μ⁺ → e⁺γ 探索実験 MEG II
2018年度の展望

Y. Uchiyama (The University of Tokyo) for the MEG II collaboration

日本物理学会第73回年次大会 (22 Mar, 2018)
Physics of $\mu^+ \rightarrow e^+\gamma$

- Charged Lepton Flavor Violation
  - Never observed yet. Practically forbidden in SM by tiny neutrino masses
- But, we know ‘flavors’ are violated in SM

- Why not in physics beyond SM?
  1. Generally no reason to be conserved.
  2. Even with some symmetry, contribution from the known $FV$ is unavoidable via radiative corrections in the new physics.

- Why charged lepton?
  1. No SM contribution, no theoretical uncertainty.
  2. Probably, connected to the mystery of neutrino.

- Many theoretical predictions are within experimental reach
MEG experiment

- $\mu^+$: World’s most intense DC muon beam @ PSI
- $\gamma$: Detect with liquid xenon scintillation detector
- $e^+$: Detect with gradient B-field spectrometer (drift chamber & timing counter inside)

Search $1.7 \times 10^{13}$ muon decays for $\mu^+ \rightarrow e^+\gamma$

No excess was found and new upper limit was set:

$$B(\mu^+ \rightarrow e^+\gamma) < 4.2 \times 10^{-13}$$

(90% C.L.)

(while $5.3 \times 10^{-13}$ expected)

$\times 30$

improvement from the prev. experiment

March 22, 2018

YUSUKE UCHIYAMA
**MEG II: \( \times 10 \) improvement**

Search for \( \mu^+ \to e^+\gamma \) down to \( 6 \times 10^{-14} \) (90% C.L. sensitivity)

- \( 3 \) years run
- \( B(\mu^+ \to e^+\gamma) < 4.2 \times 10^{-13} \) (90% C.L.)
  - (while \( 5.3 \times 10^{-13} \) expected)

- \( \times 2 \) intensity muon beam
- \( \times 2 \) resolution everywhere
- \( \times 2 \) efficiency

**MEG Upgrade Proposal**

**MEG II design**

**New**

- higher beam rate
- larger acceptance
- better resolutions
- moderate cost

**Search for \( \mu^+ \to e^+\gamma \)** down to
\[ 6 \times 10^{-14} \]
(90% C.L. sensitivity)

3 years run
Liquid xenon photon detector (LXe)

Pixelated timing counter (pTC)

Cylindrical drift chamber (CDCH)

Radiative decay counter (RDC)

Muon stopping target

Electronics & DAQ
Current status

- All the detectors except for CDCH are constructed.
- Pilot run with partial electronics was successfully carried out in Nov.–Dec.
Current status

- All the detectors except for CDCH are constructed.
- Pilot run with partial electronics was successfully carried out in Nov.–Dec.
- Struggle with the wire braking issue on CDCH.
- Struggle with the noise issue on the readout electronics.

⇒ >2 years delay from the original (2013) schedule.

- This year all the detectors will get ready.
- Full electronics will be ready toward the end of the year.

⇒ Carry out full engineering run, but not physics run this year.
Concentrate on issues and new things.
This talk is negatively biased.
Detectors in good shape/good progress last year
Skip in this talk. See dedicated talk in this/prev. meetings.
Cylindrical drift chamber

MEG I DCH
- ultra low-mass chamber (He:C₂H₆ 2 × 10⁻³ X₀)
- 16 modules
- 288 drift cells

MEG II CDCH
- ultra low-mass chamber (He:iC₄H₁₀ 1.6 × 10⁻³ X₀)
- 2-m long, single volume
- stereo angle
- 1280 active drift cells
- 13056 wires

1. Wire break problem
2. How to go this year
3. Future
Wire break

- We have reported the wire breaking issue several times

  - discovered Al wire is delicate to humidity. Took action in environmental control.
  - half-year stop, restarted wiring from scratch

  - probably human effect. Took action to review procedure, acceptance test.
  - 3 months stop

- **2017 Jul. Third problem**: Discover several wires had been broken after assembly.
  - 4 months stop to investigate/understand the problem and to take further measures.
Fundamental information

- Total 13,056 (sense wire 1,920) wires
- Ag plated Al field wire, 40 or 50 μm
- Nominal stretch +4 mm (40% of elastic limit)
- Acceptance test: 10 × +5mm stretch

The 3rd problem summary:

| 6 wires broken | out of 4540 | +4 mm | in 10 months |
| 8 wires broken | out of ~150 | +5 mm | in a week |

- All Al wires, no W wire.
- Evidence of acceleration by tension.

Aluminum 5056 alloy

Detailed investigation...
Corrosion (腐食)

環境
• 水分
• 被膜破壊性

電気化学

腐食

局部腐食

応力腐食割れ

異種金属接触腐食

腐食進行が引張力によって指数関数的に加速

破壊

\[
\text{Al(OH)}_3 + \text{Cl}^- \rightarrow \text{Al(OH)}_2\text{Cl} + \text{OH}^- \\
\text{Al} + 3\text{Cl}^- \rightarrow \text{AlCl}_3 + 3\text{e}^- \\
\text{AlCl}_3 + 3\text{H}_2\text{O} \rightarrow \text{Al(OH)}_3 + 3\text{H}^+ + 3\text{Cl}^-
\]

Al

(陽極)

\(i_C\)

Ag

(陰極)

\(i_A\)

木村「腐食概論」溶接科学誌79(2010)

“Stress Corrosion Cracking of Aluminum Alloys”
Metallurgical Trans. A 6a(1975)631

“Reliability study of wire bonds to silver plated surface”
IEEE Trans. Parts Hybrids Packaging PHP-13(1977)419
Corrosion（腐食）

電気化学
- 水分
- 被膜破壊性 アニオン (Cl⁻)

環境

腐食

応力腐食 割れ

局部腐食

異種金属 接触腐食

腐食進行 が 引張力によって 指数関数的に加速

Al₂O₃ & Al(OH)₃

上質なコーティング or コーティングなし

湿度を下げる、 チェンバーを封じる

破壊

“Reliability study of wire bonds to silver plated surface” IEEE Trans. Parts Hybrids Packaging PHP-13(1977)419

引張力を下げる

腐食に弱いアルミワイヤーにこだわる？？
Low-mass drift chambers

<table>
<thead>
<tr>
<th></th>
<th>Gas</th>
<th>Cell size</th>
<th>Sense wire</th>
<th>Field wire</th>
</tr>
</thead>
<tbody>
<tr>
<td>CLEO II</td>
<td>Ar:C₂H₆ 50:50</td>
<td>14 mm</td>
<td>20-µm Au-W</td>
<td>110-µm Au-Al, 110-µm Cu/Be</td>
</tr>
<tr>
<td>BESIII</td>
<td>He:C₃H₈ 60:40</td>
<td>12–16.2 mm</td>
<td>25-µm Au-W</td>
<td>110-µm Au-Al Crimp</td>
</tr>
<tr>
<td>Belle II</td>
<td>He:C₂H₆ 50:50</td>
<td>6–18 mm</td>
<td>30-µm Au-W</td>
<td>126-µm Al Crimp</td>
</tr>
<tr>
<td>COMET-Phase I</td>
<td>He:iC₄H₁₀ 90:10</td>
<td>16–16.8 mm</td>
<td>25-µm Au-W</td>
<td>126-µm Al Crimp</td>
</tr>
<tr>
<td>KLOE</td>
<td>He:iC₄H₁₀ 90:10</td>
<td>20–30 mm</td>
<td>25-µm Au-W</td>
<td>81-µm Ag-Al Crimp</td>
</tr>
<tr>
<td>MEG II</td>
<td>He:iC₄H₁₀ 85:15</td>
<td>6.6–9 mm</td>
<td>20-µm Au-W</td>
<td>40-µm Ag-Al Solder</td>
</tr>
</tbody>
</table>

- **KLOE** used same type of wire without any problem for **>10 years**
  Constructed under 50% R.H., never observed salt formation

Other material than Al is **not acceptable** from the resolution point of view.

- **Bare Al wire** could be a better alternative, but difficulty in soldering.
  (Naturally coated by Al₂O₃)
How to go this year

1. More strict humidity control: <20% locally
2. Reduce elongation to +3 or +3.5 mm
   - Since Aug, **no break** has happened.
   - Resumed assembly (27th Sep) to complete the chamber, but
   - reduce # of layers: 10 \(\rightarrow\) 9 layers
     - Reduced efficiency by 10%

- **Use & operate it this year**
  - Now closing chamber (humidity \(\rightarrow\) 0%)
  - Bring it to PSI in May by truck
  - then install in Jul
  - Commissioning \(\rightarrow\) engineering run

- Only the way to go; be aware of hidden/unexpected further problems
Wiring finally finished

Carbon fiber outer frame

Inner foil (Mylar)

Endcap part (sealed)
Future

- Form an **external committee by experts** to review
  - Called by PSI scientific committee in this spring
- the issues — whether we understand it

- and to discuss construction of **2nd CDCH**
  - With full layers
  - Better wire (if any), better treatment

- Take **1.5 years** to build
- Necessary budget is secured by INFN (Italy)
- Problem is the **human resource**
  - Construction in Italy in parallel with
  - Commissioning/operation/analysis of the 1st one
Readout electronics

- New DAQ/Trigger system
  - Use it for all MEG-II detectors in common
  - Dense & compact system to cope with increased # of channels.
  - Custom multi-functional readout board: **WaveDREAM**
    - Analog FE (programmable shaper & amplifier),
    - SiPM bias-voltage supply, waveform sampling (DRS4),
    - digitization, discriminator, FPGA-based trigger in one module
  - No pre-amplifier at detector side
  - Synchronization accuracy $< 20$ ps (over different crate modules)
Readout electronics

- New DAQ/Trigger system
- Use it for all MEG-II detectors in common
- Dense & compact system to cope with increased # of channels.
- Custom multi-functional readout board: WaveDREAM
  - Analog FE (programmable shaper & amplifier)
  - SiPM bias-voltage supply, waveform sampling (DRS4)
  - Digitization, discriminator, FPGA-based trigger
- No pre-amplifier at detector side
- Synchronization accuracy < 20 ps (over different crate modules)

- 2-stage amplifier
- Digitization
- Trigger
- Pole-zero cancellation
- Sync.
- HV supply

- SiPM signal waveform digitized at 2.0 GSPS
**Noise issue**

- **Observed large coherent noise**
  - Problem especially on LXe energy measurement
  - *Noise contribution larger than the target resolution.*
    - Factor 2–4 reduction necessary.
    - Drawback of granular readout of total-absorption calorimeter
      - ~5000 channels have to be summed.
      - → coherent noise more problematic

- **Efforts underway in hardware & software**
  - To solve before mass production for LXe.

---

Diagram:
- Detector
- Coaxial cables
- Feedthrough
- Sensors
- Ground
- Electronics
- Power
- Clock
- Offline subtraction of noise from system clock

---

March 22, 2018
YUSUKE UCHIYAMA
μ⁺ stopping target

- MEG II new target system
  - 150 μm thick scintillating sheet (BC400B)

Two CCD cameras view the target

1. Upstream
   - Take pictures of the dot pattern
   - To reconstruct target position and shape in photogrammetric way
   - The CCD camera didn’t work well in B field → search for alternative

2. Downstream
   - In-situ measurement of beam profile & intensity by detecting the scintillation light

Reduce the main systematic uncertainty in MEG

March 22, 2018
YUSUKE UCHIYAMA
### Schedule (summary)

<table>
<thead>
<tr>
<th></th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
<th>11</th>
<th>12</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>PSI beam-time start</td>
<td>Elec. for LXe ready</td>
<td>Elec. for CDC ready</td>
<td></td>
</tr>
<tr>
<td></td>
<td>CDC deliver to PSI</td>
<td>CDC installation</td>
<td>Mass production of elec.</td>
<td>Beamline setup</td>
<td>Engineering run</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- All detectors will be ready by summer
- LXe with full elec. from autumn
- Engineering run from Oct. to Dec.
- Physics run from 2019

MEG II design
(https://arxiv.org/abs/1801.04688)
Detensioned wires drag on teflon band

KS test with a Flat distribution: $P_{KS} = 0.01\%$
CDCH: Wires acceptance tests

- **Optical measurement** of the position of 3 reference markers on wire-PCBs
- **Alignment** and **extra-elongation** tests: +1mm wrt to the nominal wire length repeated 10 times (62.5% of the elastic range)
Humidity effect

- Test were performed in Lecce and in Pisa
  - Aluminium wires were immersed or sprayed with demineralized water and with 3% water solution of NaCl
  - In all cases wire breaking of the type observed on the chamber were induced.
- The salt near the wire edge contains Al and O: it could be aluminium oxide or aluminium hydroxide.
Past experience

- The KLOE experiment used the same type of wire
  - Core of aluminium 5056 of 80 um
  - Layer of ~0.3 um of silver

- They wired the chamber in 50% rh environment to test with HV each wire layer before starting with the following one. The wiring went on for 9 months.

- The salt formation was never observed. They were not aware of the intrinsic fragility of this type of wire.

- The chamber is still operational 10 years after the production

- The KLOE wire shows the same salt production of our wires if sprayed with water
Placement of Preamps

- No possibility to put preamps inside LXe (600W)
- No possibility to put preamps closer to detectors
- No guarantee that noise would get better

~5000 cables