

The design goals of the DUNE 35-ton Liquid Argon prototype and the first results from operation

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1. DUNE and the 35 ton prototype

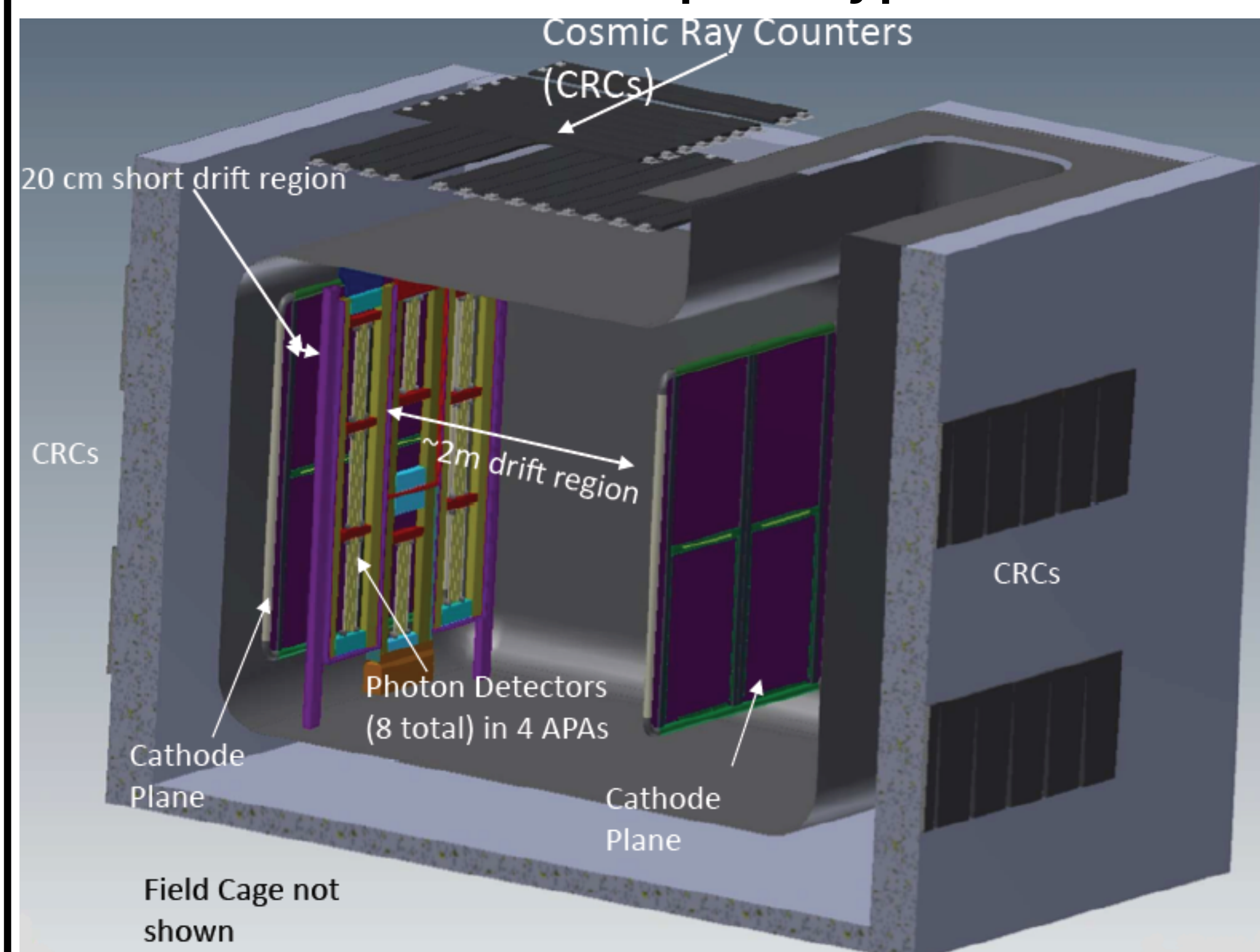


Figure 1, left. A schematic of the 35 ton prototype, showing some of the features of the detector such as multiple drift volumes, integrated cosmic ray counters and photon detectors.

- DUNE (Deep Underground Neutrino Experiment) is a next-generation neutrino experiment which will aim to measure δ_{CP} , θ_{13} , θ_{23} and determine the neutrino mass hierarchy in addition to looking for nucleon decay and supernova neutrinos. It will have four 10 kton modules, each representing a 300 fold increase in size of existing Liquid Argon Time Projection Chamber (LArTPC) experiments. A significant prototyping effort is required.
- The 35 ton, based at Fermilab is the first DUNE single phase prototype. Further prototypes are planned at CERN.
- It has many of the design features of one of the 10 kton modules;
 - 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.



Figure 2, above. The 35 ton prior to cool down during phase II.

2. Results from the phase I and phase II runs

- The phase I run aimed to show that a membrane cryostat could maintain high LAr purity and to benchmark cryogenic components.
 - The run from Dec. 2013 - Feb. 2014 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.
- 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 including:
 - Associating flashes from photon detectors to CRC coincidences.
 - Measuring the effect of gaps on reconstruction
 - Measuring an interaction time from muons which cross APAs
 - Determination of the LAr purity using reconstructed tracks in the TPC.

Figure 3, right. How the purity changed during the phase II run. Note how quickly purity was both lost, and recovered after the site wide power outage.

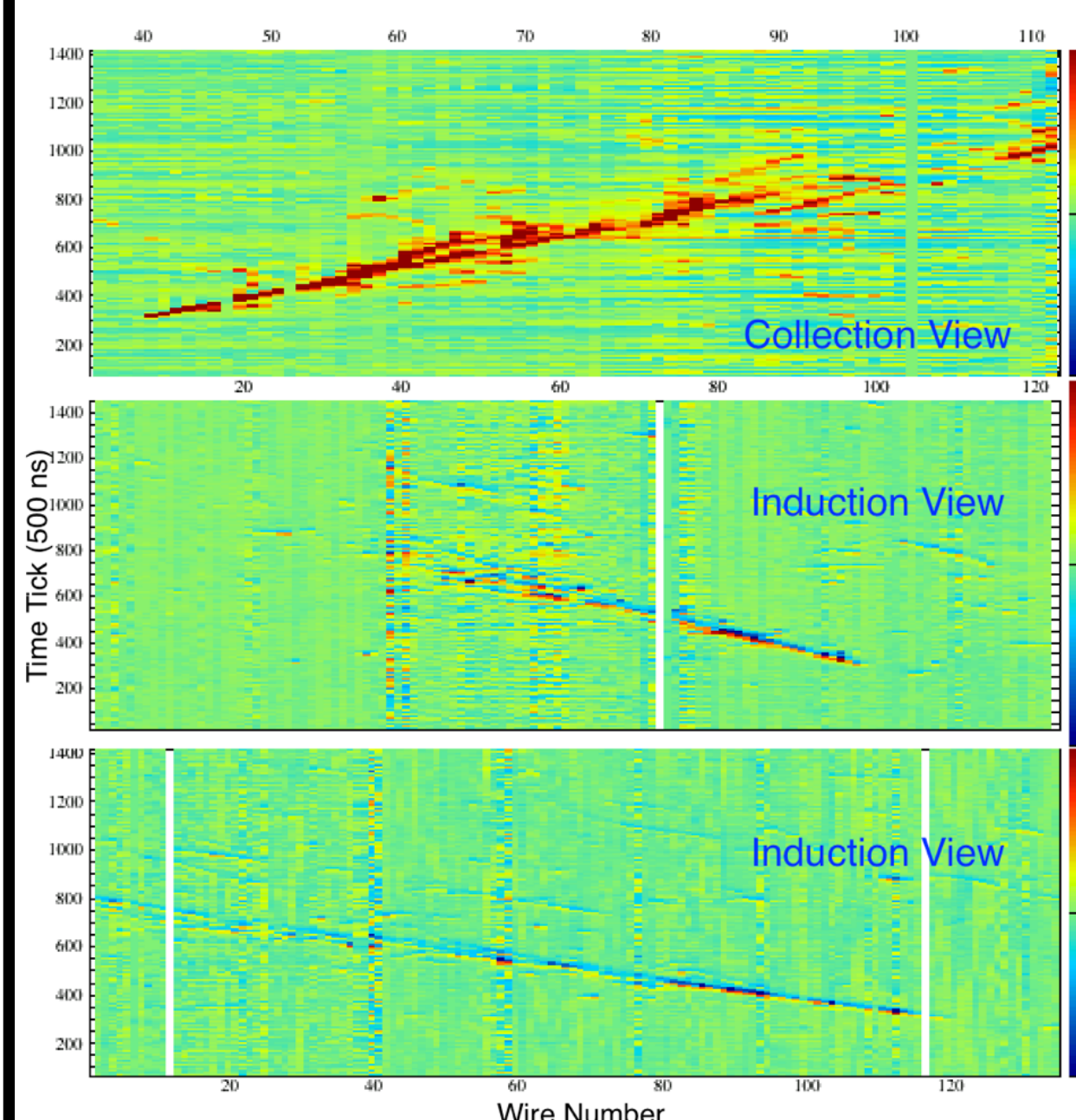
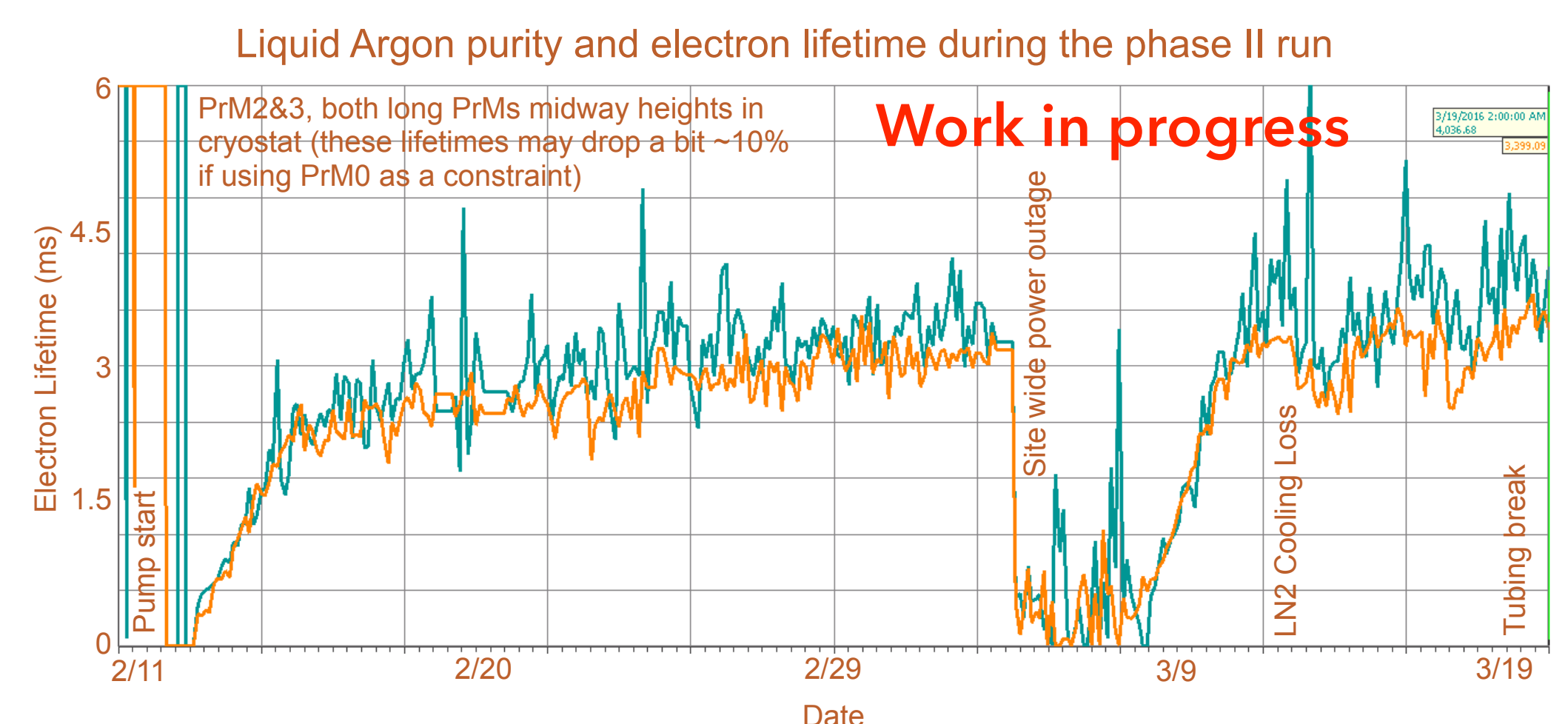


Figure 4, left. An event display showing an electromagnetic shower. The colour Z axis represents the charge deposited.

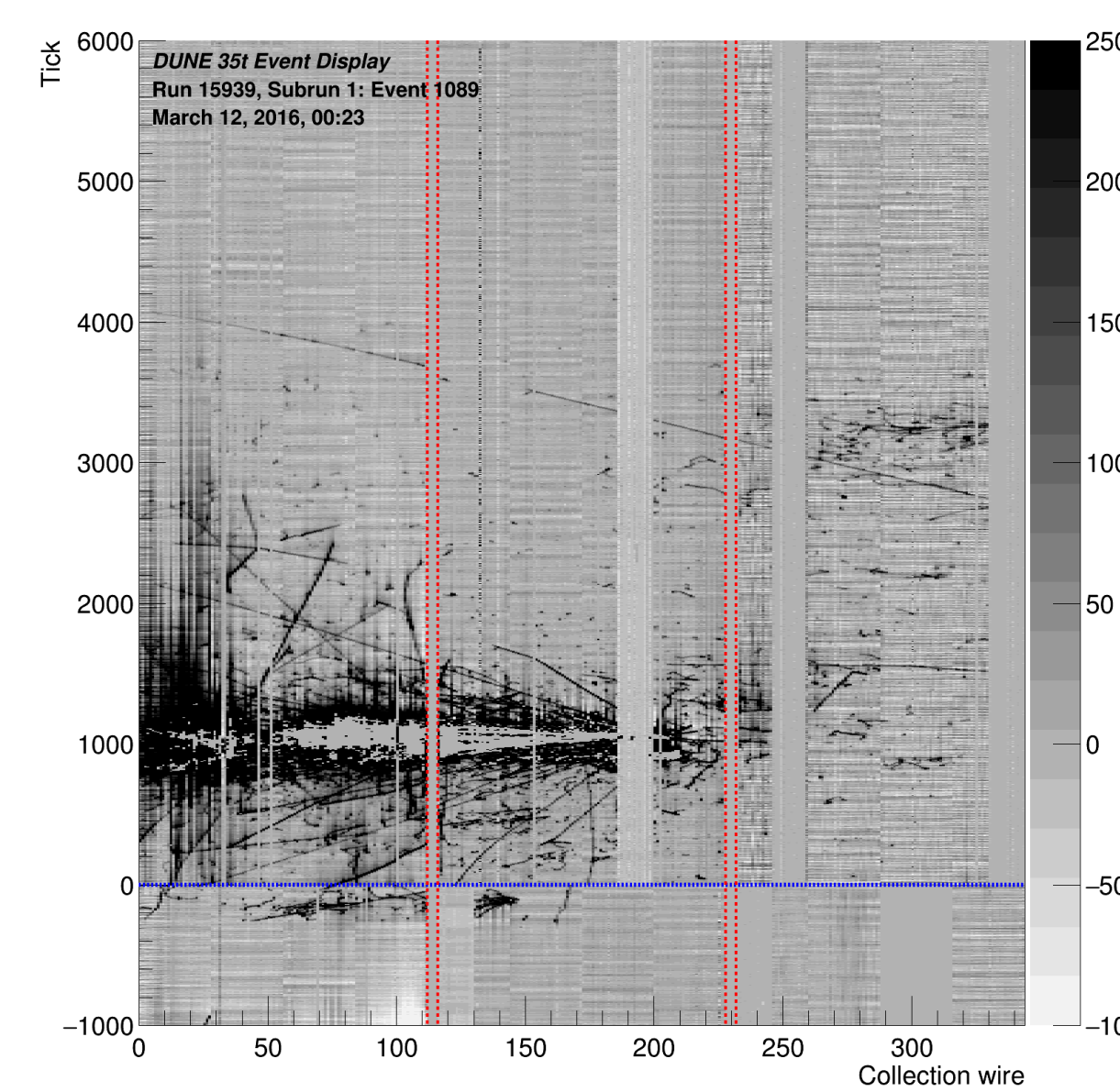


Figure 5, right. An 'online' event display showing a large shower.

3. Diffusion analysis

- Diffusion occurs as electrons drift towards the wire planes.
- Longitudinal diffusion changes the hit width on the wire.
- Transverse diffusion distributes charge between wires.
- Diffusion should be track angle and drift distance dependant.
- For this study the following steps are performed:
 - Only hits which are reconstructed into 3D tracks are used.
 - Only tracks which are aligned to a counter co-incidence are used, i.e. they have a known track angle.
 - Only hits on collection plane wires in the long drift volume, with no hits near (40 ticks either side) and less than 10 hits on the wire within 3 drift windows are used. This removes delta rays and wires with high noise.
 - Hits passing cuts are corrected in X using the time of the counter co-incidence.
 - Gaussian fits to the distributions of hit widths at fixed drift distances and track angles are performed, figure 6.
 - The mean values of the gaussian fits for a given track angle are fitted to a line, figure 7.
- After combining individual plots a dependence on distance and track angle (θ_{XZ}) is seen, figures 8 and 9.
 - X increases with drift distance, with 0 at the long drift APA.
 - Z increases parallel to APAs, with 0 at the left most APA.
 - It is observed that there are few tracks with large angles due to low acceptance.

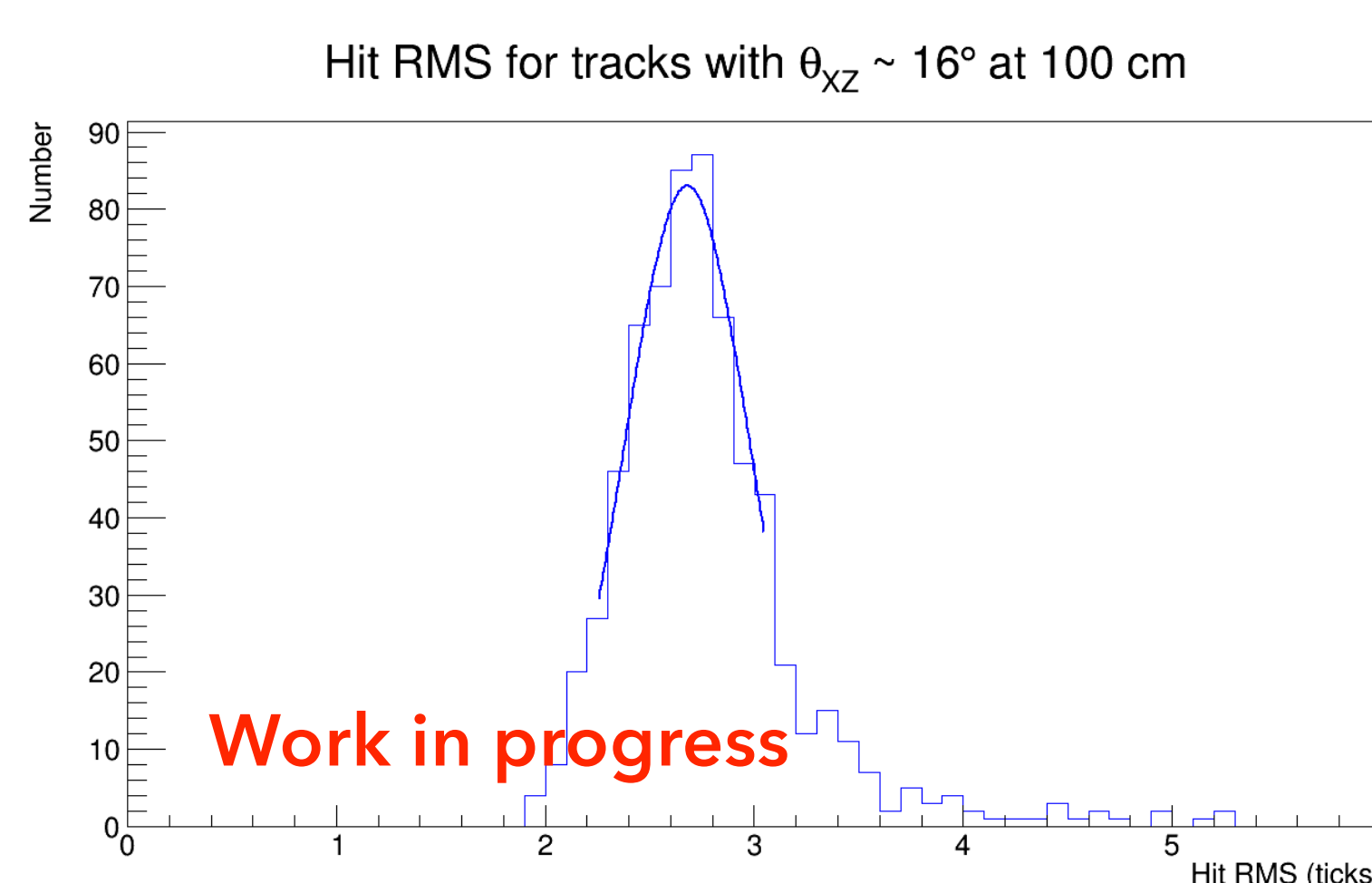


Figure 6, above. A gaussian fit around the peak of the hit widths for tracks with a θ_{XZ} of $\sim 16^\circ$ with a drift distance of 100 cm.

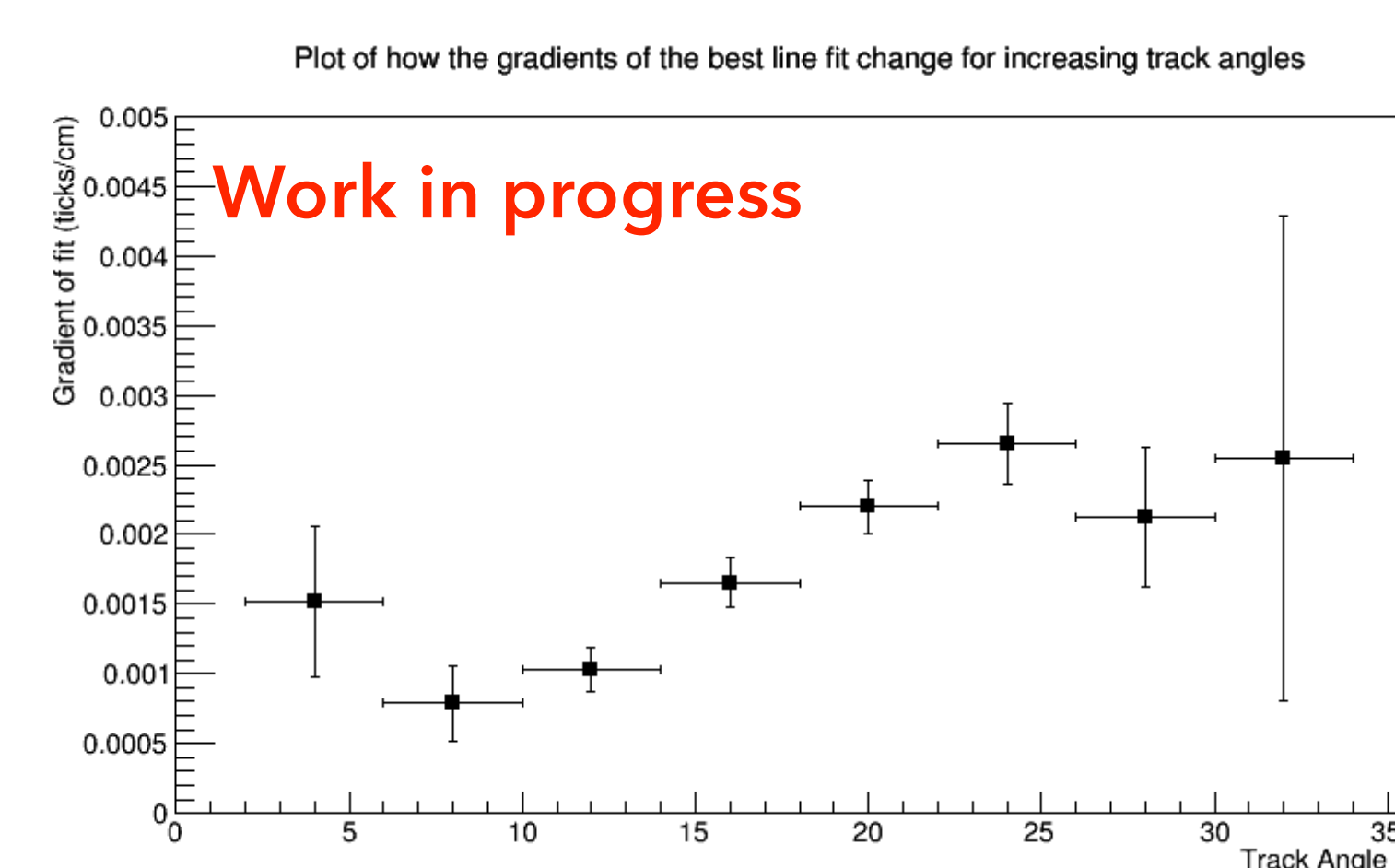


Figure 8, above. How the gradients of the best fit lines of the gaussian hit width distributions against drift distance change for a range of track angles.

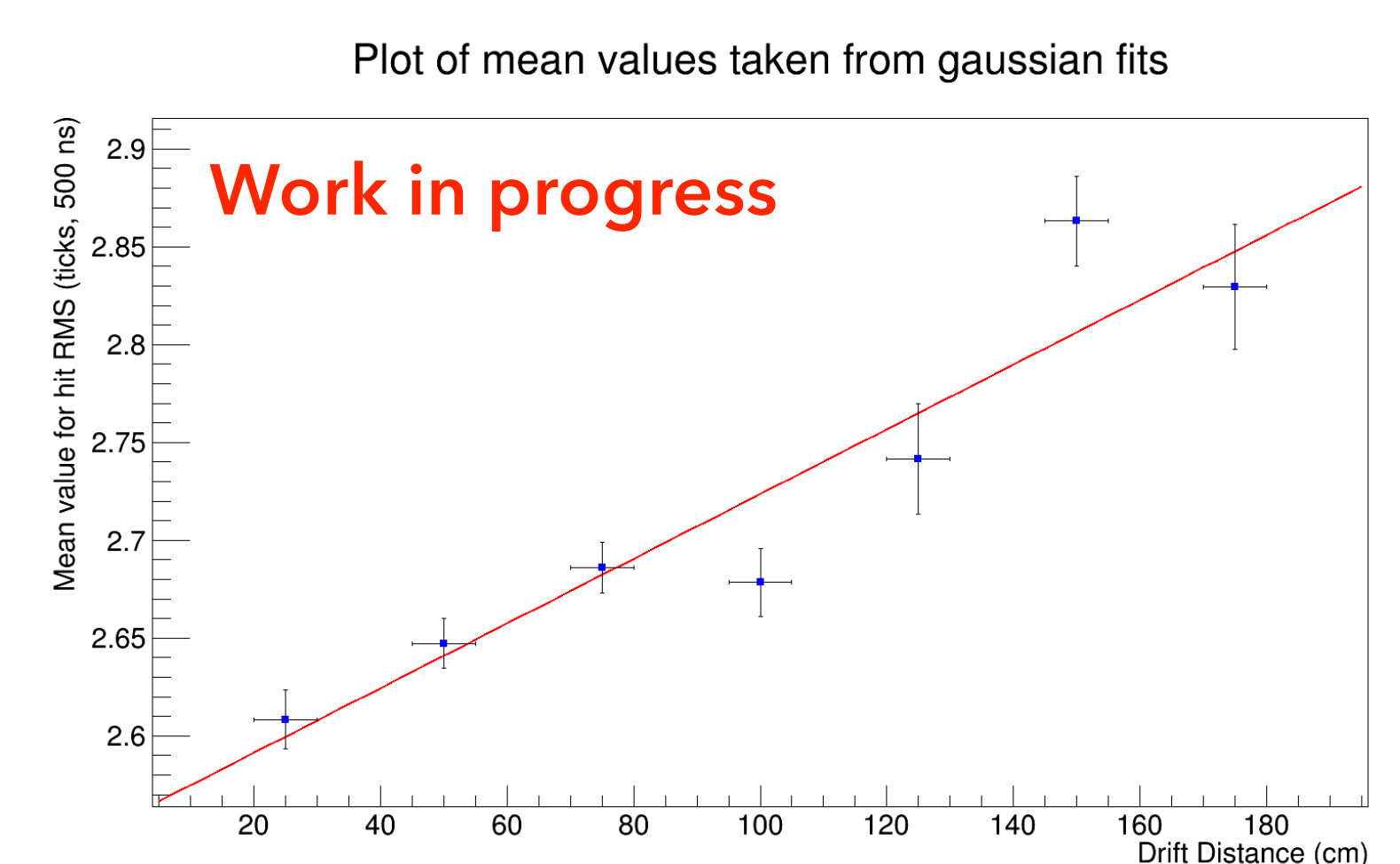


Figure 7, above. How the peaks of the gaussian distributions for hit widths for tracks with a θ_{XZ} of $\sim 16^\circ$ changes for a range of drift distances.

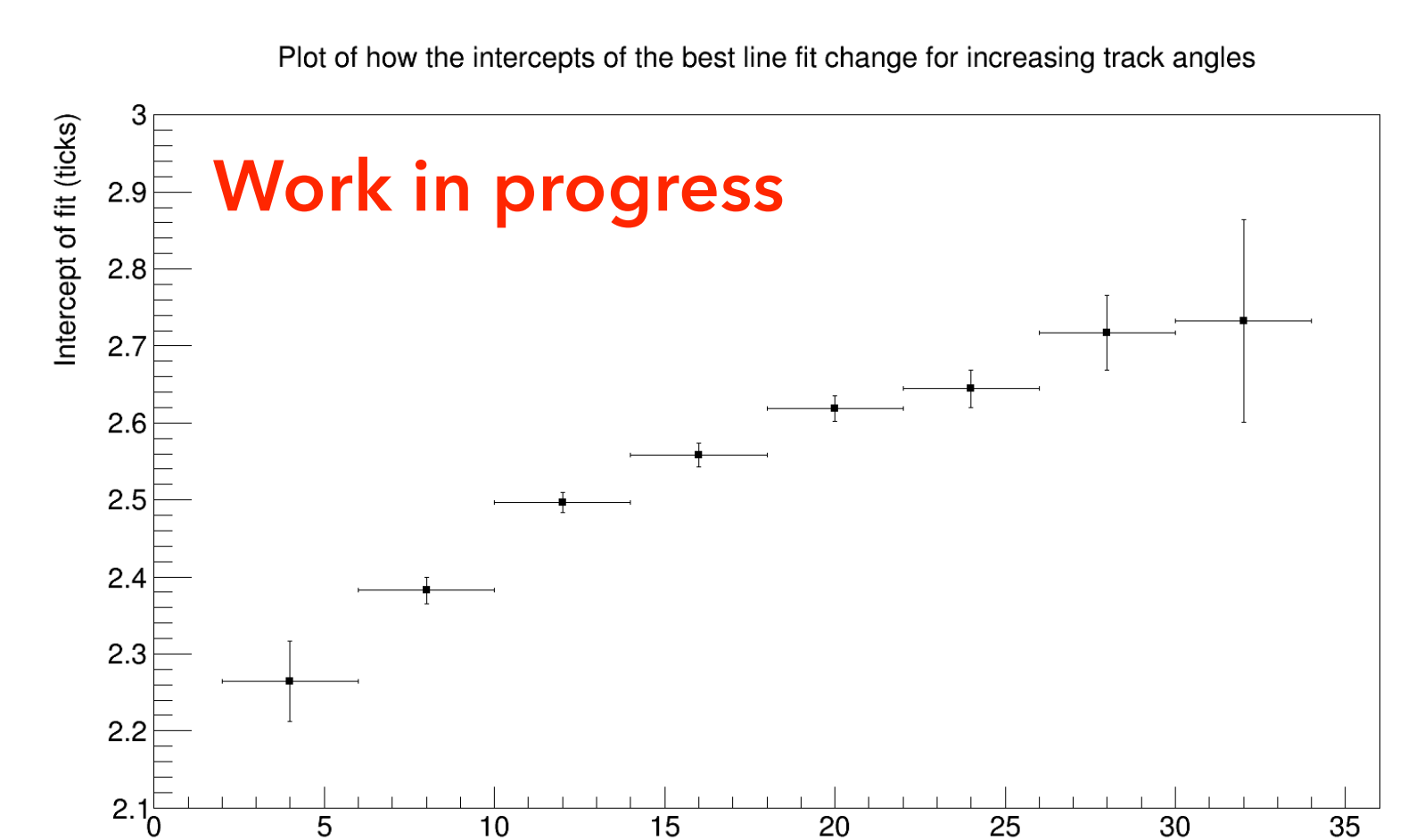


Figure 9, above. How the intercepts of the best fit lines of the gaussian hit width distributions against drift distance change for a range of track angles.