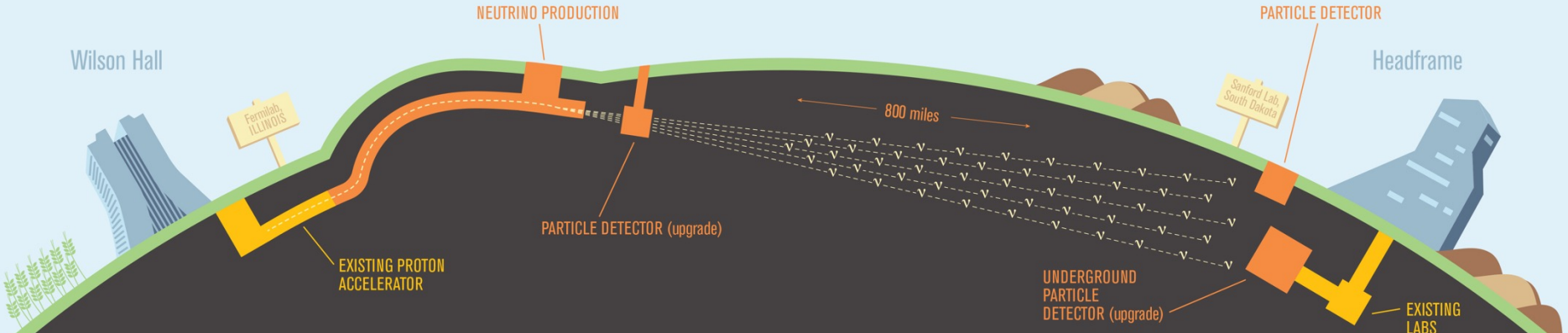
Technical progress, lessons learnt, and interfaces

Justin Evans

Addressing charge points 5 & 7



Part 1: Technical progress

Relative to ProtoDUNE-1:

- Thicker APA frame members
- Mill-Max connector improvements
- Digital wire analyser and associated board modifications
- Mesh panels
- Improvements to the winder and winding head
- APA transport frame

APA frame members

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- Side members have been increased from 3” to 4” width

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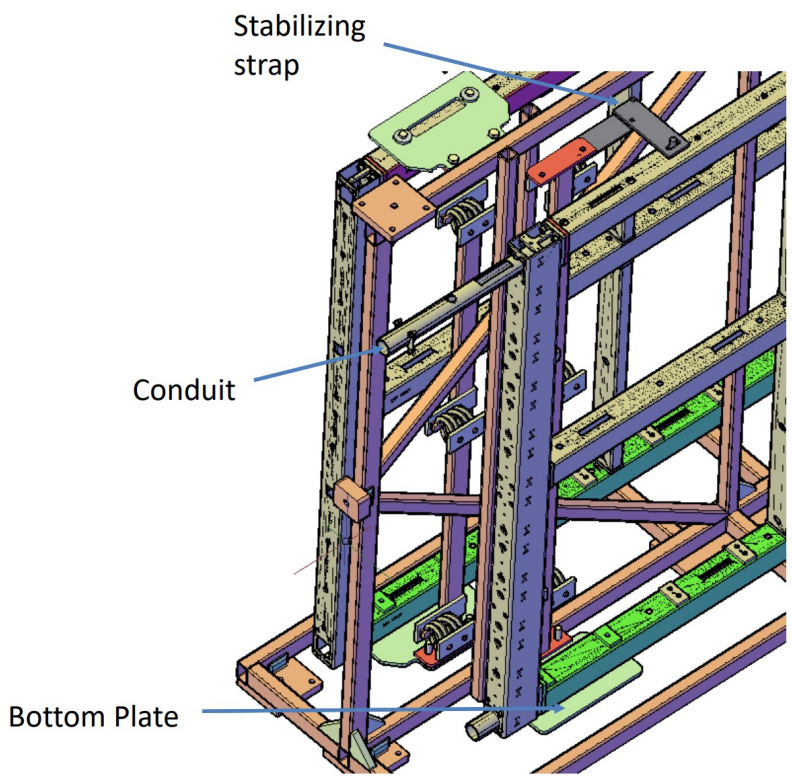

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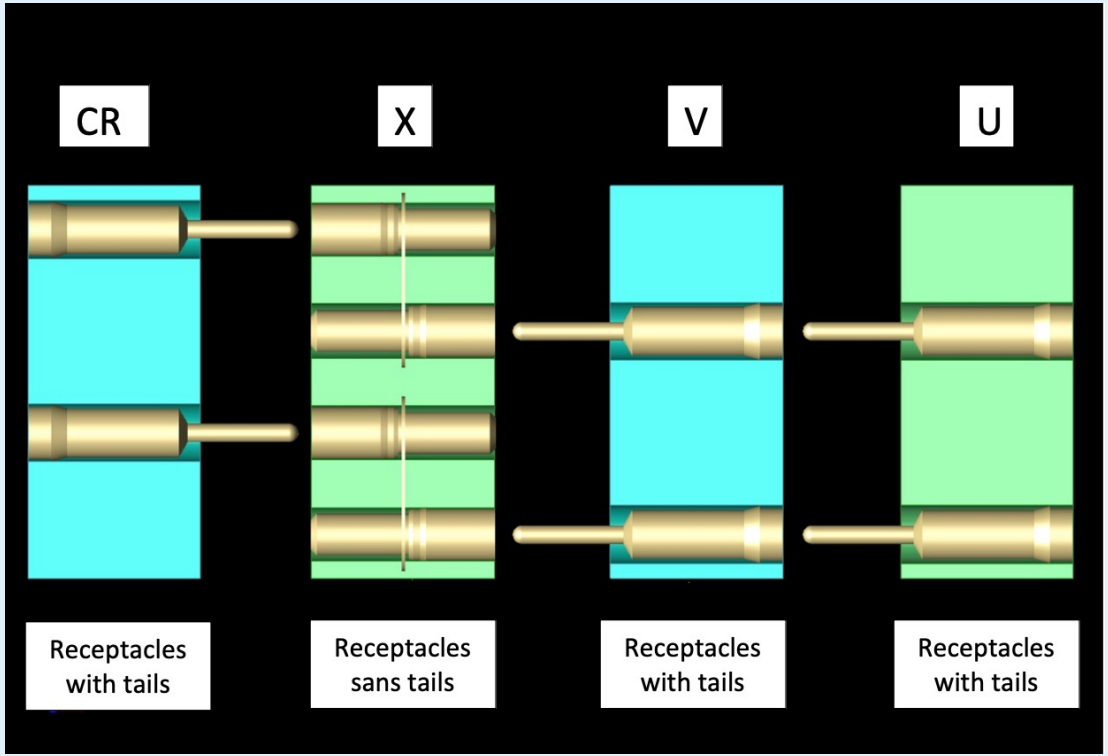
Cable-insertion process tested at Ash River

Mill-Max pins

The head-board stack is connected together with Mill-Max pins and receptacles



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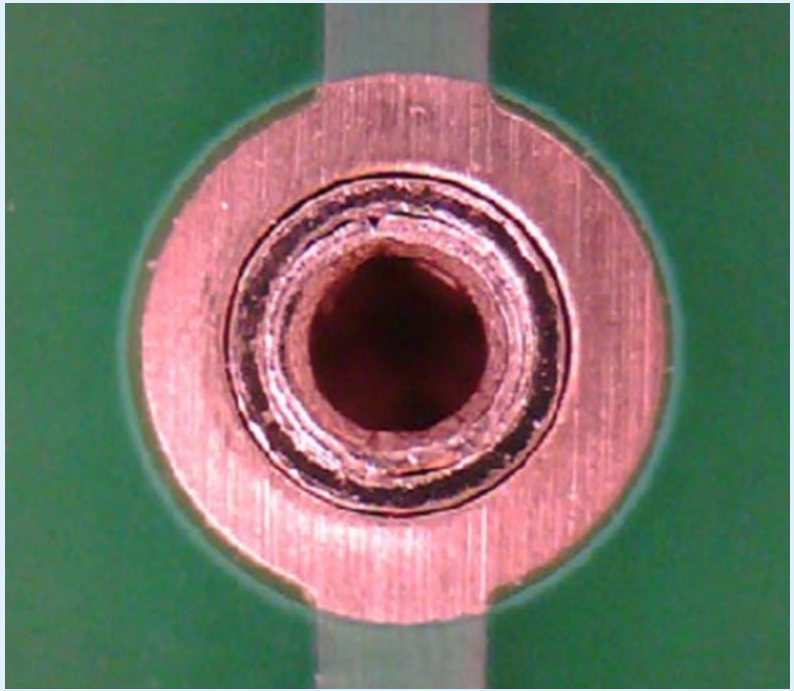

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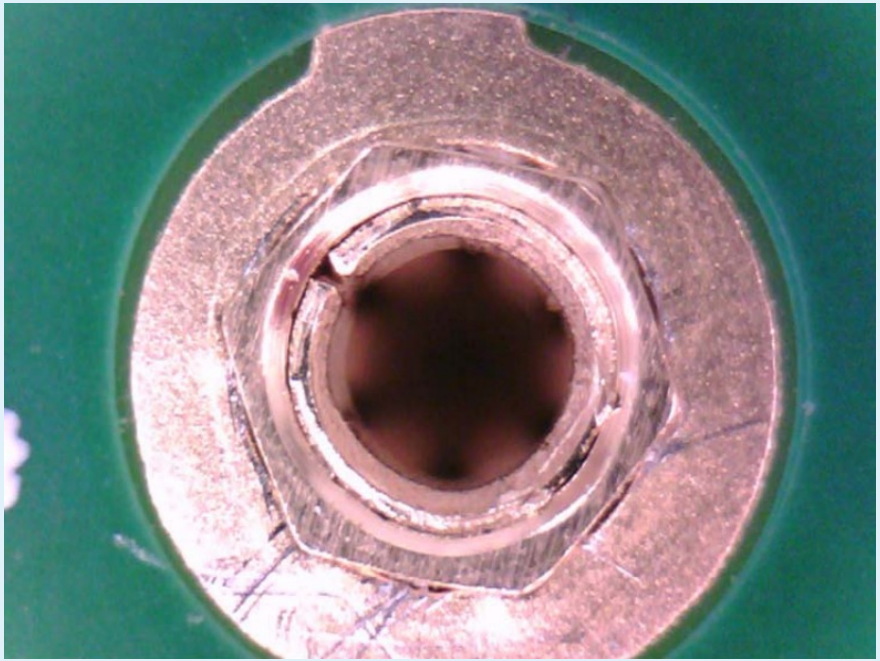
Mill-Max developed a custom design with hexagonal pins

- Stable against forward displacement forces of 147 N or more



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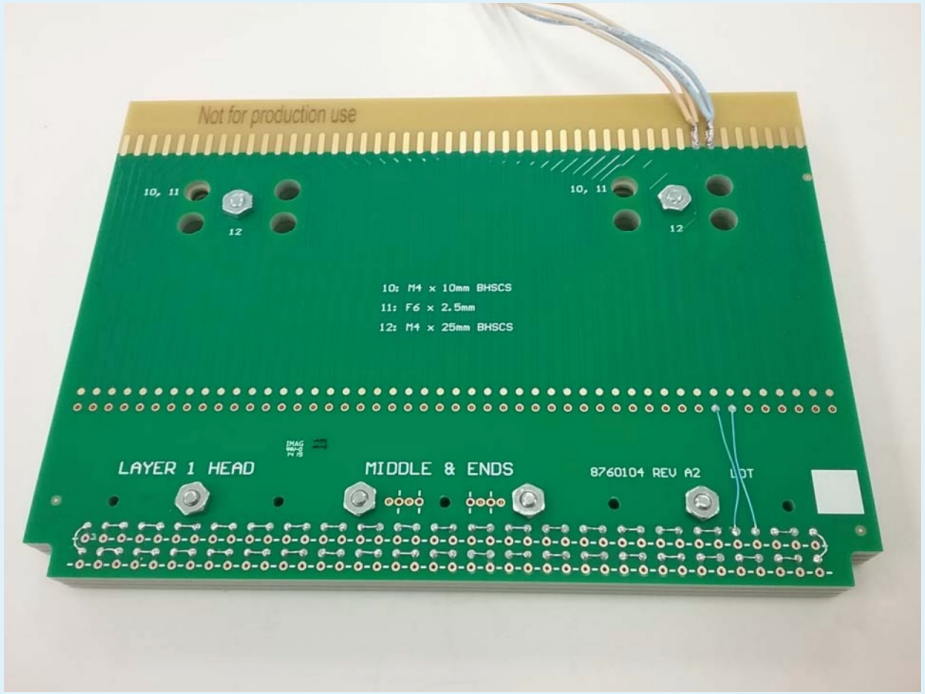
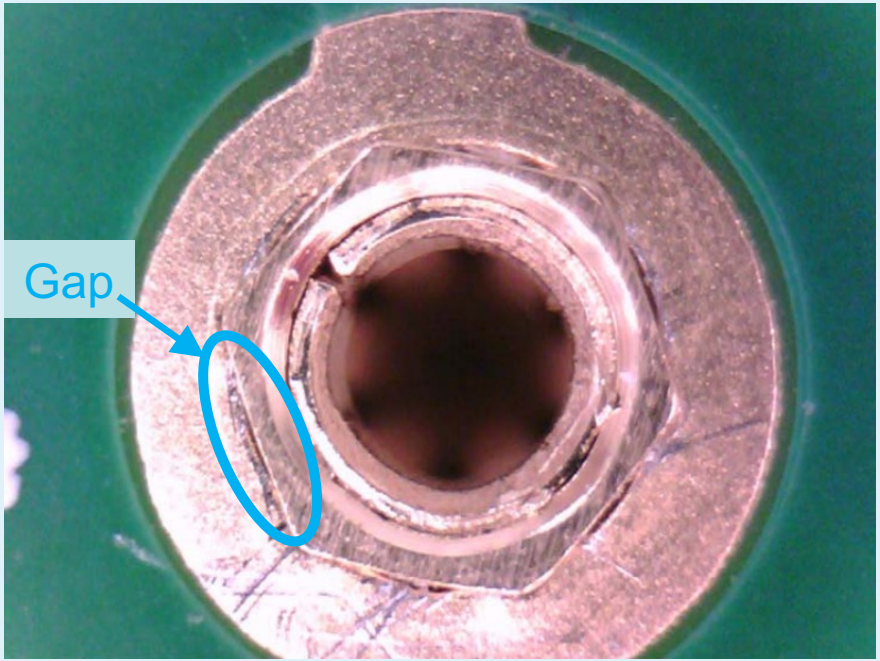
Performance of pins tested in a board stack of 160 pins and receptacles ganged in series

- Resistances measured in cold and warm
- Repeated 10 times with no resistance changes bigger than 0.002 Ω



Mill-Max pins

- There are now gaps between receptacles and plated PCB holes



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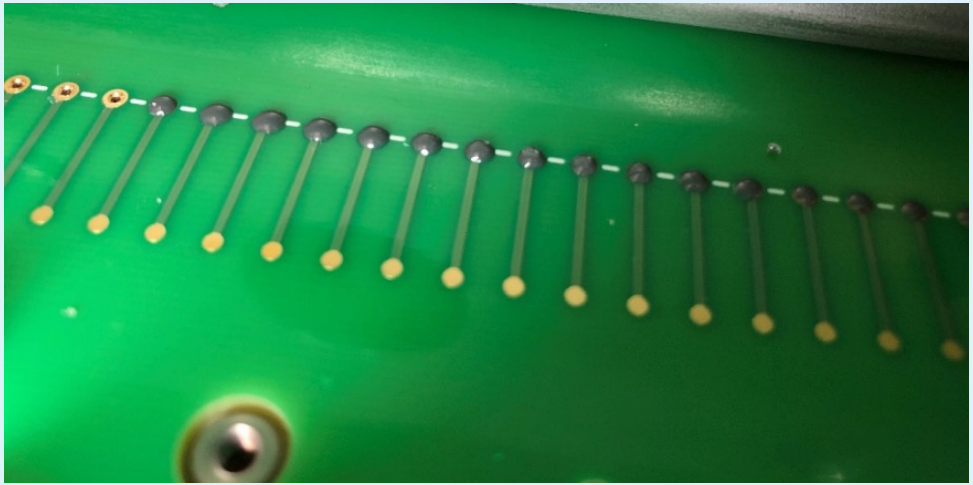
- In ProtoDUNE-2 APA 1, this led to epoxy seeping through the holes on X-head boards



Mill-Max pins

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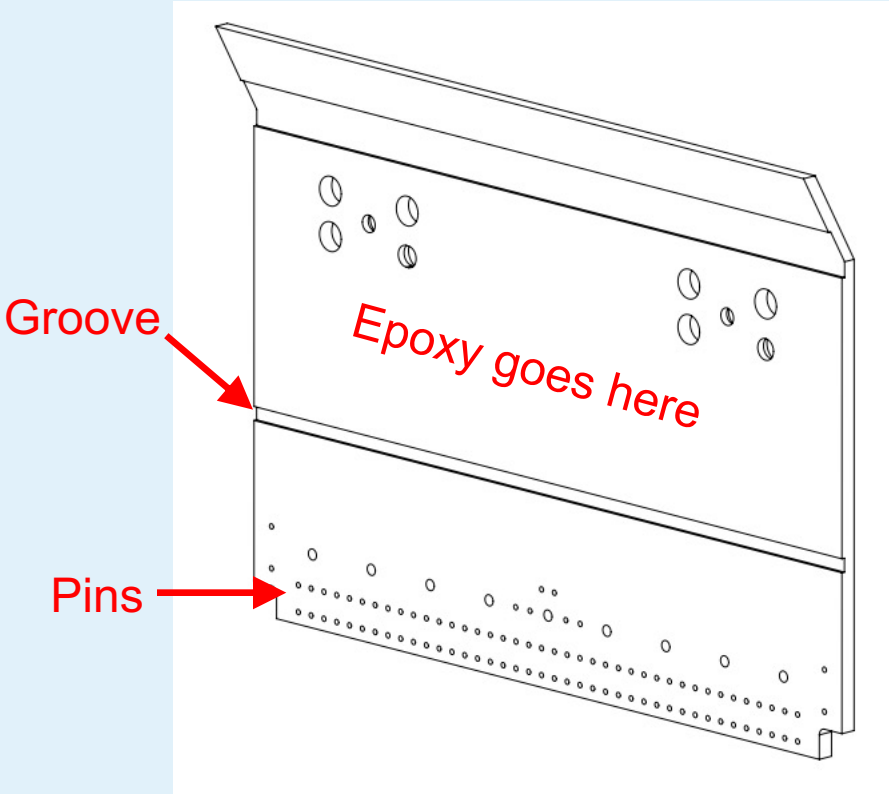
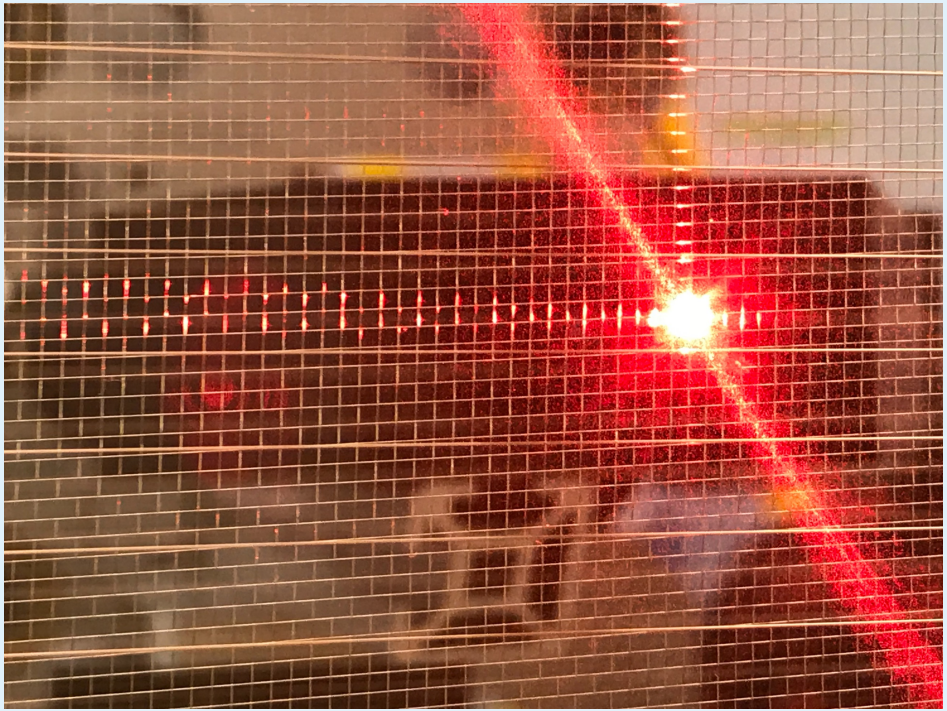
- In ProtoDUNE-2 APA 1, this led to epoxy seeping through the holes on X-head boards
- To avoid this, we have designed a groove that stops epoxy reaching the pins



Digital wire analyser

Wire tensions are currently measured using a laser

- Single wire at a time
- Can only be easily used during construction



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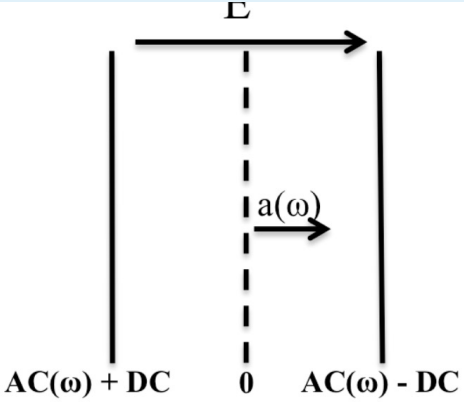
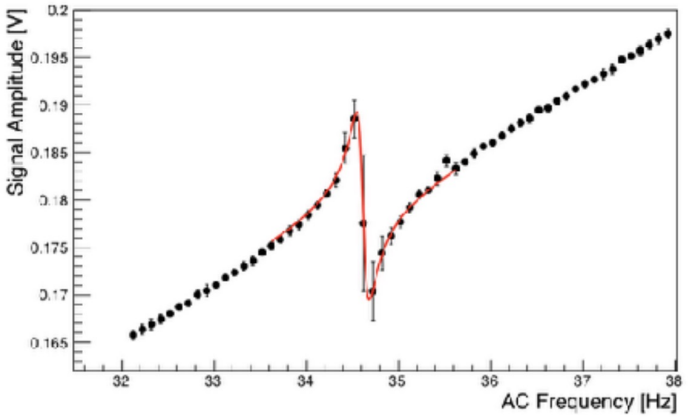
- Can be used on all wire layers at storage and installation sites
- Can also confirm wire continuity



$$T = 4\mu L^2 f_0^2$$



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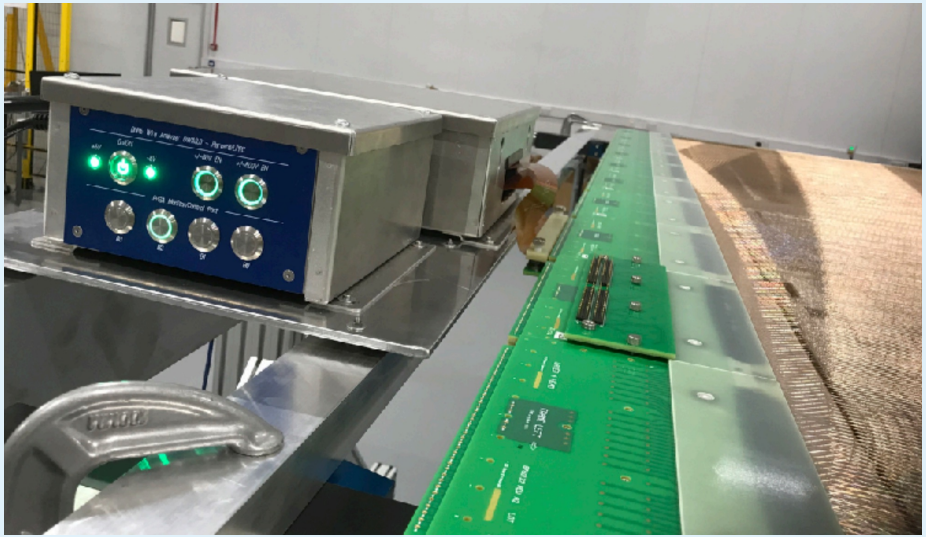

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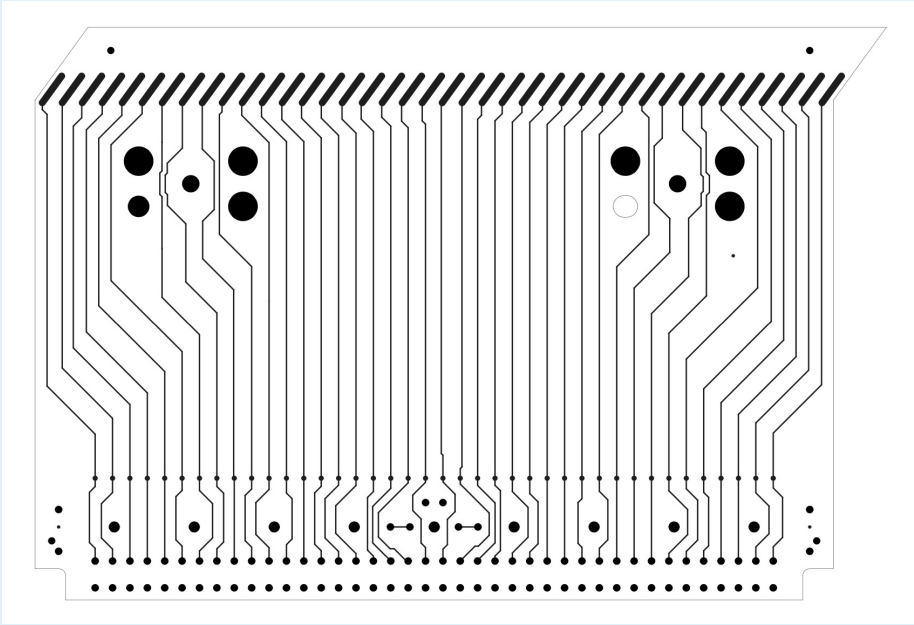
Trace spacings increased to permit bias voltages



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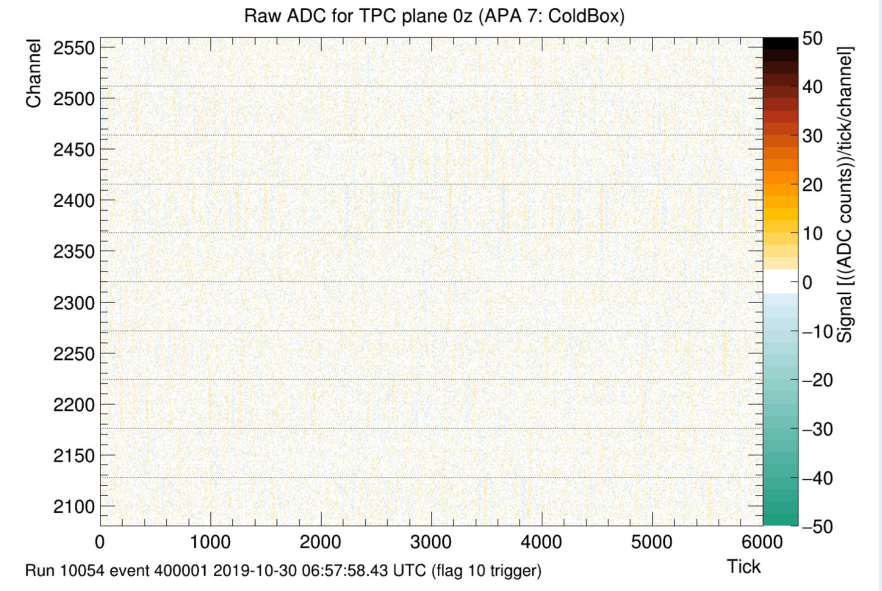
Were installed on APA 7

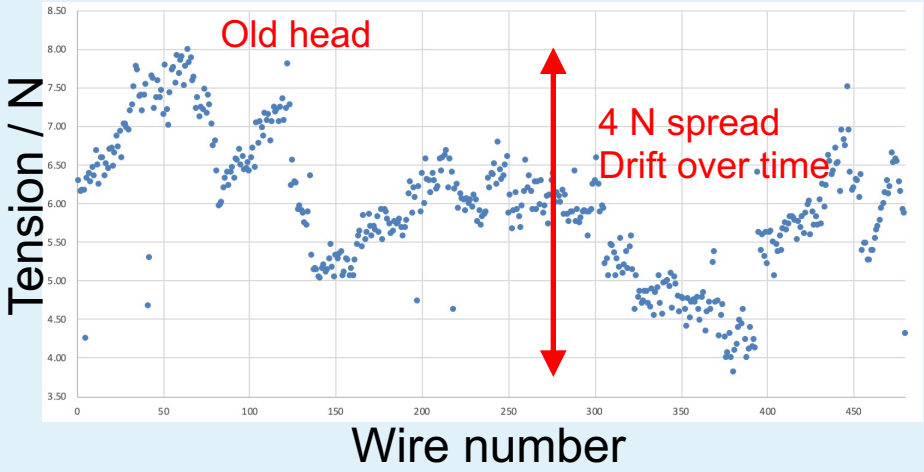
- Took data successfully in the CERN cold box



Winding head

Old winding head used a slipping clutch method for producing tension

- Warm-up period and variability



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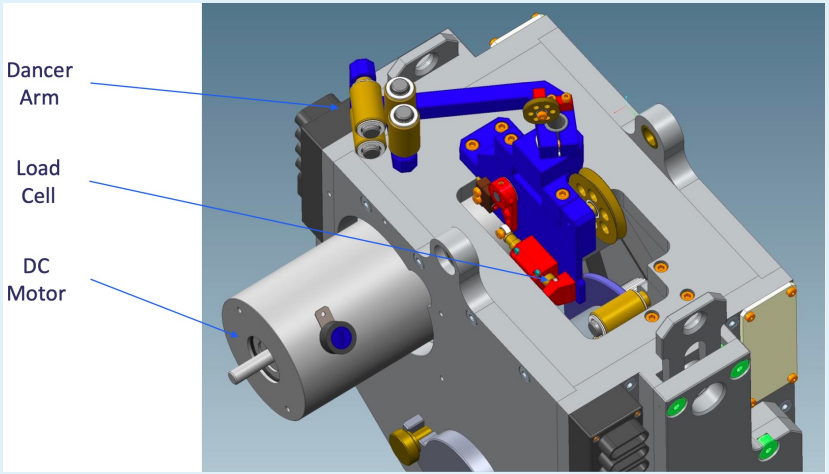
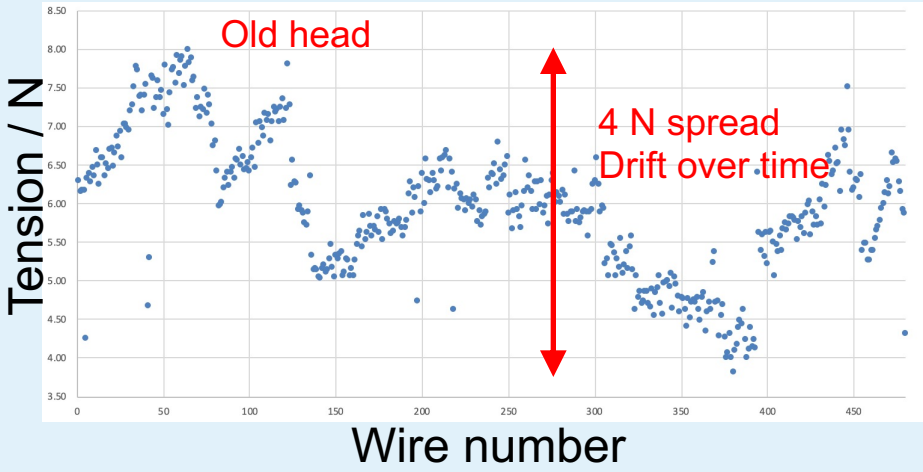
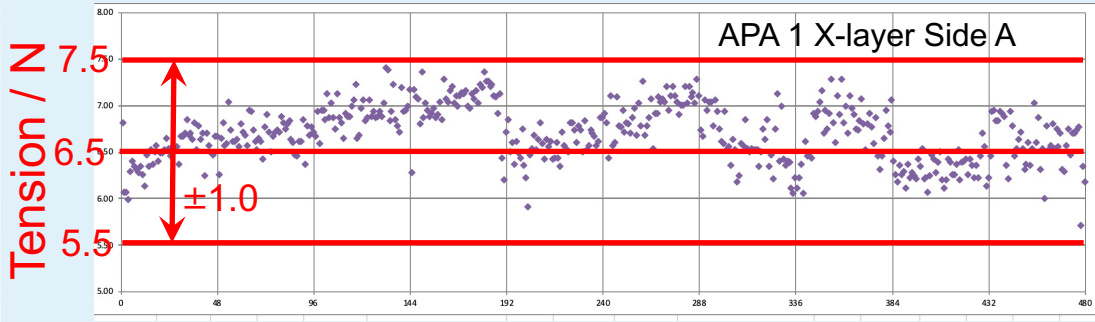
- With active tension monitoring







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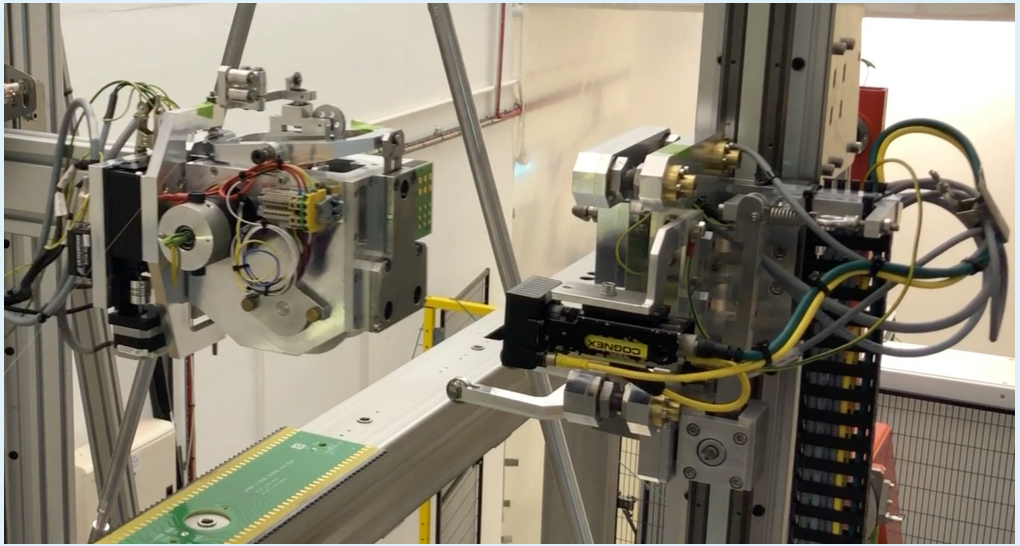

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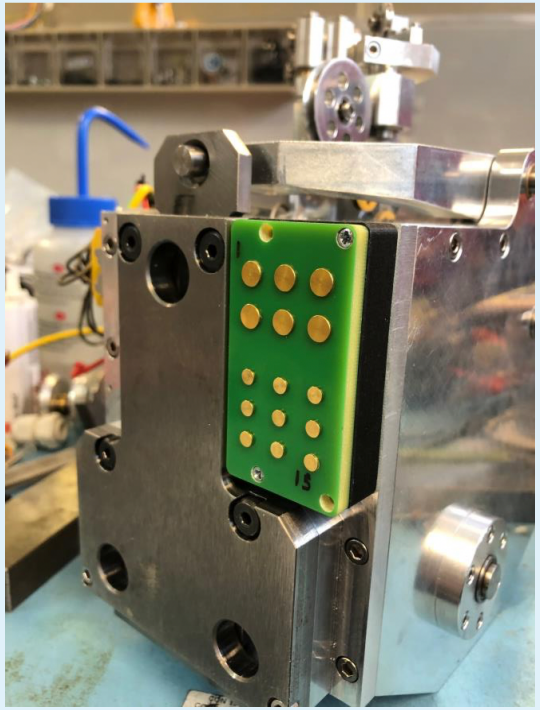
Improved transfer stability

- New three-pin latching mechanism with electrical contact pad
- Old head had a transfer problem every 10-20 transfers
- New head runs continuously without problem



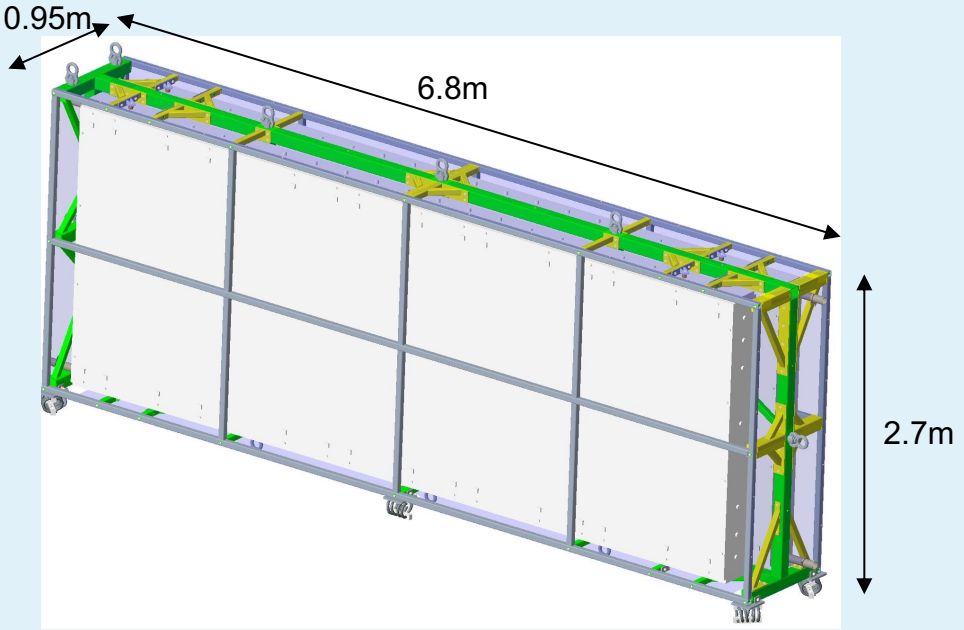
Winder

- ProtoDUNE construction required many movements of APAs between winder and process cart
- New winder allows the entire winding to be completed without removing the APA
- New safety system integrated into the controls software with interlocked safety barriers

APA transportation

Transport frame design complete

- Holds 2 APAs
- Robust support and protection during shipping
- Enables manipulation down to the detector
- Full engineering analysis completed by CERN compliance office and Fermilab

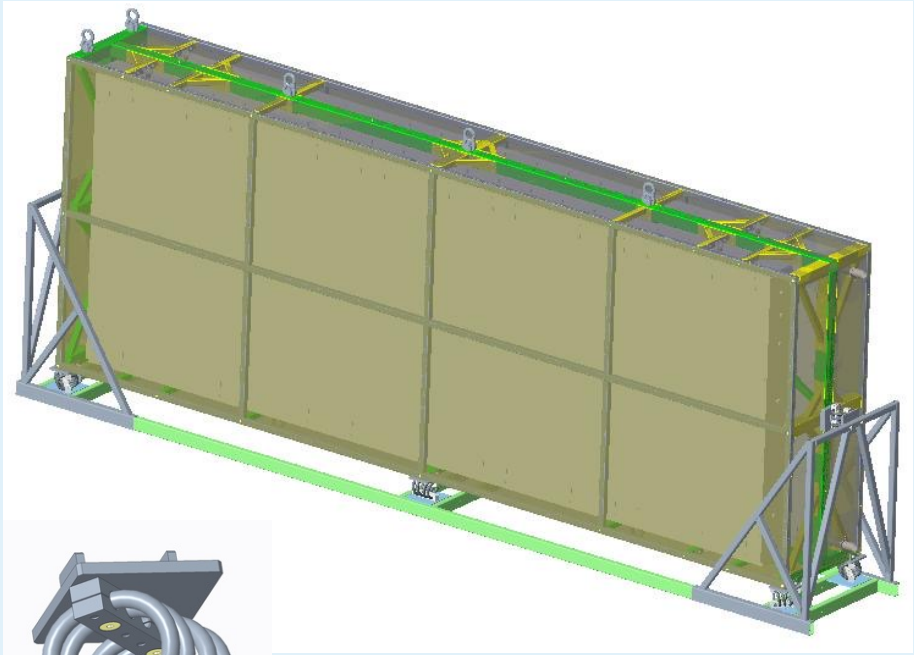


Three prototypes under construction

- 2 in UK, 1 at CERN

APA transportation

- Transport frame attached, via suspension springs, to a base cradle



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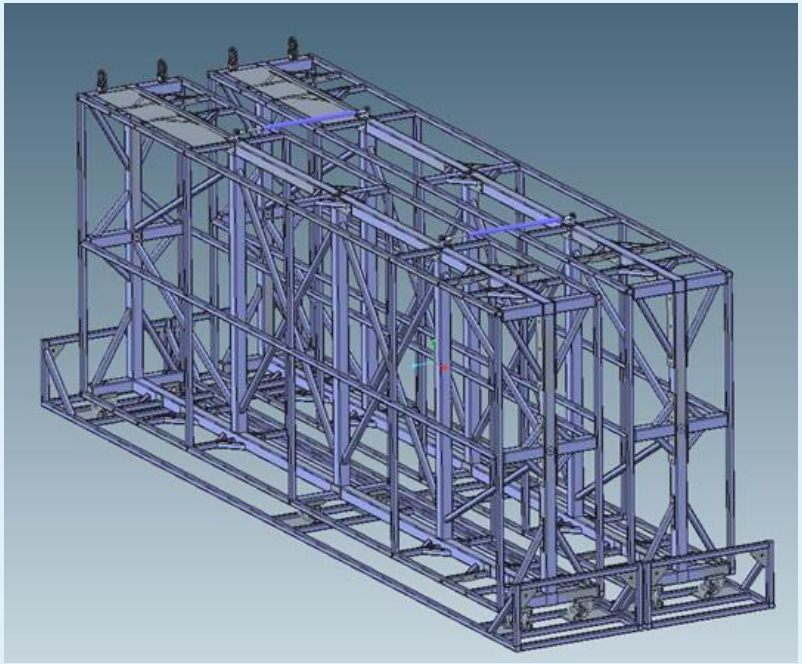
- Transport frame attached, via suspension springs, to a base cradle
- Two transport frames connect together into a single shipment of 4 APAs



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- Transport frame attached, via suspension springs, to a base cradle
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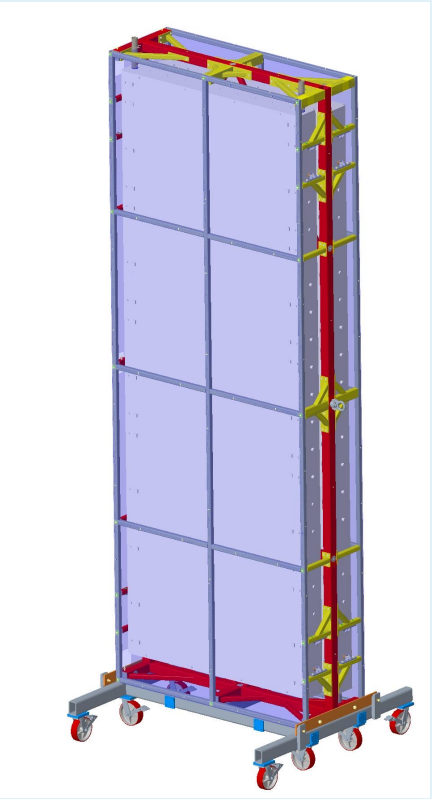
- Vertical cart design undergoing engineering analysis for maneuvering underground



Part 2: Lessons learnt

ProtoDUNE-1 was an invaluable learning experience

- We could study the number of disconnected channels
- We performed a risk-benefit evaluation of electron diverters
- We made improvements to protection panels and fastener attachment
- We have increased the target wire tension
- We responded to the discovery of broken wires during decommissioning

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We have a requirement of <1% dead channels

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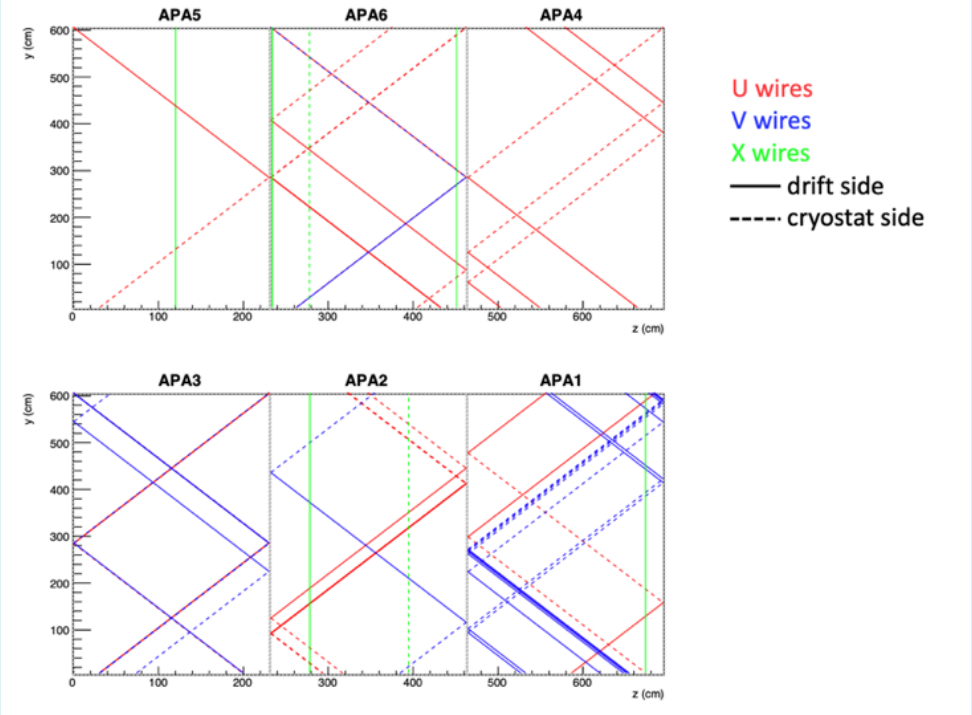

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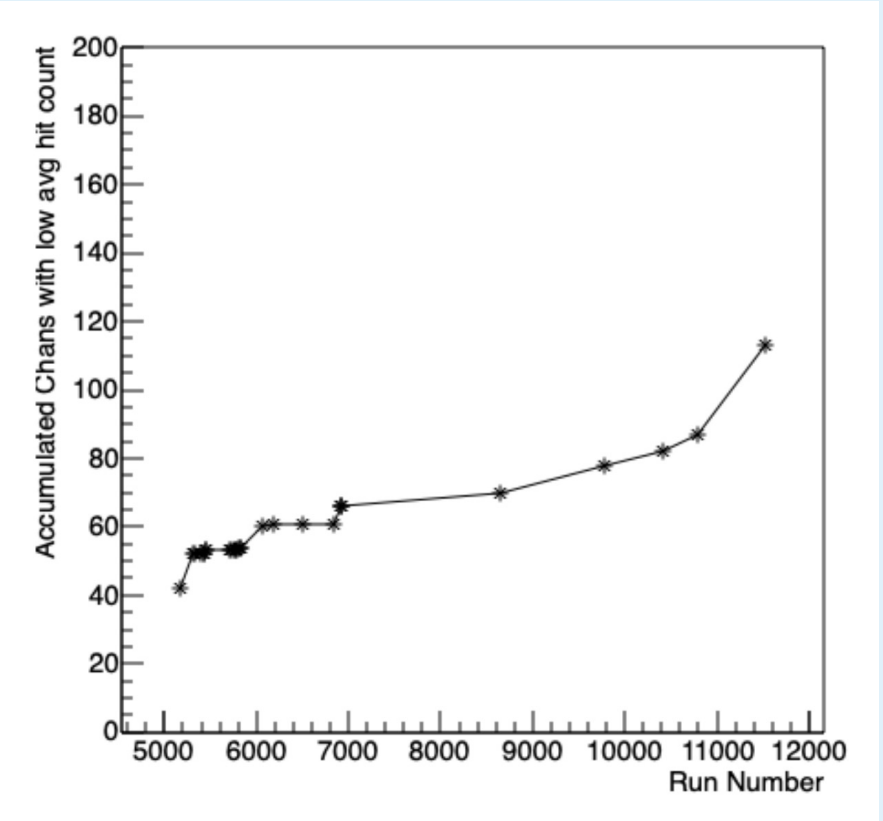
- Still <1%



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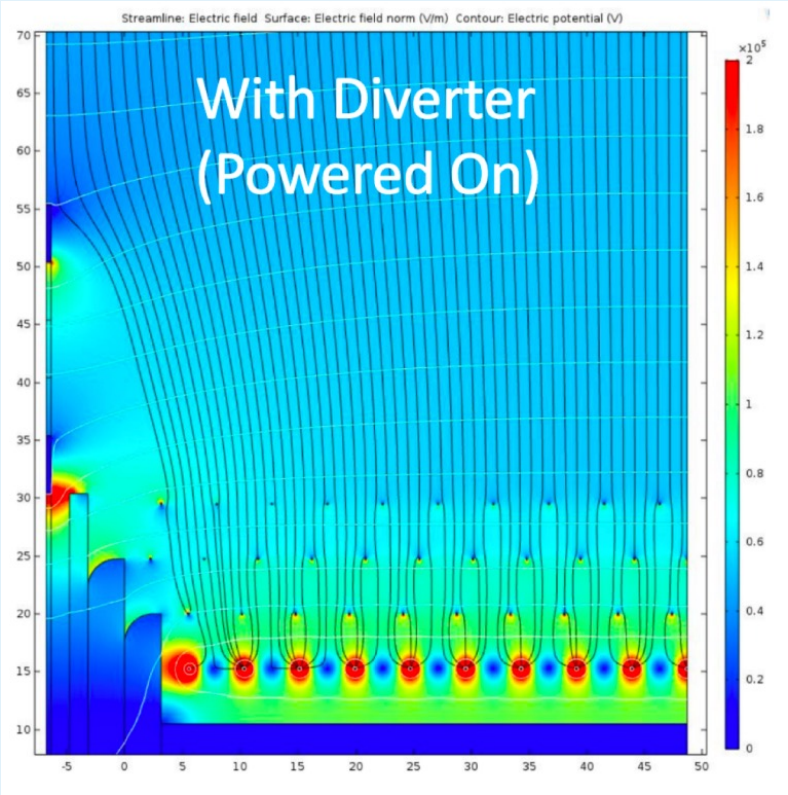
Improvements made to Mill-Max pins and to short-wire mechanical strains (see later)

Electron diverters

ProtoDUNE used active electron diverters on one APA wall

- To divert all charge to the active readout



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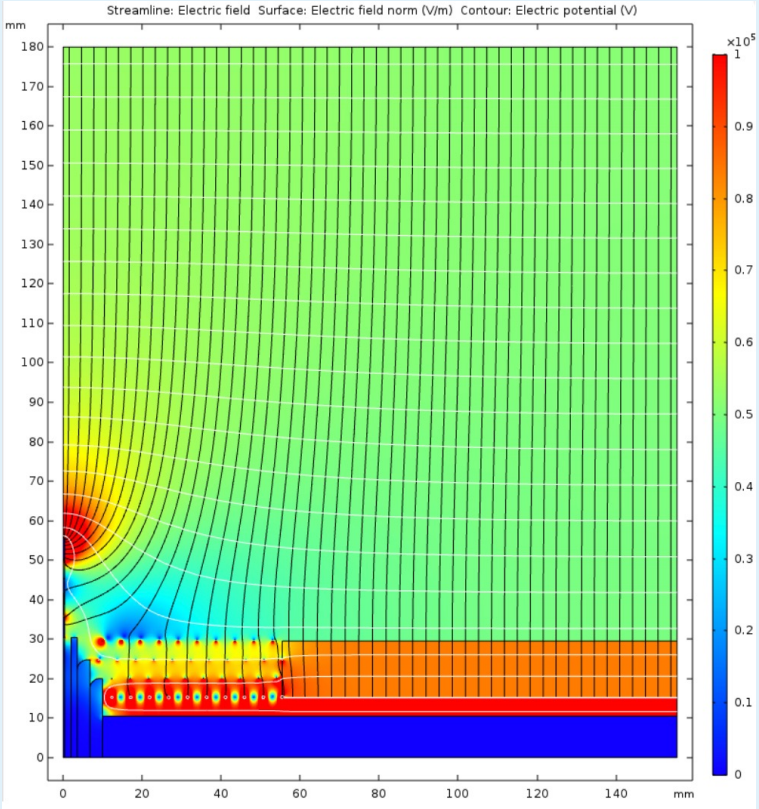
One of these diverters drew high current and was left unpowered, and therefore grounded

- Led to track distortion and broken tracks



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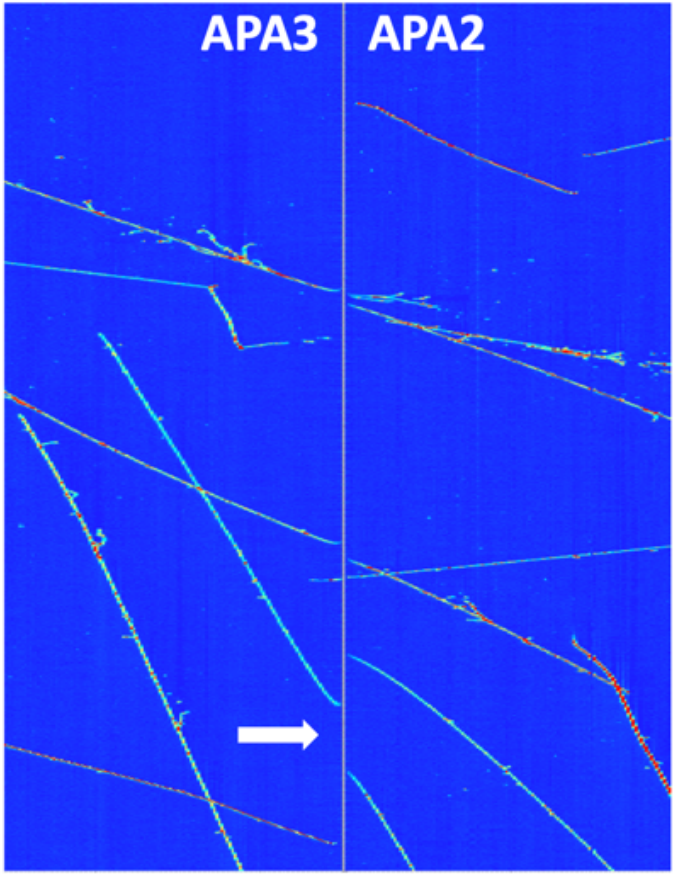
Task-force looked at the pros and cons of diverters

- Active diverters risk track distortions, broken tracks and charge losses if they short
- Passive diverters take time to charge up and respond slowly to HV changes or instabilities
- The gaps and charge losses between APAs with no diverters are relatively easy to correct for

We therefore will not use electron diverters in DUNE



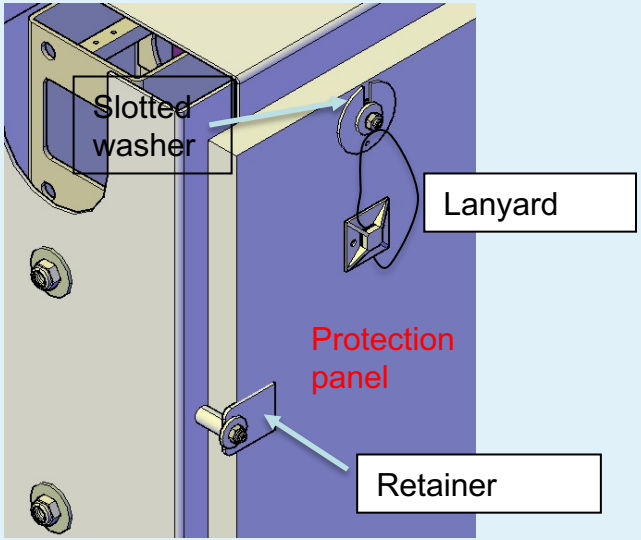
Protection panels and fasteners

Protection panels were heavy

- Some fasteners dropped into the APA

Protection panels have been redesigned to be lighter

- All fasteners are now captive



Target wire tension

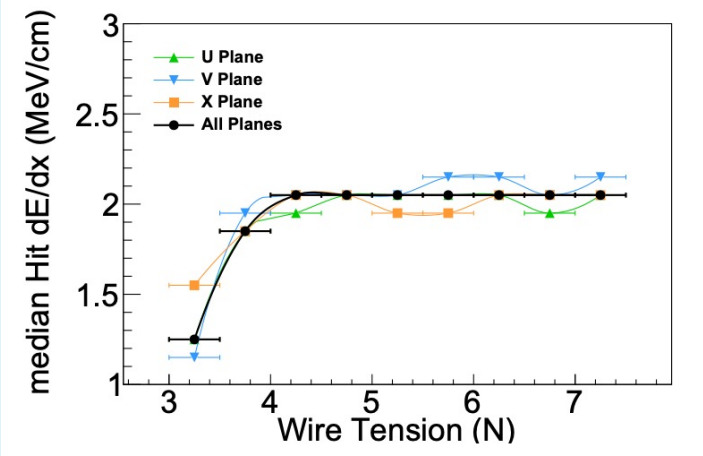
In ProtoDUNE, the wire tension requirement was >4 N

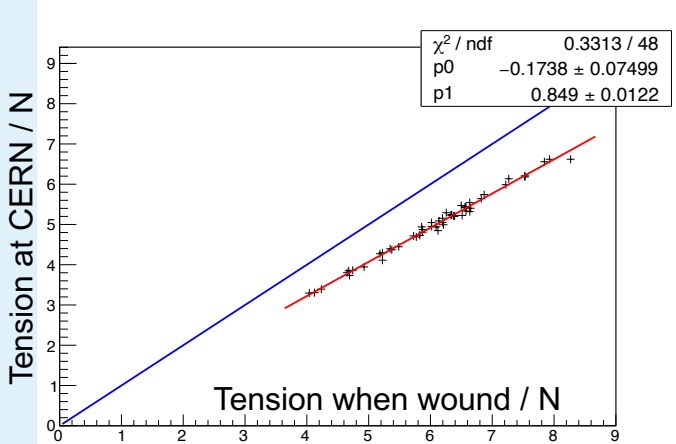
Evidence seen that dE/dx measurements drop on wires below 4.5 N tension

X-layer wires can lose some tension (0.5-1 N for 5 N wires) once other layers are wound

Therefore our tension requirement at the factories is >5.5 N

- And <7.5 N for the majority of wires to ensure frames are not over-stressed





Broken wires

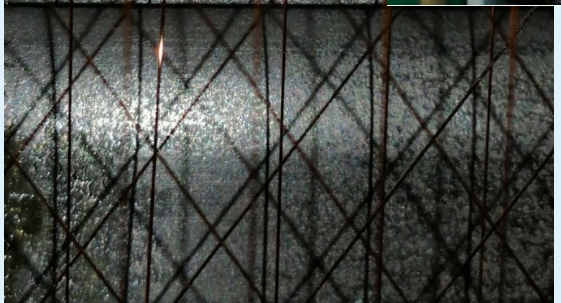
3 broken wires found during decommissioning

- 2 V-layer (APA 3) and 1 X-layer (APA 2)

Wires came loose during warm-up

- No shorting during data-taking

But the V-layer wires were dead throughout



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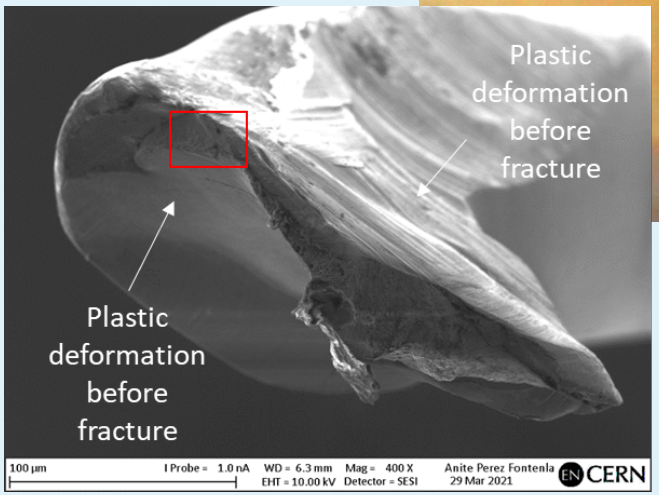
Extensive studies including electron microscopy and boroscope inspections

Causes of all broken wires understood and addressed in the design and procedures



Broken X-layer wire

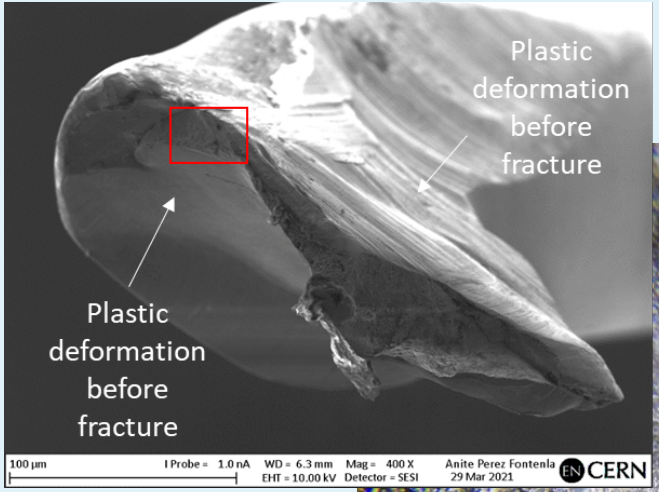
Broken end of wire shows pre-existing damage under electron microscope

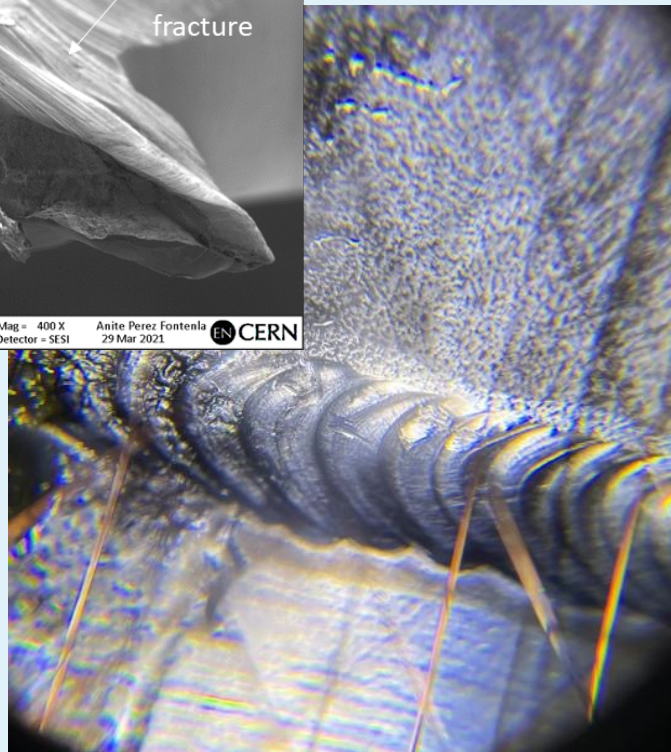
Scratch visible on frame immediately below break point

Consistent with a tool hitting the wire and frame during construction

Procedures strengthened

- If there is any suspicion that a wire might be damaged, that wire is to be removed

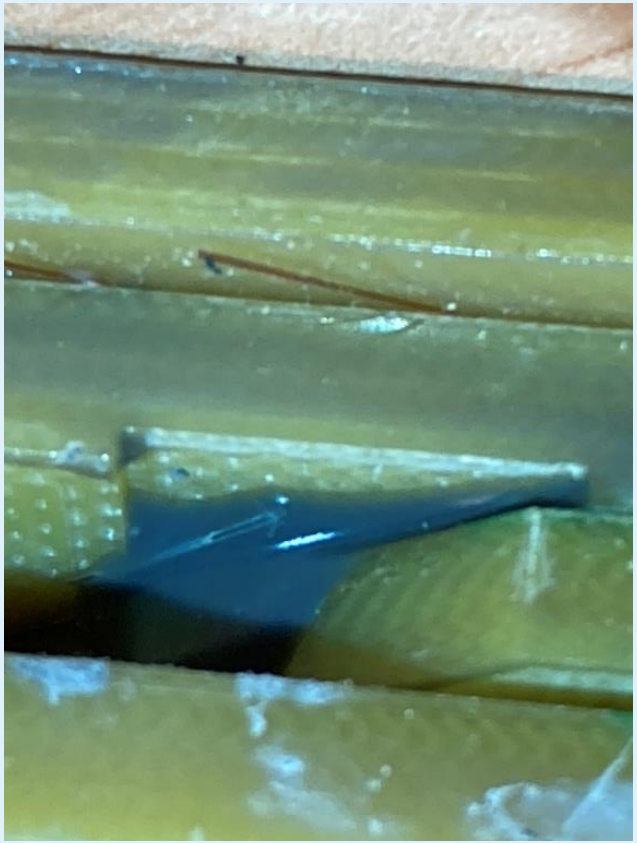




Broken V-layer wires

Epoxy leaked into the gaps between head boards

- Unintentionally bonding the wire between two adjacent boards



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Additional wire relief designed into the corner head boards

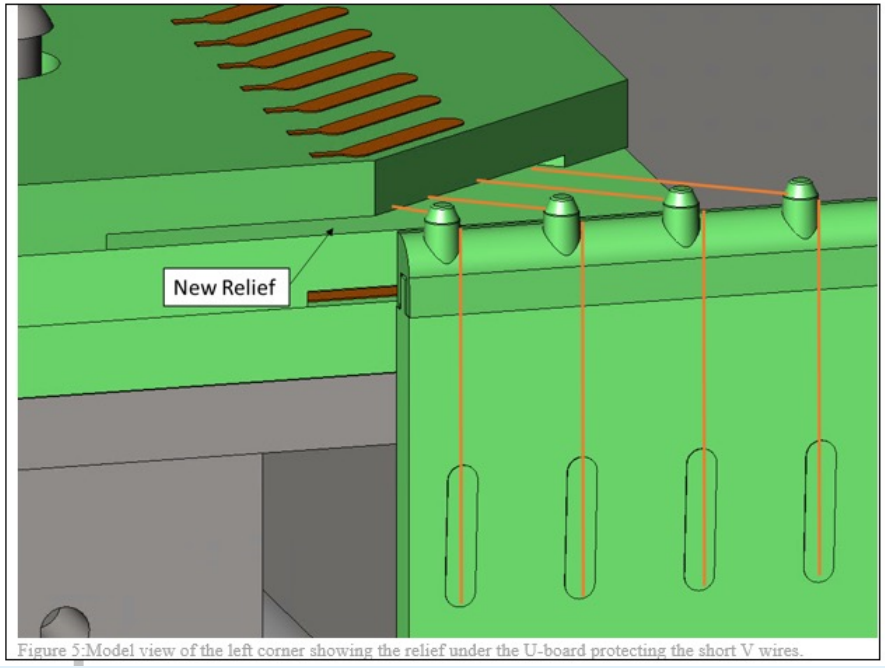


Figure 5:Model view of the left corner showing the relief under the U-board protecting the short V wires.

Part 3: Interfaces

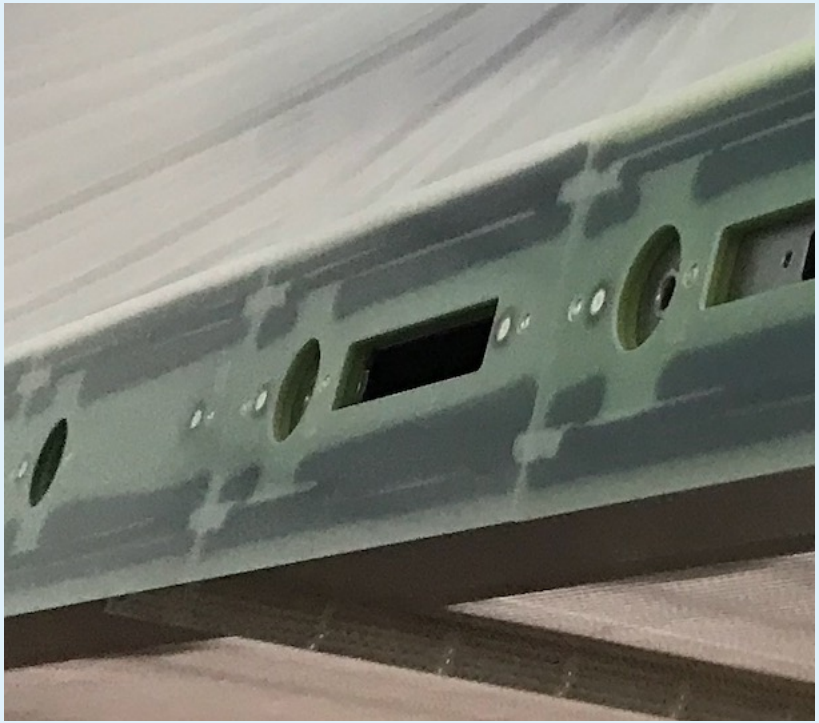
Primary interfaces with other consortia:

- Photon detectors
- CALCI
- Electronics
- HV

Photon detectors

Primary interfaces:

- Access slots for PDs through side tubes



Photon detectors

Primary interfaces:

- Access slots for PDs through side tubes
- Support rails for the PDs

Photon detectors

Primary interfaces:

- Access slots for PDs through side tubes
- Support rails for the PDs
- Cable routing

Photon detectors

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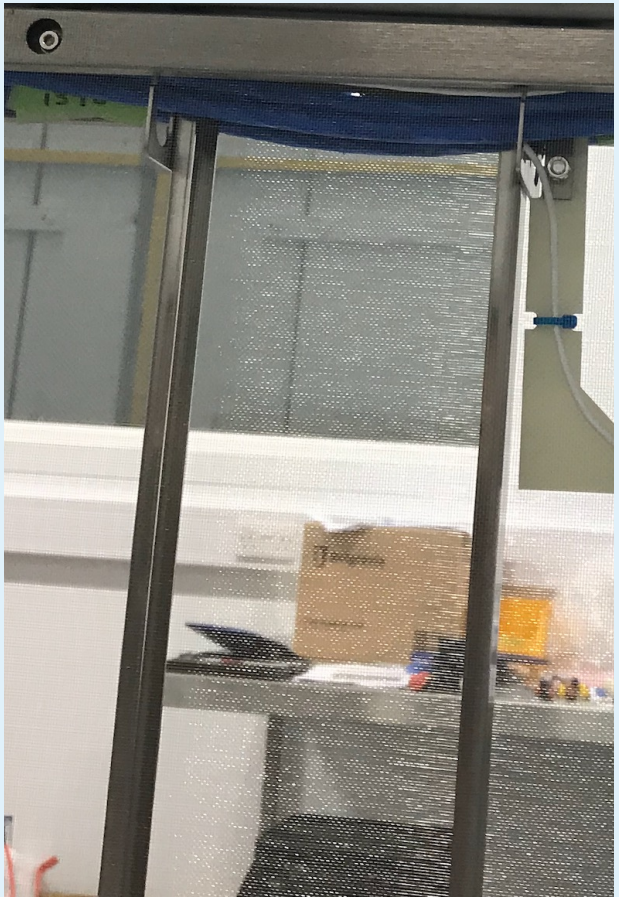
Photon detectors

Primary interfaces:

- Access slots for PDs through side tubes
- Support rails for the PDs
- Cable routing
- Cable connection
- Light occlusion from grounding mesh
  - Minimum open area: 84%



Photon detectors

Primary interfaces:

- Access slots for PDs through side tubes
- Support rails for the PDs
- Cable routing
- Cable connection
- Light occlusion from grounding mesh
  - Minimum open area: 84%

All have been installed on ProtoDUNE-2 APAs 1 & 2

CALCI

4 temperature sensors anchored to the APA frame

- With readout cables installed, following the PD cable routing
- 2 of the sensors in thermal contact with the frame on half of the APAs

Measurement of the temperature of APA frames during cool-down

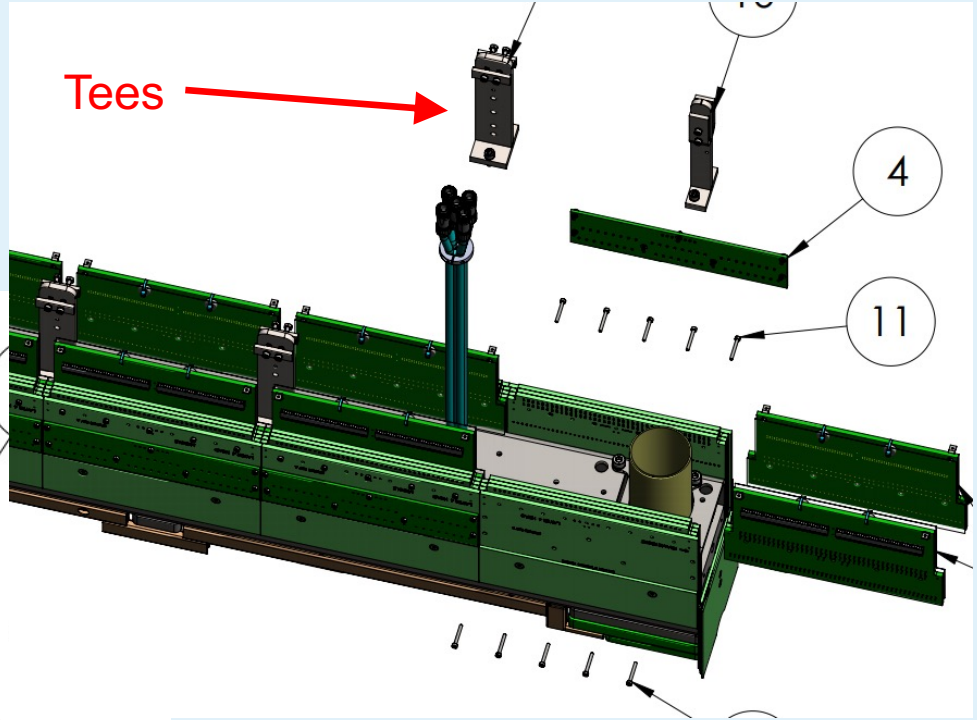
Temperature map of the liquid argon adjacent to the active volume

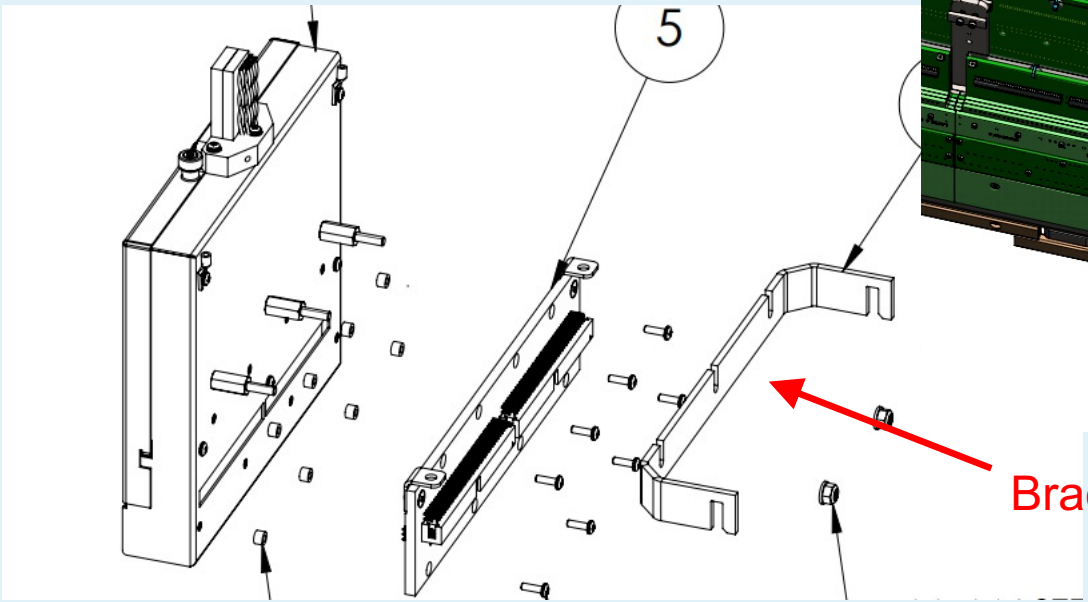
Installed on ProtoDUNE-2 APAs 1 & 2

Electronics – mechanical interfaces

Mechanical support for 20 CE boxes

- Brackets and tees



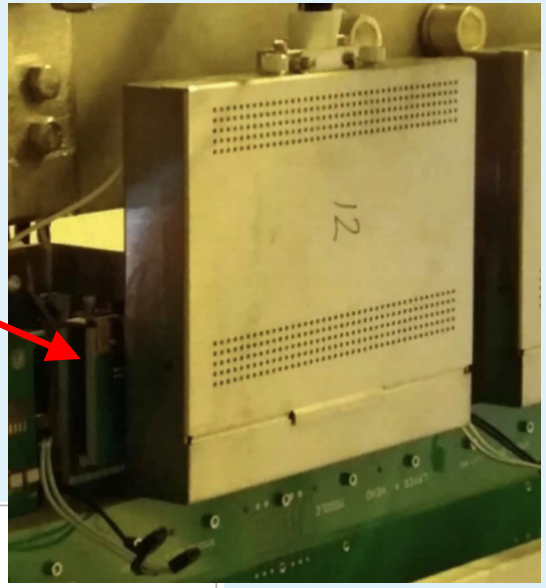


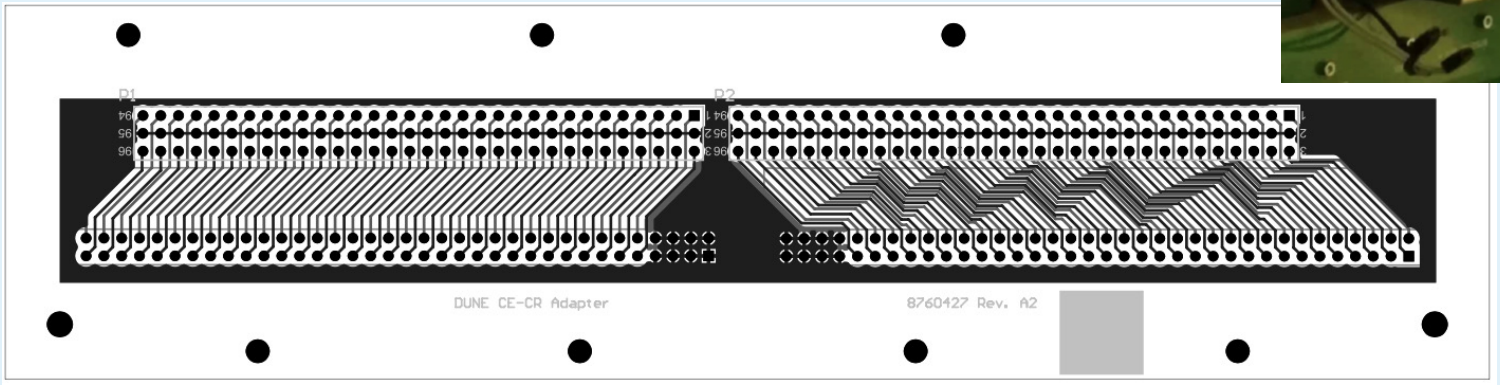
Electronics – mechanical interfaces

Mechanical support for 20 CE boxes

- Brackets and tees

Adapter boards connecting the FEMBs to the CR boards





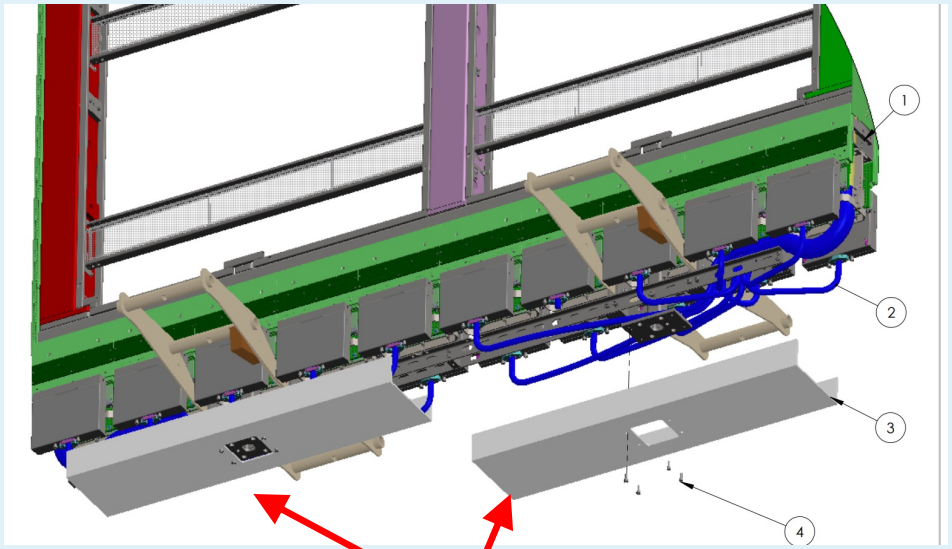
Electronics – mechanical interfaces

Mechanical support for 20 CE boxes

- Brackets and tees

Adapter boards connecting the FEMBs to the CR boards

Cable restraint on head tube of lower APA



Electronics – mechanical interfaces

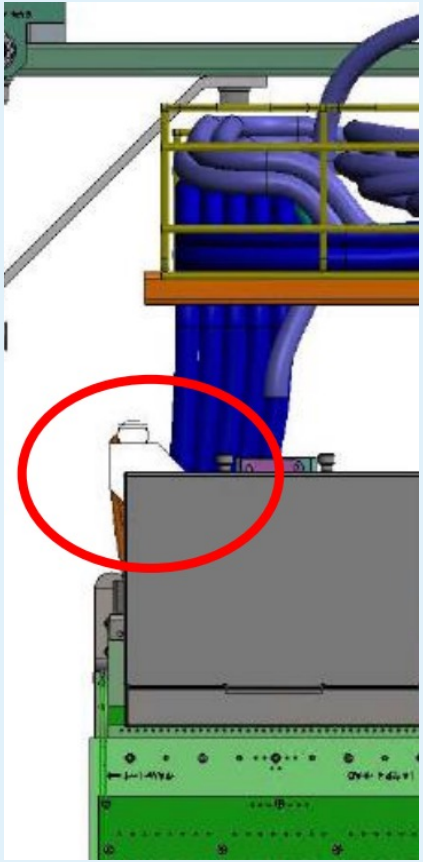
Mechanical support for 20 CE boxes

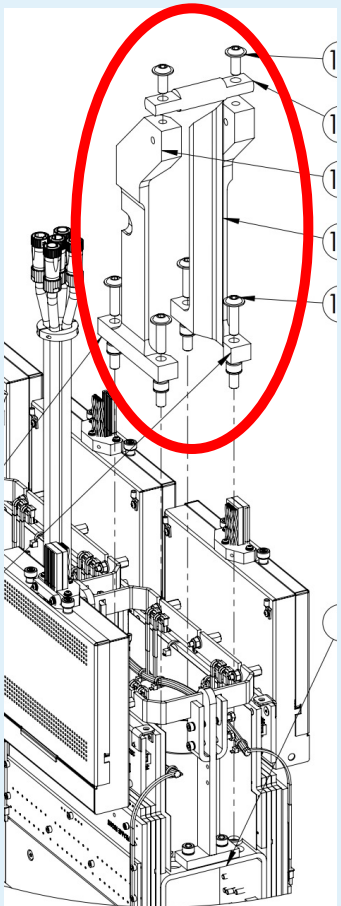
- Brackets and tees

Adapter boards connecting the FEMBs to the CR boards

Cable restraint on head tube of lower APA

Cable routing (conduit) from lower APA and cable grip





Electronics – mechanical interfaces

Mechanical support for 20 CE boxes

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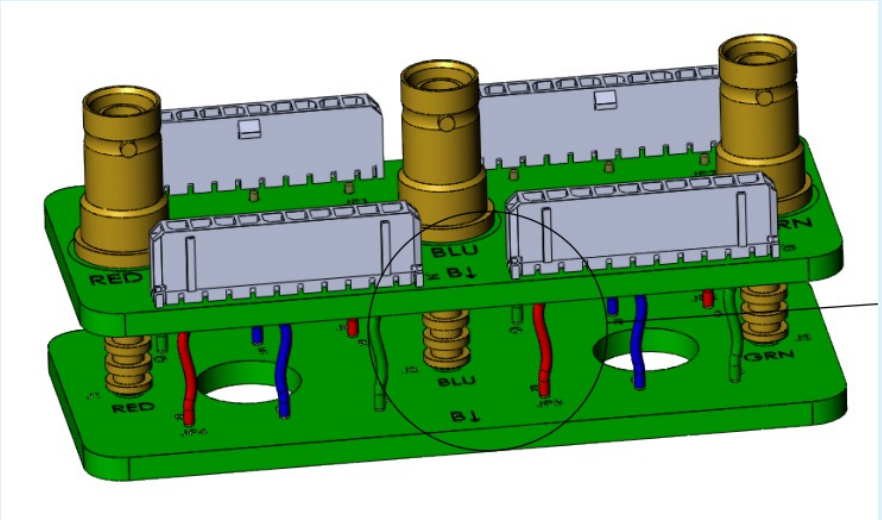
SHV connectors



Electronics – electronic interfaces

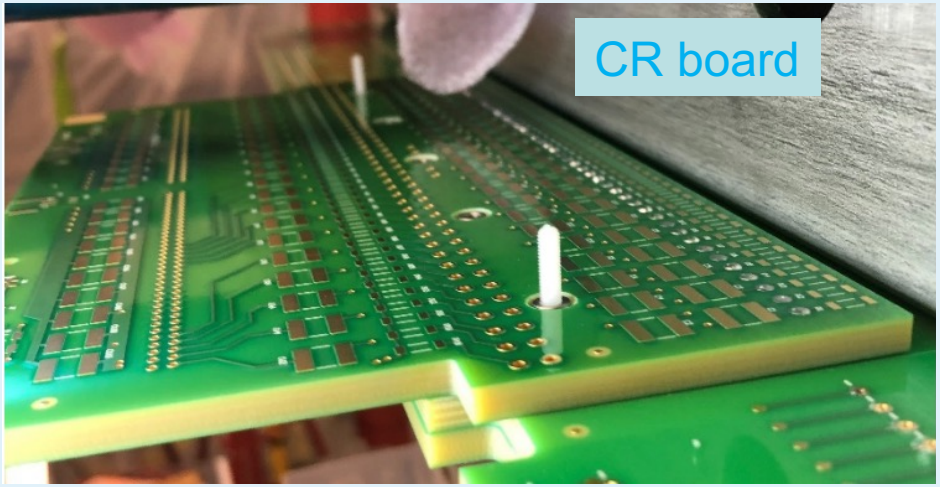
Choice of wire-bias voltages

Anode Plane	Bias Voltage
G - Grid	−665 V
U - Induction	−370 V
V - Induction	0 V
X - Collection	820 V
Grounding Mesh	0 V

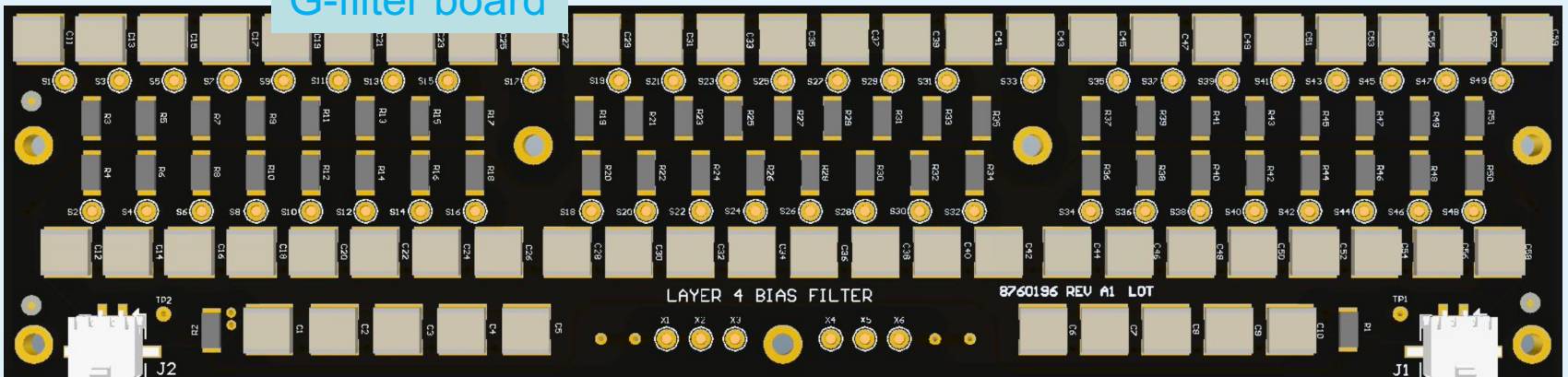
Electronics – electronic interfaces

Choice of wire-bias voltages

Filtering of wire-bias voltages through CR boards and G-filter boards



G-filter board



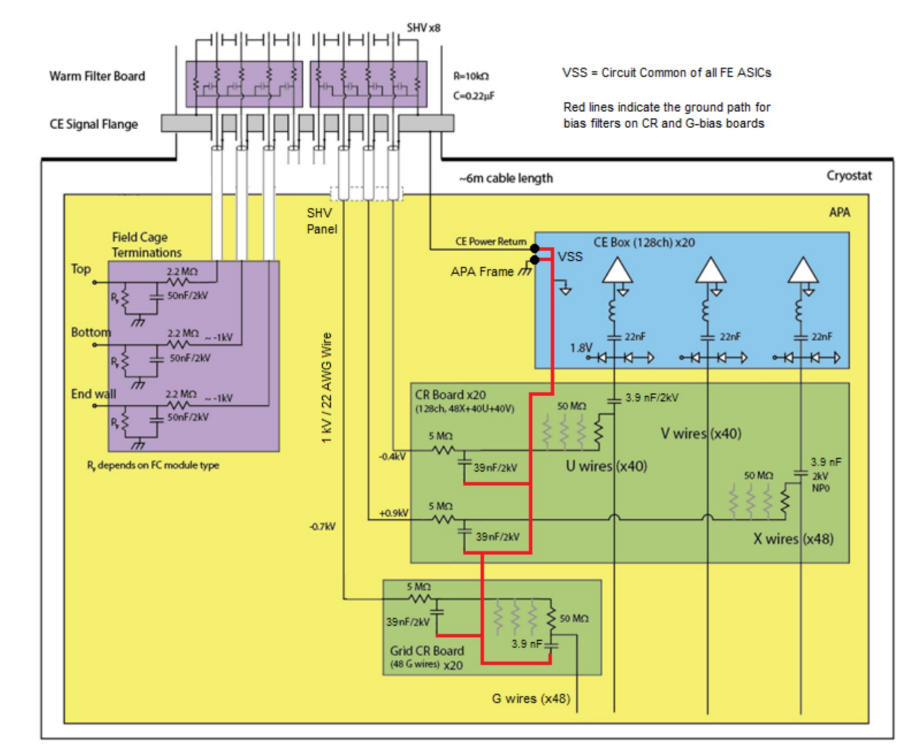
Electronics – electronic interfaces

Choice of wire-bias voltages

Filtering of wire-bias voltages through CR boards and G-filter boards

Grounding scheme and electrical insulation

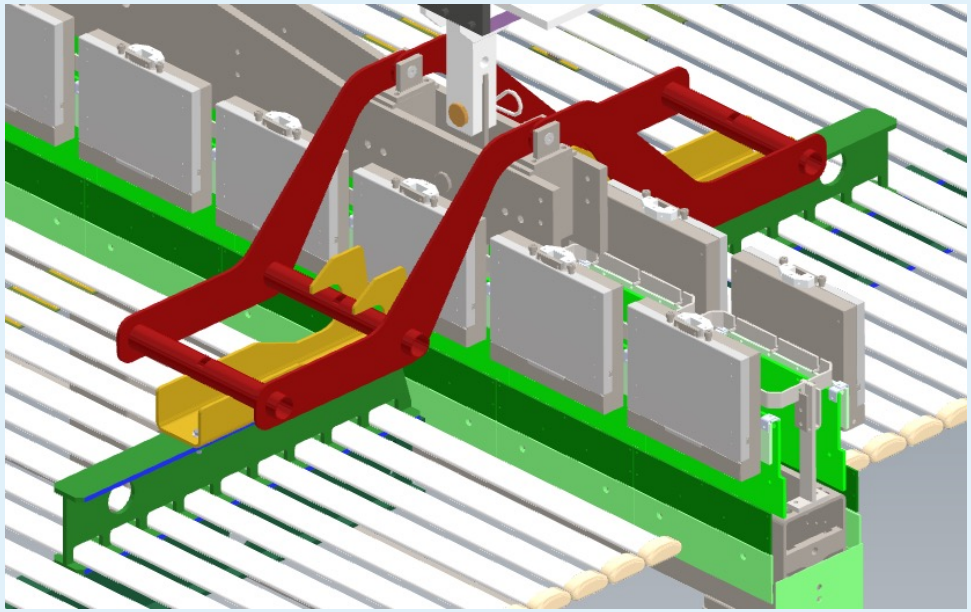
- See talk by Andy Laundrie



HV

Interface with the HV consortium comes through

- Mechanical supports for field cages
- G-plane bias voltage is related to the field-cage termination voltage



The end

Significant technical progress since ProtoDUNE-1

- Responded to lessons learnt
- Improved the production process

Many lessons learnt from ProtoDUNE-1

- All responded to in the design you are now reviewing

Interfaces with the photon-detector, CALCI, electronics and HV consortia

- All implemented in ProtoDUNE-2 APAs