Track Reconstruction on GPUs for the Mu3e Experiment

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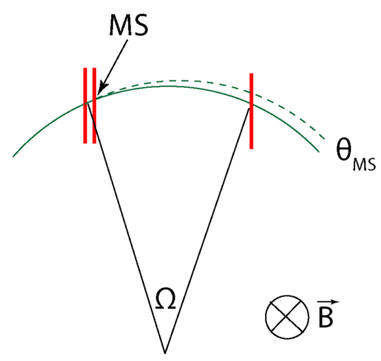
Abstract

The Mu3e experiment searches for the lepton flavor violating decay $\mu^+ \rightarrow e^+e^+e^-$, aiming at a sensitivity of 1 in 10^{16} decays. Any observation of a signal would indicate new physics beyond the Standard Model.
A high precision silicon tracking detector combined with excellent timing resolution from scintillating fibers and tiles will measure the momenta, vertices and timing of the decay products of muons stopped in a target to suppress background.
The trigger-less readout system will deliver ~100 GB/s of data. A network of optical links and FPGAs sends the full detector information for a time slice to one node of the filter farm. Tracks are fitted by the GPU of the PC using a 3D tracking algorithm for multiple scattering dominated environment. Then, three-track vertices are reconstructed, allowing for a reduction of the output data rate to below 100 MB/s by removing combinatorial background.

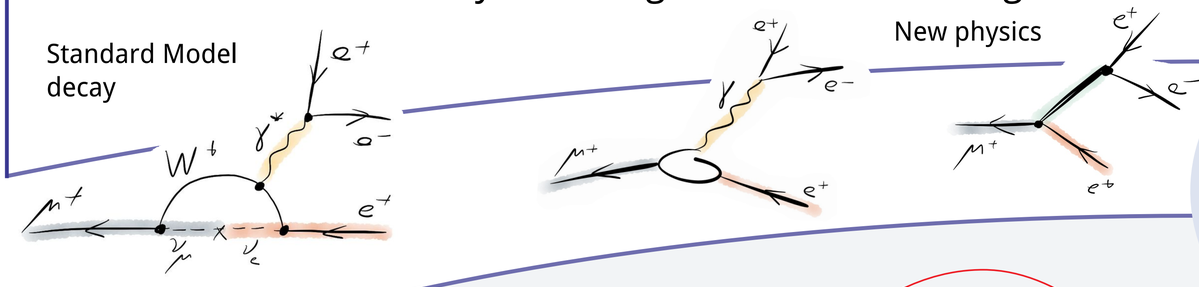
Momentum Resolution

- Electron energy: 10 - 50 MeV
- Momentum resolution σ_p dominated by multiple Coulomb scattering



- Ω: bending angle
- $\sigma_p/p \sim \theta_{MS}/\Omega$
- At $\Omega = \pi$, scattering cancels to first order

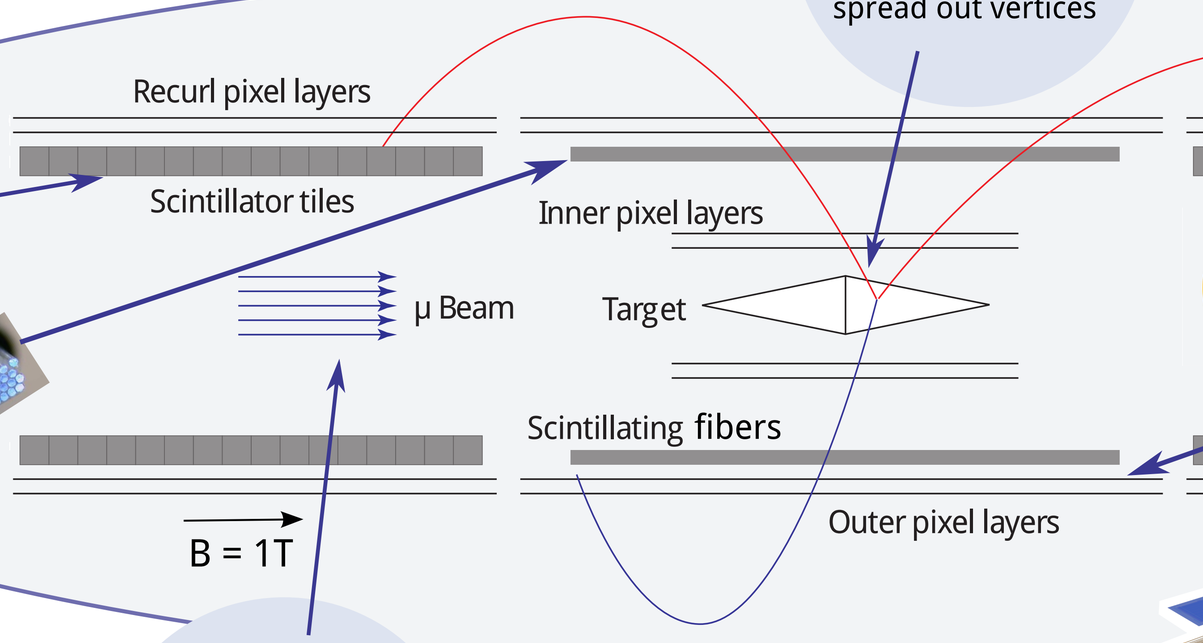
- Apply magnetic field
- Use recurling tracks
- Minimize material



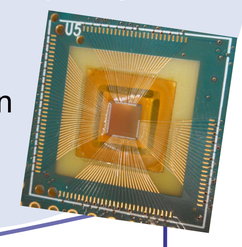
Target
- Hollow double cone
- Large area → spread out vertices

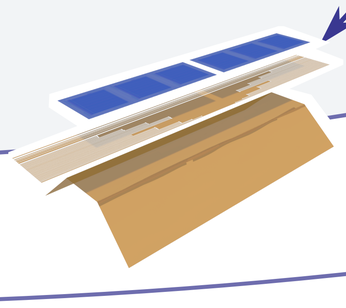
Magnet & Cooling
- 1 T solenoidal magnetic field
- Gaseous helium for cooling

Timing
- ~ 1 cm thick scintillating tiles
- σ_t ~ 70 ps
- 250 µm scintillating fibers
- σ_t ~ 1 ns



Pixel Sensors
- High Voltage Monolithic Active Pixel Sensors
- Thickness of 1 layer < 1 ‰ of a radiation length
- Maximum readout frequency ~ 20 MHz
- Digital readout
- Spatial resolution ~ 20 µm

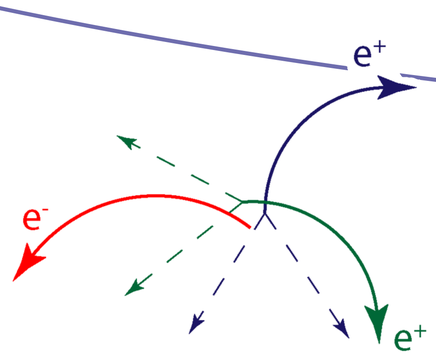




Beam
- Paul-Scherrer Institute, Switzerland
- up to 2×10^9 low energy µ/s

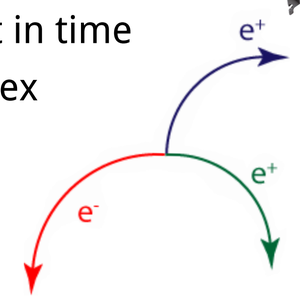
Readout
- Triggerless
- ~ 100 GB/s to online farm
- Track finding & reconstruction on GPUs

Signal & Background



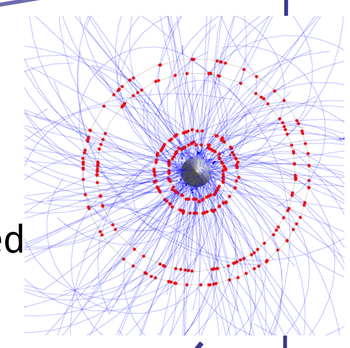
Combinatorial Background
Not coincident in time or place

Signal
- Coincident in time
- Single vertex
- $\Sigma\, p_i = 0$
- $E_{tot} = m_\mu$

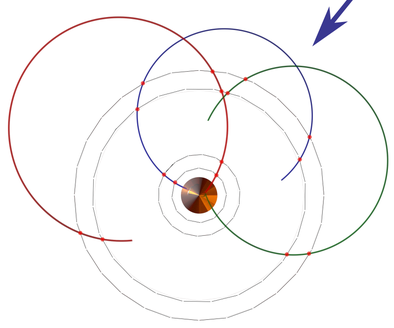


Reconstruction

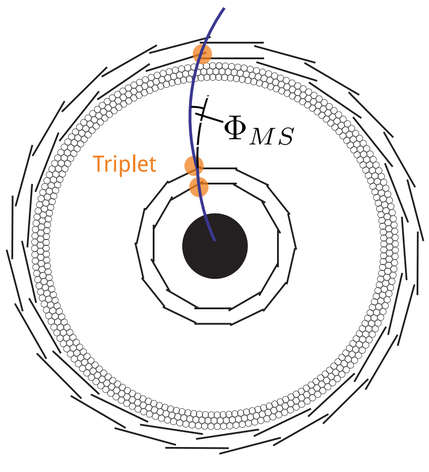
- Up to 100 tracks per reconstruction frame of 50 ns
- Triggerless → fully reconstructed on filter farm level



Signal event:
- 3 tracks
- Common vertex
- No missing energy



Multiple Scattering Fit



- Ignore spatial uncertainty
- Multiple scattering at middle hit of three hits (triplet)
- Minimize multiple scattering:

$$\chi^2 = \frac{\Phi^2_{MS}}{\sigma^2_{\Phi,MS}} + \frac{\theta^2_{MS}}{\sigma^2_{\theta,MS}}$$

GPU Workload
- Number of possible triplet candidates: ~ (number of hits per layer)^3
- Loop over all combinations for:
  - Geometrical selection cuts
  - Triplet Fit
  - Propagation to 4th layer
  - Vertex estimate (work in progress)
- Compute in parallel on 2048 cores* of GPU

Results
- Process 10^{10} triplets/s*
- 98% of true tracks found
- Reduce combinatorics by factor 300
- Reduce further with vertex constraint

*: on Nvidia GTX 980

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