Lepton flavor violation

Flavor violation in the charged lepton sector

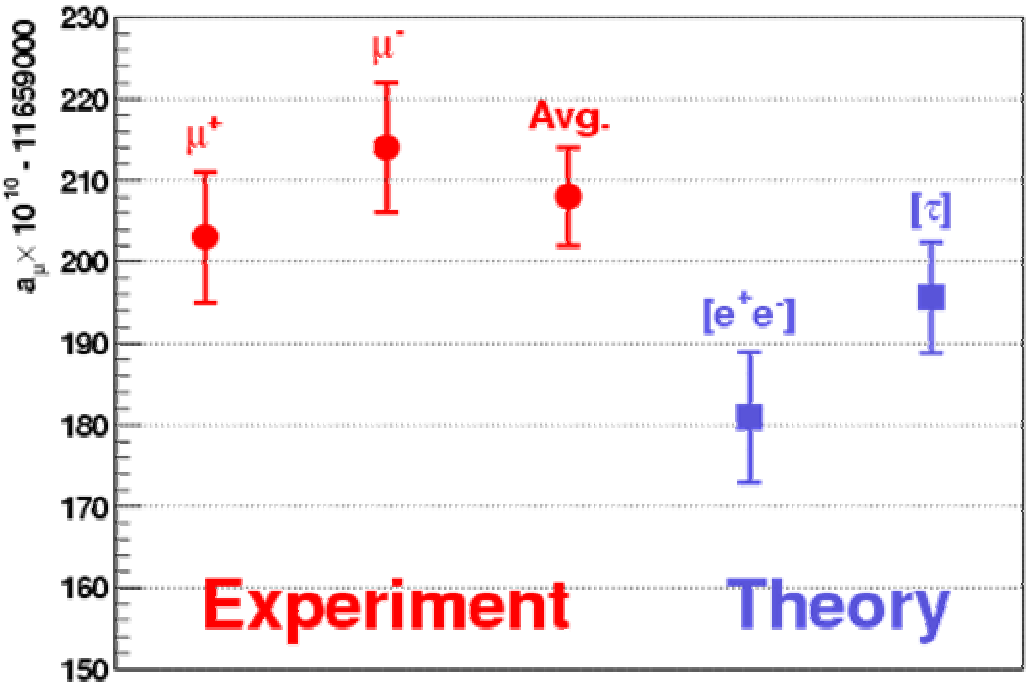
Andrzej Czarnecki  University of Alberta

Outline

- “New physics” searches with charged leptons: motivation (g-2 is back)
- Dipole moments:
  - magnetic, electric, transition
  - $\mu \to e\gamma$
- Chirality change vs. conservation
- Muon-electron conversion in nuclei
- Summary

New result on the muon *g-2*

- Brookhaven, January 2004:



$$a_\mu^{\text{exp}} - a_\mu^{\text{SM}} = 270 \pm 100 \cdot 10^{-11}$$

$$\rightarrow 2.7\sigma \ (\text{again...})$$

(based on Davier et al., 2003, e+e-)

$$a_\mu^{\text{exp}} - a_\mu^{\text{SM}} = 123 \pm 89 \cdot 10^{-11}$$

$$\rightarrow 1.4\sigma$$

(tau)

New results on *g-2* (theory)

- Hagiwara et al., e^+e^- (hep-ph/0312250)

$$\Delta a_\mu = 3.3\sigma$$

- Jegerlehner e^+e^- (hep-ph/0312372)

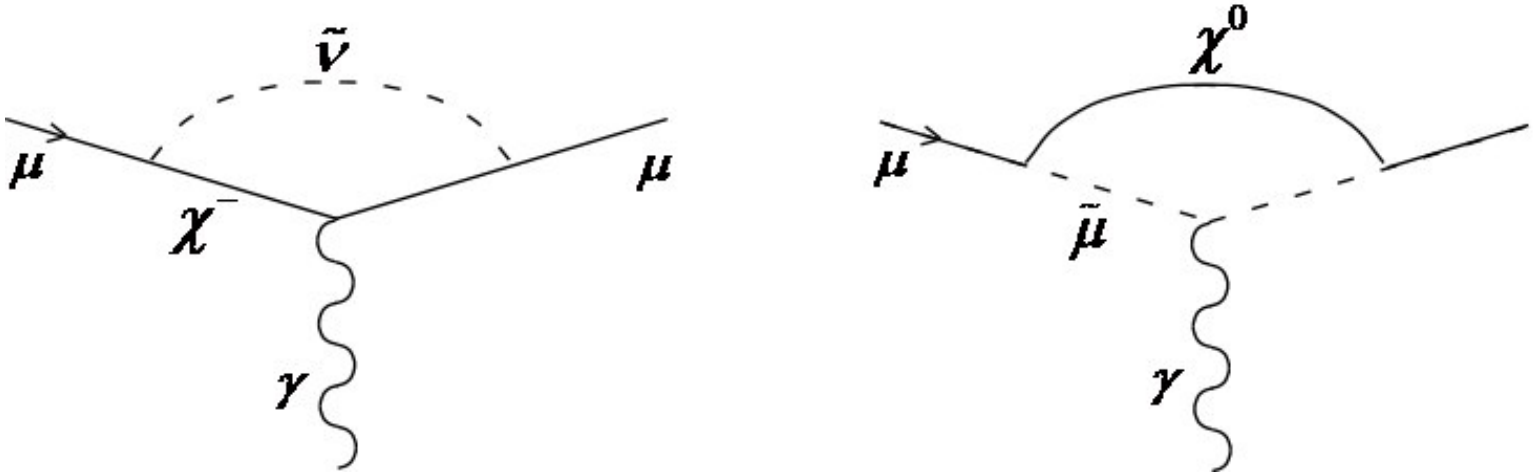
$$\Delta a_\mu = 2.6\sigma$$

- Melnikov and Vainshtein, LBL (hep-ph/0312226)

$$\Delta a_\mu = 2.3\sigma$$

Harbinger for New Physics?

Popular interpretation: SUSY



$$\Delta a_\mu^{\mathrm{SUSY}} \simeq 130 \left(\frac{100\ \mathrm{GeV}}{m_{\mathrm{SUSY}}} \right)^2 \tan\beta$$

SUSY GUT context

- Unification of couplings
- Massive neutrinos
- Anomalous dipole moments, EDM, LFV
- SUSY partners
- Proton decay

Consequences of *g-2* for other dipole moments

If $a_\mu^{\text{exp}} - a_\mu^{\text{SM}} = a_\mu^{\text{NP}} \sim 270 \cdot 10^{-11}$

- CP violating phase $\rightarrow$ EDM

$$\mathcal{L} \sim \eta \frac{e}{2m_\mu} \bar{\mu} \sigma^{\mu\nu} \gamma_5 \mu \, F_{\mu\nu}$$

$$\left| d_\mu \right| \sim 10^{-24} \, e \cdot \text{cm} \rightarrow \left| \eta \right| \sim \frac{1}{270} \cdot a_\mu^{\text{NP}}$$

- LFV $\rightarrow$ transition moment

$$\mathcal{L} \sim \frac{e}{2m_\mu} \bar{e} \sigma^{\mu\nu} \left(f + g\gamma_5 \right) \mu \, F_{\mu\nu}$$

$$\text{BR}\left(\mu \rightarrow e\gamma \right) \sim 10^{-14} \, e \cdot \text{cm} \rightarrow \left| f, g \right| \sim 10^{-6} \cdot a_\mu^{\text{NP}}$$

Limits on $\mu \to e\gamma$

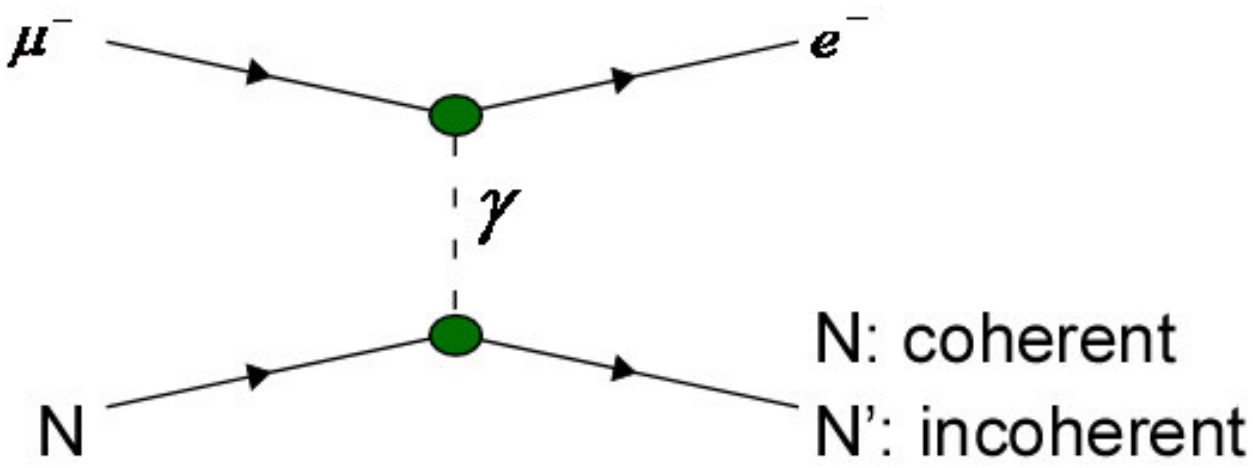
Present: $\mathrm{BR}(\mu \to \mathrm{e}\gamma) < 10^{-11}$ (MEGA)

Planed: $\mathrm{BR}(\mu \to \mathrm{e}\gamma) \sim 10^{-13}$ (PSI)

Nuclear muon-electron conversion

μ^- cascades to a 1S orbit. What happens next?

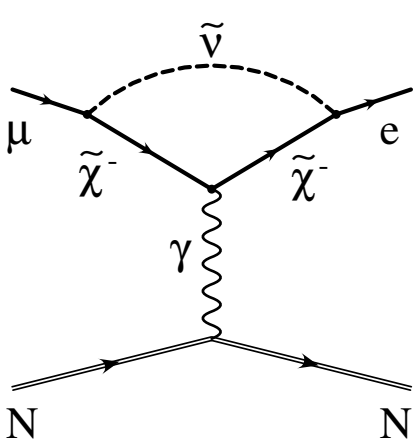
- Capture $\mu^- p \to \nu_\mu n \sim Z^4 \to$ the most likely option if $Z \geq 12$.
- Decay in orbit, $\mu^- \to e^- \nu_\mu \bar{\nu}_e$
- Exotic possibility: $\mu^- N \to e^- N \sim Z^5$

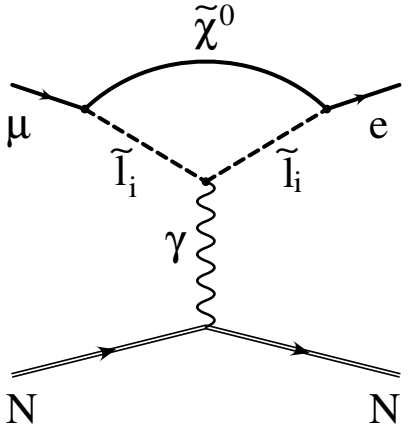


(Weinberg & Feinberg, 1959)

Muon-electron conversion: examples of new physics sensitivity

- SUSY loops (cf. *g*–2)

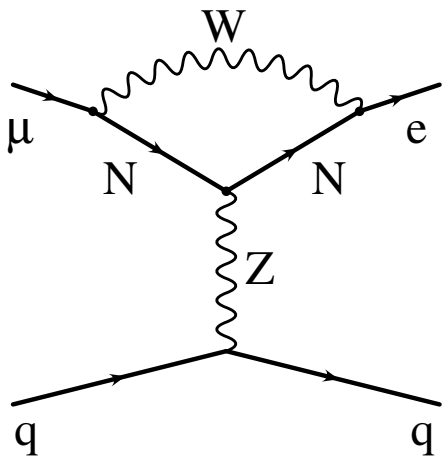


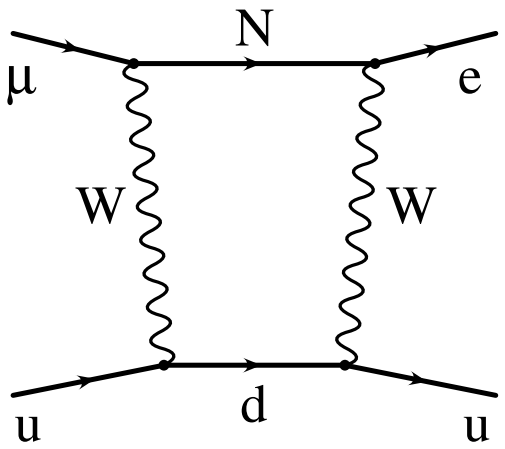


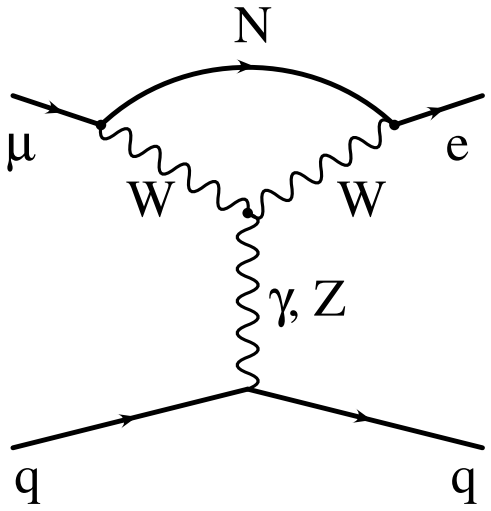
Hisano, Moroi, Tobe, Yamaguchi
Jankowski, Maybury

mu-e conversion: new physics

- Heavy neutrinos, $\left|U^{*}_{\mu N}U_{eN}\right|^{2} < 8\cdot 10^{-13}$



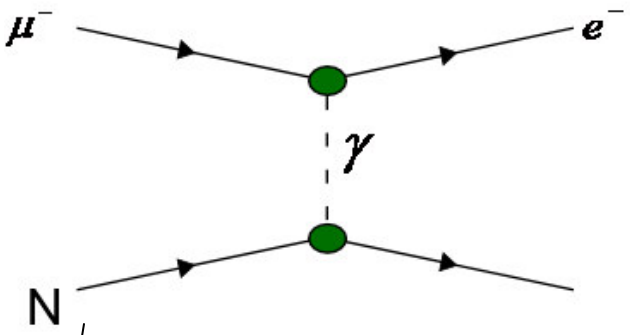


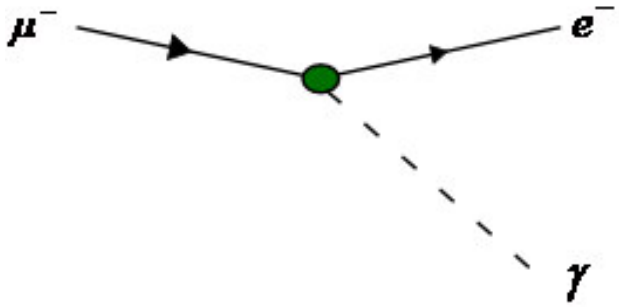


Marciano, Sanda

- Many other models, new gauge bosons, off-diagonal couplings, Higgs, etc.

Structure of LFV interactions





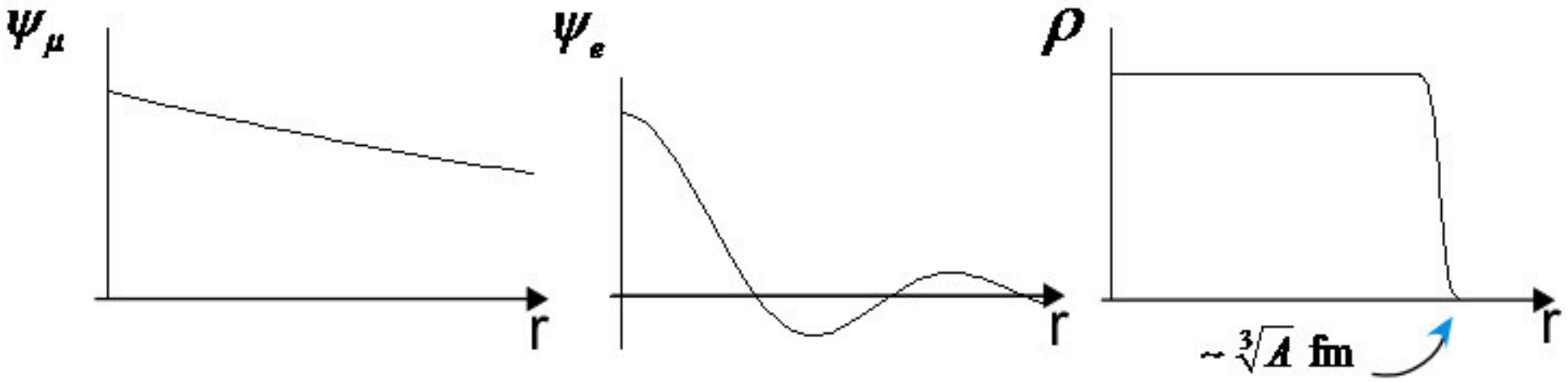
$$\left[\gamma_\alpha\left(E-M\gamma_5\right)+\sigma_{\alpha\beta}q^\beta\left(\tilde{E}-\tilde{M}\gamma_5\right)\right]A^\alpha$$

$$+\frac{G_F}{\sqrt{2}}\gamma_\alpha\left(a-b\gamma_5\right)+\text{scalar interactions}$$

Chirality conserving Chirality changing

Conversion on light nuclei

$$\text{Conversion rate} \sim \left| \int \psi_\mu^* \psi_e \rho \, \mathrm{d}^3 r \right|^2$$



$$\text{Rate} \sim \left| \psi_\mu(0) \right|^2 \left| \int \exp\left(i\vec{p} \cdot \vec{r}\right) \rho(r) \, \mathrm{d}^3 r \right|^2$$

Heavier nuclei: corrections to the Weinberg-Feinberg approximation

- Variation of the muon wave function (+)
- Coulomb distortion; oscillations of the electron wave function (–)
- Relativistic effects
- Different proton and neutron distributions

→ Precise rate formula

AC, Marciano, Melnikov, hep-ph/9801218

Kitano, Koike, Okada, hep-ph/0203110

Conversion vs. $\mu \to e\gamma$

If only $\tilde{E}, \tilde{M} \neq 0$:

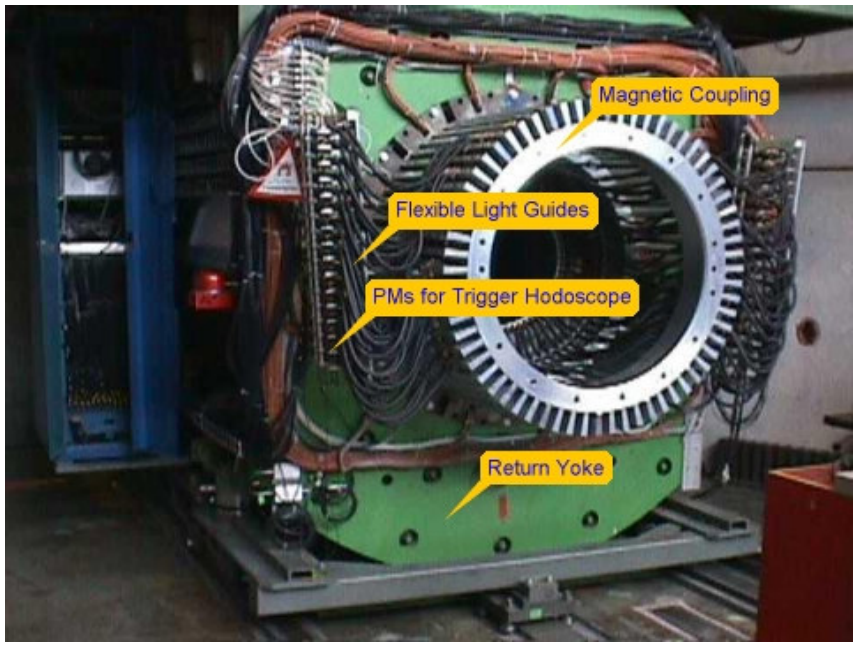
$$\frac{BR(\mu \to e\gamma)}{B_{\text{conv}}} \simeq \frac{430}{b(A,Z)} \simeq \begin{cases} 390 \text{ Al} \\ 240 \text{ Ti} \\ 340 \text{ Pb} \end{cases}$$

Present: $\text{BR}(\mu \to \text{e}\gamma) < 10^{-11} \Leftrightarrow B_{\text{conv}} < 3 \cdot 10^{-14}$

PSI goal: $\text{BR}(\mu \to \text{e}\gamma) < 10^{-13} \Leftrightarrow B_{\text{conv}} < 3 \cdot 10^{-16}$

MECO goal: $B_{\text{conv}} < 5 \cdot 10^{-17}$

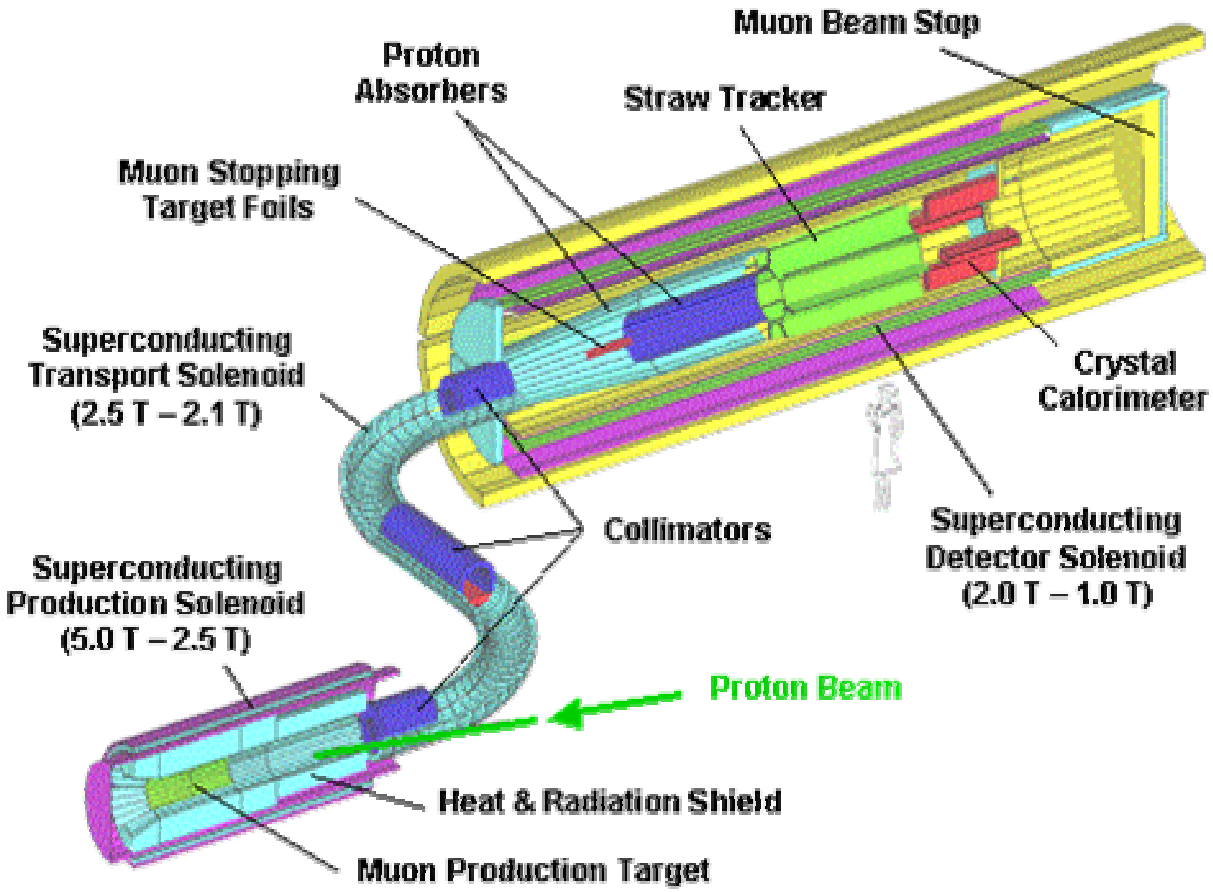
SINDRUM II: best present limit



$$B(\mathrm{Pb},\ 1995) < 4.6 \cdot 10^{-11} \qquad \text{PRL } \mathbf{76}, 200\ (1996)$$

$$B(\mathrm{Ti},\ 1995) < 8.0 \cdot 10^{-13}$$

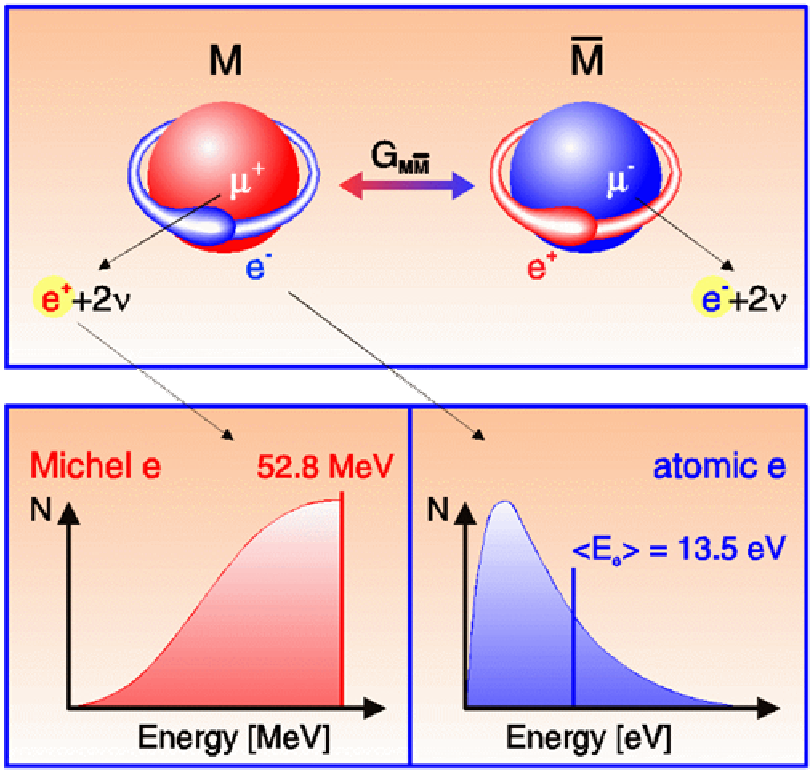
MECO: conceptual design



Goal:

$$B_{\mathrm{conv}} \sim 2 \cdot 10^{-17} \ (\mathrm{s.e.s.})$$

Muonium-antimuonium conversion



Conversion probability $\leq 2 \cdot 10^{-10}$

$\Rightarrow m_{"W"} > 1.5\,\mathrm{TeV}$

(PSI 1999)

Summary

- Present best bound on LFV: $\mu \to e\gamma$
- Future: muon-electron conversion
  - Variety of models tested
  - Clean signal → very high sensitivity

Reaction	Present limit (90% CL)	Future plans
$\mu N \to eN$	$6.1 \cdot 10^{-13}$ (SINDRUM II)	$5 \cdot 10^{-17}$ (MECO)
$\mu \to e\gamma$	$1.2 \cdot 10^{-11}$ (MEGA)	$1 \cdot 10^{-13}$ (MEG@PSI)
$\tau \to \mu\gamma$	$3.1 \cdot 10^{-7}$ (BELLE)	
$\tau \to \mu\mu^+\mu^-$	$1.9 \cdot 10^{-6}$ (CLEO)	10^{-9}? (LHC)

Improved results from Belle, see: hep-ph/0402077