The Mu3e Experiment
Introduction and Current Status

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NuFACT2014, Glasgow, 25. August 2014

International Max Planck Research School for Precision Tests of Fundamental Symmetries

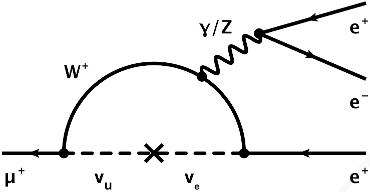
The Mu3e Experiment

- Precision experiment
- Search for $\mu^+ \rightarrow e^+e^-e^+$
- Sensitivity < 1 in 10^{16} decays

In this talk

- Experimental Concept
- Current Status
- Pixel Sensor Prototypes

$\mu \rightarrow$ eee in the Standard Model



Features

- Charged lepton flavor violating
- Via neutrino mixing
- Expected BR($\mu \rightarrow$ eee) $\ll 10^{-50}$
- Current Limit from Sindrum
  BR($\mu \rightarrow$ eee) $< 1 \cdot 10^{-12}$ @90 % CL

  Nucl.Phys. B299(1)

Importance

- Observable rate only from New Physics
- Sensitive New Physics Search

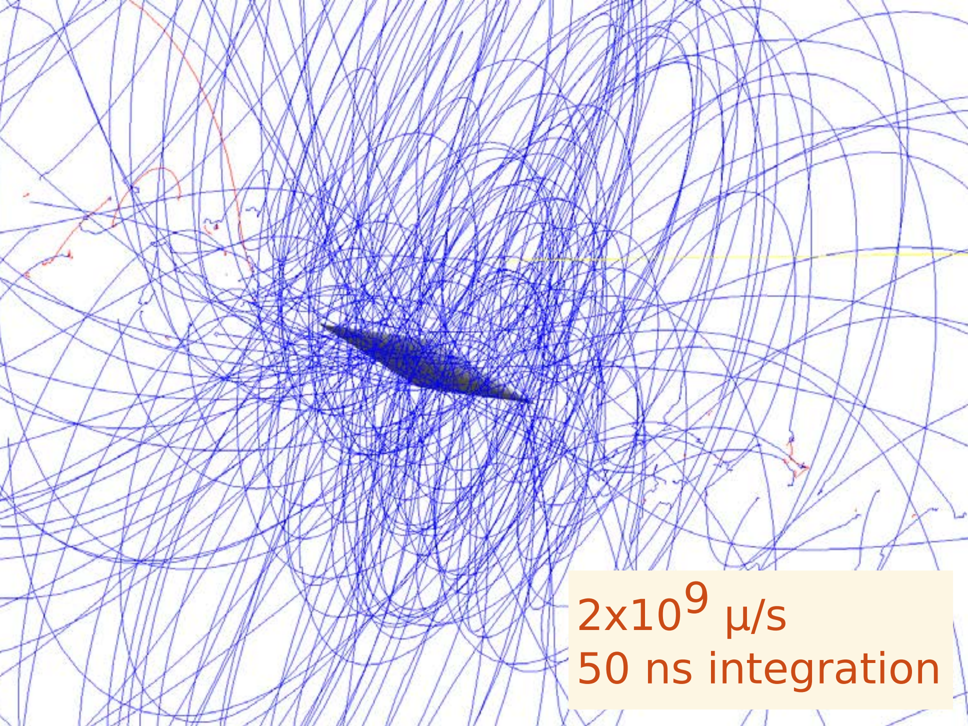
Muon Beamlines at PSI

Paul Scherrer Institute

- Villigen, Switzerland
- Currently hosts the MEG Experiment

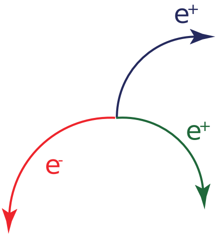
Muon Beamlines

- Low energy DC beams
- Current beam lines: $\approx 1 \cdot 10^8\ \mu/\mathrm{s}$ (πE5)
- Future high intensity beam: $> 1 \cdot 10^9\ \mu/\mathrm{s}$


2x10^{9} μ/s
50 ns integration

Signal and Backgrounds

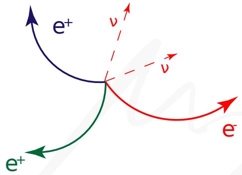
Signal



- Common vertex
- $\sum \vec{p}_i = 0$
- $p < 53\,\text{MeV}$

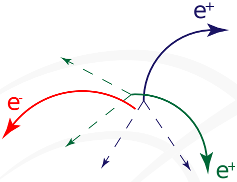
Backgrounds

Internal Conversion



- Common vertex
- $\sum \vec{p}_i \neq 0$
- In-time

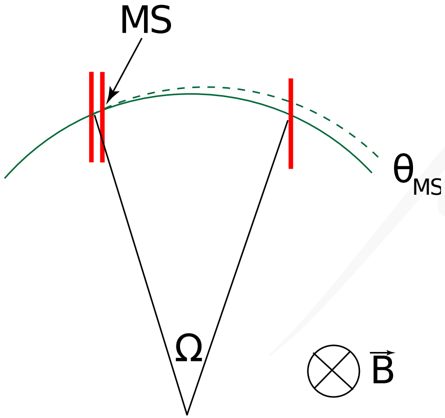
Combinatorial



- No common vertex
- Out-of-time

Requires $\sigma_p < 0.5\,\text{MeV}$
$\sigma_t < 1\,\text{ns}$

Multiple Scattering



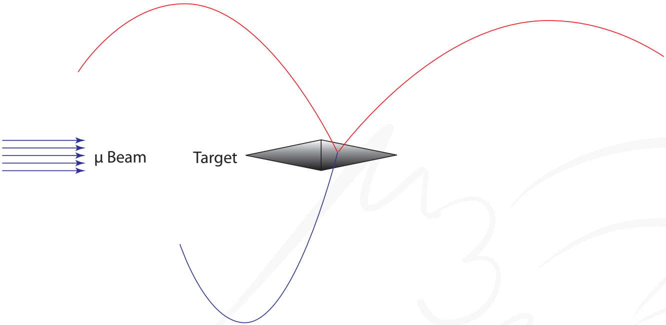
$$\theta_{MS} \sim \frac{1}{p}\sqrt{x/X_0}$$

Example

- $p = 35\,\mathrm{MeV}$
- 200 µm Si
- $\Omega R = 5\,\mathrm{cm}$
- $\Delta y \approx 1\,\mathrm{mm}$

$\rightarrow$ Low material budget

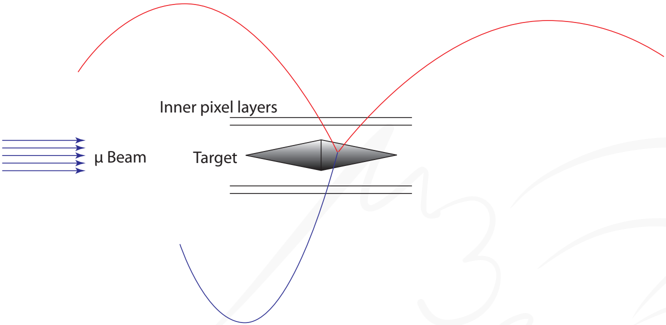
Detector Concept



Environment

- $> 10^9$ μ^+ Decays/s
- Electrons p $< 53\,\mathrm{MeV}$
- Multiple scattering dominates

Detector Concept



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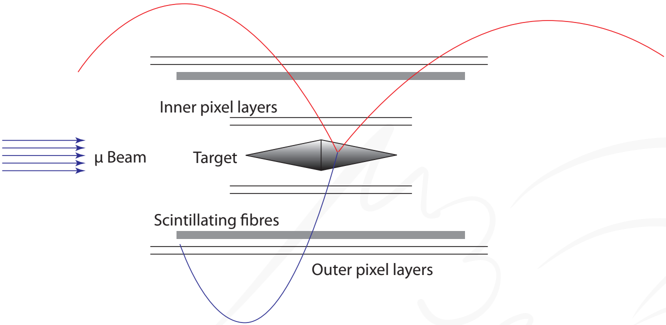

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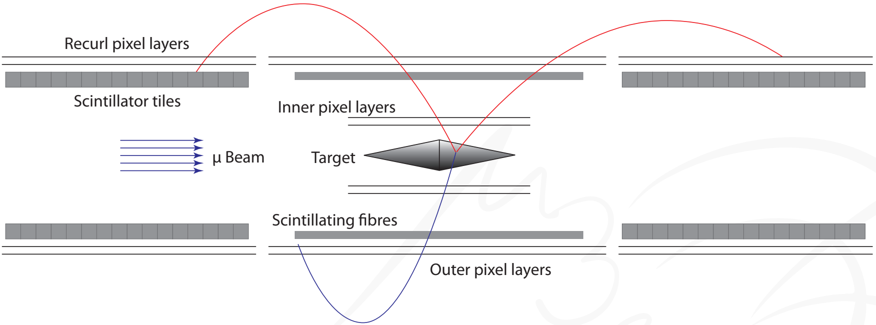
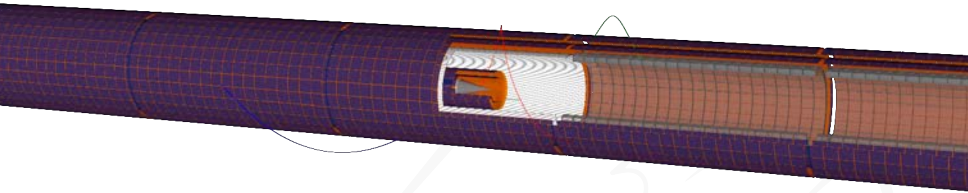


Environment

- $> 10^9$ μ^+ Decays/s
- Electrons p < 53 MeV
- Multiple scattering dominates

Full Detector

Magnetic field ~ 1 T
Continuous readout



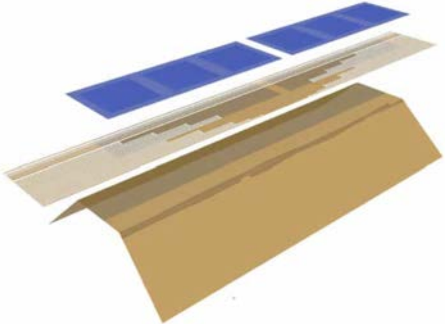
Tracker Requirements

- Fast serial readout ~ 20 MHz
- Thin < 1 ‰ X_0
- 80 µm × 80 µm pixel
- 1 cm × 2 cm sensor area

Timing

- Resolution < 1 ns

Ultra-Lightweight Mechanics

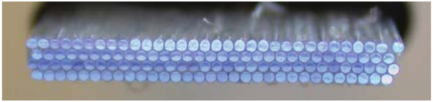


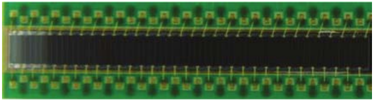
- 50 µm Silicon sensor
- 25 µm Kapton flexprint
- 25 µm Kapton support frame

→ ∼ 1 ‰ Radiation length

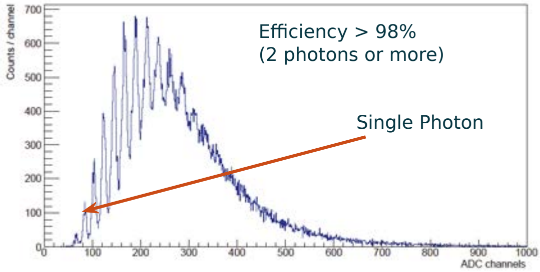
Scintillating Fibres

Fibre and SiPM Array





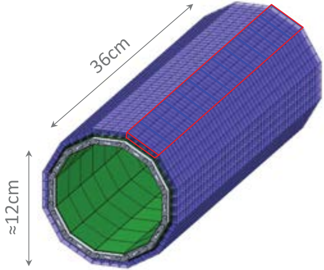
Signal Spectrum



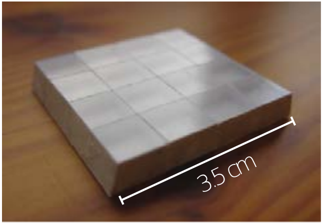
- 3-5 layers of fibres
- Readout with SiPM and custom ASIC (StiC)
- Time resolution $\sim 1\,\mathrm{ns}$ (^{22}Na-source)

Scintillating Tiles

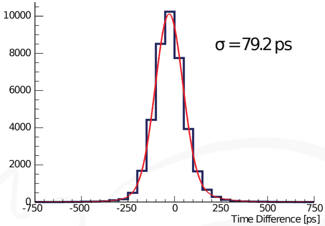
Tile Station



Tile Prototype

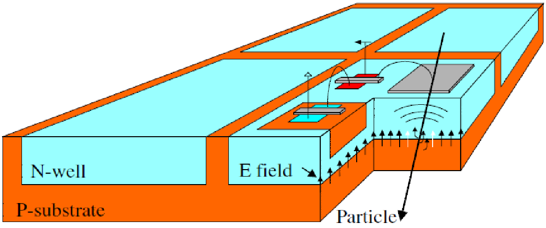


Time Resolution



- $\sim 0.5\,\mathrm{cm}^3$ per tile
- Readout with SiPM and custom ASIC (StiC)
- Time resolution $\sim$ 80 ps (testbeam)

Monolithic Active Pixel Sensors



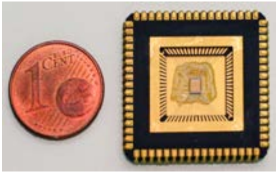
I. Peric, P. Fischer et al. NIMA 582(2007)876

- HV $\sim$ 70 V (HV-MAPS)
- Fast charge collection by drift
- Thin active zone $<$ 20 μm
- Cheap, commercial process

HV-MAPS Prototypes

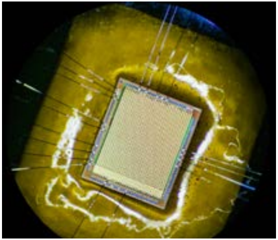
Design Specifications

- 80 µm × 80 µm pixel size
- 1 cm × 2 cm active area



MuPix2

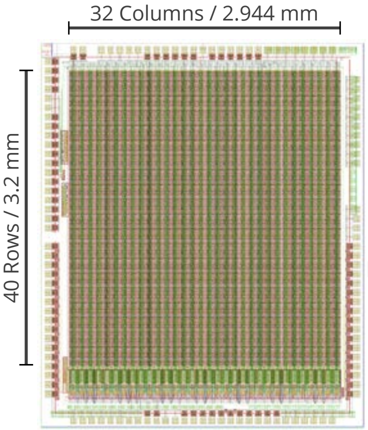
- 39 µm × 30 µm pixel size
- 1.8 mm × 1 mm active area
- Proof of Concept



MuPix3/4

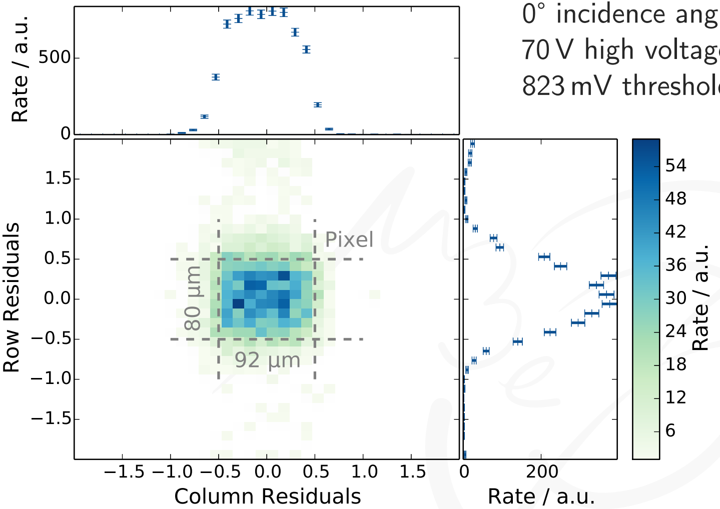
- 92 µm × 80 µm pixel size
- 2.9 mm × 3.2 mm active area

MuPix4 HV-MAPS Prototype



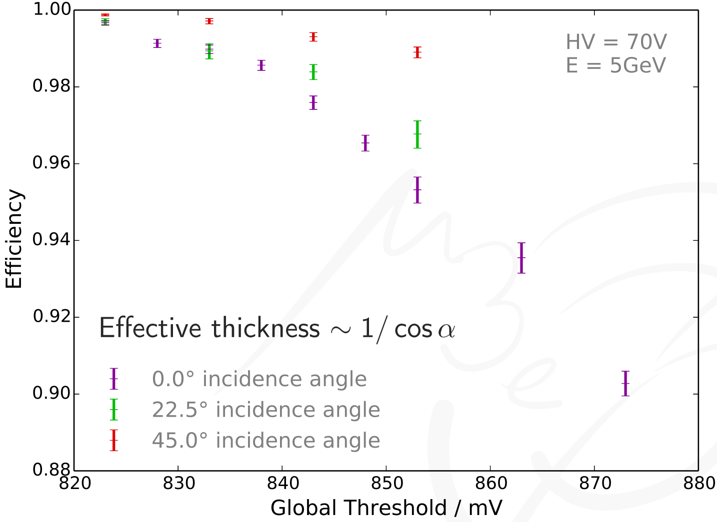
- 92 µm × 80 µm pixel size
- Global threshold
- Zero-suppressed digital readout
- Timestamps
- Additional readout FPGA

Single Hit Resolution

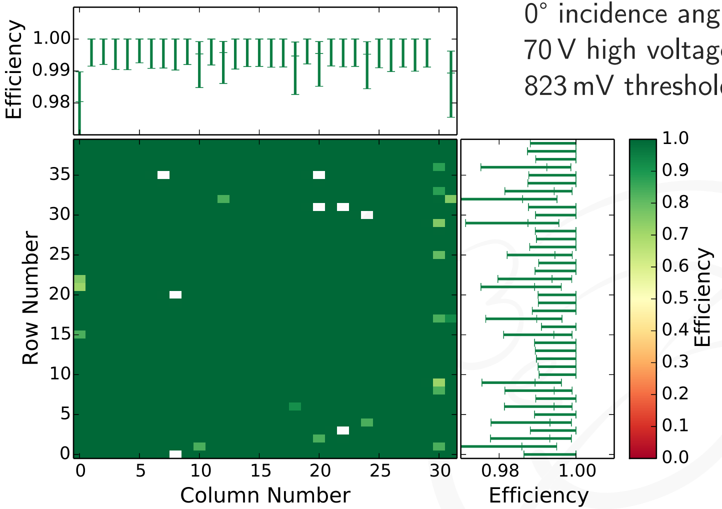


0° incidence angle
70 V high voltage
823 mV threshold

Global Efficiency



Pixel Efficiency



0° incidence angle
70 V high voltage
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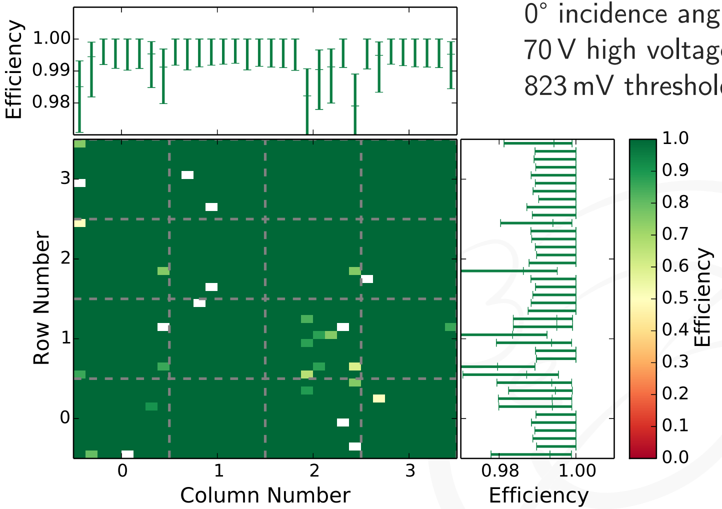
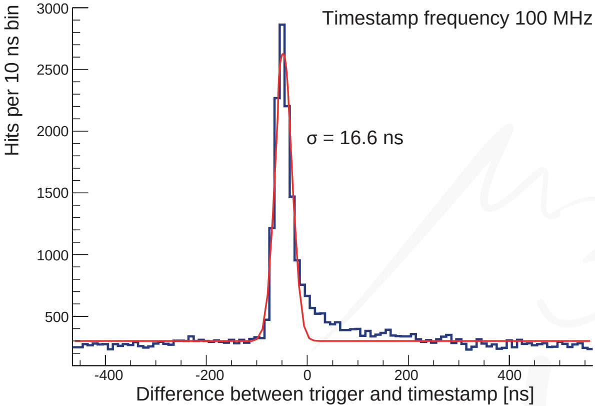
Subpixel Efficiency / 4x4 Pixels



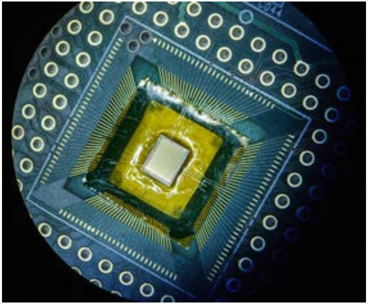
0° incidence angle
70 V high voltage
823 mV threshold

Timing



- Sensor + DAQ
- Resolution 17 ns

Future MuPix Prototypes



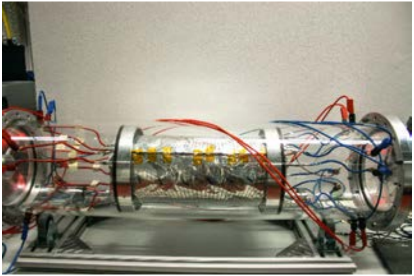
MuPix6

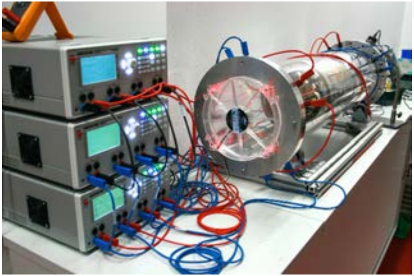
- Currently in the lab
- Updated analog part, e.g. 2-stage amplifier
- Same geometry

MuPix7

- Just submitted
- Fast serial readout
- Full digital logic
- Still small scale prototype

Cooling with Helium

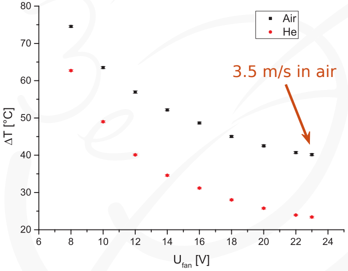




Why Helium?

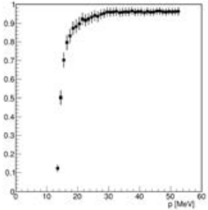
- Low density, low scattering
- High mobility

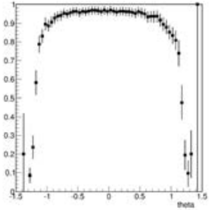
Temperature Gradient



Reconstruction

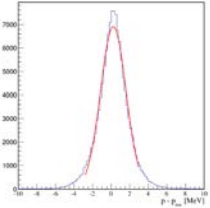
Reconstruction Efficiency



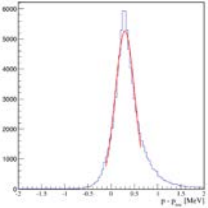


- $>90\,\%$ efficiency for 4-hit tracks
- Dropoff is detector acceptance

Momentum Resolution



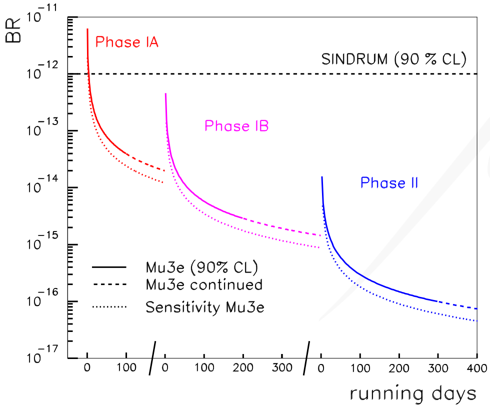
3-hit track,
$\sigma \approx 1.5\,\mathrm{MeV}$



6-hit track,
$\sigma \approx 0.2\,\mathrm{MeV}$

- Full GEANT4 simulation
- Custom reconstruction
- No energy loss correction

Expected Sensitivity



Phase IA: earliest 2016

- $2 \cdot 10^7\ \mu/s$
- Central pixel layers

Phase IB: 2017+

- $1 \cdot 10^8\ \mu/s$

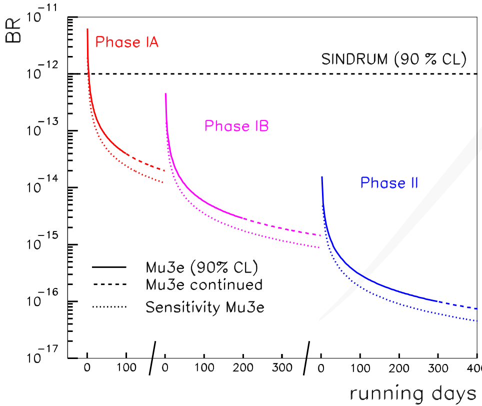
\+ Timing

\+ 1^{st} recurl stations

Phase II: 2019+

- $2 \cdot 10^9\ \mu/s$
- Full detector
- Future Muon Beamline

Expected Sensitivity



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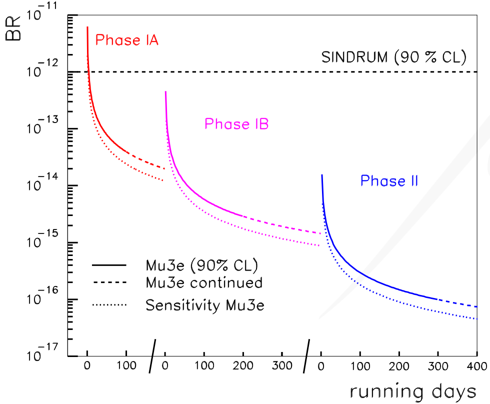

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The Mu3e Collaboration

Paul Scherrer Institute

University Geneva

ETH Zürich

University Zürich

Heidelberg University

Karlsruhe Institute of Technology

Mainz University

Summary and Outlook

Mu3e

- Search for $\mu^+ \rightarrow e^+e^-e^+$
- Sensitivity < 1 in 10^{16} decays

Features

- HV-MAPS silicon sensors
- Ultra-thin detector
- Down to 100 ps timing
- Up to $2 \cdot 10^9$ μ/s

In the Future

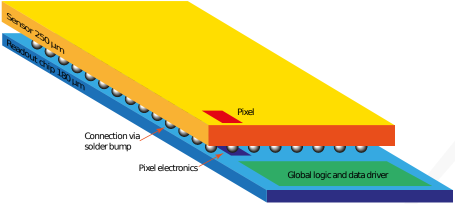
- First data in 2016+
- Full rate not before 2019

http://www.psi.ch/mu3e

Backup

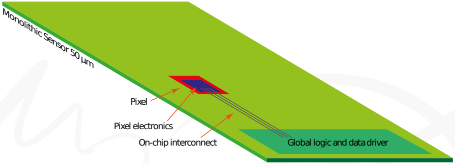
Silicon Pixel Sensors

Hybrid



- HV $\sim$ 700 V
- Sensor thickness $\sim$ 250 µm
- Extra material
- Complex and expensive

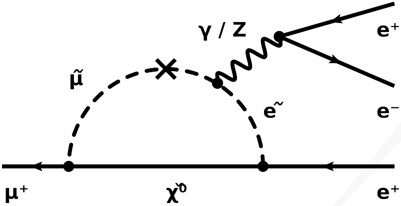
Monolithic Active Pixel Sensor



- HV $\sim$ 70 V (HV-MAPS)
- Thin active zone $<$ 20 µm
- Cheap, commercial process

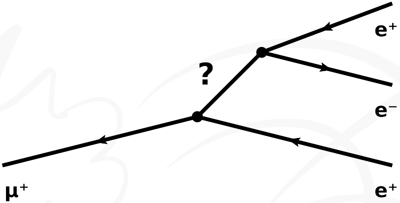
Beyond the Standard Model

In Loops



- e.g. SUSY

At Tree Level



- e.g new heavy boson

Global Efficiency / High Voltage