SiWECAL APD/PSD: Results from the test beam

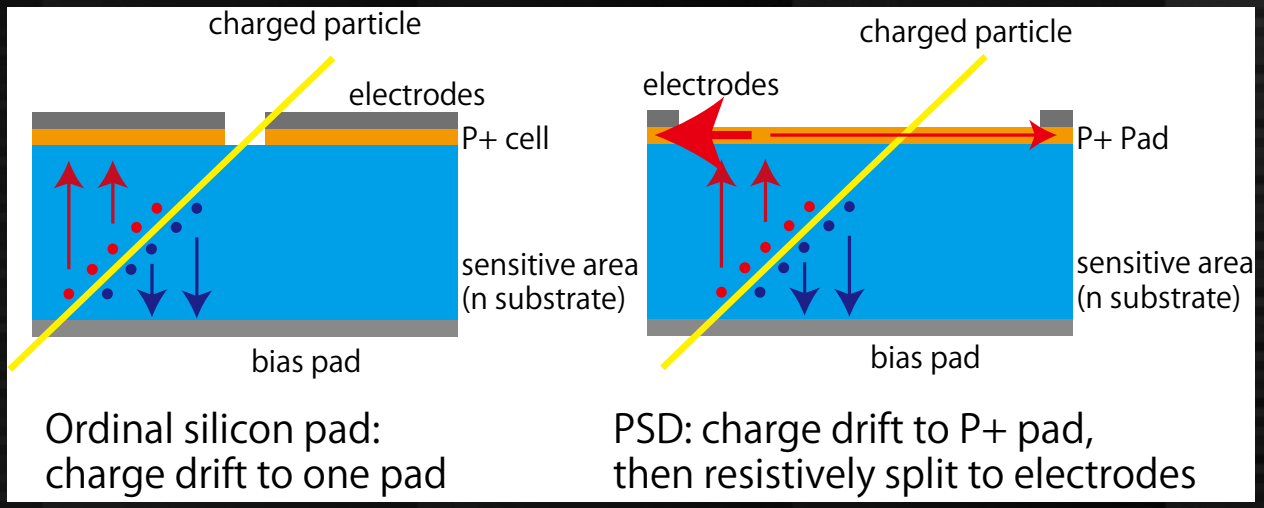
T. Suehara, Y. Deguchi, Y. Uesugi
(Kyushu University)

Sorry for not possible to attend the workshop in person…

Contents

- PSD
  - Test with ^{90}Sr source
  - Test beam (just comments)
- LGAD/APD
  - Test beam
    - Including first result on timing resolution

PSD: principles

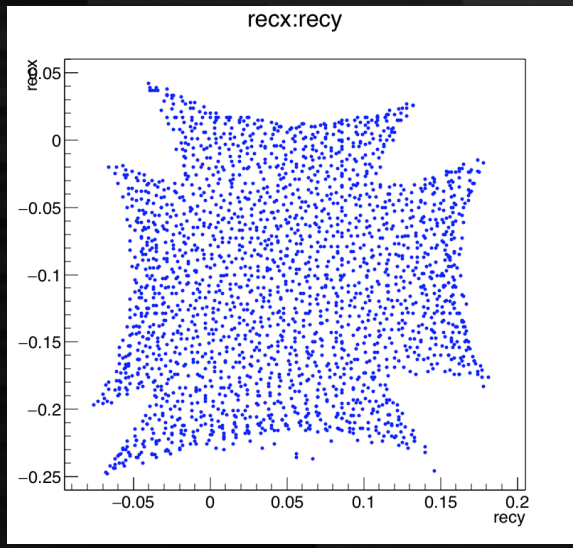


Ordinal silicon pad:
charge drift to one pad

PSD: charge drift to P+ pad,
then resistively split to electrodes

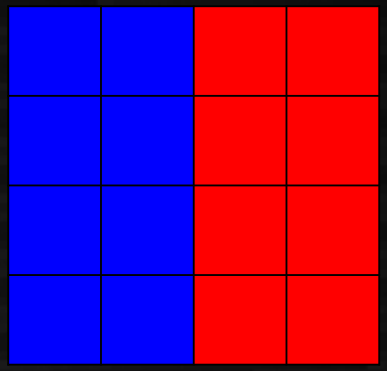
Meshed p+

- Multiple electrodes in one cell to obtain hit position by charge sharing
- Surface resistivity is a key for the dynamic range of ratio at 4 pads
- S/N ratio determines position resolution
  → thicker sensor preferred

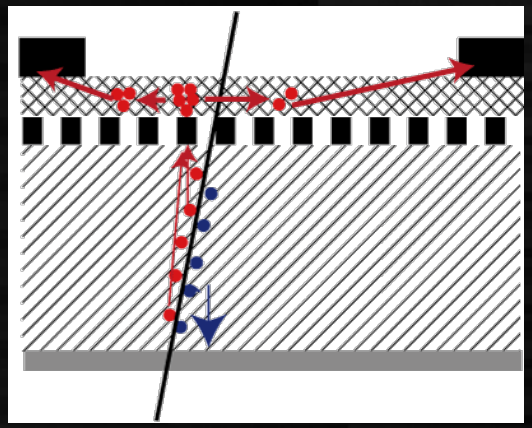


Position distortion

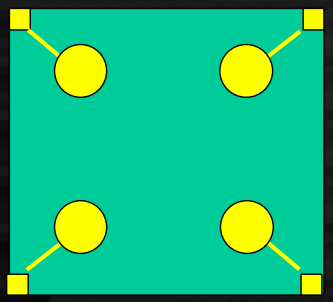
Sensor configuration



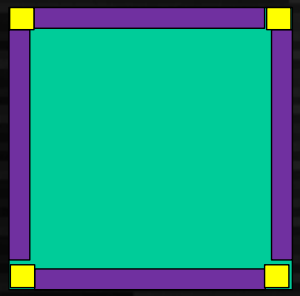
4 x 4 cells
two surface R
(meshed P+,
additional R layer)



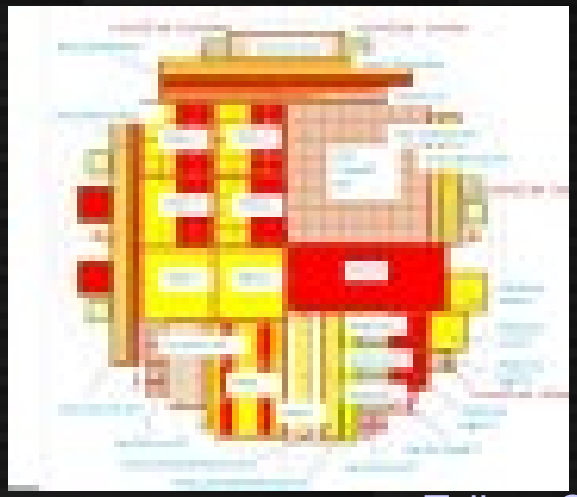
Resistive layer
for higher resistance
to enhance the ratio
of the charge



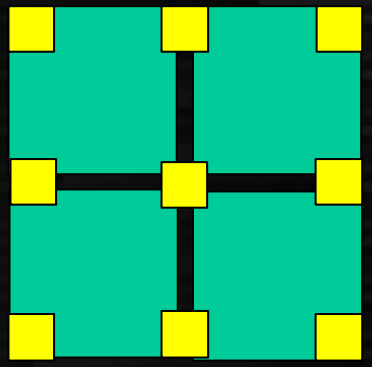
Electrodes not
at the corner to
check the response
at the corner
by laser injection



For
smaller
position
distortion

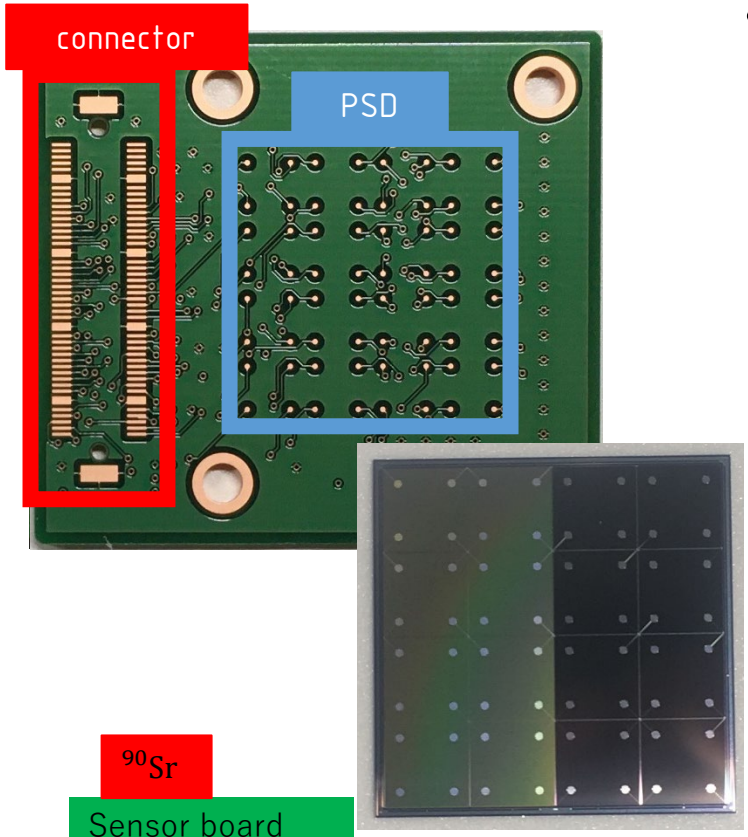


Productions with
various ideas
implemented at
production
in March 2018

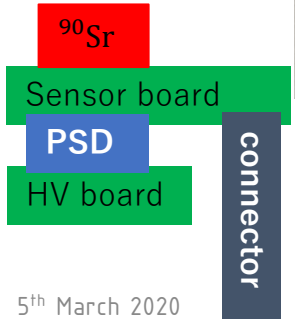


Connected
electrodes

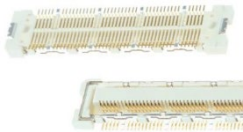
Setup with ^{90}Sr source

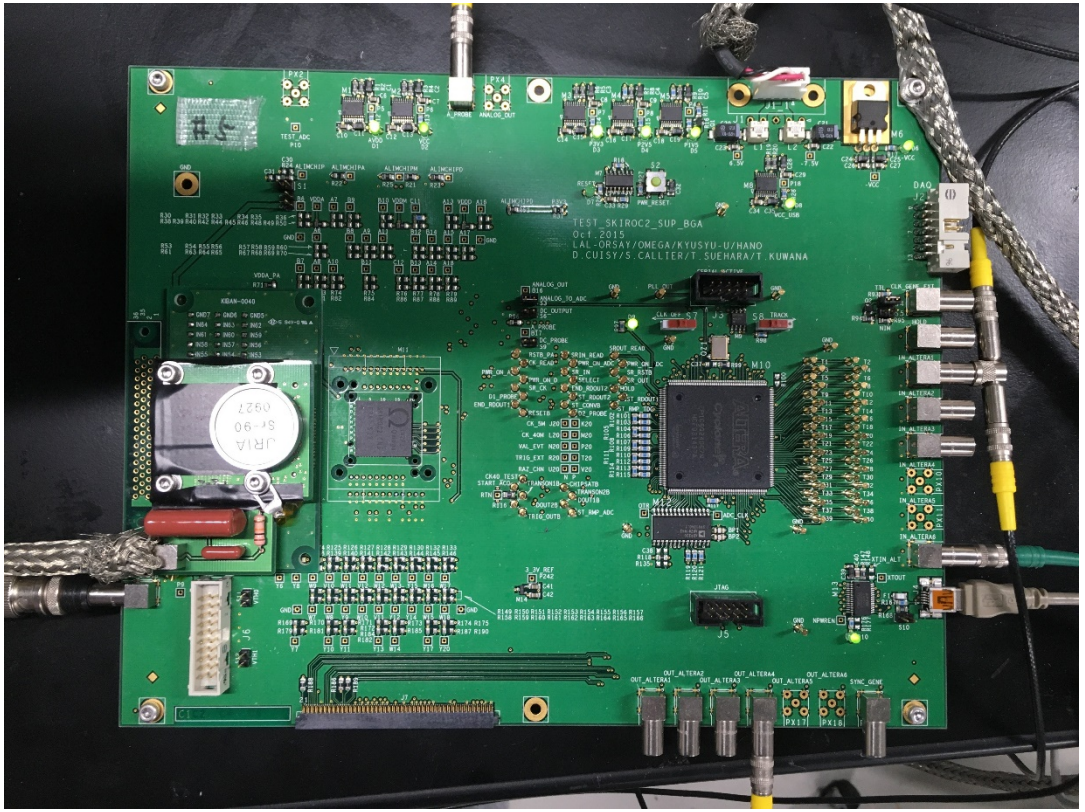


Picture of a PSD



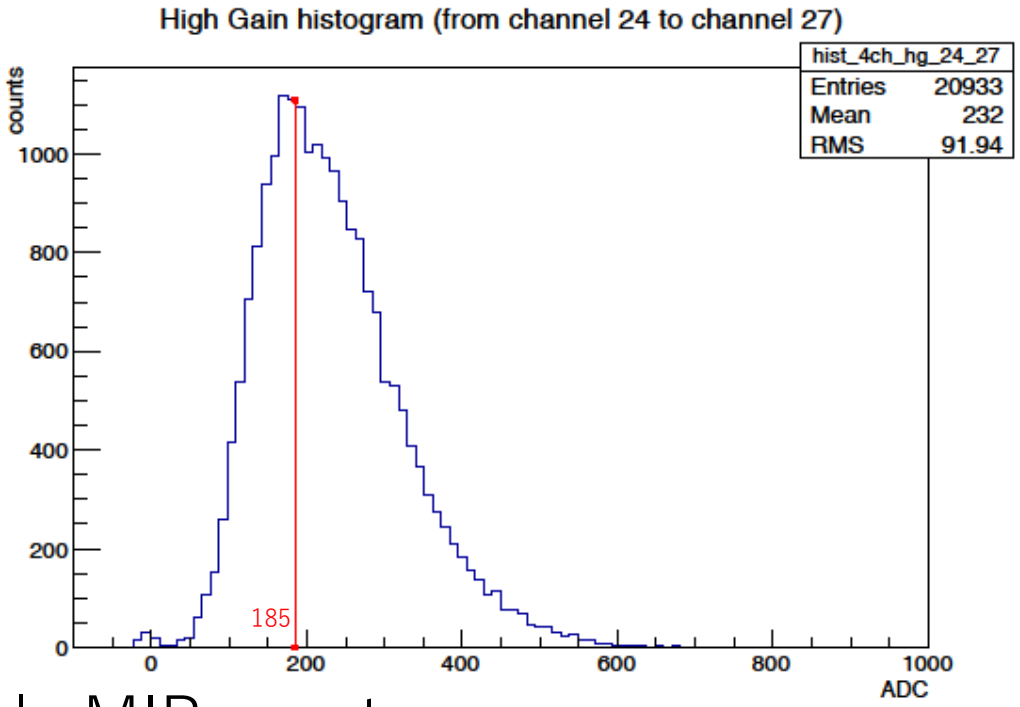
- Sensor board with PSD with 72pin connector to connect all 64 channels





MIP spectrum

- Summing up 4 channels in the same cell
- MIP with 650 μm Si corresponds to 185 ADC count



- Reasonable MIP spectrum seen
- Pedestal width corresponds to 3% of MIP

Reconstruction of the position

- Position reconstruction formula

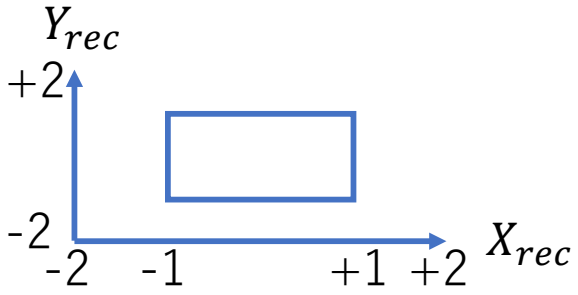
$$X_{rec} = \frac{-ch0 - ch1 + ch2 + ch3}{ch0 + ch1 + ch2 + ch3}$$

$$Y_{rec} = \frac{-ch0 + ch1 - ch2 + ch3}{ch0 + ch1 + ch2 + ch3}$$

- Range in the ideal case

$$(-1 < X_{rec} < 1)$$

$$(-1 < Y_{rec} < 1)$$

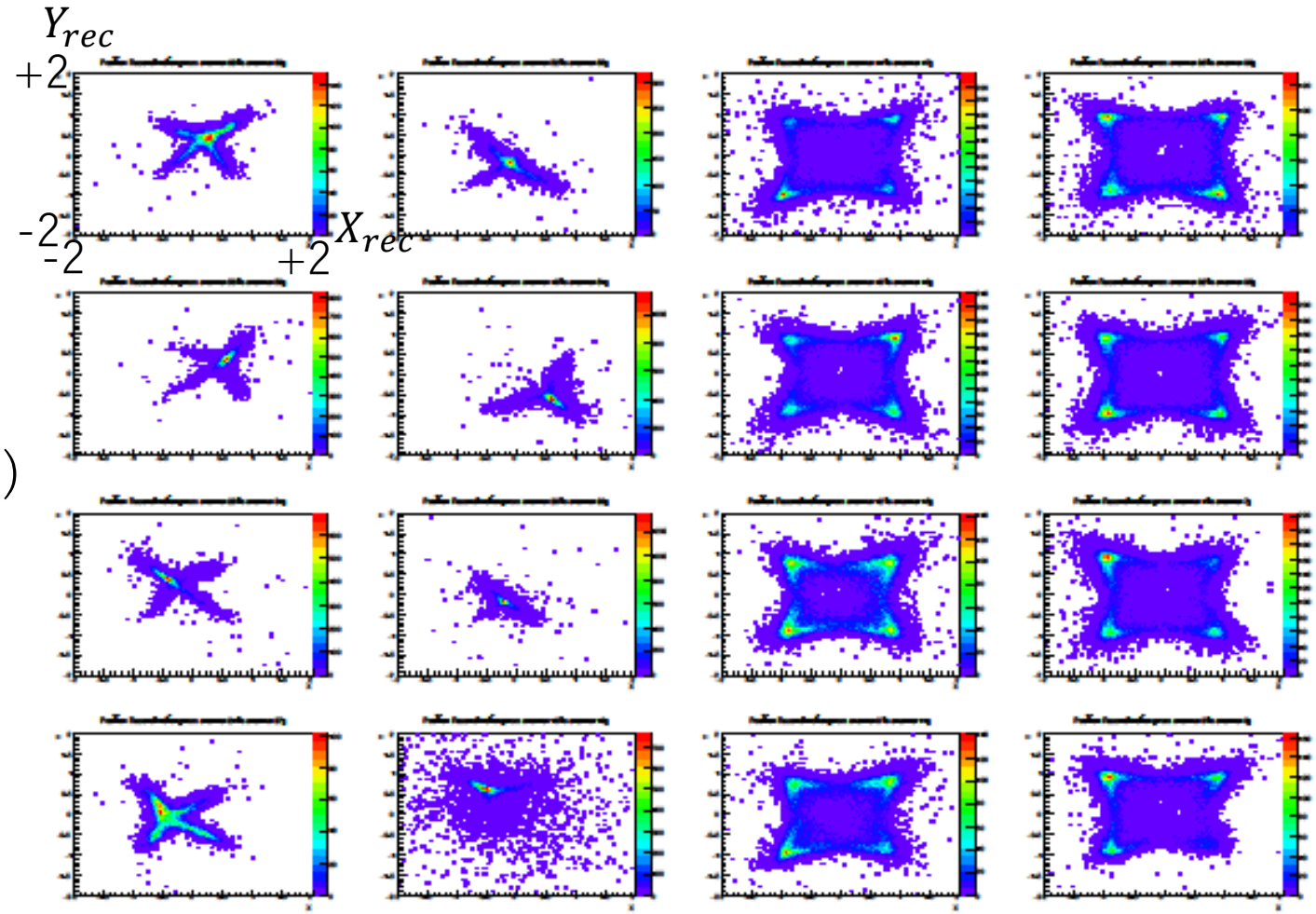


Low R (1x)				high R (20x)			
61	63	53	55	45	47	37	39
60	62	52	54	44	46	36	38
57	59	49	51	41	43	33	35
56	58	48	50	40	42	32	34
29	31	21	23	13	15	5	7
28	30	20	22	12	14	4	6
25	27	17	19	9	11	1	3
24	26	16	18	8	10	0	2

Position of each channel

Reconstructed position with ^{90}Sr

- PSD1-2-3
- 12 mm from ^{90}Sr
- Left half low R (1x)
- Right half high R (20x) good range of -1 to 1 seen



Summary for PSD

- Reconstructed position with ^{90}Sr calculated
- Good dynamic range seen with high R (20x, also 10x)
- Strange peak at (x, y) = (± 1, ± 1)
  - Probably due to trigger threshold set at ~0.5 MIP
    (at center position the efficiency should be low as 10-20%
    since all 4 channels only have ¼ of total signal)
  - To be confirmed with laser injection
- At test beam: need to reduce noise
  - Unfortunate event: SKIROC2A testboard broken just before TB
  - We used SKIROC2CMS instead: cannot do precise threshold tuning
  - Noise much higher at TB → threshold as high as 0.5 MIP
- Will be improved with next round of test beam

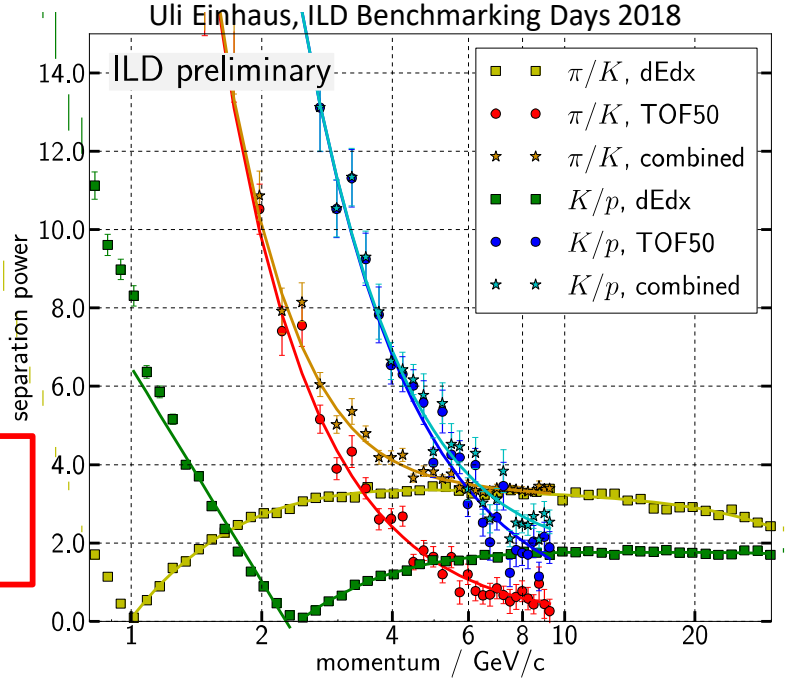
Particle ID with ToF

- Time of Flight (ToF)

Particle	Mass	$\beta = \frac{v}{c}$ (5 GeV)
π	139 MeV/c^2	0.9996
K	494 MeV/c^2	0.9951
p	938 MeV/c^2	0.9829

50 ps or less is desired for K/π separation up to 5 GeV

"Particle ID Performance with dE/dx and TOF"
Uli Einhaus, ILD Benchmarking Days 2018



- Identification power with timing only (by simple calculation)

Particles	Time resolution	Momentum for 3σ separation
K / π	100 ps 50 ps	1.94 GeV/c 2.74 GeV/c
K / p	100 ps 50 ps	3.26 GeV/c 4.60 GeV/c

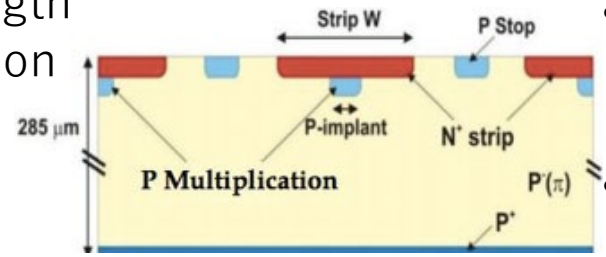
Low Gain Avalanche Diode

➢ LGAD (Low Gain Avalanche Diode)

✓ Reach-through (RS) type

Amplification just below the electrodes

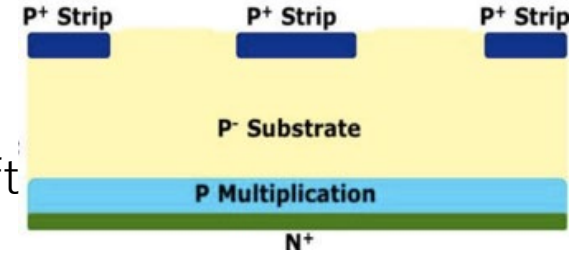
- Shorter drift length after amplification
- Non-uniformity



✓ Inverse type

Amplification at the bottom

- Better uniformity expected
- Longer drift length



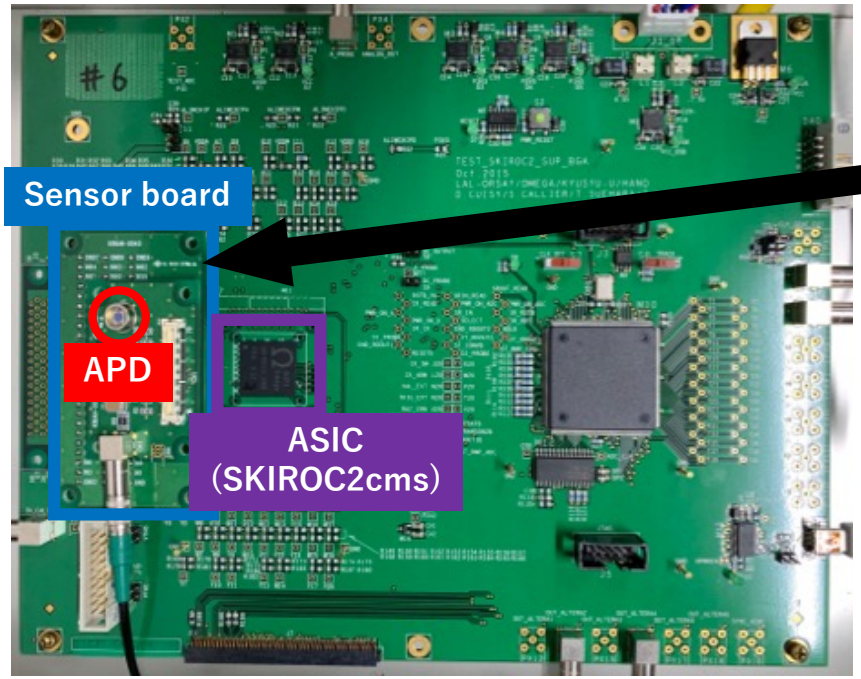
➢ APD (Avalanche Photo Diode)

Photosensor with same structure → test with radiation as LGAD prototype

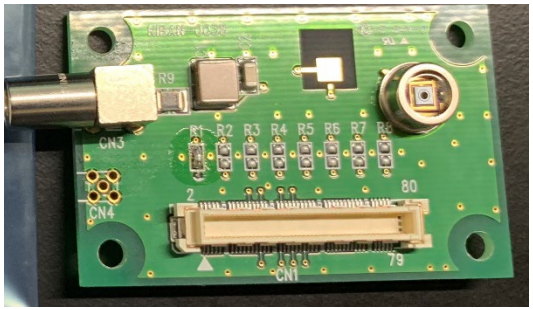
APDs in Kyushu University

APD No.	Type	BD V	Area	APD No.	Type	BD V	area
S12023-10A	RS	139 V	ϕ 1 mm	S2384	RS	159 V	ϕ 3 mm
S8664-10K	Inverse	417 V	ϕ 1 mm	S3884	RS	189 V	ϕ 1.5 mm
pkg-10	RS	~ 250 V	ϕ 1 mm	S8664-20K	Inverse	425 V	ϕ 2 mm
pkg-20	RS	~ 120 V	ϕ 1 mm	S8664-55	Inverse	433 V	5×5 mm^2

SKIROC2CMS testboard



Testboard#6 (SKIROC2CMS soldered)



Sensor board (S8664-10K soldered)

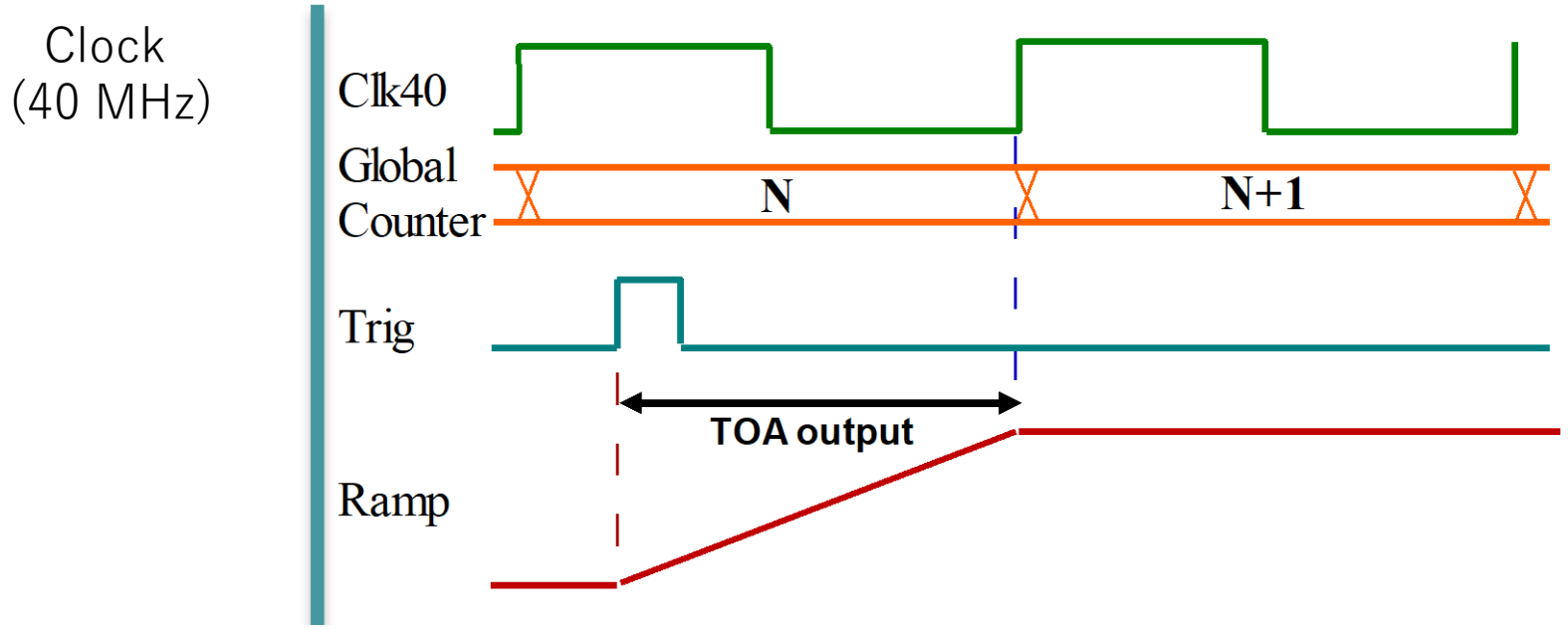
Stackable board with an ASIC channel selected by soldering R1-R8

- SKIROC2cms

  - TOA (+ TOT) with 40 MHz clock
  - Ring buffer of 13 memories
  - LG + HG ADC

TOA measurement

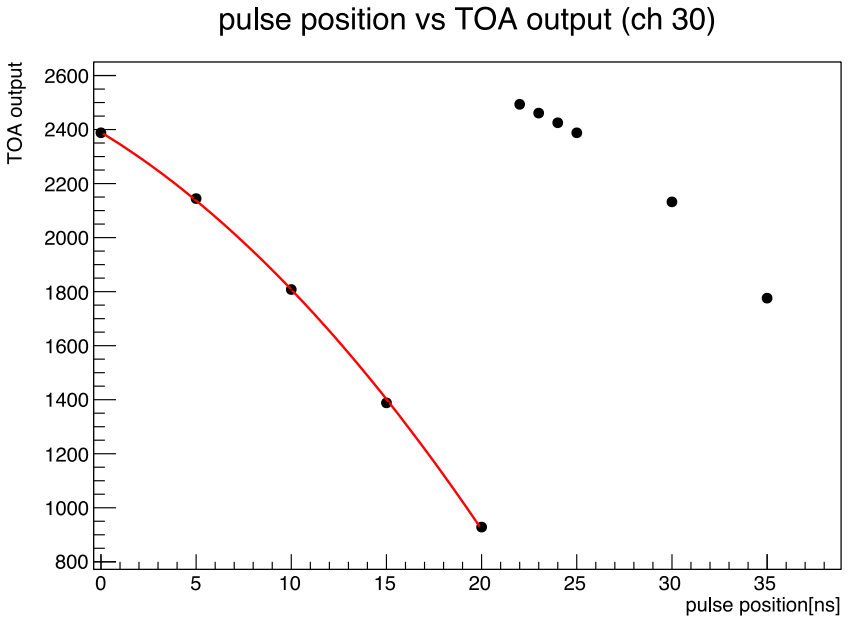
- Time Of Arrival (TOA) principle

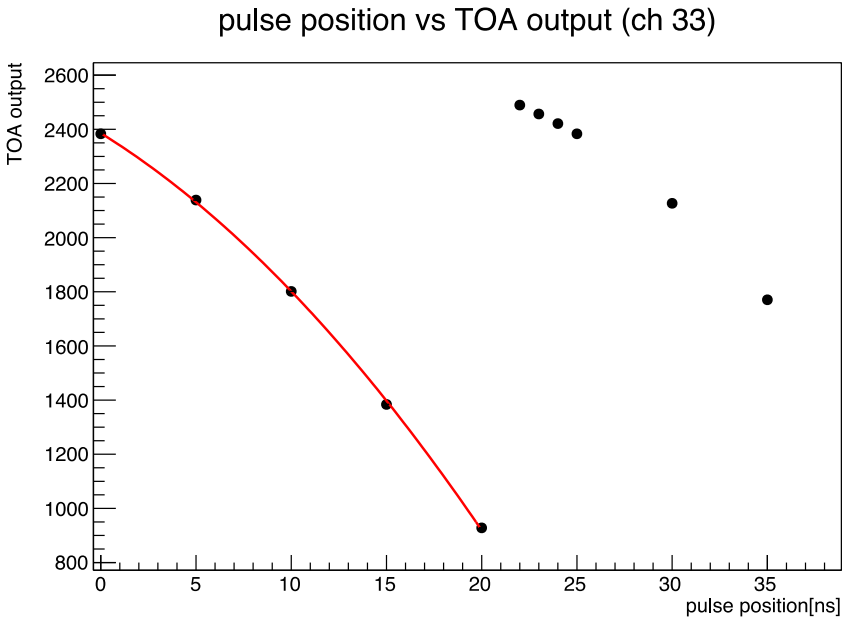


Ramp start at Trig and stop at the next rising-edge of the clock

Calibration of TOA - walltime

➢ TOA calibration

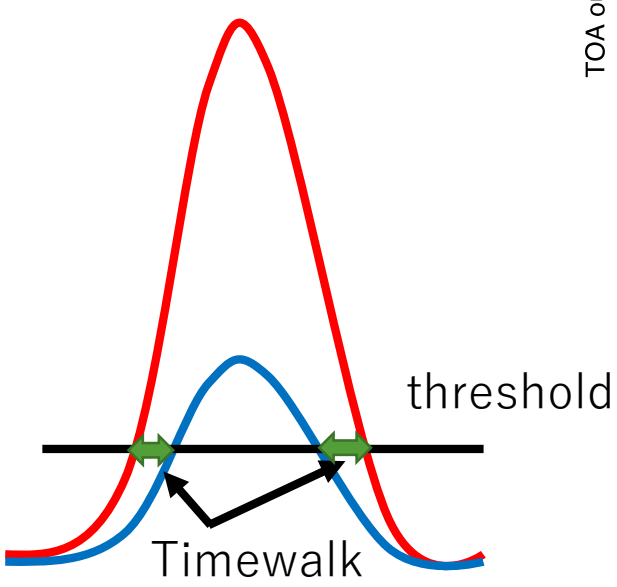




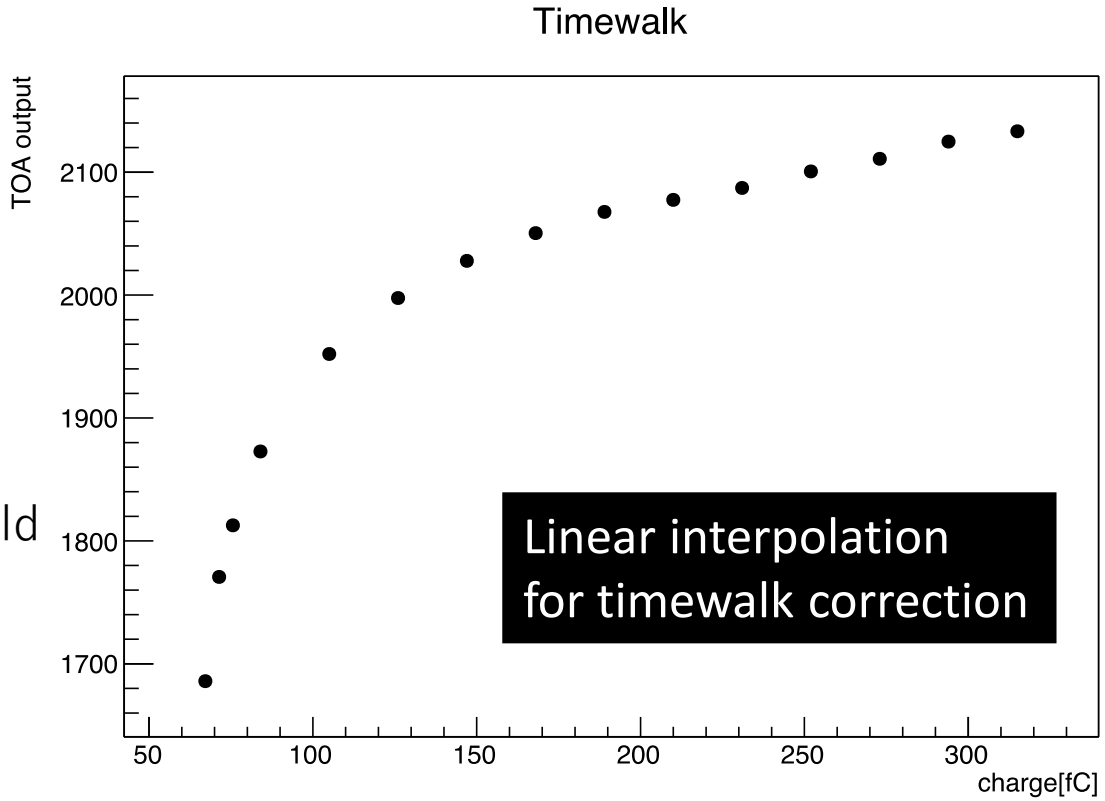
- External clock + injection with delayed clock
- 25 ns cycle ←→ 40 MHz clock
- Fitted by pol2 → used by TOA-time conversion

Timewalk

➢ Timewalk



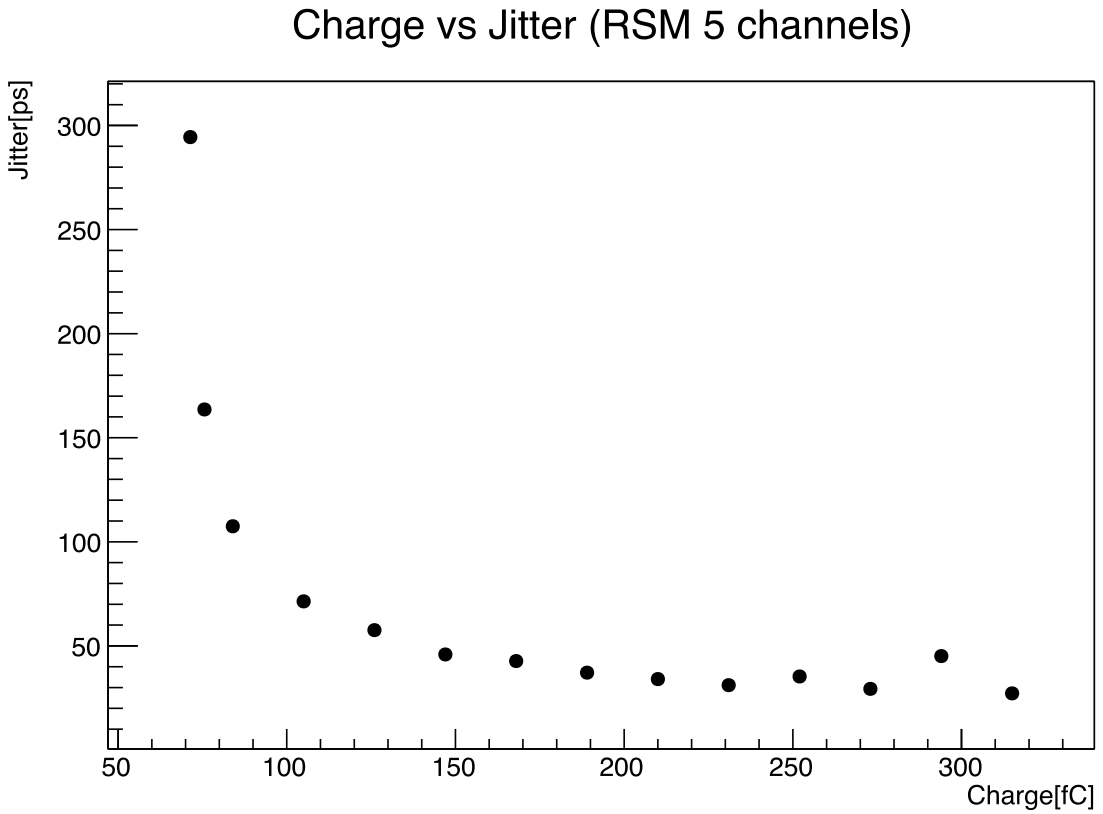
Timewalk



- Obtain TOA with various pulse height with injection
- Big timewalk below 100 fC (near the threshold)
- Correction with linear interpolation applied for following analysis

Jitter with injection (ASIC effect)

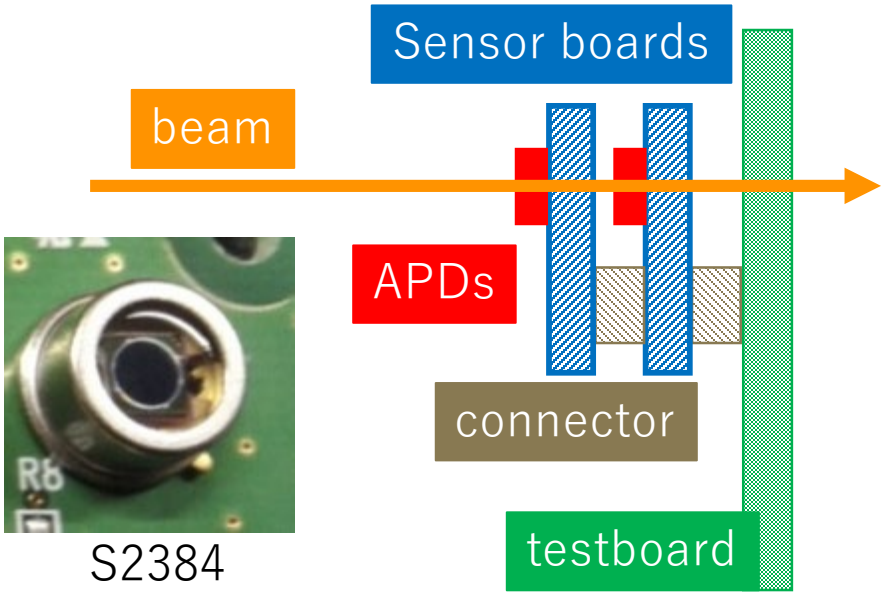
- TOA distribution with injection of various charge
- RMS of TOA distribution
- < 50 ps with > 100 fC
  (Minimum ~30 ps)



Beam test (18-22 Nov. 2019)

- Test Beam @ELPH(Tohoku)
  Positron, 500 MeV

Setup for timing resolution



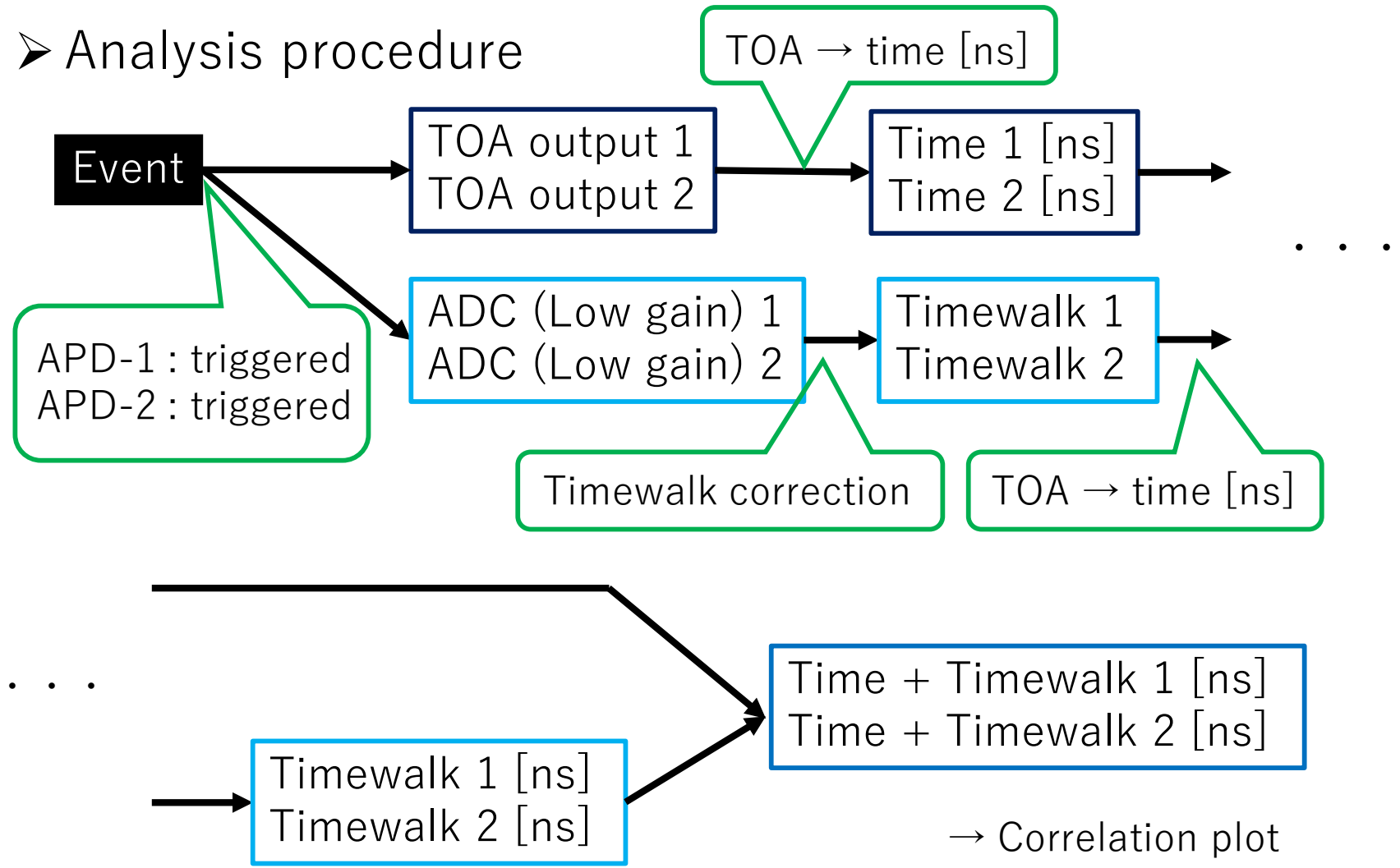
S2384

Coincidence of two APDs

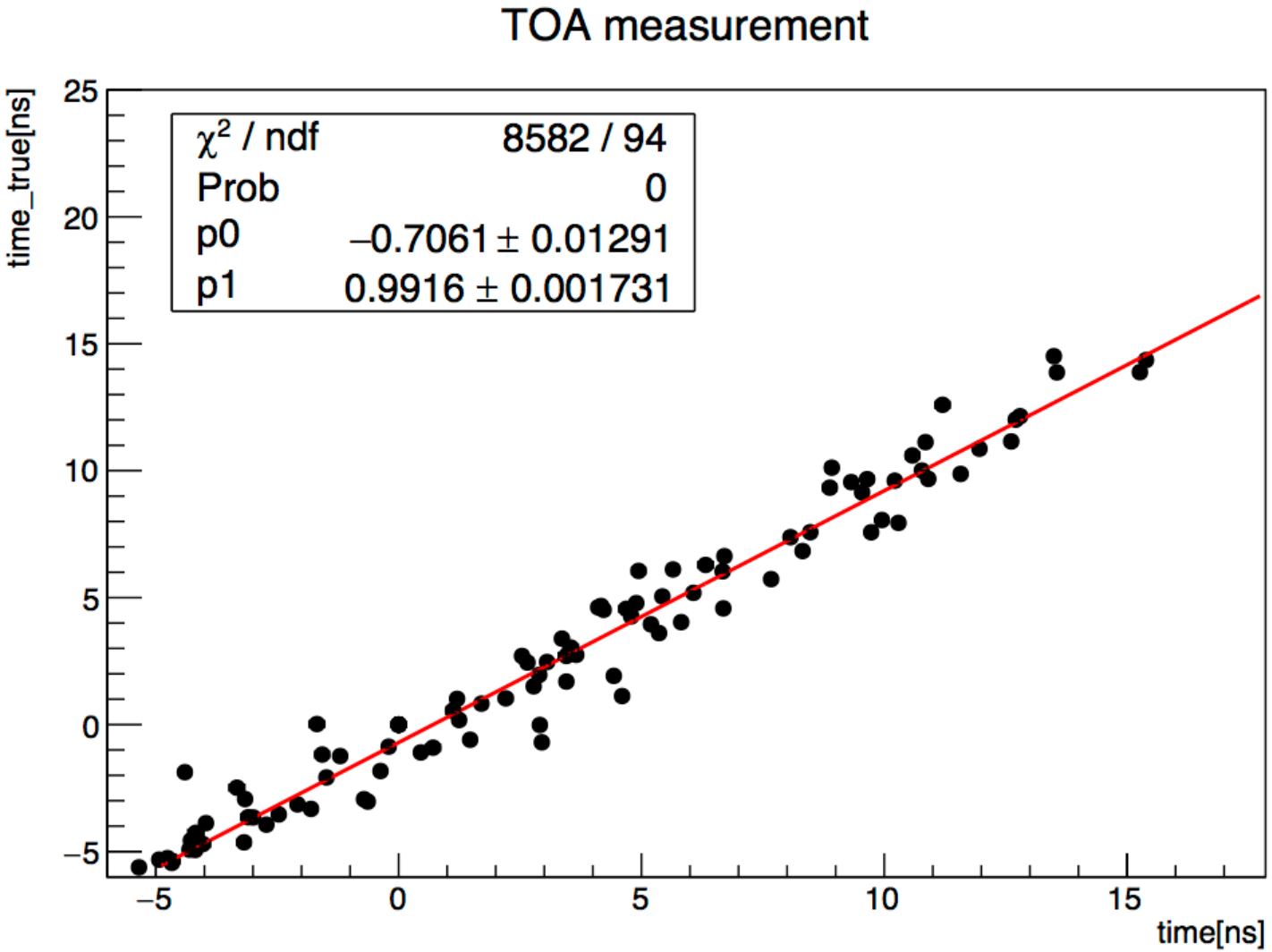
Timing resolution with correlation of 2 hits

TOA measurement

➢ Analysis procedure



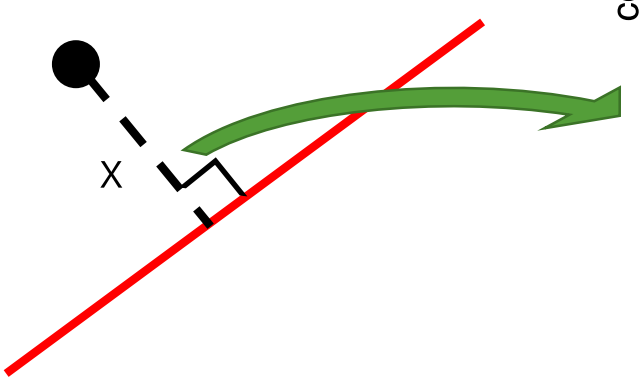
The preliminary result

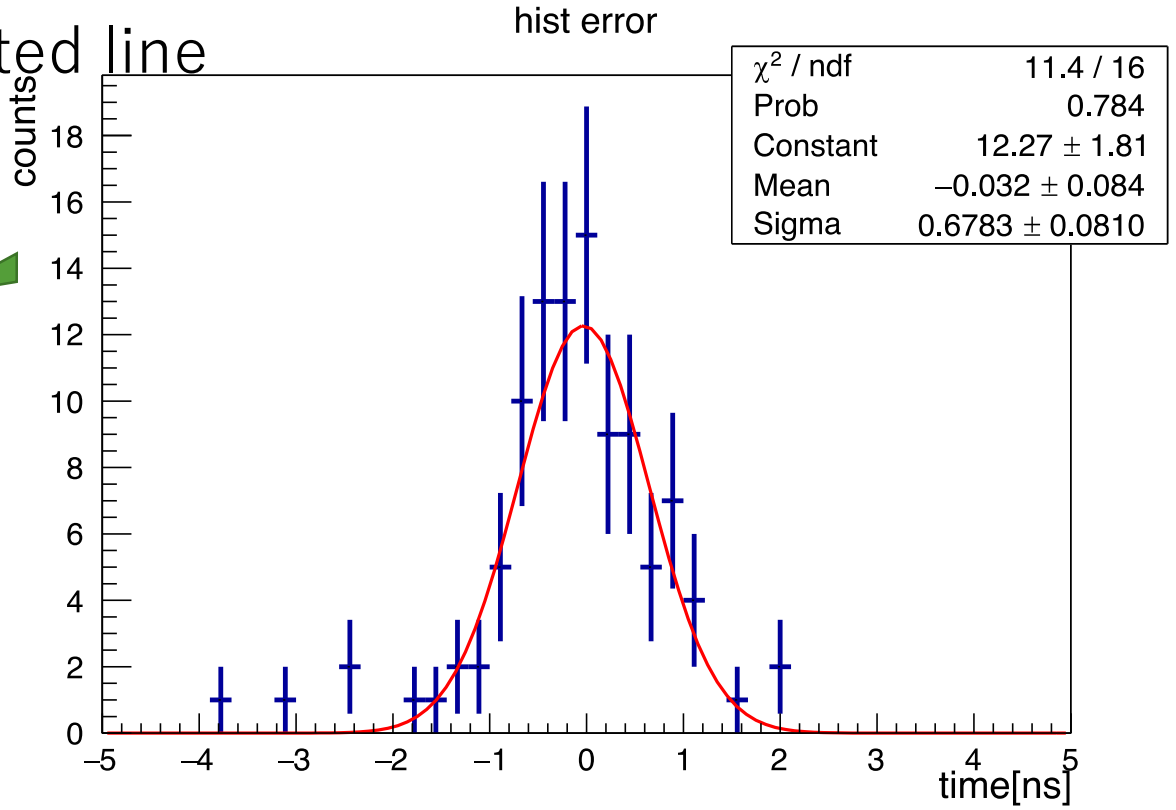


※Timewalk correction applied

Timing resolution

- Distance from the fitted line

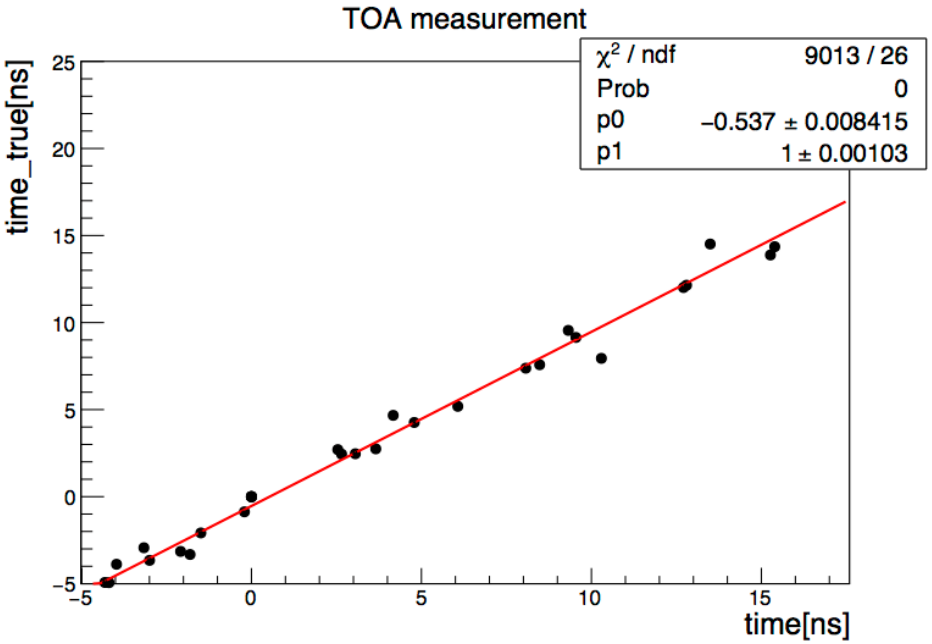


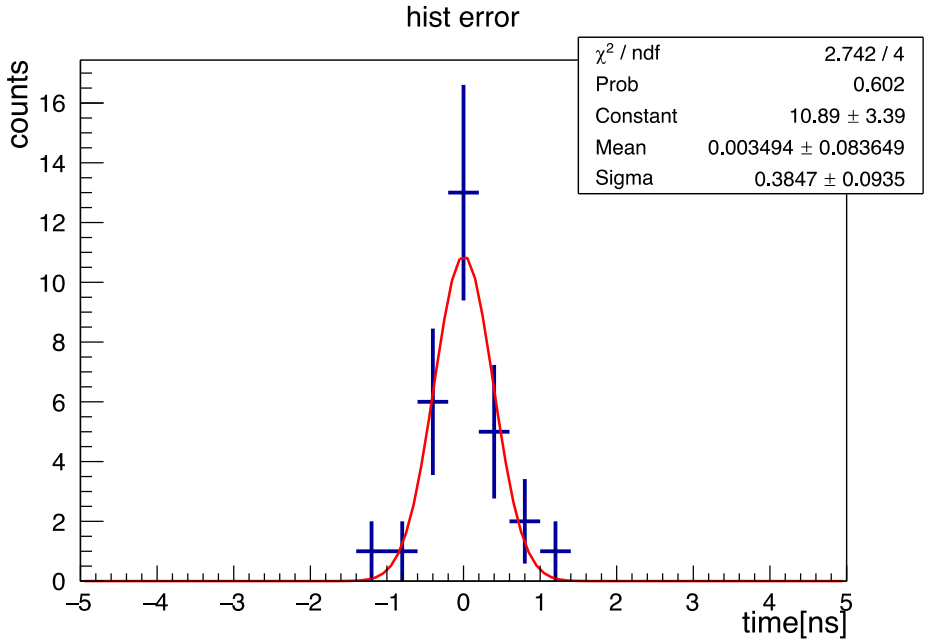


Fitted σ : 678 ± 81 ps

Timing resolution (2)

- Events only with >100 fC
  - Smaller correction of timewalk
  - Low jitter
  - Better timing resolution due to bigger signal





Timing resolution (> 100 fC) : 385 ± 94 ps

Jitter subtraction with 50ps jitter assumed: $\sqrt{385^2 - 50^2} \cong 382$ ps

Possible cause of bad timing resolution

- Imperfect timewalk correction
  - Timewalk measurement done in only single channel
    → maybe affected by channel variation
  - Timewalk measurement at Kyushu
    → can be different at Tohoku
- Imperfect TOA→time correction
  → TOA range is slightly shifted at Tohoku (observed)
- Position non-uniformity?
- Noise? (much worse in the beamline)
- More statistics necessary
  → Low efficiency seen: to be investigated

Plan

- Investigate the efficiency problem
- Use strip sensors for measuring precise position of the particle
- Lower trigger threshold (need to reduce noise)