Muon Electron Gamma Experiment (MeG) II

II

Lepton Flavour Violation (LFV)

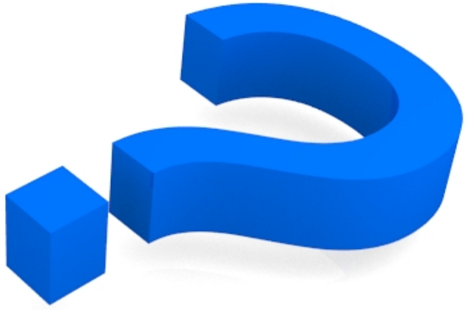
- Standard Model (SM):

$$\begin{pmatrix}\nu_e\\ e\end{pmatrix}\qquad\begin{pmatrix}\nu_\mu\\ \mu\end{pmatrix}\qquad\begin{pmatrix}\nu_\tau\\ \tau\end{pmatrix}$$

Experimentally, neutrino oscillations are observed (neutral Lepton Flavour Violation) → non-zero ν mass + **flavour coupling**

- Does charged Lepton Flavour Violation (cLFV) exist?

$$\begin{pmatrix}\nu_e\\ e\end{pmatrix}\longleftrightarrow\begin{pmatrix}\nu_\mu\\ \mu\end{pmatrix}\longleftrightarrow\begin{pmatrix}\nu_\tau\\ \tau\end{pmatrix}$$



cLFV NOT YET OBSERVED !

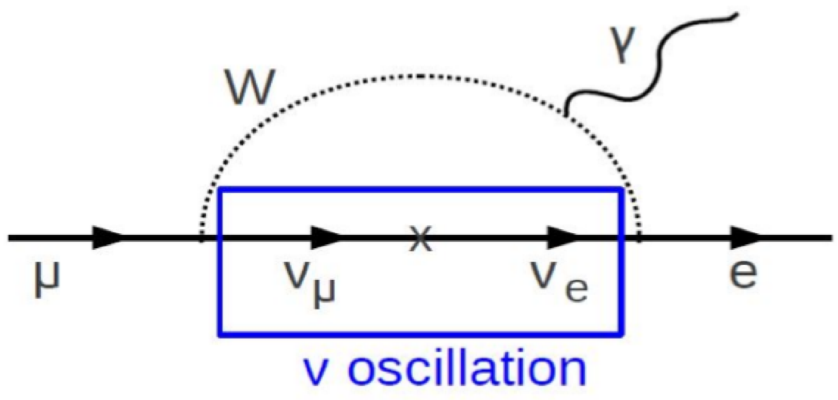
Theory in a nutshell

Strange properties SM

- $m_{\nu,L} << m_l$
- ν_r absent (or: $m_{\nu,R} > 90$ GeV

An opportunity of SM

- Charged Flavour Violating Current (cFVC): heavily supressed
- Branching Ratio= $\frac{3\alpha_{em}}{32\pi}|\sum_i U_{\mu i}U_{ei}\frac{m^2_{\nu,i}}{m^2_W}|^2 < 10^{-54}$
- $\mu \to e\gamma$: probe for new physics!



Positive muon beams have desirable properties from a practical point of view!

Theory in a nutshell

Mass term beyond SM

- Dirac mass term: $-m_D(\bar{\nu}_L \nu_R + \bar{\nu}_R \nu_L)$ (SM)
- Majorana mass term:
$-\frac{1}{2} m_M^L(\bar{\nu}_L \nu_L^c + \bar{\nu_L}^c \nu_L) - \frac{1}{2} m_M^R(\bar{\nu_R} \nu_R^c + \bar{\nu_R}^c \nu_R))$ (BSM)
(violates lepton number conservation!)

Mass eigenstate, weak eigenstate, mixing

- Suppose mass eigenstates ν and N couple to BEH:
$$L_{mass} = \begin{bmatrix} \nu & N \end{bmatrix} \times \begin{bmatrix} 0 & 0 \\ 0 & M \end{bmatrix} \times \begin{bmatrix} \nu \\ N \end{bmatrix}$$
- Obtain massless ν and (very!) massive N
- Rotate to obtain the (observable) weak eigenstates
$$L_{mass} = \frac{1}{2} \begin{bmatrix} \bar{\nu}_L & \bar{\nu}_R^c \end{bmatrix} \times \begin{bmatrix} m_m^L & m_D \\ m_D & m_m^R \end{bmatrix} \times \begin{bmatrix} \nu_L^c \\ \nu_R \end{bmatrix}$$

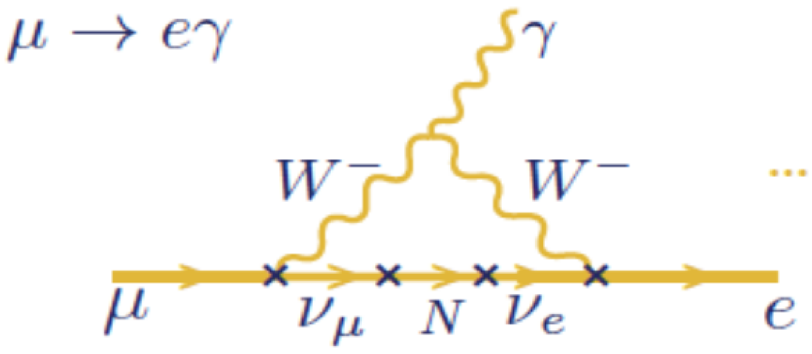
Theory in a nutshell

The seesaw mechanism

- We obtain a desirable relation between the masses: $M \approx m_m^R >> m_D > m_m^L \approx 0$
- Increasing m_m^R leads to lowering m_m^L(!)
- note weak eigenstates are superposition of mass eigenstates

New interactions

- ν_μ^L couples to ν_e^L via N!
- BR scales like $\frac{\left(c + c' \ln \frac{m_N^2}{m_W^2}\right)^2}{m_N^4}$
- Additional SUSY seesaw extensions possible



Theory in a nutshell

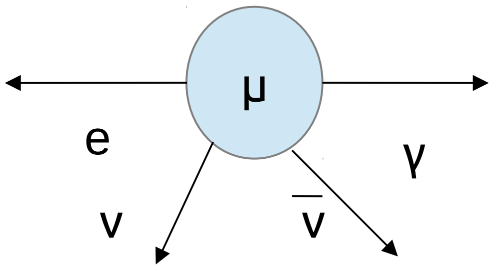
Prospects of a cFVC observation

- Any observation $\mu \rightarrow e + \gamma$ signals unambiguously new physics
- Probe for heavy mass of ν_R or SUSY particles
- A precision measurement could reveal:
  - What physics is causing the violation (heavy neutrino's, SUSY, ...)
  - Contributes to establishing neutrino is Dirac or Majorana fermion

Backgrounds for μ ⟶ eγ

Radiative muon decay

$$\mu^+ \rightarrow e^+ \nu_e \bar{\nu}_\mu \gamma$$



➔ Suppressed by good energy/momentum measurements

Michel decay + accidental photon

$$\mu^+ \rightarrow e^+ \nu_e \bar{\nu}_\mu \quad + \quad \gamma$$

DOMINANT

Sources:
* radiative muon decay
* annihilation
* Brehmstrahlung

But has a cut of at 52.8 MeV

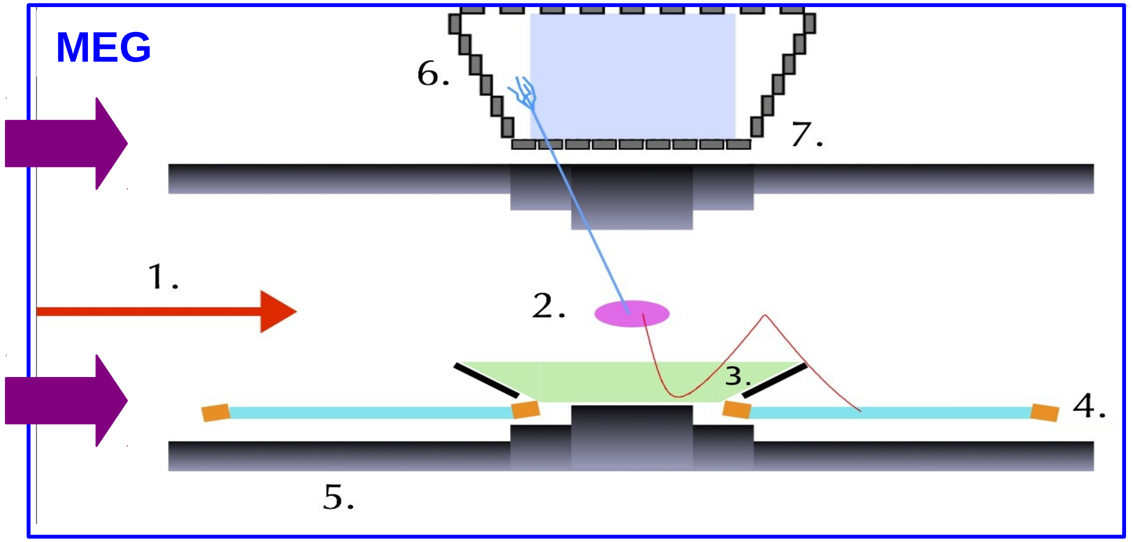
➔ Does not obey

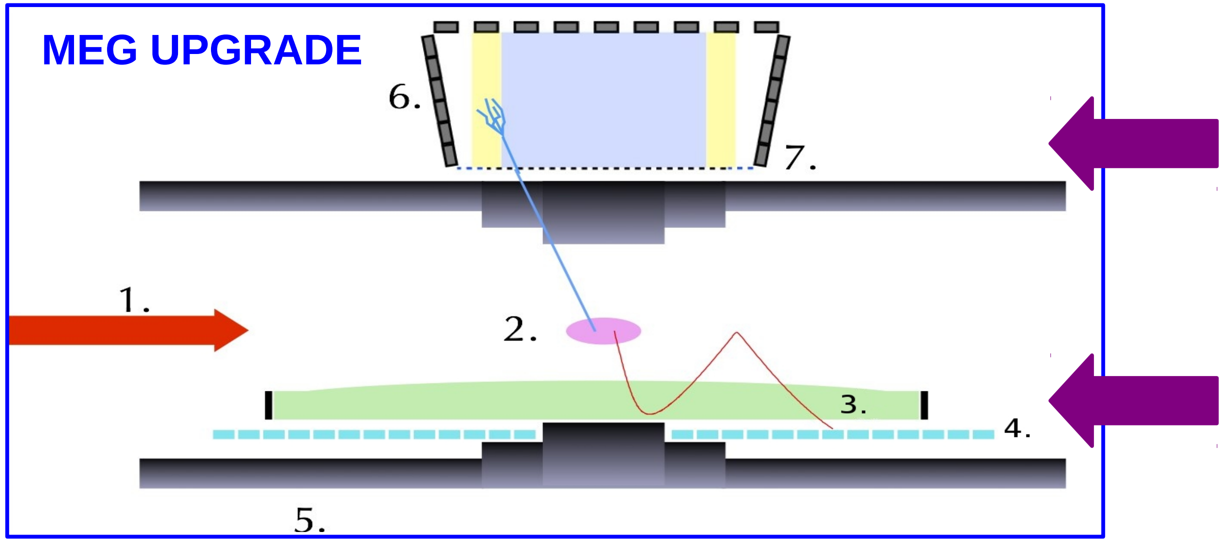
$$E_\gamma \simeq \frac{E_\mu}{2} \simeq E_e$$

$$\theta_{e\gamma} = \pi$$

$$t_\gamma \simeq t_e$$

MEG + MEG upgrade





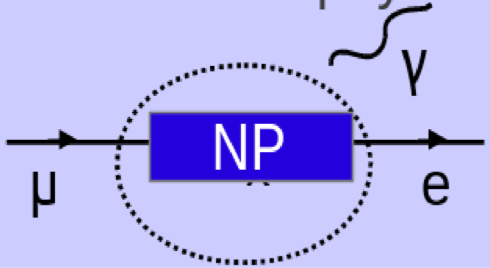
$$E_\gamma \simeq \frac{E_\mu}{2} \simeq E_e$$
$$\theta_{e\gamma} = \pi$$
$$t_\gamma \simeq t_e$$

→ Improve energy resolution

→ Improve time resolution

Improve statistics for signal
Reduce background

MEG II vs. Mu2e

<table>
<tr><td>$\mu \rightarrow e\gamma$</td><td>$\mu N \rightarrow eN$</td></tr>
<tr><td>Sensitive to all new physics processes

</td><td>Sensitive to suppressed processes in monopole penguin and box diagrams</td></tr>
<tr><td>3.7 M€ - 2.5 year (run 2016)</td><td>250 M$ - 5-7 year (run 2021)</td></tr>
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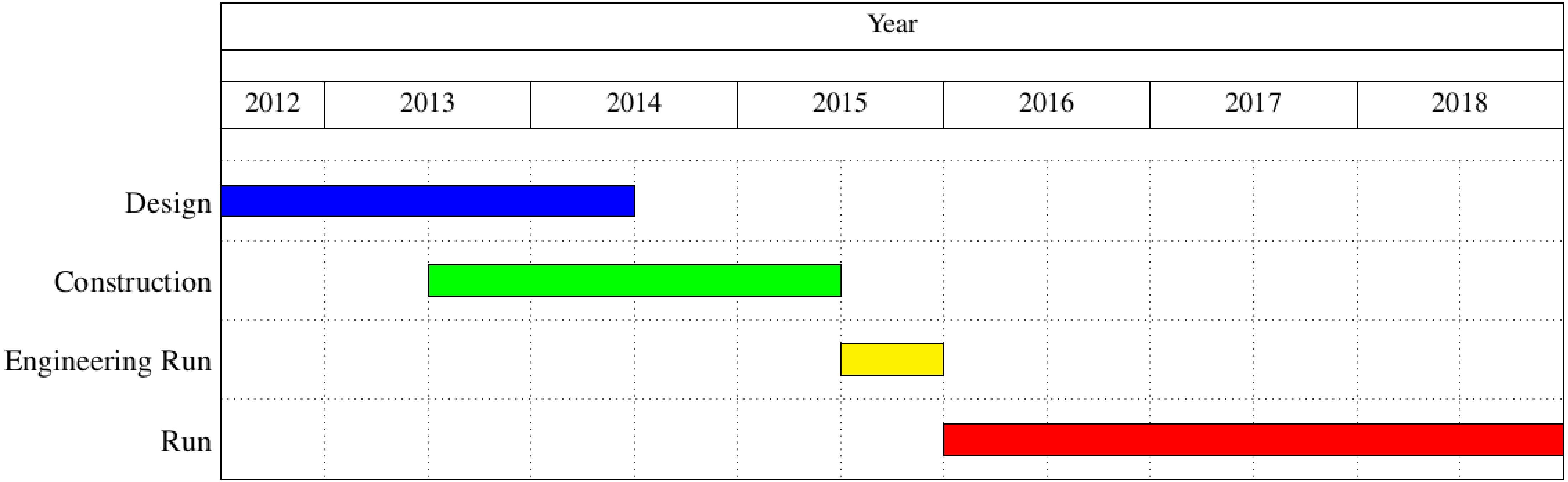
Prospects

- Expected sensitivity: one order of magnitude better ($6.\ 10^{-14}$)
- Overall MEG upgrade schedule:



Conclusions

- Upgraded MEG:
  → Higher statistics
  → Improved energy resolution
  → Improved time resolution

➡ Sensitivity is **6.10^{-14}** in the search of the $\mu \rightarrow e\gamma$ decay

→ New physics: $O(6.10^{-12}\text{-}10^{-15})$ **REACHABLE**

- Sensitive to **all** new physics
- Competitive with future projects (e.g. COMET or Mu2e), which have budgets that are **orders of magnitude higher**.

MEG Upgrade


Where We Will Be
6×10-14
×10 Sensitivity
Upgraded MEG
2.4×10-12
2008
2010
2012+2013
2017
0

All cLFV searches