ProtoDUNE DP Analysis

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LBNC

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Outline

- Simulation and Detector Modelling
- Reconstruction
- Integration of data
  - Light readout
  - Cosmic Ray Taggers
- Analysis plans

Simulation and detector modelling

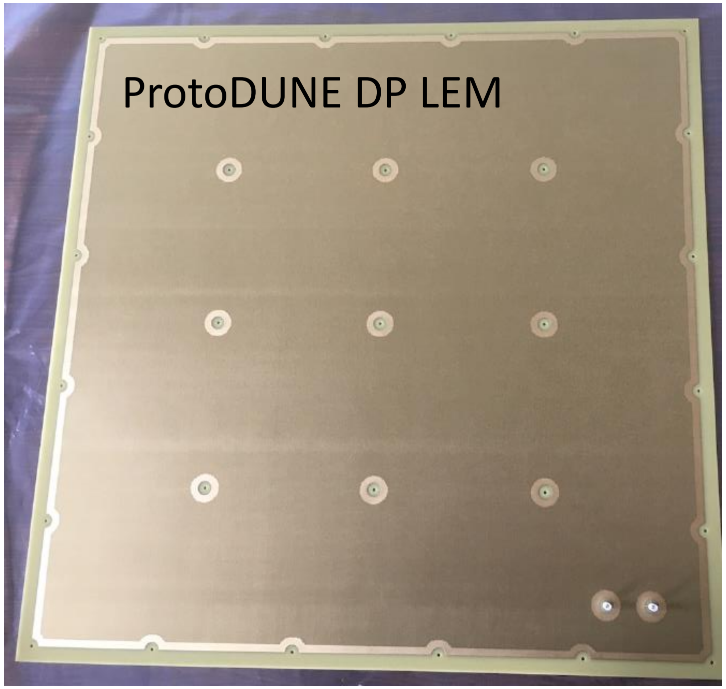
Work on improving the detector modelling for simulation and reconstruction

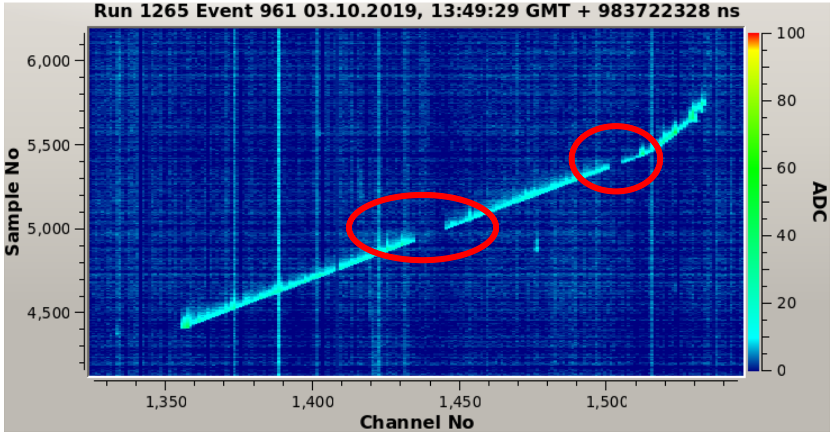
- Implementation of dead areas in LEMs
- Realistic field map description for the drift volume

Issue with vertical drift geometry

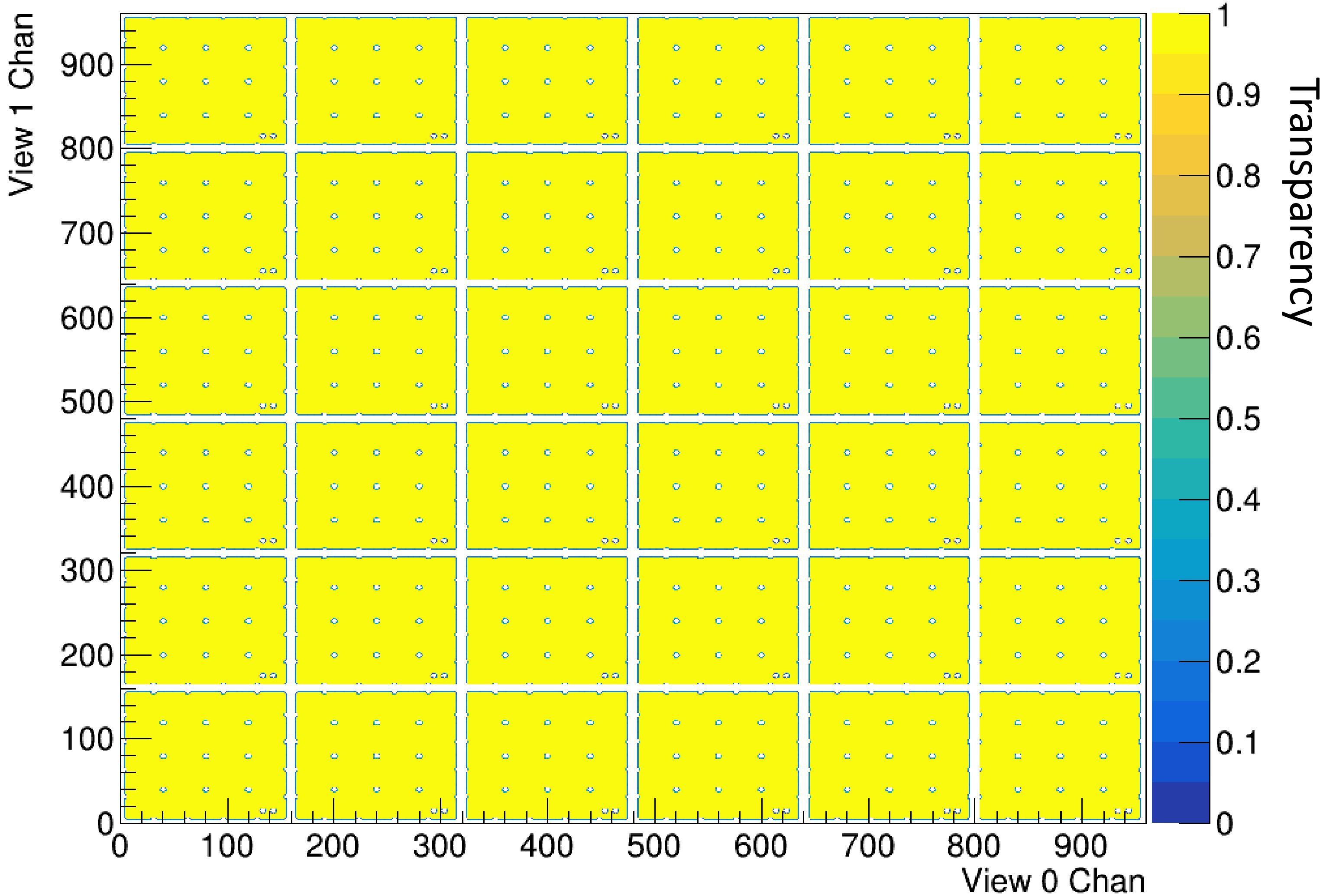
LEM dead areas

- Current LEM design has 86% active area
  - 15 mm border (10 mm FR4 + 5 mm Cu guard)
  - 20 mm annular clearance around each utility hole (29 for support + 2 for HV pins)
- Need the implementation in the simulation, since these are blind regions where the charge is not collected on the anode
  - Evaluate impact on track reconstruction
  - Eventually study impact on shower and calorimetric energy reconstruction
- Geometric shadowing effect:
  - The transparency map is computed as the fractional overlap between the readout channels and the dead areas

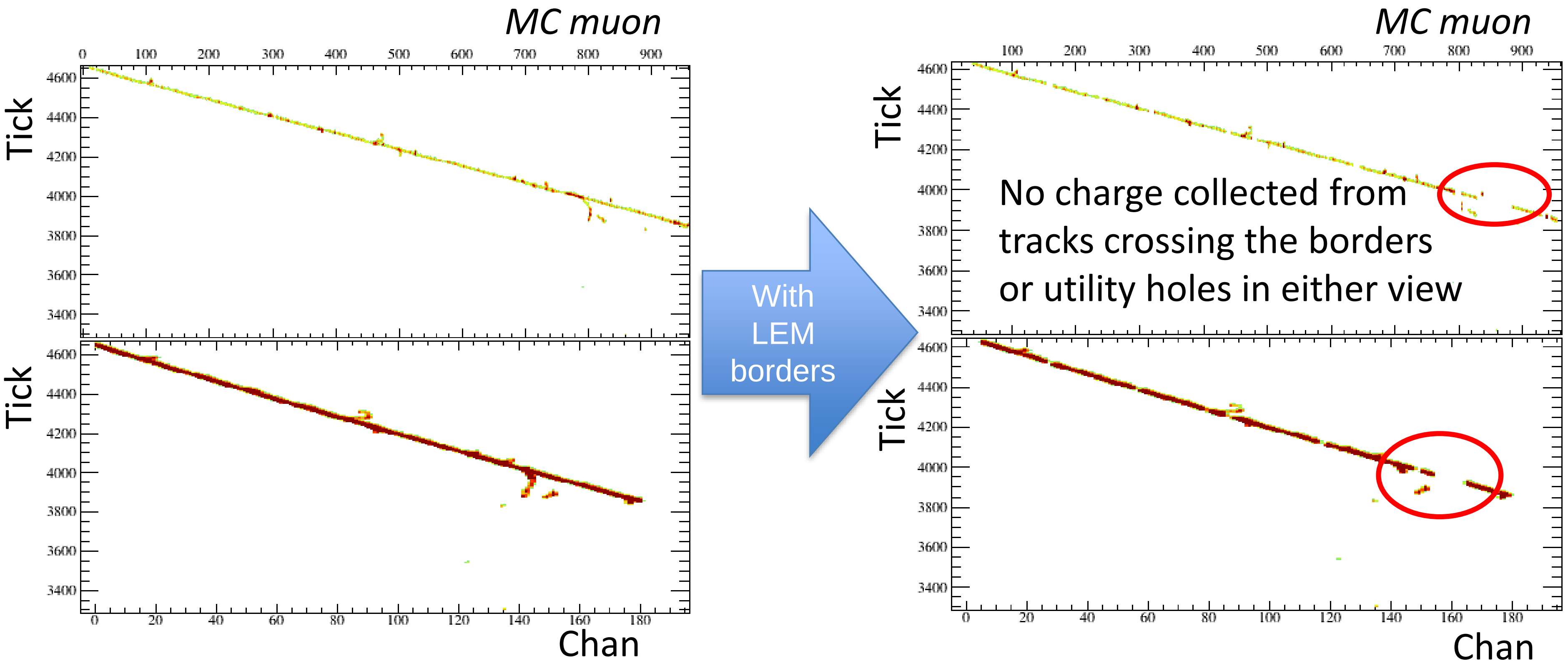




Modelled CRP transparency



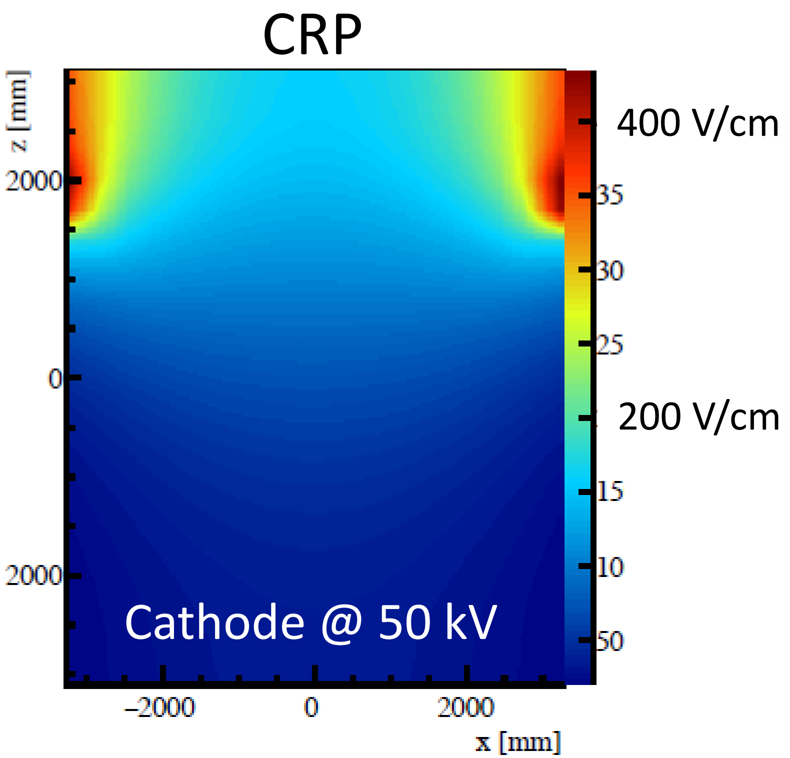
CRP transparency implemented

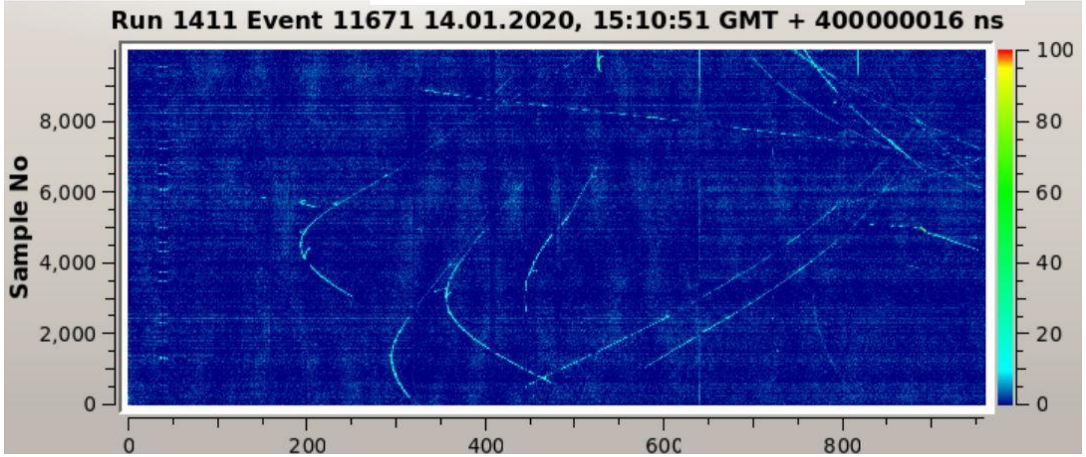


- Mechanism to include LEM dead areas have been implemented
- Should also allow in the future to study optimization of the LEM active area

TPC drift field

- Highly non-uniform after about 1m depth due to the short between HV FT and the field cage ring
- Curving of cosmic tracks
- Could impact purity estimations from tracks due to variation in the recombination factor



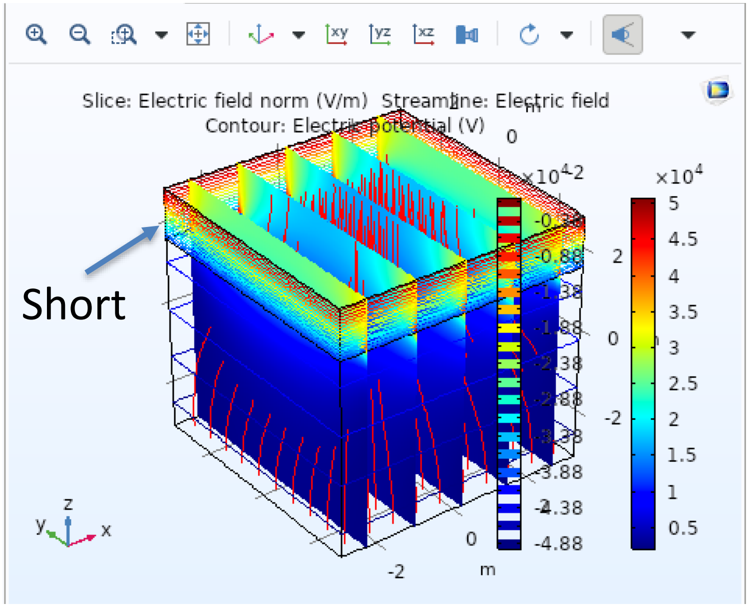


Field map simulation

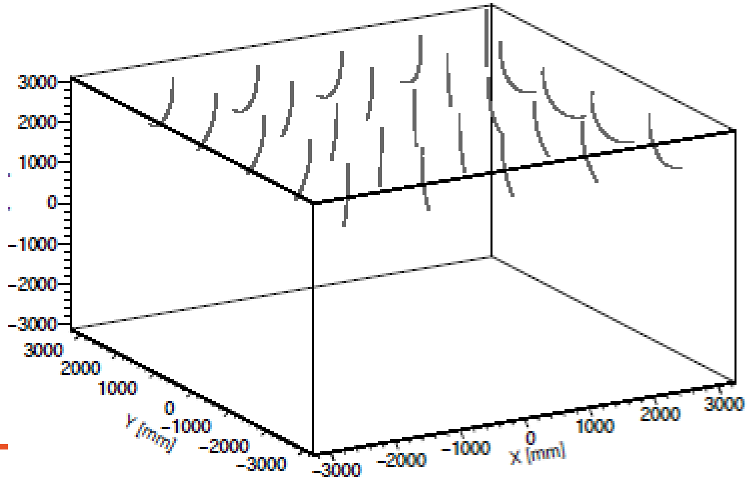
- TPC drift field strength is calculated in 3D with COMSOL
- The drift volume is voxelized and position of electrons on the anode (and diffusion coefficients) are calculated for each voxel following the field lines of computed E

  ➔ Field map

- Work on-going to export the field map for ProtoDUNE DP into the DUNE framework: should be able to use the existing tools for field distortions due to space-charge accumulation in ProtoDUNE SP
- Eventually refine the map calculation by including space-charge effects



e- drift lines from the short



Detector geometry

- Dual-phase detector geometry has the drift coordinate along the vertical axis (Y-axis in established convention within the soft framework)
- When DP detector description was made in LArSoft framework, there was problem with the simulation, since the drift direction was always assumed to be horizontal (X axis in single-phase TPCs)
  - The simulation was eventually improved to allow for a more flexible description
- However, the 3D reconstruction algorithms are not able to handle vertical drift
  - The time coordinate is used to merge the tracks between views
  - The assumption of X axis being the time coordinate appears to be still implicit
- Currently we continue to use “rotated” (drift along X) geometry

Rotated ProtoDUNE DP geometry

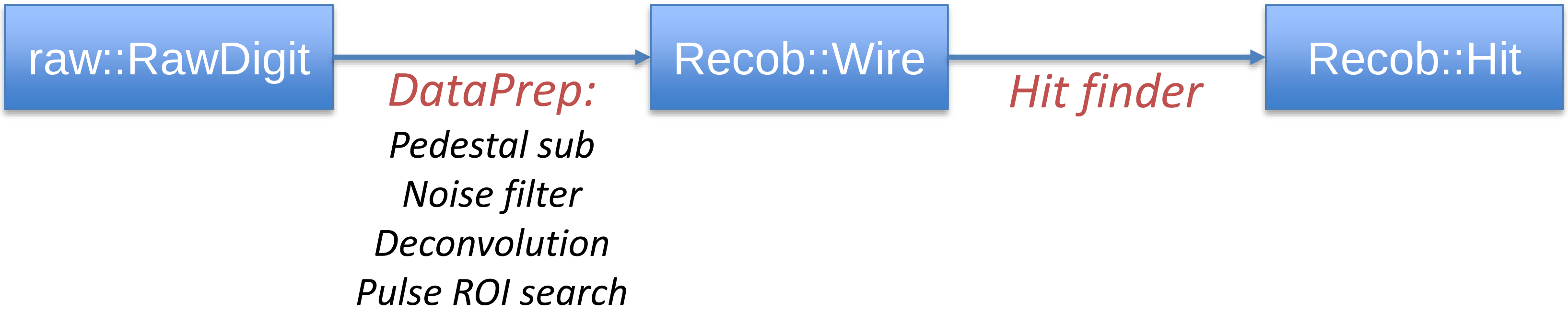
- A number of issues already popped up
  - Keep track of the non-standard convention for the coordinate system (X – up and Y is horizontal) is cumbersome
  - Some fixes were required to allow tagging cosmics correctly
  - The geometry used for the light simulation (“photon libraries”) and channel mapping of the photon detectors is the proper one with the vertical drift

- The implicit assumptions on the drift direction still need to be consistently addressed at the level of reconstruction algorithms within the framework

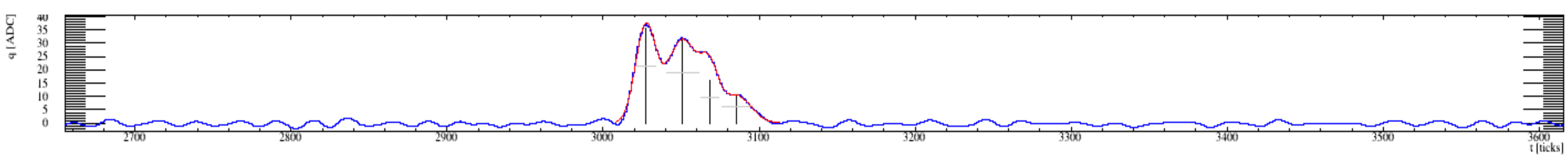
Reconstruction

- Offline reconstruction of the ProtoDUNE DP data is performed in the common DUNE software environment based on Art framework
  - The data processing is managed in a centralized way the production and data management groups
- Centralized production with reconstruction of hits + 2D tracks has been performed for all cosmics runs
- Working on improving the performance and validation of algorithms to move to full 3D event reconstruction for production

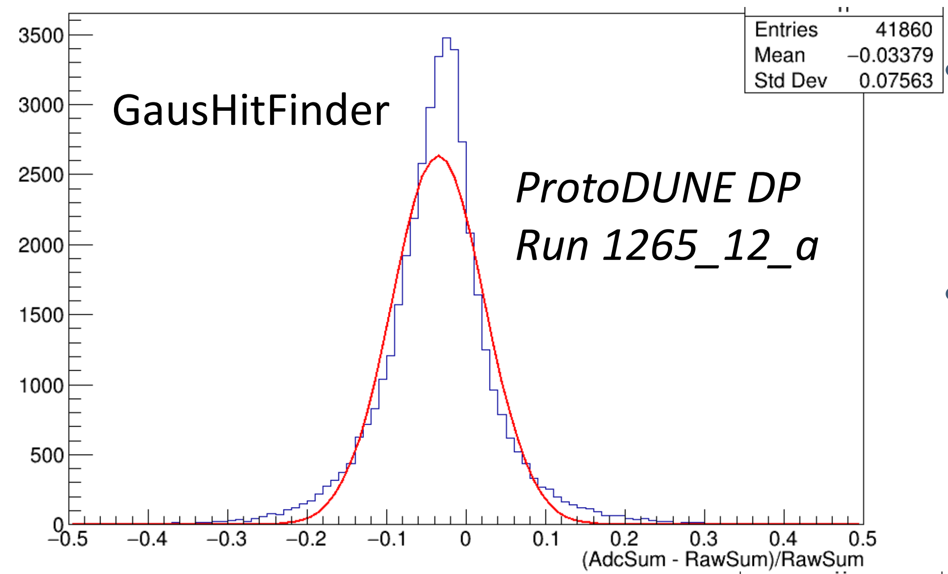
Hit finding

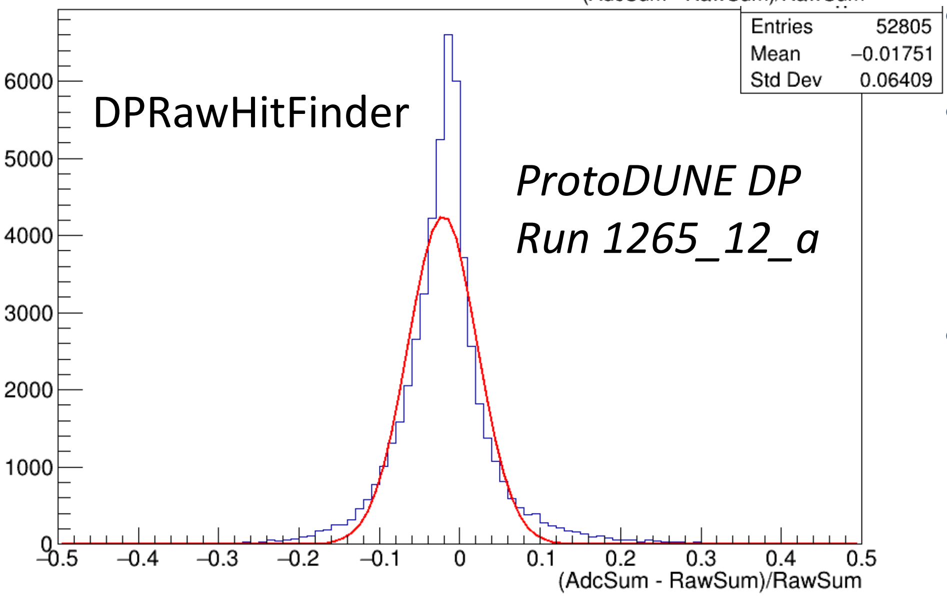


- We have been using the “DPRawHitFinder” developed for 3x1x1 prototype for hit reconstruction in ProtoDUNE DP
  - Fits asymmetric waveform to the raw waveform data after ped subtraction
- Evaluating use of GausHitFinder
  - The standard DUNE hit finder also used in ProtoDUNE SP
  - Appears to give better track reconstruction efficiency (more later)
  - Hit finder runs of deconvoluted signals and fits “N” Gaussian hypothesis within pulse ROI



Reconstructed hit charge

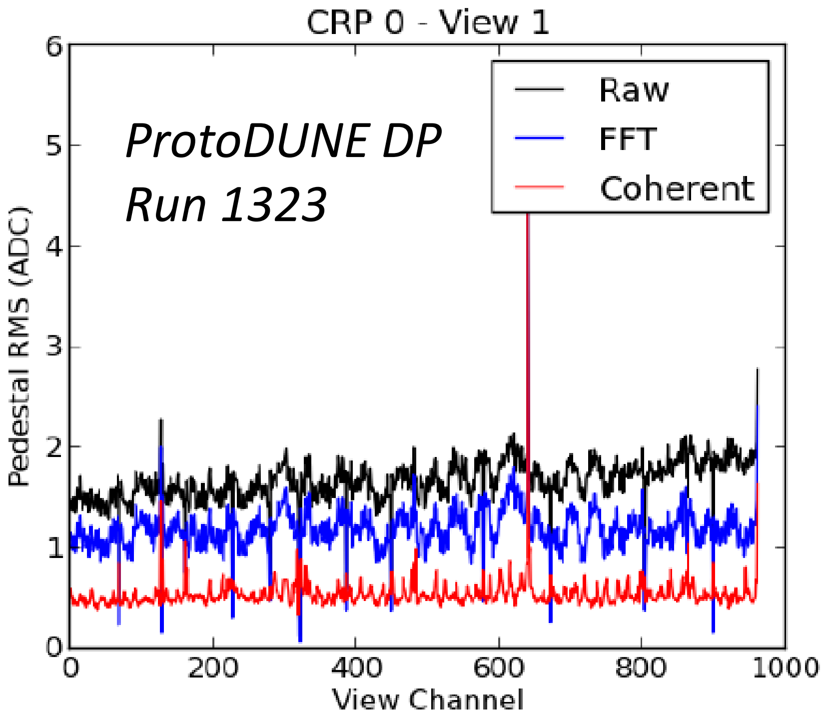




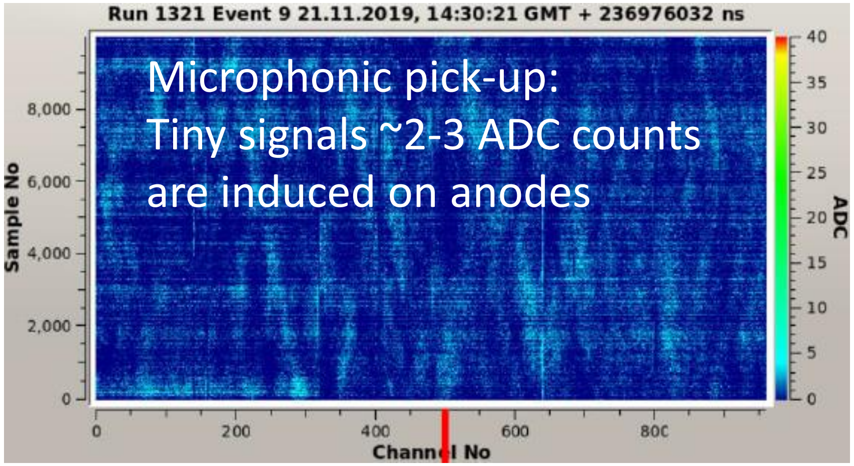
- The integral of the pulse waveform (**RawSum**) is the measure of the collected charge
- Similarly the sum of samples in reconstructed hit window (**ADCSum**) corresponds to the collected charge
- **Ideally two should be the same**
- Some tuning of GausHitFinder still needed to correct the charge loss in reconstructed hits
- DPRawHitFinder also has some inefficiency related to quality of pedestal subtraction impacted by microphonic noise

Noise filtering

- Looking into adapting algorithms developed for the 3x1x1 analysis
  - Low pass filter
  - Coherent noise subtraction
  - Pedestal flattening (remove baseline distortion due to microphonic pick-up)

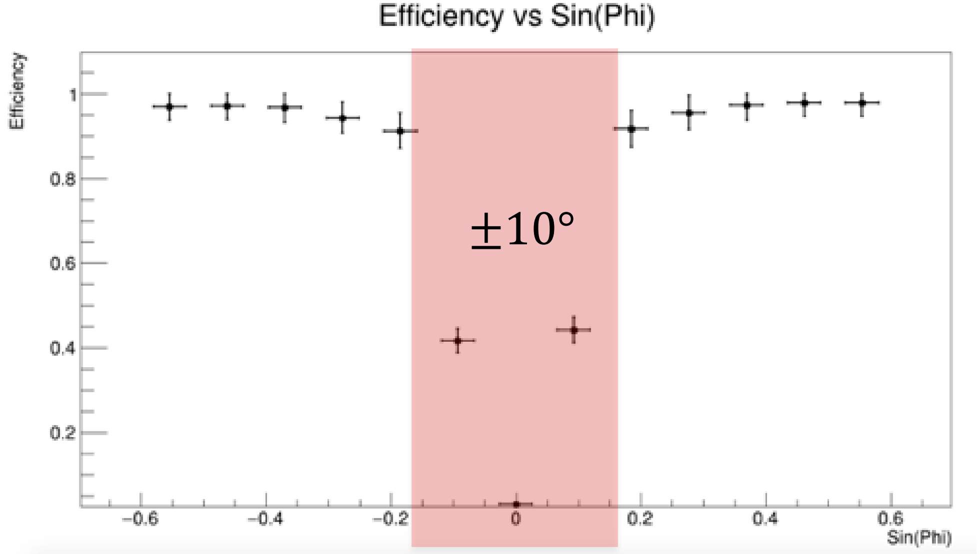


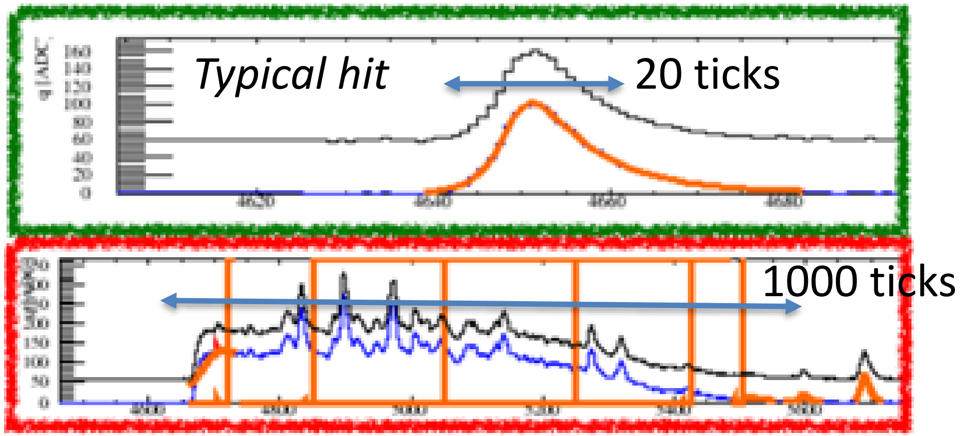
- Noise filtering would help with analyzes of the runs with low CRP gain / low purity
- Still too slow to run on ProtoDUNE DP events ➔ need to improve the speed of execution



PANDORA track reconstruction

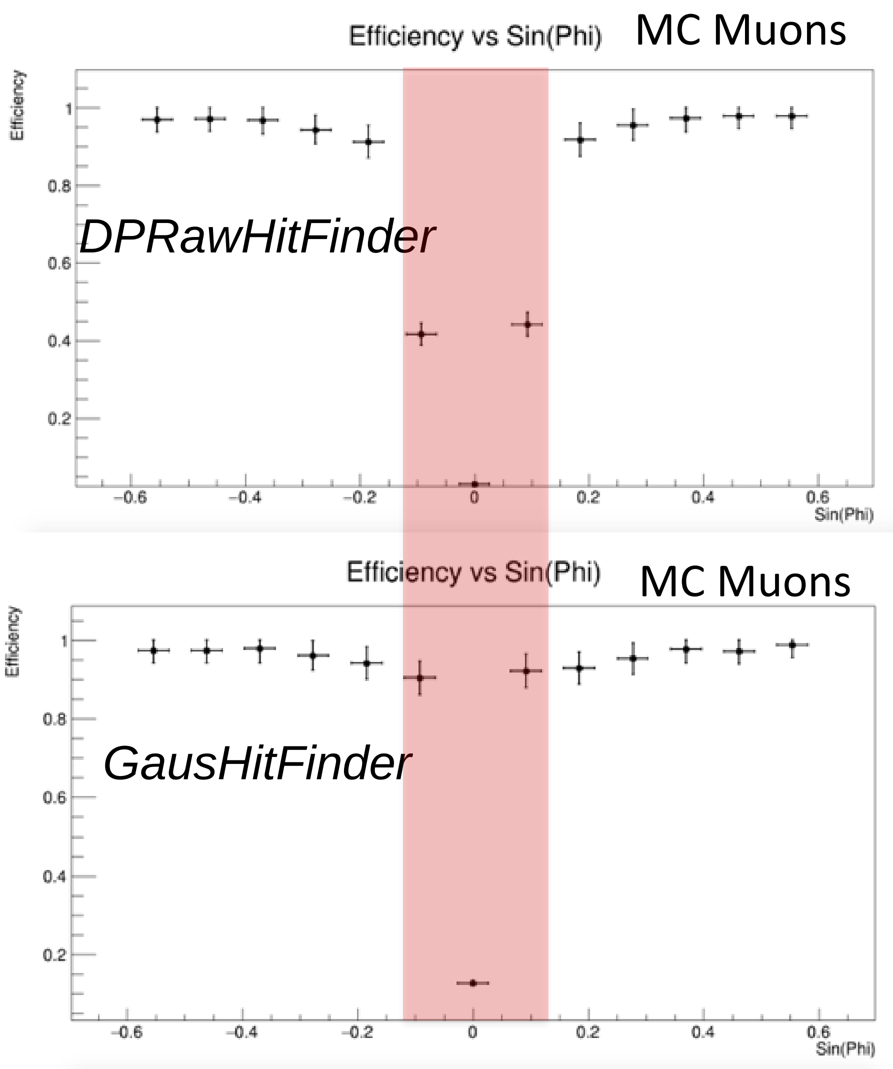
- Integrated ProtoDUNE DP into PANDORA framework
- Work is on-going on adapting / improving PANDORA specifically for ProtoDUNE DP
- Evaluation of performance on sample of simulated muons
- Loss of tracking efficiency when particles are travelling parallel to one of the collection views
  - Wide, time-extended, charge deposition on the same anode strip
- Appears possible to improve with better hit finding granularity for extended signals





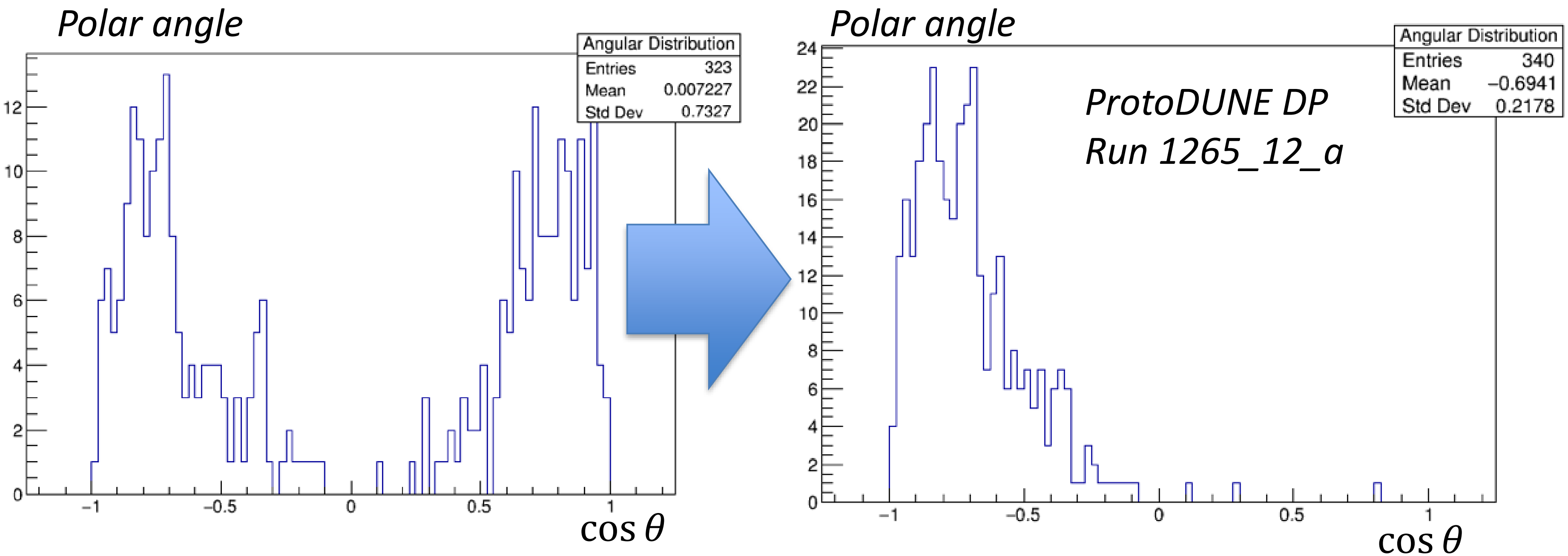
Signals from parallel tracks

Track recon efficiency with PANDORA



- Changing hit finder allows to substantially improve track recon efficiency for particles travelling close to parallel to one of the views
- Try to further improve hit granularity for long signals to recover tracking efficiency for view-parallel tracks
- Evaluate track reconstruction efficiency with LEM border effects

Angular distribution of cosmics



- Had to re-interpret the angles in PANDORA due to rotated geometry description of ProtoDUNE DP (side → up)
  - Modification of PANDORA cosmic ray vertex building algorithm for ProtoDUNE DP cosmic ray reconstruction

Data integration

- Currently data by detector readout systems are generated in separate streams (separate DAQ, different run numbers, run durations …)
    - TPC charge readout data: events are timestamped by White Rabbit system
    - Data from PMTs: events are timestamped by White Rabbit module synced to the global grand master
    - Data from Comic Ray Taggers (CRTs): 1s precision timestamp corrected to match the White Rabbit timestamp seconds

- Two principal points concerning integration of PMT and CRT data:
    - Modules to decode and put the data into common event store
    - How to make an association between different files (runs are not the same / run duration could be different) for automatic processing
        - The event association can be made on the basis of the timestamps

Charge readout TPC data

- Covered at the last LBNC meeting at CERN in December
  - The data format has been integrated in the DUNE framework and the data processing follows the established path organized and managed by the DUNE production and data management groups

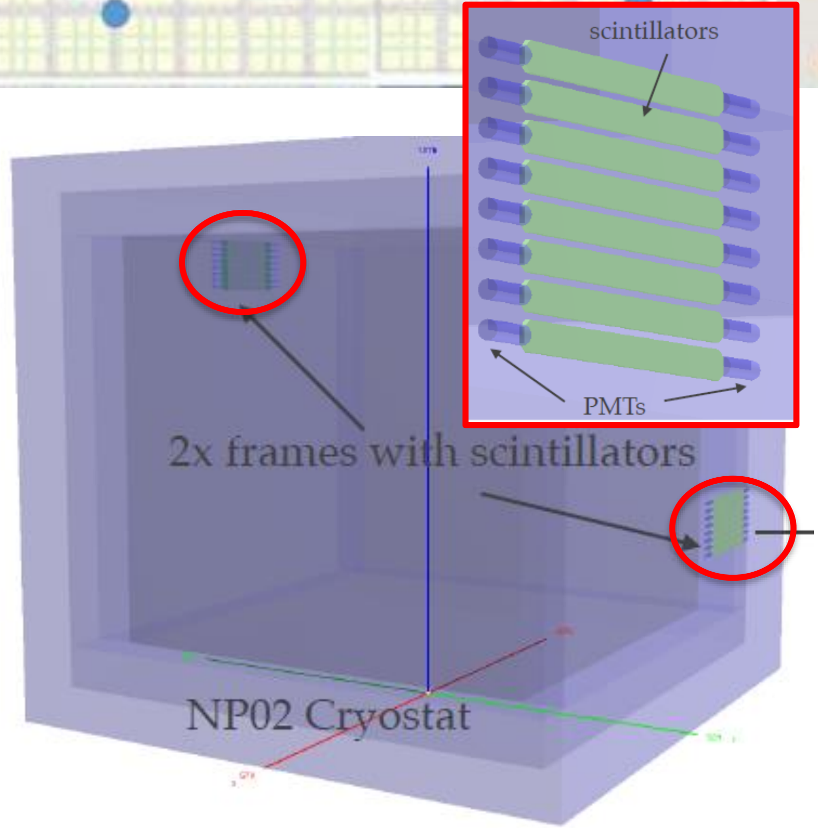
- Offline processing of all cosmics runs has been completed
  - Reconstruction of hits and 2D tracks
  - 377426 events processed

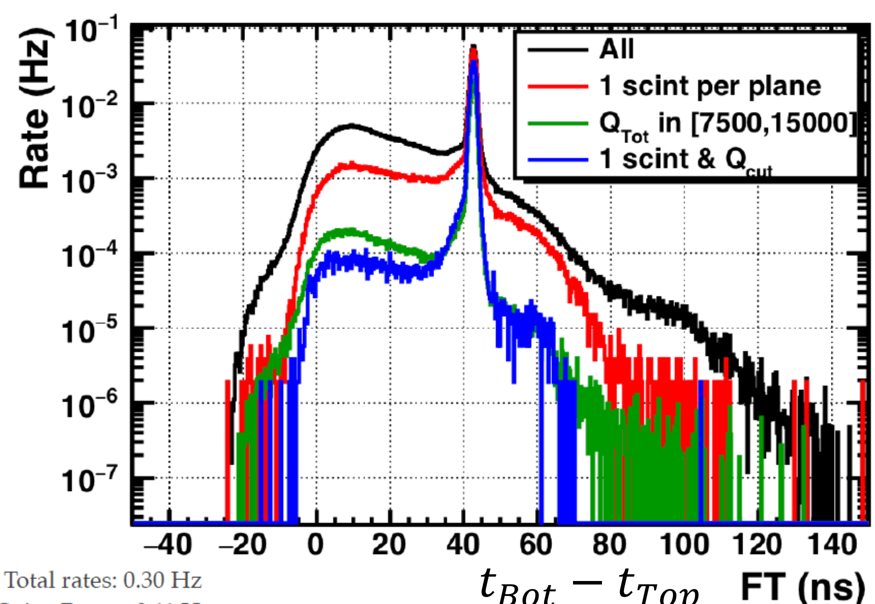
Light readout PMT data

- Module to import PMT data into LArSoft has been prepared
  - Similar to the one developed for DAQ data for charge readout
  - Creates the ART event store and adds PMT data products (waveforms data / timestamps / data quality flags)
  - Channel map depends on the geometry description (drift in Y or X): only geometry with drift in Y is currently supported
  - To be run stand-alone (light analysis jobs)
- For integration with the TPC charge readout data stream
  - Need to prepare a *producer* of PMT data products (the ART event store is generated by the TPC data decoder): simplified version of the PMT data import module
  - Principal issue is the efficient and automatic way to find the PMT data files with relevant events
- Starting point for analysis is the modules already prepared for TDR studies
  - Validation of configuration files
  - Need automated way to retrieve PMT gain settings (can be different between runs)

Cosmic Ray Taggers

- [Two cosmic ray taggers](#) configured to trigger on muons crossing CRP1 & CRP2
  - Each has 8 scintillator paddles (1.44 x (8 x 0.14) m^2 ~ 1 m^2)
- Trigger rate 0.3 Hz (~0.1 Hz crossing muons)





Total rates: 0.30 Hz
Coinc Rates : 0.11 Hz

CRT data

- DAQ runs continuously
- Runs are automatically stopped / started each 24h
- Raw data is automatically preprocessed to write a simplified summary TTree ROOT file (~2 MB / file)
- Currently data are only copied to CERN EOS
- For integration with the TPC charge readout data stream
  - Need to prepare a *producer* for CRT data products: the ART event store is generated by the TPC data decoder or PMT decoder in case of the stand-alone PMT runs with CRT trigger
  - The data must be accessible when running jobs worldwide (the file sizes are too small for tape)
  - Again need an efficient and automatic way to find the relevant files; however there is only one per day

Analysis plans (non-exhaustive)

- Evaluate impact of non-uniform drift field in particular on measurement of LAr purity from tracks
- dQ/dx from cosmics
  - CRP gain measurement (cross-check with the results from the online processing)
  - Purity, drift E-field distortions, space charge
  - Through-going muons tagged by CRTs
- Selection and measurement of energy spectrum of Michel electrons
- Identification of Ar39 events for LEM calibration
- Variety of analyses topics for the light data:
  - Properties of light yield in different field conditions; PMT gain stability; PEN vs TPB efficiency; S2 production; combined charge-light(-CRT) for T0 reconstruction, muon tagging, and light calorimetry

Conclusions

- Work on improving detector modelling:
  - LEM dead areas; non-uniform drift
- Reconstruction
  - Improving hit finding + noise filtering
  - Track reconstruction with PANDORA
    - Validation of track reconstruction with LEM dead areas
  - Optimization of algorithm tuning and validation for the full event 3D reconstruction
- Integration of PMT / CRT data streams