MEG II実験液体キセノンガンマ線検出器における MPPCのアライメント

Measurement of the position of SiPMs in the liquid xenon gamma-ray detector for the MEGII Experiment

日本物理学会
2018年秋季大会
信州大学

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Mu - E - Gamma collaboration

Core-to-Core Program

THE UNIVERSITY OF TOKYO

Outline

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  - MEG II Experiment
  - Liquid Xenon Calorimeter
- X-ray Measurement
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- Result
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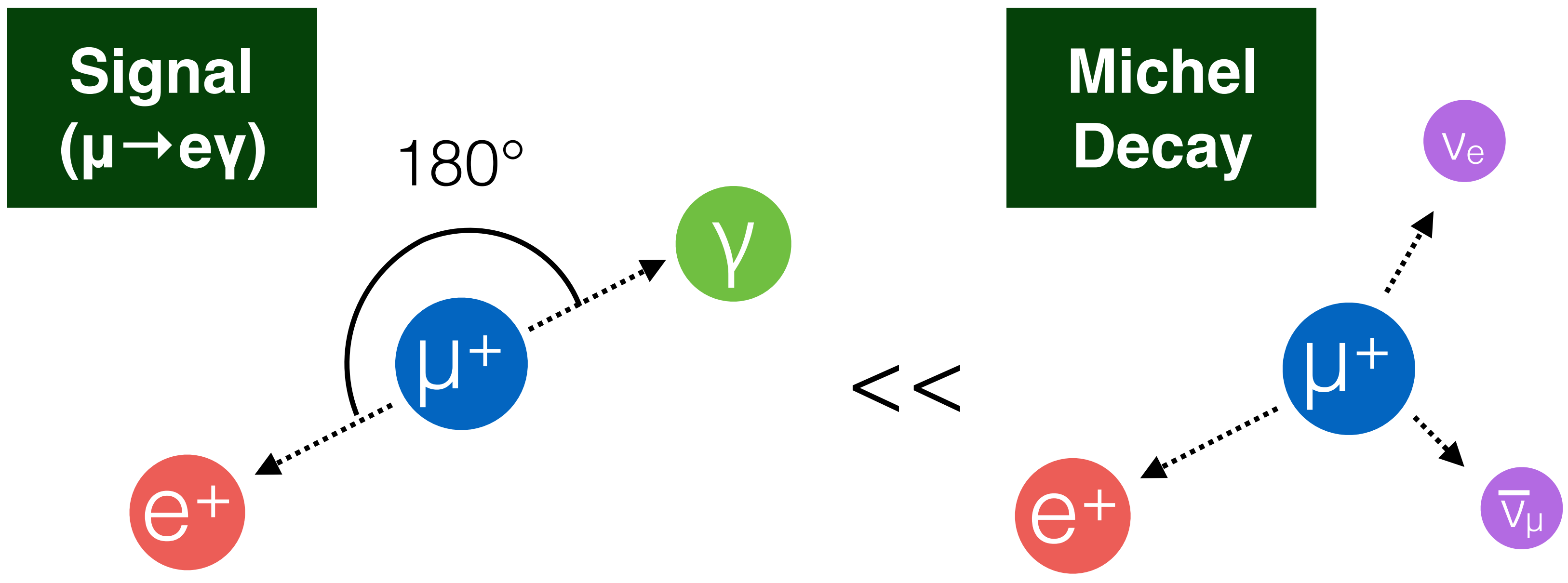
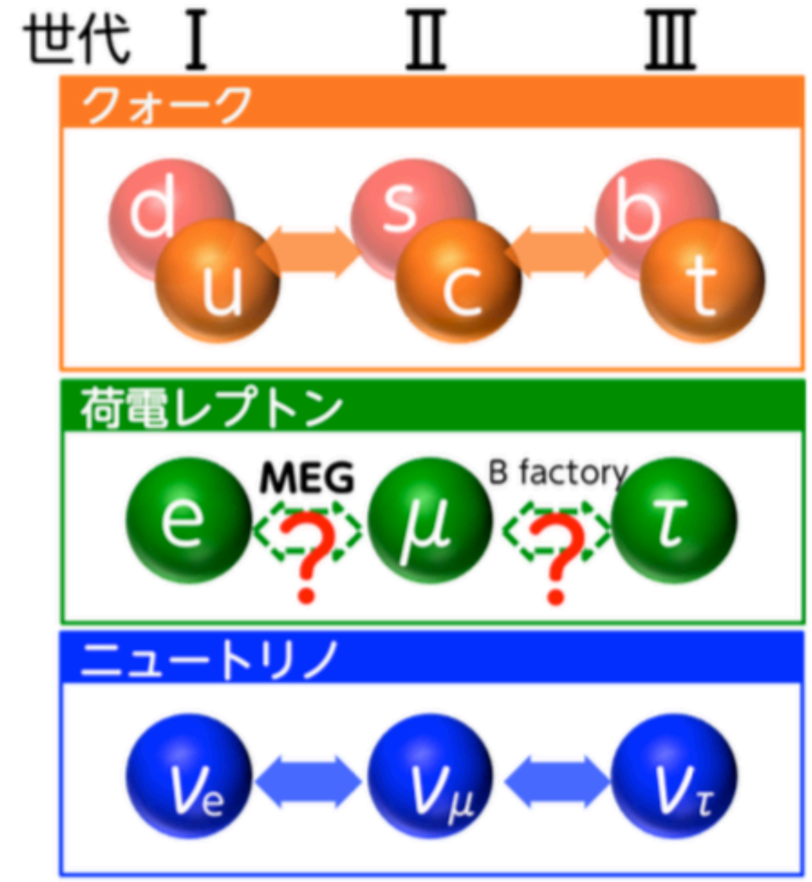
  - Reference position
- Summary

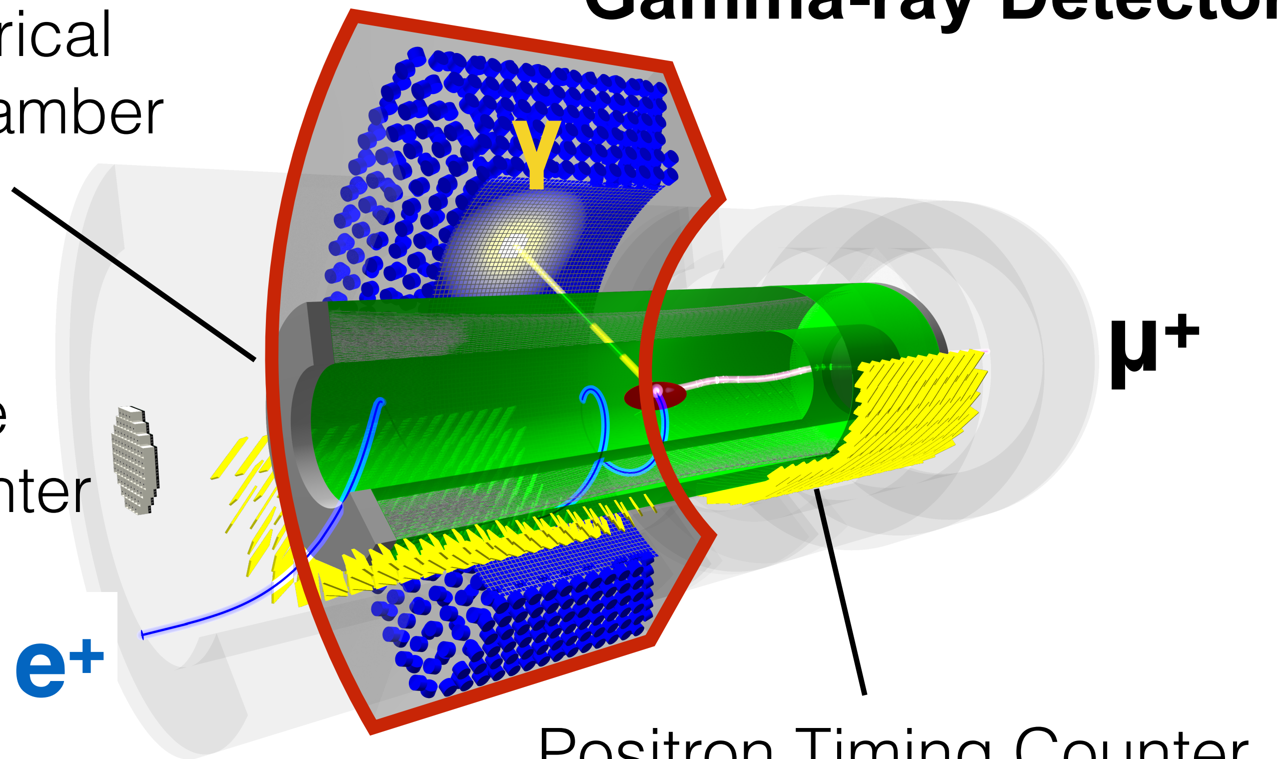
μ→eγ search





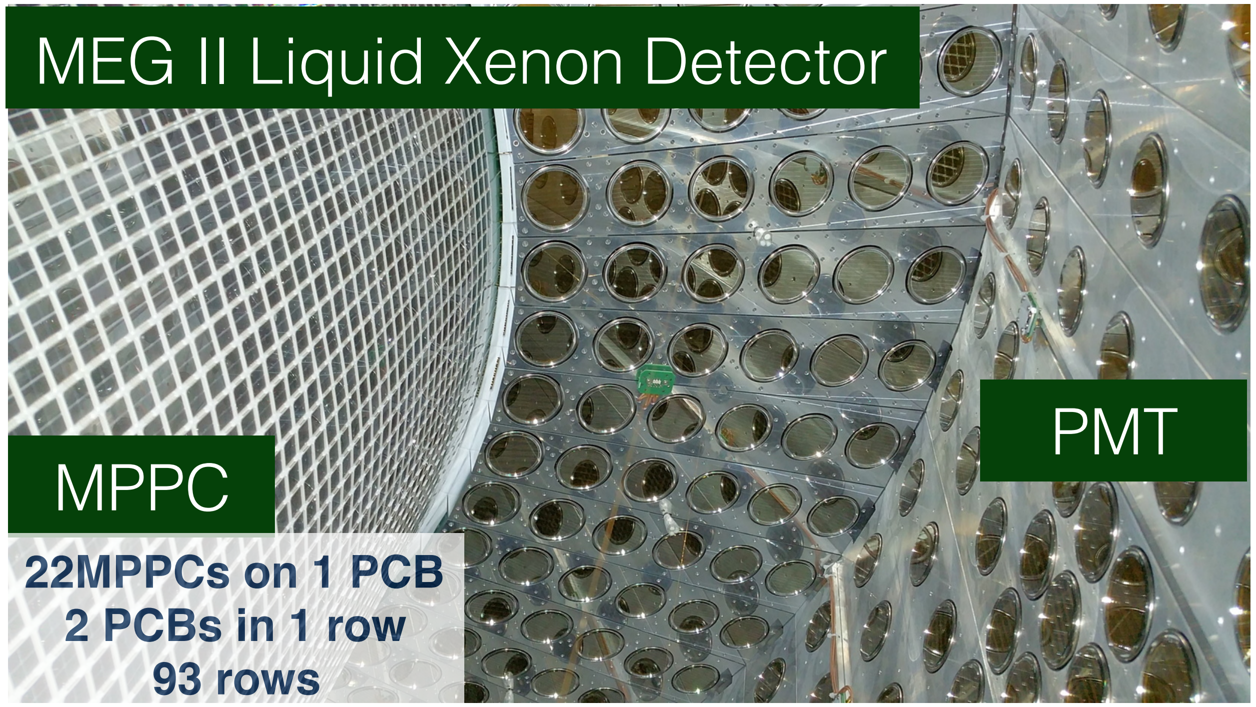
- Simultaneously emitted
- Back-to-back
- Same energy(52.8MeV)

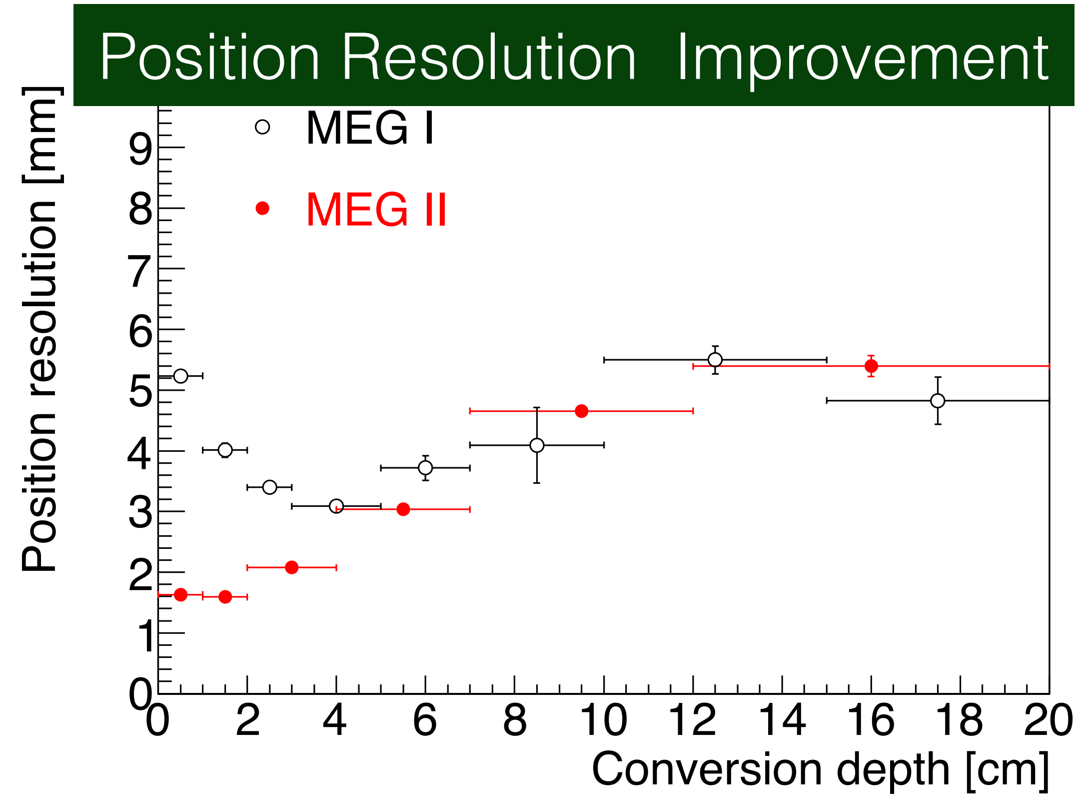
- μ→eγ decay is a lepton flavor violating decay.
  - **almost forbidden** in SM+ν. oscillation(Br(μ→eγ)<10^{-54})
  - **predicted** in some theories(Br(μ→eγ):10^{-11}~10^{-14})
- Current upper limit of Br(μ→eγ) is given by the MEG experiment
  - 4.2×10^{-13} (90% C.L.)



- MEG II experiment will search for the $\mu \rightarrow e\gamma$ decay with unprecedented sensitivity.
  - $Br(\mu \rightarrow e\gamma) \sim 6\times10^{-14}$ in 3 years
- Liquid Xenon gamma-ray detector measures position, energy and timing of the incident gamma-ray.

Liquid Xenon Detector Upgrade



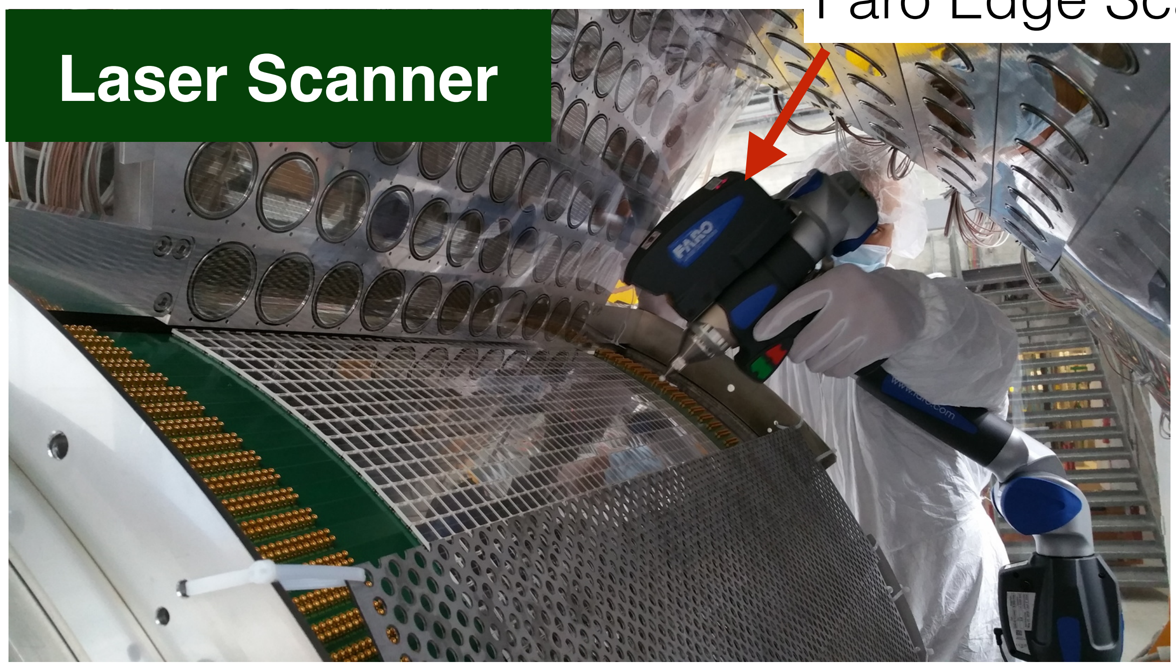


- We have replaced 216 2-inch PMTs on the γ-entrance face with 4092 12*12 mm^2 VUV-MPPCs.
  - High granularity & uniform readout
    - Better position(~2mm) & energy resolution(~1%)
  - Less material of the entrance face
    - Better detection efficiency
- There are many requirements for the alignment of the MPPCs.
  - Better precision than the detector's resolution(~2mm)
  - The position should be described in the shared coordinate of the MEG II.
  - Thermal contraction(O(1mm)) is not negligible.

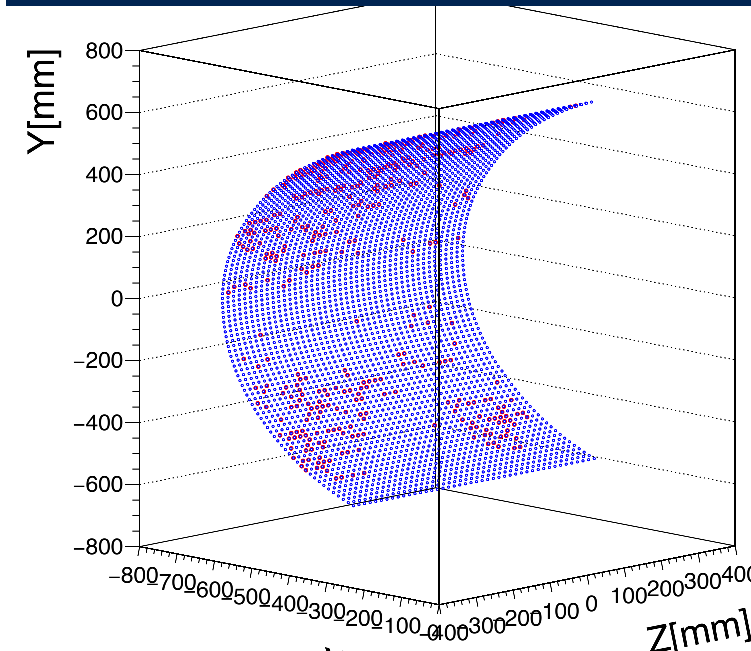
Alignment @ room temperature

Laser Scanner

Faro Edge ScanArm



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



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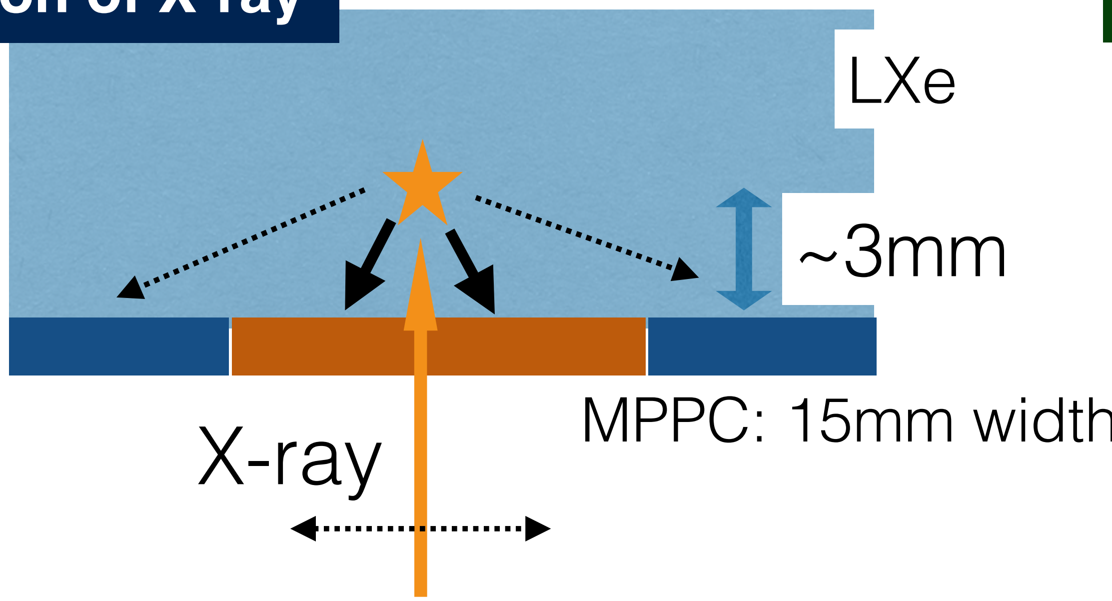
中尾@日本物理学会2017年春季大会

- The 3D position of MPPCs at room temperature was measured with laser scanner.
- The global shape of the MPPC array is reconstructed.
- The position of MPPCs can be changed due to thermal contraction, weight of LXe, etc…

Direct measurement of the position of MPPCs at LXe temperature

X-ray Measurement - Principle

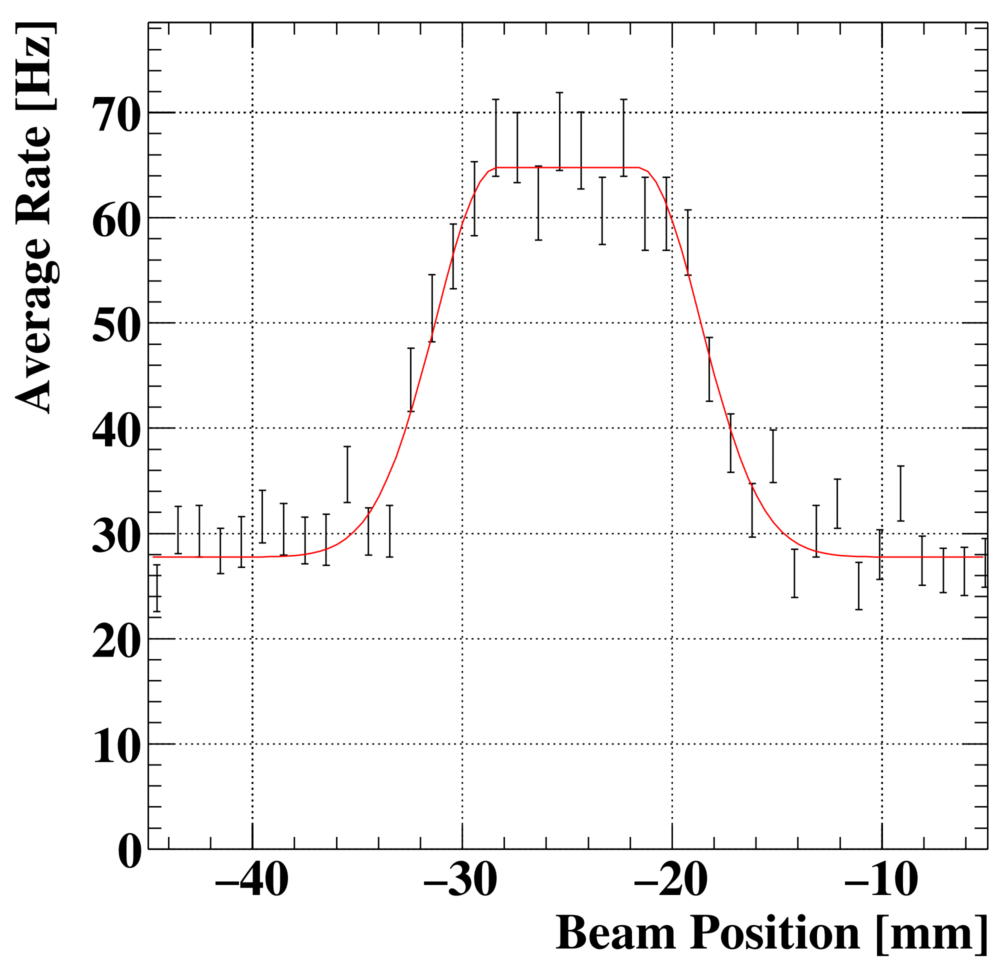
Interaction of X-ray



Properties of X-ray Beam

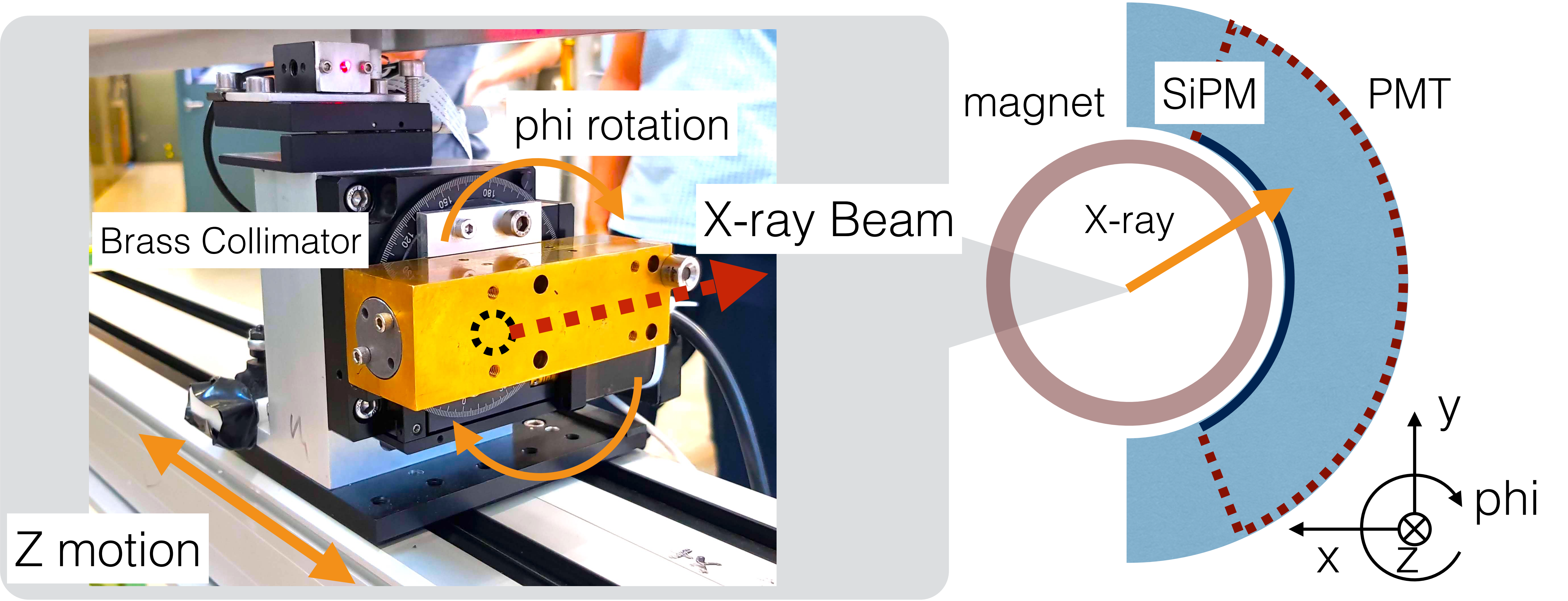
Source	^{57}Co
Activity	3GBq(2017) 1.2GBq(2018)
Beam Size	$1.5 \times 40 mm^2$
Energy	124keV(85%) 136keV(15%)

Signal in 2017



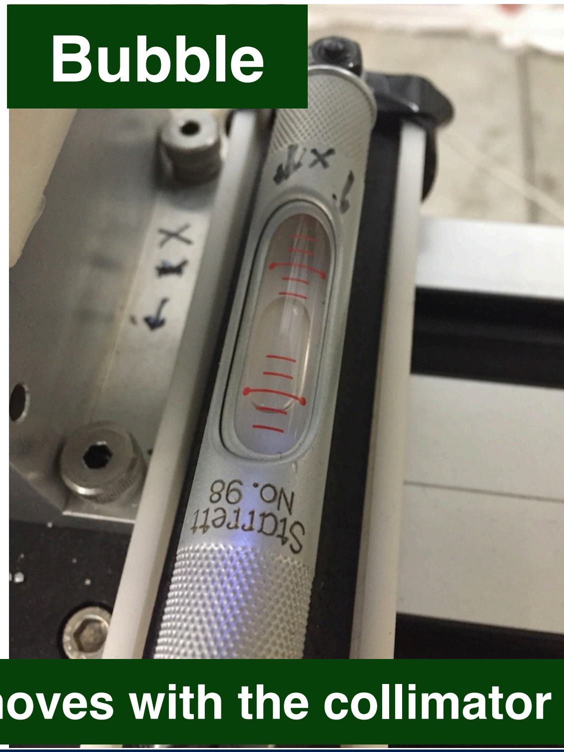
- An X-ray beam functions as a local light source in LXe.
- Requirements
  - Alignment of the beam
  - Vertical Incidence to LXe

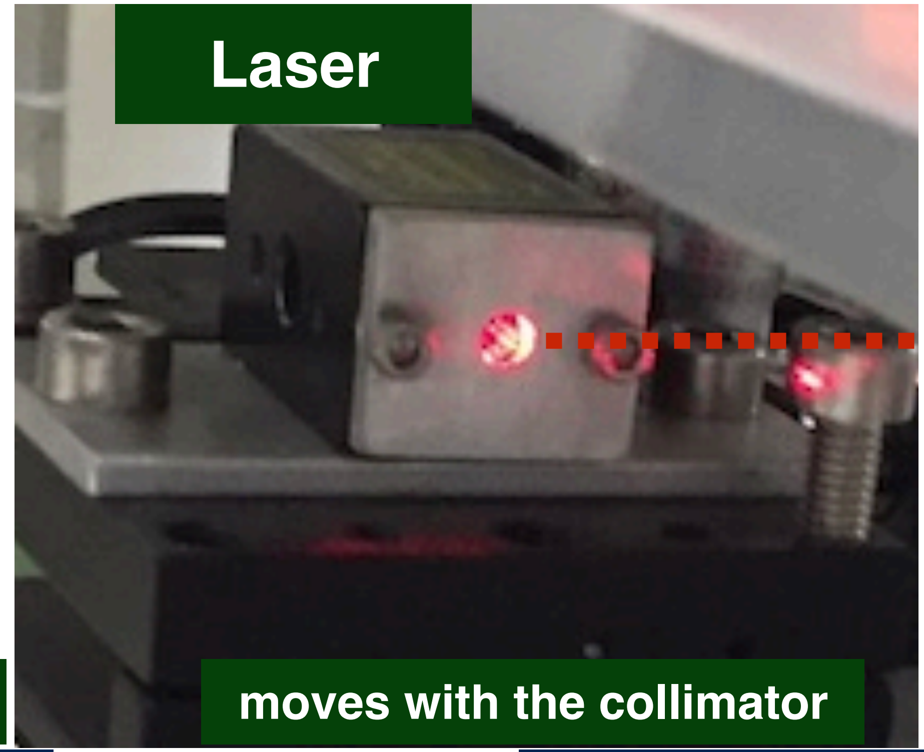
X-ray Measurement - Device

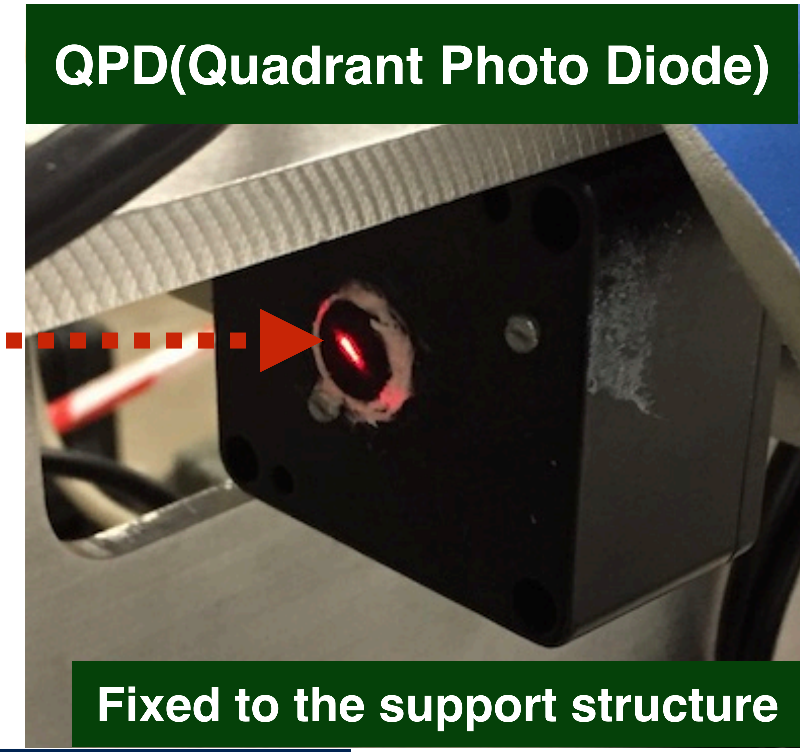


- moves in z.
- rotates in phi direction.

X-ray Measurement - Alignment





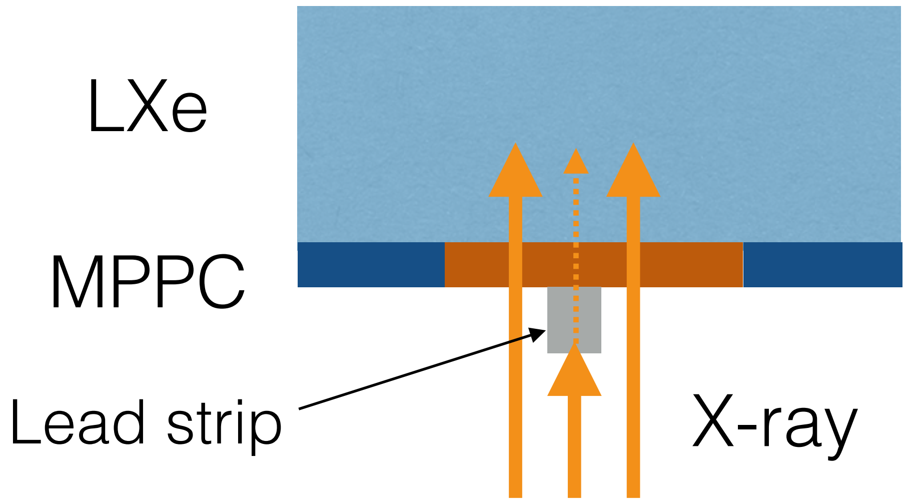


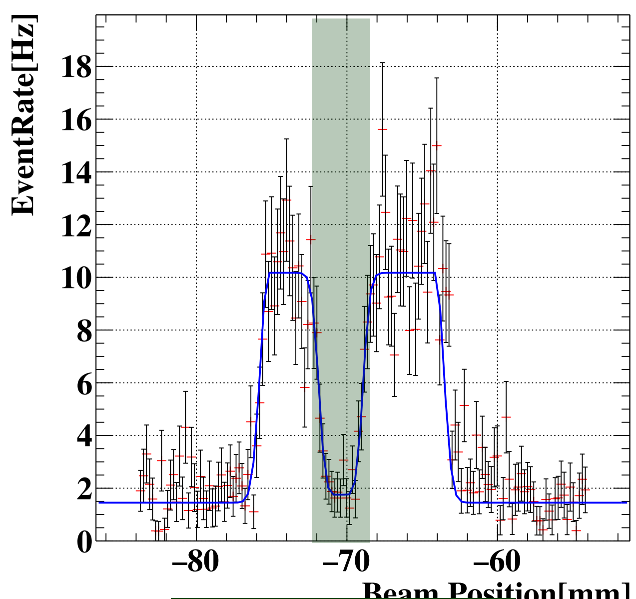
Rotation about Z axis

Rotation about X, Y axis

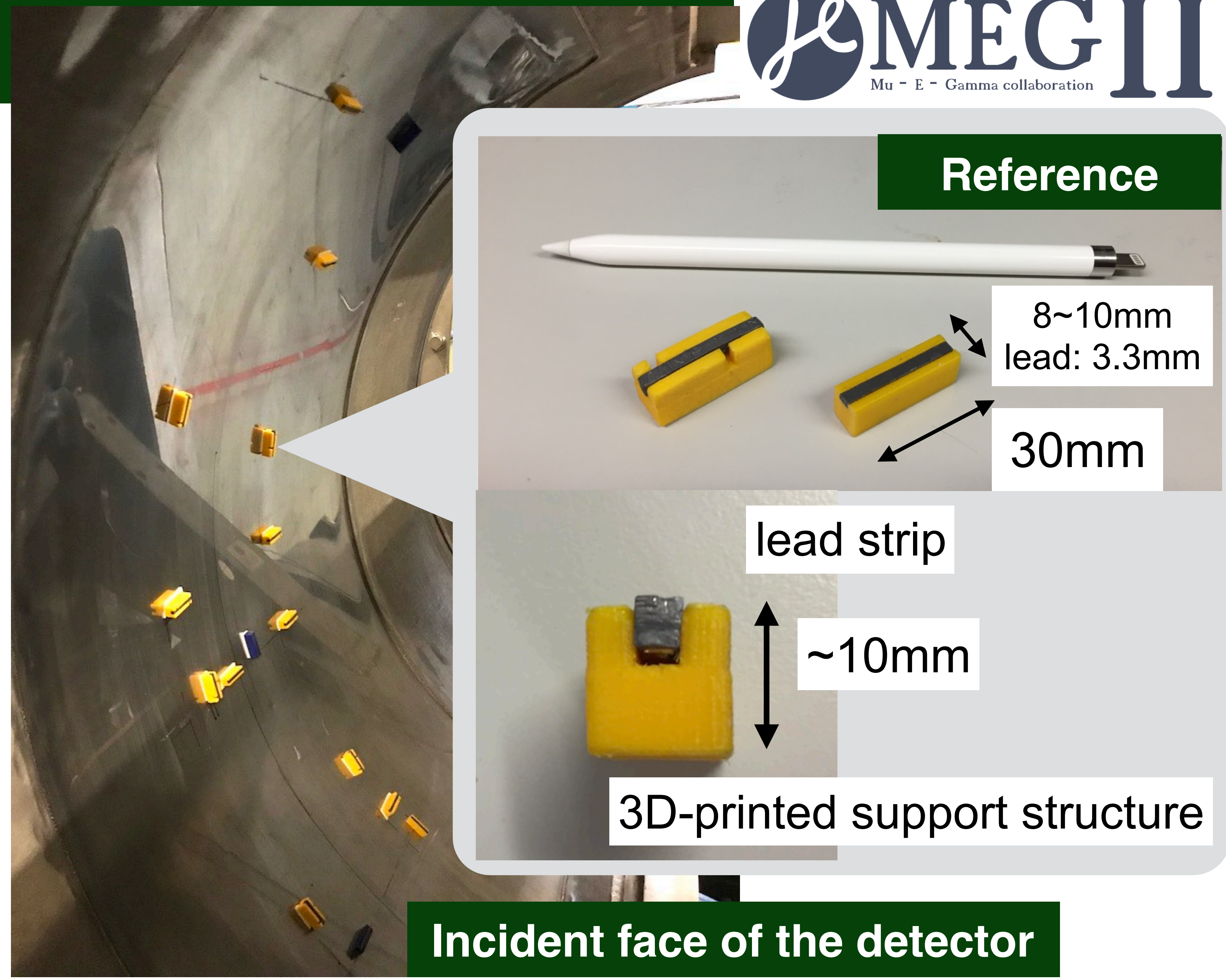
- The beam position should be more accurate than a few 100μm.
- The global position of the collimator is measured by laser tracker when it is set to Z=0mm, phi=0deg (zero position).
- The 3D rotation is monitored by QPD and bubble.
- The precision of the alignment of the beam position was estimated to be 30μm in z and 80μm in phi last year.

Reference





X-ray Signal



Incident face of the detector

- Several lead strips are mounted on the incident face of the detector as references.
  - Measurable from outside by laser tracker.
  - Visible with the X-ray beam

2017 X-ray Measurement

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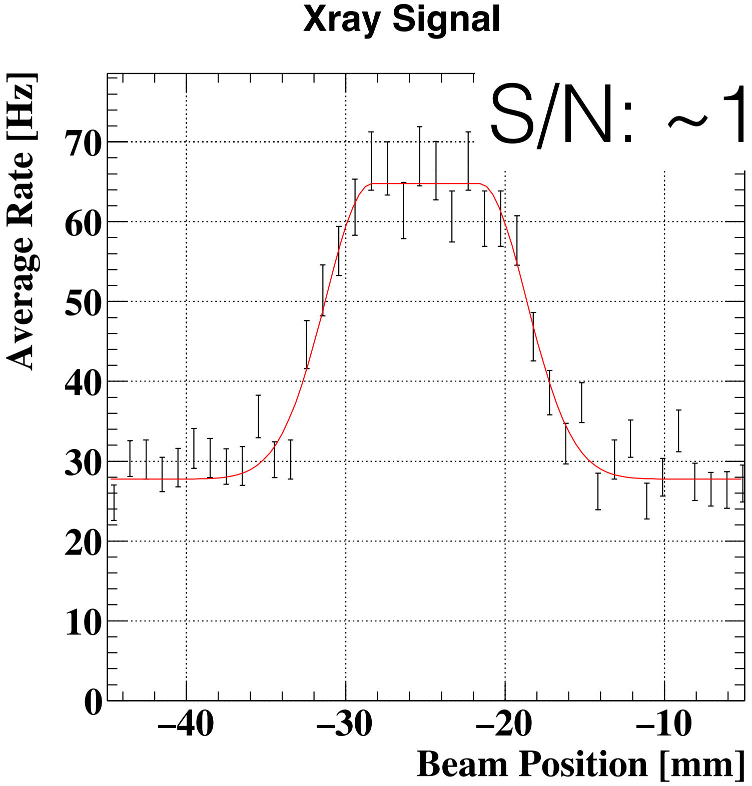
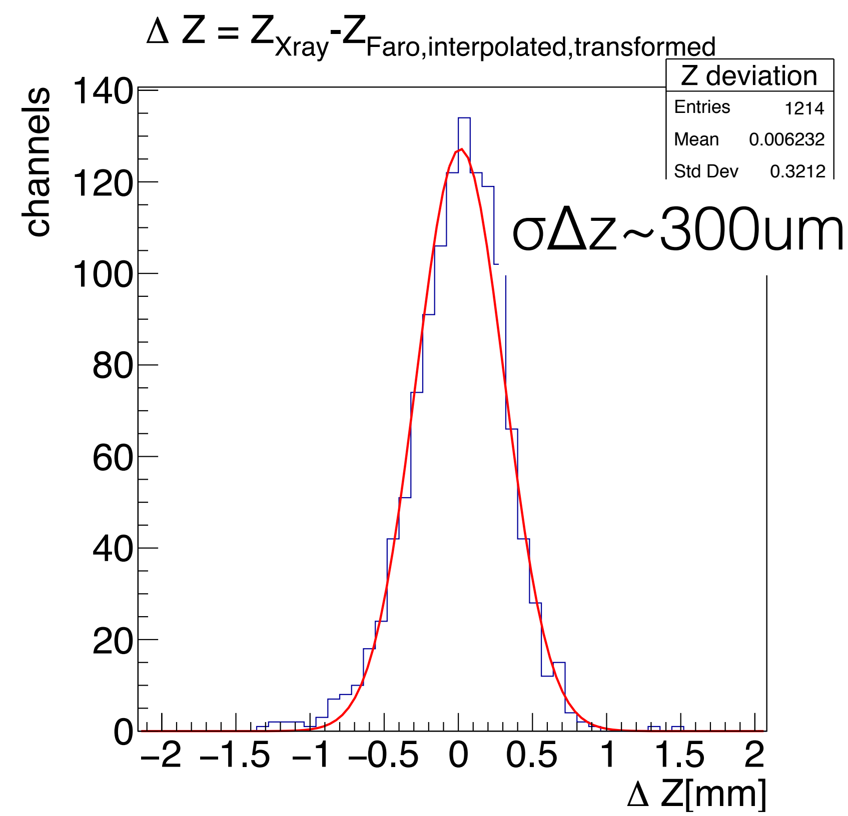
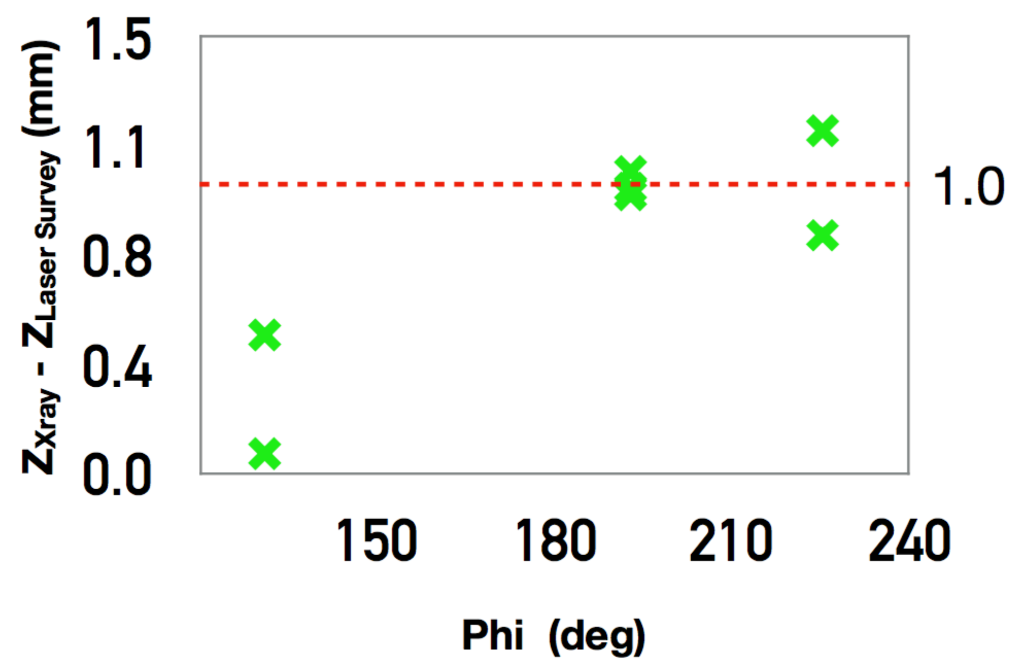
X-ray Signal



Consistency of global shape



Inconsistency of reference position

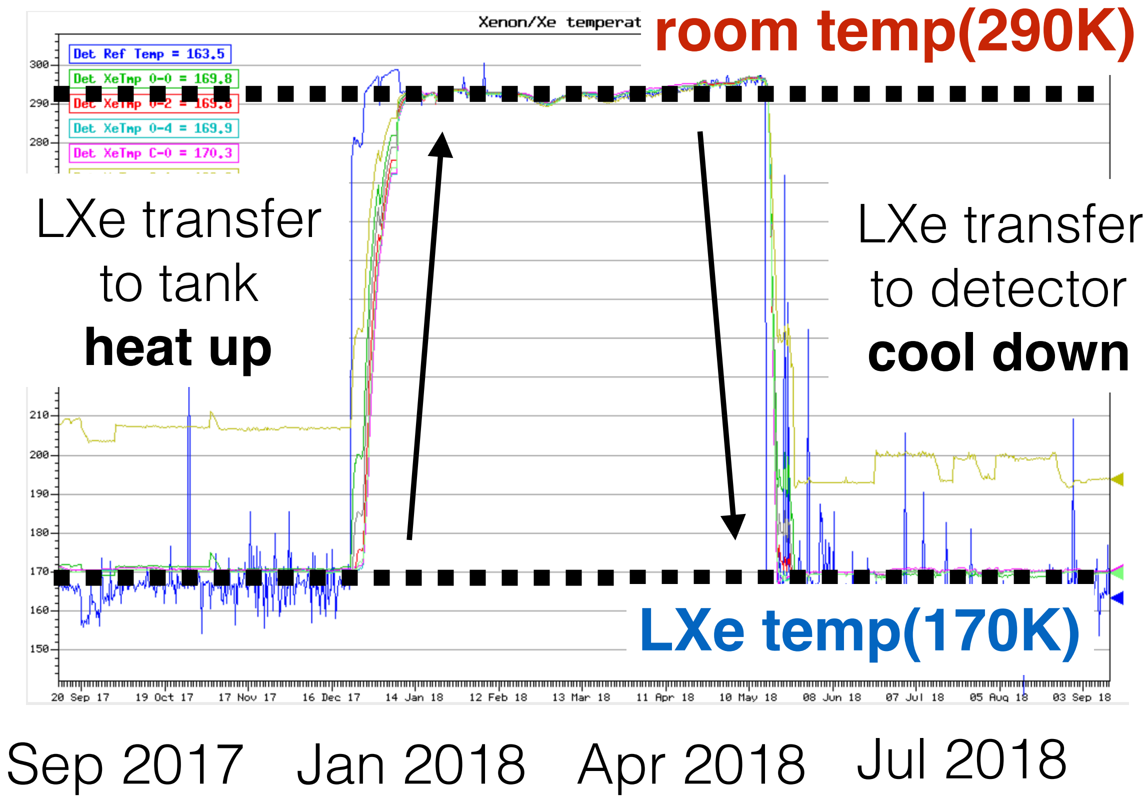


- X-ray signal was observed with the trigger rate with a low threshold.
- **The relative position of MPPCs was consistent** between the position at LXe temperature and that at room temperature.
  - Reasonable shrinking effect is considered.
- However, **the laser survey and X-ray survey indicated different position** of references.

2018 X-ray Measurement

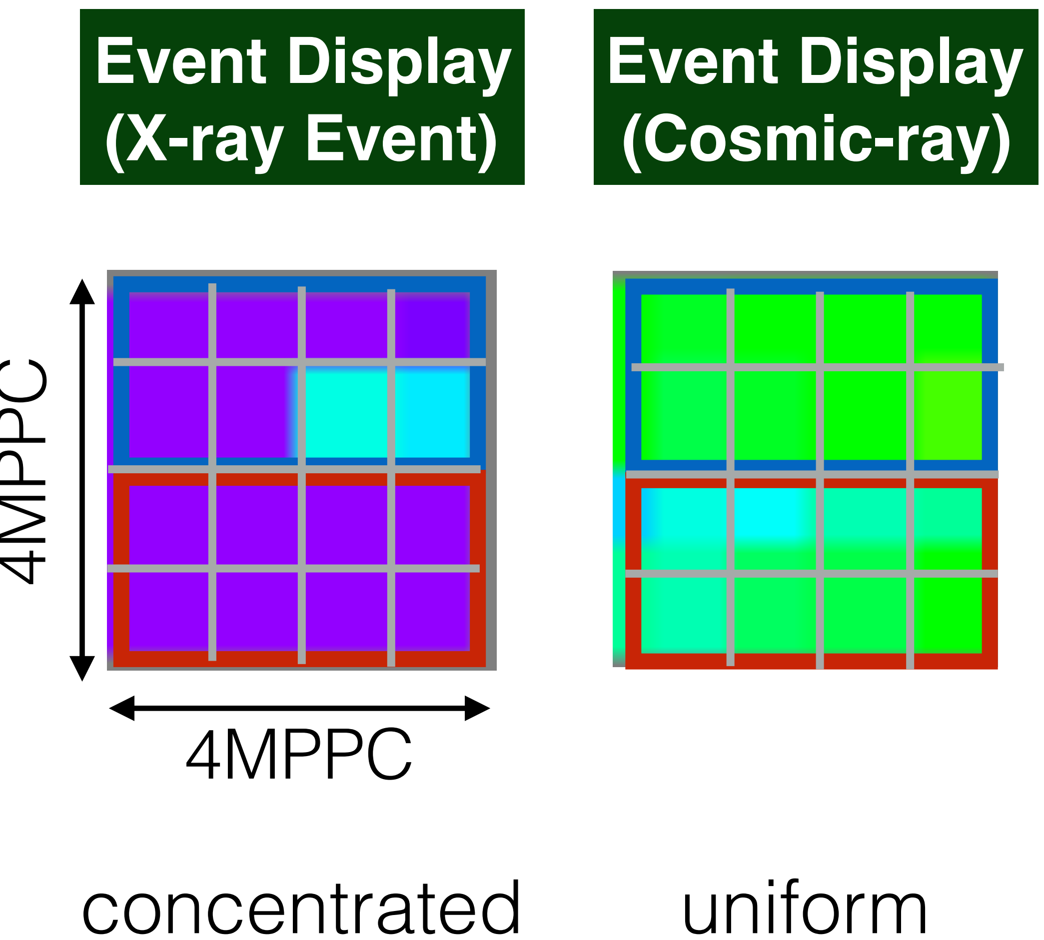
	2017	2018
Alignment of Device with laser tracker	Only once	Frequent (3 times)
# of references	6	16
Source Activity (half life: 270d)	3GBq	1.2GBq

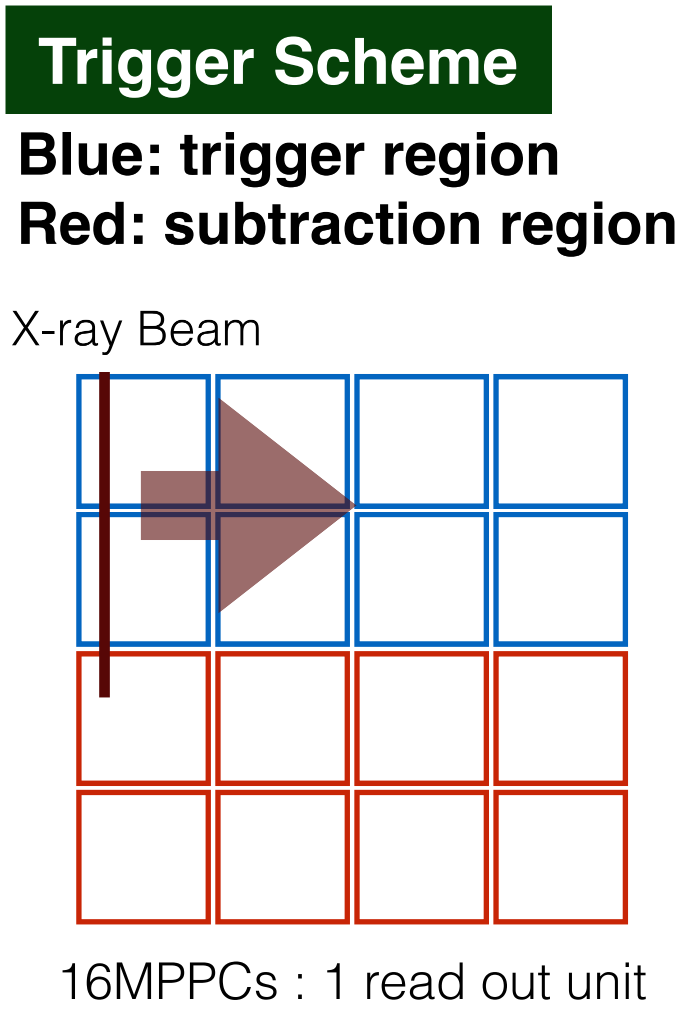
Temperature History

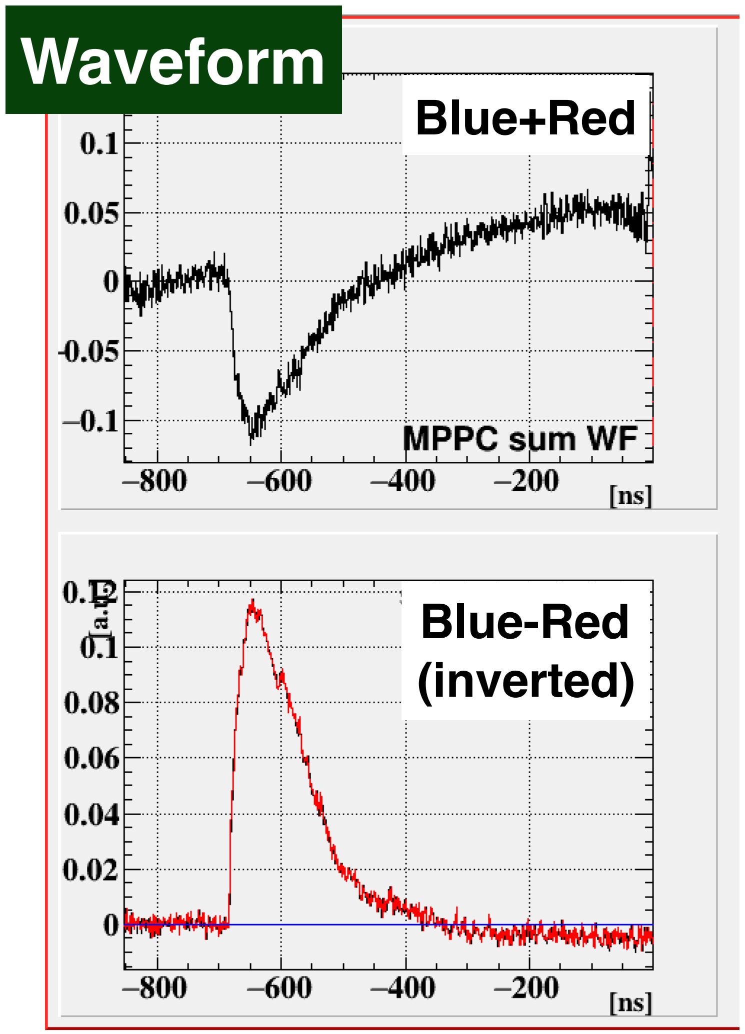


- Motivation
  - Reproduce & Find the cause of the discrepancy seen in 2017.
  - Measure the position of MPPCs in the shared coordinate.
  - See the reproducibility after the first thermal cycle.
- The question is how to realize a comparable resolution with the reduced activity of the X-ray source.

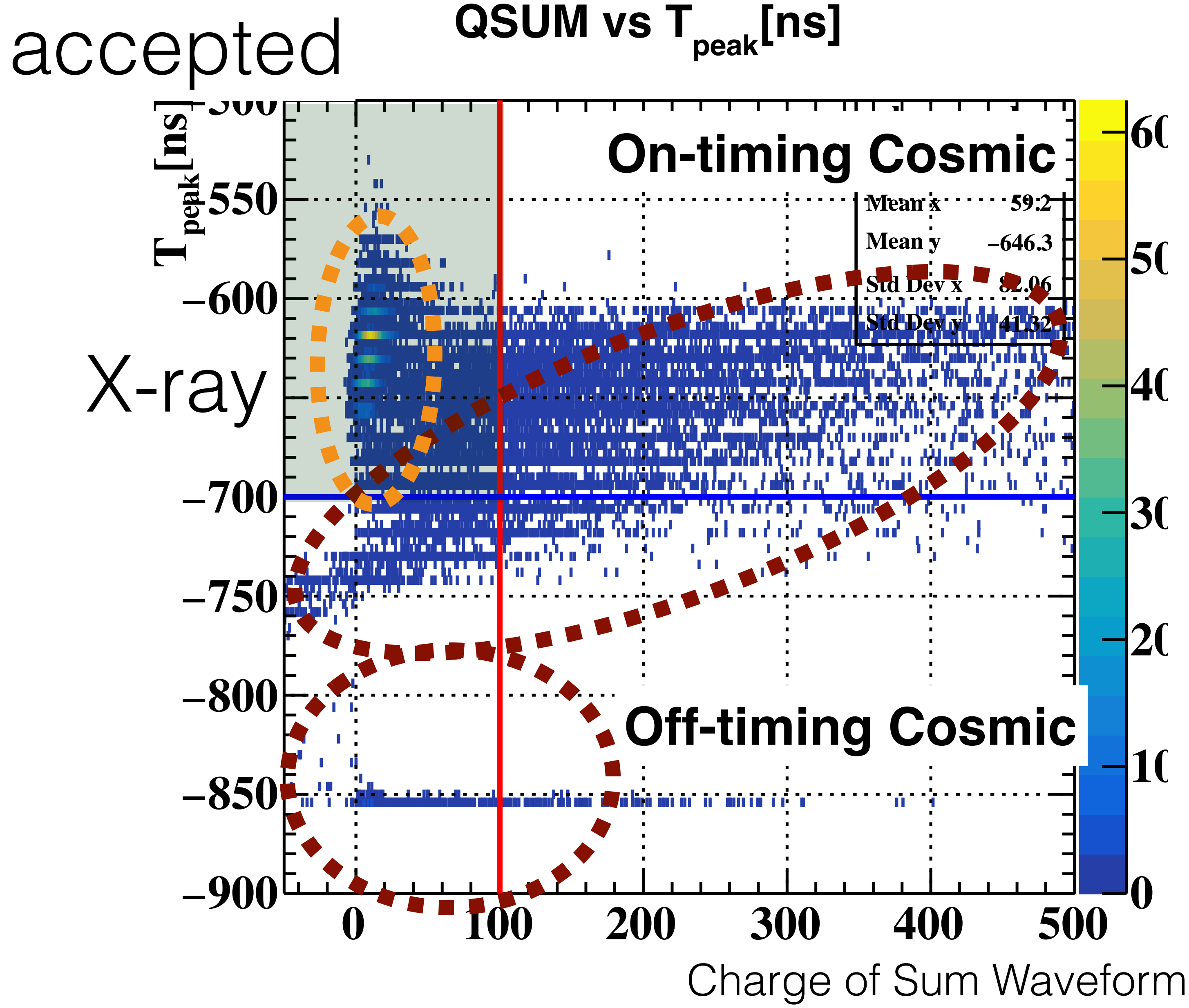
Trigger for X-ray Event

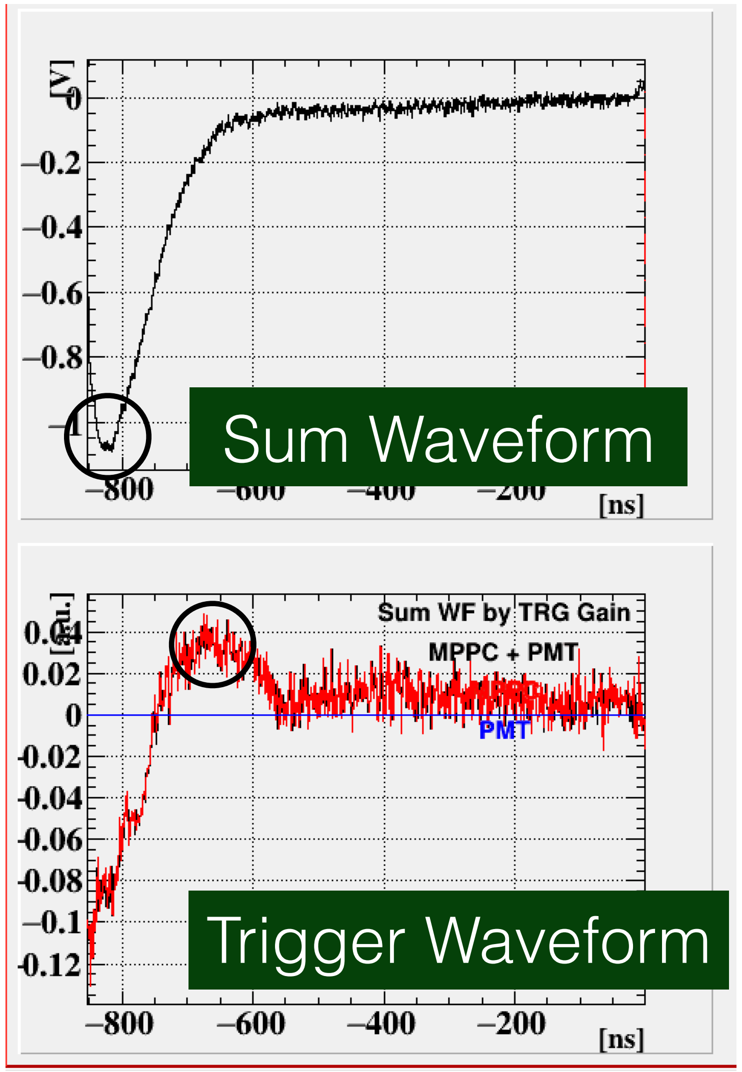






- Coherent noise on electronics and cosmic-ray can be triggered with a low threshold to trigger X-ray events.
- To trigger X-ray events efficiently, a differential trigger was used.
  - Coherent noise over a read out unit was subtracted.
  - A part of cosmic-ray events was also rejected.

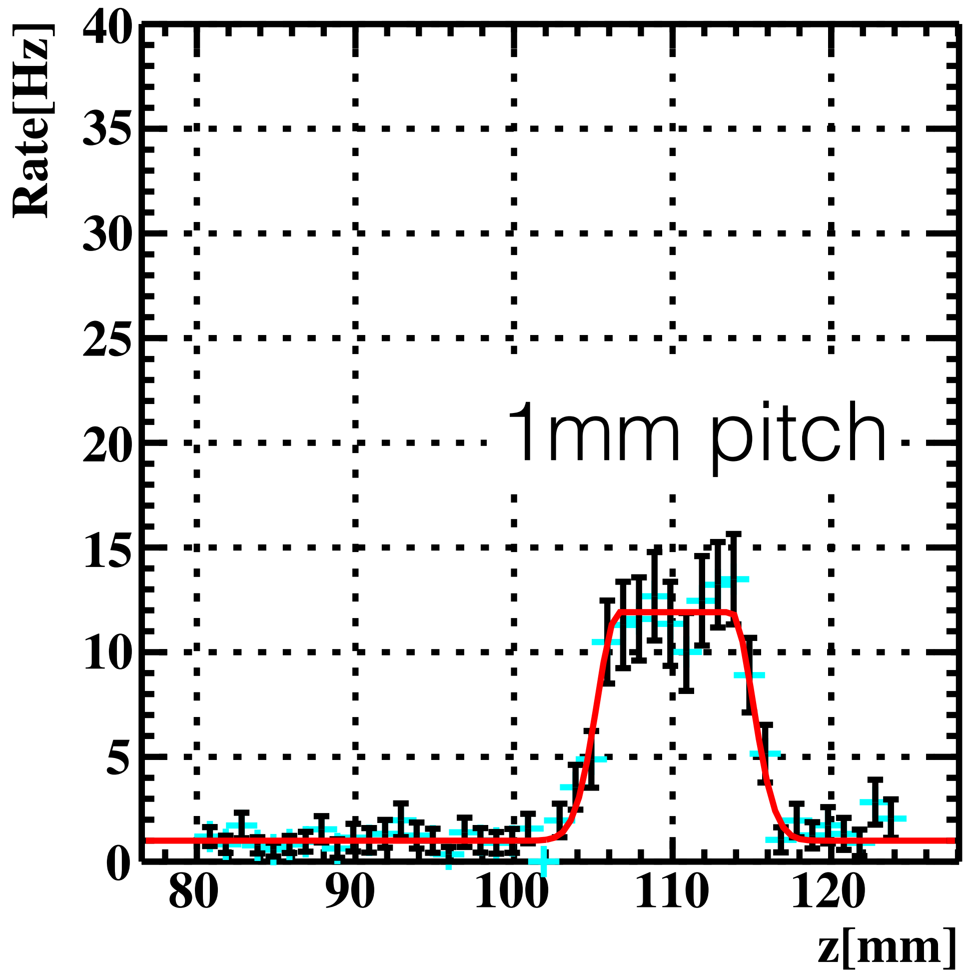




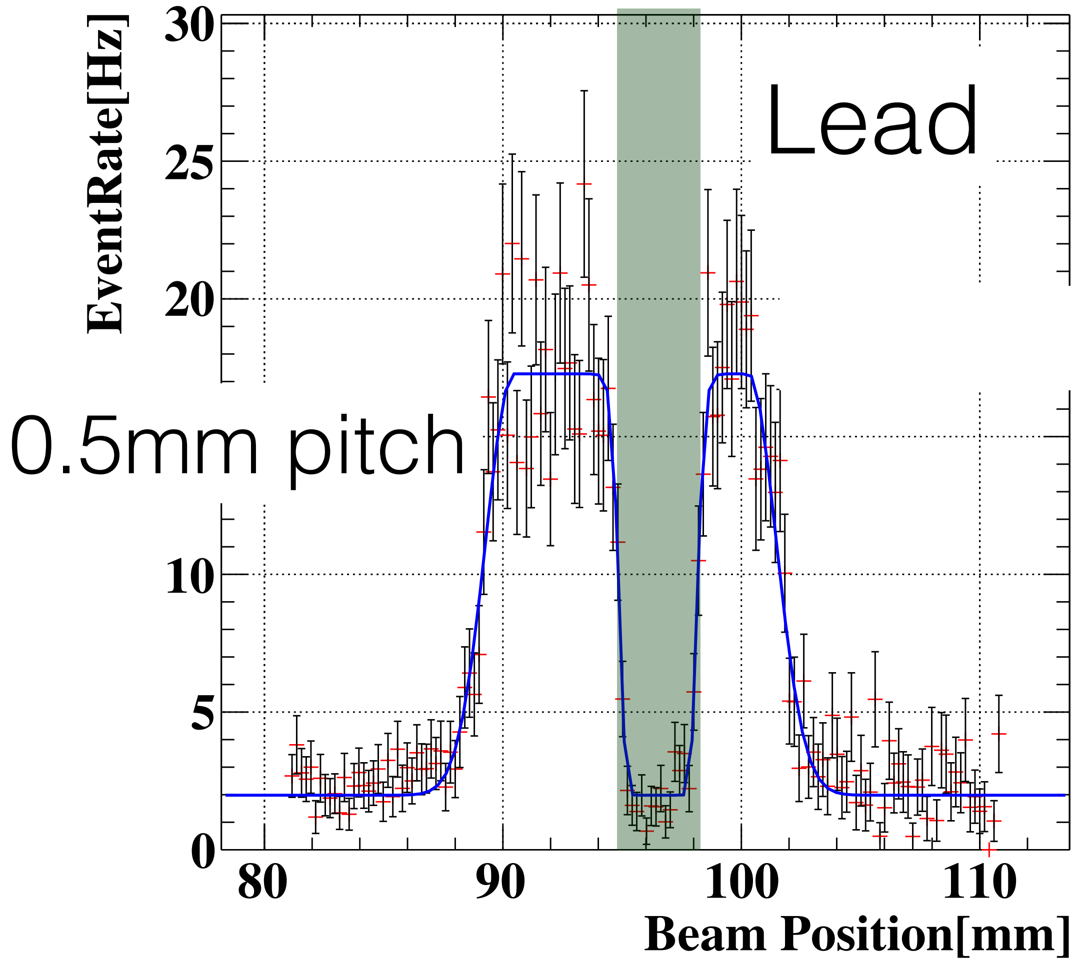
- We can distinguish X-ray events from cosmic-ray events on the basis of the timing and the amplitude of the sum waveform.
- The trigger worked successfully.
  - >60% of events are judged as X-ray events by subsequent offline analysis.

X-ray Signal & Position Reconstruction

MPPC



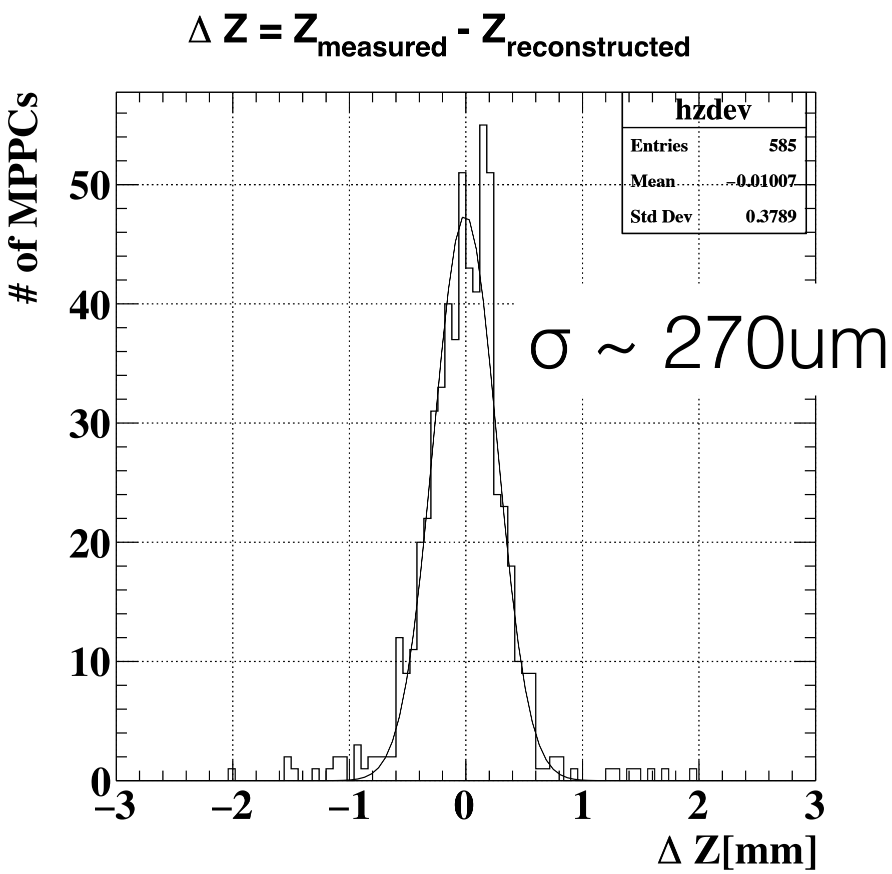
Reference



- S/N ratio dramatically improved(2017: ~1, 2018: >5)
- MPPC 's position is reconstructed as the mean of a symmetric fit function.
  - Flat line + two gaussians.
- The position of references is reconstructed as the center of symmetric absorption.

Result - MPPC Scan

preliminary

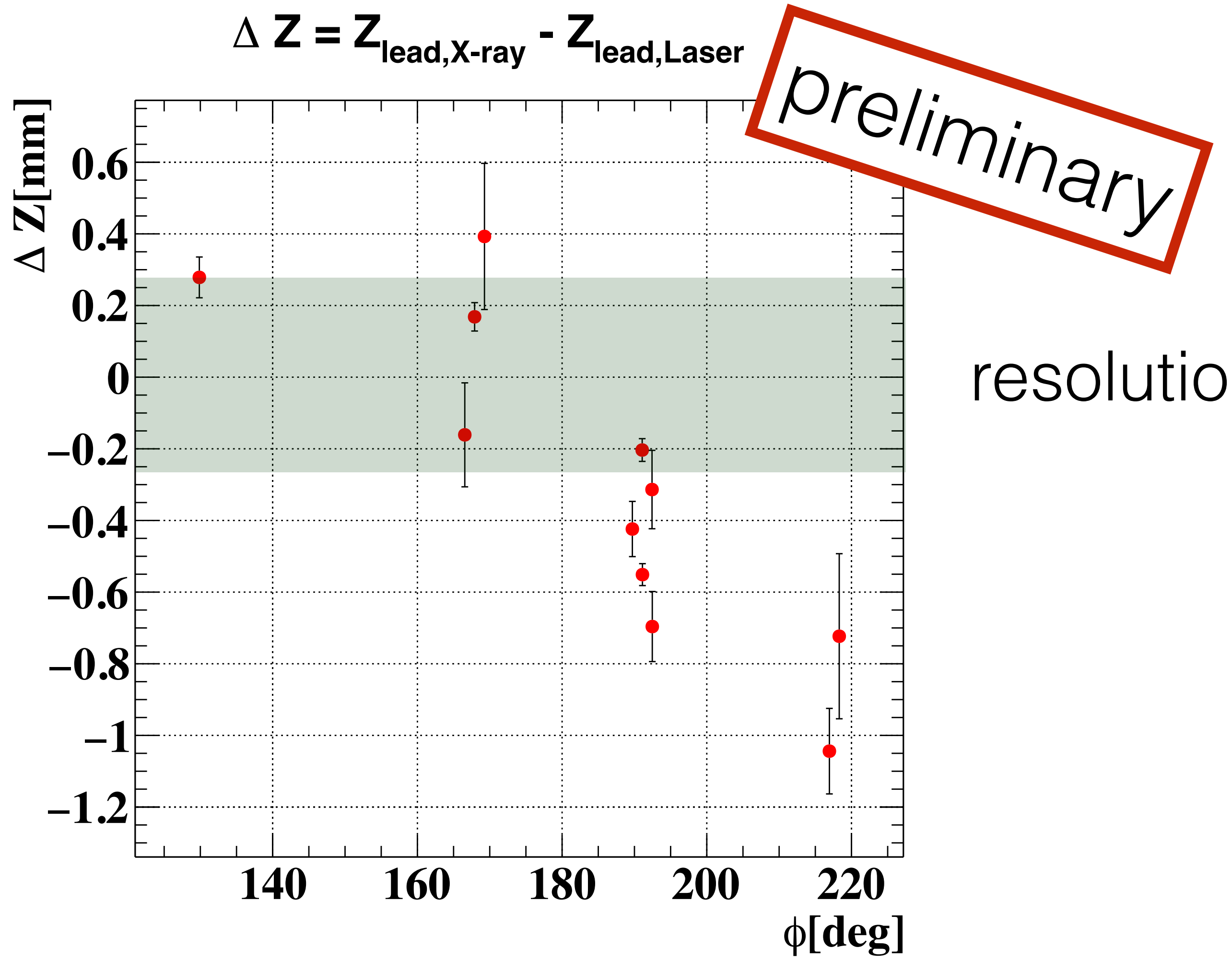


	Thermal Expansion Coefficient [ppm/deg]	# of measured MPPCs
Expected	16~17	-
2017	15.9±2.5	1214
2018	12.5±2.5	824

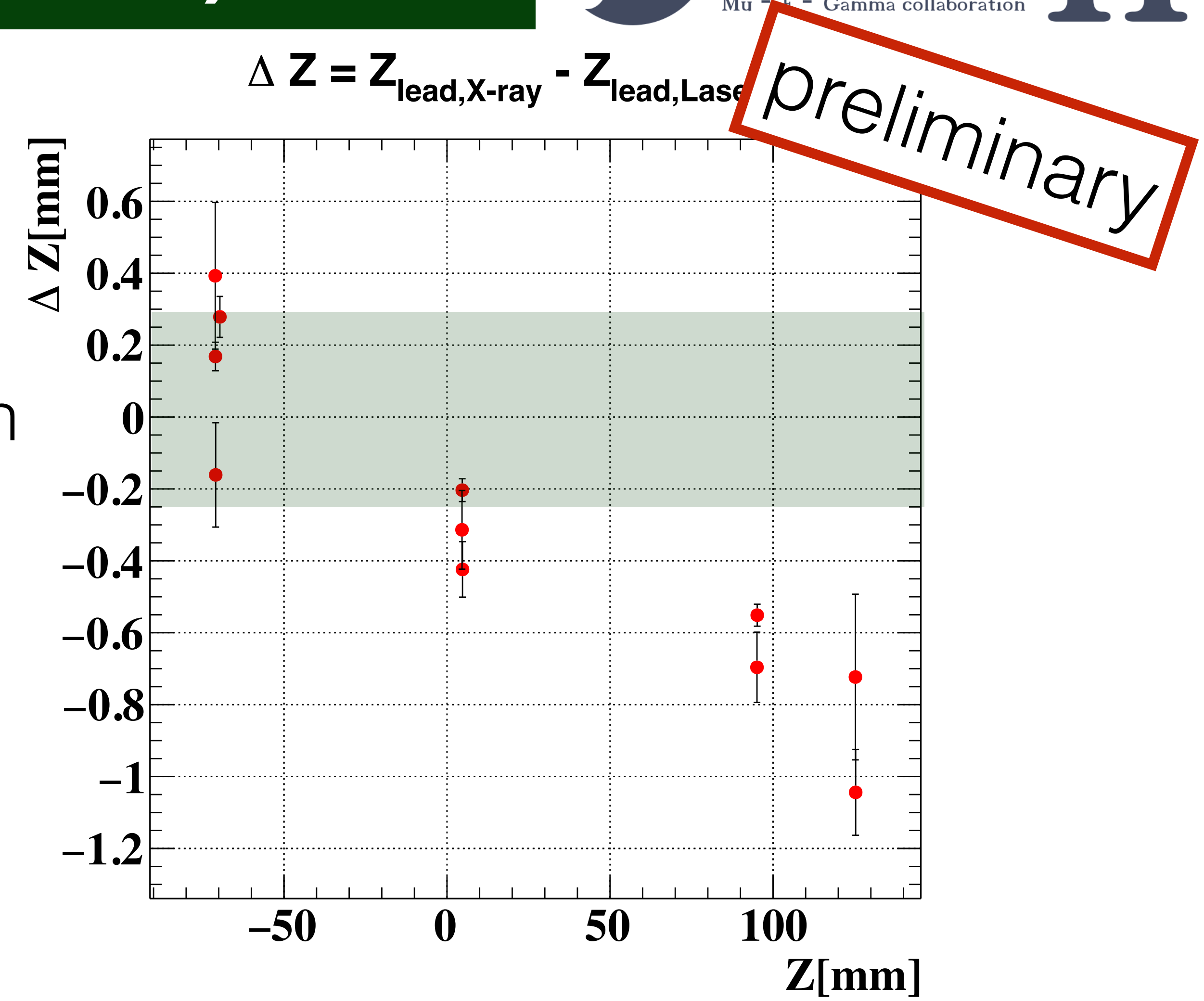
※$\underbrace{1\mathrm{m}}_{\text{Detector size: top-bottom}} \times \underbrace{100\mathrm{K}}_{T_{room}-T_{LXe}} \times 1\mathrm{ppm} \cdot \mathrm{K}^{-1} = 100\mu\mathrm{m}$

- The X-ray's result was consistent with the position measured at room temperature.
  - Precision: 270μm in both Z and phi (2017: 300μm)
  - The resolution of the measurement improved.
- The thermal expansion coefficient is estimated by comparison with the scale of the MPPC array at room temperature.
  - Consistent with last year.

Result - References (Z direction)

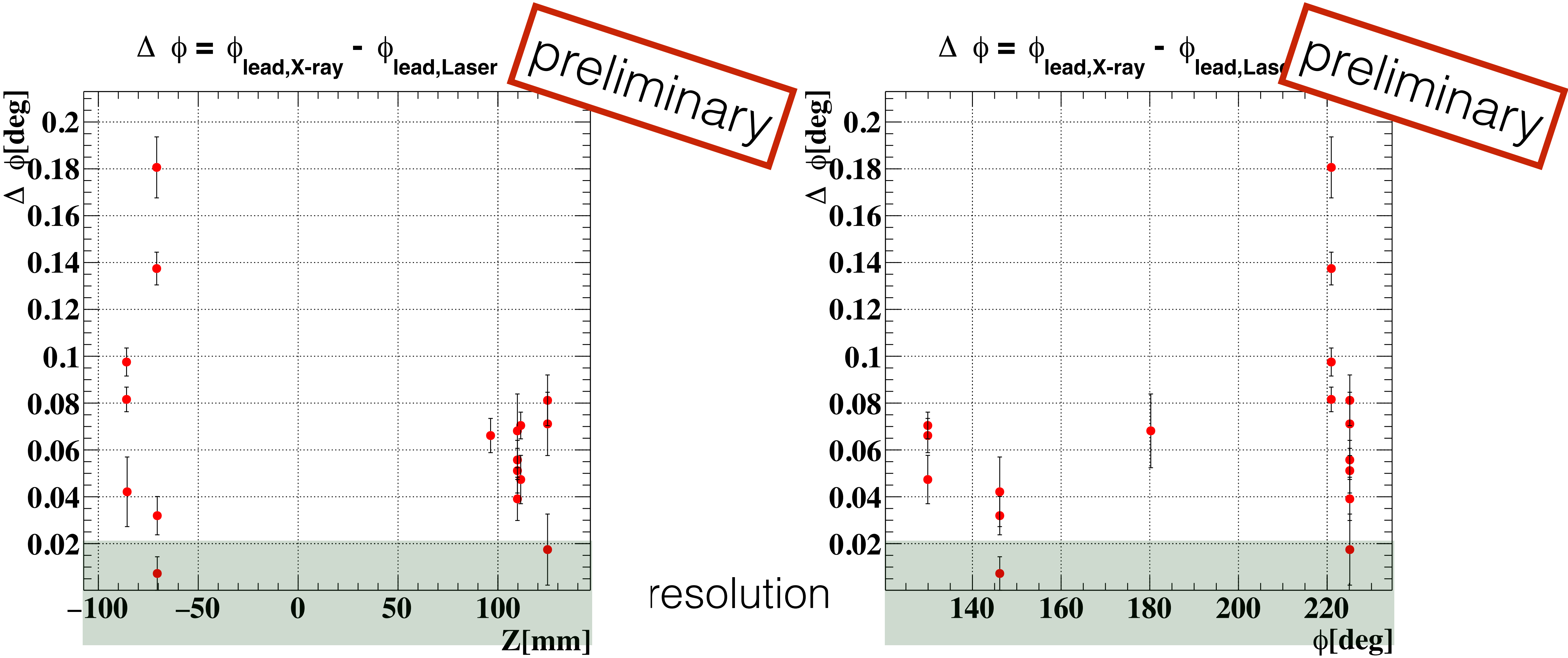


resolution



- Continuing from 2017, we observed a large Z deviation.
    - The amount of deviation is comparable with 2017.
- Z deviation looks depending both on z and phi.

Result - References (Phi direction)



- We found a large deviation in phi direction, which was not observed in 2017.
- The next step is to understand the mis-alignment on the basis of the systematic deviation.

Summary & Prospects

Summary

- We have developed a way to measure the position of MPPCs in the liquid xenon detector.
- Though the activity of Co source is fairly reduced by 60%, the position of MPPCs was measured with a comparable resolution as last year.
- **No significant deformation** due to the thermal cycle.
- There found a discrepancy between the position measured by the X-ray and that with the laser tracker.
  - Thanks to the increased number of references, the tendency of the deviation was found.

Prospects

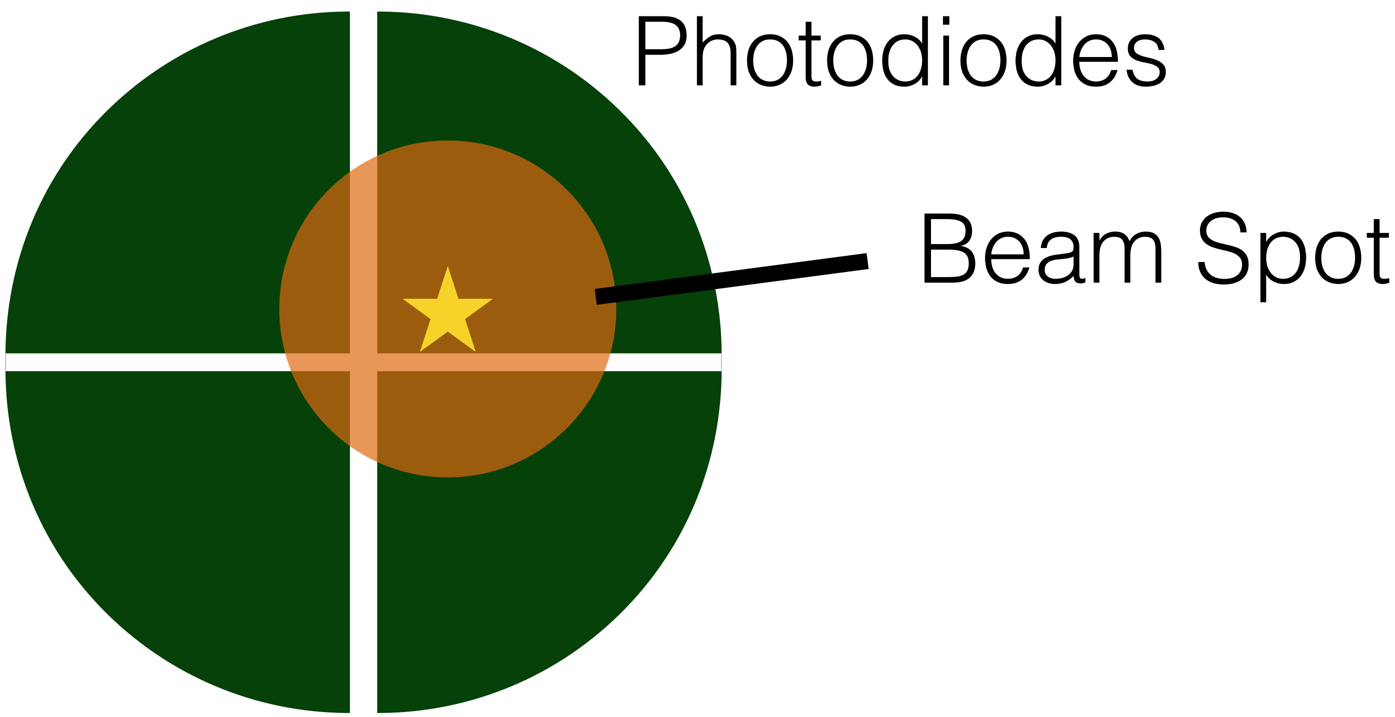
- Investigation of the mis-alignment of the X-ray device.

Back Up

Index of Backup

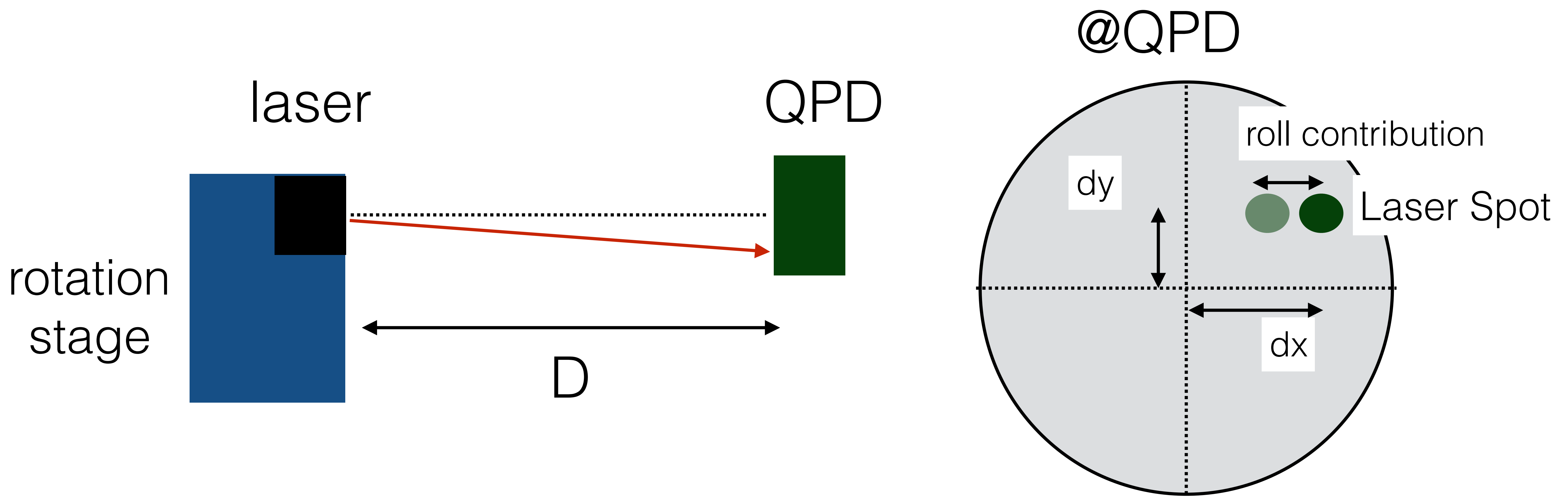
- Principle of QPD
- Monitoring of the rotation of the stage
- Principle & Measurement of Laser tracker
- Alignment at room temperature
  - Cylindrical reconstruction of the global shape
- Combination of the position at room temp. and at LXe temp.

Quadrant Photo Diode



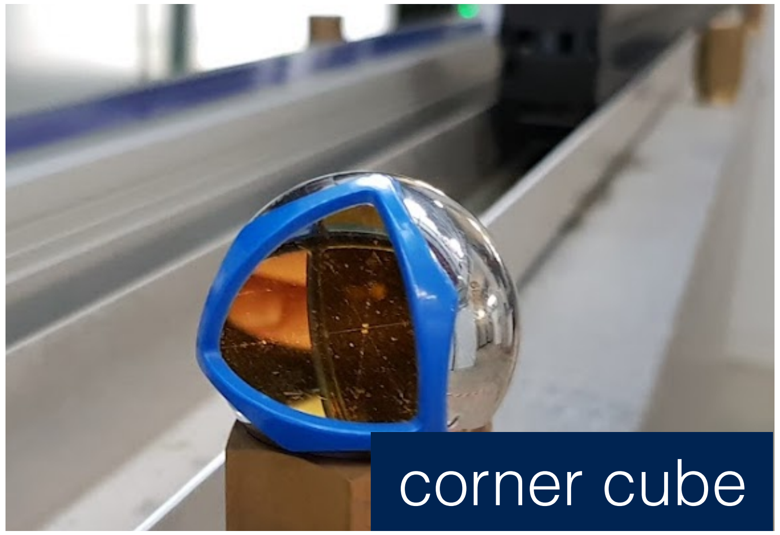
- Quadrant photo diode is composed of four photodiodes.
- From the laser intensity on each photodiode, we can reconstruct the hit position on the QPD.
- We can calculate the rotation of the beam direction from the hit position and the distance.

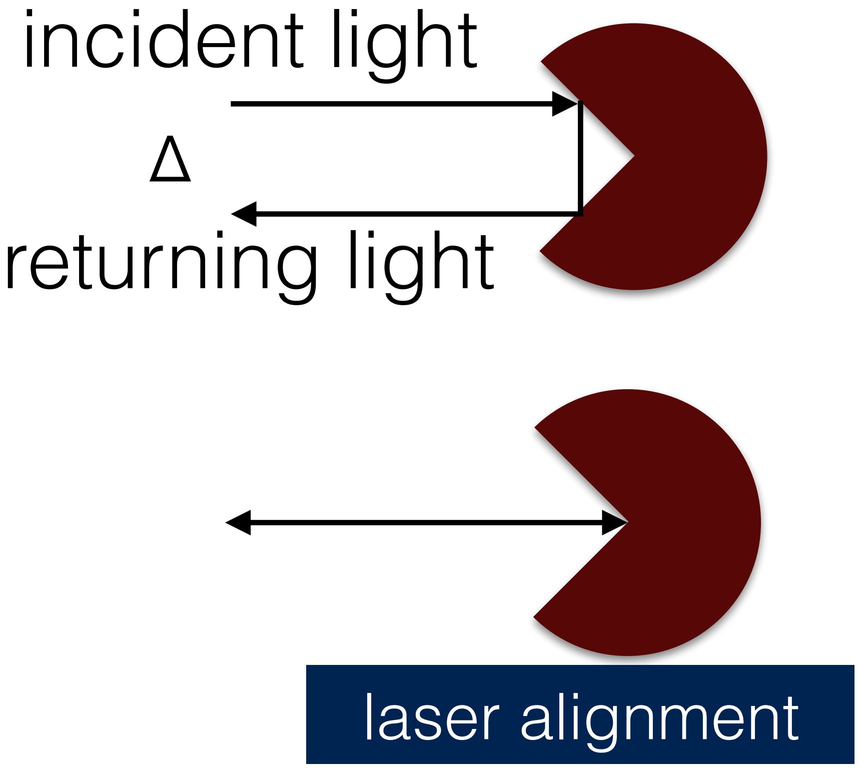
QPD Calibration



- Laser spot is monitored by QPD.
- The rotation about X(pitch), Y(yaw) is measured with the hit position of the laser and the flying distance.
- The rotation about Y axis is corrected by roll.

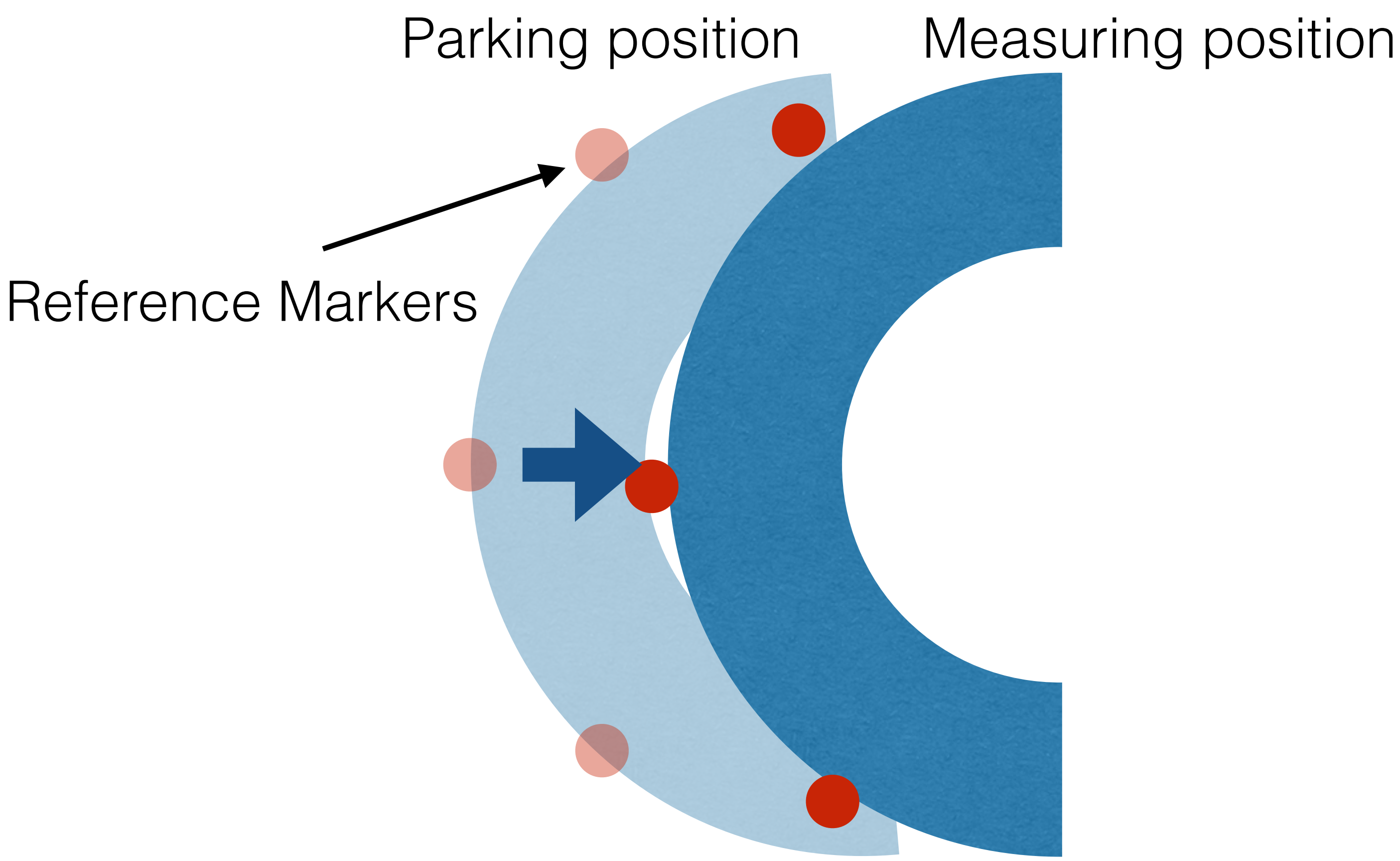
Principle of Laser Tracker





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

Lead strip position measurement



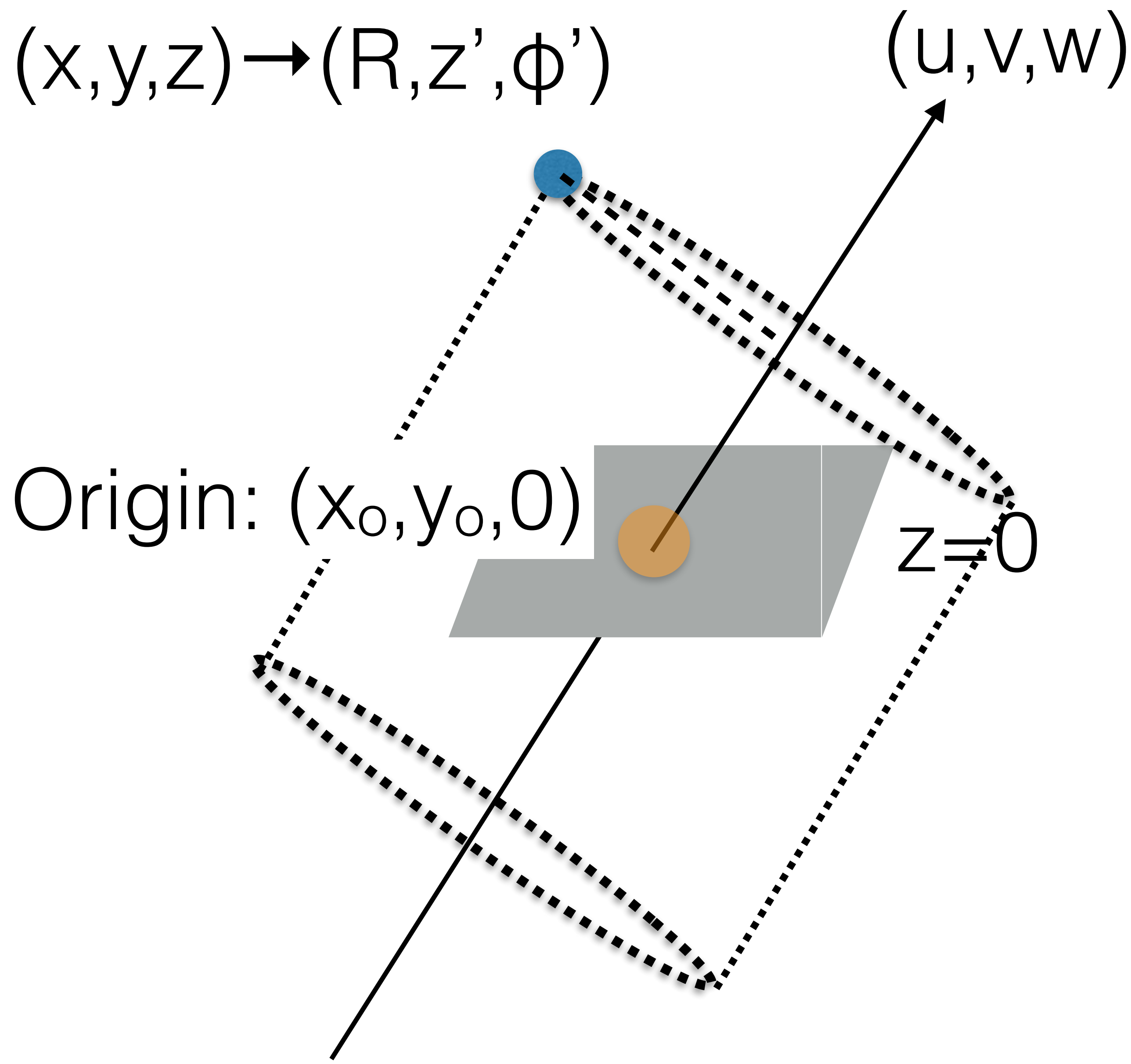
- The position of lead strips is surveyed.
  - The detector was in a retracted position.
  - T-probe was used to survey all faces of references.
- The position of reference markers on the detector is measured at each step.
  - retracted & measuring position of the detector.
  - used to calculate the position of lead strips in a measuring position of the detector.

Interpolation Strategy

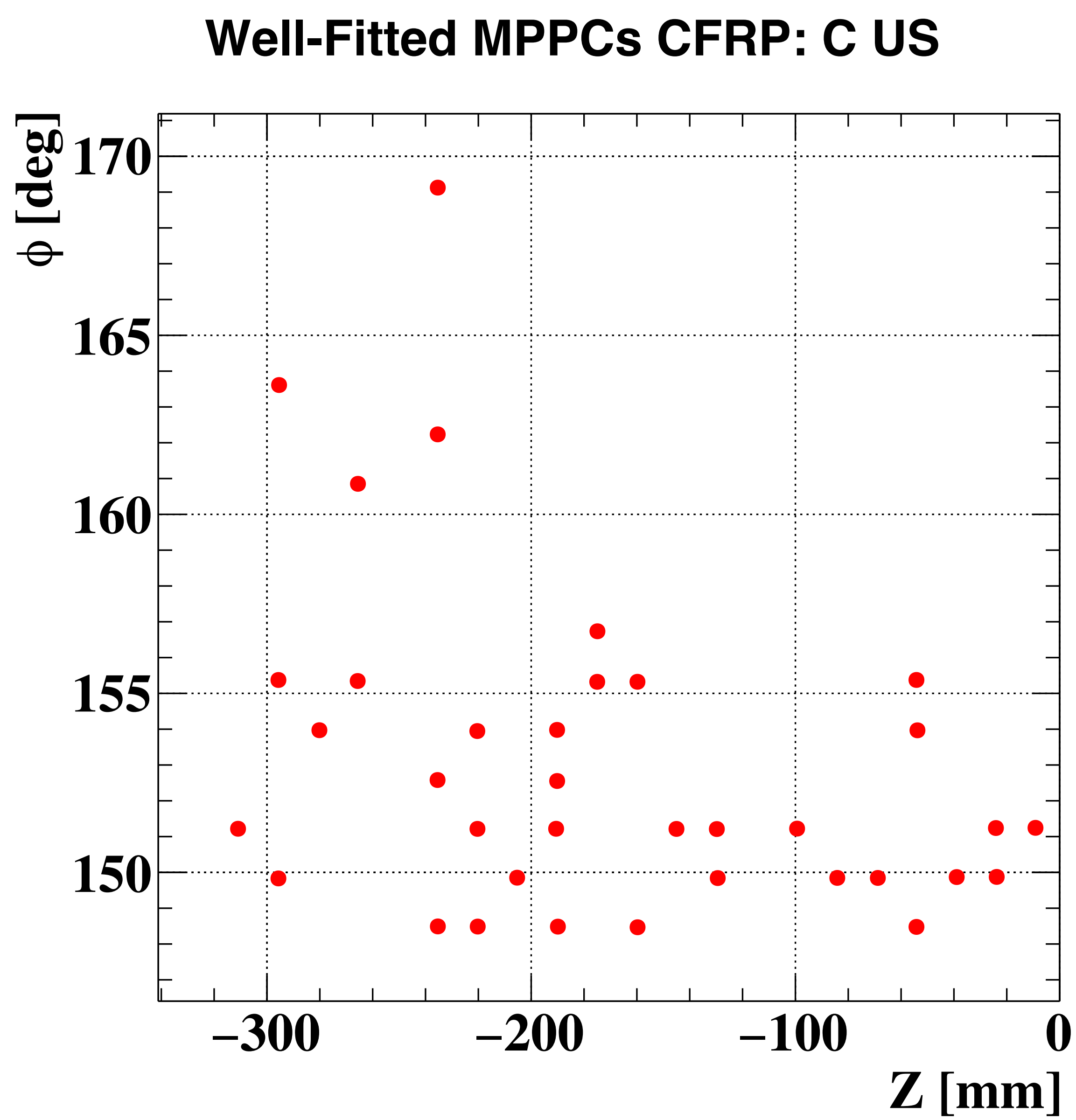
- To know the position of all MPPCs from the limited number of well-fitted MPPCs, we should interpolate the position of the rest MPPCs
- Interpolation procedure is as follows.
  - Step 1: Cylindrical fitting
  - Step 2: Transformation to the cylindrical coordinate
  - Step 3: Fitting well-fitted MPPCs 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(θ,φ)
- Chi square is minimized



Step 2: Coordinate Transformation



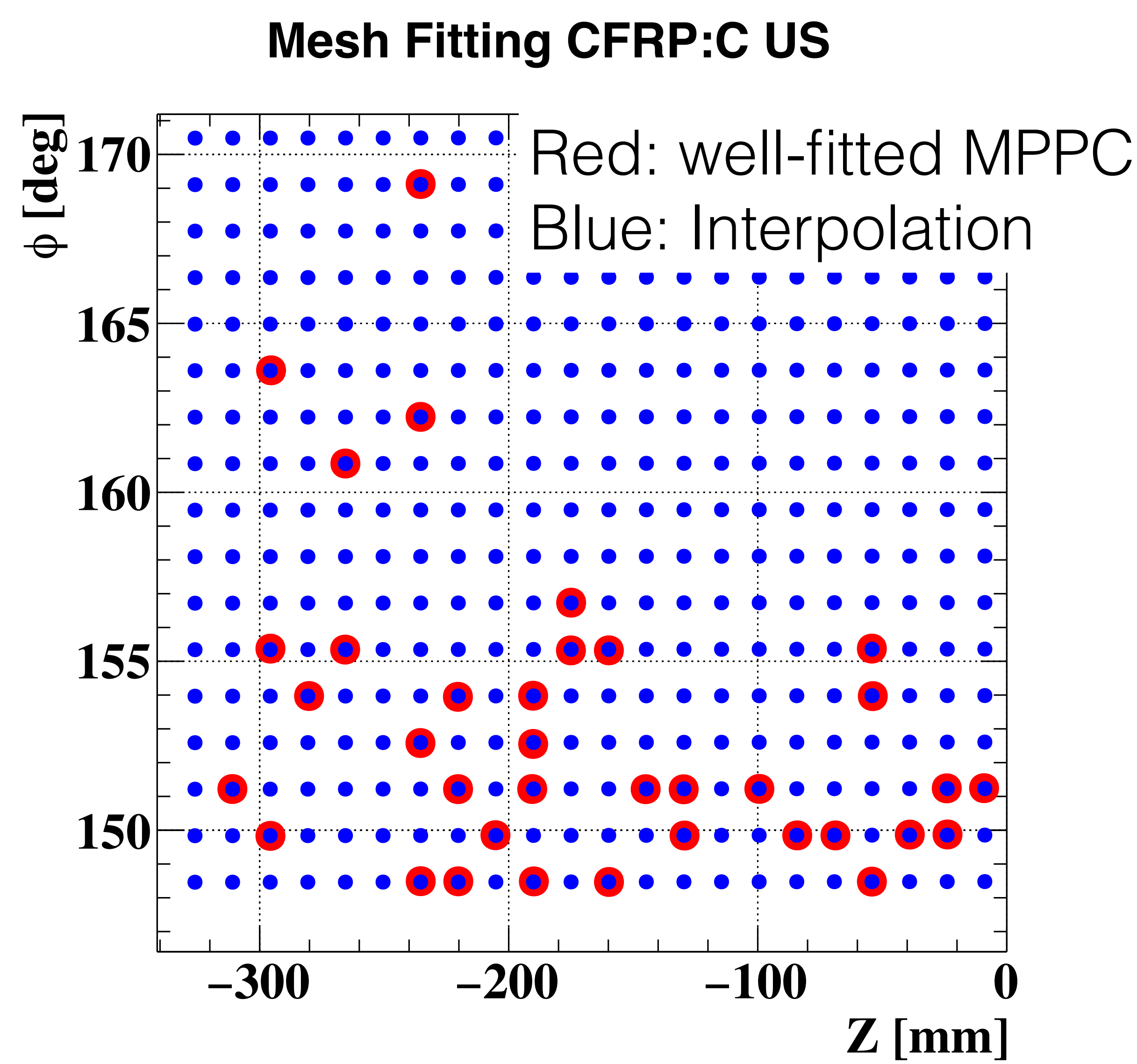
- The position of well-fitted MPPCs is transformed into the cylindrical coordinate.

Step 3: Fitting With Mesh

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

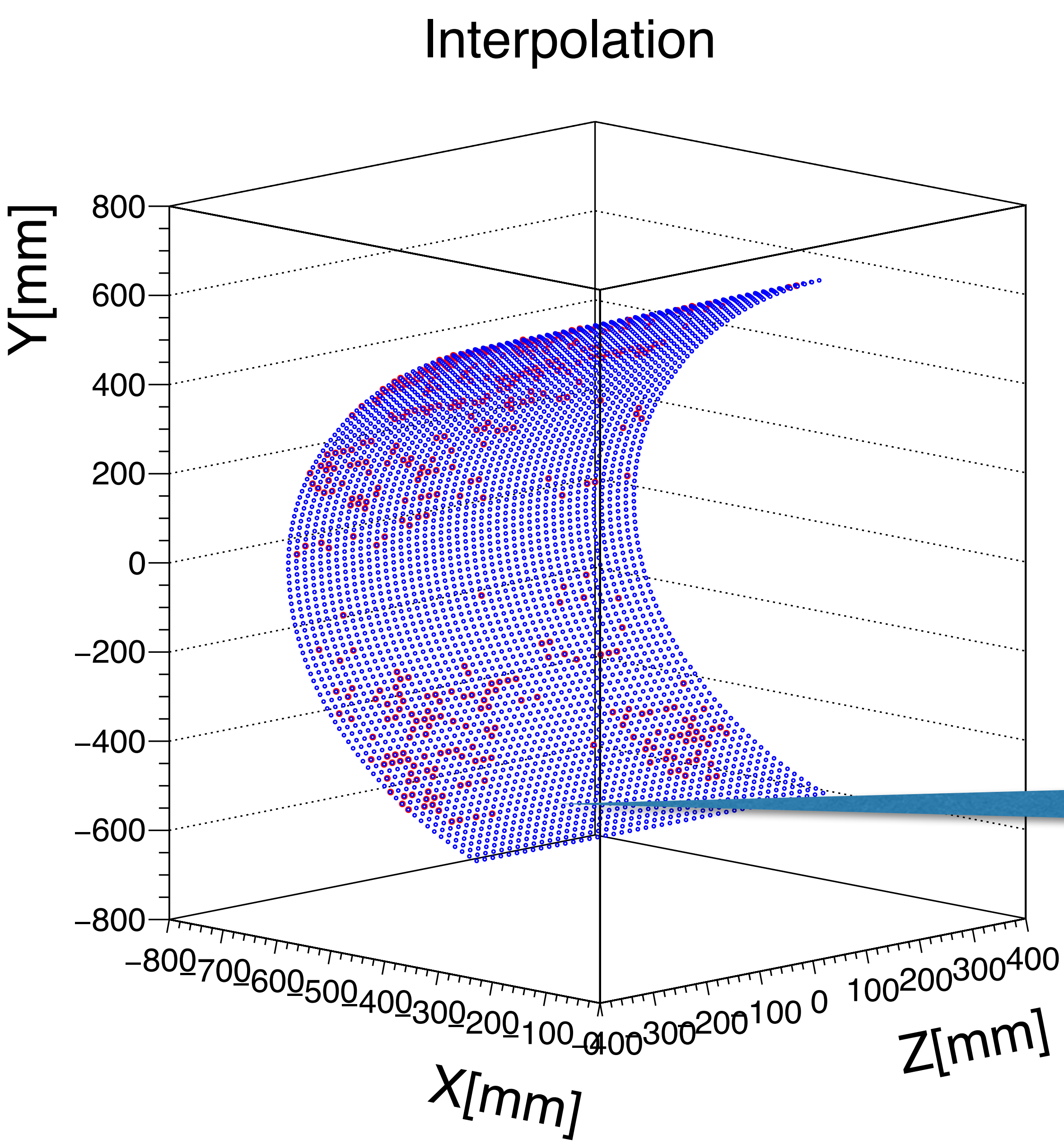
$$\phi_{mesh_{ij}} = p_{\phi 0} + j \times p_{\phi 1} + i \times p_{\phi 2}$$

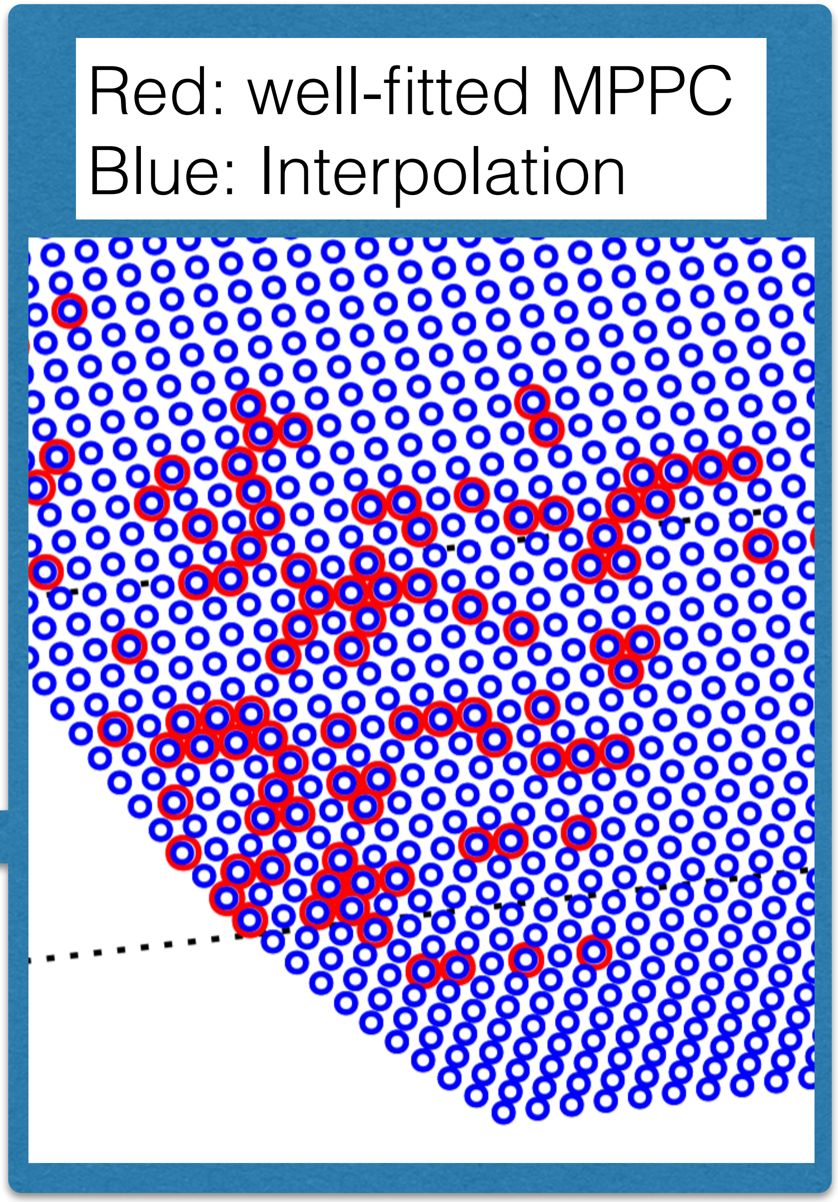
$$\chi^2 = \sum_{well-fitted} (z_{ij} - z_{mesh_{ij}})^2$$



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

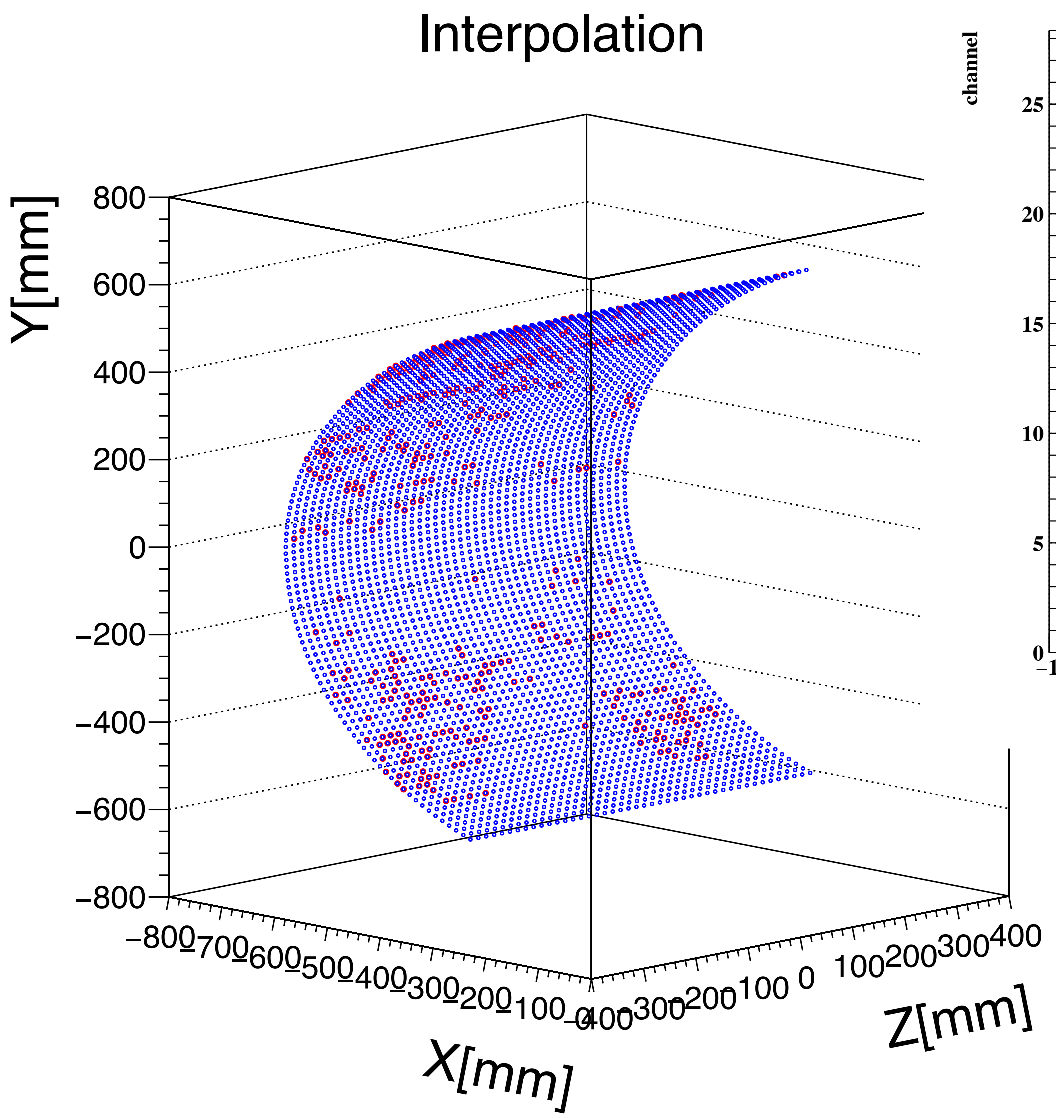
Step 4: Interpolation

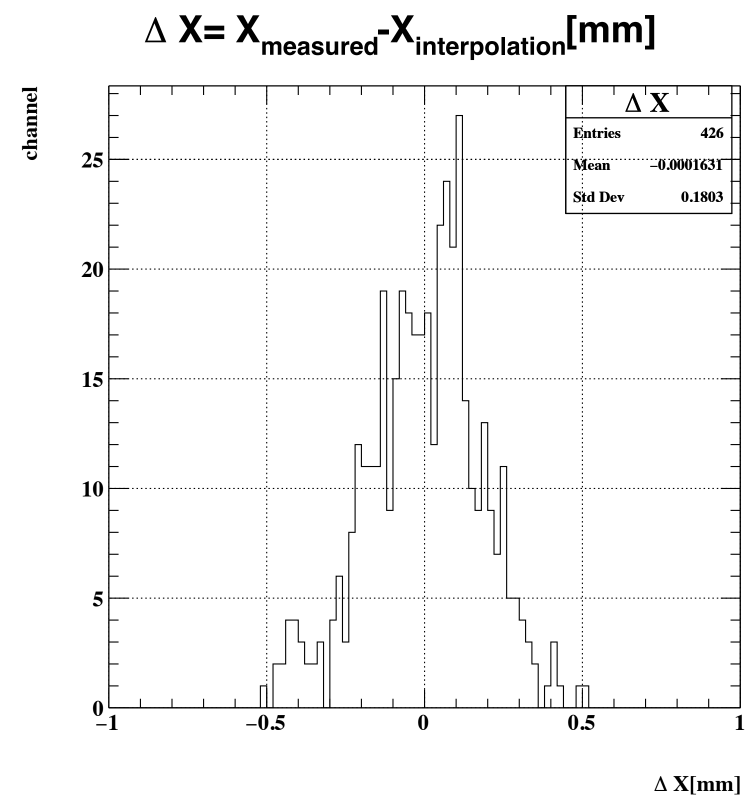


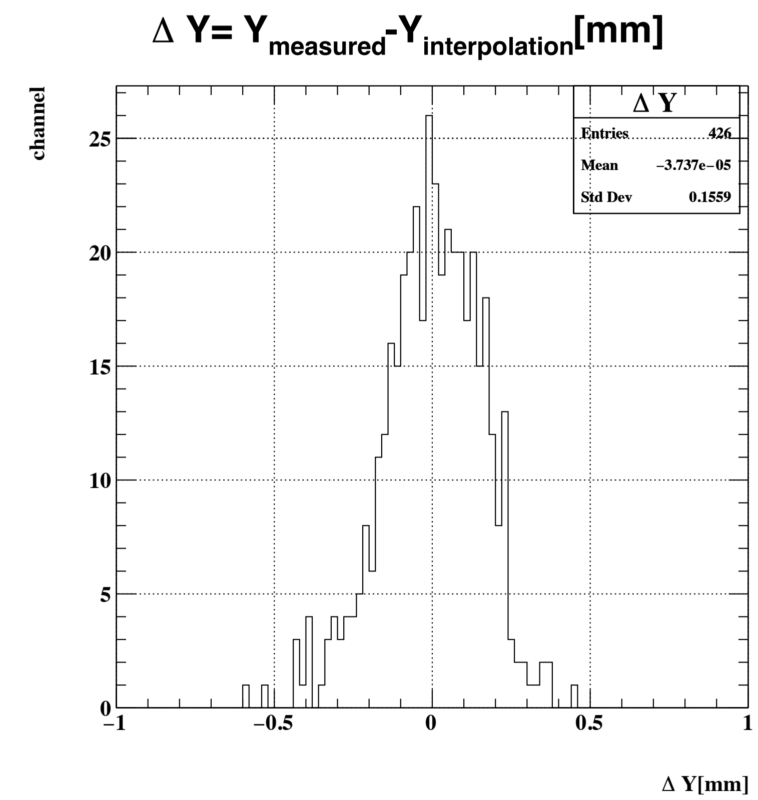


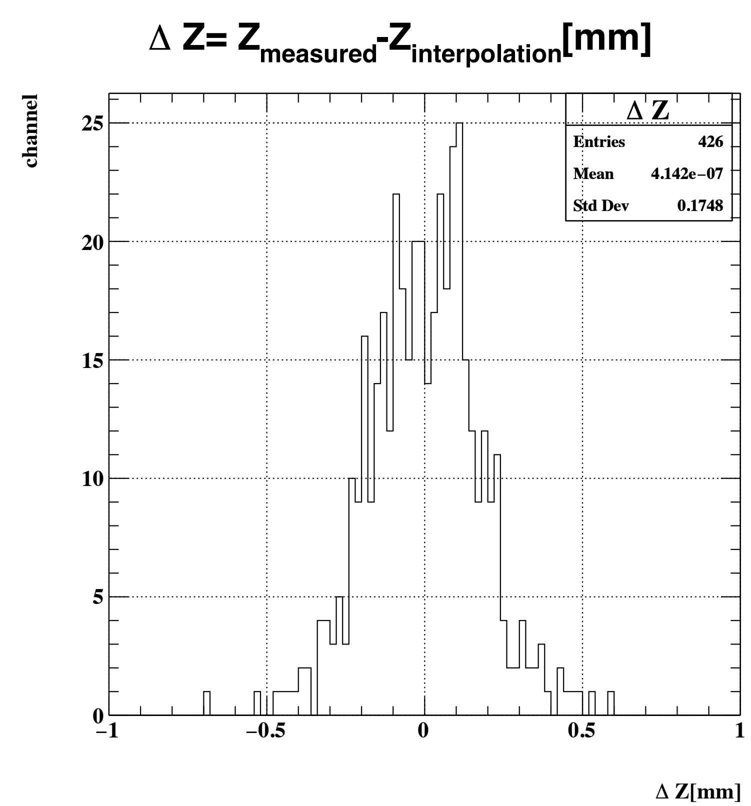
- The position of all MPPCs is interpolated.

Verification









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

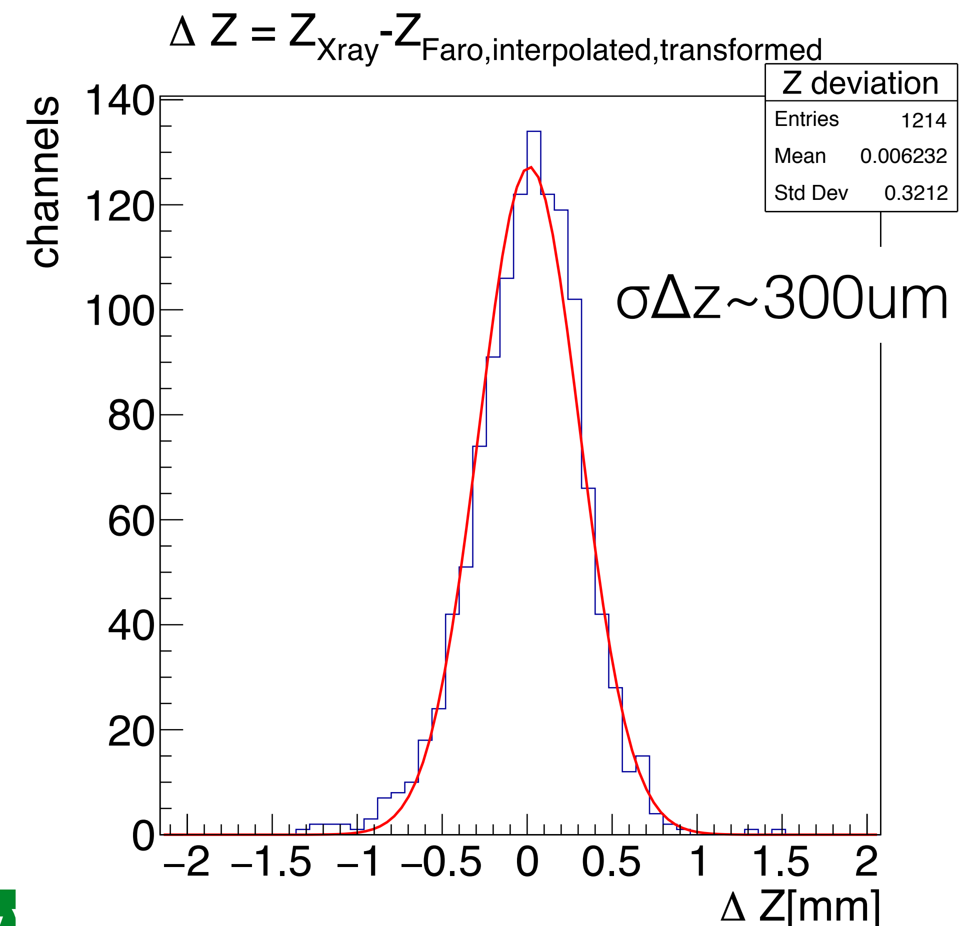
Combination of both measurements in 2017

	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
  - $\sigma_{\Delta Z}$~300um
  - $\sigma_{\Delta\varphi}$~0.4mrad(→260um@incident face)
- We obtained the position of all MPPCs at an accuracy of better than 350um.

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

coordinate transformation

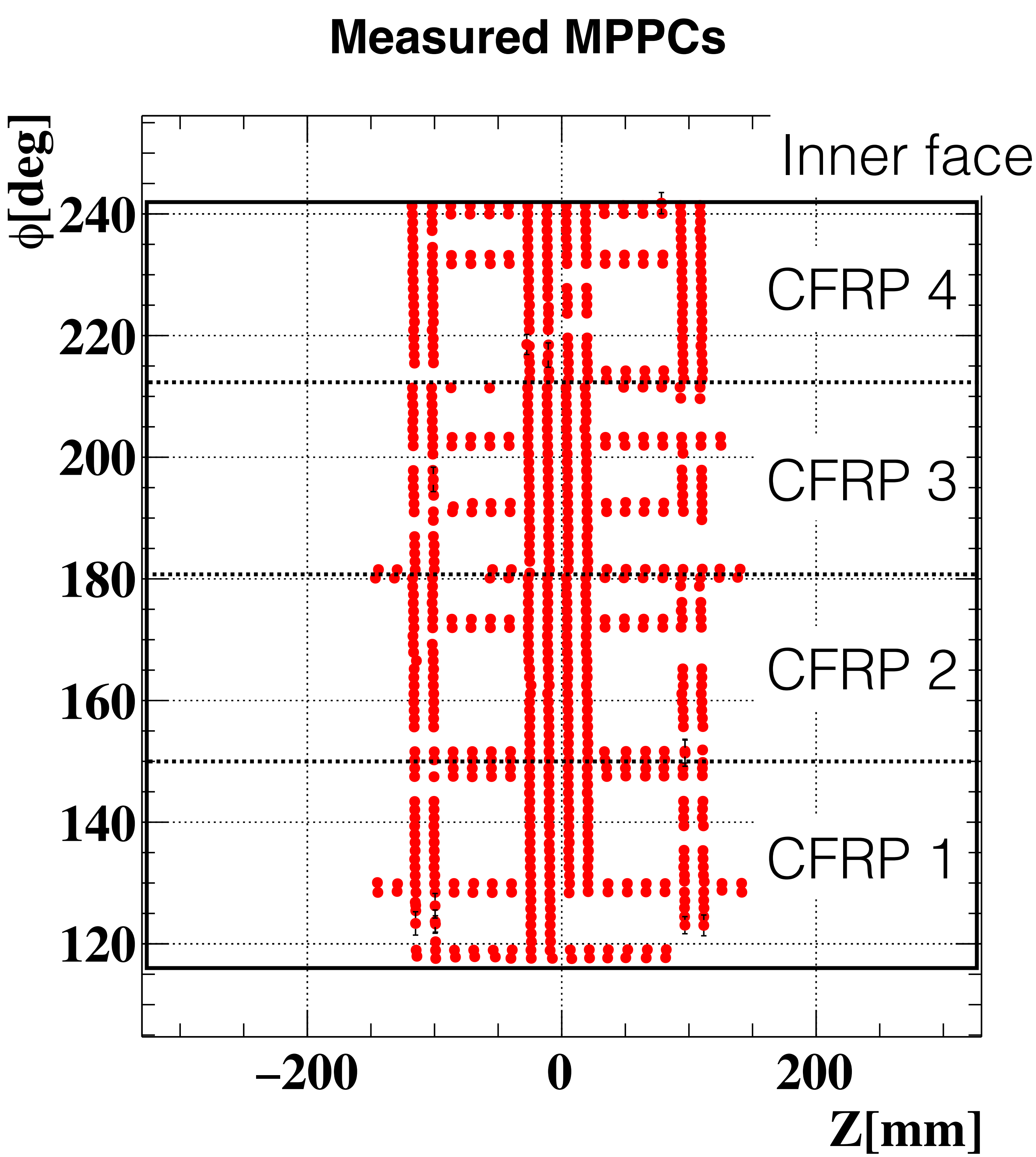


Fitting Parameters

	Parameters	2017 Value	2017 Error	2018 Value	2018 Error
extrinsic z rotation	Alpha[deg]	-25.04	0.01	-3.731	2.17
extrinsic x rotation	Beta[deg]	0.09021	0.0018	0.1734	0.002
extrinsic z rotation	Gamma[deg]	25.09	0.01	3.72789	2.17
	XOffset[mm]	0.8526	0.02	4.67	0.02
	YOffset[mm]	-3.605	0.06	-4.70	0.07
	ZOffset[mm]	0.4006	0.0126	-0.36	0.06
	Scaling factor	**0.9983**	0.0001	0.9987	0.00024

- For almost one year, the detector was moved several times.

Result - Main Scan(2018)



- 824 MPPCs are scanned in total.
  - Boundary of CFRP
  - Center
  - Edge of COBRA thin window