MDI Common issues (including physics and detector considerations)

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Interaction Region and MDI Design

The high luminosity requires:

- Low beta-function at the IP (few cm)
- High number of muons per bunch ($N_\mu \sim 2 \cdot 10^{12}$)
- Muons decay particles: 2×10^5decay per meter of lattice, E_{beam}=1.5 TeV with $2\times10^{12}\mu$/bunch

Beam induced background, if not properly treated, could be critical for:

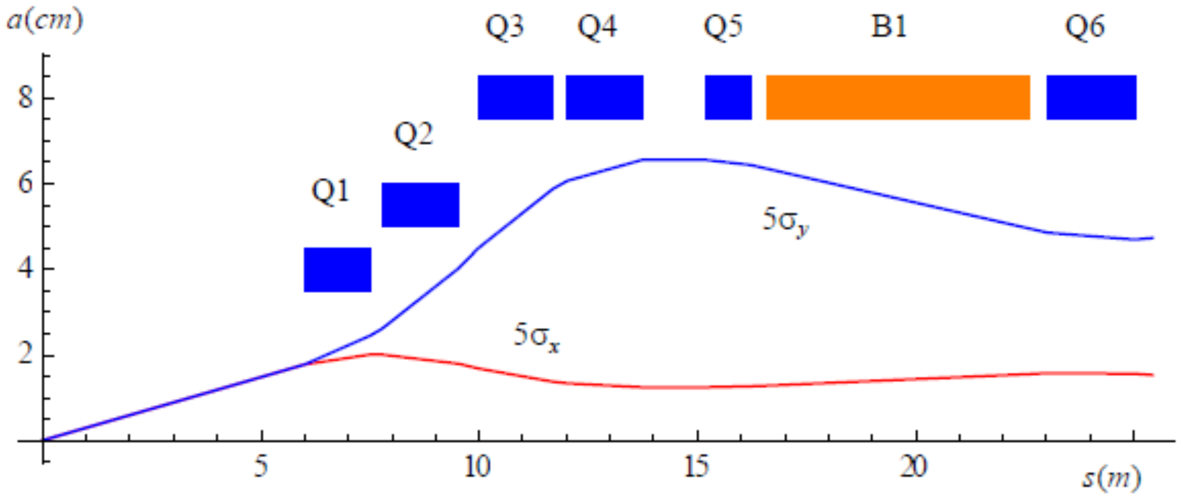
- Magnets, they need to be protected.
- People, due to neutrino induced radiation.
- Detector, the performance depends on the rate of background particles arriving to each subdetector.

A holistic approach is needed, tight together the development of the IR optics, the magnets and the shielding strategies (magnets and detector).

Optimization of Interaction Region at $\sqrt{s} = 1.5$ TeV

Y.I. Alexahin et al. *Muon Collider Interaction Region Design* FERMILAB-11-370-APC
N.V. Mokhov et al. *Muon collider interaction region and machine-detector interface design* Fermilab-Conf-11-094-APC-TD

Parameter	Unit	Value
Beam energy	TeV	0.75
Repetition rate	Hz	15
Average luminosity / IP	10^{34}/cm^2/s	1.1
Number of IPs, N_{IP}	-	2
Circumference, C	km	2.73
β^*	cm	1 (0.5-2)
Momentum compaction, α_p	10^{-5}	-1.3
Normalized r.m.s. emittance, $\varepsilon_{\perp N}$	π·mm·mrad	25
Momentum spread, σ_p/p	%	0.1
Bunch length, σ_s	cm	1
Number of muons / bunch	10^{12}	2
Beam-beam parameter / IP, ξ	-	0.09
RF voltage at 800 MHz	MV	16

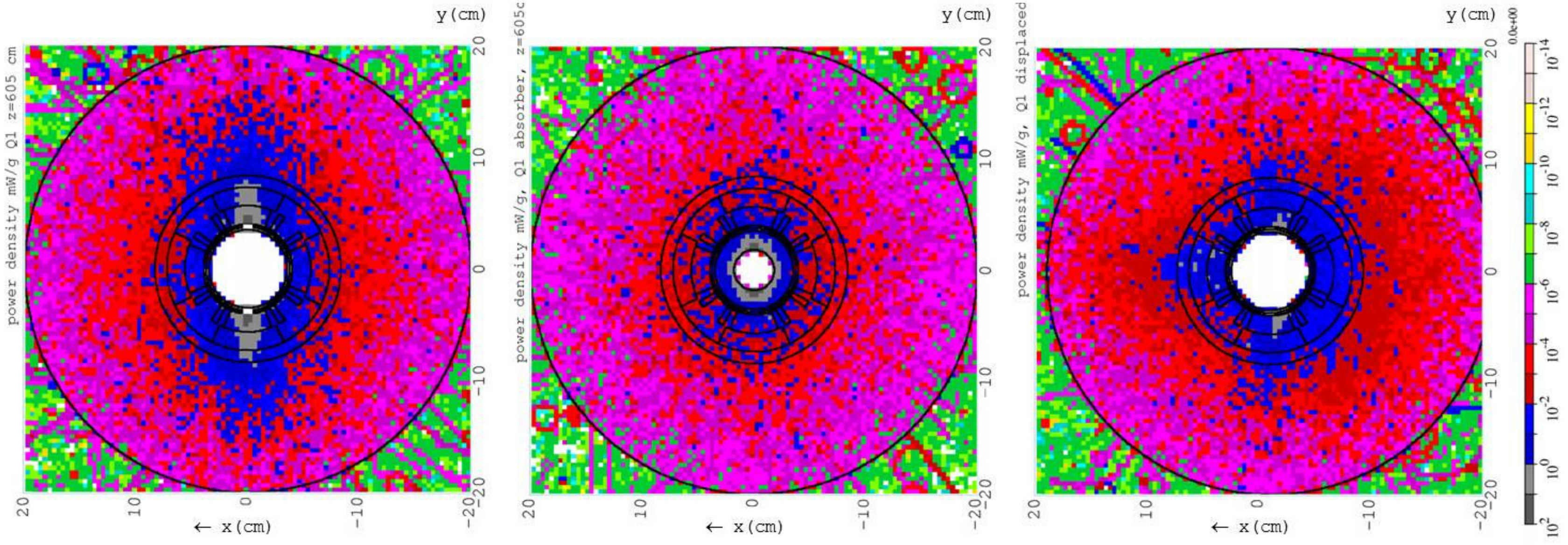


Quadrupoles in Nb_3Sn characteristics in the papers.
Dedicated dipoles to minimize the number of decay electrons in the coils and in the inner part of the detector.

Interaction Region Optimization at $\sqrt{s} = 1.5$ TeV with absorbers

See MARS IR and nozzle optimization @ 0.125, 1.5 and 3 TeV
by Nikolay Mokhov

Important role is played by the absorber materials



Standard, tungsten nozzle

+ tungsten liners inside quadrupoles

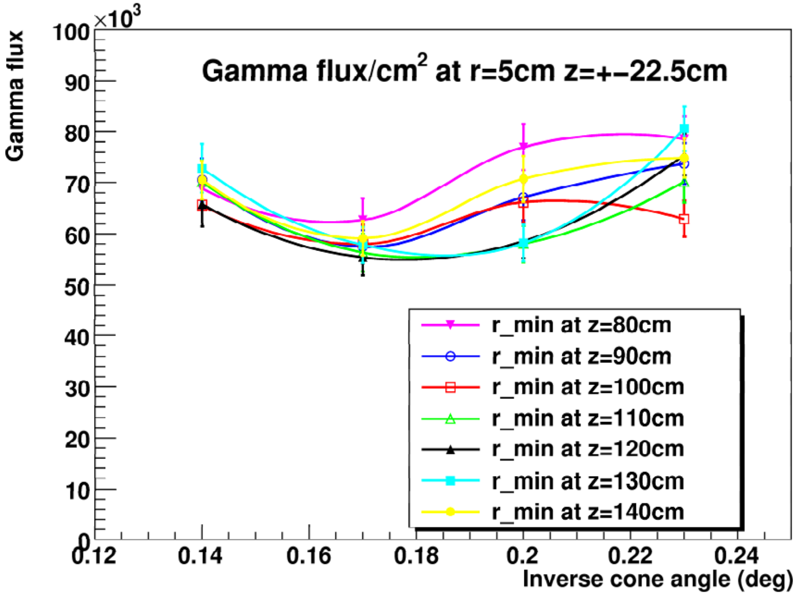
+ horizontal displacement of 0.1 of their aperture

Deposited power density in Q1 (mW/g)

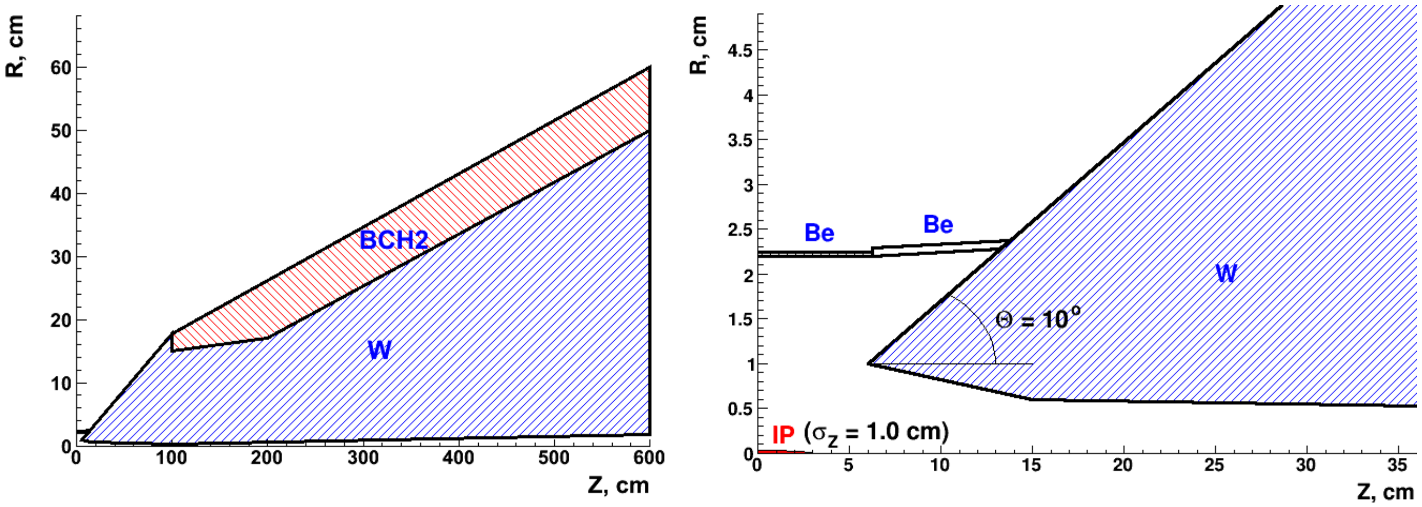
Detector Nozzle Optimization at $\sqrt{s} = 1.5$ TeV

See MARS IR and nozzle optimization @ 0.125, 1.5 and 3 TeV
by Nikolay Mokhov

For example, gamma flux as a function of the angle of inner cone opening towards IP at the outer cone angle of 10°



These studies have brought to the final nozzle configuration

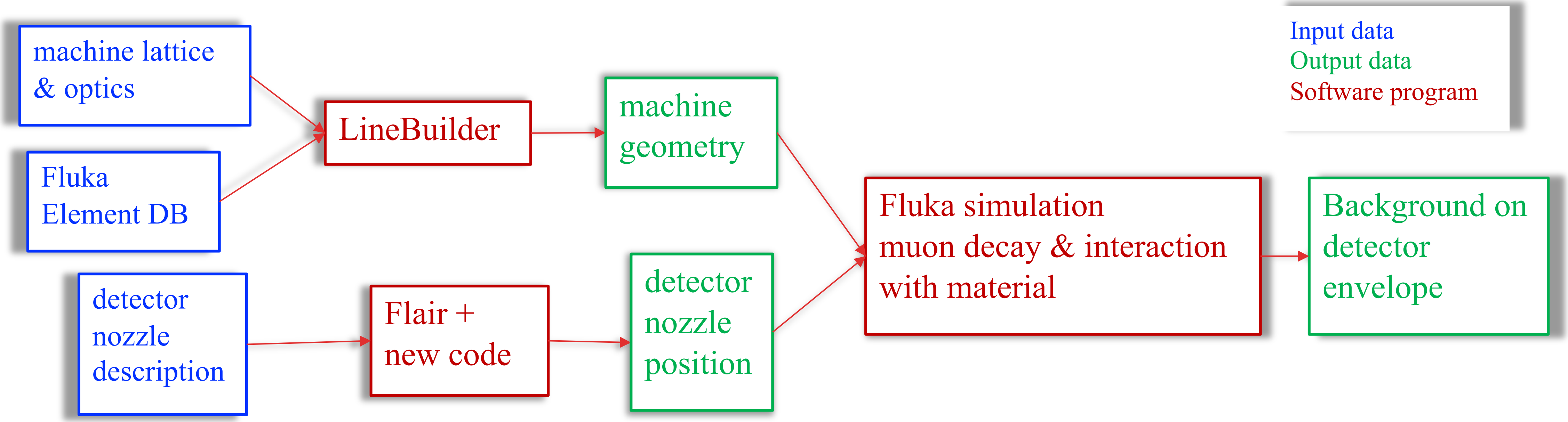


Di Benedetto et al., *A study of muon collider background rejection criteria in silicon vertex and tracker detectors*. Journal of Instrumentation13(2018)

Detector Nozzle Optimization

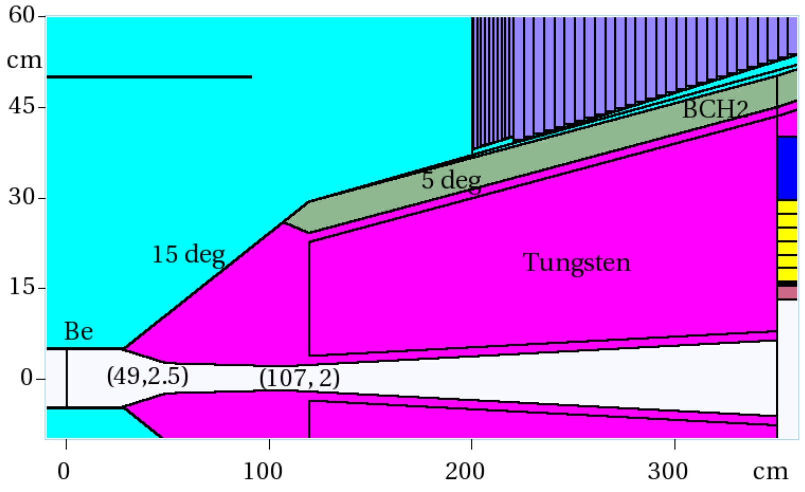
New tool, see BIB Studies @1.5-3 TeV with FLUKA by Francesco Collamati

See Advanced assessment of Beam Induced Background at a Muon Collider just out!

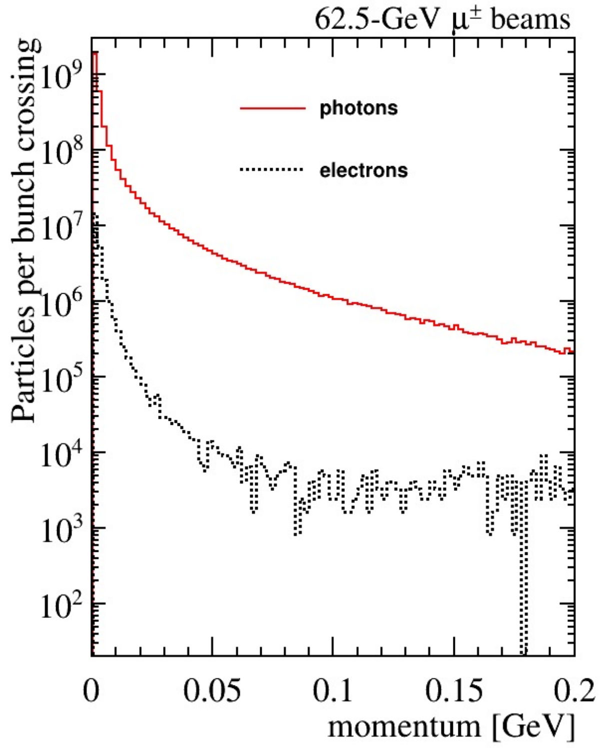


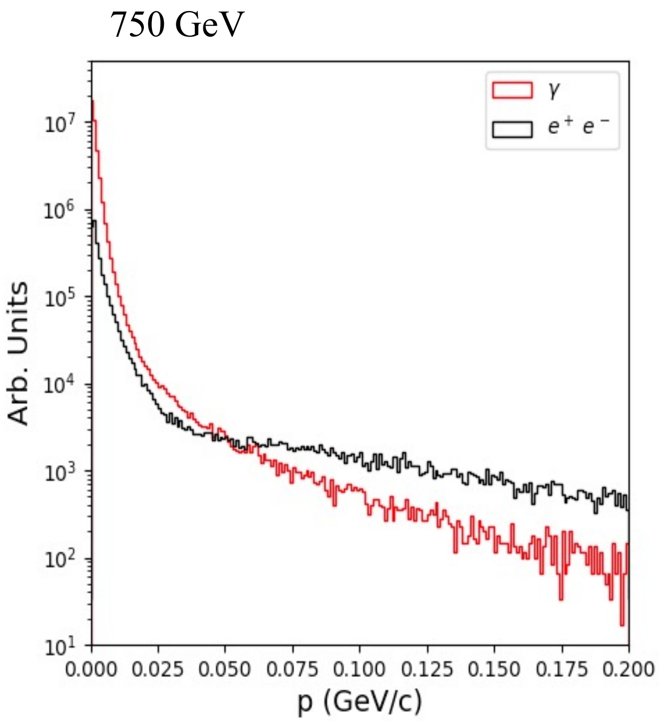
Comparison of BIB Characteristics $\sqrt{s} = 125$ GeV - $\sqrt{s} = 1.5$ TeV

S.I. Striganov et al. *Reducing Backgrounds in the Higgs Factory Muon Collider Detector* Fermilab-Conf-14-184-APC TUPRO029, and Proc. IPAC2014, Dresden, Germany, June 2014, p.1084
N. Bartosik et al. *Preliminary Report on the Study of Beam-Induced Background Effects at a Muon Collider* arXiv:1905.03725

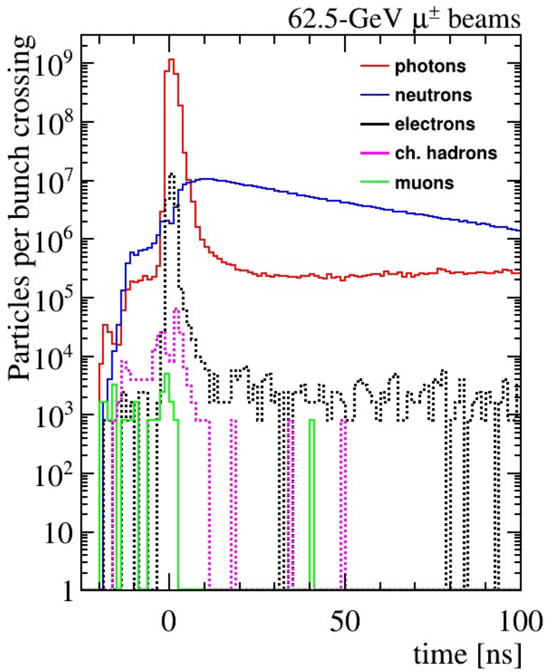


beam energy [GeV]	62.5	750
μ decay length [m]	3.9×10^5	4.7×10^6
μ decays/m per beam	5.1×10^6	4.3×10^5
photons ($E^{kin}_{\rm ph.} > 0.2$ MeV)	3.4×10^8	1.6×10^8
neutrons ($E^{kin}_{\rm n} > 0.1$ MeV)	4.6×10^7	4.8×10^7
electrons ($E^{kin}_{\rm el.} > 0.2$ MeV)	2.6×10^6	1.5×10^6
charged hadrons ($E^{kin}_{\rm ch.had.} > 1$ MeV)	2.2×10^4	6.2×10^4
muons ($E^{kin}_{\rm mu.} > 1$ MeV)	2.5×10^3	2.7×10^3

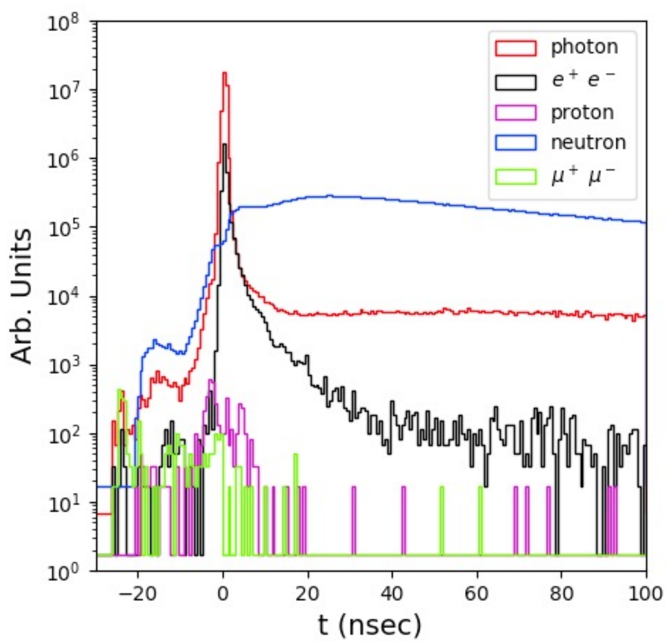


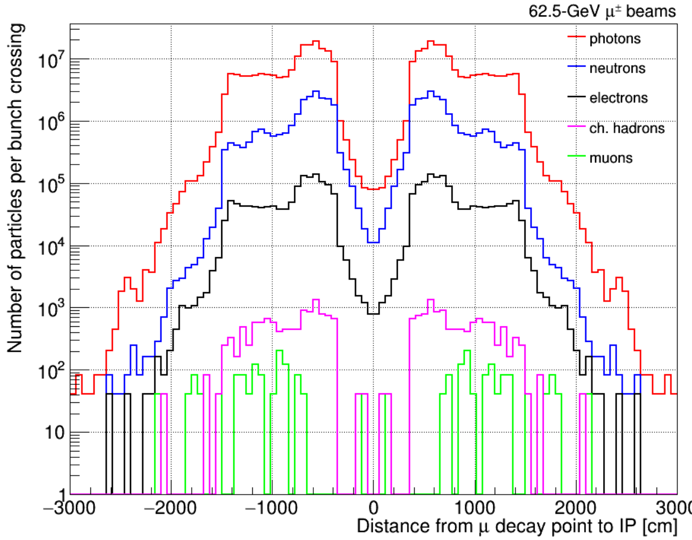


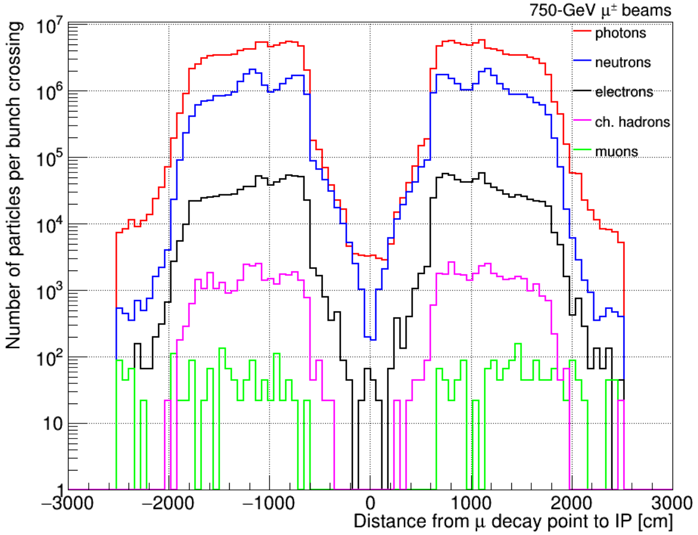
Comparison of BIB Characteristics $\sqrt{s} = 125$ GeV - $\sqrt{s} = 1.5$ TeV



750 GeV







Comparison between $\sqrt{s}$ =1.5 TeV and $\sqrt{s}$ = 125 GeV

- BIB absolute fluxes very similar
- Momentum distribution quite different
- Time distribution as expected and Z distribution very similar

The IR has been designed to obtain that.
Would be possible to do it also at high energy?

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Design a Detector with BIB

Current Detector Configuration for $\sqrt{s}$ =1.5 TeV

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CLIC Detector technologies adopted with important modifications to cope with BIB.

hadronic calorimeter

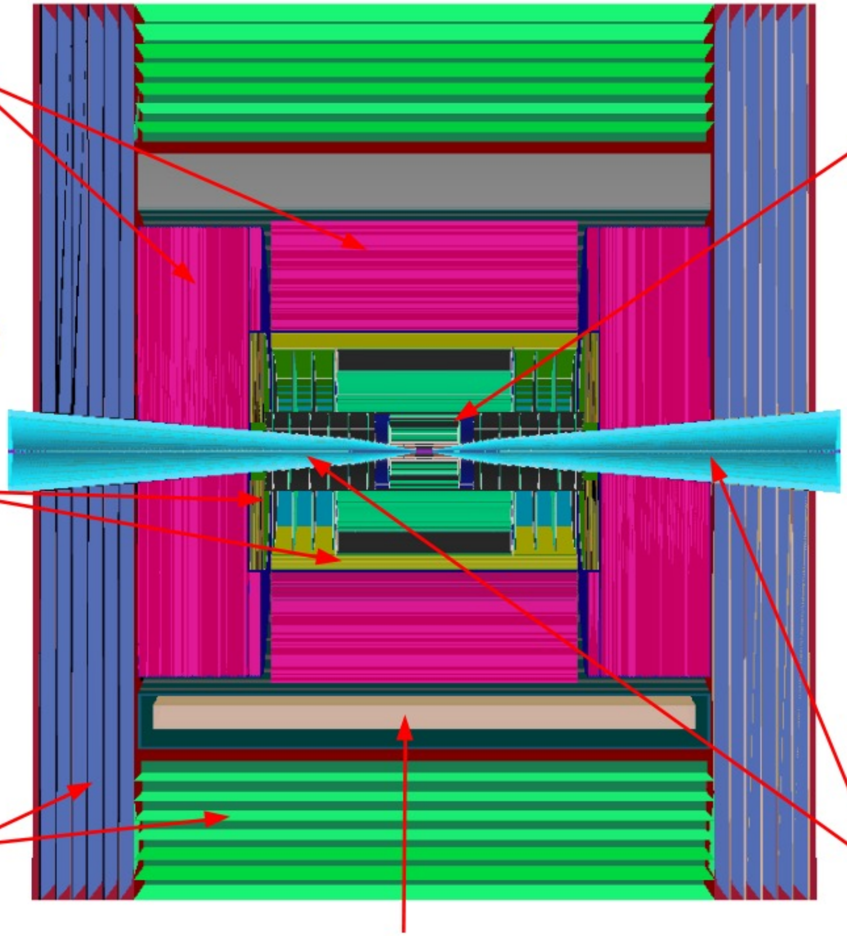
- 60 layers of 19-mm steel absorber + plastic scintillating tiles;
- 30x30 mm^2 cell size;
- 7.5 λ_I.

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 (3.57T)

tracking system

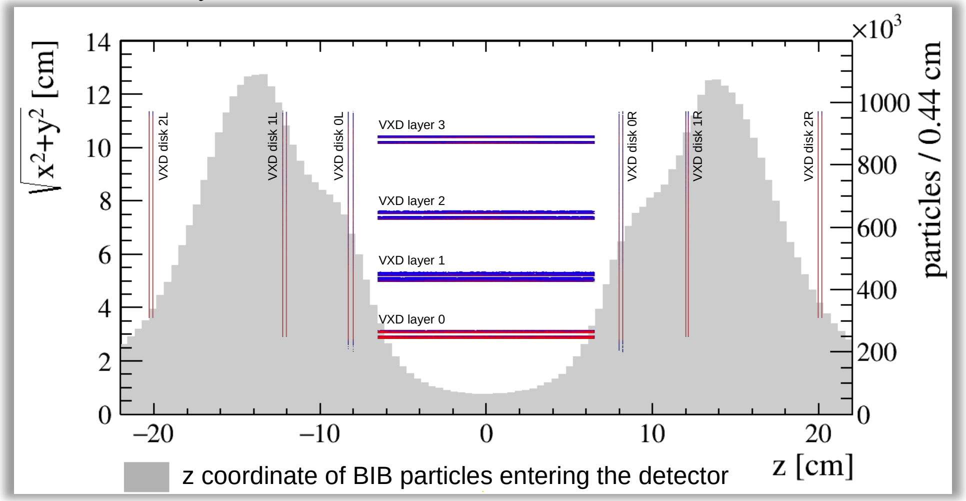
- Vertex Detector:
  - double-sensor layers (4 barrel cylinders and 4+4 endcap disks);
  - 25x25 μm^2 pixel Si sensors.
- Inner Tracker:
  - 3 barrel layers and 7+7 endcap disks;
  - 50 μm x 1 mm macro-pixel Si sensors.
- Outer Tracker:
  - 3 barrel layers and 4+4 endcap disks;
  - 50 μm x 10 mm micro-strip Si sensors.

shielding nozzles

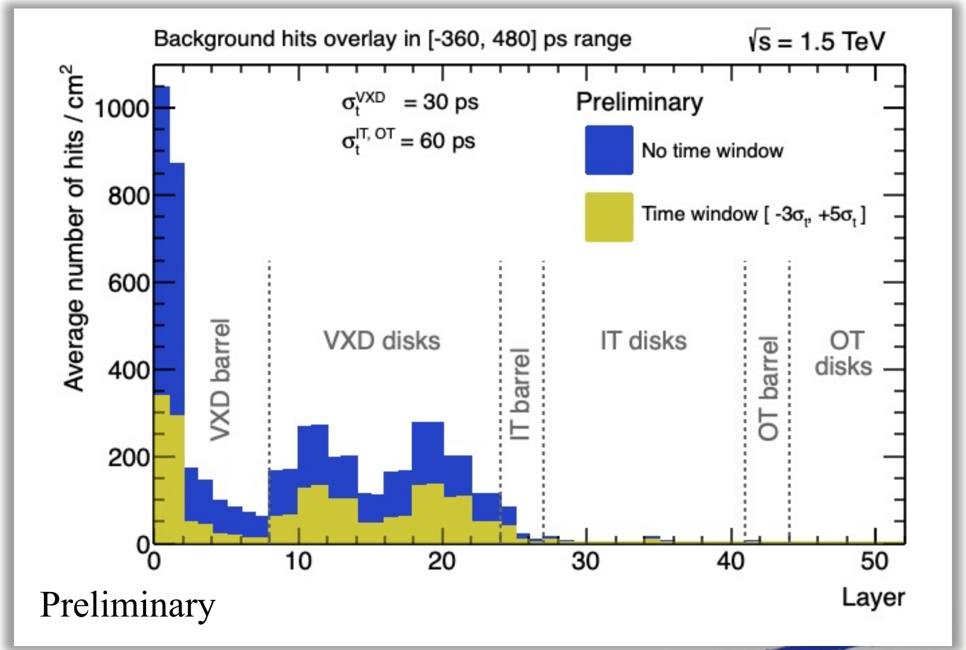
- Tungsten cones + borated polyethylene cladding.

Current Tracker Configuration for $\sqrt{s}$ =1.5 TeV

Preliminary



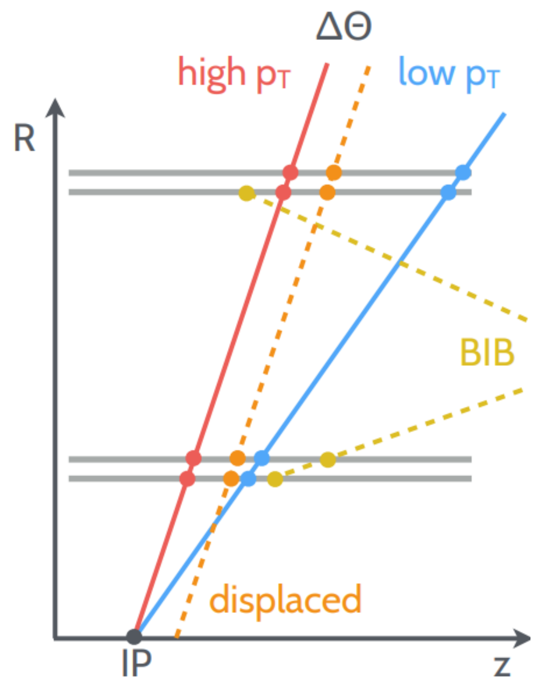
		cell size	sensor thickness	time resolution	spatial resolution	number of cells
VXD	B	25 μm × 25 μm pixels	50 μm	30 ps	5 μm × 5 μm	729M
	E	25 μm × 25 μm pixels	50 μm	30 ps	5 μm × 5 μm	462M
IT	B	50 μm × 1 mm macropixels	100 μm	60 ps	7 μm × 90 μm	164M
	E	50 μm × 1 mm macropixels	100 μm	60 ps	7 μm × 90 μm	127M
OT	B	50 μm × 10 mm microstrips	100 μm	60 ps	7 μm × 90 μm	117M
	E	50 μm × 10 mm microstrips	100 μm	60 ps	7 μm × 90 μm	56M

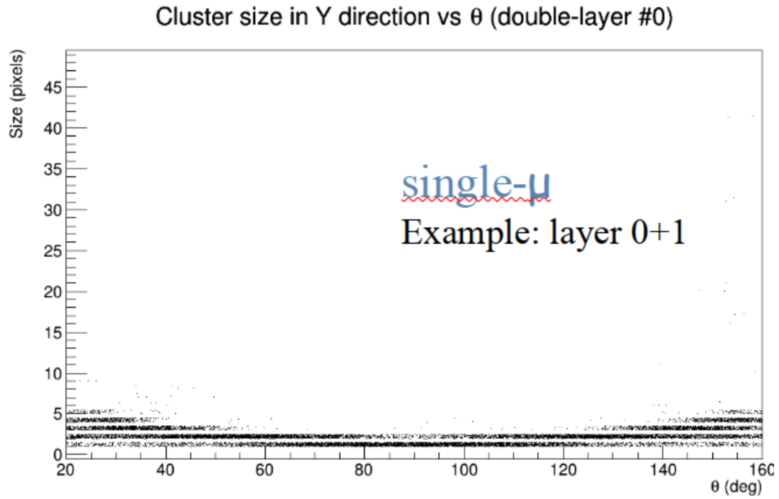


- Apply timing window to reduce hits from out-of-time BIB
- Granularity optimized to ensure $\lesssim$ 1% occupancy
- Realistic digitization in progress

Use directional Information

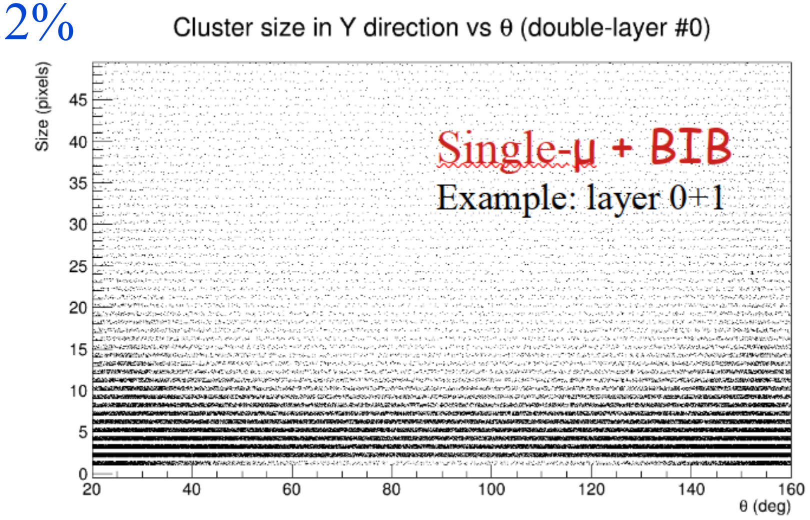
S. Pagan Griso





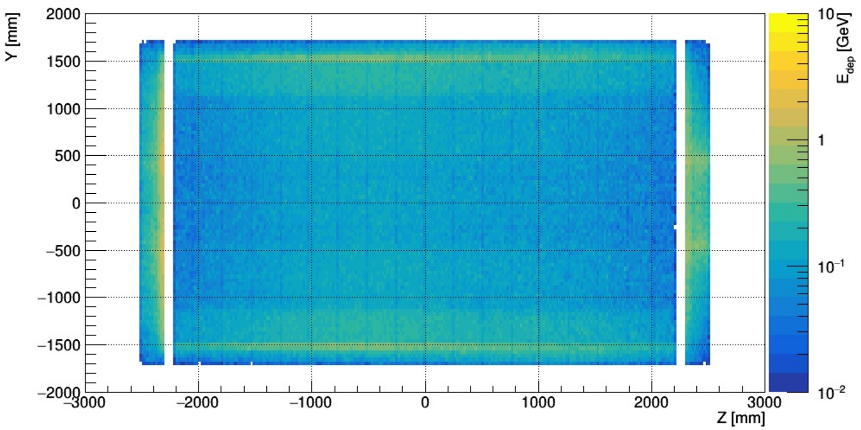
Cluster size in Y direction vs θ (double-layer #0)

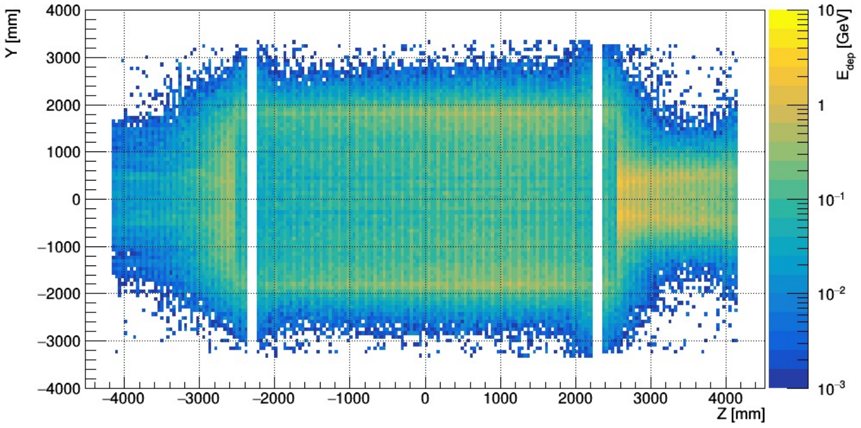
Cut Efficiency
Single muon: 99.7%
Single muon + BIB: 55.2%



- If the primary vertex is known can be very effective
- To be tuned in presence of secondary vertices or long-lived particles

Calorimeter at $\sqrt{s}$ =1.5 TeV

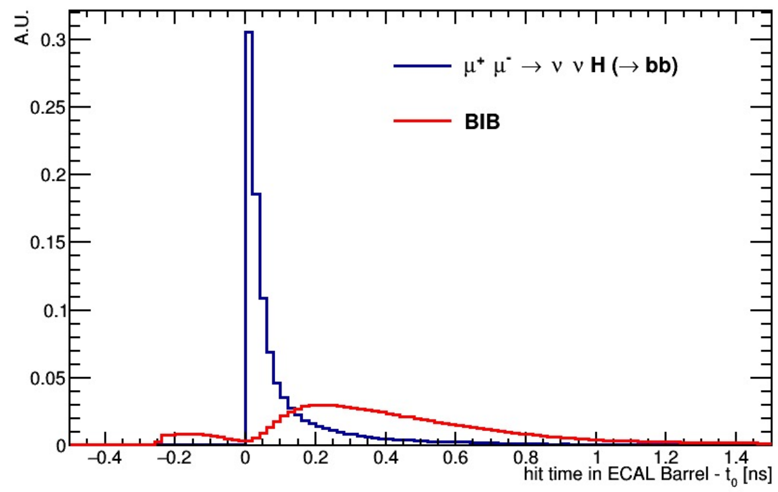


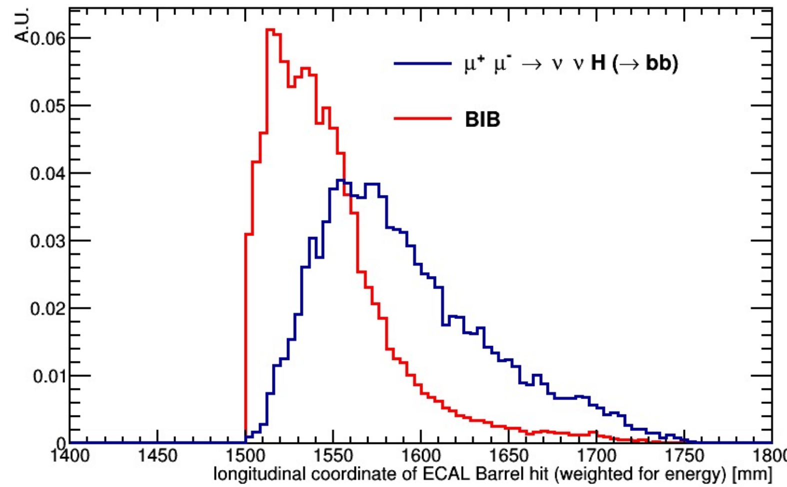


BIB deposits large amount of energy in both ECAL and HCAL

Timing and shower profile should be used in clusters reconstructions

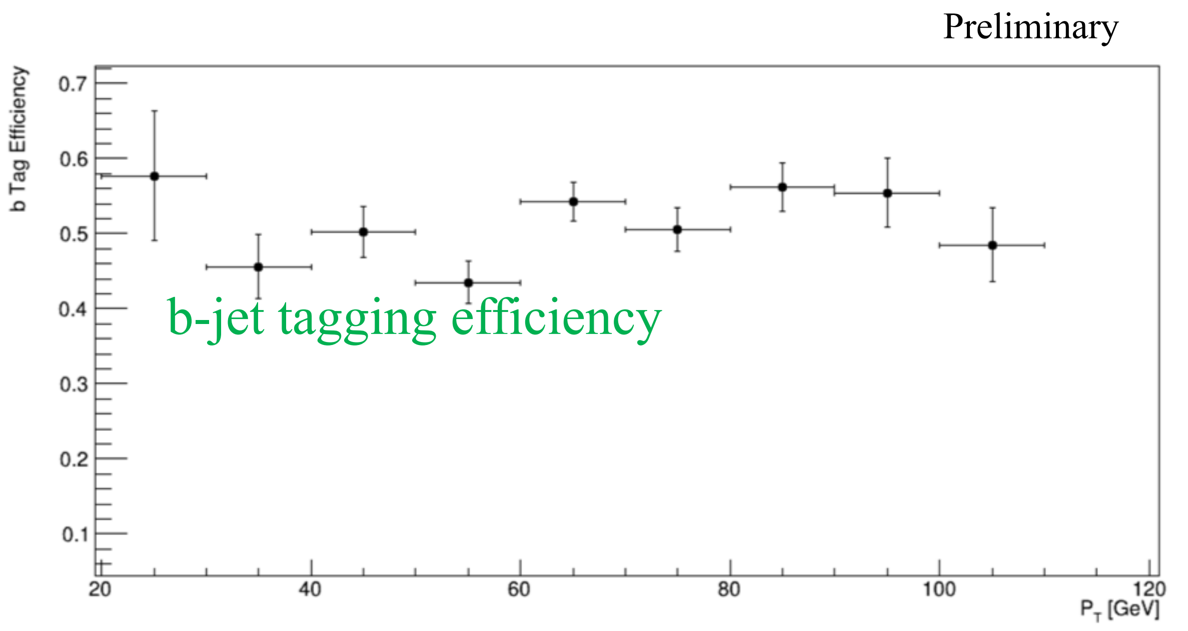
ECAL barrel hit arrival time – t_0

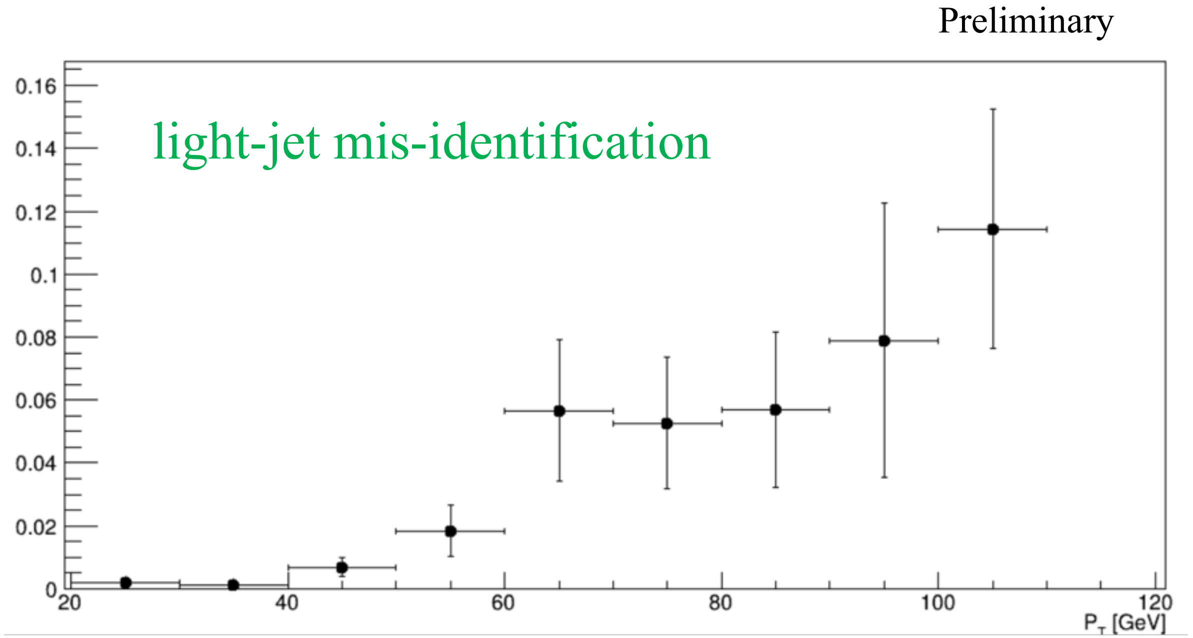




b-jets Secondary Vertex Reconstruction at $\sqrt{s}$ =1.5 TeV

L. Sestini, L. Buonincontri





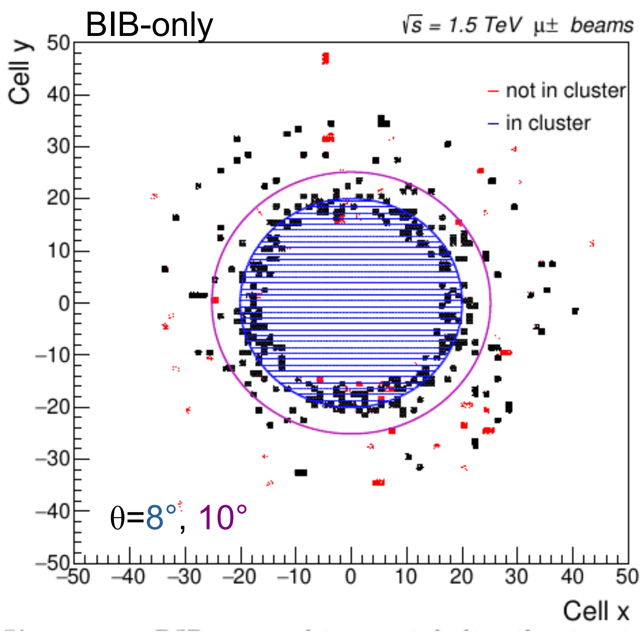
b-jet identification

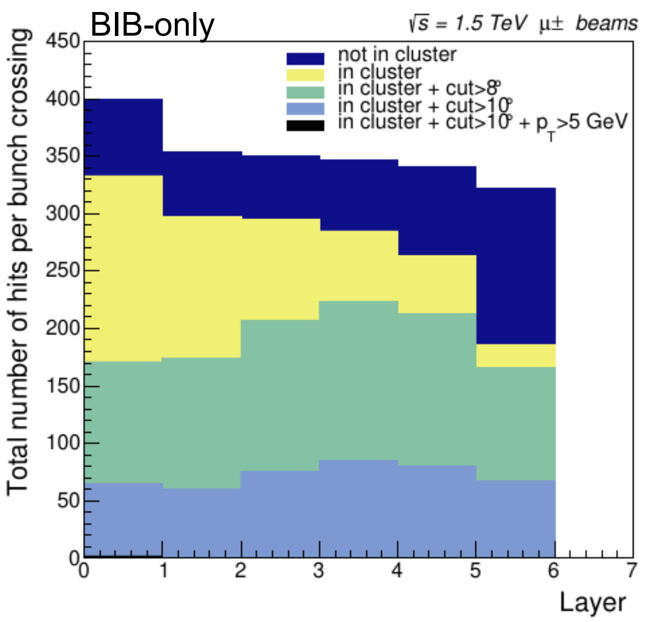
- Tracks selected by the regional tracking
- Secondary vertex requested to be inside the jet cone
- First step toward a b-jet tagging, under development a ML-based algorithm

Muon System

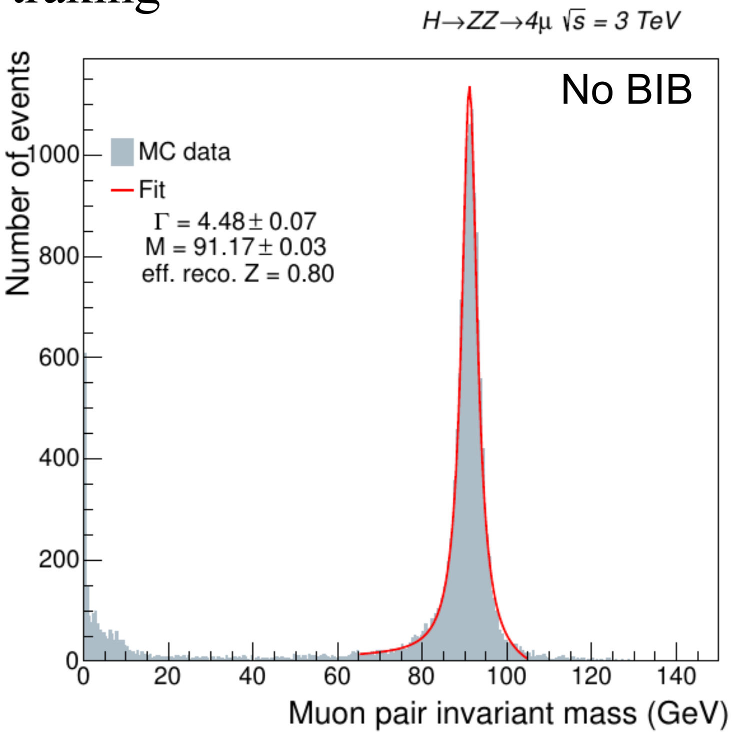
C. Aimè

- Low BIB contribution, concentrated in the low-radius endcap region
- It can be effectively removed with geometrical cuts





Muon reconstructed with high efficiency, can be used as seed for traking



Next Steps

A. Mereghetti

- Study Beam-Induced Background at $\sqrt{s} = 3$ TeV, use MAP IR and the nozzle of $\sqrt{s} = 1.5$ TeV, then
  - Optimize nozzle
  - Optimize IR

- Detector studies are just at the first step, a lot of room for improvements!
- Physics objects performance are very good even if not optimize, room for improvements in particular with ML techniques
- Dedicated studies and optimization is needed for the forward region, covered by the nozzle

Strong collaboration between accelerator and detector physicists is mandatory for the proper MDI design.