ILC バーテックス検出器に向けた SOI ピクセルセンサーの開発研究

Development of SOI pixel sensors for the ILC vertex detector

加速器科学研究室　M2
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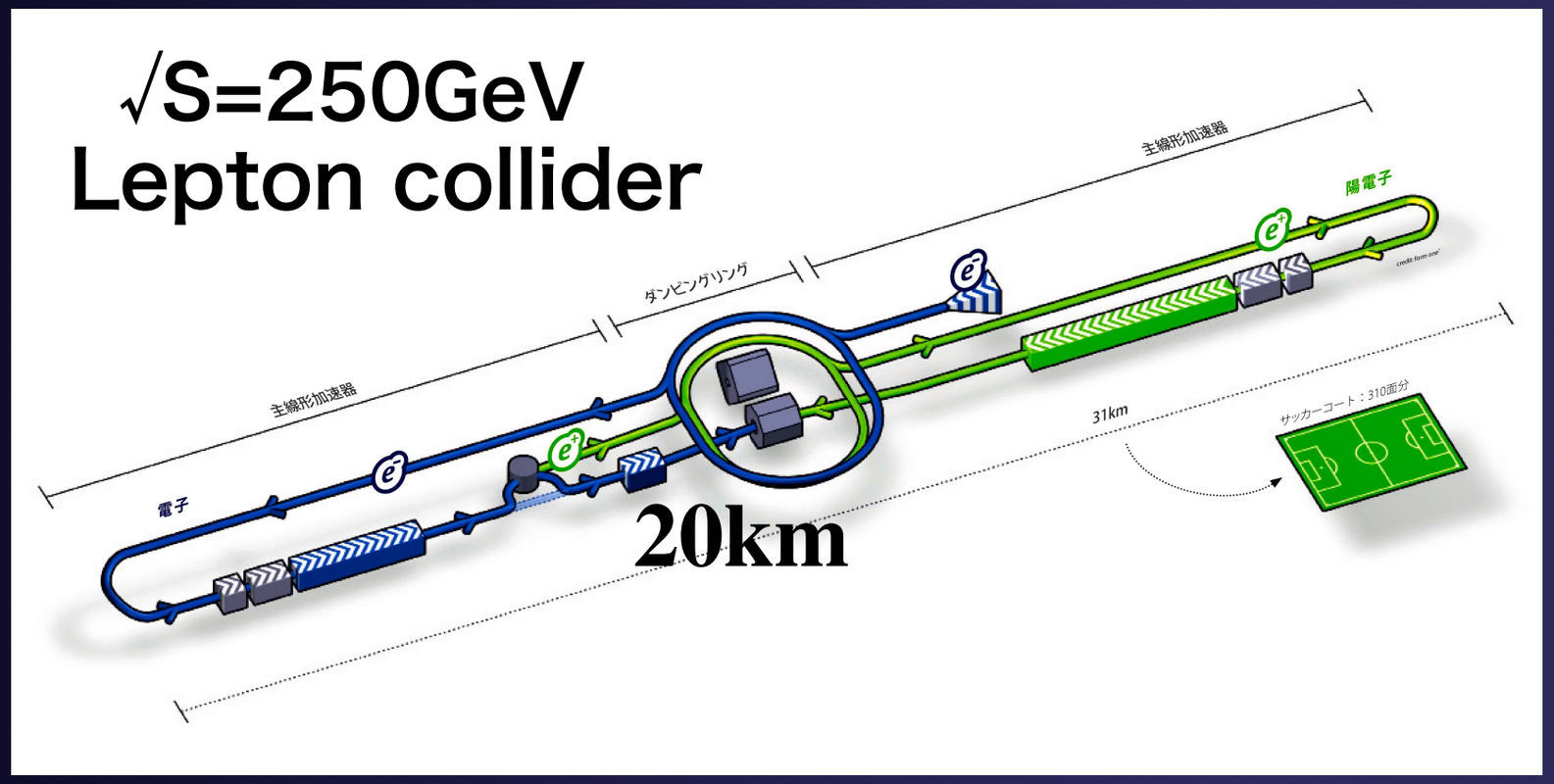
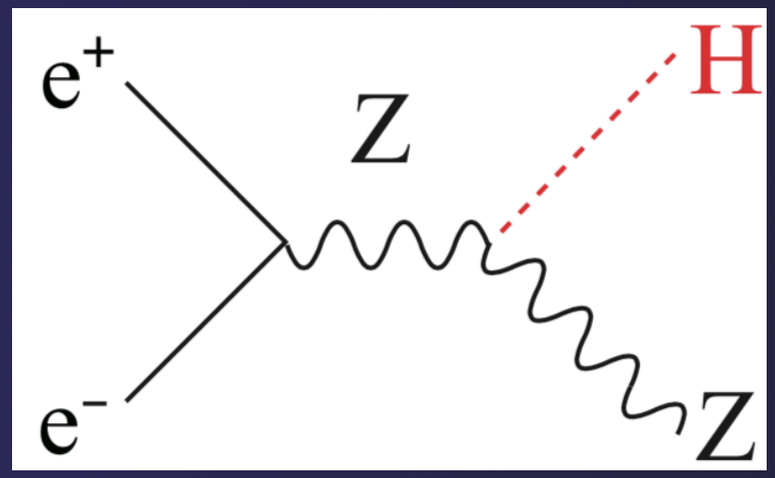
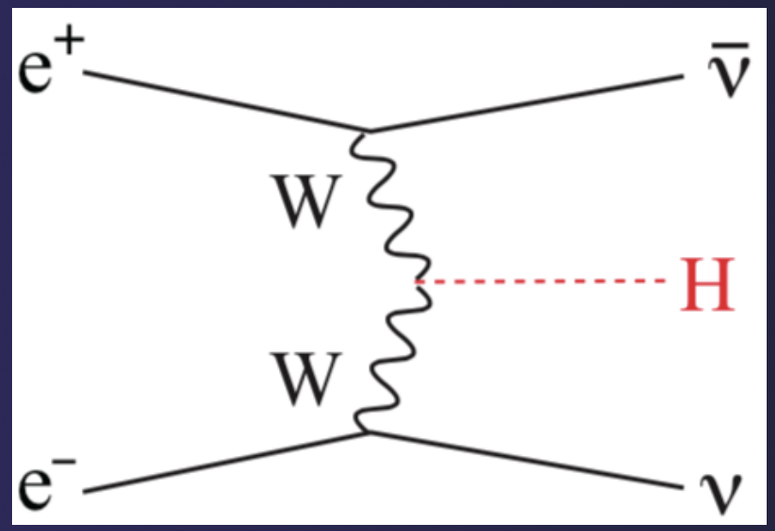
ILC(International linear collider)



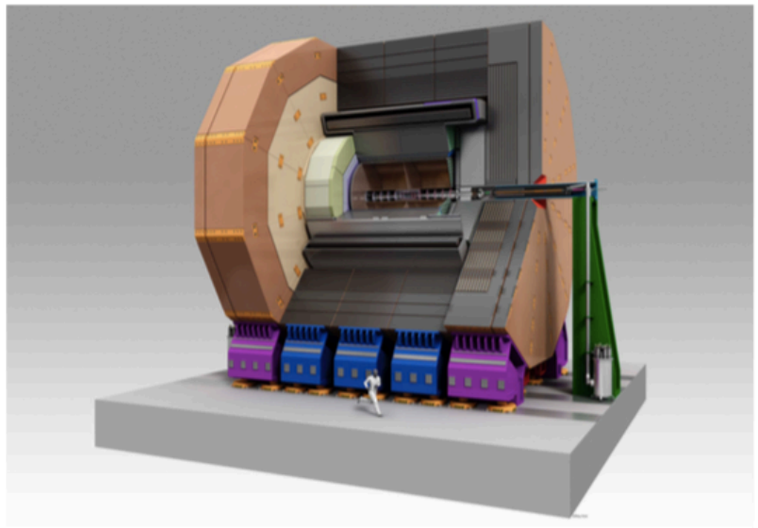


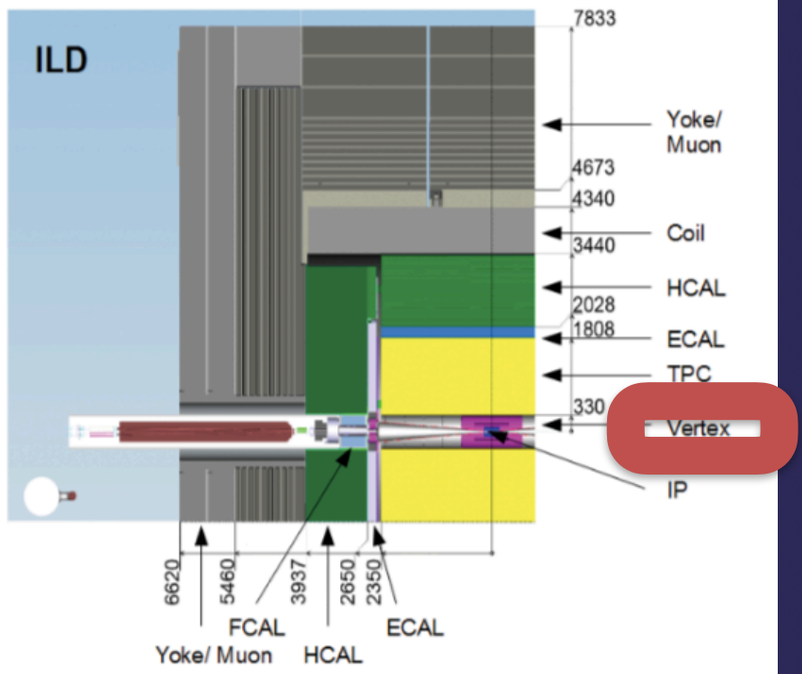


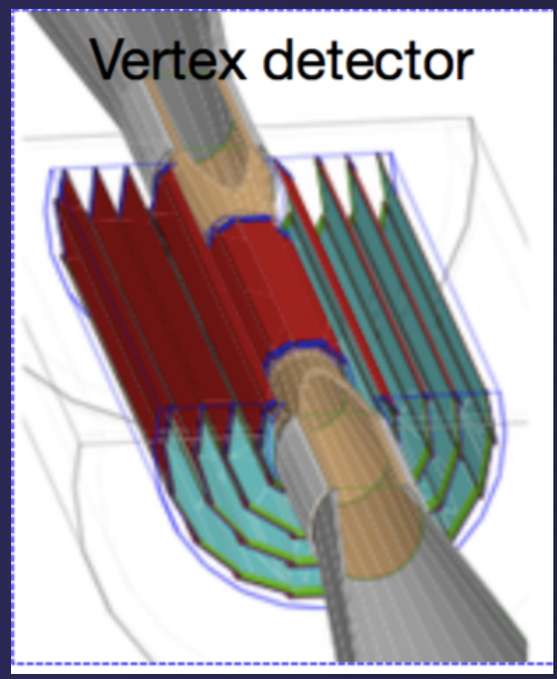
precision measurements of Higgs couplings

Motivation : for searching new physics.

ILD(International Large Detector)

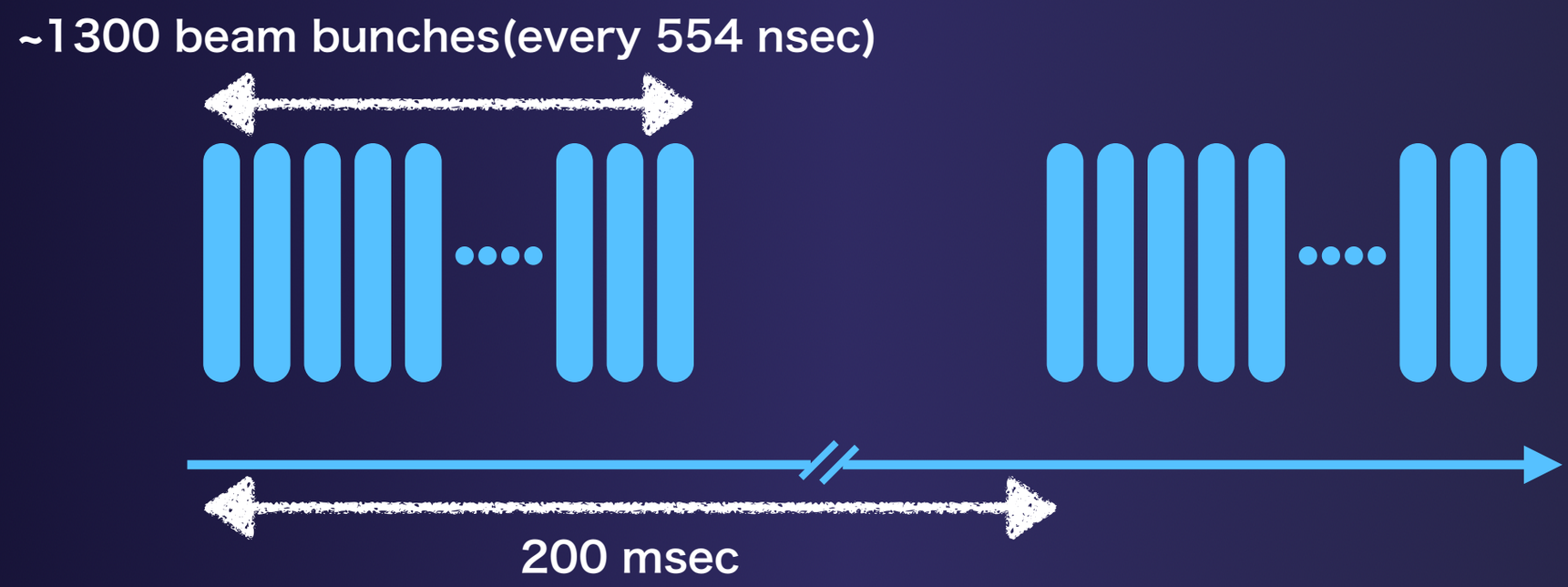






Vertex :
The identification of heavy quarks and tau leptons is essential for the ILC.
The reconstruction of decay vertices of long lived particles, such as D or B mesons, deserves therefore much attention and requires a particularly light and precise vertex detector.

Vertex detector for ILC (International Linear Collider)



Requirement :

time resolution 554 nsec for specifying the bunch which has hit.

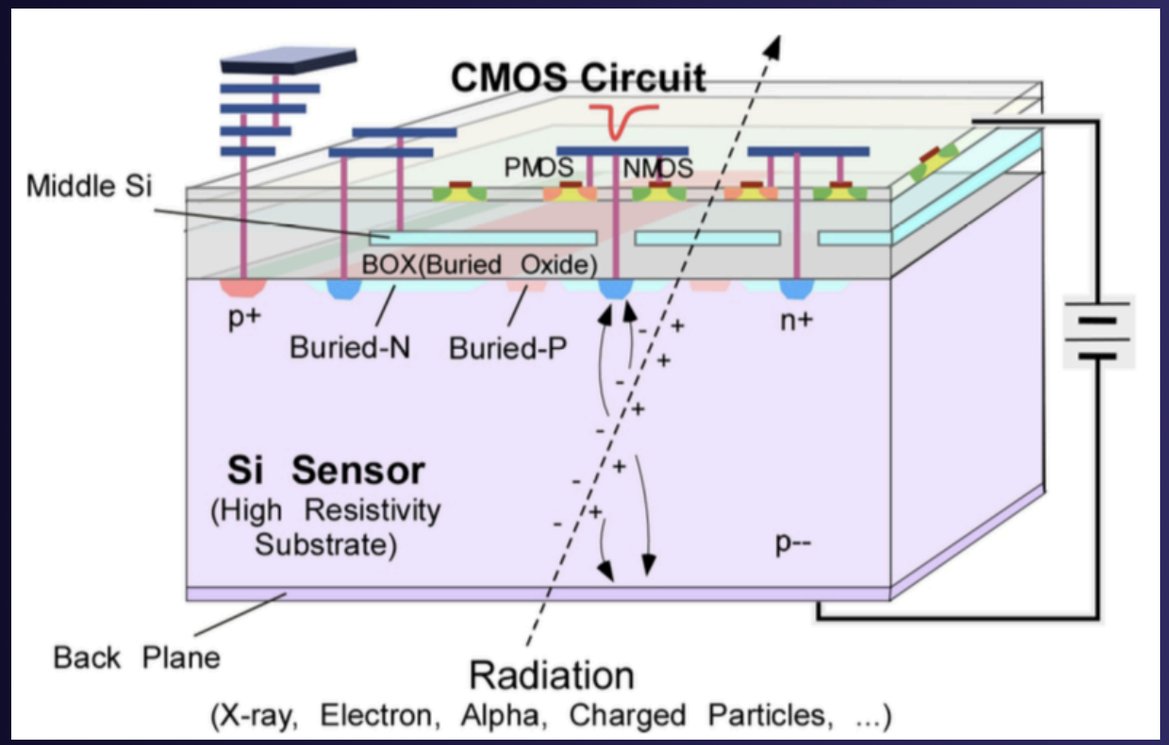
Spatial resolution 3 μm for reconstruct the interaction point.

Low material budget for lepton collider.

A pixel occupancy not exceeding a few %

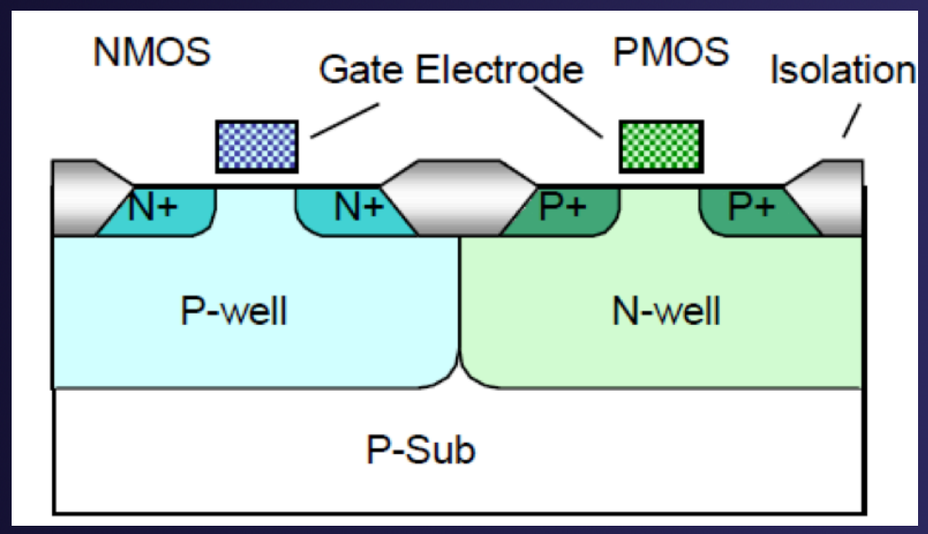
Etc.

SOI pixel detector

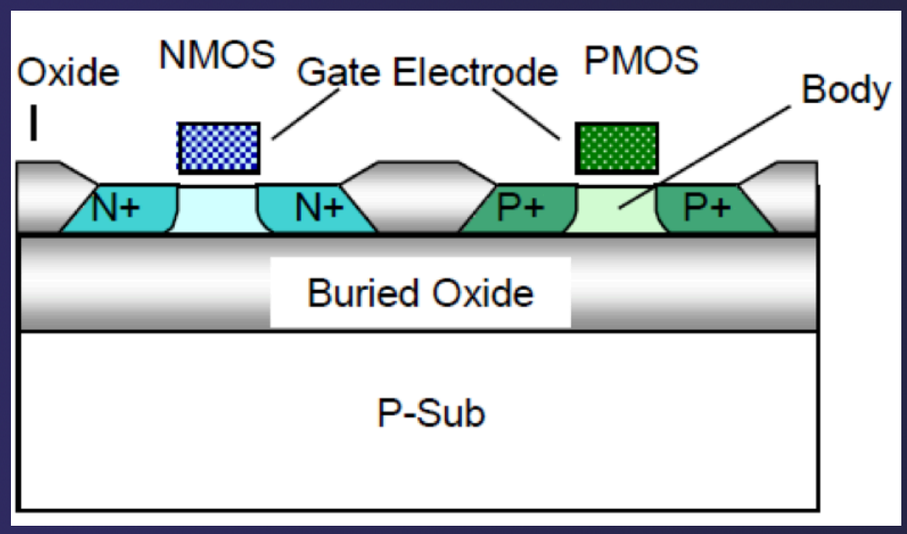


Monolithic pixel sensor

- CMOS circuit
- BOX (Buried Oxide)
- Si sensor (Full depletion)



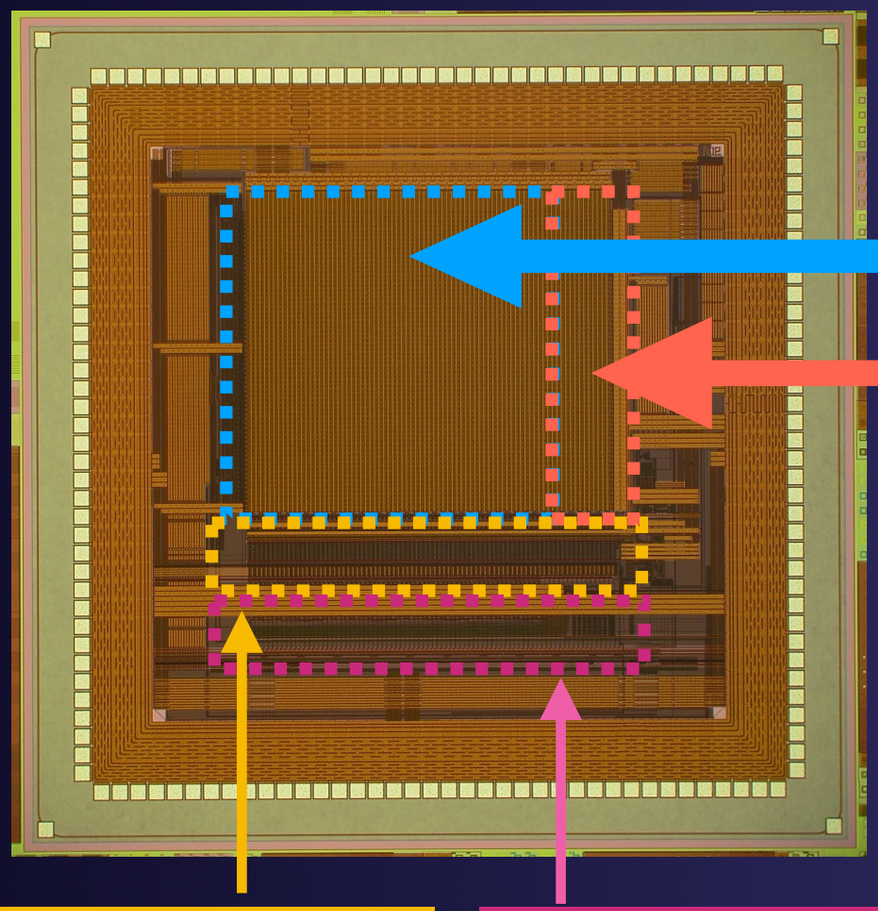
Bulk CMOS



SOI

SOI sensor can make a full depletion layer .

SOI detector designed for ILC vertex detector



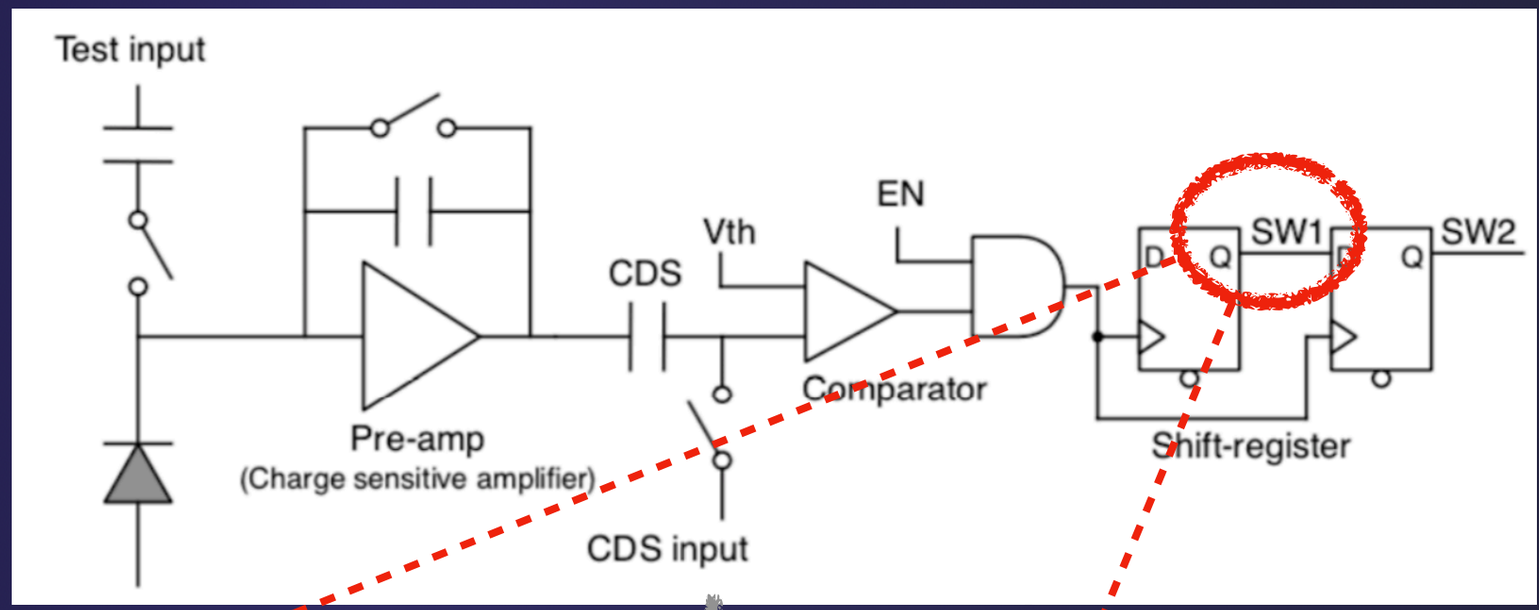
Specification of SOFIST ver.2

Item	Specification
timestamp pixel	64×64
Analog signal pixel	16×64
Pixel size	25μm×25μm
Chip size	4.45mm×4.45mm
Chip thickness	75μm

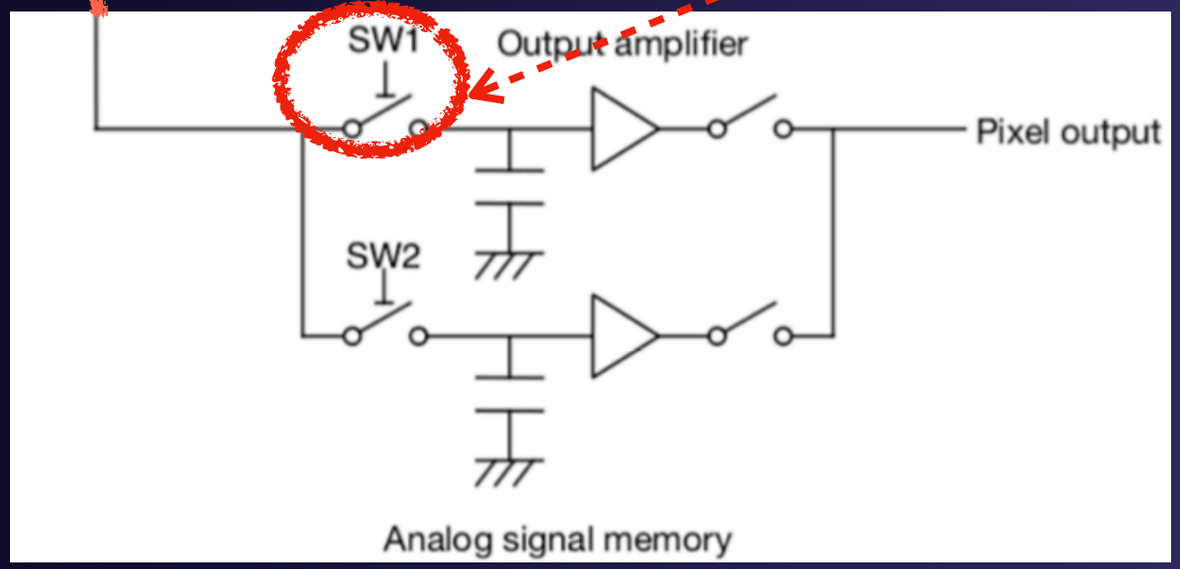
SOFIST ver.3 & ver.4 were designed that timestamp and analog signal are on one pixel.
In ver.2, timestamp and analog signal was designed on different pixels for identifying functions.

Pixel circuit of SOFIST ver.2

Charge signal is amplified by Pre-amp, then comparator has a threshold to identify whether it is a signal.

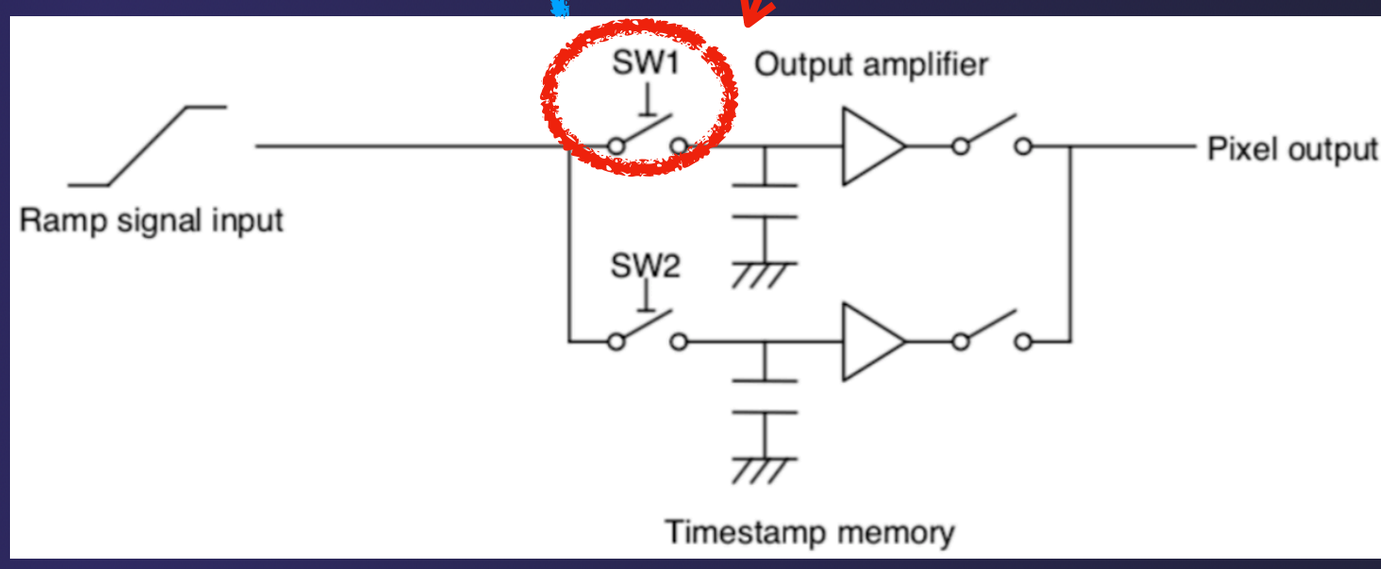


Analog



In Analog signal memory pixel, charge signal will be output in analog .

Time



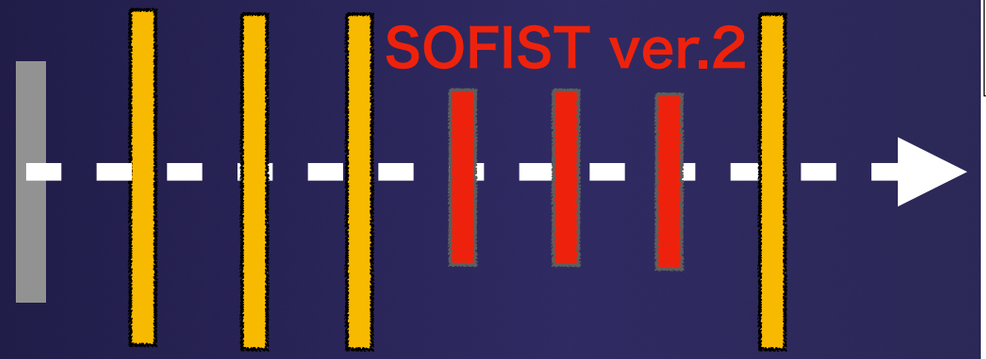
In timestamp memory, when comparator work, ramp voltage will be captured then to be output in analog.

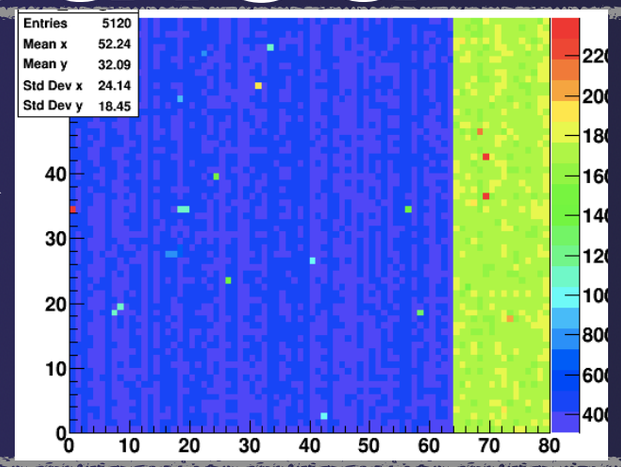
Evaluation method

Beam test

120 proton beam

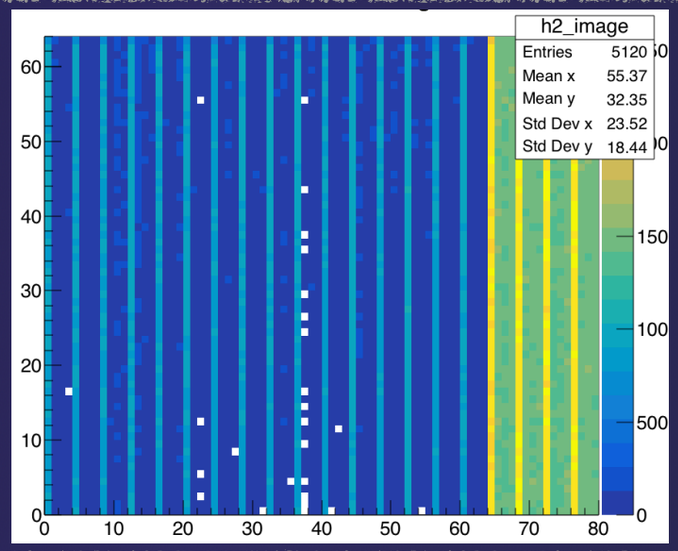
@Fermilab

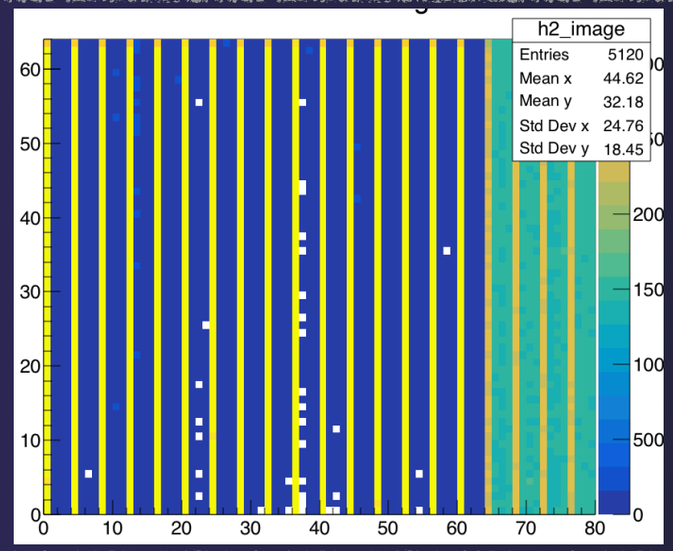




Testpulse

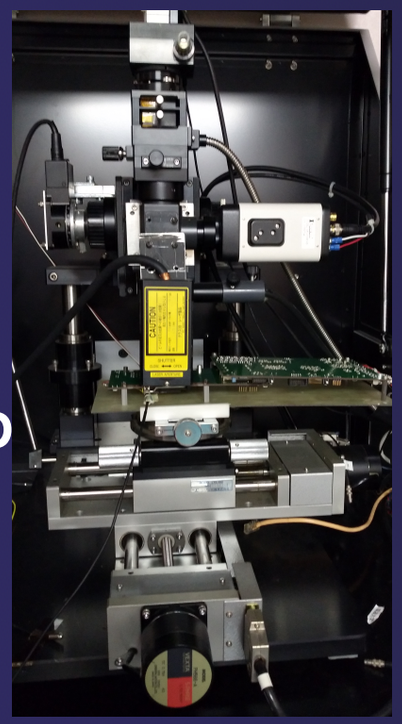
- Pixel circuit test
- Test pulse is made by FPGA
- Time and voltage of test pulse can be controlled

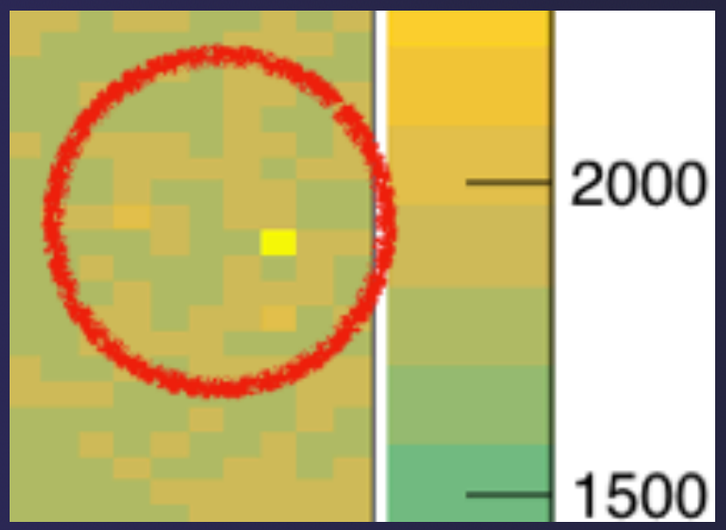




Infrared laser

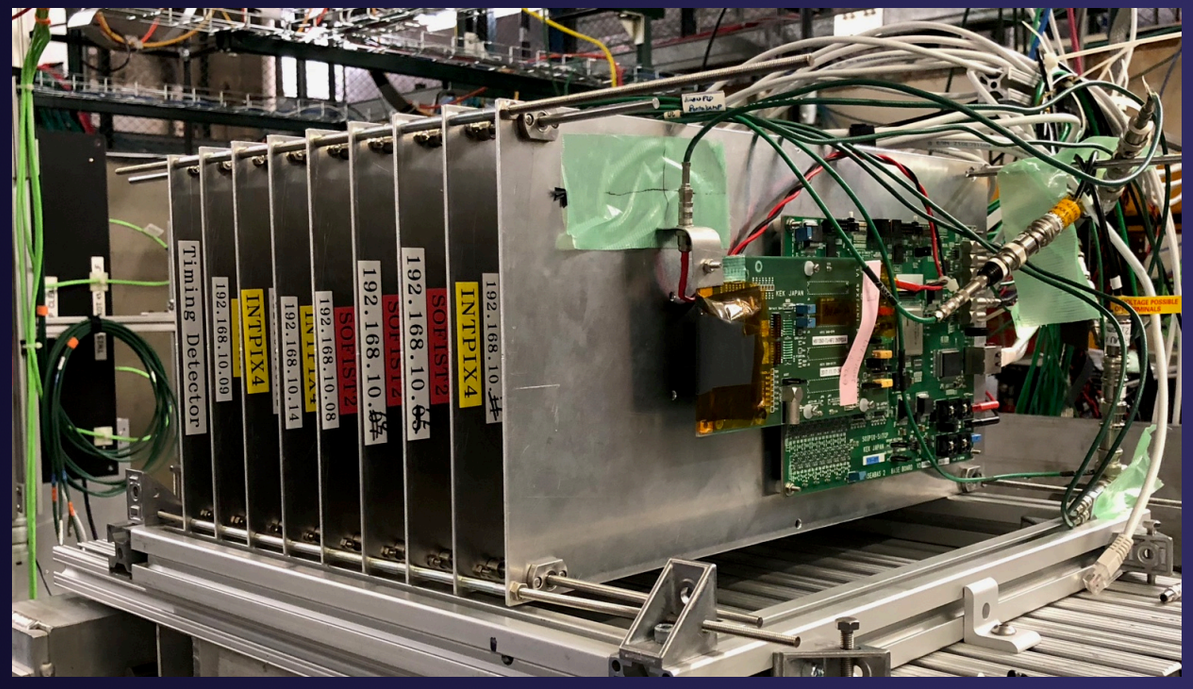
- Sensor test
- Infrared laser can go though SOFIST which has 75 μm thickness
- @Tsukuba Uni. Particle experiment lab
- time and pixel address can be controlled



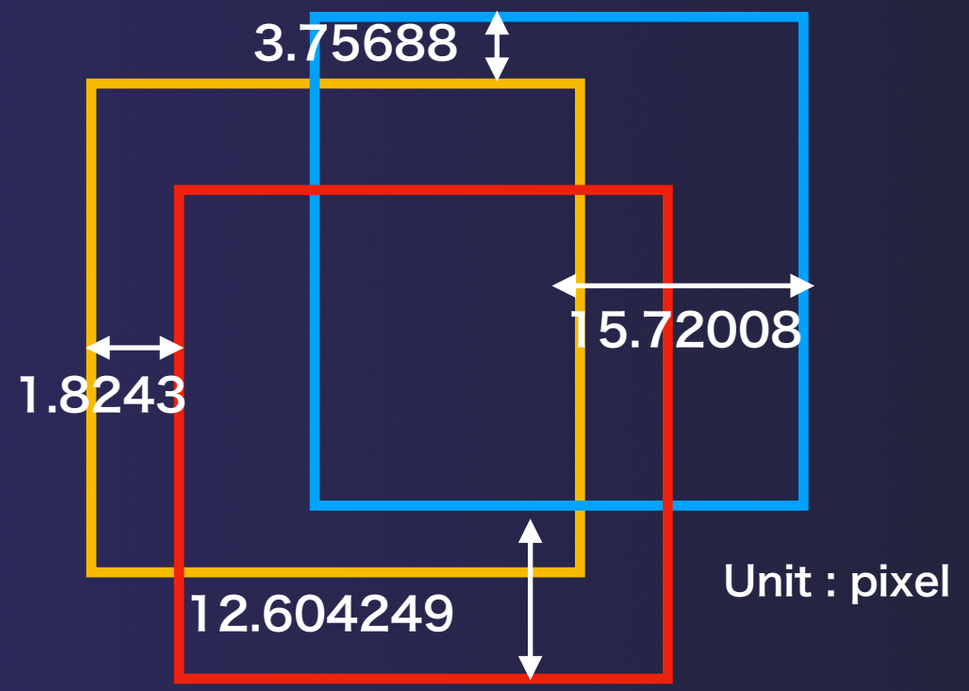


Beam test

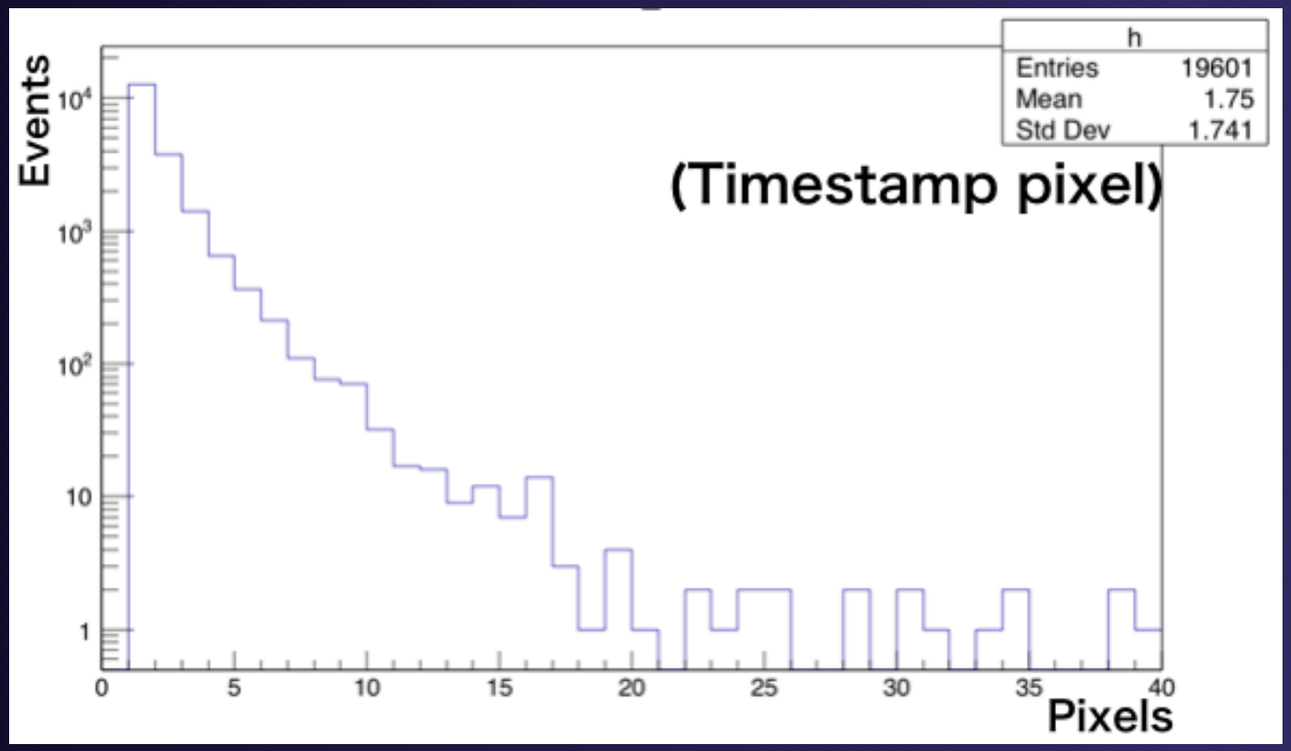
Photo of beam test set up in Fermilab



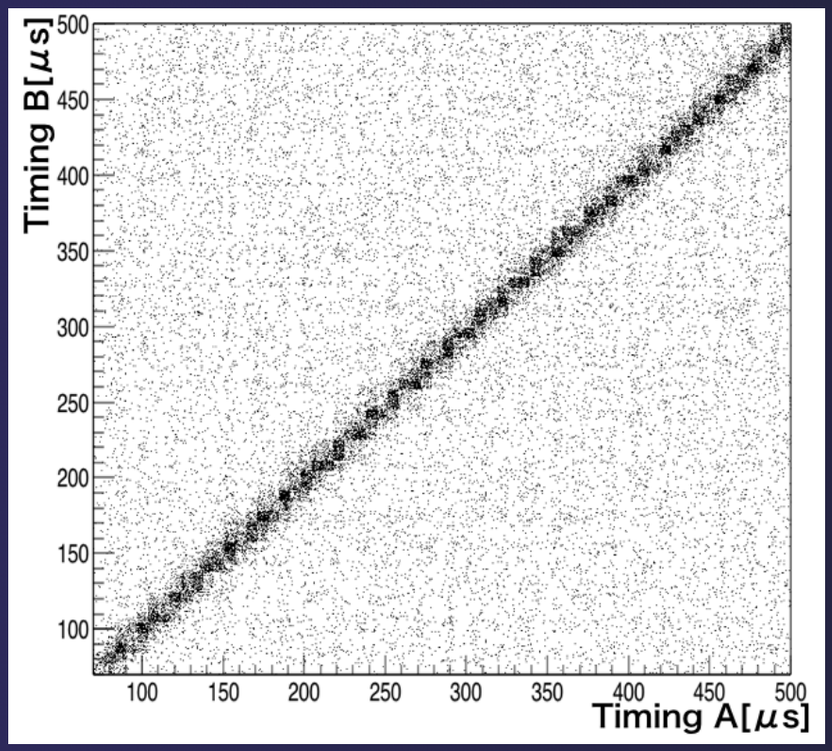
The relation of Chips' position



120 GeV protons were signals by 1 or 2 pixels on SOFIST2

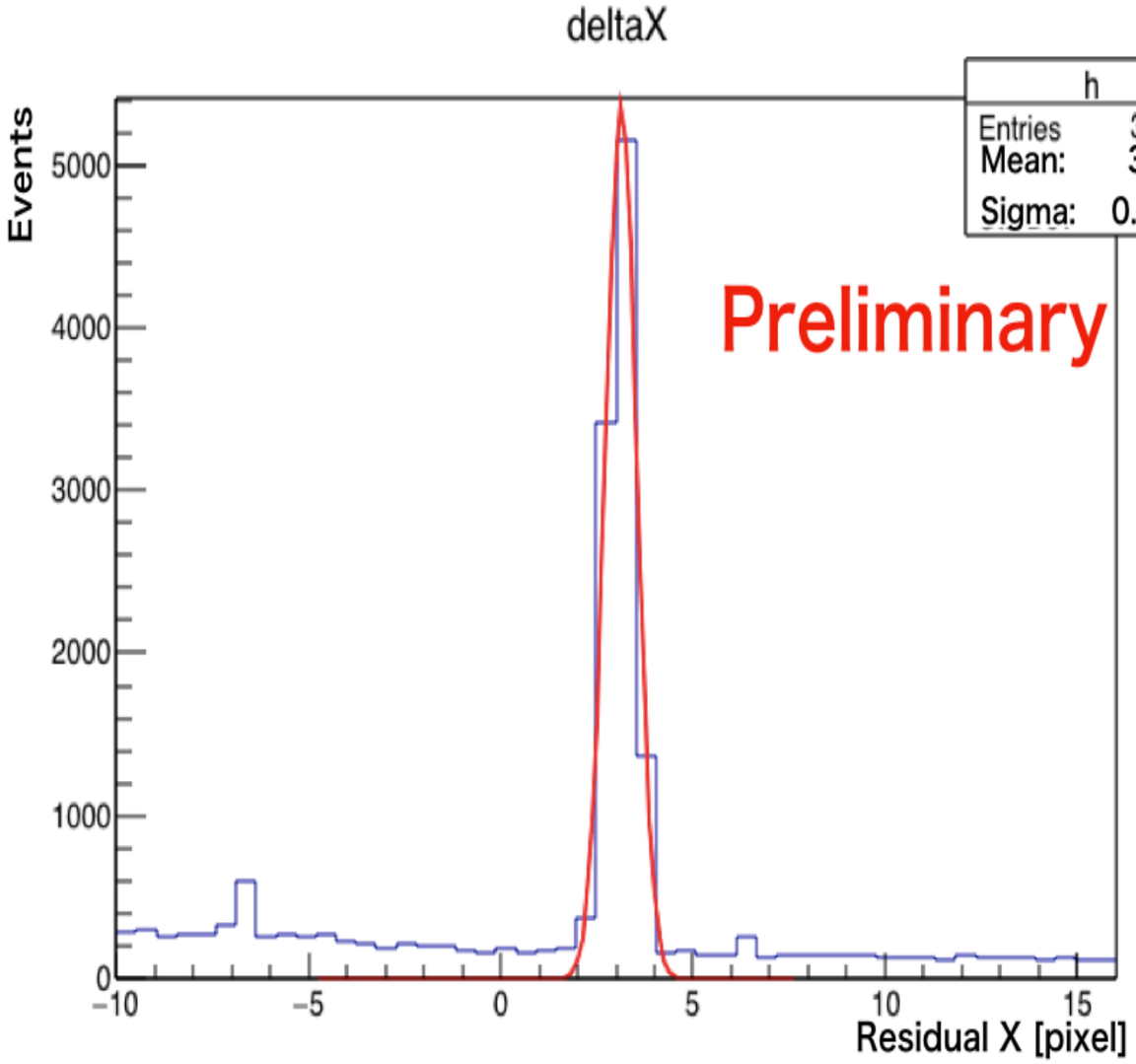


Time correlation of two sensors(protons)

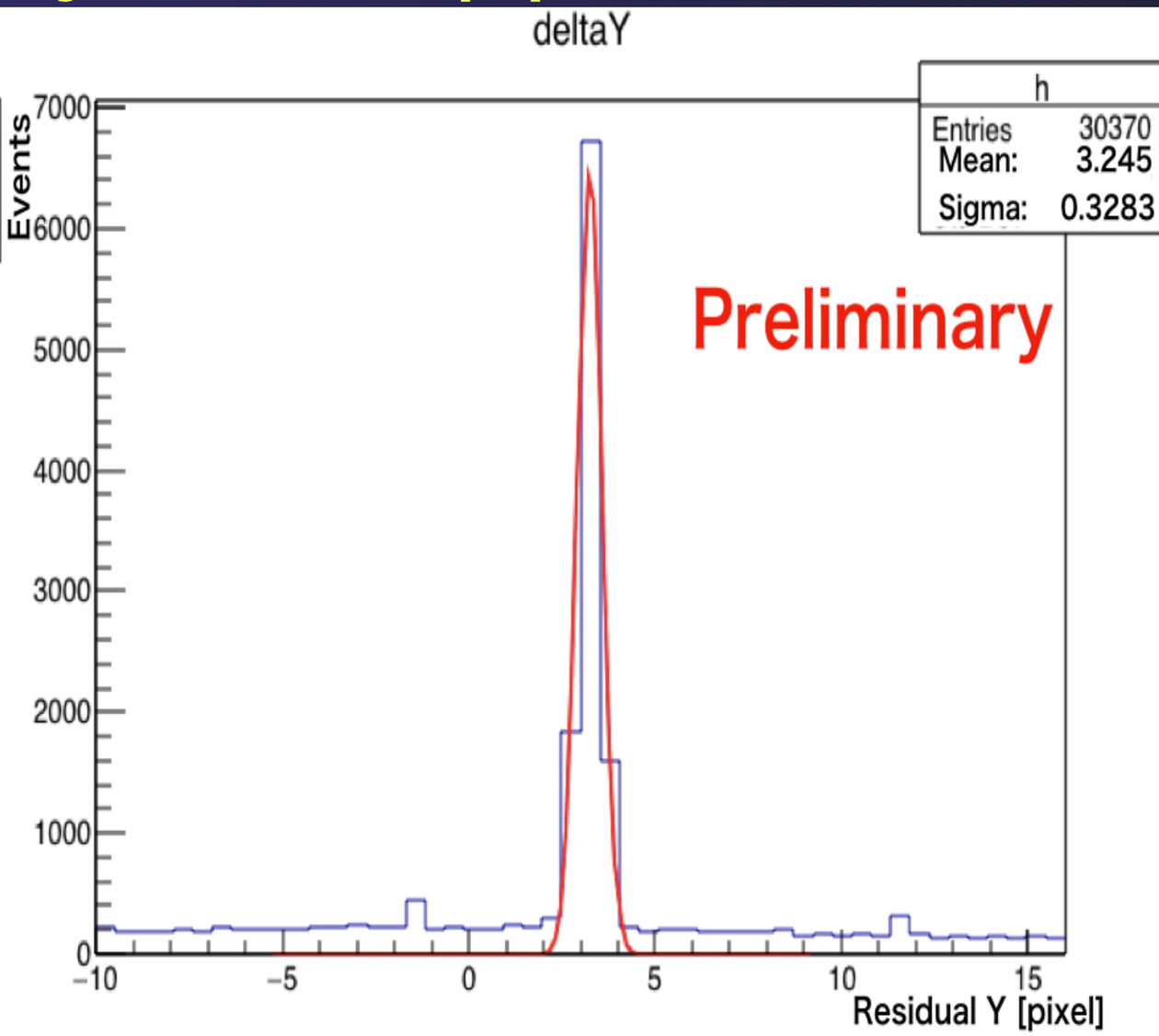


Position resolution of SOFIST ver.2
@120 GeV proton beam

Binary position measurement by timestamp pixels



(a). Residual of X axis



(b). Residual of Y axis

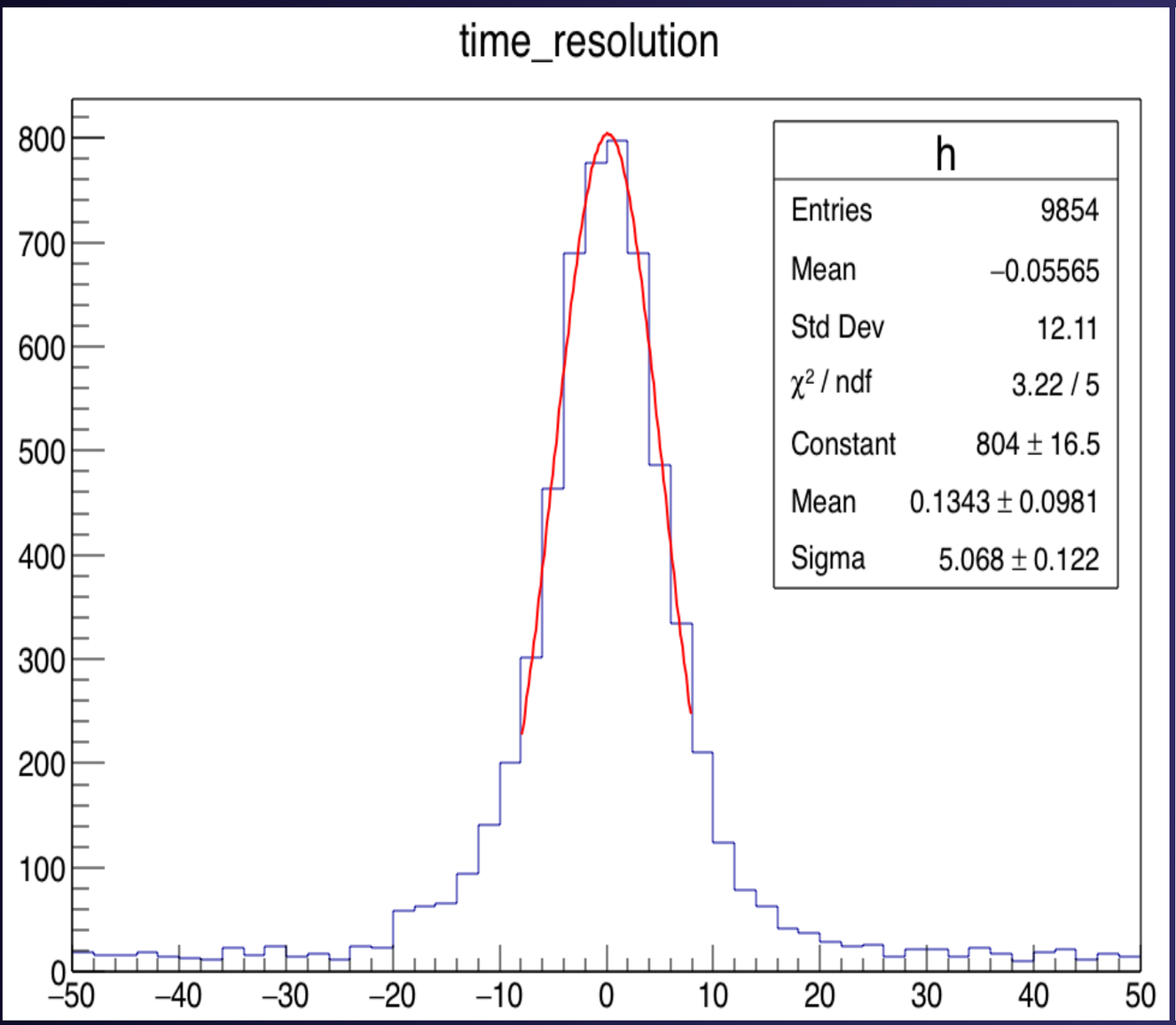
δ (X) : 8.4μm

δ (Y) : 6.7μm

Time resolution of SOFIST ver.2

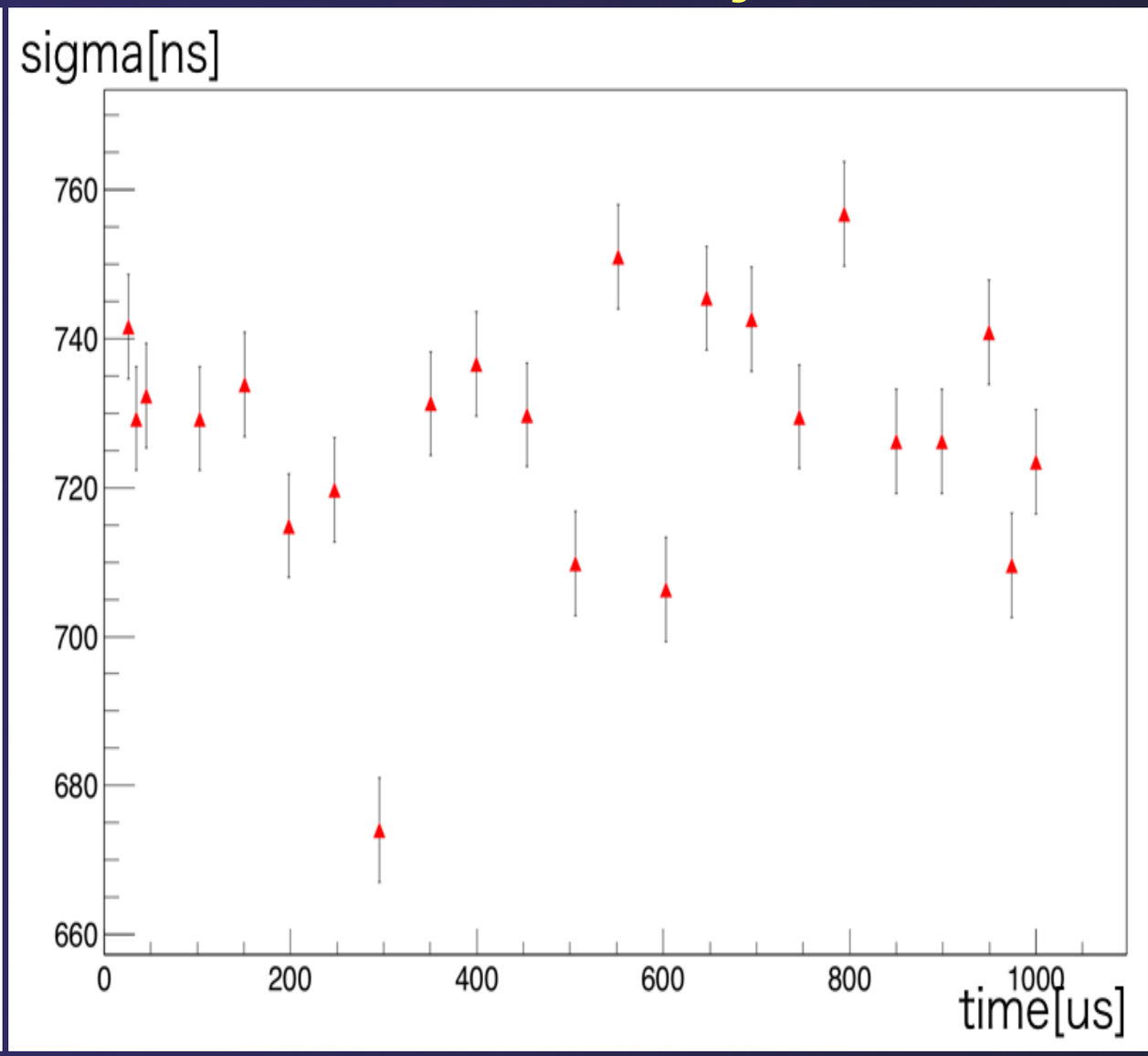
@120 GeV proton beam | @infrared laser

Time resolution Result of beam test



Time resolution 5.68/√2 = 3.58 [μs]

Time resolution by laser



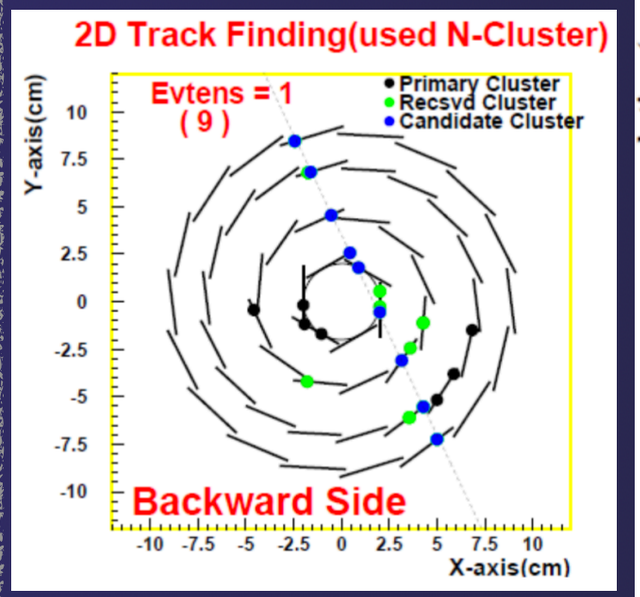
Time resolution ~ 730 ns

Time resolution of SOFIST ver.2

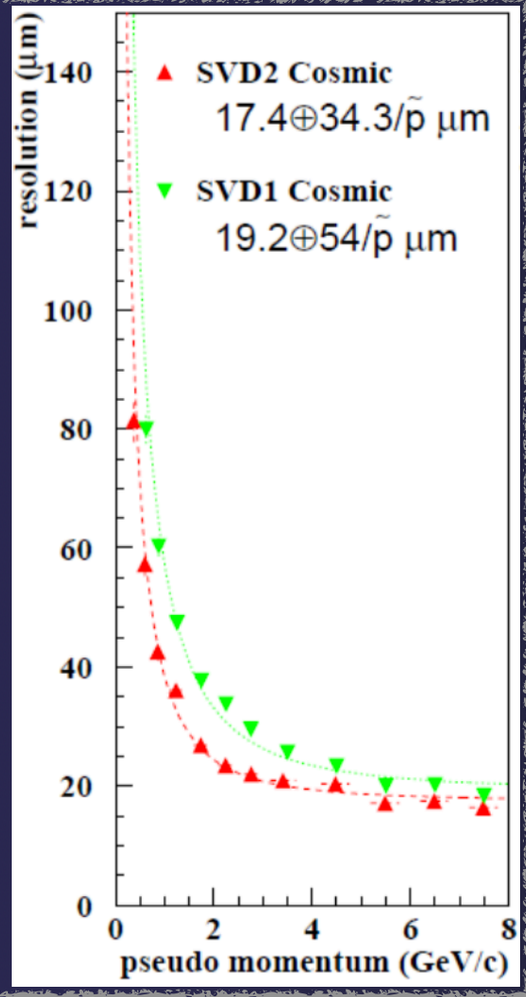
Conclusion (Is 730 nsec good?):

730 ns time resolution can identify hit with 8 bunches (6σ).

6.32 [hits/cm2/BX] ・・・・・ILC hit rate
× 1.75 [pixel/hits] ・・・・・Cluster size
× 25・25 [μm^2/pixel] ・・・・・pixel size
× 8 [bunches]
× (100・100 [μm^2/pixel] / 25・25 [μm^2/pixel])
・・・・・sensing area
≈ 5.06×10^{-3} [pixels]
～ 0.5 %

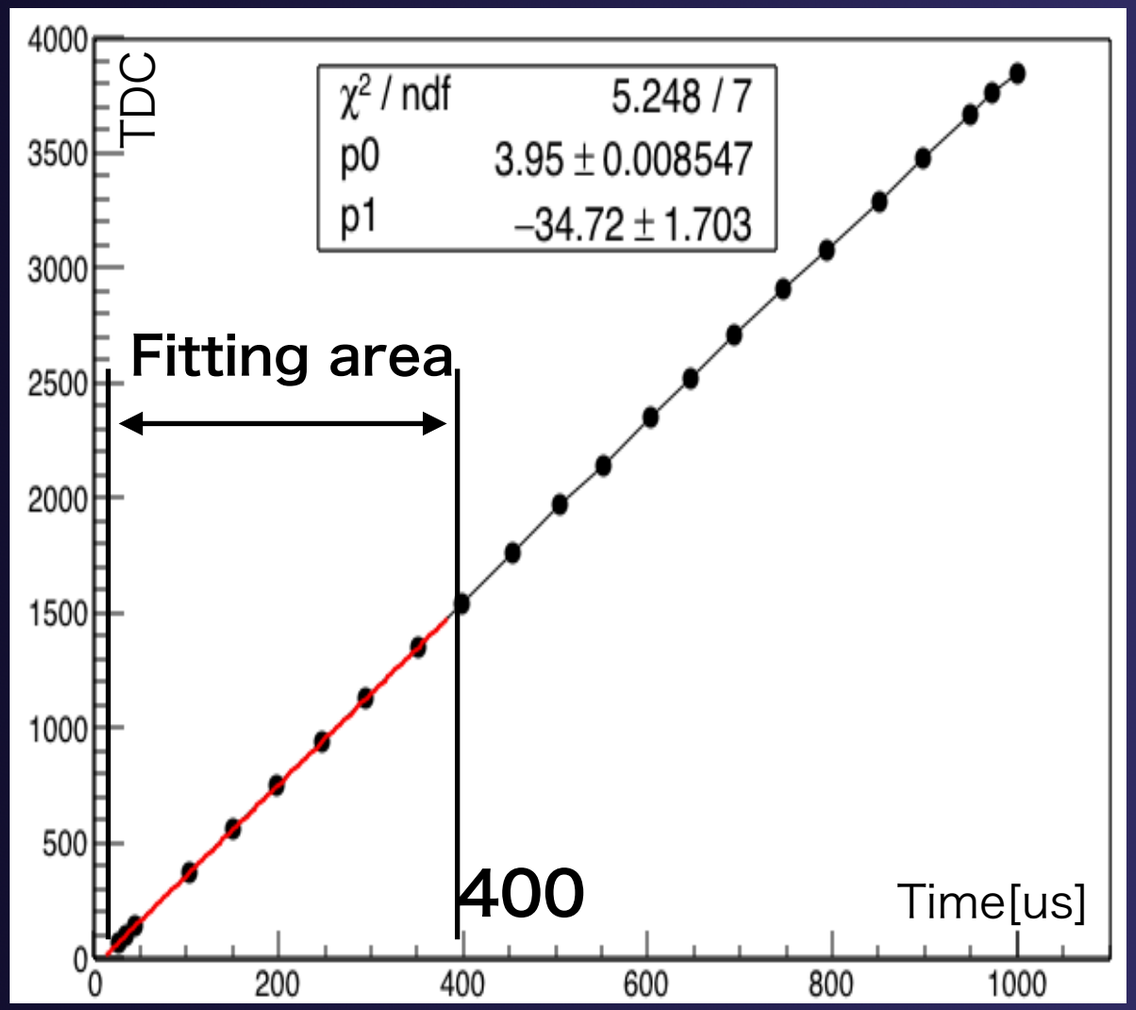


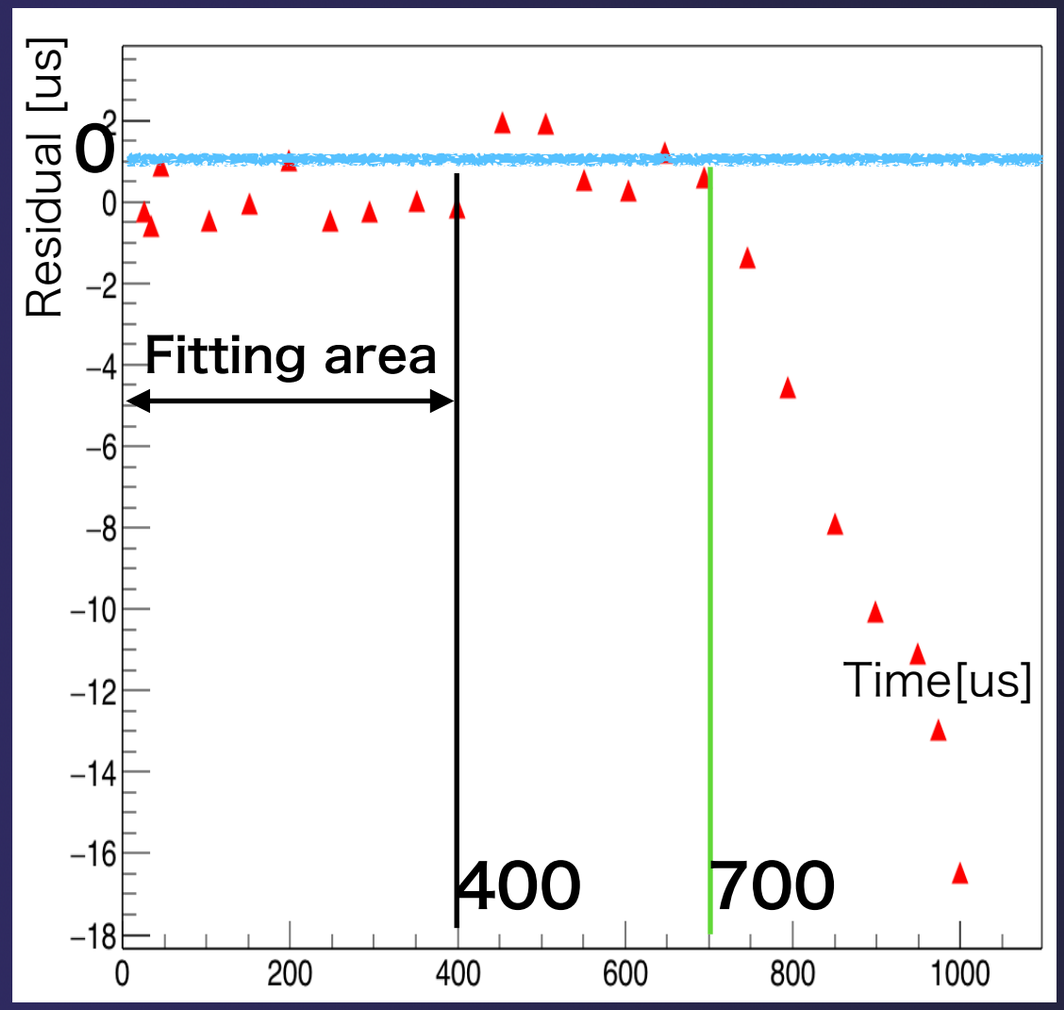
Ref : Junji Haba, private communication



Performance of Time measurement

Linearity of time measurement @infrared laser



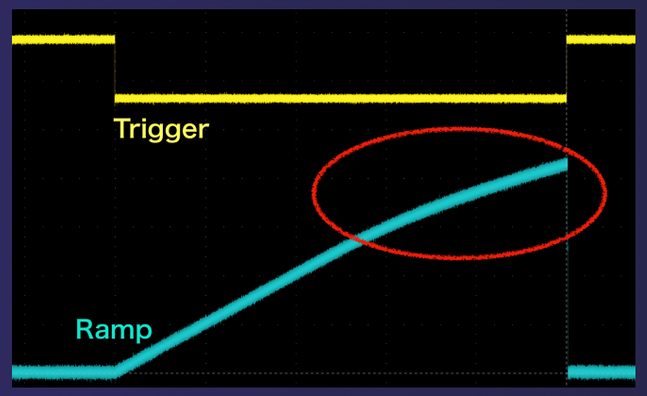


TDC = 3.96 time - 36.02

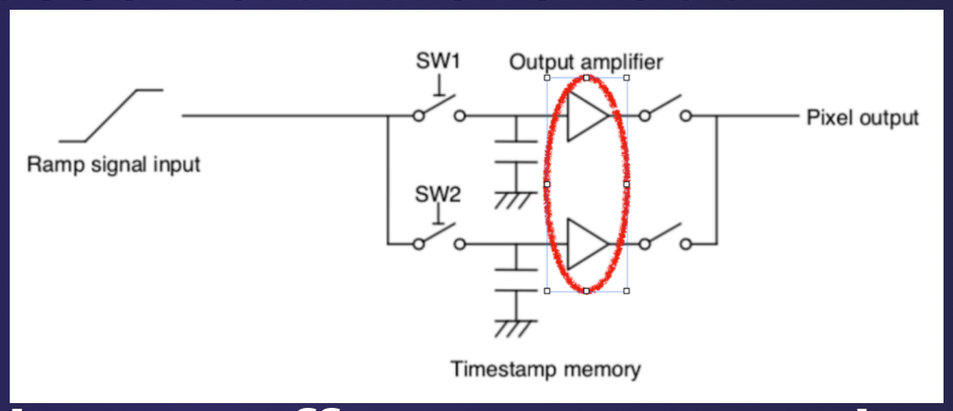
Performance of Time measurement

Linearity of time measurement @testpulse

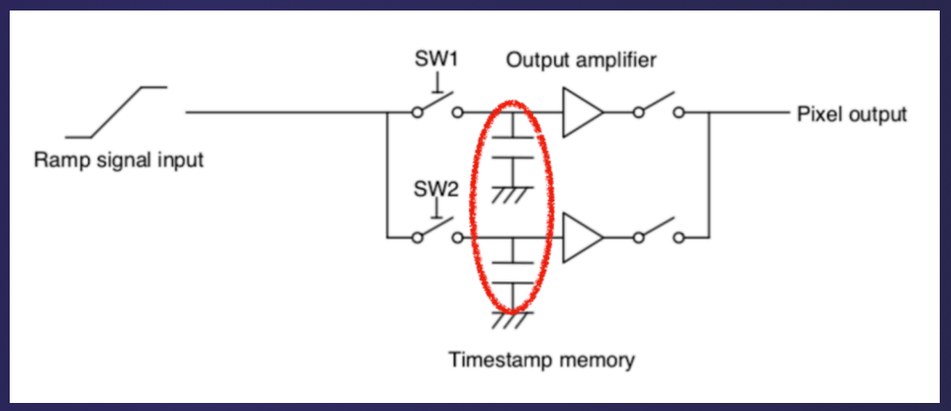
1. Ramp wave which is outputted from SEABAS board is not good ?



2. Gain of output amplifier become bad over 600 mV ?



3. Leak current from Capacitance affects output voltage ?

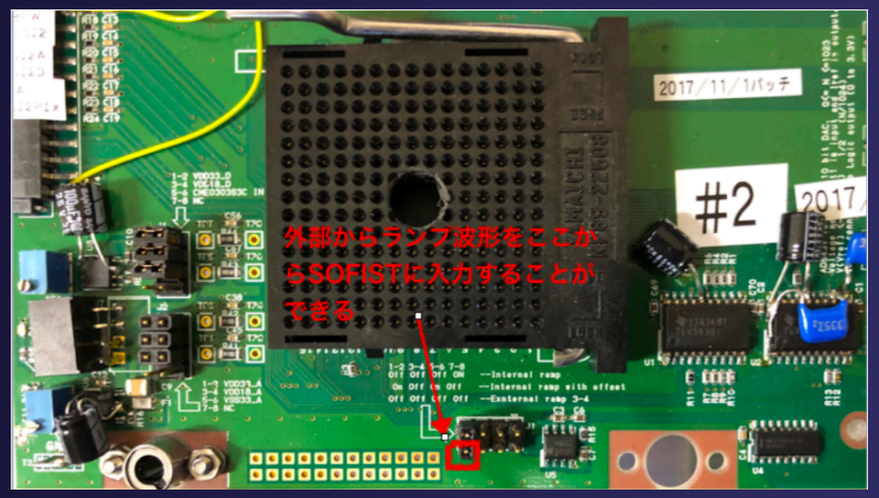


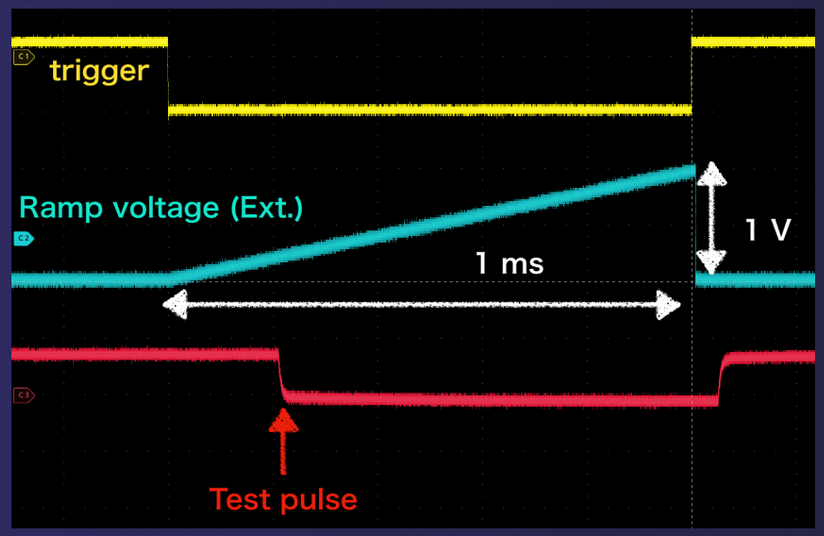
Performance of Time measurement

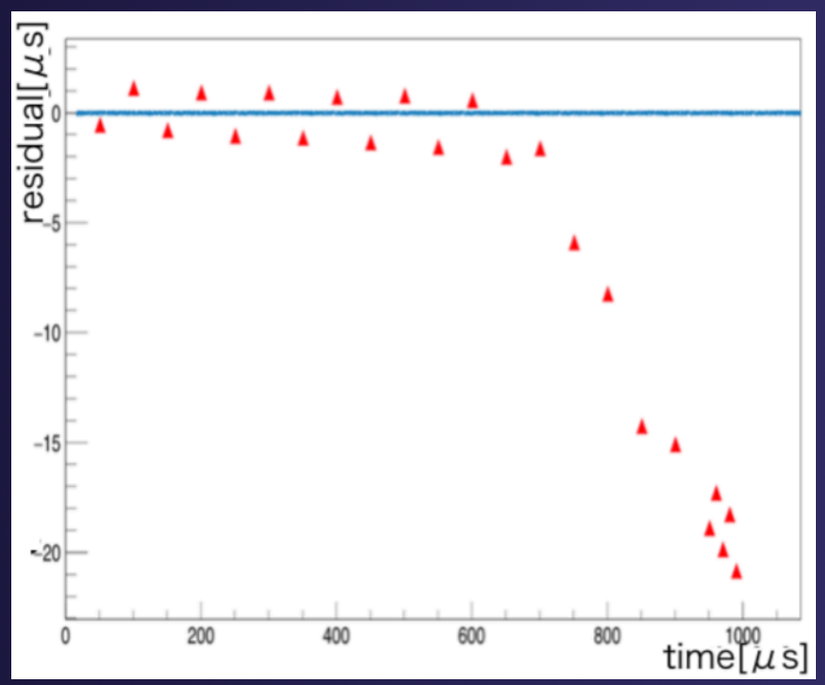
Linearity of time measurement @testpulse

1. Ramp wave which is outputted from SEABAS board is not good ?

Solution : use ramp wave from function generator instead of board.







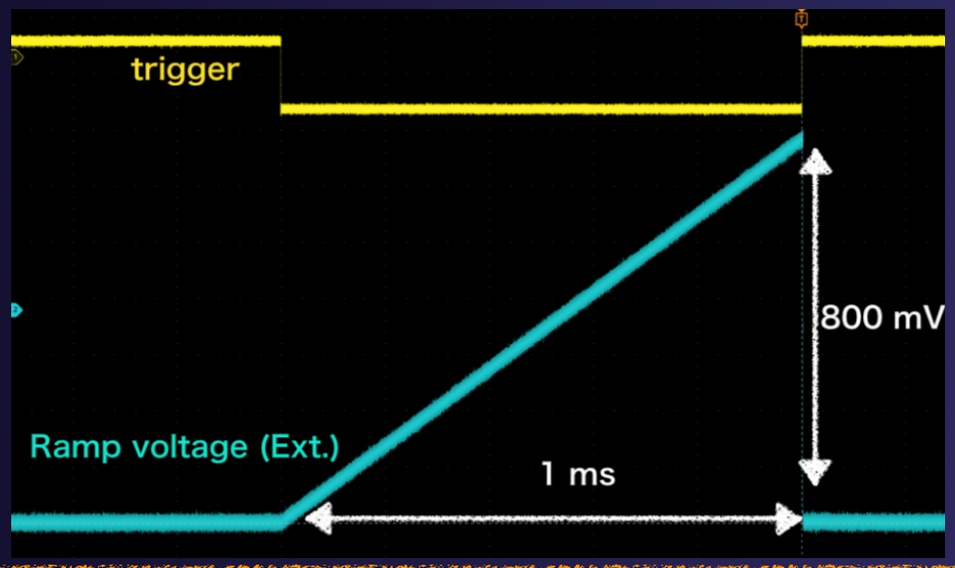
Result of residual of time measurement is same from ramp wave by board , so the reason is not from ramp wave.

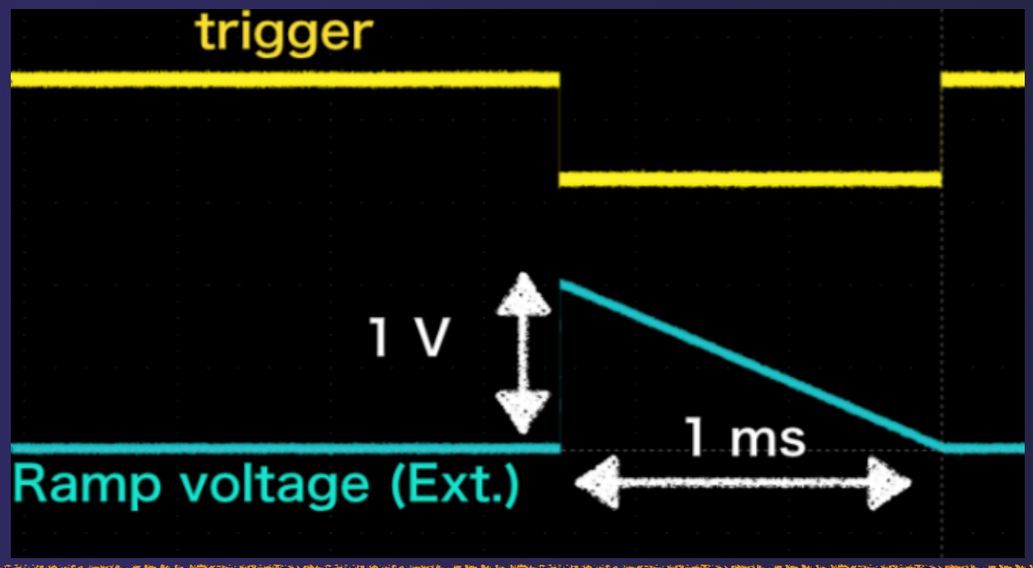
Performance of Time measurement

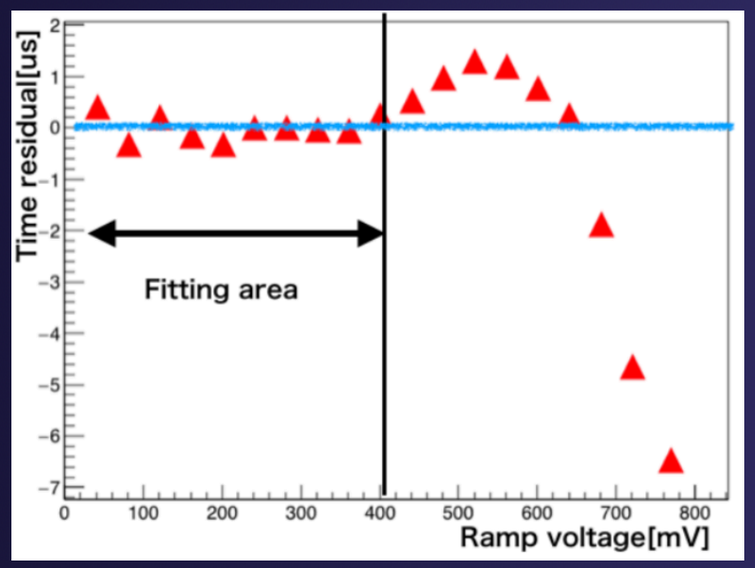
Linearity of time measurement @testpulse

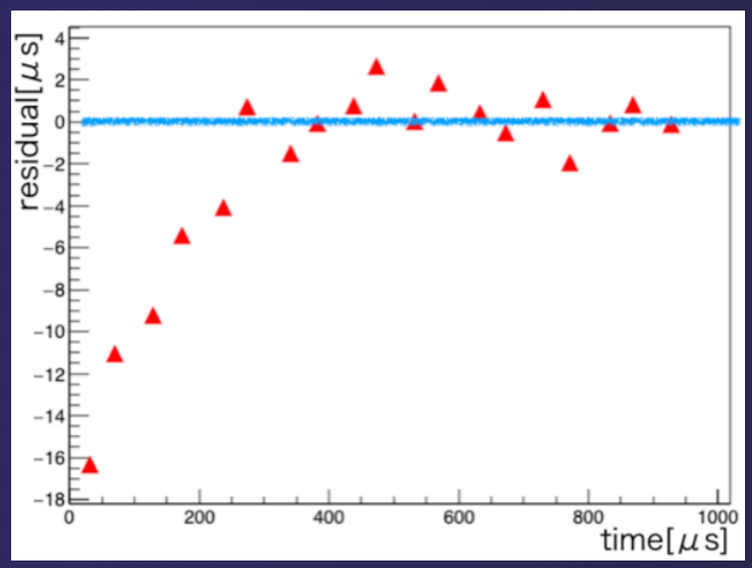
2. Gain of output amplifier become bad over 600 mV ?

Solution : input low ramp voltage and ramp wave which has different form.









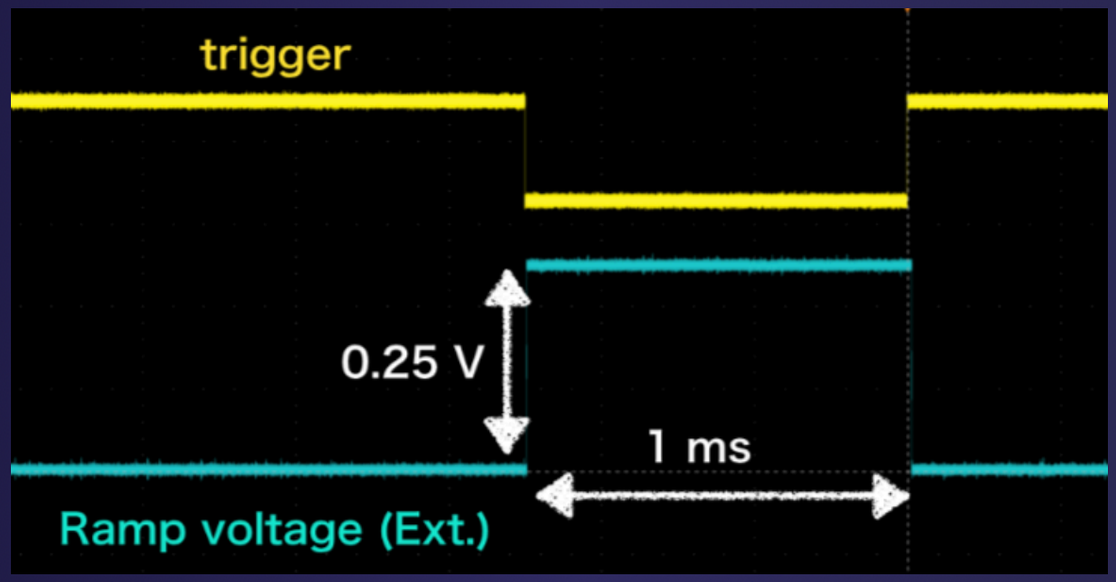
Gain of output amplifier become bad over 600 mV !!!

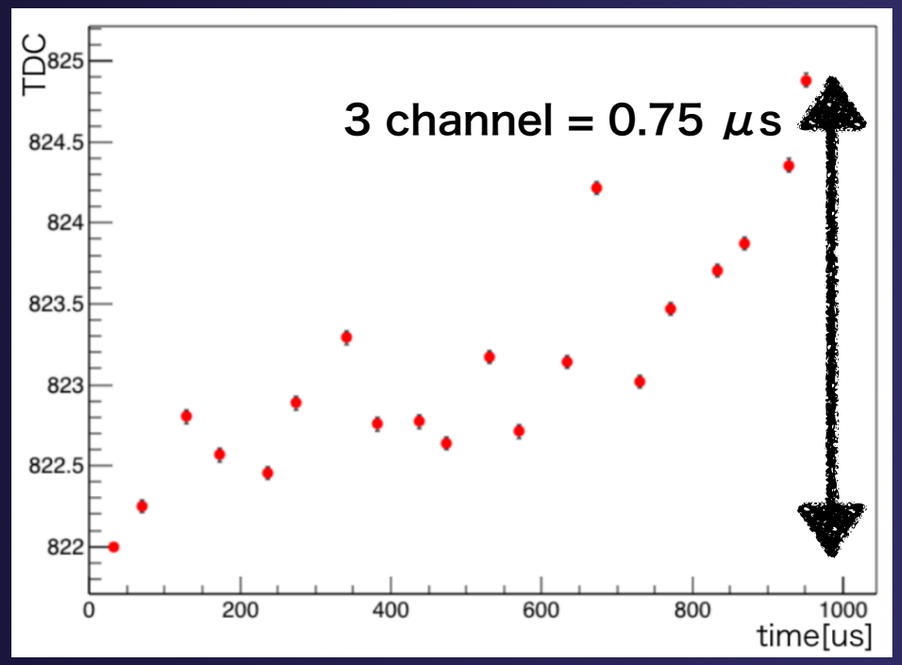
Performance of Time measurement

Linearity of time measurement @testpulse

3. Leak current from Capacitance affects output voltage ?

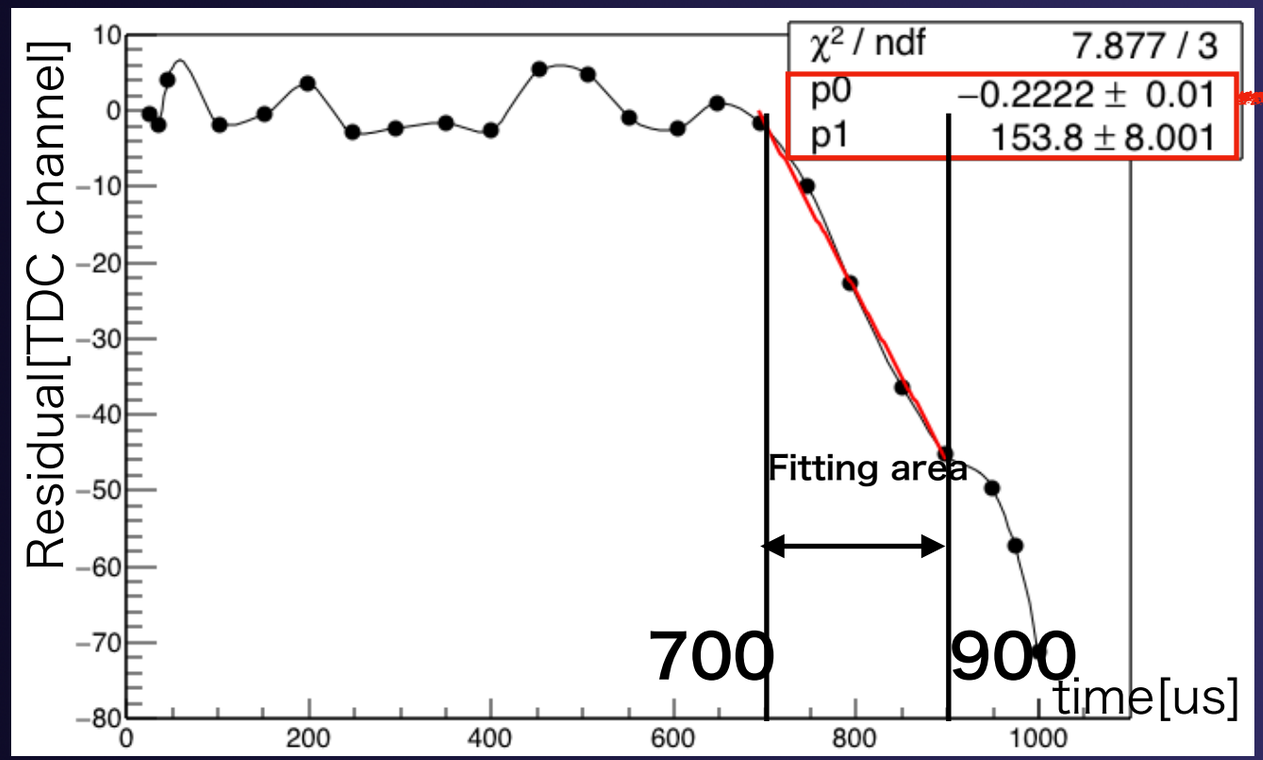
Solution : input square wave instead of ramp wave.





Capacitance leak current affects output voltage but just below 0.75 μs.

Performance of Time measurement



TDC = (3.957 + p0) time - 35.49 + p1

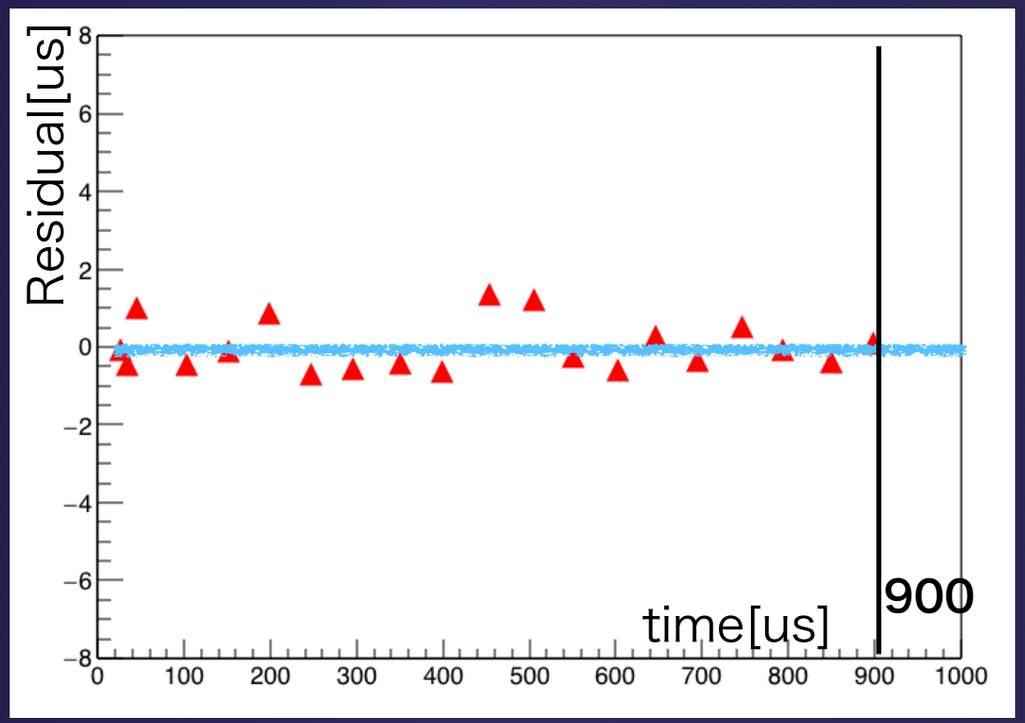
(Parameter 3.957 and 35.49 are fitted from 0~700 μs.)

(0~700 μs)

TDC = 3.957 time - 35.49 ;

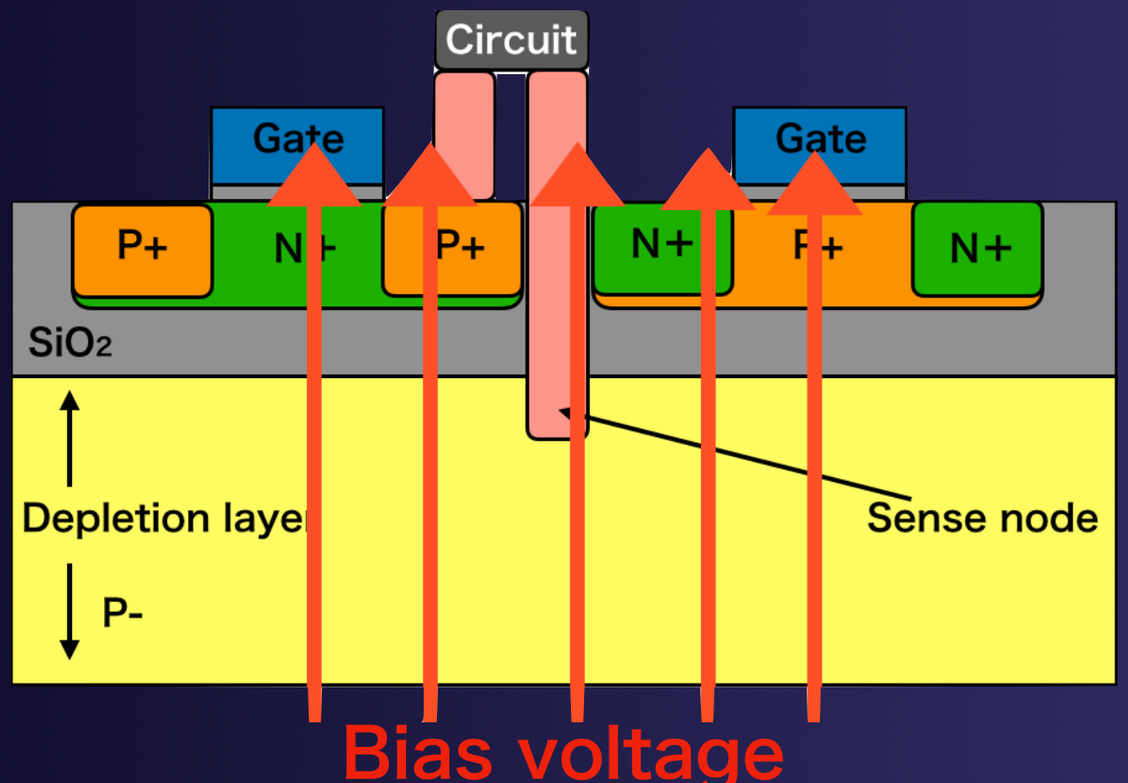
(700~900 μs)

TDC = 3.735 time + 118.31 .

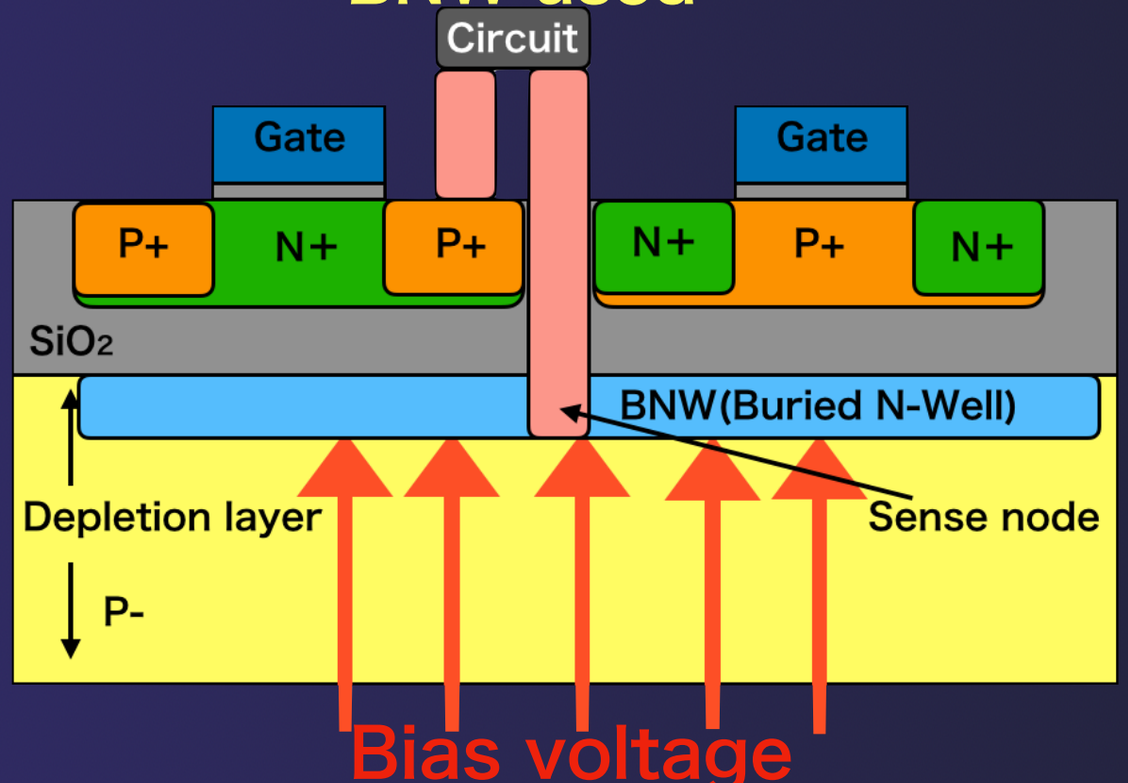


BNW(Buried N-Well)

BNW didn't used



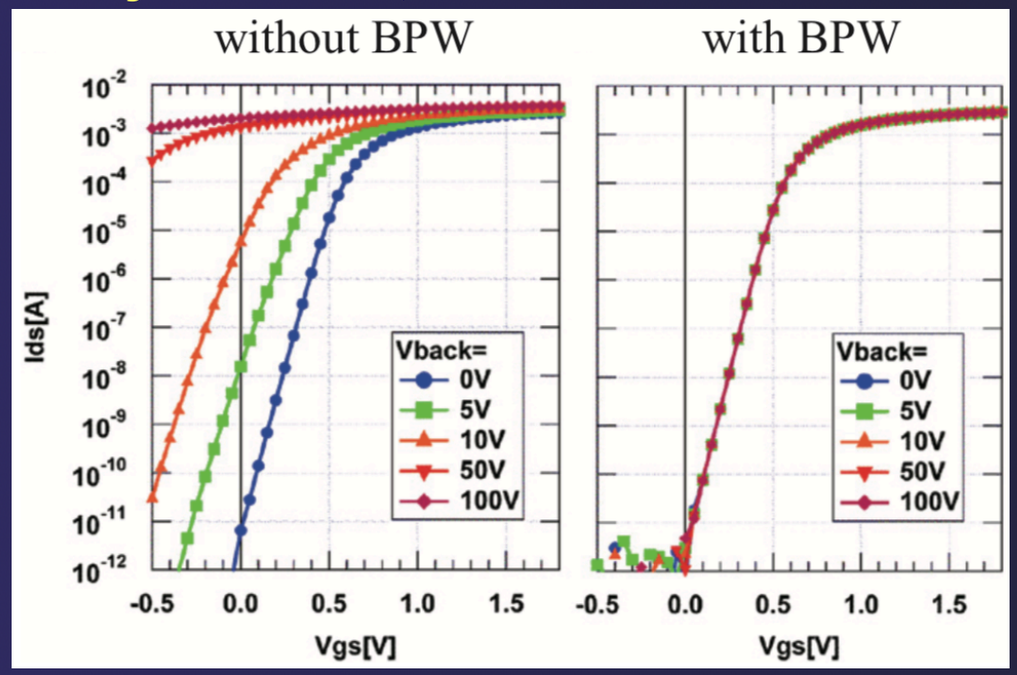
BNW used



Back gate effect Suppression:

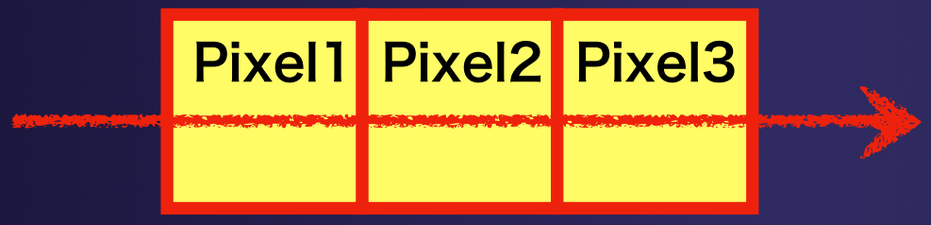
In SOI device, Electric field by bias voltage will affect the gate which is from PMOS or NMOS. Then the gate will affect pixel circuit operating. Using BNW structure can cover electric field then make electric field don't go into pixel circuit.

I/V curves show the difference of BPW didn't used and used. (BPW is for N wafer, SOFIST is made by P wafer)



Laser position scan

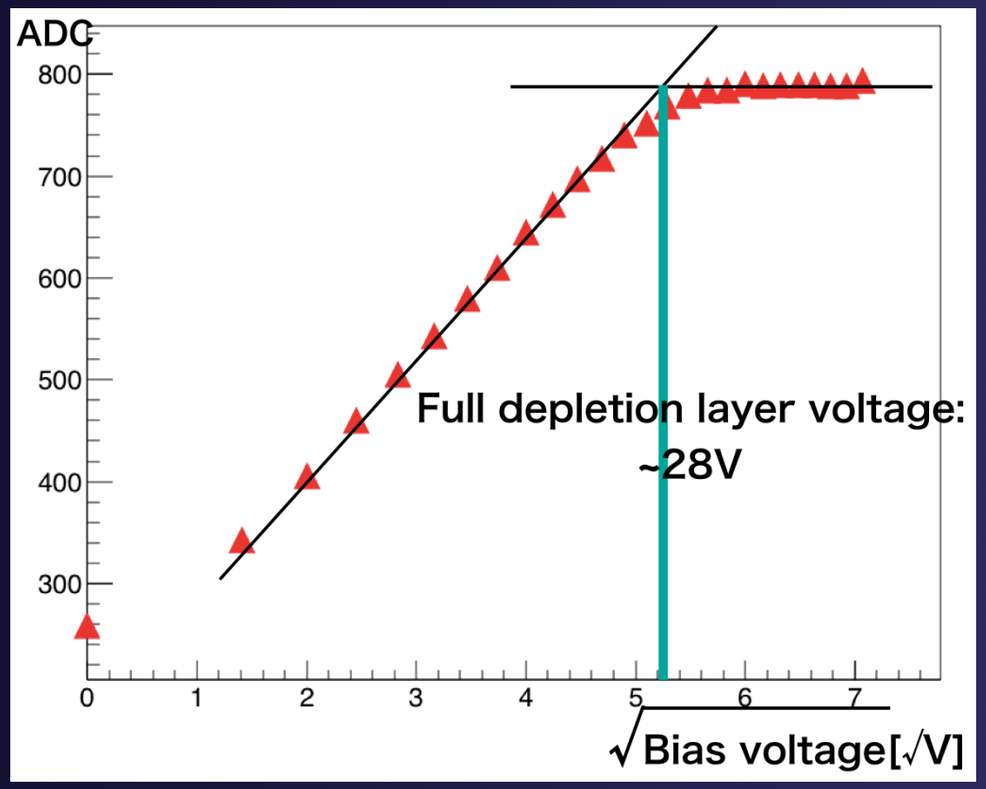
Motivation : study how depletion length and BNW affect share share & loss

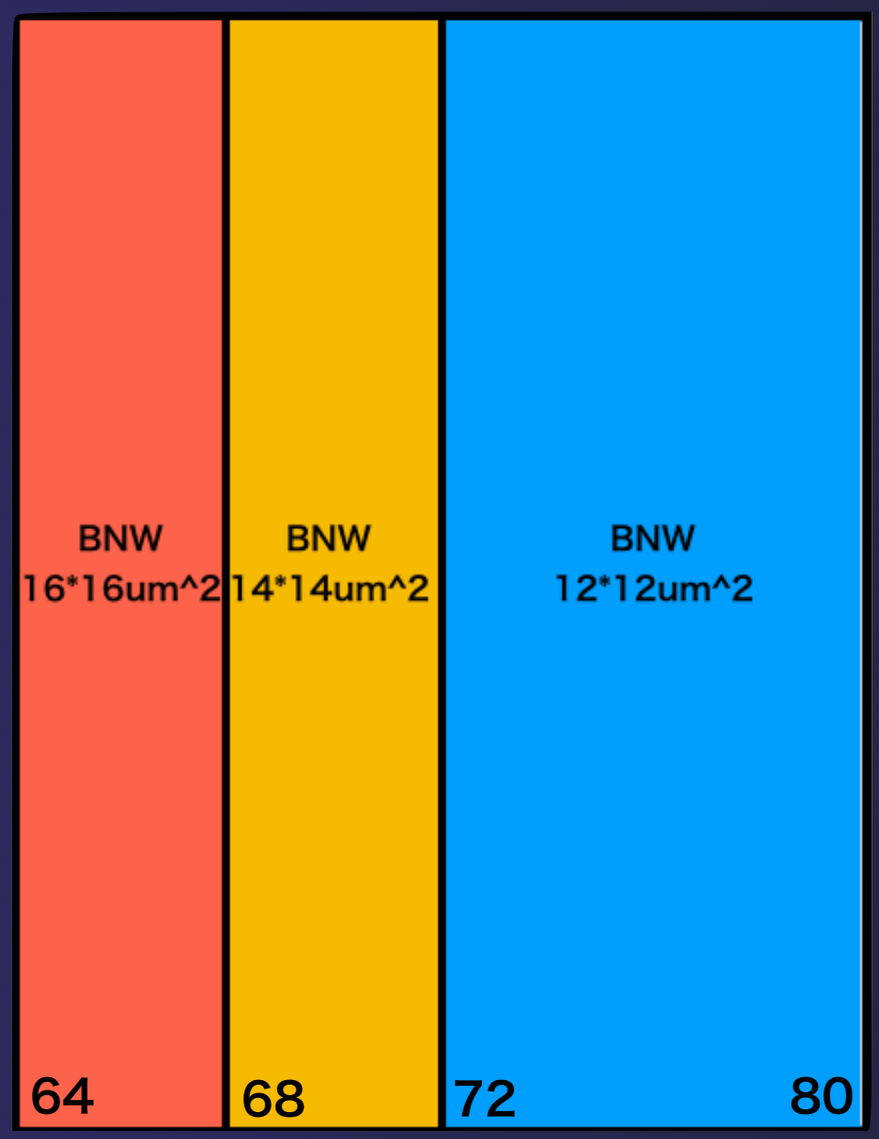


Measurement parameter :

—Depletion length 3V,13V,30V

—BNW 16μm^2,14μm^2,12μm^2

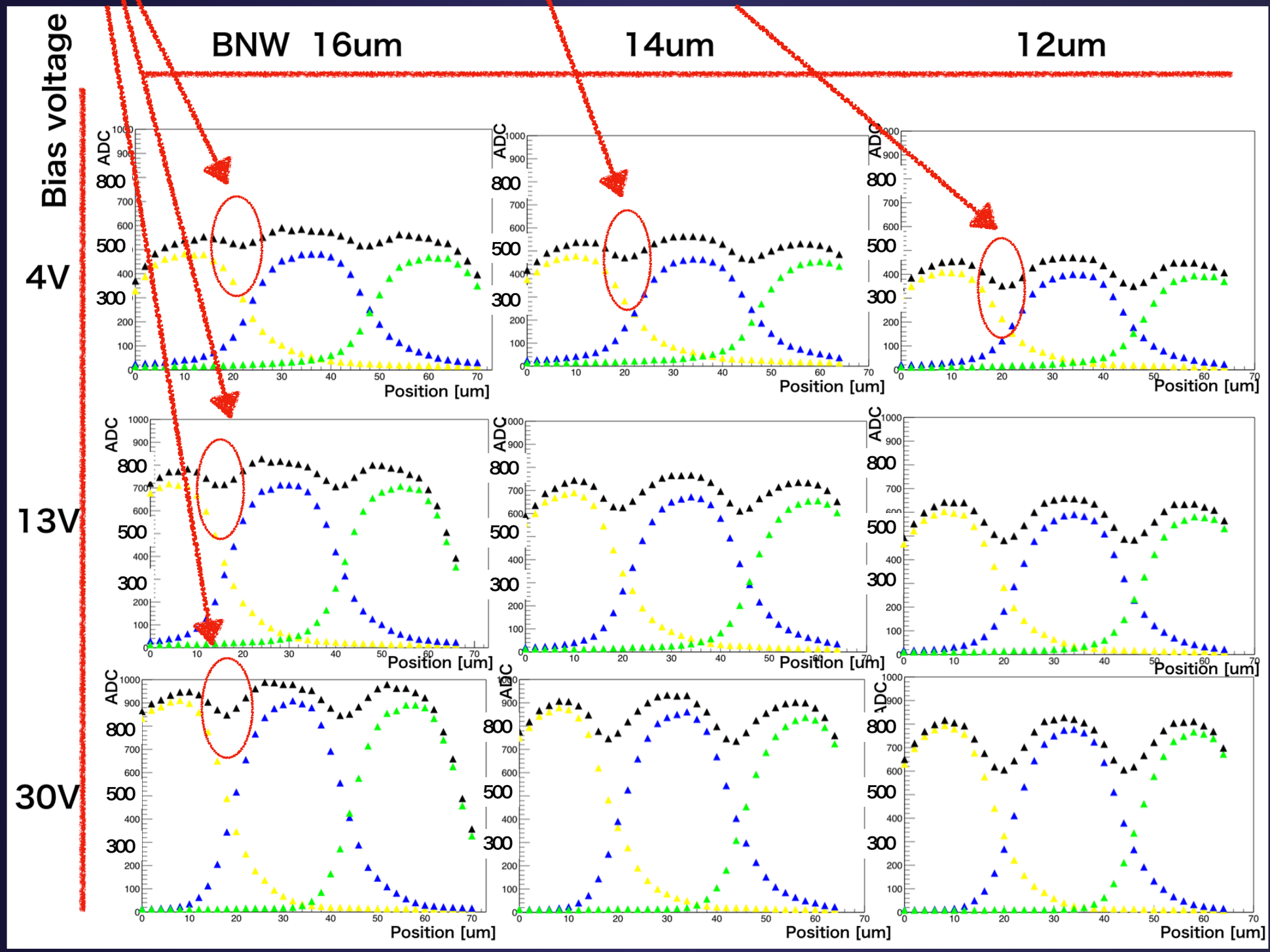




Laser position scan

These graph shows the result of the laser scan measurement in different BNW sizes and Bias voltage.

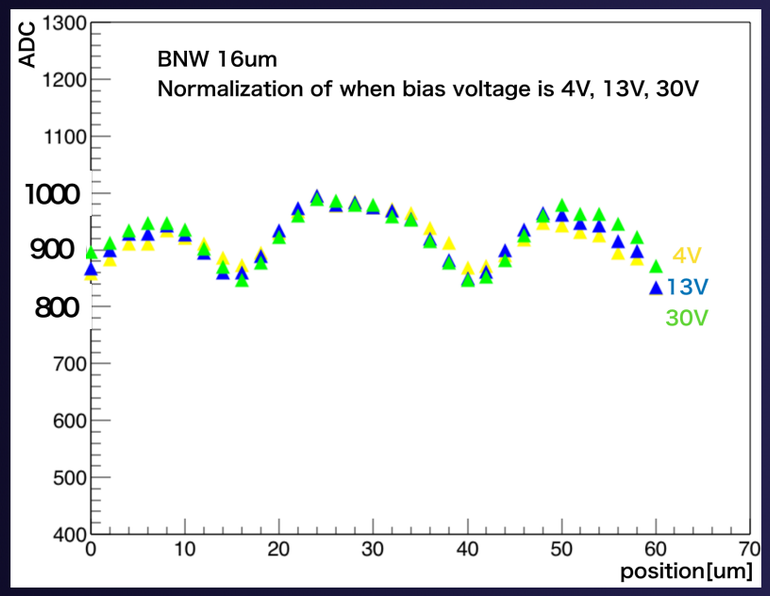
Those “falling” show charge loss. But how can we get the information of charge loss?

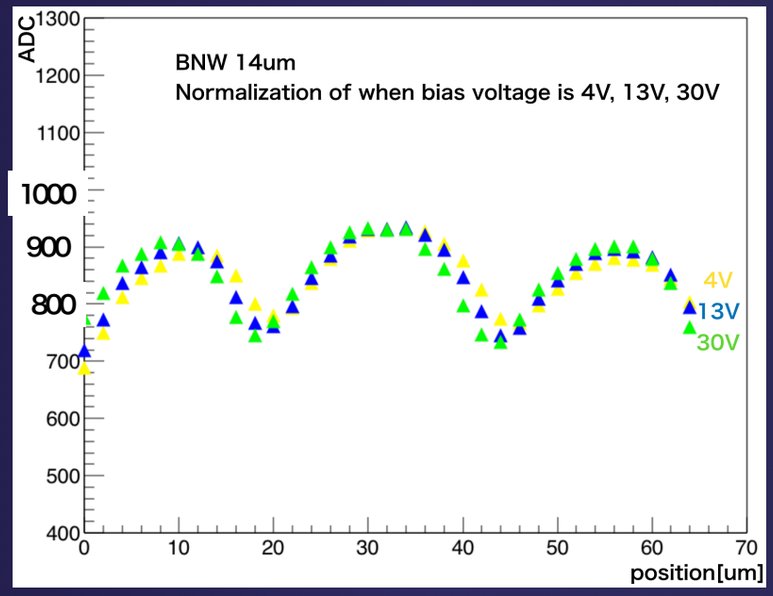


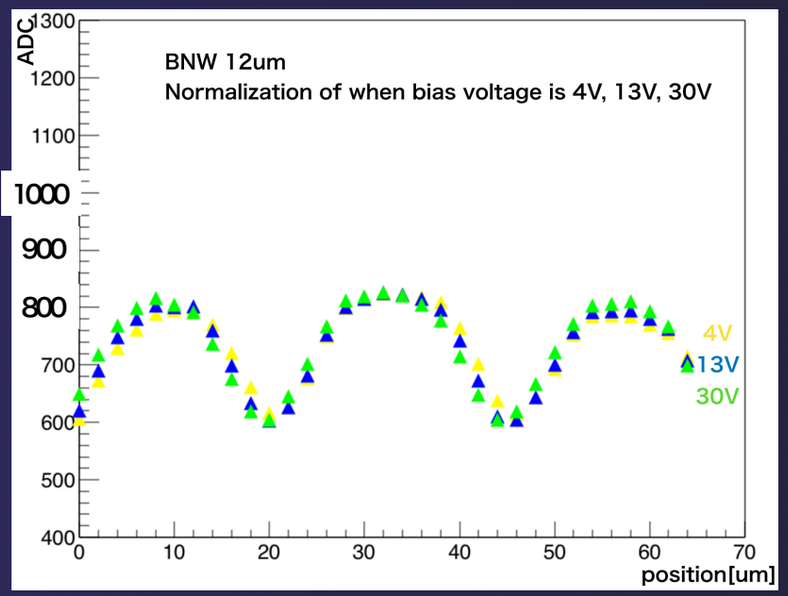
Laser position scan

Normalized Charge loss edge dependence

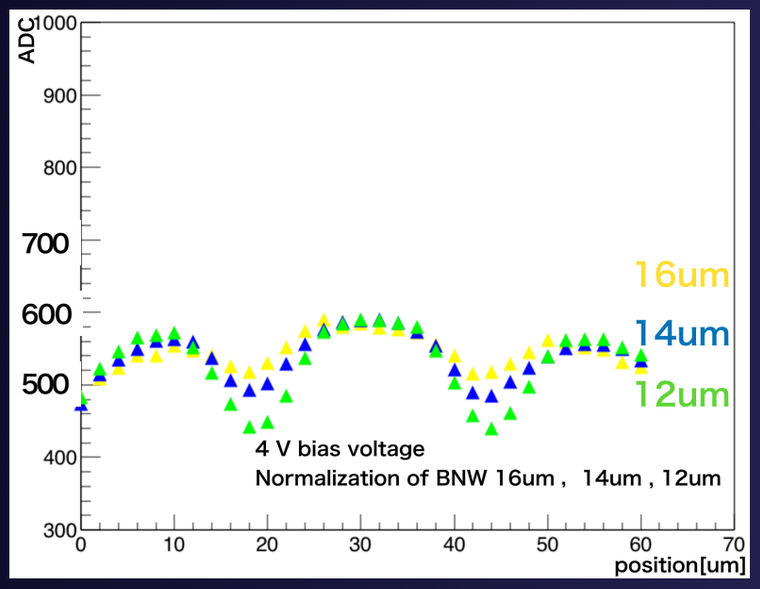
Conclusion : Charge loss is independent of depletion length

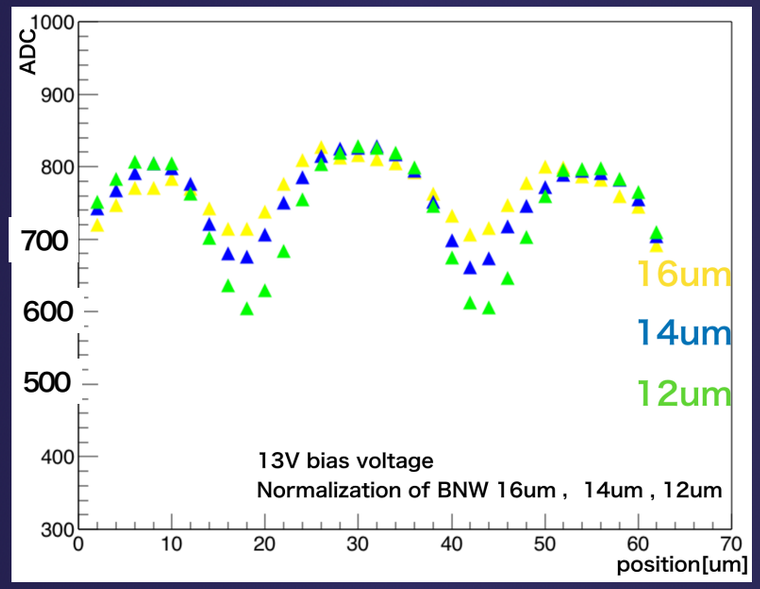


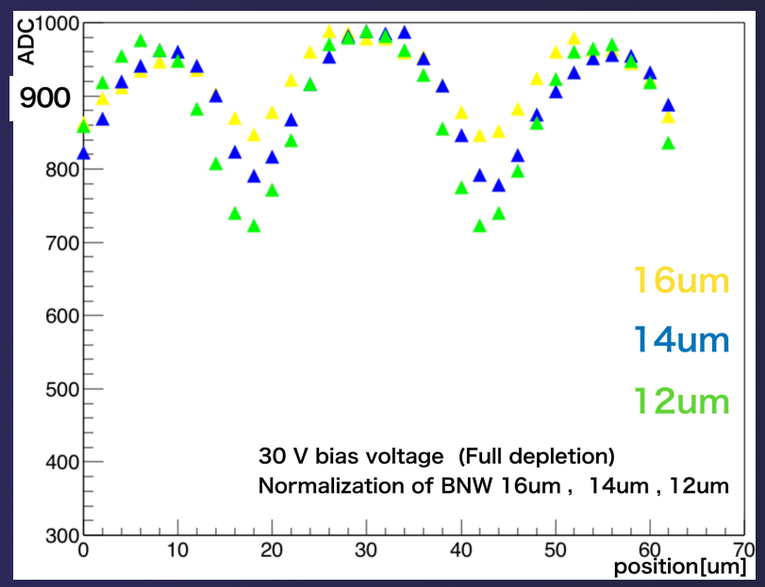




Conclusion : Charge loss is dependent of BNW size



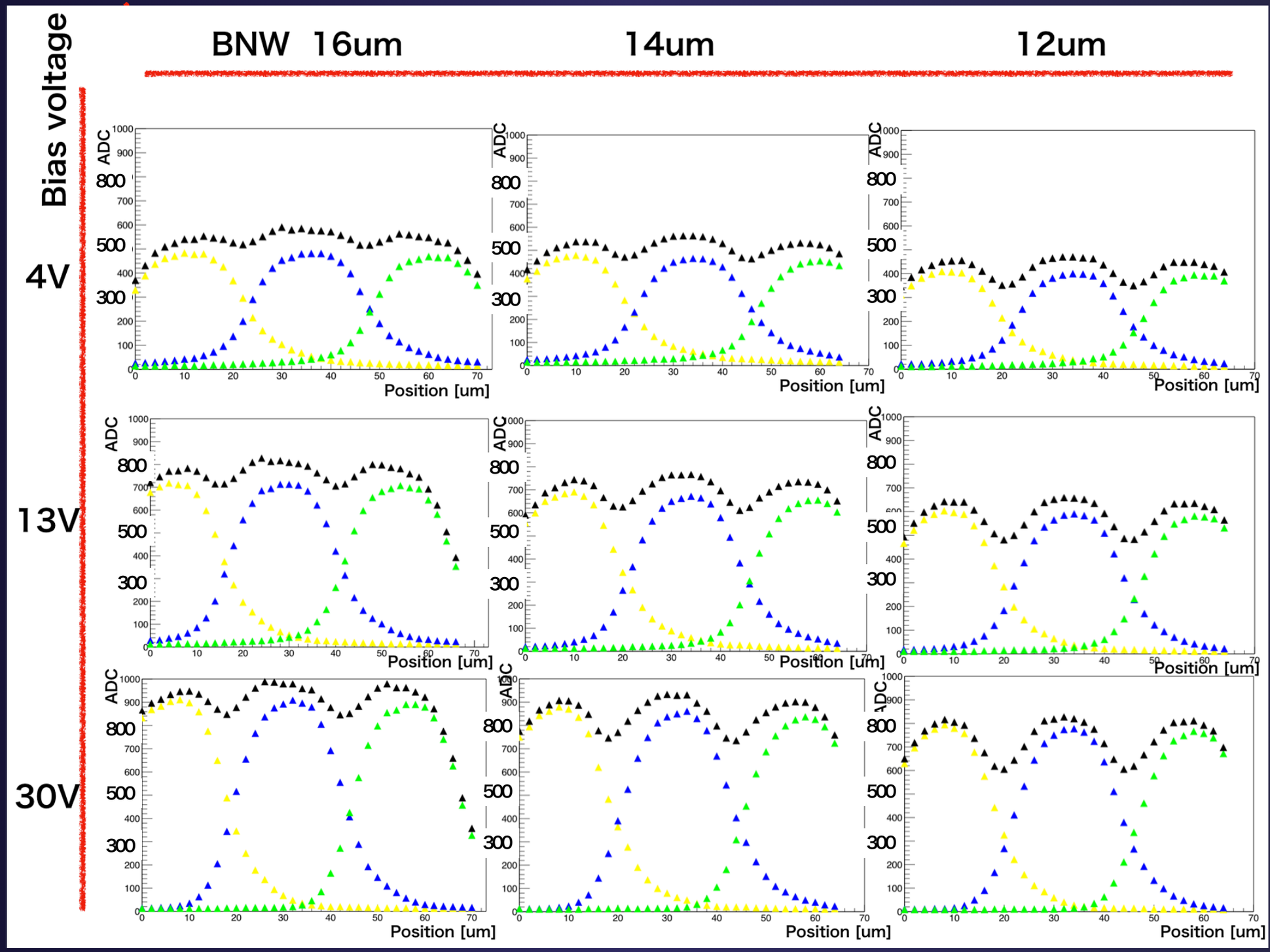




Laser position scan

These graph shows the result of the laser position scan in different BNW sizes and Bias voltage.

This blue curve shows charge share?



Laser position scan

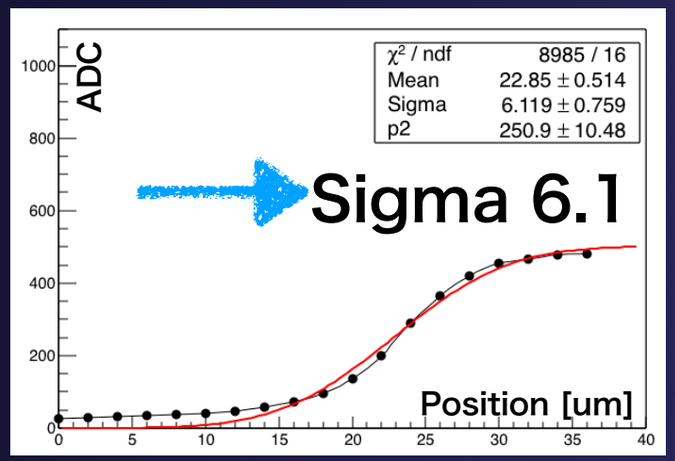
error function fitting | Charge share in different BNW and depletion length

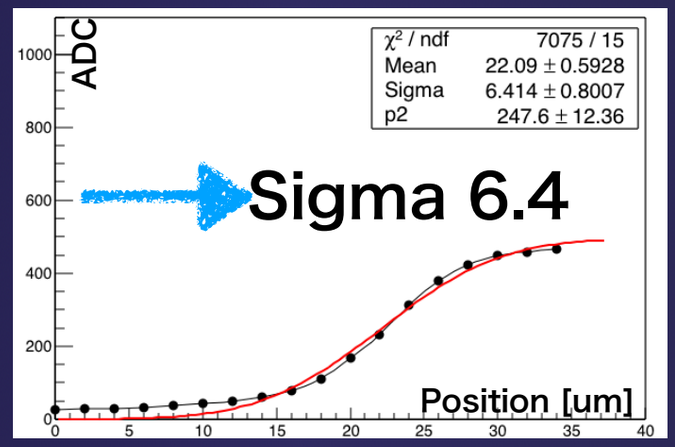
Conclusion : charge share is independent of depletion length

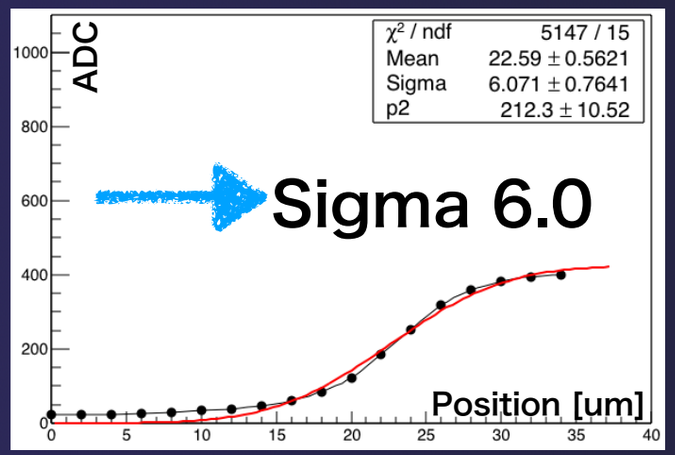
Bias voltage

BNW 16um 14um 12um

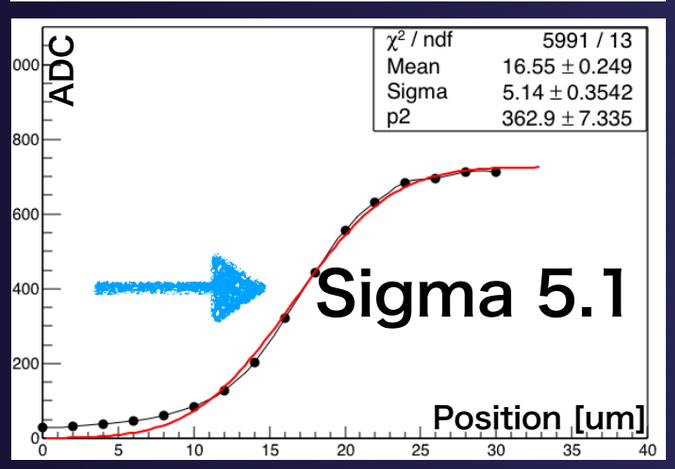
4V

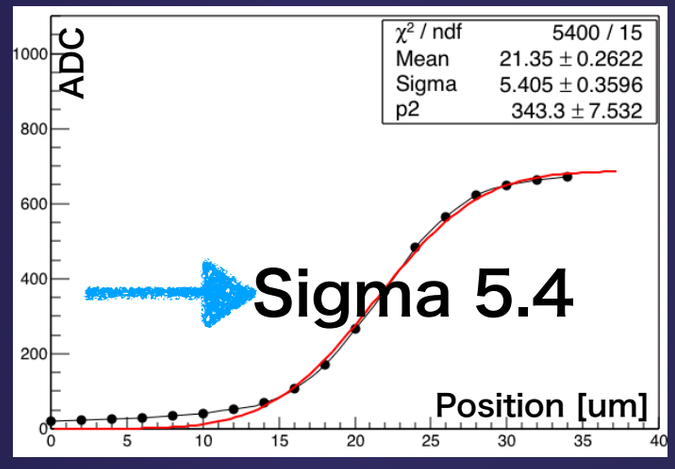


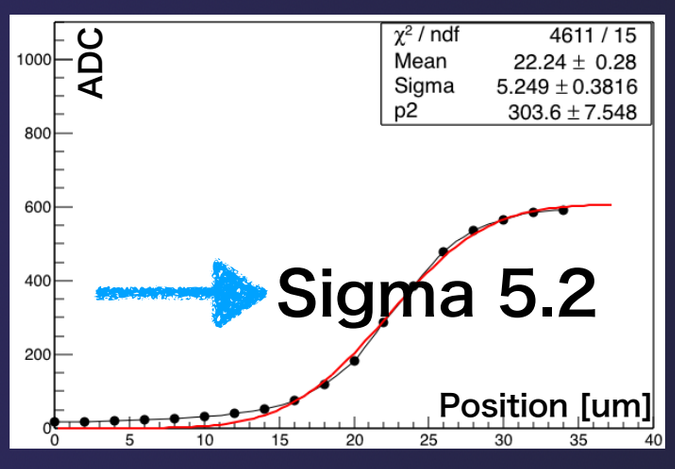




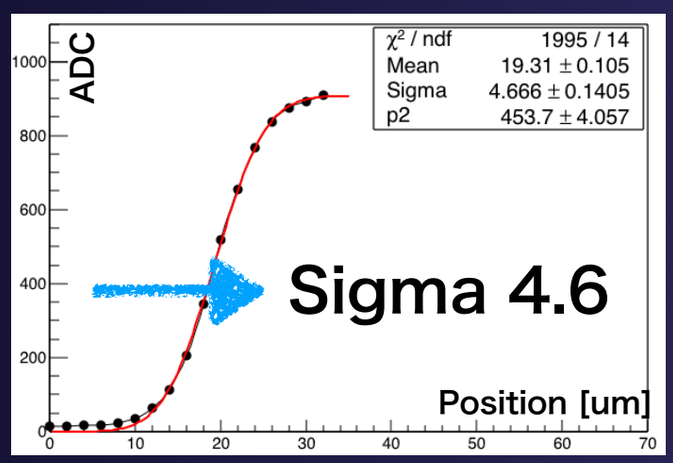
13V

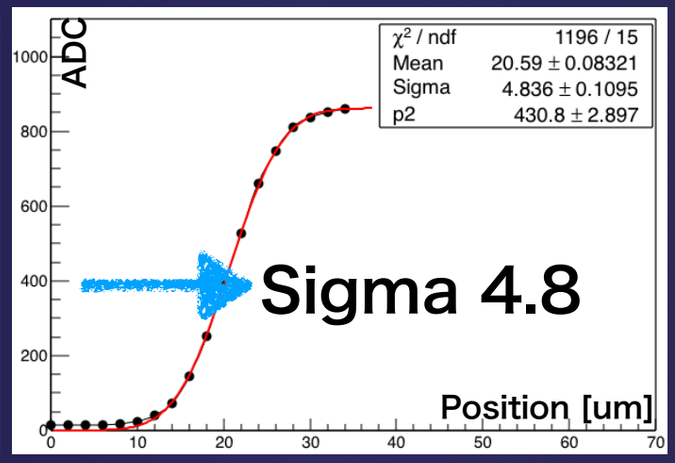


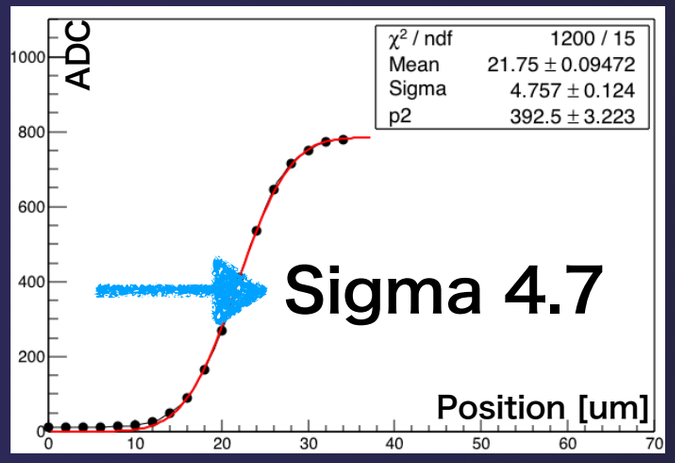




30V



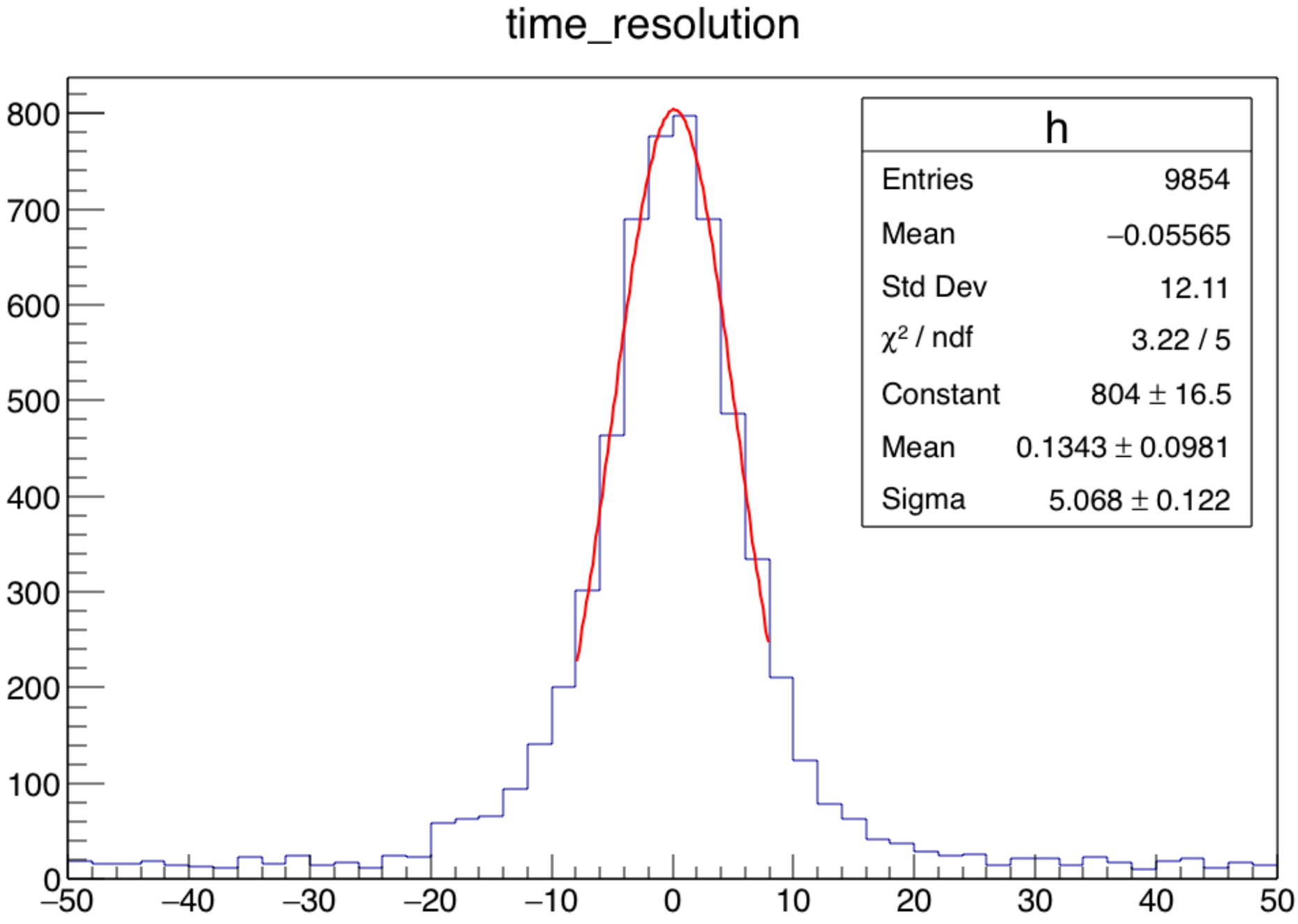




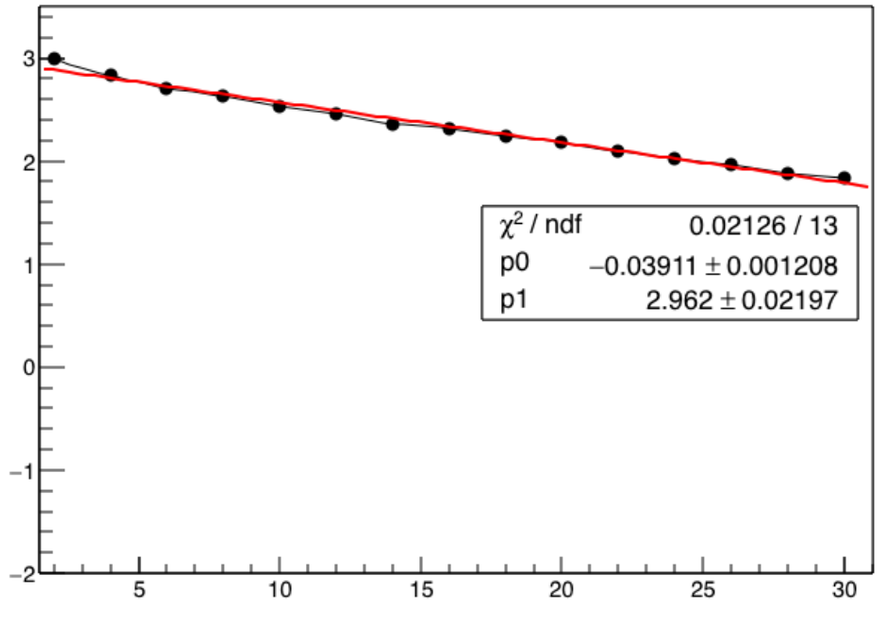
Summary

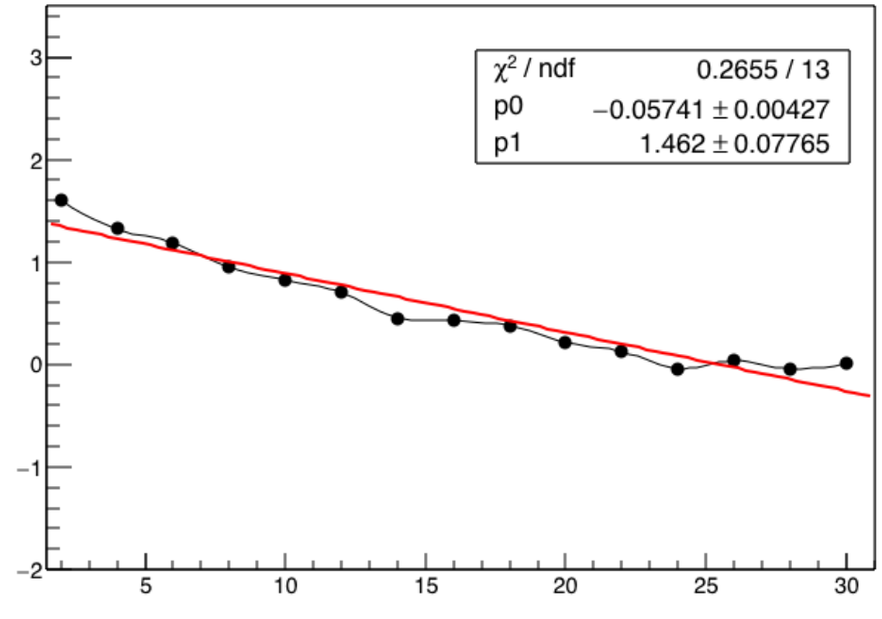
SOFIST ver.2 is a pixel sensor for ILC.
It has a fine time resolution (730 ns) and position resolution.
I evaluated SOI structure and time measurement of SOFIST ver.2

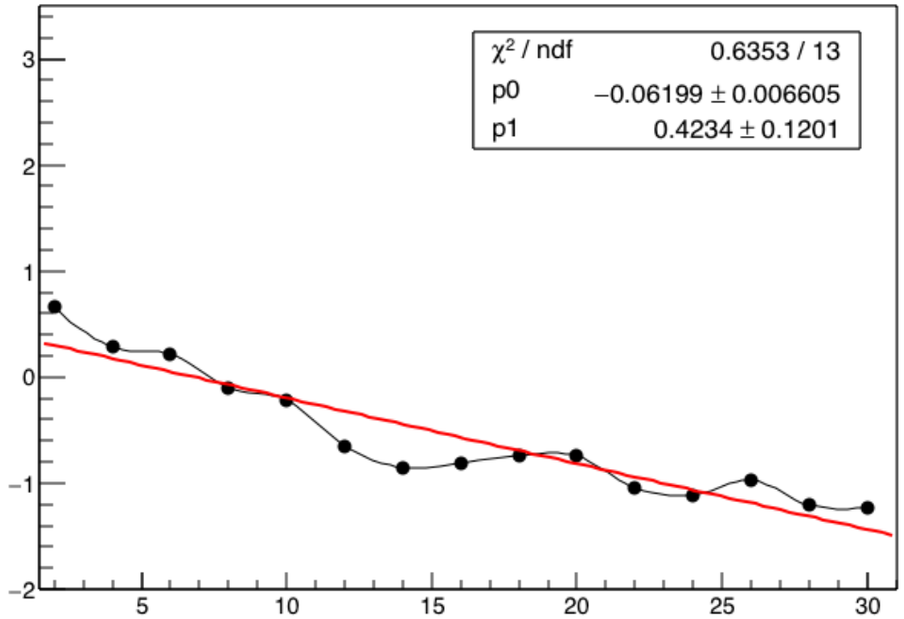
Back up

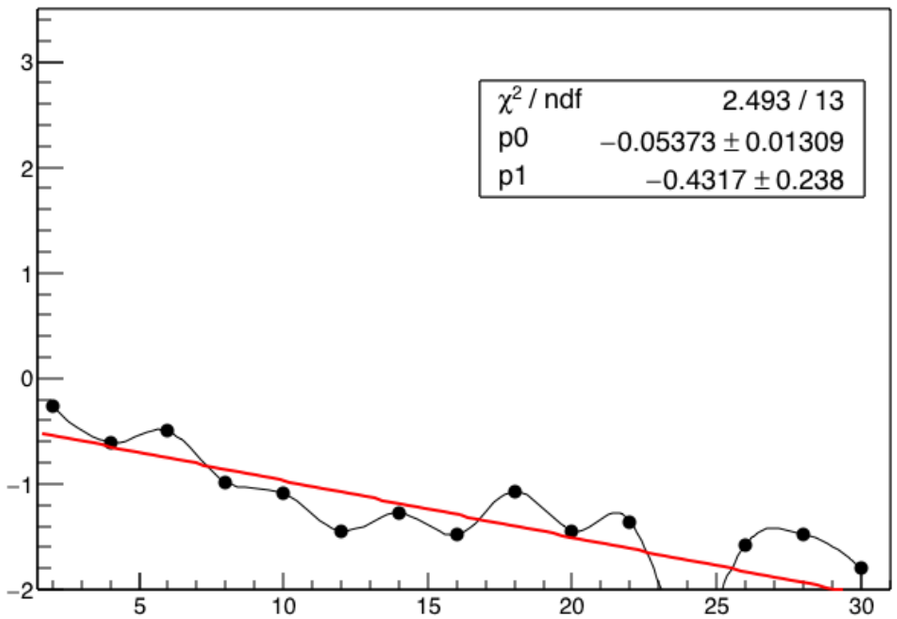


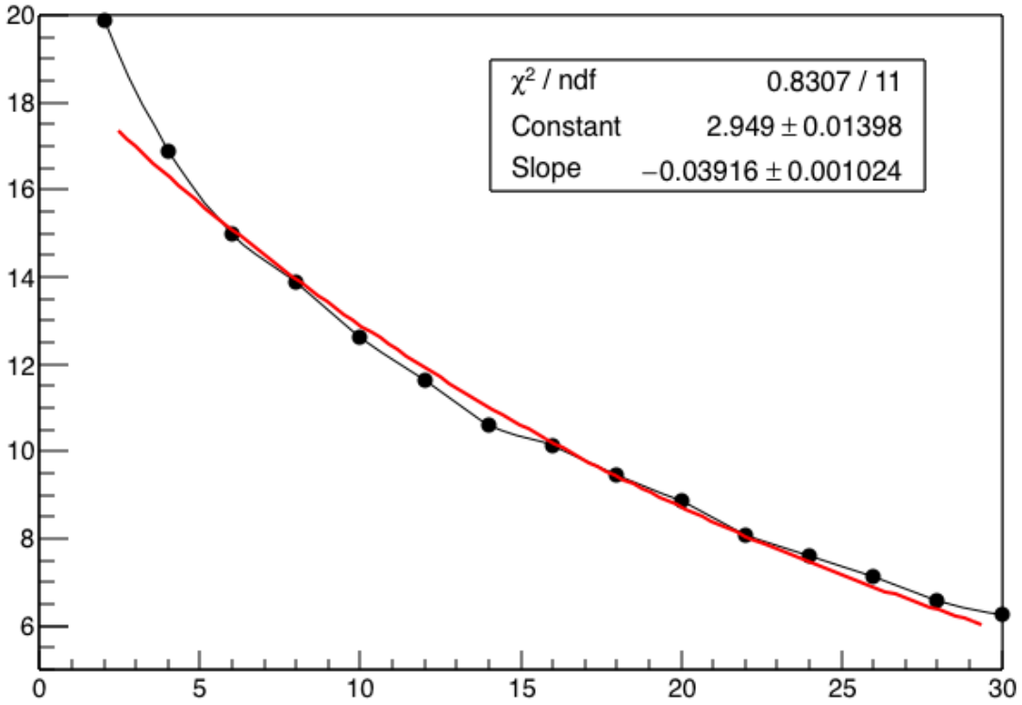
Time resolution 3.58 us

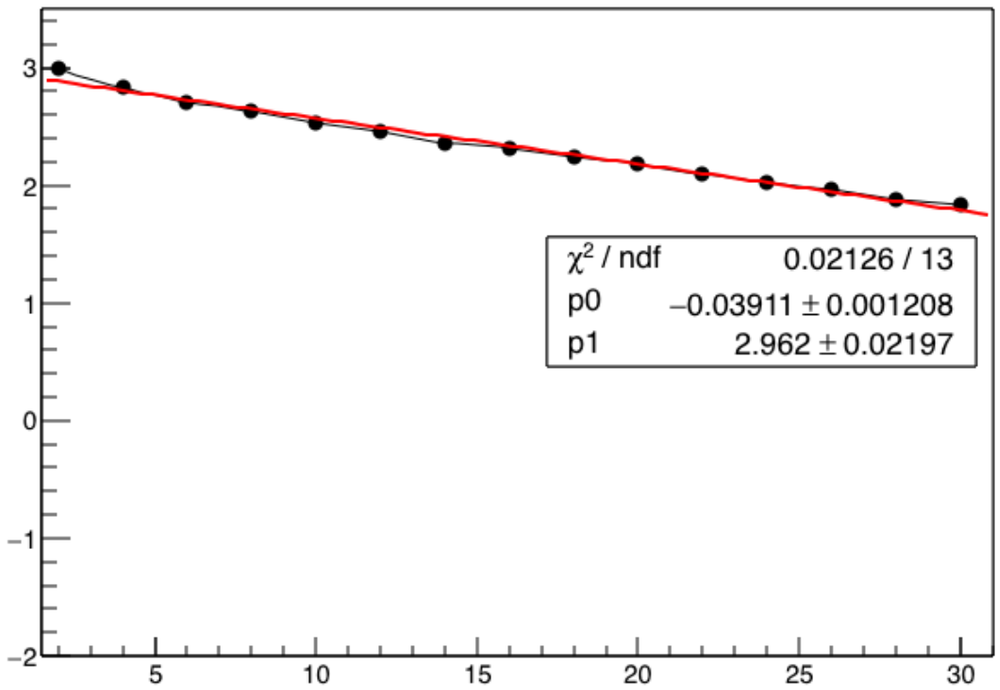

χ² / ndf 0.02126 / 13
p0 −0.03911 ± 0.001208
p1 2.962 ± 0.02197

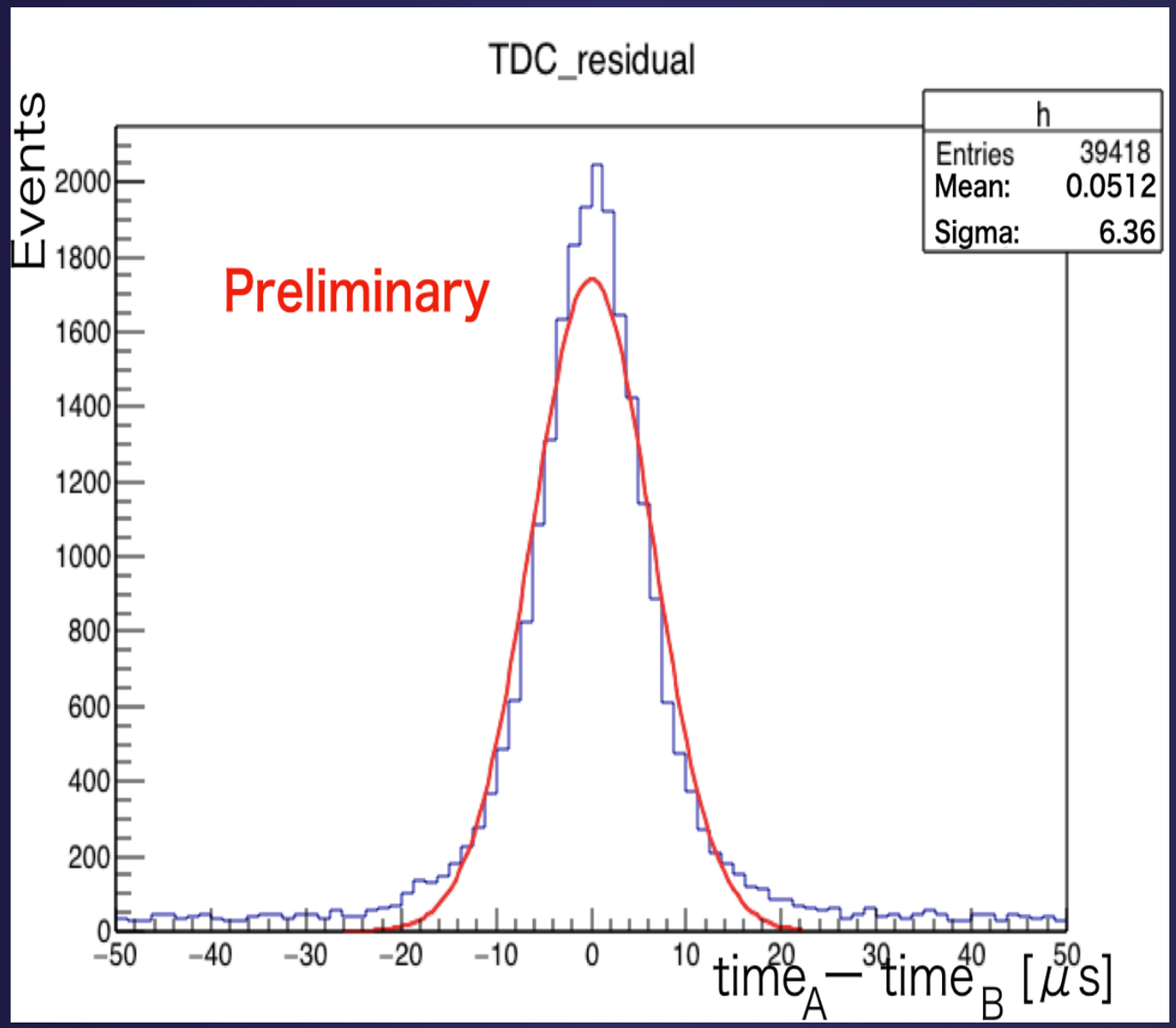

χ² / ndf 0.2655 / 13
p0 −0.05741 ± 0.00427
p1 1.462 ± 0.07765

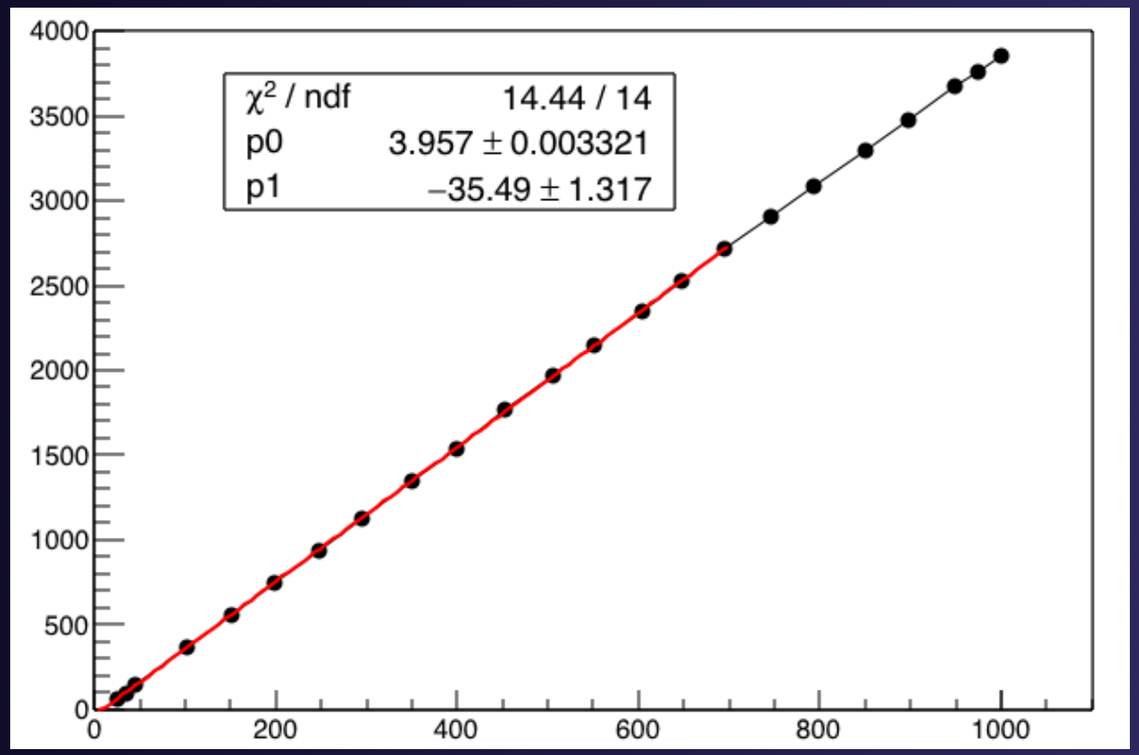

χ² / ndf 0.6353 / 13
p0 −0.06199 ± 0.006605
p1 0.4234 ± 0.1201

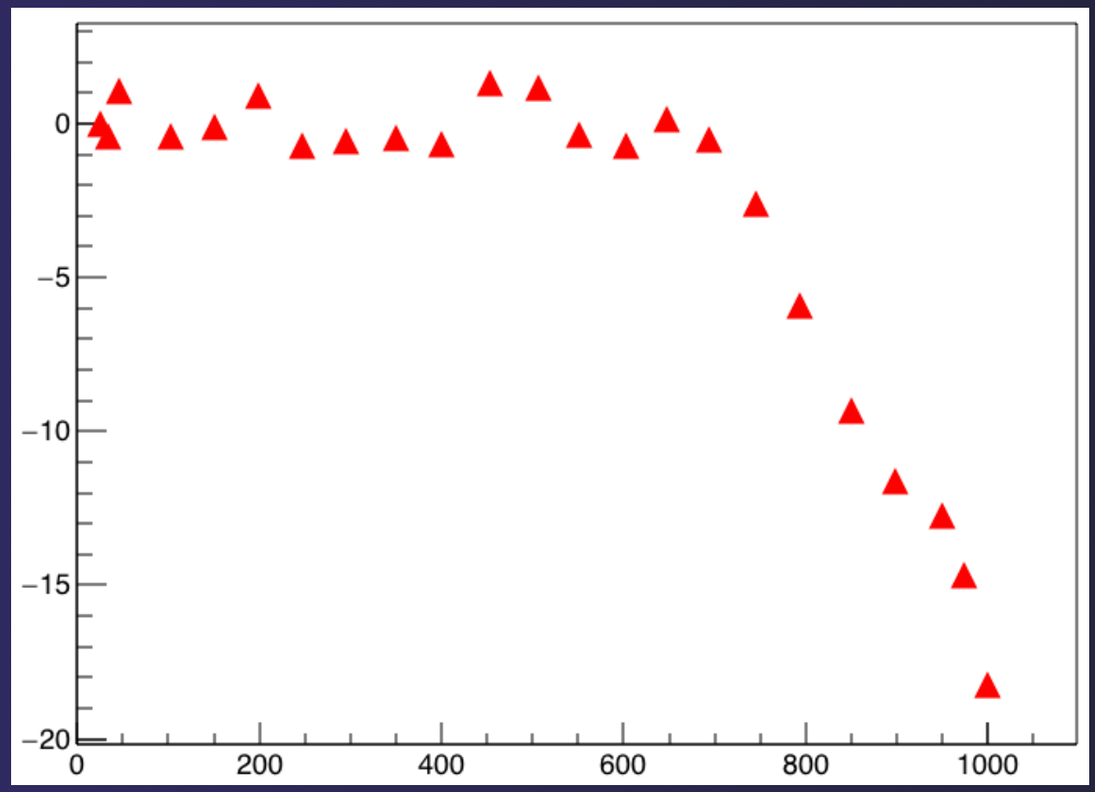

χ² / ndf 2.493 / 13
p0 −0.05373 ± 0.01309
p1 −0.4317 ± 0.238


χ² / ndf 0.8307 / 11
Constant 2.949 ± 0.01398
Slope −0.03916 ± 0.001024


χ² / ndf 0.02126 / 13
p0 −0.03911 ± 0.001208
p1 2.962 ± 0.02197


TDC_residual
h
Entries 39418
Mean: 0.0512
Sigma: 6.36
Preliminary
Events
2000
1800
1600
1400
1200
1000
800
600
400
200
0
−50
−40
−30
−20
−10
0
10
20
30
40
50
time_A − time_B [μs]


χ^2 / ndf 14.44 / 14
p0 3.957 ± 0.003321
p1 −35.49 ± 1.317
4000
3500
3000
2500
2000
1500
1000
500
0
0
200
400
600
800
1000


0
−5
−10
−15
−20
0
200
400
600
800
1000