



Mu3e Online Event Selection on GPU

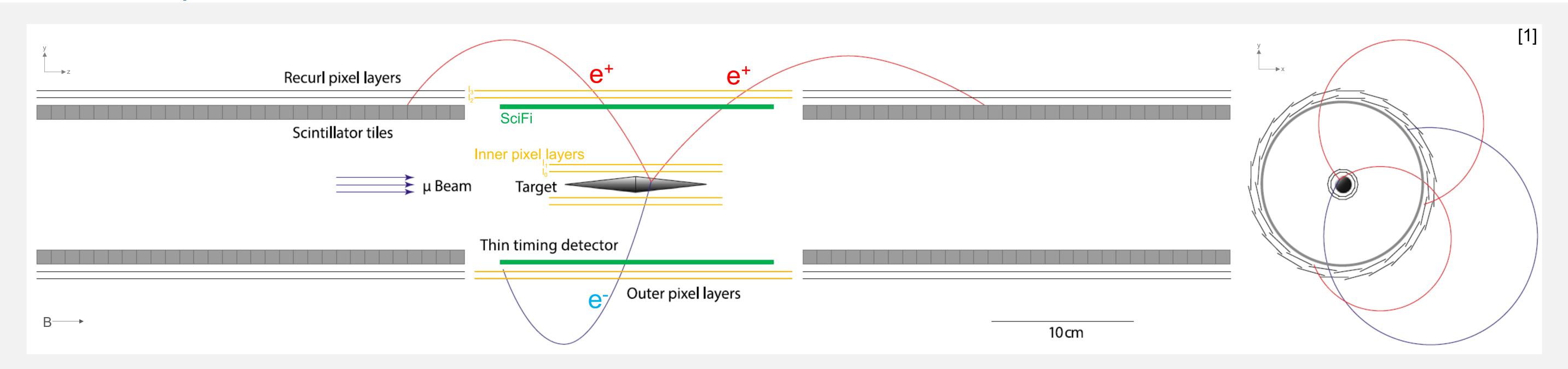
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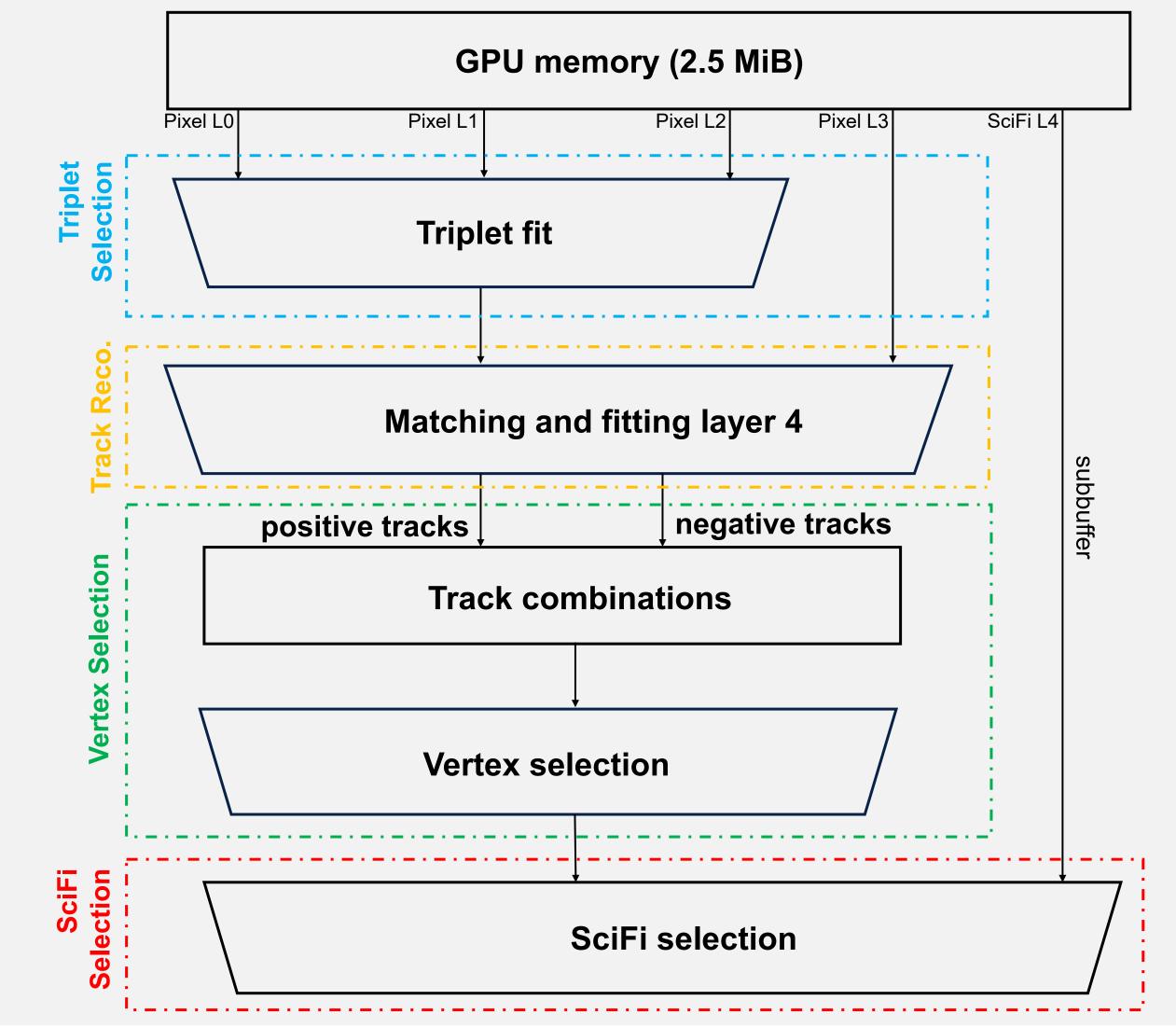
1 Introduction

The Mu3e experiment aims to search for the Charged Lepton Flavor Violation (cLFV) through the Standard Model (SM) forbidden decay µ⁺→e⁺e⁻e⁻, targeting a branching ratio sensitivity of 10⁻¹⁵ using the PSI πE5 beamline in Phase I. To cope with the exceptionally high muon rate of 108/s (equivalent to ~80 Gbps raw data rate), a triggerless, GPU-based online event selection algorithm is implemented to reconstruct the full kinematics of three tracks and their common vertex, enabling Mu3e signal identification and background suppression while reducing the data rate by two order of magnitude.

2 Mu3e Setup



3 Algorithm Flowchart



Triplet Selection:

plane radius R_t

Triplets are formed from hit

combinations in the first 3

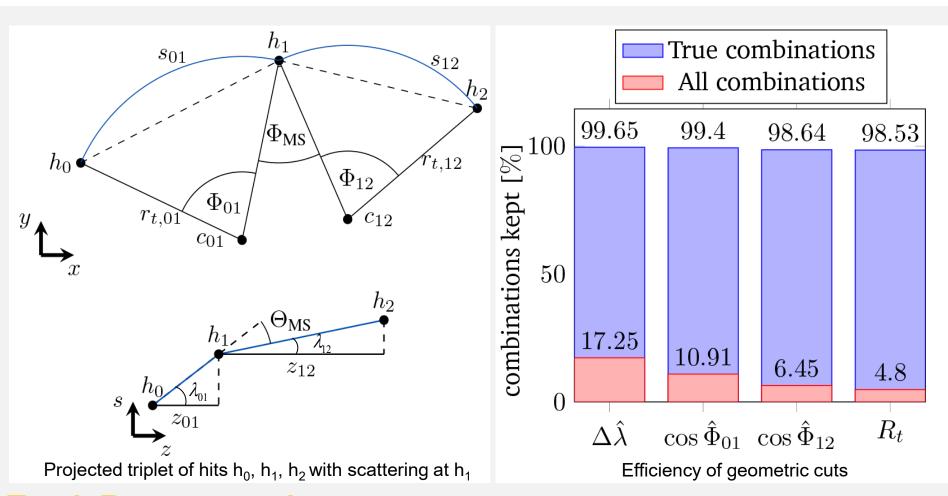
layers with applying geometric

cuts on angular differences

 (Φ_{01}, Φ_{12}) in the xy-plane; λ in

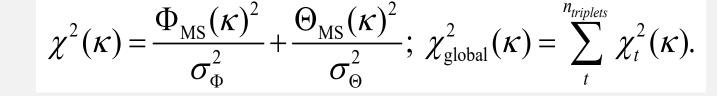
the sz-plane) and on the xy-

4 Online Event Selection^[2,3]



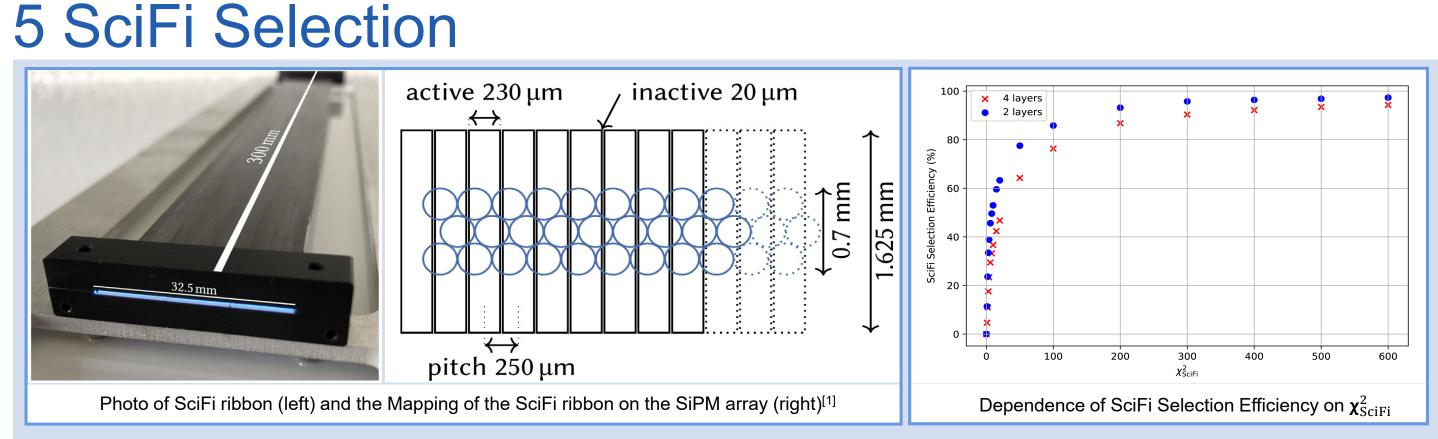
Track Reconstruction:

A preliminary helix from triplets passing the cuts is extrapolated to the 4th layer to predict the hit position, matched to the closet hit to form a second triplet. After a refined fit, tracks are kept with χ^2_{global} < 32:



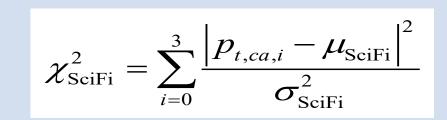
Vertex Selection:

The event vertex is defined as the spatial-uncertainty-weighted mean point μ_t of the intersection points from all combinations of 2 positive tracks and 1 negative track, with the lowest χ_t^2

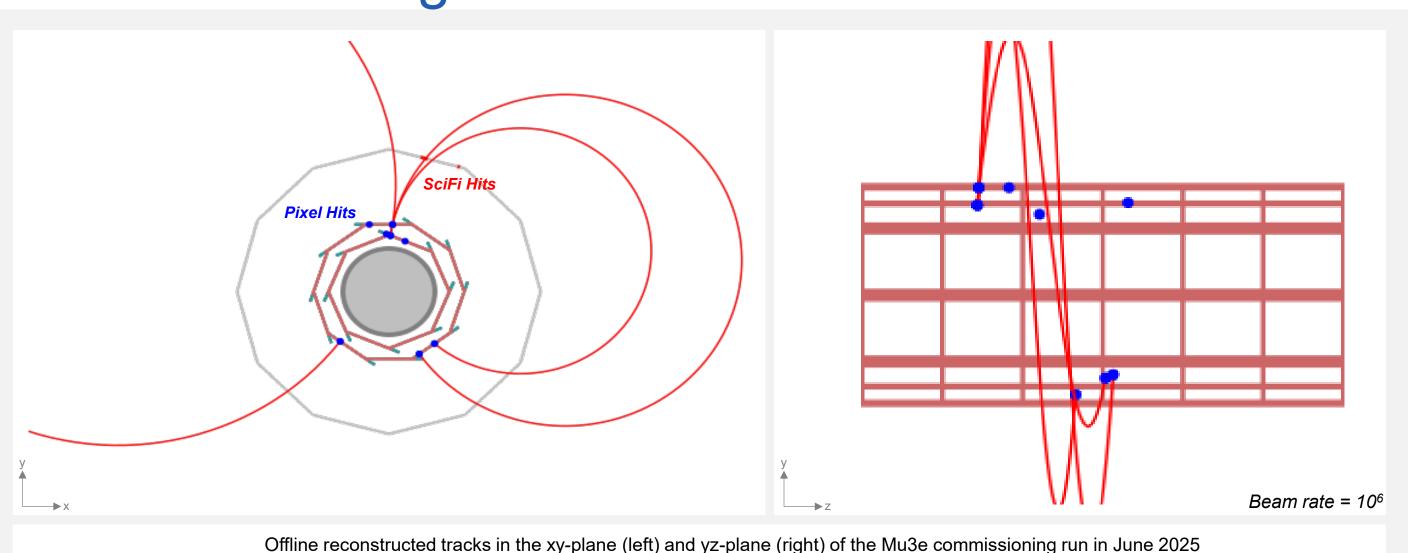


The scintillating fibre (SciFi) detector provides precise timing information with a resolution of 250 ps. Incorporating SciFi hits into the GPU-based online event selection allows tracks to be validated both spatially and in time.

Events with lower χ^2_{SciFi} tend to be accepted further by the SciFi selection after vertex selection, as χ^2_{SciFi} is correlated with the distance between the points of close approach (pca) on the SciFi and the three reconstructed tracks.



6 Commissioning Run 2025



Offline reconstructed tracks in the xy-plane (left) and yz-plane (right) of the Mu3e commissioning run in June 2025

Preliminary analysis indicates that over 50% of reconstructed pixel tracks with at least one cluster in the SciFi are correctly matched to true SciFi hits, for both 4-hit and 6-hit track reconstructions. The remaining tracks primarily fail to match due to possible misaligned ribbons or failed track reconstruction, which are still being further investigated

7. Conclusion

Monte-Carlo studies indicates that at the targeted muon rate of 10⁸ µ/s in Mu3e Phase I, more than 94% of the signal tracks are retained with a reconstruction accuracy of 97% while the data rate is reduced by a factor of $100^{[2]}$.

Meanwhile, SciFi selection has been incorporated into the online event selection and verified to run on the computing farm during Mu3e June beamtime; further validation is currently in progress.

References:

[1] K. Arndt et al., "Technical design of the phase I Mu3e experiment", Nucl. Instrum. Methods. Phys., A 1014, 165679 (2021).

[2] V.Henkys et al, "Online Event Selection for Mu3e using GPUs", ISPDC 2022, 17-24 (2022).

[3] H. Augustin et al., "The Mu3e Data Acquisition", IEEE Trans. Nucl. Sci., 68, 1833-1840 (2021).