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

![MEG II Setup Diagram]
Introduction - Liquid Xenon Detector Upgrade

- We have replaced 216 2-inch PMTs on the $\gamma$-entrance face with 4092 12*12 mm$^2$ VUV-MPPCs.
  - High granular & uniform readout
  - Better position & energy resolution
  - Less material of the entrance face
  - Better detection efficiency
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<0.5 mm accuracy is required
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.
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.
We used a collimated X-ray beam from $^{57}$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 80um in $\phi$ and 30um in $z$. 
• We scanned the surface of MPPC array in z and φ 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 LXe temperature.
• The position of ~50% of all MPPCs was measured with a resolution of 250um(=350/$\sqrt{2}$).
Combination of both measurements

<table>
<thead>
<tr>
<th></th>
<th>Laser</th>
<th>Xray</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temperature</td>
<td>Δ room temperature</td>
<td>✔ LXe temperature(170K)</td>
</tr>
<tr>
<td>Coordinate</td>
<td>✔ 3D(x,y,z)</td>
<td>Δ 2D(z,φ)</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
  - $\sigma_{\Delta z} \sim 300 \text{um}$
  - $\sigma_{\Delta \phi} \sim 0.4 \text{mrad} (\rightarrow 260 \text{um} @ \text{incident face})$
- We obtained the position of all MPPCs at an accuracy of better than 350um.
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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  \(~2.5 \text{ mm}\) resolution is expected
Position Reconstruction

• 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.

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

This chi-square is minimized
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

- $\mu \rightarrow e\gamma$ 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 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.
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.

- 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 \((\theta, \phi)\)
- Chi square is minimized

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

Origin: \((x_0,y_0,0)\)

\((u,v,w)\)

\(z = 0\)
Step 2: Coordinate Transformation

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

$$Z_{mesh_{ij}} = pZ_0 + i \times pZ_1 + j \times pZ_2$$

$$\phi_{mesh_{ij}} = p\phi_0 + j \times p\phi_1 + i \times p\phi_2$$

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

- 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.
Consistency of Both results

- 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.

\[ \phi \text{ vs } R \]

Red: @room temp.
Blue: @LXe temp.
Expected Resolution from MC

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

Red: fit region=2
Green: fit region=3
Blue: fit region=5
Yellow: fit region=7
Magenta: fit region=11
Cyan: fit region=13
Uncertainty of the position resolution

- 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.

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

**Hit position spread:**
- $\approx 3\text{mm}(\text{MC})$

**Geometry**
- Collimator: $R \approx 56\text{cm}$
- Hit position: $\approx 3\text{mm}(\text{MC})$
- outer cryostat: $R = 60\text{cm}$
- MPPCs mounted: $R = 65\text{cm}$