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

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ICEPP, The University of Tokyo

MEG II実験液体キセノンガンマ線検出器におけるMPPCのアラインメント

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Core-to-Core Program

The University of Tokyo
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  • MEG II Experiment
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  • Alignment

• Result
  • Thermal Contraction / Resolution
  • Reference position

• Summary
μ→eγ search

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

\* \* \* \* \* \* \* \* \\
\* 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

MEG II 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
- 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 mm² 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.
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

- MPPC: 15mm width
- LXe ~3mm
- X-ray
- Alignment of the beam
- Vertical Incidence to LXe

Properties of X-ray Beam

- Source: $^{57}\text{Co}$
- Activity:
  - 3GBq (2017)
  - 1.2GBq (2018)
- Beam Size: 1.5×40mm²
- Energy:
  - 124keV (85%)
  - 136keV (15%)

- An X-ray beam functions as a local light source in LXe.
- Requirements
  - Alignment of the beam
  - Vertical Incidence to LXe
- moves in z.
- rotates in phi direction.
• 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.
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

**X-ray Signal**

- X-ray signal was observed with the trigger rate with a low threshold.

**Consistency of global shape**

- **The relative position of MPPCs was consistent** between the position at LXe temperature and that at room temperature.
  - Reasonable shrinking effect is considered.

**Inconsistency of reference position**

- However, **the laser survey and X-ray survey indicated different position of references.**
## 2018 X-ray Measurement

### 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.

### Comparison of 2017 and 2018

<table>
<thead>
<tr>
<th></th>
<th>2017</th>
<th>2018</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Alignment of Device with laser tracker</strong></td>
<td>Only once</td>
<td>Frequent (3 times)</td>
</tr>
<tr>
<td><strong># of references</strong></td>
<td>6</td>
<td>16</td>
</tr>
<tr>
<td><strong>Source Activity (half life: 270d)</strong></td>
<td>3GBq</td>
<td>1.2GBq</td>
</tr>
</tbody>
</table>

### Temperature History
- **Room temp (290K)**
- **LXe temp (170K)**
- LXe transfer to tank
- Heat up
- LXe transfer to detector
- Cool down
- LXe transfer to detector
- Cool down

### Source Activity (half life: 270d)
- **2017**: 3GBq
- **2018**: 1.2GBq
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.
Offline Event Selection

- 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

• 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.
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.
• 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.
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 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

\[(x,y,z) \rightarrow (R,z',\phi')\]

Origin: \((x_0,y_0,0)\)
Step 2: Coordinate Transformation

- The position of well-fitted MPPCs is transformed into the cylindrical coordinate.
Step 3: Fitting With Mesh

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

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

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

- Fitting was separately carried out for \( Z \) and \( \phi \).
- Chi-square is minimized by MIGRAD.
Step 4: Interpolation

- The position of all MPPCs is interpolated.
• Interpolated position matches the measured position at an accuracy of 180um.
Combination of both measurements in MEGII

<table>
<thead>
<tr>
<th>Laser</th>
<th>Xray</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temperature</td>
<td>△ room temperature</td>
</tr>
<tr>
<td>Coordinate</td>
<td>✓ 3D(x,y,z)</td>
</tr>
</tbody>
</table>

- 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.
Fitting Parameters

<table>
<thead>
<tr>
<th>Parameters</th>
<th>2017</th>
<th></th>
<th></th>
<th>2018</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Alpha[deg]</td>
<td>-25.04</td>
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<td>Beta[deg]</td>
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<tr>
<td>Gamma[deg]</td>
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<td>XOffset[mm]</td>
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<tr>
<td>Scaling factor</td>
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<td>0.0001</td>
<td>0.9987</td>
<td>0.00024</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- 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