Cluster shape analysis of beam-induced background in the Muon Collider Tracking Detector

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Early Career Researchers & Muon Colliders
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MuCol

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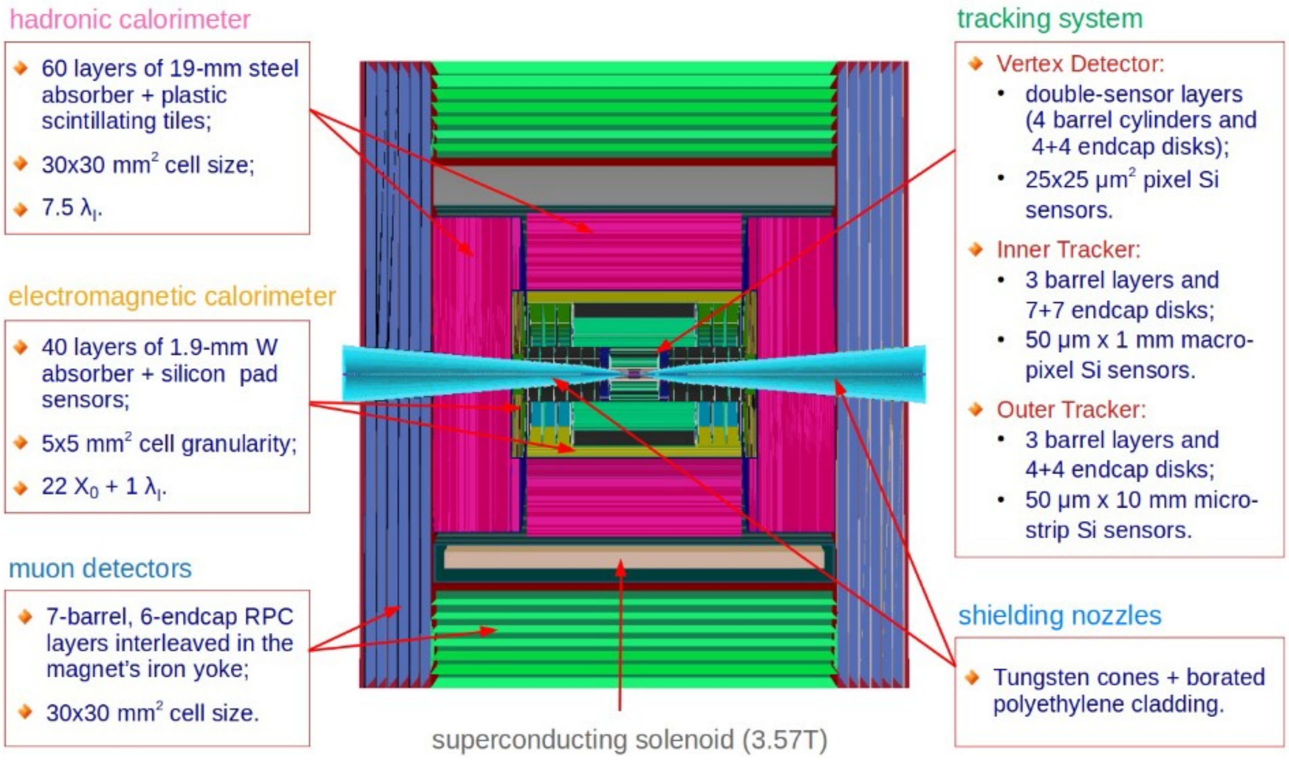
Outline

- Detector & tracker design
- Sources of beam-induced background (BIB)
- Realistic digitization
- Cluster Shape Analysis for BIB rejection
- Future studies

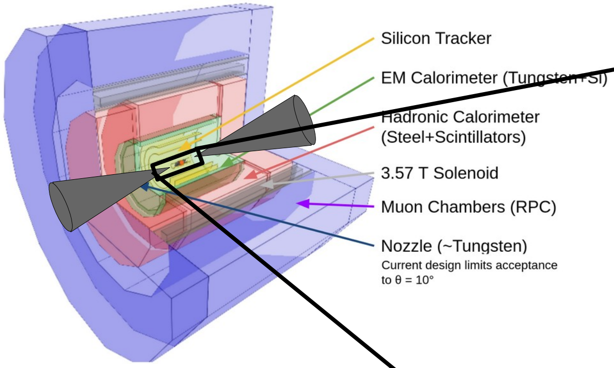
The MUSIC detector

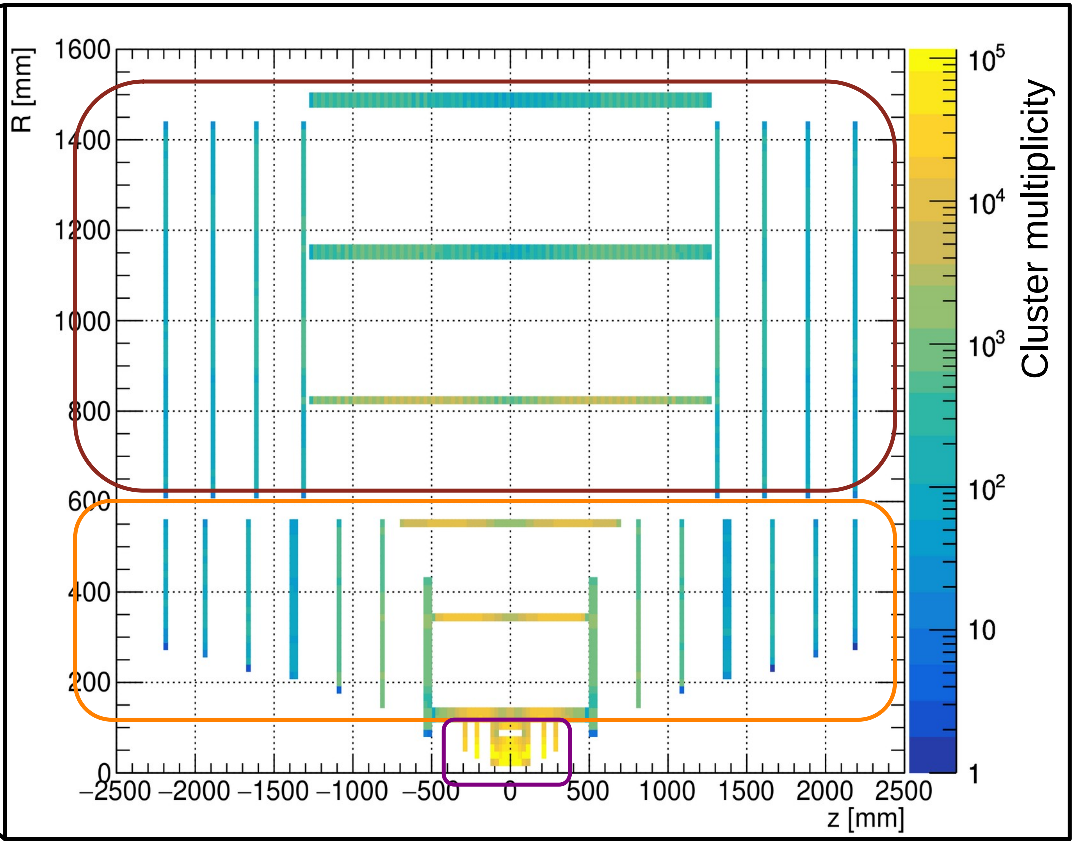
MUSIC: Muon Smasher for Interesting Collisions
Detector concept at √s = 3 TeV (frozen).

- Modified CLIC-detector, with BIB suppression from shielding tungsten nozzles and removing the forward luminosity detectors.
- Also, adapted tracker detector and magnetic field to cope with beam-induced background.



Tracker design





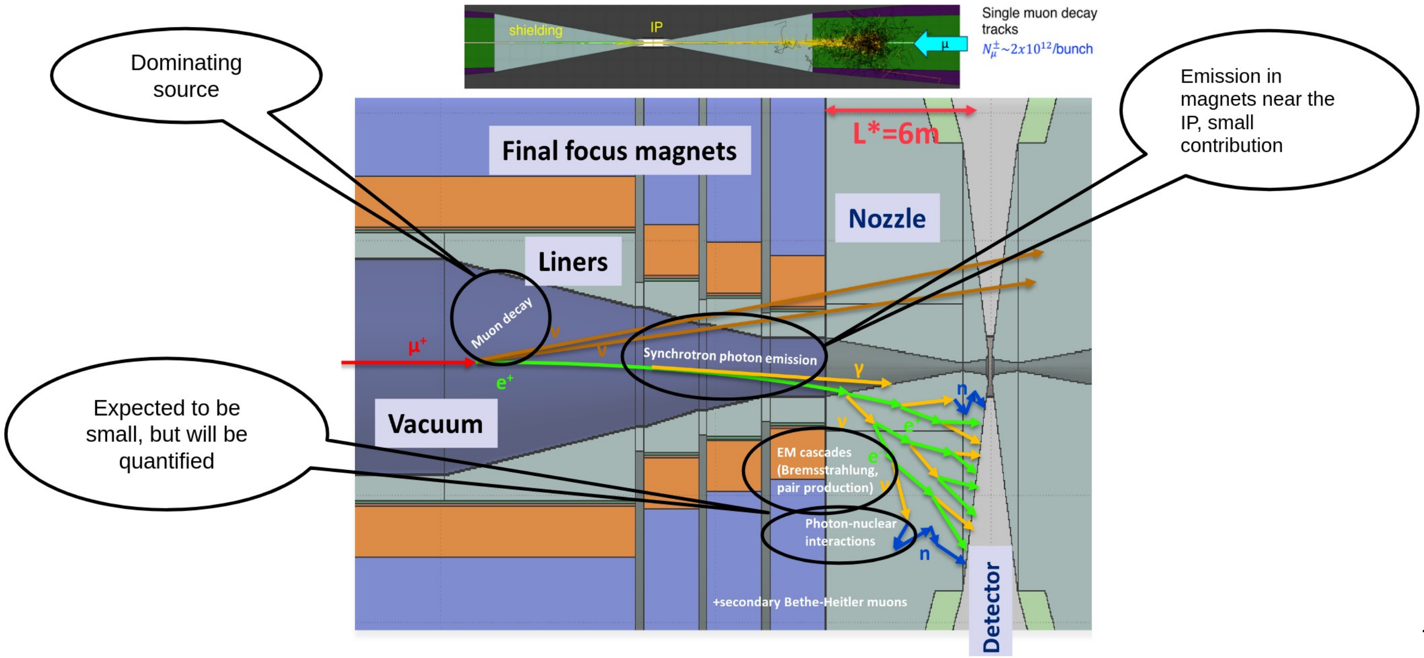
- Vertex detector: Double-sensor layers (4 barrel and 4+4 endcap disks)
- Inner tracker: 3 barrel and 7+7 endcap disks
- Outer tracker: 3 barrel and 4+4 endcap disks

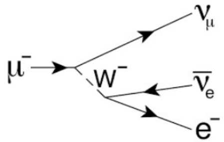
	Vertex Detector	Inner Tracker	Outer Tracker
Cell type	pixels	macropixels	microstrips
Cell Size	25 µm × 25 µm	50 µm × 1 mm	50 µm × 10 mm
Sensor Thickness	50 µm	100 µm	100 µm
Time Resolution	30 ps	60 ps	60 ps
Spatial Resolution	5 µm × 5 µm	7 µm × 90 µm	7 µm × 90 µm

Single µ-gun events with BIB.

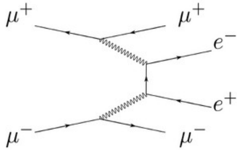
Beam-induced backgrounds

In-flight decays of the muon beams and their **interactions with beam line material and the detectors** pollutes the otherwise clean collision environment. The ensemble of all these particles is usually known as “Beam Induced Backgrounds”, or BIB.

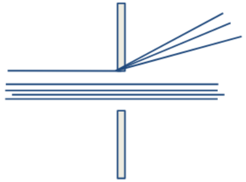




Muon beam decays

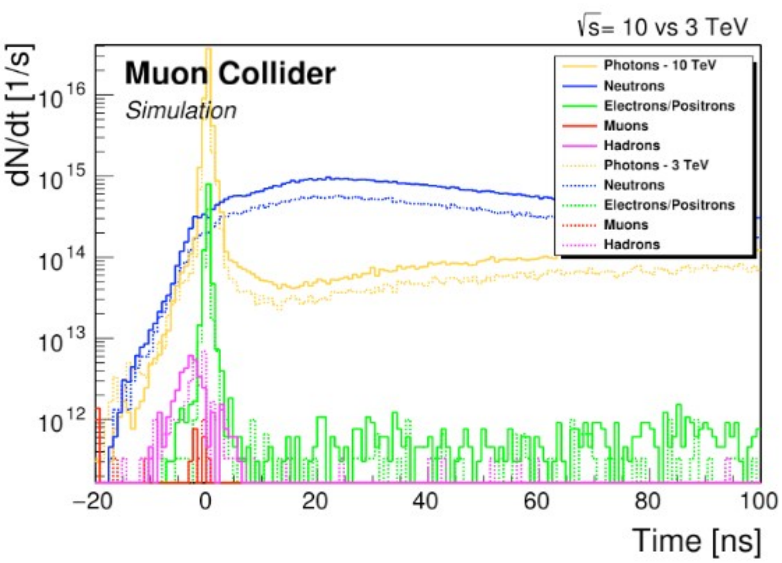


e+e- pair production

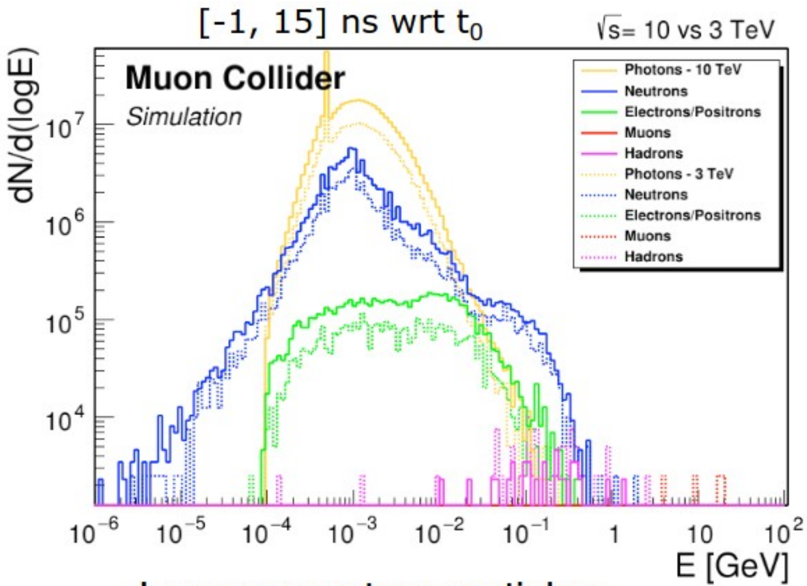


Beam halo loss on collimators

BIB characteristics



Partially out of time vs beam crossing



Low momentum particles

Background particles entering the detector per bunch crossing, with time window cut of [-1,15] ns:

- $O(10^8)$ γ (>100 KeV)
- $O(10^7)$ n (>10^{-5} eV)
- $O(10^6)$ e+, e- (>100 KeV)

Tracker realistic digitization

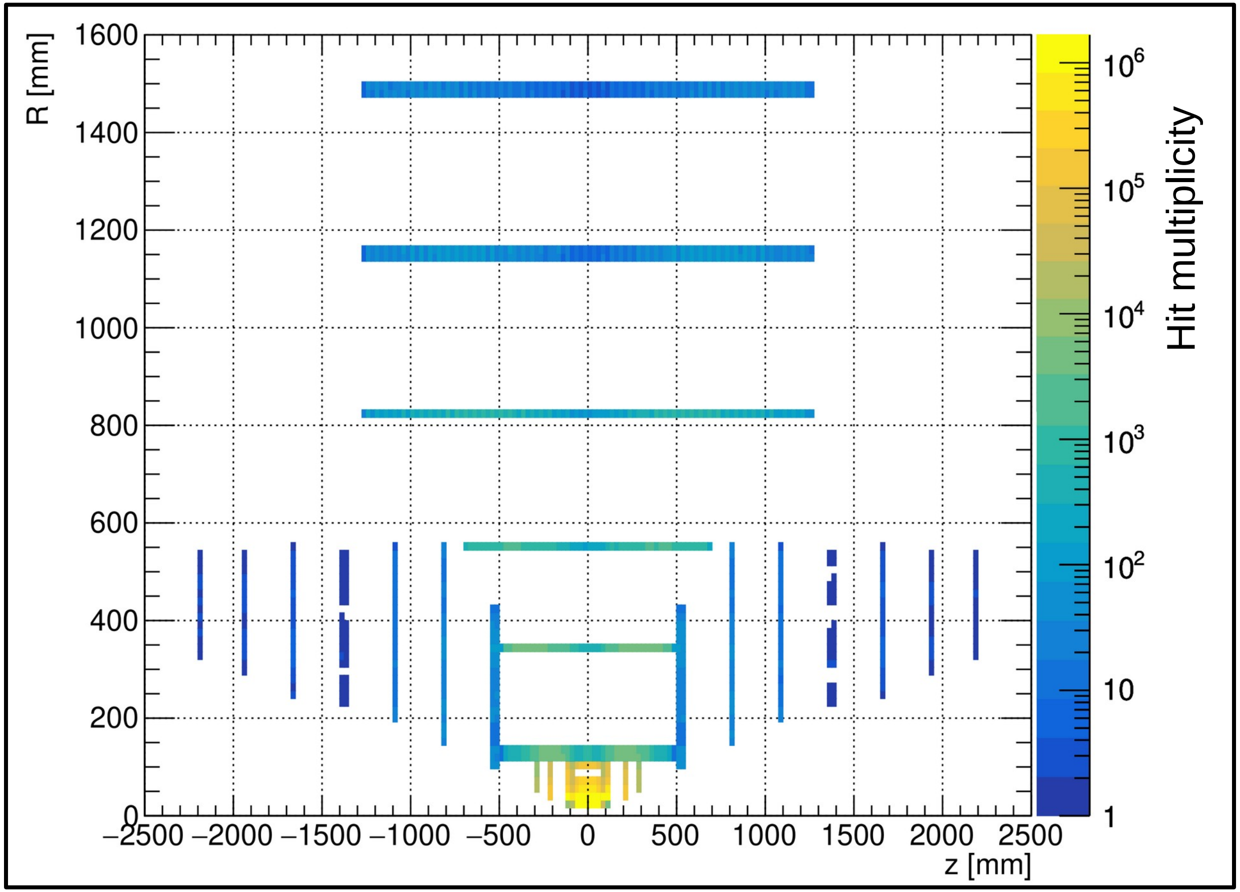
- **Simplified digitization** produces reconstructed hits from **smearing of the simulated truth-level position**, based on gaussian template of the position resolution.
  No information about pixel hits in a cluster.

- For **realistic digitization**, actual particle-material interaction is emulated i.e. **ionization losses with real sensor thickness, creating electron-hole pairs** as well as the **response of the front-end electronics for charge collection and timing information**.
  Position and charge deposition of pixel hits in a cluster available.

Sub-Detector	Typical <E> loss [e^-]	Threshold [e^-]	Threshold variation σ [e^-]	Noise [e^-]	#bits for charge	Max charge (overflow) [e^-]
Vertex	4,000	500	25	80	4	15,000
Inner Tracker	8,000	1,000	25	80	4	60,000
Outer Tracker	8,000	1,000	25	80	4	60,000

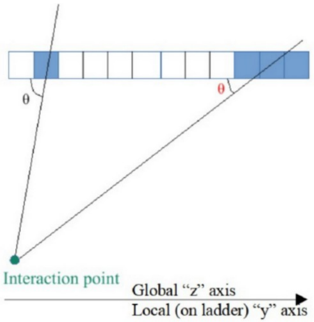
Tracker realistic digitization

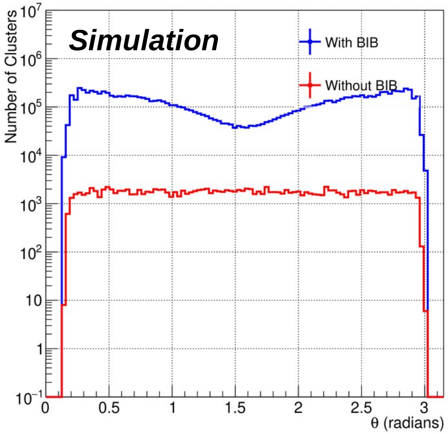
- Order of 10 times more occupancy.
- Realistic digitization for outer tracker endcap not in place yet.

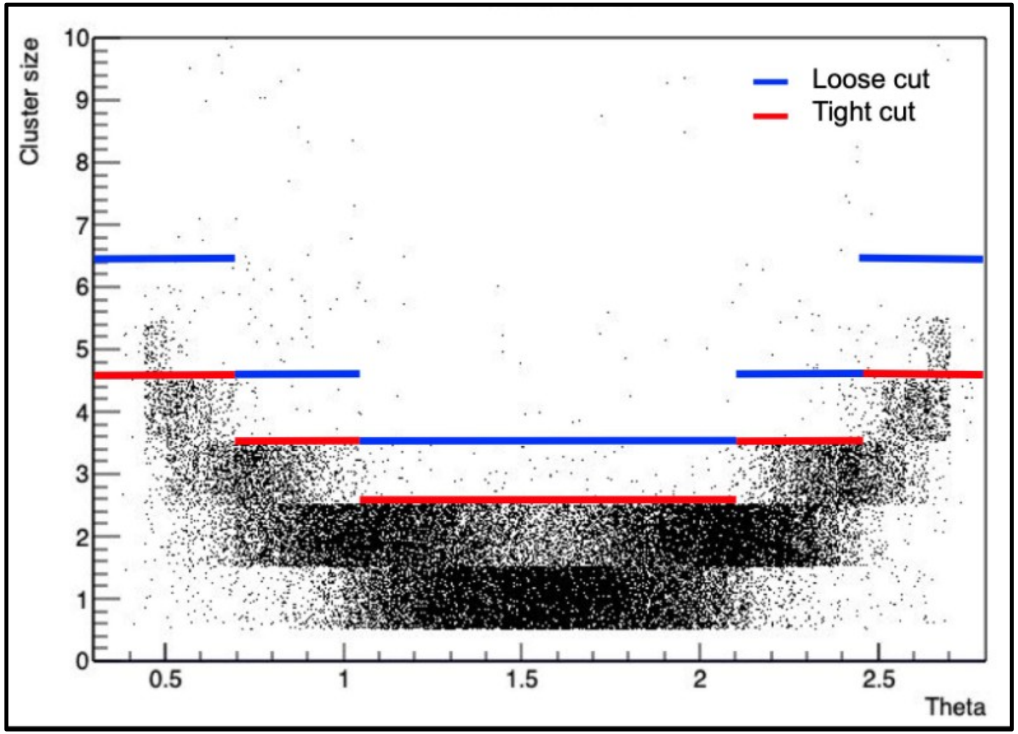


Cluster Shape Analysis

Using correlation between incidence angle and number of pixel hits per cluster, we can reject long clusters which are characteristic of BIB particles from the muon collision events.



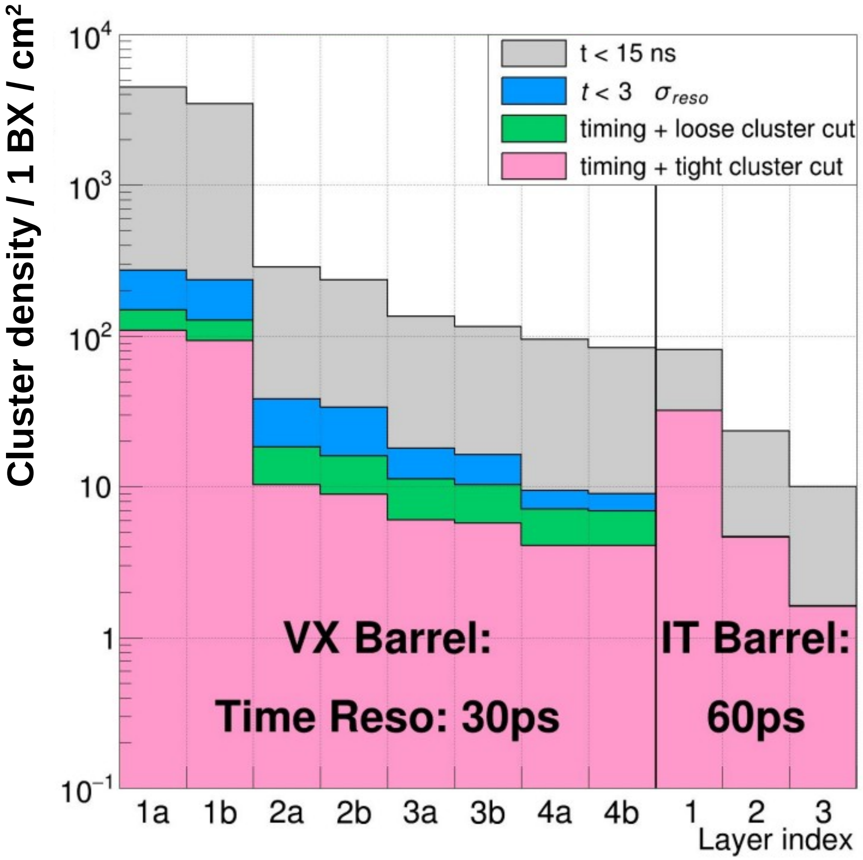




- More clusters at small and high theta with BIB events.
- Higher hit multiplicity from clusters at those angles.

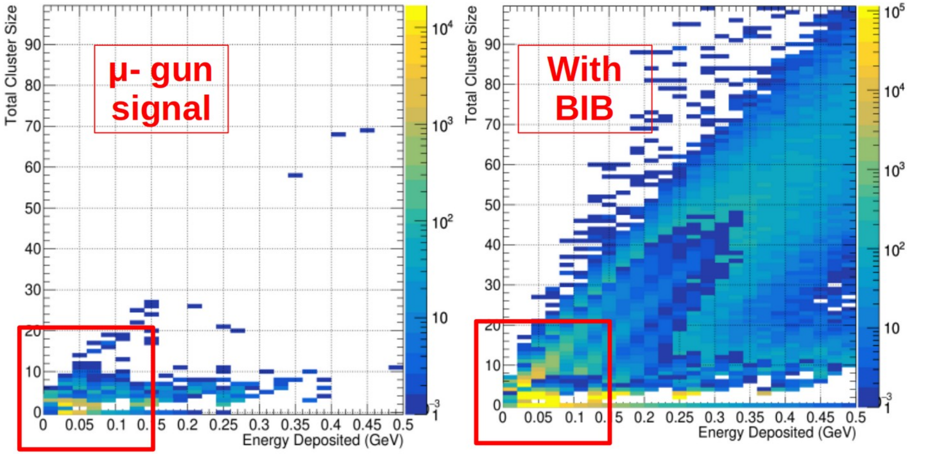
BIB rejection

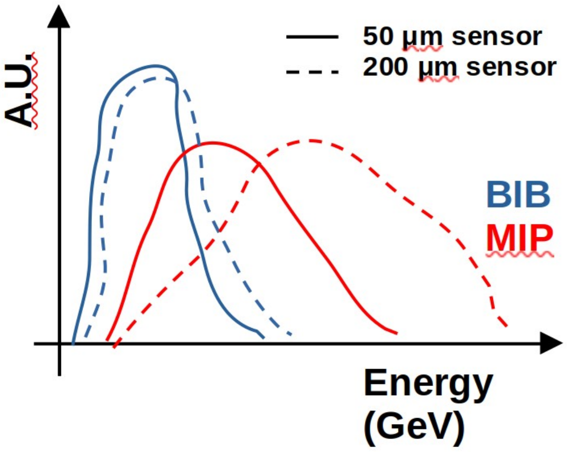
- **Tighter time window selection reduces number of hits by 92% in vertex barrel, but only 74% in inner tracker barrel.**
- The current cluster filter cuts give no additional BIB rejection in the inner tracker – scope for improvement!
- Also, need to extend to outer tracker barrel layers and all endcap layers.



Ongoing work & future studies

- Currently, not much separation exists with thin sensors between muon signal and with BIB collision events.
- However, BIB produces several particles at higher incidence angles (longer clusters) which have lower energies.





1) Plan to increase sensor thickness to study the effect on the size of clusters from muon (MIP) signal vs BIB.

Ongoing work & future studies

2) Improve the cluster shape filters to reject BIB even more efficiently, including for the inner tracker and outer tracker layers.

3) Implement the realistic digitization for tracker endcap layers.

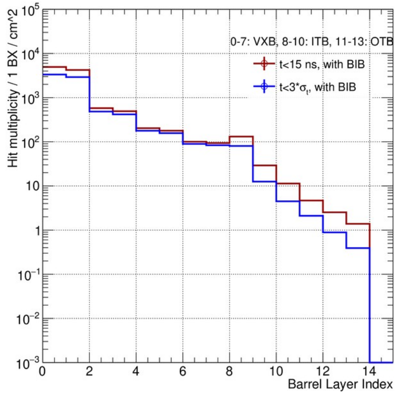
4) Optimize the time window selection for out-of-time BIB rejection.

5) **Assess DAQ bandwidth requirements from hit multiplicity after cluster filters towards a realistic front-end (FE) design.**

For example, VXB Layer 1a, with tight time window cut:

- **270 clusters / BX / cm^2**
- **4000 hits / BX / cm^2**

  (based on current state-of-the-art pixel readout chip architecture)



6) Finally, study the impact of increasing FE threshold on the pixel hit multiplicity and cluster energy, with the optimum sensor thickness and time window.