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Pandora PFA

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Contents

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Pandora Reference Material

https://github.com/PandoraPFA/Documentation

-Talks 0-3 from LArTPC workshop (on GitHub)
https://github.com/PandoraPFA/Documentation/blob/master/Pandora_LAr_Workshop/Workshop_Introduction.pdf
https://github.com/PandoraPFA/Documentation/blob/master/Pandora_LAr_Workshop/Workshop_Talk_1_Overview.pdf
https://github.com/PandoraPFA/Documentation/blob/master/Pandora_LAr_Workshop/Workshop_Talk_2_ClientApp.pdf
https://github.com/PandoraPFA/Documentation/blob/master/Pandora_LAr_Workshop/Workshop_Talk_3_SDK_Details.pdf

-LC overview doc (on GitHub)
https://github.com/PandoraPFA/Documentation/blob/master/Pandora_LC_Reconstruction.pdf

-SDK publication (on GitHub)
https://github.com/PandoraPFA/Documentation/blob/master/Pandora_SDK_Publication.pdf or https://arxiv.org/abs/1506.05348

-Example content learning library
https://github.com/PandoraPFA/Documentation/blob/master/Pandora_Example.pdf

-Pandora LCWS15 has some configuration-specific example slides
http://www.hep.phy.cam.ac.uk/~marshall/Pandora_LCWS_03.Nov.2015.pdf

-Pandora Papers: CLIC-specific PFA paper and original Pandora paper.
https://arxiv.org/abs/1209.4039
https://arxiv.org/abs/0907.3577

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Software Compensation and other energy “regularisation” techniques.

Energy "Regularisation" Techniques

Technique	Description
Pandora Sepecific Calibration	Setting Electromagnetic and Hadronic energy scales in ECal and HCal.
ScaleHotHadrons	Searches for anomalously high energy hits based on average number of MIPs per hit in a cluster.
CleanClusters	Searches for anomalously high energy hits based on average energy in a given pseudo layer of a hit.
MaxHCalHitHadronicEnergy	Truncates cell energy entering Pandora to limit effect of Landau fluctuations.
SoftwareCompensation	Adjusts neutral hadron energies based on energy density of calorimeter hits and energy of the cluster the hit belongs to.
Non-Linearity Corrections	Ad-hoc method for achieving linear response between MC and reconstructed neutral hadron energies. In past studies, this gave unphysical behaviour when examining the distribution of reconstructed energies so is effectively defunct.

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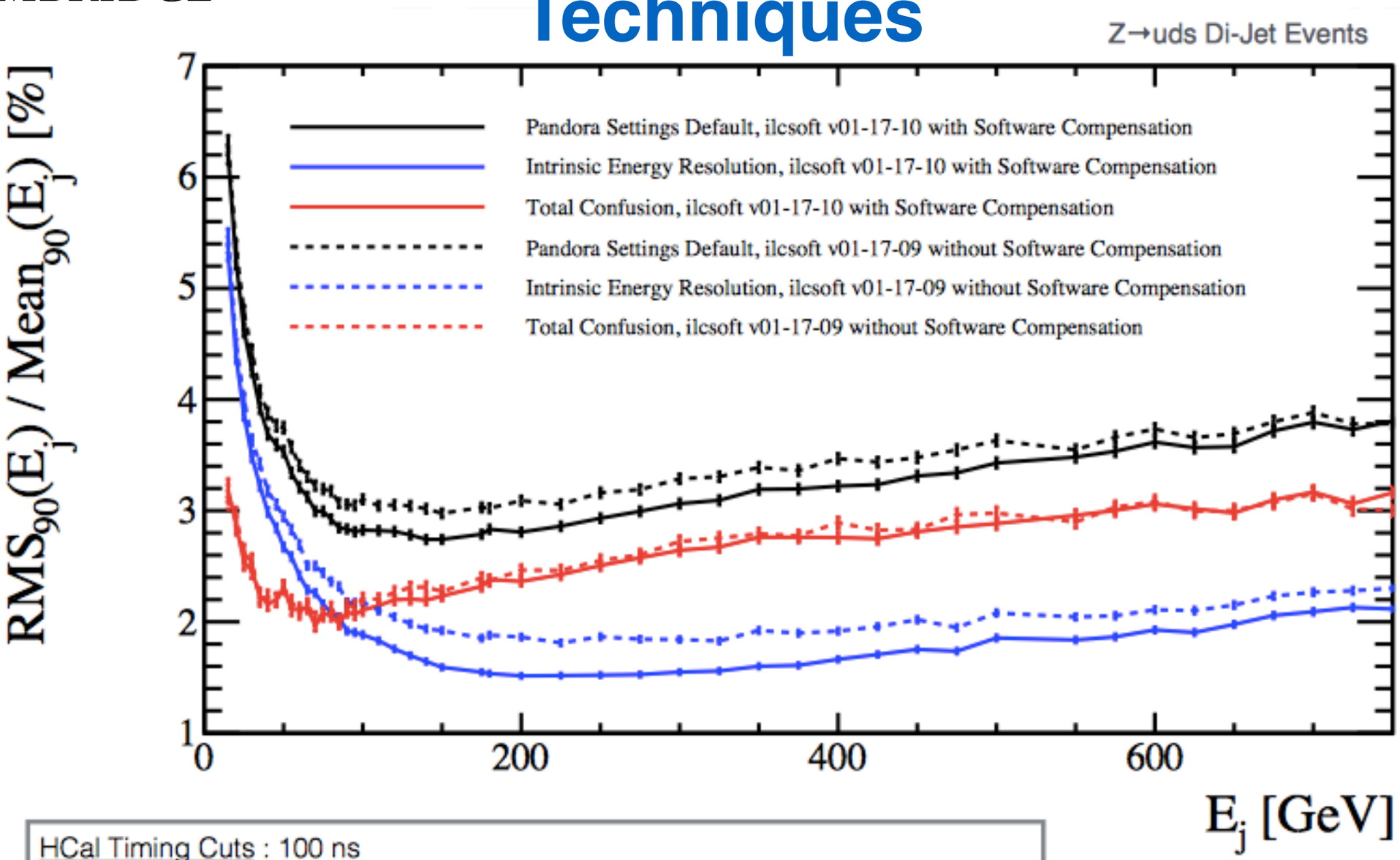
Energy "Regularisation" Techniques

Technique	Where Is It Applied	What Is It Applied To	Optimal Performance?
Pandora Sepecific Calibration	ECal & HCal	Electromagnetic and Hadronic Showers	No
ScaleHotHadrons	ECal & HCal	Hadronic Showers	No
CleanClusters	ECal & HCal	Hadronic Showers	No
MaxHCalHitHadronicEnergy	HCal	Electromagnetic and Hadronic Showers	No
SoftwareCompensation	HCal + (CleanClusters in ECal)	Hadronic Showers	Yes
Non-Linearity Corrections	ECal & HCal	Hadronic Showers	No

Energy "Regularisation" Techniques



HCal Timing Cuts : 100 ns
ECal Timing Cuts : 100 ns
HCal Hadronic Cell Truncation : Not Applied
Software : Mixed, see legend
Digitiser : ILDCaloDigi, realistic ECal and HCal digitisation options enabled
Calibration : PandoraAnalysis toolkit v01-02-00

ILD with 60 Layer HCal

Trained up to 100 GeV clusters. Benefit can be extended with retraining.

Energy “Regularisation” Techniques

-Energy Regularisation Techniques:

-S.Green Thesis (on GitHub). Most up to date reference.
https://github.com/StevenGreen1/Thesis/blob/master/thesis.pdf

- Calibration: *Section 5.2*
- Pandora Specific Calibration: *Sections 5.2.4, 5.2.5 & 5.2.6*
- Max HCal Hit Hadronic Energy: *Section 5.3.1*
- ScaleHotHadrons and CleanClusters (brief): *Section 5.3.1.1*
- Software Compensation: *Section 5.3.2*

-Detector Optimisation Studies Talk LCWS15.
https://agenda.linearcollider.org/event/6662/contributions/32710/attachments/26902/41032/LCWS_DetOpt_Green_3-11-15.pdf

- Jet Energy Resolution evolution from LoI to optimisation studies (found in thesis). Important for referencing performance.

-CLIC Workshop August 2016.
https://indico.cern.ch/event/487219/contributions/2275661/attachments/1329104/1996494/CLICdpWorkshop_OptimisationStudies_Green.pdf

- Optimisation studies talk.
- Details of calibration used for optimisation studies.
- Software compensation applied for pseudoCLIC ILD detector (ILD w 60 layers).

-Software Compensation paper. Under review for EPJC.
https://arxiv.org/pdf/1705.10363.pdf

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Clustering Algorithms

Pandora Client App Steering (Old)

```
<processor name="MyMarlinPandoraDefault" type="PandoraPFANewProcessor">
  <parameter name="PandoraSettingsXmlFile" type="String">PandoraSettingsDefault.xml</parameter>
  <!-- Collection names -->
  <parameter name="TrackCollections" type="StringVec">MarlinTrkTracks</parameter>
  <parameter name="ECalCaloHitCollections" type="StringVec">ECALBarrel ECALEndcap ECALOther</parameter>
  <parameter name="HCalCaloHitCollections" type="StringVec">HCALBarrel HCALEndcap HCALOther</parameter>
  <parameter name="LCalCaloHitCollections" type="StringVec">LCAL</parameter>
  <parameter name="LHCalCaloHitCollections" type="StringVec">LHCAL</parameter>
  <parameter name="MuonCaloHitCollections" type="StringVec">MUON</parameter>
  <parameter name="MCParticleCollections" type="StringVec">MCParticle</parameter>
  <parameter name="RelCaloHitCollections" type="StringVec">RelationCaloHit RelationMuonHit</parameter>
  <parameter name="RelTrackCollections" type="StringVec">MarlinTrkTracksMCTruthLink</parameter>
  <parameter name="KinkVertexCollections" type="StringVec">KinkVertices</parameter>
  <parameter name="ProngVertexCollections" type="StringVec">ProngVertices</parameter>
  <parameter name="SplitVertexCollections" type="StringVec">SplitVertices</parameter>
  <parameter name="V0VertexCollections" type="StringVec">V0Vertices</parameter>
  <parameter name="ClusterCollectionName" type="String">PandoraClustersDefault</parameter>
  <parameter name="PFOCollectionName" type="String">PandoraPFOsDefault</parameter>
  <!-- Calibration constants -->
  <parameter name="ECalToMipCalibration" type="float">160.0</parameter>
  <parameter name="HCalToMipCalibration" type="float">34.8</parameter>
  <parameter name="ECalMipThreshold" type="float">0.5</parameter>
  <parameter name="HCalMipThreshold" type="float">0.3</parameter>
  <parameter name="ECalToEMGeVCalibration" type="float">1.007</parameter>
  <parameter name="HCalToEMGeVCalibration" type="float">1.007</parameter>
  <parameter name="ECalToHadGeVCalibrationBarrel" type="float">1.075</parameter>
  <parameter name="ECalToHadGeVCalibrationEndCap" type="float">1.075</parameter>
  <parameter name="HCalToHadGeVCalibration" type="float">1.027</parameter>
  <parameter name="MuonToMipCalibration" type="float">10.0</parameter>
  <parameter name="DigitalMuonHits" type="int">0</parameter>
  <parameter name="MaxHCalHitHadronicEnergy" type="float">1.</parameter>
  <!-- Absorber properties -->
  <parameter name="AbsorberRadLengthECal" type="float">0.2854</parameter>
  <parameter name="AbsorberIntLengthECal" type="float">0.0101</parameter>
  <parameter name="AbsorberRadLengthHCal" type="float">0.0569</parameter>
  <parameter name="AbsorberIntLengthHCal" type="float">0.0060</parameter>
  <parameter name="AbsorberRadLengthOther" type="float">0.0569</parameter>
  <parameter name="AbsorberIntLengthOther" type="float">0.0060</parameter>
  <!--Whether to calculate track states manually, rather than copy stored fitter values-->
  <parameter name="UseOldTrackStateCalculation" type="int">0</parameter>
</processor>
```

Pandora alg steering

Input and output collection names

Pandora calibration constants

Additional geometry information

Support for old tracking software

Pandora Algorithm Steering

- **Pandora is configured via an XML file, provided by the client application.**
- It looks for algorithm XML tags within the top level Pandora tags, creating instances of any algorithms found. It will run these algorithms, in order, for each event.
- Each algorithm receives a ReadSettings callback, with a provided XML handle. Algorithms can have mandatory or optional parameters (override default values).
- Algorithms can use the ReadSettings callback to control the creation of daughter Algorithms or AlgorithmTools. Allows for use of (multiple) alternative approaches to solving a problem.

```
<!-- Pandora settings xml file -->
<pandora>
    <!-- GLOBAL SETTINGS -->
    <IsMonitoringEnabled>true</IsMonitoringEnabled>
    <ShouldDisplayAlgorithmInfo>false</ShouldDisplayAlgorithmInfo>
    <ShouldCollapseMCParticlesToPfoTarget>true</ShouldCollapseMCParticlesToPfoTarget>

    <!-- PLUGIN SETTINGS -->
    <HadronicEnergyCorrectionPlugins>CleanClusters ScaleHotHadrons</HadronicEnergyCorrectionPlugins>
    <EmShowerPlugin>LCEmShowerId</EmShowerPlugin>
    <PhotonPlugin>LCPhotonId</PhotonPlugin>
    <ElectronPlugin>LCElectronId</ElectronPlugin>
    <MuonPlugin>LCMuonId</MuonPlugin>

    <!-- ALGORITHM SETTINGS -->

    <!-- Set calo hit properties, then select tracks and hits to use for clustering -->
    <algorithm type = "CaloHitPreparation"/>
    <algorithm type = "EventPreparation">
        <OutputTrackListName>Tracks</OutputTrackListName>
        <OutputCaloHitListName>CaloHits</OutputCaloHitListName>
        <OutputMuonCaloHitListName>MuonYokeHits</OutputMuonCaloHitListName>
        <ReplacementTrackListName>Tracks</ReplacementTrackListName>
        <ReplacementCaloHitListName>CaloHits</ReplacementCaloHitListName>
    </algorithm>
    …SNIP…
```

Pandora XML tag opened here

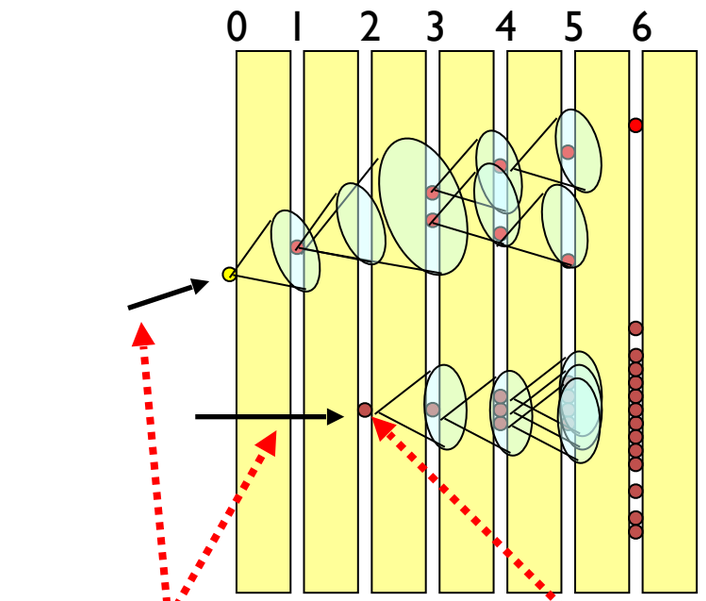
Non-default global parameters

Particle Id and Energy correction Plugins

First two algorithms, with required parameters

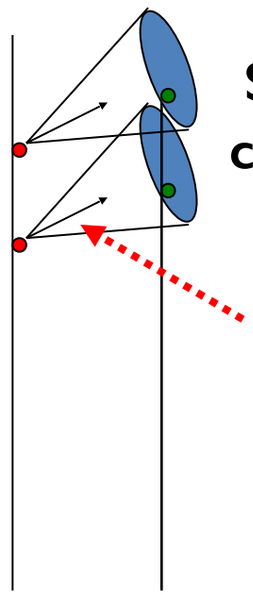
Pandora Clustering Example

- **Philosophy:** "It's easier to put clusters together, than to split them up again."
- Clustering algorithm very careful to avoid accidentally merging energy deposits from separate particles.



Initial cluster direction

Unmatched hit seeds new cluster

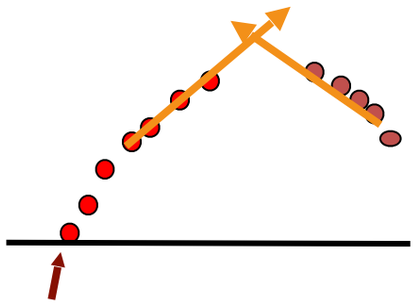


Simple cone-based clustering algorithm

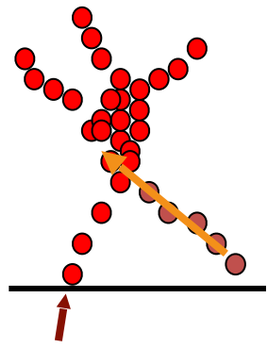
Cones based on either: initial direction or current direction

Topological Associations

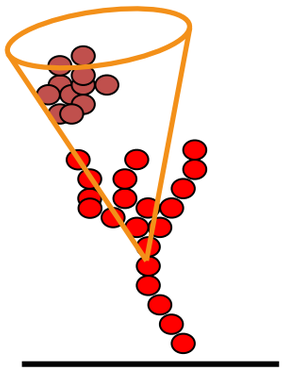
- Fine granularity of the calorimeters exploited to merge cluster fragments that are clearly associated.
- Very few mistakes made.



Looping tracks



Back-scattered tracks



Cone associations

Pandora Clustering Config

https://github.com/iLCSoft/ILDConfig/blob/master/StandardConfig/lcgeo_current/PandoraSettingsDefault.xml#L79

Parent clustering algorithm

Cluster formation daughter algorithm

```
<algorithm type = "ClusteringParent">
    <algorithm type = "ConeClusteringFast" description = "ClusterFormation"/>
    <algorithm type = "TopologicalAssociationParent" description = "ClusterAssociation">
        <associationAlgorithms>
            <algorithm type = "LoopingTracks"/>
            <algorithm type = "BrokenTracks"/>
            <algorithm type = "ShowerMipMerging"/>
            <algorithm type = "ShowerMipMerging2"/>
            <algorithm type = "BackscatteredTracks"/>
            <algorithm type = "BackscatteredTracks2"/>
            <algorithm type = "ShowerMipMerging3"/>
            <algorithm type = "ShowerMipMerging4"/>
            <algorithm type = "ProximityBasedMerging">
                <algorithm type = "TrackClusterAssociationFast"/>
            </algorithm>
            <algorithm type = "ConeBasedMerging">
                <algorithm type = "TrackClusterAssociationFast"/>
            </algorithm>
            <algorithm type = "MipPhotonSeparation">
                <algorithm type = "TrackClusterAssociationFast"/>
            </algorithm>
            <algorithm type = "SoftClusterMergingFast">
                <algorithm type = "TrackClusterAssociationFast"/>
                <AdditionalClusterListNames>PhotonClusters</AdditionalClusterListNames>
            </algorithm>
            <algorithm type = "IsolatedHitMerging">
                <AdditionalClusterListNames>PhotonClusters</AdditionalClusterListNames>
            </algorithm>
        </associationAlgorithms>
    </algorithm>
    <ClusterListName>PrimaryClusters</ClusterListName>
    <ReplaceCurrentClusterList>true</ReplaceCurrentClusterList>
</algorithm>
```

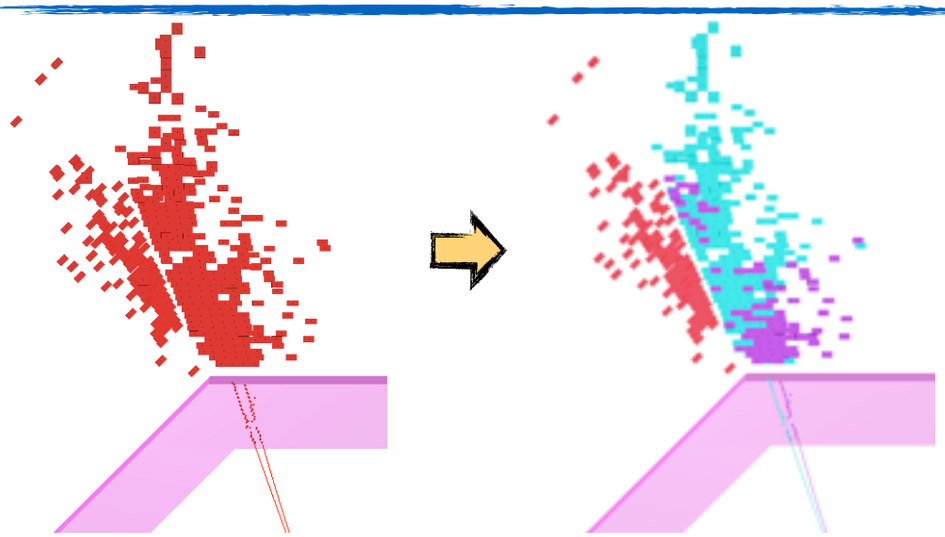
List of topological association daughter algorithms

Some topological association algs use daughter algs

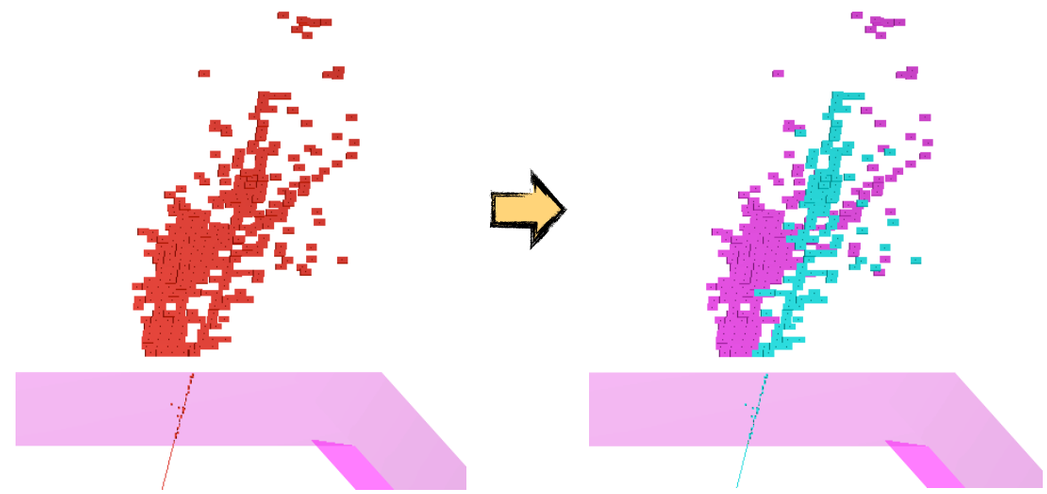
Configuration of output Cluster list

Pandora Reclustering Example

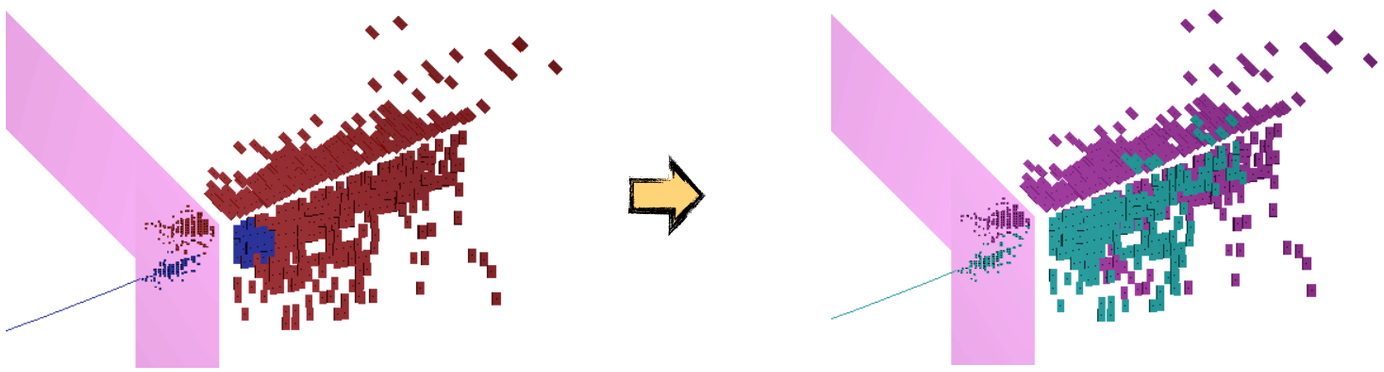
If identify significant discrepancy between cluster energy and associated track momentum, choose to recluster. Alter clustering parameters until cluster splits to obtain track-cluster consistency.



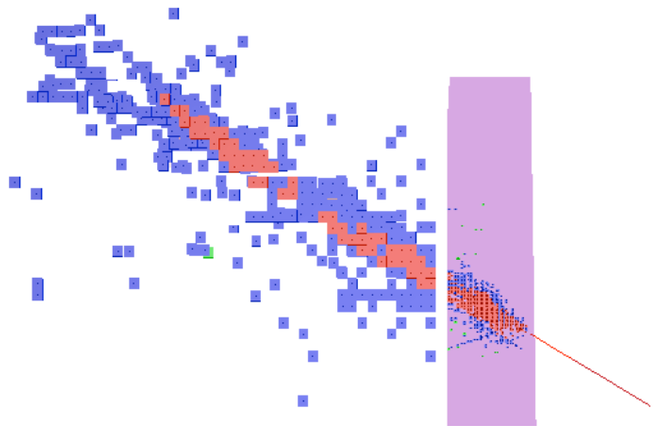
1. Multiple tracks associated to single cluster – split cluster.



2. Cluster energy much greater than track momentum – split cluster.



3. Track momentum much greater than cluster energy – bring in nearby clusters and reconfigure.



4. If, and only if, no E/p match emerges, can force track-cluster consistency ⇒ energy flow.

Pandora Reclustering Config

https://github.com/iLCSoft/ILDConfig/blob/master/StandardConfig/lcgeo_current/PandoraSettingsDefault.xml#L118

Parent reclustering algorithm, provides overall logic

```
<algorithm type = "SplitMergedClusters">
    <clusteringAlgorithms>
        <algorithm type = "ConeClusteringFast" instance = "Reclustering1">
            <TanConeAngleFine>0.24</TanConeAngleFine>
            <TanConeAngleCoarse>0.4</TanConeAngleCoarse>
            <AdditionalPadWidthsFine>2</AdditionalPadWidthsFine>
            <AdditionalPadWidthsCoarse>2</AdditionalPadWidthsCoarse>
            <SameLayerPadWidthsFine>2.24</SameLayerPadWidthsFine>
            <SameLayerPadWidthsCoarse>1.44</SameLayerPadWidthsCoarse>
            <MaxTrackSeedSeparation>100</MaxTrackSeedSeparation>
            <MaxLayersToTrackSeed>0</MaxLayersToTrackSeed>
            <MaxLayersToTrackLikeHit>0</MaxLayersToTrackLikeHit>
            <TrackPathWidth>0</TrackPathWidth>
        </algorithm>
        <algorithm type = "ConeClusteringFast" instance = “Reclustering2”/>
        <algorithm type = "ConeClusteringFast" instance = "Reclustering3"/>
        <algorithm type = "ConeClusteringFast" instance = "Reclustering4"/>
        <algorithm type = "ConeClusteringFast" instance = "Reclustering5"/>
        <algorithm type = "ConeClusteringFast" instance = "Reclustering6"/>
        <algorithm type = "ConeClusteringFast" instance = "Reclustering7"/>
        <algorithm type = "ConeClusteringFast" instance = "Reclustering8"/>
        <algorithm type = "ConeClusteringFast" instance = "Reclustering9"/>
        <algorithm type = "ConeClusteringFast" instance = "Reclustering10"/>
        <algorithm type = "ConeClusteringFast" instance = "Reclustering11"/>
        <algorithm type = "ConeClusteringFast" instance = "Reclustering12"/>
    </clusteringAlgorithms>
    <algorithm type = "TopologicalAssociationParent" description = "ClusterAssociation" instance = "reclusterAssociation"/>
    <algorithm type = "TrackClusterAssociationFast" description = "TrackClusterAssociation"/>
    <algorithm type = "ForcedClustering" description = “ForcedClustering”/>
    <UsingOrderedAlgorithms>true</UsingOrderedAlgorithms>
    <ShouldUseForcedClustering>true</ShouldUseForcedClustering>
</algorithm>
```

Alternative clustering daughter algorithm (full config)

Alternative clustering daughter algorithms (reuse existing instances)

Steering options for parent algorithm

Daughter algorithms providing specific functionality to parent

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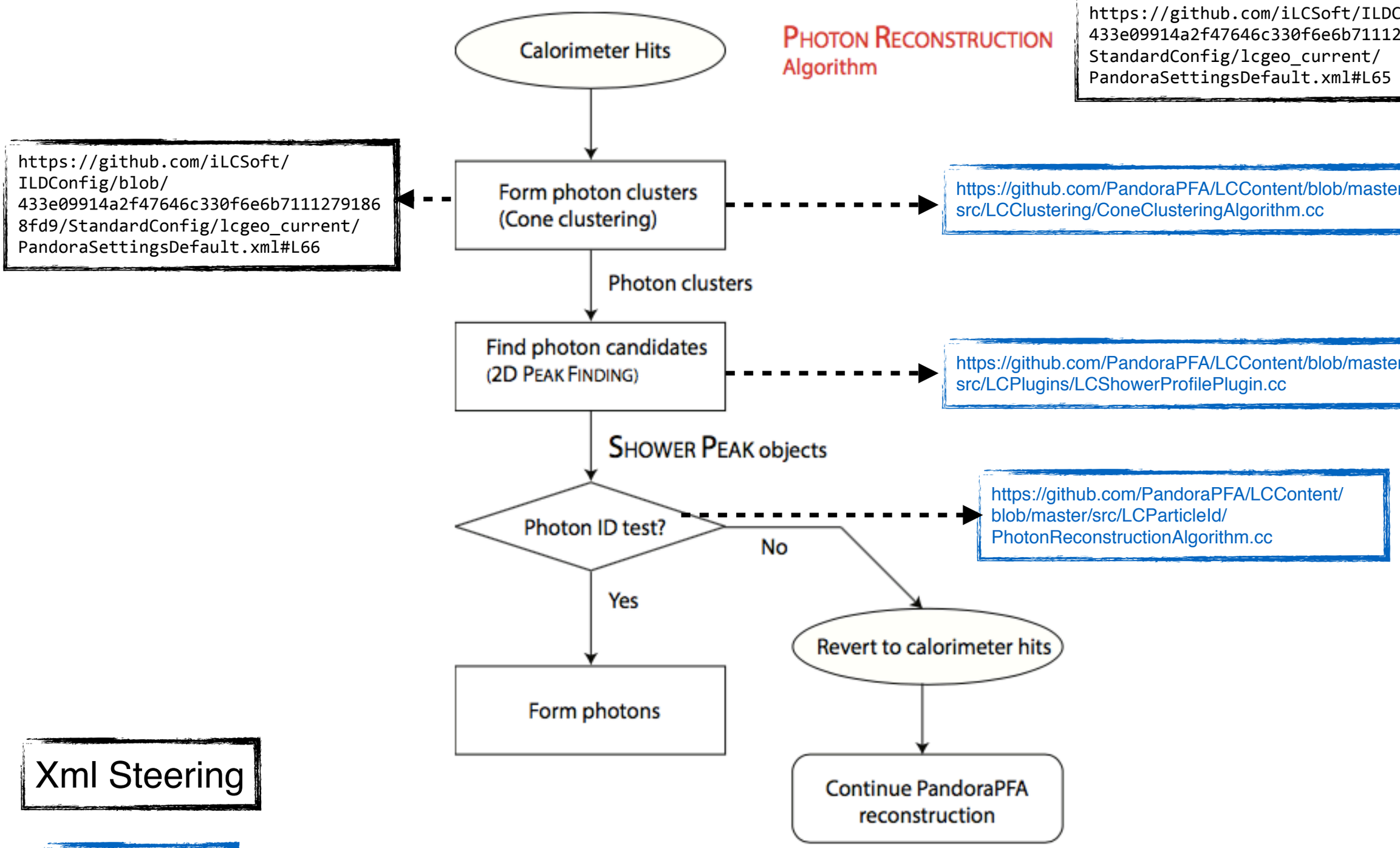
Photon ID

Photon Reconstruction



Xml Steering

C++ Code

Figure 5.3: Main steps of the PHOTON RECONSTRUCTION algorithm: forming photon clusters; finding photon candidates; and photon ID test.

Photon ID- Likelihood

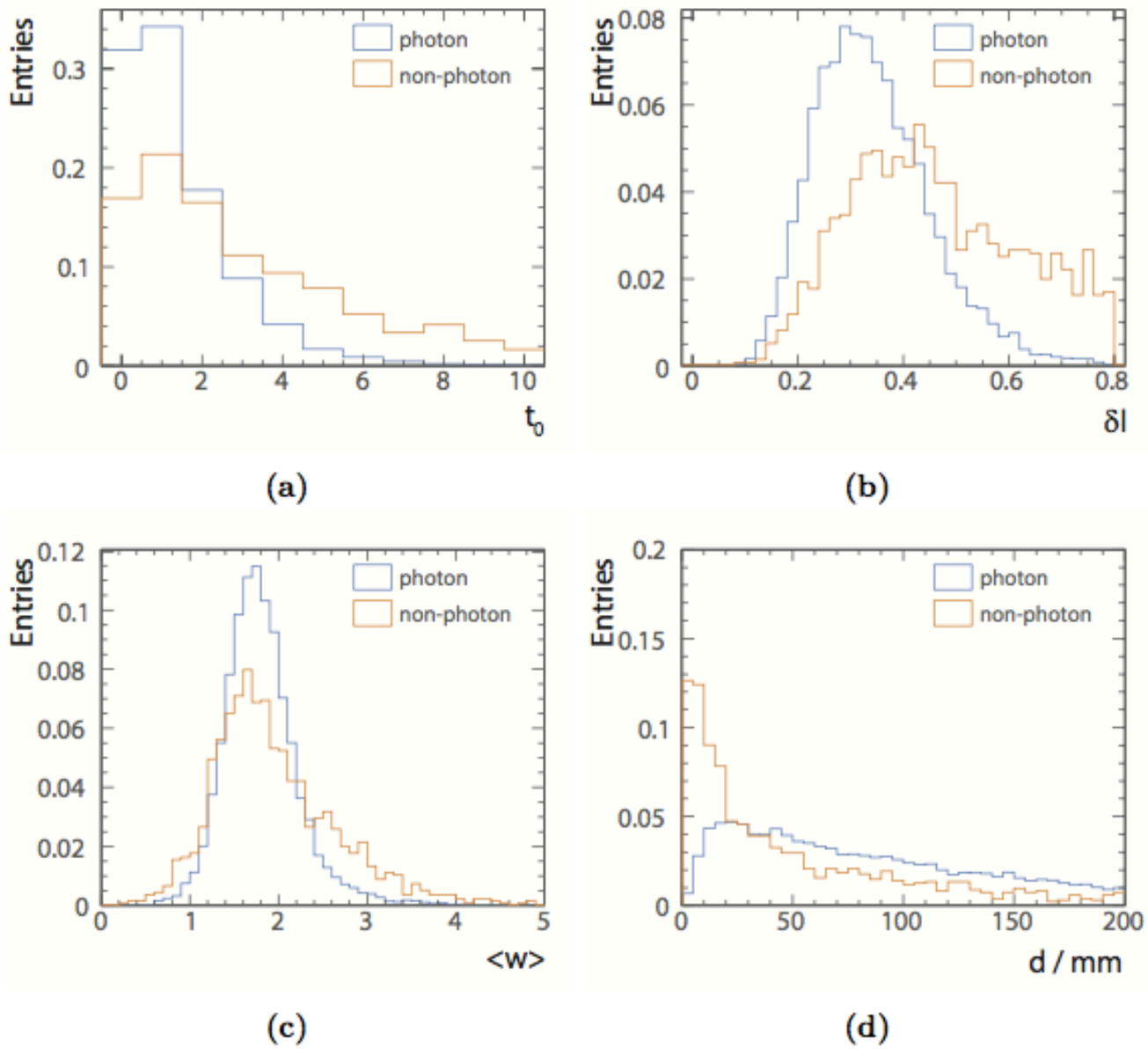


Figure 5.9: Distributions of: a) the start layer from the longitudinal shower profile (t_0); b) the fractional difference of the observed shower profile to the expected EM shower profile (δl); c) the energy weighted root-mean-square distance of all bins in a SHOWER PEAK to its peak bin ($\langle w \rangle$); and d) the distance between the photon candidate and the closest track projection onto the front of the ECAL (d). The area under each curve is normalised to unity.

-PhotonID:

-B.Xu Thesis (on GitHub).
https://github.com/bonoxu/boruoXuThesis/blob/master/main.pdf

- Photon Reconstruction in PandoraPFA: *Section 5*
- Photon ID: *Section 5.3.3*