The MEG experiment.

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On behalf of MEG collaboration

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MEG HOME

Switzerland
PSI, ETH-Z

Italy
INFN + Univ.: Pisa, Genova, Pavia, Roma I & Lecce

USA
University of California Irvine, UCI

MEG Collaboration
some 65 Physicists
5 Countries, 14 Institutes

Russia
BINP, Novosibirsk, JiNR, Dubna

Japan
Univ. Tokyo, KEK, Waseda Univ., Kyushu Univ.
Why $\mu^+ \rightarrow e^+ \gamma$

- cLFV Forbidden in SM (background: $\text{Br}(\mu^+ \rightarrow e^+ \gamma) < 10^{-54}$)
  Discovery will be an unambiguous evidence of new physics.
- So far, no cLFV signal has been observed.
- Many new physics beyond SM (e.g. SUSY, Extra dimensions etc.) predict observable $\text{Br} (10^{-14} \text{ --- } 10^{-11})$
- Complementary search of new physics:
  - LHC Run 2
  - New experiments to search for other muon channels
    ($\mu \rightarrow e$ conversion, $\mu \rightarrow eee$)
Signal and backgrounds

**Signal**  $\mu^+$ decay at rest

- 52.8 MeV (half of $M_\mu$) ($E_\gamma, E_e$)
- Back-to-back ($\theta_{e\gamma}, \phi_{e\gamma}$)
- Timing coincidence ($T_{e\gamma}$)

**Accidental background** (dominant)

Michel decay $e^+ +$ random $\gamma$

Random timing, angle, $E < 52.8$ MeV

**Radiative muon decay**

$\mu^+ \rightarrow e^+\nu\nu\gamma$

Timing coincident, not back-to-back,

$E < 52.8$ MeV
Key points of the experiment

- high quality & rate stopped $\mu$-beam $\Rightarrow$ surface muon beam, $(E \times B)$ Wien filter, SC-solenoid-focusing+degrador.
- $e^+$ magnetic spectrometer with excellent tracking & timing capabilities $\Rightarrow$ COBRA magnet, DCs & TCs.
- photon detector with excellent spatial, timing & energy resolutions $\Rightarrow$ 900 litre LXe detector (largest in world).
- Stable and well monitored & calibrated detector $\Rightarrow$ Arsenal of calibration & monitoring tools.
Layout of the experiment
Layout of the detector

The important part – gradient field COBRA magnet:
tracks radius is independent on incident angle at 52.8 MeV/c
Beam line

- High-intensity DC surface muon beam - $\pi E5+MEG$
  $\Rightarrow$ capable of $>10^8 \mu^+/s$ at 28 MeV/c (optimal rate $3\times10^7/s$)
- “pure” muon beam - Wien filter (ExB)+Collimator system
  $\Rightarrow \mu$-e separation at collimator $>7.5\sigma$ (12 cm)
- Small beam-spot + high transmission - BTS
  $\Rightarrow$ focus enhancement, beam $\sigma$~10 mm at target
  $\Rightarrow$ second focus at centre BTS – degrader 300 $\mu$m
- Thin stopping target + minimal scattering – end-caps
  $\Rightarrow$ 18mg/cm$^2$ CH$_2$ target at 70°+He COBRA environment + remote Target & End-cap insertion system
Positron spectrometer

- SC COBRA Magnet
- Gradient Bfield (1.27-0.5) T
- Constant Bending Radius
- 0.2 $X_0$ fiducial thickness
- $\gamma$-transparency 95%
- NC Compensations coils reduce Bfield at Calorimeter $< 5mT$ at PMT positions
Positron spectrometer

(a) “MEG” positrons

(b) Lower momentum positrons: Don’t trigger DAQ
Positron spectrometer

- **Drift Chambers**
  - 16 radial, staggered double-layered DCs
  - each 9 cells with “Vernier” cathodes (5 cm pitch)
  - 50:50 He/C$_2$H$_6$
  - Ultra-thin $2 \cdot 10^{-3} X_0$ along $e^+$ path

Momentum resolution $\langle \sigma p/p \rangle \ 6\%$
Angular resolution ($e^+$) $\phi \sim 7 \text{ mr}$ $\theta \sim 10 \text{ mr}$
Positron spectrometer

- **Timing Counter Arrays**
- 2 arrays of each –
  15 axial scintillator bars BC404 + 2” fine mesh PMT
  $e^+$ impact point + timing intrinsic $\sigma_t \approx 70$ps over 90 cm
- 256 orthogonal radial scintillating fibres BCF-20 + APDs triggering (angular matching)
Calorimeter

- Largest LXe calorimeter in the world 900 litres \( \Delta \Omega / 4\pi = 10\% \)
- Fast response (4, 22 ns) - minimize “pileup”
- Large light-yield \( \sim 80\% \) NaI
- high density, short \( X_0 \)
- Homogeneous medium uniform response, no segmentation needed
- Sensitive to impurities at sub –ppm level (mainly \( H_2O, O_2, N_2 \))
- Scintillation light used for shower reconstruction \( \lambda = 175 \) nm
- 846 PMTs wall-mounted inside LXe-volume signals digitized @ 1.6 GHz
- Light material between PMTs
- Thin honeycomb window
- 14 \( X_0 \) of LXe

Energy resolution \( <\sigma E/E> < 2\% \) at 52.8 MeV
Timing resolution = 67 ps
Position resolution \((X,Y)\) 5 mm, (depth) 6 mm
\( \gamma \)-efficiency \( 59\% (\varepsilon_{Detect} \times \varepsilon_{Anal}) \)
Calibration and Monitoring

- **PMT**: Gain, QE
- **LXe**: Light-yield, Attenuation-length
- **Calorimeter**: Energy-scale
- **DC**: Momentum scale
- **Calo.+TC+DC**: Relative detector timing, Alignment
e.g. $\alpha$s, LED, CEX ($\pi^- p \rightarrow \pi^0 n$ or $\gamma n$, “Dalitz-decay”),
- RMD, protons from C-W accelerator on $\text{Li}_2\text{B}_4\text{O}_7$,
n-generator+ Ni, cosmics, Mott $e^+$ beam

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**Radiative Muon Decay**

$\text{RMD } \rightarrow t_{\text{e}^+}$

**Mott mono. e+ scattering**

**Cosmic rel. alignment LXe + spectrometer**
Detector Stability

Detector Stability permanently monitored

- Light Yield stable to $< 1\%$ \(\text{rms} < 2\%\)
- Photon energy-scale cross-checked using BG-spectrum from LXe side-bands
- Timing stability checked using radiative muon decay events (RMD) taken simultaneously during run (multi-trigger)
  
  $T_{\gamma\gamma}$ stable $\sim 15$ ps over whole run
Analysis Principle

Blind likelihood Analysis:

Data Sample defined by 5 Observables:

\[ E_{e^+}, E_\gamma, \theta_{e\gamma}, \phi_{e\gamma}, T_{e\gamma} \]

Analysis-box for Likelihood fit Defined in 5D-space as:

Analysis Region shown in 2D (No Selection)

Analysis Box vs 5 Observables

(\(\sim10\sigma\) wide windows cf. res.)

- \(48 \leq E_\gamma \leq 58\) MeV
- \(50 \leq E_e \leq 56\) MeV
- \(|T_{e\gamma}| \leq 0.7\) ns
- \(|\phi_{e\gamma}|, |\theta_{e\gamma}| \leq 50\) mrad

(angles between \(e^+\) & flipped \(\gamma\) vec.)

Analysis box

"Blinded" in the \(E_\gamma\) vs \(T_{e\gamma}\) plane during calibration and optimization of physics analysis

Analysis Region shown in 2D (No Selection)

\(~10\sigma\) wide windows cf. res.

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!!! Time and \(E_\gamma\) sidebands Important Ingredient to Analysis also angular sidebands introduced

⇒ Since our background is dominated by “accidentals” the side bands can be used to estimate the background in the signal region, check of experimental sensitivity & measure the timing resolution using RMD in the \(E_\gamma\)-sideband

Analysis Region shown in 2D (No Selection)
Results


Data taking finished at 31.08.2013
Statistics is doubled compare to published

<table>
<thead>
<tr>
<th>year</th>
<th>$N_{\text{stop}} \mu$, $\times 10^{13}$</th>
<th>Sensitivity, $\times 10^{-13}$</th>
<th>Br, Upper limit (CL 90%), $\times 10^{-13}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>2009+2010</td>
<td>17.5</td>
<td>13</td>
<td>13</td>
</tr>
<tr>
<td>2011</td>
<td>18.5</td>
<td>11</td>
<td>6.7</td>
</tr>
<tr>
<td>2009+2010+2011</td>
<td>36.0</td>
<td>7.7</td>
<td>5.7 (20 times better than MEGA)</td>
</tr>
<tr>
<td>All data (expected)</td>
<td>~80</td>
<td>~5</td>
<td></td>
</tr>
</tbody>
</table>

Final result of analysis is expected by the end of 2015 with the improved analysis. The data are reprocessed now.
Improvement of the analysis

• Event reconstruction algorithm.
• Calibration procedures.
• Background rejection techniques.
  – recover positron tracks which cross the target twice (missing turn analysis)
  – Identify background $\gamma$-rays generated when a positron annihilates with an electron on some detector material (annihilation-in-flight (AIF) analysis)
  – refine the alignment procedure of the target and drift chamber system.
Conclusion

• MEG experiment successfully finished data taking 31.08.2013.

• The statistics is double compare to published result. The data analysis will be finished at 2015.

• Expected improvement of sensitivity from $7.7 \times 10^{-13}$ to $\sim 5 \times 10^{-13}$.

• MEG-2 with an order of magnitude better sensitivity is coming (see Angela Papa’s talk).
Thanks for your attention!
Backup
Confidence Interval

- Confidence interval calculated with Feldman-Cousins method + profile likelihood ratio ordering

Consistent with null-signal hypothesis