Status of the reconstruction algorithms with BIB

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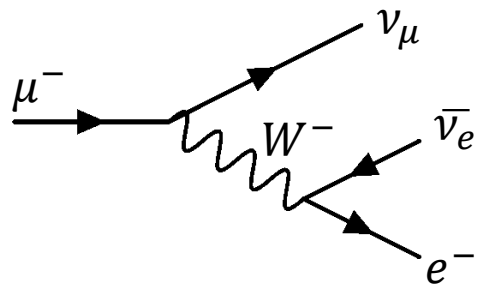
Summary

1. Beam-Induced Background (BIB) in a nutshell
2. Current detector design @ 3 TeV
3. Physics objects reconstruction and performance
    1. Tracks
    2. Electron and photon
        1. A case study: CRILIN
    3. Jets
    4. Muons
4. Conclusions and perspectives

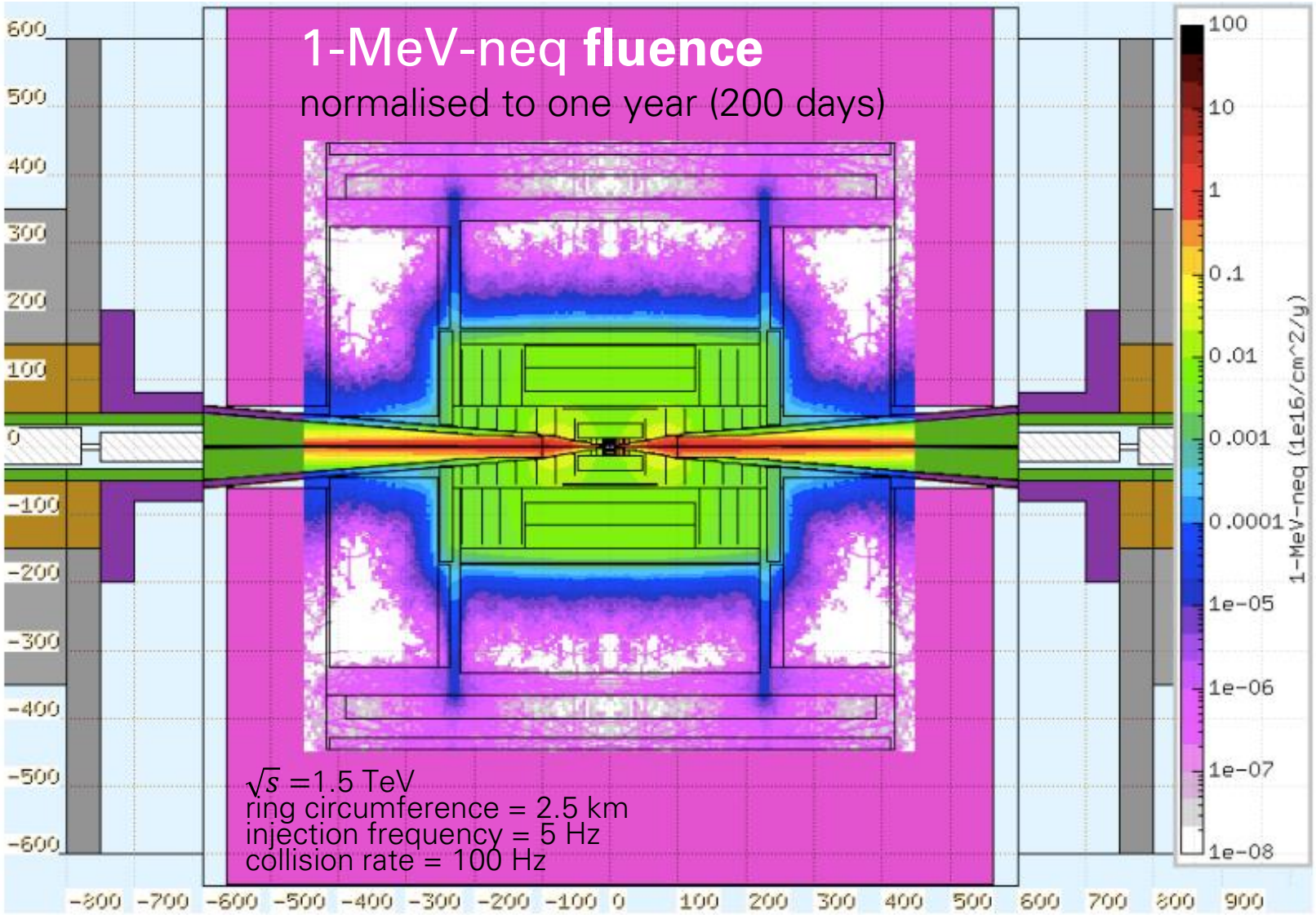
The results presented - unless otherwise specified - are published in
arXiv:2303.08533 *Towards a muon collider*

Beam-induced background

Muon decay originates electrons and positrons

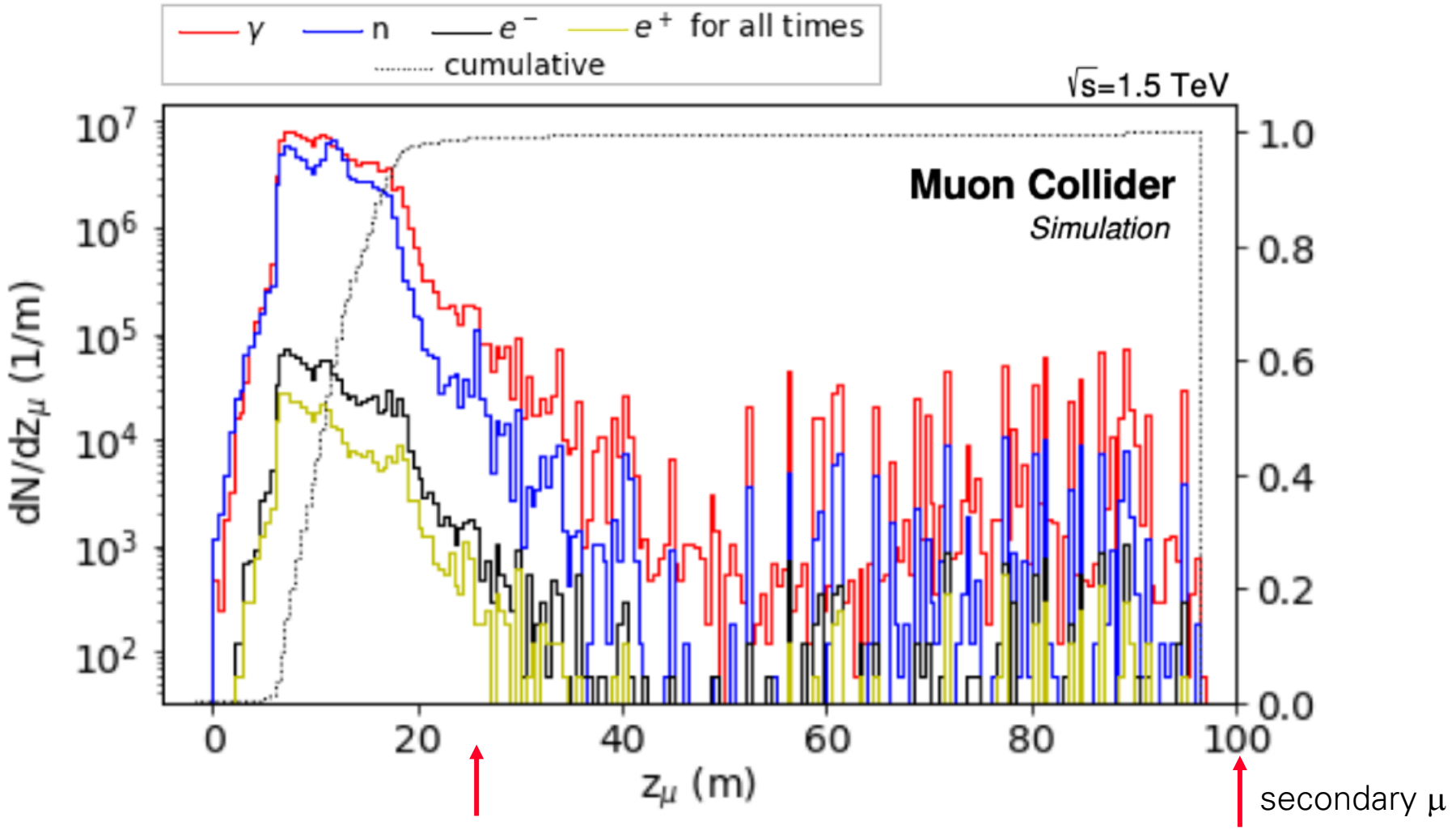


subsystem	fluence
tracker	~10^{14}-10^{15} cm^{-2}y^{-1}
ECAL	~10^{13}-10^{14} cm^{-2}y^{-1}
HCAL	~10^{11}-10^{12} cm^{-2}y^{-1}
muon	~10^{10} cm^{-2}y^{-1}



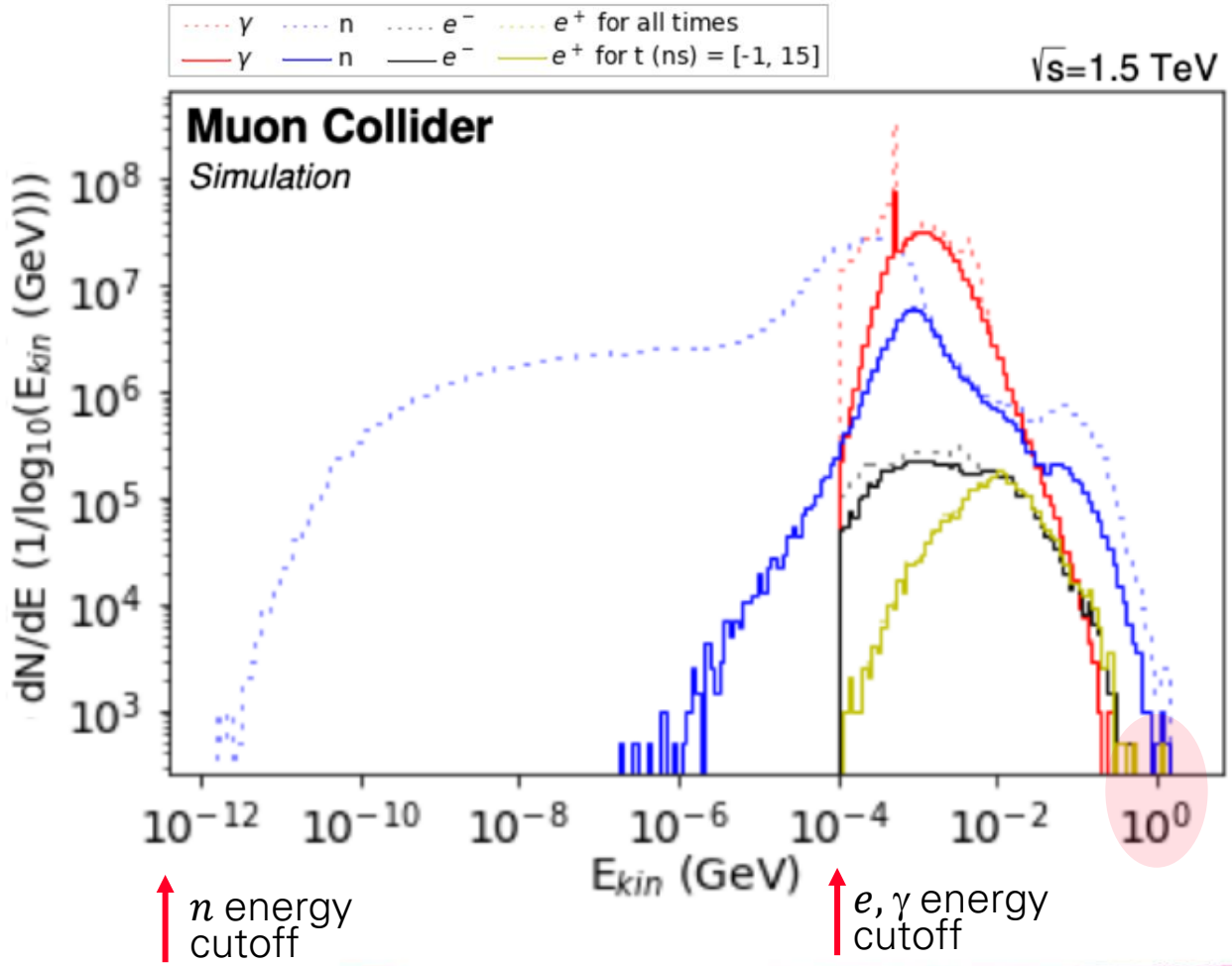
MDI joint session:
Detectors + Collider + BM

Muon decay longitudinal distance



BIB properties

- Large number of particles (~4 10^8)
- Low momentum
- Broad arrival time in the detector (few ns for e and γ, few μs for n)



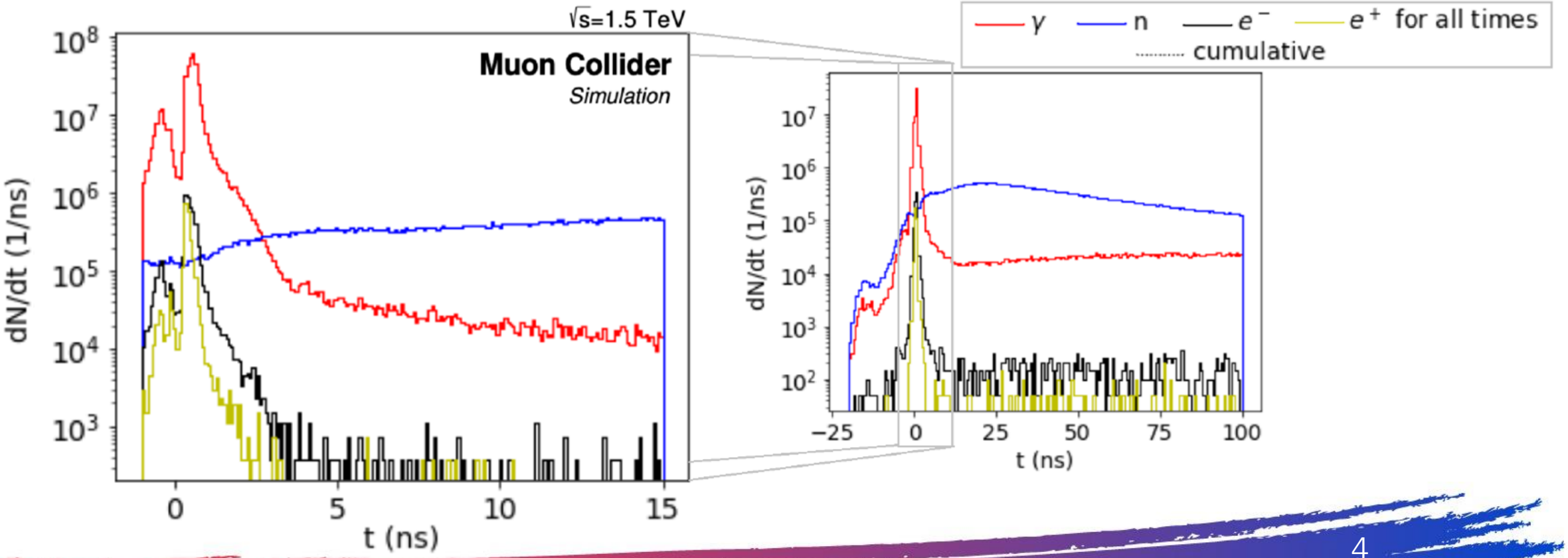
charged hadrons and secondary muons can reach higher energies

→ their rate is low (~10^3)

BIB properties

- Large number of particles (~4 10^8)
- Low momentum
- Broad arrival time in the detector (few ns for e and γ, few μs for n)

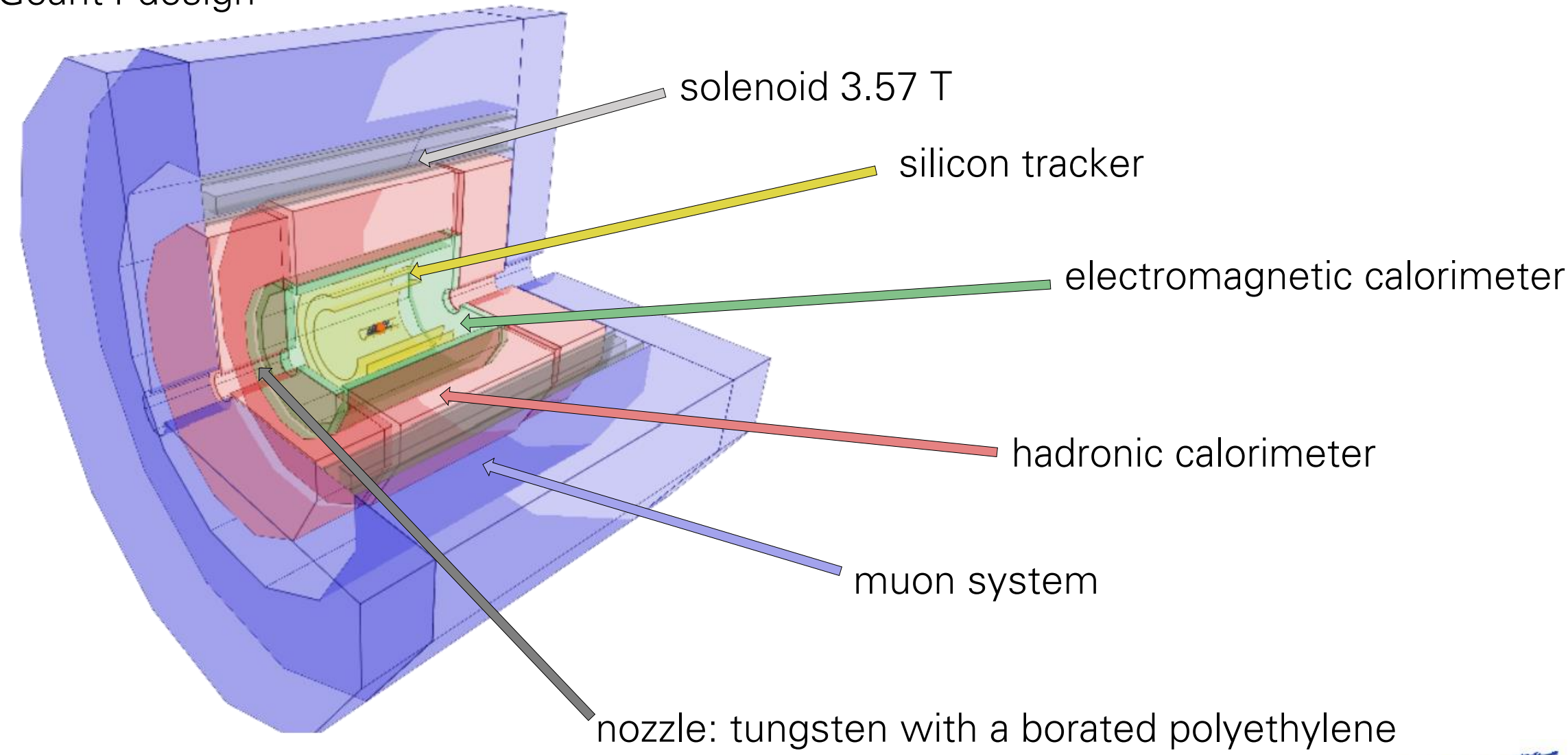
→ Time information from detectors useful for BIB suppression



Detector

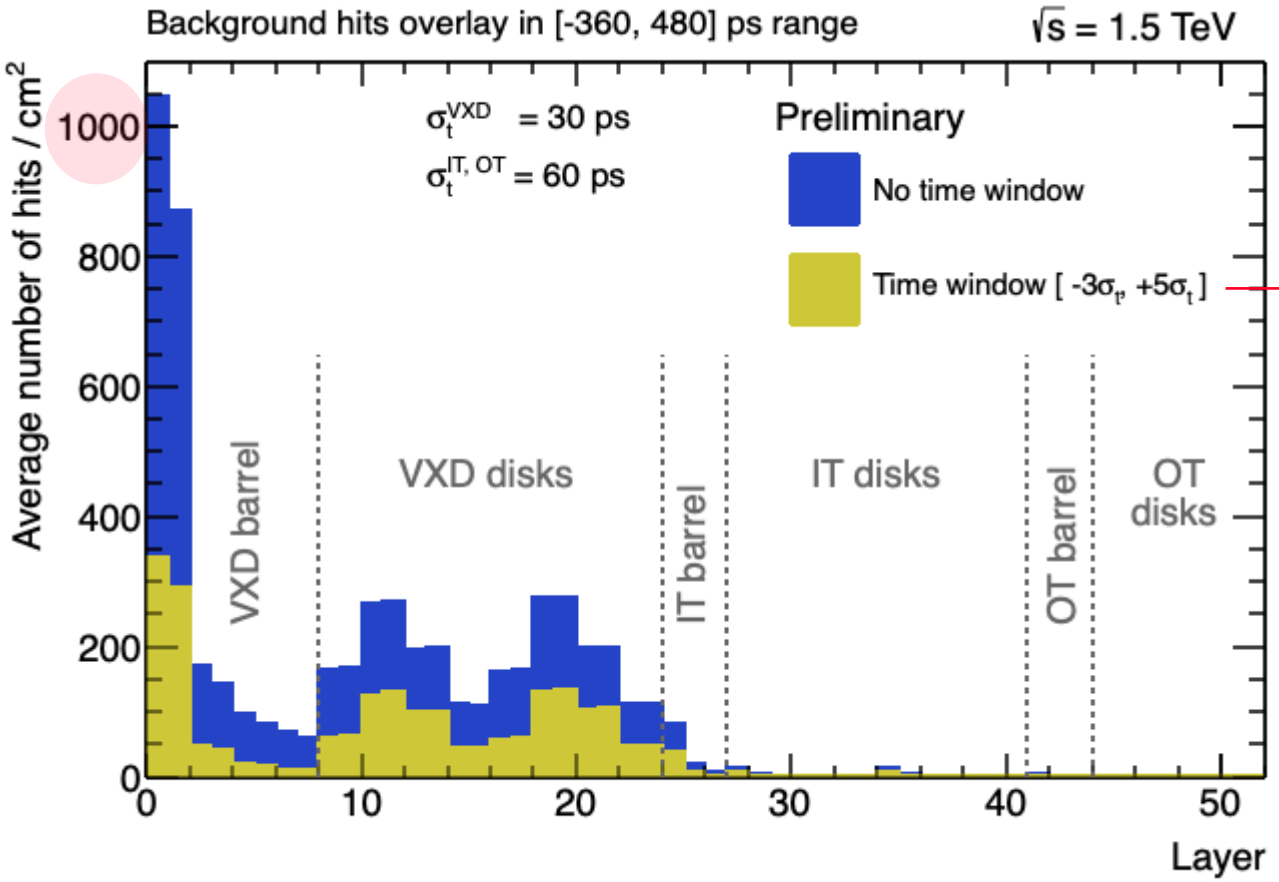
N.Pastrone *Muon Collider detectors in the ECFA/US detector R&D roadmap*
S.Jindariani *Detector R&D*
S.Pagan Griso *Detector design for √s = 1.5/3.0 TeV and path towards 10 TeV*

Geant4 design



BIB in the tracker system

BIB particles generate ~500 000 hits in the most inner layer of the tracker



Detector Reference	Hit Density [mm^{-2}] MCD	ATLAS ITk	ALICE ITS3
Pixel Layer 0	3.68	0.643	0.85
Pixel Layer 1	0.51	0.022	0.51

→ reduction of a factor 2

Track reconstruction approches

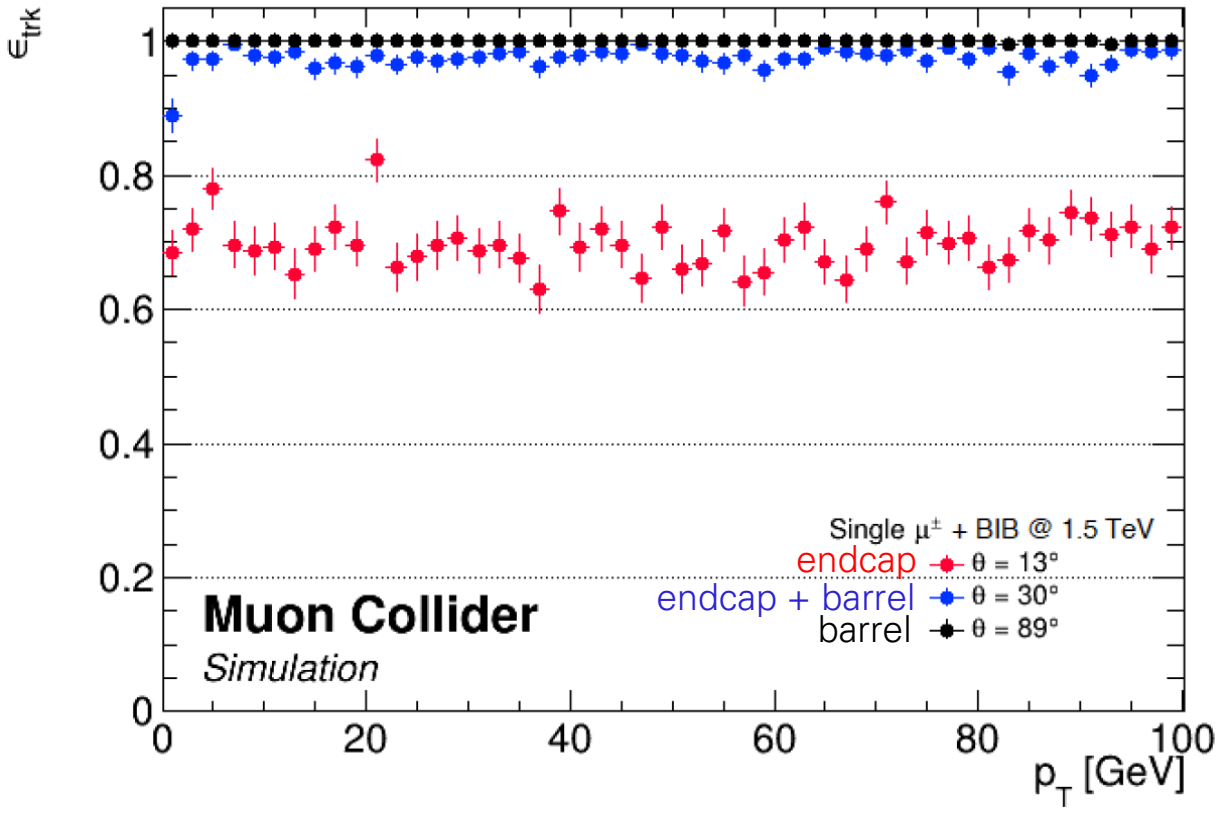
	① conformal tracking (CT)	② combinatorial Kalman filter (CKF)
developed for	electron-positron colliders	hadron colliders
implemented in	ILCSoft	A Common Tracking Software (ACTS)
time to reconstruct a single event	two weeks	four minutes

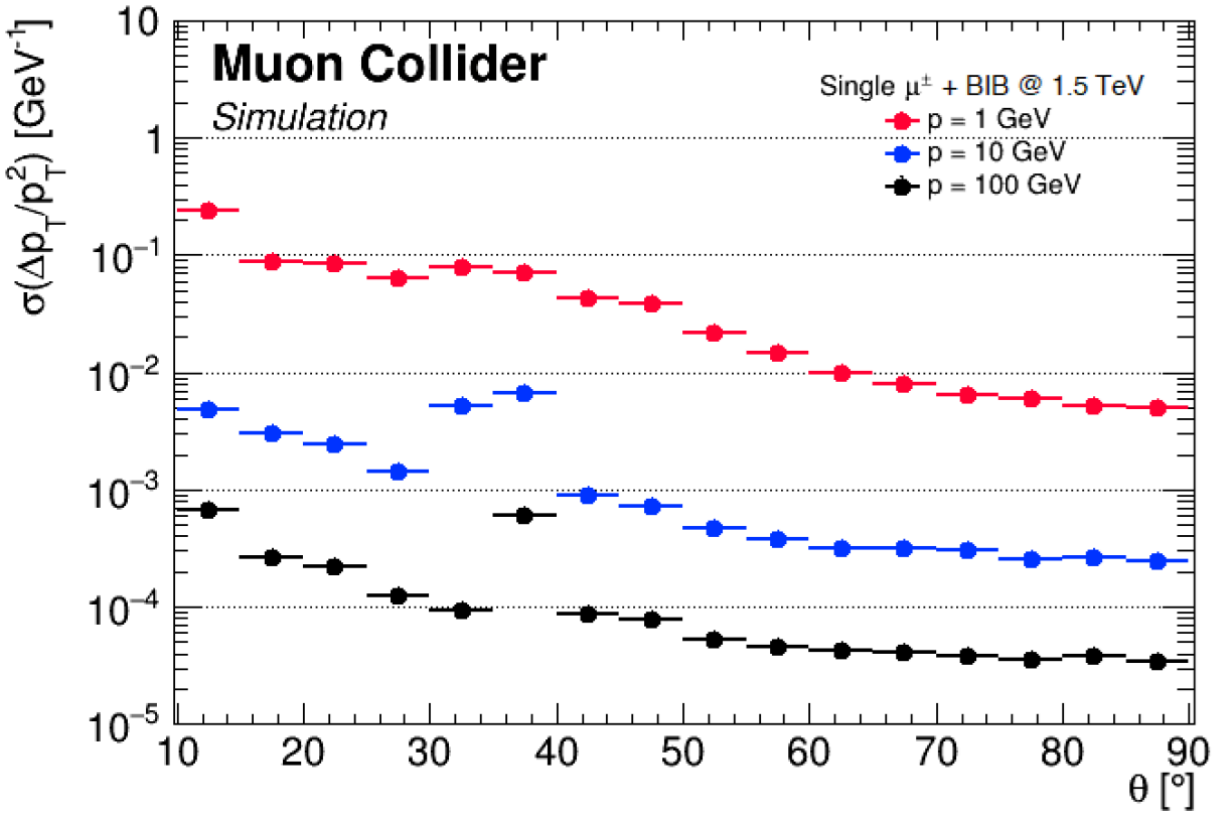
strategy: reduce the input hits

- Region of Interest
- double layer filter

① CT

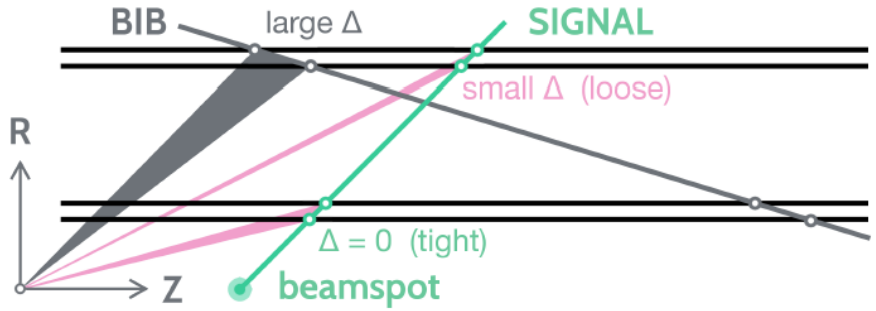
- Region of Interest: only hits within a cone of ΔR =0.5 around the signal muon
- double layer filter





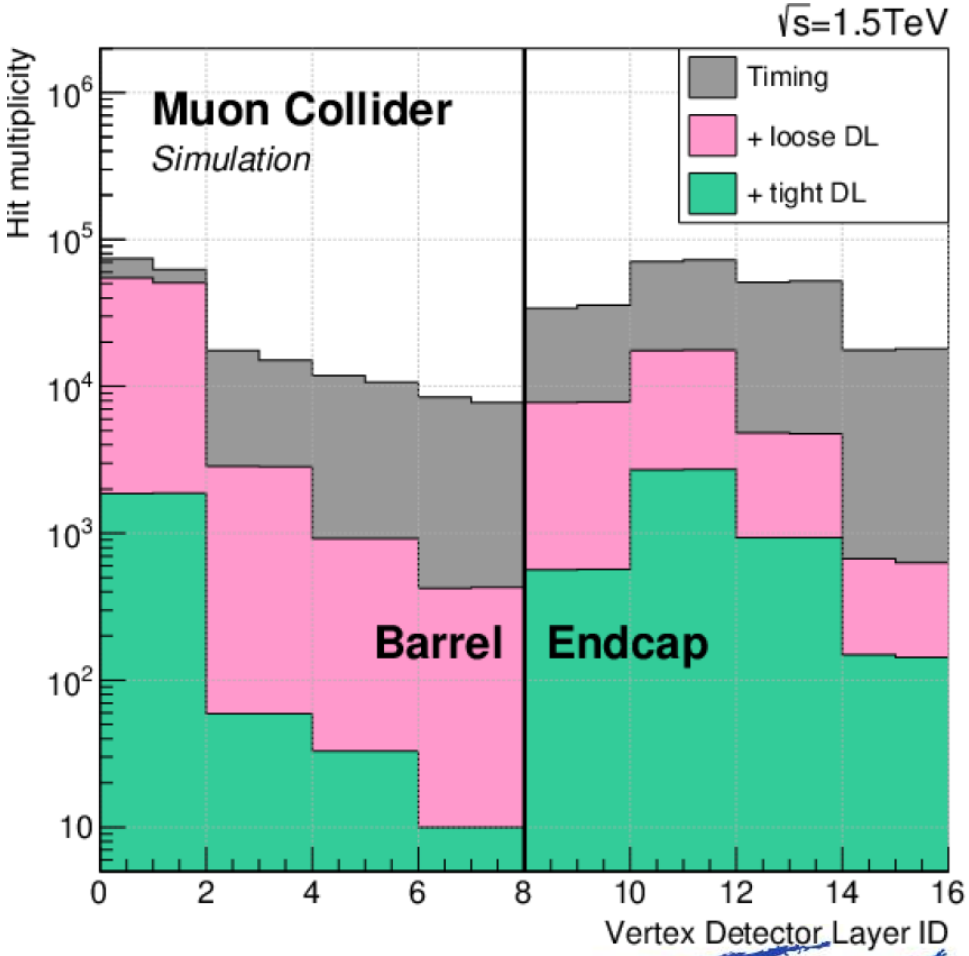
① CT

- Region of Interest
- double layer filter



	Layer IDs	Barrel 0,1	Barrel 2,3	Barrel 4,5	Barrel 6,7	Endcap 0,1	Endcap 2,3	Endcap 4,5	Endcap 6,7
Loose DL selections	Max. $\Delta\phi$ (mrad)	2.8	2.0	1.7	1.5	2.1	1.7	1.6	1.5
	Max. $\Delta\theta$ (mrad)	35	18	10	6.5	3.5	1.5	0.7	0.5
	Hit surival fraction	55%				18%			
Tight DL selections	Max. $\Delta\phi$ (mrad)	3.0	2.0	1.6	1.5	2.2	1.8	1.7	1.6
	Max. $\Delta\theta$ (mrad)	0.5	0.4	0.3	0.25	0.2	0.18	0.12	0.1
	Hit survival fraction	2%				2%			

Interaction point known precisely



Loose selection → two days/event

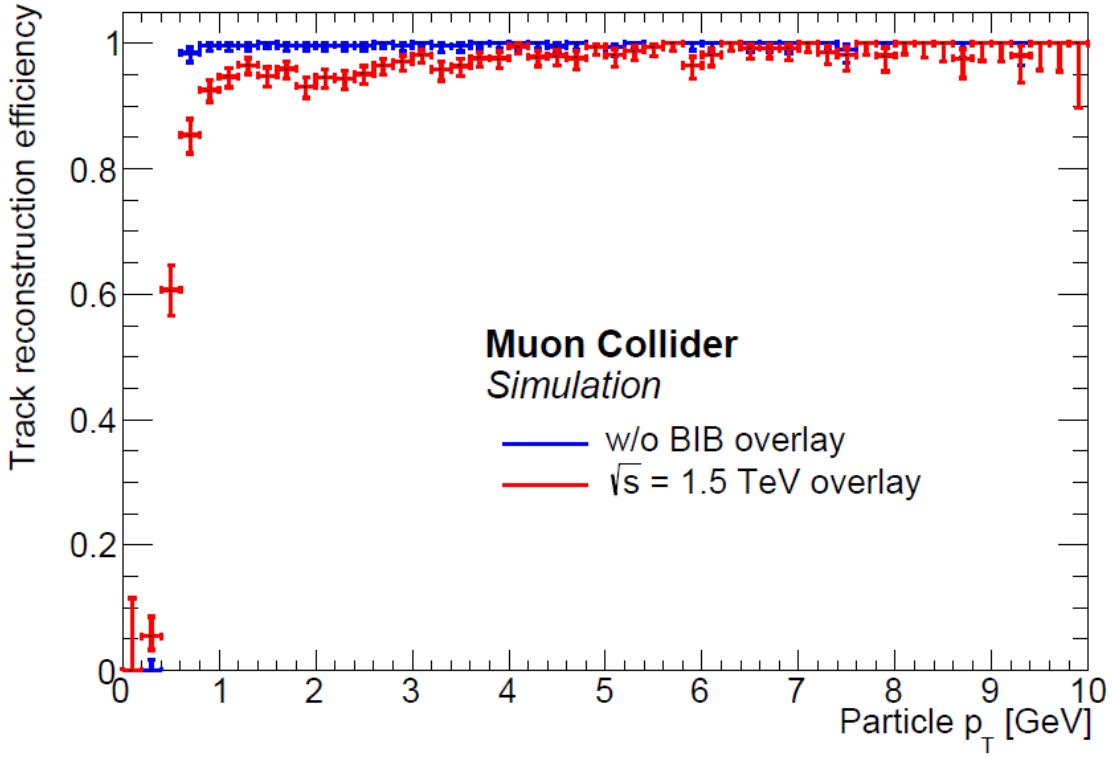
Tight selection → two minutes/event

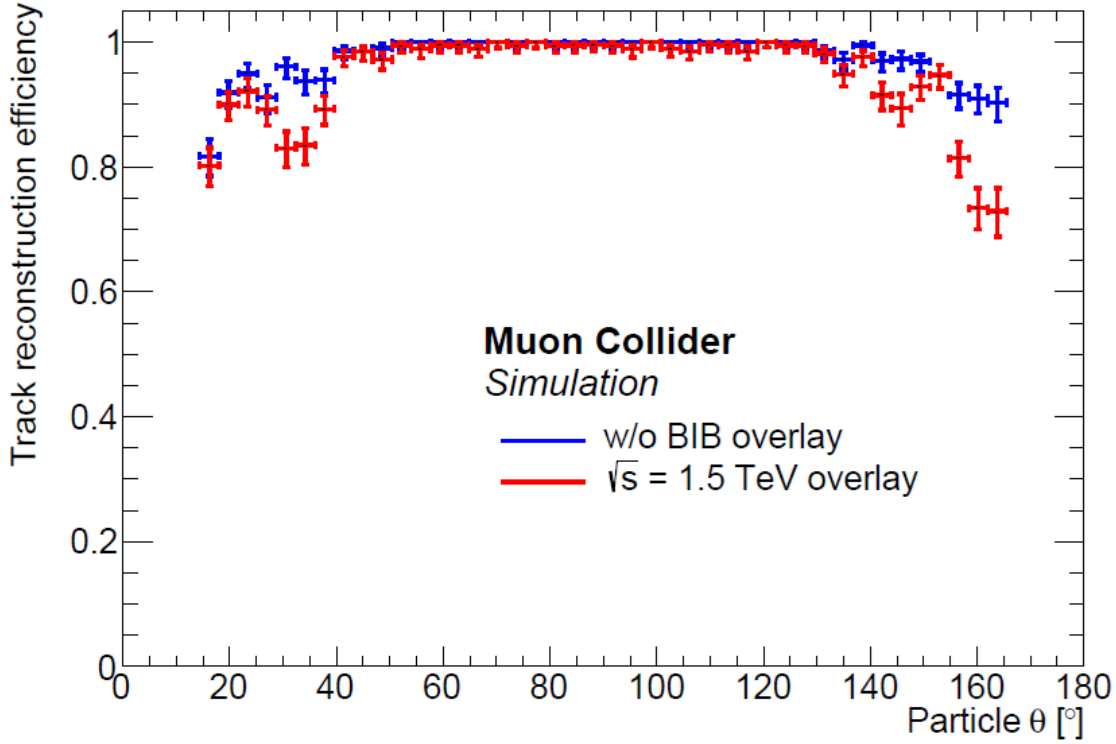
② CKF in ACTS

seeds formed from hit triplets in the four layers of the Vertex Detector: ~150000 per event

Possible strategy under study

seeding from the Outer Tracker + track extrapolation towards the centre

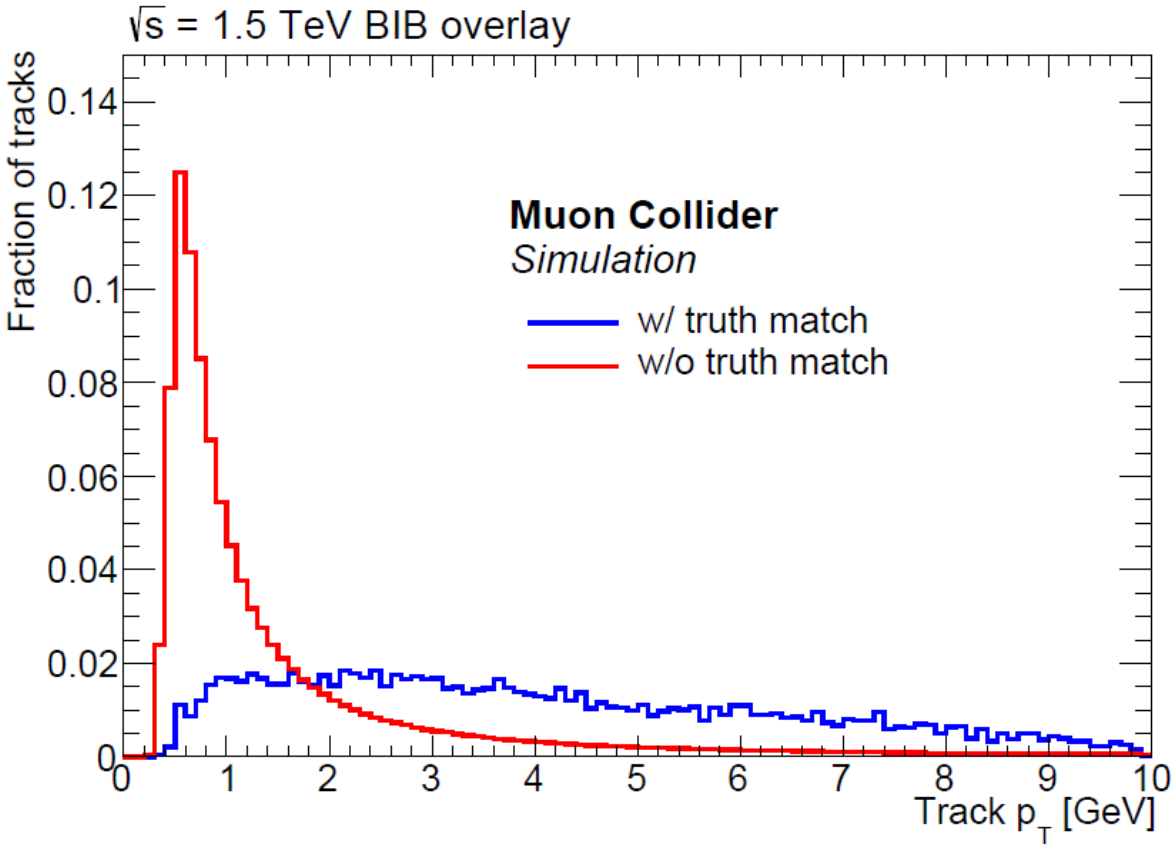


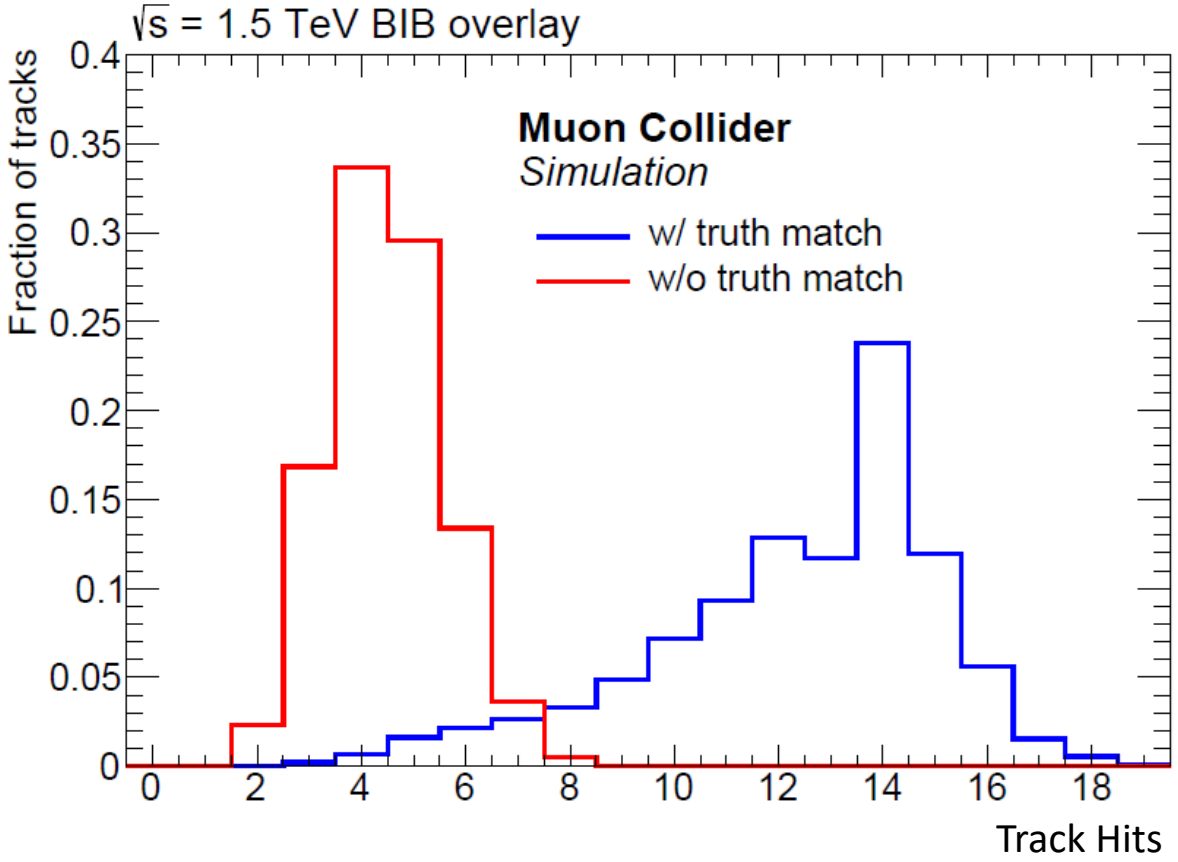


② CKF in ACTS

Fake tracks ~100, 000 per event

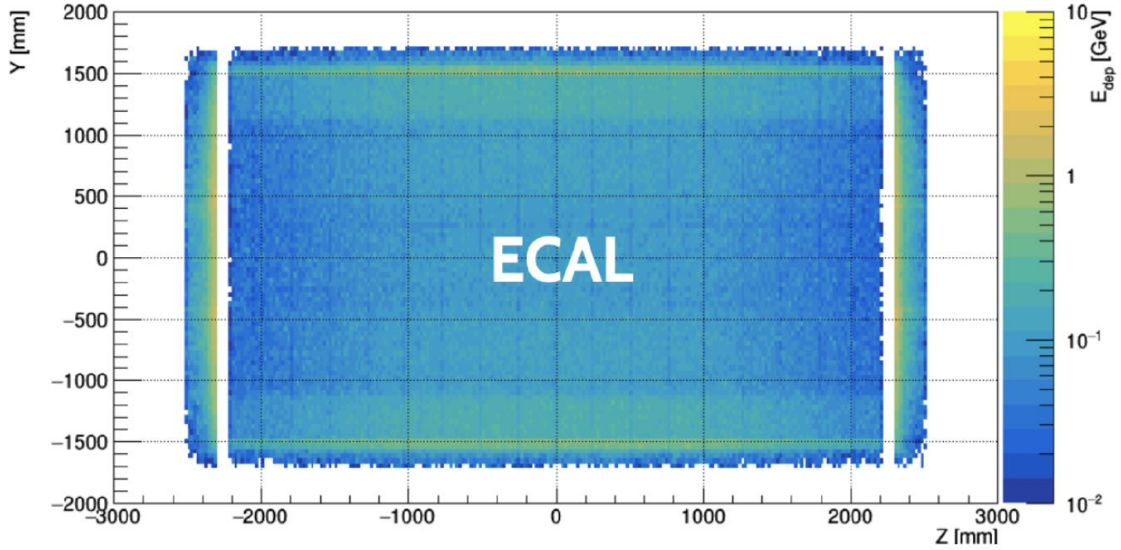
- Low momentum
- Small number of hits

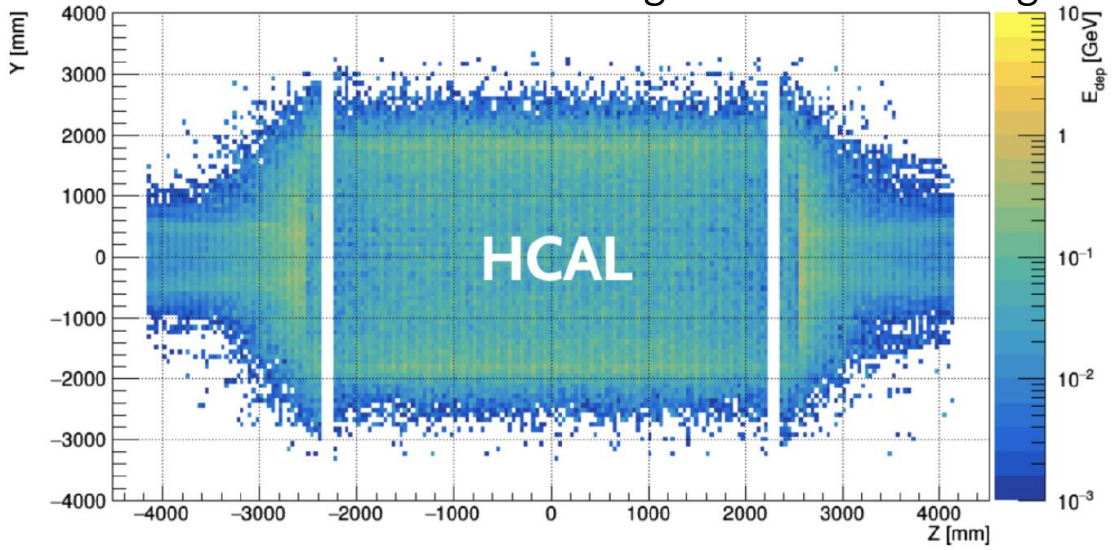


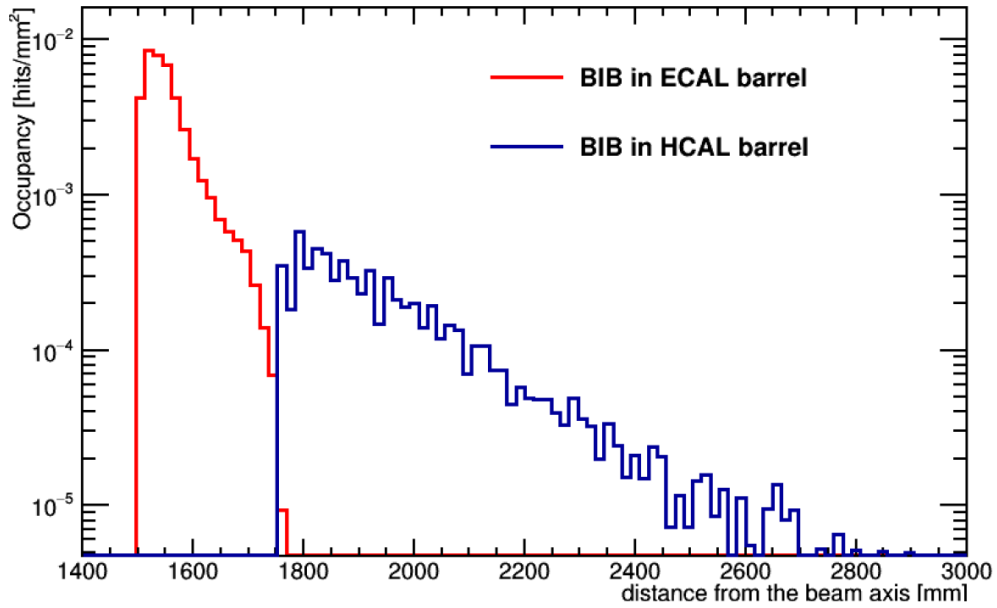


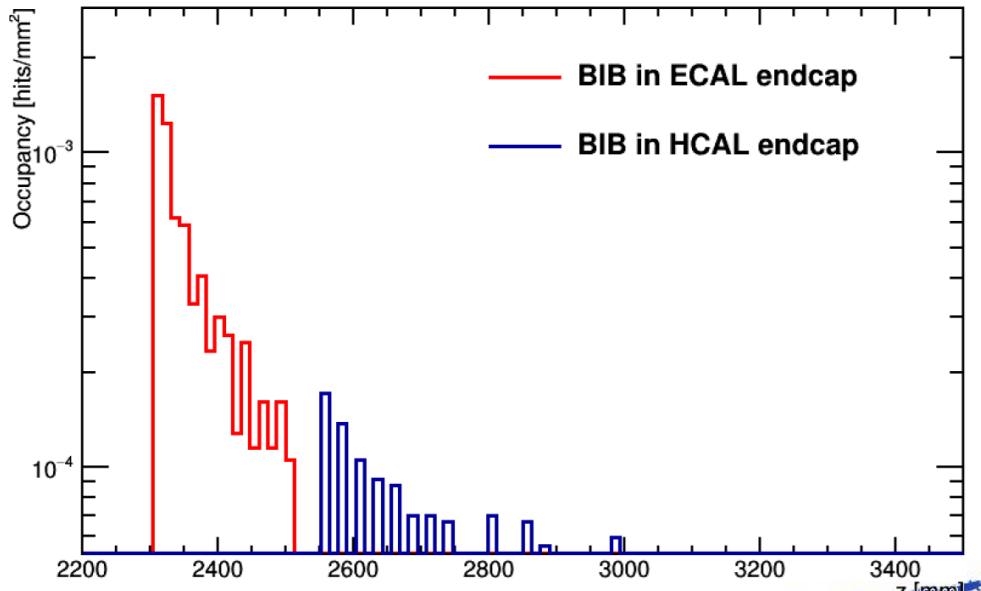
BIB (γ+n) in the calorimeters

Energy deposited by BIB in a single bunch crossing



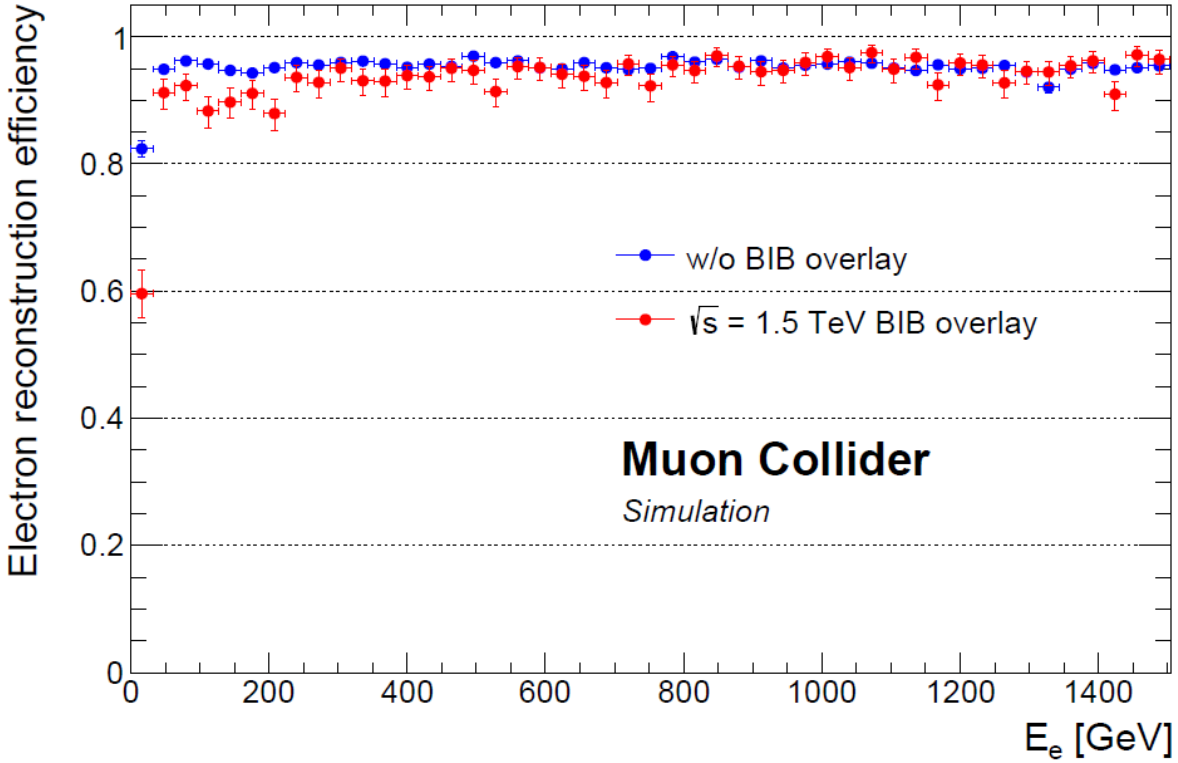


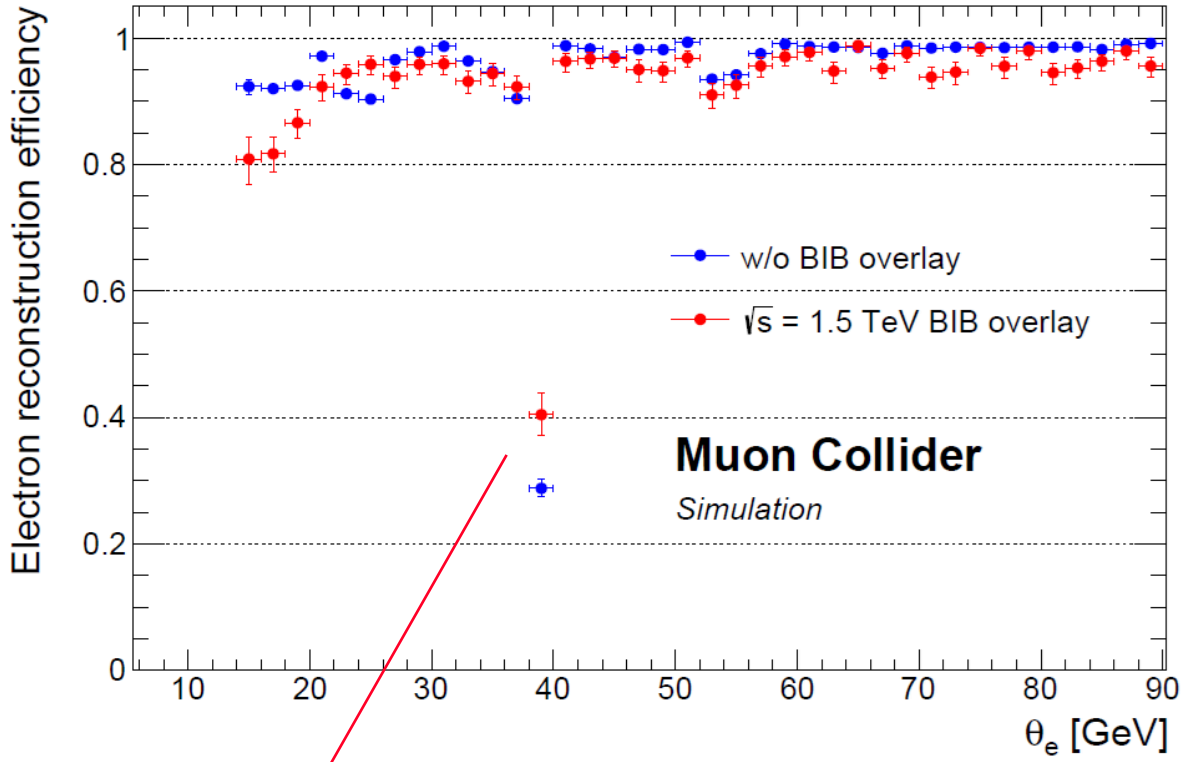




Electron reconstruction

ECAL clusters (hits energy > 5 MeV) matched with tracks (DL+CKF) if ΔR <0.1

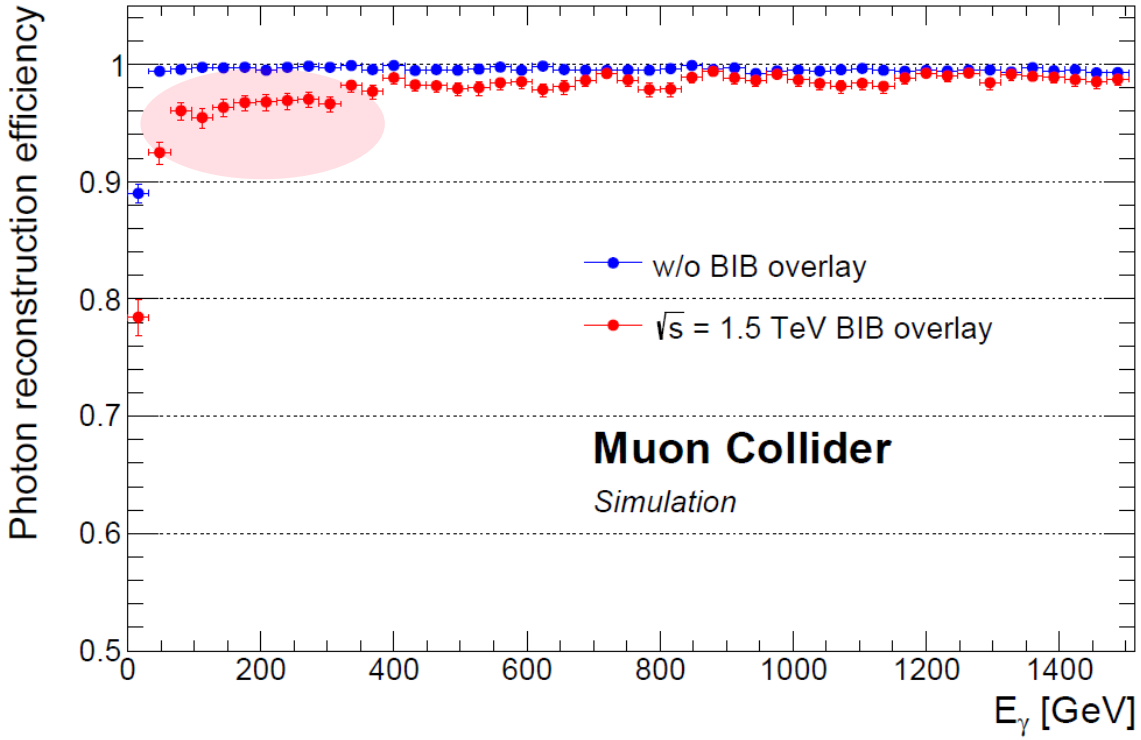


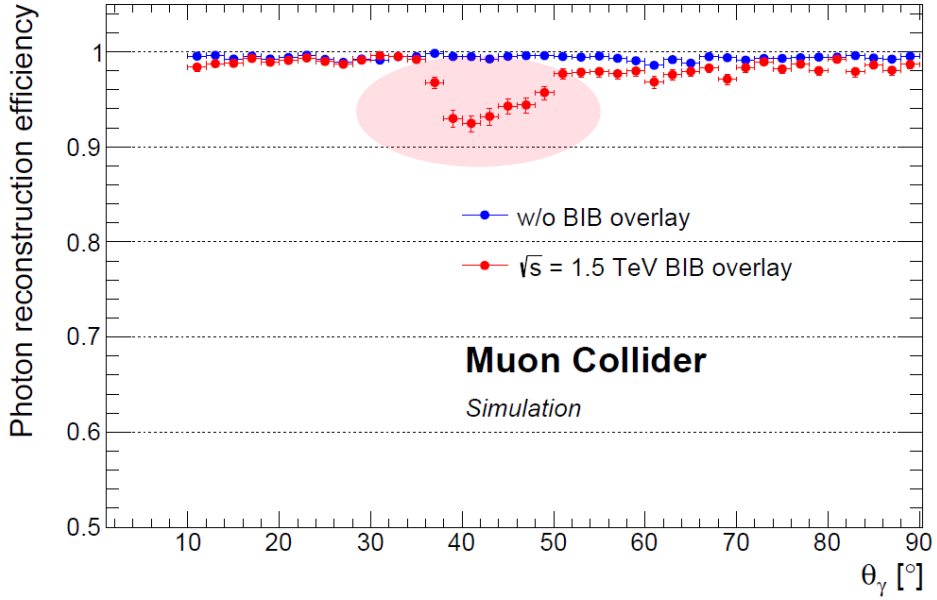


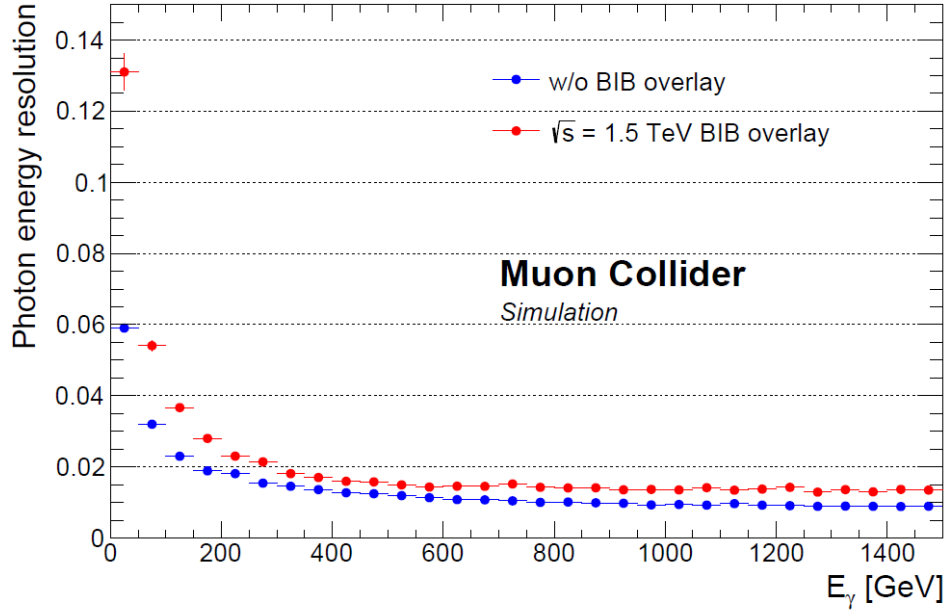
Effect of DL filter
in forward region

Photon reconstruction

ECAL clusters (hits energy > 2 MeV) matched with generated photons if ΔR <0.05





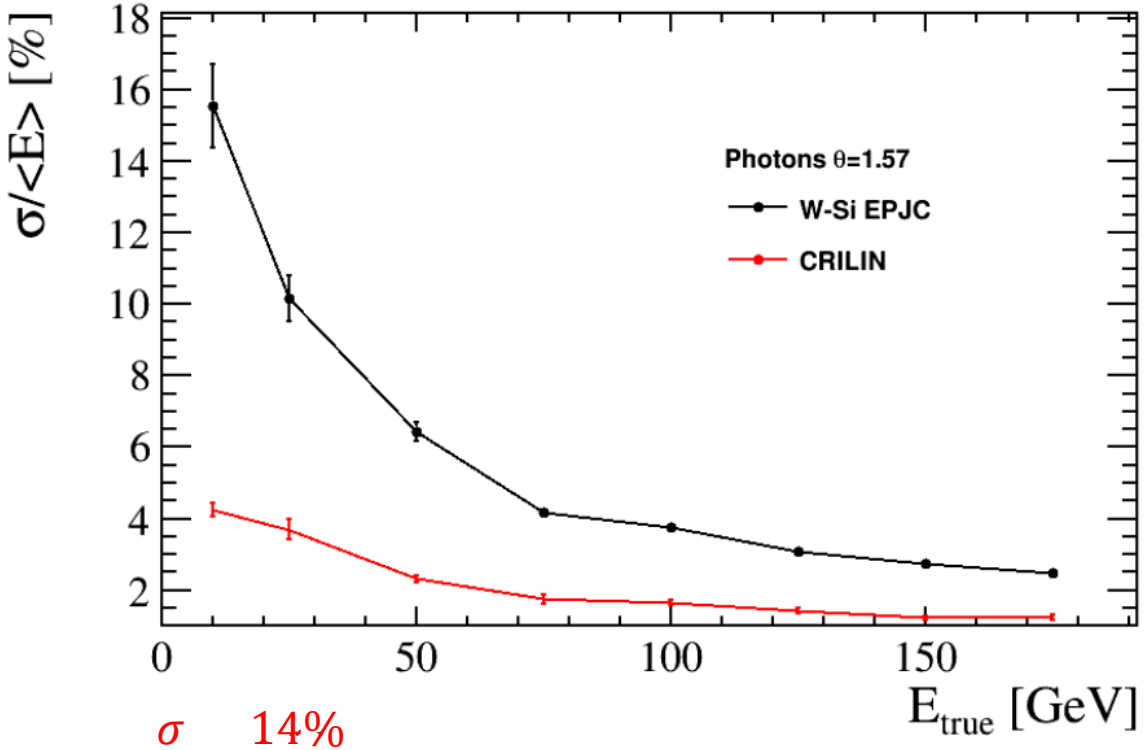


Photon to electron misidentification rate ~0.3%

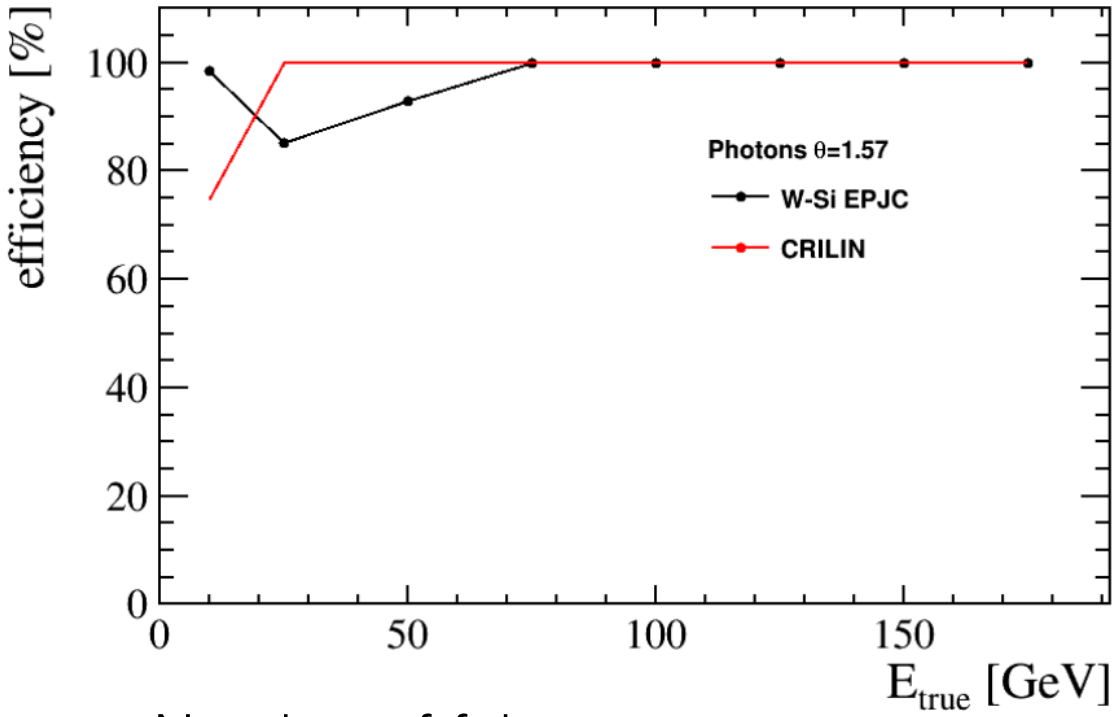
Photon reconstruction with CRILIN for ECAL barrel

Semi-homogeneous calorimeter

- Cell: 40 mm PbF2 + 3 mm SiPM + 1 mm electronics + 1 mm air
- 21.5 X0
- Integration time = 25 ns



$$\frac{\sigma}{E} \cong \frac{14\%}{\sqrt{E}}$$



Number of fake

- Crilin ~0
- W-Si ~60

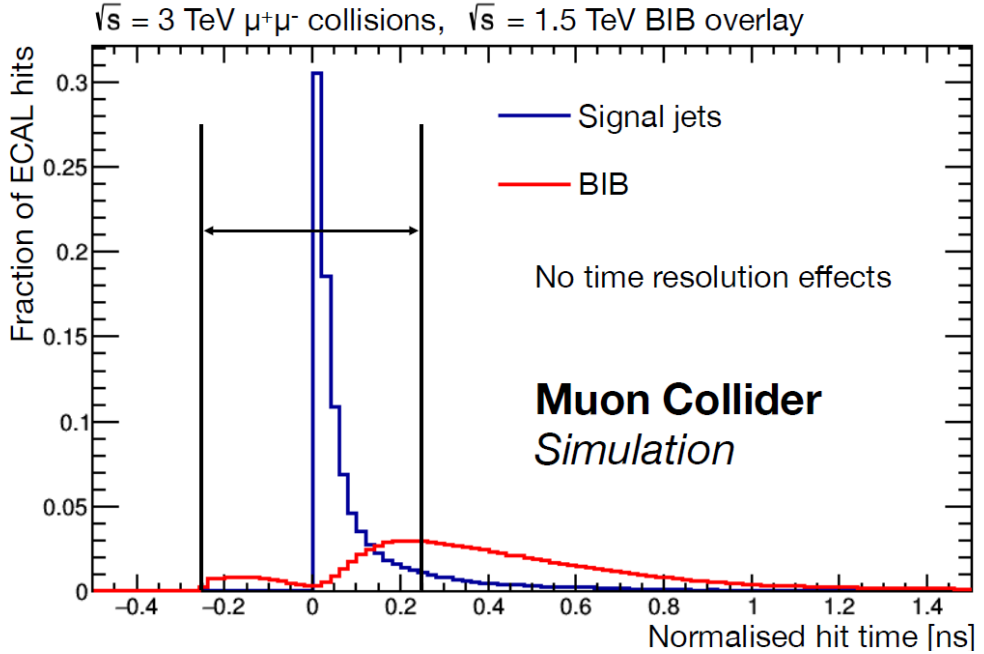
L. Sestini *Improved calorimeter reconstruction at Muon Collider*
https://indico.cern.ch/event/1274190/contributions/5351484/

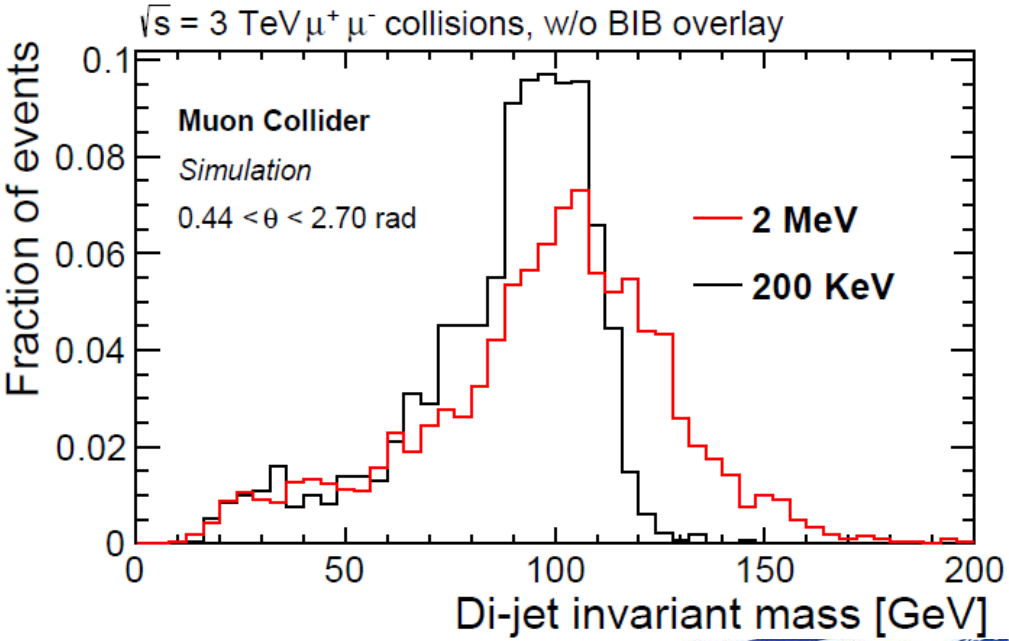
Jet reconstruction

Goal separate W and Z in dijet channel
(3-4% jet energy resolution for p_t >100 GeV)

Procedure

- Tracks reconstructed with CKF
- calorimeter hits selected (hit time window + energy threshold – 2 MeV)
- PandoraPFA algorithm for particle reconstruction
- Particles clustered into jets with k_t algorithm
- Fake jets removed
- Energy correction applied

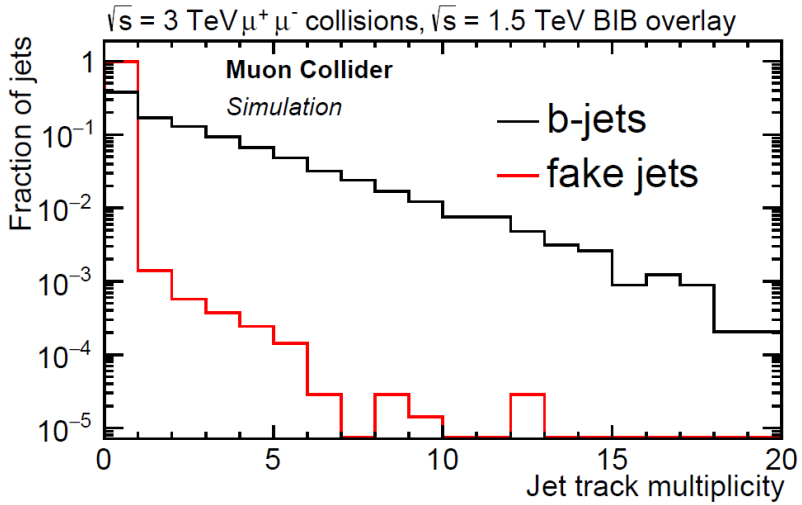


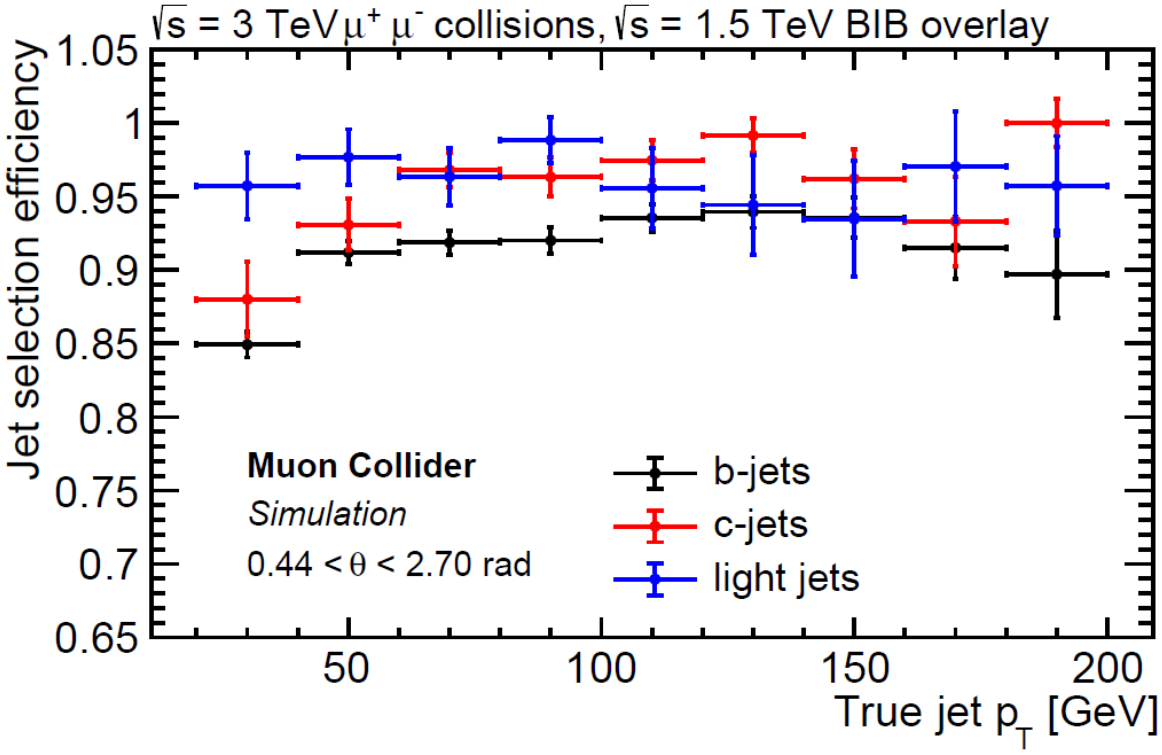


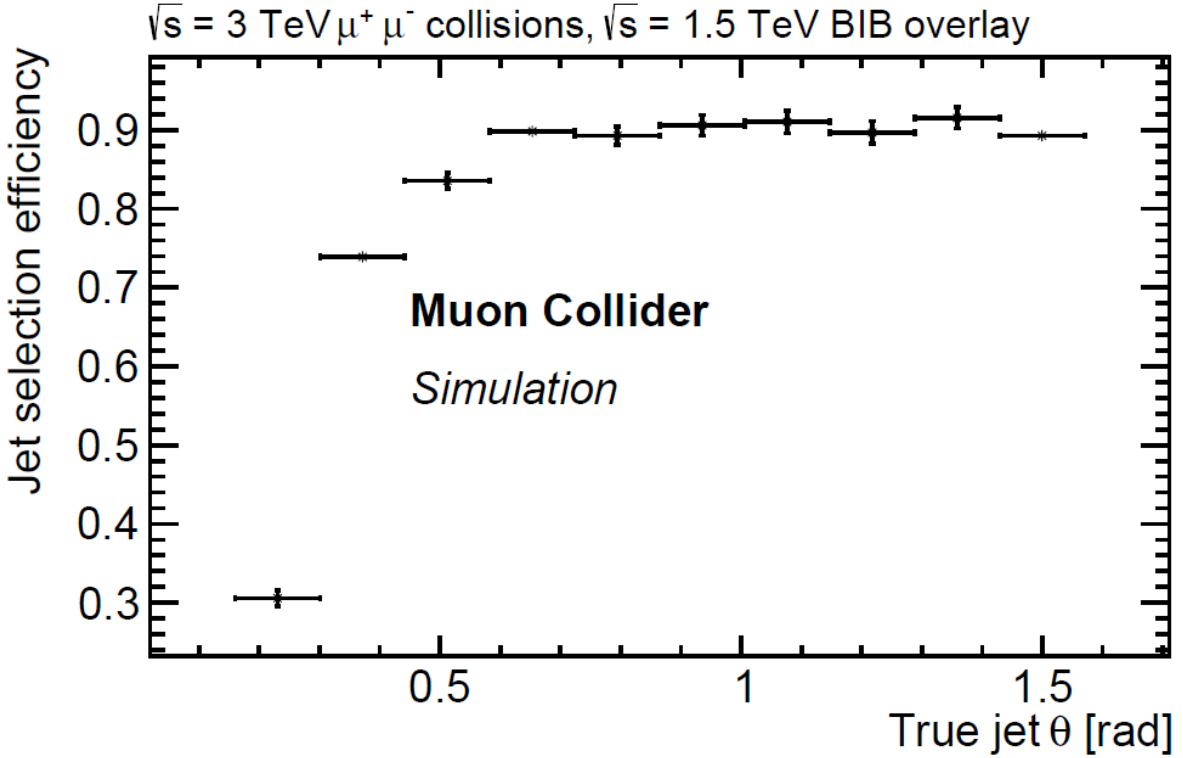
Fake jets ~13 per event

- Number of tracks is the most discriminating criterium (at least 1)

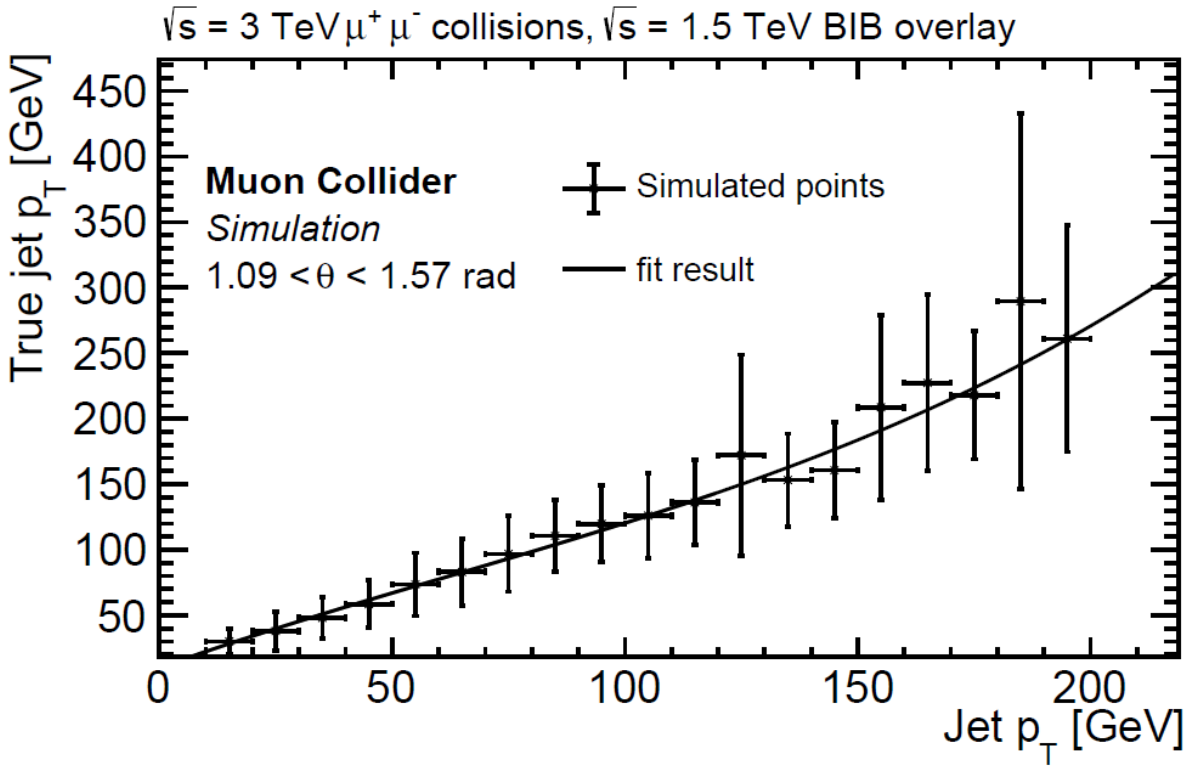
Fake rate is well below 1%

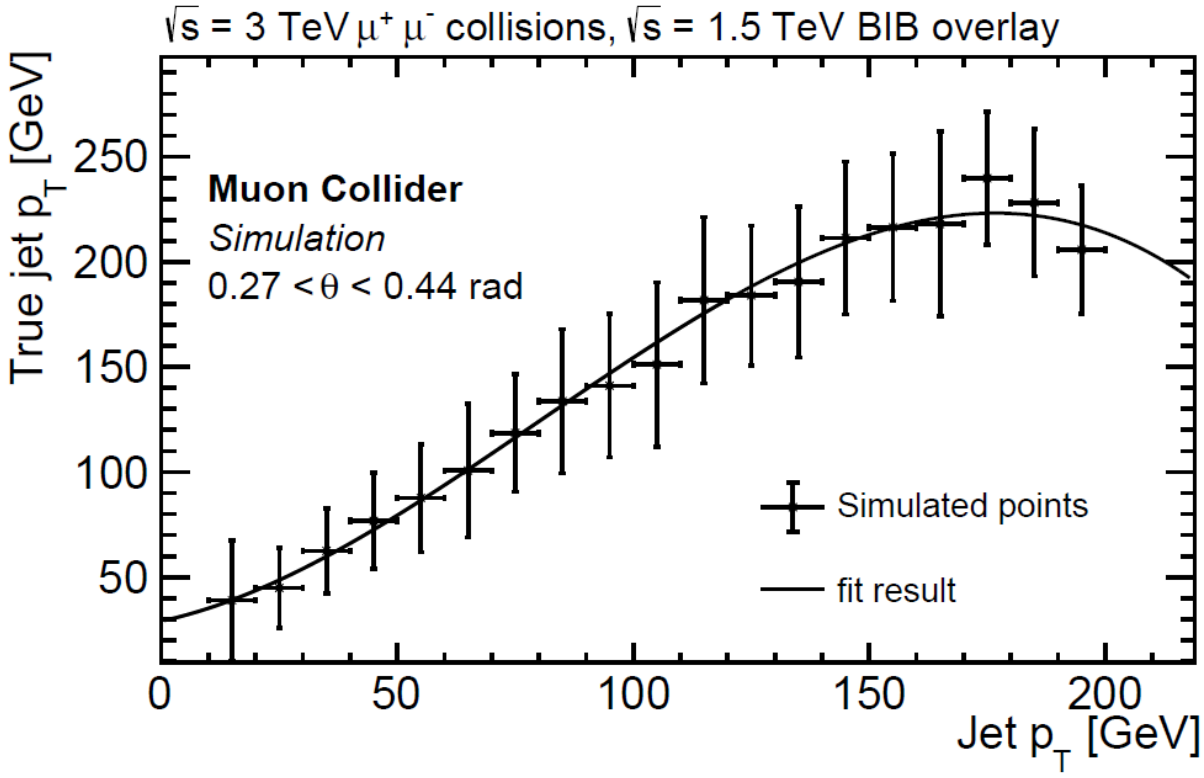




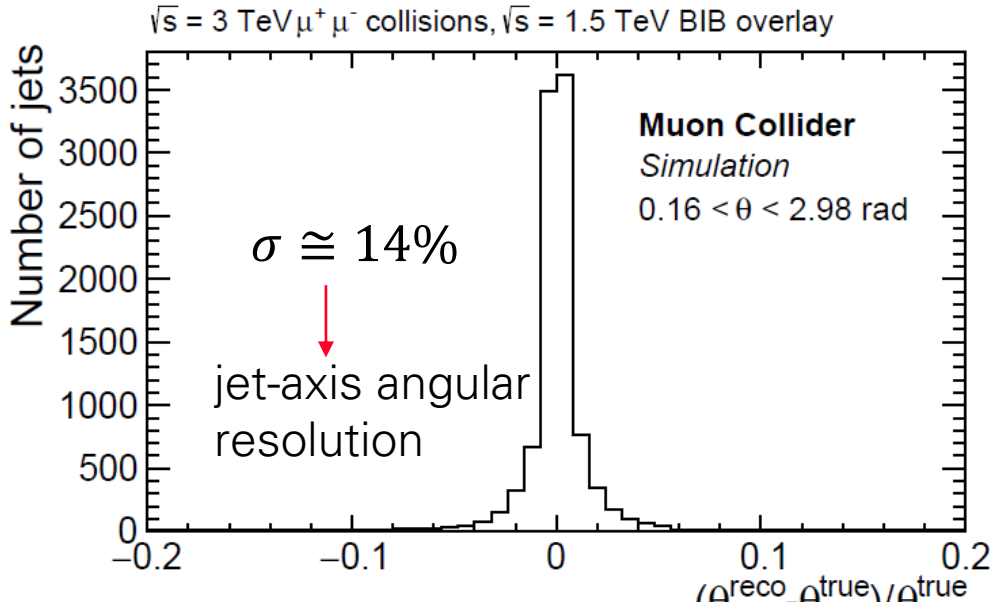


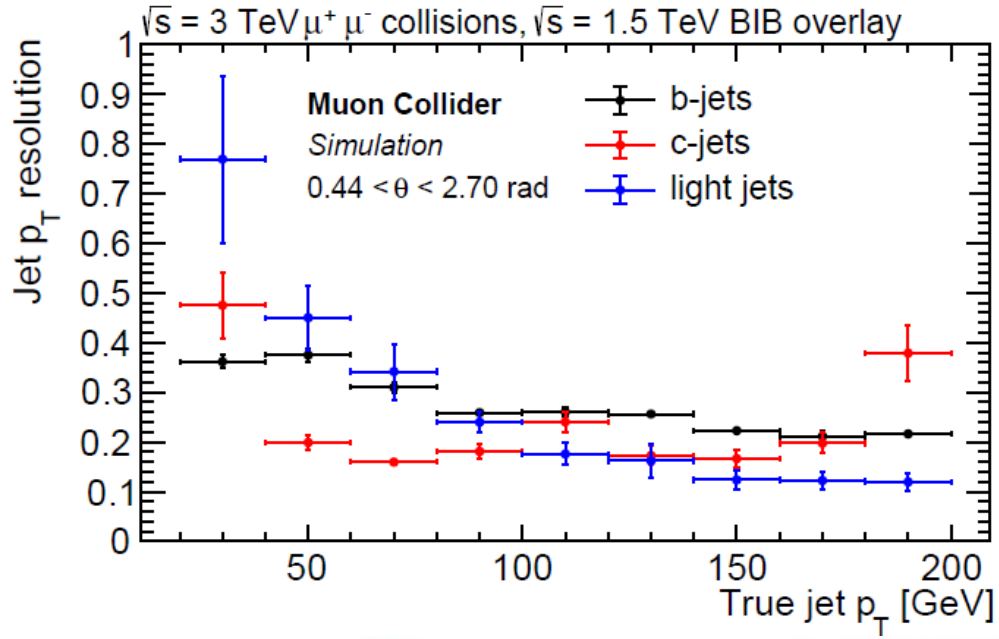
Momentum correction

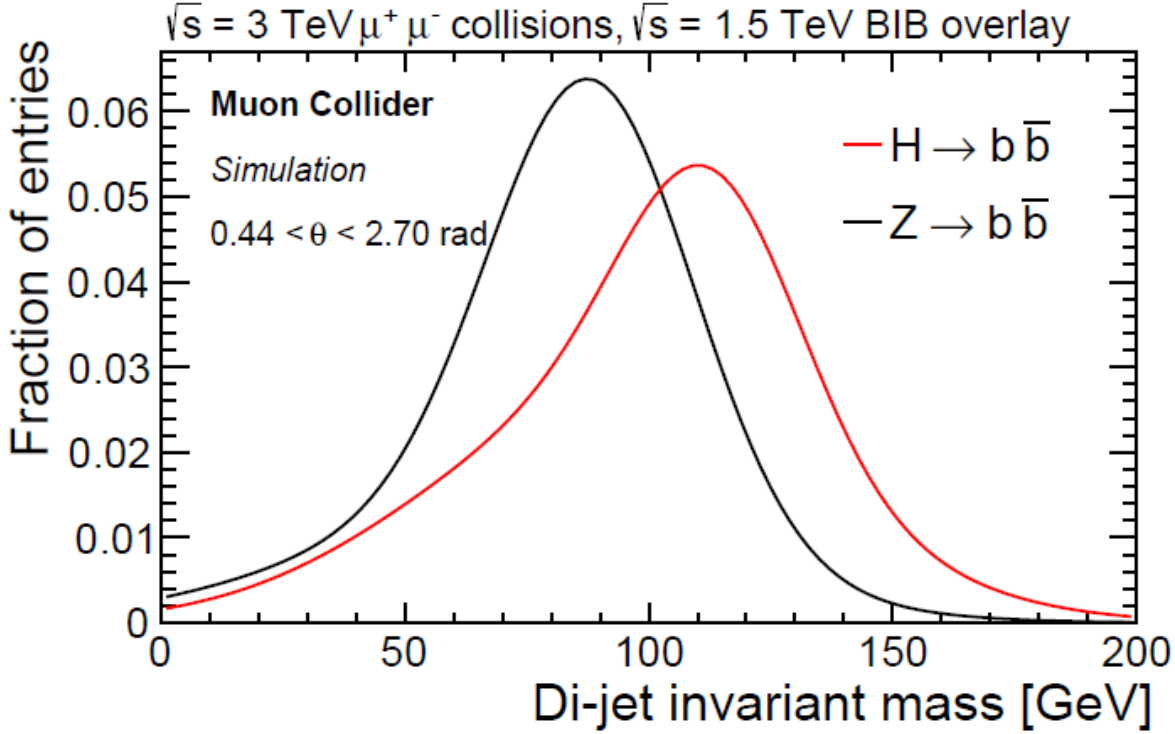




Performance







Relative width

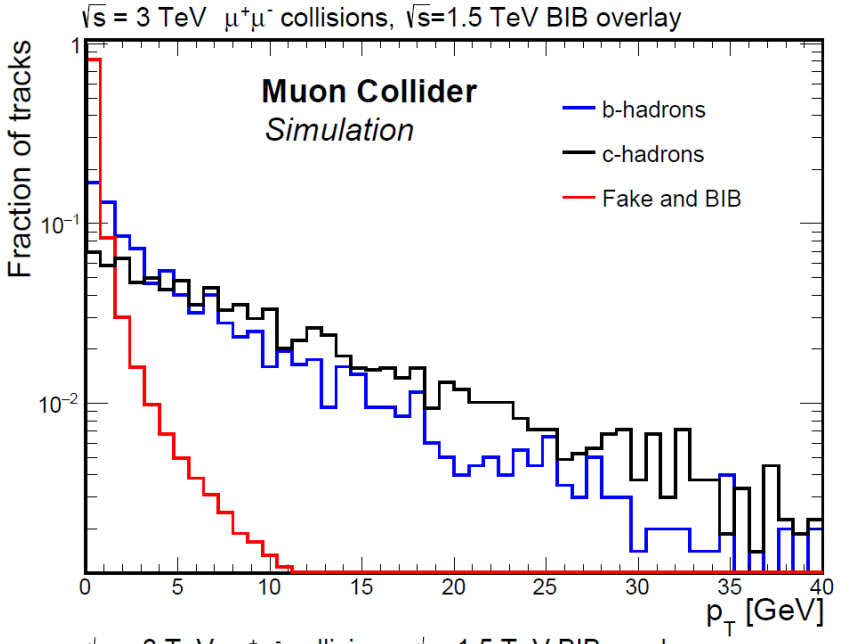
- $h \to b\bar{b}$: 27%
- $Z \to b\bar{b}$: 29%

Jet identification

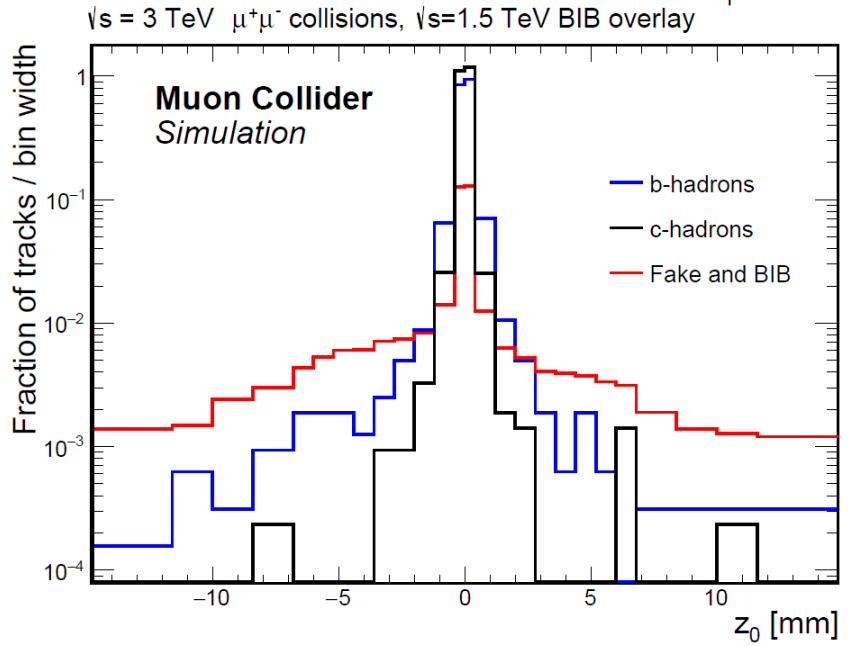
b-jet identification algorithm relies on the reconstruction of the secondary vertices

Procedure

- Primary vertex finding: tracks reconstructed with CT+DL
- Tracks selection for secondary vertex finder
- Secondary vertex finding

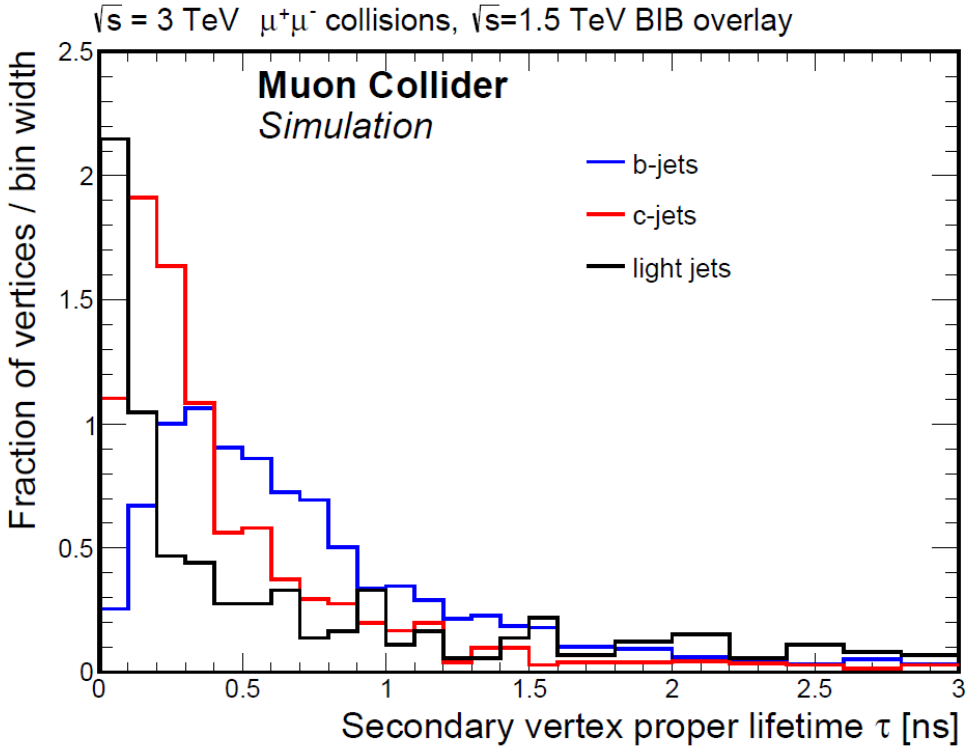


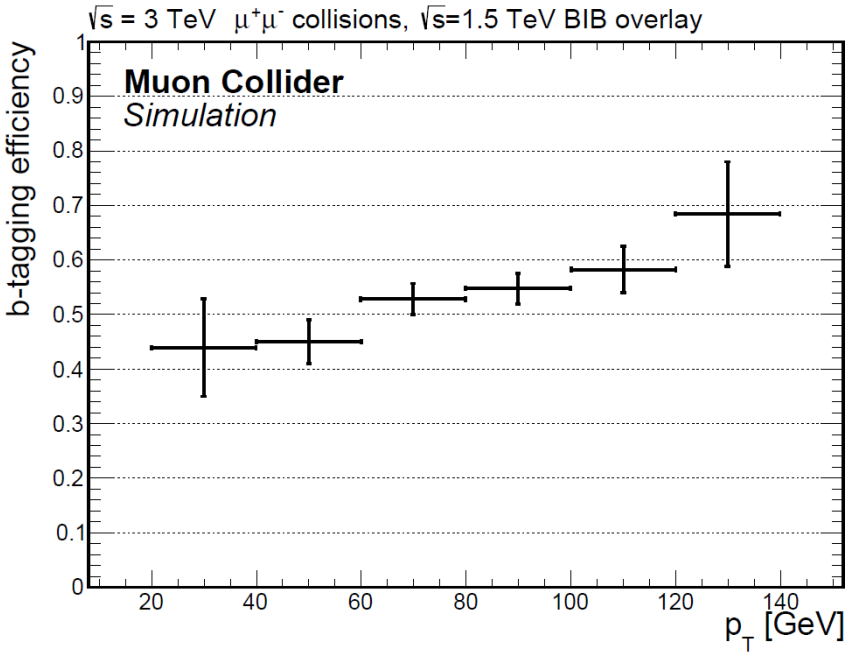
- p_t>0.8 GeV
  - 80% BIB rejected
  - 85-90% signal kept

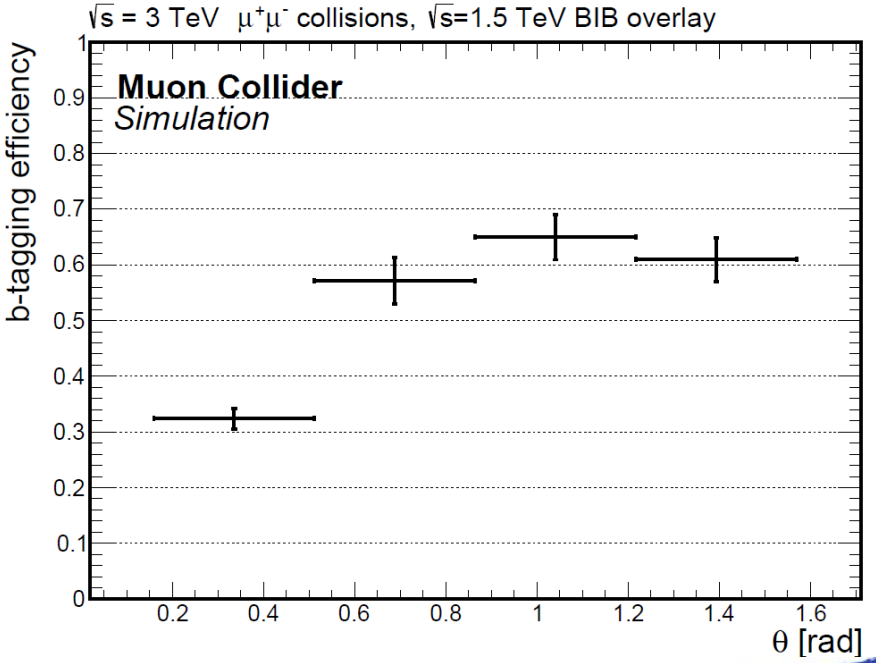


- $|Z_0|$ <5 mm

b tagging



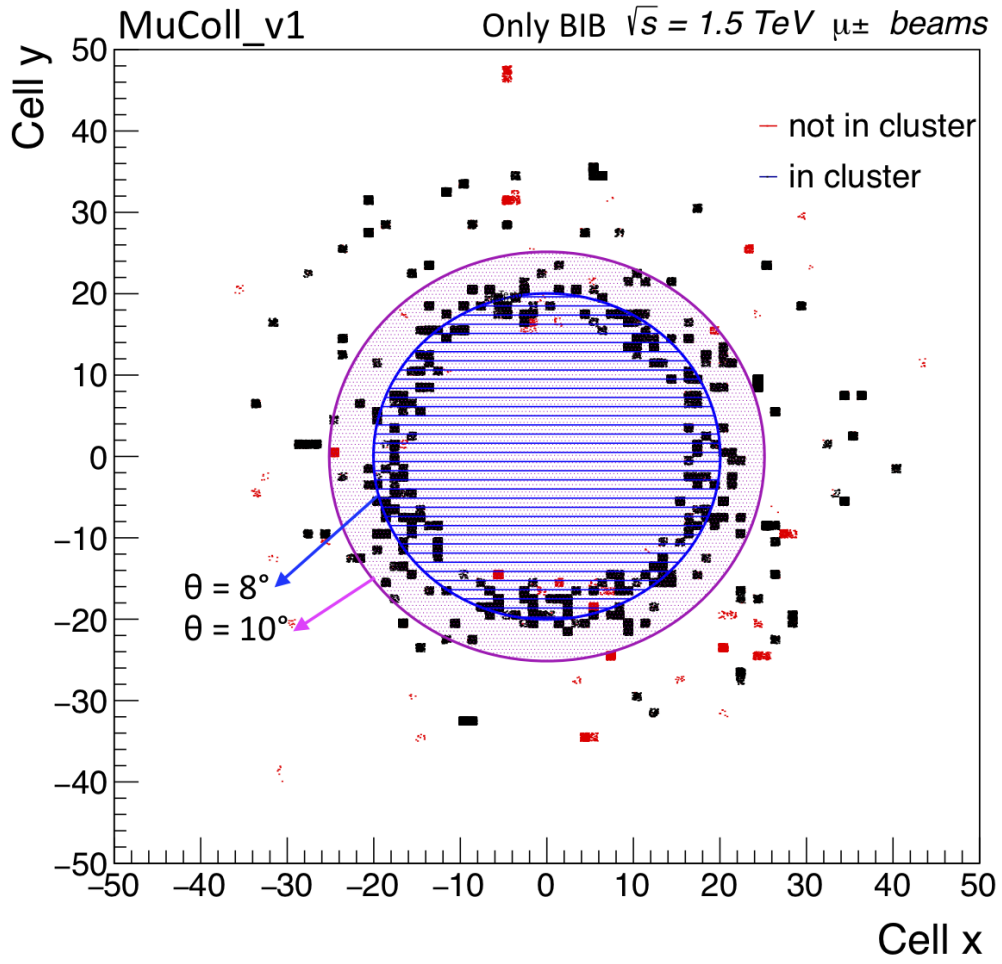


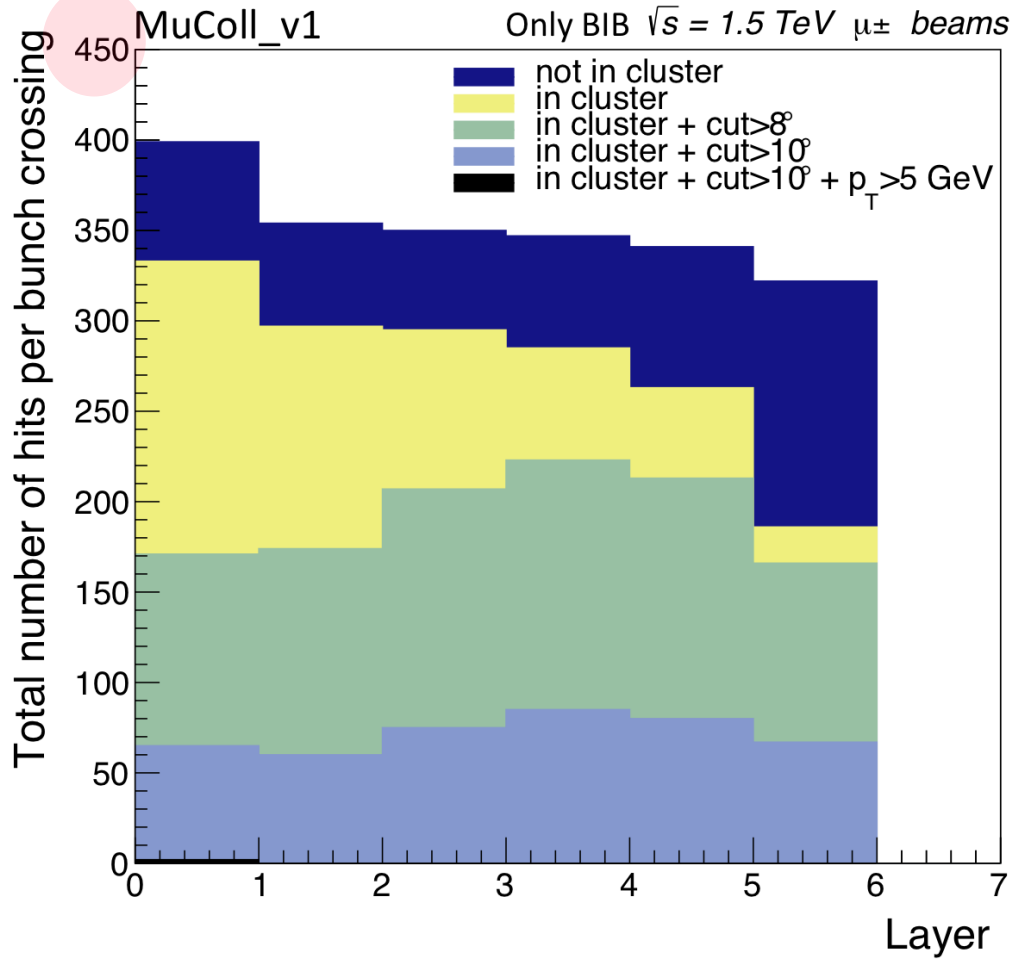


- τ>0.2 ns
  - 30% c and light jets rejected
  - 90% b jets kept

BIB (γ+n) in the muon system

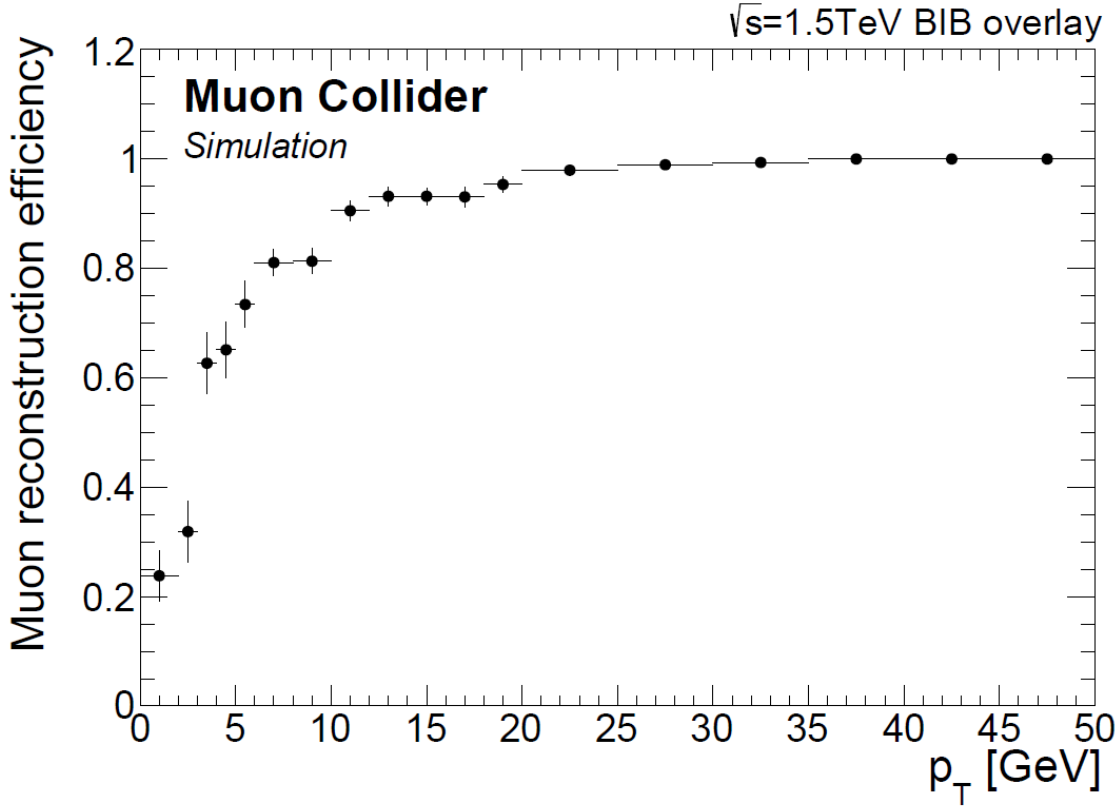
- Concentrated in the endcap around the beamline
- Low occupancy with respect to tracker and calorimeters

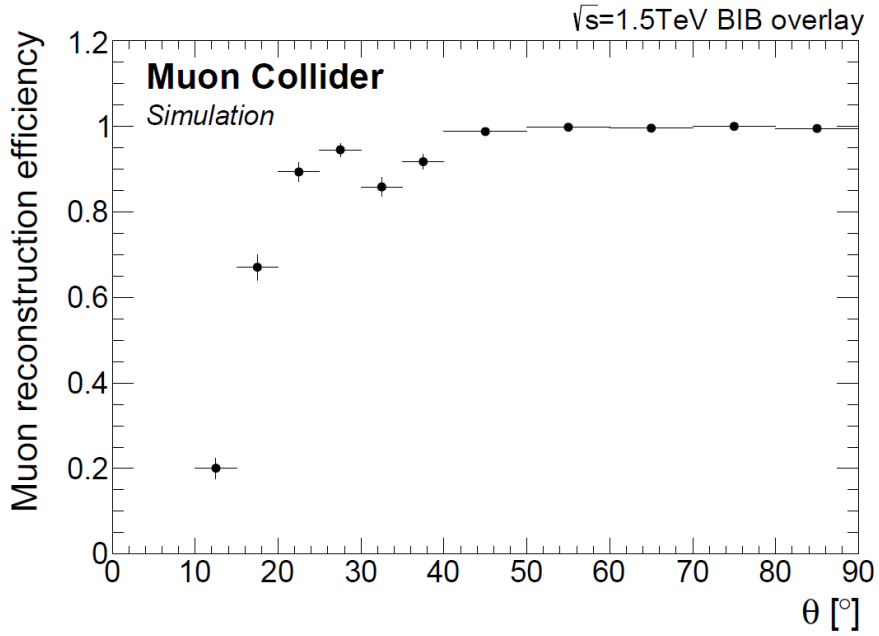


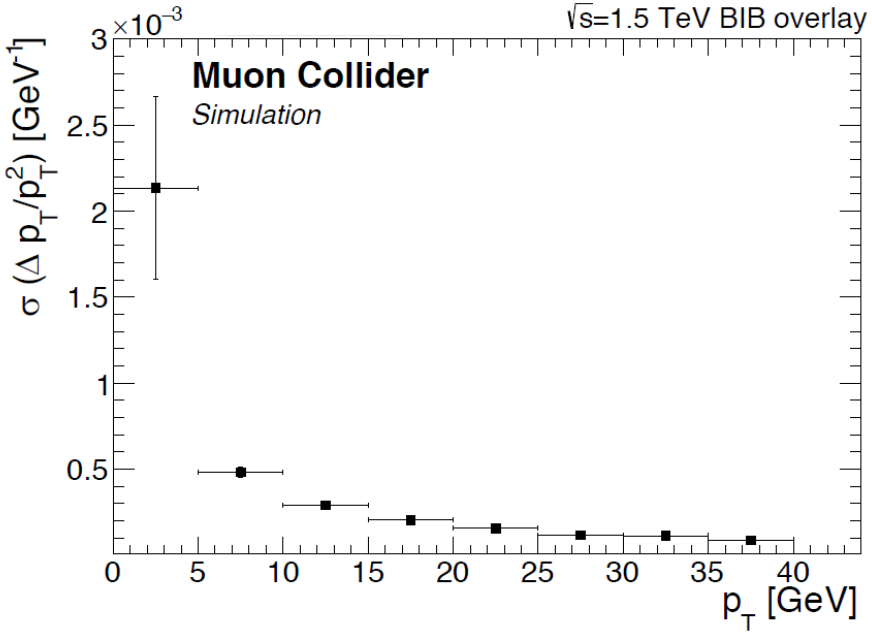


Muon reconstruction

① CKF + Pandora in → out



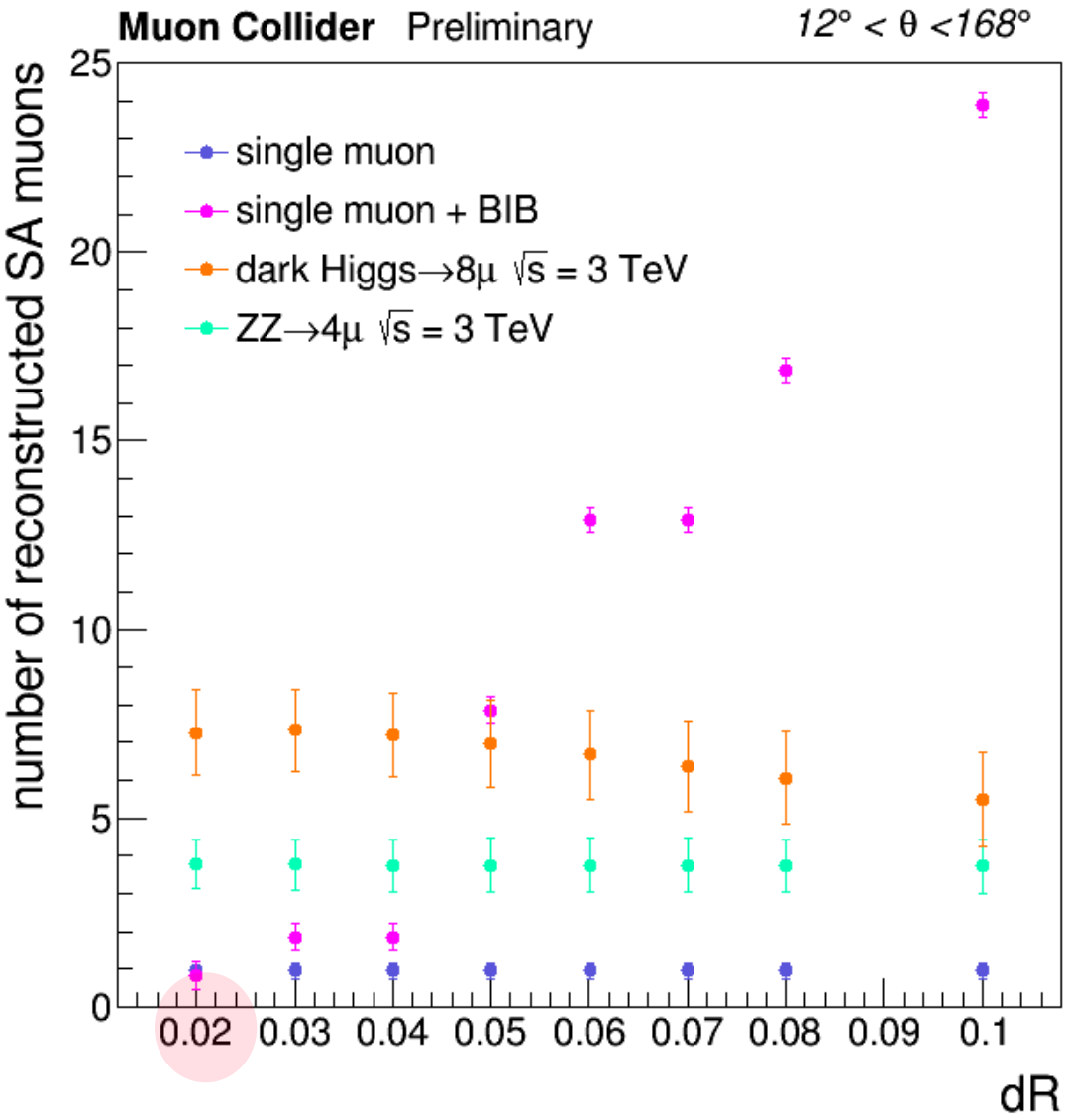




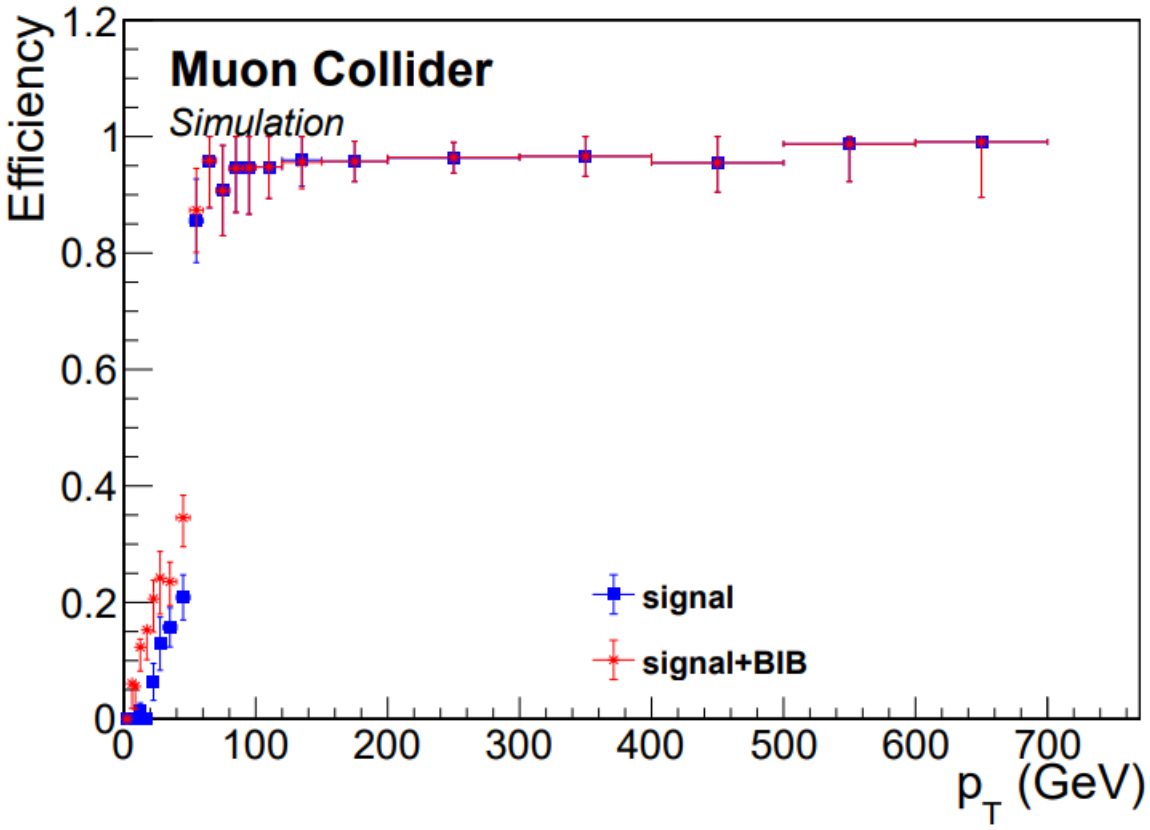
Efficiency and resolution as for single muon w/o BIB (CT track)

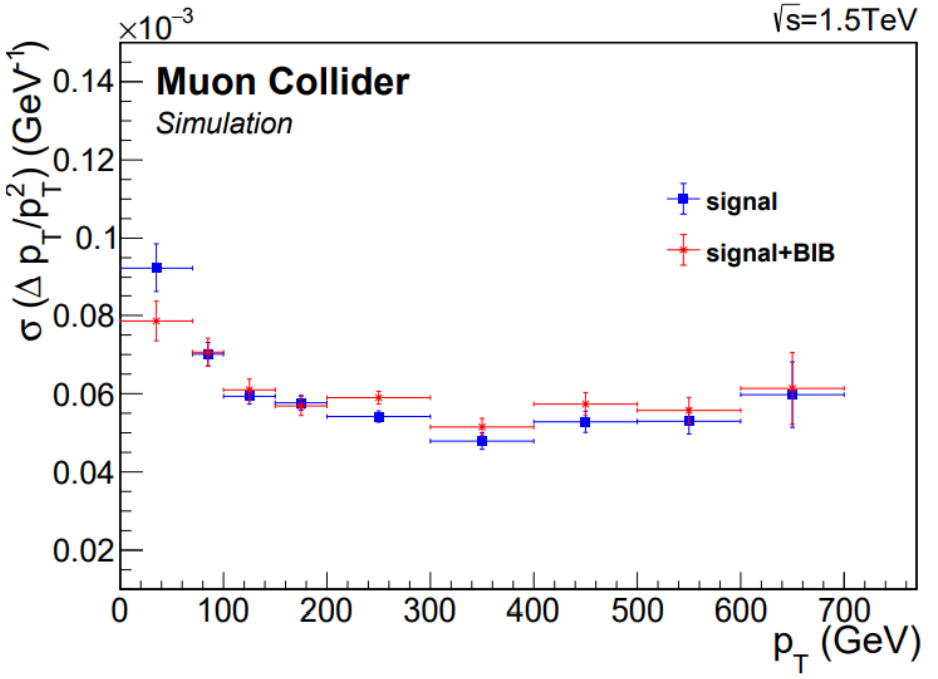
② Standalone + CT in ← out

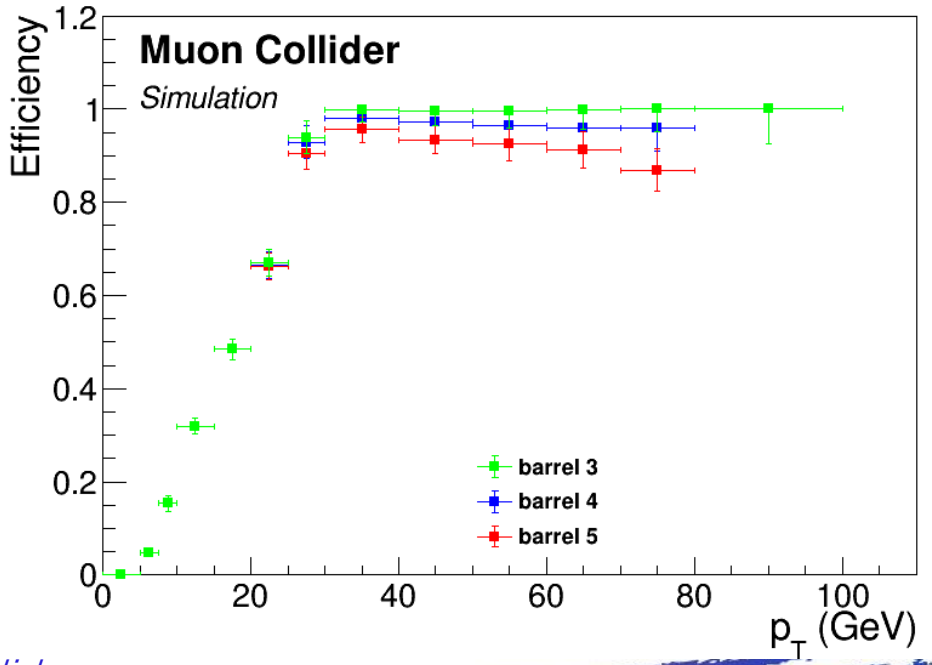
a. muon hits clustered inside a cone with angular aperture ΔR (selected value = 0.02)
b. standalone muon track created if there are hits at least in 5 layers
c. reconstructed hits in all tracker subsystems filtered (ROI)
d. CT algorithm applied



Performance







arXiv:2203.07964v1 *Simulated Detector Performance at the Muon Collider*

Conclusions

- BIB is one of the biggest challenges at a Muon Collider
- Physics object reconstruction performance obtained up to know are very satisfactory
- A lot of work is still in progress

Lesson learned from ECAL

Effort made in optimizing the detector results in better performance

The results presented - unless otherwise specified - are published in
arXiv:2303.08533 *Towards a muon collider*


Thanks for your
attention