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BIB mitigation at Muon Collider

detector level considerations

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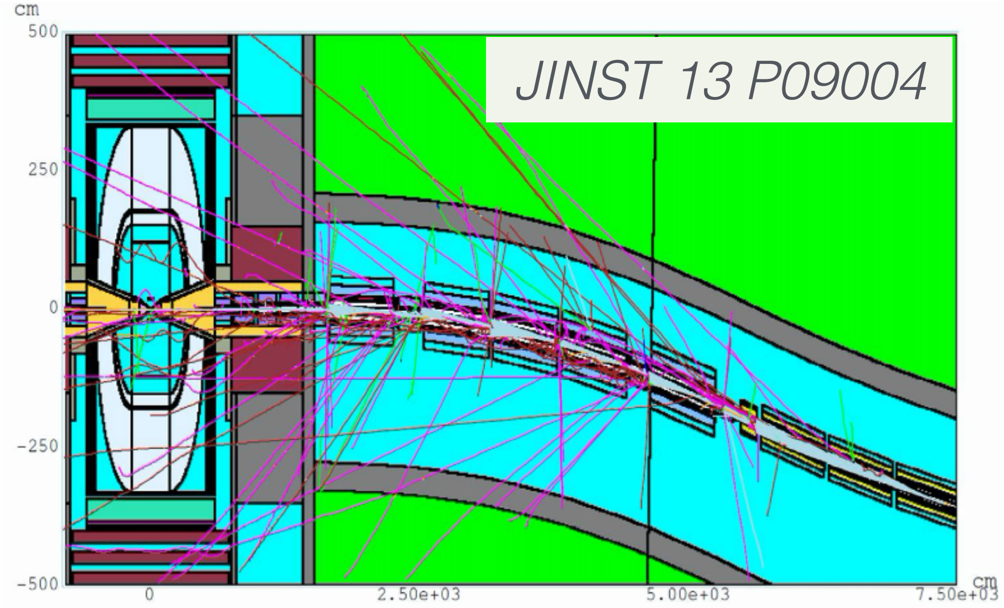
Muon Collider: BIB overview

At a Muon Collider experiment the effect of Beam Induced Background (BIB) strongly depends on the accelerator layout, MDI and detector design

A Muon Collider at √s=1.5 TeV is the best studied configuration to date

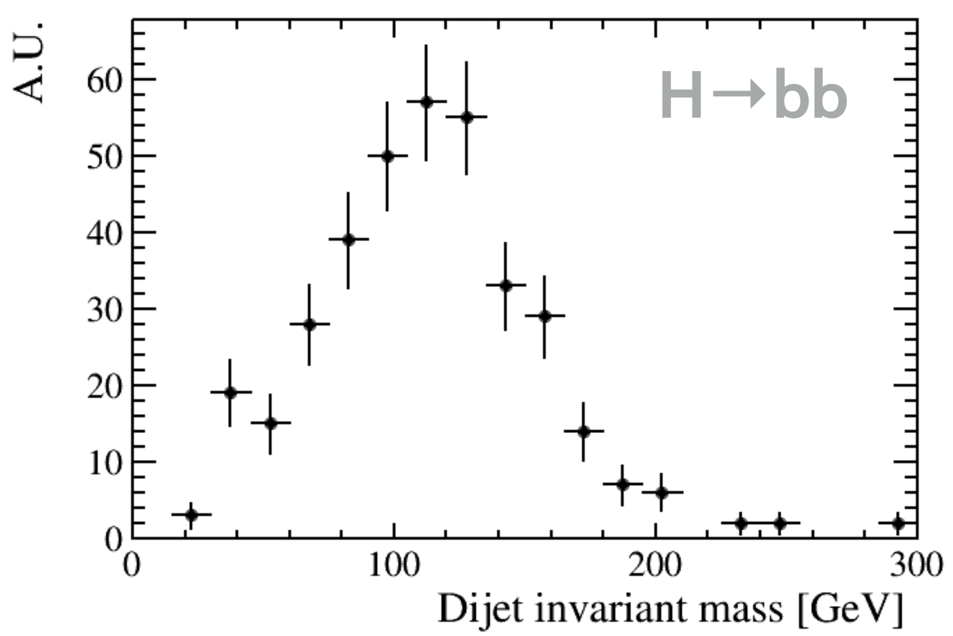
- **optimised MDI** [*by the MAP program*]
  + corresponding BIB simulation
- **full detector simulation** [*ILCSoft framework*]
- **preliminary estimates of detector performance**
  tracking, jet reconstruction, b-tagging



Allowed to estimate the potential relative precision on b-H coupling and compare it to CLIC

	$\sqrt{s}$ [TeV]	$\mathcal{L}_{int}$ [ab^{-1}]	$\frac{\Delta g_{Hbb}}{g_{Hbb}}$ [%]
Muon Collider	1.5	0.5	1.9
	3.0	1.3	1.0
	10	8.0	0.91
CLIC	0.35	0.5	3.0
	1.4	+1.5	1.0
	3.0	+2.0	0.9

JINST 15 P05001



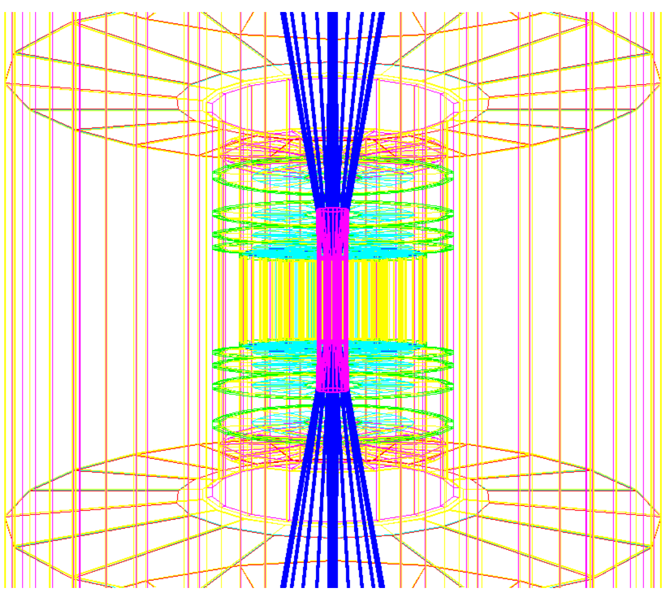
MDI optimisation: energy dependence

Increasing the centre-of-mass energy reduces the muon decay rate

- BIB simulated at $\sqrt{s}$=1.5 TeV can be considered as a worst case scenario for higher beam energies

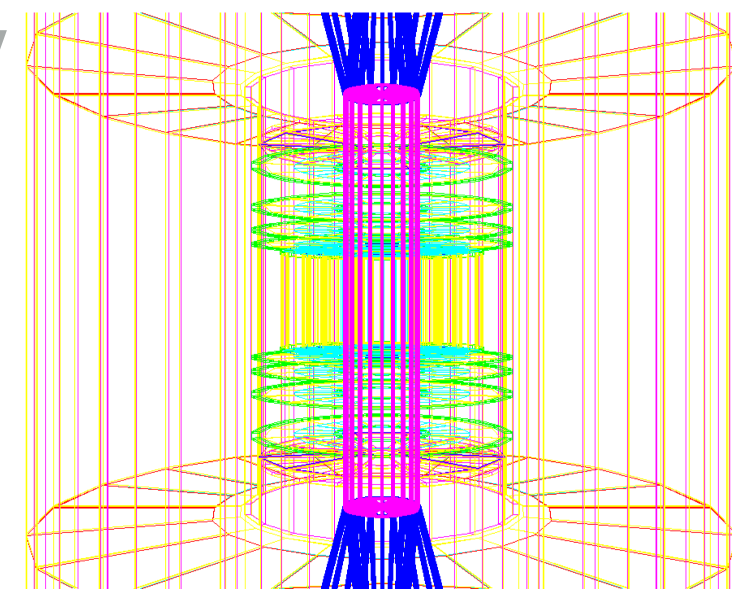
Muon Collider at $\sqrt{s}$=125 GeV (Higgs pole) **is of particular interest for measuring the Higgs-potential shape** thanks to the high μ-H coupling

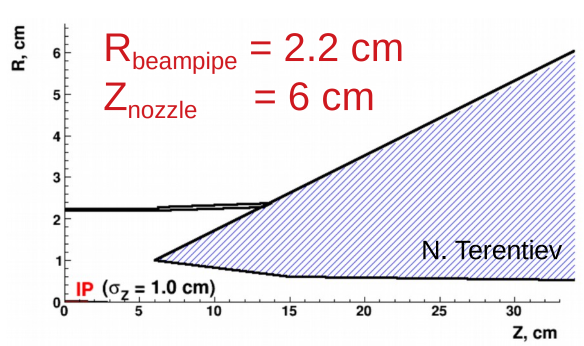
- MDI shape must be optimised to compensate for the increased BIB flux



1.5 TeV

125 GeV

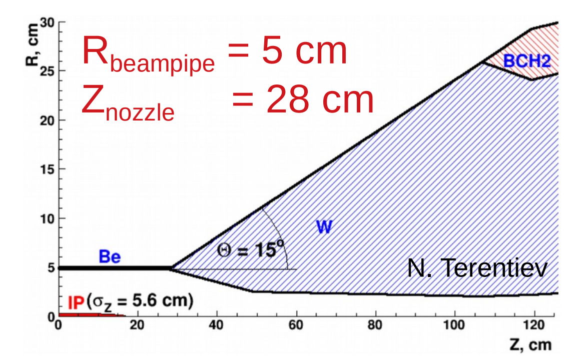




wider beapipe

larger nozzle opening angle

↳ reduced forward acceptance



MDI optimisation: energy dependence

The flux of BIB particles into the detector kept at the comparable level

	√s = 1.5 TeV	√s = 125 GeV
photons	1.8 x 10^8	2.8 x 10^8
neutrons	4.1 x 10^7	5.2 x 10^7
e±	1.0 x 10^6	2.0 x 10^6
ch. hadrons	4.8 x 10^4	1.0 x 10^4

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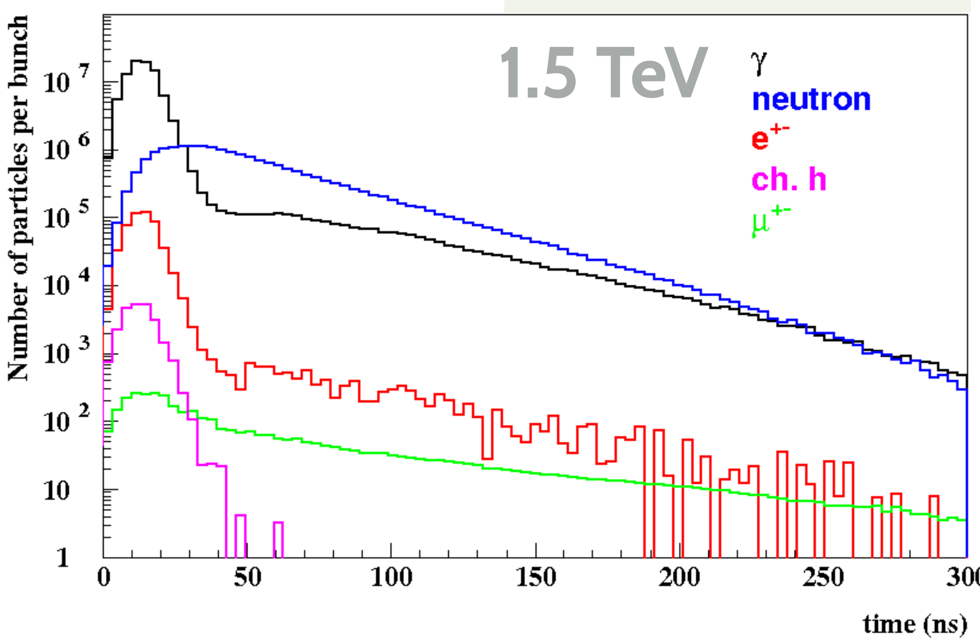

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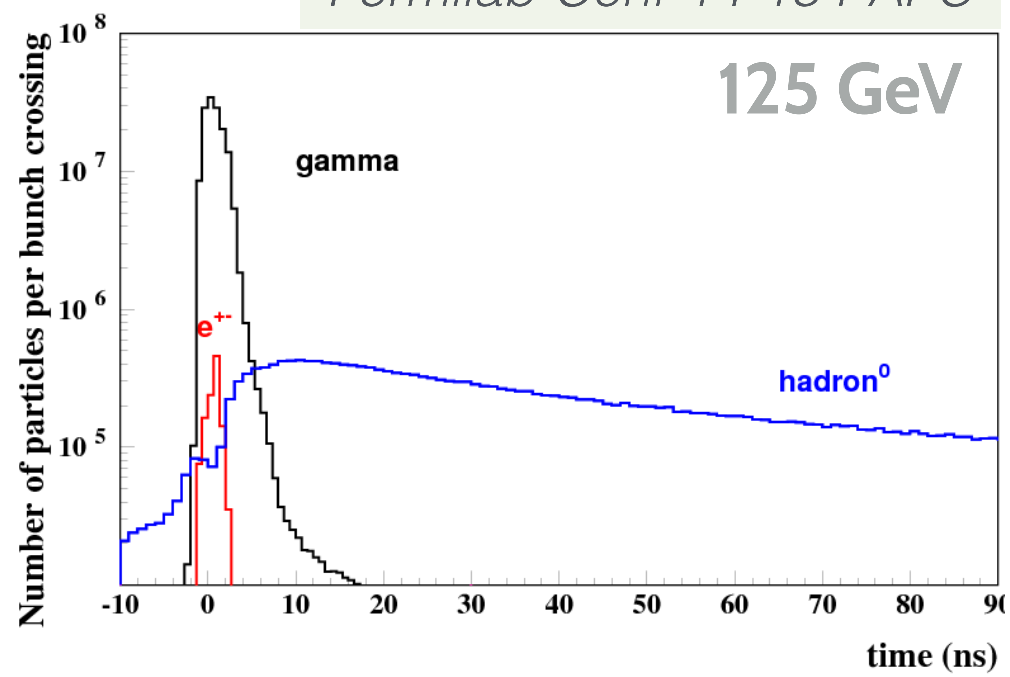
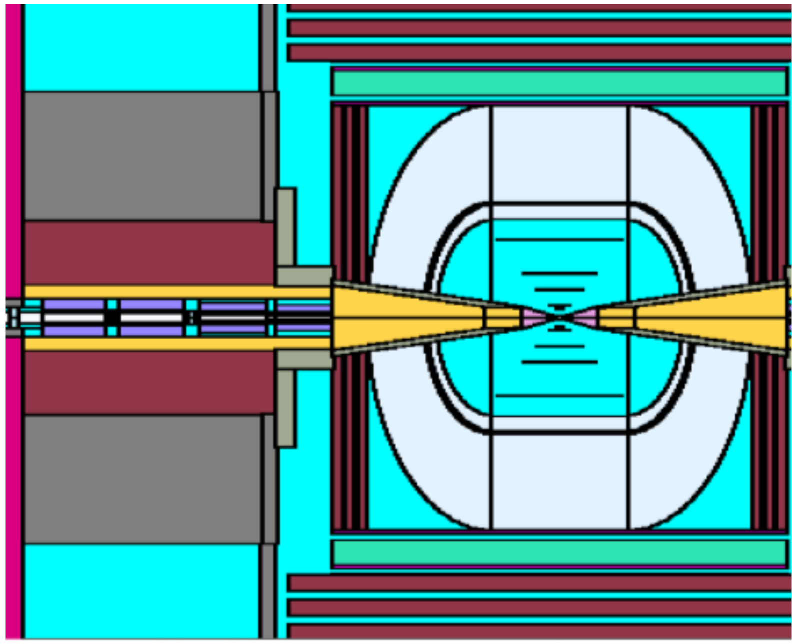


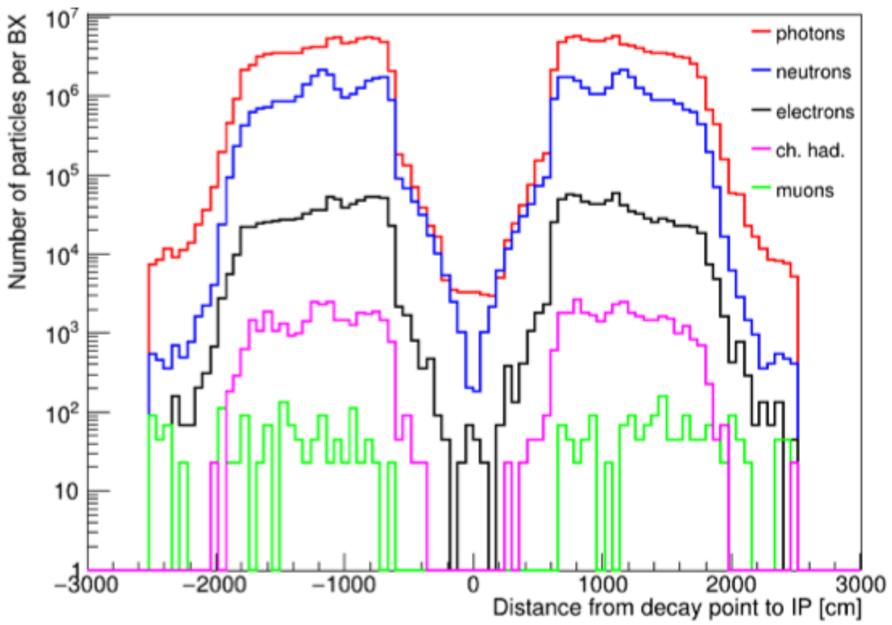
Spread of the BIB arrival time is crucial for further suppression at the detector level

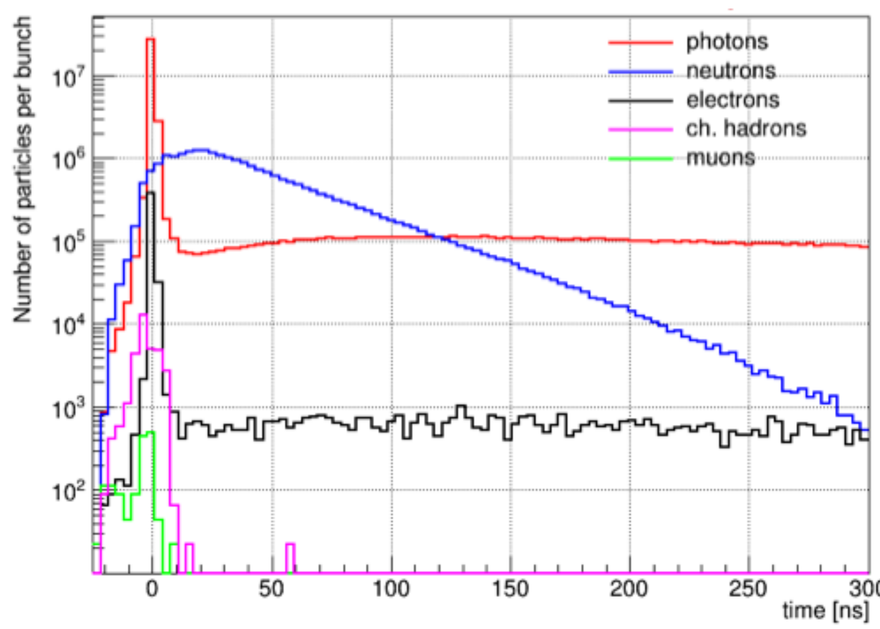
BIB composition: 1.5 TeV

Taking the √s=1.5 TeV case as a baseline to understand the main challenges

- list of particles arriving to the detector region in 1 bunch crossing simulated by MAP for ±25m of lattice from the IP

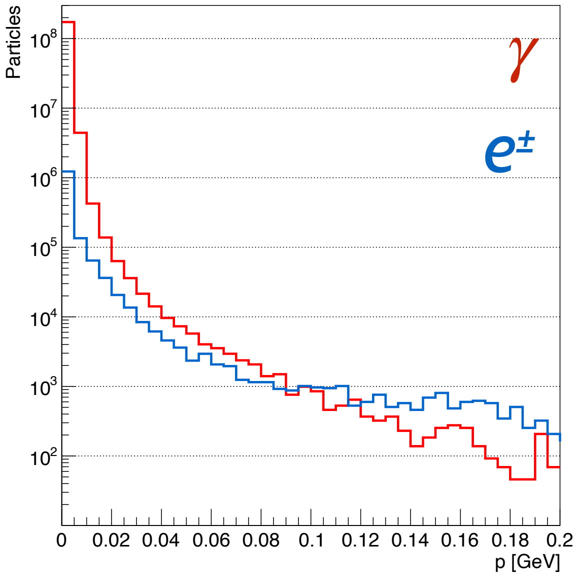


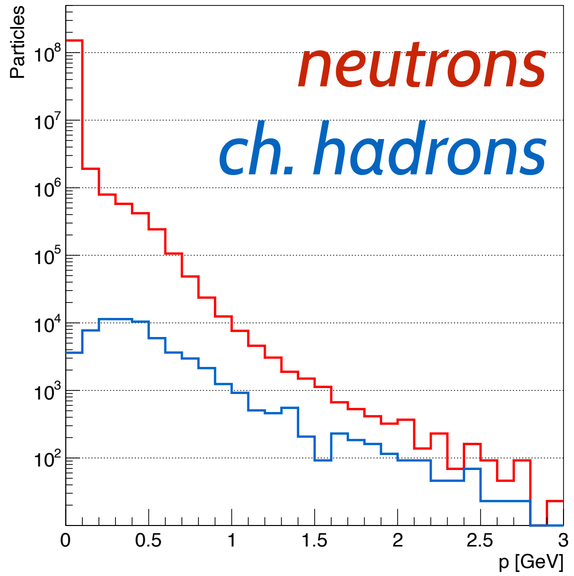




Predominantly composed of low-energy photons, electrons/positrons (~1-10 MeV) **and neutrons** (~100 MeV)

Each of those create issues in different parts of the detector

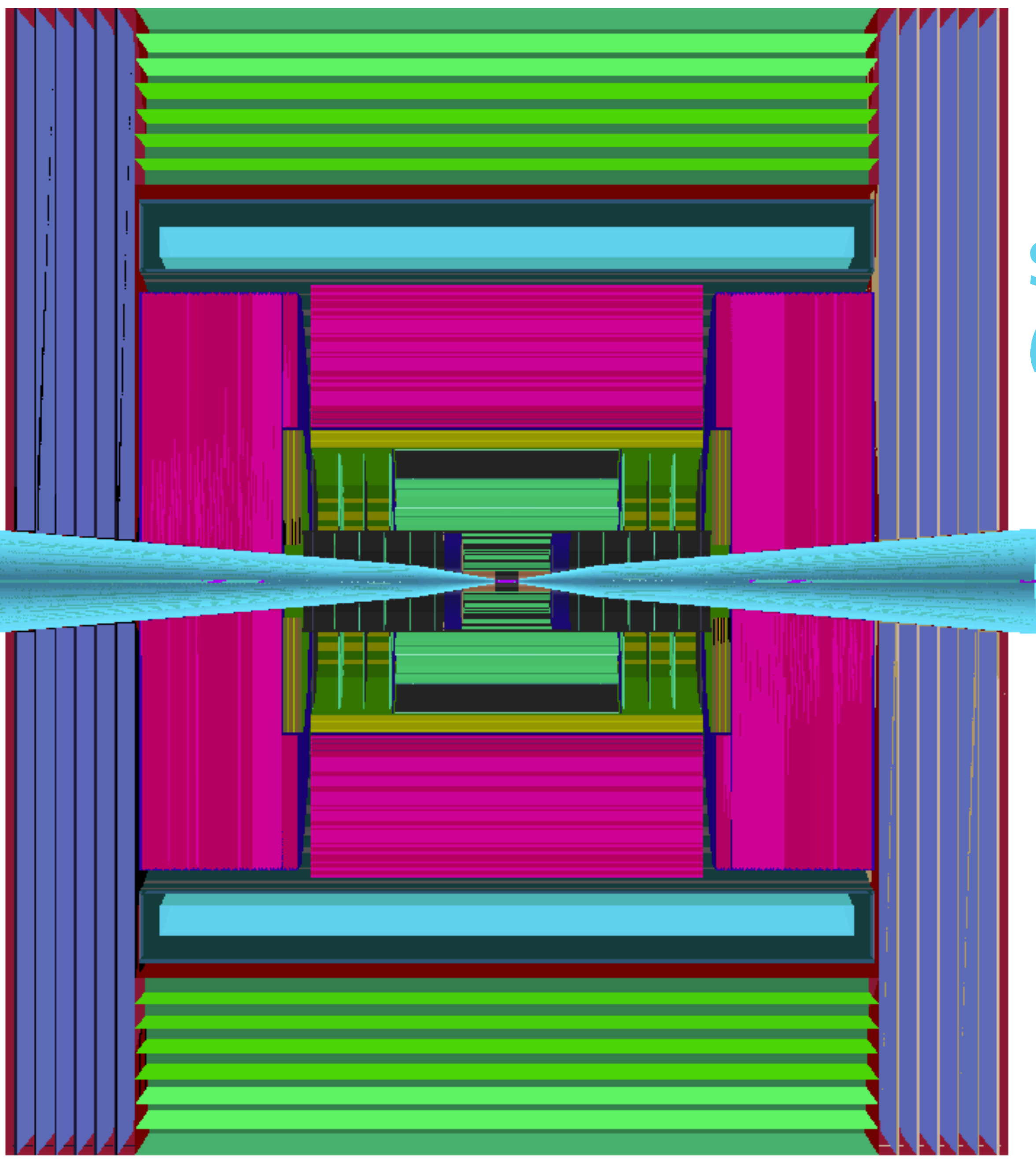


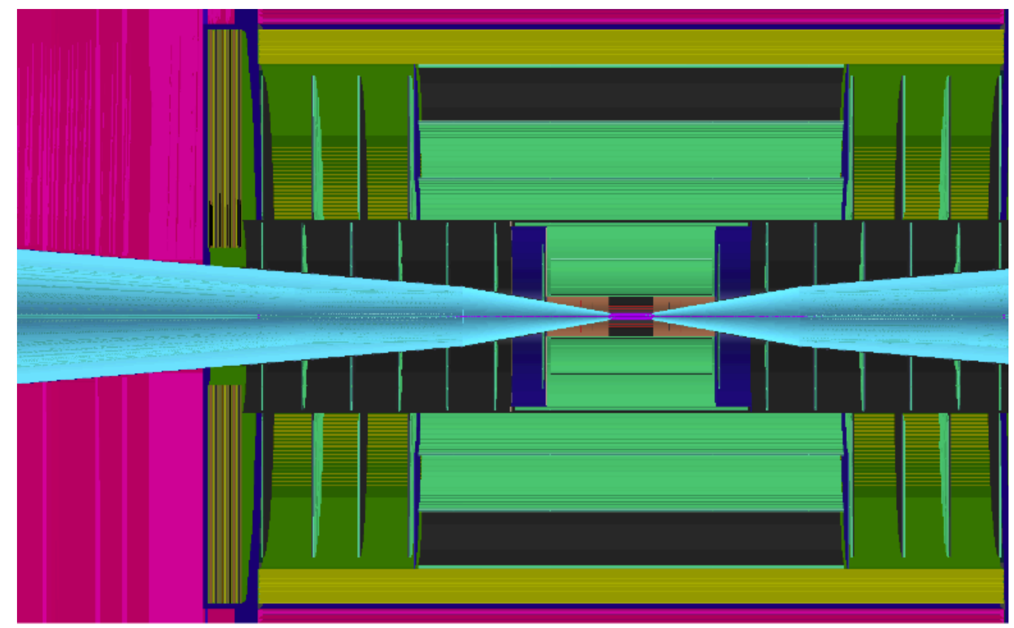


Detector geometry

Detector geometry derived from the CLIC design with a few optimisations:

Vertex Tracker,	Inner Tracker,	Outer Tracker,	ECAL,	HCAL,	Muon Detector
(4 + 4×2) × 2	3 + 6×2	3 + 4×2	40	60	7 + 6×2





- inserted BIB-absorbing tungsten nozzles developed by MAP
- inner openings of endcap detectors increased to fit the nozzles
- optimised layout of the Vertex detector to reduce occupancy

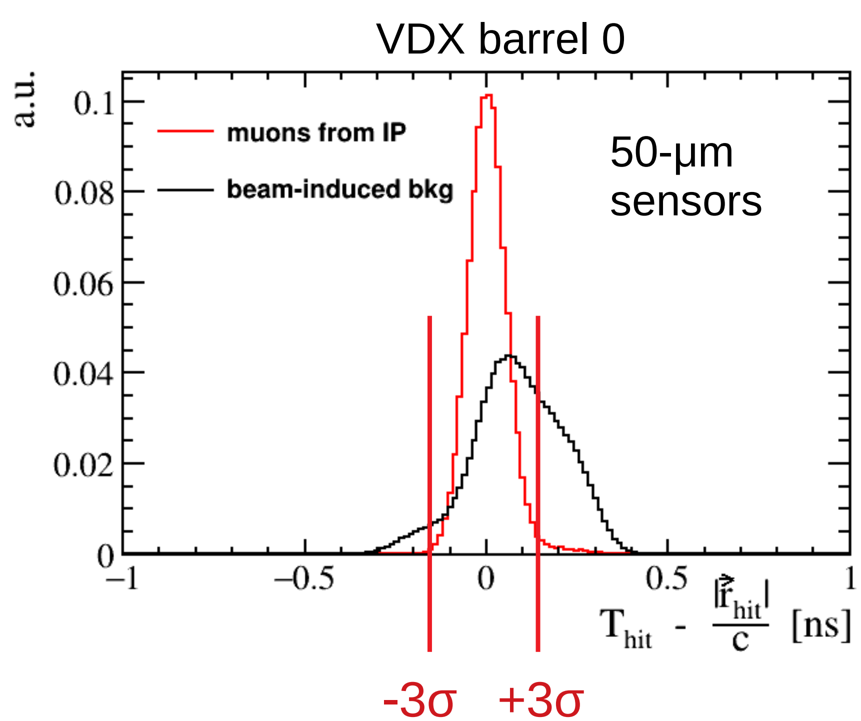
BIB suppression: tracking detectors

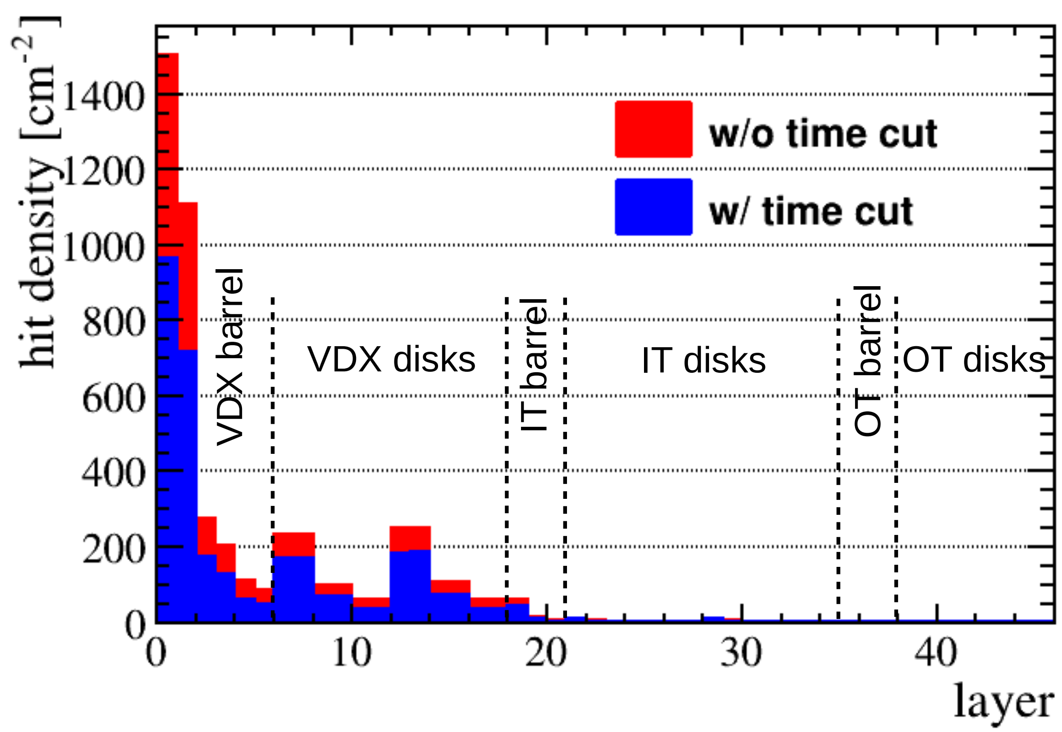
We start with 190M particles from each beam *[μ^+ and μ^-]*

- an overwhelming number of particles that have to be rejected at the earliest stage possible to make a reconstruction of a physics event possible

Hits created in the tracking detectors follow the BIB time distribution

- having precise time information for each hit allows to select hits in the narrow time window wrt bunch crossing
- ±150ps window at 50ps time resolution in the Vertex detector allows to strongly reduce the occupancy (by ~30%)



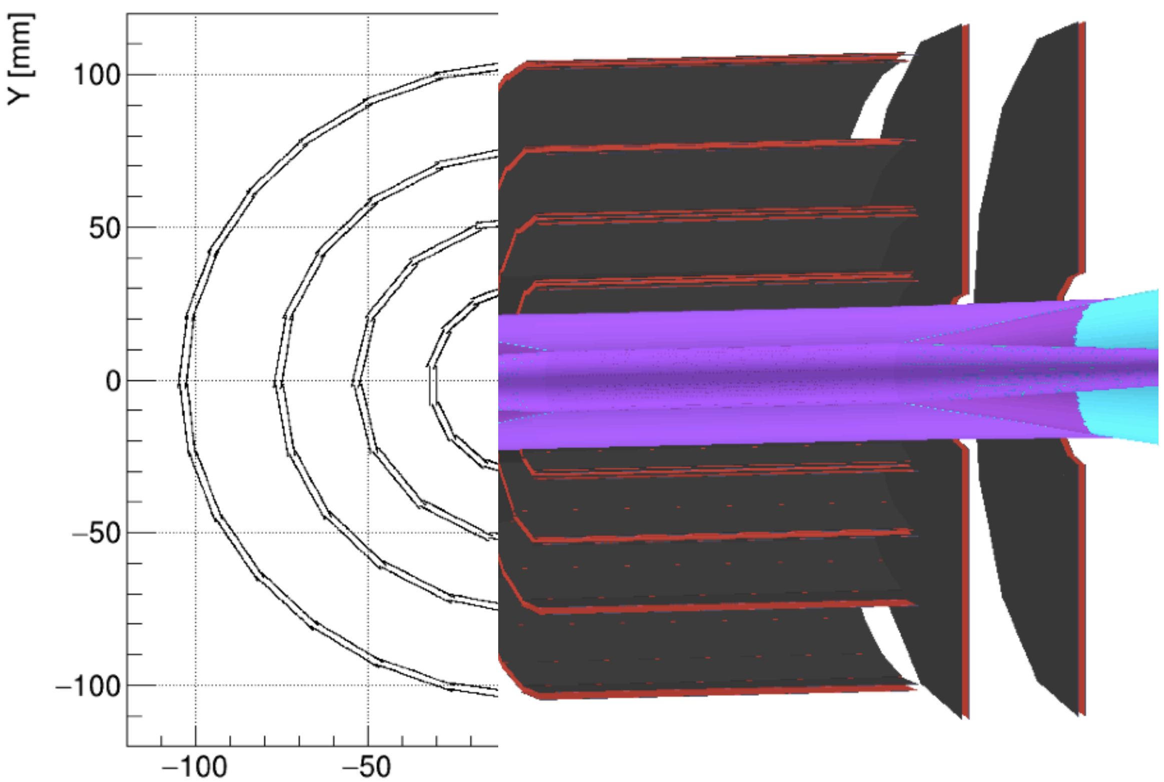


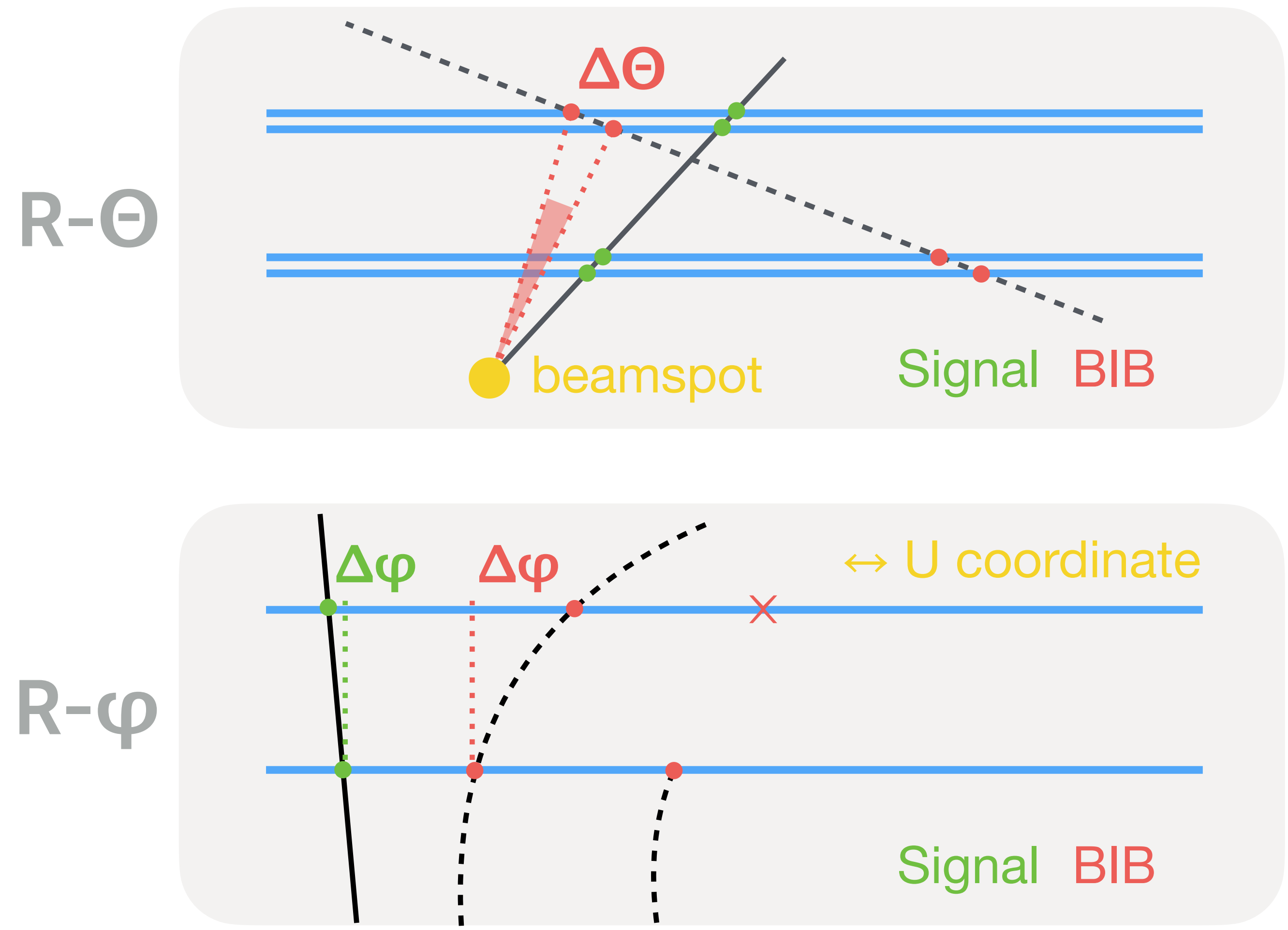
State of the art fast tracking sensors can push this even further: σ_t~10ps

Computational complexity of track reconstruction grows exponentially with the number of hits (exploding combinatorics at pattern recognition stage)

- the number of BIB hits can be further reduced by exploiting the fact that BIB is made of low-momentum particles not originating from the IP

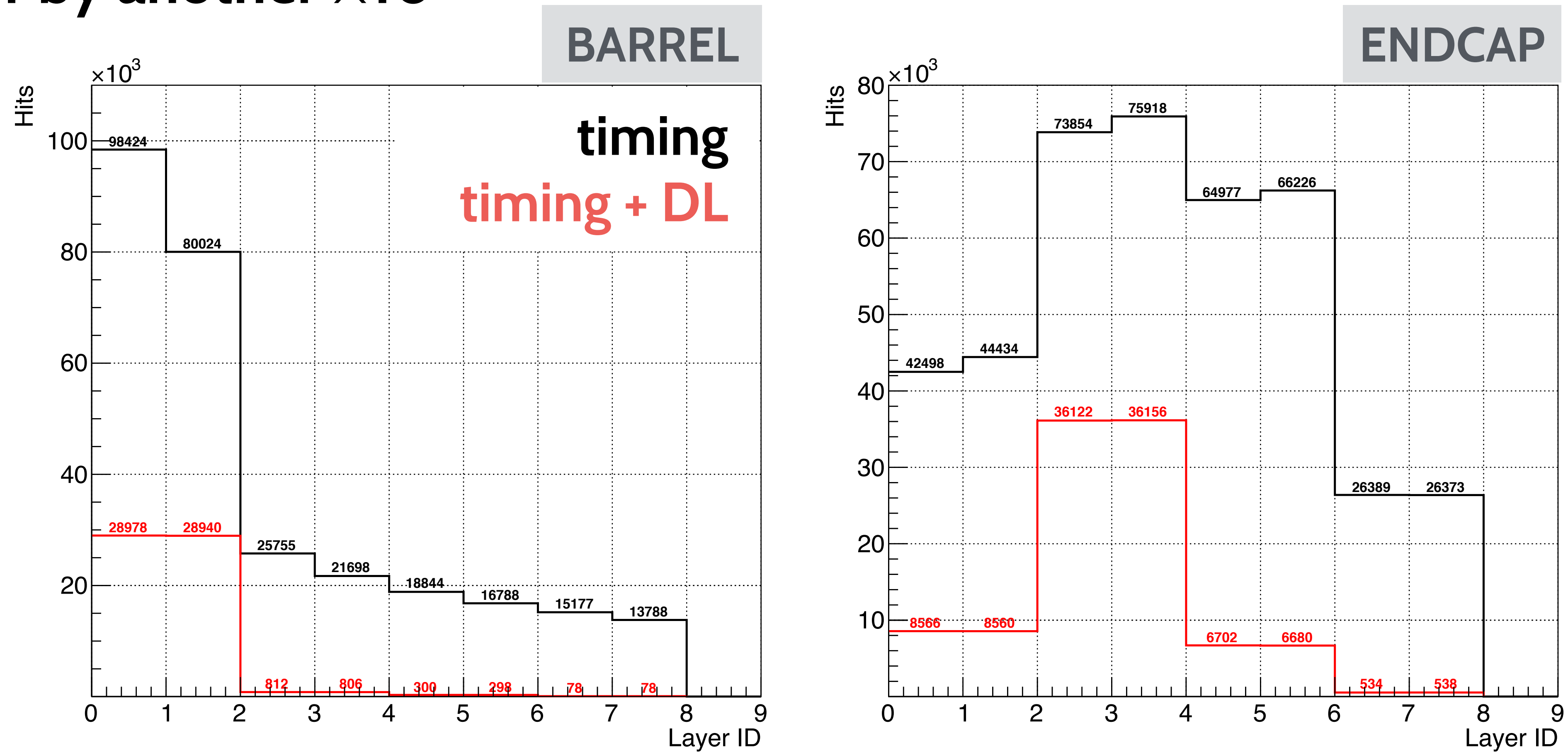
Double-layer arrangement of Si sensors allows to correlate hits from the neighbouring layers to estimate p_T and direction of a track segment





BIB suppression: track reconstruction

Requirement of correlated hit pairs in the double layers reduces occupancy in the Vertex detector by another ×10



It is now possible to reconstruct tracks in an event with all BIB included

Yet conventional track reconstruction strategies are not optimal in this case

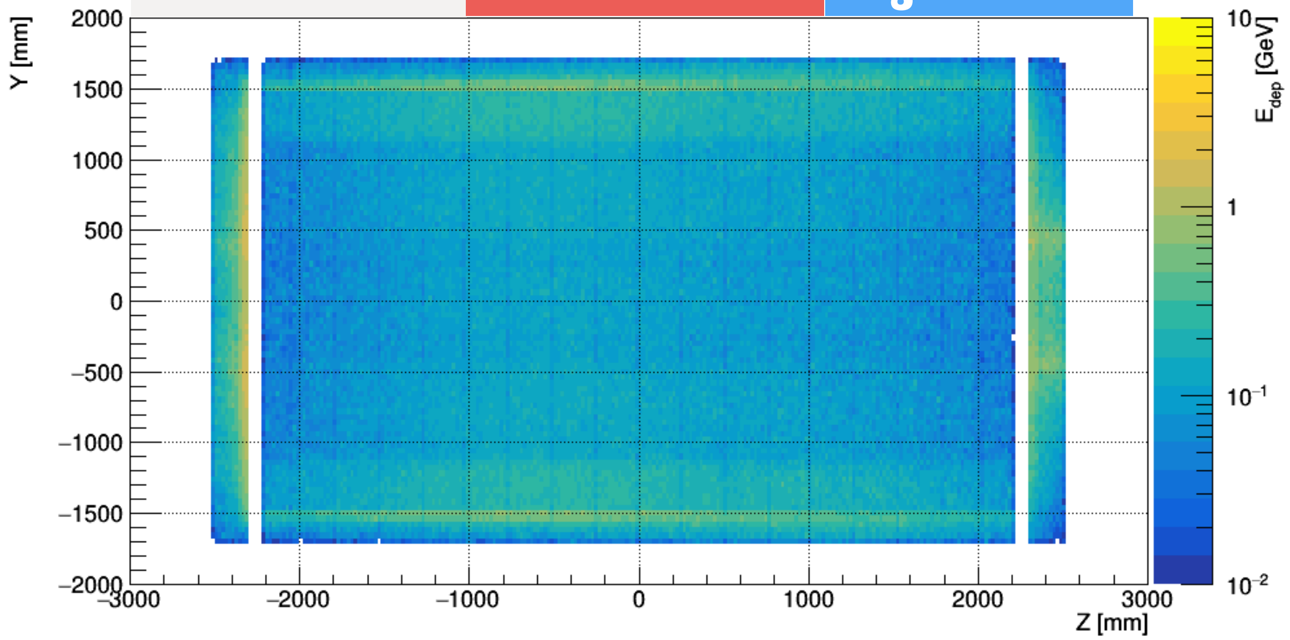
- layers/disks closest to the tips of the nozzles have much higher occupancy
- initiating track reconstruction from less busy layers can provide significant performance boost (to be studied)

BIB suppression: calorimeters

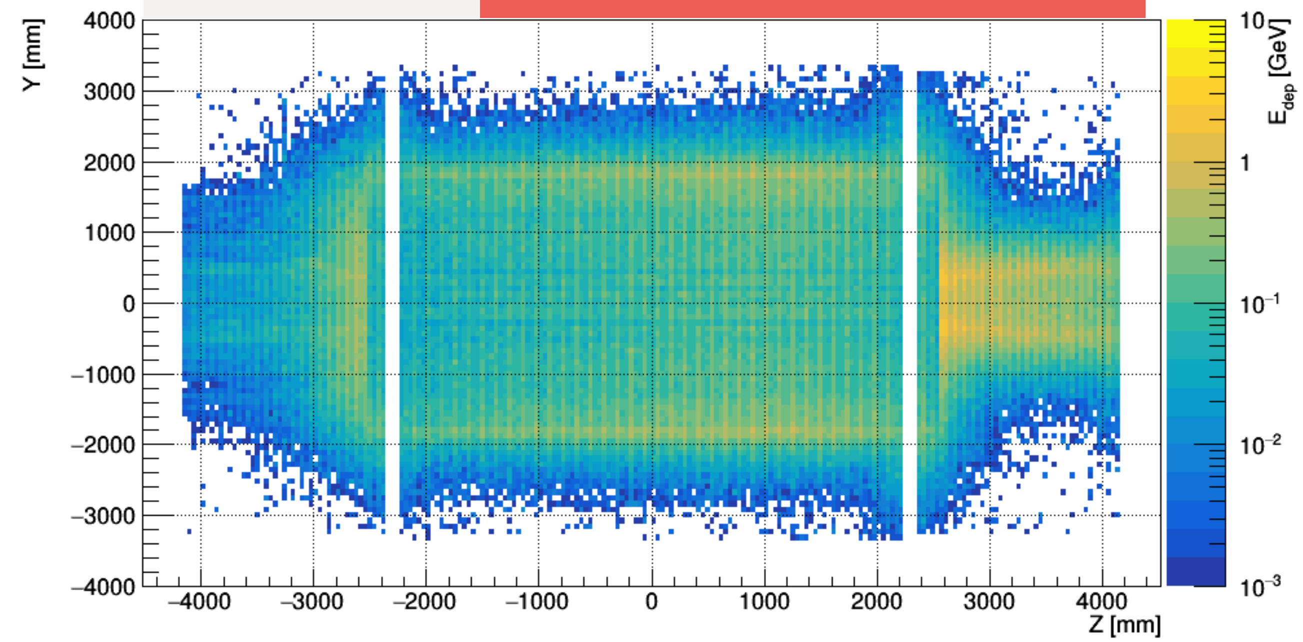
Calorimeters are almost uniformly lit by the BIB particles

μ^- beam

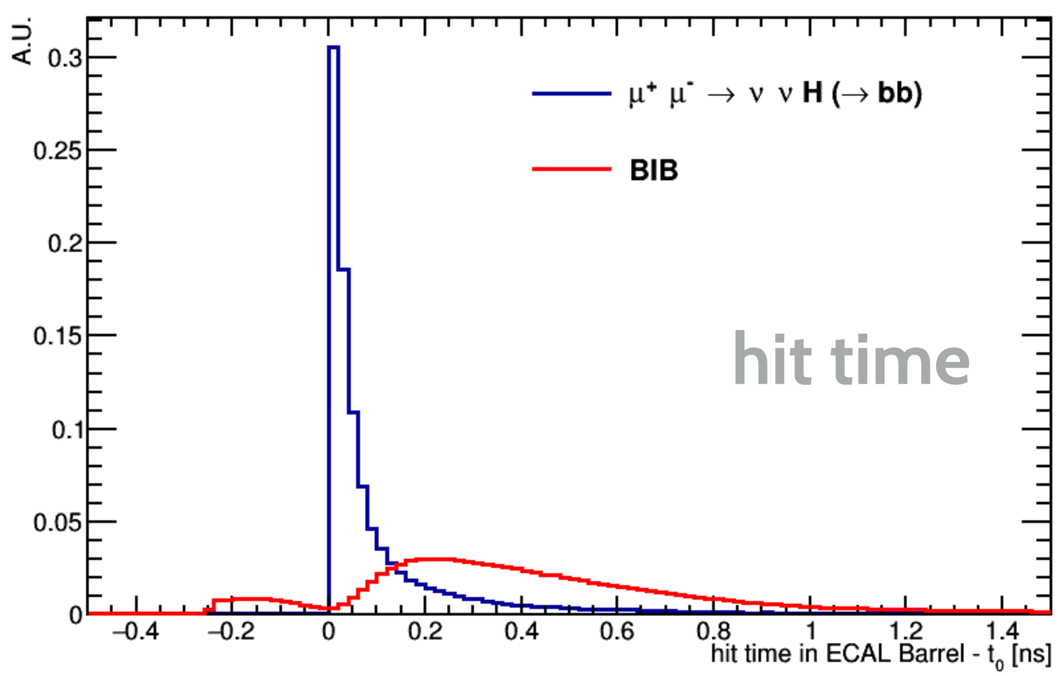
ECAL n: 48% γ: 51%

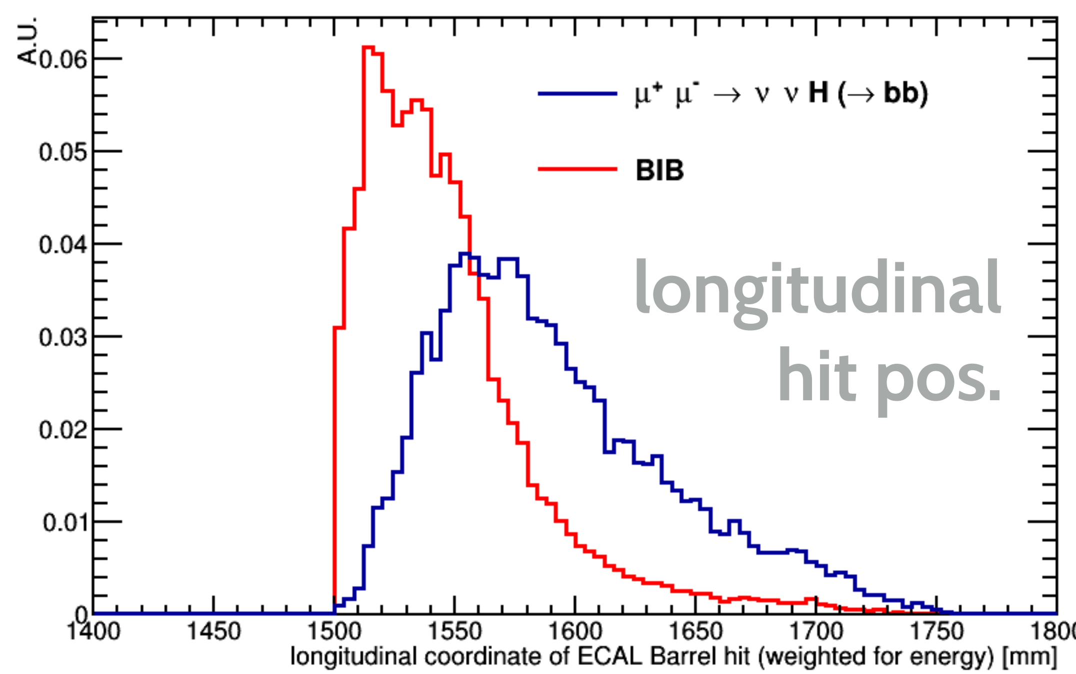


HCAL n: 99%



Timing and longitudinal shower distribution provide a handle on BIB in ECAL





BIB suppression: calorimeters

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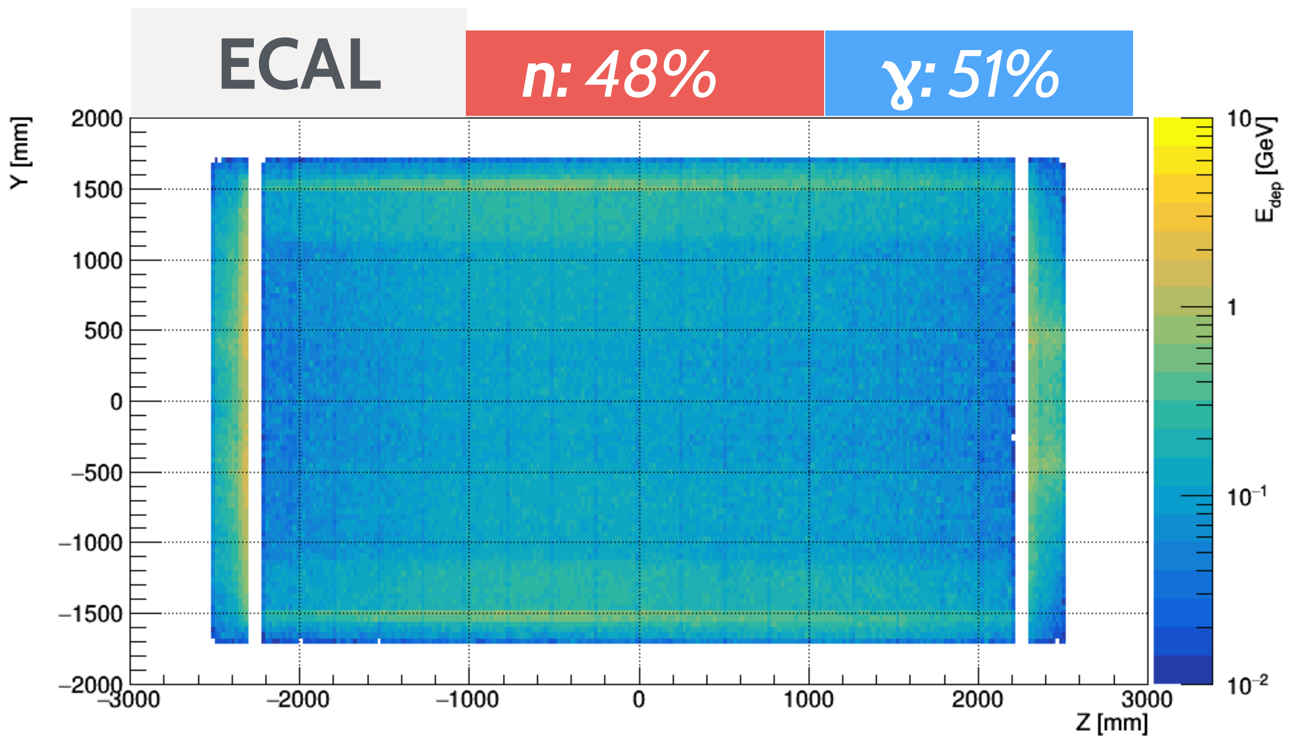
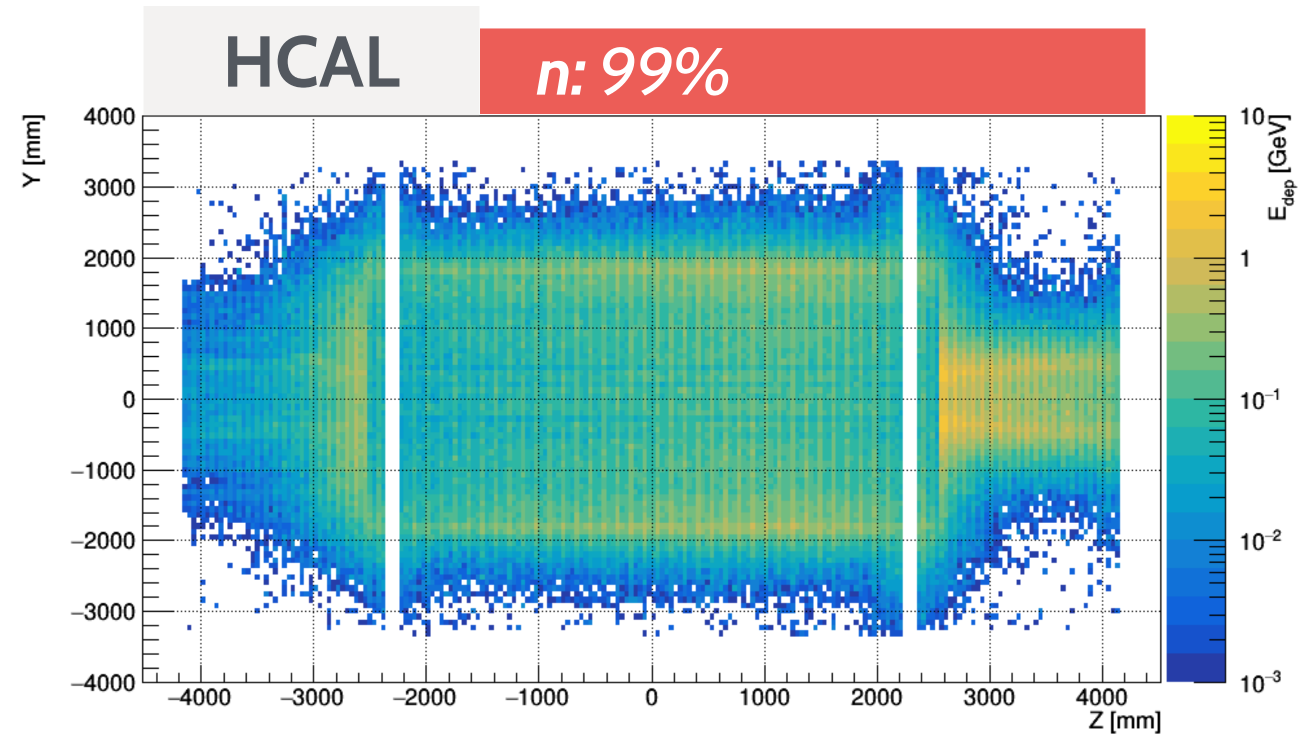
μ^- beam





Additional optimisations possible:

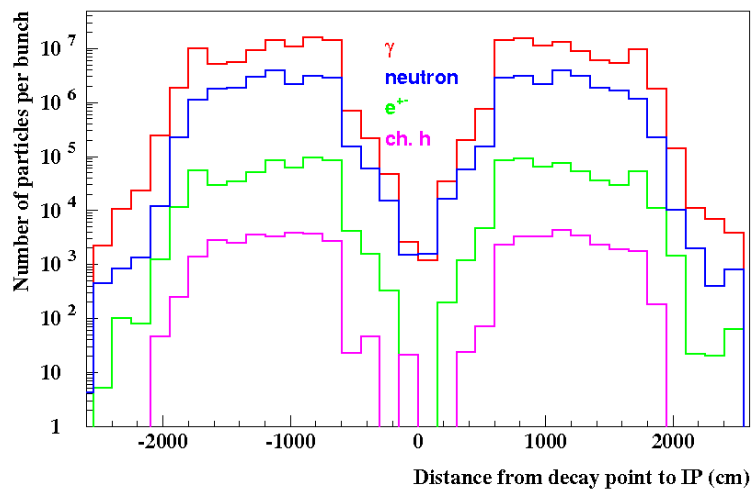
- add a preshower to push the BIB energy deposits out of ECAL
- readout of clusters with energy deposits above BIB threshold

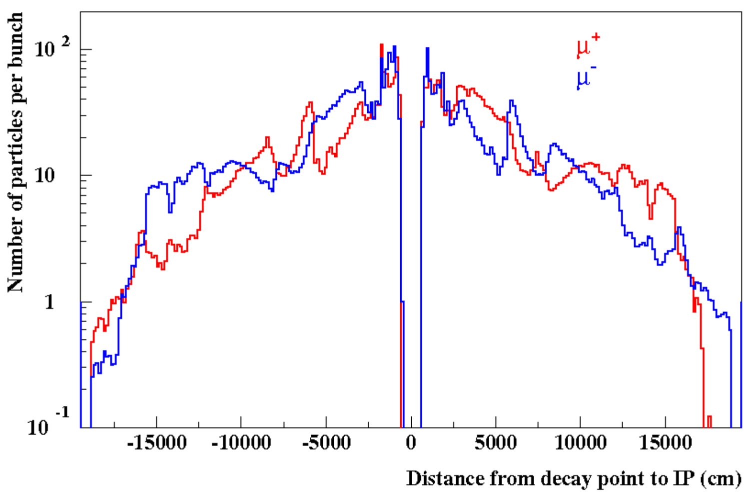
Regardless of the detector geometry and readout logics, BIB contributions can't be completely eliminated

- smart subtraction of the BIB contribution needed at the level of particle-flow reconstruction *(ML-based method already under development)*

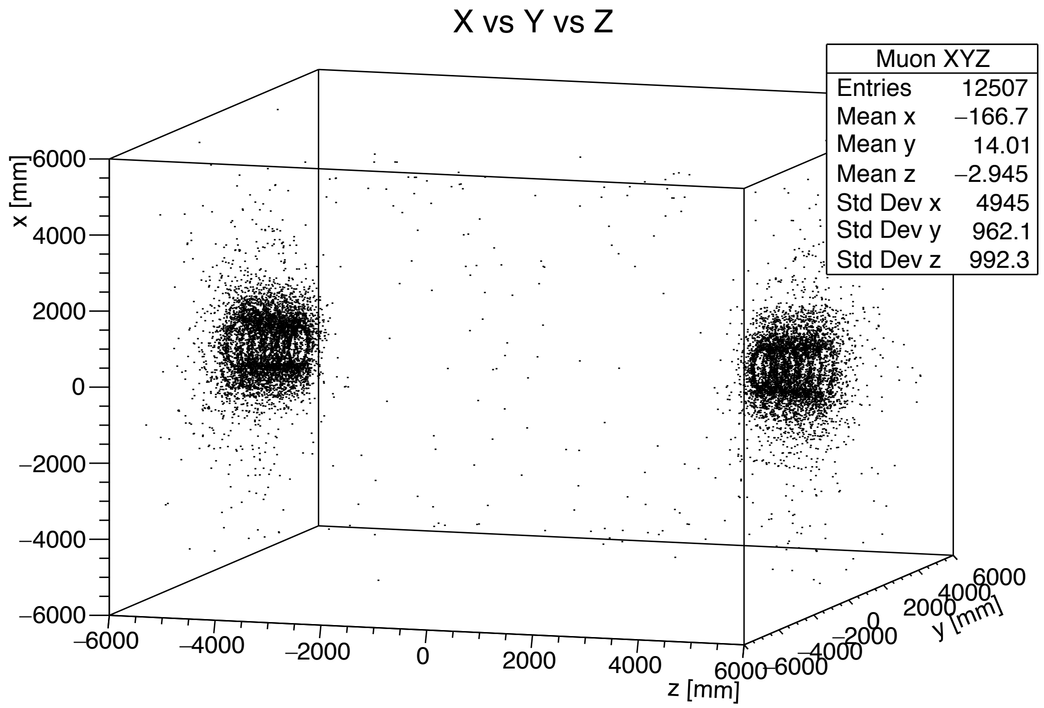
Muons from BIB can reach detector from a bigger distance along the beam

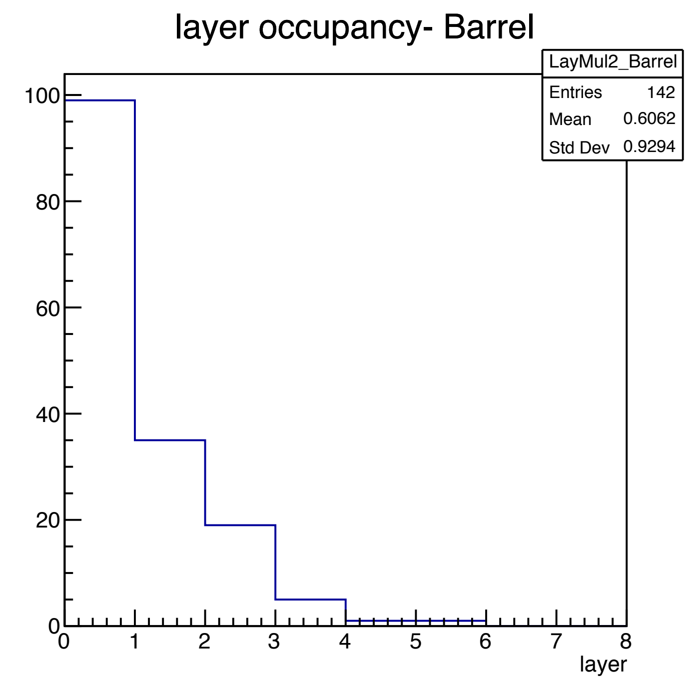
- up to ±200m
- only ±25m included in our BIB sample

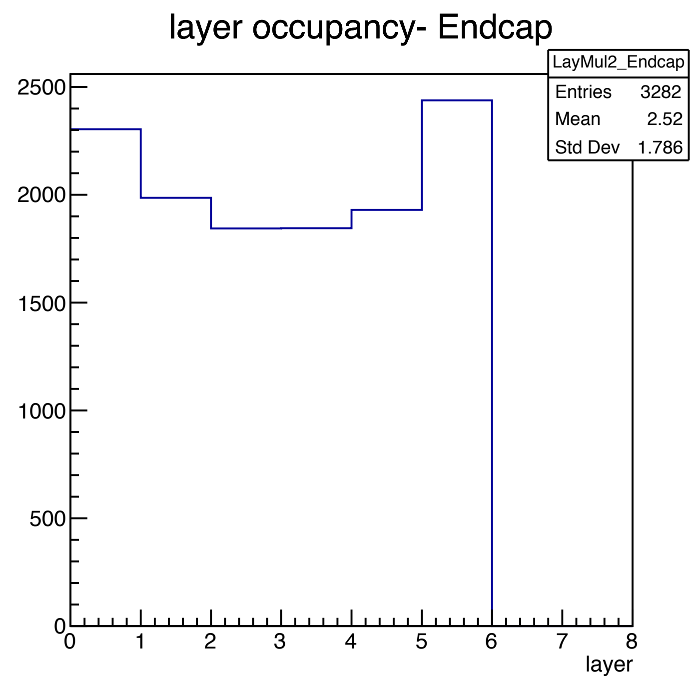




Occupancy of the muon detector is manageable *(no detector-level optimisations)*







Further reduction of occupancy expected with timing cuts

Summary

Beam Induced Background creates a number of serious challenges at a Muon Collider experiment by overwhelming it with a huge flow of particles

Careful design of the MDI and use of state-of-the-art detector technologies with optimal layout allows to keep the BIB contribution at perfectly manageable level

Competitive performance has already been demonstrated using conservative assumption on the detector capabilities (i.e. tracker timing/spatial resolution)

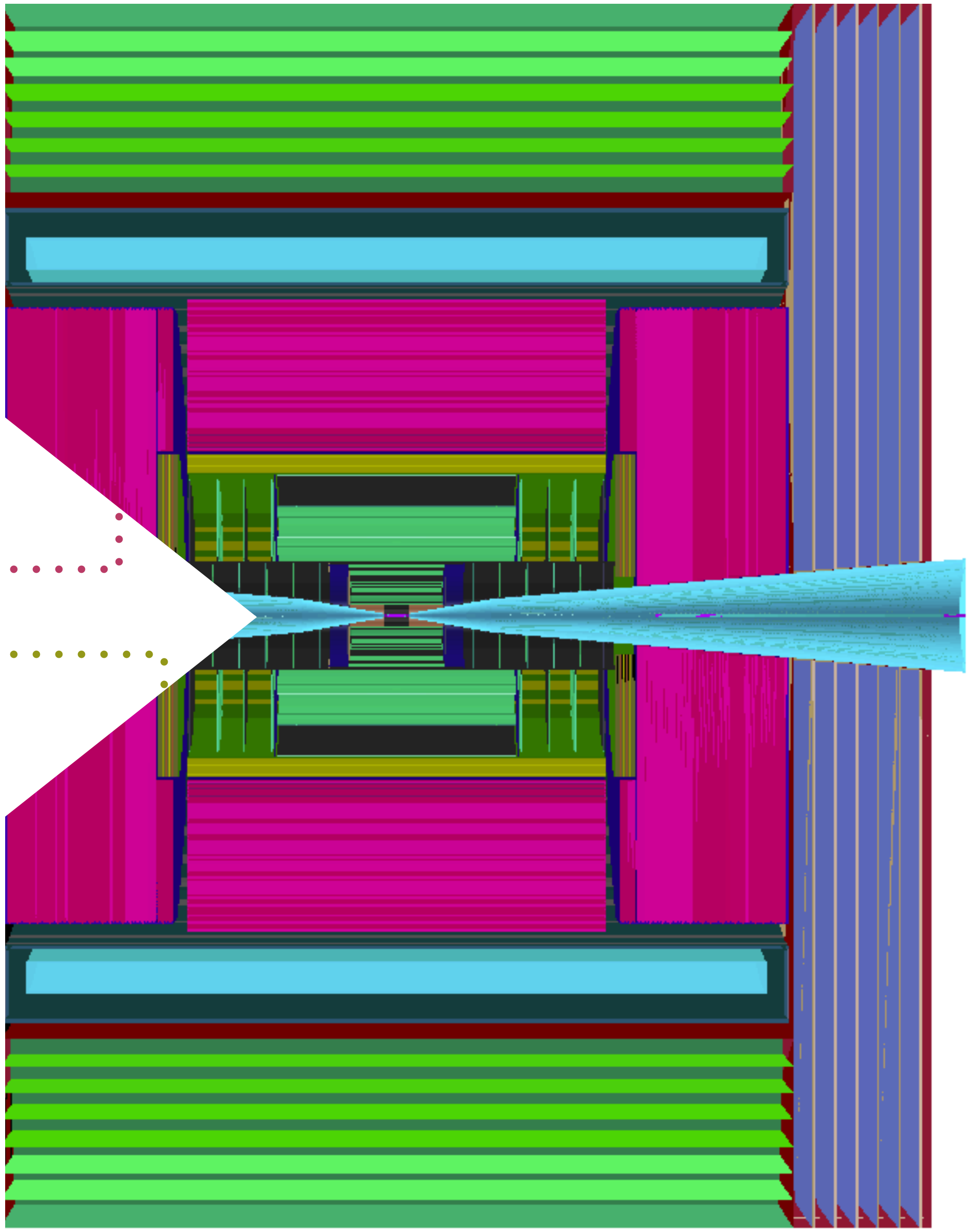
Significant improvements in performance are expected with further optimisations of the MDI, detector design and event reconstruction algorithms

Even better performance is expected at centre-of-mass energies >1.5 TeV

BACKUP

Calorimeter layout

Current geometry implementation features a high-granularity sampling calorimeter



FCC-hh expects ~30ps time resolution in ECAL

Fast tracking sensors

A number of technologies progressing towards very high timing resolution

- **UFSD (**Ultra Fast Silicon Detectors**): 20ps + ~10µm**
- **RSD (**Resistive AC-Coupled Silicon Detectors**): 20ps + 5µm**
- **TimeSpot: 20ps or less + 10µm**