Update on APA broken wires

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FD1 Technical Board Meeting

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UNIVERSITY OF LIVERPOOL

DUNE

Summary: ProtoDUNE APA 3

- A V wire on APA 3 in ProtoDUNE II broke after the cold box tests in October and before late November when the first CE readout was done in the cryostat.
- The wire was removed and examined by the CERN electron microscope and metallurgy experts: the cause appears to be pulling beyond the breaking point which weakened it and it broke after cold box warmup.
- CE readout tests of APA 3 until 15 February 2023 show no further lost wires on APA 3. See CE talk at https://indico.fnal.gov/event/58301/
- See my TB talk in December 2022 at https://indico.fnal.gov/event/57324/
- See also the presentations by Daniela and Hanjie Liu at the NP04 meeting https://indico.cern.ch/event/1231092/

Summary: New from the Daresbury Factory

- It was observed that wires do break occasionally during winding.
- It was observed that wire tails after tails are cut (standard procedure) become very curly, indicating they have been stretched at some point of the procedure.
- It was observed that momentarily the tension applied to the wires can exceed 10 N.
- *This points to a scenario where excessive tension applied during winding can break wires (if it exceeds their breaking point 22-25 N), pull them below breaking (curling, wires seen to be curly are removed) and possibly some pulled but aren't removed, this could be the case of the APA 3 broken wire.*
- **This is only a scenario at this point**. Ongoing priority actions are:
  - Identify points in the winding program (recipe) where high tension events happen,
  - Modify recipe (limit acceleration and speed at those points),
  - Improve tension recording and analysis and include remedial actions in procedures.
- A problem with a worn pulley led to some possible damage to wires on APA 6 U and G layers, currently under investigation.

APA 3 wire analysis

- Report on EDMS https://edms.cern.ch/document/2823564/1 restricted access.

Equipment

- Field Emission Gun Scanning Electron Microscope (FEG-SEM) Sigma (from ZEISS) with InLens Secondary Electron (SE), Everhart-Thornley Secondary Electron (SE2), and back-scattered electron (AsB) detectors for imaging;
- 50 mm^2 X-Max Energy Dispersive X-Ray Spectroscopy (EDS) detector and AzTEC software (from Oxford Instruments) for chemical analysis.

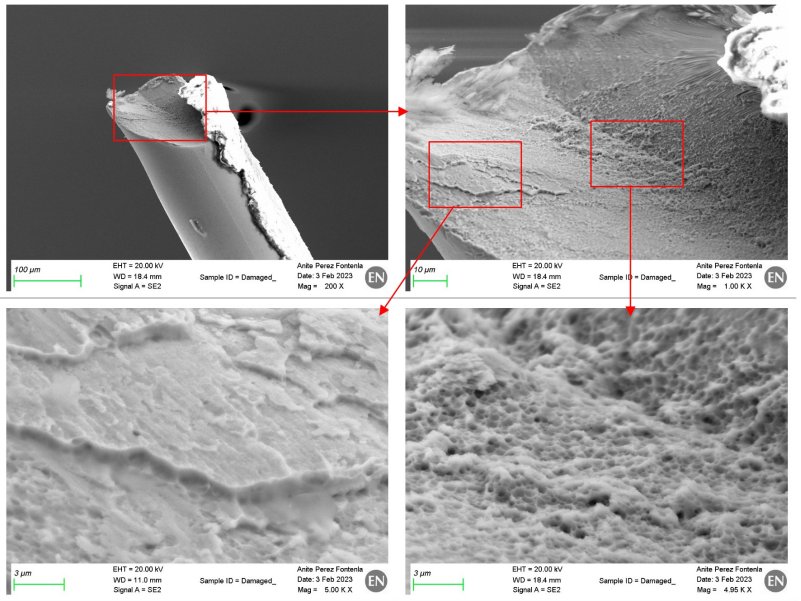


Table 1 – Summary of EDS results (wt. %)

Element	Reference extremity dark residue	Broken extremity light grey residue
C	15.14	54.98
O	0.86	35.30
Al	0.40	4.23
Si	0	3.77
Cl	0	< 0.10
K	0	< 0.10
Ca	0.13	< 0.10
Ti	0	0.13
Cu	83.48	1.39
Be	Non detectable	
Total:	100	100

APA 3 wire analysis

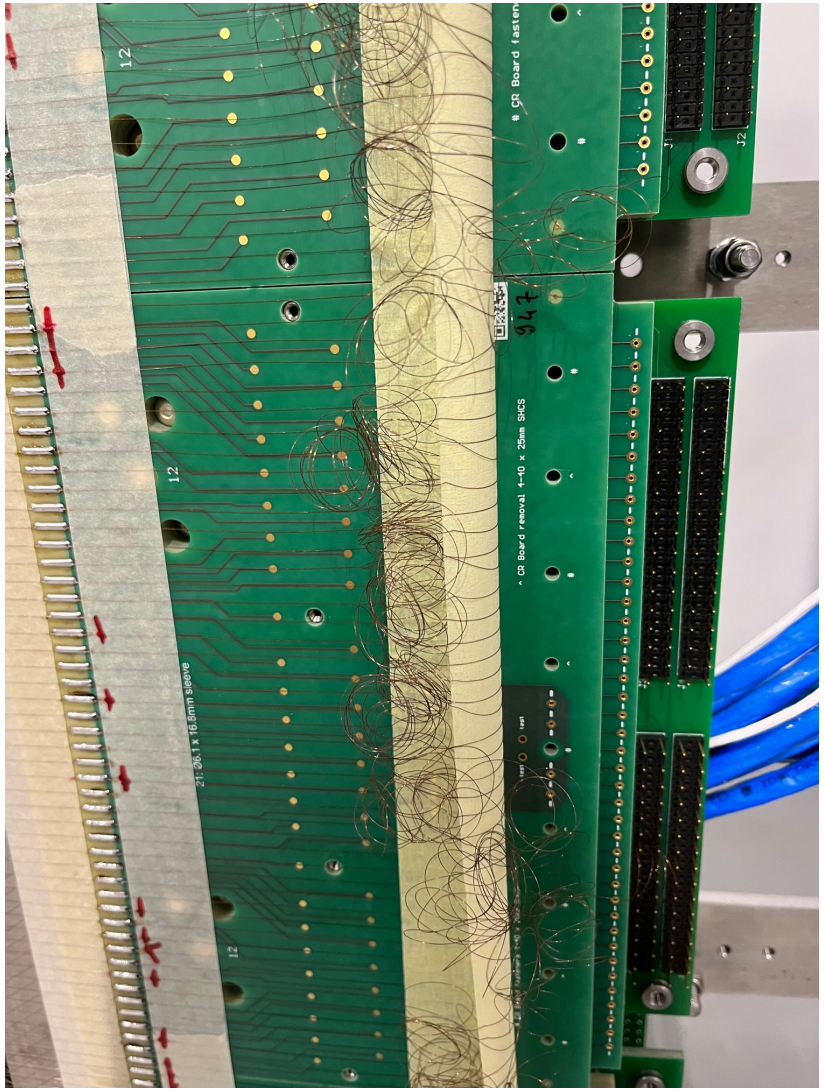
4. Summary of observations

The extremity suspected to be broken presents indeed a concave shape and the features observed on the centre (equiaxed dimples) are characteristic from a fracture surface.

The residue visible attached to the wire was analyzed and is rich mainly in C and O with traces of other elements. They correspond most probably to cross contamination and not with soldering residues.

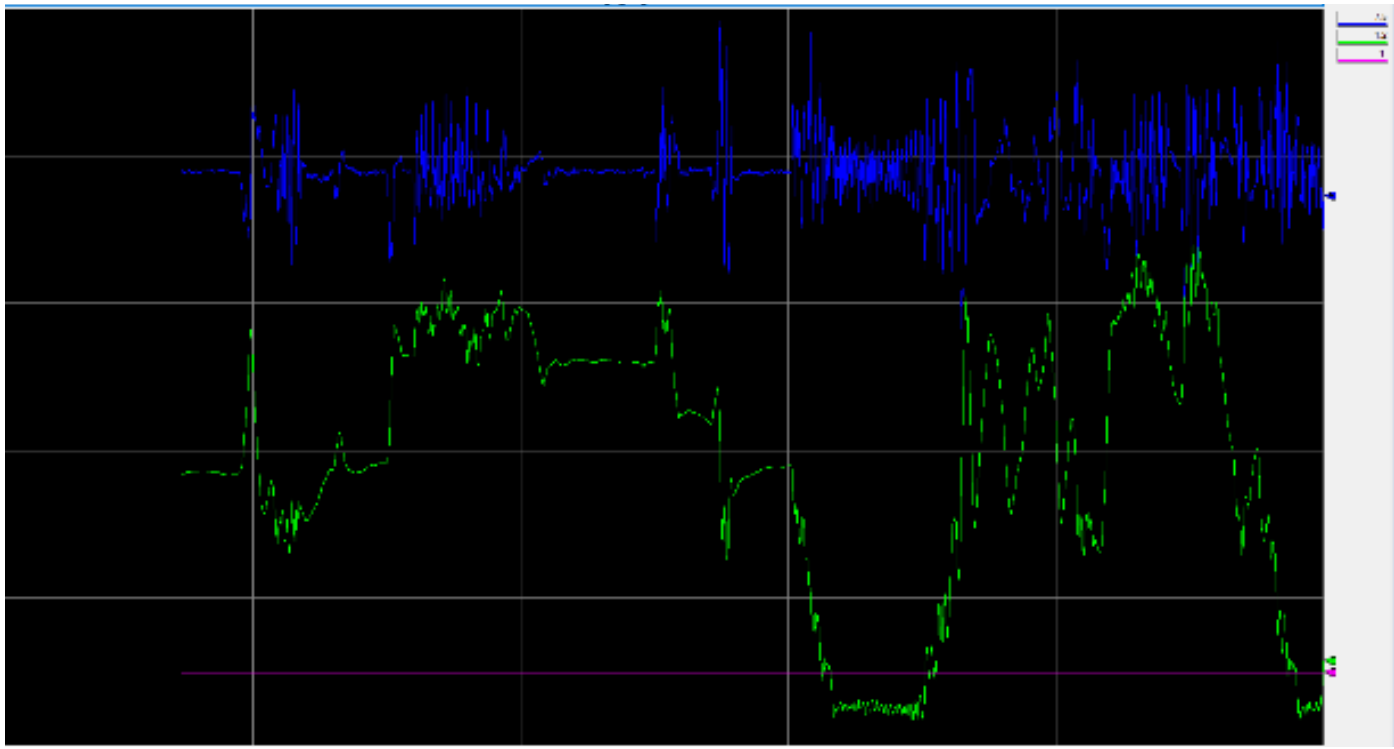
Wire issues during winding

- Wires have been breaking during winding, around a handful per APA.
- As part of the procedure wires are run beyond the APA head bar and temporarily soldered to sacrificial boards, and later cut. The ends of wires cur to some extent. Sometimes wires become very curled and are replaced. In one incident many wires nearby were very curled, all replaced.
- Both type of occurrences indicate that wires are pulled to higher tension near or above the breaking point.
- We can see spikes in tension during winding, more in the following pages.



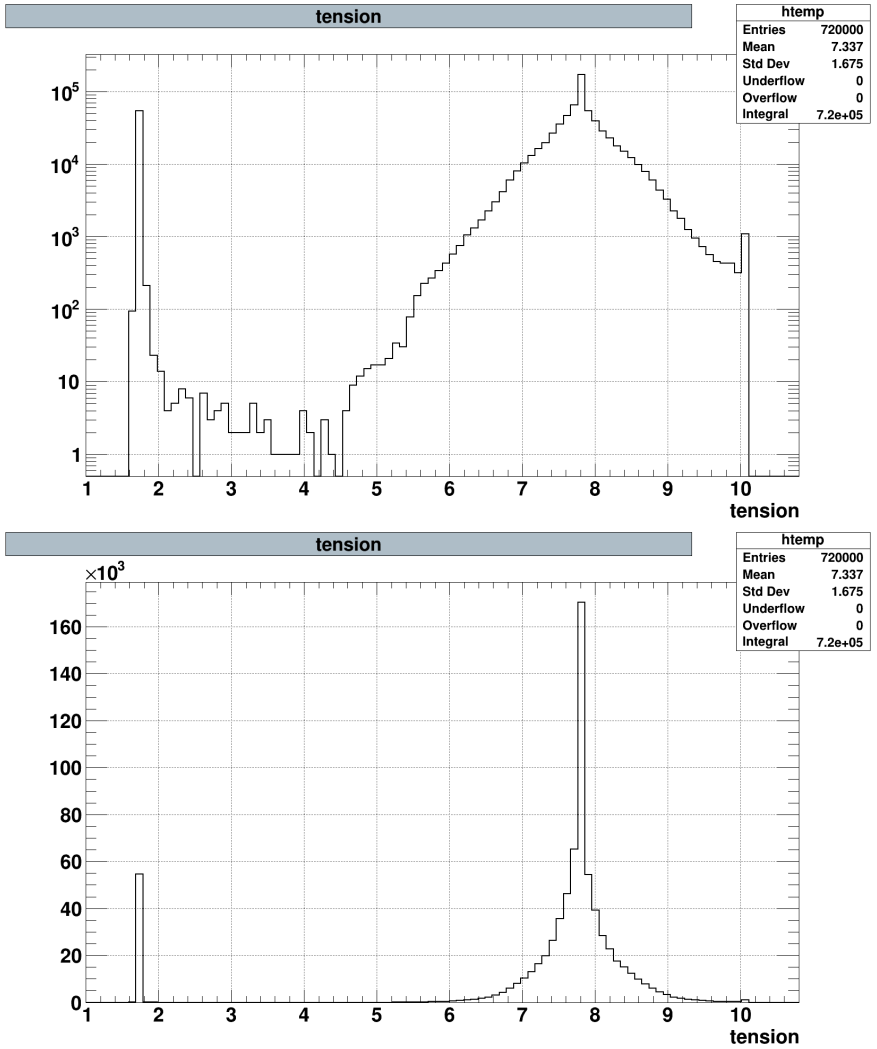
Tension monitoring in real time

- Blue line is actual wire tension.
  - Capped at 10 N due to limits of a spring and readout (will upgrade).
- Green is servo motor reaction to keep tension in limits.
- Measurements taken every 10 ms.
- Spikes at 10 N seen rather often.
- Raw data stored (last couple of weeks)
- Analyzing as we speak to count single and also double or more consecutive 10 N events.
- May assume that number of ticks at limit indicate higher actual tension in the event (think TOT).



Frequency of high tension events

- Hot – just in
- From V layer of APA 7 on winder 4
- Tension measurements histogram
- Low value peak: winder idle
- Peak around 8: normal operation
- Peak at 10 (incl. overflows): high tension events



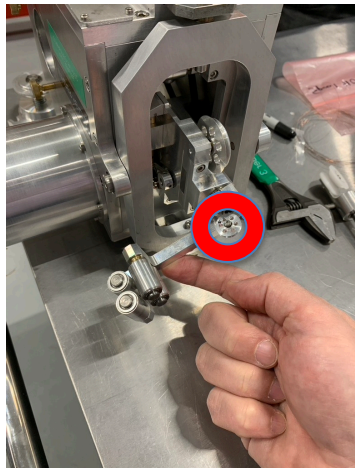
Where do we go from here

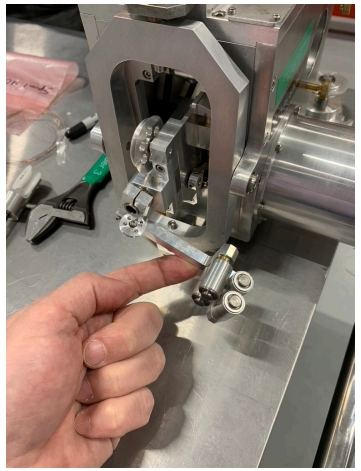
- Immediate priority actions:
  - Analyze winder tension data, count frequency of single, double or higher consecutive 10 ms ticks above 10 N.
  - Timestamp in real time all measurements at the 10 N limit and corelate with head position.
    - The aim is to identify particular parts of head movement (going around the frame, accelerating, other) and then modify recipe to reduce acceleration and speed to eliminate tension excursions.

- Mid-term actions: replace spring and modify readout so that actual tensions can be recorded up to at least 20 N.
  - Then record max tension per wire segment, aiming to identify a small number of wires per layer that experienced high tension (threshold TBD) and replace them.

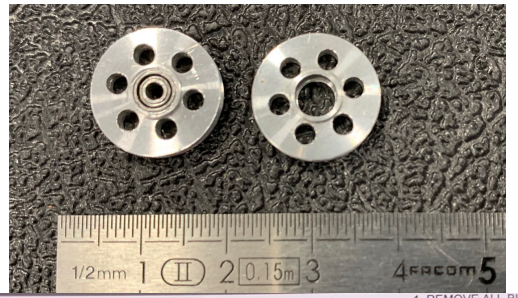
The damaged pulley and damaged wire on APA 6

- At the tip of the “dancer arm” of the winder head we have the last pulley that the wire runs through.
- This pulley gets stressed more than others due to the changes in direction.
- There is 200 micron clearance between the cross-drill holes to save mass and the bottom of the wire groove.
- On one pulley shortly after replacement the groove was worn through to the cross drill holes.
- That left marks on the wires laid on the U and G layer of APA 6.
- Winding has stopped.

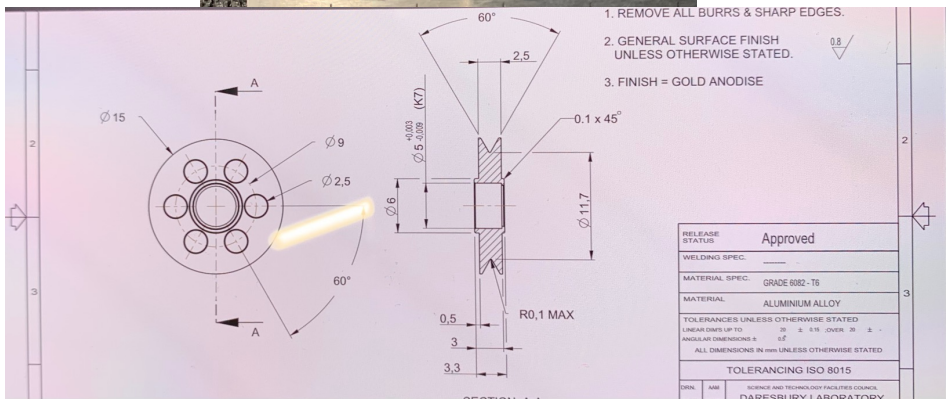




Old pulley



New (no bearing in the middle)

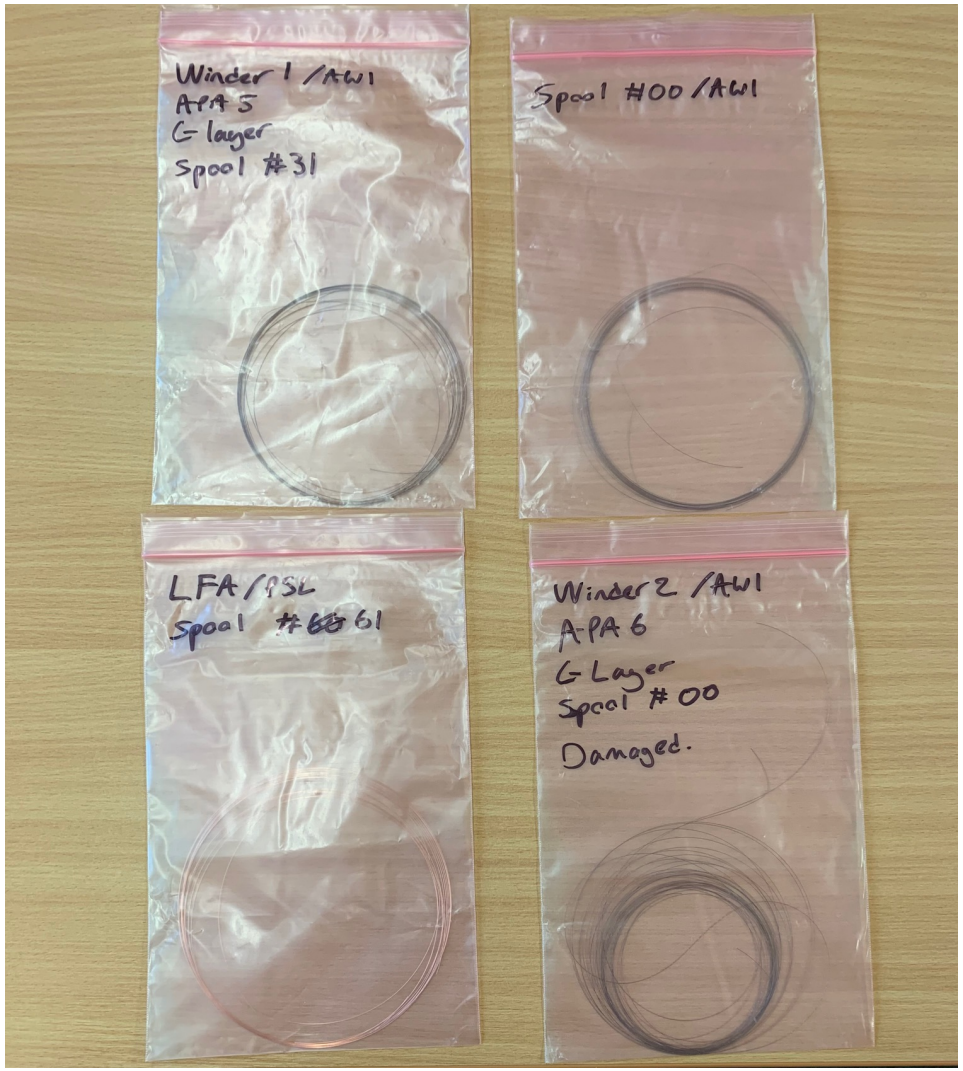


Ongoing actions

- Winding of APA 6 has stopped.
- Samples were taken form the damaged wire, the same spool, another spool (all from *Alloy Wire*), and a sample from *Little Falls Alloy Inc* used in previous APAs.
- Samples being tested (measure break point for five pieces each sample) at our Liverpool University labs.

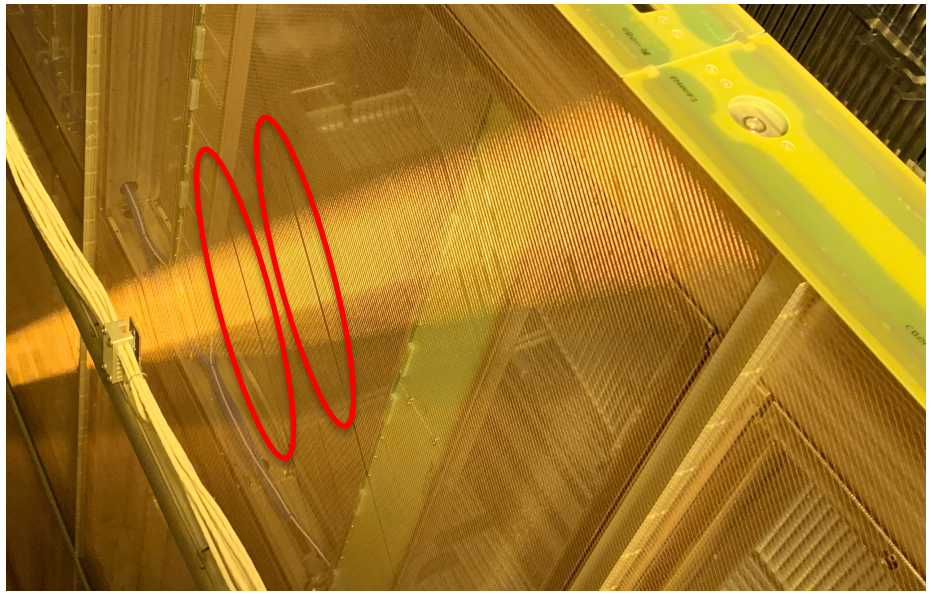
- U layer wires o APA 6 can't be replaced.
- We may have to restart APA 6.
- This is very recent (last Thursday).

- Tolerance of 200 microns in the pulley will be increased.
- The particular pulley is in metrology at Liverpool to check if it was a problem in manufacture or rapid wear due to large forces. For completeness of our understanding.



Extra material

Old and new broken V wires, APA 3 at CERN



18 November, different angle, same APA 3 zone

Timeline for the APA3 broken wire

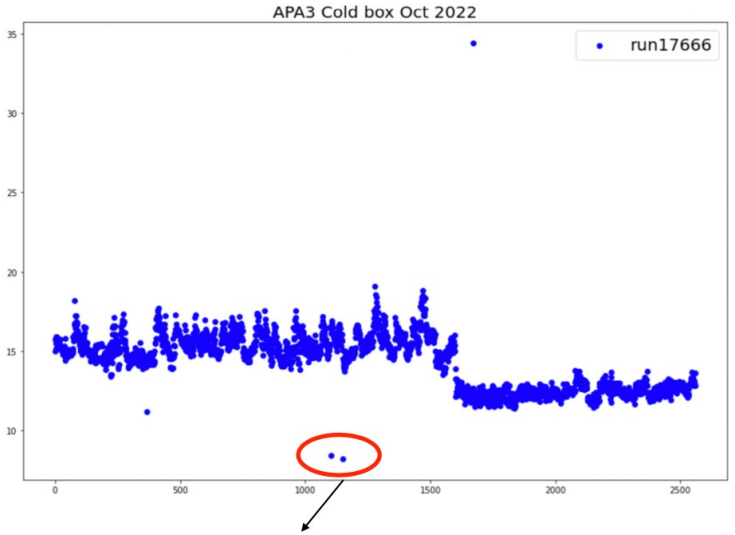
- Mid-October cold box runs show noise as expected for connected wires.
- 17 and 18 November photos show the wire in place.

- 23 November the wire appears disconnected (low noise) in first cryostat CE run, but no wires have very high noise (happens when wires are shorted).
- 28 November the wire appears in place in a photo taken for independent purpose.

- 7 December the wire is noticed to have broken free from at the headboard and curled between the other APA wires.
- 9, 11, 12 December CE runs show a few very high (shorted) wires which are not always the same: broken wire moving and touching different wires (?)

Broken wires in the readout

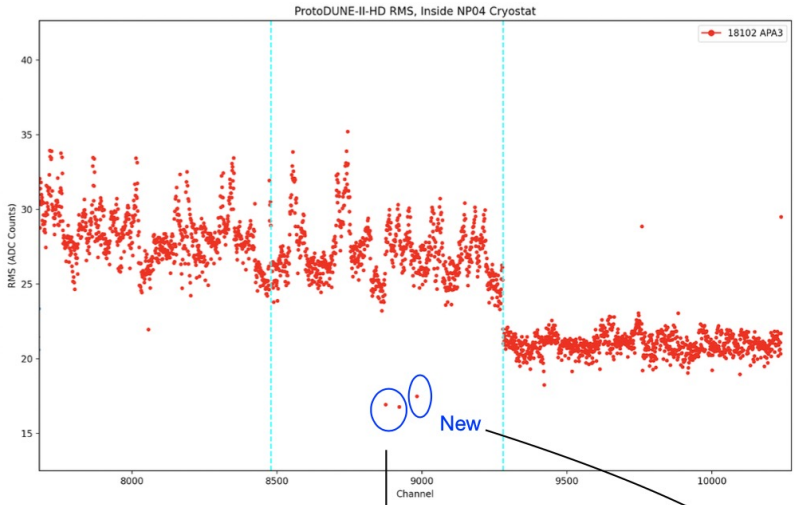
One of the last APA3 cold box on Oct 2022



Offline Channels		FEMBs
1102	—>	FEMB 8, ch 72
1149	—>	FEMB 9, ch 106

*FEMB channels are raw data channels not U, V, X channels

First cryostat run, Nov. 23 2022



Offline Channels		FEMBs
8922	—>	FEMB 8, ch 72
8875	—>	FEMB 9, ch 106
8983	—>	FEMB 7, ch 54

Newly Broken wire location:
V2 wire on adapter board 7

Run taken on Nov. 23, before photo on Nov. 28 showing the wire still in its nominal place.

Winder tensions and operations