Jet reconstruction performance at Muon Collider with beam-induced background

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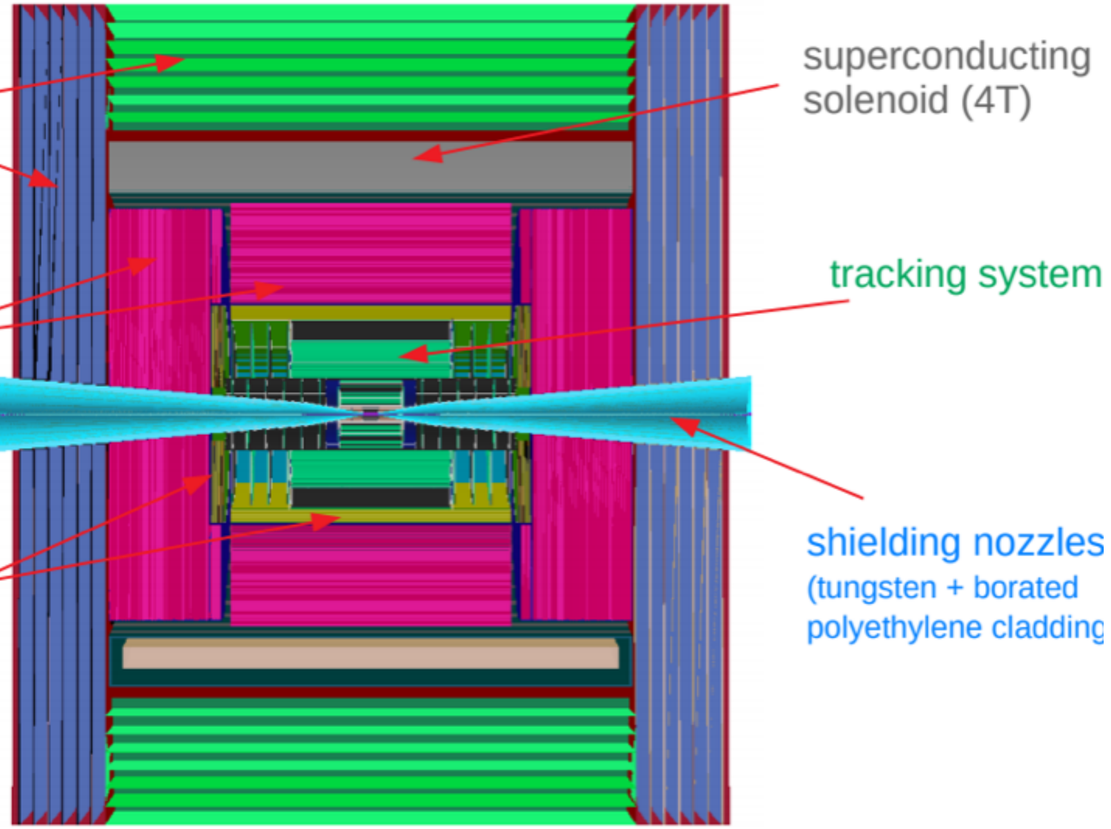
Introduction

- **Jets are key objects in Muon Collider physics**: flagship measurements like double and triple Higgs productions have jets in the final state (**Laura's talk later**)!
- As you have seen from **Camilla's talk**, **the beam-induced background (BIB) at a Muon Collider is very different from the other accelerators**. $4 \cdot 10^8$ BIB particles per bunch crossing!
- The BIB produces a high hit multiplicity in the tracking system, resulting in a huge tracking combinatorial **(Massimo's talk later** and **Hannsjörg's talk tomorrow**).
- **The jet reconstruction in this environment is challenging**, but I am going to demonstrate that with the proper strategy is possible.

Design a detector at $\sqrt{s} = 1.5$ TeV



Vertex Detector (VXD)
- 4 double-sensor barrel layers 25x25μm2
- 4+4 double-sensor disks ''

Inner Tracker (IT)
- 3 barrel layers 50x50μm2
- 7+7 disks ''

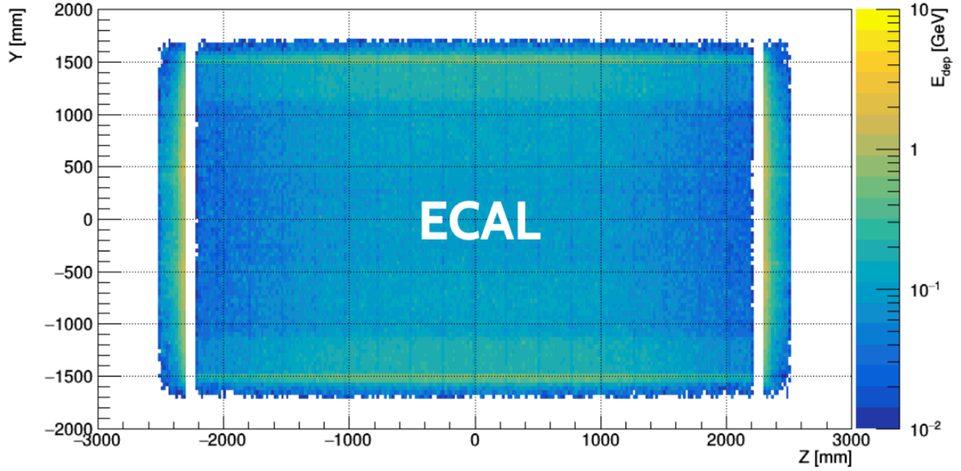
Outer Tracker(OT)
- 3 barrel layers 50x50μm2
- 4+4 disks ''

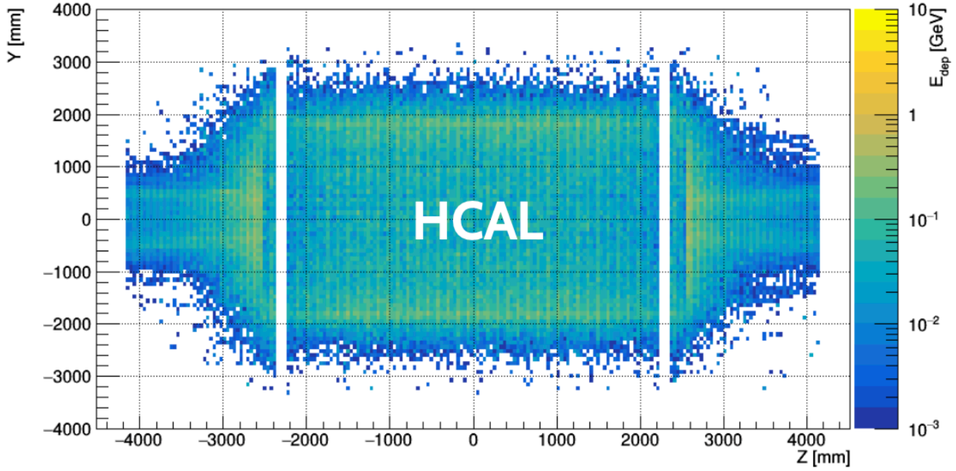
Electromagnetic Calorimeter (ECAL)
- 40 layers W absorber and silicon pad sensors, 5x5 mm2

Hadron Calorimeter (HCAL)
- 60 layers steel absorber & plastic scintillating tiles, 30x30 mm2

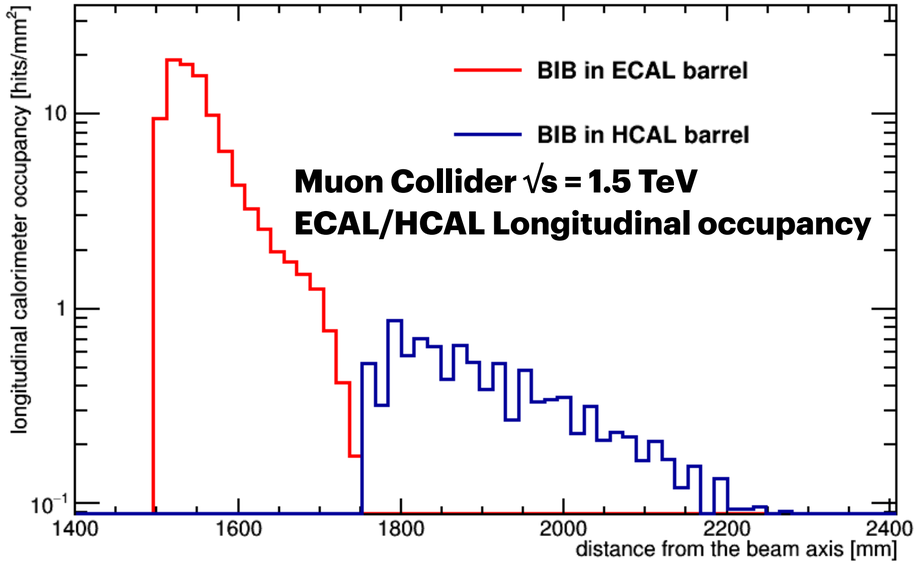
Check **Simone's talk tomorrow** for a full overview of the Muon Collider detector. For simulation software check **Nazar's talk**.

Beam induced background in calorimeters





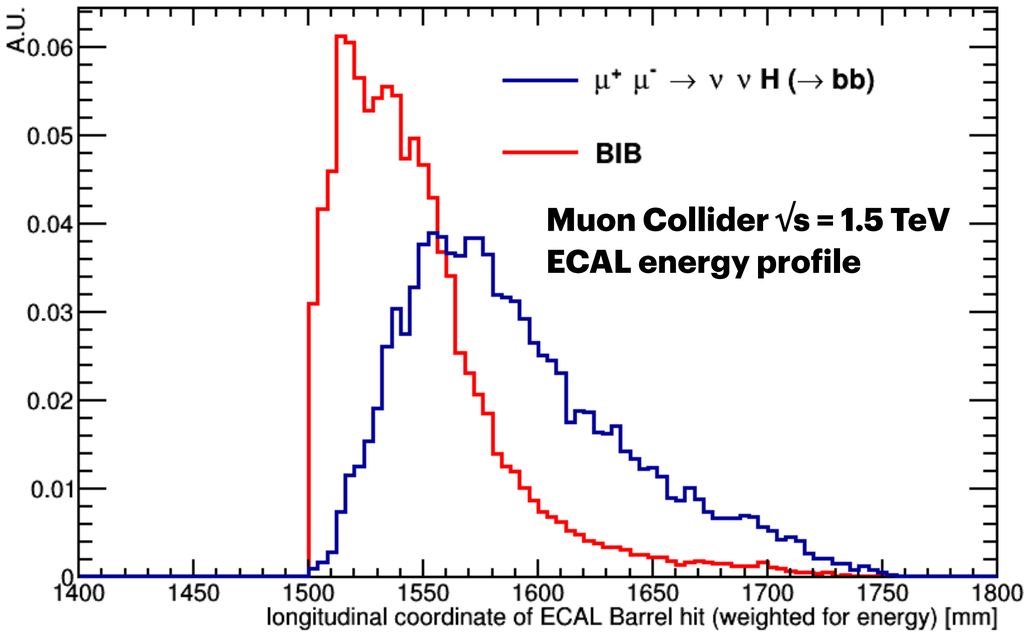
Energy deposition in calorimeters per bunch crossing

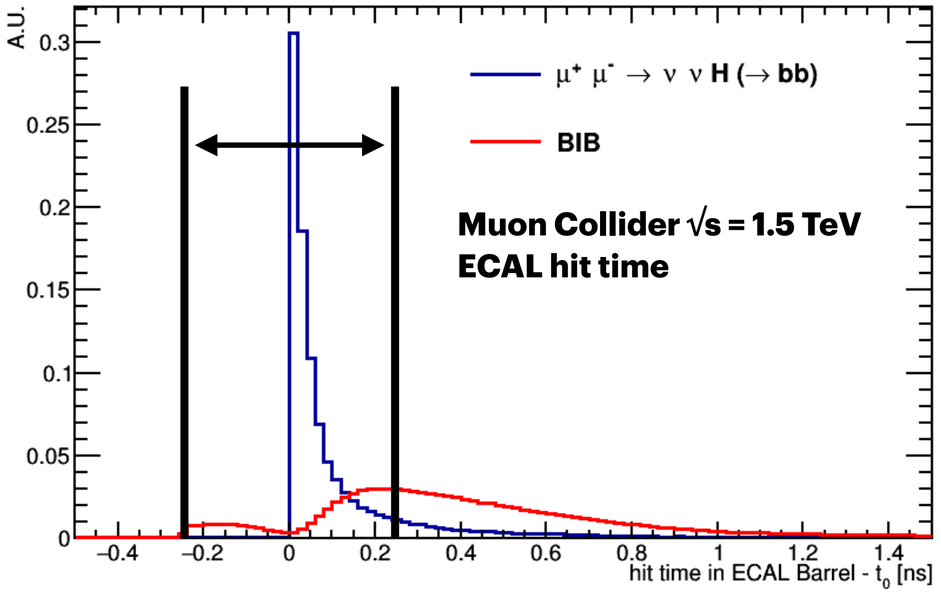


- **BIB is diffused in the calorimeters**: at the ECAL barrel surface the flux is 300 particles/cm^2, most of them are photons with <E>=1.7 MeV.
- BIB occupancy is lower in HCAL with respect to ECAL.

Beam induced background in calorimeters

- **BIB is out-of-time with respect to bunch-crossing.**
- An acquisition time of [-0.25,+0.25] ns is assumed for the following studies.

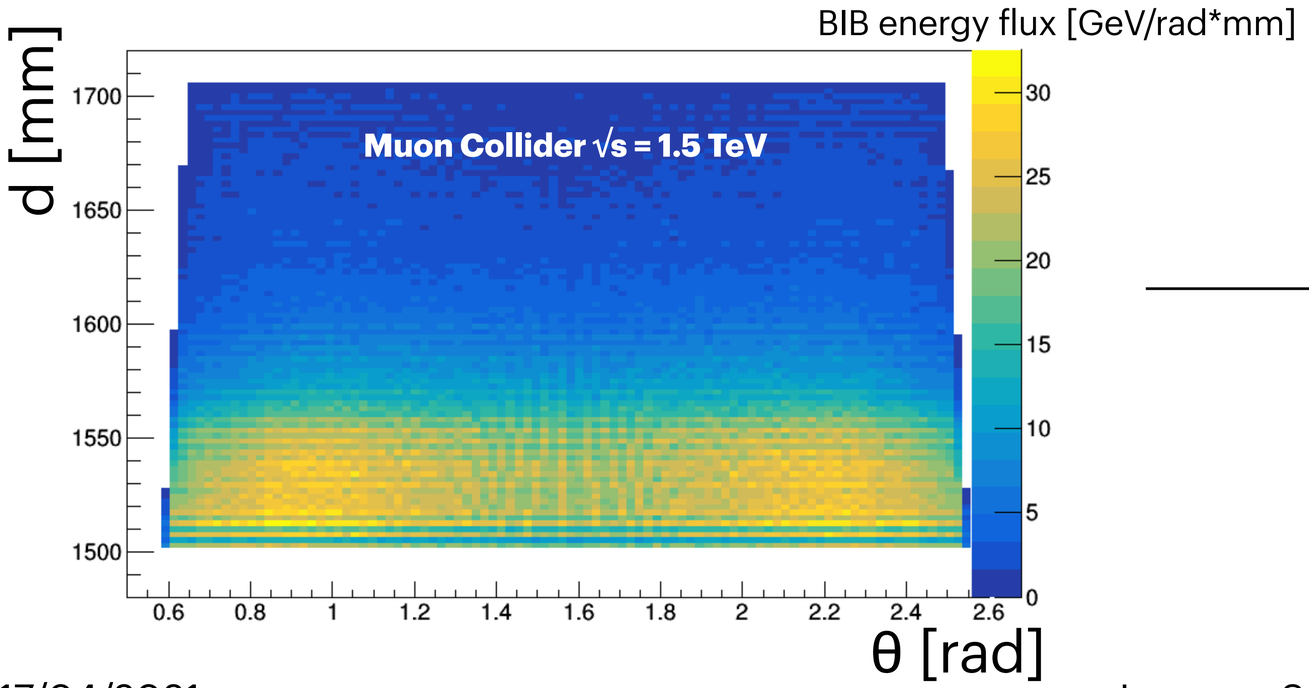


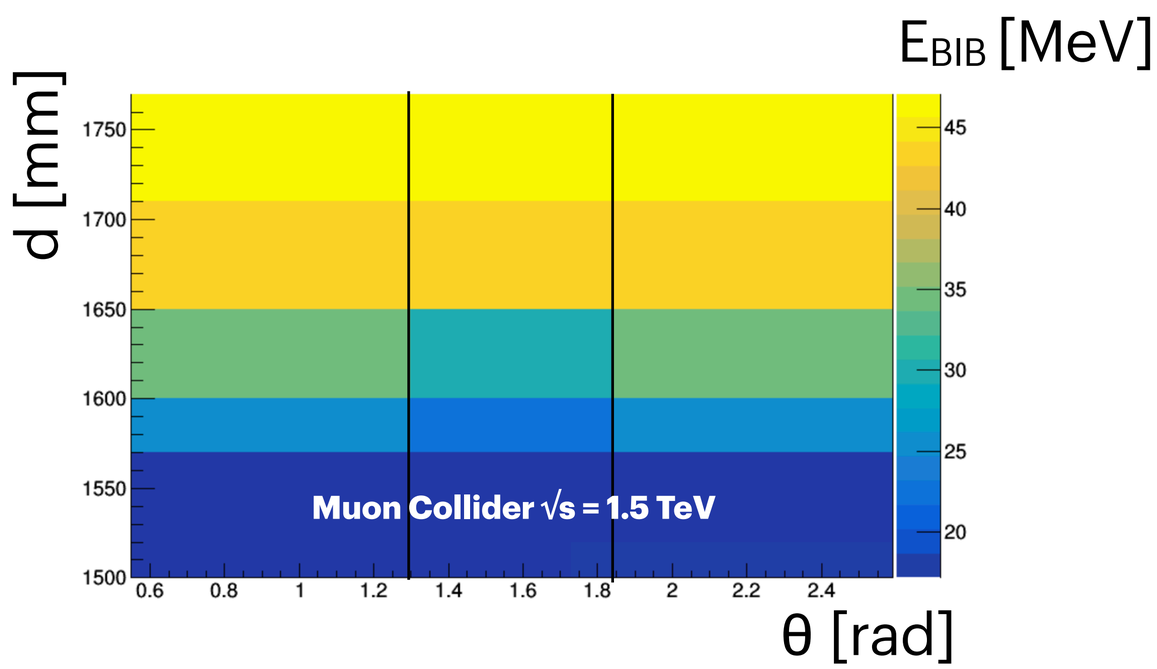


- The released energy distribution of signal showers in the longitudinal direction shows different features with respect to BIB.
- **It is clear that timing and longitudinal measurements play a key role in the BIB suppression.**

BIB subtraction in ECAL for jet reconstruction

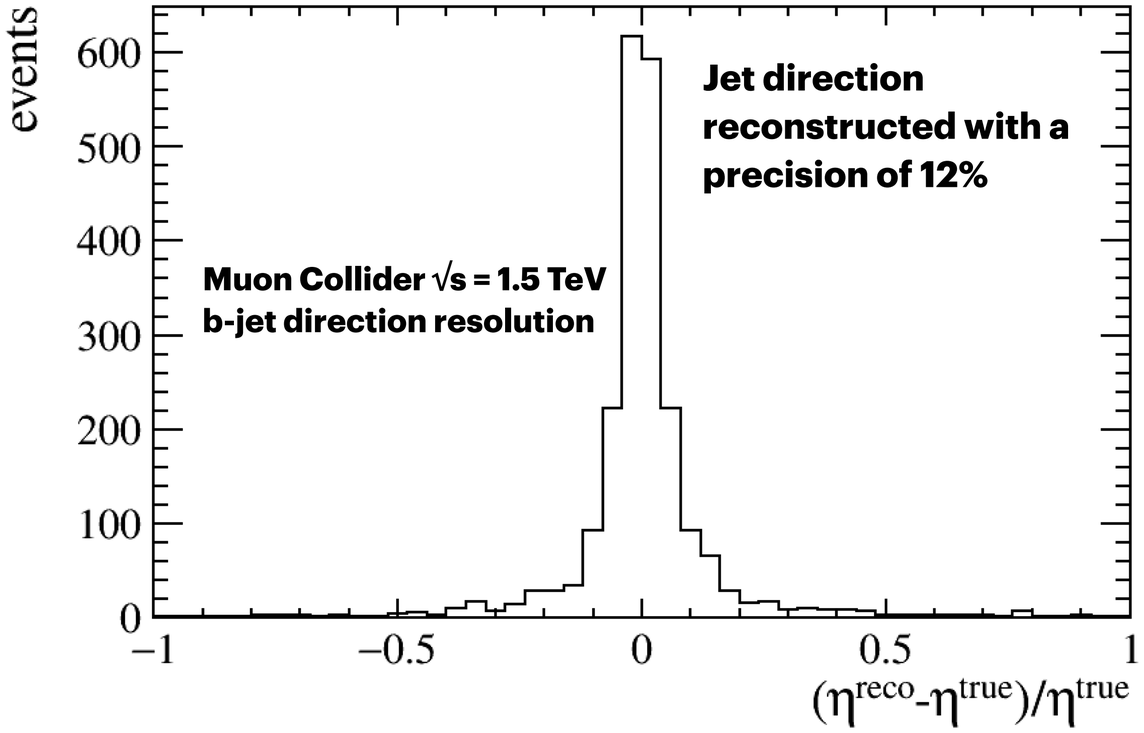
- ECAL is divided in **(θ,d) regions**: **θ** angle wrt z-axis, **d** distance wrt beam axis.
- In each region the average BIB hit energy E_{BIB} and standard deviation σ_{BIB} is determined.
- In signal+BIB reconstruction an ECAL hit is accepted if $E_{HIT} > E_{BIB} + 2\sigma_{BIB}$.
- The energy of the accepted hit is corrected: $E_{HIT} \rightarrow E_{HIT} - E_{BIB}$.

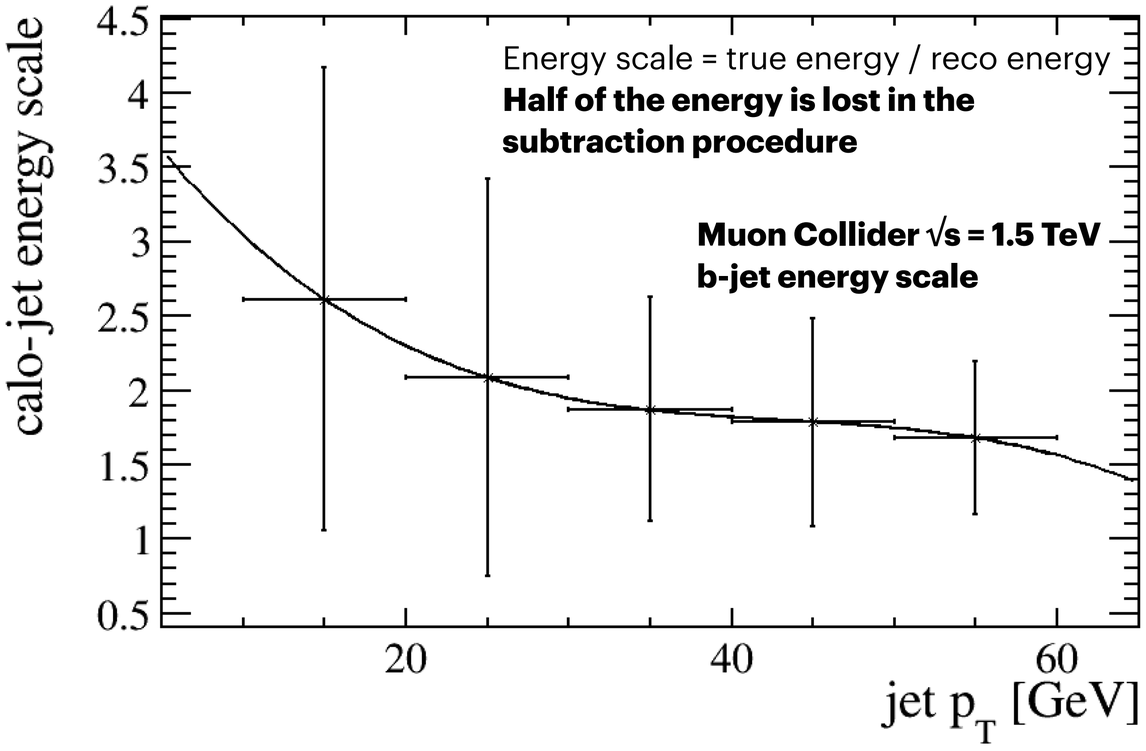




Jet reconstruction in calorimeters

- ECAL and HCAL clusters are reconstructed with **PandoraPFA** (more info in backup).
- Calorimeters jets are clustered with the kt algorithm, radius R=0.5
- **A simulated samples of $b\bar{b}$-dijet + BIB is used for this study.**





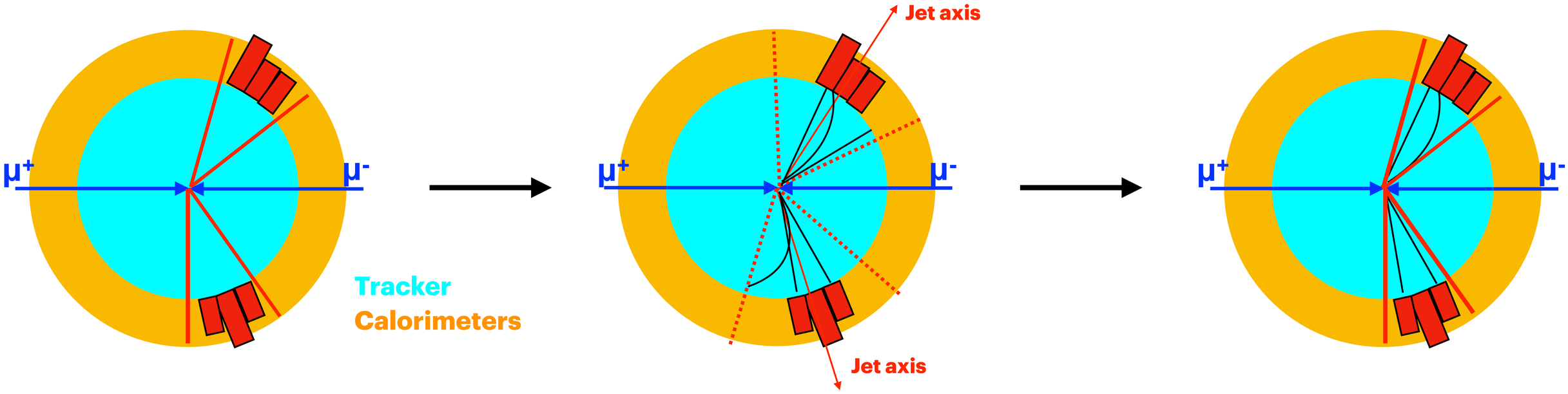
Full jet reconstruction algorithm

- To recover the jet energy, **we should perform the full reconstruction with tracking+calorimeters.**
- In order to reduce the tracking combinatorial problem, **a regional tracking strategy is employed.**

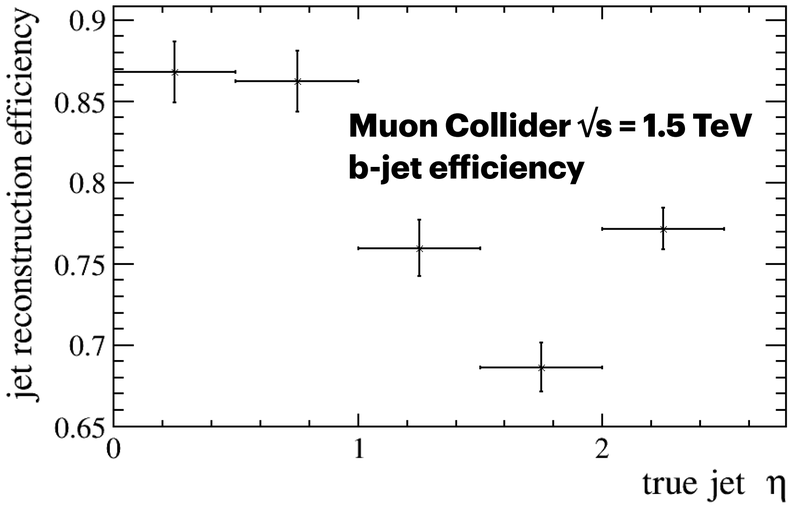
Step 1: calorimeter jet reconstruction with PandoraPFA and kt (R=0.5)

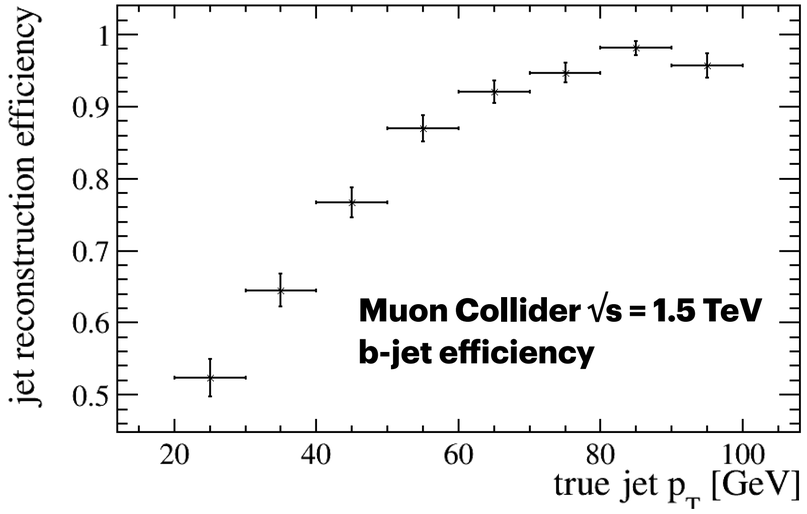
Step 2: regional tracking in cones (R=0.7) defined by the calorimeter jet directions

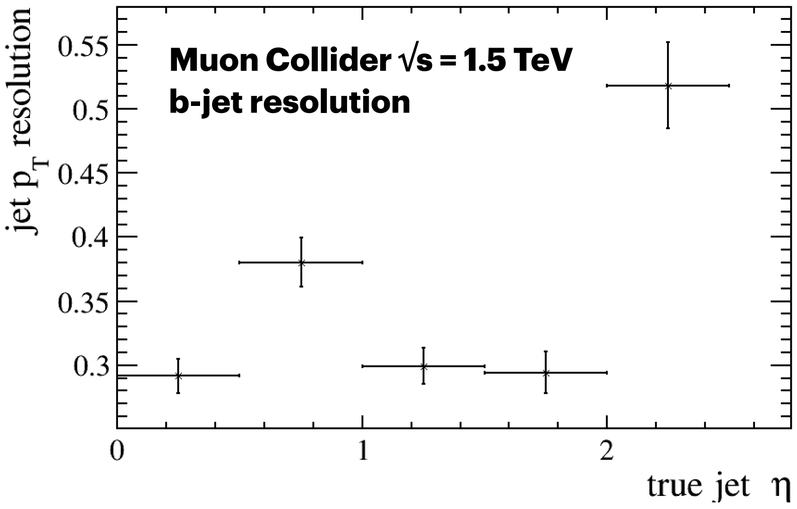
Step 3: final jet clustering using calorimeter clusters and tracks with PandoraPFA and kt (R=0.5)

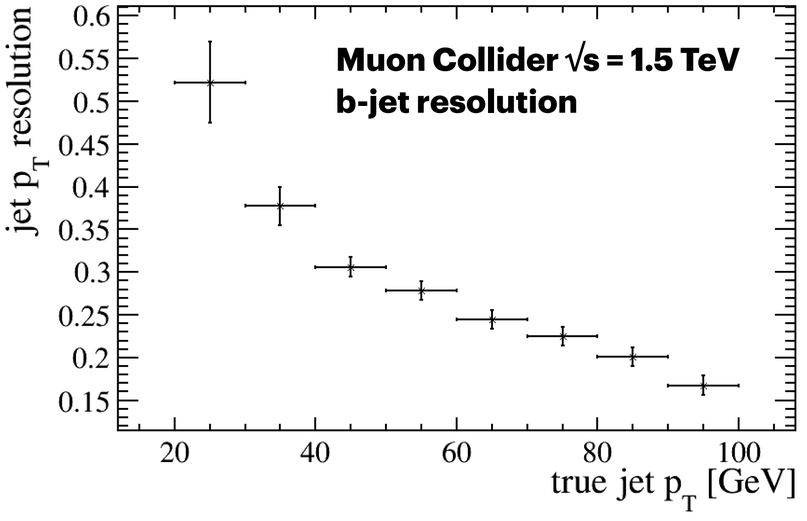


Jet reconstruction performance





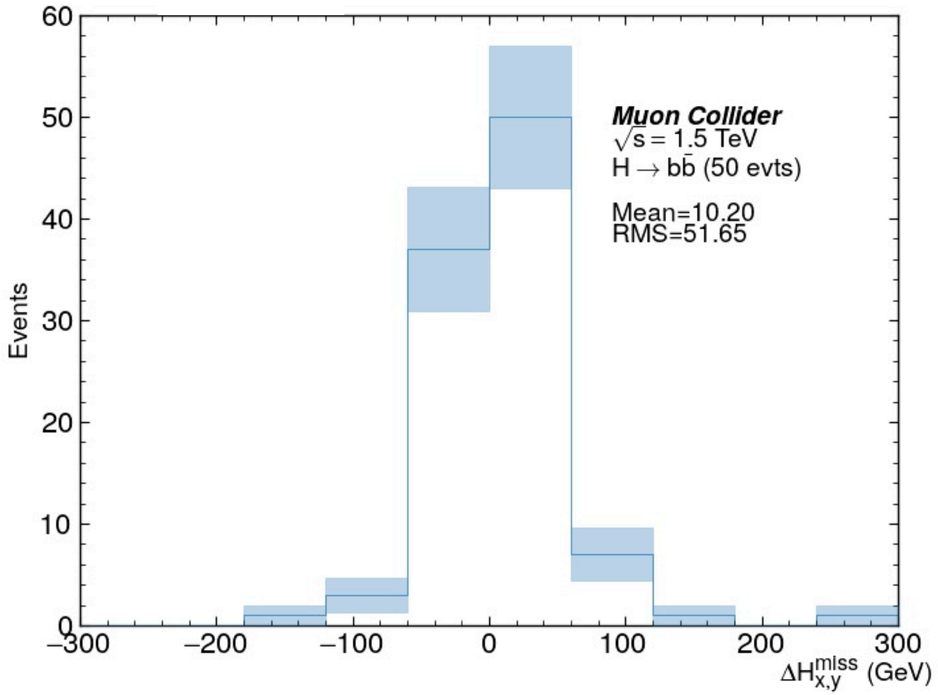


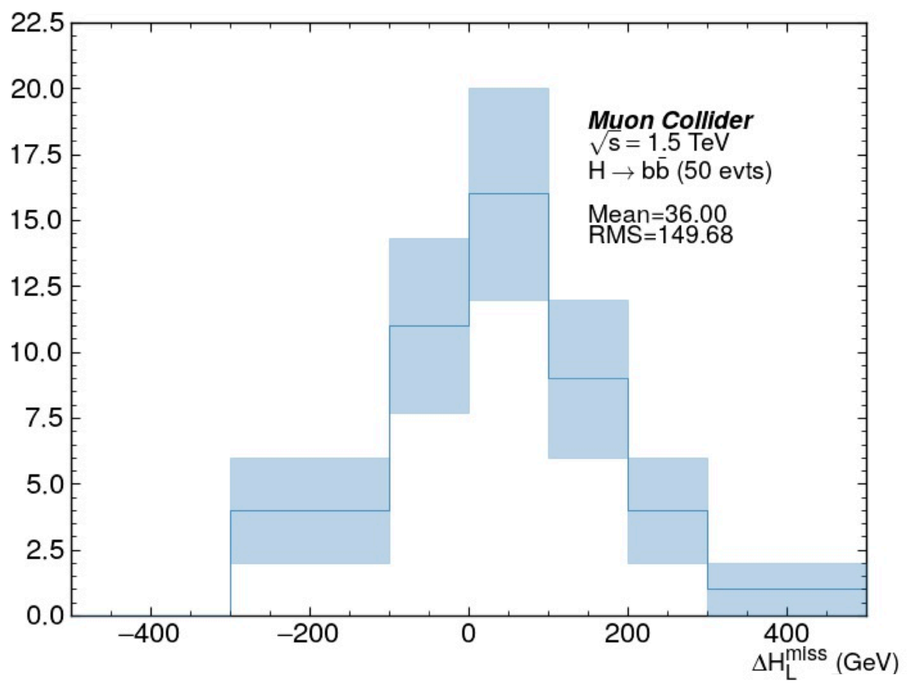


- **Good reconstruction efficiency at high transverse momentum (p_T) and low rapidities (η).**
- A jet energy correction dependent from η and p_T is applied.
- **15% p_T resolution at high p_T. The p_T resolution worsen in the region near the nozzles.**
- **There are many rooms for optimization at all the stages of the reconstruction algorithm.**
- On-going studies on jet identification and fake jet removal.

Missing energy

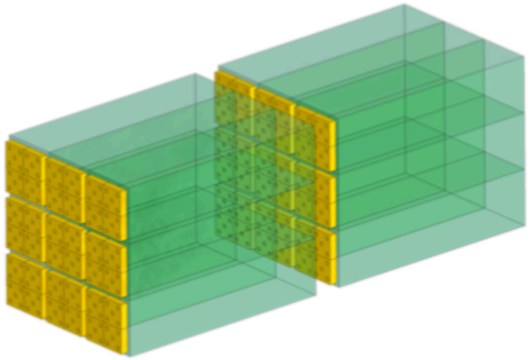
- The calorimeter-jet configuration has been considered for studies on the missing energy measurement.
- $\Delta H^{miss} = H^{miss}_{BIB} - H^{miss}_{noBIB}$ → calculated in the transverse and longitudinal plane.
- Preliminary studies show that **the measurement in the transverse plane is more precise.**





New calorimeter technologies for Muon Collider

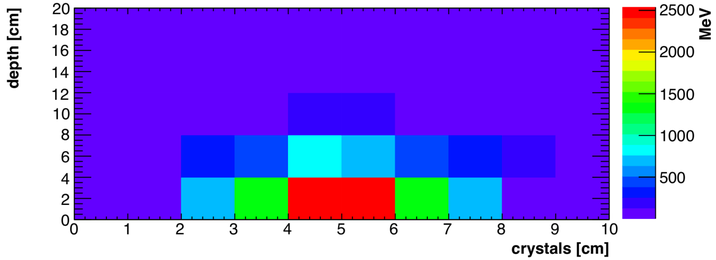
- **CRYLIN** (CRYstal calorimeter with Longitudinal Information): **specific design for Muon Collider ECAL**.
- Cherenkov light, **semi-homogeneous calorimeter**: PbF_2 + copper + SiPM read-out.
- A first layer of LYSO could be used for time measurement. PbF_2 has good light yield (3 pe/MeV), fast signal (300 ps for muons, 50 ps for pions), radiation hard, relatively cheap.



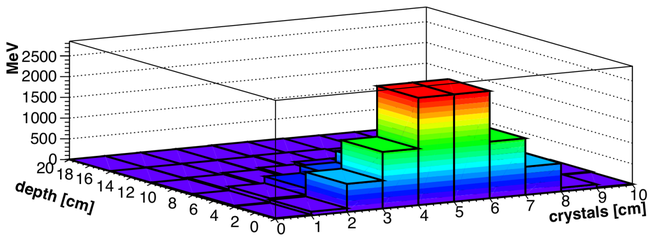
1 cm of LYSO (timing)+
3 cm of PbF_2 (BIB absorber)+
3 * 5 cm of PbF_2 +
5 * 3 mm copper bias layers

BIB parametrized as 1.7 MeV photons – 300 particles/cm^2 per event

Single Event



Average of 1000 events



Geant4 studies on-going.

Real cell prototype in preparation at Laboratori Nazionali di Frascati in Italy.

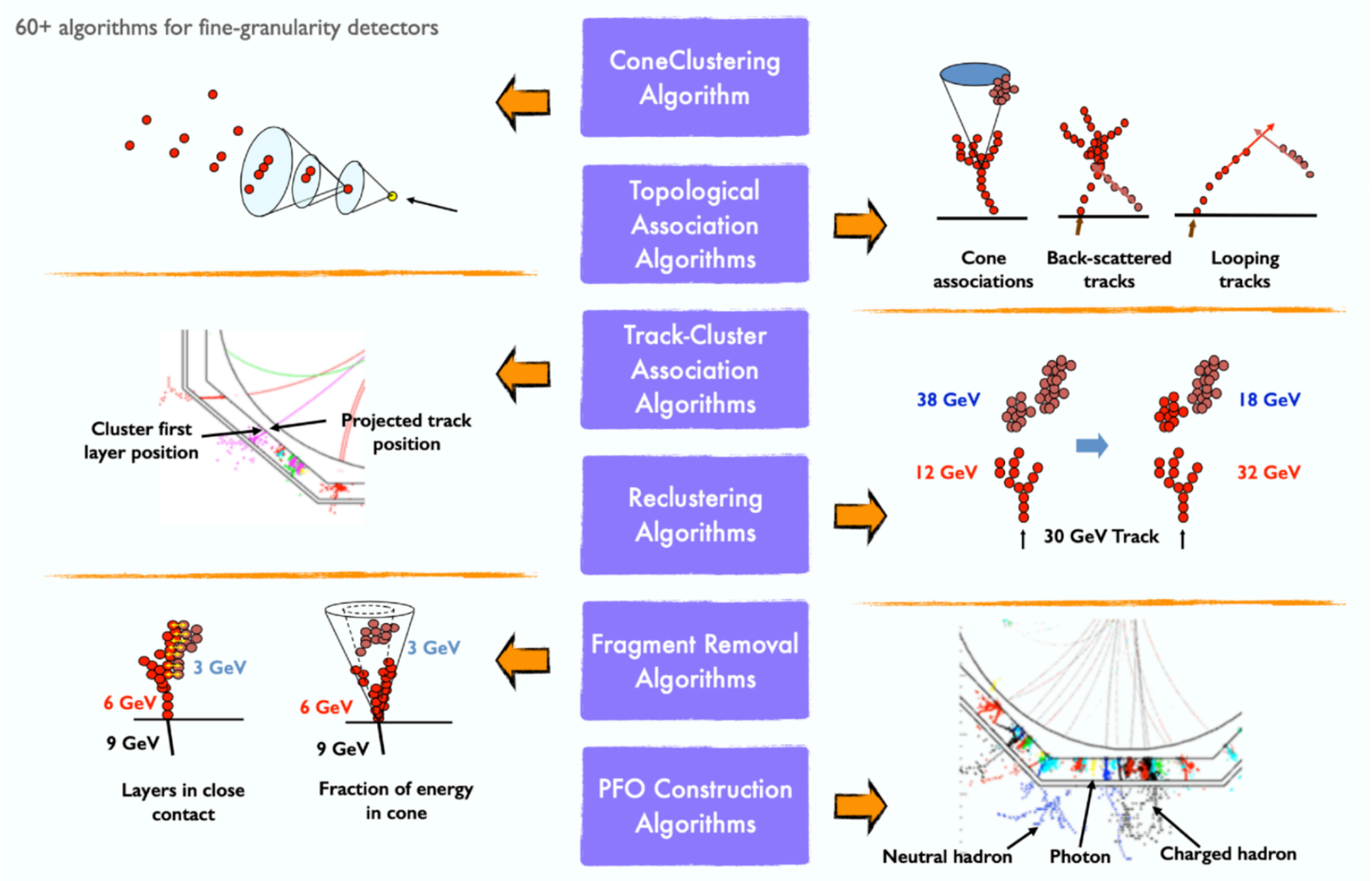
Conclusions

- **Jet reconstruction in the Muon Collider environment is challenging, but with the correct strategy is possible.**
- I have presented preliminary results on the jet performance with b-jets, but several studies are on-going: tests on c-jets and light jets, algorithm optimization etc.
- **There are also on-going studies on the jet heavy-flavor tagging.**
- **The Muon Collider can profit of innovative calorimeter technologies**: we are studying them at simulation level, but tests with prototypes are in preparation.

Thanks for your attention!

Backup

PandoraPFA



M. A. Thomson
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