Charged-Particles Reconstruction at Muon Collider

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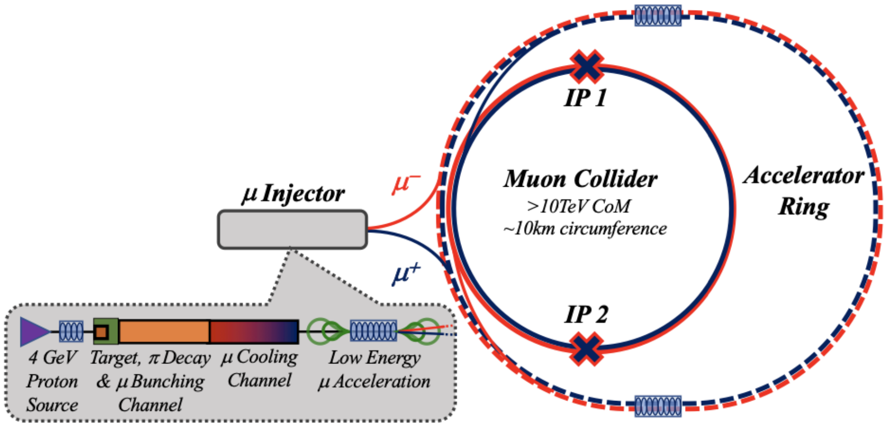
PROPOSED MUON COLLIDER

Colliders able to reach a fundamental center-of-mass energy about a factor of 10 higher than currently possible and are high priority for the field.

This can be achieved by building a muon collider.

Muons are unstable and decay into an electron or positron accompanied by a neutrino and an antineutrino.

https://muoncollider.web.cern.ch/

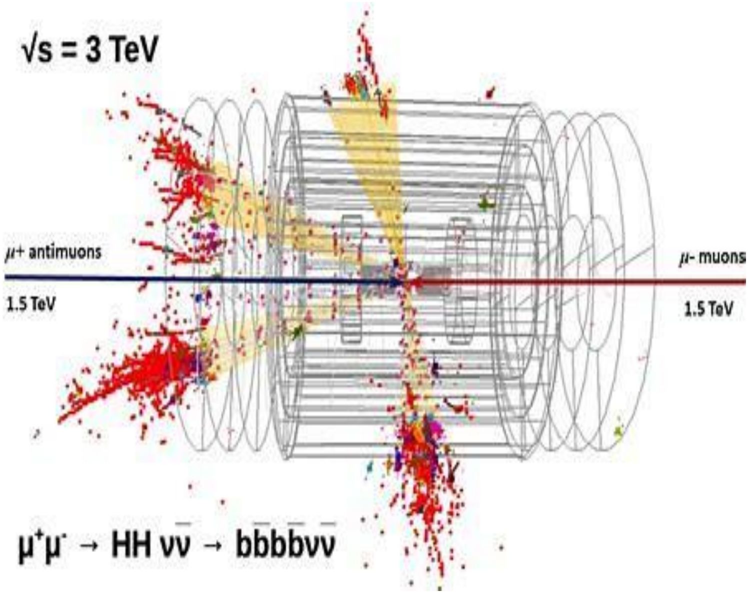


CHALLENGES

After muons decay, they tend to scatter in all directions. Some enter the detector and cause noise by colliding with the tracking detector.

Every square centimetre of the active area of the tracker detector is hit hundreds of times.

A muon collider detector (MCD) faces the challenge of separating the products of muon collisions from an intense beam-induced background (BIB) comprising of secondary and tertiary interactions of muon decay products.



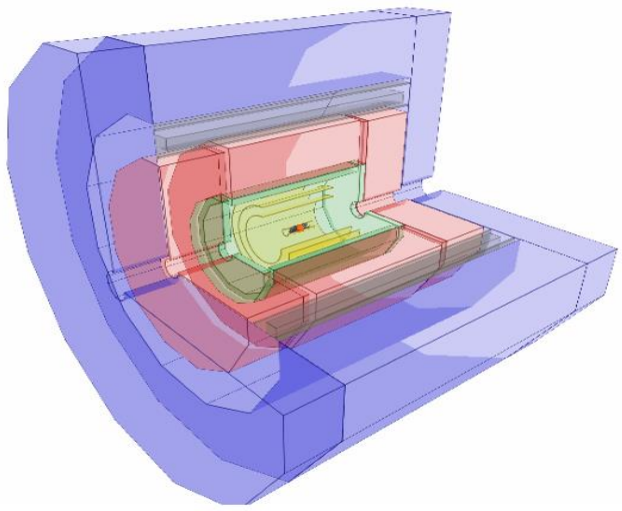
https://cds.cern.ch/record/2725875/plots

DETECTOR GEOMETRY

This is a picture of the muon-collider sub-detector system. The innermost region shown in yellow represents the tracking detectors.

The tracking detector consists of a full-silicon detector divided into 3 sub-detectors: the Vertex Detector, the Inner Tracker and the Outer Tracker.

The detector has shielding nozzles made of tungsten with covered with a borated polyethylene coating in the forward regions along the beam axis. They help mitigate BIB by trapping particles generated by muon decay.



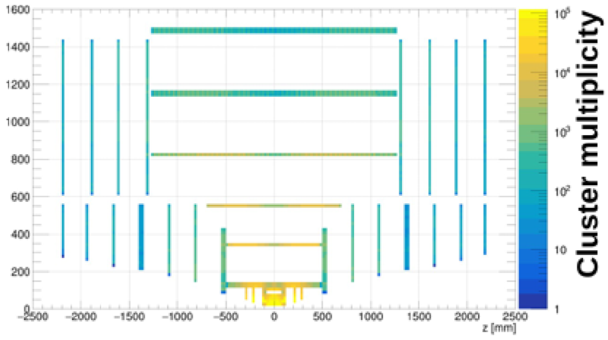
https://arxiv.org/abs/2407.12450

	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

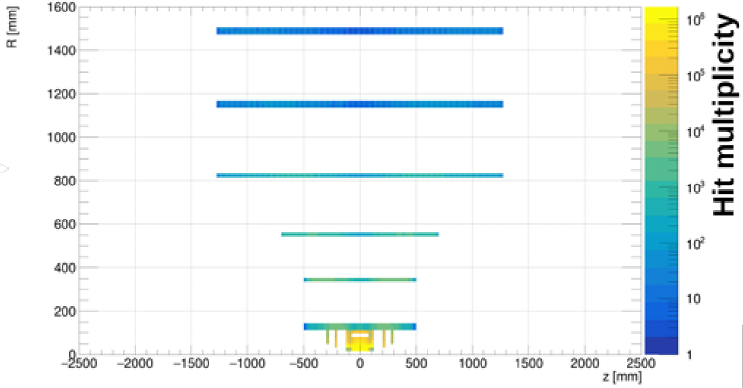
REALISTIC DIGITISATION IN TRACKING DETECTORS

Simplified digitisation is used for initial studies and feasibility assessments. Hits are generated by smearing the simulated truth-level position based on a Gaussian template of the position resolution.

Realistic digitisation is used for detailed design and performance optimization. It incorporates comprehensive models that simulate the full complexity of the collider environment, including beam-induced backgrounds (BIB), detector responses, and material interactions. Realistic digitisation for silicon detectors includes detailed modeling of the sensor thickness and the response of front end electronics.



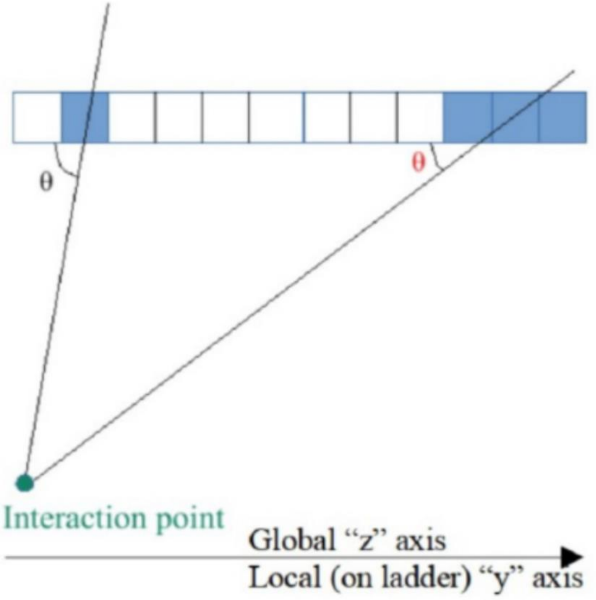
With realistic digitization, can look at actual pixel hits!



https://indico.fnal.gov/event/64493/contributions/296412/attachments/180928/248017/USMCC_poster.pdf - Angira Rastogi

CLUSTER SHAPE ANALYSIS

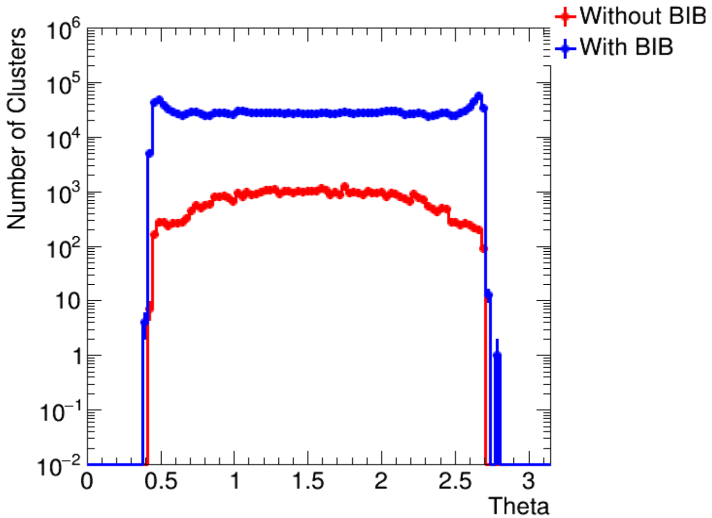
- In a muon collider detector, clusters are formed when particles interact with the detector material, producing a series of hits that are grouped together. These hits can be from signal particles (like muons) or background particles (like BIB particles).
- The characteristics of these clusters, such as their length and hit multiplicity, can help distinguish between different types of particles and interactions. BIB produces longer clusters because there are many particles with lower energies.
- The correlation between the incidence angle and the number of pixel hits per cluster is used to differentiate between signal and BIB clusters. This helps in rejecting long clusters that are typical of BIB particles.

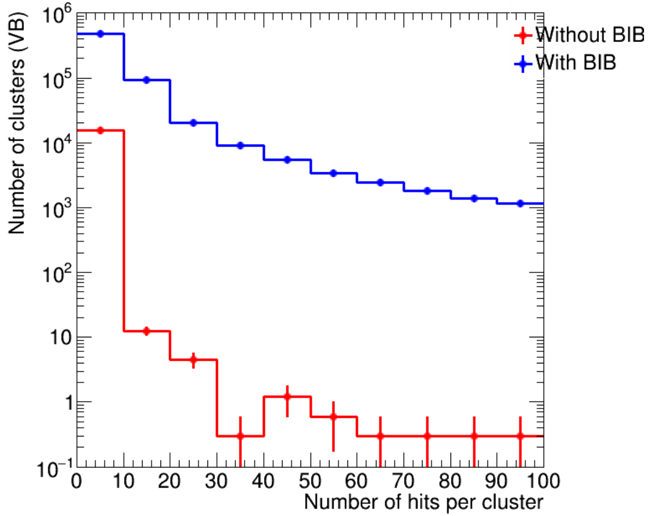


https://indico.fnal.gov/event/64493/contributions/296412/attachments/180928/248017/USMCC_poster.pdf- Angira Rastogi

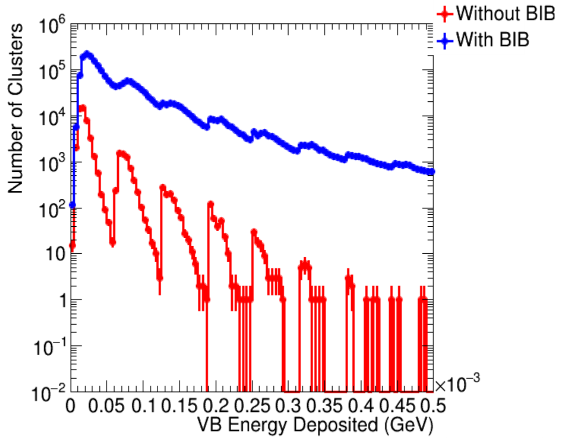
NUMBER OF HITS AND ANGLE OF INCIDENCE

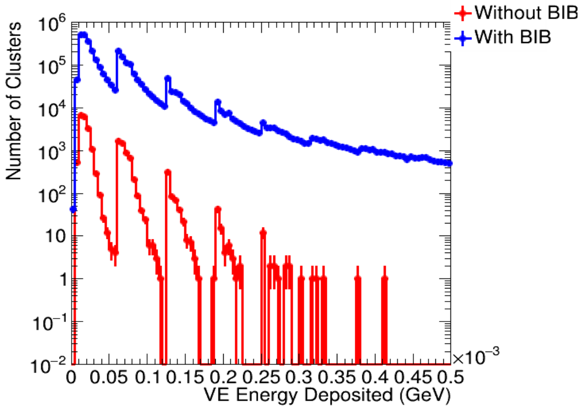
- For each cluster, we found that BIB particles had more hits compared to the muon gun signal.
- BIB particles form more clusters at very small and very large angles of incidence compared to particles from the muon gun signal.
- This is demonstrated by the following plots:





CLUSTER SHAPE ANALYSIS





The purpose of the cluster shape analysis is to reduce the readout rate from the tracker detector which in turn also improves the timing. CPU consumption is reducedand performance of the track reconstruction algorithm is enhanced (high effeciency and a lower false positive rate).

These plots show that BIB particles produces a lot more clusters than the signal for the same range of energy deposited.

The red curve without BIB shows discrete peaks that decrease as the energy level increases.

The blue curve with BIB is a smoother curve with more consistent energy levels across energy ranges.

CONCLUSION AND FUTURE STUDIES

Currently, there isn't much separation between muon gun signals and BIB collision events with thin sensors.

There are plans to increase sensor thickness to study the effect on size of clusters when BIB is present and absent.

Improve cluster shape filters and make them better at BIB rejection.

Optimise the time window selection for out-of-time BIB rejection.

Study the impact of increasing front end threshold on the pixel hit multiplicity and cluster energy, with the optimum sensor thickness and time window.

REFERENCES

- https://indico.cern.ch/event/1422393/contributions/6090599/attachments/2917632/5120338/MuCol_ECR_28Aug2024.pdf
- https://arxiv.org/pdf/2303.08533
- https://indico.fnal.gov/event/64493/contributions/296412/attachments/180928/248017/USMCC_poster.pdf

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