Prospects of a new $\mu^+ \rightarrow e^+e^+e^-$ Experiment

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In the minimal Standard Model (SM) of strong and electoweak interactions with vanishing neutrino masses lepton flavour is conserved. Hence processes such as $\mu^+ \rightarrow e^+e^+e^-$, $\mu^+ \rightarrow e^+\gamma$ and $\mu^- A \rightarrow e^+ A$ conversion would indicate Lepton Flavour Violation (LFV). Currently favoured extensions beyond the SM such as Super Symmetry (SUSY) or SUSY-GUTs predict LFV rates at a level accessibly for high intensity muon beams such as those at PSI. The current upper limit for the decay $\mu^+ \rightarrow e^+e^+e^-$ of 1.0×10^{-12} could be improved by more than one order of magnitude with a new experiment based on the technology of the MEG experiment.

Motivation

Flavour changing processes associated with non-zero neutrino mass have been demonstrated in the neutral lepton sector, though in the charged lepton sector only limits exist. This is expected to change with the next generation of LFV searches if predictions by SUSY and SUSY-GUTs prove correct. Estimates by these theories lie in the region $BR(\mu^+ \rightarrow e^+e^+e^-) \sim 6 \times 10^{-3} BR(\mu^+ \rightarrow e^+\gamma)$, making the search for $\mu^+ \rightarrow e^+e^+e^-$ viable if $\mu^+ \rightarrow e^+\gamma$ is found at a level of 10^{-12}.

A polarized experiment $\mu^+ \rightarrow e^+e^+e^-$ would allow three asymmetries to be obtained from the correlation of decay particle momenta and muon polarization. This would allow different SUSY-GUT models to be tested [1]. It would also allow the possibility of measuring T-violation [2][3] and hence give information on CP-violation in LFV interactions.

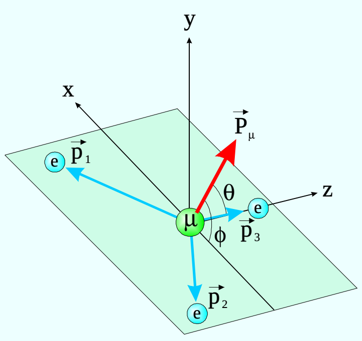
Kinematics

For a polarized muon the kinematics of the three coplanar decay particles can be described by two energies and two angles assuming muon decay at rest:

$$x_1 = \frac{2E_1}{m_\mu}, \quad x_2 = \frac{2E_2}{m_\mu} \quad with\, E_1 > E_2$$

$$allowed: \quad \tfrac{1}{2} \le x_1 \le 1, \quad (1 - x_1) \le x_2 \le x_1$$

In polarized $\mu^+ \rightarrow e^+e^+e^-$ decay, three asymmetries can be measured by projecting the muon spin onto the decay plane, which are predicted to be different in different SUSY models:



	SUSY GUT SU(5)	SUSY GUT SO(10)
$A_{P1} = \frac{N(P_{\mu z}>0) - N(P_{\mu z}<0)}{N(P_{\mu z}>0) + N(P_{\mu z}<0)}$	-0.3 - +0.4	≤ 0.1
$A_{P2} = \frac{N(P_{\mu x}>0) - N(P_{\mu x}<0)}{N(P_{\mu x}>0) + N(P_{\mu x}<0)}$	-0.2 - +0.2	≤ 0.15
$A_T = \frac{N(P_{\mu y}>0) - N(P_{\mu y}<0)}{N(P_{\mu y}>0) + N(P_{\mu y}<0)}$	≤ 0.15	≤ 0.01

Event Signature

The $\mu^+ \rightarrow e^+e^+e^-$ decay detection requires the registration of all three final state particles. One has then three handles to recognize the event signature:

- Conservation of Energy and Momentum, i.e. $|\Sigma E_i p_i| = 0, \Sigma E_i = m_\mu$
- Timing coincidence of the decay particles
- Two positive and one negative charge track originating at the same point on the target

Background

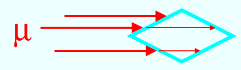
physics: $\mu^+ \rightarrow e^+e^+e^-\nu_e\nu_\mu$ for small neutrino energies. Previous experiments [4] have shown that this background is negligible.

accidental: pileup of e^+ from Michel decay with an uncorrelated e^+e^- pair from Bhabha scattering or from radiative muon decay $\mu^+ \rightarrow e\nu_e\nu_\mu(\gamma) \rightarrow e^+e^-$. Excellent position and timing resolutions are necessary to suppress this background to the necessary level. A DC muon beam is favoured compared to a pulsed muon beam with a higher instantaneous rate.

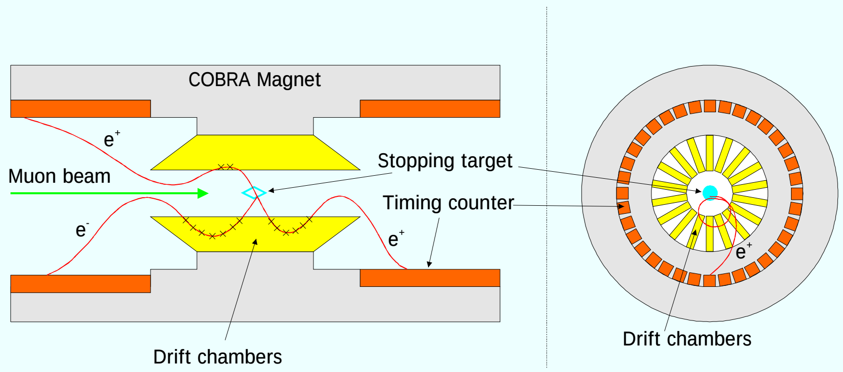
Experimental Method

A significant improvement compared to the previous experiments can be achieved by using a detector based on the technology of the MEG experiment:

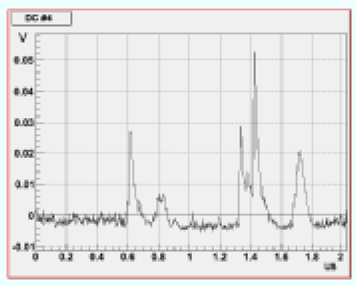
- The πE5 area delivers the currently highest available polarized DC muon beam of 10^8 μ/sec
- A thin hollow double-sided cone target distributes the muon stops along the beam axis symmetrically



- The COBRA magnet with its gradient magnetic field reduces the decay particle density close to the target (sweeping effect)
- Radial drift chambers completely surrounding the target and reaching closer in compared to the MEG drift chambers measure particle trajectories with high resolution
- Timing counters on both ends of the magnet allow precise timing coincidences
- Waveform digitizing on the drift chambers allow a powerful pile-up rejection
- A programmable FPGA based trigger loaded with possible wire patterns derived from Monte-Carlo can recognize $e^+e^+e^-$ tracks already at the first level



Digitized drift chamber signal from the innermost wire of the MEG detector at $\sim 0.6 \times 10^8$ μ/sec.



Comparison of detector parameters between the SINDRUM and the MEG detectors

	SINDRUM[4]	MEG
μ^+ stopping rate [Hz]	5×10^6	1×10^8
Momentum resol. $\Delta p/p$	12%	0.8%
Angular resol. [mrad]	65	10
Timing resolution [ns]	0.57	0.1
Background events	0.05	< 1
Stopped Muons	7.3×10^{12}	1.2×10^{15}
Result $\mu^+ \rightarrow e^+e^+e^-$	1.0×10^{-12}	

References

[1] Y. Okada et al., Phys. Rev. **D61** (2000), 094001
[2] S.B. Treiman et al., Phys. Rev. **D16** (1977), 152
[3] A. Zee, Phys. Lett. **55** (1985), 2382
[4] W. Bertl et al., Nucl. Phys. **B260** (1988), 1