



Advanced Particle Flow

- Development of advanced particle flow and pattern recognition algorithms in PandoraPFA
- Application to LHC, LC and neutrino experiments

J. S. Marshall, *introducing work on behalf of many people*, 30 September 2016

Pandora has been used for the official MicroBooNE summer analyses presented at Neutrino 2016

Also at Neutrino2016 poster session

MicroBooNE Software Stack

- Neutrino event generator: GENIE 2.8.6 (and GENIE 2.10.6 for systematics studies)
- Cosmic event generator: CORSIKA v7.4003
- Particle tracking + detector response: GEANT v4.9.6.p04d + LArSoft v04_36
- Reconstruction: LArSoft v05_08 + Pandora v2.3.0a

M. Toups

First Results From MicroBooNE

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Convolutional Neural Networks Applied to Neutrino Events in a Liquid Argon Time Projection Chamber
- ◇ 7/4/16 [MICROBOONE-NOTE-1017-PUB](#)
A Method to Extract the Charge Distribution Arriving at the TPC Wire Planes in MicroBooNE
- ◇ 7/4/16 [MICROBOONE-NOTE-1016-PUB](#)
Noise Characterization and Filtering in the MicroBooNE TPC
- ◇ 7/4/16 [MICROBOONE-NOTE-1015-PUB](#)
The Pandora multi-algorithm approach to automated pattern recognition in LAr TPC detectors

The Pandora multi-algorithm approach to automated pattern recognition in LAr TPC detectors
J. S. Marshall (marshall@hep.phy.cam.ac.uk) for the Pandora team*

Pandora Multi-Algorithm Approach

- Use a large number of algorithms (80+) to examine Hits and identify Particles.
- Each algorithm carefully developed to address a specific event topology.
- Some algorithms sophisticated, others simple; gradually build-up picture of events.
- Approach made possible by the Pandora Software Development Kit:
 1. Easy to provide the building-blocks that define a pattern recognition problem (Hits).
 2. Logic required to solve pattern recognition problems cleanly implemented in algorithms.
 3. Operations to access or modify building-blocks requested by algs, performed by Pandora.
- Build upon successes developing particle flow reconstruction for ILC/CLIC.

Two multi-algorithm reconstruction chains available: Some algorithms common to both reconstruction chains, others tailored to details of specific event topologies.

Reconstruction Overview

- 2D Clustering**: Search for unambiguous groups of Hits to form initial Clusters of high purity.
- 2D Topological Association**: A series of algorithms carefully perform Cluster merging and splitting to improve completeness and purity.
- 3D Vertex Reconstruction**: Assess distribution of Hits around vertex candidates; 3 x 2D. Use 2D Clusters to provide list of 3D vertex candidates. Chosen Vertex is candidate from which paths of Hits emerge.
- 3D Track Matching**: Assess compatibility of 2D Clusters from three readout planes. Make iterative 2D changes until combinations of Clusters representing each true particle is unambiguous.
- 2D/3D Shower Reconstruction**: Merge 2D shower-spine and branch Clusters. Match 2D Clusters between planes to form 3D shower Particles.
- 3D Event Building**: 3D Hits and Vertices created for all Track, Shower Particles. Parent-daughter links specify the Particle Hierarchy.
- Output to LArSoft**: Parent Particle, Daughter Particle, Particle Hierarchy.

Pandora LAr TPC

- Reusable software, aim to support breadth of LAr TPC programme: MicroBooNE, DUNE, ProtoDUNE, LArAT, SBND
- Range of neutrino energies
- Range of detector configurations:
 - Deal with multiple drift volumes
 - Support 2 x 2D and 3 x 2D readout
 - Deal with presence of cosmic rays

Performance: MicroBooNE MC

Subset of ν_μ CC quasi-elastic interactions: $\nu_\mu + N \rightarrow X + p + \mu^-$

Reconstruction Efficiency	Number of Hits	Number of Vertices	Number of Particles
0.87%	0.97%	0.81%	0.83%
19.8%	76.8%	5.5%	6.3%

Subset of ν_μ CC interactions with resonant charged pion production: $\nu_\mu + N \rightarrow X + p + \pi^+ + \mu^-$

Reconstruction Efficiency	Number of Hits	Number of Vertices	Number of Particles
6.8%	67.7%	6.1%	6.4%
26.5%	75.9%	4.9%	5.5%
15.6%	71.5%	3.8%	4.1%

Subset of ν_μ CC interactions with resonant neutral pion production: $\nu_\mu + N \rightarrow X + p + \pi^0 + \mu^-$

Reconstruction Efficiency	Number of Hits	Number of Vertices	Number of Particles
7.8%	67.6%	4.4%	4.5%
19.8%	76.5%	5.5%	6.7%
15.6%	69.5%	3.2%	3.5%

Status at time of Neutrino 2016 very well documented

Public note available [here](#)



- Hosted inaugural **Pandora Workshop** this summer in Cambridge, focused on MicroBooNE LAr TPC reco.
- 4 days of talks and exercises after Neutrino 2016. Opportunity to understand all aspects of Pandora.

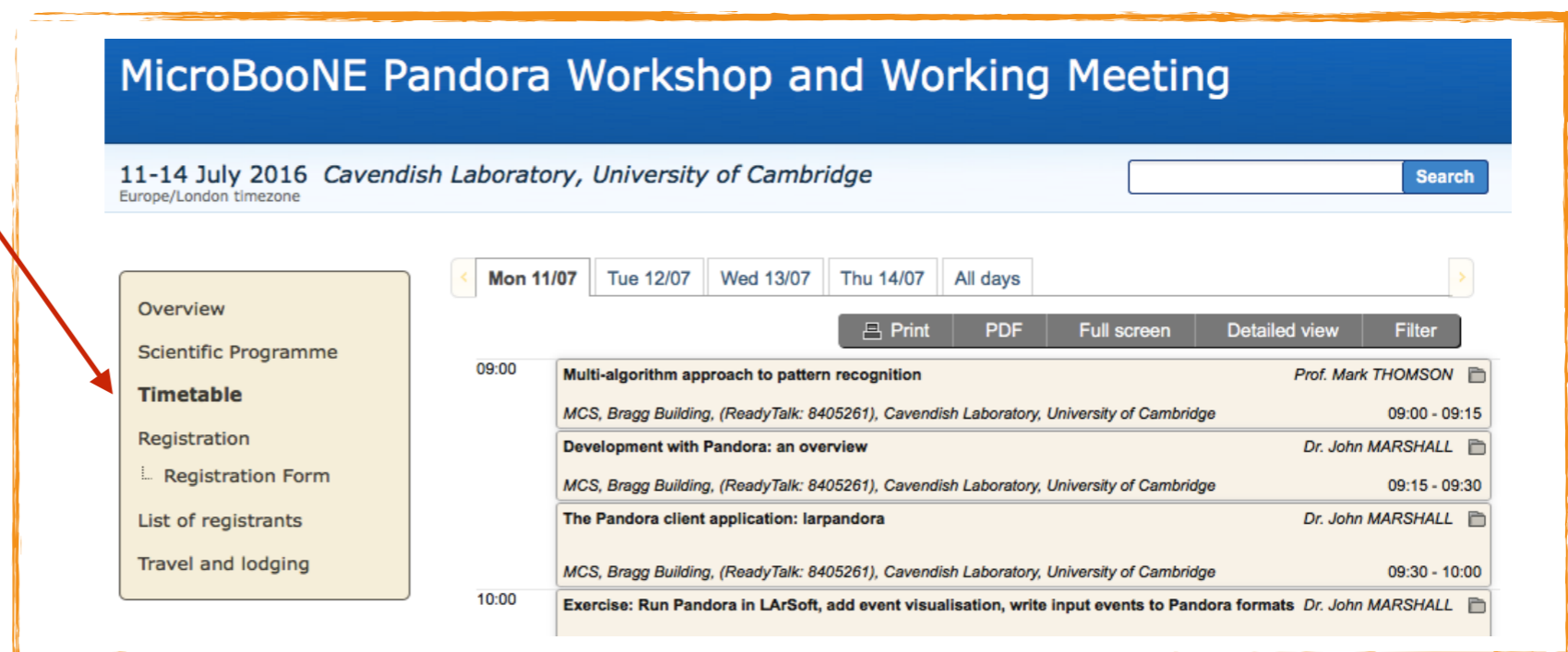


Exercises:

1. Run Pandora in LArSoft
2. Create and configure a new algorithm
3. Add alg implementation for cluster creation
4. Add alg implementation for cluster merging
5. Add alg implementation for particle creation
6. Use output to LArSoft in an analyser
7. Particle merging
8. Track-Shower ID
9. More (Example content)

Exercises and Talks available from [Indico](#) or [GitHub](#)

A great success, very good feedback. Will likely repeat (and inc. DUNE)



MicroBooNE Pandora Workshop and Working Meeting

11-14 July 2016 Cavendish Laboratory, University of Cambridge
Europe/London timezone

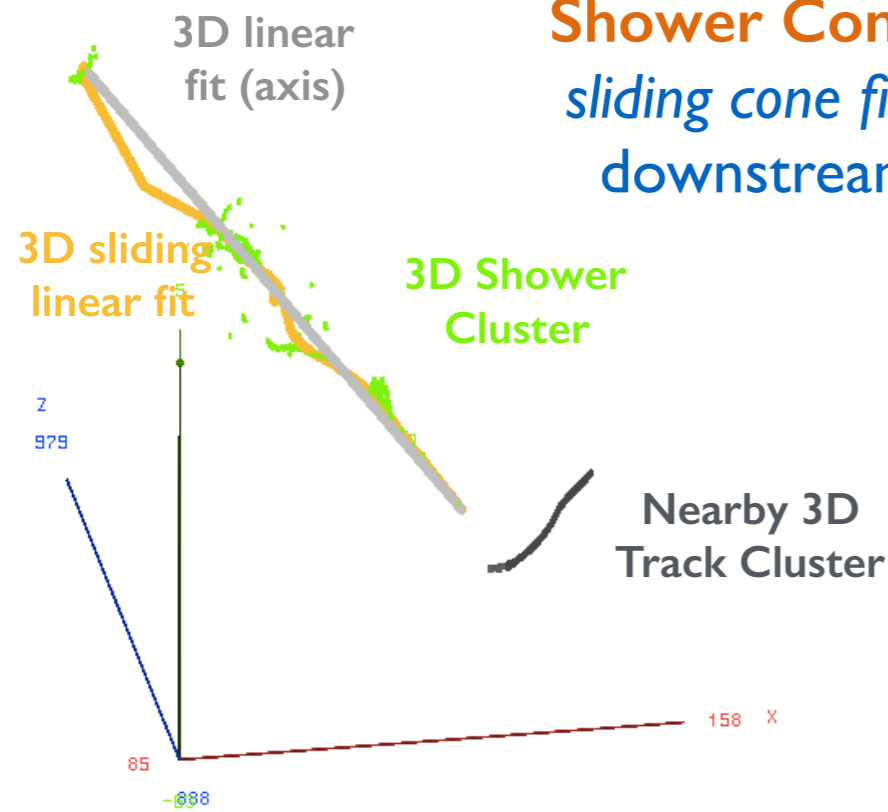
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Mon 11/07 Tue 12/07 Wed 13/07 Thu 14/07 All days

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09:00	Multi-algorithm approach to pattern recognition Prof. Mark THOMSON
	MCS, Bragg Building, (ReadyTalk: 8405261), Cavendish Laboratory, University of Cambridge 09:00 - 09:15
	Development with Pandora: an overview Dr. John MARSHALL
	MCS, Bragg Building, (ReadyTalk: 8405261), Cavendish Laboratory, University of Cambridge 09:15 - 09:30
	The Pandora client application: larpandora Dr. John MARSHALL
	MCS, Bragg Building, (ReadyTalk: 8405261), Cavendish Laboratory, University of Cambridge 09:30 - 10:00
10:00	Exercise: Run Pandora in LArSoft, add event visualisation, write input events to Pandora formats Dr. John MARSHALL

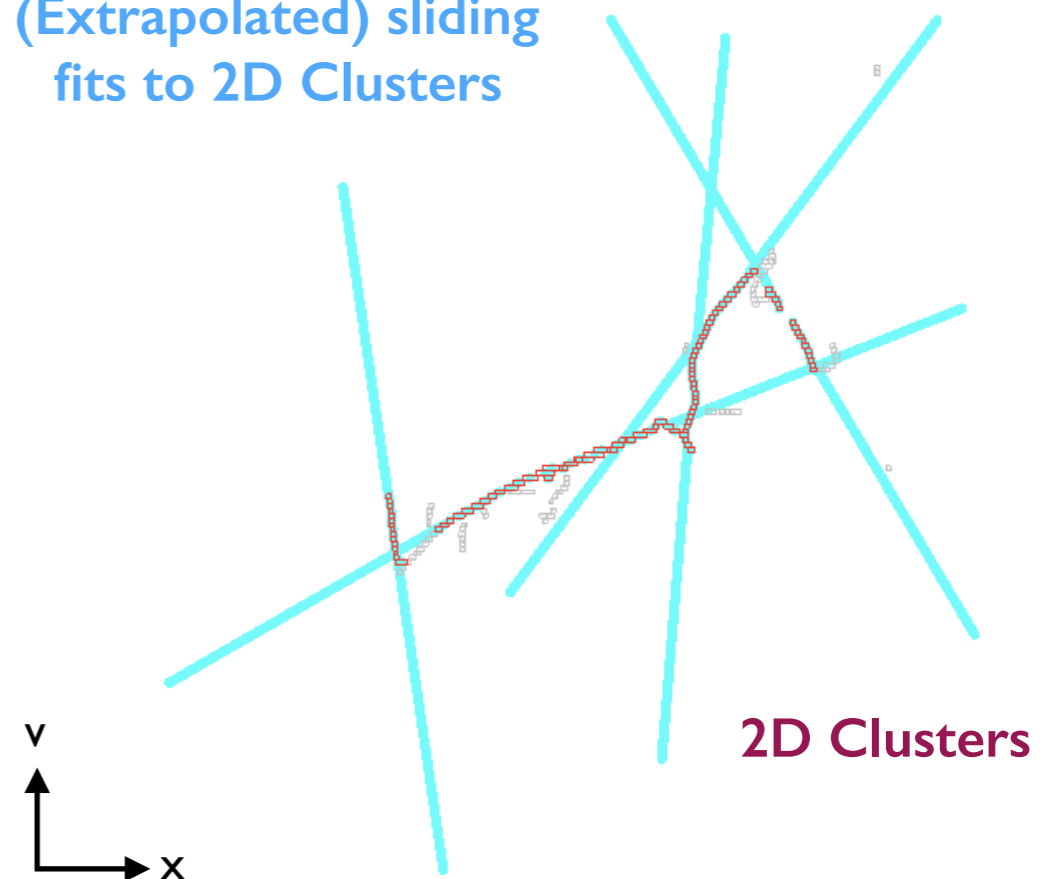
Shower Completeness:
sliding cone fits to collect downstream fragments



Currently working hard to identify and address remaining issues in the complex and diverse event topologies

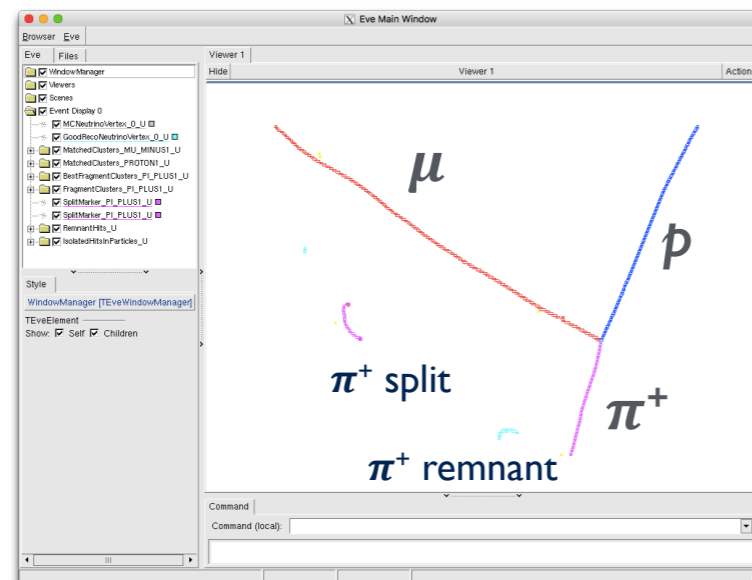
Vertex Improvements:
Additional vertex candidates and improved vertex selection approach

(Extrapolated) sliding fits to 2D Clusters



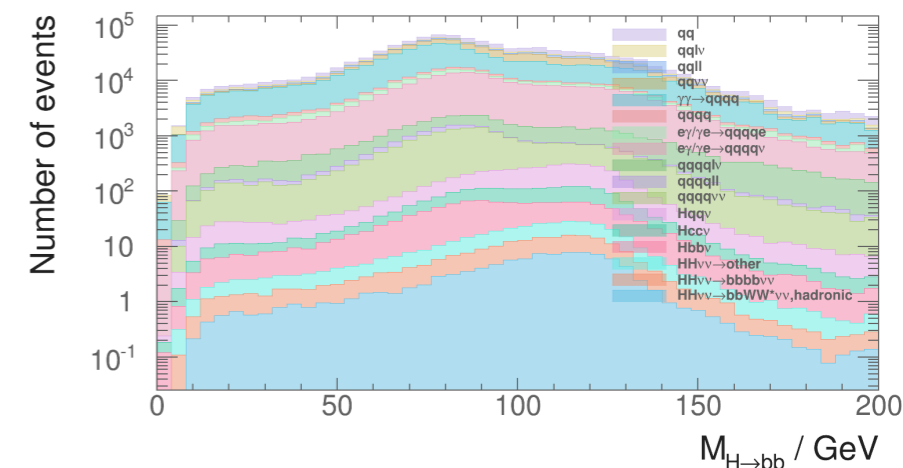
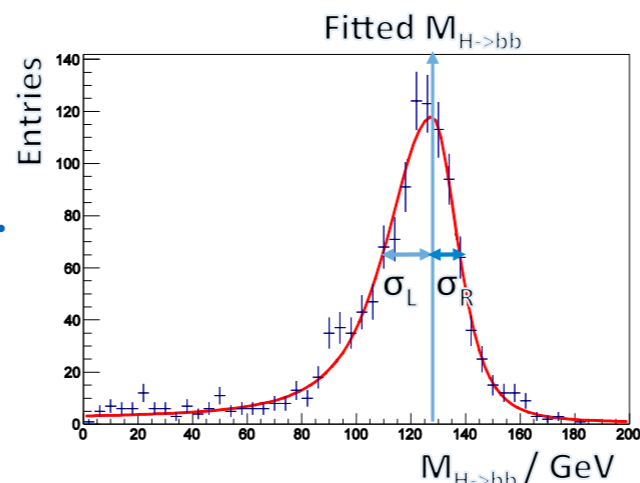
Event Validation Tools:

Colour-coded Particles and feature points



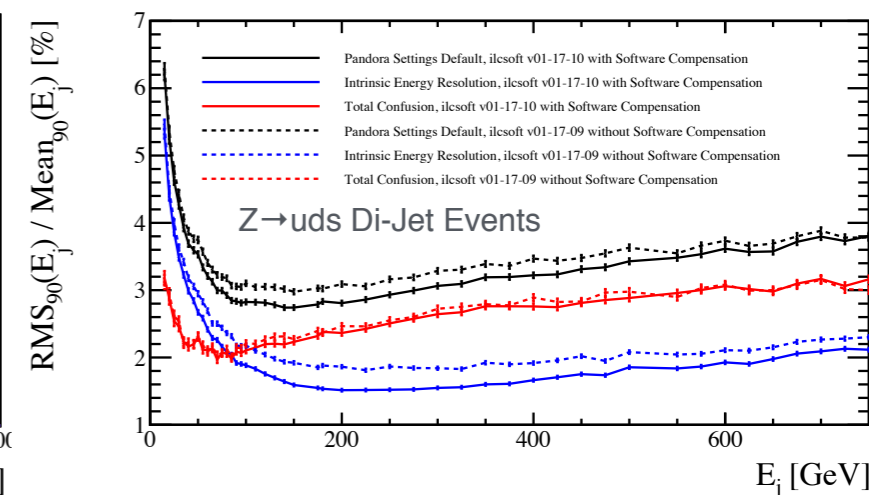
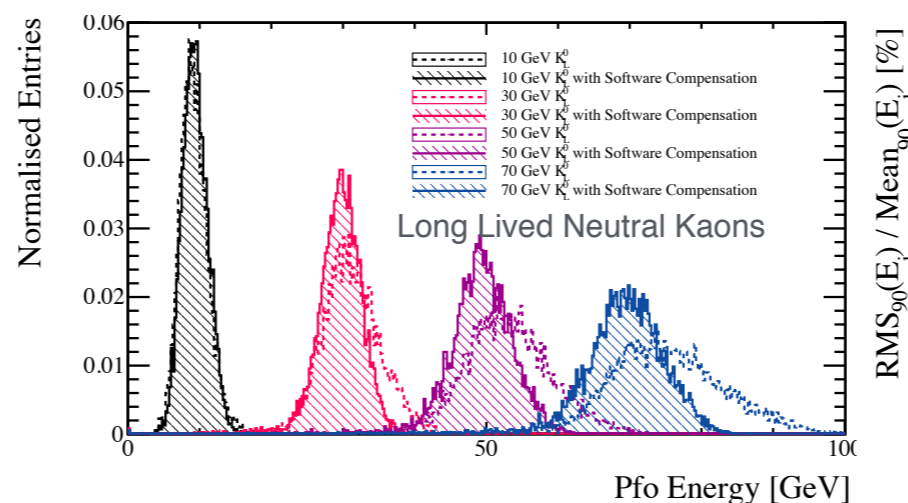
- Double higgs analysis to measure the triple higgs coupling and the quartic coupling using $HH \rightarrow WWbb$ sub-channel.

- Reconstructed invariant mass is important for jet pairing and for MVA.
- PFA crucial for providing an excellent jet energy and di-jet mass resolution.



- Software compensation has been applied to a non-default ILD detector that contains 60 layer HCal. The performance was then tested at CLIC like energies exceeding 1.4 TeV.

- Calibration procedure refined to include training for software compensation.
- Once again a significant gain in performance was observed.



ILD with 60 Layer HCal

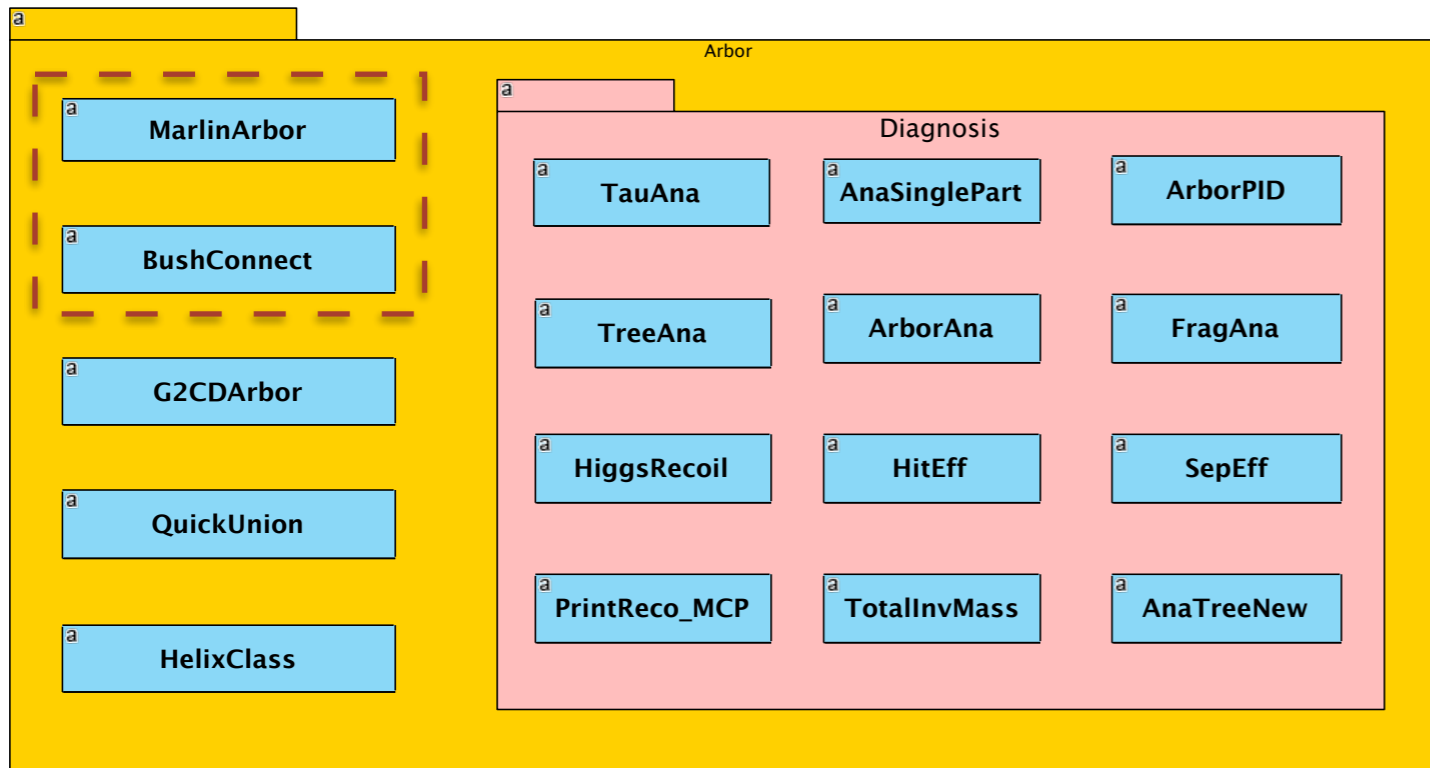
Update from CERN:

- Matthias Weber has been using the Pandora calibration toolkit with data simulated and reconstructed using DD4hep.
- Includes retraining of latest Pandora photon reconstruction algorithms, which uses a multivariate approach to separate photons from nearby charged hadrons.

Update from LLR / IHEP:

- Will now hand-over to Bo Li, who will describe recent progress with Arbor.

The updates of Arbor



- **Refactoring**

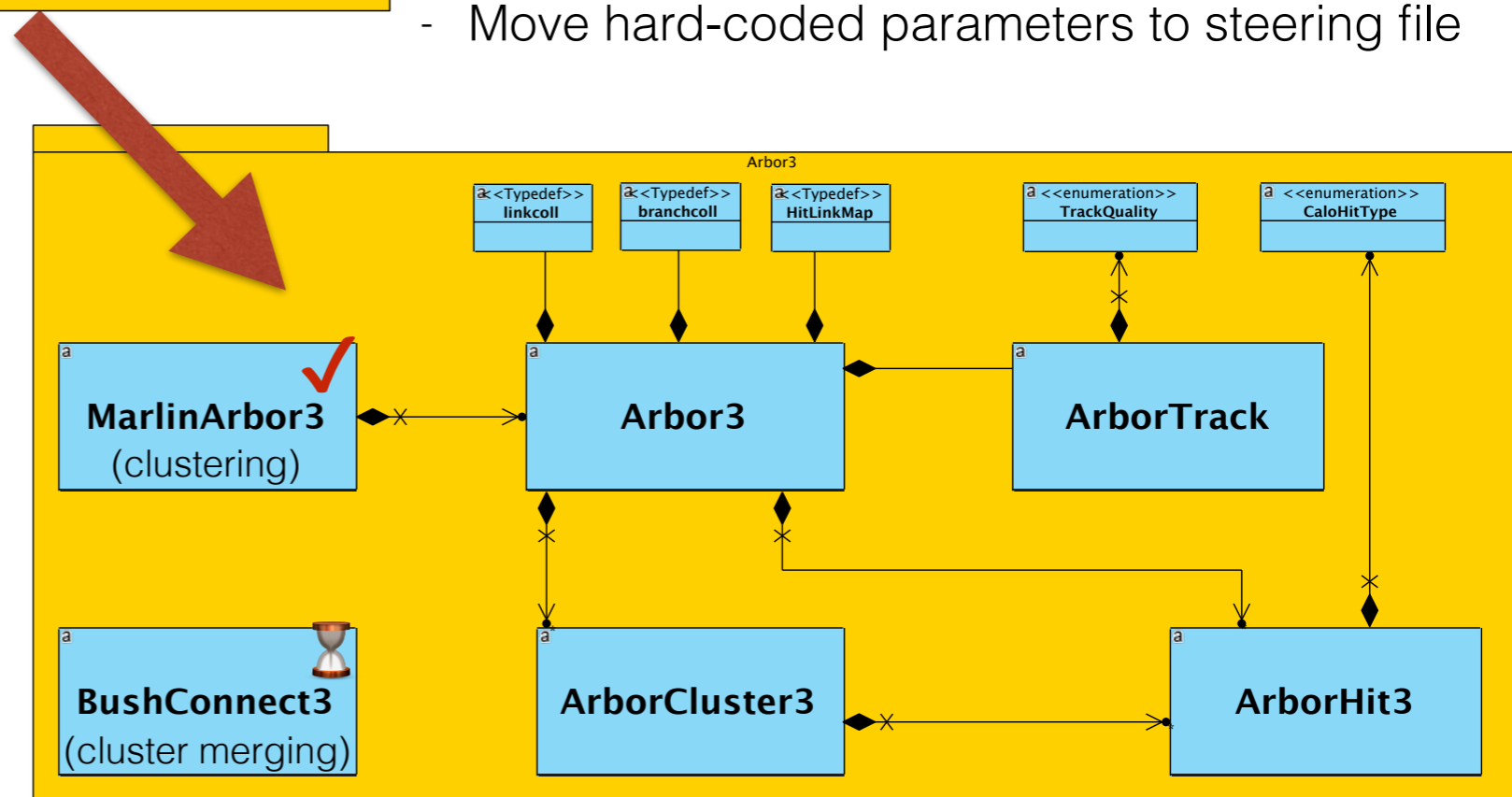
- Reimplement the clustering code with considerations of clarifying the algorithm logic and reducing CPU time.
- Rewrite the codes in an OOP style.

- **Updates**

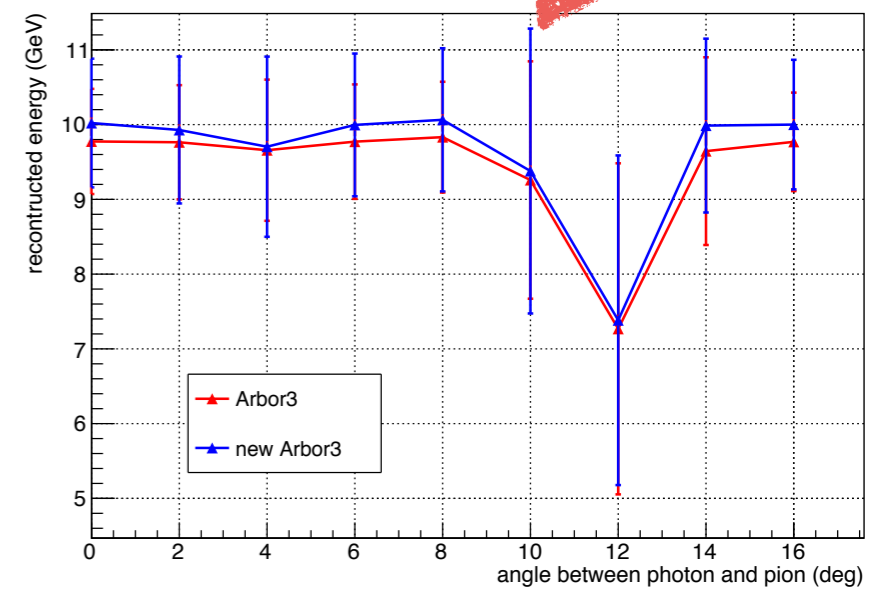
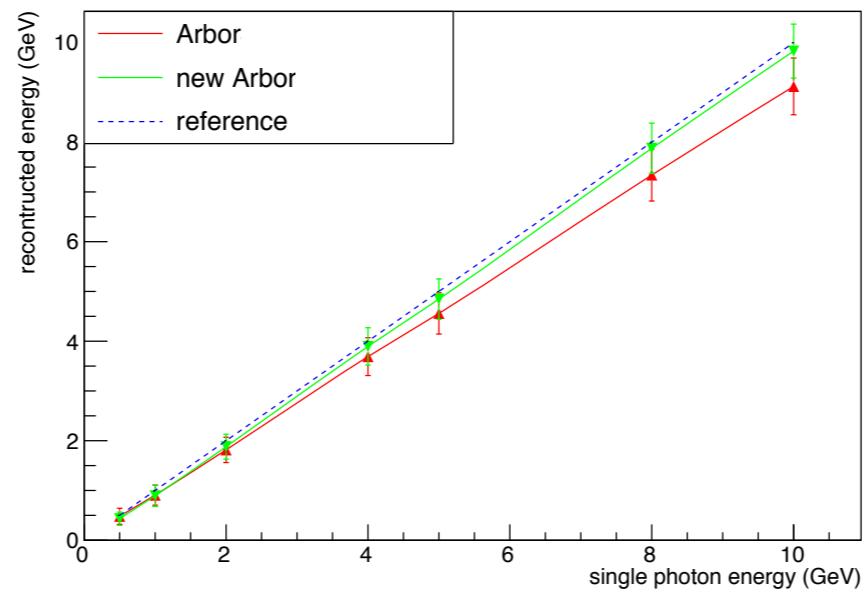
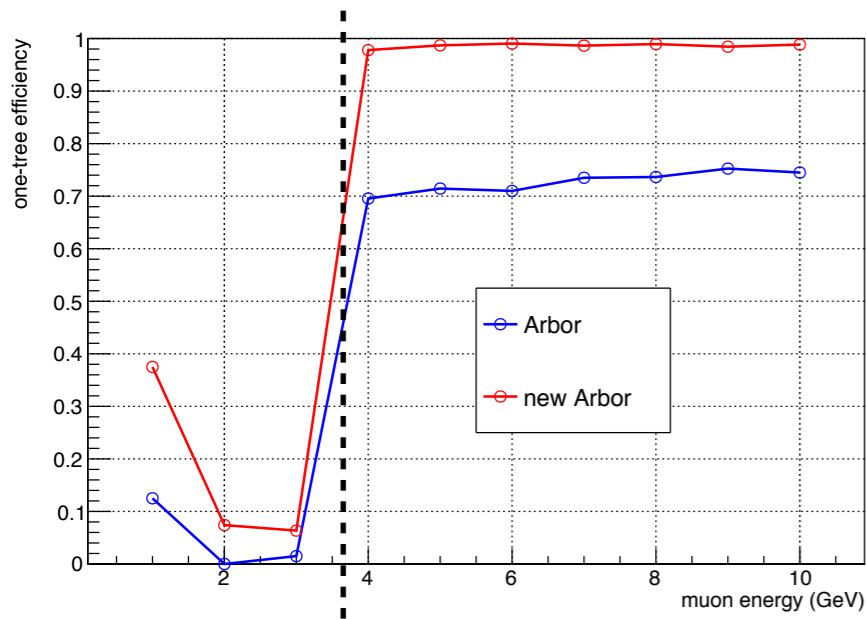
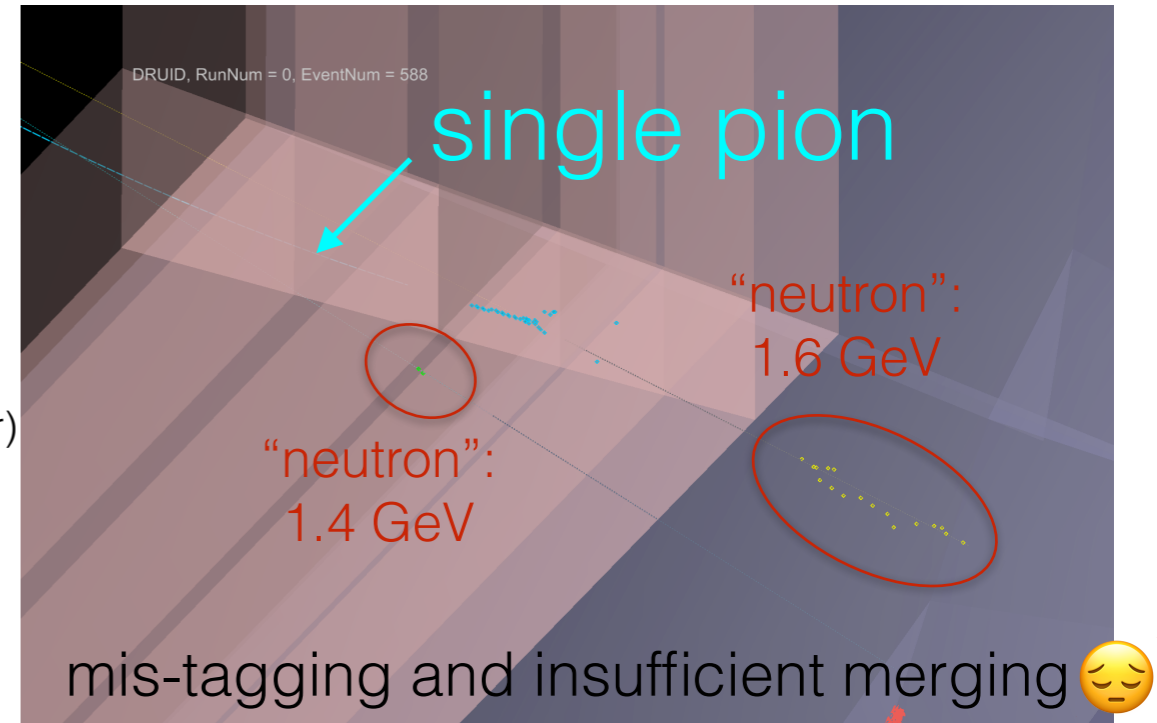
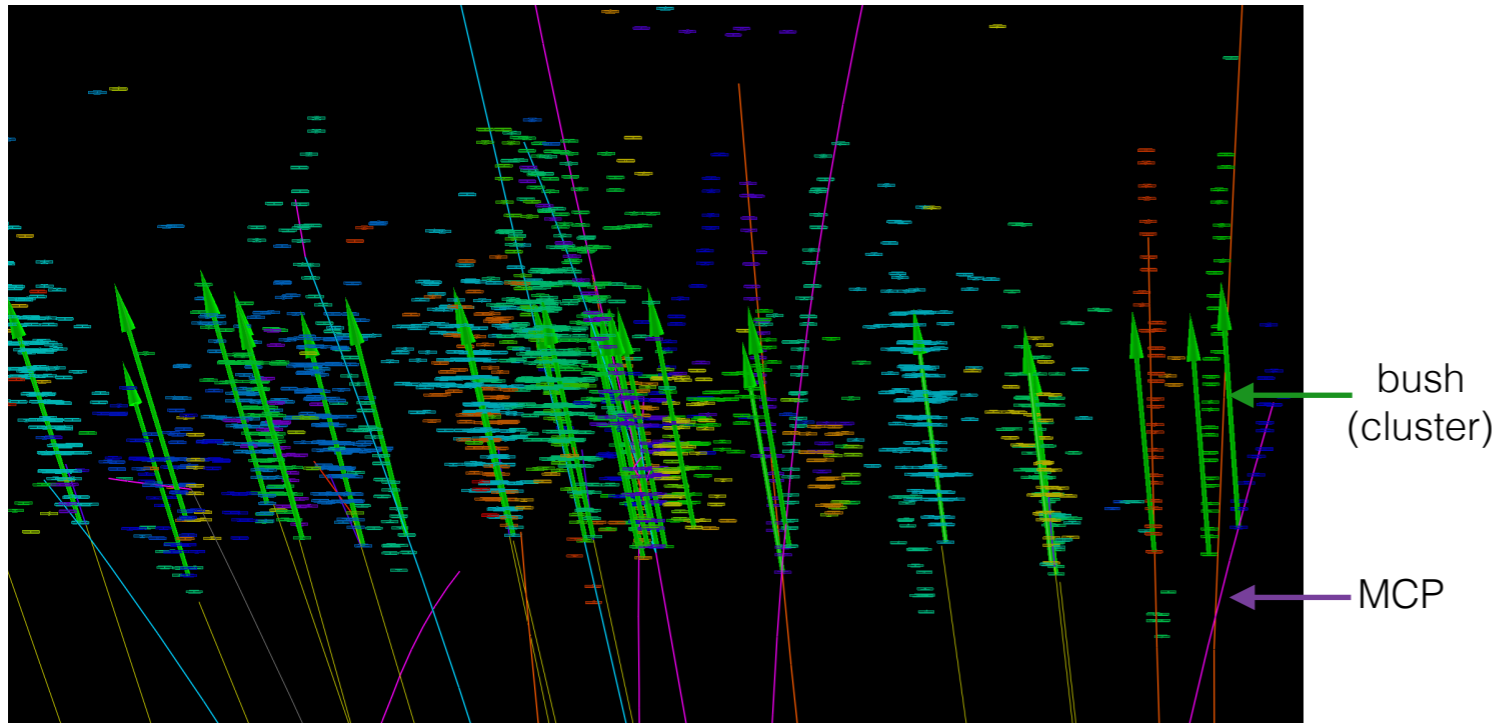
- Add the options of using time and pre-clustering in the clustering procedure
- Take hits in TCMT into account
- Move hard-coded parameters to steering file

- **Ongoing**

- The algorithm of track-cluster matching and cluster merging(BushConnect) is still under optimization.
- The performance of the sub-algorithms used, such as photon tagging, is to be validated.



Preliminary performance



- The clustering performance of new Arbor3 is better than before
- Merging and tagging performance have to be improved

The git repository

master ▾ Arbor Find File Download

Name	Last Commit > 2b5810b4 – about 14 hours ago Merged code from branch. History	Last Update
examples	Build the k-d tree just before the hit linking.	about a month ago
source	Merged code from branch.	about 14 hours ago
.gitignore	Cosmetics	about 21 hours ago
Arbor Code v3.mm	Cosmetics	about 21 hours ago
CMakeLists.txt	update Vincent's email	about 23 hours ago
README	new commit	5 months ago

<https://gitlab.com/bo.li/Arbor>

- For studying the performance, the old Arbor code is still kept in the repository.
- Here is a tag (v3.4.0) of Arbor. We will keep going on for optimizing and test algorithm, and hopefully a formal release will be before December.