Acceptance Testing Plans for the ProtoDUNE Anode Plane Assembly

Jonathan Asaadi
protoDUNE APA Review
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Requirements and Testing

- **This presentation is meant to help provide an overview of the various acceptance testing that will be performed during the construction of the protoDUNE Anode Plane Assembly (APA)**

- **The requirements on the APA's construction and design are motivated to ensure protoDUNE can meet its physics goals**

- **Where possible we draw upon experience from other LArTPC's**
  - E.g. MicroBooNE, 35ton, LArIAT, etc...

Overview of APA Tests

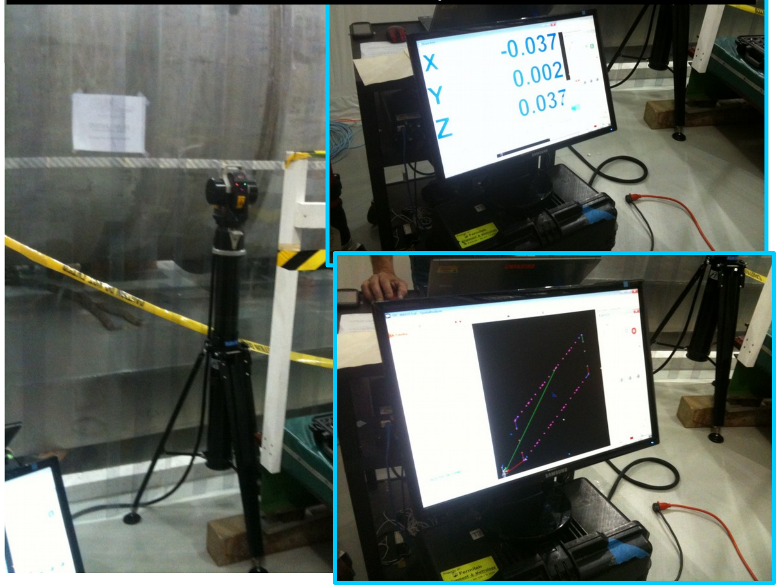
Test	Requirement	Testing Technique
APA Dimensions and Planarity	Various (See subsequent slides)	Metrology Survey during construction
Wire Tension	5 Newtons +/- 1 Newton per wire	Laser-PhotoDiode Tension Measurement
Wire Position	Design Location per wire +/- 500 µm	Made using Cognex Camera on winding machine
Wire Electrical Continuity	< 500 Ω resistance per channel	Resistance measured between top and bottom of the wire
Wire Electrical Isolation	> 10 MΩ between adjacent channels	Resistance between adjacent channels where they will mate with the cold electronics
Wire Plane Bias	>100 % nominal voltage	
Cryogenic Performance	Various (See subsequent slides)	Cool with N_2 gas to verify APA function

APA Planarity and Dimensions

- **The dimensions of the APA are a basis of the total active volume as well as determine how well other components mate (wires/Field Cage/ etc)**
- **The planarity of the APA determines the wire plane-to-plane position as well as sets the precision for position reconstruction within the TPC**
  - Measuring the plane-to-plane wire spacing across the APA post construction is difficult (impossible) making the planarity even more important
- **The goal is to have any spatial distortions in the frame to have less impact then that due to diffusion / space charge**

protoDUNE APA at PSL

Metrology at µBooNE



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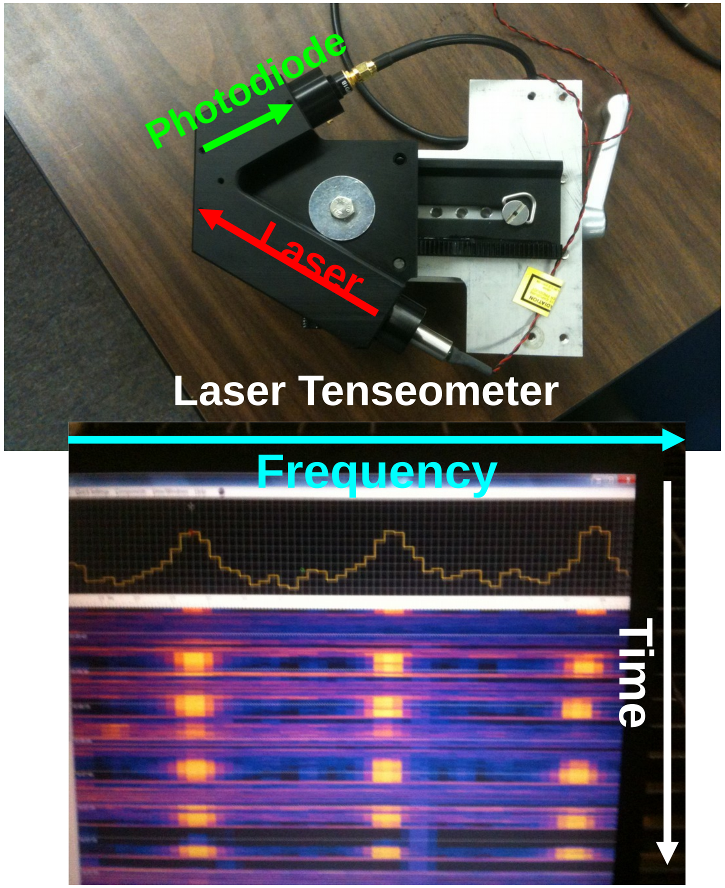
APA Requirement

Requirement	Value	Notes	Verification Scheme
APA Planarity	5 mm	Frame flatness tolerance. Mechanically achievable.	Measure during construction.
APA planarity error	500 microns	uncertanty in the frame flatness measurement	Test at PSL. Recheck at CERN
Wire plane-to-plane position tolerance	500 microns	Frame distortions shift the wire positions. This is the max devistion of the relative wire postions.	Impact of wire mis-alignemnts on fields are simulated. The impact on HV to preserve charge transparency are determined.
Wire position tolerance	500 microns	The wire position accuracy is determined by the guide placement precision and wire sag variation. Measured relitive to the frame.	Test at PSL. Recheck 10% at CERN pre-ProtoDUNE installation.
Wire guide positioning uncertainty	100 microns	Edge board placement and fabricaiton tolerance. Measured with a flat frame.	Measure during construction. Provides the start of calibration.
APA Frame Bow / Twist	5 mm	Contribution to the APA flatness	Measure during construction. Provides the start of calibration.
APA fiducial mark location	5 mm	Must be able to locate x,y,z at all fiducial marks	Survey at CERN

Wire Tension

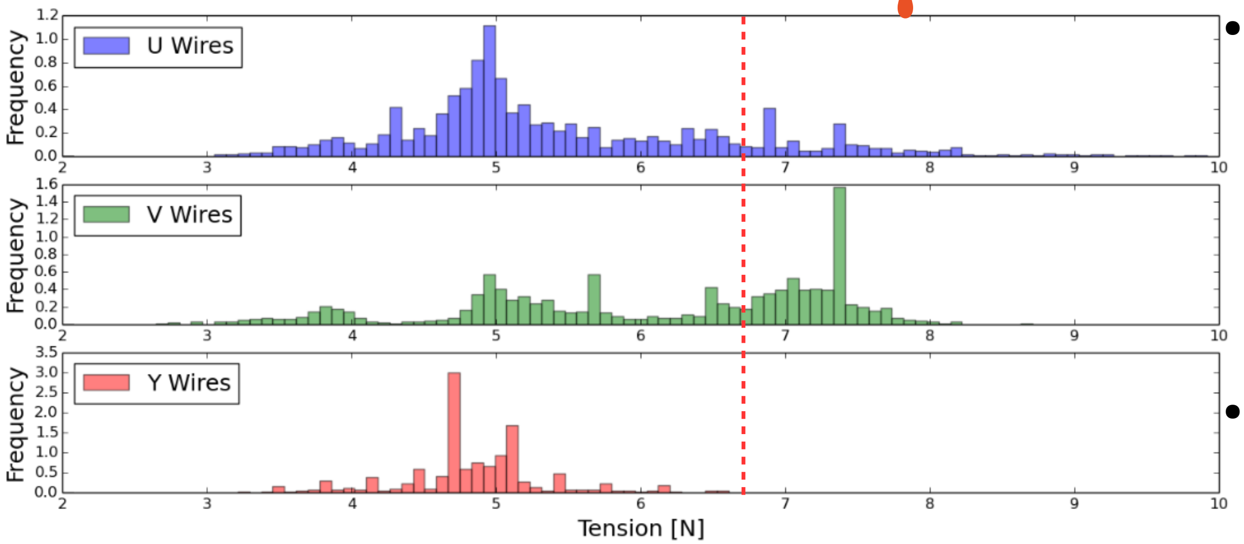
- **Wire tension is a critical parameter for the successful operation of the TPC**
- **The wire tension will be measured and stored using a laser/photodiode system developed at PSL**
  - Similar device was used on MicroBooNE, LArIAT, 35 ton
  - With the existing equipment the wire tension of the APA can be measured in a matter of a few weeks
  - Methods to mount the tense-o-meter to the winding head and further automating the process are currently under design



$$f = \frac{1}{2L}\sqrt{\frac{T}{\rho}}$$

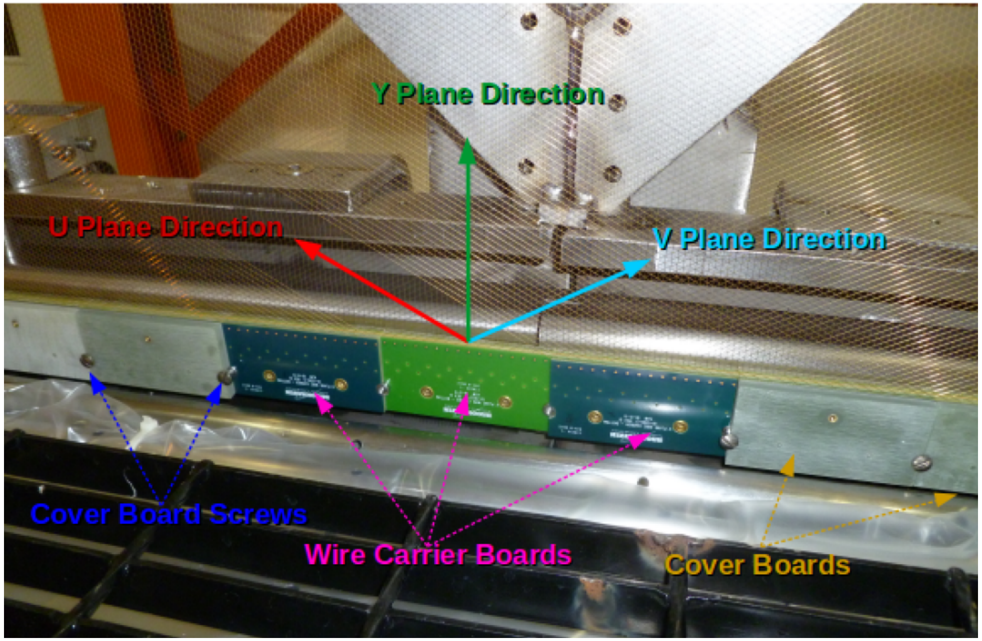
L = Length of the wire
T = Tension of the wire
ρ = density of the wire

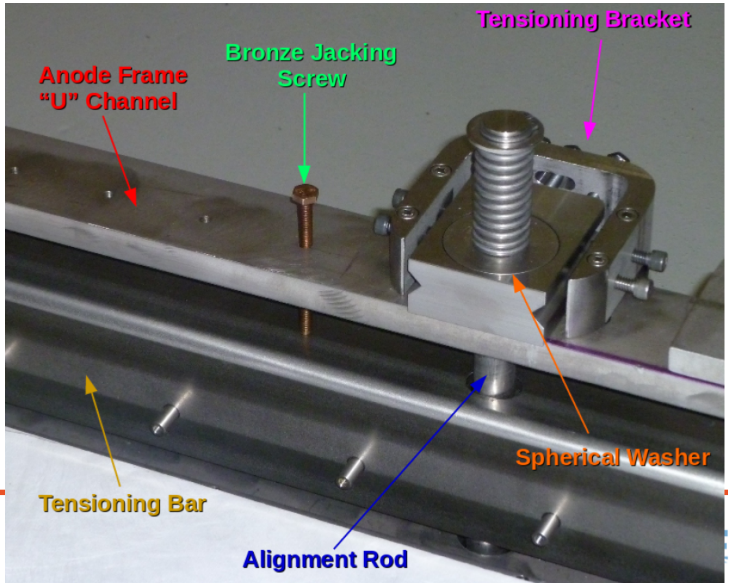
Wire Tension in μBooNE



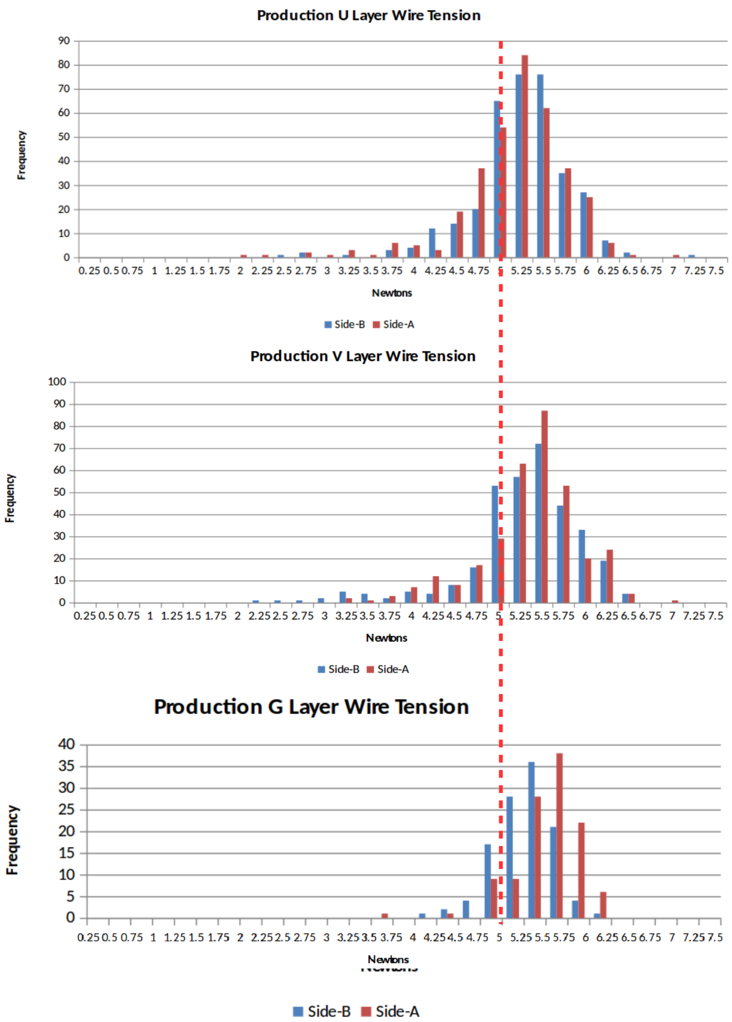
- Given MicroBooNE's anode frame layout and restrictions on tension movements, many wires were left under-tensioned

- Average U/V/Y Tension (Nominal 0.7 kg = 6.86 N)
  - 0.589 +/- 0.012 kg
  - 0.664 +/- 0.014 kg
  - 0.525 +/- 0.009 kg



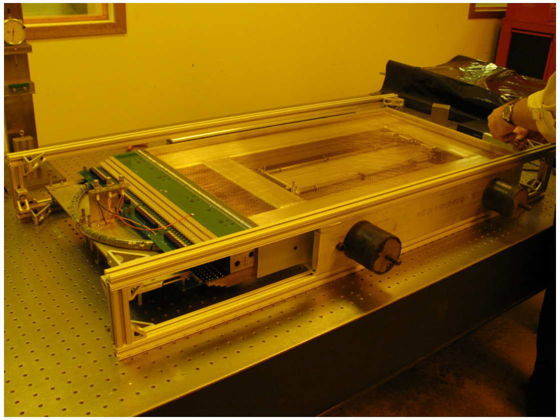


Wire Tension in 35ton

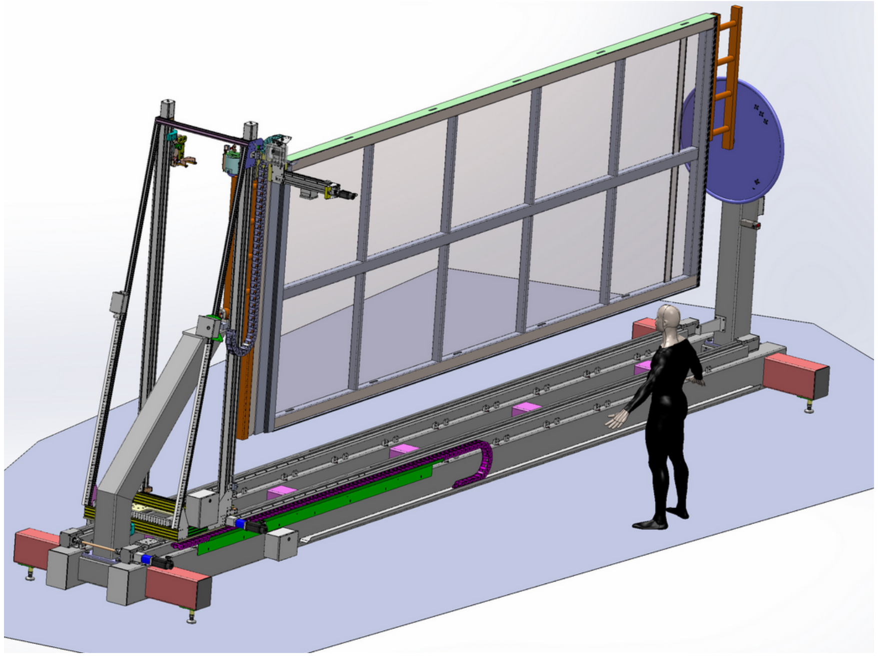


- 35tons tensions measured at production time at PSL and was able to achieve very good wire tension distributions with a target tension of 5 Newtons
  - 35ton were able to identify low tension wires and replace them during production

- Average U/V/G Tension (Nominal 5.0 N)
  - 5.20 +/- 0.62 N
  - 5.26 +/- 0.57 N
  - 5.27 +/- 0.37 N



Wire Tension and Position



Essential to have this data in a format readable and accessible to the collaboration for use in calibration and detector performance studies

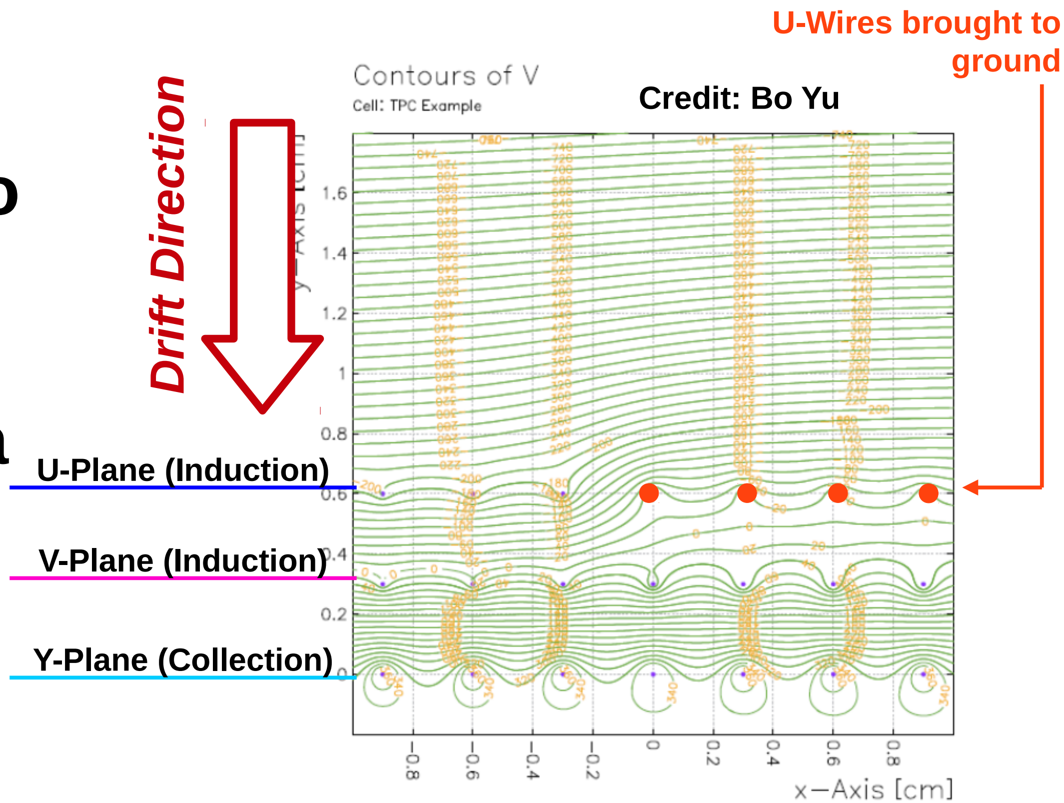
- **After each wire plane is wound onto the frame a tension and position measurement will be performed**
  - The winder auto-locating the position of the wire pins will use a Cognex Camera on the winder head to record the position measurement
- **If any wire is found to be out of tolerance (position or tension) the wire is removed and when possible replaced**

Wire Tension Requirement

Requirement	Value	Notes	Verification Scheme
Wire Tension	5 +/- 1 N (0.51 +/- 0.10 kg)	Value for each wire during construction	Laser/Photodiode measurement at construction. Remeasure 10% of wires upon arrival at CERN
Wire Position	Design location +/- 500 μm	Position set relative to APA fiducial	Auto-located position using the winding machine

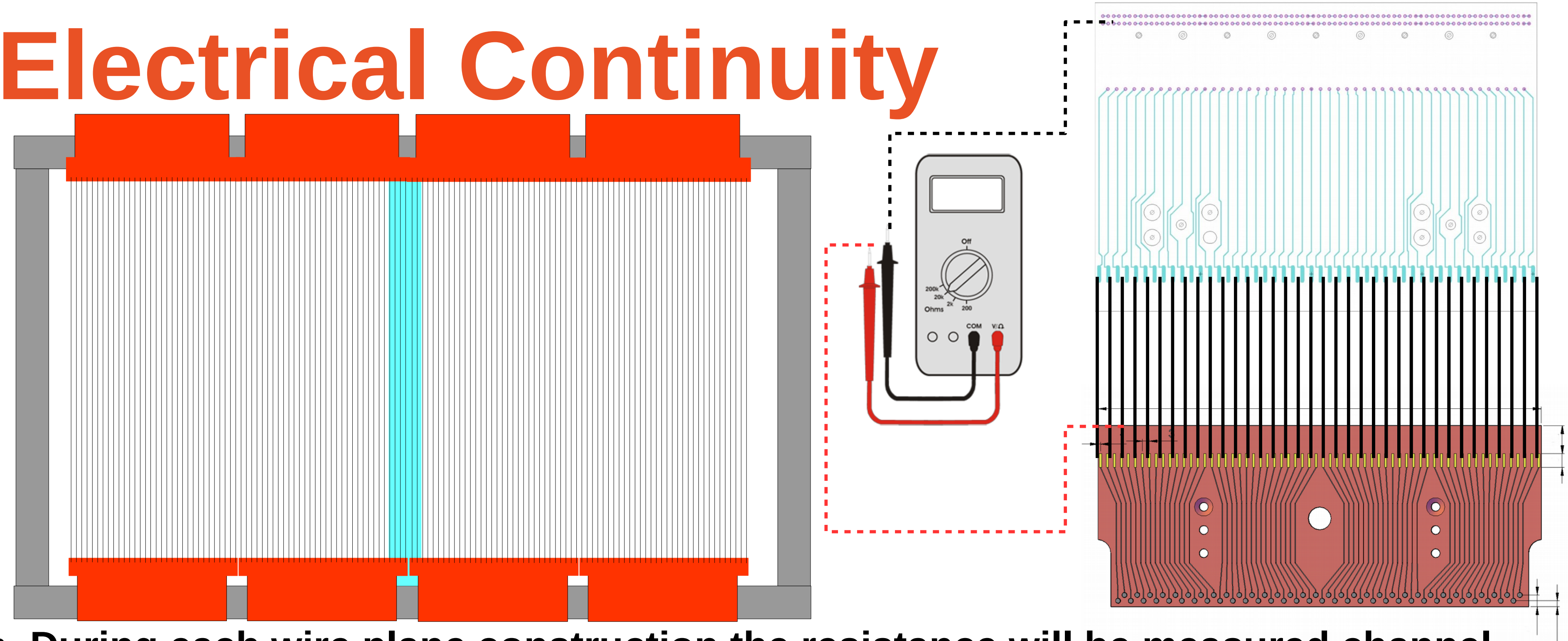
Electrical Continuity and Isolation

- Verification that every wire has good electrical connection to the readout pins used by the cold electronics is essential to ensure a minimum number of non-reachable channels
- Electrical isolation of each wire prevents field distortions and unexpected noise in the TPC



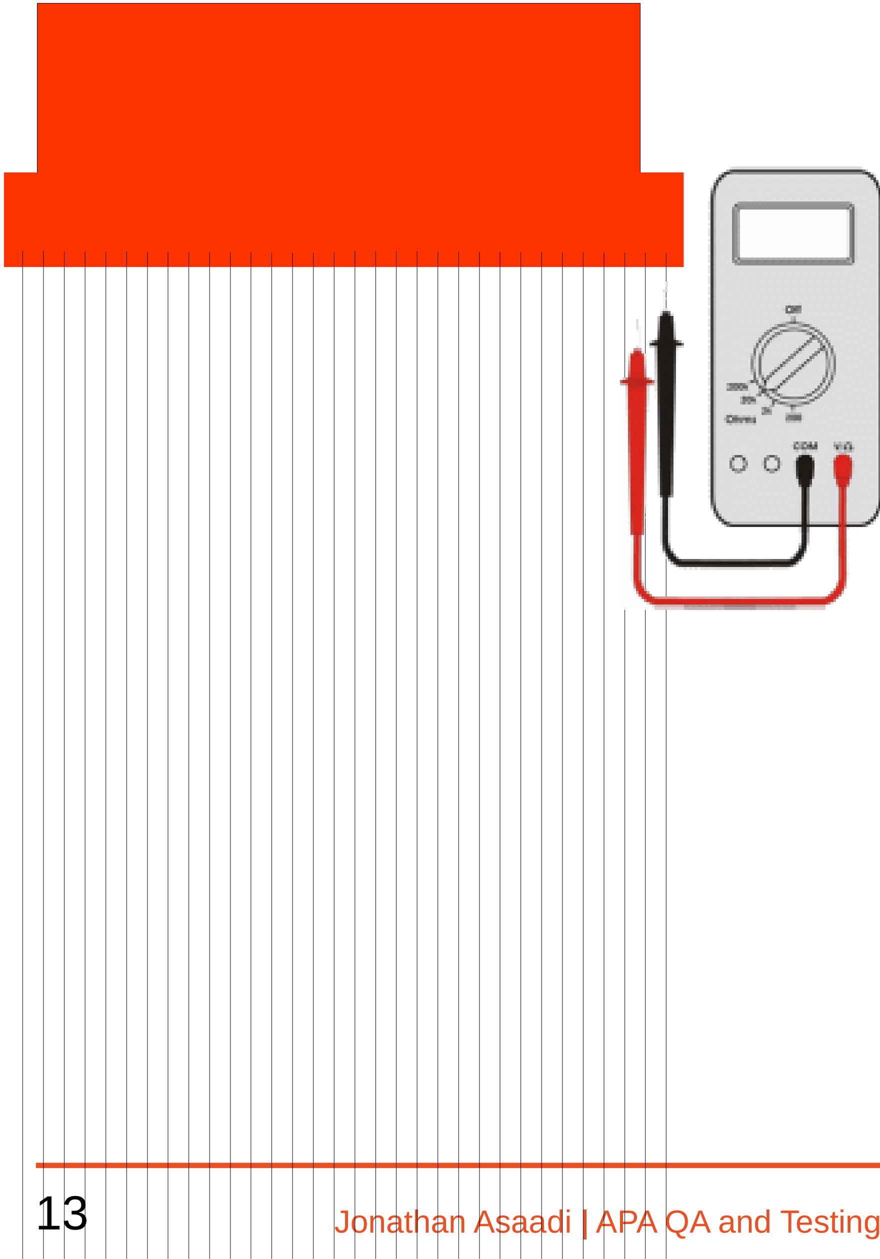
Simulation of the distortion of the field when wires induction wires are unexpectedly grounded

Electrical Continuity



- **During each wire plane construction the resistance will be measured channel by channel to ensure no cold solder joints or broken wires which are still held in place by epoxy**
- **This measurement can be done by probing the “bottom” of the wire (the end not read out) and the pin the cold motherboard will mount to**
  - Similar tests were performed for previously for MicroBooNE and give a time estimate of the order of days to complete for all wires
- **Any wire failing this test will be fixed/removed and replaced if possible**
  - BeCu wire has a resistance of ~4.4 Ohms/meter
  - Longest wire is 7.3 m (resistance ~32 Ohms)

Electrical Isolation



- **During each wire plane construction the resistance between adjacent channels using a multimeter**
- **This test looks for “touching” wires and electrical shorts between neighboring boards**
  - The wire bias test will be used to look for plane-to-plane electrical shorts
- **Any channel failing this test will be fixed/removed and replaced if possible**

Electrical Continuity and Isolation

Requirement	Value	Notes	Verification Scheme
Continuity	< 500 Ω resistance per channel	Test done on cold electronic readout pins prior to electronic installation	Measured using a multimeter (or similar device) channel by channel
Isolation	> 10 MΩ between adjacent channels	Test done during each wire plane construction	Using multimeter (or similar device) and can be done in tandem with the continuity test

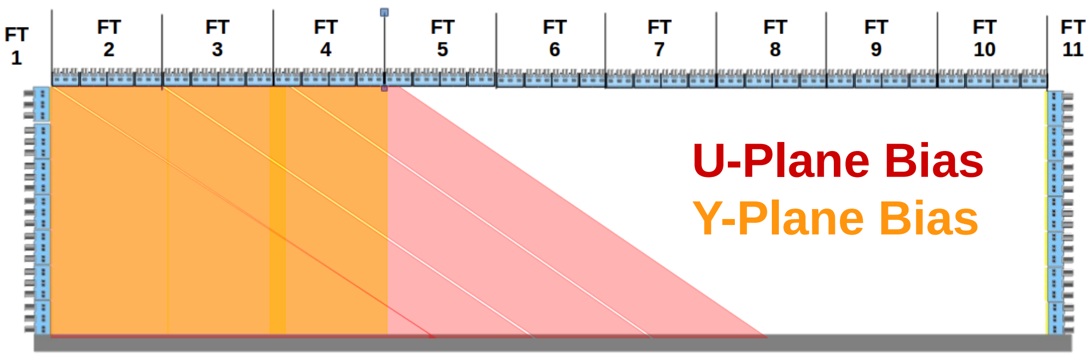
Working to establish the time required for this procedure and the scope of this test that will be repeated at CERN

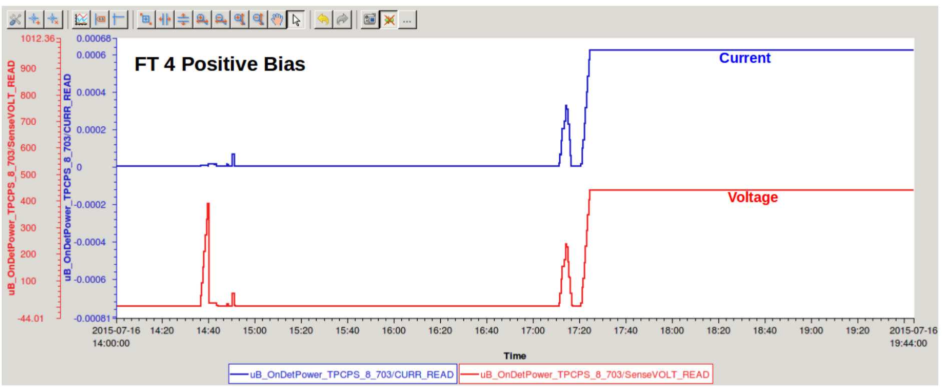
Wire Bias Test

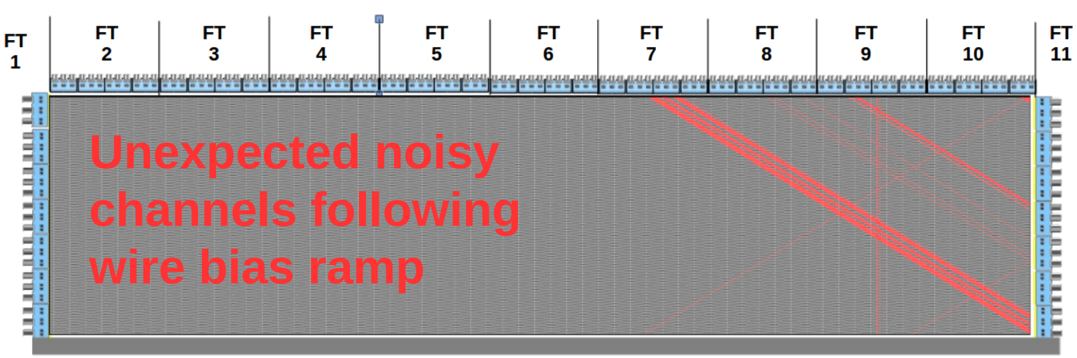
- **All CR boards will be tested in air prior to installation on the APA**
  - The test will ensure they can hold >100% of nominal wire plane bias without unexpected current draw
    - Grid Plane Nominal Voltage: -665 V
    - Induction Plane Nominal Voltage: -370 V
- **After all wire planes are installed on the APA, the bias voltage will be applied in incremental steps (10 V/step) to monitor for unexpected current draw**
  - The planes will be brought to nominal voltage
  - If > 1mA of current draw is observed, the electrical short will be investigated and remediation should be explored (e.g. channel removal)

Wire Bias Test Experience

** image for illustration purposed only*

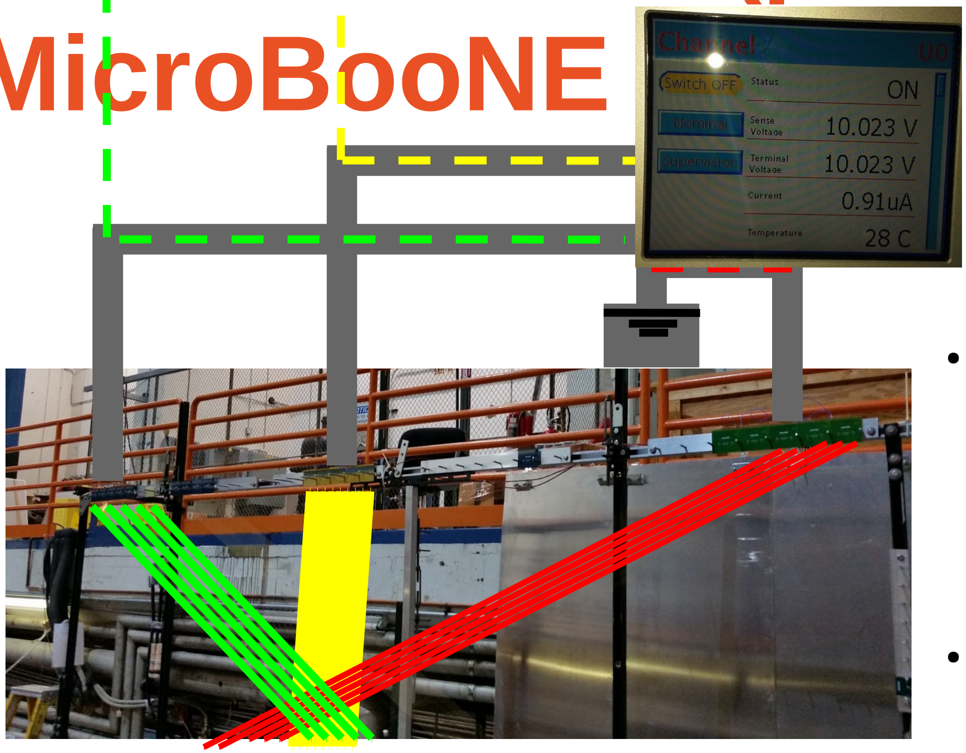


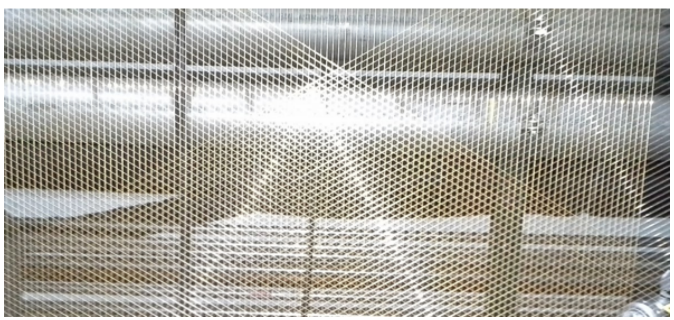




- Prior to installation into the cryostat, the MicroBooNE wire bias was not applied
- Following installation, unexpected current draws were observed in a number of feedthroughs with previously unobserved noisy channels manifesting themselves

Wire Bias Test (post-installation) at MicroBooNE





A mock-up of the MicroBooNE APA was built in the D0 assembly pit to investigate the effects of wire bias when wires were under tension

- Safe operation was approved by FNAL safety after necessary precautions were put in place

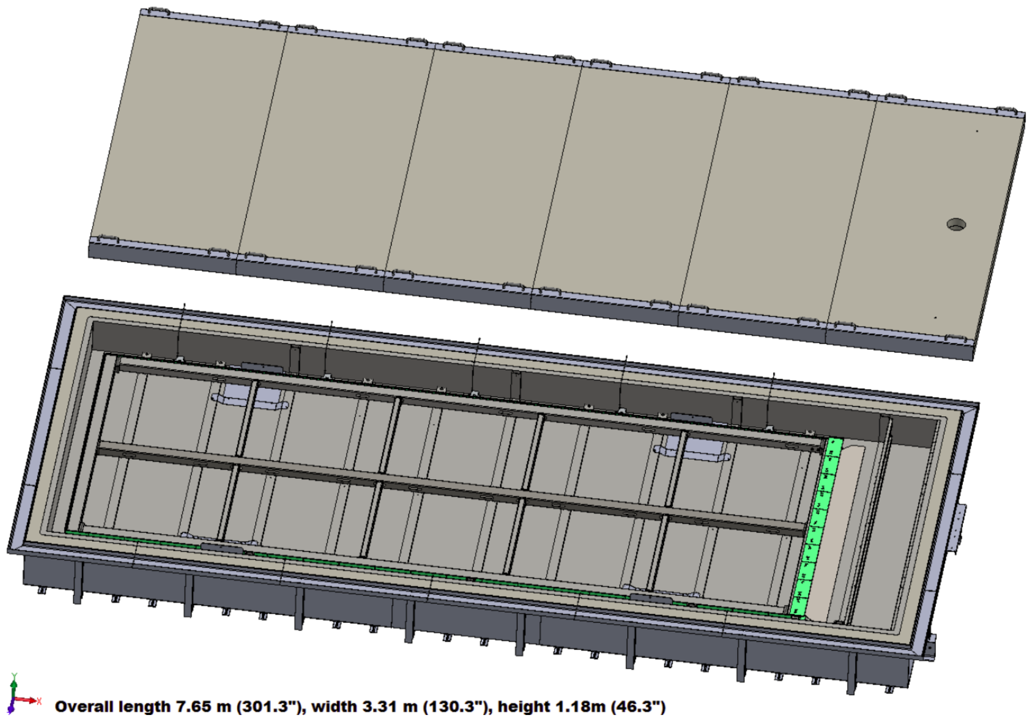
- **The wires were brought to their nominal potential in air using spare Weiner Power Supply**
  - Collection Plane +440 V
  - Induction Plane -210 V
- **Electrical shorts could be observed using the current meter on the power supply**
  - The number of effected channels could even be calculated using simple ohms law calculation
  - Remote visual inspection was done via a camera stationed in front of the wires
- **Similar test can be done at APA production sites if the necessary power-supplies and bias voltage connectors are supplied**

Wire Bias Test

Requirement	Value	Notes	Verification Scheme
Maximum Bias	> 100% of the nominal voltage per plane	Ensure can do a full drift voltage range scan	Voltage and current outputs from the power supply
Current Draw	< 1 μA current	Test done during each wire plane construction	Done at nominal voltage for the wire planes when fully assembled

Cryogenic Performance

- Ideally, testing in LAr/LN_2 would be done, however given the technical and time constraints a gas test will be performed instead
- This test verifies there were no manufacturing issues during the APA construction following exposure to cryogenic temperature



Overall length 7.65 m (301.3"), width 3.31 m (130.3"), height 1.18m (46.3")

Cryogenic Performance

Requirement	Value	Notes	Verification Scheme
Electrical Continuity after cryocycle	Any failures will be investigated and the test will be repeated	This tests for a break between the epoxy and the solder pad that might not be visually apparent	Done using multimeter following the full APA construction (may not be possible to measure center plane)
Broken Wires after cryocycle	Any failures will be investigated and the test will be repeated	This is looking for wires which are visually slack or disconnected	Visual inspection following cryocycle

The location and nature of any failures after the cryotest will strongly determine the next course of action.

For example, if a wire breaks electrical continuity, but does not appear to have become mechanically loose, the channel may be left alone

Wires which become mechanically loose should be removed, but the APA assembly may still be fine to use

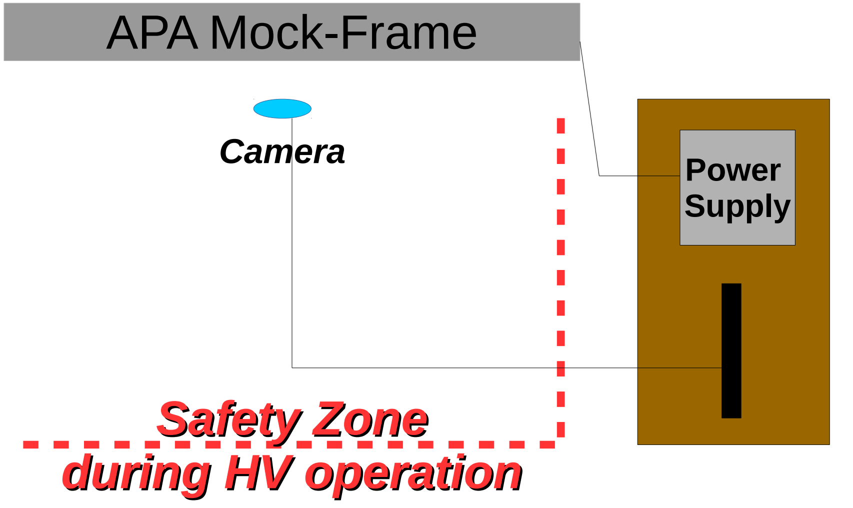
Review Charge

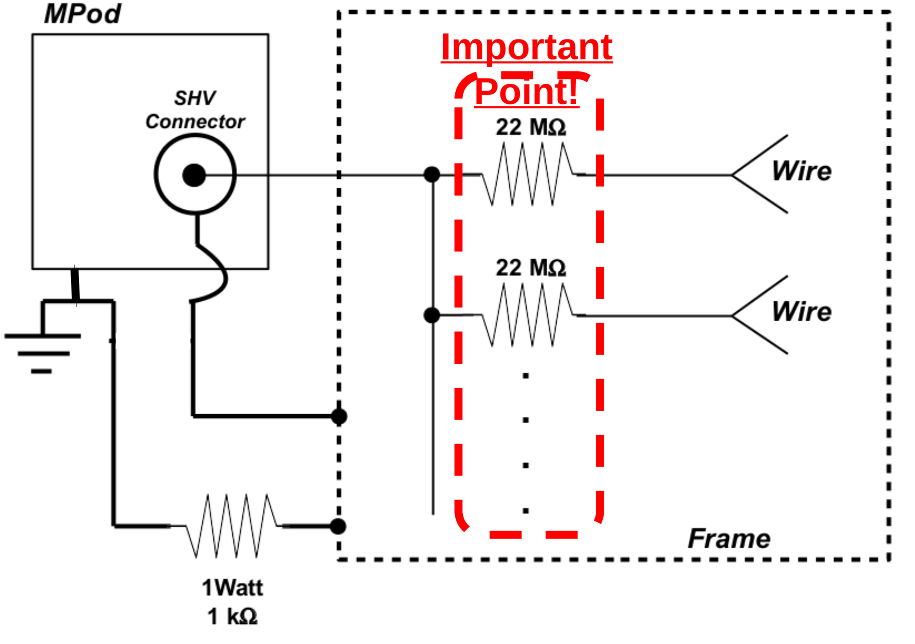
- **10) Does the APA quality assurance plane include applicable and sufficient features of internationally recognized quality programs? Have applicable lessons learned from previous LArTPC devices been documented and implemented into the QA plan? Does the plan appropriately account for APA production at multiple international sites with different standards (metric/imperial) for available stock?**
  - **We are developing a complete QA plan now, identifying groups to execute this plan, and working to complete the documentation**
  - **Many lessons/procedures from 35ton, MicroBooNE, and LArIAT have been documented and incorporated thus far.**
  - **The full testing plan and comprehensive procedural documentation will be finalized in time for a Production Readiness Review**
- **11) Are the APA quality control test plans and inspections regimes sufficiently comprehensive to assure efficient commissioning and safe operation of the NP04 experiment? Does the QC plan appropriately account for APA production at multiple international sites?**
  - **Testing and inspections to be performed during installation and commissioning are still being defined and will be defined to allow for successful operation of protoDUNE.**
  - **Full QC plan and procedural documentation will be finalized for the Production Readiness Review**

Summary

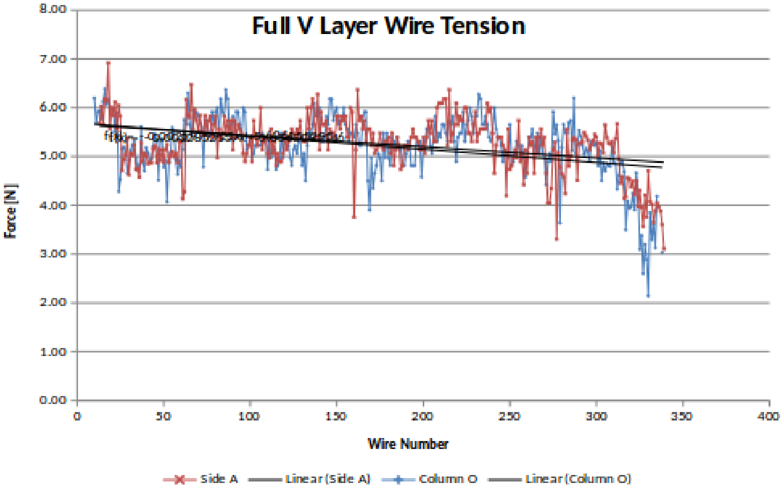
- **Layout a series of APA related tests to be done during the fabrication**
- **These tests verify the dimensions, planarity, and basic electrical function of the APA**
- **Some tests will be repeated upon arrival at CERN to verify APA following the shipping**
  - e.g. 10% of channels will have their tension remeasured
  - Electrical continuity and isolation tests should be repeated prior to installation

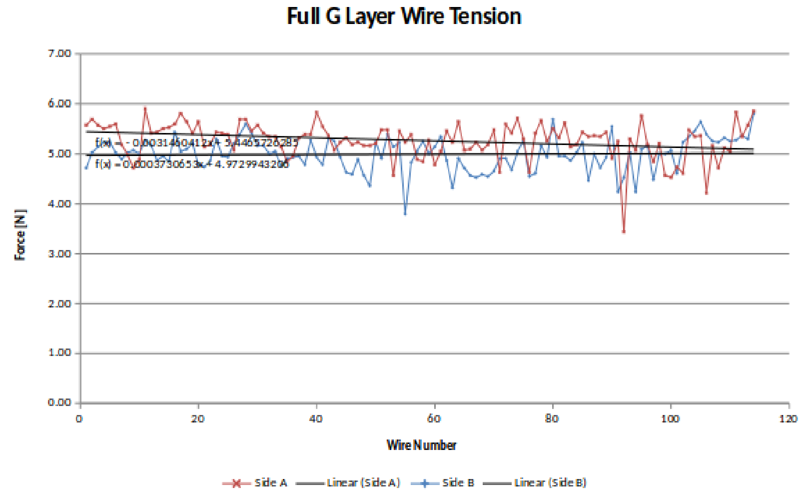

APA Frame
with wires
Safety
Light

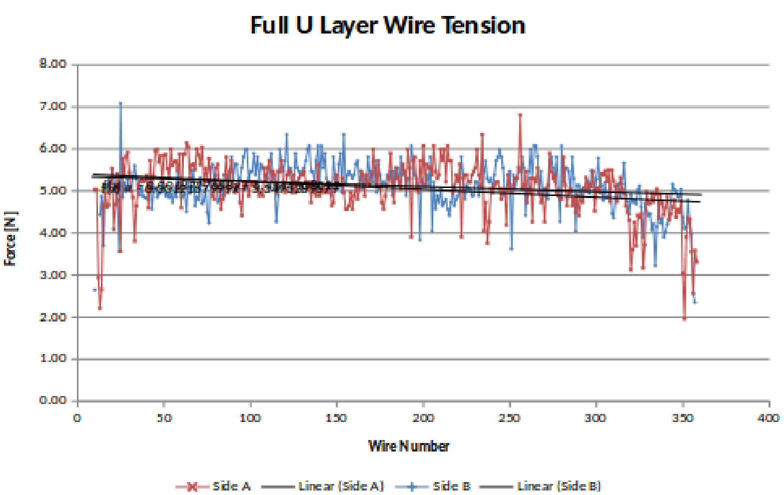

APA Mock-Frame
Camera
Power
Supply
Safety Zone
during HV operation


MPod
SHV
Connector
Important
Point!
22 MΩ
22 MΩ
Wire
Wire
Frame
1Watt
1 kΩ

Wire Tension in 35ton







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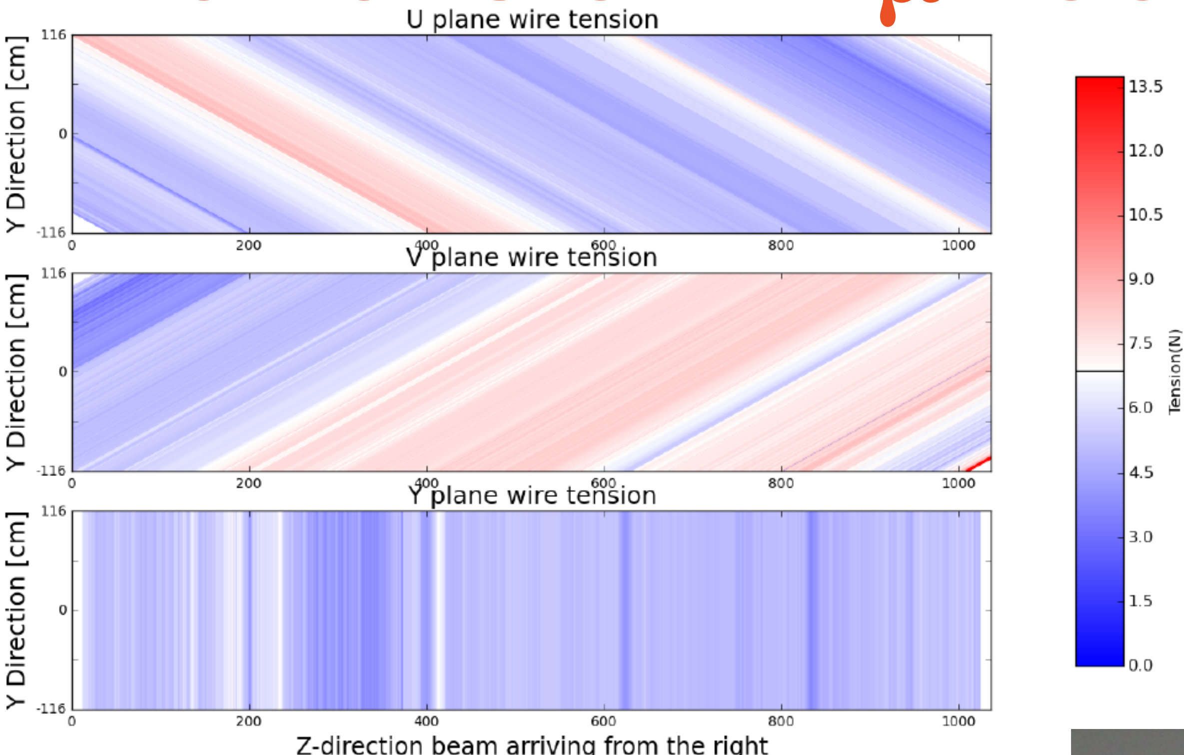
Wire Tension in µBooNE



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