Track Reconstruction at a Muon Collider in the Presence of Beam-induced Background

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APS April Meeting "Quarks to Cosmos"
Muon Collider Symposium
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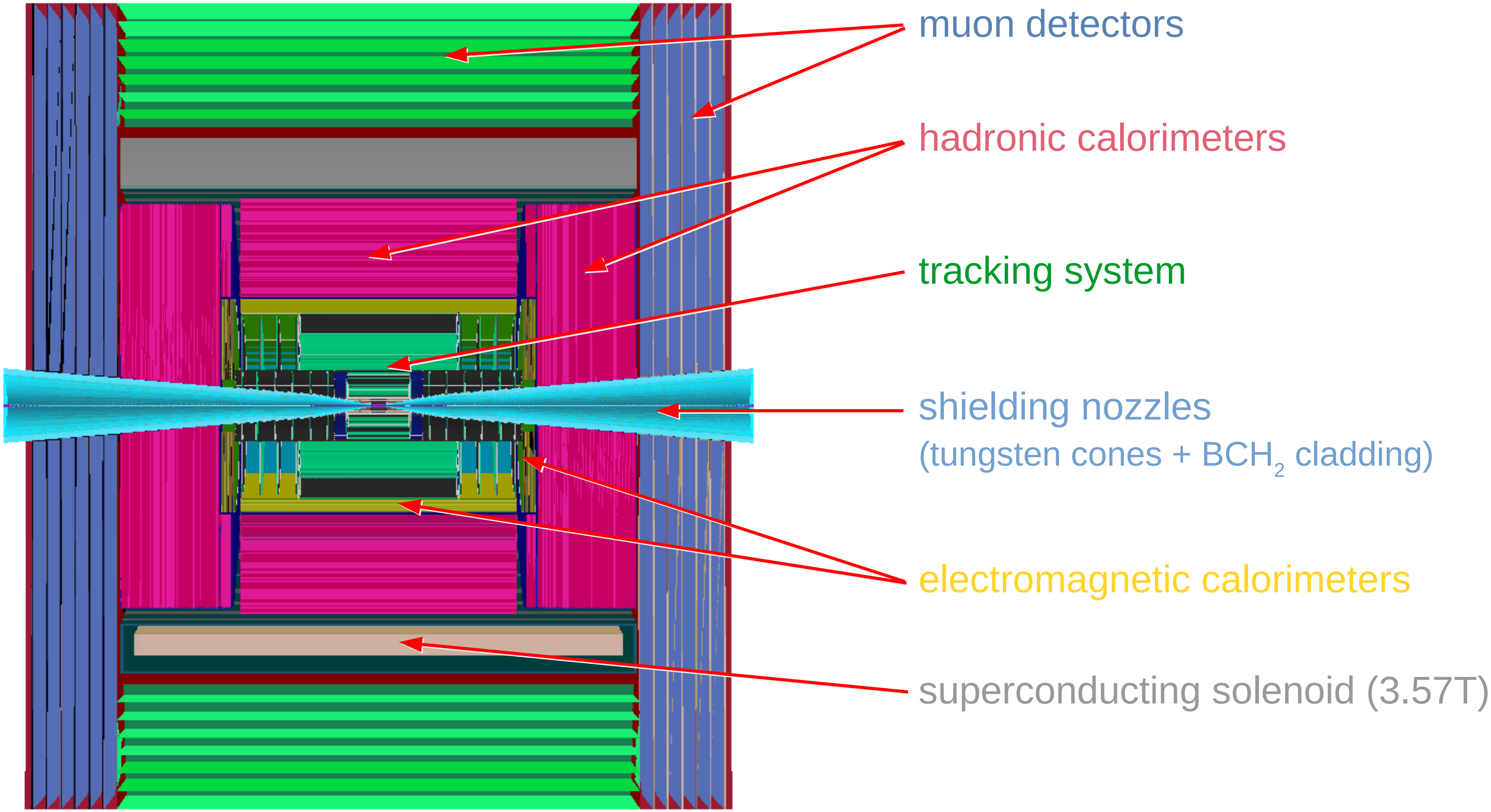
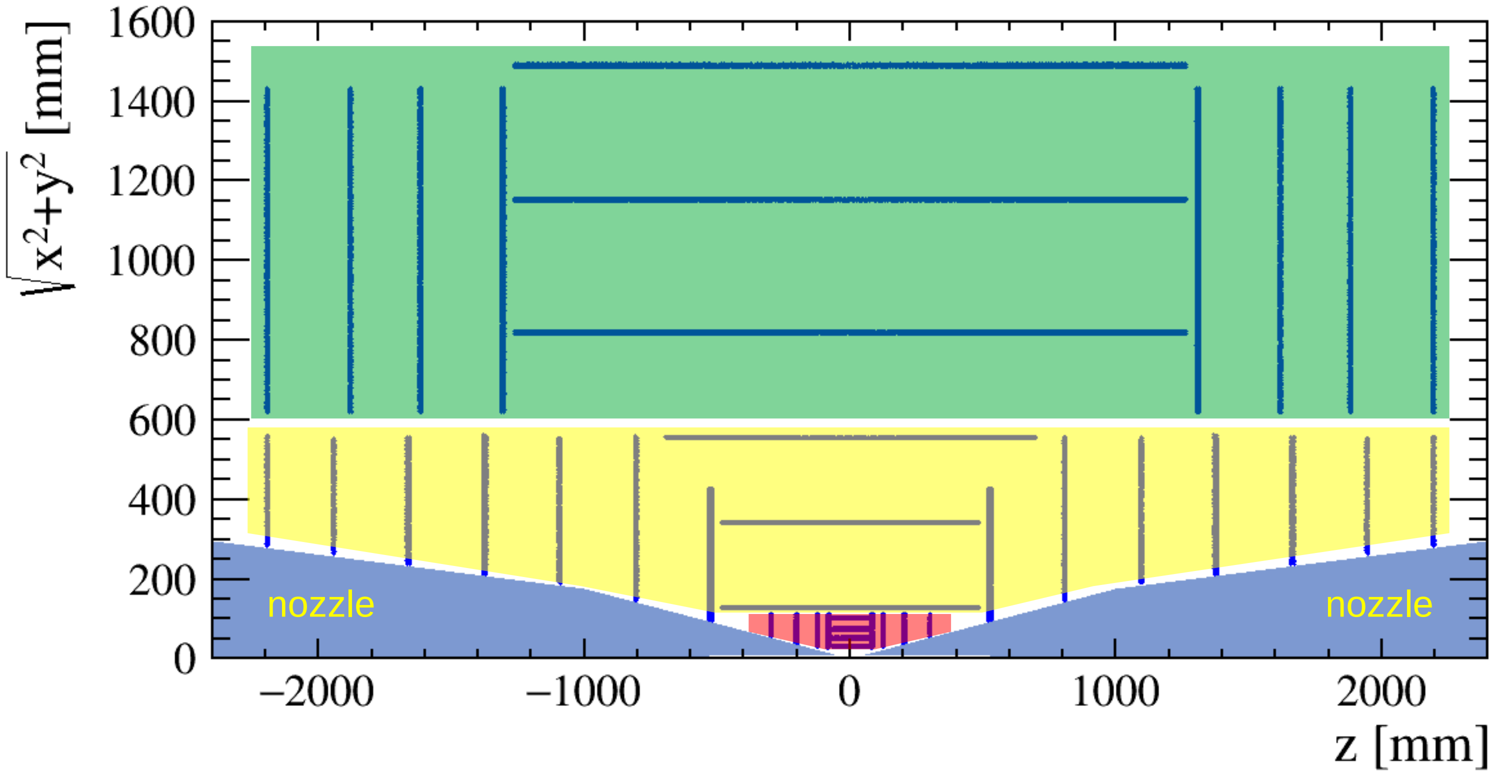
Detector overview

- Based on CLIC's detector model + the MDI and vertex detector designed by MAP.



- S. Pagan Griso, "Design a detector for a Muon Collider experiment" in Session H08.1

The tracking system



Vertex detector (VXD)

- barrel: 4 cylindrical layers
  endcaps: 4 + 4 disks
- double-layer Si sensors:
  25x25 μm² pixels
  50 μm thick
  σ_T = 30 ps

Inner Tracker (IT)

- barrel: 3 cylindrical layers
  endcaps: 7 + 7 disks
- Si sensors:
  50 μm x 1 mm macro-pixels
  100 μm thick
  σ_T = 60 ps

Outer Tracker (OT)

- barrel: 3 cylindrical layers
  endcaps: 4 + 4 disks
- Si sensors:
  50 μm x 10 mm micro-strips
  100 μm thick
  σ_T = 60 ps

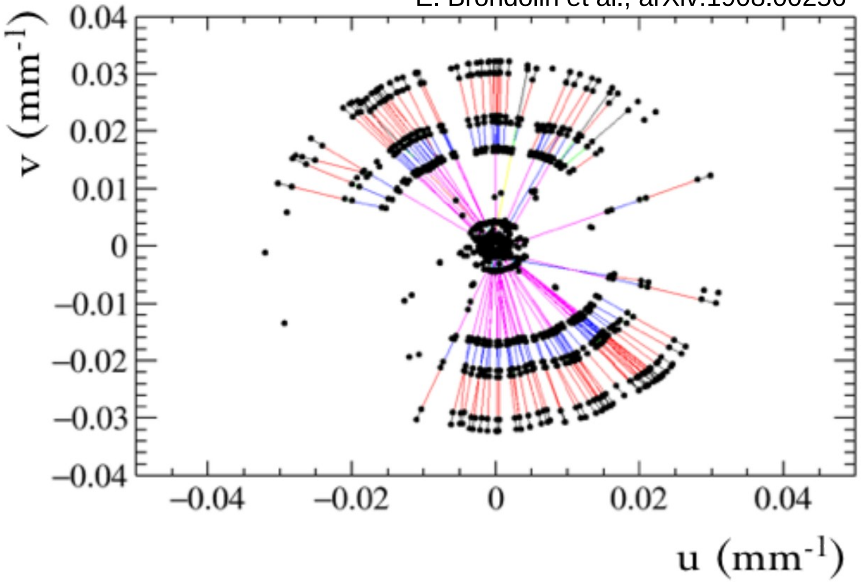
- H. Weber, “Studies of Tracker Timing and Granularity for the Muon Collider Environment” in Session H08.3

Tracker sim/reco software

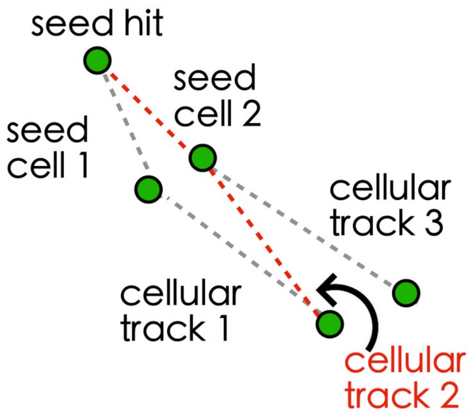
- Current tracker full simulation and reconstruction software based on CLIC's ILCSoft:
  - parametric tracker digitization:
    - simple Gaussian smearing of the simulated hits' positions and times;
  - track reconstruction:
    - pattern recognition uses a conformal mapping + a cellular automaton search;
    - track parameters from a Kalman filter fit.
- New code developments for the muon collider soon available:
  - digitization with pixelated Si modules and a realistic Si sensor response;
  - new tracking algorithm with the ACTS library;
    - K. Krizka, "ACTS Tracking For Muon Collider" in Session Y07.9
  - object-reconstrucion optimization.
    - N. Bartosik, "Object-reconstruction optimisation at Muon Collider" in Session B08.3

conformal space

E. Brondolin et al., arXiv:1908.00256



cellular automaton

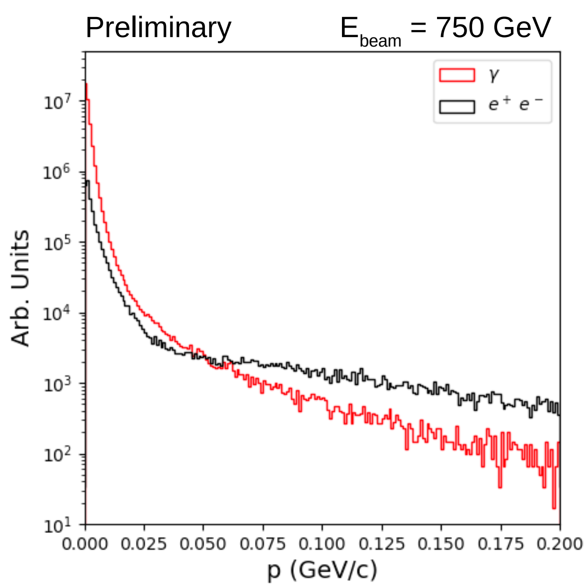


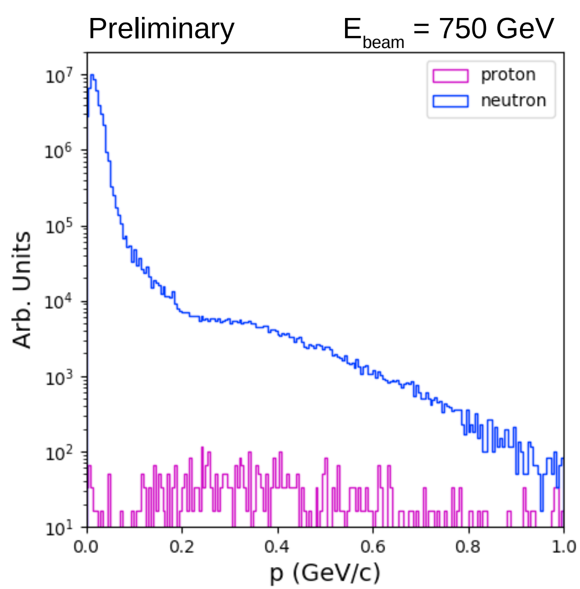
Beam-induced bkg in a nutshell

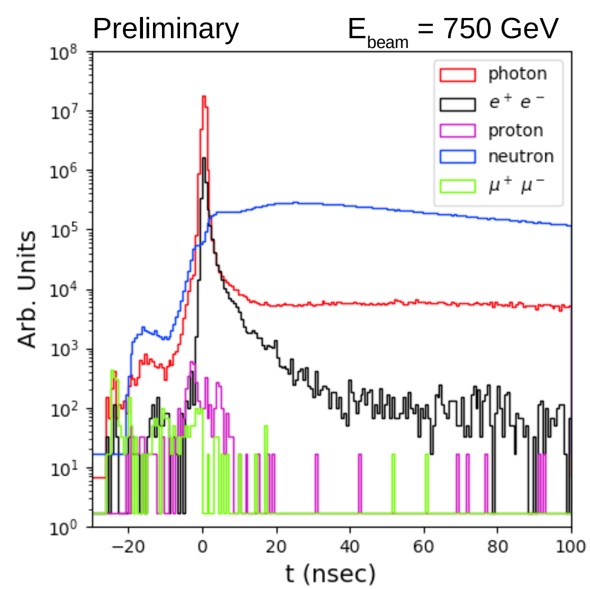
- The interaction of the beam muons decay products with the machine elements produces a pervasive flux of secondary and tertiary particles (mainly γ, n, $e^{\pm}$, $h^{\pm}$) that eventually may reach the detector.
- The amount and characteristics of the beam-induced background (BIB) depend on the collider energy and the machine optics and lattice elements.

particles entering the detector per bunch crossing

Preliminary		E_{beam} = 750 GeV
photons	(E_{γ} > 0.2 MeV)	4.3×10^{7}
neutrons	(E_{n} > 0.1 MeV)	5.4×10^{7}
electrons	(E_{e} > 0.2 MeV)	2.2×10^{6}
ch. hadrons	(E_{h} > 1 MeV)	1.5×10^{4}
Bethe-Heitler μ	(E_{μ} > 1 MeV)	1.2×10^{3}



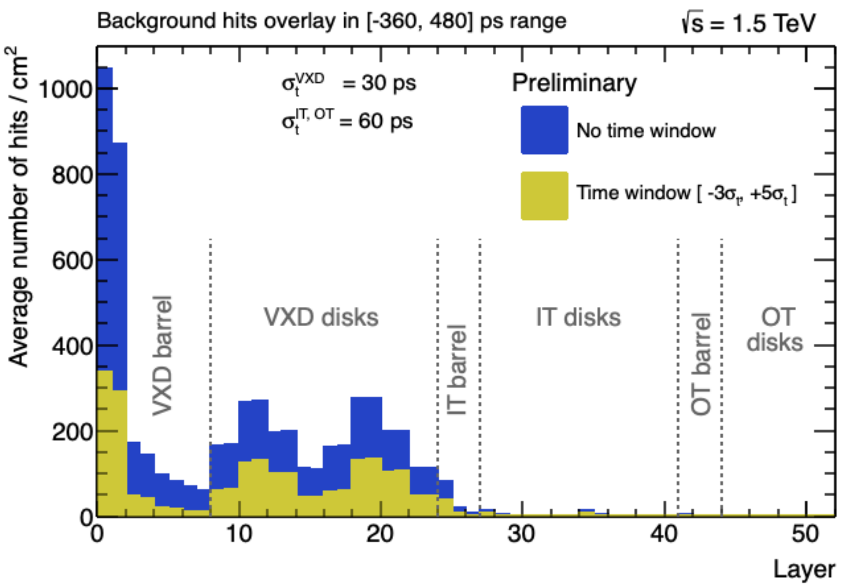


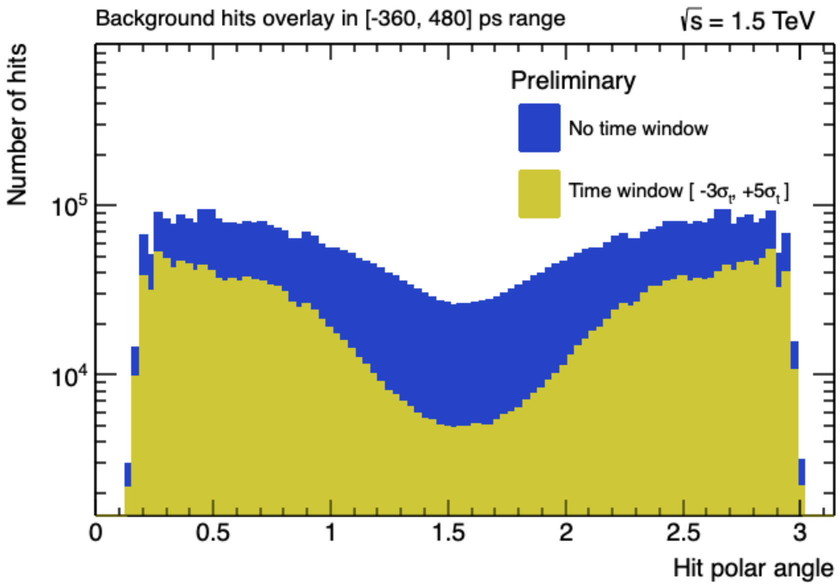


- C. Curatolo, "Simulation of Beam Induced Background at Muon Collider and Study of its Properties" in Session B08.2

Hit timing selection

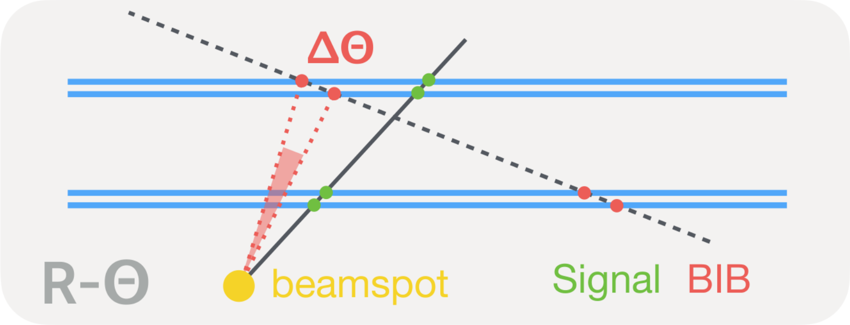
- Being the closest detector to the beamline, the tracker is affected the most by the BIB, which produces a huge number of spurious hits. If not mitigated, it could severely compromise:
  - the detector operations (too many data to be read out);
  - the track reconstruction performance (huge combinatorics).
- A big fraction of BIB particles reaches the detector out of time w.r.t. the bunch crossing ➔ exploit hit timing information.

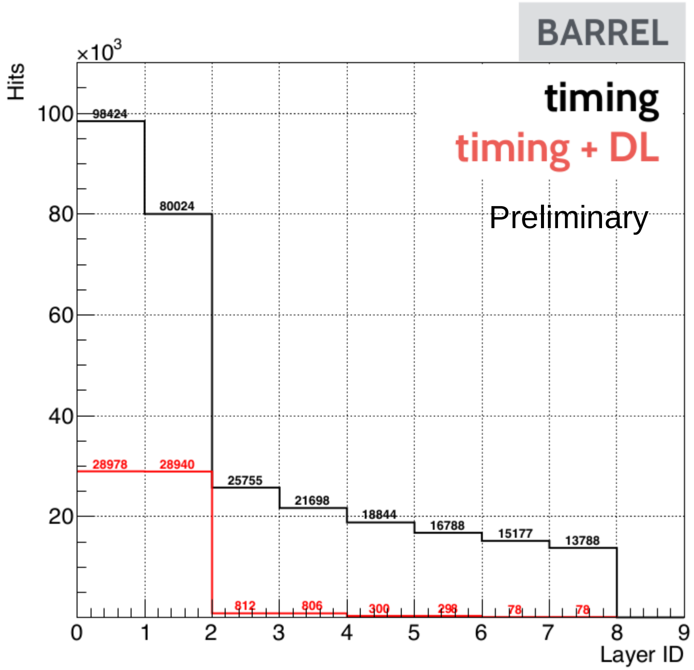


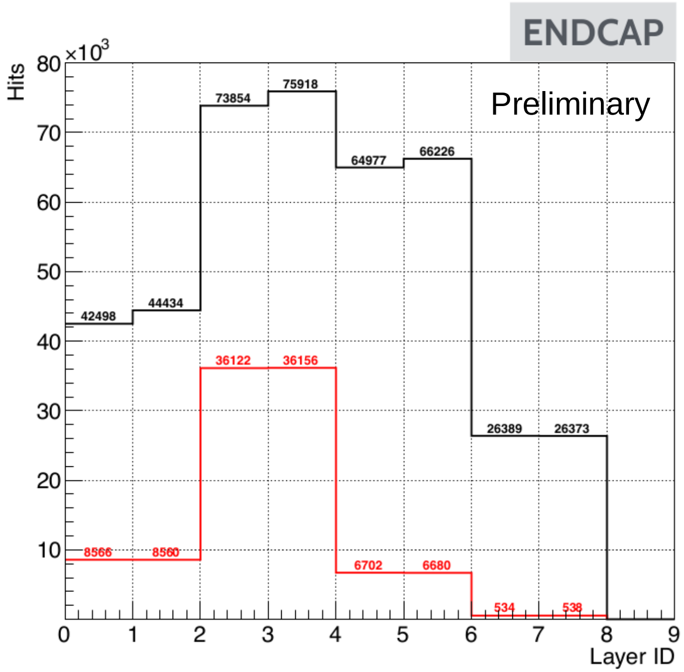


Double-layer selection

- BIB particles are not produced in collisions at the beamspot.
- The double-layer structure of the VXD modules can be exploited to correlate hit pairs on adjacent sensors to estimate the incoming particle direction.

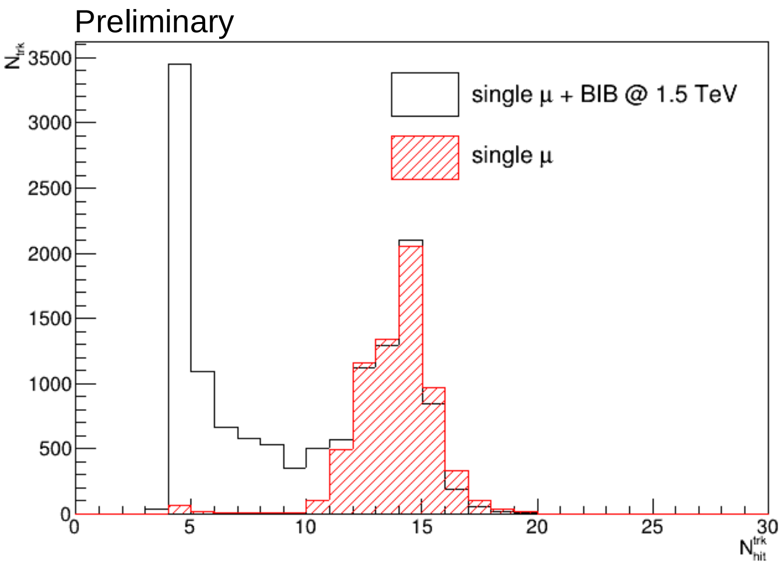


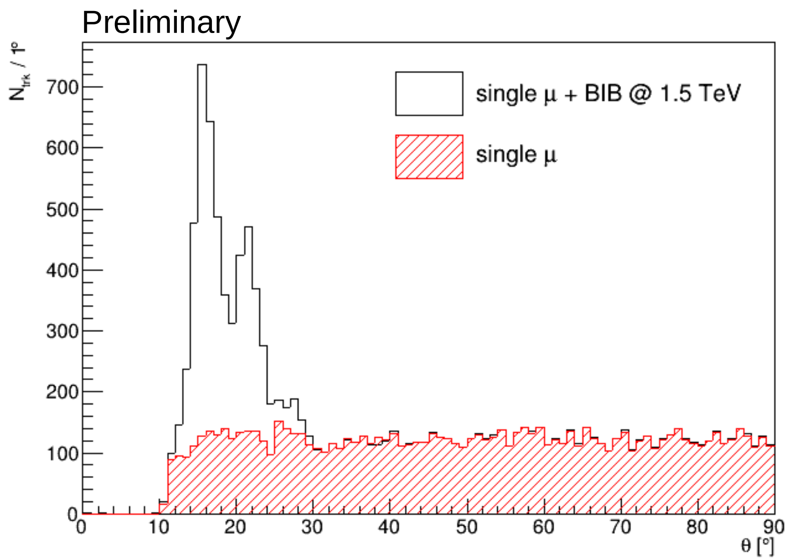


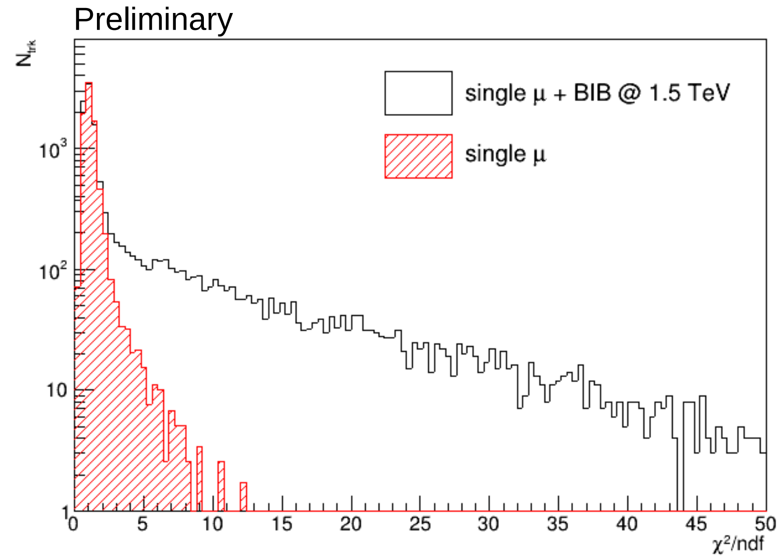


Tracking performace w/ single μ

- Sample: 10k single prompt muons with p = 10 GeV + BIB @ 1.5 TeV.
- Timing + double-layer selection applied.
- Tracking performed in a region of interest: only hits in a cone around the muon direction are used (ΔR = 0.05).

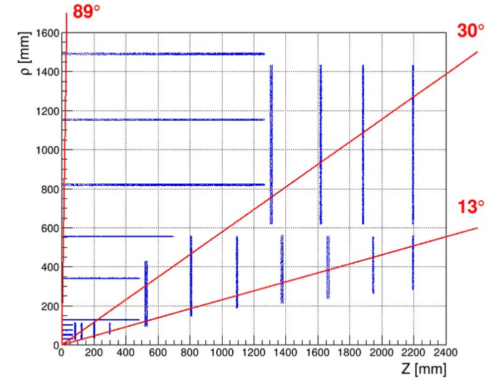


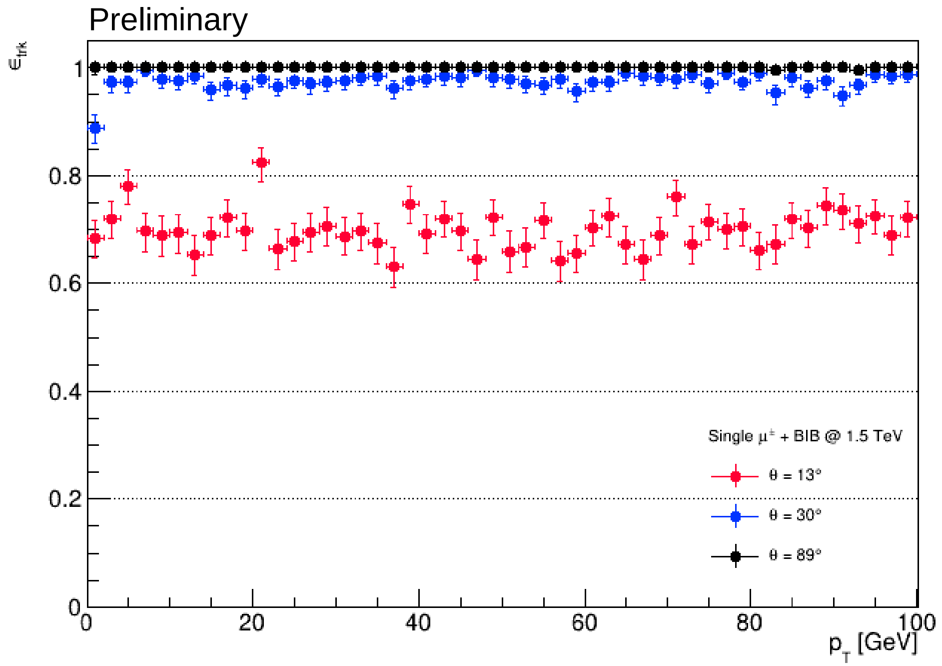


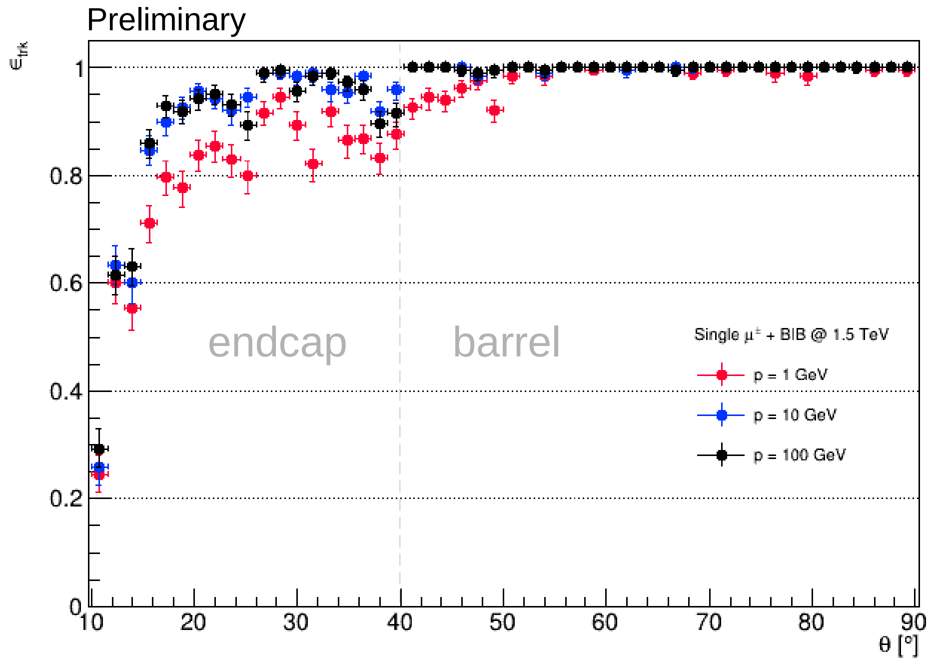


Track reconstruction efficiency

- Track reconstruction efficiency vs p_T and polar angle.
- 10k single prompt muon samples + BIB @ 1.5 TeV:
  - p = 1, 10, 100 GeV;
  - θ = 13°, 30°, 89°.

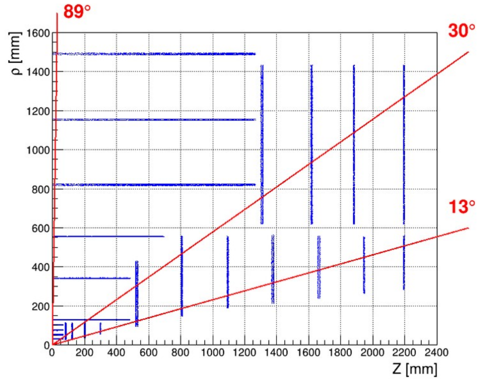


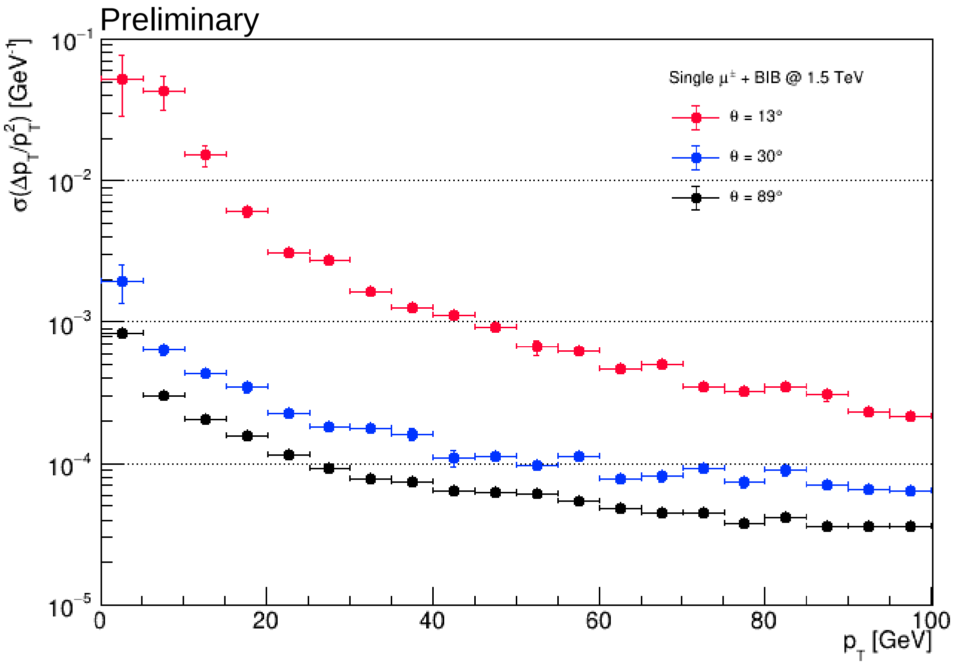


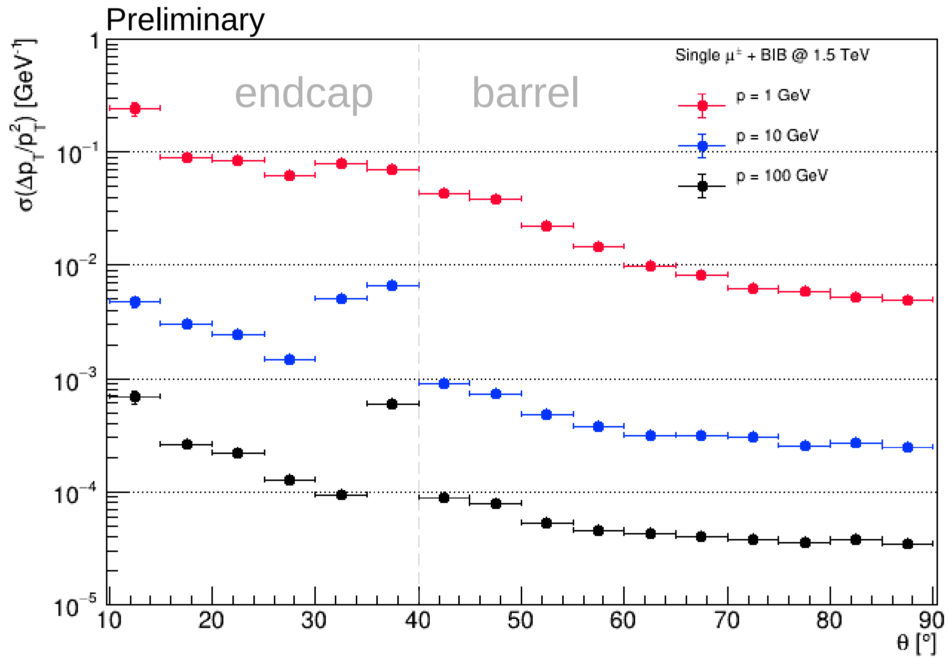


Reconstructed p_T resolution

- Track p_T resolution vs p_T and polar angle.
- 10k single prompt muon samples + BIB @ 1.5 TeV:
  - p = 1, 10, 100 GeV;
  - θ = 13°, 30°, 89°.







Conclusion

- The exploitation of the full physical potential that a muon collider can offer will depend on the capacity of the experiment to mitigate and cope with the beam-induced background.

- As far as the tracker is concerned, preliminary full-simulation studies indicate that cutting-edge technologies and new sophisticated reconstruction algorithms will be needed to overcome the BIB:
  - optimized detector design integrated with the MDI: double (triple?) layers in the VXD;
  - in-chip real-time data reduction;
  - high granularity and precise timing information at every level;
  - new algorithms based on artificial-intelligence and machine-learning for pattern recognition and reconstruction of physical objects;
  - heterogeneous highly-parallelized computing model (CPU, GPU, FPGA).