

$\mu$ BooNE

# Pandora - preparing for TDR writing

**L. Escudero**  
**for the Pandora Team**

**DUNE FD sim/reco meeting**  
**26th of November 2018**



DUNE



# Recently in Pandora...

## Persisting Slices in Pandora (should be available in this weeks' LArSoft release)

**Pandora uses the concept of slice internally since its (LAr) beginning:**

- They represent topologically distinct collection of hits (grouped by proximity and pointing info)
- They become a candidate neutrino or beam-particle interaction in the pattern recognition
- They are produced after the unambiguous cosmic-rays have already been identified

**Now that the appropriate object exists in the LArSoft EDM, they can be persisted and used downstream:**

- As topologically distinct collection of hits that represents any particle hierarchy
  - Which could be from a cosmic-ray, a neutrino interaction or a test-beam particle interaction.
- Added a method to also create a slice of unambiguous cosmic-ray hierarchies

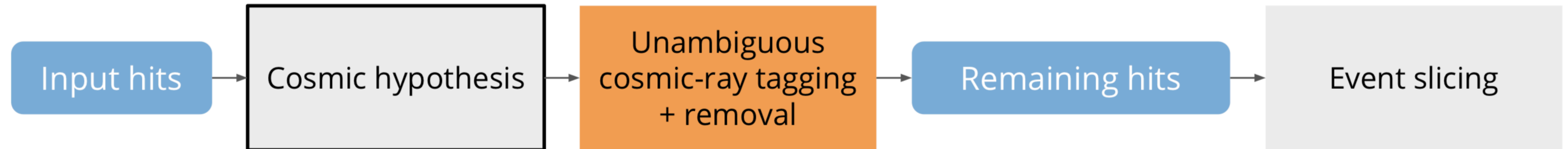
**More information in talk at last week's LArSoft coordination meeting**



# Recently in Pandora...

Persisting Slices in Pandora (should be available in this weeks' LArSoft release)

## REMINDER ABOUT PANDORA SLICES



Slices are produced after unambiguous cosmic-ray hierarchies are tagged and set aside in the pattern recognition, to avoid merging ambiguous cosmic-ray remnants into a neutrino/test-beam interaction.

This is relevant for MicroBooNE and proto-DUNE (DUNE FD configured as single slice)

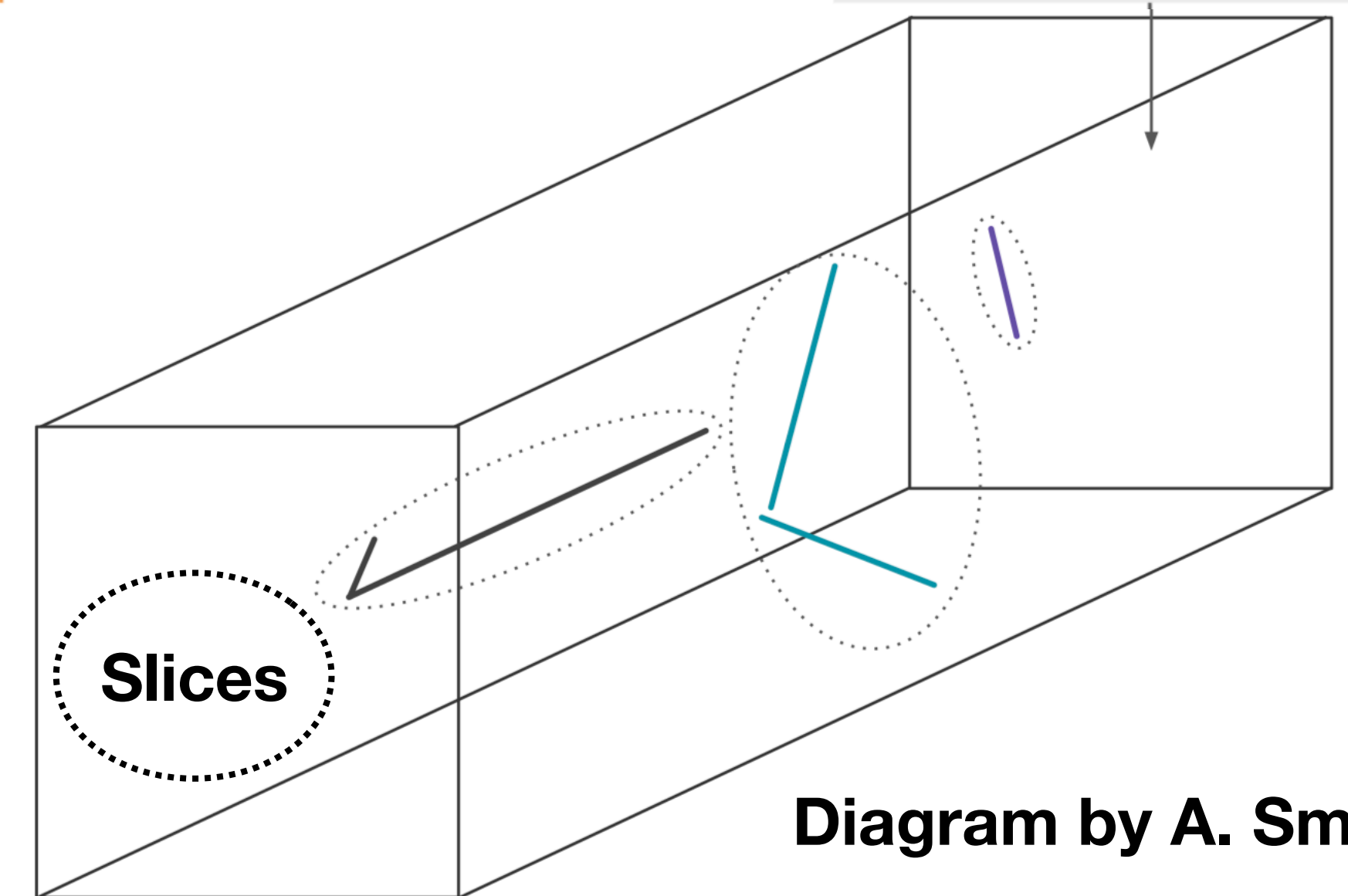


Diagram by A. Smith





# Recently in Pandora...

## Persisting Slices in Pandora (should be available in this weeks' LArSoft release)

- **New products:**

- `std::vector<recob::Slice>`
- `art::Assns<recob::Slice, recob::Hit, void>`
- `art::Assns<recob::PFParticle, recob::Slice, void>`

- All unambiguous cosmic-ray hierarchies:
  - one `recob::Slice` per hierarchy
- All Pandora internal slices:
  - each `PFParticle` is associated to a single `recob::Slice`
  - a `recob::Slice` can contain multiple `PFParticles`
  - Hits can be in a slice even if not associated to a `PFParticle`





# TDR-ing

I'm currently updating the Pandora section in the Physics Tools and Methods part

## 1 Tools and Methods

- 1.1 Monte Carlo simulations
  - 1.1.1 Hadron production and Beam Line modeling
  - 1.1.2 Neutrino interaction generators
  - 1.1.3 Detector simulation
  - 1.1.4 DAQ simulations/assumptions
- 1.2 Event reconstruction in the far detector
  - 1.2.1 TPC Signal Processing
  - 1.2.2 Gaussian Hit Finder
  - 1.2.3 Disambiguation
  - 1.2.4 Blurred Cluster
  - 1.2.5 Line Cluster
  - 1.2.6 TrajCluster
  - 1.2.7 Pandora
  - 1.2.8 Projection Matching Algorithm
  - 1.2.9 EMShower
  - 1.2.10 Calorimetric Energy Reconstruction and Particle Identification
  - 1.2.11 WireCell
  - 1.2.12 Optical Reconstruction

1.2.7.1 Pandora Inputs and Outputs

1.2.7.2 Overview of Pattern  
Recognition Algorithms

1.2.7.3 Performance

Pattern Recognition

1.2.7.4 High Level Reconstruction

New

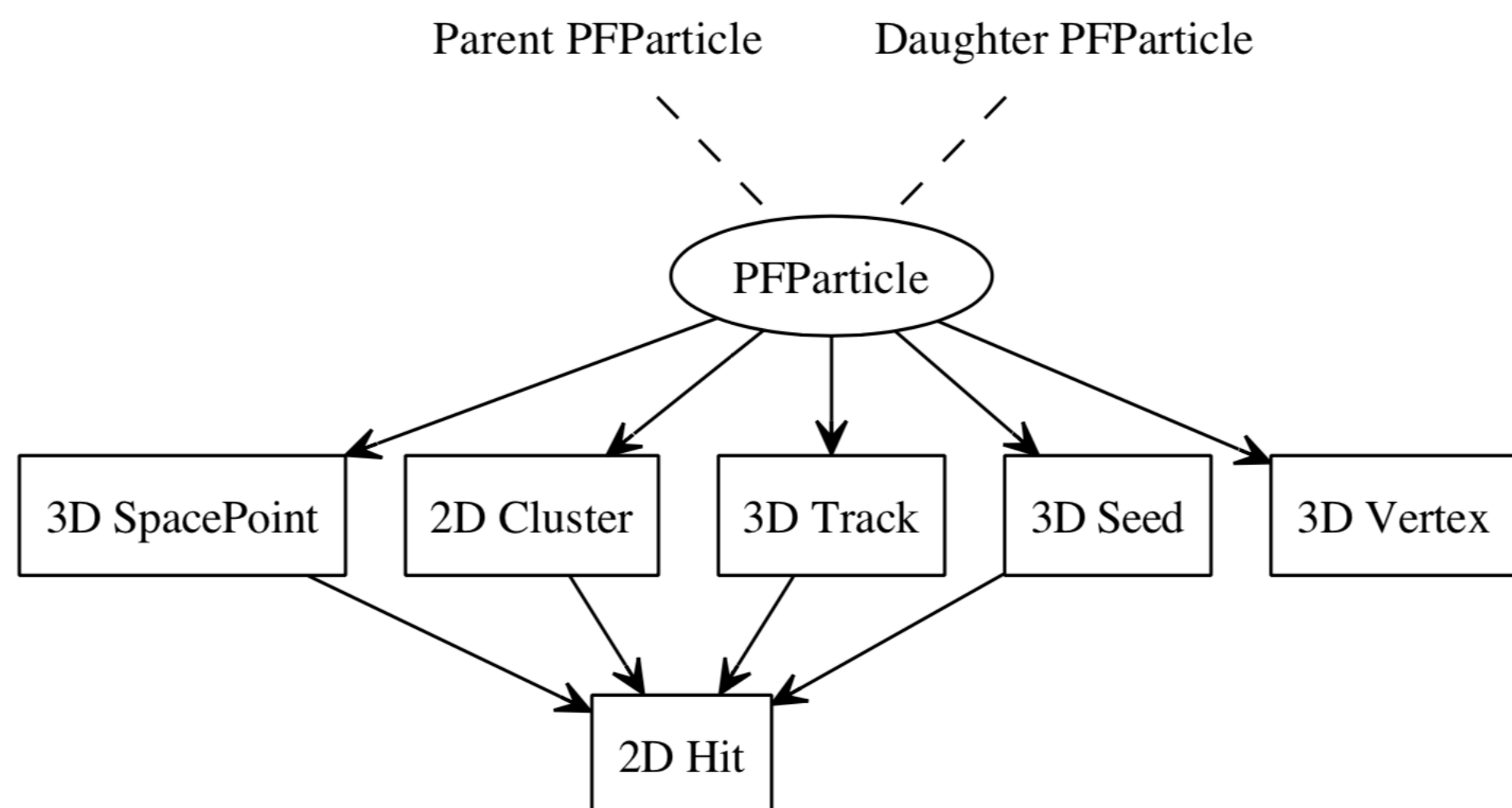
Interplay with protoDUNE section?  
Should we also add protoDUNE metrics in this section?

Current draft from DUNE FD Task Force report, written by Andy Blake, circa summer 2017 (?)



# TDR-ing

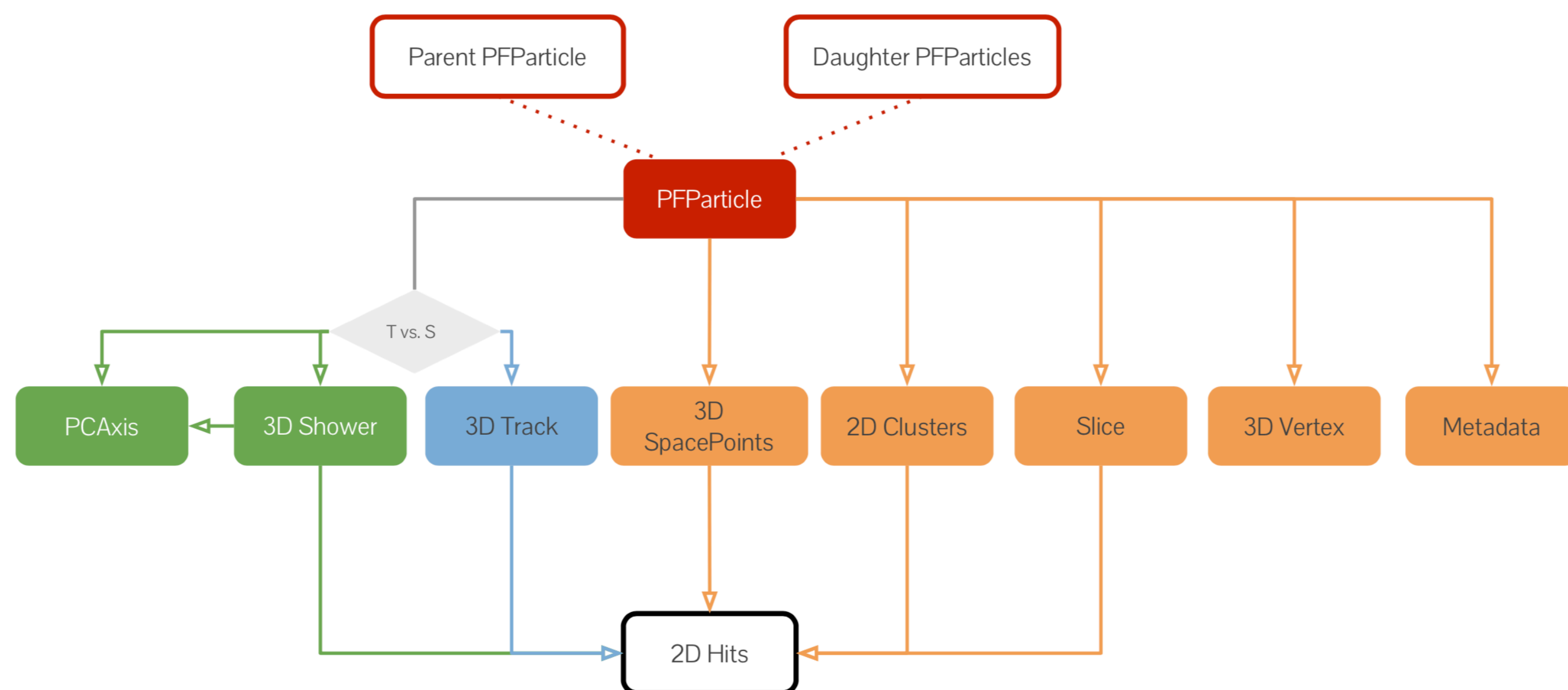
Old, circa summer 2017 (?)



## 1.2.7.1 Pandora Inputs and Outputs

### Pandora output to LArSoft

New



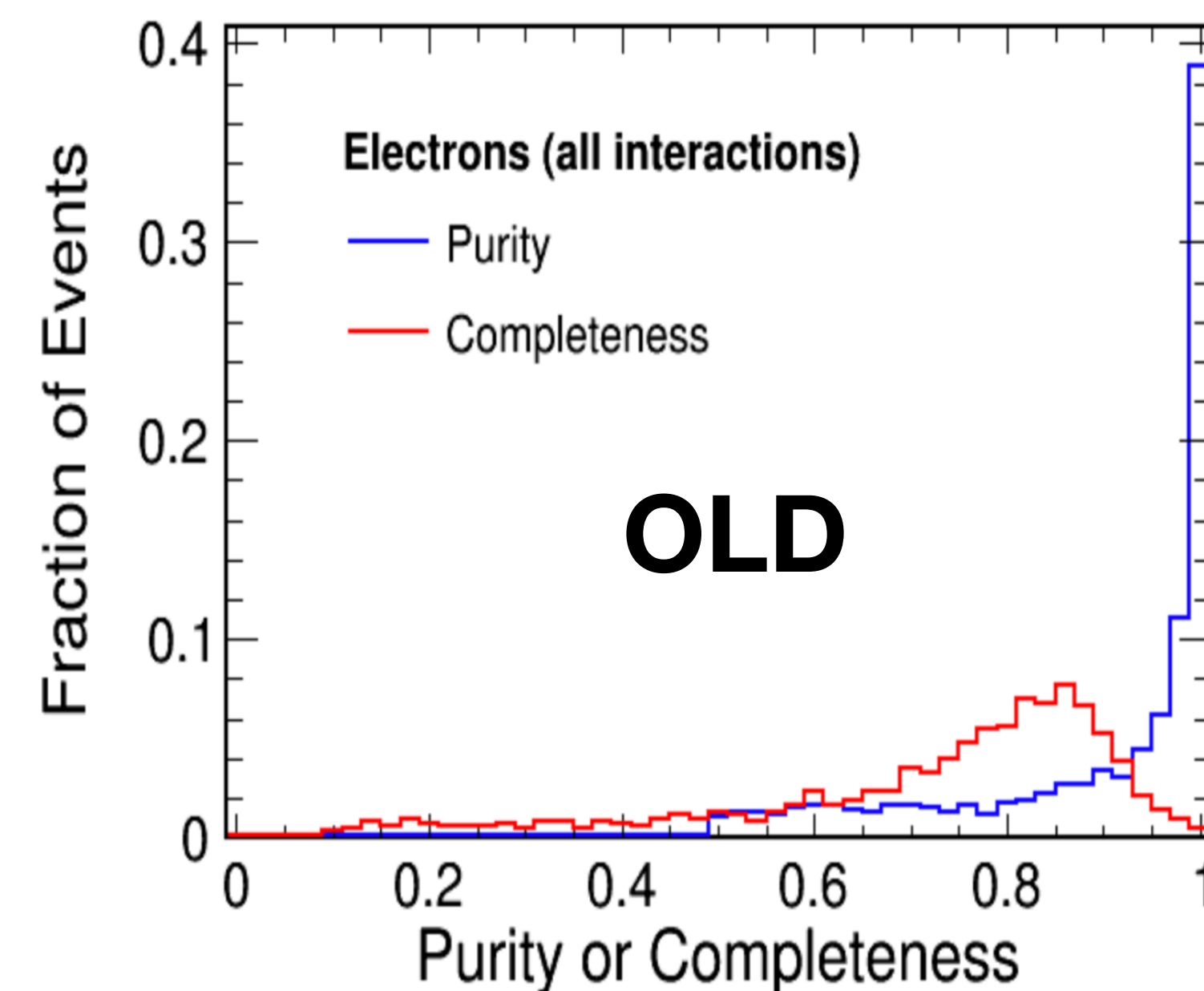
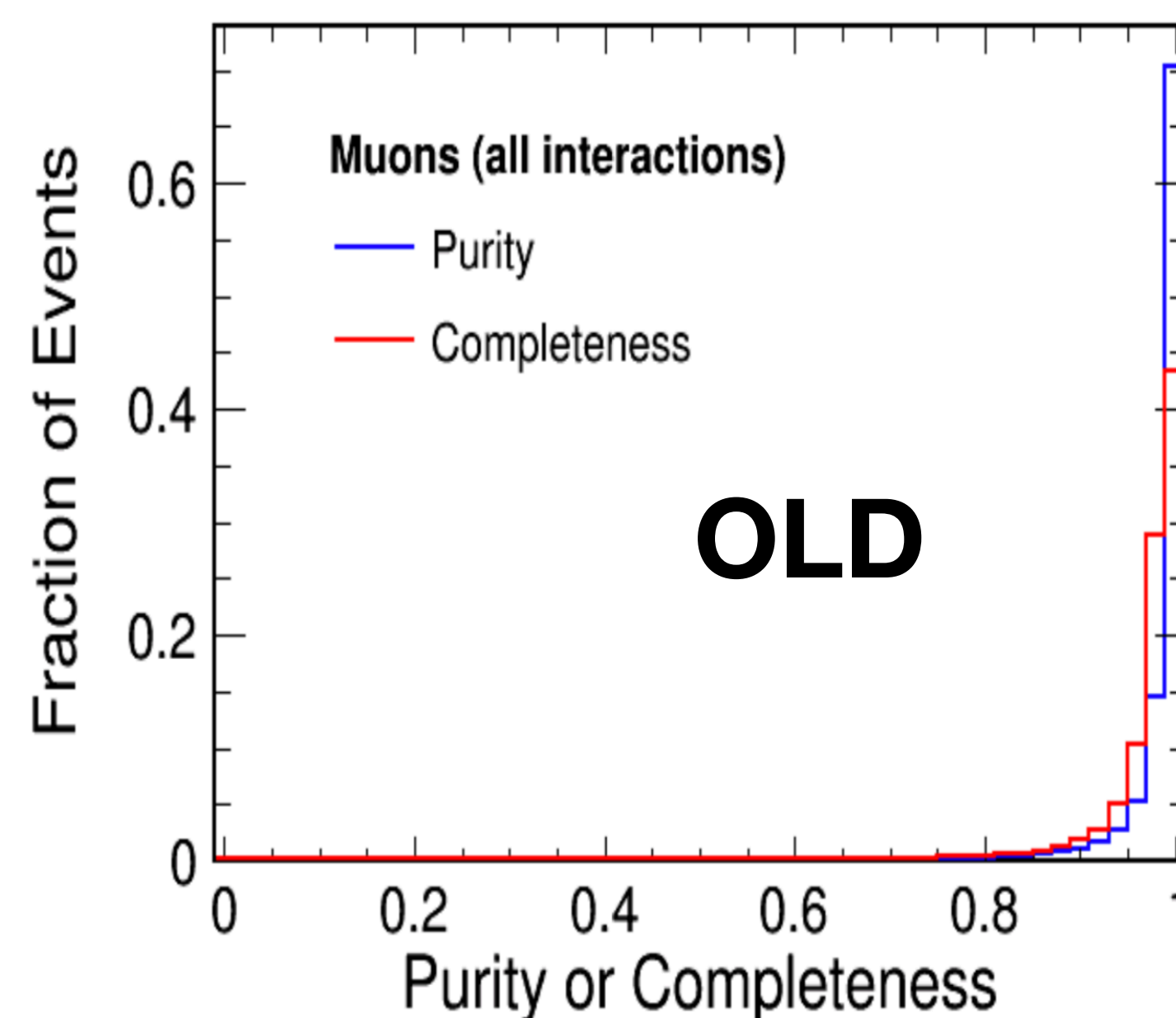
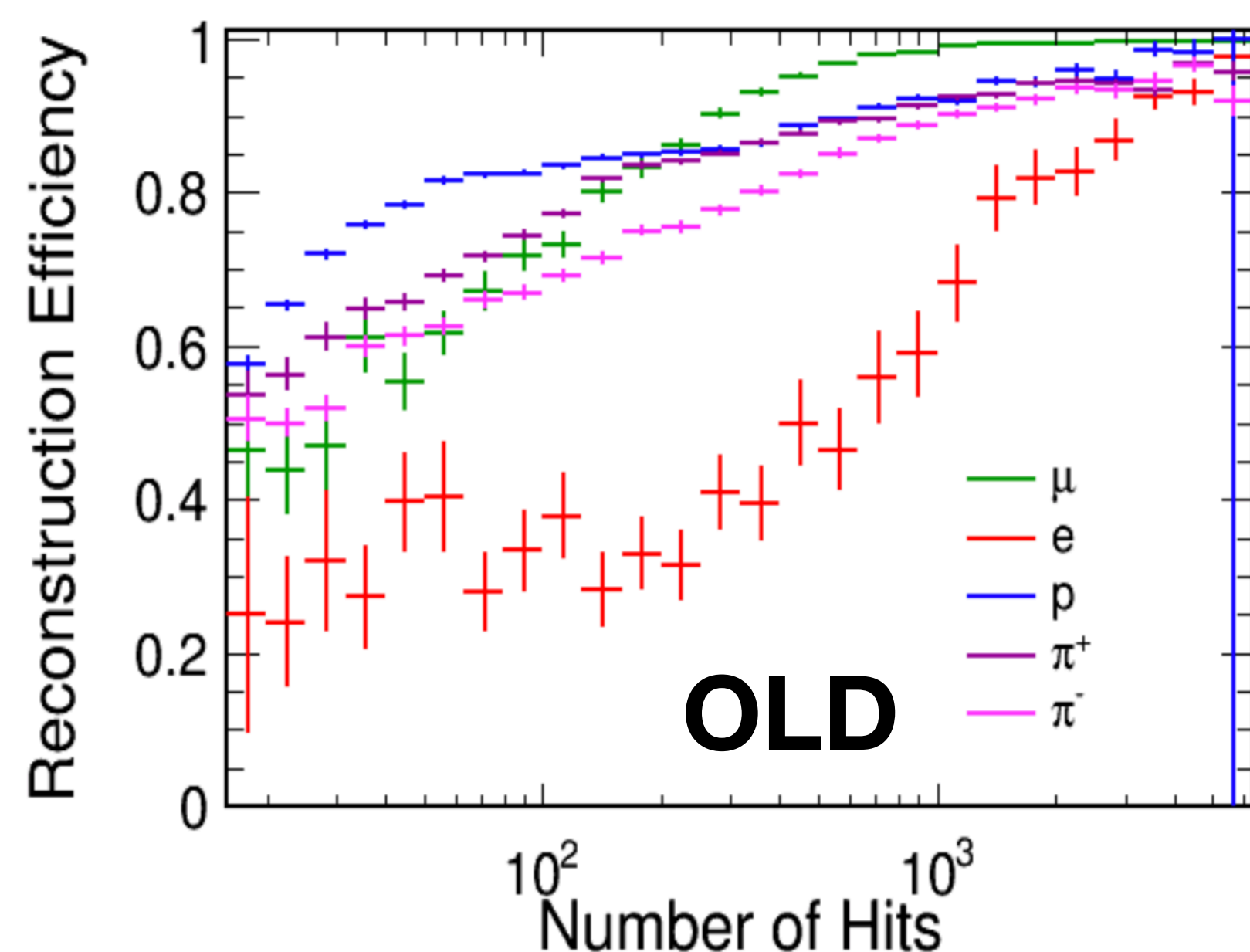




# TDR-ing

## 1.2.7.3 Performance

Old, circa summer 2017 (?)



More information about these plots in backup and in the Pandora MicroBooNE paper <https://arxiv.org/abs/1708.03135>





# TDR-ing

## 1.2.7.3 Performance

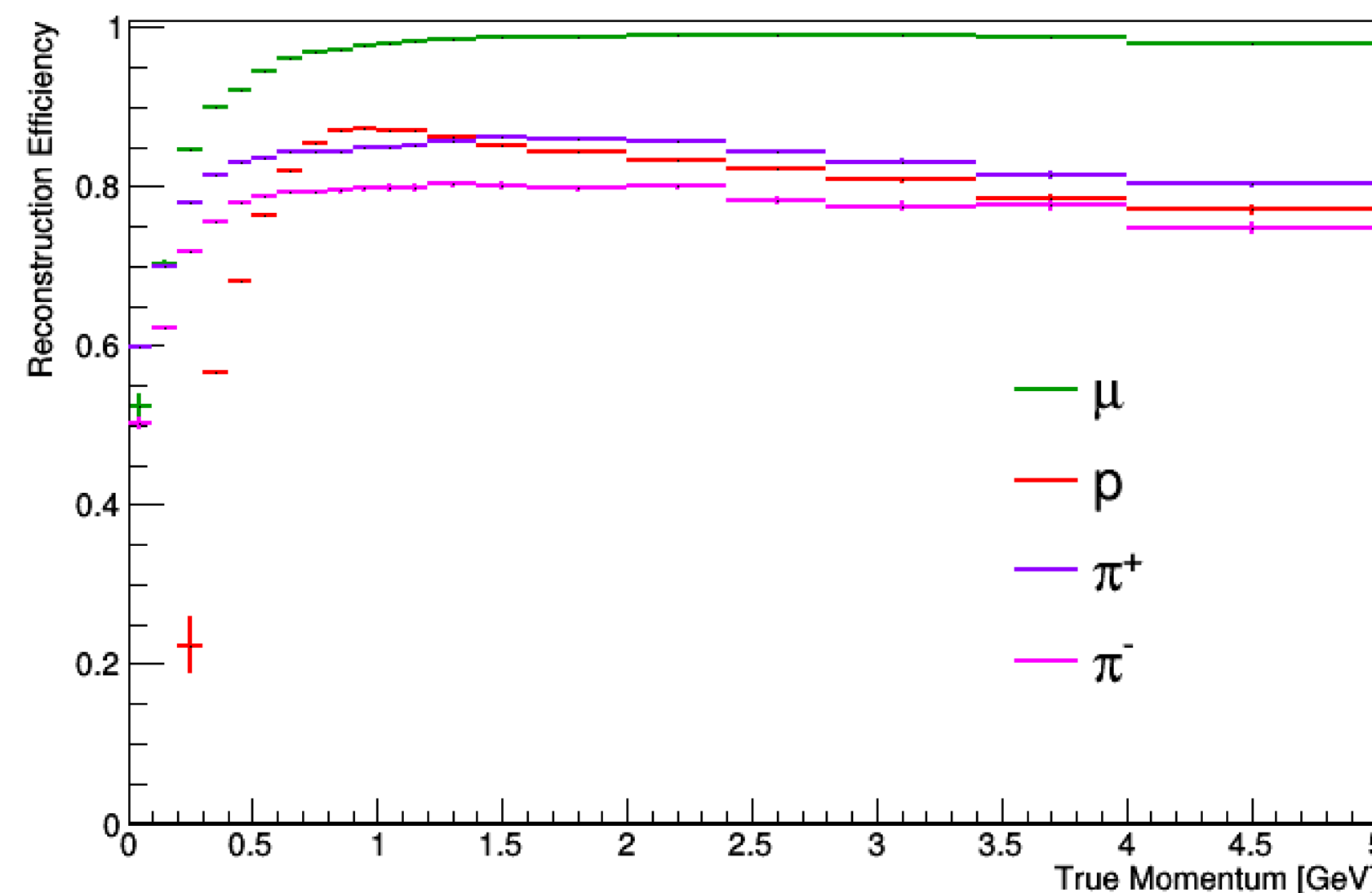
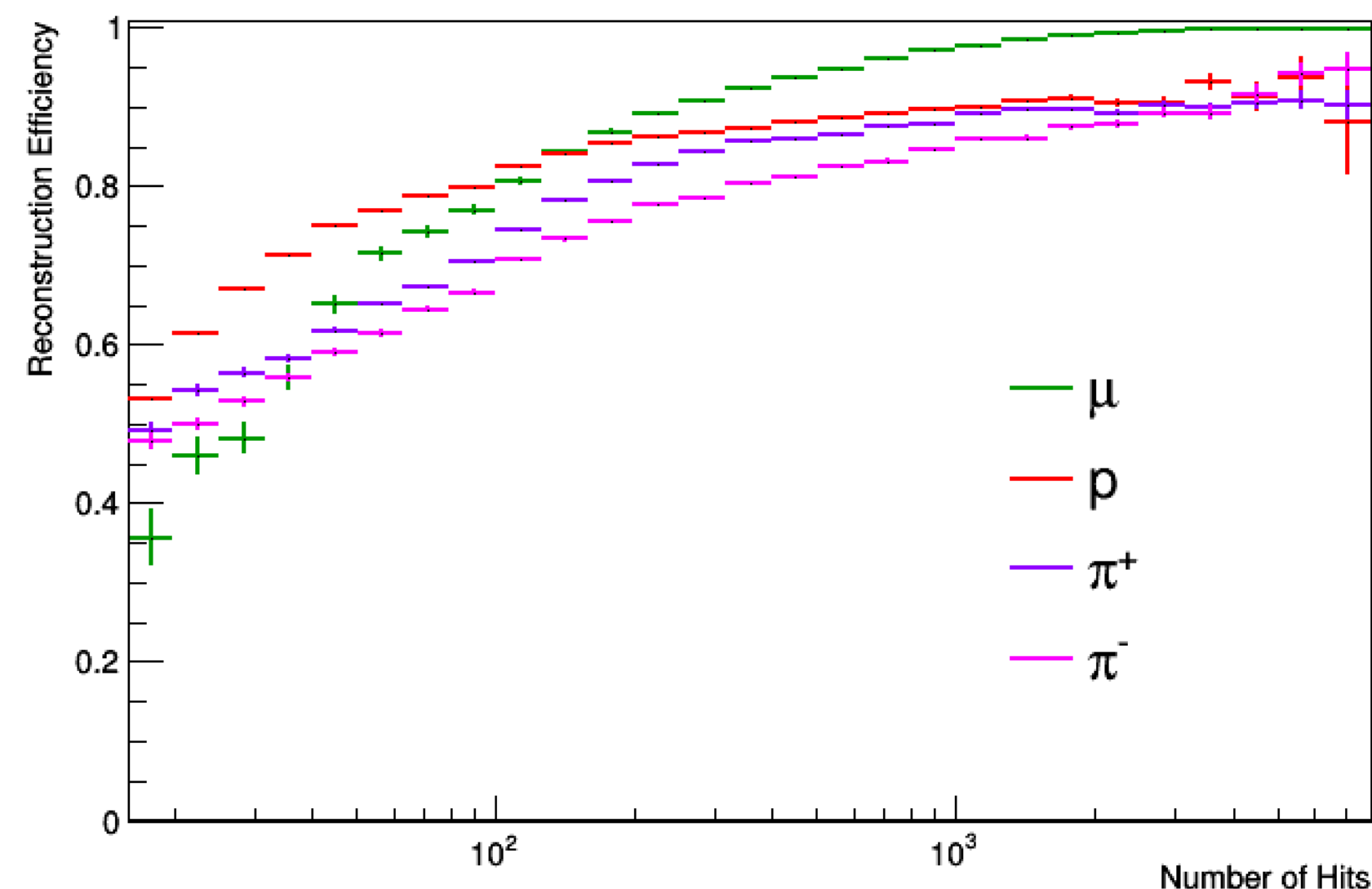
ALL INTERACTIONS

New: MCC10 samples  
(1x2x6) and latest  
Pandora

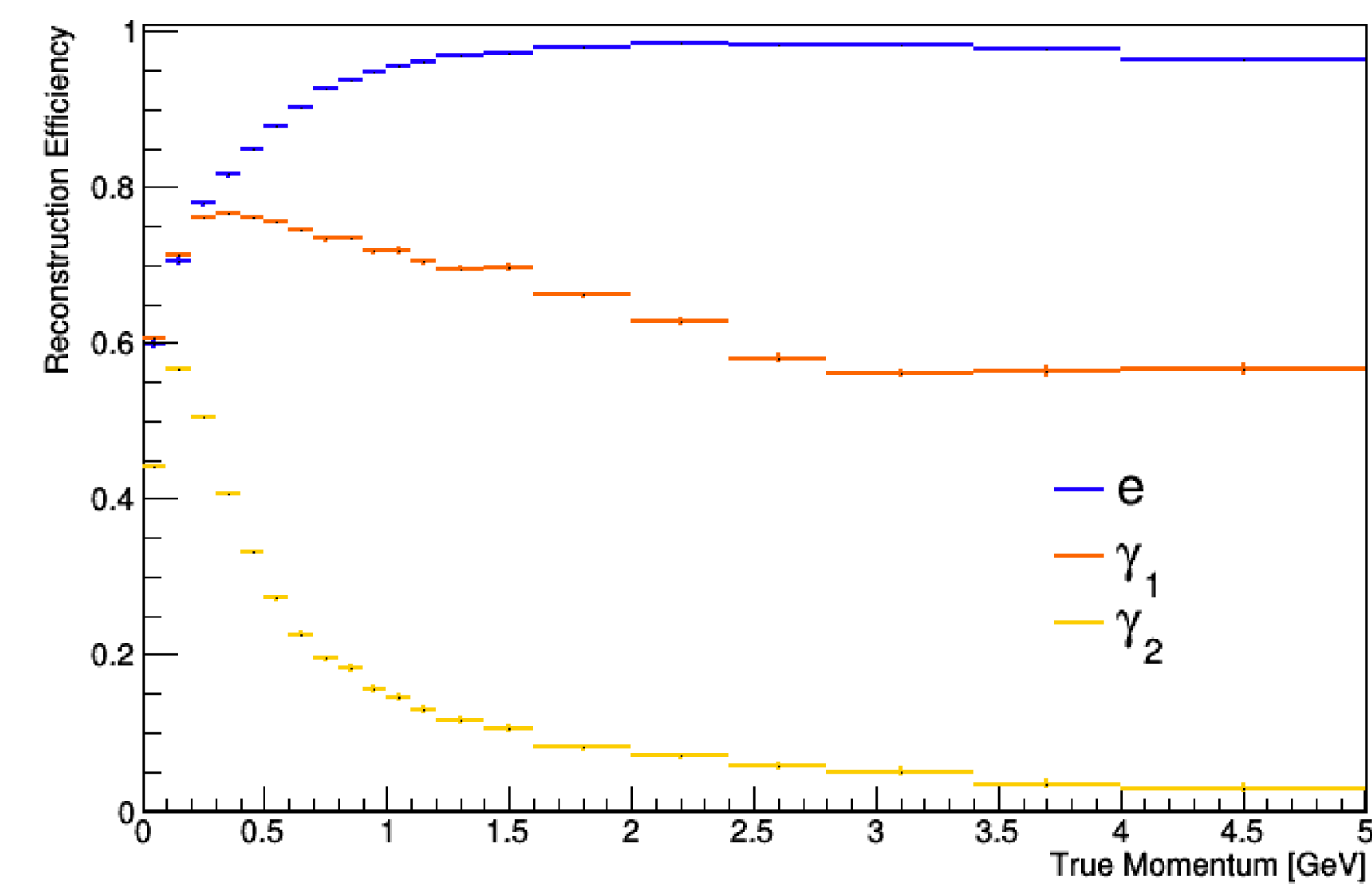
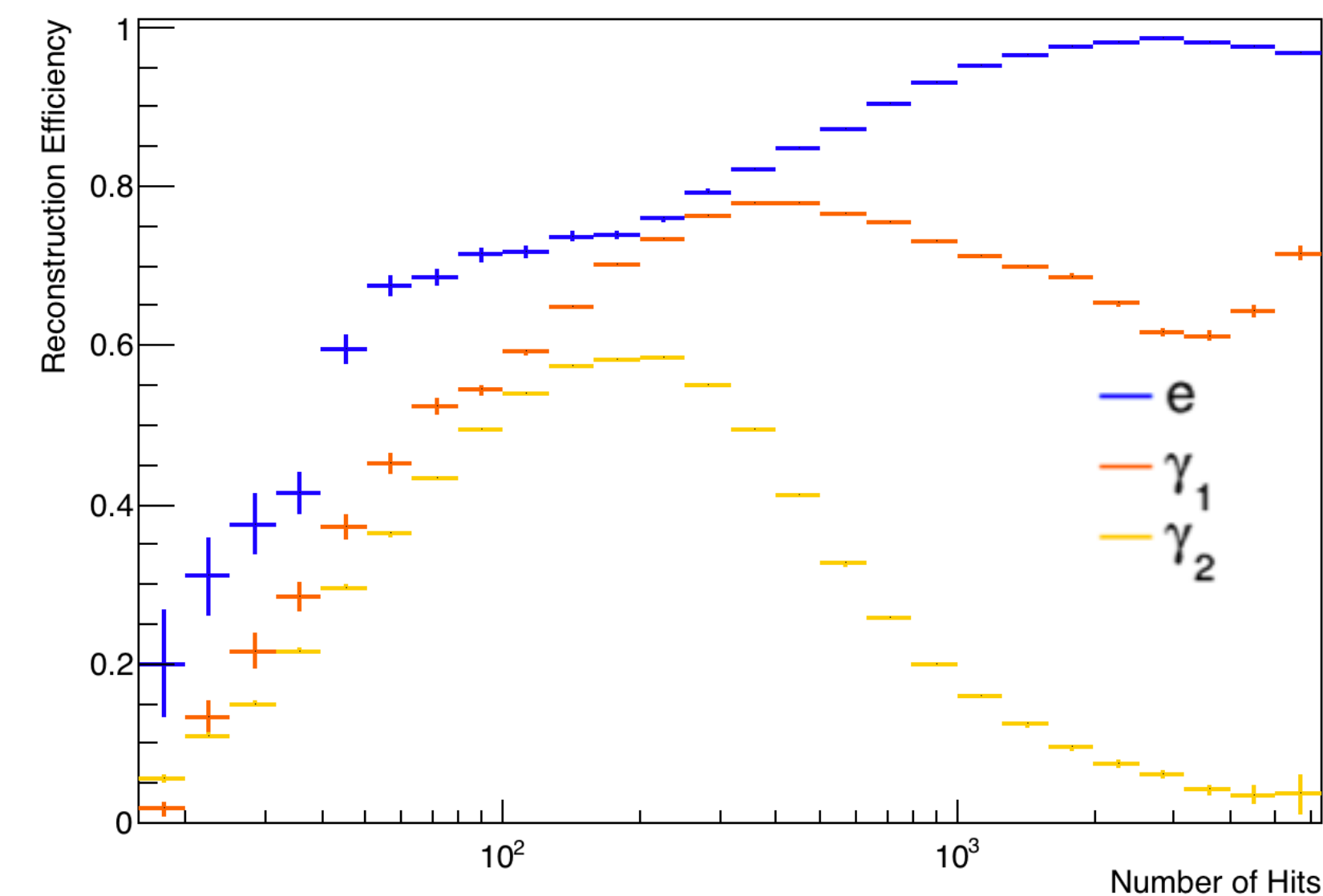
Preliminary! Plots to  
be repeated with  
MCC11 (?)

Question 1: vs  
Number of Hits or vs  
Momentum?

### Tracks



### Showers



Note: only leading proton (with largest #hits in the event),  $\gamma_1$  (largest #hits),  $\gamma_2$  (second largest #hits)



# TDR-ing

## 1.2.7.3 Performance

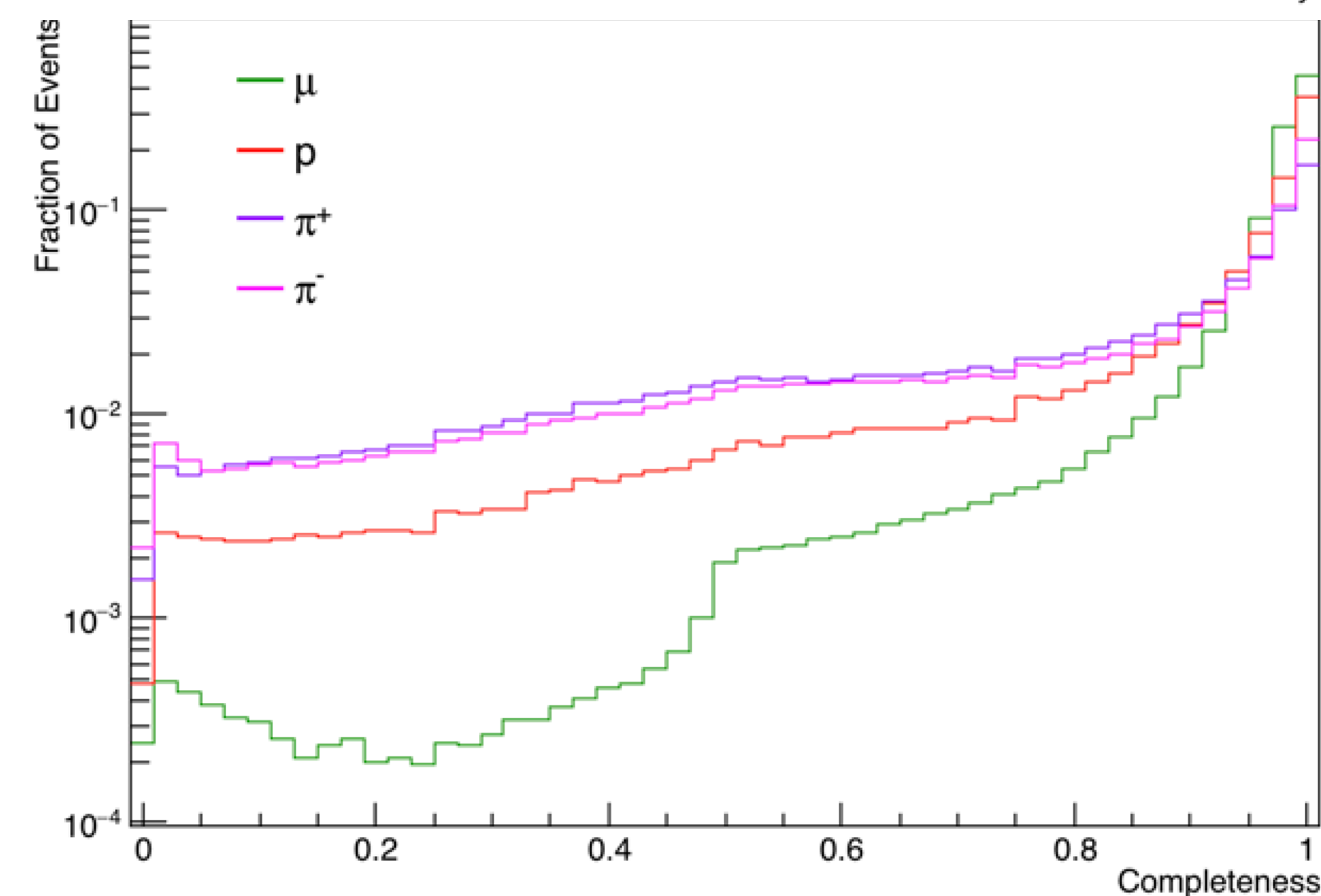
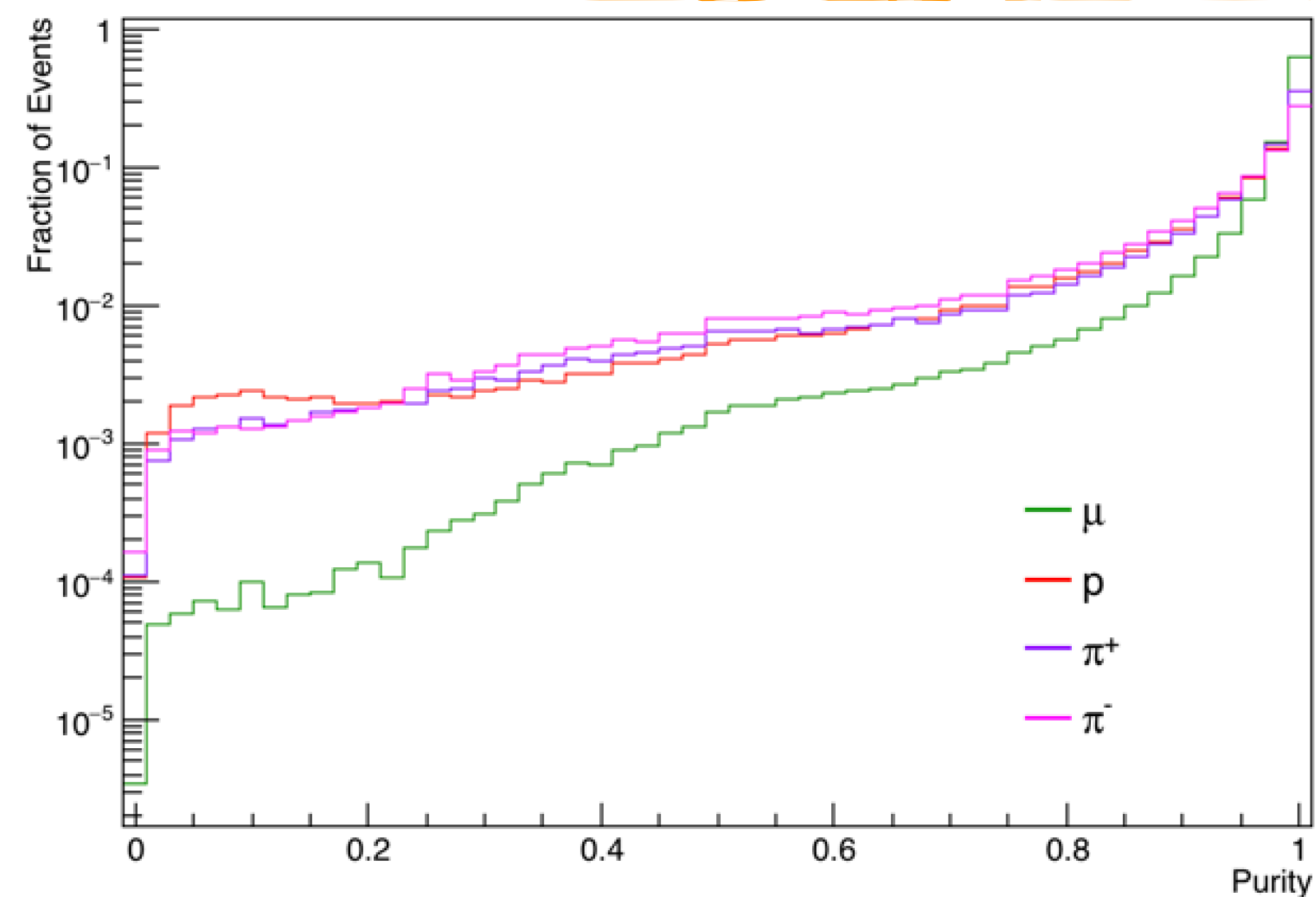
ALL INTERACTIONS

New: MCC10 samples  
(1x2x6) and latest  
Pandora

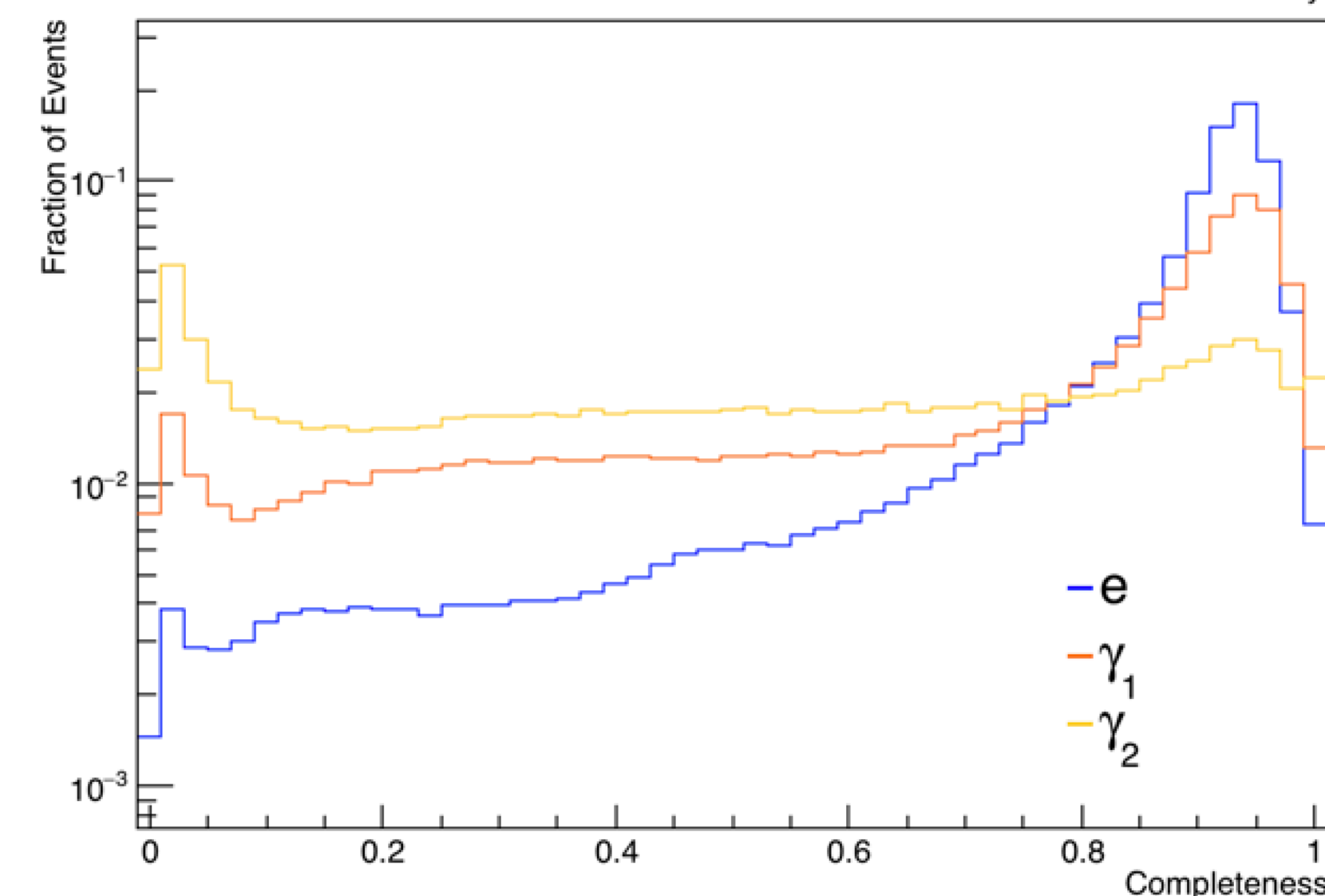
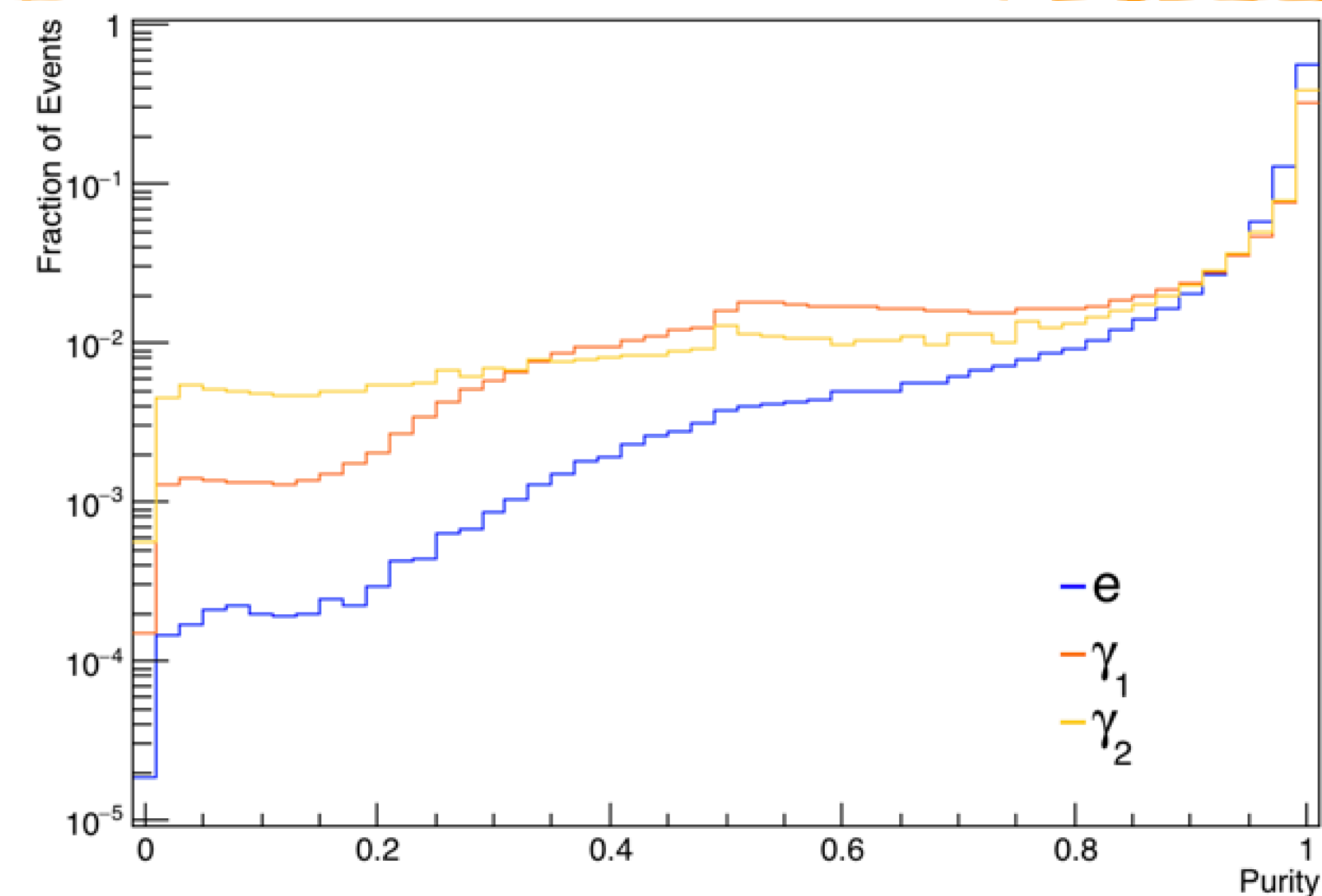
Preliminary! Plots to  
be repeated with  
MCC11 (?)

Purity and  
completeness

### Tracks



### Showers



Note: only leading proton (with largest #hits in the event),  $\gamma_1$  (largest #hits),  $\gamma_2$  (second largest #hits)



# TDR-ing

## 1.2.7.3 Performance

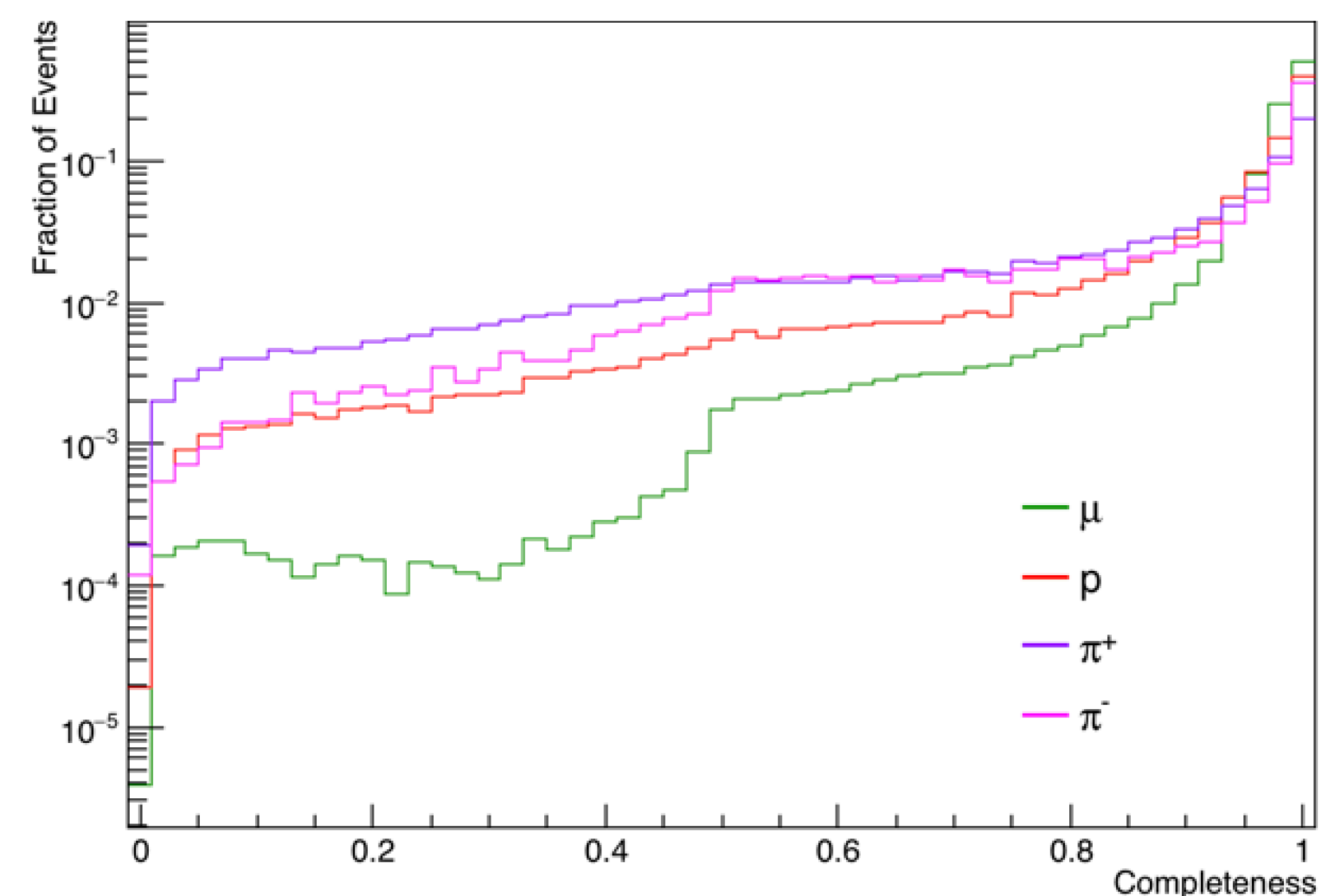
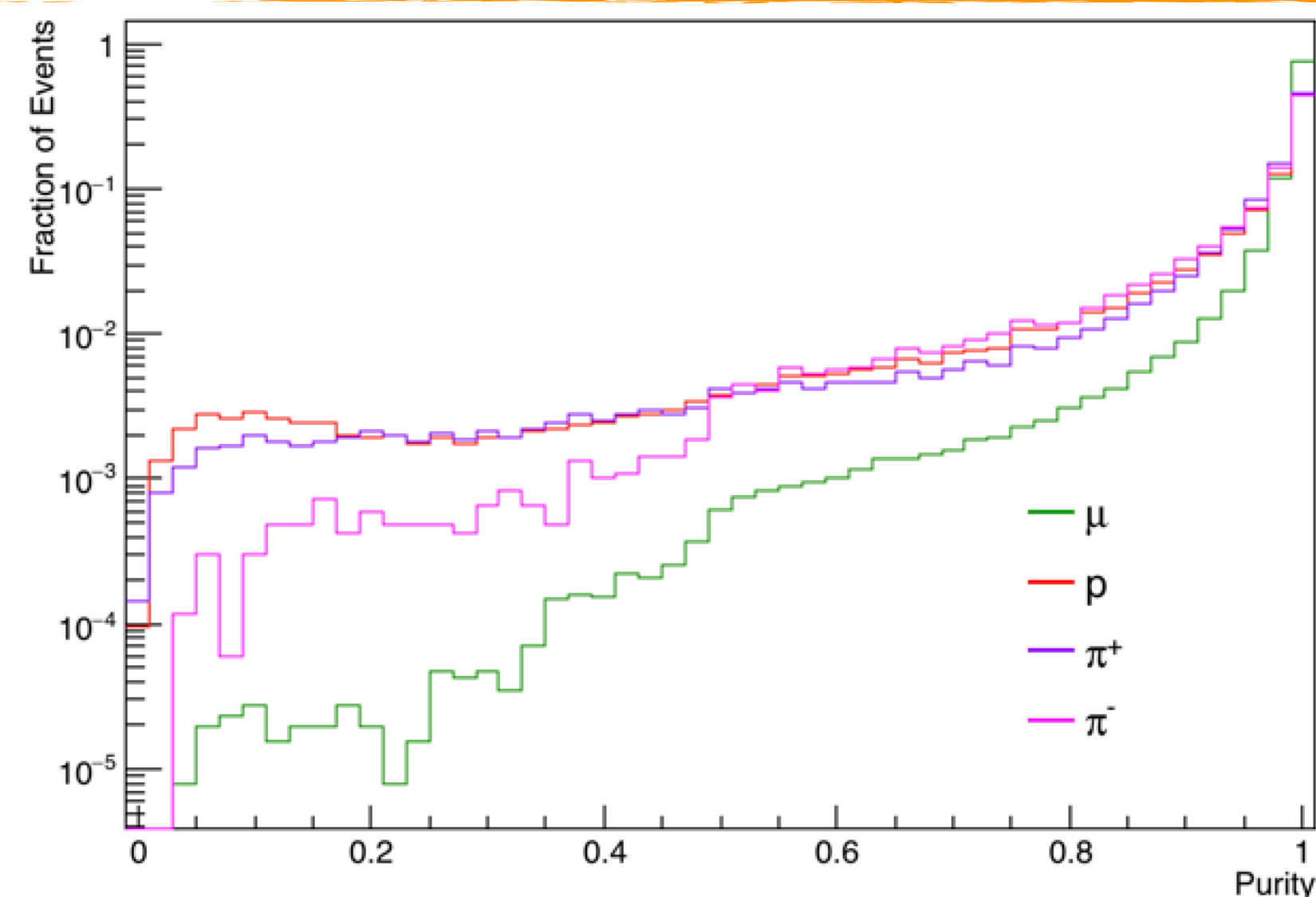
ALL BUT DIS  
(and OTHER\*)

New: MCC10 samples  
(1x2x6) and latest  
Pandora

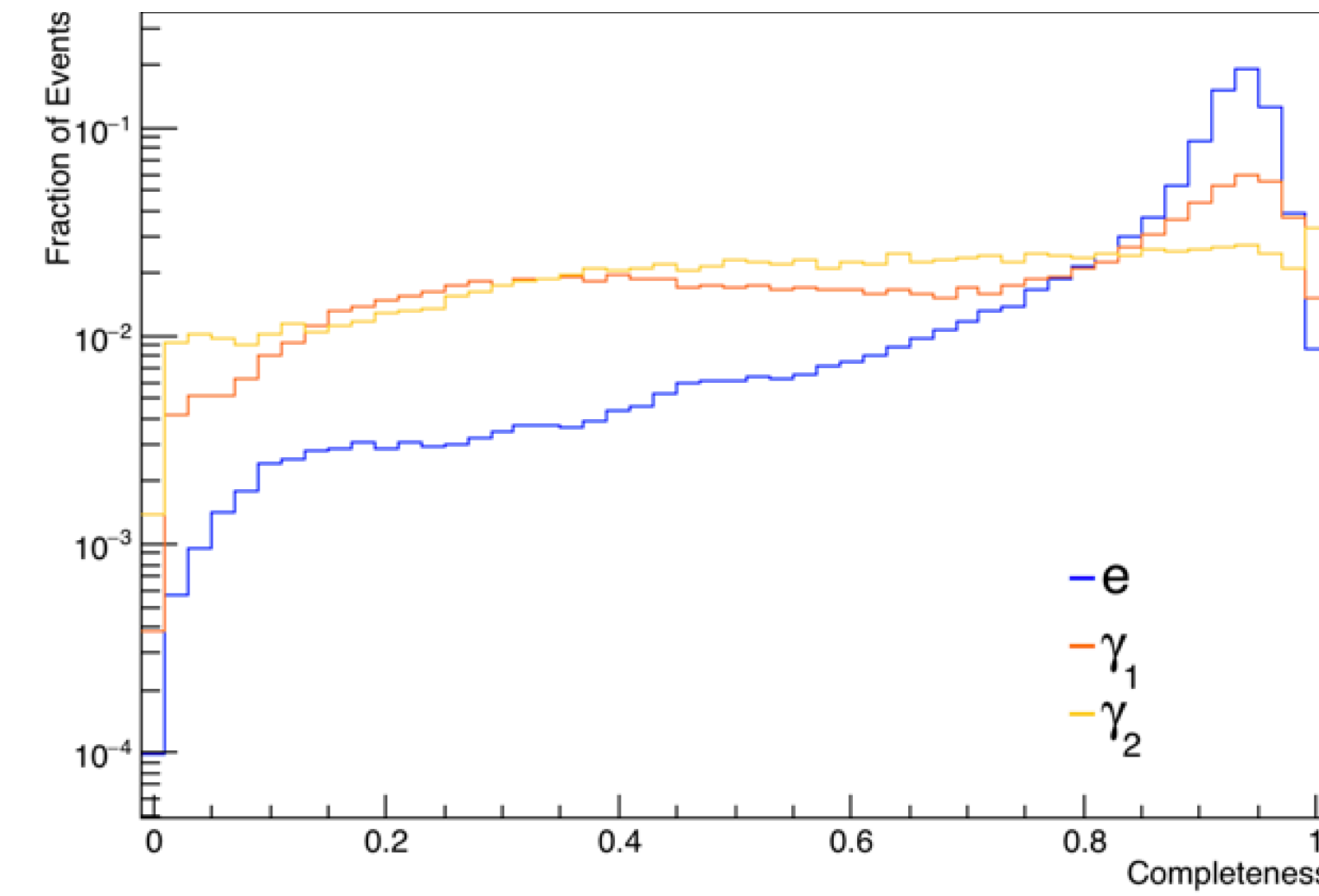
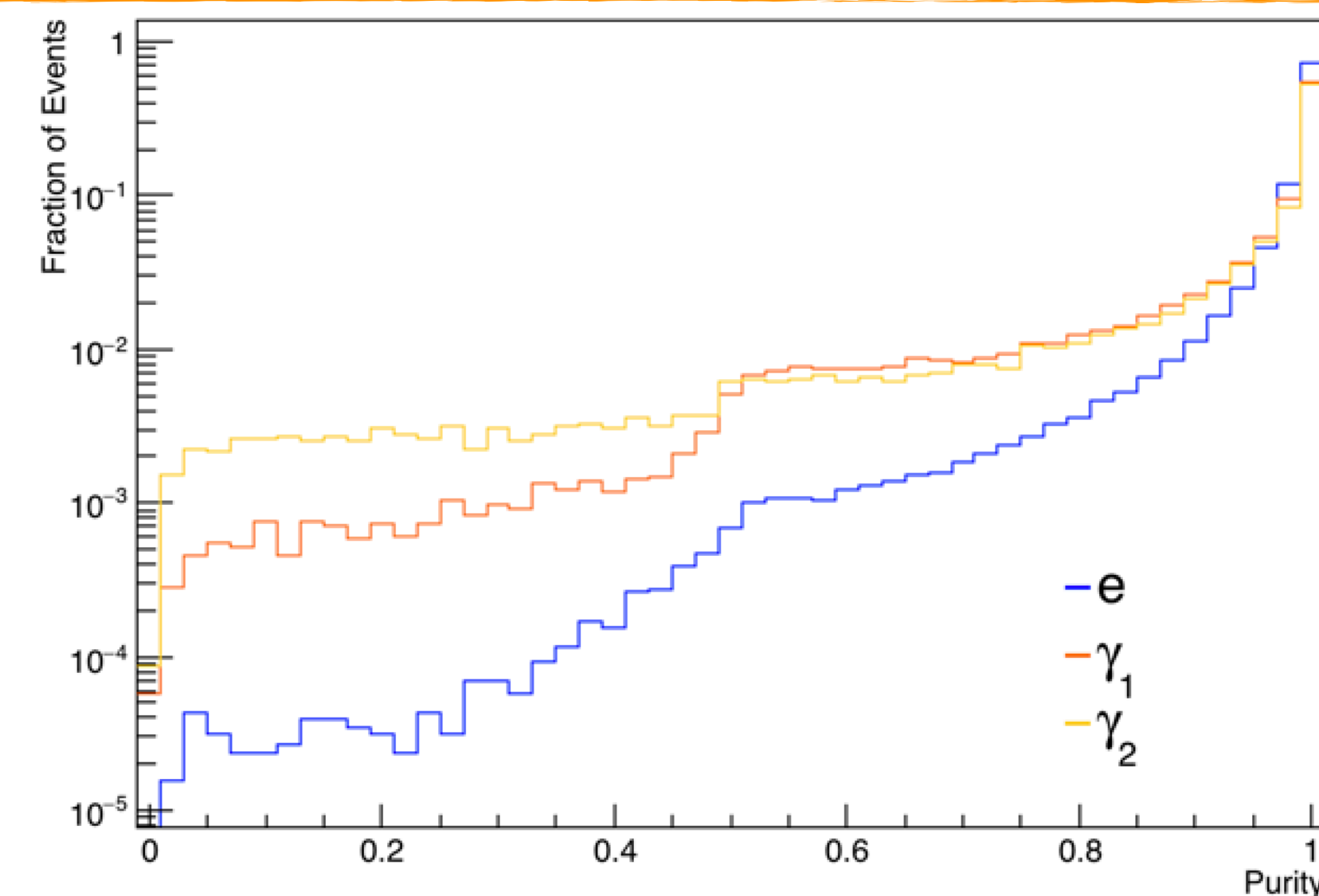
Preliminary! Plots to  
be repeated with  
MCC11 (?)

Question 2: Consider  
ALL INTERACTIONS  
except DIS ones?  
(compare to slide 9)

### Tracks



### Showers



Note: only leading proton (with largest #hits in the event),  $\gamma_1$  (largest #hits),  $\gamma_2$  (second largest #hits)





# TDR-ing

## 1.2.7.3 Performance

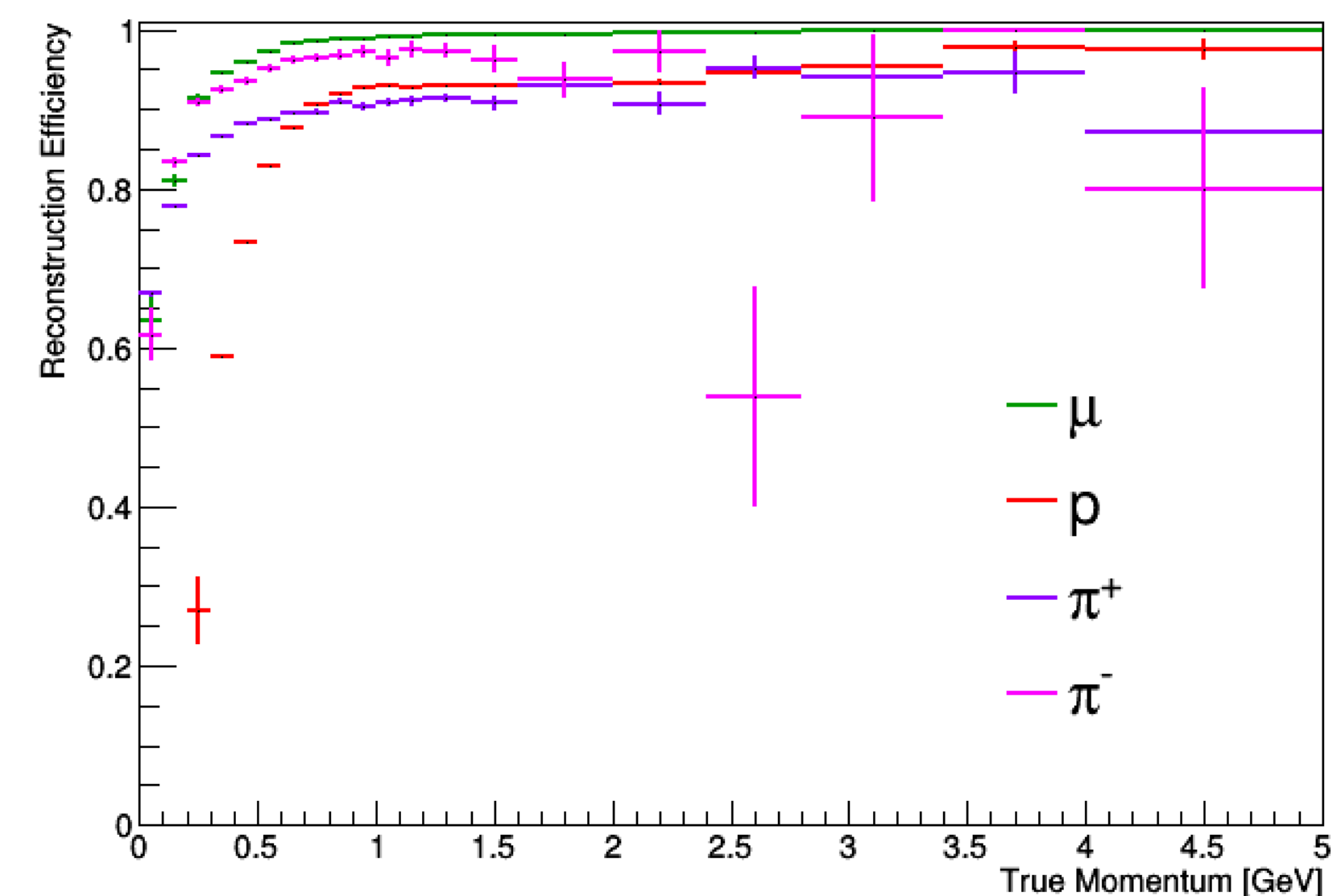
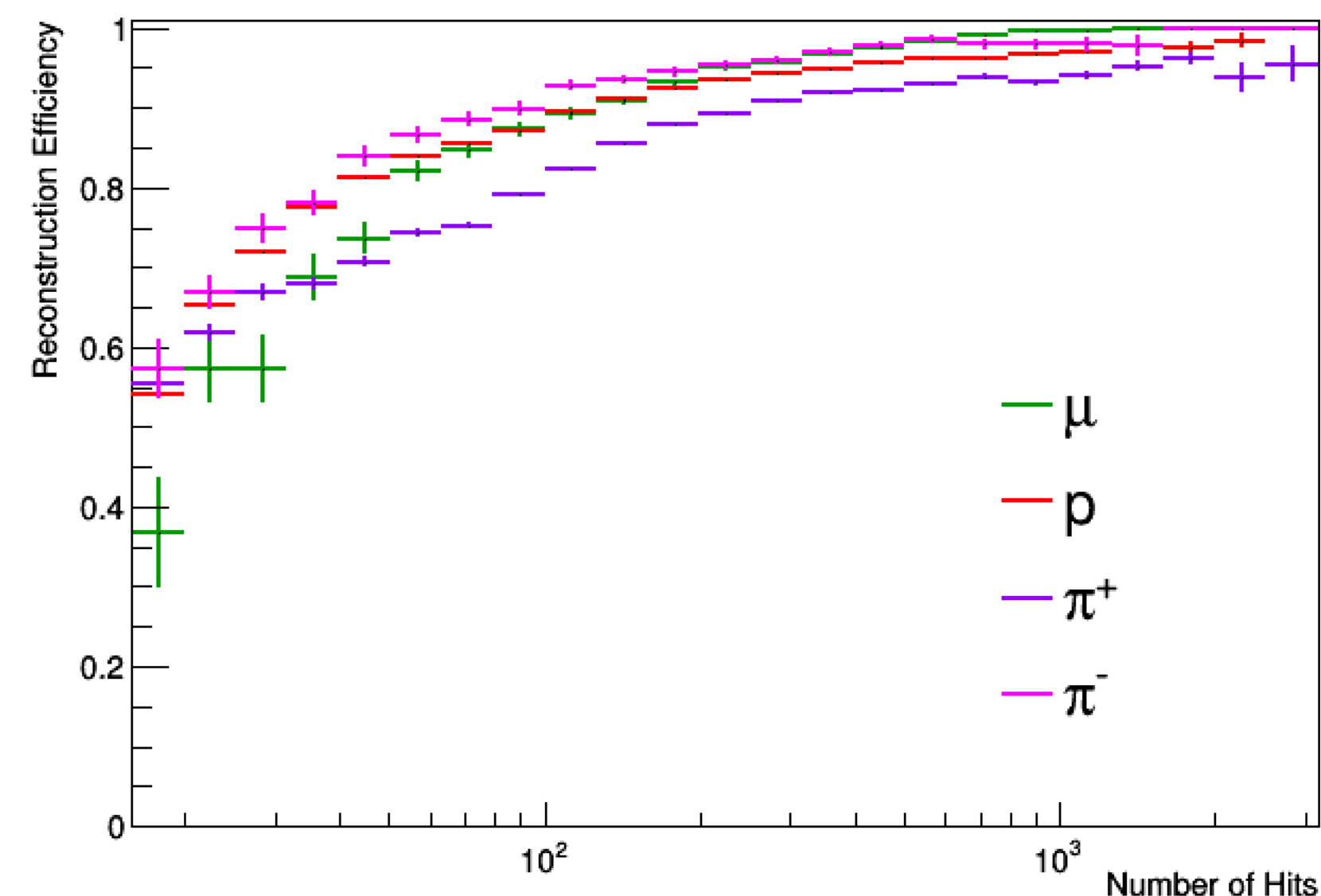
ALL BUT DIS  
(and OTHER\*)

New: MCC10 samples  
(1x2x6) and latest  
Pandora

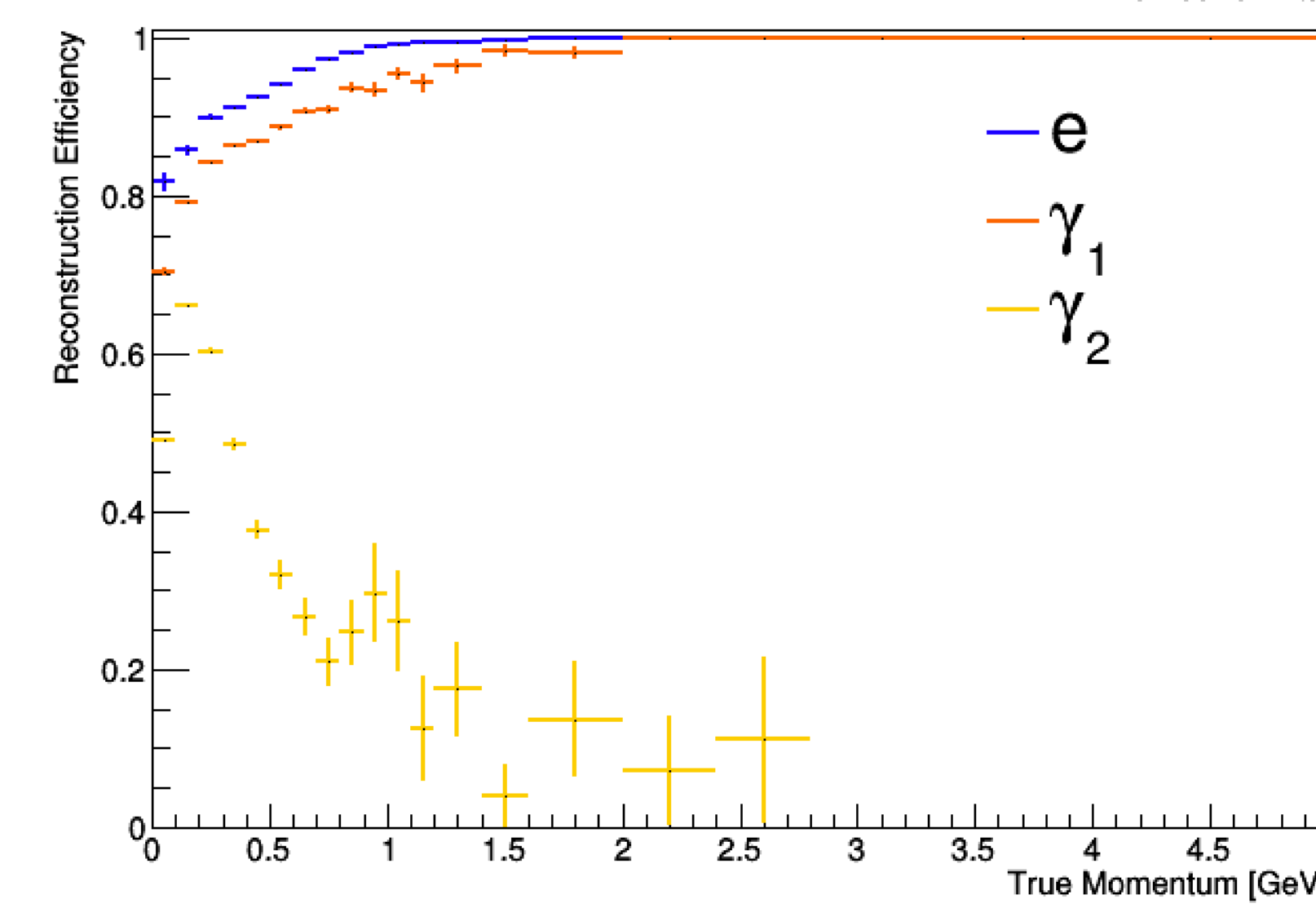
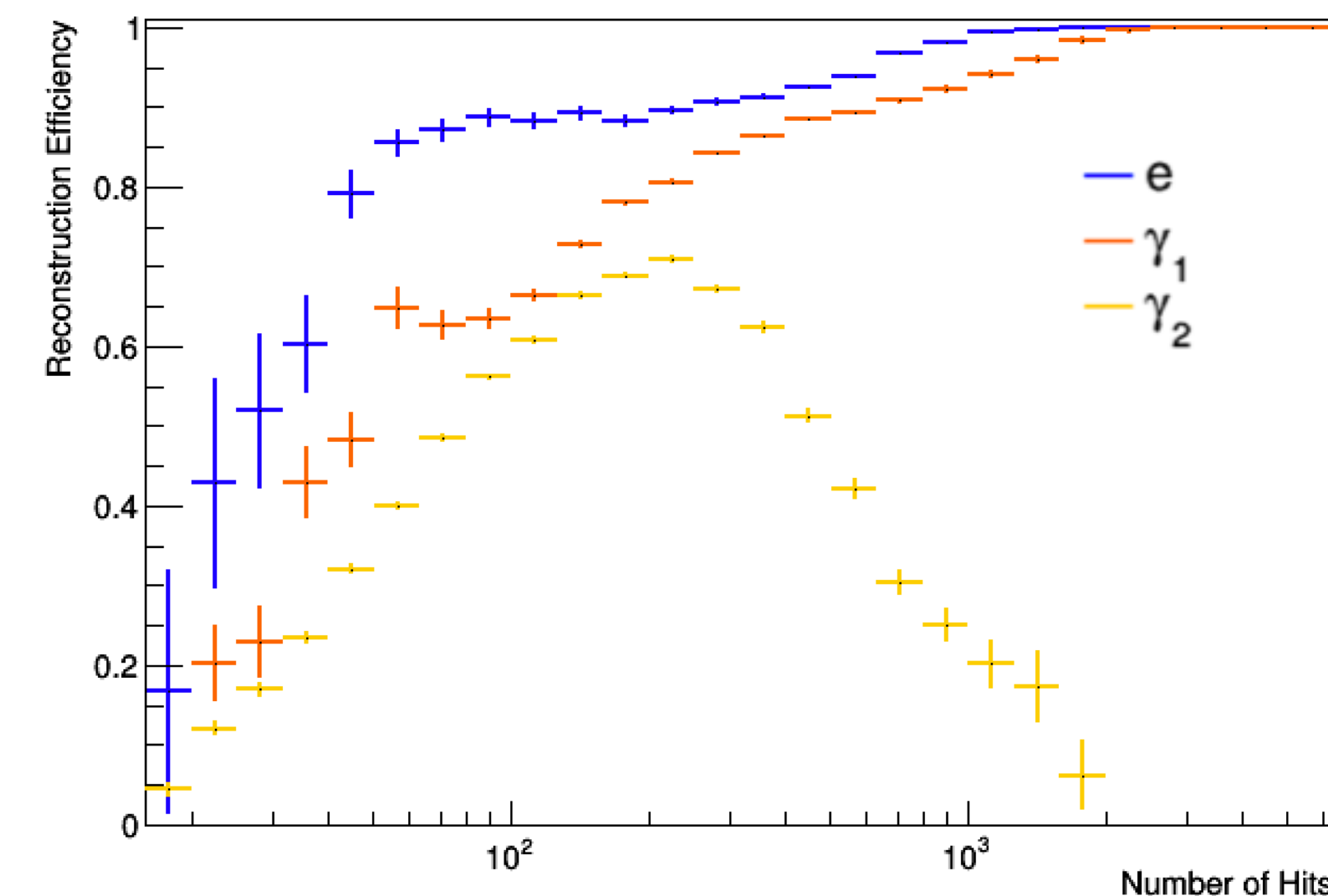
Preliminary! Plots to  
be repeated with  
MCC11 (?)

Question 2: Consider  
ALL INTERACTIONS  
except DIS ones?  
(compare to slide 8)

### Tracks



### Showers



Note: only leading proton (with largest #hits in the event),  $\gamma_1$  (largest #hits),  $\gamma_2$  (second largest #hits)

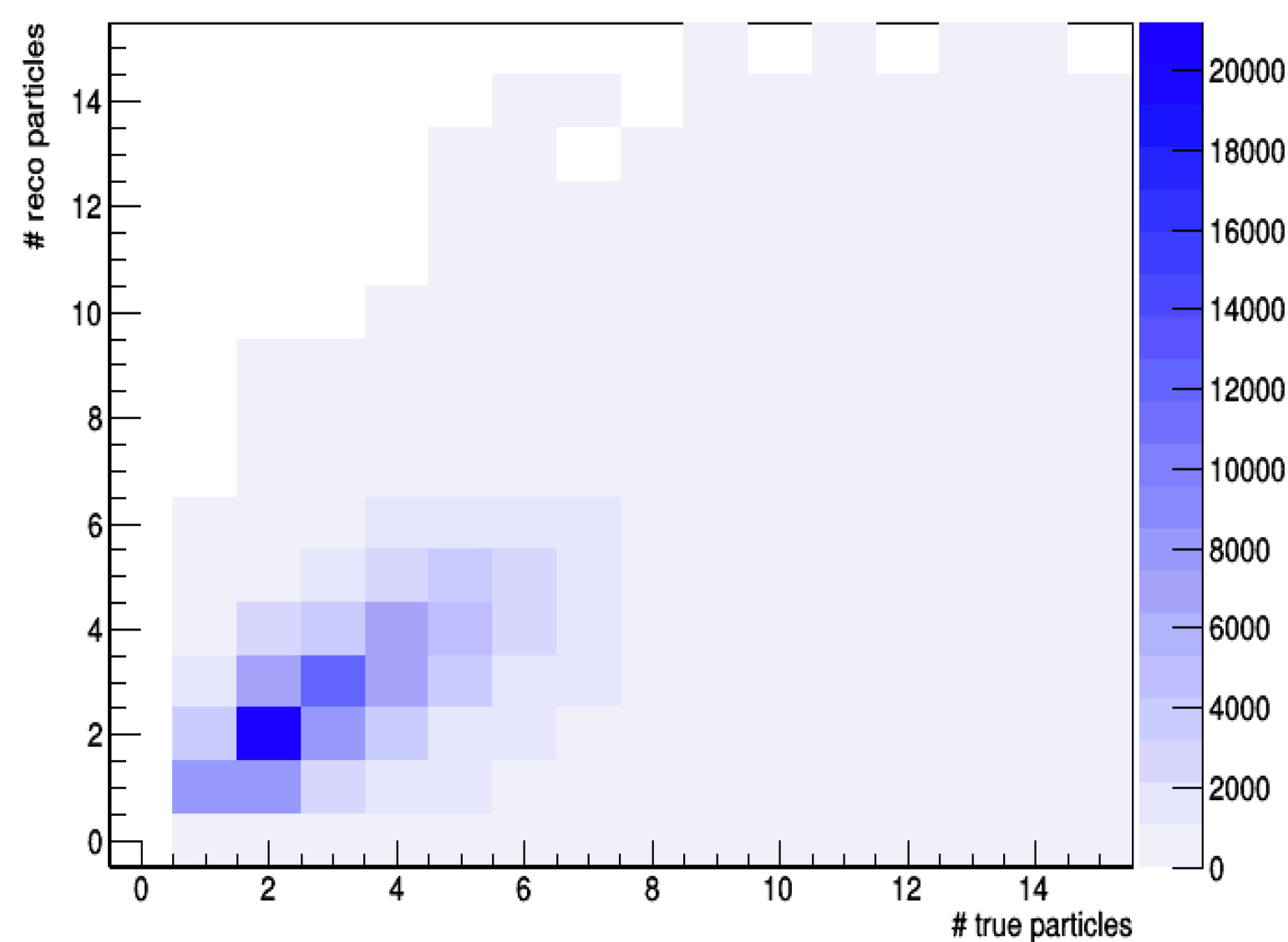


# TDR-ing

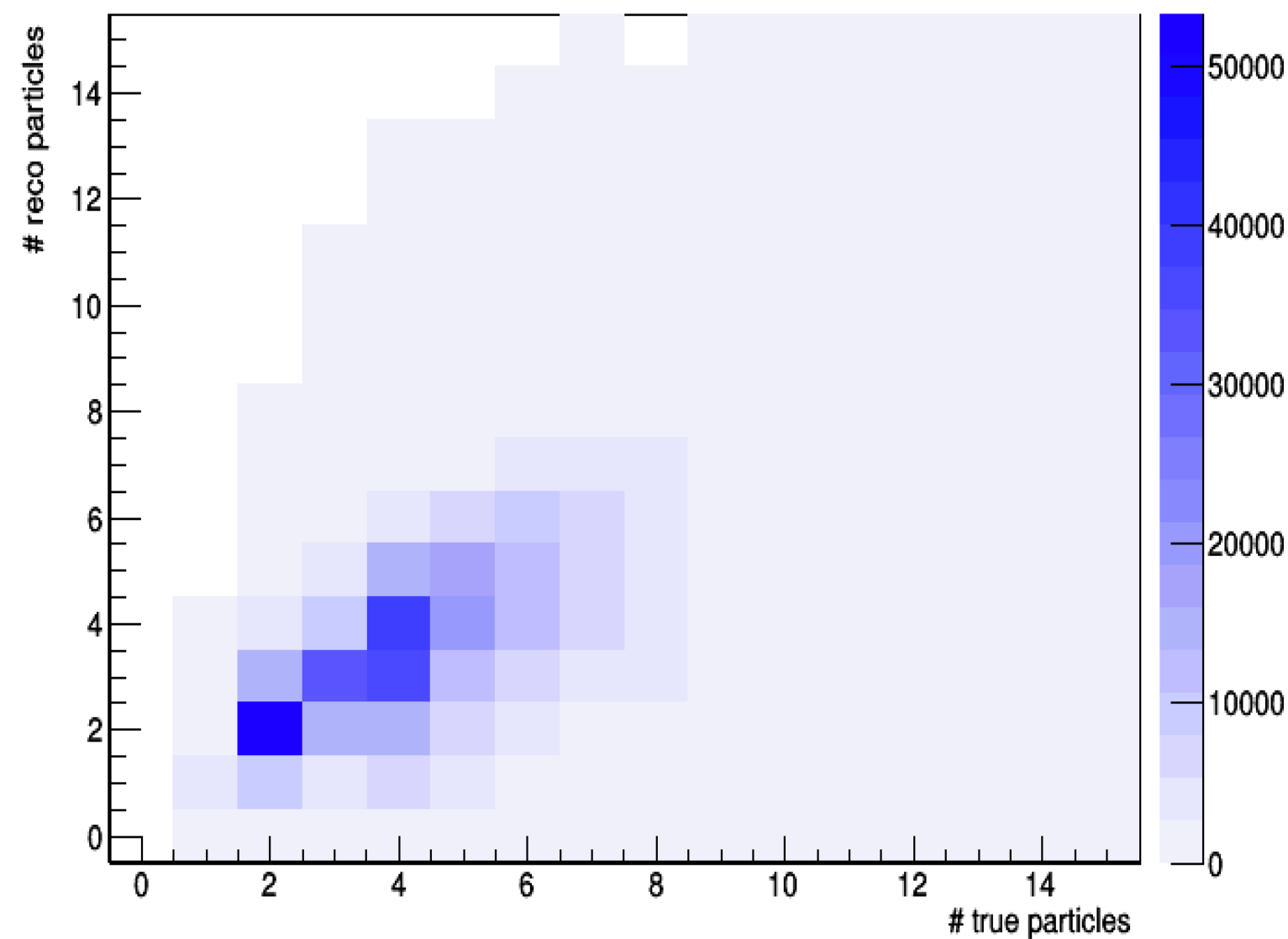
## 1.2.7.3 Performance ONLY DIS

New: MCC10 samples (1x2x6) and latest Pandora  
Preliminary! Plots to be repeated with MCC11 (?)

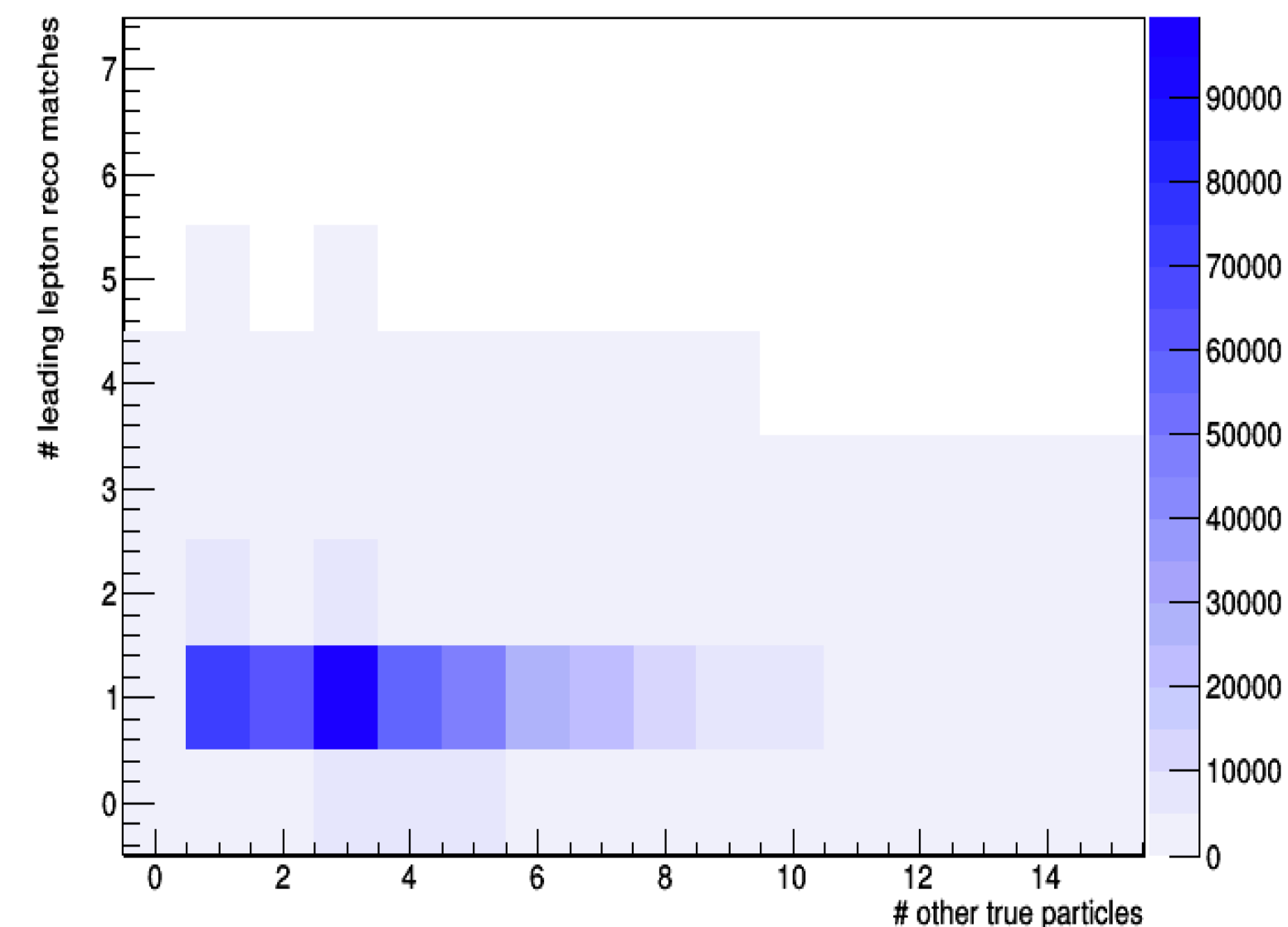
NC DIS



CC DIS



#reco vs #true particles



Lepton Matches

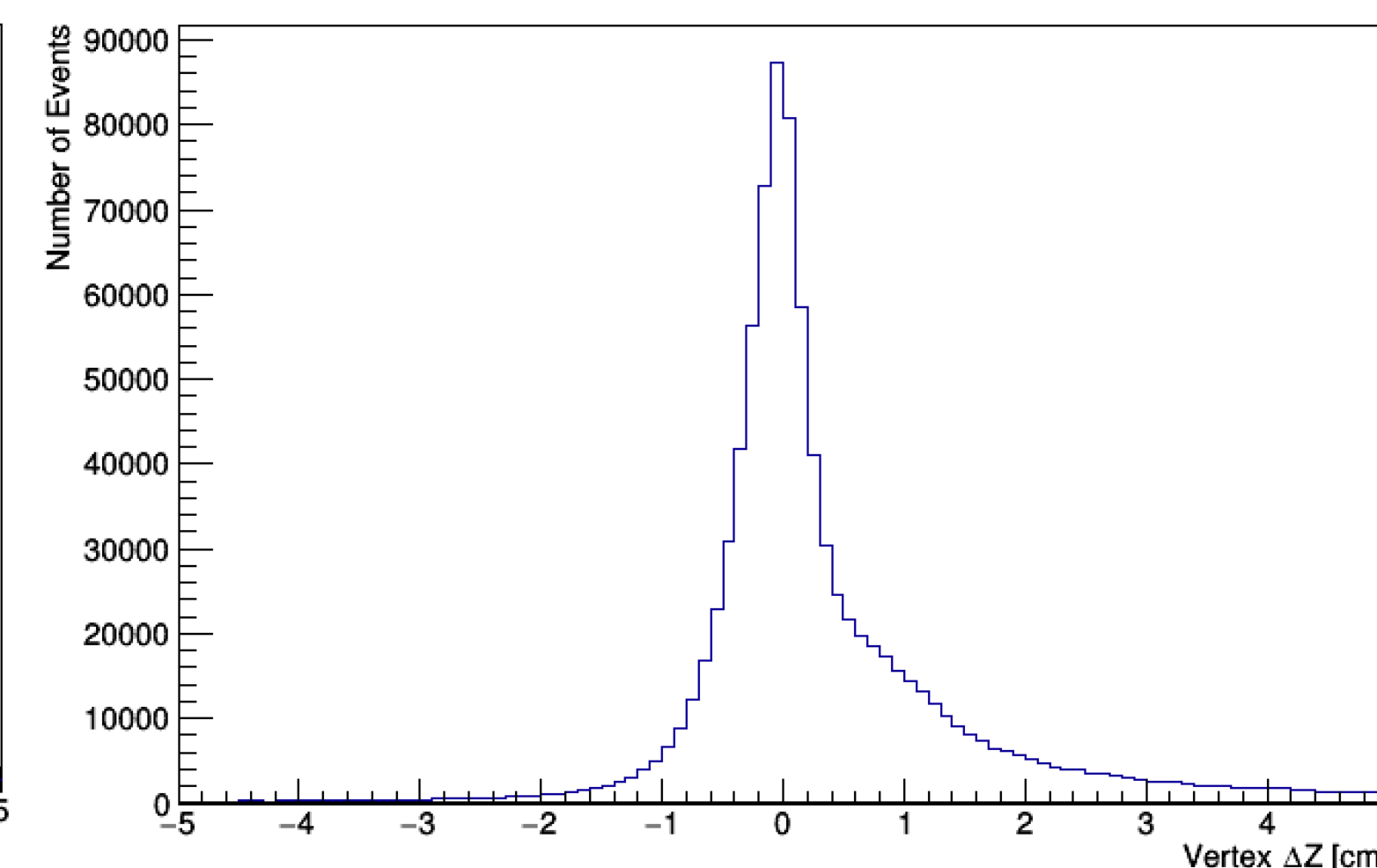
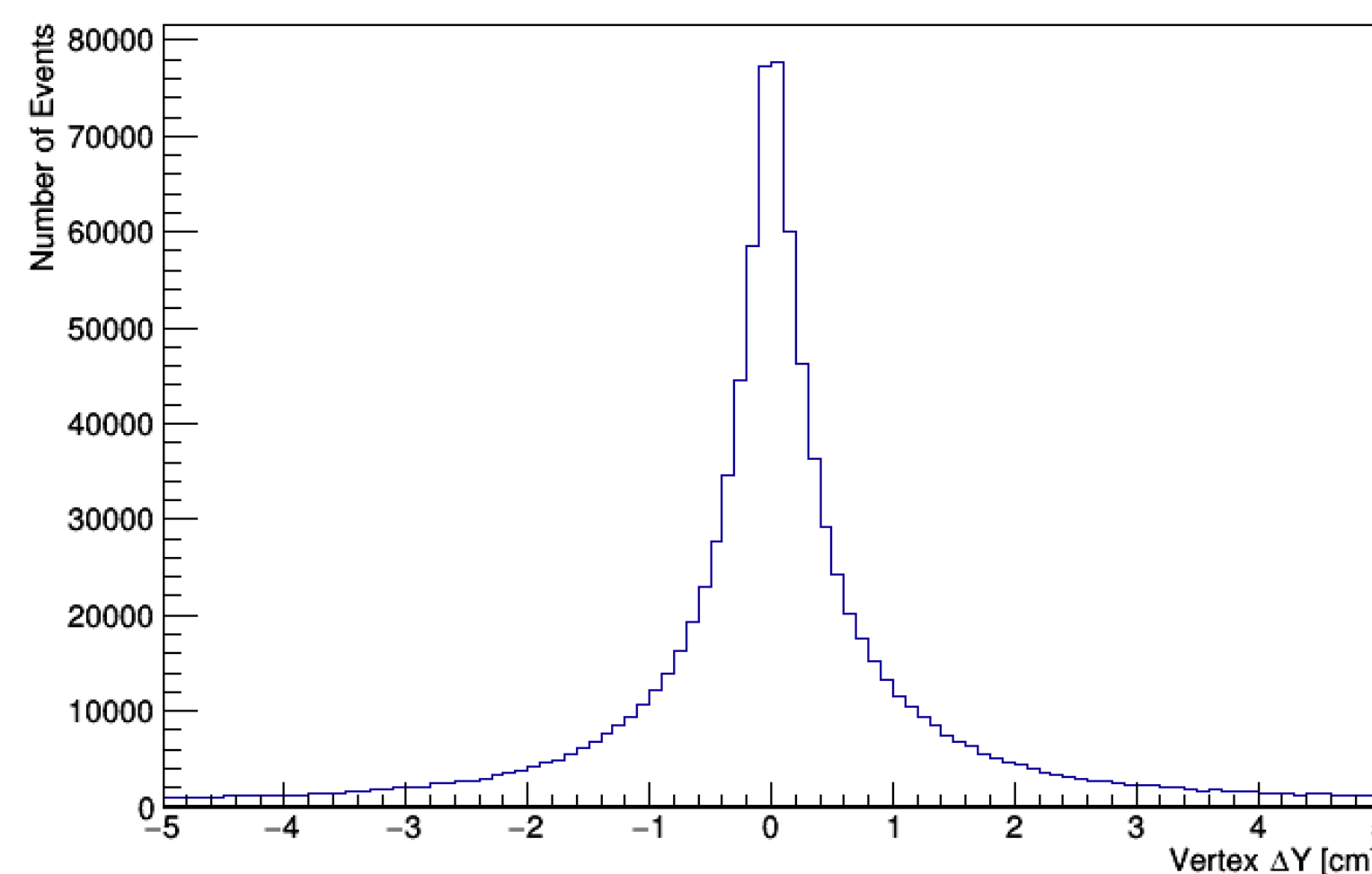
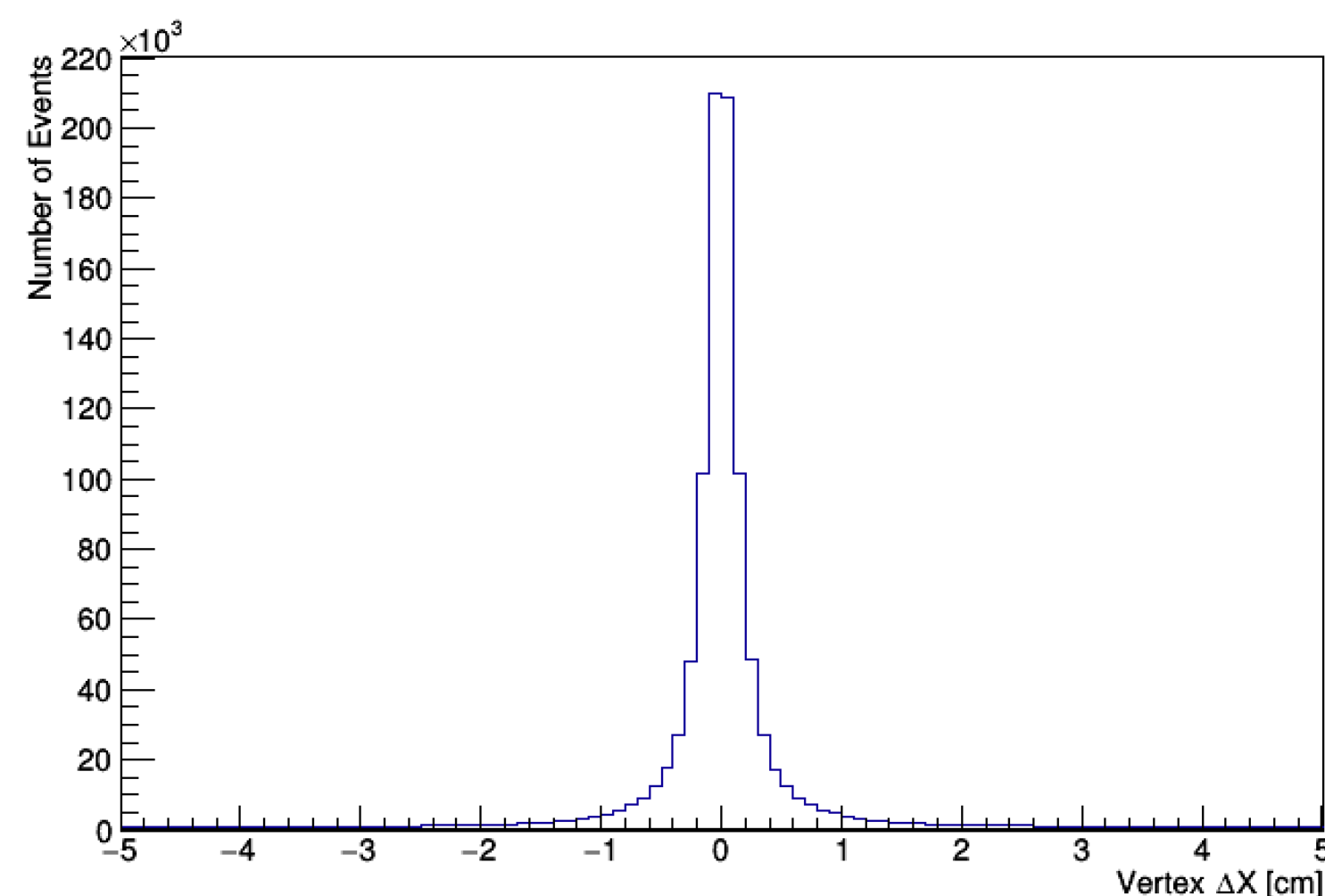


# TDR-ing

## 1.2.7.3 Performance

### ALL INTERACTIONS

**New: MCC10 samples (1x2x6) and latest Pandora**  
**Preliminary! Plots to be repeated with MCC11 (?)**



**Asymmetry observed in Z, feature associated with hits shared between overlapping particles (see backup)**





# TDR-ing

## 1.2.7.4 High Level Reconstruction TO PREPARE

### TRACKS

- Reco vs true length
- Reco vs true start position
- Reco vs true end position

### SHOWERS

- Reco vs true direction
- Reco vs true opening angle
- Reco vs true Energy
- Reco dEdx



# Pandora Pattern Recognition

Pandora is an open project and new contributors would be extremely welcome.  
We'd love to hear from you and we will always try to answer your questions.

## Pandora SDK Development

John Marshall ([John.Marshall@warwick.ac.uk](mailto:John.Marshall@warwick.ac.uk))

Mark Thomson ([thomson@hep.phy.cam.ac.uk](mailto:thomson@hep.phy.cam.ac.uk))

## LAr TPC algorithm development

John Marshall ([John.Marshall@warwick.ac.uk](mailto:John.Marshall@warwick.ac.uk))

Andy Blake ([a.blake@lancaster.ac.uk](mailto:a.blake@lancaster.ac.uk))

## DUNE FD Integration

Lorena Escudero ([escudero@hep.phy.cam.ac.uk](mailto:escudero@hep.phy.cam.ac.uk))

## ProtoDUNE Integration

Steven Green ([sg568@hep.phy.cam.ac.uk](mailto:sg568@hep.phy.cam.ac.uk))

## MicroBooNE Integration

Andy Smith ([asmith@hep.phy.cam.ac.uk](mailto:asmith@hep.phy.cam.ac.uk))

## Other team members

MicroBooNE: Joris Jan de Vries, Jack Anthony

ProtoDUNE: Stefano Vergani



<https://github.com/PandoraPFA>



<https://pandorapfa.slack.com>



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University



WARWICK  
THE UNIVERSITY OF WARWICK





# Pandora Performance Metrics

## 1. Determine the primary true particle in each 2D hit.

- Use true particle hierarchy to determine primary “reco targets”.
- Associate hits to primary particles making largest E contribution.

True particles must have  
 $\geq 15$  true hits

Reco/true particles must  
share  $\geq 5$  hits to match

## 2. Match reconstructed particles to true particles:

- For each reco/true combination, find number of ‘matched’ 2D hits (common to both reco and true particles). Fold all daughter reco and true particles back into parent primaries.
- Matching algorithm, find all “strong” matches, then pick-up remaining “weak” matches:
  - i. Find strongest (most shared hits) match between any reco and true particle
  - ii. Repeat step i, using reco and true particles at most once, until no further matches possible
  - iii. Assign any remaining reco particles to true particle with which they share most hits

## 3. ‘Efficiency’ = fraction of true particles with at least one matched reco particle

‘Completeness’ = fraction of 2D hits in true particle shared with the reco particle

‘Purity’ = fraction of 2D hits in reco particle shared with the true particle

Accurately match one reco particle to each true particle  $\Rightarrow$  **Correct Event**

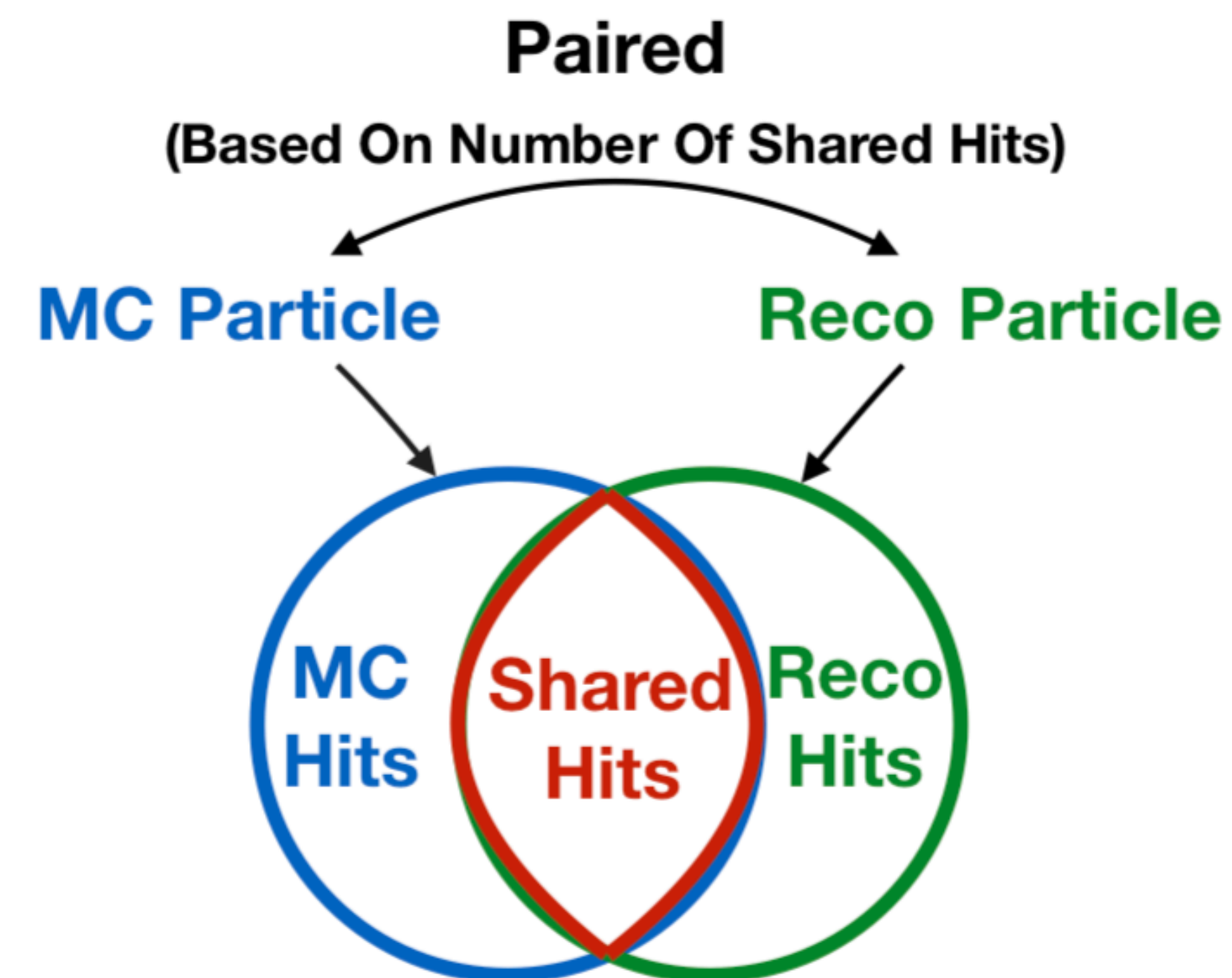




# Pandora Performance Metrics

There are different ways of defining *efficiency*, for us reconstruction efficiency is:

Fraction of target MCParticles (step 1 in previous slide) with at least one matched reconstructed particle, where a match needs to fullfill conditions based on number of shared hits:



\*Purity =  $\text{nSharedHits} / \text{nRecoHits} > 50\%$

\*Completeness =  $\text{nSharedHits} / \text{nMCHits} > 10\%$

\*OTHER (pages 10-11): We breakdown interactions in different categories based on the generator interaction code (e.g. CCQEL, DIS, etc.) and # of final state particles (e.g. CCQEL\_MU\_P). We do this to be able to look at efficiencies vs # of final particles in the event, informative to some extent (e.g. we split up to CCQEL\_MU\_P\_P\_P\_P\_P) while other combinations would fall into OTHER category

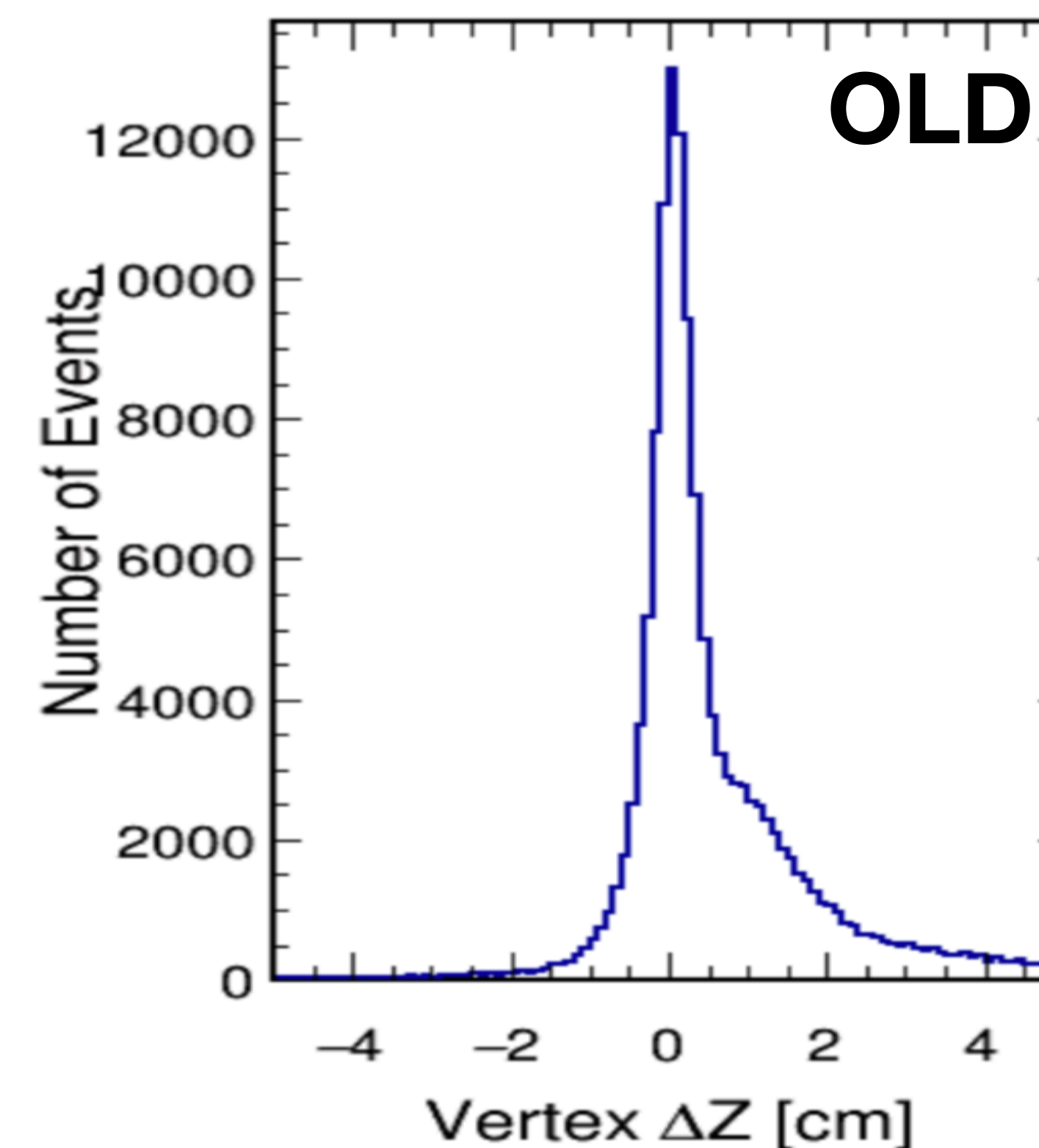
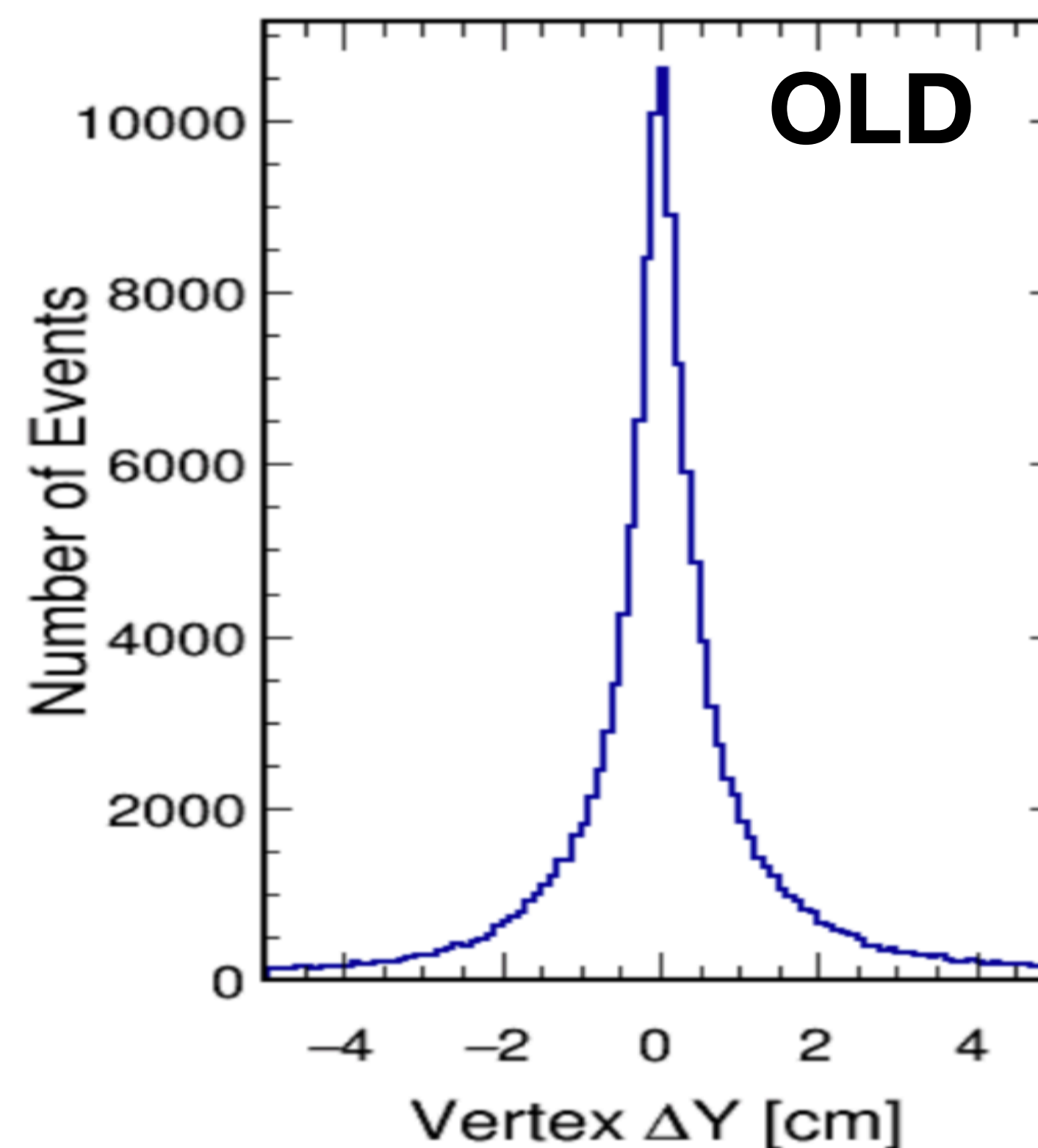
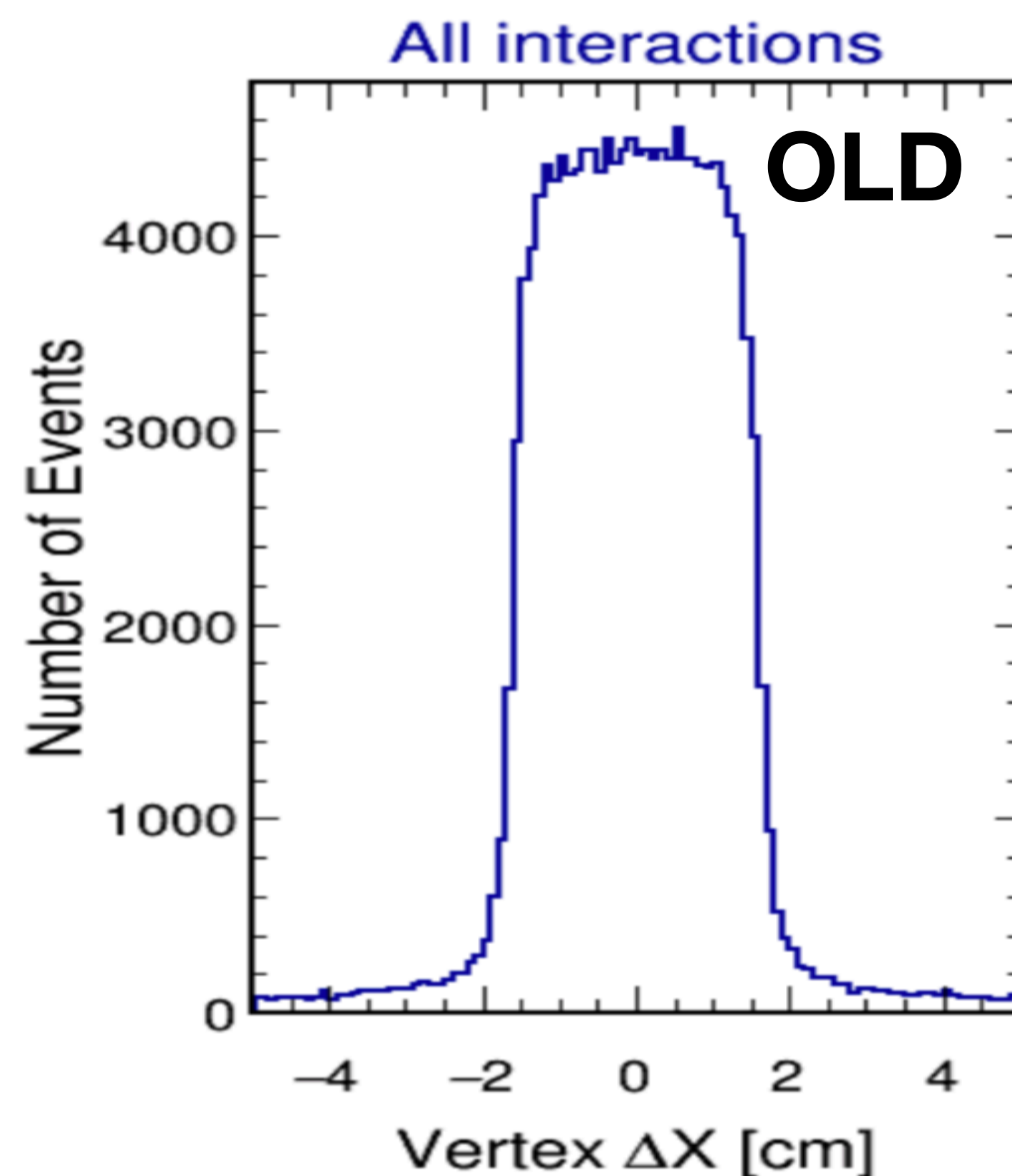


# TDR-ing

## 1.2.7.3 Performance

Old, circa summer 2017 (?)

Range of T0 values between generated particles and hit placements explaining DeltaX in old samples





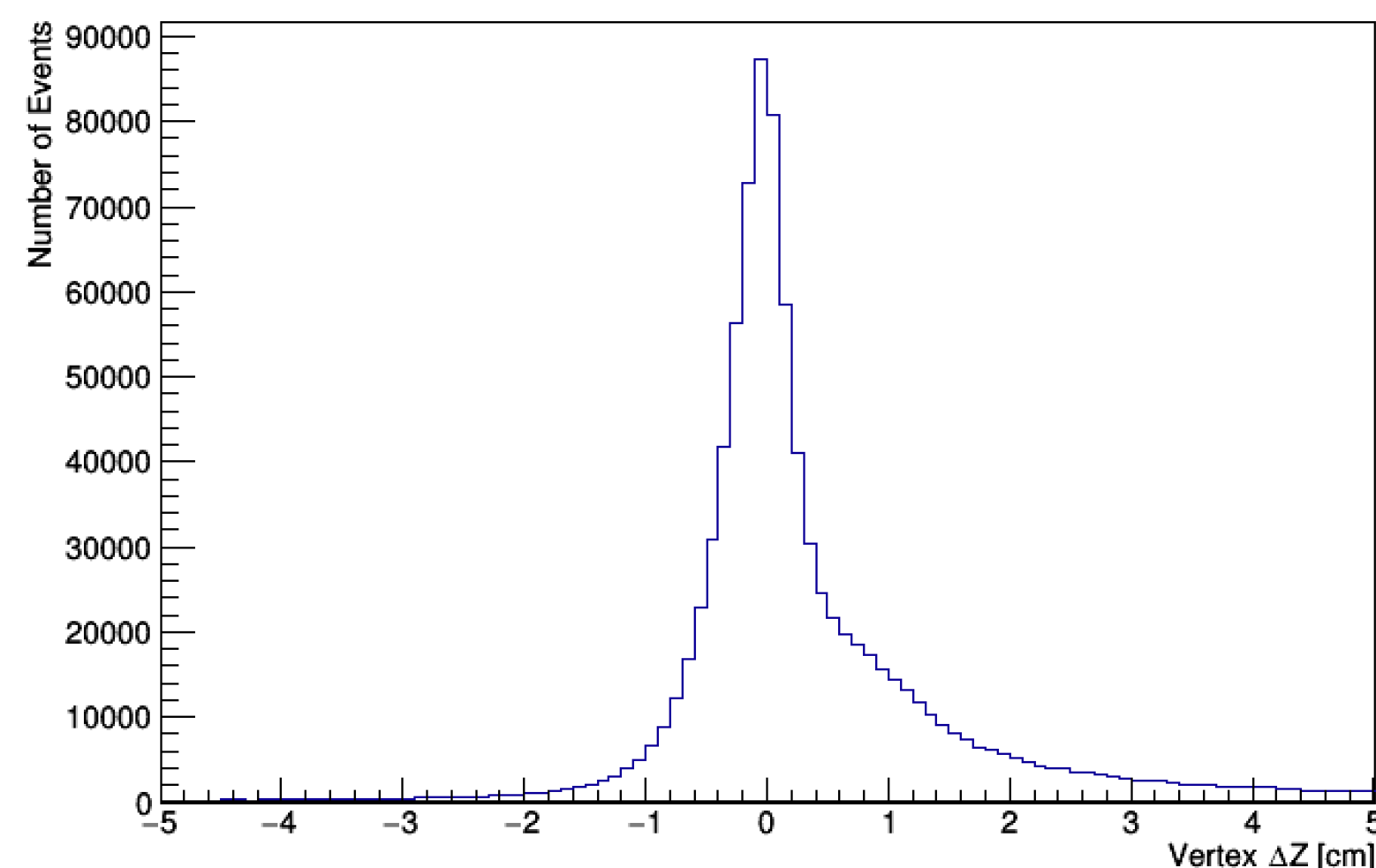


# TDR-ing

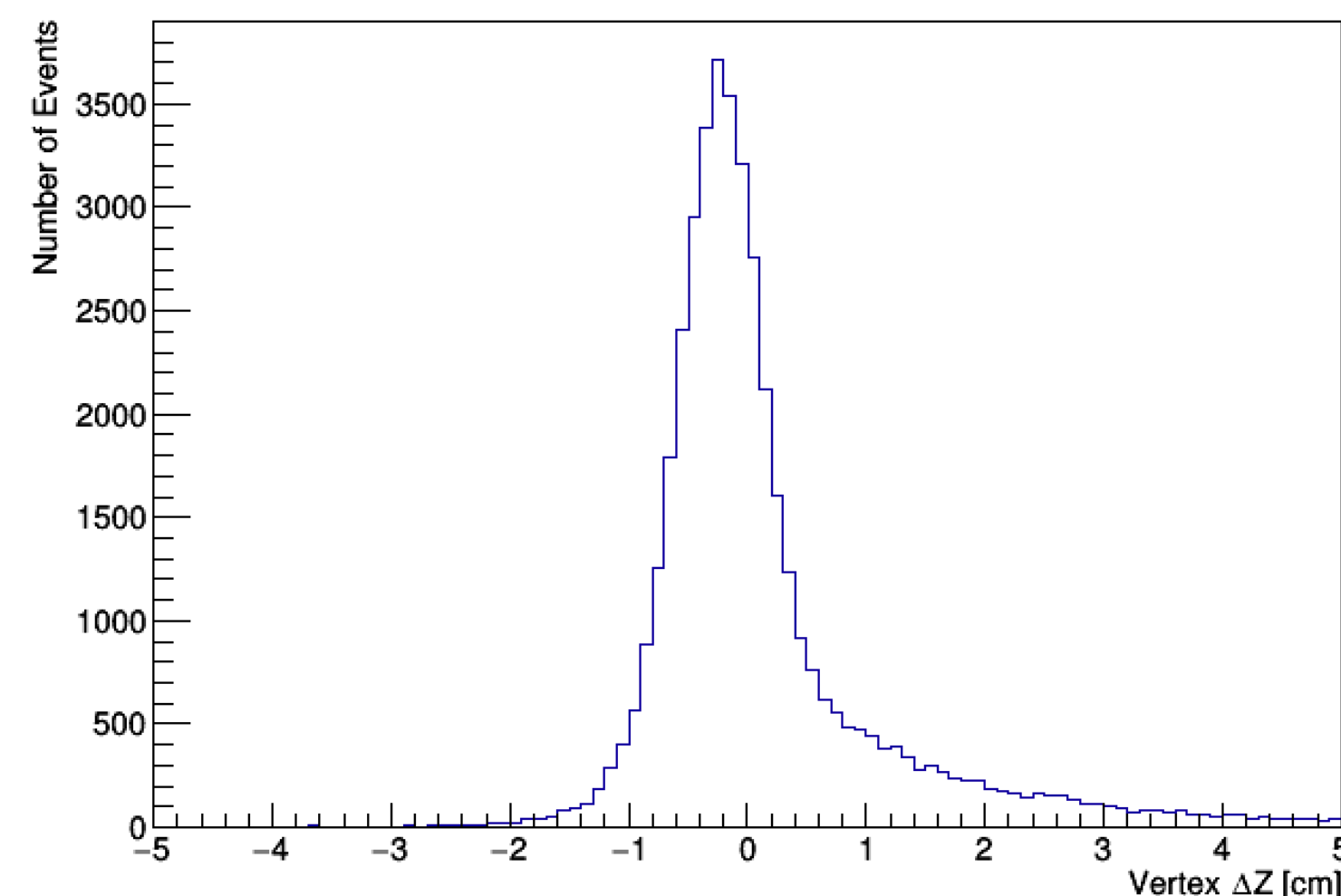
## 1.2.7.3 Performance

**New: MCC10 samples (1x2x6) and latest Pandora**  
**Preliminary! Plots to be repeated with MCC11 (?)**

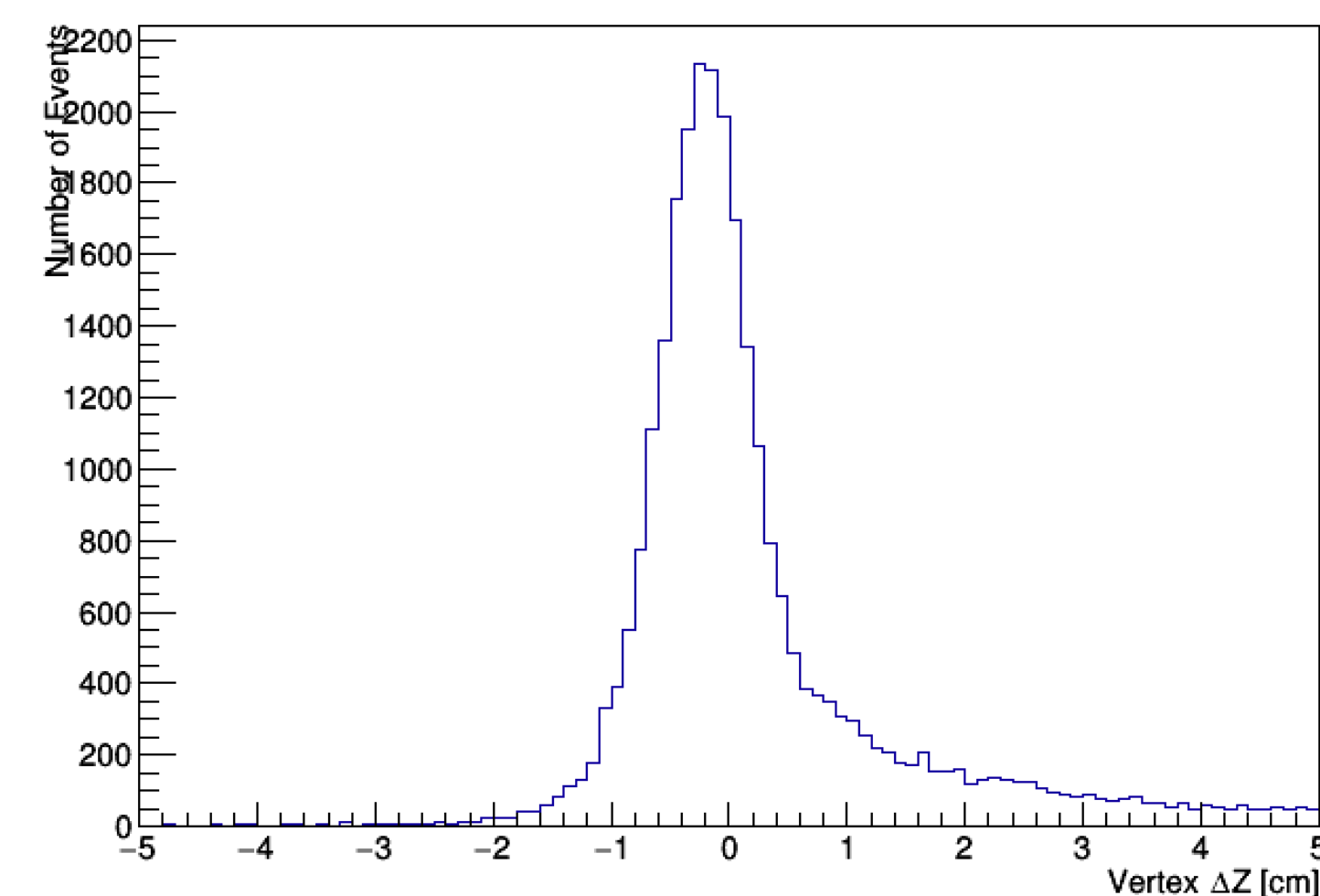
### ALL INTERACTIONS



### CCQEL\_MU



### CCQEL\_E



**Asymmetry observed in Z, feature associated with hits shared between overlapping particles, highly reduced when looking at events with single final state particles. Observed, but not so pronounced, in MicroBooNE as well.**