Full simulation study of a hadronic calorimeter for a future muon collider

Performances test of an MPGD-based HCal through physics events

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BIB overlay:

- Available Generated BIB :

  1500 events at $\sqrt{s} = 1.5\ TeV$ Muon Collider for :

  positive muon beam $\mu^+ \rightarrow e^+ \overline{\nu_\mu} \nu_e$

  negative muon beam $\mu^- \rightarrow e^- \nu_\mu \overline{\nu_e}$

- Simulation step in **3 TeV** Detector configuration at *(ECal-HCal-Solenoid)* with technologies :

  - *CRILIN-MPGD1x1cm^2*

- Merging of **SIGNAL** and **BIB** in the digitization step :

  - BIB + Pion Guns at 5 and 20 GeV

  - BIB + Neutrino Guns at 0.1 GeV (BIBonly study)

BIB SIMULATION

SIMULATED HIT IN ECAL AND HCAL

PION GUN AT 20 GEV + BIB

- Large number of SimHits in ECAL → **filtered** out to perform signal reconstruction

- One order of magnitude less of SimHits in HCAL with respect to ECAL

```
RUN: 0          EVENT: 0          DETECTOR: MuColl_v1
-----------------------------------------------------------------
COLLECTION NAME                 COLLECTION TYPE           # OF ELEMENTS
=================================================================
AllTracks                       Track                                1
CaloHitsRelations               LCRelation                         247
ECALBarrelHits                  CalorimeterHit                       3
ECALEndcapHits                  CalorimeterHit                       0
ECalBarrelCollection            SimCalorimeterHit                 1251
ECalEndcapCollection            SimCalorimeterHit                  236
HCALBarrelHits                  CalorimeterHit                     189
HCALEndcapHits                  CalorimeterHit                      23
HCALOtherHits                   CalorimeterHit                      32
HCalBarrelCollection            SimCalorimeterHit                  206
HCalEndcapCollection            SimCalorimeterHit                   27
HCalRingCollection              SimCalorimeterHit                   36
```

- **BIB filter** for the ECAL Barrel based on the energy and the position of the SimHits implemented by the **CRILIN group in Padova**

    → look at particles traversing the **barrels regions** only in HCAL

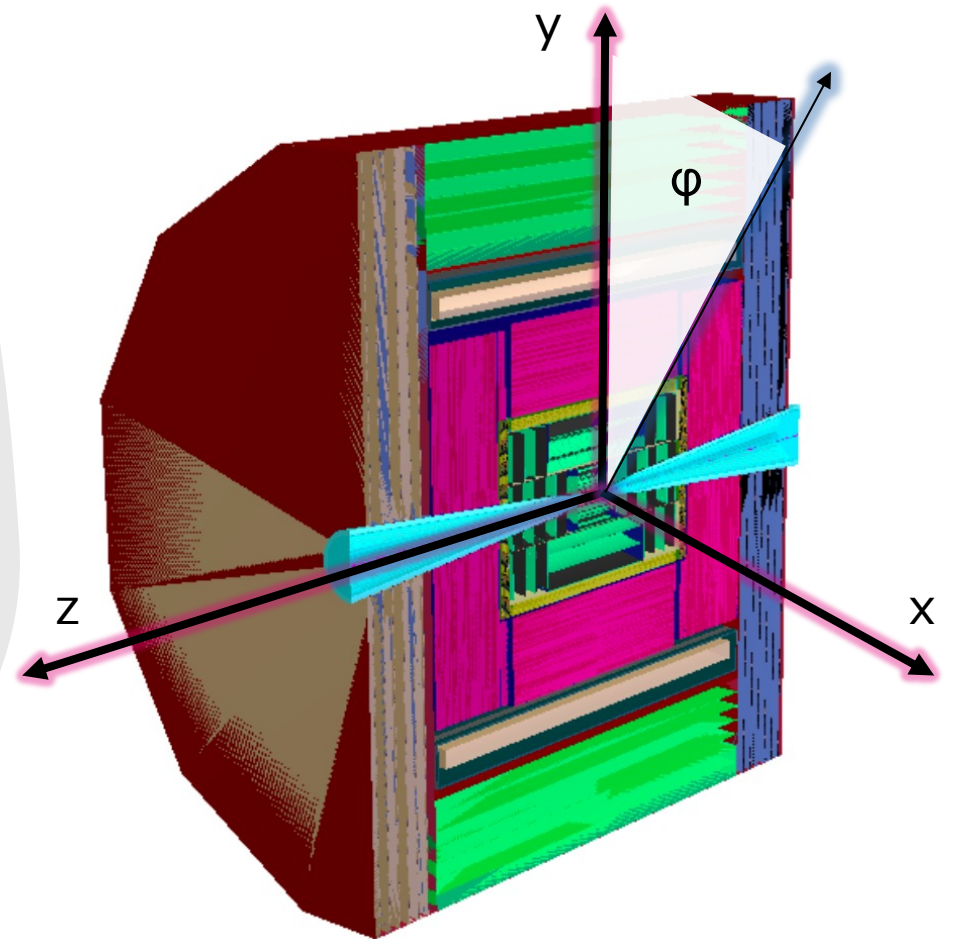- Most of the ECAL Hits are rejected by the filter

BIB IDENTIFICATION

- Looking for signature variables capable of discarding BIB:

SIMULATED HITS:

- *Occupancy (x-y and z-φ)*

- *Longitudinal distribution (z)*

- *Energy*

- *Arrival time*
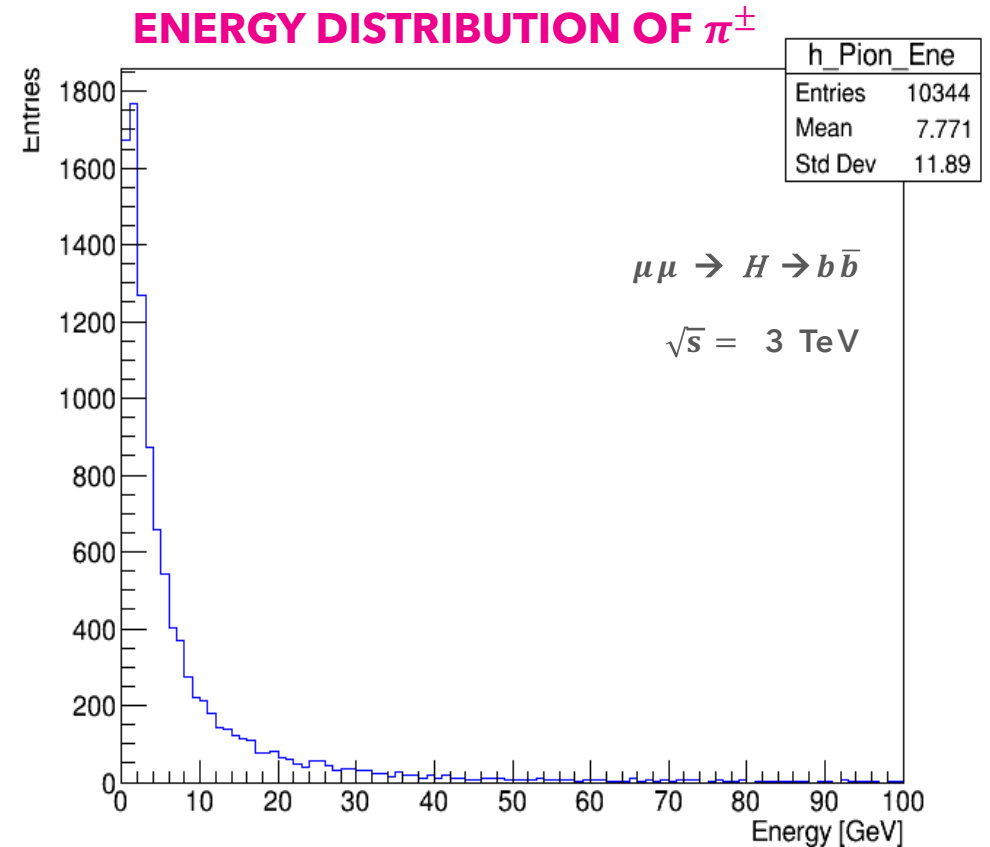
RECONSTRUCTED CLUSTERS :

- *Cluster Size*

- *Cluster Energy*

BIB COMPARISON WITH SIGNAL

STUDY OF $\mu\mu \rightarrow$ **H** $\rightarrow b\bar{b}$ **-** $\sqrt{s} =$ **3 TEV**

From previous studies of $\boldsymbol{\mu\mu} \rightarrow H \rightarrow b\bar{b}$ at $\sqrt{s} =$ 3 TeV, the energy distribution of pions in the jets shows :

- **mean** energy is **7.77 GeV**

- **94.5%** of particles below **20 GeV**

- Energy points to work with are chosen accordingly :
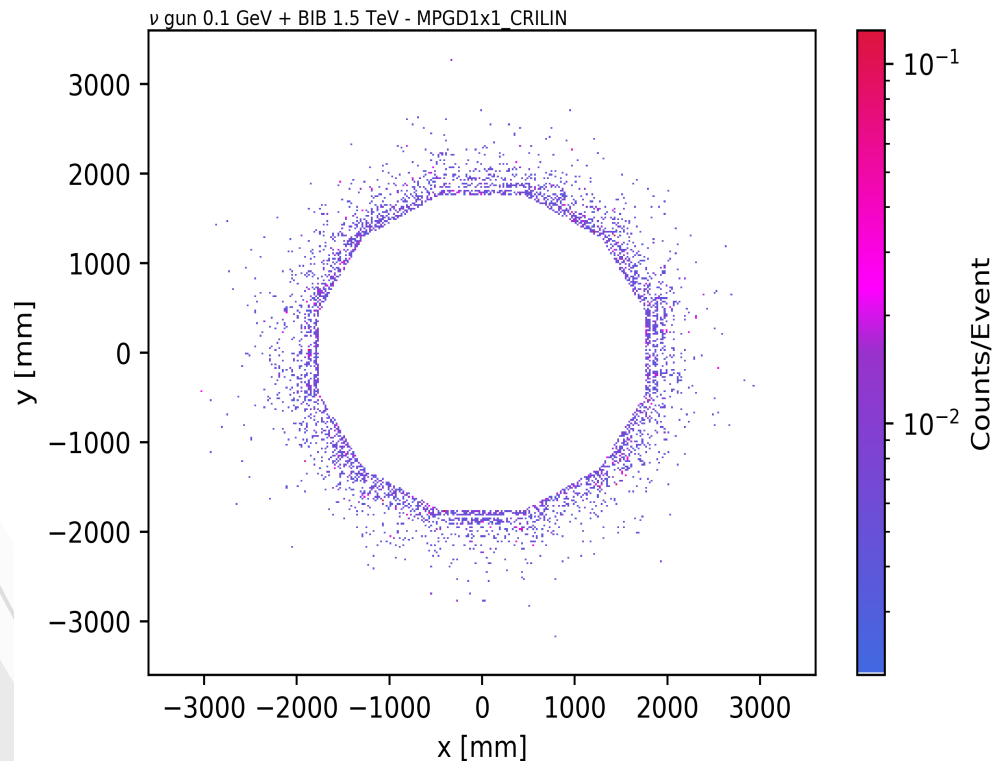
  - **Pion guns at 5 GeV**

  - **Pion gun at 20 GeV**

ENERGY DISTRIBUTION OF $\pi^{\pm}$

BIB CHARACTERIZATION

SIMULATED HITS IN MPGD 1X1 CM² HCAL BARREL

DISTRIBUTION IN X-Y

- Uniform distribution of BIB SimHits on each layer

- BIB contained within the first 20 Layers

ENERGY IN X-Y

- Uniform distribution in plane x-y of the energy deposits of BIB SimHits

- Mean enegy deposits of ~ 4 keV
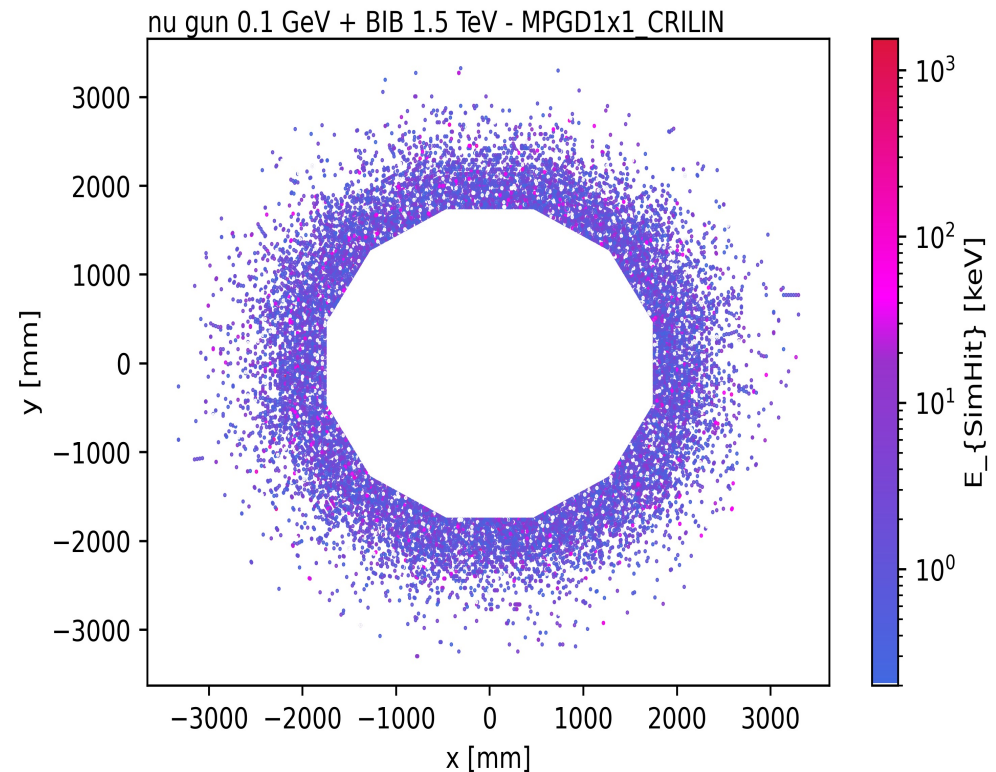
SIMHIT OCCUPANCY

SIMULATED HITS IN MPGD 1X1 CM² HCAL BARREL
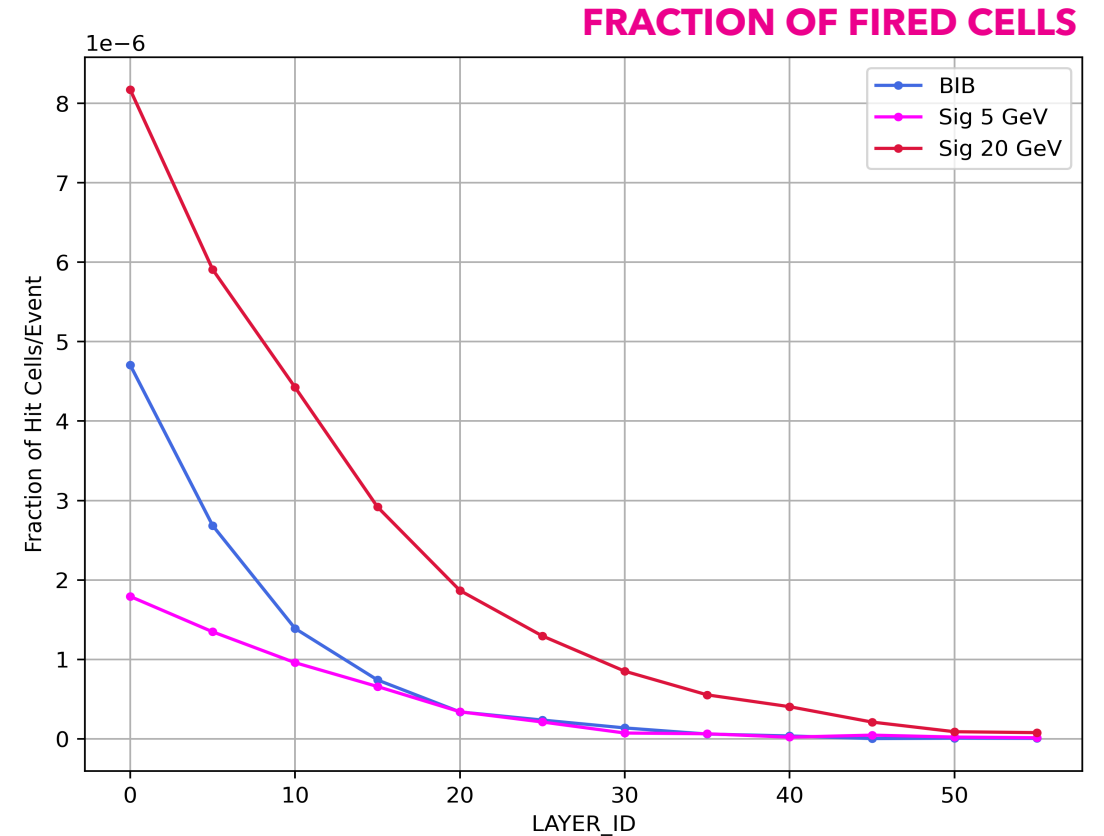
- In all the samples, the occupancy is generally quite low :

  Most of the cells are never fired within one event, and a fraction of cells are fired mostly once

- In all the samples, the occupancy is generally quite low :

  BIB-only: ~ 5 x 10^{-6}

  Pion 5 GeV : ~ 2 x 10^{-6}

  Pion 20 GeV : ~ 8 x 10^{-6}

FRACTION OF FIRED CELLS

LONGITUDINAL DISTRIBUTION

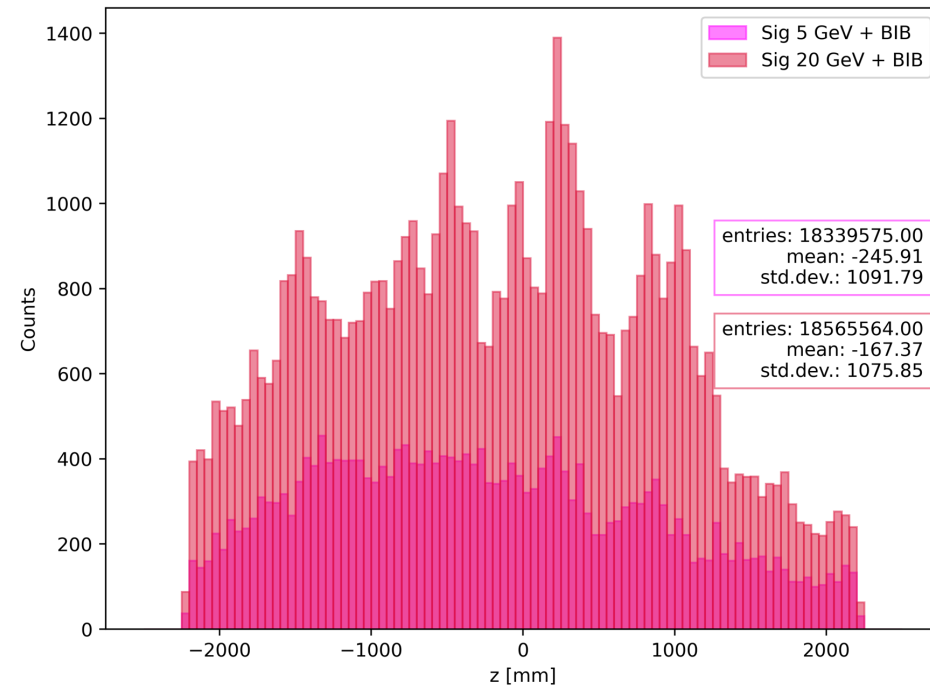## SIMULATED HITS IN MPGD 1X1 CM² HCAL BARREL

For each sample, the spatial distributions result in being quite uniform along the whole z range, minor differences can be noticed :

→ BIB hits have a small hump on the left side, which is unexpected given the symmetry between positive and negative muon beams → more investigation on how DDMarlin Pandora merges the two beams

→ 20 GeV pions are more concentrated in the region close to the IP
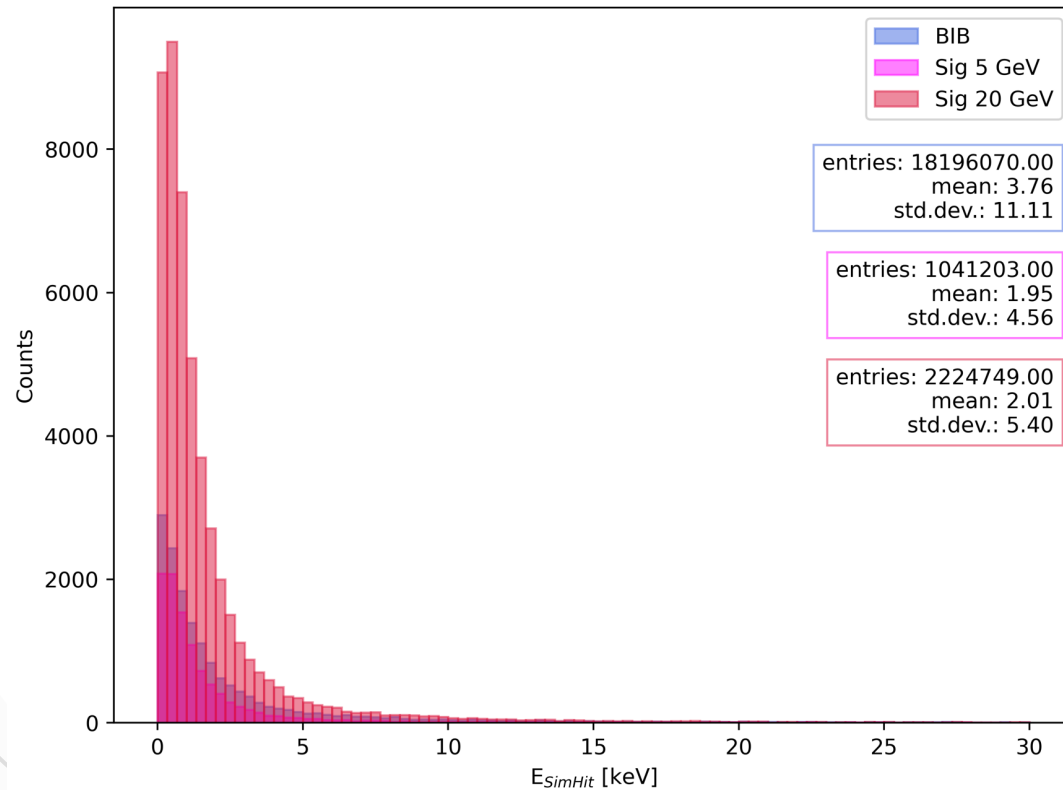

SIGNAL AND BIB SEPARATELY
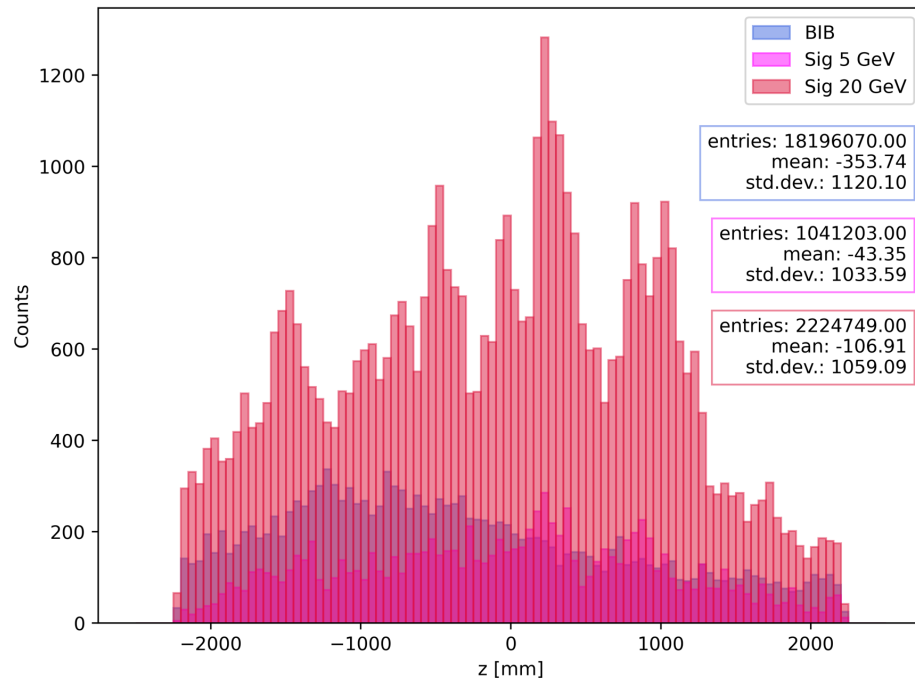
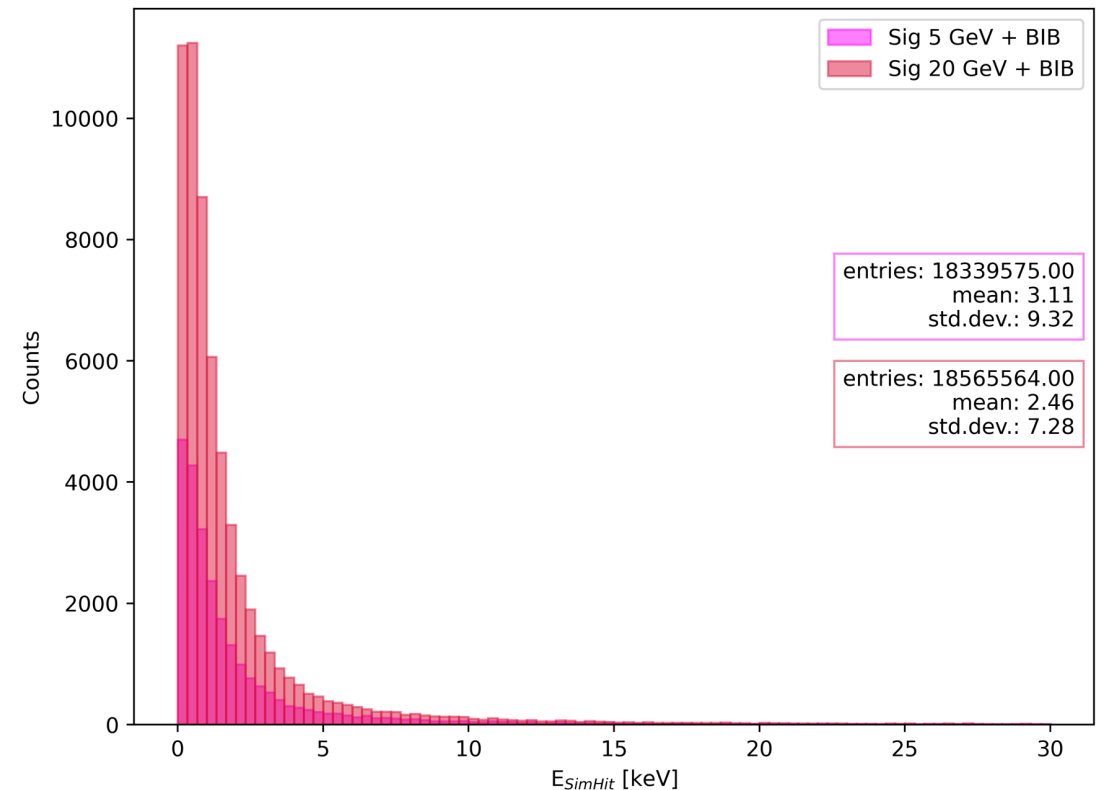SIGNAL AND BIB MERGED

ENERGY DISTRIBUTION

SIMULATED HITS IN MPGD 1X1 CM² HCAL BARREL

- The energy of the BIB SimHit is larger than the one of pure signal:

  → No possible cut of BIB hits based on SimHit energy
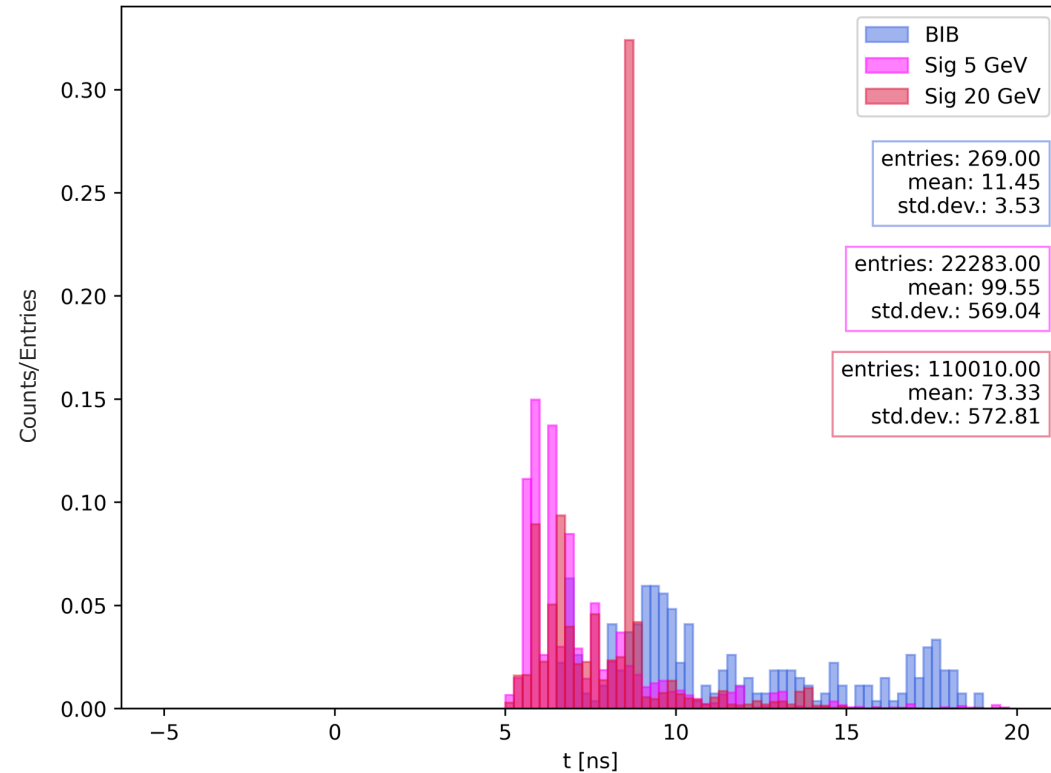
SIGNAL AND BIB SEPARATELY

Legend:
- BIB
- Sig 5 GeV
- Sig 20 GeV

entries: 18196070.00
mean: 3.76
std.dev.: 11.11

entries: 1041203.00
mean: 1.95
std.dev.: 4.56

entries: 2224749.00
mean: 2.01
std.dev.: 5.40

SIGNAL AND BIB MERGED

Legend:
- Sig 5 GeV + BIB
- Sig 20 GeV + BIB

entries: 18339575.00
mean: 3.11
std.dev.: 9.32

entries: 18565564.00
mean: 2.46
std.dev.: 7.28

ARRIVAL TIME DISTRIBUTION

SIMULATED HITS IN MPGD 1X1 CM² HCAL BARREL

SIGNAL AND BIB SEPARATELY

Legend:
- BIB
- Sig 5 GeV
- Sig 20 GeV

entries: 269.00
mean: 11.45
std.dev.: 3.53

entries: 22283.00
mean: 99.55
std.dev.: 569.04

entries: 110010.00
mean: 73.33
std.dev.: 572.81

- Most of the signal SimHit have arrival times between **5 and 10 ns**

  Assuming relativistic pions, the average time of flight to reach the first layer (~ 1.7 m from IP) is around 6 ns

- Overflow events with t > 20 ns are unexpected, they may derive from bugs in the simulation step

- **BIB** SimHit **time** distribution is **uniform** in the range from about **7 to 20 ns**

→ A **cut on t > 10** should exclude half of the BIB SimHit while neglecting a small fraction of signal

SUMMARY OF THE SIMHIT PROPERTIES

- BIB containment within the first 20 layers

- Very low occupancy in the z- φ view :
  - ~ 5 x 10^{-6} probability for a cell to be fired (1st layer)
  - ~ 3 hits per event (1st layer)
  - → Larger than values at 5 GeV → problematic for pion reconstruction at 5 GeV

- Uniform longitudinal distribution without prominent differences from the pion guns
  - → No possible cut on the z
- SimHit average energies of ~ 4 keV → twice the value of the signal hits
  - → No possible cut changing the RO energy thresholds
- Arrival time distribution is uniform in the range 7-20 ns, while signal peaks at 6 ns
 - Possible cut at t > 10 ns

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CLUSTER MULTIPLICITY

COMPARISON AT 20 GEV

BIB-only: Low clustering efficiency: ~80% of 0-cluster events

SIGNAL-only vs SIGNAL+BIB:

- Increase of multicluster events: on average from 1.61 (SIGNAl-only) to 2.30 (SIGNAL+BIB) clusters per event

- Decrease in clustering efficiency: from ~50% (SIGNAl-only) to ~40% (SIGNAL+BIB) 1-cluster events
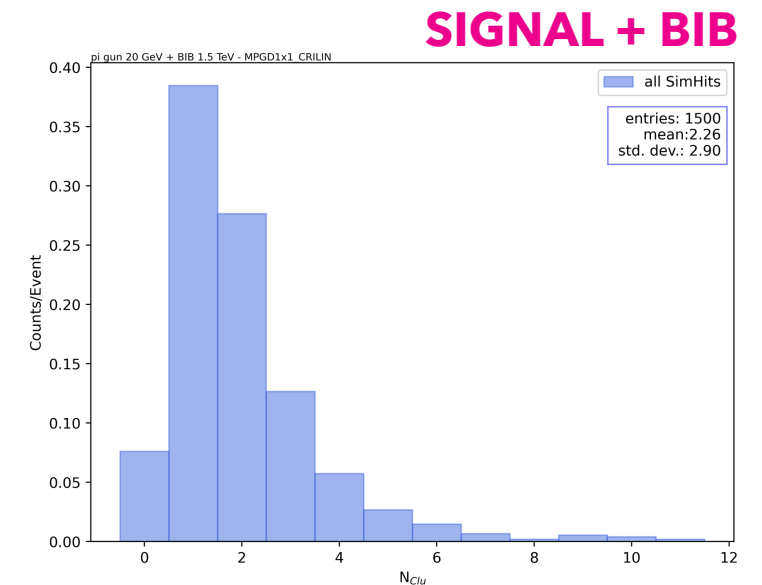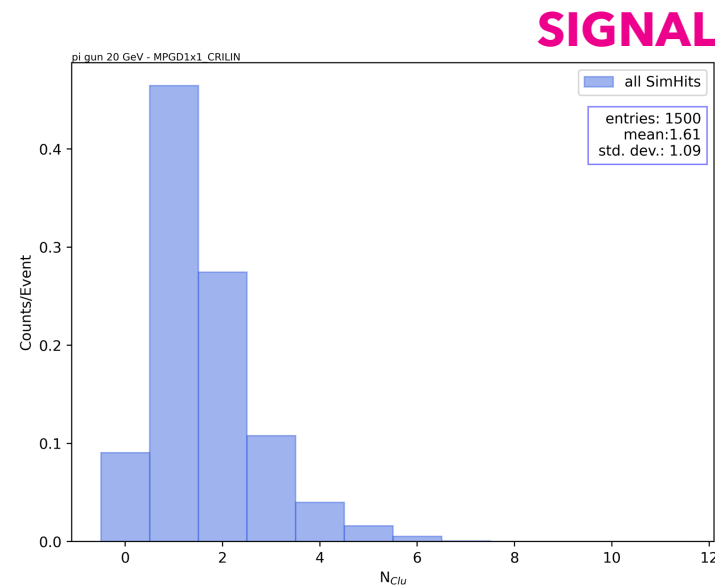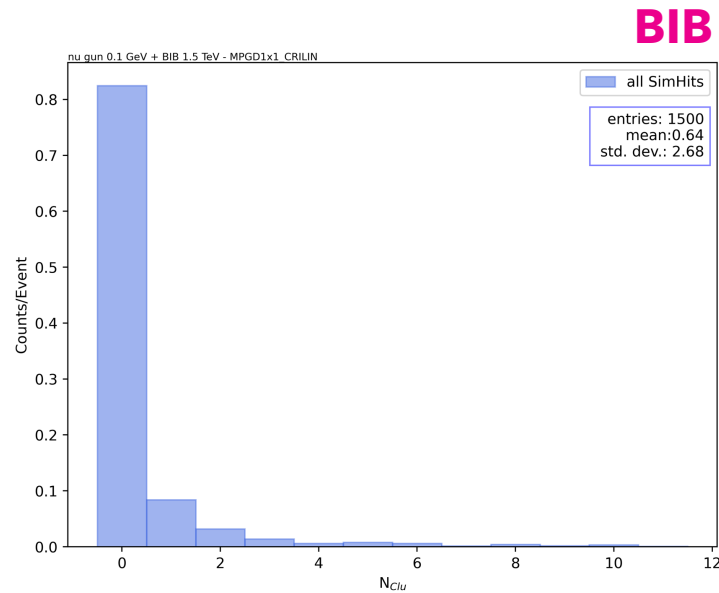
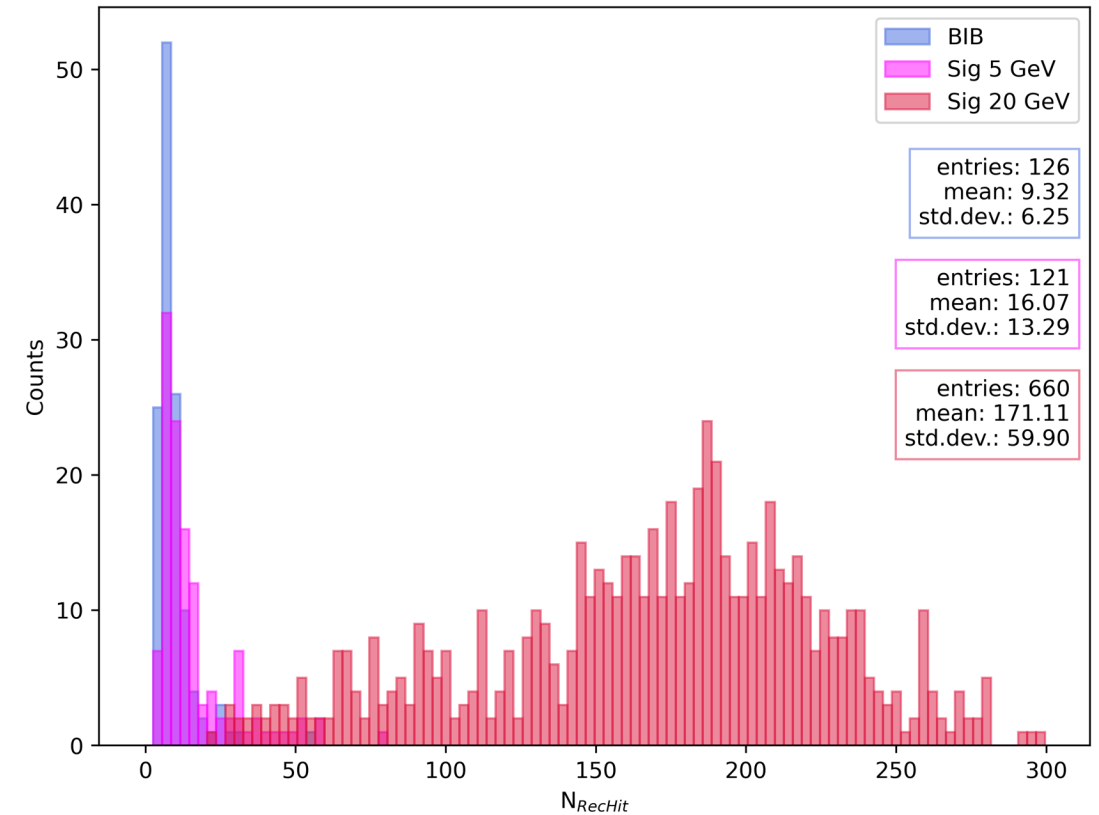# CLUSTER SIZE
COMPARISON BETWEEN BIB AND SIGNAL

- Selection of events with one single cluster

- Signal clusters matched to MC pions within **ΔR < 0.2**

BIB-only clusters are made of **~10 reconstructed hits:**

- one order of magnitude smaller than cluster sizes of 20 GeV pions

- comparable to sizes for 5 GeV pions

→ **CLUSTER SIZE** can be only a signature at high energies

SIGNAL AND BIB SEPARATELY

Legend:
- BIB
- Sig 5 GeV
- Sig 20 GeV

entries: 126
mean: 9.32
std.dev.: 6.25

entries: 121
mean: 16.07
std.dev.: 13.29

entries: 660
mean: 171.11
std.dev.: 59.90

Counts vs N_{RecHit}

CLUSTER SIZE
COMPARISON : SIG+BIB

Overlaying BIB on the signal → slight **increase in size** and **decrease in clustering efficiency** (1% at 5 GeV – 5% at 20 GeV) :

- **MIXED CLUSTERS** contain RecHits originating both from the pion or the BIB

- Hits from the BIB are uniformly distributed in space and arbitrarily far from the pion path

- Mixed clusters have on average a larger **ΔR < 0.2** not passing the matching selection criterion

SIGNAL AND BIB SEPARATELY
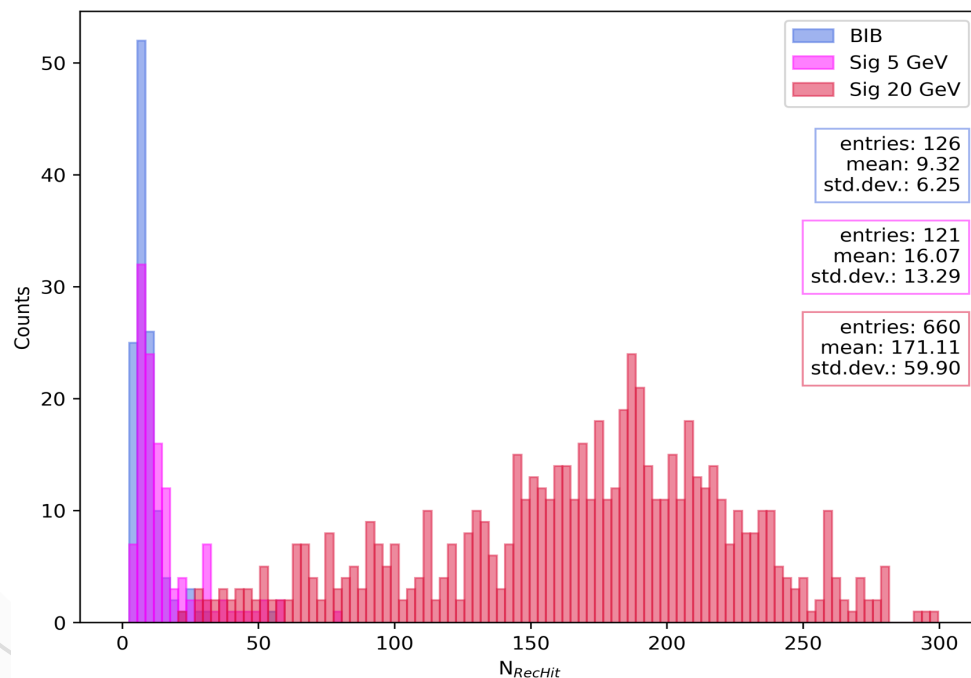
SIGNAL AND BIB MERGED
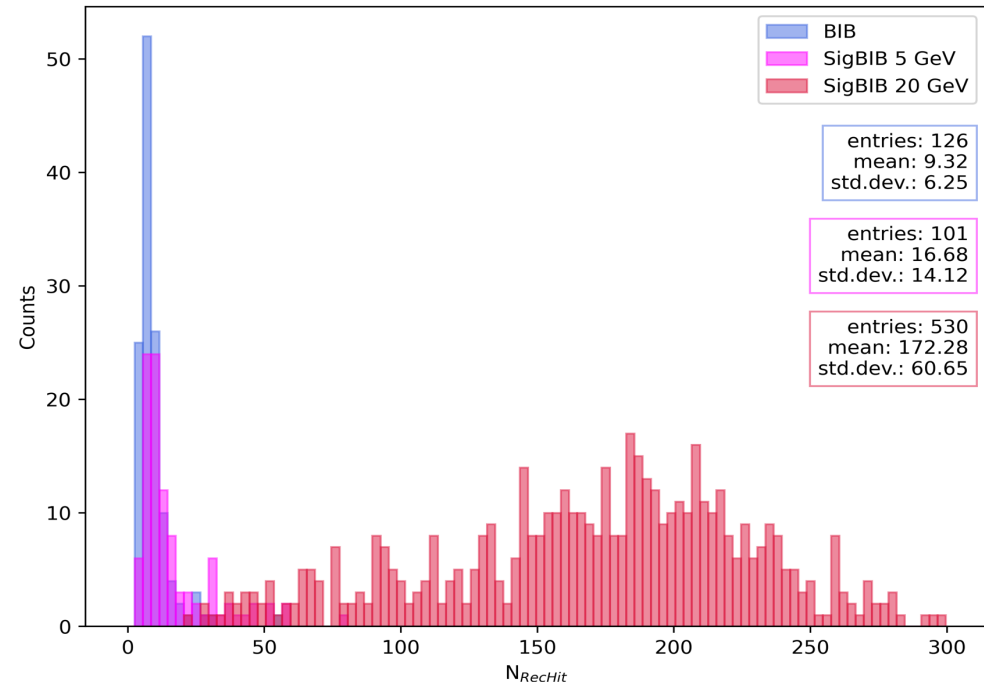
CLUSTER ENERGY

## COMPARISON : SIG – BIB – SIG+BIB

BIB-only clusters have average energies of ~ **0.5 GeV**

- small high-energy tail partially overlapping with cluster energies of 5 GeV pions

- well distinguishable from cluster energies of 20 GeV pions

Overlaying BIB on the signal → almost negligible **increase in energy** :

- Due to **MIXED CLUSTERS** containing additional RecHits from BIB with energies that exceed the RO thresholds

→ Overall BIB does not affect Custer energy reconstruction at E_{MC} > 5 GeV
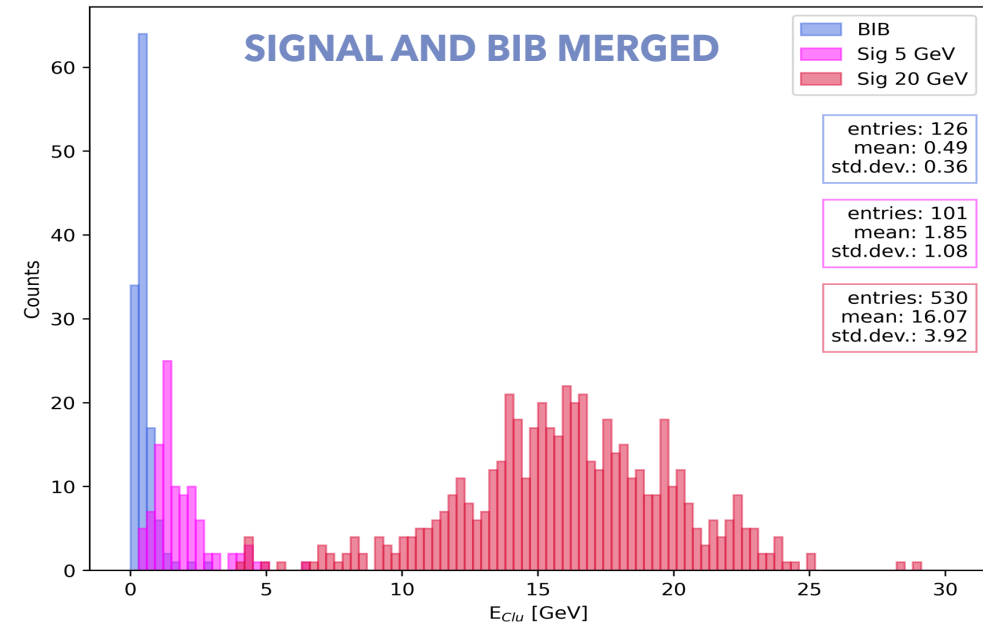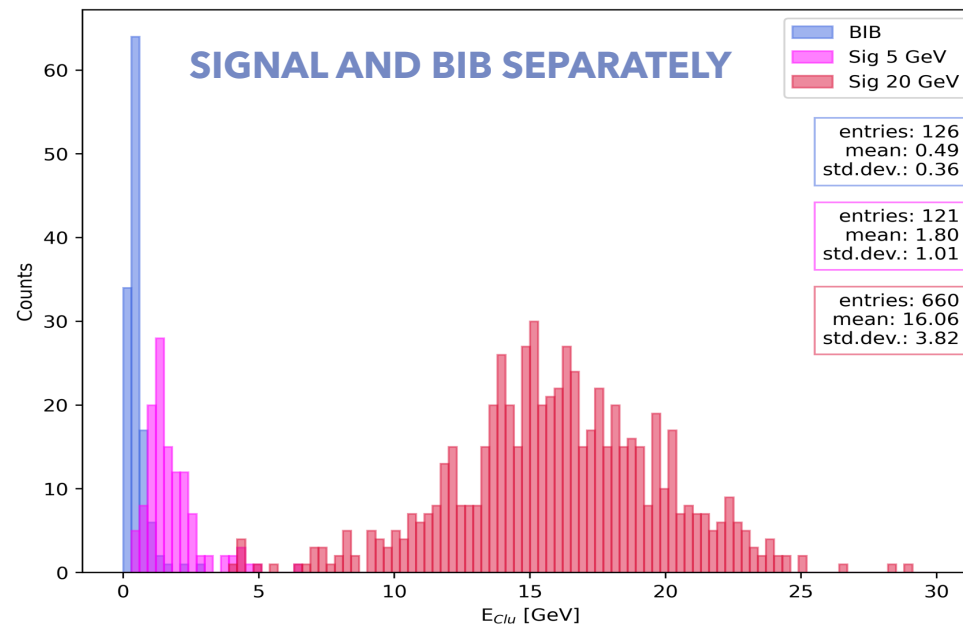
CONCLUSIONS

- BIB containment within the first 20 layers

SIMULATED HITS

- Very low occupancy of BIB SimHits
- No possible cut on the z-coordinate of SimHits
- No possible cut changing the RO energy thresholds
- Possible cut at arrival times > 10 ns

CLUSTERS

- BIB cluster size compatible with signal cluster size at low energies
  - → No possible cut on cluster size for the whole energy range
- The energy of the clusters is negligibly affected by BIB overlay even at 5 GeV

Thanks to Lorenzo Sestini for providing support with CRILIN reconstruction
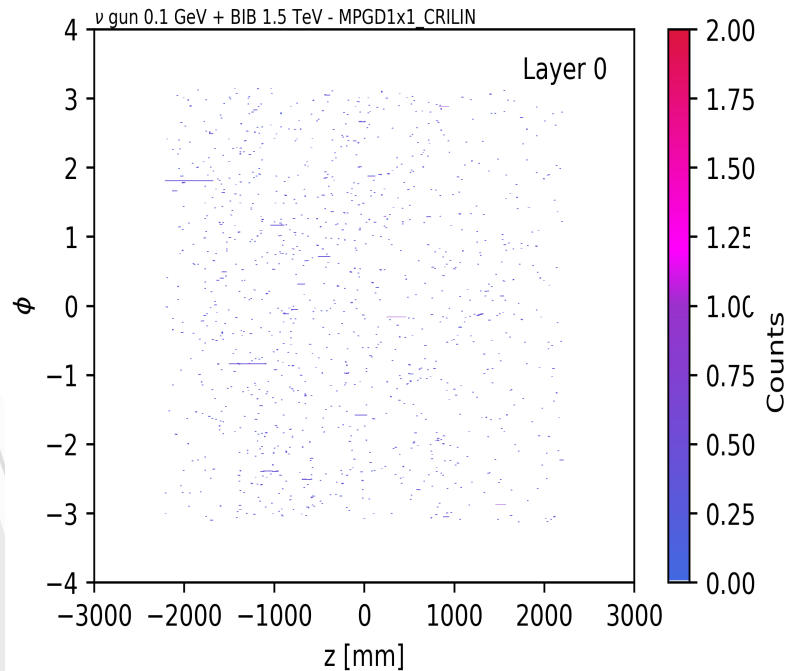
BACK UP SLIDES

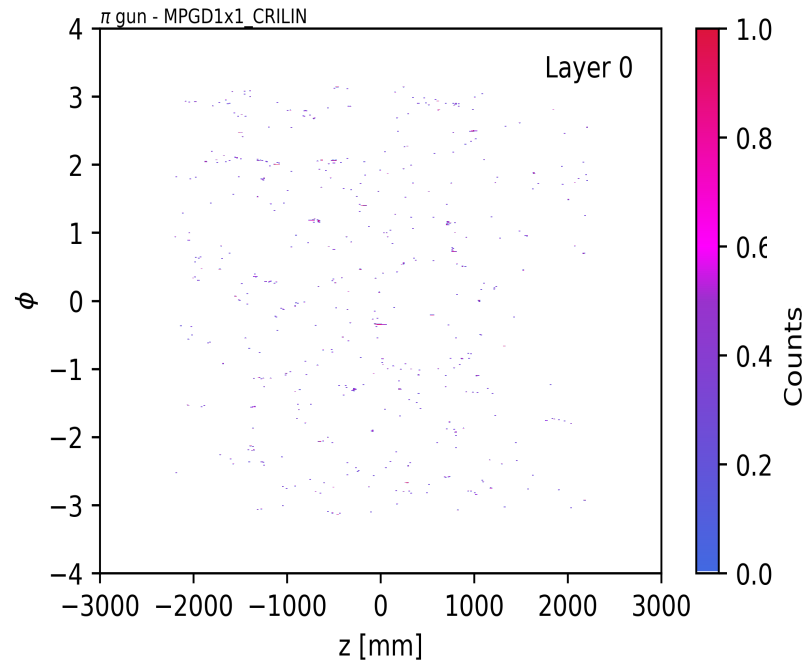# BIB OCCUPANCY

SIMULATED HITS IN MPGD 1X1 CM² HCAL BARREL

Analysis of 500 events from BIB-only and signal-only samples at 5 and 20 GeV

- Each bin of the histogram has roughly the dimensions of an MPGD-HCAL cell in z-φ

- Most of the cells are never fired within the 500 events, and a fraction of cells are hit just once
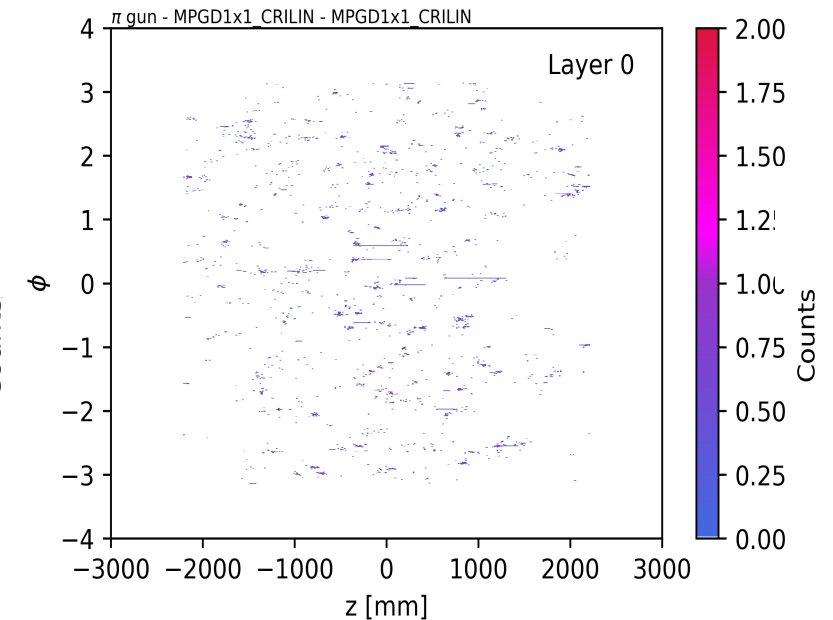
BIB-ONLY

PION 5 GEV

PION 20 GEV

BIB OCCUPANCY

SIMULATED HITS IN MPGD 1X1 CM² HCAL BARREL

- The simhit multiplicty of the signal at 20 GeV dominates at each layer

- The SimHit multiplicity within the first 20 layers is larger for the BIB than for the 5 GeV pions

NUMBER OF HIT PER EVENT