The Mu3e Experiment
Searching for the lepton flavour violating decay μ → eee

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Abstract

The Mu3e experiment is a novel experiment to search for the lepton flavour violating (LFV) decay μ → eee with an ultimate sensitivity of one in 10^{16} muon decays. This would be an improvement in sensitivity by four orders of magnitude compared to previous experiments. The Standard Model prediction for the branching ratio of this decay mode is less than one in 10^{50}. Any observation of such a decay is therefore a clear indicator of new physics.

The improvements are made possible by a novel experimental design based on high voltage monolithic active pixel sensors for high spatial resolution and fast readout and hodoscopes using scintillating fibres and tiles providing precise timing information at high particle rates.

Requirements

- High rates
- Excellent momentum resolution
- Great vertex resolution
- Good timing resolution
- Extremly low material budget

Signal

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

- Single vertex
- Coincident

Backgrounds

Internal Conversion — Coincident

Combinatorial — Not coincident

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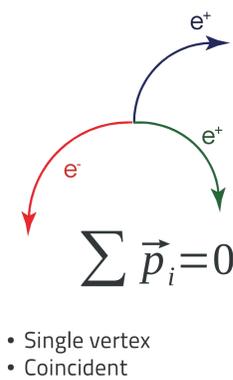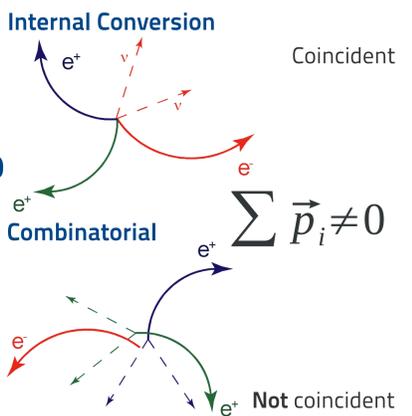
Detector Concept

Transverse View

Longitudinal View

Phase 2
+ Recurl station
+ Timing tiles

Phase 1b
+ Recurl station
+ Timing tiles
+ Timing fibres

Phase 1a
Central pixel detector

Phase 1b
+ Recurl station
+ Timing tiles
+ Timing fibres

Phase 2
+ Recurl station
+ Timing tiles

Tiles

μ-beam

Target
Inner pixel layers

Fibres

Tiles

Long tube design

Outer pixel layers

High acceptance for recurling particles
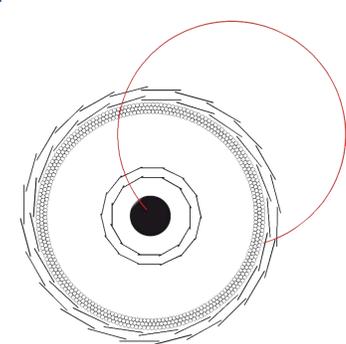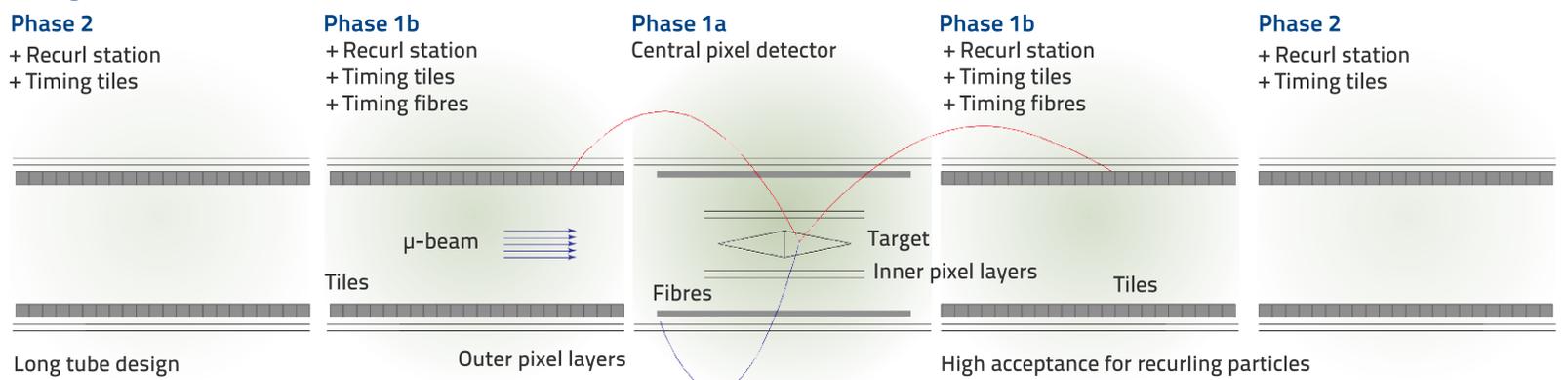
Muon Beam

Existing / Future Beamlines at the Paul-Scherrer Institute, Switzerland
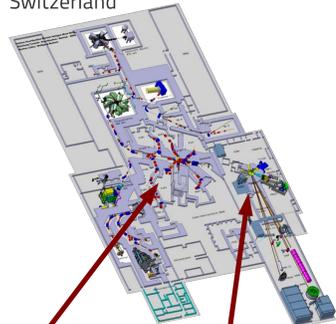
Phase 1:
- Existing πE5 Beam
- Rate ~ 10^8 μ/s

Phase 2:
- Future High Intensity Beamline
- Rate ~ 10^9 μ/s

Pixel Sensors

- High Voltage Monolithic Active Pixel Sensors
- 80x80 μm² pixel size
- Thinned to < 50μm
- Total thickness of 4 layers < 4‰ X_0
- Binary readout
- Total number of pixels ~ 300 million

N-well
E field
P-substrate
Particle
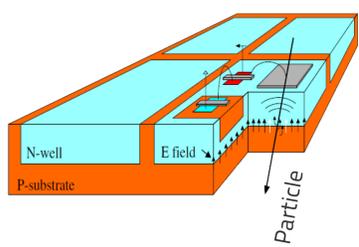
Target

- Extented hollow double cone target
- ~70 μm Aluminium
- Reduces combinatorial background

Timing

- 250 μm scintillating fibres in the central detector
- Thick (~ 1cm) scintillating tiles in the recurl stations for precise timing

Magnet & Cooling

- Solenoid Magnet ~ 1T
- Cooling using gaseous Helium

Readout

- Triggerless readout ~ 100 Gbyte /s
- Online tracking and event filter based on GPUs
- Data reduction to ~ 50 MByte /s for storage and offline analysis

Expected Performance for Phase 2 (simulated)

Single Track Momentum Resolution

RMS: 0.28 MeV/c

Rec. Momentum - Gen. Momentum [MeV/c]
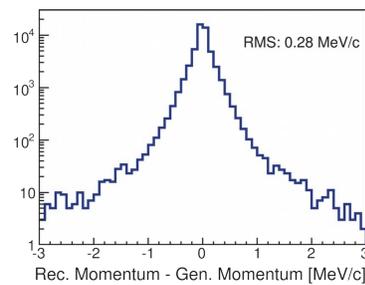
Signal Decay Mass Resolution

RMS: 0.52 MeV/c²
σ_1: 0.31 MeV/c²
σ_2: 0.71 MeV/c²
σ_{av}: 0.37 MeV/c²

Reconstructed Mass [MeV/c²]
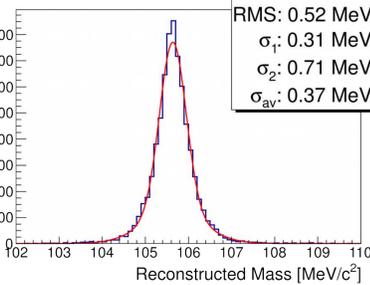
Branching Ratio Sensitivity

μ → eevv generated
μ → eevv simulated
Signal BF 10^{-12}
Signal BF 10^{-13}
Signal BF 10^{-14}
Signal BF 10^{-15}
Signal BF 10^{-16}
Signal BF 10^{-17}

Events per muon decay and 0.1 MeV

Reconstructed Mass [MeV/c²]
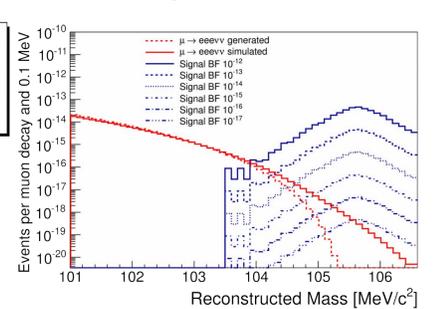
Mechanical Prototypes

Central Detector and Construction Tool

Sensor Strip Sandwich

Thinned HV-MAPS Sensors

25 μm Flexprint Power & Signals

25 μm Kapton™ Support Structure
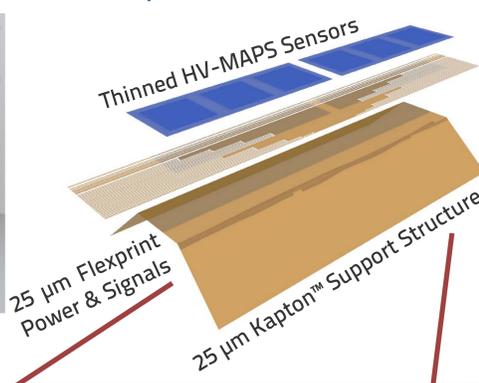
Kapton Support Structure
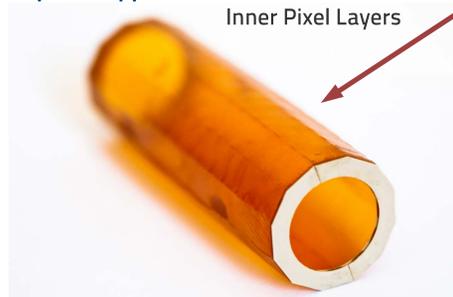
Inner Pixel Layers

Outer Pixel Layers (Single Segment)

Testbeam Measurements

Setup at DESY

EUDET Telescope Aconite
MuPix Prototype
Electron beam 3-6 GeV

Setup at CERN

TimePix Telescope
Pion beam 180 GeV
MuPix Prototype
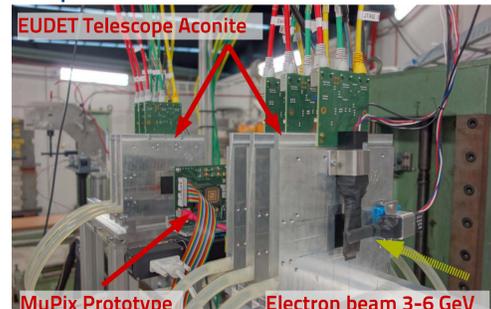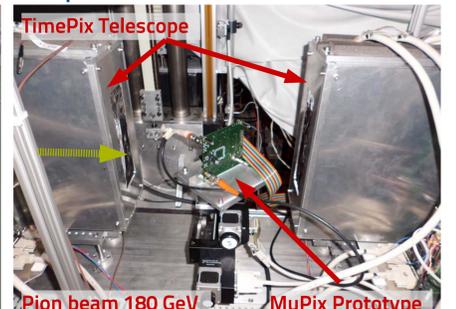
MuPix Prototype v2

- High Voltage Monolithic Active Pixel Sensor
- 42x36 pixels
- 30x39 μm² pixel size
- Binary Readout
- Single Threshold
- Developed by Ivan Peric, ZITI Mannheim

Example Measurement: Single Hit Resolution

Work in Progress

x
y

single hit resolution / μm

pixel threshold / V