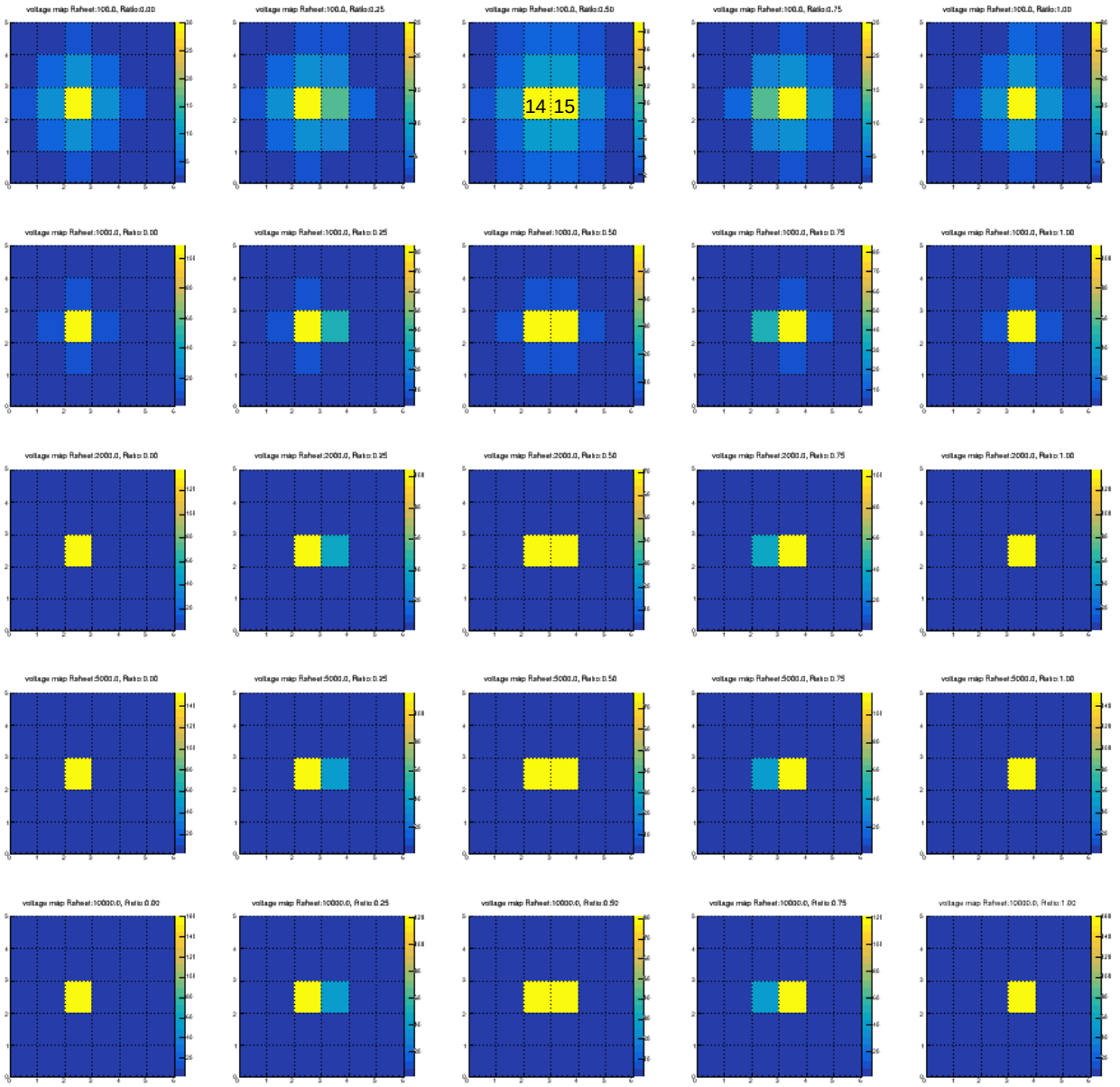


We only consider these 12 channels (3x4 region)
when we reconstruct the injected point

Simulation

Ratio: 0 → Ratio: 1

Rsheet: 100Ω



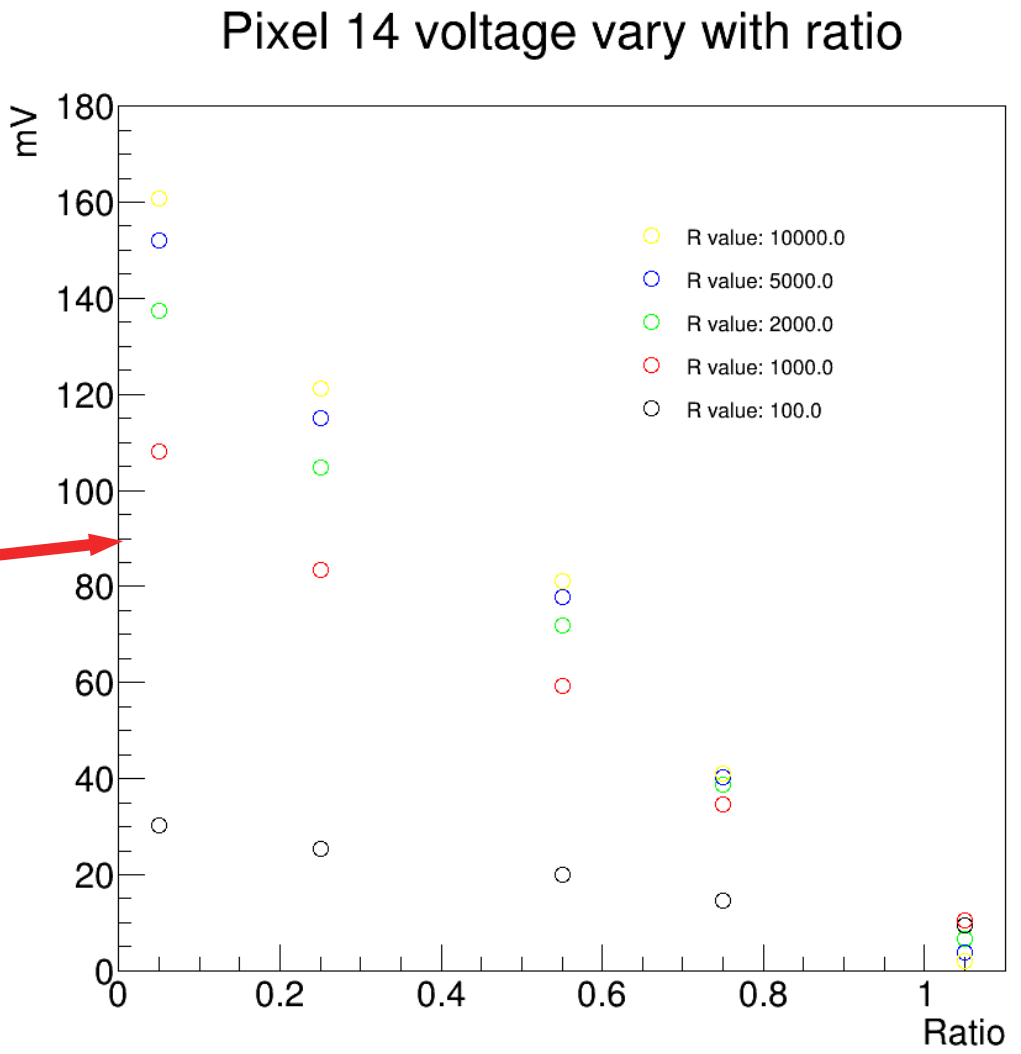
Rsheet: 10kΩ

y pos						
5	24	25	26	27	28	29
4	18	19	20	21	22	23
3	12	13	14	15	16	17
2	6	7	8	9	10	11
1	0	1	2	3	4	5
	1	2	3	4	5	6 x pos

Draw Maxime simulation data followed above map

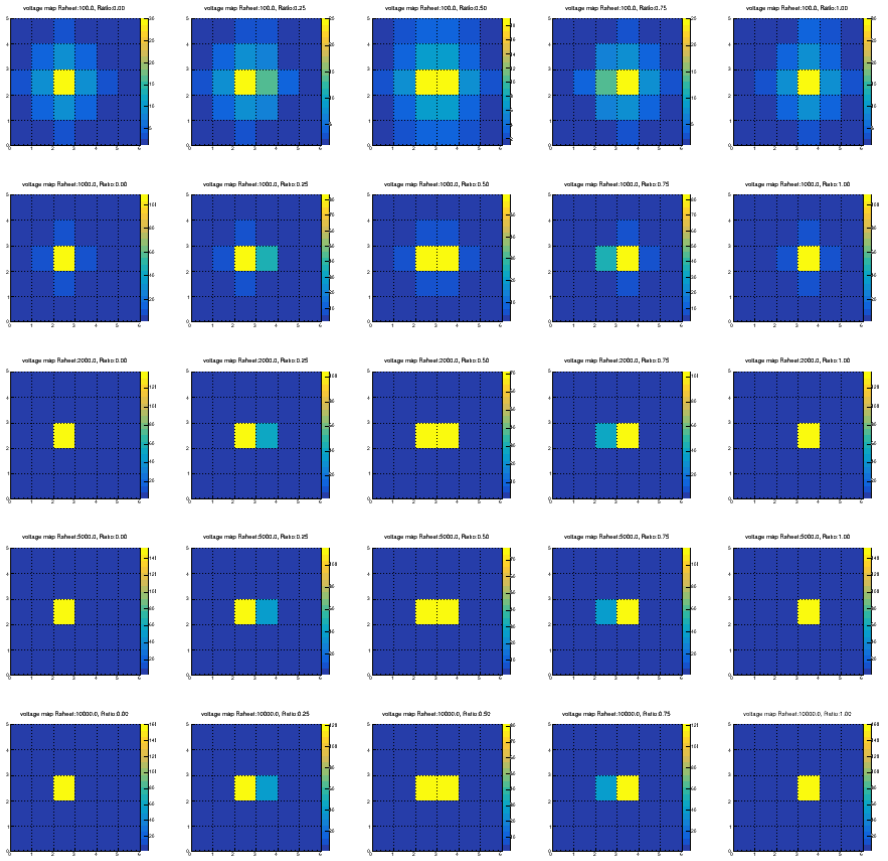
Linearity vs ratio

- We can estimate the amplitude at any given ratio between 0~1
- The significant Amp difference between different R value.

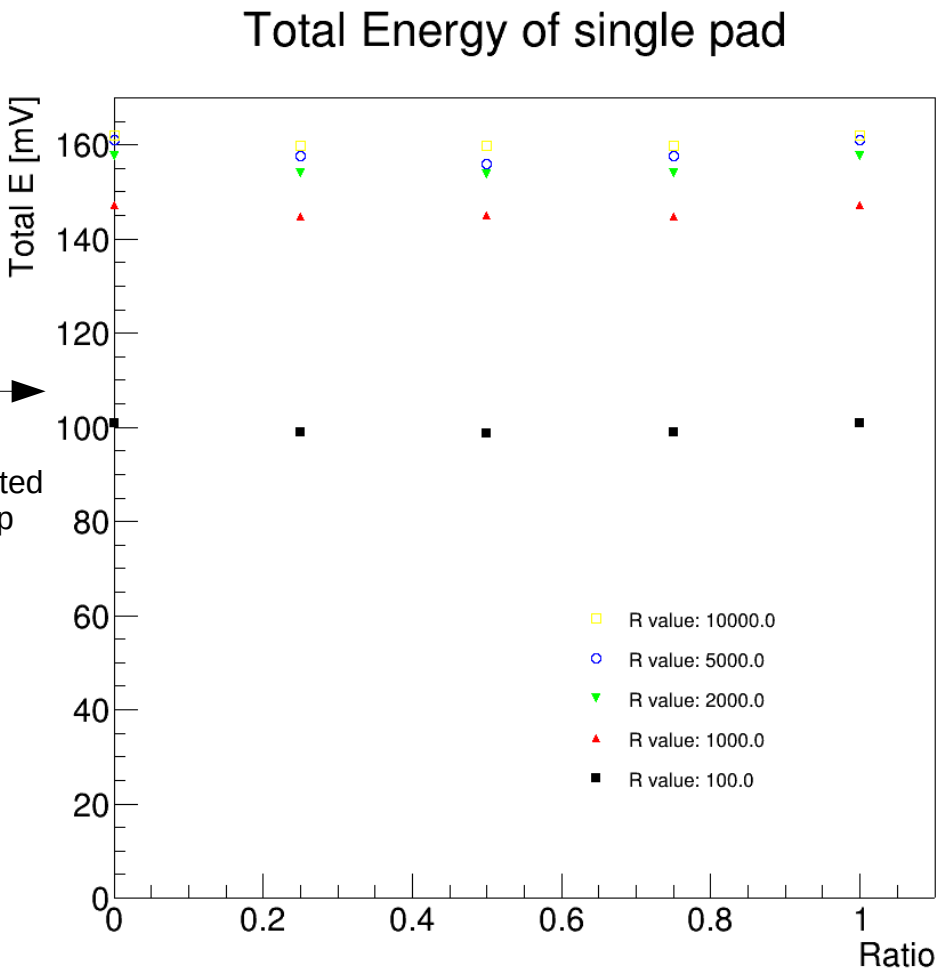


From Maxime simulation data without subtraction and scaling

Total E



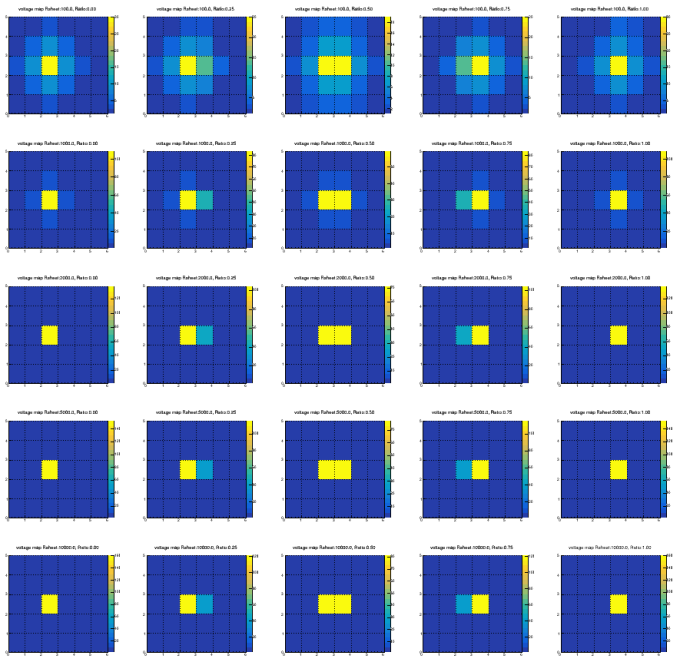
Sum up
all subtracted
pixels' Amp



Rsheet100 -> Scale 1.6
Rsheet1000 -> Scale 1.1

Simulation

- Reconstruct inject position:
  $\Sigma(Pos_i * V_i) / \Sigma V_i$
- 3 differet cases for Maxime data:
  - Reconstruct with all pixels without subtraction
  - Reconstruct with all pixels with subtraction
  - Reconstruct with 3x4 pixels with subtraction



Ratio

0	0.25	0.5	0.75	1
0.116	0.301	0.503	0.707	0.888
0.103	0.3	0.5	0.7	0.897
0.0962	0.285	0.5	0.715	0.904
0.0941	0.289	0.5	0.711	0.906
0.0934	0.296	0.5	0.704	0.907

100 ↓ 10000

-0.0271	0.226	0.504	0.785	1.03
0.00177	0.249	0.5	0.751	0.998
0.000273	0.233	0.5	0.767	1
-0.000267	0.239	0.5	0.761	1
-0.000556	0.249	0.5	0.751	1

100 ↓ 10000

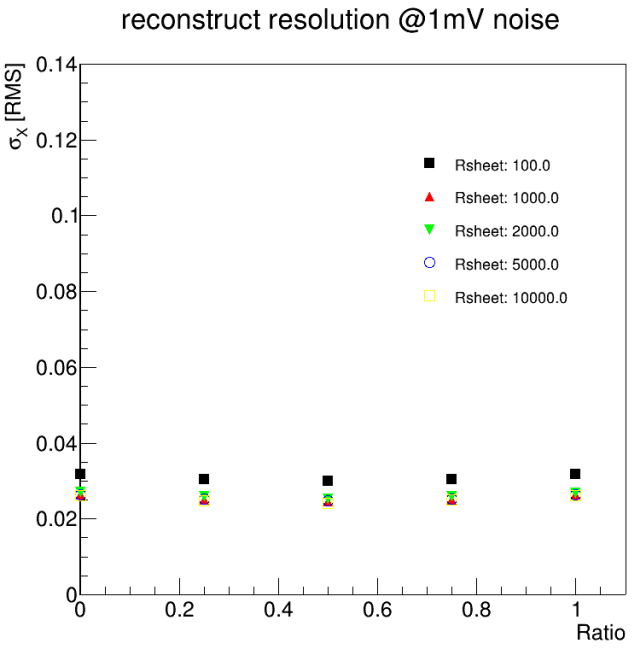
0.0842	0.292	0.502	0.711	0.919
-0.000246	0.247	0.5	0.753	1
-0.000311	0.232	0.5	0.768	1
-0.000329	0.239	0.5	0.761	1
-0.000339	0.249	0.5	0.751	1

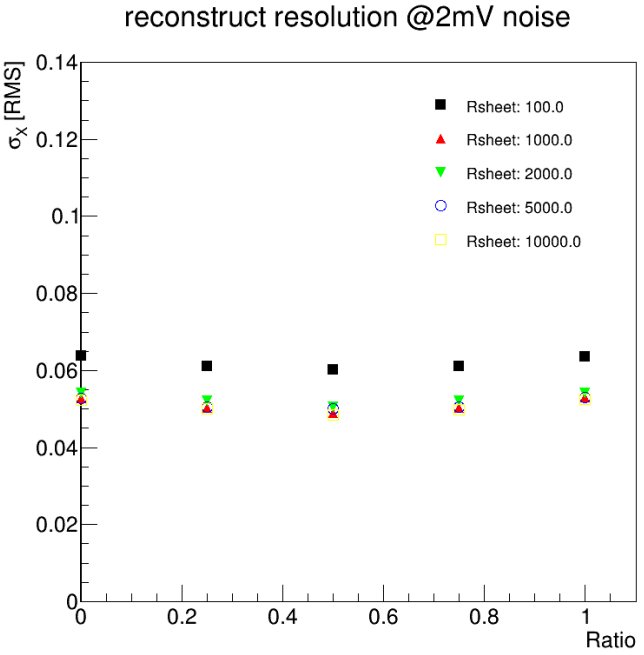
100 ↓ 10000

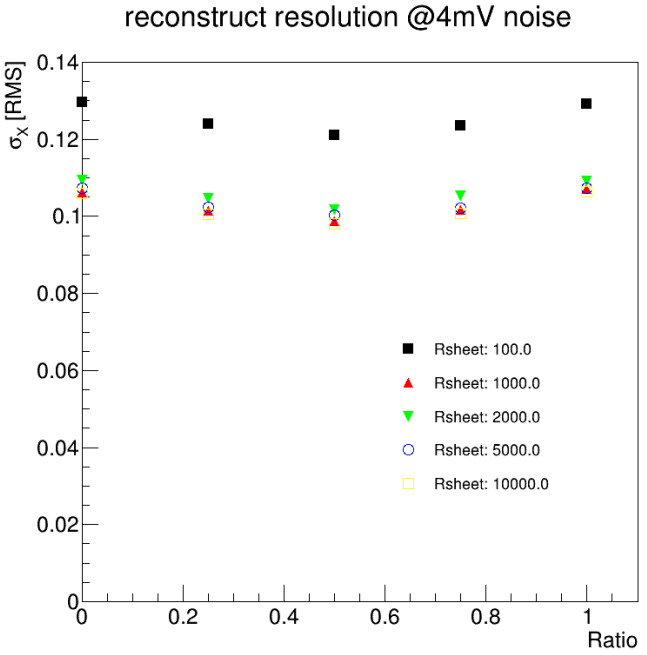
Reconstructed ratio

Simulation

- Add noise to each pixel independently.
- $noise_i$: Gaus(mean: 0mv, width: 1, 2, 4mv)
  $\Sigma(Pos_i * (V_i + noise_i)) / \Sigma(V_i + noise_i)$, V_i: Maxime data after the zero subtraction
  When Rsheet=100Ω & 1000Ω, $\Sigma(Pos_i * (scale * V_i + noise_i)) / \Sigma(scale * V_i + noise_i)$, scale 1.6 & 1.1
- The reconstruction only consider 3x4 region







Y-axis in same scale

Simulation

- Smear the injection energy with Landau
- Multiply each pixel voltage with value from Landau distribution

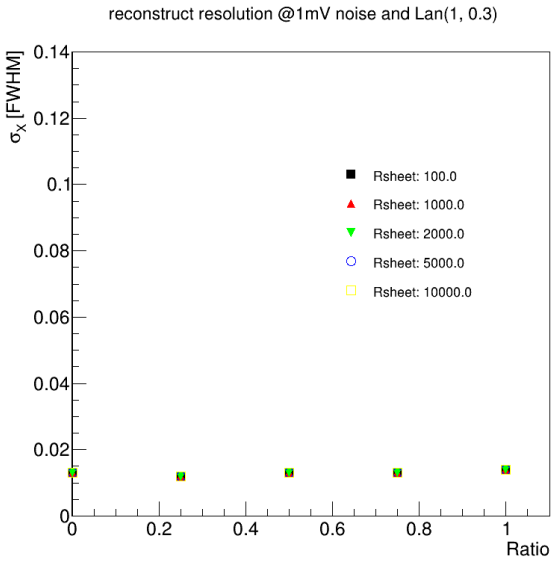
  Lan = Landau(1., 0.3), $noise_i$ = Gaus(0, 1mV)

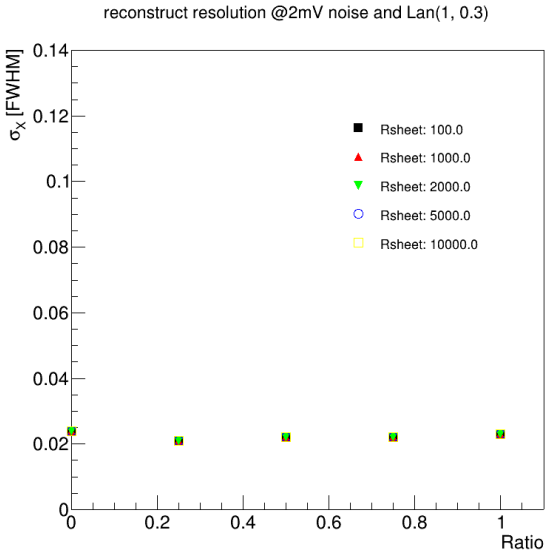
  $\sum(Pos_i * (V_i * Lan + noise_i)) / \sum(V_i * Lan + noise_i)$, V_i: Maxime data after the zero subtraction

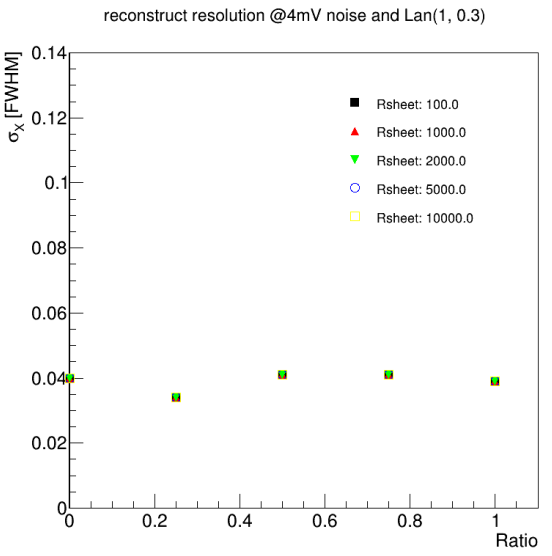
  When Rsheet=100Ω & 1000Ω, $\sum(Pos_i * (scale * V_i * Lan + noise_i)) / \sum(scale * V_i * Lan + noise_i)$, scale 1.6 & 1.1
- The reconstruction only consider 3x4 region
- The position resolution will calculated by FWHM and RMS.

Simulation

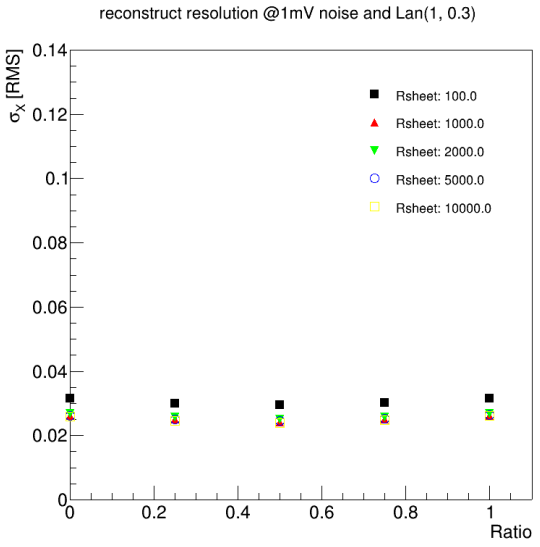
Y-axis in same scale

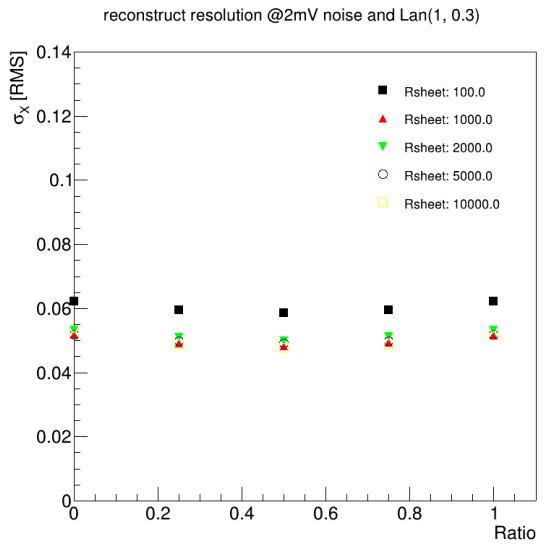


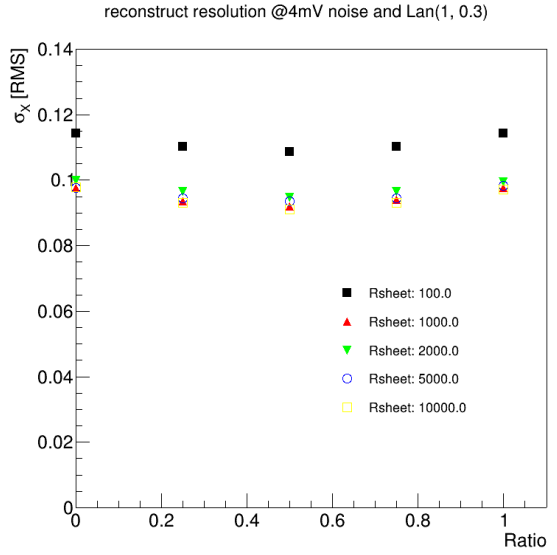




FWHM







RMS

Lan(1, 0.3), noise: 1mV

Lan(1, 0.3), noise: 2mV

Lan(1, 0.3), noise: 4mV

ADC

- Randomly choose the inject ratio from Uniform(0, 1): R_U (ratio uniform), pixel 14 - 15
- Dynamic range: **1000mV**
- Noise scale: **1** and **4 mV**, Smear with **Lan(1, 0.3)**
- LSB: Dynamic range / $2^{n\text{-bit}}$
- ADC bit: 4, 6, 8, 10, 12
- The reconstruction only consider 3x4 region
- Calculate the amplitude of $pixel_i$:

  $Amp_{i,\,analog} = [V_{i,0} + (V_{i,1} - V_{i,0}) \times R_U] \times Lan(1, 0.3) + Gaus_i(0, 1)$, Rsheet100, 1000 need to be scaled

  $Amp_{i,\,digital} = Ceil[(Amp_{i,\,analog} + 5 \times 1mV) / LSB]$ (non saturated case)

  $Amp_{i,\,digital} = Ceil[1000 / LSB]$ (saturated case)

- Reconstruct the position:

  $\Sigma(Pos_i \times Amp_{i,\,digital}) / \Sigma(Amp_{i,\,digital})$

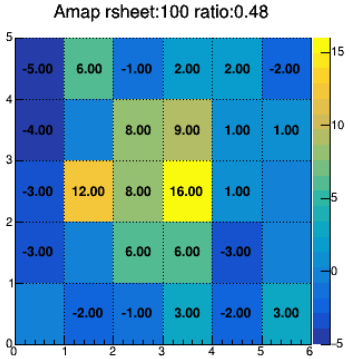
Simulation

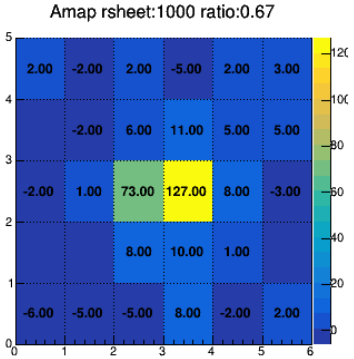
- Saturation means the amplitude > dynamic range[**1000mV**] and, Satu.[%] = #saturated / 1M
- The analog and digital map comparison

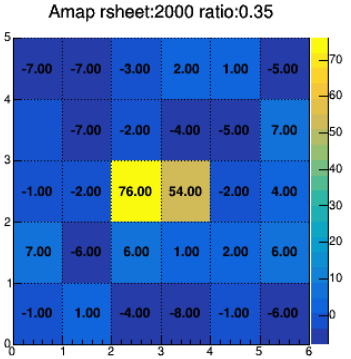
Rsheet	100	1000	2000	5000	10000
Satur.[%]	**1.3%**	**3.4%**	**3.9%**	**4.3%**	**4.7%**

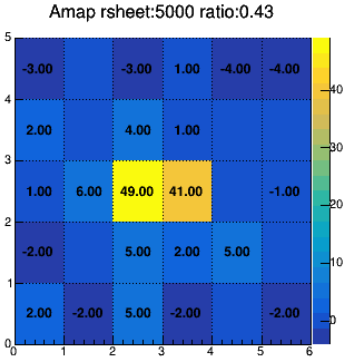
Lan(1, 0.3), noise level: 4mV

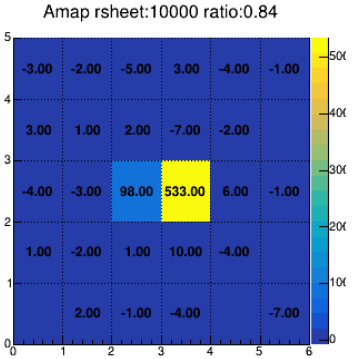
Analog



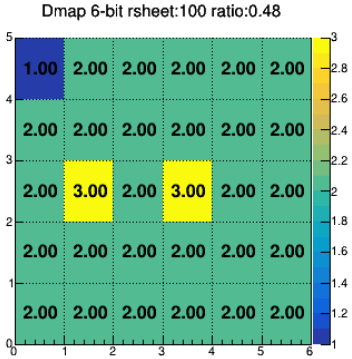


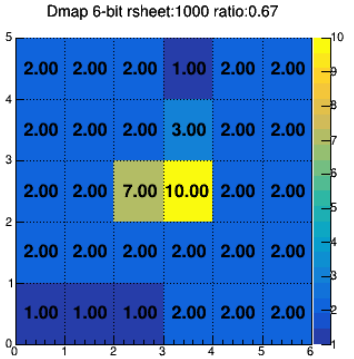


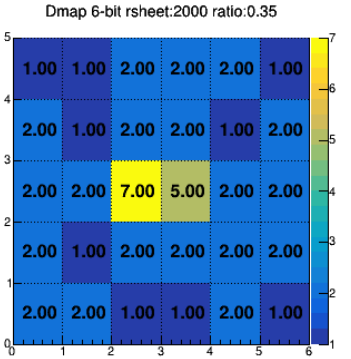


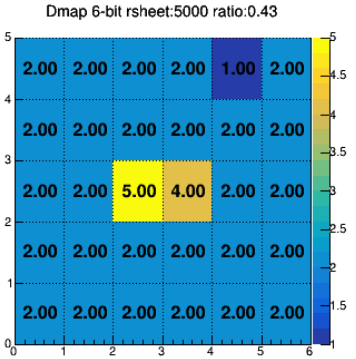


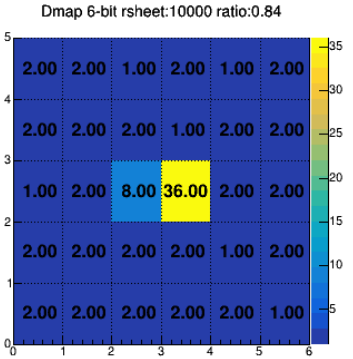
6-bit







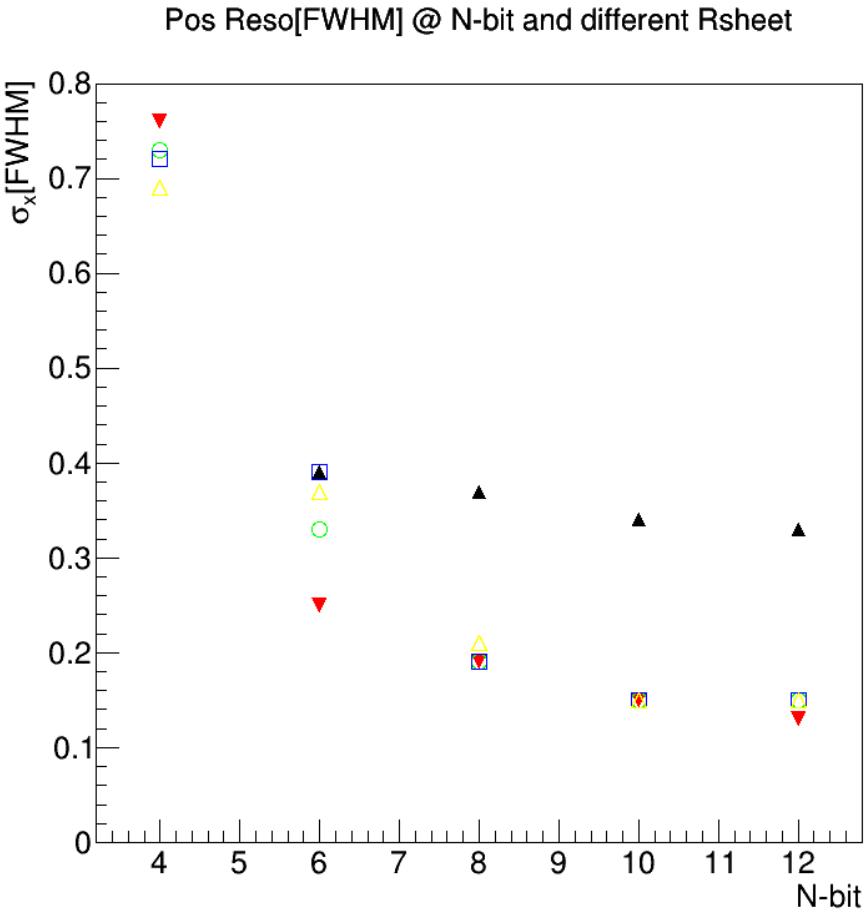


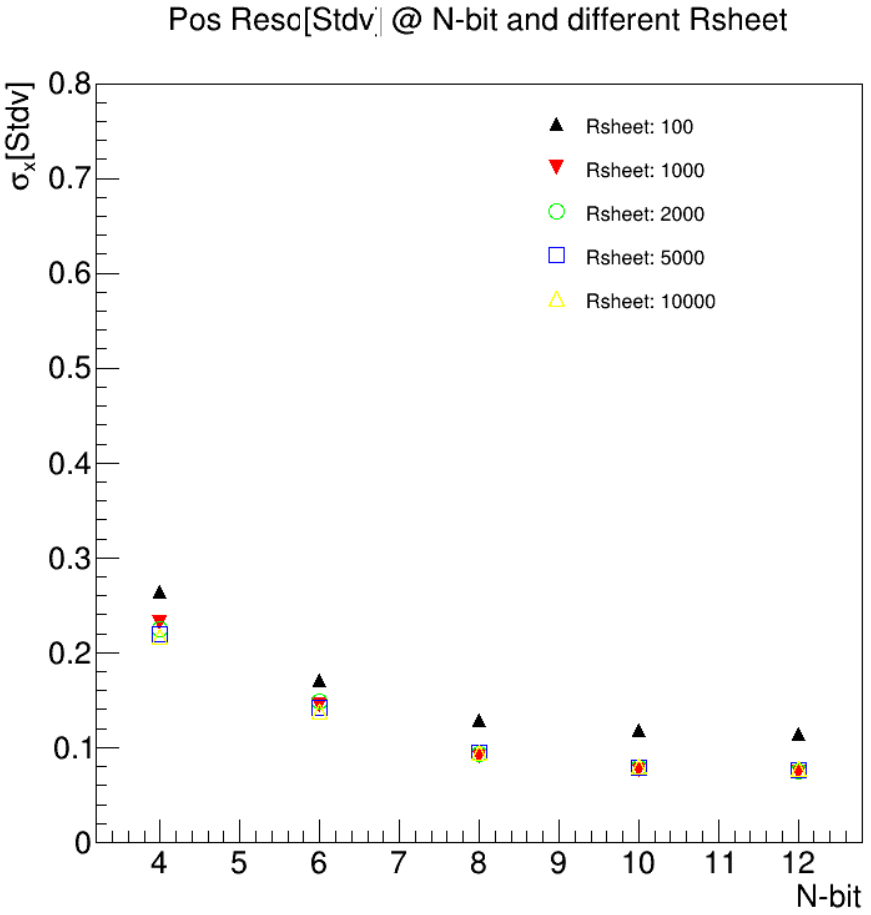


1 LSB for 6-bit = 15.625mV
And there is 5-sigma shift(5*4mV = 20mV) for the pedestal the digital noise would around 2bits.

Simulation ADC

Smear with Lan(1, 0.3)
Noise: 1mV

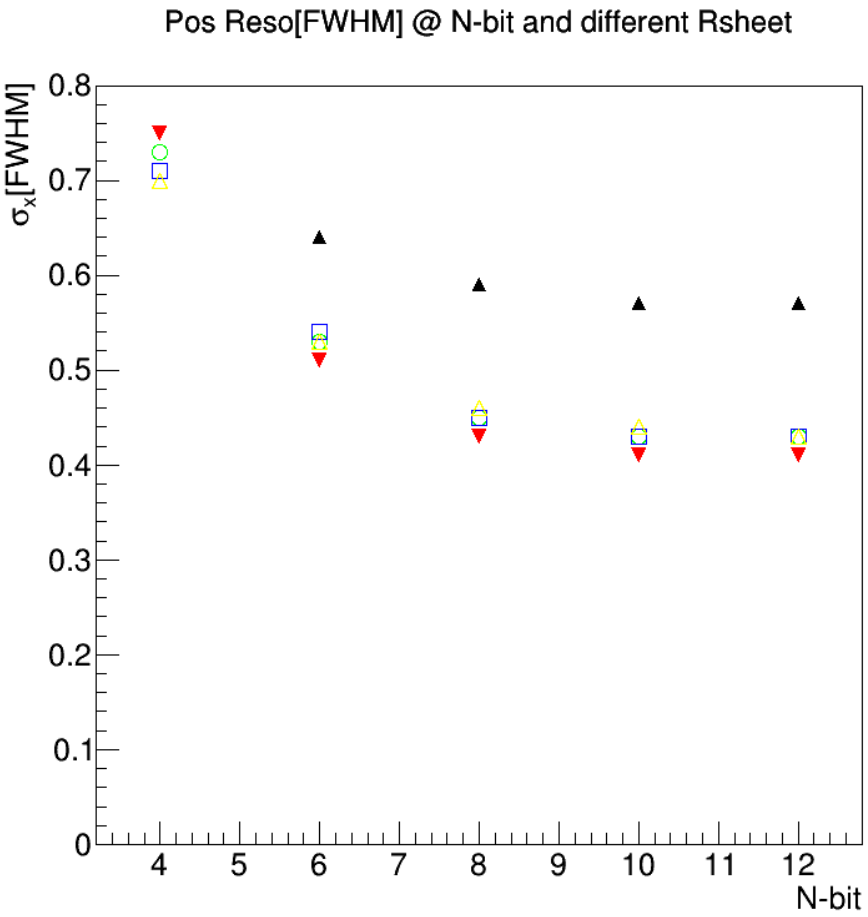


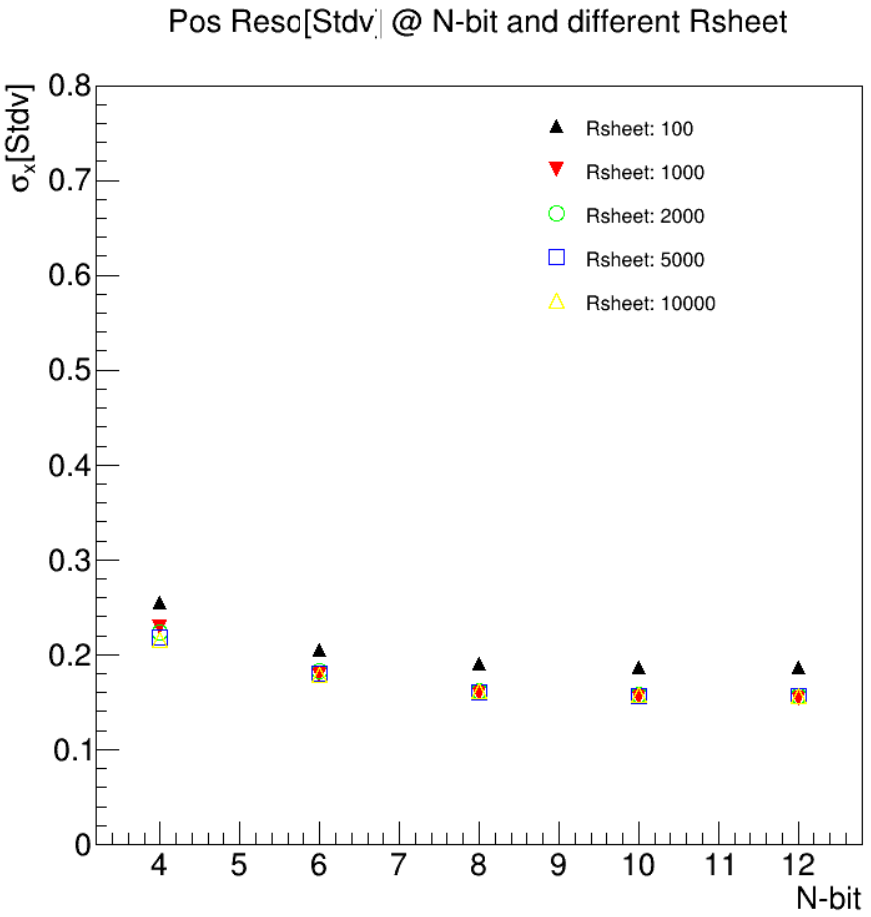


Y-axis in same scale

Simulation ADC

Smear with Lan(1, 0.3)
Noise: 4mV



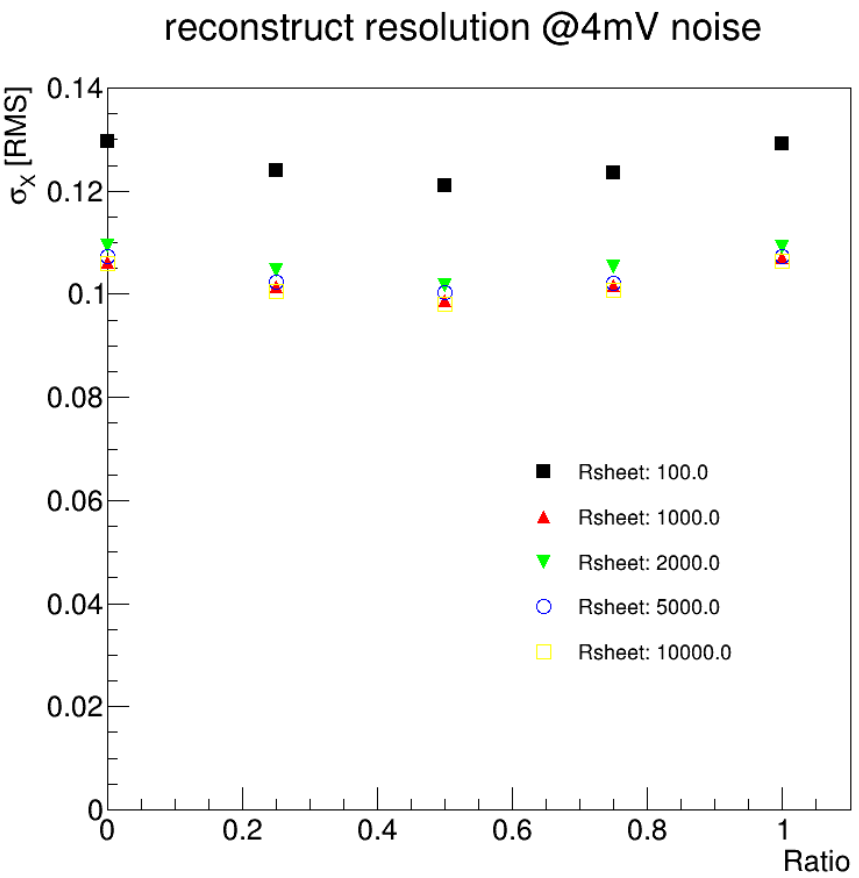


No significant difference between 1mV and 4mV noise level @ 4-bit case.
Since the LSB for 4-bit case is 62.5mV is much larger than change of noise.

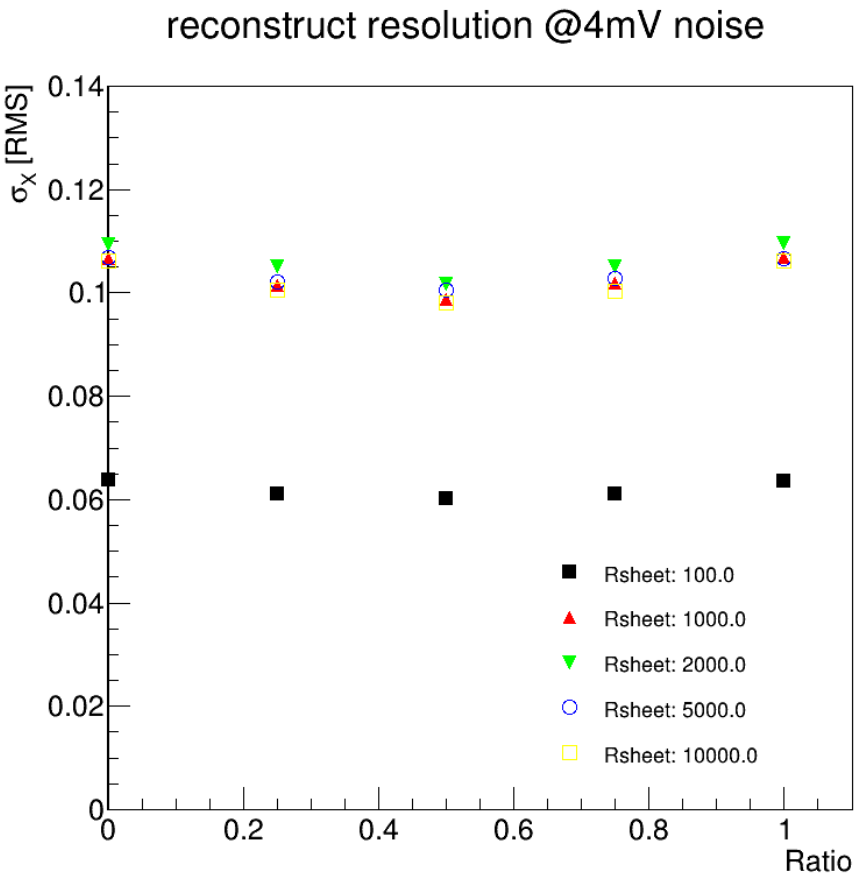
Conclusion

- The smaller noise and higher ADC-bit give the better resolution
  - 8 & 10 bit has 10% difference between noise @ 1mV and 4mV for [RMS]
  - 8 & 10 bit has 25% difference between noise @ 1mV and 4mV for [FWHM]
- The resolution[FWHM] difference between 10 and 8-bit is ~ 5% pixel width.
- The small Rsheet value(100) have too much sharing to reconstruct well.

Backup

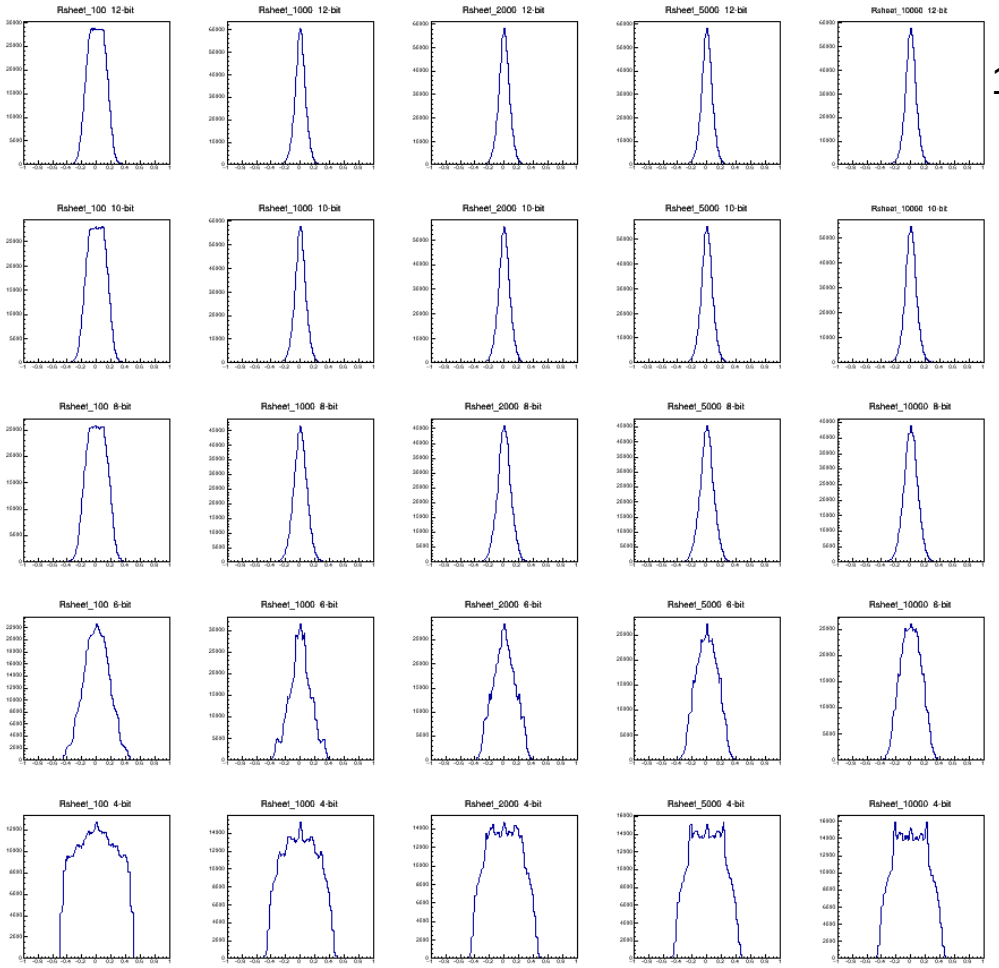


Scale amp of all pixels in Rsheet100 with 1.6



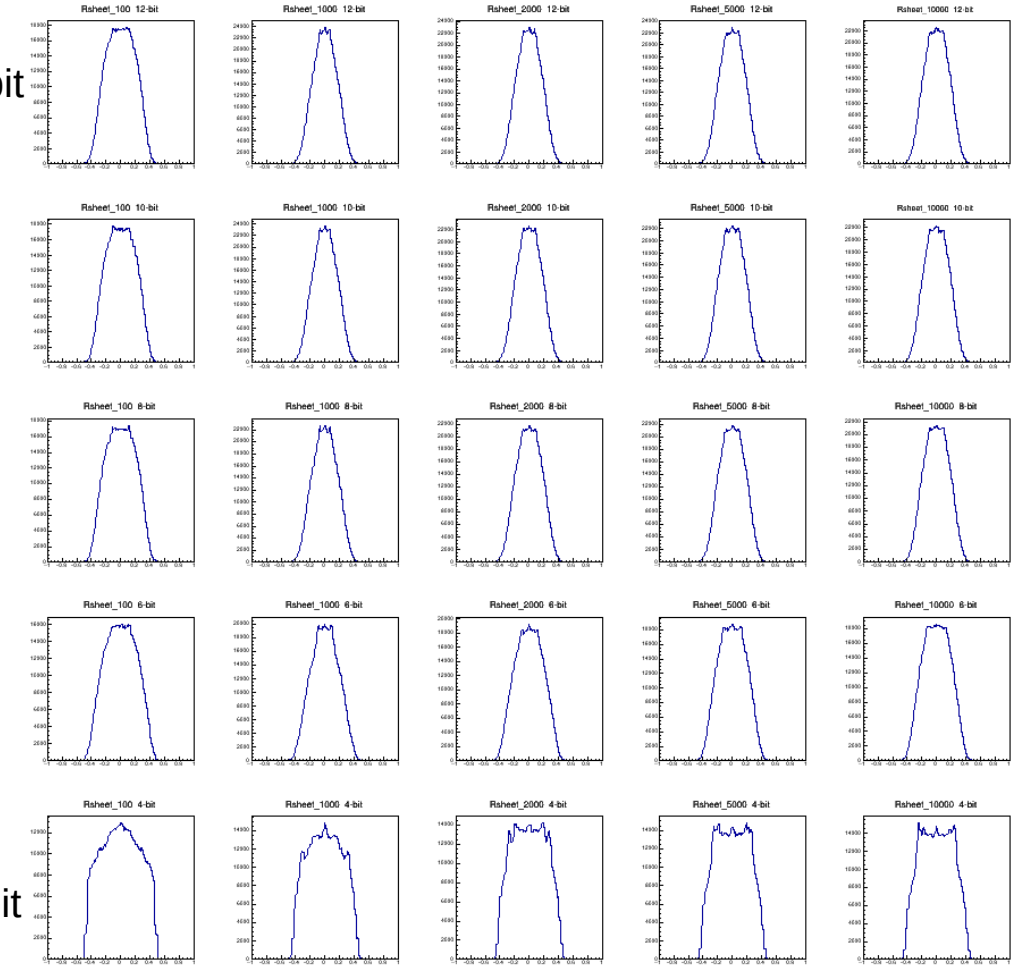
Scale amp of all pixels in Rsheet100 with 3.2

Backup



12bit

4bit



Rsheet 100 → Rsheet 10000

1mV noise

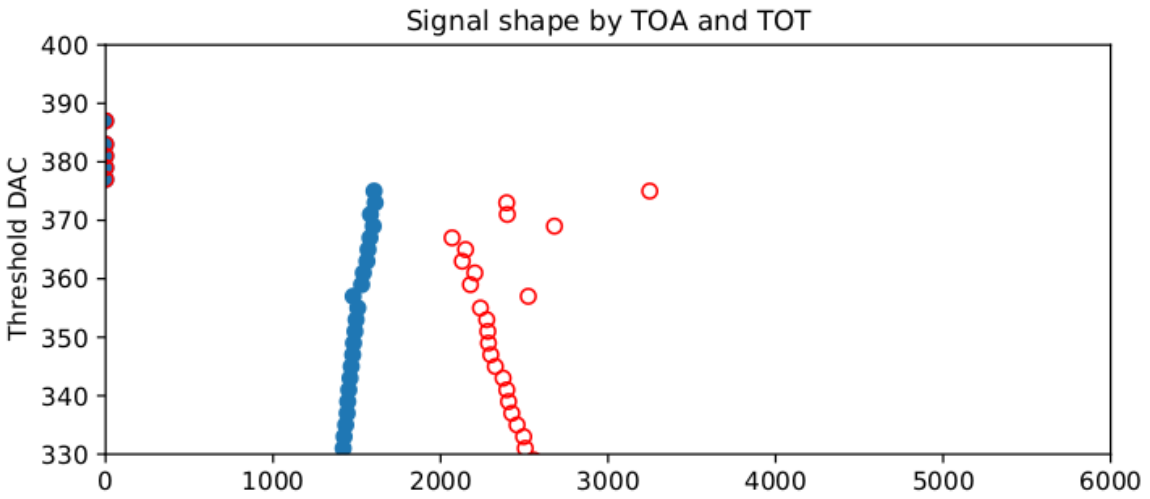
Rsheet 100 → Rsheet 10000

4mV noise

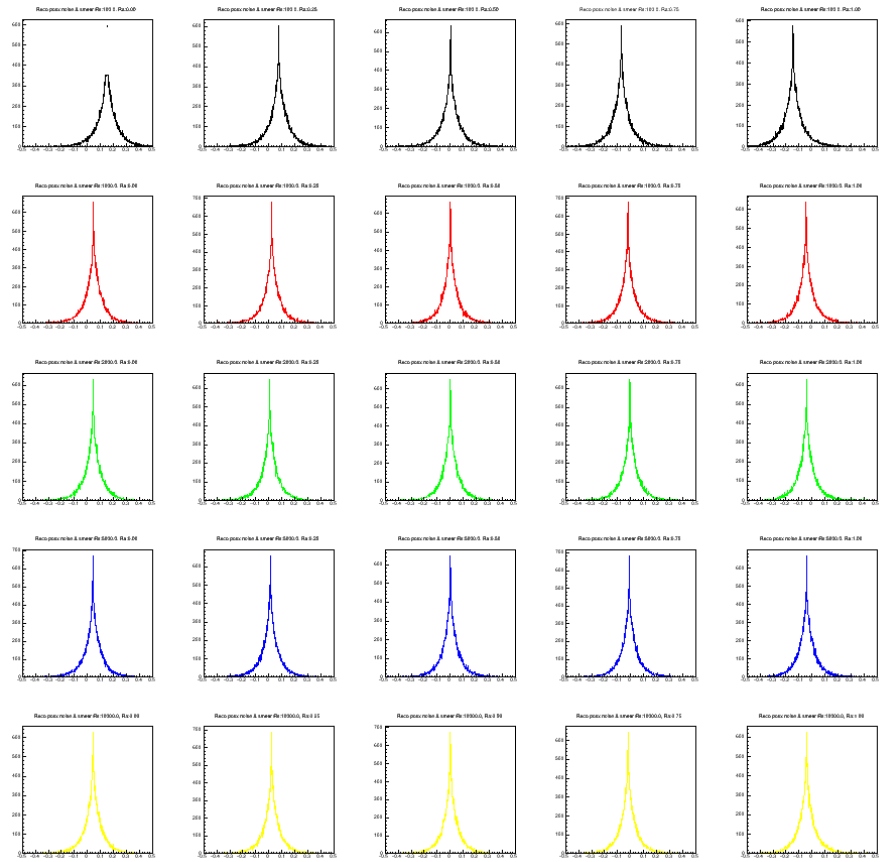
Backup - Testboard

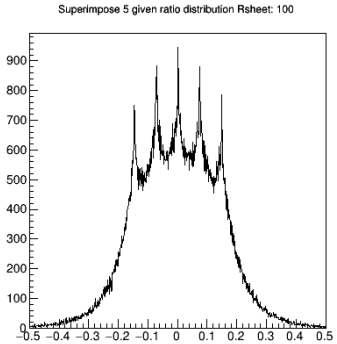
TOA LSB: 30ps TOT LSB: 160ps

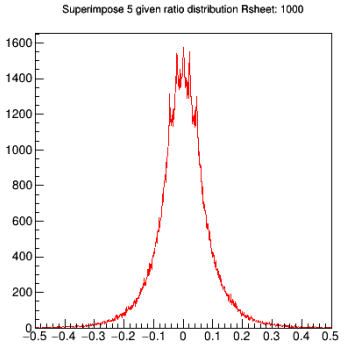
Ch02, Q = 3
Delay = 2450
Cd = 0

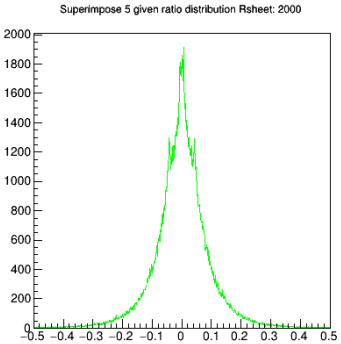


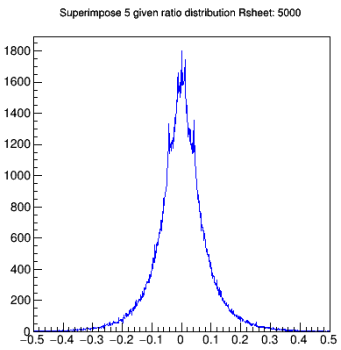
Backup - simulation p22 & 26

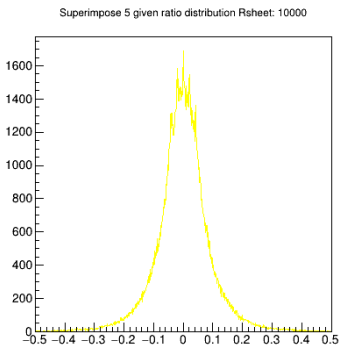








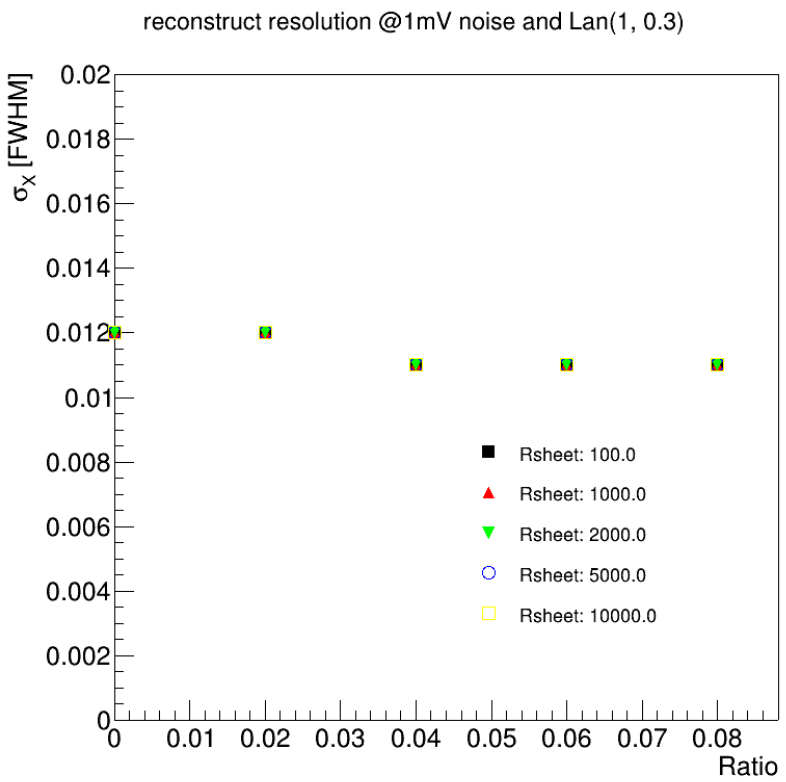


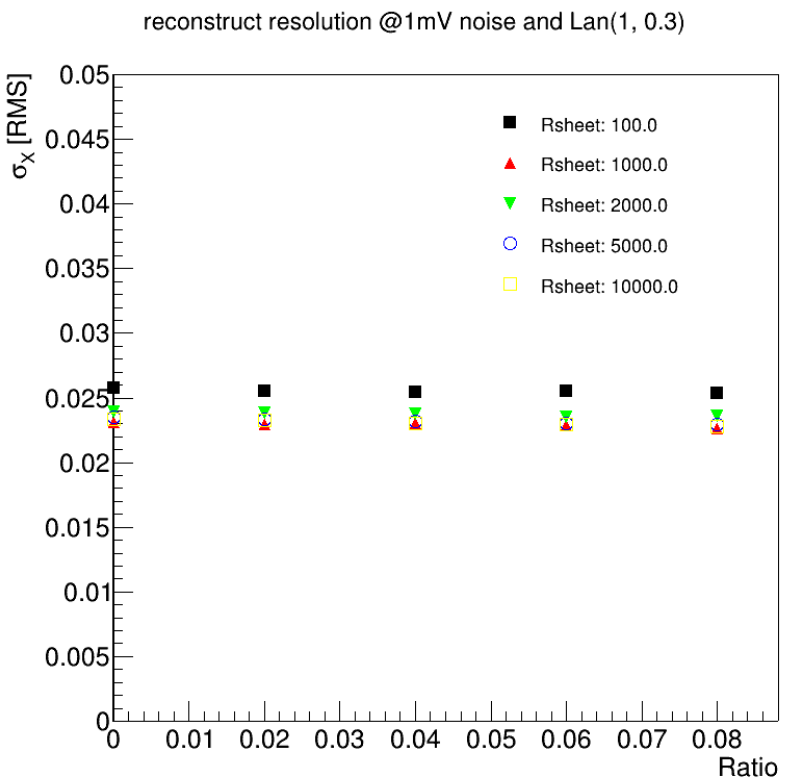


5 given ratio [0, 0.25, 0.5, 0.75, 1] → superimpose

Backup - Simulation specific small ratio

- compare with p22 ratio[0, 0.25, 0.5, 0.75, 1]





- ratio[0, 0.02, 0.04, 0.06, 0.08]