Detector Performance Studies at a Muon Collider

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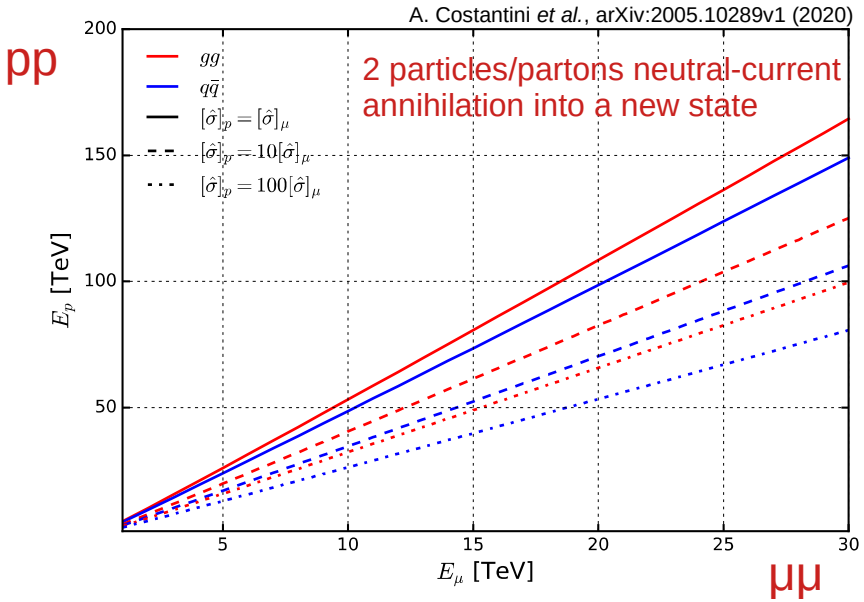
Physics potential of a muon collider

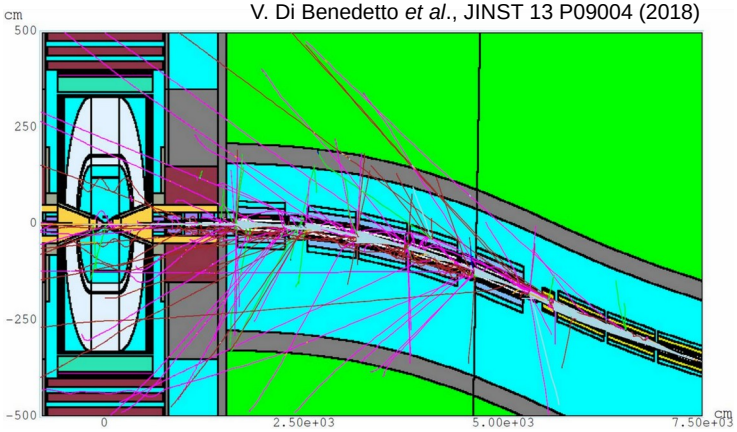
- A muon collider represents a unique machine, that can provide leptonic collisions in the multi-TeV energy regime.
- Differently from composite-particles collisions, in muon collisions all the center-of-mass energy is available for the short-distance processes, opening the way to a tremendous physical potential for:
  - direct detection of new states up to the collision energy;
  - measurement of the higher order terms of the Higgs potential at a few percent level;
  - precision measurements of standard model processes.



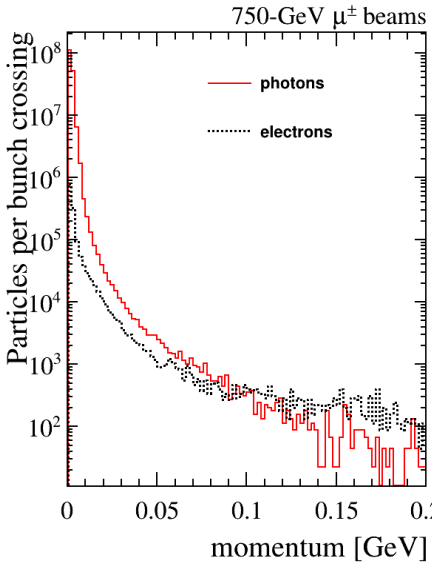
A. Costantini *et al.*, "Vector boson fusion at multi-TeV muon colliders", arXiv:2005.10289v1 (2020)

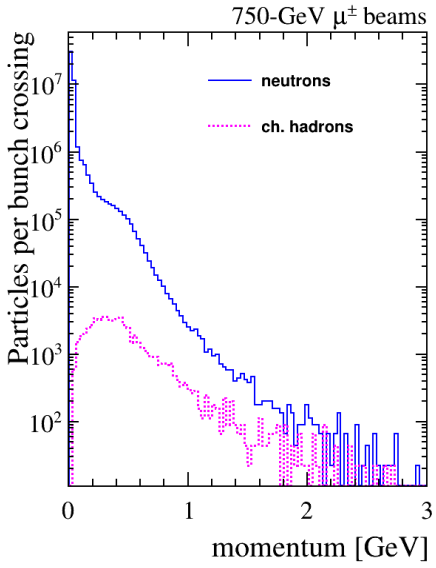
M. Chiesa *et al.*, "Measuring the quartic Higgs self-coupling at a multi-TeV muon collider", arXiv:2003.13628v1 (2020)

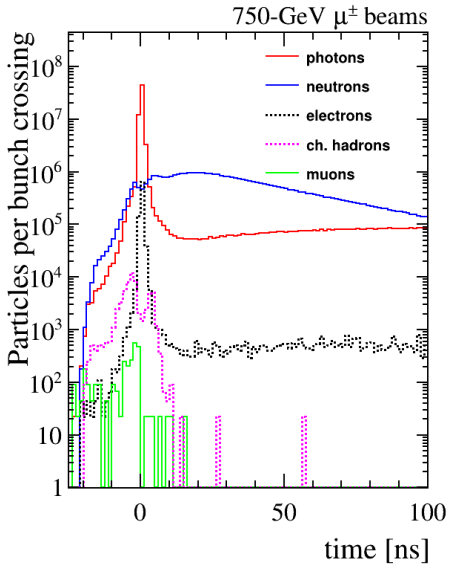
Beam-induced background



- The interaction of the beam muons decay products with the machine elements causes a continuous flux of secondary and tertiary particles (mainly γ, n, $e^{\pm}$, $h^{\pm}$) that eventually 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.







- BIB poses unprecedented challenges to every aspect of an HEP experiment:
  - radiation hazard from ν's;
  - protection of the machine elements from beam radiation;
  - detector operation and response at very high background levels.

More details from F. Collamati, "A flexible tool for Beam Induced Background Simulations at a Muon Collider", Accelerator: Physics, Performance, and R&D for Future Facilities.

BIB must be suppressed

- 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 through cutting-edge technologies and a dedicated design of:
  - the machine-detector interface (MDI);
  - the detector: optimized geometry, high granularity, timing information at every level;
  - new algorithms based on artificial-intelligence and machine-learning for pattern recognition and reconstruction of physical objects.
- In the following, the findings of a first preliminary study will be presented of the beam-induced background effects on the detector response in the case of a 1.5-TeV collider:
  - the study is based on a detector full simulation + reconstruction tools provided by CLIC's ILCSoft framework;
  - the 1.5-TeV beam-induced background was generated by N. Mokhov (FNAL) with MARS15 for the US Muon Accelerator Program (MAP).

Detector overview

hadronic calorimeter

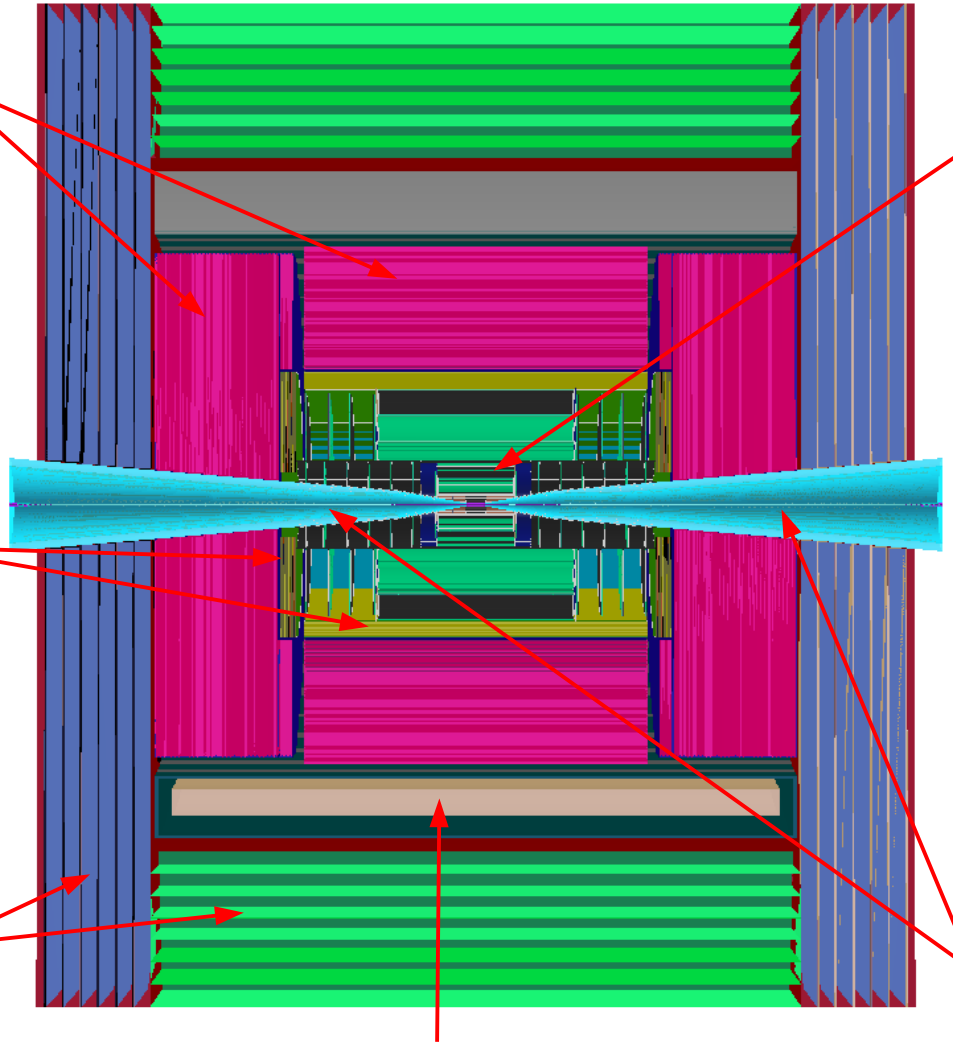
- 60 layers of 19-mm steel absorber + plastic scintillating tiles;
- 30x30 mm^2 cell size;
- 7.5 λ_I.

electromagnetic calorimeter

- 40 layers of 1.9-mm W absorber + silicon pad sensors;
- 5x5 mm^2 cell granularity;
- 22 X_0 + 1 λ_I.

muon detectors

- 7-barrel, 6-endcap RPC layers interleaved in the magnet's iron yoke;
- 30x30 mm^2 cell size.



superconducting solenoid (4T)

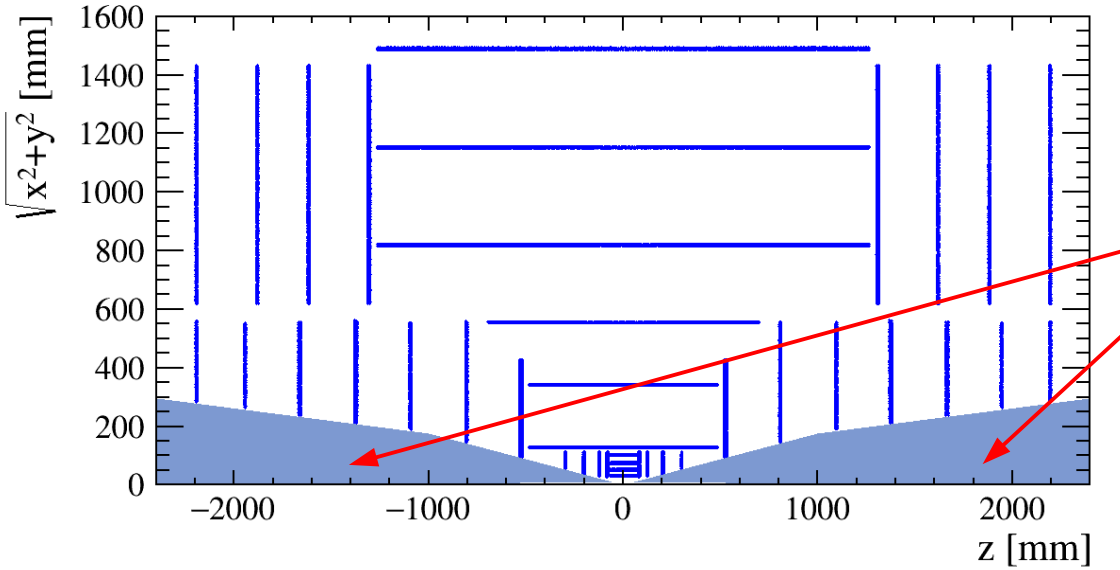
tracking system

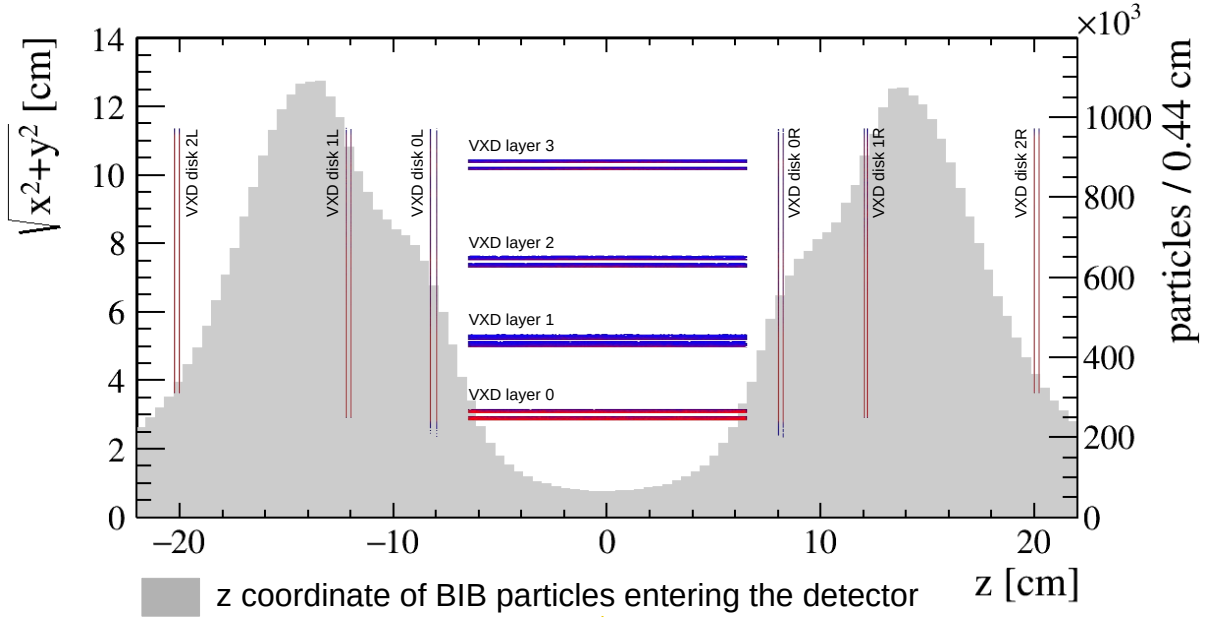
- Vertex Detector:
  - double-sensor layers (4 barrel cylinders and 4+4 endcap disks);
  - 50-μm thick, 25x25 μm^2 pixel Si sensors.
- Inner Tracker:
  - 3 barrel layers and 7+7 endcap disks;
  - 100-μm thick, 50x50 μm^2 pixel Si sensors.
- Outer Tracker:
  - 3 barrel layers and 4+4 endcap disks;
  - 100-μm thick, 50x50 μm^2 pixel Si sensors.

shielding nozzles

- Tungsten cones + borated polyethylene cladding.

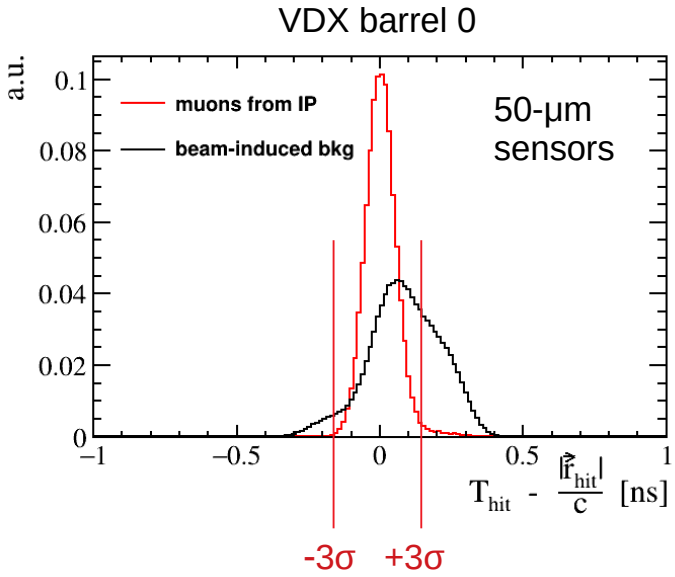
MDI and detector design

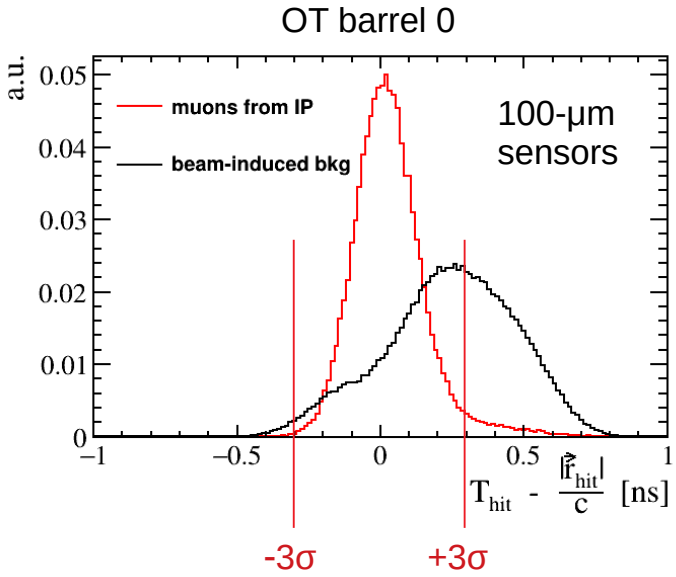




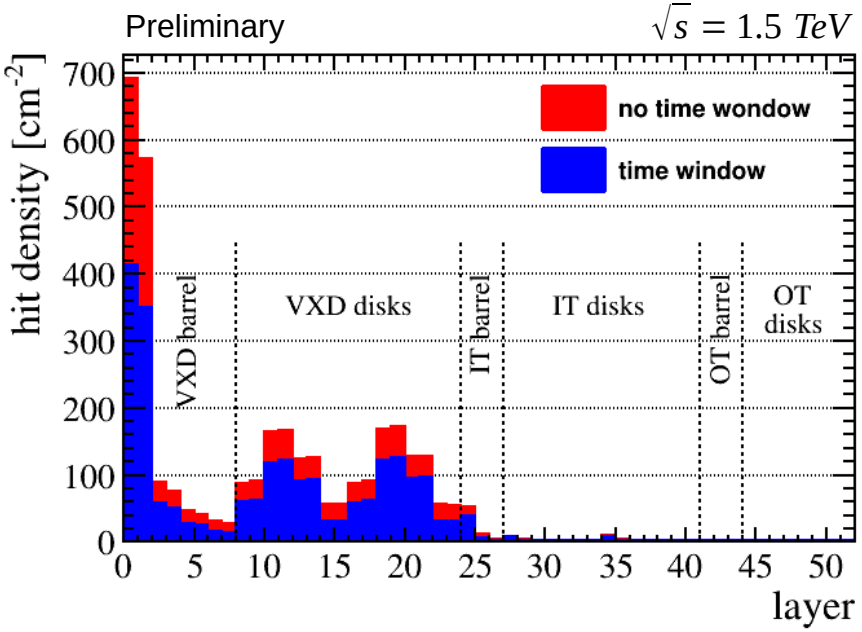
- Two examples of MAP's solutions to cope with the BIB:
  - MDI: two tungsten nozzles with 5-cm polyethylene cladding for neutrons reduce the beam-induced background in the detector by a factor of ~500.
  - VXD geometry: the vertex detector barrel is designed in such a way not to overlap with the BIB hottest spots around the interaction region.

BIB mitigation for the tracker



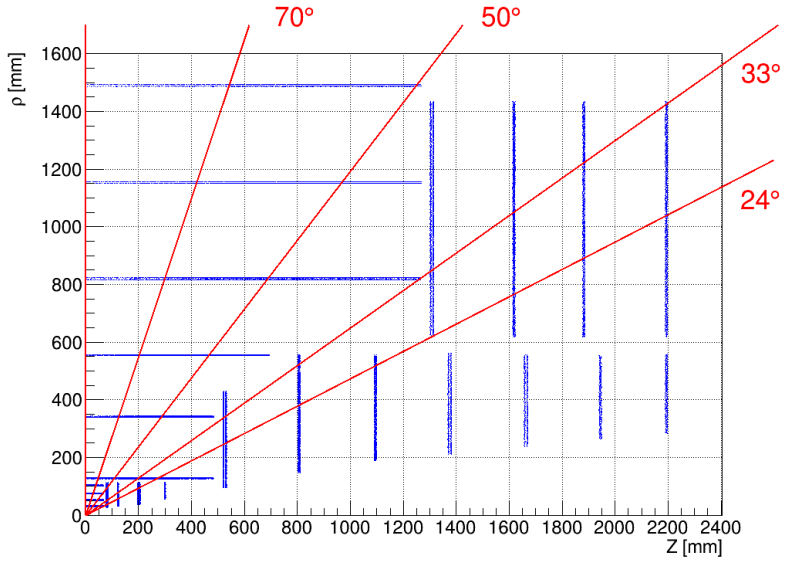


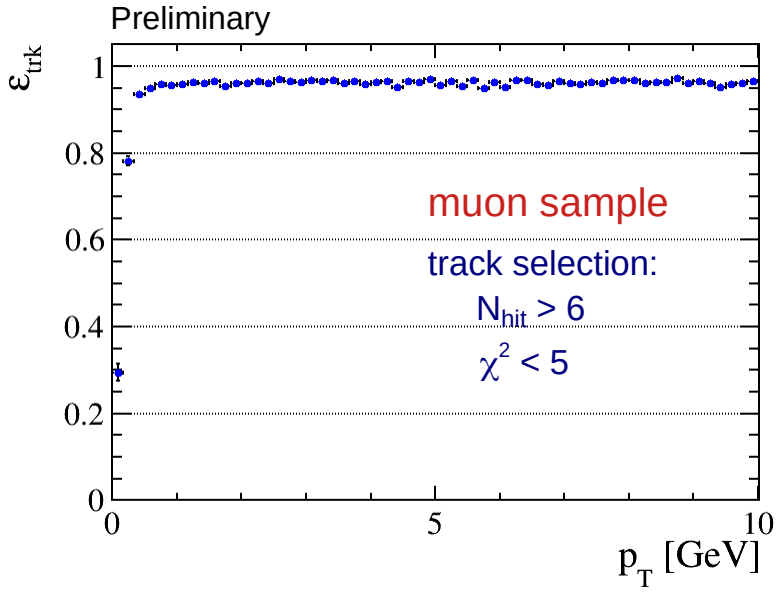
- Handles to reject spurious hits from BIB:
  - applying a time window to readout only hits compatible with particles originating from interaction region;
  - exploiting energy deposited in the tracker sensors (under development);
  - correlating hits on double-layer sensors (under development).

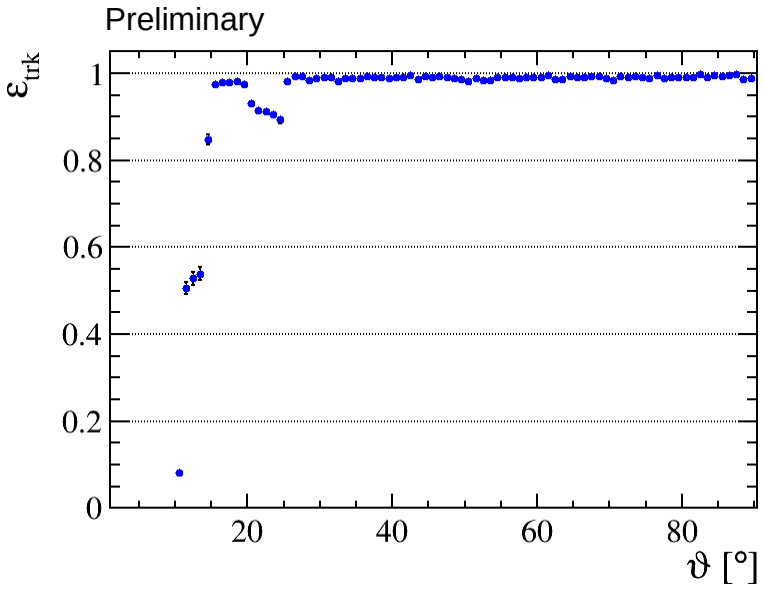


Regional tracking

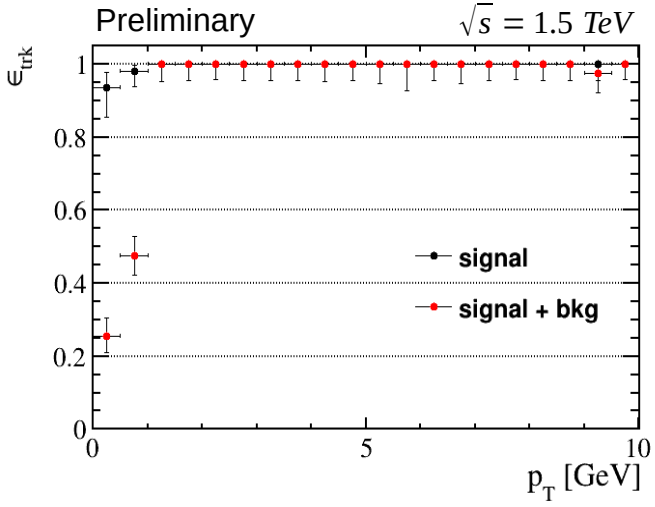
- Because of the huge number of hit combinations to fit tracking of events with BIB currently requires enormous computational resources.
- As a first step, tracking of a complete event performed in ten independent ϑ-regions.
- Pattern recognition and track finding strategy are being revised.

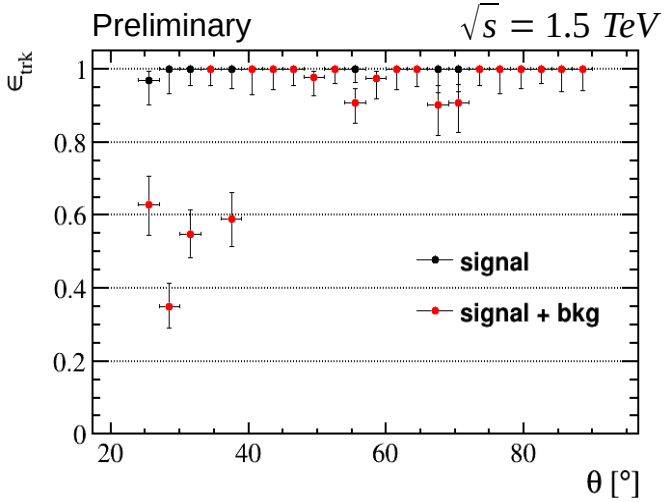


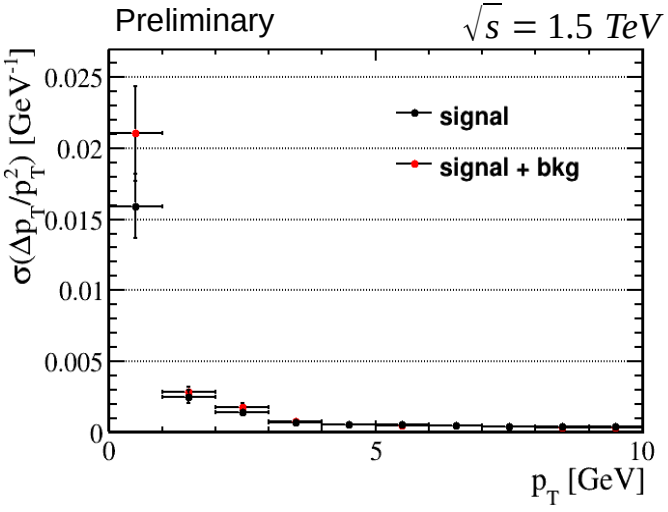


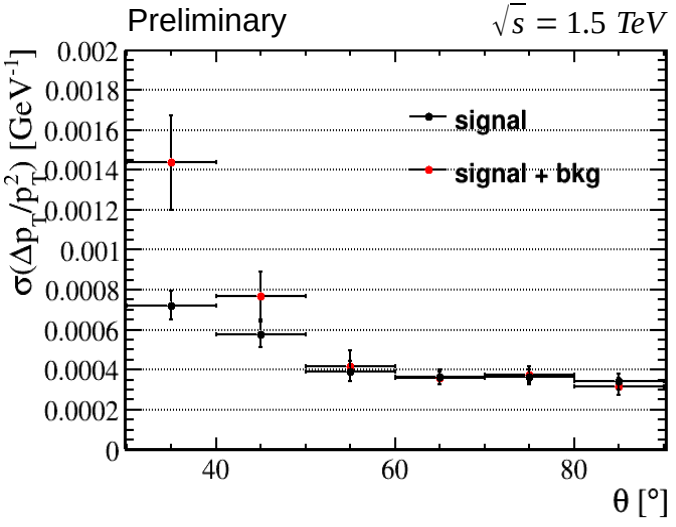


Tracking performance w/ BIB









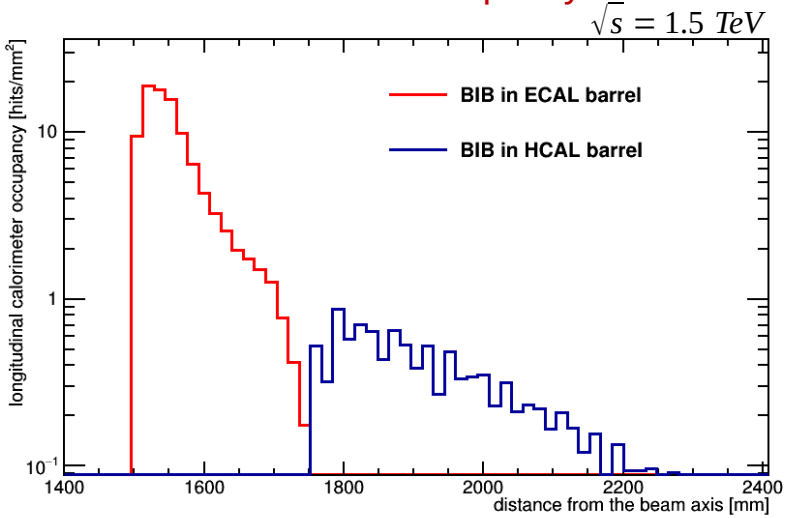
signal = muons from IP

signal + bkg = muons from IP superimposed to the beam-induced bkg

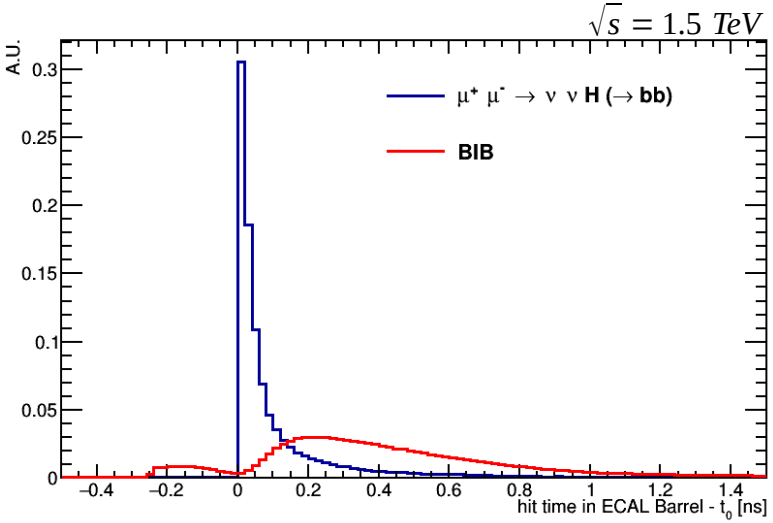
BIB mitigation for the calorimeters

- Also for calorimeters timing represents the most powerful handle to mitigate the BIB effects.
- A very high granularity and a fine longitudinal segmentation allow to exploit the differences in shower shapes between signal and BIB.

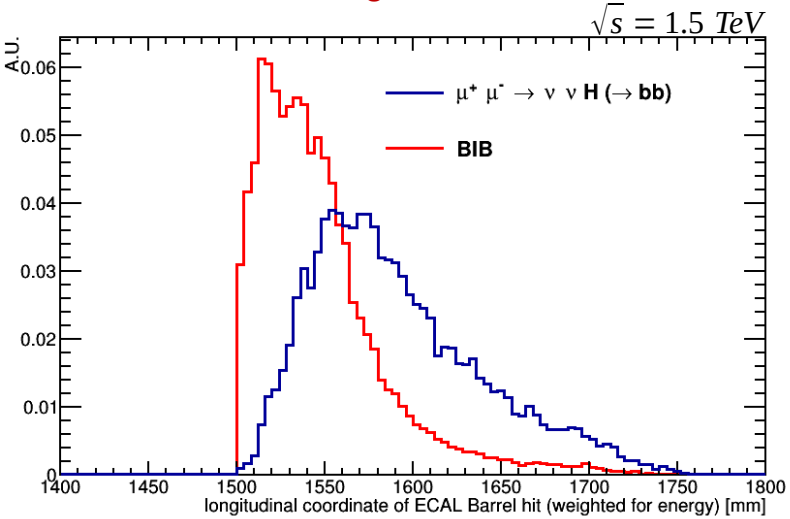
calorimeter occupancy



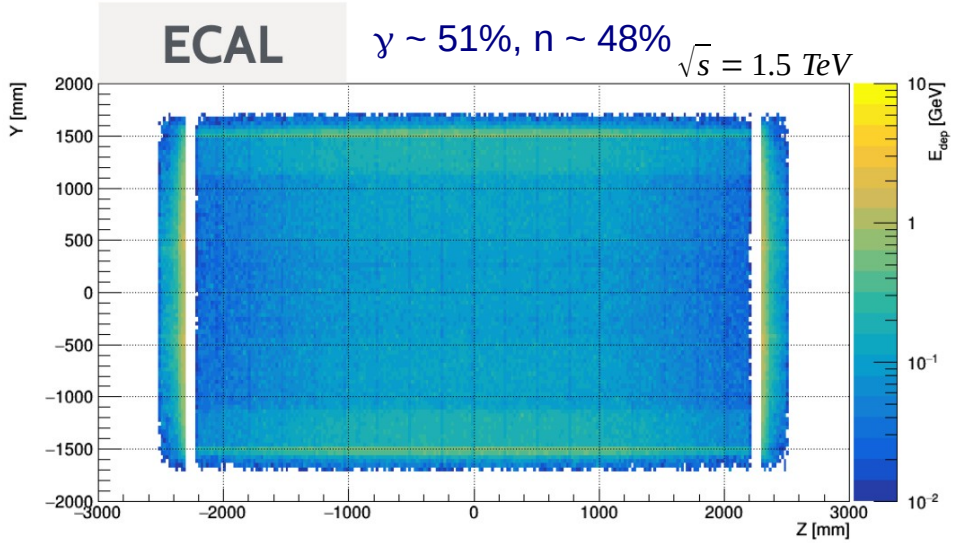
ECAL barrel hit arrival time – t_0

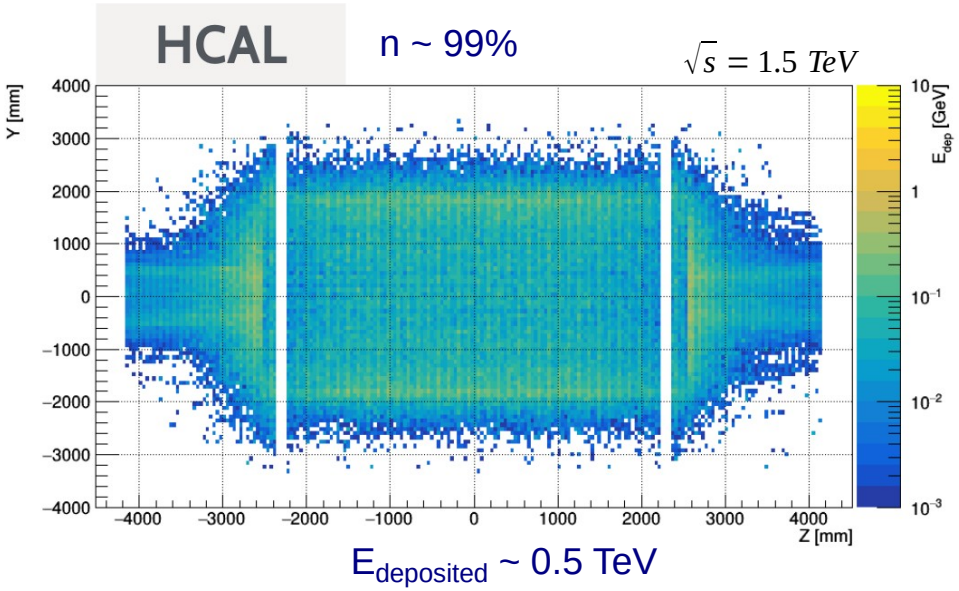


ECAL barrel longitudinal coordinate



Perspective for jets and muons reco





- BIB is ~uniformly distributed in the electromagnetic and hadronic calori-meters
- Ongoing study of a jet reconstruction algorithm based on Particle Flow, which takes into account the BIB.
- Being the outermost detector the muon RPCs should be mildly affected by BIB; an assessment is underway.

Summary

- The Muon Collider would be a unique machine with an extraordinary Physics potential, that poses, however, unprecedented experimental and technological challenges on both the machine and the experiment side.

- On the experiment side, we are confident that a well-thought design and the exploitation of cutting-edge detector technologies and novel reconstruction and analysis techniques (like 5D tracking, Particle Flow algorithms, the highly-parallelized reconstruction algorithms based on GPUs that are currently under development for HL-LHC) will allow to take advantage of such a potential.

- An example may be found in Lorenzo Sestini's contribution "Higgs Physics possibilities at a Muon Collider" in the Higgs Physics session on July 31.