Lepton Flavor Violation Searches with the MEG-II Experiment

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Lepton Flavor Conservation in the Standard Model

• Lepton Flavor conservation in the Standard Model is an *accidental symmetry*, arising from the particle content of the model

• Generally violated in most of New Physics models

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**Standard Model**

\[ \text{BR} < 10^{-54} \]

**SUSY**

\[ \text{BR} \sim 10^{-11} - 10^{-15} \]

“Charged Lepton Flavor Violation (cLFV) is THE signature for New Physics”

— A. Schöning
cLFV and direct NP searches at the LHC

- cLFV rates strongly depend on the details of the flavor structure of new physics:
  - even within the same model, cLFV constraints can be much stronger or much weaker than LHC constraints, depending on the flavor structure that is chosen
  - LHC searches still leave a lot of place for cLFV

STRONG COMPLEMENTARITY

cLFV searches in the muon sector - the naive view

- cLFV in the muon sector searched for decays ($\mu \rightarrow e \gamma$, $\mu \rightarrow e e e$) and $\mu \rightarrow e$ conversion in nuclei

- Effective Field Theory (EFT) approach:
  - $\mu \rightarrow e \gamma$ sensitive to dipole operators
  - $\mu \rightarrow e e e$ and $\mu N \rightarrow e N$ sensitive to both dipole and 4-fermion operators

Naive conclusion: the upcoming $\mu \rightarrow e$ conversion experiments will overcome the muon decay experiments
cLFV searches in the muon sector - the full view

- Operators mix at the loop level:
  - $\mu \rightarrow e\gamma$ also sensitive to 4-fermion operators
  - $\mu \rightarrow e\gamma$ can give the strongest bound in some scenarios

**STRONG COMPLEMENTARITY**

A. Crivellin et al., JHEP 1705 (2017) 117

Even in the era of the upcoming $\mu \rightarrow e$ conversion experiments, $\mu \rightarrow e\gamma$ (and $\mu \rightarrow e\gamma\gamma$) will continue to play a crucial role
History of cLFV searches

Hincks & Pontecorvo
[Phys. Rev. 73 (1948) 257]
*muon is not an “excited electron”*

Lokanathan & Steinberger
*lepton flavors*

MEG Experiment
\[\text{BR}(\mu \rightarrow e \gamma) < 4.2 \times 10^{-13}\]
\( \mu \rightarrow e \gamma \) searches

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

**Accidental Background**

**Radiative Muon Decay (RMD)**
µ -> e γ searches

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

\[
\Gamma_{acc} \propto \Gamma_{\mu}^2 \cdot \varepsilon_e \cdot \varepsilon_\gamma \cdot \delta E_e \cdot (\delta E_\gamma)^2 \cdot (\delta \Theta_{e\gamma})^2 \cdot \delta T_{e\gamma}
\]

DOMINANT
The most intense DC muon beam in the world

- The ring cyclotron at PSI (Villigen, CH) serves the most intense DC muon beam lines in the world

πE5 - up to $10^8\ \mu/s$
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 Photon Energy**
- **Reconstruct the Relative Angle**
- **Reconstruct the Positron Energy**
- **Reconstruct the Relative Time**

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

**Detector Components**
- **LXe**
- **μ⁺**
- **e⁺**
- **DC**
- **TC**

**Diagram Details**
- Muon Beam
- Thin Superconducting Coil
- Stopping Target
- Timing Counter
- Drift Chamber
The final MEG result (I)

The final MEG result (I)

**N_{ACC} = 7684 \pm 103**

**N_{RMD} = 663 \pm 59**

**N_{SIG} (best fit) = -2.2**

**BR < 4.2 \times 10^{-13}**

@ 90% C.L.

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

The final MEG result (II)

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

- The MEG experiment is undergoing an upgrade that involves all sub-detectors

First physics run expected in 2020

UL \( \sim 6 \times 10^{-14} \) in 3 years of run

MEG-II Highlights - The LXe Calorimeter

We developed large-area (12x12 mm²), UV-sensitive MPPCs to cover the inner face of the LXe calorimeter.

Better Resolution, better pile-up rejection

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

5mm-thick Scintillator Tiles read out by 3x3 mm² SiPM

Detector completed, data taken in 2017 and 2018

Calibration with dedicated laser
MEG-II Highlights - The Timing Counters

5mm-thick Scintillator Tiles read out by 3x3 mm² SiPM

Detector completed, data taken in 2017 and 2018

σ_T ~ 35 ps

Already reached the design resolution
MEG-II Highlights - The Drift Chamber

**The challenge:** **minimal material budget** (to reduce MS of 50 MeV $e^+$) and **very high granularity** (to cope with the high rate) $\rightarrow$ small cells (down to $< 6$ mm) + extremely thin wires ($20 \mu m$ W(Au) + 40-50 $\mu m$ Al(Ag))

Innovative wiring technique (no feedthroughs)

Severe problems of wire fragility in presence of contaminants + humidity

$\sigma_E \sim 130$ keV, $\sigma_{\text{angles}} \sim 5$ mrad, 2x larger positron efficiency
MEG-II Highlights - The Drift Chamber

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Innovative wiring technique (no feedthroughs)

problems of wire fragility in presence of contaminants + humidity

Assembly completed in summer 2018
First data on beam in fall 2018

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MEG-II Highlights - The Drift Chamber

- Low wire elongation in 2018 (50% of elastic limit) to limit the impact of wire fragility —> electrostatic stability problems (inner layers could not reach the working point)

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Working point + 100V

Elongation increased in Spring 2019

New HV tests show that all the chamber can now be operated at the proper working point (1400-1500 V, 5 x 10^5 gain) with 100 V safety margin

\[ \text{green = goal reached} \]
RDC & Target monitoring

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.) built and tested in 2017 -> 16% better sensitivity

The target position in MEG-II has to be known with an accuracy ~ 100 µm to not compromise the angular resolution

A system of photo cameras has been installed to monitor the target position

<< 100 µm resolution reached
MEG-II Highlights - RDC, DAQ, Trigger

Trigger and DAQ will be integrated in a single, compact system (WaveDAQ)

Also provides power and amplification for SiPM/MPPC

Had to face severe common-noise problems — now fixed —

The design and test of the DAQ electronics is going to be finalized in the next few months, mass production will start immediately after
MEG-II Highlights - Calibrations
MEG-II schedule & sensitivity

- **2013**
- **2014**
- **2015**
- **2016**
- **2017**
- **2018**
- **2019**
- **2020**
- **2021**
- **2022**
- **2023**

- **PROPOSAL**
- **R&D**
- **Construction & Commissioning**
- **Engineering Runs**
- **Physics Runs**

Graph showing:
- **MEG final result**
- **MEG II in 3 years**

6 x 10^{-14}
Conclusions

- cLFV in muon decays is a **golden probe** for NP beyond the SM

- MEG currently gives the **best limits** on muon cLFV

- **MEG-II** will improve the sensitivity by a factor $\sim 10$
  
  - Calorimeter & Timing counter tested in 2017 and 2018
  
  - Drift chamber construction completed and first data collected on beam in 2018 — recommissioning in Spring 2019 allowed to bring the full detector to running conditions

- Engineering run in 2019 with the full detector under running conditions

- **First physics data expected in 2020**