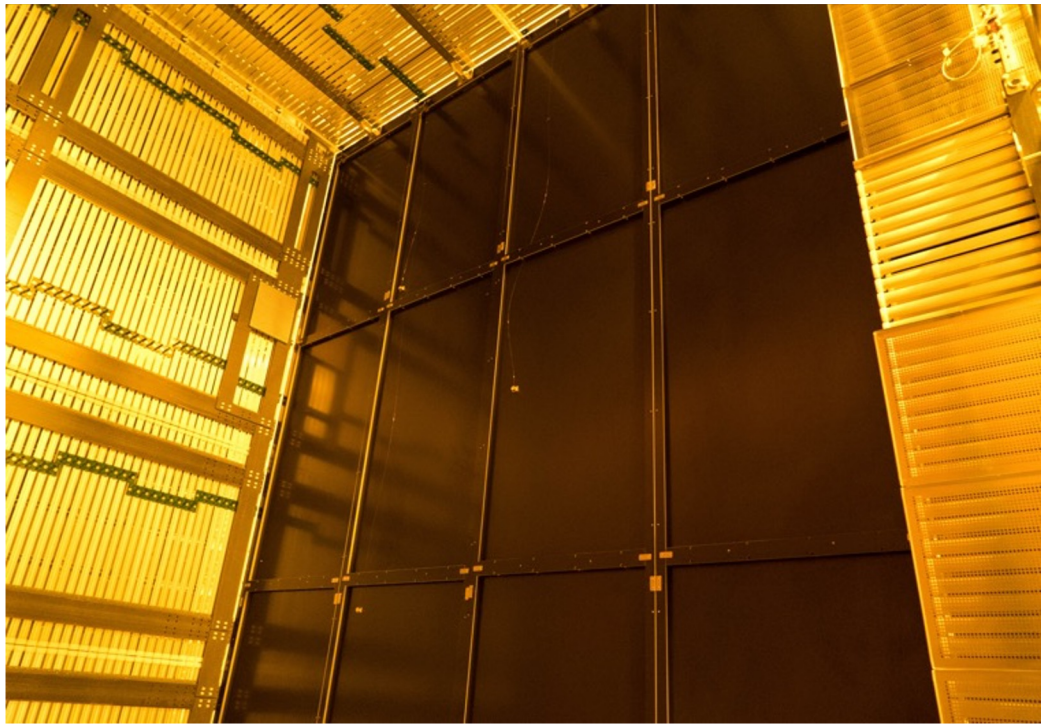
Cathode Plane Assembly (CPA) – Production Readiness Review

Steve Magill

CPA PRR

1 Oct 2024



EDMS Folder CERN-0000246072
EDMS #307991 v.2 Guide to CPA PRR Documentation

Argonne NATIONAL LABORATORY

DUNE

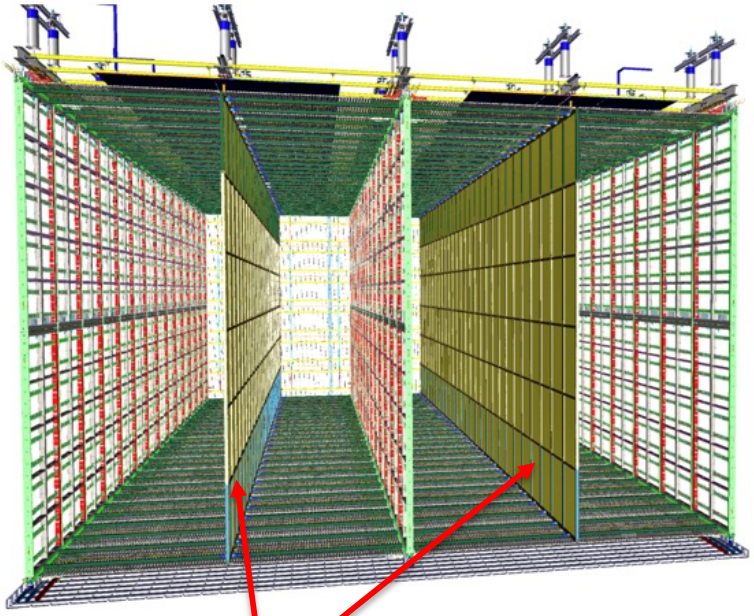
DUNE Production Readiness Review
Charge
Cathode Plane Assemblies (CPA)

1 October 2024

The committee is requested to review the readiness of the DUNE cathode plane assemblies (CPA) for production and determine if they meet the requirements of production readiness as outlined in the LBNF/DUNE Review Plan (edms-2173197) supported by the DUNE Far Detector PRR deliverables defined in (edms-2493568). Based on the documentation to be posted in edms-CERN-0000246072, the committee should provide answers to the following questions:

1. Scope, Cost and Schedule
   a. Is the scope of work defined properly?
   b. Are the proposed schedule and resources appropriate for achieving the defined scope and satisfying detector installation milestones with opportunities for schedule recovery in, for example, scenarios where supply issues or needs for component rework arise?
   c. Are the prototype test-results consistent with initial acceptance criteria?
2. Design Status
   a. Are all design specifications, requirements, performance, and interface documents reviewed, approved, and released?
   b. Are the drawing packages complete and released?
   c. Have all previous review recommendations been closed out?
   d. Is there a process for change management in place?
3. Work planning and control
   a. Have all key project team members been identified, with defined roles and responsibilities?
   b. Are staffing levels suitable to support the production plan?
   c. Is there evidence of work planning for day-to-day procedures?
   d. Has an appropriate hazard and safety assessment been performed and appropriate risk-mitigation measures implemented?
4. Production and Quality Assurance
   a. Have all of the major risks been identified and managed?
   b. Is the supply chain in place and well planned, including shipments between partner institutes?
   c. Is the process for incoming component inspection well planned?
   d. Are all travelers, and assembly and quality control procedures updated and available?
   e. Is there a plan to manage all relevant inspection, assembly and testing data?
   f. Have the acceptance criteria been clearly defined and documented in each applicable procedure, drawing, and specification?
   g. Is there a credible plan for post-production testing and storage to ensure that the quality of the modules will be preserved through to their installation in the detector?

CPA for FD-HD



CPA Arrays

- 2 – 25 row Arrays
- 25 CPA/FC Assemblies per Array
- 1 CPA Plane per CPA/FC Assy.
- 2 CPA Panels per Plane
- 6 CPA Units per Panel

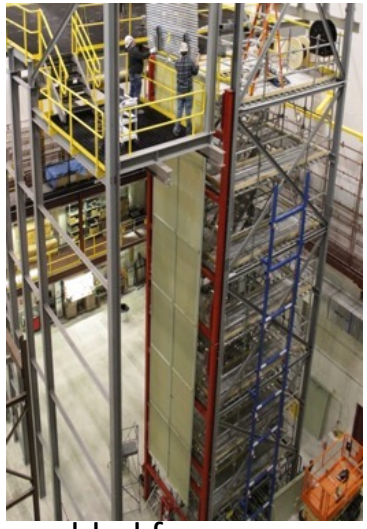
-180 kV -> (E_{drift} = 500 V/cm)

CPA Unit

600 produced in 2 factories – ANL and College of William and Mary
Shipped 12 Units per crate to SURF

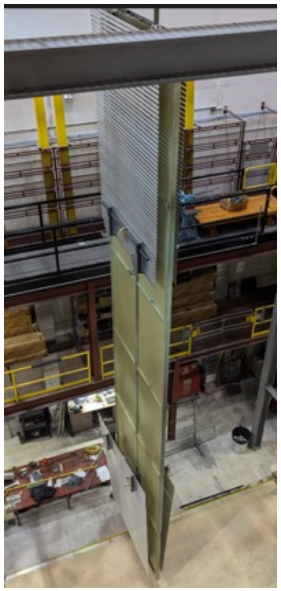
CPA Panel

100 assembled from CPA Units at SURF



CPA Plane

50 assembled from CPA Panels at SURF

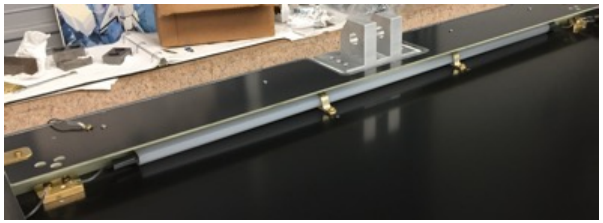


CPA/FC Assembly

50 assembled from CPA Planes and Top/Bottom FC modules at SURF

CPA Changes after FDR

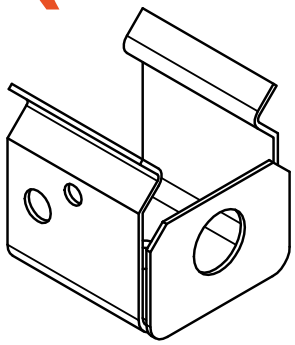
- Doubled HV Bus *(PD2)*
  - Recommendation from FDR – increase redundancy of connections
  - HV bus (both sides of CPA - connection redundancy > 8

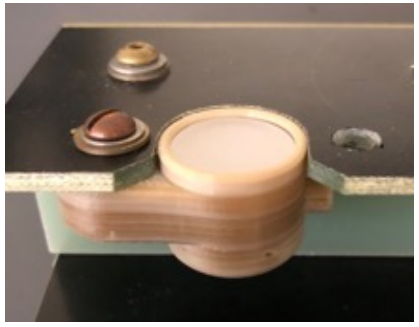


- FR4 insulating bead for exterior FSSs *(Cold Tests)*
  - Process time for manual application of glue bead – 25 minutes per meter of FSS edge (includes edge prep, mixing of epoxy, stiffener, application – *20 minute working time*)
  - For FD-HD, ~600 m of glue bead -> 6.5 weeks 1 FTE
  - FR4 bead – 10 minutes per FSS piece -> 2.5 weeks 1 FTE

CPA Changes after FDR (cont.)

- Mounting clips used for all Profiles ***(PD2)***
  - Easier mounting – self-centering – accommodates anti-rotation rod
- Anti-rotation rods connecting Panels ***(PD2)***
  - Prevents ”zig-zag” hanging of CPA Panels seen in ProtoDUNE SP
  - SS rods applied under Profiles through holes in clips
- 3D-printed PEEK PD diffusers ***(PD2)***
  - On ProtoDUNE SP, SS diffuser housings machined individually
  - 3-D printing of PEEK diffuser housings - << cost





1. Scope, Cost and Schedule

Is the scope of work defined properly?

Scope includes : Production of CPA Units at 2 factories, Checklists including uploaded data to DUNE HWDB, Shipping to SURF

The following items are complete, tested and ready for production:

- Production procedures in place in iPad app (used to produce ProtoDUNE 2 of FD1-HD).
- Production checklists complete (tested on ProtoDUNE 2).
- Checklist data uploaded to the DUNE HWDB through the app (tested on ProtoDUNE 2).
- Complete QC data is uploaded to and unique Part IDs are assigned by the HWDB (tested on ProtoDUNE 2 in developmental version of the HWDB).
- Shipping crate design and use (tested in Ash River trial fall 2020).

EDMS #3078044 v.1 Production Status and Manufacturing Procedures

Are the proposed schedule and resources appropriate for achieving the defined scope and satisfying detector installation milestones with opportunities for schedule recovery in, for example, scenarios where supply issues or needs for component rework arise?

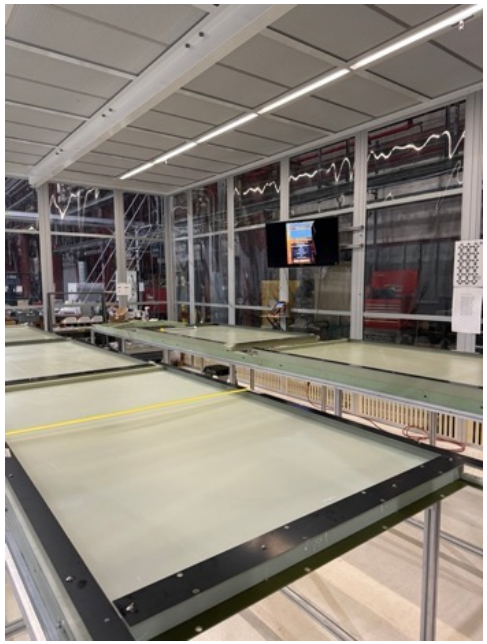
Production Schedule :

- Production rate of CPA Panels has been consistent throughout prototyping and installation trials at 1 CPA Panel per (half-time) week by 2 workers.
- Total time to produce 100 CPA Panels from 2 factories is ~32 weeks
- Personnel required at each factory is 4 people working 4 hours per day (allows for non-overlapping hours between personnel, class attendance, etc.)
- TPC position of the CPA Panels is naturally pre-determined for each factory avoiding row assignment mixups
- Shipping rate is 2 crates every 2 weeks from each factory

Estimated start of CPA production		Mar 2026
Production schedule per factory	32 weeks	
Estimated all CPA crates at warehouse		Dec 2026
Estimated start of SURF clean room assembly		Dec 2027
Float in schedule between end of production, start of assembly		12 months

EDMS #3078042 v.1 Production Schedule

CPA production factory resources



Interior of Clean Room:
Air flow – filtered ceiling fans blow air down and out vent slots at the base of walls
2 production tables with templates
TV monitor with iPad attached

- iPad procedures, checklists, drawings, HWDB
- Display of production progress (shipped Panels, Panels under construction, etc.)

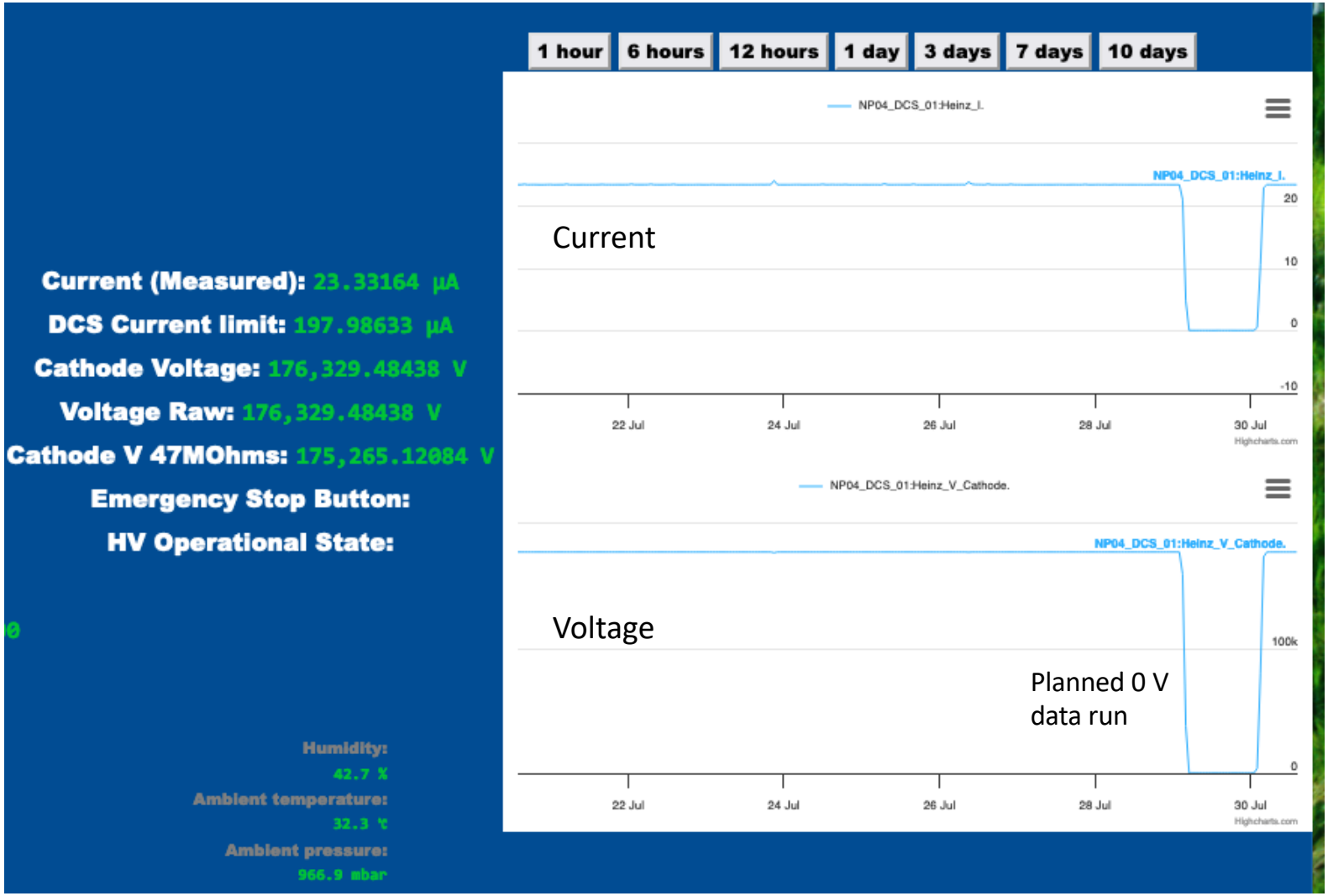
Panel production :
3 Units on table aligned and pinned
Upper Unit is completed both sides with FSSs
A-frame cart holds all parts for Panel production
Top Unit strapped and ready for bagging and tagging -> crate

Panel production :
2 Units on table (Units 5, 6)
Front side FSSs installed
Unit 5 (upper) ready for strapping and flipping to rear side for assembly

CPA production area :
Loading dock (behind camera)
Crates location (to be covered with 10’ x 10’ tent w/sides)
Frame cleaning area
Storage/QC testing of parts
Clean room structure

Cordless torque screwdriver ~all connections

Are the prototype test-results consistent with initial acceptance criteria?



Stable running at -180 kV for > 4 months

>99.99% uptime

>50 ms e lifetime

2. Design Status

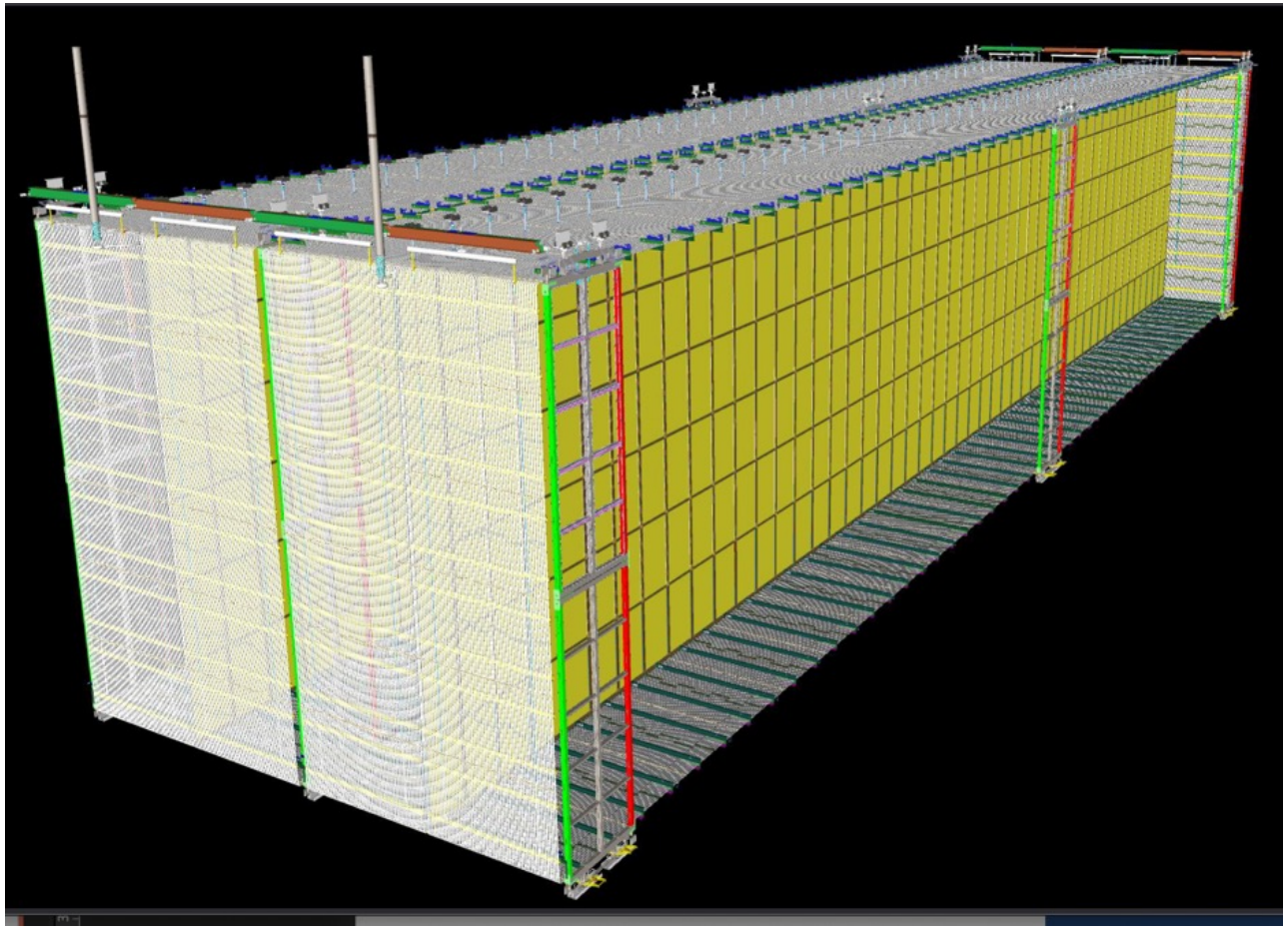
Are all design specifications, requirements, performance, and interface documents reviewed, approved, and released? Have all previous review recommendations been closed out?

Design Specifications, requirements
-> DUNE FD TDR, Vol IV : Far Detector Single Phase Technology
DUNE Docdb 16880 v4

Interface documents
JT-HV to JT-PD Far Detector1 Interface Control Document
EDMS #3078020 v.1

Final Design Review Closeout
FD1 HD FDR Closeout
EDMS #2796146 v.1

Are the drawing packages complete and released?



3D of TPC HVS

CPA Array shown in yellow

Final drawing package for CPA production waiting for 1 final drawing of Profile clip for release

EDMS #2144461 v.7 DUNE FD1 HVS 3D model
EDMS #2633164 v.1 HV-CPA

Is there a process for change management in place?

If changes to the CPA parts and hardware are found to be necessary or desirable during production, reviews and approvals of the proposed change must follow strict guidelines as follows:

1) Any proposed change involving part design and/or hardware used must be reviewed and approved by the engineer responsible for that component. In the FD1-HD HVS Consortium, that person is Vic Guarino of ANL – HVS Consortium Project Engineer.
2) Once approved by the Project Engineer, the HVS Consortium Technical Lead – Bo Yu of BNL, must also review and approve the change. And Francesco Pietropaolo of CERN, HVS Consortium Lead must also be made aware and approve of the change. In some cases, testing of the changed components may be requested by the Technical Coordinator before approval.
3) After approval by the Technical Lead, the Project Engineer can make the approved changes to the drawings and/or hardware list and the change becomes part of the CPA production procedure. Approved changes should be documented and tracked in an EDMS folder for the Consortium.

With this system, the relatively few expected changes will be thoroughly reviewed before implementation and will be tracked throughout the production process.

EDMS #3078041 v.1 Process for requesting and approving engineering changes during production

3. Work Planning and Control

Have all key project team members been identified, with defined roles and responsibilities? Are staffing levels suitable to support the production plan?

Production tables and templates are identical in the 2 production factories at ANL and College of William and Mary

-> At each factory, 2 personnel are required at each of the production lines to produce 2 CPA Panels in 2 weeks working 4 hours per day, 20 hours per week

-> This production rate has been tested and proven in ProtoDUNE-SP, ProtoDUNE 2 and for trials at Ash River

-> At each of the production lines, when CPA Units are flipped, all 4 personnel are used to ensure safe performance of that process

-> It is the intention to train at least 5 personnel per factory so that a 4-person crew can be maintained allowing for illness, vacation, or other absence by a member of the team

EDMS #3078044 v.1 Production Status and Manufacturing Procedures

Is there evidence of work planning for day-to-day procedures?

CPA Procedures and Checklists for DUNE FD1-HD TPC HVS: iPad App Users Guide

Table of Contents

EDMS #3078053 v.1 CPA iPad app user guide

Has an appropriate hazard and safety assessment been performed and appropriate risk-mitigation measures implemented?

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Task-Based Worker Package

WCD 80321.0 Pre-production activities for DUNE FD1-HVS Cathode Plane Assembly (CPA)

Hazard Level: Low L

WCD Status:	Approved	**Status Date:** 09/27/2023	
Authorization Status:	See Authorization Package		
Revision Type:	Original		
Minor Revision Reason:	N/A		
Responsible Individual:	Magill, Stephen R.		
Work Planner:	Magill, Stephen R.	ESH Coordinator:	Landowski, Gregory Joseph
Approving Division:	HEP	Approver:	Yoshida, Rikutaro
Next Review Date:	09/27/2024		

EDMS #3078048 v.1 Production Facility Safety Plan and Hazard Analysis

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4. Production and Quality Assurance

Have all of the major risks been identified and managed?

Risk	Severity	Mitigation strategy
Damage to parts	Low	Replace with spare part, repair if possible
Damage to CPA Unit	Medium	Remove damaged parts, start reconstruction of Unit at appropriate place in procedures on app using spare parts - include all checklists - new PID if needed
Damage to full shipping crate	Medium	Assess whether contents are damaged - notify factory for replacement of parts and/or Units
Damage during assembly, installation at SURF	High	Assess extent of damage - repair and/or replace individual parts if possible - if entire Units, arrange for reconstruction in SURF clean room
Loss of personnel during production	Low	Production schedule accounts for this. Also, will have 5 trained workers per factory where 4 are required (2 workers can keep 1 of the 2 tables in production for a short time)

EDMS #3078045 v.1 Production risk assessment and proposed mitigation

Is the supply chain in place and well planned, including shipments between partner institutes?

- CPA production includes component parts supplied by commercial vendors, CERN, and Kansas State University
- Purchasing and delivery of parts will be divided between the ANL and W&M factories, optimizing time and effort for parts QC and shipping of parts between the factories

Part	Quantity (incl spares)	Source	Location	Prep/Checklist	QC Data Storage
RP	660	CERN	ANL/W&M?	No/Yes	Local
FR4 Frames	2466	Vendor	ANL	Yes/Yes	Local
Hanger Bars	110	Vendor	ANL	Yes/Yes	Local
FSS	3882	CERN	ANL	Yes/Yes	Local
Hinge Blocks	200	Vendor	W&M	No/Yes	Local
Profiles	340	CERN/ANL	ANL	Yes/Yes	Local
HV Bus	470	KSU	ANL/W&M	No/Yes	Local
Al Hardware	3716	Vendor	W&M	No/Yes	Local
MRBs	470	KSU	ANL/W&M	No/Yes	HWDB
AR Rods	210	Vendor	W&M	Yes/Yes	Local

EDMS #3078039 v.1 Procurement plans and responsibilities

Is the process for incoming component inspection well planned?

Parts to ANL:

1. RPs : 6 pieces per Panel -> 600 + 60 spares from CERN
   Time for QC and packaging for 2 people : 20 min per pack -> 1.5 weeks (55 hours).
2. FSSs : 38 pieces per Panel -> 3800 + 82 spares from CERN
   Total time for gluing edge strips and testing is ~4 weeks for 2 people. Time for QC and packaging for 2 people : 45 min per 38 piece package -> 2 weeks (80 hours each).
3. FR4 Frames : 24 pieces per Panel -> 2400 + 72 spares from vendor
   With 2 cleaning and 1 large drying trough, ~48 days to clean and dry 2472 pieces, so ~10 weeks of time but with minimal personnel (only ~0.5 hours per day to fill troughs).
4. Hanger Bar : 1 per Panel -> 100 + 10 spares from vendor
   1 person ~1 day for QC and packing.
5. Profiles : 4 bent profiles per Array -> 8 bent profiles, 198 short T Profiles, 98 B profiles, 48 long profile clips, 400 T/B short profile Z-brackets from CERN
   1 person ~1 week to do QC and pack for factories.

Parts to William and Mary:

1. HV Bus : 4 T/B pieces per Panel -> 400 T/B pieces, 12 pieces per first and last Panel -> 24 total per Array, 198 Panel-to-Panel jumpers, 2000 Section-to-Section jumpers, 8 brass tabs per Panel + 40 additional for ends -> 840 + spares
   1 person ~1 week to do QC and pack for factories.
2. Hinge Blocks : 1 T, 1 B per Panel -> 100 Top + 100 Bottom + 8 spares from vendor
   1 person ~1 week to inspect, check fitting in template and re-pack for factories.
3. Machined Hardware : 20 T-tabs per Panel -> 2000 + 100 spares, 8 rectangle tabs per Panel -> 800 + 80 spares
   ~2 days for 1 person to do QC and pack for factories.
4. MRBs: 4 per Int Panel T/B + 12 per Ext ends -> 448 + 32 spares
   ~1 week for 1 person to do QC, enter into database and pack for factories.
5. Anti-rotation Rod : 198 + 20 spares
   1 person ~1 day to do QC and pack for factories

~4-5 weeks for 2 people at each factory

-> *However – 10 weeks to clean FR4 frames*

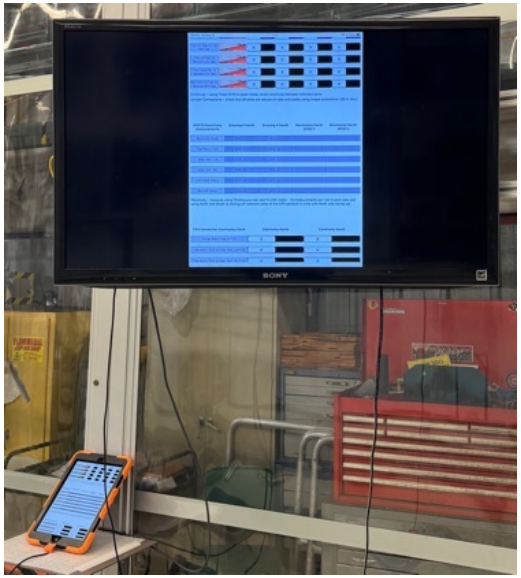
Frame parts lead time ~5 months

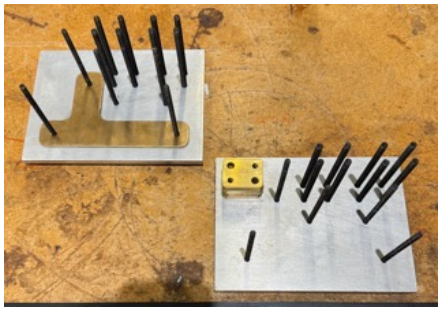
-> Monthly shipment of parts

-> Start of production - ~6 months after PO

EDMS #2952719 v.1 CPA Parts QC, Personnel and Schedule Requirements

Are all travelers, and assembly and quality control procedures updated and available? Is there a plan to manage all relevant inspection, assembly and testing data?





iPad app Home Page, Checklist displayed on monitor in clean room

QC tooling:

- HV Test box for FSS
- Resistance measurements
- Hardware tab templates
- Laser plumb bob

Tagging system for Units, Panels, Planes and CPA/FC Assemblies

EDMS #3078051 v.1 QC Plan, traveller docs and HWDB data, EDMS #3078026 v.1 CPA Part Identifier Assignments

Have the acceptance criteria been clearly defined and documented in each applicable procedure, drawing, and specification?

Some QC testing of parts can be required of and performed by the vendor before shipping to the factories. The following table lists the part type, vendor type, and QC required for critical parts of the CPA production.

Part	Source	QC required	Supplied Tooling	Requirement	Report
FR4 Frames	Commercial Vendor	Check of tongue and groove	Aluminum templates	Spot check – first 10 then at bit change or every 40th piece	Pass - each test
FR4 Frames	Commercial Vendor	1.Strictly adhere to mesh orientation requirement 2. Strict observation of marked tolerances			
Hanger Bars	Commercial vendor	Visual Inspection	NA	No machining residue	Pass - each piece
Hinge Blocks	Commercial Vendor	Fit to frame	Piece of top/bottom frame part	Spot check – first 10 then every 20th piece	Pass – each test
FSS, RPs	CERN	Visual Inspection	NA	No delamination, isolated areas	Pass
HV Bus	KSU	Visual Inspection of cables	NA	End constraints intact	Pass

EDMS #3078040 v.1 Plan for commercial vendor QC documentation

Is there a credible plan for post-production testing and storage to ensure that the quality of the modules will be preserved through to their installation in the detector?

50 - 4’ X 8’ X 5’ tall wooden crates will be stored at the Rapid City warehouse from the 2 CPA factories starting in January 2026

-> No large area for storage of crates at the factories will be needed
-> Plan would be to ship 4 crates from each factory every 4 weeks to Rapid City
-> Floor space required for non-stackable crates is then 1600 square feet
-> No pre-assembly or QC needs to be done at the warehouse – crates will not be opened there except for the case of damage to the crate.

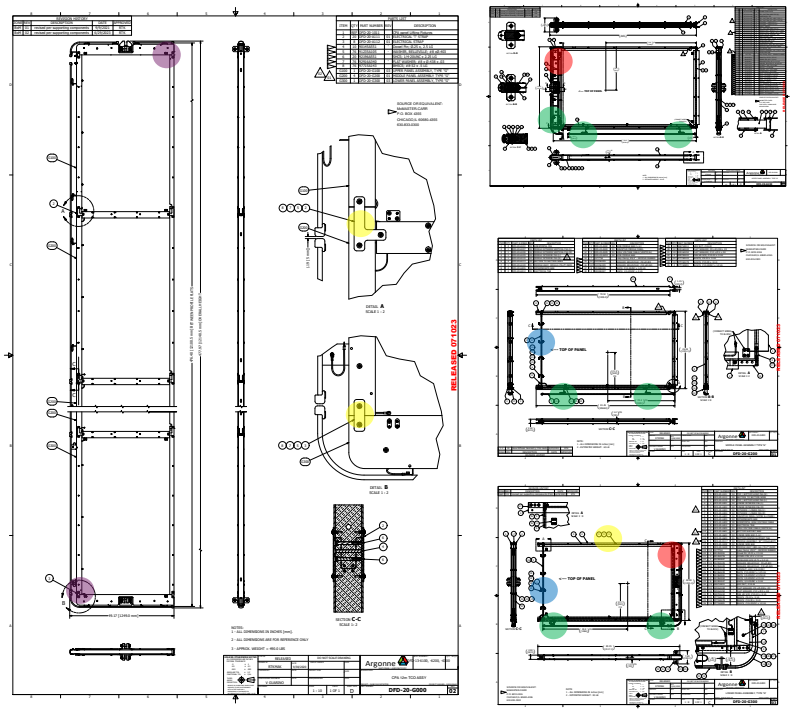
EDMS #3078049 v.1 Shipping, handling and storage specs

Informal Site Visit

- Visit ~1 month ago by members of Fermilab management, safety and quality assurance :
  - Janet Bishop
  - Kevin Fahey
  - Jim Mateyack
  - Mike Andrews
  - Jim Niehoff

  Tour of ANL Factory setup with demo of production in progress, storage for completed crates

Electrical Safety Analysis



Identifies all electrical connections on the CPA, includes pictures and a table of all connection properties

Item	ΔV (kV)	Wire type[1]	Max I² (Amps)	Max Volts (kV)	Wire Gauge	Conn.	Screw (SS)	Flat Washer	Belleville washer	Hex Nut
Donut to HV Bus	0	HV Hook-Up	6.4	17	22 AWG	#10 Ring Lug	¼-20 x 2" BHSCS		X	X
HV Bus Segments	0	200 kV DC HV Cable	25	200	12 AWG	#10 Ring Lug	10-24 x ¾" BHHD		X	
HV Bus Jumpers	0	HV Hook-Up	6.4	17	22 AWG	#10 Ring Lug	10-24 x ¾" BHHD		X	
Unit-Unit jumpers	0	Solid bare tinned Cu	6.4	-	22 AWG	#10 Ring Lug	10-24 x ½" BHHD	XX	X	X
Profile jumpers (FSS)	0	HV Hook-Up	6.4	17	22 AWG	#10 Ring Lug	8-32 x 3/8" BHHD	X	X	X
Profile jumpers (Profile)	0	HV Hook-Up	6.4	17	22 AWG	#10 Ring Lug	8-32 x 3/8" BHHD		X	X
FSS Tabs	0	-	-	-	-	0.06" thick Al tab	8-32 x ½" BHHD		X	
T/B, EW MRBs (FSS)	1.5	HV Hook-Up	4.4	17	22 AWG	#10 Ring Lug	8-32 x 3/8" BHHD	X	X	X
T/B, EW MRBs (HV Bus)	1.5	HV Hook-Up	4.4	10	22 AWG	#10 Ring Lug	10-24 x ¾" BHHD		X	

EDMS #3094498 v.3 Electrical safety analysis of CPA for DUNE FD1-HD

Shipping

At each CPA Factory :
Production of 4 Panels every 2 weeks
2 crates every 2 weeks ready for shipment to warehouse

Shipping Tracker in iPad app
QR code in pouch on crate:

- Crate PID
- 12 CPA Unit PIDs, 1 or 2 Hardware package PIDs (contents of crate)
- CPA Panel types (GH, HH, or HJ)

When crate leaves factory, scan QR code (in pouch) from Shipping Tracker (PIDs tracked)

Scan QR code:
- When crate arrives at warehouse
- When crate arrives at SURF
- When crate is unpacked underground

EDMS #3078046 v.1 Shipping plan details