The Mu3e Experiment Searching for the Lepton Flavour Violating Decay $\mu^+ \rightarrow e^+ e^+ e^-$

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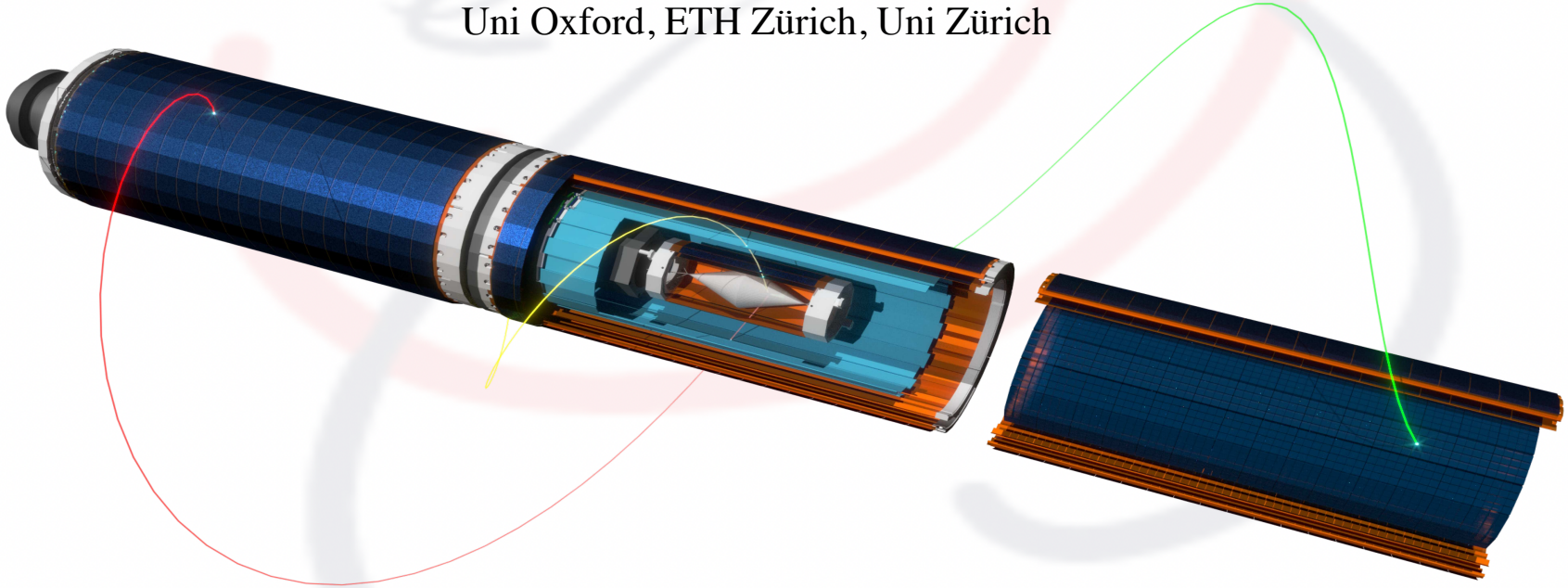


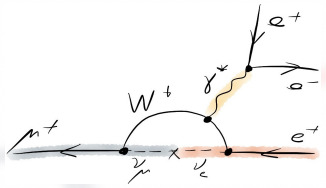
The Mu3e Experiment @ PSI

Motivation & Challenges

Search for Lepton Flavour Violation:

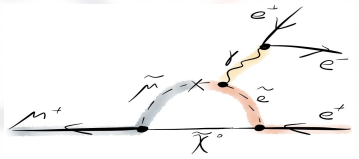
Decay : $\mu^+ \rightarrow e^+ e^+ e^-$

- Negligible in Standard Model (**Br < 10^{-54}**)
- Can be enhanced in New Physics : (SUSY, leptoquarks, etc.), any observed decay will point to NP



Muon decay in the SM

- Current status: **Br < 10^{-12} (SINDRUM)** at 90% CL
- **Mu3e Phase I**: Aiming for **O(10^{-15})** sensitivity at existing πE5 beamline**: 10^8 *μ*/s**
- **Mu3e Phase II**: Aiming for **O(10^{-16})** sensitivity at a new high-intensity muon beamline (HiMB)**: >10^9 *μ*/s**



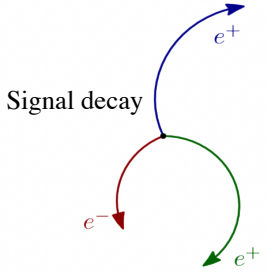
Muon decay BSM (SUSY)

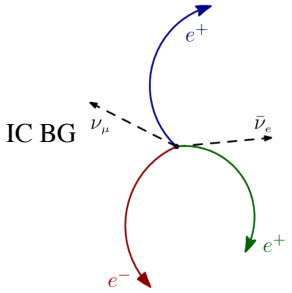
Signal:

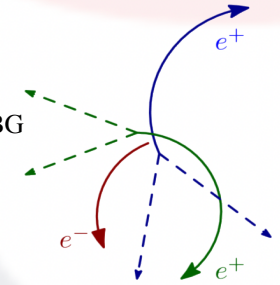
- Three tracks: $\mu^+ \rightarrow e^+ e^+ e^-$
- Decay at rest
- $P_e < 53$ MeV/c
- Common vertex
- Coincide in time
- $\Sigma P = 0$, $\Sigma E = m_\mu$

Background:

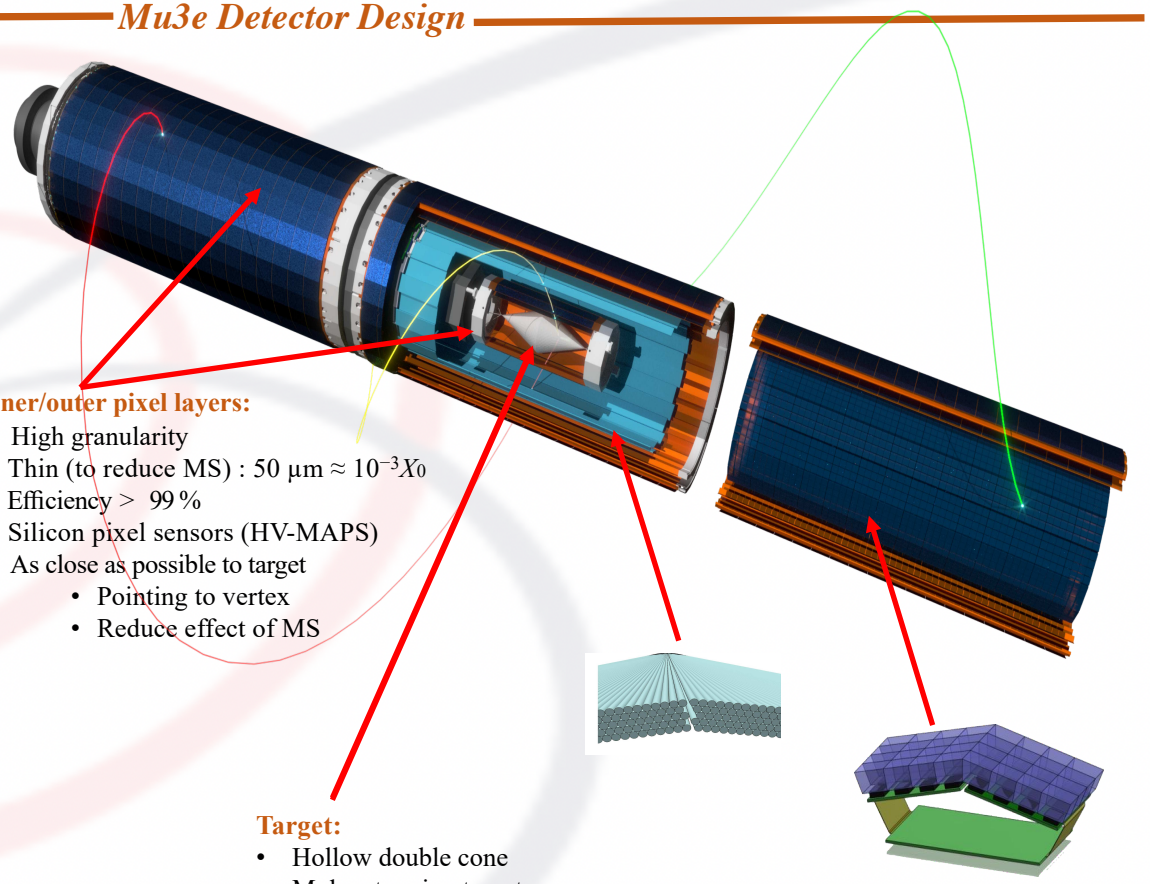
- Internal conversion background (IC BG): $\mu^+ \rightarrow e^+ e^+ e^- \nu^+ \nu^-$ (suppressed by good momentum resolution)
- Accidental background (Acc. BG): Michel $\mu^+ \rightarrow e^+ \nu^+ \nu^-$ with $e^+ e^-$, etc (suppressed by good time and vertex resolution)







Mu3e Detector Design



Inner/outer pixel layers:

- High granularity
- Thin (to reduce MS) : 50 μm ≈ $10^{-3} X_0$
- Efficiency > 99 %
- Silicon pixel sensors (HV-MAPS)
- As close as possible to target
  - Pointing to vertex
  - Reduce effect of MS

Target:

- Hollow double cone Mylar stopping target
- vertex separation

Fibre/tile timing detector:

- Precise timing
- Suppress Acc. BG
- Charge ID

Simulation and Track/Vertex Reconstruction of the Mu3e Detector

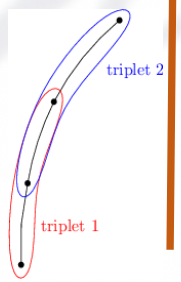
Reconstruction

- Full detector Simulation (Geant4) in 50 ns framelength with 4.3v.v

Track Reconstruction

Triplet:

- Track is a sequence of triplets
- Basic block for track reconstruction
- 3 hits (combination 2 helices)
- Optimization the nonlinear problem multiple scattering



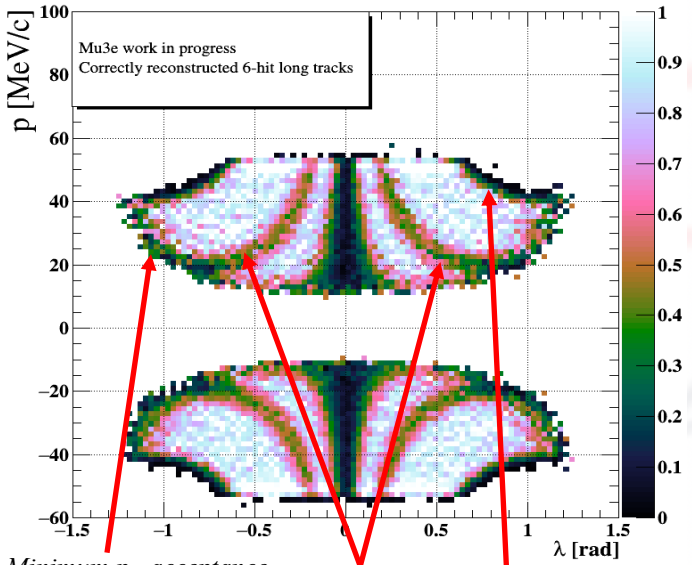
Short tracks:

- 4 hits in the silicon layers
- Seeds for long tracks

Long (recurl tracks):

- Combine 1 short track with 2 hits in recurl detector (6 hits)
- Combine 2 short tracks (8hits)

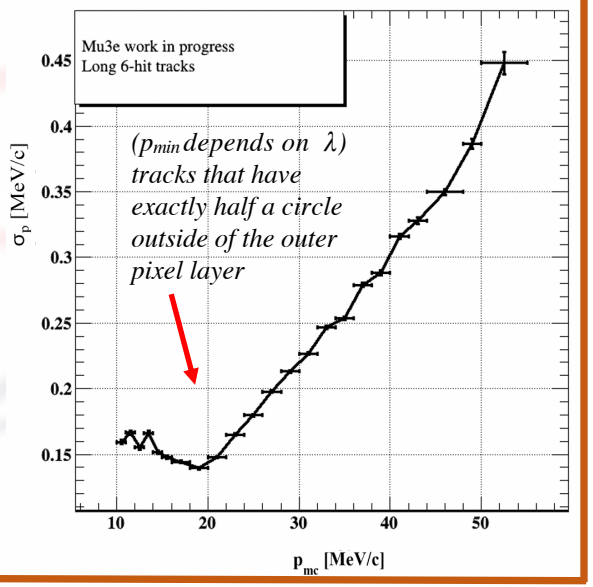
Acceptance and Efficiency



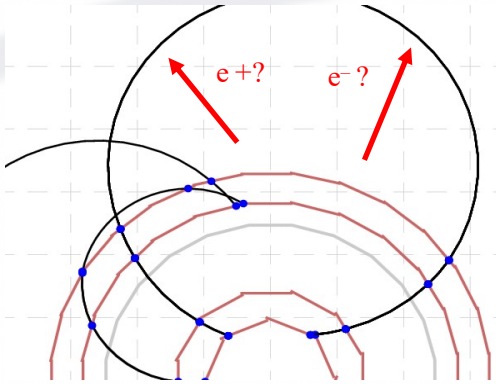
Minimum p_T acceptance ~ 12 MeV/c (Limited by outer layer radius)

Service areas b/w stations

Ends of recurl stations



Timing and Charge ID



Ambiguity for central 8-hit tracks:

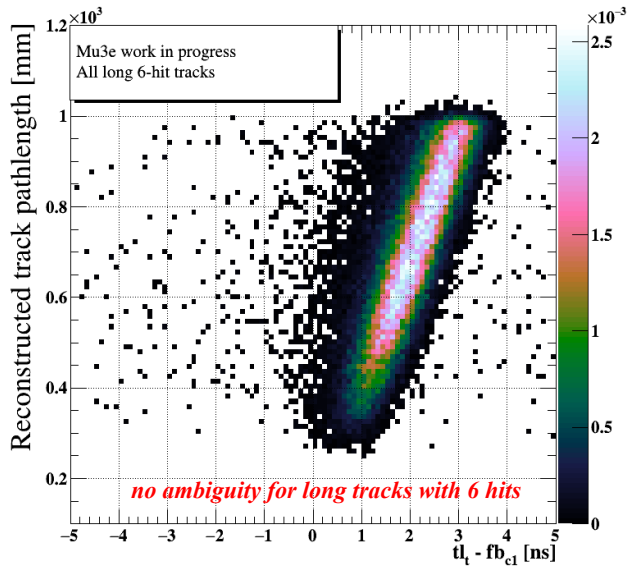
Charge ID for long 8-hit track:

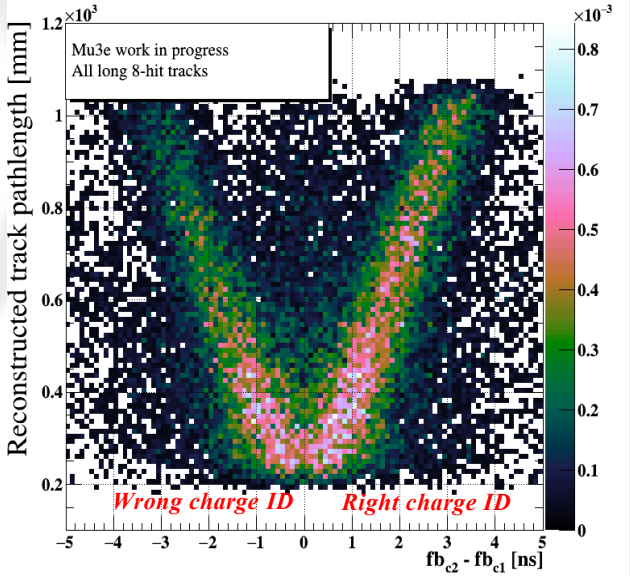
- Unknown direction
- Use fibre time information and path length between fibre hits

Track/Vertex Efficiency After Track Reconstruction and Vertex Fit Step for Phase Space Distributed Signal Muons Events

(Mu3e work in progress)

Phase space	ϵ all tracks (4, 6, 8 hits)	ϵ 3 long tracks (6, 8 hits)
events in acceptance	0.412(1)	0.265(1)
relative to events in acceptance		0.643(3)
events after track reconstruction	0.368(1)	0.185(1)
relative to events in acceptance	0.892(5)	0.698(5) ←
events with reconstructed vertex	0.374(1)	0.188(1)
relative to events in acceptance	0.907(5)	0.708(5)
relative to events after track reconstruction	0.998(8)	0.998(8) ←
events with reconstructed vertex after cuts	0.290(1)	0.163(1)
relative to events with reconstructed vertex before cuts	0.776(4)	0.866(7)
relative to events in acceptance	0.704(4)	0.614(4)
relative to events after reconstruction	0.789(4)	0.879(7)



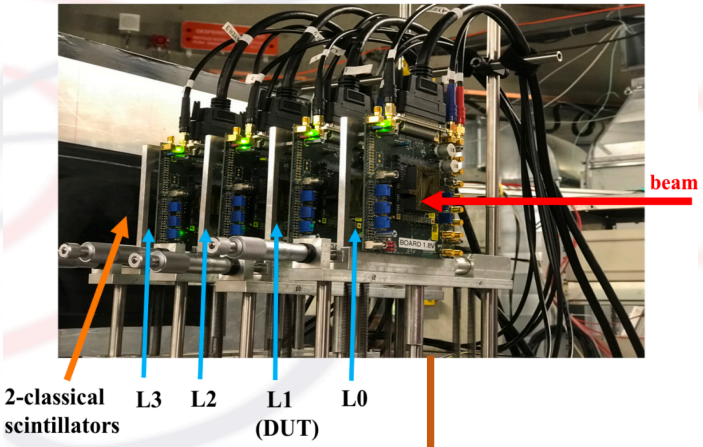


Test-beam Data Acquisition System and Characterisation of HV-MAPS

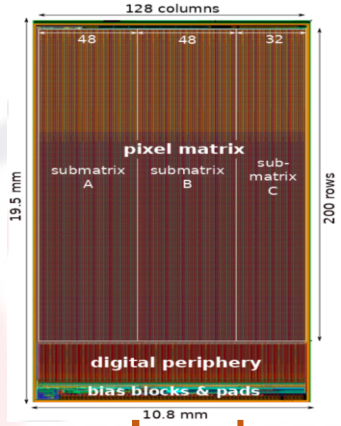
Test-beam @ PSI

The beam with momentum 270 MeV (pion, electrons, and muons), and electrical current is 1860.10μA at πM1 beam area in PSI

Setup of MuPix Telescope



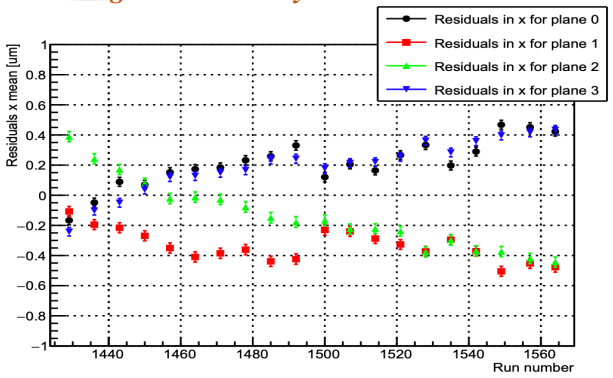
- 3-layers of MuPix8 sensors with DUT layer
- Layer 1 is DUT layer
- 2-classical trigger scintillators
- All PCBs were connected to a HV power supply, and set to - 60 V for all MuPix8 measurements

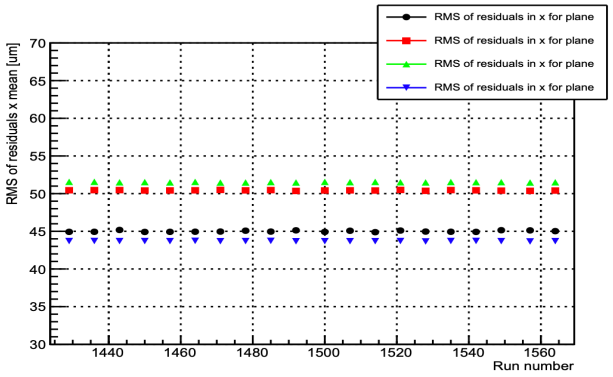


MuPix8 sensor?

- First large prototype in MuPix group
- Pixels have a size of $81\times80\mu m^2$
- Pixels are arrayed in 128 × 200pixel matrix
- Fast charge collection (O(1ns))
- Integrated readout electronics
- Thickness: 100 μm

Alignment Stability





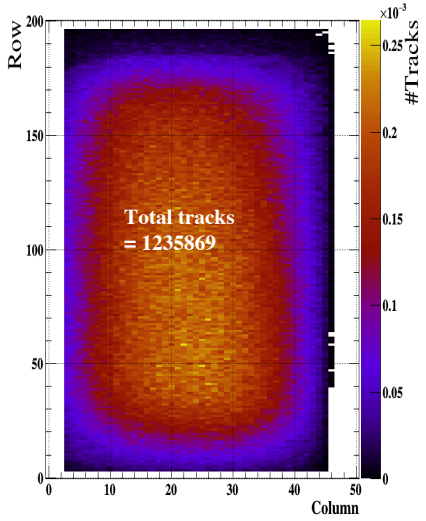
Efficiency Analysis

- Efficiency of run 1429 with threshold 545 mV

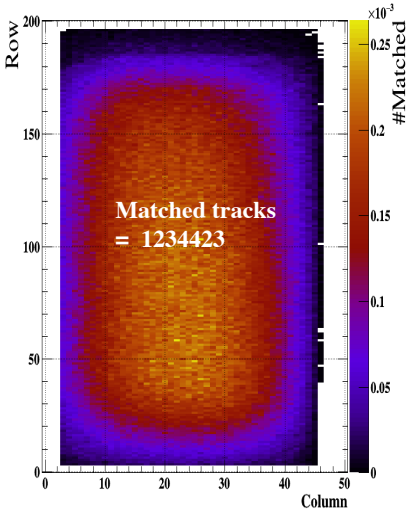
$$\mathbf{Eff_{ROI}} = \frac{\#\text{matched tracks}}{\#\text{total tracks}}$$

Noise rate per pixel $= \frac{\#\text{hits} - \#\text{matched tracks}}{\text{runtime} \cdot \#\text{pixels}}$

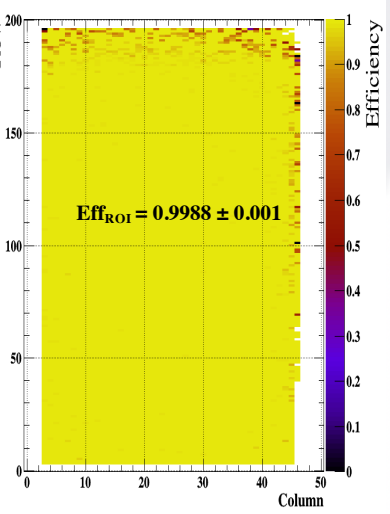
Track map



Matched track map



Efficiency map



Efficiency and Noise Rate per Pixel for Different DAQ Runs