九州大学
KYUSHU UNIVERSITY

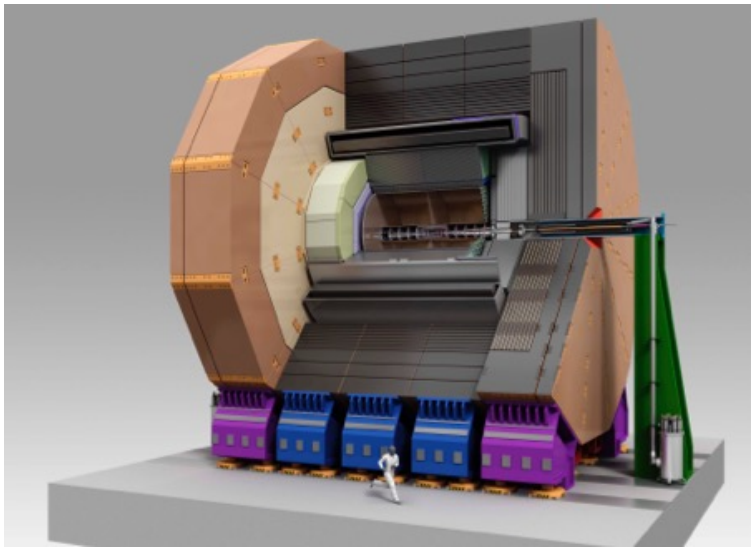
Study of silicon sensors for precise timing measurement

Yuto Deguchi (Kyushu University)
Kiyotomo Kawagoe, Tamaki Yoshioka, Taikan Suehara,
Ryosuke Mori (Kyushu University)
Eloïse Mestre (Université PARIS-SACLAY/IN2P3)
Stéphane Callier (Omega/IN2P3)

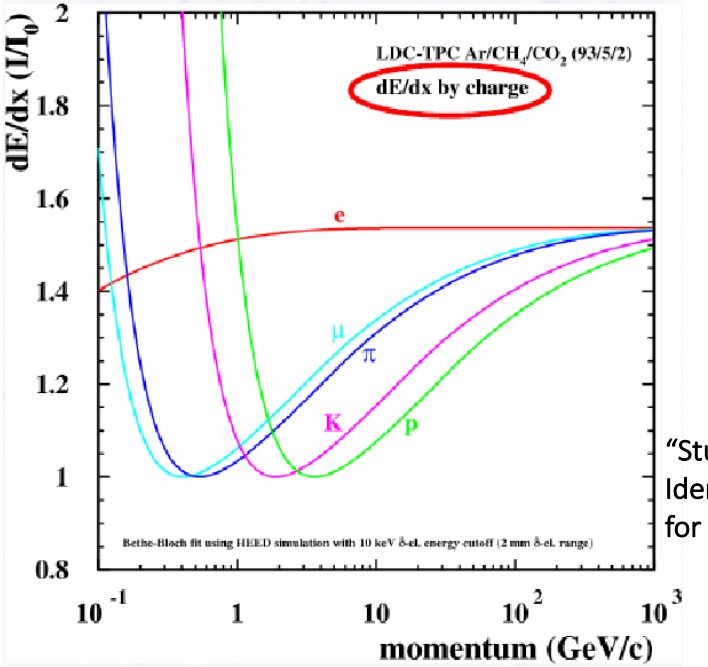
UNIVERSITÉ PARIS SUD
Comprendre le monde, construire l'avenir
université PARIS-SACLAY

International Large Detector (ILD)

- One of the detectors placed at the collision point of ILC
- Mainly charged particles are detected by tracking detectors, and neutral particles are detected by calorimeters
- In the TPC, dE/dx is calculated by the collected charge to identify the particles



International Large Detector (ILD)



"Studies on Particle Identification with dE/dx for the ILD TPC."

Identification of particles

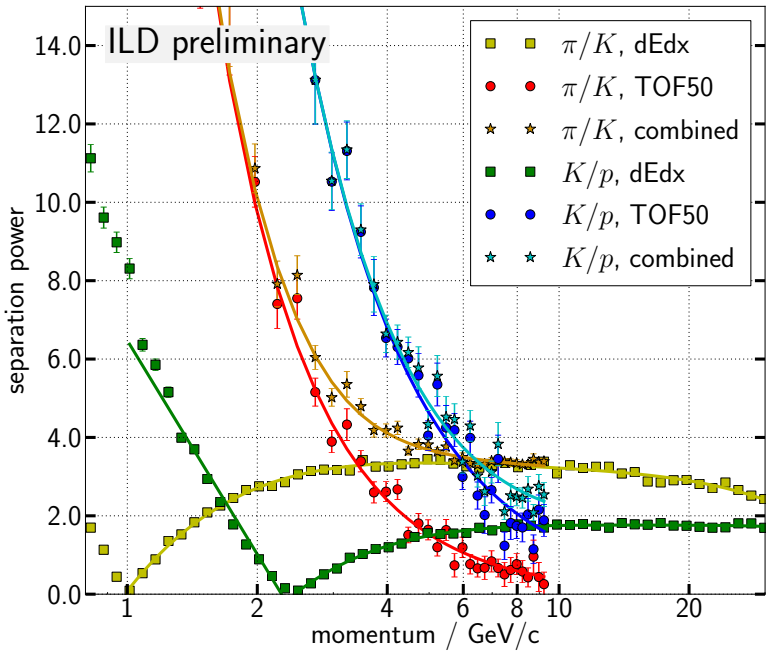
- Time of flight

Particles have differences of flight time depending on their mass

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

In order to identify K and π, we need to have time resolution less than 50 psec

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

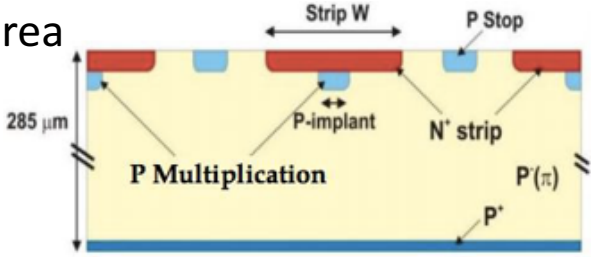


➢ LGAD (Low Gain Avalanche Diode)

→ The time resolution : ~30 psec (in ATLAS study)

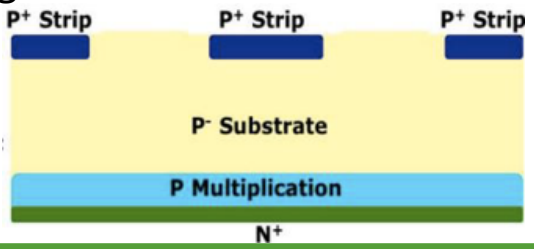
■ Reach-through type

- Fast charge collection speed
- Insensitive area



■ Inverse type

- Multiplication layer covered bottom layer
- Less variation in gain



Avalanche Photo Diode

LGADs have same structure as APDs ➡ We study APDs for LGAD development

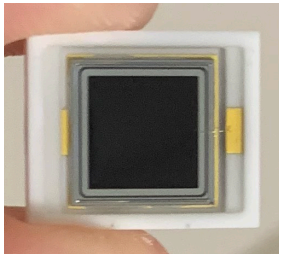
Model number	Type	V_{br}	Size
S12023-10A	Reach-through	139 V	ϕ 1 mm
S8664-10K	Inverse	417 V	ϕ 1 mm
pkg-10	Reach-through	about 250 V	ϕ 1 mm
pkg-20	Reach-through	about 120 V	ϕ 1 mm
S2384	Reach-through	159 V	ϕ 2 mm
S3884	Reach-through	189 V	ϕ 1.5 mm
S8664-20K	Inverse	425 V	ϕ 2 mm
S8664-55	Inverse	433 V	5×5 mm^2

LGAD prototype (for LHC)

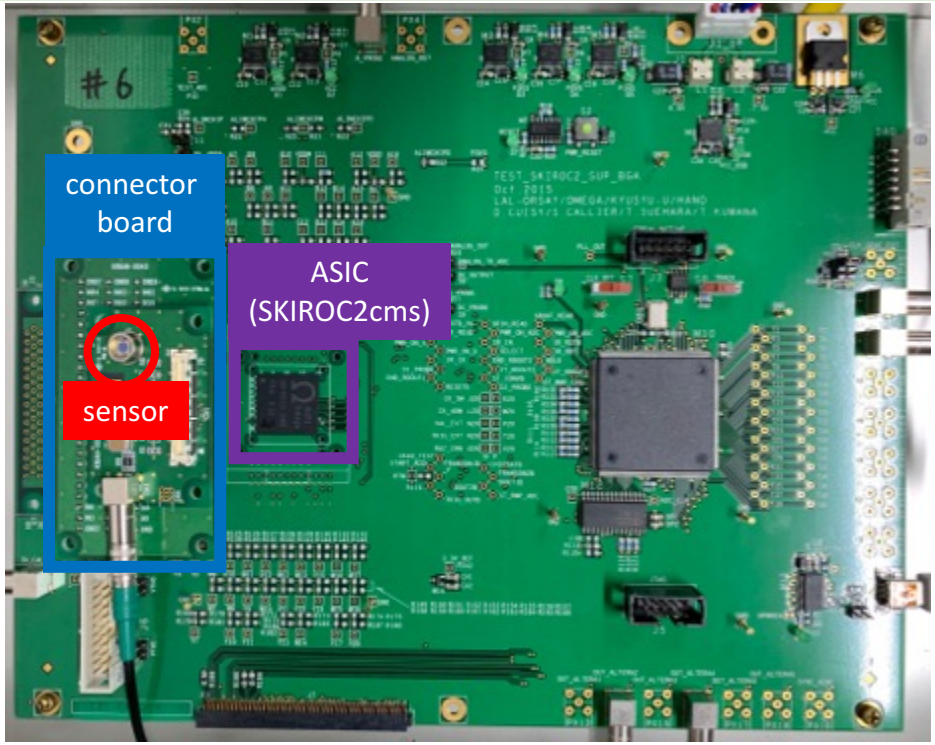

S12023-10A


S8664-10K

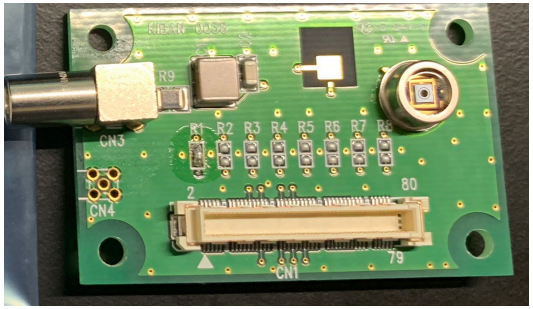

pkg-10, pkg-20


S8664-55

Set up of DAQ

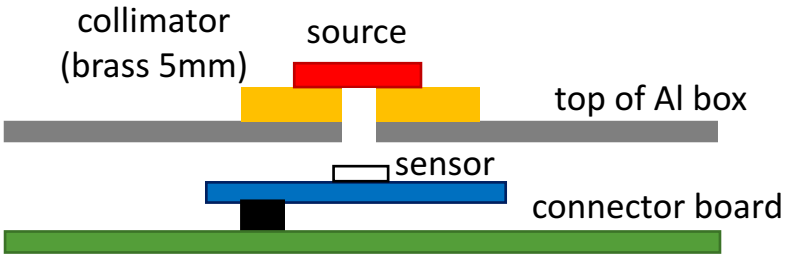


Testboard#6 (SKIROC2cms is soldered)



connector board (with S8664-10K)

into the Al box



Sources

γ source : ^{133}Ba, 81 keV + 356 keV

(compton edge : 207 keV)

β source : ^{90}Sr, 2.2 MeV (Max)

SKIROC2cms

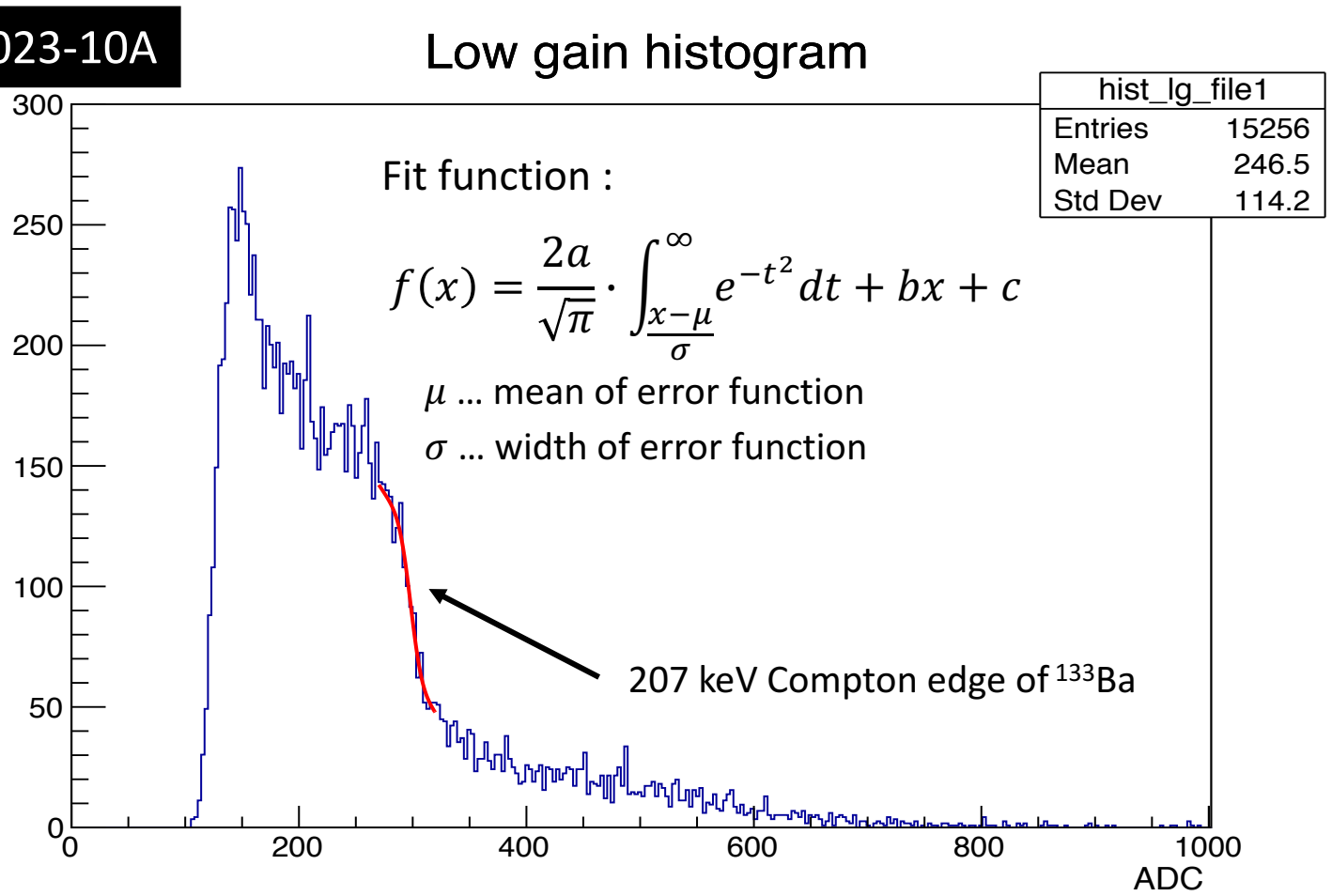
- SKIROC2cms is an ASIC to readout signals from sensors

- Time over threshold and Time of arrival can be acquired
- Preamp polarity can be changed

Measurement using γ source

APD : S12023-10A

HV : 129 V



Calibration with 207 keV compton edge to convert from ADC value to Gain value

$$\text{Gain} = \frac{\mu}{a} \cdot \frac{\text{HV}}{\text{Compton edge}} \cdot \frac{1}{e}$$

a = ADC output / Charge [/C]
$= 2.25 \times 10^{15}$

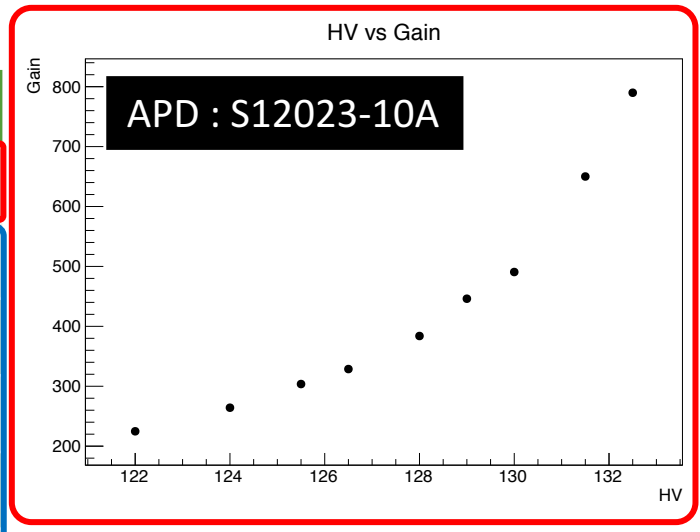
e = Elementary charge [C]

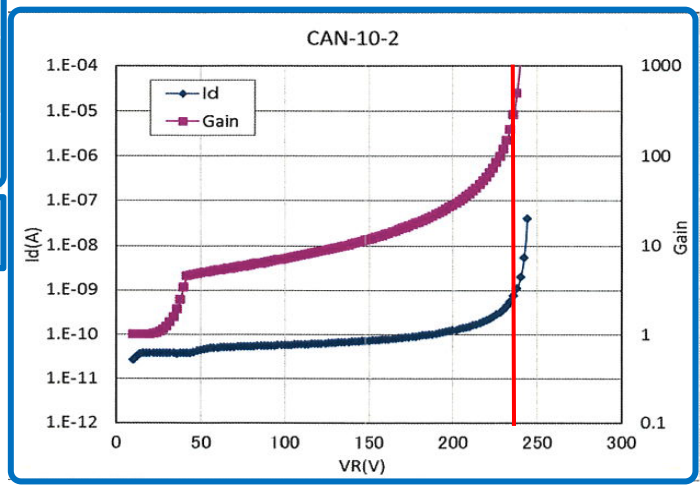
Set up of DAQ

➢ Measurement

Model number	Type	HV	Gain at each HV
S12023-10A	Reach-through	129 V	520 (Measured value)
S8664-10K	Inverse	407 V	about 500~1000
pkg-10	Reach-through	240 V	about 1000
pkg-20	Reach-through	110 V	about 1000
S2384	Reach-through	149 V	about 1000
S3884	Reach-through	179 V	about 1000
S8664-20K	Inverse	415 V	about 500~1000
S8664-55	Inverse	415 V	about 500~1000

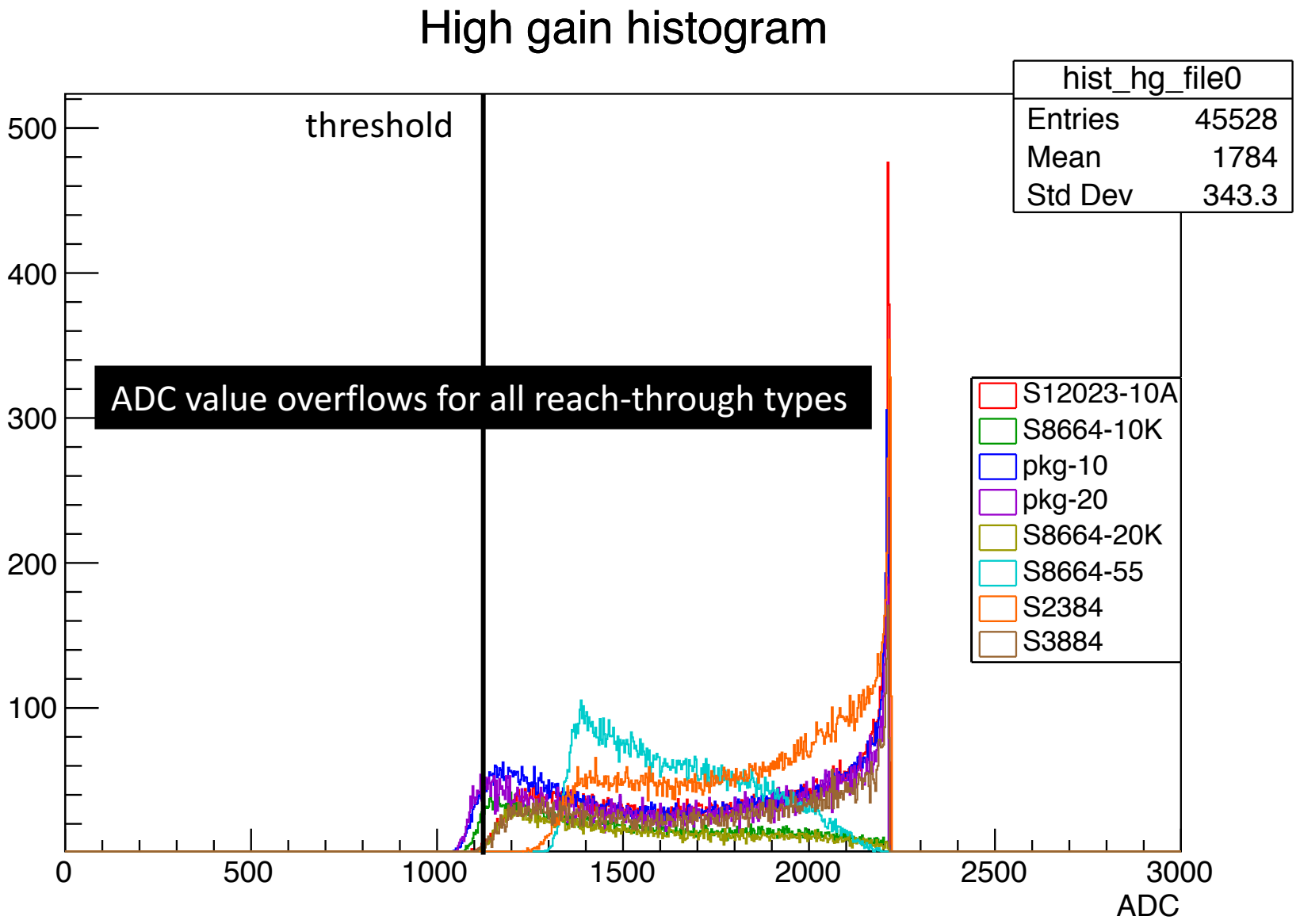
Hamamatsu datasheets



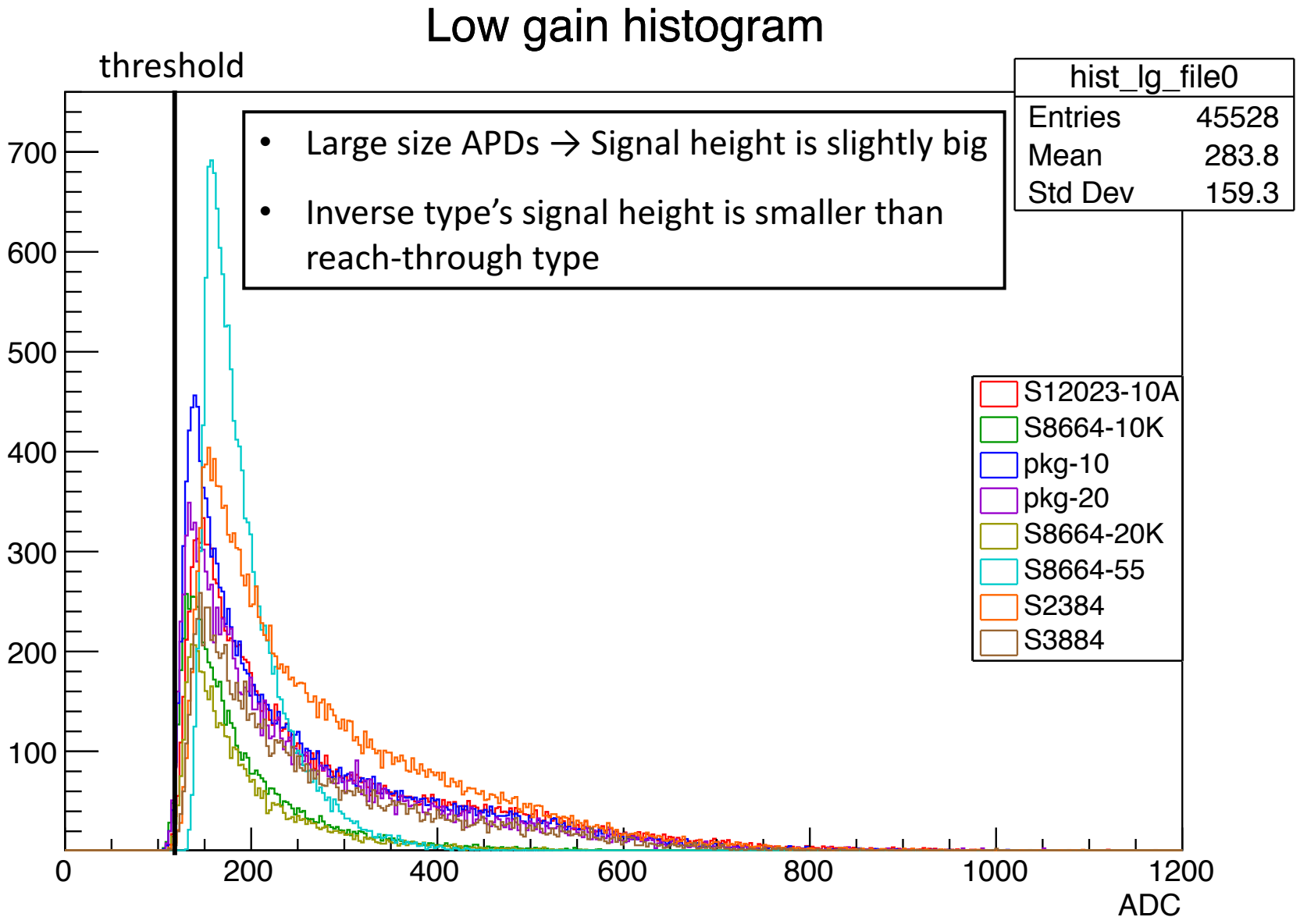


- S12023-10 : The Gain value is measured by DAQ with the γ source
- Other APDs : The Gain value is referenced by datasheet

Result

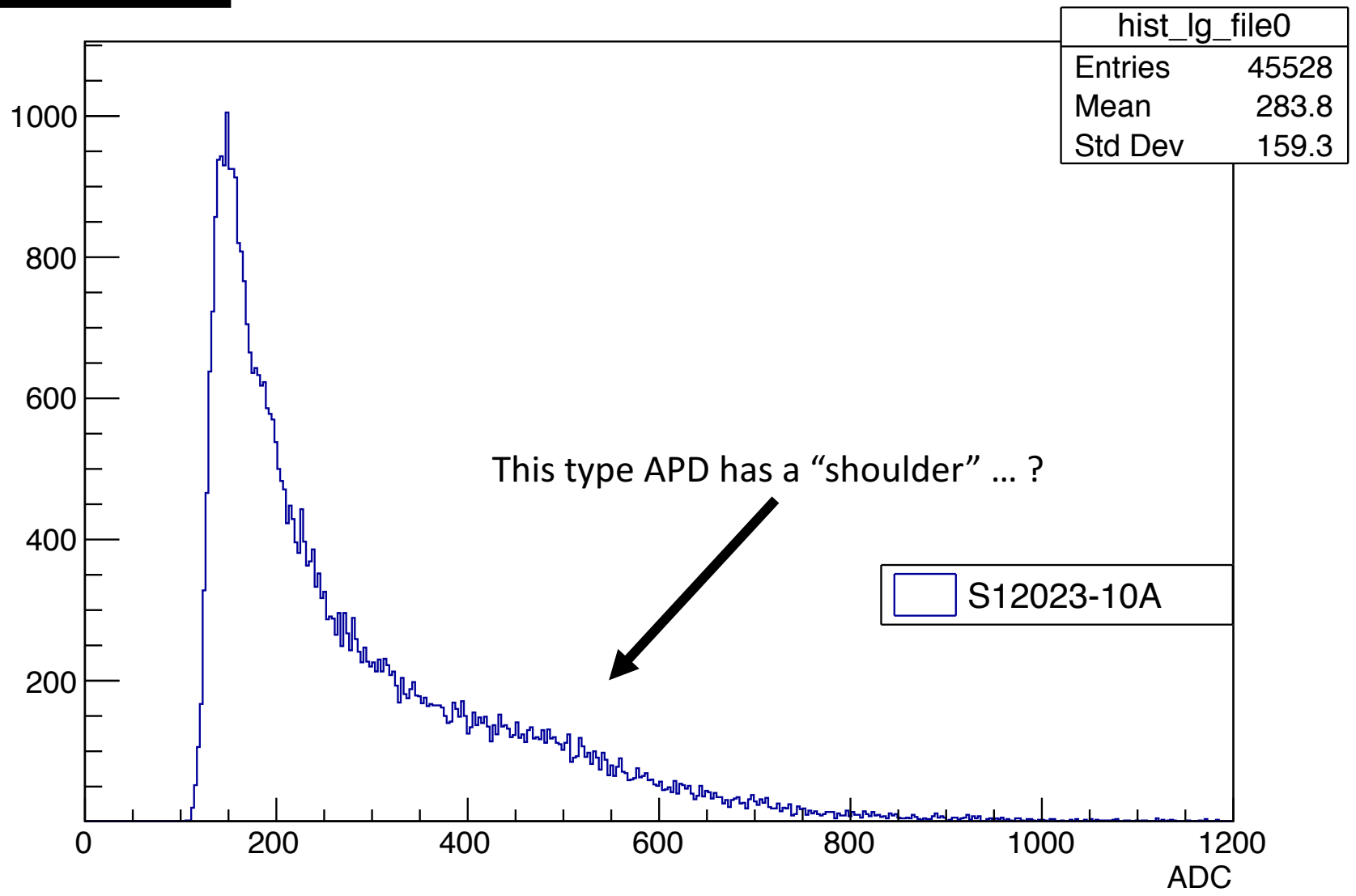

High gain histogram
hist_hg_file0
Entries 45528
Mean 1784
Std Dev 343.3
threshold
ADC value overflows for all reach-through types
S12023-10A
S8664-10K
pkg-10
pkg-20
S8664-20K
S8664-55
S2384
S3884
500
400
300
200
100
0
500
1000
1500
2000
2500
3000
ADC

Result


Low gain histogram
threshold
hist_lg_file0
Entries 45528
Mean 283.8
Std Dev 159.3
• Large size APDs → Signal height is slightly big
• Inverse type's signal height is smaller than reach-through type
S12023-10A
S8664-10K
pkg-10
pkg-20
S8664-20K
S8664-55
S2384
S3884
700
600
500
400
300
200
100
0
200
400
600
800
1000
1200
ADC

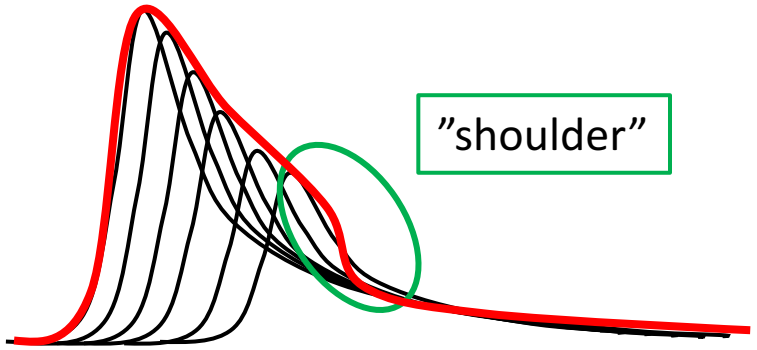
Result

S12023-10A only



Result

Due to the gain variation inside the APD, signals by ^{90}Sr will be landau distribution for each gain (such as black lines), and the total distribution can be like red line



The “shoulder” will be made by the landau distribution of the maximum gain

The active thickness can be calculated using the “shoulder”

The relation between Charge and ADC output of SKIROC2cms are known (such as right figure)

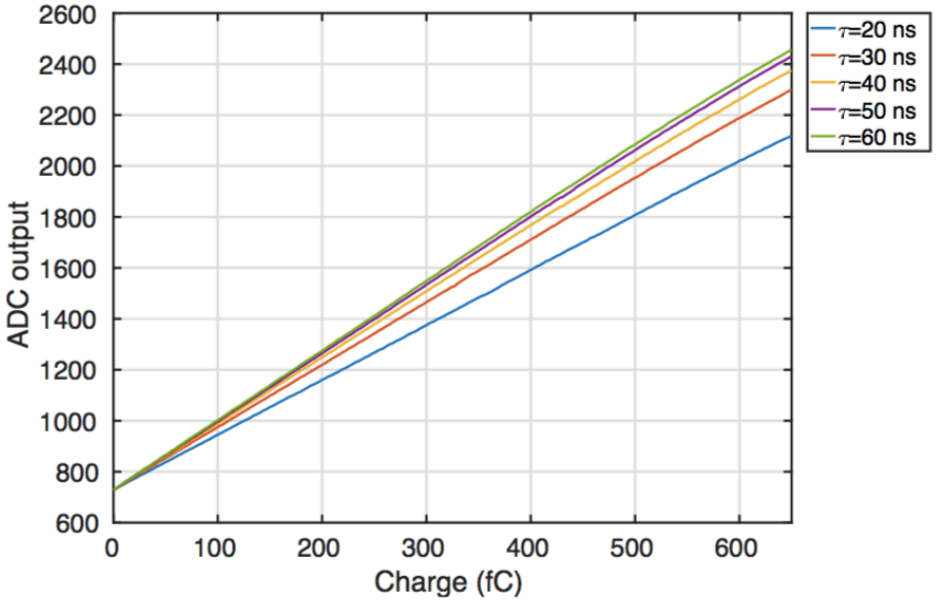
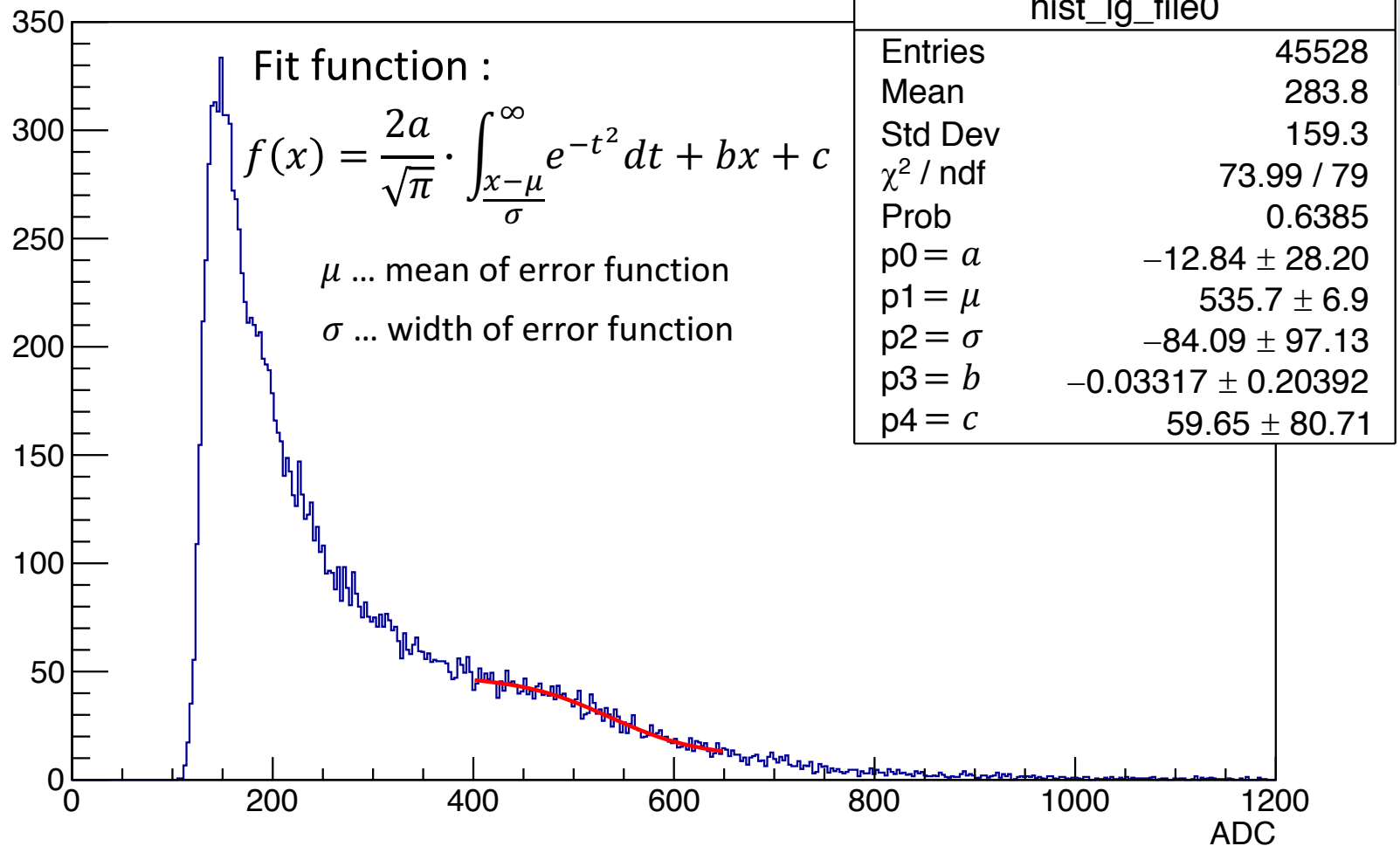


Figure 19: Low-gain transfer function for different shaper settings.

Result

- S12023-10A (reach-through)

S12023-10A



Result

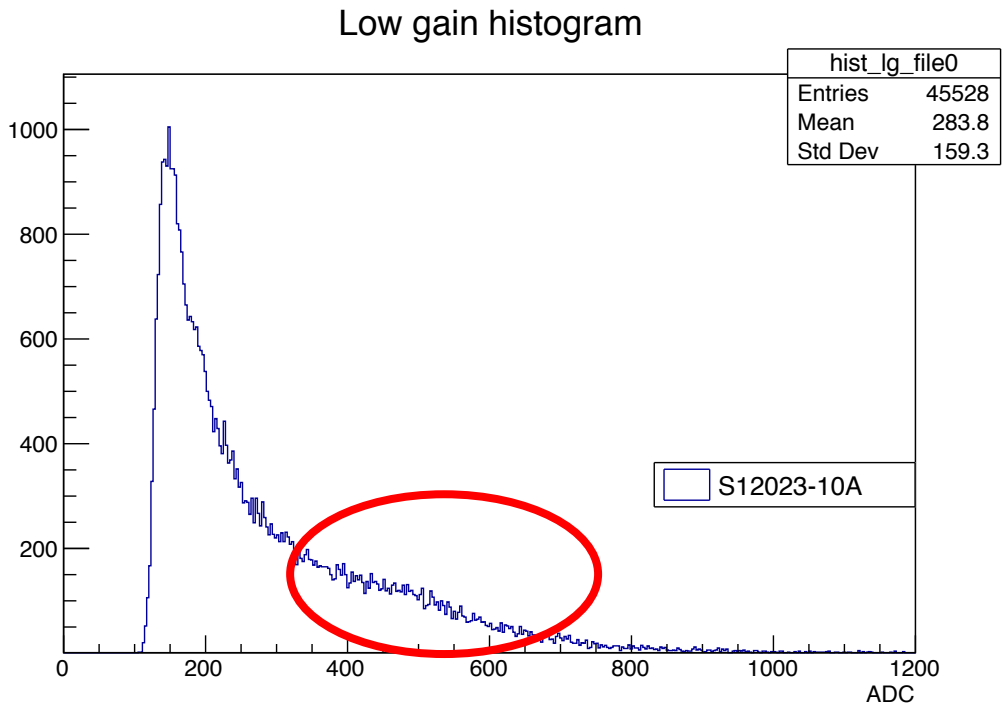
- Active thickness

A MIP particle makes 76 electron and hole pairs per 1 μm in a silicon sensor

Active thickness $=$

$$\frac{\mu}{a} \cdot \frac{1}{\mathrm{Gain}} \cdot \frac{1}{76 \cdot e} \ [\mu\mathrm{m}]$$

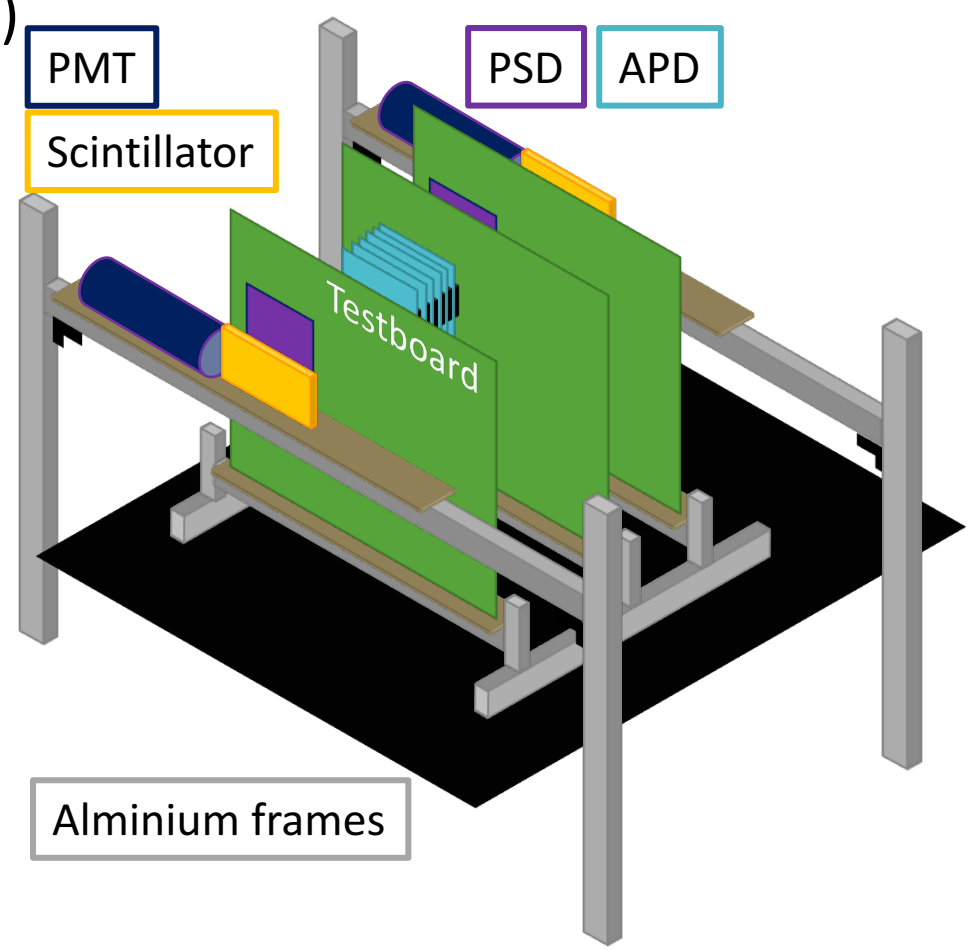
$a =$ ADC output / Charge [/C]
$= 2.25 \times 10^{15}$
$\mu =$ mean of fit function
$e =$ Elementary charge [C]

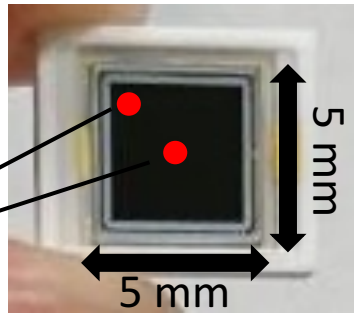


Active thickness of S12023-10A : ~40 μm

Preparation of Test Beam

- ✓ Place : ELPH (Tohoku University)
- ➢ Basic characteristics
  - Active thickness
  - Comparison between Reach-through type and Inverse type
- ➢ Time resolution
  - Measurement time resolution using the three identical type APDs
- ➢ Position dependence in sensor
  - ADC measurement at several points in a sensor



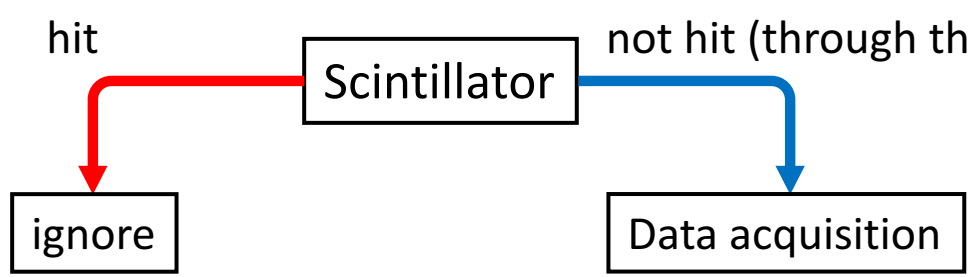


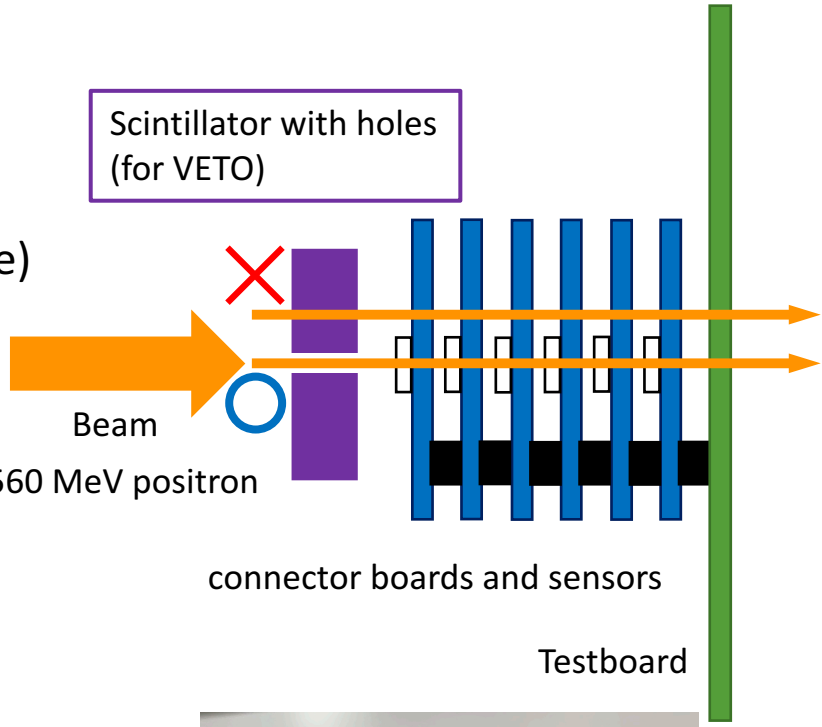
Compare the characteristics at the center and corner

Preparation of Test Beam

- Active collimator

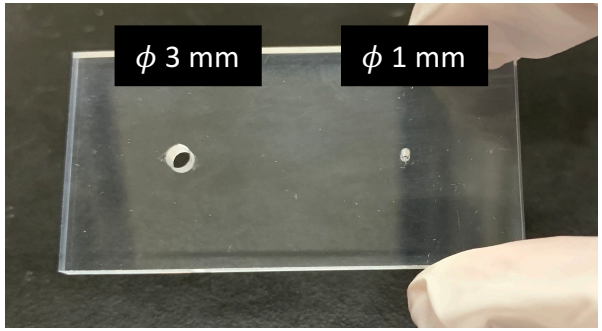
Scintillators will be used as collimator



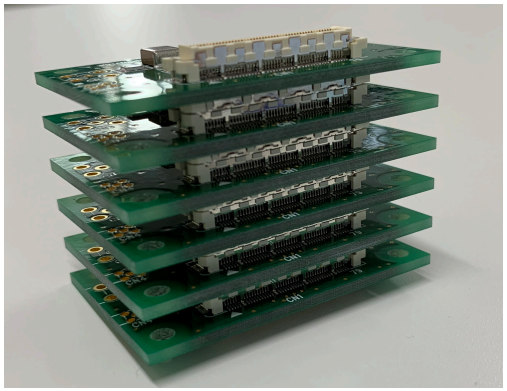


↓ The signal of scintillator is read out by PMT

PMT



Scintillator



stacking connector boards

Summary

- Signal heights are measured with 8 types of APDs for development of LGADs
- SKIROC2cms was used to take data
- Differences between reach-through type and inverse type were obtained
- In S12023-10A (reach-through), the active thickness was estimated
- Test Beam preparation is ongoing

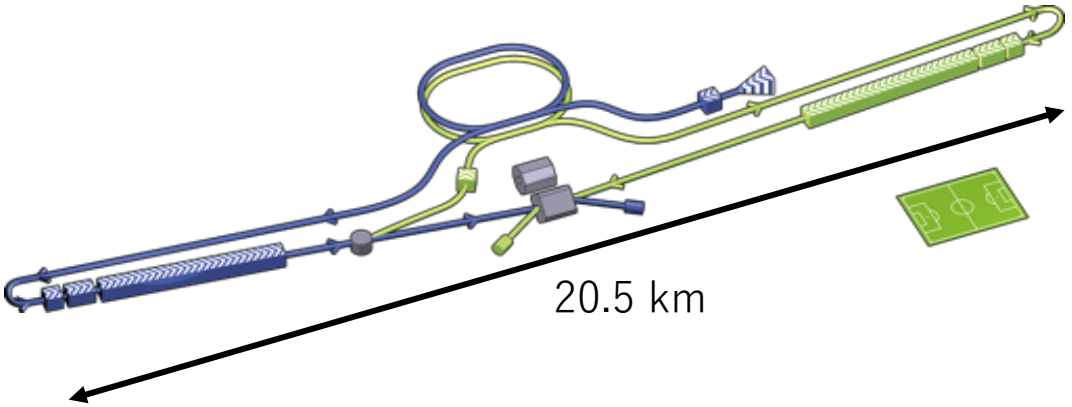
➢ Next step

- Analysis of the Test Beam data
- Producing the LGAD prototype for ILC

Back up

International Linear Collider (ILC)

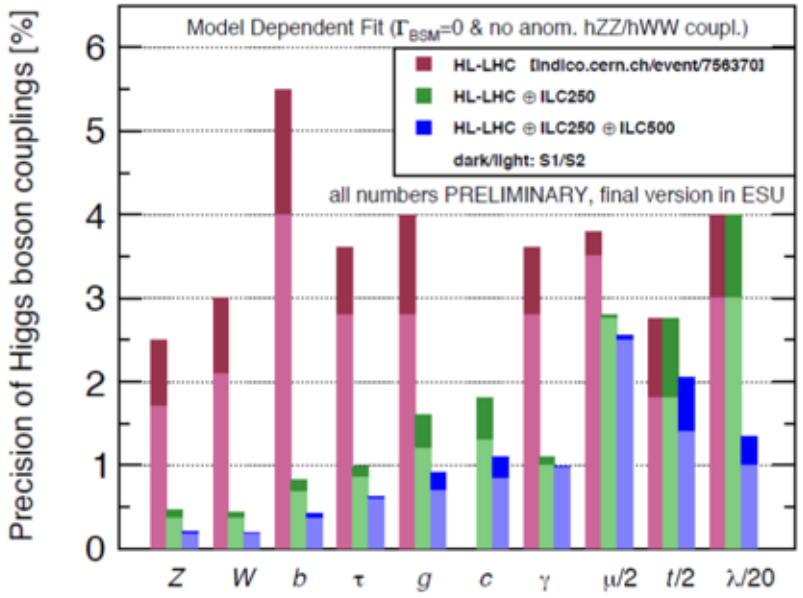
- What is the ILC ?
  - Electron and positron collider
  - Site : Mt. Kitakami, Japan
  - $\sqrt{s} = 250$ GeV
    → Up to 1 TeV in the future
  - Length：about 20 km
  - Search for new physics with precise measurement of Higgs and other particles



HL-LHC only

HL-LHC + ILC250

HL-LHC + ILC250 + ILC500



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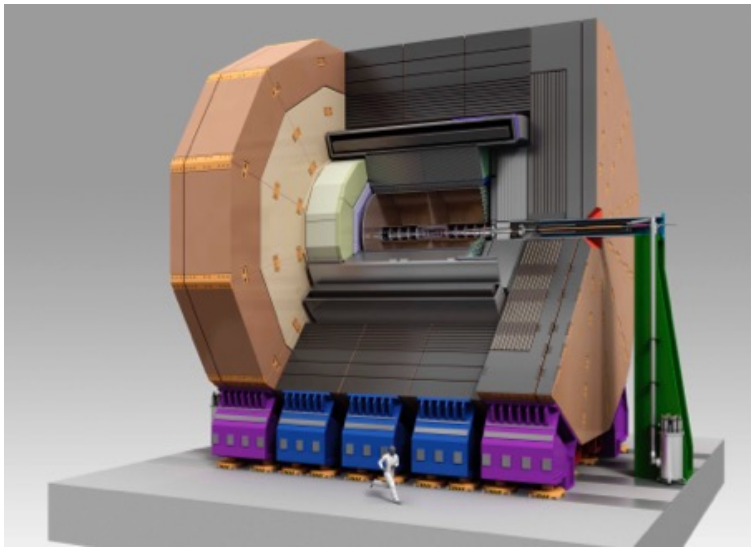
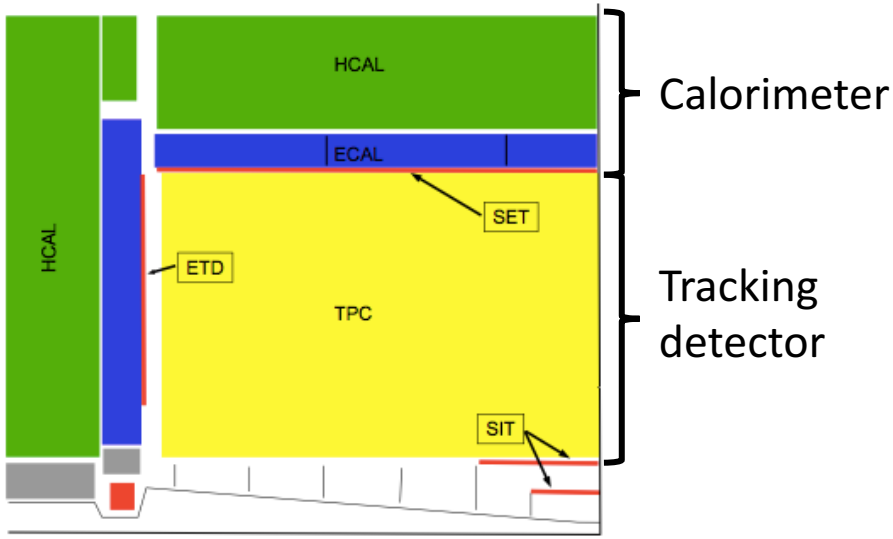
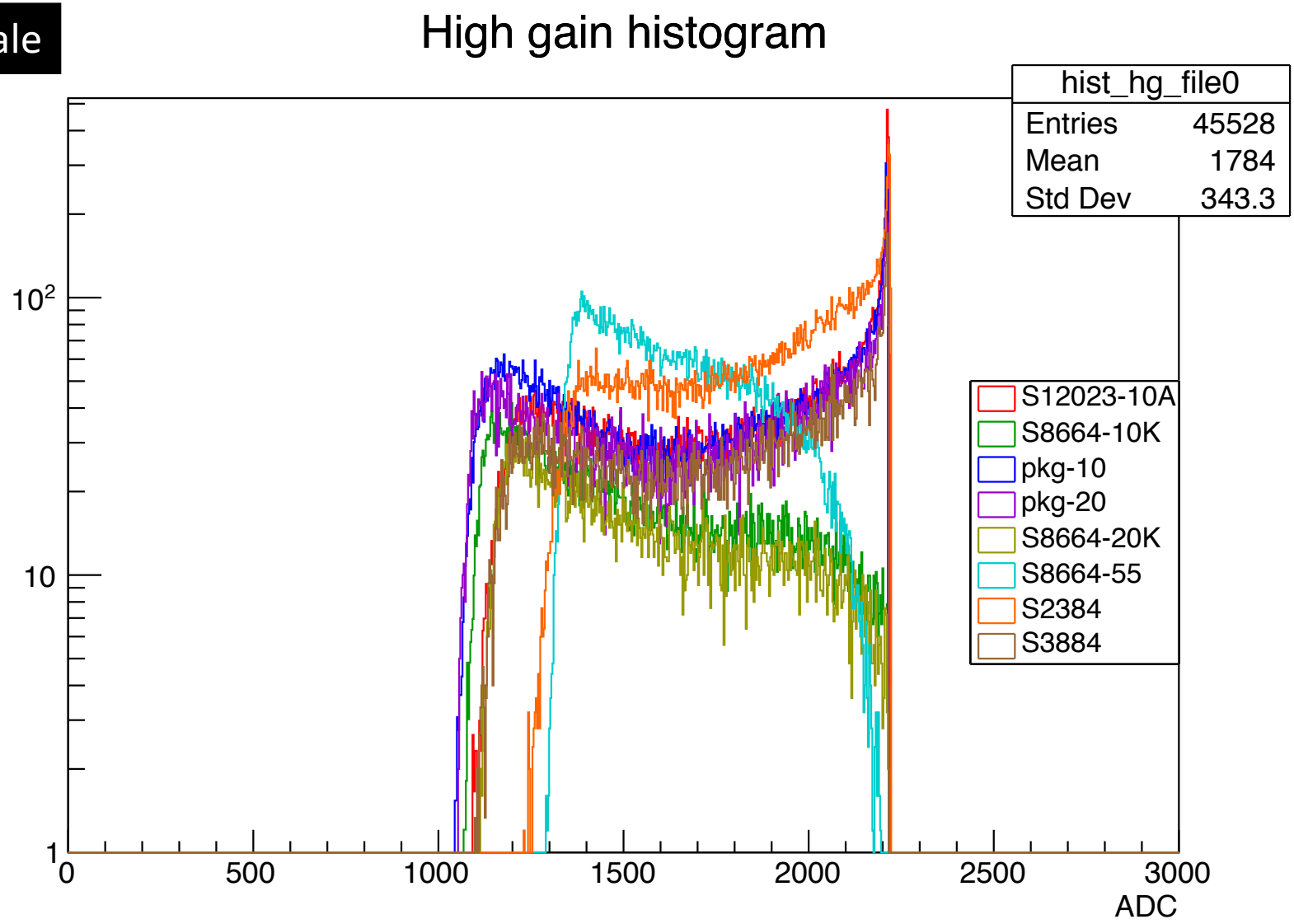


International Large Detector (ILD)



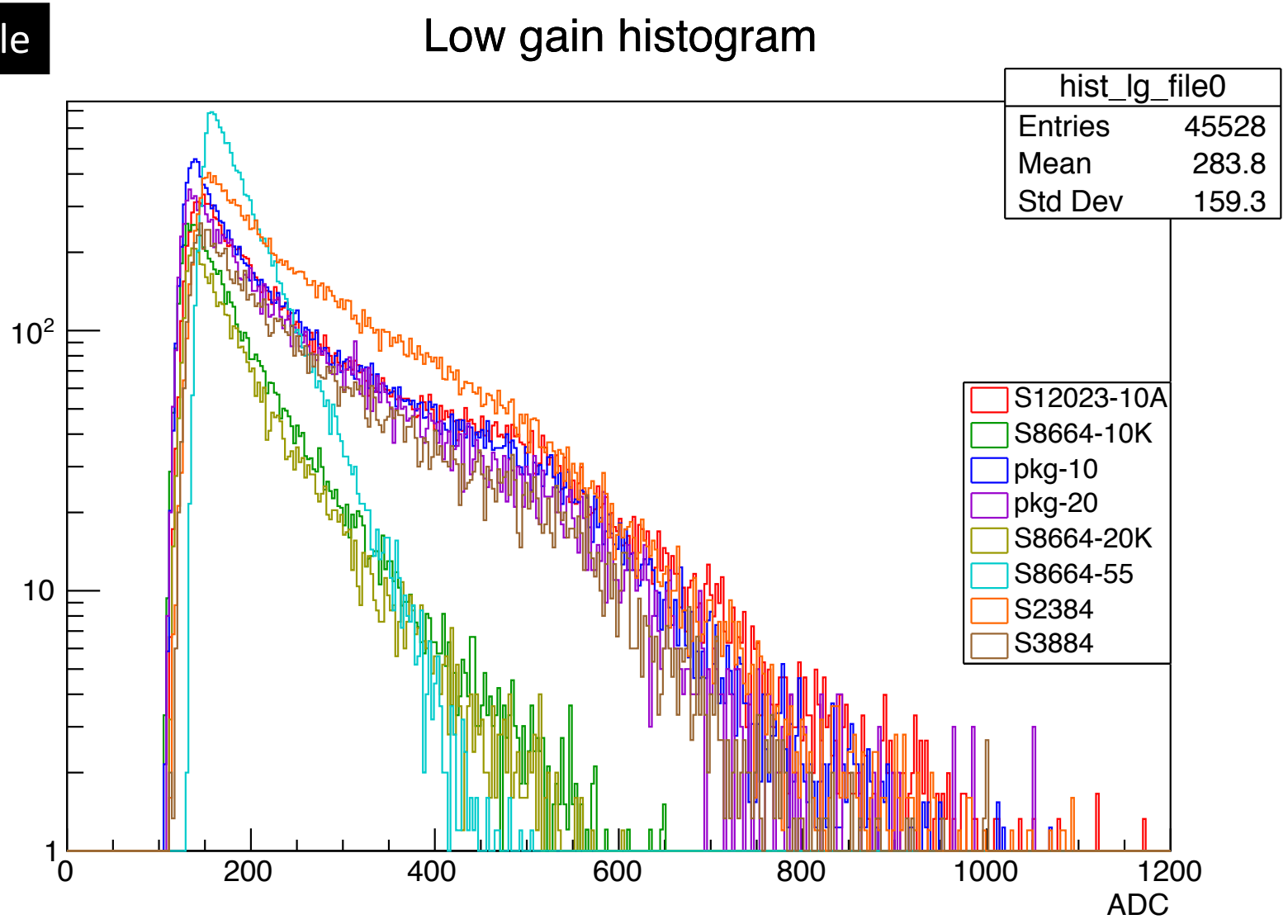
Measurement using β source

Log scale

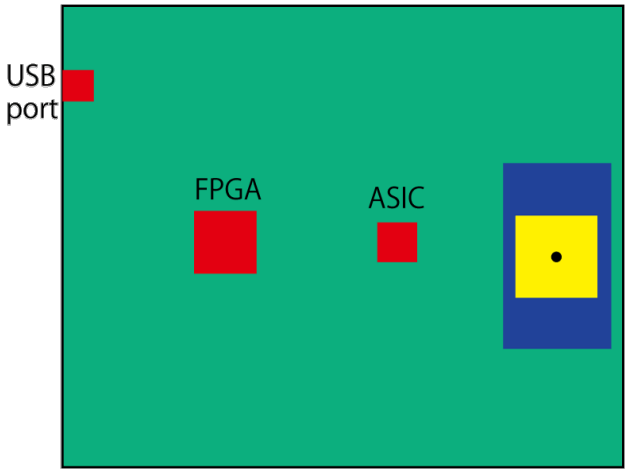


Measurement using β source

Log scale



Test Beam Overview



Testboard