New ECAL implementation in Muon Collider simulation and performance study

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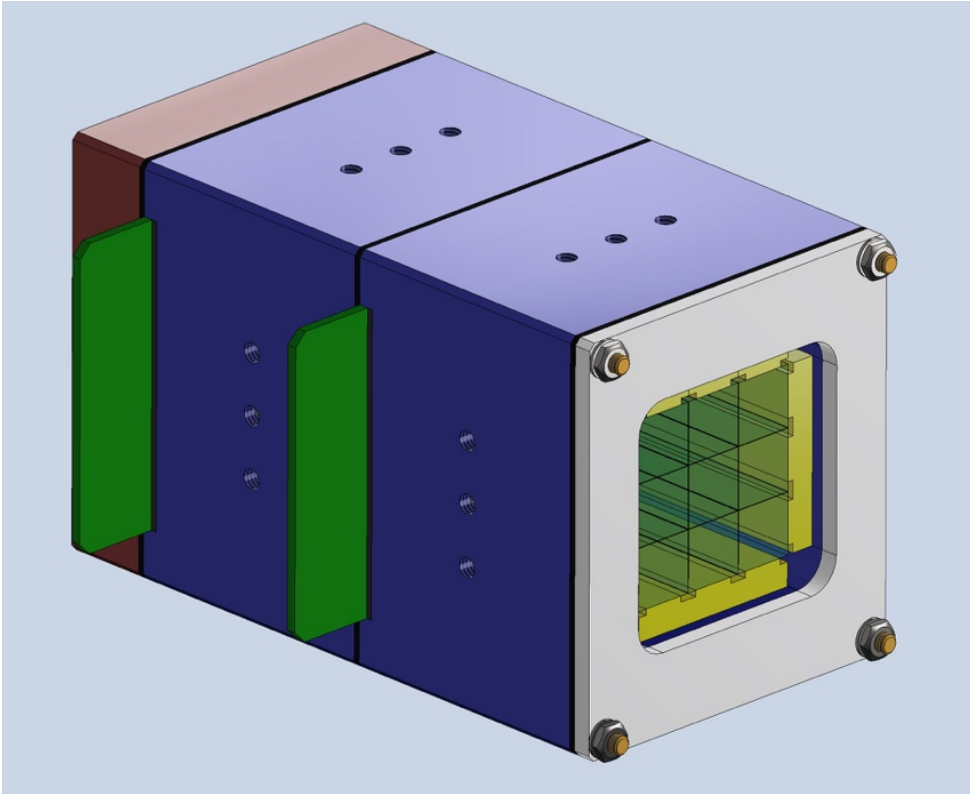
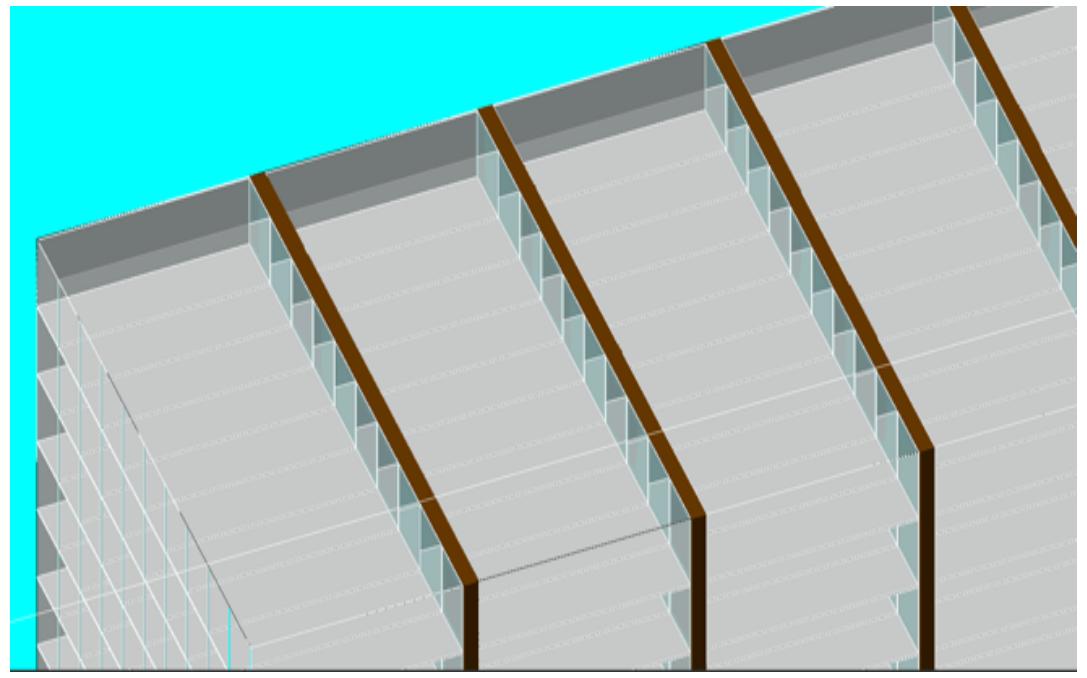
Introduction

- **Do we have solutions alternative to the W-Si sampling calorimeter (CLIC CDR) for ECAL barrel?**
- **New idea: Crilin** (crystal calorimeter with longitudinal information) -> a semi-homogeneous crystal calorimeter (PbF_2), where Cherenkov light is read by SiPMs.
- PbF_2 has good light yield (3 pe/MeV), fast signal (300 ps for muons, 50 ps for pions), radiation hard, relatively cheap.
- Five layers (40 mm thick), 10 x 10 mm^2 of cell area.
- Real cell prototype has been built at the National Laboratory of Frascati.
- **In this talk**: **the full simulation is used to assess the performance of the new ECAL.**

Crilin prototype at LNF

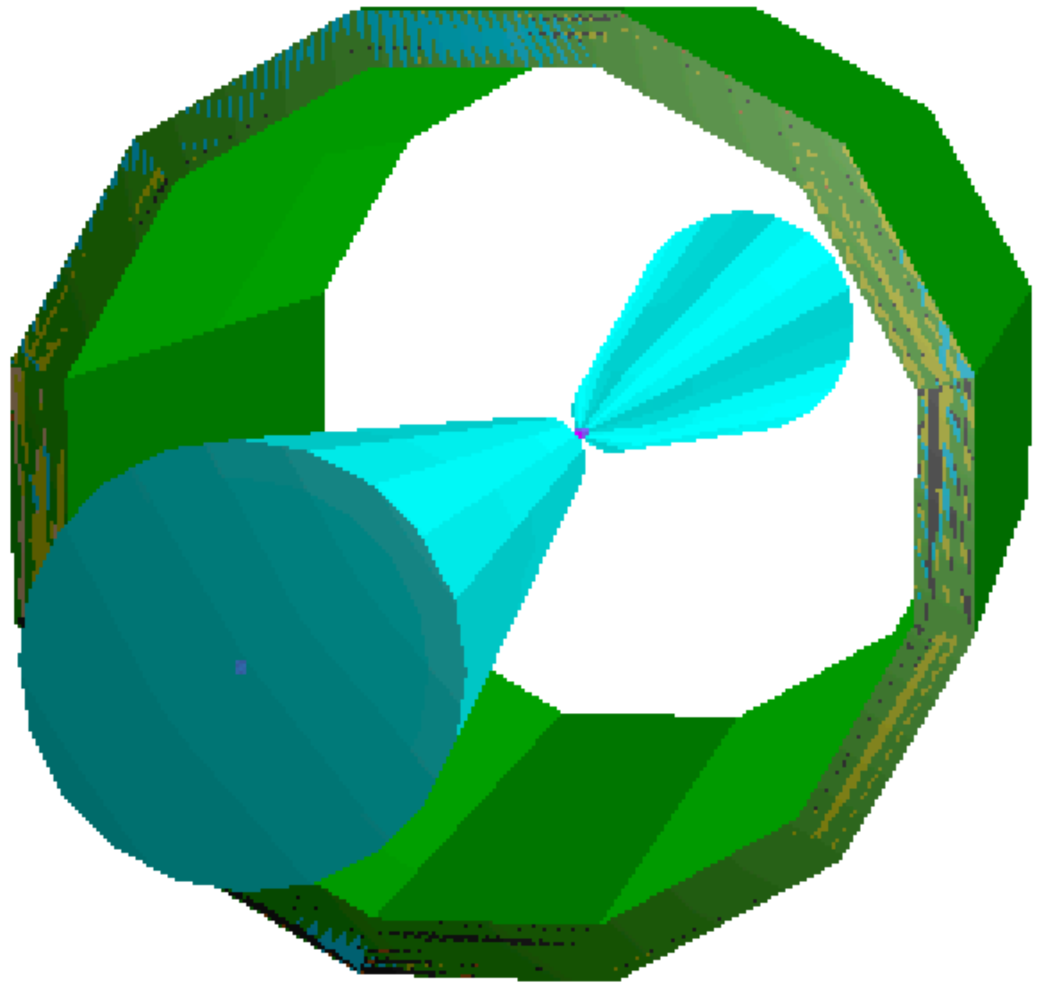


Crilin layers



Implementation in DD4HEP

- The new ECAL barrel (**Crilin**) has been implemented in the Muon Collider simulation framework.
- As for the other detectors, the implementation is done with the DD4HEP interface to Geant4.
- 5 layers of 40 mm length, 10 X 10 mm^2 cell area. Dodecahedra geometry.

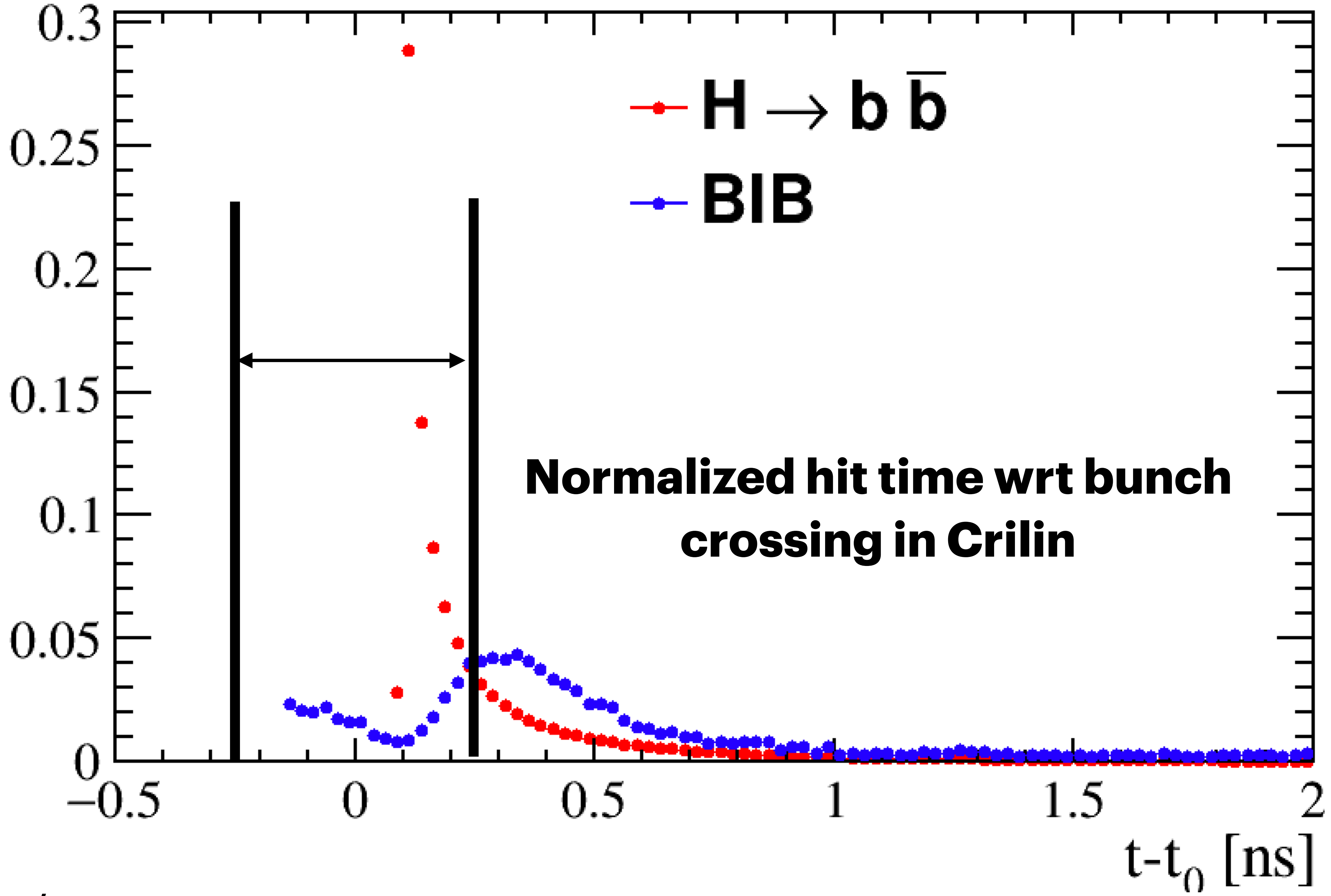


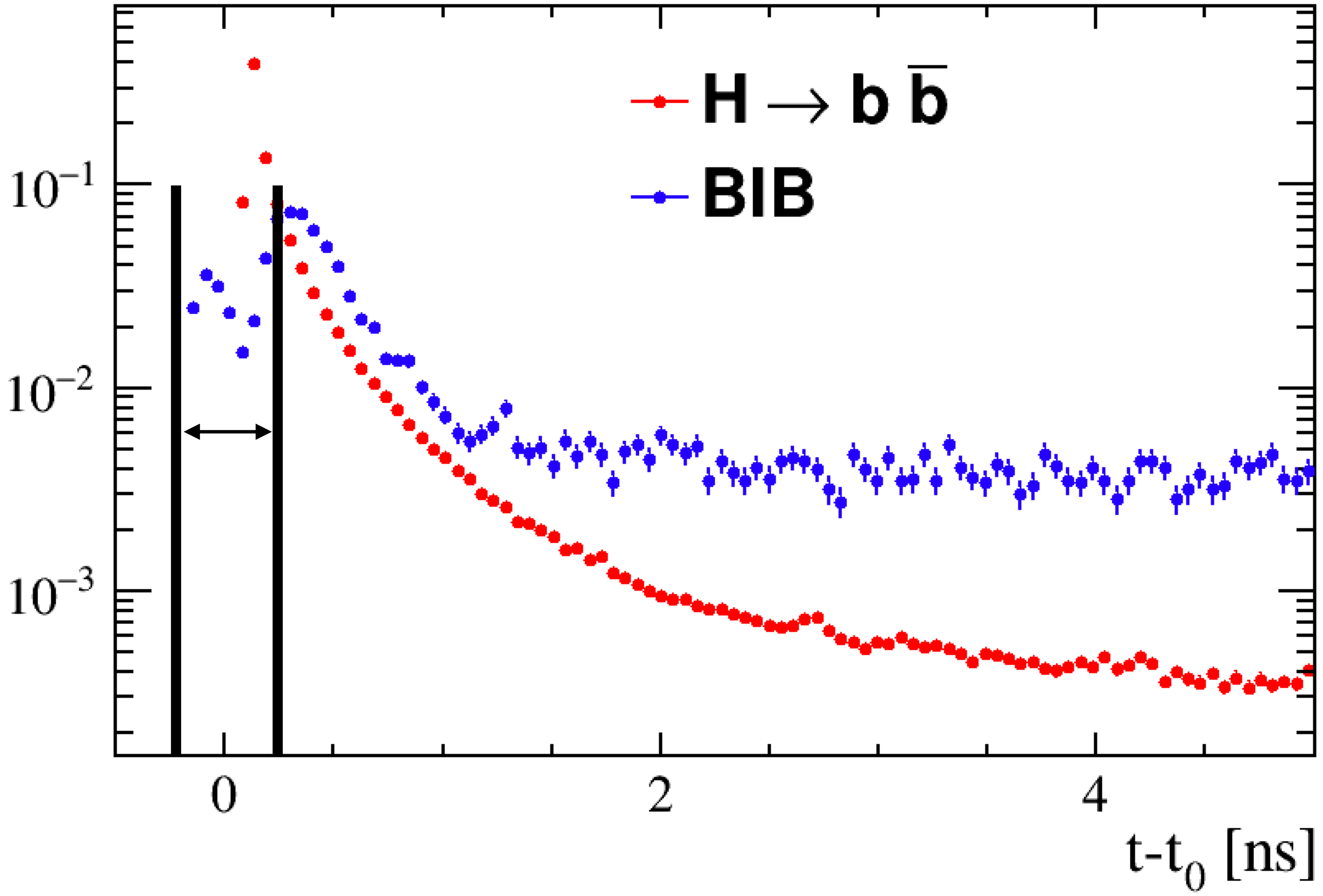
Elementary cell definition in DD4HEP

```
<detectors>
    <detector name="ECalBarrel" type="GenericCalBarrel_o1_v01" id="DetID_ECal_Barrel" readout="ECalBarrelCollection" vis="BlueVis" gap="0.*cm">

        <comment>EM Calorimeter Barrel</comment>

        <type_flags type=" DetType_CALORIMETER + DetType_ELECTROMAGNETIC + DetType_BARREL"/>

        <envelope vis="ECALVis">
            <shape type="PolyhedraRegular" numsides="ECalBarrel_symmetry"  rmin="ECalBarrel_inner_radius" rmax="ECalBarrel_outer_radius" dz="2.*ECalBarrel_half_length"  material="Air"/>
            <!-- Radii definitions as in http://cern.ch/go/r9mZ -->
            <rotation x="0*deg" y="0*deg" z="90*deg-180*deg/ECalBarrel_symmetry"/>
        </envelope>

        <dimensions numsides="ECalBarrel_symmetry" rmin="ECalBarrel_inner_radius" z="ECalBarrel_half_length*2" />
        <staves vis="ECalStaveVis" />
        <layer repeat="5" vis="ECalLayerVis">
            <slice material = "LeadDiflourite" thickness = "35*mm" vis="ECalAbsorberVis" radiator="yes"/>
            <slice material = "Silicon"        thickness = "1*mm" sensitive="yes" limits="cal_limits" vis="ECalSensitiveVis"/>
            <slice material = "siPCBMix"       thickness = "3*mm" vis="ECalAbsorberVis"/>
            <slice material = "Air"            thickness = "1*mm" vis="InvisibleNoDaughters"/>
        </layer>
    </detector>
</detectors>
```

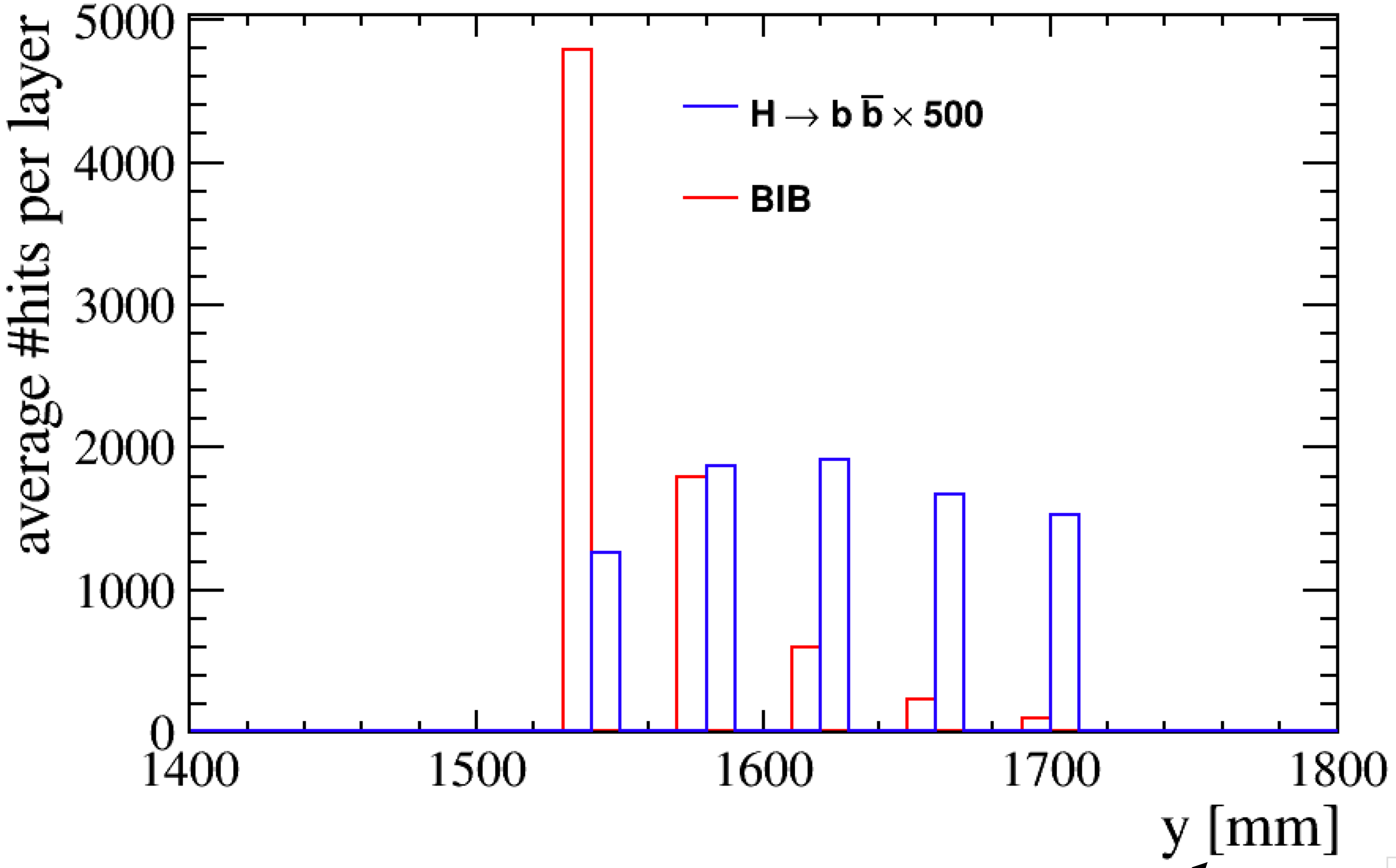
Timing

- Full simulation of the signal (H->bb) and beam-induced background in the detector **with Crilin as ECAL barrel** has been performed at 1.5 TeV.
- Timing is crucial to remove most of the beam-induced background.
- **An acquisition time window of [-250,+250] ps wrt bunch crossing is applied. It is achievable with a time resolution of about 80 ps (window ≈ 3σ).**





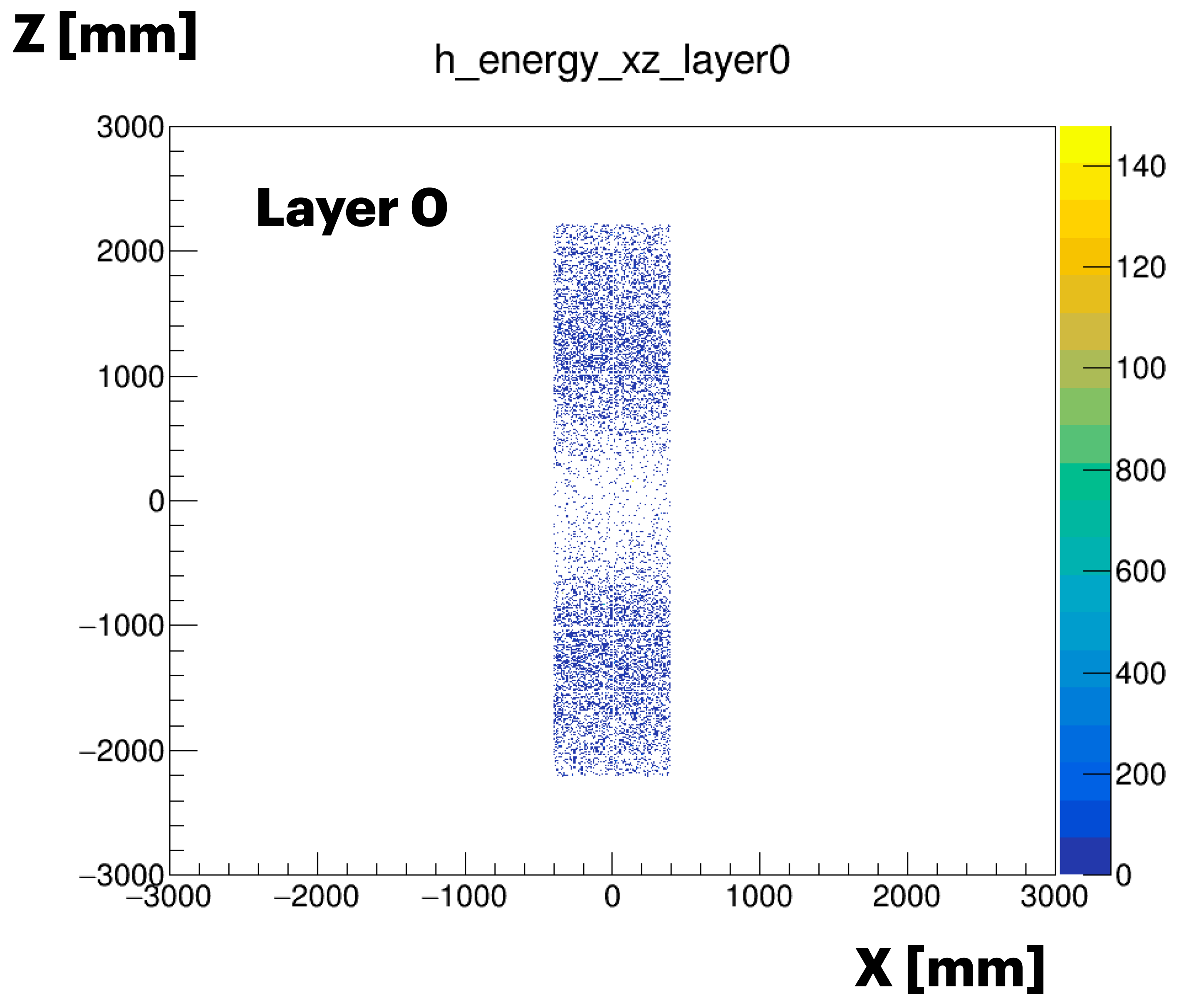
Longitudinal hit distribution

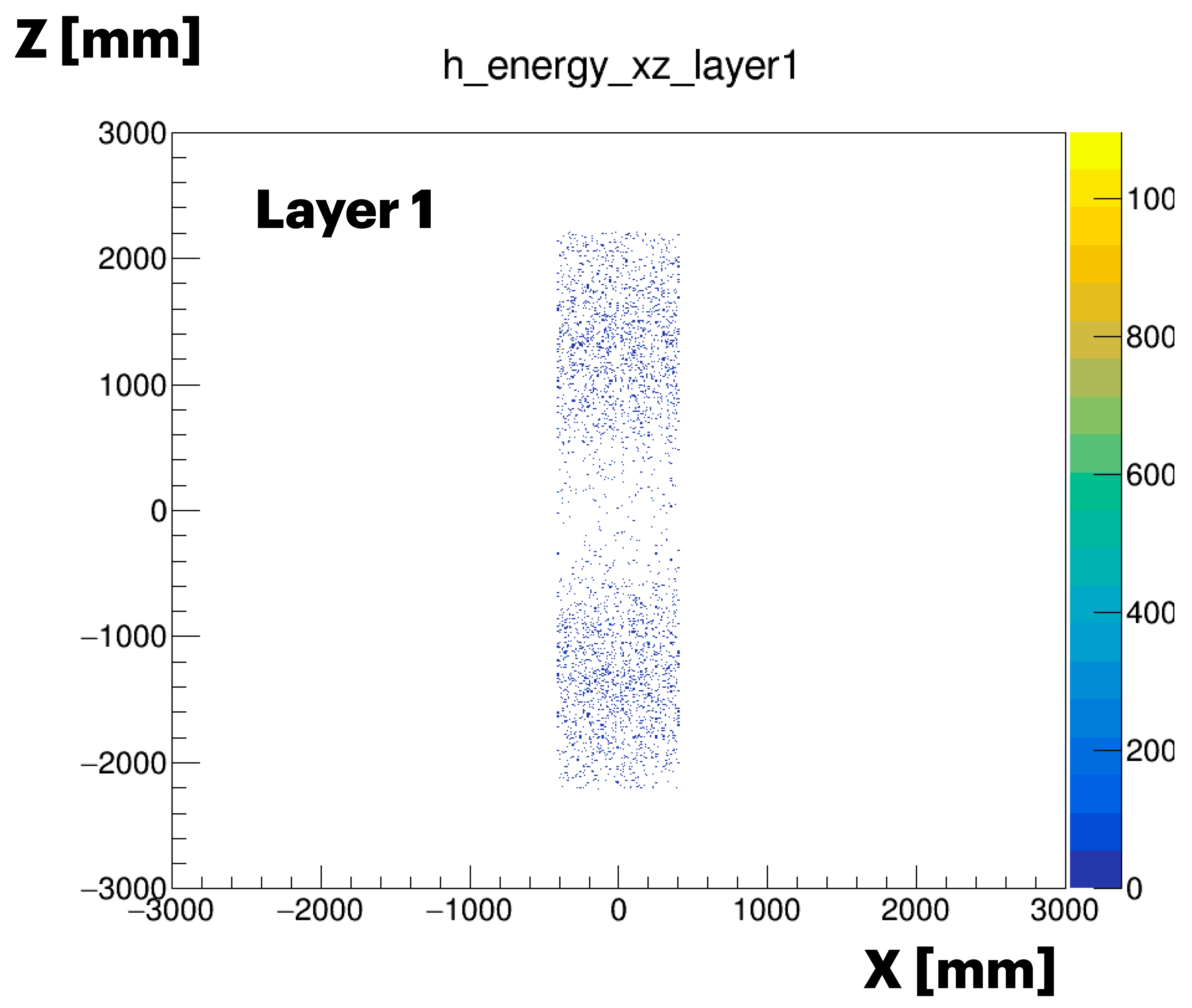


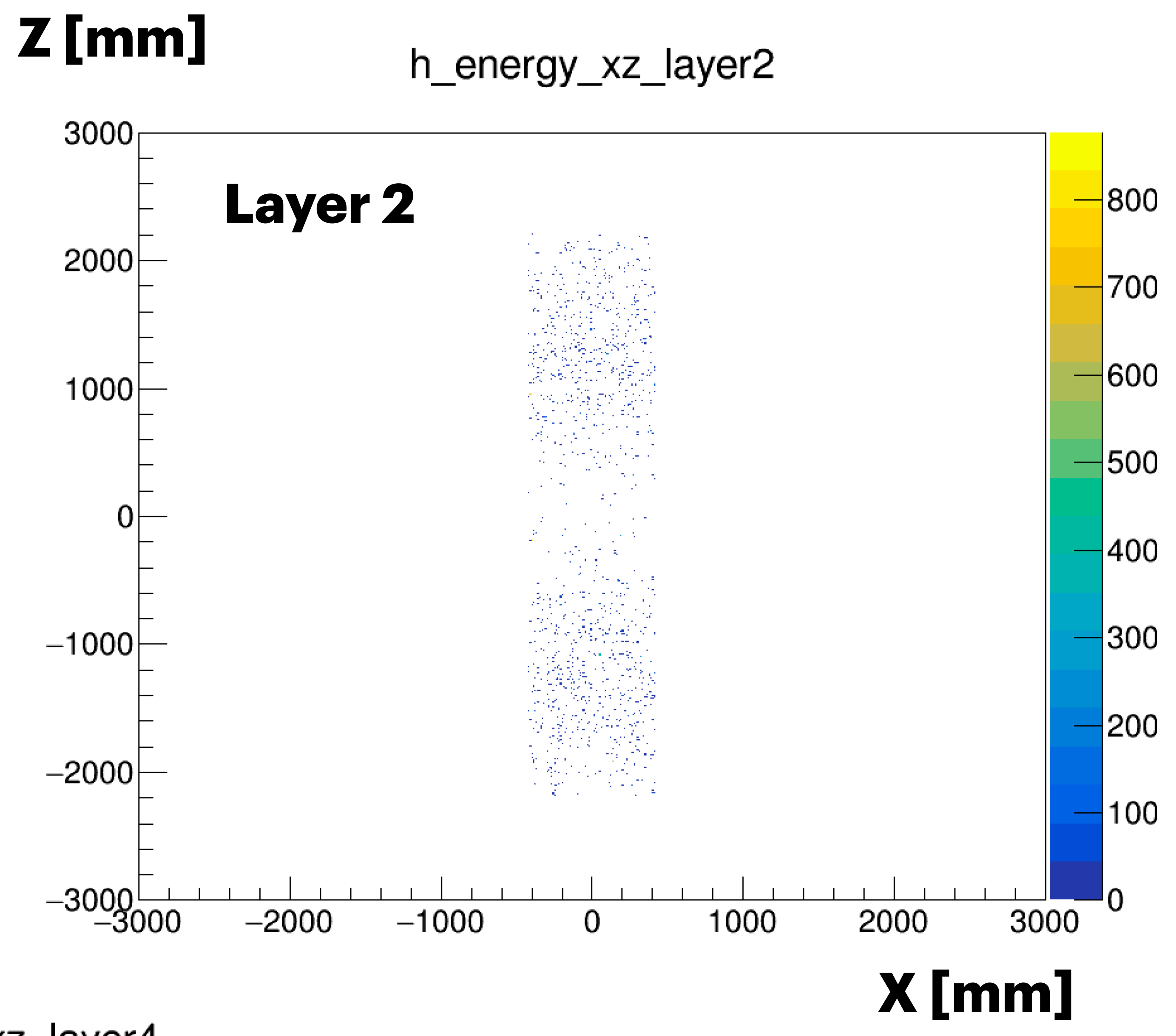
Distance of the layer plane from the beam axis

- **The longitudinal measurement can be an important information for distinguish signal from background**.
- This is evident in the 5 Crilin layers: the BIB leaves most of the hits in the first layer, on the other hand the signal is more uniform in all the 5 layers.

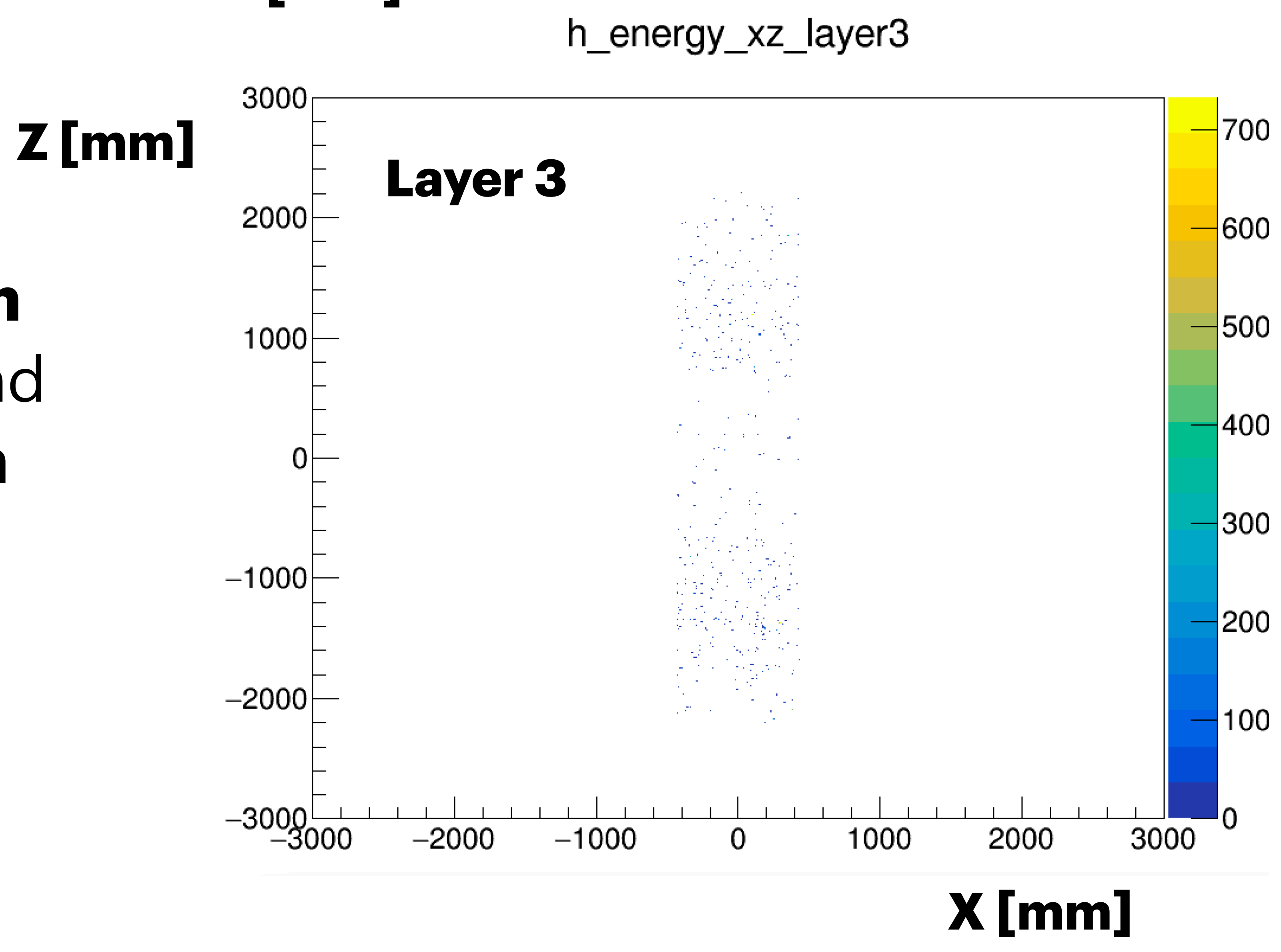
BIB hit distribution in the layer planes

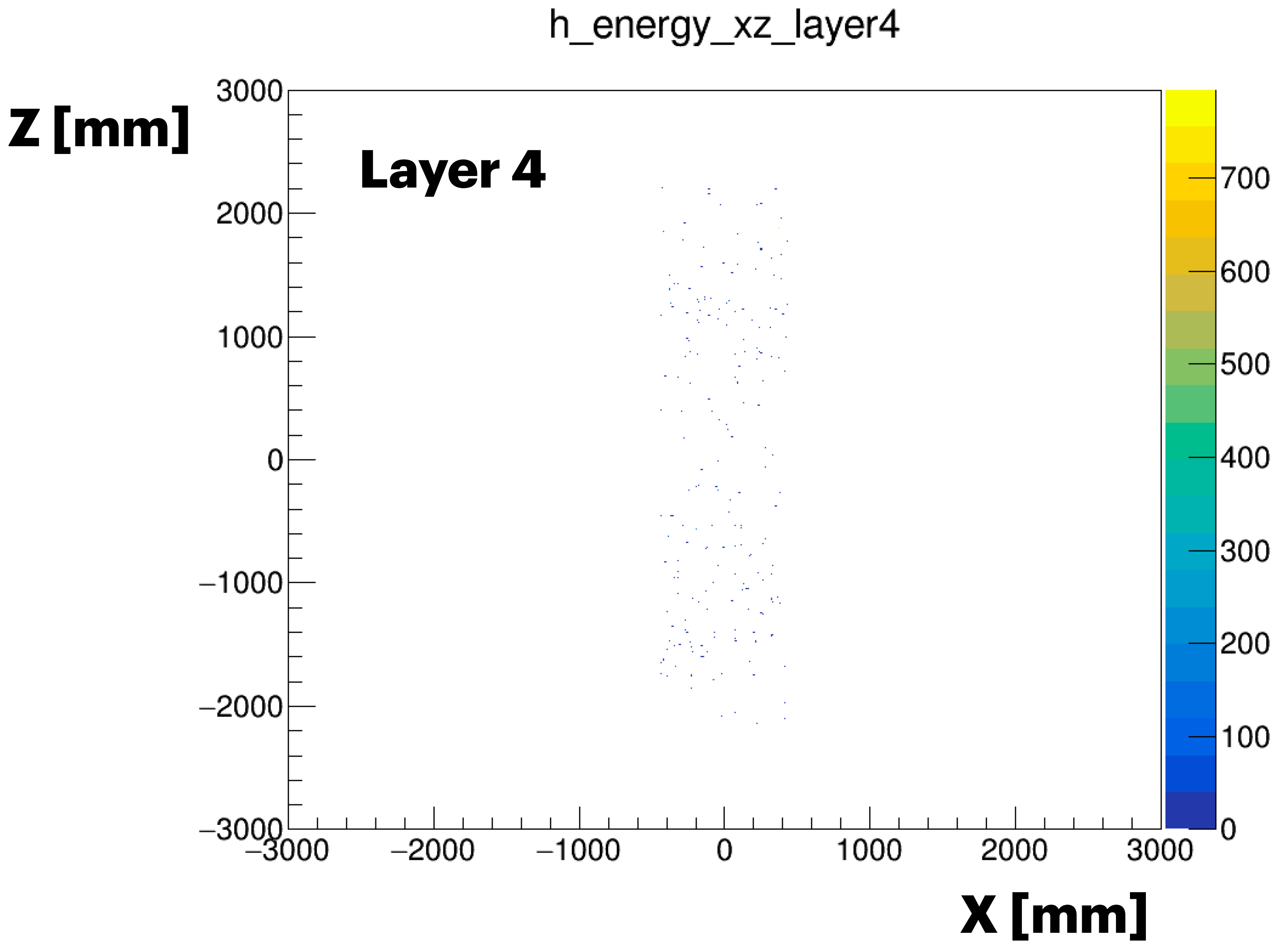




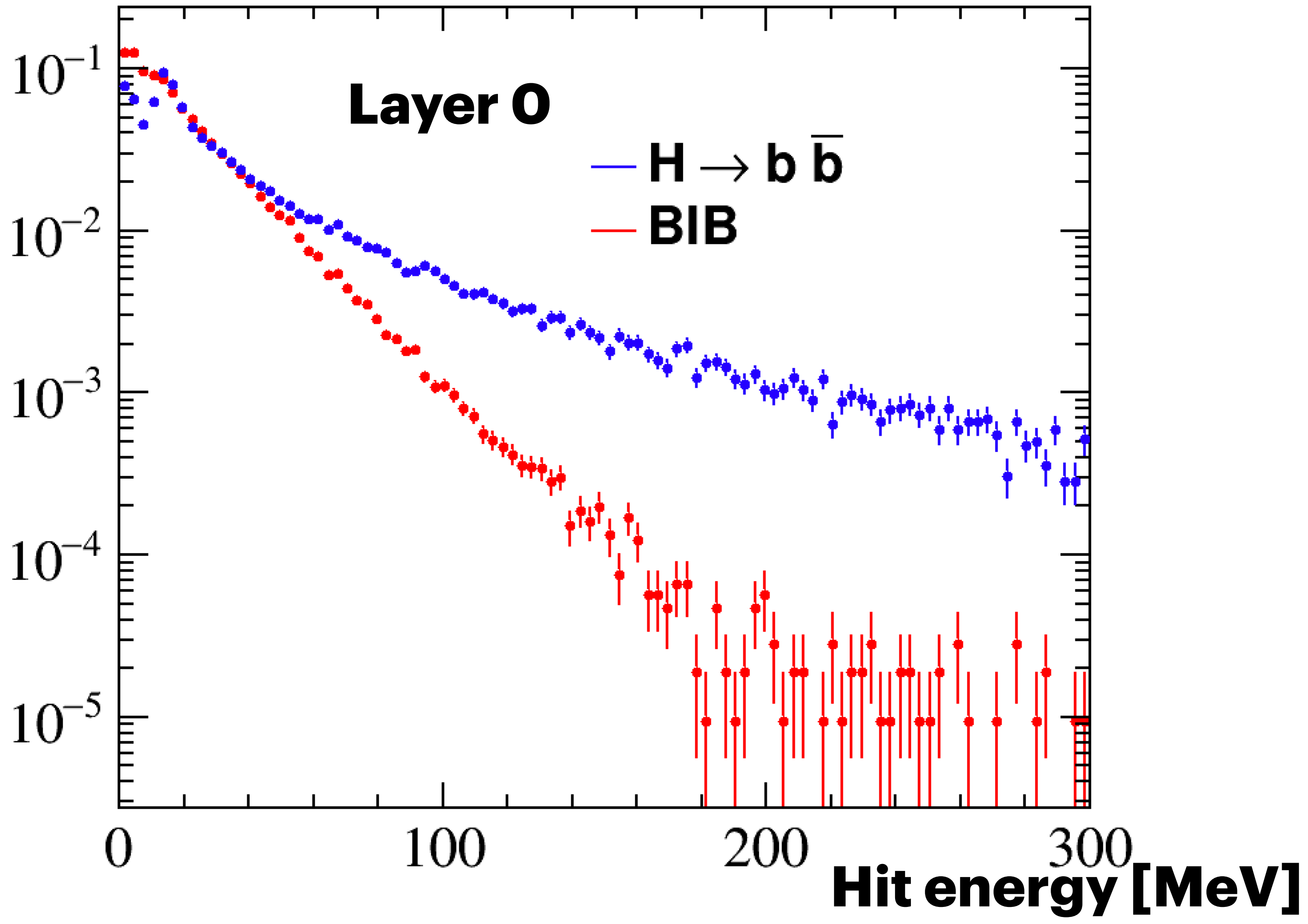


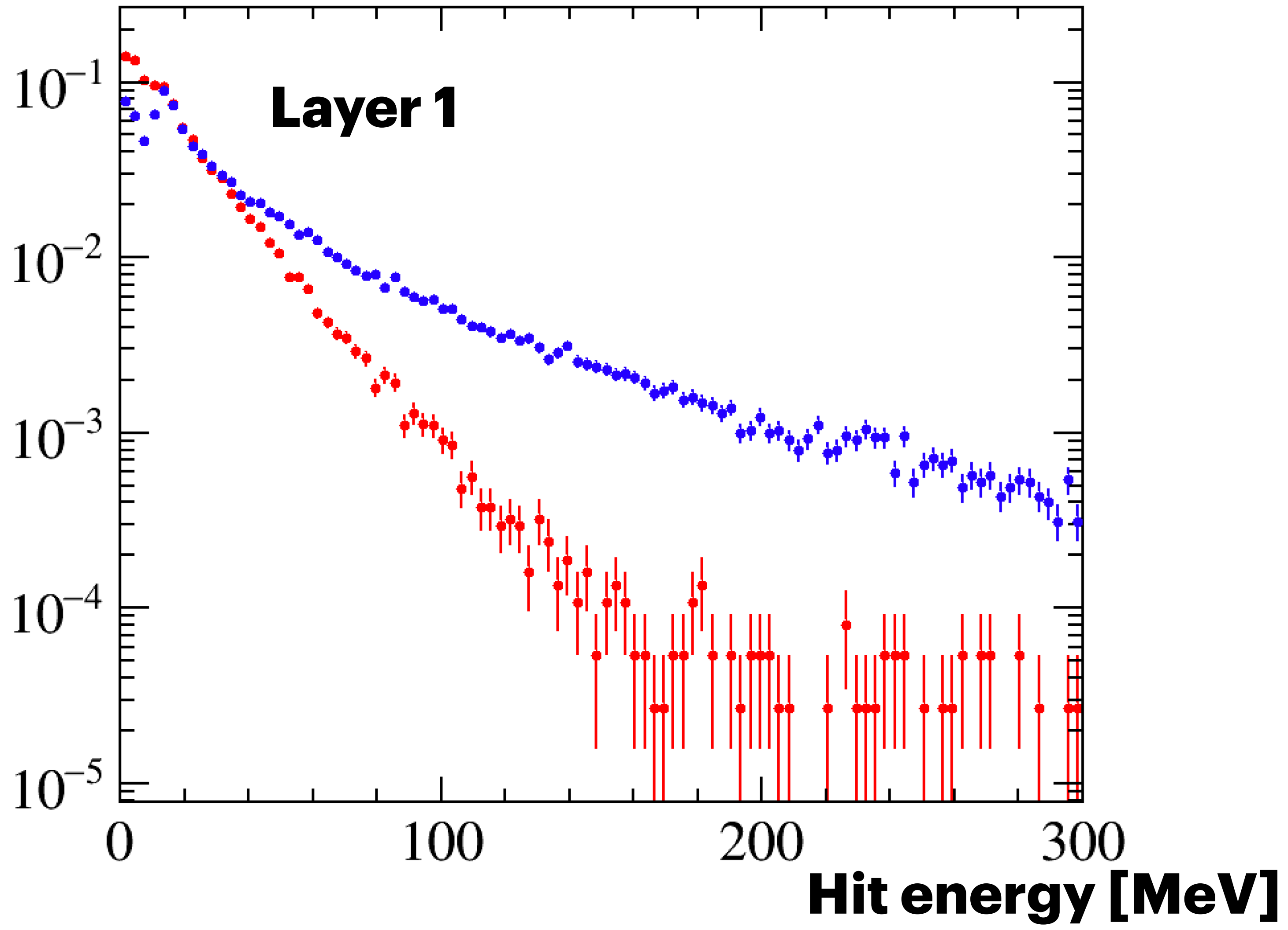
The **forward region with |z|>500 mm** and the **central region with |z|<500 mm** show different occupancies

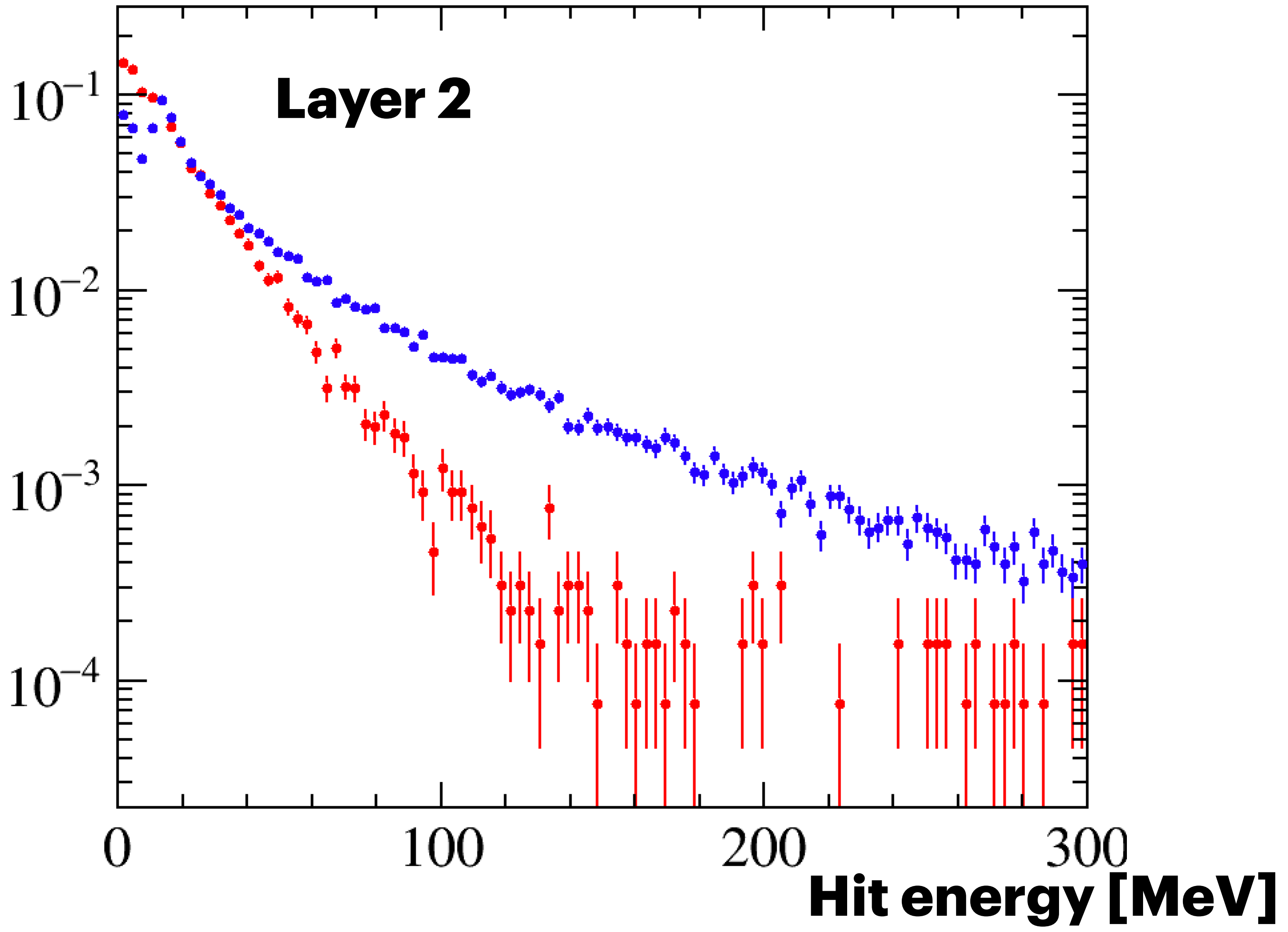




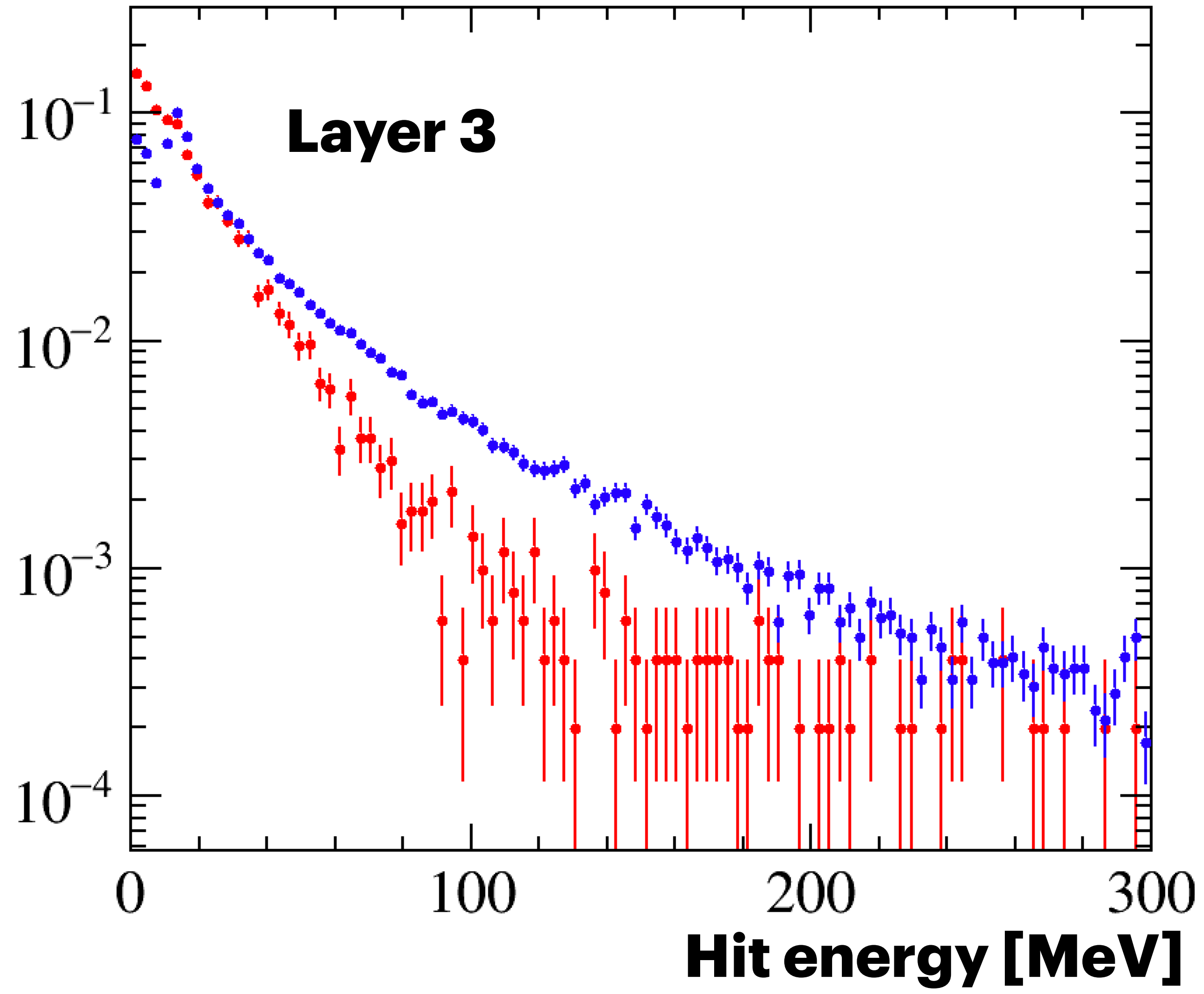
Hit energy distribution: forward region

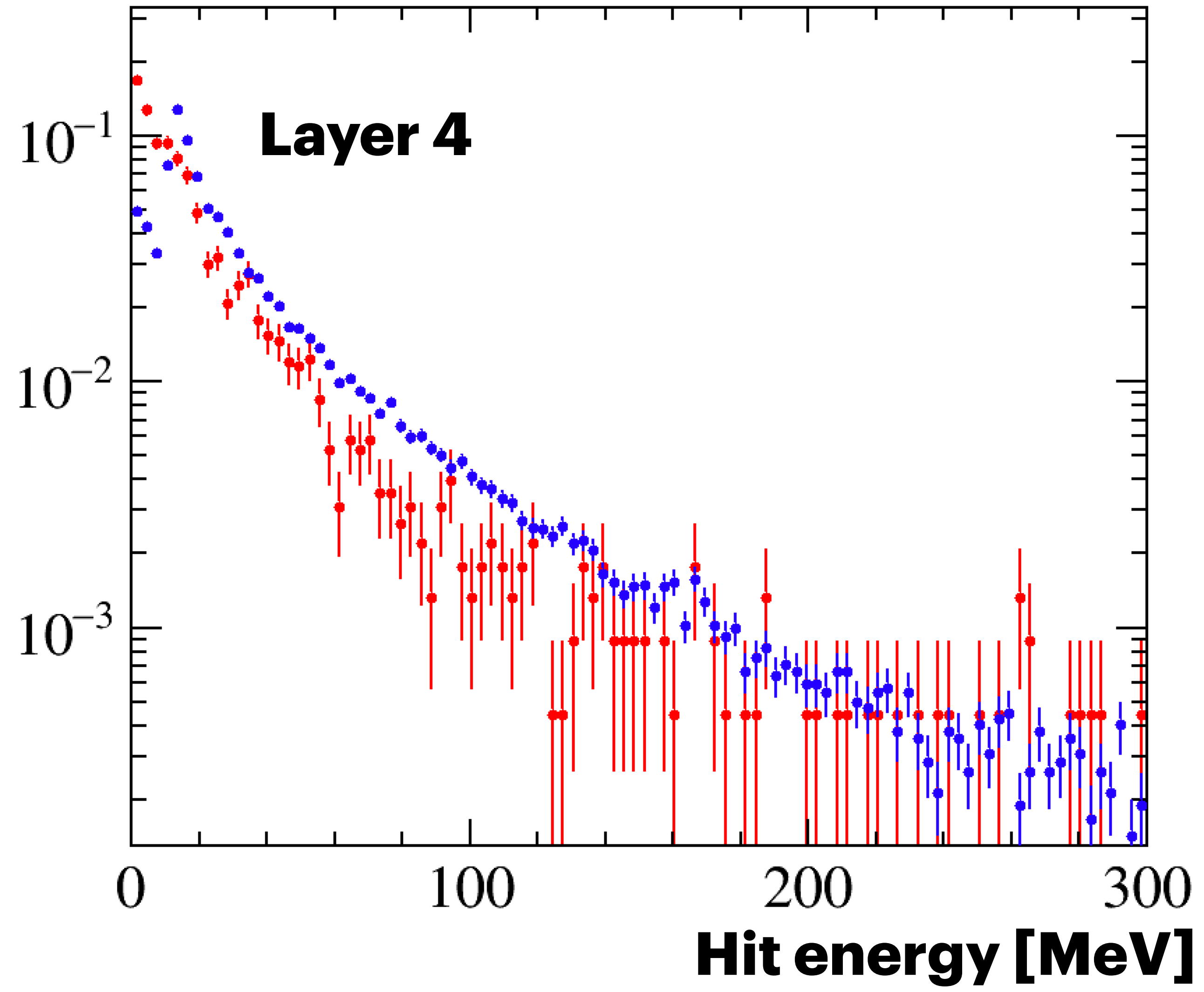






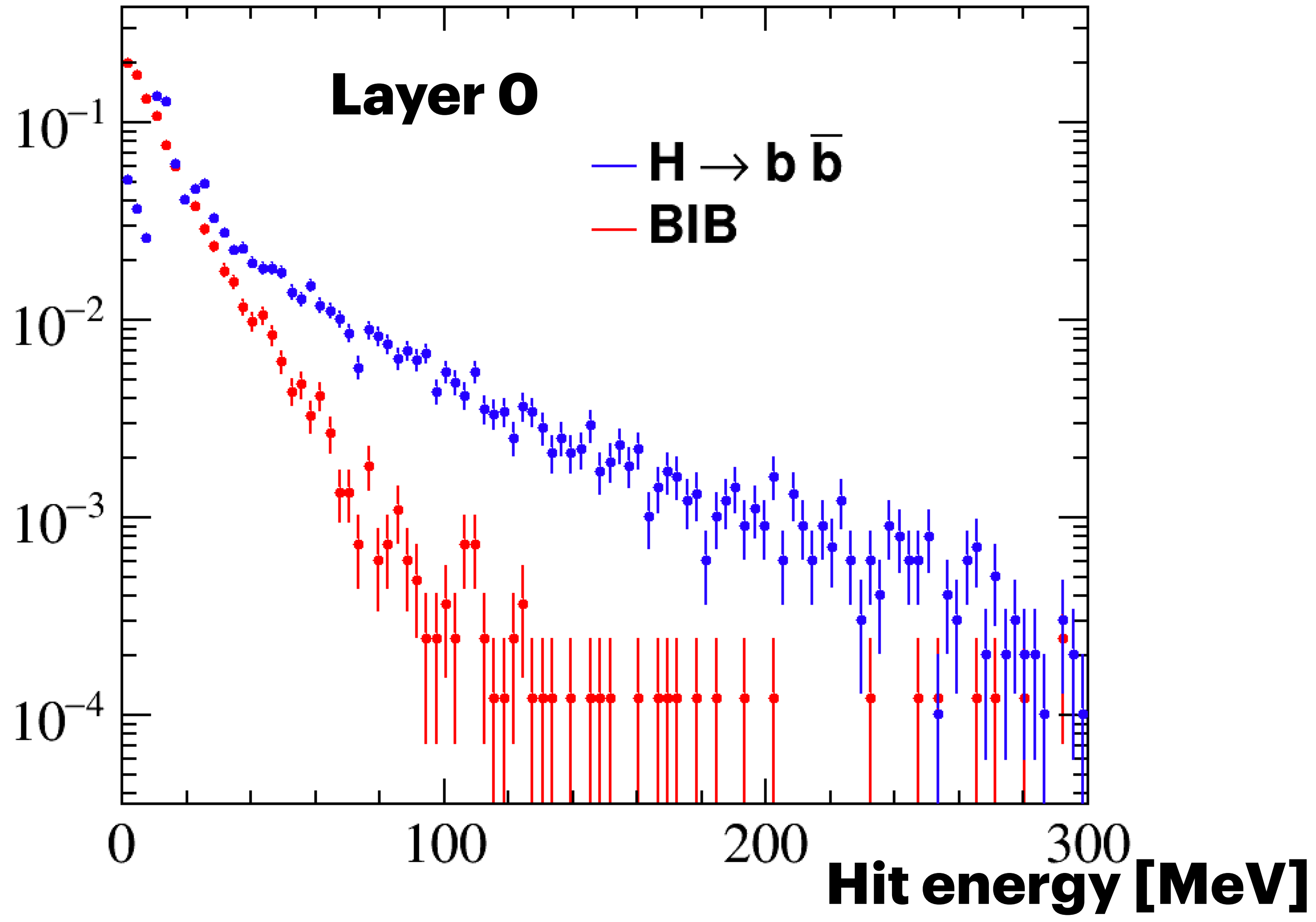
The hit energy distribution is different in the 5 layers (**longitudinal information is important!**)

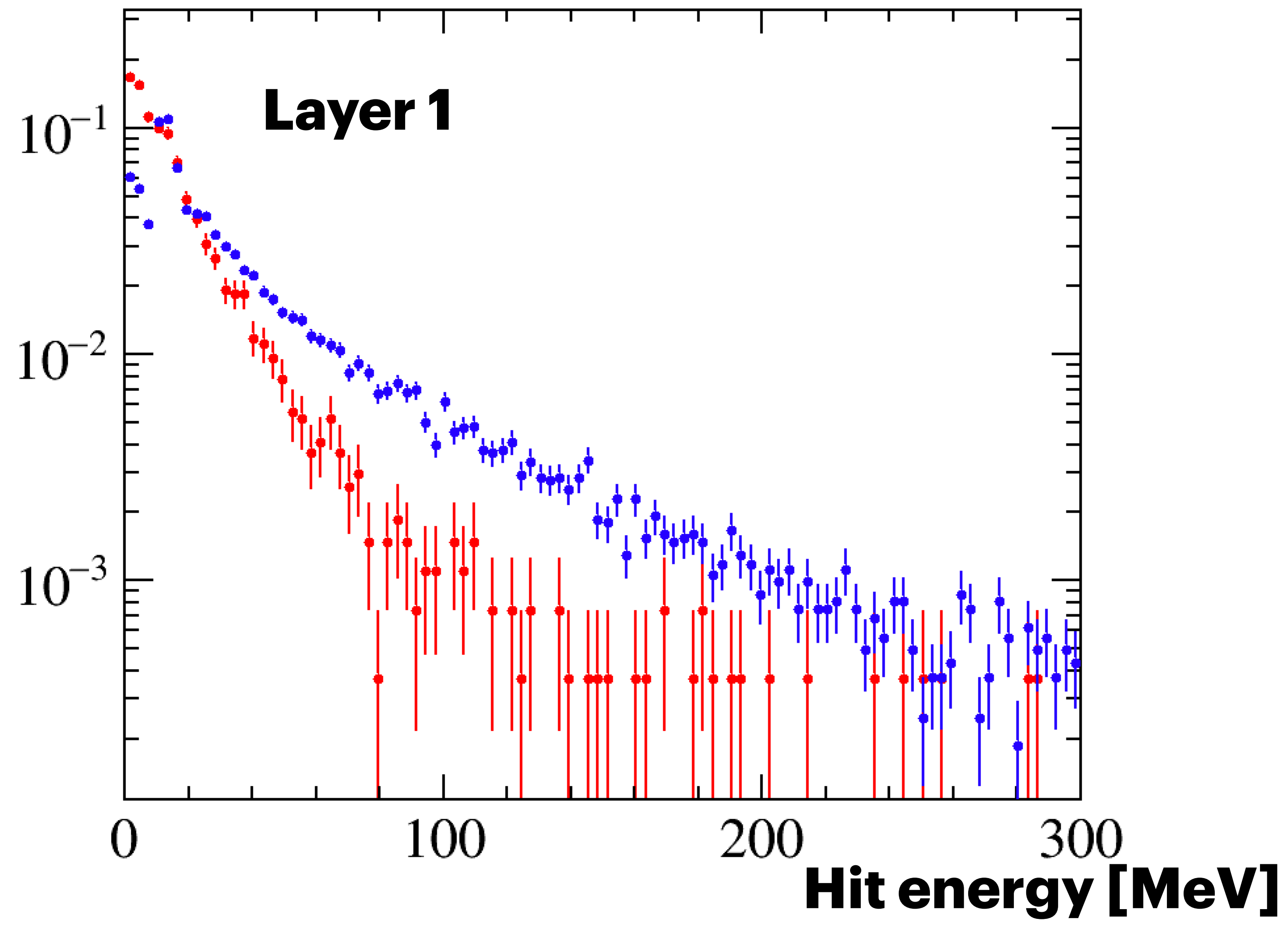


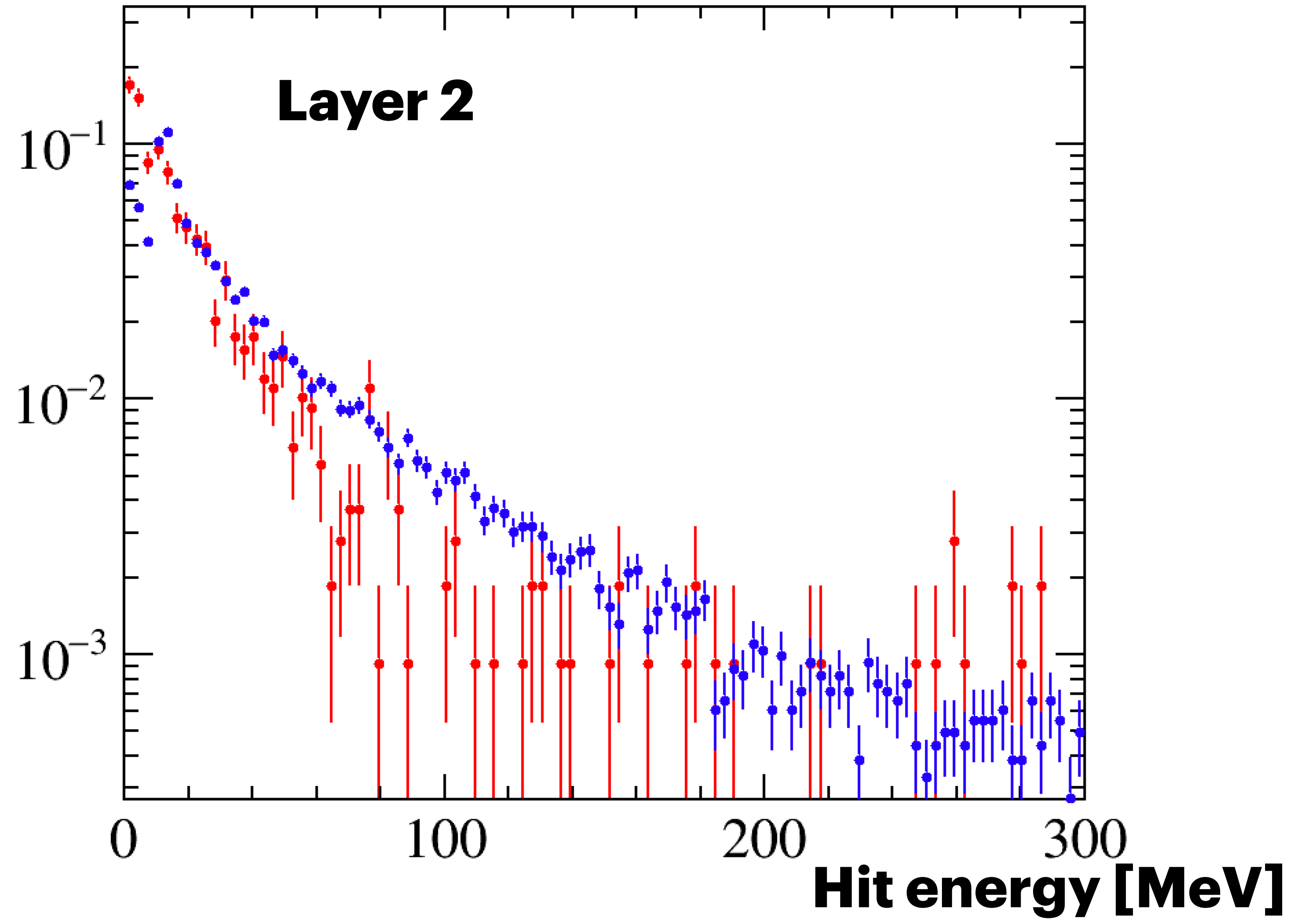


- **Thresholds on the hit energy are set as a function of the layer and of the region (forward or central).**
- Thresholds are obtained as $\mathbf{E_{TH} = E_{BIB} + 2\sigma_{BIB}}$, where E_{BIB} is the average energy of the BIB distribution, and σ_{BIB} is the standard deviation.

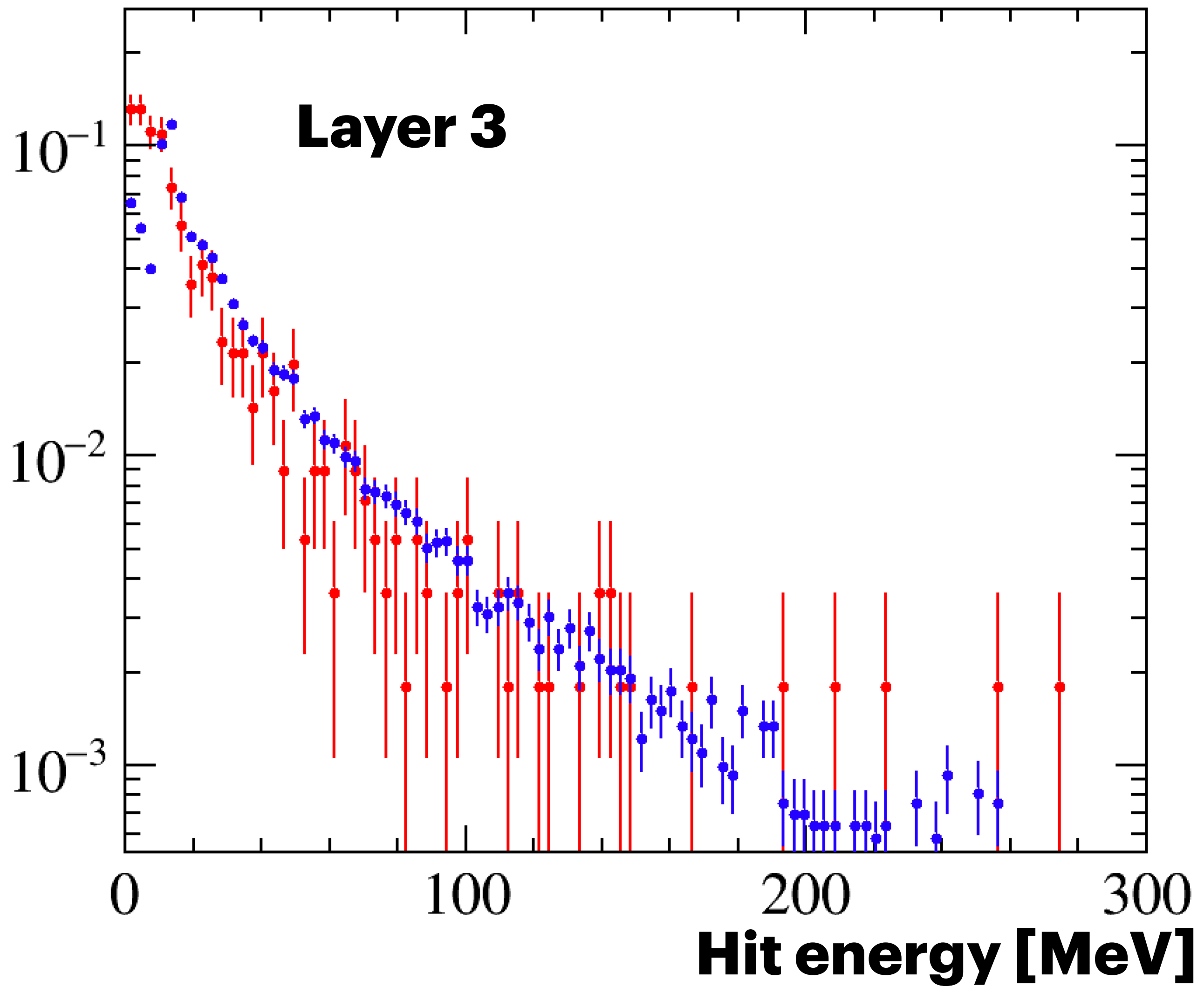
Hit energy distribution: central region

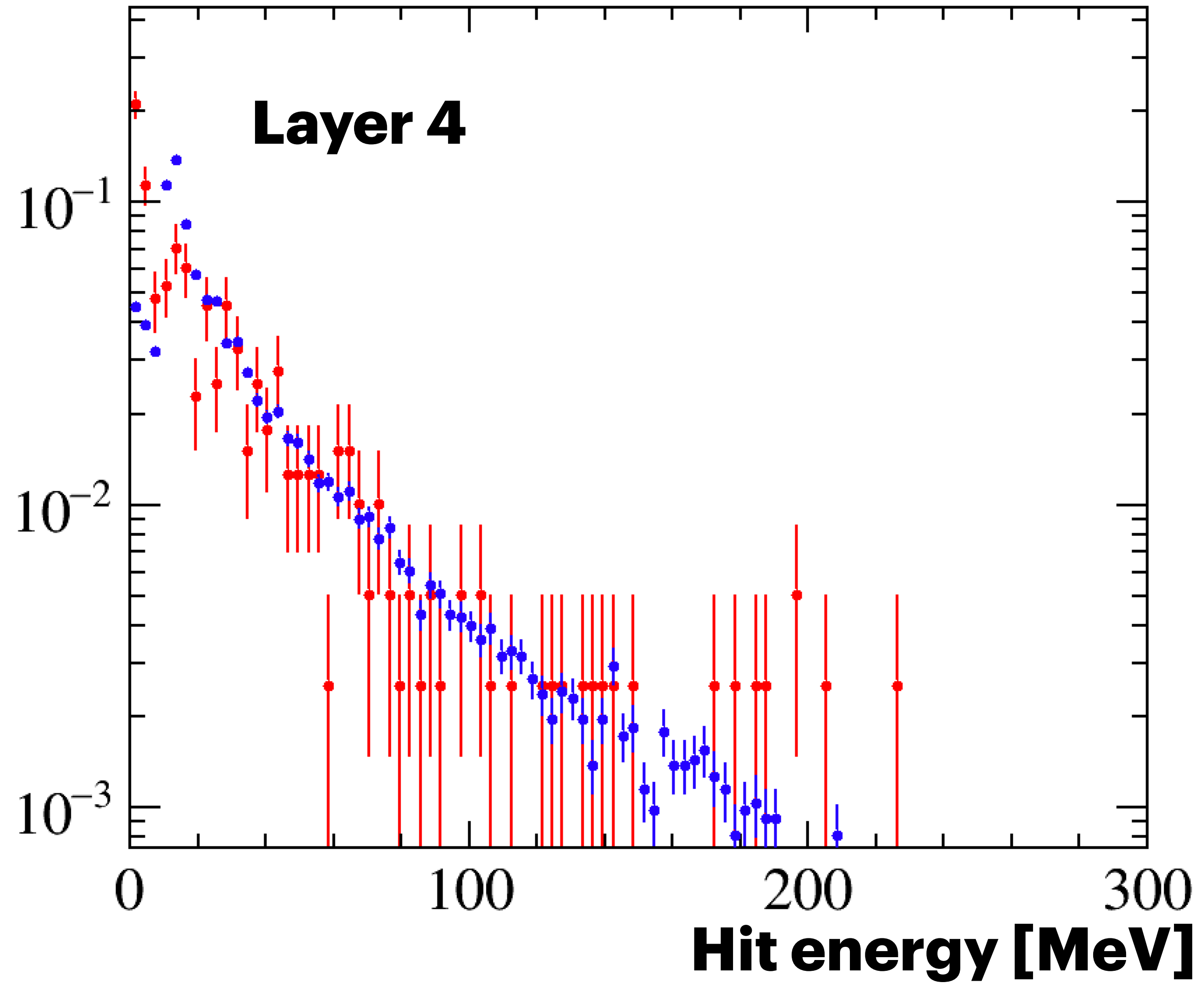






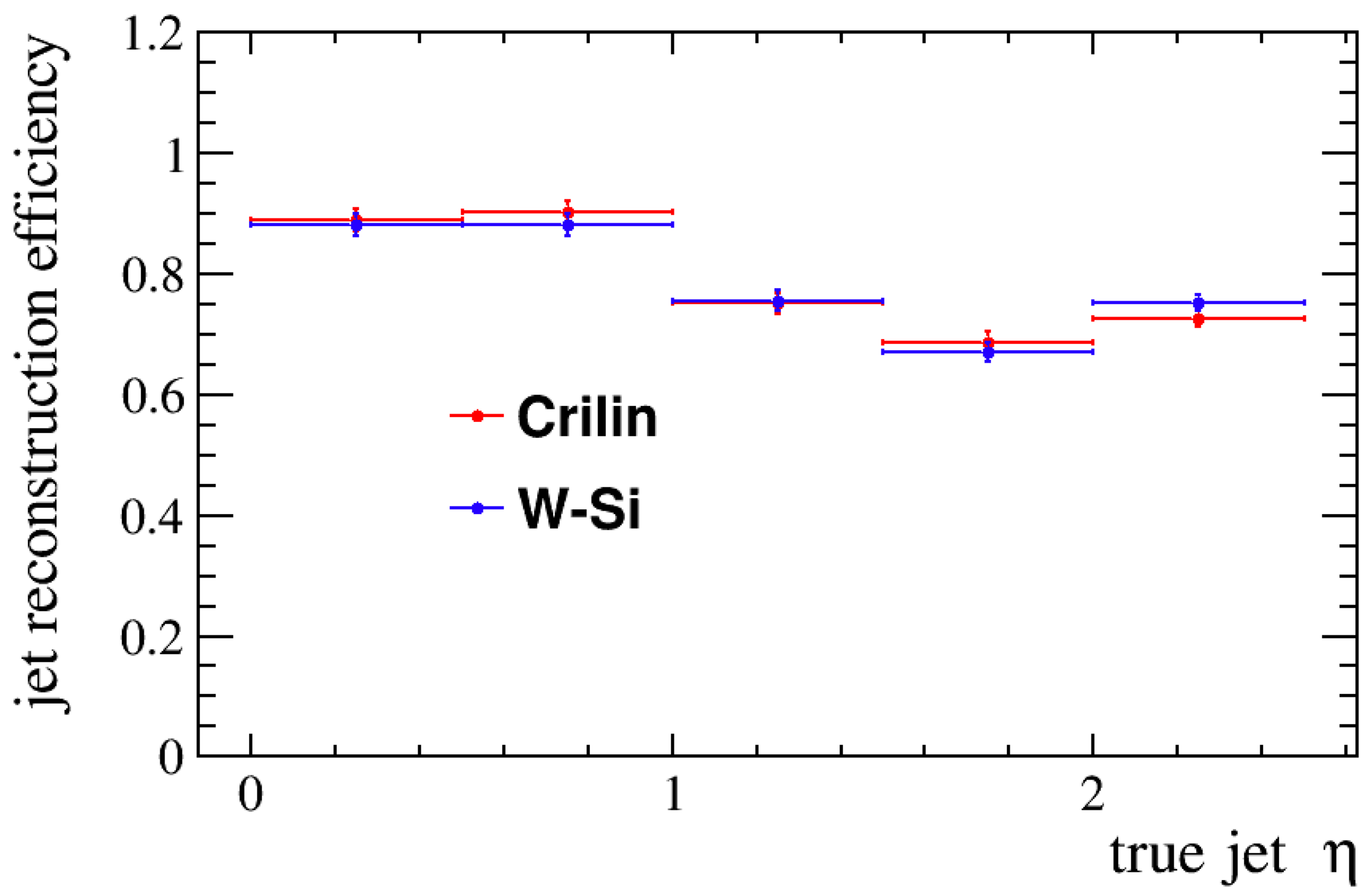
The hit energy distribution is different in the 5 layers (**longitudinal information is important!**)

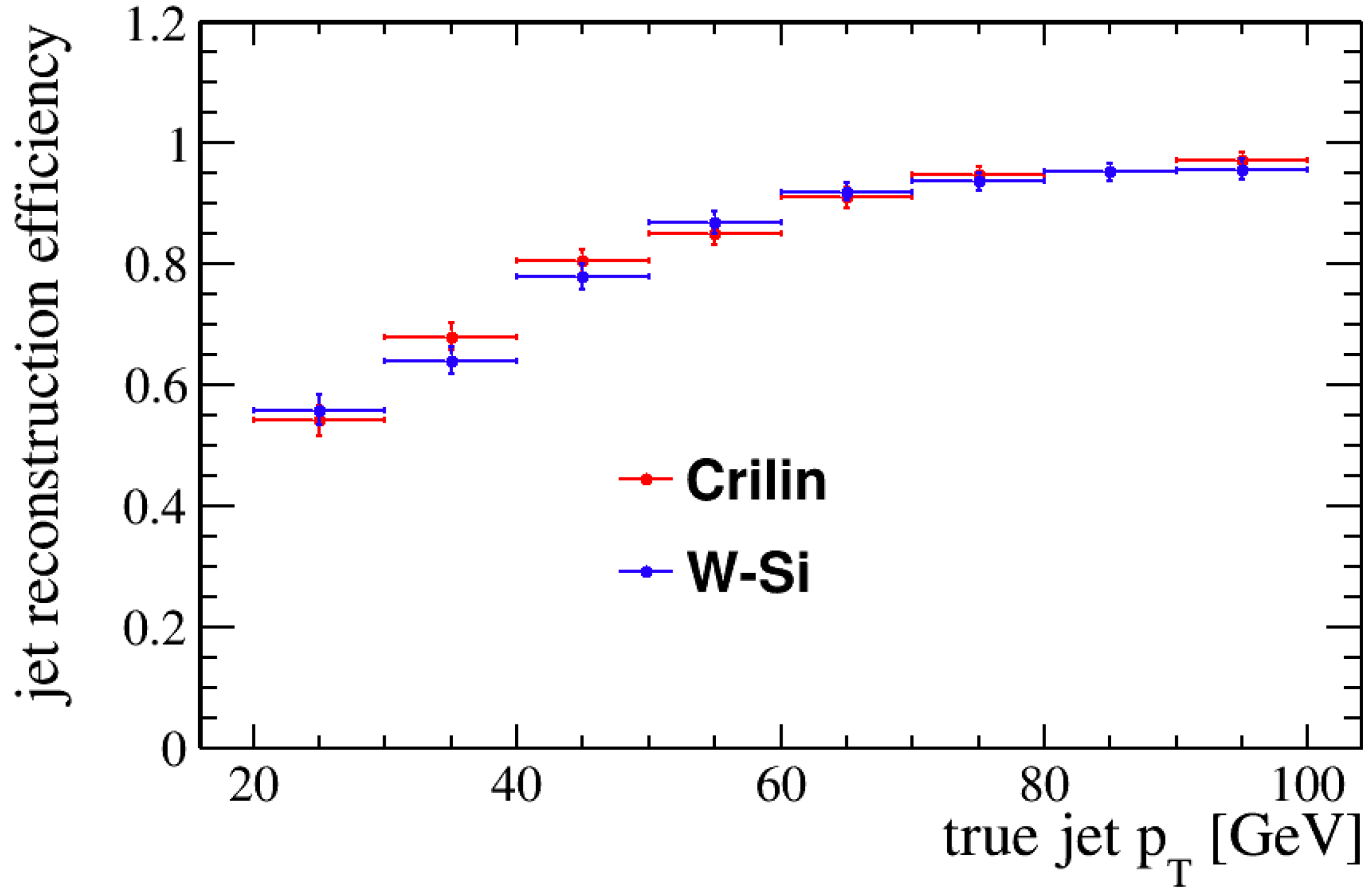


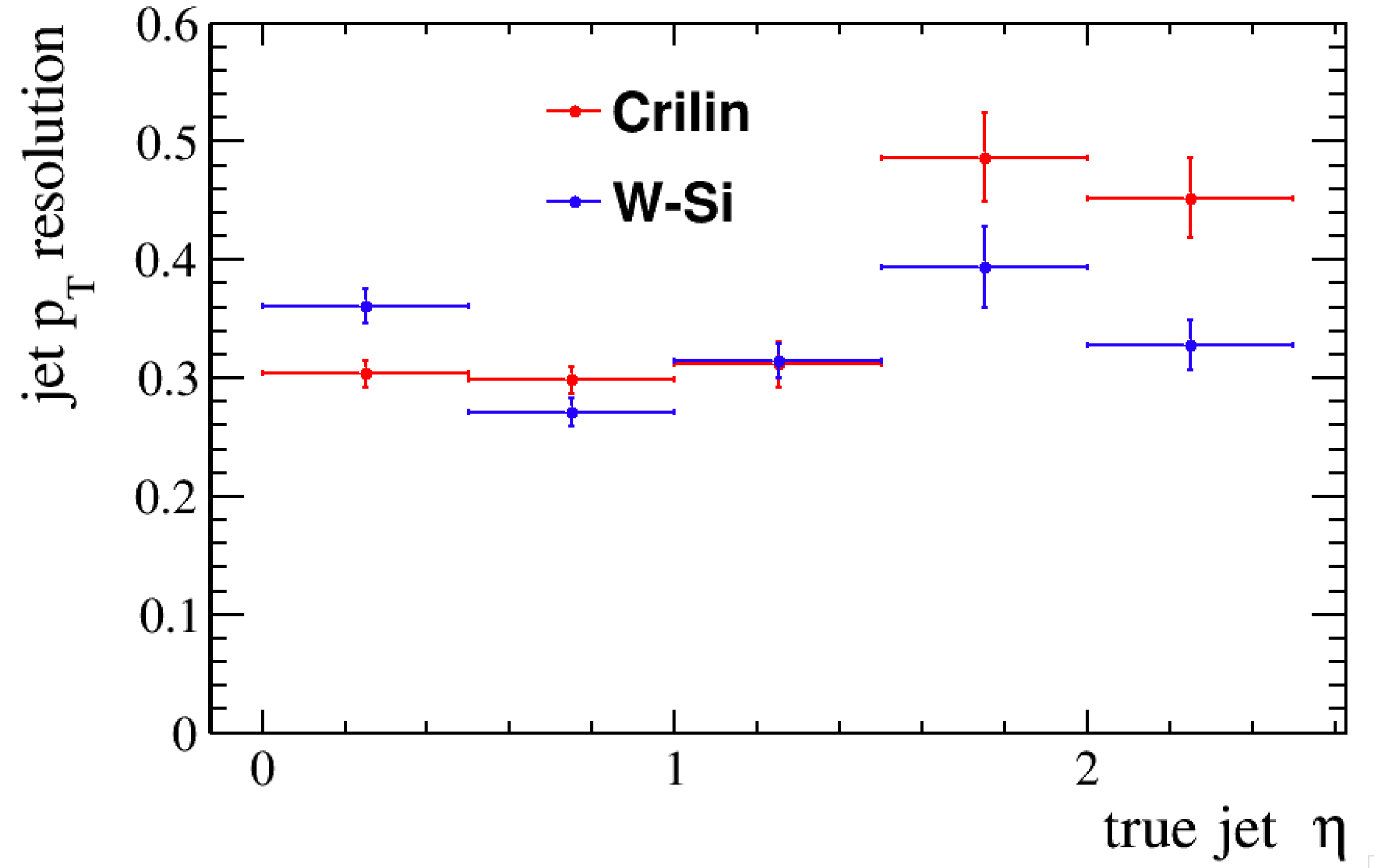


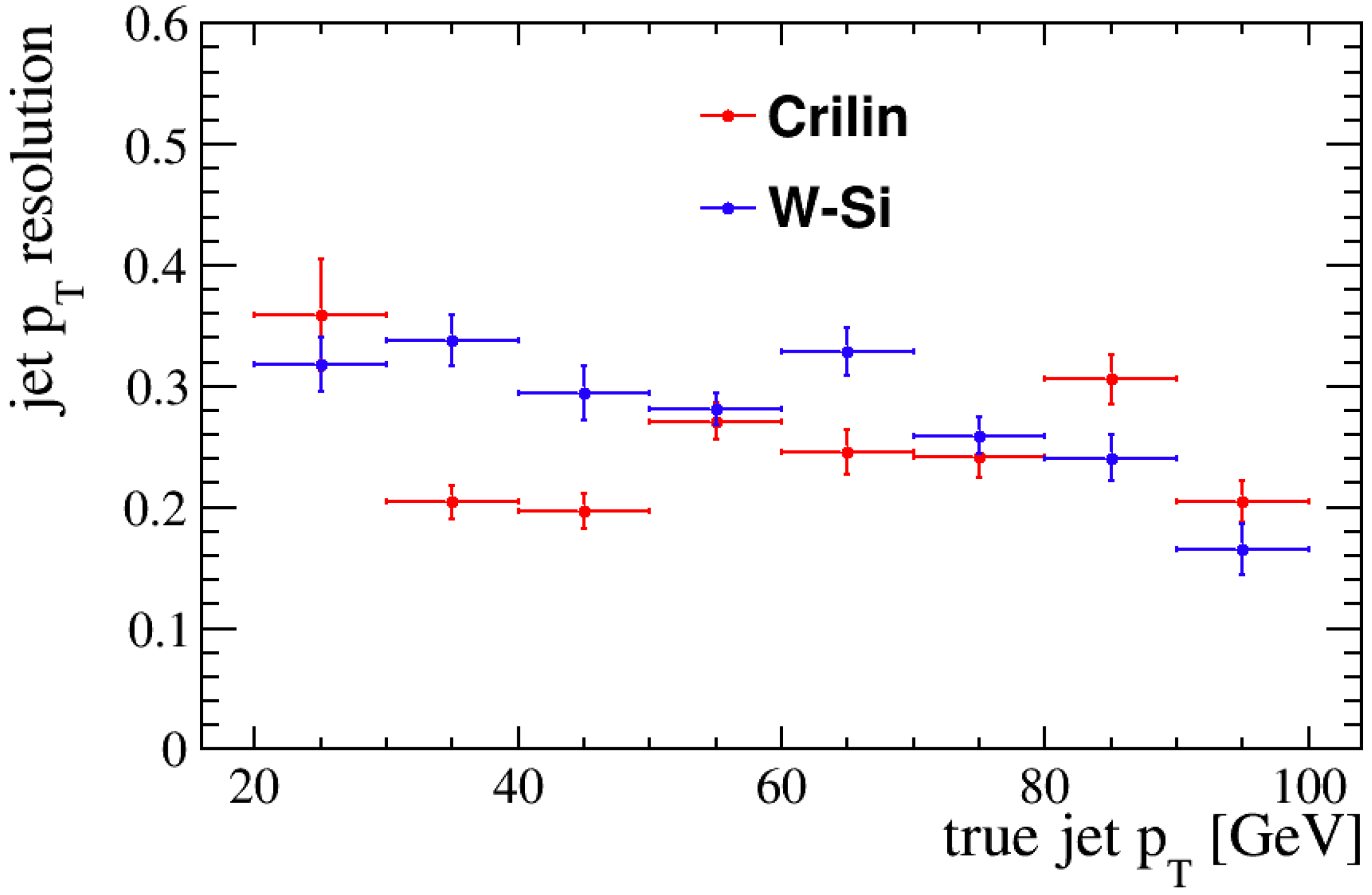
- **Thresholds on the hit energy are set as a function of the layer and of the region (forward or central).**
- Thresholds are obtained as $\mathbf{E_{TH} = E_{BIB} + 2\sigma_{BIB}}$, where E_{BIB} is the average energy of the BIB distribution, and σ_{BIB} is the standard deviation.

Jet reconstruction performance









- **The jet performance obtained with Crilin is compared with the one obtained with the W-Si ECAL barrel** from the CLIC design report. A **particle flow algorithm** is used for the jet reconstruction (combined information from tracker and calorimeters).
- **The performance obtained with Crilin is at the same level of W-Si (but the money cost of Crilin is a factor 10 less!)**
- Notice that there are still many rooms for optimization, therefore these performance can be improved in the future.

Conclusions

- **The performance of the jet reconstruction with Crilin as ECAL Barrel is at the same level of that obtained with the CLIC W-Si calorimeter.**

- **Even if the segmentation of the W-Si calorimeter is higher than Crilin, the BIB is a limiting factor, therefore the high segmentation is not really necessary. It is also true that Crilin can measure more precisely the energy (semi-homogeneous).**

- There are still many rooms for improving the study: implement the lateral dead material around the cells (cables etc. but not present even in CLIC simulation), implement a better digitization model.

- The study should be also repeated when a better version of the reconstruction will be available.

- The flexibility of DD4HEP allows to easily implement new detectors in the Muon Collider framework.

- **The full simulation is an excellent way to test the performance of a new detector.**

Thanks for your attention!

Backup

Thresholds

- **Thresholds on the hit energy are set as a function of the layer and of the region (forward or central).**
- Thresholds are obtained as $\mathbf{E_{TH} = E_{BIB} + 2\sigma_{BIB}}$, where E_{BIB} is the average energy of the BIB distribution, and σ_{BIB} is the standard deviation.
- In the future more sophisticated algorithm to set the energy threshold will be applied (e.g. SoftKiller).
- Thresholds varies from 50 to 100 MeV.
- Clustering is performed with hits that have passed the threshold, using the PandoraPF algorithm. **ECAL endcaps are not used in this reconstruction**.

Full jet reconstruction algorithm

- The jet reconstruction algorithm used in previous studies is applied.
- **It is a particle flow algorithm that combines information from tracker and calorimeters (ECAL + HCAL).**

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)