A Brief Description of Data Products

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ProtoDUNE Analysis Workshop

Jan 27, 2019

CERN

Introduction

- What will be discussed in this talk
  - Data products saved in the reconstructed files.
  - A very brief description of main algorithms that produce these data products.
- What will not be discussed
  - How to retrieve the data products in either an art analyzer module or a gallery script.
  - Detailed information on simulation or reconstruction algorithms.
  - Other talks will cover these topics.

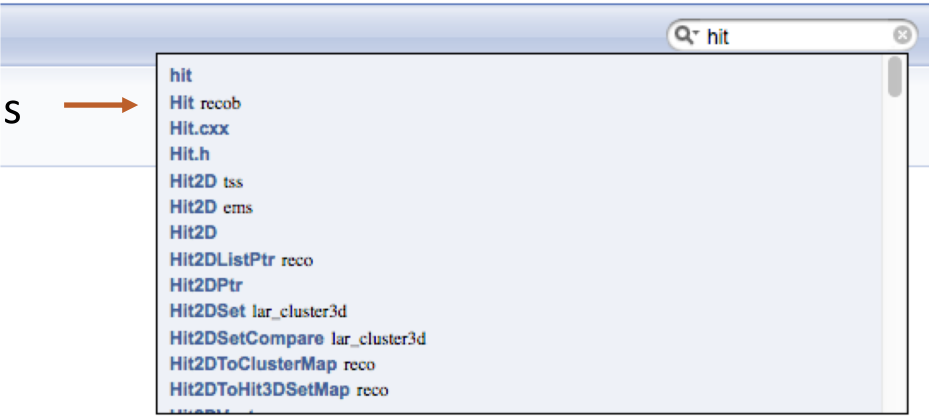
Data products

- raw::* - raw data
  - raw::RawDigit, raw::AuxDetDigit, raw::OpDetPulse, raw::OpDetWaveform, raw::Trigger, raw::BeamInfo, etc.
- recob::* - reconstructed information
  - recob::Wire, recob::Hit, recob::Cluster, recob::EndPoint2D, recob::Vertex, recob::PFParticle, recob::Track, recob::Shower, recob::OpHit, recob::OpFlash, etc.
- anab::* - information that is derived from reconstruction information
  - anab::Calorimetry, anab::ParticleID, anab::CosmicTag, anab::T0, etc.
- simb::* - simulation information
  - simb::MCTruth, simb::MCParticle, simb::MCFlux, etc.
- Associations - links between different data products
  - https://cdcvs.fnal.gov/redmine/projects/larsoft/wiki/Use_associations

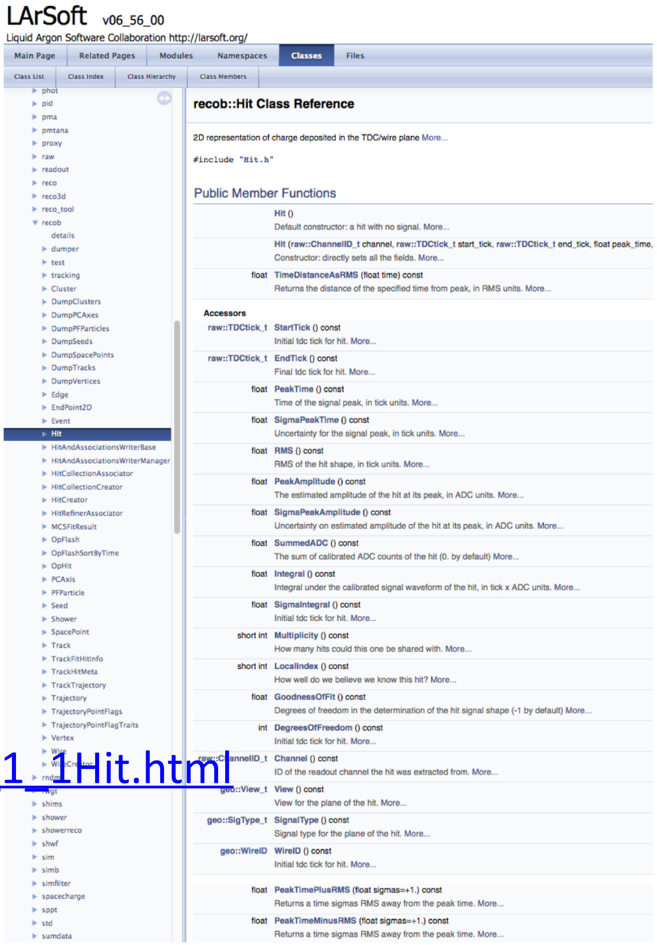
Get information from Doxygen

- http://nusoft.fnal.gov/larsoft/doxsvn/html/index.html

If you want to get information for recob::Hit, type hit here



Click this



recob::Hit Class Reference

2D representation of charge deposited in the TDC/wire plane More...

```
#include "Hit.h"
```

Public Member Functions

Hit ()
Default constructor: a hit with no signal. More...

Hit (raw::ChannelID_t channel, raw::TDCtick_t start_tick, raw::TDCtick_t end_tick, float peak_time,
Constructor: directly sets all the fields. More...

float TimeDistanceAsRMS (float time) const
Returns the distance of the specified time from peak, in RMS units. More...

Accessors

raw::TDCtick_t StartTick () const
Initial tdc tick for hit. More...

raw::TDCtick_t EndTick () const
Final tdc tick for hit. More...

float PeakTime () const
Time of the signal peak, in tick units. More...

float SigmaPeakTime () const
Uncertainty for the signal peak, in tick units. More...

float RMS () const
RMS of the hit shape, in tick units. More...

float PeakAmplitude () const
The estimated amplitude of the hit at its peak, in ADC units. More...

float SigmaPeakAmplitude () const
Uncertainty on estimated amplitude of the hit at its peak, in ADC units. More...

float SummedADC () const
The sum of calibrated ADC counts of the hit (0. by default) More...

float Integral () const
Integral under the calibrated signal waveform of the hit, in tick x ADC units. More...

float SigmaIntegral () const
Initial tdc tick for hit. More...

short int Multiplicity () const
How many hits could this one be shared with. More...

short int LocalIndex () const
How well do we believe we know this hit? More...

float GoodnessOfFit () const
Degrees of freedom in the determination of the hit signal shape (-1 by default) More...

int DegreesOfFreedom () const
Initial tdc tick for hit. More...

raw::ChannelID_t Channel () const
ID of the readout channel the hit was extracted from. More...

geo::View_t View () const
View for the plane of the hit. More...

geo::SigType_t SignalType () const
Signal type for the plane of the hit. More...

geo::WireID WireID () const
Initial tdc tick for hit. More...

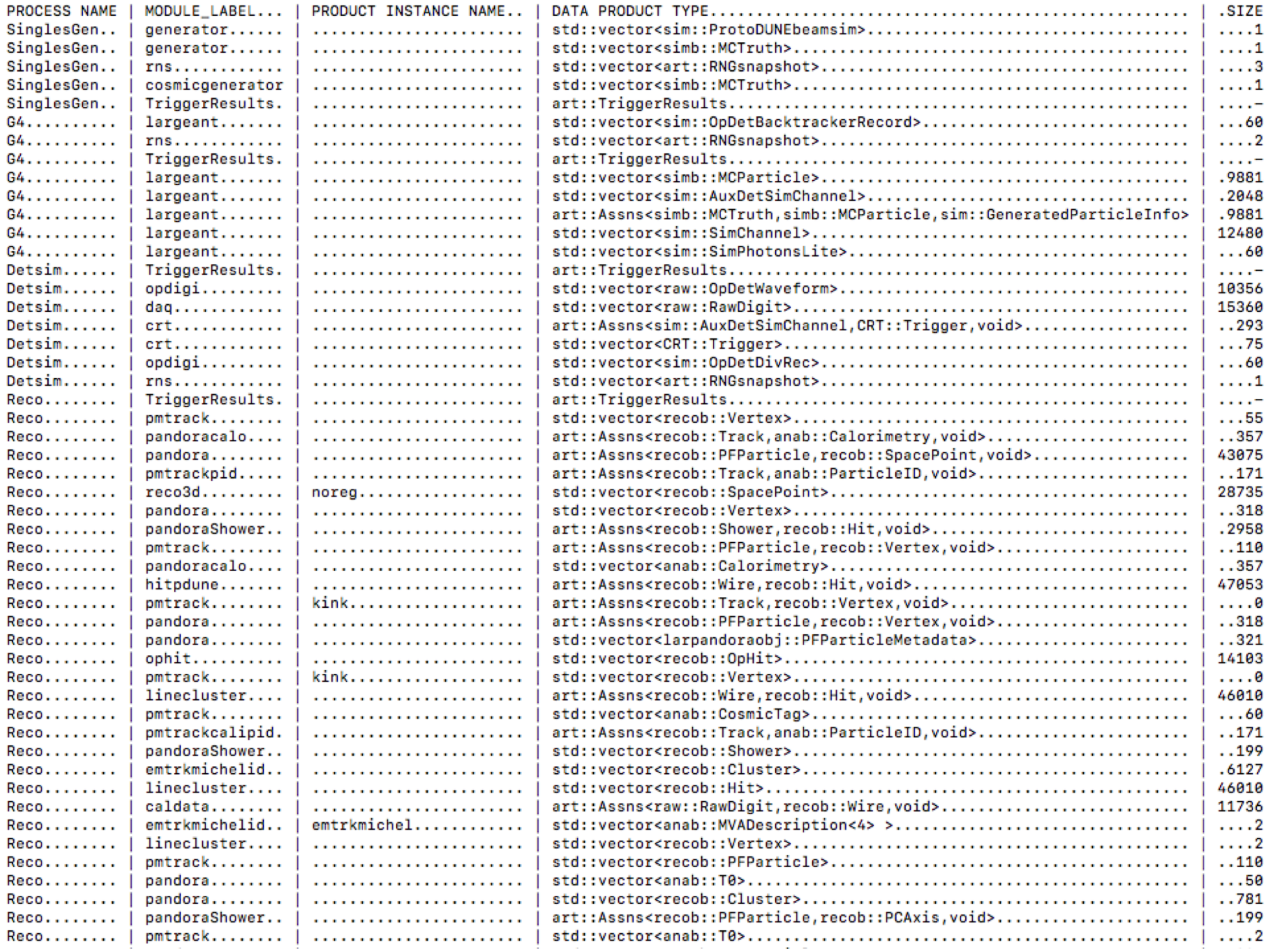
float PeakTimePlusRMS (float sigmas=+1.) const
Returns a time sigmas RMS away from the peak time. More...

float PeakTimeMinusRMS (float sigmas=+1.) const
Returns a time sigmas RMS away from the peak time. More...

http://nusoft.fnal.gov/larsoft/doxsvn/html/classrecob_1_1Hit.html

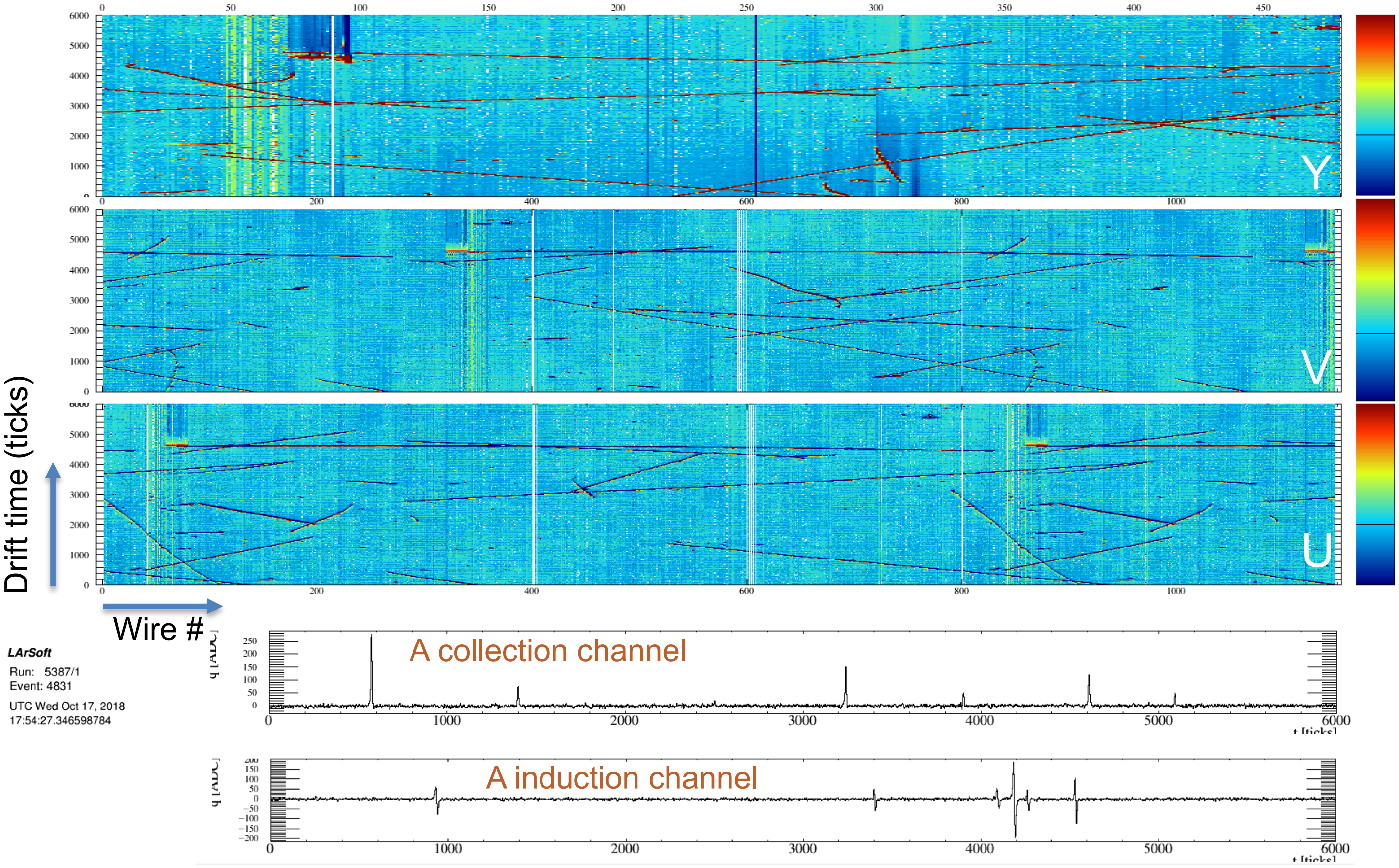
Get information from an art file

- lar -c **eventdump.fcl** /pnfs/dune/tape_backed/dunepro/mcc11/protodune/mc/full-reconstructed/06/67/65/21/mcc11_protoDUNE_sp_reco_12231114_0_4a73bdae-00a8-428a-9269-fe18d6cb6db4.root -n 1



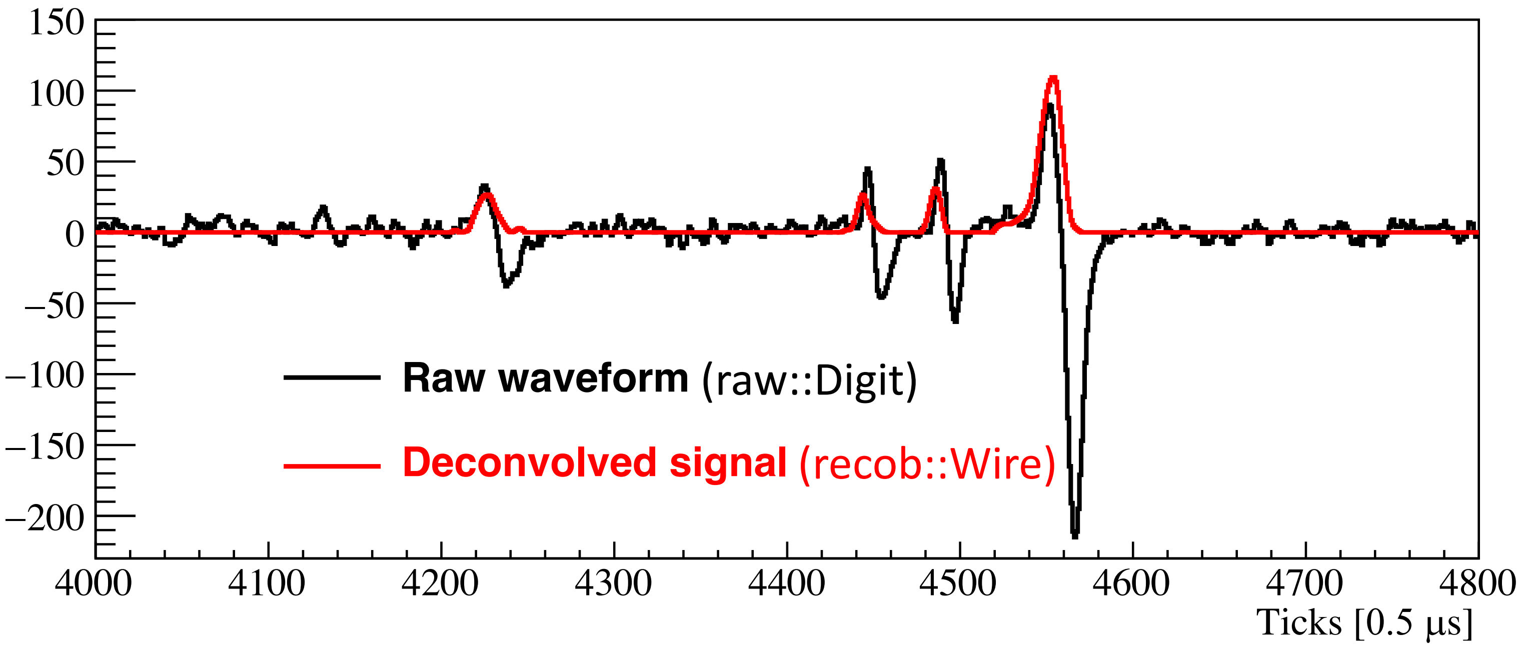
```
PROCESS NAME | MODULE_LABEL... | PRODUCT INSTANCE NAME.. | DATA PRODUCT TYPE.................................................... | .SIZE
SinglesGen.. | generator...... | ....................... | std::vector<sim::ProtoDUNEbeamsim>................................... | ....1
SinglesGen.. | generator...... | ....................... | std::vector<simb::MCTruth>........................................... | ....1
SinglesGen.. | rns............ | ....................... | std::vector<art::RNGsnapshot>........................................ | ....3
SinglesGen.. | cosmicgenerator | ....................... | std::vector<simb::MCTruth>........................................... | ....1
SinglesGen.. | TriggerResults. | ....................... | art::TriggerResults.................................................. | ....-
G4.......... | largeant....... | ....................... | std::vector<sim::OpDetBacktrackerRecord>............................. | ...60
G4.......... | rns............ | ....................... | std::vector<art::RNGsnapshot>........................................ | ....2
G4.......... | TriggerResults. | ....................... | art::TriggerResults.................................................. | ....-
G4.......... | largeant....... | ....................... | std::vector<simb::MCParticle>........................................ | .9881
G4.......... | largeant....... | ....................... | std::vector<sim::AuxDetSimChannel>................................... | .2048
G4.......... | largeant....... | ....................... | art::Assns<simb::MCTruth,simb::MCParticle,sim::GeneratedParticleInfo> | .9881
G4.......... | largeant....... | ....................... | std::vector<sim::SimChannel>......................................... | 12480
G4.......... | largeant....... | ....................... | std::vector<sim::SimPhotonsLite>..................................... | ...60
Detsim...... | TriggerResults. | ....................... | art::TriggerResults.................................................. | ....-
Detsim...... | opdigi......... | ....................... | std::vector<raw::OpDetWaveform>...................................... | 10356
Detsim...... | daq............ | ....................... | std::vector<raw::RawDigit>........................................... | 15360
Detsim...... | crt............ | ....................... | art::Assns<sim::AuxDetSimChannel,CRT::Trigger,void>.................. | ..293
Detsim...... | crt............ | ....................... | std::vector<CRT::Trigger>............................................ | ...75
Detsim...... | opdigi......... | ....................... | std::vector<sim::OpDetDivRec>........................................ | ...60
Detsim...... | rns............ | ....................... | std::vector<art::RNGsnapshot>........................................ | ....1
Reco........ | TriggerResults. | ....................... | art::TriggerResults.................................................. | ....-
Reco........ | pmtrack........ | ....................... | std::vector<recob::Vertex>........................................... | ...55
Reco........ | pandoracalo.... | ....................... | art::Assns<recob::Track,anab::Calorimetry,void>...................... | ..357
Reco........ | pandora........ | ....................... | art::Assns<recob::PFParticle,recob::SpacePoint,void>................. | 43075
Reco........ | pmtrackpid..... | ....................... | art::Assns<recob::Track,anab::ParticleID,void>....................... | ..171
Reco........ | reco3d......... | noreg.................. | std::vector<recob::SpacePoint>....................................... | 28735
Reco........ | pandora........ | ....................... | std::vector<recob::Vertex>........................................... | ..318
Reco........ | pandoraShower.. | ....................... | art::Assns<recob::Shower,recob::Hit,void>............................ | .2958
Reco........ | pmtrack........ | ....................... | art::Assns<recob::PFParticle,recob::Vertex,void>..................... | ..110
Reco........ | pandoracalo.... | ....................... | std::vector<anab::Calorimetry>....................................... | ..357
Reco........ | hitpdune....... | ....................... | art::Assns<recob::Wire,recob::Hit,void>.............................. | 47053
Reco........ | pmtrack........ | kink................... | art::Assns<recob::Track,recob::Vertex,void>.......................... | ....0
Reco........ | pandora........ | ....................... | art::Assns<recob::PFParticle,recob::Vertex,void>..................... | ..318
Reco........ | pandora........ | ....................... | std::vector<larpandoraobj::PFParticleMetadata>....................... | ..321
Reco........ | ophit.......... | ....................... | std::vector<recob::OpHit>............................................ | 14103
Reco........ | pmtrack........ | kink................... | std::vector<recob::Vertex>........................................... | ....0
Reco........ | linecluster.... | ....................... | art::Assns<recob::Wire,recob::Hit,void>.............................. | 46010
Reco........ | pmtrack........ | ....................... | std::vector<anab::CosmicTag>......................................... | ...60
Reco........ | pmtrackcalipid. | ....................... | art::Assns<recob::Track,anab::ParticleID,void>....................... | ..171
Reco........ | pandoraShower.. | ....................... | std::vector<recob::Shower>........................................... | ..199
Reco........ | emtrkmichelid.. | ....................... | std::vector<recob::Cluster>.......................................... | .6127
Reco........ | linecluster.... | ....................... | std::vector<recob::Hit>.............................................. | 46010
Reco........ | caldata........ | ....................... | art::Assns<raw::RawDigit,recob::Wire,void>........................... | 11736
Reco........ | emtrkmichelid.. | emtrkmichel............ | std::vector<anab::MVADescription<4> >................................ | ....2
Reco........ | linecluster.... | ....................... | std::vector<recob::Vertex>........................................... | ....2
Reco........ | pmtrack........ | ....................... | std::vector<recob::PFParticle>....................................... | ..110
Reco........ | pandora........ | ....................... | std::vector<anab::T0>................................................ | ...50
Reco........ | pandora........ | ....................... | std::vector<recob::Cluster>.......................................... | ..781
Reco........ | pandoraShower.. | ....................... | art::Assns<recob::PFParticle,recob::PCAxis,void>..................... | ..199
Reco........ | pmtrack........ | ....................... | std::vector<anab::T0>................................................ | ....2
```

raw::Digit



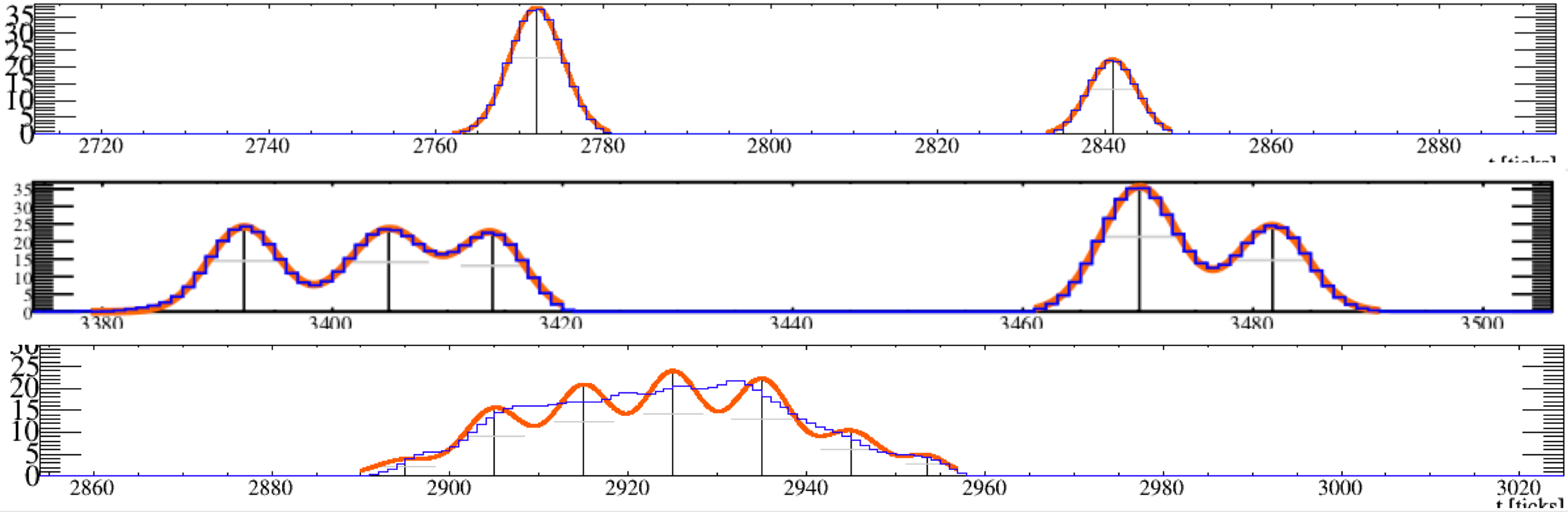
- One raw::Digit per channel, 15360 in total.
- A raw::Digit has a vector of raw ADC counts. The size is determined by readout window, 6k by default, some runs were taken with 15k.
- Each tick is 0.5 μs.

recob::Wire



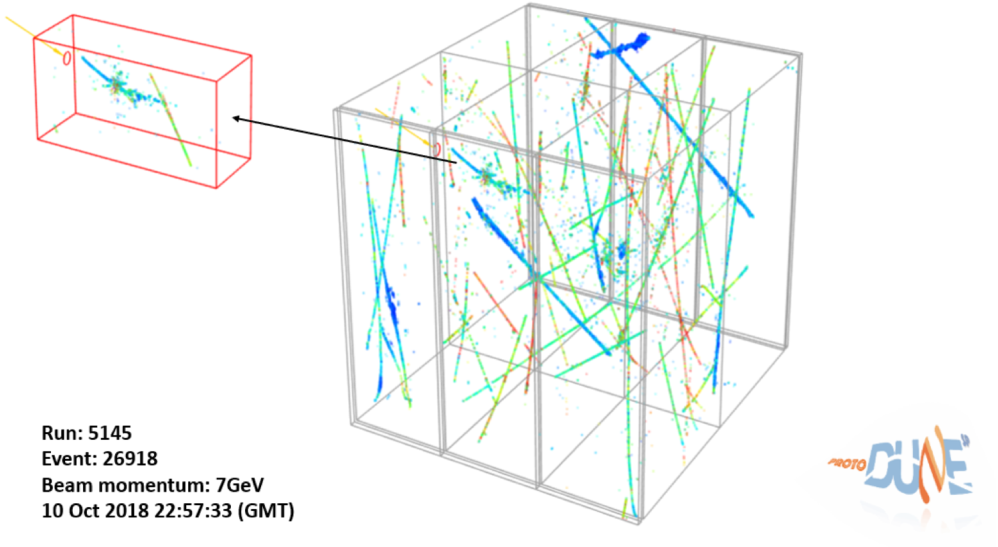
- Output of signal processing after noise filtering and deconvolution and ROI finding.
- A recob::Wire has a vector of float point numbers, which are deconvolved ADC counts.
- 2D deconvolution to account for induced charge on neighboring wires.

recob::Hit



- The gaussian hit finder module fits the deconvolved signal to a gaussian.
- Multiple gaussians are used to fit overlapping signal.
- The gaussian fit returns the peak time and the area, as well as wireID, width, peak amplitude etc.
- There can be several copies of hit collections – hits after disambiguation and refined hits after pattern recognition (e.g. trajcluster).
- Fit a very long pulse, the hit finder will return a train of hits with the same width. The maximum number of gaussians to fit and hit width are configurable.

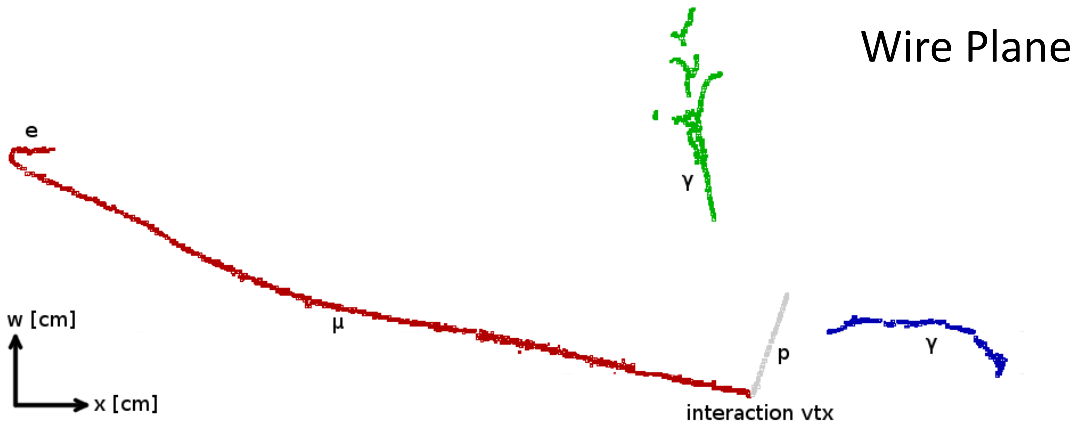
recob::SpacePoint



Run: 5145
Event: 26918
Beam momentum: 7GeV
10 Oct 2018 22:57:33 (GMT)

- A object to save 3D points.
- It saves the x,y,z coordinates as well as charge information.
- Used in ProtoDUNE DQM event display.
- Can be by-product of track fitting.
- SpacePointSolver, wire-cell and Pandora can make space points using hits.
- Can have associations with hits on 3 planes – help disambiguation and cluster matching.

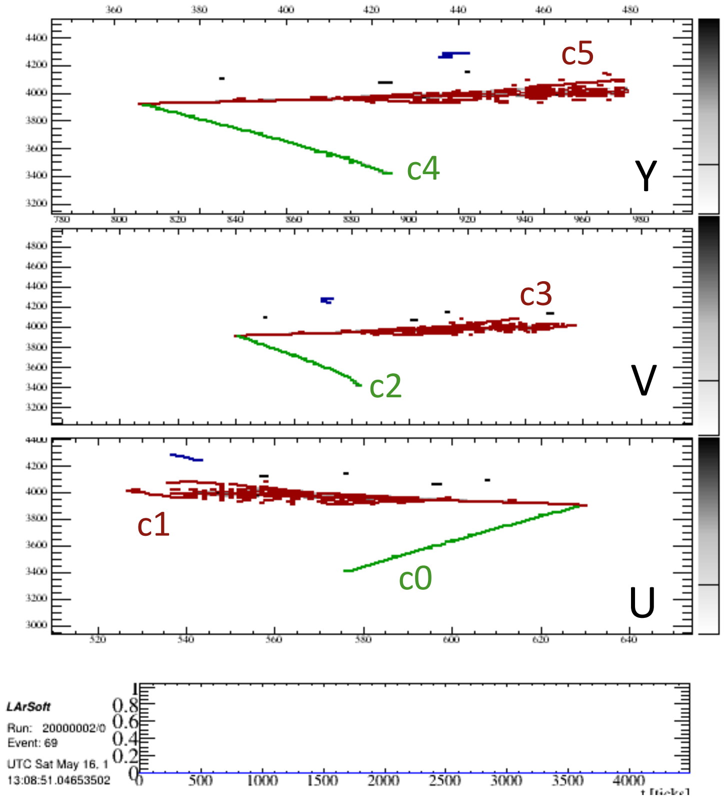
recob::Cluster



- A recob::Cluster is a collection of hits produced by the same particle.
- Spatial and charge information is used to cluster hits.
- Several pattern recognition algorithms produces recob::Clusters, the two main ones are Pandora and TrajCluster.

recob::PFParticle

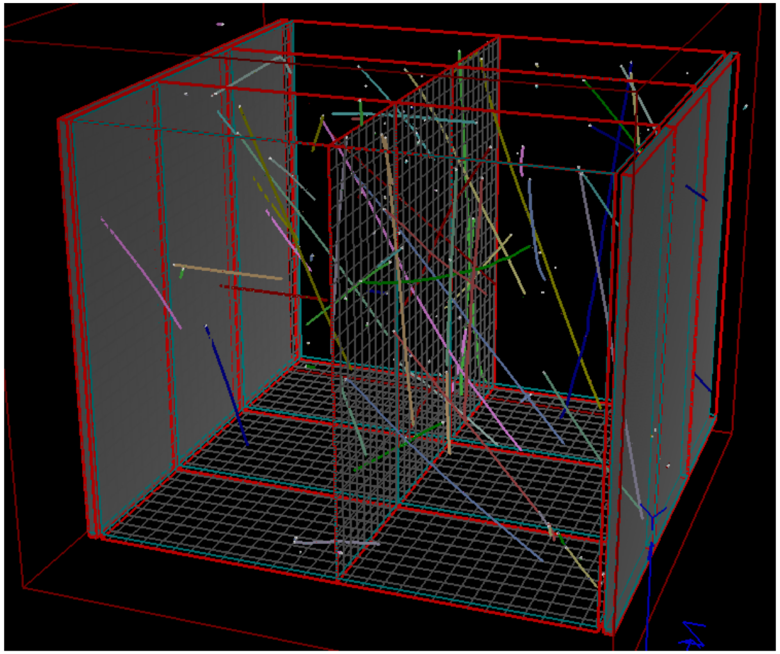
- A recob::PFParticle is a collection of matched recob::Clusters on all planes
  - It is the main outcome of pattern recognition.
  - It is supposed to include all the hits produced by a single particle on all three planes.
  - Other useful information can be associated with a PFParticle
    - T0
    - Track/shower-like (through pdg)
    - Primary beam particle
    - Hierarchy information (one pfparticle can be the daughter of another)



PFP0: c0, c2, c4 track-like
PFP1: c1, c3, c5 shower-like

recob::Track

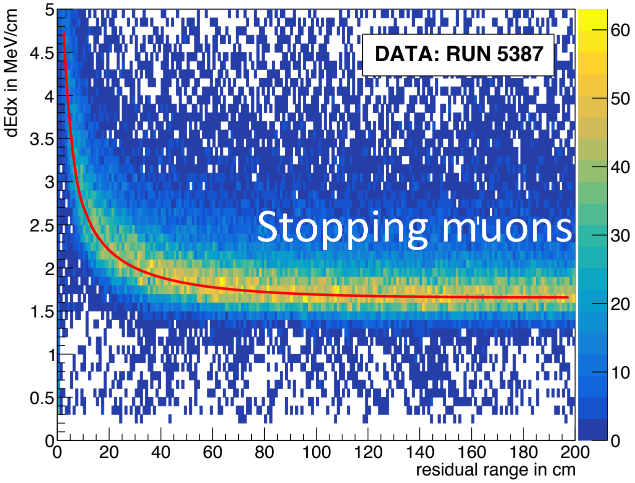
- Tracks are fitted using track-like PFParticles as input.
  - Tracking may not use all hits
- Three main algorithms
  - Pandora track fitter, PMA, Kalman filter
- Output can include
  - Trajectory points (one trajectory point corresponds to one hit). Some trajectory points can be flagged as invalid.
  - Directions
  - Covariance matrix

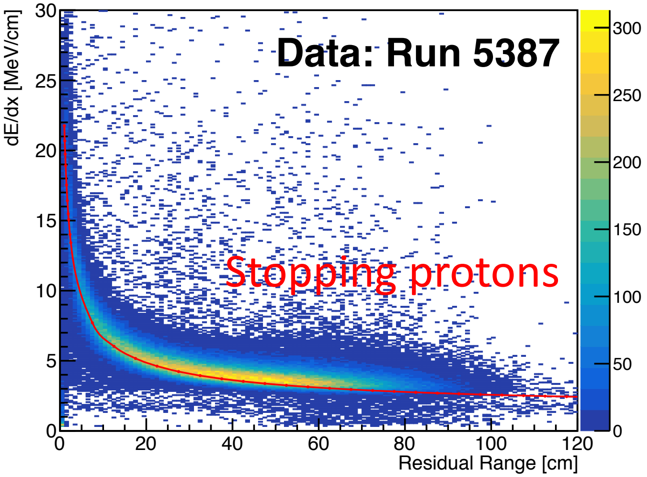


Pandora tracks in one ProtoDUNE-SP data event

anab::Calorimetry

- Each plane provides an independent calorimetric measurement.
  - 3 anab::Calorimetry objects associated with each recob::Track
- 3 vectors of quantities
  - Residual range – distance with regards to the track end.
  - dQdx – uncorrected dQdx values
  - dEdx – after correcting for attenuation, SCE (on-going), recombination
- Input to calorimetry-based particle ID

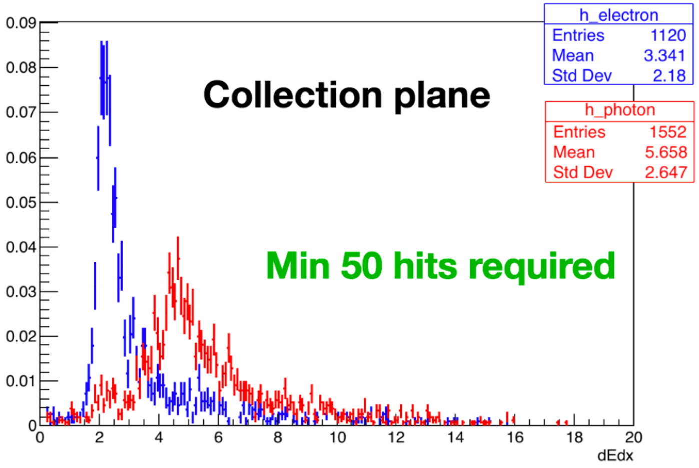




recob::Shower

- Reconstruct shower using shower-like PFParticle as input.
- Ideally one recob::Shower for one single electron or one single photon.
- It is supposed to provide both geometry and calorimetric information.
  - The Pandora shower maker provides direction and vertex information.
  - dE/dx information is being developed for e/gamma separation.

Using cheated reconstruction!



Collection plane

Min 50 hits required

Work in progress.

Other data products

- Photon detector
  - recob::OpHit - regions of the waveforms containing pulses.
  - recob::Flash – higher level object, built from nearby optical hits. Provides spatial, t0 and PE information.
- CRT
  - CRT::Trigger – module information
  - CRT::Hit – strip information on each module
- beam::ProtoDUNEBeamEvent – beam information
  - https://wiki.dunescience.org/wiki/Look_at_ProtoDUNE_SP_data#Parsing_Beamline_Information
- raw::ctb::pdspctb – CTB trigger information
  - https://wiki.dunescience.org/wiki/Look_at_unpacked_Trigger_Words

simb::MCTruth

- simb::MCTruth saves the output of any generator: neutrino interaction, nucleon decays, supernova neutrinos, etc.
- Origin: beam neutrino, cosmic interaction, supernova neutrino, single particle, unknown.
- Produce a list of simb::MCParticles before detector simulation.
- Neutrino interaction information saved in simb::MCNeutrino (CCNC, W, X, Y, Q^2, etc.)

simb::MCParticle

- In the geant simulation, simb::MCParticles from all the generators will be copied first (with process name “Primary”) and then propagated through geant. Scattered or any new particles will be saved as new simb::MCParticles.
  - Two sets of simb::MCParticles, one from MCTruths, one from geant.
- simb::MCParticle saves the particle trajectory, momentum at each trajectory point, pdg, process name, mother/daughter information.
- The energy deposition and timing information are saved in sim::SimChannel.

Backtracker

- Backtracker connects hit information with true energy deposition.
- const std::vector<sim::TrackIDE> cheat::BackTrackerService::HitToTrackIDEs (recob::Hit const &hit)
  - sim::TrackIDE provides geant MCParticle track ID and energy deposition through sim::SimChannel
  - Useful to evaluate efficiency and purity of reconstructed objects.
  - By default, shower daughter particles are not saved as MCParticles. But their energy deposition and parent particle's geant ID (with a minus sign) are saved in sim::SimChannel and can be retrieved through backtracker.
- http://nusoft.fnal.gov/larsoft/doxsvn/html/classcheat_1_1BackTrackerService.html
- Another service particle inventory service connects MCParticle with MCTruth. It can also give MCParticle parent
  - http://nusoft.fnal.gov/larsoft/doxsvn/html/classcheat_1_1ParticleInventoryService.html