The Rare and Forbidden

Testing Physics Beyond the SM with Mu3e

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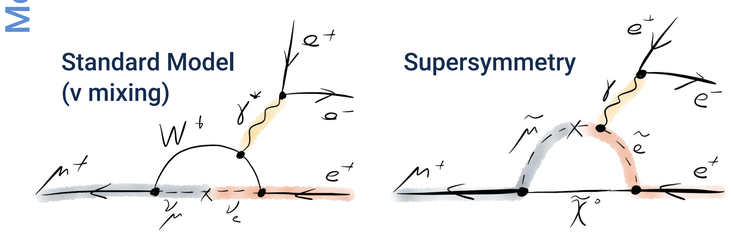
Summary

The upcoming **Mu3e experiment** at **PSI** searches for **lepton flavour violation via $\mu^+ \to e^+e^-e^+$** with a sensitivity in the order of 10^{-15} (phase I) to 10^{-16} (phase II). The innovative experimental design is based on a **lightweight tracking detector** with large acceptance allowing for a precise tracking of the decay electrons. An unprecedented number of muon decays will be observed in the experiment which enables further competitive BSM searches such as for **$\mu \to eX$** and e^+e^- resonances as a signature of a **dark photon** decay.

Decay $\mu \to eee$

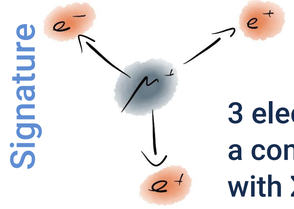
Motivation

Lepton-flavour violating (LFV) decay $\mu \to eee$ in the Standard Model (SM) possible via neutrino mixing, but suppressed to a branching ratio $Br < 10^{-54}$



Observation of $\mu \to eee$ ⇒ Physics beyond SM
e.g. SUSY, GUT, extended electro-weak sector

Signature



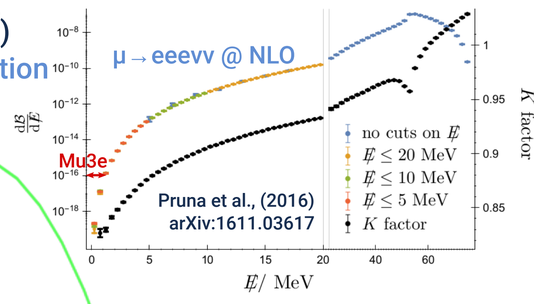
3 electrons from a common vertex with $\Sigma P_e = (m_\mu, 0)$

Test $\mu \to eee$ with a sensitivity of $Br \leq 10^{-16}$

Background

Combinations of Michel decays with Bhabha scattering, photon conversion, ...
→ suppress by good vertex and timing resolution

SM background $\mu \to eee\nu\nu$ ($Br = 3.4 \cdot 10^{-5}$)
→ suppress by good momentum resolution



Challenges

- High muon rates > 10^8μ/s to 10^9μ/s
- Excellent momentum resolution despite low momentum of electrons
→ Extremely low material budget (low multiple scattering)

Detector Design

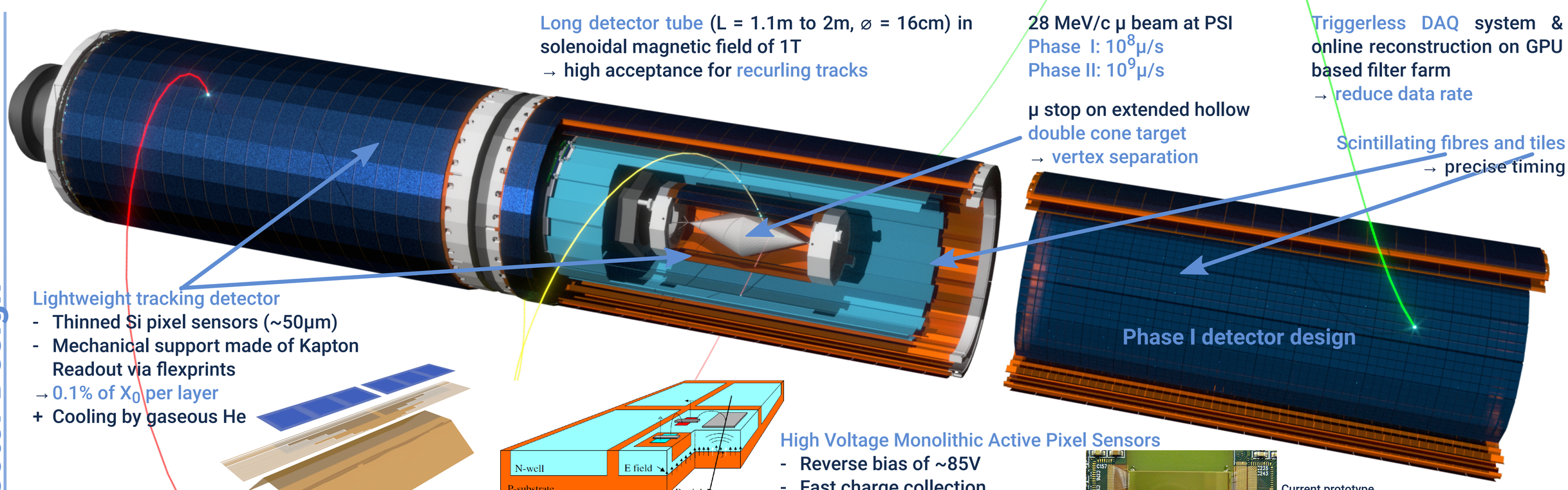
Long detector tube (L = 1.1m to 2m, ⌀ = 16cm) in solenoidal magnetic field of 1T
→ high acceptance for recurling tracks

28 MeV/c μ beam at PSI
Phase I: 10^8μ/s
Phase II: 10^9μ/s

μ stop on extended hollow double cone target
→ vertex separation

Triggerless DAQ system & online reconstruction on GPU based filter farm
→ reduce data rate

Scintillating fibres and tiles
→ precise timing



Lightweight tracking detector
- Thinned Si pixel sensors (~50μm)
- Mechanical support made of Kapton Readout via flexprints
→ 0.1% of X_0 per layer
\+ Cooling by gaseous He

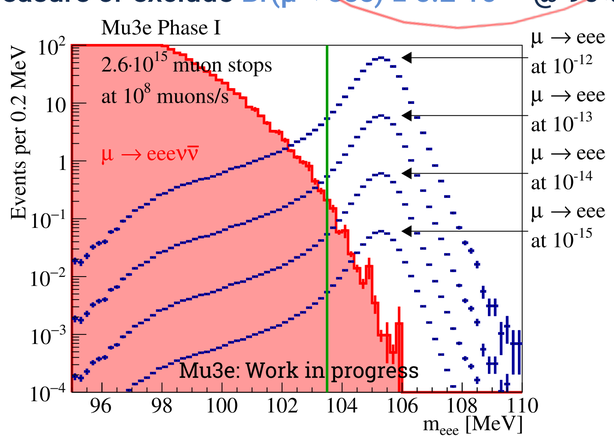
developed by Ivan Perić (KIT)
NIM A582 (2007) 876-885

High Voltage Monolithic Active Pixel Sensors
- Reverse bias of ~85V
- Fast charge collection
- Integrated readout electronics
- Zero-suppressed hit data

Current prototype MuPix8 (1x2 cm²)

Sensitivity in Phase I

Background-free operation
⇒ Measure or exclude $Br(\mu \to eee) \geq 5.2 \cdot 10^{-15}$ @ 90% CL

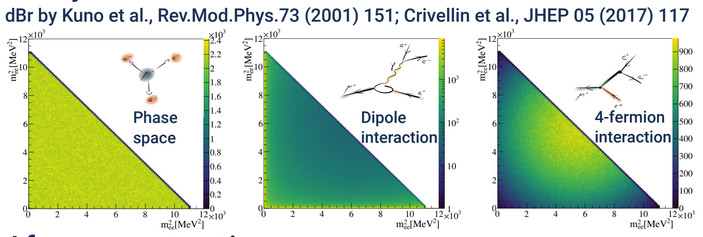


Sensitivity to $\mu \to eee$ Effective Field Theory Approach

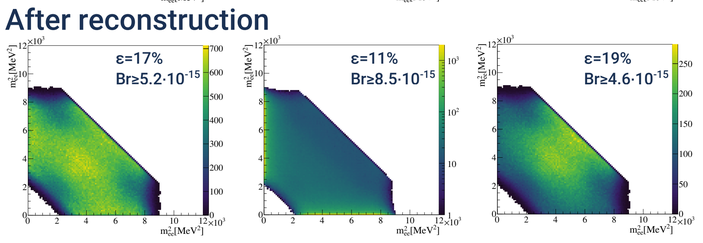
Type of interaction determines kinematics and affects signal reconstruction efficiency

Decay distributions

dBr by Kuno et al., Rev.Mod.Phys.73 (2001) 151; Crivellin et al., JHEP 05 (2017) 117

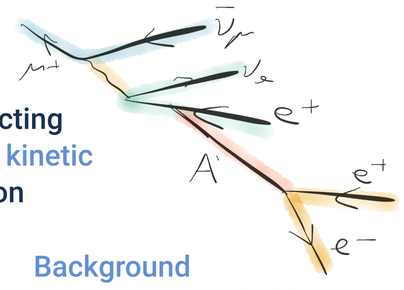


After reconstruction



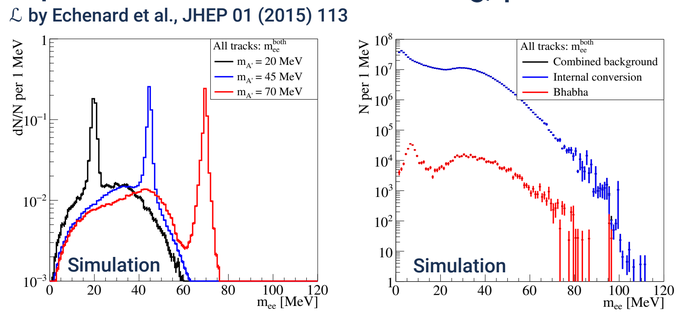
Dark Photons in Muon Decays

Dark photon A' interacting with SM particles via kinetic mixing with the photon



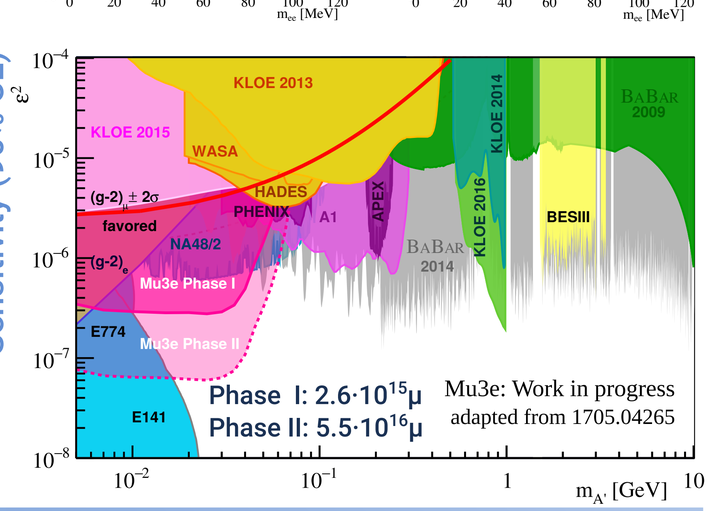
Signal
A' → ee resonance in μ → eeevv
ℒ by Echenard et al., JHEP 01 (2015) 113

Background
SM μ → eeevv, Bhabha scattering, γ conversion



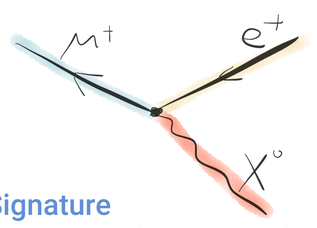
Resonances in e^+e^-

Sensitivity (90% CL)

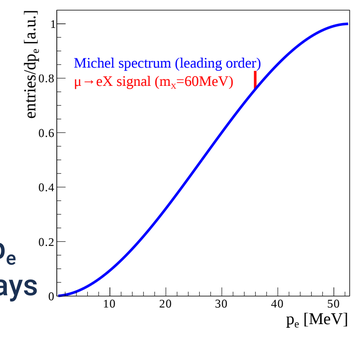


Familons

Familon is a neutral light pseudo-Goldstone boson from an additional broken flavour symmetry, emitted in flavour-changing processes e.g. $\mu \to eX$
Wilczek, PRL 49 (1982) 1549



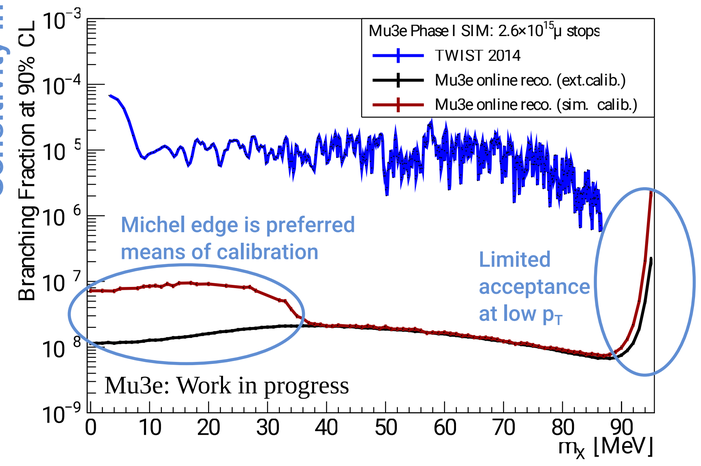
Signature
Narrow peak on smooth p_e spectrum from SM μ decays



LFV Two Body Decays $\mu \to eX$

Sensitivity in Phase I

Full event information not available in offline data
⇒ Search in spectra from online reconstruction (limited p resolution)



www.psi.ch/mu3e

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