MEG II実験のための液体キセノンガンマ線検出器のアップグレードの現状

東京大学素粒子物理国際研究センター
岩本敏幸 他MEG IIコラボレーション
日本物理学会 2015年秋季大会
大阪市立大学 杉本キャンパス
\[ \mu^+ \rightarrow e^+ \gamma \]

- Many parameters and issues are not explained by SM.
- No definitive discovery of new physics from any experiments yet.

**Lepton flavor violation**

- Neutrino oscillation is violating lepton flavor.
- Long history in charged lepton (\( \mu^+ \rightarrow e^+ \gamma \), \( \mu \rightarrow e \), \( \mu \rightarrow 3e \), etc.) search, but no discovery yet.
- \( \text{BR(} \mu \rightarrow e \gamma \text{)} \approx 10^{-54} \) in the SM with neutrino mass.
- Observation of \( \mu \rightarrow e \gamma \) decay is a clear signature of new physics.
- Many new physics such as SUSY-GUT, SUSY-seesaw etc. predict large \( \text{BR}( \mu \rightarrow e \gamma ) \).
- MEG experiment set an upper limit of \( \text{Br}(\mu^+ \rightarrow e^+ \gamma) = 5.7 \times 10^{-13} \) in 2013, and the final result will be published this year (金子 25aSG1).
• Target sensitivity: $4 \times 10^{-14}$
  (one order of magnitude improvement from the MEG experiment)
MEG Liquid Xenon Detector

- LXe 900L (2.7ton) homogeneous detector
  - High light yield, fast response, good uniformity
  - World largest LXe detector (still?)
- UV sensitive 846 2” PMTs directly in LXe
- Low T (165K), LXe scintillation $\lambda=175$nm
- Basically it was working well. However, limited resolution against shallow events
MEG II LXe detector

- 2" PMT
- Smaller photo sensors for γ-ray incident face
- Increase granularity
- Different PMT angle of lateral face
- Uniform response
- Wider incident face
- Reduce shower leakage
- Increase #PMTs on top/bottom faces
- Uniform response
Performance

- Improvements
- Better imaging power
- Energy resolution <1% (2-3%)
- Position resolution ~2mm (5-6mm)
- Detection efficiency 9% improvement
- Simulation study by S. Ogawa (27aSN-10)
LXe detectors in the world

- LFV
  - MEG (2008-2013), MEG II
- Double beta decay
  - EXO-200, nEXO
- Medical Imaging
  - LXe compton PET, TOF PET
- Gamma-ray Astrophysics
  - LXe Compton telescope, ionization calorimeter

WIMP physics: sensitivity

- E = [3-70] pe ~ [4-50] keV
- 200 t y exposure, 99.98% discrimination, 30% NR acceptance, LY = 8 pe/keV at 122 keV
- Note: “nu floor” = 3-sigma detection line at 500 CNNS events above 4 keV

- Dark Matter search
  - Single-phase
    - XMASS
  - Dual-phase TPC
    - XENON1T (3.3ton LXe), start soon
    - XENONnT (7ton)
    - LZ (7ton) in 2016
    - DARWIN-LXe (30-50tons!) after 2020

LXe detectors play the leading part in many fields
VUV SiPM

- Silicon photomultiplier (SiPM)
  - already used in many other experiments
  - commercial ones were not sensitive to VUV light.
- HPK and MEG developed VUV sensitive MPPC (S10943-4186(X))
- Large area MPPC (12x12mm) is realized with four series connection on PCB.
- 4092 MPPCs will be used in the front face of the MEG II LXe detector (K. Ieki, 27aSN-9)
- Other experiments are also testing this model
  - EXO, XENON, mu2e (BaF2, 200nm), ...
  - Application also for LAr scintillation light (128nm) detection (ANKOK).
  

- Promising device for many applications
Upgrade status

- Detector cryostat check
- MPPC production, mass test
- Support structure production
- Alignment
- Calibration devices
**X-ray test**

- Detector cryostat has a thin entrance window to reduce gamma-ray interaction in front of the LXe detector.
- Whole region of the inner surface was scanned by X-ray, and **the honeycomb structure is fine**!
- Want to check the status, but direct access is limited.
- Next, gas pressure test in October.

Figure 7. Cross section of transition area of carbon-fiber honeycomb panel.
MPPC PCB

- MPPC mounting method
  - 22 MPPCs on a PCB
  - 93 PCBs at both US/DS
  - 4092 MPPCs on the inner face
- Series connection on the PCB
- PCB has multi-layers to realize coaxial like signal lines surrounded by separate ground lines and ground layers
- Signals are transmitted with RG178 thin cables from the PCB MMCX connectors to the feedthrough
MPPC Support structure

- Any space between MPPC and Cryostat wall cause detection inefficiency
- Need to fill the gap with light material
Feedthrough

- Coaxial like signal line surrounded by ground lines/planes
- Separate ground lines inside PCB
- Cable soldering at both ends
PMT support structure

- Modification
  - Wider inner face
  - PMT angle of lateral sides
- Top/bottom, and lateral PMT support structure will be modified
- To reduce the total volume of the cables, thinner cables (RG178 for signal cables, RG196 for HV) will be used
- Test assembly in November
New refrigerator

- Increased # MPPCs, cables
- More heat income
- More powerful refrigerator is necessary
- Pulse tube refrigerator (current system, 200W) + GM refrigerator (AL300, >300W) outside the detector hut
- Vacuum insulated tube is connected from the refrigerator to the detector
- The vessel is constructed now. Once the refrigerator is delivered, cooling power test will be done at PSI.
• Position resolution: **2mm**

• We want to know the **MPPC position within 0.5mm precision**

• MPPC position scan by PSI 3D laser scan beforehand

  • Thin window was already scanned by PSI 3D laser, and MPPC scan will be done after all the MPPCs are mounted on the inner face

• Monitor the cryostat shape with LXe (SUS cryostat will shrink with the temperature)

• Later X-ray injection from the COBRA center with LXe?
Calibration devices

- LED for gain, cross talk + after pulse etc.
- Alpha for PDE, QE estimate
- If we need \#p.e. > 10, we need new alpha wire configurations
- Production for four months

Wire of \approx 120\,\text{micron} diameter
Material: gold plated tungsten
Total length 150\,\text{cm}
Spacing of dot sources 90.5\,\text{mm}
Linear dimension of dots 1—2\,\text{mm}
Activity \approx 100\,\text{Bq per dot}

MEG I
MEG II

PDE case 1

Reference Mark
Am dots
Summary and schedule

• Summary
  • We will upgrade the LXe detector by replacing PMTs on the gamma-ray incident face with MPPCs, increasing the length of the inner face, modifying the lateral PMT angle, and the number of PMTs on top/bottom faces.
  • We are now in a construction phase, MPPC, support structure, feedthrough, a new refrigerator, etc.

• Schedule
  • Components will be ready in January-February in 2016
  • Assembly by April in 2016
  • Installation & liquefaction in the area in May
  • Calibration with LED, alpha, cosmics, Cockcroft-Walton, π0 calibration, together with purification in June - August, ready for engineering run
Structure of the inner window

❖ a thin metal sheet (0.4mm SUS)
❖ honeycomb-based structure combined with carbon fiber sheets
  ❖ thickness of honeycomb 24mm(aluminum alloy), density 0.05g/cm3, HC5052 (hexcel)
  ❖ The panel is fixed to the inner vessel with screws at the edges of the panel
❖ Outer vessel (0.7mm SUS)

Table 1. Specifications of honeycomb panel used in MEG liquid xenon detector.

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Honeycomb material</td>
<td>Aluminum 5052</td>
</tr>
<tr>
<td>Hexagonal cell thickness</td>
<td>0.0254 mm</td>
</tr>
<tr>
<td>Hexagonal cell size</td>
<td>4.76 mm</td>
</tr>
<tr>
<td>Hexagonal cell height</td>
<td>19 mm</td>
</tr>
<tr>
<td>Carbon fiber sheet</td>
<td>T300 (Toray)</td>
</tr>
<tr>
<td>Carbon fiber sheet thickness</td>
<td>1.5 mm</td>
</tr>
<tr>
<td>Prepreg layers per sheet</td>
<td>0.13 mm × 8</td>
</tr>
<tr>
<td>Glue</td>
<td>EA 9361 (Hysol)</td>
</tr>
</tbody>
</table>
Measurement condition

Manufacturer: Philips
Type: MG 160 L
Voltage: max. 160 KV (for the actual examination we will use approx. 80-100 KV)
Tube Current Intensity: max 10 mA
Focal Spot Size: 1.6 mm

Objekt: Others
Aufnahmedatum: 07.03.2015 12:12:47
Röntgen: Strom [mA]=4 Spannung [kV]=90 Belichtungszeit [s]=20
Röntgenplatz:<??> Hersteller: Typ:
Bildgeber: CR-System / A212306005 / A212306005
Projekt: PSI liquid xenon dedector, PSI liquid xenon dedector, 07.03.2015, 15110253
Firma: Qualitech AG, 2883629035
DPI= 503 | 503
X-ray to measure MPPC position

- X-ray beam x=y=0, precisely known z, theta=\(\pi/2\), precisely known phi
- Appropriate energy
  Interaction length in LXe <1cm, Compton electrons range<1mm
- Possible source
  Cobalt-57, 122/134keV or X-ray tube
- Alignment
  0.2mm, 0.2mrad required
- Collimated beam
  Slit like 10cm, 0.1mm slit x 5mm thickness