Bottom CRP Installation Tooling

Design status and proposed FD work

Ian Jentz

June 10th, 2024

WISCONSIN
UNIVERSITY OF WISCONSIN–MADISON

DUNE

Overview

Overview of Bottom CRP Lifting Tools

- UW Team and collaboration integration
- FD bottom CRP installation requirements

Modifications to tine lifting system

- Integration with FD boom crane
- Powered control through electronics

CRP Installation Truss

- Use of Truss in Module 0 install
- Lessons learned / outstanding improvements

Modifications to Truss for use in FD install

- Truss retrieval system overview
- Truss retrieval process
- Design details

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UW Madison Team

Primary Investigators

Dr. Brian Rebel
Professor in
Dept. Physics
Senior Scientist at
Fermilab

Physicist with over 20 years of experience building neutrino detectors.

Dr. Franklin Miller
Professor in
Dept. Mechanical Eng.

NASA civil servant with experience in mission critical systems for James Webb Space Telescope.

Supporting Staff

Dr. Greg Nellis
Professor in Dept.
Mechanical Eng.

5 years of industry experience and 24 years as a ME Prof.

Dr. Ian Jentz
Scientist in Dept.
Mechanical Eng.

Nuclear engineering with 5+ years experience in experimental thermal-hydraulic systems

Students

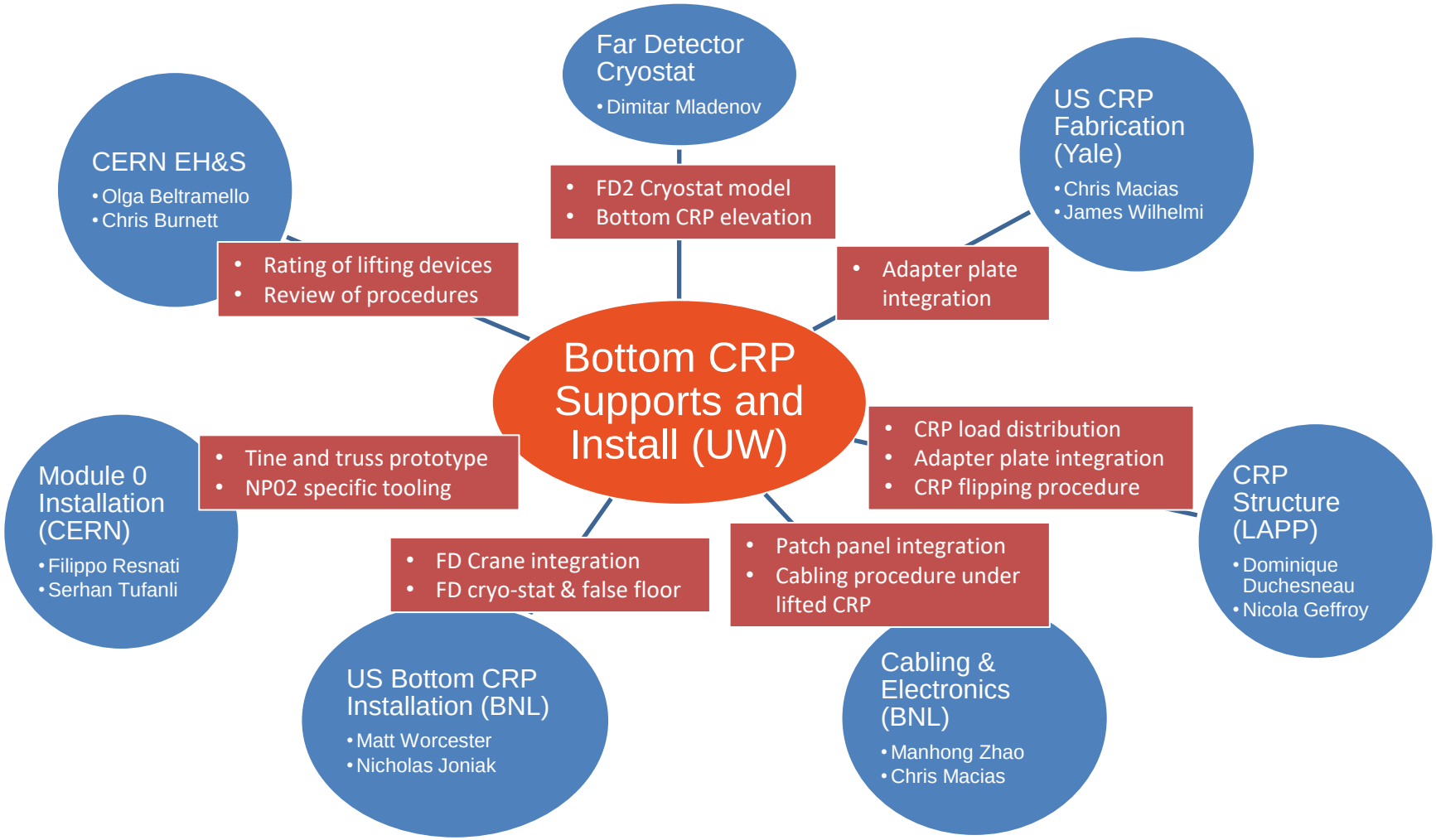
Yannis Pandiscas
MS Student,
Mech. Engr.

5+ years of professional and student automotive engineering, with experience in structural analysis.

Jonathan Stone
MS Student,
Mech. Engr.

New student with undergrad experience in automation and robotics

Product of continuous input across DUNE Collaboration



Previous Presentations on Bottom CRP Installation Tools

March 30th, 2022: Preliminary Design Report

- Initial design concepts for bottom supports and installation truss,
  - https://edms.cern.ch/file/2718664/1/03-30-2022_PDR_BottomSupports.pptx

September 28th, 2023: Collaboration Meeting Session

- Bottom CRP Installation Update: updates to bottom supports and installation following Module 0
  - https://indico.fnal.gov/event/58097/contributions/276018/attachments/171521/231343/28-09-2023_CollaborationMeeting_UWUpdate.pdf
- Updates to bottom CRP supports and CRP adapter plates following CRP structure design revision.
- Outlined issues of truss retrieval and FD last row installation

January 24th, 2024: Collaboration Meeting Session

- Installation Truss Retrieval System: proposed for truss modifications to be demonstrated
  - https://indico.fnal.gov/event/60987/contributions/283306/attachments/174494/236576/24-01-2024_IntegrationMeeting_TrussRetrievalSystem.pdf
- Presented proposed modifications to Module 0 truss design so that it could be retrieved from underneath lifted CRPs in FD

March 26th, 2024: Value Engineering Meeting

- Bottom CRP Install Tools: design and value of tools to FD installation,
  - https://indico.fnal.gov/event/63907/contributions/287131/attachments/176279/239421/26-03-2024_ValueEngineeringMeeting_BottomCRPInstallationTools.pdf
- Presents component design requirements, Module 0 solution, and proposed changes for FD

Bottom CRP Installation evolved in stages

March-May 2023: Module 0 Install of CRP5 and CRP6 in NP02 Cryostat

- Produced FD design bottom supports and adapter plates
- Prototype of install tools (lifting system and truss) designed to FD requirements. Modifications to work in NP02 and to meet schedule.

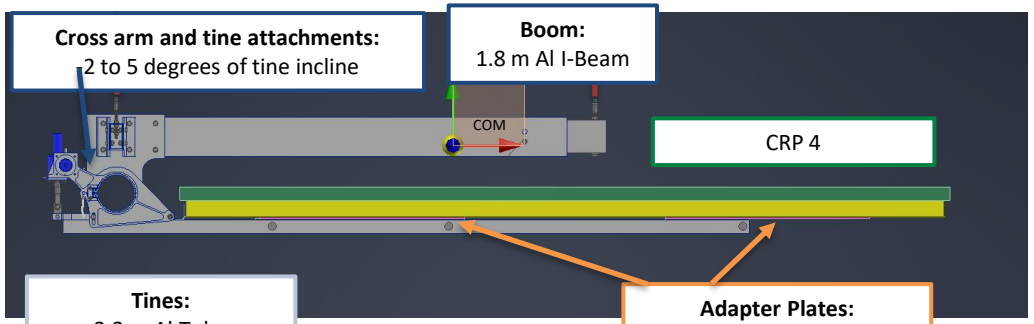
August 2023 - March 2024: Far Detector Concept Development

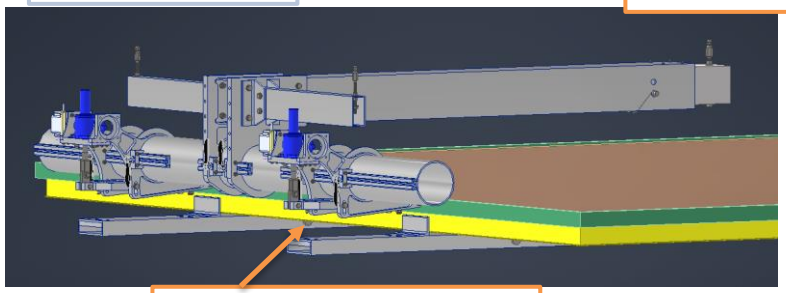
- Defined objectives and requirements of FD bottom CRP install test
- Developed concepts for refining installation tools
- Submitted proposal for UW work on Install tools and procedures

Future: Far Detector Installation Demonstration

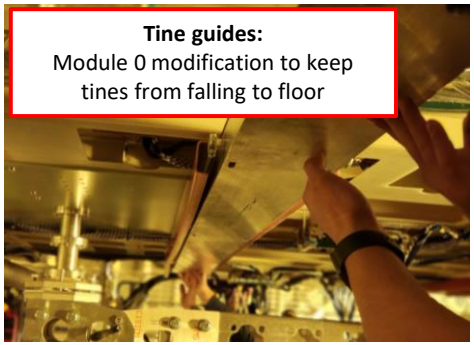
- Date and location TBD, either CERN or YALE in late 2024 - early 2025

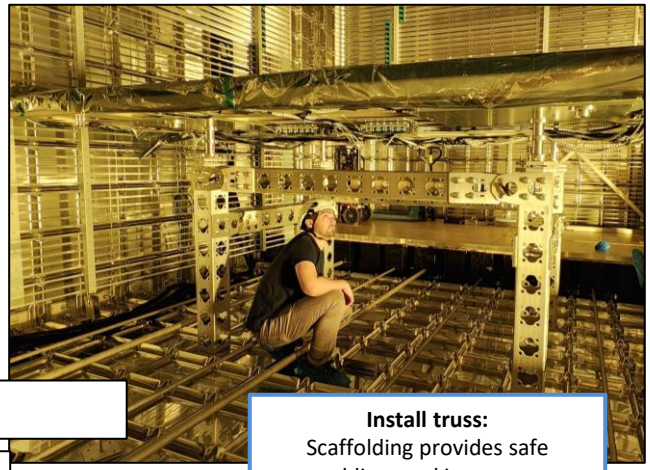
Overview of Bottom CRP Installation Tool Prototypes used in Module 0 install of CRP 5 and CRP 6





Detaching tines:
Allow tines to stay below false floor level for later retrieval





Install truss:
Scaffolding provides safe cabling working space

Installation Tools:

CRP Tine Lifting Tool
Manipulation tool that picks up CRP from below, contacting adapter plates.

Installation Truss
Scaffolding structure for holding the CRP while electronic cabling hookup is performed underneath the CRP

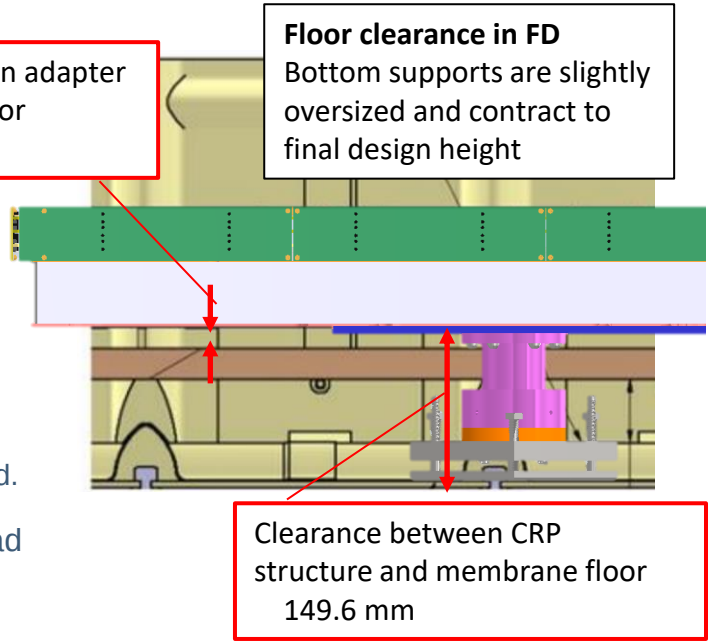
Module 0 Integration
Additional components and modifications needed for install in the NP02 cryostat. These are not used in FD2.

Gantry and spreader:
Module 0 hoist solution as FD2 boom crane didn't fit in NP02

Overview of Installation Compliance in Far Detector

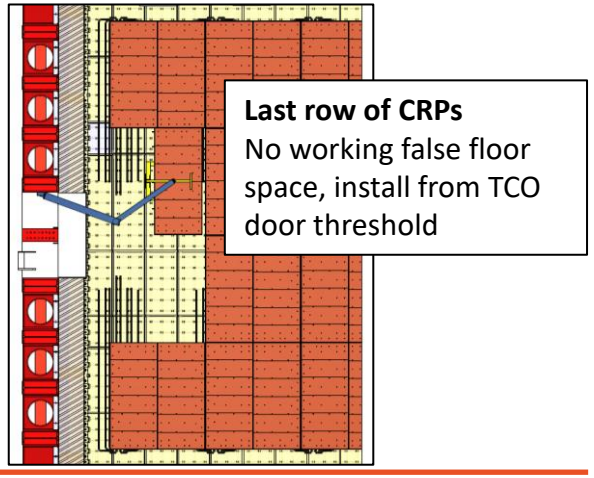
Installation is complicated by the FD install space

- **Limited access** to install site and CRP
  - CRPs are installed **with tight spacing** to field cage and each other
  - **Low CRP height** is below the false floor working platform.
  - Tight **clearance below the CRP** limits tine access
- **Vanishing floor space**, working floor disappears in last row of CRPs
  - Last CRP has no false floor, work has to be performed from TCO door threshold.
- **Safety considerations,** work cannot be performed under a slung or lifted load
  - Extra install truss scaffolding system needed to protect cabling team



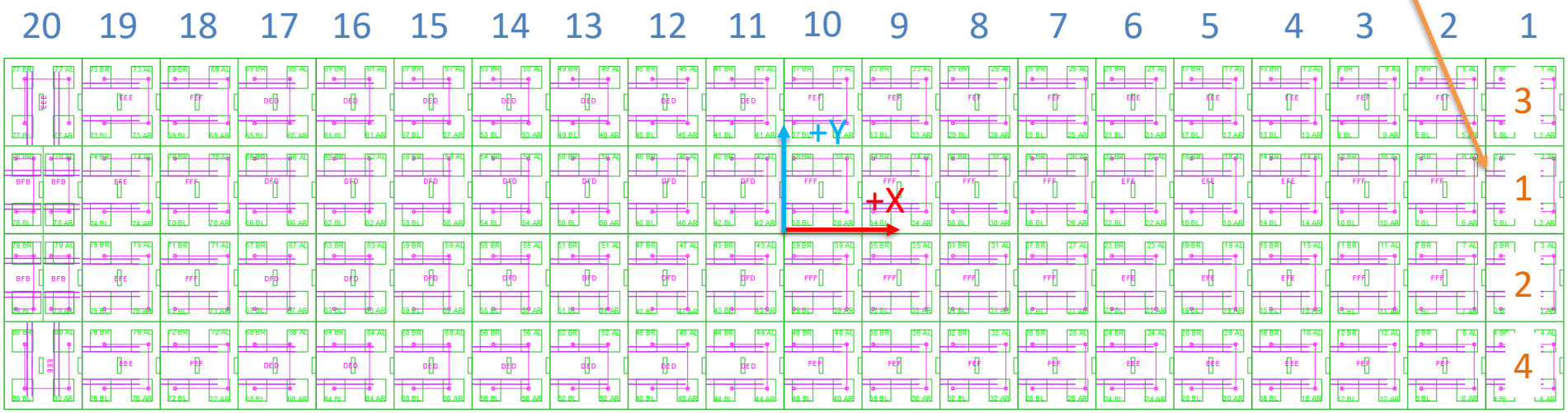
Tailored Installation tools for best compliance

- **Tine Lifting System**, connects with boom-crane for singular system
  - Tine leveling and winch system keep CRP level during full range of lift and lowering
  - Custom tines are slim enough to fit under CRP and detach once below false floor
- **Installation Truss,** structural solution for safely working under CRP
  - No tooling/machinery needed, entirely person assemblable and movable
  - Can be retrieved from underneath raised CRP.



FD Layout of Bottom CRPs

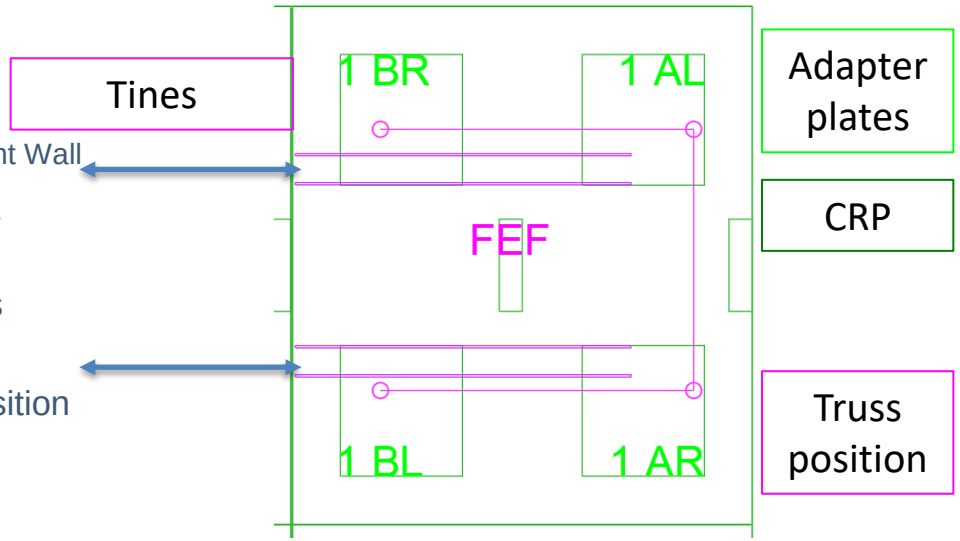
Placement order:



. . . To last row by TCO

Install from back row. . .

- CRPs are lifted and lowered using Tines
- CRPs are installed in rows
  - Rows 1-19: order: Left Center, Right Center, Left Wall, Right Wall
  - Row 20: outside CRPs first, then last 2 CRPs installed as 4 separate CRUs
- CRPs are held up at install site using installation truss system, coded DED, FEF, FFF etc.
- Adapter plates, coded by CRP number, CRU, and position
  - e.g. 01AL is CRP 1, CRU A, left side



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Lifting System: Planned Modifications for FD

Gantry/Crane

- A counter balanced boom crane will be used in FD

Spreader

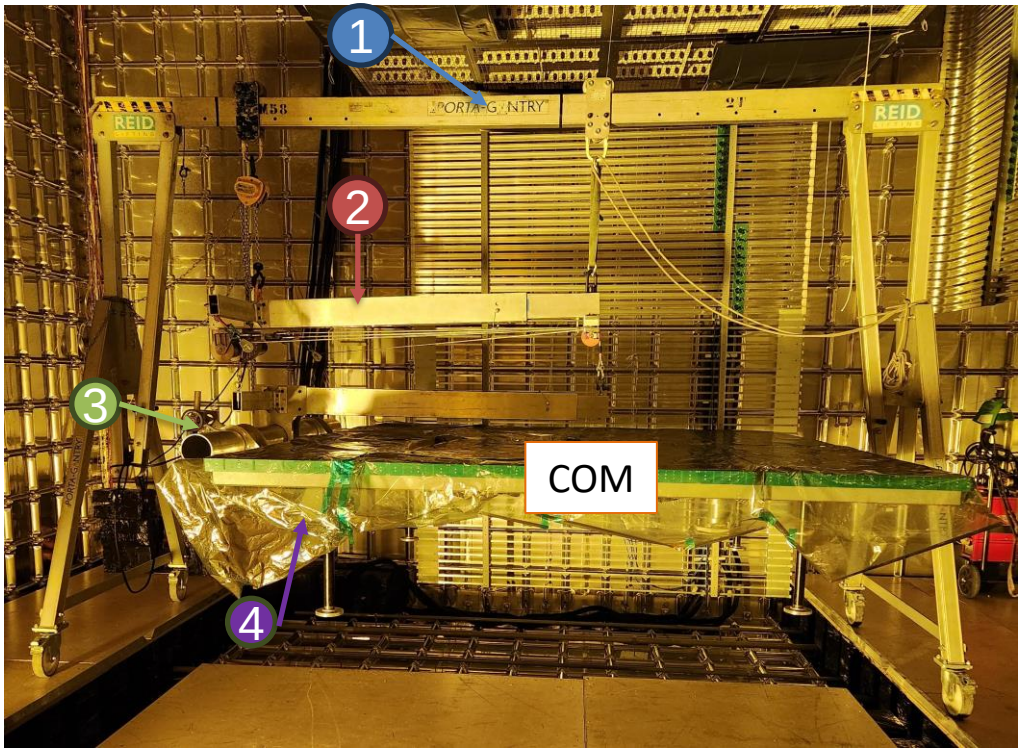
- Modifications for FD with boom crane hook point over front of COM and tilt/sway stabilization at back
- Keep winch in FD, provides smooth and planar hoist/lower motion. Will not need to reposition crane.

Carriage

- Rebuilding tine straps for FD to get higher 3x proof weight capability (2x in Module 0)
- Motorized control of drives for smoother and safer remote operation.

Tines

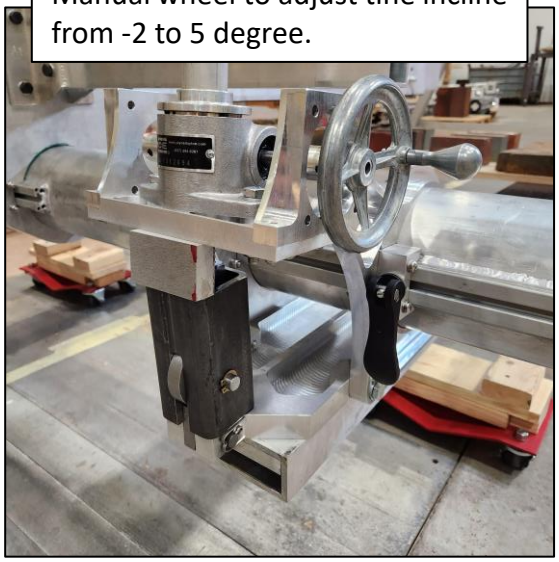
- Addition set of short tines for FD install of last CRUs. These will be small enough to retrieve when against the TCO wall.



Lifting System in Module 0
Prototype of FD system with modifications for NP02 Installation

Lifting System: Motorized Control

Tine inclination adjustment
Manual wheel to adjust tine incline from -2 to 5 degree.

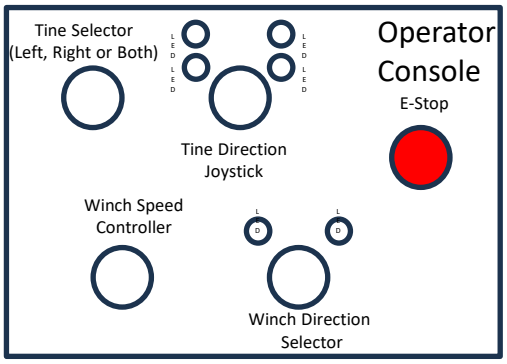


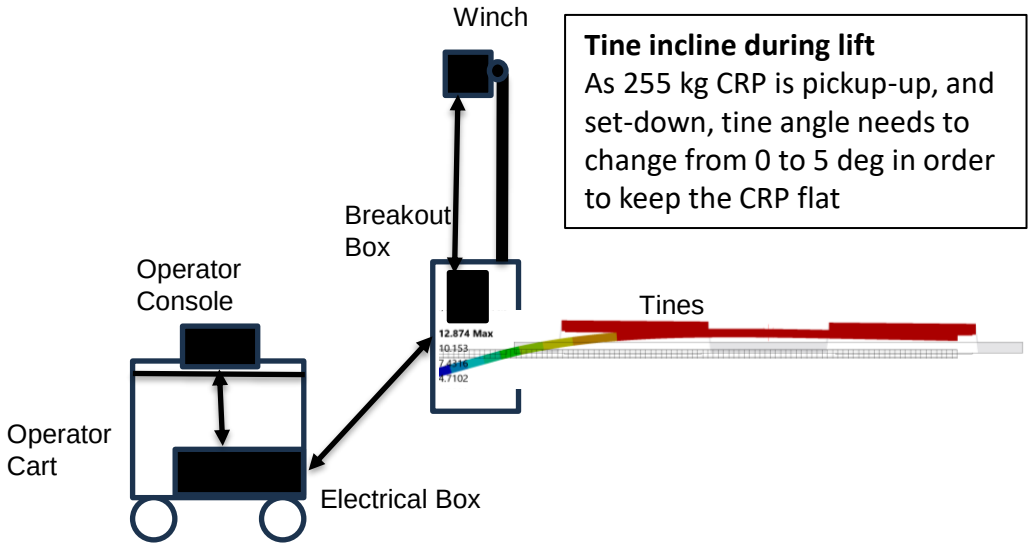
Tine Lifting (Demonstrated at Module 0)

- Manual hand wheels for actuating tine angle. Required special permission from EH&S for operator to crank from right behind suspended system.
- Lift/raise of suspended CRP through OEM winch and controller. Only 1 speed forward and reverse made for bouncy system.
- Safety will require better control and operator limits

Controlled Motorized Lifting (to be demonstrated)

- motor control system (PLC) with limit switches for the tine and winch will limit angle of approach and top/bottom of winch lift.
  - Control the angle of approach for either left, right or both tines at a time.
  - Lift a CRP with winch speed control.
- Consolidate controls to one operator console.





Tine incline during lift
As 255 kg CRP is pickup-up, and set-down, tine angle needs to change from 0 to 5 deg in order to keep the CRP flat

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Install truss consists of 2 systems

Truss Structure (Demonstrated at Module 0)

- Support the CRP while technicians attach cables and test the CRP's electronics.
- Allow for accurate leveling and adjustment of the CRP, including installing any shims, spacers or other adjustment hardware.
- This is made possible by the full contact with the membrane floor made by the truss.
- CERN EH&S guided and approved approach and operations in Module 0. Rigid structure is easy to justify.

Retrieval System (to be demonstrated)

- Ad hoc system of catch rails only approved for use at Module 0.
- Ability to be retrieved to the false floor without personnel underneath the CRP while it is suspended
- Cannot interfere with the load bearing capacity of the truss. Safety considerations make it necessary to have the truss disengage from any retrieval rails

Personnel safely operate under the structure

CRP weight directly transferred through columns

Catch rail system used in Module 0
Needs to be replaced by truss retrieval

Modularity is a Key Feature

- Module 0 demonstrated that components that could be broken down into person carriable pieces were easier to work with and safer to use.
- Disassembly allows system to be moved without additional machinery and stored without occupying much space.

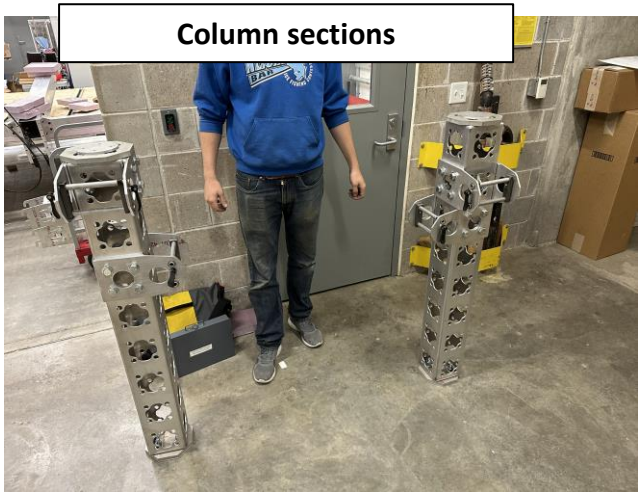
Truss Structure (Demonstrated at Module 0)

- 7 truss configurations required in FD can be assembled out of common members
  - 4 columns, 10 beams (2xB, 2xD, 3xE, 3xF)
- Members are person portable and can easily be carried through TCO. Assembly can be performed with 2 people.
  - 1 truss assembles out of 8 lightweight members (20kg max)
  - Fully an assembled truss won't fit through TCO

Retrieval System (to be demonstrated)

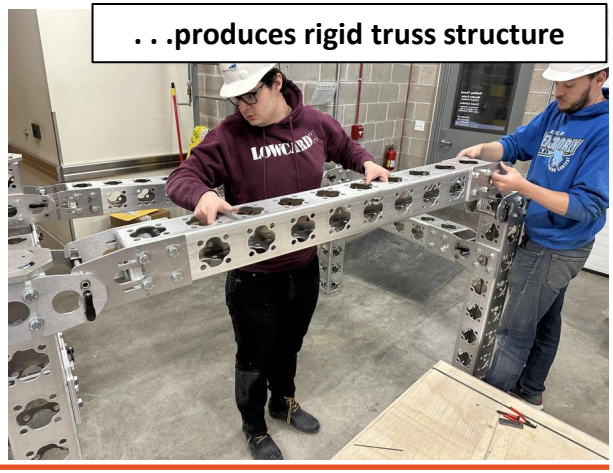
- Retrieval system components are person portable
  - 4 x rails, 4 x rail retrieval rollers
  - 4 x trucks, 2 x truck tie rods, 2 x retrieval rods

Column sections



Tool-less clamp connections

. . .produces rigid truss structure



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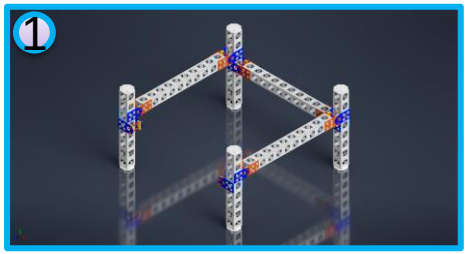
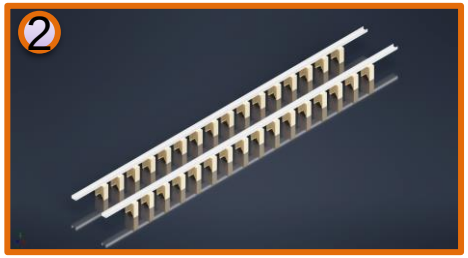
Truss Retrieval Concept uses three components

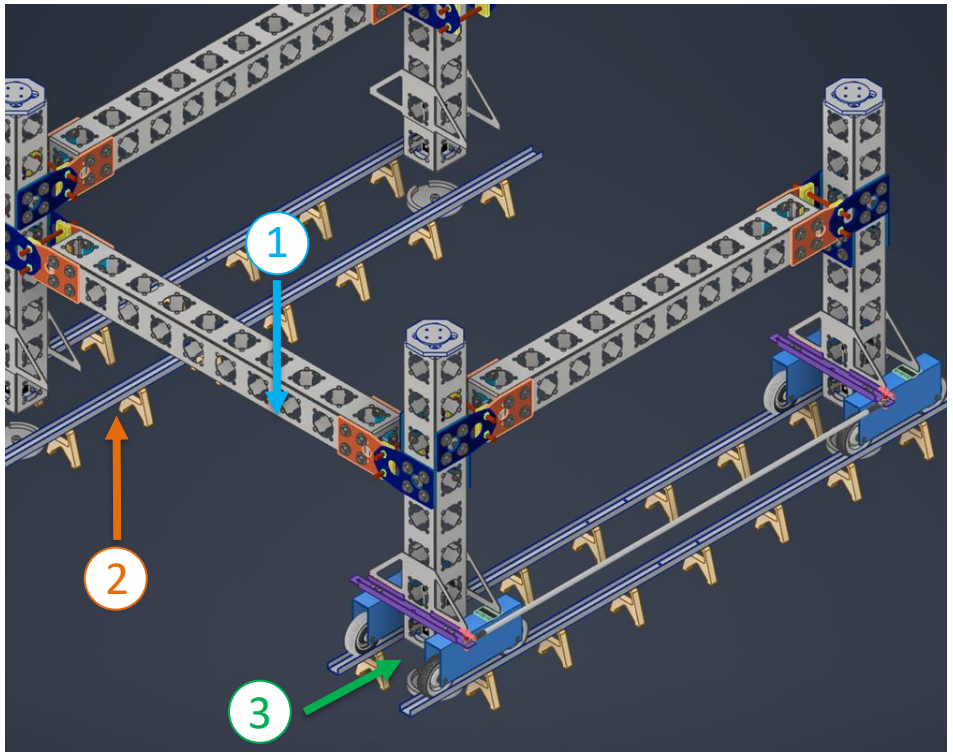
1) Installation Truss modified to lift off membrane floor and engage with train



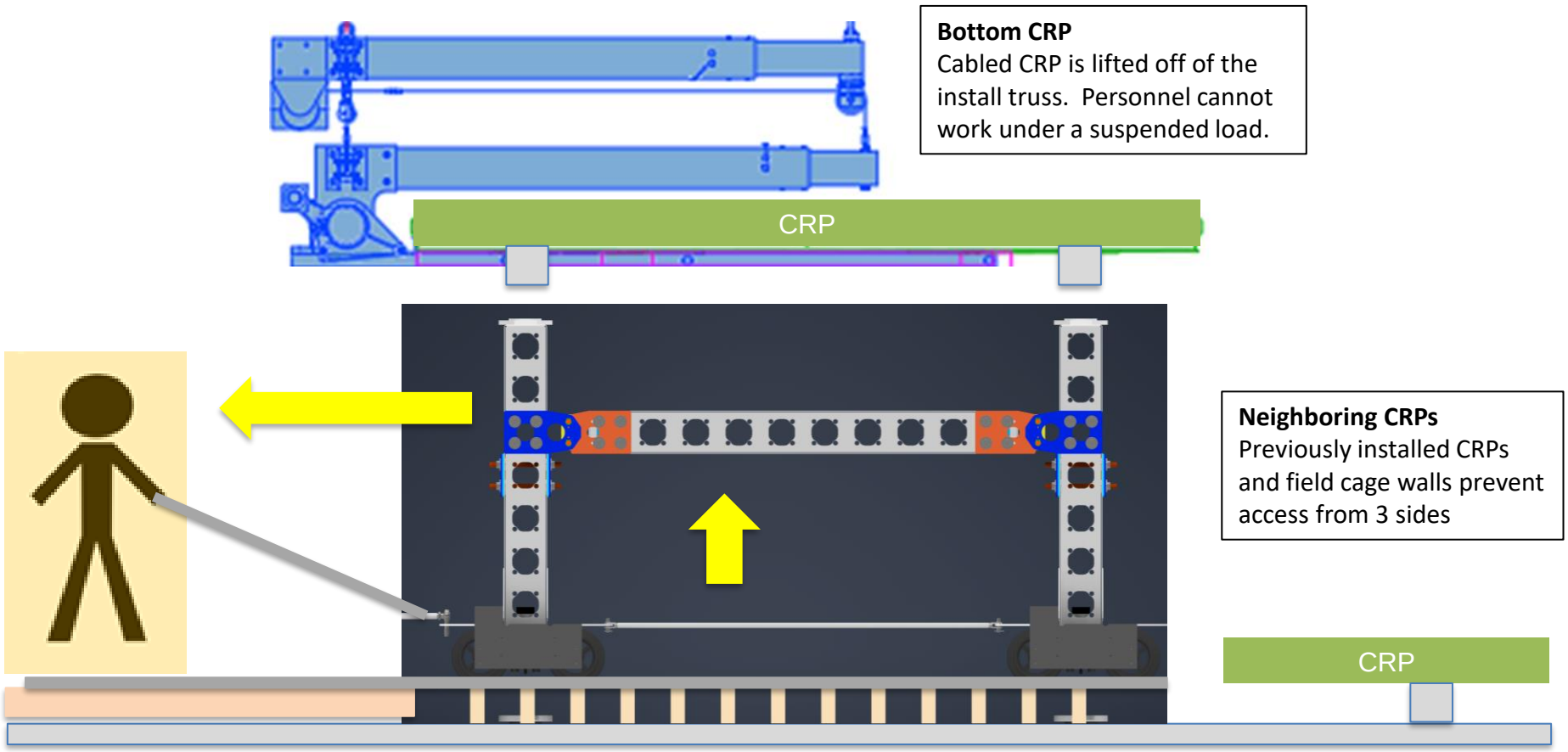
2) Temporary Rails are placed on the ridges of the cryostat floor, use plastic supports



3) Rolling Trains are retrieved remotely using manipulator rods



Retrieval system brings truss out from under CRP



Bottom CRP
Cabled CRP is lifted off of the install truss. Personnel cannot work under a suspended load.

Neighboring CRPs
Previously installed CRPs and field cage walls prevent access from 3 sides

False floor
Open working area at 1 side of CRP. Truss can be lifted off the membrane floor and rolled back to the false floor.

FD Installation Truss Process

Install Site Preparation

- Remove false floor at site of CRP install.
- Assemble and Prepare installation truss out of 4 columns and 4 beams.
- Pre-rout 4 patch cables on the floor
- Place truss retrieval rails, referencing their positions using the corrugations with one end affixed to the false floor.
- Place the retrieval carts onto the rails, near the truss.

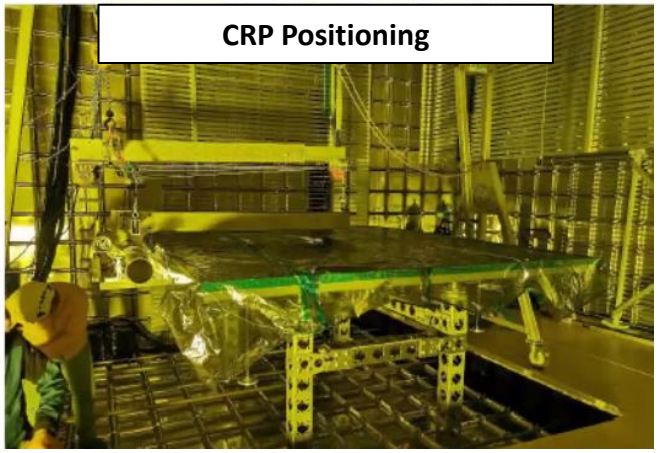
CRP Positioning

- Place CRP on top of install truss using CRP lifting system
- Technicians go underneath supported CRP and install cabling, then clear out
- CRP is leveled by adjusting height screws at baser of feet.

Truss Removal

- Raise CRP 25 cm off of truss
- Use pneumatic system to jack up installation truss
- Using remote manipulator poles, push trains underneath truss columns
- Use pneumatic system to lower installation truss onto trains.
- Pull trains and truss back onto false floor
- Disassemble install truss on false floor
- Retrieve Temporary Rails. These roll out by pivoting on floor mounted rollers.

Lower CRP to membrane floor



Preparation: Before Retrieval

Installation truss is assembled on open membrane floor prior to bringing in CRP

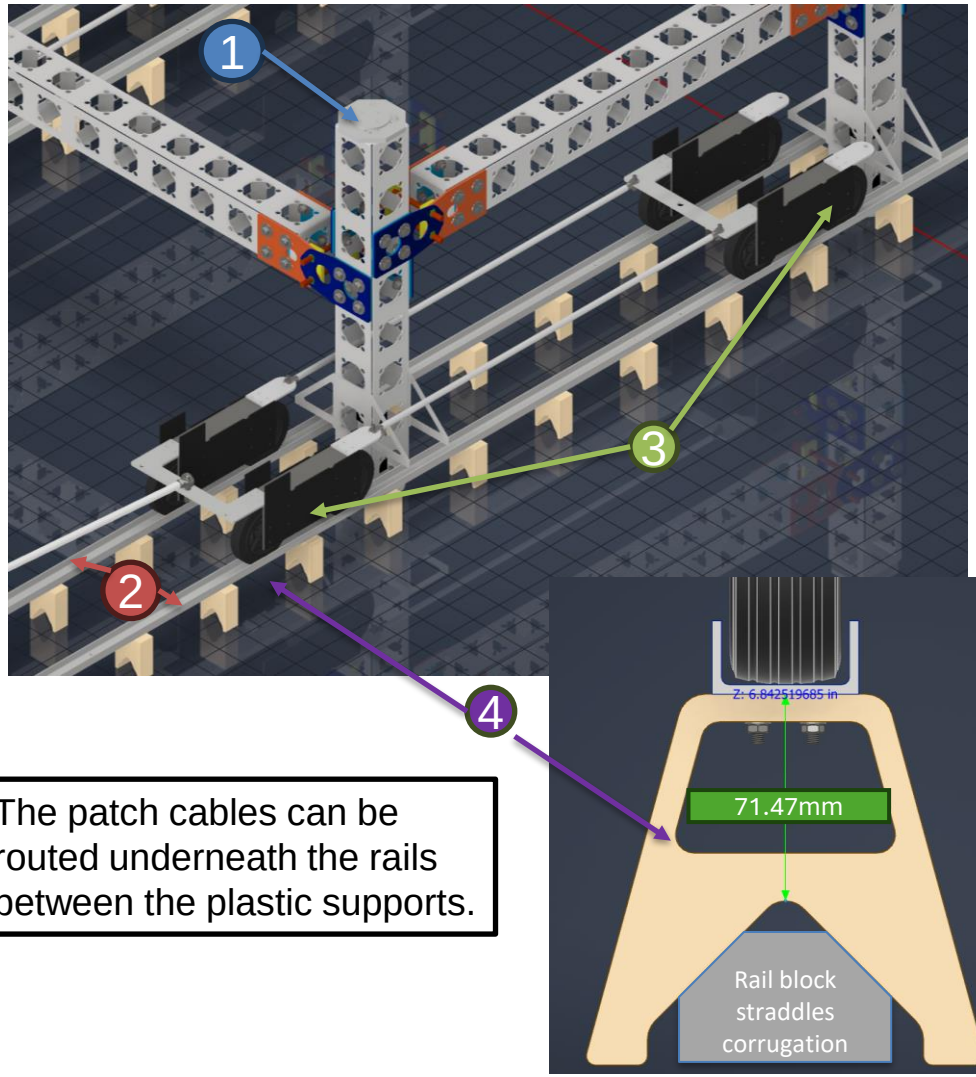
- Assemble the truss per the required application according to previously defined procedure from Module 0. (Balloon 1)

Retrieval equipment is placed prior to lifting CRP from installation truss

- Place rails over the cryostat floor ridges using the machined groove on the plastic supports. (Balloon 2)
- Place trains onto tracks offset to side of truss columns. Install links between train trucks (Balloon 3)

Run cables under rails (31.5 mm clearance)

- Cables run over corrugations and under retrieval rails. (Balloon 4)
- Cable bundle is 40mm diameter and there is 71.5 mm between rails and corrugation.



The patch cables can be routed underneath the rails between the plastic supports.

Preparation: Roles and Timeframe

5 Temporary roles will be created from the cabling teams for the 20 minutes we estimate the retrieval process to take.

Operator

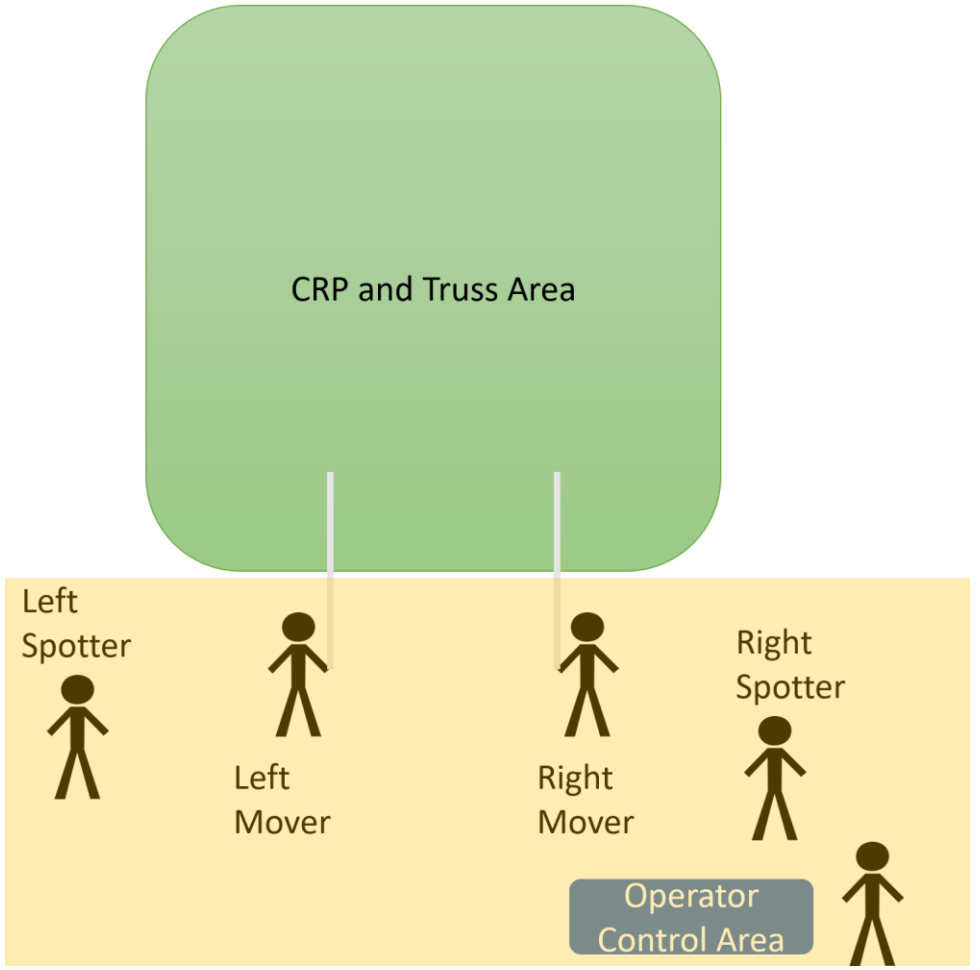
- Operates the tine lifting system, levelling and truss pneumatics.

2 Spotters

- Responsible for checking clearances and avoiding hazards and maintaining safety.
- Disassemble truss as it is brought back over false floor

2 Movers

- Interact with the manipulator rods to position the trucks.



Retrieval: moving the truss with the retrieval rails

CONCEPTUAL DESIGN (BY NO MEANS THE FINAL FD DESIGN)

A concept uses pneumatics to disconnect from the retrieval track, effectively transitioning the truss from a rolling train to a floor supported structure

Shown: a rapid prototyping MOCK UP that we slapped together out of leftover material from the Module 0 truss build, scrap aluminum, hardware from a bucket, and plastic. THIS IS NOT THE FINAL DESIGN

1) Initial Position

- Assemble and Prepare installation truss and retrieval equipment.
- Place CRP on top of install truss using CRP lifting system
- Technicians go underneath supported CRP and install cabling, then clear out

2) Jack Up the Truss

- Raise CRP 25 cm off of truss to allow proper clearance
- Spotters ensure that the all personnel are clear of the truss.
- Spotters ensure that no cabling will be caught.
- Operator raises truss with the pneumatic system.

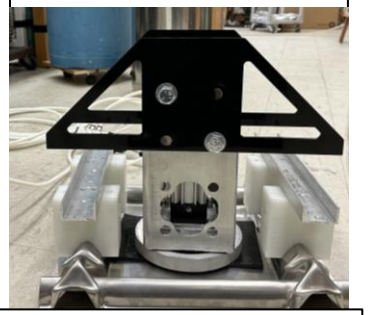
3) Position the Trucks

- Movers push trucks into position. Truck stops contact the gusset plate.

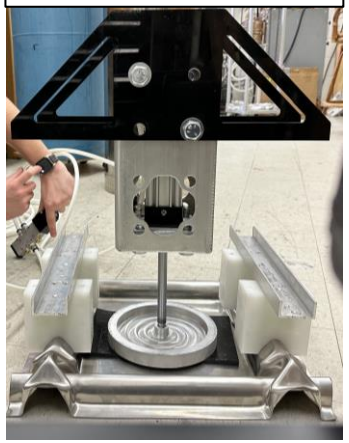
4) Lower Truss onto Truck

- Spotters check alignment.
- Operator lowers the truss.

1) Initial Rest Position

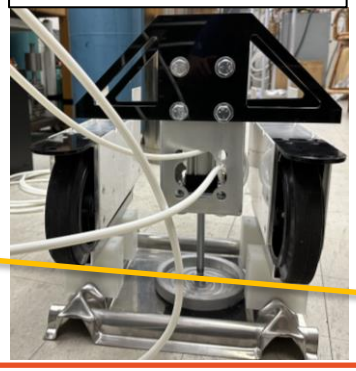


2) Jack up the Truss

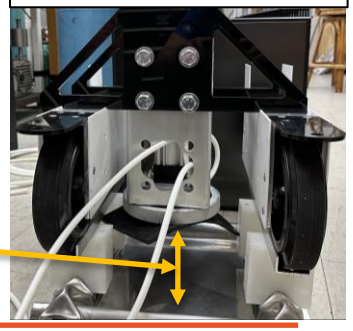


Secure transfer of column directly to the false floor. A truss that exclusively rests on rails will not be as stable of a structure.

3) Position the Trucks



4) Lower Truss onto Truck



NOTE: Truss column and foot raise to level of rail, and will clear all cables by 31.5 mm

Retrieval: Pulling back the train on rails

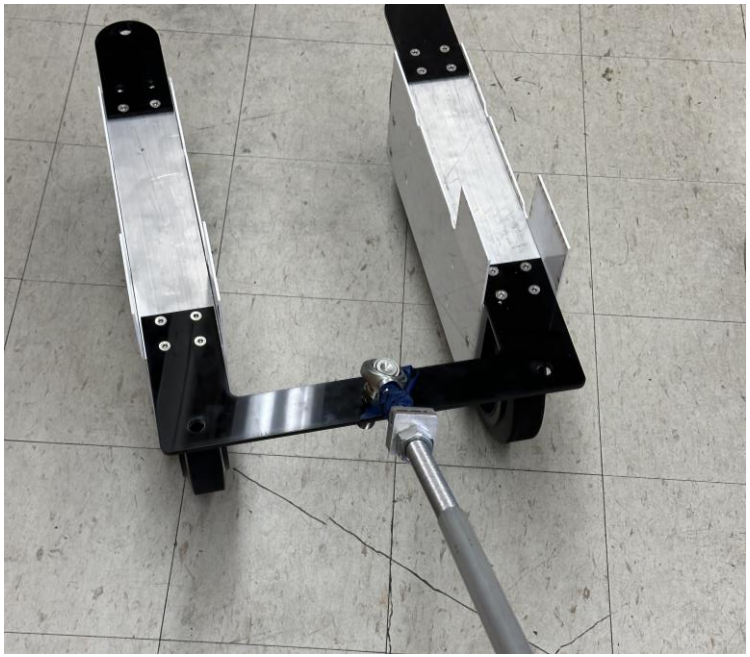
1) Movers pull back the trains

- Movers pull back the truss to the false floor.

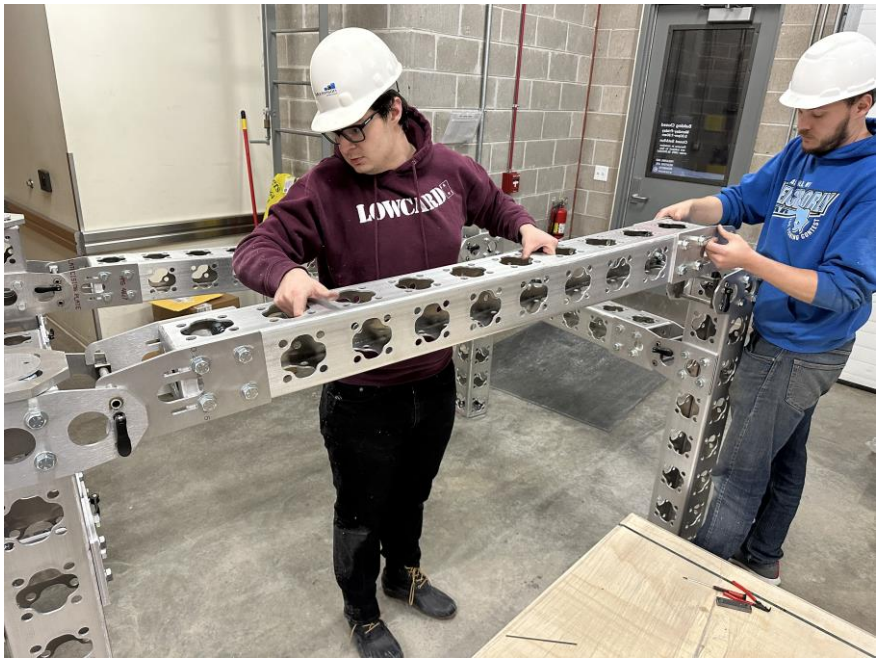
2) Spotters disassemble truss

- Spotters begin disassembling the truss once the truss is on the false floor.

1) Moving the Trains

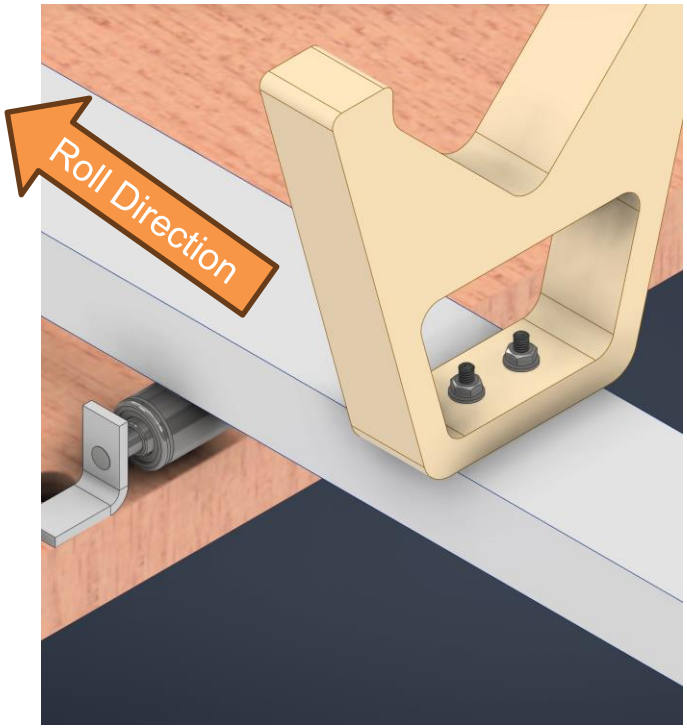


2) Spotters Disassemble the Truss



Retrieval: Retrieving the rails.

- Rails are lightweight with a total mass of 5.18 kg for a full 80 inch long rail.
- Rails have a low moment of inertia about their long axis, making them easy to flip.
- Process:
  - Flip Rails so that support blocks are out of the way.
  - Slide back along roller on the false floor.



Proposed Truss work for FD Install Demonstration

Design

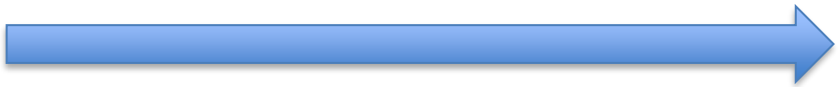
- Complete the design of the retrieval system.
- Perform loading analysis for each member of the retrieval system.
- Manufacture then test components for one truss column and rail
- Draft safety documents and procedures
- Produce full system manufacturing drawings and engineering notes
- Evaluate cabling runs and clearances

Prototype at UW

- Manufacture full retrieval system and integrate with Module 0 truss.
- Test truss assembly, retrieval, and disassembly using UW's mock plywood CRP.
- Iterate and implement improvements based on lessons learned from full system test.
- Complete safety documents and procedures and submit to FD Install Demo

FD Install Demonstration

- Ship the system to the installation demonstration.
- Attend Installation demonstration, showing others how to operate the system, and note the performance of the system.
- Iterate based on lessons learned from Installation Demonstration.
- Write finalized FD install procedures



Summary and Design Integration Work

Summary

- Prototyped a design and process for safe truss retrieval
  - Entire truss retrieval is performed remotely away from CRP on the false floor.
  - Estimated to take 20 minutes using five people that are already underground.
  - Components are lightweight enough to be handled by personnel.
- Would like to demonstrate full system in FD integration test
  - Modification of installation truss with 4 pneumatic jacks
  - Build temporary rails and trains
  - Integrates with bottom CRP lifting system and install procedure

Design Integration Work

- Ensure compatibility with CRP patch cables.
- Work with FD safety on review of design and procedure concept
- Component design iteration from prototype
  - Improve the links between trucks to gain more clearance.
  - Further reduce weight of the trucks as much as possible.

Proposed Extension of work for FD2 install demonstration

Item	notes
CRP Lifting Mechanism Update	**Tine lifting system for FD2 demonstration**
Tine Lifting System v2	Updates to the Module 0 tine lifting system prototype, motorized tine lift
Control Console	Integrated mobile console, operator controls for lifting system and truss retrieval system, tool storage
Boom Crane Integration	hardware modifications to lifting system in order to integrate with the mobile boom crane
CRU Lifting System	**Adaptation of Tine lifting system for installation of last CRUs**
Short tine prototyping	special short tines for install of last 2 CRUs, can disassemble with limited retrieval space
CRU Install Truss	install truss for smaller CRU install footprint and tight install space
Floor Surveying System	**System for surveying the flatness/position of the membrane floor prior to bottom CRP install**
Surveying Columns	Targets for Theodolite surveying tool, target mimics position and weight of CRP bottom supports on the membrane floor
Height Adjustment Tools	Toolset for accurately adjusting the height of bottom support feet to match survey height adjustments

Additional Item	notes
Travel	**Travel and shipping of equipment**
FD2 Install Demonstration	Travel to CERN for 2 people for 3wk demonstration of bottom CRP install
FD2 Install Material Shipping	Shipping of FD2 lifting system to and from CERN, shipping back Module 0 install system
FD2 Demo Bottom Supports (limited production run that is reused in FD2)	**Bottom supports and materials for install of CRP 77 and 78**
Install Truss Modification	Additional beams and retrieval tools to match FD2 demonstration support spacing
Bottom Supports	12 bottom supports
Adapter Plates	4 single support adapter plates and 4 double support adapter plates

Resource expense for FD2 install demonstration

Proposed **FD Demonstration** items **require work**

- **Design**: component drawings, load analysis (ANSYS or simplified calculations)
- **Documentation**: safety documents and SOPs
- **Production of Tools**: construction and assembly of tools
- Leverage student resources
  - Masters and undergraduate student projects produce design, documentation, and construction
  - Fellowship students bring their own funding

Proposed **FD Demonstration** items require **material and equipment expense**

- **Design**: component drawings, load analysis (ANSYS or simplified calculations)

Resource	Fully Burdened Hourly Rate Total Hours To Complete	Total Hours To Complete
Student	$90	1728
Associate Professor	$193	146
Professor	$322	35
Research Scientist	$98	1021

Item	Materials and Supplies Cost
CRP Lifting Mechanism Update	$34,000
CRU Lifting System	$15,000
Floor Surveying System	$7,000

Additional Item	Additional Costs
Travel	$35,213
FD Demo Bottom Supports (limited production run that is reused in FD)	$34,000