Vertical drift TPC simulation and reconstruction

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DUNE UK meeting
5th July 2022

The Vertical Drift (VD) detector

- The 2nd DUNE far detector

    - 13.5m x 13.0m x 60m

    - Vertical drift direction

    - Separated into two drift volumes, separated by a central horizontal cathode

    - 6m drift length

    - Charge collected on anode by strips on printed circuit boards

    - Same charge projection-based principle as the Horizontal Drift (HD) detector

- Two potential designs of interest to the simulation and reconstruction

    - The '48 deg' geometry: 48, 0 and 90 degree views

    - The '30 deg' geometry: 30, -30, 90 degree views

- Here 'view' means PCB strip orientation, defined relative to the beam direction

Reported at the previous meeting

- Most of the core simulation and reconstruction had been configured

  - Neutrino generator (GENIE)

  - G4 tracking

  - Wirecell signal simulation and processing
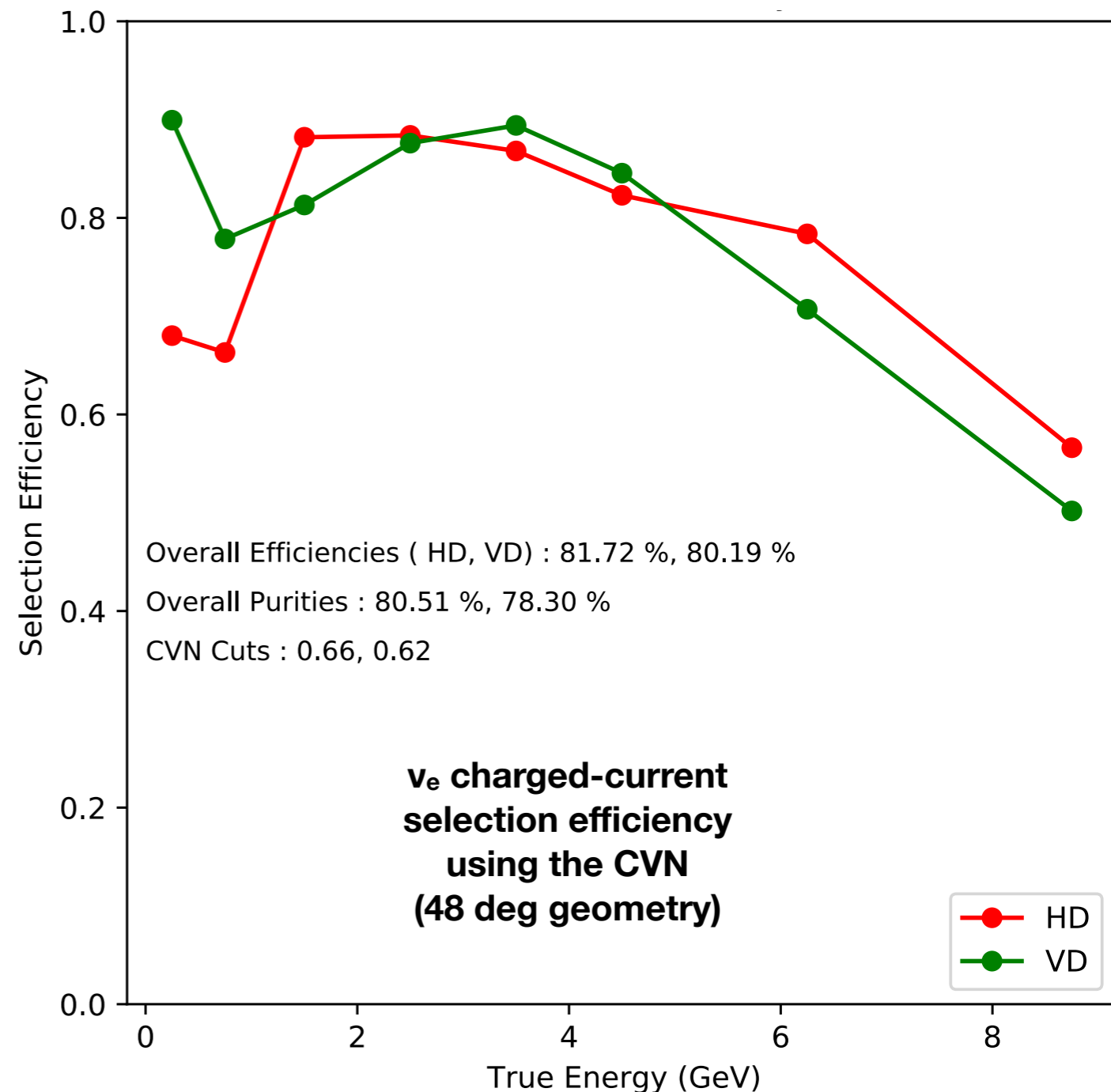
  - Pandora for pattern recognition

  - Basic PID
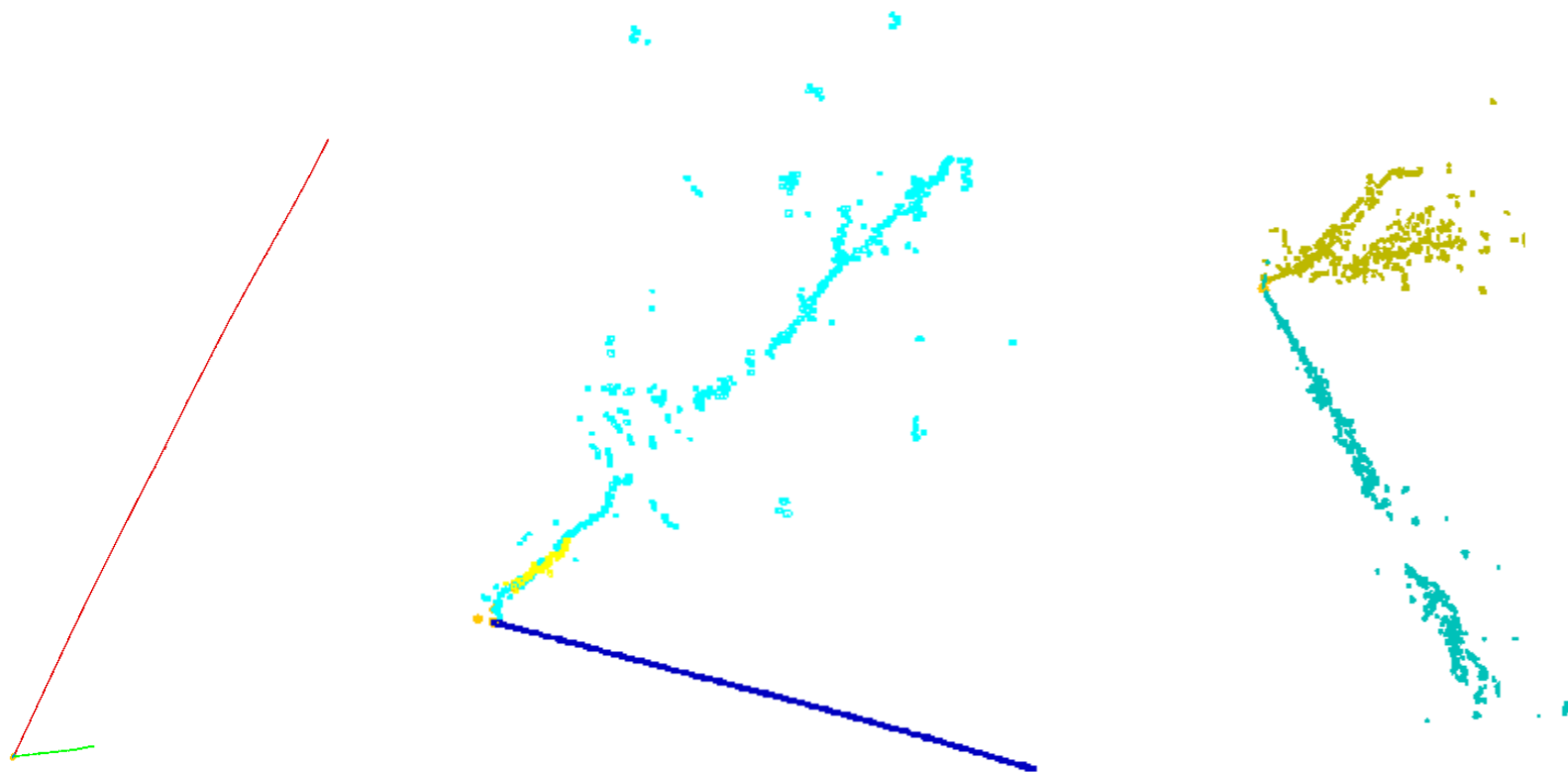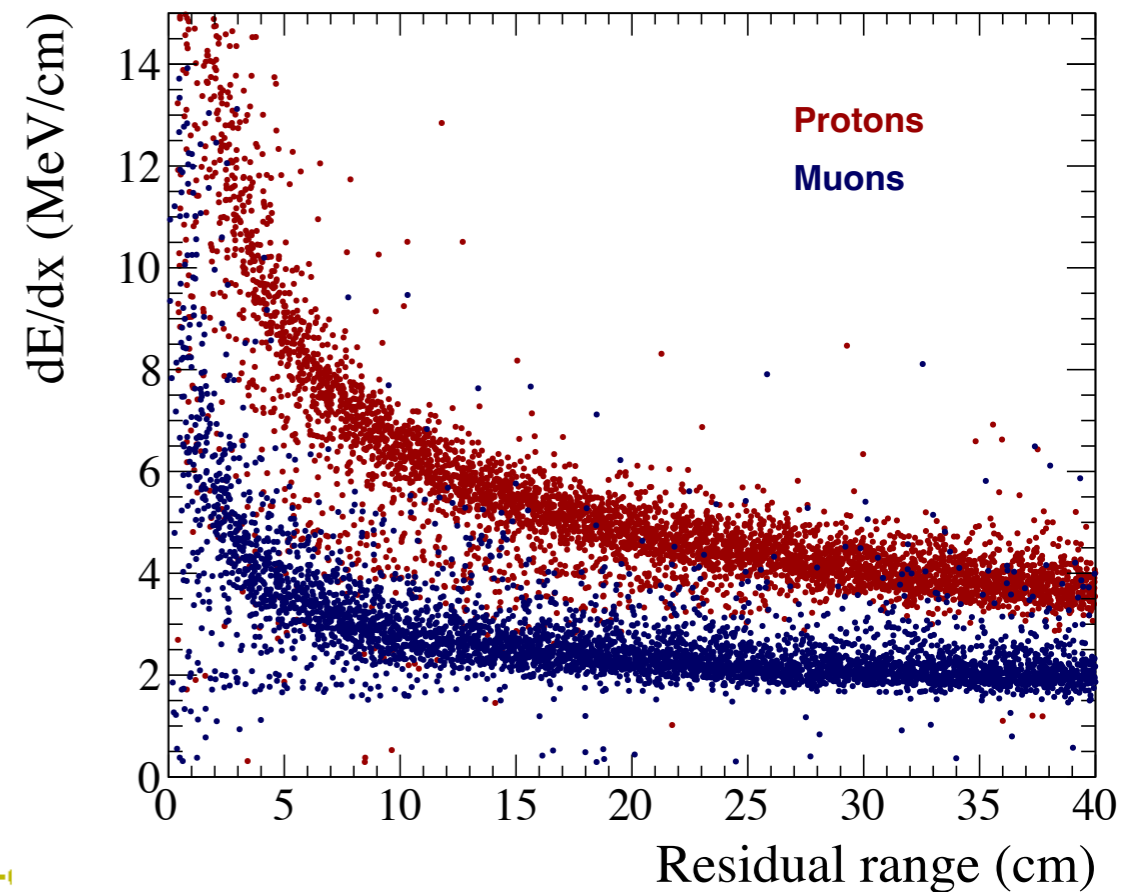
3D reconstruction of neutrinos in the 48 deg. Geometry using Pandora

Since the previous meeting

- Software developments

    - Event level PID with the Convolutional Visual Network

    - Pandora benchmarking

    - Neutrino energy reconstruction

- An MC production was successfully run in January using the 48 degree geometry

- An imminent new MC production using the 30 degree geometry

- Both productions will involve ~6 million simulated neutrinos

- Contributed to a 3rd LBNC review

    - LBNC said very little regarding sim/reco's progress

- Planned major contributions to the vertical drift Technical Design Report (TDR)

    - Now the main focus of the FD sim/reco WG

   - The next few slides overview the main developments for the TDR provided by the WG

Convolutional Visual Network (CVN)

- Deep learning-based, neutrino flavour tagger

  - Developed by L. Whitehead and S. Alonso Monsalve

- Used to select neutrino is the horizontal drift TDR analysis

- Retrained for the vertical drift

- Vertical drift performance is already competitive with the horizontal drift

Overall Efficiencies (HD, VD) : 81.72 %, 80.19 %
Overall Purities : 80.51 %, 78.30 %
CVN Cuts : 0.66, 0.62

v_e **charged-current selection efficiency using the CVN (48 deg geometry)**

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Pandora

- Vertical drift configurations and tunings taken from the horizontal drift

  - Algorithms worked out of the box; the only needed change was in the geometry parser

- Performance is competitive for reconstruction of the lepton

- ~10% efficiency drop for hadrons

  - Under investigation, possibly due to merging hadrons together

  - This should not impact the planned contributions to the TDR

Plot made by M. Brigida Brunetti
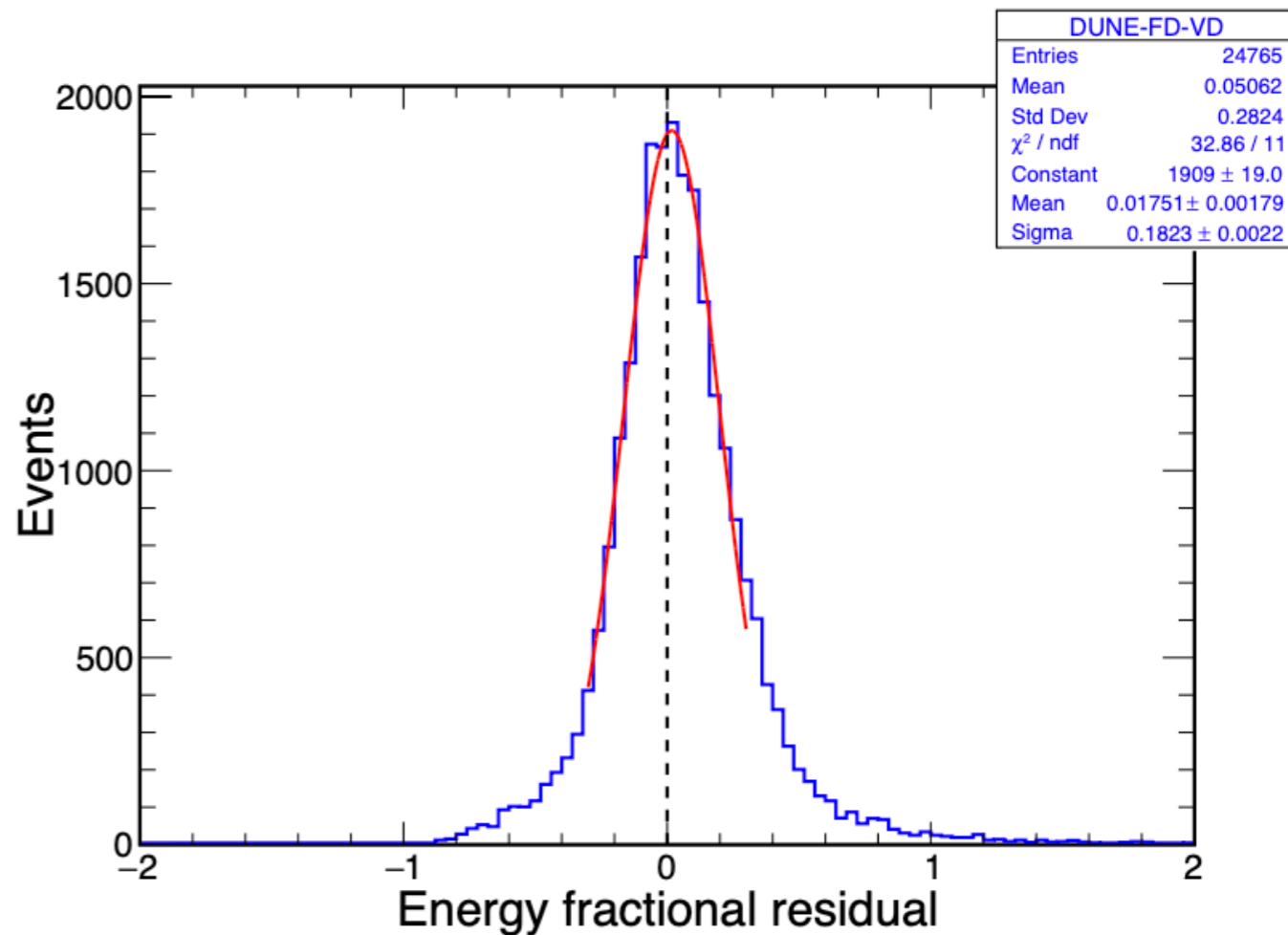

Plot made by M. Brigida Brunetti
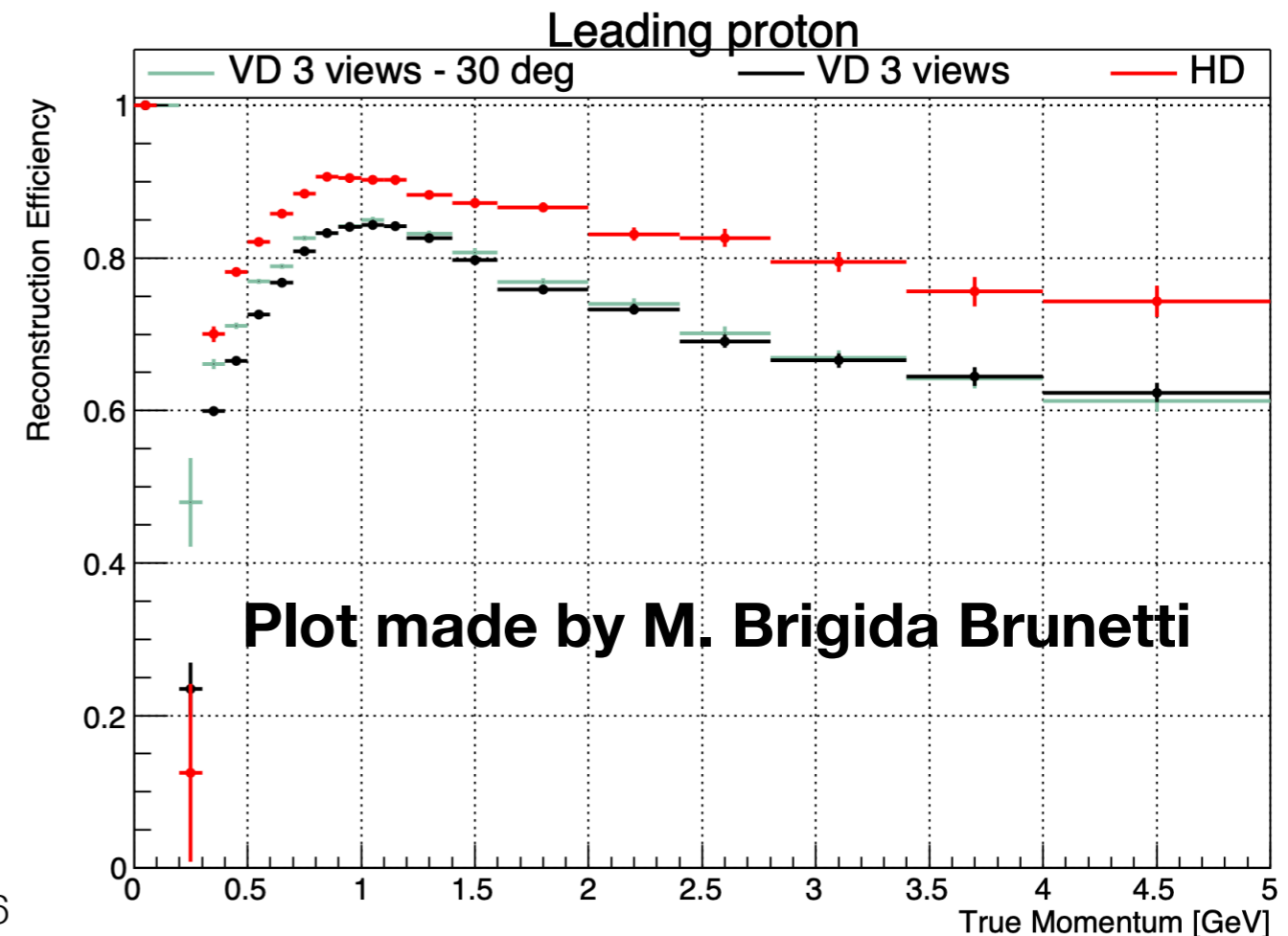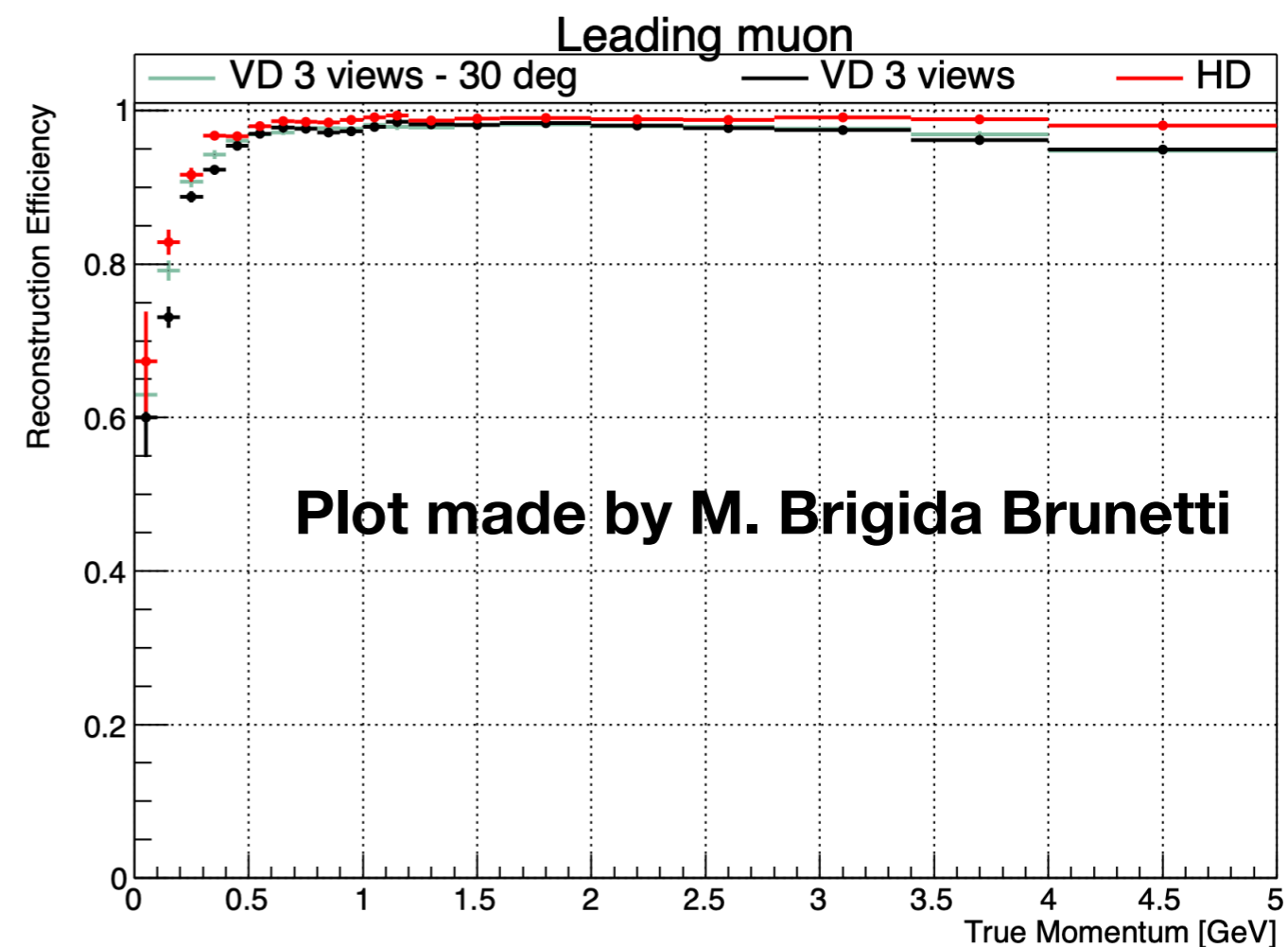
Energy reconstruction

- Horizontal Drift TDR era method (N. Grant)

$$E_\nu = E_{\text{lep}}^{\text{cor}} + E_{\text{had}}^{\text{cor}}$$

- Pandora's 3D reconstruction is used to find the lepton track/shower; the remainder of the event is the hadronic system

- Lepton energy reconstructed using:

  - Calorimetry (electrons)

  - Ranging (contained muons)

  - Multiple Coulomb Scattering (exiting muons)

- Hadron energy estimated by calorimetry

- Competitive performance between vertical drift and horizontal drift

DUNE-FD-VD	
Entries	24765
Mean	0.05062
Std Dev	0.2824
χ² / ndf	32.86 / 11
Constant	1909 ± 19.0
Mean	0.01751 ± 0.00179
Sigma	0.1823 ± 0.0022

Resolutions	HD	VD 48 deg.	VD 30 deg.
nu_e	13%	16.7%	14.3%
Numu (contained)	18%	20.4%	19.6%
Numu (exiting)	20%	18.4%	18.2%

# The Vertical Drift Technical Design Report (TDR)

- The VD TDR will include a simplified HD TDR-style oscillation analysis

  - Neutrino selection efficiencies provided by the CVN

  - Neutrino energy biases/resolutions provided by Pandora + the energy estimator

  - Quantitive comparisons to the HD then provide expected sensitivities to oscillation physics

- An MC production for the TDR is about to begin that will provide

  - Officialised numbers for the analysis

  - HD/VD and VD 30 deg/VD 48 deg detector performance comparisons

- The current deadline for the TDR draft is end of September

Summary

- Massive developments/improvements in the vertical drift detector's simulation and reconstruction since the last UK meeting

  - CVN training for neutrino flavour tagging

  - Pandora benchmarking

  - Neutrino energy reconstruction

- An MC production has been completed with another due to start imminently

- The main focus is now the VD TDR

Backup

# Long waveform (48 deg.)
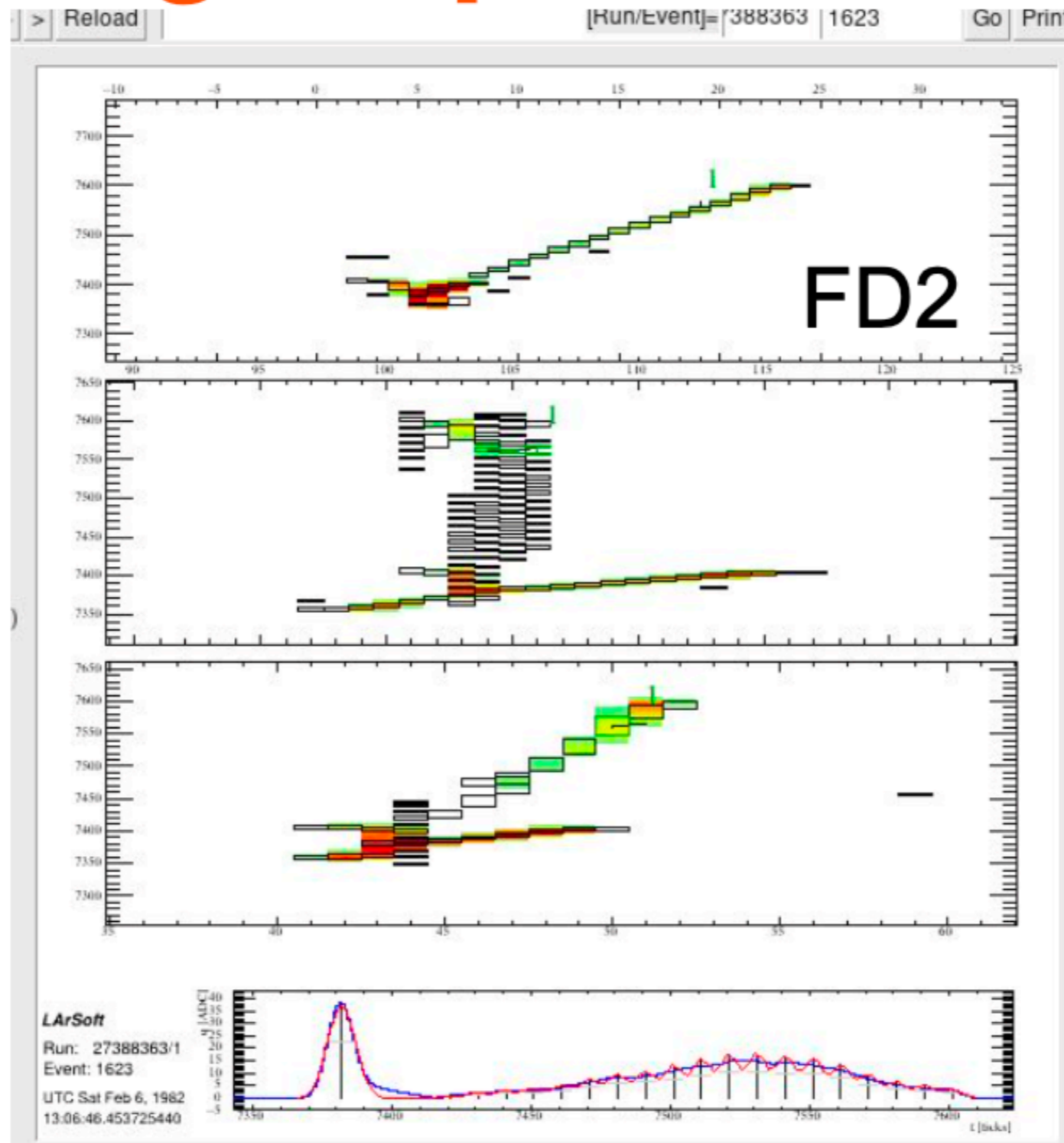
The 1x8x6 workspace geometry
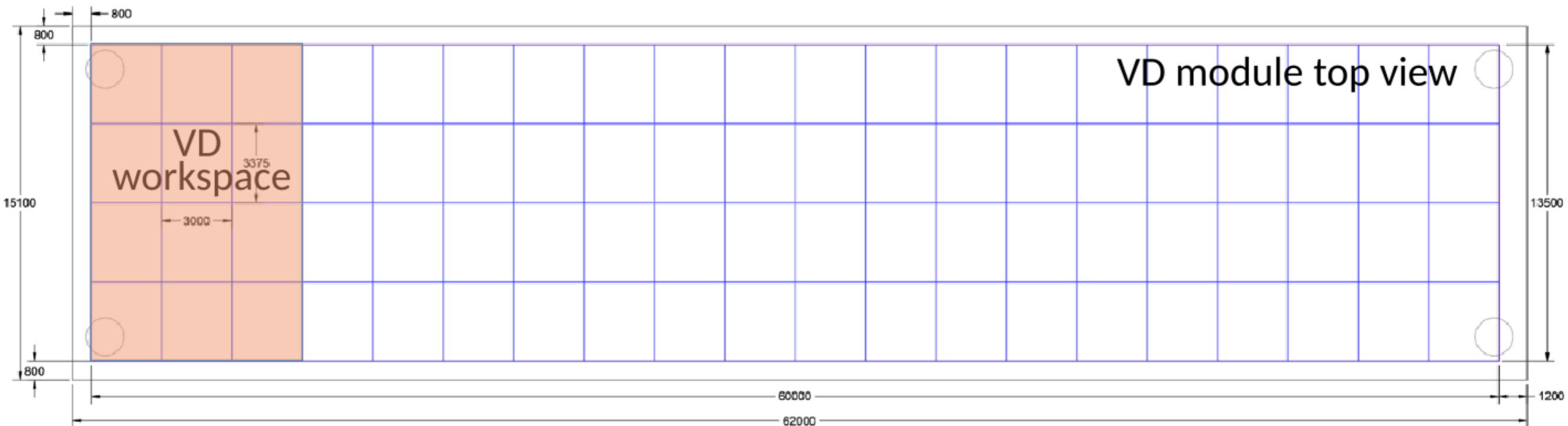
- The usual stuff applies: full size geometry 'too big' (memory consumption, run time etc) for current LArSoft workflow ideology

- Additional constraint comes from ROOT I/O limitation of max 1GB per serialised object

- So, we use the '1x8x6' geometry for all development work

```
---- FatalRootError BEGIN
  Fatal Root Error: TBufferFile::WriteByteCount
  bytecount too large (more than 1073741822)
  ROOT severity: 3000
---- FatalRootError END
```

  - 1 'CRM' high by 8 'CRMs' wide by 6 'CRMs' long

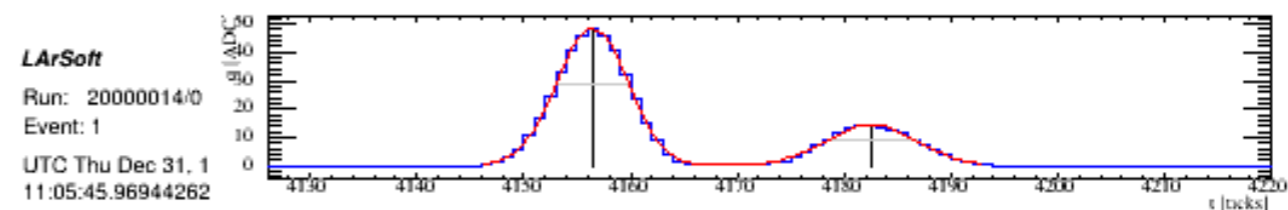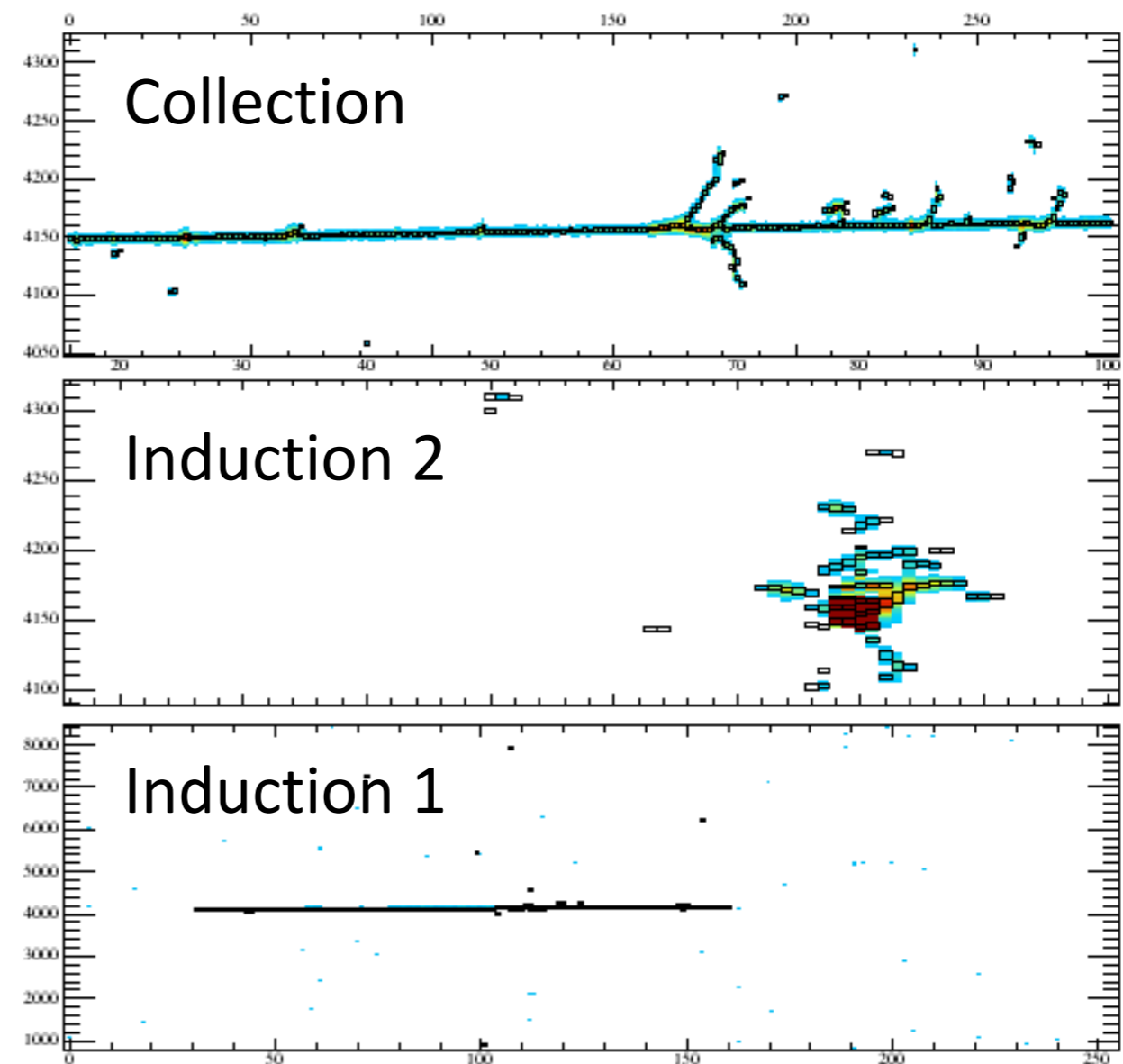 - Above diagram is in terms of CRPs (1CRP == 2CRU == 4 CRMs)

Simulation

- LBNF neutrino simulation uses GENIE + LBNF flux

  - Flux comes from weighted dk2nu files

  - Simulation includes the beam's incident angle

- Particles are tracked through the detector using the refactored LArG4

  - Refactorisation of LArG4 breaks up the simulation into more manageable chunks

  - Physics contents remains unchanged

- The electron drift simulation and signal simulation on the readout is all performed in wirecell

  - Wirecell is a 2D drift simulation, incorporating field effects from electrons on non-incident wires

  - Wirecell includes a signal processing to disentangle the 2D effects and recover the readout true signal

Raw induction signal
H. Yu
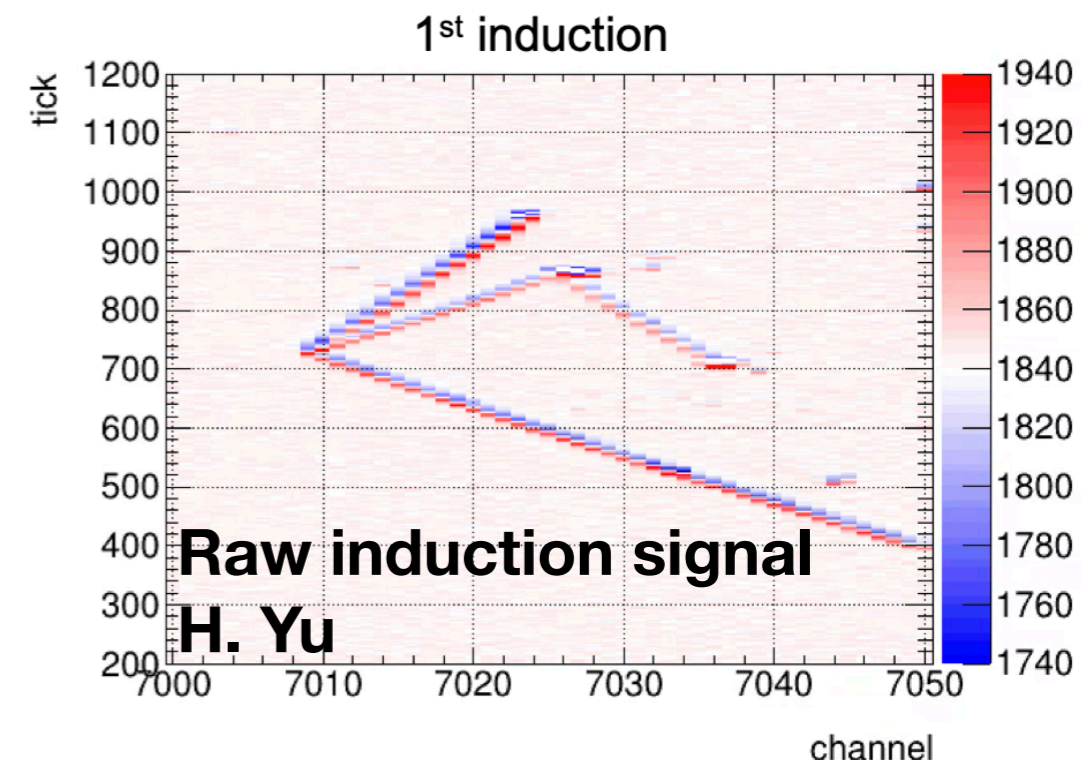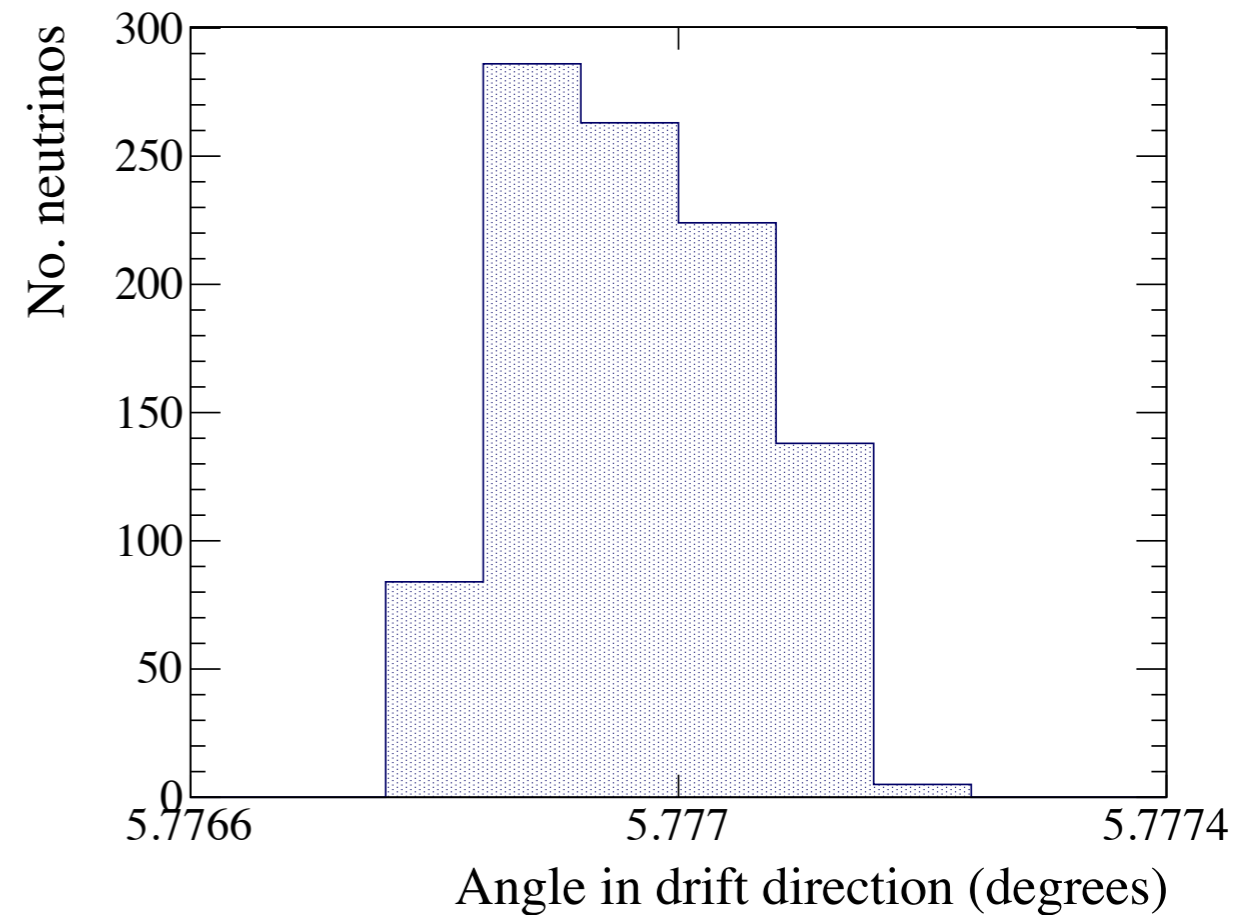
Hit reconstruction

- Uses the ubiquitous ***Gaushit***

  - Hit reconstruction is run on deconvolved waveforms produced in wirecell

- Hit reconstruction hand-tuned using single muon particle gun

Collection

Induction 2

Induction 1

LArSoft

Run: 20000014/0
Event: 1

UTC Thu Dec 31, 1
11:05:45.96944262

Pandora pattern recognition and track/shower reconstruction

LArSoft	→	larpandora	→	Pandora

- Pandora's multi-reconstruction algorithm suite is detector agnostic

- 'larpandora' is the I/O bridge between LArSoft and pandora

- Larpandora's geometry interface maps detectorisms to pandora, keeping pandora detector agnostic

  - Geometry interface originally written for a MicroBooNE-style TPC

  - Other detectors (ICARUS, ProtoDUNE-DP etc) have been tacked onto the geometry interface, keeping development time small

  - The vertical drift detector cannot be tacked onto the geometry interface without breaking other detector operation

- The detector specific part of the interface was completely re-written such that

  - The vertical drift could be included

  - No other detectors were broken

  - It is much easier to include new detectors in the future

Pandora event displays - 2D reconstruction (col. plane)
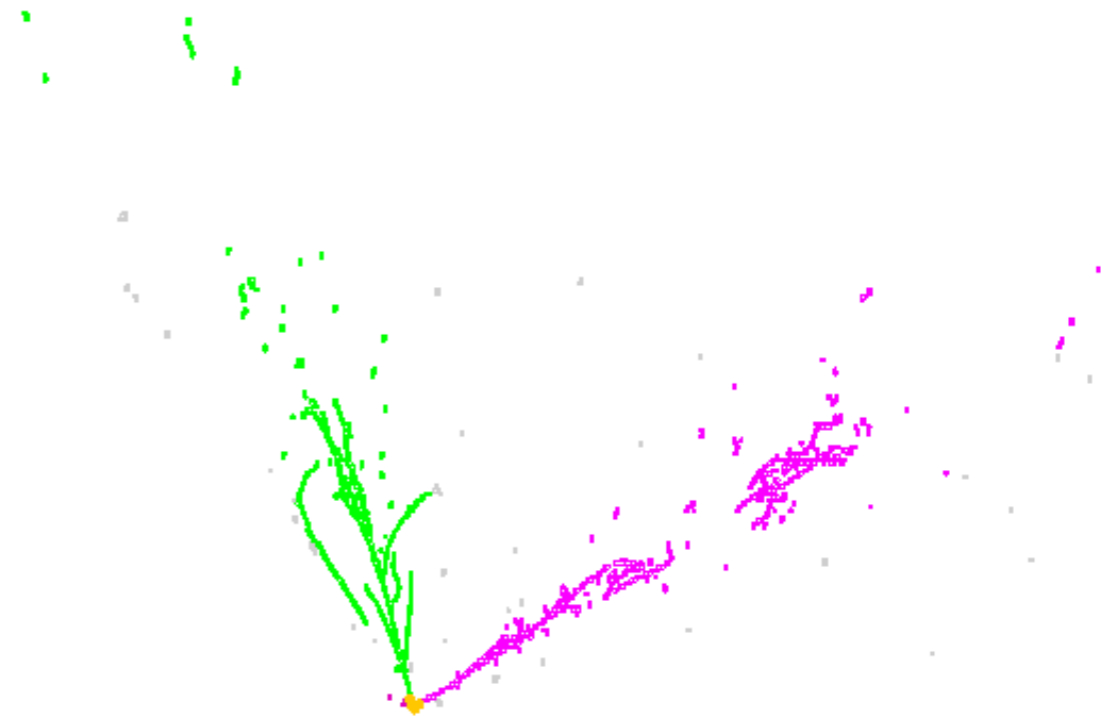
- All reconstruction ran end-to-end once the geometry interface was updated

- All necessary pandora tunings taken from horizontal drift
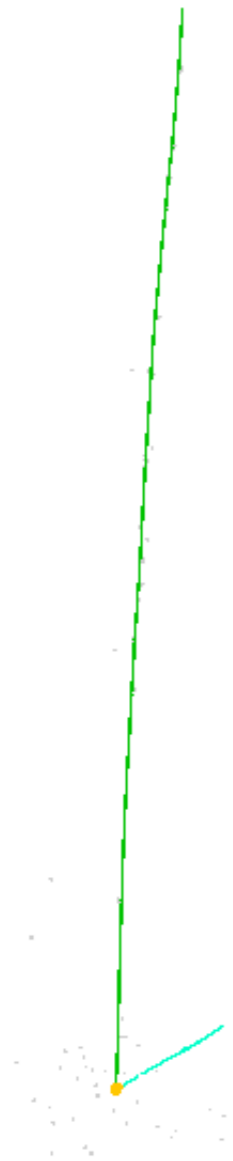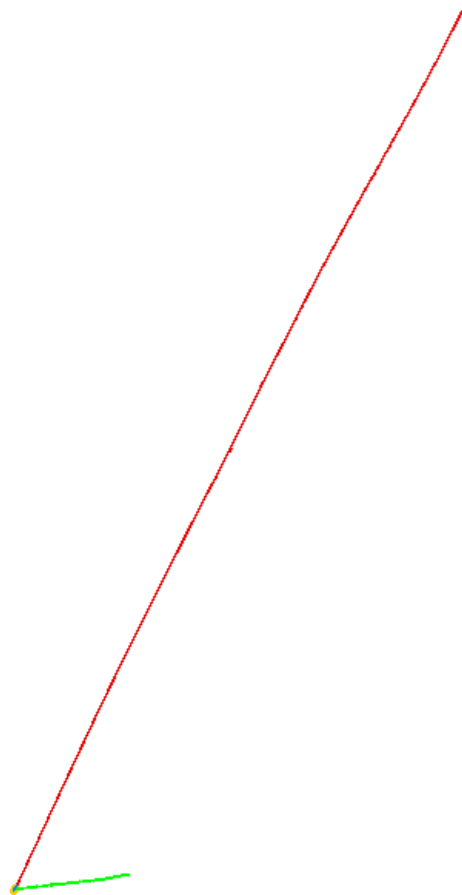

'OTHER INTERACTION'
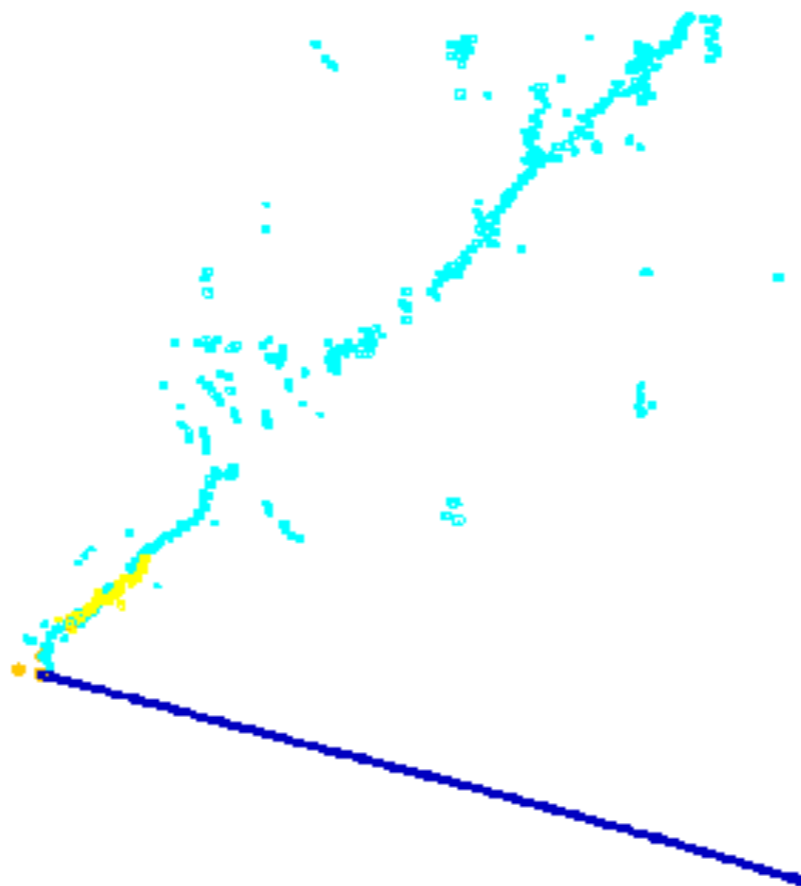**1mu +1p + many small p**
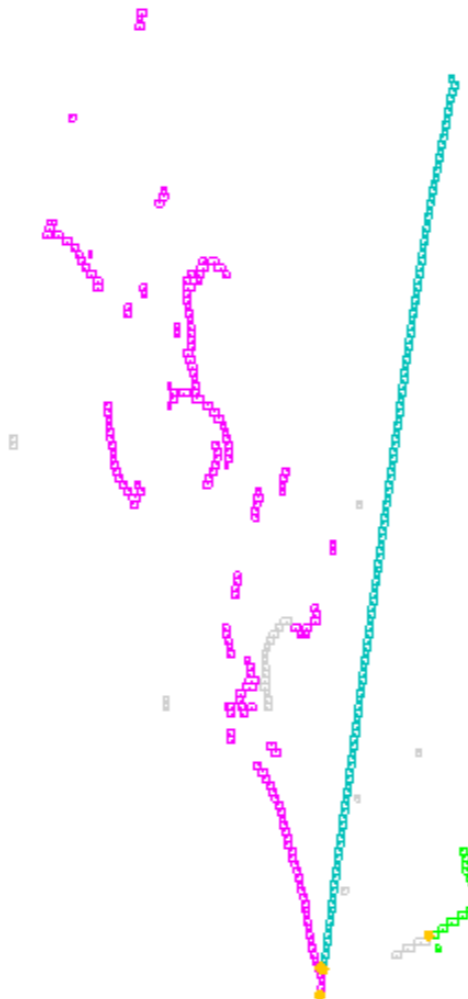
'NC RES P PI0'
1P + 1Pi0

'CCRES E P Pi0'
1e- + 1p + 1Pi0
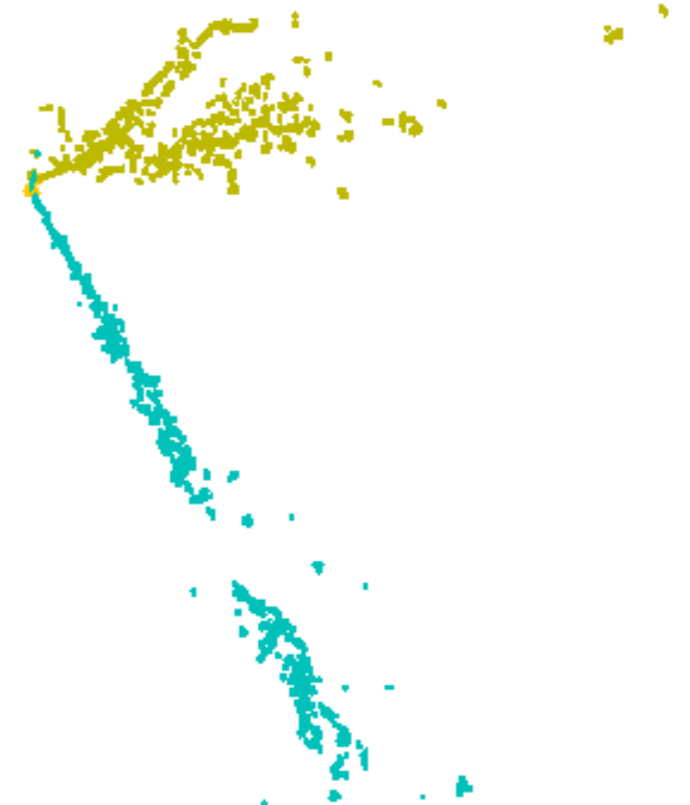
Pandora event displays -
3D reconstruction

'OTHER INTERACTION'
1mu +1p + many small p

'NC RES P PI0'
1P + 1Pi0

'CCRES E P Pi0'
1e- + 1p + 1Pi0

Correctly reconstructed   **Correctly reconstructed**   **Missing photon and proton**
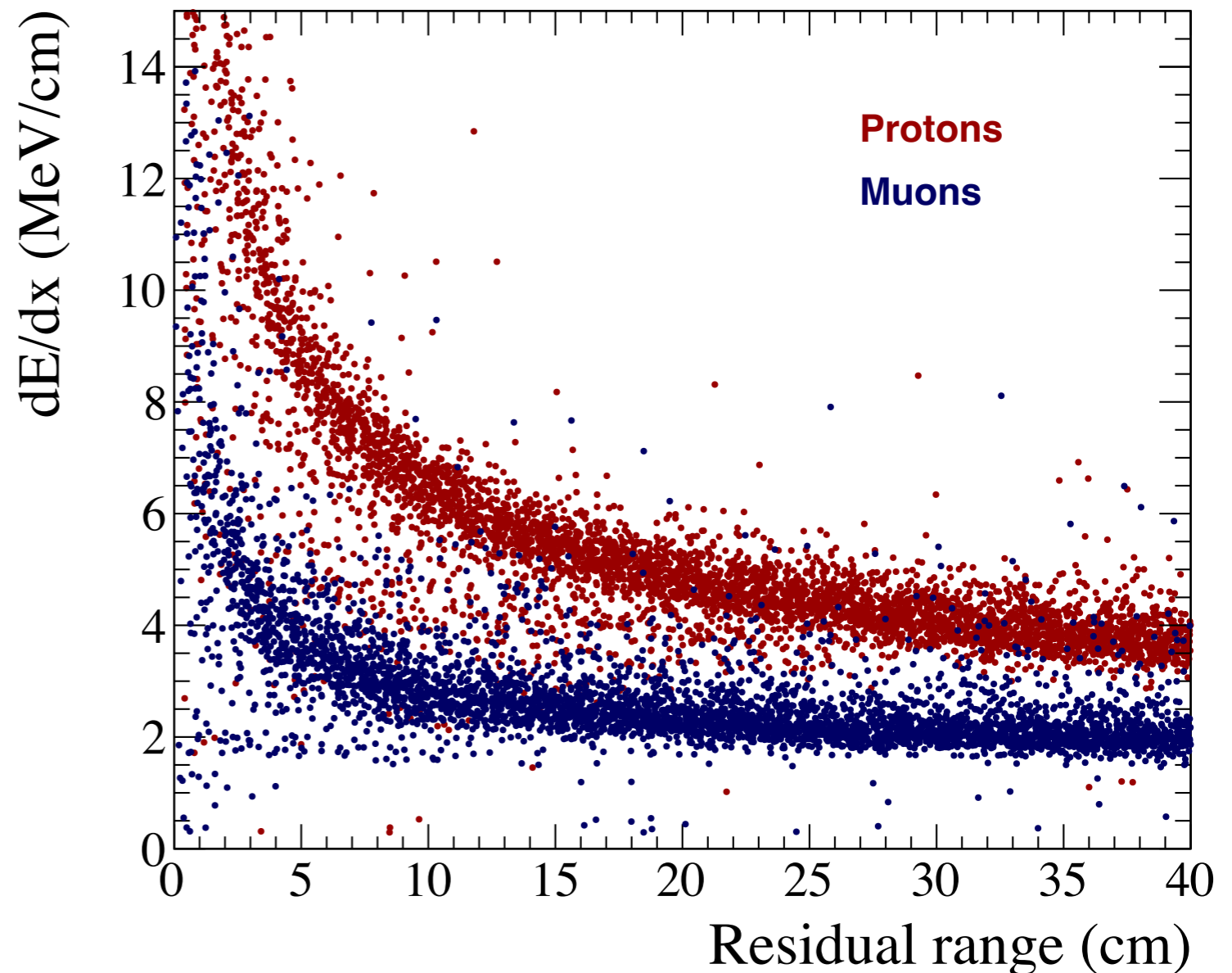
Calorimetry and PID

- 100x 1mu1p events
  - Fixed momentum and angles
- Demand:
  - exactly two tracks are reconstructed
  - Reject the dE/dx values for the first/last hit in a track
- Plot shows reconstructed dE/dx vs residual range using the standard calorimetry tools available in LArSoft
- Calorimetry constants were hand-tuned

Current status

- The software is up and running, ready for public consumption

- There is currently a large-scale production ongoing, to produce O(1 million) neutrinos that are fully reconstructed using pandora

- The production will be used to validate the reconstruction, but we are also expecting analysis-level output from downstream working groups

- Future work

  - Pattern recognition validation (the pandorians)

  - CVN (BNL + L. Whitehead + S. Alonso Monsalve)

  - Neutrino energy reconstruction (unassigned; formerly developed by N. Grant)

- We have participated in LBNC reviews in May and December

  - The FD sim/reco group (who oversees the software development) have not received any specific comments back from LBNC

Reconstruction in the vertical drift cold box (REAL DATA)
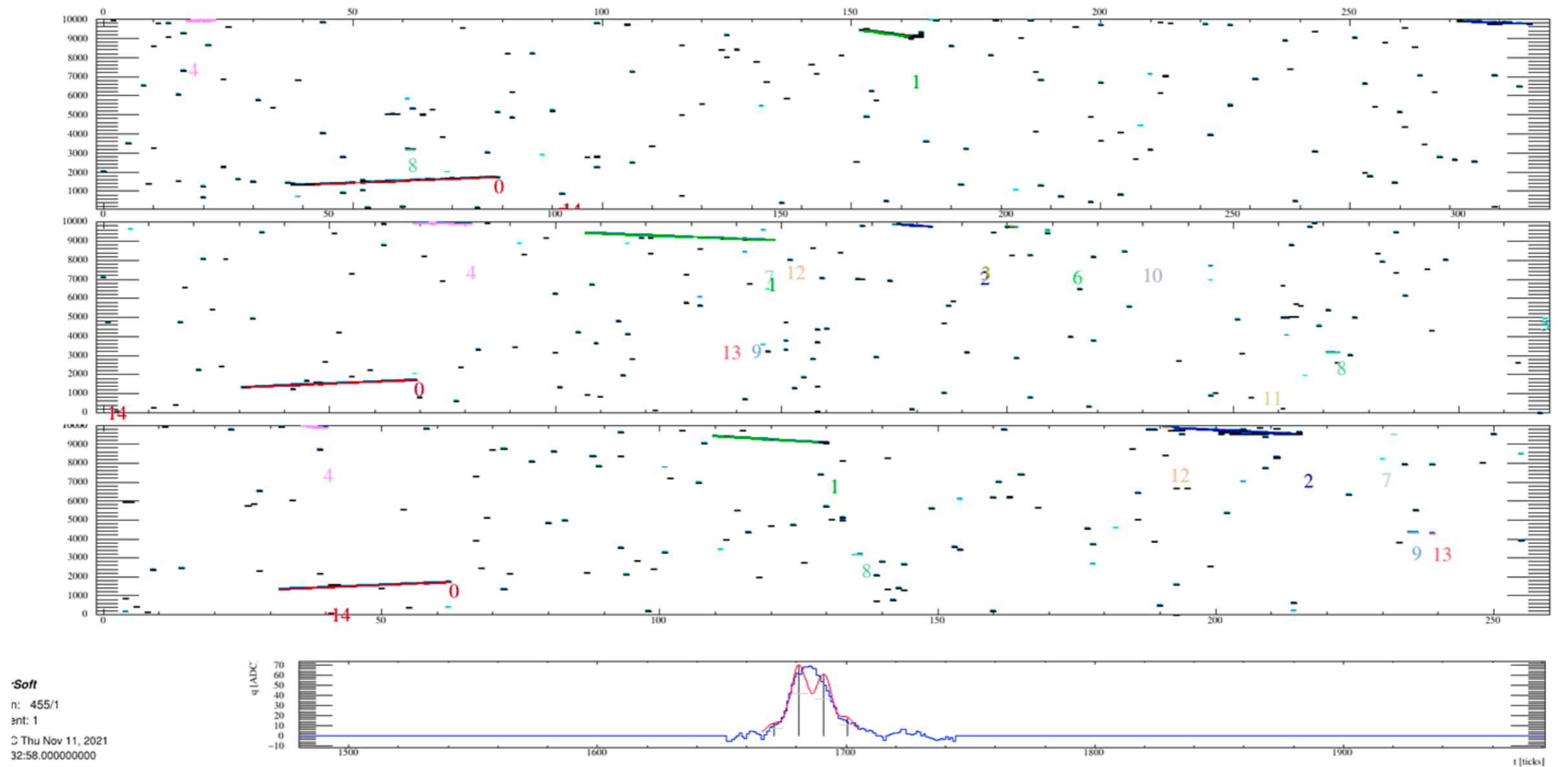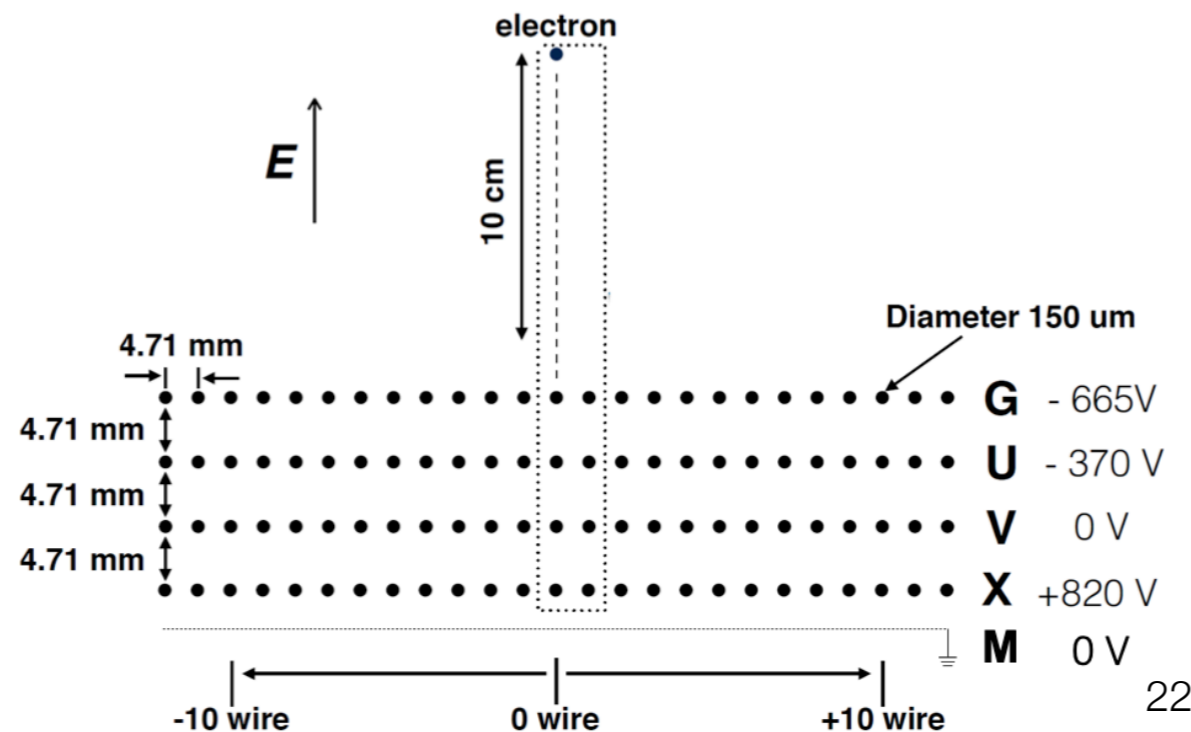

- Test of vertical drift technology ongoing in cold box at CERN with a 30 cm drift length

- Cosmic rays are being observed in the raw data

- Pandora successfully runs 'out of the box' on the collected data

Refactored LArG4

- The 'legacy' larsim has been used extensively in DUNE FD, but has a few limitations

  - An 'all in one' simulation

  - A physics list that is hard to change/extend

  - Difficult to retrieve the energy deposits in the active detector volume

  - Many others

- The refactored larg4 fixes all of those problems.

  - For anyone who is active in simulation, this is a great addition to the workflow

  - If you're removed from the simulation, you shouldn't notice a difference in your analysis

- One key benefit is the particle tracking and electron drift simulation are completely separate entities -> you are able to use completely different drift simulation models without needing to edit larsim
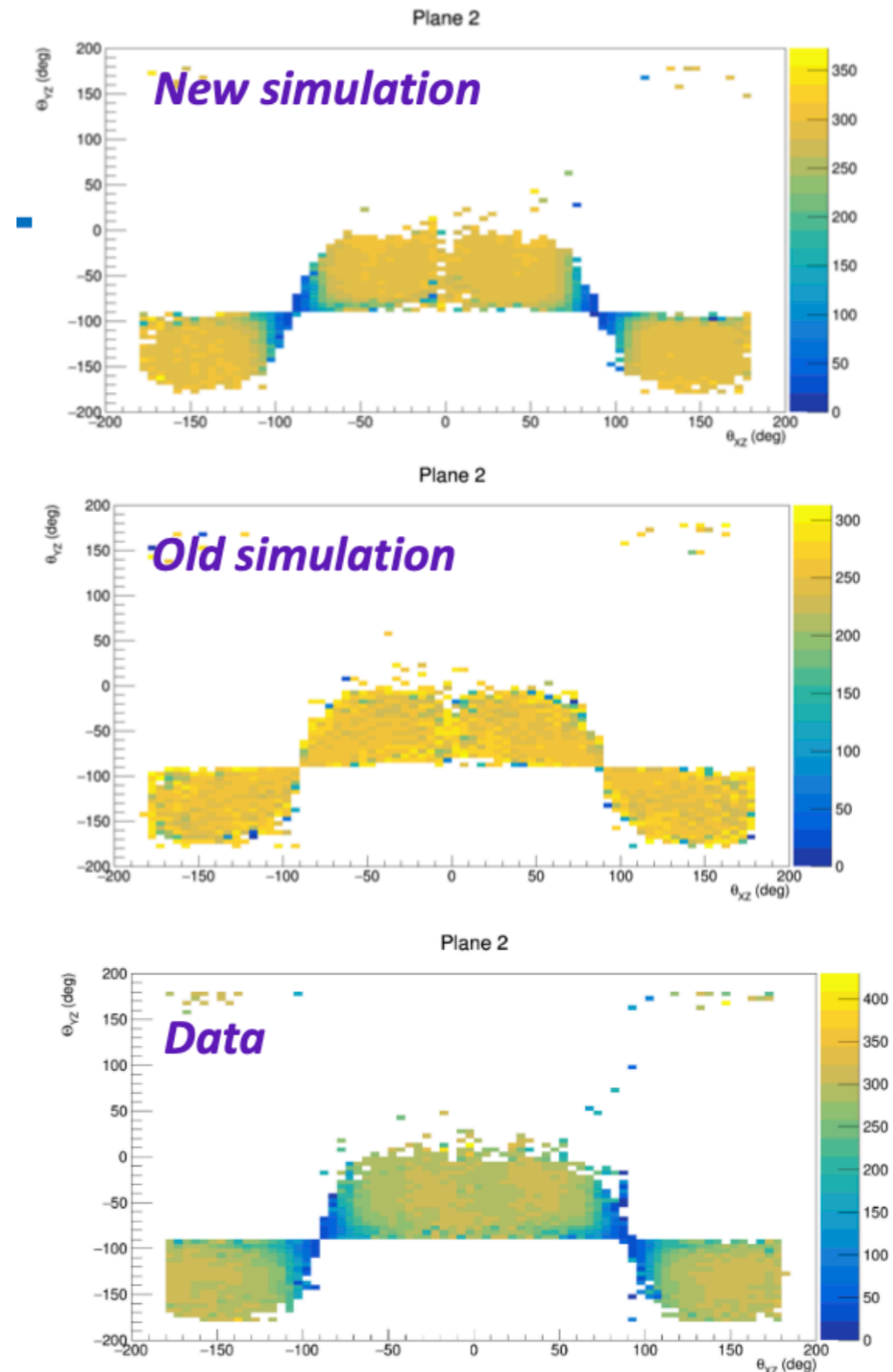
Signal simulation and processing using wirecell

Plots by W. Gu, A. Paudel
Reconstructed cosmic dQ/dx MPVs in protodune

- TDR-era drift simulation simulates the effect an electron has on a wire as it marches towards it

- In truth, the electron induces a signal on neighbouring wires too

- The wirecell package from BNL provides

  - a 2D drift simulation, encapsulating this effect

  - A 2D wire signal deconvolution, disentangling this correlated effect

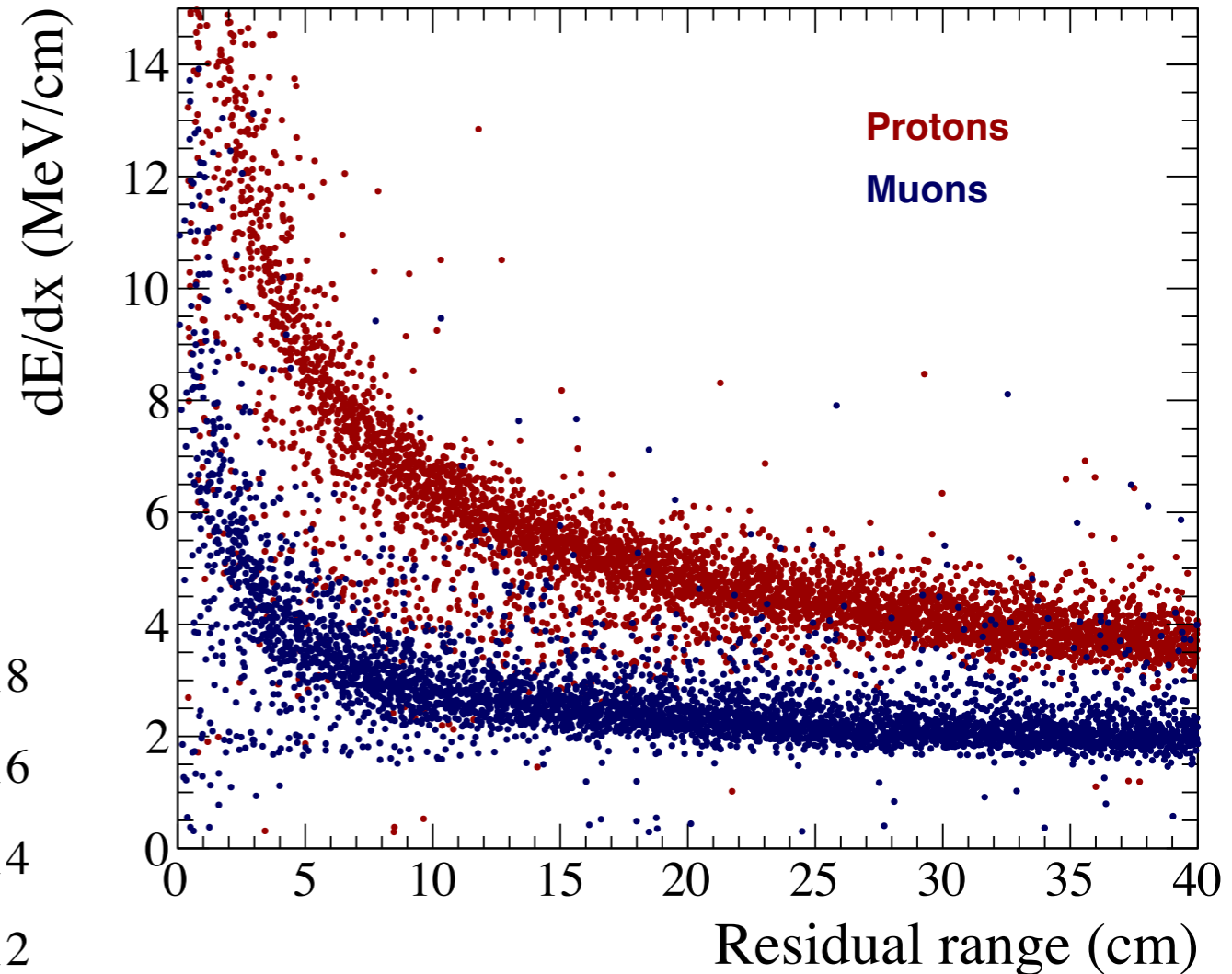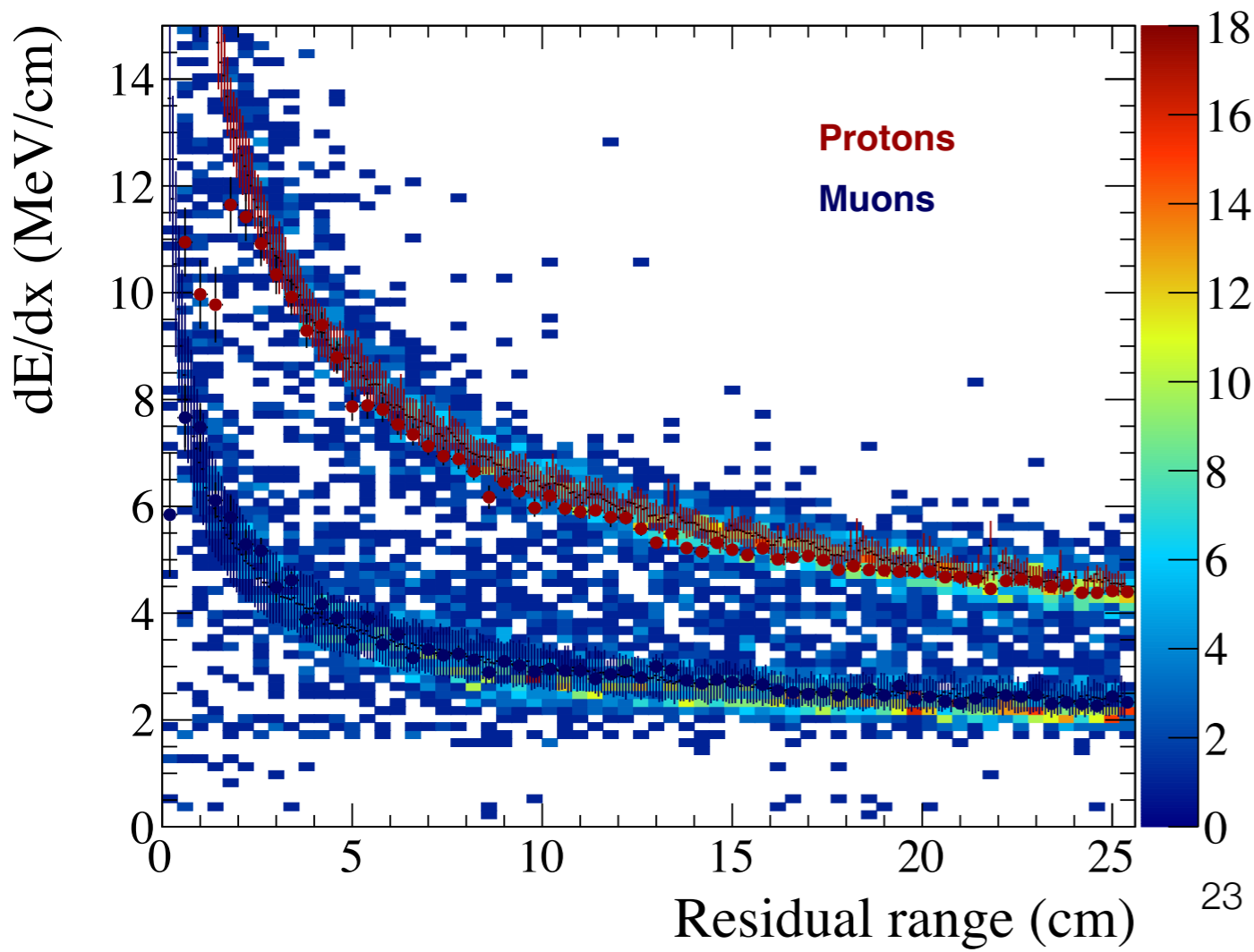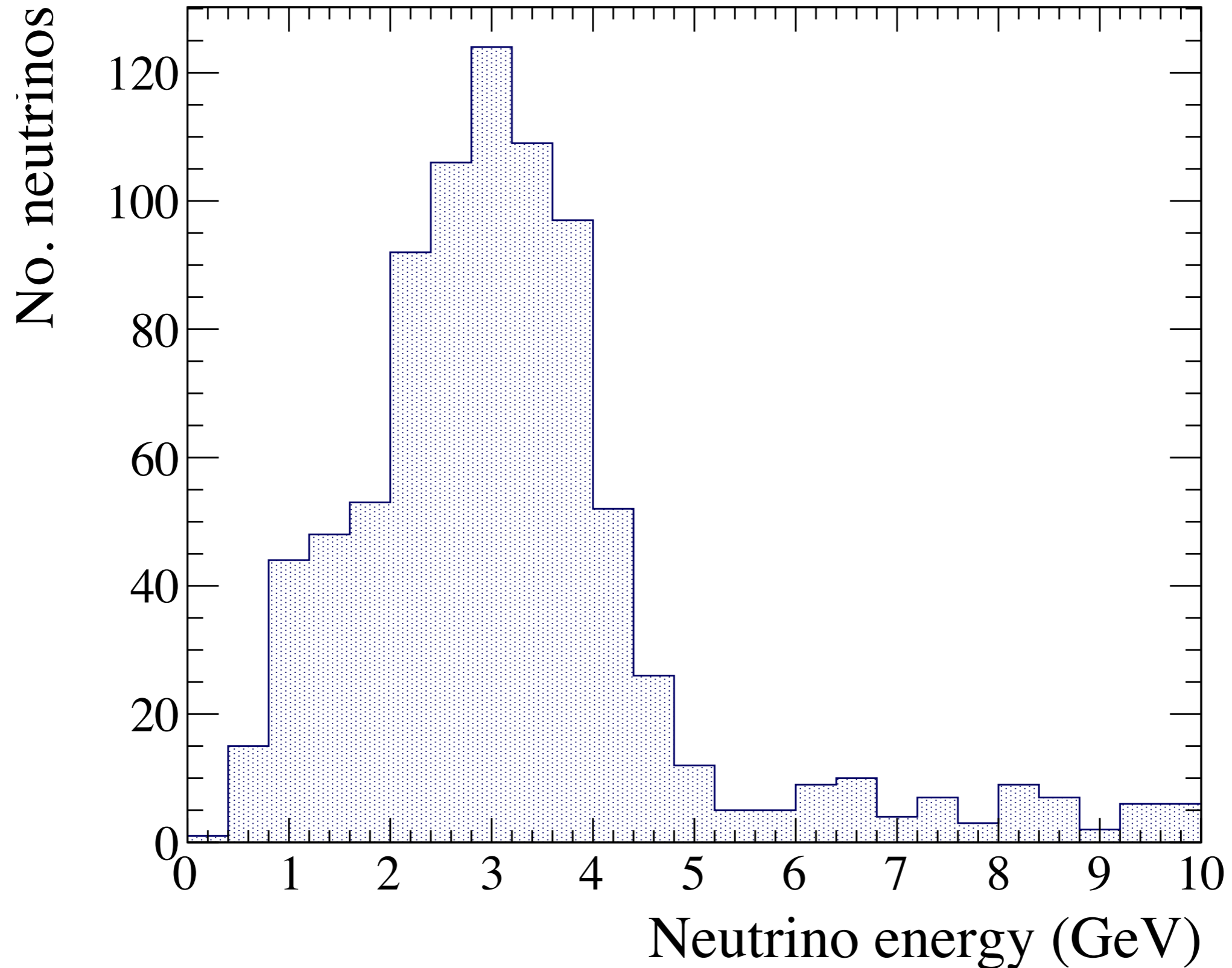- Extensively tested in ProtoDUNE and MicroBooNE

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Calorimetry and PID

- 100x 1mu1p events
  - Fixed momentum and angles
- Demand:
  - exactly two tracks are reconstructed
  - Reject the dE/dx values for the first/last hit in a track
- RHS plot shows reconstructed dE/dx vs residual range using the standard calorimetry module in LArSoft (included in the sim/reco workflow)
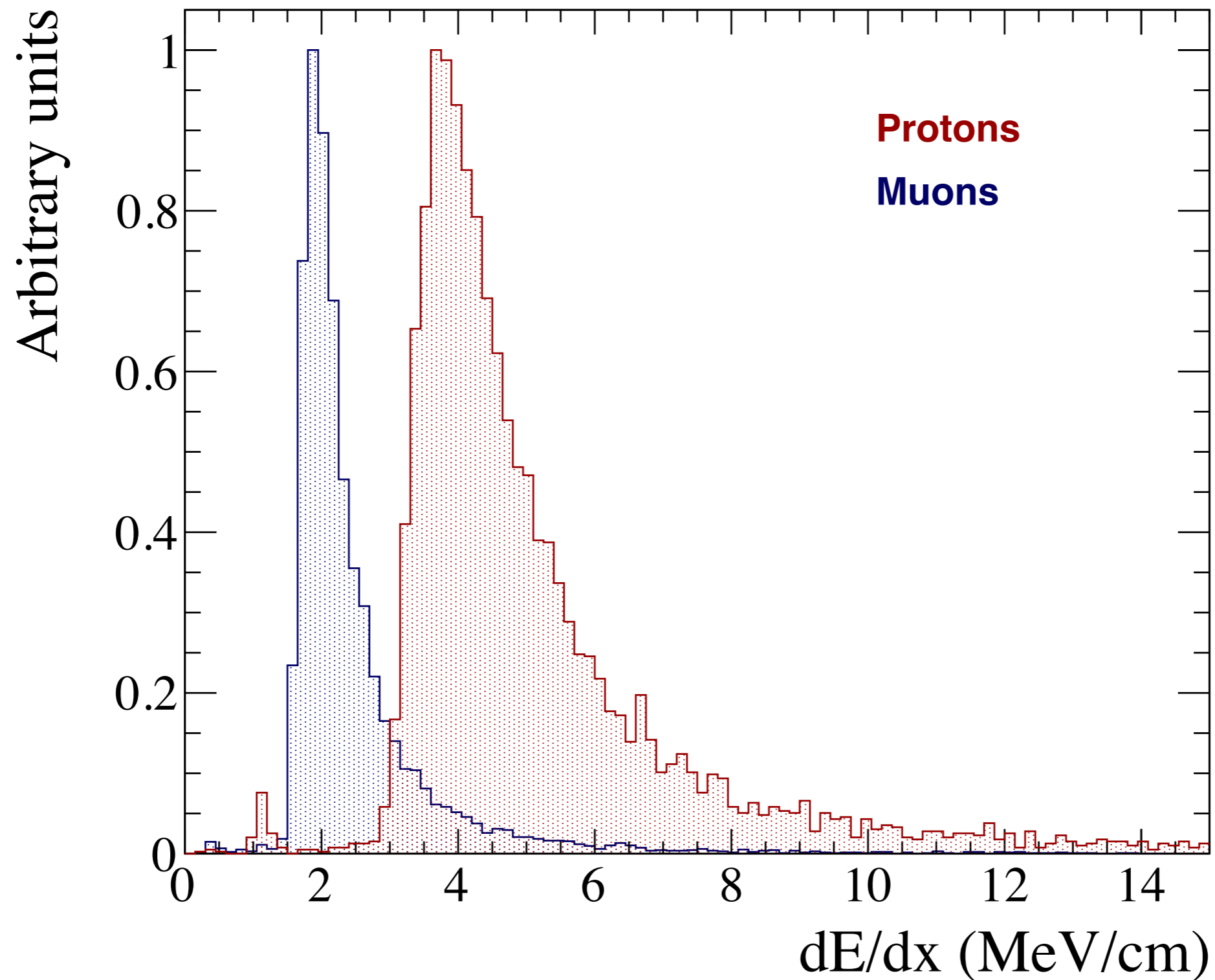

- Calo constants were hand 'tuned'

  - Calc'd a mean dE/dx per residual range bin (the thick red/blue points)

  - Calo constants varied until the muon mean dE/dx aligned with the dE/dx templates used in the chi2 PID (thin points)

- Calibration group have been notified of the reco status so that they can undertake a better tuning

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Nu energy

dE/dx (1mu+1p sample)

CRU