Overview and Physics Requirements

Christos Touramanis

APA Final Design Review

31 August 2021

Outline

- Part 1, overview, context, and points of general interest
- Part 2, Physics requirements

DUNE APA reviews

- Design Review: July 2016
- Mechanical 60% Design Review: March 2019
- Electrical 60% Design Review: November 2019
- Transport Box 60% Design Review: July 2020
- Final Design Review: Aug 31 – Sept 2 2021
- Production Readiness Review: January 2022

- We present regularly to the LBNC. No recommendations in the last two years
- We also present to Director's and DOE reviews as required

- Responses to past review recommendations can be found in a dedicated document

Changes in consortium membership and plan

- 300 APAs were planned to be made for FD1 and FD2, 150 in the UK and 150 in the US
- The NSF proposal to fund the US production wasn't approved
- The current DUNE baseline includes one Horizontal Drift FD (150 APAs) and one Vertical Drift FD (no APAs)
- APAs must be available for FD1 installation at SURF in August 2026 – June 2027
- In response to the above:
  - 130 APAs will be made at Daresbury Lab (STFC funding)
  - 20 APAs will be made at U. Wisconsin and U. Chicago (DOE funding)
  - A number of US institutions have decided to focus their DUNE activity in other areas
- The updated Cost Estimate, Institutional Responsibilities, and Schedule can be found in the corresponding documents.

Technical Leads

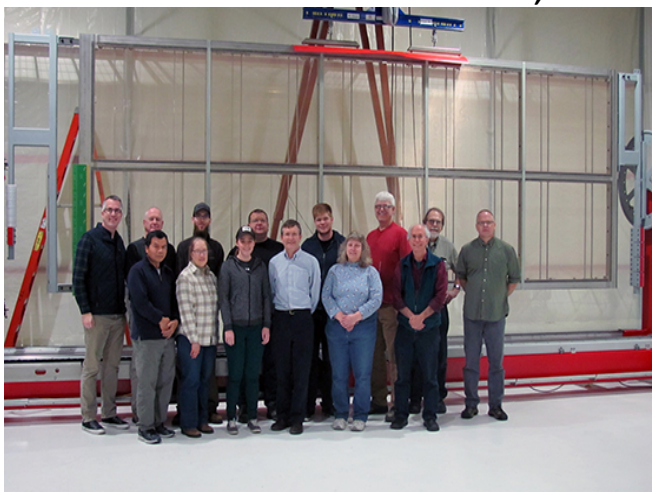
- Alberto Marchionni (Fermilab) has moved on after 3 years of outstanding contributions
- Brian Rebel (UW-Madison & Fermilab) and Justin Evans (Manchester) took over as technical co-leads
- The transition was smooth with a long overlap period

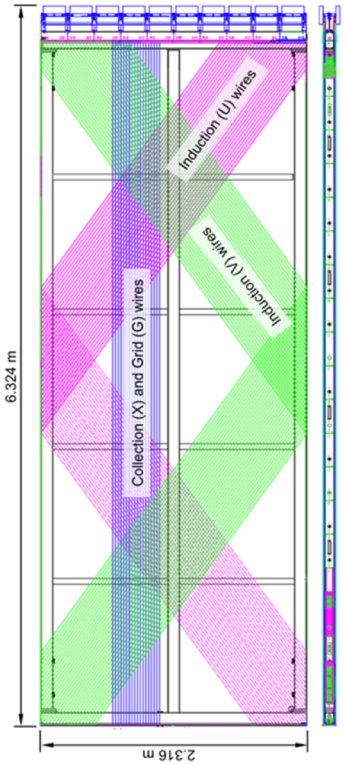
Anode Plane Assembly

The charge sensing device in DUNE FD HD

- 2,760 m^2 sensitive area
- 150 APAs + 2 spares
- 3,500 km wire; ~10^6 segments

PSL, UW





Daresbury, STFC

ProtoDUNE and DUNE APAs

- The DUNE APA design is an evolution from ProtoDUNE which:
  - Satisfies the technical requirements of the FD
    - Allows to integrate APA doublets, a bottom one hanging from a top one
    - Allows the efficient routing of CE cables through the side tubes
    - Allows the routing of PD cables the two wire planes sets
  - Reduces assembly time and uniformity of the final product using pre-fabricated grounding mesh panels made in industry
  - Addresses lessons learned in ProtoDUNE and recommendations from the Electrical Review with modified boards
- So far we have made:
  - 7 ProtoDUNE APAs
  - 1 DUNE APA (for ProtoDUNE II)
  - 3 more to be completed by 01/22

Improvements to the production equipment

- Winder improvement
  - New frame support system eliminates the need to unload/load the frame multiple times during wiring: significant gains in time and reduced risk of damage
  - Used in APA 7 and DUNE APA 1
- New winding head
  - Active wire tension control improves tension consistency
  - Used in DUNE APA 1
- Digital Wire Analyzer
  - Allows measurement of all wire tensions during construction and at later stages
  - Significant production time gain
  - New ability to measure fully all wires on a completed APA

Other ideas that were considered

- Electron Diverters between adjacent APAs
  - In a perfect implementation they shape the field between APAs and improve charge collection
  - Test on ProtoDUNE gave technical and operation problems
  - Specific Task Force with hardware and data analysis experts recommended against deployment in FD
  - See presentation by Justin Evans
- Removal of G wire layer separating the charge sensing volume from the drift volume
  - Studied with simulations
  - Took into account the increased risks of damage to the electronics from large discharge events in the drift volume, with advice from the CE consortium
  - Decision was that the risks clearly exceed the potential benefit to charge collection

APA performance in ProtoDUNE

- Exceptional performance in ProtoDUNE SP
  - *B. Abi et al, 2020, JINST 15 P12004*
  - > 2 years operation in LAr
  - 99.8% live channels
  - No loose wires, no shorts between wires during operation
  - noise, S/N exceeded DUNE FD specifications

Disconnected and broken wires

- After ProtoDUNE decommissioning 3 broken wires were found
- They came loose during warm-up
- An on-site autopsy confirmed the theory developed by Dan Wenman that U and V wires wrapping around the frame near the corners of the APA can be accidently glued to headboards where they pass between the stack, creating short segments that suffer from large forces from differential cooling during cooldown and can break. This explains the two broken V wires and a number of disconnected but not loose U and V wires.
- The third X wire that broke had suffered from some tool hitting it against the frame during construction.
- With mitigation for both cases (design and procedures) we expect the DUNE APAs to have less inactive wires than the 0.2% observed in ProtoDUNE.
- We have produced a *Root Cause Analysis* for this matter.
- See talk of Justin Evans for the details.

APA Shipping Frame

- The two APAs that will make a doublet in the FD will be loaded on to a single ASF which will carry them and protect them all the way to the Integration Clean Room in front of the cryostat underground at SURF.
- Meeting all use case requirements (mounting, dismounting, testing, rotating, bringing down the shaft) and all the safety requirements (involving both US and EU codes and CERN and DOE/Fermilab safety requirements) is a big challenge and that is behind the change of design after the ASF 60% review.
- We now have concluded the design and analysis and prototypes are being made at CERN and by UK industry.
- See talks by Jeff Nelson and Mariana Zimbru on Thursday.

What is not completed: analysis

- The mechanical analysis of the APA is still ongoing.
- It is a demanding and important amount of expert work.
- New inputs came recently from the dynamic analysis of the ASF and the two APAs mounted on it.
- Olga Beltramello will present the Compliance Office view on where we stand.
- We don't expect modifications to the APA design which would be relevant for this review.

What is not completed: APA tests in transit

- Completed APAs will be tested for wire tension, continuity and isolation at the factories.
- They will be stored at Fermilab where a sample of them will be checked visually and with the DWA.
  - Sampling ratio TBC
- 10% of all APAs, with emphasis on the first ones to be built at each factory, will be cold tested.
  - Option 1: at CERN
    - Existing infrastructure but introduce one extra land/sea/land transportation for UK APAs and two Atlantic crossings for US APAs
  - Option 2: at Fermilab
    - Less travel steps for all APAs but new infrastructure has to be built (cold box, cryo system, lifts and rotation of ASF/APAs)
- The consortium will take decisions as a matter of priority in the following weeks, with appropriate consultations with management, such that QC requirements are met, risks are minimized, and the plan is compatible with the available resources envelope.

Physics Requirements

Following DUNE practice we have a cascade of requirements:

- Physics requirements guide the design and are held by the EB
- Specific design details are derived from the physics requirements and technical considerations and are held by the TB
- The consortium holds further requirements addressing interfaces, fabrications, transportation & storage, installation

I will address here only the physics requirements (held by EB)

Requirement SP-FD-6

- What is addressed
  - Gaps between APAs in the FD TPC
- Aim
  - To minimize loss of fiducial volume and distortion of charge collection
- Value
  - < 15 mm between APAs on the same DSS beam, < 30 mm between APAs on adjacent beams
- Rationale
  - Gaps are required to ensure that APAs don't crash into one another when warm, when cold, and in cooldown

Requirement SP-FD-7

- What is addressed
  - Drift field non-uniformity
- Aim
  - Control misalignments of TPC components so that drift field uniformity meets the HVS requirements
- Value
  - < 1% throughout the TPC volume
- Rationale
  - DSS design, the mounting system of APAs on it, and APA specific fixtures will maintain APAs planes flat and at 90 degrees to CPA and FC planes

Requirement SP-FD-8

- What is addressed
  - APA wire angles
- Aim
  - The wire angles shall be set such that each induction wire crosses each collection wire only once, reducing ambiguities.
- Value
  - 0 degrees for collection wires, plus/minus 35.7 deg for induction wires
- Rationale
  - This stems from the constraint that wire readout electronics sits on top of the APA to minimize dead space between APAs

Requirement SP-FD-9

- What is addressed
  - APA wire spacing
- Aim
  - To optimize between good S/N (coarser pitch) and good vertex resolution (finer pitch)
- Value
  - 4.7 mm (4.669 for U,V; 4.790 for X,G)
- Rationale
  - S/N consistent with 100% hit reconstruction efficiency for MIPs
  - Spacing fine enough to provide 1.5cm vertex resolution in y-z plane

Requirement SP-FD-10

- What is addressed
  - APA wire position
- Aim
  - Wire position tolerances should ensure uniform wire plane transparency and required precision on dE/dx reconstruction
- Value
  - $\pm$ 0.5 mm tolerance on both wire pitch within a layer and layer to layer distance
- Rationale
  - Simulations and analytical calculations, ProtoDUNE data analysis

In lieu of conclusions

The APA consortium has invested huge amounts of effort to be at the position to stand in front of this review committee.

Many thanks to all involved for their dedication and hard work.

This review is key for us, to allow us to transition from the preparatory phase (design, development, demonstrations) to full production.

We wish to express our appreciation to all of you, our reviewers, for accepting to put in your time and effort.

Welcome, and let's get to business!