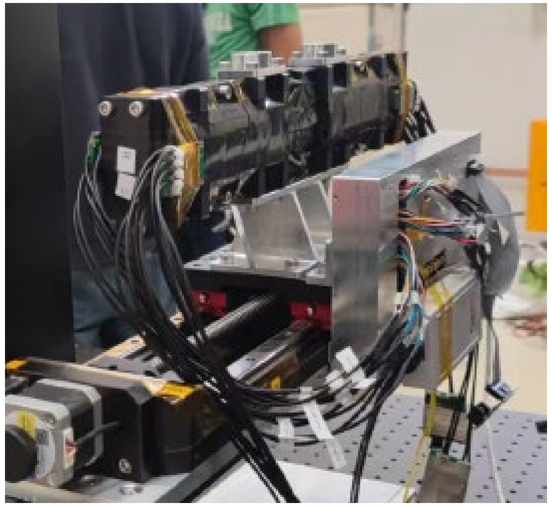
# Nonlinear function of PSD from TB Analysis

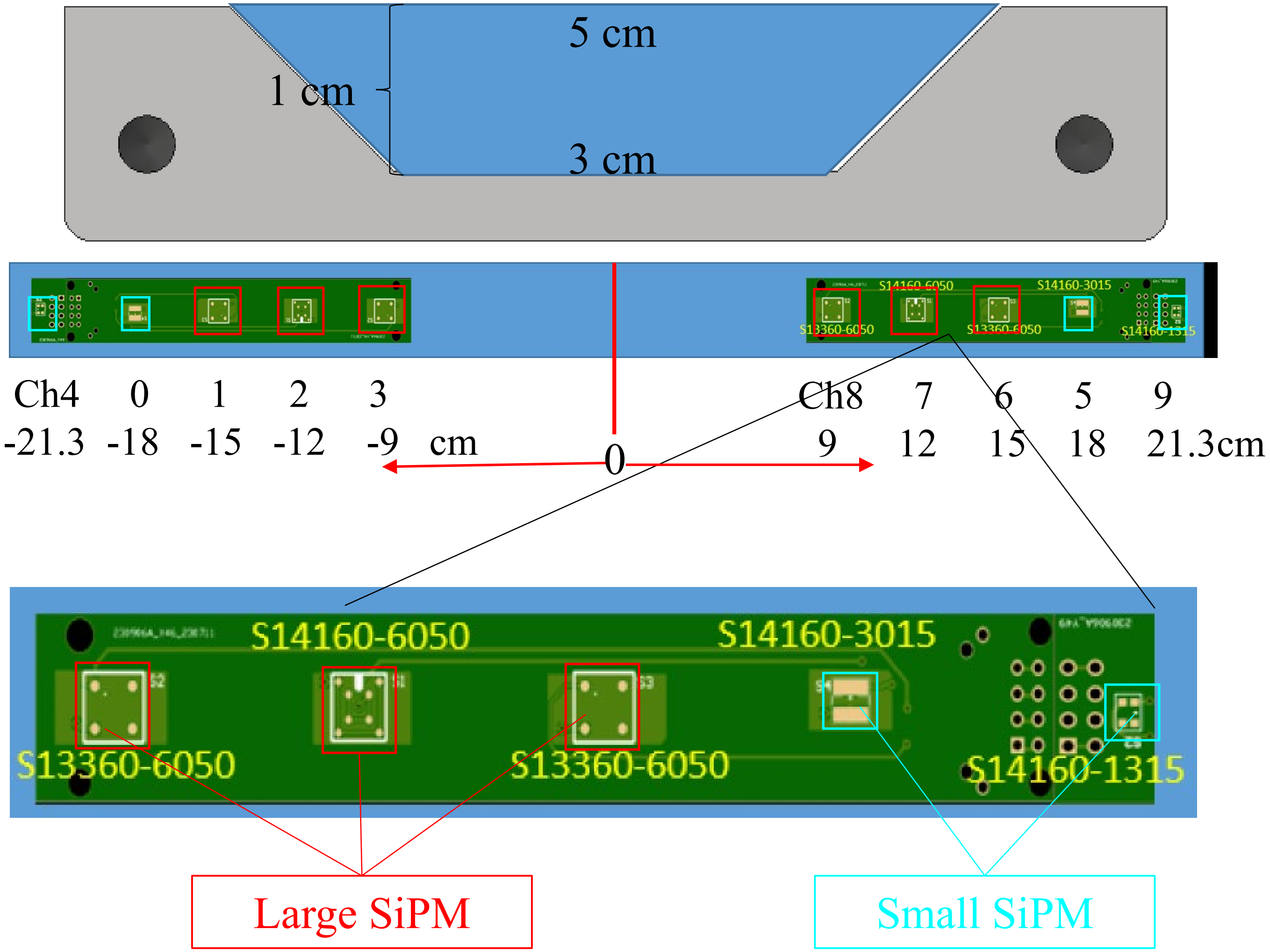
Hengyi Cai, Mengjiao Li, Quanyin Li, Zhicheng Tang

2024.09.05

# Introduction of PSD

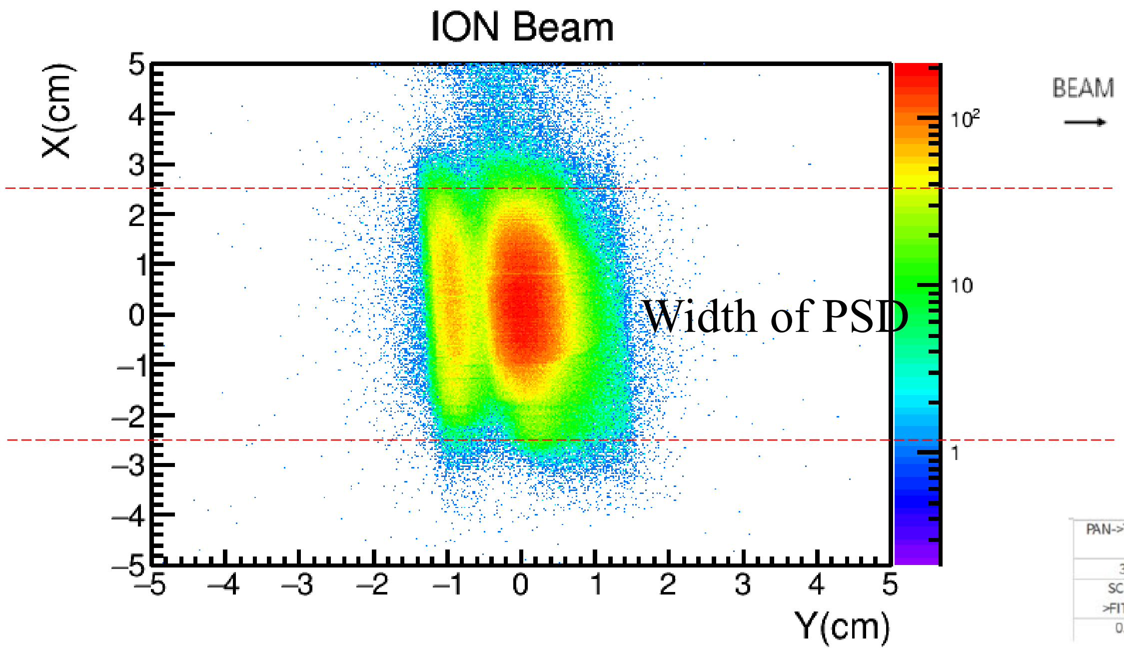
- Geometry of PSD:
  - Two PSD assembled
  - Framework: nylon66
  - Size: 45 cm * 1 cm * (3 ~ 5 cm)
  - PSD is covered by ESR film (65 nm).
  - Ten SiPMs on each PSD
  - 6 chs with high gain & 4 chs with low gain



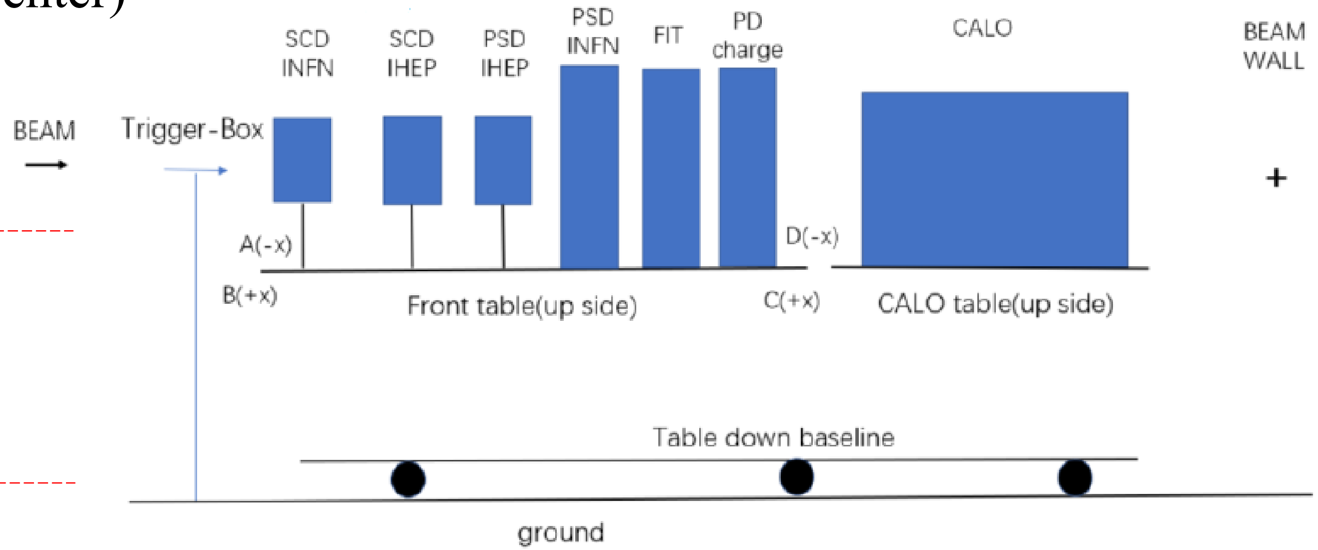


# Setup and data of SPS IONs

- Run summary (position: movement along X):
  - Hadron (330 GeV/n) in position: 0 mm (center)

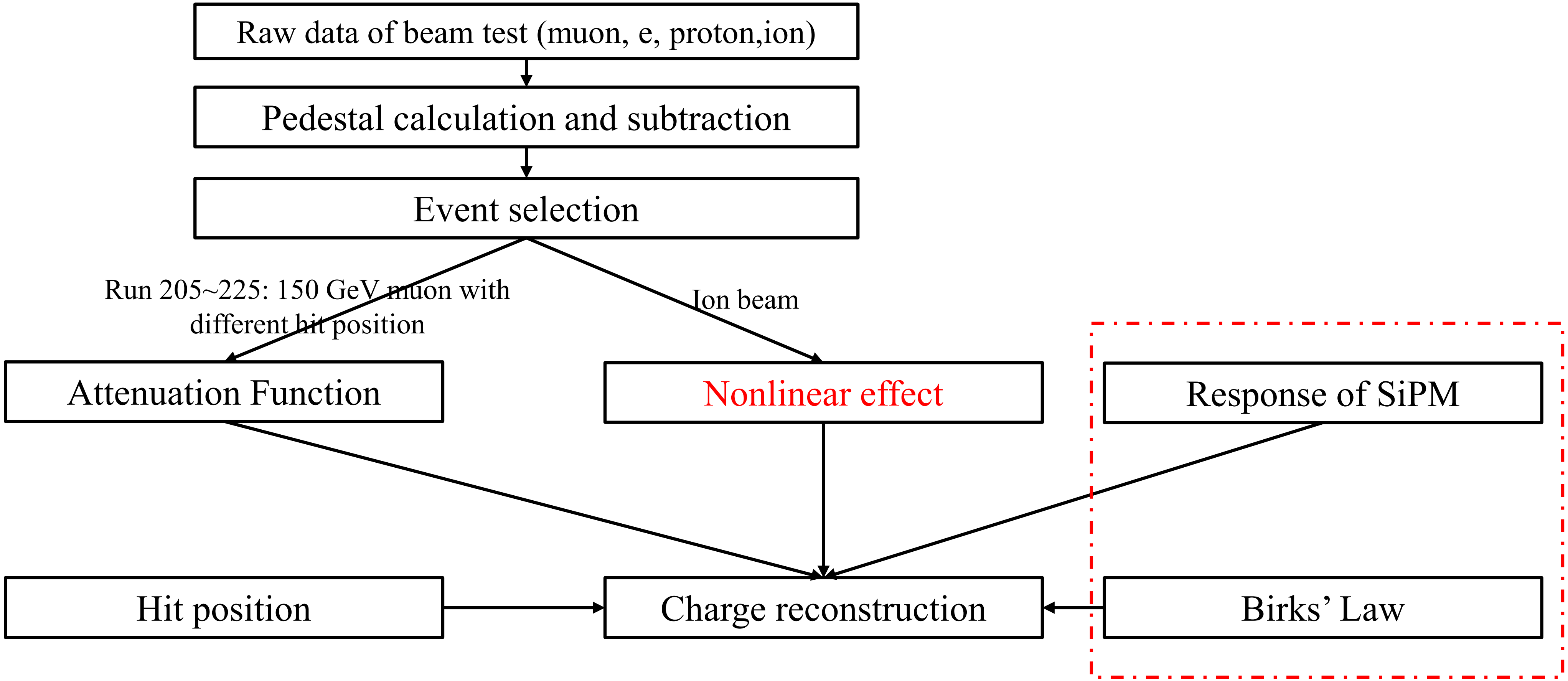



Beam Profile of SPS IONs




| PAN->Trigger_box | Beam_tube->Trigger_box | Trigger_box edge outside width | Trigger_box->SCD_INFN | SCD_INFN width | SCD_INFN->SCD_IHEP | SCD_IHEP width | SCD_IHEP->PSD_IHEP | SCD_IHEP->PSD_INFN |
|---|---|---|---|---|---|---|---|---|
| 3.507m | 0.264m | 0.005m | 0.534m | 0.117m | 0.2848m | 0.13m | 0.177m | 0.365m |
| SCD_INFN->FIT(side_B) | SCD_INFN->FIT(side_C) | FIT->CALO | PD_charge->CALO | PD_charge width | | | | |
| 0.2784m | 1.5458m | 0.35m | 0.187m | 0.034m | | | | |

# Process of Beam Test Analysis




- 1. Select the particles with different charges (reference detector SCD_INFN, PD..)
- Calculate the PathLength and sADC/PathLength
- 2. Fit the distribution of PSD sADC/PathLength for different charges and get MPV
- 3. Fit the 2D plots of MPV and referenced charge, get the correlation function.

# Event selection: PD & SCD charge

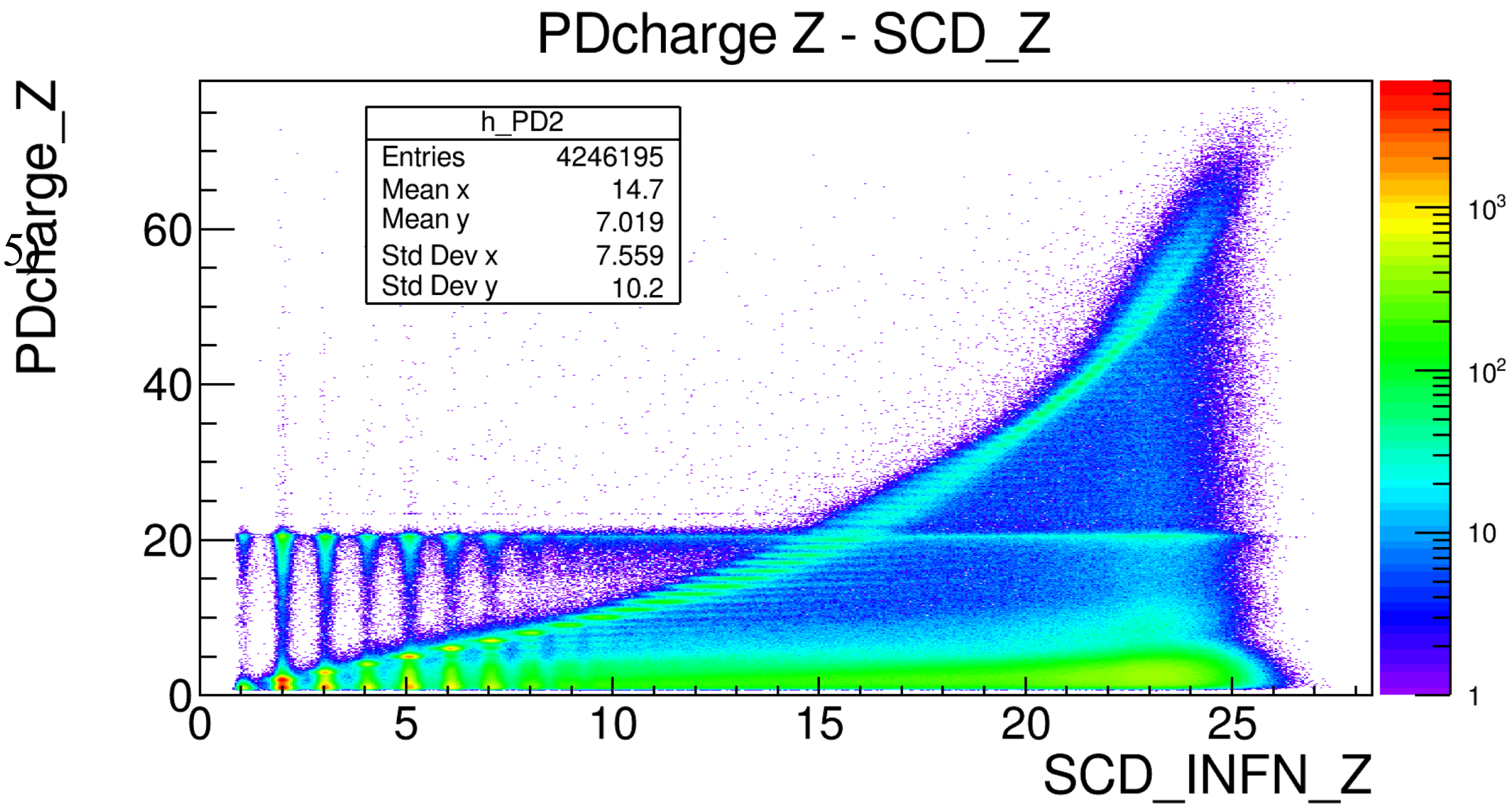
Data: All ion data in SPS

1. Both PD & SCD have signals
2. SCD area($-1.5<x<1.5$, $-3<y<1.5$
3. Chi2 of SCD track fit: $<10$
4. PD signal quality cut:

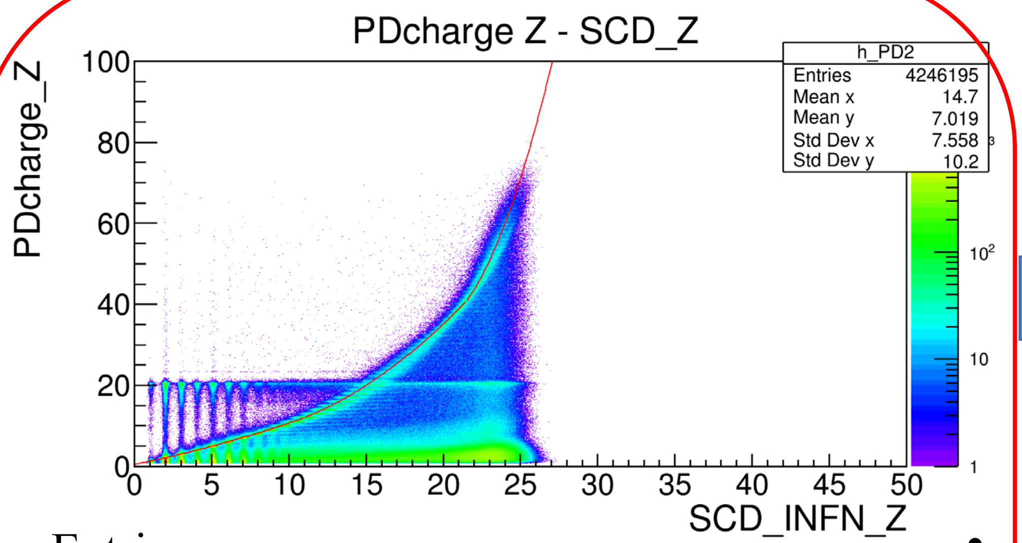
    nPDConsistent==6 &&

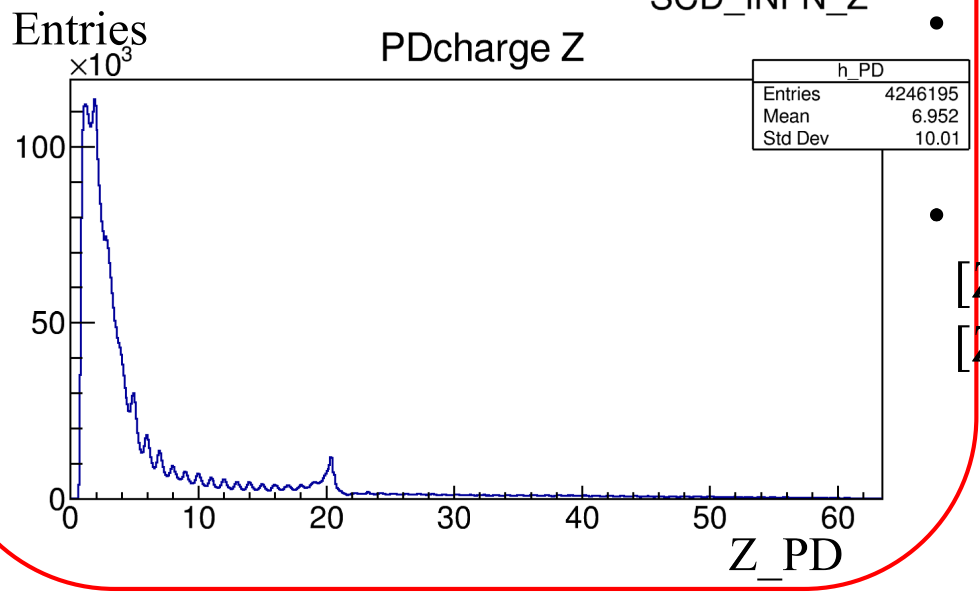
    nPDAboveThresh>4 &&

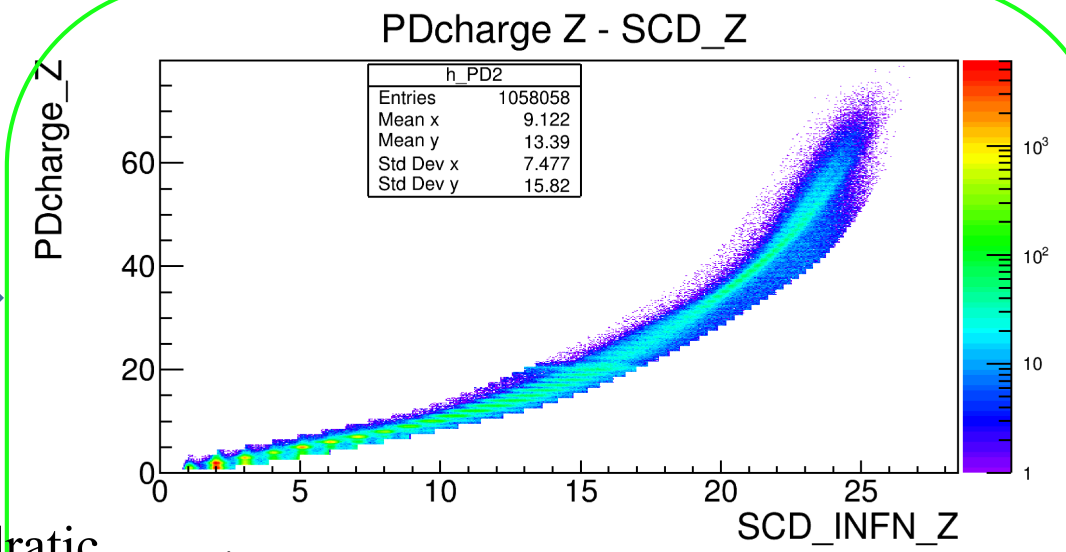
    casisTime>100

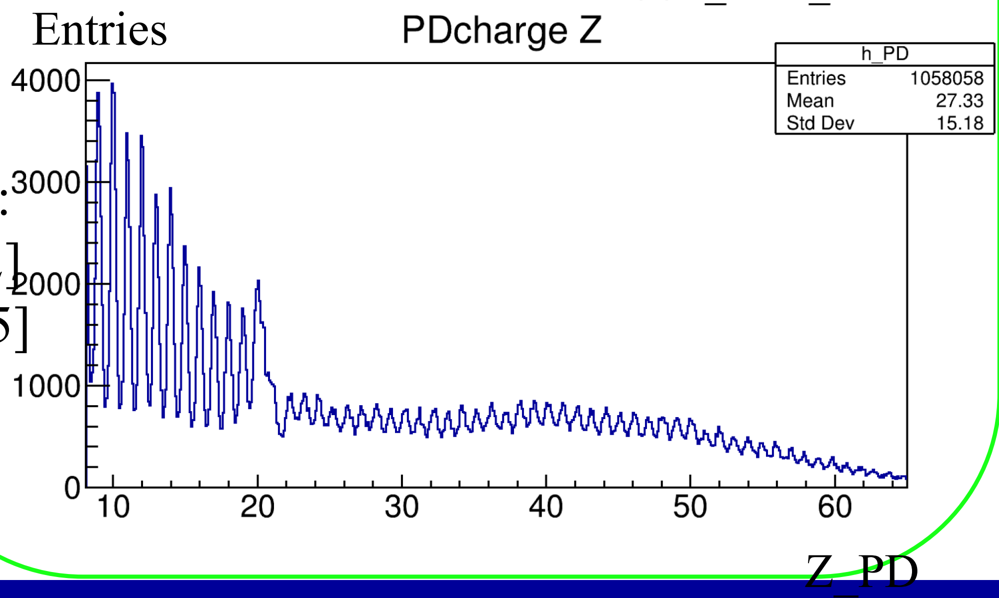


# Event selection: coarse selection



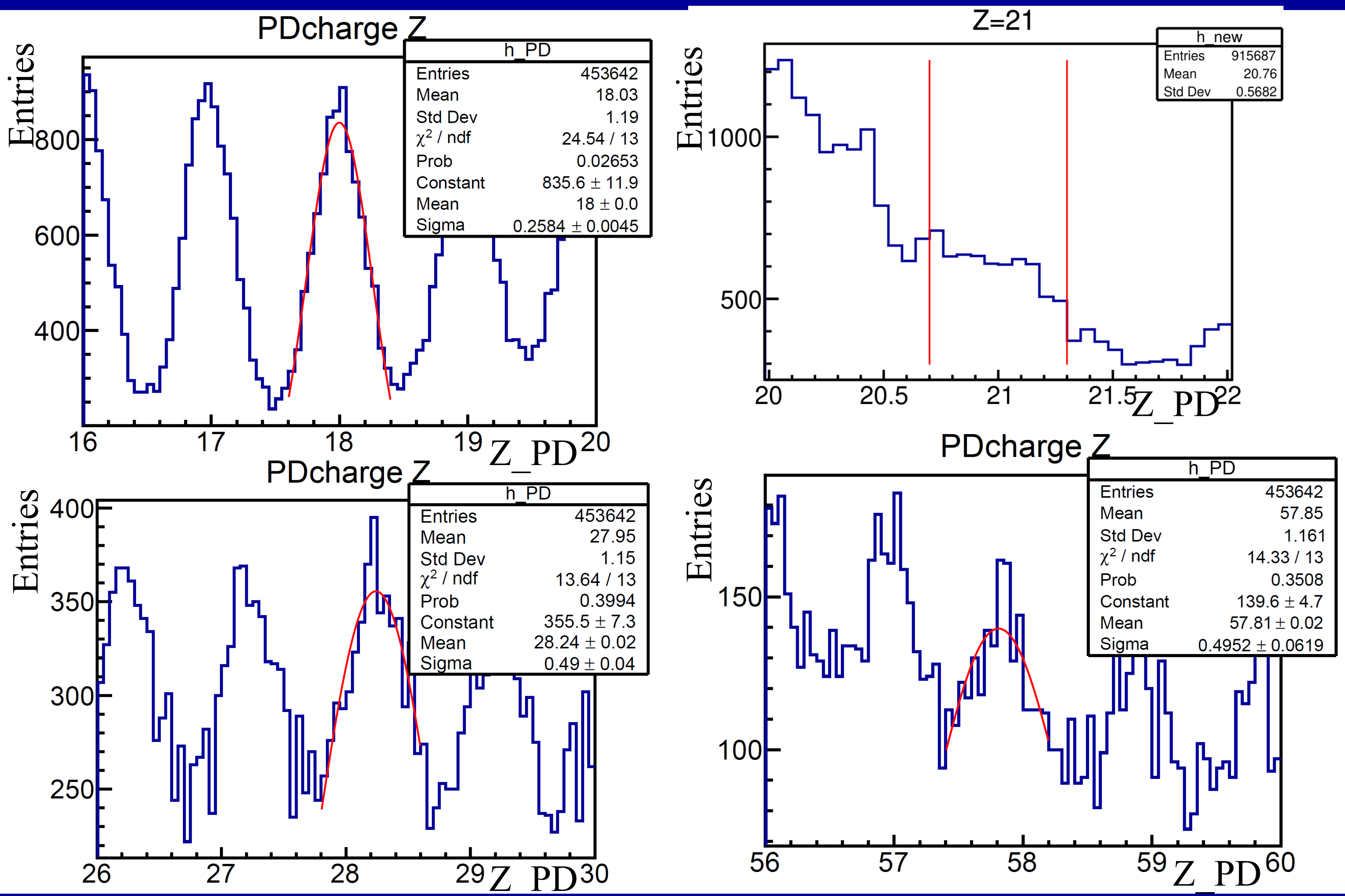




- Use three quadratic function to describe the band area.
- In each point Z_PD:

[Z_SCD-2, Z_SCD+2]
[Z_PD-0.5, Z_PD+0.5]

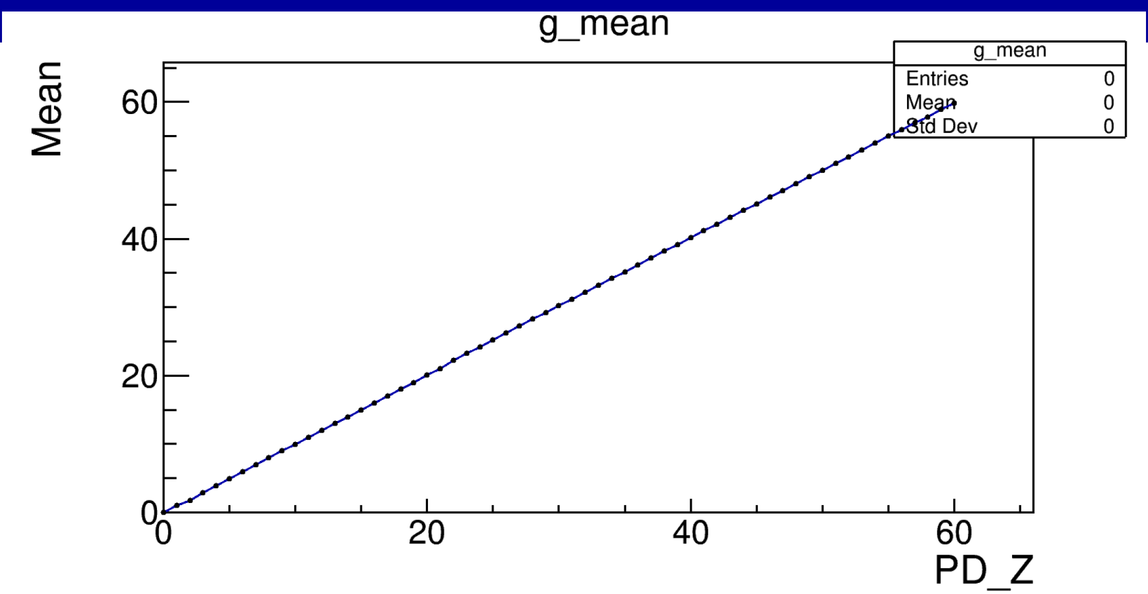
# Event Selection: fit of PD charge

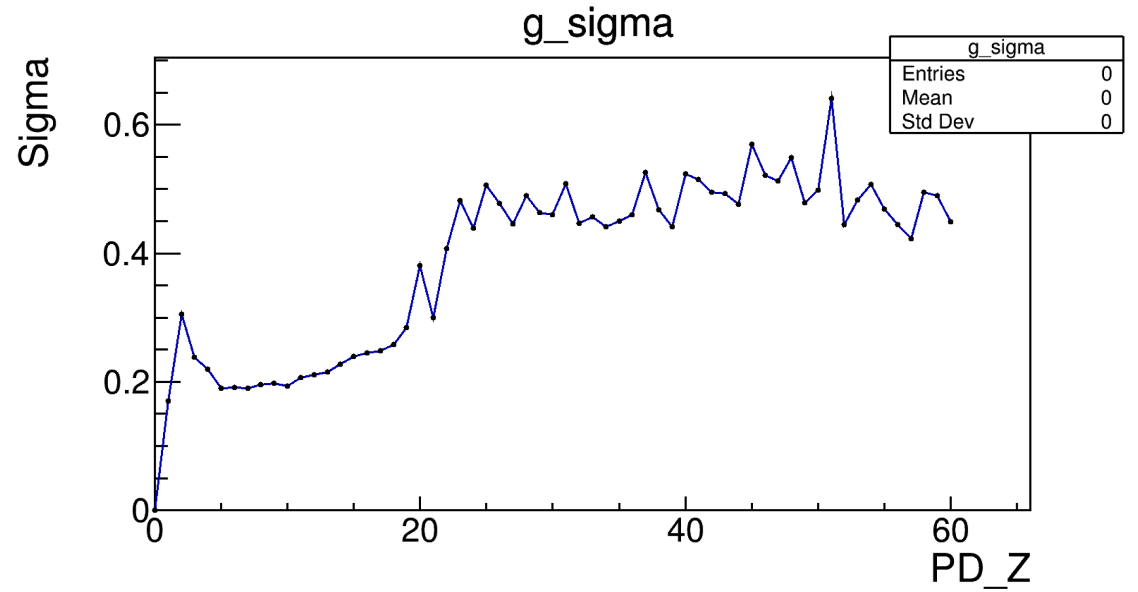
- Use gaussian function to fit the mean value and sigma



# Event Selection: fine selection

- ➢ Events with charge up to 60 can be selected.
- Z ∈ [1,12]: Z_SCD (manually)&& Z_PD+-0.3;
- Z ∈ [13,60]: only Z_PD +- 0.3
  - Z ∈ [13,20]: only Z_PD +- 0.3
  - Z = 21 , the peak is bad, reject this charge.
  - Z ∈ [22,45]: only Z_PD +- 0.3 (peak of Z_PD has about +0.2 offset.)
  - Z ∈ [58,60]: only Z_PD +- 0.3 (peak of Z_PD has about -0.2 offset.)



# Final selected events

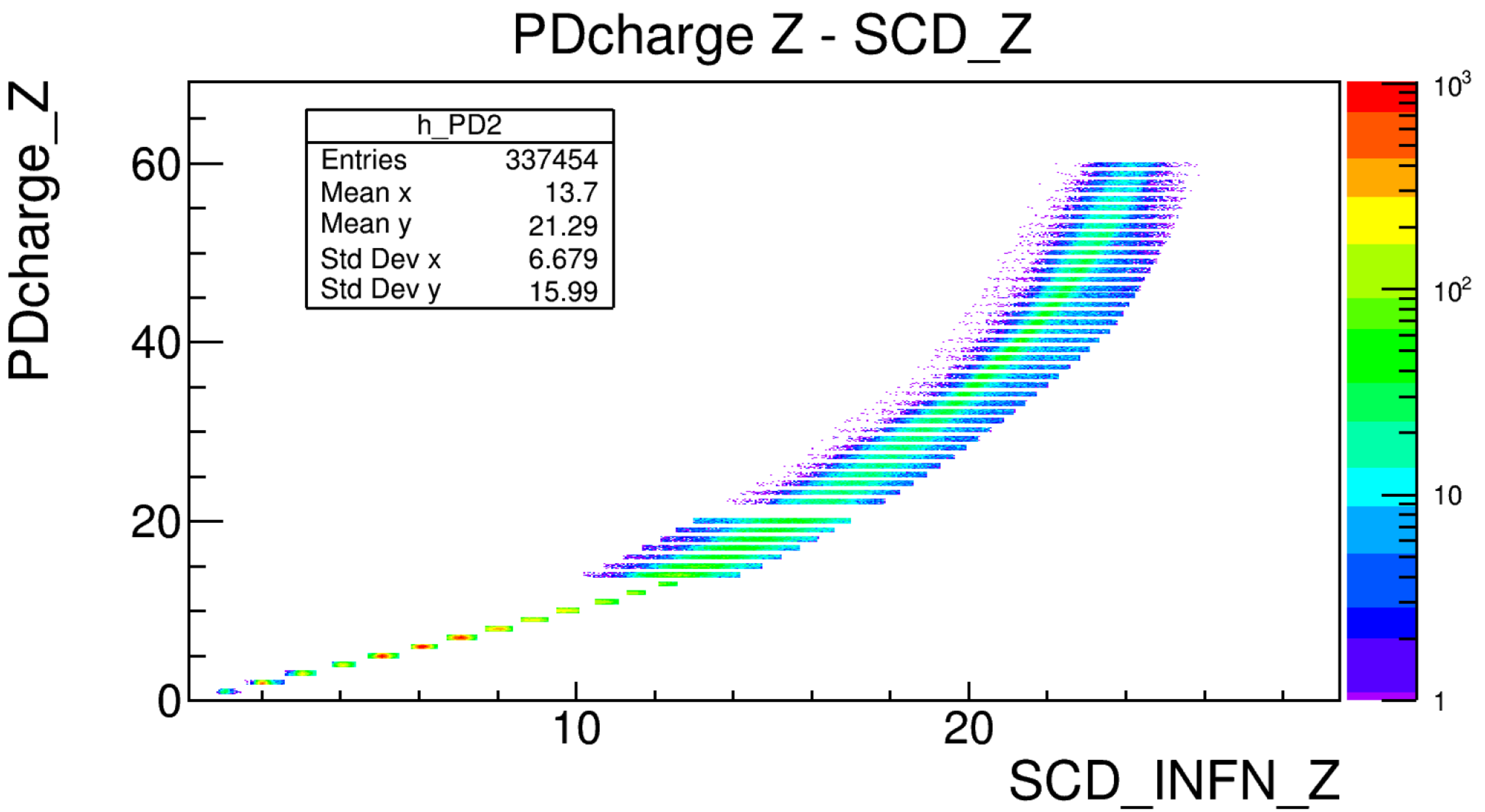
Final event selection requirements:

1. Both PD & SCD have signals
2. SCD area(-1.5<x<1.5, -3<y<1.5)
3. Chi2 of SCD track fit: <10
4. PD signal quality cut:

    nPDConsistent==6 &&

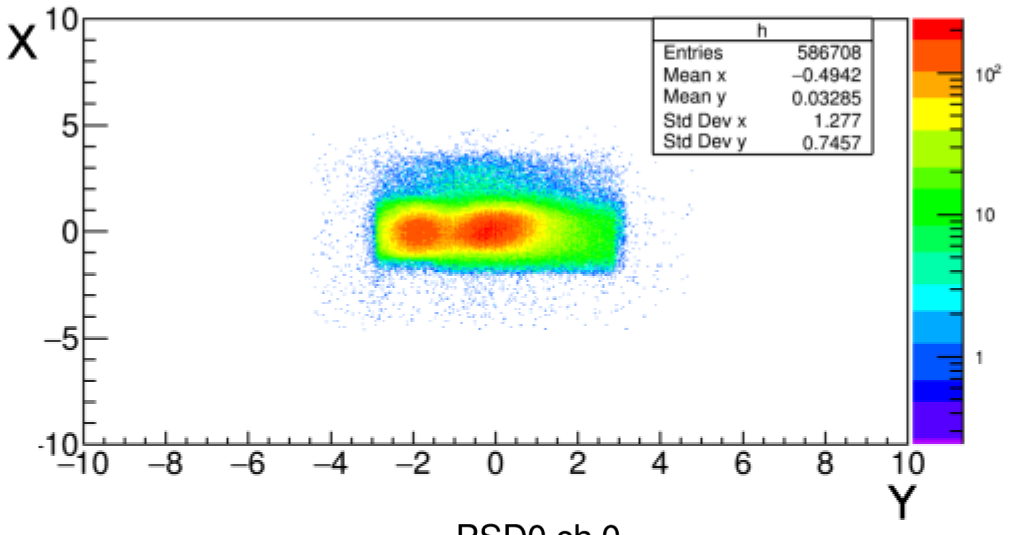
    nPDAboveThresh>4 &&

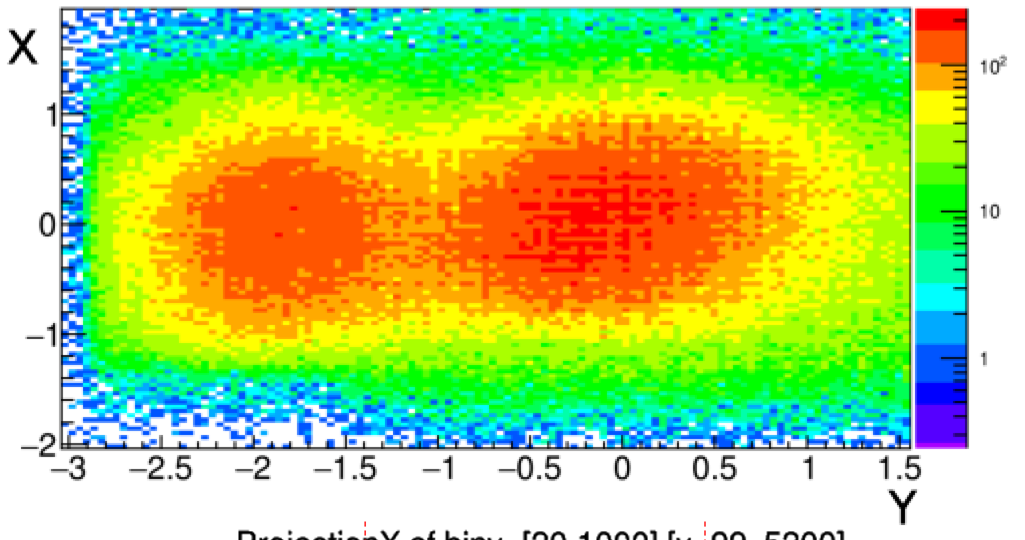
    casisTime>100
5. Coarse selection
6. Fine selection



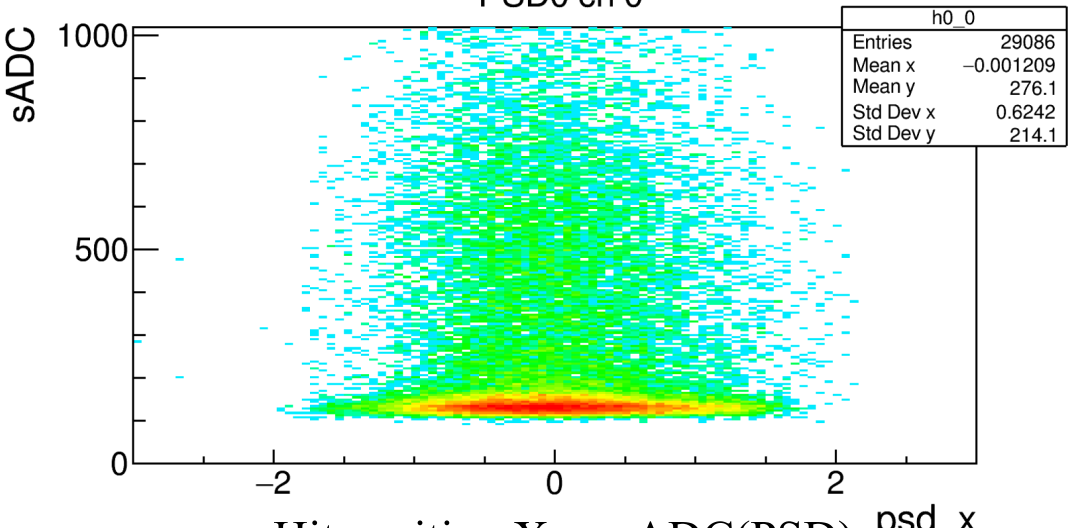
# Alignment of detectors

Beam Profile of SPS Ion (reconstructed by SCD_INFN)

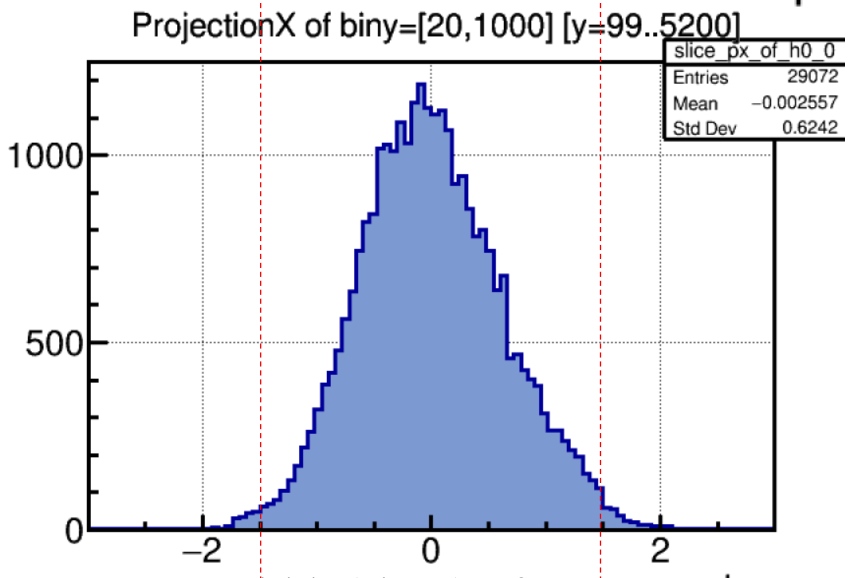



Distribution of hits with the requirement of PSD signals

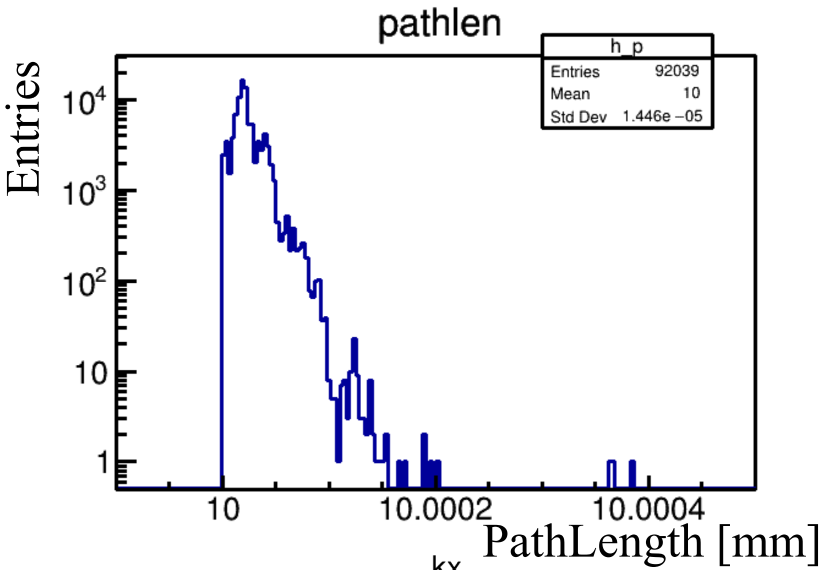


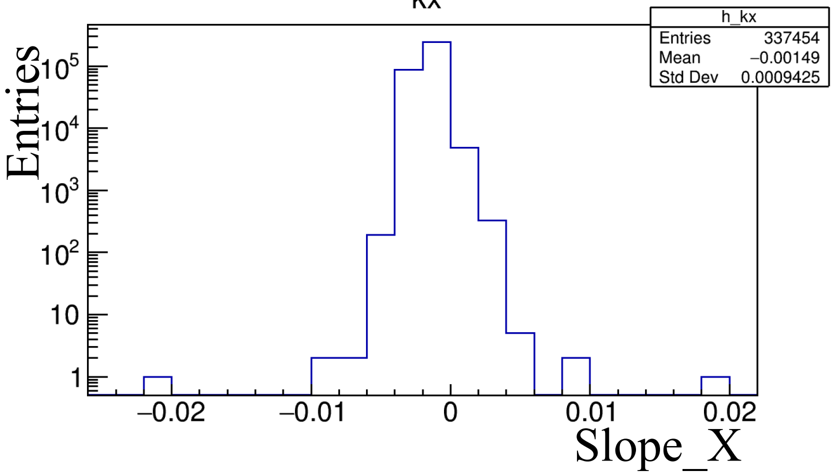

Hit position X vs sADC(PSD)



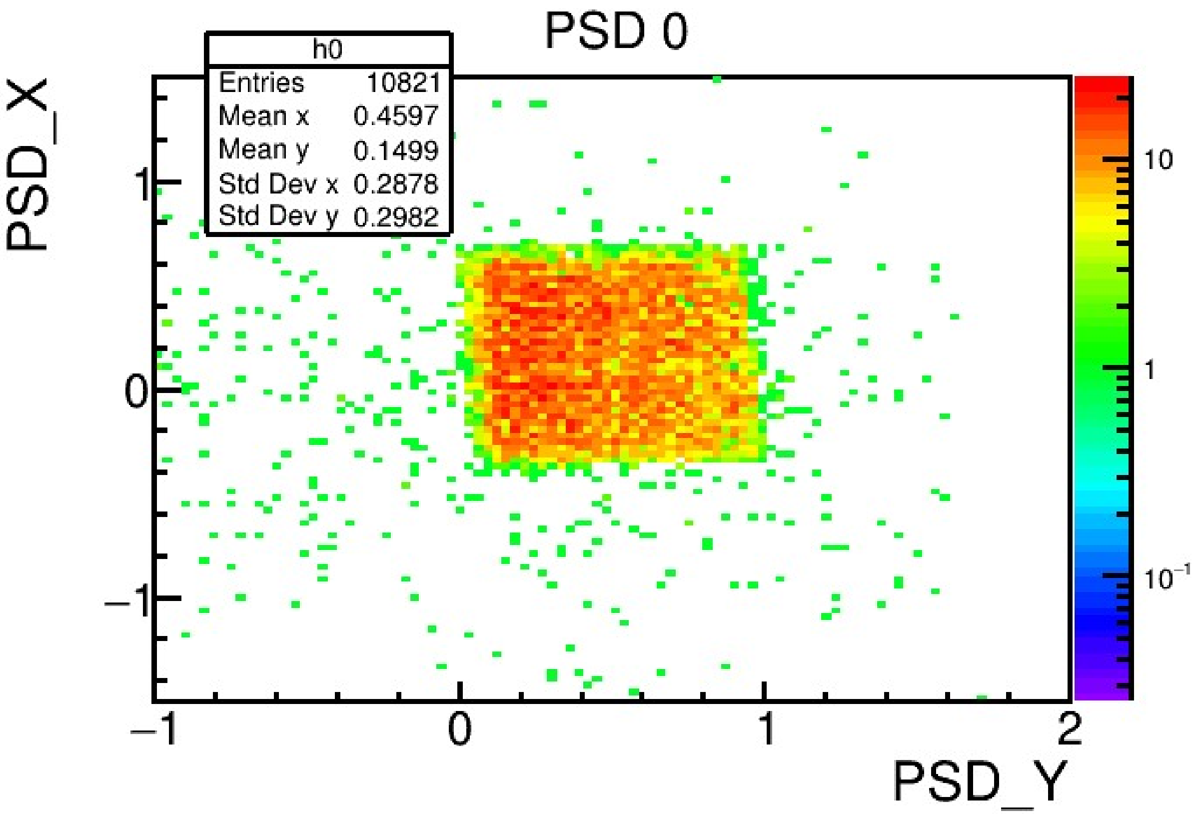

Width (short) of PSD

# Distribution of track



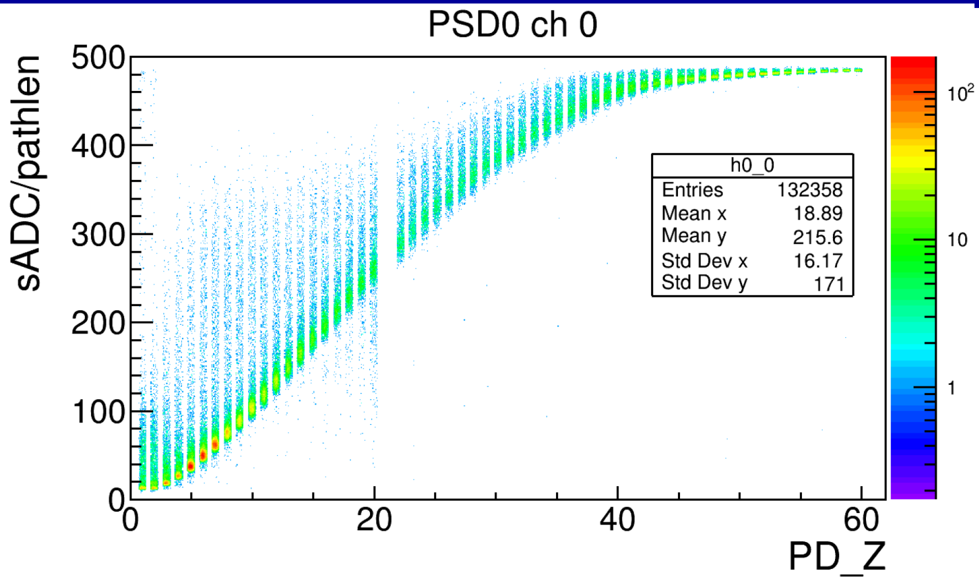

Distribution of track with the events selected by SCD and PSD

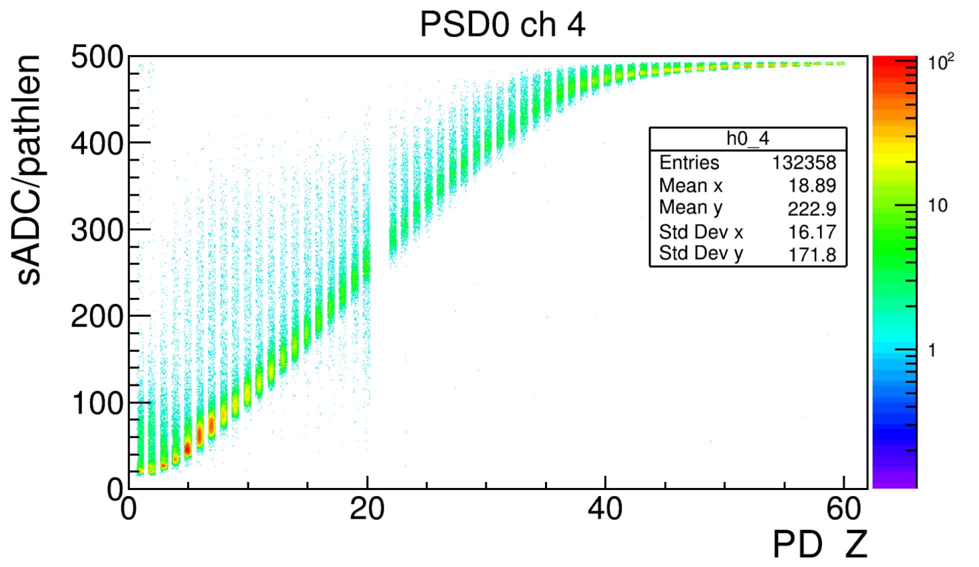


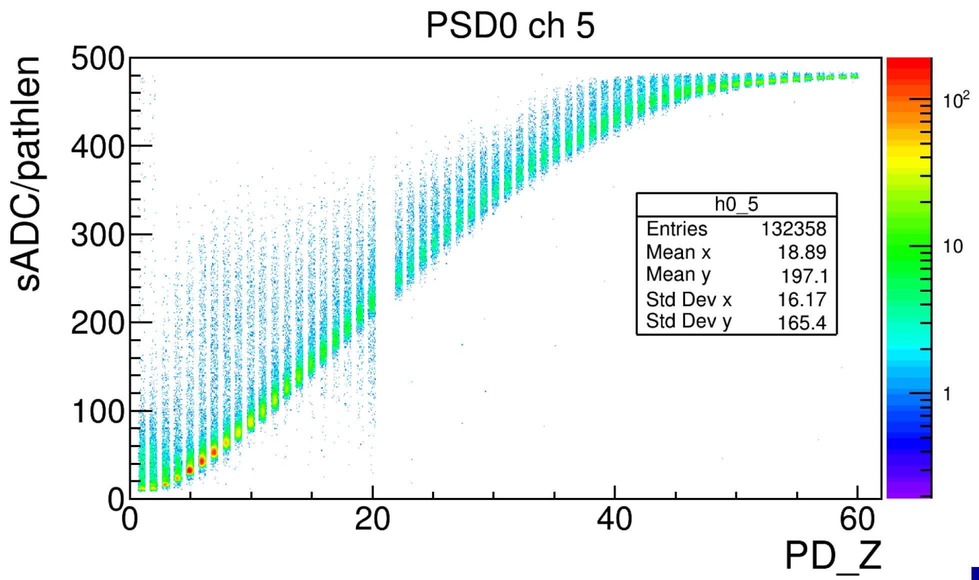

Beam profile of the final selection

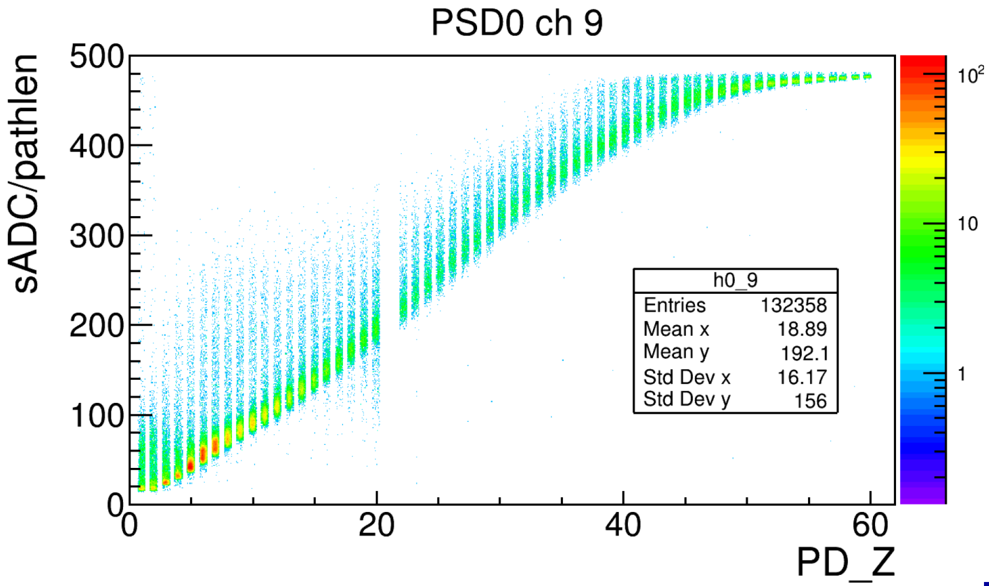
# Distribution of sADC/PathLength

- Data: Run 552 ~ 605 (gain of SiPMs are same.)
- sADC: the raw sADC value of SiPM with pedestal subtraction
- PathLength: The pathlength of particle passing through the PSD, calculated by the SCD track.



# Distribution of sADC/PathLength and Fitting

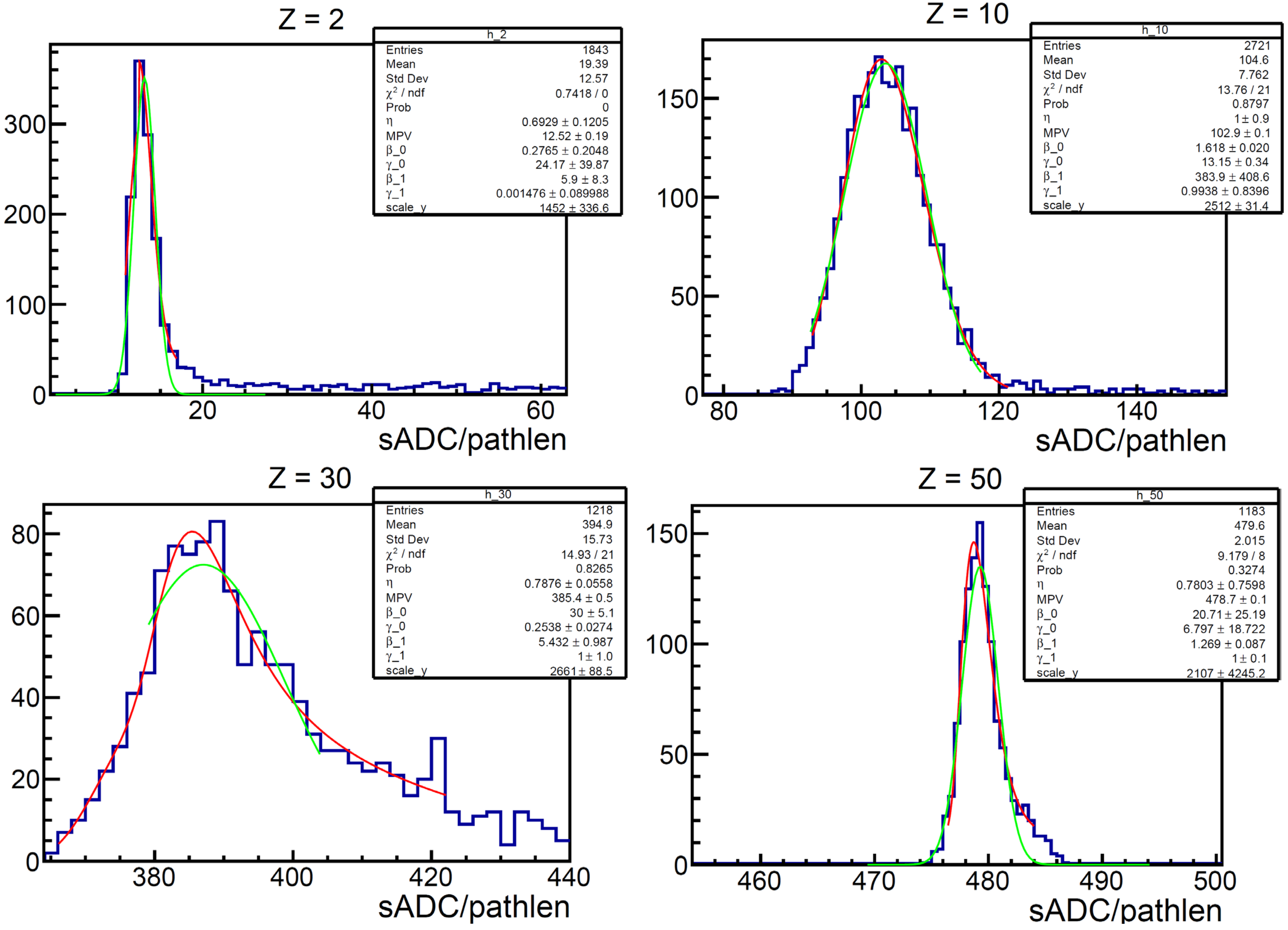
Fitting function:

**MIP template** is defined by the analytic function

$$f(x|\eta,\alpha,\vec{\beta},\vec{\gamma}) = \frac{N\eta}{\Gamma(\gamma_0)\beta_0} e^{\gamma_0\left(\frac{x-\alpha}{\beta_0\gamma_0} + e^{-\frac{x-\alpha}{\beta_0\gamma_0}}\right)} + \frac{N(1-\eta)}{\Gamma(\gamma_1)\beta_1} e^{\gamma_1\left(\frac{x-\alpha}{\beta_1\gamma_1} + e^{-\frac{x-\alpha}{\beta_1\gamma_1}}\right)} \tag{2}$$

$\eta$ is the fraction of the first component, $\alpha$ is the peak position, $\vec{\beta}$ and $\vec{\gamma}$ are the shape parameters. This function is fitted to the MIP energy

- Pre-fit the distribution with gaussion function and get the coarse value of mean.
- Fit the distribution with range around the coarse mean value.
- MPV is got.

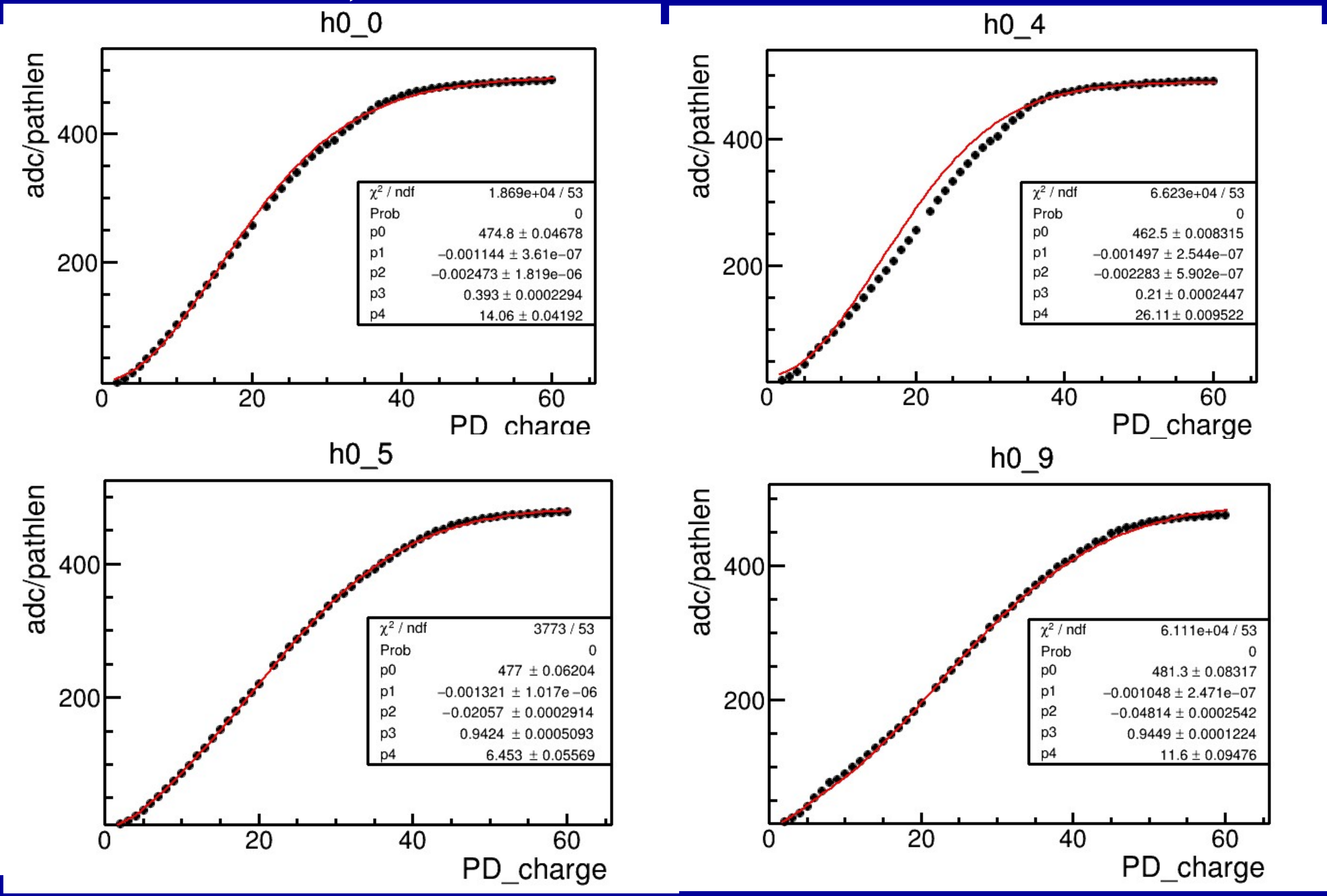


# Result (PSD0 ch0, 4, 5, 9)

Current fitting function:

$$y = p0 * (1 - p3 * exp(p1 * x)) - (1 - p3)exp(p2 * x)) + p4$$

A new function combined with Birks Law, nonlinear of SiPM and saturation of electronics will be tested.



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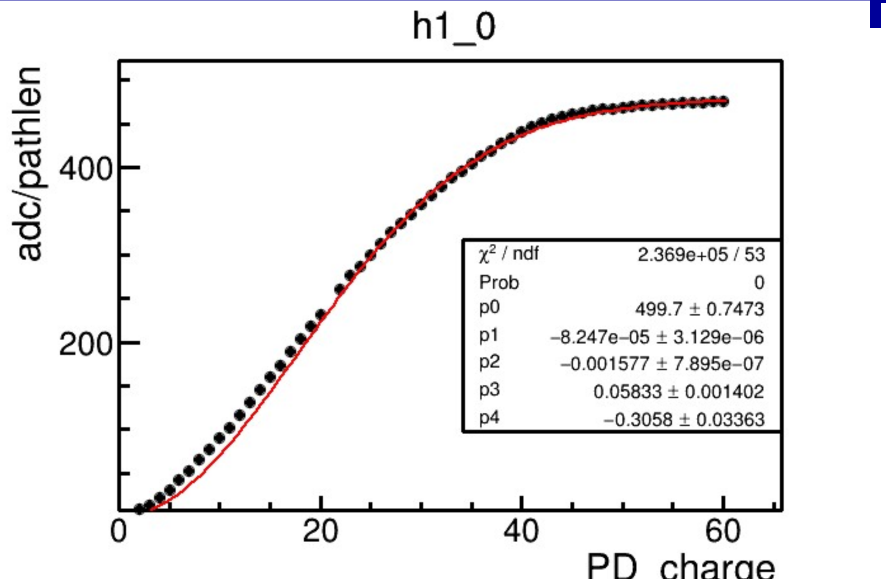
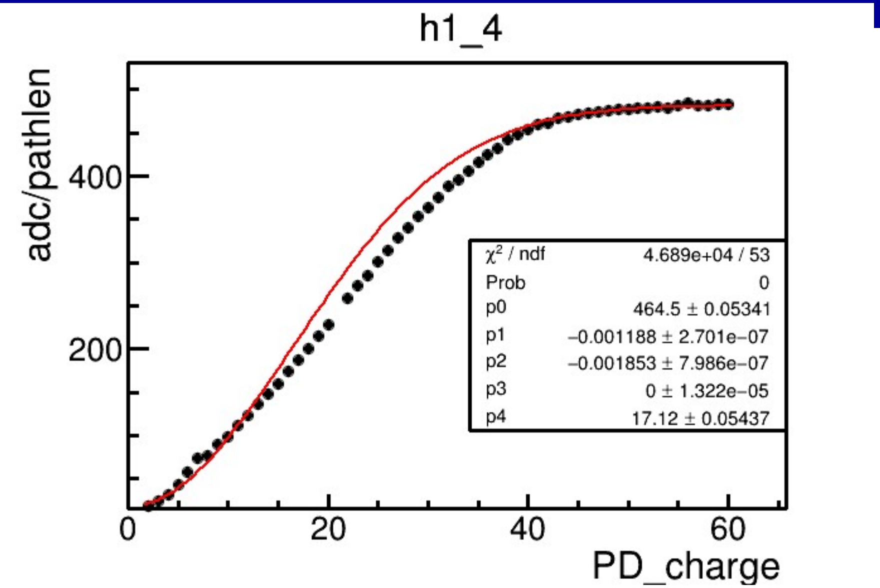
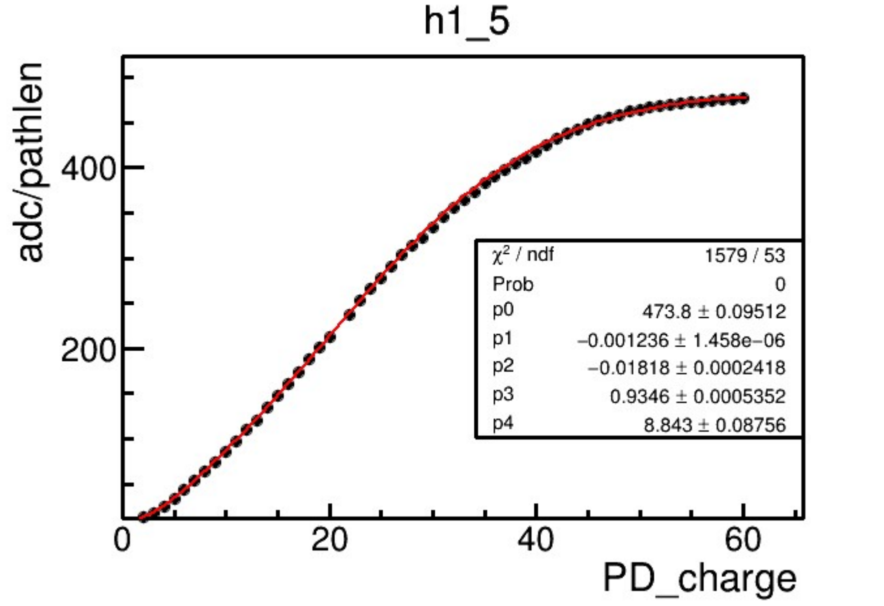
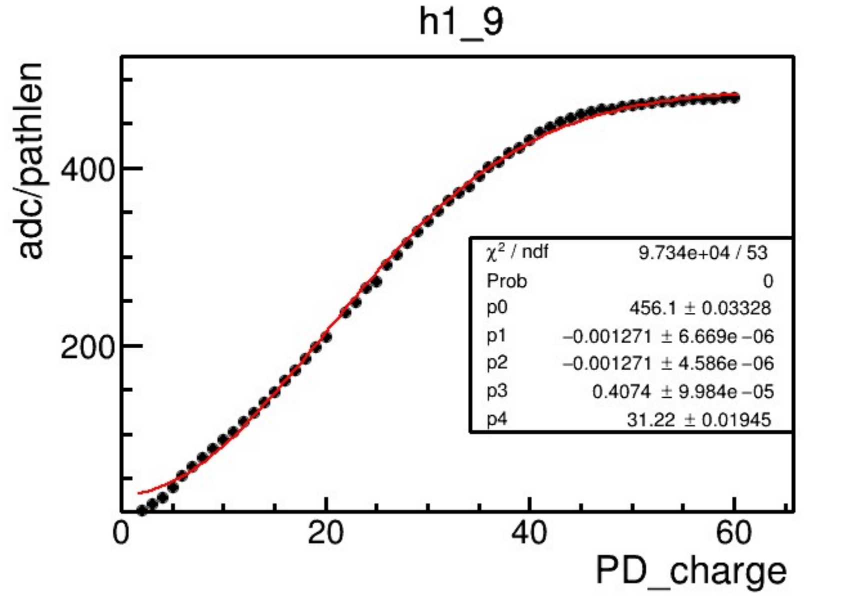



A new function combined with Birks Law, nonlinear of SiPM and saturation of electronics will be tested.

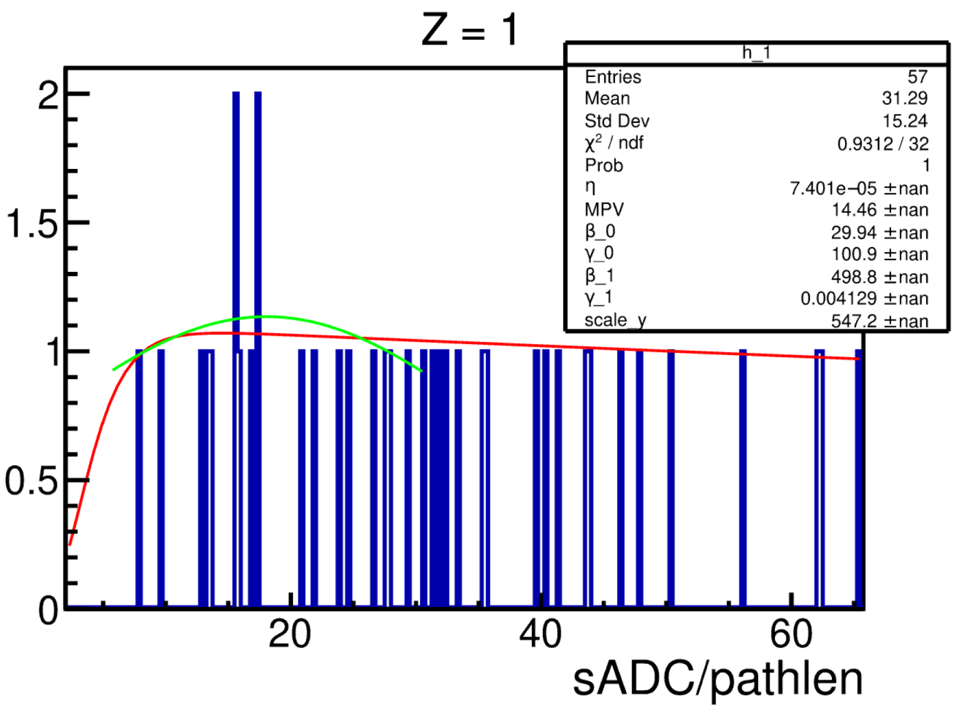
# Summary

- Several strict cuts are applied to select events with precise charge.
- Channel 0,4,5,9 are used to fit the nonlinear function.
- New function combined Birks Law, nonlinear of SiPM and saturation of electronics will be tested for the final function.

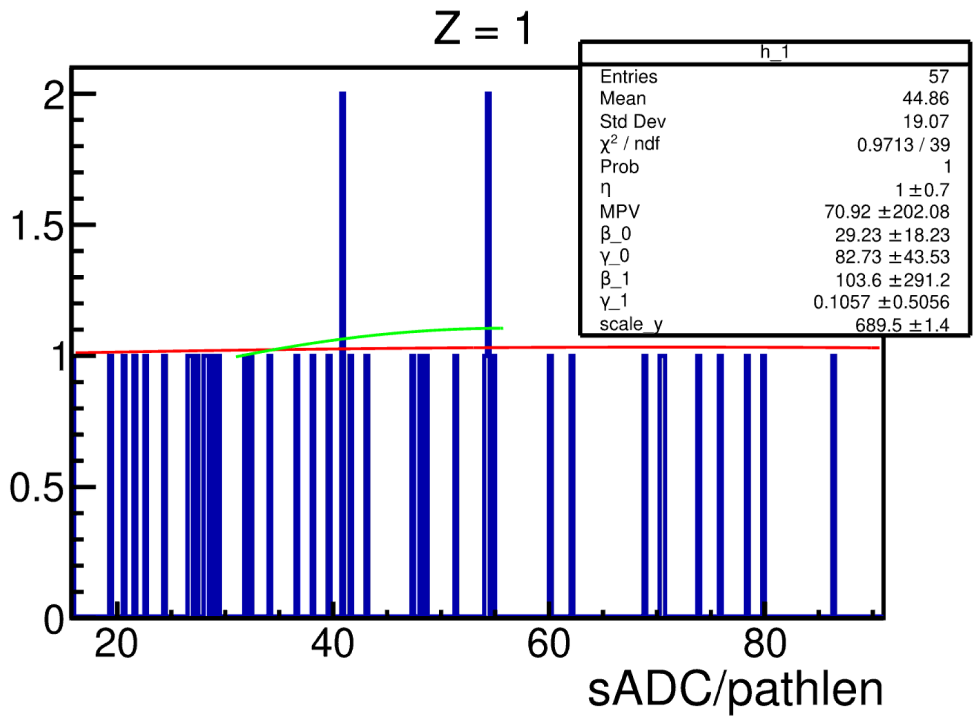
# Backup

# sADC/PathLength (Z=1) in CH 0 and 4

Channel 0




Channel 4



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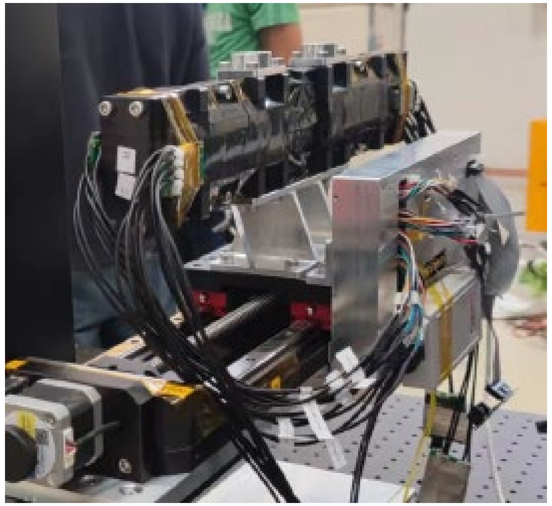
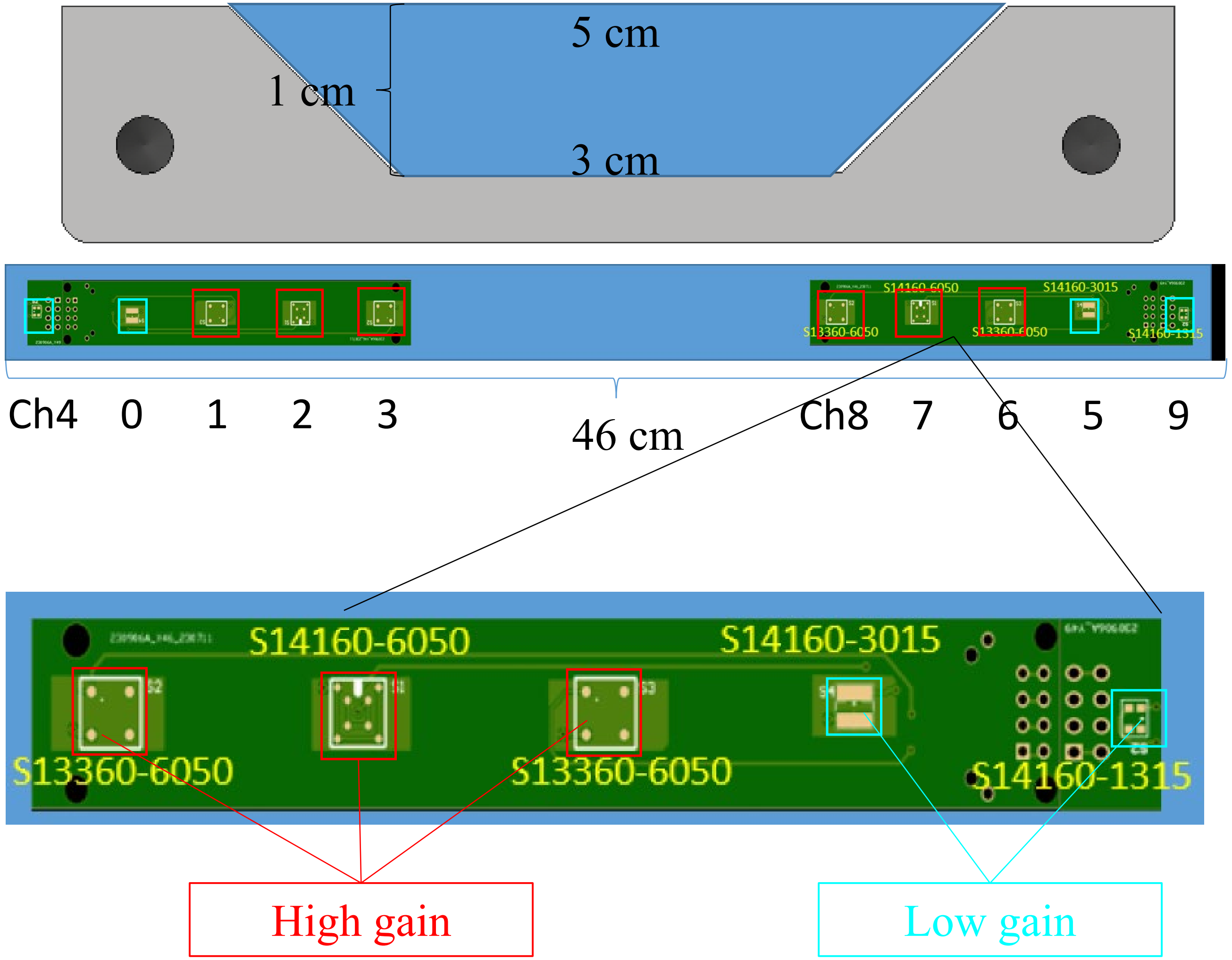
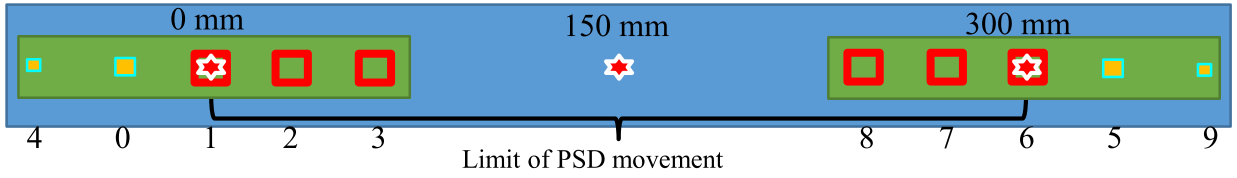
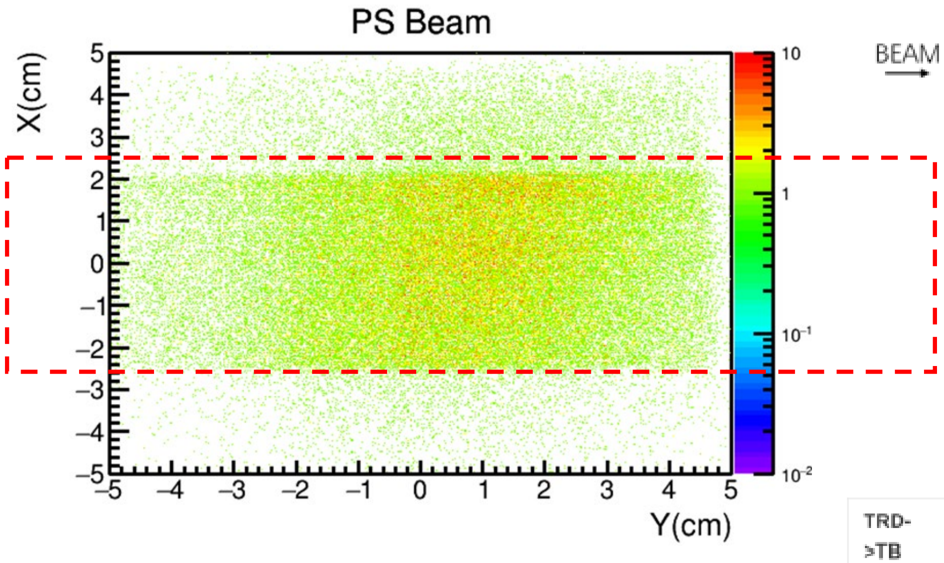




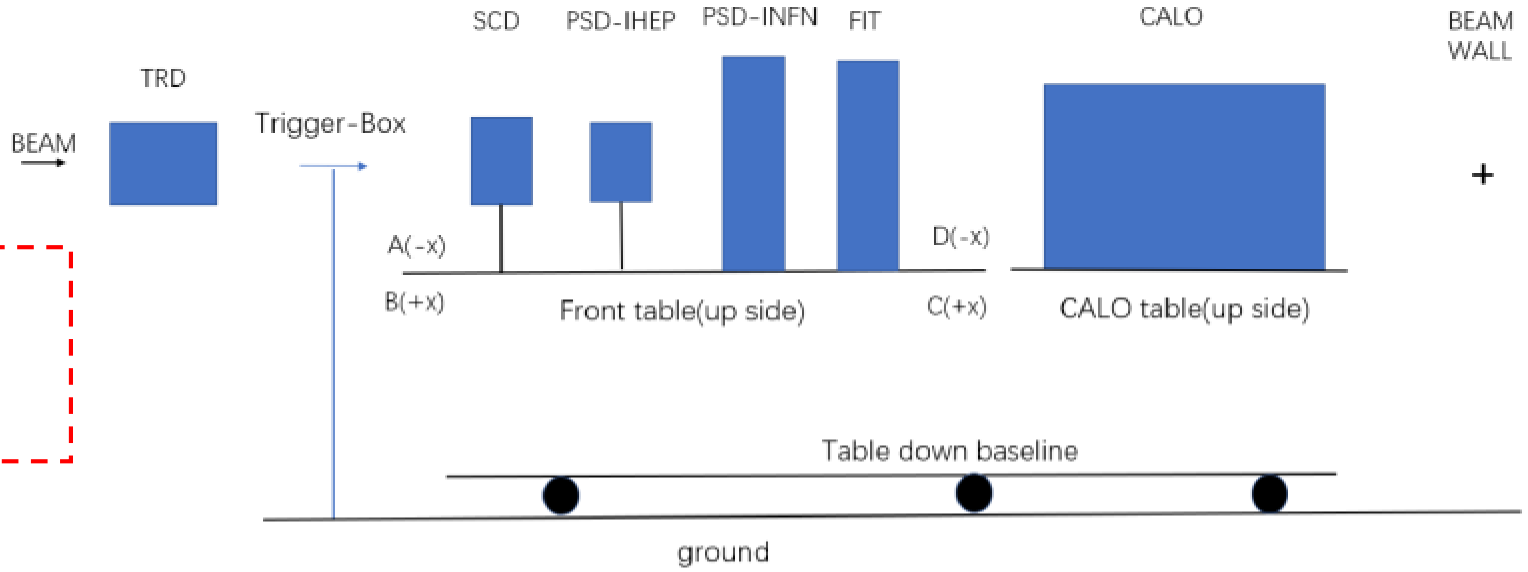
# Setup and data of PS

- Run summary (position: movement along X, central pos 150 mm):
  - Muon (5 GeV) in position: 0, 75, 150, 225, 300 mm
  - Electron (3 GeV) in position: 75, 150, 225 mm
  - Electron (1, 2, 3, 4, 5 GeV) in position: 150, 225 mm
  - Pion (10 GeV) in position: 150 mm



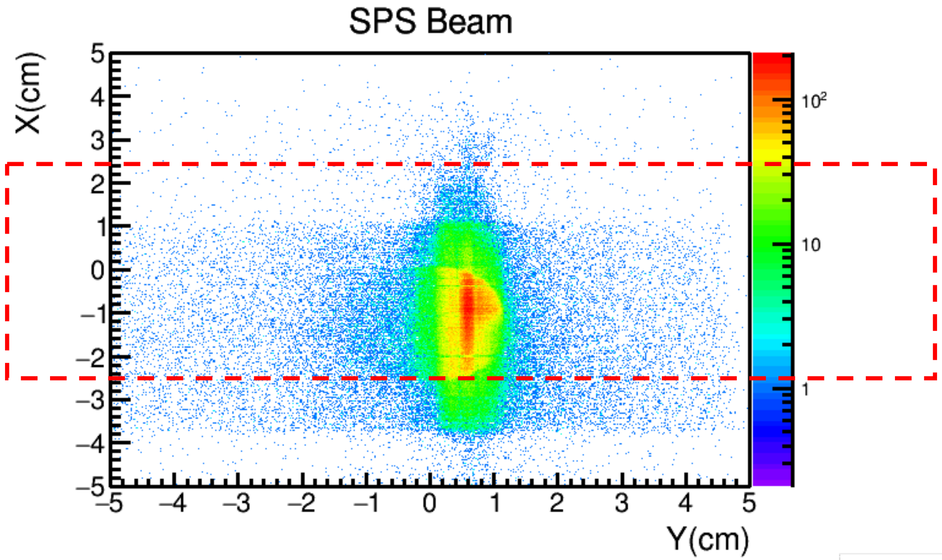

Beam Profile of PS



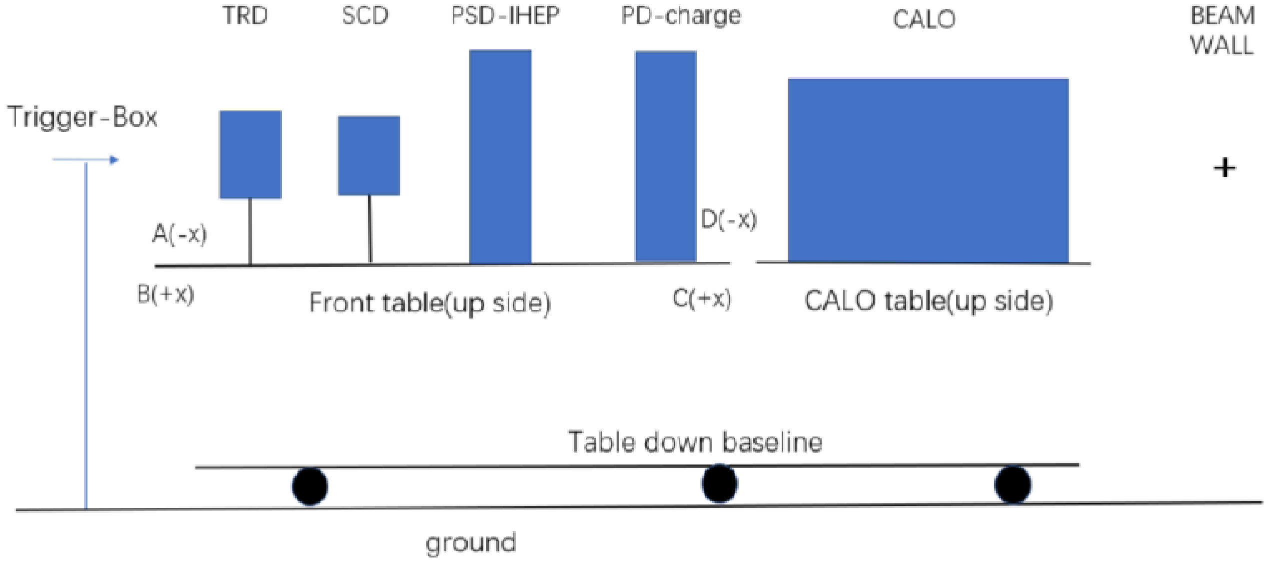

| TRD->TB | TB_width | TB->SCD | SCD_width | SCD->PSD(IHEP) | PSD(IHEP)_width | PSD(IHEP)->PSD(INFN) | PSD(INFN)_width | PSD(INFN)->FIT | FIT_width | FIT->CALO |
|---|---|---|---|---|---|---|---|---|---|---|
| 2.0189m | 0.3625m | 0.343m | 0.12m | 0.365m | 0.02m | 0.2247m | 0.09m | 0.3040m | 0.2710m | 0.4016(0.4027)m |

# Setup and data of SPS

- Run summary (position: movement along X):
  - Muon (150 GeV) in position: 0, 30, 60, 90, 120, 150, 180, 210, 240, 270, 300 mm (no SCD_INFN as reference)
  - Muon (250 GeV) in position: 285, 255, 225, 195, 15 mm (no SCD_INFN as reference)
  - Electron (197.27 GeV) in position: 300, 195, 65, 75, 45 mm
  - Proton (300 GeV) in position: 15, 285 mm
  - Electron (243.48, 149.12, 49.99, 99.83, 20… GeV) in many different positions



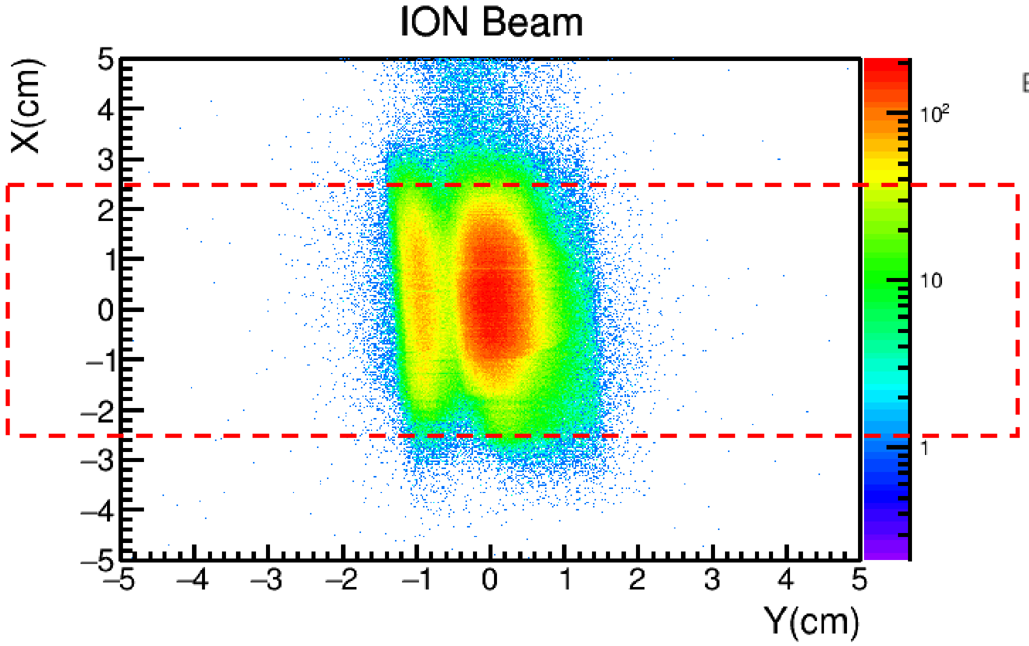

Beam Profile of SPS



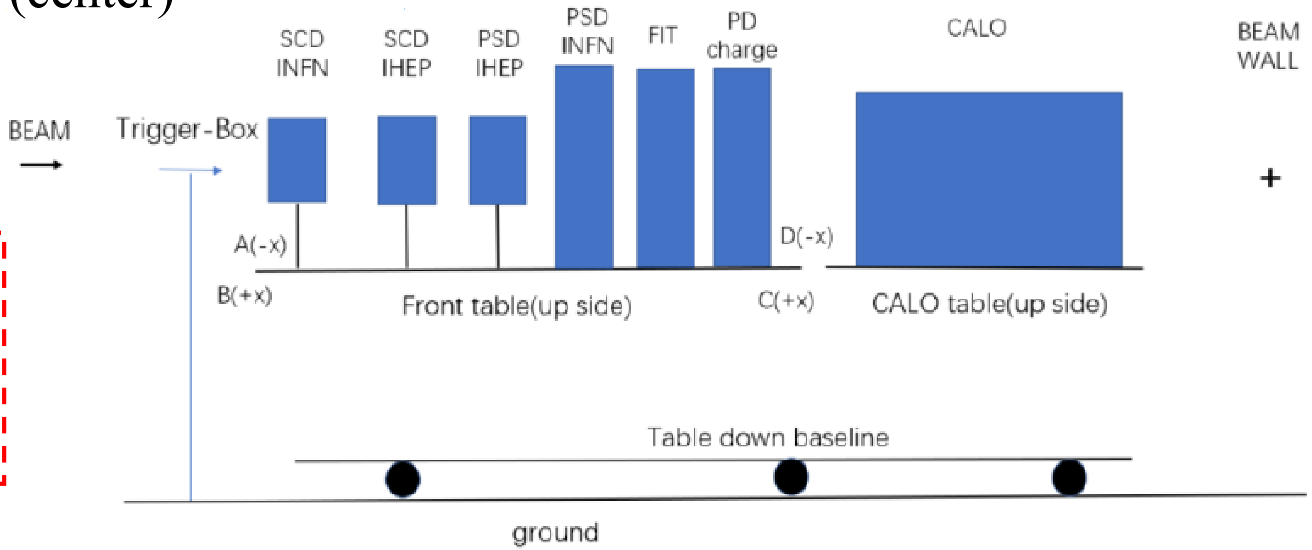

| TB_width | TB(edge)->TRD | TRD_width | TRD->SCD | SCD_width | SCD->PSD(IHEP) | PSD(IHEP)_width | PSD(IHEP)->CALO | PD(charge)_width | PD(charge)->CALO | SCD->CALO |
|---|---|---|---|---|---|---|---|---|---|---|
| 0.3625m | 0.535m | 0.23m | 0.80m | 0.12m | 0.253m(inaccurate) | 0.02m | 0.442m(inaccurate) | 0.034m | 0.166m | 0.7193m(accurate) |

# Setup and data of SPS IONs

- Run summary (position: movement along X):
  - Hadron (330 GeV/n) in position: 150 mm (center)




Beam Profile of SPS IONs




| PAN->Trigger_box | Beam_tube->Trigger_box | Trigger_box edge outside width | Trigger_box->SCD_INFN | SCD_INFN width | SCD_INFN->SCD_IHEP | SCD_IHEP width | SCD_IHEP->PSD_IHEP | SCD_IHEP->PSD_INFN |
|---|---|---|---|---|---|---|---|---|
| 3.507m | 0.264m | 0.005m | 0.534m | 0.117m | 0.2848m | 0.13m | 0.177m | 0.365m |
| SCD_INFN->FIT(side_B) | SCD_INFN->FIT(side_C) | FIT->CALO | PD_charge->CALO | PD_charge width | | | | |
| 0.2784m | 1.5458m | 0.35m | 0.187m | 0.034m | | | | |

# SCD impact rgion

## Get MPV for each Z

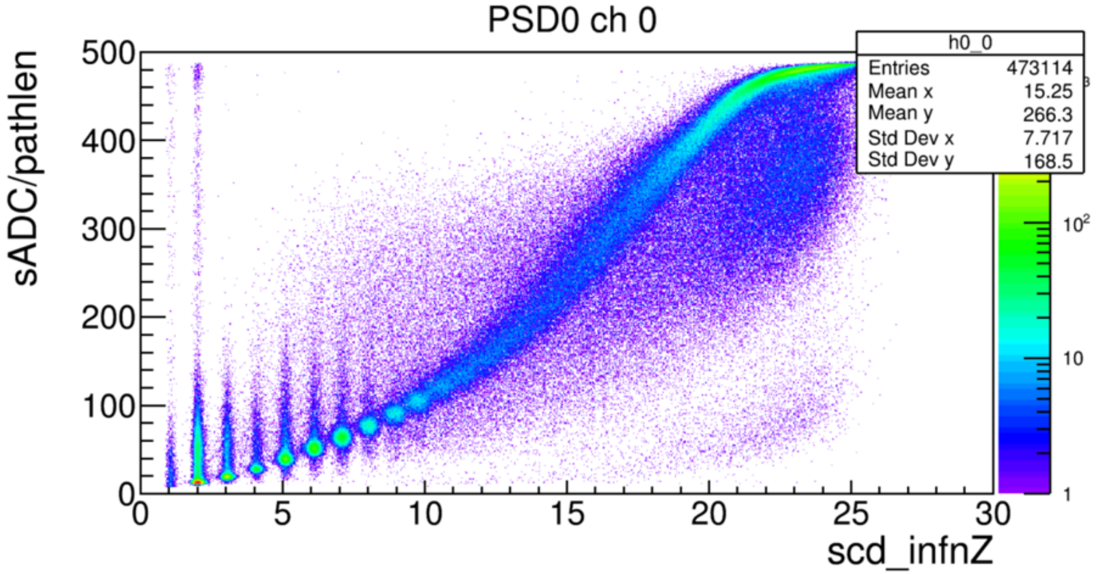
event selection:

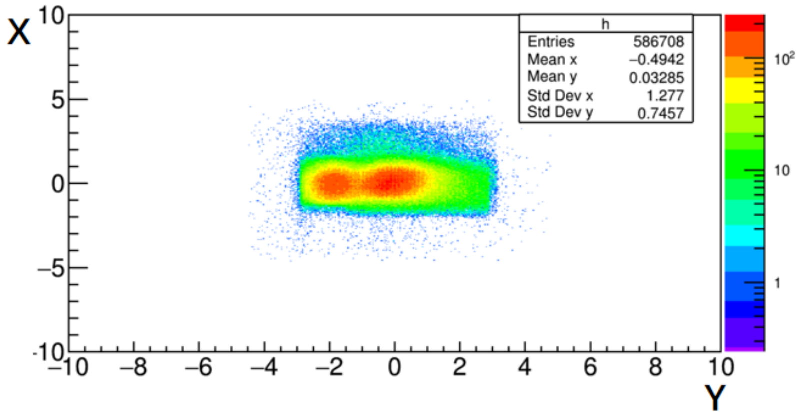
1.has signal on PSD & SCD

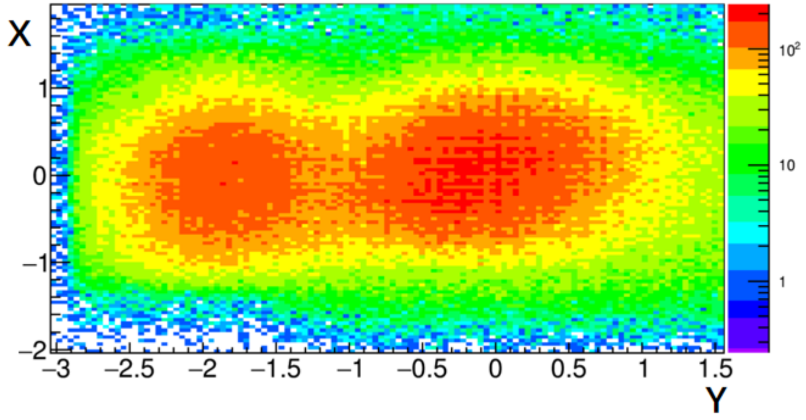
2.SCD_chi2 < 10

3.cut ped(over 3*ped_sigma)

4.SCD_impact:-2<X<2 , -3<Y<1.5

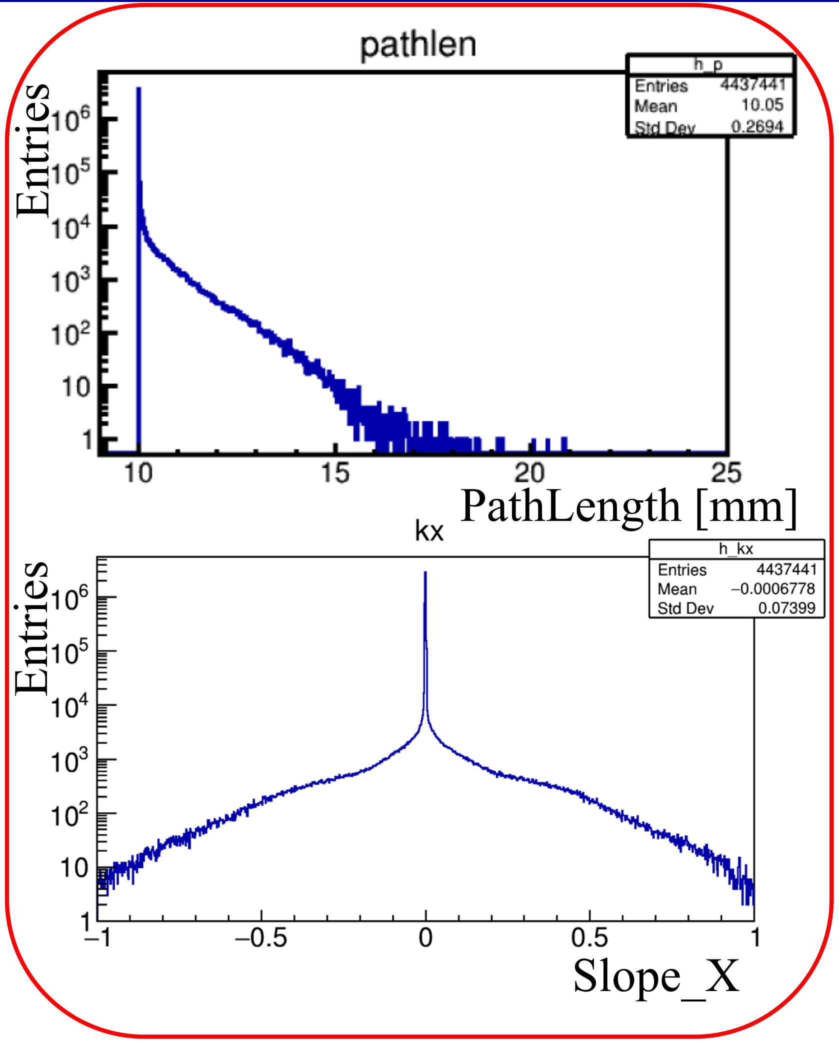


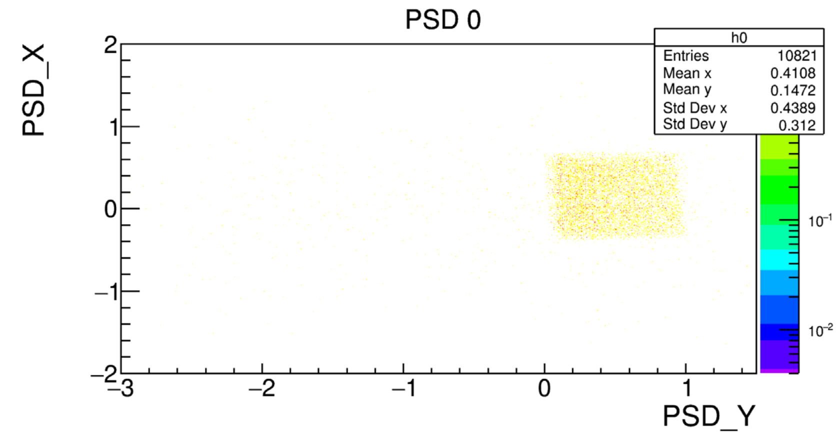



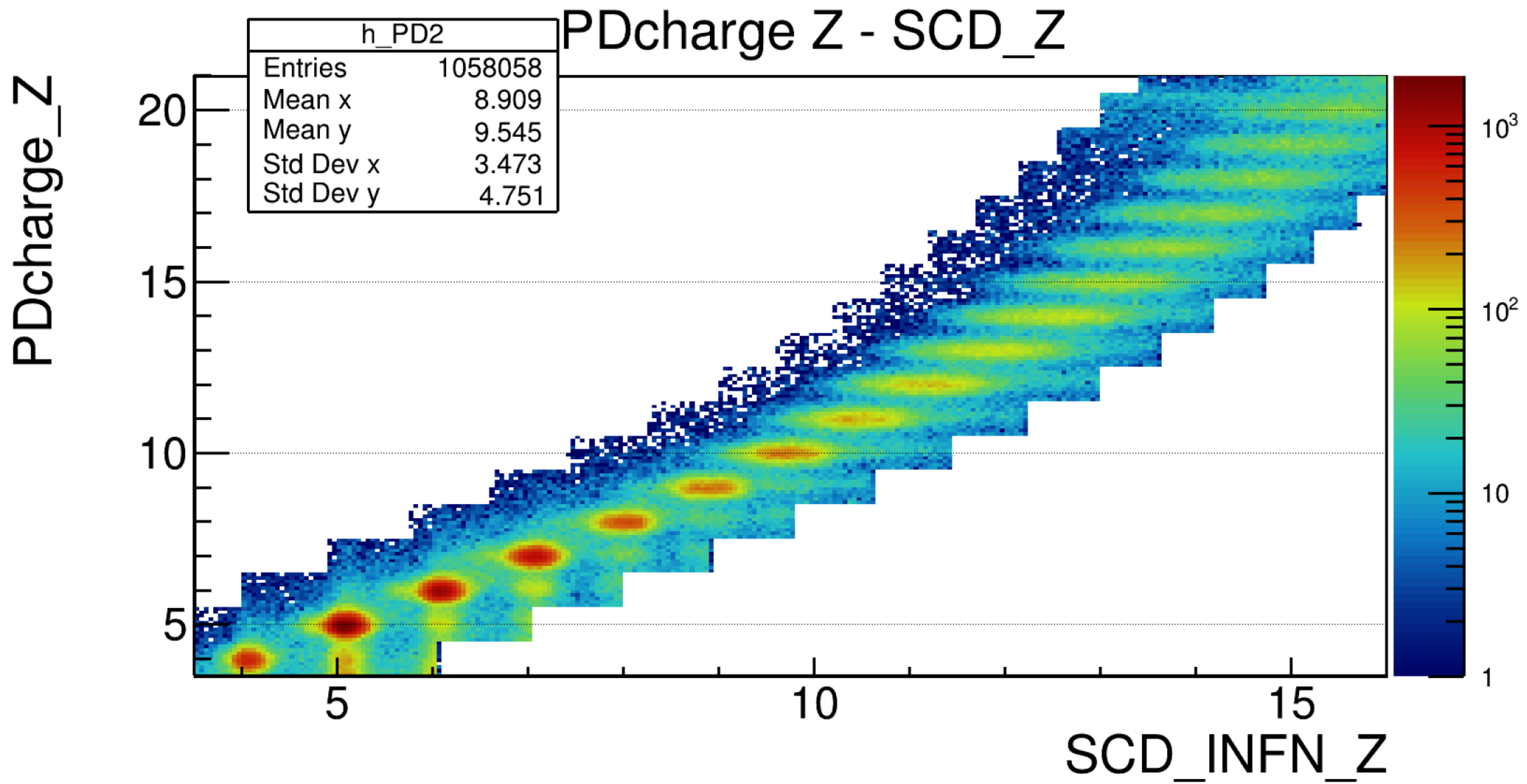

data: ion run 622,add cut 1,2

# Aligment of detectors



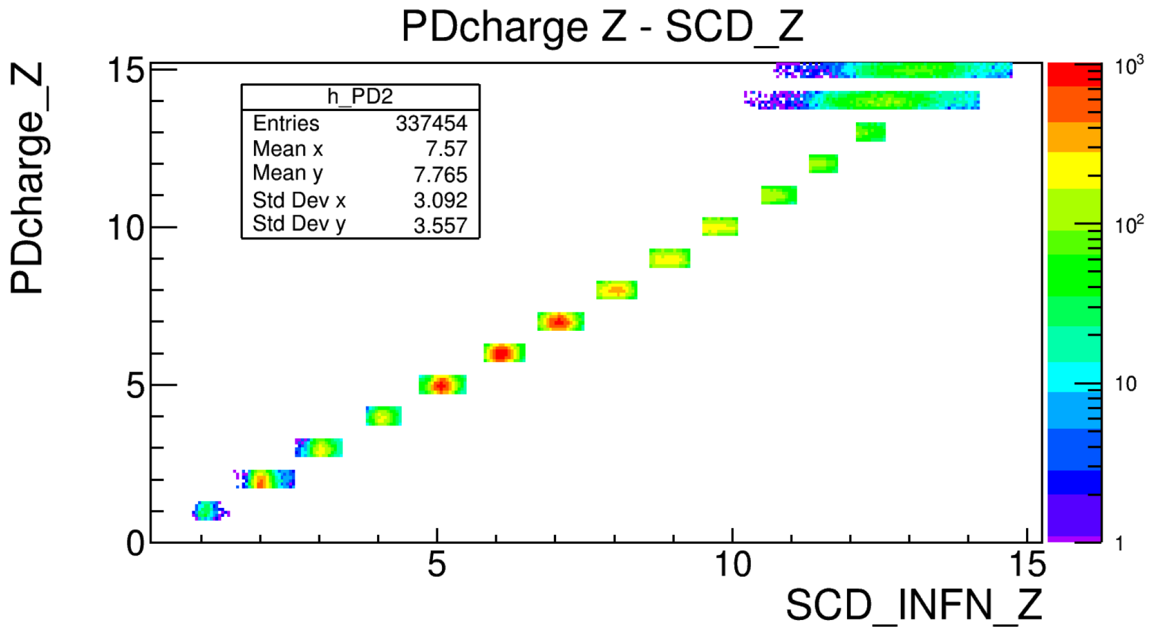



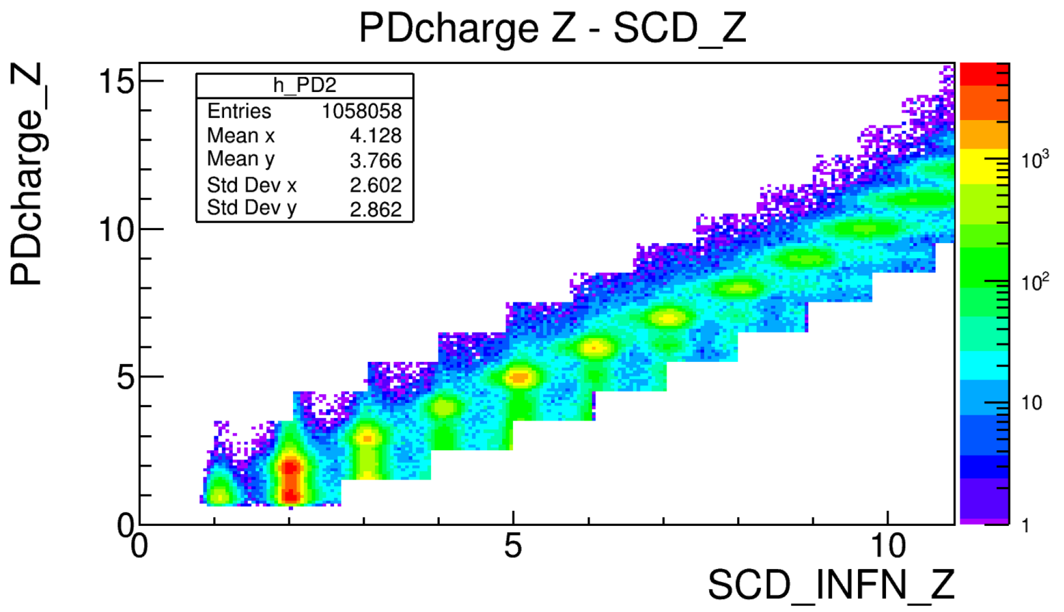

Beam profile of the final selection

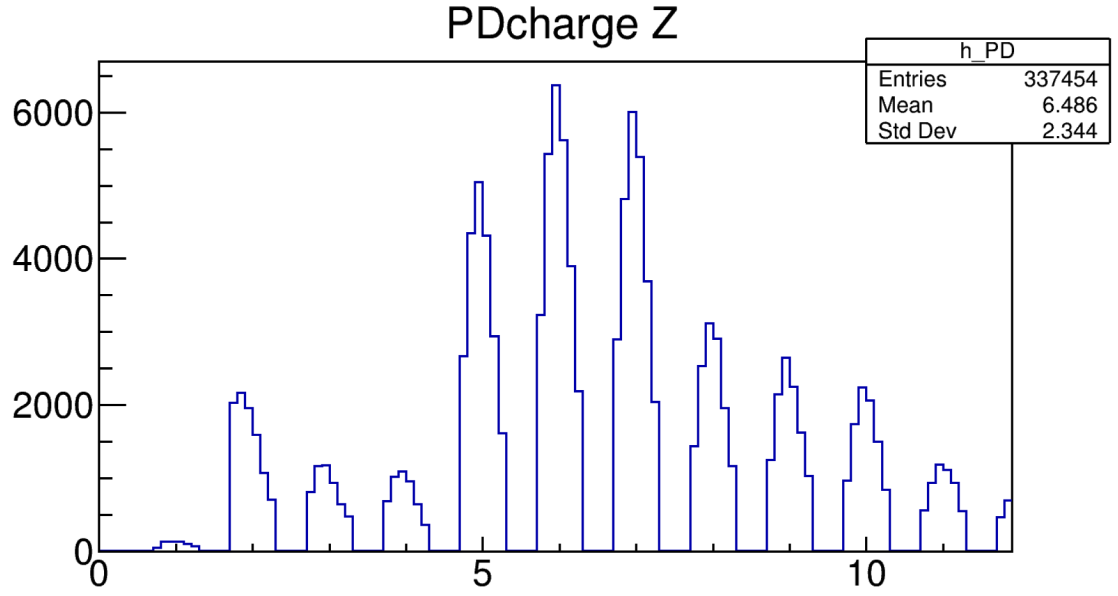


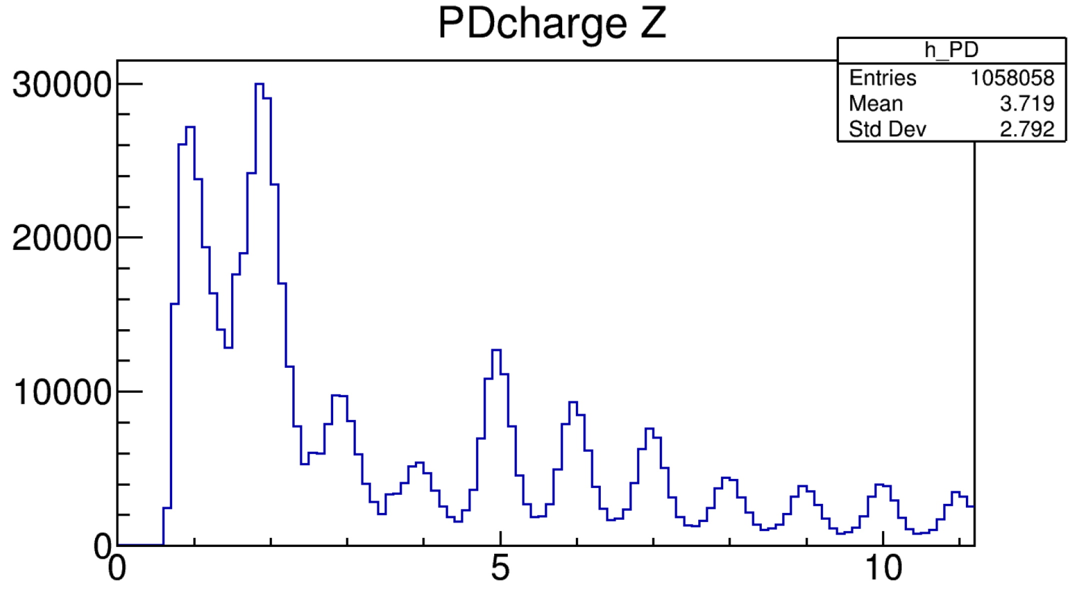
PDcharge Z - SCD_Z
h_PD2
Entries 1058058
Mean x 8.909
Mean y 9.545
Std Dev x 3.473
Std Dev y 4.751
PDcharge_Z
SCD_INFN_Z
5
10
15
20
1
10
$10^2$
$10^3$

# PD Z peak offset

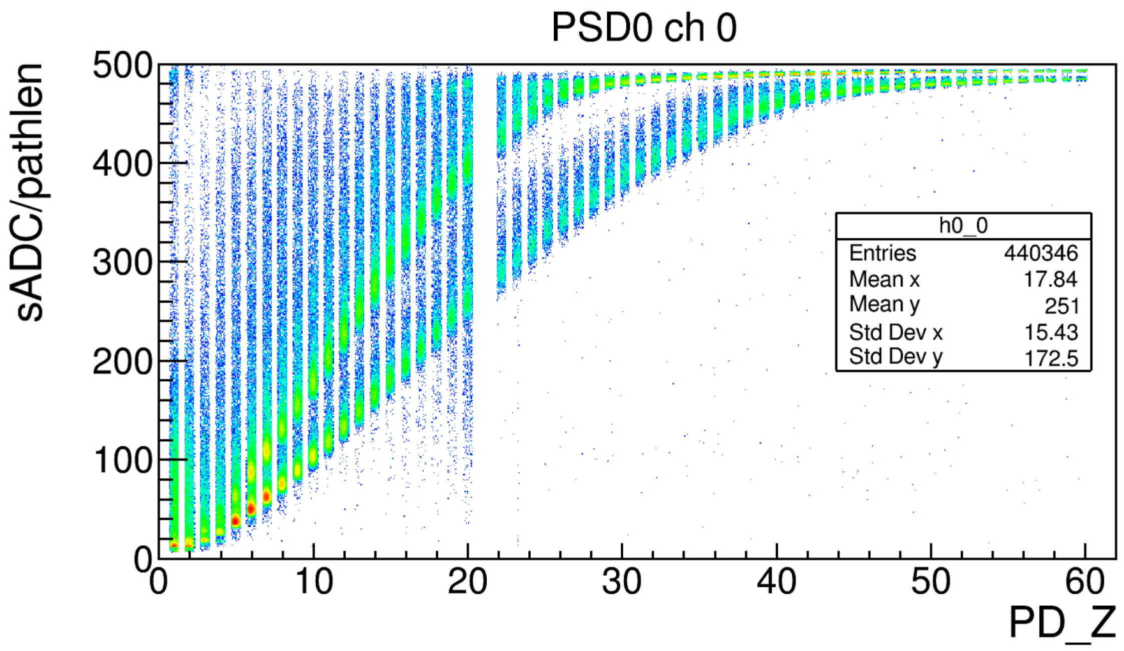


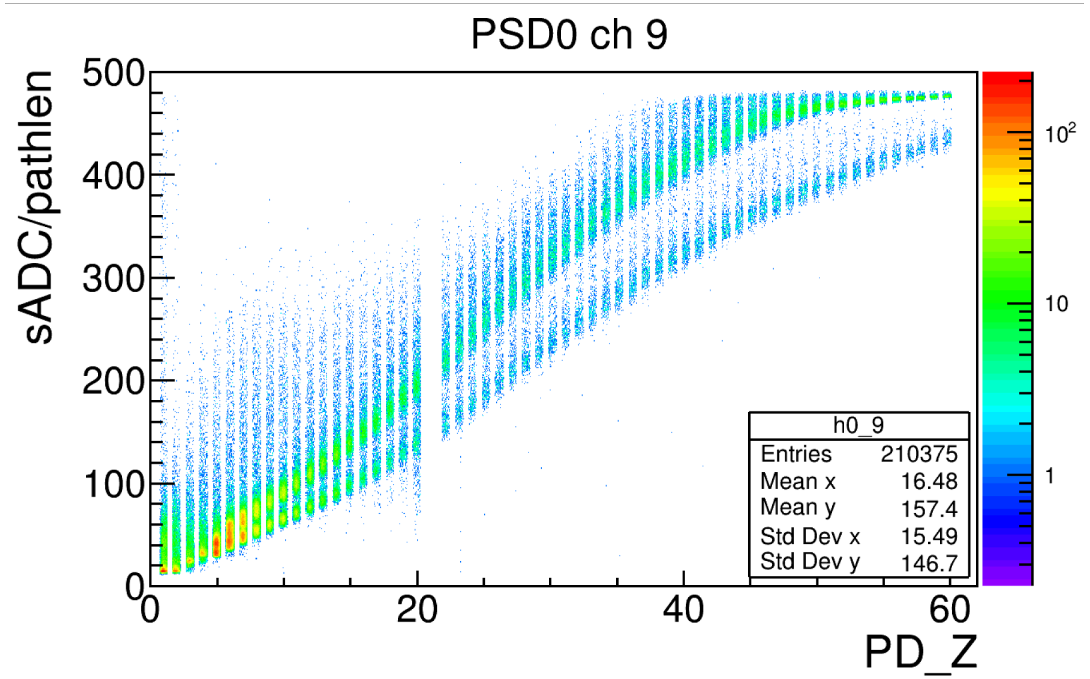



# psd_adc - PD_Z



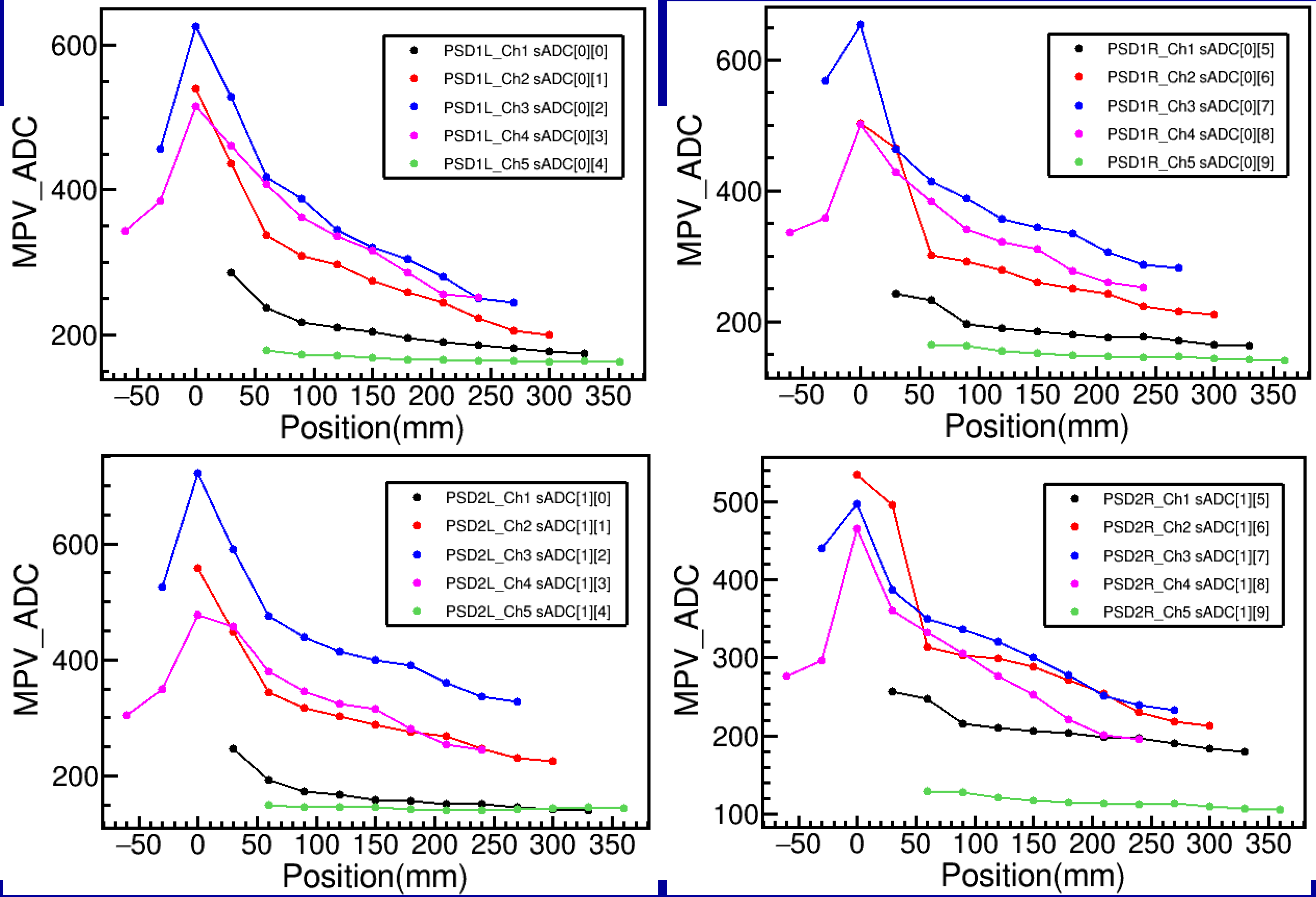

All Ion run



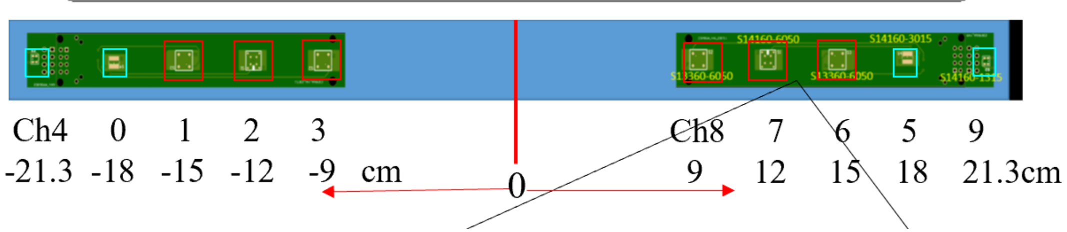

run after 552

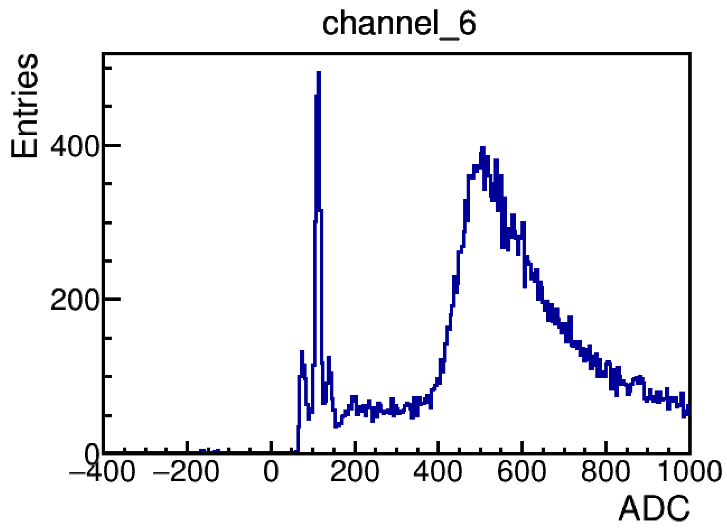
# Attenuation

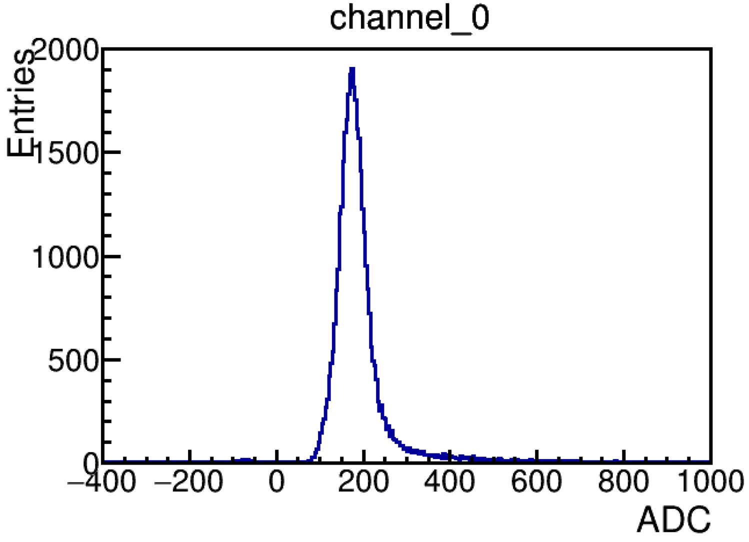
- SiPMs of ch 1, 2, 3, 6, 7, 8 (type:6050) are able to calibrate the attenuation function.
- SiPMs of ch 0 and 5 (type:3015) are also could be used for calibration in such gain.
- SiPM of ch 4 and 9 (type:1315) can not be used for calibration.

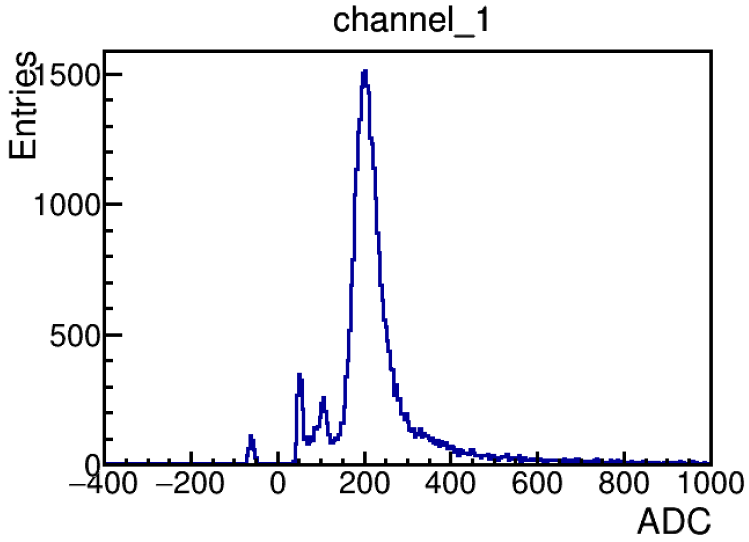


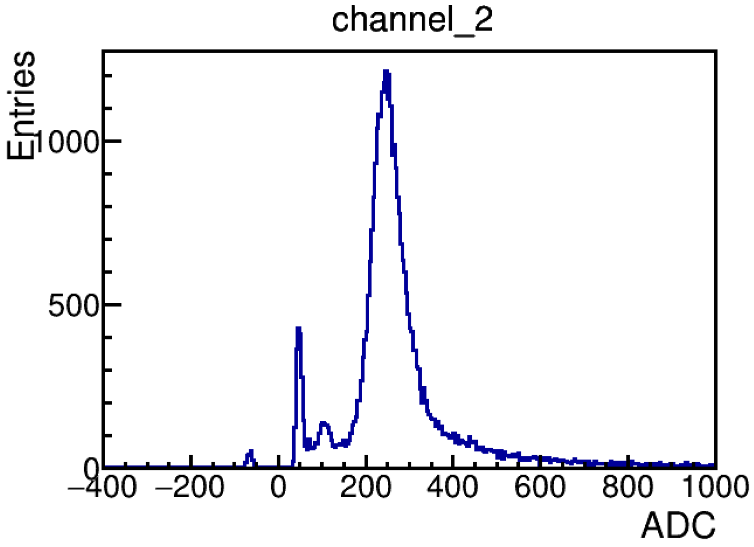
# Distribution of ADC

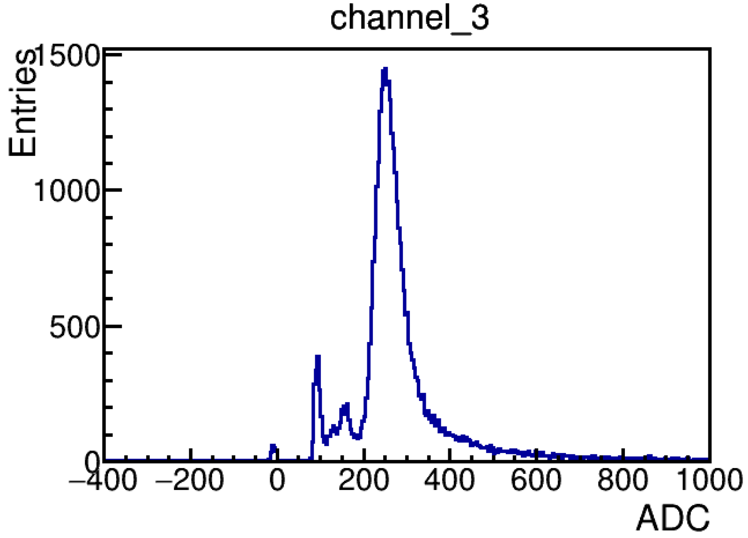


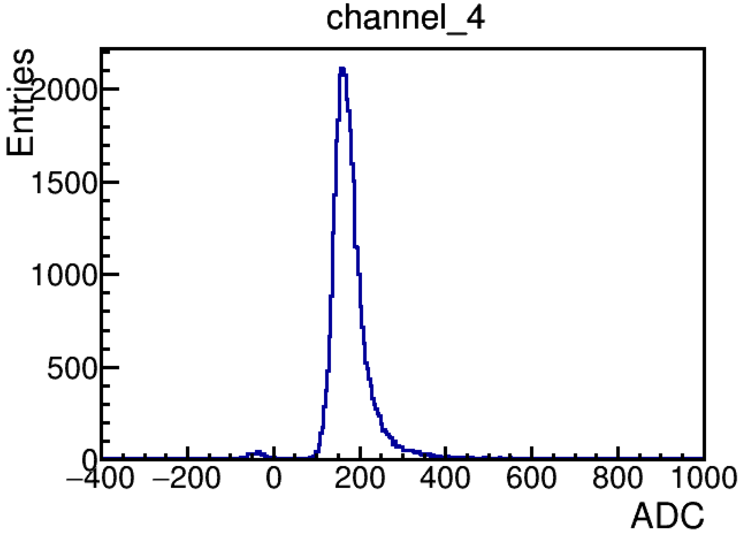



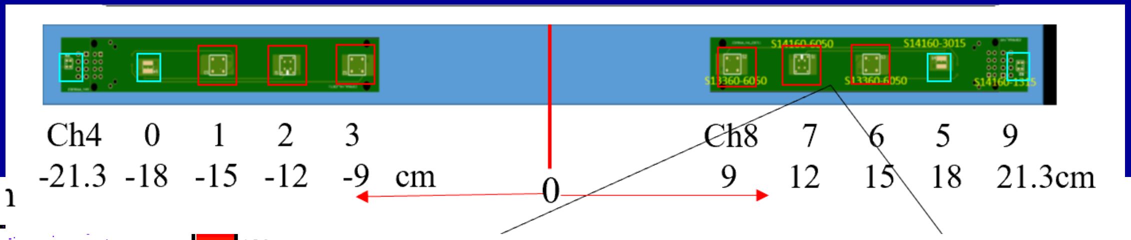



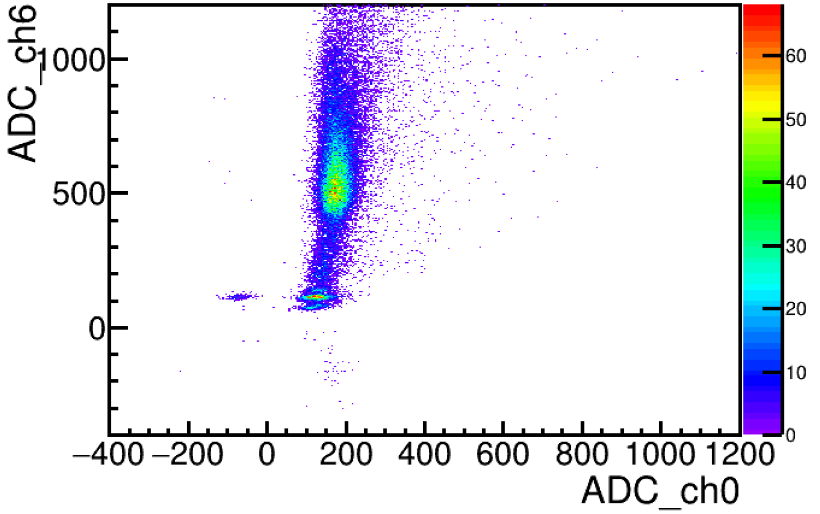



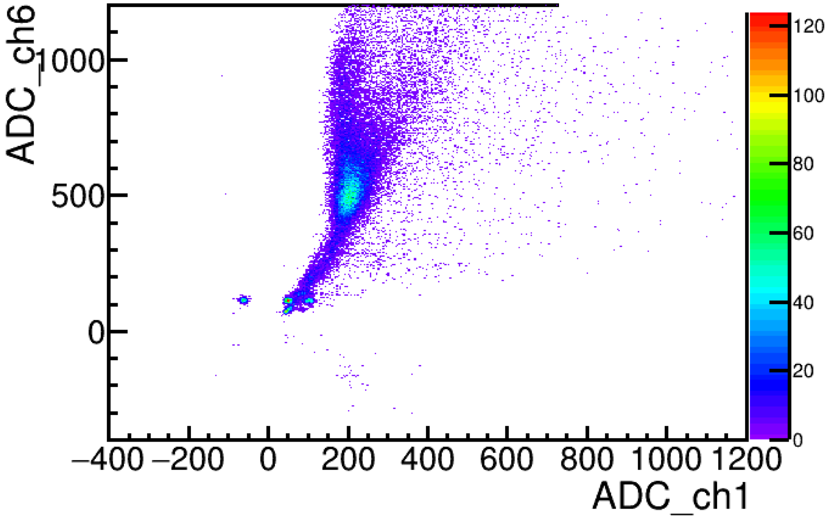



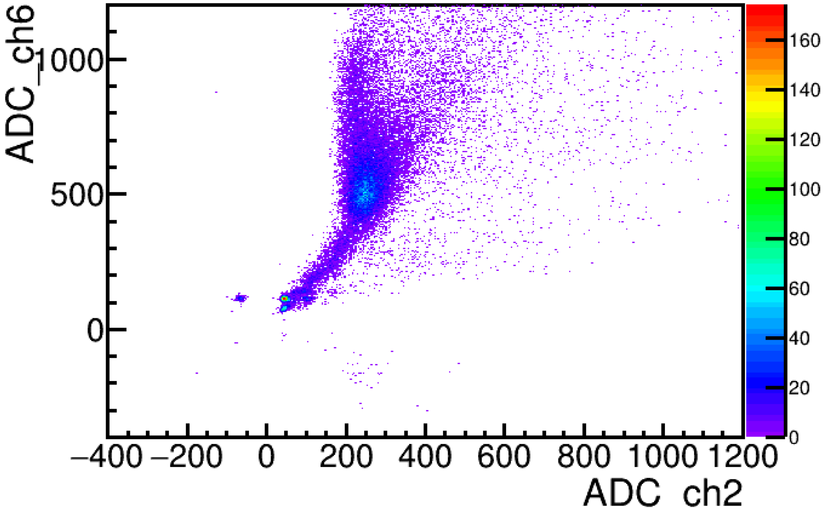



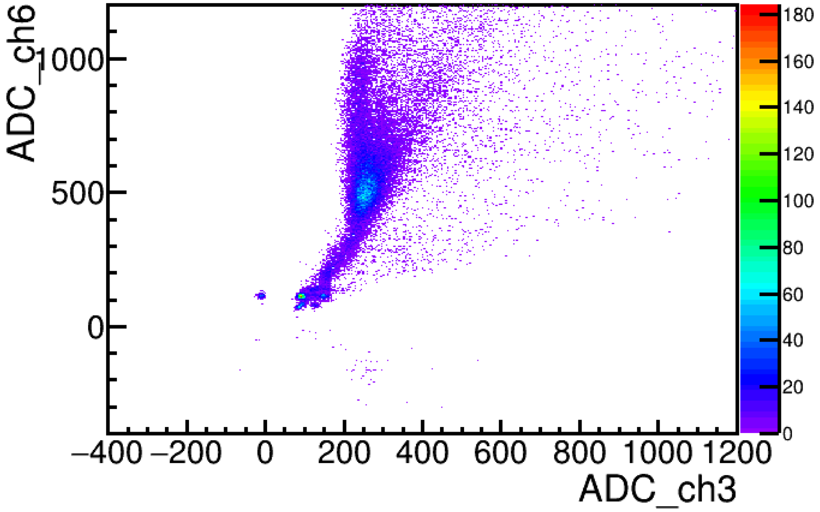
# Distribution of ADC

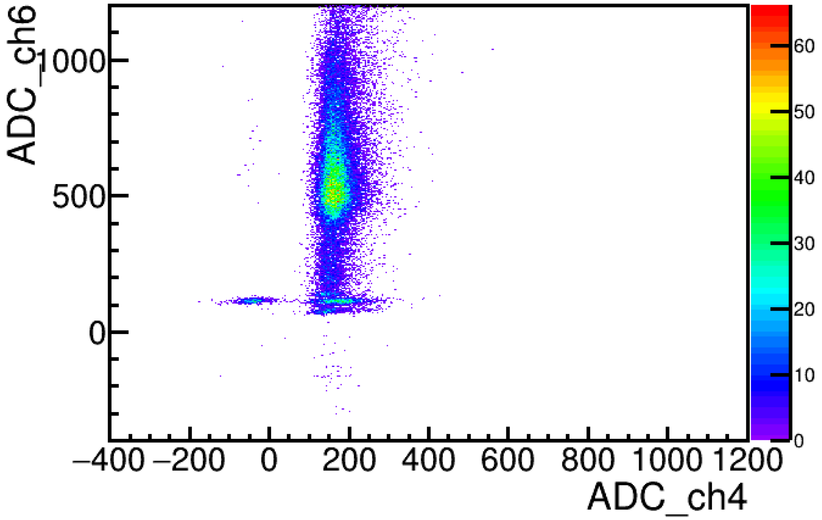


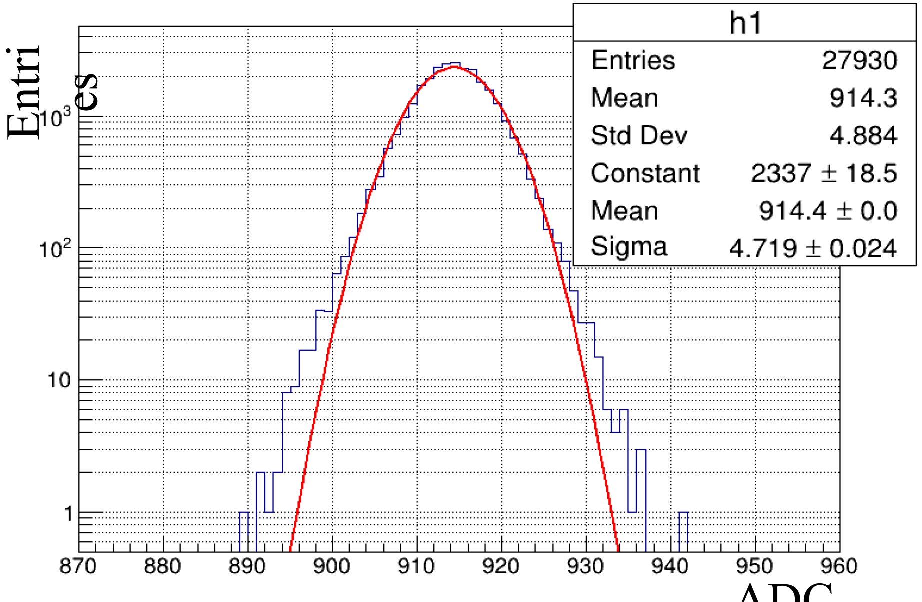



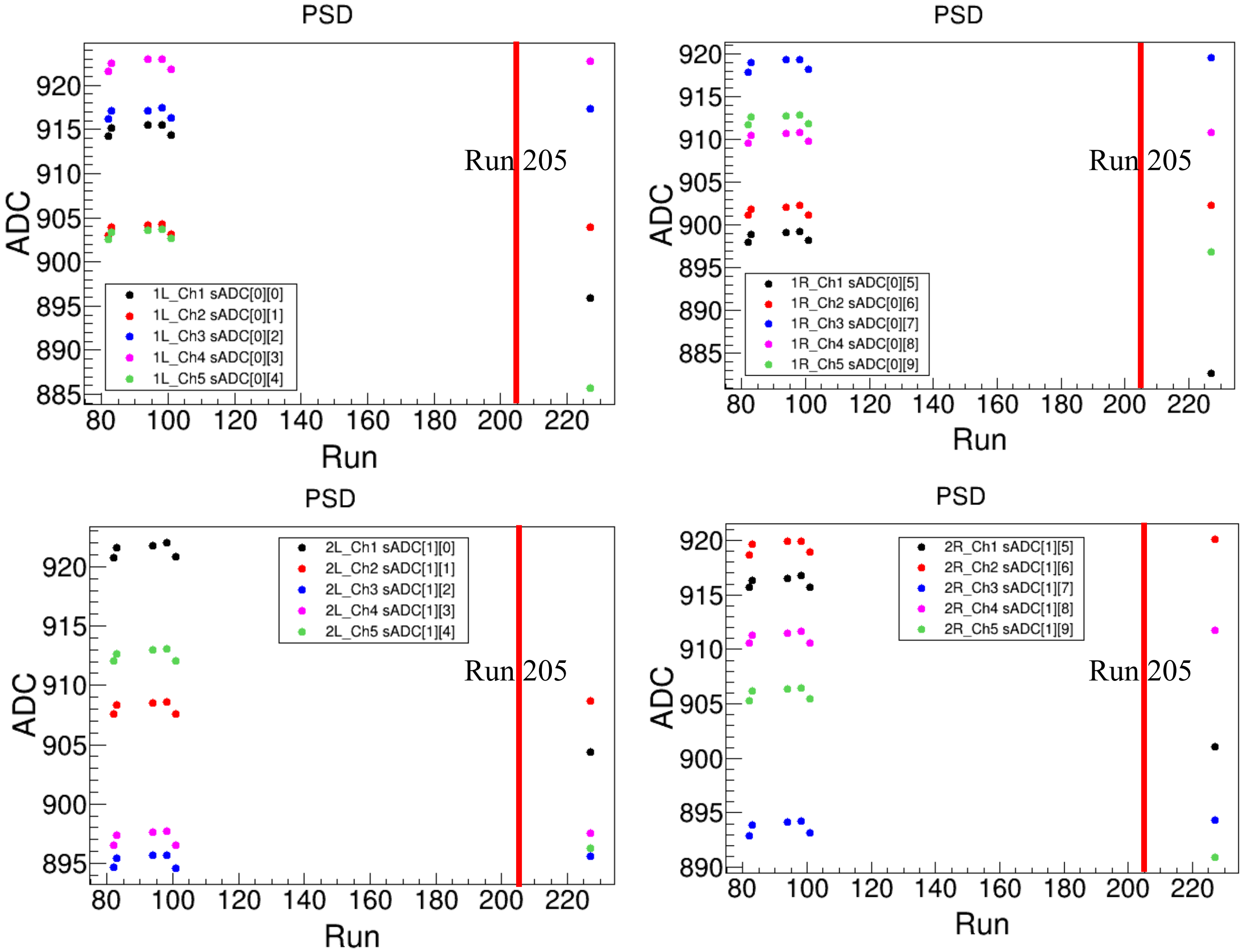
# Pedestal calculation and subtraction

- The pedestal is calculated with calibration runs (RN: 82,83,94,98,101,227).
- The distribution of ADC in each channel is fitted with Gaussion Function.
- The gains of small SiPMs are changed from run 205.
- Use different pedestals for run < 205 or run>=205.



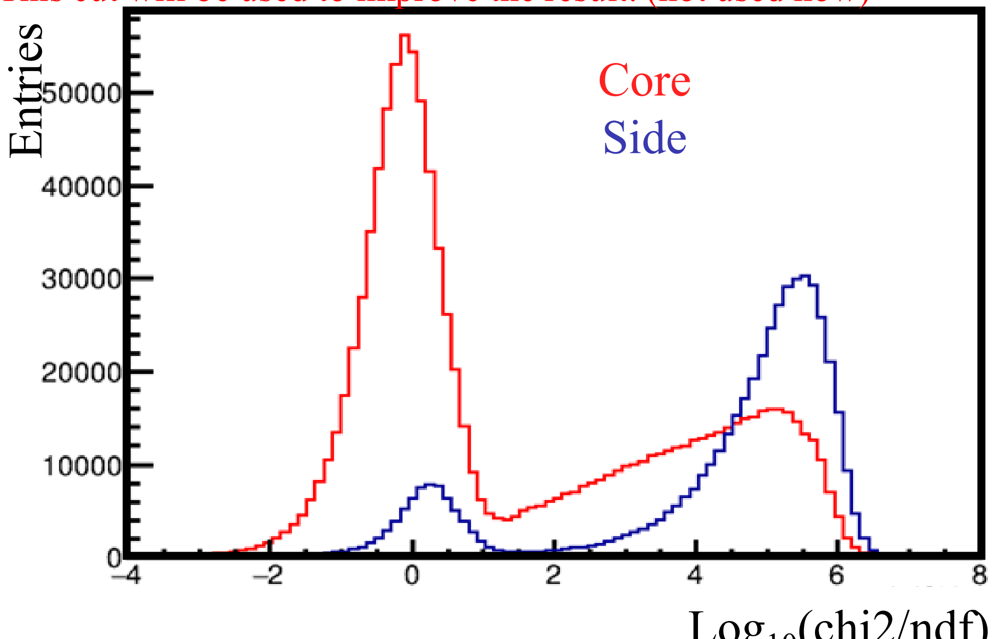

Example of fitting.

Pedestal of 20 SiPM



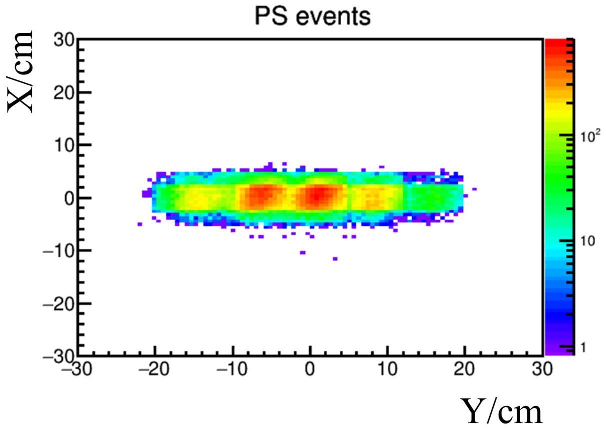
# Event selection by SCD_INFN

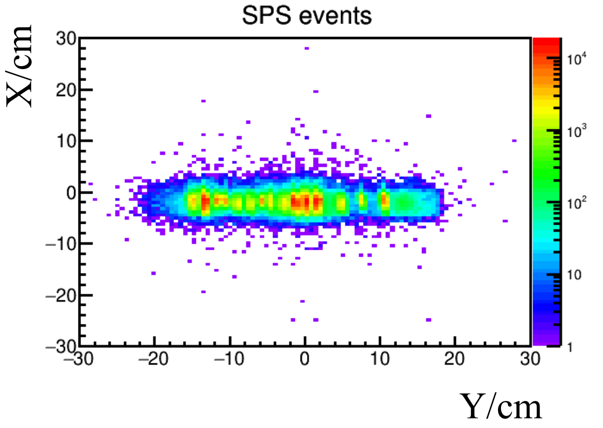
- Tracks reconstructed by SCD_INFN need to be selected to have good qualities.
- Define regions with the X and Y reconstructed by SCD_INFN:
  - Core: Region -2.5<X<2.5 && -22.5<Y<22.5 (cm)
  - Side: Region out of core
- Distribution of chi2/ndf (SCD track fitting result) is drawn.
- Events will be selected with requirement chi2/ndf<10.
- This cut will be used to improve the result. (not used now)

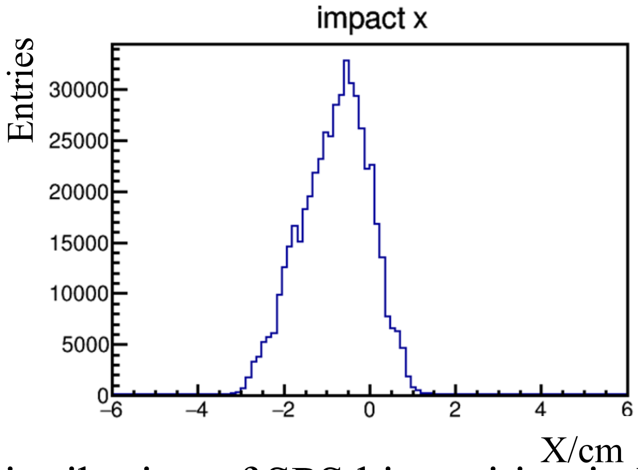



Distribution of log10(chi2/ndf) in core and side

- Distribution of hit position with:
  - Chi2/ndf < 10
  - ADC of 6 large SiPMs > 200



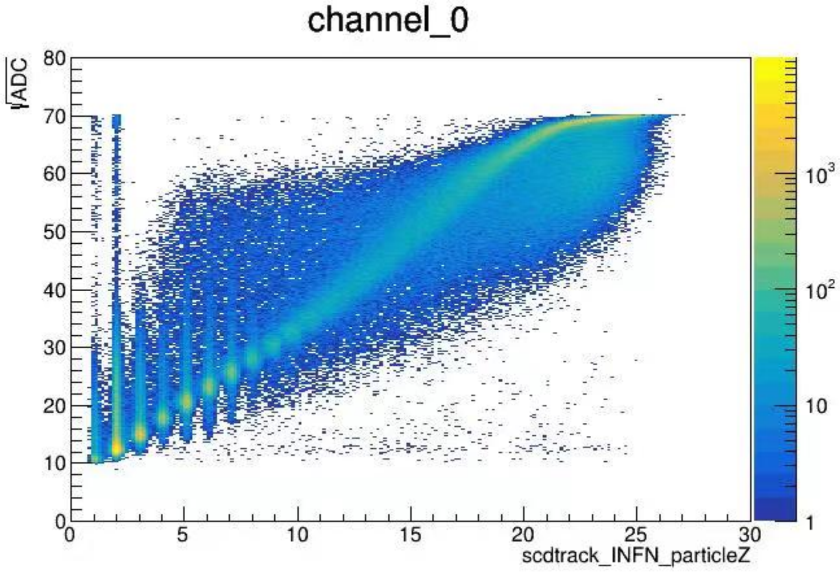




Distribution of SPS hit position in X axis.

Alignment along X axis run by run to improve the result.

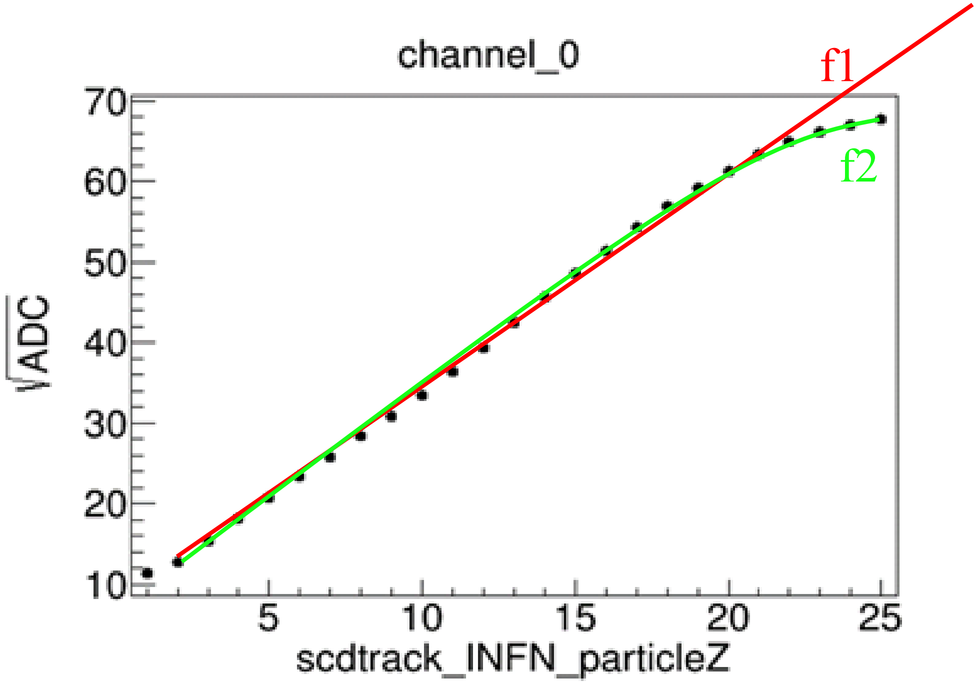
# Nonlinear effect

- Nonlinear effect is studied with SPS ions.
- Channel 3 and channel 8 are not used in SPS ion runs.
- Requirement of SCD track: -3<Y<3 && -1.5<X<1.5
- Fit the Low-Z part with linear function f1
- Fit the whole plot with nonlinear function f2




Sqrt(ADC) vs Charge from SCD

TProfile




- Simply evaluate the nonlinear effect of SiPM in a specific hit position (center).
- Effect of both Birks' Law and Nonlinear of SiPM

# Bottom level reconstruction of ADC

ADC value of SiPM

↓

Pedestal subtraction

↓

Assume the saturation is only correlated with SiPM nonlinear (approximation)

↓

Correct the ADC: ADC→ SCD_Z (f2) → unsaturated ADC (f1)

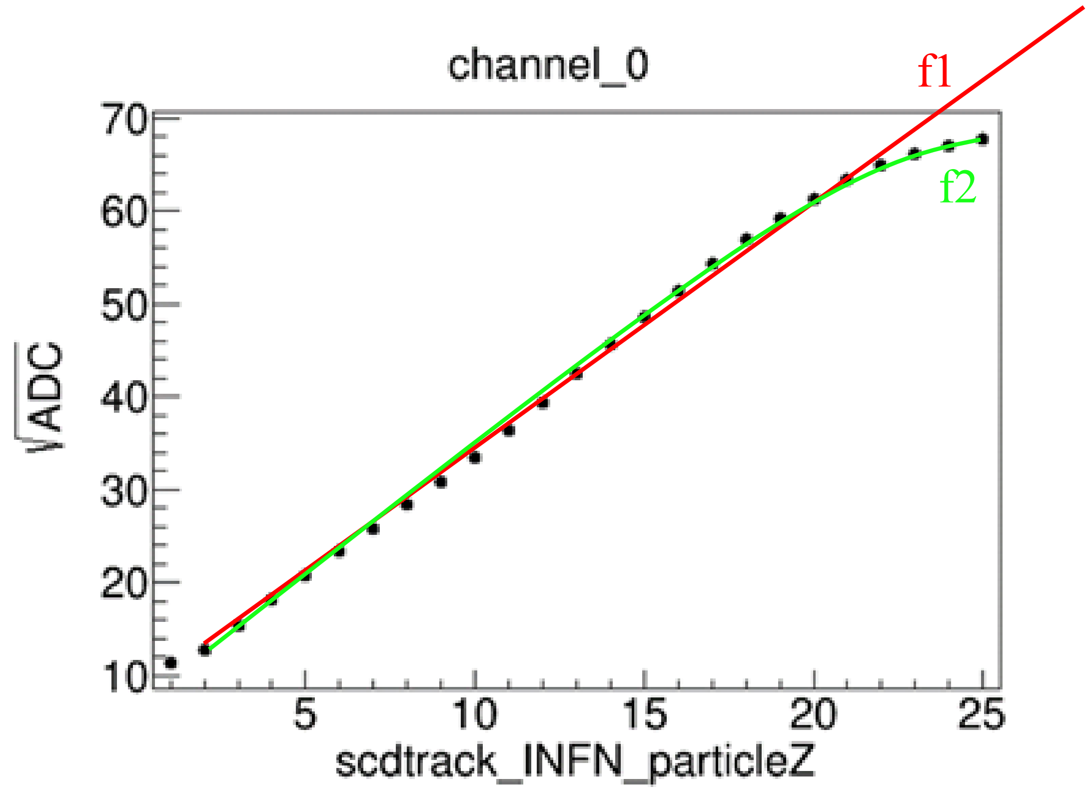
↓

Hit position from other detector →

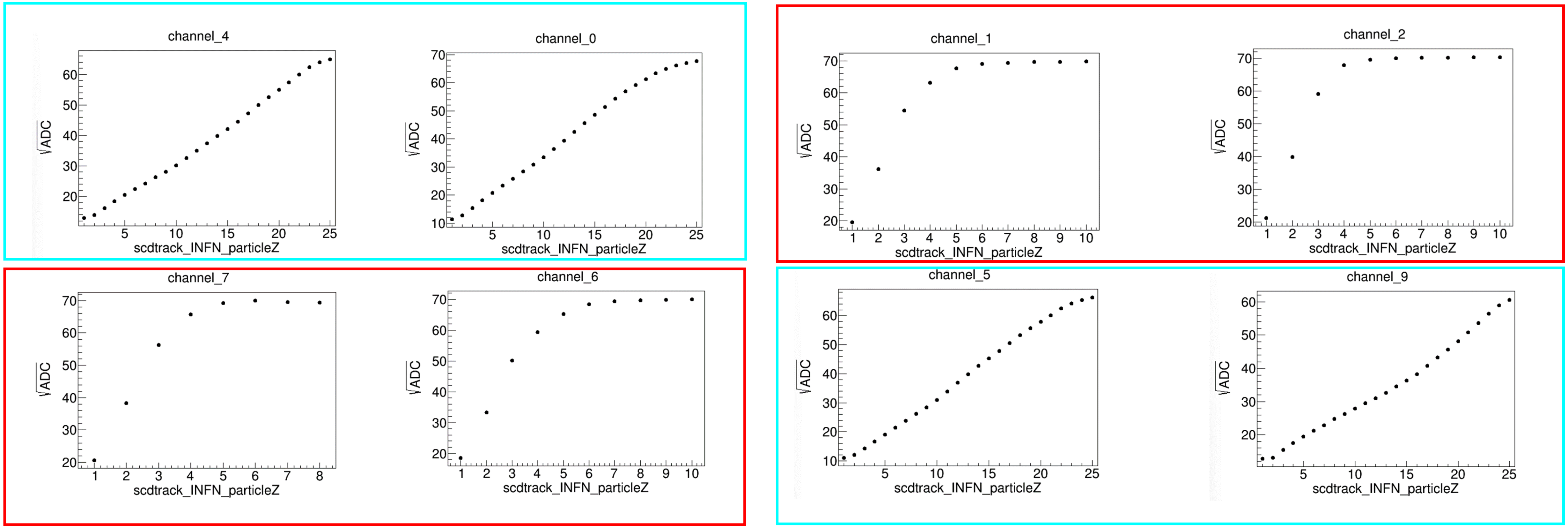
Correct the ADC with attenuation function

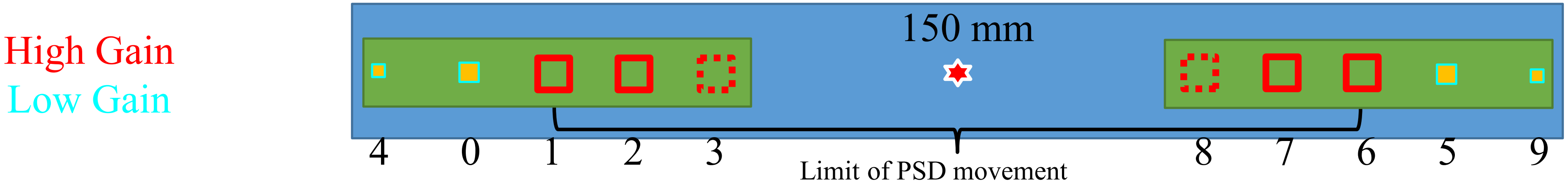
↓

Original ADC



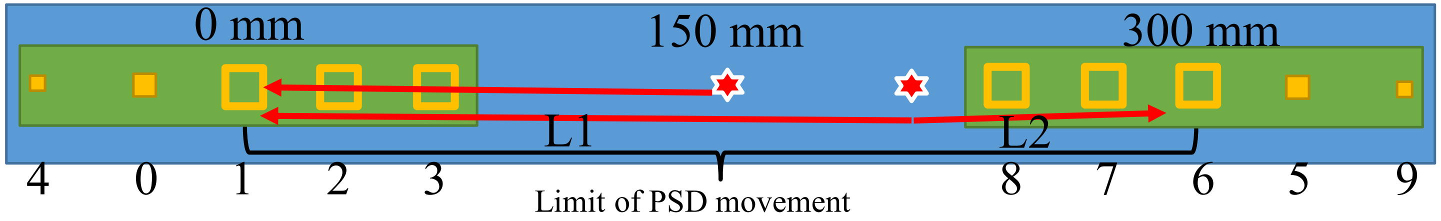
# Preliminary result of nonlinear effect

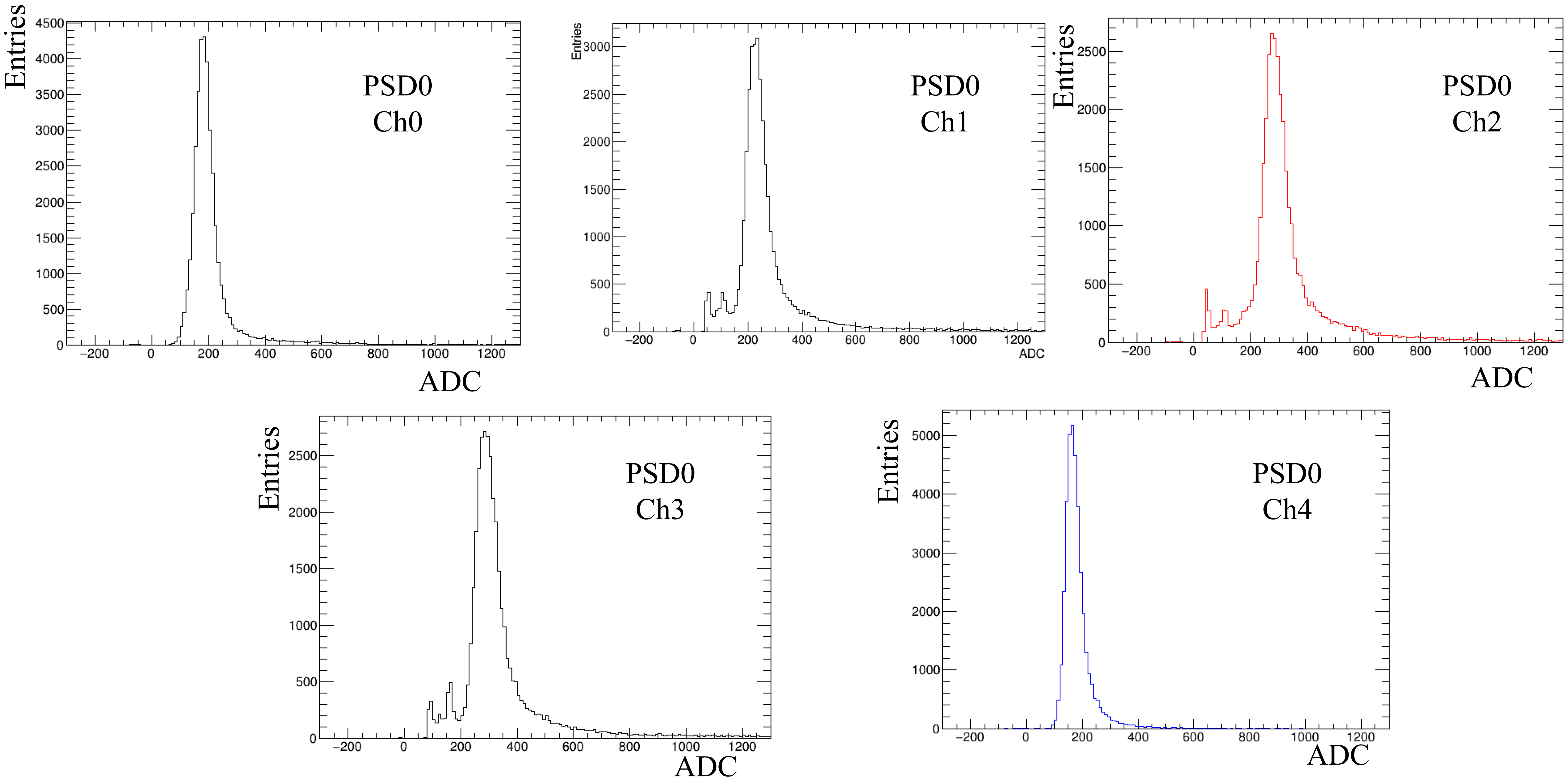


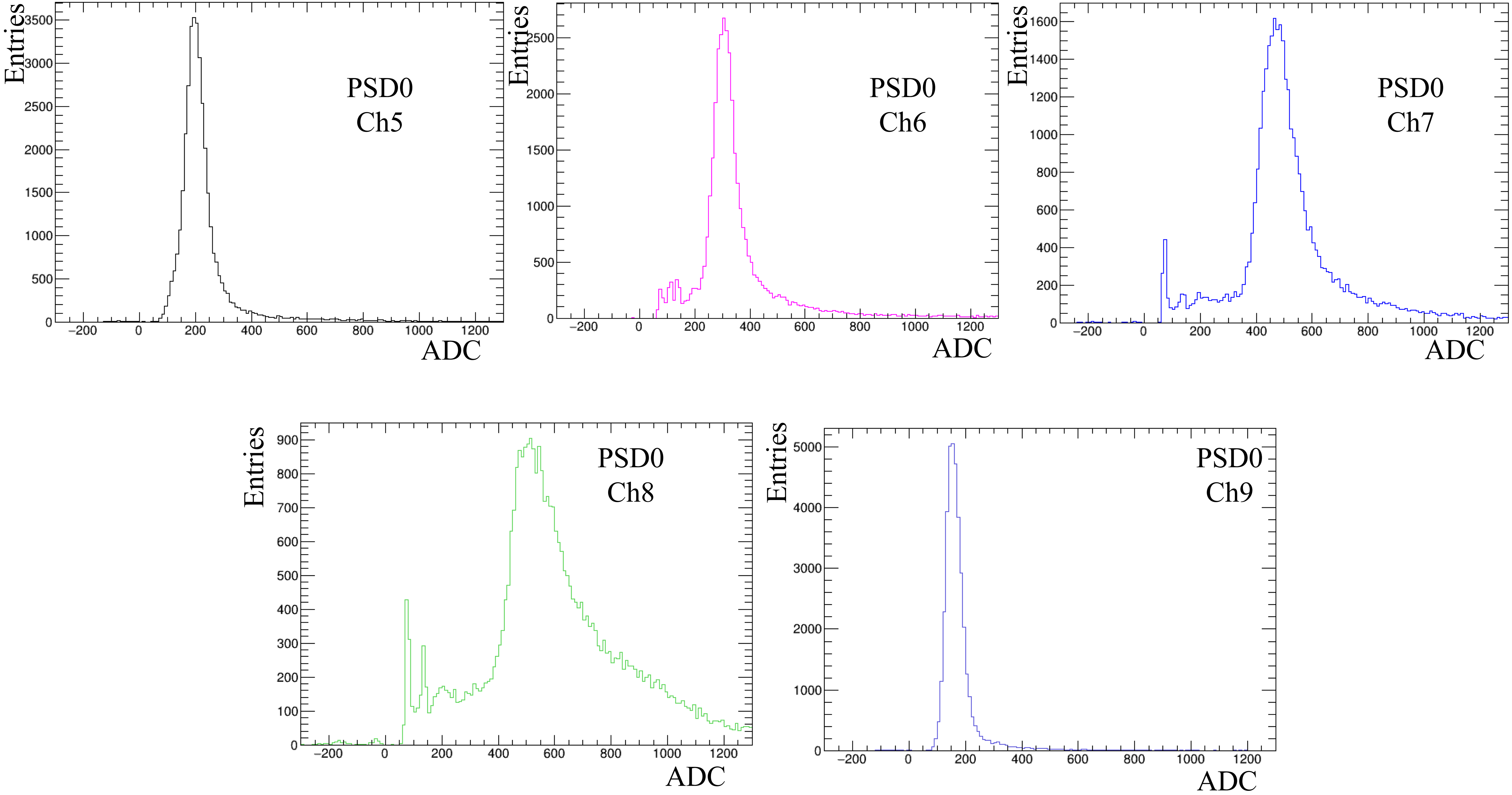



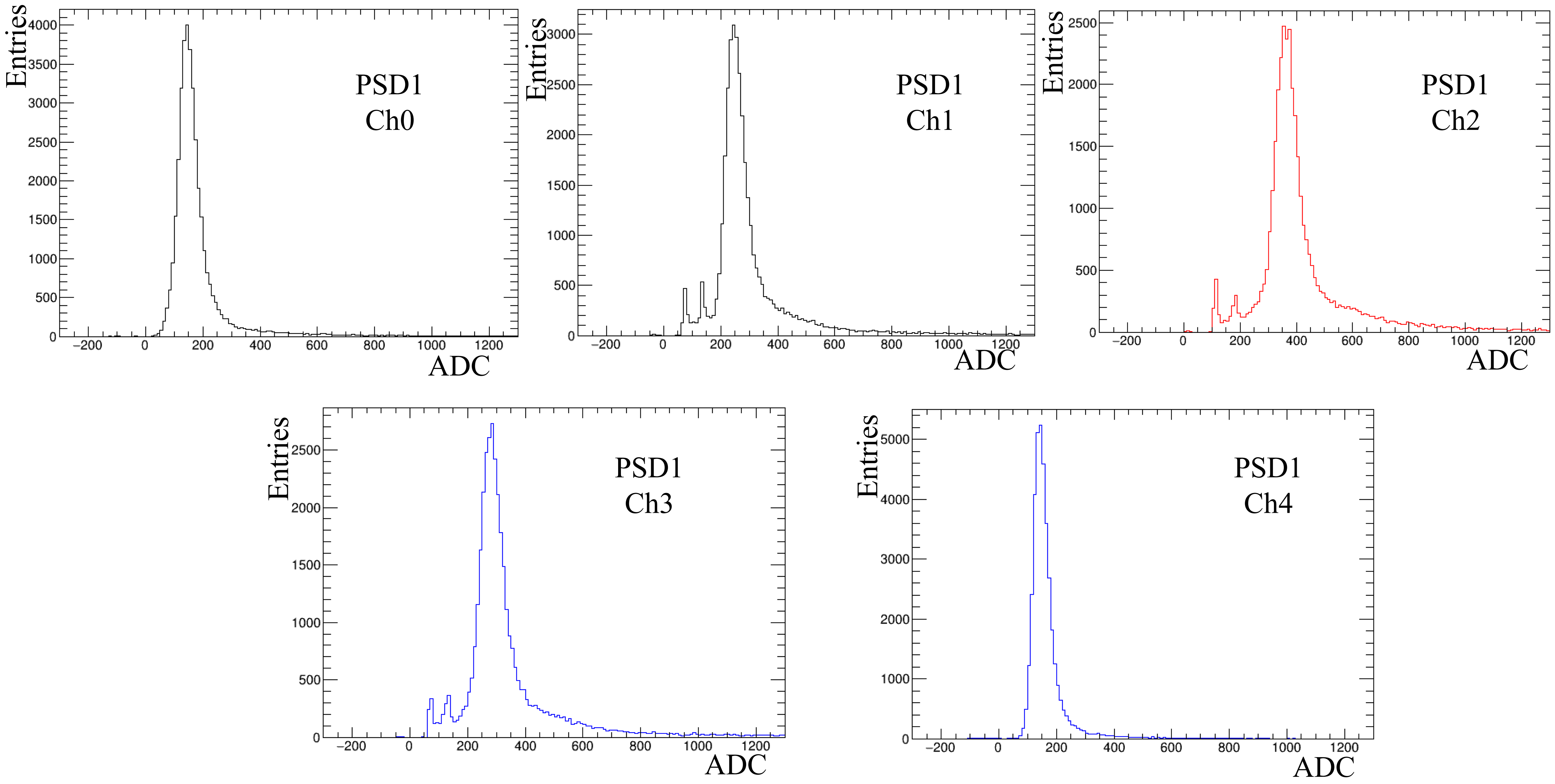
# Charge/hit position reconstruction

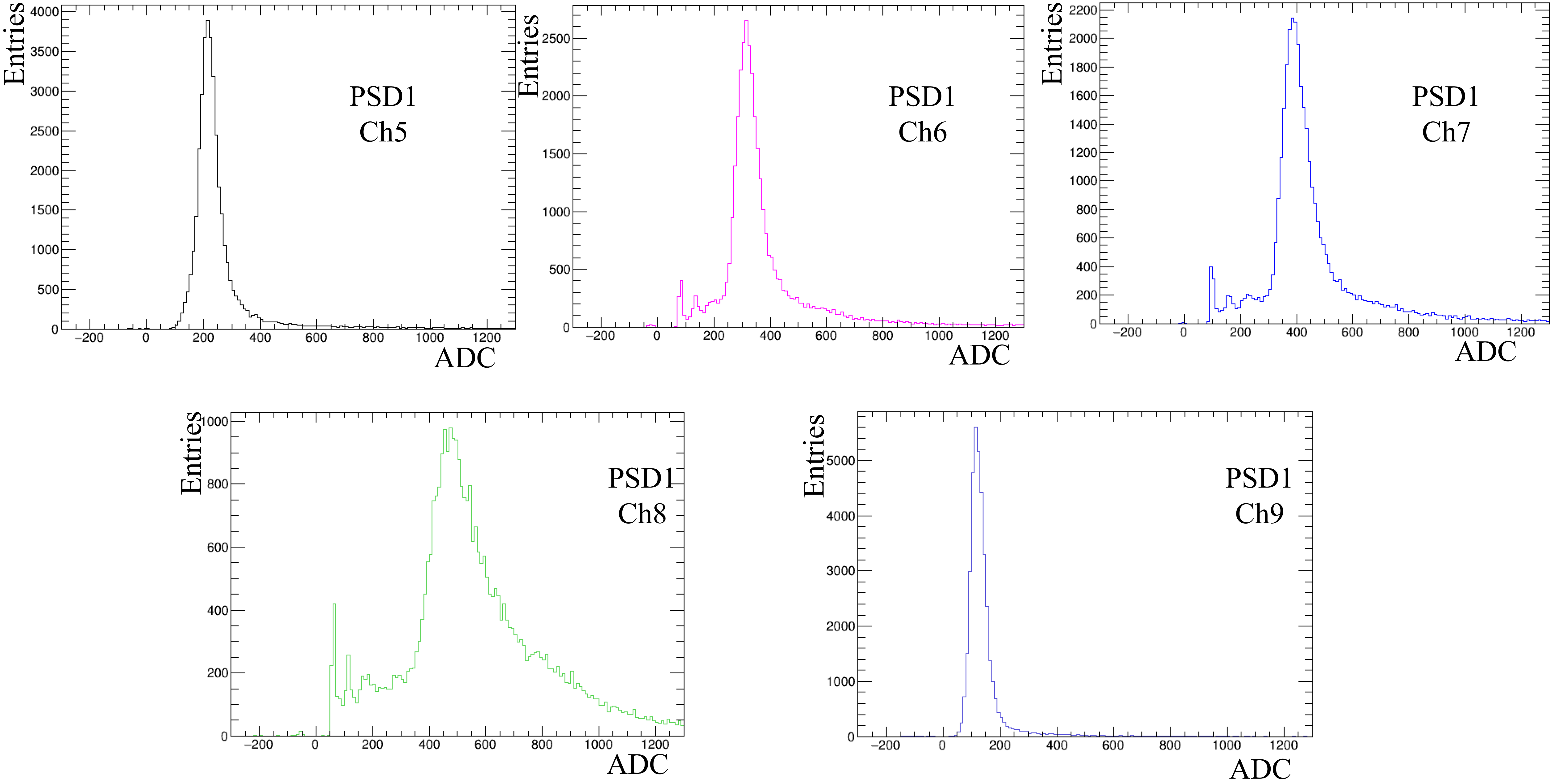
- Process of charge reconstruction (without the measurement of SiPM response):
  - Construct the relationship between mean value of original ADC vs SCD_Z (based on ion beam)
  - Reconstruct the charge of a single SiPM with the reconstructed original ADC
  - Averaged charge of the 8 SiPMs (part of SiPMs, based on high Z or low Z)
- Study of hit position reconstruction:
  - $\frac{ADC_{ch1}}{ADC_{ch6}} = \frac{F(L1)}{F(L2)}$, where ADC is the corrected unsaturated ADC, F(x) is attenuation function and L1+L2 is a constant.
  - Hit position could be reconstructed by a pair of SiPMs.
  - Average of 5 reconstructed hit positions.



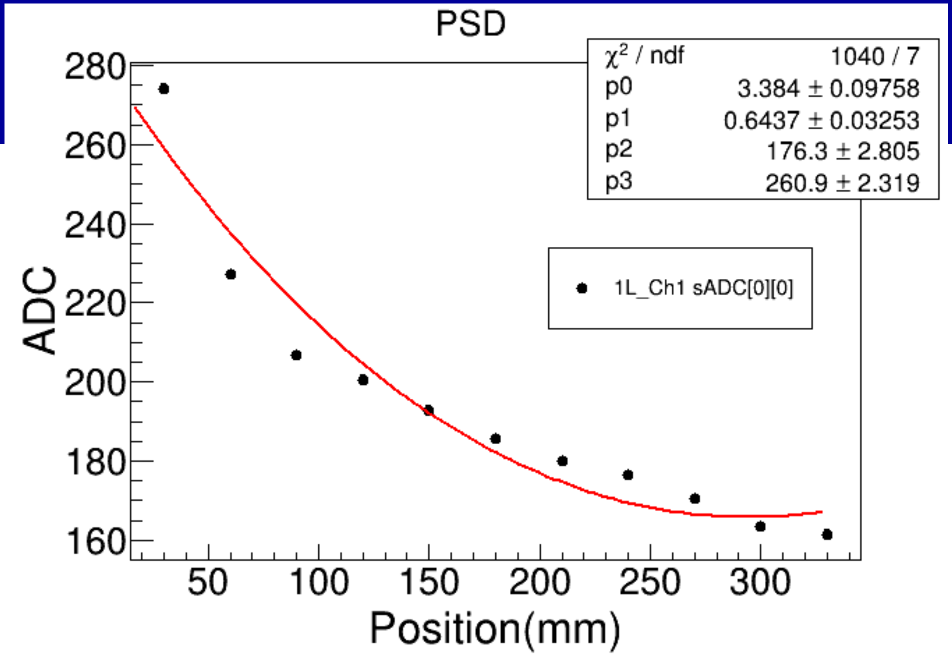

Entries
PSD0
Ch0
ADC
Entries
PSD0
Ch1
ADC
Entries
PSD0
Ch2
ADC
Entries
PSD0
Ch3
ADC
Entries
PSD0
Ch4
ADC

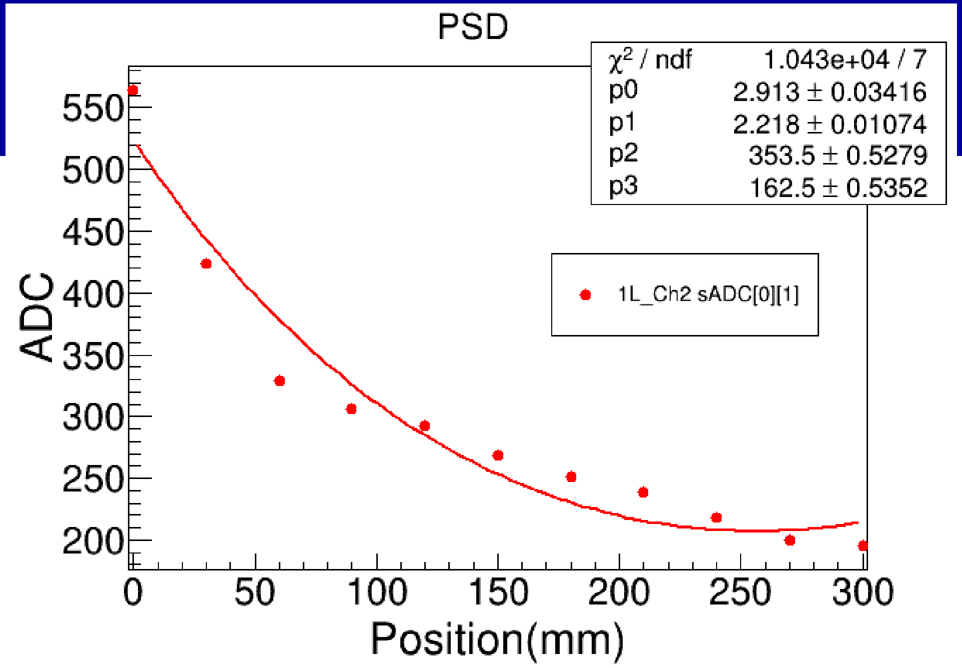

PSD0
Ch5
PSD0
Ch6
PSD0
Ch7
PSD0
Ch8
PSD0
Ch9
Entries
ADC

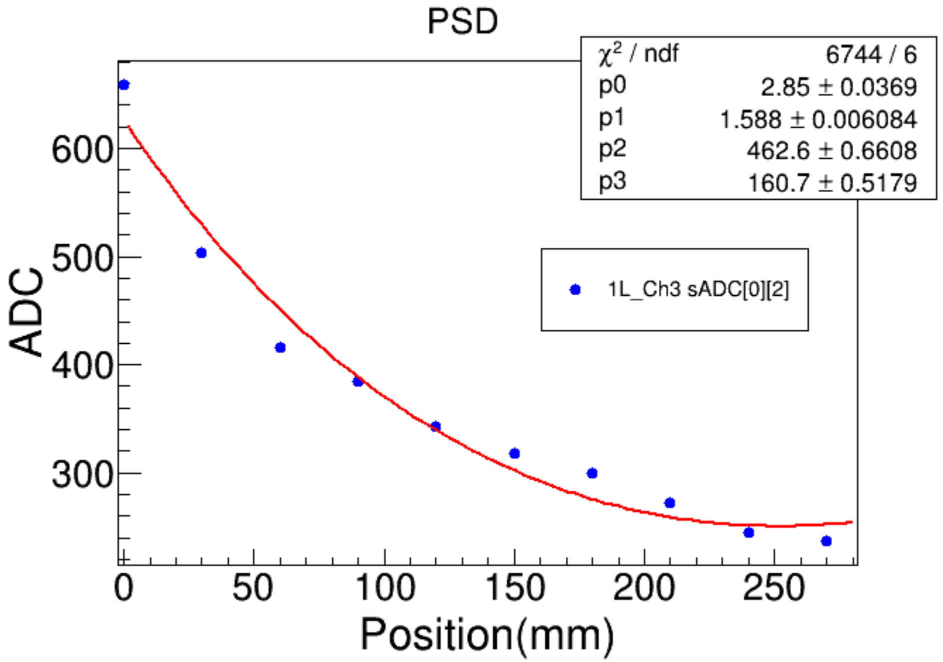

PSD1
Ch0
PSD1
Ch1
PSD1
Ch2
PSD1
Ch3
PSD1
Ch4
Entries
ADC

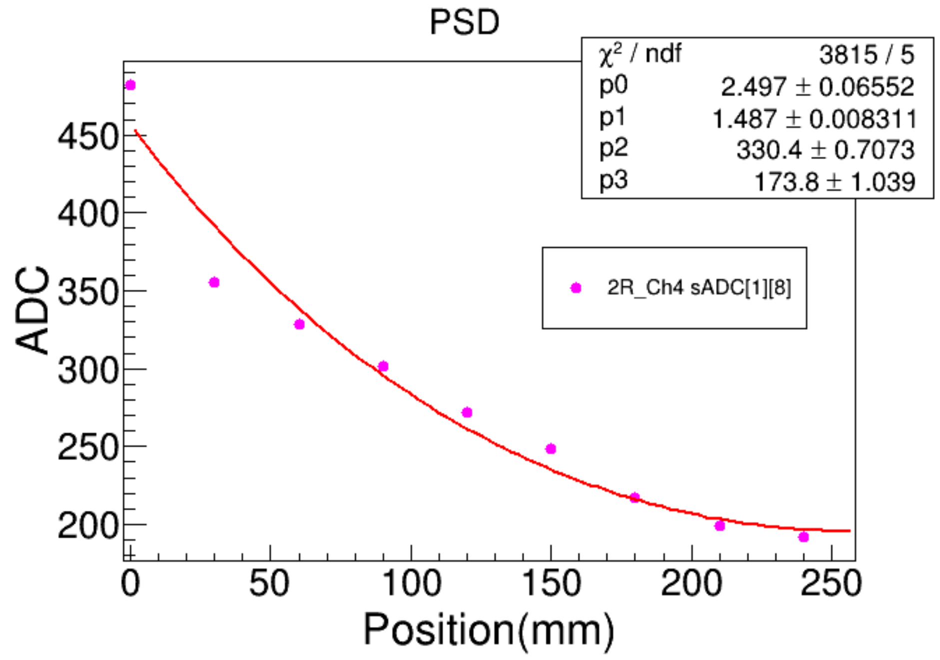


Entries
PSD1
Ch5
ADC
Entries
PSD1
Ch6
ADC
Entries
PSD1
Ch7
ADC
Entries
PSD1
Ch8
ADC
Entries
PSD1
Ch9
ADC

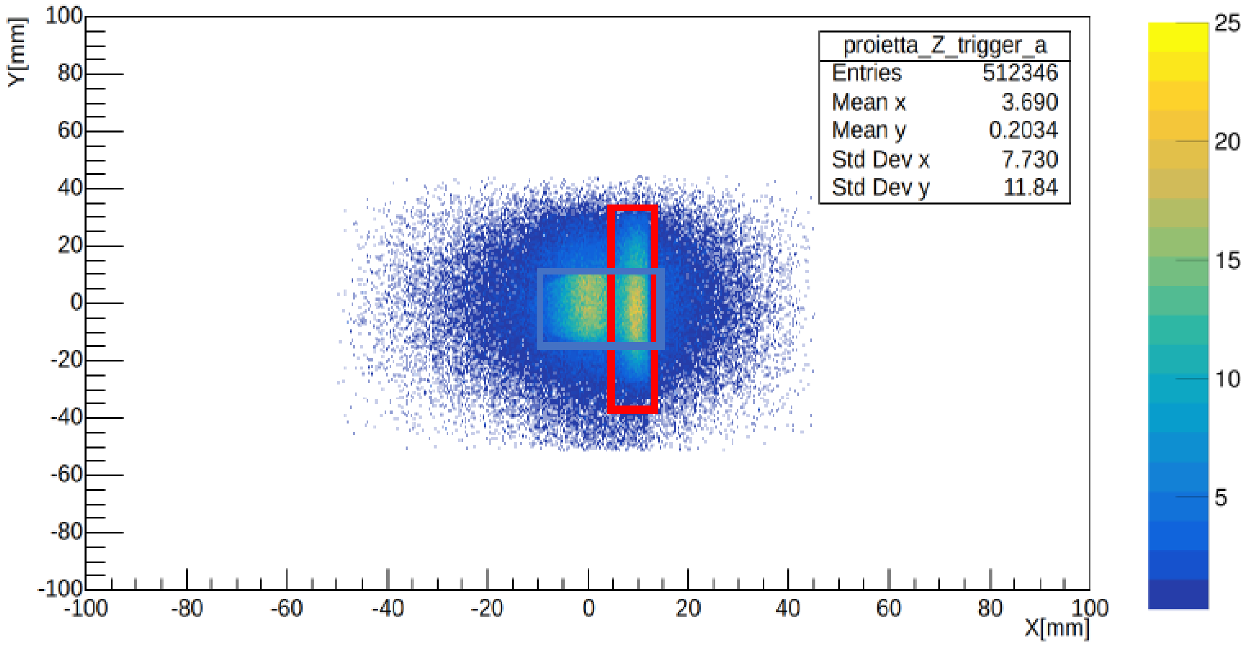

PSD
χ² / ndf 1040 / 7
p0 3.384 ± 0.09758
p1 0.6437 ± 0.03253
p2 176.3 ± 2.805
p3 260.9 ± 2.319
1L_Ch1 sADC[0][0]
ADC
Position(mm)

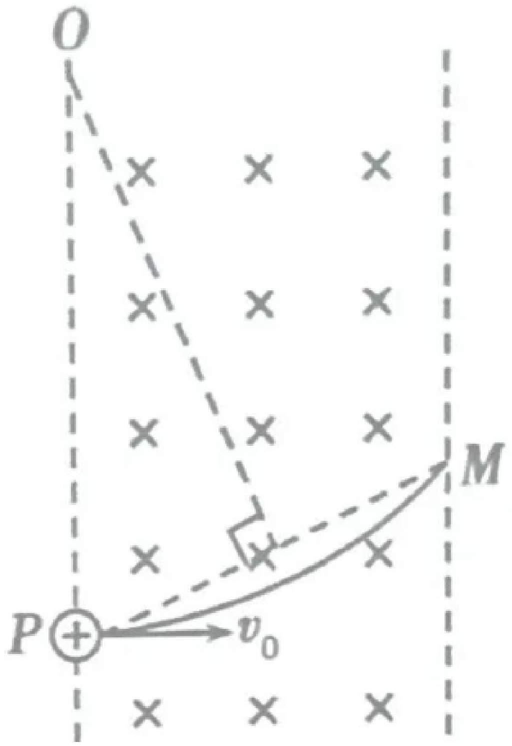

PSD
χ² / ndf 1.043e+04 / 7
p0 2.913 ± 0.03416
p1 2.218 ± 0.01074
p2 353.5 ± 0.5279
p3 162.5 ± 0.5352
1L_Ch2 sADC[0][1]
ADC
Position(mm)


PSD
χ² / ndf 6744 / 6
p0 2.85 ± 0.0369
p1 1.588 ± 0.006084
p2 462.6 ± 0.6608
p3 160.7 ± 0.5179
1L_Ch3 sADC[0][2]
ADC
Position(mm)


PSD
χ² / ndf 3815 / 5
p0 2.497 ± 0.06552
p1 1.487 ± 0.008311
p2 330.4 ± 0.7073
p3 173.8 ± 1.039
2R_Ch4 sADC[1][8]
ADC
Position(mm)

# Tracks projected to the Z position of SCD



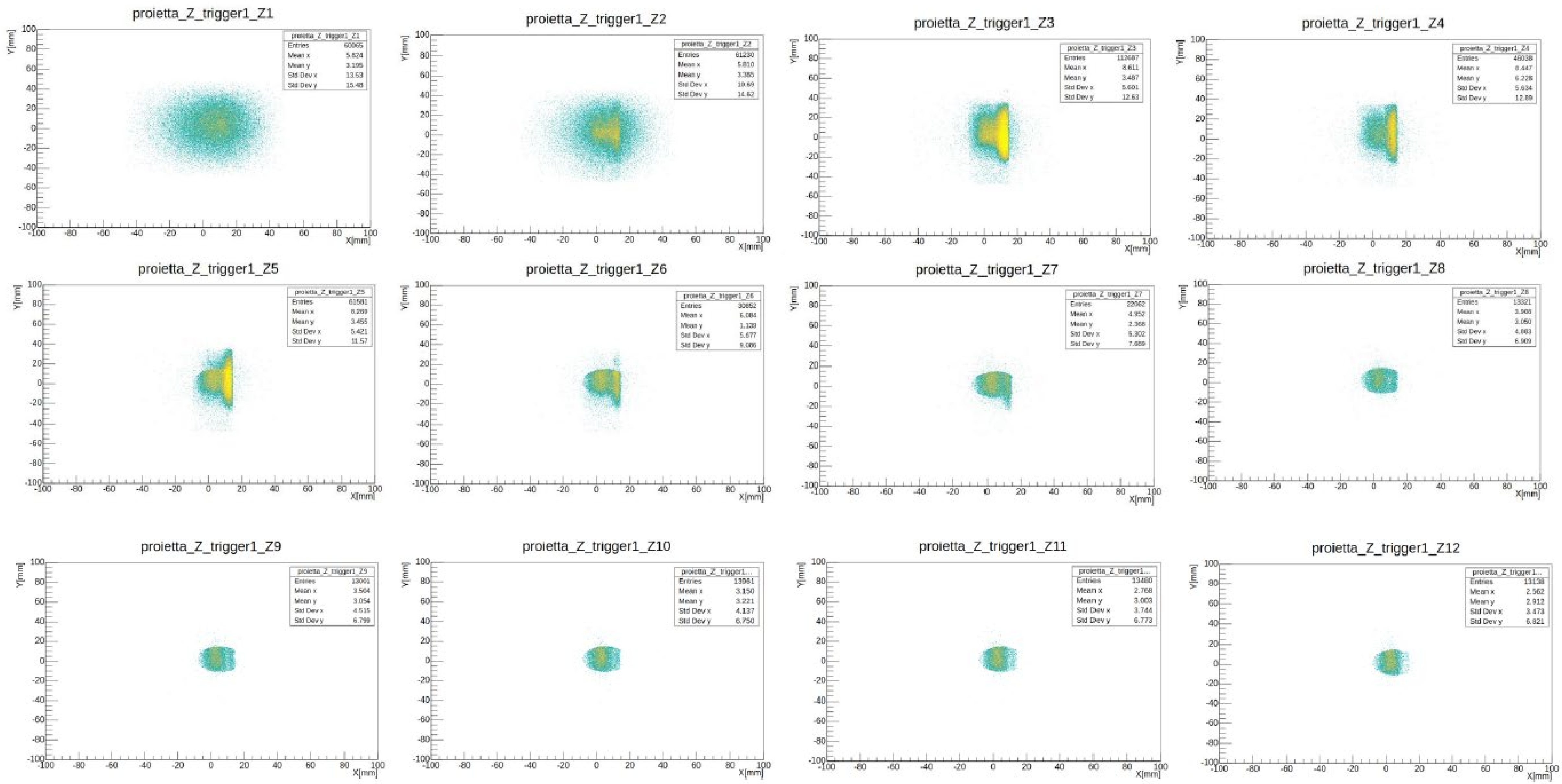

$$qv_0B = m\frac{v_0^{\ 2}}{R}$$

$$R = \frac{mv_0}{qB}$$

- The events within the red square represent fragmentation with low velocity or high charge, and they are deflected by the magnetic field (pan). The events within the blue square are particles from the original beam.

- To obtain pure beam particles without fragmentation, we can select events in which only the deposited energy is high because fragmentations, to have the same high deposited energy, must either have lower velocity or larger charge. In both cases, when under the influence of the magnetic field, the curvature of their trajectory becomes greater (smaller radius), and they no longer enter the activated area of the trigger box.

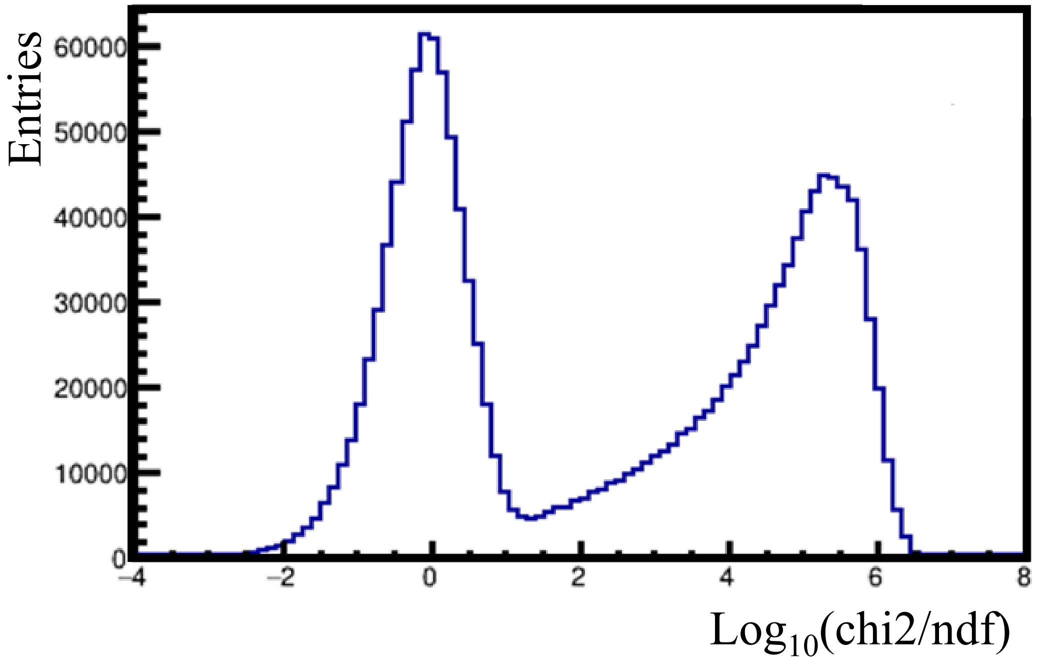
# Events with the deposited energy increasing

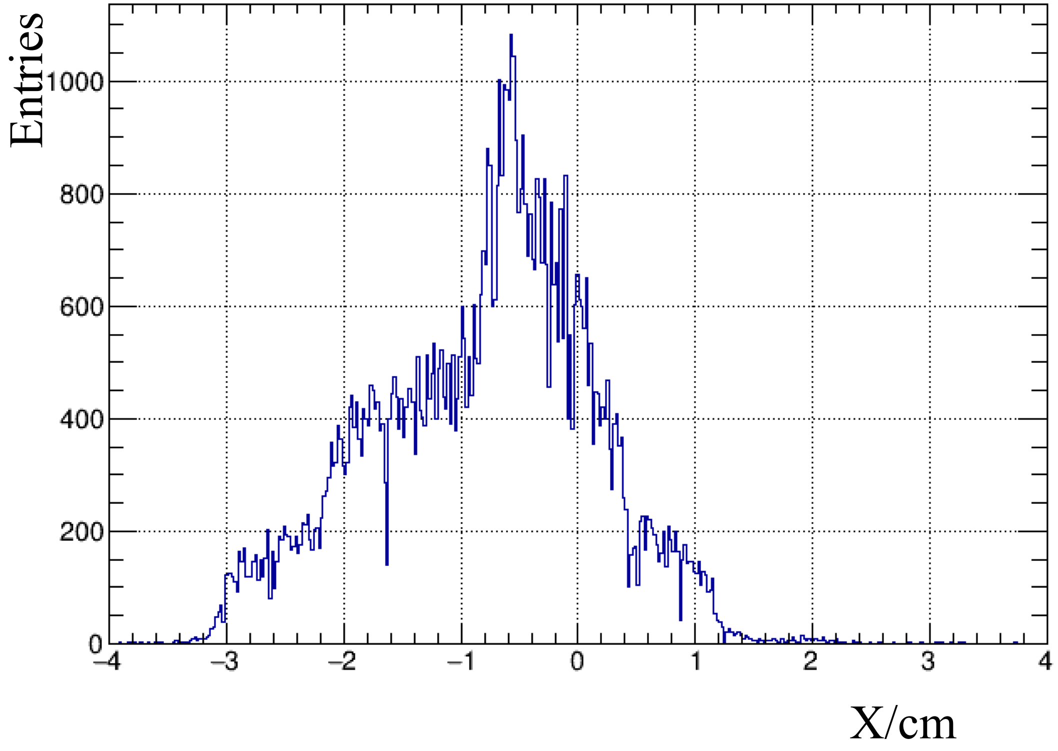


# Event selection by SCD_INFN

- Definition of region:
  - Core: Region -2.5<X<2.5 && -23<Y<23 (cm)
  - Side: Region out of core
- Events will be selected with requirement chi2/ndf<10.

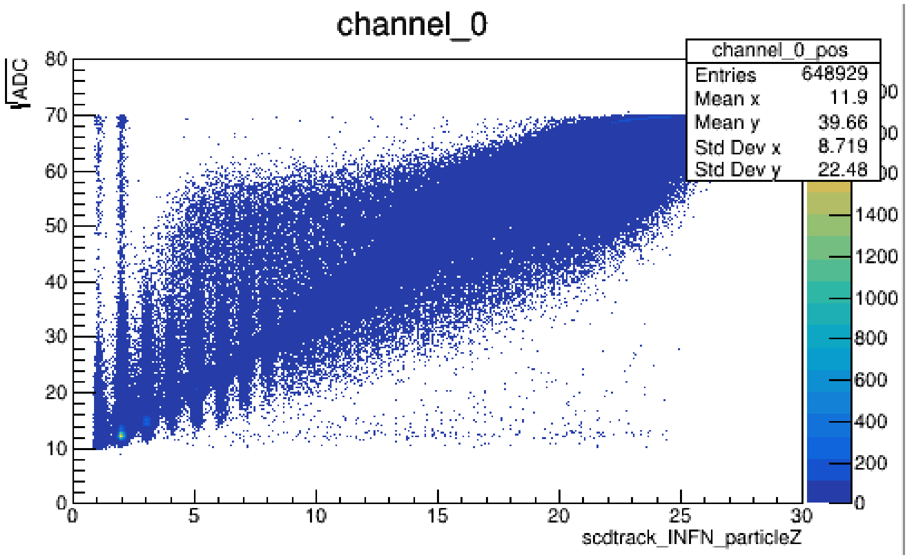
Distribution of log10(chi2/ndf)

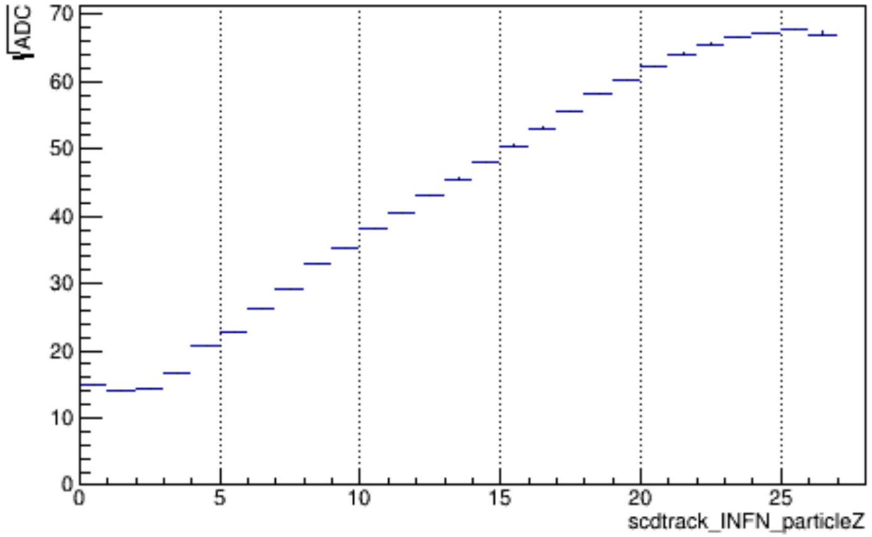


# Function between photons and charge

- ➢ The response of SiPM:
  - Convert ADC to number of photons
- ➢ Correct the number of photons with attenuation function
- ➢ Fit the function G(x) between sqrt(corrected photons) and charge from SCD_INFN.

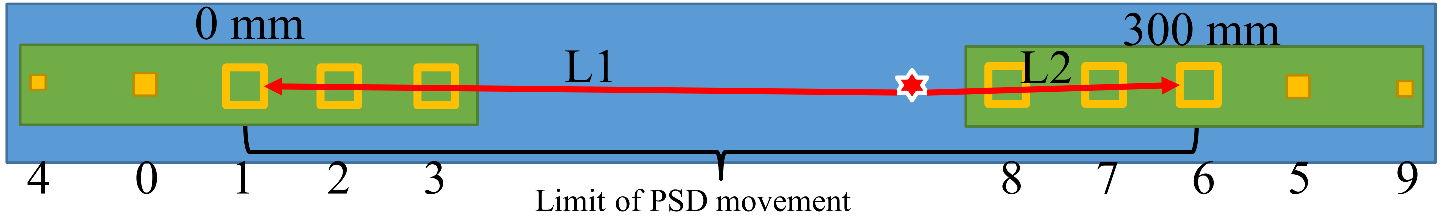



Need To Do

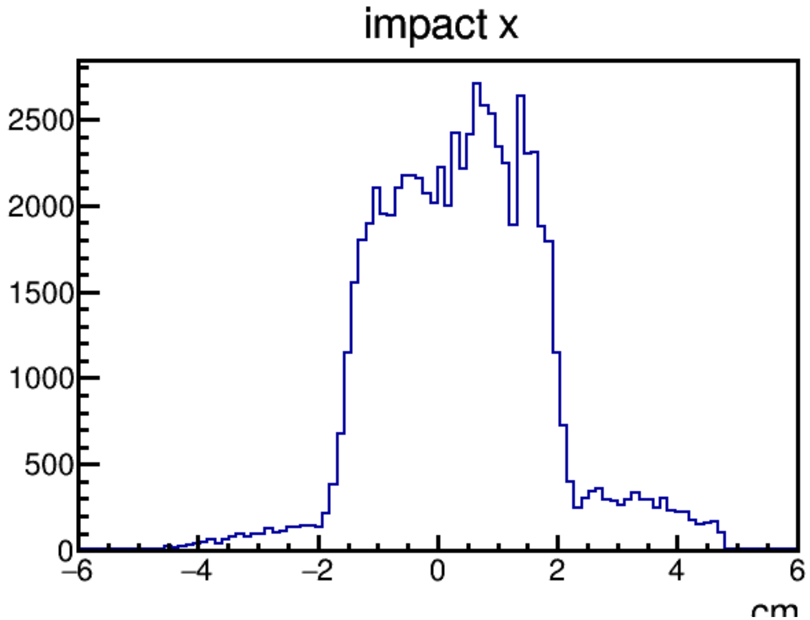
# Hit position reconstruction

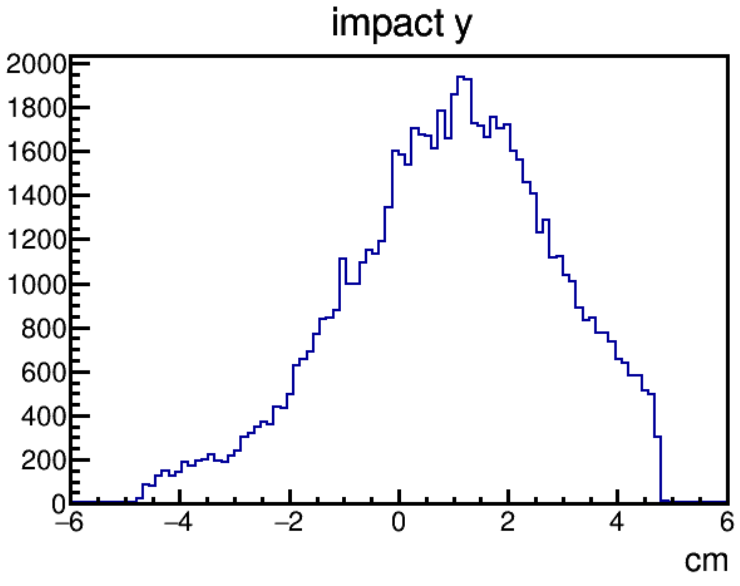
- Hit position reconstruction:
  - $\frac{R\prime(ADC_{ch1})}{R\prime(ADC_{ch6})} = \frac{F(L1)}{F(L2)}$, where R'(x) is the inverse function of SiPM response, F(x) is attenuation function and L1+L2 is a constant.
  - If ADC is not saturated, $\frac{ADC_{ch1}}{ADC_{ch6}} = \frac{F(L1)}{F(L2)}$ could also be used.
  - Hit position could be reconstructed by a pair of SiPMs.
  - Average of 5 reconstructed hit positions.



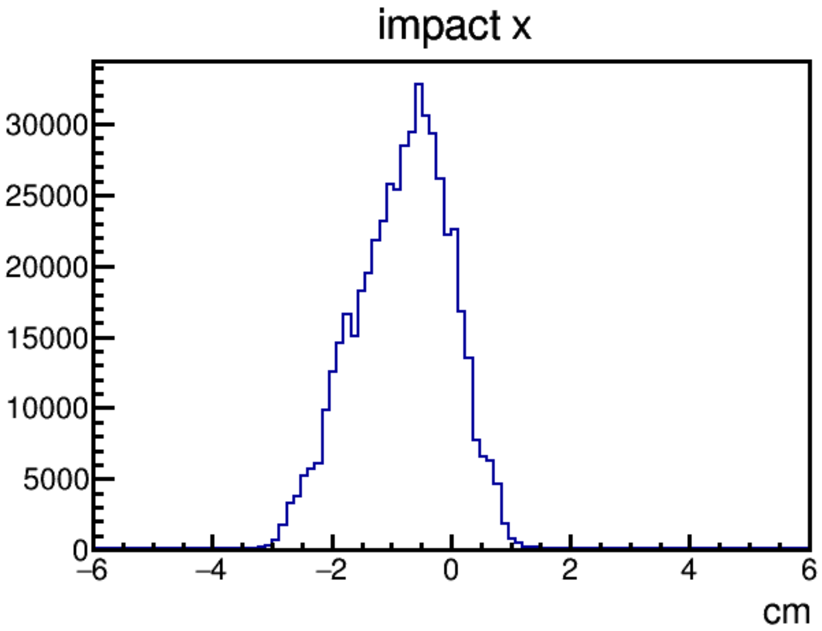
SCD_INFN击中位置的x，y分布(没有用直线斜率外推的坐标)

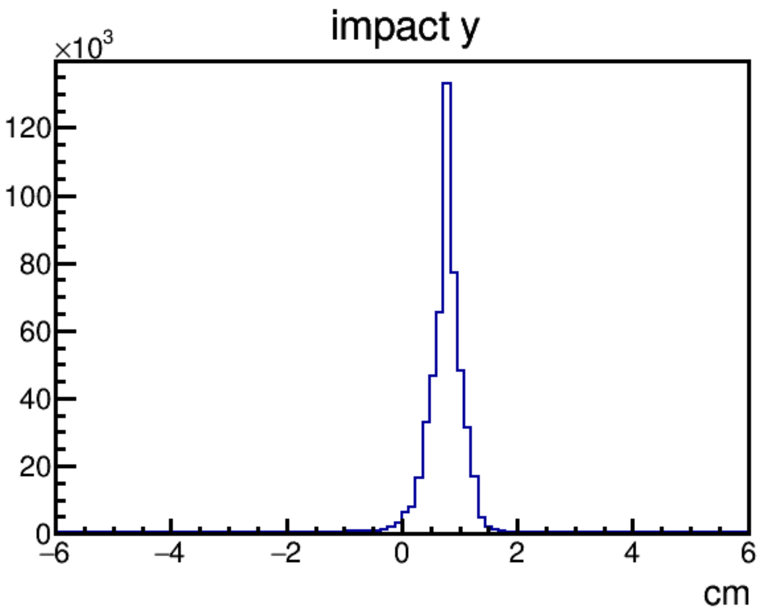
PS

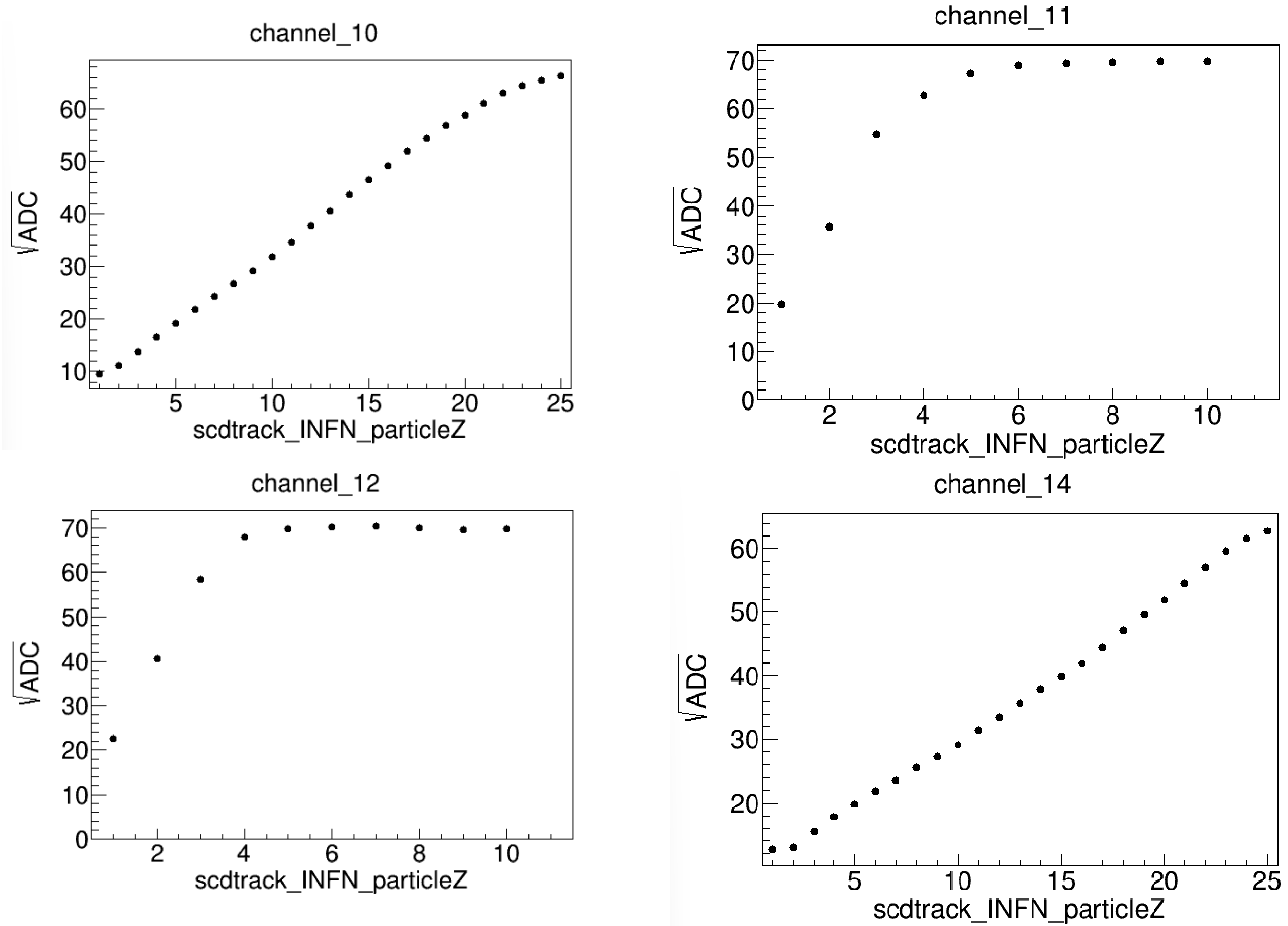


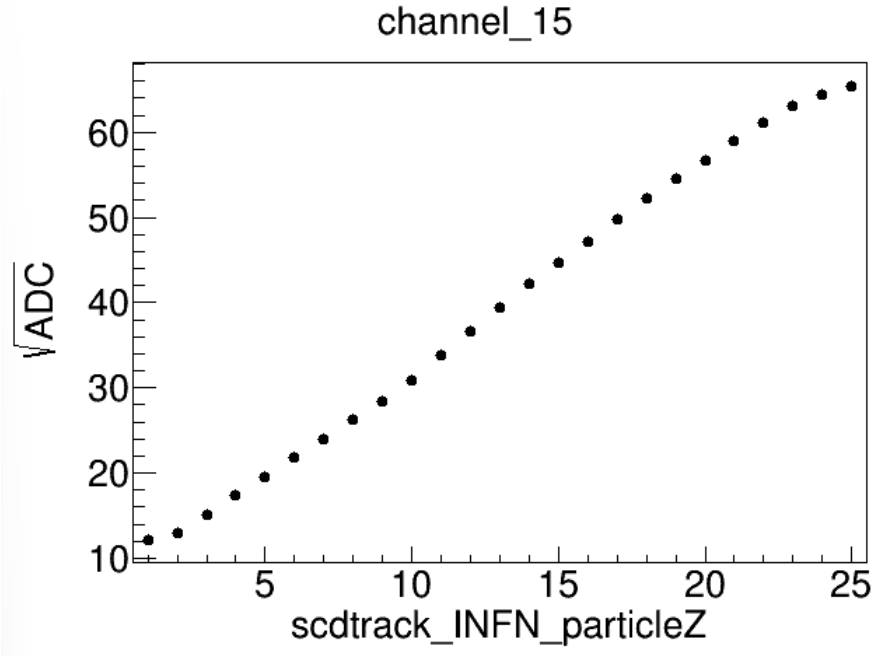



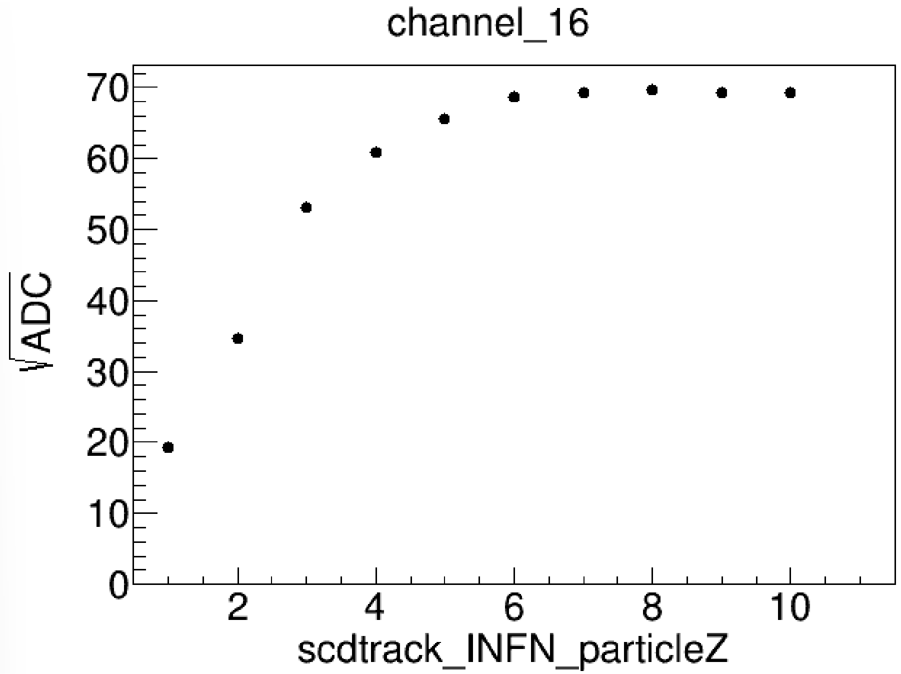

SPS

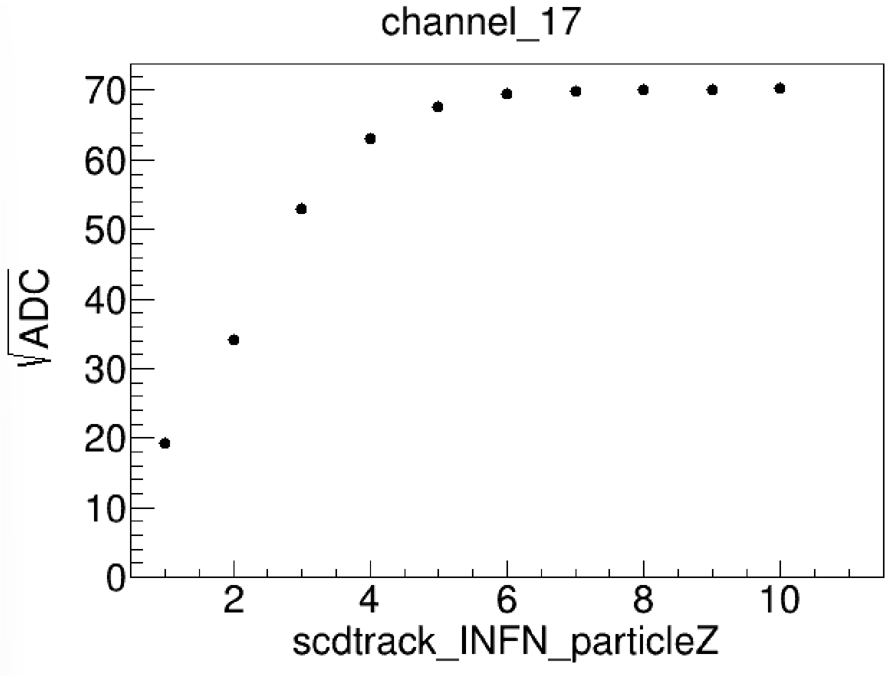


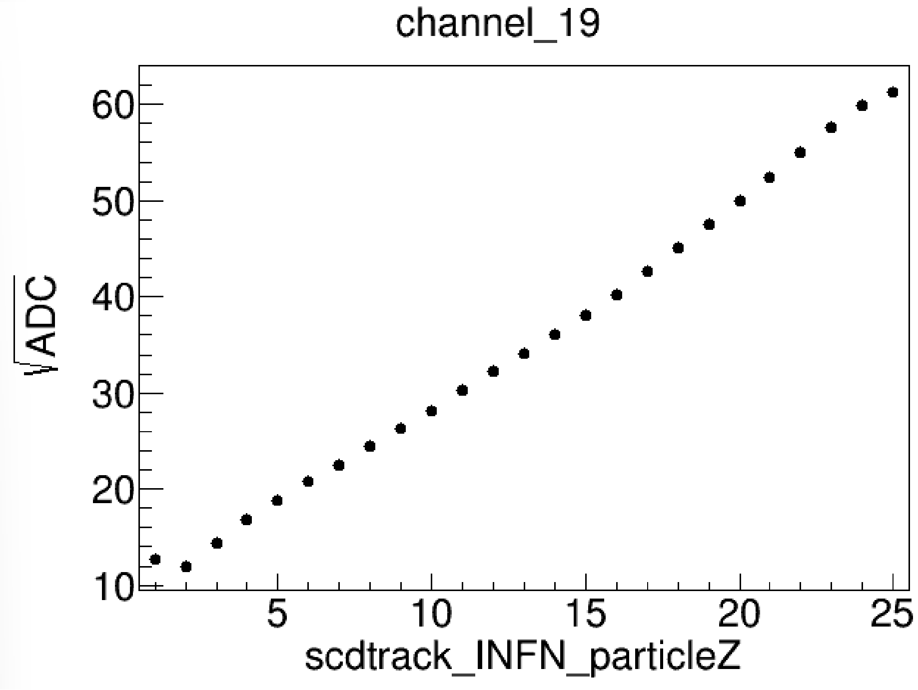



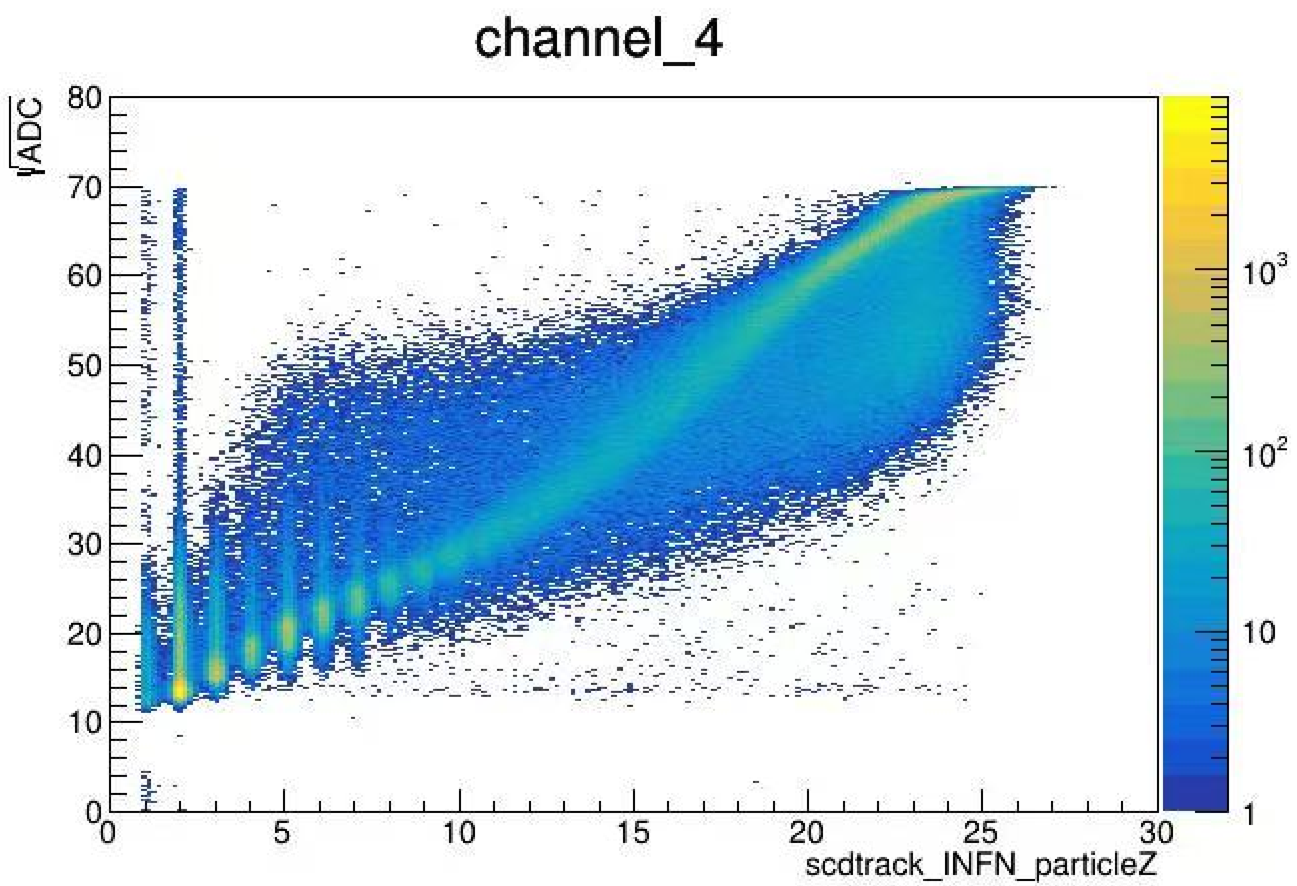

channel_10
√ADC
scdtrack_INFN_particleZ
channel_11
√ADC
scdtrack_INFN_particleZ
channel_12
√ADC
scdtrack_INFN_particleZ
channel_14
√ADC
scdtrack_INFN_particleZ


channel_15
$\sqrt{ADC}$
10
20
30
40
50
60
5
10
15
20
25
scdtrack_INFN_particleZ


channel_16
$\sqrt{ADC}$
0
10
20
30
40
50
60
70
2
4
6
8
10
scdtrack_INFN_particleZ


channel_17
$\sqrt{ADC}$
0
10
20
30
40
50
60
70
2
4
6
8
10
scdtrack_INFN_particleZ


channel_19
$\sqrt{ADC}$
10
20
30
40
50
60
5
10
15
20
25
scdtrack_INFN_particleZ



channel_4
√ADC
80
70
60
50
40
30
20
10
0
0
5
10
15
20
25
30
scdtrack_INFN_particleZ
$10^3$
$10^2$
10
1

# Processes of PSD Reconstruction