An overview of the DUNE 35 ton prototype at Fermilab

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New Perspectives

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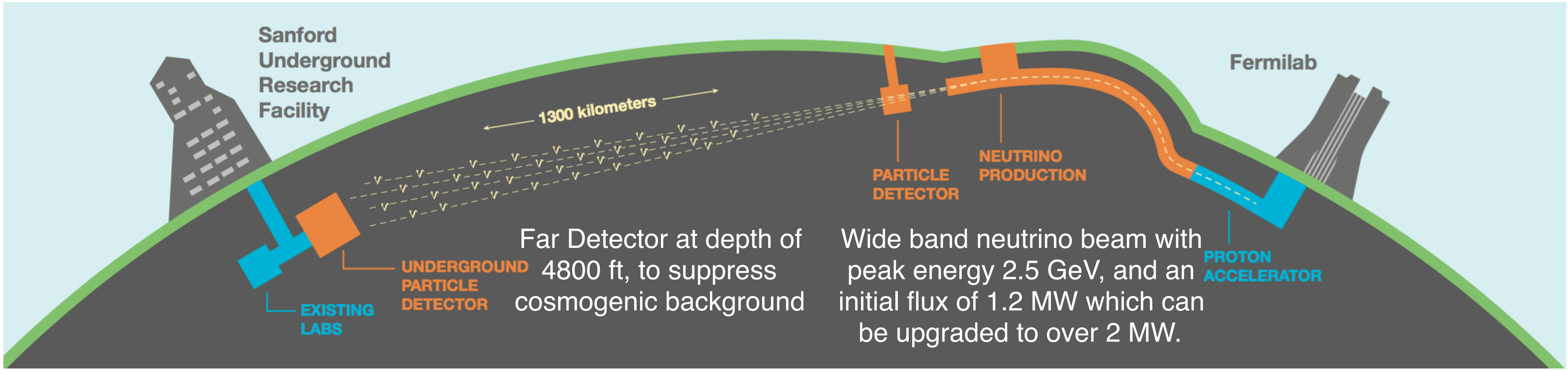
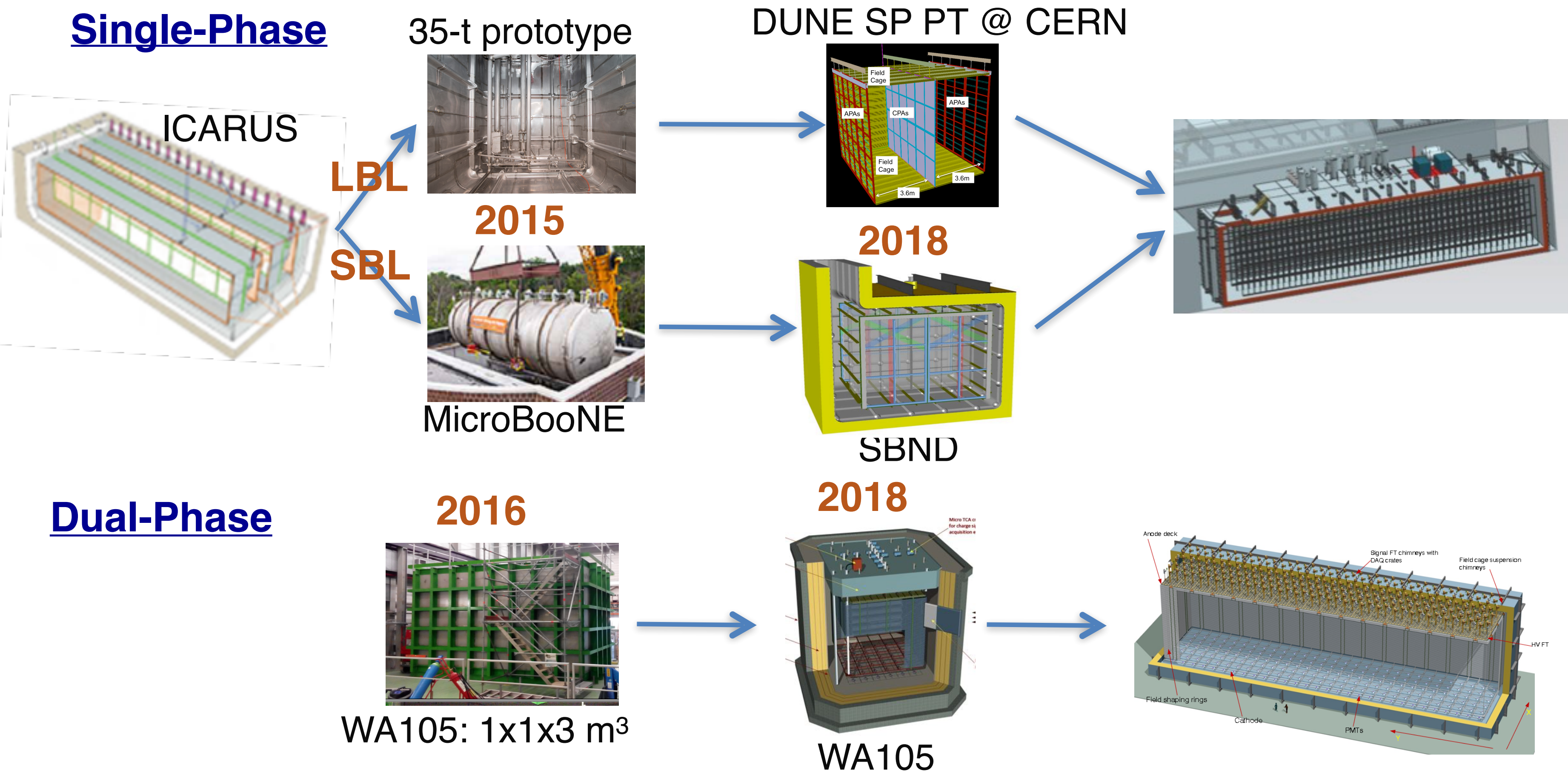
The University Of Sheffield.

DUNE - Deep Underground Neutrino Experiment



- The flagship experiment of America's Neutrino program, due to start taking data in 2024, and beam data in 2026 with 10 kton active LAr.
    - Full completion of four modules by early 2030's.
- Staged construction of 4 x 10 kton fiducial LAr detectors.
    - The detector will be a single phase LArTPC.
- Will have a high precision near detector, technology still to be decided.
- Designed to have a very rich neutrino oscillation programme, plus searches for nucleon decay and neutrinos from supernova bursts.

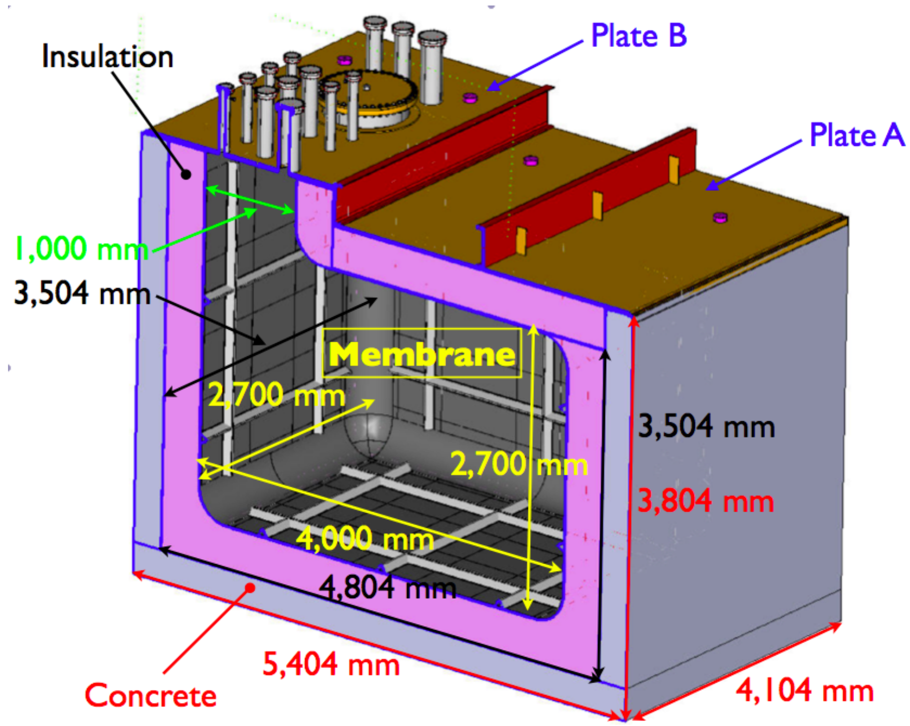
The path to realising DUNE



- Neutrino platforms at both CERN and Fermilab provide important development and prototyping paths.

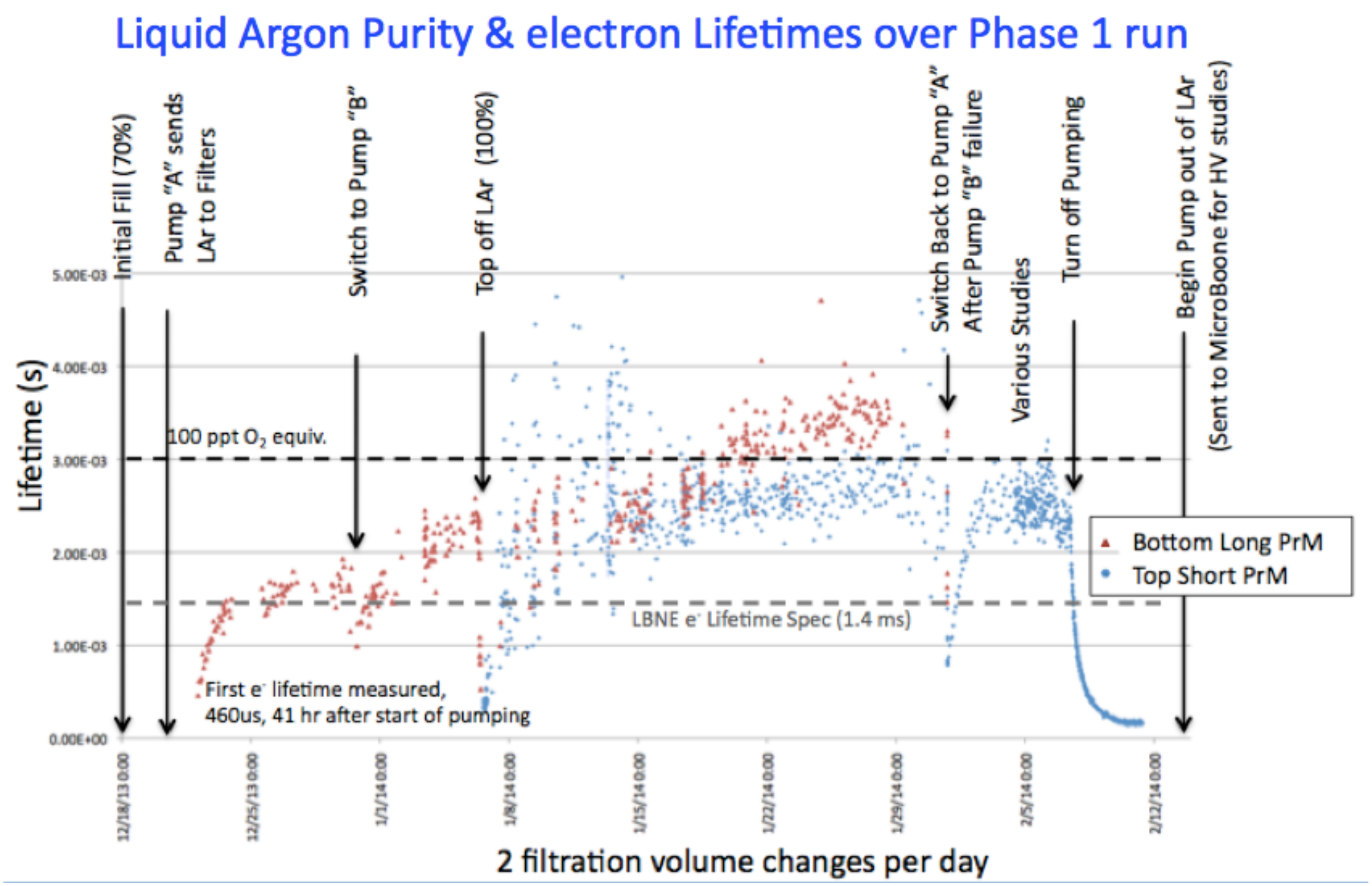
The 35 ton prototype

- Designed as one of a series of prototypes for LBNE.
  - Absorbed into the prototyping effort for DUNE.
- Phase I, Jan 2014.
  - Demonstrate that a membrane cryostat can hold LAr at high purity.
- Phase II, Nov 2015 - Mar 2016
  - Test detector design and readout technologies for DUNE.



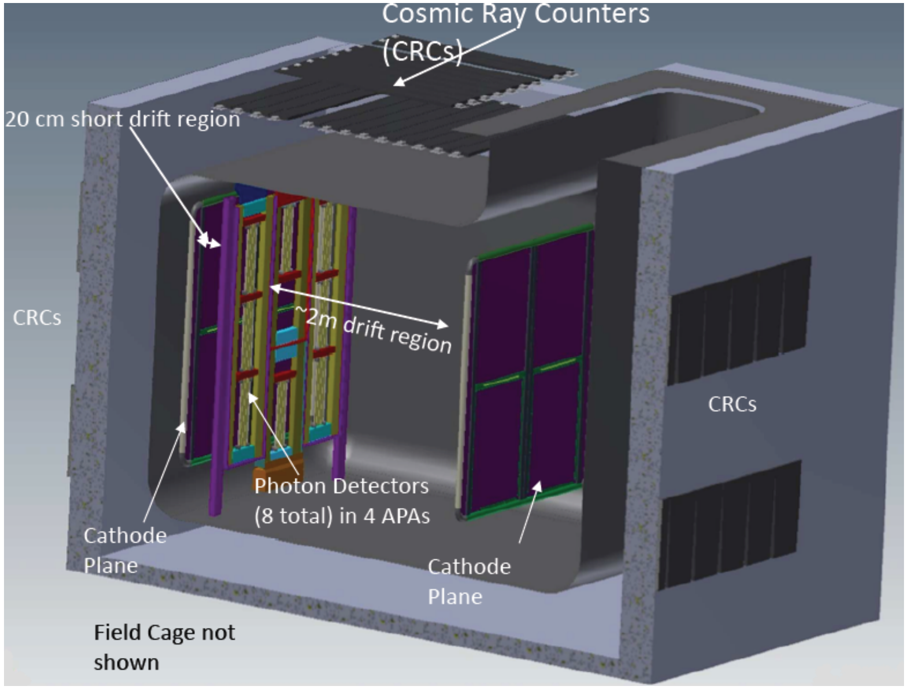
Schematic of the 35 ton cryostat

Purity during Phase I run



The 35 ton Phase II

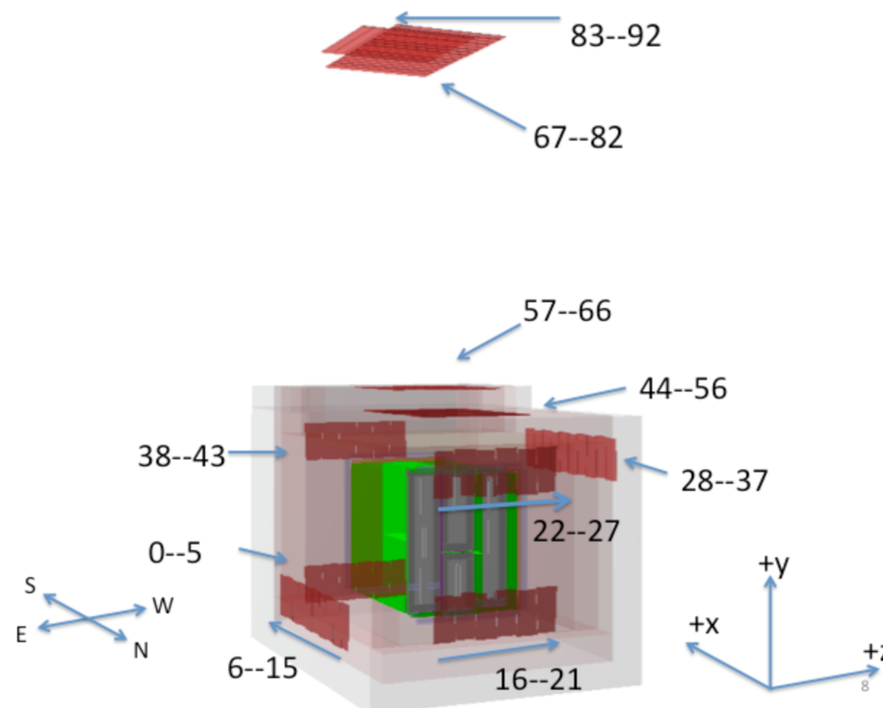
- An important step in developing the FD.
- Detector design features:
  - Wrapped wire planes
  - Multiple drift volumes
  - Cold electronics
  - Triggerless DAQ operation
  - FR4 printed circuit board field cage
  - Light-guide style photon detectors
- All items are part of the FD design and before December 2015 all but one had not been demonstrated to work in an integrated system.



Schematic of the 35 ton phase II

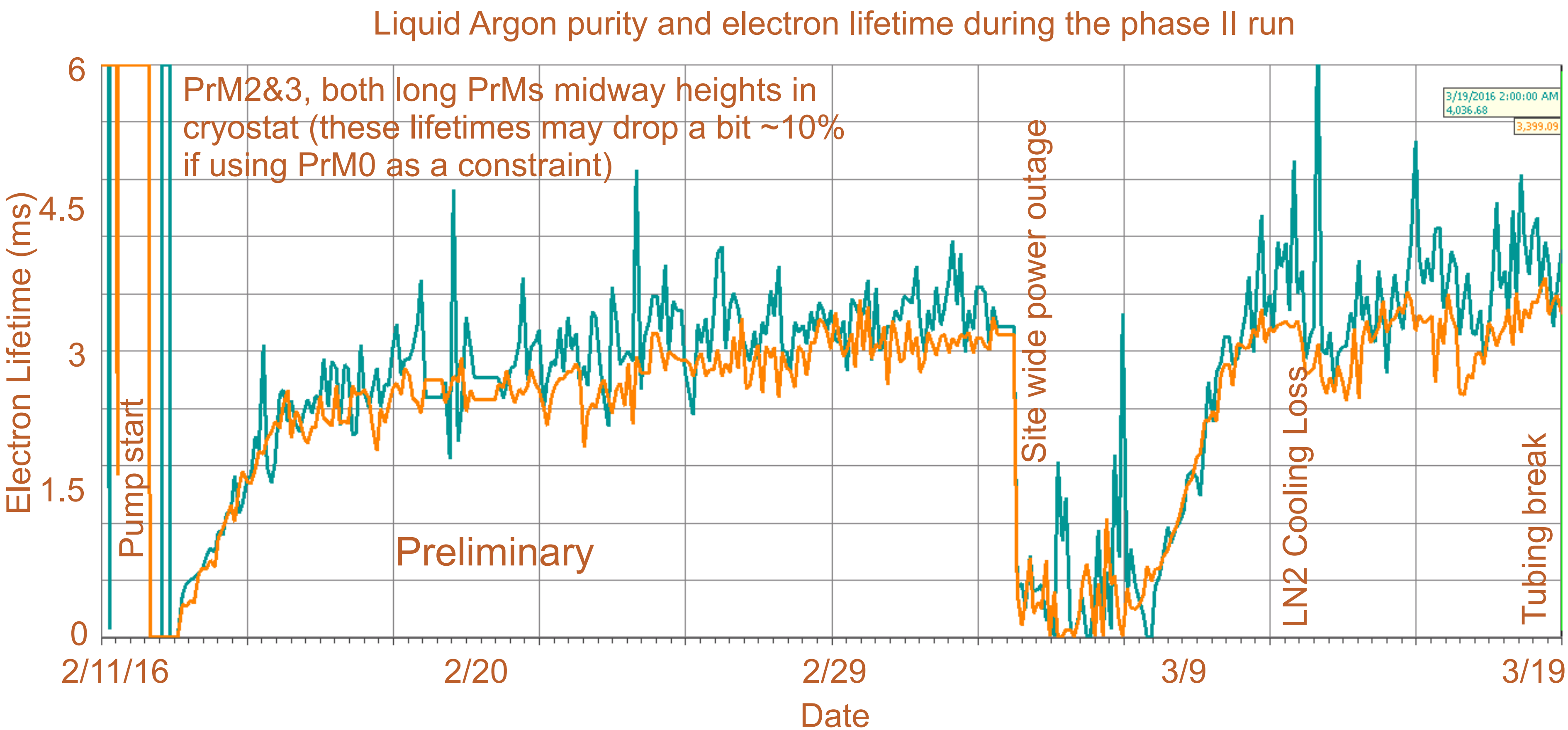
The cosmic ray counters

- Layers of plastic scintillator panels.
- Used for triggered running.
  - Activated when have a ‘coincidence’ on two oppositely facing counters.
- Orientated to give maximal coverage of the detector.
  - Particles crossing APAs
  - Particles traversing detector
  - Particles travelling vertically
- Allow interaction times to be assigned to cosmic events during continuous running



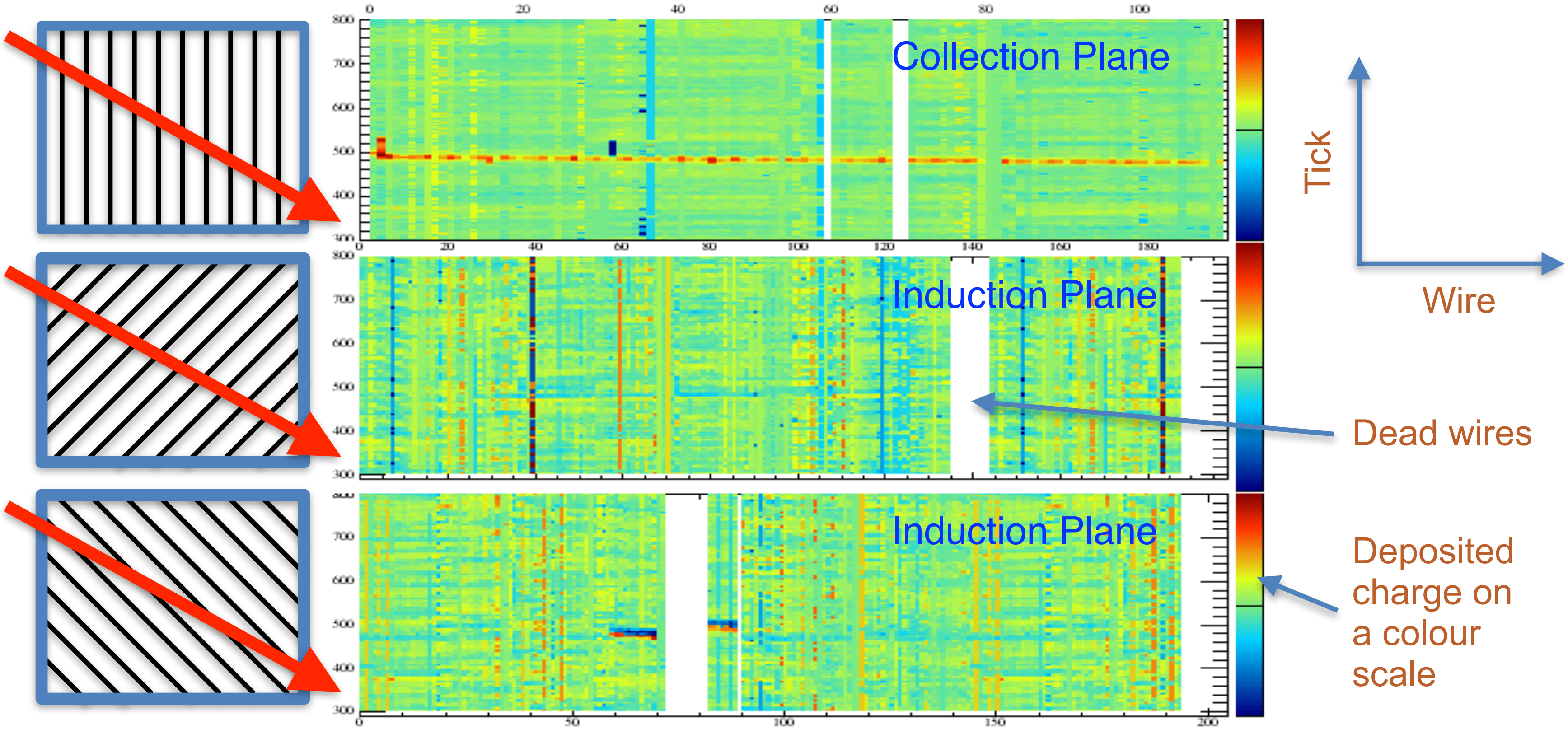
Labelled diagram of the 35 ton counters used for triggering data

Purity during Phase II run



- Same purity level achieved as in Phase I, which was quickly recoverable.
- Purity level in 35 ton is cryostat limited, not detector component limited.

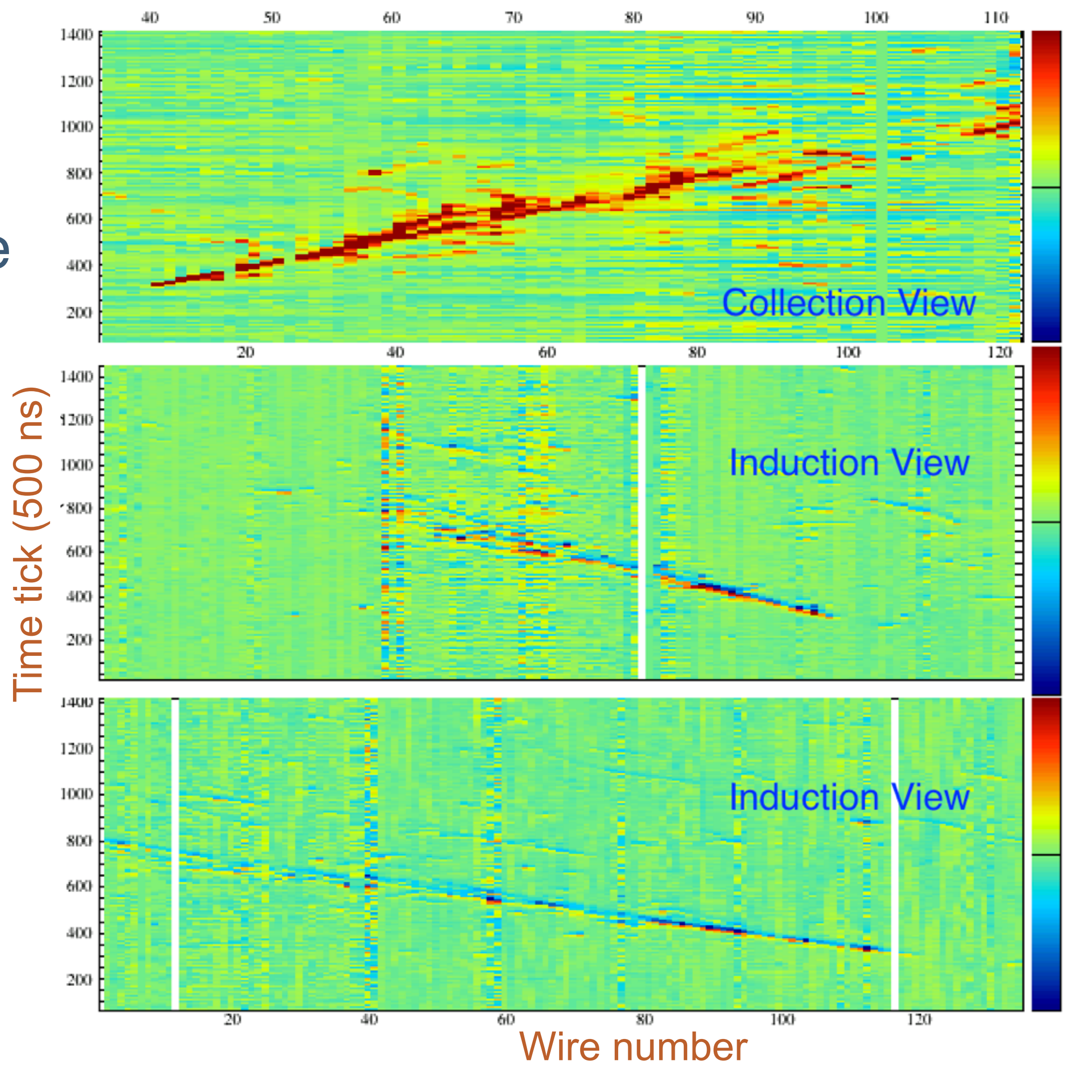
Event display for a through-going muon



- Orientation of wire planes and track angles triggered on leads to:
  - Good collection plane coverage - strong signals on many wires.
  - One plane seeing charge deposited on many wires - weak signals on many wires.
  - One plane seeing charge deposited on few wires - strong signals on few wires.

Event display for an electromagnetic shower

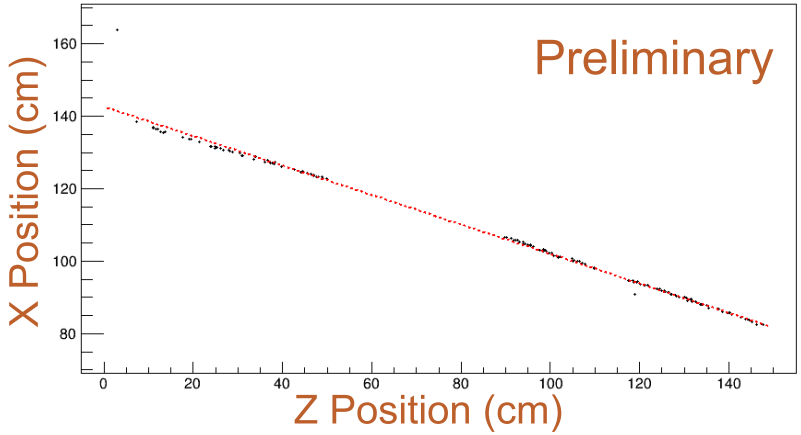
- Event display after noise mitigation is shown.
  - ‘Stuck’ ADCs are removed.
  - Coherent noise is removed.
  - A frequency filter is applied.
- Stronger signals due to more deposited charge.

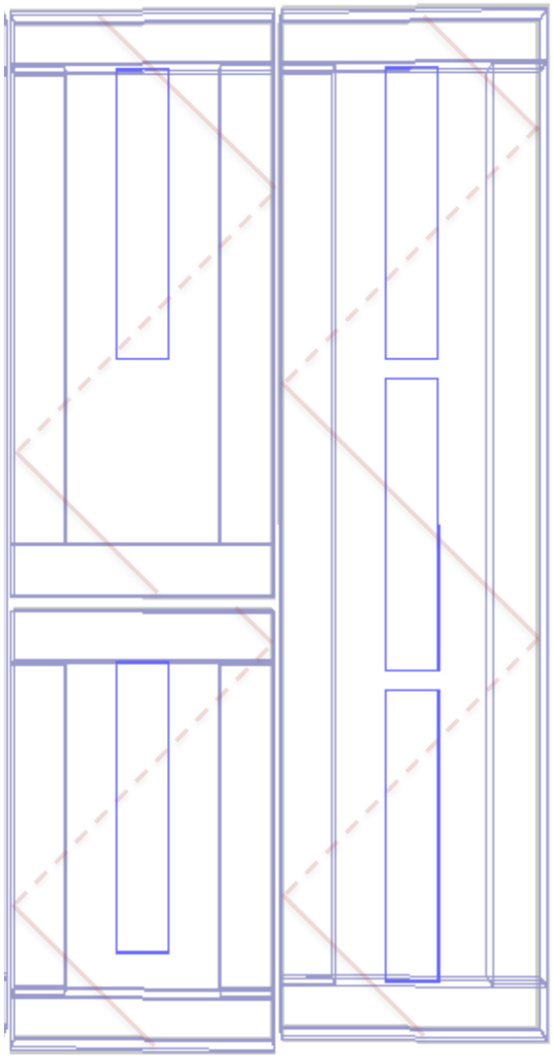


Hit disambiguation using cosmic ray counters

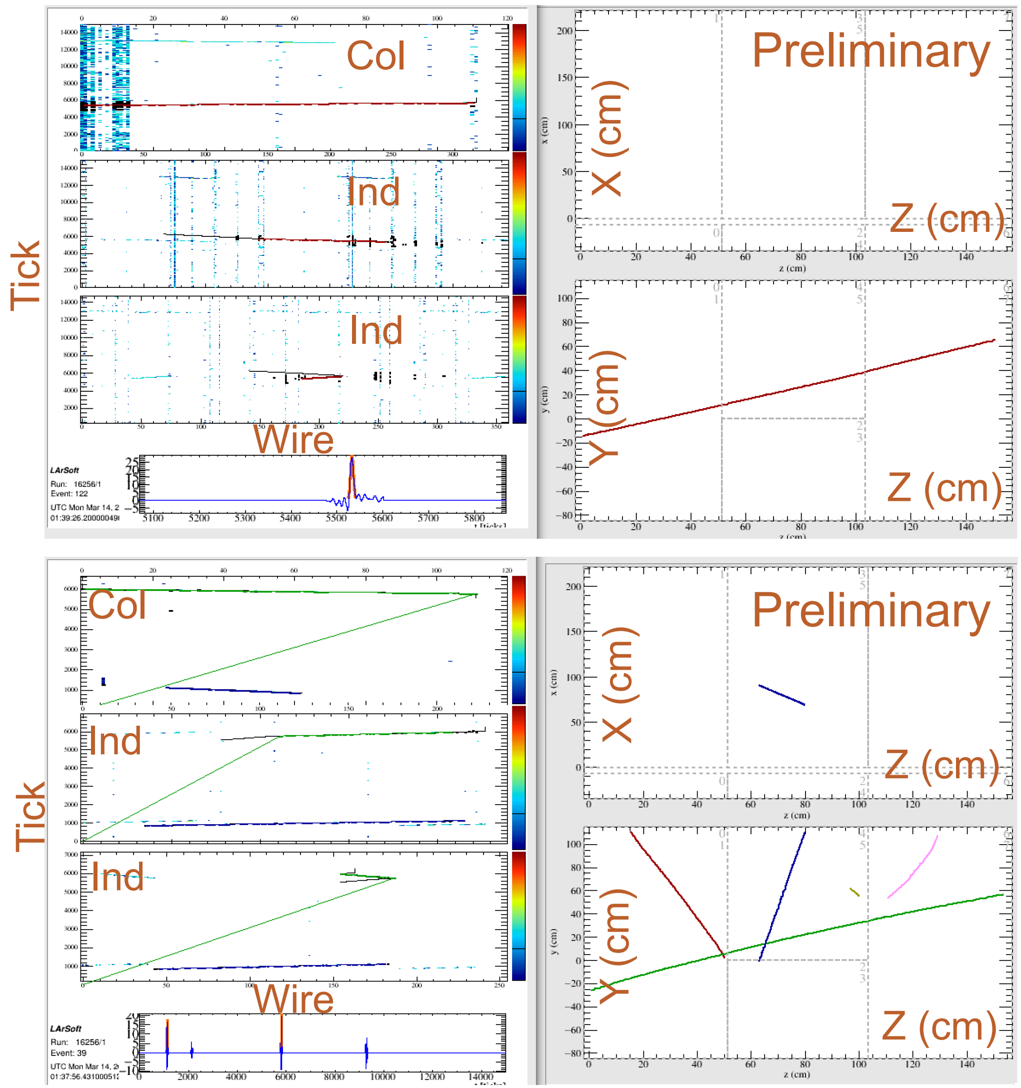
- Due to wrapping disambiguation is required.
- Existing algorithm assumes 'triple points'
  - Absence of induction signal can cause a hit to be discarded as noise.
- Counters offer a method of performing disambiguation.
  - Hits have to be within a 3 dimensional coincidence window.
    - Removes noise hits.
    - However, tracks which did not produce a counter coincidence are discarded.
  - Can use unambiguous collection plane signals to constrain ambiguous induction signals.

Collection plane hits in the XZ plane





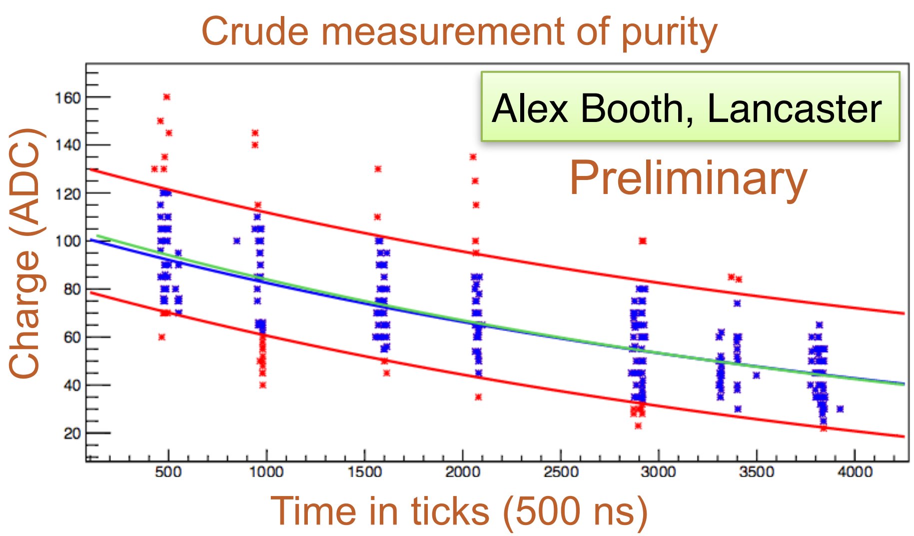
Reconstructed tracks

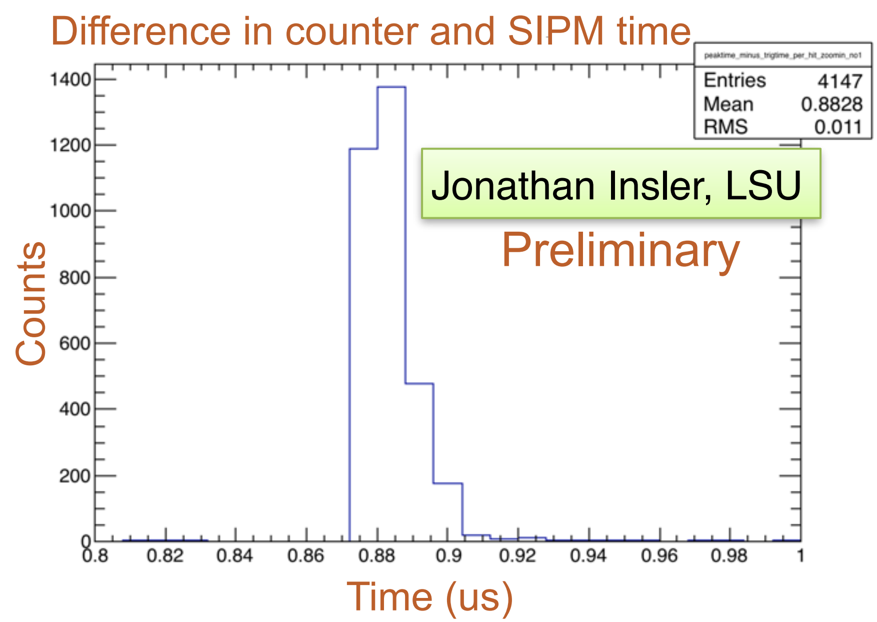


- Digitised waveforms shown on the left
  - Same structure as previous event displays.
  - Fourth window shows reconstructed hits in orange.
- Three dimensional view shown on the right.
  - XZ plane shown in top window
  - YZ plane shown in bottom window
  - X position of tracks is not corrected.

Ongoing Analyses

- Measuring purity with TPC data, crude analysis shown below.
- Measuring longitudinal and transverse diffusion.
- Using through going muons to study APA gap width.
- Using through going muons to study charge collected in the centres of APAs.
- Using Michel electrons to study energy resolution.
- Event time resolution of the photon detectors.
- Interaction time assignment from photon detectors, initial result shown below
- Signal/Noise ratio of the TPC.



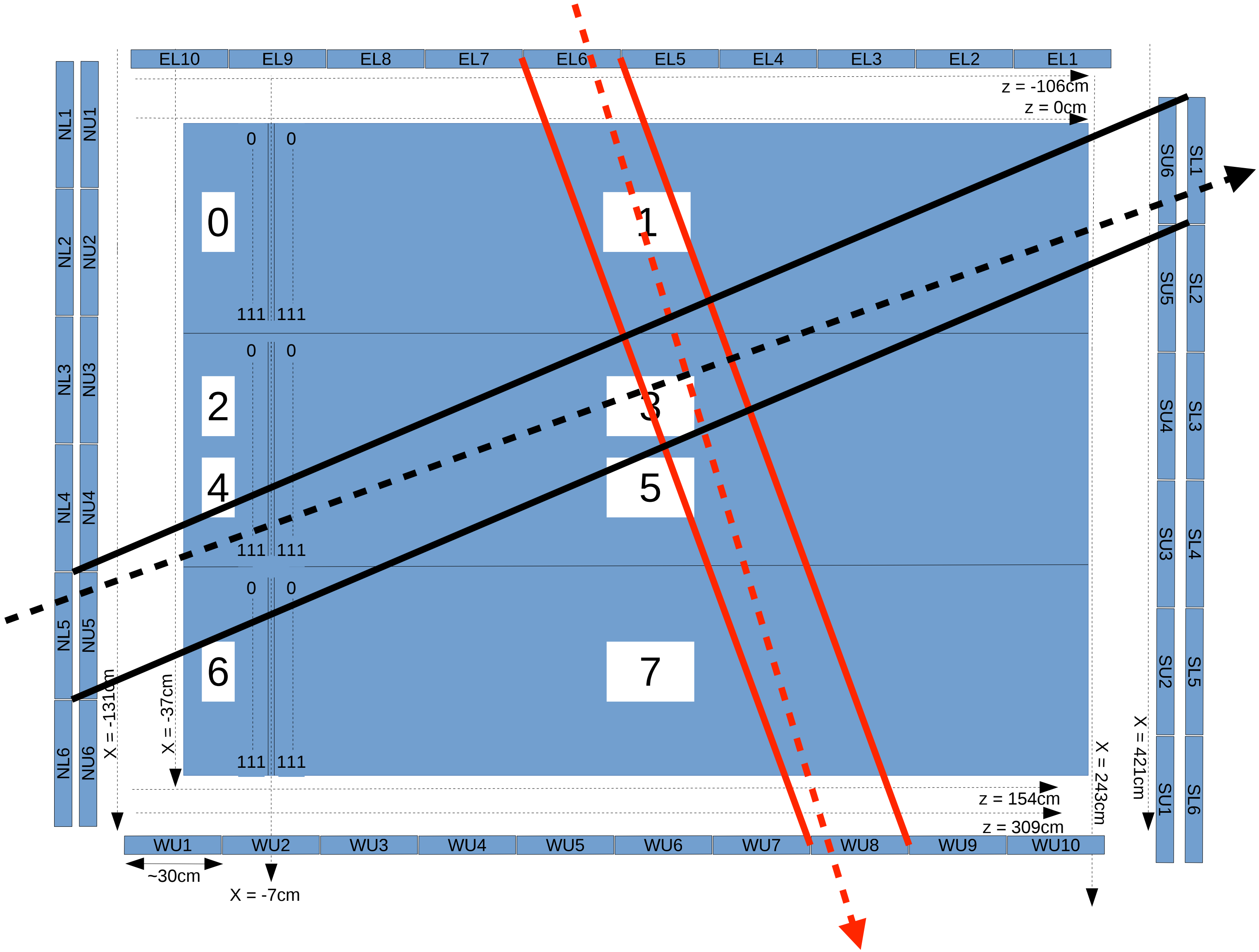


Conclusions

- Phase II of the 35 ton showed that cryostat purity was not instrumentation limited.
- Cosmic ray counters will play an important role in data analysis of the 35 ton.
- Developing tools to recover from low signal / noise in the data.
- Lots of analyses are progressing nicely.
- The 35 ton is a vital stepping stone in building the DUNE far detectors.
- As Bruce said, exciting times lie ahead!

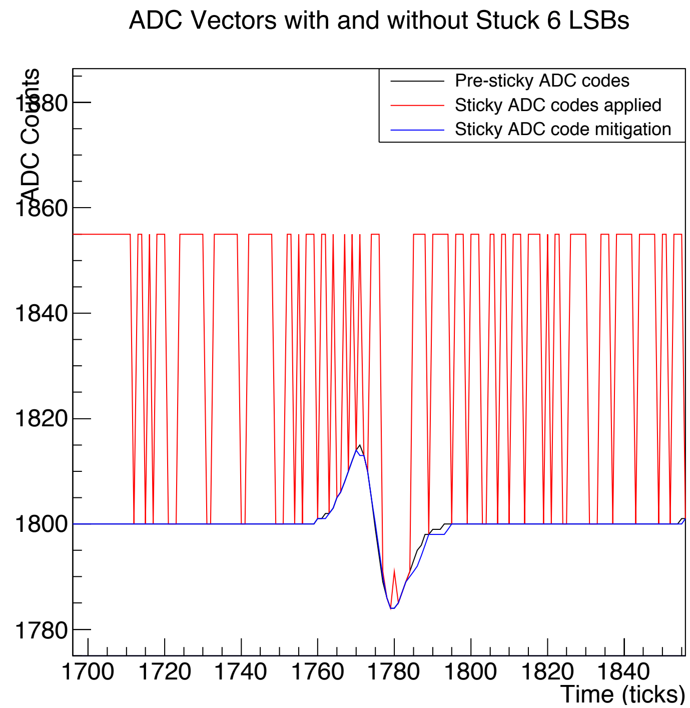
Backup slides

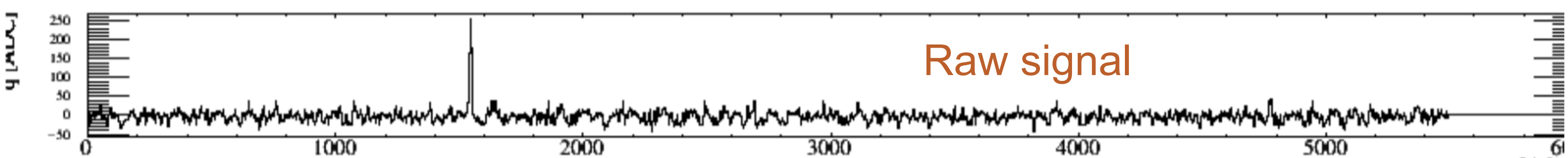
Schematic of the detector with two counter coincidences

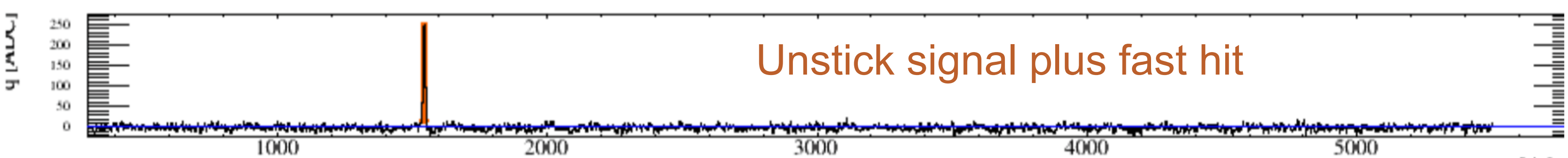


Stuck ADC code removal

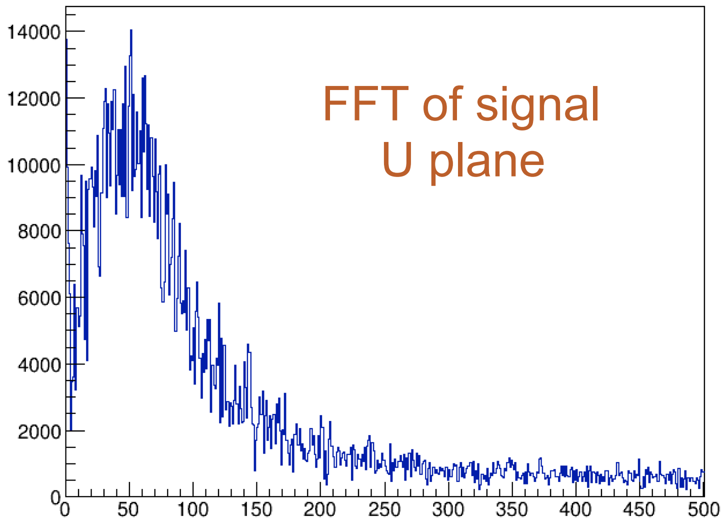
- Stuck codes were observed in ADC chips, this can be recovered by removing latched values and extrapolating between neighbouring samples.
- A redesign of the chip is being tested for future use.
- Code developed by Jonathan Insler, presented here.

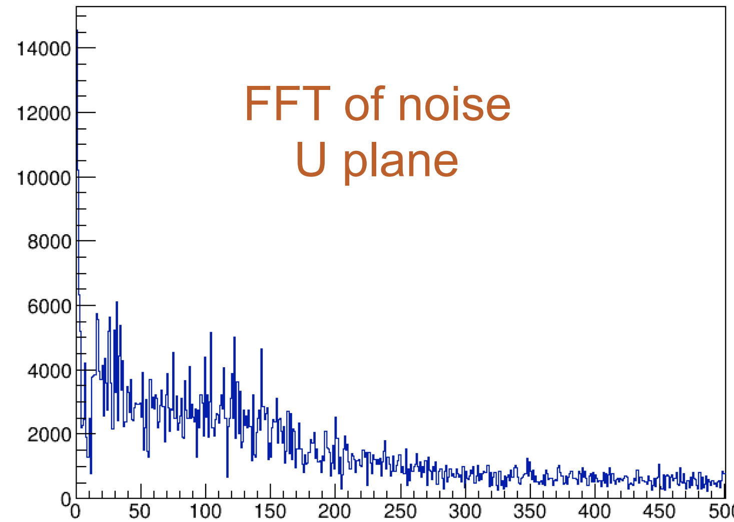




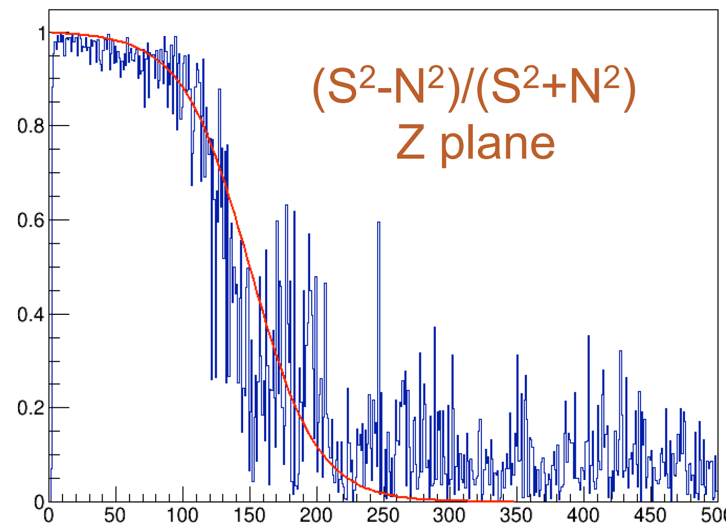


The Wiener frequency filter

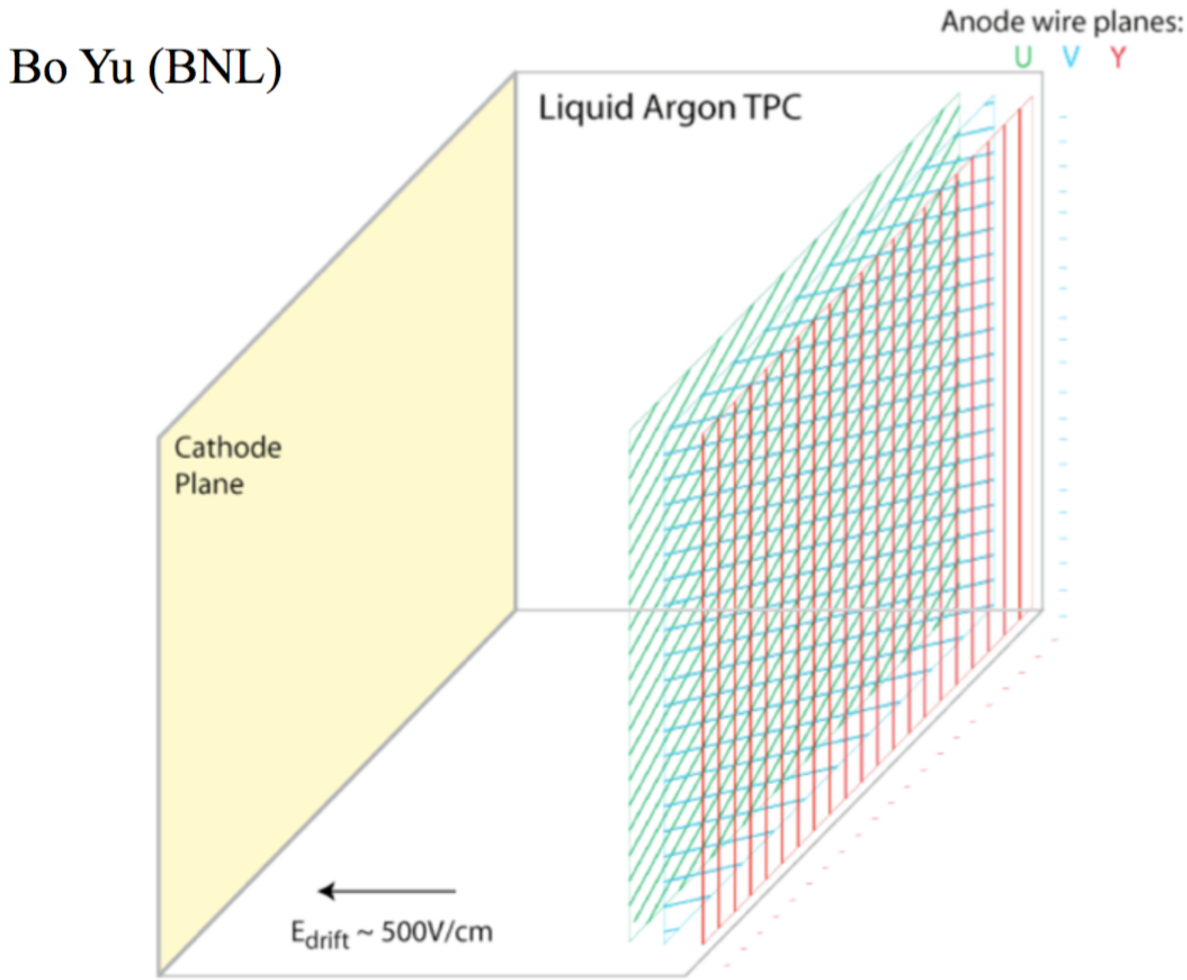




- Spike in noise frequency around 0 frequency.
- Collection plane signal goes to very low frequency, so want to keep all but the very lowest frequencies.
- Induction planes have more of a peaked structure, with little components at the lowest frequencies.



LAr TPC concept



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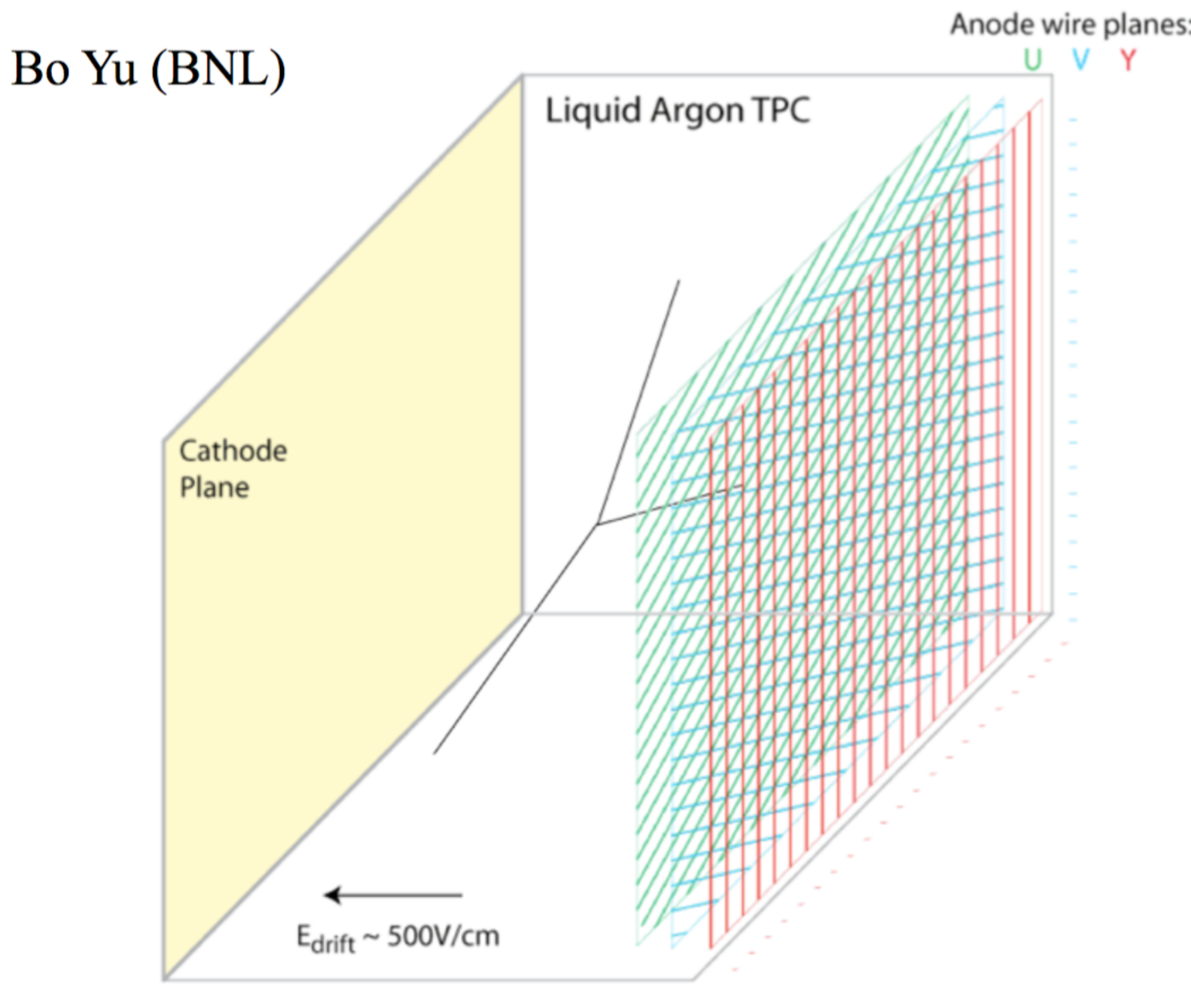
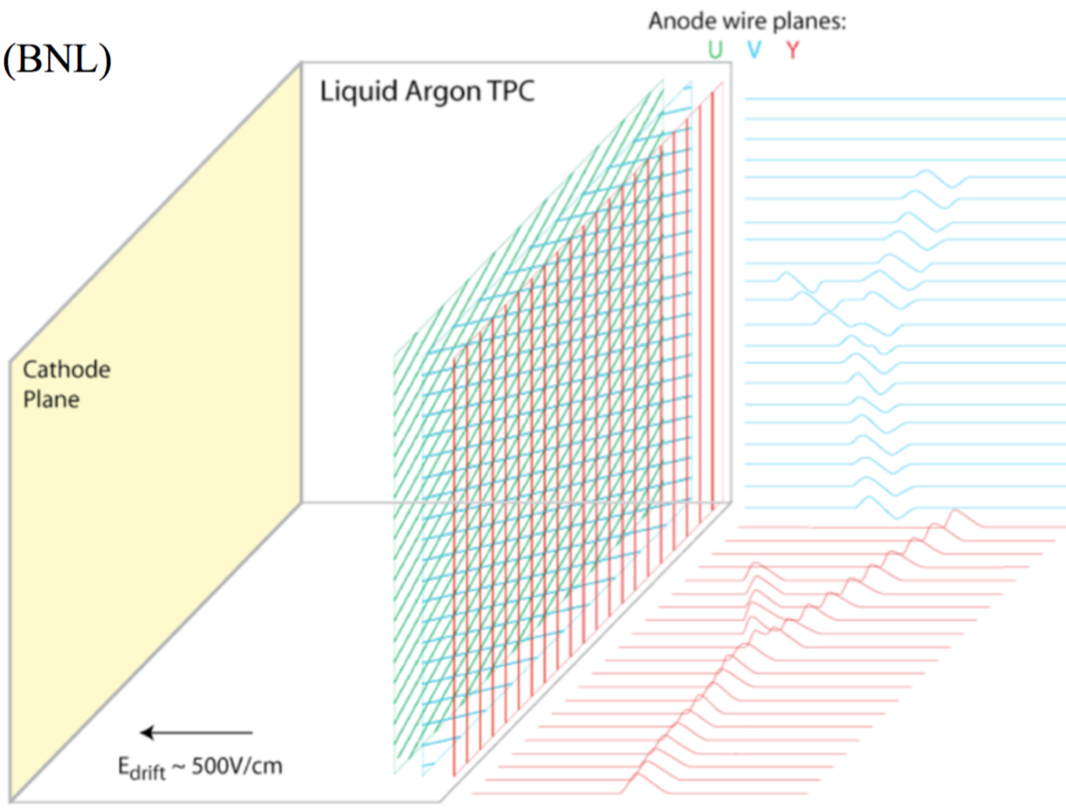


LAr TPC concept

Bo Yu (BNL)



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LAr TPC concept

- A step-by-step guide as to how hits are combined into tracks.
  - The first image shows raw signals
  - The second image shows the signals being reconstructed into hits
  - The third image shows clusters being combined into tracks.
- The 35 ton has and DUNE will have, a step between images 2 and 3 where due to the wrapped wires, hits have to be disambiguated as to which part of a wire the hit was on.