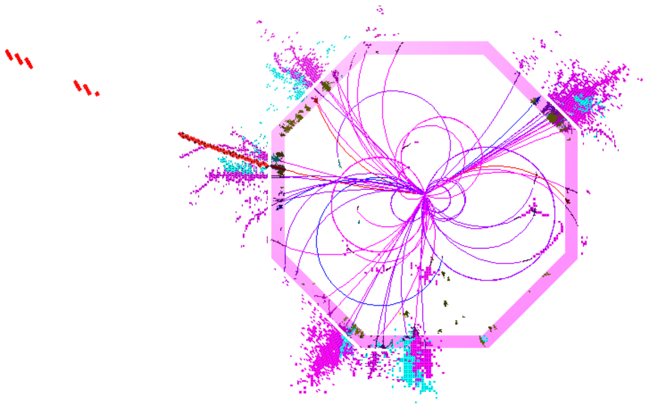

Lepton Identification at CLIC

J.S. Marshall

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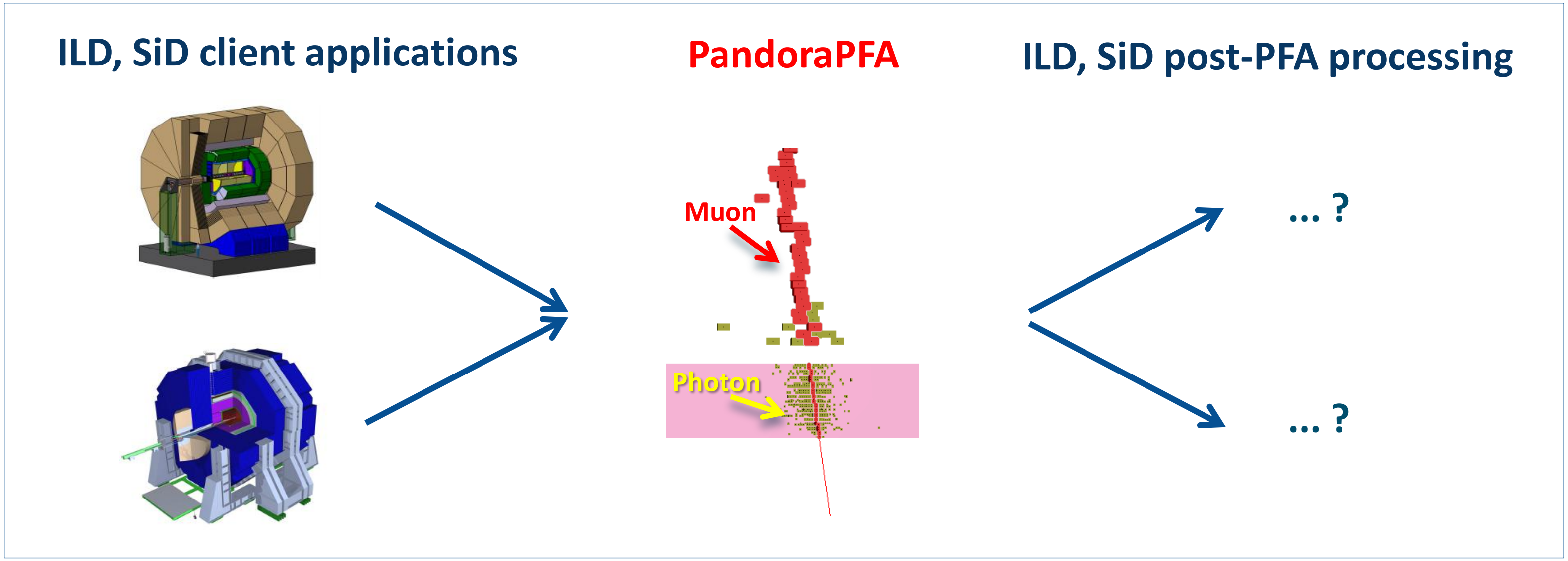
Overview

- Efficient identification of high energy leptons is of crucial importance to analyses of potential beyond the standard model physics at CLIC.
- Particle ID takes place during the particle flow reconstruction and is performed by algorithms implemented in the **PandoraPFA** framework, which is used for both CLIC ILD and CLIC SiD.
- Identical algorithms are used for both detectors, with detector differences handled by the self-describing Pandora objects e.g. hit objects contain radiation length information.



- **This talk will describe the particle ID algorithms and discuss their performance...**

Pandora Particle ID

- Pandora algorithms are ultimately responsible for tagging particle flow objects with a PDG code, but particle ID helper functions can be registered to aid the algorithms.

  C++: PandoraApi::RegisterParticleIdFunction(pandora, “MyFastMuonId”, &MyClass::MyFastMuonId);
  xml: <MuonFastFunction> MyFastMuonId </MuonFastFunction>

- Algorithms can call helper functions and decide how to respond to results.
- Alternatively, algorithms can perform their own dedicated reconstruction for specific particle types. Can include separate clustering, followed by removal of particles from subsequent reconstruction.

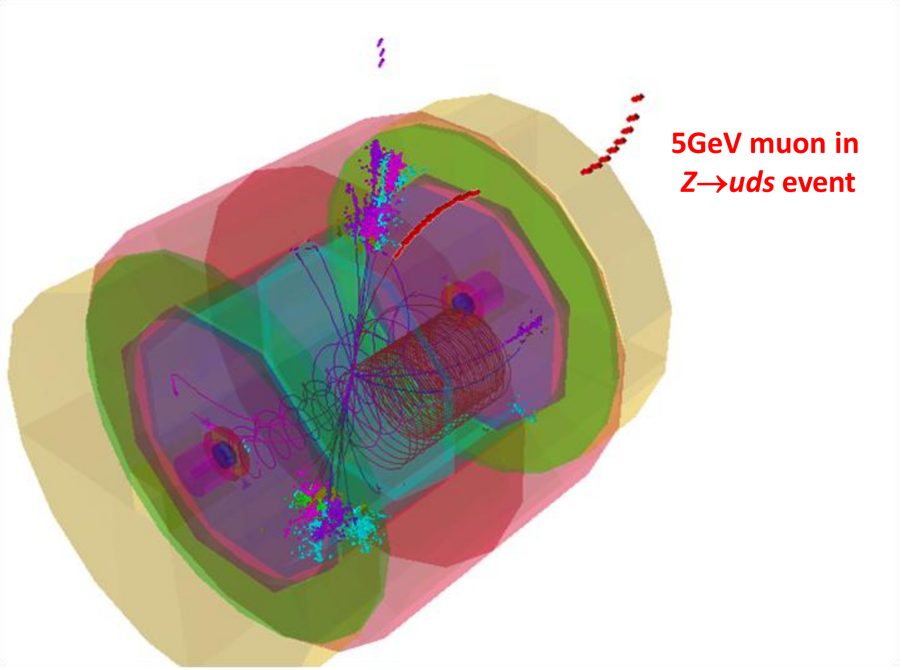
- What happens in CLIC Pandora reconstruction? **All of this!**
  - Some algorithms (e.g. FragmentRemoval) want to avoid working with objects that look like muons/electrons, so call the fast muon/electron id.
  - Some algorithms (e.g. FinalParticleId) simply call helper functions and apply results to the particle flow objects.
  - Some algorithms (e.g. MuonReconstruction) perform a full reconstruction and identification of specific types of particle.

Muon ID Function

- The muon ID function is cut-based and looks for an inner detector track, followed by consistent, minimal energy deposition throughout the calorimeters and muon yoke. It targets muons with energy greater than 2.5GeV

Selection cuts:

- Number of occupied layers in each of the ECAL, HCAL and YOKE regions.
- Energy deposited in ECAL and HCAL regions. Energies are path-length-corrected and cuts are linear functions of associated track energy.
- RMS values for straight-line fits in the ECAL, HCAL and YOKE regions.
- Fraction of mip-like hits in the ECAL and HCAL regions.
- Number of YOKE hits.

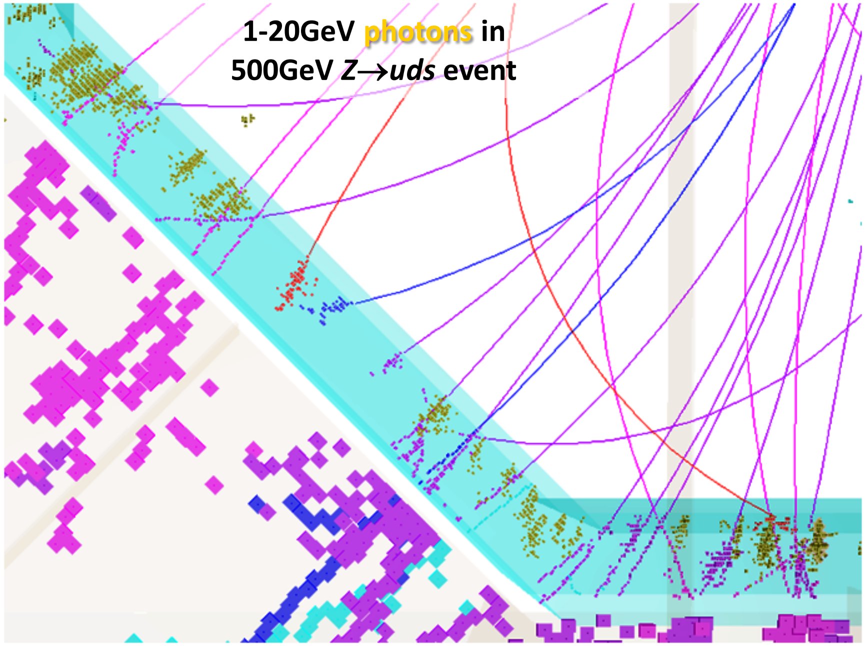


EM Shower ID Function

- The electromagnetic shower ID code is shared by both the photon and electron ID functions. The photon ID function simply looks for identified EM showers without associated inner detector tracks.
- The electron ID function places further cuts on the shower profile and associated tracks (see later).

Selection cuts:

- Cluster inner layer, which must lie within ECAL.
- Fraction of mip-like hits in the cluster.
- Radial direction cosine and RMS, as obtained from a straight-line fit.
- Cluster longitudinal shower profile. Cuts are applied to number of radiation lengths before ShowerStart, Layer90 and ShowerMax layers.
- Cluster transverse shower profile. Cuts are applied to Radial90 distance.

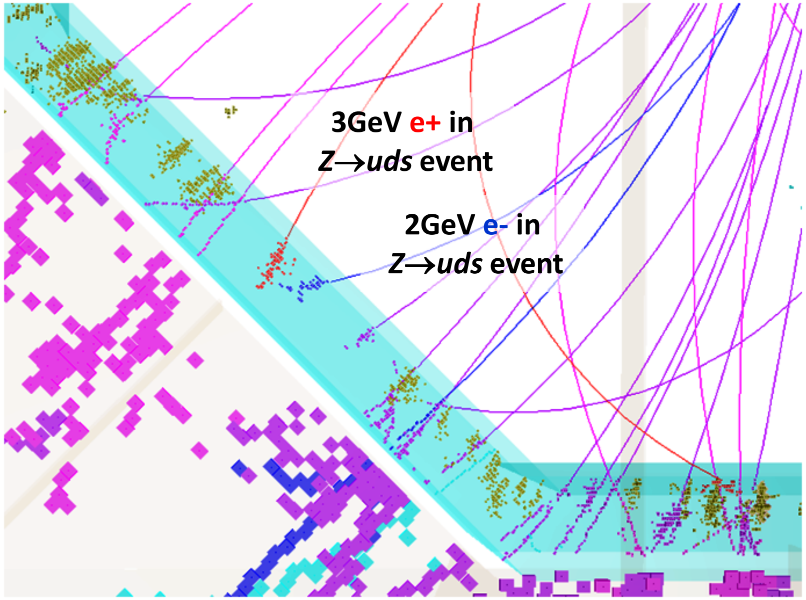


Electron ID Function

- The electron ID function requires that a cluster has an associated inner detector track and that it passes the EM shower ID, previously described.

Further selection cuts:

- Number of radiation lengths before observed start of the longitudinal shower profile.
- Discrepancy between observed shower profile and expectation for an EM shower.
- Absolute value of ($E_{cluster}/P_{track} - 1$) for the cluster/track pairing.

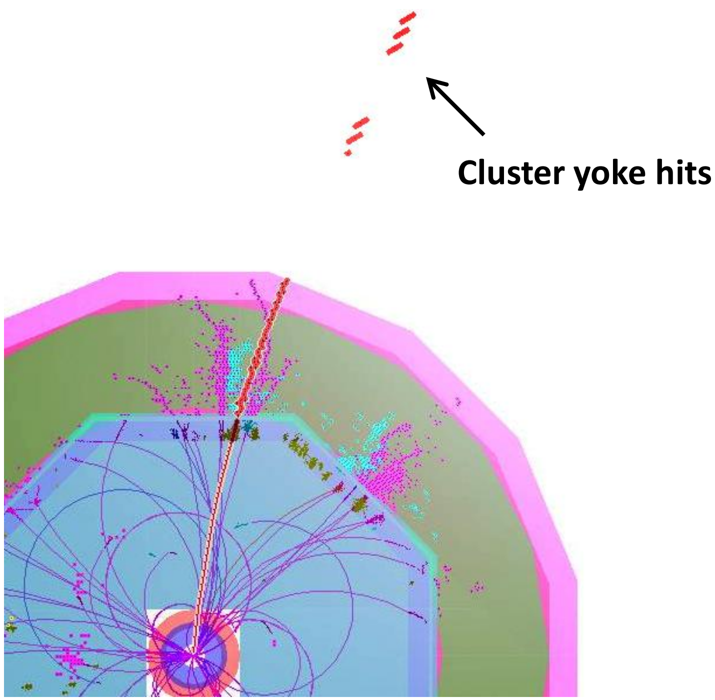


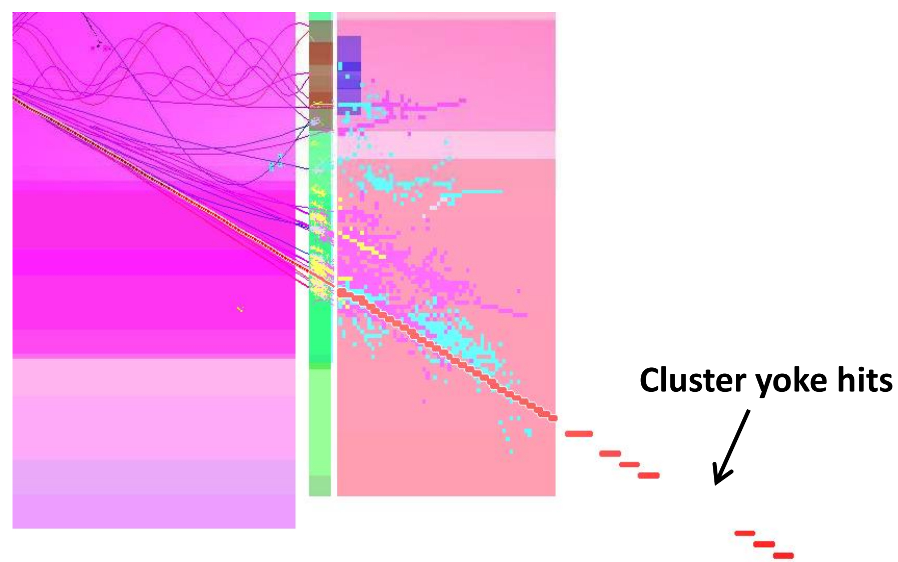
- Any cluster not identified as a muon, electron or photon is labelled as a pion (associated track), or a neutron (no associated track). A specific algorithm searches for V0s.

Muon Reconstruction Algorithm

A standalone muon reconstruction algorithm has been implemented to improve the efficiency for identifying and accurately reconstructing high energy muons.

1. Yoke track candidates identified using an instance of the cone-based clustering algorithm, configured appropriately for coarse instrumentation. Clusters crossing all yoke layers, whilst containing a minimal number of hits are selected.



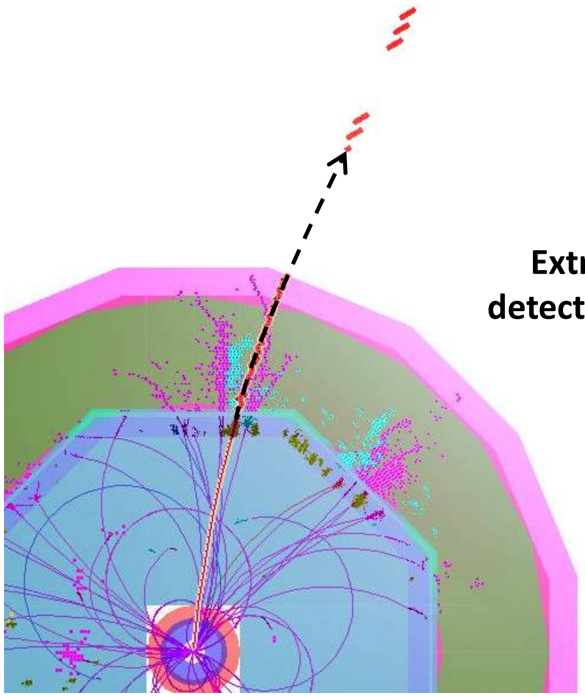


Muon Reconstruction Algorithm

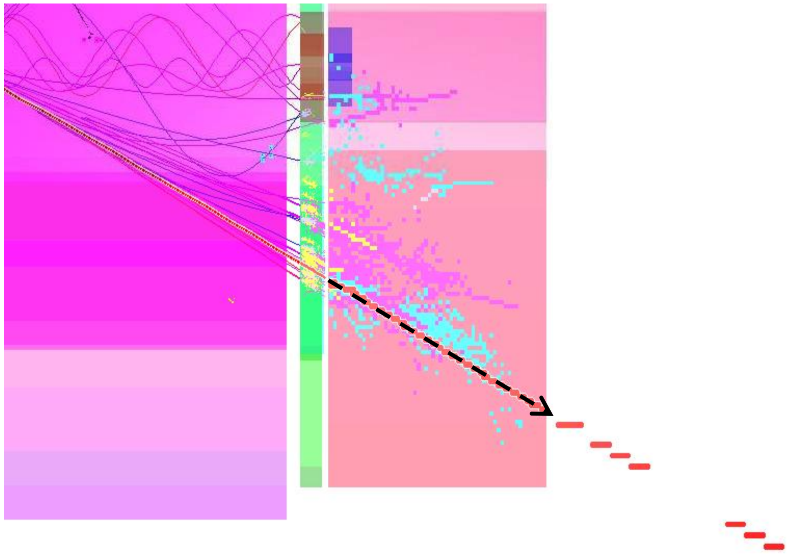
2. For every inner detector track >7GeV, a helix fit is extrapolated to the position of each yoke cluster. This extrapolation accounts for changes in the B-field upon crossing coil.

   Helix extrapolation is used to calculate distance of closest approach to each yoke cluster and also angle between helix direction and linear fit to the cluster.

   Track candidates with opening angles >0.2rad, or distances >200mm are excluded. The closest track is selected and used to calculate muon properties.



Extrapolate inner detector tracks to yoke

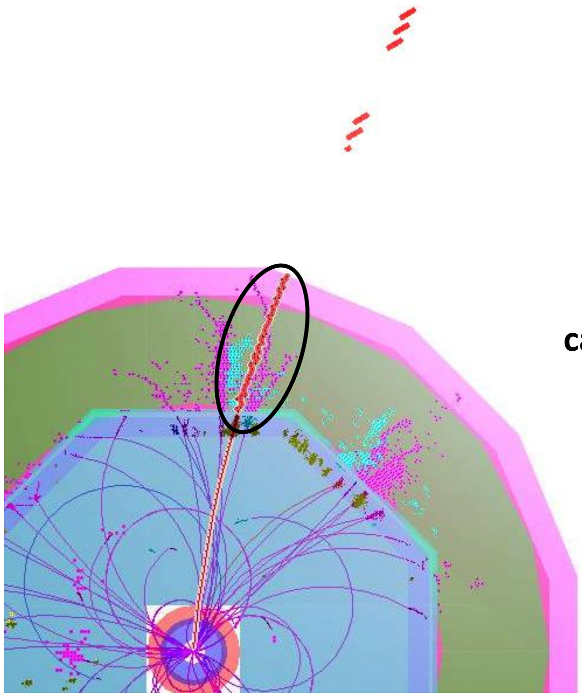


Muon Reconstruction Algorithm

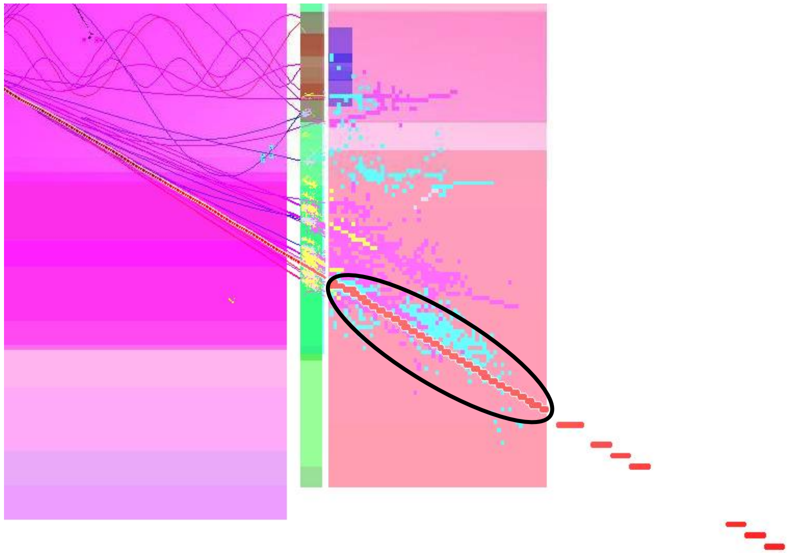
3. The helix fit is projected through the calorimeters to identify remaining hits from muon.

   Hits are added to reconstructed muon based upon distance from helix. If muon is not deemed to be isolated (based on hit density), only single closest hit in each layer is added. If the muon is isolated, all nearby hits (within a certain distance) are included.

   Finally, all muon components (hits/tracks) are removed from the subsequent reconstruction.



Select calorimeter hits



Particle ID Performance

- Particle ID performance has been studied by **J. Nardulli**, using samples of single particles and isolated leptons in simulated physics events with and without $\gamma\gamma \rightarrow$hadrons background.

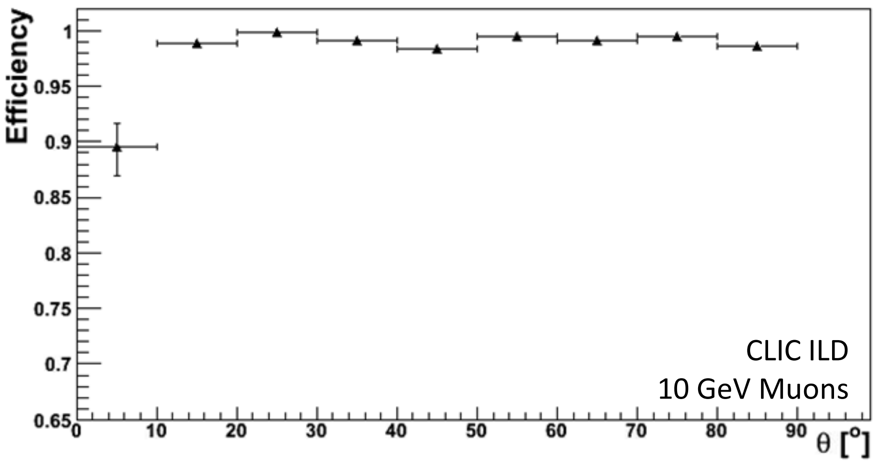
- Particle ID efficiency and purity measurements are obtained by matching reconstructed particles to generated particles.
- The following cuts are applied to the lists of all generated and reconstructed particles, so that only relevant/findable particles are considered:
  - Energy > 7.5GeV.
  - Polar angle $8^\circ < \theta < 172^\circ$.
  - Specified particle type and charge (MC particles must be stable).

- Matched particles are then those for which there is a reconstructed particle of the same type and charge within a cone of 1° around a generated particle.

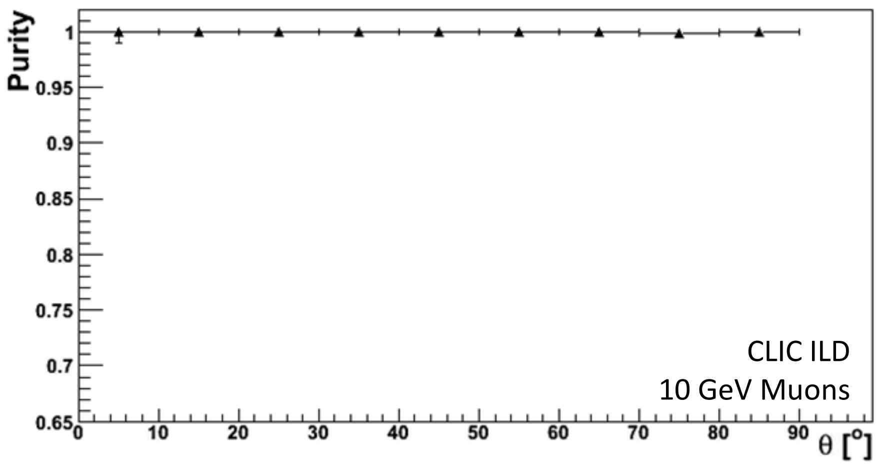
$$\textbf{Particle ID efficiency} = \frac{\textbf{matched particles}}{\textbf{generated particles}}$$

$$\textbf{Particle ID purity} = \frac{\textbf{matched particles}}{\textbf{reconstructed particles}}$$

CLIC ILD: Muons



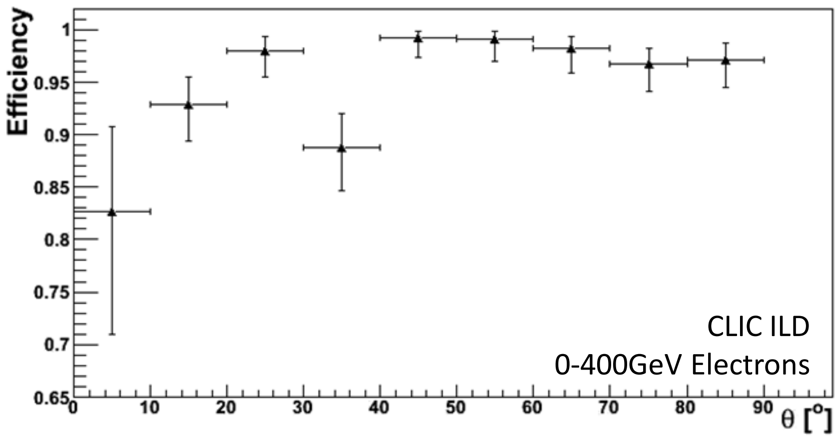
Mean efficiency: 99% ± 1%

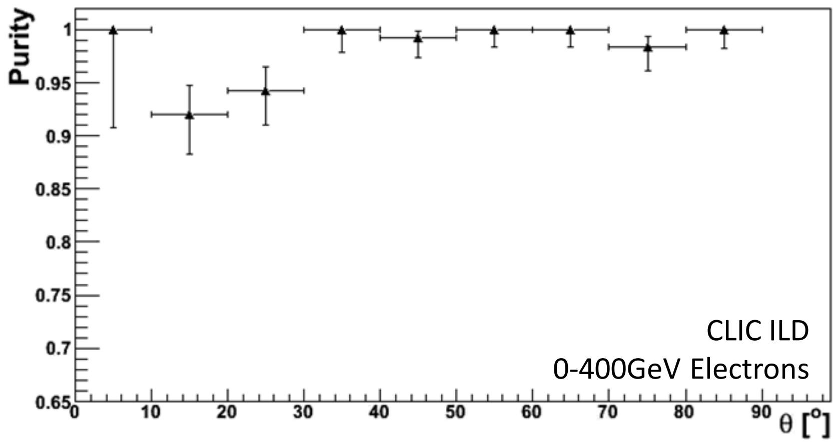


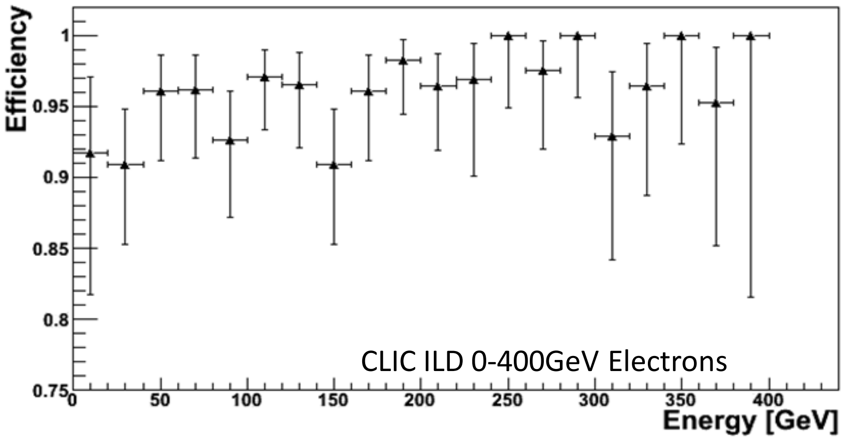
Mean purity: 100% ± 1%

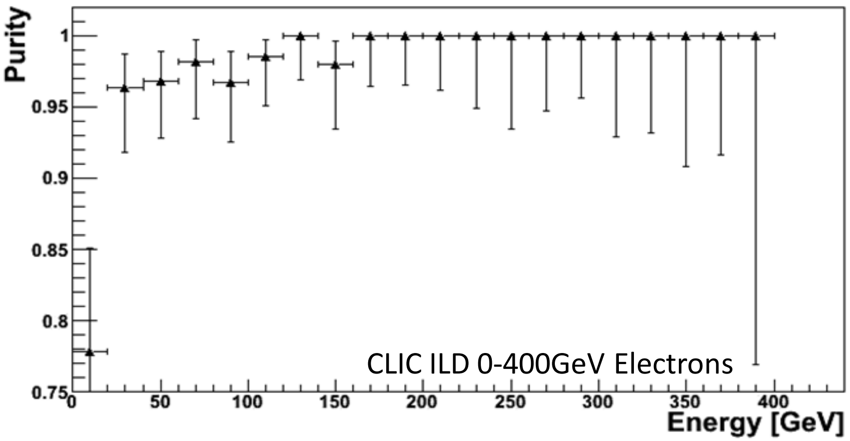
- 10GeV muons generated uniformly in θ and ϕ directions.
- Particle ID efficiency includes both efficiency for reconstructing a particle and efficiency for correctly identifying the particle type.
- At this energy, reconstruction and identification will mostly be performed by standalone muon reconstruction algorithm. Muon ID function may recover small number of remaining muons.

CLIC ILD: Electrons







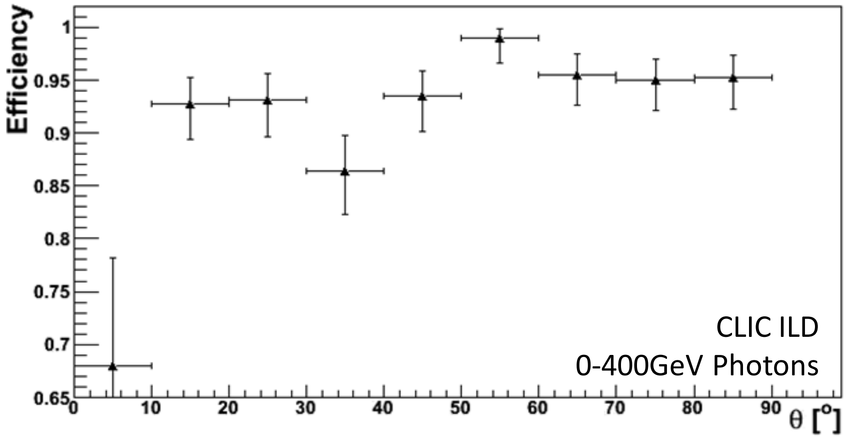


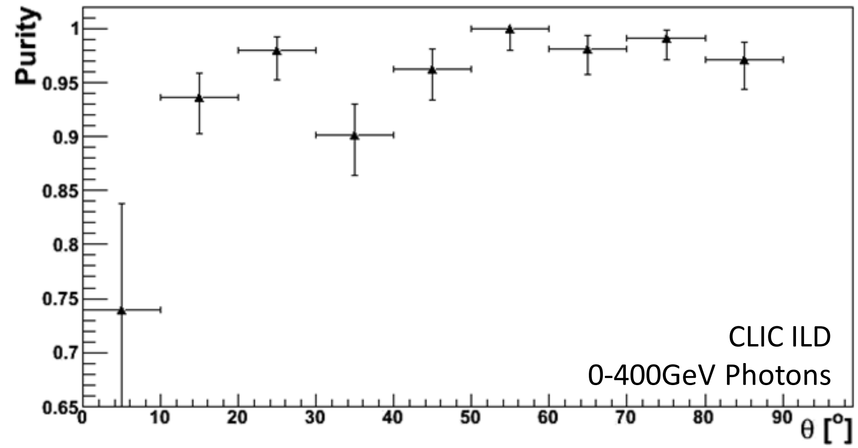
Mean efficiency: 96% ± 1%

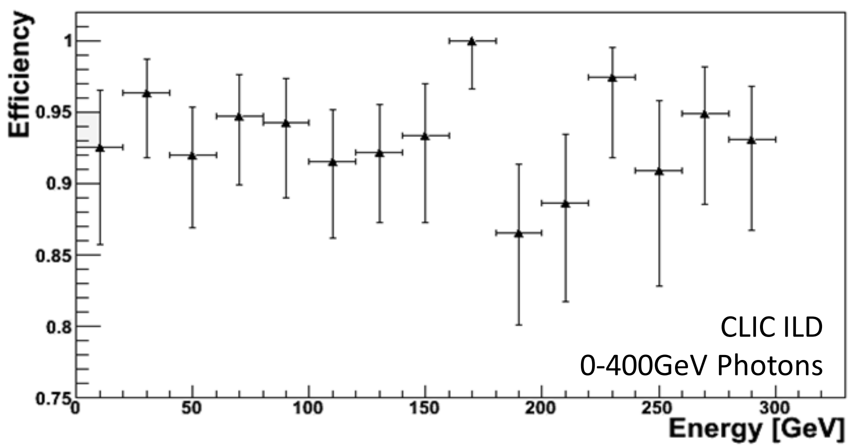
Mean purity: 97% ± 1%

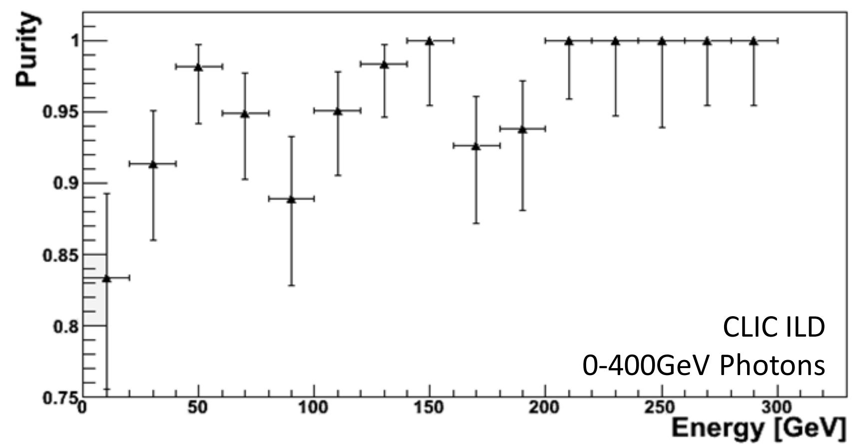
CLIC ILD: Photons

(Included for interest)







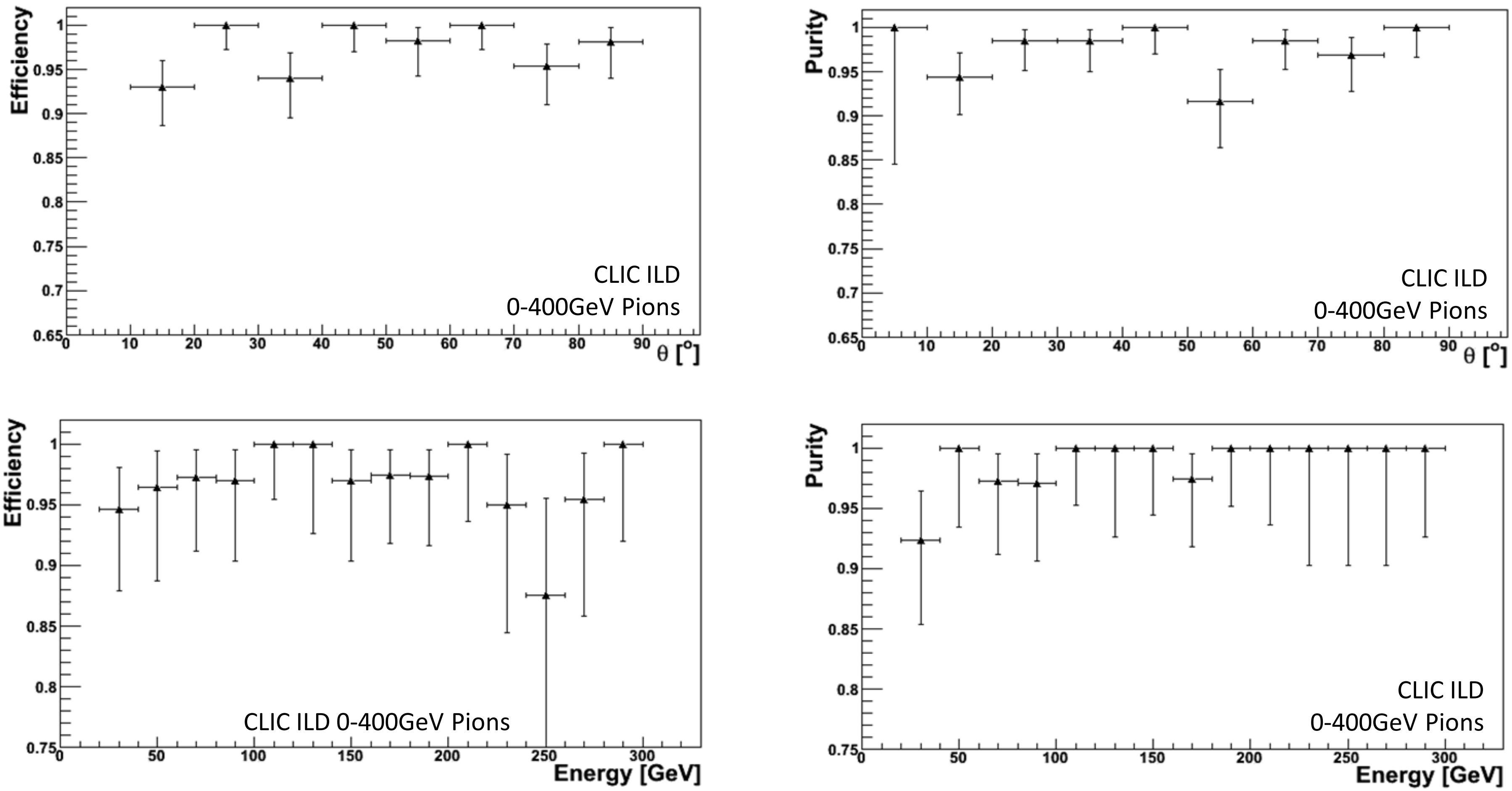


Mean efficiency: 93% ± 1%

Mean purity: 96% ± 1%

CLIC ILD: Charged Pions

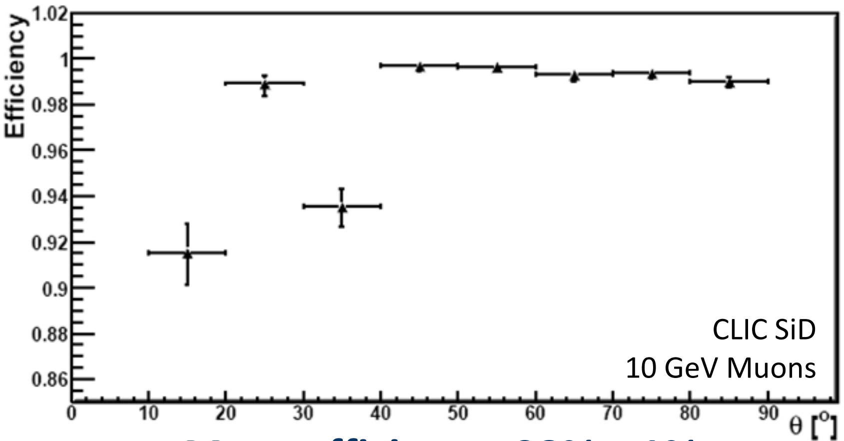
(Included for interest)



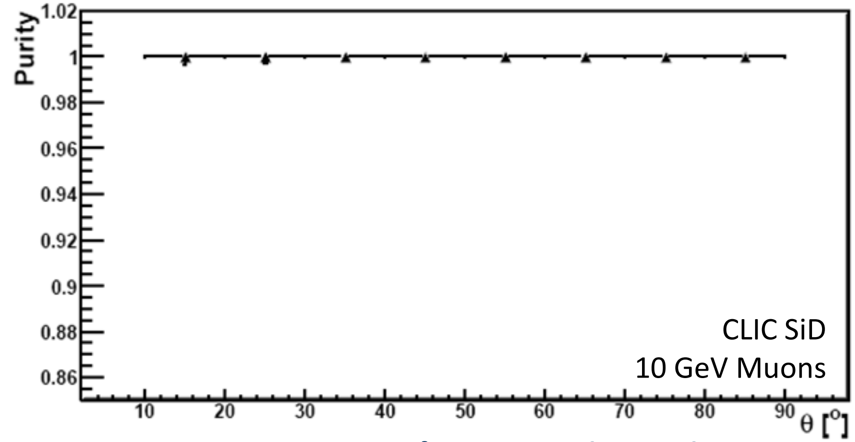
Mean efficiency: 96% ± 1%

Mean purity: 99% ± 1%

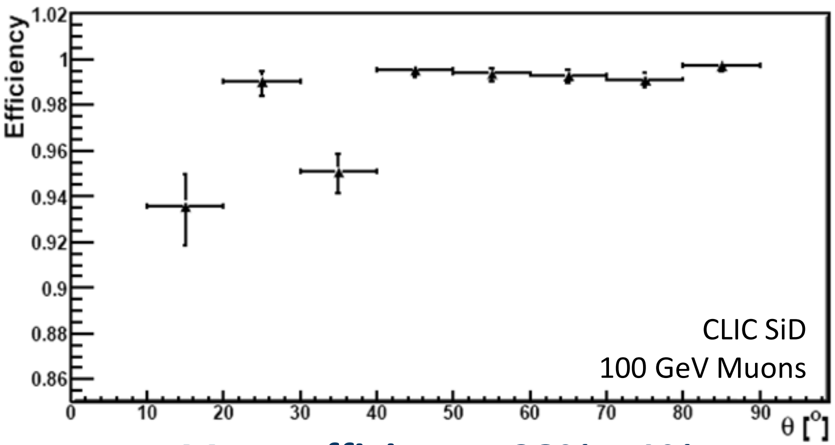
CLIC SiD: Muons



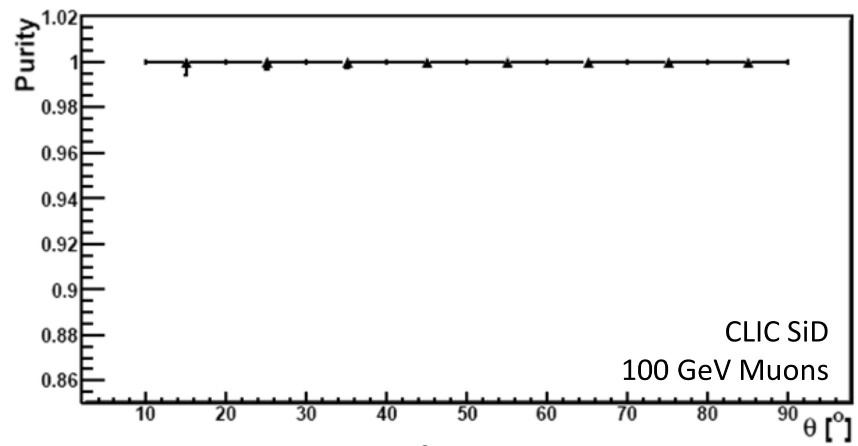
Mean efficiency: 98% ± 1%



Mean purity: 100% ± 1%

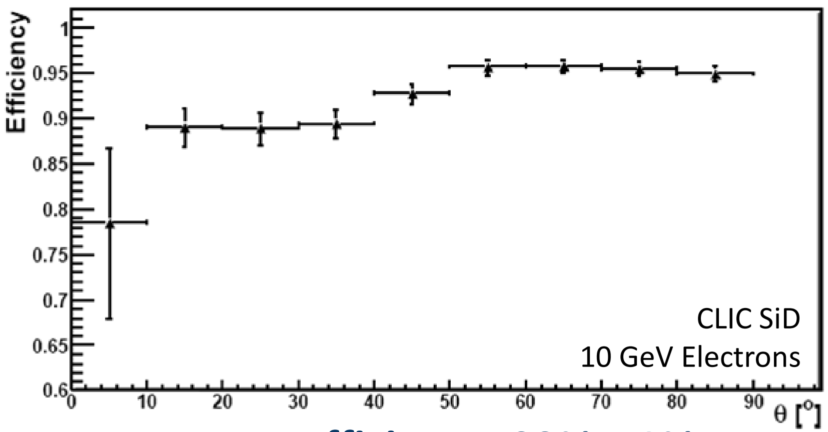


Mean efficiency: 98% ± 1%

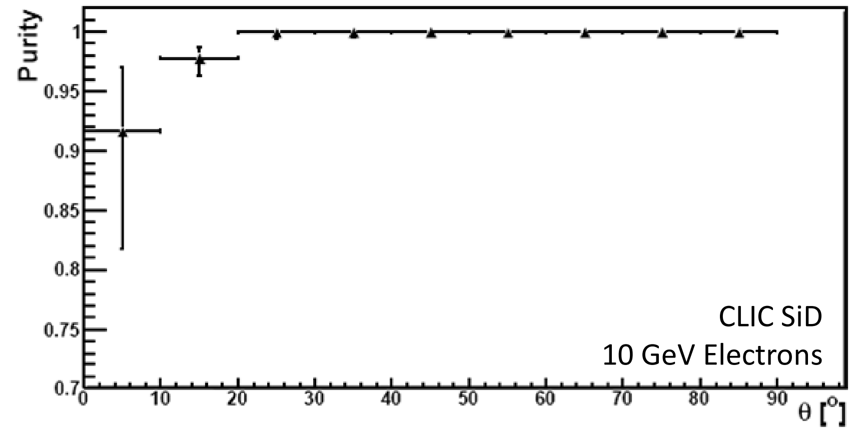


Mean purity: 100% ± 1%

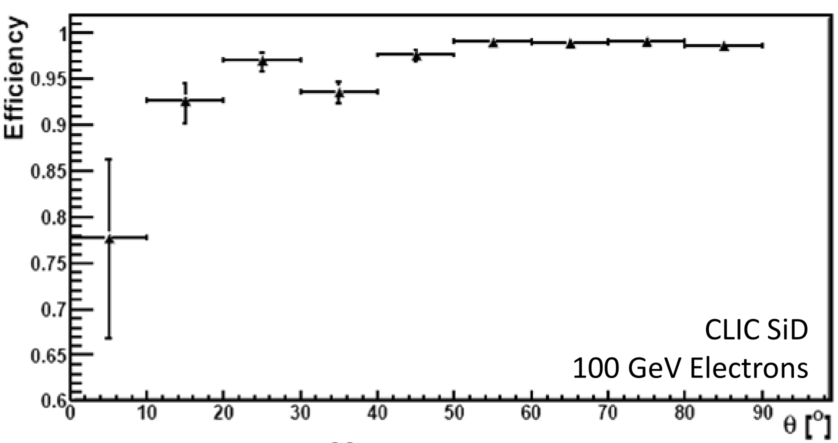
CLIC SiD: Electrons



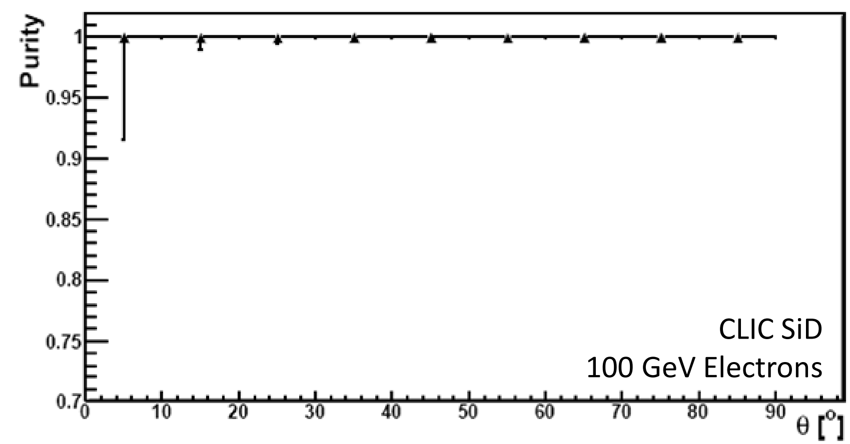
Mean efficiency: 92% ± 1%



Mean purity: 99% ± 1%

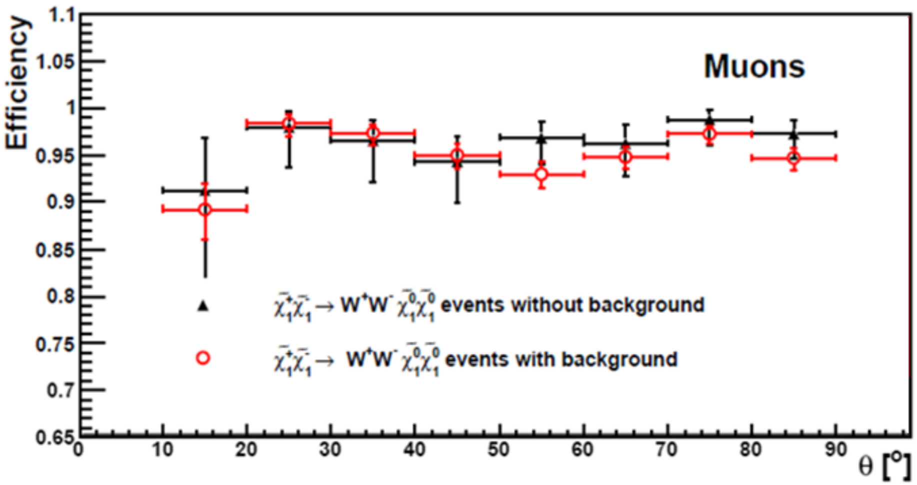


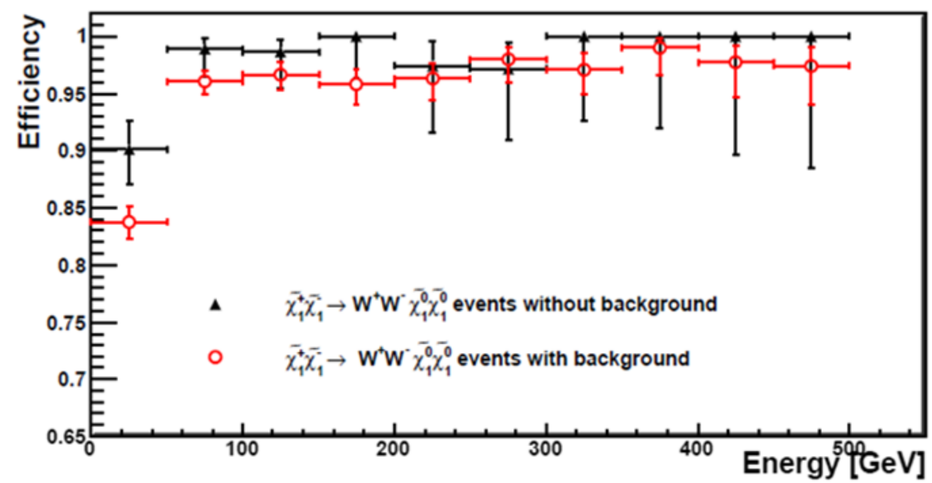
Mean efficiency: 97% ± 1%



Mean purity: 100% ± 1%

CLIC SiD: Particle Id in Jets

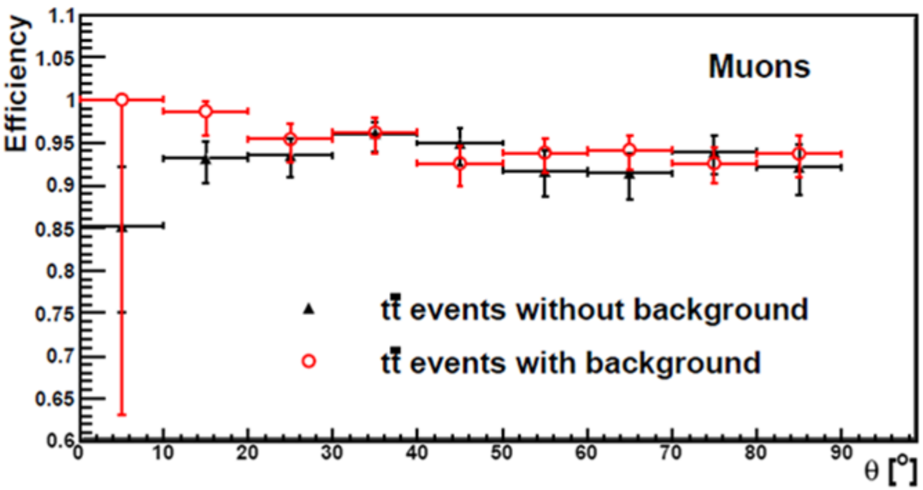


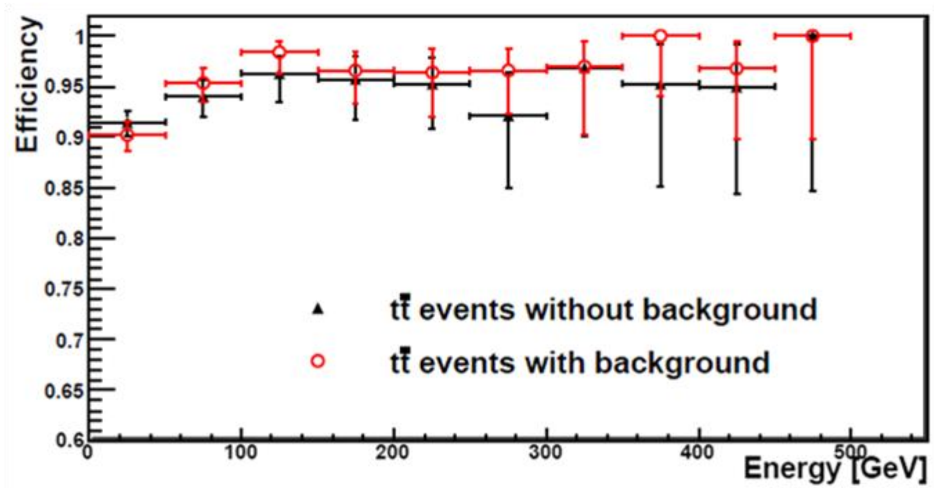


- For the CLIC SiD detector model, the effect of $\gamma\gamma \rightarrow$hadrons background on the muon ID efficiency has been studied using $e^+e^- \rightarrow \tilde{\chi}_1^+\tilde{\chi}_1^- \rightarrow W^+W^-\tilde{\chi}_1^0\tilde{\chi}_1^0$ events generated at $\sqrt{s}$ = 3TeV.
- Muons arise from semi-leptonic hadronic decays of the *W* boson and are, in general, not isolated. Efficiency is > 90% over almost entire energy range, even in the presence of background.

Mean efficiency without background: 96% ± 1%
Mean efficiency with background: 93% ± 1%

CLIC ILD: Particle Id in Jets





- For the CLIC ILD detector model, the events considered are $e^+e^- \rightarrow t\bar{t}$ at $\sqrt{s}$ = 3TeV.
- The simulated samples included both fully-hadronic and semi-leptonic final states: $t\bar{t} \rightarrow b(q\bar{q})\bar{b}(q\bar{q})$ (six jets) and $t\bar{t} \rightarrow b(q\bar{q})\bar{b}(l\nu)$ (four jets, lepton and missing energy).

Mean efficiency without background: 94% ± 1%
Mean efficiency with background: 94% ± 1%

Summary

- The Pandora framework provides a number of ways to perform particle ID. Algorithms make the final decisions, but they can be supported by plugin helper functions.
- Provided with Pandora are a number of particle ID functions and algorithms that are designed for use with any Fine Granularity particle flow detector.

- Fast muon, electron and photon identification functions have been used for the reconstruction of events in CLIC ILD and CLIC SID detector concepts.
- Also used was a standalone muon reconstruction algorithm, which attempts to fully reconstruct and tag muons above 7GeV, removing their hits and tracks from the subsequent reconstruction.

- The particle ID performance has been studied using samples of single particles and isolated leptons in simulated physics events with and without $\gamma\gamma \rightarrow$hadrons background.
- The particle ID efficiencies and purities are very similar for CLIC ILD and CLIC SiD and are greater than 90% for all the samples considered.