Background in the Mu3e Experiment
Searching for Lepton Flavour Violation

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on behalf of the Mu3e Collaboration

Physikalisches Institut, Heidelberg

International School of Subnuclear Physics, Erice 2015

BEYOND STANDARD MODEL

HGSFP

The Mu3e Experiment

Indirect search for the lepton flavour violating decay $\mu^+ \rightarrow e^+e^-e^+$

In this talk

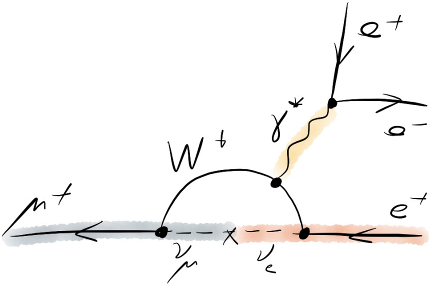
- Introduction to Mu3e
- Detector Concept
- Background Studies

The Mu3e Experiment

Charged Lepton Flavour Violating Decay $\mu^+ \rightarrow e^+e^-e^+$

Lepton Flavour conserved in Standard Model

... but ν oscillations



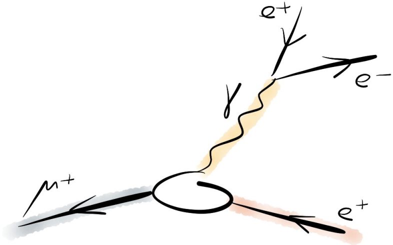
Expectation from lepton mixing: $\mathrm{BR}_{\mu \rightarrow eee} \sim \left(\frac{\Delta m_\nu}{m_W}\right)^4 < 10^{-54}$

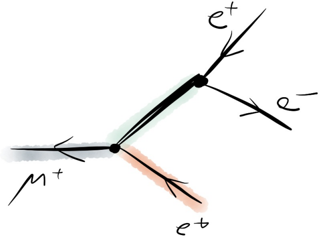
The Mu3e Experiment

Charged Lepton Flavour Violating Decay $\mu^+ \rightarrow e^+e^-e^+$

Observation of $\mu \rightarrow eee$ is a clear sign for New Physics

SUSY, extra heavy vector bosons (Z'), . . .

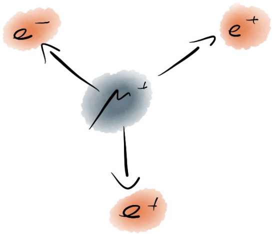




Mu3e is sensitive to one in 10^{15} μ decays

Current limit: $BR_{\mu \rightarrow eee} < 1.0 \cdot 10^{-12}$ at 90 % CL [SINDRUM, 1988]

Signal Decay $\mu \to eee$



Signature for μ decay at rest

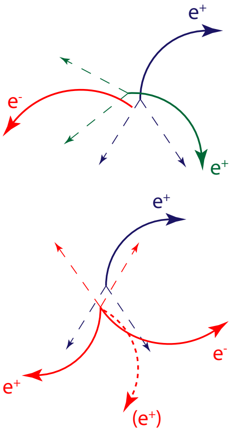
- Common vertex
- Coincident in time
- $\sum E_e = m_\mu c^2$
- $\sum \vec{p}_e = 0$

$E_e = (0 - 53)\,\text{MeV}$

Multiple Coulomb scattering limits momentum resolution

Background

Accidental Combinations



Overlays of Michel decay, Bhabha scattering, photon conversion, ...

No common vertex

Not coincident

$\sum E_e \neq m_\mu c^2$

$\sum \vec{p}_e \neq 0$

Increases with beam intensity

Background

Internal Conversion Decay $\mu \rightarrow ee e\nu\bar{\nu}$

$$BR_{\mu^+ \rightarrow e^+e^-e^+\bar{\nu}_\mu\nu_e} = (3.4 \pm 0.4) \cdot 10^{-5}$$ [Nucl.Phys.B260, 1985]

Common vertex

Coincident in time

$\sum E_e < m_\mu c^2$

$\sum \vec{p}_e \neq 0$

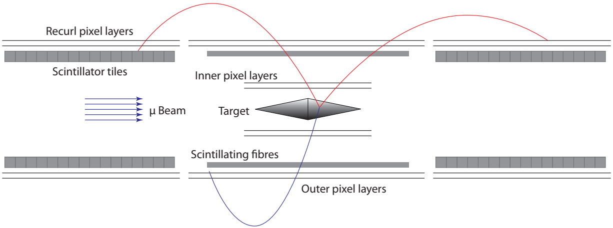
$\rightarrow$ Missing energy due to neutrinos

Need very good momentum resolution

The Mu3e Detector

Tracking detector:
50 µm Si pixel sensors (HV-MAPS)
+ Lightweight mechanics

+ Timing detector:
Scintillating fibres and tiles



Paul-Scherrer Institute (CH)
Polarized μ beam with $10^8 \mu/s$

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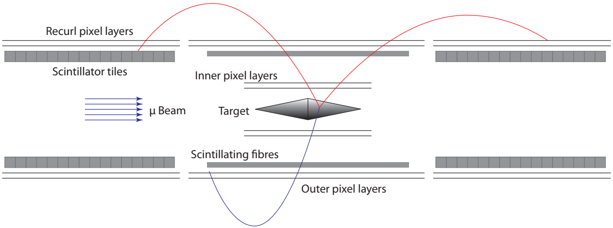


Paul-Scherrer Institute (CH)
Polarized μ beam with $10^8\,{}^{\mu}/_{s}$

Full Geant4-based simulation

Mu3e Simulation

Physics Processes

Background decays

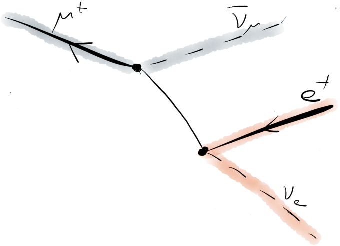
- Michel decay $\mu \rightarrow e\nu\bar{\nu}$
- Radiative decay $\mu \rightarrow e\gamma\nu\bar{\nu}$
- Internal conversion $\mu \rightarrow eee\nu\bar{\nu}$

Signal $\mu \rightarrow eee$

- 3-body decay

Other effects

- Multiple Coulomb scattering
- Bhabha scattering



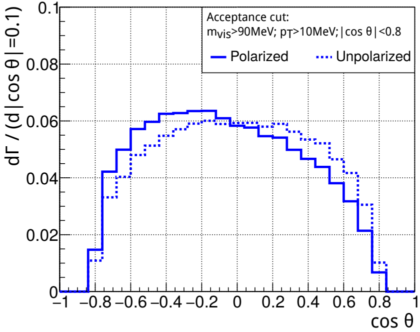
Internal Conversion Decay $\mu \to eee\nu\bar{\nu}$ in Simulation

$$\Gamma_{\mu \to eee\nu\bar{\nu}} \propto \left|T_{\mu \to eee\nu\bar{\nu}}\right|^2 \rho$$

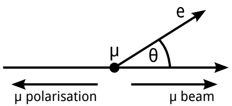
Matrix element by Djilkibaev and Konoplich [Phys.Rev.D79, 2009]

Only unpolarized muons

Internal Conversion Decay $\mu \to ee e\nu\bar{\nu}$ in Simulation



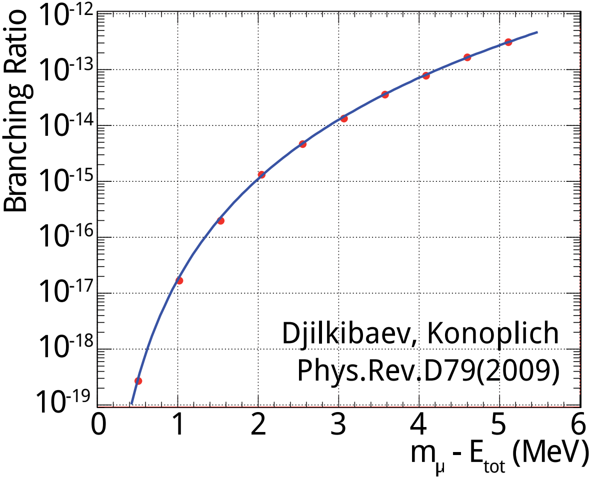
High-energy positrons in acceptance



$$\Gamma_{\mu \to eee\nu\bar{\nu}} \propto \left| T_{\mu \to eee\nu\bar{\nu}} \right|^2 \rho$$

New calculations by
A. Signer et al. (PSI) take
polarisation into account

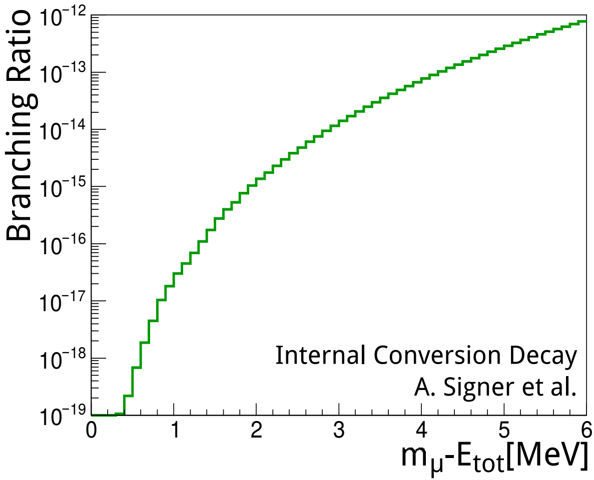
Internal Conversion Decay $\mu \to eee\nu\bar{\nu}$ in Simulation



Suppress $\mu \to eee\nu\bar{\nu}$ by cuts on electron energy

$$E_{tot} = \sum E_e \xrightarrow{\mu \to eee} m_\mu c^2$$

Internal Conversion Decay $\mu \rightarrow eee\nu\bar{\nu}$ in Simulation



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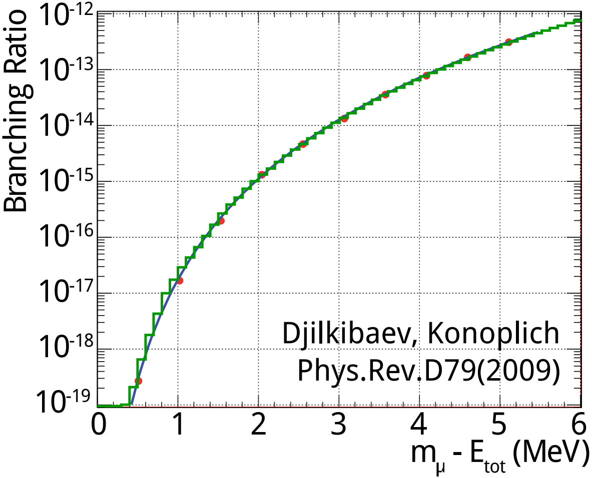

Suppress $\mu \to eee\nu\bar{\nu}$ by cuts on electron energy

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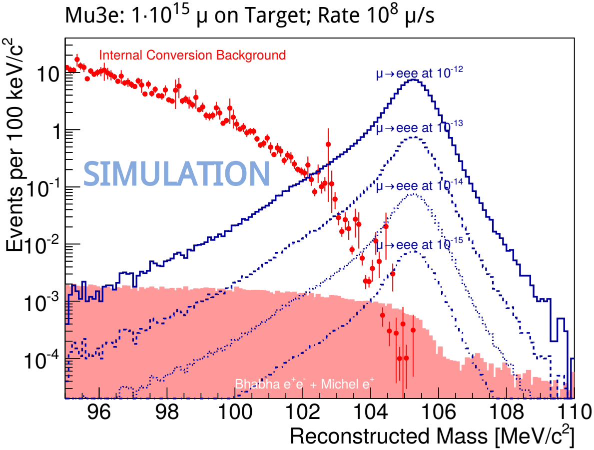
Sensitivity Studies

Reconstructed mass for signal and background events



Summary

Mu3e

- Precision experiment searching for LFV decay $\mu \rightarrow eee$
- Aiming at a sensitivity of BR $\sim 10^{-15}$

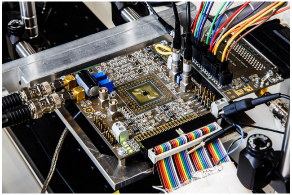
Simulation

- Full description of the experiment
- All background processes consider μ polarization

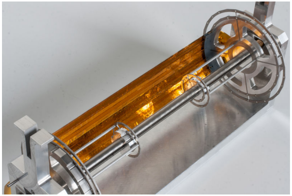
Next steps

- Higher order corrections for background
- Sensitivity studies for different models beyond SM

Status



Tests of HV-MAPS prototype



Mechanical prototype

Current status

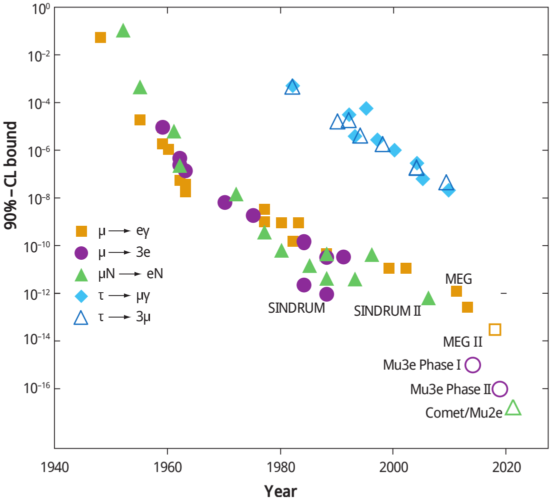
- Research proposal approved in 2013
- Technical design report in preparation (Q1 2016)
- Research and development of subsystems
- Preparation of detector construction

Outlook

- Commissioning and first data in 2017

μ3e

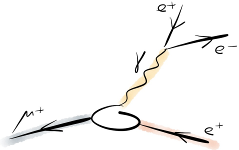
History of LFV Searches in μ and τ Decays

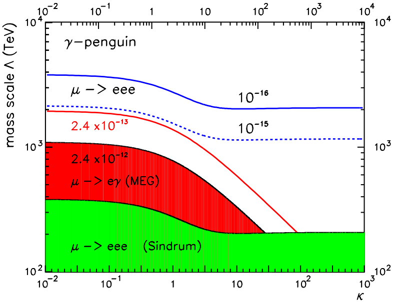


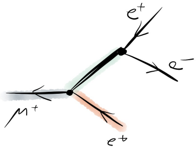
Adapted from Marciano et al. [Ann.Rev.Nucl.Part.Sci.58, 2008]

Loop and Tree Level Contributions

$$L_{\text{LFV}} = \left[\frac{m_\mu}{(\kappa+1)\Lambda^2}\overline{\mu_R}\sigma^{\mu\nu}e_L F_{\mu\nu}\right]_{\gamma \text{ penguin}} + \left[\frac{\kappa}{(\kappa+1)\Lambda^2}(\overline{\mu_L}\gamma^\mu e_L)(\overline{e_L}\gamma_\mu e_L)\right]_{\text{tree}}$$





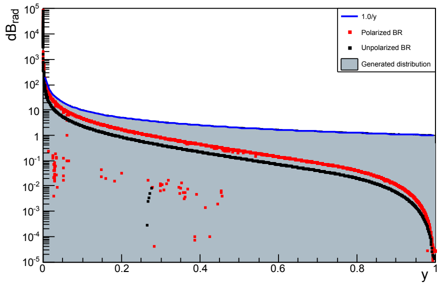


Adapted from A. de Gouvêa [Nucl.Phys.B188 2009]

Mu3e Simulation

Radiative Muon Decay $\mu \rightarrow e\gamma\nu\bar{\nu}$

$\mathrm{BR}_{\mu\rightarrow e\gamma\nu\bar{\nu}} = (1.4 \pm 0.4)\%$ for $E_\gamma^{\mathrm{min}} > 10\,\mathrm{MeV}$
Use BR calculated by Kuno et al. [Rev.Mod.Phys 73, 2001]

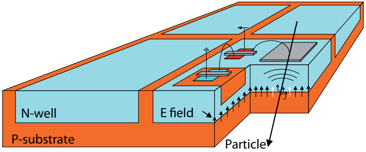


Distribution of photon momentum $y = \frac{2p_\gamma}{m_\mu}$

Divergence for $E_\gamma \rightarrow 0$

- Generate γ momentum distributed according to $\sim \frac{1}{E_\gamma}$
- Accept/reject events based on BR
- Assign minimum E_γ^{min}, typ. $10\,\mathrm{MeV}$
- Scale BR using MC integration for $E_\gamma^{\mathrm{min}} \neq 10\,\mathrm{MeV}$

Pixel Sensors



I. Perić, NIM A 582 (2007)

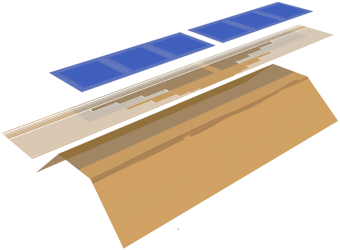
High Voltage Monolithic Active Pixel Sensors

- High voltage of $> 50\,\text{V}$
- Fast charge collection via drift
- Depletion zone of $\sim 10\,\mu\text{m}$

  Thinning possible ($\lesssim 50\,\mu\text{m}$)
- Integrated readout electronics
- Pixel size $80 \times 80\mu\text{m}^2$

Thin and highly granular

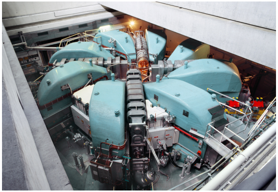
Lightweight Mechanics



- 50 µm silicon sensor
- 25 µm Kapton flexprint with aluminum traces
- 25 µm Kapton support structure

→ ∼ 1 ‰ of radiation length

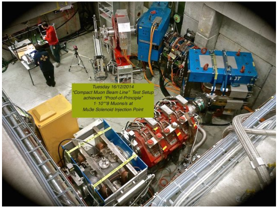
Muon Beam at PSI



Paul-Scherrer Institute in Switzerland

2.2 mA proton beam 590 MeV

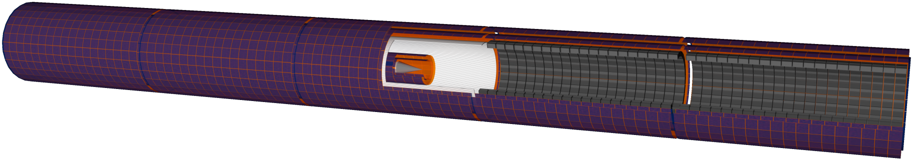
Secondary beamlines: μ^+ with 28 MeV/c



10^8 muons/s at existing beamline $\rightarrow$ Phase I

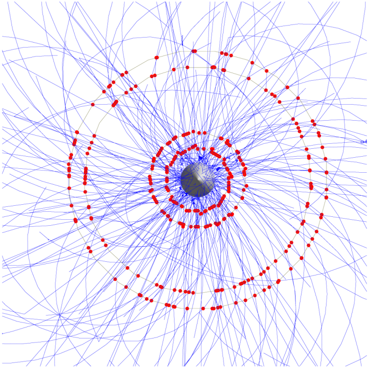
10^9 muons/s at future beamline $\rightarrow$ Phase II

Phase II Detector

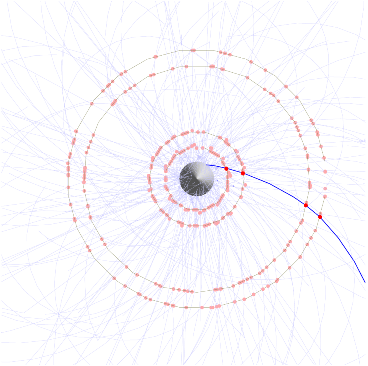


Reach BR $\sim 10^{-16}$ with a muon rate of $10^9\,\mu/\mathrm{s}$

Simulation of 50 ns of Beam Time (Phase II)



Tracks per readout frame of 50 ns



Exploiting time resolution of scintillating fibres (1 ns) and tiles (0.1 ns)

Readout Concept