

# MEG II実験液体キセノン検出器におけるMPPC のアライメント及び位置分解能の評価

Evaluation of Alignment of MPPCs and position  
resolution of MEG II liquid Xe detector

日本物理学会

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東京理科大学 野田キャンパス

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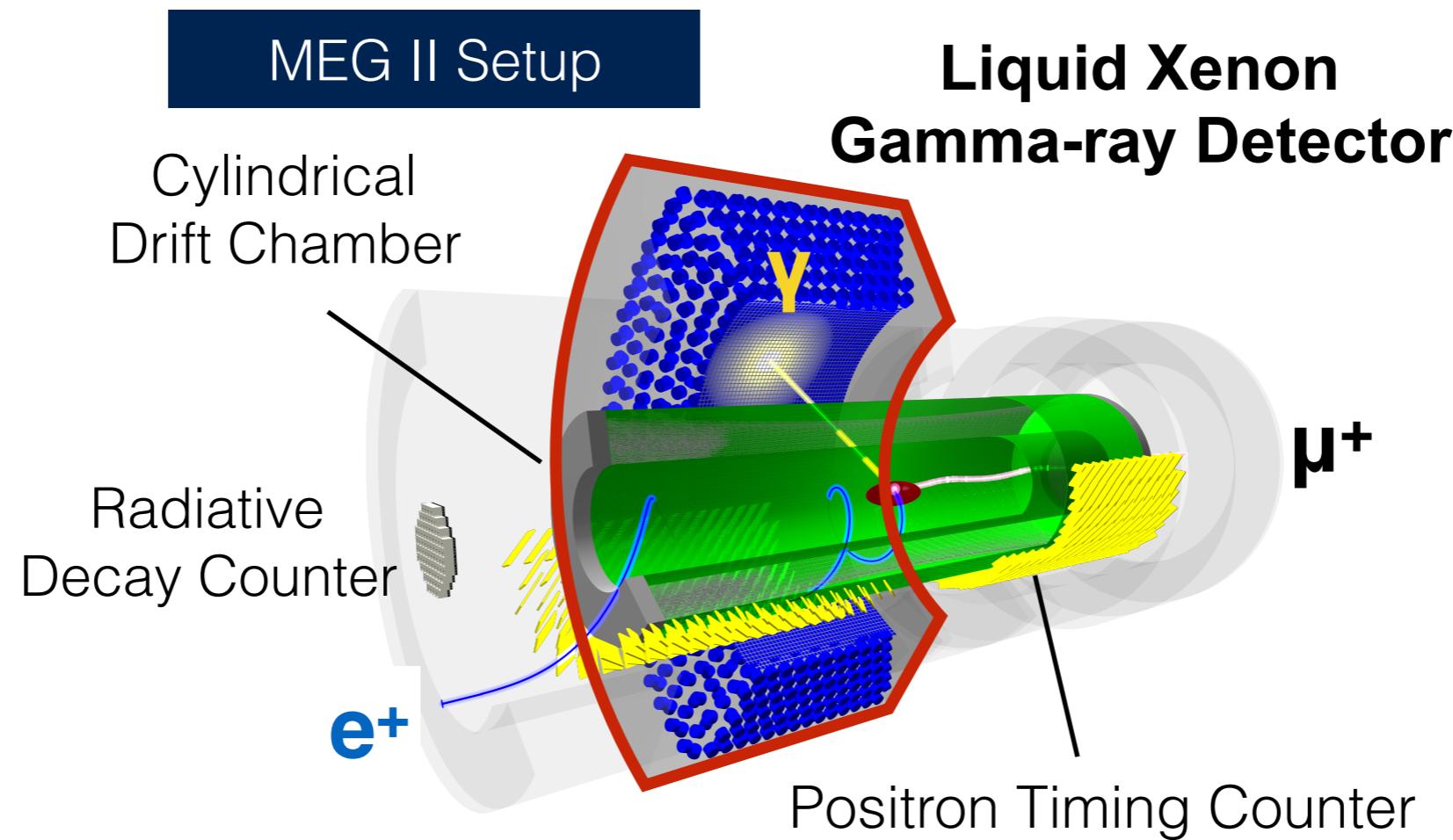


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International Center for Elementary Particle Physics  
The University of Tokyo

# Outline

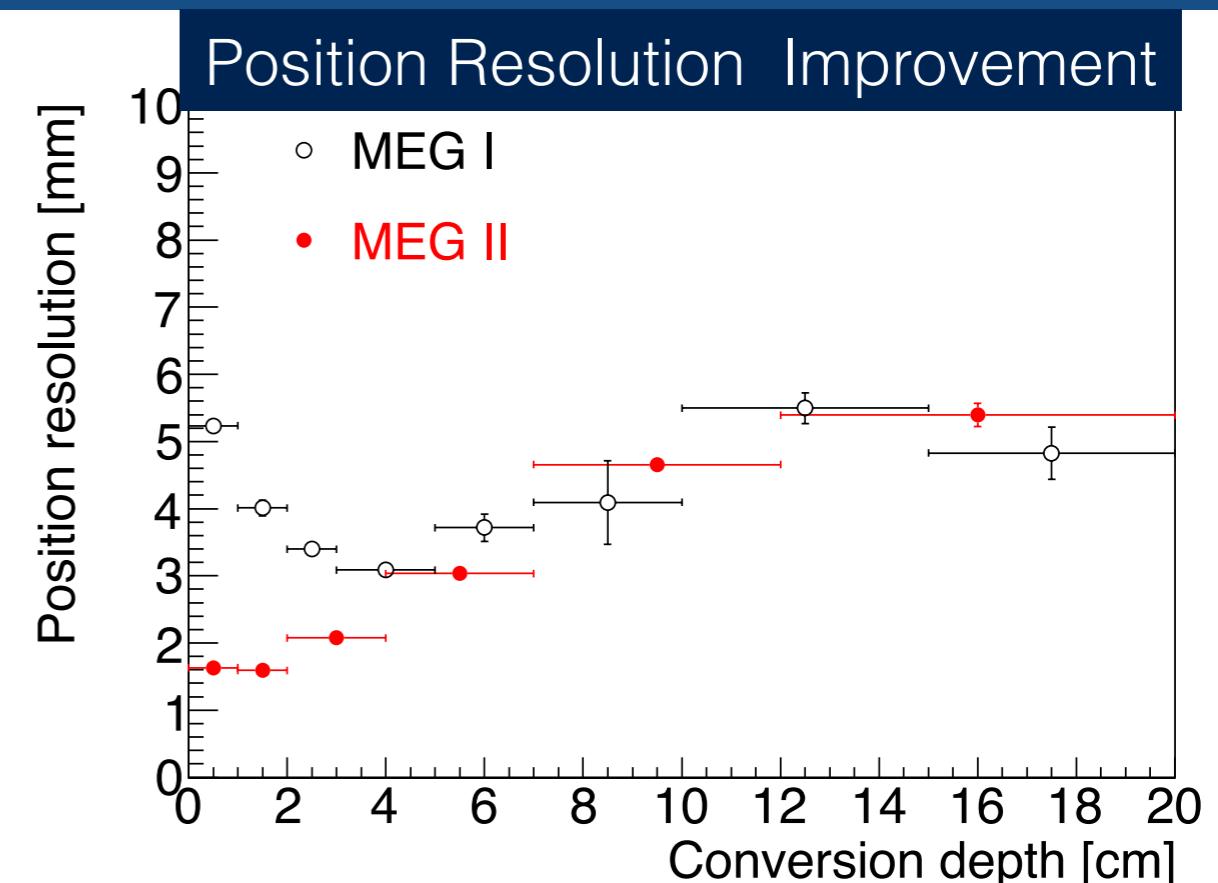
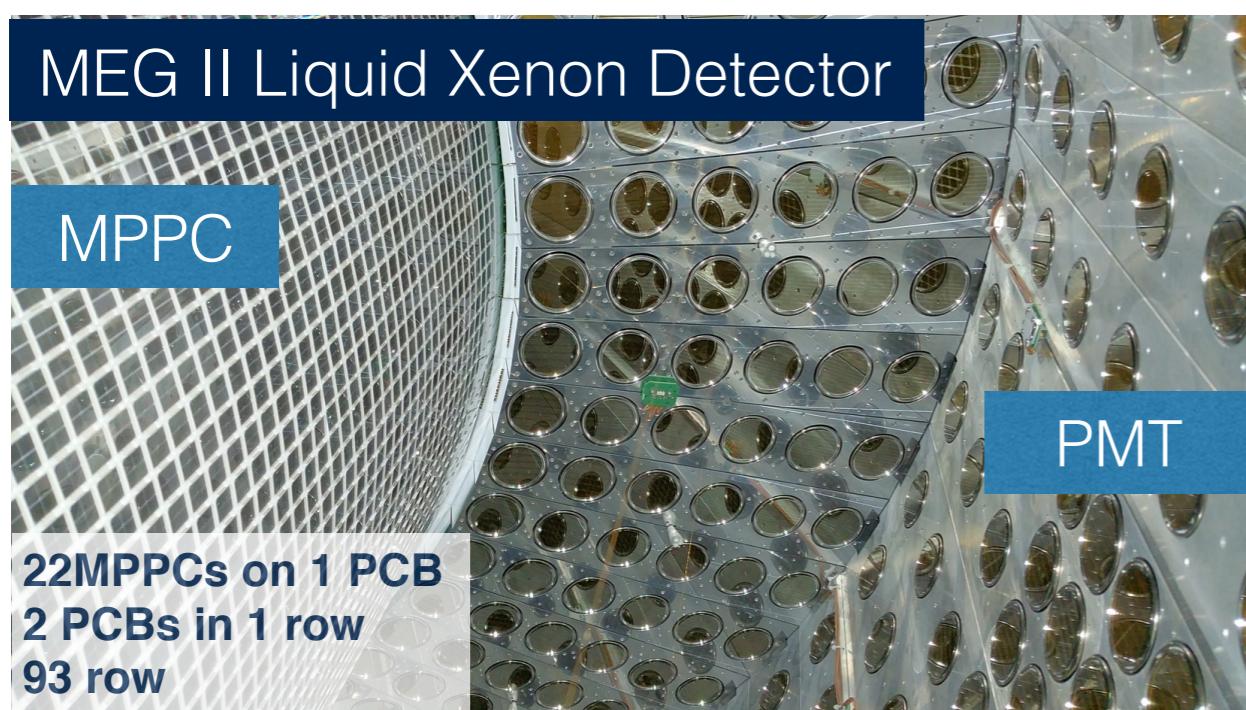
- **Introduction**
  - **MEG II experiment**
  - **Liquid Xenon Detector Upgrade**
- MPPC Alignment
  - Laser based measurement
  - X-ray based measurement
  - Combination of both measurements
- Position resolution @ 2017 pilot run
  - Position reconstruction algorithm
  - Result

# Introduction - MEG II Experiment



- MEG II experiment will search for the  $\mu \rightarrow e\gamma$  decay with unprecedented sensitivity.
  - $\text{Br}(\mu \rightarrow e\gamma) \sim 6 \times 10^{-14}$  in 3 years
  - One order of magnitude better than MEG
    - $\text{Br}(\mu \rightarrow e\gamma) < 4.2 \times 10^{-13}$  (90% C.L.) (2016)
- Liquid Xenon gamma-ray detector measures position, energy and timing of the incident gamma-ray.

# Introduction - Liquid Xenon Detector Upgrade



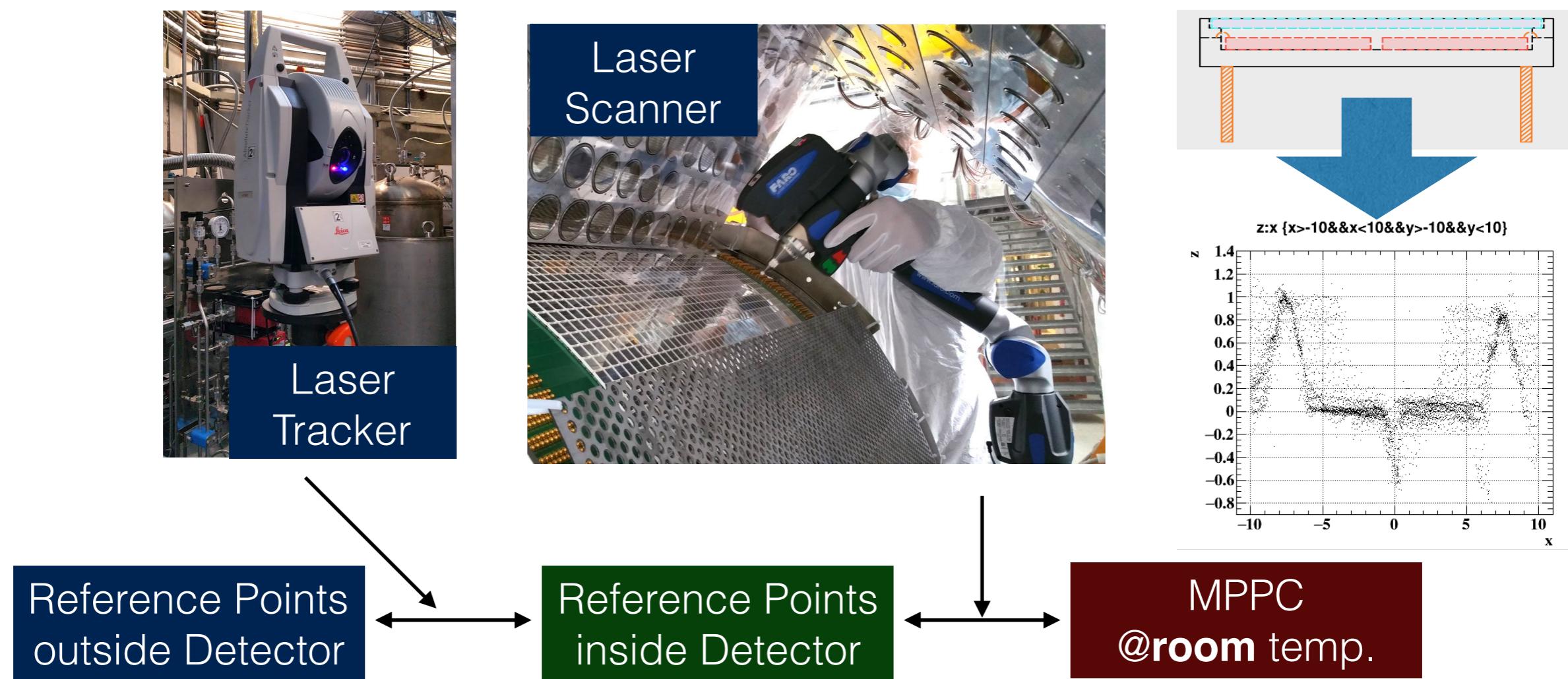
- We have replaced 216 2-inch PMTs on the  $\gamma$ -entrance face with 4092  $12 \times 12 \text{ mm}^2$  VUV-MPPCs.
  - High granular & uniform readout
    - Better position & energy resolution
  - Less material of the entrance face
    - Better detection efficiency

# Outline

- Introduction
  - MEG II experiment
  - Liquid Xenon Detector Upgrade
- **MPPC Alignment** <0.5 mm accuracy is required
- **Laser based measurement**
- **X-ray based measurement**
- **Combination of both measurements**
- Position resolution @ 2017 pilot run
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# Method - Laser-based Measurement

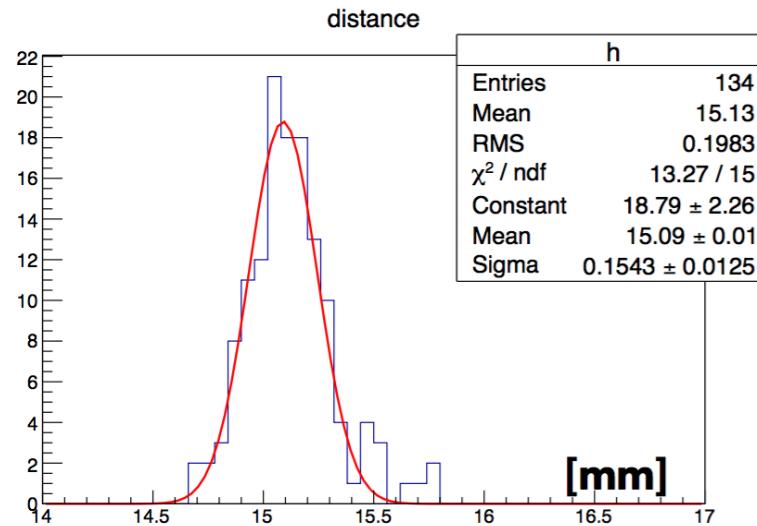
MPPC side view



- The position of MPPCs is measured by laser tools at room temperature.
  - Laser tracker provides the detector's position in the global coordinate.
  - Laser scanner measures the position of each MPPC in the local coordinate.

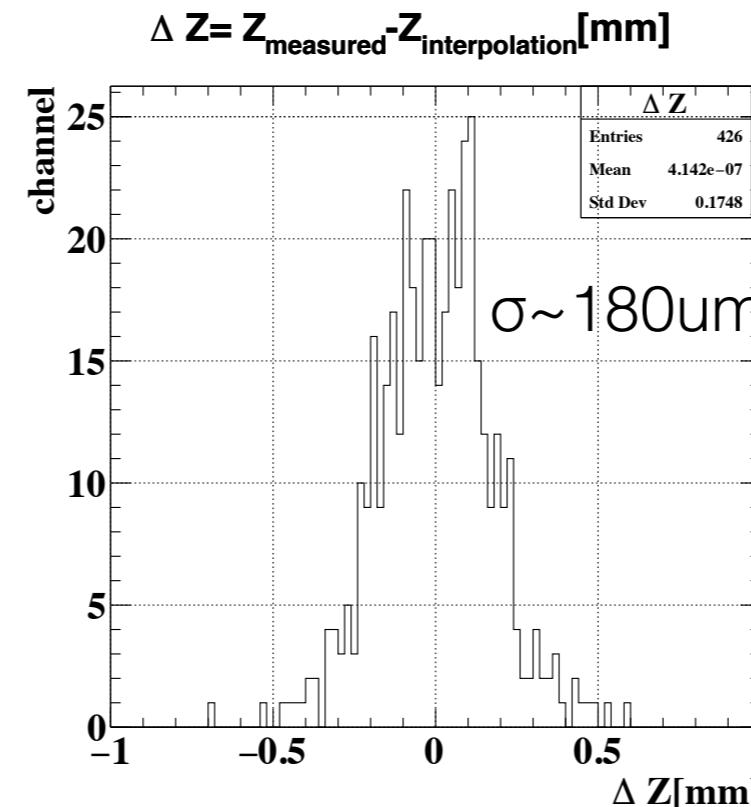
# Result - Laser-based Measurement

Distance b/w adjacent MPPCs  
calculated only for fitted MPPCs

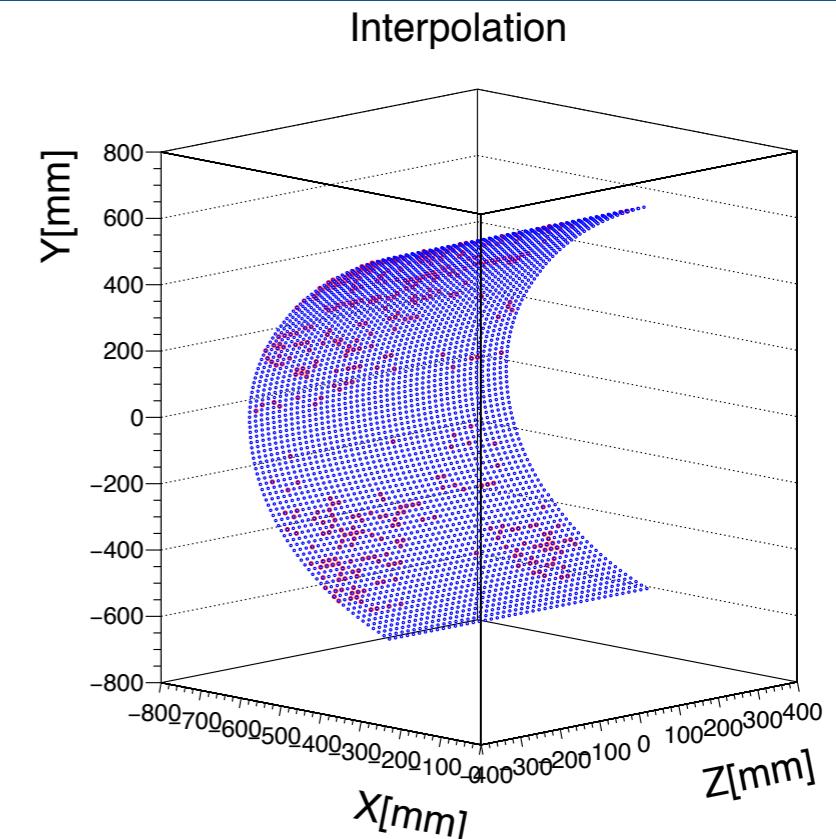


M. Nakao @ JPS(2017 spring)

Measured position of  
~10% MPPC



Interpolation

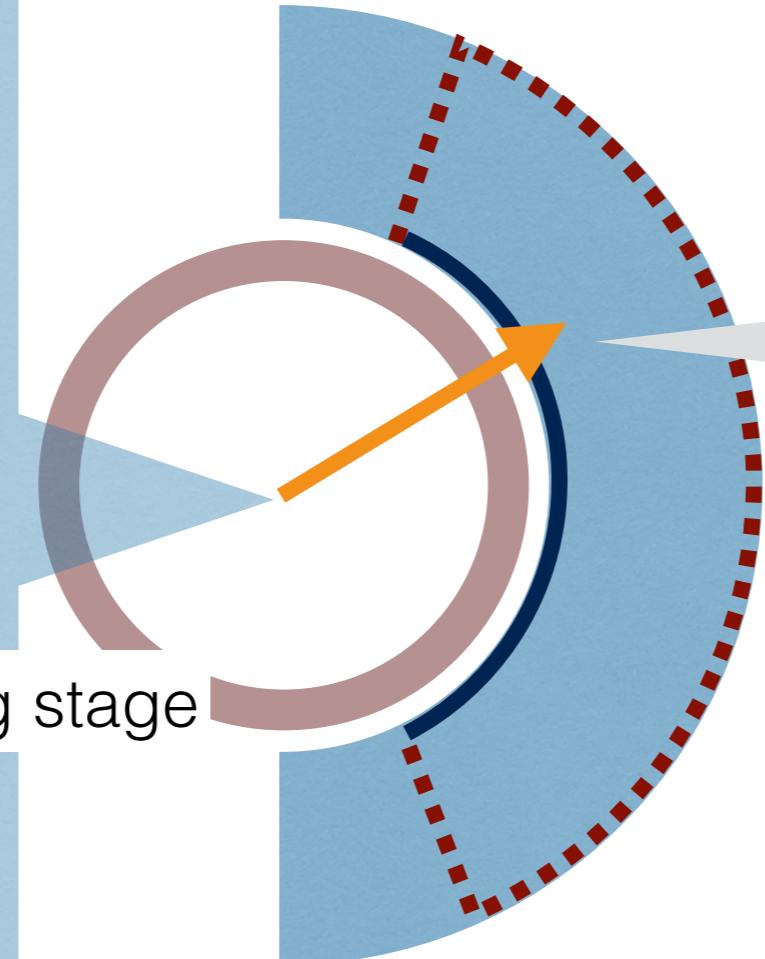
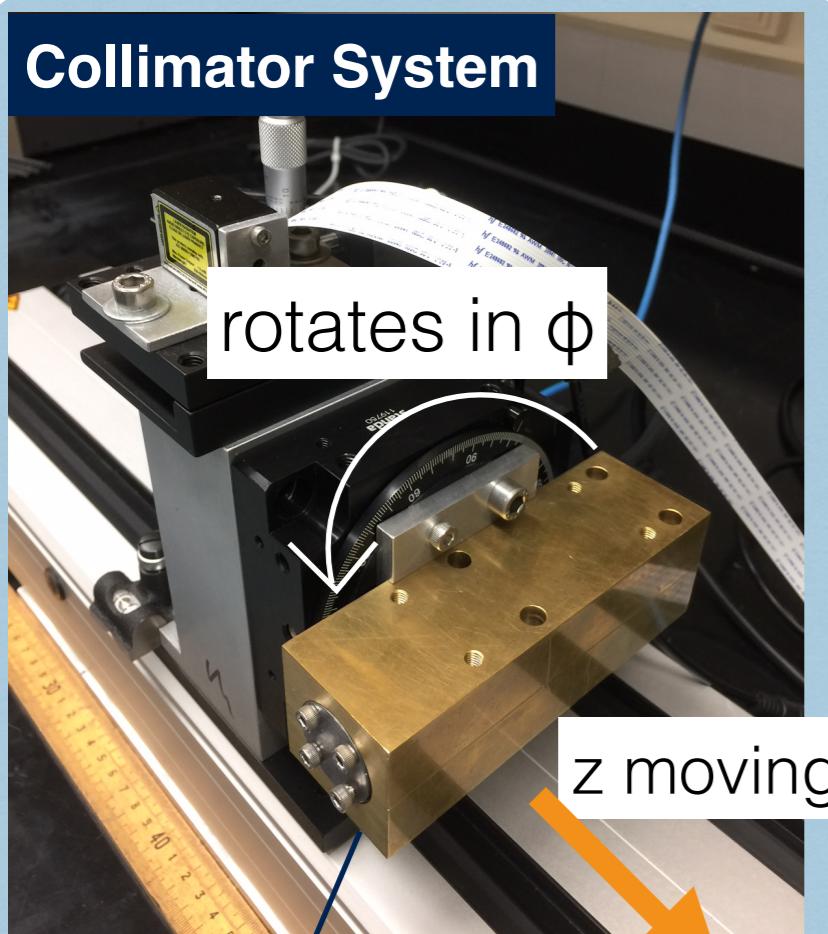


The 3D position of **all** MPPCs  
@ room temp.

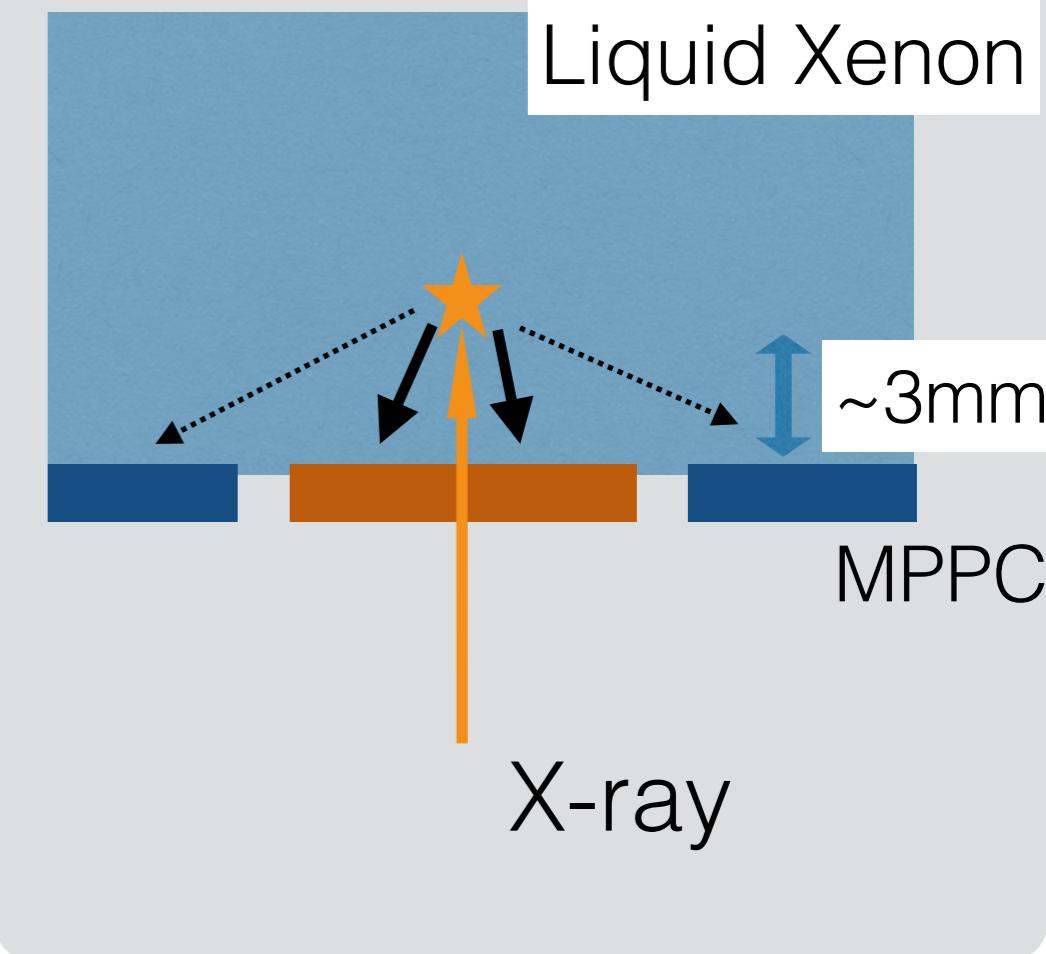
- The number of measured channels is limited to ~10% due to the limited motion range of the laser scanner.
- We calculated the position of all MPPCs by use of the measured position with a resolution of 180um.
  - MPPCs are mounted on the precisely machined sub-structure.
    - We assumed that all MPPCs are regularly mounted on a cylindrical plane.
  - MPPC array shrinks in non-negligible level at the LXe temperature.
    - We carried out the measurement also after the detector is filled with LXe.

# Method - X-ray based Measurement

Collimator System



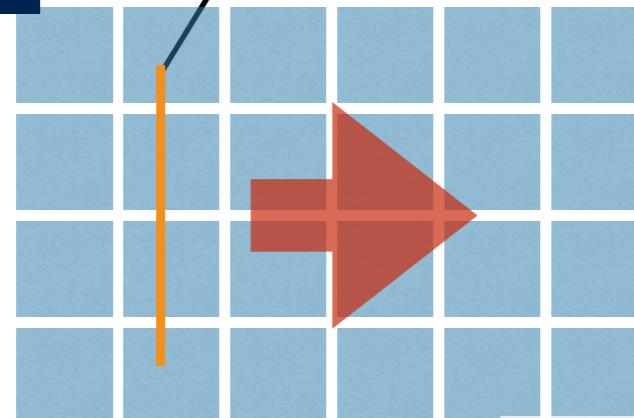
Interaction of X-ray



- We used a collimated X-ray beam from  $^{57}\text{Co}$  source as a probe.
- The incident X-ray is stopped at very shallow region and scintillation photons from the conversion is highly localized.
- The collimator is moved and rotated on a moving stage.
  - Irradiation point is aligned at a precision of 80 $\mu\text{m}$  in  $\phi$  and 30 $\mu\text{m}$  in z.

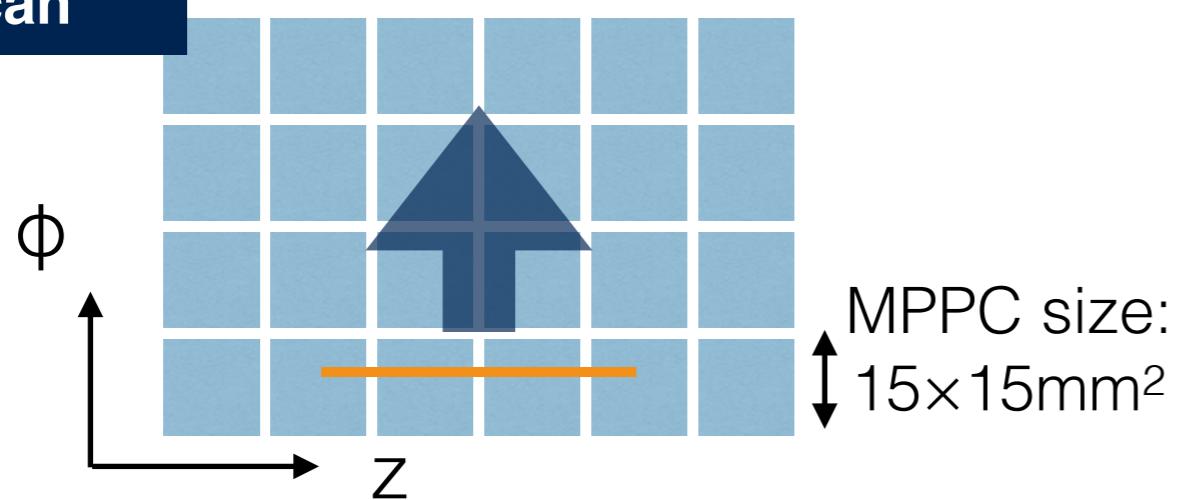
# Method - X-ray based measurement

Z scan



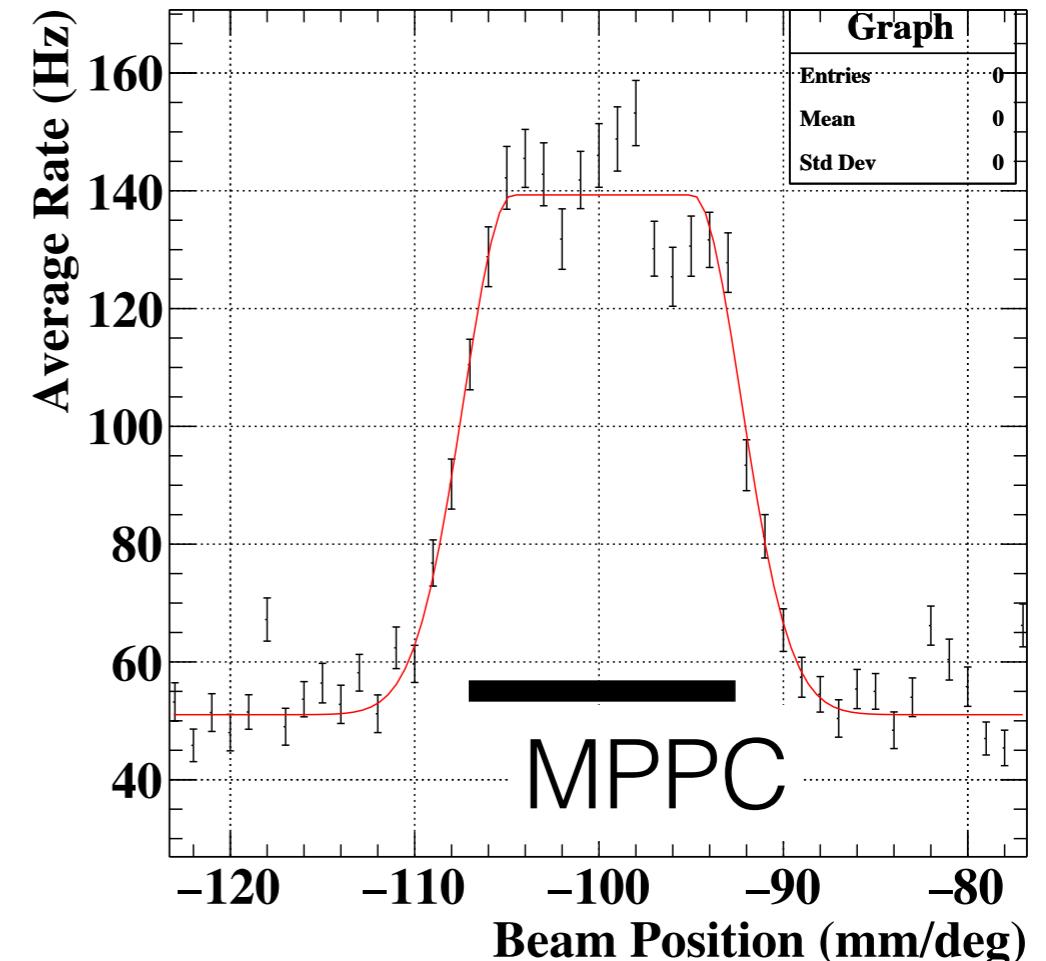
MPPC array

$\phi$  scan



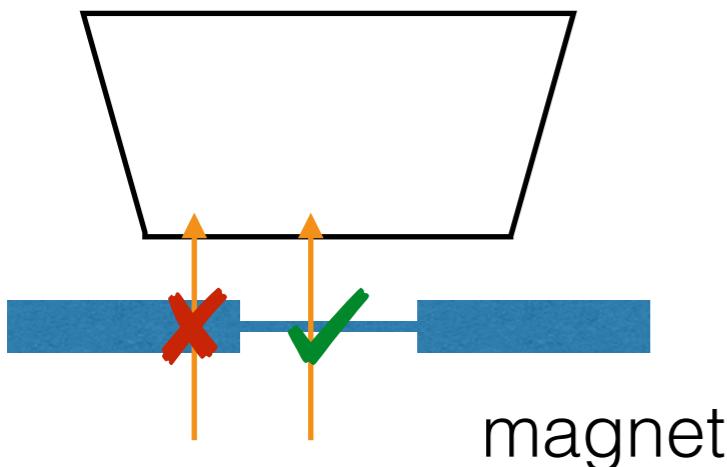
MPPC size:  
15×15mm<sup>2</sup>

Typical Signal

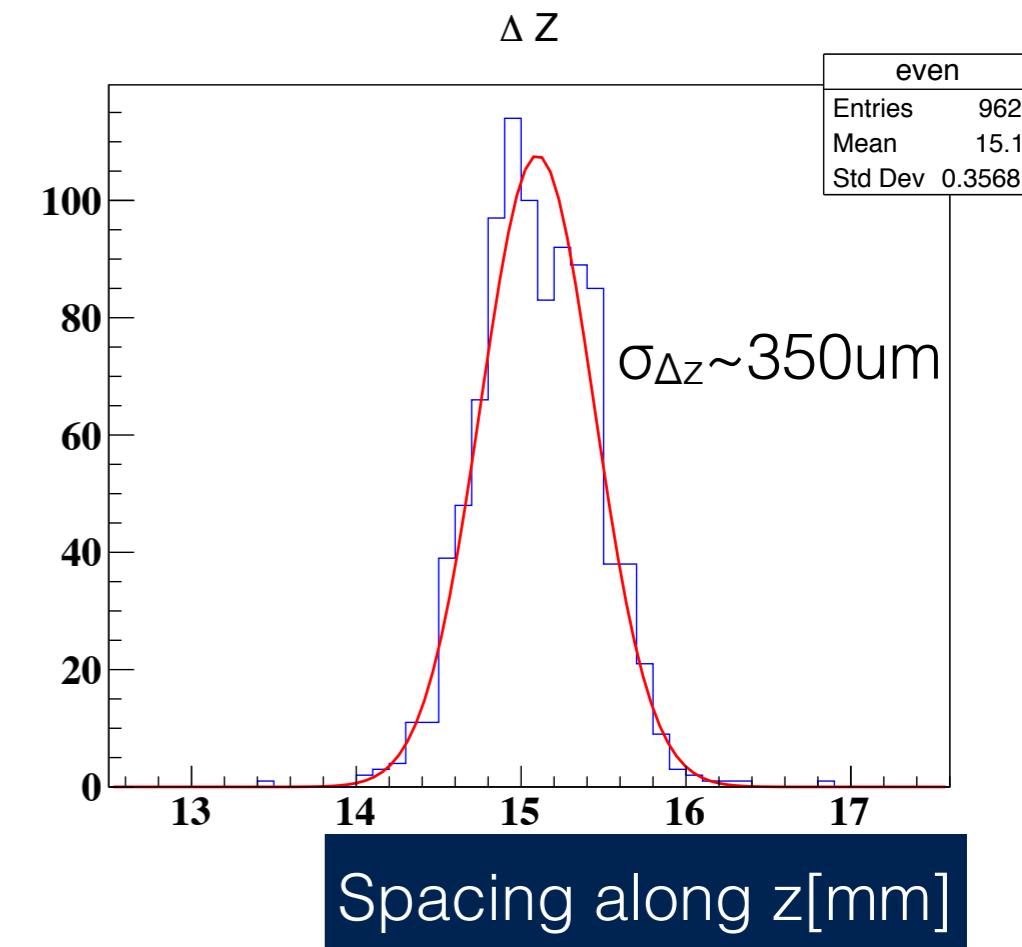
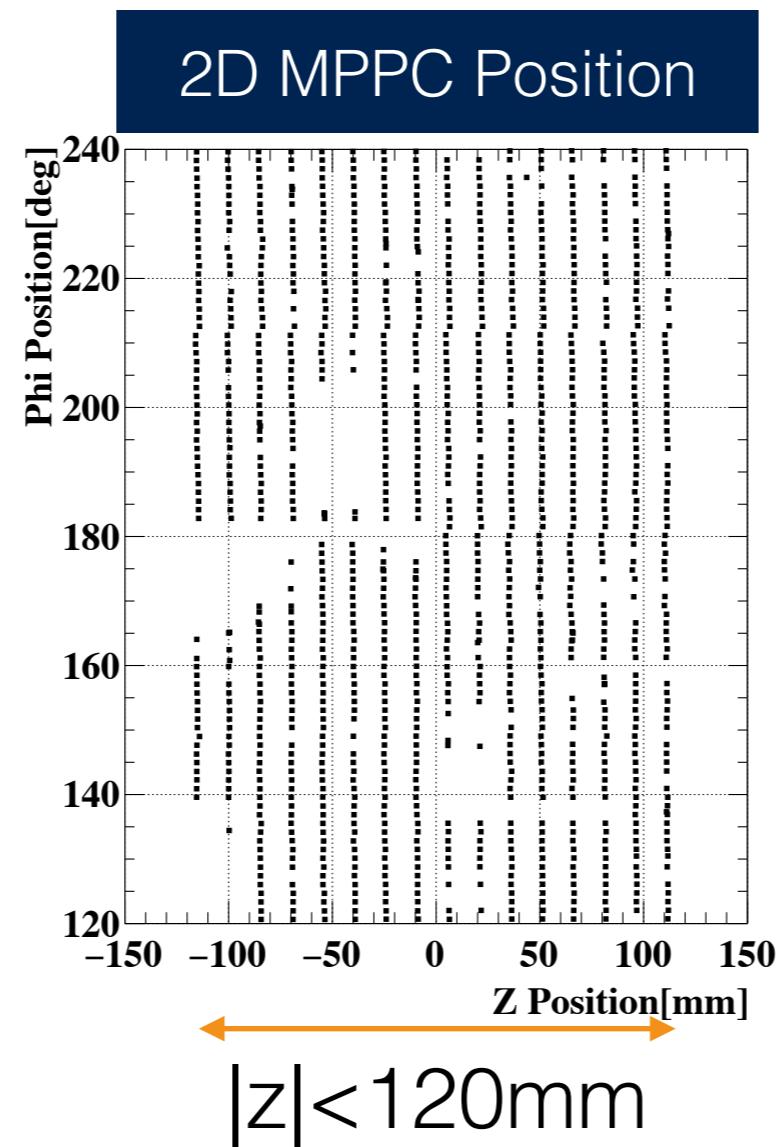


- We scanned the surface of MPPC array in  $z$  and  $\phi$  direction with the beam and measured the trigger rate of each MPPC.
- By fitting the dependence of the trigger rate on the irradiated position, we reconstructed **2-D** position of the MPPC **at L<sub>Xe</sub> temperature**.

# Result - X-ray based Measurement



magnet



- The position of  $\sim 50\%$  of all MPPCs was measured with a resolution of  $250\text{um} (=350/\sqrt{2})$ .

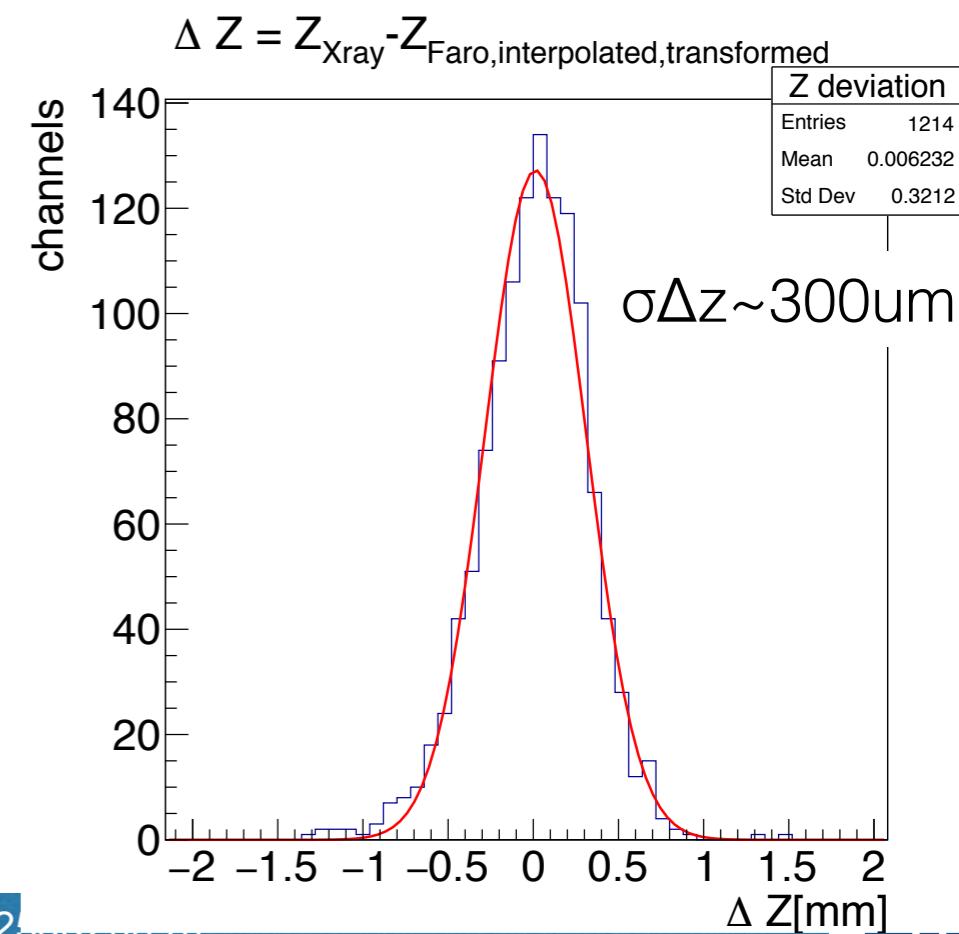
# Combination of both measurements

	Laser	Xray
Temperature	⚠ room temperature	✓ LXe temperature(170K)
Coordinate	✓ 3D(x,y,z)	⚠ 2D(z,φ)

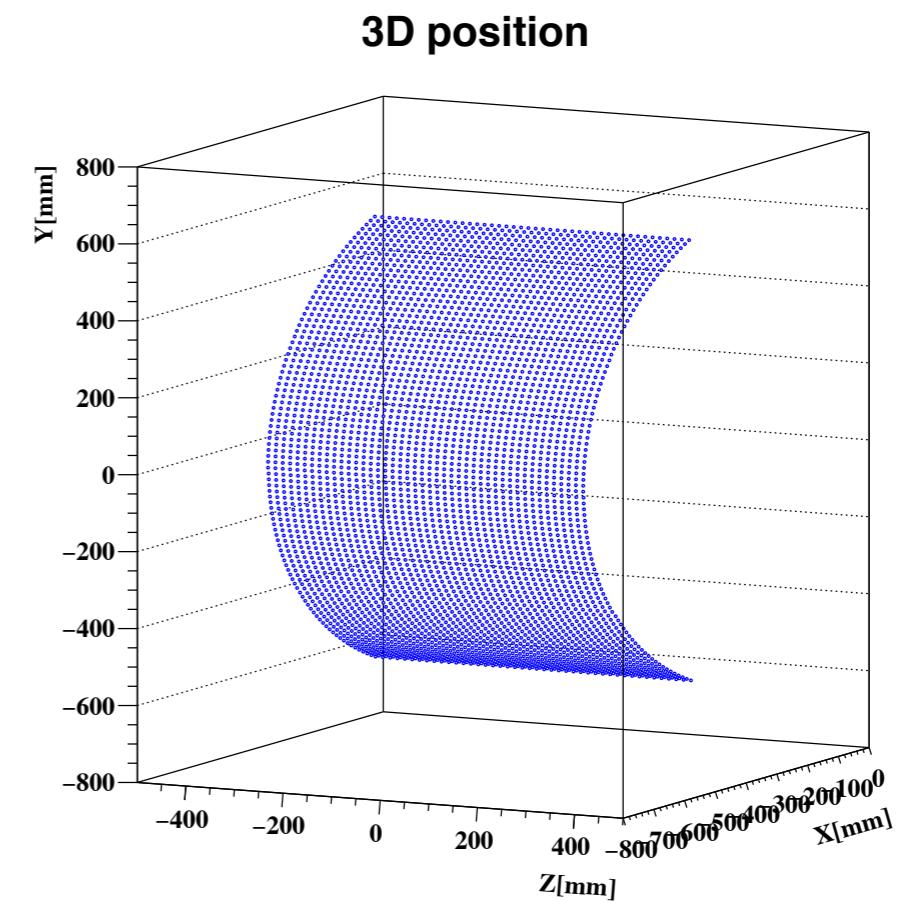
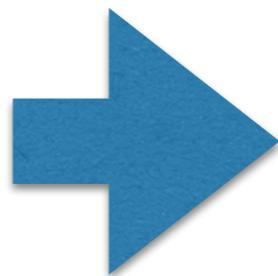
- The global 3D shape of the MPPC array is fitted to the result of the X-ray measurement on z-φ plane.
- After fitting, the residual of the position is
  - $\sigma_{\Delta z} \sim 300\text{um}$
  - $\sigma_{\Delta \phi} \sim 0.4\text{mrad} (\rightarrow 260\text{um}@incident face)$
- We obtained the position of all MPPCs at an accuracy of better than 350um.

$$\vec{x}_{laser} \mapsto \underbrace{aR(\alpha, \beta, \gamma)}_{\text{scale rotation}} \vec{x}_{laser} + \underbrace{\vec{c}}_{\text{shift}}$$

▲ coordinate transformation



# Prospects



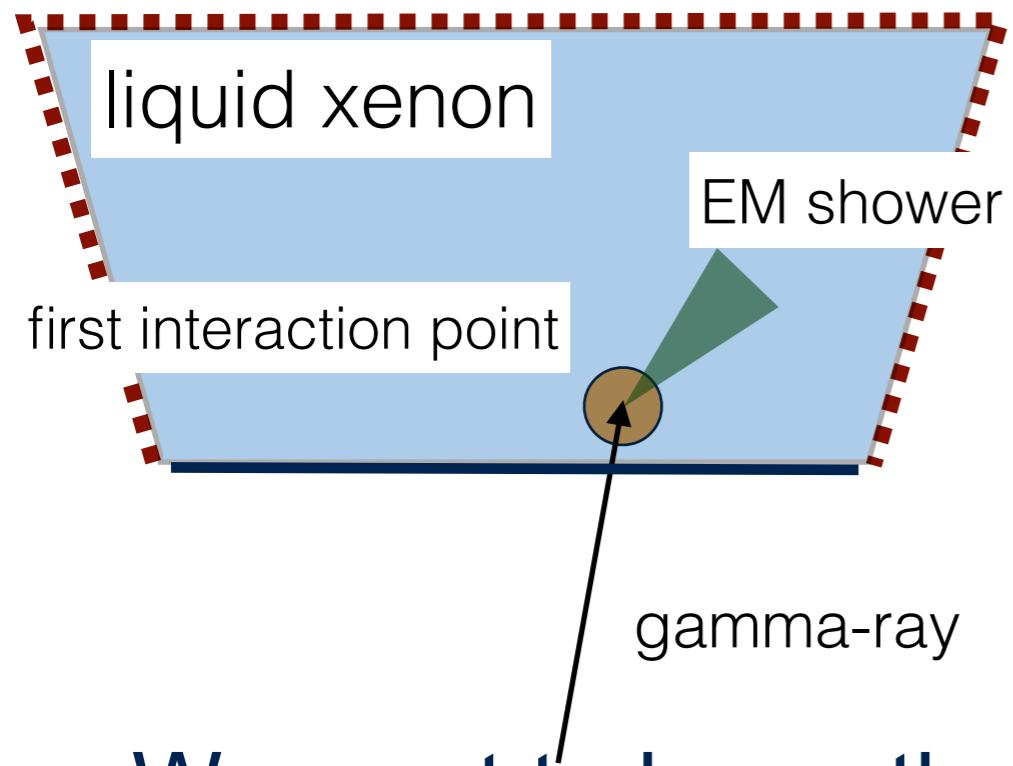
- Prospects
  - The position of MPPCs after a thermal cycle will be measured.
  - X-ray measurement outside the COBRA magnet to measure the position of MPPCs at large Z in June-July this year.

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- **Position resolution @ 2017 pilot run**
  - **Position reconstruction algorithm**
  - **Result**

**~2.5 mm** resolution is expected

# Position Reconstruction



Number of detected photo-electrons of  $i_{th}$  MPPC

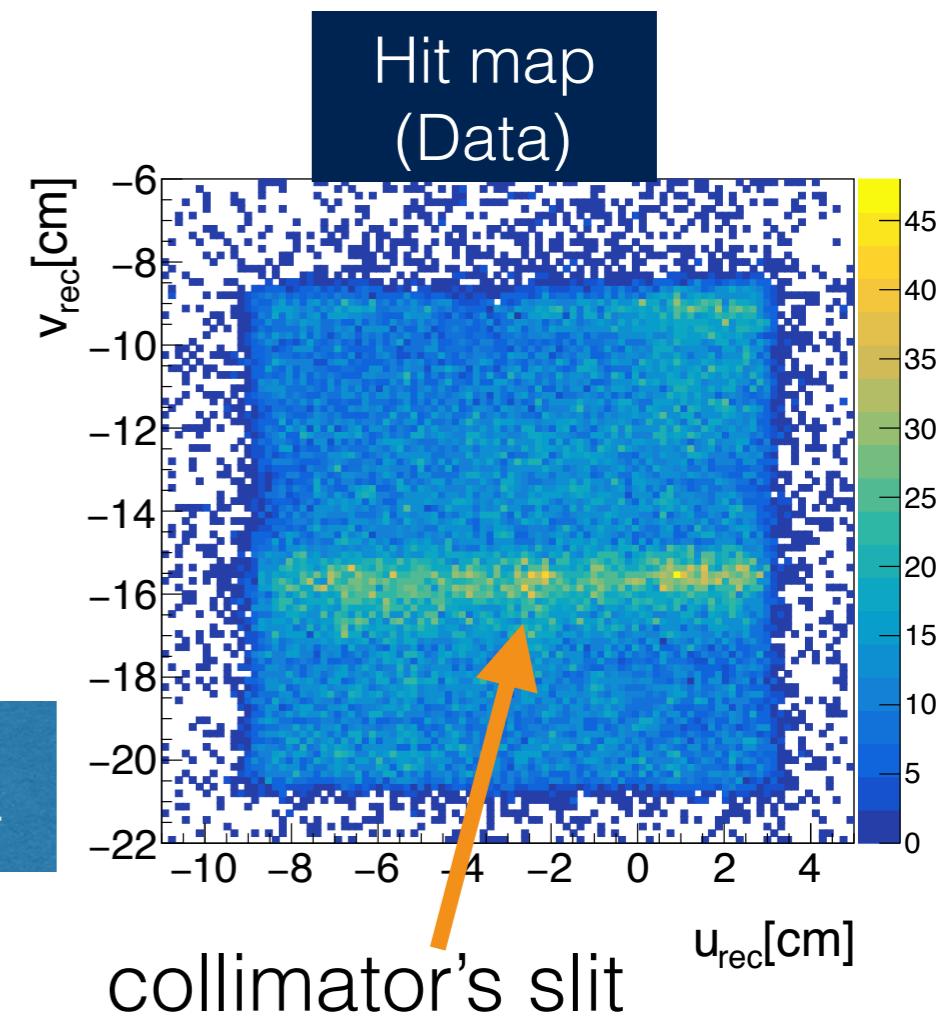
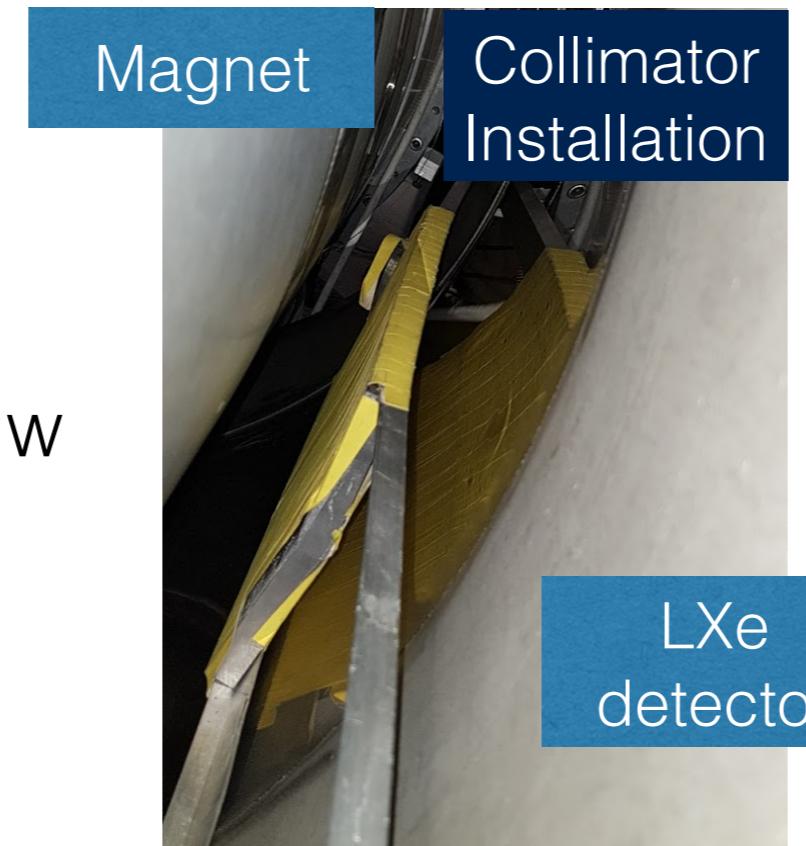
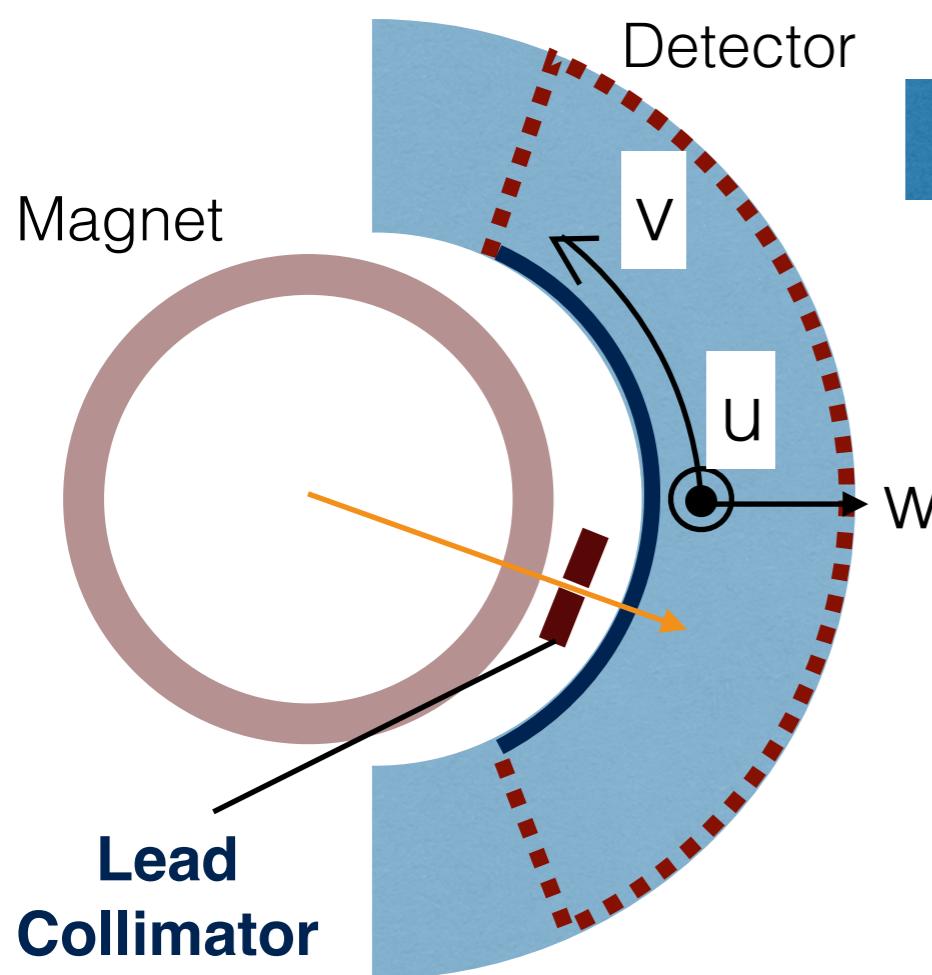
Solid angle of  $i_{th}$  MPPC from  $(x, y, z)$

$$\chi^2_{pos} = \sum_i \frac{(N_{pho,i} - C \times \Omega_i(x, y, z))^2}{\sigma_{pho,i}(N_{pho,i})^2}$$

▲ This chi-square is minimized

- We want to know the position of the **first interaction point** in LXe.
- The distribution of the number of photoelectrons is fitted and some corrections are applied to eliminate the shower's contribution.
- MPPC's information is used for position reconstruction
  - PMT is not used.

# Collimator run @ 2017 Pilot run



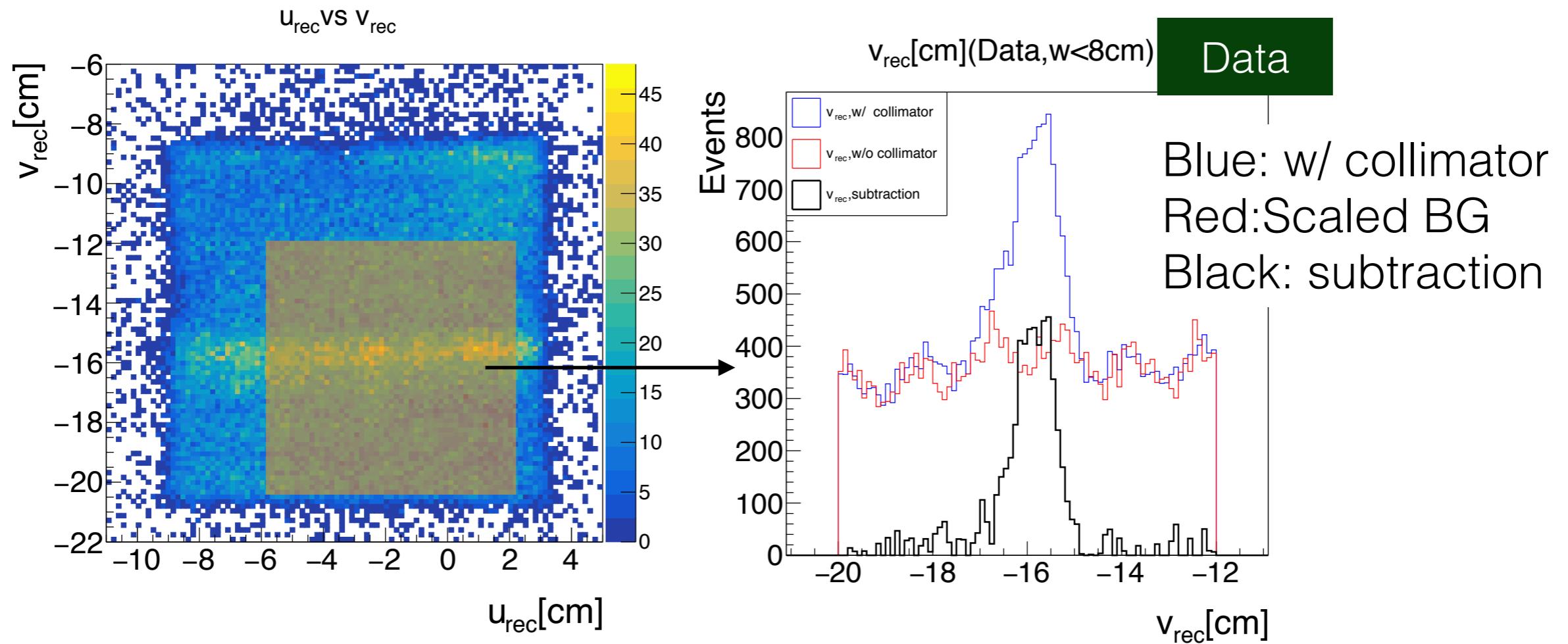
## Motivation

- We can evaluate the position resolution by observing the edge of the shadow of the collimator and comparing it with MC's.

## Configuration

- Lead collimator with a 5mm slit and 18mm thickness.
- DAQ channel is limited to 960 MPPCs (~25%).
- $E\gamma > \sim 40\text{MeV}$  ( $\gamma$  is from the radiative muon decay)
- Background data was also taken without the collimator.

# Result - Data



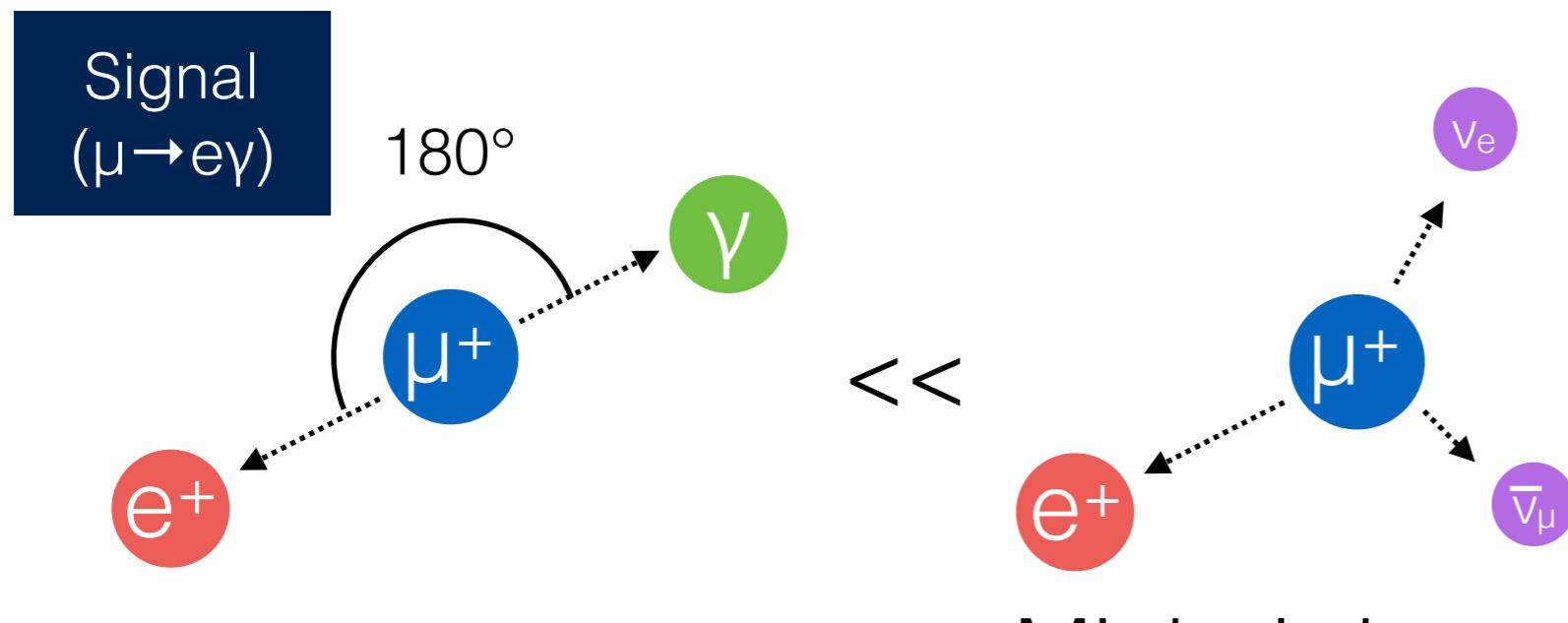
- The peak structure due to the slit of the collimator will be compared to MC simulation.
  - The scale of BG is adjusted to the region fully covered by lead.
- The evaluation of the position resolution is ongoing.

# Summary

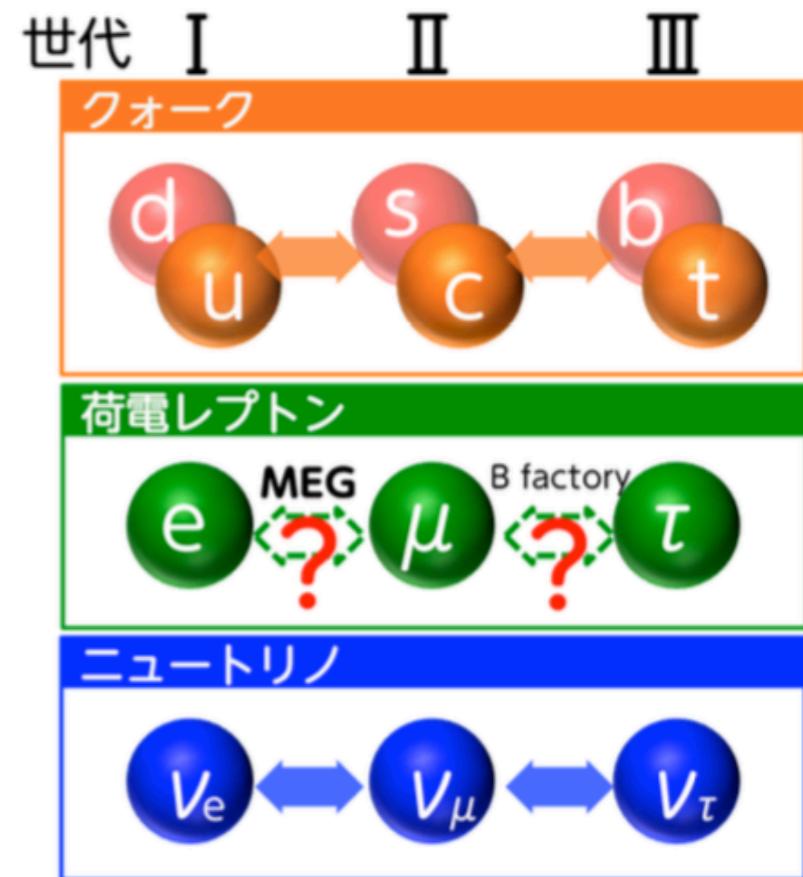
- MPPC Alignment
  - The position of **all** MPPCs is calculated by combining the result of two measurements.
  - The uncertainty of the position measurement is **350um**.
- Position Resolution
  - The evaluation of the position resolution is now ongoing

# Back Up

# Introduction - $\mu \rightarrow e\gamma$ search



- ▶ Simultaneously emitted
- ▶ Back-to-back
- ▶ Same energy

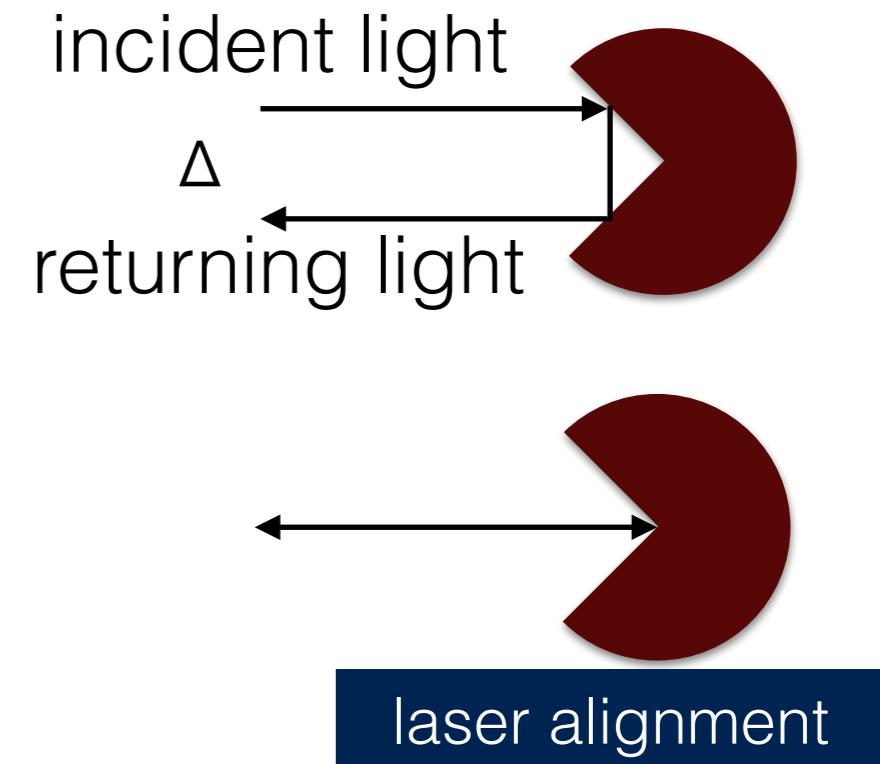
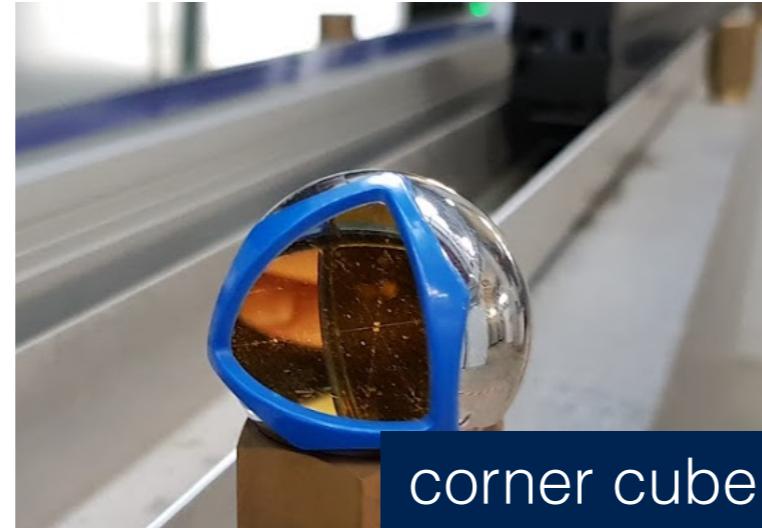


- $\mu \rightarrow e\gamma$  decay is a lepton flavor violating decay.
  - **almost forbidden** in the SM( $\text{Br}(\mu \rightarrow e\gamma) < 10^{-54}$ )
  - **predicted** in some theories( $\text{Br}(\mu \rightarrow e\gamma): 10^{-11} \sim 10^{-14}$ )
- Current upper limit of  $\text{Br}(\mu \rightarrow e\gamma)$  is given by the MEG experiment
  - $4.2 \times 10^{-13}$  (90% C.L.)

# Principle of Laser Tracker

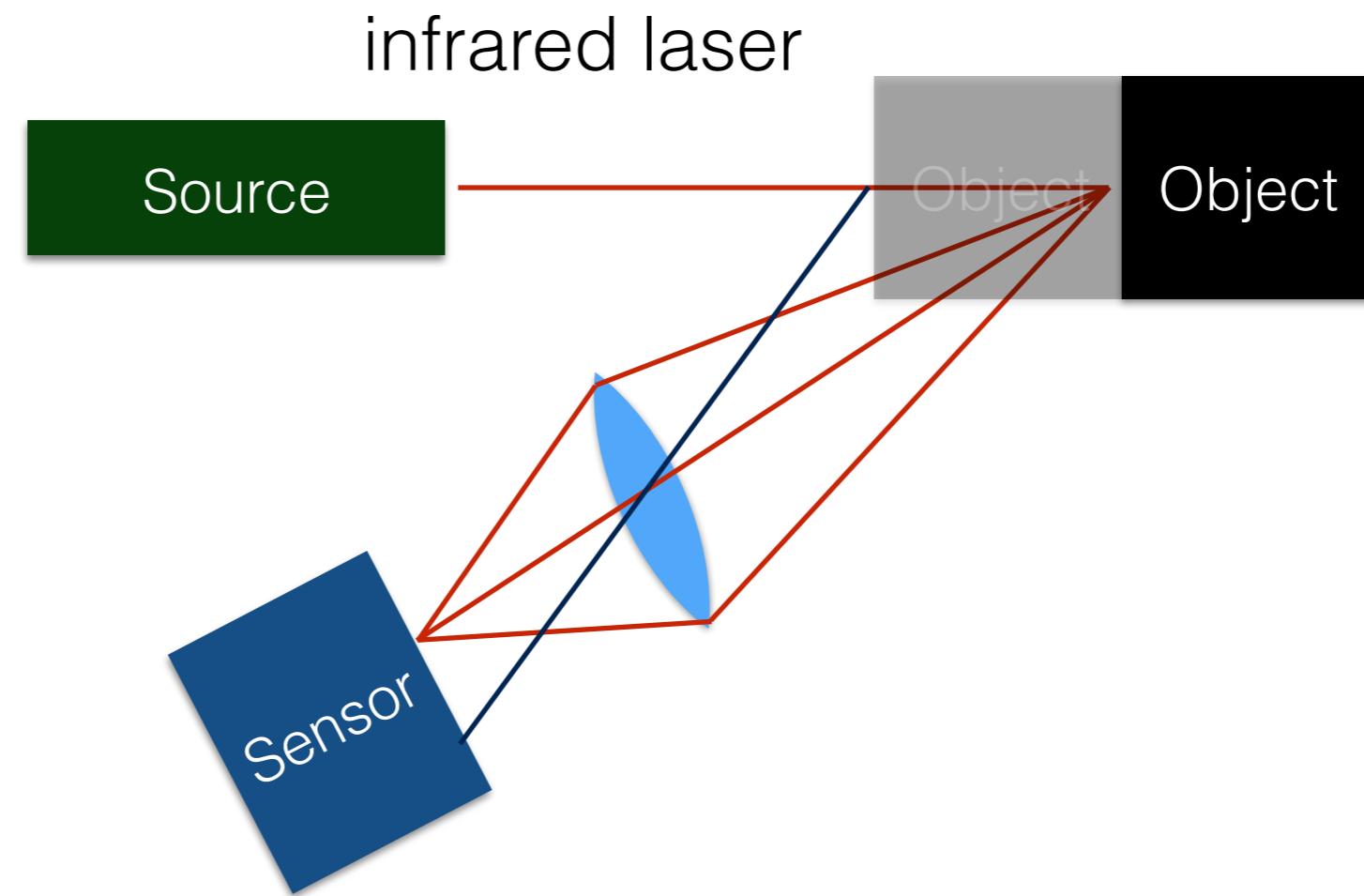


laser tracker



- Laser tracker measures the position of the center of a corner cube.
- The direction of the laser is aligned so as to match the returning light to the emitted light.
- The absolute distance is measured by use of the interferometer inside the laser tracker.
- The direction of the laser and this distance gives the 3D-position of the corner cube.

# Principle of Laser Scanner

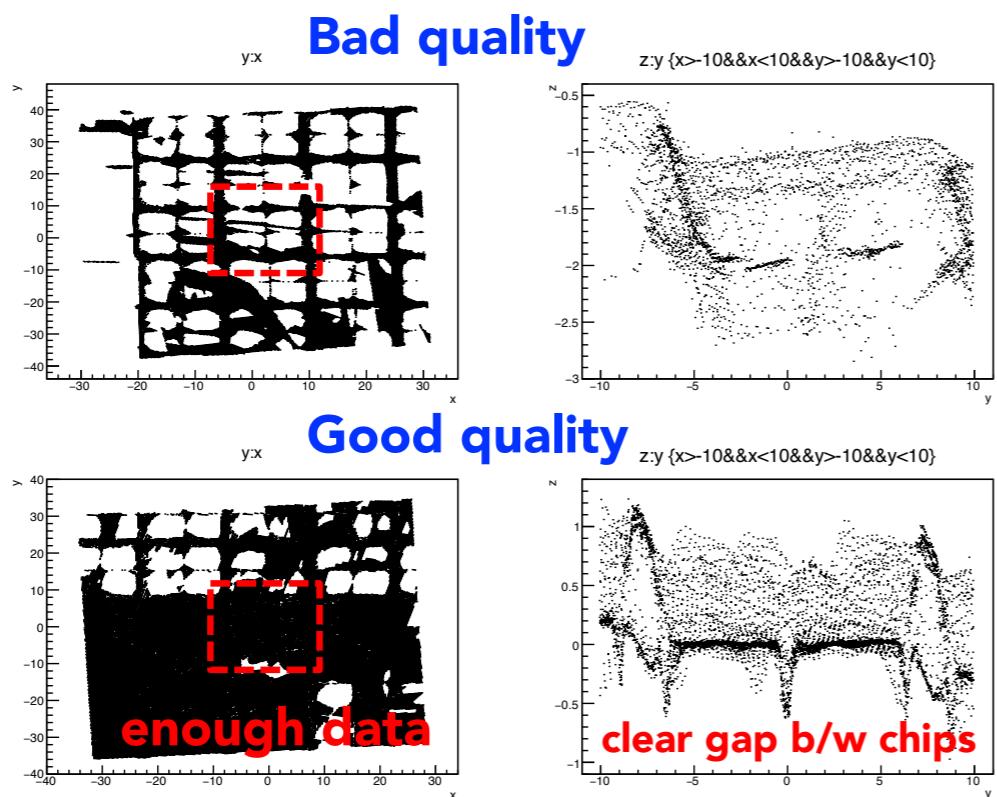


- Laser scanner measures the position of an object by use of triangulation.
  - The spot of the laser is detected by the photosensor.

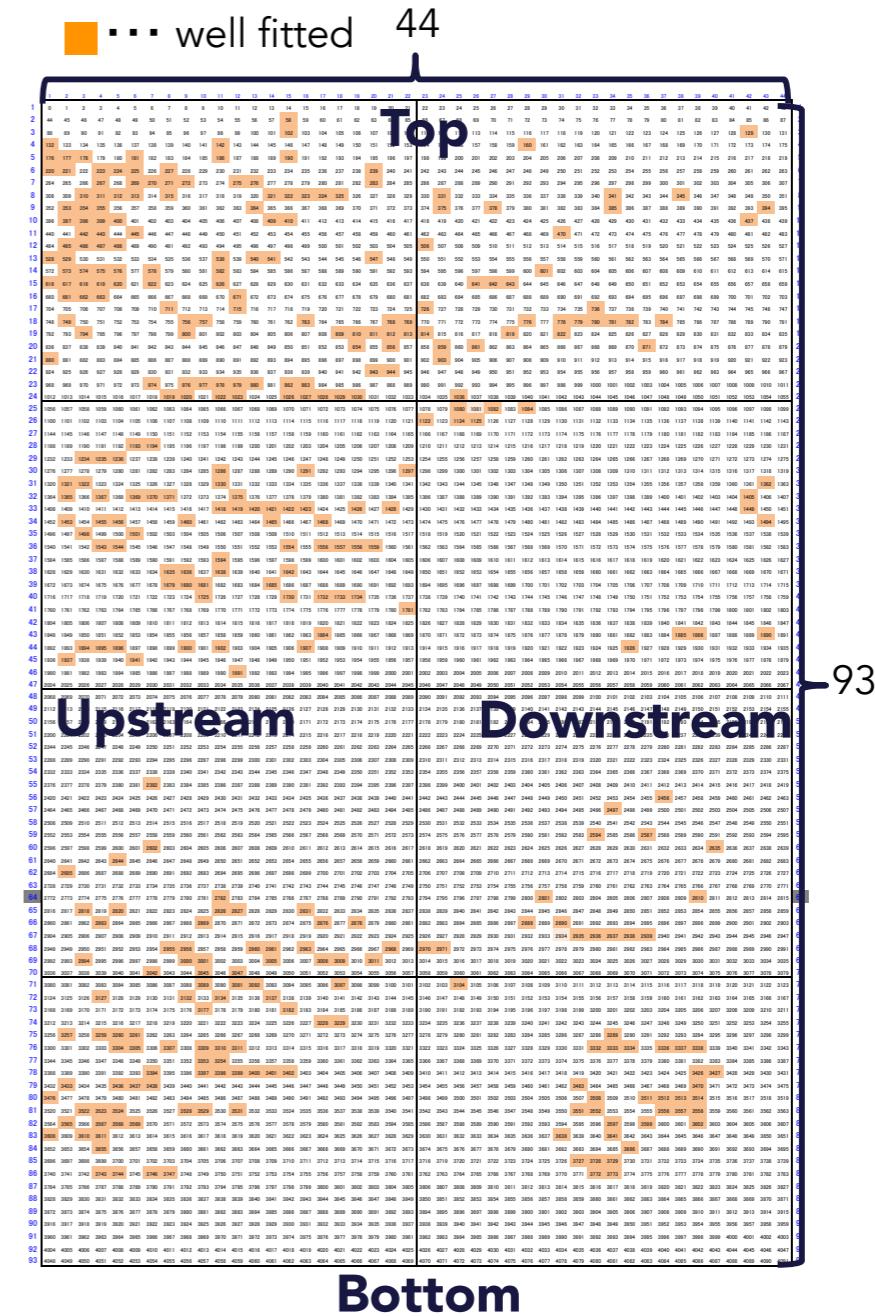
# Measured MPPC

## Results & Discussion (1)

- Only 356 MPPCs out of 4092 are well fitted and find the position and direction.
- This is due to bad quality of data.
- Data quality depends on reflection and is restricted by accessibility of FARO arm.



Tokyo Meeting 2017 (28<sup>th</sup>-29<sup>th</sup>, Mar.)



MITSUTAKA NAKAO ★ Page: 8/12

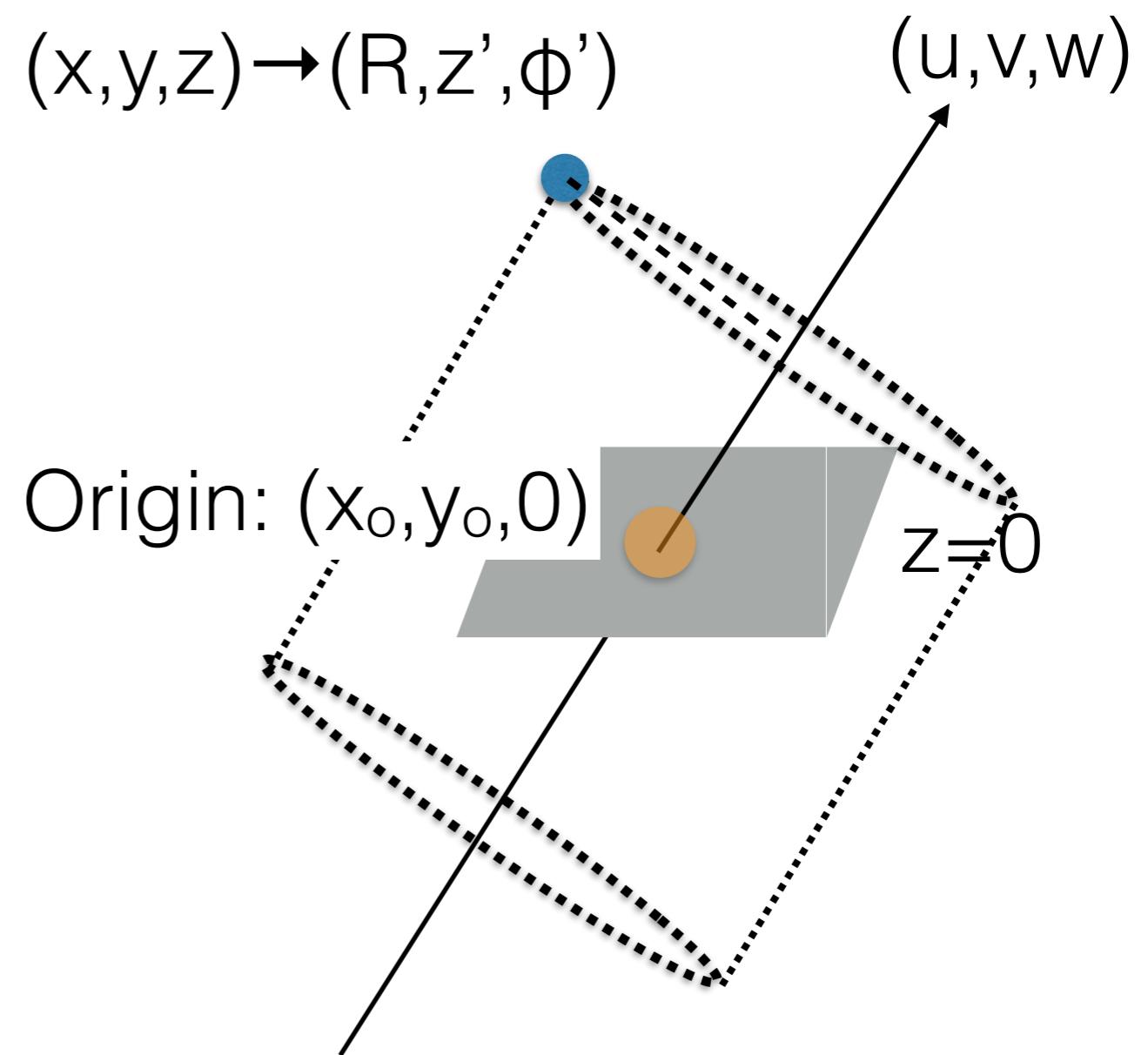
- Only 10% of MPPCs are measured by laser scanner.

# Interpolation Strategy

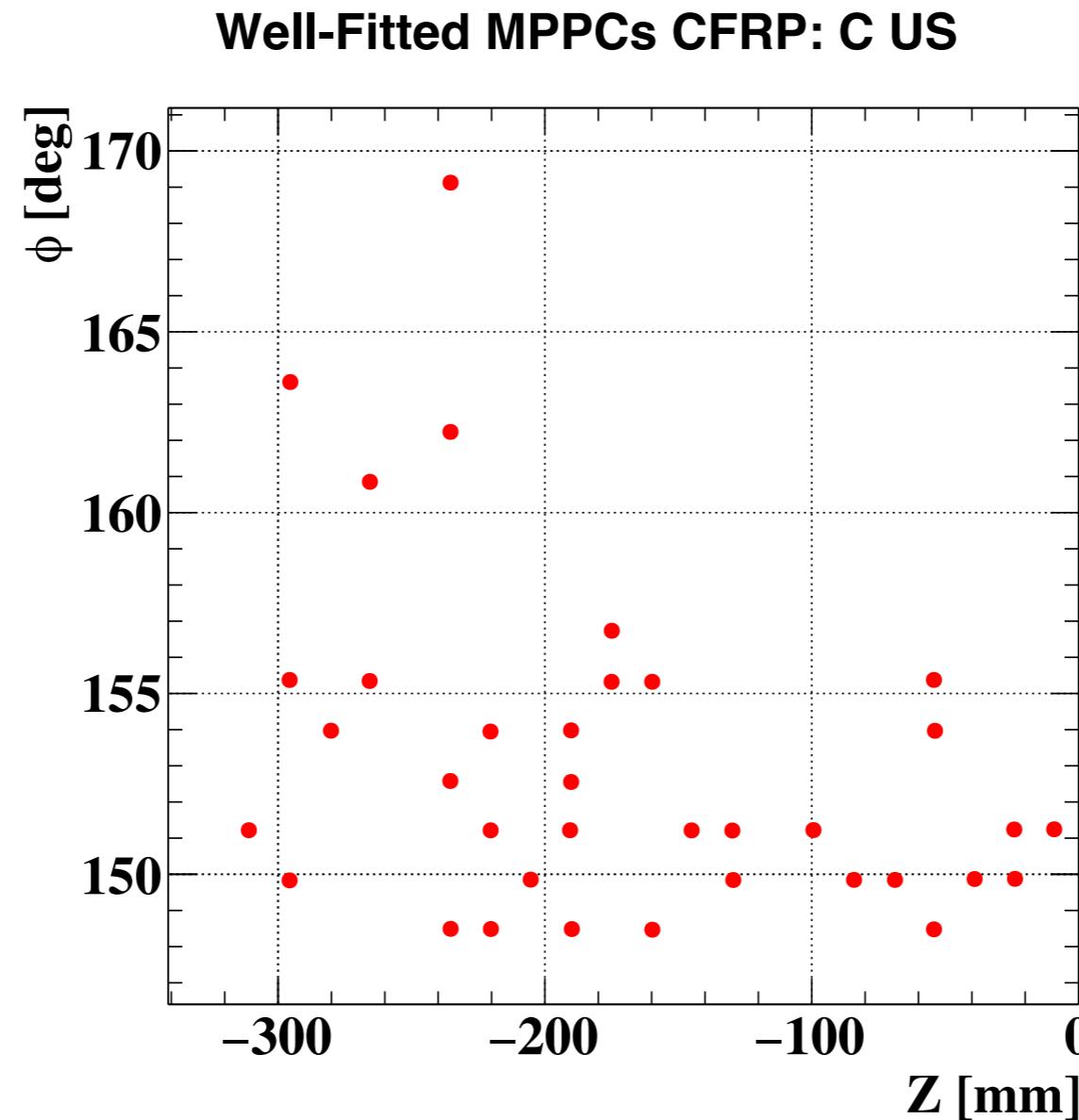
- To know the position of all MPPCs from the limited number of well-fitted MPPCs, we should interpolate the position of the rest MPPCs
- Interpolation procedure is as follows.
  - Step 1: Cylindrical fitting
  - Step 2: Transformation to the cylindrical coordinate
  - Step 3: Fitting well-fitted MPPCs with mesh
  - Step 4: Interpolation with mesh's parameters
- All steps are performed separately for 4 CFRPs
- Interpolation with this method is expected to be effective because all well-fitted MPPCs are used.

# Step 1: Cylindrical Fitting

- We assumed that MPPCs on the same CFRP are located on a cylinder
- 5 degree of freedom
  - 1 Radius
  - 2 Origin( $x, y, 0$ )
    - $z$  : fixed to 0mm.
  - 2 Vector( $\theta, \varphi$ )
  - Chi square is minimized



# Step 2: Coordinate Transformation



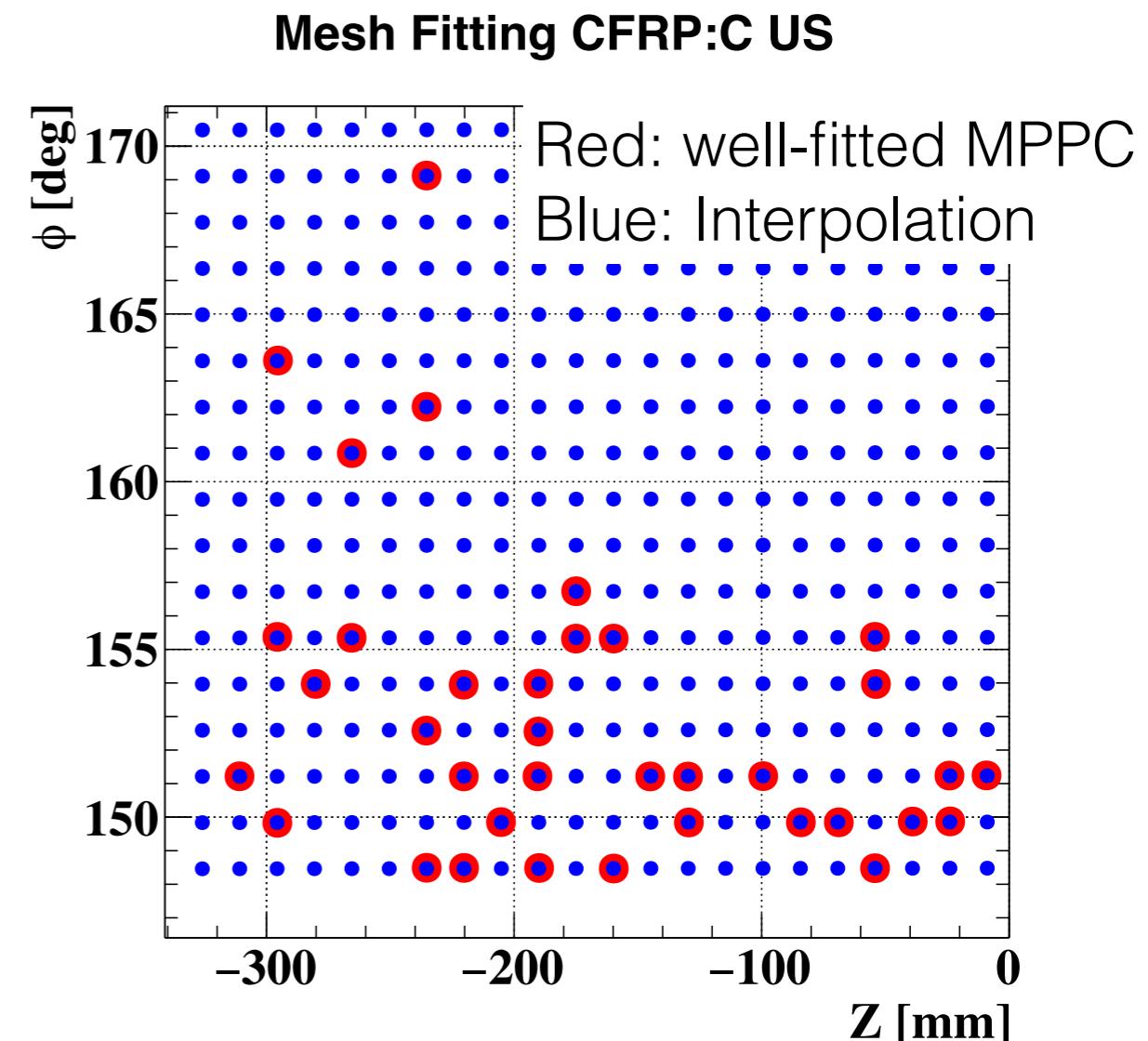
- The position of well-fitted MPPCs is transformed into the cylindrical coordinate.

# Step 3: Fitting With Mesh

$$Z_{mesh_{ij}} = p_{Z0} + i \times p_{Z1} + j \times p_{Z2}$$

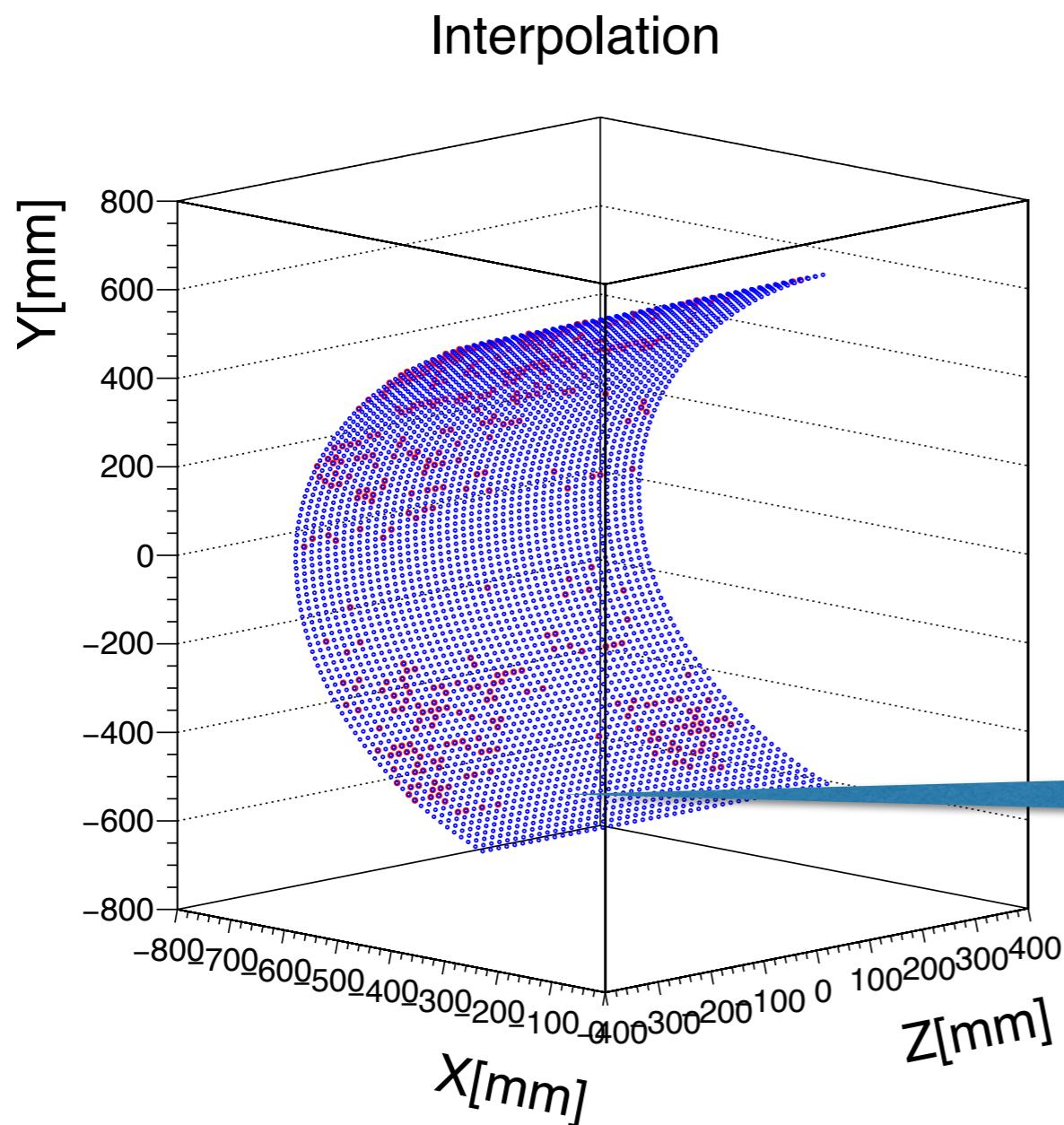
$$\phi_{mesh_{ij}} = p_{\phi0} + j \times p_{\phi1} + i \times p_{\phi2}$$

$$\chi^2 = \sum_{well-fitted} (z_{ij} - z_{mesh_{ij}})^2$$

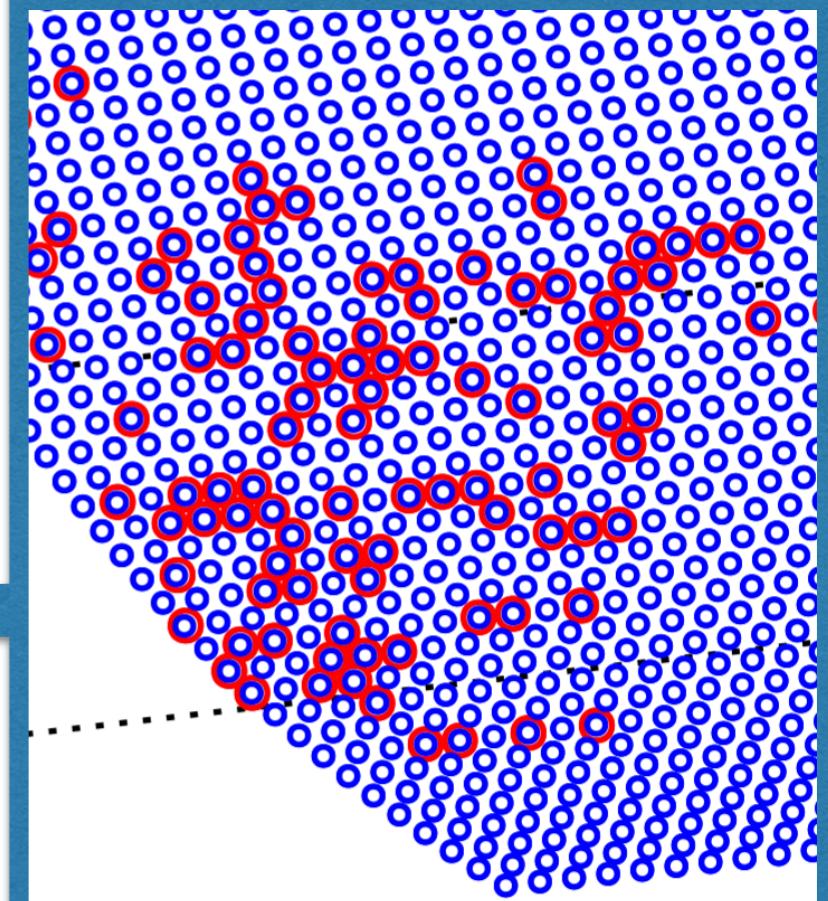


- Fitting was separately carried out for Z and  $\phi$ .
- Chi-square is minimized by MIGRAD.

# Step 4: Interpolation

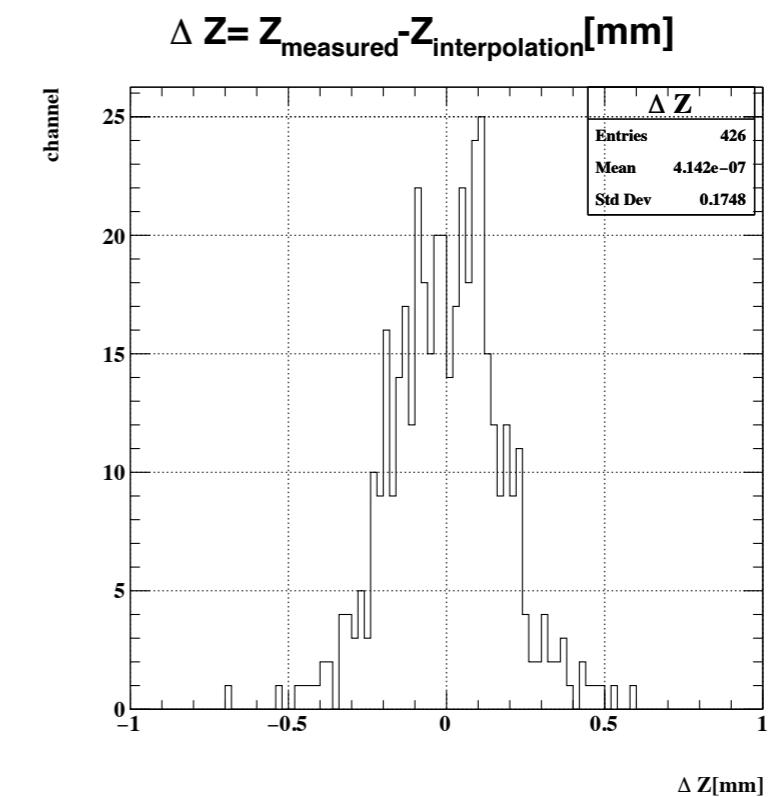
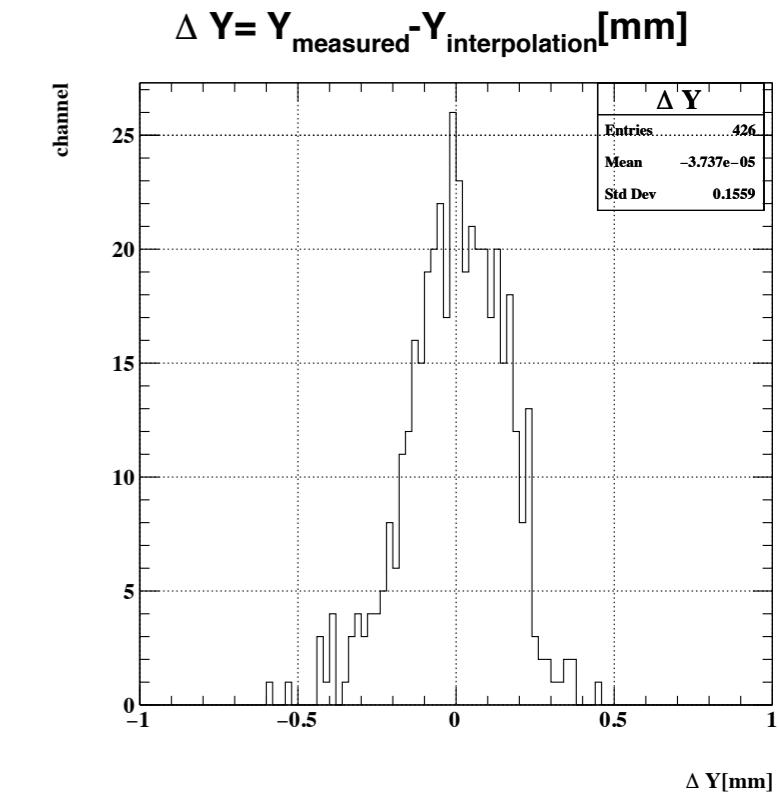
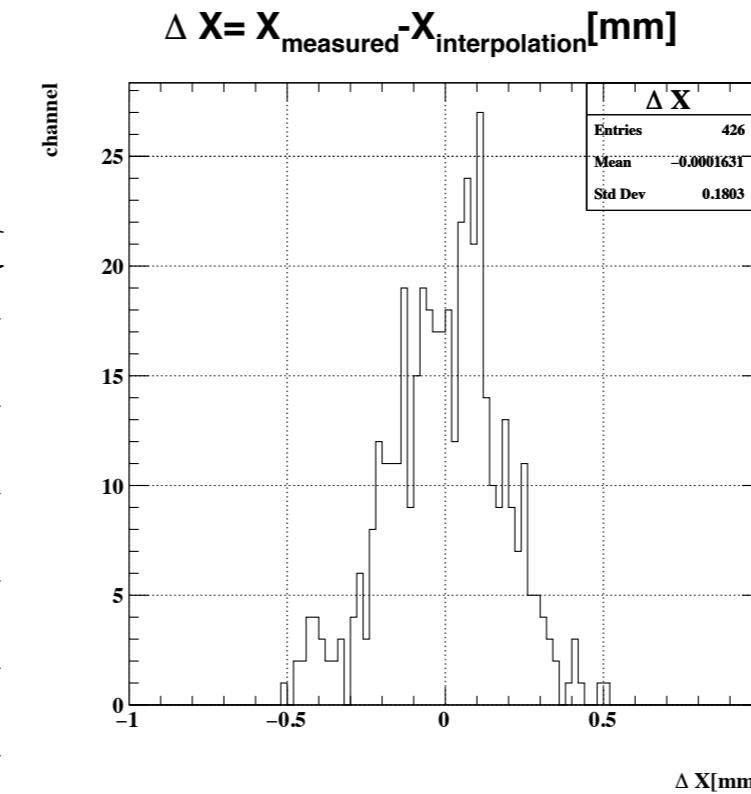
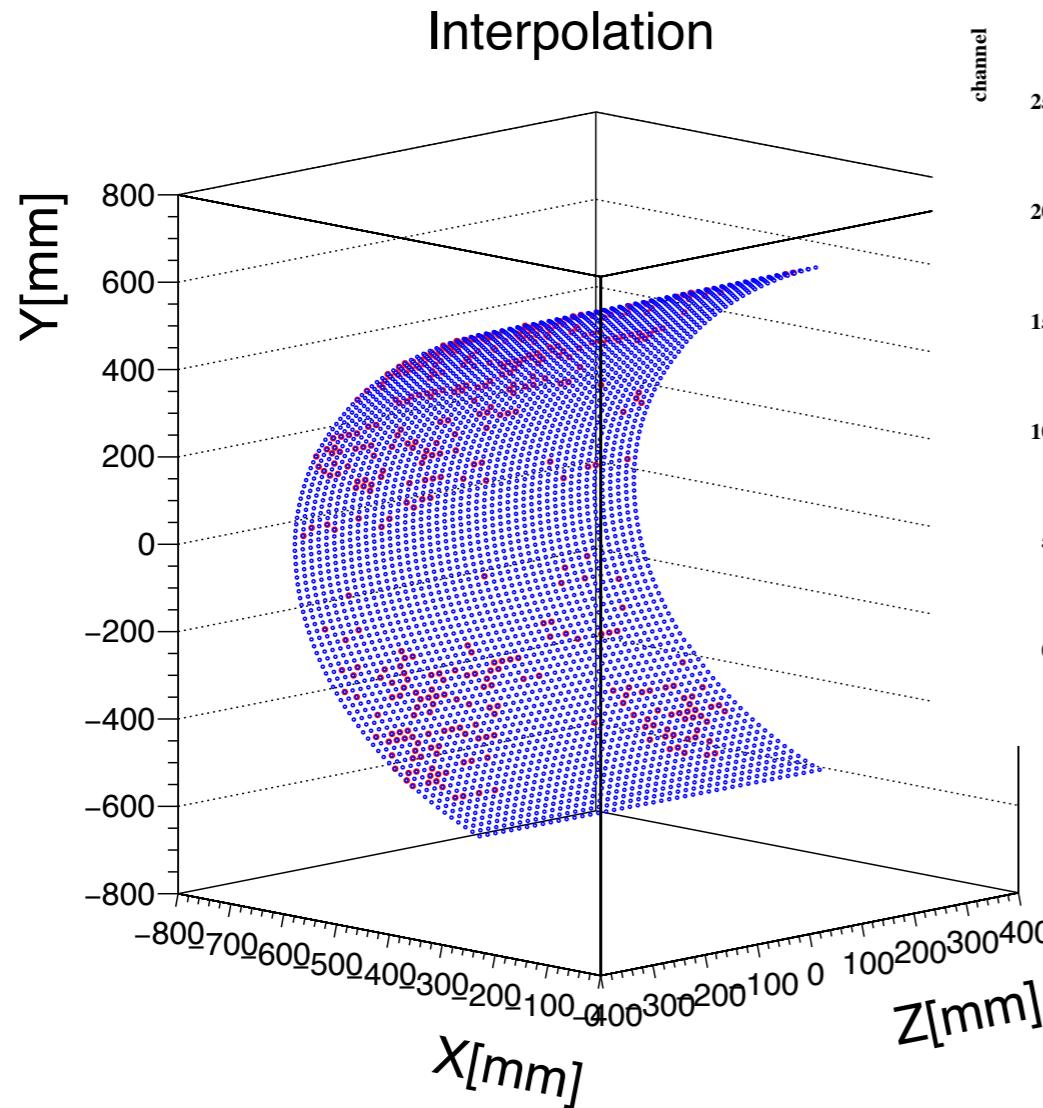


Red: well-fitted MPPC  
Blue: Interpolation



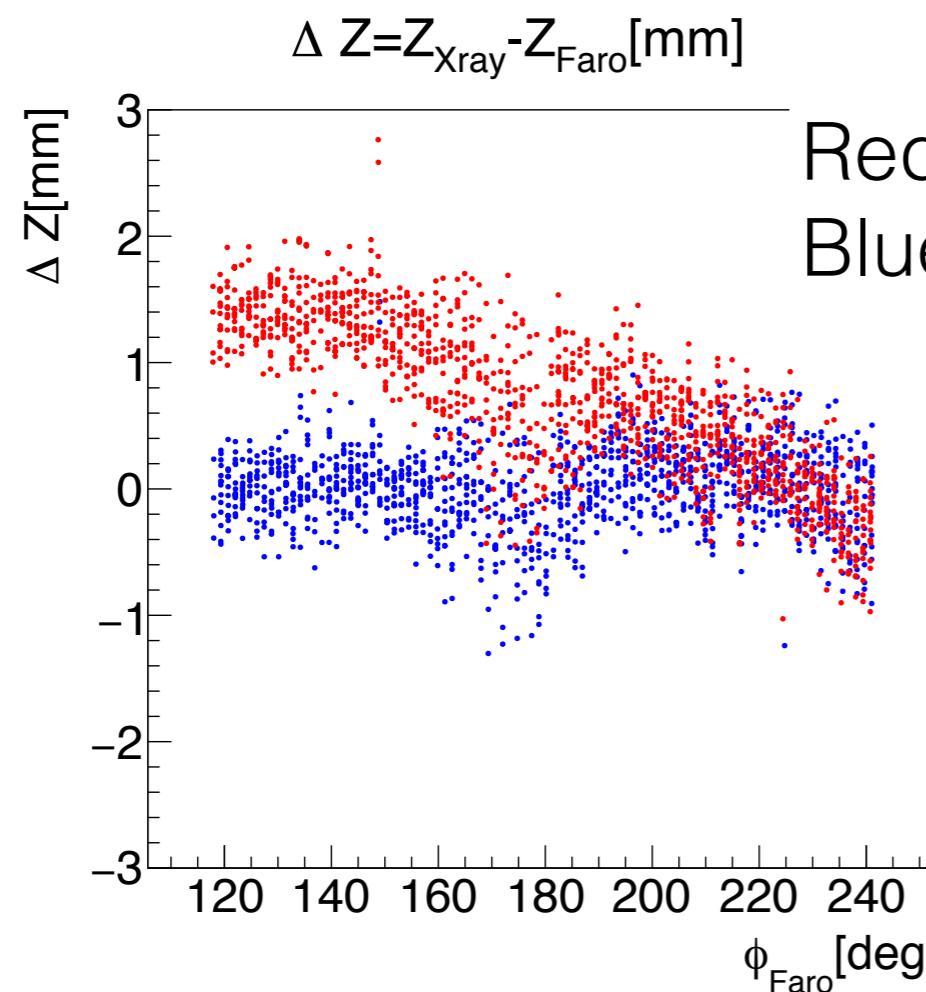
- The position of all MPPCs is interpolated.

# Verification

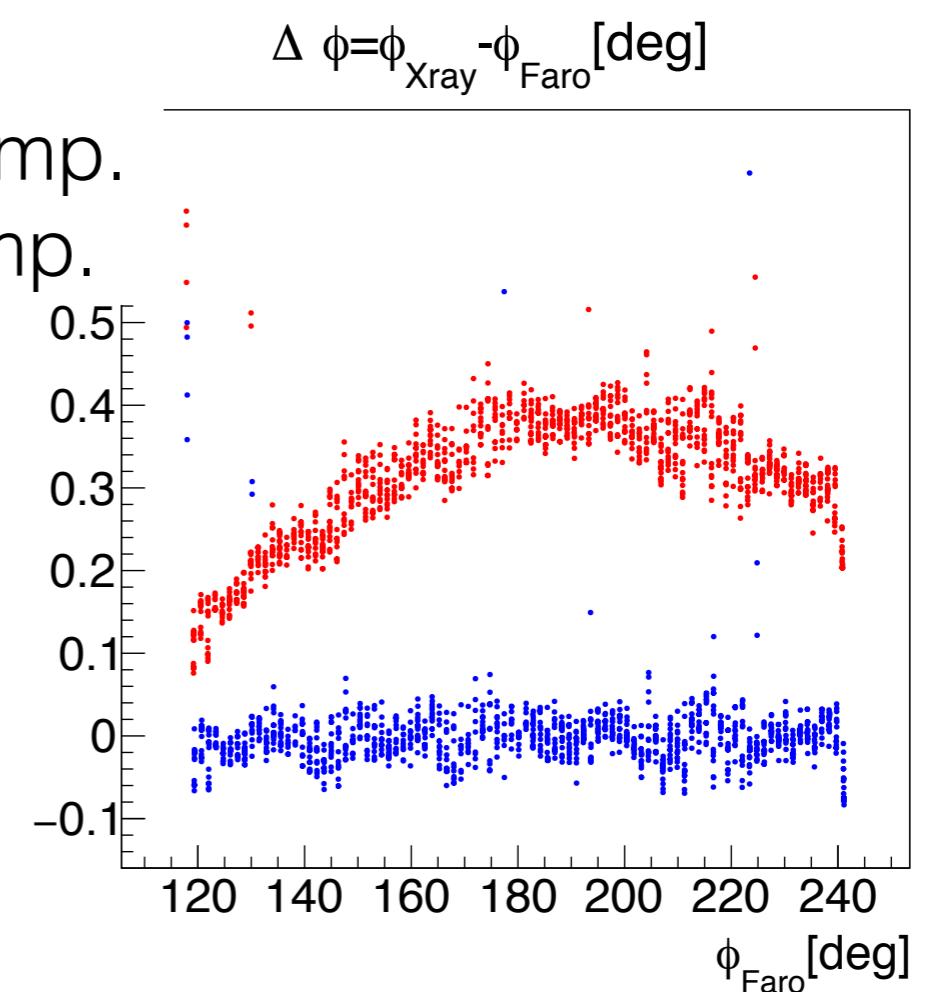


- Interpolated position matches the measured position at an accuracy of 180um.

# Consistency of Both results

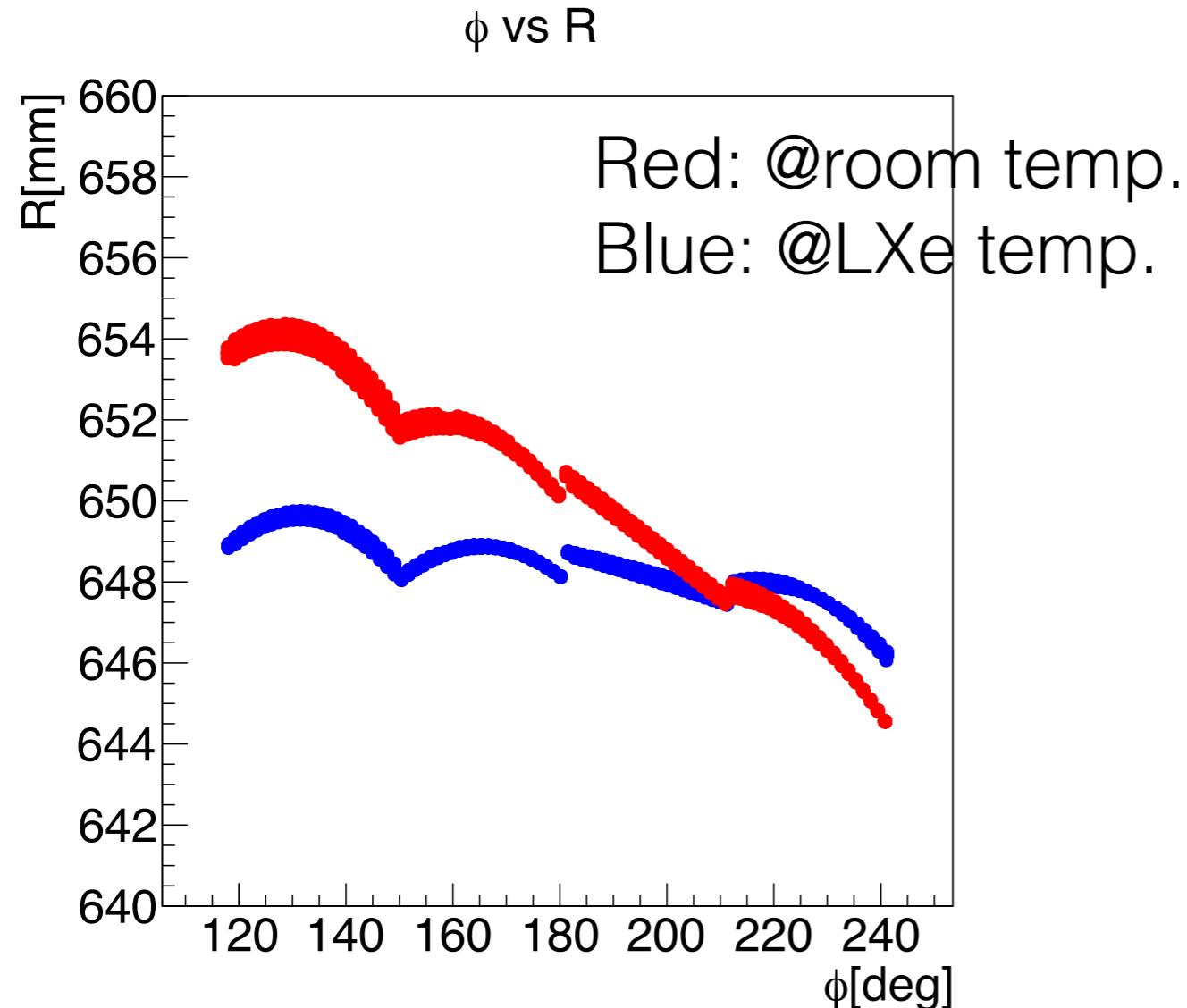


Red: @room temp.  
Blue: @LXe temp.



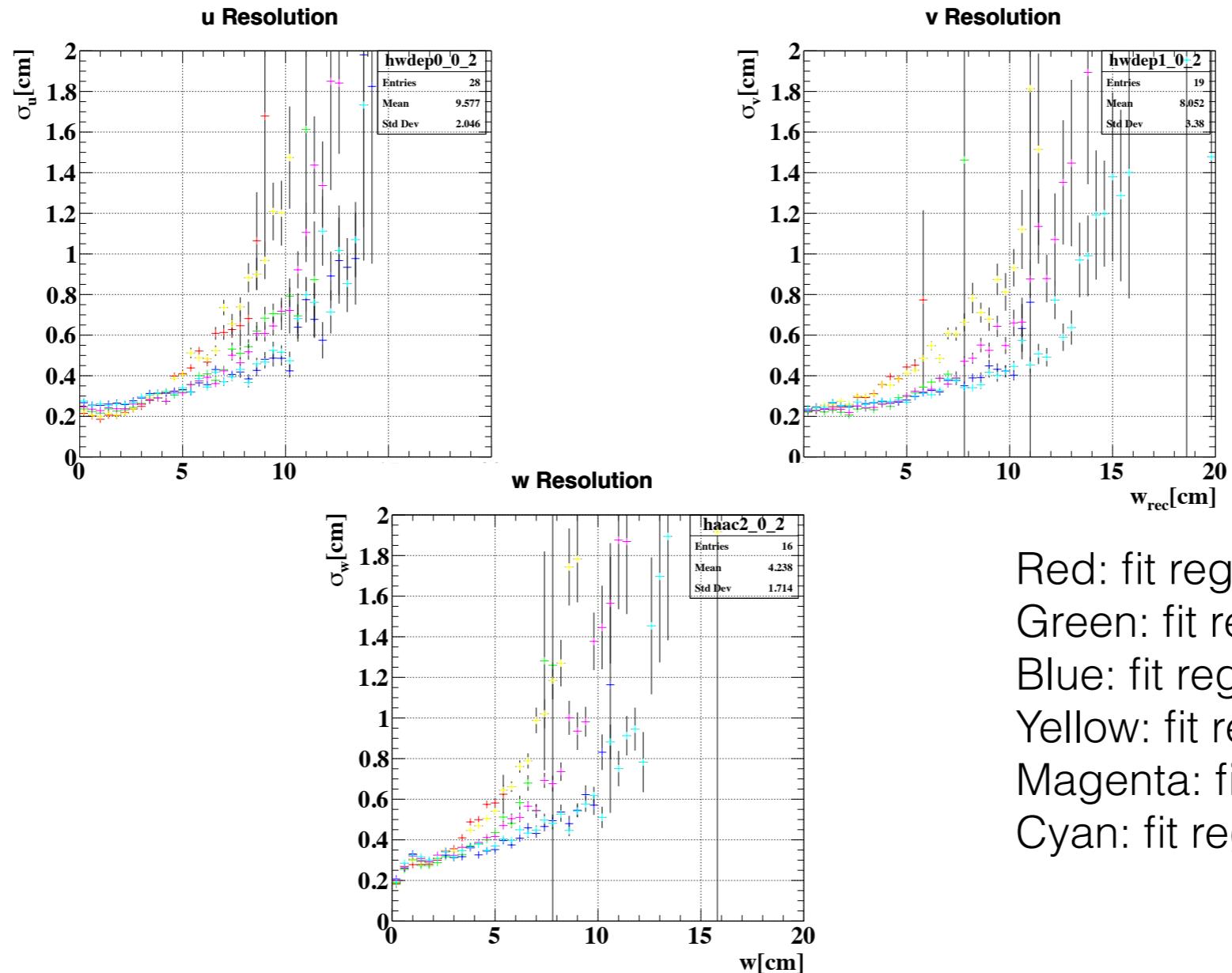
- No apparent bias can be seen in the phi dependence.

# Radial Position of MPPC



- Laser-based measurement is sensitive to the radial position of MPPC.

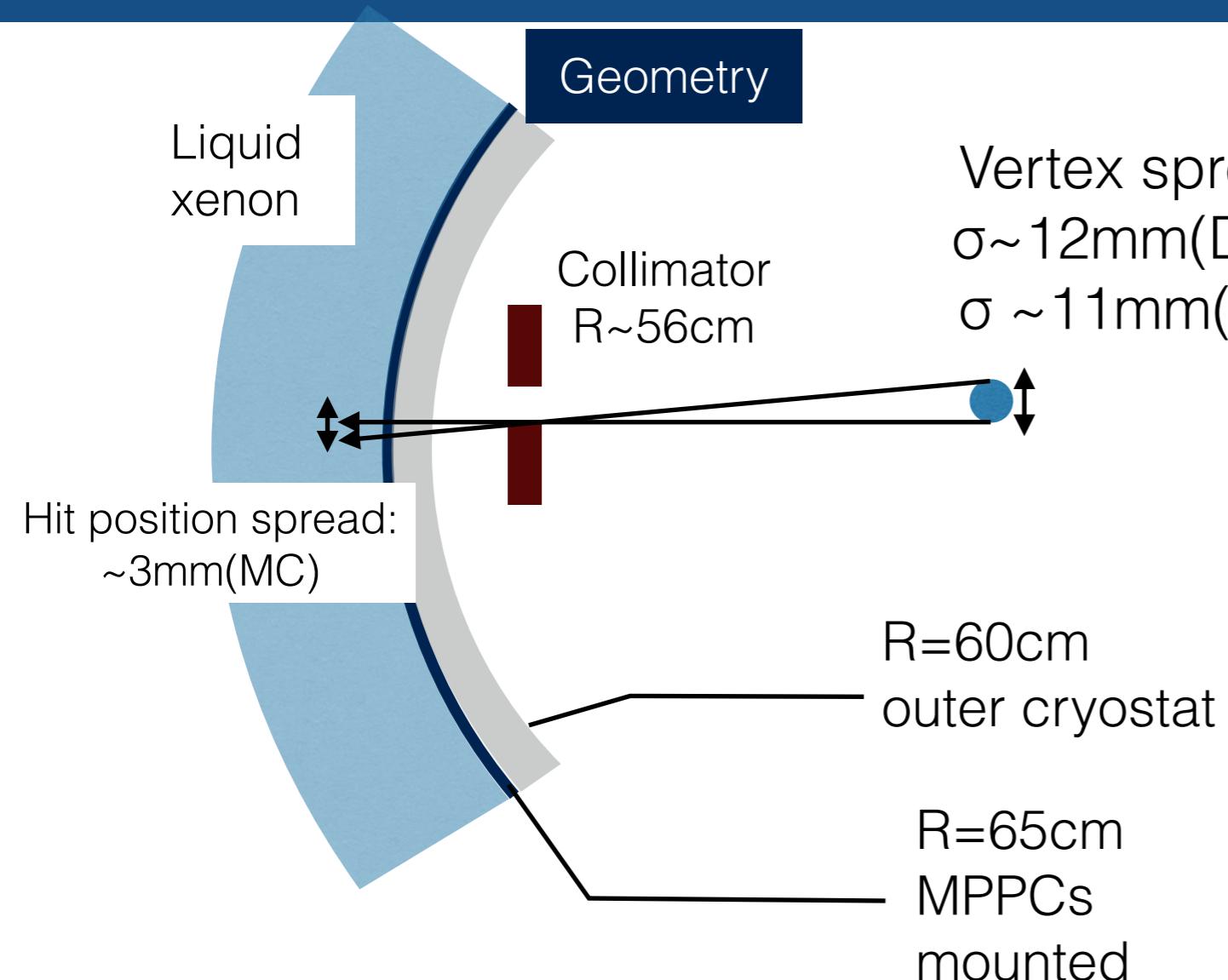
# Expected Resolution from MC



Red: fit region=2  
Green: fit region=3  
Blue: fit region=5  
Yellow: fit region=7  
Magenta: fit region=11  
Cyan: fit region=13

- From a MC, it is known that
  - the resolution is around 2mm( $w < 10\text{cm}$ )
  - narrow fit range is suitable for reconstruction of the shallow events
  - wide fit range is suitable for that of the deep events.

# Uncertainty of the position resolution



Vertex spread:  
 $\sigma \sim 12\text{mm(Data)}$   
 $\sigma \sim 11\text{mm(MC)}$

Hit position spread:  
~3mm(MC)

R=60cm  
outer cryostat

R=65cm  
MPPCs  
mounted

- There are many factors that affect the event distribution.
  - The spread of the vertex at the target
  - Geometry
- The position of the collimator and the detector is not measured.