UW Work Scope: Bottom CRP Supports

Value Engineering Meeting

Ian Jentz

March 26th, 2025

Bottom Support Design driven by FD2 Requirements

Categorize broad **Design Requirements**

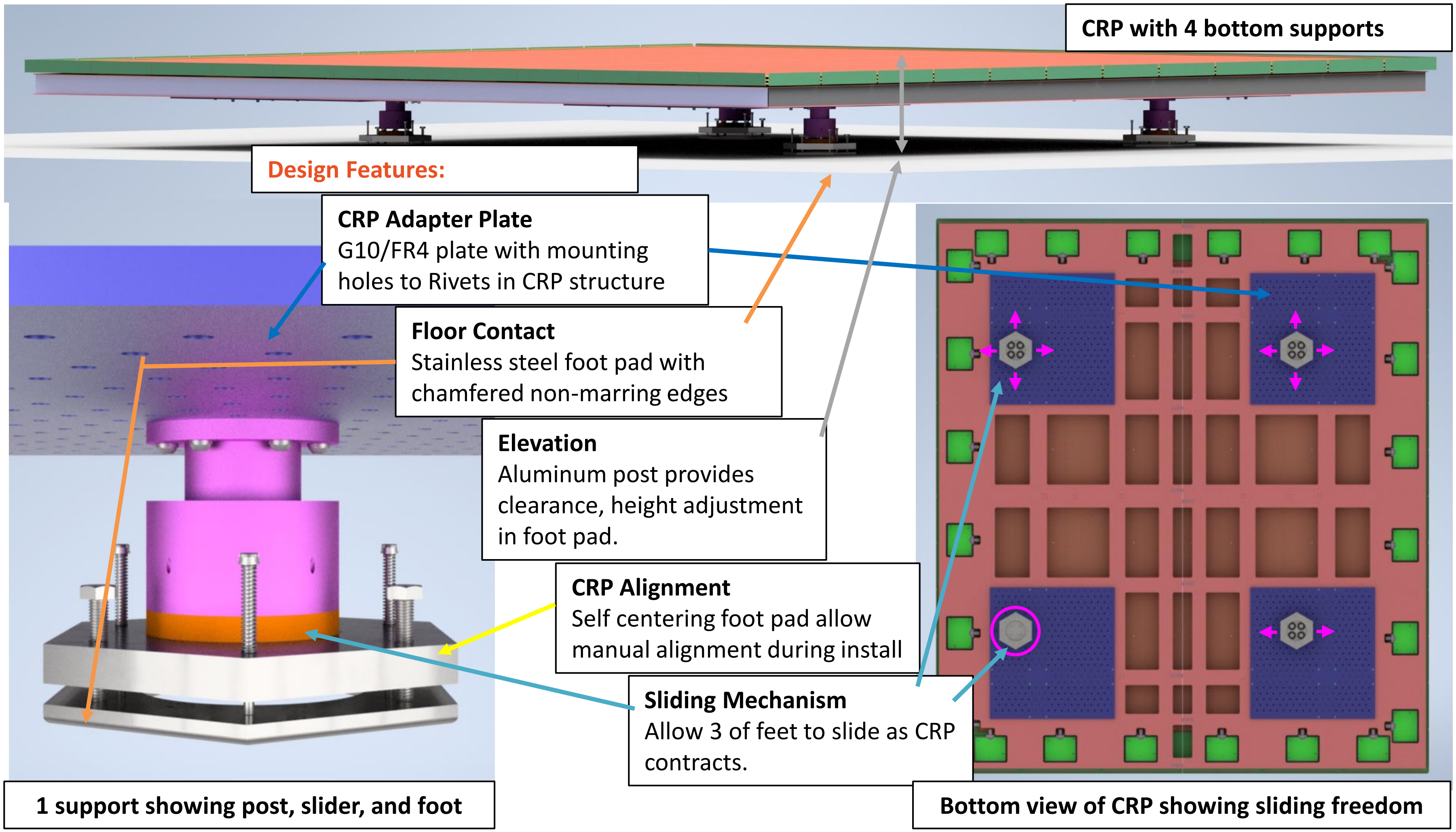
- **Compliance** with engineering requirements
- **Integration** with other FD2 components and install procedures
- **Value** in cost and delivery of components

Consider **Design Features** that address specific requirements

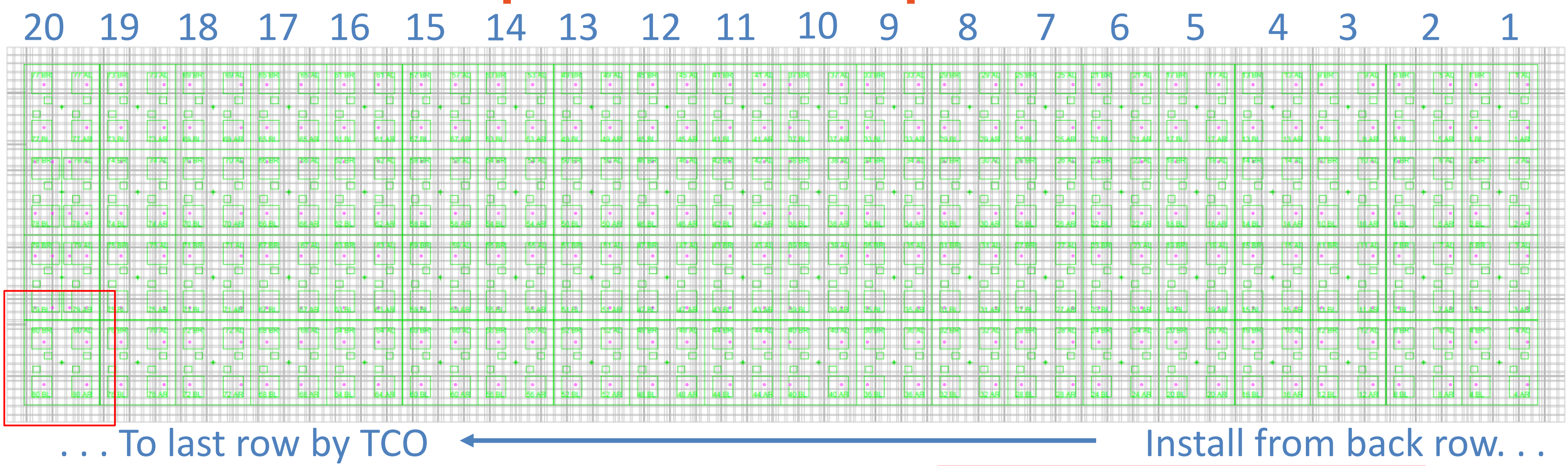
- All features address **Value** requirement by reducing cost of material, manufacture, and assembly labor
- Cost has improved over course of bottom support design and verification
  - March 2022, Preliminary Design Review: $11,232 cost per CRP
  - March 2023, Module 0 install: $6,790 cost per CRP
  - March 2024, FD2 production estimate: $4,887 cost per CRP

Overview of Features and Components

- Bottom CRP support design submitted in March 2022 PDR



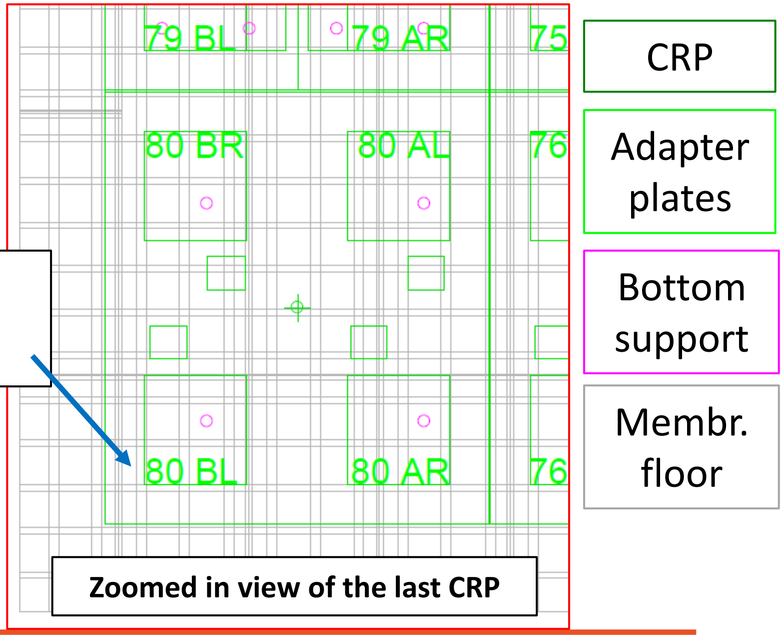
Overview of CRP placement compliance in FD2



This is complicated by the FD2 Layout

- bottom support design **considered FD2 cryostat Design Requirements**
  - Models of FD2 Cryostat and Membrane floor provided by Dimitar Mladenov
- **Limited** set of locations for **floor contact**
  - Center of corrugation panel is only non-contracting space
  - Cannot place any supports on welded seems or corrugations
- **Bottom CRP layout** mirrors that of top CRPs
  - Groupings of 2 and 6 CRP sets, with 5 mm CRP gap within the set, larger gaps between sets.
- **Forces** the use of **large adapter** plates

Adapter Plate ID
Unique id: 80 BL
CRP 80, CRU B, side L



Consider Design Features that address requirements

Design Feature	Design Requirements	
	compliance	integration
all features	-LAr compatible materials and designs that do not trap atmosphere during LAr fill.	-minimizes/eliminate assembly/adjustment of components within FD2 cryostat
CRP Adapter Plate	-distribute CRP structure loading to bottom support -match thermal expansion of CRP structure, preventing thermal contraction loading of CRP	-rectify differences in FD2 membrane floor layout and bottom CRP layout -attachment to CRUs at the CRP factory prior to shipping to FD2
Floor Contact	-distribute weight to membrane floor -maintain contact with floor during LAr fill (no slipping)	-allow CRP install without modification/attachment to membrane floor
Elevation	-raise CRP above membrane floor to desired detector height	-height adjustment possible during FD2 install
CRP Alignment	-installed CRPs achieve exact placement on membrane floor -maintain designed edge gap (5mm) to neighboring CRP	-no modification of CRP structure
Sliding Mechanism	-supports allow thermal contraction of CRP relative to membrane floor	-components maintain orientation during CRP installation -thermal contraction does not put excessive force or displacement on CRP Value

Each **Design Feature** has been improved and FD2 design determined

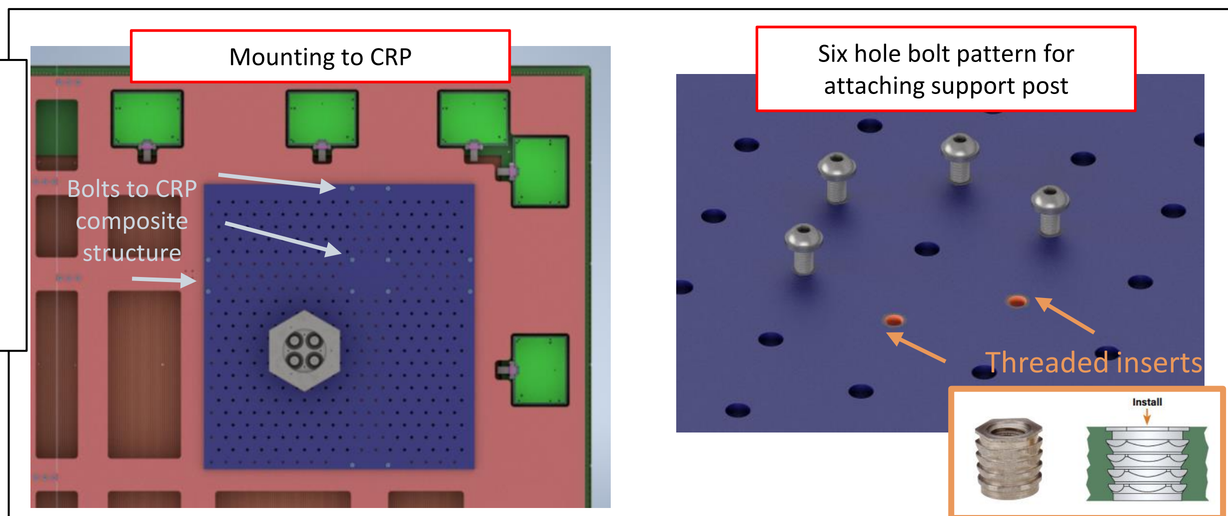
- **Design Solution** that was identified at the Preliminary Design Review (PDR)
- **Value Engineering** prototyping, testing, and analysis performed to evolve the design
- Value **Optimized design for FD2** production scaling (next step FD2 integration test)

CRP Adapter Plates: Design

CRP Adapter Plate

Design Requirement	Design Solution
compliance	**compliance**
-distribute CRP structure loading to bottom support -match thermal expansion of CRP structure, preventing thermal contraction loading of CRP	-G10/FR4 plate spans opening in CRP structure and being of the same material contracts with the structure -bolt on connection of bottom support allows variable support placement and attachment to CRP once within “FD2”
integration	**integration**
-rectify differences in FD2 membrane floor layout and bottom CRP layout -attachment to CRUs at the CRP factory prior to shipping to FD2	-CRP and support specific placement of threaded holes in the adapter plate -adapter plate identifier is engraved in same process as drilling support attachment holes. This allows correct adapter plates to be matched to CRUs when installed at the CRP factory. - mounting holes for bolting plate to rivets in CRP structure.

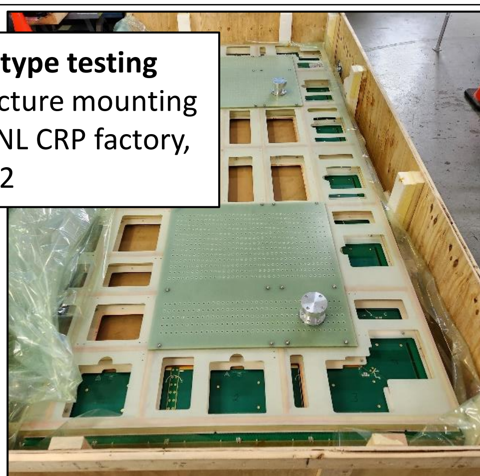
Initial Adapter Plate Design
From March 2022 PDR. Initial plate had many holes for all foot positions and used threaded inserts



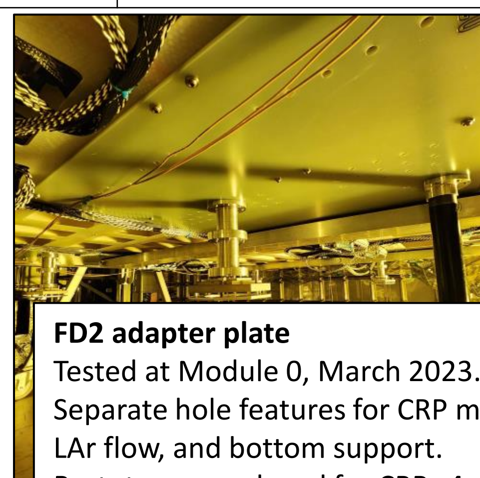
CRP Adapter Plates: Value Engineered Solution for FD2

CRP Adapter Plate

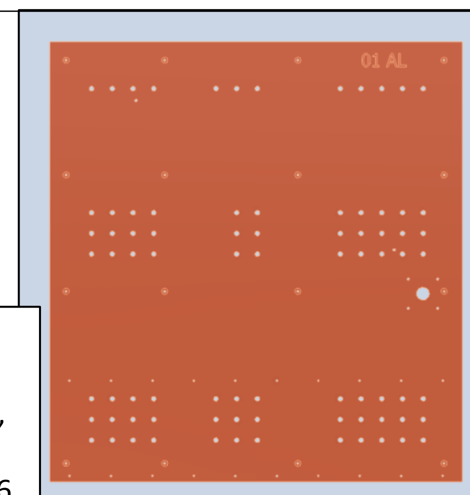
Value Engineering	Optimized FD2 Design
compliance	**compliance**
-model of loading of CRP structure with adapter plates and supports to determine optimum plate thickness -prototyped bottom support attachment hardware, testing threaded inserts vs threaded holes in an attempt to reduce machining and assembly costs.	-Reduced G10/FR4 plate thickness from 0.500 to 0.250 inches, saving material and machining cost -Determined that reduced number of larger bottom fasteners (4 M6 threaded holes) was more efficient than smaller holes with threaded inserts. Tapping 4 threaded holes per plate is slightly more machining, but no additional labor of installing threaded inserts. Threaded inserts also generated some brass dust when fastening. -Could remove LAr flow holes
integration	**integration**
-prototype iteration with CRP structure team on what threaded rivet nuts to attach to in the CRP structure -Tested adapter plate fit during CRU construction both at BNL and CERN Module 0 test.	-adopted common M6 rivet attachment design for FD2 -added lifting tool holes for integration of factory and FD2 CRP lifting frames. -included larger adapter plate to accommodate CRU-by-CRU installation of last 2 CRPs in FD2



1st prototype testing
CRP structure mounting test at BNL CRP factory, Sep. 2022



FD2 adapter plate
Tested at Module 0, March 2023.
Separate hole features for CRP mount, LAr flow, and bottom support.
Prototypes produced for CRPs 4, 5, & 6.

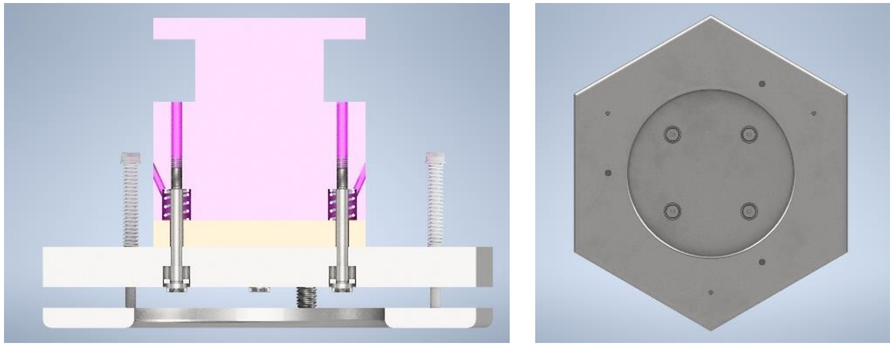


Floor Contact: Design

Floor Contact

Design Requirement	Design Solution
compliance	**compliance**
-distribute weight to membrane floor -maintain contact with floor during LAr fill (no slipping)	-stainless steel foot pad with chamfered non-marring edges provides like membrane floor thermal contraction
integration	**integration**
-allow CRP install without modification/attachment to membrane floor	-flat metallic foot distributes weight at membrane floor center. Open indexing hole in center of foot allows hardware-less alignment and attachment to installation truss.

Initial Foot design
From March 2022 PDR. Made out of stainless steel was found to be too slippery under LN to work as fixed foot

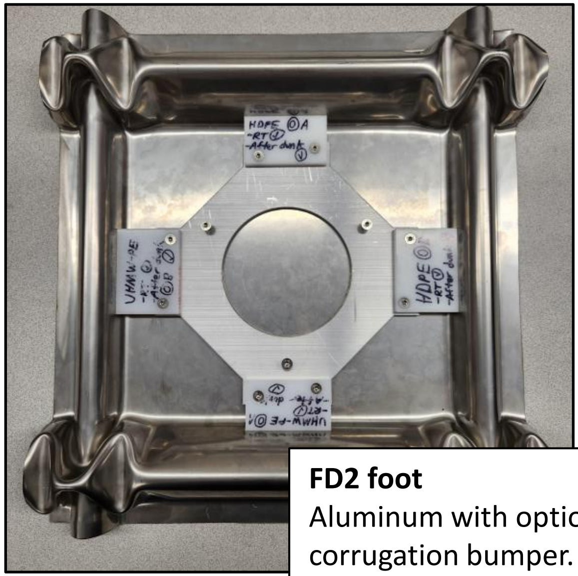


Floor Contact: Value Engineered Solution for FD2

Floor Contact	
Value Engineering	**Optimized FD2 Design**
compliance	**compliance**
-component testing of foot pad in LN determined threshold force to slip from membrane floor. Tested stiction of various foot pad materials	-higher grip Aluminum foot pad prevents slip at the membrane floor
integration	**integration**
-demonstrated place-down installation of CRP 4 and 5 within NP02 cryostat -repeated loaded foot drag testing showed no marring of stainless-steel membrane floor.	-octagonal aluminum foot with chamfered edges provides cryo temp grip with membrane floor.

Foot friction testing
Testing foot-membrane floor slip at differing loading and RT air or submerged LN conditions. Aluminum foot provided best grip in all cases.

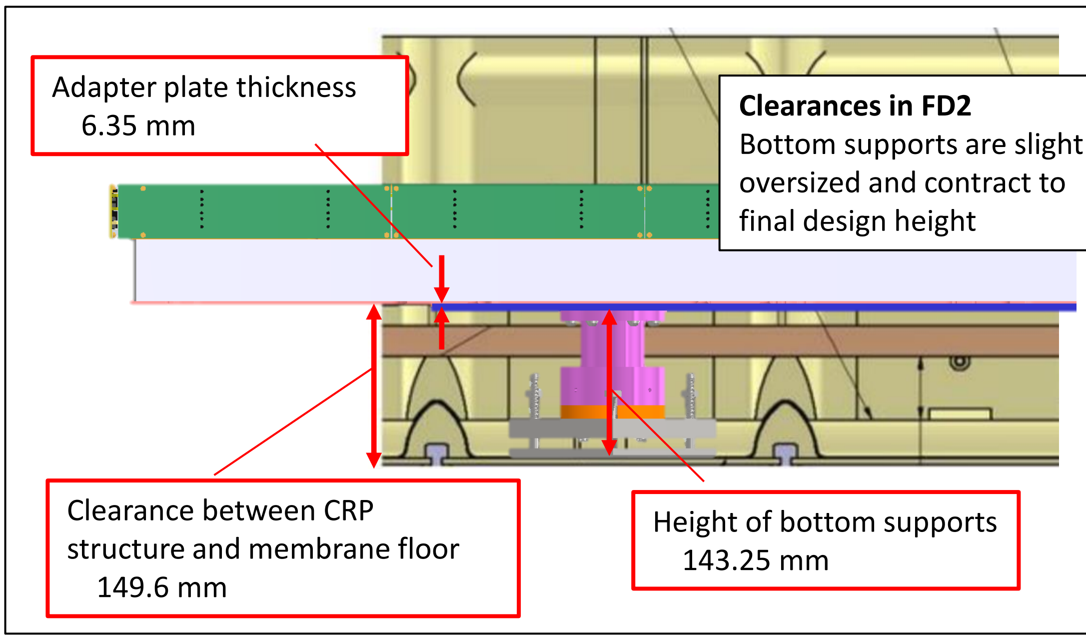
Material	Static Coef. Of Friction under LN
Stainless Steel Foot	0.27
Aluminum Foot	0.49
Rubber Foot	0.24
*all on stainless-steel membrane floor	



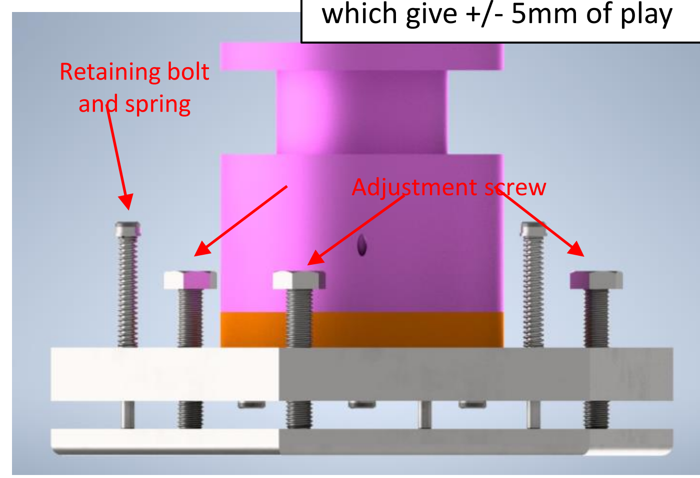
FD2 foot
Aluminum with option to add corrugation bumper. Bumperless design installed in Module 0

Elevation: Design

Elevation	
Design Requirement	**Design Solution**
compliance	**compliance**
-raise CRP above membrane floor to desired detector height	-Aluminum post machined to desired height of support.
integration	**integration**
-height adjustment possible during FD2 install	-Set of three leveling screws allow +/- 5 mm height adjustment of a support.



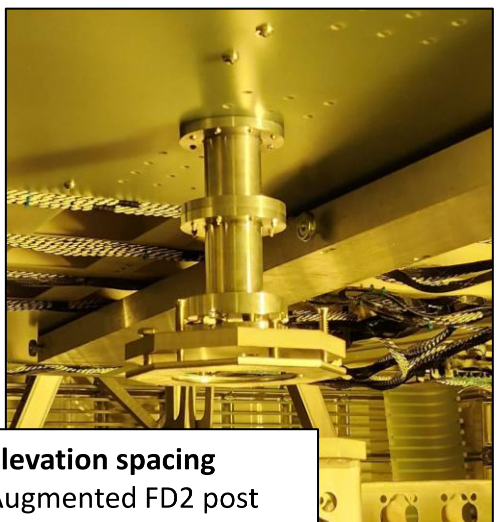
Height Adjustment
PDR design showing three height adjustment screws which give +/- 5mm of play



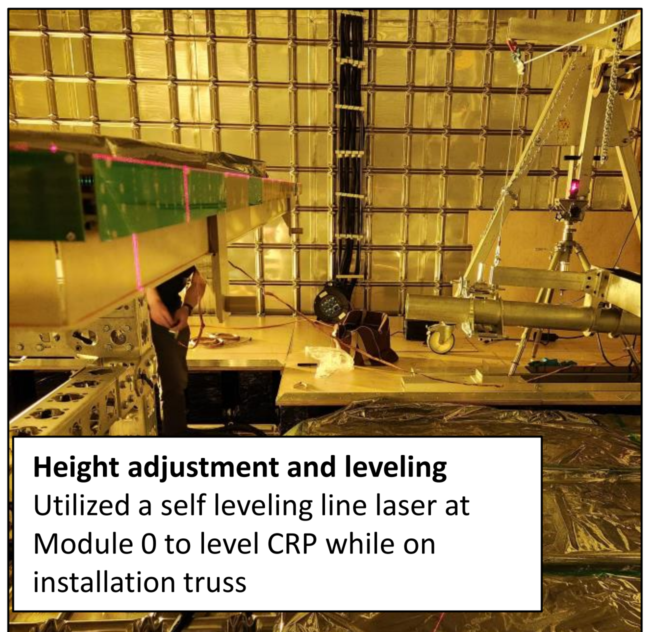
Elevation: Value Engineered Solution for FD2

Elevation

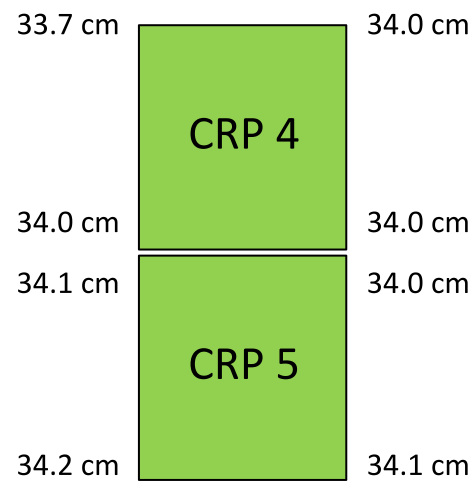
Value Engineering	Optimized FD2 Design
compliance	**compliance**
-Aluminum post machined to desired height of support. -Module 0 install tested the control of elevation spacing using posts. Additional spacer posts used as CRP 4 and 5 are installed at higher elevations than FD2 CRPs.	-Mounting hardware reduced to 4 M6 bolts. -Could evaluate cheaper plastic materials, but need to consider load capacity and creep at LAr temp.
integration	**integration**
-Tested leveling/height adjustment of CRP 4 and 5 while on installation truss during Module 0 install.	-Stainless steel thread inserts allow smooth height screw adjustment within Aluminum foot body.



Elevation spacing
Augmented FD2 post spacing with additional space for Module 0 bottom CRP height



Height adjustment and leveling
Utilized a self leveling line laser at Module 0 to level CRP while on installation truss

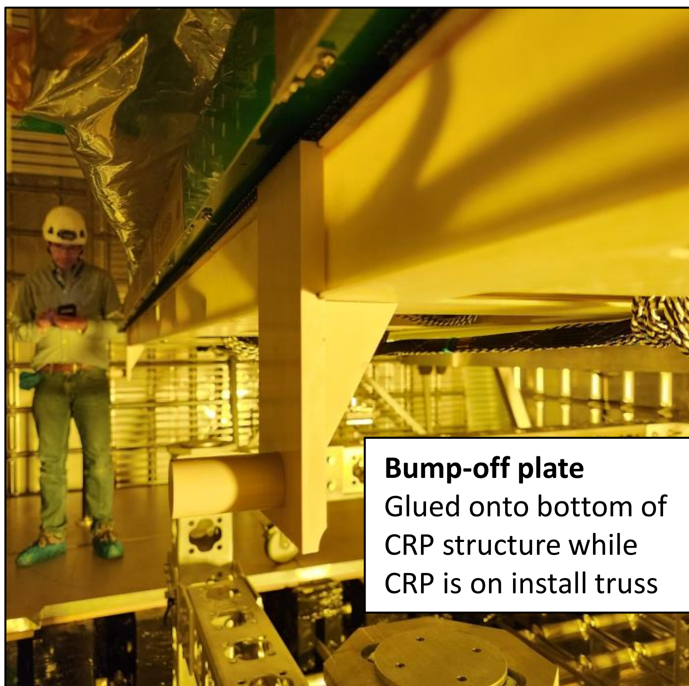


Installed height at Module 0
Height of top of edge board to membrane floor. Measured at corners using measuring tape.

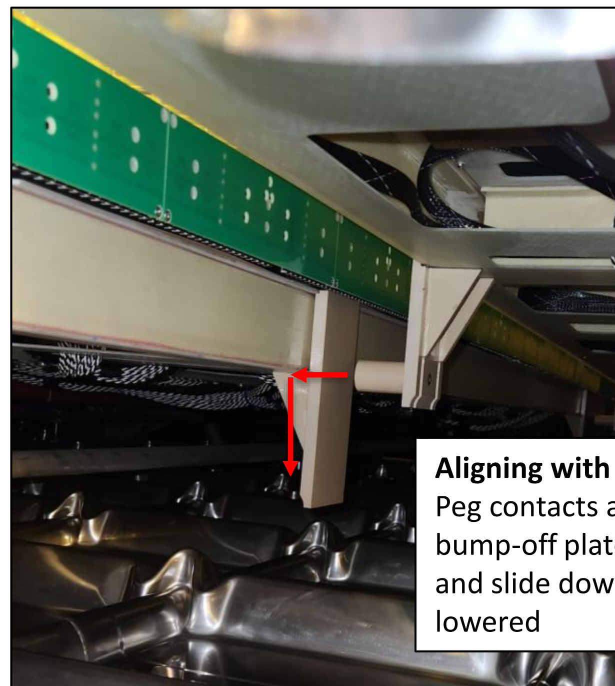
CRP Alignment: Design

CRP Alignment

Design Requirement	Design Solution
compliance	**compliance**
-installed CRPs achieve exact placement on membrane floor -maintain designed edge gap (5mm) to neighboring CRP	-Bump-off plates are mounted to sides of CRP structure. These allow installation personnel to gently push CRP against a reference plate of neighboring CRP bump-off plate
integration	**integration**
-no modification of CRP structure	-Bump-off plates are glued to CRP structure



Bump-off plate
Glued onto bottom of CRP structure while CRP is on install truss

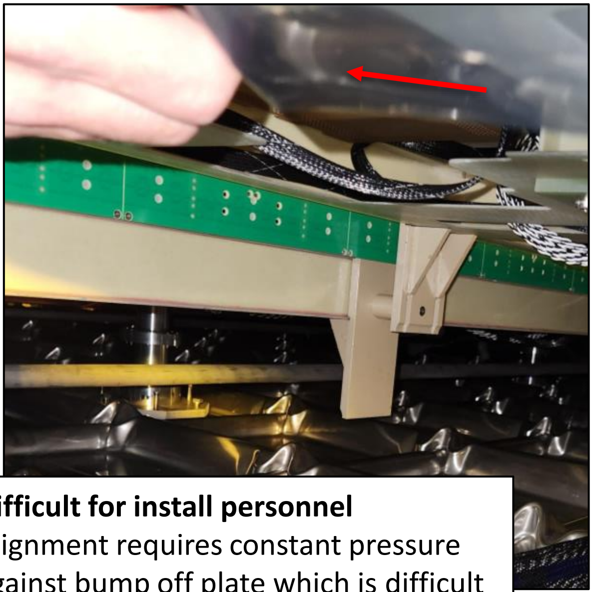


Aligning with bump-off plate
Peg contacts against PEEK bump-off plate of other CRP and slide down as CRP is lowered

CRP Alignment: Value Engineered Solution for FD2

CRP Alignment

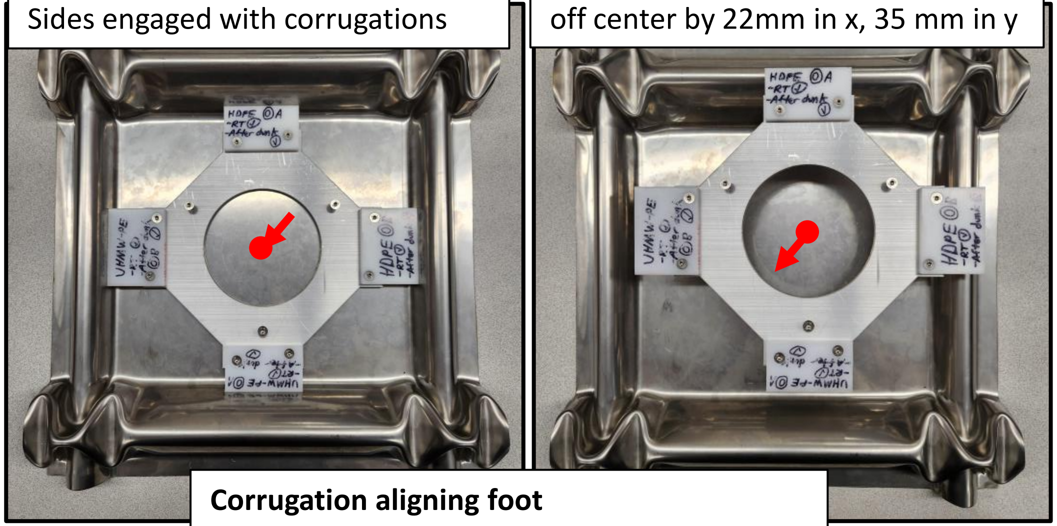
Value Engineering	Optimized FD2 Design
compliance	**compliance**
-Bump-off plate design tested in the installation of CRP 5. Gap of 3-4mm between CRP 4 and CRP 5 edge cards achieved. Alignment involved tedious and difficult labor on part of installation personnel which would be difficult to replicate in FD2.	-switch to new corrugation aligning foot design. Bumpers added to bottom support foot guide CRP into final position as it is lowered to the floor.
integration	**integration**
-Were able to glue on bump-off plates within NP02 cryostat. Added a tedious step.	-corrugation aligning foot design does not modify the CRP structure



Difficult for install personnel
Alignment requires constant pressure against bump off plate which is difficult for personnel to pull off in practice.

Centered Foot on Membrane Floor
Sides engaged with corrugations

Off-Center Foot above Corrugations
off center by 22mm in x, 35 mm in y



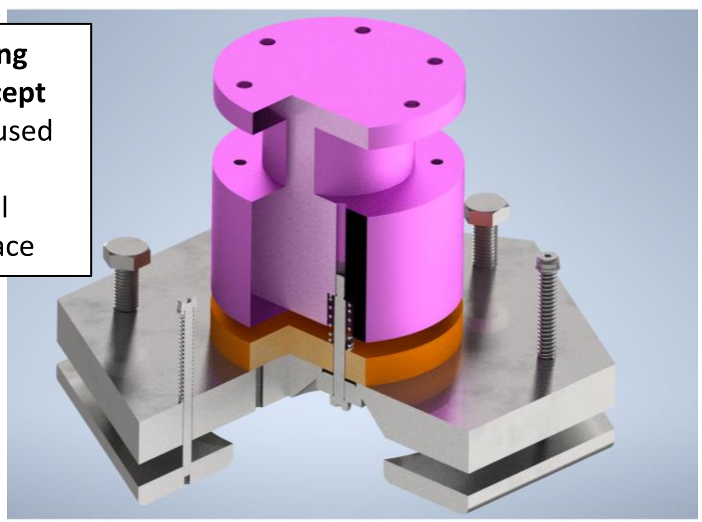
Corrugation aligning foot
Would perform similar function of bringing CRP over and down into final position

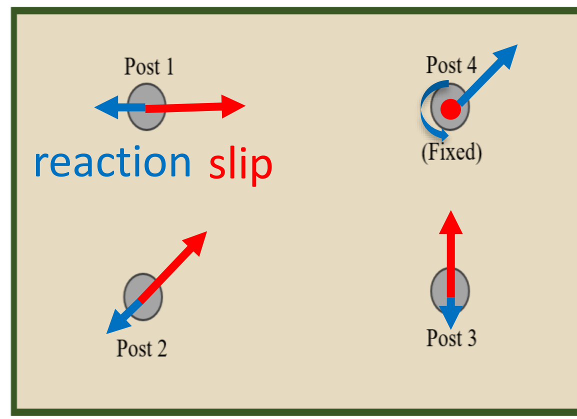
Sliding Mechanism: Design

Sliding Mechanism

Design Requirement	Design Solution
compliance	**compliance**
-supports allow thermal contraction of CRP relative to membrane floor	-provide a sliding interface within the bottom support which can give +/- 7 mm of travel in x and y. Thermal contraction of CRP is at most 6.3 mm for the longest span between supports. -centering mechanism keeps support from sliding when load is < 15.5 kg on support. Weight of CRP must be placed on supports before they can slide, allowing centering of the CRP feet in corrugation as CRP is lowered
integration	**compliance**
-components maintain orientation during CRP installation -thermal contraction does not put excessive force or displacement on CRP Value	-fixed foot provides center of contraction for CRP, free 2D sliding support contract toward this center. CRP rotation is prevented by fixed foot and 1D sliding support

Original sliding support concept
PDR version used a PEEK on stainless steel sliding interface





Contraction about fixed support
Orientation of CRP is maintained. Reactions for opposite the slip direction. A small torque can be realized at the fixed post if slip is not uniform between the free posts.

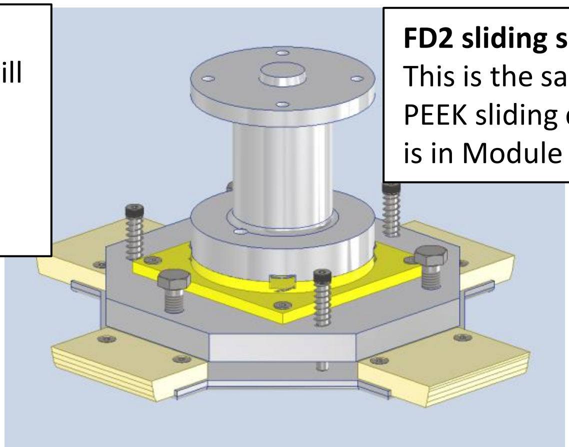
Sliding Mechanism: Value Engineered Solution for FD2

Sliding Mechanism

Value Engineering	Optimized FD2 Design
compliance	**compliance**
-component testing campaign in LN. Tested loaded prototype bottom support components varying sliding interface design and material to find most reliable configuration.	-identified PEEK-PEEK interface and stainless-stainless interfaces as comparable in low sliding friction. PEEK is slightly favored due to machinability and test experience in Module 0.
integration	**integration**
-modeled CPR contraction and sliding interaction using experimentally determine variation of sliding coefficient of friction. Found no adverse changes in displacement or excessive force applied to CRP during contraction-slip phase. -models did show that constrained 1D slip interface was unnecessary and could be replace by the easier to machine free 2D slip interface. Rotation of CRP was adequately prevented by the fixed foot, with only a low torque accumulating at the fixed foot.	-Design simplified to just the 2D slip interface. 1D slip interface was found to be unnecessary through modeling and testing.

Sliding component testing

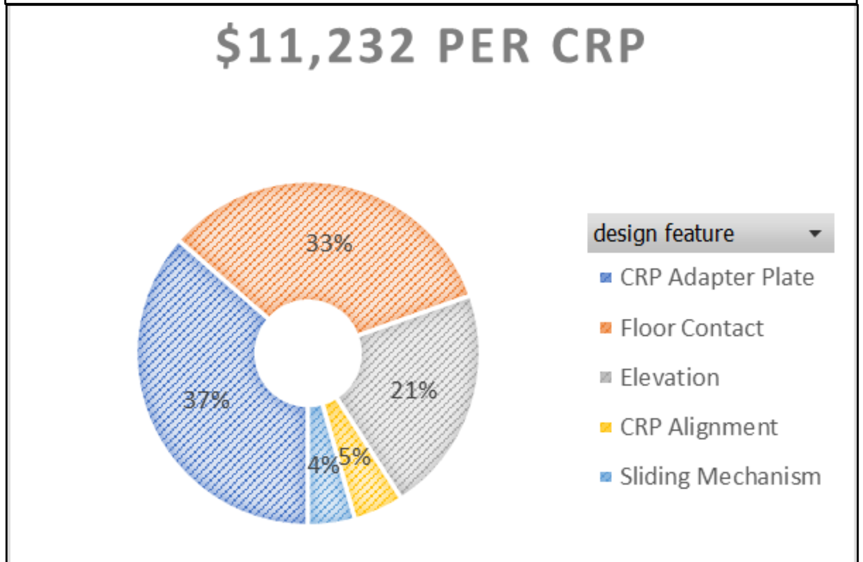
- We are 99% confident that the frictional force will reside within a window of **55.5-134.8 [N]**
- **134.8 [N]** per foot would be the greatest force experienced by the feet.
- Design Value (1.5 SF) gives **202 [N]** per foot

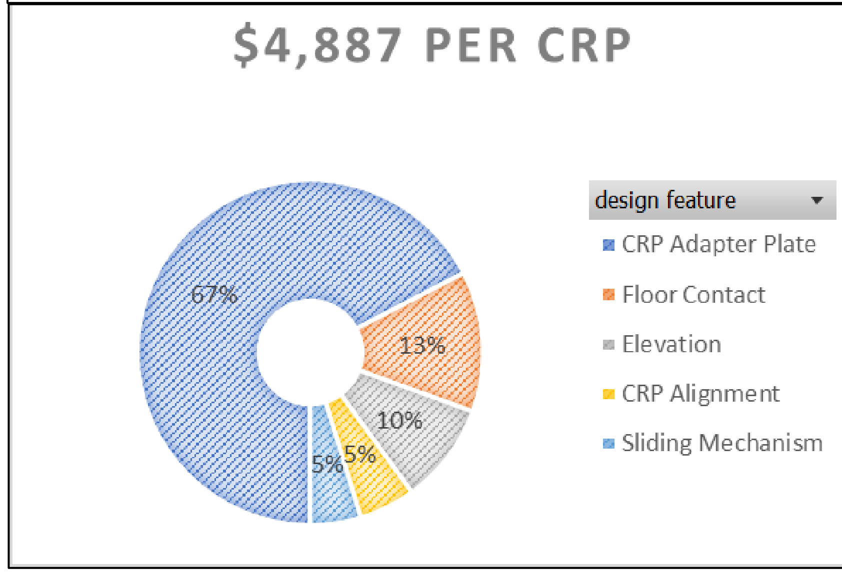


FD2 sliding support
This is the same PEEK-PEEK sliding design that is in Module 0

Improvement in Bottom Support Costs

March 2022, PDR Prototype	March 2024, FD2 Estimate





Cost savings realized by

- Material change from stainless steel to aluminum construction reduced material and machining costs for custom made parts
- Reduction in quantity and complexity of hardware through re-design of centering mechanism
- Assembly costs can be kept low by performing assembly at UW Madison.
  - Assembly by undergrads covered through UW base grant.,est 1 hour per support =~350 hours of undergraduate labor
- Cost of adapter plate material was reduced by going from 0.5 inch thick to 0.25 thick G10/FR4

Adapter Plates, 67% of bottom support cost

FedTech Order			price per adapter plate			cost ratio
date	description	quantity	FedTech price	material estimate	machining estimate	machining/ material
6/6/2022	0.500 thick Initial prototype plates	2	$ 1,016.55	$ 783.77	$ 232.78	0.30
1/4/2023	0.250 thick Module 0 plates, for CRP 4 & CRP 5	8	$ 946.55	$ 391.91	$ 554.64	1.42
10/3/2023	0.250 thick Module 0 plates, for CRP 6	4	$ 1,194.63	$ 391.91	$ 802.72	2.05
	0.250 thick FD2 adapter plates, prediction	328	$ 823.17	$ 261.27	$ 561.90	2.15

Prediction of $823 per FD2 adapter plate

- **Material** cost for G10/FR4 plates **lowers** for **high volume** orders. First estimates are a **0.667 x reduction** (ePlastics.com). However there might by large suppliers who could get lower volume pricing
- **Volume production cost** of machining **should lower** as well. First estimate shows regular ordered CRP 4 & 5 plates at **0.7 machining cost reduction** compared to rush ordered CRP 6 plates. Need to work with manufacturers to get more accurate high-volume pricing.

Can cost be further reduced

- **G10/FR4** is expensive to work with. It **dulls tooling** quickly and requires **dedicated machines** that get beat up (fiber glass dust wrecks everything).
- Need to **expand search for G10/FR4 manufacturers**. When in production phase we will go through a more rigorous bid process. A ~$150k job will attract offers that prototyping runs didn't.
- Potential cost savings by matching tolerances to CRP structure

Conclusion

CRP Bottom Support Value Engineering

- Bottom support **design to compliance and integration** requirements
  - Allows for **thermal contraction of CRP** and can be **installed in FD2**
- **Evolved** design through testing
  - **Component Testing** of bottom support sliding system under LN
  - Demonstrated **installation of CRPs 4 and 5** with bottom supports at Module 0
- Design **improved based on lesson learned** in testing and Module 0
  - Identified **preferred PEEK-PEEK 2D slider d**esign
  - **Improved CRP alignment systems** base on Module 0 experience
- Extensive **value engineering** to **reduce cost** and **improve ease of installation**
  - Design and fabrication changes to reduce hardware, machining, and switch to cost effective materials
- **Cost has improved** over course of bottom support design and verification
  - March 2022, Preliminary Design Review: $11,232 cost per CRP
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