MEG II実験液体キセノン検出器の目標位置精度達成に向けた研究

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MEG II
Mu - E - Gamma collaboration

Outline

- Introduction
  - Charged Lepton Flavor Violation(CLFV)
  - μ→eγ decay
  - MEG II experiment
    - Liquid xenon gamma-ray detector upgrade
- MPPC alignment
  - Strategy
  - Alignment @ room temperature
  - Alignment @ LXe temperature
  - Comparison & Combination
- Summary & Prospects

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  - **μ→eγ decay**
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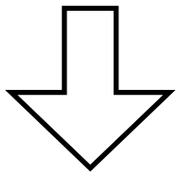
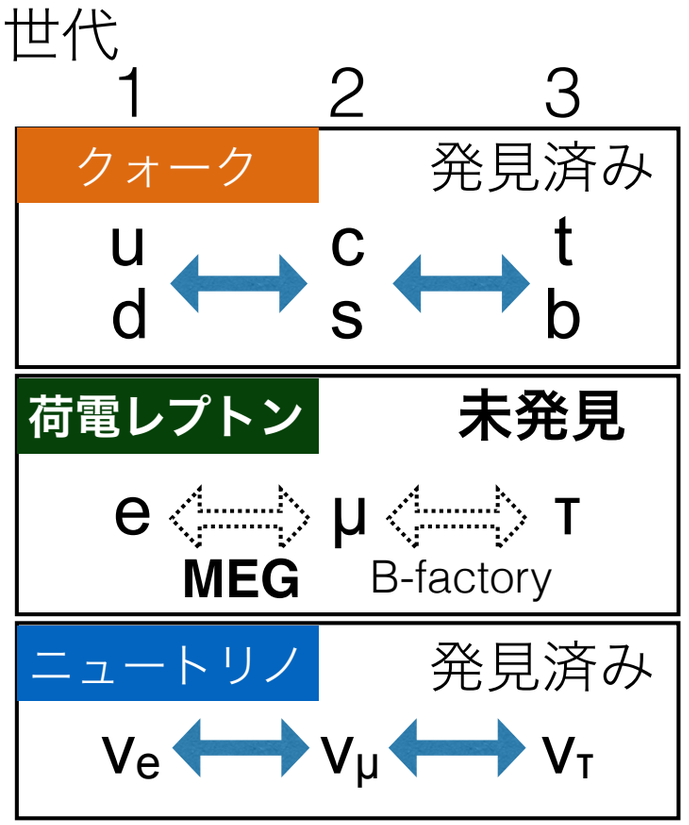
Charged Lepton Flavor Violation(CLFV) as BSM

- **Observation of ν oscillation**
  - Flavor mixing among neutral leptons



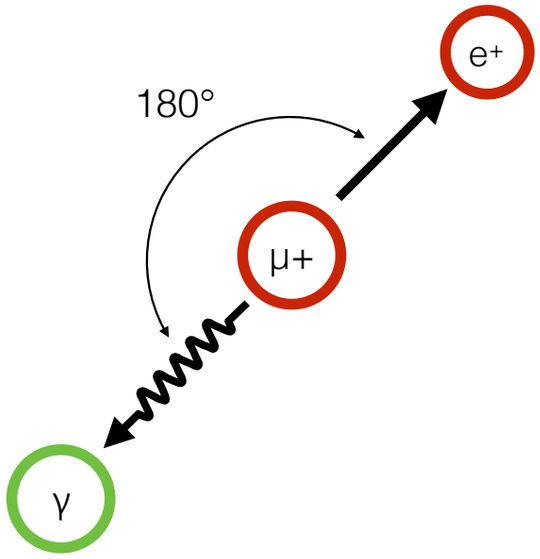
- **Charged Lepton Flavor Violation(CLFV)**
  - No flavor mixing has been observed only among charged leptons.
  - Many BSM models predict detectable mixing.



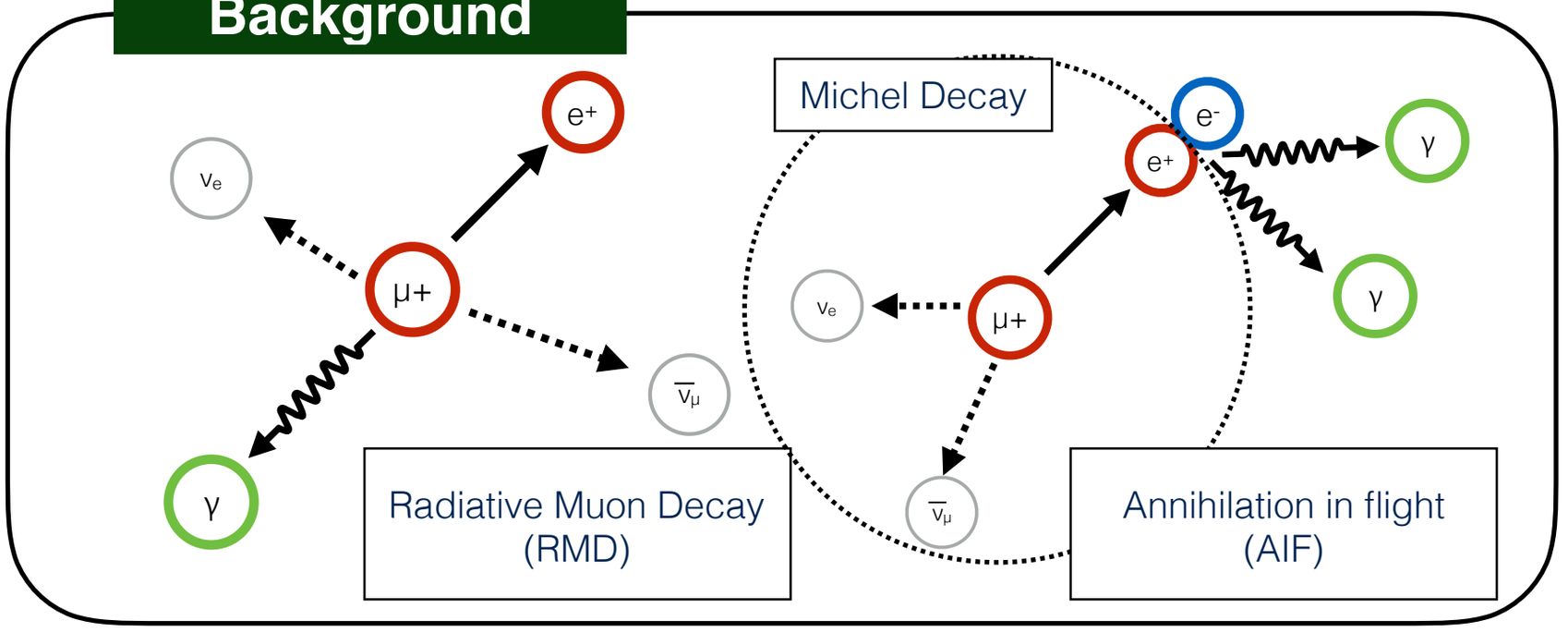
- MEG experiment searched for **μ→eγ decay**, one of CLFV processes.
  - Upper limit: Br(μ→eγ)<4.2×10^{-13}(90%C.L., 2016).
  - ×30 better than previous upper limit by MEGA experiment.

μ→eγ Decay Search

Signal



Background

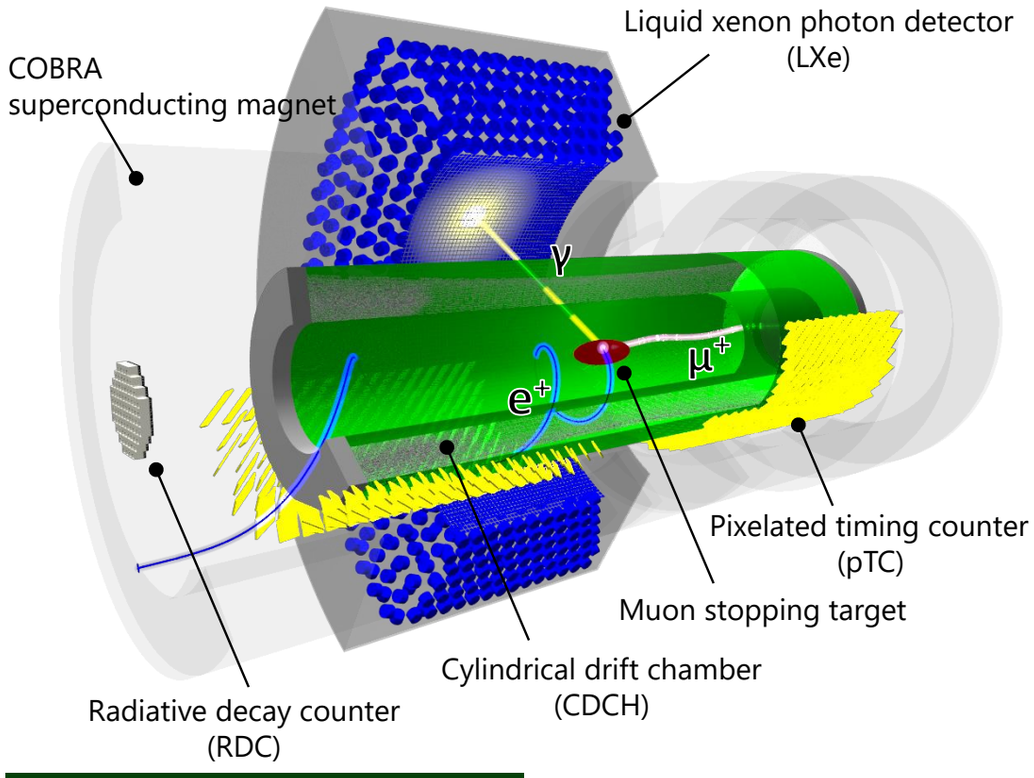


- Signal: Gamma-ray and positron are emitted from single muon decay.
  - **same energy**, same **timing** and **opposite direction**
- Physical background: Radiative muon decay with low energy neutrinos.
- Accidental background: Michel positron + gamma-ray from RMD / AIF.
- High performance detector → less background

$$N_{BG} \propto R_{\mu}^{2} \times \Delta E_{\gamma}^{2} \times \Delta P_{e} \times \Delta \Theta_{e\gamma}^{2} \times \Delta t_{e\gamma} \times T$$

High resolution detector is essential to achieve sensitivity to μ→eγ!!

MEG II Experiment



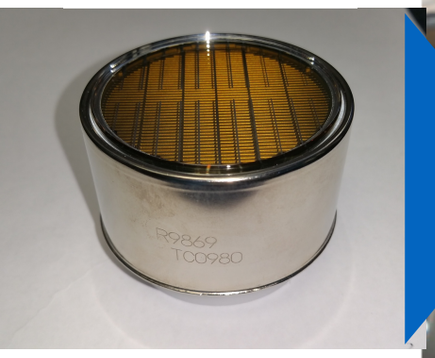
MEG II Detectors

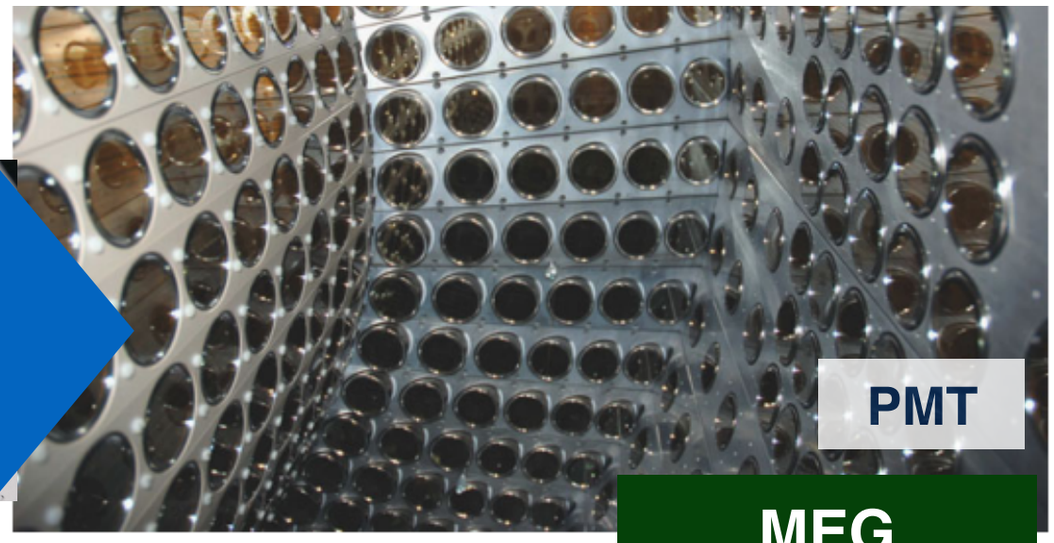
	Resolution /Efficiency	MEG	MEGII
e+	Energy[keV]	306	130
	Angle[mrad]	9.4/8.7	5.3/3.7
	Vertex position[mm]	1.2/2.4	0.7/1.6
	Detection Efficiency[%]	30	70
γ	Energy[%]	1.7/2.4	**1.0/1.1**
	Position[mm]	5/5/6	**2.6/2.2/5**
	Detection Efficiency[%]	63	**69**
	Relative Timing[ps]	122	84

- Goal: Search for μ→eγ down to Br(μ→eγ)~6×10^{-14}.
- Detector commissioning is in progress.
  - 2018: Pre-engineering run with all detectors.

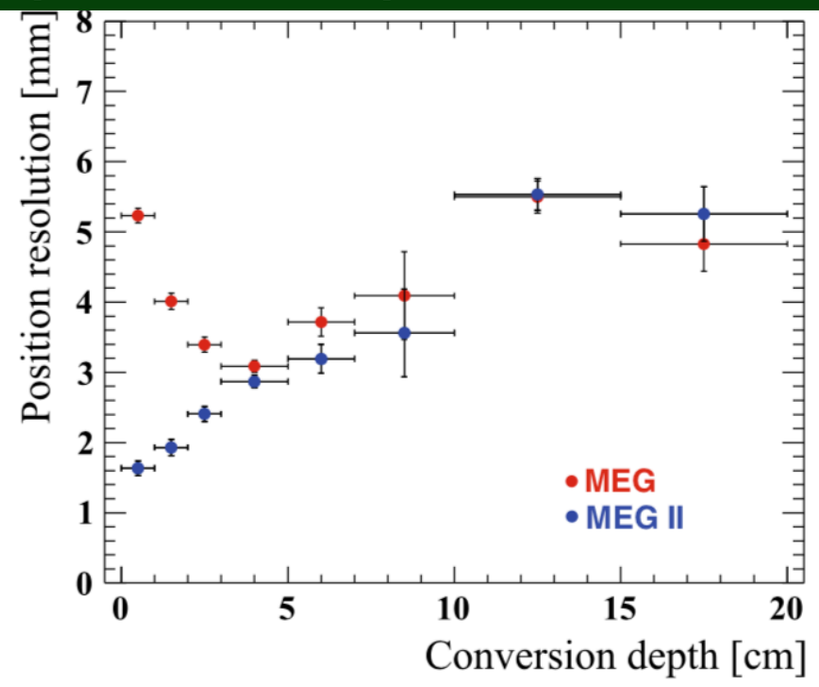
Upgrade of Liquid xenon Gamma-ray Detector

PMT
24×9=216





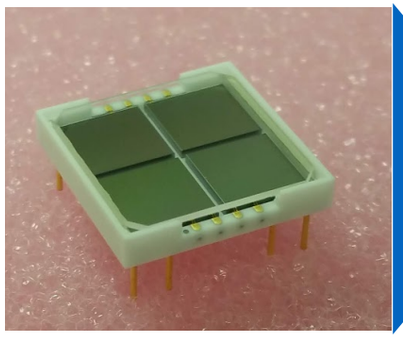
Improvement of position resolution

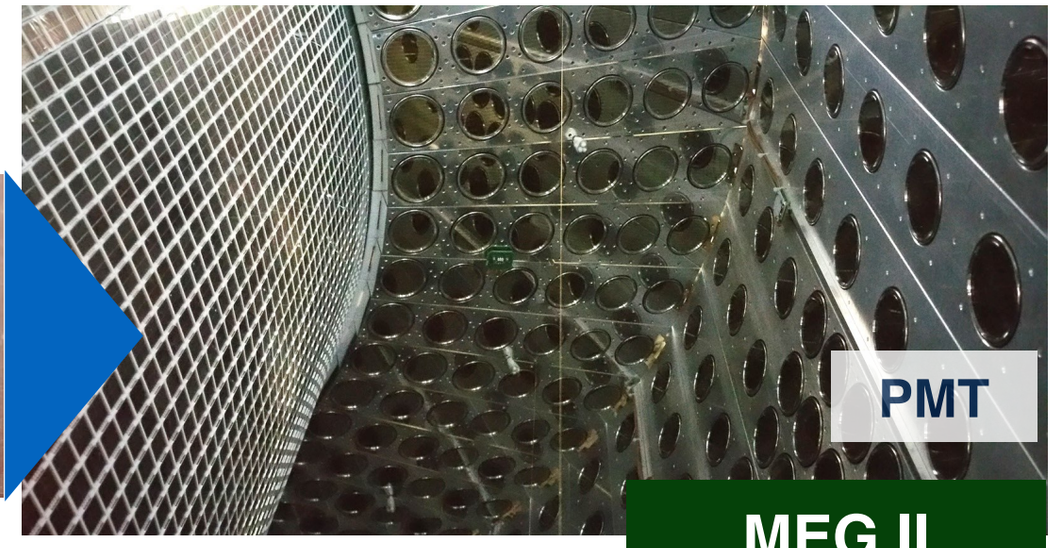


- Total absorption calorimeter using liquid xenon.
  - Detect VUV scintillation photons(λ~175nm).
- 216 PMTs → 4092 MPPCs @ incident face.
  - ×2 better resolution on energy(~1%) & position(**~2.5mm**).
  - **Alignment** & Calibration of MPPC are essential to achieve the goal.
- 2018: performance evaluation with limited number of channels(1016/4092).

Upgrade of Liquid xenon Gamma-ray Detector

MPPC
44×93=4092





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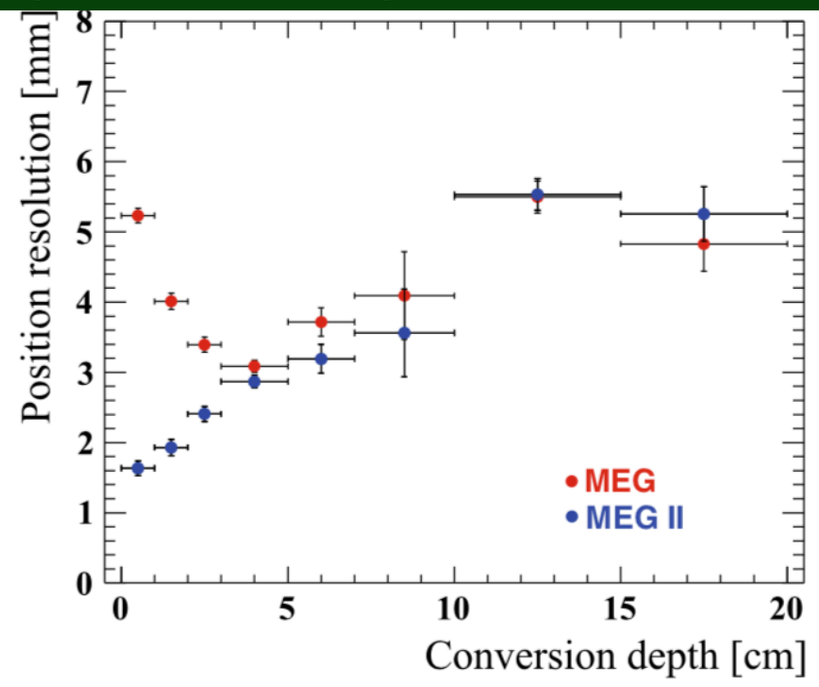

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Alignment Strategy

- Goal: Measure the position of MPPCs with **<500μm accuracy**.

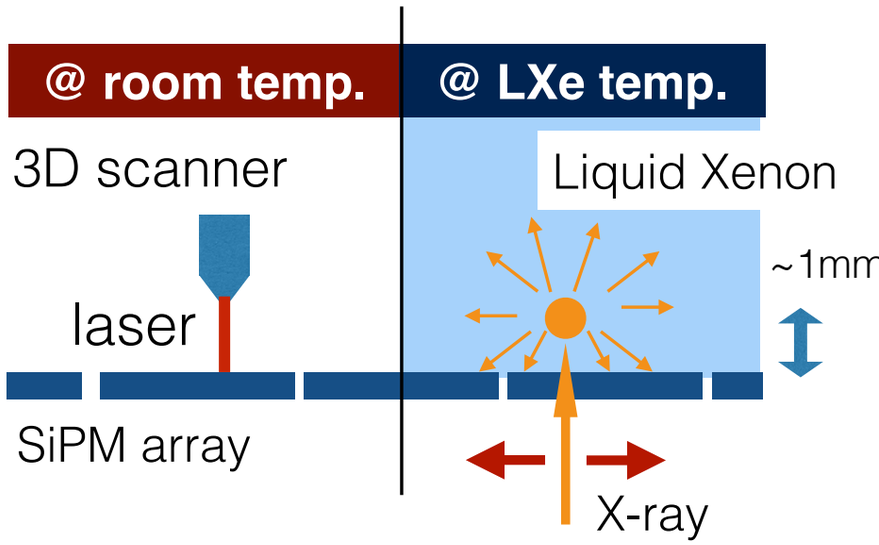
✓ MPPCs are aligned on precisely machined PCBs.

✗ MPPC array shrinks ~2mm at LXe temperature(165K).

→ Perform two complementary measurements.

  - Understand the size of shrinking effect by comparison.
  - Combine them to reconstruct 3D position at LXe temp.

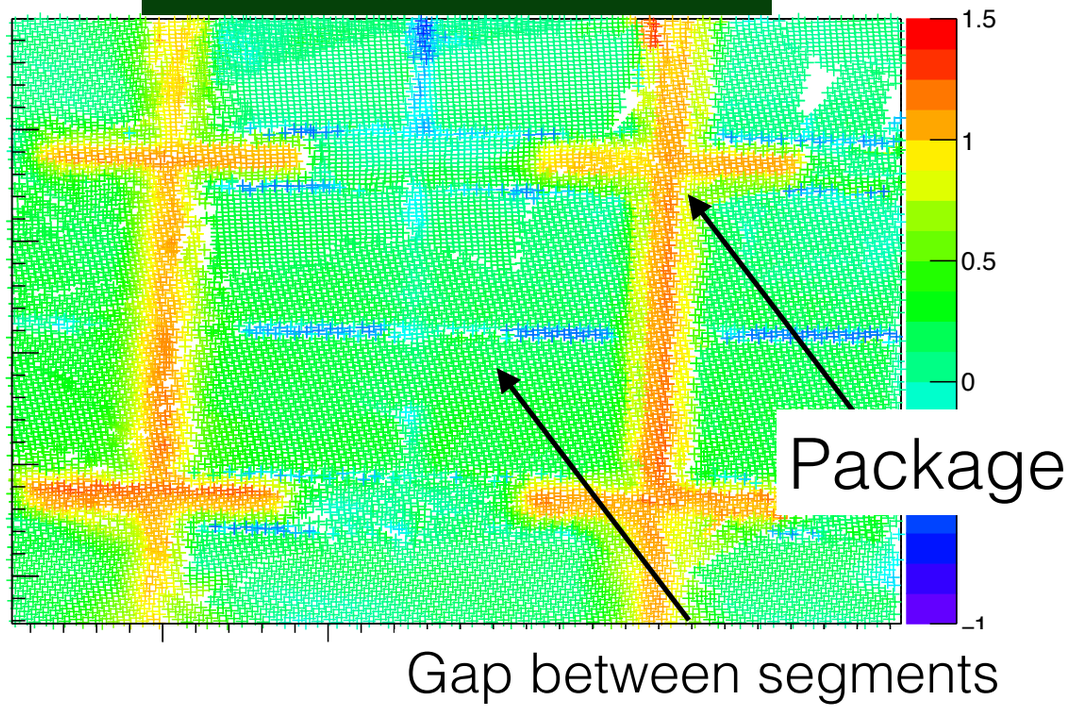
Tool	Laser scanner	Gamma-ray
Temperature	room temp.	LXe temp(~165K)
Position	3-D	2-D(@incident face)
Coordinate	Local coordinate	Global coordinate



MPPC Alignment at room temperature

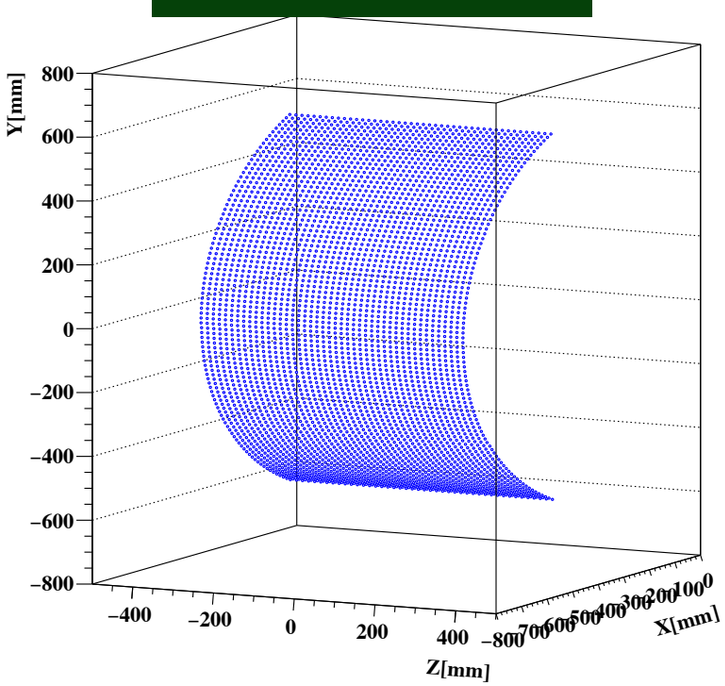
Measurement with Quantum FaroArm

3D image of surface

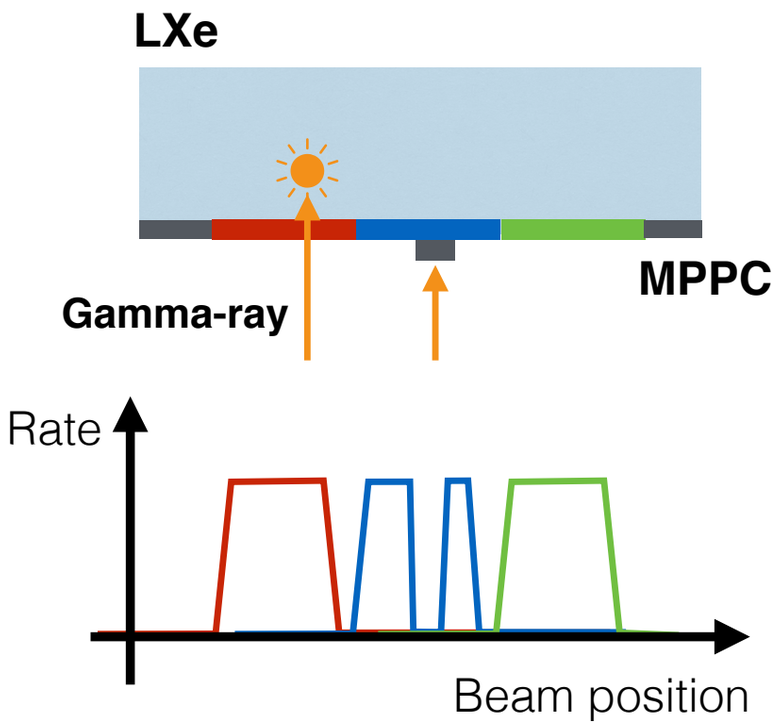


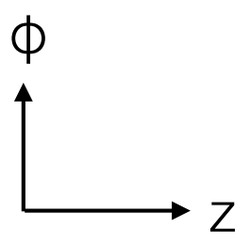
- Take images of the surface of MPPC array before filling LXe.
  - MPPC position was reconstructed with the surface image.
  - The position of 426 MPPCs was measured to an accuracy of **120μm.**
  - For the rest of MPPCs, data quality was not good enough due to limited motion range of the scanner arm.
- Since MPPCs are aligned on PCBs, the whole structure of MPPC array was reconstructed from the position of limited channels.

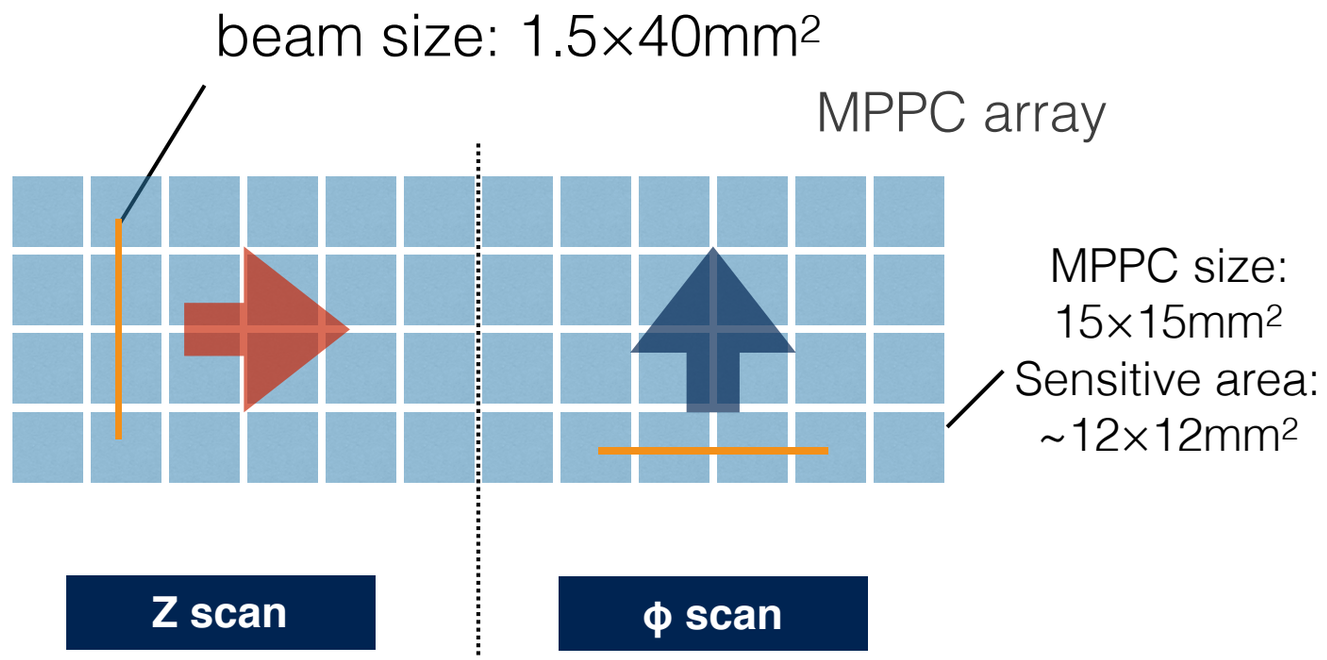
Reconstructed MPPC array



MPPC Alignment at LXe temperature - method



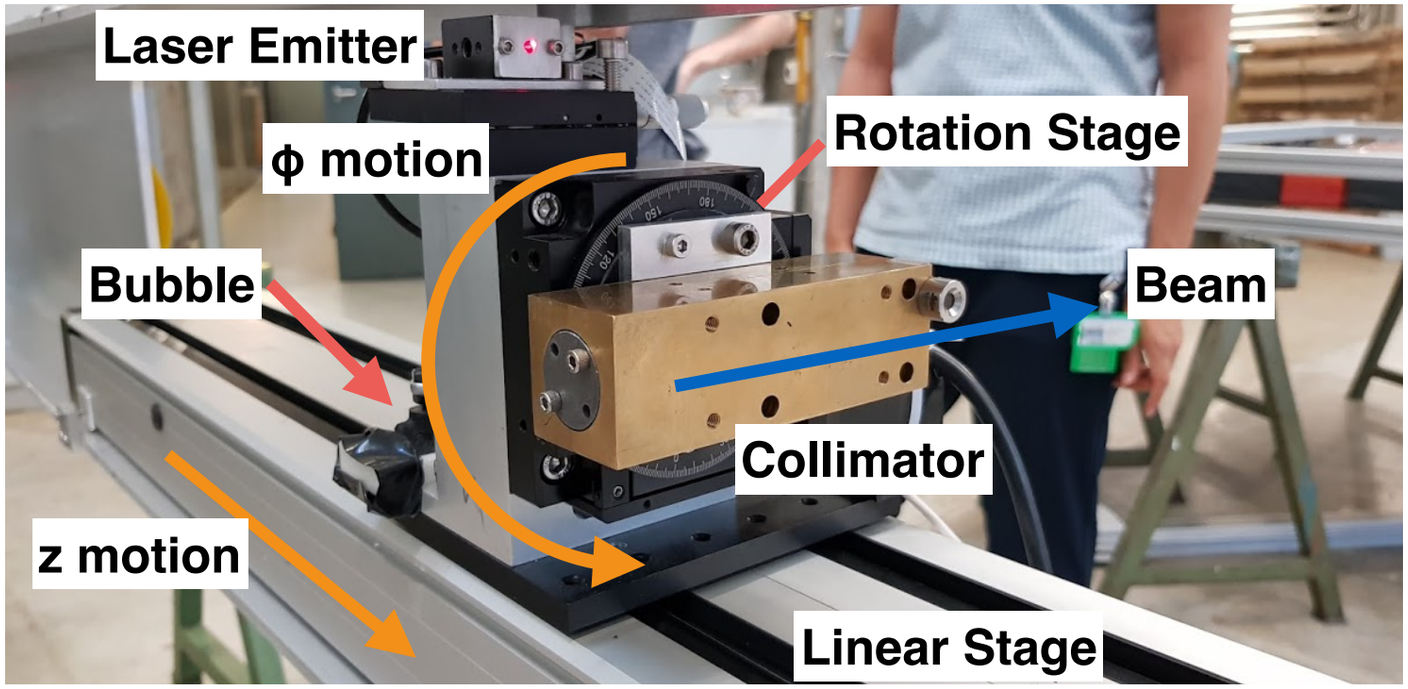


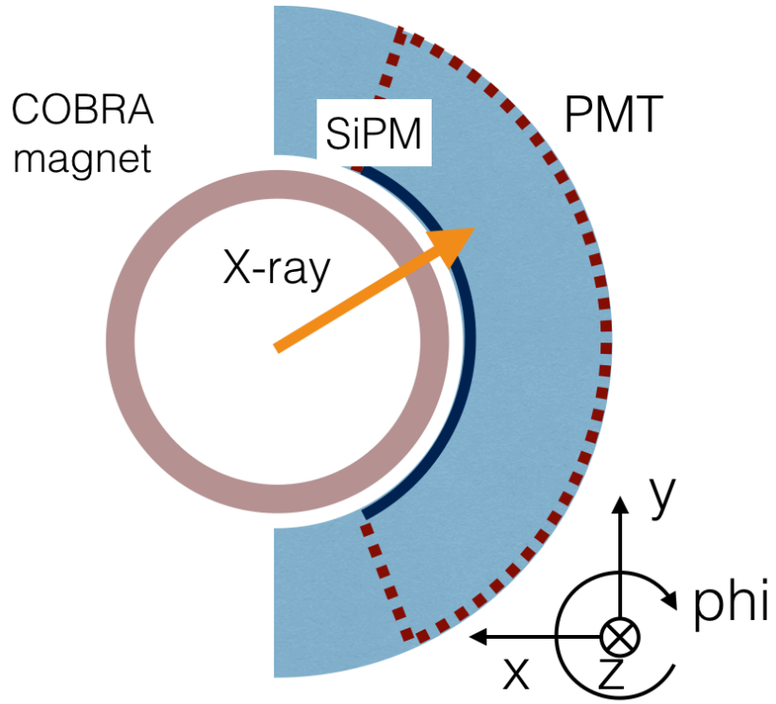


- Liquid xenon stops ~100keV gamma-ray with short range(~3mm).
- When a gamma-ray enters LXe from incident face, it strongly illuminates single MPPC.
  - We can find a gamma-ray spot from MPPC signal.
  - **MPPC position can be reconstructed with beam position and the rate.**

MPPC Alignment at LXe temperature - set up

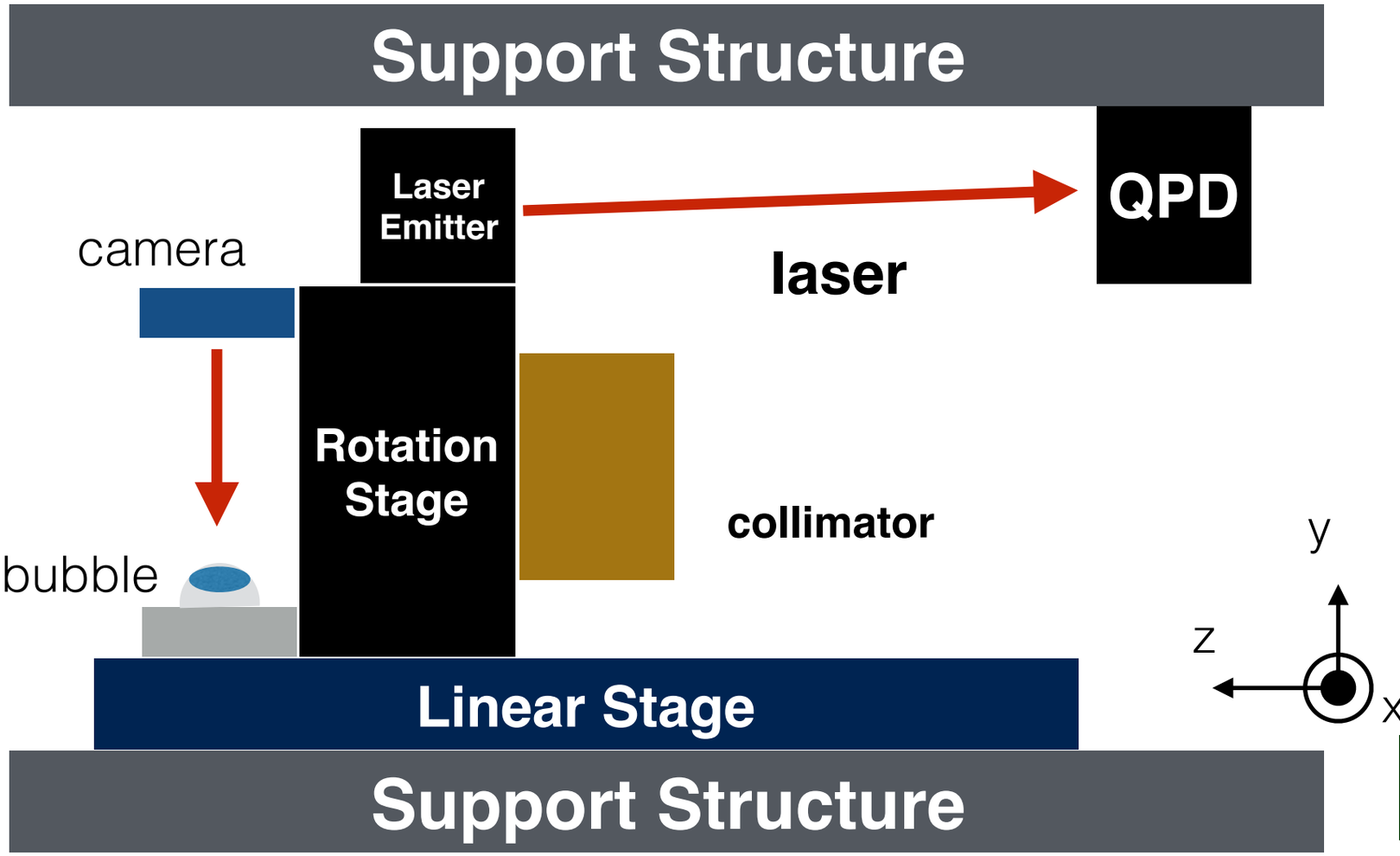
Collimator / Stage





- Use ^{57}Co(E=**122keV**,**136keV**) as a gamma-ray source.
- Make a strip gamma-ray beam with a brass collimator.
- Combine a linear stage and a rotational stage.
  - Realize the vertical incidence of gamma-ray to MPPC array.

MPPC Alignment at LXe temperature - set up

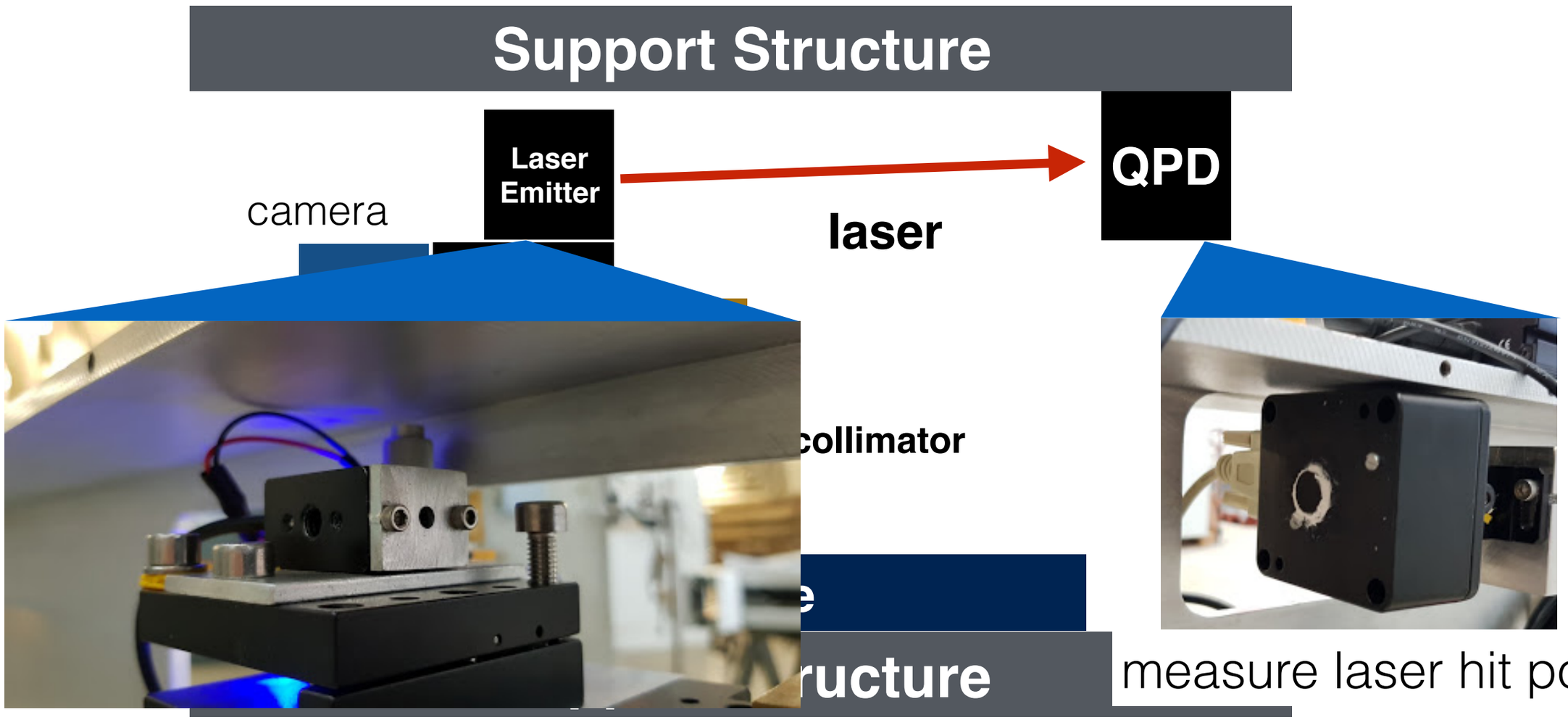


laser tracker

- **Goal : Alignment of collimator's position and direction.**

1. **Laser tracker gives the position and direction of collimator at single point.**
2. Laser's hit position in Quadrant Photodiode(QPD) gives relative rotation about x and y.
3. Bubble gives relative rotation about z(beam axis).

MPPC Alignment at LXe temperature - set up



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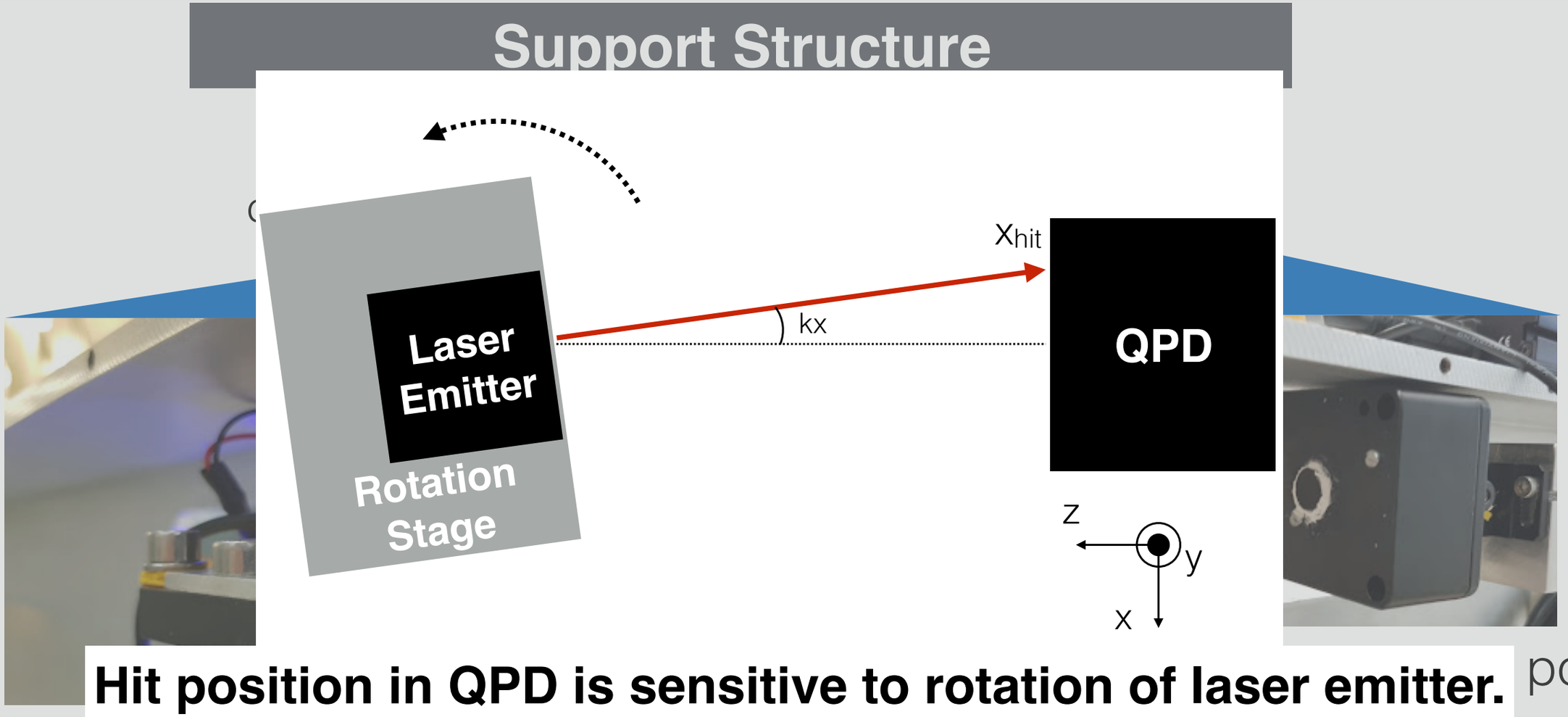

Hit position in QPD is sensitive to rotation of laser emitter. position

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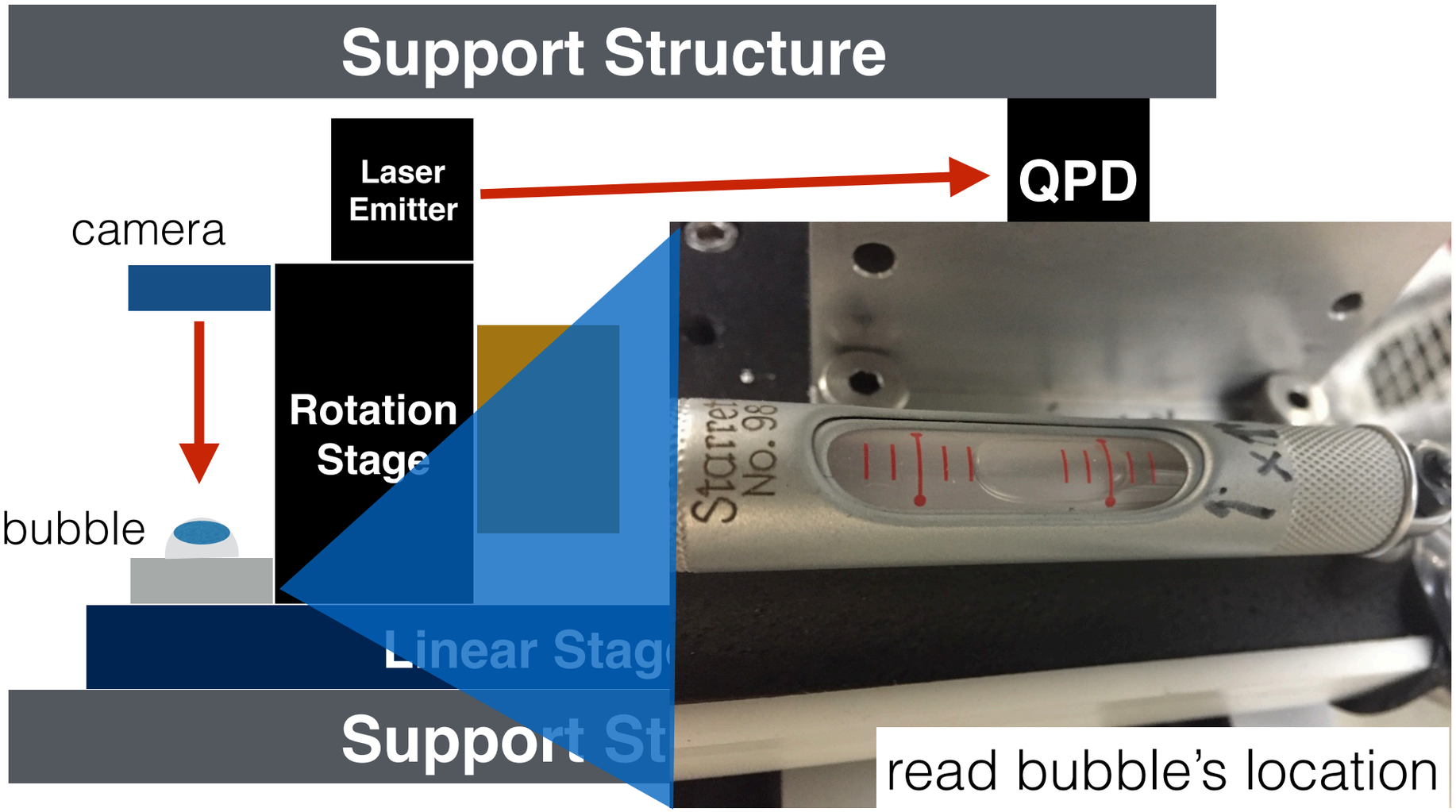

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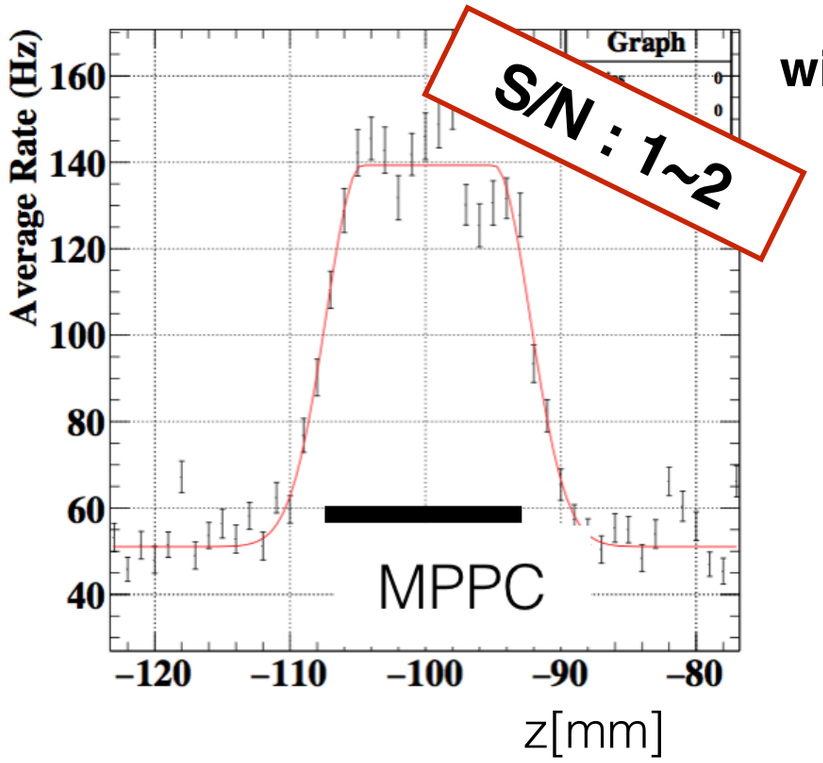
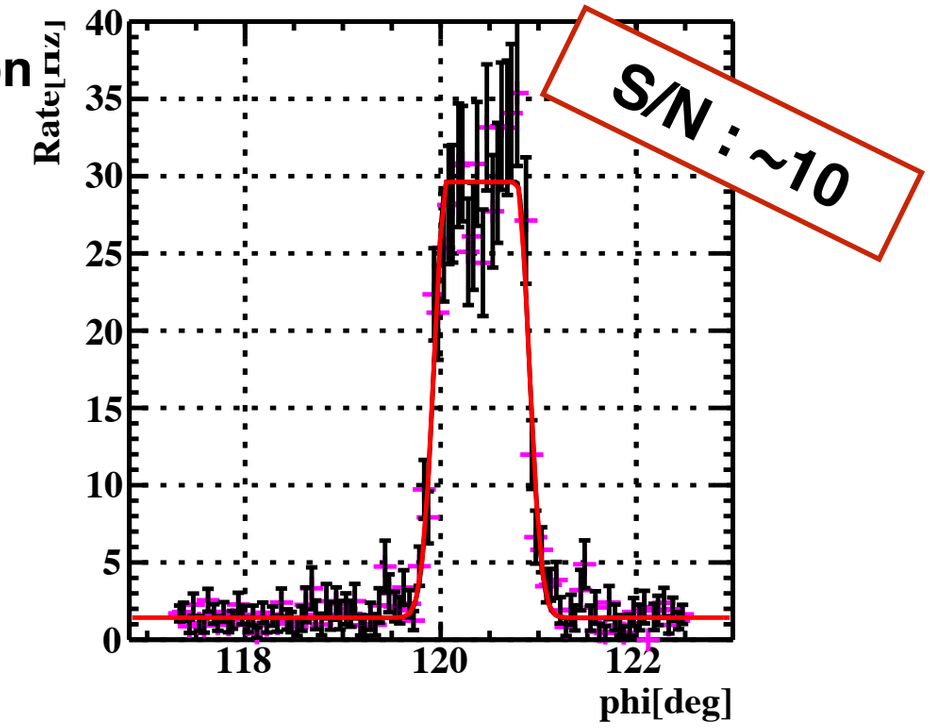
MPPC Alignment at LXe temperature - Improvement

Signal in 2017



Background rejection with waveform information

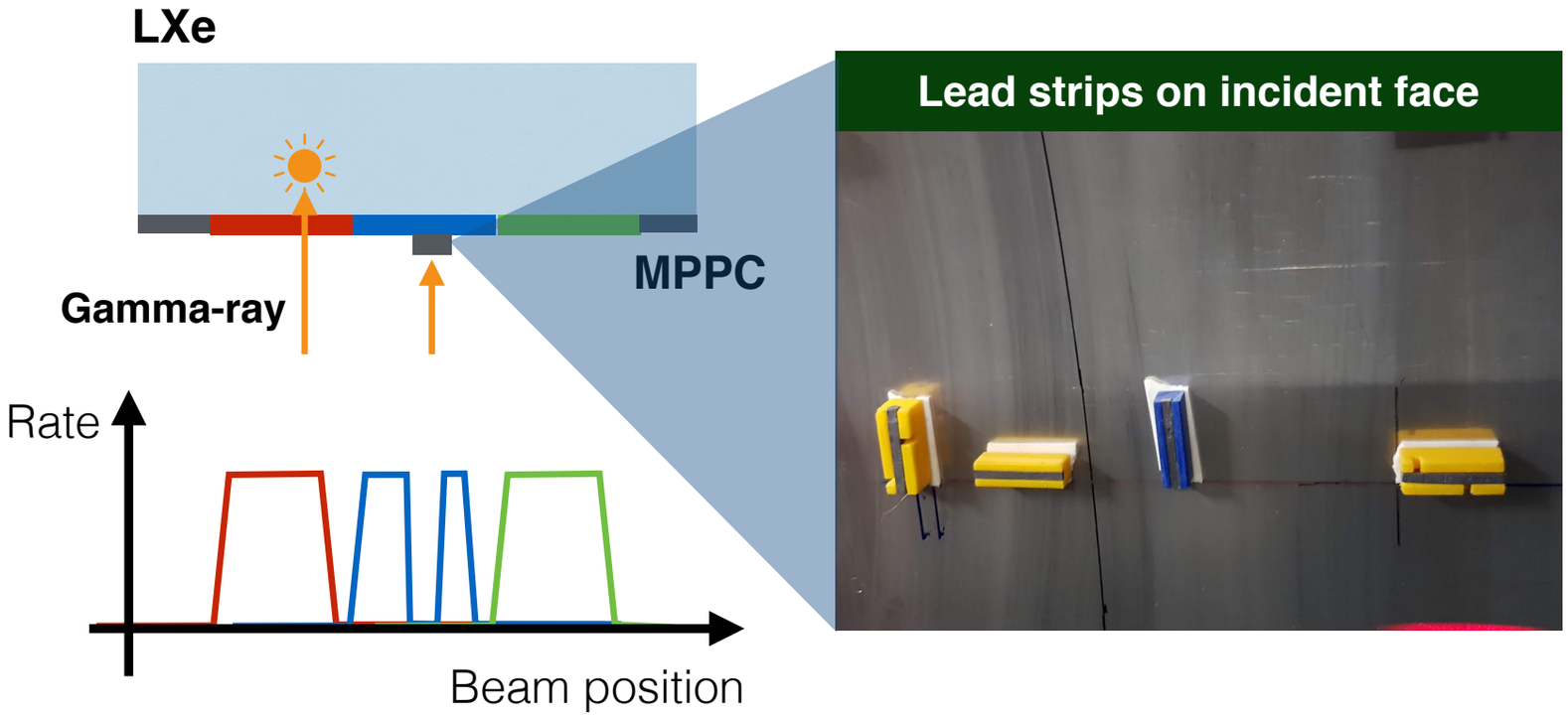
Signal in 2018

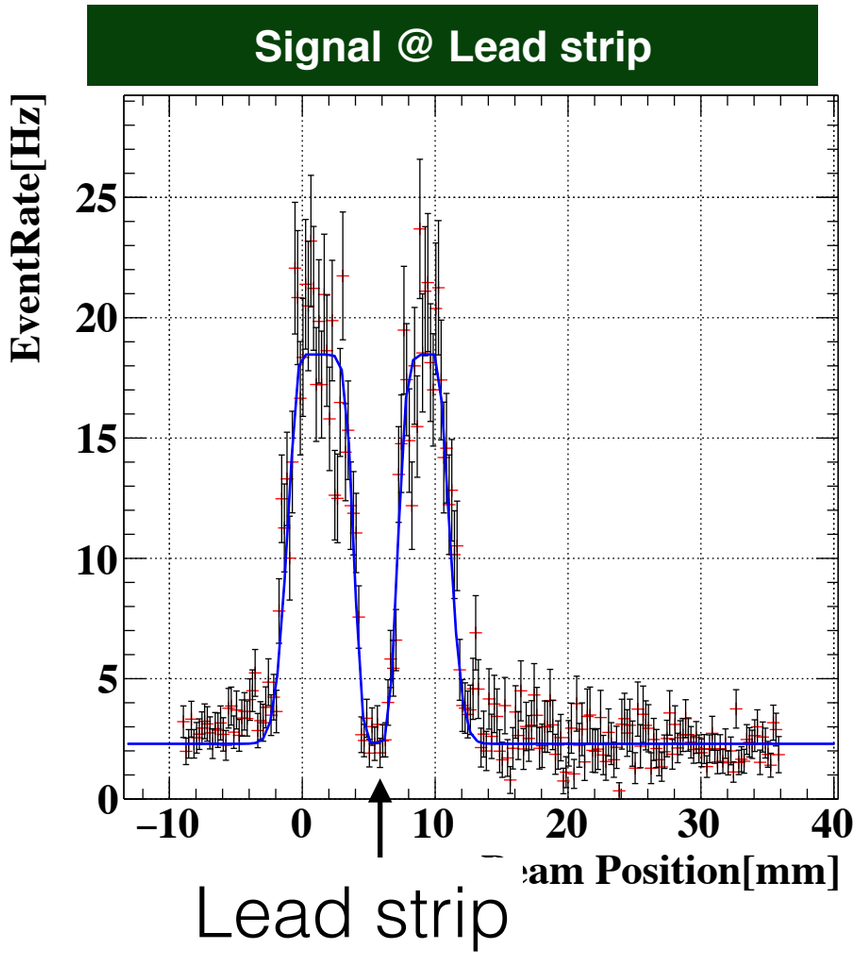


- 2017: The first measurement
  - S/N: 1~2, only with trigger data.
- 2018: Second measurement
  - **Despite the decrease of beam intensity, we achieved better S/N(~10).**
    - Short lifetime of ^{57}Co(271 days).→Decrease of S/N because of cosmic-ray BG.

    ➡ **Cosmic-ray BG is successfully rejected** with the waveform of many MPPCs.
- **MPPC position is reconstructed as the mean of symmetric fitting function.**
- The position of 827 MPPCs was measured within the limited time slot.

MPPC Alignment at LXe temperature - beam alignment

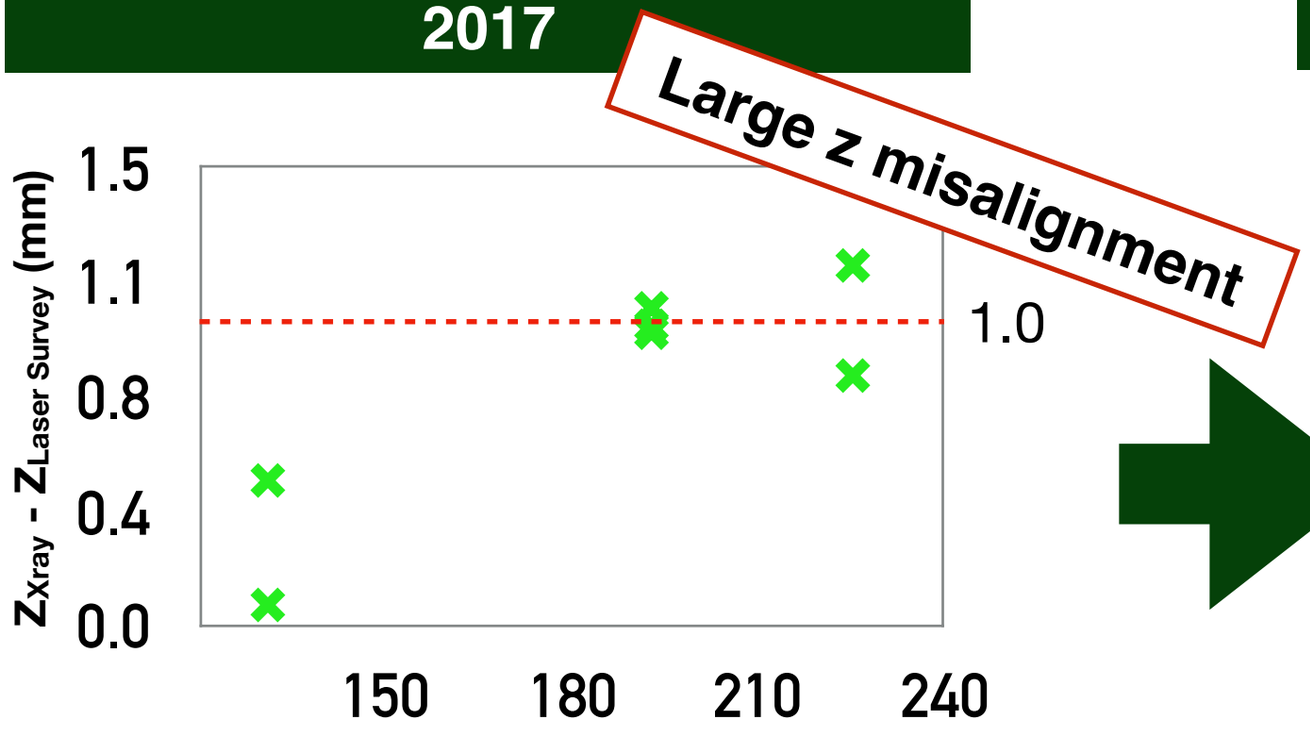




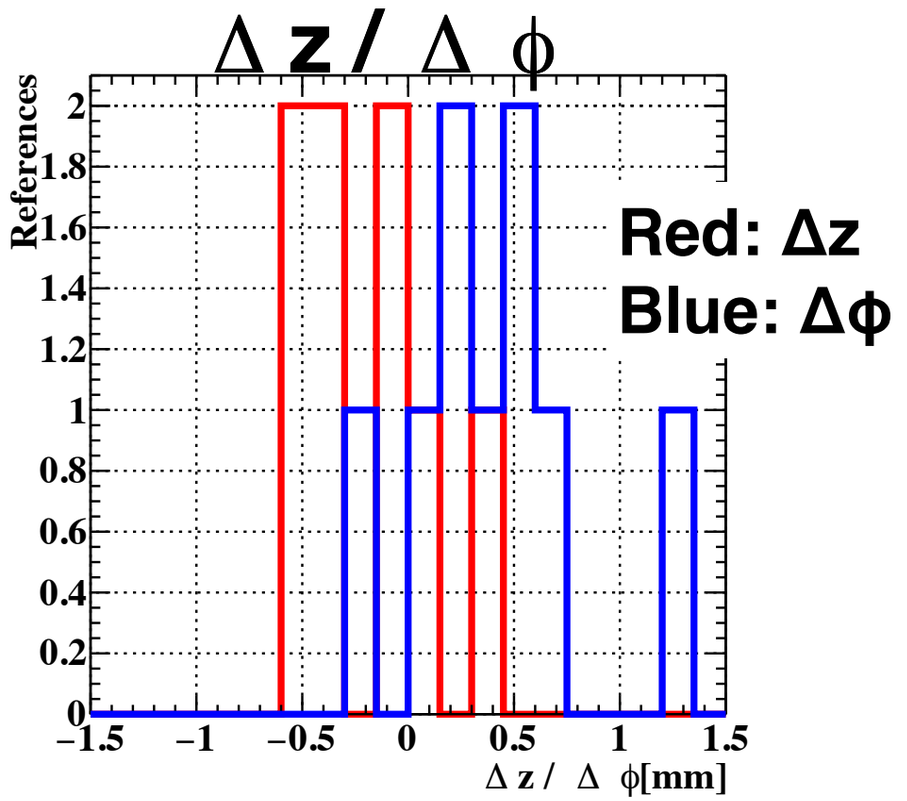
- Lead strips are mounted outside of incident face.
- The position is measured by two ways.
  - They cause a sharp rate drop in gamma-ray scan.
  - Also measurable from outside by laser tracker.

MPPC Alignment at LXe temperature - References

Deviation of reference position 2017



Deviation of reference position 2018



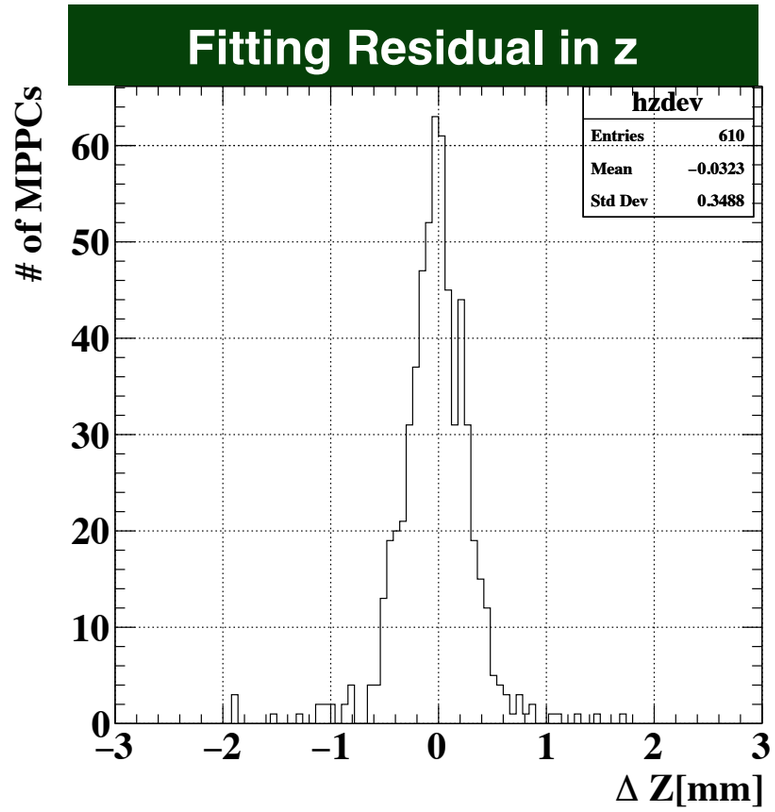
- 2017: **1mm misalignment** of gamma-ray beam was found.
- 2018: **Sufficient precision was achieved(<500μm).**
  - **Some causes of misalignment in 2017 were identified.**
  - RMS of deviation : 280μm in z / 420μm in φ
    - This includes uncertainties from laser tracker measurement.
  - Systematic offset : -200μm in z / +400μm in φ
    - To be investigated.

Combination of two results

$$\vec{x}_{laser} \mapsto (1-a)R(\alpha,\beta,\gamma)\vec{x}_{laser} + \vec{c}_{offset}$$

Scaling parameter Rotation Systematic offset

- Fit two results assuming uniform shrinking.
  - 4092 MPPCs @ room temp.
  - 827 MPPCs @ LXe temp.
  - Minimize the distance on zφ-plane.
- **Scale of shrinking effect: as expected.**
  - Measured: 18±3ppm/deg(Scaling parameter)
  - Expected: 16~17ppm/deg(PCB, CFRP)
- RMS of fitting residual was 280μm both in z and φ.
  - There is no significant deviation of the shape of MPPC array.



Summary

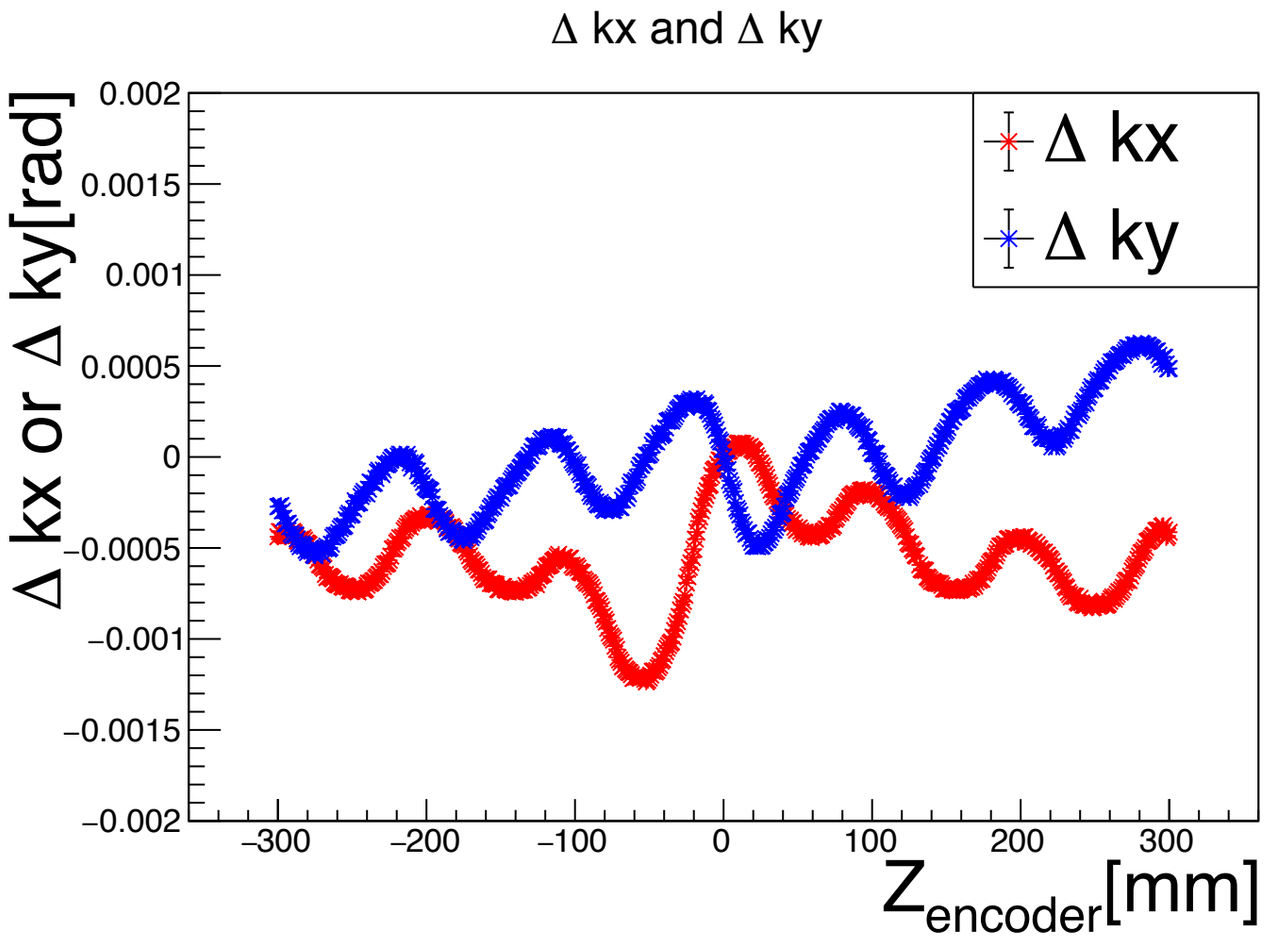
- MEG II experiment will search for **μ→eγ** down to Br(μ→eγ)~6×10^{-14}.
- Improvement of gamma-ray position & energy resolution is expected with MPPCs.
  - It requires precise MPPC alignment.
- We performed two complementary measurements to achieve MPPC alignment with <500μm accuracy.
  - Laser scanner @room temp.
  - Low energy gamma-ray beam@LXe temp.
- In particular, gamma-ray measurement improved in 2018.
  - **We achieved the sufficient precision**.
  - The systematic offset of MPPC array is to be investigated.

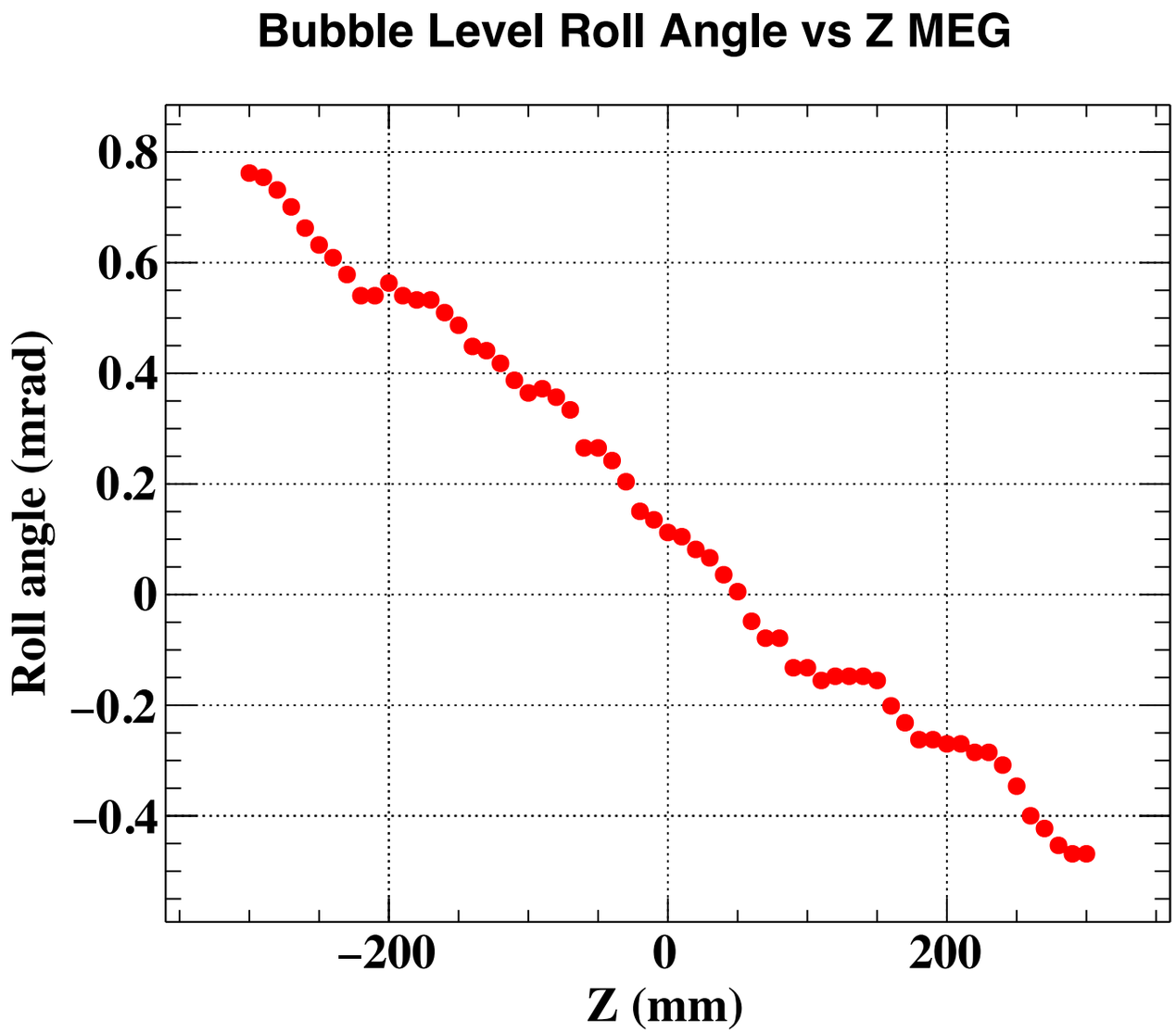
Back Up

Misalignment

- The rotation axis was not perpendicular to the front surface of the collimator.
  - Gamma-ray beam direction is tilted.
- QPD was not correctly calibrated.
  - Found in the verification with laser tracker.

QPD


Δ kx and Δ ky
Δ kx
Δ ky
Δ kx or Δ ky[rad]
0.002
0.0015
0.001
0.0005
0
−0.0005
−0.001
−0.0015
−0.002
−300
−200
−100
0
100
200
300
Z encoder [mm]


Bubble Level Roll Angle vs Z MEG
Roll angle (mrad)
0.8
0.6
0.4
0.2
0
−0.2
−0.4
−200
0
200
Z (mm)

Measured MPPCs