LArTPC TECHNIQUE for NEUTRINO EVENTS and CHARGED PARTICLE RECONSTRUCTION

Visual scanning of neutrino Interactions in LArTPC

Decoding data from FTBF beam counters and conversion into ROOT format

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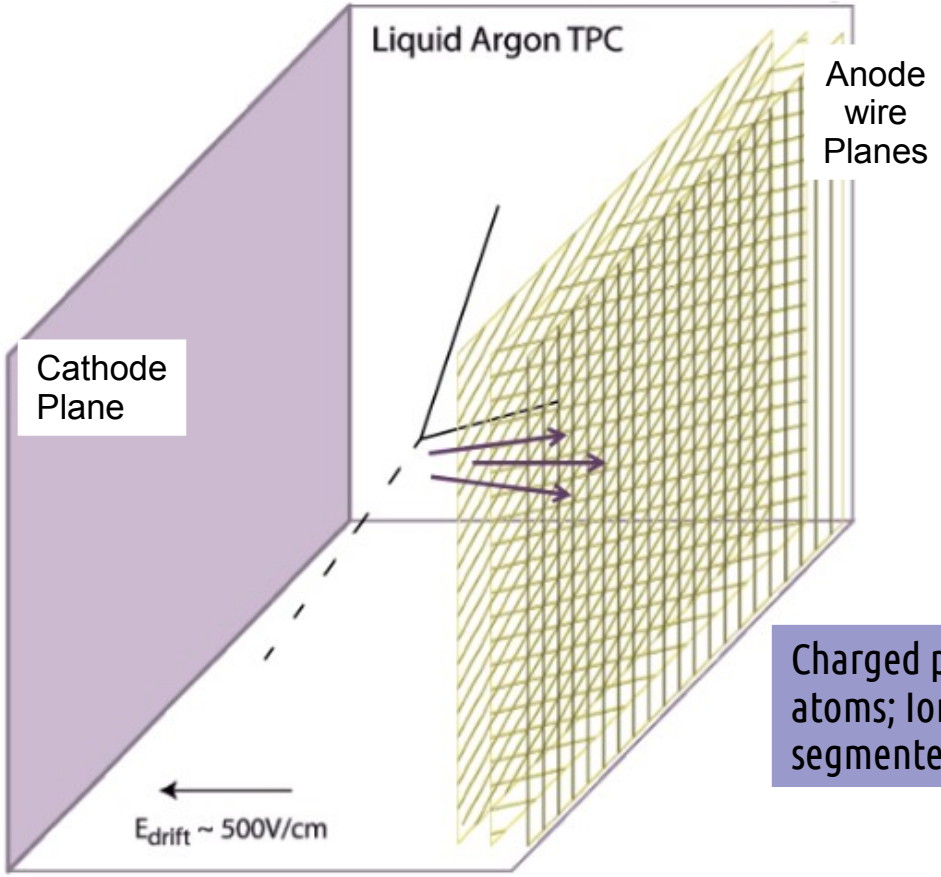
LArTPC



MAIN FEATURES:

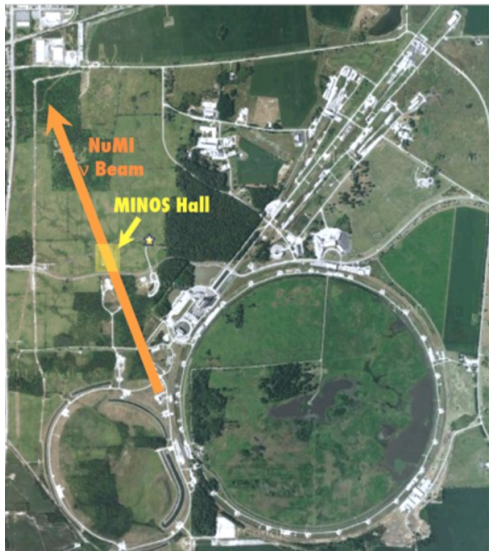
- Imaging:
  induction plane + collection plane + time = 3D reconstruction
- Calorimetric information:
  dE/dx PID
- Low energy threshold – down to few MeV

Charged particle tracks ionize argon atoms; Ionization charge drifts to finely segmented charge collection planes.

*"There are several reasons why pure LAr can be considered as an almost ideal material for a liquid target TPC: it is **dense**, it **does not attach electrons** and hence it permits **long drift-times**, it has a **high electron mobility**, it is **easy to obtain** and to **purify**, it is **inert**, it is **cheap**..."*

C. Rubbia, The Liquid-Argon Time Projection Chamber: A New Concept For Neutrino Detector, CERN-EP/77-08 (1977)

ArgoNeuT



ArgoNeuT was a R&D project at Fermilab (USA) to expose a small **Liquid Argon TPC** to the **NuMI** neutrino beam.

ArgoNeuT detector was located between MINERvA and the MINOS near detector (ND) at NuMI Tunnel – 100m underground. Muons escaping the TPC are reconstructed in **MINOS ND**.

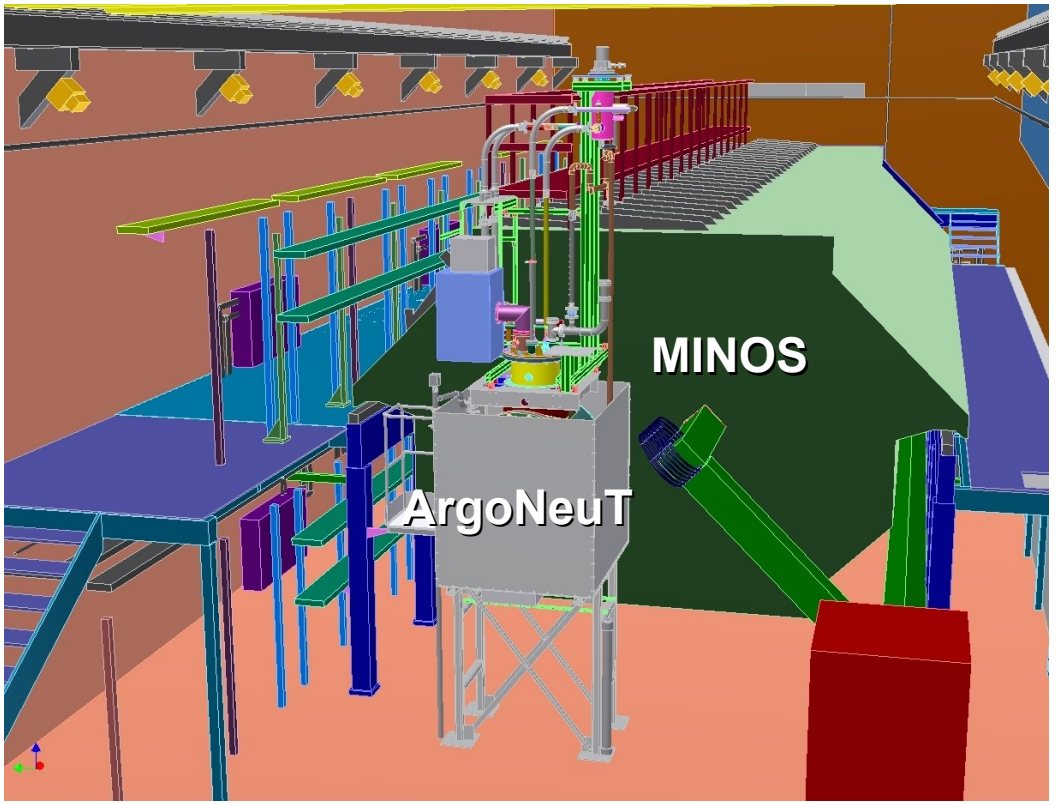
Collecting events in the 0.1 to 10 GeV range, ArgoNeuT was producing the first ever data for low energy neutrino interactions within a LArTPC.

GOALS:

Demostrate PID capabilities of LArTPC with dE/dx and range measurements.

Study CC and NC neutrino events in the few GeV Range in LAr.

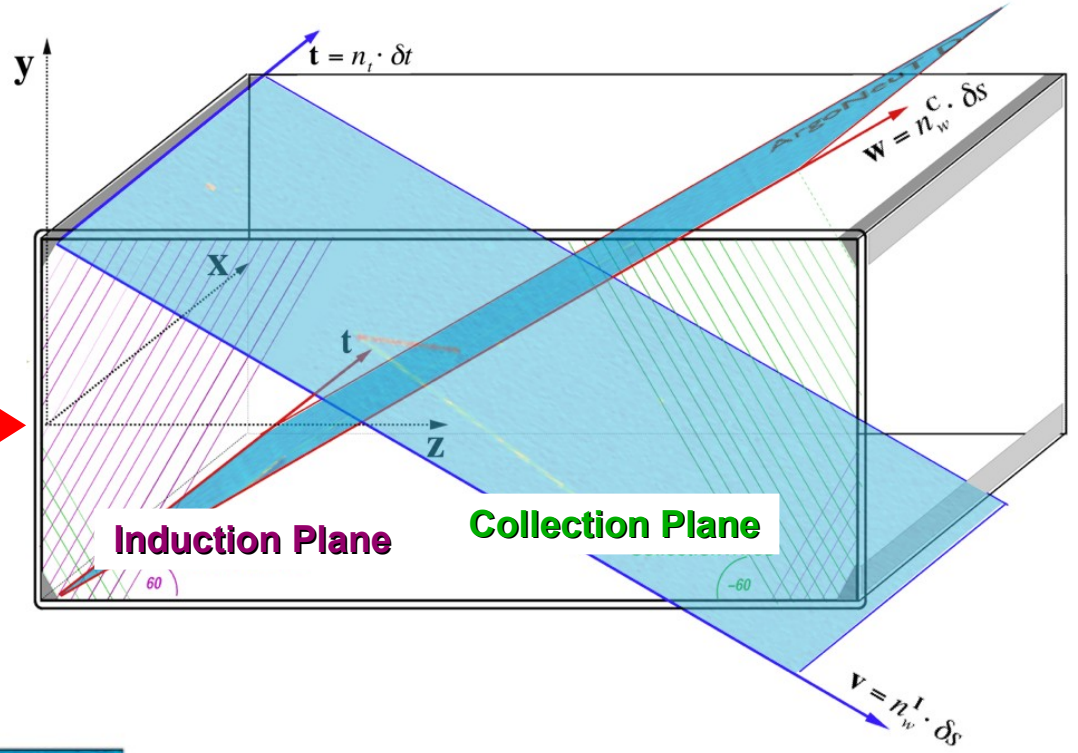
Precise CC QE muon neutrino cross section measurement in Argon.

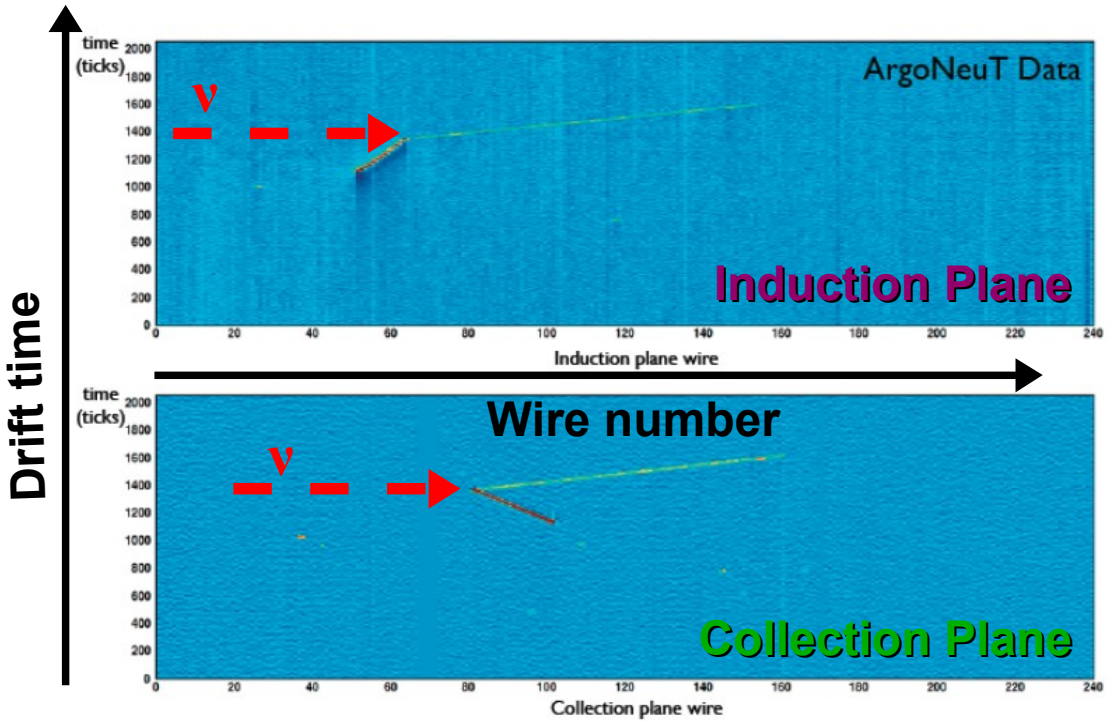


Neutrino Interactions in ArgoNeuT detector

2 wire planes at the edge of a 170 l TPC
240 wires on each plane
4 mm spacing
Plane orientation → 60°

Each of the two instrumented wire-planes provides a **2D-image** corresponding to the event projection on a plane whose axes are identified as "wire coordinate" and "time coordinate".

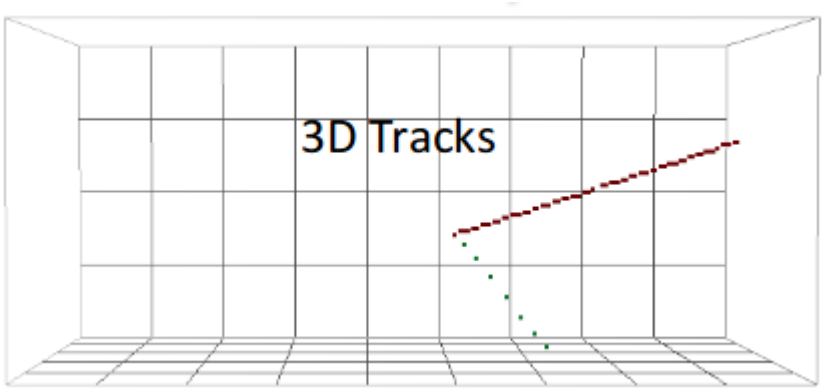




2D views → 3D-image
(w, t) + (v, t) → (x, y, z)

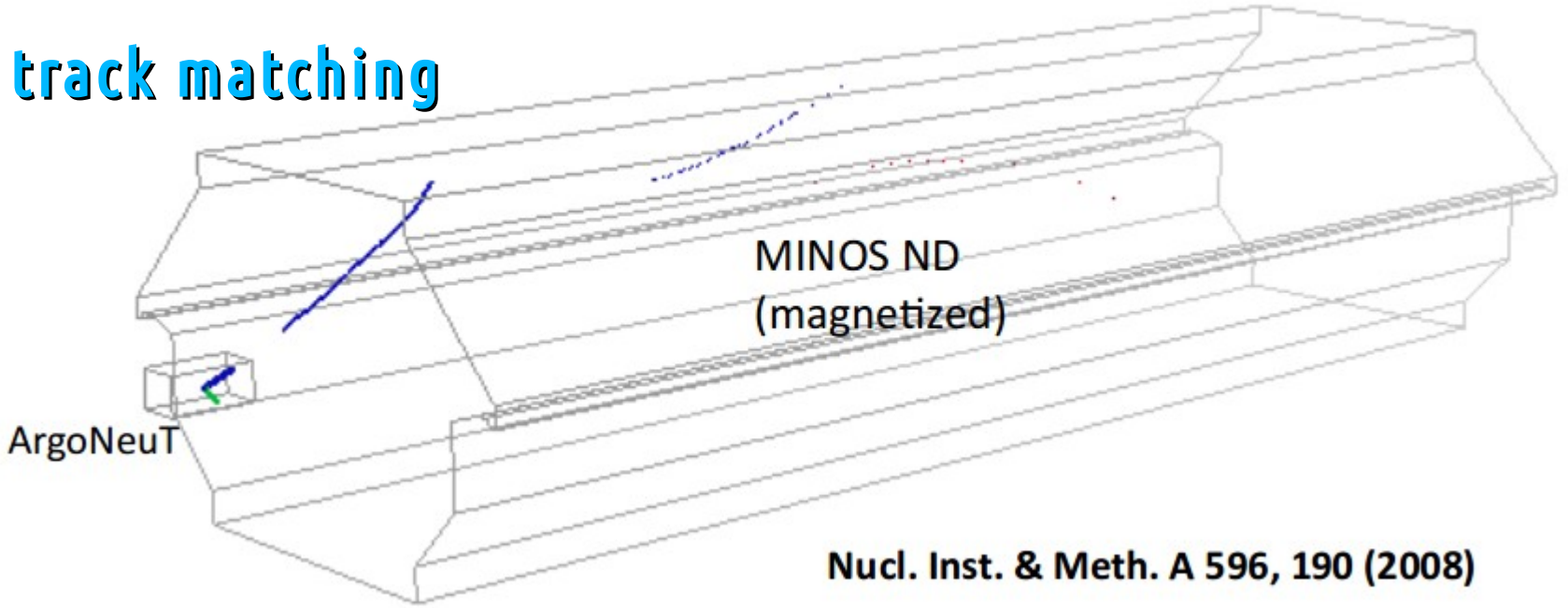
Color is representative of the amount of charge detected by the wires.

Low charge — High charge



3D-image

MINOS track matching



The presence of the **MINOS ND** allows for **energy reconstruction** and **charge identification** of escaping muons.

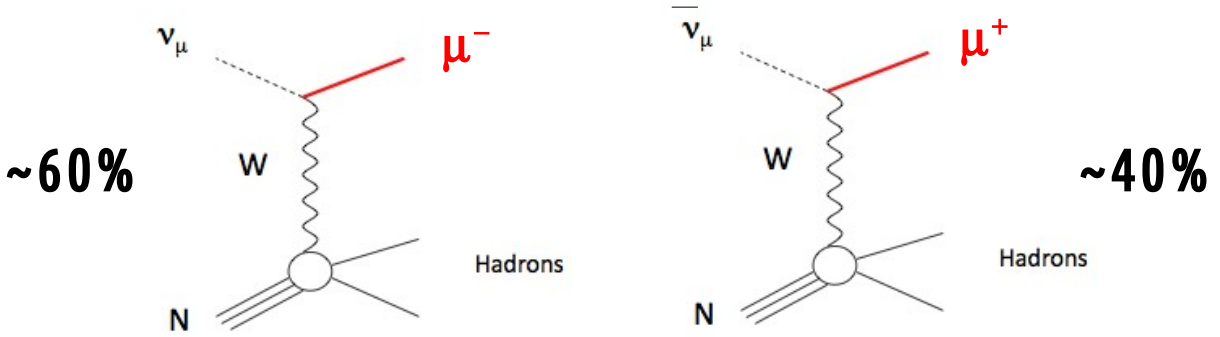
CURRENT ANALYSIS TOPIC

Muon AntiNeutrino Inclusive Charged Current Cross-Section

Measurements of the muon neutrino and antineutrino **CC-inclusive cross-section** using the Antineutrino running data

→ NuMI beam: % neutrinos > % antienutrinos

→ use the magnetized MINOS ND to distinguish between neutrino and antineutrino.



Automatic Event Selection

(frame recorded at every spill – most frames are empty or with crossing particles generated by neutrino interactions in the upstrem material)

+

Visual Scanning inefficiencies of the automated selection (and validate final CC-inclusive sample)

+

Muon kinematics and **Cross-section measurement**

Visual scanning of CC-inclusive sample

TASK: Remove from the CC inclusive sample those events that were not rejected by reconstruction.

Neutrino events characterization takes place with the LARSOFT automated reconstruction software: hit finding → hit clustering → cluster fitting as linelike objects → TRACK identification.

DATA:

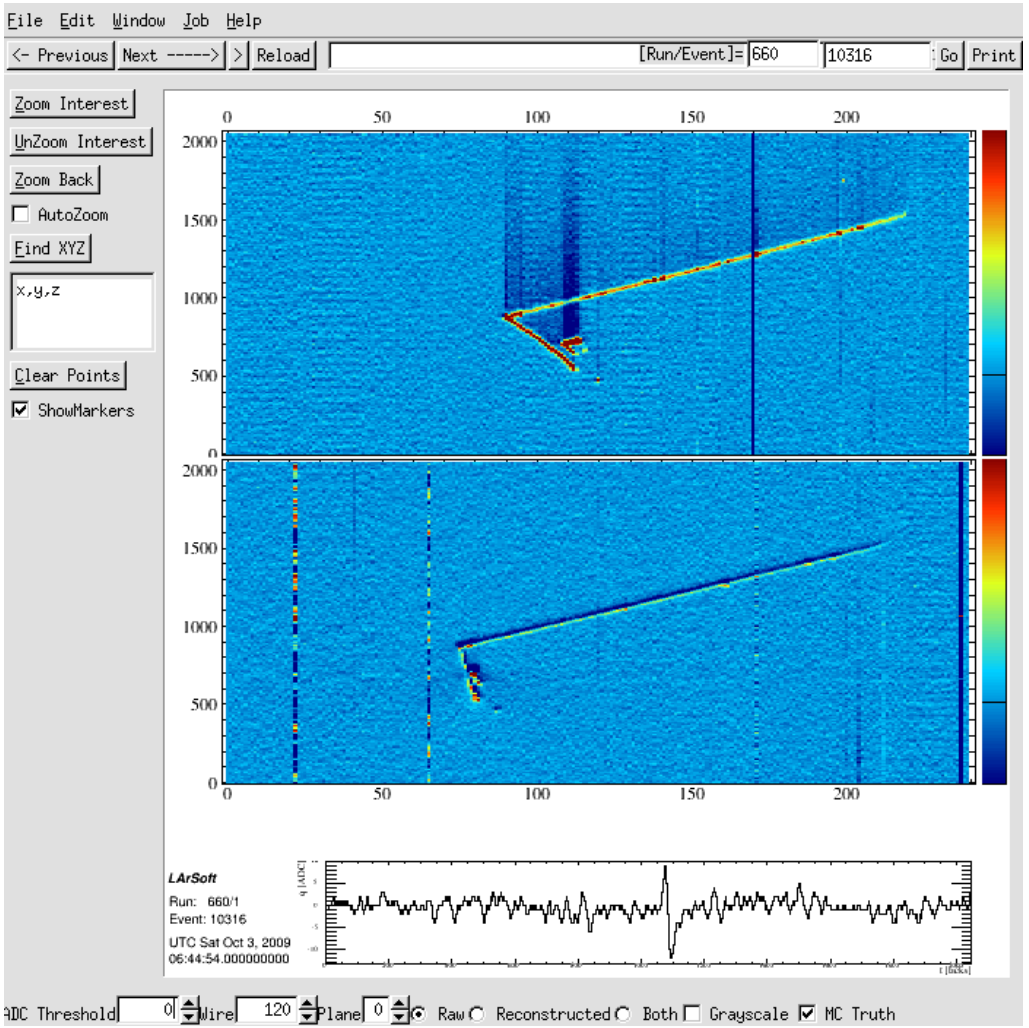
Neutrino-mode (2 weeks → 8.5×10^{18} POT)
414 events

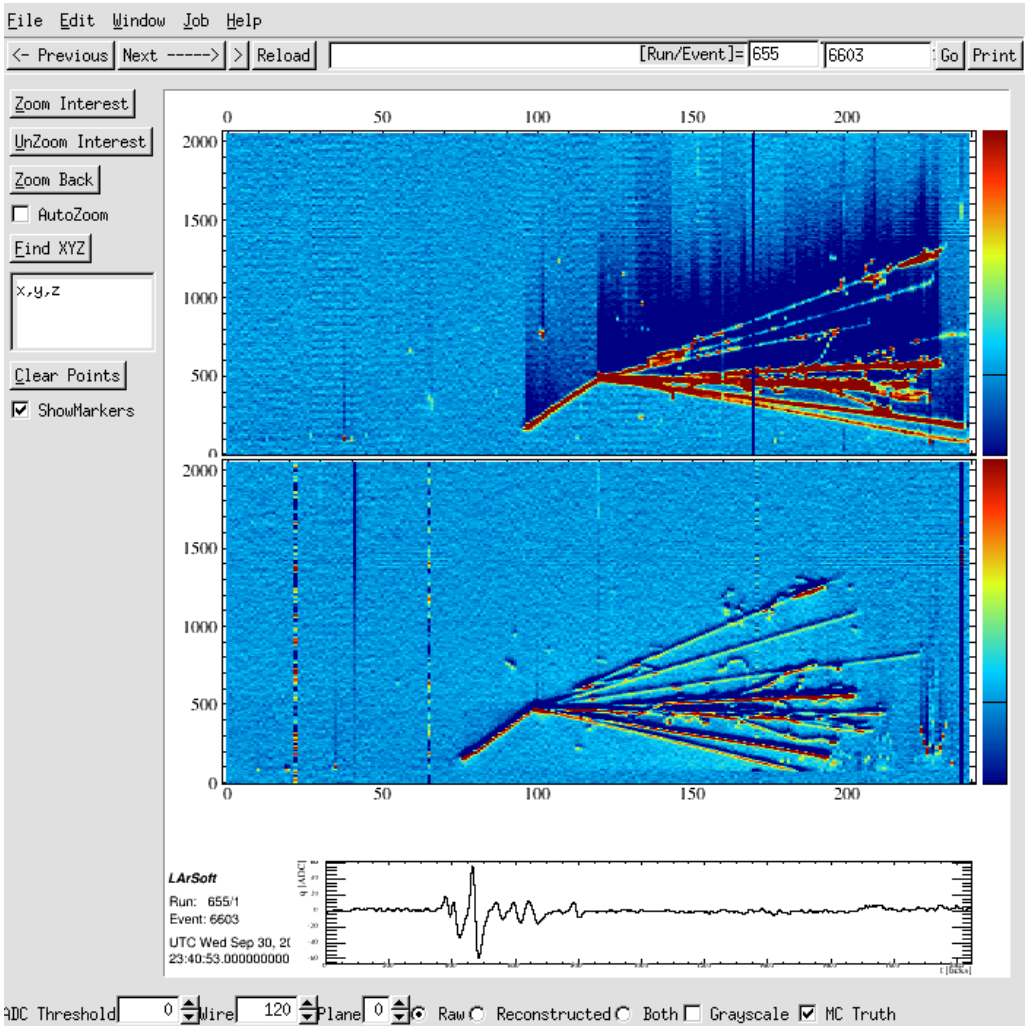
Antineutrino-mode (6 months → 1.2×10^{20} POT)
~2000 events

Selection criteria on the events:

- MINOS matching
- Fiducial volume

ν_μ interaction to keep in the CC-inclusive sample



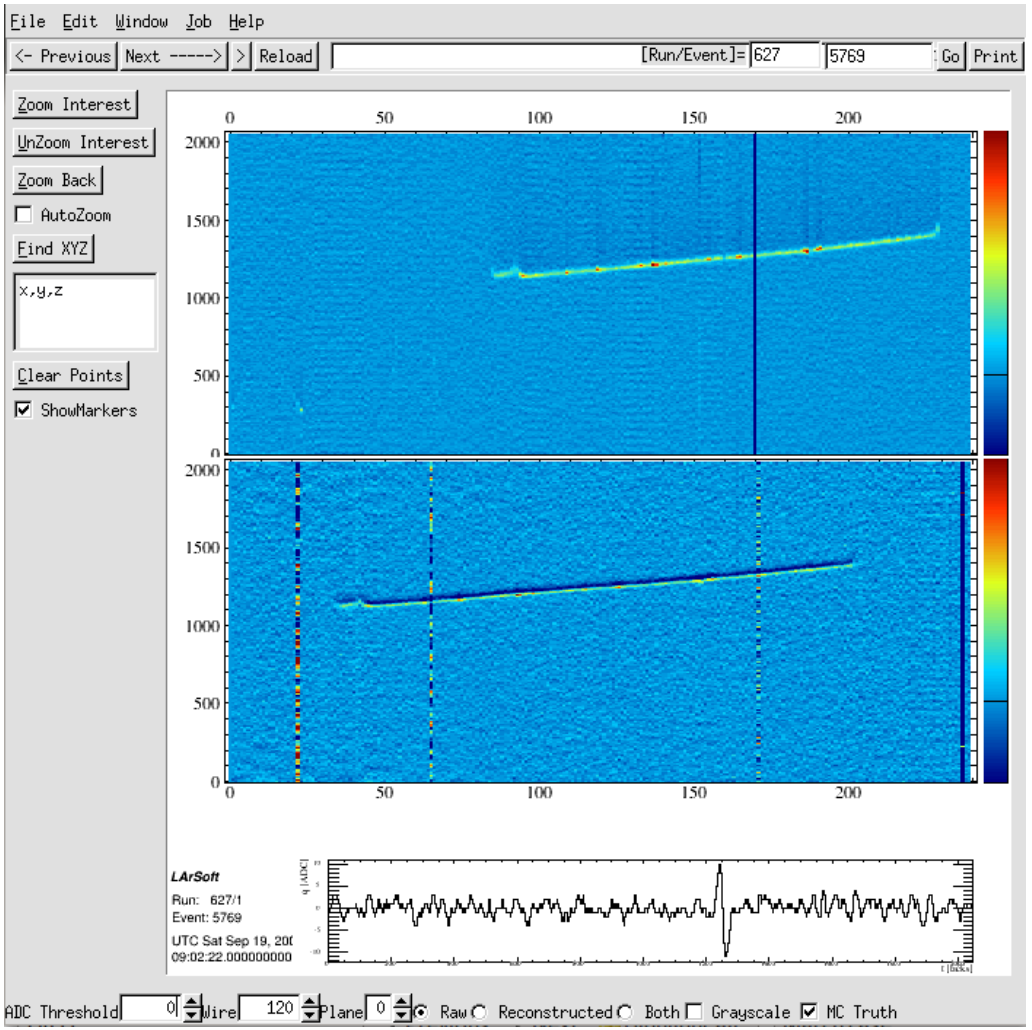


EVENT CLASSIFICATION

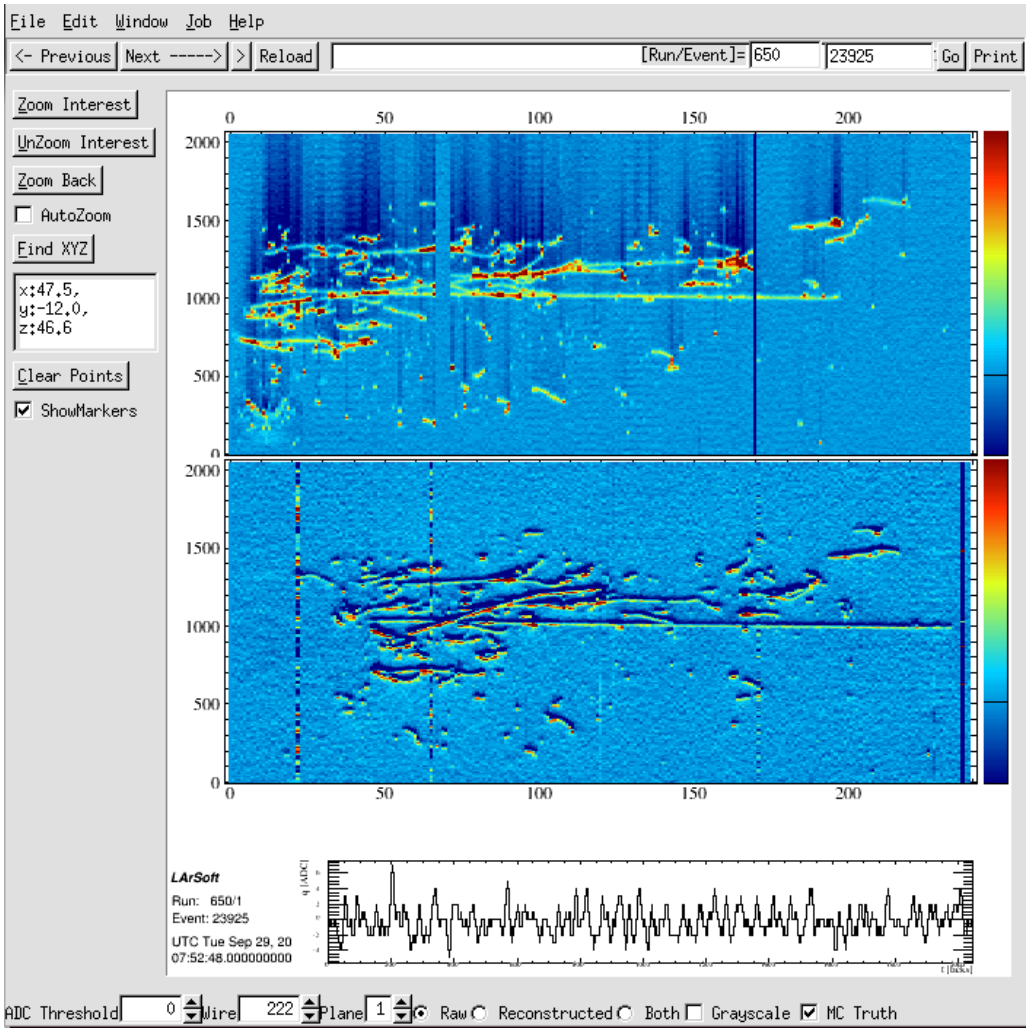
- **upstream events:** upstream events produced by interactions outside the detector.
- **heavily ionizing:** events that probably would be rejected if we checked the dE/dx info.
- **piddly tracks:** very short tracks (contained or not).
- **garbage:** events where erroneously a track was reconstructed.
- **the unknown:** events that we don't understand how to interpret.
- **"ν_e's"** : events that look like electron neutrino interactions.

UPSTREAM EVENTS

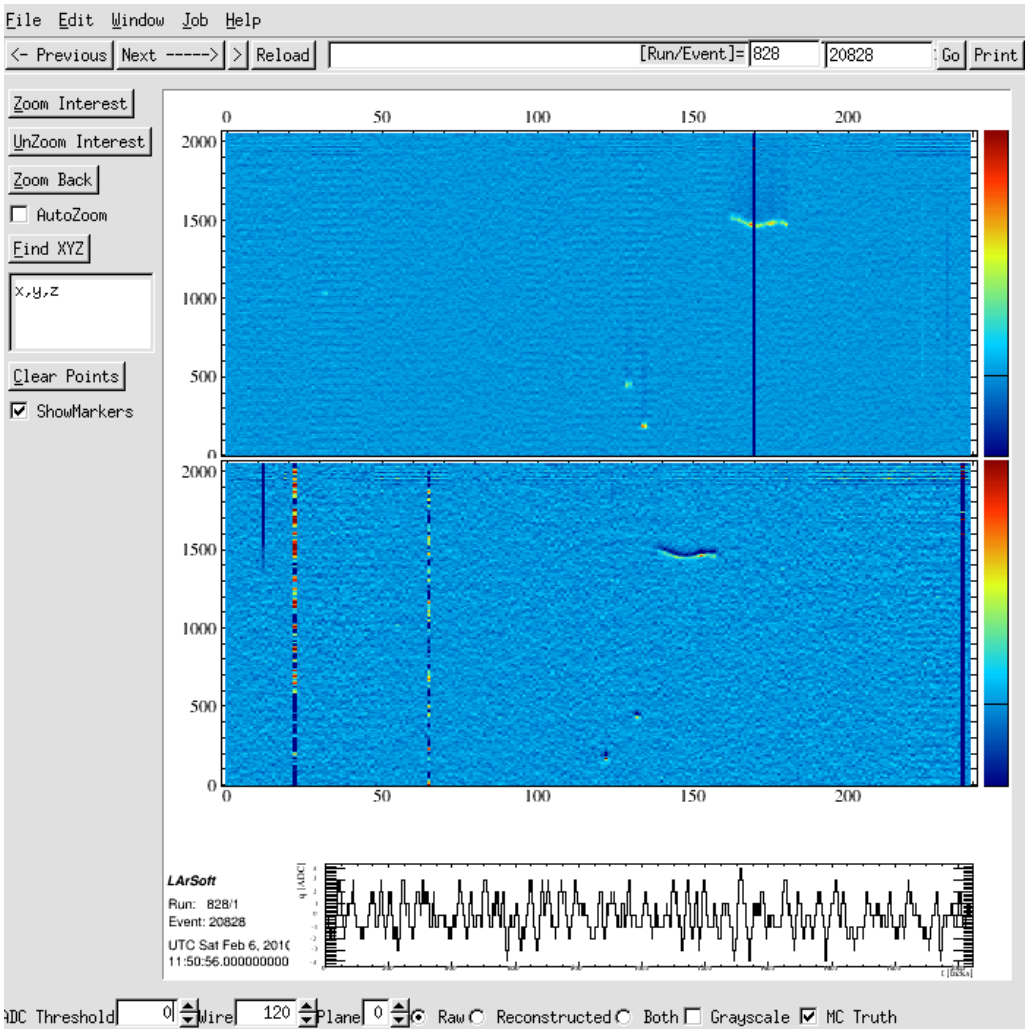
CROSSING MUONS



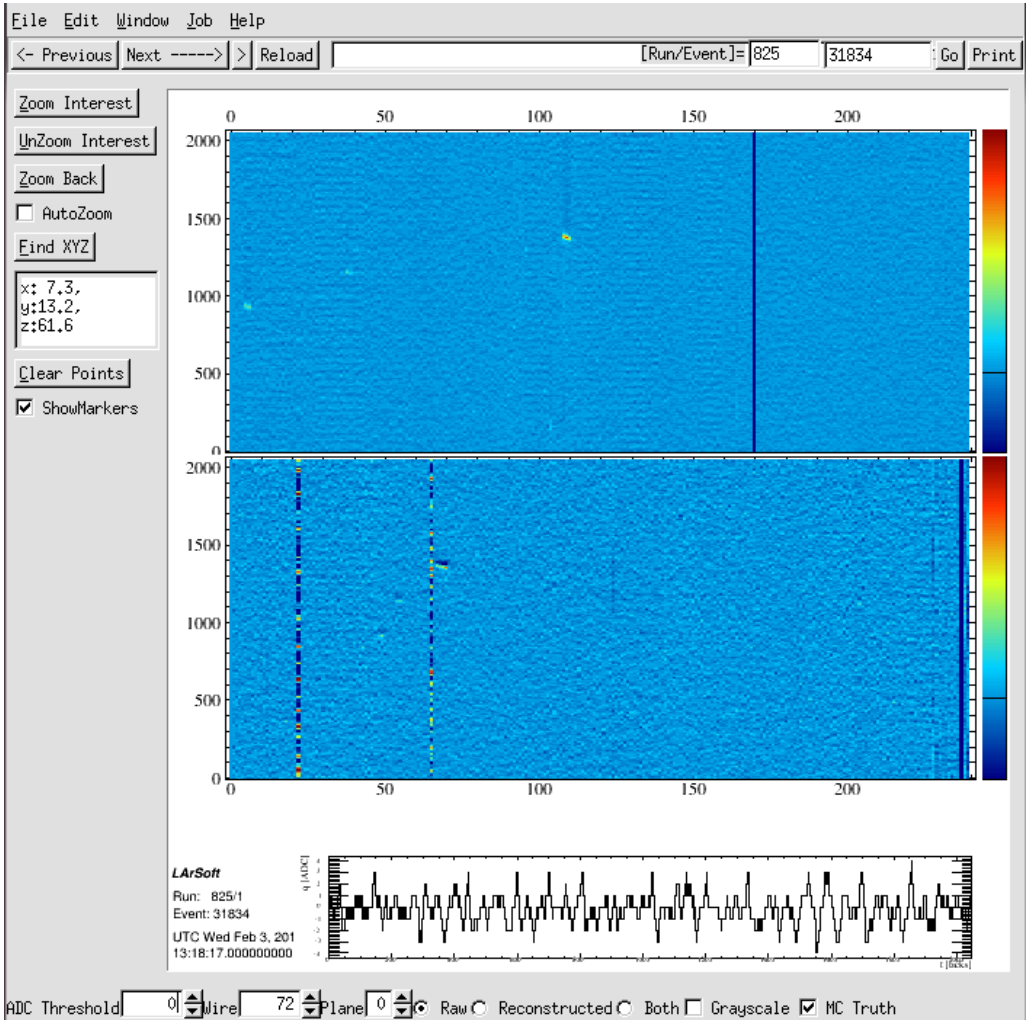
NEARBY INTERACTIONS



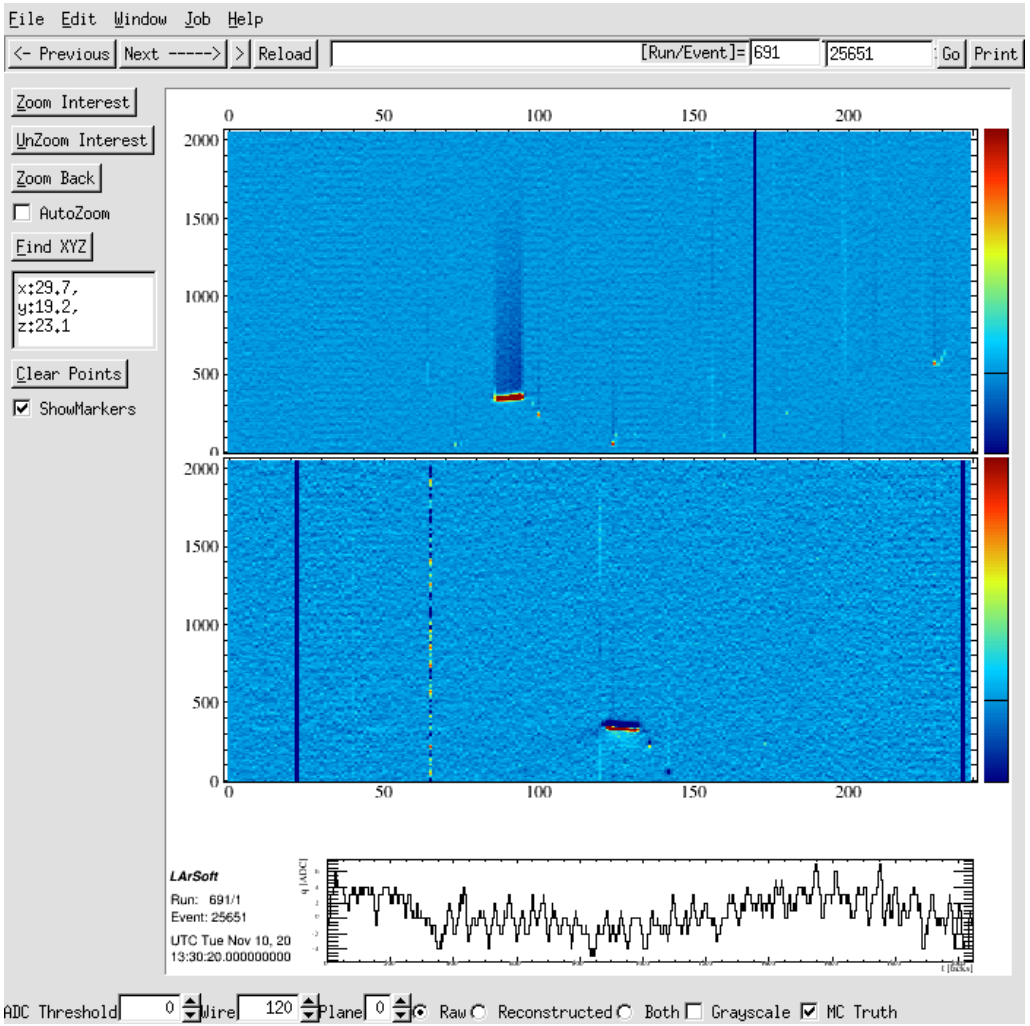
PIDDLY TRACK



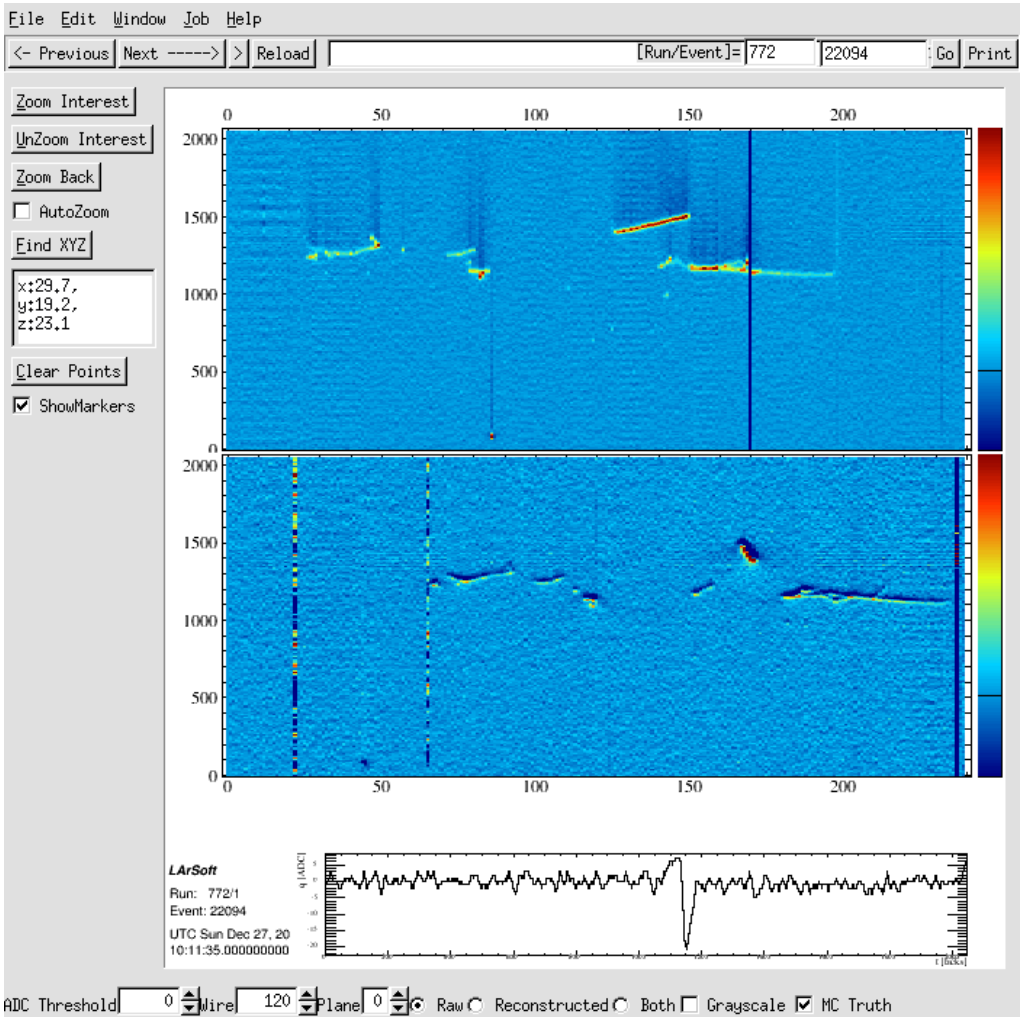
GARBAGE



HEAVLY IONIZING



UNKNOWN



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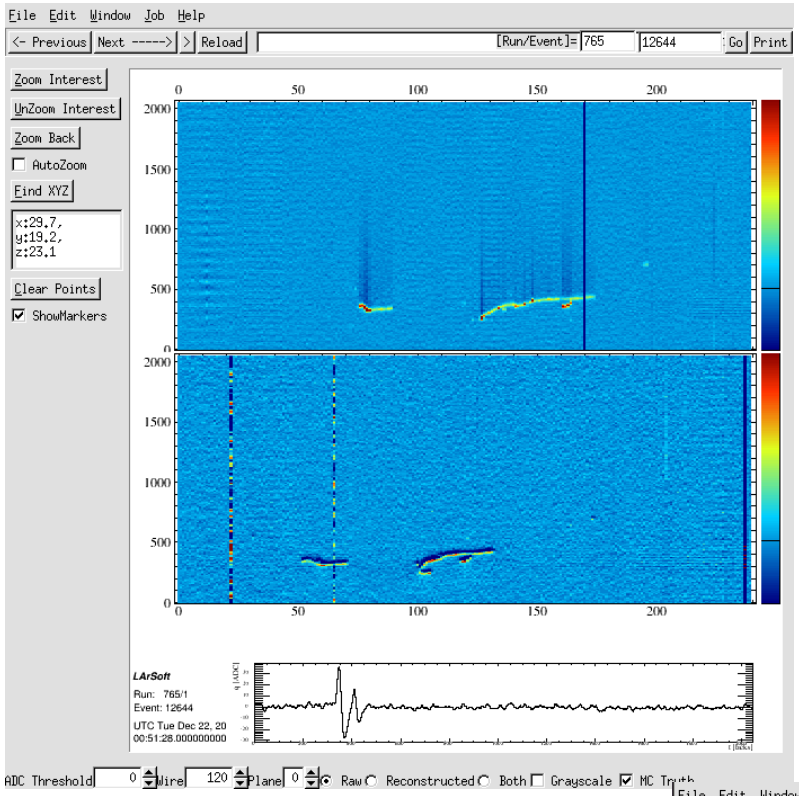
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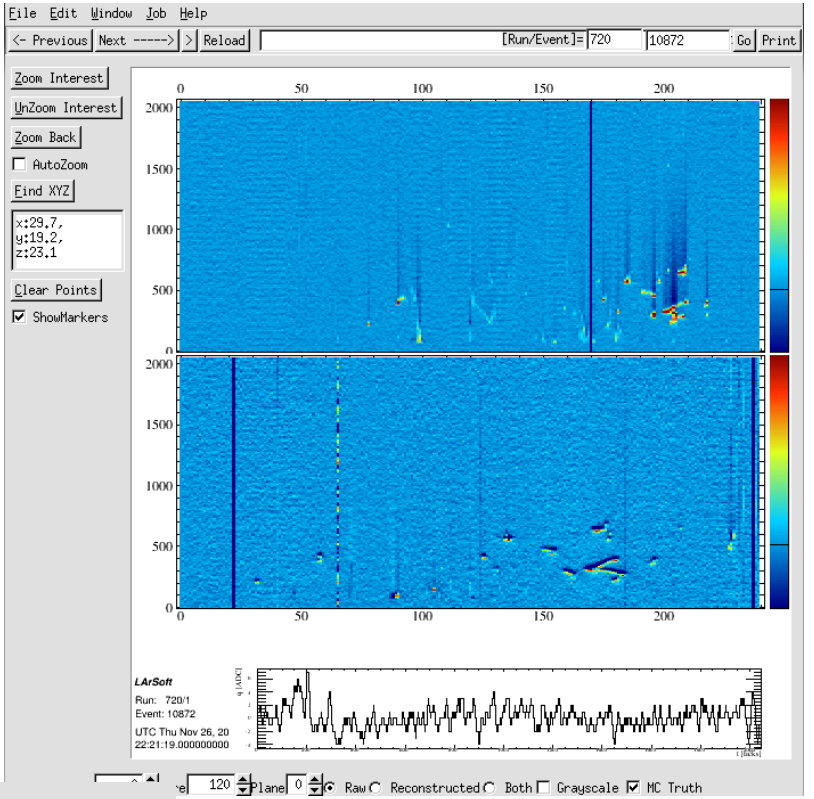
Both
Grayscale
MC Truth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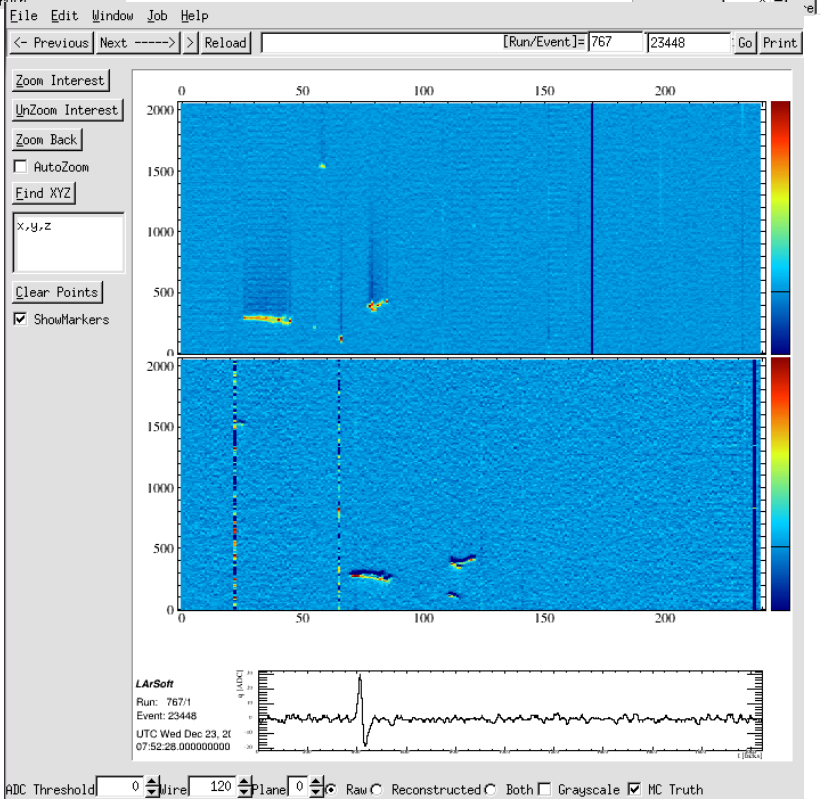
MC Truth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LArSoft
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Event: 23448
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Plane 0
Raw
Reconstructed
Both
Grayscale
MC Truth

CONCLUSIONS

Neutrino Mode

- EVENTS TO BE REJECTED:
  - 54 CROSSING MUONS
  - 5 NEARBY INTERACTIONS
  - 10 PIDDLY TRACKS
  - 3 HEAVLY IONIZING
  - 3 GARBAGE
  - 3 ELECTRON NEUTRINO LIKE
- 5 EVENTS TO BE CHECKED (UNKNOWN)

➡ **~15%** of events potentially to be removed.

Antineutrino Mode

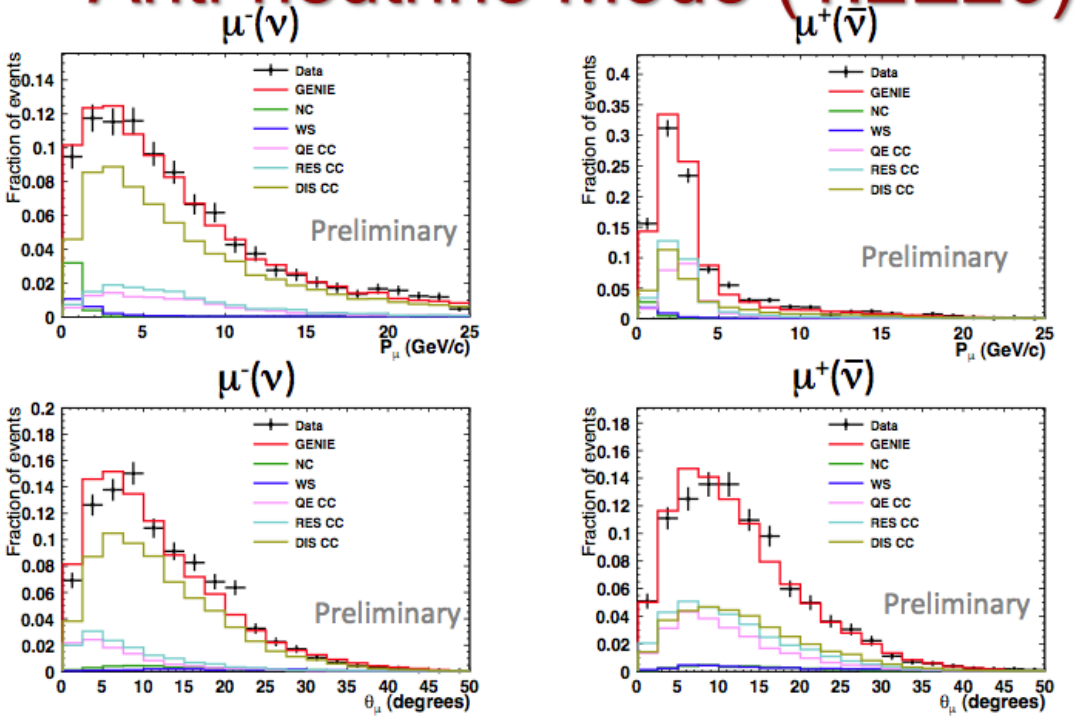
- EVENTS TO BE REJECTED:
  - 360 CROSSING MUONS
  - 36 NEARBY INTERACTIONS
  - 45 PIDDLY TRACKS
  - 9 HEAVLY IONIZING
  - 29 GARBAGE
- 45 EVENTS TO BE CHECKED (UNKNOWN)

➡ **~26%** of events potentially to be removed.

Muon kinematics analysis and Cross-section measurement

- IN PROGRESS -

Anti-neutrino Mode (1.2E20)



- Area normalized
- Need to improve flux prediction
- Paper in preparation

Data from a subsample (~1/4) from which the bad reconstructed events were rejected thanks to visual scanning analysis.

➡ Now the whole data file is ready to be analyzed.

CURRENT ANALYSIS TOPIC

Study EM shower events

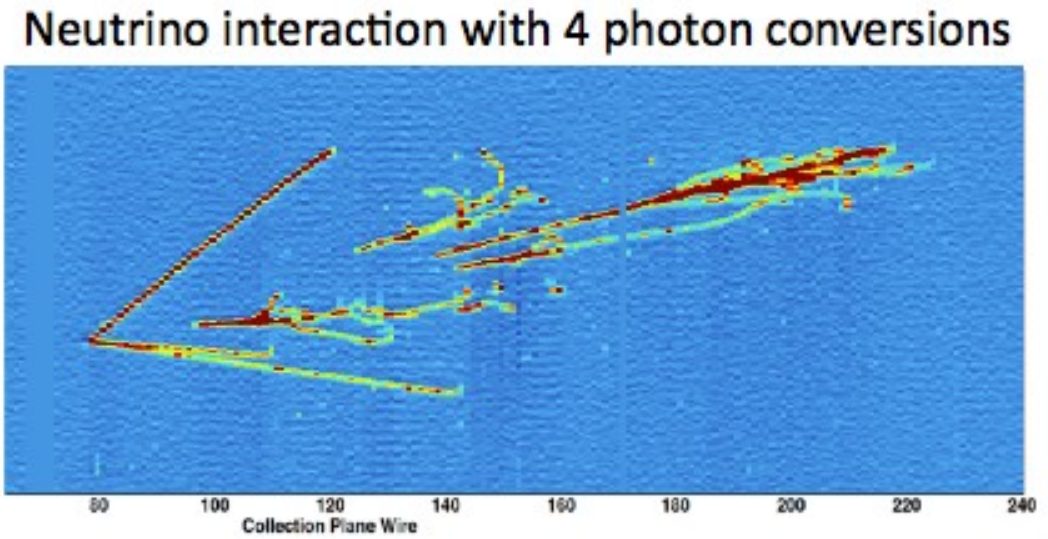
EM showers sources:

1) electron neutrino contamination in muon neutrino beam (CC reaction)

2) neutral pion production (Delta resonance channel/DIS channel) → 2 γ → 2 EM Showers.

3) $\nu_\mu \rightarrow \nu_e$ oscillations !!!

(excluded in ArgoNeuT because at near location from the neutrino beam source)



Automated EM showers event selection

+

Visual scanning to remove inefficiencies of the automated selection

(and validate final EM shower event sample)

Visual scanning of shower events

TASK: Classification of events from a data sample obtained after a shower filtering selection was applied
→ improvement of the Filter performace.

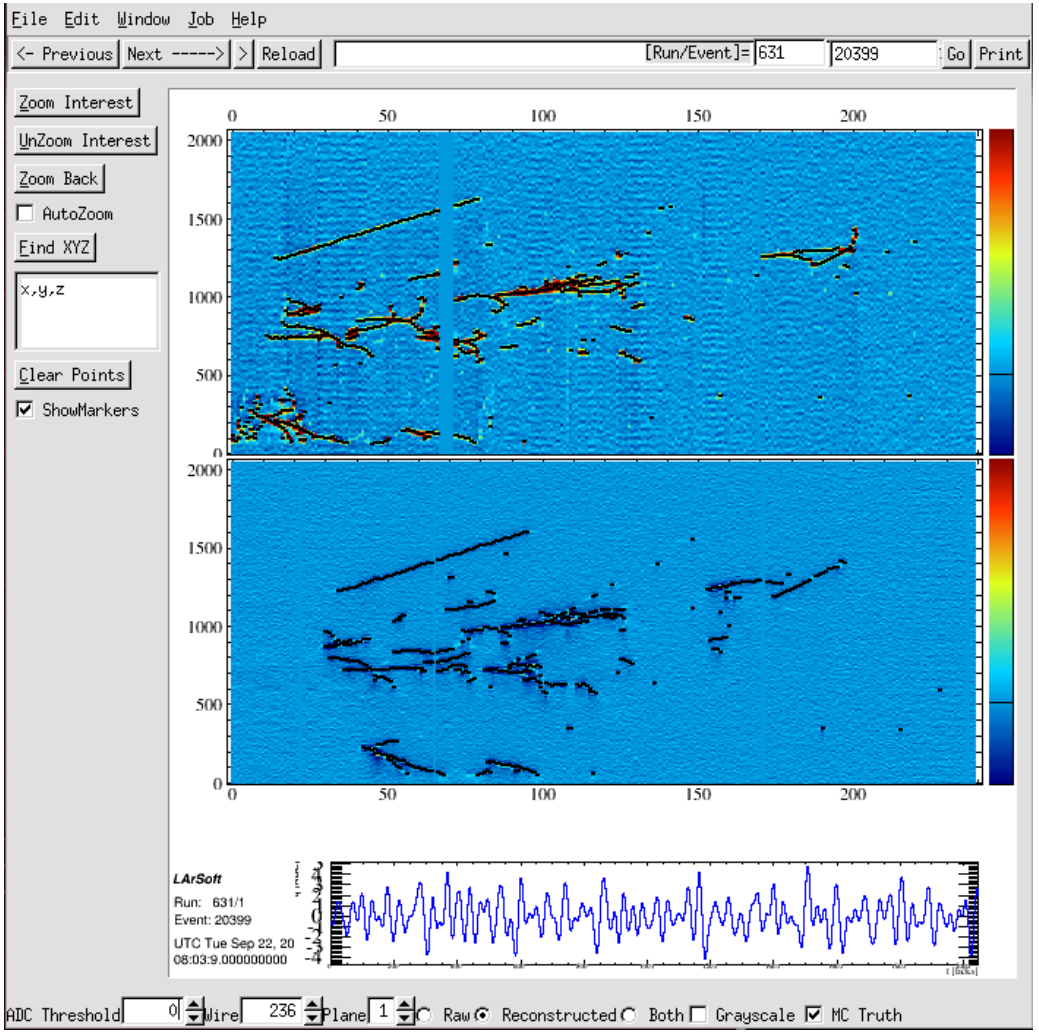
DATA: **Neutrino-mode** (2 weeks → 8.5×10^{18} POT)
611 events

Selection criteria on the events:
- Shower Filter

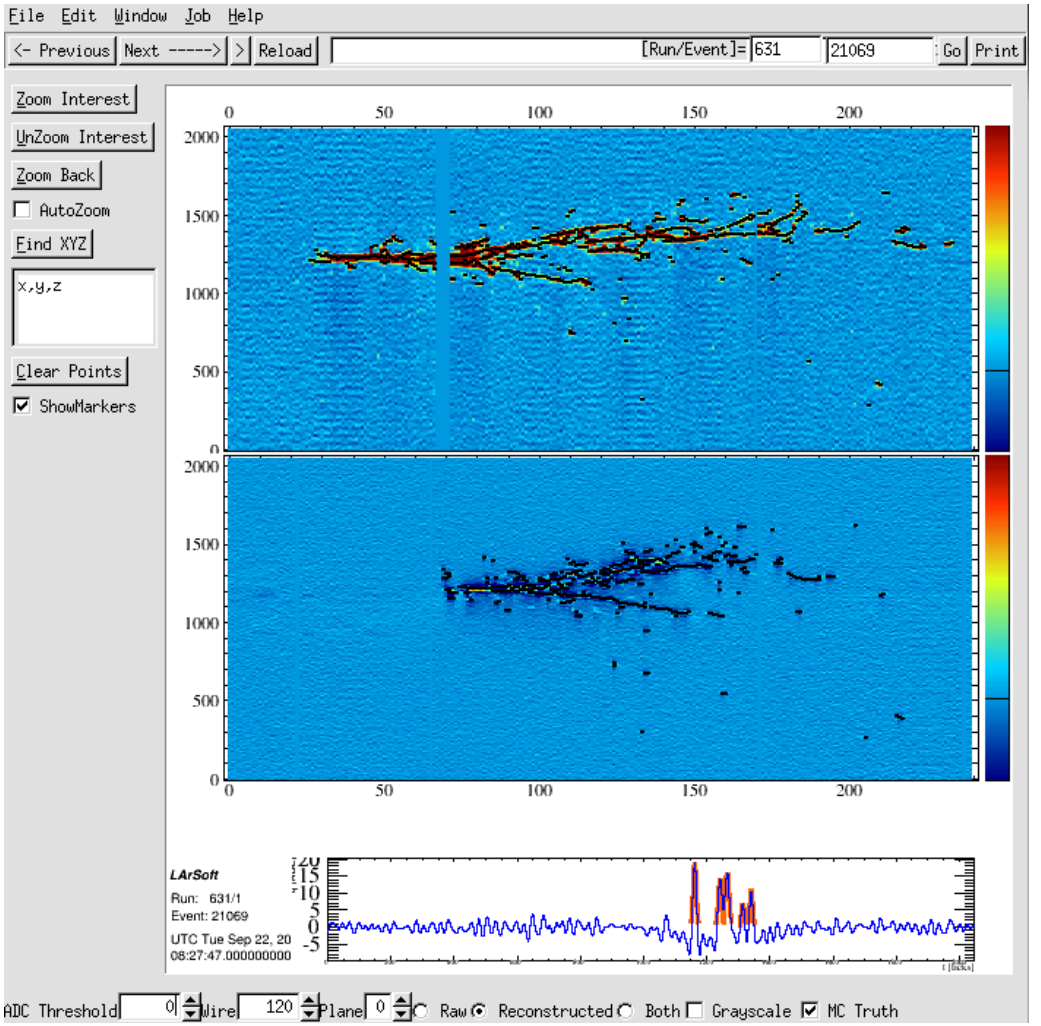
EVENT CLASSIFICATION

- **shower with gap:** showers probably due to $\pi^0 \rightarrow \gamma\,\gamma$
- **shower NO gap:** showers connected to the primary vertex or isolated.
- **shower + muon:** showers with a well defined muon track.
- **single track + gamma rays:** single tracks with spots induced by photon interactions inside the TPC.
- **single track + delta rays:** single tracks with low energy secondary electrons close to the main track.
- **many tracks:** muon neutrino interactions with more than one particle at the vertex.
- **busy:** events with high multiplicity (contained or not).
- **other:** all other kind of events.

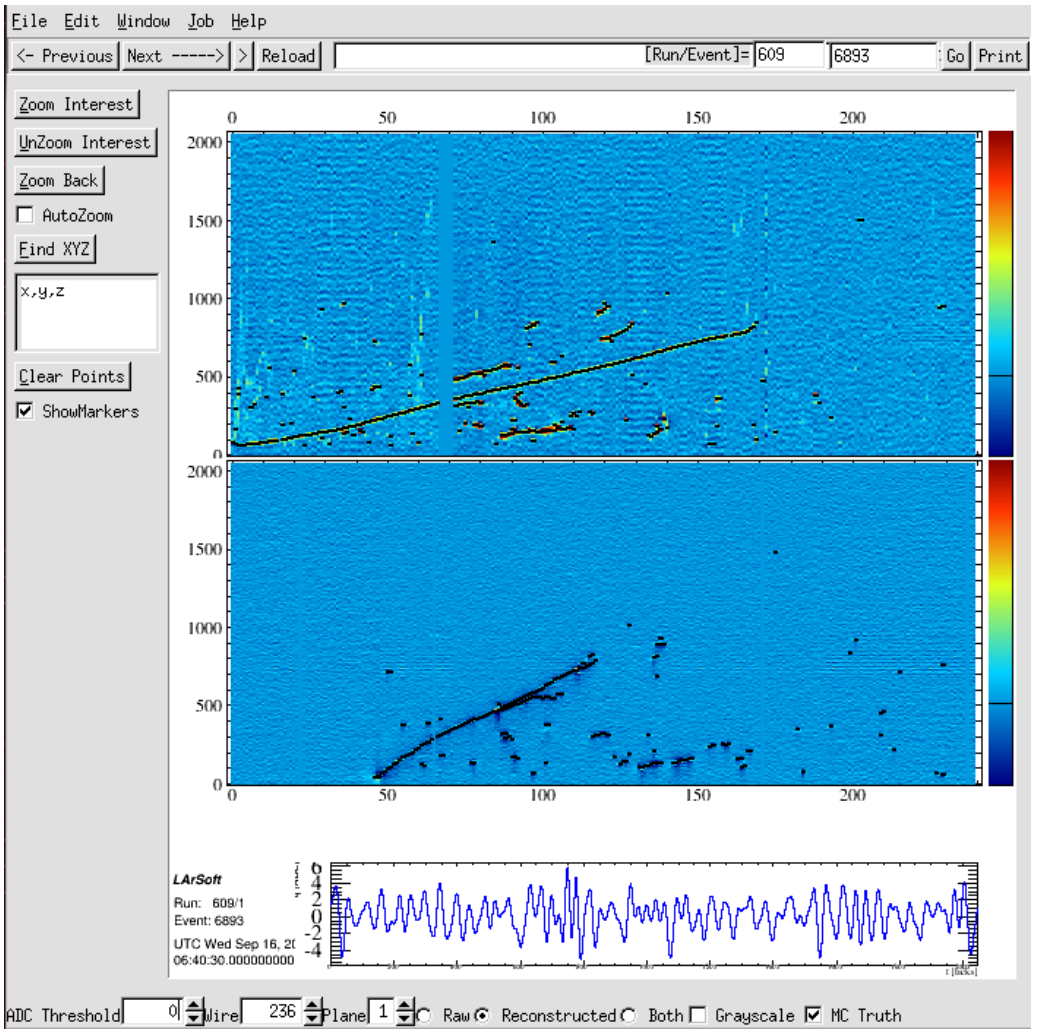
SHOWER WITH GAP



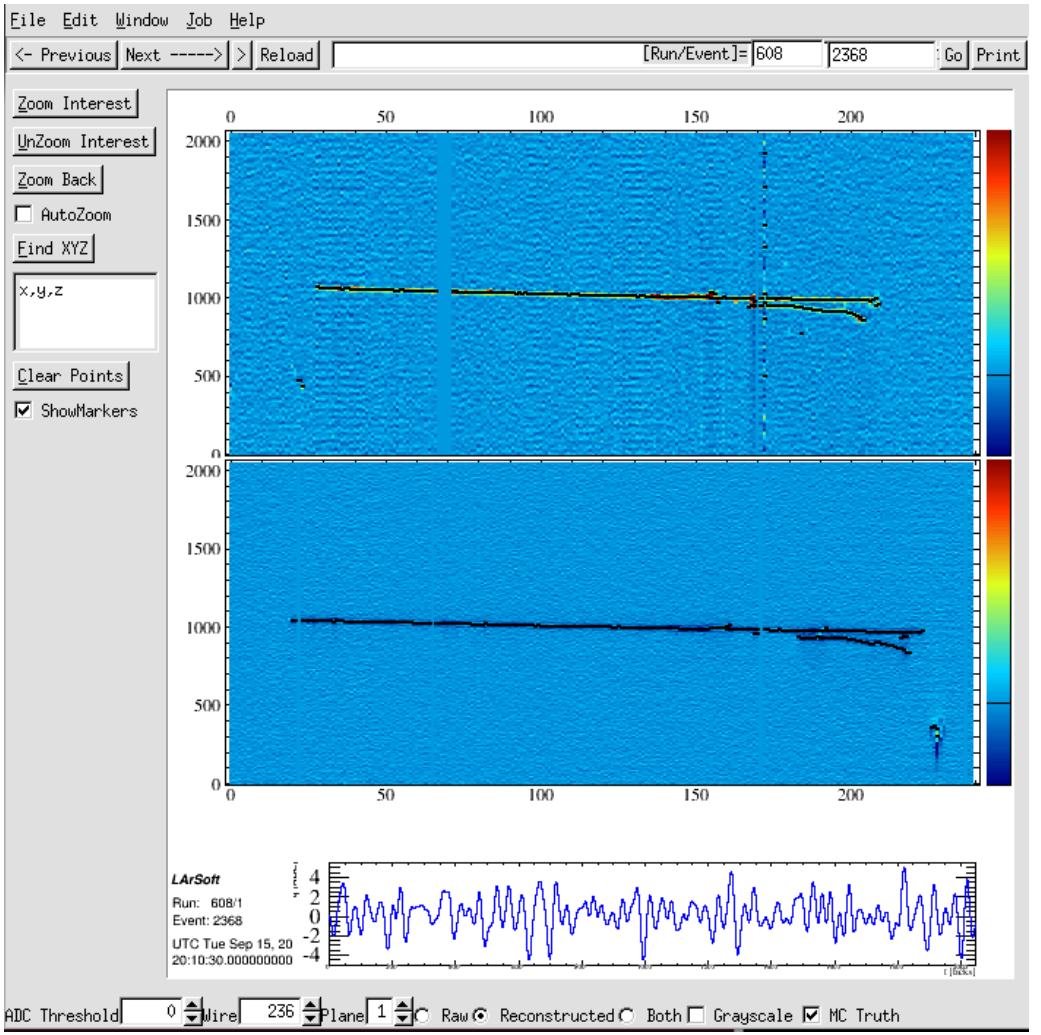
SHOWER NO GAP



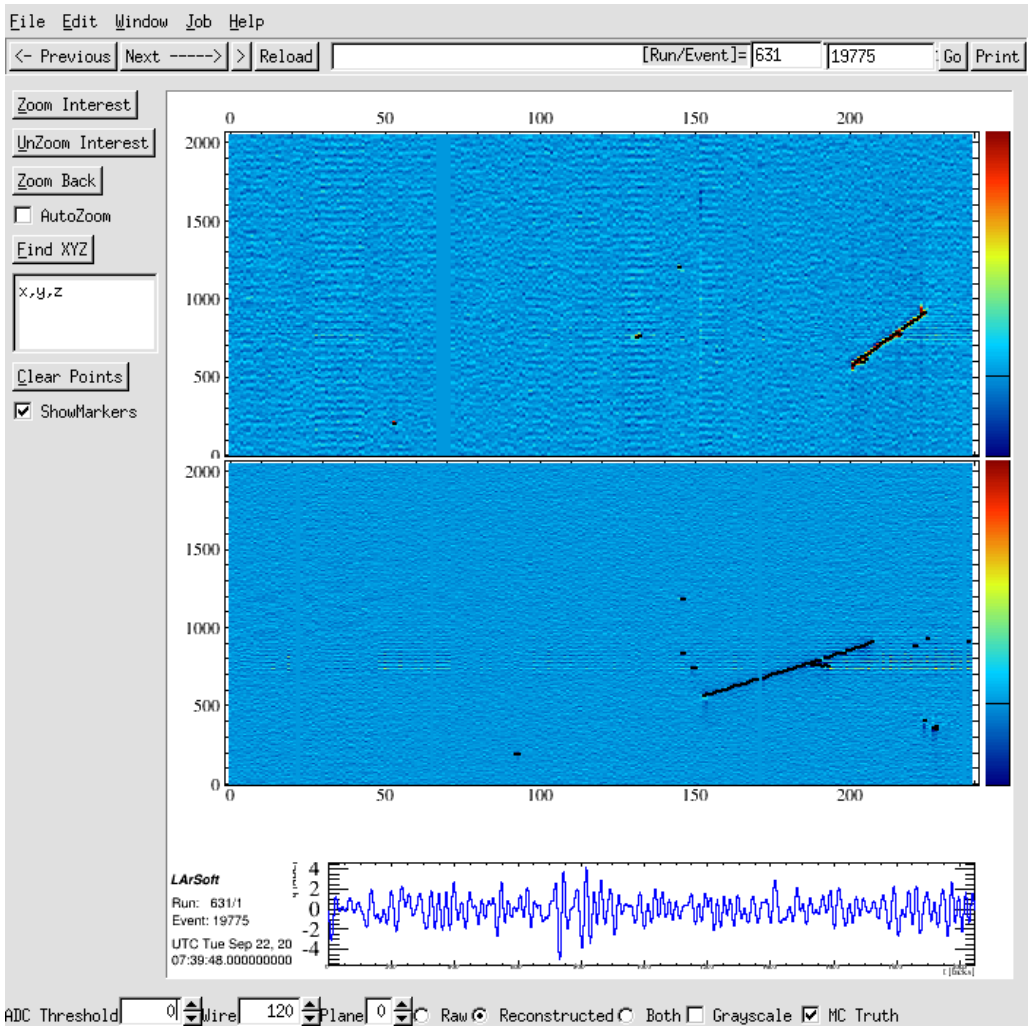
SHOWER + MUON



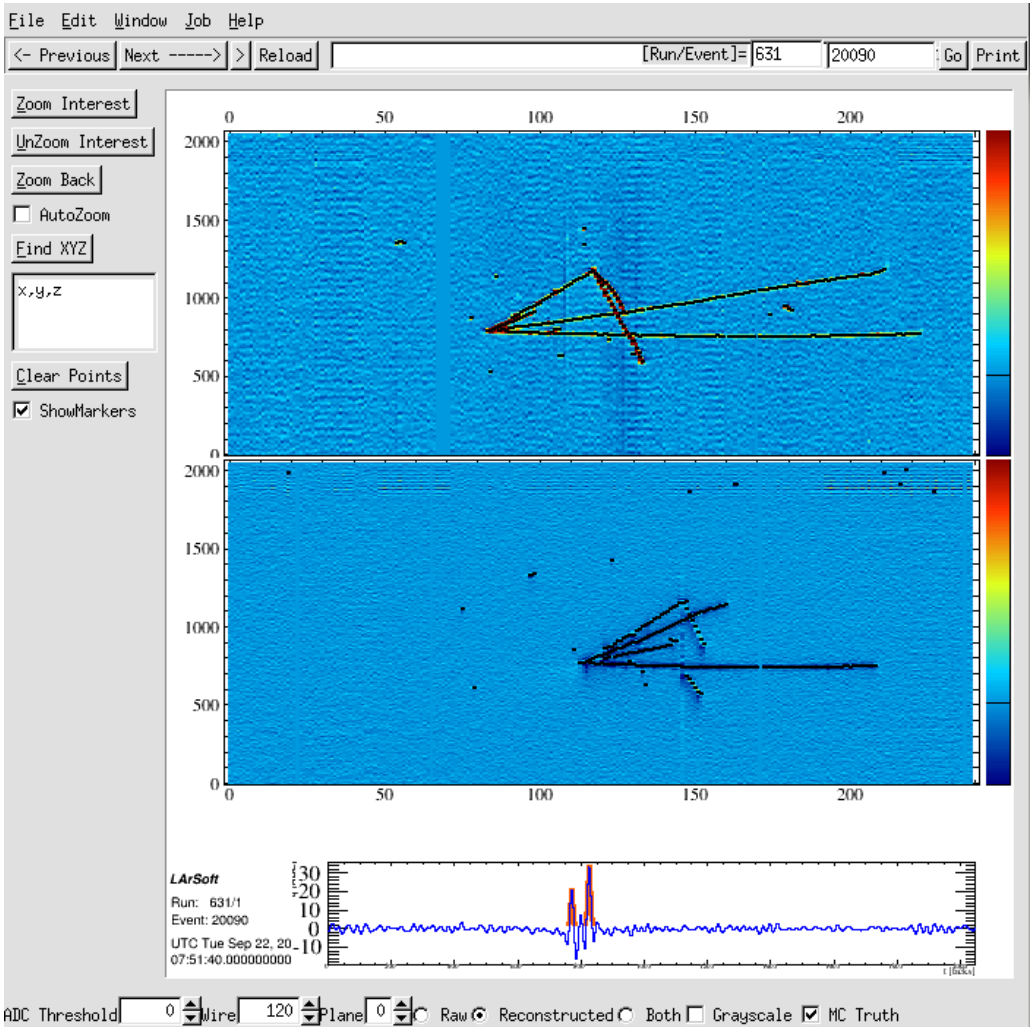
TRACK + DELTA RAYS



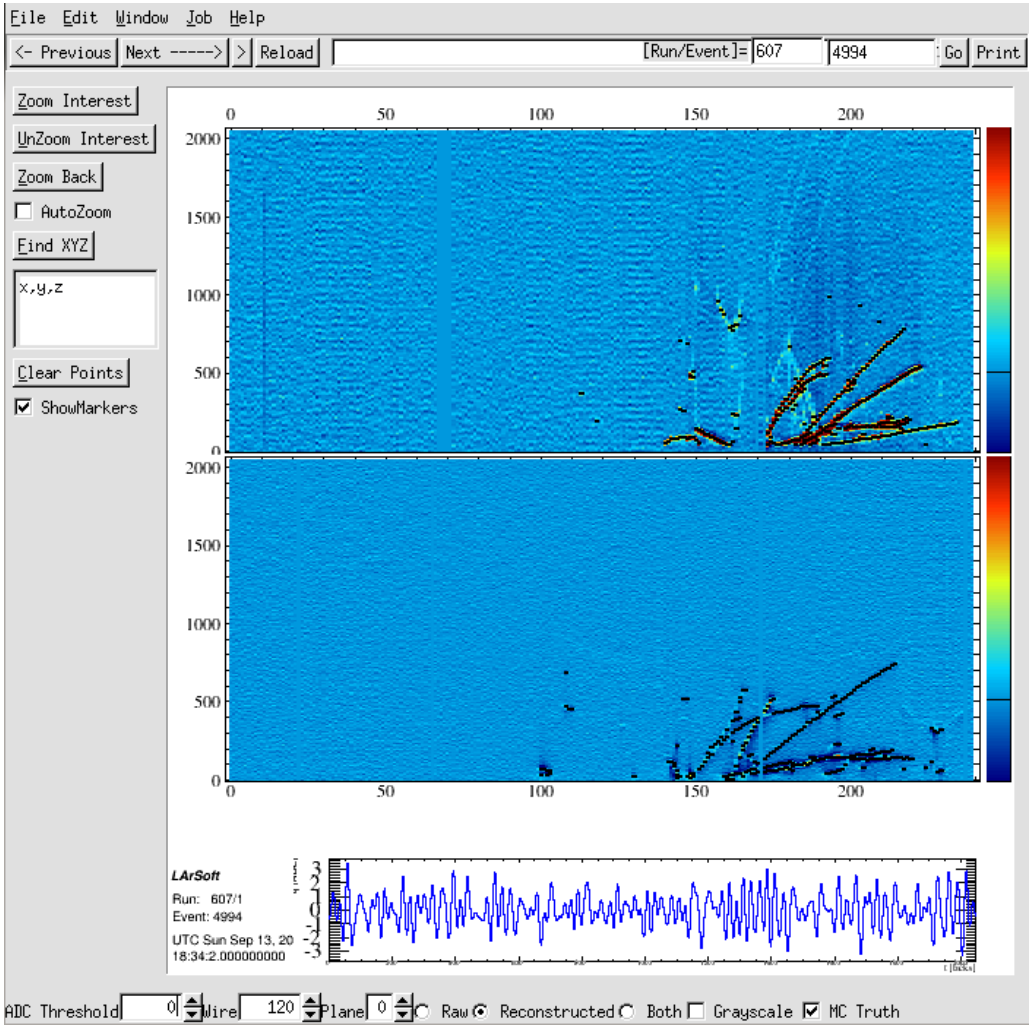
TRACK + GAMMA RAYS



MANY TRACKS



BUSY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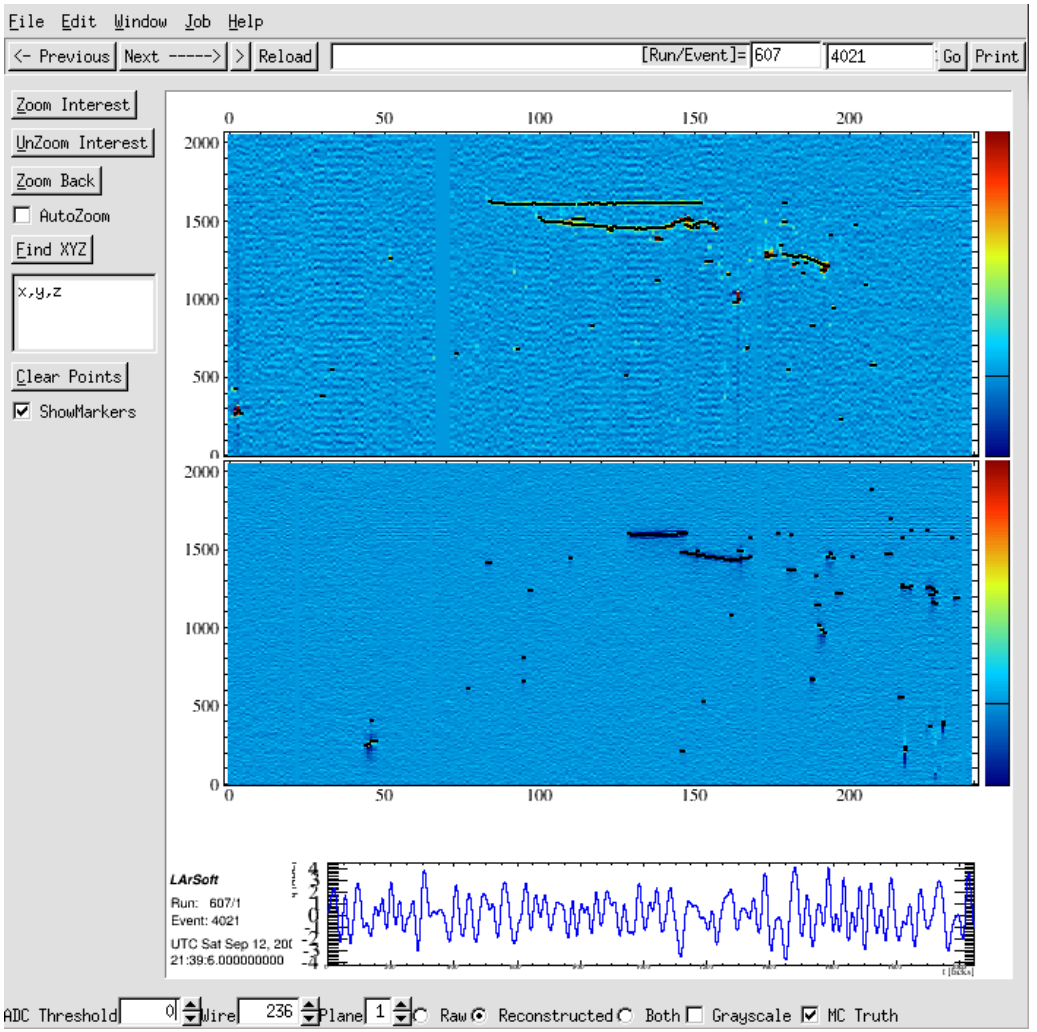
Plane 0
Raw
Reconstructed
Both
Grayscale
MC Truth

OTHER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ADC Threshold 0
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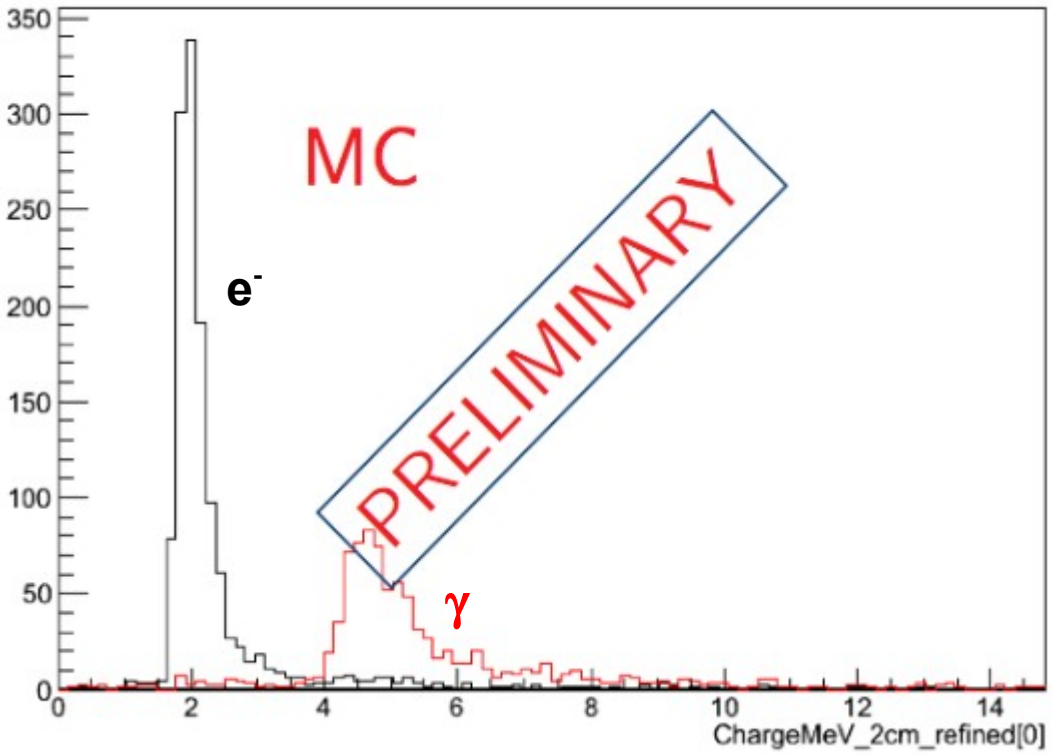
Plane 1
Raw
Reconstructed
Both
Grayscale
MC Truth

THE NUMBERS:

- 108 SHOWERS WITH GAP
- 57 SHOWERS NO GAP
- 33 SHOWERS + μ
- 74 SINGLE TRACK + γ
- 82 SINGLE TRACK + δ
- 63 MANY TRACKS
- 37 BUSY
- 157 OTHER

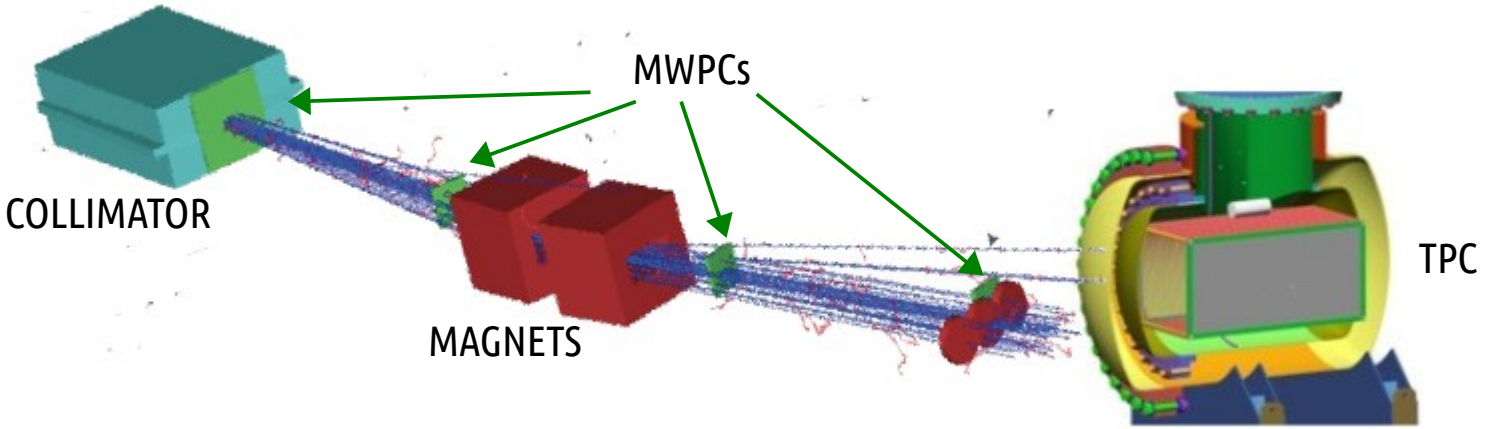


165 shower events

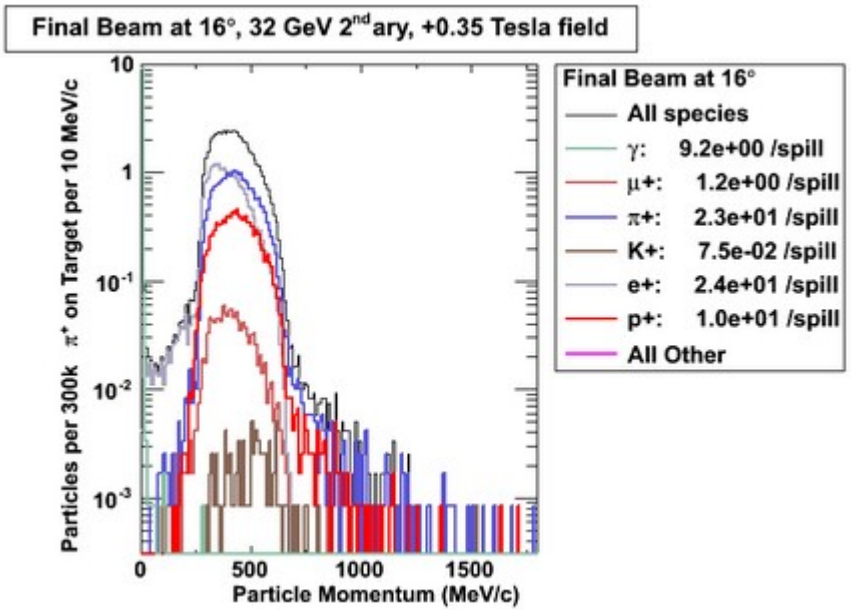
Preliminary studies of dE/dx for electron-gamma separation are feasible!

LArIAT

Experiment set to calibrate LarTPC technology by palcing the detector on a beam of charged particles of kown type an momentum at FTBF.



LArIAT dedicated Tertiary Beam at FTBF (MCentral)

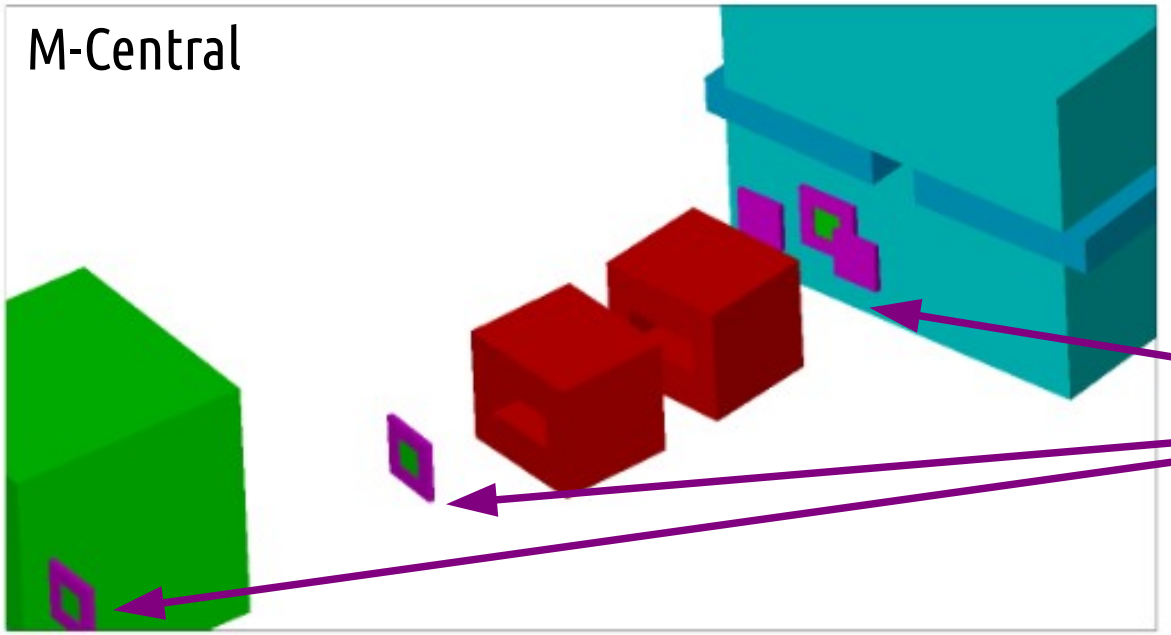


GOALS:

Cryogenic/purification facility at FNAL designed to allow future test of LAr detectors.

Optimize the particle ID:
– For protons, kaons and pions measuring the recombination factors.
– For electrons and gammas measuring the dE/dx separation, crucial for studing $\nu_\mu \rightarrow \nu_e$ oscillations.

Non-magnetic muon sign determination.

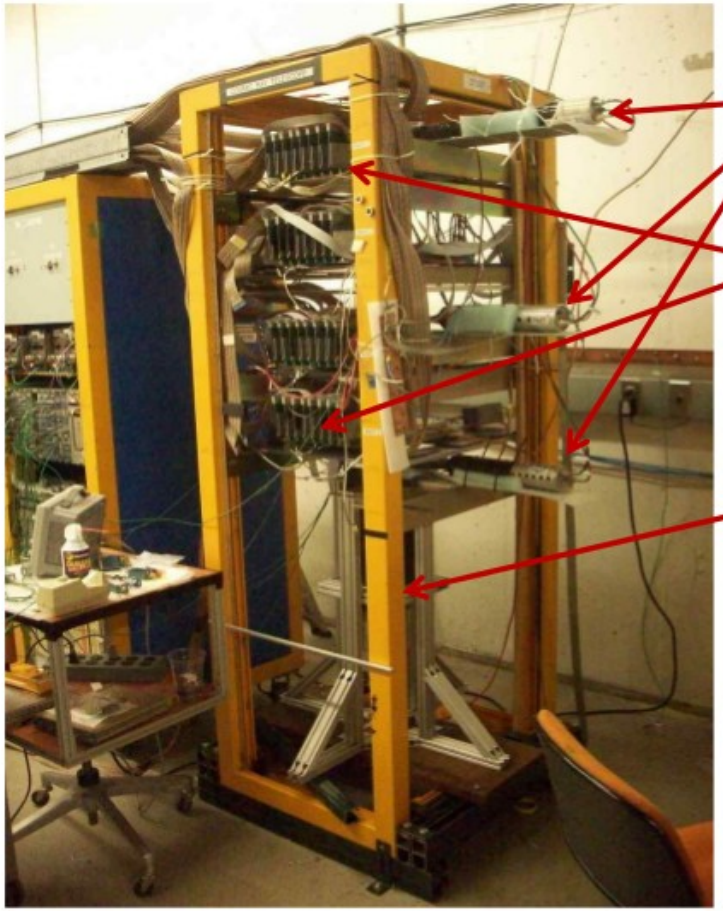


FTBF Phyton script
to collect data
from 4 MWPC (Fenker)
Chambers
and ToF counters

TASK:

We want to define an online routine to convert the output from the data acquisition into a ROOT file in order to define a standard format output to be used for further analysis.

Cosmic Ray Telescope at FTBF



128 wires per view (X,Y)
1 mm spacing
4X, 4Y planes

FTBF counters initially arranged in a Cosmic Ray Telescope geometry for test purposes.

Software

python program to collect data from CAMAC

PAW programs to do some analysis

ana4r.for - quick monitor while running

anatk.for - 4 chamber reconstruction

>> ntuple (paw, or >> root)

graphic tracks

Data file from the Cosmic Ray Telescope: apr19.dat

```
Wait for event ...
... event seen at Fri Apr 19 09:55:12 2013
EVENT          1                    Fri Apr 19 09:55:12 2013
Crate       CC0215
Module           1
scaler           0       1
scaler           1       2
scaler           2       0
scaler           3       0
Module           2
tdc              0    4095
tdc              1    3444
tdc              2    3532
tdc              3     892
tdc              4       0
tdc              5       0
tdc              6       0
tdc              7       0
tdc              8       0
tdc              9       0
tdc             10       0
tdc             11       0
tdc             12       0
tdc             13       0
tdc             14       0
tdc             15       0
Module           3
adc              0     227
adc              1     220
adc              2     160
adc              3     438
Crate       CC0211
Module           1
Module           2
Channel         29     291     145.5 ns
Module           3
Module           4
Module           5
Module           6
Module           7
Module           8
Channel         28     284     142.0 ns
Module           9
Module          10
Channel         20     179      89.5 ns
Module          11
Module          12
Module          13
Module          14
Module          15
Module          16
Channel         25     269     134.5 ns
Crate       CC0208
Module           1
Module           2
Channel         12     284     142.0 ns
Module           3
Module           4
Module           5
Module           6
Module           7
Module           8
Channel         21     295     147.5 ns
Module           9
Module          10
Channel          4     288     144.0 ns
Module          11
Module          12
Module          13
Module          14
Module          15
Module          16
Channel         19     288     144.0 ns

Wait for event ...
... event seen at Fri Apr 19 09:55:46 2013
EVENT          2                    Fri Apr 19 09:55:46 2013
```

INFORMATION TO BE KEPT

EVENT event number

SCALER event number – crate – module – scalerID – scaler value

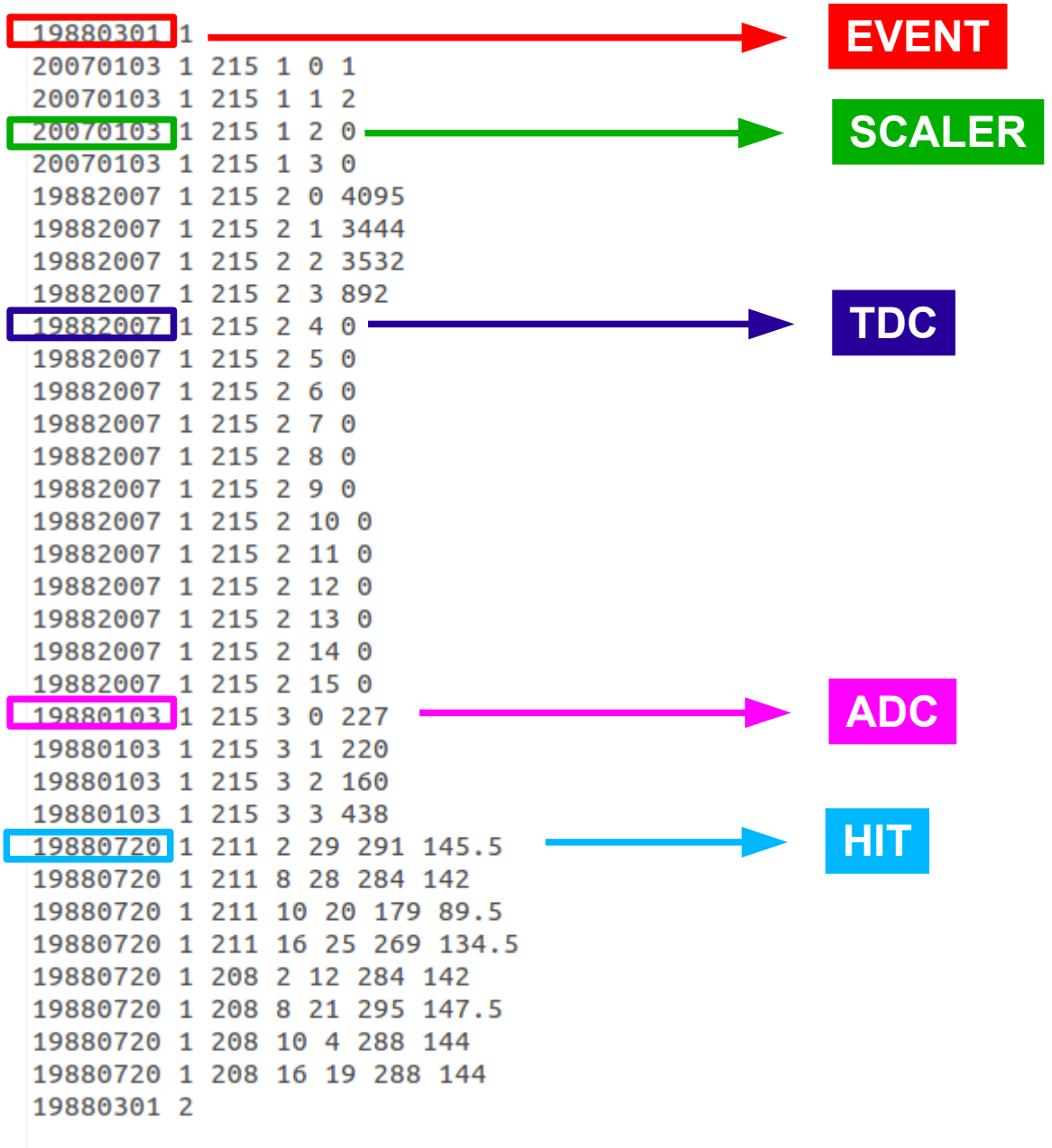
TDC event number – crate – module – tdcID – tdc value

ADC event number – crate – module – adcID – adc value

HIT event number – crate – module – channel – wireID – time

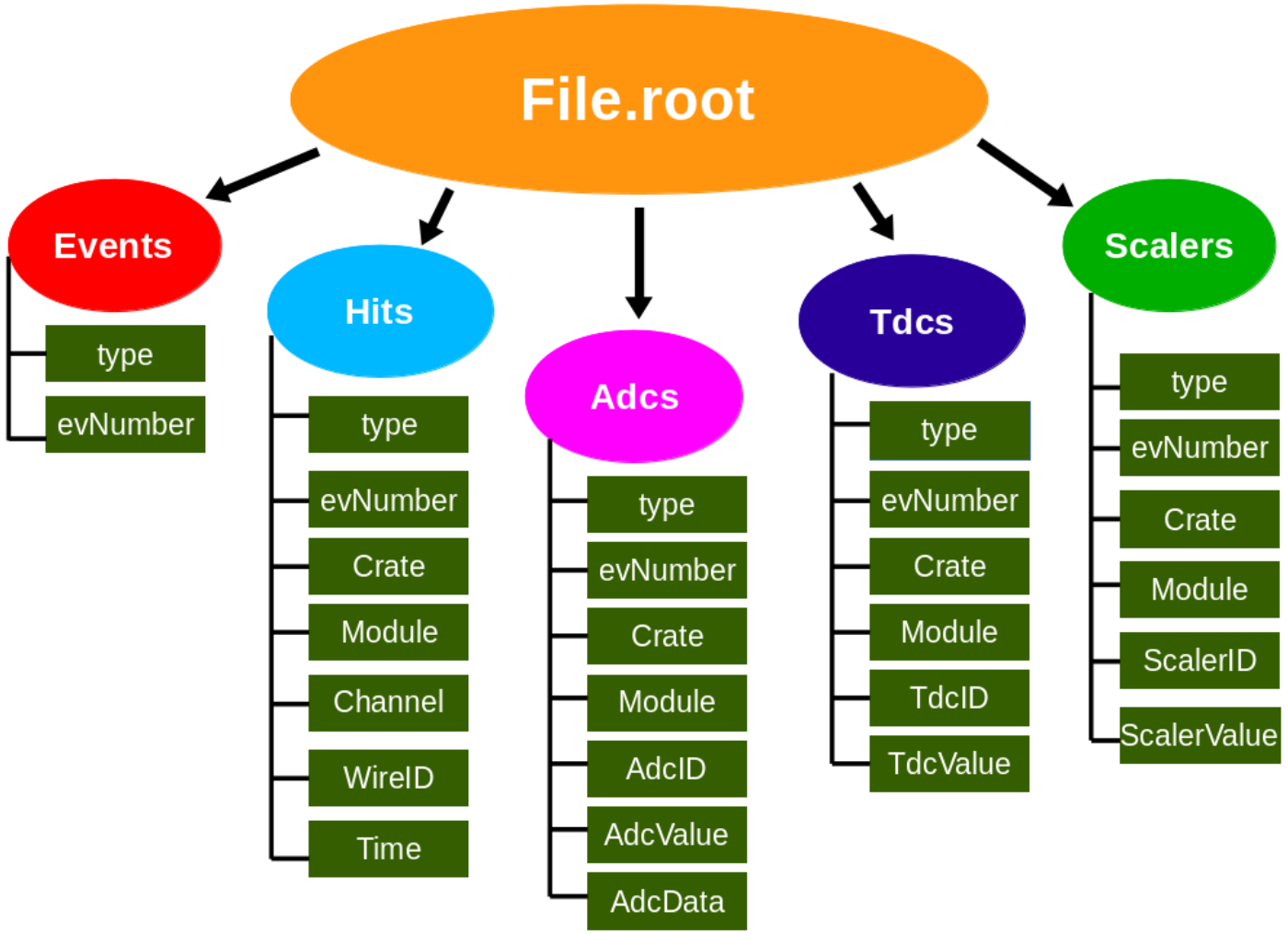
Simplified .txt Data file

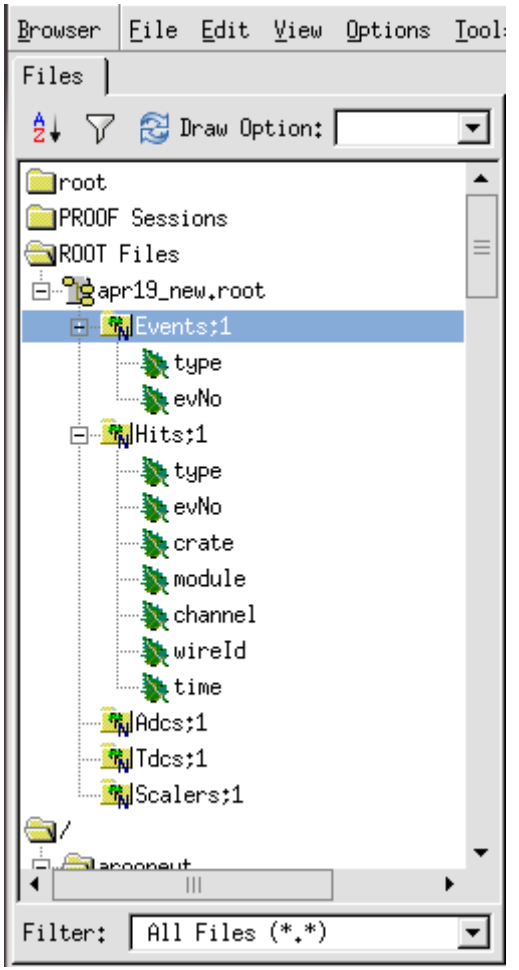
apr19.txt



Final .root Data file

apr19.root





Class Event **Class Hit** **Class Adc** **Class Tdc** **Class Scaler**

SUMMARY

dataformat.h Defines the classes needed to fill the root file with different kind of entries.

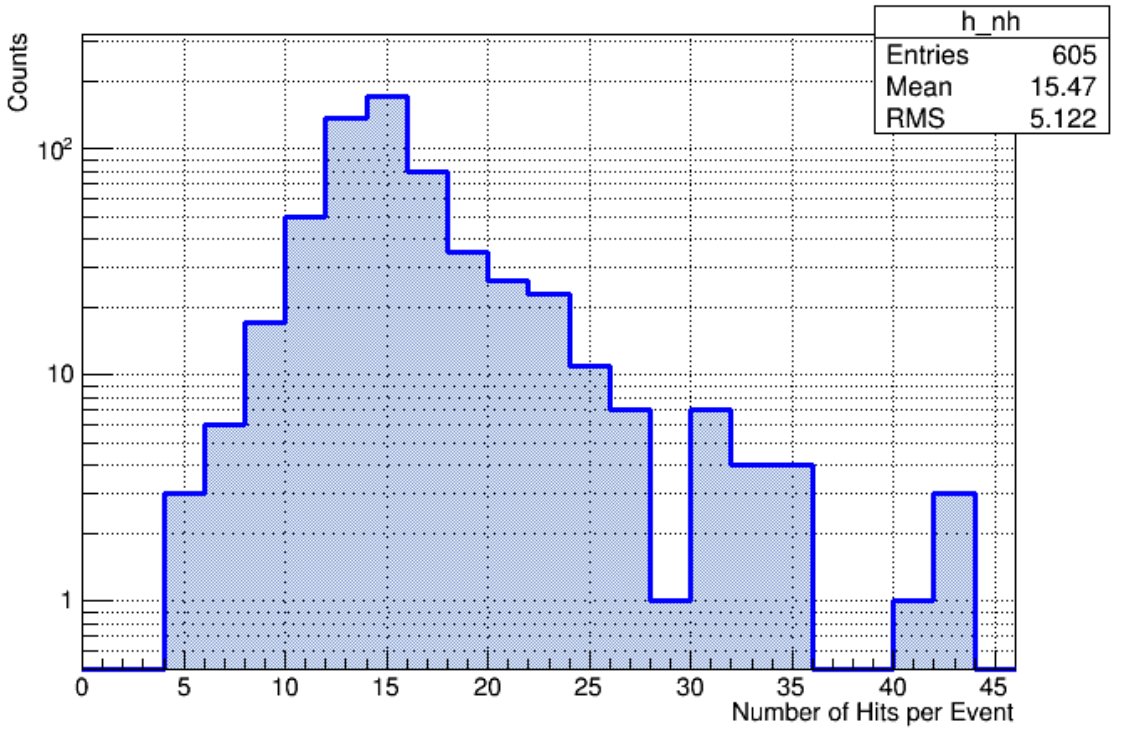
makeTxT.C Takes the original data file as input and converts it into a simplified txt file.

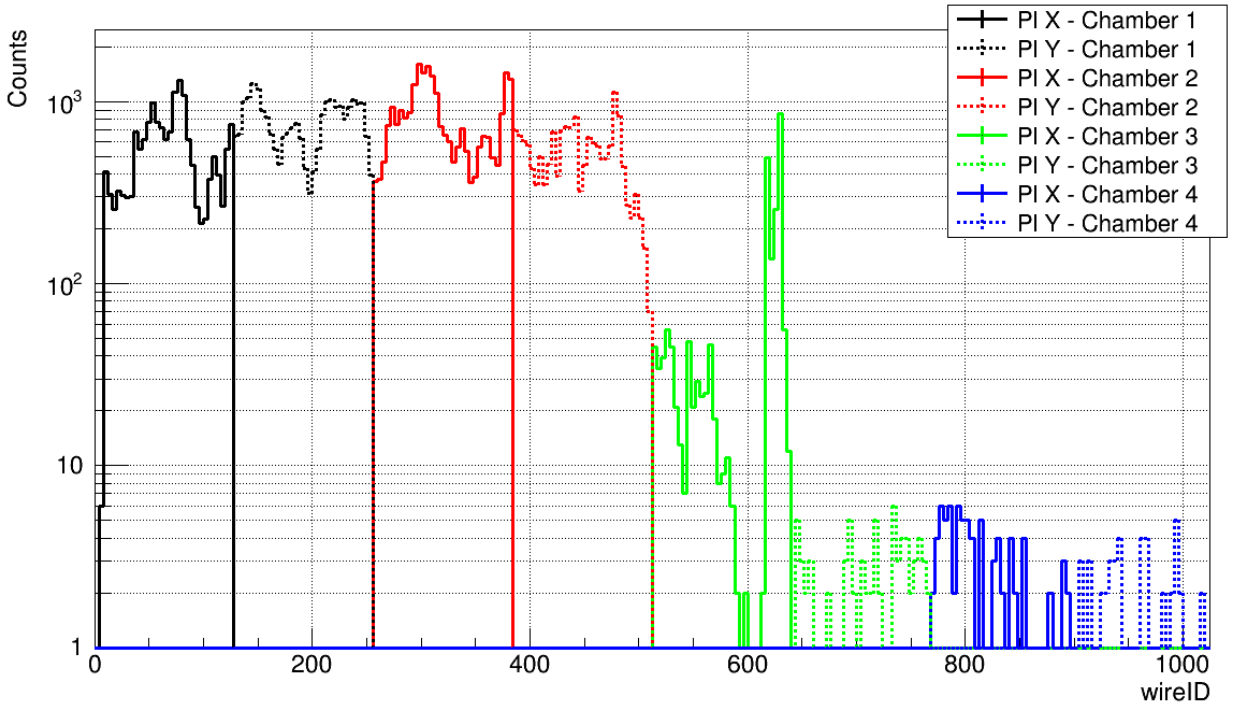
makeRoot.C Takes the .txt file as input and converts it into a root file with all the information from the data acquisition.

run.sh

readRoot.C Retrieves the information from the root file.

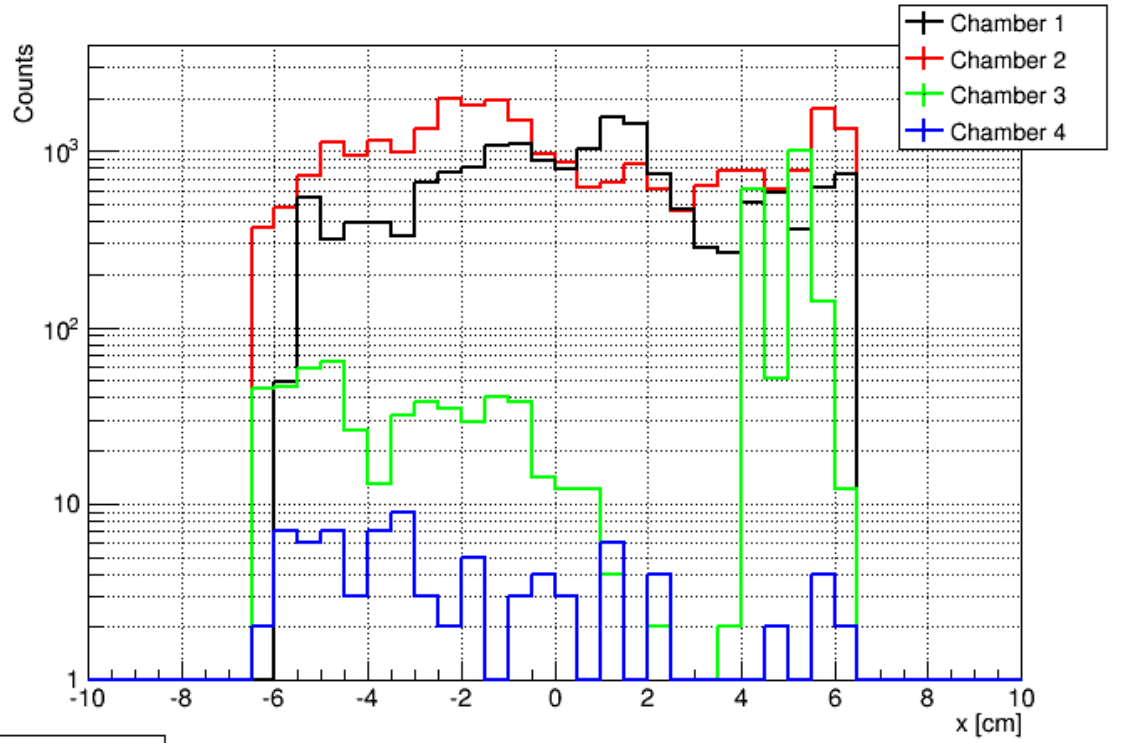
Number of Raw Hits per Event

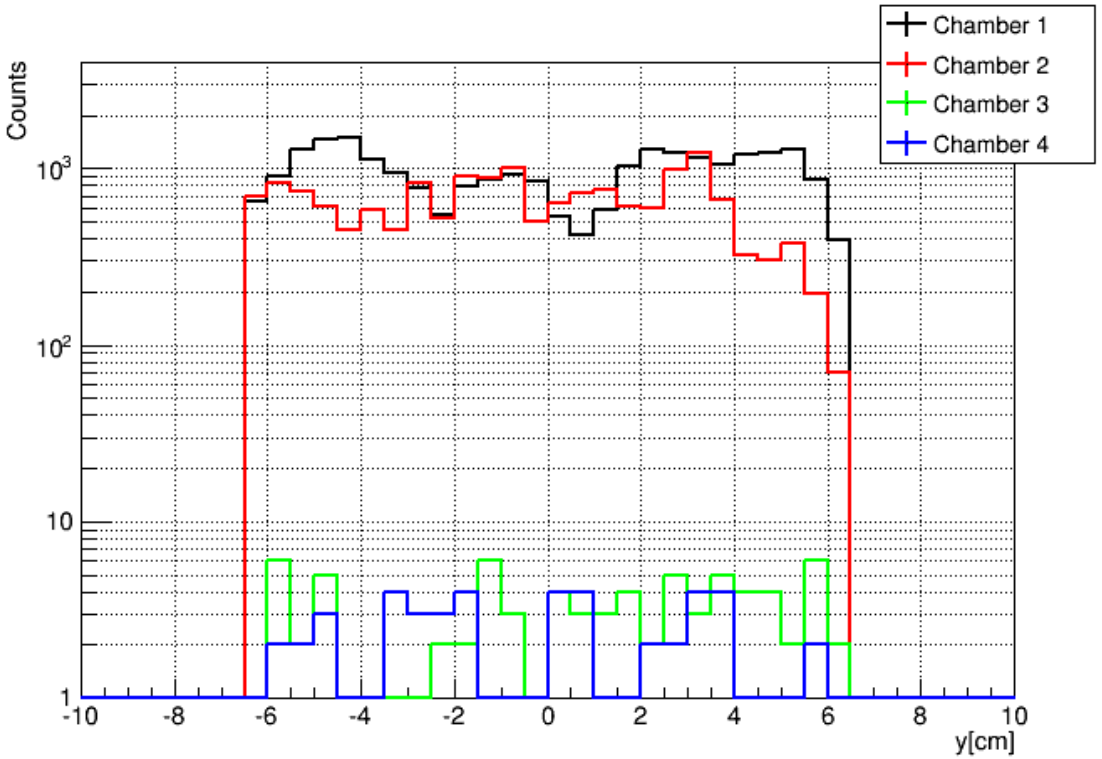




WireID
for X and Y PLANES

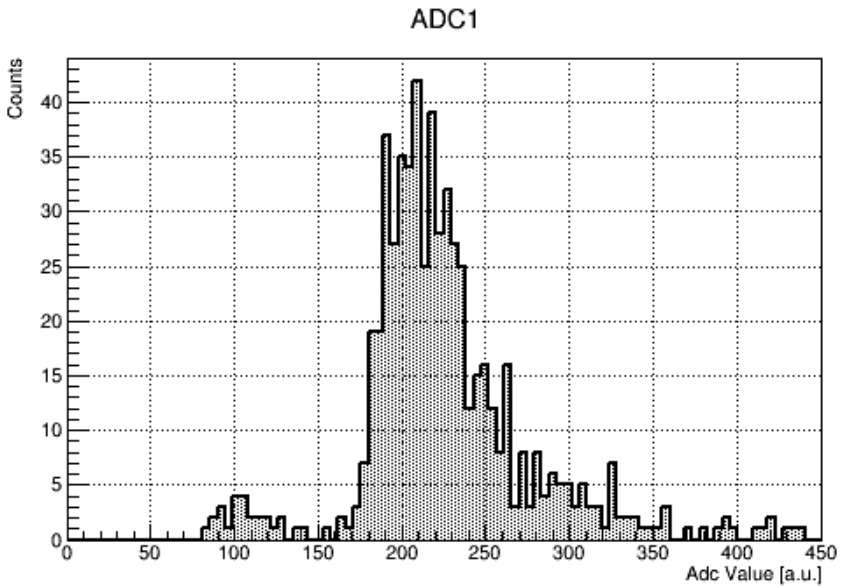
Reconstructed positions of the raw hits – **X PLANES**

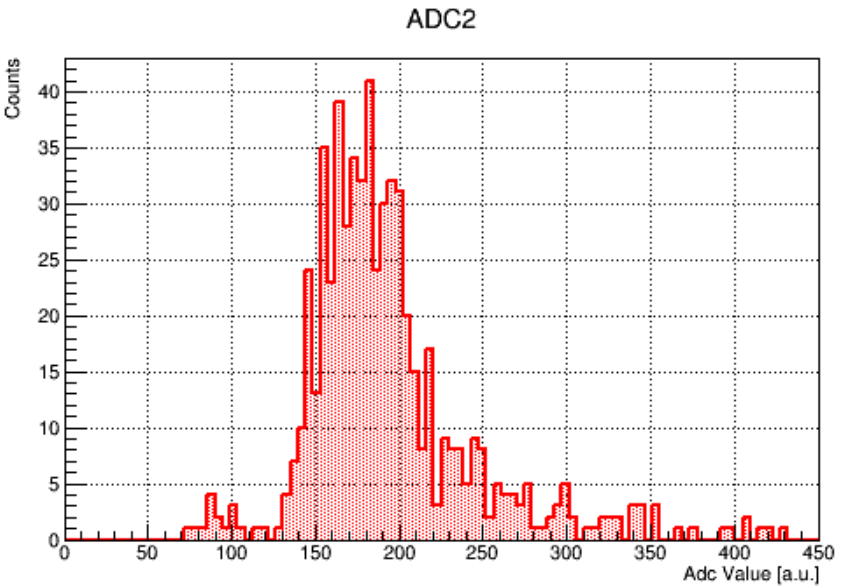


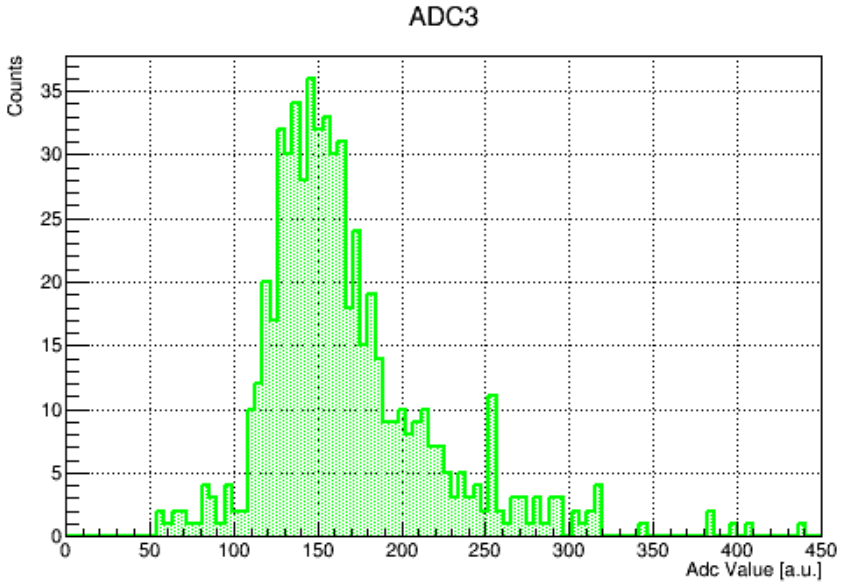


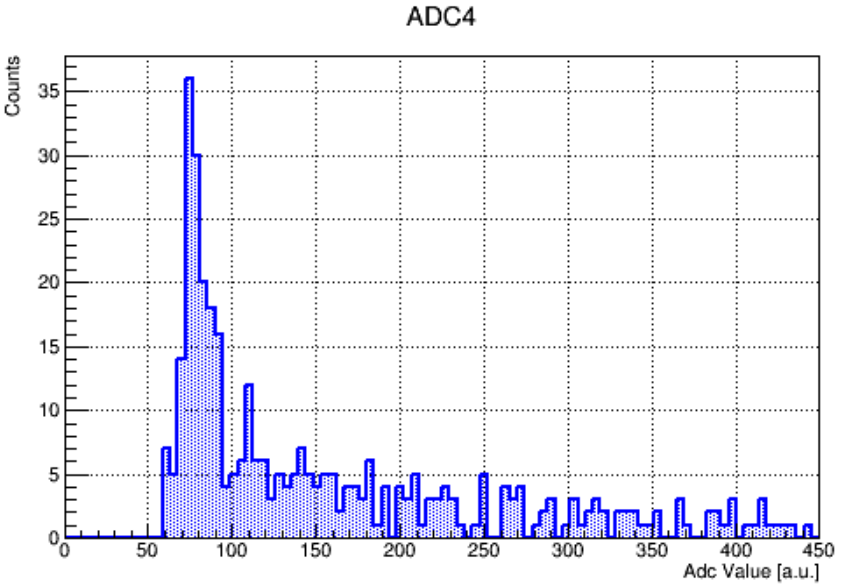
Reconstructed positions of the raw hits – **Y PLANES**

ADCs


ADC1
Counts
Adc Value [a.u.]


ADC2
Counts
Adc Value [a.u.]


ADC3
Counts
Adc Value [a.u.]


ADC4
Counts
Adc Value [a.u.]

CONCLUSIONS

- We implemented a code to convert the output data file into a ROOT tree.

- .dat file → .txt file → .root file

- The test data files we used as input are the ones from the Cosmic Ray Telescope → new data files from the FTBF (M-test) should be avaiable in next future - output data structure remains almost the same as for the Cosmic Ray Telescope.

  * The FTBF counters are now positioned along the M-Test beam line for beam particle definition/characterization.

Thank you!

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