APA shipping frame (ASF) use cases, requirements, and overview of prototyping

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APA Engineering Design Review

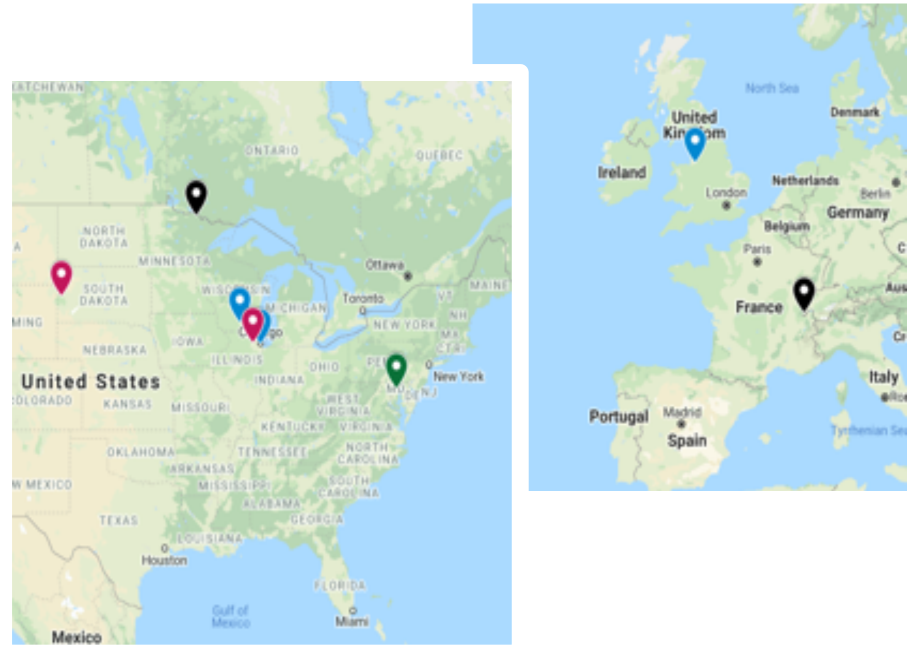
2 September 2021

Outline

- Overview of the APA shipping and packaging
  - Intro to APA packaging
  - Summary of development process since the PDR in Aug, 2020
  - Shipping process overview → use cases → load case
  - Many more details in Mariana's design and analysis talk
- Prototyping/production plan overview
- Overview of documentation

- The goal of this talk is to address, in part, charge question #4:
  - If the design of the APA shipping frame and plans for installation of the APAs in both ProtoDUNE-II and the DUNE Far Detector are mature enough to provide assurance that APAs, as currently designed, can be safely transported and installed within the detectors.

Overview of APA shipping



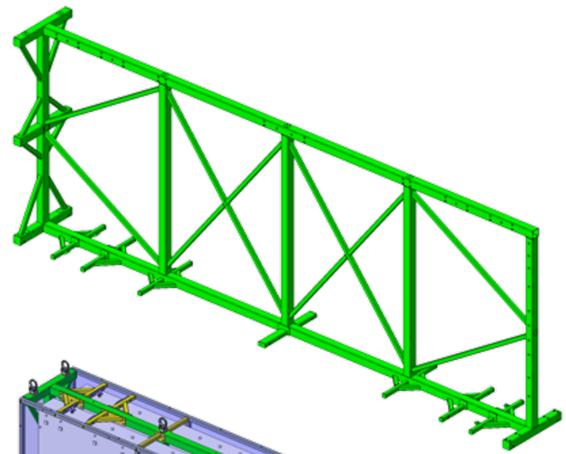
- APAs assembly sites (Blue)
  - Daresbury Laboratory (DL) in England
  - Physical Sciences Laboratory (PSL) of the University of Wisconsin
  - University of Chicago (UC)
- At the sites, the APAs will be transferred from the process cart to mounted ASFs
- The US APAs will be crated and moved by truck
- The UK APAs will be moved by truck to the Port of Liverpool for crating, crates will be shipped from Liverpool to Baltimore (green) by sea, then loaded onto a truck
- The APAs will be stored at the D0 Building at Fermilab until needed for installation
- APAs will be directly shipped by truck from D0 to the Ross shaft head frame
- The crates will be disassembled and the ASFs will be lowered down the shaft as slung loads
- They will be moved through the drift to the hall on horizontal carts
- In the hall they will be rotated to vertical and stored on a vertical cart
- Finally, the APA will be inspected, integrated with the PDs, and mated into top-bottom pairs prior to final testing

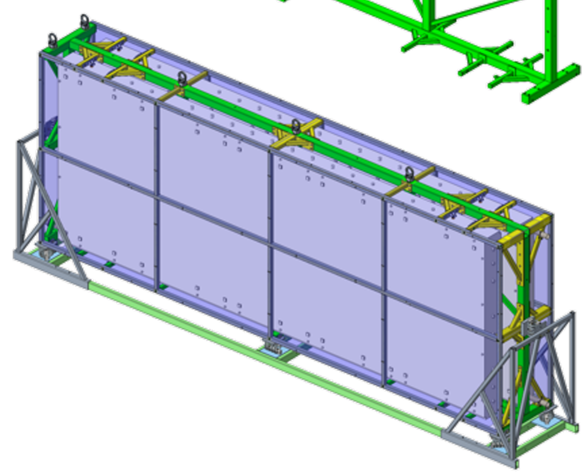
Later: I'll step through this process visually

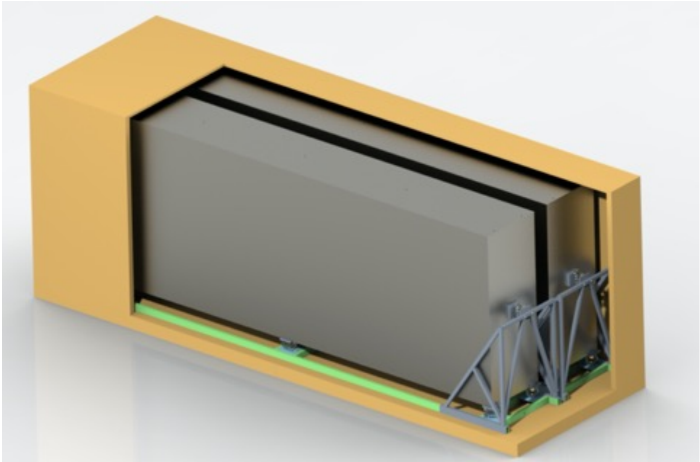
APA shipping packaging

Models/drawings EDMS 2477326

- Each APA Shipping Frame (ASF) will be used to move 2 APAs from the factory sites until they are integrated inside the clean room in the detector cavern
- The key component the shipping packaging is the central welded steel frame (green)
- The APAs are loaded end-for-end swapped for balance and eventual top-bottom mating
- Structurally integral to the shipping frame is the removable side frames with aluminum skins (shown in semi-transparent purple) and removable mounts (yellow)
- Lifting ring mounts are integrated into the central frame's design
- ASFs are attached to a base through an array of wire-rope isolators (WRI) to dampen shock and vibration during shipping and handling
- 2 ASFs (4 APAs) will be packaged within each wooden shipping crate







Since the last review…

- A key recommendation from the ASF PDR (Aug, 2020) was to analyze a simplified integrated FEA model (ASF, WRIs & APAs with tensioned wires)
- The CERN team lead developed the beam model and tested PDR design
  - They found the frame was not stiff enough to dampen random vibrations during shipping
- The CERN team used their model as a tool to develop a new concept that would meet requirements
- Biggest changes were to:
  - Move WRIs to between ASF and base (instead of between APAs and ASF)
  - Make the side cover structural to stiffen the frame
  - Add end WRIs
- APA team (lead by Liverpool) integrated that design within APA constraints
- A revised engineering analysis plan was iterated between the CERN engineering team, the consortium, and TC
- A CERN team lead by Mariana completed the engineering analysis
  - Results of this analysis yielded new load cases for the APA engineering analysis plan
- The base design, crate dimensions, and drawings were developed at Liverpool
- Manufacturing, testing/certification protocols, and shipping logistics plans are being developed with commercial vendors
- A very busy year!

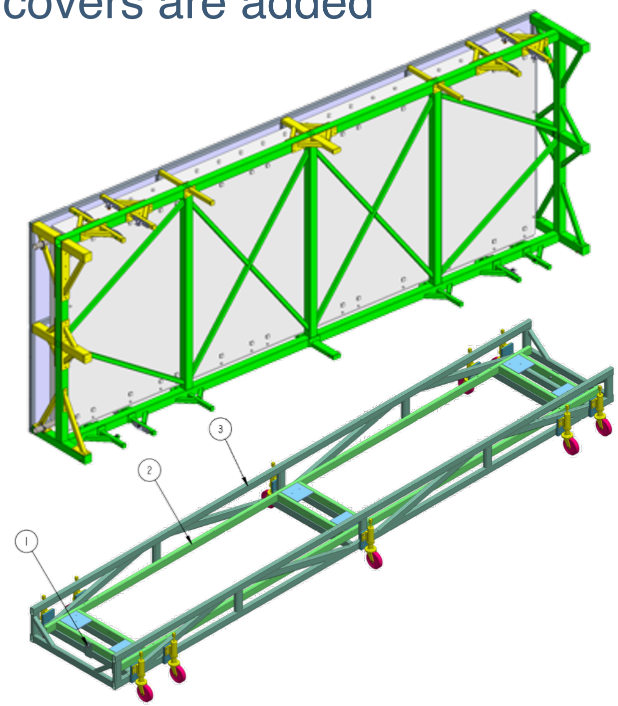
The engineering analysis plan, inputs, and resulting analysis are posted in EDMS 206057.

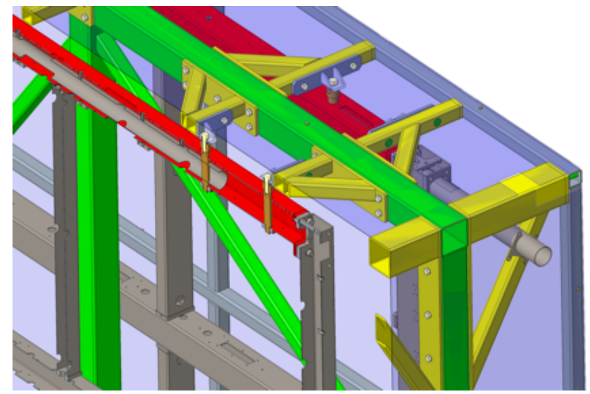
Usage cases for the ASF

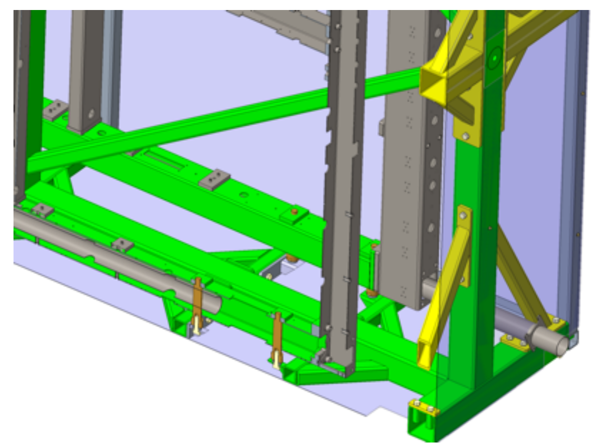
- Stepping through the stages in shipping an APA
- These **use cases** lead to the applicable **load cases**, which are specified in the ASF engineering analysis plan

Use case 1 - loading & moving at factory sites

- ASF is attached onto a horizontal cart (UK) or a shipping crate base (US)
- The completed APAs are loaded onto the ASF with an overhead crane; they are bolted in place
- Stability/load cases for both 1 and 2 APAs loaded on the cart
- Wrapped in plastic film, side covers are added



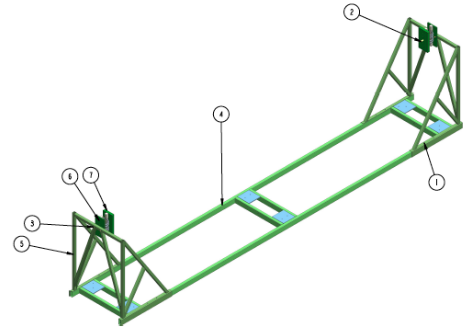


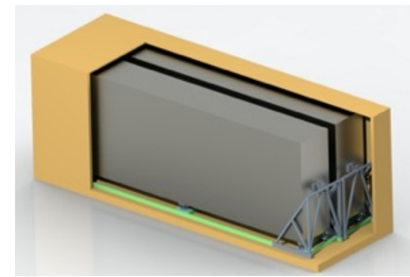


Horizontal cart for UK site: EDMS 2581209

Shipping base: EDMS 2581209

Use case 2 – transport from production sites to D0 at Fermilab





In the US

- Two shipping frames are secured to their WRIs, which are mounted onto a pallet through shipping bases
- Walls and top are added to complete a wooden packing crate
- The crate is craned onto a trailer
- The shipping frame is shipped (on an air-ride low-boy flatbed trailer) the D0 building at Fermilab for storage
- The shipping frames are then trucked in the same way to the Ross Headframe at SURF when needed underground

Crate on roller cart for RORO (Not ours)

In the UK

- Two loaded APA shipping frames are loaded onto a base secured to a truck, and tarped
- The frames are shipped (~20 miles) to the Port of Liverpool for crating
- They are loaded onto a roll-on-roll-off (RORO) ship in Liverpool and delivered to Baltimore
- The crates are then loaded onto a trailer and shipped to D0 at Fermilab (as in the US)

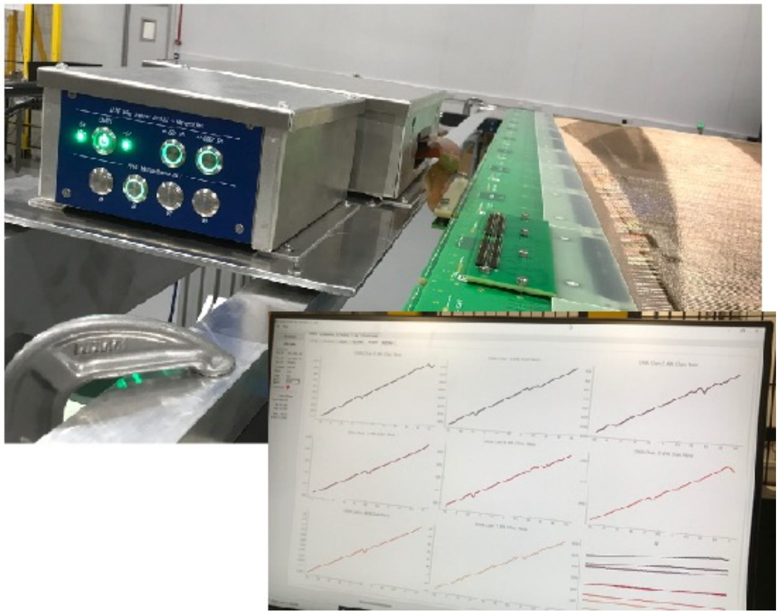
RORO @ Port of Baltimore

Shipping frames will incorporate multi-dimensional monitoring instrumentation to verify the they and APAs have not undergone excessive acceleration during each stage of transport

Shipping base & end WRI mounts: [EDMS 2581209]

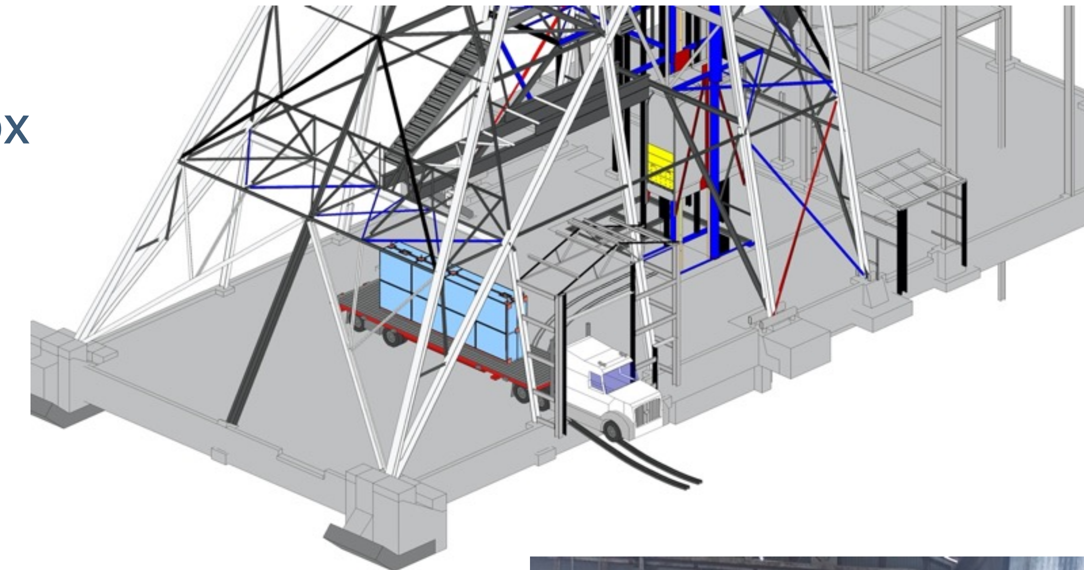
Use case 3 - Storage and testing in the warehouse

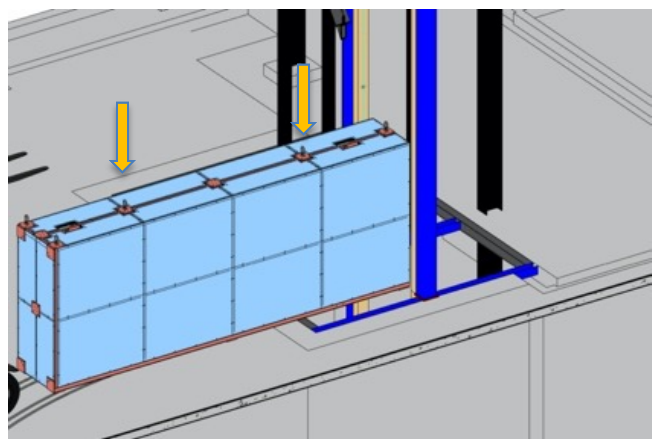
- We anticipate a number of tests prior to those in the underground clean room
  - Visual inspection of the shipping frames exterior
  - Checking the dataloggers
  - Electrical tests for wire continuity/isolation
  - Wire tension testing using electrical pulses to generate vibrations
- The last two tests require disassembling the crate and removing side covers from the ASFs to access the headboards on each tested APA
- More on this later (Use case 9)



Use case 4 - Transport to the Ross Shaft

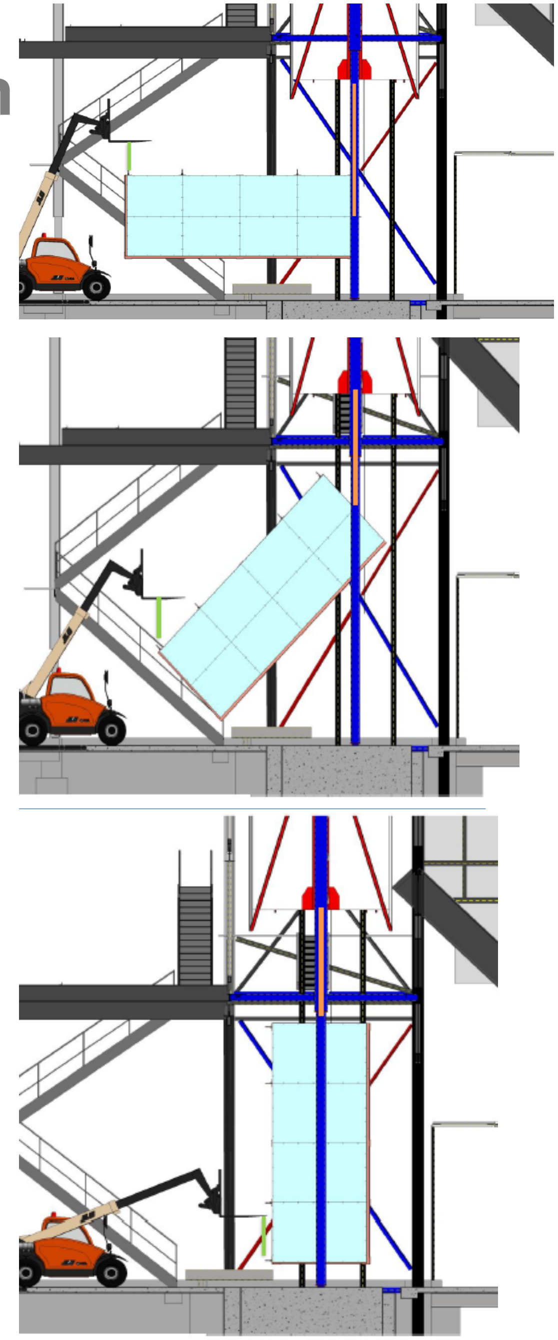
- When the crates arrive at the Ross Shaft the top and walls of the exterior wooden shipping box are removed and discarded
- The trailer is backed into the lift door at the headframe
- Then a spreader (or slings to a single hook) from a hoist on the overhead monorail is attached.
- They are freed from their pallets (8 bolts), lifted, turned, and placed at the shaft
- The lift points for this operation are the same as those used at the factories

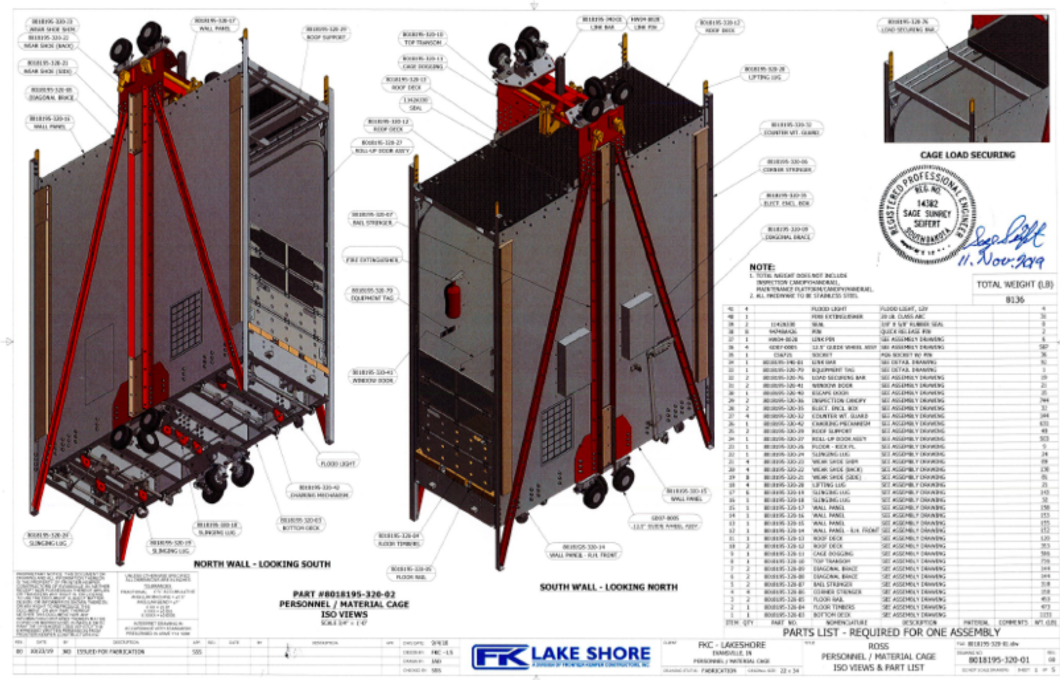


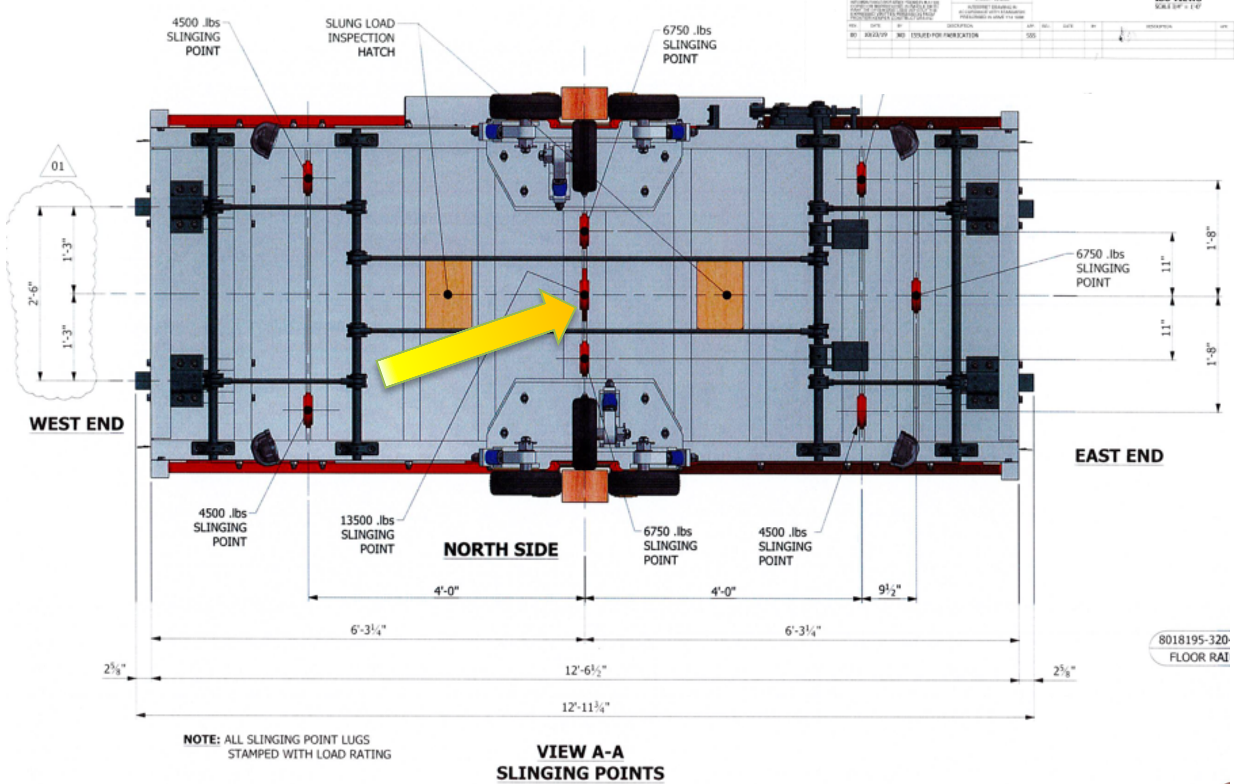


Use case 5 - Loading into, transport down and unloading out of the Ross Shaft

- The details for the materials handling equipment loading/unloading the shipping frame from the cage are still be negotiated between the project and SURF
  - The general plan is well enough defined to well specify the required structural analysis load cases for shipping frame
  - The end of the shipping frame under the cage (upper) will be attached to the hooks underneath the cage [slide]
  - The cage/hoist will be used to lift the shipping frame from horizontal until vertically slung below the cage
- The shipping frame design clears the headframe during this operation
- The lower end will be hung from from a telehandler to control the shipping frame as it is rotated to vertical over the shaft
  - Throughout this operation the forces on the shipping frame (and cage) are almost completely vertical with only small horizontal deviations to control the rotation in the later stages
  - This is a very similar process to that at CERN for ProtoDUNE [slide]
- This operation implies a variety of unique load cases
- Vertical shaft-timber guides (provided by the SD team) will be added to the sides of the frame and deployed





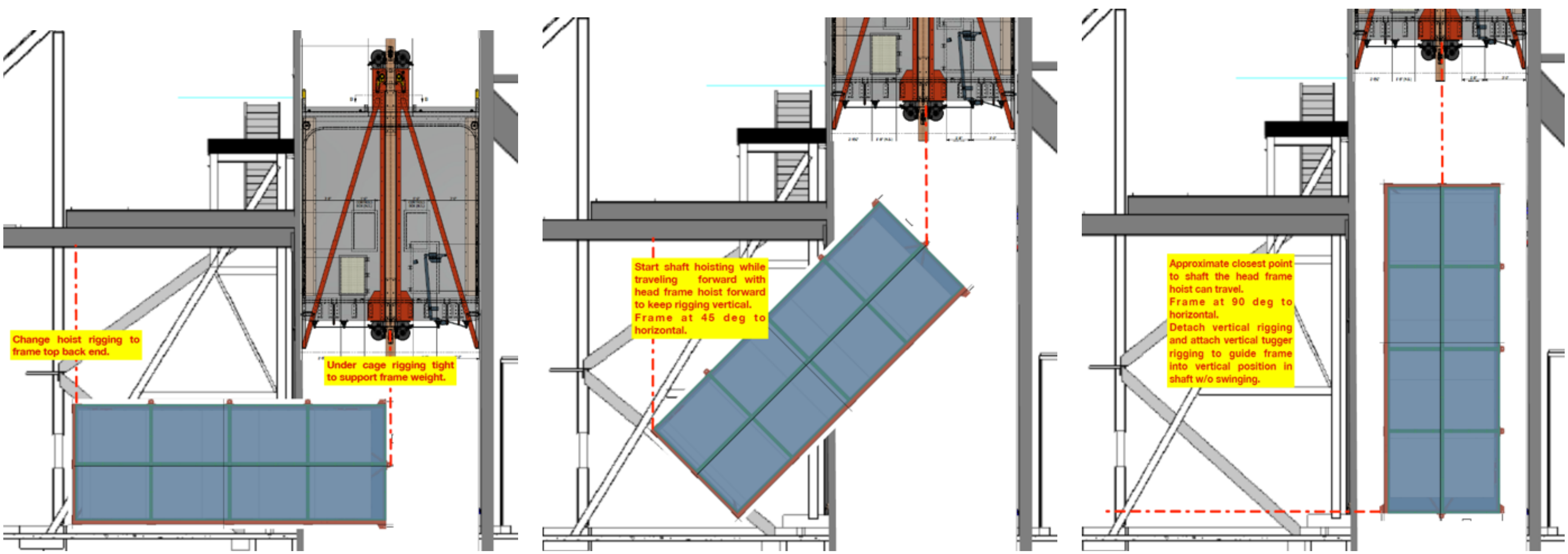


Cage drawing: EDMS-2331510


500
MAHLER
MERLO

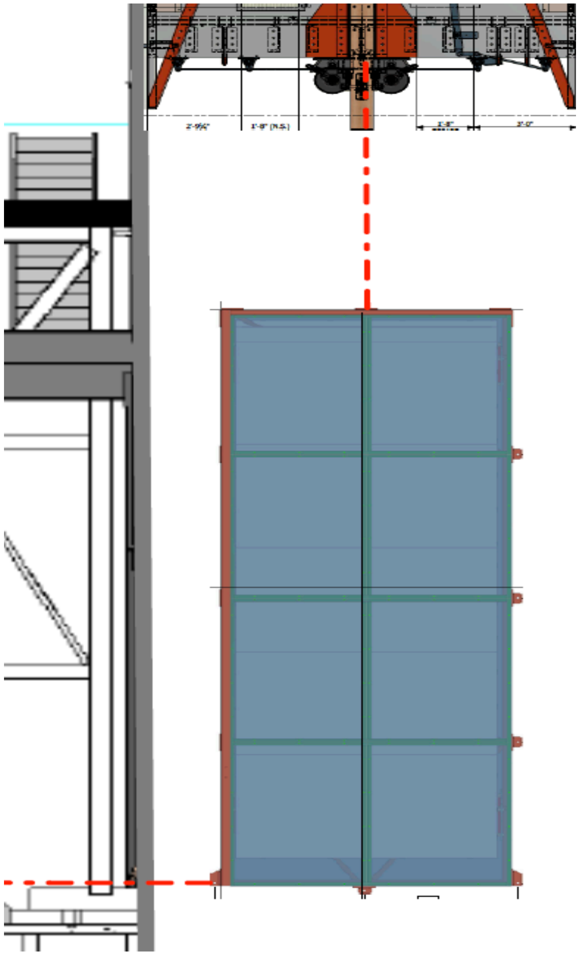
Use case 5 - Loading into, transport down and unloading out of the Ross Shaft

- SURF has proposed alternative equipment for the operation
  - Overhead free-moving monorail and horizontal tugger
- As the hook points and angles of the forces are consistent with our load cases, they can pick their equipment for the job



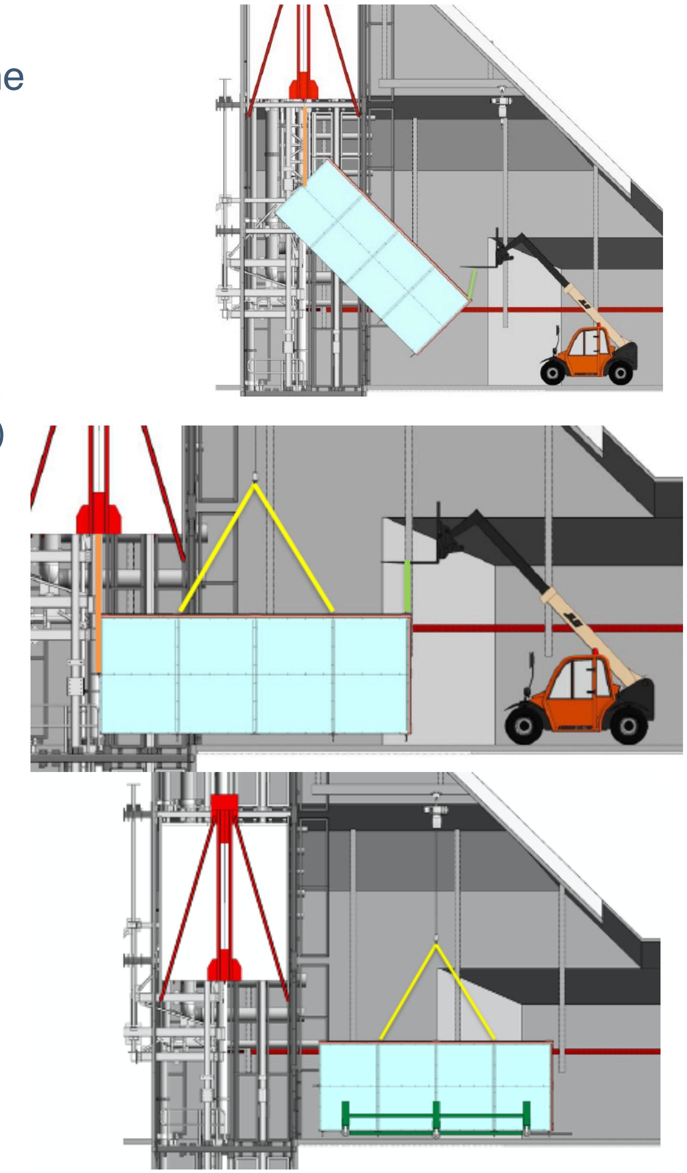
Use case 5 - Loading into, transport down, and unloading out of the Ross Shaft

- The APA shipping frame will be slung load below the main cage
- These loads are moved down the shaft slowly to reduce movement of the load
  - Dynamic loads specific to the facility
- In an accident a dogging system would stop the cage
  - We consider this an accident condition
  - We want to ensure the facility and workers are protected in such an incident
  - Analysis of this condition is focused on failure of materials – none expected



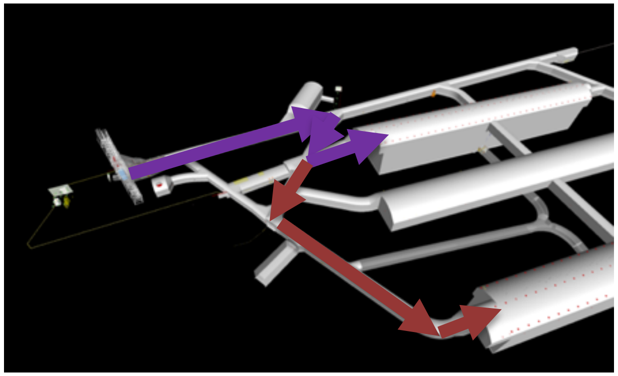
Use case 5 - Loading into, transport down, and unloading out of the Ross Shaft

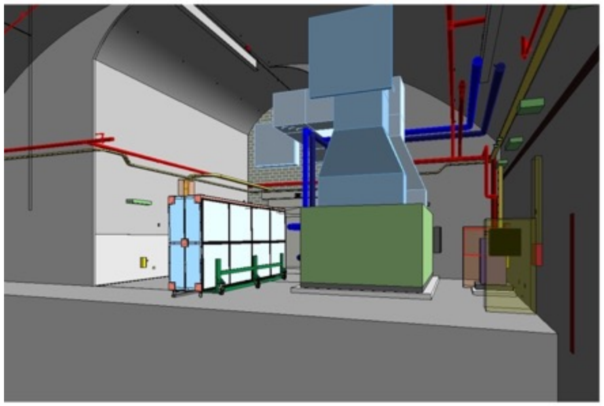
- The details for the materials handling equipment loading/unloading the shipping frame from the cage are still be negotiated between the TC and SURF
  - The general plan is well enough defined to specify the required structural analysis cases for shipping frame
- The surface rigging operation will be reversed
  - The shipping frame will be pulled out of the shaft and landed on the opposite long edge of the shipping frame than was used on the surface (upside down)
  - A suggested method is shown here; There are alternative proposals
  - As the hook points and angles of the forces are consistent with our load cases, they can pick their equipment for the job
- The shipping frame will be placed on a horizontal transport cart
  - This cart is not provided by the APA consortium
- As this is the inverted version of that on the surface, the orientation implies a variety of unique load cases, but they are very similar to those on the surface



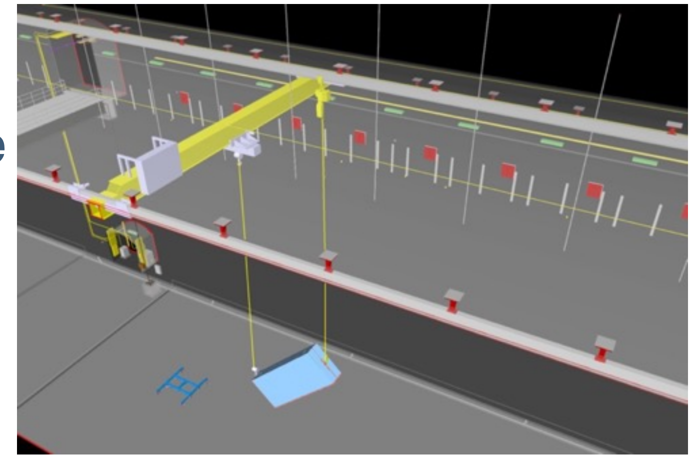
Use case 6 - transport to & inside the cavern

- The cart must be stable when moved down the drift, on modestly inclined surfaces (<2^0)
  - The ASFs are hauled along the drift to the cavern at SURF using a general-purpose horizontal cart still to be specified powered by a vehicle still to be specified by the SD
  - These systems will be supplied by SDSS and will need to meet similar stability requirements to the carts used in the APA assembly sites
- Surface quality of the drifts should be sufficient, and the speed of the transporter sufficiently slow, to ensure that they do not impose dynamic conditions larger than expected during over-land shipping
  - It is reasonable to assume that WRIs are not required in this operation

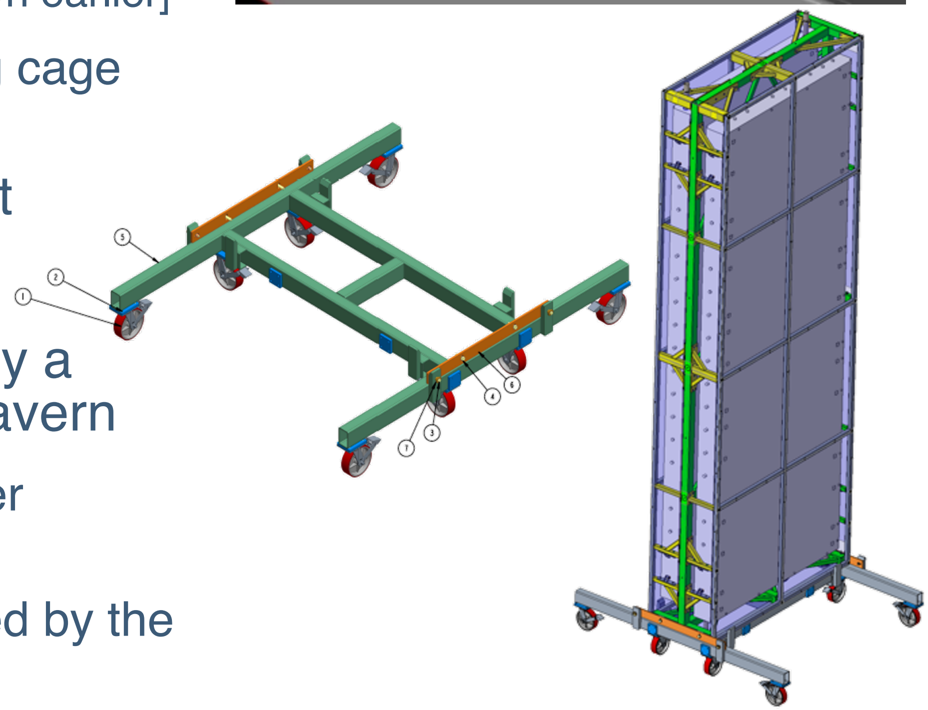




Use case 6 - transport to & inside the cavern



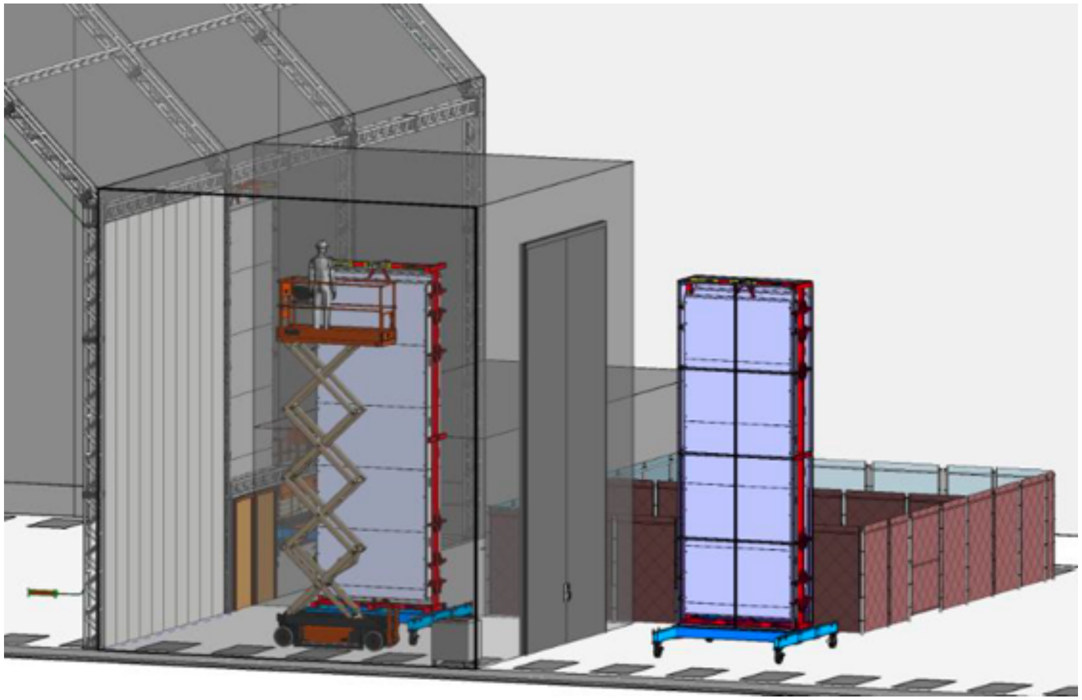
- The frame is connected to the cavern bridge crane and monorail, the cart is released, and the frame is lowered toward the hall floor
- They are rotated to the vertical position,
  - Rotation to vertical will use two cranes
    - Similar to the ProtoDUNE operation [shown earlier]
  - Same mounting locations as used during cage loading and unloaded operations
- They are bolted onto a vertical APA cart
  - APA consortium provides these carts
- APA shipping frames are then moved by a transporter into a storage area in the cavern
  - 1 month of APAs will be stored as a buffer (12 shipping frames)
  - Floor space for storage will be determined by the size of these vertical carts



Vertical cart: EDMS-2581210

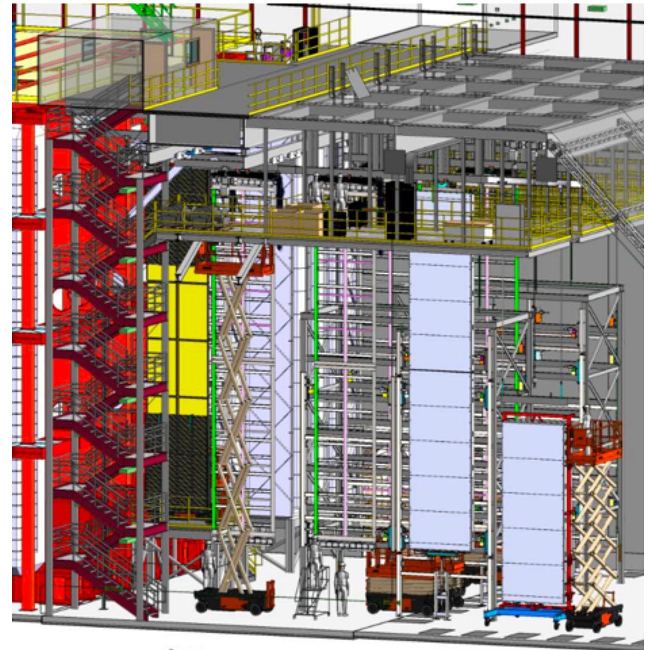
Use case 7 - transport to the SAS, APA integration, APA mating, and testing

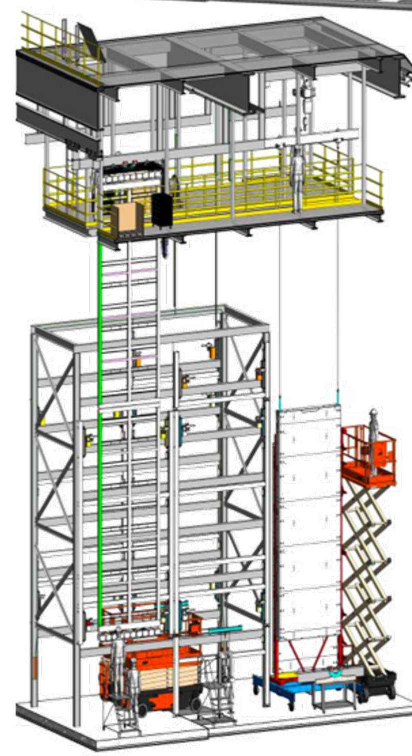
- They are rolled to the SAS
  - Outer packaging (side frames and wrap) is removed and the carts (esp. wheels) are cleaned
  - They will be connected to a transport via an A-frame towing bar to allow for both pull & push
- The SAS door will be sized to fit this object (expected to be largest)



Use case 7 - transport to the SAS, APA integration, APA mating, and testing

- APA shipping frame is moved to the cleanroom
  - PDs are installed and cable management is completed
  - Frames+carts allow access to all photodetector slots
- APAs are unloaded from the shipping frame and loaded onto the assembly tower using the cleanroom crane
  - 1st APA is lifted from the shipping frame using a fixture on a monorail-mounted hoist & placed on a lower rail
  - The cart is moved a short distance to put other APA under the monorail
  - 2nd APA is lifted from the shipping frame using a fixture on a monorail-mounted hoist & placed on an upper rail
  - This completes APA operations with the shipping frame
  - More details on this process in an earlier talk
- APAs will be tested for continuity, isolation, and wire tension in the clean room after the APAs are mated





Use case 8 - transport to the surface

- If the APA factory sites are still in production, if would be cost effective for a fraction of the crates, shipping frames, and protective covers to be shipped back to the factories and reused
  - The shipping frames will be returned to the surface (in the reverse of the operation that brought them underground), and trucked back to the warehouse
  - This is not the current schedule expectation
- More typically…
  - Empty frames/crates will be cut up and treated as waste or salvage
  - Protective covers from a number of APAs will be packed (e.g. in wire cages or bins) and periodically shipped to the surface in bulk and disposed
  - Wrapping materials will be bailed and shipped to the surface with other waste packaging
- If an APA failed quality tests and needed repair at PSL, a counterweight would be added to the frame (or we wait for a 2nd APA) and it would be brought to the surface and shipped to PSL
- No unique load cases are implied

Use case 9 - Above-ground cold testing

- We will fully test the first few APA pairs from each factory including cold tests
- During steady-state operations APAs may be sample tested (c.f. discussion in Christos's talk)
- For testing, the APAs will be unloaded and completely stripped of packaging material for the cold tests
- They must be repackaged and reloaded onto the shipping frames for storage and eventual shipping to SURF
- No unique load cases are implied

Requirements

- APA must not undergo more acceleration that they can sustain (quasi-static 6g for vertical/portrait or 4g for horizontal/landscape orientations)
  - Documented in the APA engineering analysis
- The shipping frame should isolate the APAs from shock and vibration due to transportation and handling so to not damage the APAs and meet applicable standards
- All the engineering design, fabrication, QC and documentation process will follow the documented expectations as summarized in
  - Validation of the DUNE/LBNF structures and mechanical components for equipment and detectors (EDMS #2172998)
- The operational requirements lead to the specification that the APA shipping frames are considered, in their entirety, to be a *Below the Hook* lifting device
  - Below the Hook Lifting device - Design Category A lifting equipment, Service Class 0 as defined in ASME BTH-1 Chapter 2, Table 2-3-1 and Appendix B.2.1 Table B-3-1 and ASME B30.20.2013 section 20-0.4
  - To comply with ASME B30.20 and the European Machine Directive, the load factor of 1.5 will be applied
- Each shipping frame will need its welds individually inspected and individually be subjected to load testing
  - Load tests of each shipping frame shall follow the ASME B30.20 requirements except to use a load factor of 1.5 on the work load limit so as to also be compliant with the European Machine Directive
- ANSI/AISC 360 (Specification for Structural Steel Buildings – American Institute of Steel Construction)
- Structural Welds consistent with ANSI/AWS D14.1 and ASME BTH-1
- EN1090, Class 2 (all applicable parts or US equivalent) - execution of steel and aluminium structures
- DOE 10 CFR851 – Work Safety and Health Program
- OSHA – CFR-2005-title29-vol8 PART 1926 – SAFETY AND HEALTH REGULATIONS FOR CONSTRUCTION, especially
  - *§1926.451(general requirements*) requires a safety factor of 4 for stability to tipping analysis

Analysis requirements (load cases)

- Requirements for assessing road transportation loads of APA and transport frame were determined within the APA consortium aided by a helpful literature review complied by the Compliance Office
  - EDMS #2366873
- Ocean shipping standards within the IMO/ILO/UNECE *Code of Practice for Packing of Cargo Transport Units (CTU code)* determined that quasi-static load cases during transport as acceleration coefficients 0.8 g horizontally and -1 g vertically
  - This applies to cases where up to 1/3rd of waves being >12m !
  - This analysis is being treated a preliminary and it will need to be updated when data from the specific shipper is made available
- Standards test scenarios defined in the “transportation shock test sequence” from MIL-STD-810H
  - 21 shocks consisting of a half sine wave of 6.4 G over 11 ms over common roads for a distance of 1000km
  - We will investigate the feasibility of such a test on a vibration table
  - For now, results from an FEA analysis under those conditions are documented in the engineering analysis note (Mariana’s talk)
- For resilience to handling conditions the isolation system, the acceleration experienced by the APAs when exposed to a drop should be evaluated
  - MIL-STD-810H overs a guidance height, but it also notes that is may not be practicable, and the limit should be analysed to determine to the highest drop allowable drop

Specifications from handling at SURF

- The shaft is controlled by SDSTA; they approve all loads transferred into the shaft
  - DocDB 4781, "Drawings and Analysis of Vertical Slung Loads in the Ross Cage Shaft for SURF," Matt Sawtell (drawing F10071028).
  - Docdb-328, "Far Site Shaft Hoisting Assumptions and Parameters"

  - Maximum slug load weight not to exceed 13,000 lbs. (5,896 Kg)
  - Maximum length is 22'-11 7/16" (6996) *
  - Maximum width is 4'-8" (1422)
  - Maximum depth is 11'-0"
  - Load must maintain center of gravity
  - Suspension points will be from the two midline hooks underneath the cage

  * NOTE: The specifications have a round corner cutout which the shipping frame design overlaps. The specifications also allow an alternative envelop to be used if approved by SDSTA. The current design has been shown to their engineering team, and they are working with Fermilab engineering staff and materials handling experts at CERN to jointly specify the required materials handling equipment.

- The shipping frame must be able to withstand rotation from landscape (up-side up) to vertical in the shaft, be able to be pulled out to landscape (up-side down), and be able to be loaded onto transport carts at the underground shaft station
  - Throughout this set of operations the center of gravity should be safely below the plane created by the array of points used for rigging to ensure stability

DOE considerations

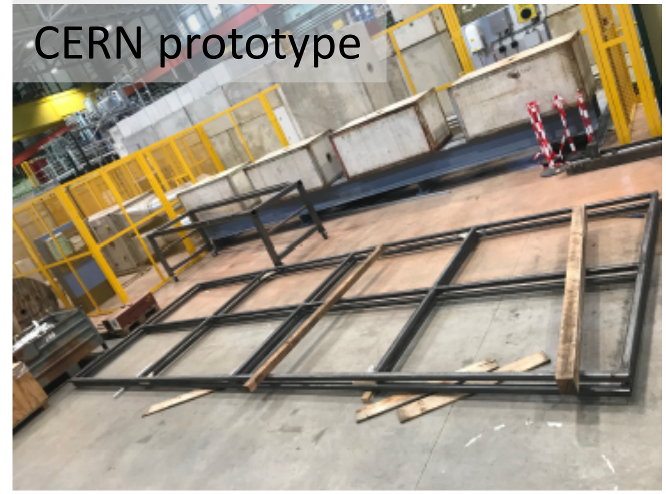
- The APA shaft operations meet the DOE category “Critical lift” conditions for the initial tests and also for the initial production lifts in 2025 as defined in DOE STD-1090-2011 based on § 2.1
  - “The load item is unique and, if damaged, would be irreplaceable or not repairable and is vital to a system, facility or project operation.”
  - “The cost to replace or repair the load item, or the delay in operations of having the load item or facility damaged would have a negative impact on facility, organizational, or DOE budgets to the extent that it would affect program commitment.”
- CO specifies that all lifts with an APA-loaded frame be considered critical lifts
  - All such lifts must be engineer overseen (including at the ports)
- Assuming successes in the initial production lifts and an after-action review, one might propose that the transport activities be reclassified as either as a DOE “Critical Lift – multi-use plan” or as a DOE “Pre-Engineered Production Lift”

Production plans

- Liverpool has taken the lead working with the firm TSG Marine to develop a commercial inspection, testing, certification, and logistics plan
- The UK APA production requires ~50 units
  - After collecting a number of bids, they have identified an experience fabricator they have used in previous similar projects (DSM fabrications)
  - Two initial frames being ordered for PD2 shipping and shaker-table tests
  - They have been working with a TSG Marine for crating and point-to-point shipping
- William & Mary (WM) will coordinate the procurement and testing of the shipping packaging for US APA production (10 units)
  - Working with Fermilab experts we have solicited quotes from 10 different vendors with verified testing/certification capabilities to produce the shipping frames
  - None of these were price competitive with the multiple UK quotes (even if one considers shipping)
  - The current plan is to order the US frames from the same UK vendor, and shipping bare frames to the US in shipping crates through the Port of Norfolk (near W&M)
  - US crating and bases will be assembled by a crating company near the port of Norfolk, VA
  - They would then be shipped to the US factories
- CERN is planning to internally build an ASF for shipping tests [slide]

Prototyping plans

- The UK is producing 2 prototype frames
  - One for use for shipping the 2nd and 3rd PD2 APAs (a matched top/bottom pair)
  - One for tests on a shaker table in the UK to validate the FEA analysis of the frame
- CERN is producing 1 prototype frame
  - It will be loaded with 2 PD1 APAs for shipping and instrumentation testing, collaborating with consortium effort
    - It will be shipped to SURF on the route anticipated for production
    - The rotation operation at the headframe will be tested
    - Test as a slung load
    - [Lower shaft station and rigging systems not ready at that time]
  - After the SURF tests, it will be shipped to Ash River
    - The tests of top-bottom mating using final hardware with their blank APA frames
    - Access for PD installation & testing will be verified on a vertical cart (made by W&M)



Shipping planning

- The shipping from the UK is being organized with a large company with experience in custom loads, from sensitive industrial equipment to telescopes:
  - https://pkmarine.co.uk
  - Our contact is Peter Ellison who has organized the shipments of the UK APAs for ProtoDUNE to CERN, and 12 years ago all 13 T2K ECAL modules to J-PARC
  - These discussions on APA transport to the US have been on going since summer 2018
- Over the last six months Peter has participated in the discussions and in meetings with UK, CERN, and Fermilab/US colleagues on definition of the special crates for the APAs, fixation to the truck bed and associated details
- When we have a prototype ASF and closer to the time of starting the shipments we will be in direct contact with the ship's captain to discuss the details of the sea crossing
- All shipments will be monitored by logging sensors on the APAs
  - The exact type, number and locations of the sensors will be defined based on advice from the CERN team, and it will be informed by their dynamic analysis, to ensure that we get the most relevant data from the most sensitive locations
- In the prototype shipping tests we will log Power Spectrum Density (PSD) data during each shipping stage from APA transport
  - On sea
  - On roads
  - During handling operations (CERN, DL, SURF & AR)
  - In the shaft
  - enDAQ sensors (Slam Stick) are the planned instrumentation
- Detailed testing plans and procedures are to be developed with APA consortium (Liverpool, W&M), the CERN Engineering team, AR, and SURF
  - APA consortium will supply effort for the preparations and execution of the testing program, and in extraction and analysis of the shipping data to aid in validation of the engineering analysis models

APA shipping packaging documentation

- APA shipping requirements https://edms.cern.ch/document/2620060/3.0

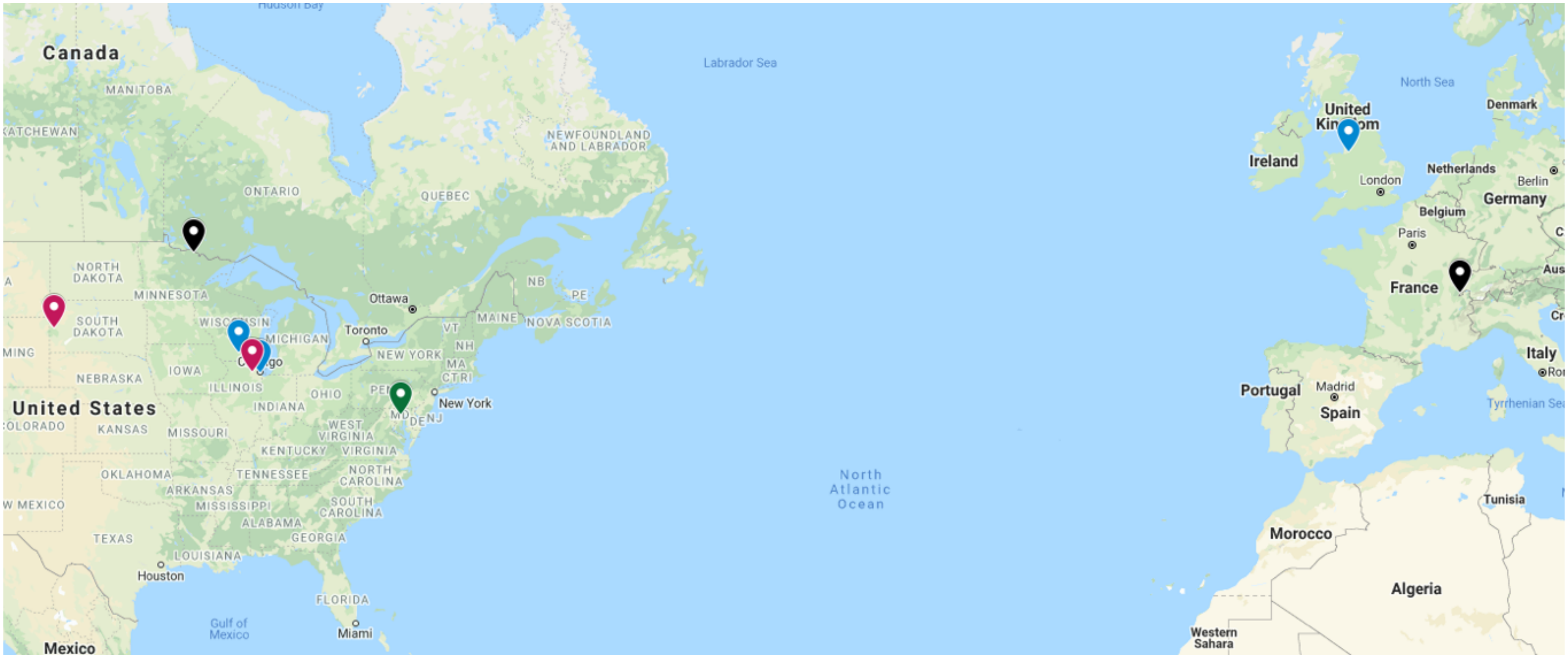
- Engineering models
  - Shipping frame: https://edms.cern.ch/document/2477326/1
  - Horizontal cart for DL: https://edms.cern.ch/document/2581209/1
  - Vertical cart for SURF: https://edms.cern.ch/document/2581210/1
  - Shipping frame/APA interface: https://edms.cern.ch/document/2439065/1
  - Simplified APA model used in shipping frame design integration: https://edms.cern.ch/document/2281501/4
  - APA protective packaging: https://edms.cern.ch/document/2509555/1
  - Wooden shipping crate: Work in progress (dimensions specified; vendors agree they can be built within those constraints)

- Fabrication drawings
  - Shipping frame: https://edms.cern.ch/file/2477326/1/Technical_Drawings.pdf
  - Shipping base: https://edms.cern.ch/ui/file/2581209/1/01_NP79-07-01.pdf
  - End WRI mounts: https://edms.cern.ch/file/2581209/1/02_NP79-07-02.pdf
  - Horizontal cart for UK site: https://edms.cern.ch/ui/file/2581209/1/04_NP79-07-04.pdf
  - Vertical cart: https://edms.cern.ch/file/2581210/1/03_NP79-07-03.pdf
  - Procurement, testing and shipping plans: proprietary – currently in revision with tendered vendors in UK

- Engineering analysis of the APA shipping frame
  - APA shipping memorandum: https://edms.cern.ch/document/2330505/2
  - Transportation analysis guidelines: https://edms.cern.ch/document/2366873/1
  - APA shipping frame analysis plan: https://edms.cern.ch/document/2509414/2
  - APA shipping frame engineering analysis: https://edms.cern.ch/document/2607623/1
  - Vendor shipping frame analysis (Vibrostop): https://edms.cern.ch/document/2617816/1

- Earlier documentation
  - Report from the ASF PDR: https://edms.cern.ch/project/CERN-0000211668
  - Stability analysis of frame on carts and during rigging operations (from the PDR, Section E of https://edms.cern.ch/ui/file/2370041/2/Engineering_analysis_of_the_APA_shipping_frame_v3.4_docx_cpdf.pdf

[redacted]



Blue – APA assembly sites (PSL, Chicago, Daresbury)
Green – US port of entry (Baltimore)
Red – Destinations (D0/Fermilab, SURF)
Black – testing program shipping locations (Ash River, CERN)