131.ND.02.08 TPC Assembly & Testing: Technical Description

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ND-LAr Preliminary Design Review

29 June 2022

Schweizerische Eidgenossenschaft
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U.S. DEPARTMENT OF ENERGY | Office of Science

Introduction – Who am I?

- Senior Mechanical Designer
- 22 years experience Colorado State University HEP Group
- Extensive mechanical design history
  - Single Cube LAr Cryostat & Filter System (CSU)
  - DUNE Photon Detector LN2 test stand (CSU)
  - T2K PI-Zero Detector (J-PARC)
  - HAWC-High Altitude Cherenkov Observatory (LANL)
  - Pierre Auger Observatory (NSF)

Outline

- Documentation Reference
- TPC Assembly Procedure
- TPC A&T Components
- TPC Module Testing
- TPC A&T CAD & Analysis
- Overview of TPC A&T Documentation on EDMS
- Code and Standards Compliance
- Open issues – road to FDR
- Summary

Document Reference

https://edms.cern.ch/document/2611200

Folder/Document	Description	EDMS Link
TPC Assembly & Test Folder	Top level folder for TPC Assembly & Test documentation	https://edms.cern.ch/project/CERN-0000217531
Requirements	Spreadsheet with all ND-LAr requirements, see sheet "TPC Assembly & Test (08)"	https://edms.cern.ch/document/2589287
Internal ICDs	Interface control documents (ICDs) internal to the ND-LAr Consortium	https://edms.cern.ch/project/CERN-0000223195
Analyses	Collection of analyses write-up: FEAs, bench testing, 2x2 prototype evaluations	https://edms.cern.ch/project/CERN-0000231224
QAQC Plan	Subsystem QAQC plan with focus on high-level QAQC test plans	https://edms.cern.ch/document/2459134
Assembly Plan	TPC module assembly plan	https://edms.cern.ch/document/2745786
Testing Plan	TPC module testing plan	https://edms.cern.ch/document/2459133
Previous Review Tracking	Spreadsheet with previous review recommendations, see "TPC Assembly & Test"	https://edms.cern.ch/document/2741842
Cost	High-level cost estimate for ND-LAr and subsystems	https://edms.cern.ch/document/2742778
Schedule	High-level "one-pager" schedule for ND-LAr Consortium activities	https://edms.cern.ch/document/2603073
CAD Model (Fixtures)	Solidworks "Pack & Go" and Parasolid exports of CAD models	https://edms.cern.ch/project/CERN-0000231029
Mechanical Component Drawings	Subsystem mechanical component drawings	https://edms.cern.ch/project/CERN-0000218266
Mechanical Assembly Drawings	Subsystem assembly drawing	https://edms.cern.ch/project/CERN-0000230840
Parts List	Subsystem parts list	https://edms.cern.ch/project/CERN-0000231225
Flow Diagram	Flow diagram of assembly and test activities	https://edms.cern.ch/document/2742799

TPC Assembly Procedure

- Assembly & Testing flow diagram can be found at EDMS 2742799
  - Overview of the life of a TPC from component reception to assembled & tested Module
- Assembly procedure can be found at EDMS 2745786
  - Slide Show detailing the step by step assembly of the a TPC module
- Procedure guided by lessons learned from 2x2 assembly
- Procedure will be tested & refined through future prototyping at CSU
  - Assemble Mechanical Mock-Up
  - Build and exercise Assembly & Testing fixtures
  - Develop Cabling procedure
  - Develop Rotation & Critical Lift Procedures

TPC A&T Components - Overview

Lid Support Structure

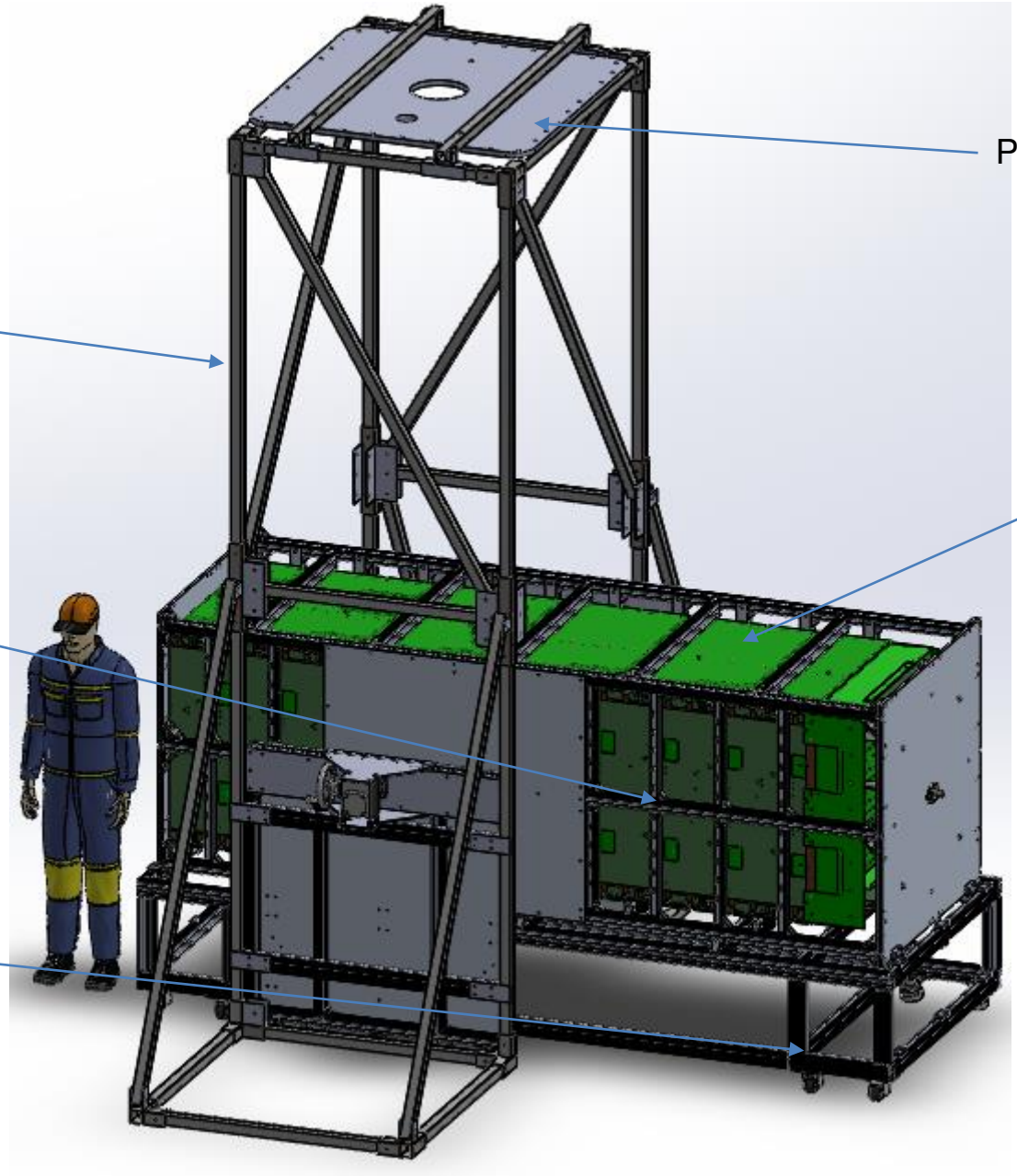
- Supports Lid & TPC during cabling and Rigging

Assembly Fixture

- Locates Field Cage components during assembly
- Rigidly supports TPC during required rotations

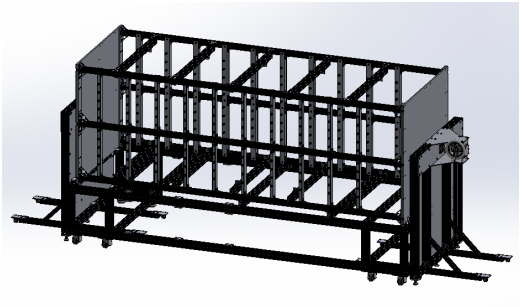
Handling Fixture

- Supports TPC while moving from Assembly to testing area
- Rotates TPC to vertical position

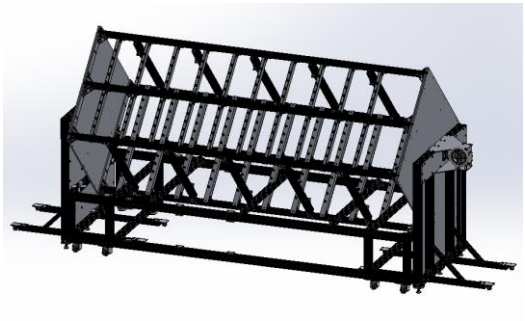


TPC A&T Components – Configurations for Assembly

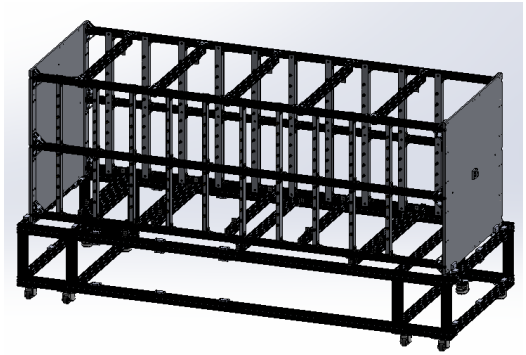
Setup Assembly Frame in Clean Room



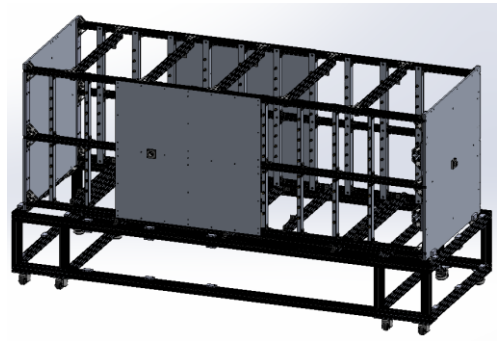
Rotate for Component Installation



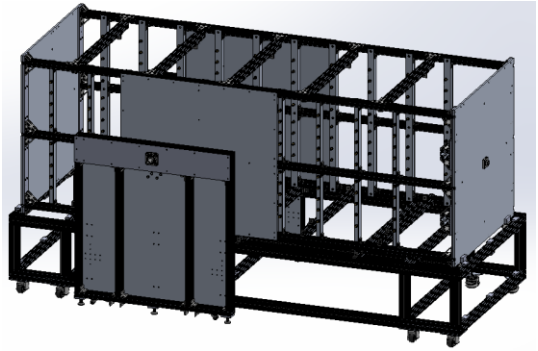
Remove Bearing Support Frames then relocate to Testing Area



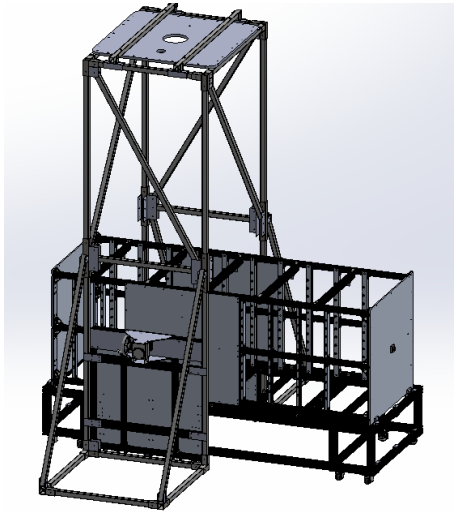
Add Shaft Support Plates



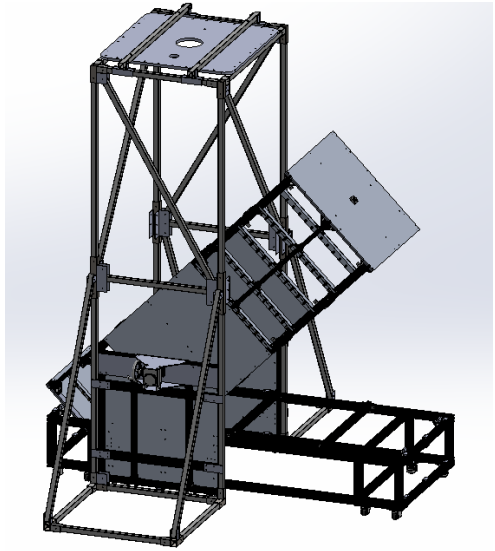
Add Bearing Support Frames



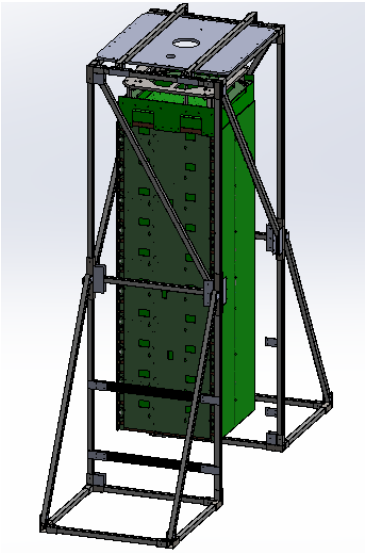
Handling Fixture mounted to Support Structure



Rotate Upright

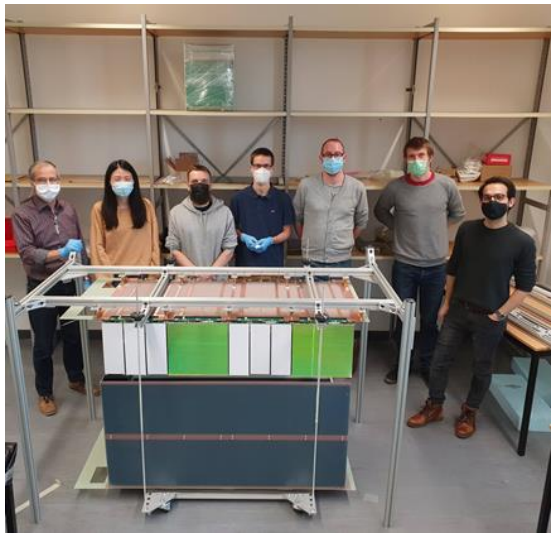


Integrated TPC

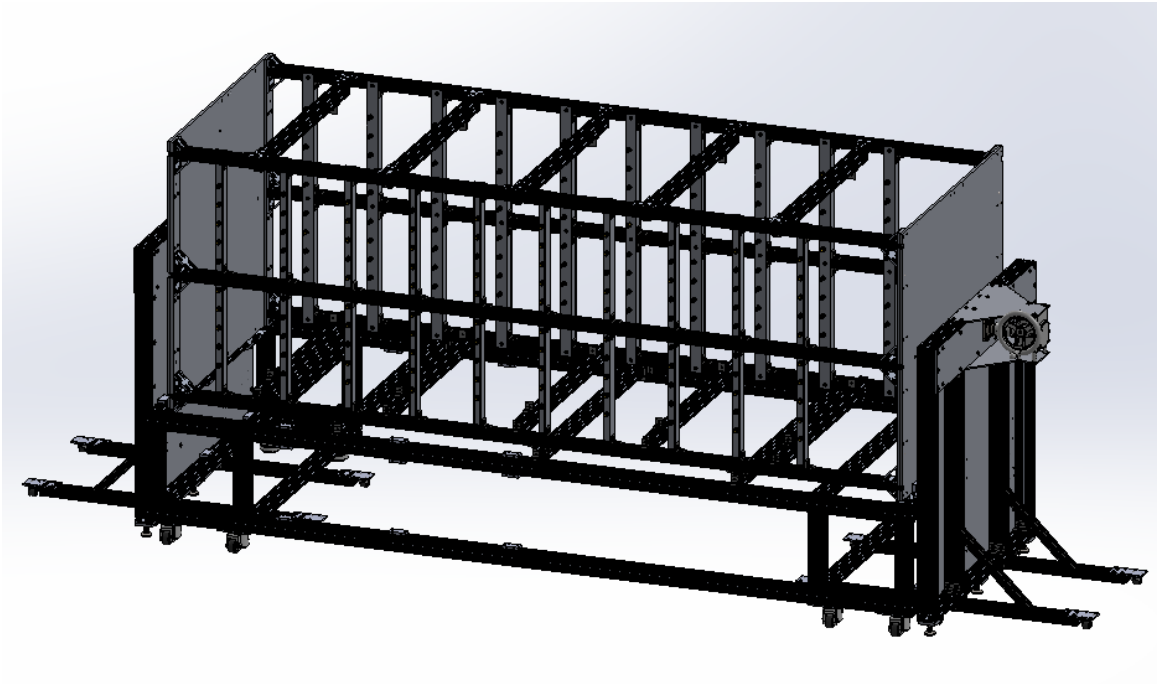


TPC A&T Components – Assembly Fixture

- Aligns & supports TPC components during assembly
  - Pixel Tiles must remain flat throughout the entire assembly process
- Rigid Open Frame Design
  - Design driven by experience gained from 2x2 assembly
  - Frame elements built from 80/20 extrusion & brackets
  - Fixture plates to be water jet cut & finish machined
  - Rigid backing bars made from structural aluminum angle
- Gear reduced controlled rotation
  - Allows access to mount & install components at their optimal orientation
- Working Area Required ~ 5m x 4m
- TBD - Future Prototyping 2022
  - Cutouts added to plates for assembly access
  - Stops, pins & jigs added for fixture/component locating
- Fully assembled TPC is then transported from clean room to testing area



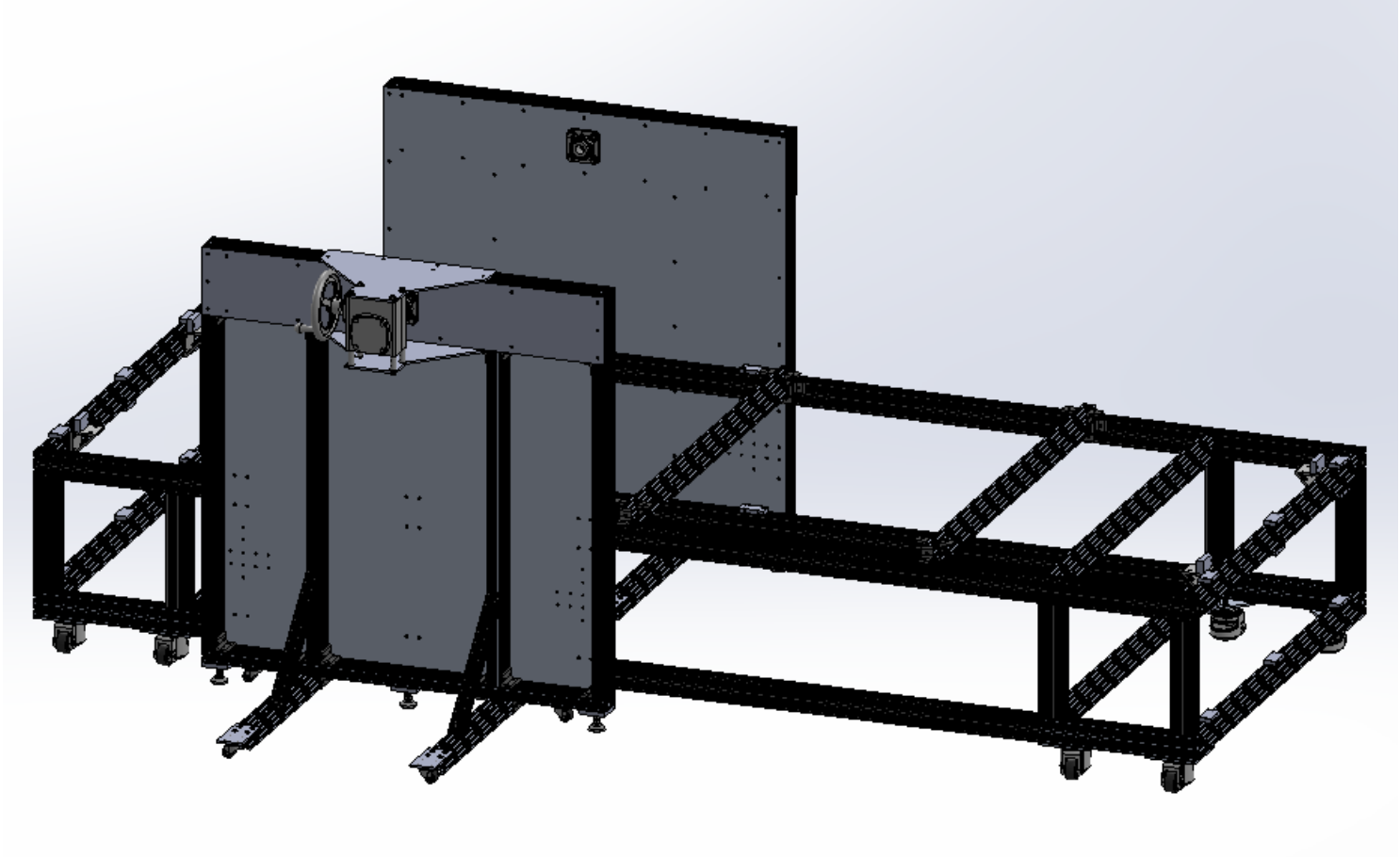
2x2 Assembly Fixture (Bern)



TPC Assembly Fixture-Cathode Vertical

TPC A&T Components – Handling Fixture

- Fixture used for support, transporting & rotating of assembled TPC
  - Designed to rotate the TPC from horizontal to vertical with minimal stress on the module
- Mounts to Assembly Fixture & Support Structure to add strength & stability
- Modular design allows Bearing Support Frames to be used for both types of rotation
- TBD – Future Prototyping 2022-2023
  - Further understand various configurations of fixture
  - Confirm stability of fixture while transporting & rotating of TPC
- Vertical TPC is then mounted to the Physics Lid



TPC Handling Fixture

TPC A&T Components – Lid Support Structure

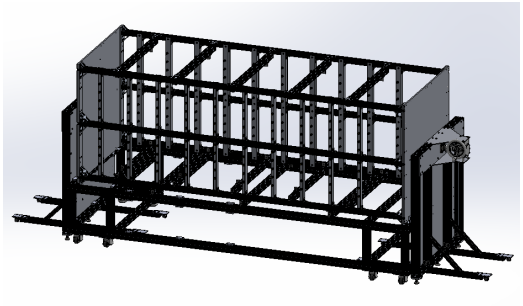
- Supports Physics Lid & integrated TPC
  - Final Mechanical QC
  - Cold Cabling
  - Warm QC
  - Crane Rigging
- Modular Design allows for prototyping at CSU then easy shipment to FSD & MATF
- TBD – Future Prototyping 2022
  - Final TPC – Lid integration procedure
  - Ease of access for Cabling
- Ready for Cold Testing

2x2 Support Stand

Lid Support Structure

TPC A&T Components – Assembly

Setup Assembly Frame in Clean Room

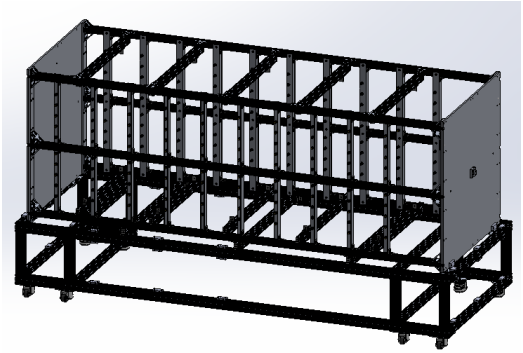


- Assembled using a flat reference surface
- Rigid support frame specifically designed to keep pixel tiles flat throughout assembly
- Designed for optimal working height while installing pixel tiles

Rotate for Component Installation

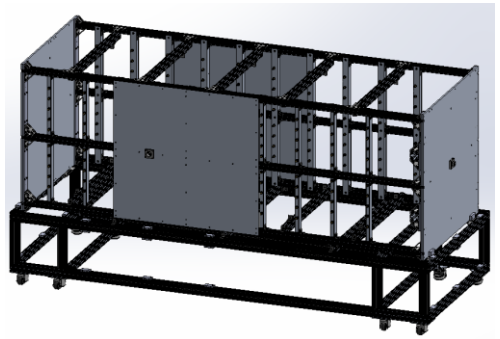
- Rigid support frame rotates to give access for installation pixel tile & light readout modules
- Rotation precision controlled with off the shelf gear reduction system

Remove Bearing Support Frames then relocate to Testing Area



- TPC & frame is supported by the Handling Fixture
- Bearing Support frames removed
- Relocated to testing area

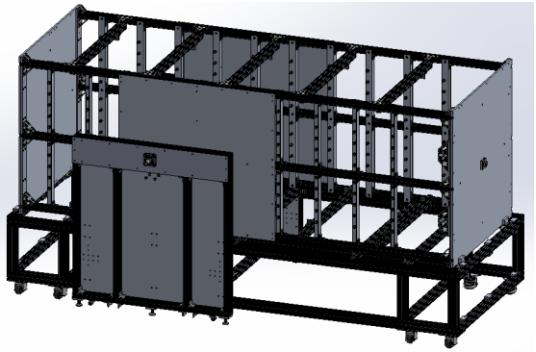
Add Shaft Support Plates



- Increases rigidity of the frame
- Distributes the load throughout the frame

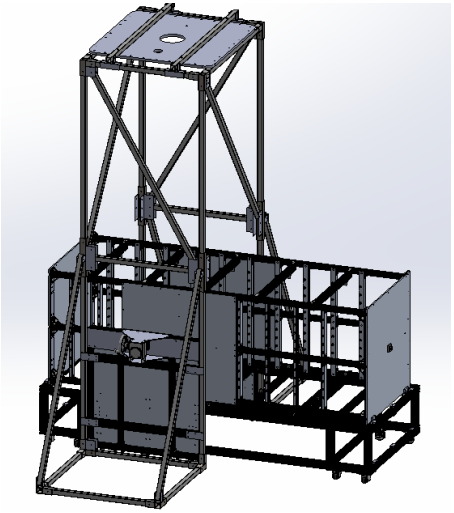
TPC A&T Components – Assembly

Add Bearing Support Frames



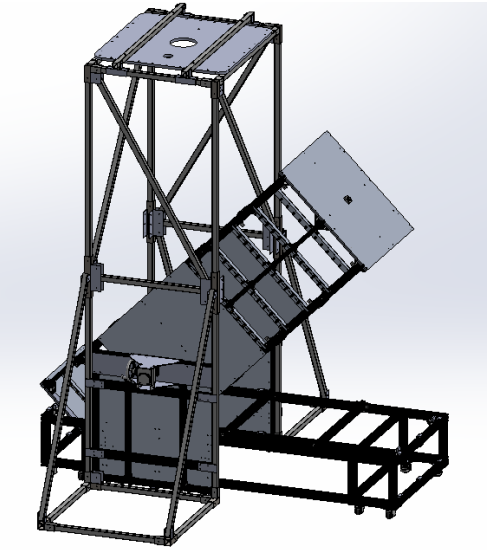
- Reconfigured for Vertical rotation
- Bearing Support Frame economically designed for both horizontal & vertical rotation

Handling Fixture mounted to Support Structure



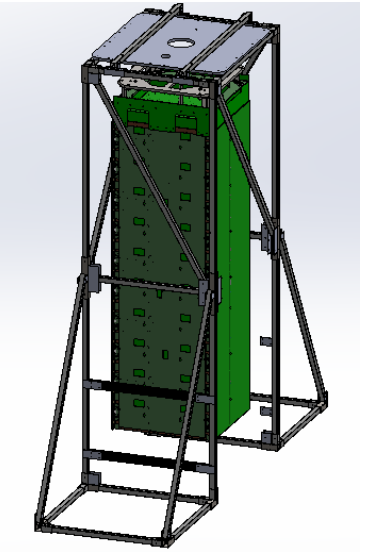
- Handling Fixture & Support Structure bolt together to increase stability
- Modular design meant to cut down on cost & minimize working space required

Rotate Upright



- Controlled rotation meant to minimize torque & acceleration of the TPC Module
- Rotated vertically to get ready for testing
- Rotated back to horizontal after cold testing to prepare for shipping & storage

Integrated TPC

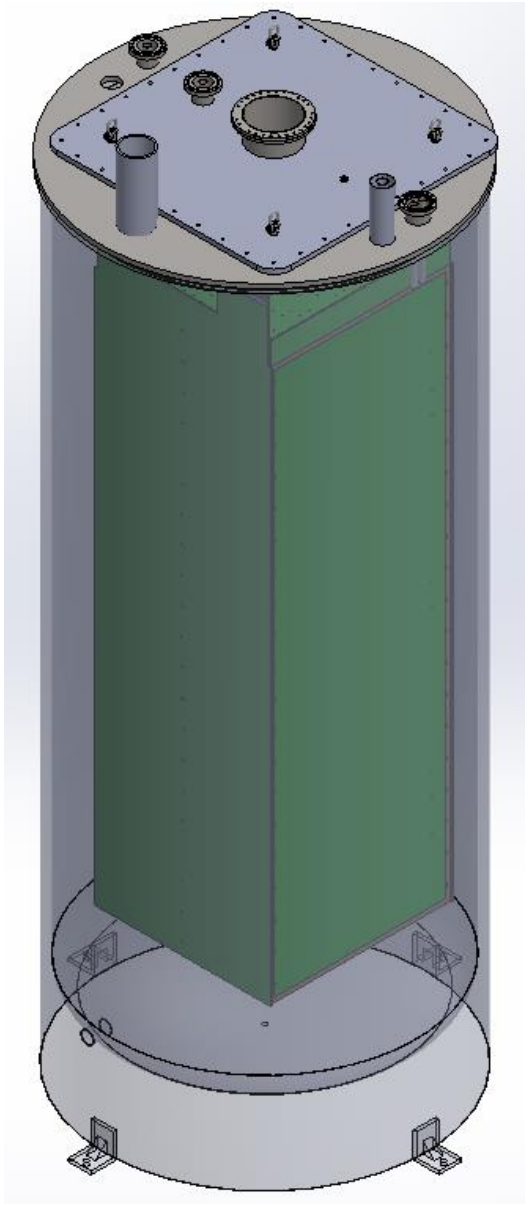


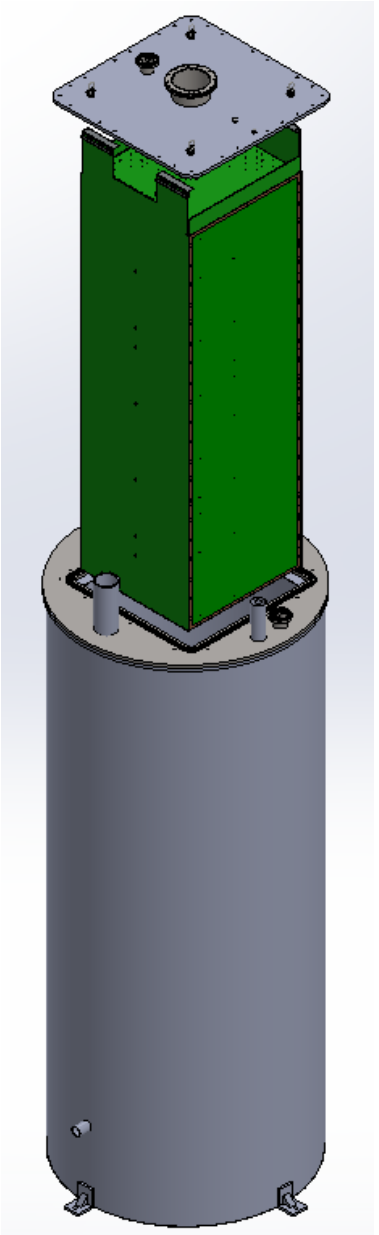
- TPC Mounted to Lid
- Handling Fixture & frame removed
- Final Mechanical QC
- Cabling
- Warm QC

TPC Module Testing in Cryostat

- Each TPC Module will complete a final cold QC test
  - Overview of testing is depicted in the Assembly & Testing Flow Chart EDMS 2742799
  - See TPC Testing Plan EDMS 2459133 for detailed description

- Cryostat & Lid designs were optimized for rapid cycle testing
  - Inner Physics Lid supports TPC and supplies feedthroughs for power, readout & liquid cryogenic directly to top of TPC
    - Minimal number of fittings need to be removed & replaced when swapping TPC's out
  - Outer Lid contains permanent connections to required utilities
    - Pressure relief
    - Pneumatic vent
    - Cryogenic Supply
    - Gas Supply
    - Depth Sensor
    - Pressure Monitor

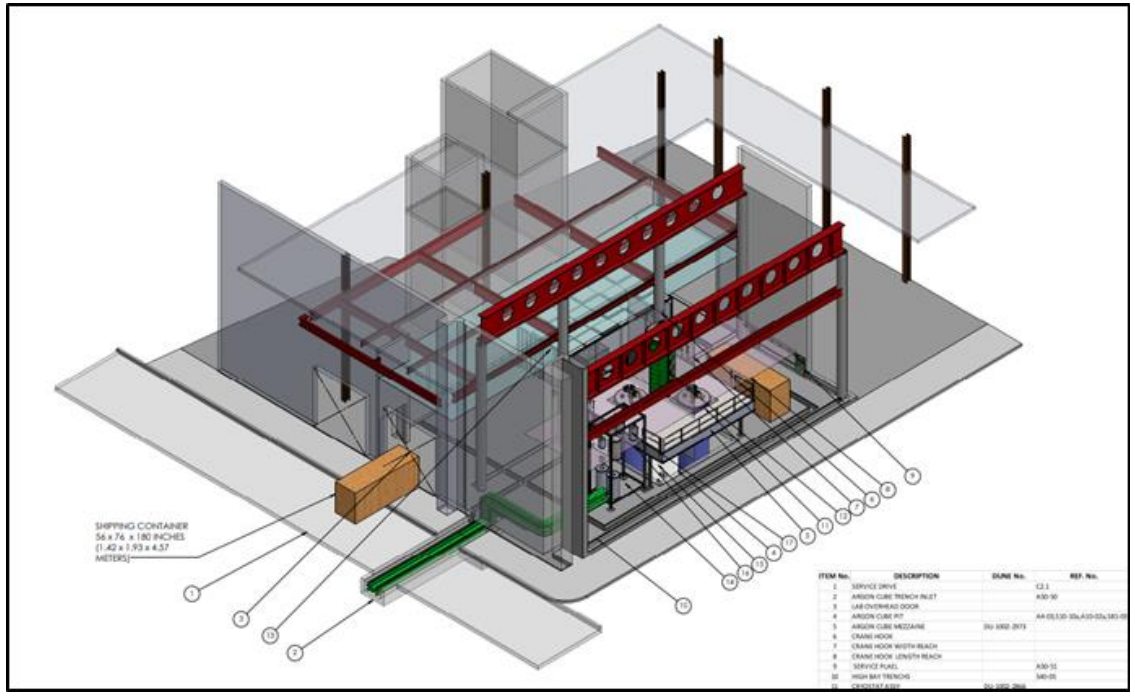




Fixtures & Testing Plan developed for use at Module Assembly & Test Facility (MATF) at FermiLab, see talk by L. Suter (FNAL)

- A&T has been working closely with MATF team at Fermilab
  - A&T – MATF Interface Document EDMS 2458077
  - Assembly & Testing Requirements EDMS 2612986

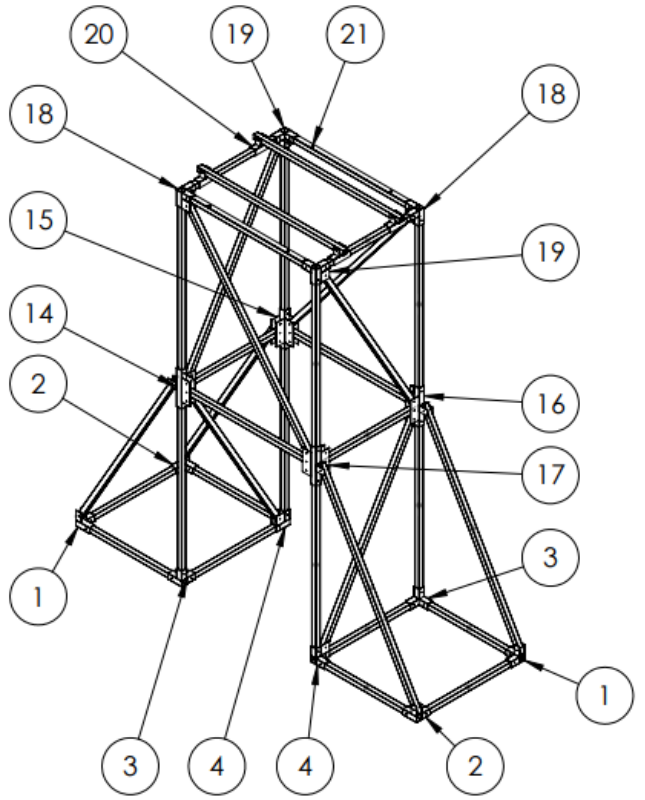
- A&T – MATF Combined effort
  - Minimum crane hook height
    - Pit added to accommodate the combined height of the Cryostat, TPC, Lid & Rigging
  - Mezzanine size and layout
  - Clean space required for assembly
  - Required cryogenic system
  - Cryostat design
  - Common lid design



MATF - EDMS 2590791

TPC A&T CAD

- TPC Assembly Fixture
  - CAD - EDMS 2742798
  - Assembly drawing - EDMS 2742797
  - Design Maturity = 70%
- TPC Handling Fixture
  - CAD - EDMS 2742798
  - Assembly drawing - EDMS 2742797
  - Design Maturity = 65%
- Lid Support Structure
  - CAD - EDMS 2741384
  - Assembly drawing - EDMS 2739474
  - Design Maturity = 80%



ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	BASE WELDMENT - CF1	OUTRIGGER SWIVEL JOINT	2
2	BASE WELDMENT - CF2	OUTRIGGER SWIVEL JOINT - MIRROR	2
3	BASE WELDMENT - CF3	BASE INTERIOR CORNER JOINT	2
4	BASE WELDMENT - CF4	BASE INTERIOR CORNER - MIRROR	2
5	6527K38 - 2 X 125 TUBE	46"	8
6	6527K38 - 2 X 125 TUBE	44.75"	4
7	6527K38 - 2 X 125 TUBE	93"	4
8	6527K38 - 2 X 125 TUBE	74.5"	8
9	6527K38 - 2 X 125 TUBE	88.48"	4
10	6527K38 - 2 X 125 TUBE	61"	2
11	6527K38 - 2 X 125 TUBE	61" - INTERFACE	2
12	6527K38 - 2 X 125 TUBE	97.1"	2
13	6527K38 - 2 X 125 TUBE	70"	2
14	BEAM INTERFACE - CF1	DEFAULT	1
15	BEAM INTERFACE - CF2	DEFAULT - MIRROR	1
16	BEAM INTERFACE - CF3	SWIVEL OFFSET	1
17	BEAM INTERFACE - CF4	SWIVEL OFFSET - MIRROR	1
18	TOP JOINT - CF1	DEFAULT	2
19	TOP JOINT - CF2	ROTATED VERTICAL BEAM PIN	2
20	BEARING SLIDE WELDMENT	DEFAULT	4
21	LID INTERFACE STRIP	BEARING SURFACE	2

Weldment & Components Assembly Layout

CG Data and footprint dimensions listed on sheet 15

DRAFT: NOT FOR PRODUCTION

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UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN IN
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
ONE PLACE DECIMAL ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
FINISH
NEXT ASSY | USED ON
APPLICATION | DO NOT SCALE DRAWING

	NAME	DATE
DRAWN	ZGR	
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:
Dimensions per ASME Y14.5M-2009

Colorado State University
High Energy Physics Laboratory

TITLE: Assembly Stand

SIZE A | DWG. NO. | REV 2.0

SCALE: 1:50 | Weight (lb) 706.42 | SHEET 1 OF 18

TPC A&T Analysis

- Completed by Zach Rautio – TPC A&T Engineering Analysis Lead

- TPC Assembly Frame FEA study
  - -EDMS 2745787
  - Study to validate the design of the Assembly Fixture
    - Frame deflection during TPC assembly
      - Horizontal load case yields no simulation results that are cause for concern
    - Determine stress on the keyed bearing pin
      - Rotational Bearing shaft will need upsized to a 25mm radius
      - Rotational cranks should be geared to comfortably generate 4000Nm of torque

- Lid Support Structure FEA study
  - -EDMS 2745013
  - Study to validate the design of the Lid Support Structure
    - Confirm sizing of structural square tubing
    - The main item of concern is validating the size selection of the clevis pins used in the assembly
      - Pinned assembly method found to be more than sufficient (SF 15)

Stress

Minimum (MPa)	Average (MPa)	Maximum (MPa)
0.001	4.5	397

Table 3.4: Stress Value Range

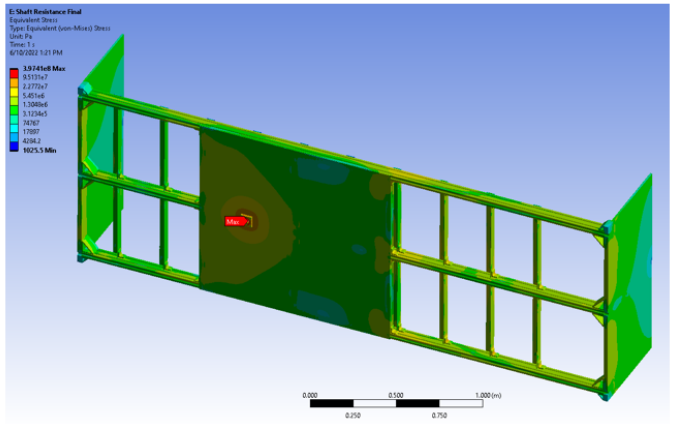


Figure 5.6: Stress visualization of moment balance during static rotational orientation

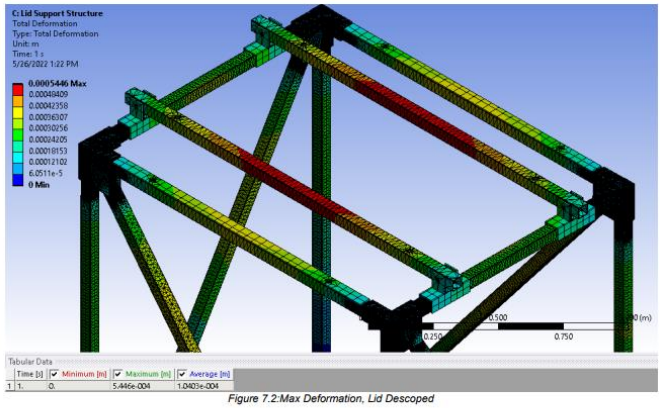


Figure 7.2:Max Deformation, Lid Descoped

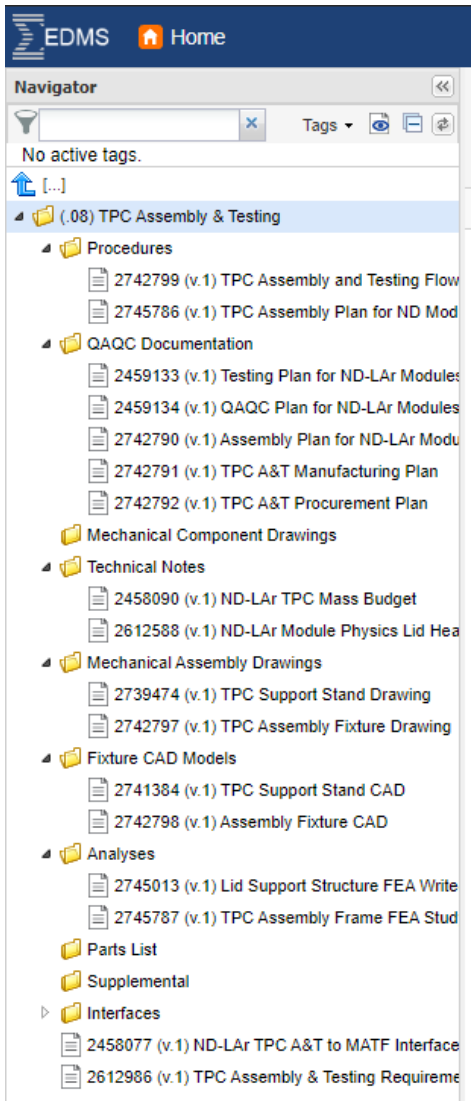
Minimum (m)	Average (m)	Maximum (m)
0	1.04e-4	5.45e-4

Table 3: Deformation Results

10.2 Equivalent Stress

Equivalent stress results shown below. The peak equivalent stress is 136MPa, with an average stress of 2.7MPa.

Documentation Tour [EDMS 217531]



TPC A&T Flow Diagram	Details Assembly & Testing from start to finish	https://edms.cern.ch/document/2742799/1
TPC Assembly Plan	Step by step plan to assemble TPC Modules	https://edms.cern.ch/document/2745786/1
Physics Lid Heat Transfer	Detailed write up of FEA analysis of heat transferred through Physics Lid	https://edms.cern.ch/document/2612588/1
Lid Support Structure Assembly Drawing	Detailed assembly drawing of Lid Support Structure	https://edms.cern.ch/document/2739474/1
Assembly Fixture CAD	CAD model of TPC Assembly Fixture	https://edms.cern.ch/document/2742798/1
Lid Support Structure Analysis	Detailed write up of Lid Support Structure FEA Study	https://edms.cern.ch/document/2745013/1
TPC A&T Requirements		https://edms.cern.ch/document/2612986/1
TPC A&T Interfaces		https://edms.cern.ch/document/2458077/1

ESH Codes and Standards

- Adheres to all ESH codes/standards established by LBNF/DUNE Project plus home institutional ESH requirements

- All Near Site deliverables must satisfy FNAL FESHM requirements
  - **2x2 Program providing experience through ORC process**

- Specifically ND-LAr has completed an initial review of applicable areas of FESHM, found at EDMS 2602421

- ND-LAr has also completed a Hazard Registry in coordination with the ND sub-project, found at EDMS 2663898

ES&H, EDMS 2602421

- Lifting Safety
  - Development of lifting fixtures (FESHM 10110)
  - Development of lifting plans (FESHM 10200)
  - Slings and rigging hardware (FESHM 10130)
- Occupational Safety
  - Fall Protection (FESHM 7060)
  - Ladder and Scaffold Safety (FESHM 7070)
- Structural Safety
  - Design and construction of structures at FNAL (FESHM 5100)
- Electrical Safety
  - Electrical safety program (FESHM 9100)
  - Grounding requirements (FESHM 9190)
  - Cable Tray Systems (FESHM 9130)
  - High Voltage Connections (FESHM 9150)

Open Issues – Road to FDR

- Finalize fixture CAD models & drawings for procurement of FSD components
  - Update designs driven by FEA results
- Preparation for FSD – Prototyping at CSU
  - Validate TPC Assembly Procedure
  - Assemble Mechanical Mock-Up
  - Build and exercise Assembly & Testing fixtures
  - Develop Cabling procedure
  - Develop Rotation & Critical Lift Procedures
- Complete FSD
- Update Production Assembly Procedure
- Finalize CAD models & drawings for production fixtures

Summary

- The CAD models and associated design documentation are developed and in-place to continue to final detailing and construction of the FSD module
- Remaining technical challenges will be addressed through continued design development, future prototyping at CSU and the completion of the FSD test
- No undefined design choices or scope gaps exist
- The TPC A&T system design maturity meets PDR requirements
- **Ready for the final design phase and construction of the FSD module**