Photon and electron reconstruction

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on behalf of the Muon Collider Physics and Detector Group

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Outline

- Will present the status of photon and electron reconstruction and identification (given the current detector model and the employed reconstruction software):
  - main features of the experimental signatures of photons and electrons at a multi-TeV muon collider;
  - preliminary performance assessment of photon and electron reconstruction and identification with a detailed detector simulation.
- Perspectives and conclusions.

The detector model

hadronic calorimeter

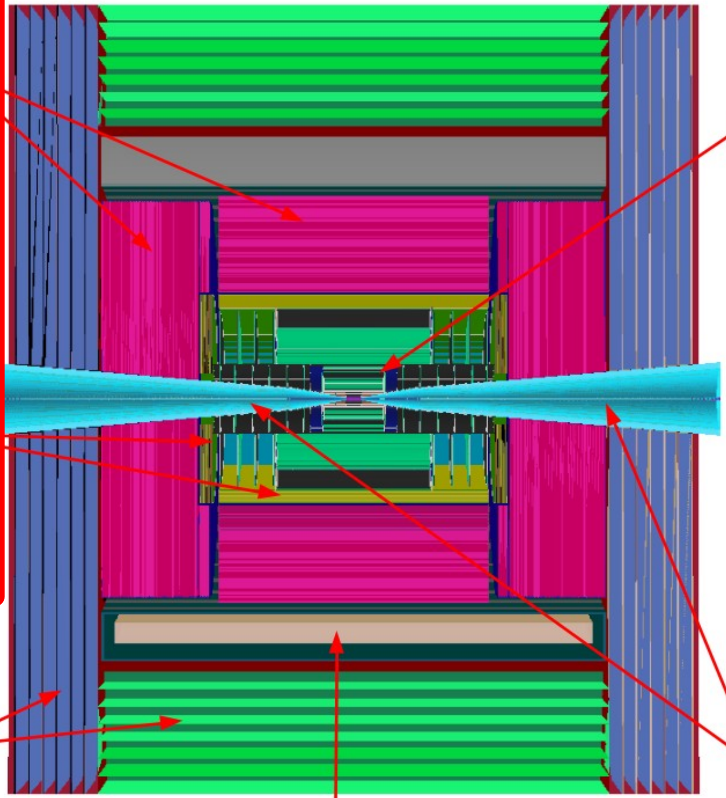
- 60 layers of 19-mm steel absorber + plastic scintillating tiles;
- 30x30 mm^2 cell size;
- 7.5 λ_I.

electromagnetic calorimeter

- 40 layers of 1.9-mm W absorber + silicon pad sensors;
- 5x5 mm^2 cell granularity;
- 22 X_0 + 1 λ_I.

muon detectors

- 7-barrel, 6-endcap RPC layers interleaved in the magnet's iron yoke;
- 30x30 mm^2 cell size.



superconducting solenoid (3.57T)

tracking system

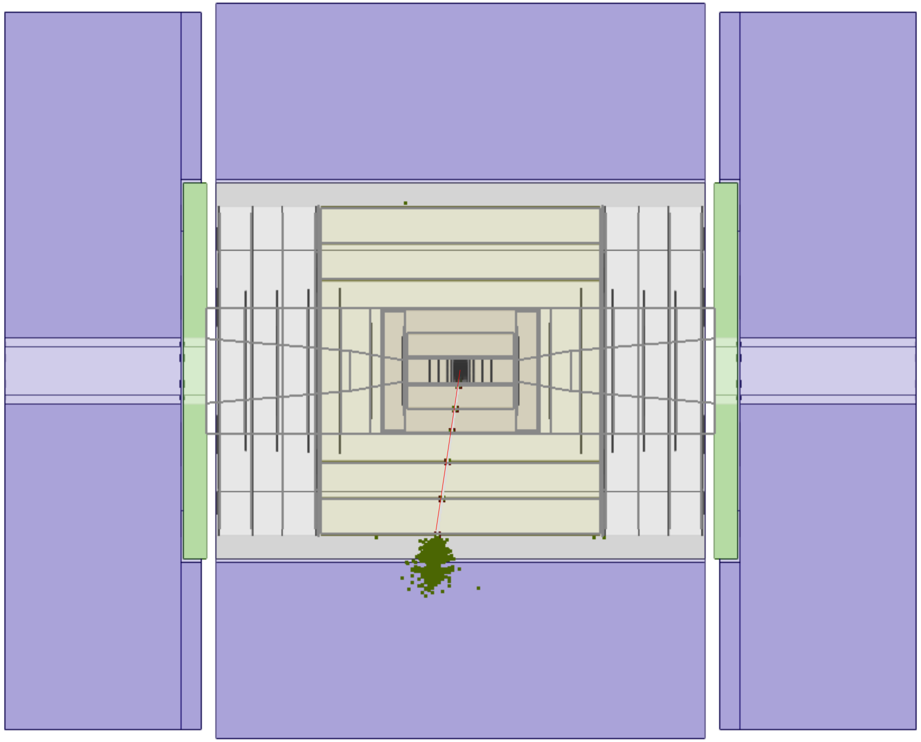
- Vertex Detector:
  - double-sensor layers (4 barrel cylinders and 4+4 endcap disks);
  - 25x25 μm^2 pixel Si sensors.
- Inner Tracker:
  - 3 barrel layers and 7+7 endcap disks;
  - 50 μm x 1 mm macro-pixel Si sensors.
- Outer Tracker:
  - 3 barrel layers and 4+4 endcap disks;
  - 50 μm x 10 mm micro-strip Si sensors.

shielding nozzles

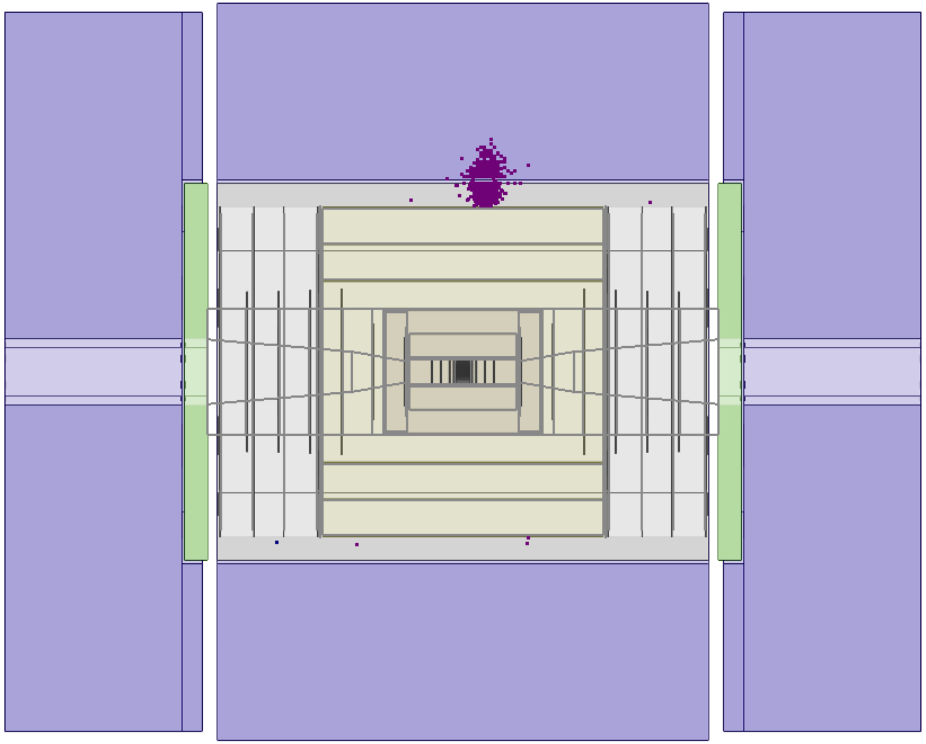
- Tungsten cones + borated polyethylene cladding.

Electron and photon signatures

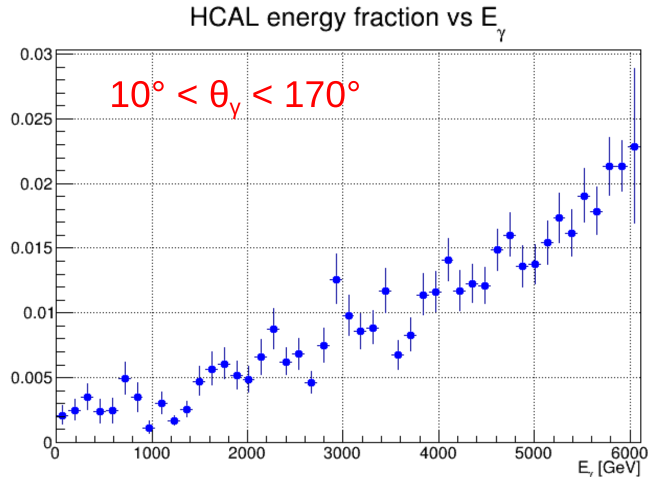
1 TeV electron



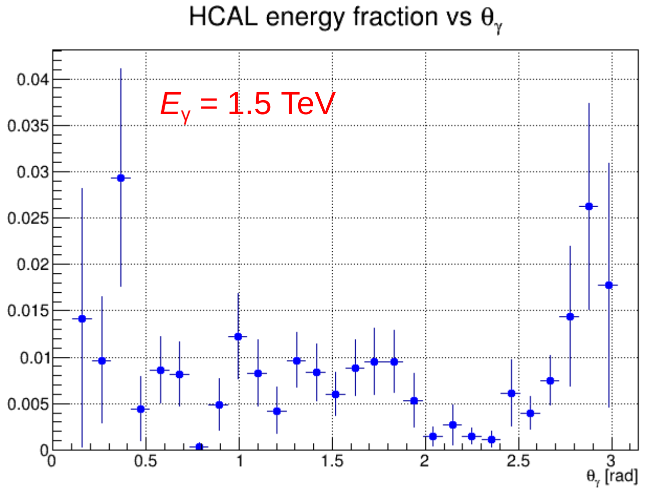
1 TeV photon

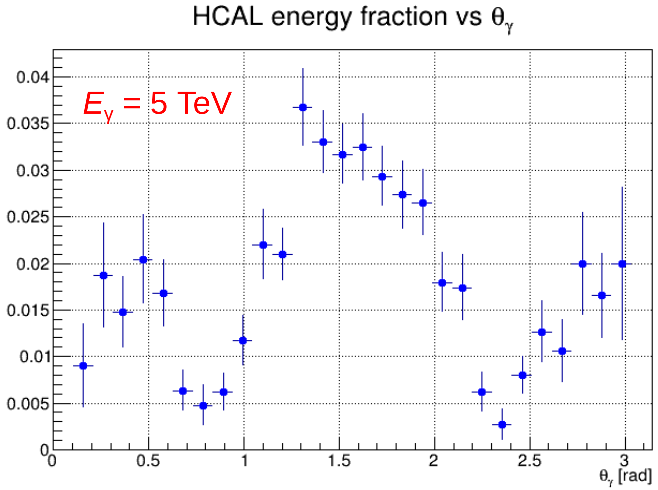


Fraction of e.m. energy in the HCAL



- The electromagnetic showers from high-energy photons and electrons ($E \gtrsim 50$ GeV) spill into the HCAL.
- The fraction of e.m. energy in the HCAL ranges from a few per mill to a few percent, depending on e/γ energy and polar angle.





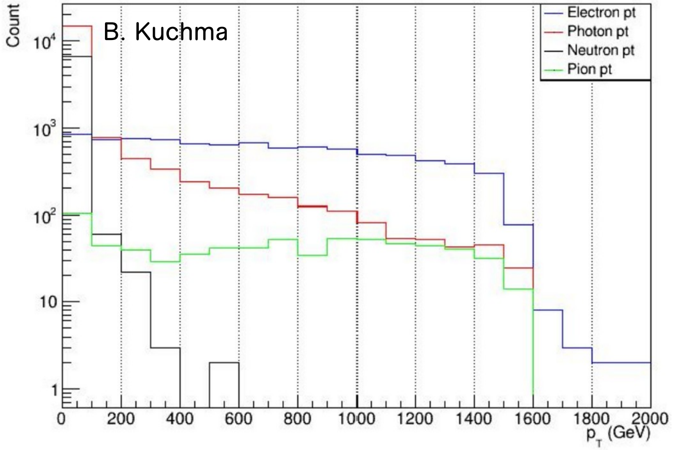
Electron and photon reconstruction/ID

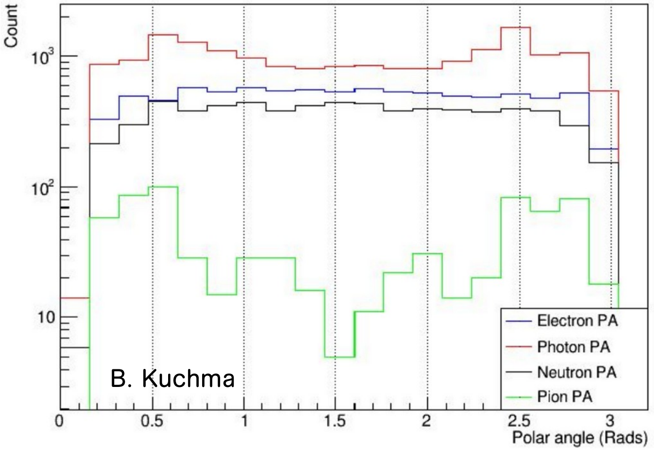
- Reconstruction and identification software for photons and electrons inherited from CLIC and based on the Pandora Particle Flow package.

- First preliminary studies carried out with the default Pandora settings.

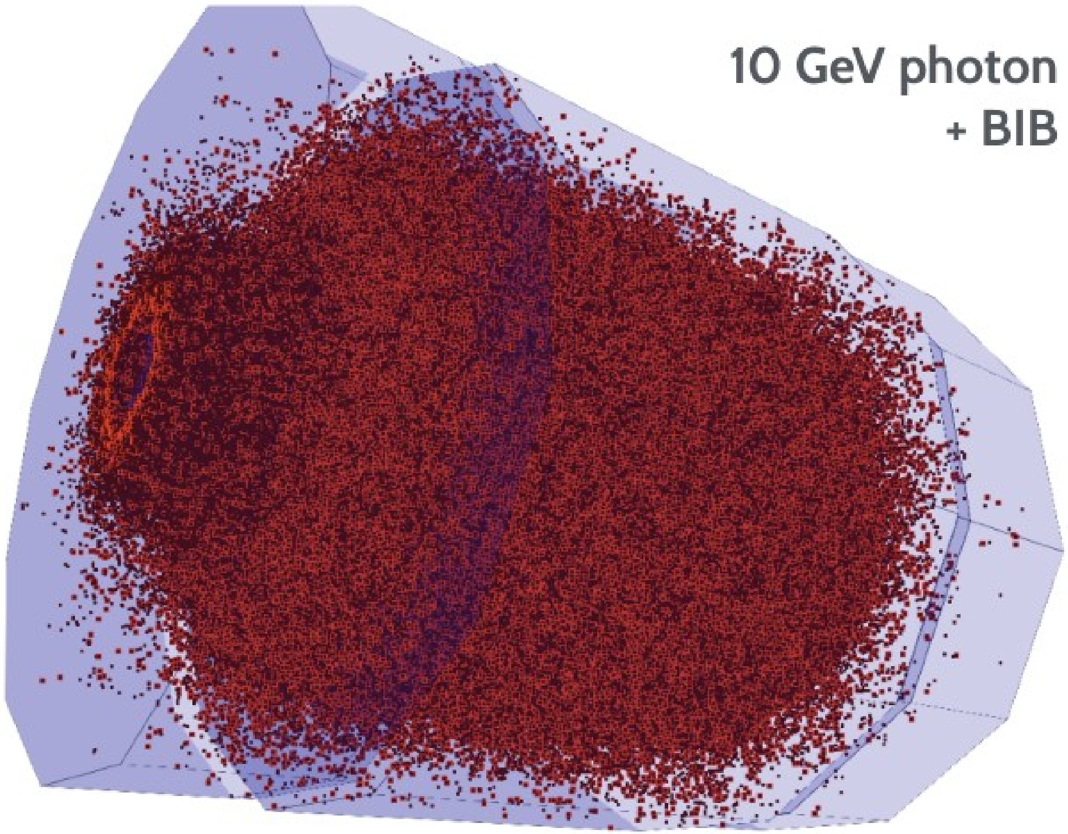
- Energy deposits of high-energy photons and electrons are reconstructed as two nearby clusters in the ECAL and HCAL:
  - photons are identified as a photon plus a neutron;
  - a non-negligible fraction of electrons is misidentified as pions.

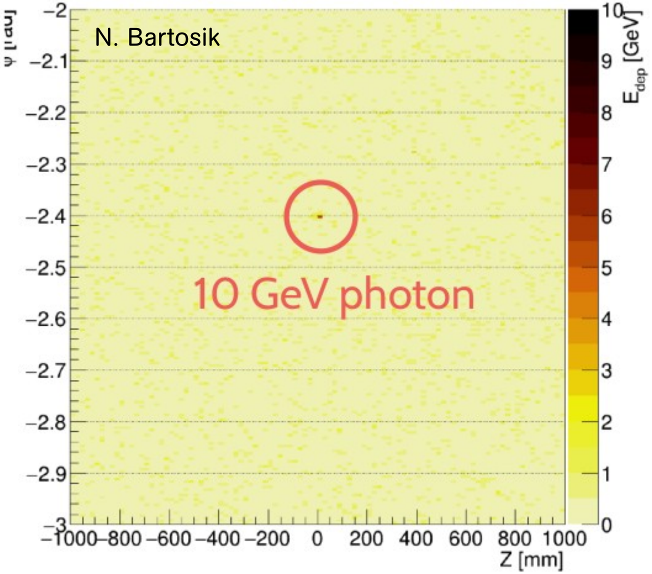
particles identified by Pandora in a sample of electrons



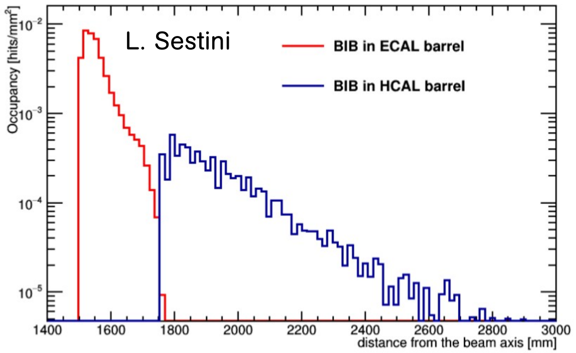


BIB makes things complicated





hit density vs distance from beamline

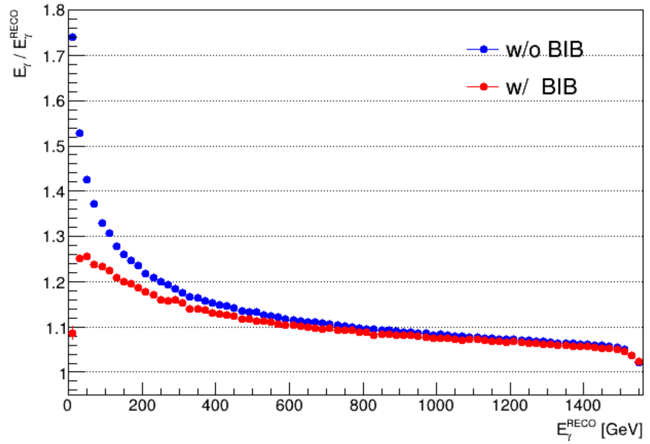


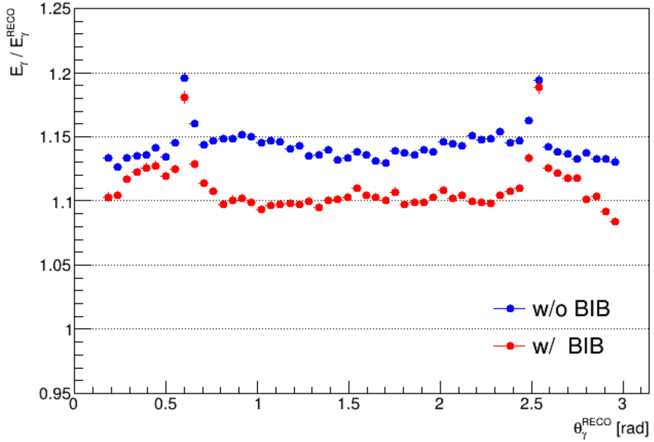
Current reconstruction strategy

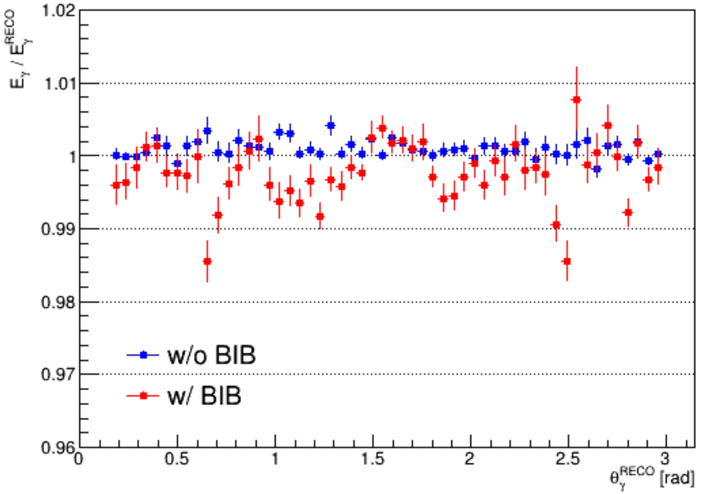
- Electromagnetic cluster reconstruction:
  - no recovery for e.m. energy leaked in the HCAL;
  - no subtraction of BIB energy;
  - BIB effects mitigated by raising the energy thresholds of the ECAL and HCAL hits.

- Cluster energy scale corrected as a function of E and θ to make the detector response uniform:
  - the energy corrections are calculated from the ratio of the reconstructed electromagnetic energy to the photon energy at generator level;
  - the energy corrections compensate for energy spilled in the HCAL and the BIB effects.

Electromagnetic energy scale correction







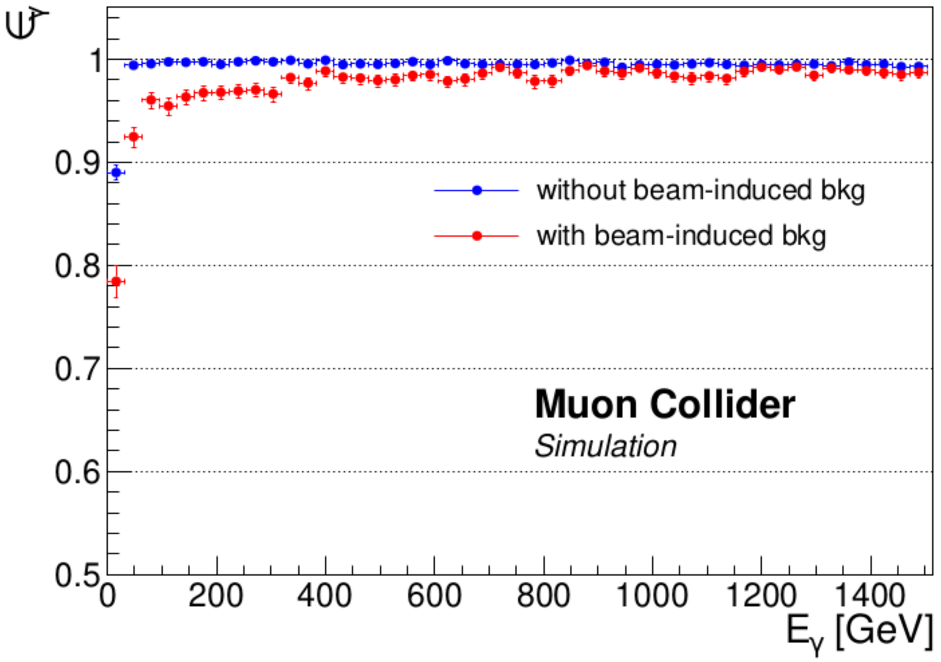
Photon reconstruction and ID performance

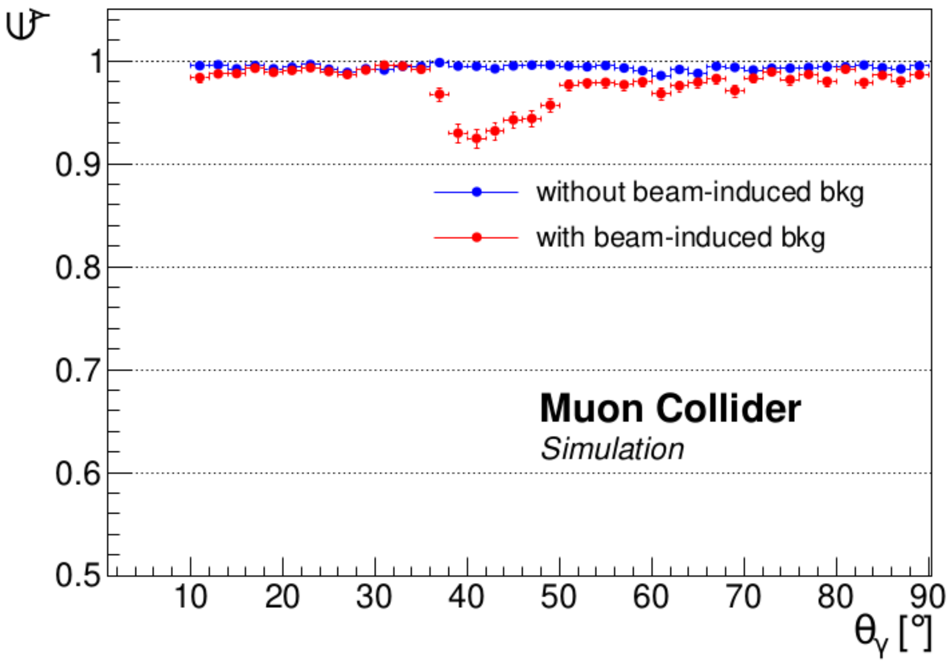
- Track reconstruction:
  - Double-Layer Filter ON;
  - ACTS tracking;
  - track quality selection before track refitting: $N_{VXD} \geqslant 3$, $N_{IT} \geqslant 2$.
- Calorimeter reconstruction:
  - ECAL and HCAL hit E_{thr} = 2 MeV;
  - hit clustering: default Pandora settings.
- Photon identification:
  - default Pandora settings.

Samples:

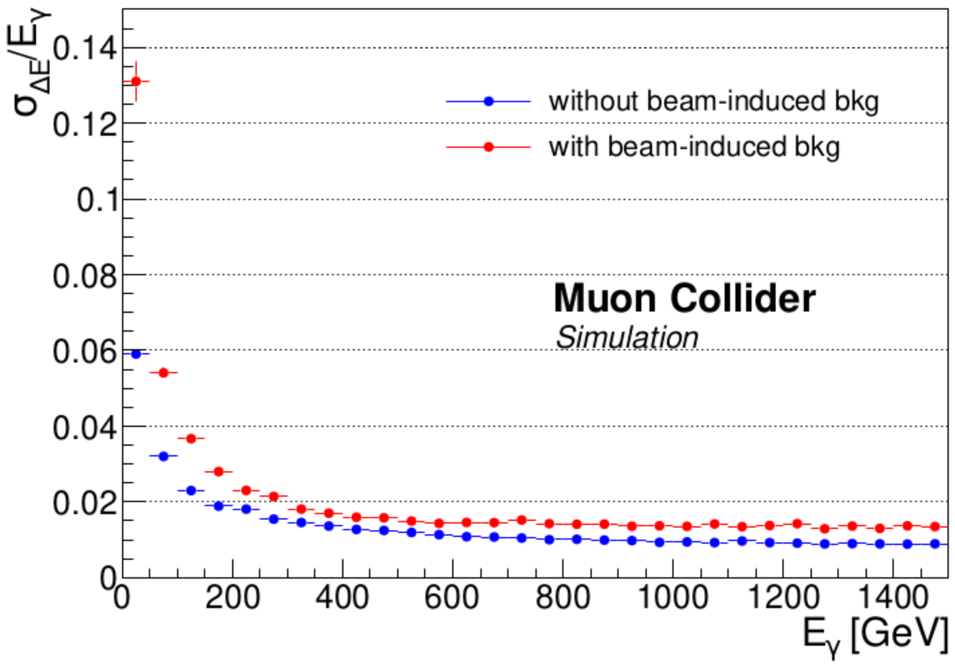
- 100k single photons shot from (0, 0, 0):
  - $1 < E_\gamma < 1500$ GeV;
  - $10° < \theta_\gamma < 170°$;
  - $0° < \phi_\gamma < 360°$;
- 100k events reconstructed w/o BIB;
- 40k events reconstructed with BIB overlaid.

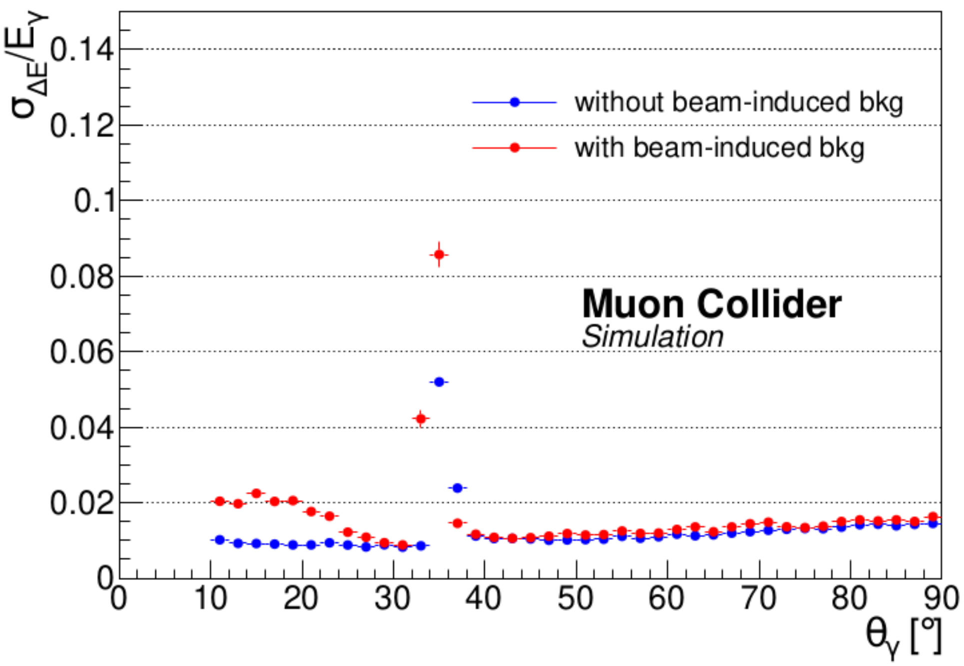
Photon reconstruction efficiency



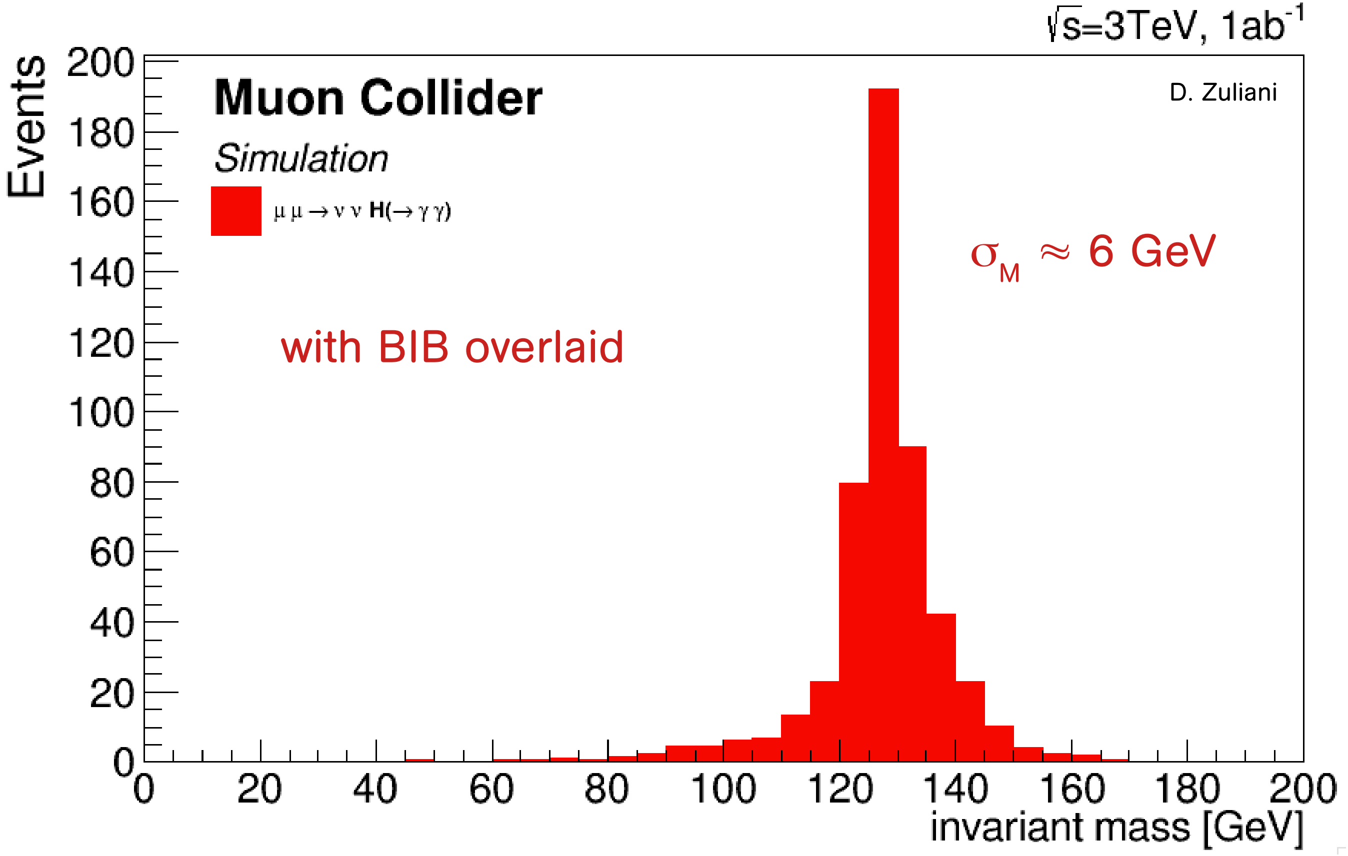


Photon energy resolution

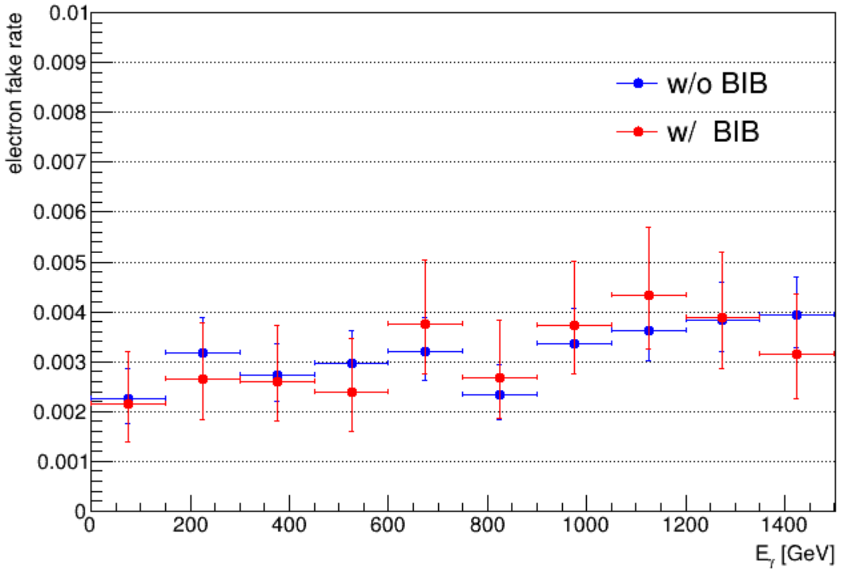


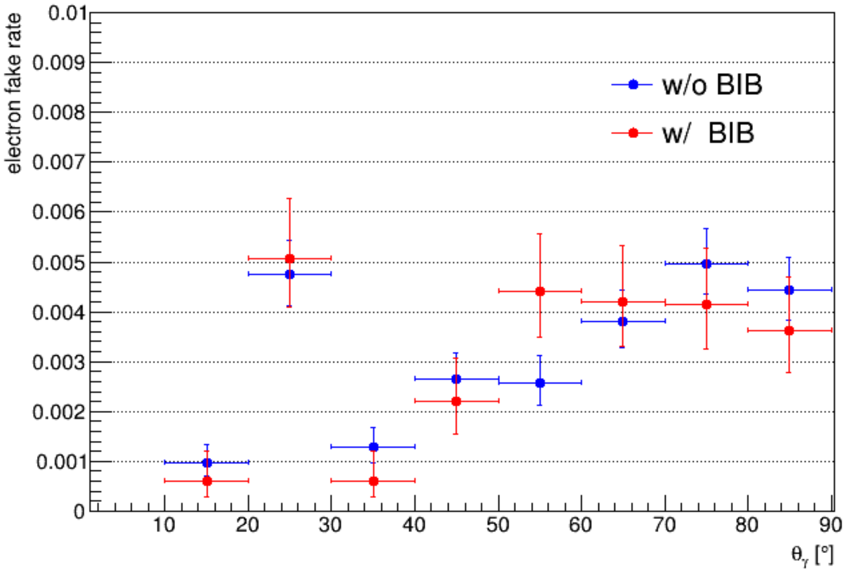


$H \to \gamma\gamma$ reconstructed mass



electron-photon misidentification rate





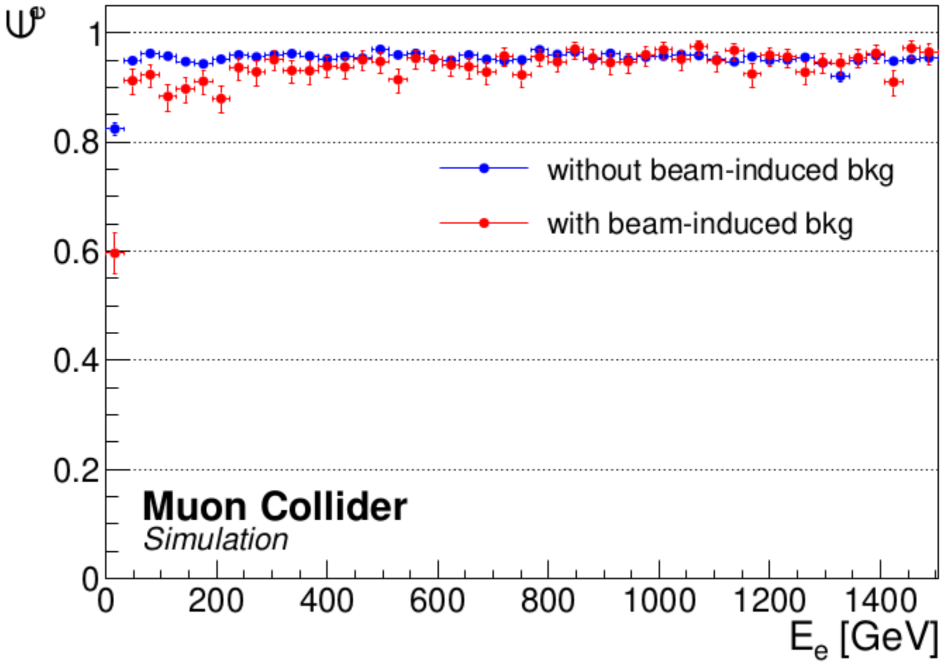
Electron reconstruction and ID performance

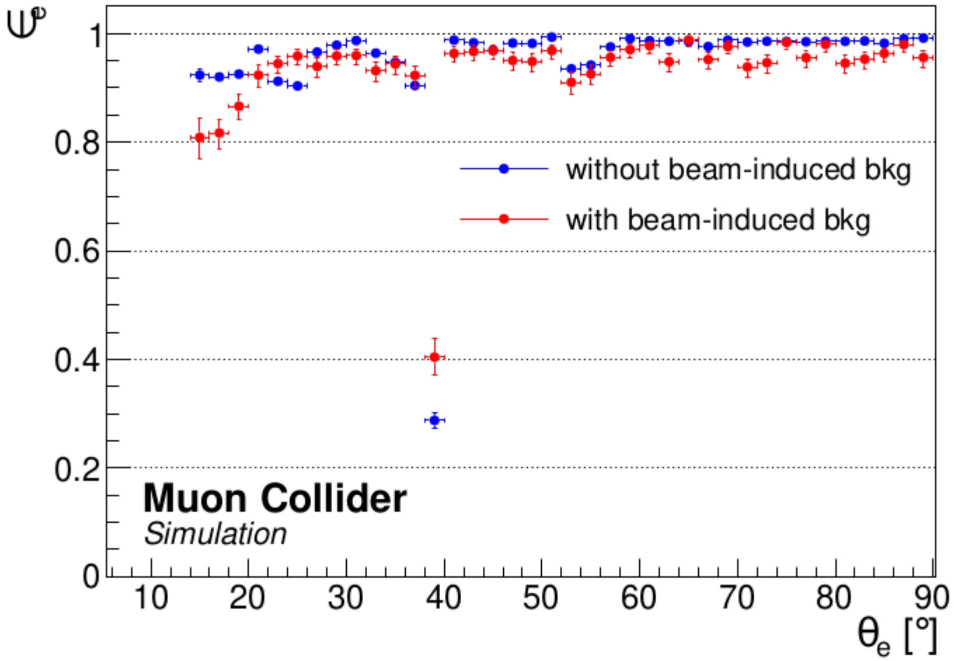
- Track reconstruction:
  - Double-Layer Filter ON;
  - ACTS tracking;
  - track quality requirement: χ^2/ndof < 10.
- Calorimeter reconstruction:
  - ECAL and HCAL hit E_{thr} = 5 MeV;
  - hit clustering: default Pandora settings.
- Electron identification:
  - angular matching of the e.m. clusters with the reconstructed tracks in a R=0.1 cone.

Samples:

- 50k single electrons shot from (0, 0, 0):
  - $1 < p_e < 1500$ GeV;
  - $10° < \theta_e < 170°$;
  - $0° < \phi_e < 360°$;
- 50k events reconstructed w/o BIB;
- 46k events reconstructed with BIB overlaid.

Electron reconstruction efficiency





What's next

- A lot of work ahead and many uncovered areas.
- Electromagnetic cluster reconstruction:
  - tuning hit energy thresholds and improving BIB mitigation (in coordination with the Jets Group);
  - recovering energy spillage (?);
  - refining the energy calibrations.
- Photon and electron identification:
  - tuning Pandora setting;
  - exploring more sophisticated identification algorithms.

Conclusions

- First preliminary results, based on a detailed simulation of the baseline detector, show:
  - good performance in photon and electron reconstruction, despite a nonoptimal detector, untuned reconstruction/identification algorithms, and a very crude mitigation of BIB effects.
- Current studies on the physical objects were mostly done out of necessity to explore some physical channel of interest:
  - there is plenty of room for improvement that a more systematic and thorough approach can achieve on many fronts: detector design, algorithms, BIB mitigation strategy.

Backup

Angles

D. Arominski *et al.*, arXiv:1812.07337v1

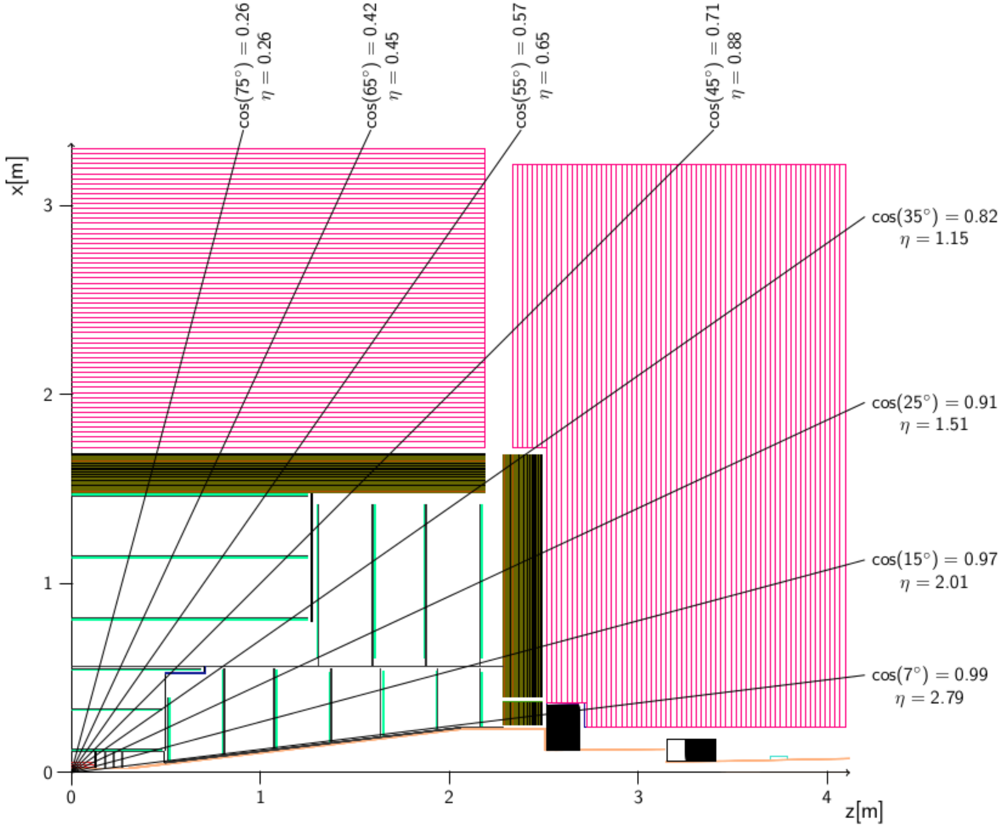


Figure A.3: Illustration of selected angles in CLICdet.

Pandora algorithms

```
> Running Algorithm: Alg0001, CaloHitPreparation
> Running Algorithm: Alg0002, EventPreparation
> Running Algorithm: Alg0003, MuonReconstruction
----> Running Algorithm: Alg0004, ConeClustering
> Running Algorithm: Alg0005, PhotonReconstruction
----> Running Algorithm: Alg0006, ConeClustering
> Running Algorithm: Alg0007, ClusteringParent
----> Running Algorithm: Alg0008, ConeClustering
----> Running Algorithm: Alg0009, TopologicalAssociationParent
--------> Running Algorithm: Alg0010, LoopingTracks
--------> Running Algorithm: Alg0011, BrokenTracks
--------> Running Algorithm: Alg0012, ShowerMipMerging
--------> Running Algorithm: Alg0013, ShowerMipMerging2
--------> Running Algorithm: Alg0014, BackscatteredTracks
--------> Running Algorithm: Alg0015, BackscatteredTracks2
--------> Running Algorithm: Alg0016, ShowerMipMerging3
--------> Running Algorithm: Alg0017, ShowerMipMerging4
--------> Running Algorithm: Alg0018, ProximityBasedMerging
------------> Running Algorithm: Alg0019, TrackClusterAssociation
--------> Running Algorithm: Alg0020, ConeBasedMerging
------------> Running Algorithm: Alg0021, TrackClusterAssociation
--------> Running Algorithm: Alg0022, MipPhotonSeparation
------------> Running Algorithm: Alg0023, TrackClusterAssociation
--------> Running Algorithm: Alg0024, HighEnergyPhotonRecovery
------------> Running Algorithm: Alg0025, TrackClusterAssociation
--------> Running Algorithm: Alg0026, SoftClusterMerging
------------> Running Algorithm: Alg0027, TrackClusterAssociation
--------> Running Algorithm: Alg0028, IsolatedHitMerging
> Running Algorithm: Alg0029, SplitTrackAssociations
----> Running Algorithm: Alg0060, TrackClusterAssociation
> Running Algorithm: Alg0062, SplitMergedClusters
----> Running Algorithm: Alg0063, TrackClusterAssociation
> Running Algorithm: Alg0065, TrackDrivenMerging
----> Running Algorithm: Alg0066, TrackClusterAssociation
> Running Algorithm: Alg0067, ResolveTrackAssociations
----> Running Algorithm: Alg0068, TrackClusterAssociation
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> Running Algorithm: Alg0029, SplitTrackAssociations
----> Running Algorithm: Alg0060, TrackClusterAssociation
> Running Algorithm: Alg0062, SplitMergedClusters
----> Running Algorithm: Alg0063, TrackClusterAssociation
> Running Algorithm: Alg0070, TrackDrivenAssociation
----> Running Algorithm: Alg0071, TrackClusterAssociation
> Running Algorithm: Alg0029, SplitTrackAssociations
----> Running Algorithm: Alg0060, TrackClusterAssociation
> Running Algorithm: Alg0062, SplitMergedClusters
----> Running Algorithm: Alg0063, TrackClusterAssociation
> Running Algorithm: Alg0072, ExitingTrack
----> Running Algorithm: Alg0073, TrackClusterAssociation
> Running Algorithm: Alg0075, ClusteringParent
----> Running Algorithm: Alg0076, ConeClustering
> Running Algorithm: Alg0077, MuonClusterAssociation
> Running Algorithm: Alg0078, PhotonRecovery
----> Running Algorithm: Alg0079, TrackClusterAssociation
> Running Algorithm: Alg0080, MuonPhotonSeparation
----> Running Algorithm: Alg0081, TrackClusterAssociation
> Running Algorithm: Alg0082, TrackPreparation
----> Running Algorithm: Alg0083, TrackClusterAssociation
----> Running Algorithm: Alg0084, LoopingTrackAssociation
----> Running Algorithm: Alg0085, TrackRecovery
----> Running Algorithm: Alg0086, TrackRecoveryHelix
----> Running Algorithm: Alg0087, TrackRecoveryInteractions
> Running Algorithm: Alg0088, MainFragmentRemoval
> Running Algorithm: Alg0089, NeutralFragmentRemoval
> Running Algorithm: Alg0090, PhotonFragmentRemoval
> Running Algorithm: Alg0091, ClusterPreparation
> Running Algorithm: Alg0092, PhotonSplitting
> Running Algorithm: Alg0093, PhotonFragmentMerging
> Running Algorithm: Alg0094, ForceSplitTrackAssociations
> Running Algorithm: Alg0095, PfoCreation
> Running Algorithm: Alg0096, PfoPreparation
> Running Algorithm: Alg0097, FinalParticleId
> Running Algorithm: Alg0098, V0PfoCreation
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