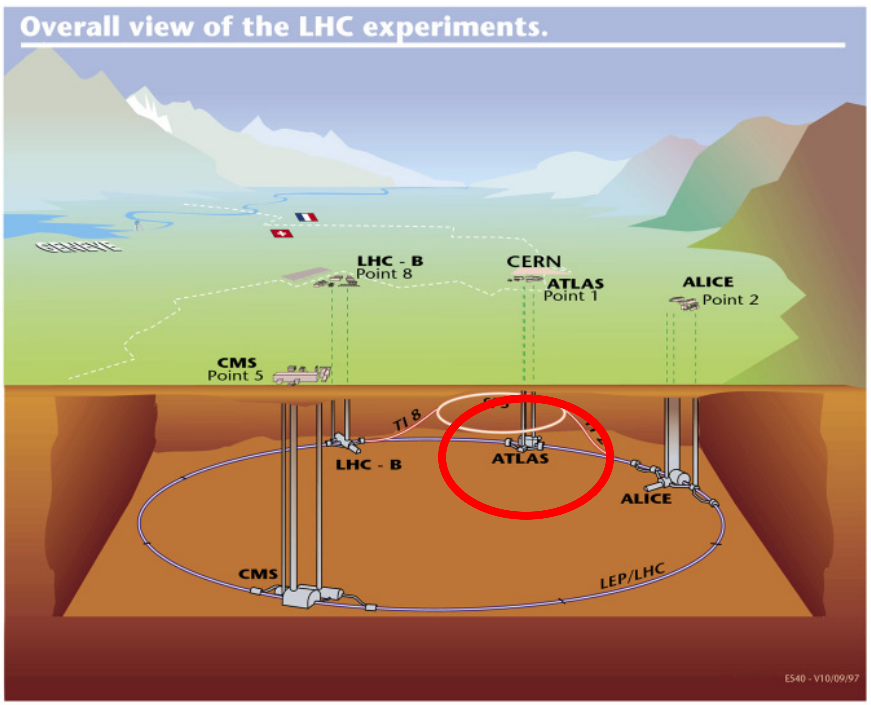
# Evaluation of 50 μm square pixel detector with test ASIC for the HL-LHC ATLAS upgrade

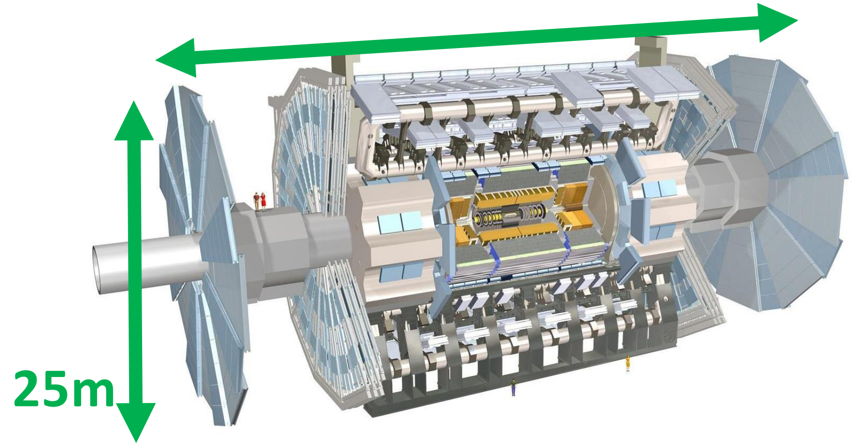
Yamanaka Group M2 Daiki Yamamoto

# LHC-ATLAS Experiment

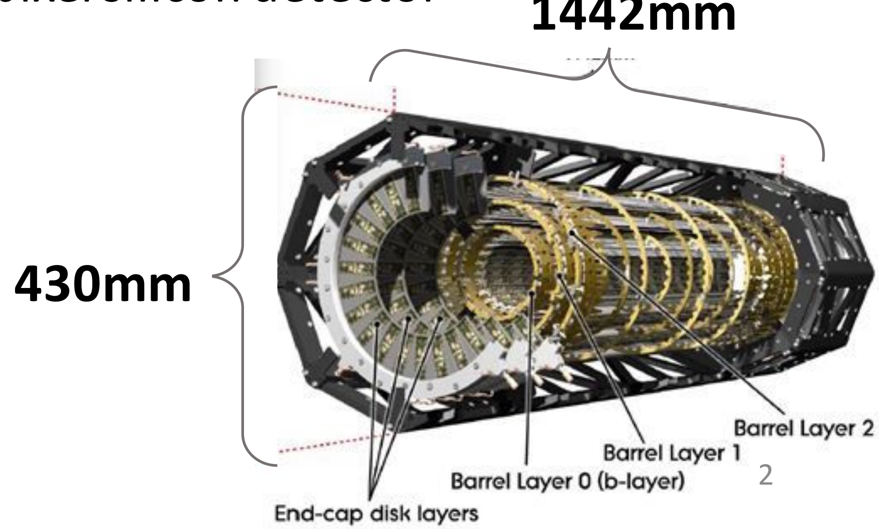
LHC（Large Hadron Collider）




ATLAS detector




pixel silicon detector



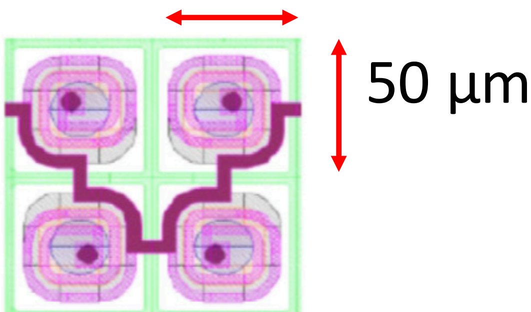
# Beam Test

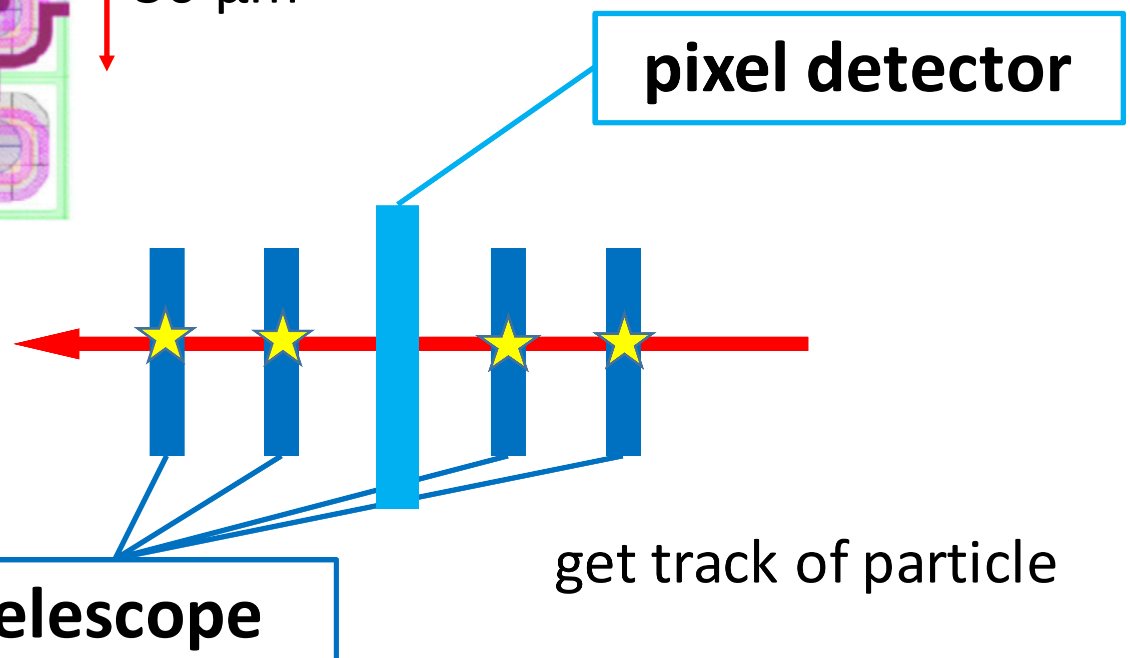
**goal**

efficiency study of pixel detector

✓ structure effect

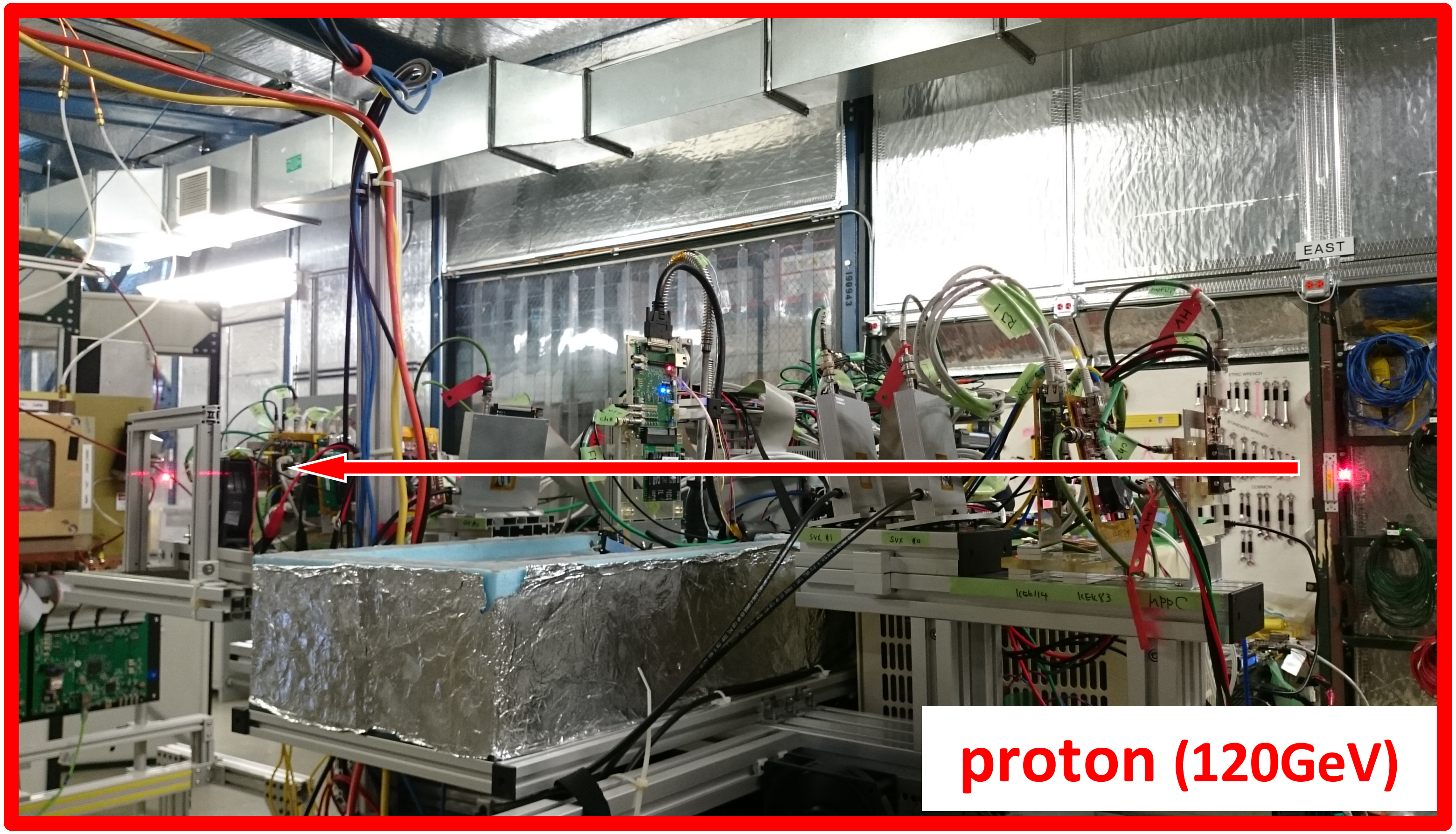
➡ tracking resolution must be less than 10 µm



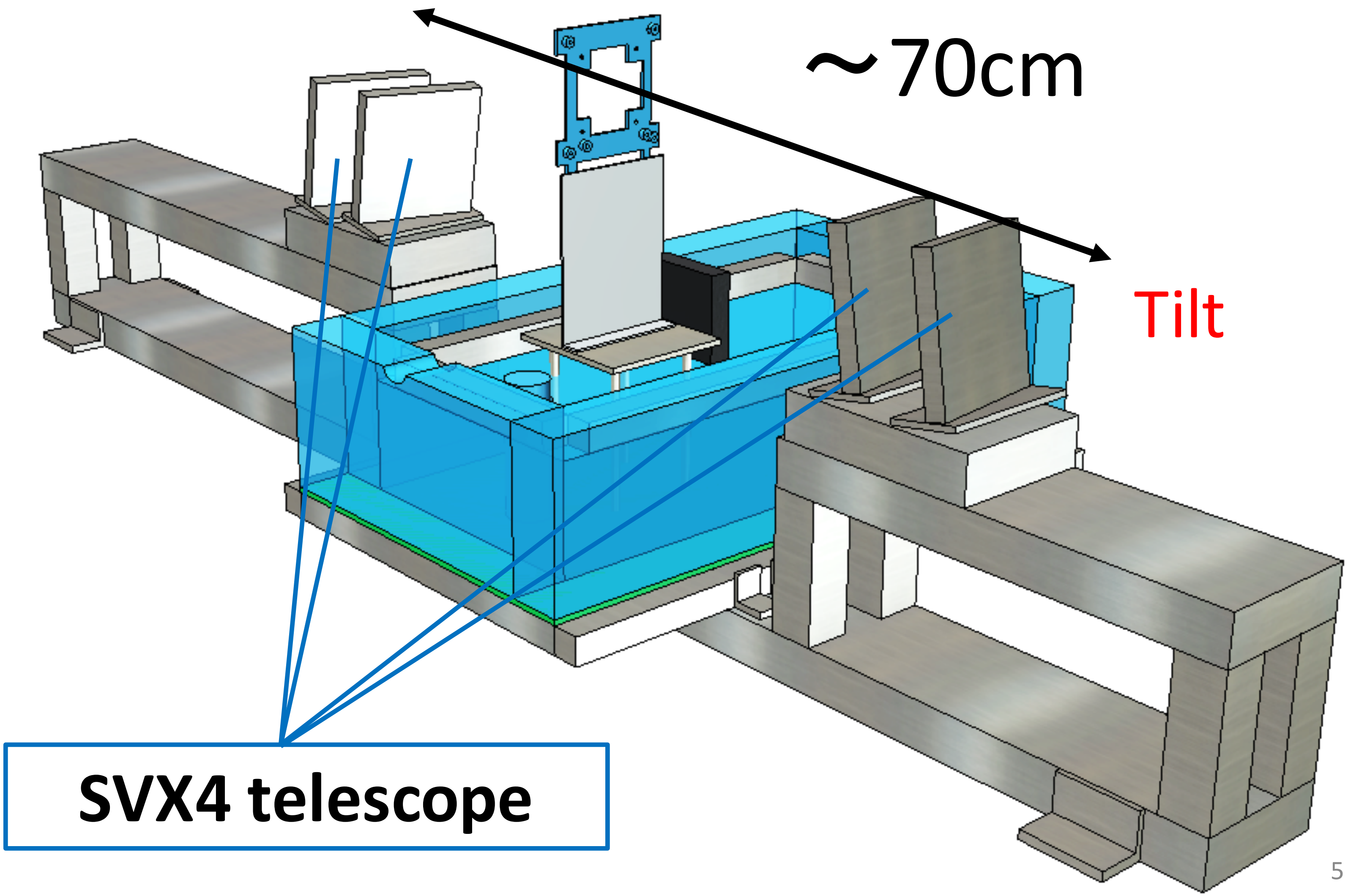




get track of particle

# Beam Test @Fermilab



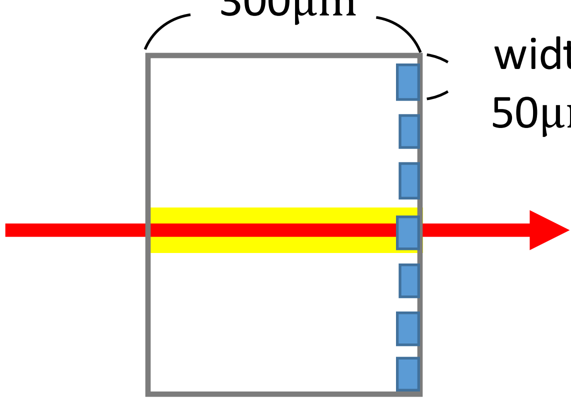
# Experimental Setup



# SVX4 telescope track reconstruction

# Merit of Tilting the Sensors

**vertical**

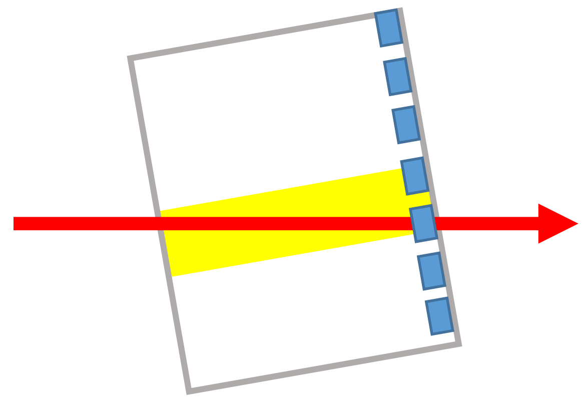



signal can be detected
at only 1 strip

resolution $\sigma = \frac{50}{\sqrt{12}}$

$\sim 14\,[\mu\mathrm{m}]$

**tilted**



more than 1 strip

centroid method ⇨ hit position

this time, tilted sensors by 10 degree

# Data Processing

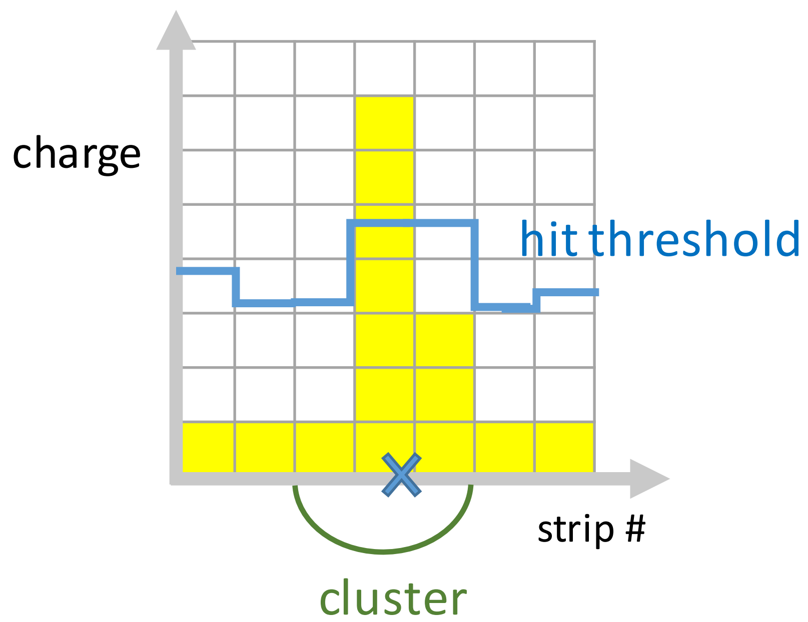
Hit Selection

↓

Clustering

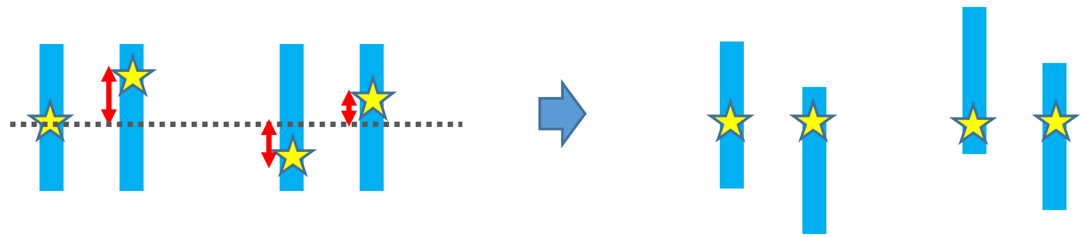
↓

GetLocalPosition

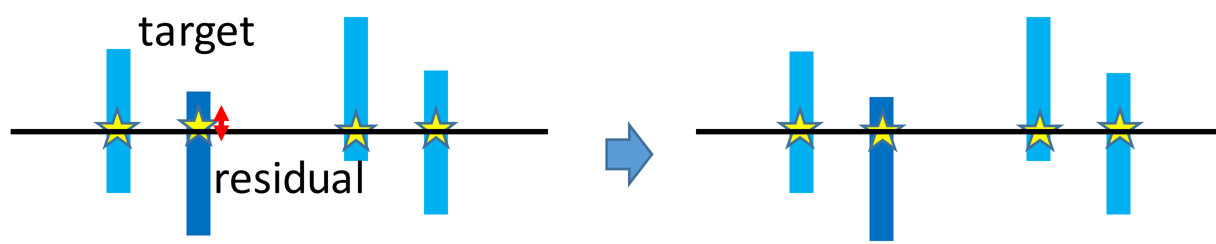


# Alignment

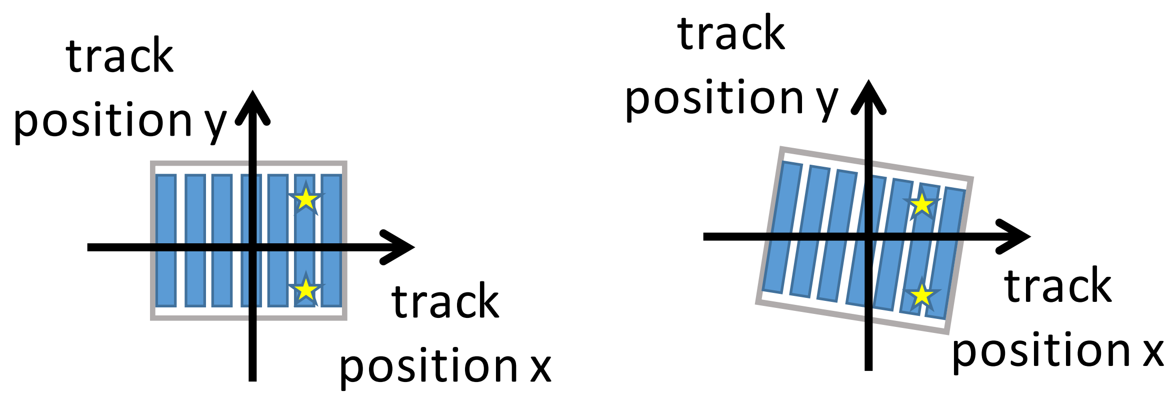
GetGlobalPosition



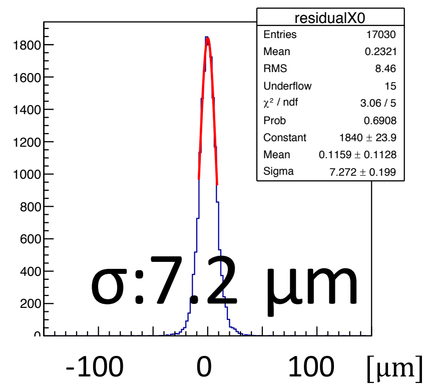
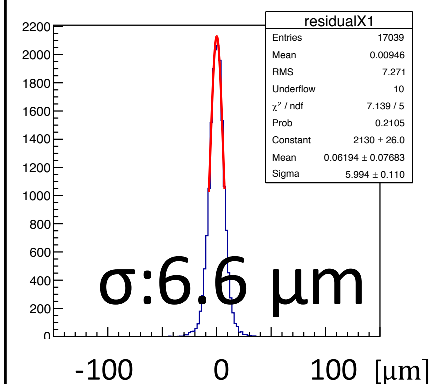
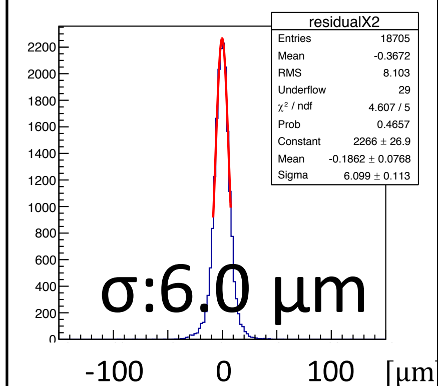
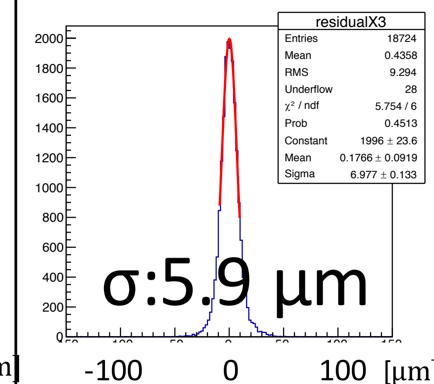
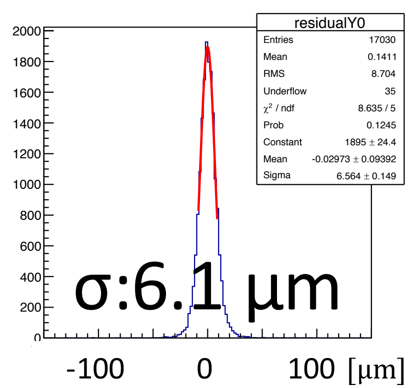
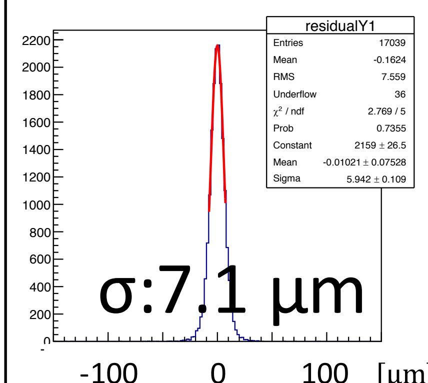
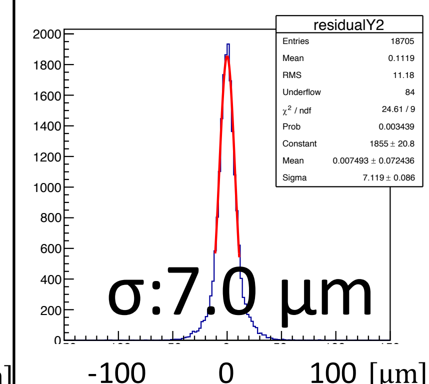
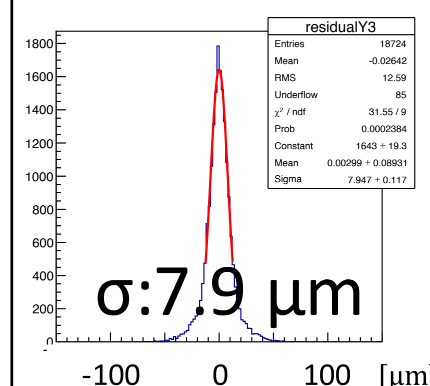
Shift




Rotation



# Residual Distribution (after alignment)

| | 1st layer | 2nd layer | 3rd layer | 4th layer |
|---|---|---|---|---|
| X |  |  |  |  |
| Y |  |  |  |  |

# Position Resolution of Sensor

## Assumption

- Track is parallel to the Z axis
- Each sensor has almost same resolution

$$\sigma_{1residual}^2 = \sigma_1^2 + \sigma_{track}^2$$

$$= \sigma_1^2 + \left(\frac{\sqrt{\sigma_2^2 + \sigma_3^2 + \sigma_4^2}}{3}\right)^2$$

$$\sigma_{1residual} \sim \sigma_{4residual}$$

| layer | $\sigma_x$ [μm] | $\sigma_y$ [μm] |
|---|---|---|
| 0 | 6 | 6 |
| 1 | 5 | 6 |
| 2 | 5 | 6 |
| 3 | 6 | 7 |

# Analysis of Position Resolution

## Factors

- fluctuation of dE/dx

according to the FWHM of cluster charge,

$\frac{\delta Q_{tot}}{Q_{tot}} \sim 0.2$

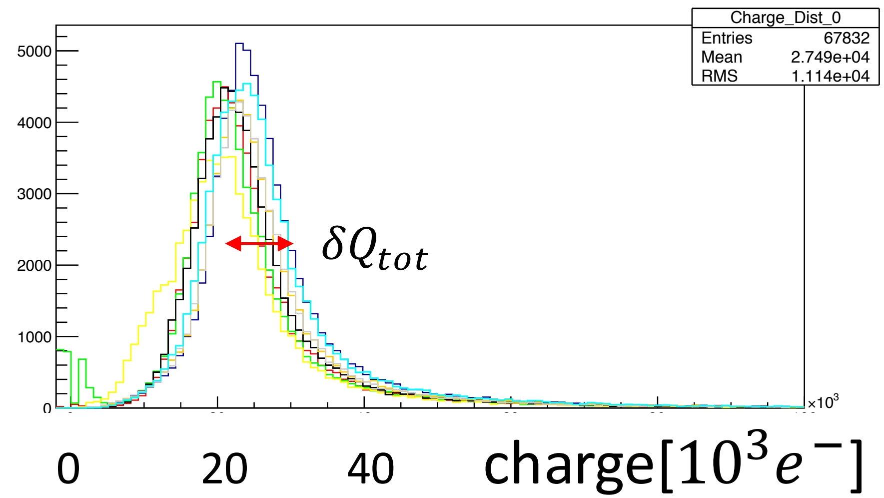
$$x = \frac{x_1 Q_1 + x_2 Q_2}{Q_1 + Q_2}$$

$$\delta_x \sim \frac{\sqrt{2}(width)\, Q_1 Q_2}{(Q_1 + Q_2)^2} \frac{\delta Q}{Q}$$

if $Q_1 = Q_2$ ,

$\sim$4 µm

cluster charge




- multiple scattering $\sim$2 µm

- noise of ADC $\sim$ 1 ADC $\sim$ 1 ke

  (this effect is included in δQ)

# Tracking Resolution

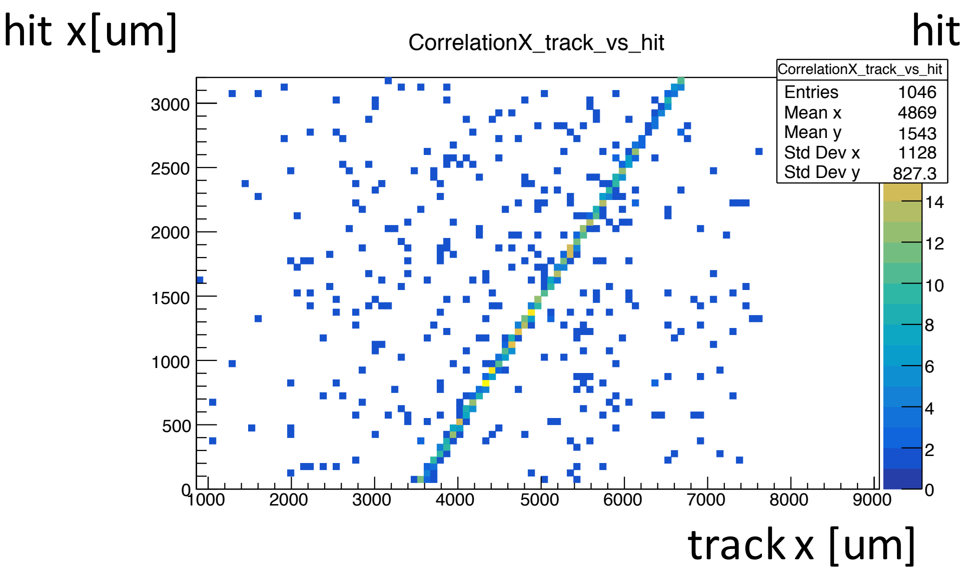
Evaluating by weighting of each sensor resolution

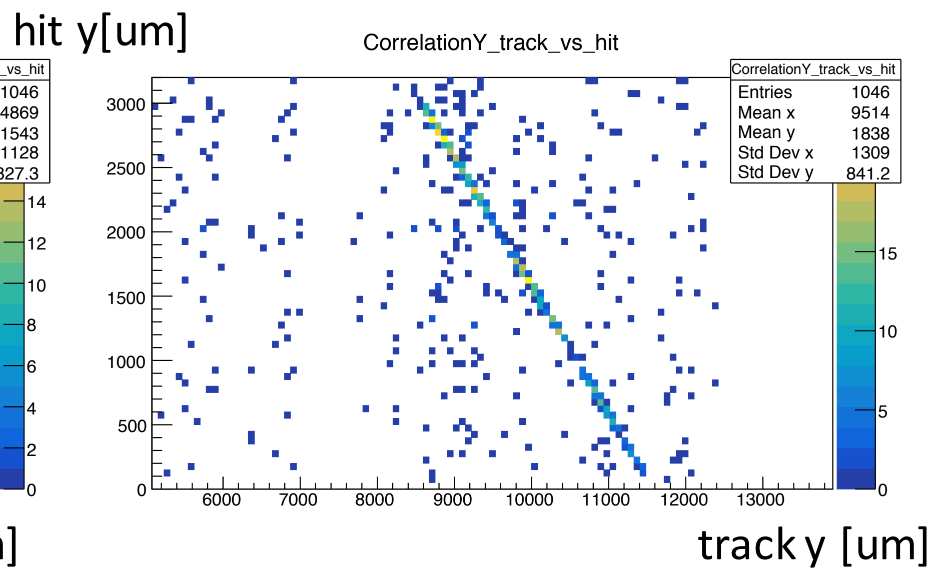
| $\sigma_{x-track}$ [μm] | $\sigma_{y-track}$ [μm] |
|---|---|
| 3 | 3 |

✓ Enough resolution ( ＜ 10 μm ) for evaluating pixel sensor

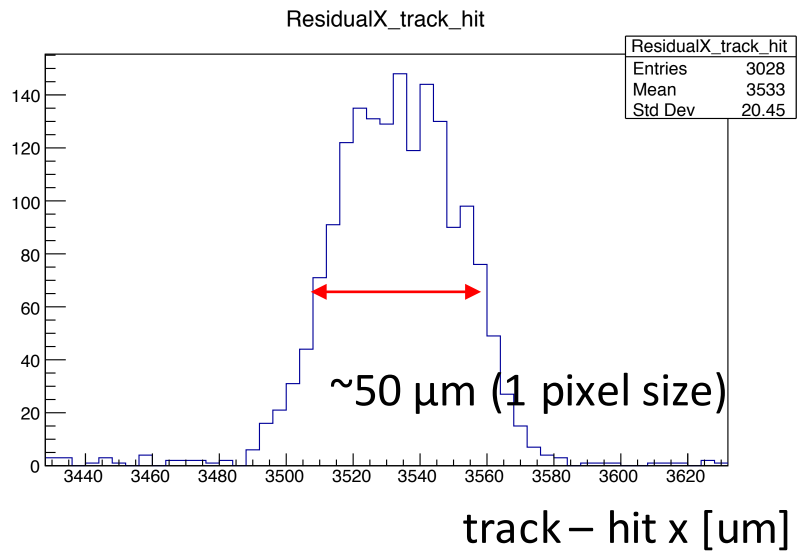
# FE65 pixel detector

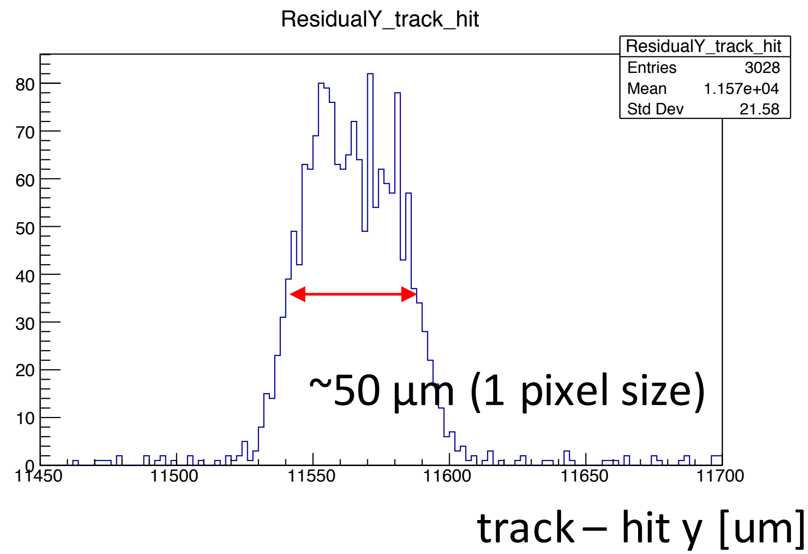
# track vs hit   Correlation



# Residual Histogram

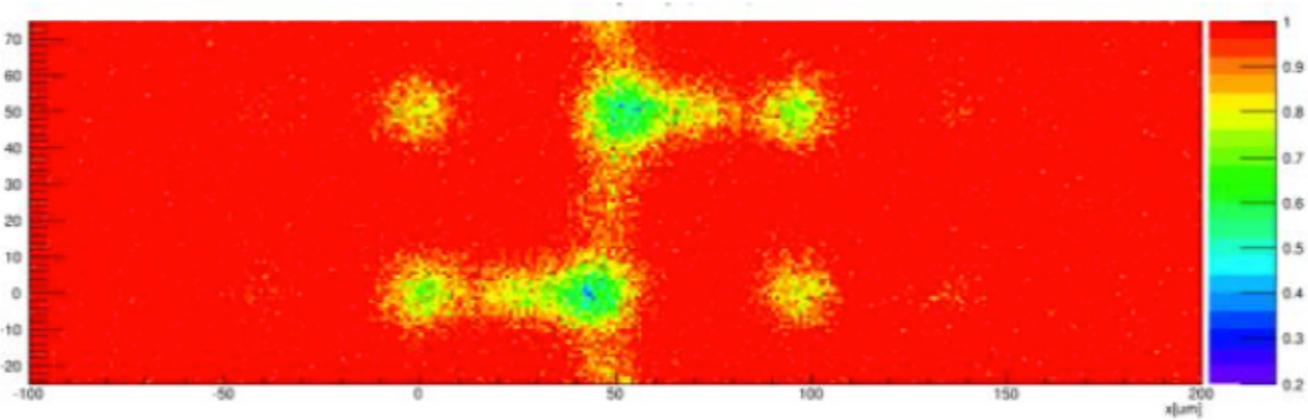


# To Do

- Draw Hit Efficiency map

like this



# Backup

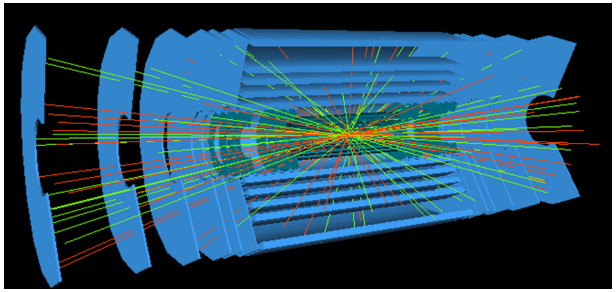
# High Luminosity LHC

ATLAS実験の目的

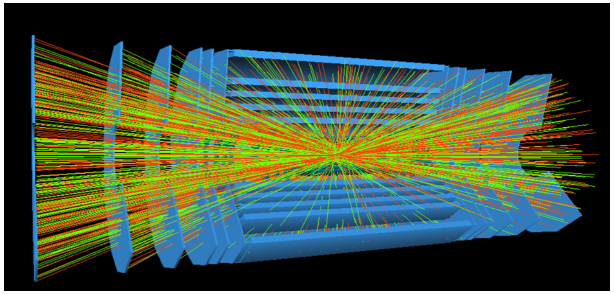
- ◆ Higgs粒子の精密測定
- ◆ 超対称性粒子の探索

HL-LHCにより
高統計を期待

現在



HL-LHC
現在の**5倍**の輝度



# HL-LHCにおける検出器への要求

**High Luminosity**
5倍の粒子密度

→

**より細かい目のピクセル**
新型ASIC搭載
50μm角ピクセル検出器

**Integrated Luminosity**
$1.7\times10^{15}\ [n_{eq}/cm^2]$
相当のダメージ
@ピクセル3層目

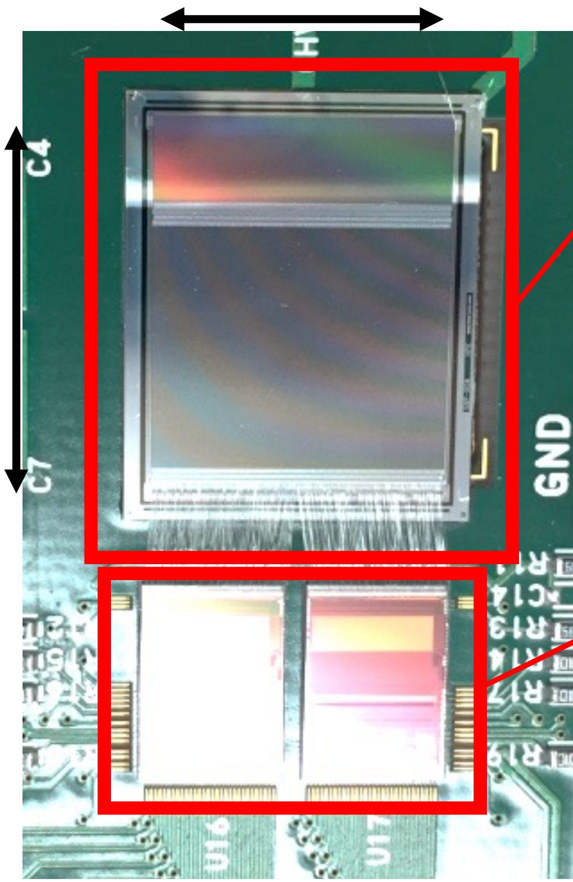
→

**高放射線耐性**
陽子線照射後、
ビームを用いて性能評価

# Silicon Strip Sensor (Telescope)

13mm

15.4 mm




strip sensor

| | |
|---|---|
| width | 50 µm |
| # of strip | 256 |
| thickness | 300 µm |

SVX4 chip

- ✓ charge readout（8bit ADC）
- ✓ 128ch

8 sensors (x, y)
↓
4layer

# 位置分解能とノイズ

$x_2 - x_1 = 50\ [\mu m]$(ストリップ間隔)、$\delta Q_1 = \delta Q_2$とする

$$x = \frac{x_1 Q_1 + x_2 Q_2}{Q_1 + Q_2}$$

$$\delta x = \sqrt{\left(\frac{\partial x}{\partial Q_1}\right)^2 \delta Q_1^2 + \left(\frac{\partial x}{\partial Q_2}\right)^2 \delta Q_2^2}$$

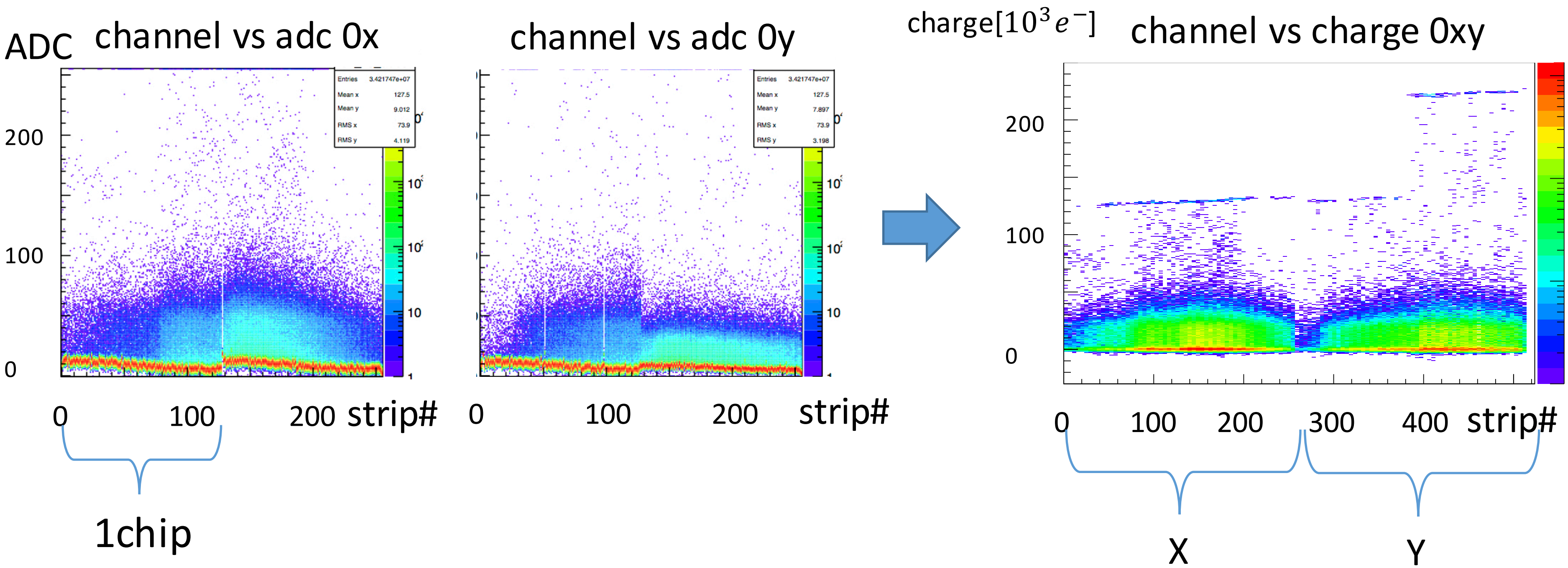
$$= \sqrt{\left(\frac{w Q_2}{(Q_1 + Q_2)^2}\right)^2 \delta Q_1^2 + \left(\frac{-w Q_1}{(Q_1 + Q_2)^2}\right)^2 \delta Q_2^2}$$

$$= \frac{w \delta Q_1}{(Q_1 + Q_2)^2} \sqrt{(Q_1 + Q_2)^2 - 2 Q_1 Q_2}$$

# Convert ADC to Charge

✓Evaluate pedestal of each strips

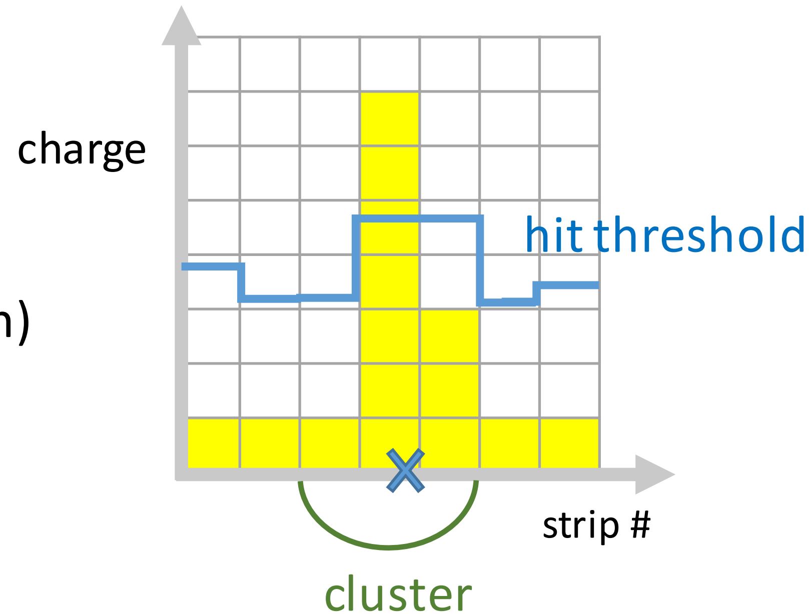
✓charge = (ADC-pedestal) × gain



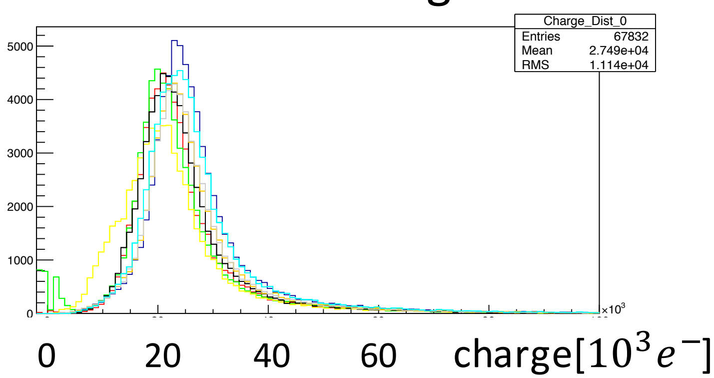
# Hit Selection & Clustering

✓ hit selection
(ADC) > (pedestal) + 9 × (pedestal width)

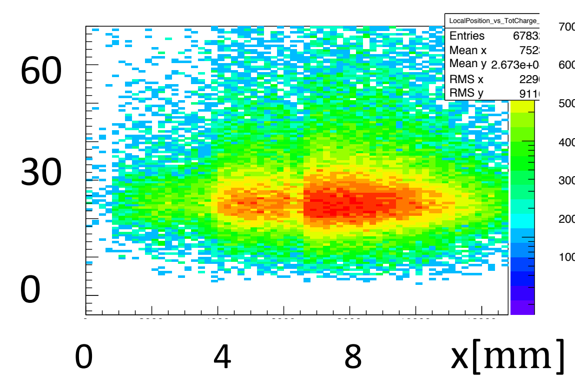
✓ centroid method ⇨ local hit postion



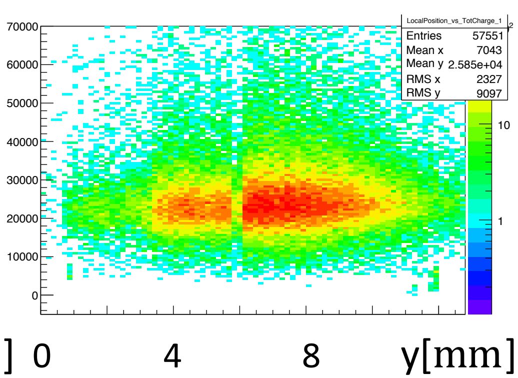

cluster charge



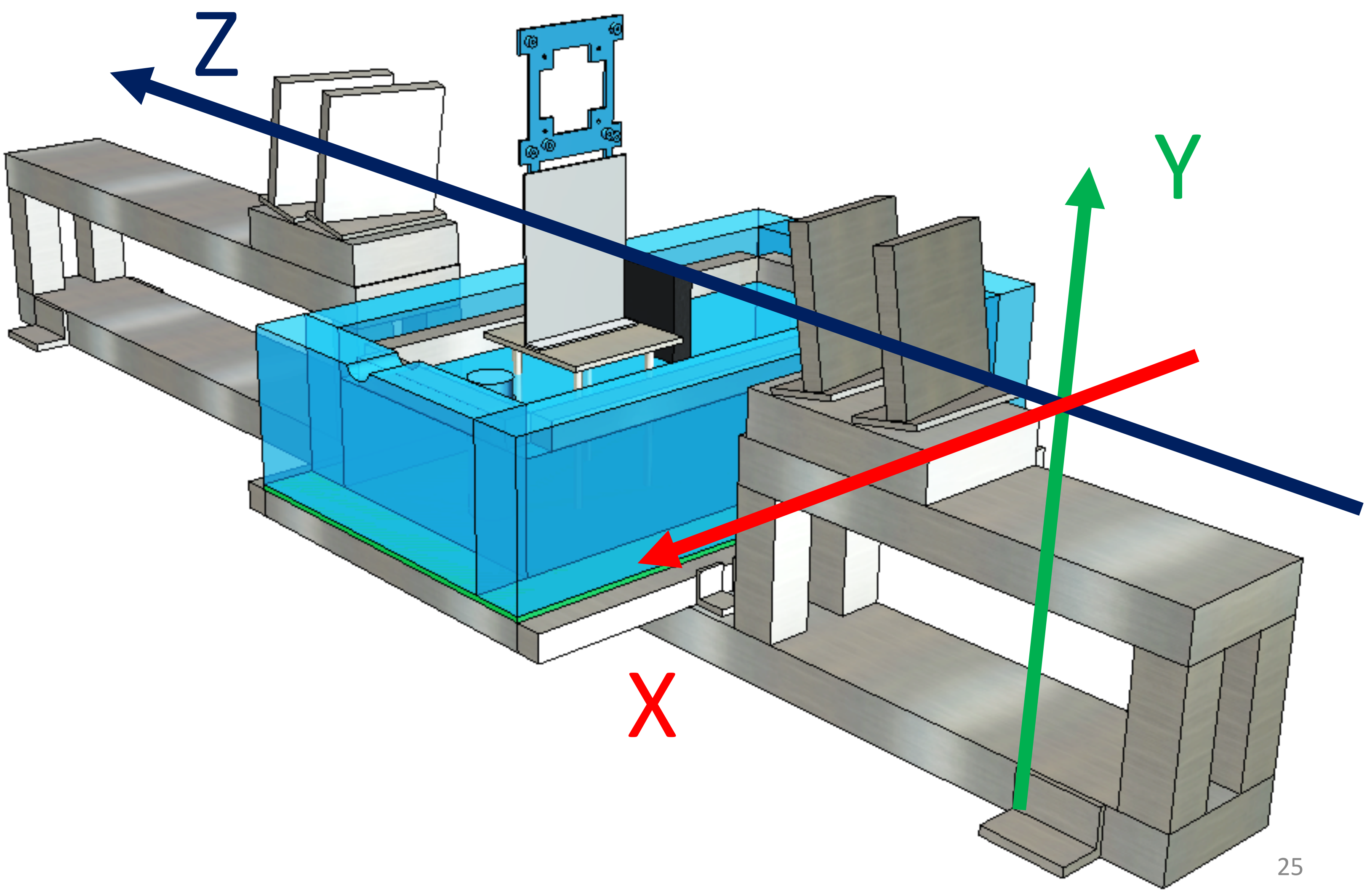

[$10^3 e^-$] local x vs cluster charge




local y vs cluster charge



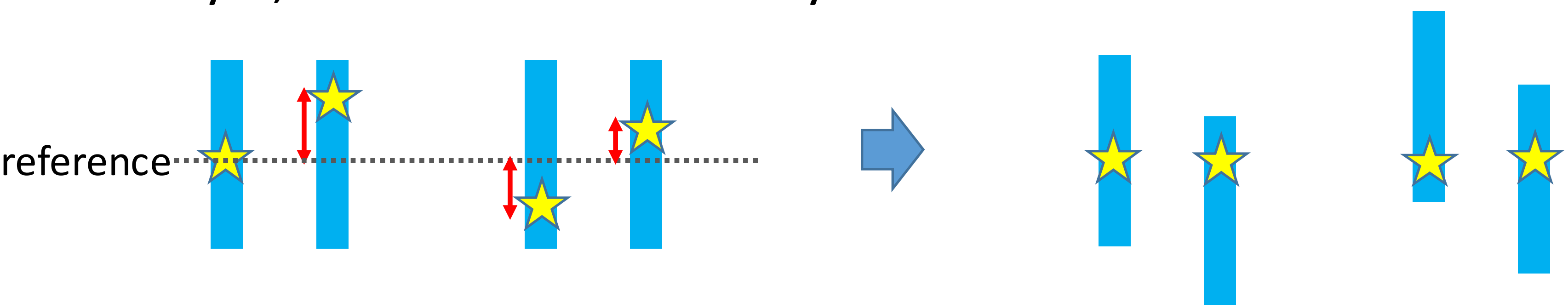
# Definition of Global Coordinate



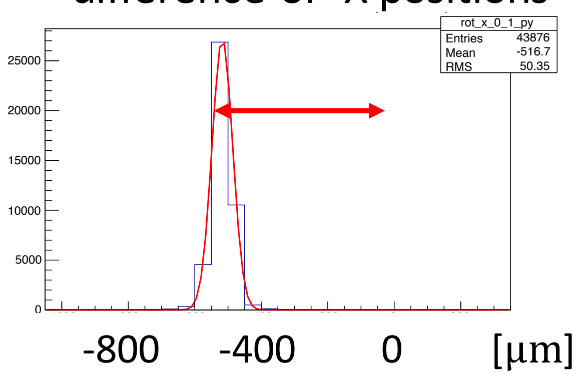
# Prealignment

✓Convert local position to global position

✓Calculate difference of hit positions of first layer and other layer, then shift the each layers




difference of X positions

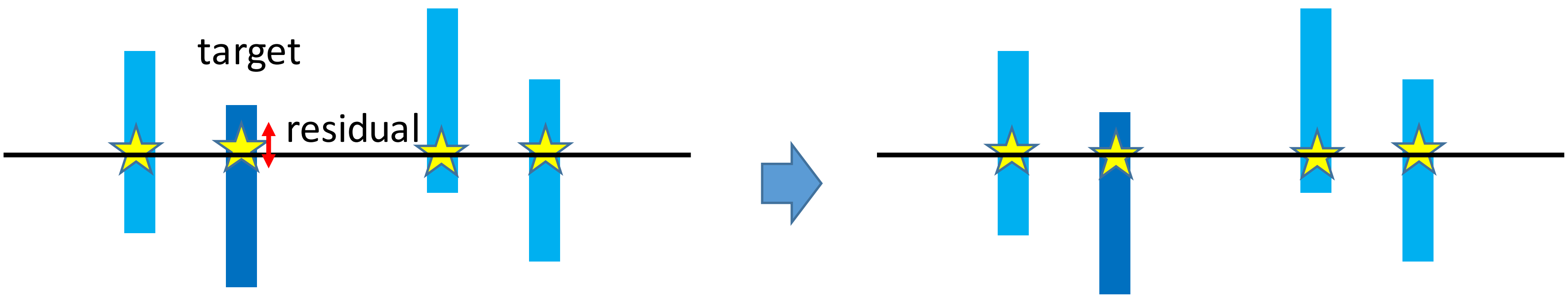



✓ x shift & y shift

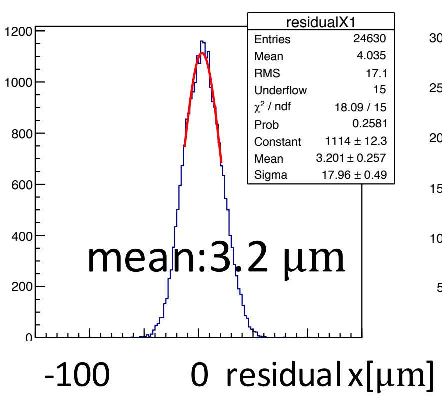
# Shift

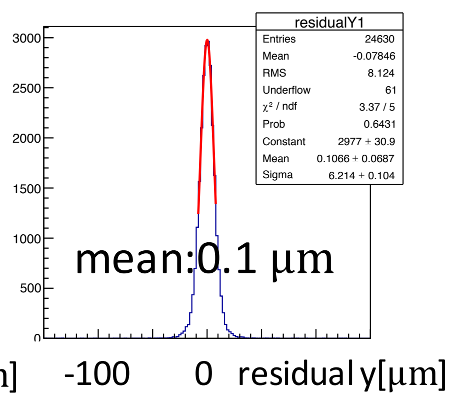
✓3 points excluding target layer ⇨ tracking

✓mean of residual ⇨ correction



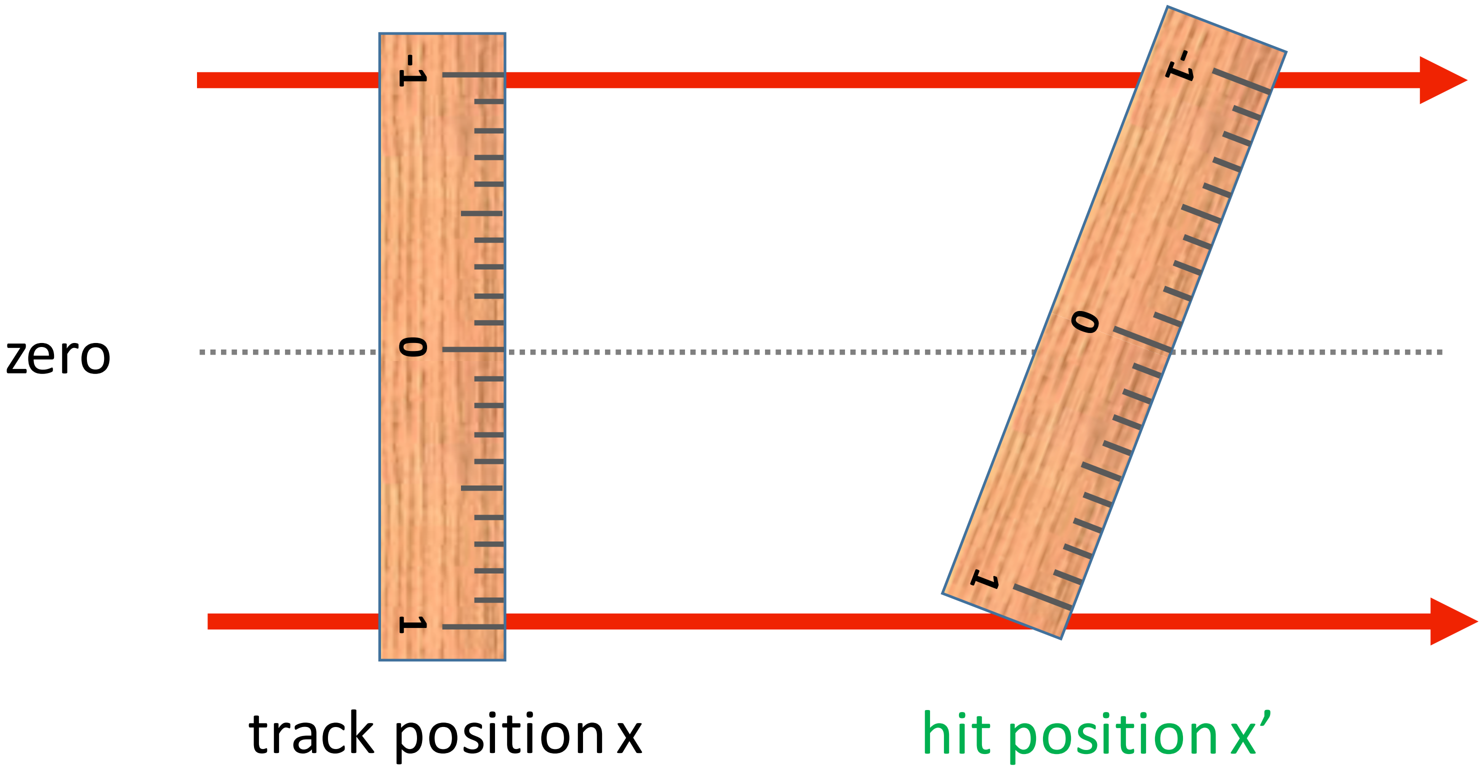

Residual of X, Y




✓ After correction, mean of residual equal to zero

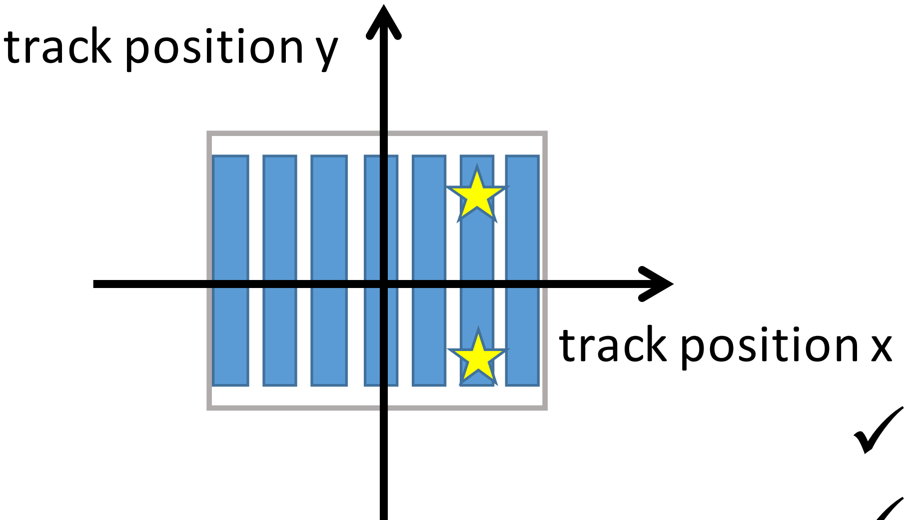
# Rotation　Y axis、X axis

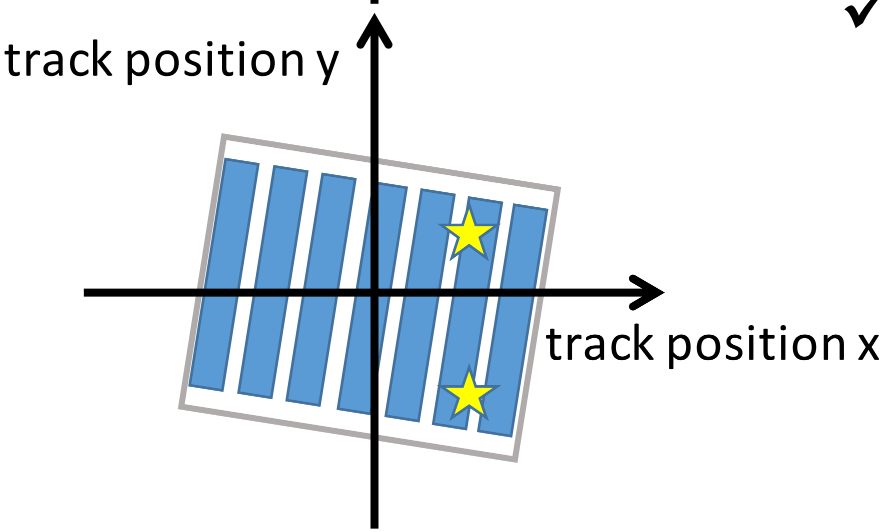



✓residual x = x – x’ correlates to x

✓slope of “x vs residual x” ⇨ estimate Y axis rotation

# Rotation Z axis



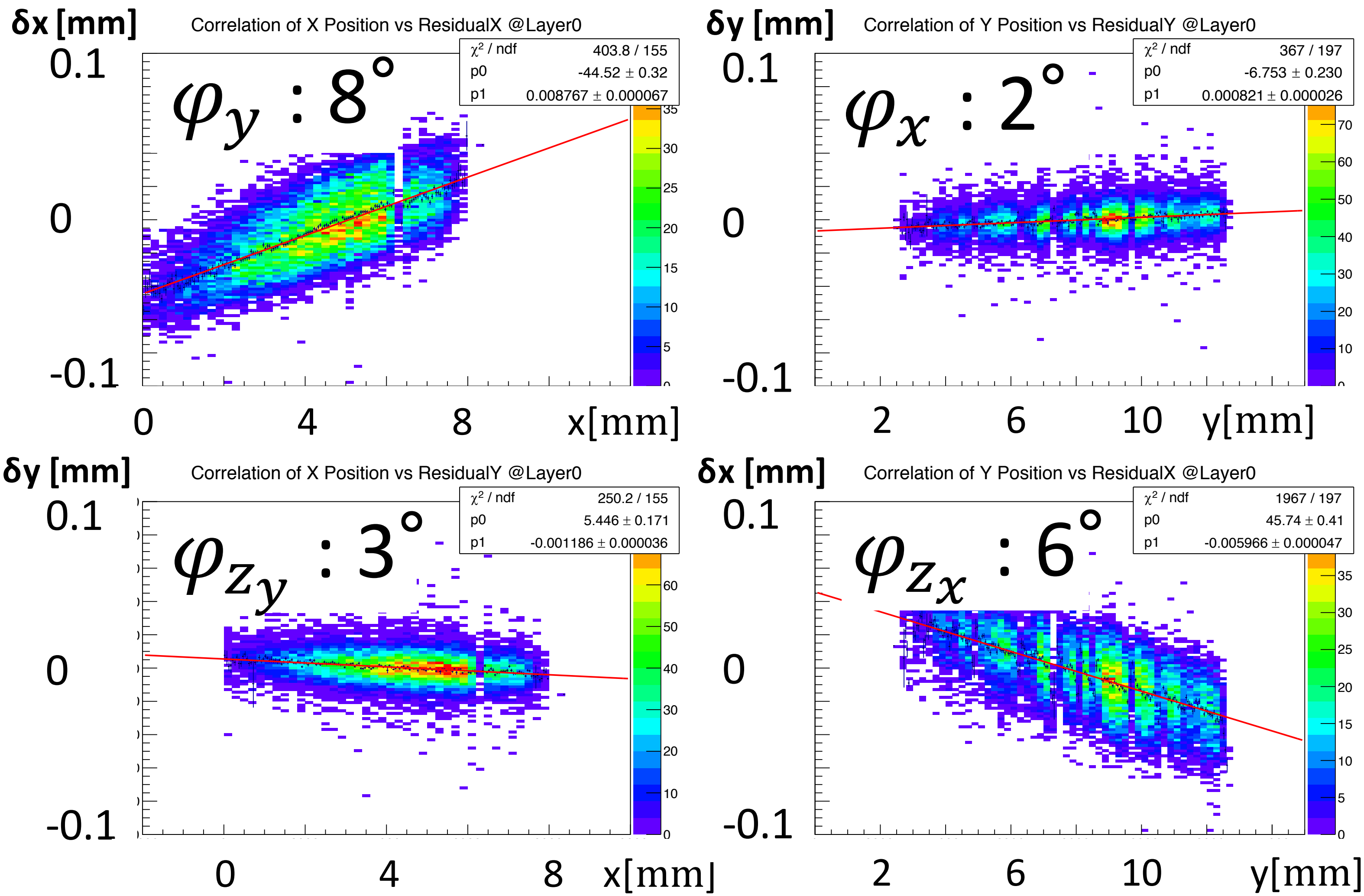

✓ residual = x – x' correlates y

✓ slope of "y vs residual x"

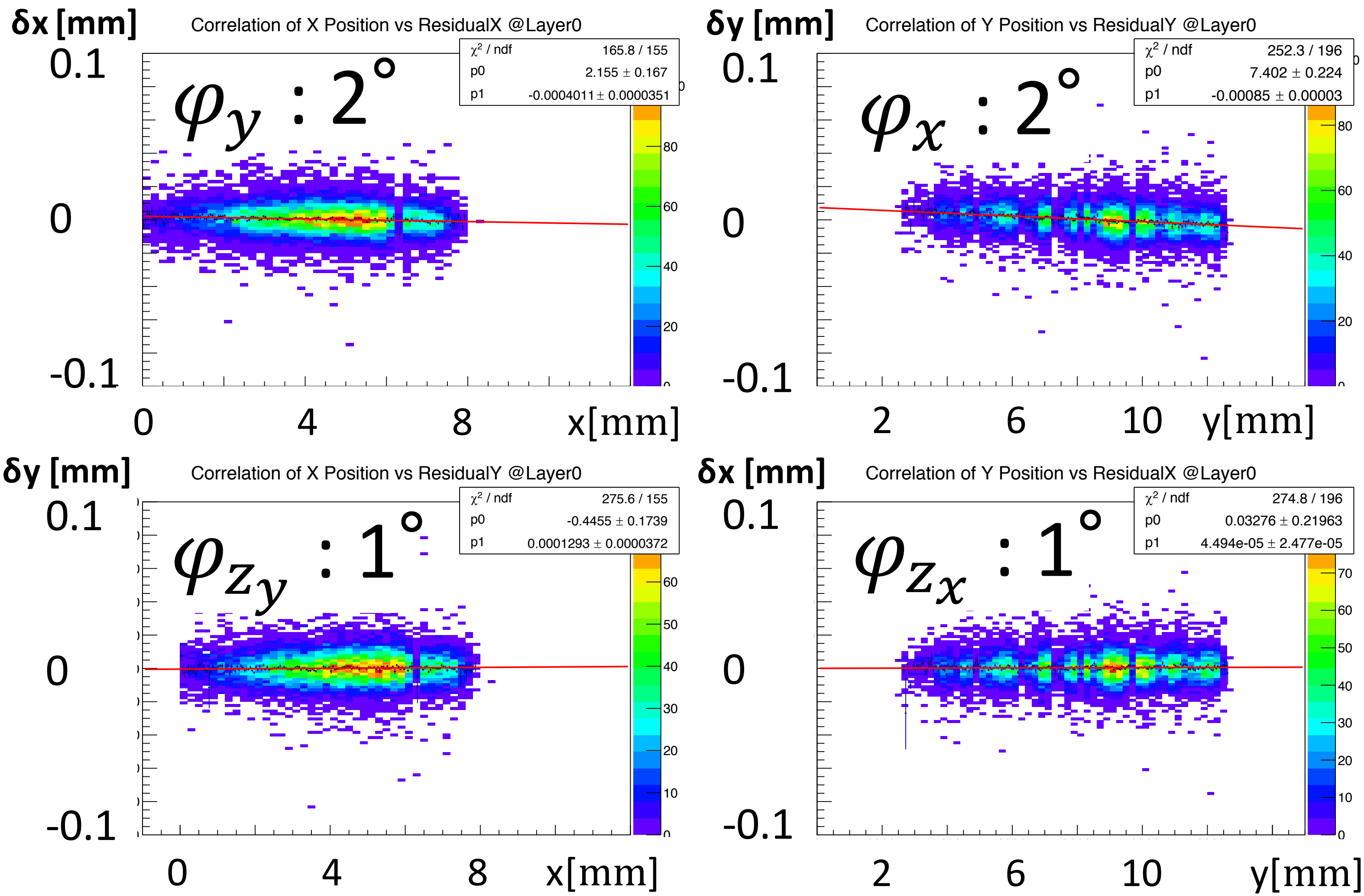
⇩

estimate Z axis rotation

# Rotation (before alignment)



# Rotation (after alignment)

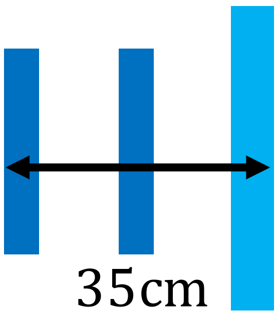


# 位置分解能と多重散乱

多重散乱による寄与

$$\theta_{plane}^{rms} = \frac{13.6[MeV]}{\beta cp} z \sqrt{\frac{x}{x_0}}$$

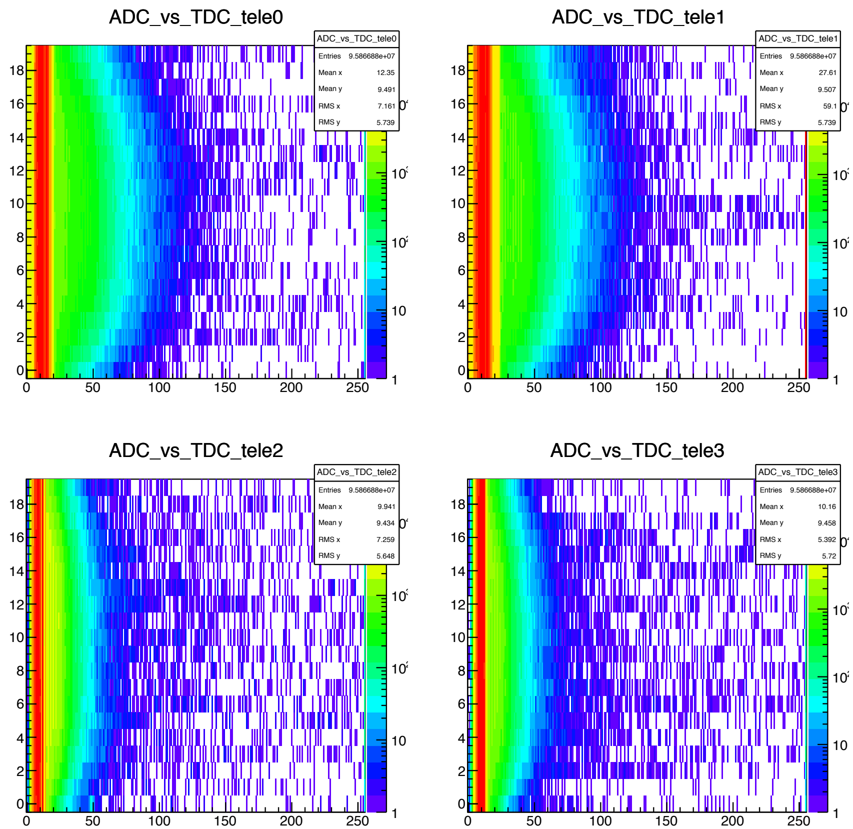
$$= 5.9\times 10^{-6}$$




評価対象検出器における散乱の寄与は

$$\tan\left(\theta_{plane}^{rms}\right)\times 0.35 \approx 2\ \mu m$$

# TDC cut



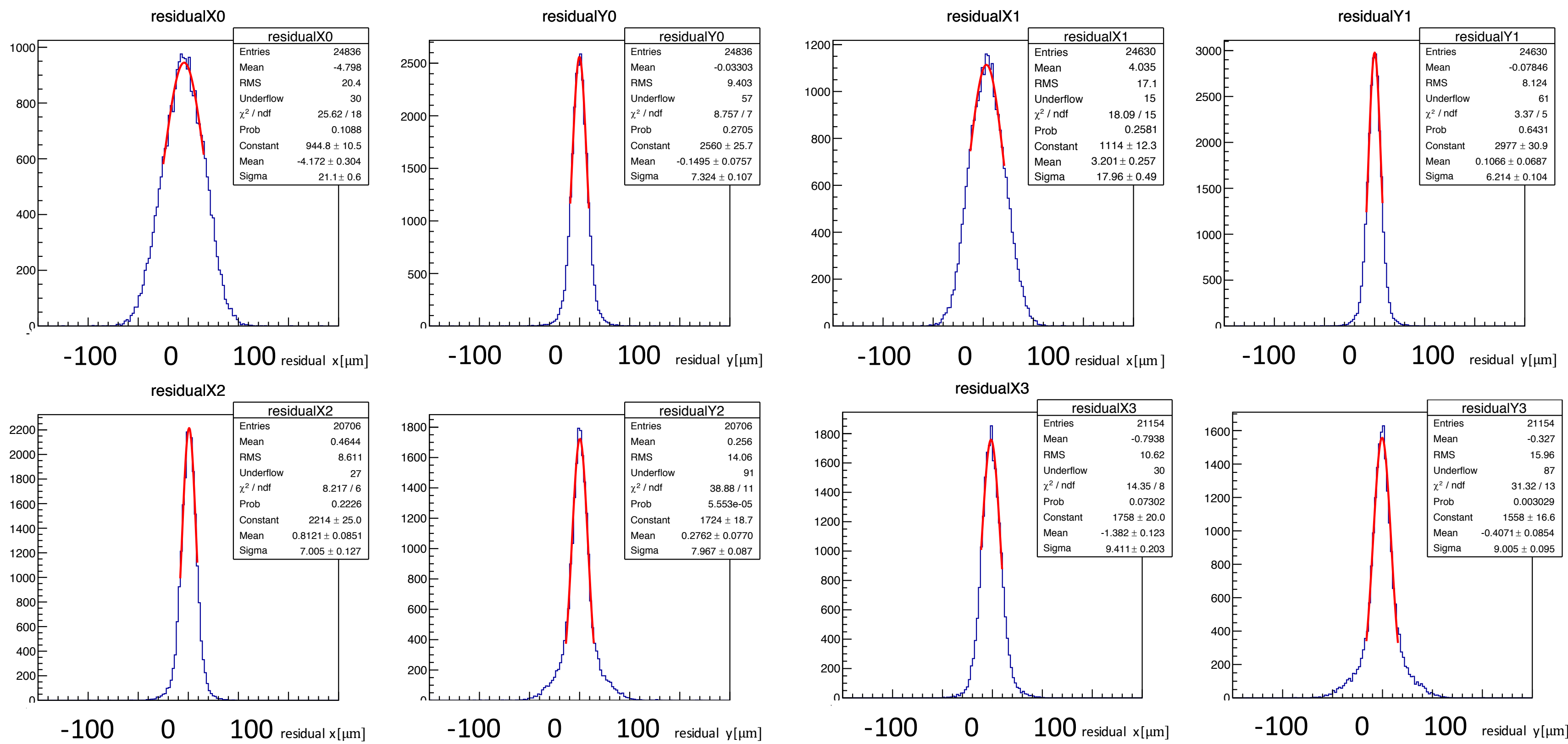

シグナルの大きさはTDCの値に依存する。

今回の位置分解能の最小値の見積もりには、

4<TDC<16

を用いた。

# alignment前の残差分布



# 位置分解能の評価

位置分解能に影響するファクター

- 電離損失の揺らぎ

cluster chargeの幅より、δQ～2.4 ke
cluster total charge の幅から見積もり

$$x = \frac{x_1 Q_1 + x_2 Q_2}{Q_1 + Q_2}$$

$$\delta_x = \frac{\sqrt{(x_1 - x_2)^2 \ \ (Q_2^2 \delta Q_1^2 + Q_1^2 \delta Q_2^2)}}{(Q_1 + Q_2)^2}$$

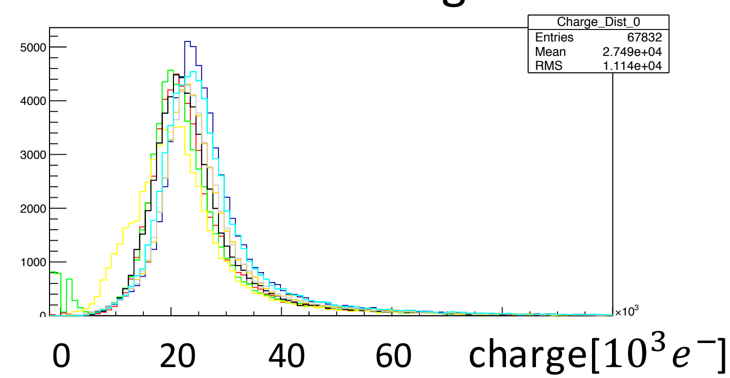
$$\sim \frac{d\delta Q_1}{2\sqrt{2} Q_1}$$

$$\sim 3.9 \ \mu\mathrm{m}$$

- 多重散乱　～4μm

- ADCのnoise　～ 1ADC ～ 1ke
δQに含まれる

cluster charge

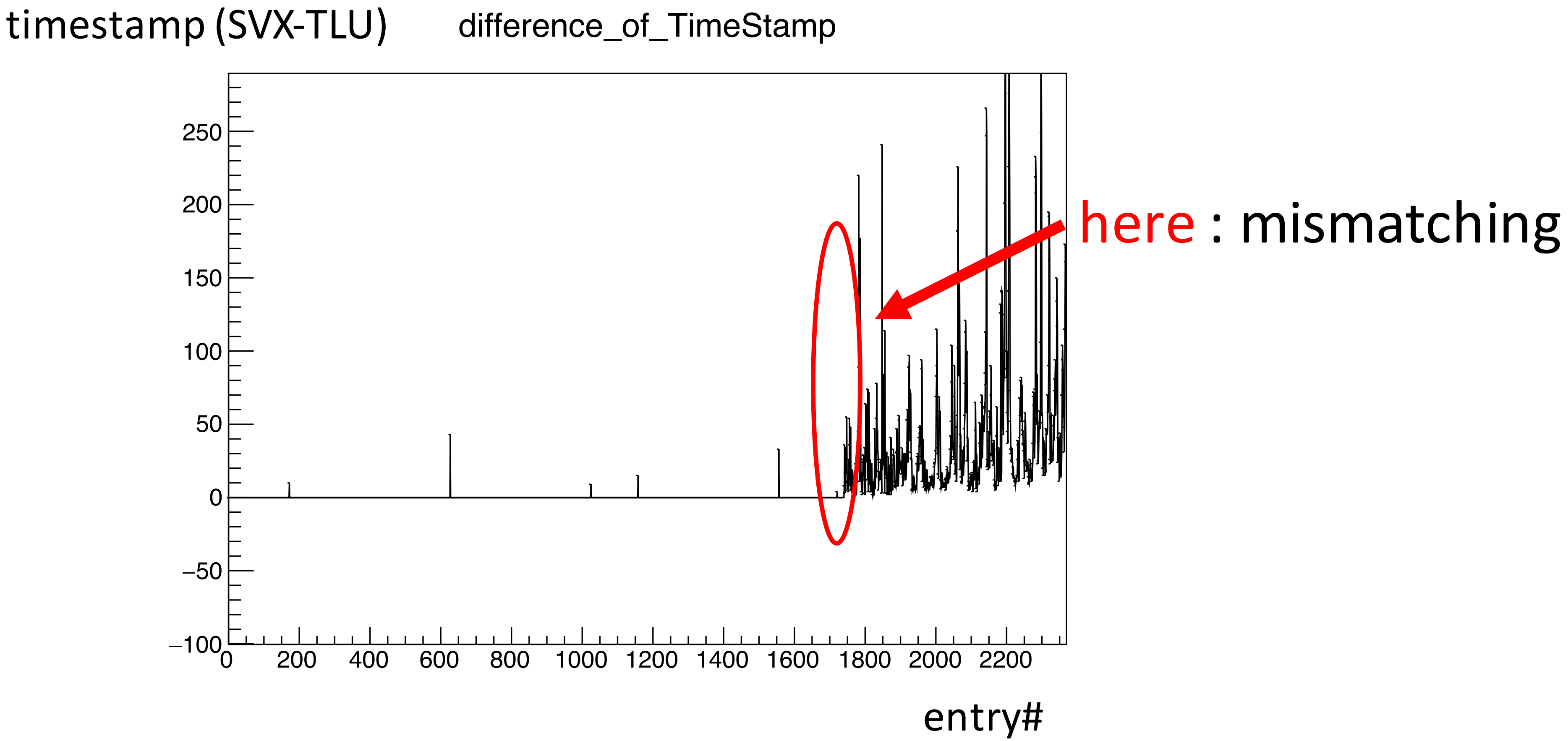


# Data Structure of detectors

| | SVX4 (telescope) | FE65 (pixel sensor) | TLU (trigger) |
|---|---|---|---|
| EventNumber | ○ | ○ | ○ |
| TimeStamp | ○ | × | ○ |
| ADC | ○ | × | × |
| ToT | × | ○ | × |

However, There is mismatching of EventNumber...

# TimeStamp

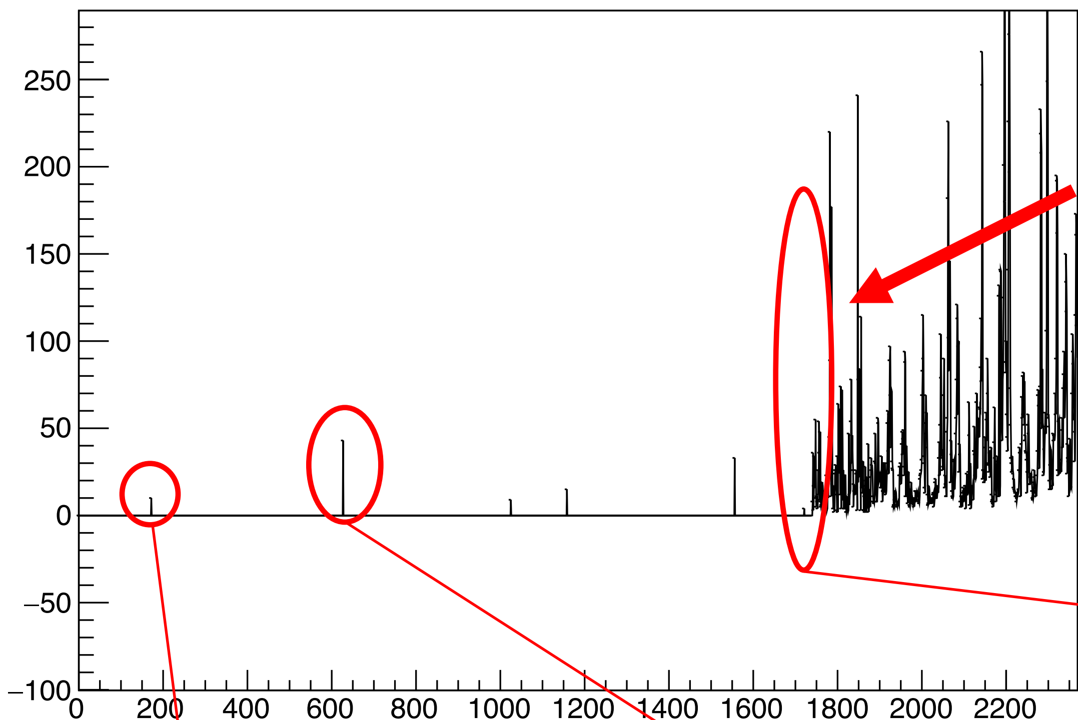


timestamp (SVX-TLU)
difference_of_TimeStamp
250
200
150
100
50
0
−50
−100
0
200
400
600
800
1000
1200
1400
1600
1800
2000
2200
entry#
here : mismatching

# TimeStamp

timestamp (SVX-TLU)

difference_of_TimeStamp




here : mismatching

entry#

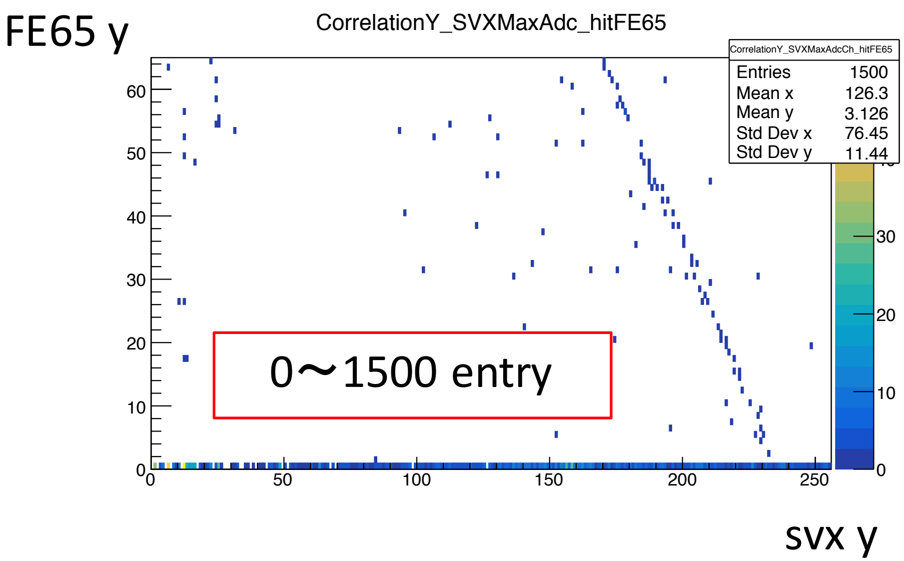
| | SVX | TLU | |
|---|---|---|---|
| 1739 | 58096 | 58096 | 0 |
| 1740 | 58101 | 58101 | 0 |
| 1741 | 58135 | 58127 | 8 |
| 1742 | 58171 | 58135 | 36 |
| 1743 | 58174 | 58171 | 3 |
| 1744 | 58191 | 58174 | 17 |
| 1745 | 58225 | 58191 | 34 |

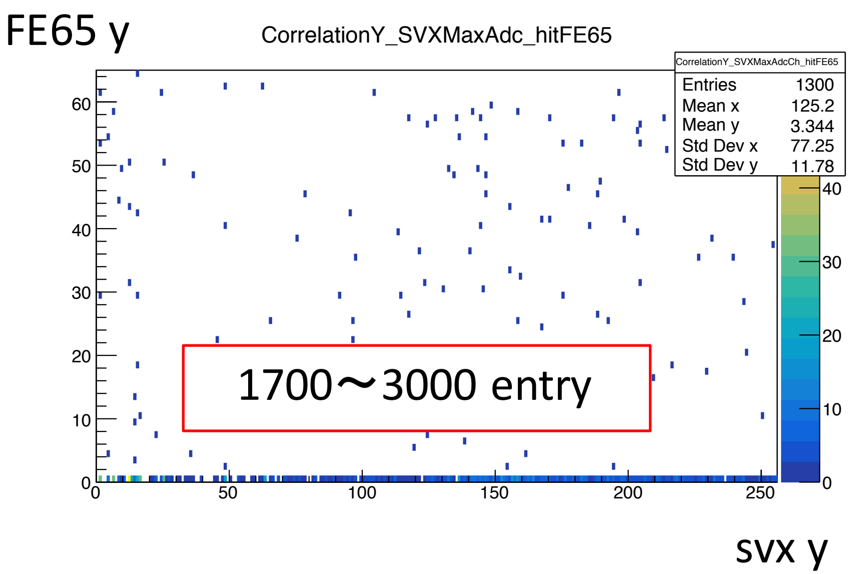
| | SVX | TLU | |
|---|---|---|---|
| 170 | 13651 | 13651 | 0 |
| 171 | 13674 | 13674 | 0 |
| 172 | 13684 | 13674 | 10 |
| 173 | 13703 | 13703 | 0 |

| | | | |
|---|---|---|---|
| 625 | 30685 | 30685 | 0 |
| 626 | 30690 | 30690 | 0 |
| 627 | 30733 | 30690 | 43 |
| 628 | 30855 | 30855 | 0 |

# TimeStamp

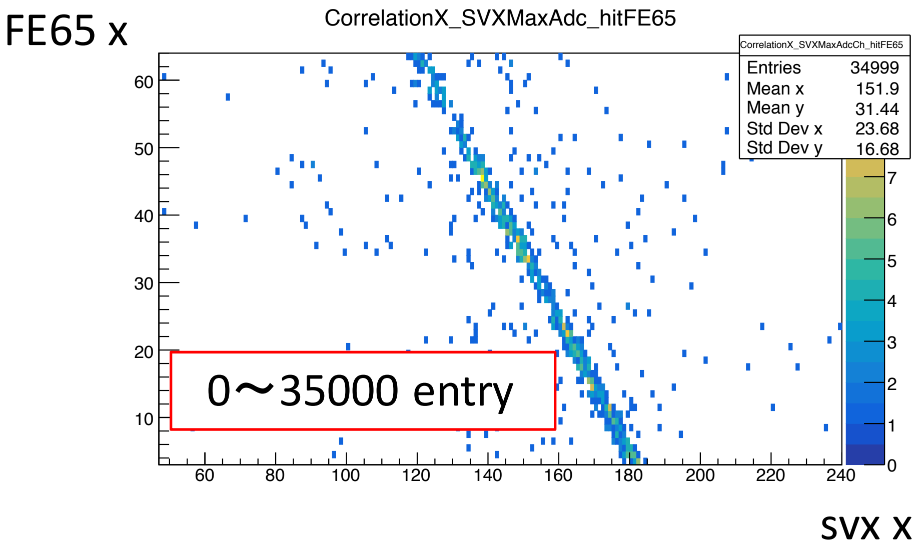
correlation disappear
after event mismatching occurred

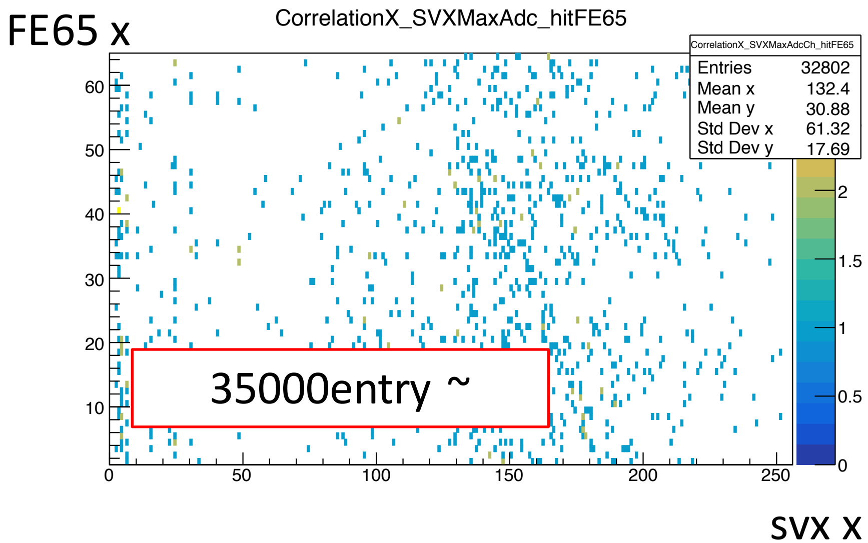


# TimeStamp

✓Making list of EventNumber whose TimeStamp matching
→ This will resolve mismatching between SVX4 and TLU




However, there is also mismatching between TLU and FE65