Overview of Field Cage Assembly for FD1

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Overview

- Goal of this talk is to provide an impression of how much effort is required to build something as seemingly simple as a field cage module
  - Even though we have gone through several design phases, we continue to find increasingly smaller issues that we will try to correct in the next iteration (i.e. FD1)
- Several “construction” phases were used, and every one of them was very valuable
  - Test module assemblies at Stony Brook and elsewhere
  - Mechanical mockups of the ProtoDUNE1 installation in Ash River, MN
  - ProtoDUNE1 installation itself
  - Mechanical mockups of the ProtoDUNE2 installation in Ash River, MN
  - ProtoDUNE2 installation itself
- Finally, a few final thoughts on issues to consider for APEX

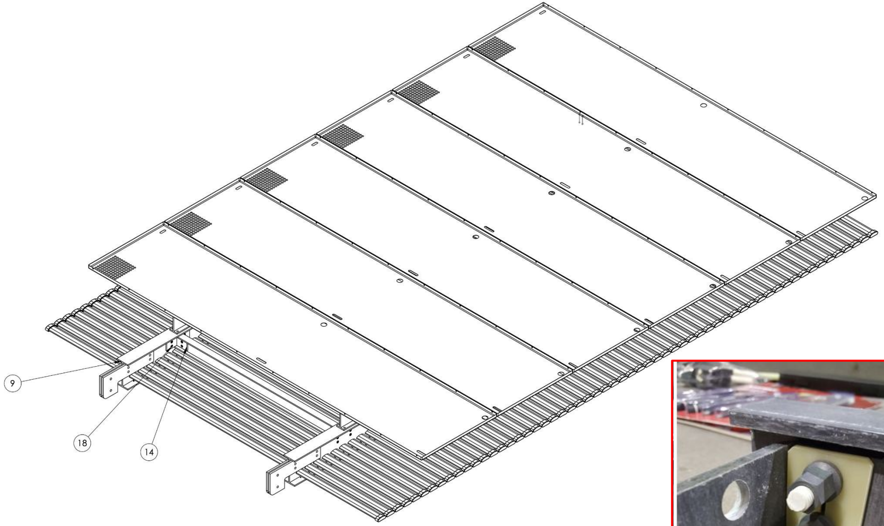
FD1 FC Assembly Effort

- Our group has been involved with each stage of FD1 Field Cage development, production, and installation
  - Built the top and bottom field cage modules for ProtoDUNE1 Single-Phase
  - Built the top modules for ProtoDUNE2 Horizontal Drift
    - UTA was brought on to build bottom modules to ramp up 2nd factory for FD1 installation
  - Responsible for procuring, assembling, and installing 100 top modules for FD1
- The design process has required continuous iteration between engineers and the fabrication team over the past 6 years (this continues to this day)

ProtoDUNE 1 “Super Module”
(4 FC modules hung on 1 CPA)

ProtoDUNE 1 FC Design

- 6-inch Fiber-Reinforced Plastic (FRP) I-beam provides primary structural support
  - Aluminum profiles (changed from stainless steel) are threaded through machined holes in the I-beams
- Additional cross beams connected to main I-beams with non-conductive hardware
- Ground planes attached to stand-off I-beam segments were used to shield the cryostat from the high-voltage CPA side of the module
- Custom “slip nuts” slid inside the profiles to allow connection to the I-beams
  - Differential torque on the 2 sides of the slip nut had to be carefully balanced to avoid profile bending



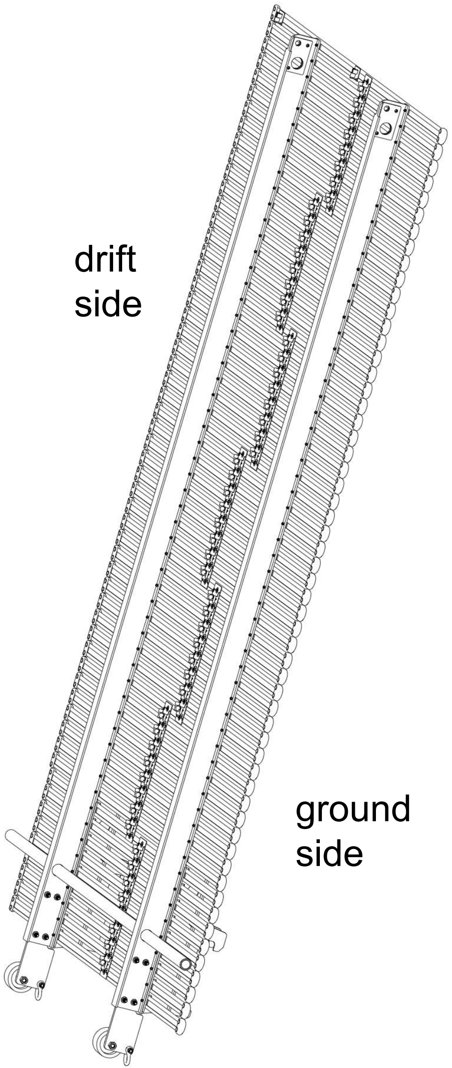
ProtoDUNE 1 Installation

- Prior to installation at CERN, a full mechanical mockup was produced at the NOvA far-site hall in Ash River, MN
  - Many lessons learned and subsequent design improvements were derived from this process
    - Still, many *additional* lessons learned during ProtoDUNE installation (alignment, tolerances, module manipulation, deployment strategy, etc.)
    - See long list of issues from K. Wood here: https://indico.fnal.gov/event/14582/contributions/26281/attachments/16728/21145/protoDUNE-SP-HVS-LessonsLearned.compressed.pdf
  - A full-height FD1 installation has also been simulated at Ash River
- Students can play a big role in the installation process
  - SBU student helped to coordinate much of the on-site installation activities, and integration of all subsystems

SBU Student
Kevin Wood
“Last person out of the cryostat”

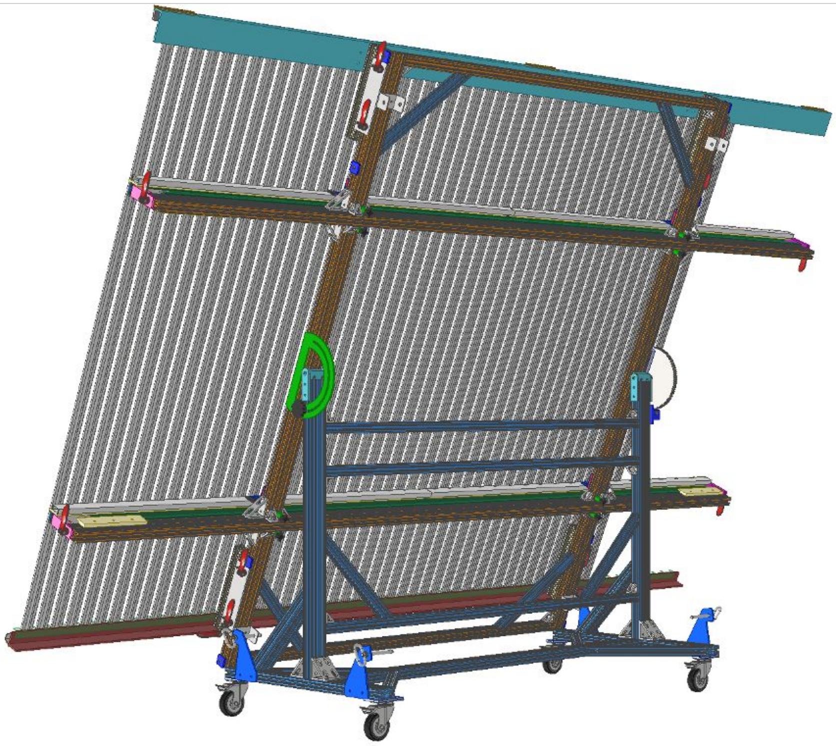
ProtoDUNE 2 Simplifications

- Based on the PD1 experience (some charge transfer from profiles to the ground planes), Bo Yu (BNL) proposed several simplifications to the FC design for PD2
- All non-conductive material between profiles and ground planes was eliminated
  - Ground planes are now separately supported from cryostat
  - Profiles on CPA side are attached to outer flange of I-beam
    - Profiles are not threaded through holes, except on APA side
- Primary support: two 4-inch I-beams
  - No cross beams, no non-conductive hardware, etc.
  - Profiles now provide mechanical support
    - Must be handled with care to avoid profile bending/buckling
- Simplified module lifts, rotations, and installation sequence



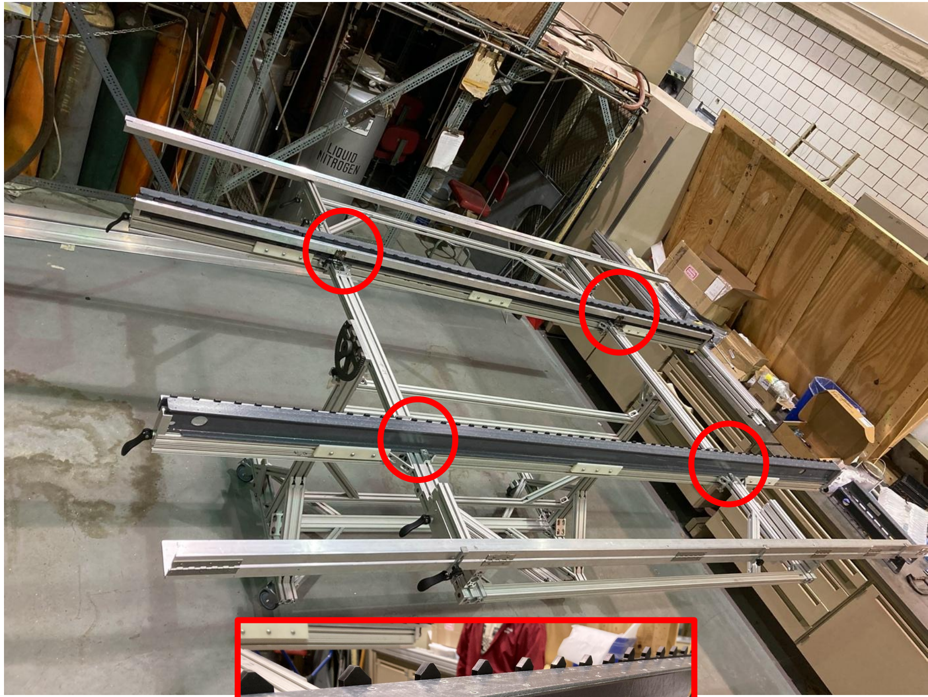
Field Cage Assembly Challenges

- Field Cage modules are large in 2 dimensions (2.3 m x 3.5 m)
- FRP I-beams will flex, and there are no cross/diagonal supports, so handling can produce out-of-plane movements
  - FRP I-beam are also not perfectly straight, which caused issues during PD2 assembly
- Hence, a custom assembly table is needed
  - Table can be tilted from side to side to allow profiles to be secured to each I-beam, one at a time
- Once assembled, the modules must be released from the table, lifted on 1 end, and attached to a CPA



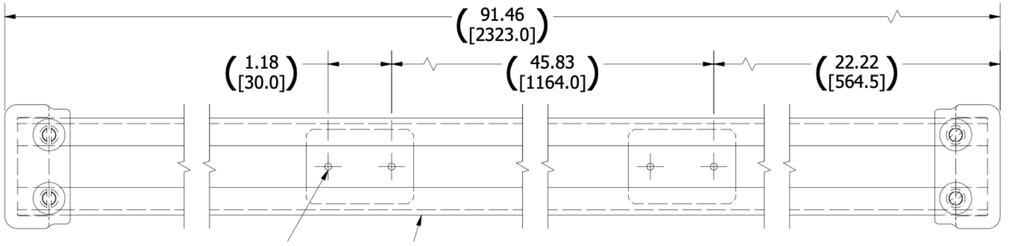
Brief Overview of Assembly Procedure I

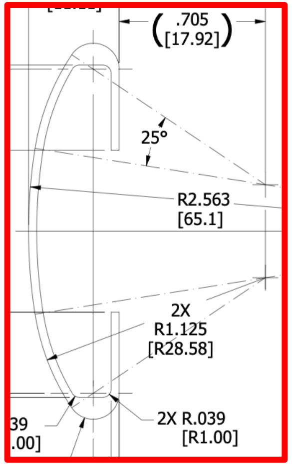
- Table begins in a horizontal position
- I-beams are placed on the table and aligned by fixtures at each end
- Each I-beam is secured in 4 places
  - Change for PD2: I-beam clamps were redesigned to make better contact
  - Change for FD1 (not pictured): accommodate “curvy” I-beams
    - Side guide plate removed
    - Slotted clamp holes to allow for additional travel
    - Size of guides for I-beam ends reduced to avoid compression and interference with glued on support plates

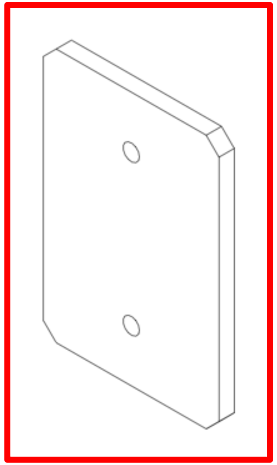


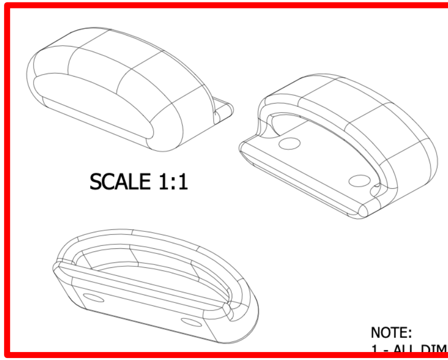
Profile Design & Assembly

- The aluminum profiles are fabricated via a custom extrusion (profile procurement via CERN)
- Rounded edge faces the ground planes (avoid discharges)
- Custom machined “slip nuts” slide in the channel; threaded holes allow profile to be secured to I-beam
- HDPE end caps are secured via plastic rivets



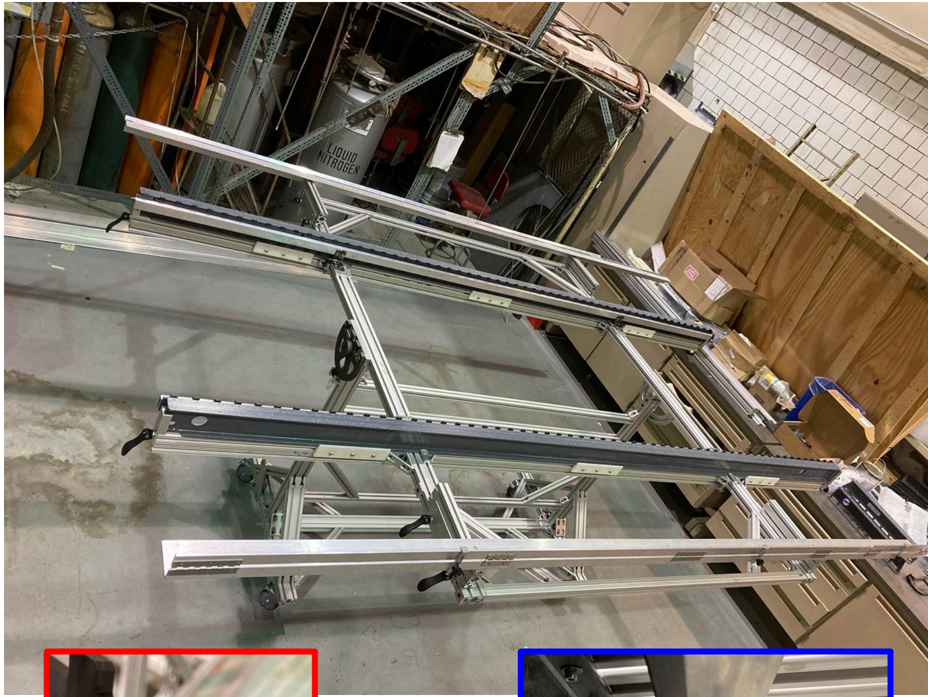






Brief Overview of Assembly Procedure II

- “Slip nut fingers” are attached to an aluminum box beam that rotates to contact the I-beam
  - These fingers stop the slip nuts in the correct position to align their threaded holes with the holes in the I-beam
  - Design change for PD2: top of each finger was shaved off
    - To avoid contact with the profiles as they are rotated away after installation
  - Design change for FD1: reduce width of fingers; now align profiles via end caps



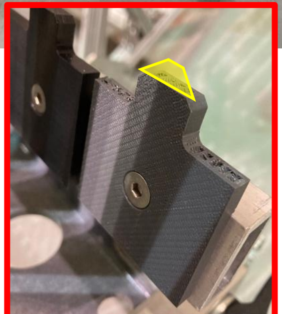
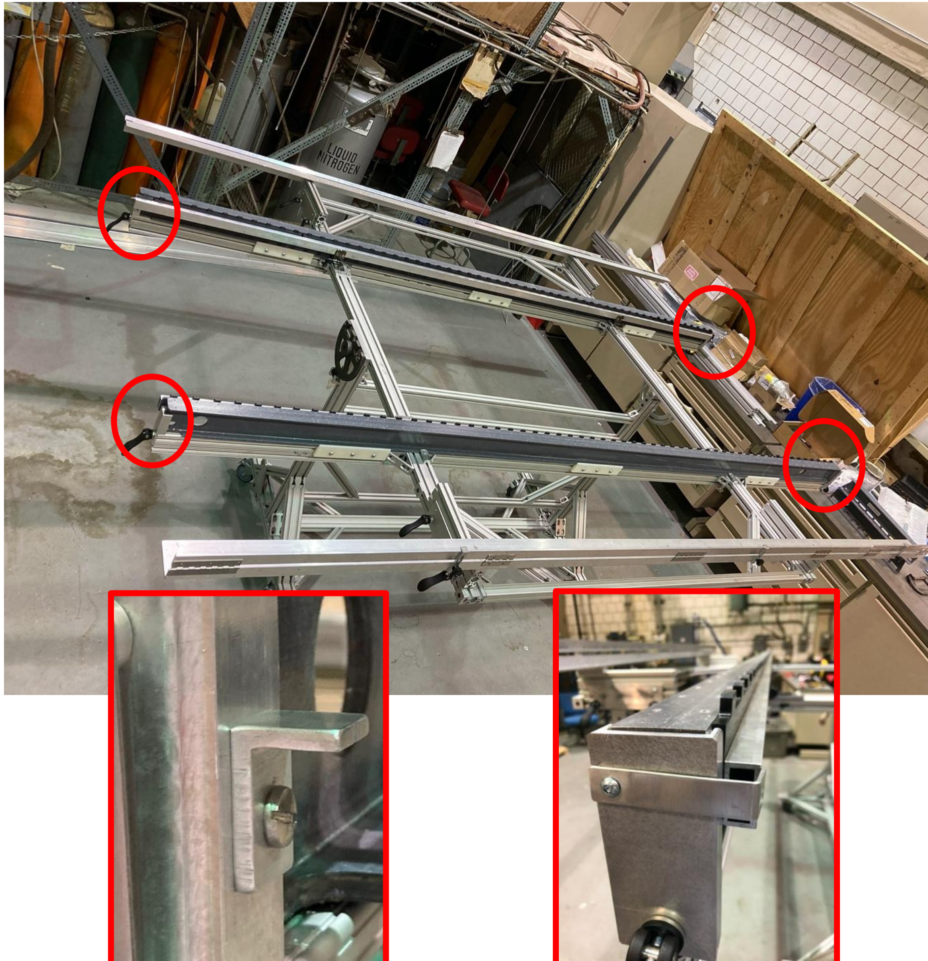


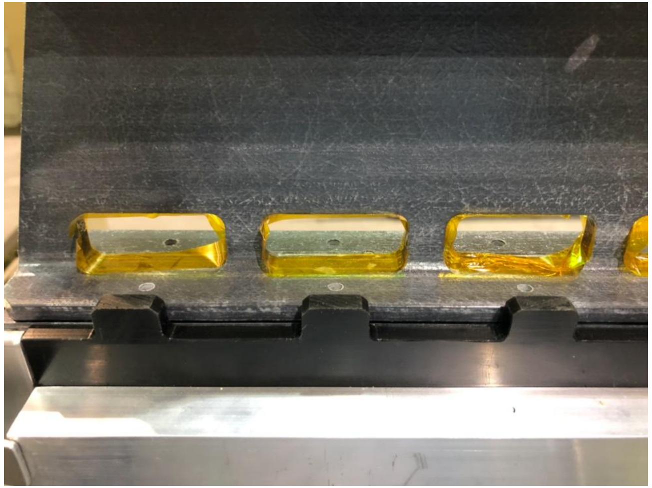
Table Alignment Modifications

- The box beams that hold the fingers are not perfectly rigid
    - Good news: this allows the fingers to conform to curved I-beams
    - Bad news: the fingers on the ends were often misaligned, allowing slip nuts to pass by
- Additional pieces were added to raise the ends of the fingers to the correct height, and pull the fingers toward the I-beam
    - Assembly procedure involves engaging and disengaging the pulling mechanism for different sections of the I-beam



Latch Beam

- An additional beam is needed to secure the field cages to the APAs (not needed for vertical drift)
    - Secured with a large clamp
- Profiles have a coating that is easily scratched
    - Kapton tape is placed in each latch beam hole to protect profiles as they slide through
        - Tape is removed before securing the profiles
- Note that the latch beam holes are machined down to the I-beam flange to avoid profile angle issue seen in PD1



Profile Installation

- Profiles are placed on fingers (for alignment & slip nut stopping) or in latch beam holes
- Slip nuts are inserted on both sides
- End caps are installed, locking in the slip nuts
- The table is then tilted to one side
    - All the slip nuts slide into place, and can be secured via screws inserted through the I-beams
- Then, the table is tilted to the other side
    - The slip nuts on the other side slide into place and the process is repeated
- Finally, the table is returned to the horizontal position, and the I-beam clamps are released
    - This step used to be very difficult, since the fingers were used to align the profiles, and produced substantial friction and were difficult to rotate away (fixed in new design for FD1)

Resistor Boards

- Resistor boards are attached with “twist nuts”
  - Can be inserted into profile channel and twisted to lock into place
- Aligning 9 twist nuts to insert into profile channels can be time consuming
  - Various schemes have been explored to speed up this process
- Boards are located on the drift side of the field cage
  - New design needed for APEX, and location may need to be optimized (blocks PDs)

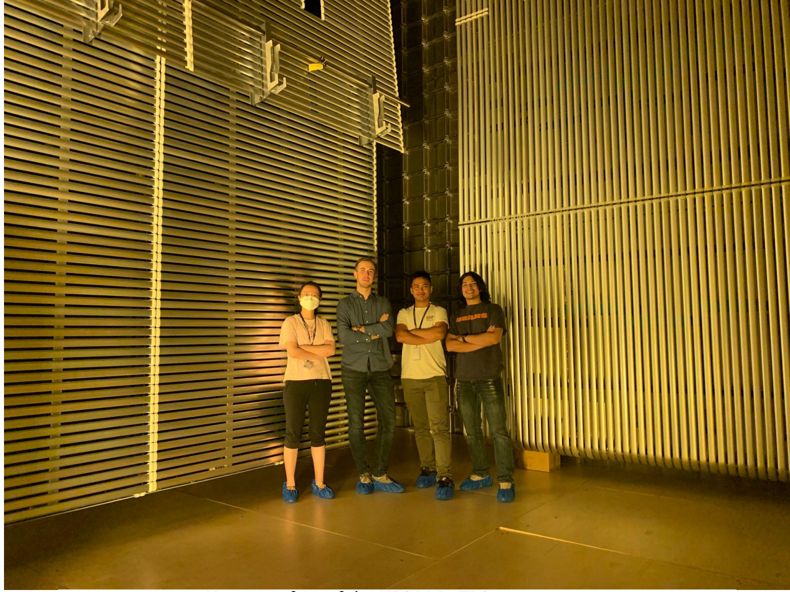
ProtoDUNE Assembly Time Summary (Projected; Idealized)

Step Number	Step	Average Time (min)	Comment
1	I-beams & Latch beams	~10	Include the time for preparing the assembly cart
2	Profile assembly	~60	Factors that limit the speed: profile QC, end-cap installation (holes on the current profiles)
3	Inserting screws to profile nuts	40~60	with prepared screw+washers combinations: ~40 with screws being prepared at the same time: ~60
4	Mounting RDBs to the module	~40	Due to time constraint, this step is not optimized
5	Latch hooks, lifting plate, etc.	10~15	Not optimized due to limited number of tools for tightening the screws

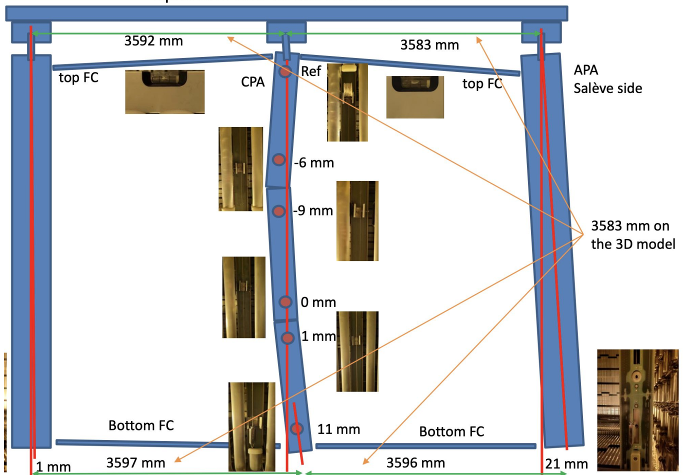
- 1 FD module will likely take a 3 person crew half a shift (~ 4 hours)
- After constructing 4 modules, they are loaded onto a CPA for insertion into the cryostat

ProtoDUNE 2 Installation

- Took place last spring/summer
- Another set of lessons learned (Grad students T. Stokes LSU, J. Jiang SBU, Eric Garcia UTA, G. Gurung UTA):
  - https://indico.fnal.gov/event/53965/contributions/258493/attachments/163253/216017/January2023_CollabMeet_NP04%20Installv3.pdf
- For example, all HV system pieces (FC, CPA) are big and wobbly
  - Small forces can easily push modules out of alignment
  - Significant care is needed to straighten all sides of the TPC

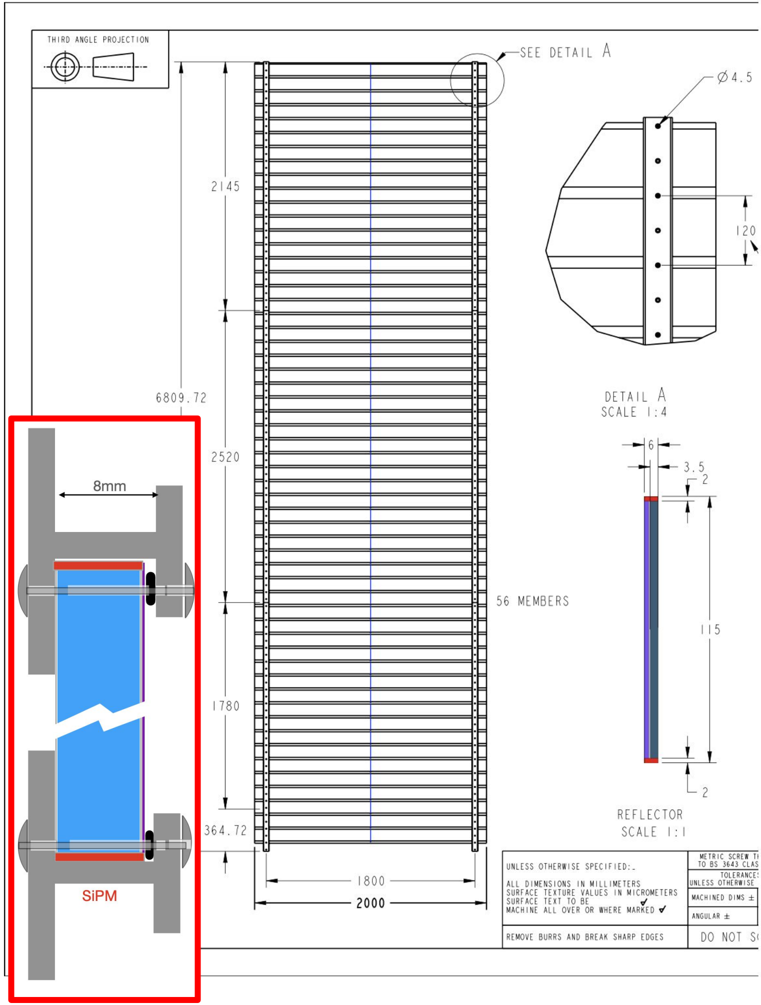


Upstream face of the NP04 LAr-TPC



Challenges for APEX

- Mechanical support
  - Long extended objects are wobbly (and PDs add extra weight)
    - Must ensure PDs are not damaged during handling
- Electrical
  - Significant cabling required through H-shaped (T-shaped?) profiles
  - New scheme needed for resistor boards; Bo Yu has been investigating integrating boards with support structure
- Installation
  - Structure is very tall, and assembly at height is significantly more challenging – assembly sideways? Tilted?
  - The sooner we begin working with large-scale mechanical mock ups, the better



Summary

- Working with large, extended, non-rigid objects is more difficult than you might expect a priori
- The feedback loop between design and assembly was critical for the ProtoDUNEs and to prepare for FD1
  - Several iterations between design engineers and assembly teams were needed for part design and assembly procedures
- Several iterations will almost certainly be needed to develop the assembly and installation procedures for APEX as well
  - Substantial additional complication: delicate detector objects, integrated SiPMs, substantial cabling, routing of resistor boards etc.
- Mechanical R&D should get started soon to uncover/address critical issues with the design