Track Reconstruction on GPUs for the Mu3e Experiment

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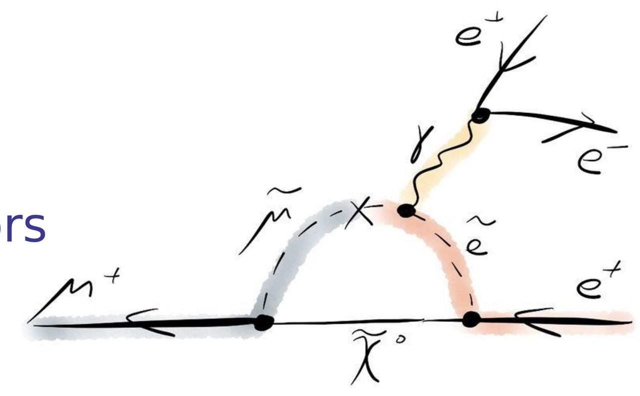
Motivation

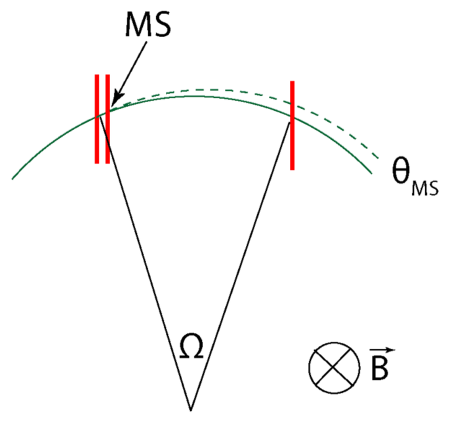
- Discovery of neutrino oscillations
  → Lepton flavour not conserved
- Lepton flavour violation in charged sector so far unobserved
- Mu3e searches for $\mu^+ \to e^+e^+e^-$ at a sensitivity of 1 in 10^{16} decays
- Requirements:
  - Rates O(10^9 μ/s)
  - High precision tracking detectors
  - Excellent timing precision

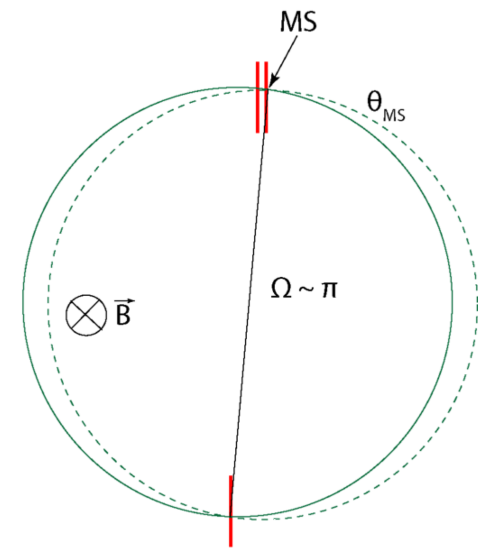


⇒ Ultimately, improve sensitivity by 4 orders of magnitude compared to previous SINDRUM experiment (BR< 10^{-12})

Momentum Resolution

- E_e: 10 - 50 MeV
- Momentum resolution dominated by multiple Coulomb scattering

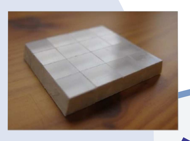




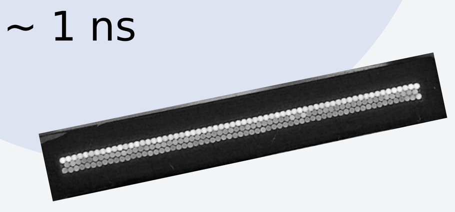
- Minimize material
- $\sigma_p/p \sim \theta_{MS}/\Omega$
- At Ω = π, scattering cancels to first order
- Apply magnetic field
- Use recurling tracks

Timing

- ~ 1 cm thick scintillating tiles
- σ_t ~ 100 ps



- 250 μm scintillating fibres
- σ_t ~ 1 ns

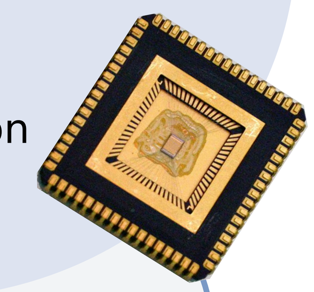


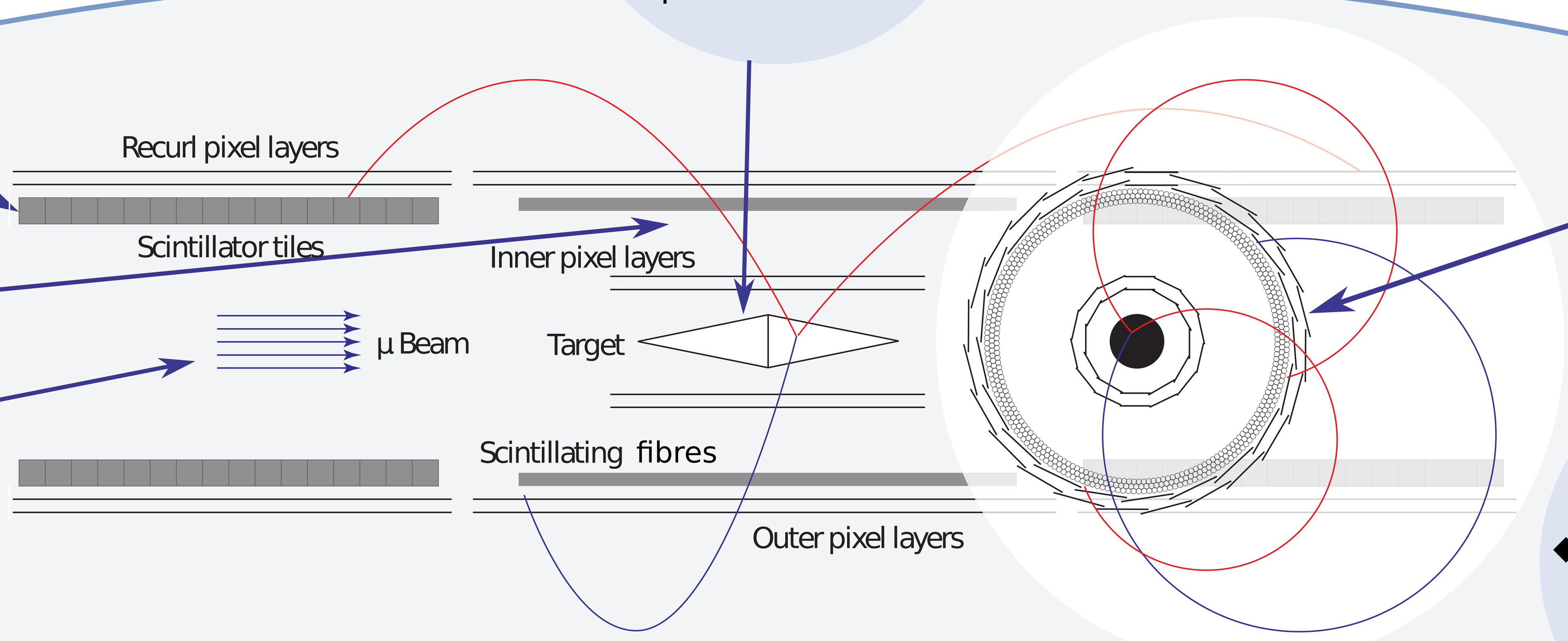
Target

- Hollow
- Double cone
- 70 μm aluminum
- Large area → spread vertices

Pixel Sensors

- High Voltage Monolithic Active Pixel Sensors
- Thickness of 4 layers < 4 ‰ radiation lengths
- Maximum readout frequency ~ 20 MHz
- Binary readout
- Spatial resolution ~ 100 μm in Mu3e





Beam

- Paul-Scherrer Institute, Switzerland
- up to 2×10^9 μ/s

Magnet & Cooling

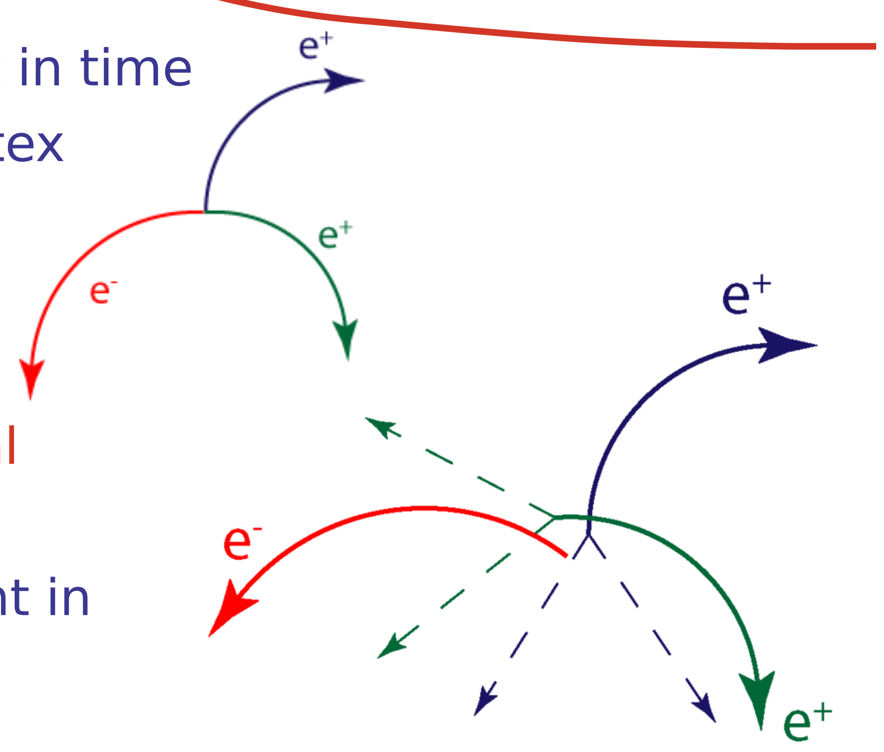
- 1 T solenoidal magnetic field
- Gaseous helium for cooling

Signal & Background

Signal

- Coincident in time
- Single vertex
- $\Sigma \vec{p}_i = 0$

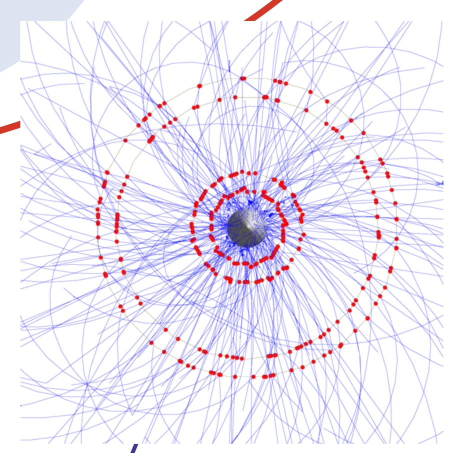
Combinatorial Background
Not coincident in time or place



Readout

- Triggerless
- ~ 1 Tbit/s to online farm
- Track finding & reconstruction on GPUs

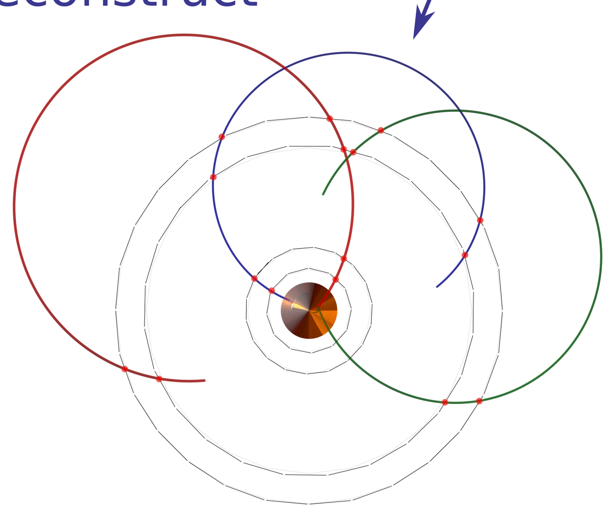
Reconstruction

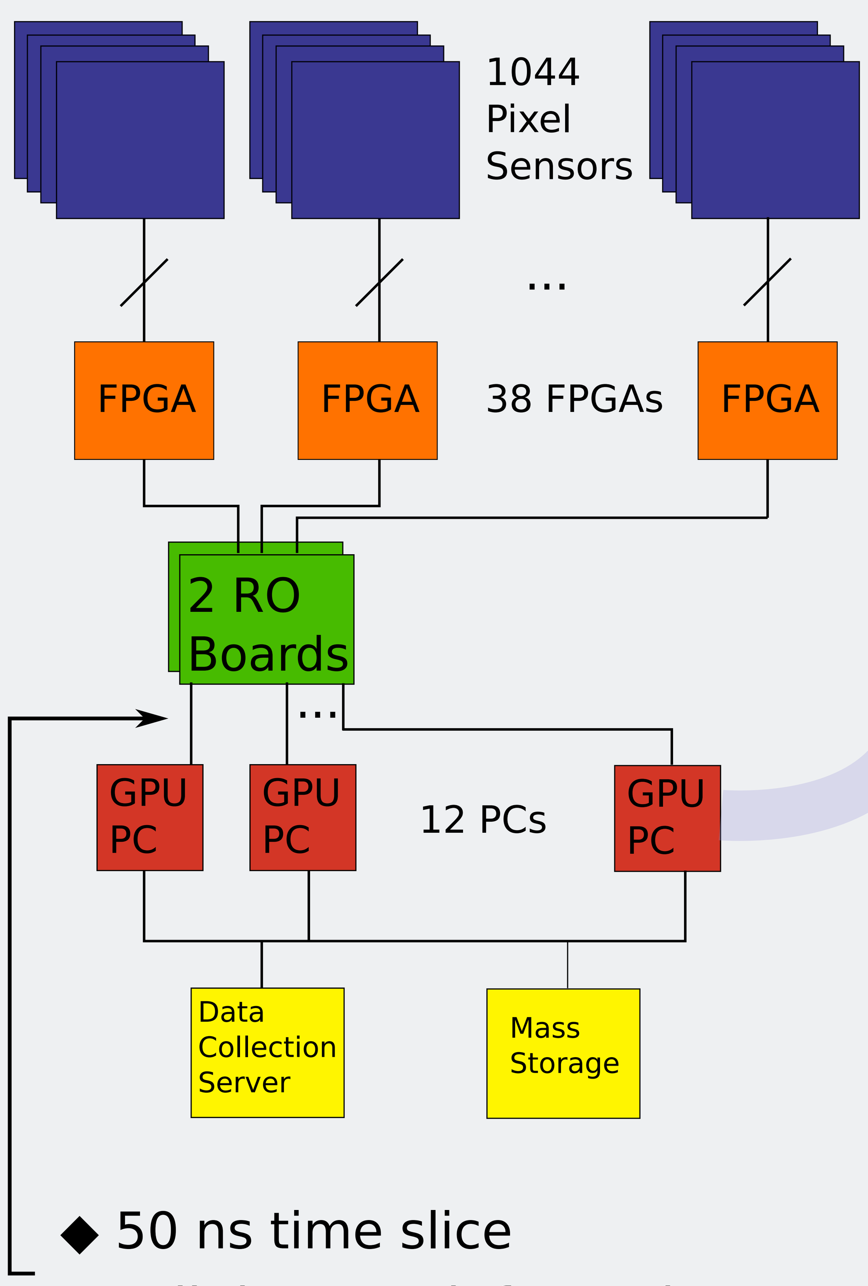


- Up to 100 tracks per readout frame of 50 ns (~ 1 Tbit/s)
- Reduce to ~ 100 Mbytes/s
- Triggerless → fully reconstruct on filter farm level

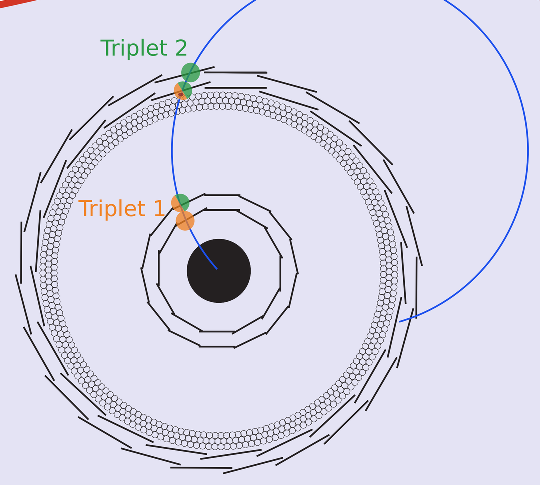
Signal event:

- 3 tracks
- Common vertex
- No missing energy





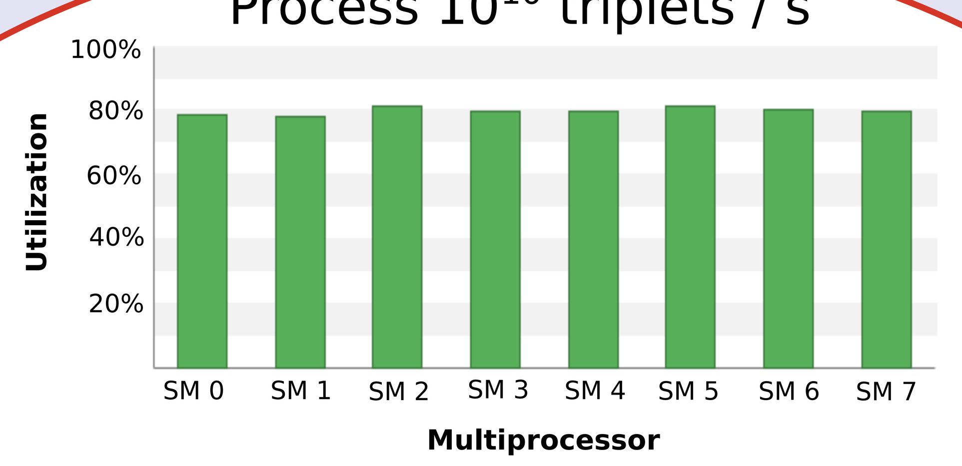
- 50 ns time slice
- Full detector information



- Ignore spatial uncertainty
- Describe track as sequence of hit triplets
- Multiple scattering at middle hit of triplet
- Minimize multiple scattering:

$$\chi^2 = \frac{\phi_{MS}^2}{\sigma_{MS}^2} + \frac{\theta_{MS}^2}{\sigma_{MS}^2}$$

Process 10^{10} triplets / s



Keeping 1536 cores busy
Using ~80 % of the GPU's compute capability

- Consider first three detector layers
- Number of possible track candidates ~ n[1] x n[2] x n[3]
- On GPU: Loop over all combinations
  - Geometrical selection cuts
  - Triplet Fit
  - Vertex Fit
- Compute in parallel on blocks and threads of GPU

~ 50 hits / plane / 50 ns
↓
100k combinations / 50 ns
↓
Filter farm with 50 GPUs