Tracking for the Mu3e experiment

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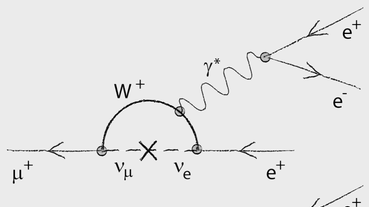
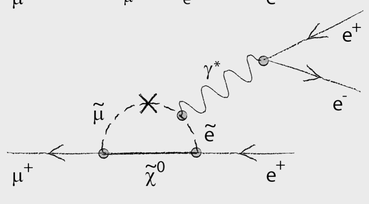
The Mu3e experiment

- Search for Lepton Flavor Violation
  - Decay $\mu^+ \to e^+e^+e^-$
  - Standard Model: $Br < 10^{-54}$
  - Can be enhanced in New Physics (SUSY, BSM, etc.)
- Current status: $Br < 10^{-12}$ (SINDRUM)
- Mu3e:
  - Location: Paul Scherrer Institute
  - Phase I: $Br < 10^{-15}$; Phase II: $Br < 10^{-16}$

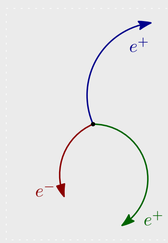
SM



SUSY

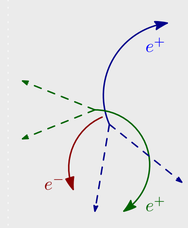


$\mu^+ \to e^+e^+e^-$ signal and background



Signal:

- Three tracks
- Decay at rest
  - $p_e < 53$ MeV/c
  - Common vertex
  - Same time
  - $\sum \mathbf{p} = 0$
  - $\sum E = m_\mu$

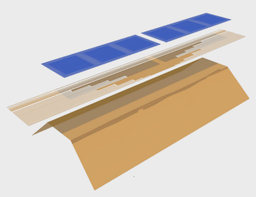


Background:

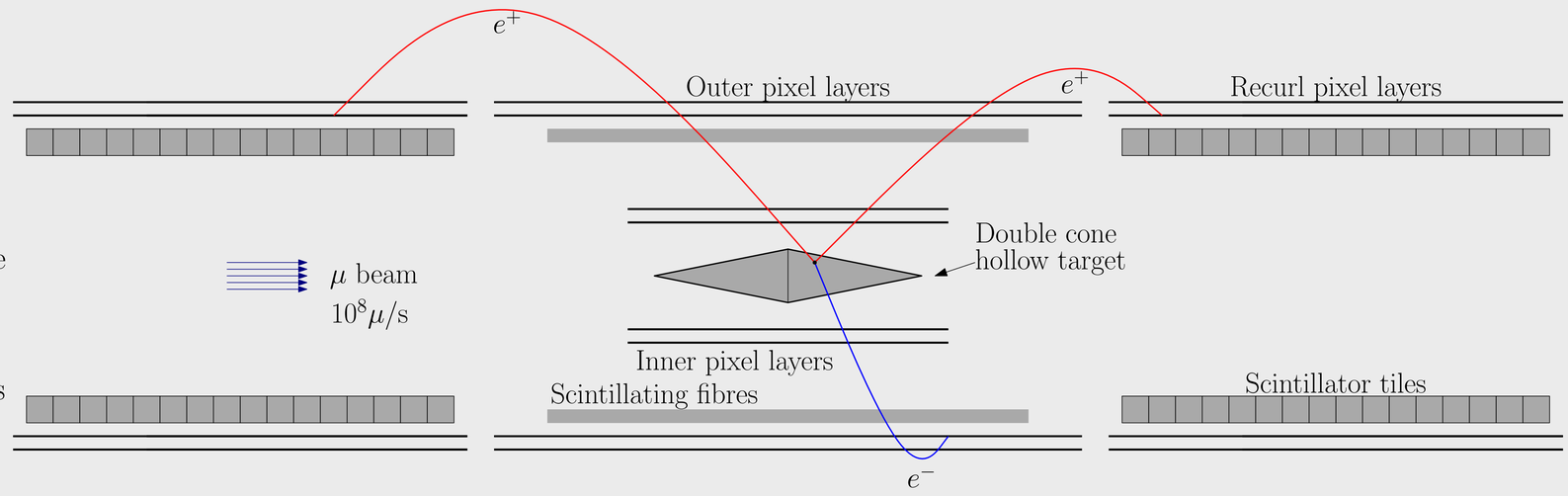
- Internal conversion
  - $\mu^+ \to e^+e^+e^-\nu\bar{\nu}$
- Random combinations
  - Michel: $\mu^+ \to e^+\nu\bar{\nu}$
  - e^+e^- scattering, etc.
  - Fake tracks
- Not same vertex, time, etc

Mu3e detector

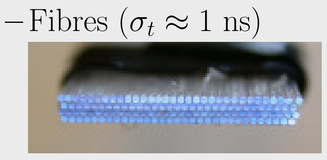
Pixel layers:



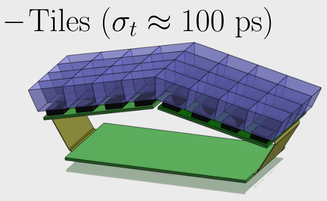
- High Voltage Monolithic Active Pixel Sensor - HVMAPS
  - NIM A582 (2007) 876-885
  - 2×2 cm^2, 80×80 μm^2 pixels
- Thin: 50 μm $\approx 10^{-3} X_0$
- Efficiency $> 99\%$



- Recurl layers - improve momentum resolution
- Timing:
  - Fibres ($\sigma_t \approx 1$ ns)



  - Tiles ($\sigma_t \approx 100$ ps)



Triplet fit

Triplet:

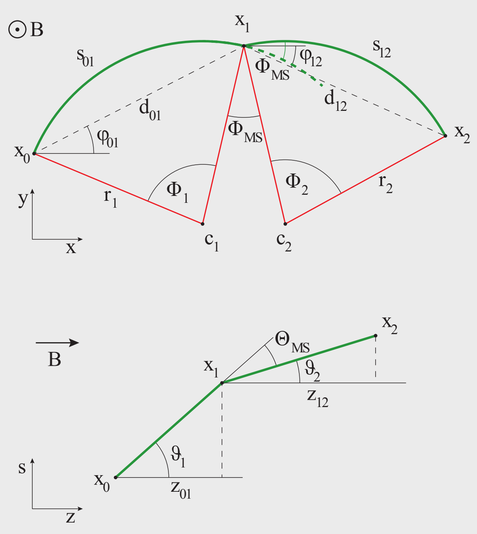
- Basic block for track reconstruction
- 3 hits (combination of 2 helices)
- Neglect energy loss and hit position uncertainty

Triplet fit (arXiv:1606.04990):

- Minimizes scattering angle in middle hit
- Linear approximation around circle solution (small Multiple Scattering angles)

Track fit:

- Track is a sequence of triplets
- Fit - weighted average of triplets



Track reconstruction

Make triplets:

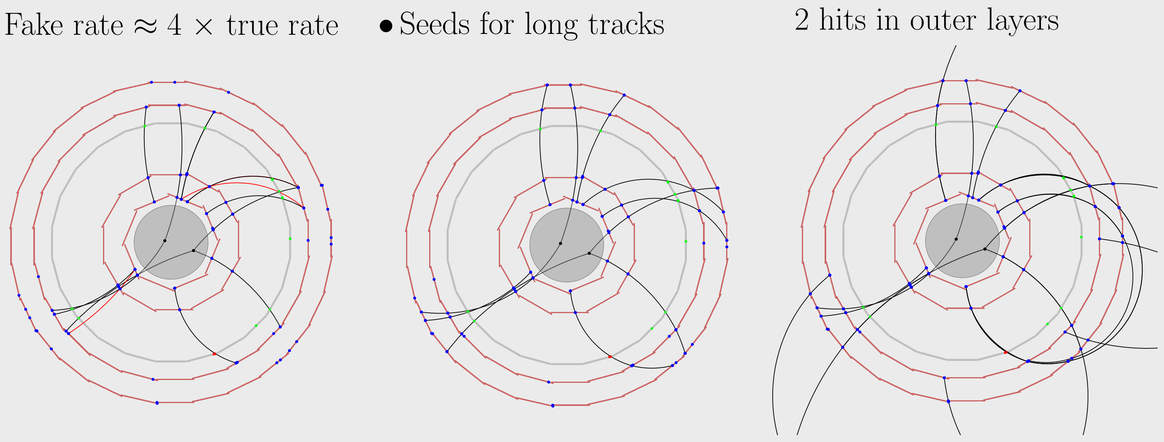
- Hits in first 3 layers
- $O(n_{hit}^3)$ combinations
- Fake rate $\approx 4 \times$ true rate

Short (4 hits) tracks:

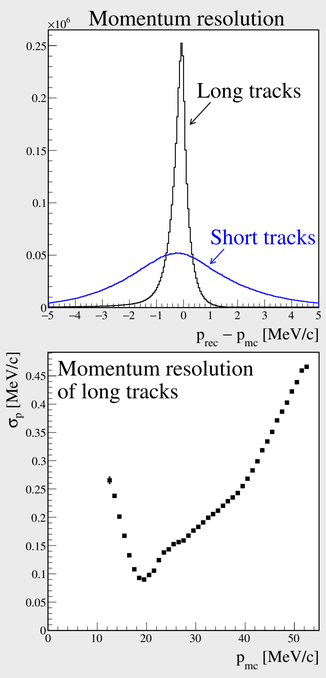
- Add 4th hit to triplet
- Fake rate ≈ 0.25
- Seeds for long tracks

Long (recurl) tracks:

- Combine 2 short tracks or
- Combine short track with 2 hits in outer layers

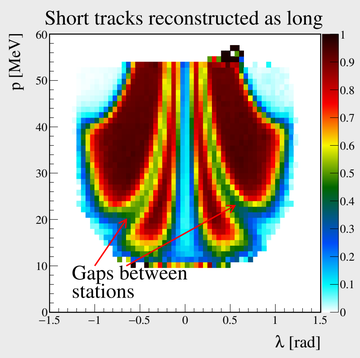


Efficiency and resolution



Short tracks (4 hits):

- Acceptance: 80%
- Reconstruction efficiency: 95%
  - Geometrical and χ^2 selections
- $\sigma_p \approx 1.4$ MeV/c

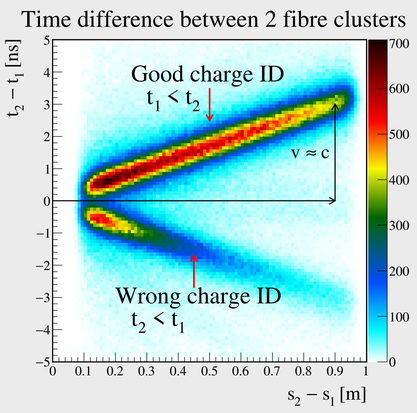


Long tracks (6 and 8 hits):

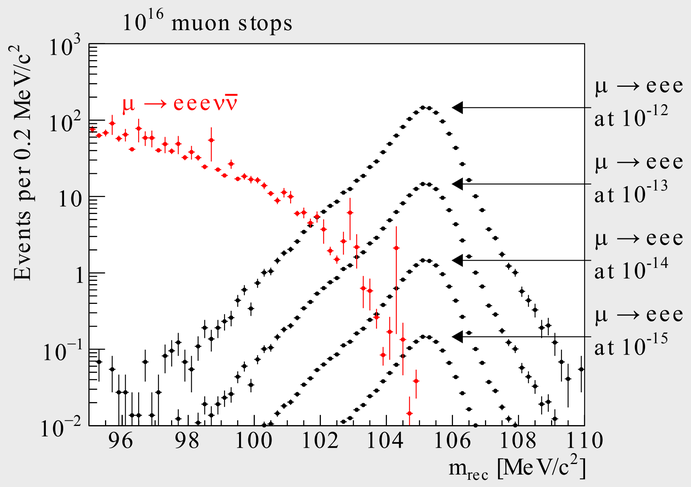
- 80% of short tracks are reconstructed as long
  - Gaps between stations
- $\sigma_p \approx 0.1 \div 0.5$ MeV/c
  - $5 \div 10$ better than for short tracks

Fibre and tile timing

- Fibre clusters and tile hits are linked to short and long tracks
- Linking efficiency $\approx 95\%$ (within fible/tile detectors acceptance)
- Charge ID for long tracks
  - Resolve direction of flight ambiguity
  - Time difference between 2 fibre clusters
- Reduce combinatorics and fakes



Signal sensitivity



Signal sensitivity of 10^{-14} at 10^{16} stopped muons.

Selections:

- Long tracks
- Vertex $\chi^2 < 14$
- Track/vertex $DCA < 1$ mm
- $|\sum \mathbf{p}| < 4$ MeV/c
- Efficiency 14%

GPU filter farm

- Need factor 100 data rate reduction
- Full online reconstruction
  - Track and vertex reconstruction
- Implemented on GPU
  - Currently $O(10^9)$ track fits/s

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