The design goals of the DUNE 35-ton Liquid Argon prototype and the first lessons learned

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1. Motivation for DUNE

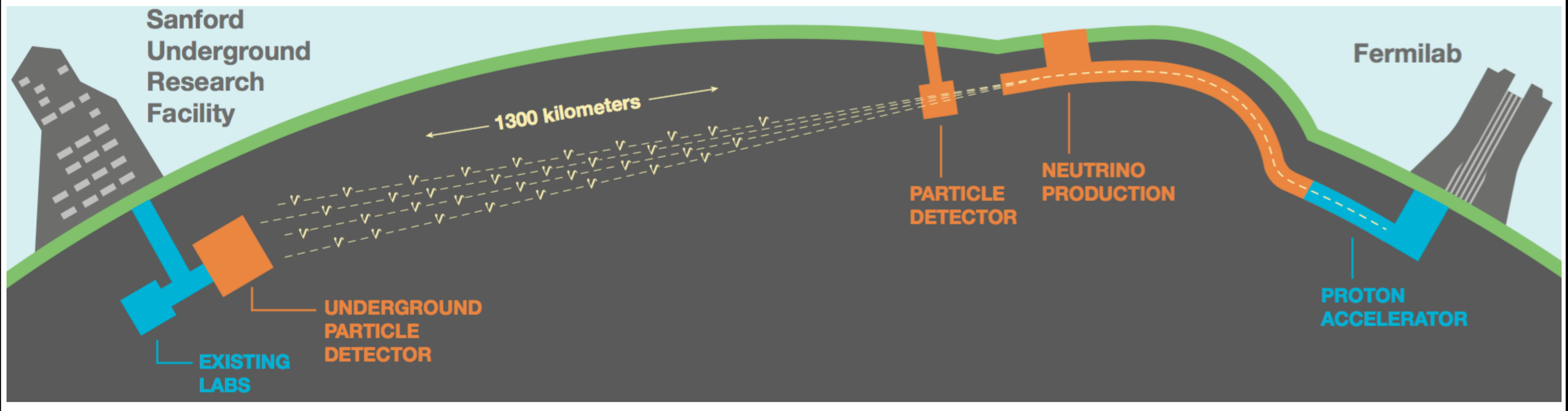

Figure 1, above.
A schematic of the DUNE experiment, where neutrinos are sent from Fermilab to the far detector site at SURF.

- DUNE (Deep Underground Neutrino Experiment) is the USA's flagship neutrino experiment. It will send neutrinos 1300 km from Fermilab to SURF using a neutrino beam with peak energy of 2.5 GeV and initial flux of 1.2 MW.
- There will be four staged 10 kt Liquid Argon (LAr) modules, each representing a factor of 300 increase in size of current LAr experiments.
  - Single (liquid) and dual phase (liquid/gas) designs are being considered.
  - The first module, to be built in 2024 will be single-phase.
- DUNE will also have a high precision near detector, the technology of which is still being decided.
- Rich neutrino physics program plus searches for supernovae neutrinos and nucleon decay.

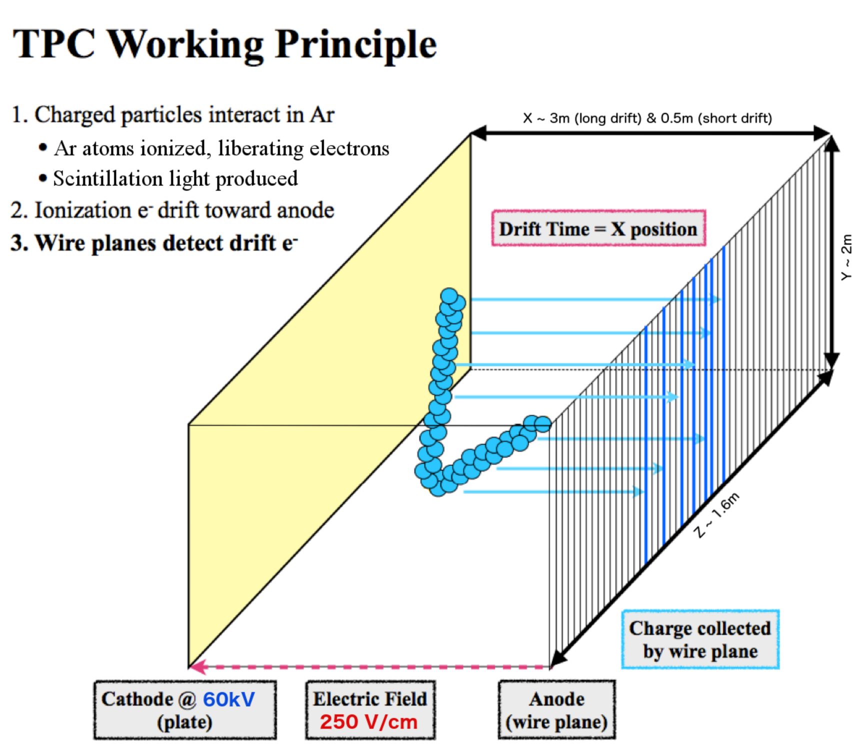

Figure 2, left.
A schematic of how a wire plane TPC works, as is planned for the single phase design. The voltages, fields and distances shown are the running values for the 35 ton.

2. The 35 ton prototype

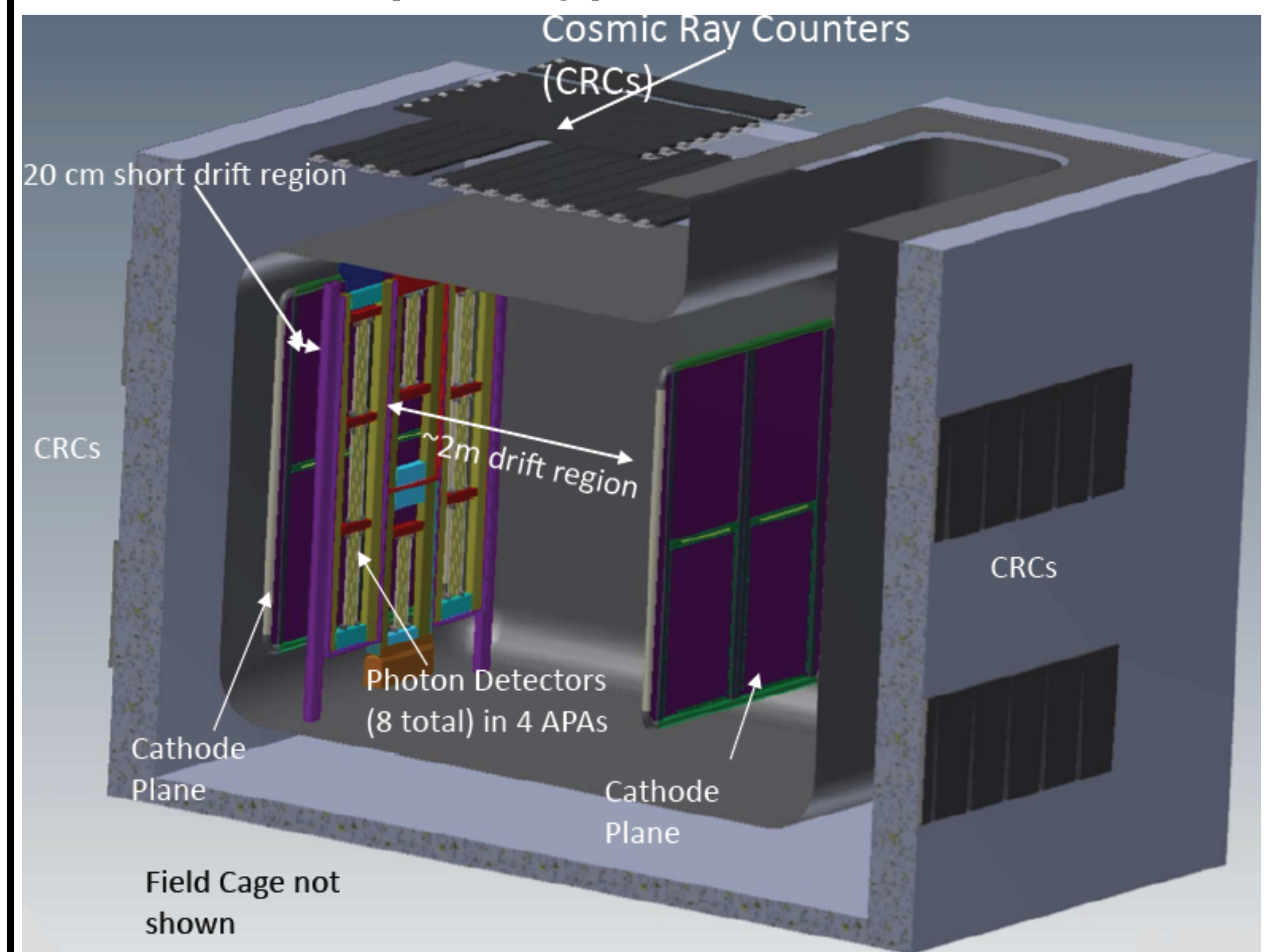

Figure 3, left.
A schematic of the 35 ton prototype, showing some of the features of the detector such as multiple drift volumes, integrated cosmic ray counters and photon detectors.

- The 35 ton, based at Fermilab is the first DUNE single phase prototype, further single and dual phase prototypes are planned at CERN.
- It has many of the design features required to build a 10 kton module;
  - Wrapped wire planes
  - Multiple drift volumes across multiple Anode Plane Assemblies (APAs)
  - Cold analog and digital electronics
  - Light-guide style photon detectors
  - FR4 printed circuit board field cage
  - Modular membrane cryostat.
- Many of these features were untested in an integrated system prior to December 2015.
- External plastic scintillator panels triggering on muons were also installed.

3. Results from phase I and motivation for phase II

- The phase I run aimed to show that a membrane cryostat can maintain high LAr purity and to benchmark cryogenic components.
  - The run from Dec. 2013 - Feb. 2014 successfully observed and maintained an electron lifetime of 3 ms, thus achieving its goal.
- A second run was required to;
  - Test the components and features which are required by the far detector.
  - Establish that an instrumented detector can hold LAr at high purity.

Figure 4, left.
The 35 ton prior to cool down during phase II.

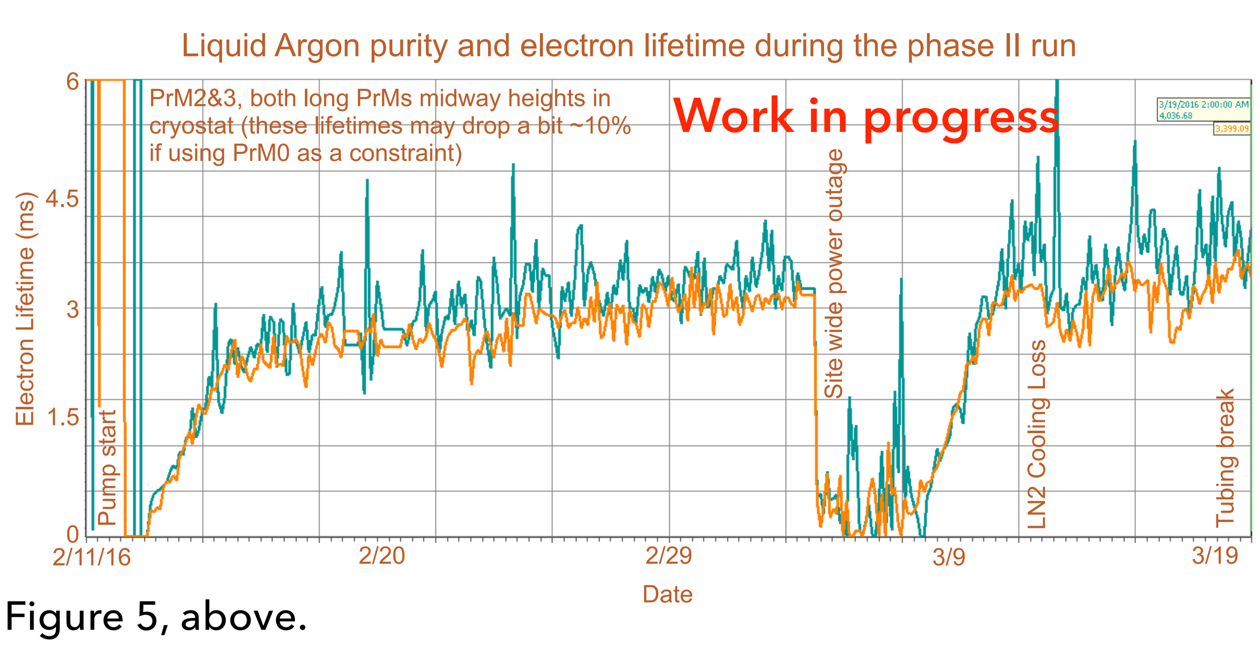

Figure 5, above.
How the purity changed during the phase II run.

4. Phase II run of the 35 ton prototype

- Run from Nov. 2015 - Mar. 2016 achieved;
  - Electron lifetime of 3 ms, showing TPC components did not reduce purity.
  - Simultaneous, triggered readout from TPC, PD and CRC data streams.
  - Reconstruction across multiple drift volumes and TPCs.
- Many analyses of the data are underway.

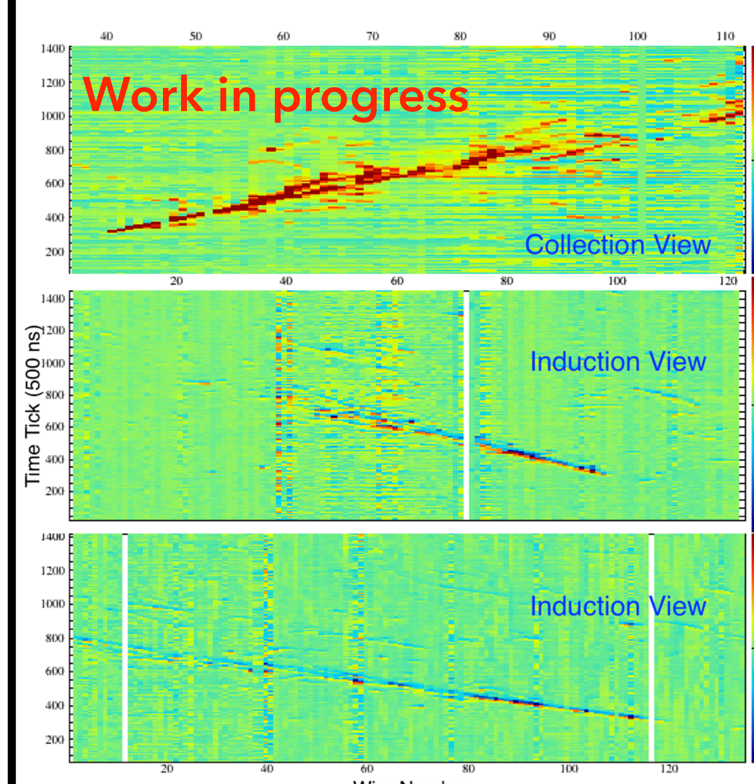

Figure 6, left.
An event display showing an electromagnetic shower.
The colour Z axis represents the charge deposited.

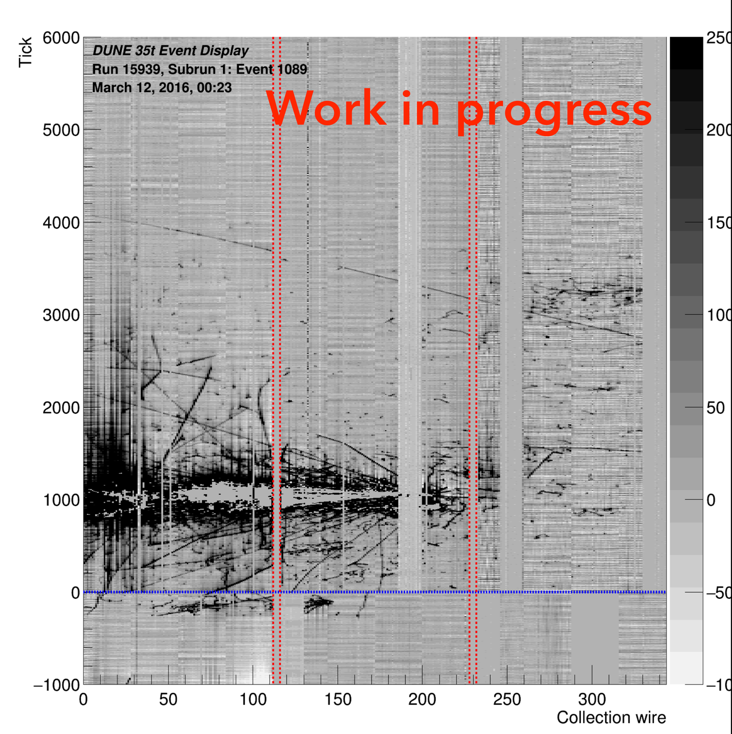

Figure 7, right.
An 'online' event display showing a large shower.

5. Diffusion analysis

- Diffusion occurs as electrons drift towards the wire planes.
- Longitudinal diffusion distributes charge in time.
- Transverse diffusion distributes charge between wires.
- Diffusion should be track angle and drift distance dependant.
  - Perform gaussian fits to the distributions of hit widths at fixed drift distances and track angles.
  - Fit the mean values of the gaussian fits for a given track angle to a line.
- Only collection plane wires are used and ∂ rays are excluded.
- After combining individual plots a dependence on distance and track angle (θ_{XZ}) is seen.
  - X increases with drift distance, Z increases parallel to APAs.

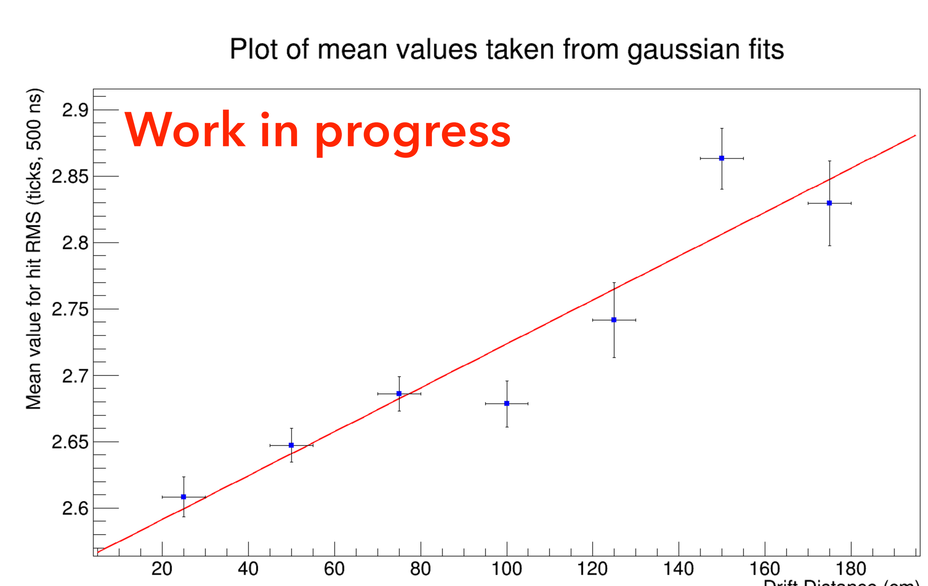

Figure 8, above.
How the peaks of the gaussian distributions for hit widths for tracks with a θ_{XZ} of ~16˚ changes for a range of drift distances.

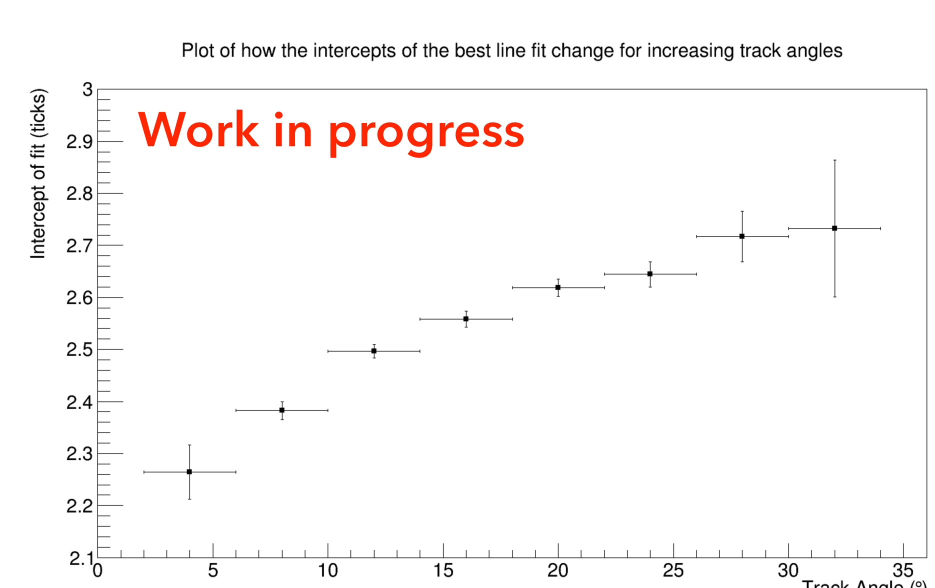

Figure 9, above.
How the intercept of the best fit line of the gaussian hit width distributions against drift distance changes for a range of track angles.