The MEG experiment: status and upgrade.

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On behalf of MEG and MEG-2 collaborations

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MEG HOME

Switzerland
PSI, ETH-Z

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

MEG Collaboration
some 65 Physicists
5 Countries, 14 Institutes

USA
University of California Irvine
UCI

Russia
BINP, Novosibirsk, JiNR, Dubna

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

- cLFV Forbidden in SM (background: $\text{Br}(\mu^+ \rightarrow e^+ \gamma) < 10^{-45}$)
- So far, no cLFV signal has been observed.
- Many new physics beyond SM (e.g. SUSY, Extra dimensions etc.) predict observable $\text{Br} \left(10^{-14} \rightarrow 10^{-11}\right)$
- Discovery will be an unambiguous evidence of new physics.
- 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, \( E < 52.8 \text{MeV} \)

**Radiative muon decay**

- \( \mu^+ \rightarrow e^+\nu\nu\gamma \)
- Timing coincident, not back-to-back,
- \( E < 52.8 \text{MeV} \)
Key points of the experiment

- high quality & rate stopped $\mu$-beam $\Rightarrow$
  surface muon beam ($10^8$/s), $(E \times B)$ Wien filter, SC-solenoid+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
Calibration and Monitoring

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

**Cosmic rel. alignment LXe + spectrometer**

**Radiative Muon Decay**

$$\text{RMD} \rightarrow t_{\gamma\nu}$$

**Mott mono. e$^+$ scattering**

**Pion CEX on LH$_2$**

$$\pi^-p\rightarrow\pi^0n, \pi^-p\rightarrow\gamma n$$

$$\pi^0\rightarrow\gamma\gamma, 55,83,129\text{MeV}$$

**monochromatic**

$$\pi^0\rightarrow\gamma e^+e^-, \text{Relative timing}$$

**Similar topology**
Detector Stability

- Light Yield stable to $< 1\%$ 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 Box vs 5 Observables

(\(\sim 10\sigma\) 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 Region shown in 2D (No Selection)

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

!!! 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
Results

Published


Data taking finished at 31.08.2013
Statistics is doubled compare to published

<table>
<thead>
<tr>
<th>year</th>
<th>Nstop μ, x10^{13}</th>
<th>Sensitivity, x10^{-13}</th>
<th>Br, Upper limit (CL 90%), x10^{-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 γ-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.
MEG-2

- Goal to reach sensitivity in order of magnitude better than MEG:
  - More statistics (double beam rate)
  - Improve efficiency ~2 and background rejection ~30
    (upgrade of LXe calorimeter, new cylindrical Drift Chamber, new Timing counters).
Layout of MEG-2 detector

- Liquid Xenon Gamma-ray Detector
- COBRA Superconducting Magnet
- Drift Chamber
- Positron Timing Counter
- Radiative Decay Counter

Thinner target active?

Identify gammas from muon radiative-decays
Calorimeter upgrade

- Improved layout of PMTs
- Replace 2” PMTs on inner face with newly developed VUV-sensitive SiPMs

<table>
<thead>
<tr>
<th></th>
<th>Present</th>
<th>Upgraded</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy resolution [%]</td>
<td>2.4 / 1.7</td>
<td>1.1 / 1.0</td>
</tr>
<tr>
<td>Position resolution [mm]</td>
<td>5 / 5</td>
<td>2.6 / 2.2</td>
</tr>
<tr>
<td>Detection Efficiency</td>
<td>63%</td>
<td>69%</td>
</tr>
</tbody>
</table>

Factor 2 better energy and position resolutions and 10% higher efficiency

2 inch PMT 216 ch

12×12 mm2 MPPC ~ 4000 ch

shallow / deep events (d = 2cm)

horizontal / vertical
New drift chamber

Gas volume
- Lower Z gas mixture (85% He + 15% iso-butane)
- Unique 2m-long chamber-gas volume, improved transparency to timing-counters.
  - Double the detection efficiency
  - Improve the Time-Of-Flight error down to 10 psec.

Wire configuration
- Stereo-angle configuration for longitudinal position.
- Finer granularity (7 mm cell) and higher multiplicity (15 → 60 hits per track).
- Single hit spatial resolution of 120~μm.
New timing counters

- Many small plastic counters.
- Six SiPMs are directly attached on both sides for high light-collection efficiency.
- SiPMs on the same side are attached in series to read with a single channel.
- In average, ~8 counters hit by a signal positron.
- 30 psec time resolution by averaging the hit-times
Current status

Xenon calorimeter
- Development of LXe MPPC is finished. PDE of 15% is achieved for LXe light. Production of 600 MPPCs is done. 568 MPPCs has been sucessfully tested at LXe temperature with large prototype. 4000 MPPCs will be delivered by August to have the full set.
- The PCBs for MPPC mounting has been designed and tested.

Drift chamber
- The Mock-up chamber will be ready soon.
- The fully automatic wiring machine is operational.
- The production of chamber is almost ready to start.

Timing counters
- All SiPMs and about 50% of scintillator plates are in hand.

**GOAL:** to have pre-engineering run at the end of 2015 and to start physical run at 2016.
Near future

Nstop muons $\times 10^{13}$
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 $\sim 5 \times 10^{-13}$.
• Preparation of MEG-2 is in good shape. The pre-engineering run is planed at the end of 2015.
• Expected MEG-2 sensitivity after data taking in 2016-2018 is $\sim 5 \times 10^{-14}$. 
Thanks for your attention!
Beam line

- High-intensity DC surface muon beam - $\pi E5+MEG$
  $\Rightarrow$ capable of $>10^8 \mu^+/s$ at 28 MeV/c + $\sim10^9$ beam $e^+/s$
- "pure" muon beam - Wien filter + Collimator system
  $\Rightarrow \mu$-e separation at collimator $>7.5\sigma$ (12 cm)
- Small beam-spot + high transmission – BTS
  $\Rightarrow$ focus enhancement, beam $\sigma$$\sim$10 mm at target
  $\Rightarrow$ focus at centre BTS – degrader
- Thin stopping target + minimal scattering – end-caps
  $\Rightarrow$ 18 mg/cm$^2$ CH$_2$ target + He COBRA environment
  + remote Target & End-cap insertion system
Positron spectrometer

- SC COBRA Magnet
- Gradient Bfield (1.27-0.5) T
- Constant Bending Radius
- $0.2 \times_0$ fiducial thickness
- $\gamma$-transparency 95%
- NC Compensations coils reduce Bfield at Calorimeter $< 5\text{mT}$ at PMT positions
Positron spectrometer

- **Drift Chambers**
  - 16 radial, staggered double-layered DCs
  - each 9 cells with “Vernier” cathodes
  - 50:50 He/C_2H_6
  - Ultra-thin $2 \cdot 10^{-3} X_0$ along $e^+$ path

Momentum resolution $<\sigma p/p)$ 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 $e^+$ 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

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 $59\% (\varepsilon_{Detect} \times \varepsilon_{Anal})$
Confidence Interval

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

Consistent with null-signal hypothesis