The MEGII detector
Paolo W. Cattaneo (INFN Pavia) on behalf of MEGII collaboration
\[ \mu \to e\gamma \]

Standard Model incl. Dirac \( \nu \)'s:

\[
\text{Br}(\mu \to e\gamma) = \frac{3\alpha}{32\pi} \left| \sum_{i=2,3} U_{\mu i}^* U_{ei} \frac{\Delta m^2_{1i}}{m_W^2} \right|^2 < 10^{-54}
\]

Impossible to detect

\[ \mu \to e\gamma \] and other CLFV processes have never been observed

New Physics (e.g. SUSY):

\[
\text{Br}(\mu \to e\gamma) \approx \frac{\alpha^3 (\delta_{LL})^2_{\mu e}}{G_F^2 m_{\text{SUSY}}^4} \tan^2(\beta) \\
\approx 10^{-11} \sim 10^{-14}
\]

Small but not impossible!

Observation of CLFV is clear evidence of new physics!
Detection principle

Signal:

BG 1: Radiative muon decay

- $E_\gamma < 52.8$ MeV
- $E_e < 52.8$ MeV
- $\Theta_{e\gamma} < 180^\circ$
- $T_{e\gamma} = 0$ s

BG 2: Accidental coincidences

Positron from Michel decay
- $E_\gamma < 52.8$ MeV
- $E_e < 52.8$ MeV
- $\Theta_{e\gamma} < 180^\circ$
- $T_{e\gamma} \sim$ flat

Photon can come from:
1. Radiative muon decay
2. Positron annihilation in flight
3. Positron Brehmsstrahlung

$$N_{\text{acc}} \propto R_\mu^2 \cdot (\sigma_{E_\gamma})^2 \cdot \sigma_{E_e} \cdot (\sigma_{\Theta_{e\gamma}})^2 \cdot \sigma_{T_{e\gamma}}$$
The MEG/MEGII experiment

• The MEGII Collaboration: ~60 physicists, 12 institutes

• Detector location: The Paul Scherrer Institut
  Zürich, Switzerland

• The world’s highest intensity muon & pion beams
  ($\pi E5$: DC surface muons, $R_\mu > 10^8 \mu^+/s$, $|p_\mu| \approx 28$ MeV/c)
Cyclotron

MEG detector area

MEG control room

The MEGII detector
Dedicated detector with asymmetric coverage ($\Omega_{MEG}/4\pi = 11\%$):

1. Low-mass positron spectrometer with gradient B-field to reconstruct the positron track
2. Innovative liquid Xenon detector to measure the gamma position, time and energy
3. High performance DAQ system: multi-GHz waveform digitization of all 3k channels
4. Arsenal of calibration & monitoring tools to make sure we understand our detector
The MEG/MEGII COBRA magnet

Superconducting COBRA magnet:

- Solenoidal gradient B-field: 0.5 - 1.3 T
  (COnstant Bending RAdius, quick
  sweep out)

- 0.2 $X_0$ fiducial thickness
MEG-II

Goal: 10x improvement in sensitivity ($\sim 5 \times 10^{-14}$)

How?
- Higher beam rate & efficiencies
- Improved detector resolutions
- Moderate costs ($\sim 5$ M$\$$)

Upgrades:
1. Increased beam intensity ($7 \times 10^7 \mu^+/s$)
2. Thinner (140 $\mu$m) or active target
3. Enlarged cylindrical single-volume DC
4. Pixelated TCs with SiPM readout
5. New high-bandwidth DAQ boards
6. Enlarged LXe volume, SiPM readout
7. RMD counters
Gamma detector

Upgrade:

- Replace PMTs on inner face of detector by MPPCs (SiPMs)
- Extend inner face along z-direction and modify PMT layout at lateral faces

MPPC development:

- VUV sensitive (PDE > 15%)
- Large area sensor (12x12 mm²)
- Fast response (short pulse using novel SiPM connection method)
Gamma detector

Improvements:
• Improved detector response at sides
• Improved detection efficiency (+10%)
• Improved position and energy resolutions
• Improved pile-up handling

Status:
• Ready to be installed this summer

Pile-up MC event (28 + 25 MeV):
Gamma detector

Position resolution (mm)

Photon conversion depth (cm)

Red: PMT (present)
Blue: MPPC (upgrade)

40% 60% of all events

Depth < 2 cm (40% of all events):

- Present: \( \sigma_E = 2.4\% \)
- Upgrade: \( \sigma_E = 1.1\% \)

Depth \( \geq 2 \text{ cm} \) (60% of all events):

- Present: \( \sigma_E = 1.7\% \)
- Upgrade: \( \sigma_E = 1.0\% \)
Electronics

# of readout channels:

Motivation:
- Increased # of readout channels
- Higher bandwidth to preserve full waveform digitization
- Higher event rate → faster readout

WaveDREAM board:
Multi-functional purpose board that integrates analog frontend, trigger, digitization (DRS4 chips, 2 GHz sampling) and HV supply on a single board

Status:
Design finished
Production between end 2017 and begin 2018
Positron detector upgrade

e^+ are scattered by frame or preamp

e^+ tracking up to the TC
Positron detector

Cylindrical DC:
- Single-volume, low-Z gas mixture (He:iC$_4$H$_{10}$ = 85:15)
- 1200 sense wires (2 m long, 20 μm diameter) with stereo angle (7°) configuration

DC improvements:
- Larger tracking volume
- Less material ($1.7 \times 10^{-3}$ $X_0$ per track)
- Finer granularity (7×7 mm$^2$ drift cells), higher multiplicity (15 – 60 hits per $e^+$)
- Possibility of cluster counting under study

Improvements:
- Improved detection efficiency (x2)
- Improved timing resolution (eliminates 75 ps contribution to $\sigma_t$)

TC improvements:
- Faster timing ($\sigma_{tile} < \sigma_{bar}$)
- Finer granularity (16 bars $\Rightarrow$ 256 tiles), higher multiplicity (1 bar $\Rightarrow$ 9 tiles per $e^+$)

Pixelated TCs:
- 512 ultra-fast plastic scintillator tiles
- Each tile read-out by multiple SiPMs

The MEGII detector

Paolo W. Cattaneo INFN Pavia  Mar 07, 2017
Cylindrical Drift Chamber

Long R&D to optimize a chamber design able to stand the design higher rate and improve resolution. Described in detail in the next talk:
G. Tassielli “The construction technique of high granularity and high transparency Drift Chamber for MEGII upgrade”
Pixelated Timing counter

Long R&D to optimize scintillator, SiPM, Connection, bias, wrapping etc.

Single tile:

AdvanSiD SiPM (6-series):

Single tile prototype tests using $^{90}$Sr source:

![Graph showing resolution vs. over voltage/SiPM (V)]
Pixelated Timing counter

Multi hit counters exploited to improve resolution
Tested at BTF (LNF) and PSI with magnetic field.

Beam test @ LNF:

\[
\begin{align*}
\langle N_{\text{tiles}} \rangle \text{ per track} &= 9 \\
\sigma_t &\propto 1/\sqrt{N_{\text{tiles}}} \\
\end{align*}
\]

Status:
- Excellent resolution achieved with single tile prototypes
- Resolution improvement using multiple tiles confirmed at BTF and PSI (pre-engineering run)
- Tile configuration and detector layout finalized
- All detector ready this fall
Laser system for calibration

Diagram showing the laser system for calibration, including components such as the laser head, mode scrambler, photodiode, optical fibre, optical switch, optical splitter, DAQ electronics, and counter module.

The MEGII detector
Paolo W. Cattaneo INFN Pavia
Mar 07, 2017
Radiative Decay Counter

The RDC detect low momentum positrons time-correlated with high energy photons (>48MeV). These photons are a major source of accidental background when associated to positron from different muon decay.
Calibration & Monitoring

### LED
PMT Gain

### Alpha
PMT QE

### Absorption
Am source on wire

### Profile beam scan with scintillating fiber
New for MEGII

### Radiative Decay
\[ \mu \rightarrow e\nu\nu\gamma \]
Relative timing
Similar topology

### Michel Decay
\[ \mu \rightarrow e\nu \]

### e⁺ Mott-scatter
Monochro, tunable momentum

#### Ni-n
9MeV \(\gamma\) source
n-Generator

#### AmBe
AmBe source 4.4MeV \(\gamma\) source

#### C-W accel.
Li(p,\(\gamma\))Be
- 18MeV \(\gamma\)
B(p,\(\gamma\))C
- 4,11MeV 2\(\gamma\)

### CosmicRay
DC alignment
TC uniformity
LXe monitor

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*The MEGII detector*  
Paolo W. Cattaneo INFN Pavia  
* Mar 07, 2017
MEG-II outlook

<table>
<thead>
<tr>
<th>Resolution</th>
<th>MEG I</th>
<th>MEG II</th>
</tr>
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<tbody>
<tr>
<td>$e^+$ momentum</td>
<td>0.31 MeV</td>
<td>0.13 MeV</td>
</tr>
<tr>
<td>$e^+$ angle</td>
<td>8.7/9.4 mrad</td>
<td>3.7/5.3 mrad</td>
</tr>
<tr>
<td>$e^+$ vertex</td>
<td>2.4/1.2 mm</td>
<td>1.6/0.7 mm</td>
</tr>
<tr>
<td>$e^+$ time</td>
<td>107 ps</td>
<td>33 ps</td>
</tr>
<tr>
<td>$\gamma$ energy</td>
<td>1.27/0.9 MeV</td>
<td>0.58/0.53 MeV</td>
</tr>
<tr>
<td>$\gamma$ position</td>
<td>5/5/6 mm</td>
<td>2.6/2.2/5 mm</td>
</tr>
<tr>
<td>$\gamma$ time</td>
<td>67 ps</td>
<td>76 ps</td>
</tr>
</tbody>
</table>

Efficiency

<table>
<thead>
<tr>
<th></th>
<th>MEG I</th>
<th>MEG II</th>
</tr>
</thead>
<tbody>
<tr>
<td>trigger</td>
<td>$\approx$ 99%</td>
<td>$\approx$ 99%</td>
</tr>
<tr>
<td>$\gamma$</td>
<td>63%</td>
<td>69%</td>
</tr>
<tr>
<td>$e^+$</td>
<td>40%</td>
<td>88%</td>
</tr>
</tbody>
</table>

Engineering run end of 2017
Physics run end of 2018
On behalf of the MEGII Collaboration

MEGII Collaboration @ UCI, May 2014

Thank you for your attention!
MEG-I conclusion

Most recent analysis:

Combined 2009-2011 analysis did not show a significant excess of signal over background, resulting in a factor 4 improvement of the world’s most stringent \( \text{BR}(\mu \rightarrow e\gamma) \) upper limit:

\[ \text{BR}(\mu^+ \rightarrow e^+\gamma) < 5.7 \times 10^{-15} \text{ (90\% C.L.)} \]

MEG-I outlook:

- MEG-I data taking finished in 2013
- Total statistics incl. 2012+2013 data is expected to double
- Final MEG-I results coming this summer

**Observed BR limits & sensitivity:**

- **MEG-I data statistics**

- **Accumulated DAQ days**

\[ \frac{\text{Norm. factor}}{10^{-13}} \]

\[ 0 \quad 1 \quad 2 \quad 3 \quad 4 \]

\[ 2009 \quad 2010 \quad 2011 \quad 2012 \quad 2013 \]
Drift chamber R&D

Cosmic ray telescope:

Single hit resolution: 105 μm

Beam tests @ LNF and PSI:

Single hit resolution: 125 μm

Status:

- Prototypes successful, resolution and ageing better than design specs
- Chamber design finalized
- Mock-up chamber with full sector of wires to be tested at PSI this fall