CRP Composite frame PRR

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- About prototyping and changes since FDR
- Documents
- Tender plan and Schedule
- Calculation notes and Compliance Office validation
- Conclusions

Scope of the PRR

- Production of 166 (½ Top CRP) composite frames in the industry (~1300 k€)
  - For 80 CRPs + 6 spare CRUs

- Production of the 166 (½ Bottom CRP) composite frames in the industry (~1400 k€)
  - For 80 CRPs + 6 spare CRUs

Out of the scope

- Complete CRP Assembly and tests at Top and Bottom CRP factories
- Composite frame Transportation to Bottom CRP factories

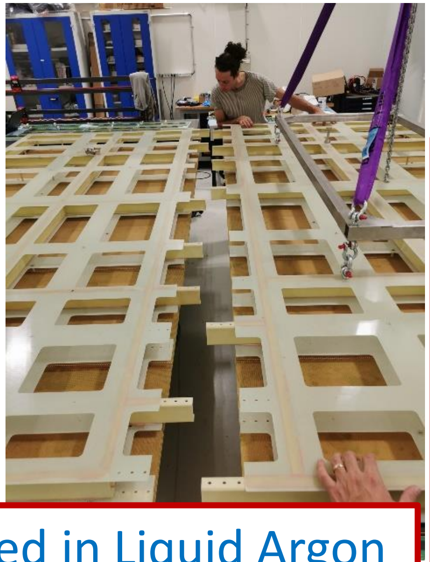
Composite structure

- Imbricated Glass/Epoxy U-shaped profile
- Glass/Epoxy skins
- Epoxy glue

Charge question#3

cf: N. Geffroy's talk

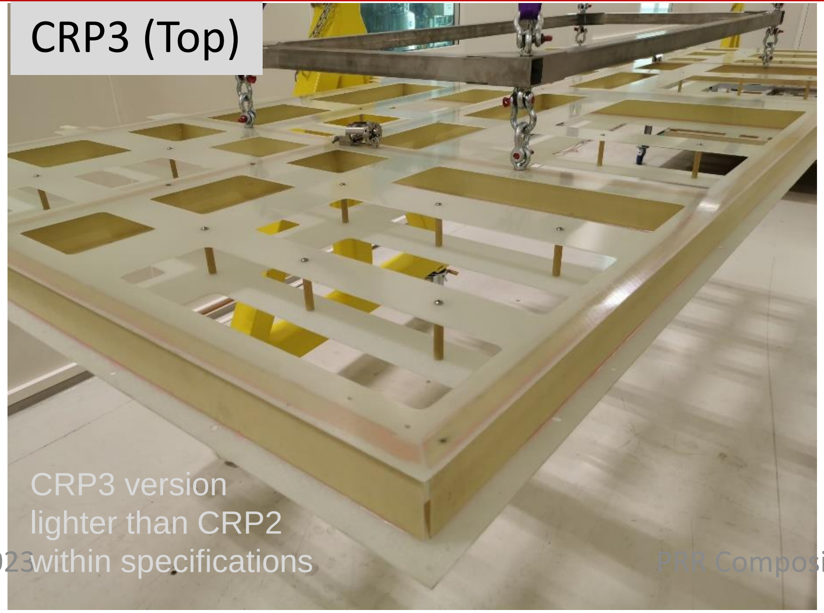
CRP2 (Top)



- Design and material validated with large scale structure as well as the industrial process
- The composite frame technology has been demonstrated in real environment in 2021 with CRP1.
- The design for FD2-VD has been produced and it has been validated at full scale in the coldbox for top and bottom structures in 2022 and 2023
- Minor Design modifications after FDR:

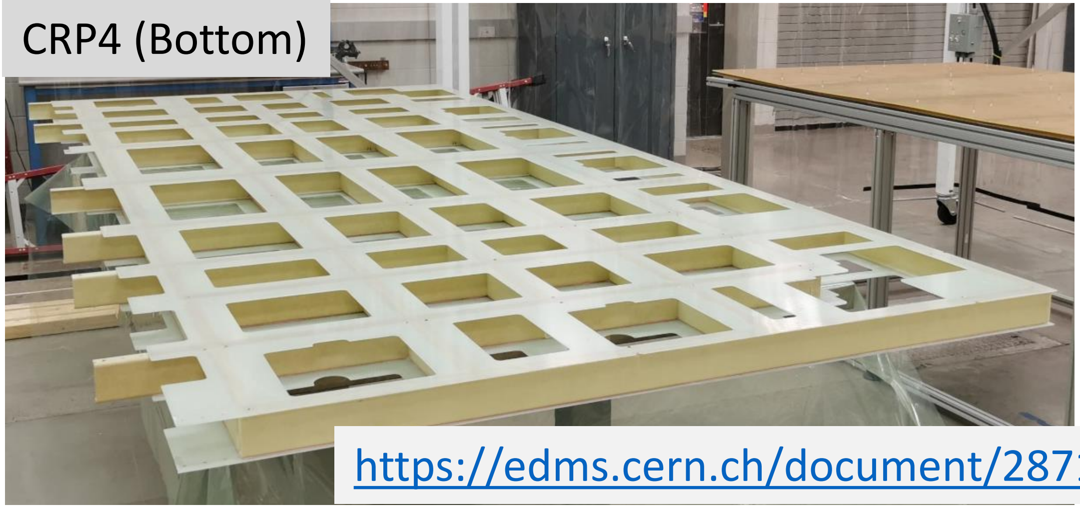
Since 2022: 6 CRP prototypes built and fully tested in Liquid Argon in TPC mode with multiple cold cycling and manipulation => without any failure or out of specifications

CRP3 (Top)



CRP3 version lighter than CRP2 within specifications

CRP4 (Bottom)

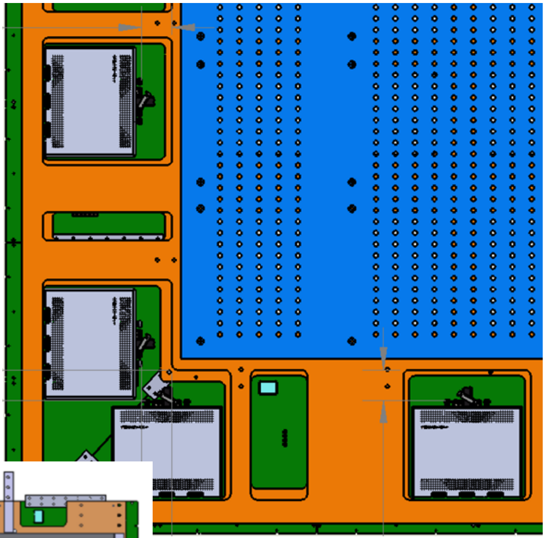


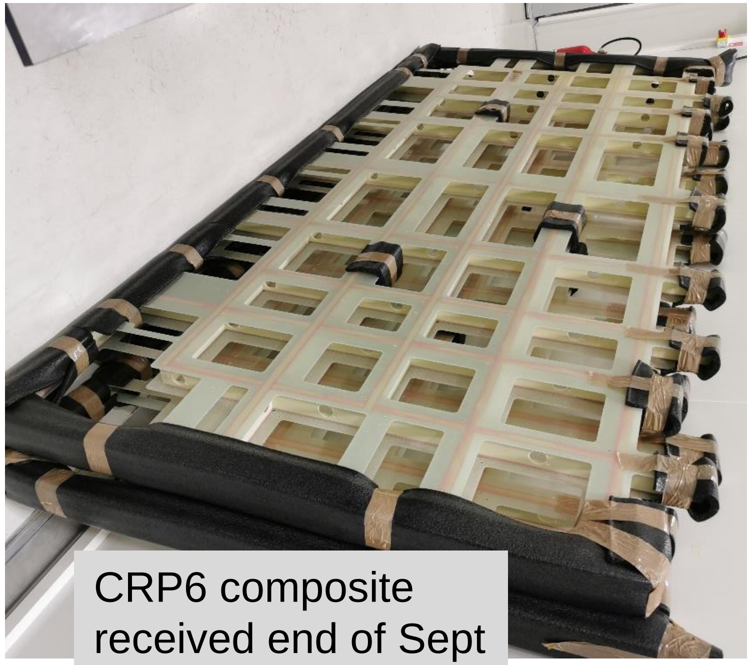
https://edms.cern.ch/document/2871580/1

Updated composite structure after FDR

- Design modifications implemented since FDR:
  - Increase openings around the FEMBs
  - Hole position for patch panels and for HV cold filter box
  - Add holes for manipulation toolings
  - Add chamfer to the ½ CRP profile junctions
  - Add holes in profiles to route all cables inside the structure

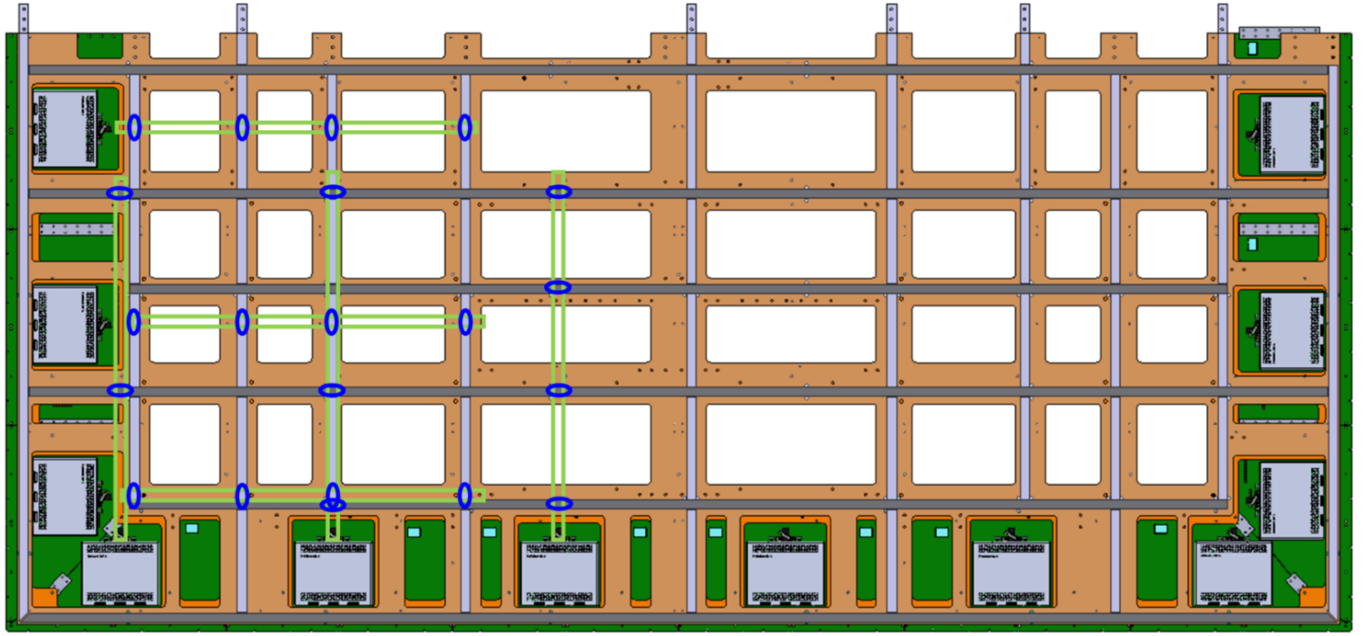
Charge question#2

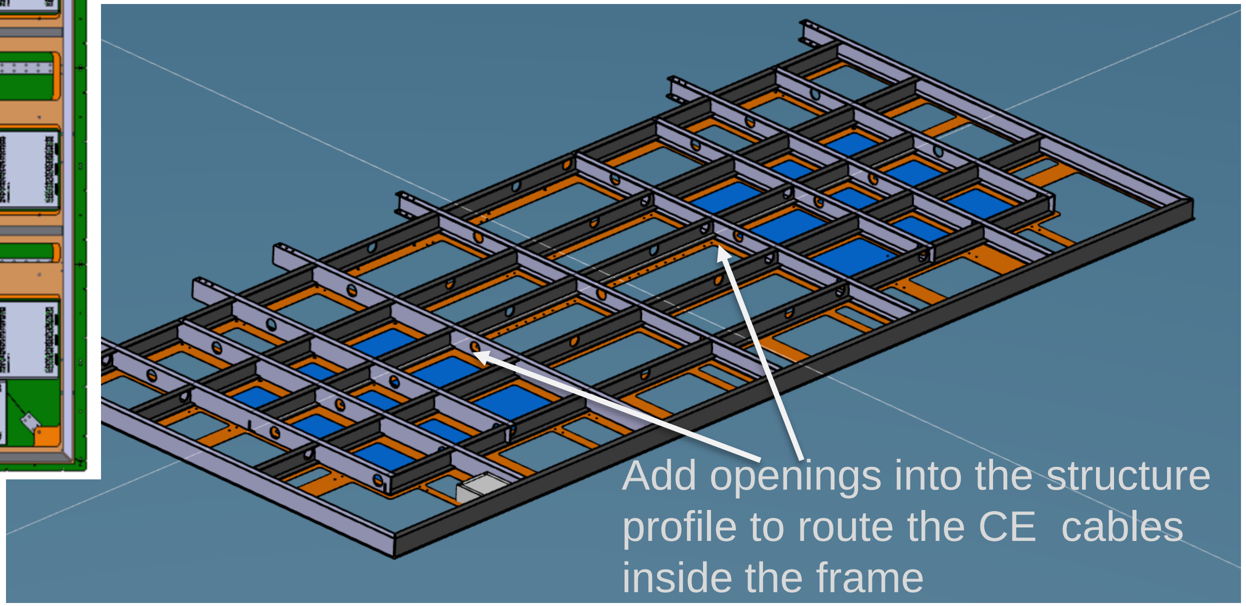




CRP6 composite received end of Sept

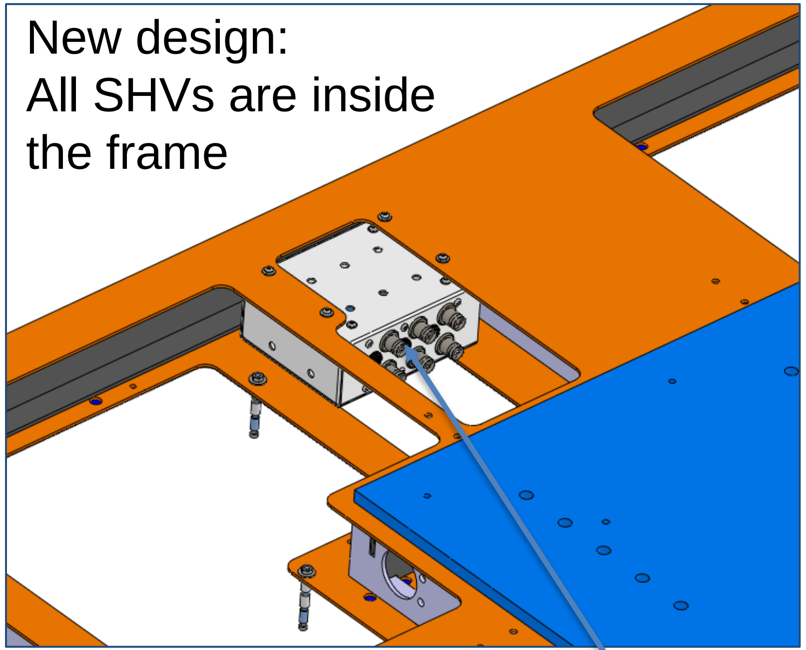
Bottom CRP updated design and cable routing



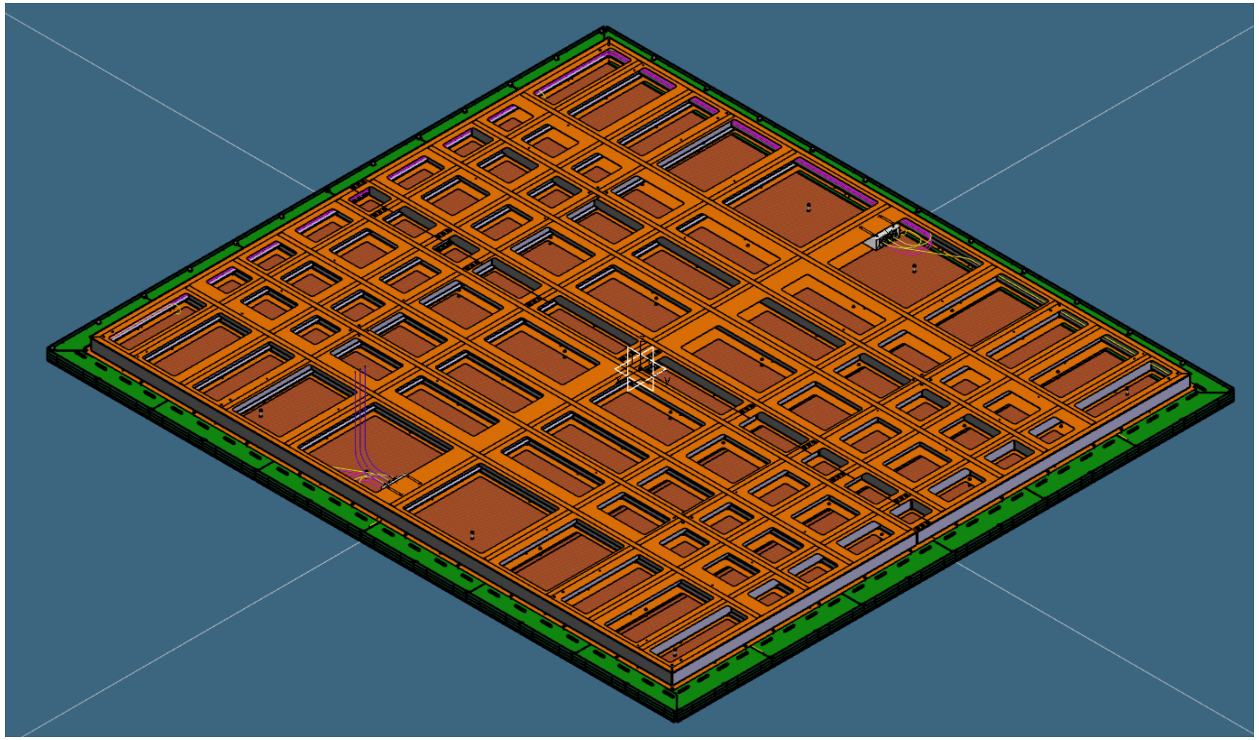


Updated composite structure

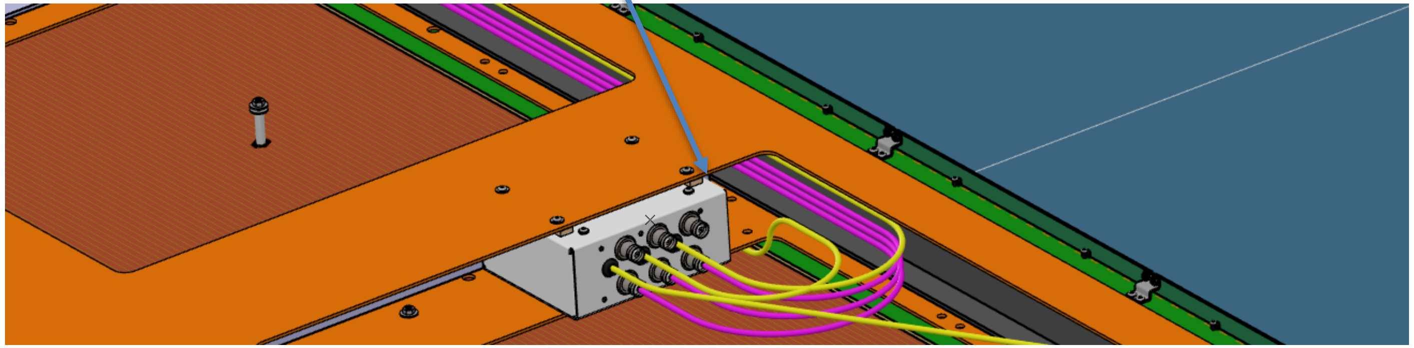
Charge question#2



Top CRP updated design: based on CRP2 heavier structure



Cold HV filter box is now embedded in the composite frame for both top and bottom CRPs



Documents for PRR

Documents are stored there: CRP composite PRR edms

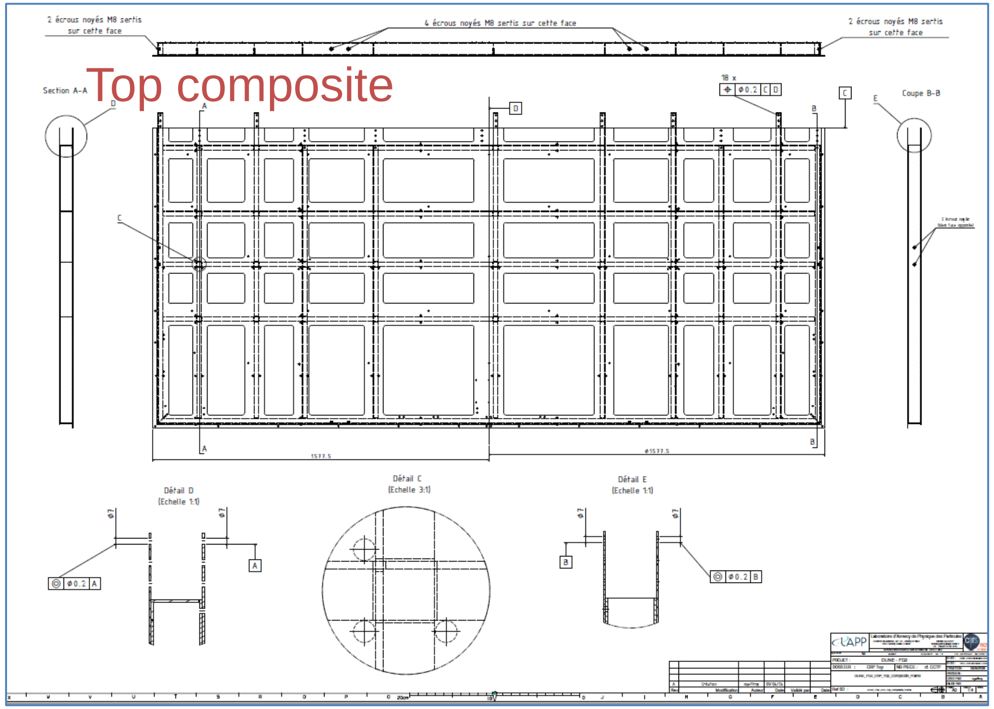
Category		EDMS	File or Directory Name	
Systems Engineering/Mechanical Engineering	Final fabrication drawings and CAD models	3127504	Top CRP composite drawings and CAD models	
		3127505	Bottom CRP composite drawings and CAD models	
Compliance Office	Calculation note for the Top CRP	3102010	FEA_validation_Top_CRP-v2-250924.pdf	
	Calculation note for the Bottom CRP	3070040	FEA_validation_Bottom_CRP-v2-031024.pdf	
	Engineering codes and standards to be applied in the manufacturing process	3127636	Technical specifications and Terms for the CRP composite frames	Chapter 2 about material specifications
	Commercial vendor QC requirements			Chapter 5 about panel control and reception plan
	Documentation of mechanical safety reviews Compliance Office Approvals	2884394	Compliance Office FD2 CRP composite Structural Validation document	
		2881657	Top CRP and SST Analysis plan	
		2881656	Bottom CRP Analysis plan	
Technical Coordination	Production Schedule	3127636	in Technical specifications and Terms for the CRP composite frames	Chapter 1
	Shipping plan and schedule			Chapter 1
	Plans for component procurement including procurement specifications			Chapter 2
	Delineation of responsibilities and required signoffs for each stage of shipping process			
QA/QC Documents	Detailed manufacturing procedures	3127636	in Technical specifications and Terms for the CRP composite frames	Chapter 3 and 4
	Shipping, handling, and storage requirements			
	QC Plan			Chapter 5
	Manufacturing traveller documents			
	Documentation of assigned responsibilities for who signs-off on each step in the QC process			
Review Office	Responses to previous review recommendations	3170811	FD-VD CRP composite PRR October 2024 document summary	section 2 Review Office page 4
	Final testing and performance results from prototyping activities			section 2 Review Office page 4-5
	Description of design changes occurring after the Final Design Review			section 2 Review Office page 5

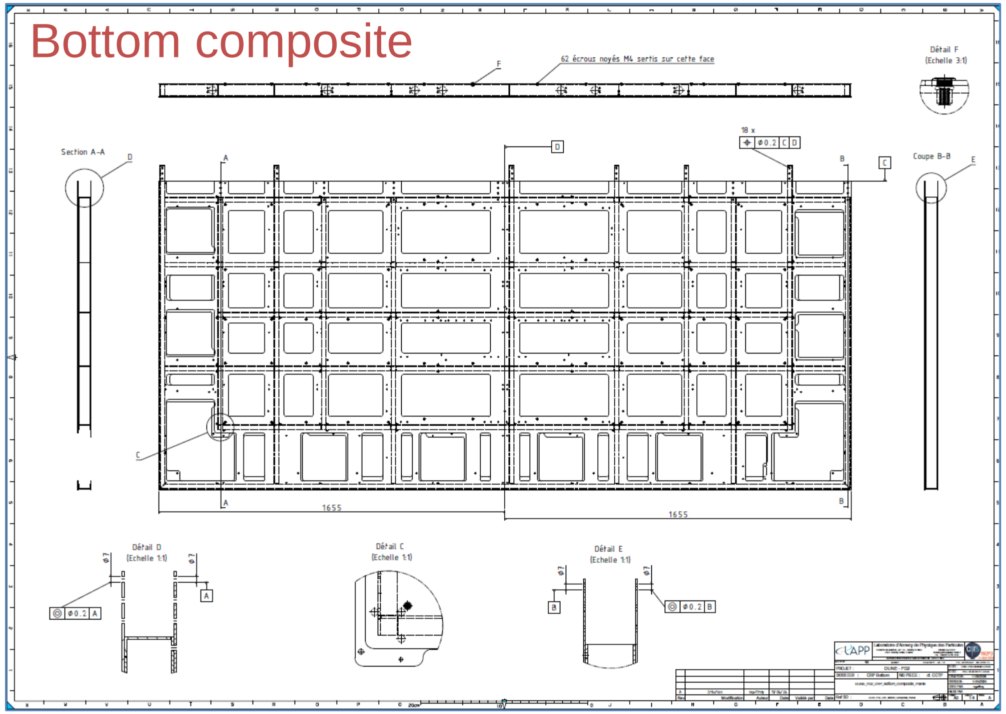
Composite frame technical documentation

Technical specification: written and provided during the first step of the tendering process
https://edms.cern.ch/document/3127636/1
based on the evolution of the prototypes and the experience gained with the composite company since 3 years:

⇒ nearly finalised with the structures used for CRP6 and CRP7: feedback from cabling of the FEMBs have brought some modifications for the cable hole positions

⇒ Drawings and CAD models: https://edms.cern.ch/project/CERN-0000257026





Technical specifications for manufacturing

Material specification:

Skins and profiles

- The lower and upper skins are made of pre-impregnated fabrics with the following references: PREG VERRE EQUI 600 T2 M9.6GF 40% 1300MM, or other equivalent reference. “HexPly® M9.6GF/40%/600T2/G” (stack up of E-Glass Epoxy woven fabrics)
- The fabrics are stored in a suitable environment and used within the duration specified by the manufacturer.
- The minimum apparent modulus of elasticity in bending (ISO 178 standard) of pultruded profiles is 10 MPa.
- Pultruded profiles comply with the EN 13706 standard.
- The profiles are made of fiberglass and epoxy resin and have the following references:
  - Röchling Durostone EPGM, or equivalent reference

Assembly:

- The glue used for assembling the skins and profiles should be Epoxy Sika H9951, or another equivalent reference which allows its use in cryogenic conditions characterized by cooling to around -187°C (liquid argon temperature)

Rivet Nuts:

- The countersunk rivet nuts to be crimped on the Top panels are M8 stainless steel nuts with the reference: BOLLHOFF – RIVKLE – 233 06 080 233 (M8 / stainless steel / flat head / Knurled / Open)
- The countersunk rivet nuts to be crimped on the Bottom panels are M4 stainless steel nuts with the reference: BOLLHOFF – RIVKLE – 233 06 040 230 (M4 / stainless steel / flat head / Knurled / Open)

QA/QC at the production site

FORESEEN PANEL CONTROL AND RECEPTION PLAN

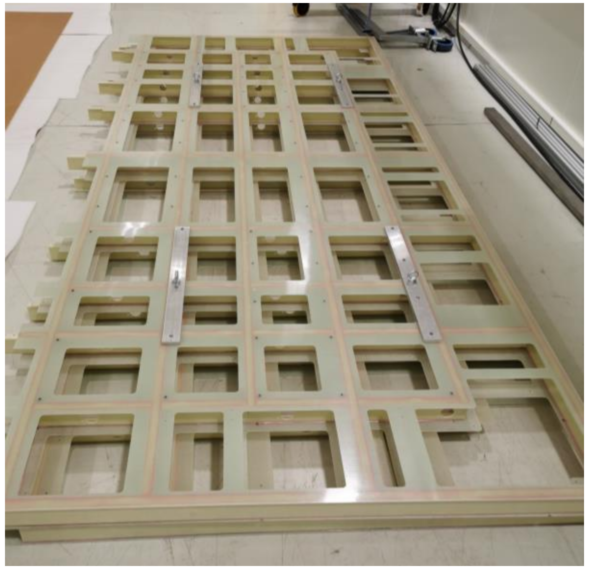
The verification of all the specifications covers at least the following elements, and is recorded in a validation report for each panel:

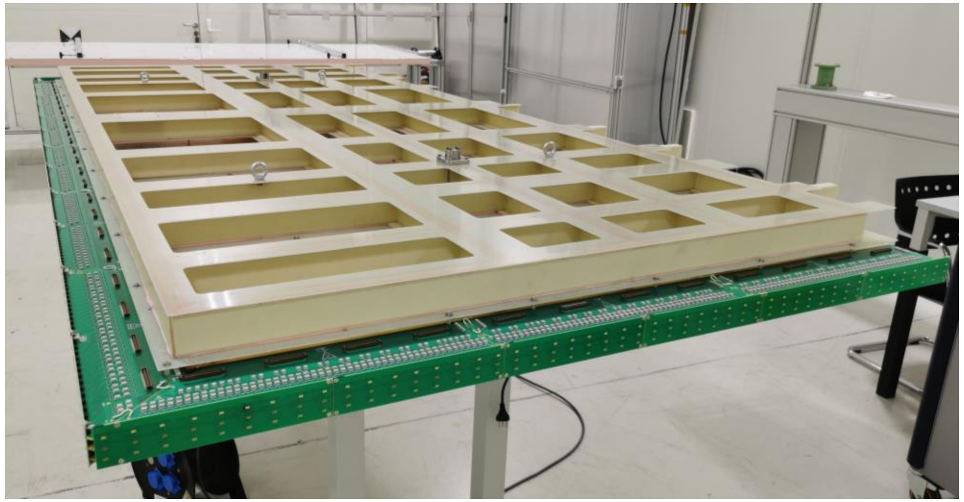
- Material certificates for pre-impregnated fabrics constituting the skins, profiles and glue
- Presence of the reference label
- Presence and correct positioning of holes with diameters of 6mm, 6.8mm and 7mm
- Panel flatness
- No obstruction for the passage of electrical cables within the Bottom panels.
- Presence and correct positioning of the countersunk rivet nuts for the Top and Bottom panels.
- Validation of structural bonding of all bonding surfaces
- Dusting and cleaning with alcohol
- Plastic packaging

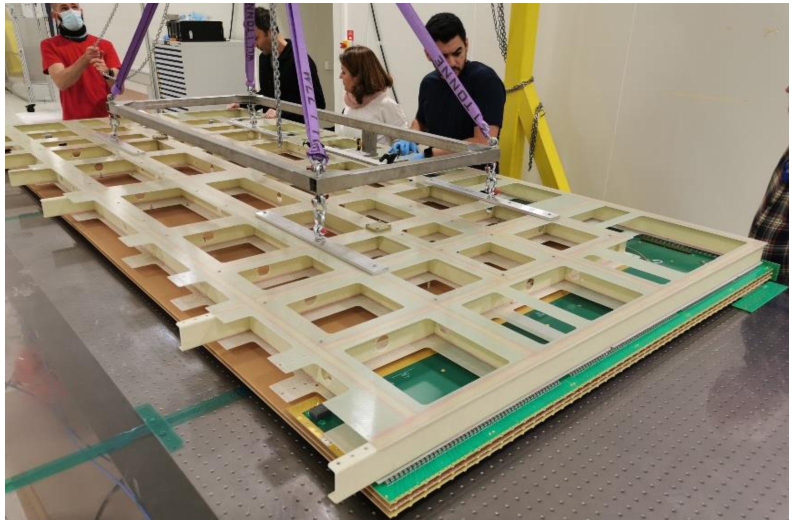
This will provide the necessary data for acceptance tests

Tendering process steps and tentative planning

- First step for the tendering process has been completed this summer (started in January): company candidacies received end of August ✓
- After company selection => ask the accepted candidate to send a detailed production proposal by end of October with tentative schedule, procedures etc.. ✓
- Start a negotiation period in order to validate the company and agree on timeline and production details
- **Goal is to sign a contract in Jan 2025**
  - ➢ Pre-production (2 top and 2 bottom panels) : 3 months
  - ➢ Production (166 top + 166 bot): covers 20 months for both Top and Bottom







CRP composite frame tender

Production contract: split in 3 parts:

1) 2 Top and 2 bottom preproduction panels
2) 166 Top panels
3) 166 Bottom panels

Shipping model :

- For the top CRPs: it is foreseen to send to Grenoble 20 panels (CRU size) every 2 months on average in a simple transport packaging defined by the company

- For the Bottom CRPs: it is foreseen that the producer send to CERN 20 panels (CRU size) every 2 months on average in a transport packaging compatible with transport standard to US (wood boxes with proper treatment etc)..

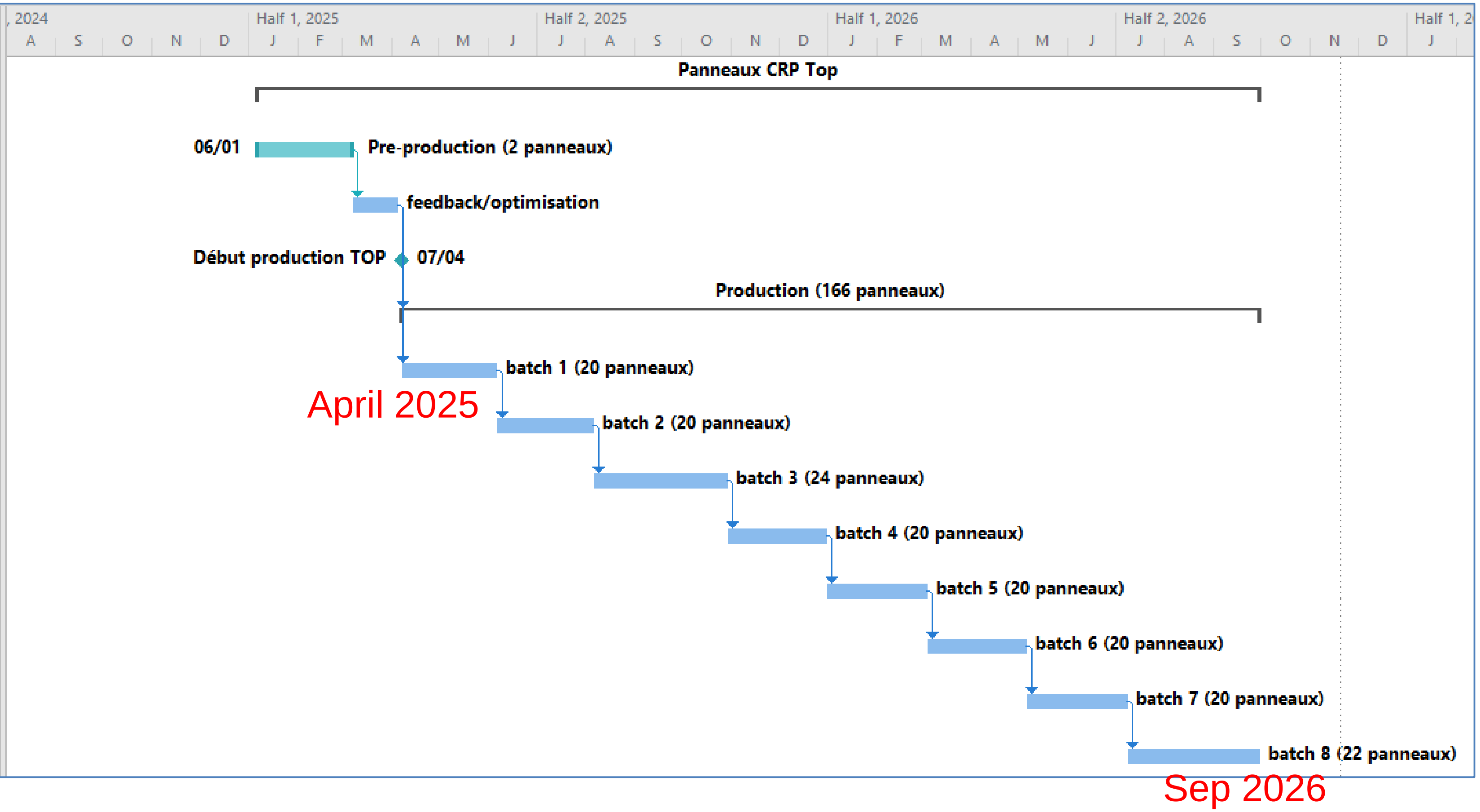
Production and delivery Schedule

Top composite:

To match the assembly time line of the CRP factories and anode delivery

Proposed planning of production in the tendering documentation :

Task Name	Duration	Start	Finish
Panneaux CRP Top	**452 days**	**Mon 06/01/25**	**Tue 29/09/26**
Pre-production (2 panneaux)	44 days	Mon 06/01/25	Thu 06/03/25
feedback/optimisation	21 days	Fri 07/03/25	Fri 04/04/25
Début production TOP	0 days	Mon 07/04/25	Mon 07/04/25
Production (166 panneaux)	**387 days**	**Mon 07/04/25**	**Tue 29/09/26**
batch 1 (20 panneaux)	44 days	Mon 07/04/25	Thu 05/06/25
batch 2 (20 panneaux)	43 days	Fri 06/06/25	Tue 05/08/25
batch 3 (24 panneaux)	60 days	Wed 06/08/25	Tue 28/10/25
batch 4 (20 panneaux)	45 days	Wed 29/10/25	Tue 30/12/25
batch 5 (20 panneaux)	45 days	Wed 31/12/25	Tue 03/03/26
batch 6 (20 panneaux)	45 days	Wed 04/03/26	Tue 05/05/26
batch 7 (20 panneaux)	45 days	Wed 06/05/26	Tue 07/07/26
batch 8 (22 panneaux)	60 days	Wed 08/07/26	Tue 29/09/26



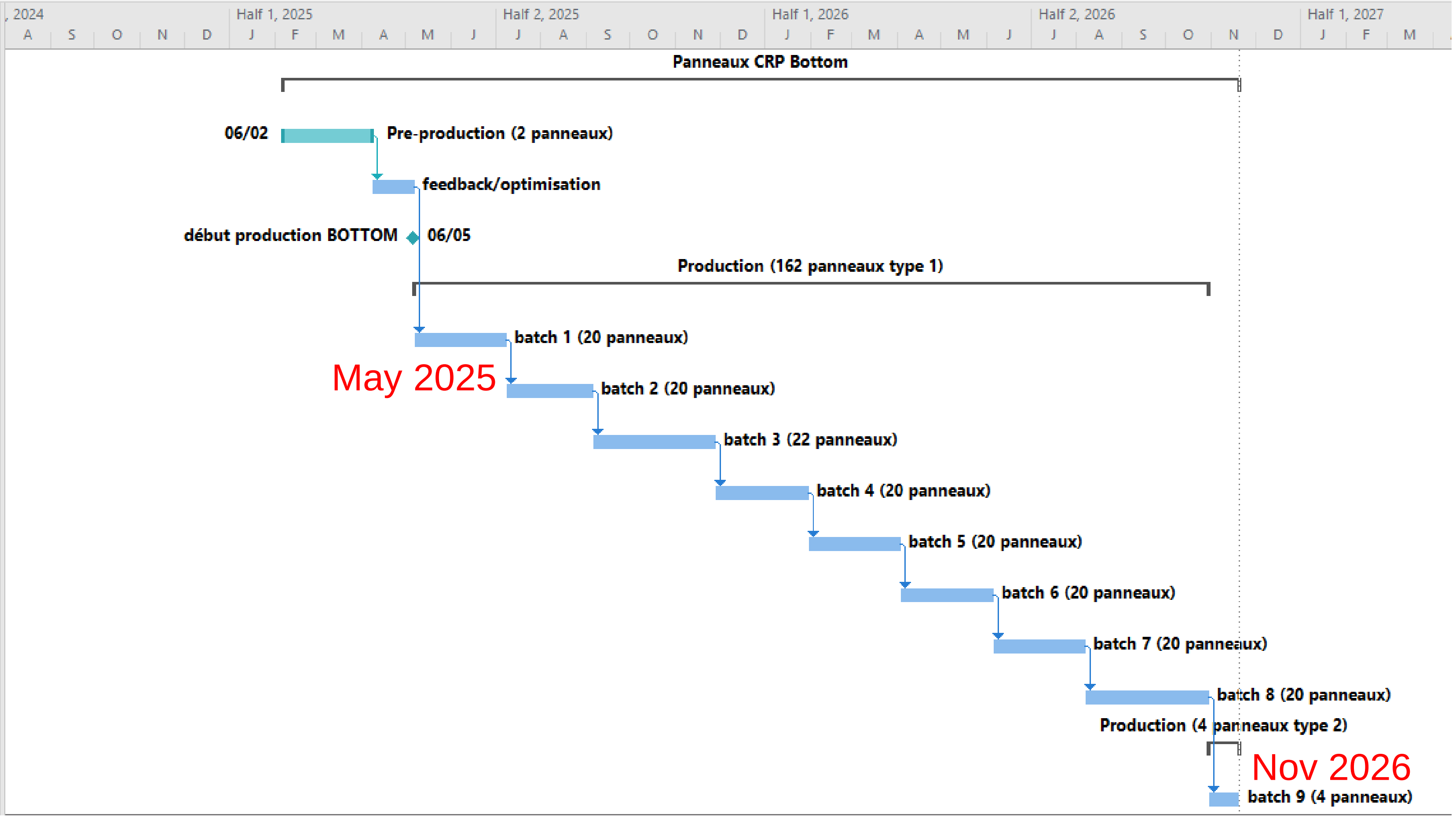
Production and delivery Schedule

Bottom composite

To match the assembly time line of the CRP factories and anode delivery

Proposed planning of production in the tendering documentation :

Task Name	Duration	Start	Finish
Panneaux CRP Bottom	**466 days**	**Thu 06/02/25**	**Thu 19/11/26**
Pre-production (2 panneaux)	43 days	Thu 06/02/25	Mon 07/04/25
feedback/optimisation	21 days	Tue 08/04/25	Tue 06/05/25
début production BOTTOM	0 days	Tue 06/05/25	Tue 06/05/25
Production (162 panneaux type 1)	**387 days**	**Wed 07/05/25**	**Thu 29/10/26**
batch 1 (20 panneaux)	44 days	Wed 07/05/25	Mon 07/07/25
batch 2 (20 panneaux)	43 days	Tue 08/07/25	Thu 04/09/25
batch 3 (22 panneaux)	60 days	Fri 05/09/25	Thu 27/11/25
batch 4 (20 panneaux)	45 days	Fri 28/11/25	Thu 29/01/26
batch 5 (20 panneaux)	45 days	Fri 30/01/26	Thu 02/04/26
batch 6 (20 panneaux)	45 days	Fri 03/04/26	Thu 04/06/26
batch 7 (20 panneaux)	45 days	Fri 05/06/26	Thu 06/08/26
batch 8 (20 panneaux)	60 days	Fri 07/08/26	Thu 29/10/26
Production (4 panneaux type 2)	**15 days**	**Fri 30/10/26**	**Thu 19/11/26**
batch 9 (4 panneaux)	15 days	Fri 30/10/26	Thu 19/11/26



CRP calculation notes

Calculation note for Top CRP: https://edms.cern.ch/document/3102010/1 S. Canva

Analysis		Structural parts	Von Mises Stress (MPa)	Load factor	Max yield Strength (MPa)	Strength Factor	Allowable max Strength	SF
1	½ CRP handle with spreader	Skin composite	31.3	1.4	205	0.245	50.2	1.1
		G11 composite	NA	1.4	375	0.245	91.9	NA
		C beam composite	8.9	1.4	250	0.245	61.3	4.9
		Anode	2.5	1.4	440	0.245	107.8	30.9
		Spacers	0.8	1.4	90.9	0.245	22.3	18.8
2	½ CRP handle with spreader - cold test factory	Skin composite	10.6	1.4	205	0.245	50.2	3.4
		G11 composite	NA	1.4	375	0.245	91.9	NA
		C beam composite	2.2	1.4	250	0.245	61.3	20.0
		Anode	11.1	1.4	440	0.245	107.8	7.0
		Spacers	0.5	1.4	90.9	0.245	22.3	31.9
3	CRP on assembly table	Skin composite	11.9	1.4	205	0.245	50.2	3.0
		G11 composite	34.8	1.4	375	0.245	91.9	1.9
		C beam composite	12.8	1.4	250	0.245	61.3	3.4
		Anode	2.4	1.4	440	0.245	107.8	31.6
		Spacers	1.5	1.4	90.9	0.245	22.3	10.6

Analysis		Structural parts	Total deformation (mm)	X deformation Max abs (mm)	Y deformation Max abs (mm)	Z deformation Max abs (mm)
1	½ CRP handle with spreader	Composite frame	1.38	0.05	0.09	1.38
		Anode	1.52	0.09	0.03	1.52
2	½ CRP handle with spreader - cold test factory	Composite frame	4.46	2.08	3.99	1.13
		Anode	5.22	2.10	4.68	1.24
3	CRP on assembly table	Composite frame	0.08	0.00	0.01	0.08
		Anode	0.12	0.01	0.01	0.12
4	CRP on lifting table	Composite frame	1.09	0.02	0.04	1.09
		Anode	1.21	0.03	0.03	1.21
5	CRP installed under the SST frame	Composite frame	2.29	0.08	0.05	2.29
		Anode	2.45	0.13	0.02	2.45
6	CRP in use in the cryostat	Composite frame	5.51	3.53	3.99	1.40
		Anode	6.26	3.93	4.68	1.55

Table 4: Summary Displacement Results - Top CRP

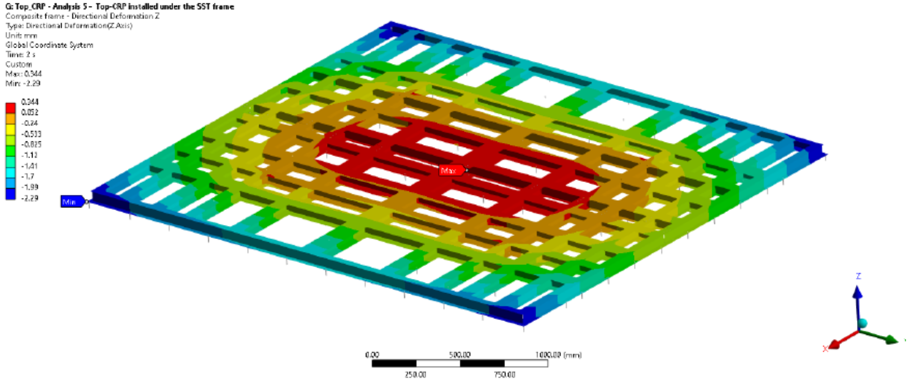


Figure 75: Analysis 4 - Composite frame - Directional deformation Z

Calculation note for Bottom CRP: https://edms.cern.ch/document/3070040/1 S. Canva

Analysis		Composite structural parts	Von Mises Stress (MPa)	Load factor	Max yield Strenght (MPa)	Strenght Factor	Allowable max Strenght	SF
1	½ CRP handle with spreader	Skin composite	21.0	1.4	205	0.245	50.2	1.7
		G11 composite	NA	1.4	375	0.245	91.9	NA
		C beam composite	3.7	1.4	250	0.245	61.3	11.8
		Anode	4.9	1.4	440	0.245	107.8	15.9
		Spacers	1.3	1.4	90.9	0.245	22.3	12.4
		Adapter plate	15.1	1.4	375	0.245	91.9	4.4
2	½ CRP handle with spreader - cold test factory	Skin composite	12.3	1.4	205	0.245	50.2	2.9
		G11 composite	NA	1.4	375	0.245	91.9	NA
		C beam composite	1.7	1.4	250	0.245	61.3	25.4
		Anode	11.6	1.4	440	0.245	107.8	6.6
		Spacers	0.8	1.4	90.9	0.245	22.3	20.6
		Adapter plate	4.1	1.4	375	0.245	91.9	15.9
3	CRP on assembly table	Skin composite	11.9	1.4	205	0.245	50.2	3.0
		G11 composite	35.0	1.4	375	0.245	91.9	1.9
		C beam composite	13.7	1.4	250	0.245	61.3	3.2
		Anode	2.6	1.4	440	0.245	107.8	29.5
		Spacers	3.2	1.4	90.9	0.245	22.3	5.0
		Adapter plate	0.3	1.4	375	0.245	91.9	214.2
4	CRP handled for reversal	Skin composite	29.6	1.4	205	0.245	50.2	1.2
		G11 composite	35.2	1.4	375	0.245	91.9	1.9
		C beam composite	15	1.4	250	0.245	61.3	2.9
		Anode	5.1	1.4	440	0.245	107.8	15.2
		Spacers	1.3	1.4	90.9	0.245	22.3	12.0
		Adapter plate	15.1	1.4	375	1.245	466.9	22.1
5	CRP handled with two tines (handling tool)	Skin composite	26.3	1.4	205	0.245	50.2	1.4
		G11 composite	38.0	1.4	375	0.245	91.9	1.7
		C beam composite	6.8	1.4	250	0.245	61.3	6.4
		Anode	52.7	1.4	440	0.245	107.8	1.5
		Spacers	1.4	1.4	90.9	0.245	22.3	11.4
		Adapter plate	10.7	1.4	375	1.245	466.9	31.2

Analysis		Structural parts	Total deformation (mm)	X deformation - Max abs (mm)	Y deformation Max abs (mm)	Z deformation Max abs (mm)
1	½ CRP handle with spreader	Composite frame	0.89	0.02	0.02	0.89
		Anode	0.87	0.02	0.02	0.87
2	½ CRP handle with spreader - cold test factory	Composite frame	9.09	3.70	8.30	0.43
		Anode	9.61	3.88	8.81	0.56
3	CRP on assembly table	Composite frame	0.24	0.03	0.01	0.24
		Anode	0.23	0.02	0.01	0.23
4	CRP handled for reversal	Composite frame	1.34	0.05	0.03	1.34
		Anode	1.42	0.07	0.02	1.42
5	CRP handled with two tines (handling tool)	Composite frame	95.61	2.60	0.15	95.57
		Anode	96.40	4.44	0.07	96.30
		TINES	66.56	0.82	0.18	66.55
6	CRP on feet on the cryostat floor	Composite frame	1.97	0.07	0.08	1.97
		Anode	1.99	0.08	0.07	1.99
7	CRP in use in the cryostat	Composite frame	9.00	5.43	7.17	1.01
		Anode	9.49	5.62	7.67	0.96

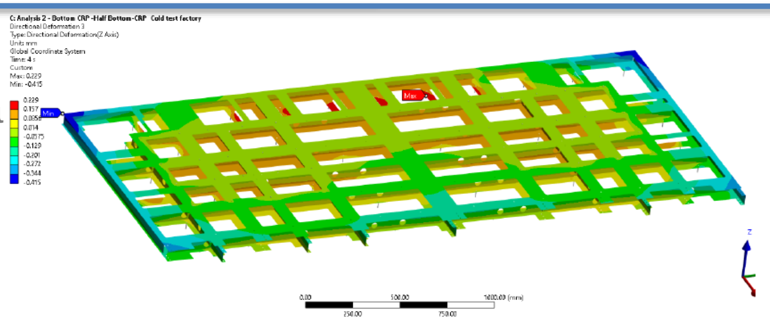


Figure 81: Analysis 2 - Composite frame - Directional deformation Z

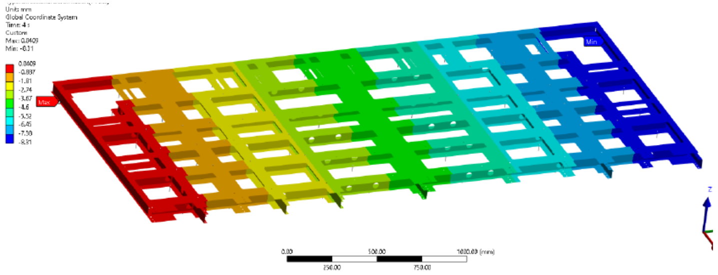


Figure 80: Analysis 2 - Composite frame - Directional deformation Y

Compliance office validation

https://edms.cern.ch/document/2884394/3

EDMS No.: 2884394
Date: 04.10.2024

LBNF / DUNE COMPLIANCE OFFICE
SYSTEM STRUCTURAL VALIDATION DOCUMENT – DESIGN

DUNE FD2 Charge Readout Plane (CRP)

From O. Beltramello, G. Buccino
To: D. Duchesneau, Sebastien Canva, Nicolas Geffroy
Cc: M. Nessi, S. Kettle

1. System identification:

The CRP system is composed of:

- Top CRP
- Bottom CRP

To be noted that this validation form refers only to the CRPs and equipment explicitly addressed in the submitted calculation note.

Any other equipment needed for lifting and manipulating the CRPs, or its subassemblies, shall be selected appropriately and are not covered by the present validation form.

The spreader beams and the so-called "handling tool" are not covered by the present validation form.

6. Conclusions

The components of the CRP system for the DUNE Vertical Drift (FD2-CRP) have been analyzed.

It is noted that the material to be used for the so-called "adapter plates" has not been chosen yet. In the provided engineering note, the material G11 has been considered in the analysis for those components. To avoid high-stress zone on the composite frame, the future chosen material shall have a CTE as close as possible to the one from the skin composite frame, which is 12E-6 K-1.

Despite the final choice of the materials to be used for the "adapter plates" still pending, it can be concluded that the verifications on the Top and Bottom CRP are considered satisfactory and the design is considered validated based on applicable design codes and project requirements.

Once the material selection process for the "adapter plates" is completed, the Compliance Office shall be notified and the relevant documentation listing the mechanical and thermal characteristics shall be provided.

Before the selected material is used for the "adapter plate", the approval of the Compliance Office is required.

Compliance office validation

https://edms.cern.ch/document/2884394/3

The main outcomes of the review process are:

- The CRP engineering documents satisfactorily define the design, initial data and expected load cases.
- The strength of the structural elements was verified for the ambient and cryogenics temperature load cases with acceptable safety factors.
- The flexibility of the installation tool tines has been accounted for in the calculation of the bottom CRP.
- Analysis of the bolted connections between structural elements of the assemblies has been performed.
- The deformations of the CRPs are within the project requirements limits.

Installation tools

- Several prototypes of tools have been used for the installation of the Module 0 detector. For the CERN use purposes, an assessment was done by the HSE unit and they were successfully used.
- Final engineering notes must be submitted to the CO validation before the Installation PRR.

Conclusions

- 12 Composite structures have been manufactured and used for the construction of 6 CRP prototypes in the last 3 years and tested in cryogenic conditions in the CERN coldbox with more than 11 cold tests
  => Inputs for design optimization made coherently with a manufacturer
  => Validation of the design at warm and for cold operation conditions
  => Validation of the design for the CRP assembly process and electronic integration

- The composite design takes into account installation constraints for both Top and Bottom CRPs:
  - already tested during coldbox manipulation and during first integration/installation in **Module-0** in January 2023 (Top CRP) and May 2023 (Bottom CRP)
  - Status of these four CRPs after 18 months in the cryostat shows no measurable differences of any kind of deformation

- Structural analysis notes, materials and results validated by the Compliance Office

- QA/QC requirements at the manufacturer are defined with an acceptance validation plan

- Proposed production schedule and batch sequence are defined to guarantee a constant flow to the Top and Bottom CRP factories with a minimum of 2 months production in advance (including transport time).

- Fabrication & assembly drawings, technical specification documents completed

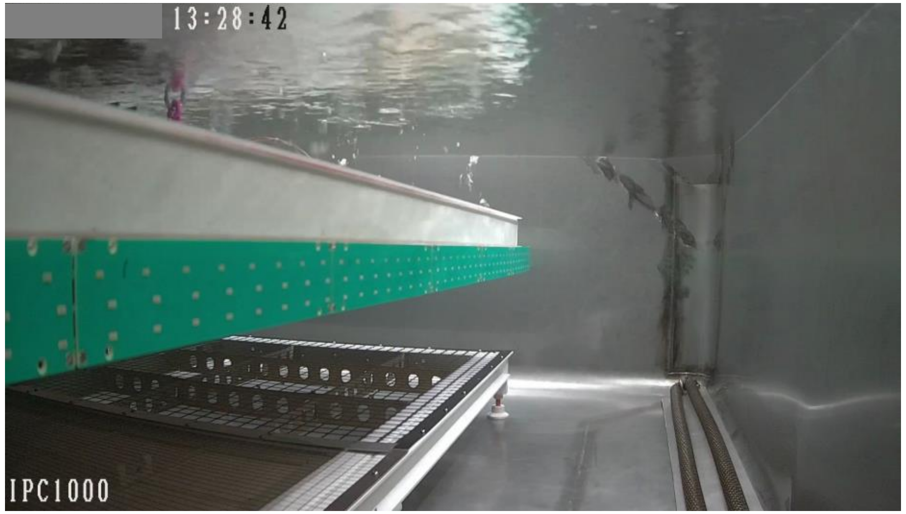
- Steps for tendering process are defined and already agreed with CNRS office of purchase; round of negotiation with the selected company completed by the end of the year with the aim for a contract signature beginning of 2025 spares

CRP prototyping:

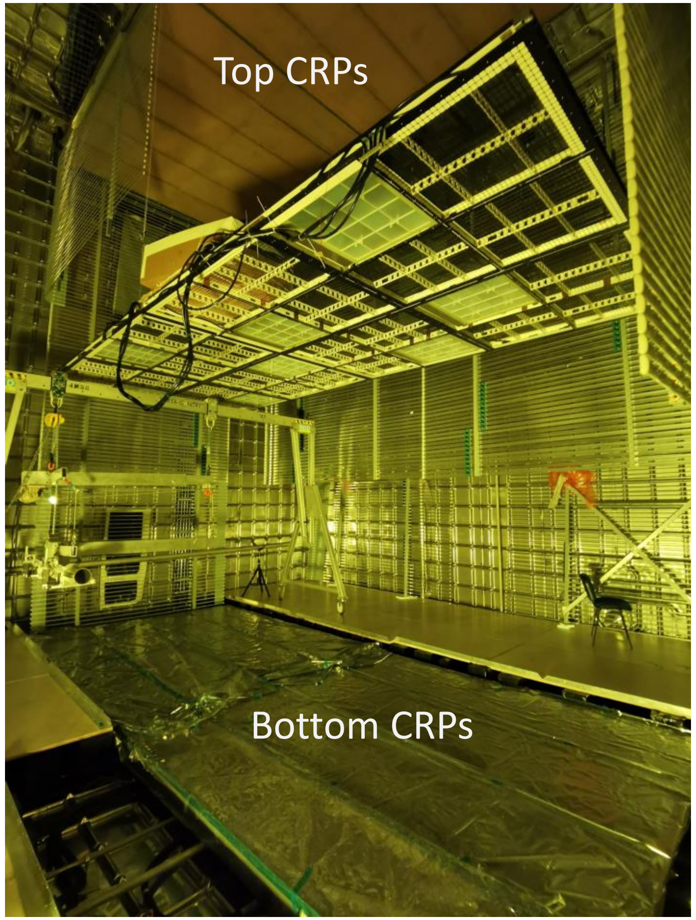
Since 2022: 6 CRP prototypes built and fully tested in Liquid Argon in TPC mode with multiple cold cycling and manipulation => without any failure or out of specifications

Construction of 4 CRPs for ProtoDUNE-VD and installed in NP02 cryostat

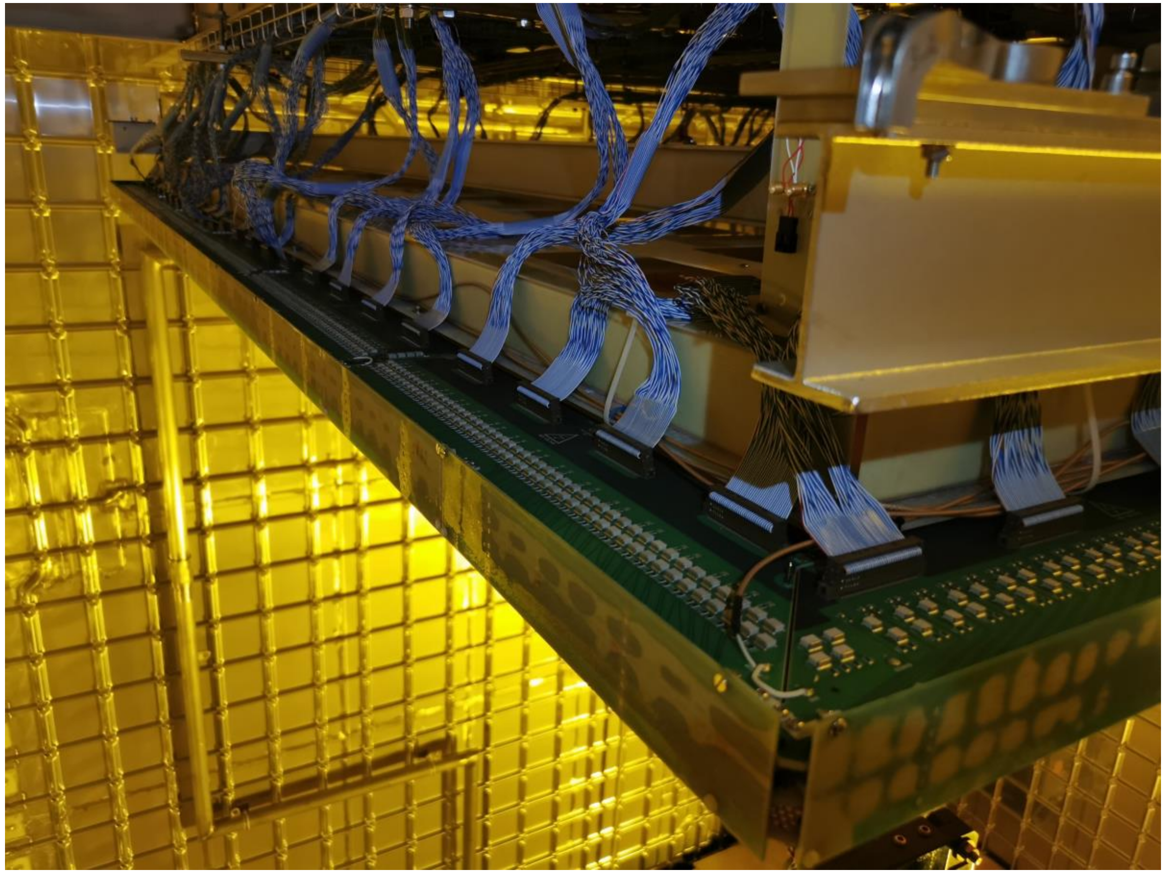
1 of the top CRP prototype after full assembly

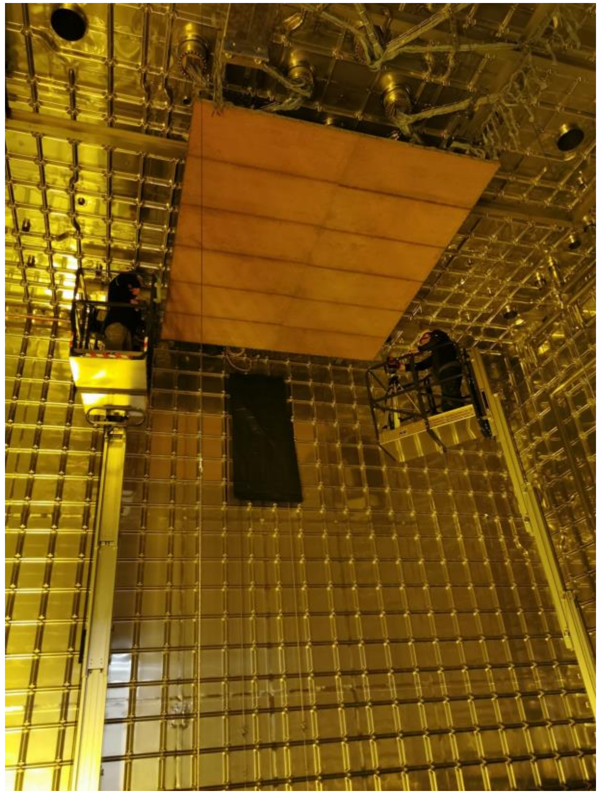


Tested in liquid argon in the CERN coldbox



4 CRP integrated in the NP02 cryotstat in 2023





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Technical aspects and description of the composite frame:

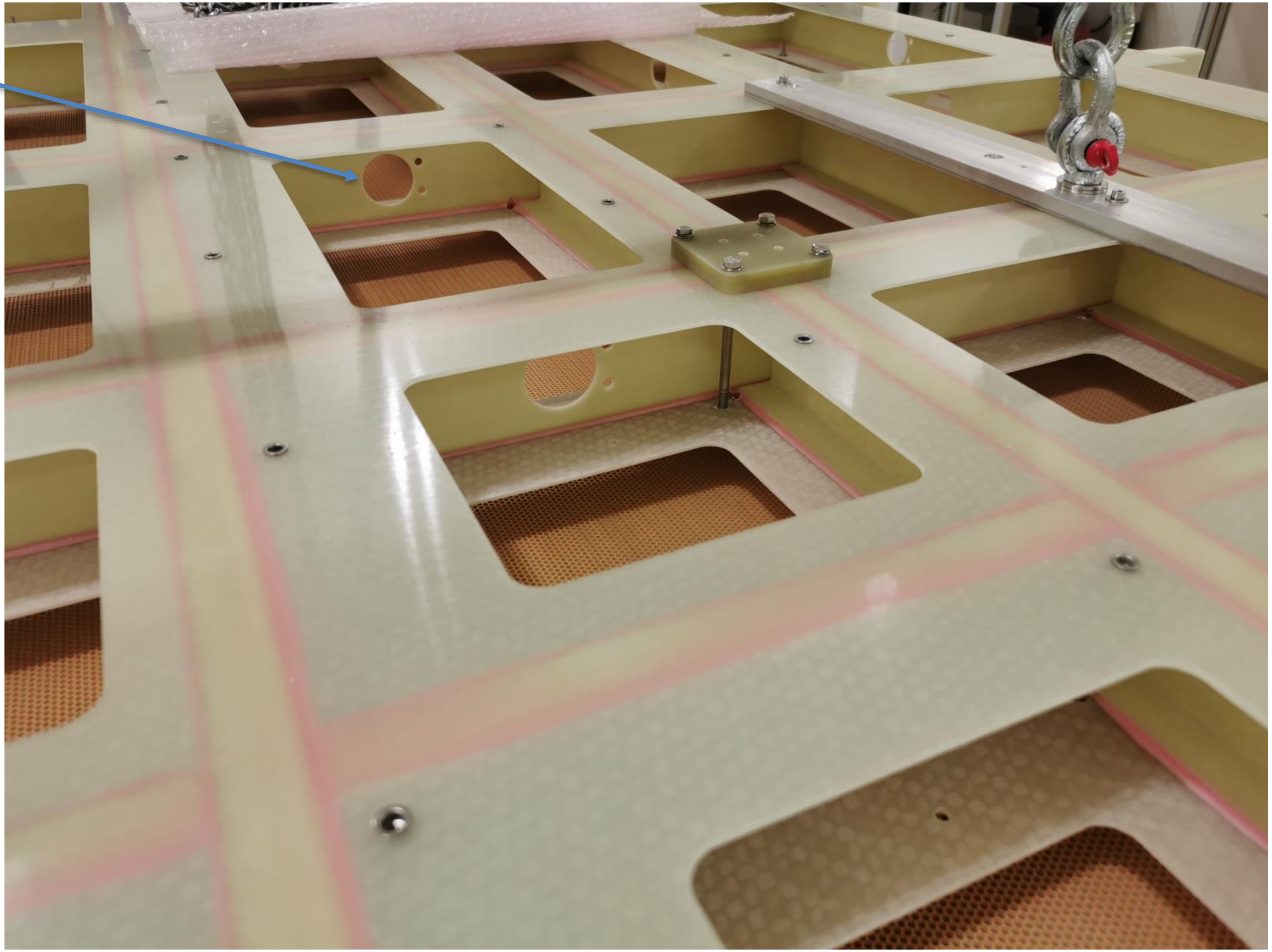
- The rigid composite frame for a CRP is made of two layers (“skins”) made of perforated (water-jetcut) glass-reinforced epoxy laminate material, each 2.4mm thick, separated by imbricated (overlapping) U-shaped profiles made of Durostone® EPGM Epoxy (), of transverse dimensions 60mm× 23mm × 3mm. The frame is composed of two identical sections (half-frames)of dimensions 3.3m×1.56m for a bottom half-CRP and 3.2m×1.5m for a top one.

- A CRU is connected via attachments to the composite half-frame for mechanical support.
- The advantage of having the structure split into two parts that are easily connectable, allows building, testing and transport of the smaller half-CRPs from the production sites to Sanford Underground Research Facility (SURF). Each full-size CRP is assembled from two half-CRPs only after transport into the cryostat.

- The anode PCBs and adapter boards are connected to the composite frame via a number of suspension points using machined pins and spacers made of PEEK material.

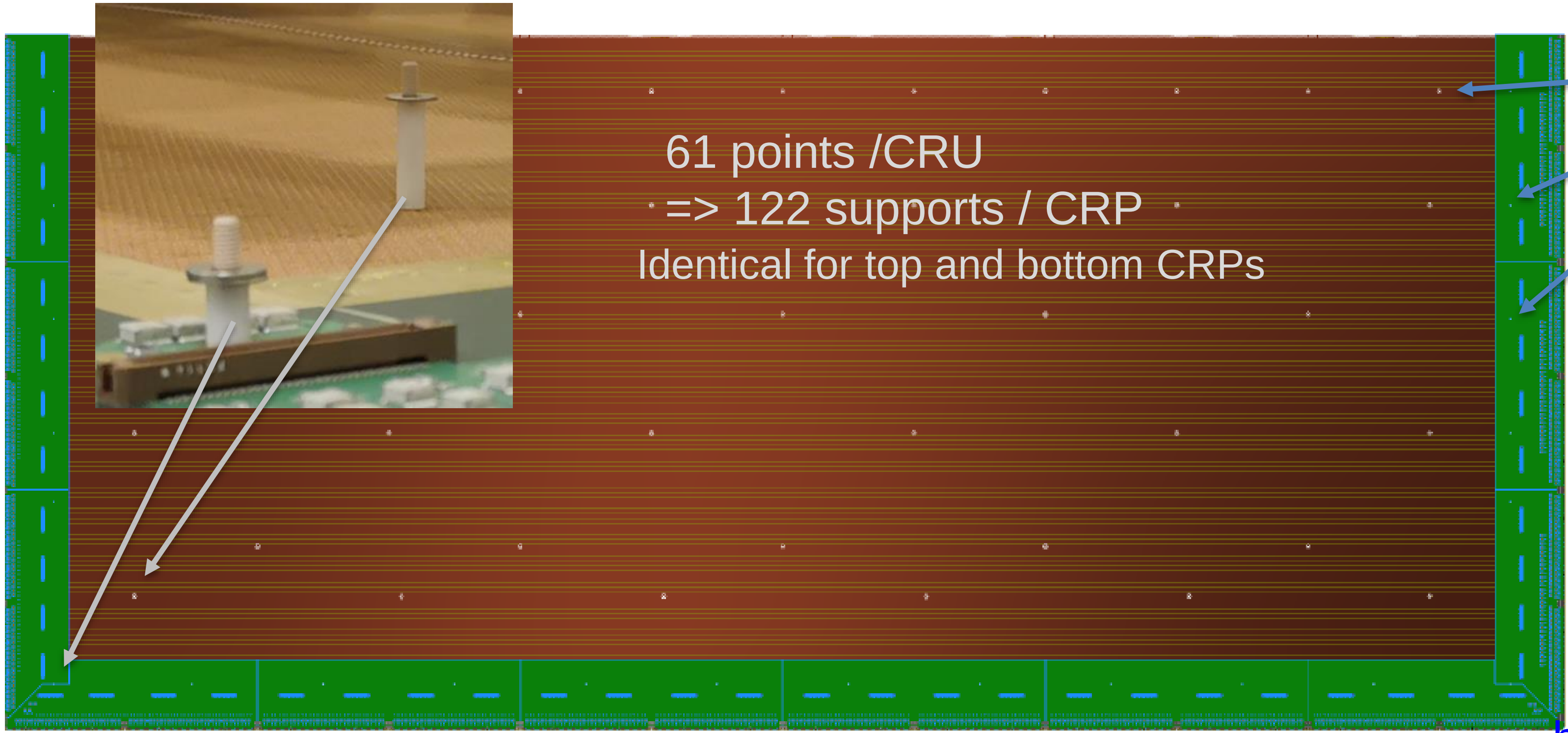
- The two fiber glass-epoxy water-jet-cut skins are fabricated from prepreg with two $0_{\circ}/90_{\circ}$ layers and two $+45_{\circ}/-45_{\circ}$ layers for the glass-fiber orientation of the composite material. The skins are produced between two metallic plates before being cured in an oven under vacuum.
- The glass-reinforced epoxy laminate material for the skin of the frame was chosen to match the thermomechanical behavior of the CRUs to (1) avoid over-stress from differential thermal contraction, and (2) control the (horizontal) spacing between CRUs. The coefficients of thermal contraction of both the perforated anodes and the composite frame material have been measured to be the same within $1 \times 10_{-6}K_{-1}$.
- The holes in the structure serve to reduce the weight, allow for LAr flow across the anode planes, and allow access to the adapter boards and connectors in order to connect the readout electronics.

Example of modification done after FDR (April 2023)



Peek spacers and support points

PCB stack is attached to the composite with peek spacers

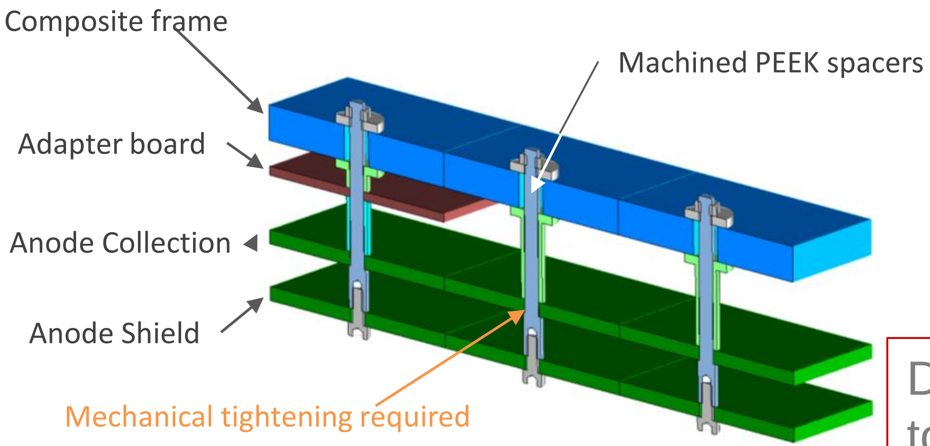


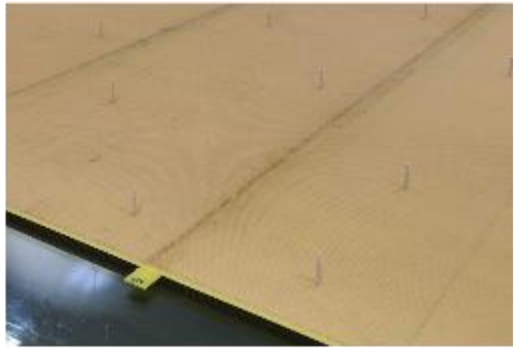
Support points to the composite

Positions optimized by FE simulation to minimize deformations
Especially on edges including connectors

- ❑ The support and spacer axes have been tested in relevant environment and validated with CRP1;
- ❑ they have been manufactured for all subsequent prototypes based on the same technology with the final layout

https://edms.cern.ch/document/2721904/1





Design finalised and ready to be produced