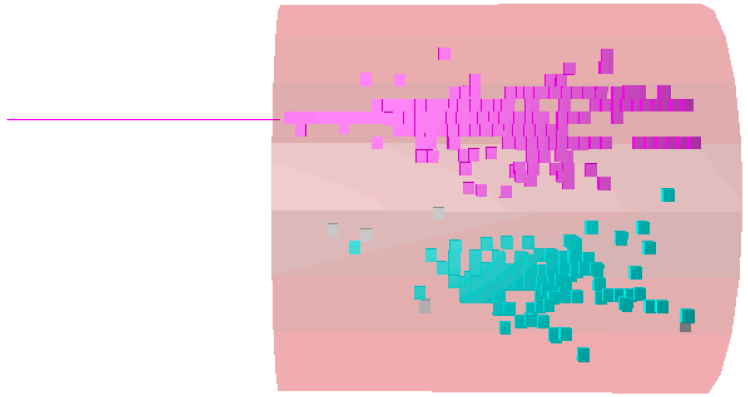
PandoraPFA on AHCAL 2018 Data Studies

Single and Double Particle Reconstruction



Magenta: Charged Hadron
Cyan: Neutral Hadron
Grey: Unclustered Hits

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daniel.heuchel@desy.de
CALICE Analysis Meeting
20. Mai 2020

Work done in cooperation with
Linghui Liu (The University of Tokyo)

HELMHOLTZ RESEARCH FOR GRAND CHALLENGES

UNIVERSITÄT HEIDELBERG ZUKUNFT SEIT 1386

HGSFP

CALICE

DESY.

Outline

For this Talk

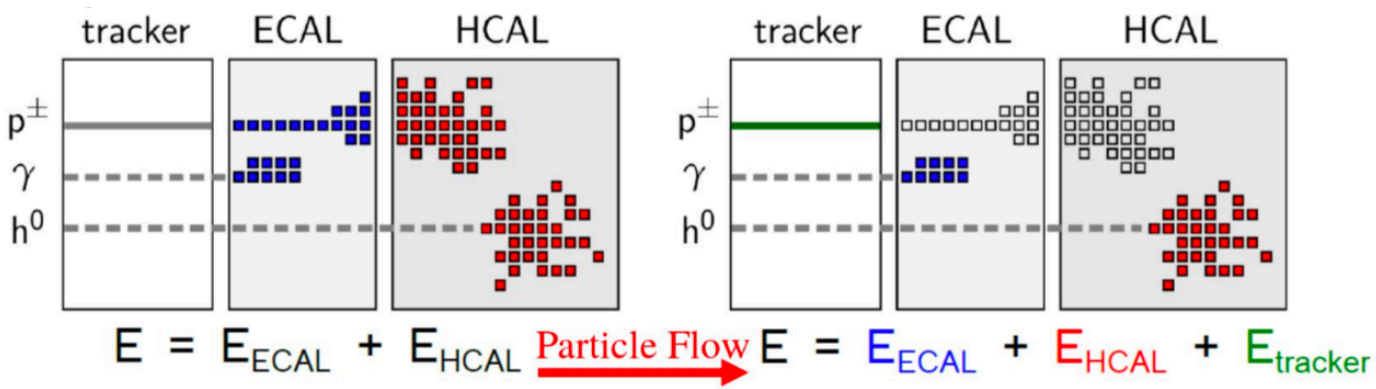
- Particle Flow and PandoraPFA
- Idea & Goals of Analysis
- Samples Preparation and Selection Tools
- Framework, Implementation and Technical Aspects
- Calibration
- First Look into Single and Two Particle Reconstruction

- Summary & Outlook

Particle Flow and PandoraPFA

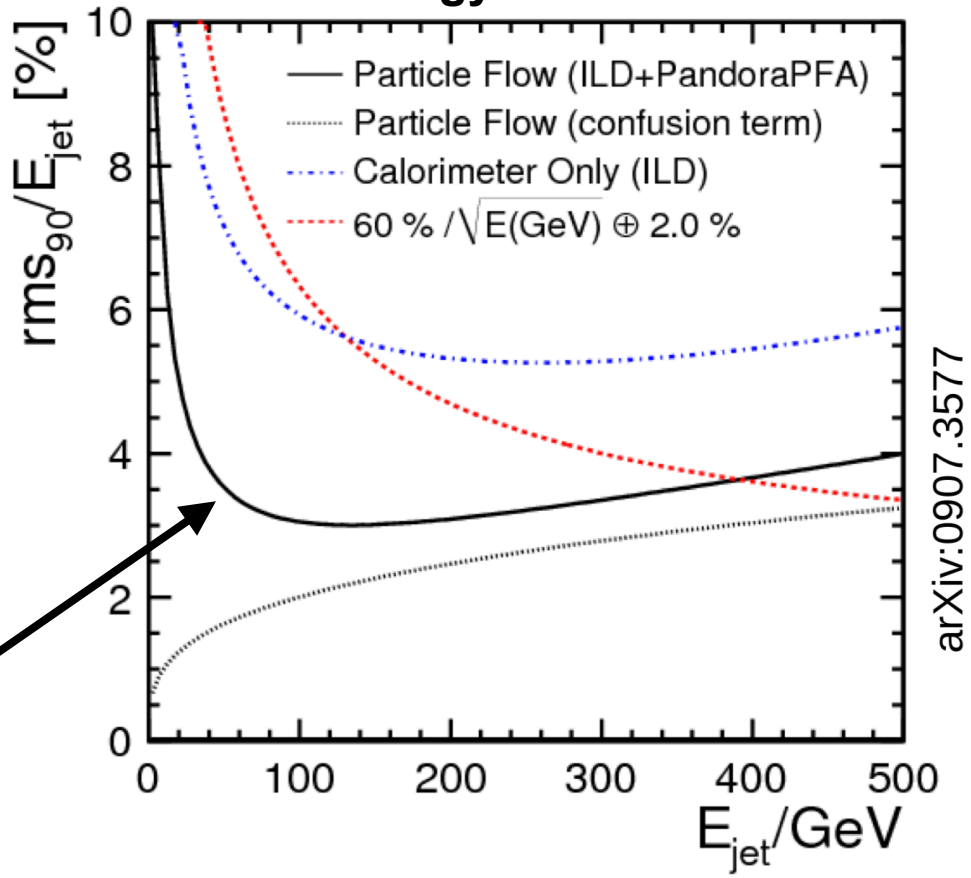
The Basics: Part I

The Particle Flow Approach



Do **this** to achieve **this…**

Jet Energy Resolution

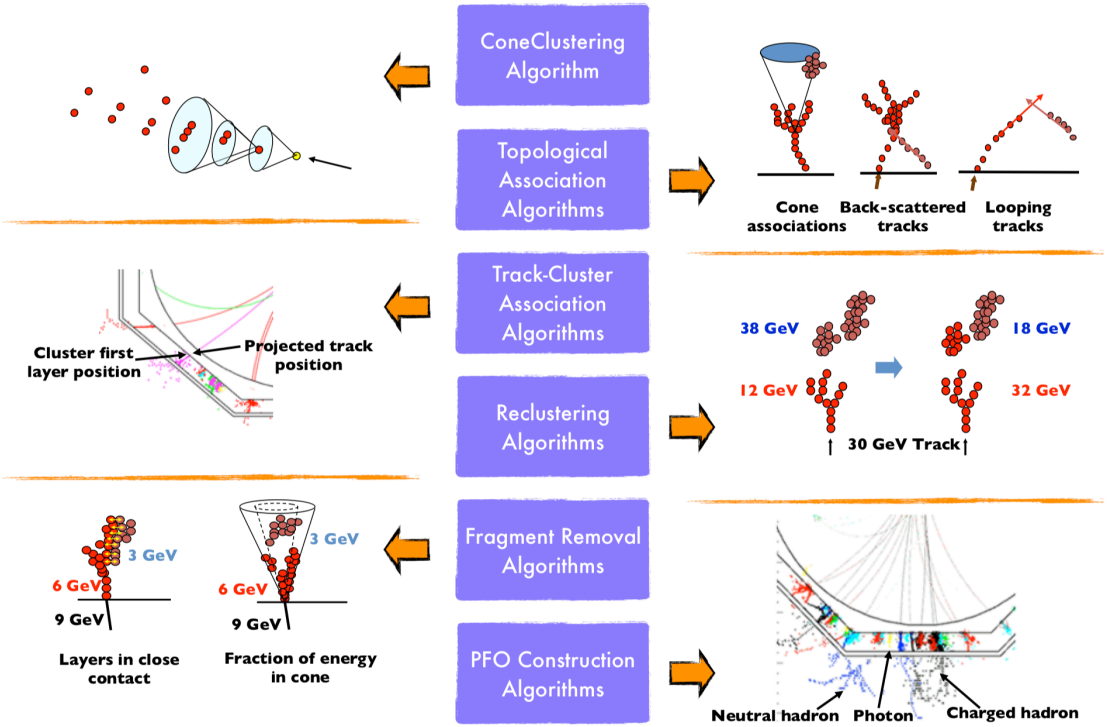


arXiv:0907.3577

Particle Flow and PandoraPFA

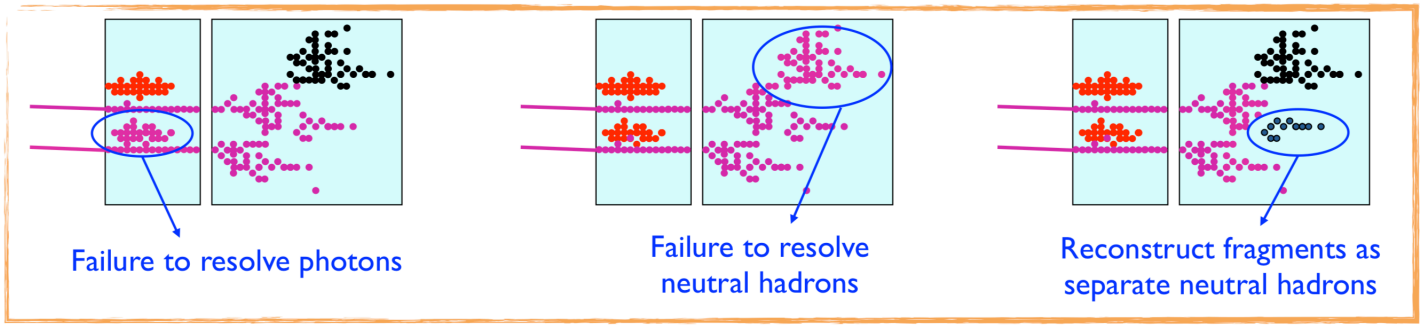
The Basics: Part II

The Magic of PandoraPFA



J. S. Marshall: https://indico.in2p3.fr/event/7691/contributions/42712/attachments/34375/42344/3_john_marshall_PFA_marshall_24.04.13.pdf

Types of confusion



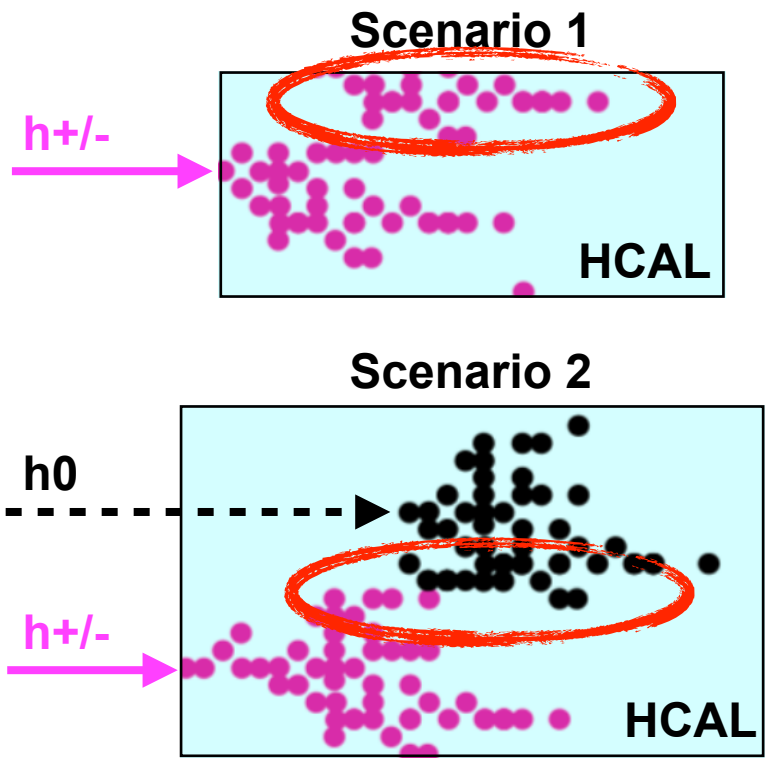
J. S. Marshall: https://indico.in2p3.fr/event/7691/contributions/42712/attachments/34375/42344/3_john_marshall_PFA_marshall_24.04.13.pdf

…with **this, but take care of that.**

Idea and Goals of Analysis

PandoraPFA on AHCAL 2018 Prototype Data

- **Scenario 1**: One charged hadron in event
  - ➡ Confusion: Fragment of charged hadron shower reconstructed as separate neutral hadron
- **Scenario 2**: Overlaid charged and neutral hadron event
  - ➡ Confusion: Failure to resolve neutral hadron; Neutral hadron hits fully or partly added to charged hadron cluster or the other way around



- **Goal**: **Run PandoraPFA on AHCAL 2018 prototype standalone data & MC (+ tracks for charged hadrons)**
  - ➡ Study of single and two particle reconstruction performance with regard to confusion
    - ➡ Different scenarios (energies, transversal separation, amount of leakage, etc.)

Overview

Pandora PFA Studies

AHCAL data & MC →

Unselected charged pion events

→ **Event preparation & selection (Shower start finding, PID,…) + adding of tracks**

Selected charged pion events

→ **Primary track removal and dedicated event overlay**

Selected events with overlaid charged and "neutral" hadron

↓ **Pandora PFA**

Scenario 1: Single particle reconstruction studies

↓ **Pandora PFA**

Scenario 2: Two-particle separation studies

Analysis inspired by first CALICE PFA Paper: https://arxiv.org/abs/1105.3417
&
Remi Ete's ArborPFA Studies on SDHCAL CAN: http://cds.cern.ch/record/2669487/files/fulltext.pdf

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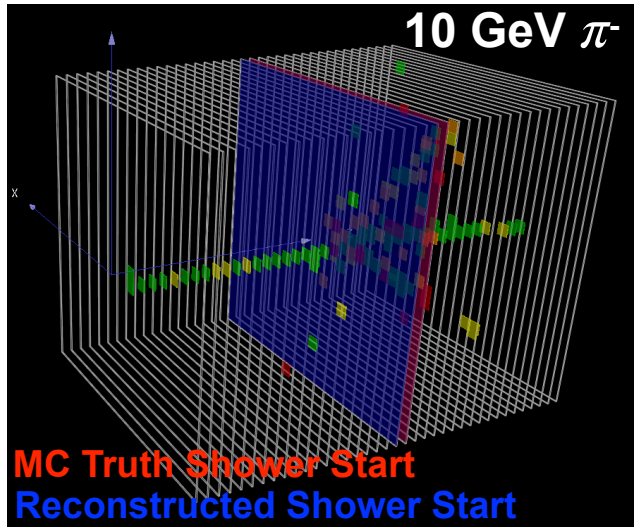
Sample Preparation & Selection Tools

Pre-Pandora Processors

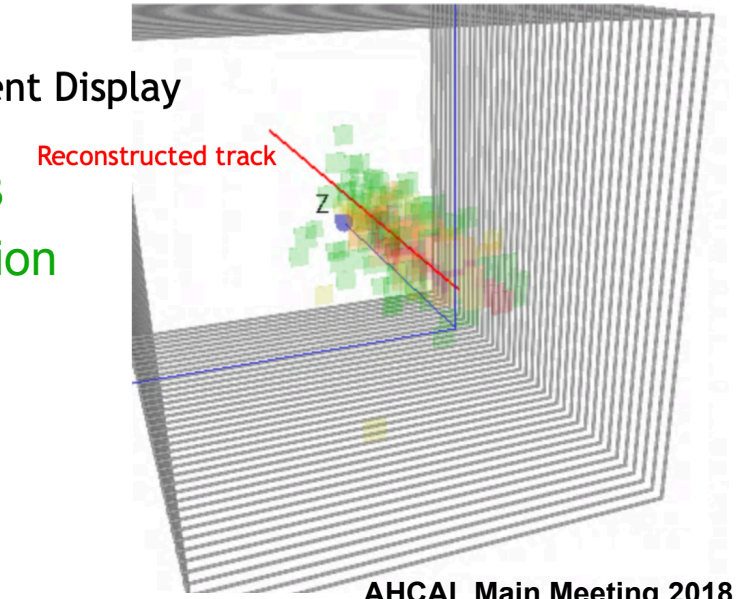
- Shower start finder: Implemented and optimised for 10-100 GeV hadrons
- PID: Very advanced ⟶ Talk by Vladimir Bocharnikov
- MIP to GeV calibration and conversion: Done for EM and HAD scale

- Primary track removal: Basically implemented, validation study to be done
- Event selection/filter: Implemented with simple selections on shower start, proper tracks, position, energy, hits, etc.
- Event overlay: Adapted from ILCsoft

- Data tracks from delayed wire chamber (DWC): Implemented for June18 TB
- Tracks for MC: Implemented as beam gun to calorimeter position extrapolation
  - ➡ Performed track validation study



Event Display

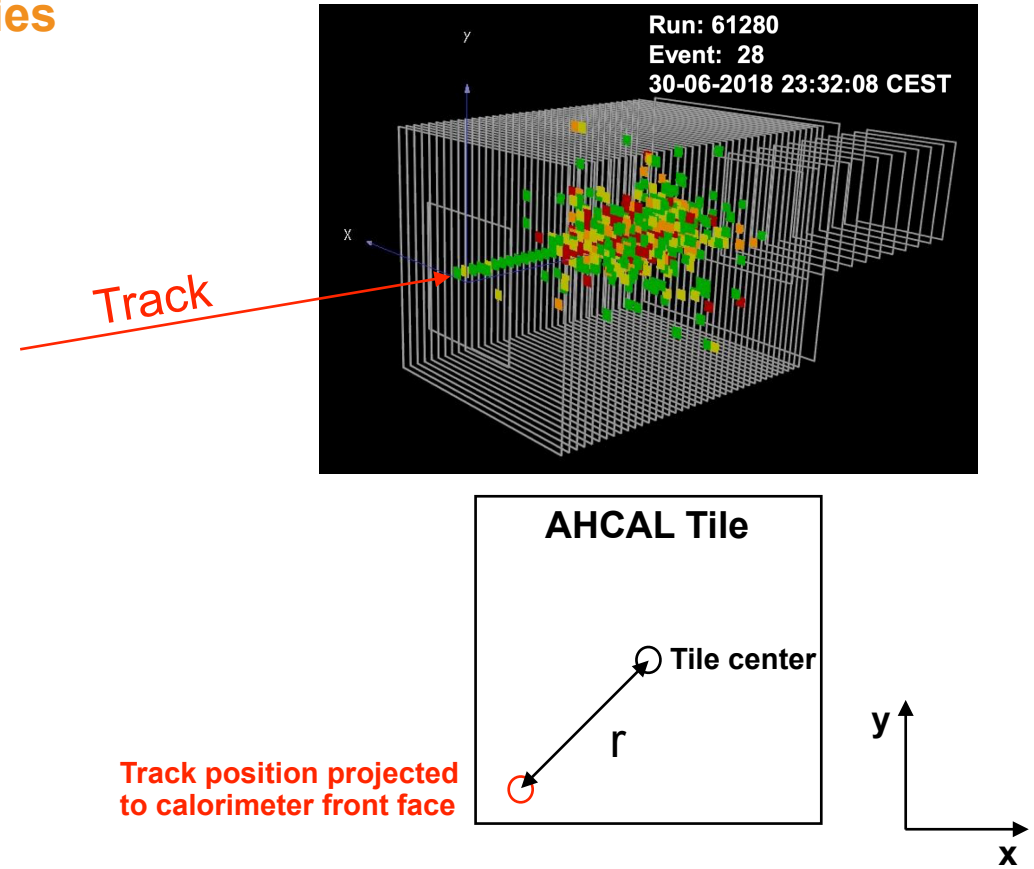


AHCAL Main Meeting 2018

Track Quality Check

Implemented MC and Data Tracks for PandoraPFA Studies

How well does track hit first tile of primary track in layer 1?



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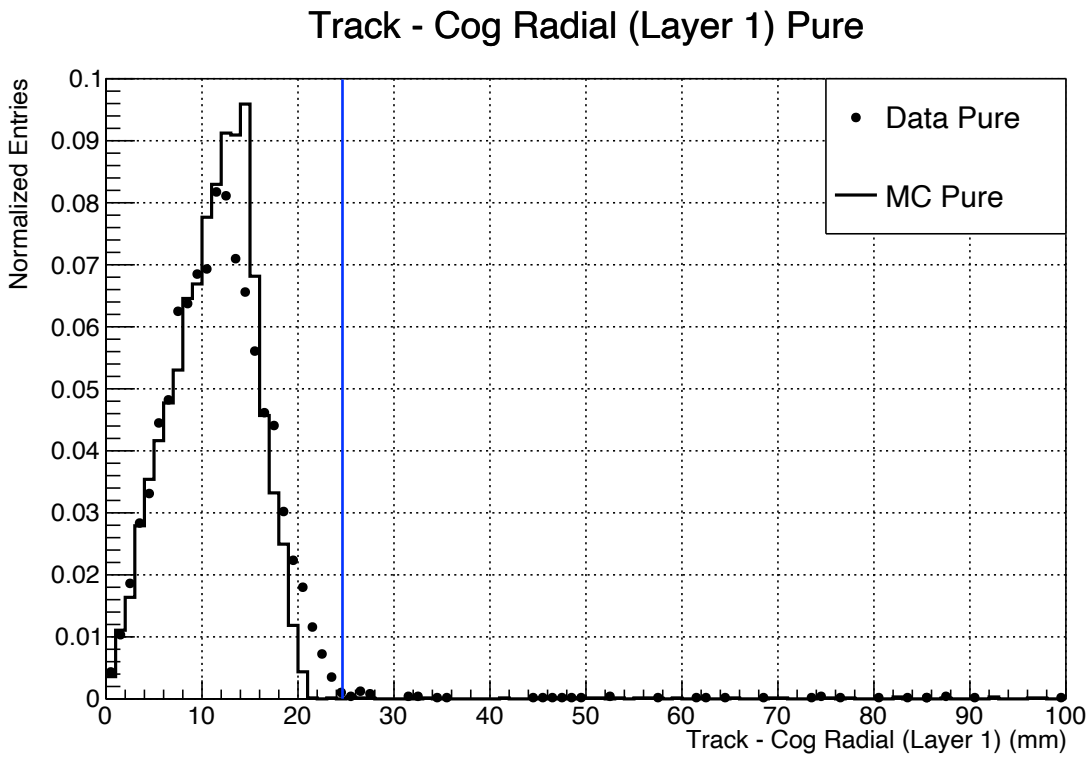
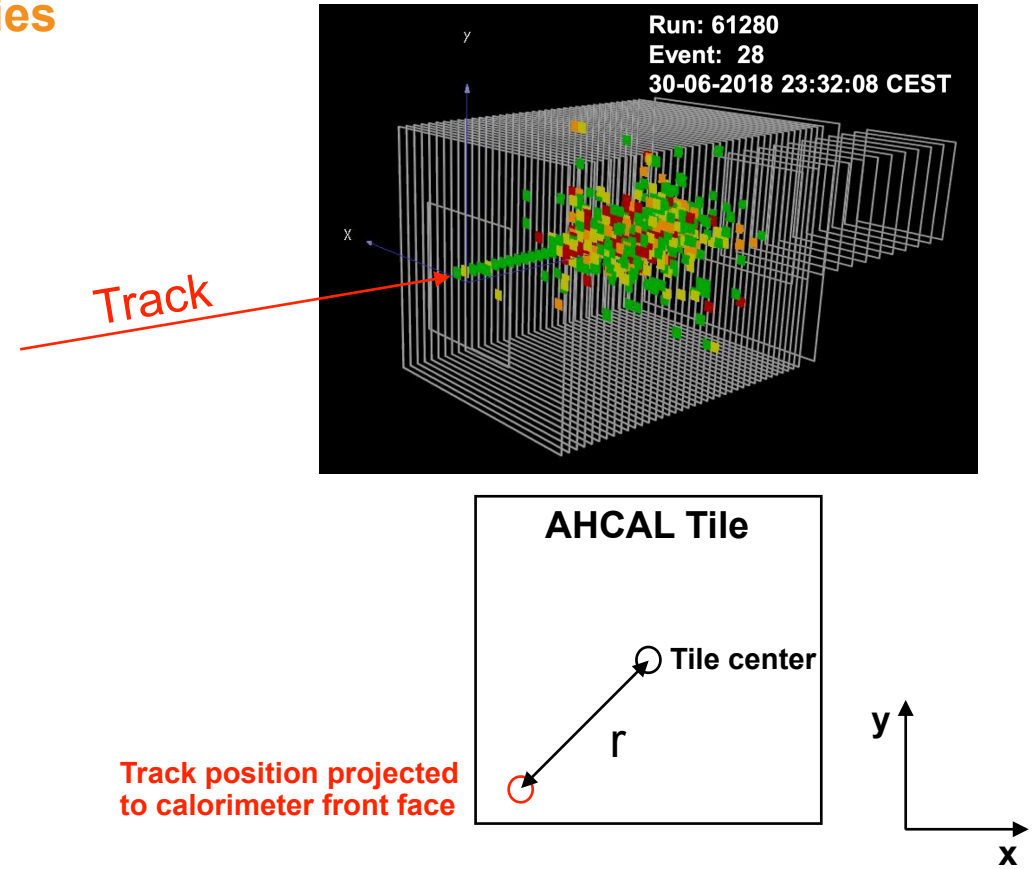


$$r = \sqrt{(x_{track} - x_{cog,layer1})^2 + (y_{track} - y_{cog,layer1})^2}$$

How well does track hit first tile of primary track in layer 1?



- Event selection for clean primary tracks: nHits == 1 in layer 1 (cog = hit position)
- Most of the tracks hit first tile of primary track in layer 1:
  - ➡ 98.7% (data) and 99.5% (MC) of events within 22 mm radius (tile center - tile corner distance)

Overview

Pandora PFA Studies

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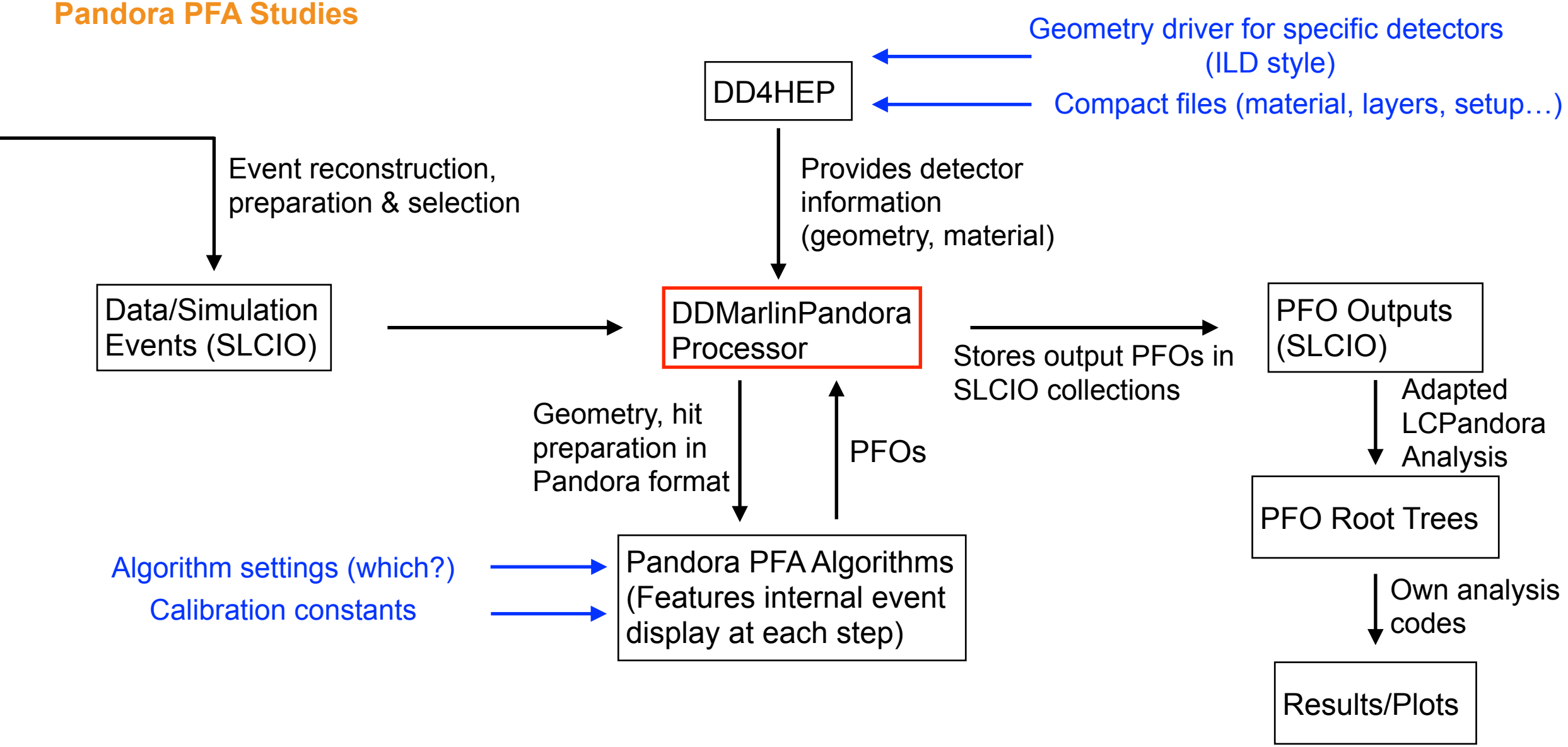
Framework / Data Flow Diagram

Pandora PFA Studies



Setting up the PandoraPFA Framework - Technical Status

For the AHCAL 2018 Prototype Studies

1. Adapt DD4HEP geometry driver and compact files (4π detector style) ✓
2. Adapt DDMarlinPandora interface processor ✓
   - Main processor, geometry creator, hit creator, track creator, PFO creator,…
3. Adapt steering files for AHCAL standalone scenario ✓
   - ➡ Pandora visual monitoring: Geometry and data is read in correctly?
4. Enable basic algorithms step-by-step and check for dependencies and limits ✓
   - ECAL, tracks, detector gaps, pseudo layer & b-field plugin

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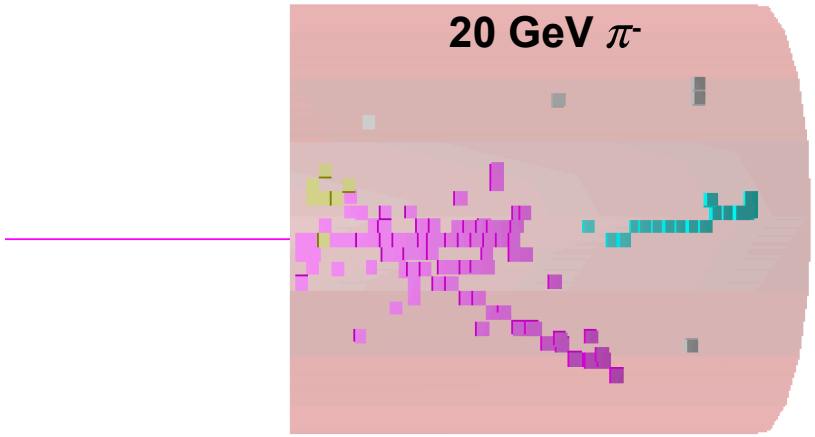
4. Enable basic algorithms step-by-step and check for dependencies and limits ✓
   - ECAL, tracks, detector gaps, pseudo layer & b-field plugin ✓
5. Check PFO outputs and set up analysis processor/plots ✓
6. Internal Pandora calibration ✓
7. Check available plugins (software compensation, energy correction, PID, etc.) ✓

Pandora Visual Monitoring

Hits, Clusters & PFOs

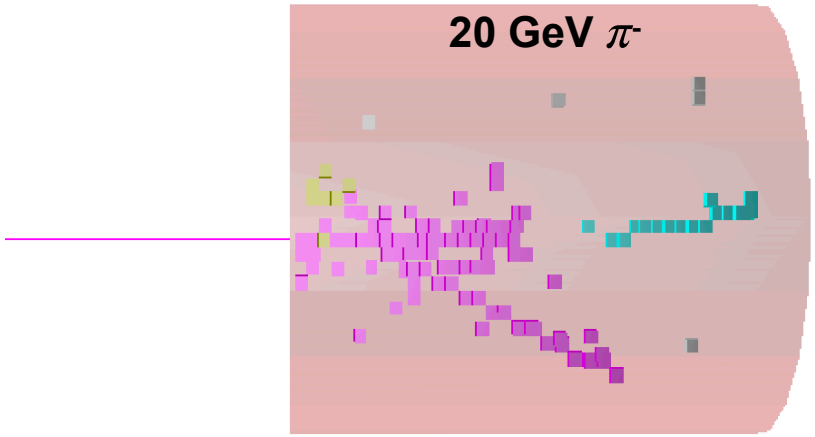


Magenta: Charged Hadron
Cyan: Neutral Hadron
Yellow: Photon
Grey: Unclustered Hits

- Existing HCAL-Endcap class used for our setup
- Pandora visual monitoring working fine displaying hits, clusters, tracks and PFOs at different reconstruction steps
  - ➡ Great tool to precisely track down technical problems and problematic events

Pandora Visual Monitoring

Hits, Clusters & PFOs



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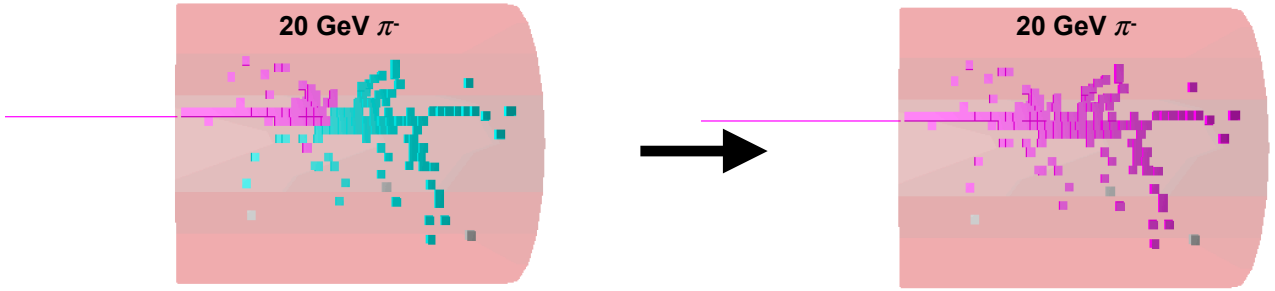
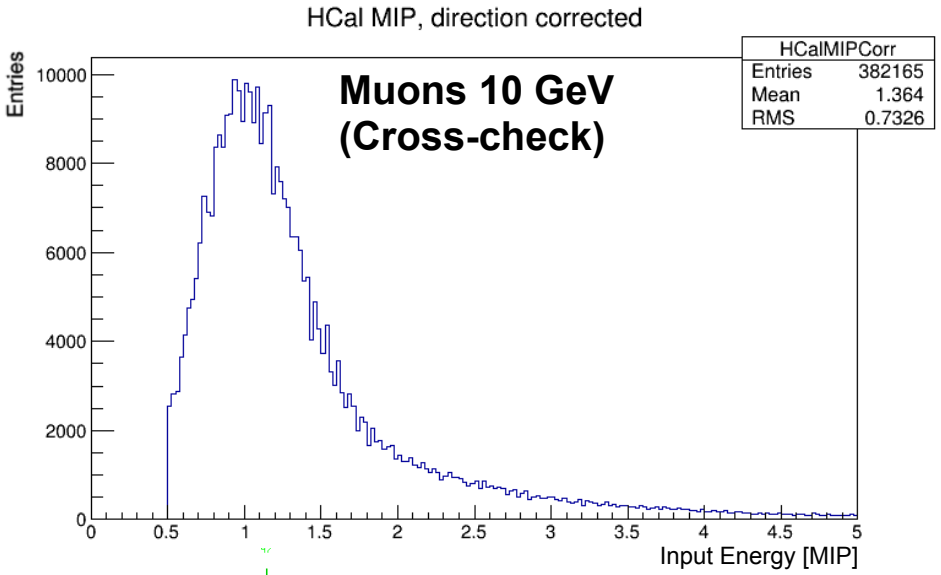
Solved: Non working Track-Cluster association for few events

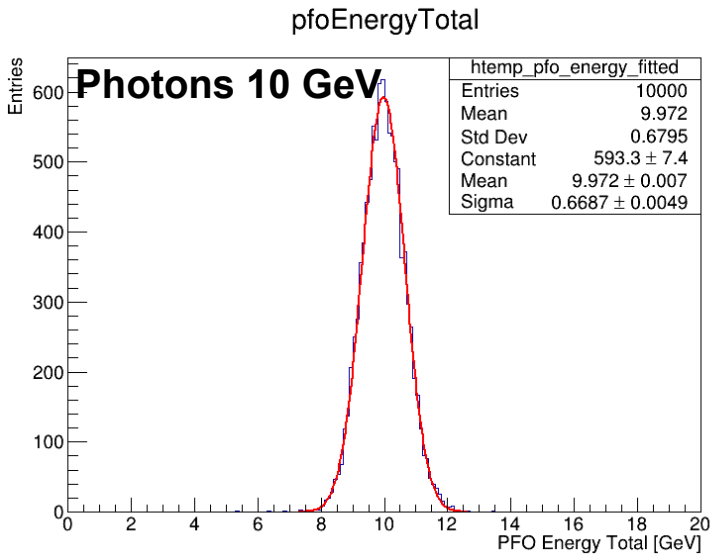


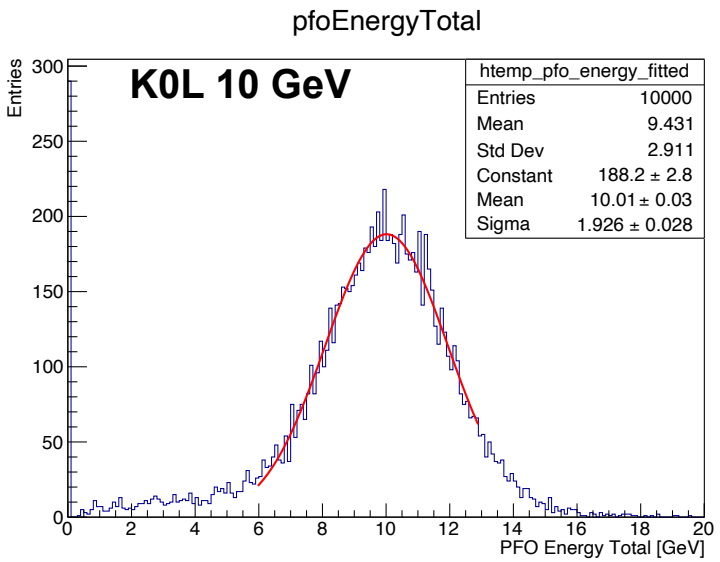
Pandora Energy Calibration

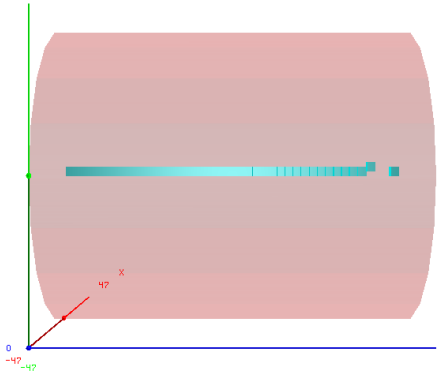
MC Muons, Photons, K0L

Following instructions in PandoraPFACalibrator.h

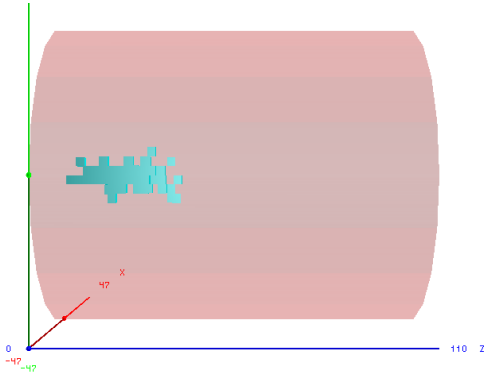


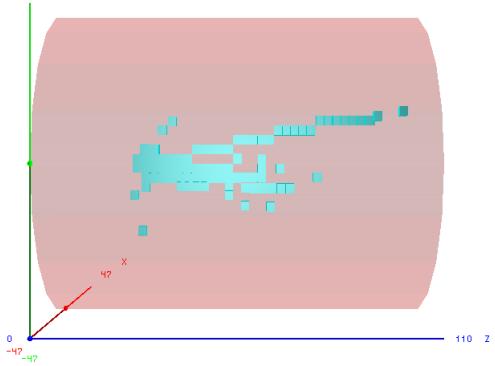






Without tracks and ECAL everything classified as neutral hadrons





- **Muons**: AHCAL energy GeV -> MIP with negligible angle correction since straight TB tracks
- **Photons and K0L's**: Used to determine EM and HAD response, PFO energy tuned to peak at 10 GeV

Pandora Basic Energy Calibration Results

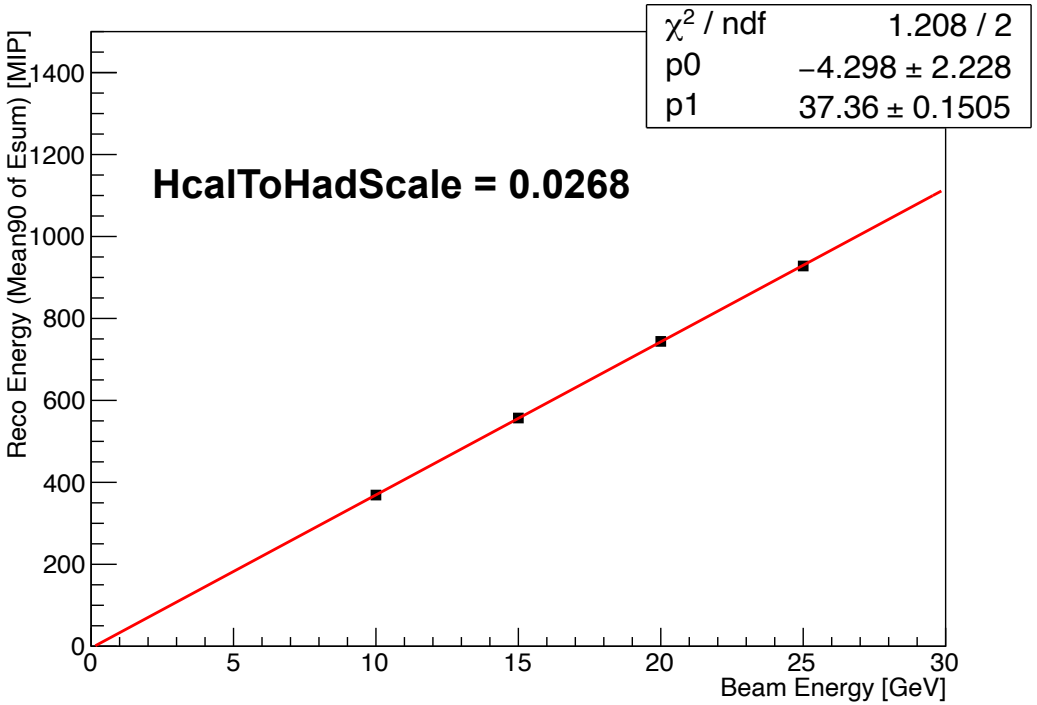
EM and HAD Responses (MC)

```
<constant name="PandoraHcalToMip">37.36</constant>

<constant name="PandoraHcalToEMScale">1.005</constant>
<constant name="PandoraHcalToHadScale">1.03</constant>
```

- Both factors a bit higher than for raw AHCAL response (=1.0)
  - ➡ Pandora clustering isolation cuts

Simple HAD Response Determination (K0L)



PandoraPFA on Single Particles

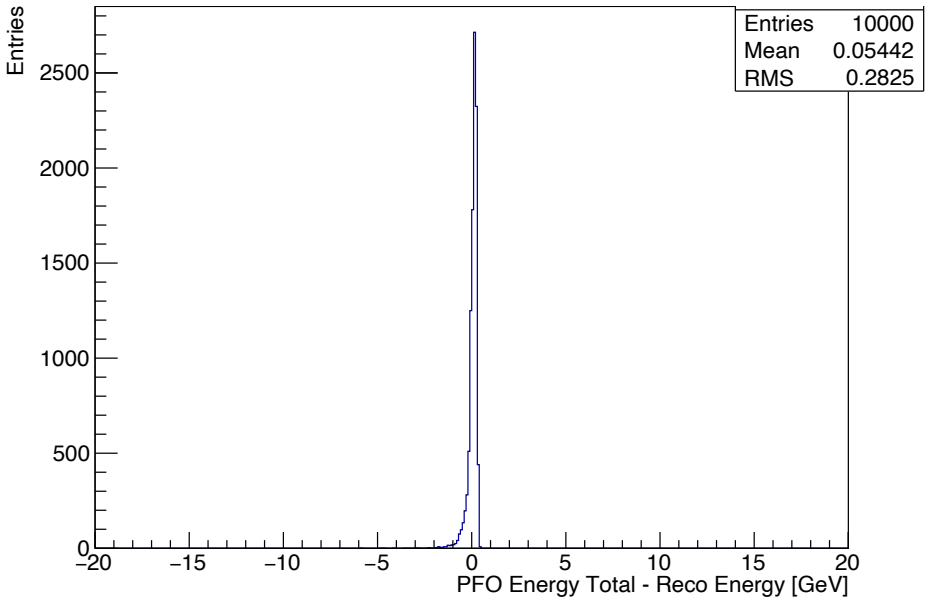
(10 GeV K0L MC - Basic Checks)

Basic Check: K0L 10 GeV (MC)

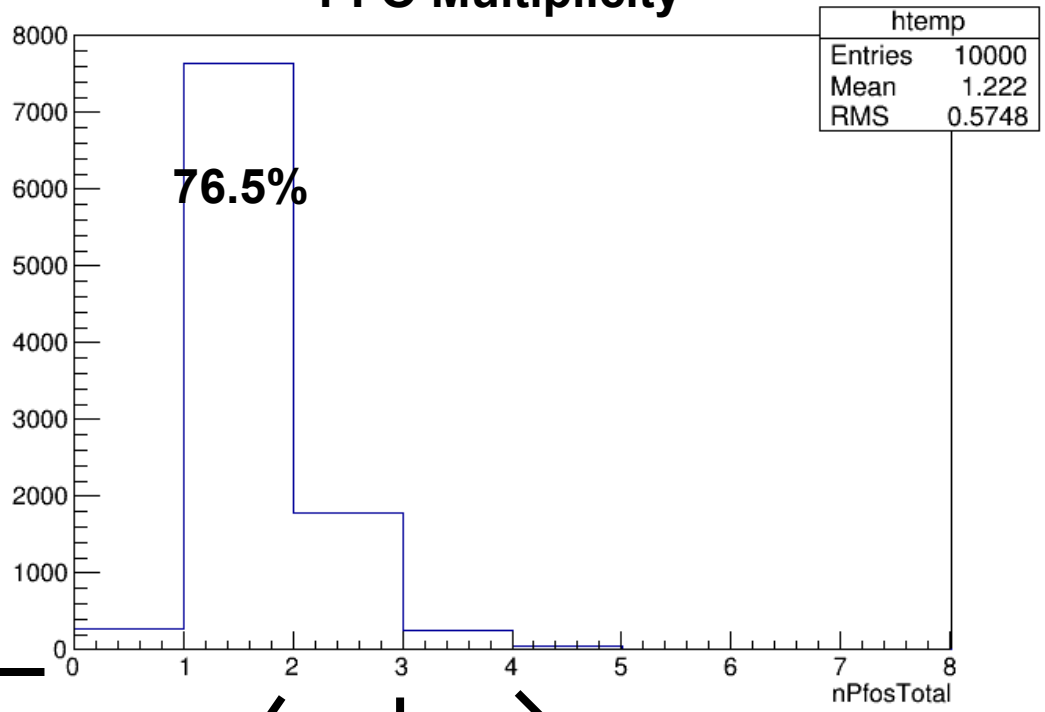
Energy and PFO Multiplicity

- Goal: Get a feeling for initial clustering without any track related algorithms running

PFO Esum - AHCAL Esum (HAD)



PFO Multiplicity



- Fairly good agreement between AHCAL and Pandora reconstruction as expected

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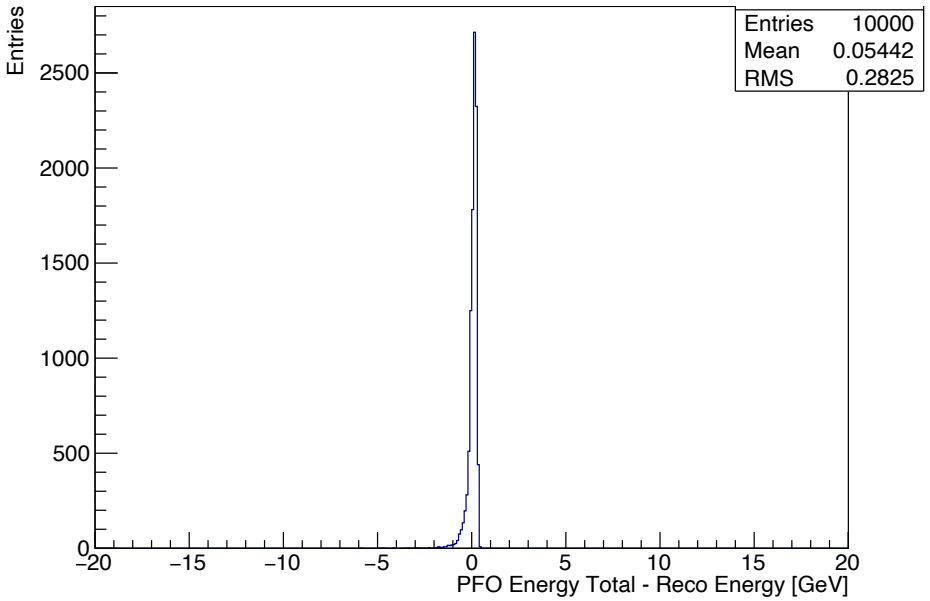

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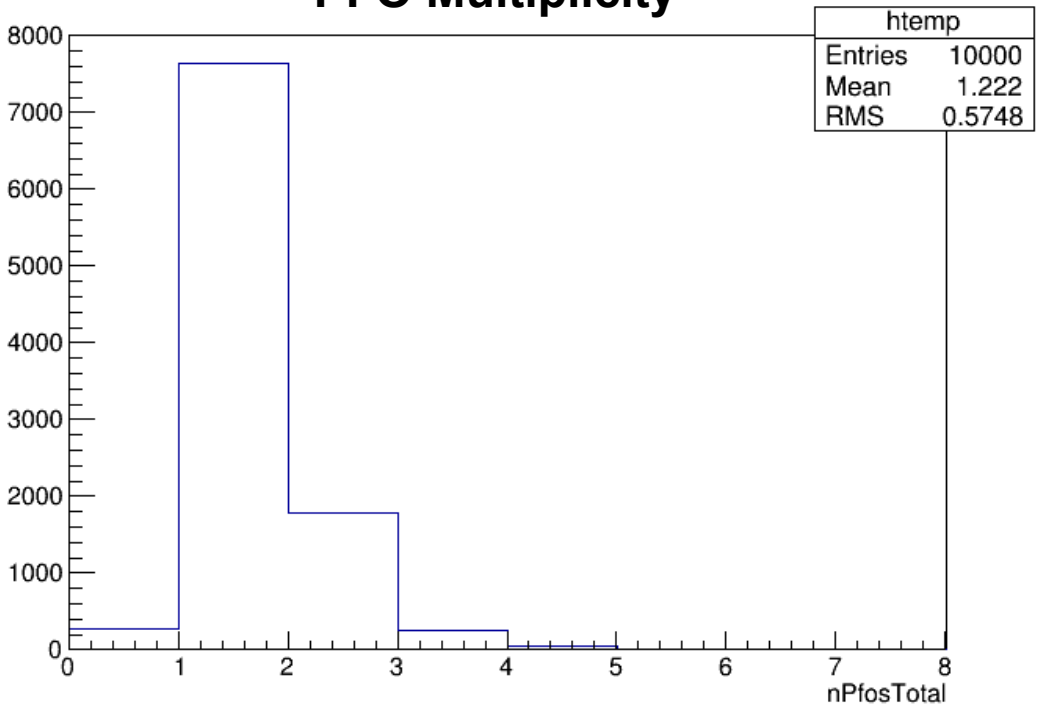
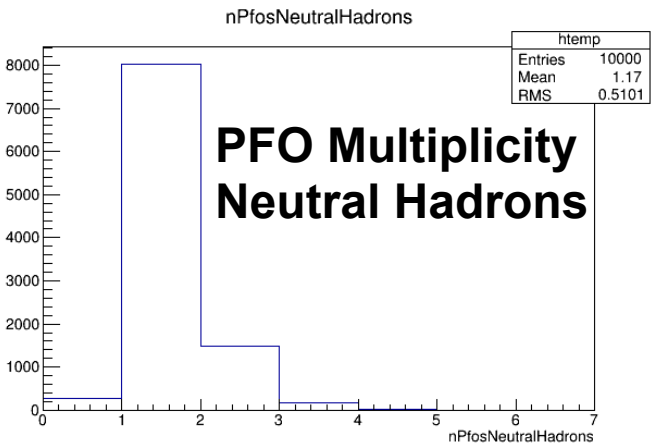
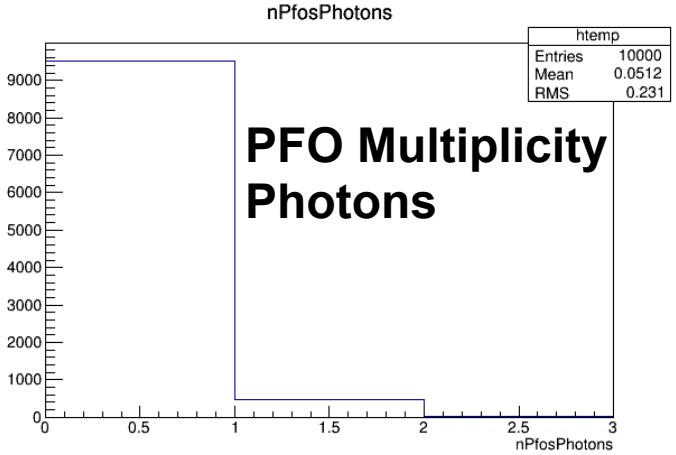




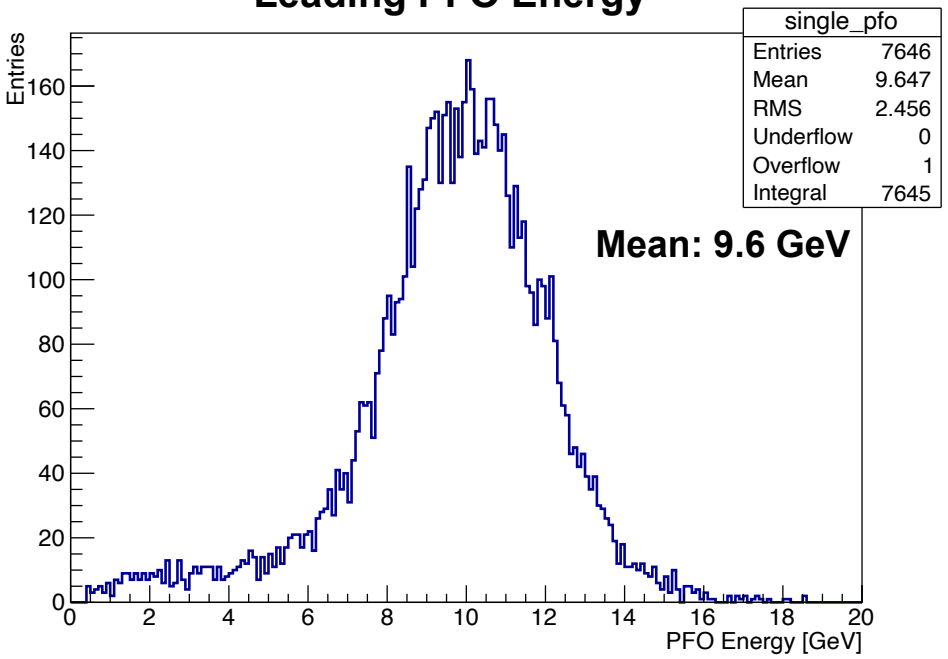


➡ Few photons as additional PFO, but mostly neutral hadrons!

Basic Check: K0L 10 GeV (MC)

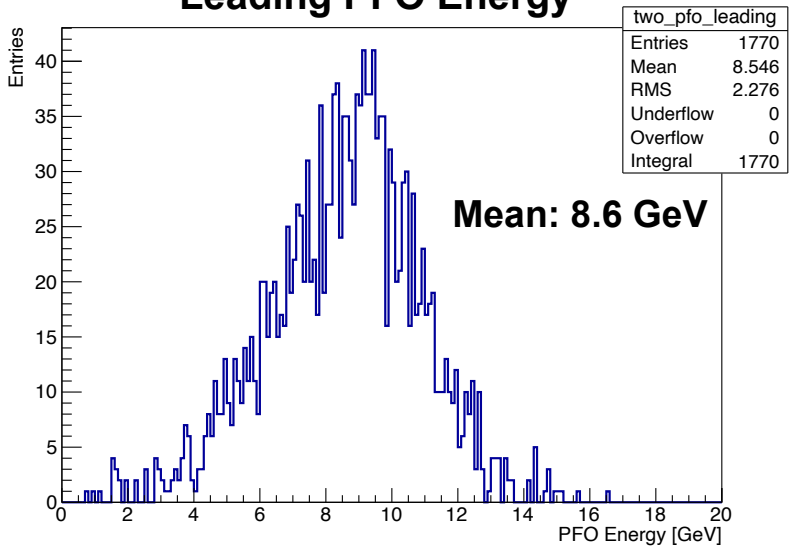
Clustering

Single PFO Events
Leading PFO Energy

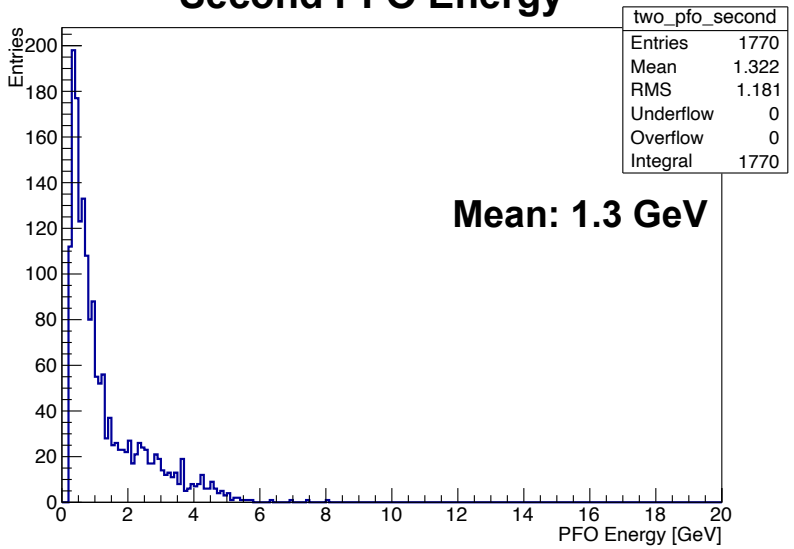


- If multiple PFOs: Leading PFO with most energy of event and lower energy PFOs with on average ~10-20% energy of event

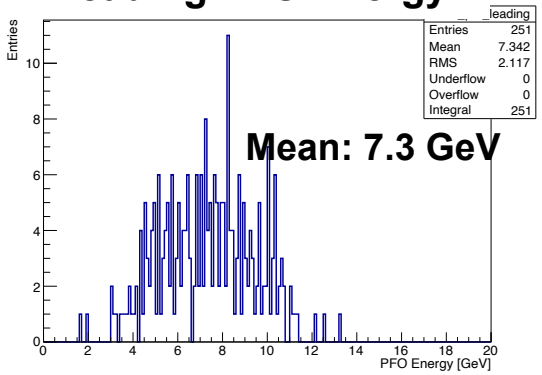
Two PFO Events
Leading PFO Energy



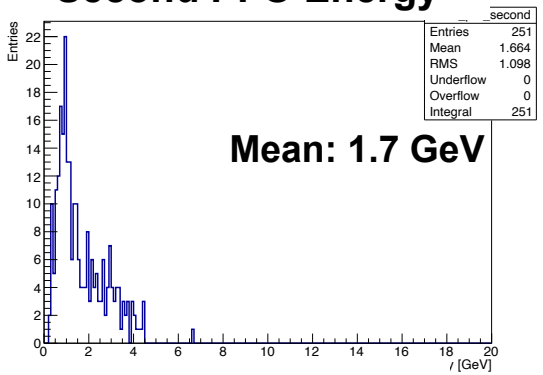
Second PFO Energy



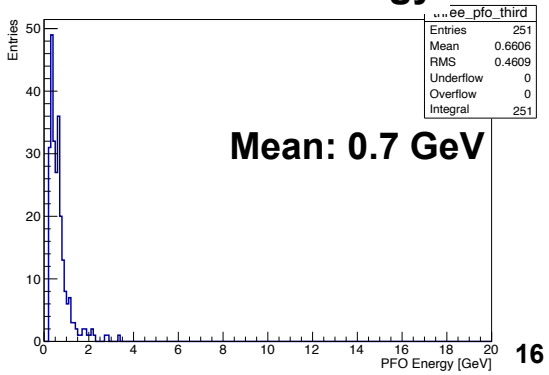
Three PFO Events
Leading PFO Energy



Second PFO Energy



Third PFO Energy



PandoraPFA on Single Particles

(20 GeV Pions - Work in Progress)

Data & MC Pion Samples

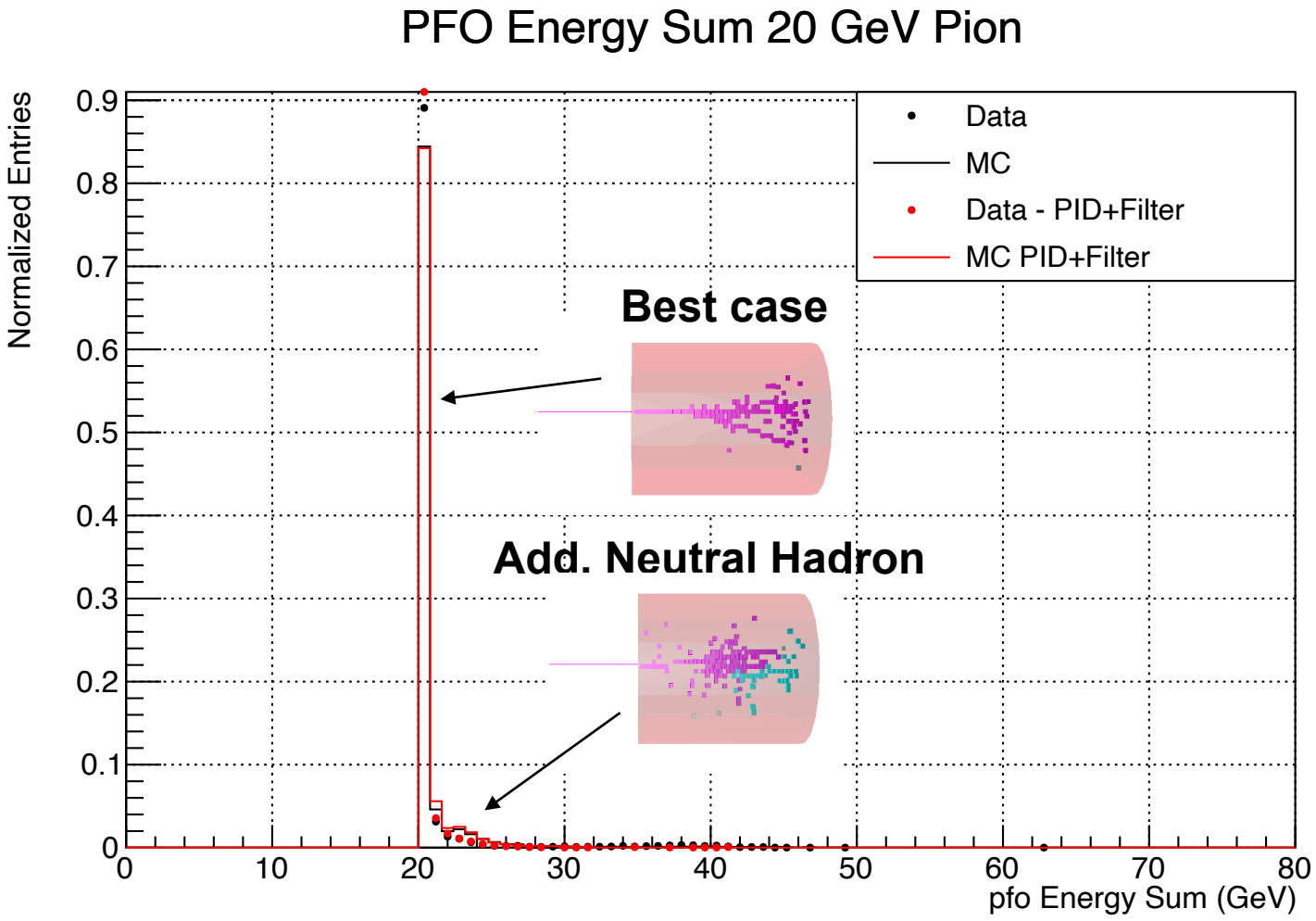
Pandora Single Particle Reconstruction

- Samples: **10k pions** events for **20 GeV** simulated **(QGSP_BERT_HP)** and from **June TB SPS 2018**
  - ➡ Approximately same beam position
  - ➡ Reconstructed in **GeV** with simple MC determined hadronic MIP2GeV factor **(0.0268)**
  - ➡ For data and MC: Fixed **track momentum of 20 GeV**
  - ➡ For data: Pre-selection of events with a **single track** (no missing or double track events)
- Applied Vladimirs PID for hadrons (default cuts of cut based method)
- Applied simple event filter: At least one hit in layer 1+2+3, shower start layer < 20, E(calo,max) = 28 GeV

Pion Samples (10k each)	Single Track Requirement (Pure)	PID + Filter
Data - 20 GeV (Run61270)	7383	4522
MC - 20 GeV	10000	7057

PFO Energy Sum Total

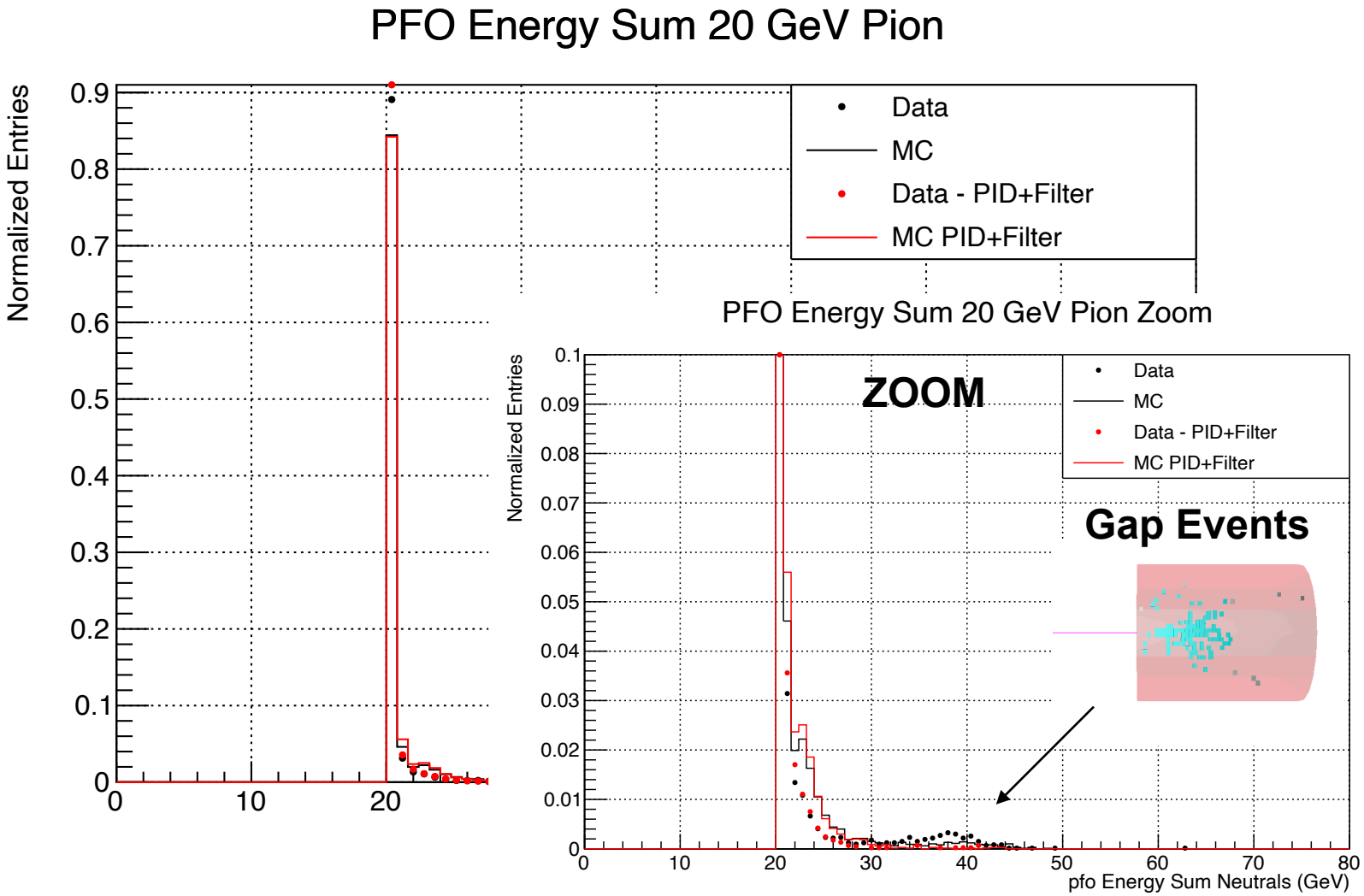
20 GeV Pions Data & MC



- Most events proper track-cluster assignment: 20 GeV
- Tail to higher energies: Events with identified additional neutral hadron cluster
- For data Pandora seems to perform slightly better

PFO Energy Sum Total

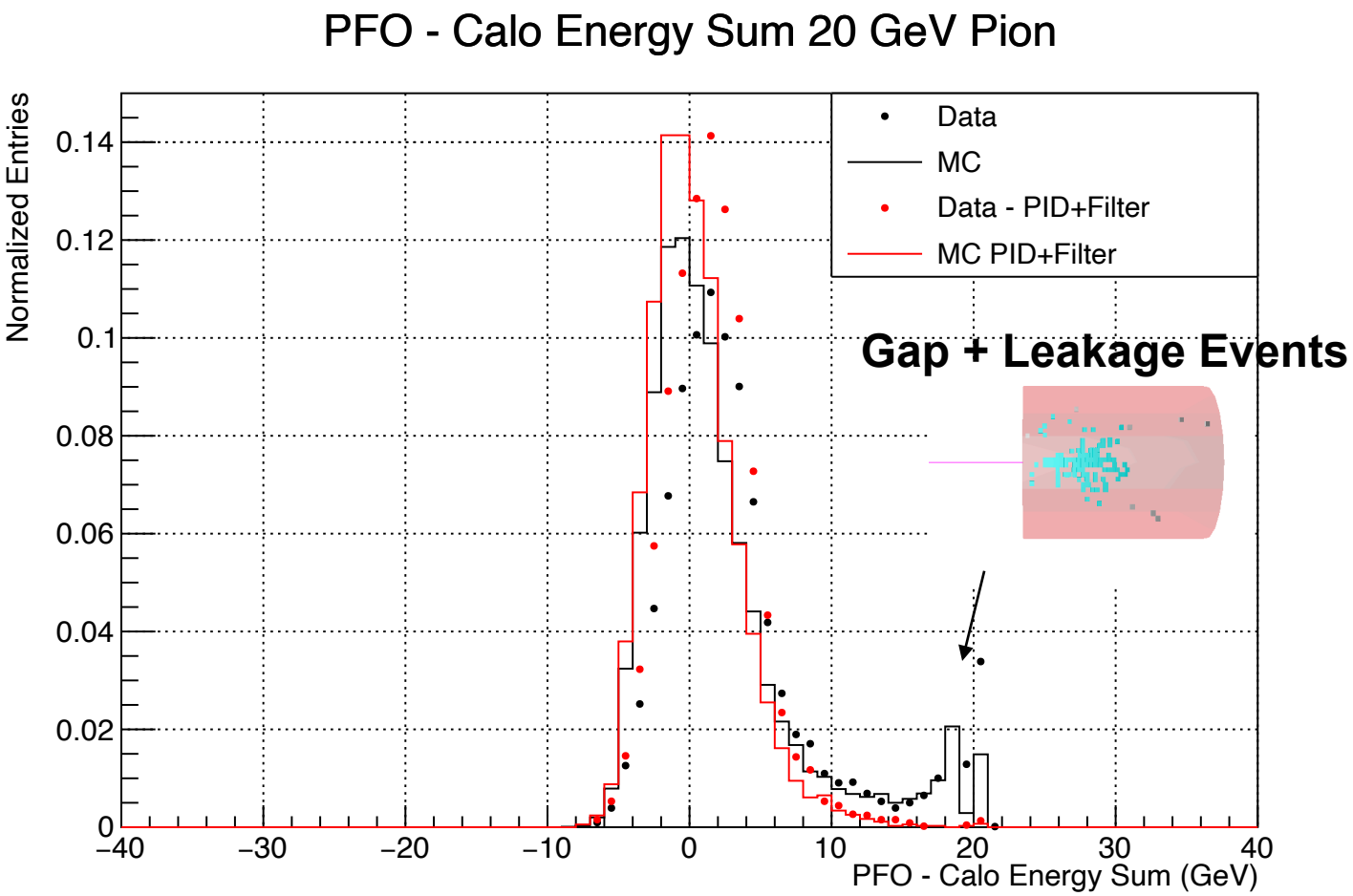
20 GeV Pions Data & MC



- Most events proper track-cluster assignment: 20 GeV
- Tail to higher energies: Events with identified additional neutral hadron cluster
- For data Pandora seems to perform slightly better
- PID+Filter helps to remove most of problematic (gap) events

PFO Energy Sum - Calorimeter Energy Sum Total

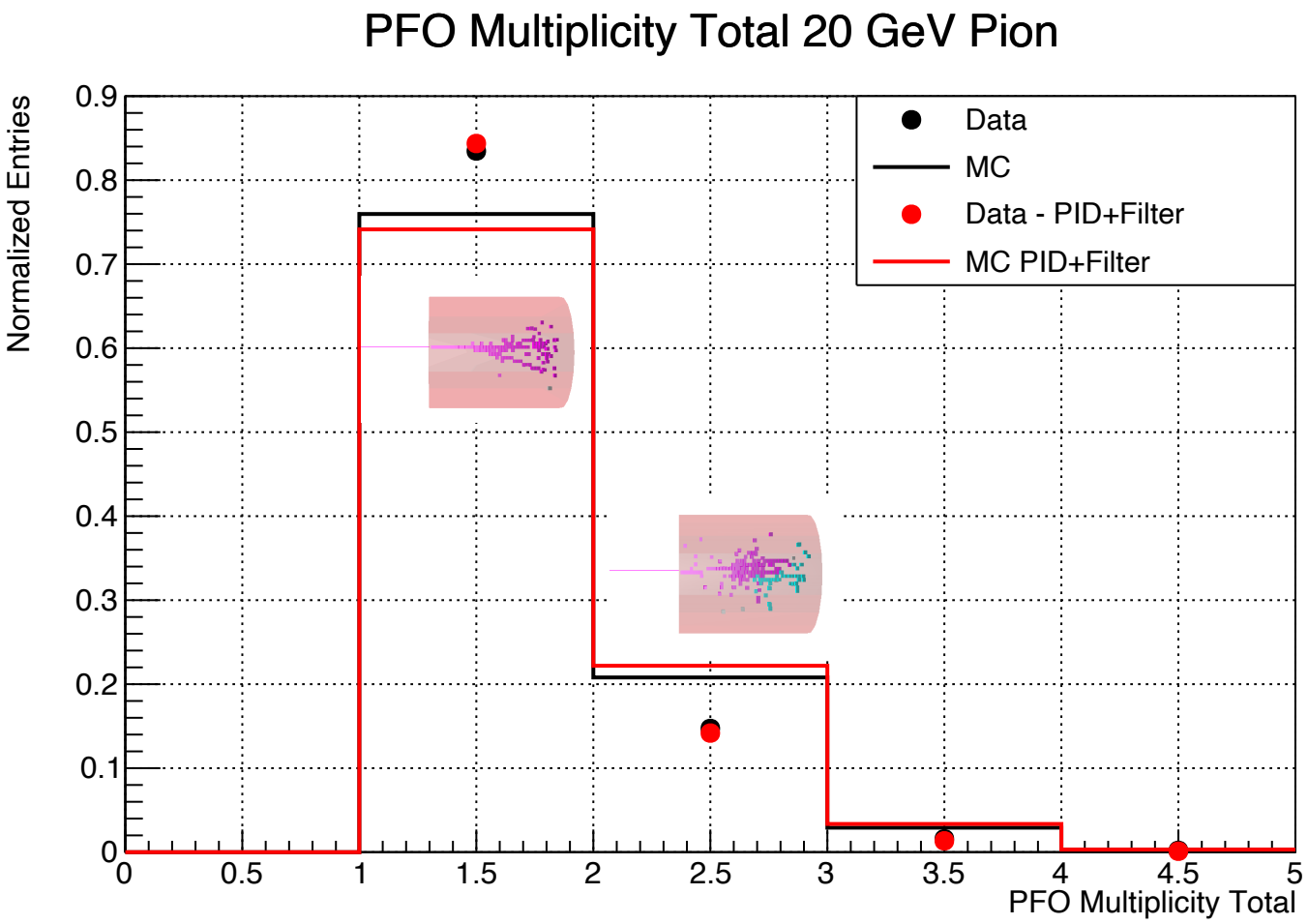
20 GeV Pions Data & MC



- Most events around 0 GeV: Good reconstruction case
- Offset for data due to MC MIP2GeV calibration and constant track momentum
- PID+Filter removes most of gap and leakage events and therefore raising fractional part of good events

PFO Multiplicity Total

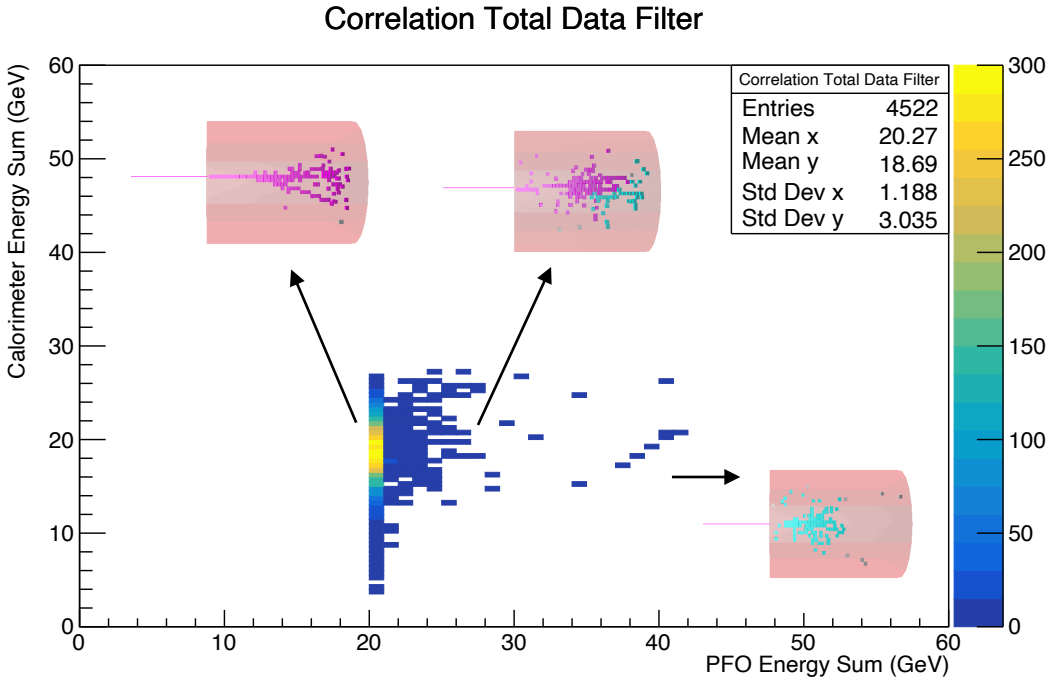
20 GeV Pions Data & MC

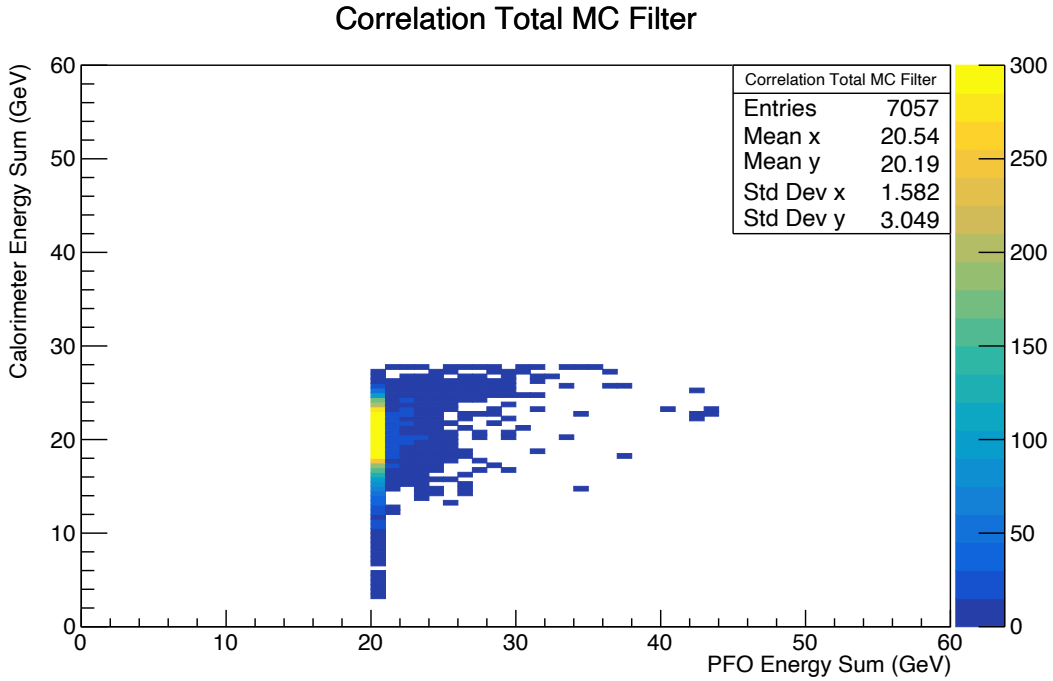


- In general: Pandora reconstructions seems to perform better on data
  - ➡ Less additional neutral PFOs in events
  - ➡ Remaining electron contamination in data?
- Pure to PID+Filter difference for MC
  - ➡ To be investigated, filter?

PFO Energy to Calo Energy Sum Correlation

20 GeV Pions Data & MC Filtered





- Three classified areas: Perfect reconstruction, „cloud" region, right diagonal „gap events“
- MC seems to have some larger "cloud" between 20-30 GeV
  - ➡ Higher neutral PFO multiplicity
  - ➡ Careful: MC more events!

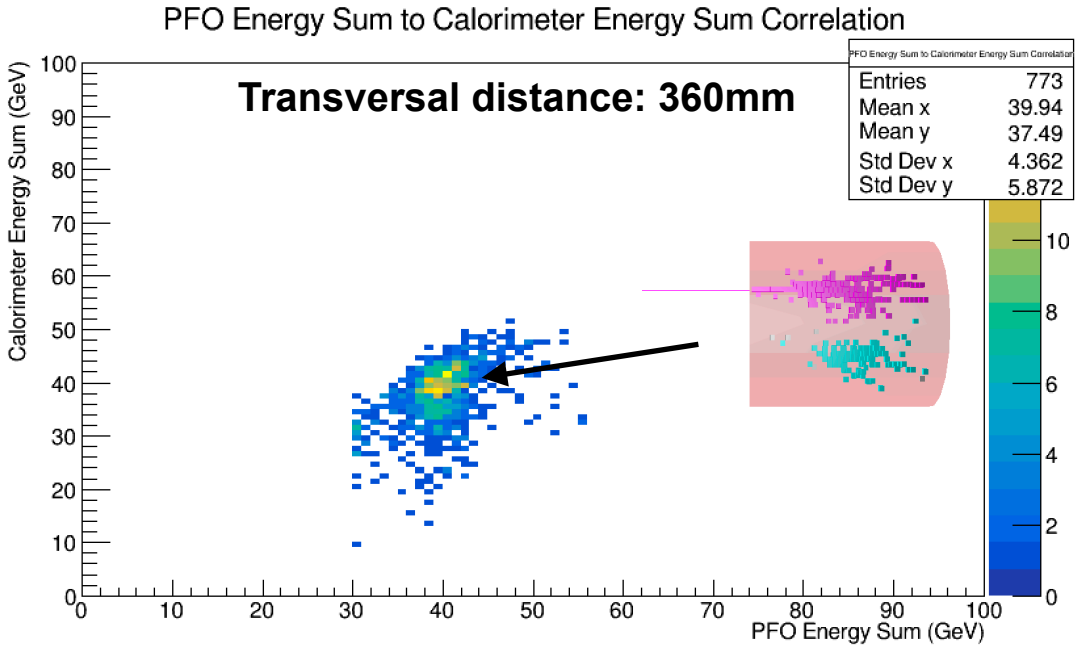
PandoraPFA on Double Particles

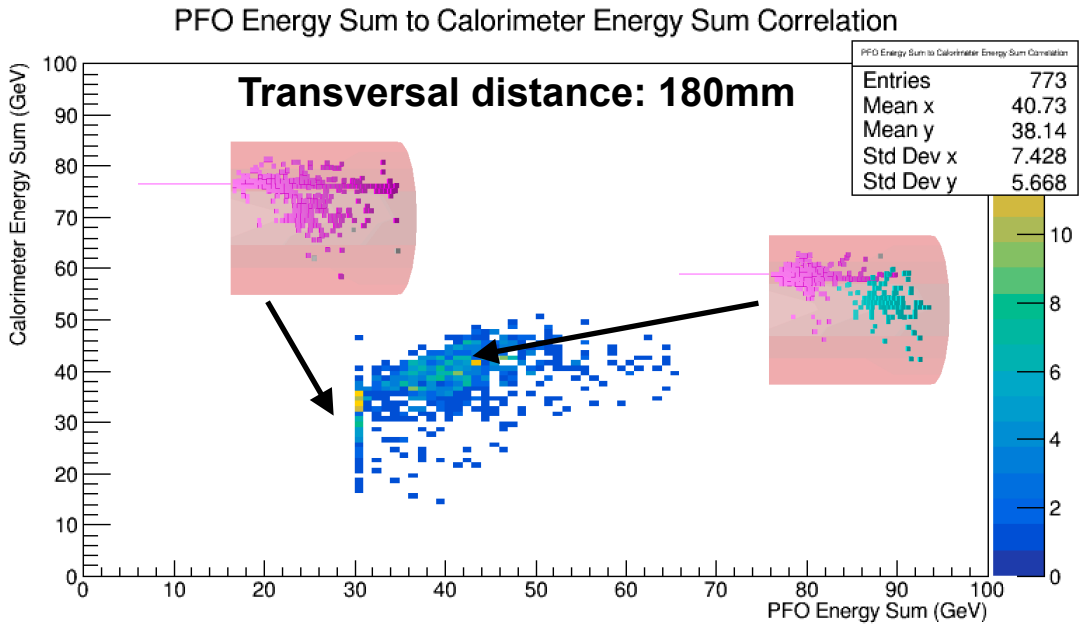
(Pions + K0L MC - First Look)

PFO Energy to Calo Energy Sum Correlation: Two Particles

30 GeV Pions + 10 GeV K0L, MC Filtered

- Same PID and filter applied on pions as for single particle scenario





First Look:

- Far scenario: Most events reconstructed properly with well separated charged and neutral hadron (40 GeV cloud)
- Closer scenario: Broader cloud around good reconstruction area and more events at PFO Energy Sum = 30 GeV (Neutral hadron hits assigned to charged cluster completely)

Summary

- Well working PandoraPFA environment for MC and data reconstruction of AHCAL standalone scenario + tracks
- Far advanced sample preparation and well working event selection tools
- First more quantitative look into PandoraPFA single & double particle reconstruction:
  - ➡ First impression: General trends as expected
  - ➡ Observed MC to data difference to be checked and validated

Outlook

- Only few last remaining technical checks (e.g. gap implementation)
- "Artificial" neutral hadron validation study
- Detailed quantitative studies of data vs. MC (single & double particle reconstruction)
  - ➡ With tuned beam profiles (Olin Pinto) and latest BDT PID (Vladimir Bocharnikov)
- Leakage correction plugin in PandoraPFA

Summary

- Well working PandoraPFA environment for MC and data reconstruction of AHCAL standalone scenario + tracks
- Far advanced sample preparation and well working event selection tools
- First more quantitative look into PandoraPFA single & double particle reconstruction:
  - ➡ First impression: General trends as expected
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Thank you!

What will be inside of Pandora's box?

Outlook

- Only few last remaining technical checks (e.g. gap implementation)
- "Artificial" neutral hadron validation study
- Detailed quantitative studies of data vs. MC (single & double particle reconstruction)
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Backup

Geometry Driver - DD4HEP - ILD "Style"

For the 38 Layer AHCAL Prototype - SPS May Test Beam

- Uses the **HCALEndcap class** already implemented in DD4HEP/DDMarlinPandora
  - ➡ Better choice than HCALBarrel…
- In contrast to our „standalone“ DD4HEP driver implementation for our simulation:
  - ➡ Needs caloData and caloLayer classes defined
  - ➡ Additional information on symmetries, gaps, radii, etc…
  - ➡ Inner and outer λ and X0 + specific distances

dumpdetector output

```
##############################################################################
 detector model : AHCALDetector_May18
    title : AHCALDetector_May18
    author : Huong Lan Tran
    status : development
  barrel trackers :
  endcap trackers :
  vertex barrel trackers :
  vertex endcap trackers :
  barrel calorimeters :
  endcap calorimeters : HcalEndcap,
  other detecors :
---------------------------- HcalEndcap ----------------------------
------     DetType( 0x100a) : CALORIMETER, ENDCAP, HADRONIC,
-- LayeredCalorimeterData :
LayoutType : EndcapLayout
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outer_symmetry : 0
inner_symmetry : 0
outer_phi0 : 0.000000e+00
inner_phi0 : 0.000000e+00
gap1 : 0.000000e+00
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---------------------------- world ----------------------------
```

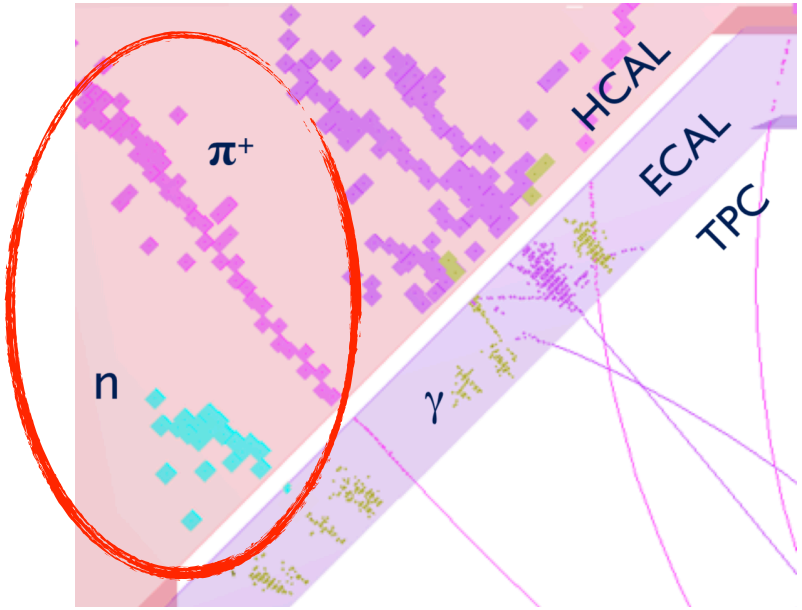
Pandora Calibration

Overview

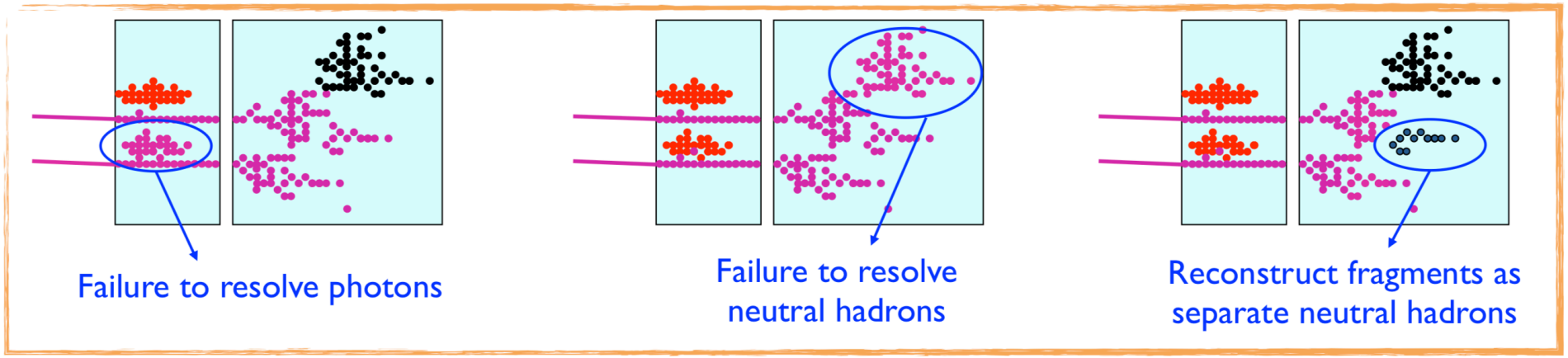
Instruction within Pandora Calibration Processor

```
PandoraPFACalibrator is a processor to aid calibration of PandoraPFA.
<pre>
There are three sets of constants that need to be calibrated:
  i) CaloDigi raw hit to GeV
 ii) PandoraPFA energy in GeV -> MIP equivalent conversion
iii) PandoraPFA MIP equivalent -> PFO energy
One might expect that factor iii) is the reciprocal of factor ii). However,
due to the isolation cuts used in PandoraPFA this is not quite the case.
```

J. S. Marshall: https://indico.in2p3.fr/event/7691/contributions/42712/attachments/34375/42344/3_john_marshall_PFA_marshall_24.04.13.pdf

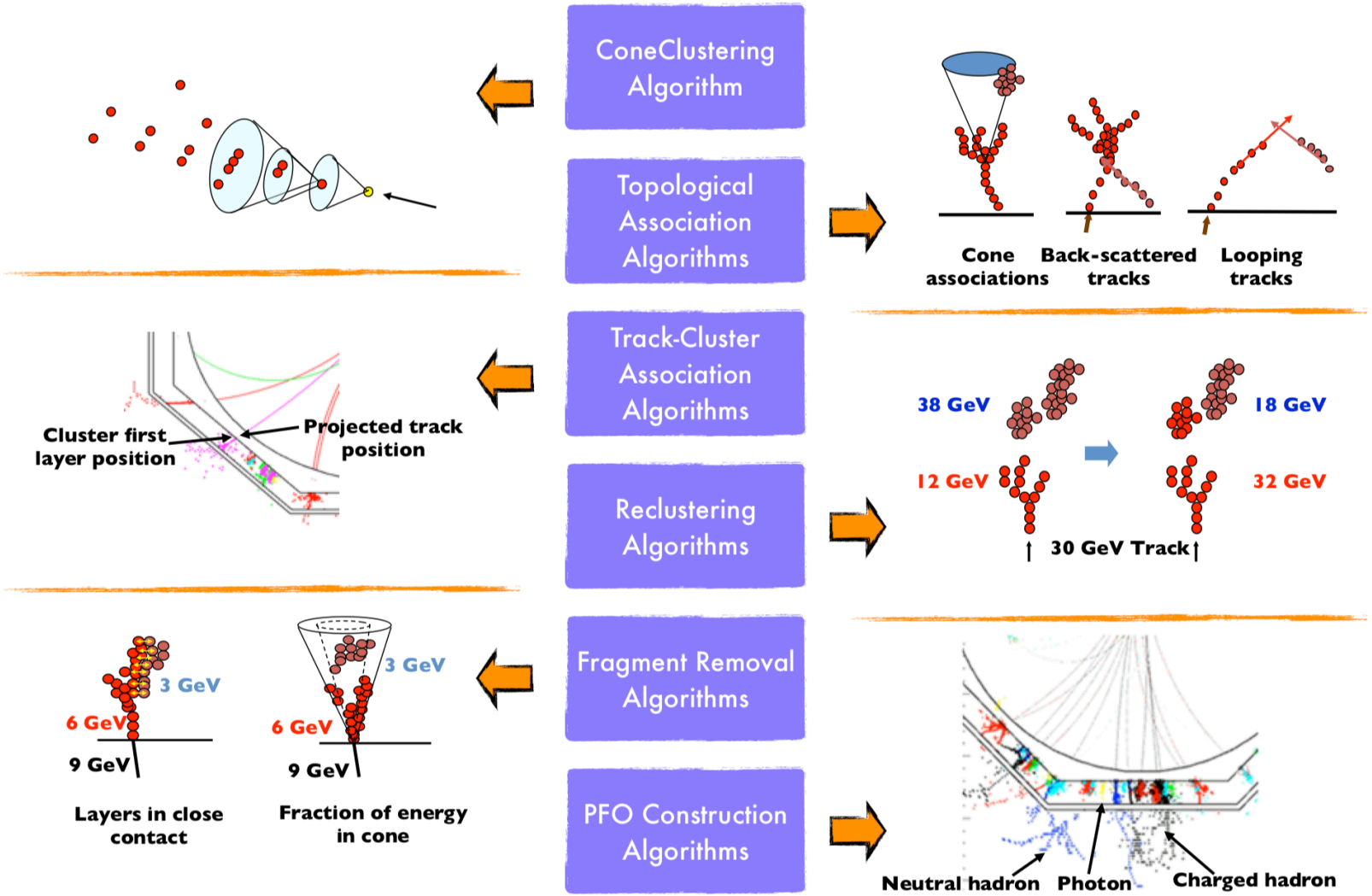


Types of confusion

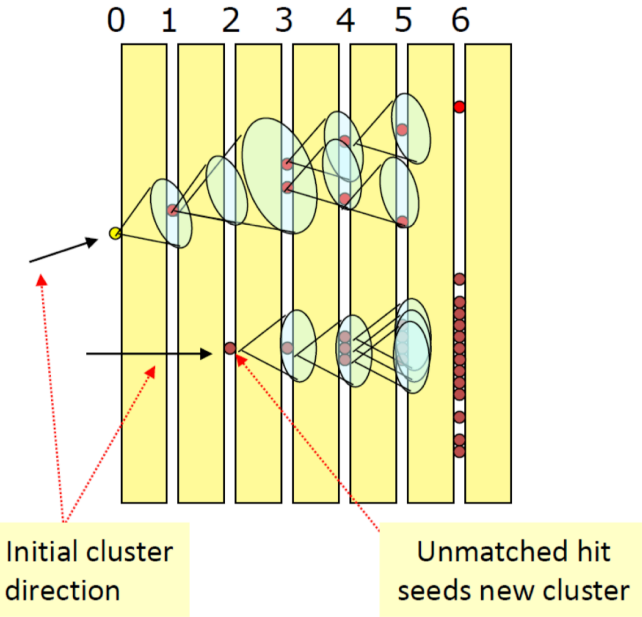


J. S. Marshall: https://indico.in2p3.fr/event/7691/contributions/42712/attachments/34375/42344/3_john_marshall_PFA_marshall_24.04.13.pdf

Pandora PFA

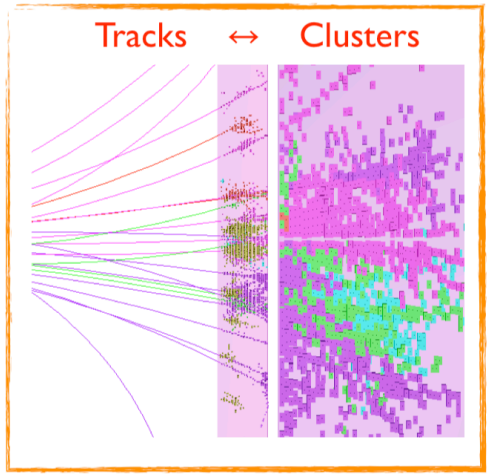


Clustering



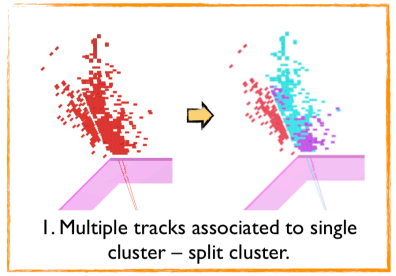
Track to Cluster Association

- Track-cluster association algs match cluster positions and directions with helix-projected track states at calorimeter.
- In very high-density jets, reach limit of "pure" particle flow: can't cleanly resolve neutral hadrons in hadronic showers.
- Identify pattern-recognition problems by looking for significant discrepancies between cluster E and track p.
- Choose to recluster: alter clustering parameters or change alg entirely until cluster splits and consistent E/p achieved.

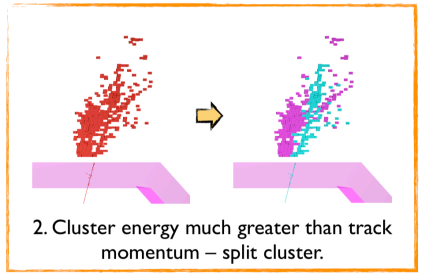


J. S. Marshall: https://indico.in2p3.fr/event/7691/contributions/42712/attachments/34375/42344/3_john_marshall_PFA_marshall_24.04.13.pdf

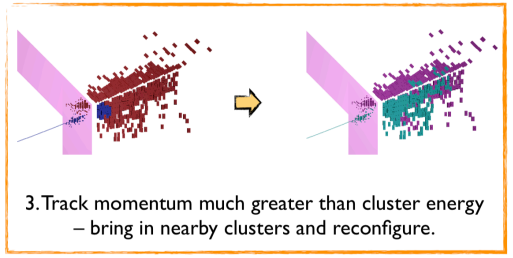
Re-Clustering



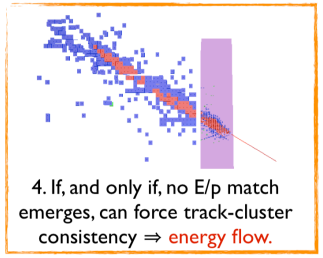
1. Multiple tracks associated to single cluster – split cluster.



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

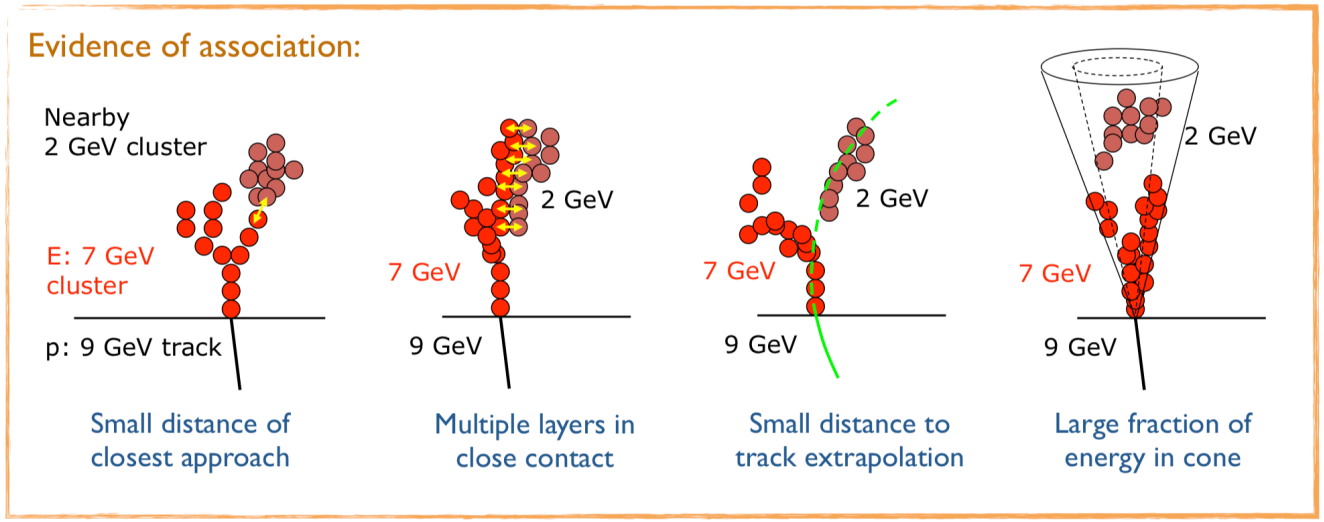


3. Track momentum much greater than cluster energy – bring in nearby clusters and reconfigure.



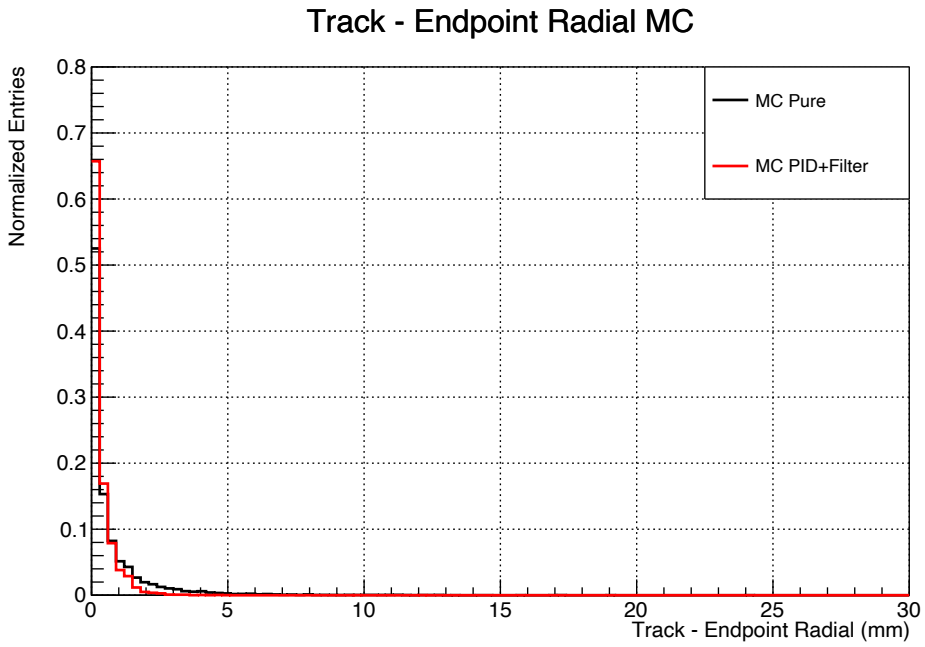
4. If, and only if, no E/p match emerges, can force track-cluster consistency ⇒ energy flow.

Fragment Removal



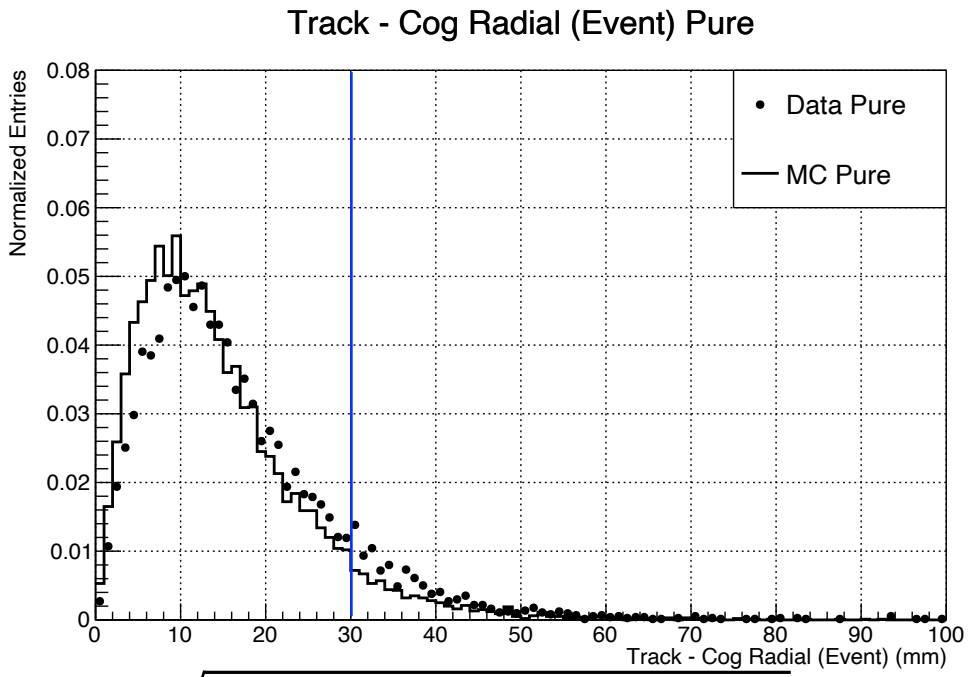
Track Quality Part 2

Implemented MC and Data Tracks for PandoraPFA Studies



$$r = \sqrt{(x_{track} - x_{endpoint})^2 + (y_{track} - y_{endpoint})^2}$$

- 100% of events have MC endpoint to track position difference within 10mm

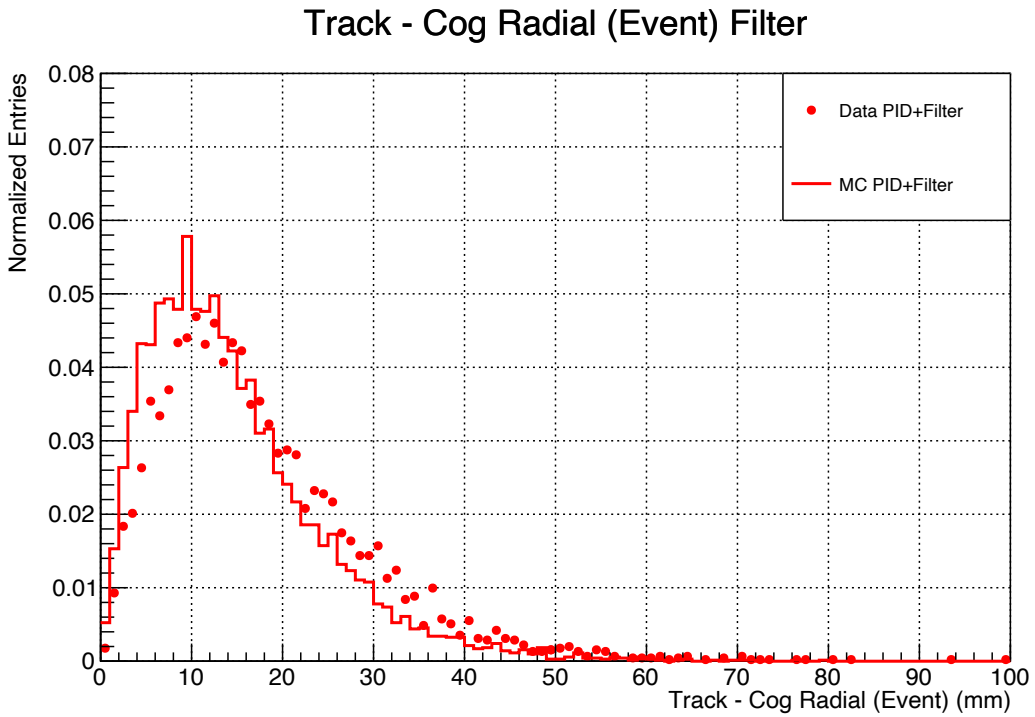


$$r = \sqrt{(x_{track} - x_{cog})^2 + (y_{track} - y_{cog})^2}$$

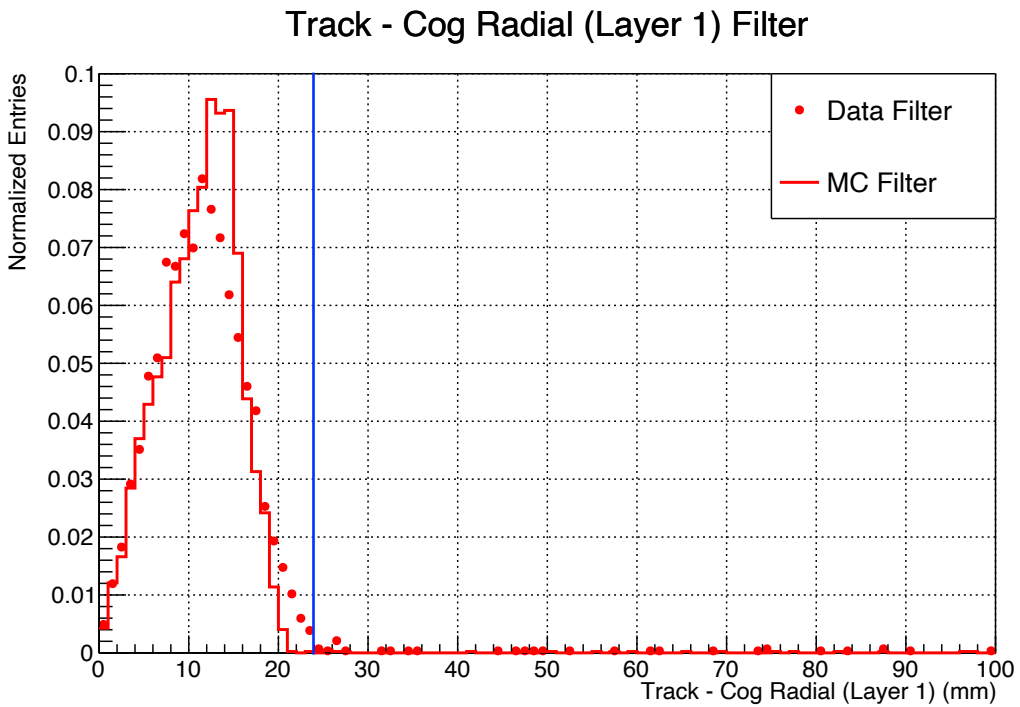
- Good agreement of track position and shower center of gravity:
  - ➡ 90% (data) and 93% (MC) of events within 30 mm distance

Track Quality Part 3

Implemented MC and Data Tracks for PandoraPFA Studies



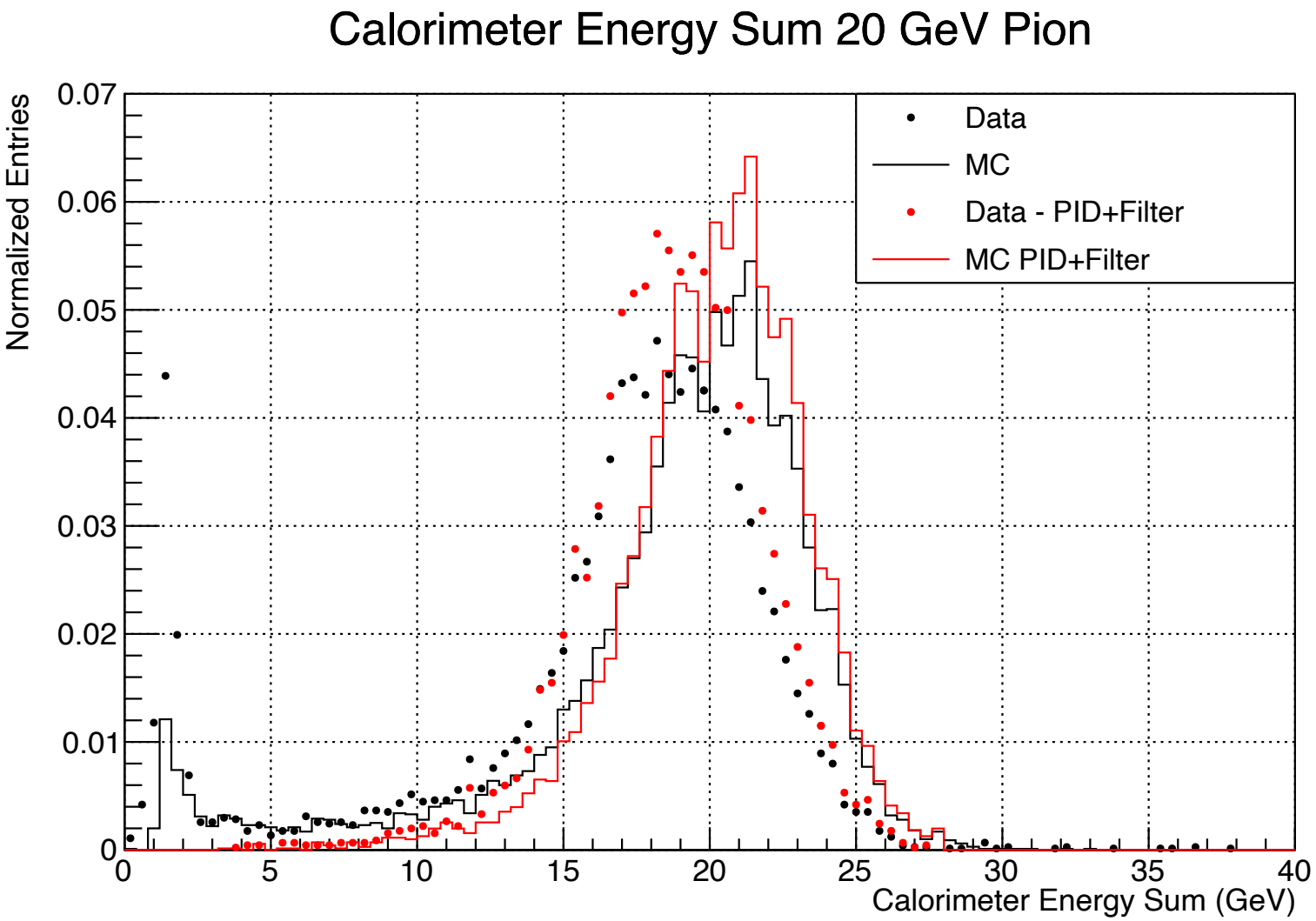
$$r = \sqrt{(x_{track} - x_{cog})^2 + (y_{track} - y_{cog})^2}$$



$$r = \sqrt{(x_{track} - x_{cog,layer1})^2 + (y_{track} - y_{cog,layer1})^2}$$

Calorimeter Energy Sum in GeV

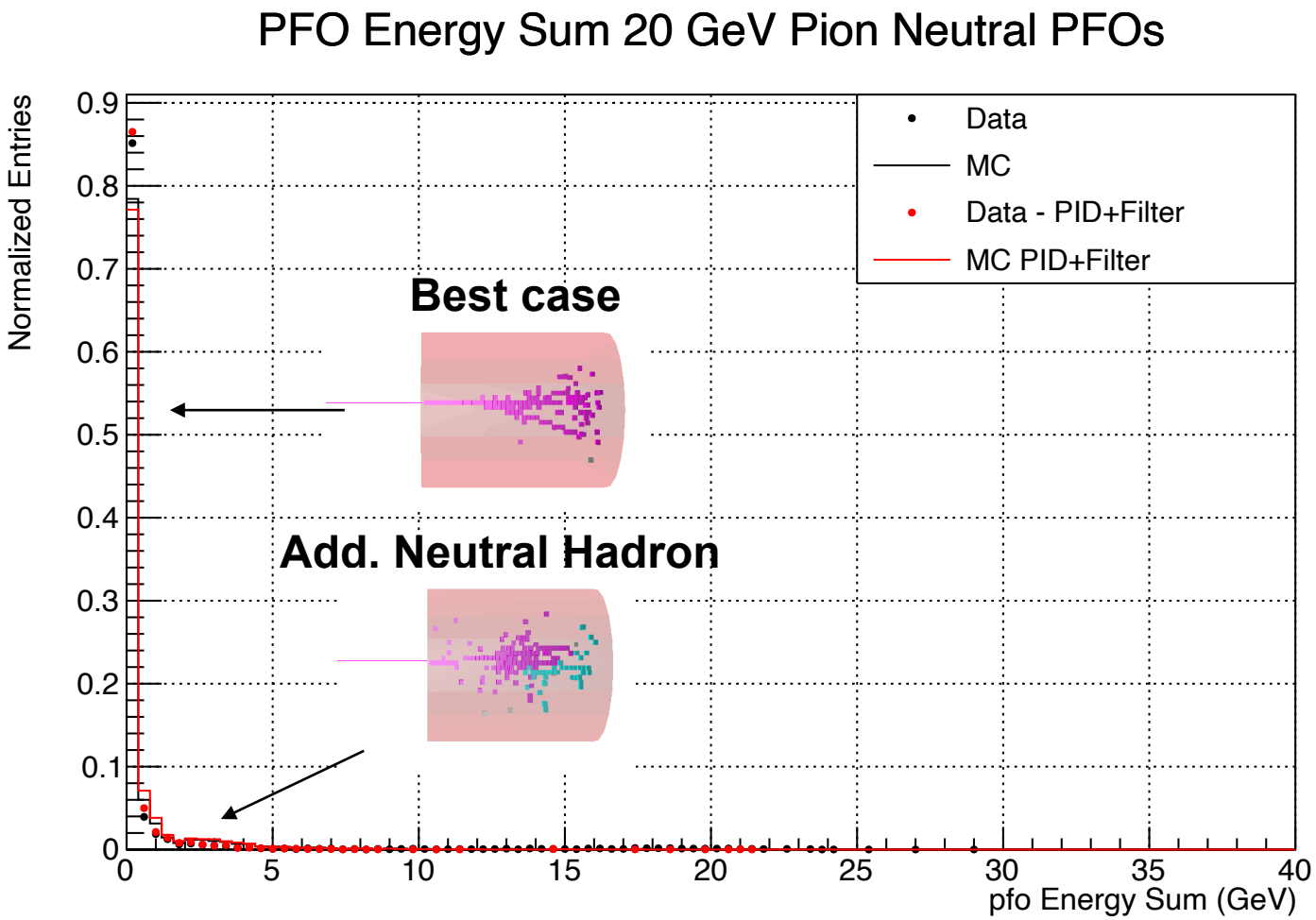
20 GeV Pions Data & MC



- Similar to Olins pion studies:
  - ➡ Observed discrepancy between data and MC
  - ➡ PID+Filter remove reasonable fraction of leakage and muon like events
- MIP2GEV conversion factor was determined with MC:
  - ➡ Even for MC still not perfect

PFO Energy Sum Neutral PFOs

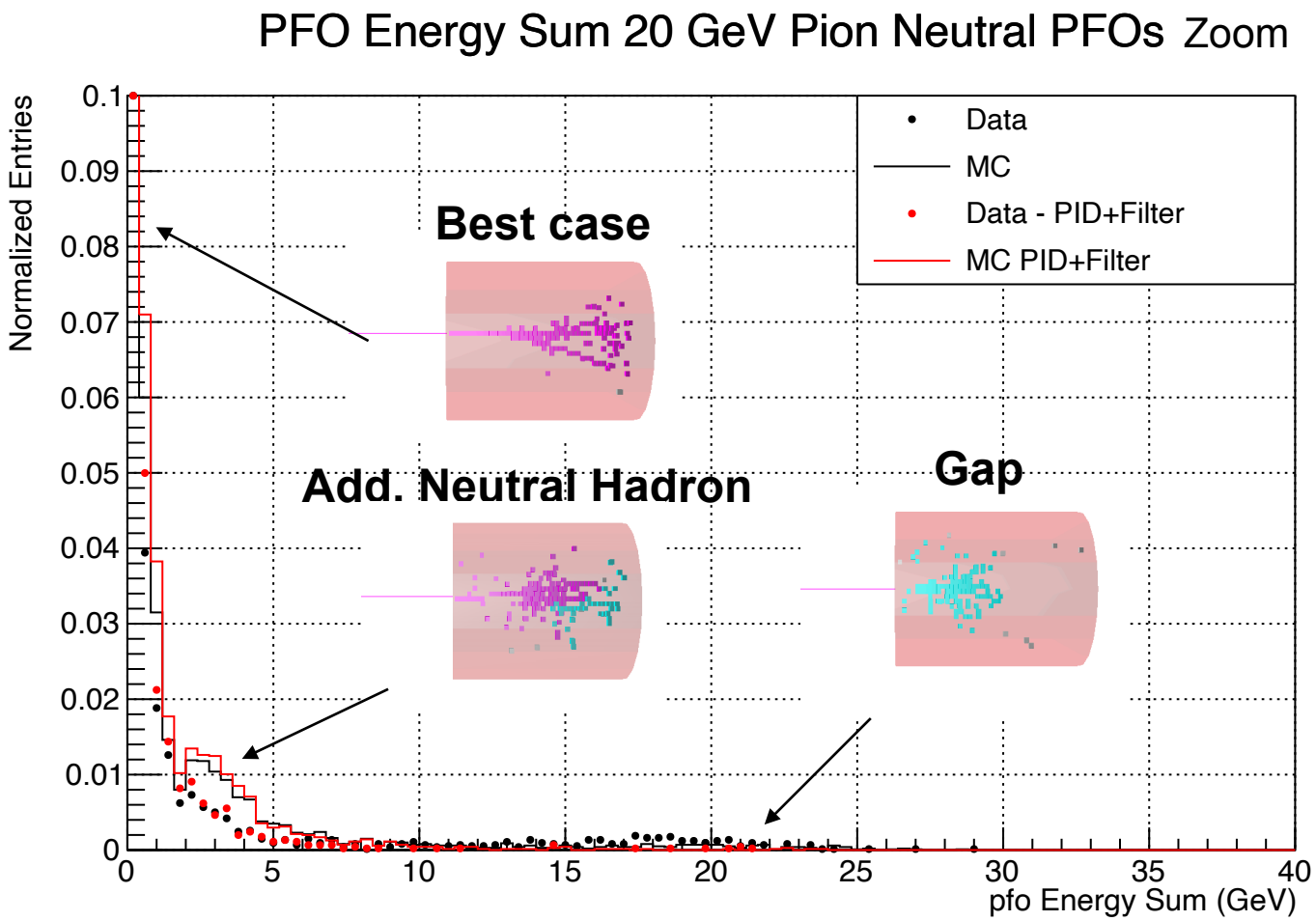
20 GeV Pions Data & MC



- Best case: 0 GeV = No neutral PFO
- Tail to higher energies: Events with identified additional neutral cluster
- For data Pandora seems to perform a bit better
- PID+Filter helps to remove most of problematic events

PFO Energy Sum Neutral PFOs

20 GeV Pions Data & MC



- Best case: 0 GeV = No neutral PFO
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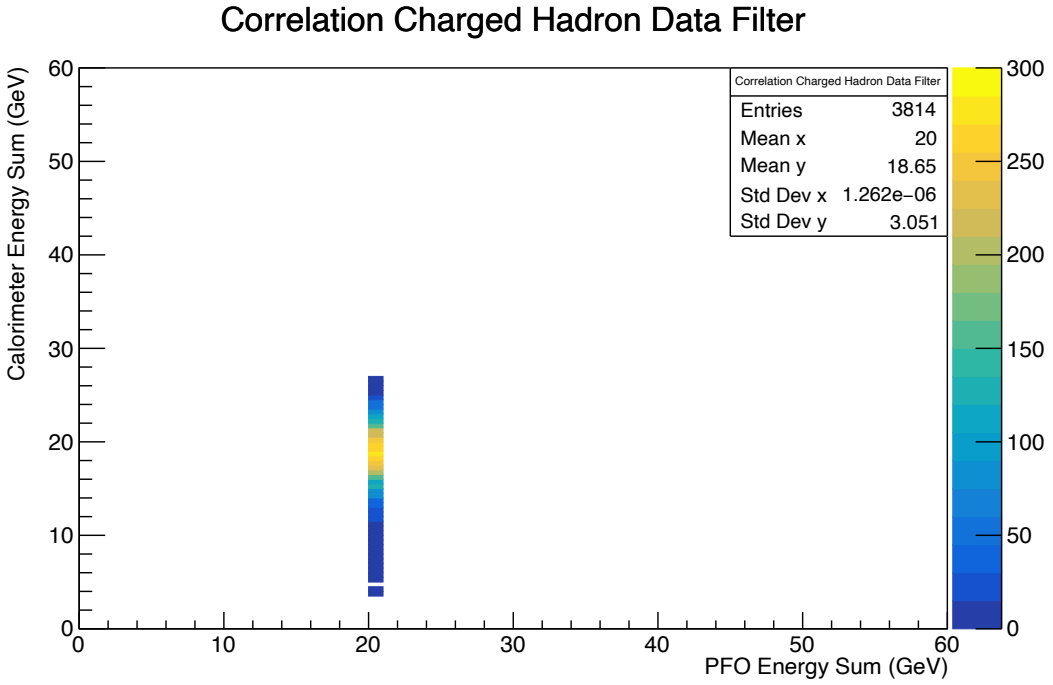
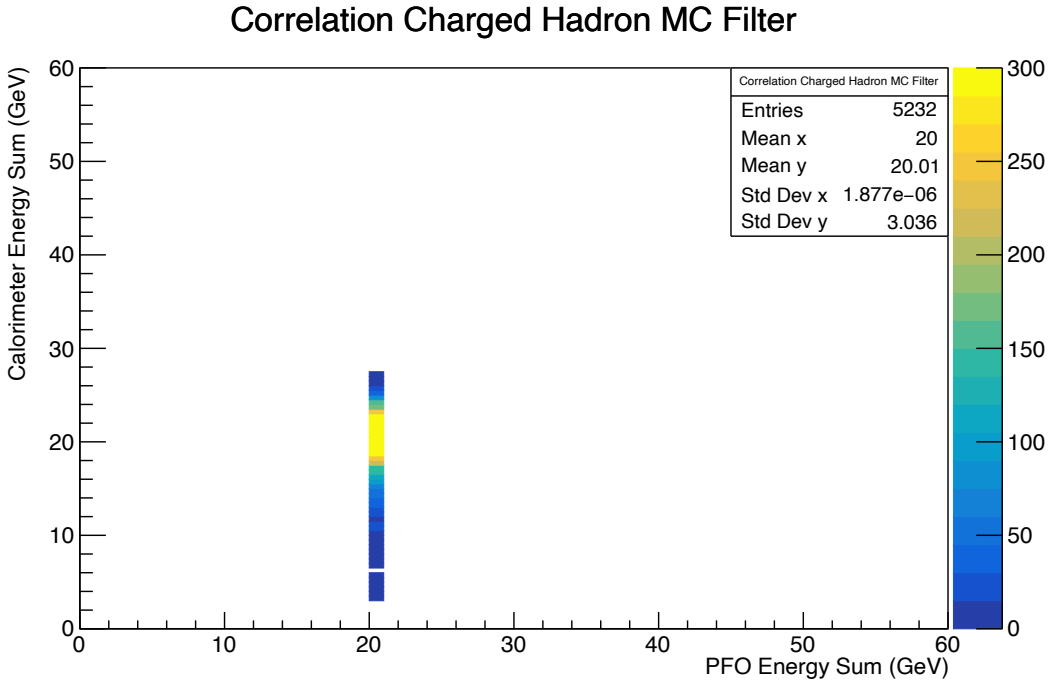
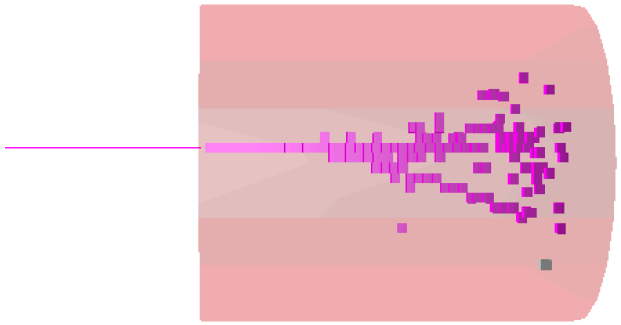
PFO Energy to Calo Energy Sum Correlation: Only One Charged PFO

20 GeV Pions Data & MC Filtered



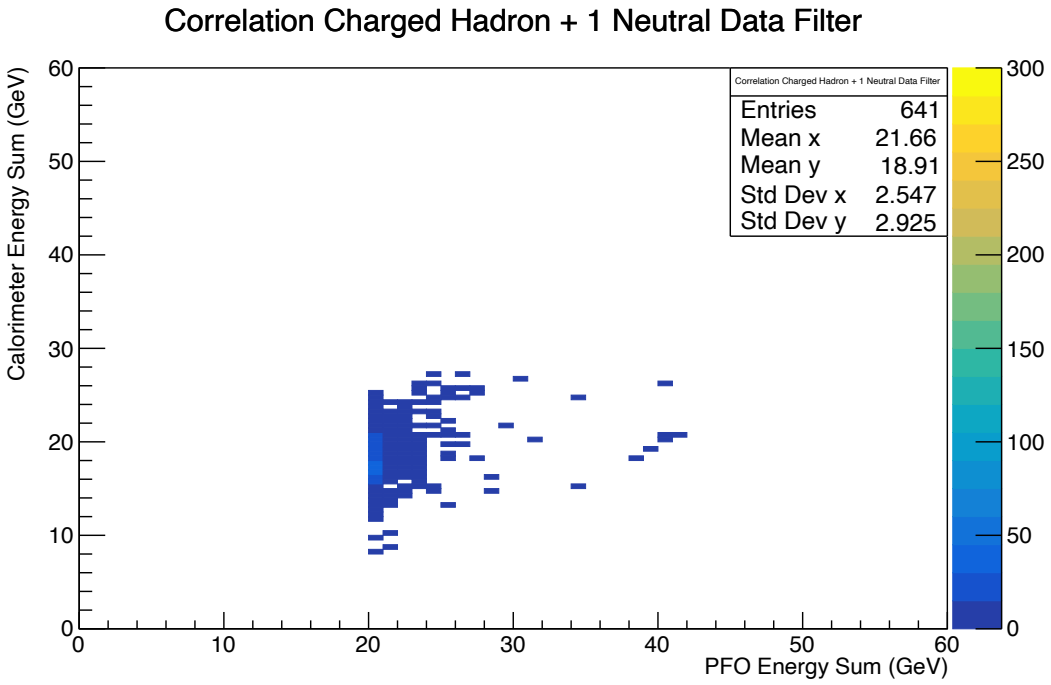


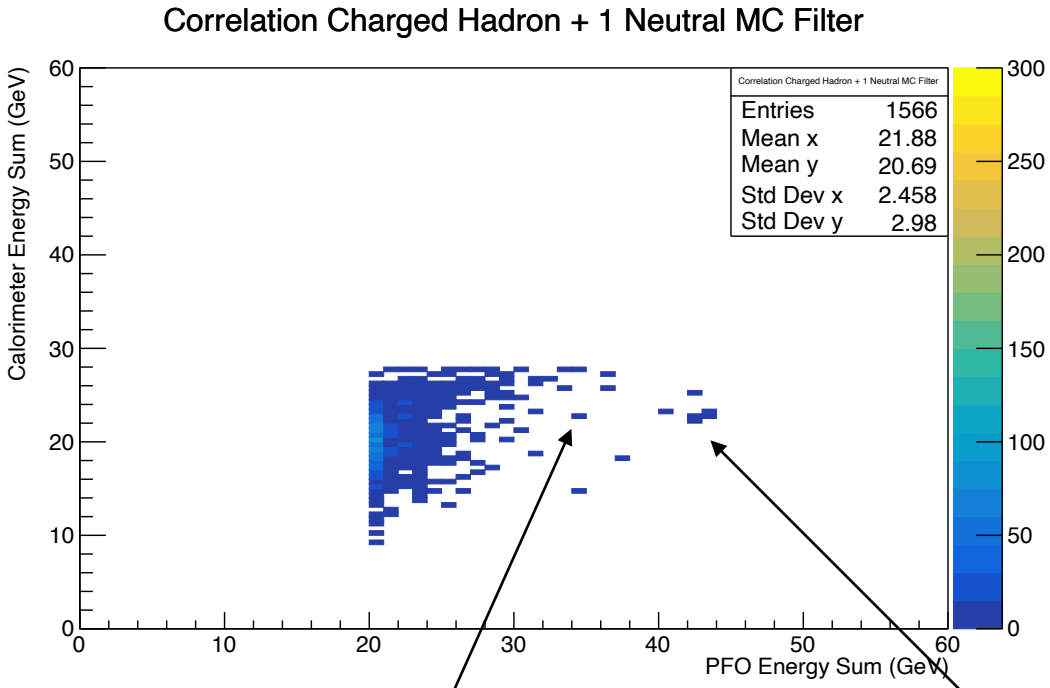
- Only events with a charged PFO and no neutral PFOs
  - ➡ Perfect reconstruction scenario



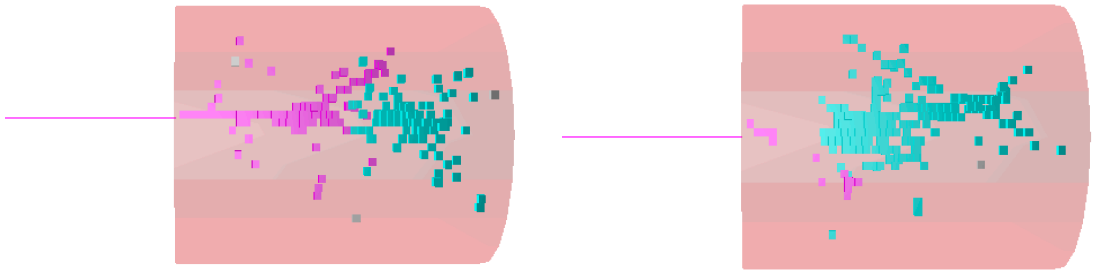
PFO Energy to Calo Energy Sum Correlation: One Neutral PFO

20 GeV Pions Data & MC Filtered



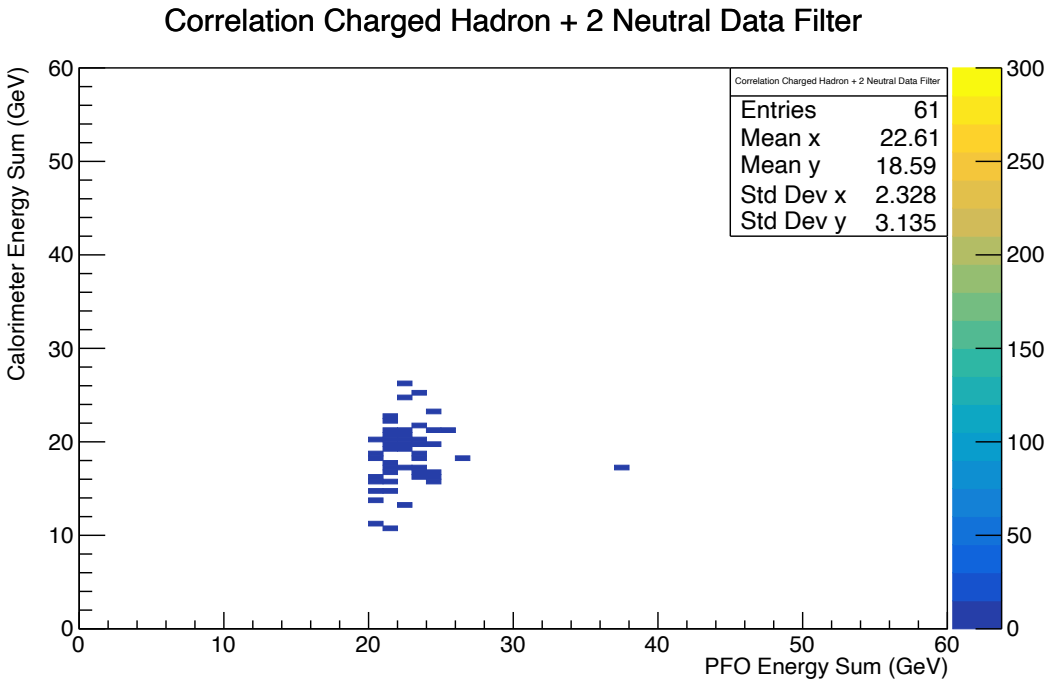


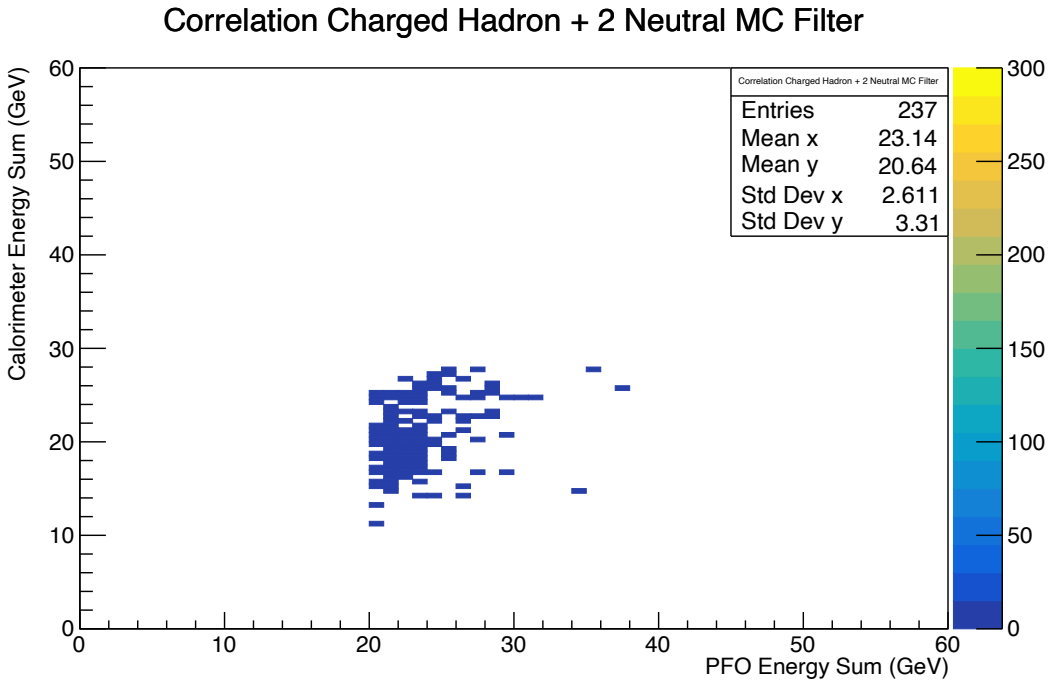
- Events with charged PFO and one additional neutral PFO
  - ➡ Most of the "cloud" region between 20-30 GeV
  - ➡ Diagonal and few outliers: Remaining "gap" and difficult topological events



PFO Energy to Calo Energy Sum Correlation: Two Neutral PFO

20 GeV Pions Data & MC Filtered





- Events with a charged PFO and two additional neutral PFOs
  - ➡ Only a few events of the "cloud" region between 20-30 GeV