Final Results from the MEG Experiment and the Status of MEG-II and Mu3e

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LFV in muon decays

\[ \mathcal{L}_{\text{CLFV}} = \frac{m_\mu}{(\kappa + 1)\Lambda^2} \bar{\mu}_R \sigma_{\mu\nu} e_L F^{\mu\nu} + h.c. \]

\[ \frac{\kappa}{(1 + \kappa)\Lambda^2} \bar{\mu}_L \gamma_\mu e_L (\bar{e} \gamma^\mu e) + h.c. \]
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A. De Gouvea & P. Vogel
Prog.Part.Nucl.Phys. 71 (2013)
Experimental Signature of $\mu \rightarrow e \gamma$

Positron and photon are **monochromatic** (52.8 MeV), **back-to-back** and produced at the **same time**;

**Accidental Background**

**DOMINANT**

$\sim R_\mu^2$

**Radiative Muon Decay (RMD)**
Ingredients for a search of $\mu \rightarrow e \gamma$

Reconstruct the Relative Angle

Reconstruct the Photon Energy

Reconstruct the Relative Time

Reconstruct the Positron Energy
The MEG Experiment

Reconstruct the Relative Angle

Reconstruct the Photon Energy

Reconstruct the Positron Energy

LXe calorimeter
16 Drift Chambers in a magnetic field
30 scintillating bars for timing & trigger

LXe

Reconstruct the Relative Time

Muon Beam

Thin Superconducting Coil

Stopping Target

Timing Counter

Drift Chamber
Beam & Detectors

- The most intense DC muon beam in the world (3 x 10^7 µ/s @ PSI, Switzerland)
  - 2009-2011: 3.5 x 10^{14} µ on target, BR(µ -> e γ) < 5.7 x 10^{-13}
  - 2009-2013: 7.5 x 10^{14} µ on target, results presented here
- 800l LXe detector read out by 846 PMTs

![Detector diagram]

Eγ Resolution
~ 1.9%
Beam & Detectors

- 16 Drift Chamber modules:
  - $\sigma_R \sim 300 \, \mu m$, $\sigma_Z \sim 1 \, mm$
  - Very light ($\sim 10^{-3} X_0$ over the whole spectrometer)
- 30 scintillating bars (Timing Counters)
  - $\sim 60$ ps positron time resolution

$E_e$ Resolution $\sim 300$ keV

$T_{\gamma}$ Resolution $\sim 130$ ps
Likelihood Analysis

- Likelihood analysis of 5 discriminating variables (E_e, E_γ, θ_eγ, φ_eγ, T_eγ):
  - year-by-year and event-by-event PDFs
  - careful treatment of correlations (from well understood geometrical effects)

- **Accidental Background PDFs** are fully defined from data sidebands:
  - very solid determination of the (largely) dominant background

- Signal and radiative decay PDFs by combining the results of the calibration procedures

- Normalization from the observed number of μ -> e ν ν and RMD
Results (I)

\[ N_{\text{ACC}} = 7684 \pm 103 \]
\[ N_{\text{RMD}} = 663 \pm 59 \]
\[ N_{\text{SIG}} \text{ (best fit)} = -2.2 \]

\[ \text{BR} < 4.2 \times 10^{-13} \]
@ 90\% C.L.


Magnified signal (BR = 4 \times 10^{-11})
Results (II)

Toy MC sensitivity
Median UL = $5.3 \times 10^{-13}$

DATA
The MEG-II Experiment

- Larger LXe volume with finer light detector granularity
- Higher beam intensity $7 \times 10^7 \mu/s$
- Unique-volume Drift Chamber
- Scintillator Tile TC
- RMD Veto
MEG-II Highlights - The LXe Calorimeter

We developed large-area (12x12 mm$^2$), UV-sensitive MPPCs to cover the inner face of the LXe calorimeter

Better Resolution, better pile-up rejection

The detector just entered the experimental area, ready for a first round of calibrations

$\sigma_E \sim 1\%$, $\sigma_{\text{position}} \sim 2/5 \text{ mm (x,y/z)}$
MEG-II Highlights - The Timing Counters

5mm-thick Scintillator Tiles read out by 3x3 mm$^2$ SiPM

1/2 sector
(1/4 of the full system)
already took data at PSI

1 sector already built, final assembly to be completed by this summer

$\sigma_T \sim 35$ ps
MEG-II Highlights - The Drift Chamber

> 50% of the chamber has been wired, after having solved severe problems of wire fragility in not dry enough environments

Expected to be wired and sealed by the end of the year

\[ \sigma_E \sim 130 \text{ keV}, \sigma_{\text{angles}} \sim 5 \text{ mrad}, 2x \text{ larger positron efficiency} \]
MEG-II Highlights - RDC, DAQ, Trigger

50% of acc. background photons come from RMD w/ positron along the beam line

Can be vetoed by detecting the positron in coincidence with the photon

A new detector (LYSO + plastic scint.) already built -> 16% better sensitivity

Trigger and DAQ will be integrate in a single, compact system (WaveDream TDAQ)

Also provides power and amplification for SiPM/MPPC
Expected Sensitivity

- MEG-II is expected to start taking data with the full detector next year
- x10 improvement in sensitivity w.r.t. MEG

\[4 \times 10^{-14}\] in 4 years
The Mu3e Experiment
Signal and Background

2 positrons and 1 electron produced at the **same time**, in the **same place**, with $M_{\text{inv}} = M_\mu$

**Accidental Background**
(e.g. 2 $\mu$ decays + Bhabha)

**eee$\nu\nu$ Muon Decay (RMD + IPC)**

**DOMINANT**
Mu3e concept

- Silicon tracker in a solenoid + scintillators for timing
  - 50 µm HV-maps
  - 250 µm fibers + 1x1 mm\(^2\) SiPM
  - 5 mm thick tiles + 3x3 mm\(^2\) SiPM

- Phase-I:
  - New compact beam line for a quick switch between MEG & Mu3e

- Phase-II:
  - New high intensity muon beam line (HiMB)
Status

- HV-maps (MuPix):
  - pixel prototypes already built and tested
  - module prototypes in 2017
  - module production in 2018-2019

- Scintillating fibers:
  - Successful tests of fibers and SiPM (700 ps single fiber resolution)
  - New readout chips received in Jan. 2017

- Scintillating tiles:
  - Tiles and readout ASIC successfully tested
  - < 100 ns resolution
  - Module prototypes in 2017
Expected Sensitivity

- Data taking expected to start ~ 2020
Conclusions

• Both MEG and Mu3e are on track for a further step forward in the search for charged Lepton Flavor Violation

• Within the next 5 years, significative improvements in the current limits or (hopefully) a discovery!
Backup
Target hole reconstruction

$\Delta x' = 0.2 \pm 0.1 \text{ mm}$
Likelihood plots

\[ R_{\text{sig}} = \log_{10} \left( \frac{S(x_i)}{f_R R(x_i) + f_A A(x_i)} \right) \]
Normalization

![Graph showing normalization data with years 2009 to 2013 and data sets labeled Michel, RMD, and Combined.]
Trigger and DAQ

- FPGA based trigger system + (since 2011) multiple buffer:
  - Beam intensity x acceptance…………..10^6 Hz
  - XEC Energy E > 45 MeV………………..10^3 Hz
  - e-γ Timing T_{eγ} < 10 ns………………10^2 Hz
  - e-γ Angle…………………………………10 Hz

- Full digitization of all readout channels for offline analysis:
  - custom digitization chip (DRS4)