Mu3e: A Search for the Lepton Flavour Violating Decay mu to eee

Simon Corrodi on behalf of the Mu3e Collaboration

27th April, 2015
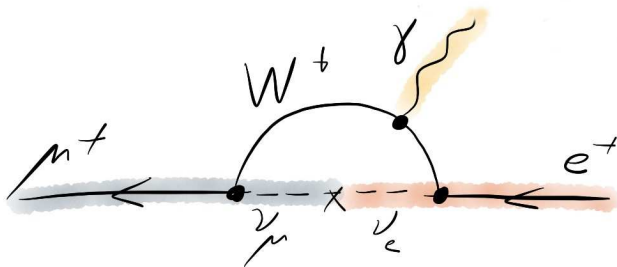
ETHzürich   University of Zurich^{UZH} UNIVERSITÉ DE GENÈVE   PAUL SCHERRER INSTITUT PSI   JGU JOHANNES GUTENBERG UNIVERSITÄT MAINZ   RUPRECHT-KARLS- UNIVERSITÄT HEIDELBERG
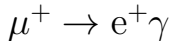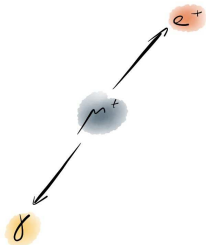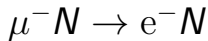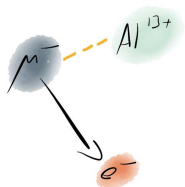
Charged Lepton (Muons) Flavour Violating

Standard Model branching fractions
$$\ll 10^{-50}$$

Charged Lepton (Muons) Flavour Violating **Decays**

$\mu^- N \to e^- N$ $\qquad$ $\mu^+ \to e^+ \gamma$ $\qquad$ $\mu^+ \to e^+ e^- e^+$
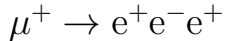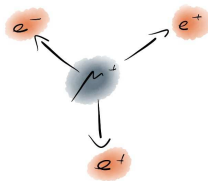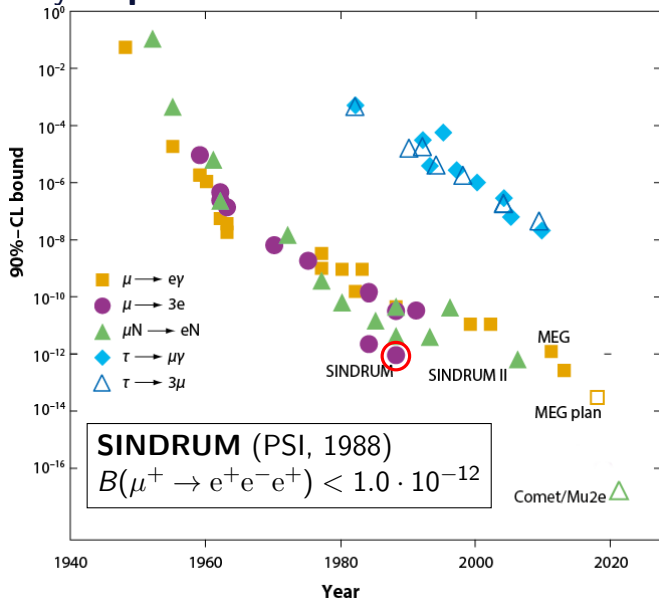
complementary processes
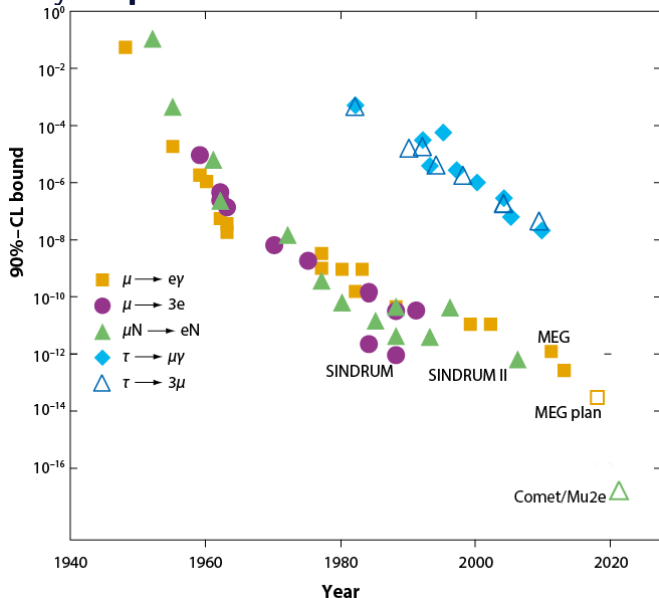
CLFV Decay **Experiments**

Updated from W.J. Marciano, T. Mori and J.M. Roney, Ann.Rev.Nucl.Part.Sci. 58, 315 (2008)

CLFV Decay **Experiments**

SINDRUM (PSI, 1988)
$B(\mu^+ \to e^+e^-e^+) < 1.0 \cdot 10^{-12}$

Updated from W.J. Marciano, T. Mori and J.M. Roney, Ann.Rev.Nucl.Part.Sci. 58, 315 (2008)

CLFV Decay Experiments: **Mu3e**

Figure legend (within plot):
- $\mu \longrightarrow e\gamma$
- $\mu \longrightarrow 3e$
- $\mu N \longrightarrow eN$
- $\tau \longrightarrow \mu\gamma$
- $\tau \longrightarrow 3\mu$

Plot labels: SINDRUM, SINDRUM II, MEG, MEG plan, Mu3e Phase I, Mu3e Phase II, Comet/Mu2e

Axis labels: 90%–CL bound (y-axis), Year (x-axis)

Mu3e (PSI, $>=$ 2017)
I: $B^{I}_{Mu3e} < 1.0 \cdot 10^{-15}$
II: $B^{II}_{Mu3e} < 1.0 \cdot 10^{-16}$
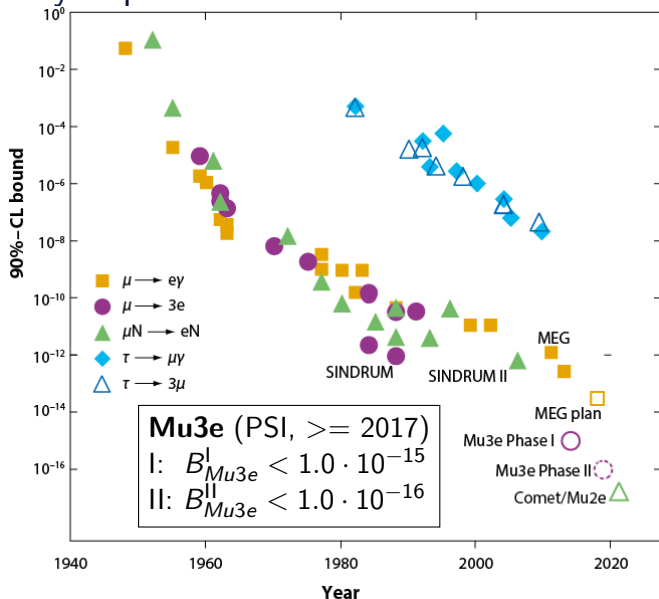
Updated from W.J. Marciano, T. Mori and J.M. Roney, Ann.Rev.Nucl.Part.Sci. 58, 315 (2008)

The Mu3e Experiment

Mu3e is a **dedicated** experiment for the **exotic search**
$\mu^+ \to e^+e^-e^+$ that aims for a sensitivity better than 10^{-16}.
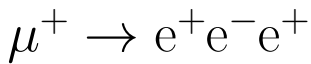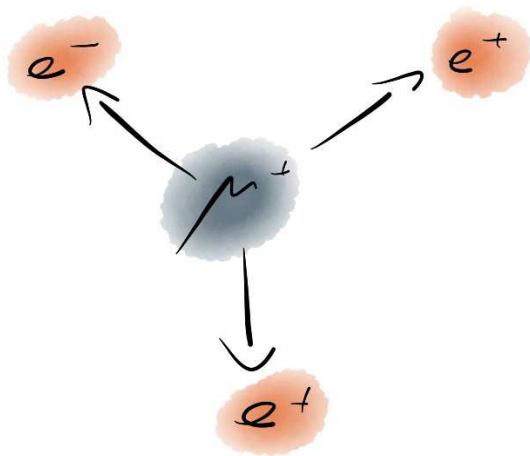
The Mu3e Experiment

Mu3e is a **dedicated** experiment for the **exotic search**
$\mu^+ \to e^+ e^- e^+$ that aims for a sensitivity better than $\mathbf{10^{-16}}$.
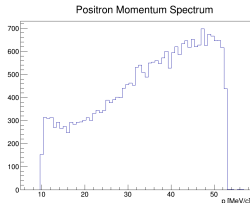
any observation
is new physics
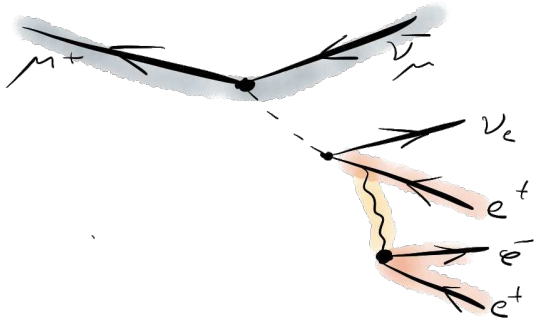
experimental limits
number of μ^+
background suppression

Signal Signature

$$\mu^+ \rightarrow e^+ e^- e^+$$

– 3-body decay

– same vertex

– same time

– $|\sum \mathbf{P}_e| = m_\mu^2$

– $p_{max} = \frac{m_\mu}{2}$
  $= 53$ MeV/c

Internal Conversion Background

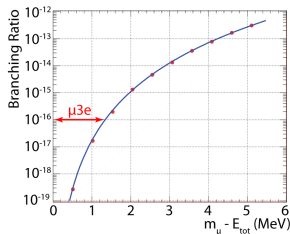$$\mu^+ \rightarrow e^+ e^- e^+ \nu \overline{\nu}$$

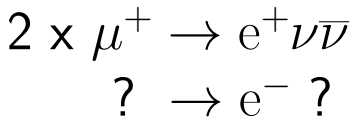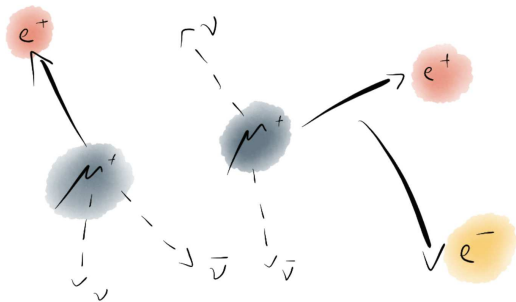$$B = (3.4 \pm 0.4) \cdot 10^{-5}$$

Requirements

Excellent momentum resolution

– radiative decay with internal conversion

– distinction: **Missing p** carried by neutrinos

(R. M. Djilkibaev, R. V. Konoplich,

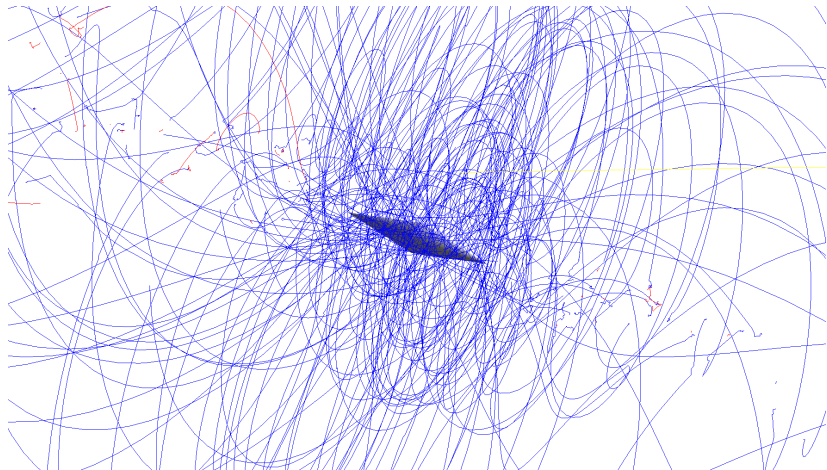Phys.Rev. D79 (2009) 073004)

Accidentals Background

$$2 \times \mu^+ \rightarrow e^+ \nu \overline{\nu}$$
$$? \rightarrow e^- ?$$

Ordinary μ^+ decay superposed with e^- from:

- Bhabha scattering
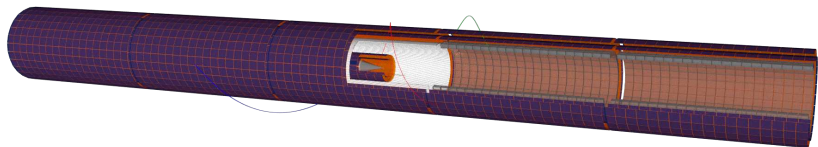
- photon conversion

- mis-reconstruction

Requirements

Excellent momentum resolution
Excellent vertex/timing resolution

Another Challenge: **High Rates**

reasonable time → high rates required
online reconstruction

The Mu3e Detector

The *Mu3e* detector, build out of **3 sub-detectors**,
is designed for excellent
vertex ($< 200 \ \mu m$) ,
timing ($< 100/500 \ ps$) and
momentum ($< 0.5 \ MeV/c$)
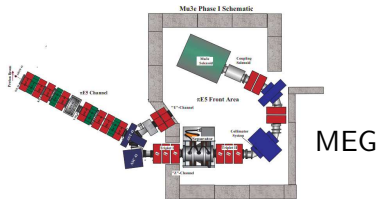resolution.

multiple scattering (< 53 MeV/c)
low material budget

Muons at PSI

PAUL SCHERRER INSTITUT

Phase I (πE5)

MEG

up to $\sim 10^8$ 28 MeV/c surface μ/s extracted from carbon target in proton beam
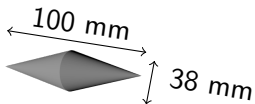
APPROVED

Phase II (HiMB)
High Intensity Muon Beam

2-year feasibility study ongoing
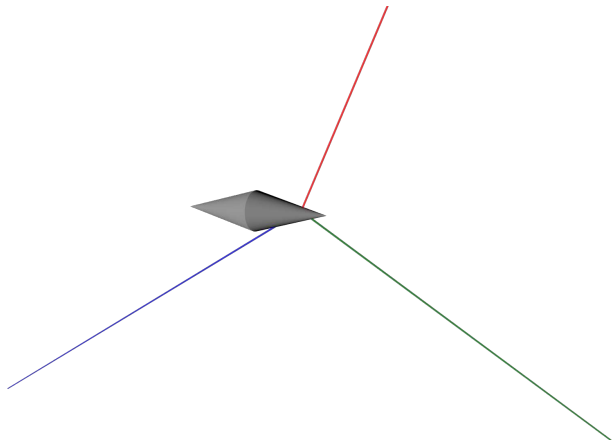- Mu3e: $\sim 10^9$ μ/s
- PSI Goal: 10^{10} μ/s

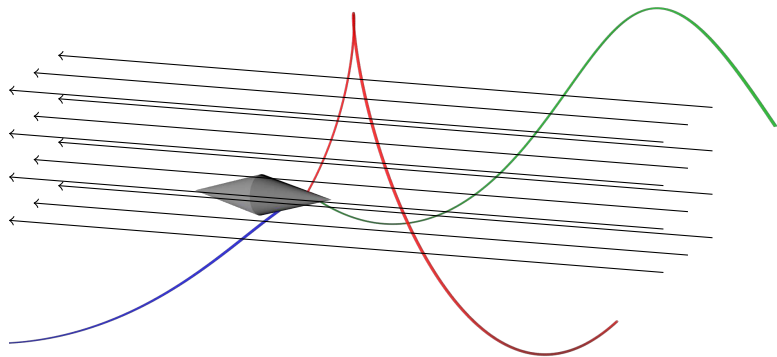- study with solenoidal target station in p-channel
- SINQ: not feasible

Target

μ^+ **stop** in hollow mylar double cone
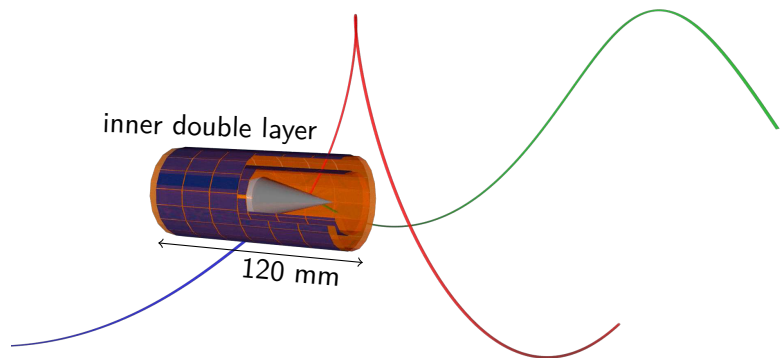(thickness: $\sim 50 - 150\ \mu m$, length: 100 mm, diameter: 38 mm)
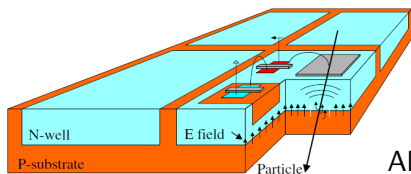
Target

and decay

Target

bended tracks due to **homogeneous 1 T** magnetic field
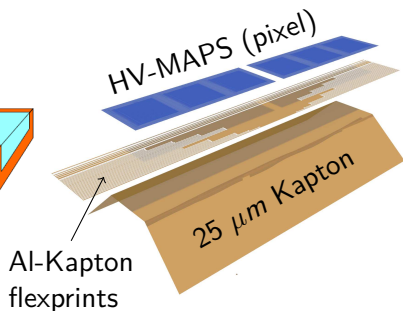
Pixel Sub-Detector

inner double layer

120 mm

48 + 60 sensors, 2 x 2 cm^2 with 80 x 80 μm^2 pixels

Pixel Sub-Detector

(I.Perić, P. Fischer et al., NIM A 582 (2007) 876)

Al-Kapton flexprints

HV-MAPS: High Voltage Monolithic Active Pixel Sensors
fast: small active region, charge collection via drift ($\mathcal{O}(10ns)$)
thin: $< 50~\mu m$
zero-suppressed data: addresses and timestamps
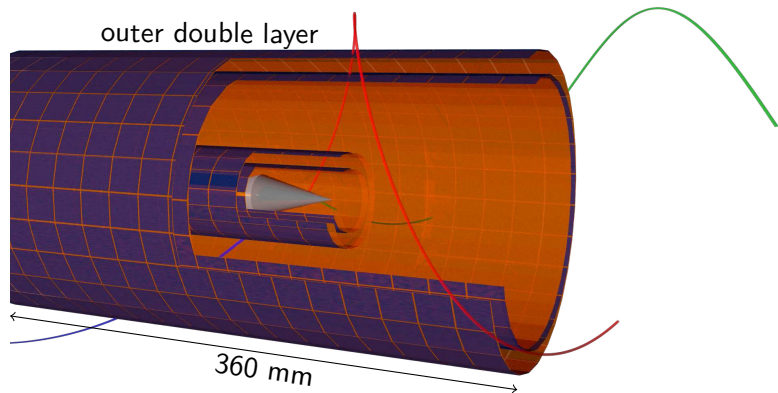
< 1 ‰ radiation length per layer

Pixel Sub-Detector
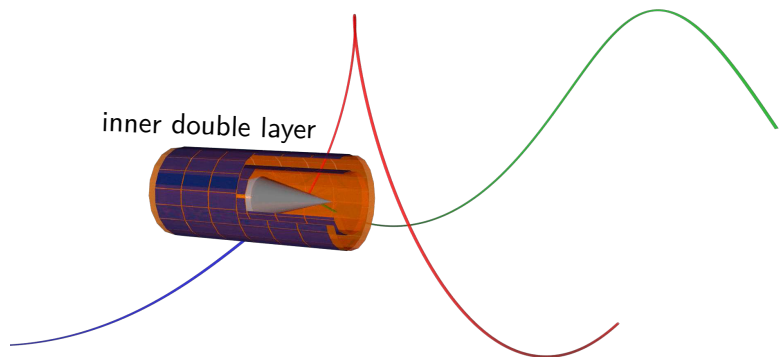
inner double layer

vertex ($\checkmark$)
momentum
timing

Pixel Sub-Detector

outer double layer

360 mm

432 + 504 sensors provide tracking information

Pixel Sub-Detector
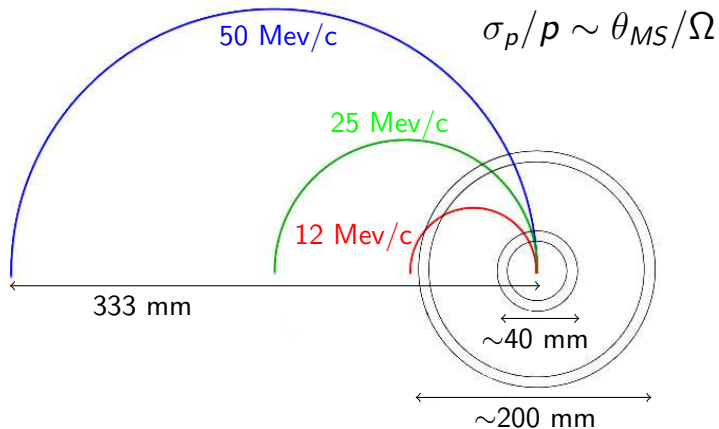
$\sigma_p / p \sim \theta_{MS} / \Omega$

< 53 MeV/c: multiple scattering θ_{MS}

Ω: lever arm

Pixel Sub-Detector

$$\sigma_p/p \sim \theta_{MS}/\Omega$$

50 Mev/c

25 Mev/c

12 Mev/c

333 mm

~40 mm
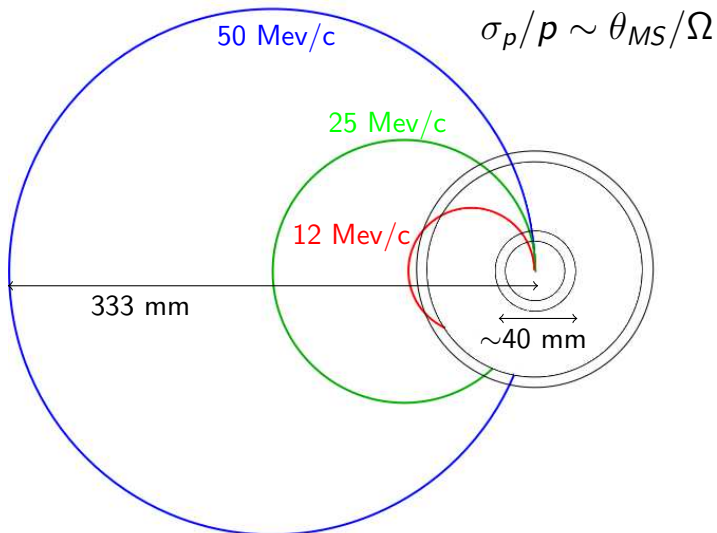
< 53 MeV/c: multiple scattering θ_{MS}
Ω: lever arm
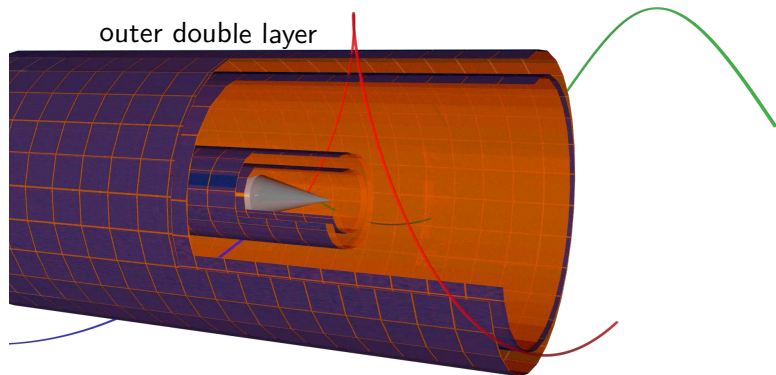
Pixel Sub-Detector

outer double layer

vertex ✓
momentum ✓
timing

Fibre Sub-Detector

outer double layer
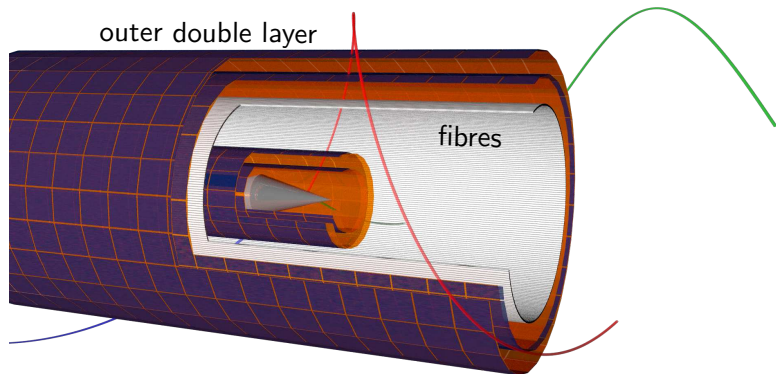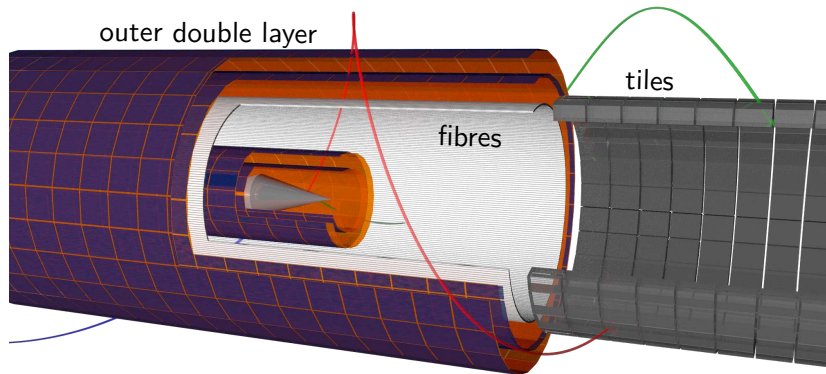
fibres

3 layer of ∼ 1500 scintillating fibres with an diameter of **250 μm**
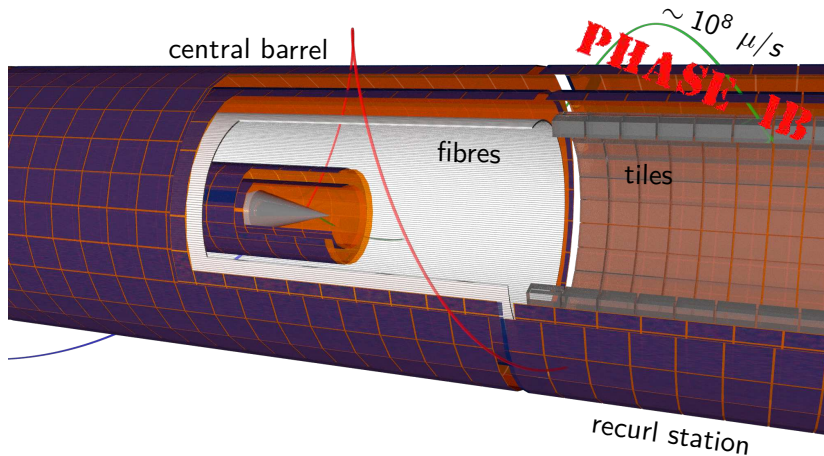read out by MPPC arrays provide a time resolution < **1ns**.

Fibre Sub-Detector

outer double layer

fibres

PHASE 1A

$\sim 10^7\ \mu/s$
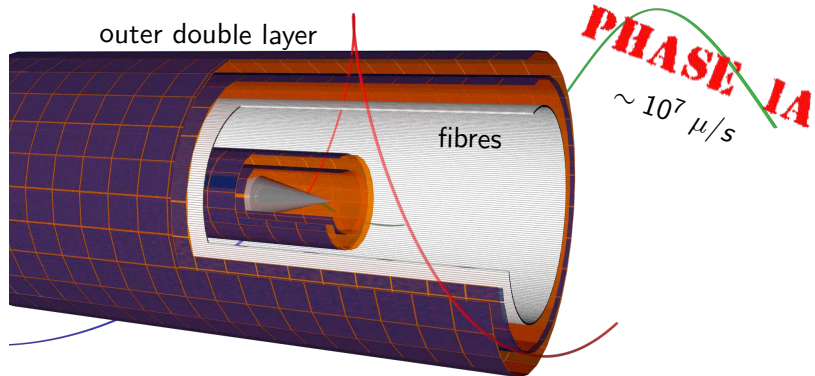
vertex ✓
momentum ✓
timing ✓

Tiles Sub-Detector

3360 scintillating tiles $\sim$ **1 x 1 x 1 cm^2** read out by single MPPCs
provide a time resolution $<$ **100ps**.

Recurl Stations

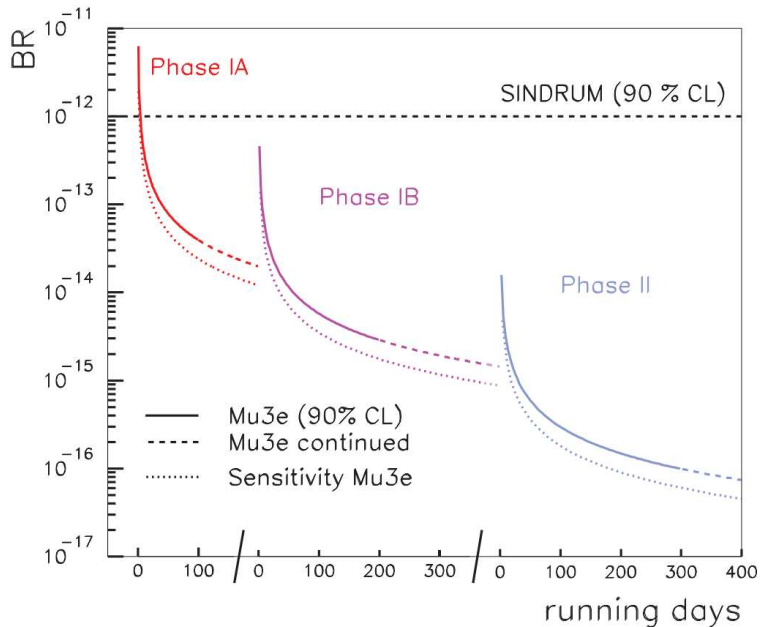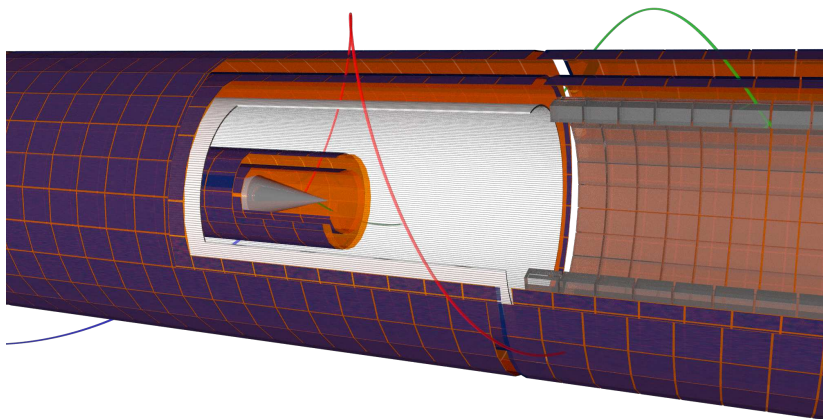vertex ✓
momentum ✓(improved)
timing ✓(improved)
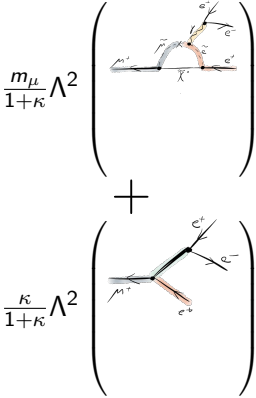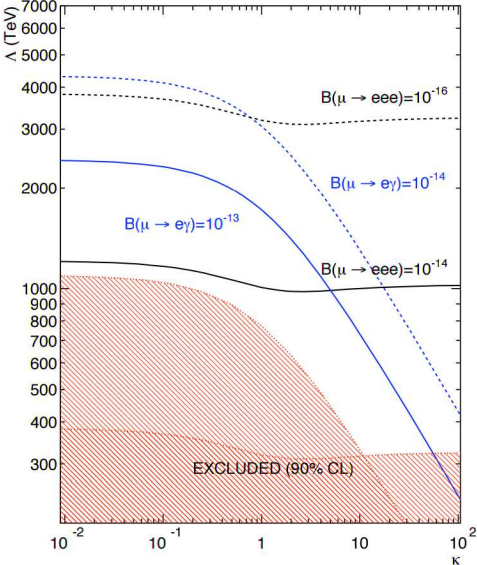
Recurl Stations

Expected Sensitivity

Summary

Mu3e is a **dedicated** experiment for the **exotic search** $\mu^+ \to e^+e^-e^+$ aiming for a ultimate sensitivity better than $\mathbf{10^{-16}}$.

Thank You

Mu3e/MEG Processes

$$\frac{m_\mu}{1+\kappa}\Lambda^2 \left(\right)$$

$$+$$

$$\frac{\kappa}{1+\kappa}\Lambda^2 \left(\right)$$
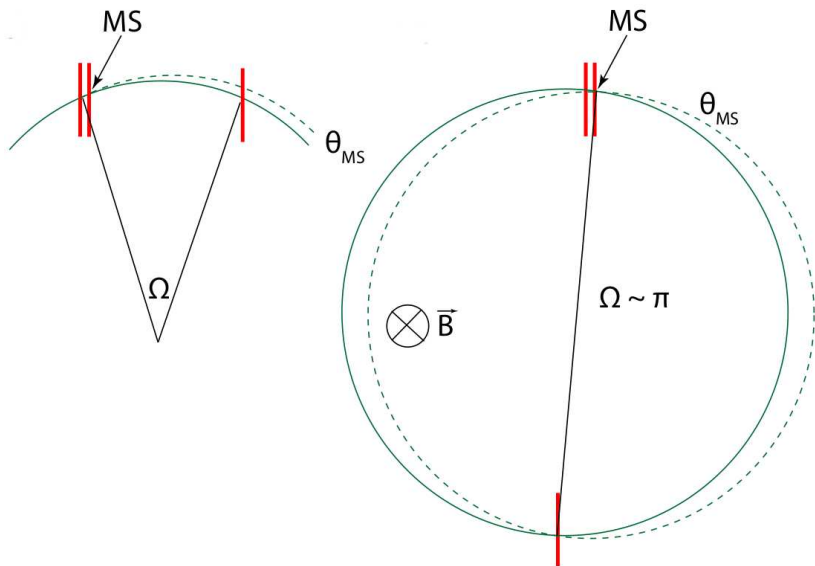
A. Gouvea1 and P. Vogle, Lepton Flavor and Number Conservation,

and Physics Beyond the Standard Model, arXiv:1303.4097 (2013)

Multiple Scattering

HiMB @ SINQ: not feasible