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

Performances test of an MPGD-based HCal through physics events


Università degli Studi di Bari Aldo Moro - INFN Sezione di Bari
• Available Generated BIB:

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

- positive muon beam $\mu^+ \rightarrow e^+\nu_\mu\bar{\nu}_e$
- negative muon beam $\mu^- \rightarrow e^-\nu_\mu\bar{\nu}_e$

• 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

<table>
<thead>
<tr>
<th>RUN: 0</th>
<th>EVENT: 0</th>
<th>DETECTOR: MuColl_v1</th>
</tr>
</thead>
<tbody>
<tr>
<td>COLLECTION NAME</td>
<td>COLLECTION TYPE</td>
<td># OF ELEMENTS</td>
</tr>
<tr>
<td>AllTracks</td>
<td>Track</td>
<td>1</td>
</tr>
<tr>
<td>CaloHitsRelations</td>
<td>LCRelation</td>
<td>247</td>
</tr>
<tr>
<td>ECALBarrelHits</td>
<td>CalorimeterHit</td>
<td>3</td>
</tr>
<tr>
<td>ECALEndcapHits</td>
<td>CalorimeterHit</td>
<td>0</td>
</tr>
<tr>
<td>EcalBarrelCollection</td>
<td>SimCalorimeterHit</td>
<td>1251</td>
</tr>
<tr>
<td>EcalEndcapCollection</td>
<td>SimCalorimeterHit</td>
<td>236</td>
</tr>
<tr>
<td>HCALBarrelHits</td>
<td>CalorimeterHit</td>
<td>189</td>
</tr>
<tr>
<td>HCALEndcapHits</td>
<td>CalorimeterHit</td>
<td>23</td>
</tr>
<tr>
<td>HCALOtherHits</td>
<td>CalorimeterHit</td>
<td>32</td>
</tr>
<tr>
<td>HcalBarrelCollection</td>
<td>SimCalorimeterHit</td>
<td>206</td>
</tr>
<tr>
<td>HcalEndcapCollection</td>
<td>SimCalorimeterHit</td>
<td>27</td>
</tr>
<tr>
<td>HcalRingCollection</td>
<td>SimCalorimeterHit</td>
<td>36</td>
</tr>
</tbody>
</table>

• 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-\( \phi \))
- 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 $\mu\mu \rightarrow H \rightarrow b\bar{b}$ 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
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 energy 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**: $\sim 5 \times 10^{-6}$
  - **Pion 5 GeV**: $\sim 2 \times 10^{-6}$
  - **Pion 20 GeV**: $\sim 8 \times 10^{-6}$
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
ARRIVAL TIME DISTRIBUTION

SIMULATED HITS IN MPGD 1X1 CM² HCAL BARREL

• 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
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 $\Delta R < 0.2$

BIB-only clusters are made of $\sim 10$ 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
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 $\Delta R < 0.2$ not passing the matching selection criterion
**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 Cluster energy reconstruction at $E_{MC} > 5$ GeV

![Signal and BIB separately](image1)

![Signal and BIB merged](image2)
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
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

Università degli Studi di Bari Aldo Moro | Lisa Generoso | Full simulation study of a hadronic calorimeter for a future muon collider
The simhit multiplicity 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.