Summary of the LGAD (APD) test beam at ELPH, Tohoku University

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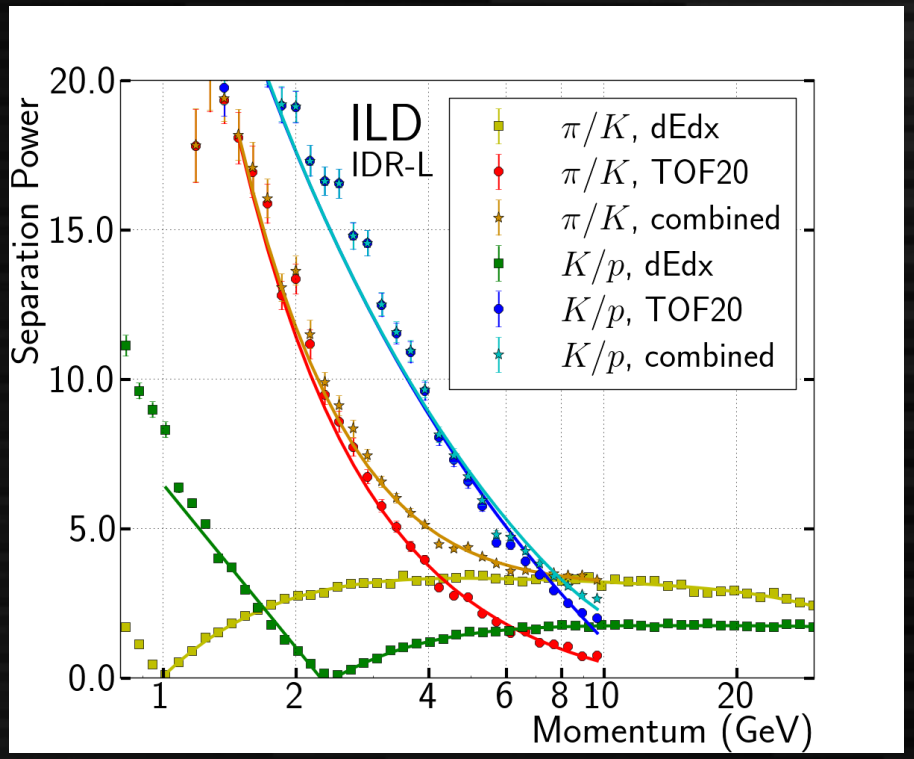
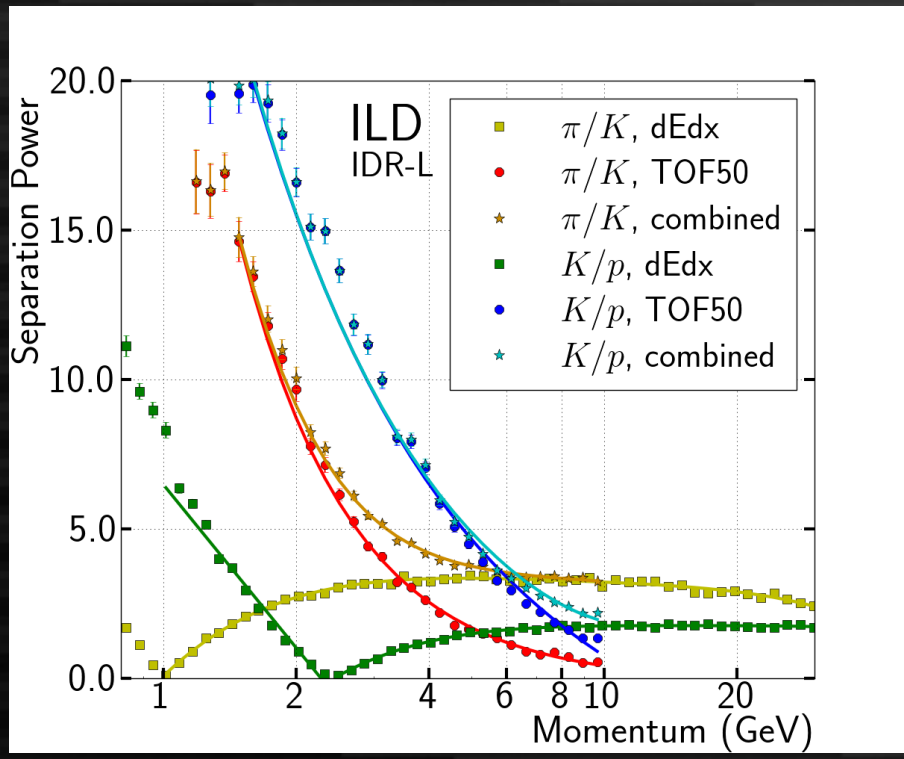
KYUSHU UNIVERSITY

PID and timing resolution

PID at ILD

- dE/dx at TPC
  - ~3σ for K/π
  - <2σ for p/K
  - Ineffective range at 1-3 GeV/c
- ToF at Calo
  - ECAL: ~100 ps with standard Si (with ASIC upg)
    - Powerful up to 2-3 GeV
  - LGAD: 20-30 ps?
    - 5-10 GeV in target
  - HCAL: 50-100 ps?
  - "Good averaging method" necessary (with pattern recognition (DNN?))



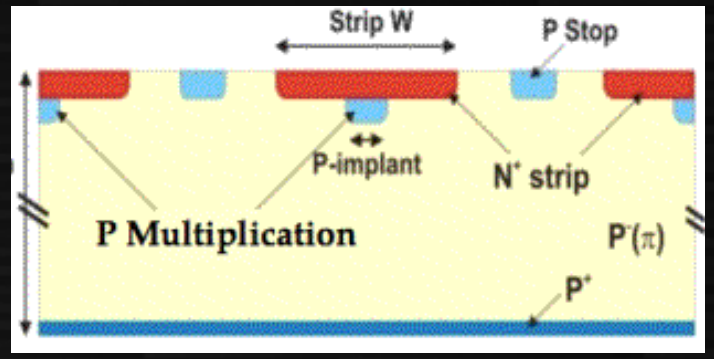


ILD simulation with simple method
To be improved for higher timing resolution
→ M. Kuhara's talk tomorrow (for status)

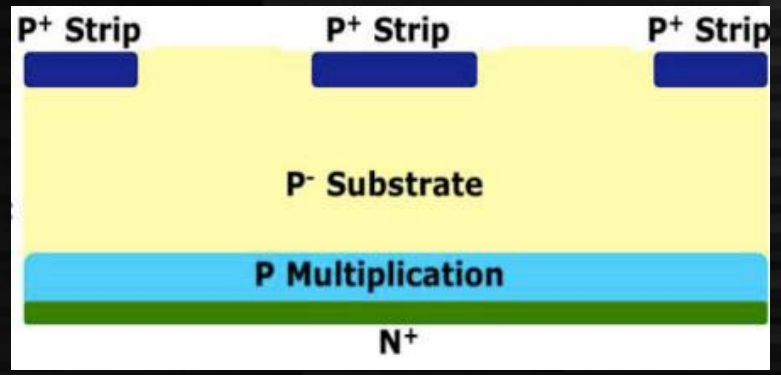
@2m

Energy	β (π)	β (K)	β (p)	Δt (π/K)	Δt (K/p)
5 GeV	0.9996	0.9951	0.9822	30 ps	88 ps
10 GeV	0.9999	0.9988	0.9956	7 ps	21 ps

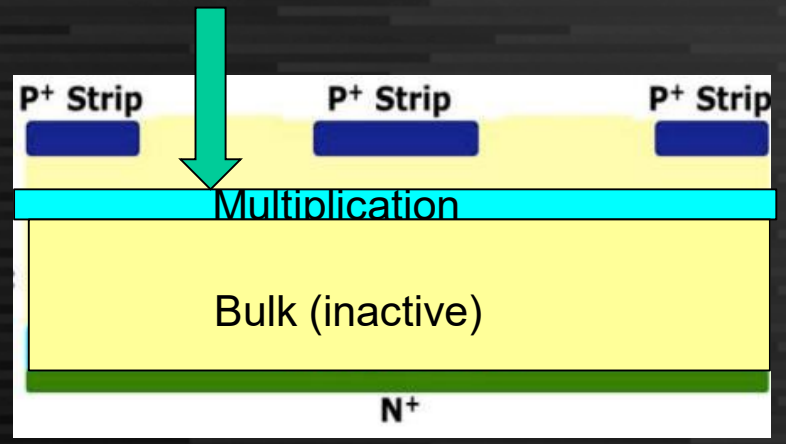
LGAD types



Reach-through type:
intensively studied
for ATLAS HGTD

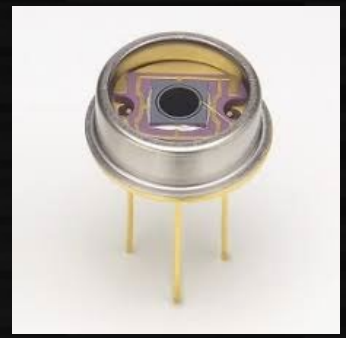


Inverse type: (Europe)
better gain flatness expected
Double-sided process



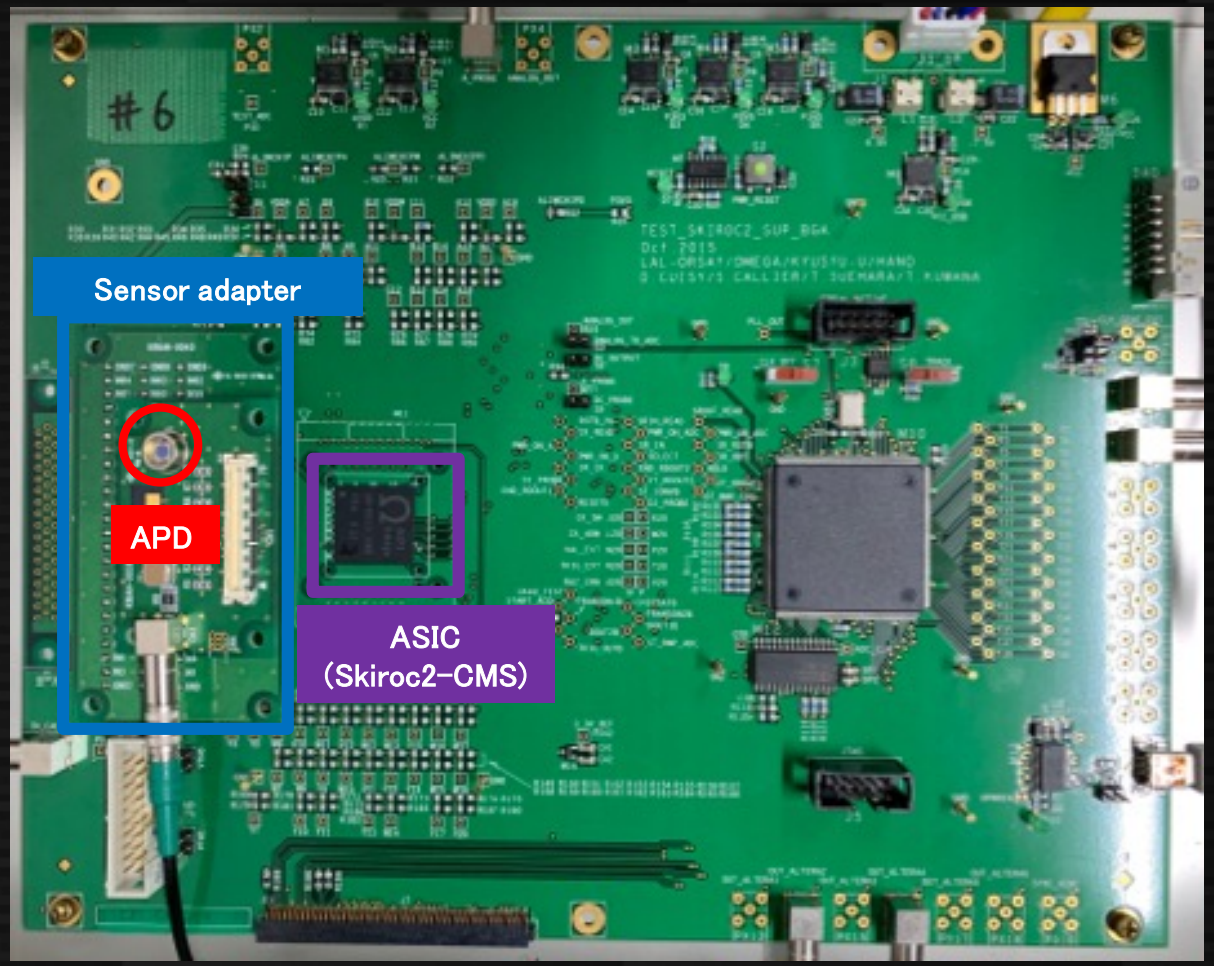
Inverse type: (Hamamatsu)
Multiplication by deep injection
Single-sided process (cheaper)
Thinner active layer
→ Better timing resolution??
→ More Landau fractuation

Spec. no	type	VBR[V]	size [mm]
S8664	Inverse	400	3ϕ, 5ϕ
S5344/5345	Inverse	150	3ϕ, 5ϕ
S2384/2385	RS	150	3ϕ, 5ϕ
S6045	RS	200	3ϕ, 5ϕ
S8550-02	Inverse	400	Array (32ch, 1.6x1.6/cell)

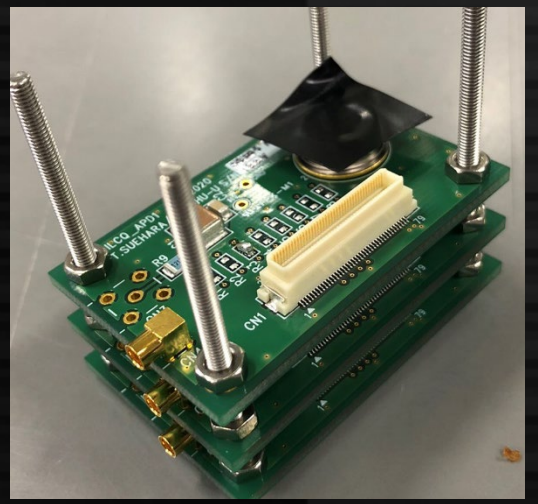


S8664-50K
CAN package (5ϕ)

Electronics



SKIROC2 testboard
with a Skiroc2-CMS soldered
Sensor adapter board attached

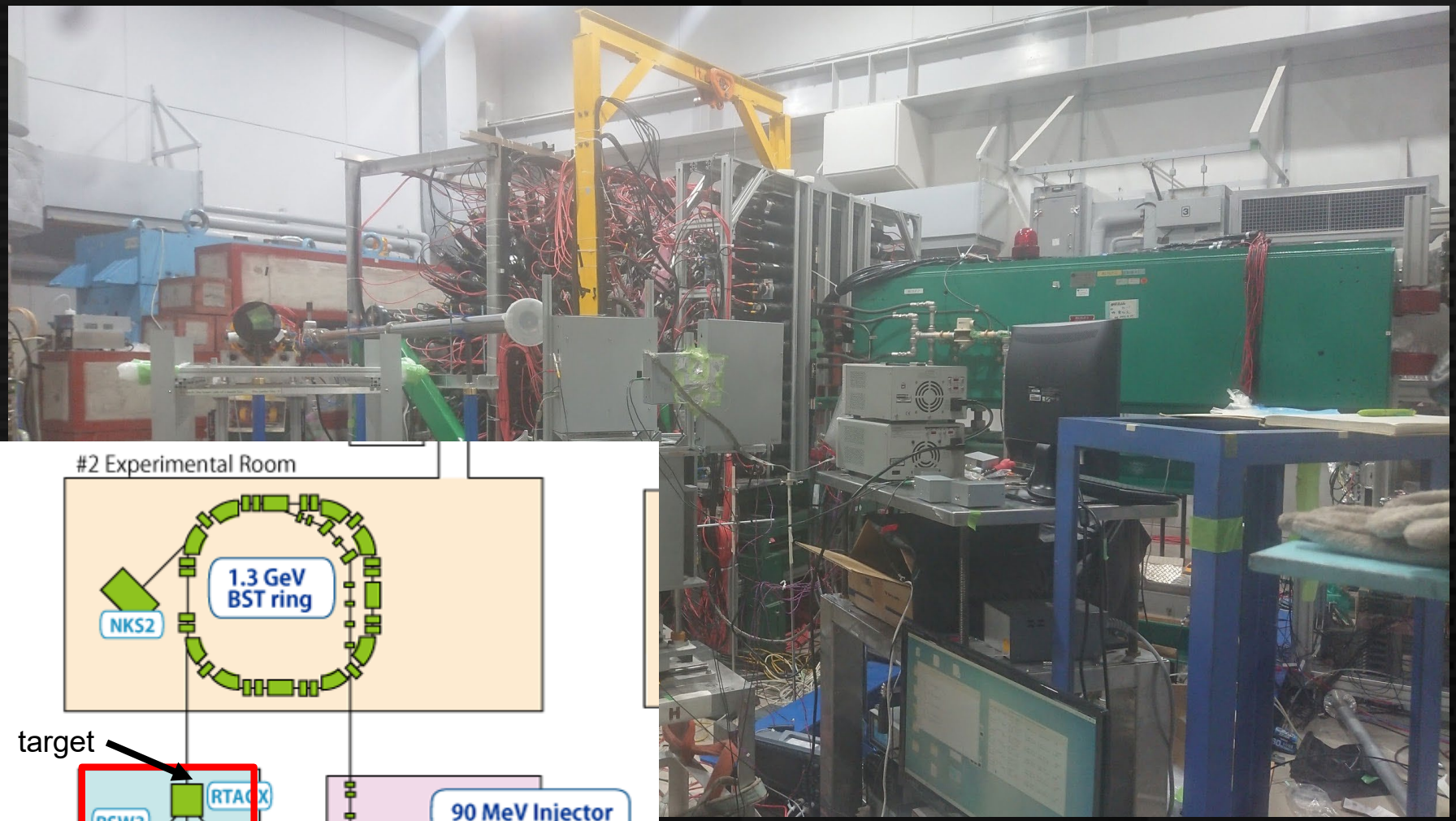


Sensor assembly
3 APDs are
stacked for the
concurrent signal
at beam
(for timing study)

Individual bias voltage

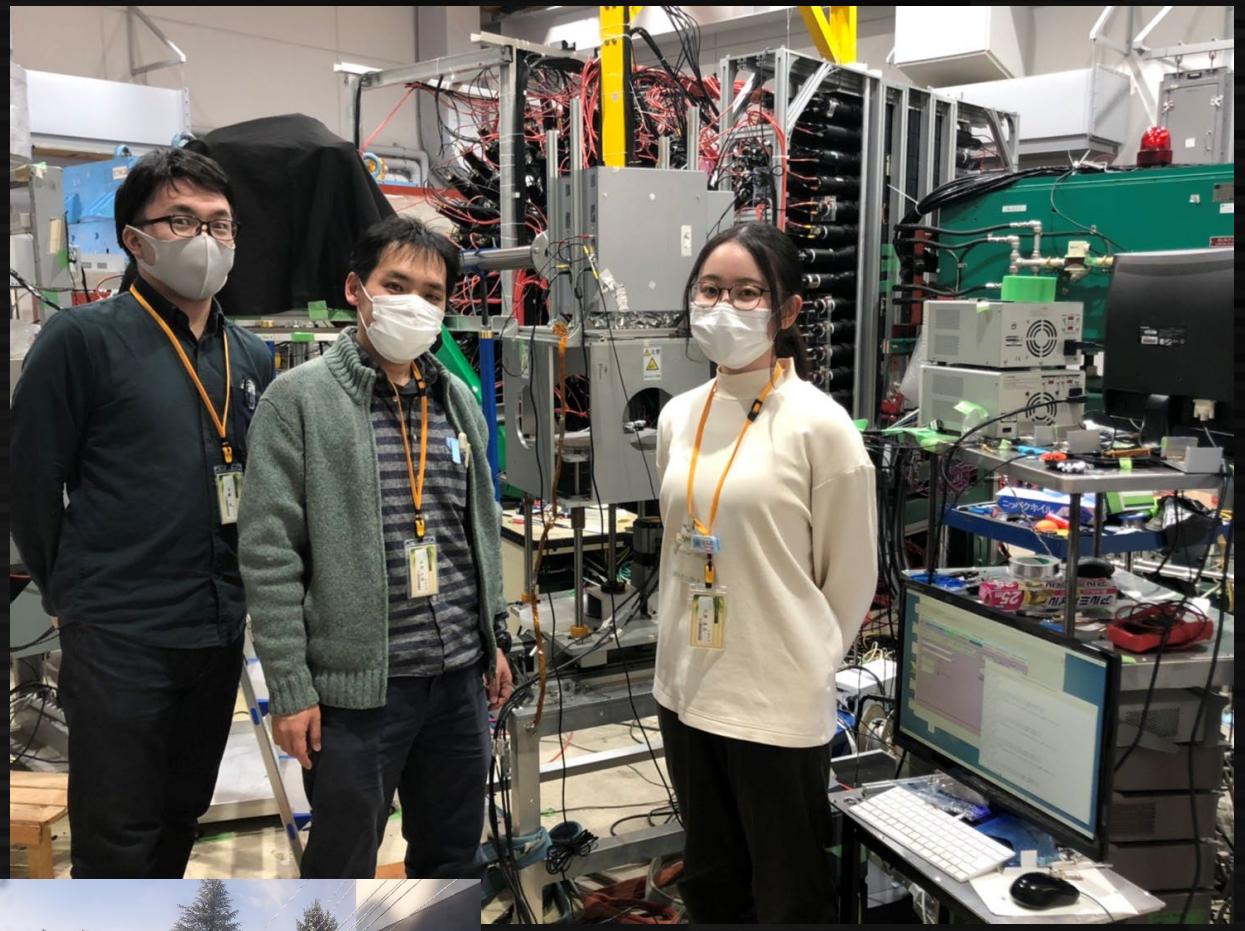
2 x testboards
with sensor stacks
inside the boxes
set on the beam

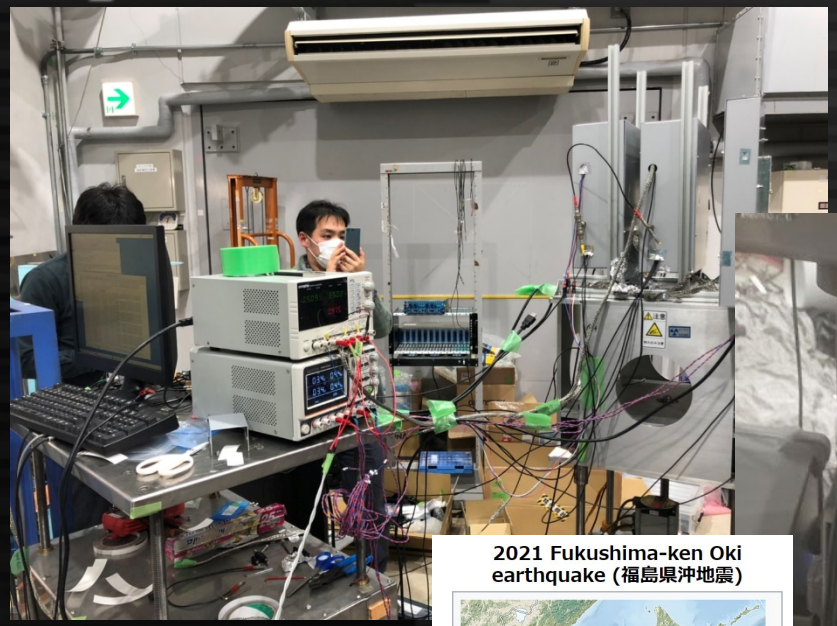
Test beam at ELPH, Tohoku University

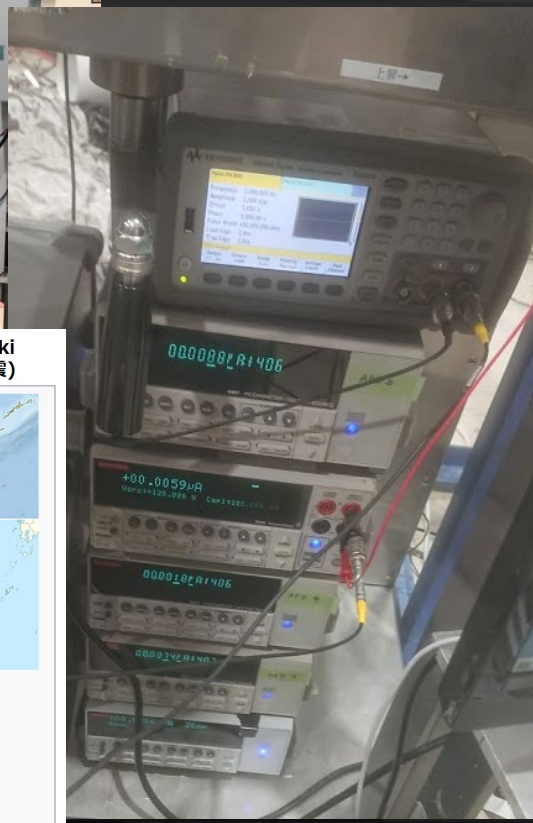


- 16-19 Feb. 2021
  9am – 9pm, 48 h in total
- Positron, ~770 MeV
  (possible up to 1 GeV)
- Rate: ~1 kHz
  with spot of a few cm
- Quasi-CW (~50% duty)
- Beam time shared with Tsukuba group (ALICE FoCAL pad detector
  - 2 beam lines
  - Priority on one group, parasitic for another (2 days each)

Test beam photos





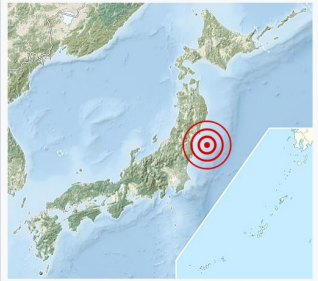


A morning at ELPH

3 members from left:
Y. Kato (Tokyo)
T. Suehara (Kyushu)
M. Kuhara (Kyushu)

We encountered an earthquake (M7.1) just before TB. It's said to be an aftershock of 2011 great Tohoku earthquake. Railways damaged.

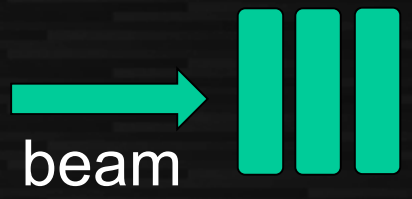
2021 Fukushima-ken Oki earthquake (福島県沖地震)



UTC time	2021-02-13 14:07:49
ISC event	619834062
USGS-ANSS	ComCat
Local date	13 February 2021
Magnitude	7.1 M_w (USGS) 7.3 M_{JMA} (JMA)
Depth	51.9 km (USGS) 55 km (JMA)
Epicenter	37.720°N 141.762°E
Fault	Japan Trench

Tower of picoammeters (survived)

Setup & readout



Position layers 1x1 mm cell pads & 100 μm pitch strips (x-y)

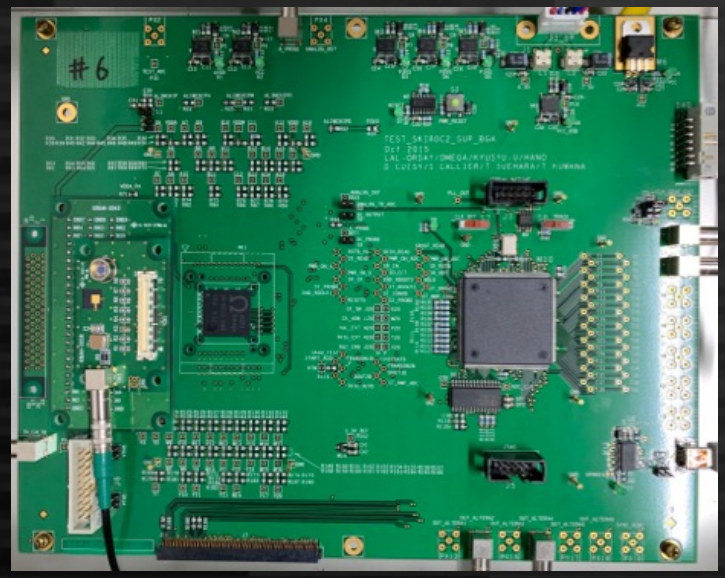
Readout by FEV13

Single-cell APDs 3 identical sensors readout with a Skiroc2-CMS testboard

4 types of APDs are measured with replacement

Multi-cell APDs 2 identical sensors readout with a Skiroc2-CMS testboard

32 ch x 2 sensors

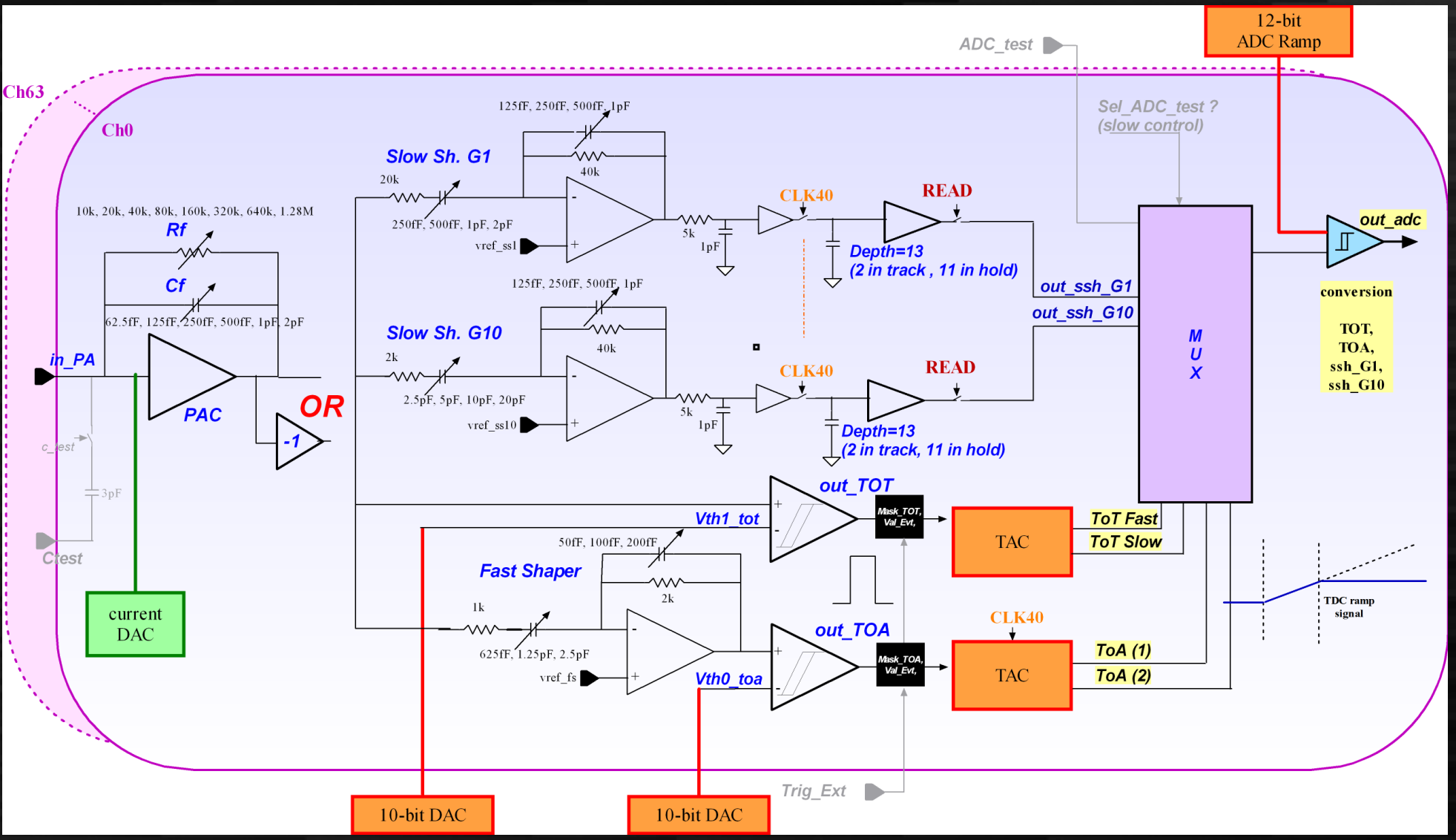


Skiroc2-CMS testboard

FEV13 with adapter board and cables

Calibration of TOA

Measurement with Skiroc2-CMS



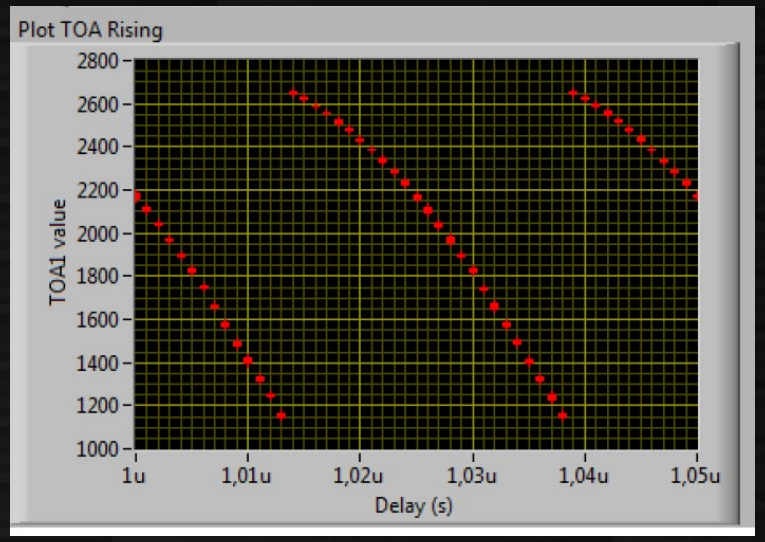
ADC:
13 cell (11 in effect)
waveform digitizer
at 50 MHz
ring buffer
x10 / x1 gain

Trigger:
Fast shaper
(tc: 0.625 – 5 ns)
Th. tunable with DAC

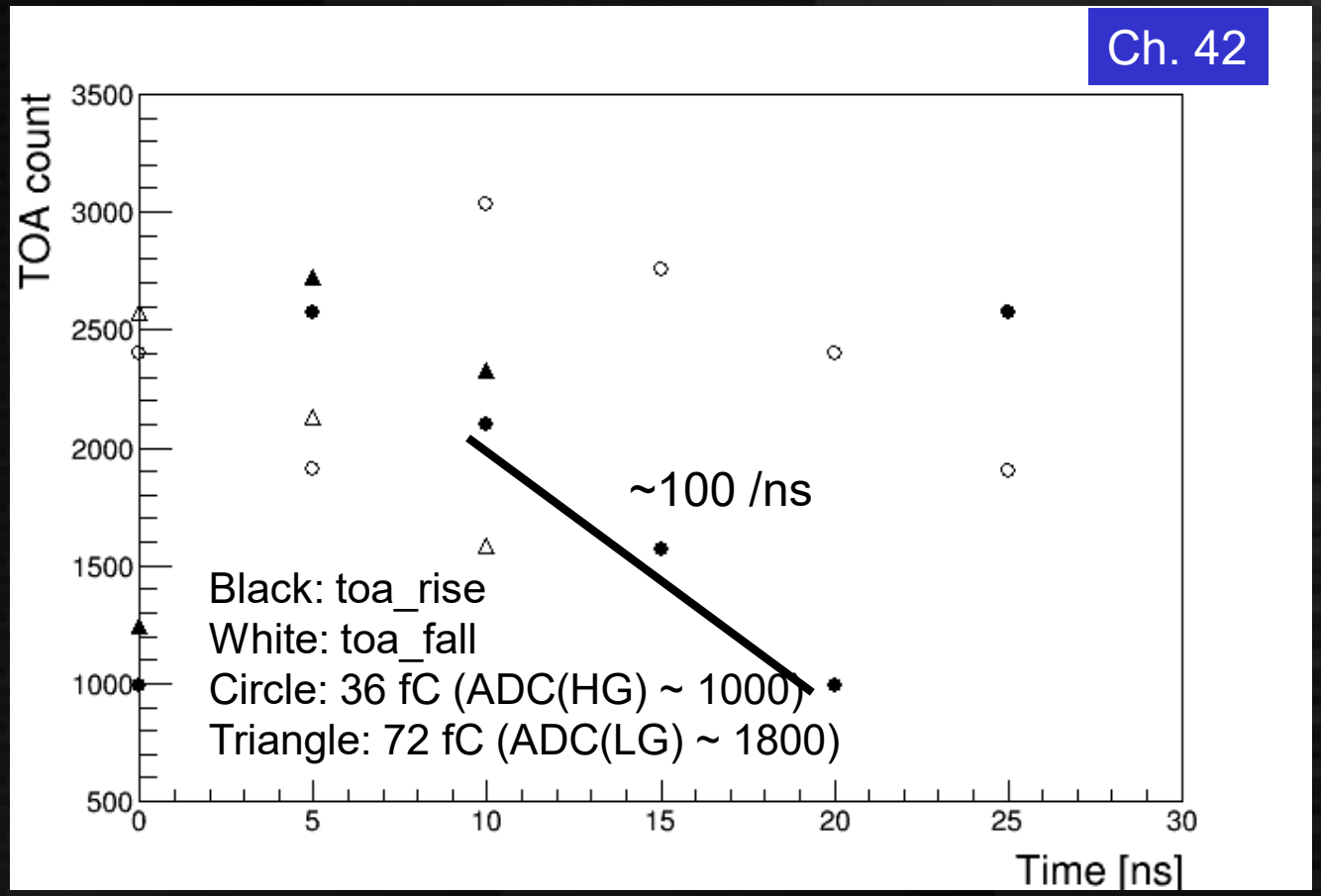
TOA: (toa_rise, toa_fall)
Sweeping voltage
to be clipped
at trigger
(TOT: not used)

Global_ts:
clock count (26 bit)
can count up to 1.3 sec

TOA vs timing with charge injection



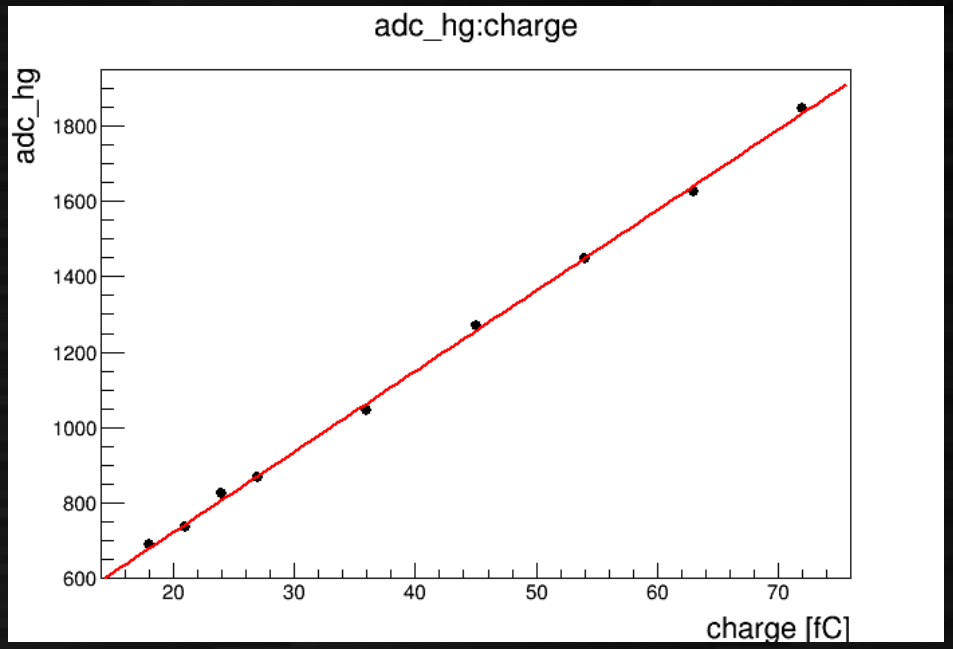
Provided from Omega



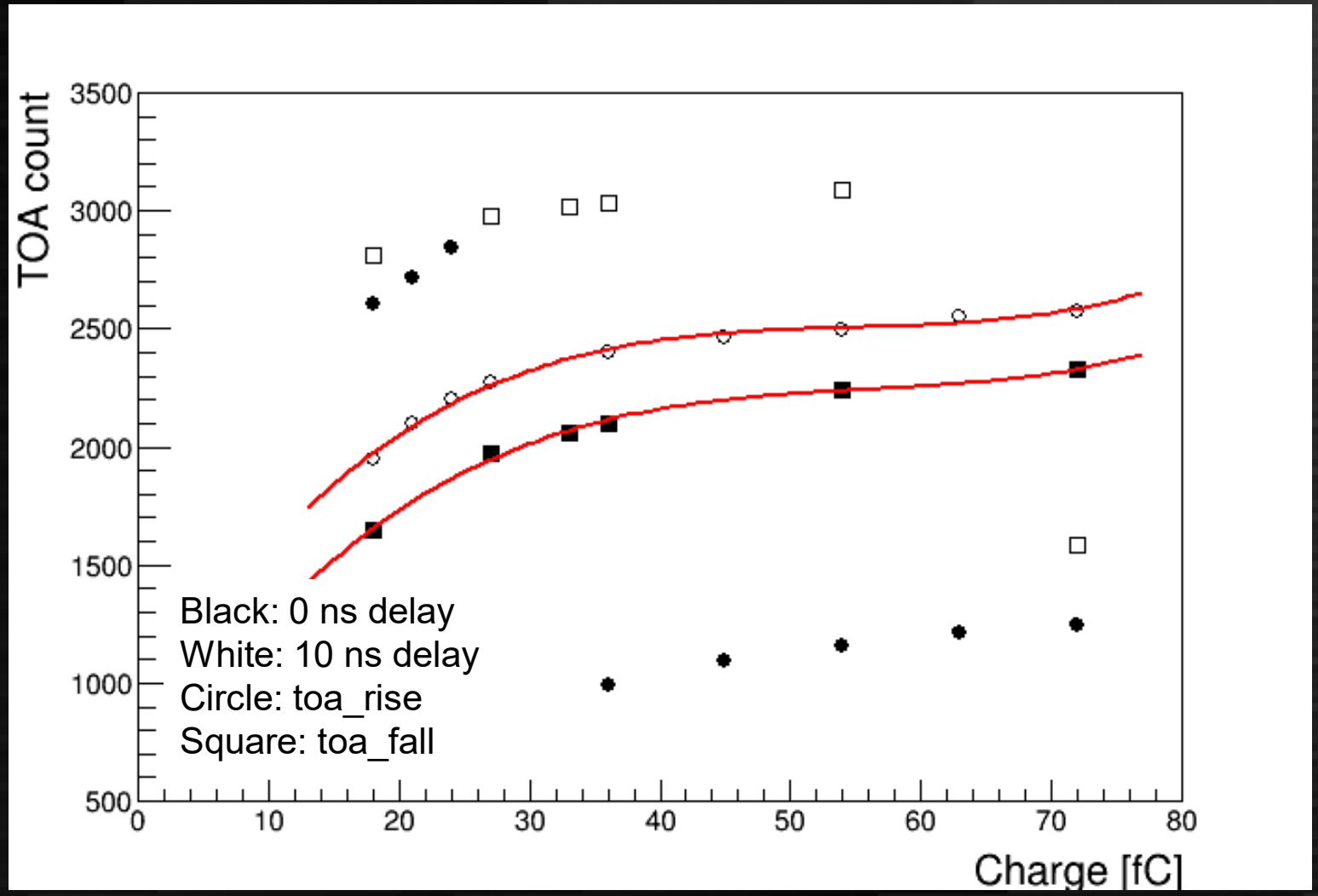
Dynamic range is wider in toa_rise

TOA vs delay with charge injection
Timewalk needs to be corrected
~100 / ns seen below TOA < 2400 (lower in TDC > 2400)

Timewalk



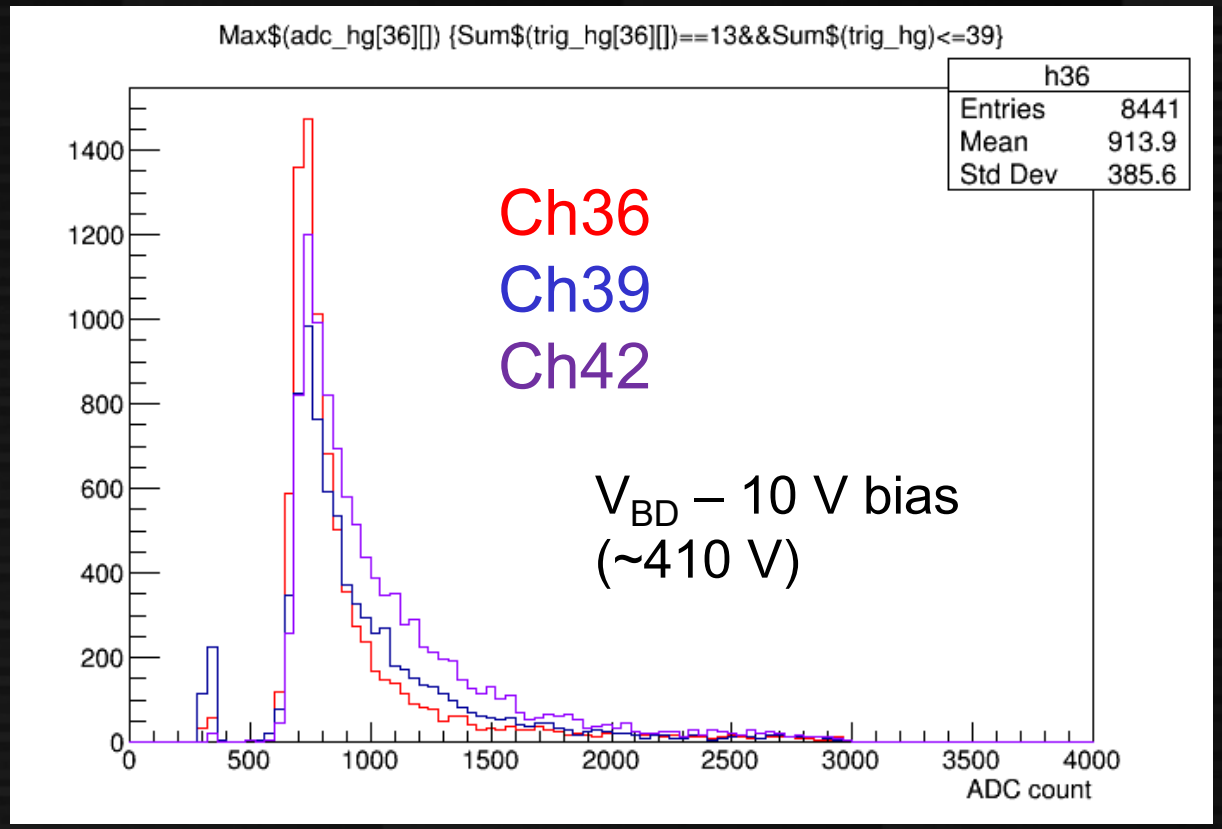
Injection charge vs adc_hg

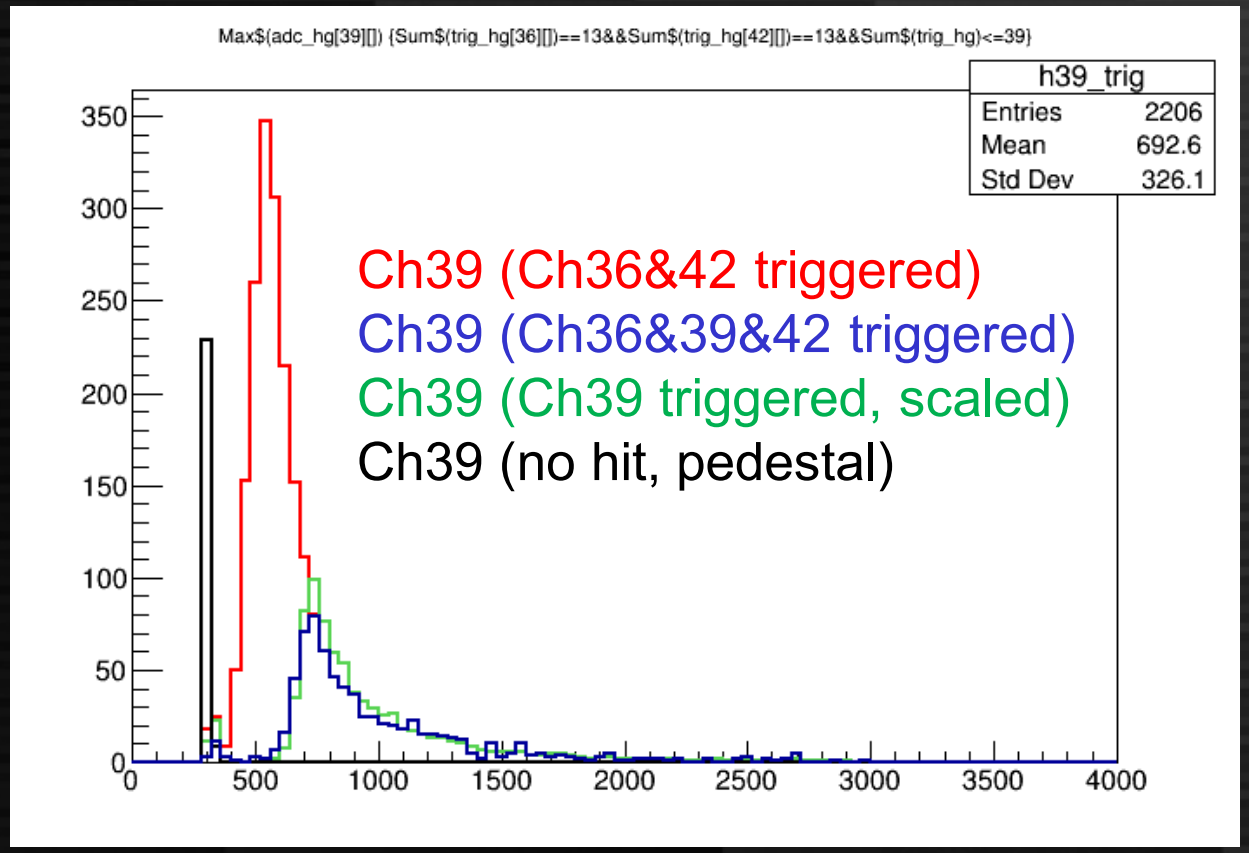


Timewalk by injection
temporal fit with pol3

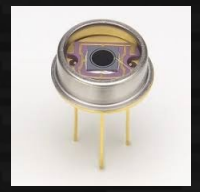
Quick look of the data
(S8664-50K x 3, 60 minutes run)

ADC spectrum



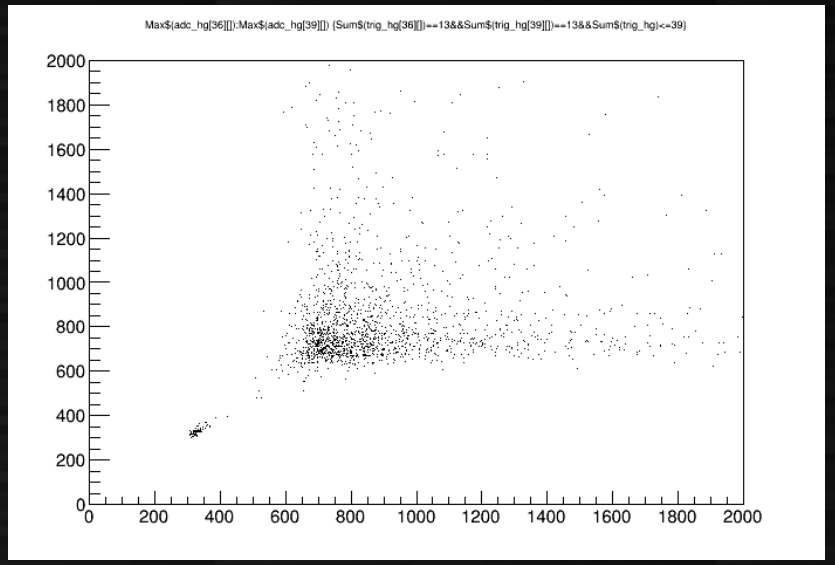


S8664-50K x 3

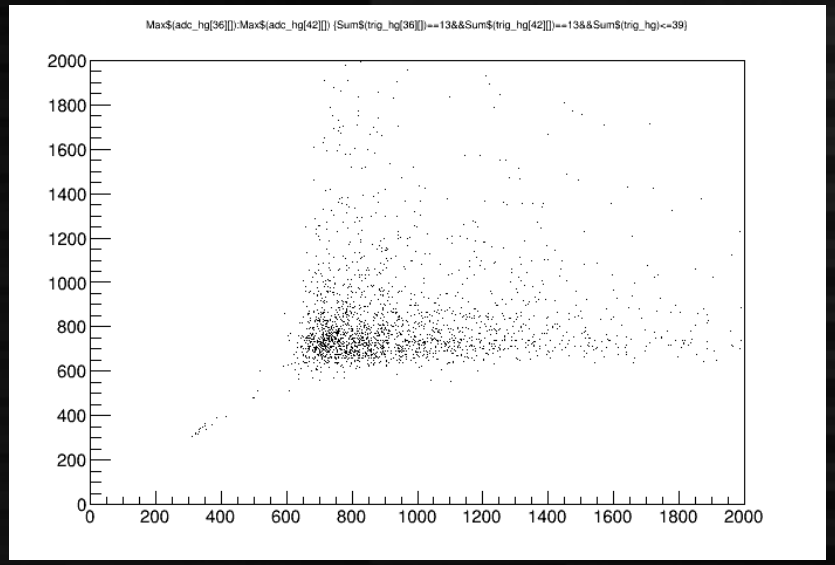


- TOA threshold is high; causing low efficiency
  - To lower threshold, have to reduce shot noise
- Pedestal and signal well separated (red - black)
  → Reaction efficiency is near 100%

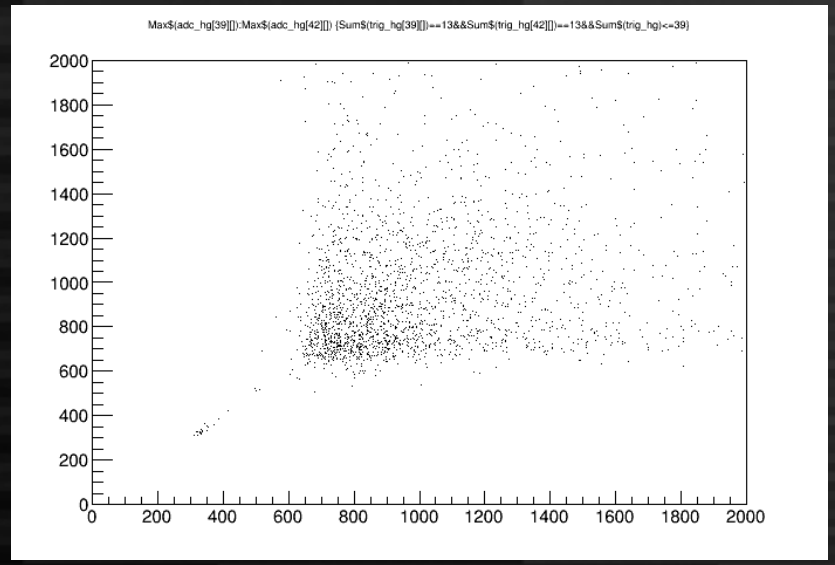
ADC 2D distribution



Ch 36 and 39



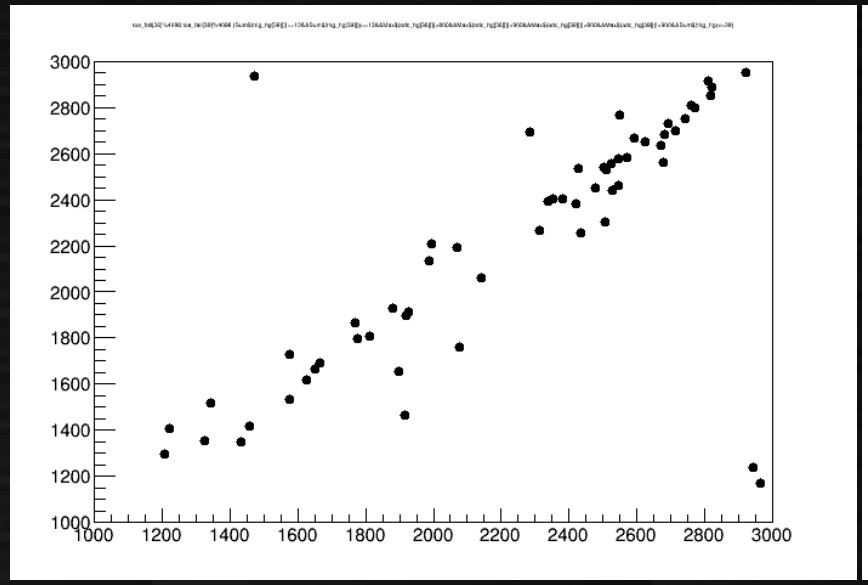
Ch 36 and 42



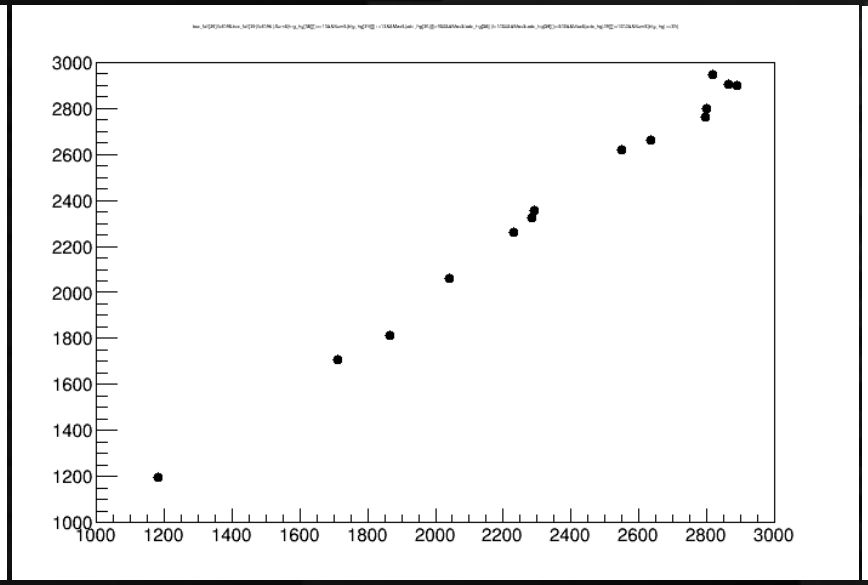
Ch 39 and 42

No strong correlation on hits
→ signal-like distribution (Landau fluctuation or APD gain variation)

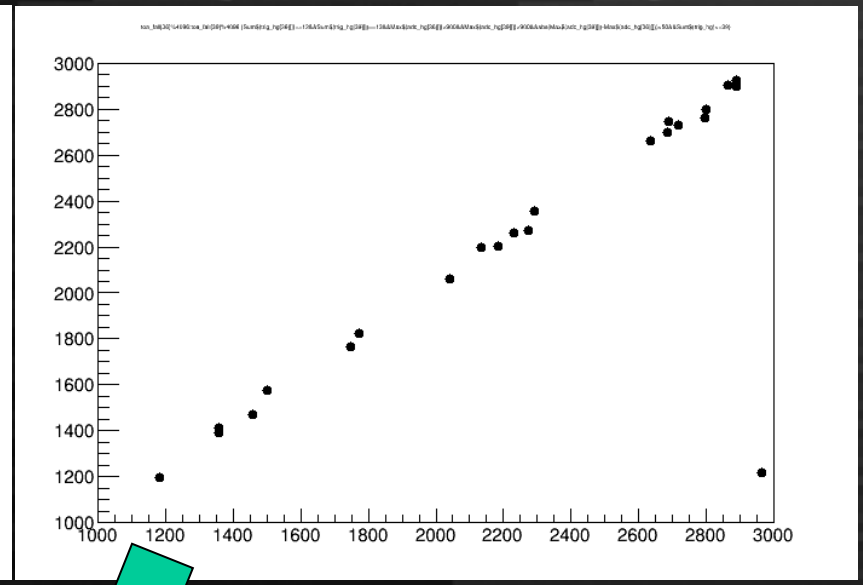
TOA without timewalk correction (ch36-39)



800 < ADC < 900



900 < ADC < 1000

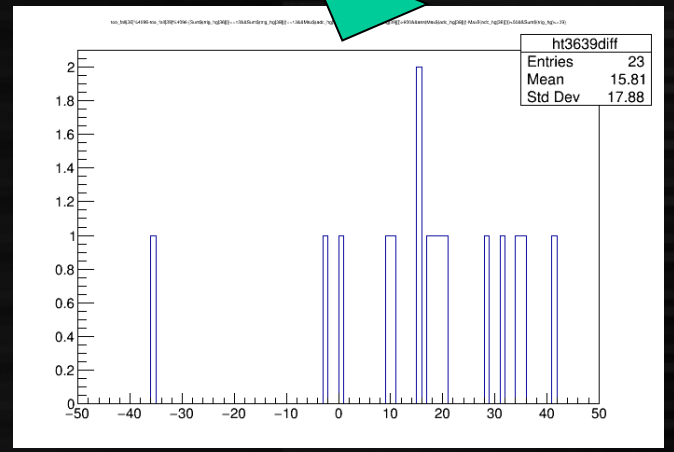


ADC > 900
ADC difference < 50

TOA difference
StDev = 17.88 count ~ 180 psec

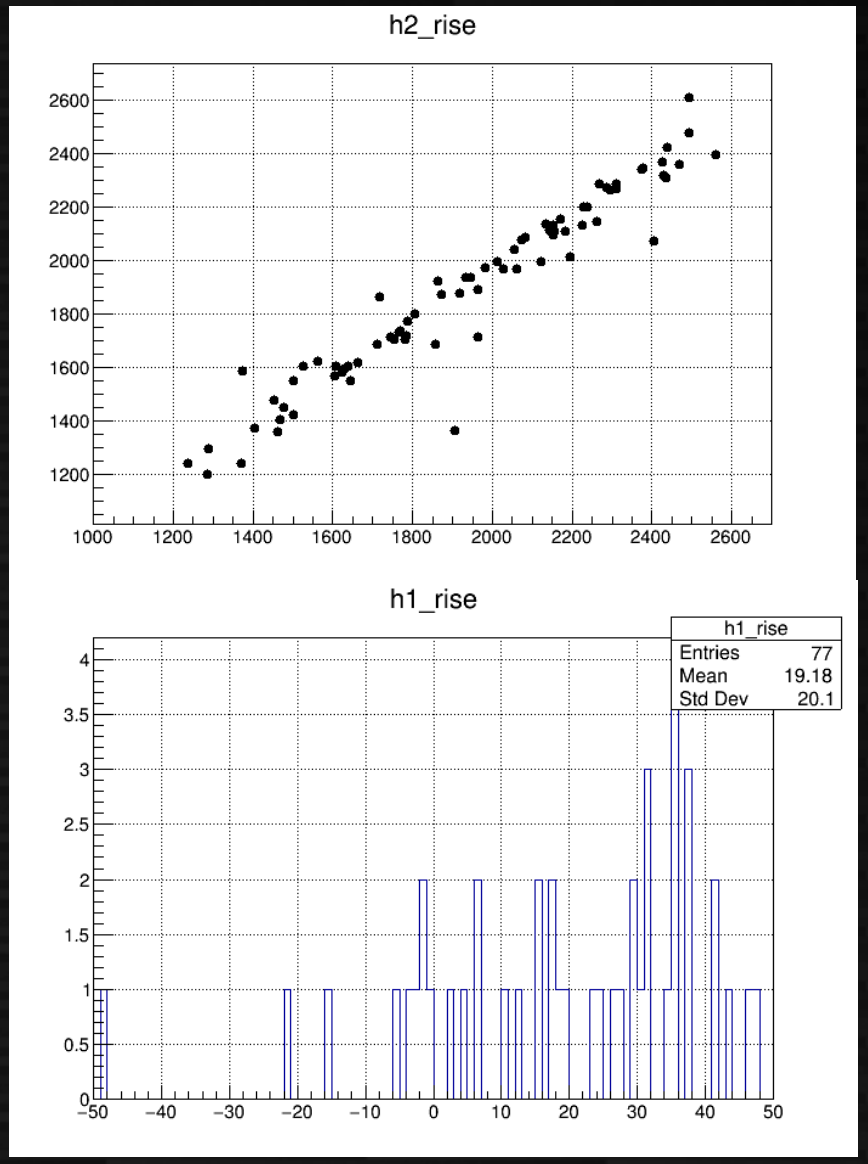
If remove a hit at -35,
StDev = 12.26 count ~ 120 psec

Promising! (?)

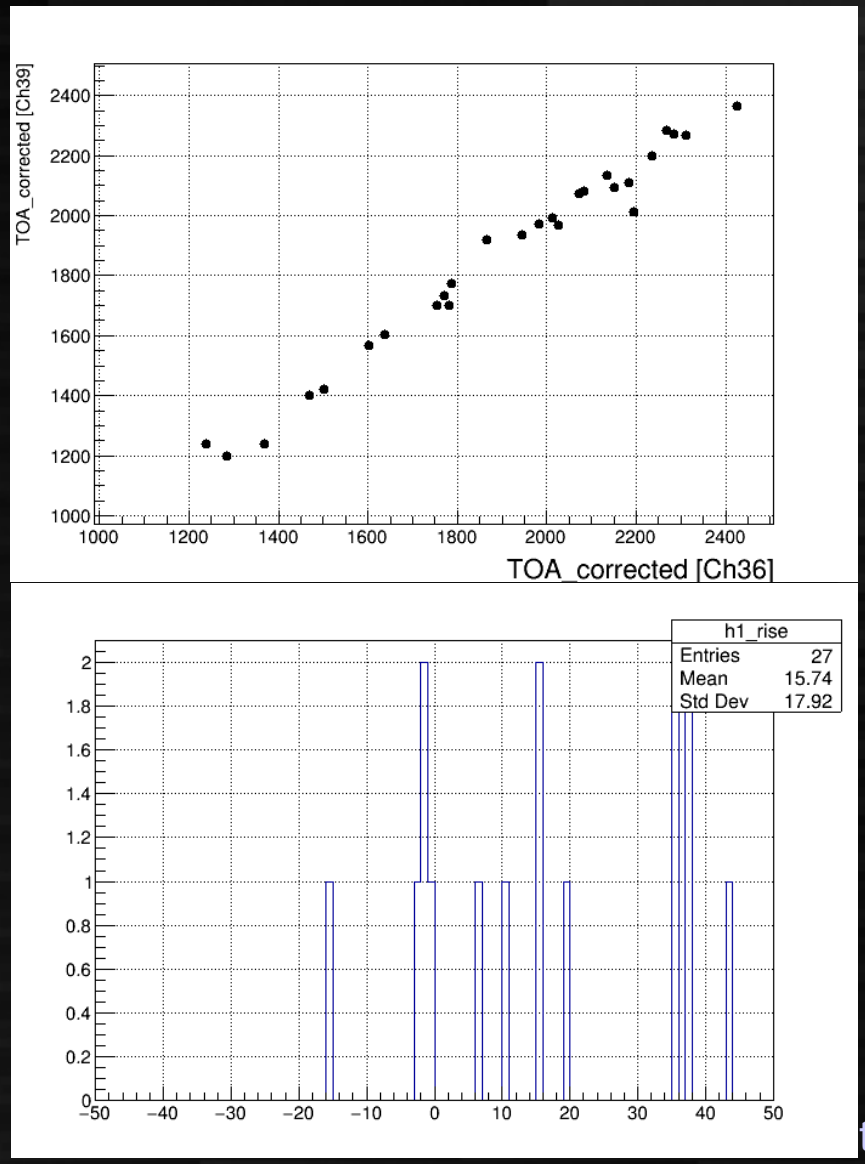


TOA with timewalk correction (preliminary)

ADC > 800, ADC difference < 100



ADC > 900, ADC difference < 100



No big improvements (looser condition)

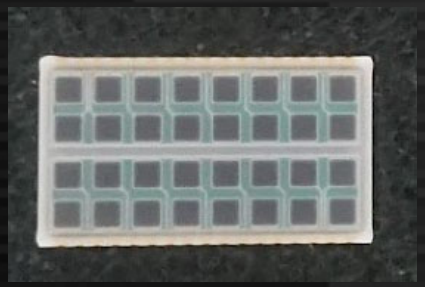
Shift at ADC > 800: imperfect timewalk correction?

Still need to be investigated

Summary and plans

Summary

- Test beam has been conducted. Data integrity of S8664-50K is OK.
- Efficiency of the amplification is high if we set the threshold low enough.
- 100-200 ps resolution is about to be seen.
- More effort needed for correction.



Plan

- Dependence on bias voltage and fast shaper time constant
- Cosmic test (have taken multi-cell sensors, singles ongoing but low stat)
- Lowering threshold (noise reduction…)
- Reach-through sensors (data probably bad due to misconfiguration…)
- Position dependence (using position-sensitive sensors (cell/strip))