



# Track reconstruction for the Mu3e experiment

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*on behalf of the Mu3e collaboration*

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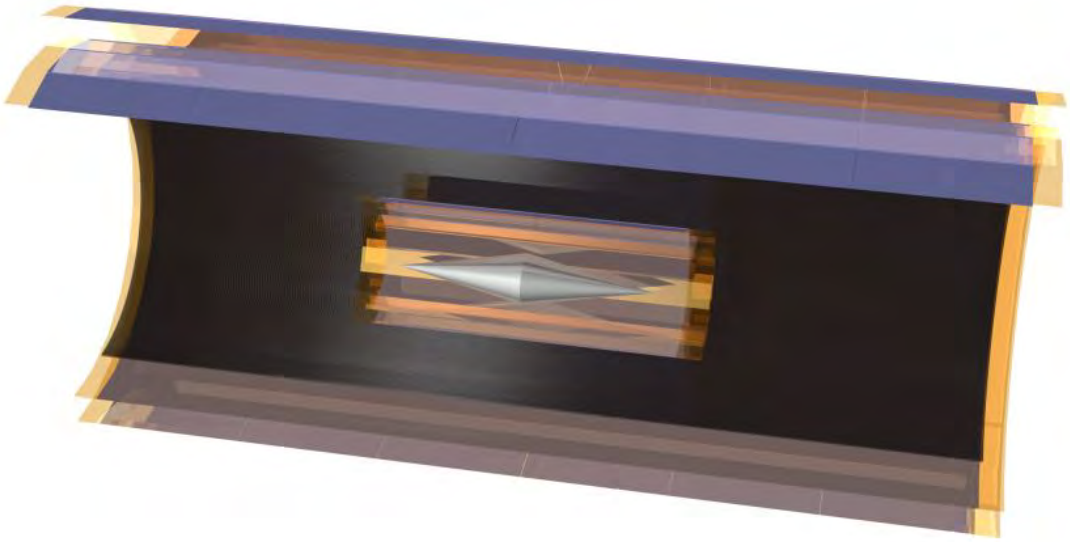
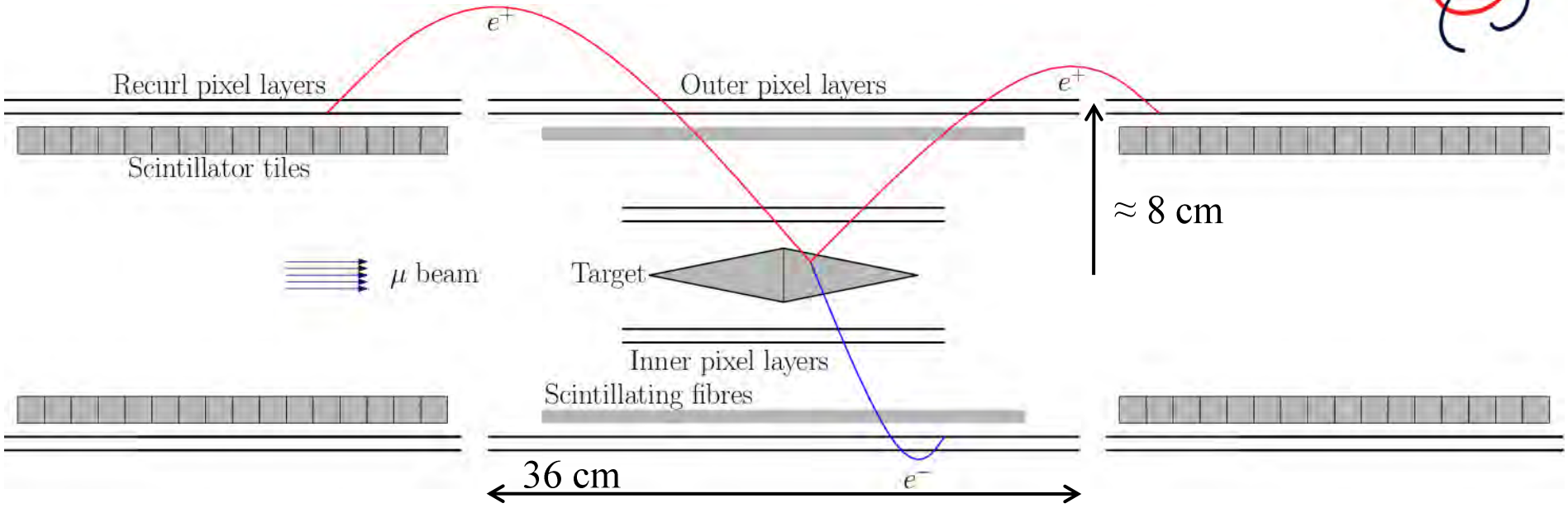
# Mu3e experiment



Mu3e experiment:
- Search for $\mu^+ \rightarrow e^+e^+e^-$
- Current experimental status:
  - SINDRUM *Nucl.Phys.B299(1988)1*
  - $Br(\mu^+ \rightarrow e^+e^+e^-) < 10^{-12}$ at 90% c.l.
- Mu3e goal: $Br < 10^{-15}$

Requirements:
- $10^8$ $\mu^+$/s on target
- Good momentum resolution: < 0.5 MeV
- Good vertex resolution: 300 µm
- Timing measurement
- Fast readout

# Mu3e detector




Detector:

- Muons stop on target and decay at rest:
  - Maximum $e^{\pm}$ energy: 53 MeV
- Target: hollow double cone
- Central pixel detector (4 layers) + 2 recurl stations:
  - HV-MAPS (80µm pixel size, 50µm thin ≈ $10^{-3}$ $X_0$)
- Readout at 20 MHz (50 ns frame size)

Timing:

- Fibre detector ≈ 1 ns
- Tile detector ≈ 100 ps

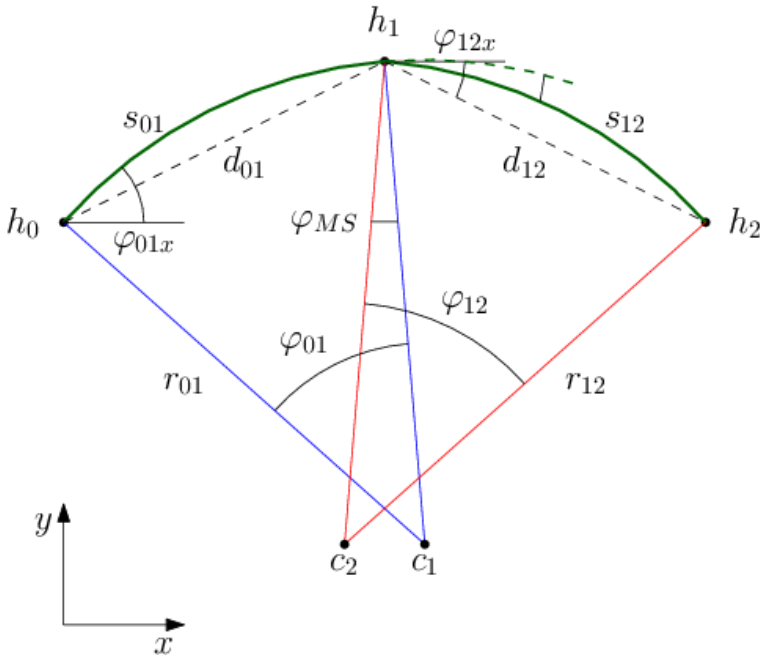
# Triplet fit

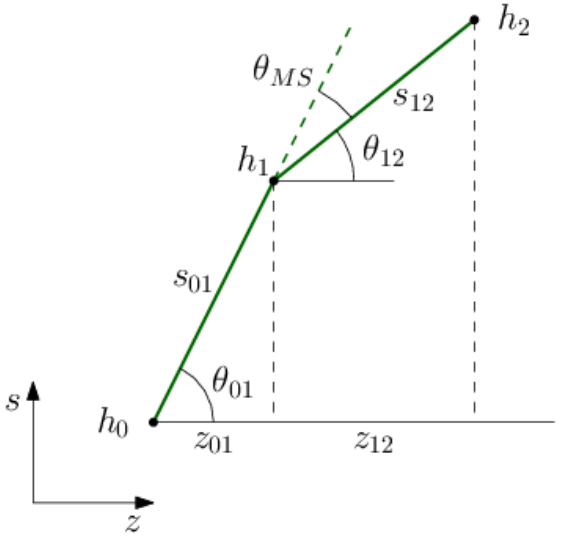
Triplet:
- Basic block
- 3 hits (3D points) form triplet
- Multiple scattering at middle hit
- No energy loss, no hit position uncertainty (MS dominates)

Triplet fit solution:
- Minimize scattering angle ($\chi^2$)

$$\frac{\varphi^2_{MS}(R_{3D})}{\sigma^2_{MS}} + \frac{\theta^2_{MS}(R_{3D})}{\sigma^2_{MS}}$$

- Solve by linearizing around circle solution
- Easy to calculate and fast



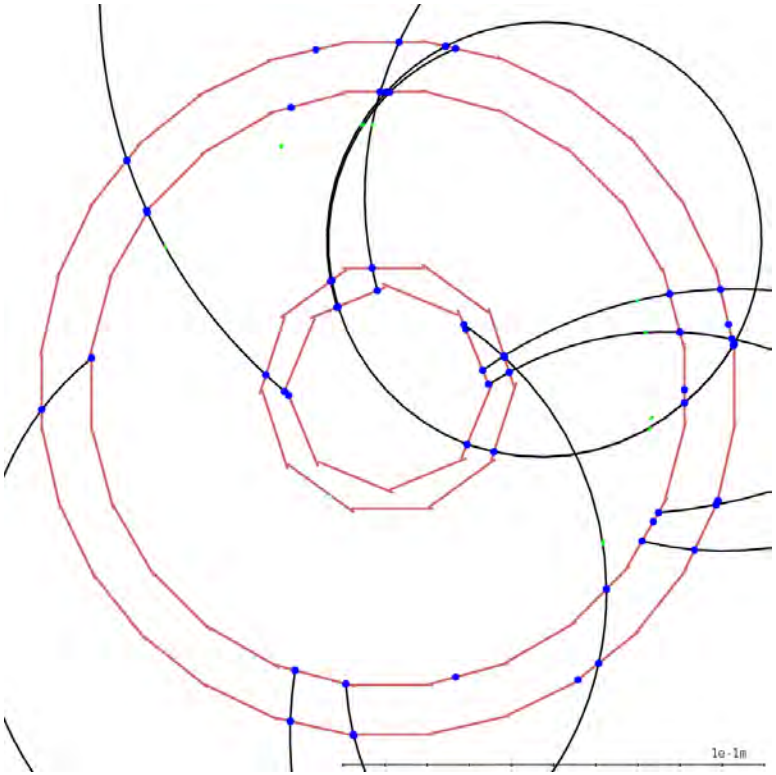



# Track reconstruction

MC simulation:
- Geant4 simulation of full detector geometry & readout
- 100% pixel efficiency & no noise

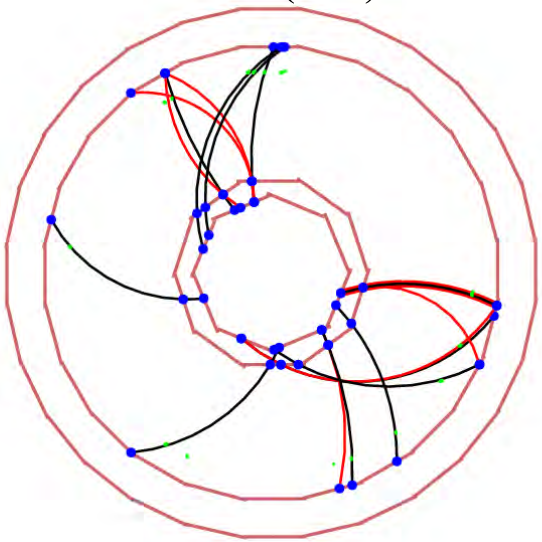
- Beam: $10^8$ muon decays on target
  - Decay $\mu \rightarrow e\nu\nu$ (Michel decay)
  - 5 decays in 50 ns frame

Typical 50 ns frame at $10^8$ μ/s on target

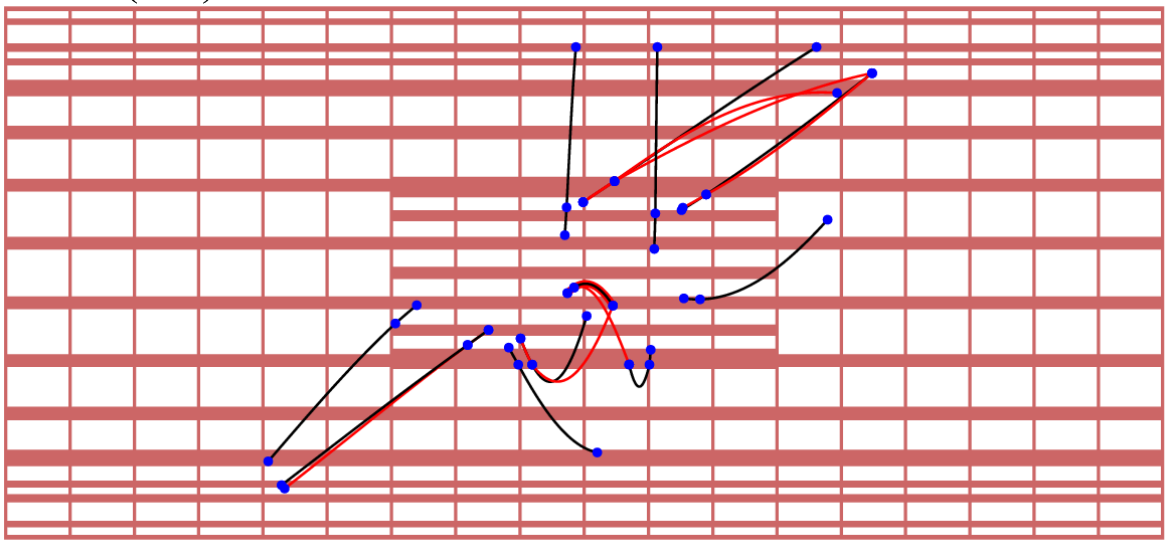


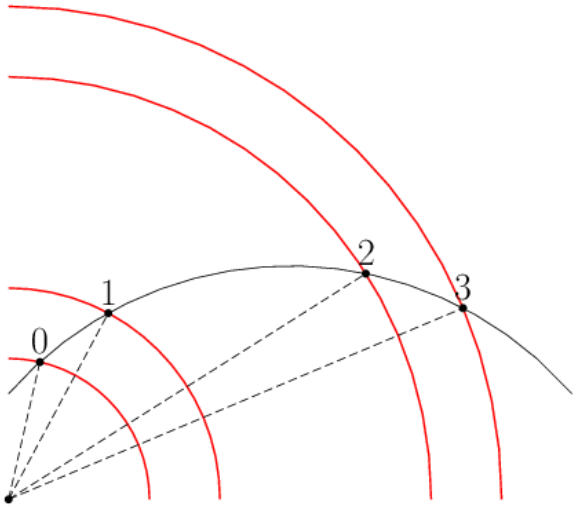
# Reconstruction: triplets

Transverse (XY) view



Side (ZY) view





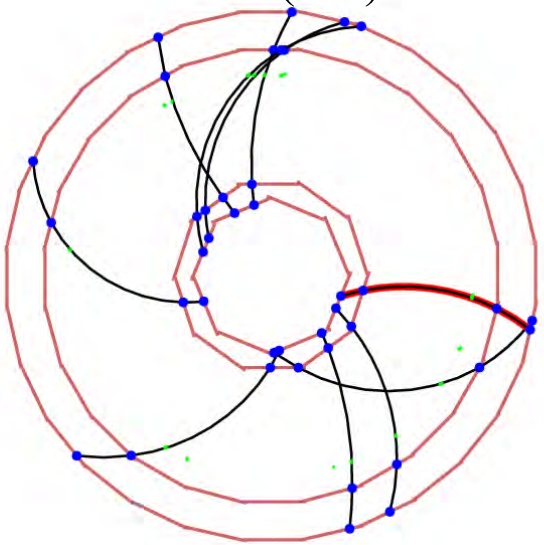

Make triplets:

- Combination of hits in first 3 layers (hits 0, 1 and 2)
  - $n^3$ combinations (n – number of hits in a layer)
- Geometrical selections + $\chi^2$ cut

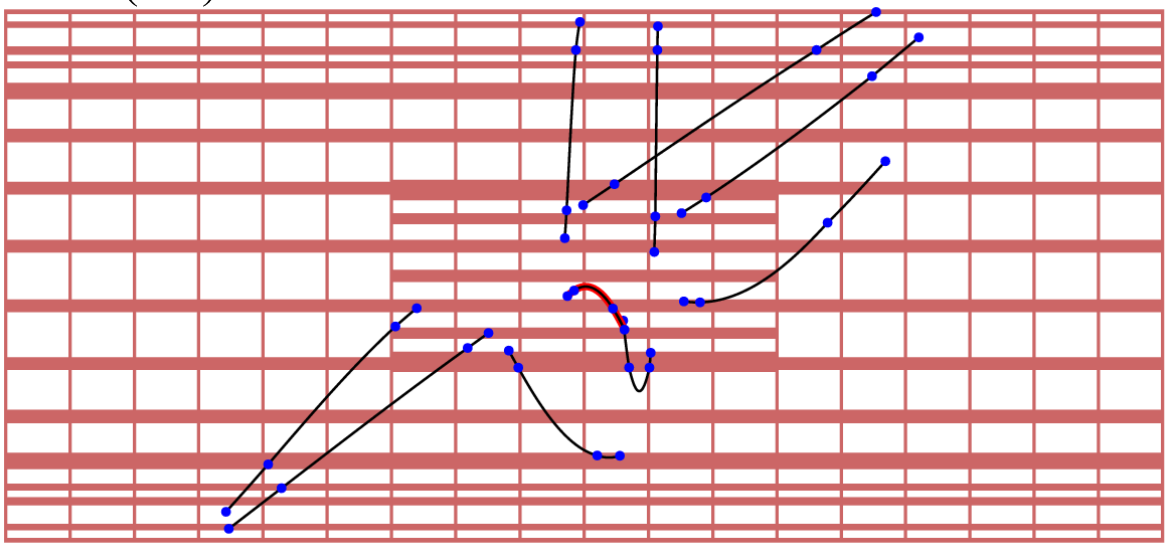
- Fake rate ~ 2 (fake combinations per one MC track)

# Reconstruction: short tracks

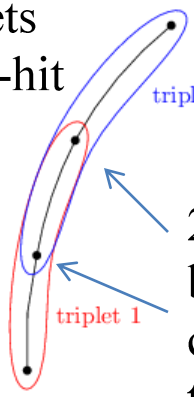
Transverse (XY) view



Side (ZY) view



2 triplets form 4-hit track




2 hits shared between consecutive triplets

Short 4-hit tracks:

- Use triplets as seeds:
  - approximate position of hit 3
- 2 triplets form short track
- Weighed average of individual triplets:

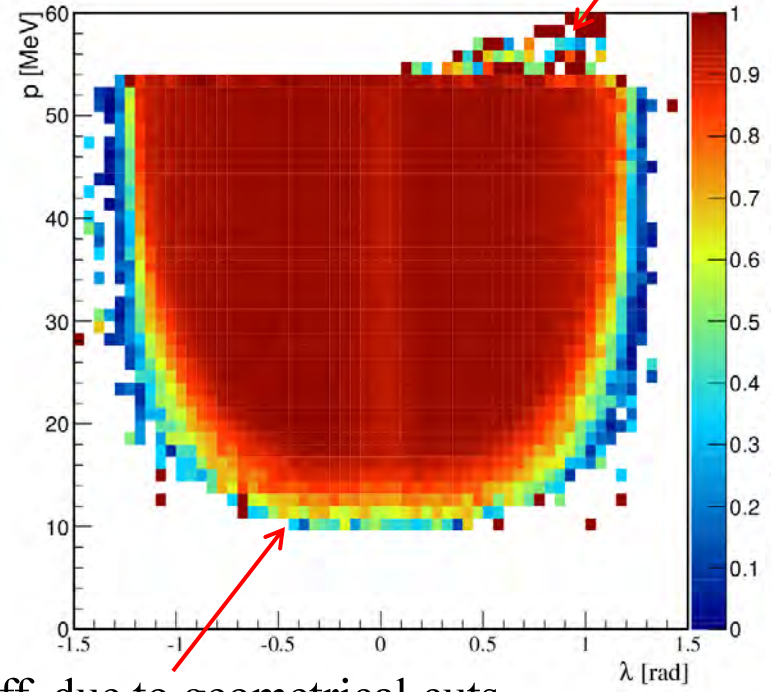
$$r = \frac{\sum r_i/\sigma_i^2}{\sum 1/\sigma_i^2}$$

# Short tracks: efficiency and resolution

- 95% efficiency for short tracks with at least one hit in each layer (~80% acceptance).
- Efficiency limited by geometrical and $\chi^2$ cut
- Fake rate ~ 0.02
- Momentum resolution: **1.4 MeV/c**

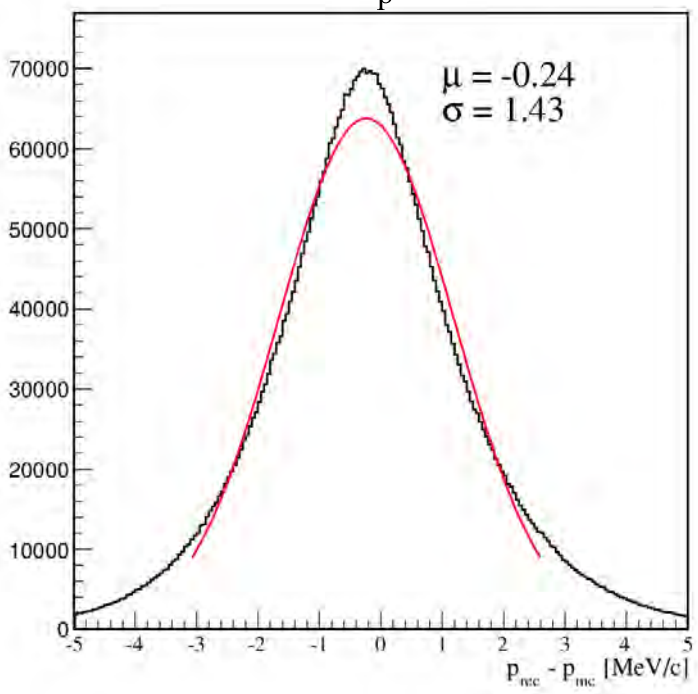
4-hit track reco.eff.

decay in flight




Ineff. due to geometrical cuts

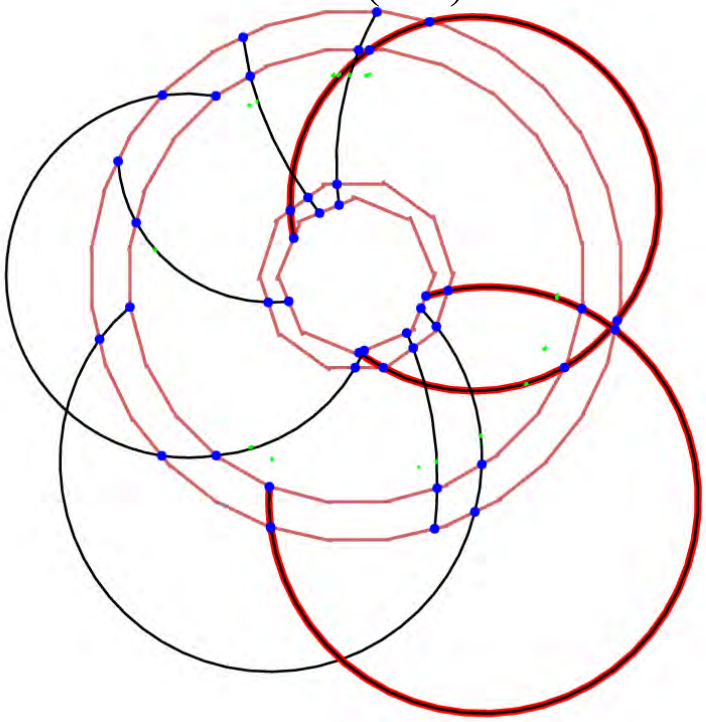
Short tracks: $\sigma_p \approx 1.4$ MeV/c



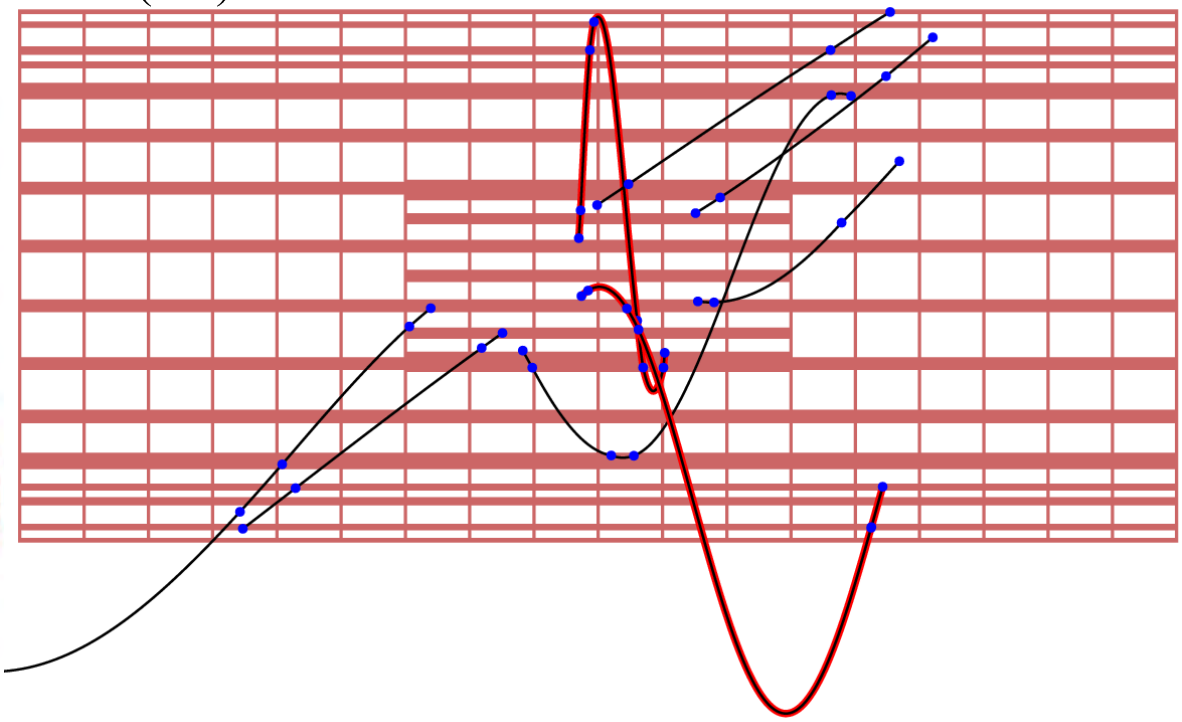

*Note: no correction for energy loss*

# Reconstruction: long tracks

Transverse (XY) view



Side (ZY) view



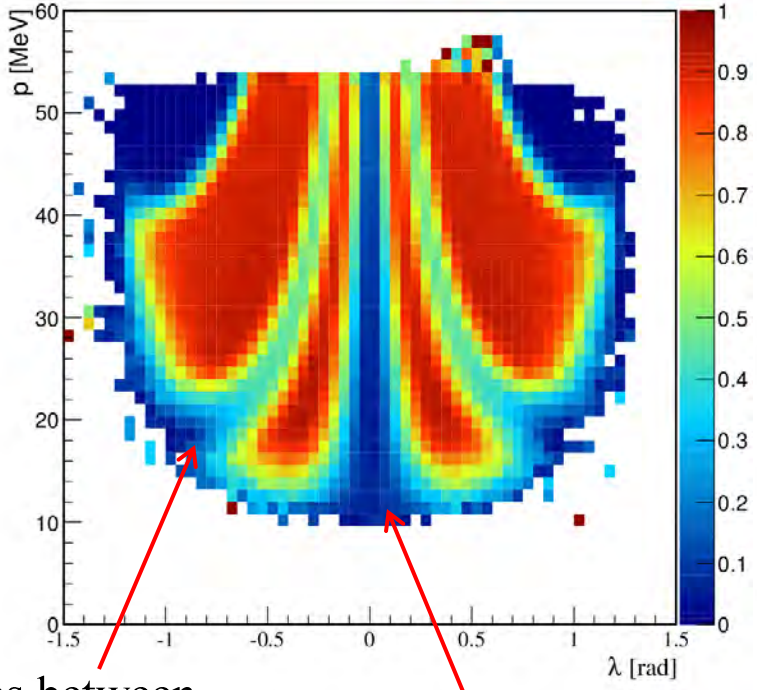
Long 6,8-hit tracks:

- Long tracks made from combination of 2 short tracks or short track and a pair of hits.
- Strong constraint (pixel size) on 3D radius
  - $\sigma_p \approx 0.2$ MeV/c

# Long tracks: efficiency and resolution

- 10% of short tracks promoted to 8-hit tracks
  - fake rate ~ 0.5 (wrong combination of short tracks)
- 65% of short tracks promoted to 6-hit tracks
  - fake rate ~ 0.01
- Momentum resolution: **0.2 MeV/c**

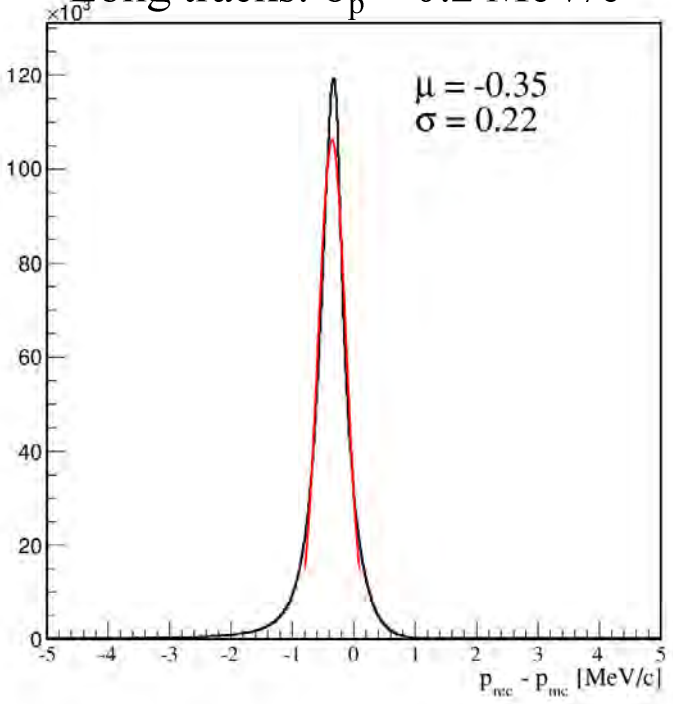
Efficiency of reconstructing long 6-hit track from short track




Gaps between stations

Long 8-hit tracks

Long tracks: $\sigma_p \approx 0.2$ MeV/c



# Summary

Mu3e experiment:
- Search for $\mu^+ \rightarrow e^+e^+e^-$, Br < $10^{-15}$
- Require high precision & efficiency
- Large data rates (fast online reconstruction)

Reconstruction:
- Use triplet fit for track reconstruction
- Good performance (resolution and efficiency):
  - short 4-hit tracks: $\sigma_p \approx 1.4$ MeV/c
  - long 6,8-hit tracks: $\sigma_p \approx 0.2$ MeV/c

Work is ongoing:
- Energy loss correction
- Effect of pixel size
- Alignment
- Fibre and tile matching (timing information)
- Optimization for high rates ($10^9$)