An Introduction to the Mu3e Experiment

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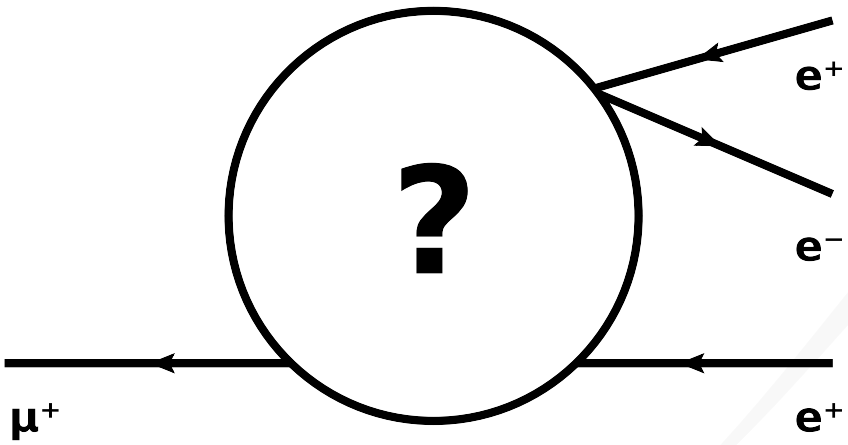
Introduction



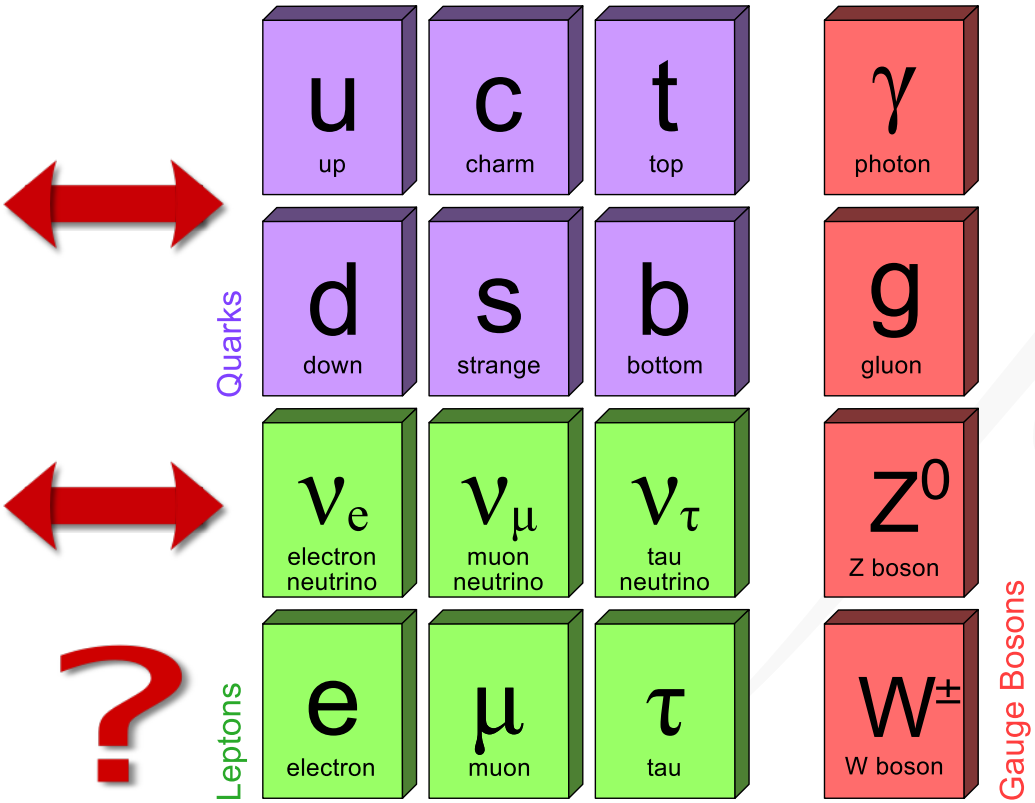
The Mu3e Experiment

- Precision experiment
- Search for $\mu^+ \rightarrow e^+e^-e^+$
- Charged Lepton Flavor Violation (cLFV)
- New Physics search (Indirect)

In this Talk

- Theoretical motivation
- Experimental design
- Current status

Flavor in the Standard Model



adapted from [Wikipedia]

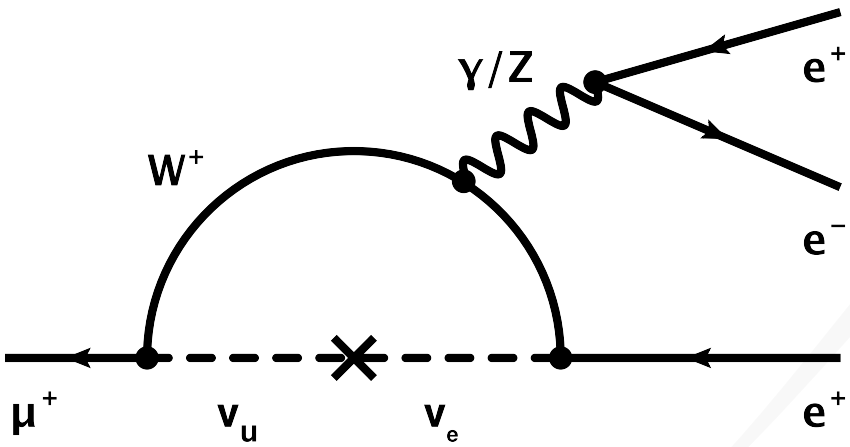
Original Formulation

- Quark transitions via Weak Interaction
- Lepton flavor conserved

Neutrino Mixing

- LFV in neutral sector
- Charged sector?

$\mu \to$ eee in the Standard Model



Features

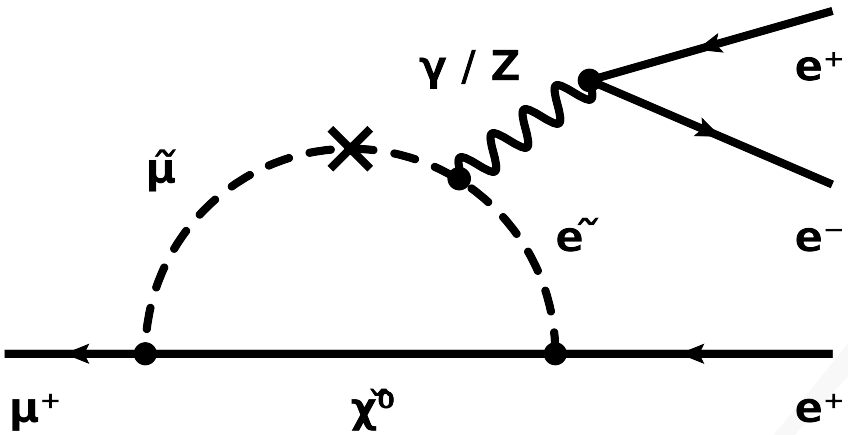
- Charged lepton flavor violating
- Via neutrino mixing
- Suppressed by $\sim \left(\frac{\Delta m_\nu^2}{m_W^2}\right)^2$
- Expected BR($\mu \to$ eee) $< 10^{-50}$

Importance

- Observable BR only from New Physics

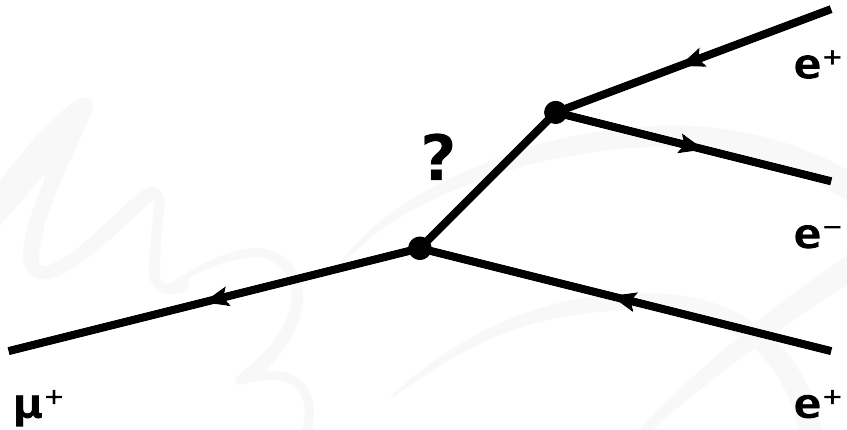
Beyond the Standard Model

In Loops



- e.g. SUSY
- Also enhances $\mu \to e\gamma$

At Tree Level



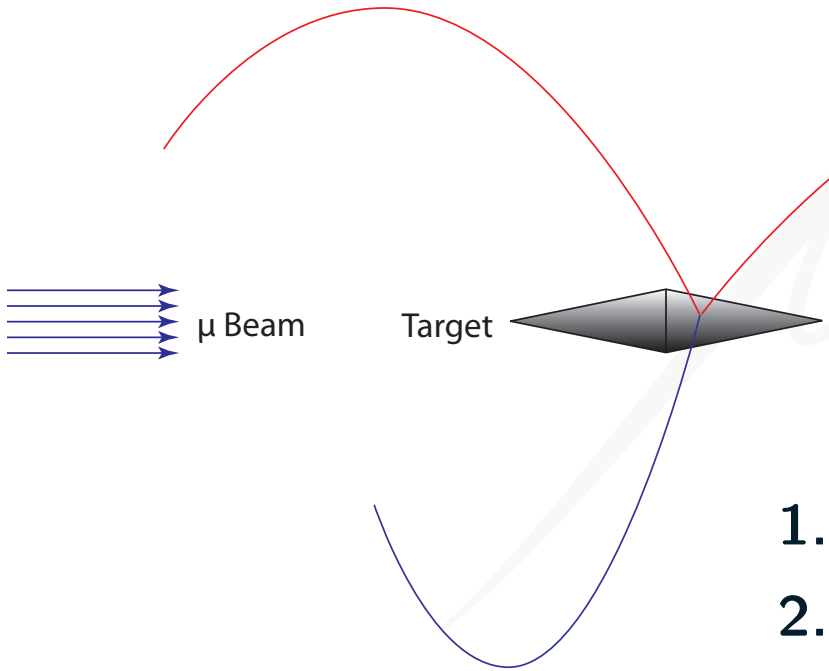
- e.g new heavy boson
- No $\mu \to e\gamma$ enhancement

Current Limits

cLFV Process	BR @ 90 %CL	Experiment
$\mu^+ \to e^+e^-e^+$	$< 1 \times 10^{-12}$	Sindrum [Nucl.Phys. B299(1)]
$\mu^+ \to e^+\gamma$	$< 5.7 \times 10^{-13}$	MEG [arXiv:1303.0754]
$\mu^- + \mathrm{Au} \to e^- + \mathrm{Au}$	$< 7 \times 10^{-13}$	Sindrum II [Eur. Phys. J. C47 337-346]

Our Goal: $\mathrm{BR}(\mu^+ \to e^+e^-e^+) < 1 \times 10^{-16}$ @ 90% CL

Experimental Idea



1. Stop a lot of muons
2. Let them decay
3. Measure decay electrons
4. Find three coincident electrons

Muon beams at PSI

Paul-Scherrer Institute

- Villigen, Switzerland
- Currently hosts the MEG Experiment

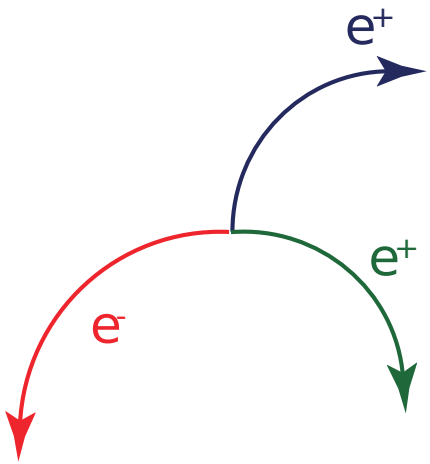
Muon Beam Lines

- Low energy DC Beams
- Current beam lines:
  $\approx 1 \times 10^8$ muons /s
- Future high intensity beam:
  $> 1 \times 10^9$ muons /s

$\rightarrow$ High Rates

Signals and Backgrounds

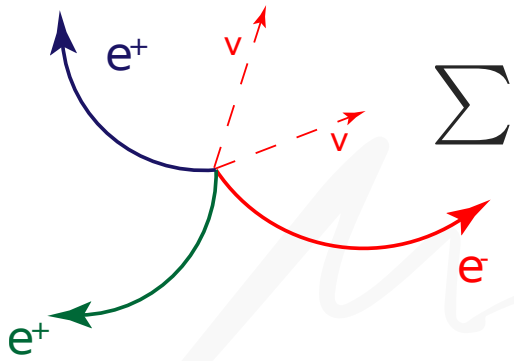
Signal



- $(\sum P_i)^2 = m_\mu^2$
- $\sum \vec{p}_i = 0$
- $p_{max} \approx 53\,\text{MeV}$

Backgrounds

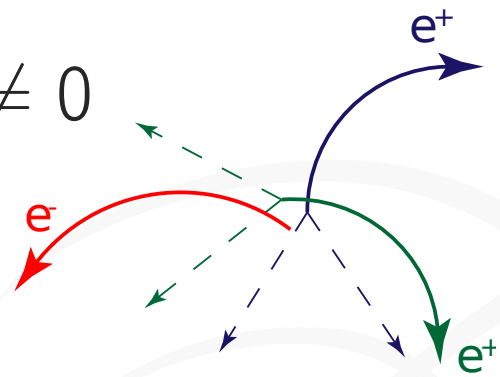
Internal Conversion



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

- Single vertex
- In-time

Combinatorial

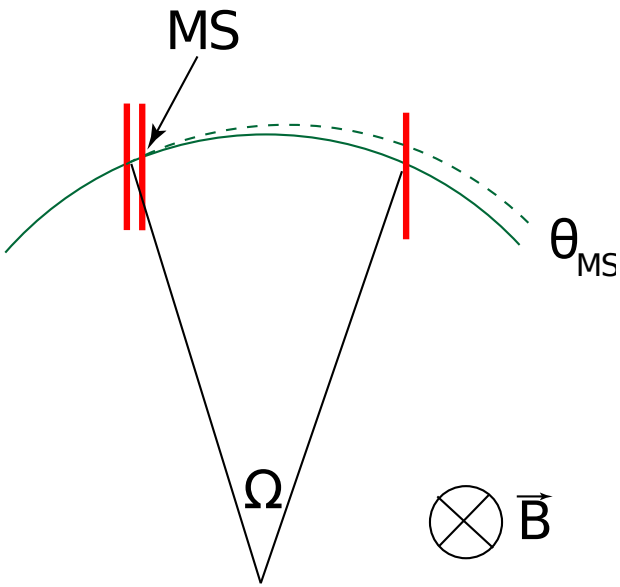


- No single vertex
- Out-of-time

→ Fast, precise electron tracker + timing

Multiple Scattering

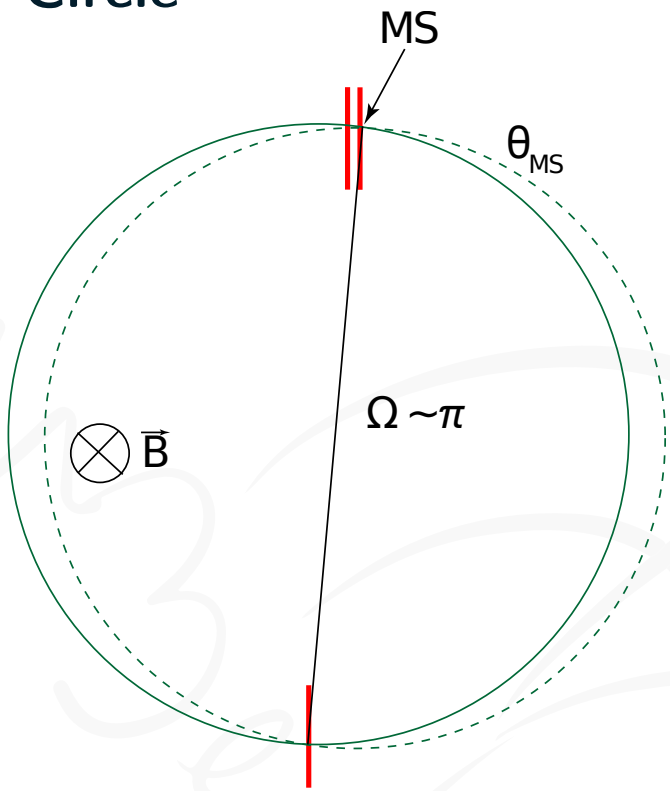
Short Tracks



$$\theta_{MS} = \frac{13.6\,\text{MeV}}{p}\sqrt{x/X_0}$$

e.g. p = 35 MeV, 200 µm Si,
$\Omega R = 5\,\text{cm} \rightarrow \Delta y \approx 1\,\text{mm}$

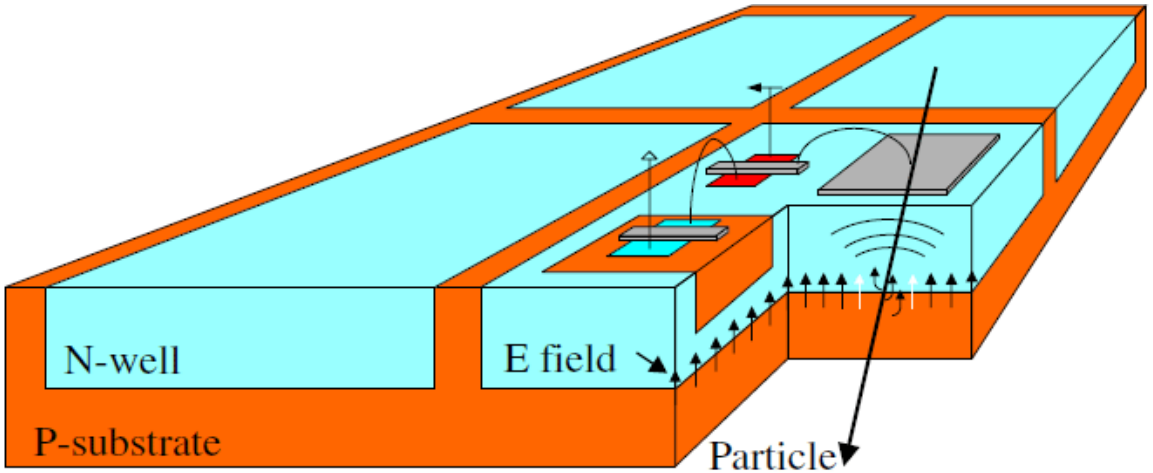
Semi Circle



In first order / fixed momentum

→ Minimize material, optimize geometry

High Voltage MAPS



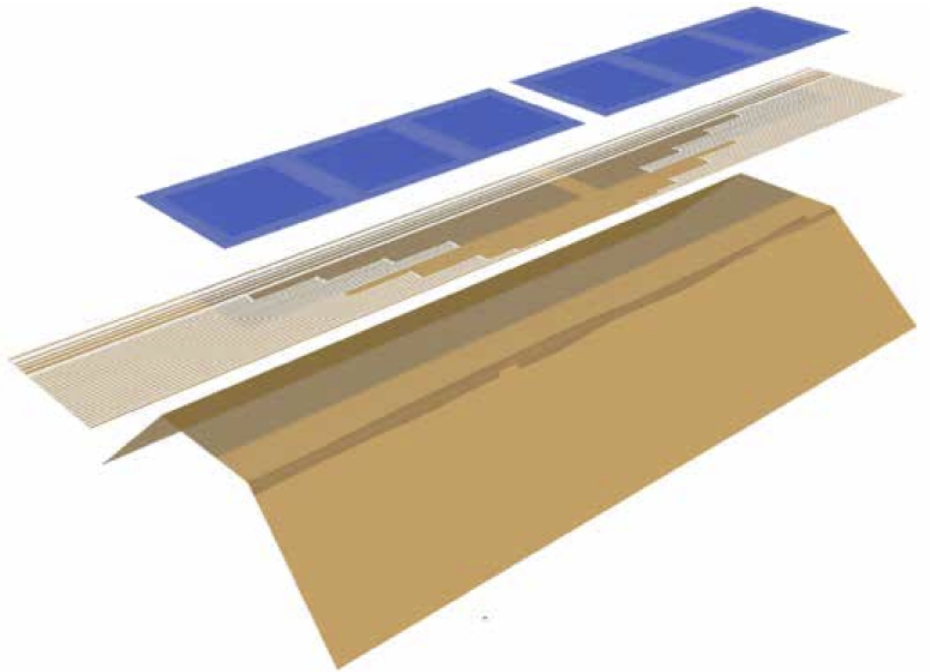
[I. Peric et al., NIM A, 2013]

Monolithic
Active
Pixel
Sensor

- High voltage $\sim 60\,\mathrm{V}$
- Fast (drift time $\sim 1\,\mathrm{ns}$)
- Can be thinned $< 50\,\mu\mathrm{m}$
- Integrated Readout
- Integrated Zero-Suppression

$\rightarrow$ no extra readout chip

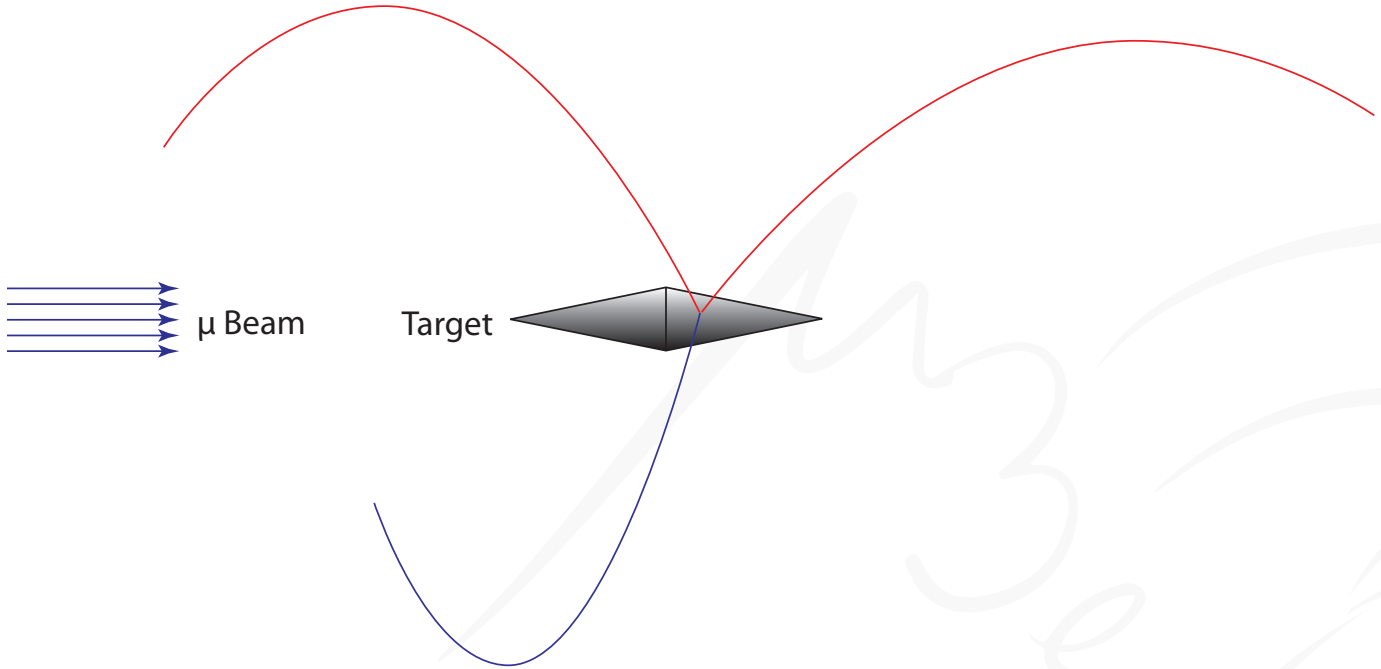
Ultra-Lightweight Mechanics



- 50 µm Silicon
- 25 µm Kapton Flexprint
- 50 µm Kapton support frame

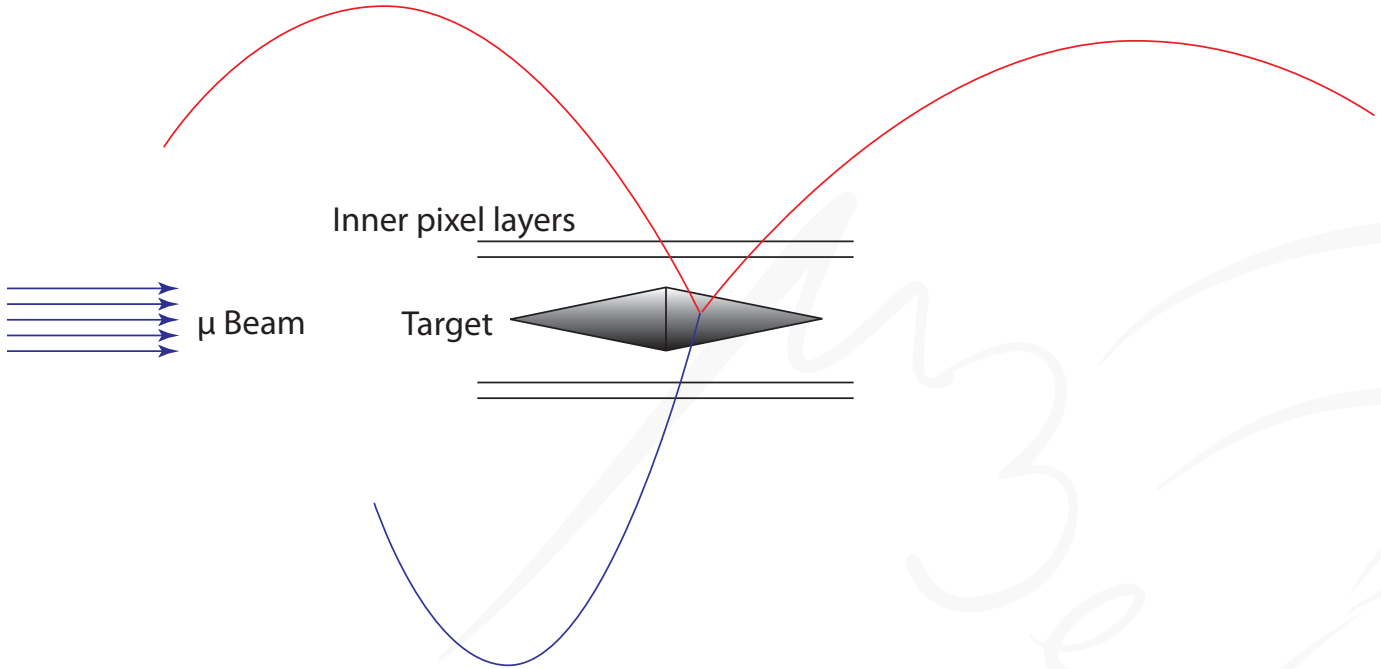
$\rightarrow$ $< 1\,‰$ Radiation length

Experimental Design



- Magnetic field $\sim 1\,\mathrm{T}$
- Fibres $\sigma_t \sim 1\,\mathrm{ns}$
- Tiles $\sigma_t < 250\,\mathrm{ps}$

Experimental Design



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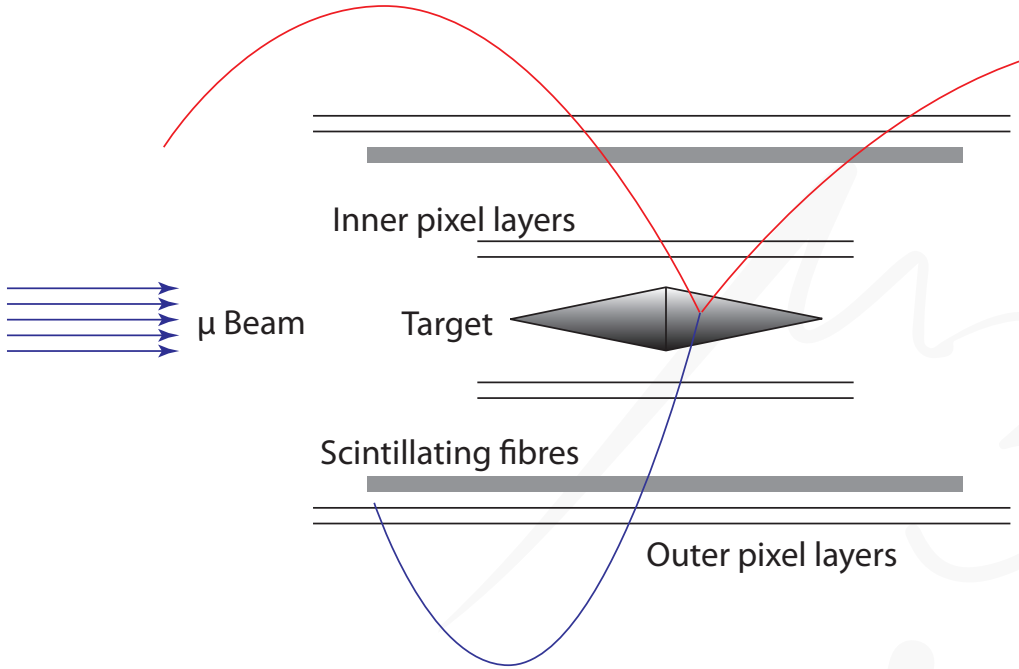

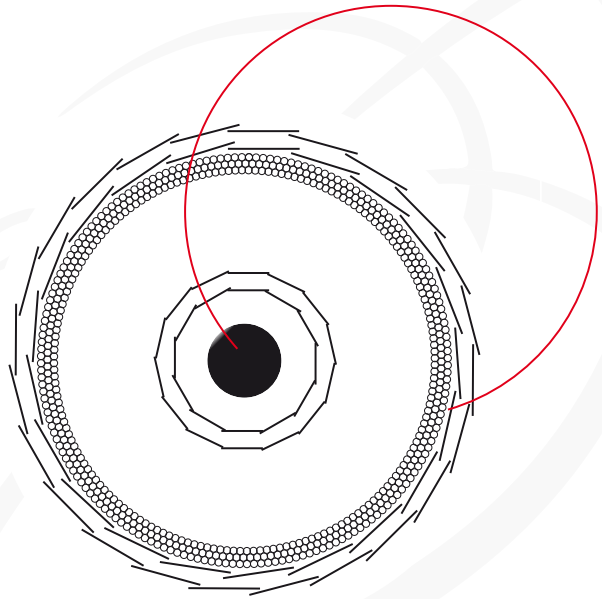

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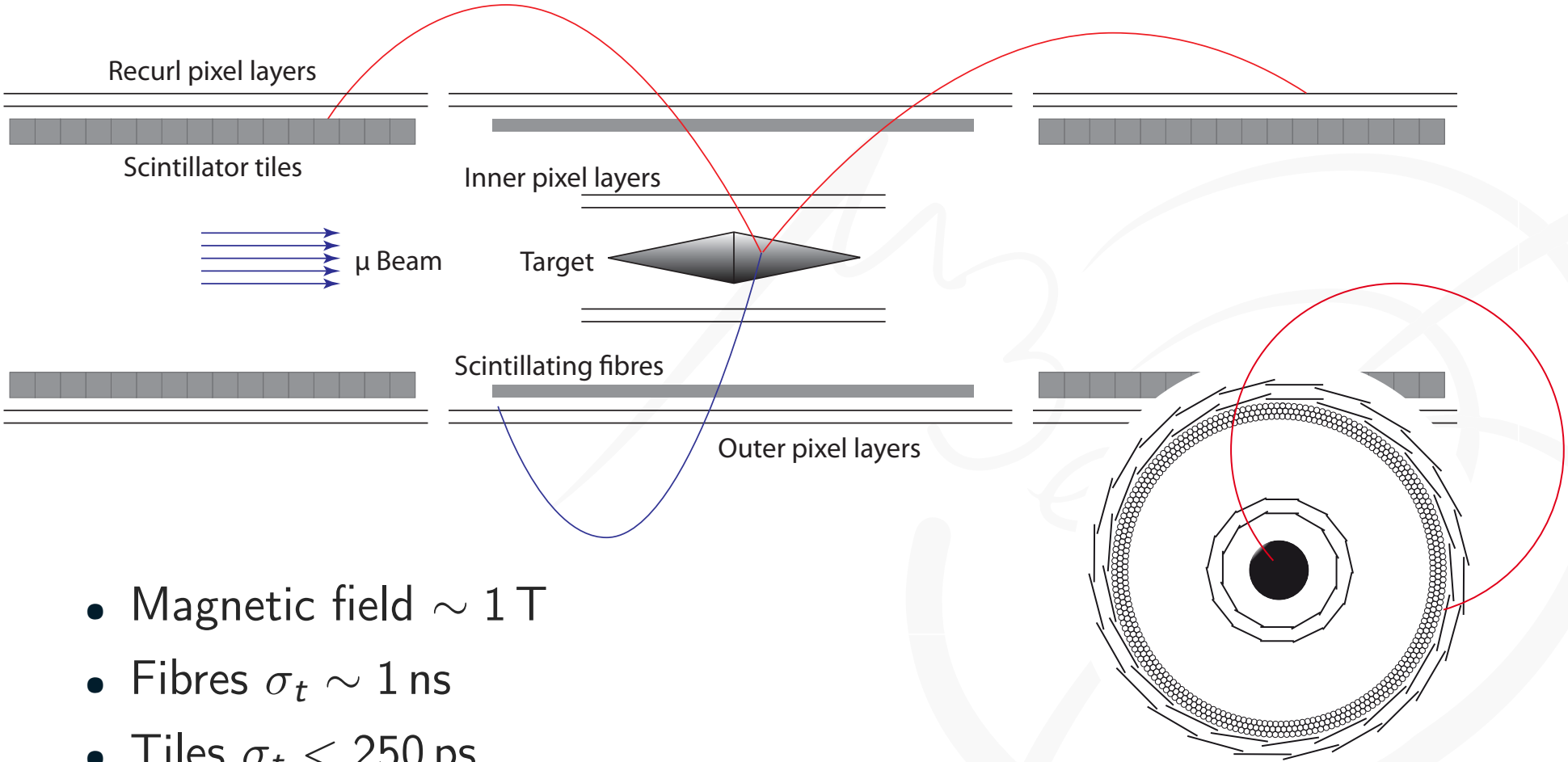

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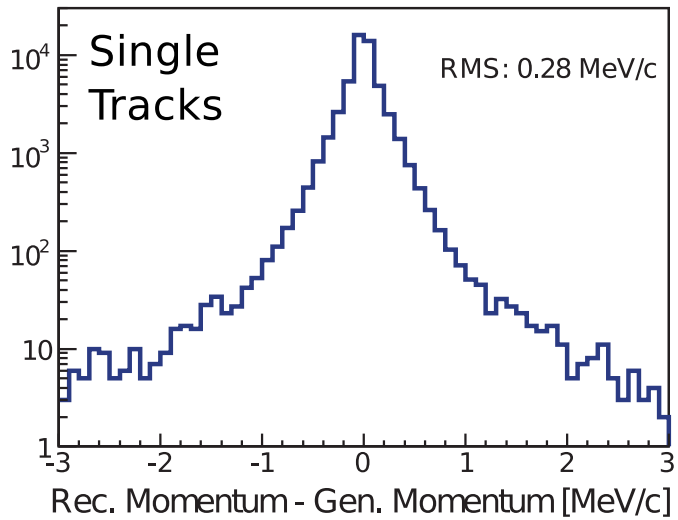
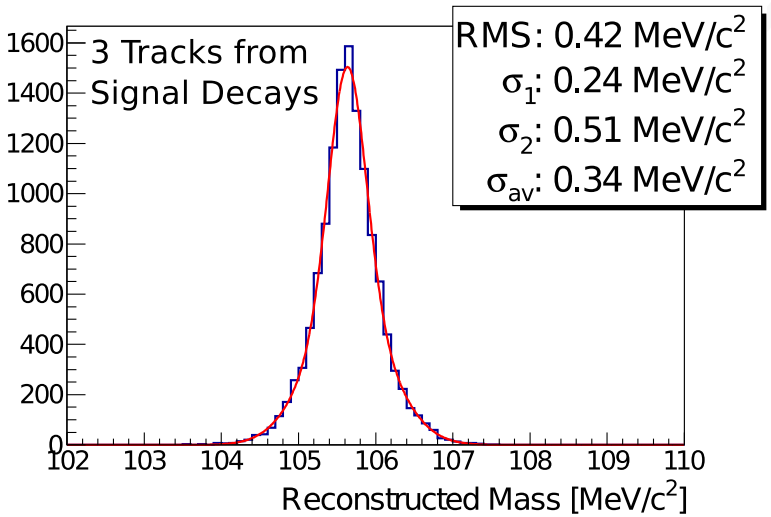
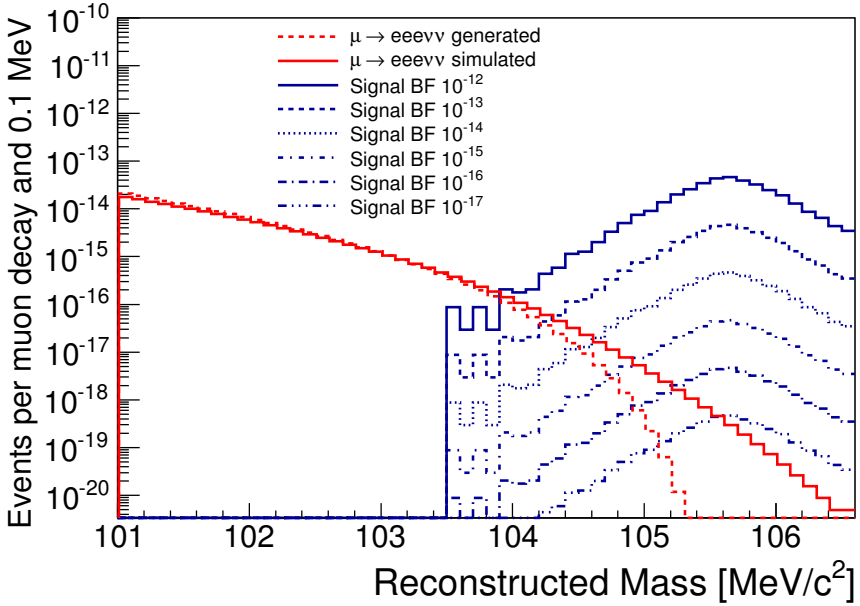
Simulated Sensitivity

Resolution





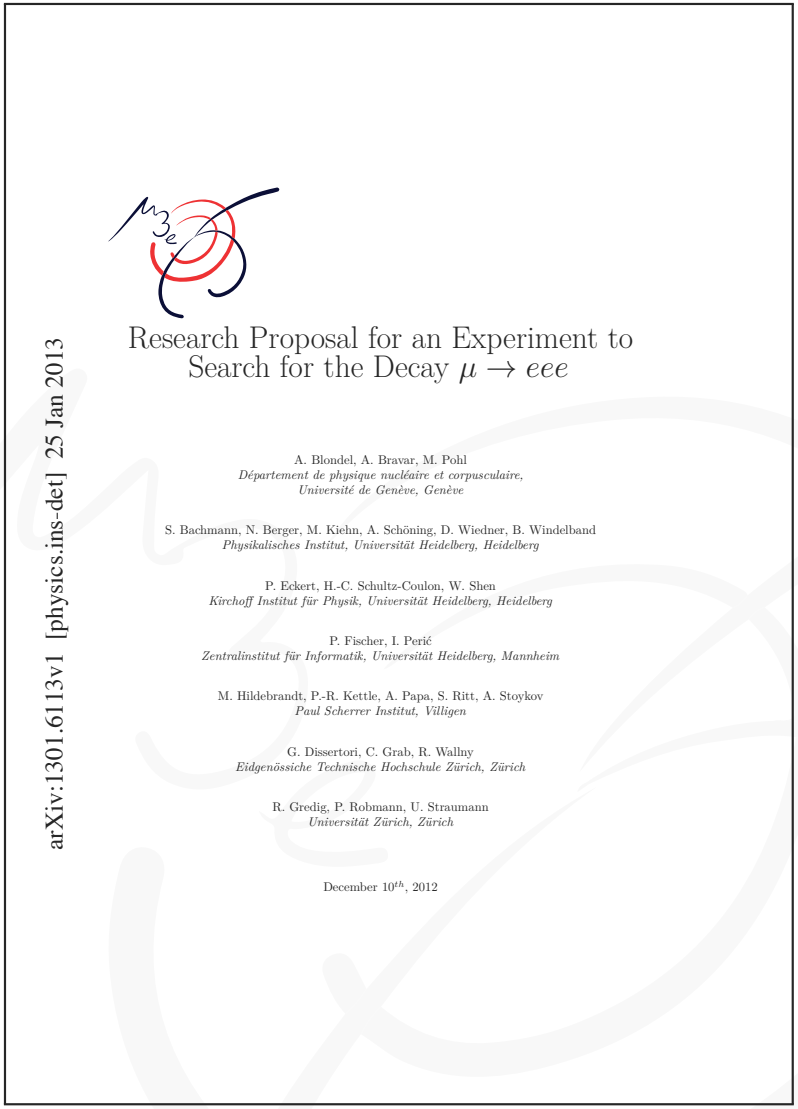
Sensitivity



- Full detector simulation
- Combinatorics reduced by timing / vertex cuts
- Sensitivity down to BR $< 1 \times 10^{-16}$

Status

- Research Proposal [arXiv:1301.6113] (accepted in January 2013)
- Pixel Sensor Prototypes
- Mechanical Prototypes
- Testbeam Measurements
- ...



Research Proposal for an Experiment to Search for the Decay $\mu \to eee$

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Département de physique nucléaire et corpusculaire, Université de Genève, Genève

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P. Eckert, H.-C. Schultz-Coulon, W. Shen
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P. Fischer, I. Perić
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M. Hildebrandt, P.-R. Kettle, A. Papa, S. Ritt, A. Stoykov
Paul Scherrer Institut, Villigen

G. Dissertori, C. Grab, R. Wallny
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R. Gredig, P. Robmann, U. Straumann
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December 10^{th}, 2012

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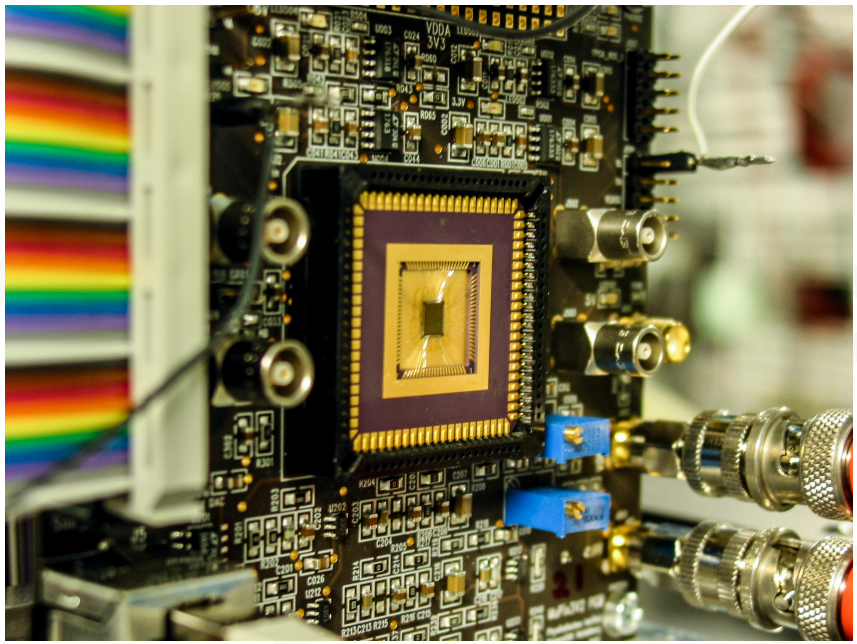

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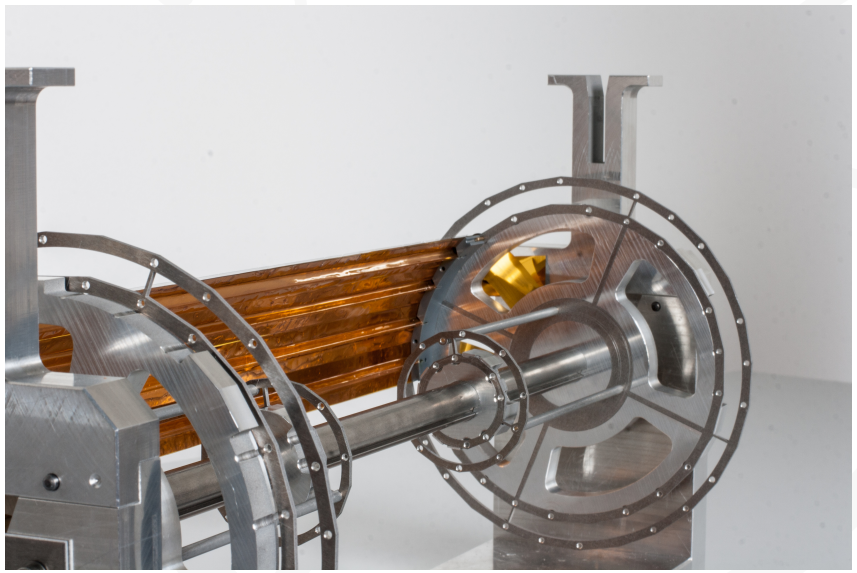
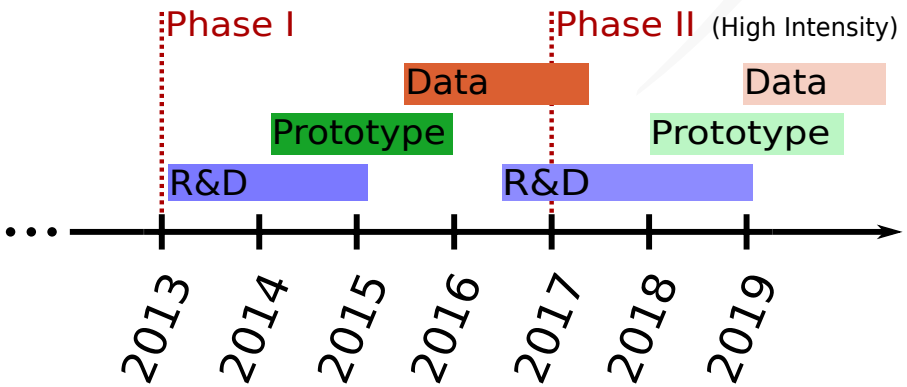


Summary & Outlook

Summary

- Search for $\mu^+ \to e^+e^-e^+$
- Fast and precise elecron tracker
- additional timing
- ultimate sensitivity
  $\mathrm{BR}(\mu^+ \to e^+e^-e^+) < 1 \times 10^{-16}$

Timeline

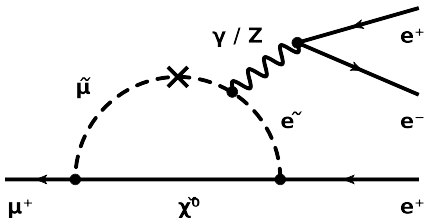


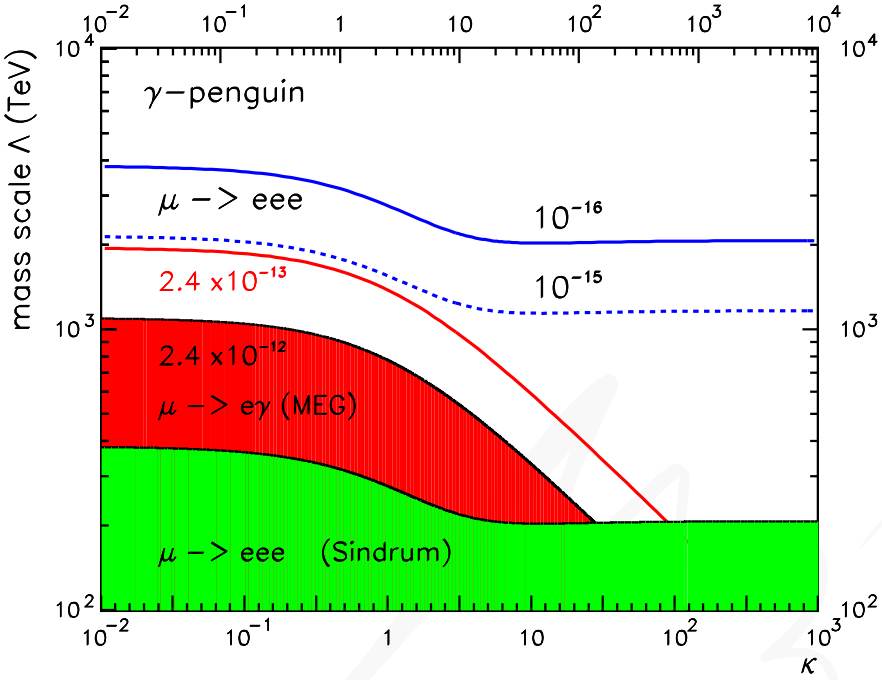
Collaboration

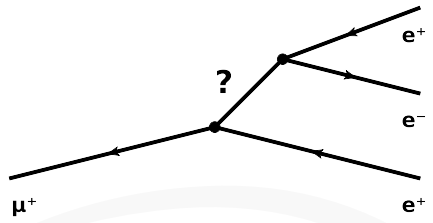
- Paul-Scherrer Institute
- ETH Zürich
- University Zürich
- University Geneva
- Heidelberg University
- ZITI Mannheim

Backup

Effective Lagrangian Example



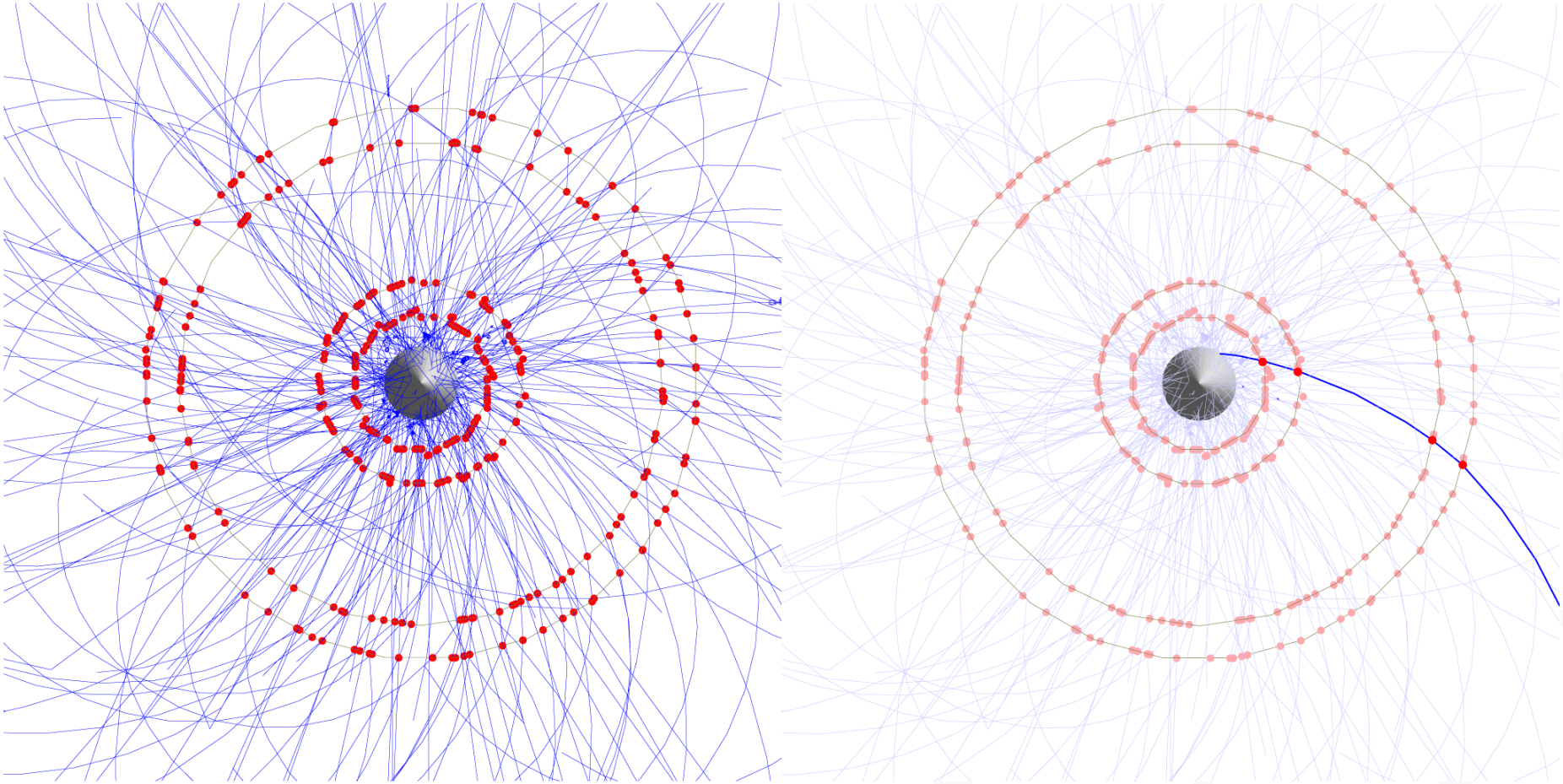




$$L_{LFV} = \left[\frac{m_\mu}{(\kappa+1)\Lambda^2}\ \overline{\mu_R}\sigma^{\mu\nu}e_L F_{\mu\nu}\right]_{\gamma-\text{penguin}} + \left[\frac{\kappa}{(\kappa+1)\Lambda^2}\ (\overline{\mu_L}\gamma^\mu e_L)(\overline{e_L}\gamma_\mu e_L)\right]_{\text{tree}}$$

adapted from [A. de Gouvea, Nucl. Phys B. (Proc. Suppl.), 188 303-308] and [arXiv:hep-ph/9909265]

Example Frame at High Intensity



High Intensity: 2×10^9 muons / s

$\rightarrow$100 tracks / 50 ns readout frame (before / after timing cuts)

Expected Sensitivity over Time