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DUNE Far Detector APA Shipping Frame Requirements Document

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Distribution List

History of Changes

DocDB	Version Number	Submitter	Version Date	Description of Changes
	0	W. Miller		
	1.0	J.K. Nelson	6/4/19	Updated to new installation/logistics model
	1.1	J.K. Nelson	6/17/19	Added a reference, noted scraping of single-use crates, temperature spec updated to +/-10C based on discussions with PSL and UK groups.
	1.2	J.K. Nelson	8/17/19	Feedback from Lee Greenler. Refined wording on the spring system’s goals and specifications. Refined the warehouse facility environmental specifications.
	2.0	J.K. Nelson	1/24/20	New handling model, design revisions to remove top cut corners, new pick points, and new mount orientation in the drawings. Updated basis for specifications based applicable standards in the US and UK.

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1 Introduction

The APA shipping frame has an extensive list of requirements to protect two APAs positioned end-to-end (one top and one bottom) on their journey from the factory into the clean room in the detector hall. The size of the package and rigging hardware is modestly constrained by the headframe at the Ross Shaft and more significantly constrained by US/UK/EU over-road shipping and below-the-hook fixture standards. The current design of the shipping frame and packaging is shown in Figure 1.

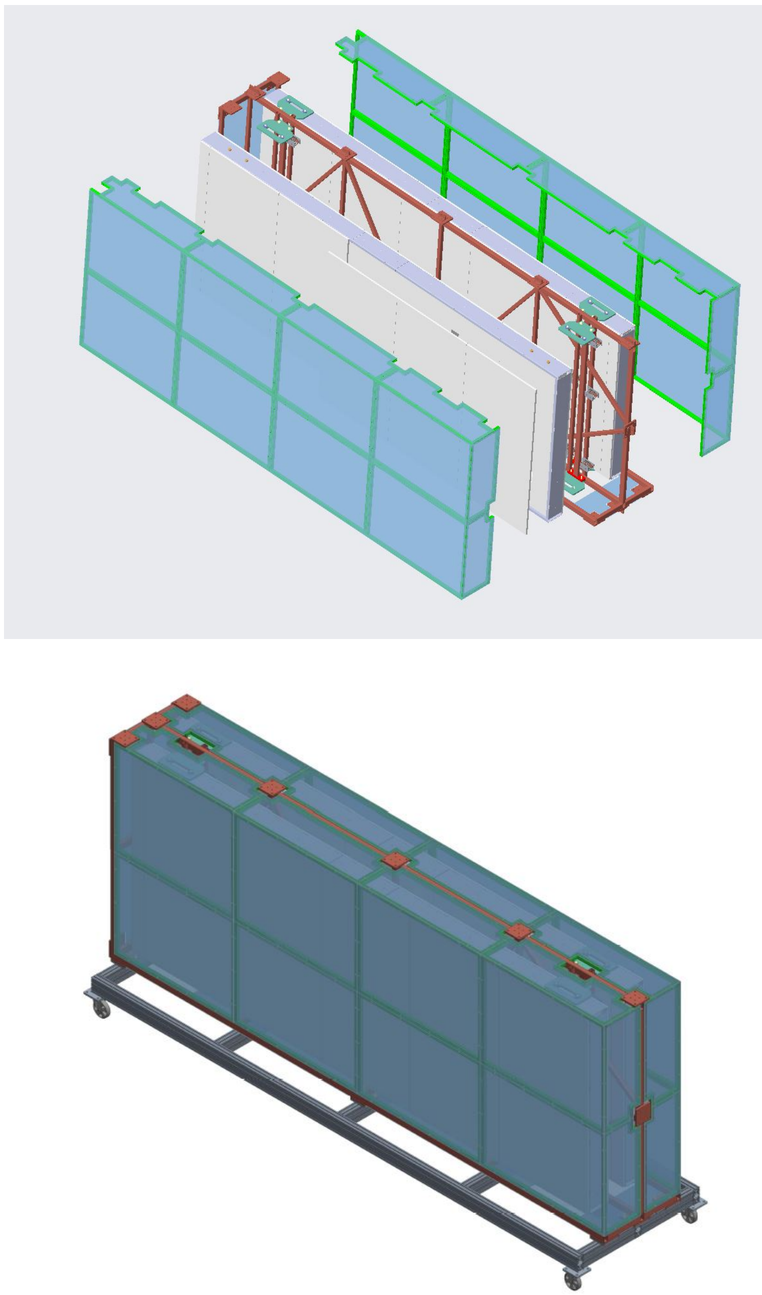

Figure 1 - The current design (top) of the APA shipping frame (rust color), APAs, removable side frames (green) and covers (grey) with two APAs covered with protective panels (light grey).[1] A frame mounted on a horizontal transport cart as used in the factories and the drafts at SURF. (Peter Sutcliffe and George Stavrakis)

Motion during shipping and possible handling conditions will be the source of the largest acceleration on the load, and that a spring system is required to dampen the maximum anticipated acceleration to 4g to avoid damage to the APA frames.[4] The natural frequencies of the loaded frame should be sufficiently different from the repeated driven vibrations expected from shipping so as to not induce large amplitude oscillations of the mounted APAs or the shipping frame. Another plausible source of acceleration to the load would be an accidental drop of modest height during handled or a similar impact. Note that the maximum emergency braking deceleration in the Ross Shaft is 2g, so handling and shipping are expected to be the limiting operations.

The US APA production will be packed individually on pallets and shipped via truck from the APA factories, to temporary warehouses, and eventually shipped the South Dakota Warehouse Facility (SDWF) near Rapid City when that site is available for APA use. The shipping frames from the UK will be packed in pairs inside wooden crates for shipping; they then will be stored in a warehouse before being trucked to the port of Liverpool, eventually transported by ship to the port of Baltimore, and then shipped by truck to SDWF.

Upon arrival in South Dakota the crates will be visually inspected for damage and logging devices checked for excessive accelerations by APA consortia-designated personnel or SD-based laboratory staff. We also want to allow for tests of the APA in the SDWF warehouse that would involve removing a portion of the removable side frames, a portion of the hermetic wrapping, and a protection panel at the head for each APA. The APAs are tested inside the crates, the APAs are then resealed, and the covers replaced. This inspection will require a basic class 100,000 clean room large enough for a UK crate plus sufficient working space. They are then placed for long-term storage in appropriately controlled conditions (only modest temperature/pressure swings to avoid condensation within the wrapped APAs) and until needed underground. In some cases they could be stored for three years or longer.

When required underground, the UK frames will be stripped of their wooden crating, placed on a pallet, tarped, and then transported via flatbed trailer to the Ross Headframe. At the headframe the truck will be backed into the shaft enclosure. The APA frame will be lifted by a monorail-mounted hoist and spreader beam, turned, moved to a position with one end below the cage, and set on the floor. The end of the frame under the cage (upper end) will be attached to the hooks below the cage and will be used to lift the crate from horizontal to vertical and pull it into the shaft until vertically slung below the cage. The shipping frame must be designed to clear the headframe during this operation. The other end (lower end) will be will be hung from a telescoping (boom) truck that controls the frame as is it rotated to vertical and into the shaft. This will be very similar to the rotation operation performed with the ProtoDUNE-SP APAs at CERN. When in the shaft, fixturing on the sides of the crate must engage the wooden guides in the shaft to provide control against swinging or rotating during lowering.

Upon arrival underground, the rigging operation will be reversed and the frame will be pulled out of the shaft and landed on the opposite long edge of the frame than what was used on the surface. The crate will be placed on a transport cart and rolled down the drift to the cavern. The loaded frame and cart must be stable while moved down the drift, which has some inclined surfaces.

When in the cavern, the APAs will be rotated to vertical, mounted on a vertical cart, inspected, and temporarily stored in the cavern for up to a few weeks.

At the SAS, outer layers of plastic sheeting will be removed and the carts wheels are cleaned. The APAs are then rolled into the clean room and integrated with photon detectors (PDs) and tested. The APAs are then unloaded from the frames and mounted onto the integration workstation. The vertical cart must allow a single APA to be removed from the frame and still remain stable.

The shipping frames are then returned to the surface, then to the SDWF, and finally are possibly shipped back to the APA factories for the second module's production in the US if the first installation happened while the factories are still in production. Cost effectiveness for a similar operation is still to be determined for the UK frames. Any frames not designated for reused will be cut up, and brought to the surface inside the cage (instead of slung) allowing for more efficient use of the shaft.

2 Use cases

Use case 1: Loading APAs at the factory

At the factory, APAs are covered in protective panels. Two APAs are individually loaded onto the shipping frame with an overhead crane or forklift. The APAs are loaded end-for-end swapped for balance and eventual top-bottom mating. The shipping frames must be stable while loaded with a single APA, which is be aided by securing to a "horizontal" cart with a wider wheel base than the frame itself (Figure 1). The carts also ease movement within the factory sites. APA pairs are mounted into the frame's mounts and secured. The outer removable covers (green parts in Figure 1) must be able to be efficiently installed with protection in place to ensure that they and cannot damage the APAs during their installation. Then the shipping frame is covered in plastic sheeting covered except for locations to access pick and bearing points.

The loaded frame is then packaged for shipping. In the UK two shipping frames are placed on a pallet and then surrounded with wooden panels to form a shipping crate with exposed sling/fork pockets. The crate is then covered with a tarp.[3] In the US the frames are loaded onto a pallet. They are then covered (current model is they are sealed with plastic sheeting and/or a plywood skin – blue-grey in Figure 1) and secured.

Use case 2: Shipping the APAs to load warehouses and eventually to South Dakota

The packaged frame is loaded onto a trailer for shipment with either a forklift or slings from an overhead crane depending on the site.

In the US, the packaged frame is shipped covered (either roll-sided trailers or tarped on a flatbed trailer) and transported to a local warehouse. When the SDWF (a TBD location regional to SURF) has availability for APA occupancy (currently estimated to be late 2023) the crates are then covered in the same way and transported to the SDWF.

In the UK, the crated frames are similarly moved a local warehouse. When space is available in the US, they will be loaded onto a ship in Liverpool and delivered to Baltimore. The crates are then covered (either roll-sided trailers or tarped on a flatbed trailer) and transported to the SDWF.

The frame and crating must be designed for the maximum expected dynamic loads during shipping. This is anticipated to define the design for the acceleration damping system. The crates must incorporate a spring system that will lower the expected accelerations to no more than 4g to ensure that the APAs are not damaged in transport.[4] The crates and transport frames will need to incorporate multi-dimensional monitoring instrumentation to verify the crates and APAs have not undergone excessive acceleration during transport.

Use case 3: Testing and storage in the warehouse

Upon arrival to the local warehouses and to the SDWF the crates are visually inspected for damage and any logging devices checked for excessive accelerations in transit.

The crating and frame designs should allow for efficient continuity and isolation tests of the APAs in the warehouse by APA consortium members. We may also tension test the initial APAs if the electrical stimulation method is viable. At some point we may decide that experience renders these tests as no longer valuable, but the capabilities must be in place for at least the initial phases of shipping. The tests involve removing a portion of the shipping crate, cutting the plastic wrap, and removing a protective panel for each APA to expose the head boards. The APAs are tested inside the crates, the protective covers replaced, and the frame is resealed. This inspection will require a basic clean room (class 100,000) large enough for a UK crate and work space around the crate to remove sides and access head boards (roughly 7m by 5m). The APAs are then placed in long-term storage at SDWF until needed underground. In some cases they maybe be stored for three years or longer. We do not intend for loaded crates to be tilted or stacked, and the crating should be labeled accordingly.

The environmental specifications are intended to ensure that temperature swings are limited to keep relative humidity low enough to avoid condensation within the wrapped APAs. A 50% relative humidity at 20C (68F) the temperature would have to drop to about 8C (46F) before the humidity would hit the condensation point. 50% relative humidity in summer and 40% in winter are fairly ordinary household conditions so they should obtainable. If this turns out to be unrealistic or expensive due to the type of warehouse, other combination of temperature and humidity specifications can be found (depending on what *can* be maintained within the warehouse).

Use case 4: Transport to the Ross Shaft

Prior to transport to the Ross Shaft, the exterior wooden shipping box for the UK frames is removed in the warehouse and discarded and the frames are placed on US-style pallets. Frames are loaded onto a trailer by forklift or craned onto a flatbed trailed, covered, and driven for a couple-hour drive to the Ross Shaft. The trailer backs into the lift door at the headframe (Fig 2). The APAs packages are uncovered, with a spreader beam mounted on a hoist on the overhead rail and are rotated to be in line with the cage and placed at the shaft (Figure 3).

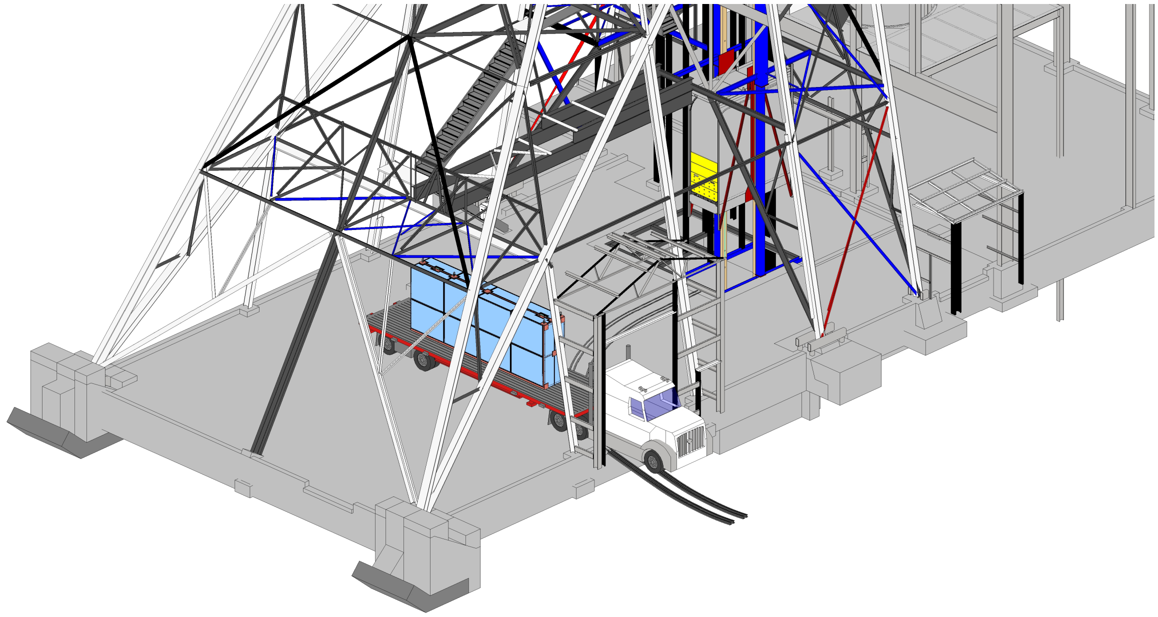

Figure 2 – An APA shipment being delivered to the shaft station. (Justin Freitag)

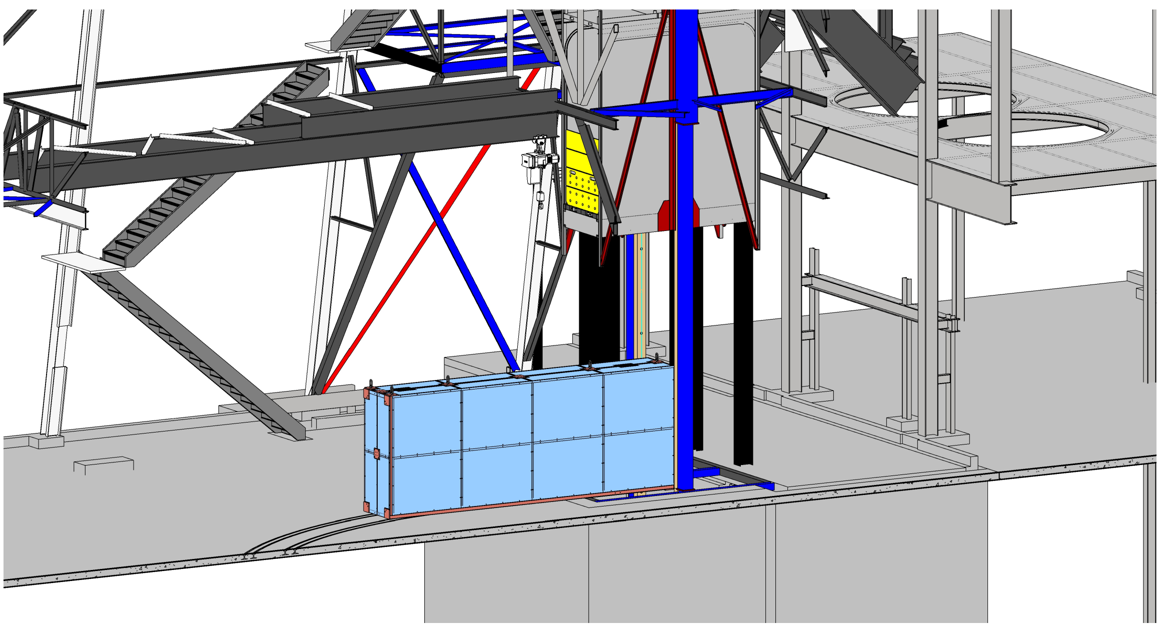

Figure 3 - The shipping frame is rotated 90 degrees and moved to that shaft with "upper" end located below the hooks underneath the cage. (Justin Freitag)

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

The shipping frames are delivered laying on their long skinny edge (so-called landscape orientation as shown in Figure 3). The upper end of the frame will be attached to the mount points underneath the cage with two (or possibly four) cables (Figure 4). These hook points should be along the frame's center of gravity when hung vertically and the minimum allowed cable length is 12ft.[5] The lower end of the frame will be slung from telescopic handler (telehandler or boom truck) as depicted in Figure 5. After both ends are attached the spreader and hoist are backed away from the cage area.

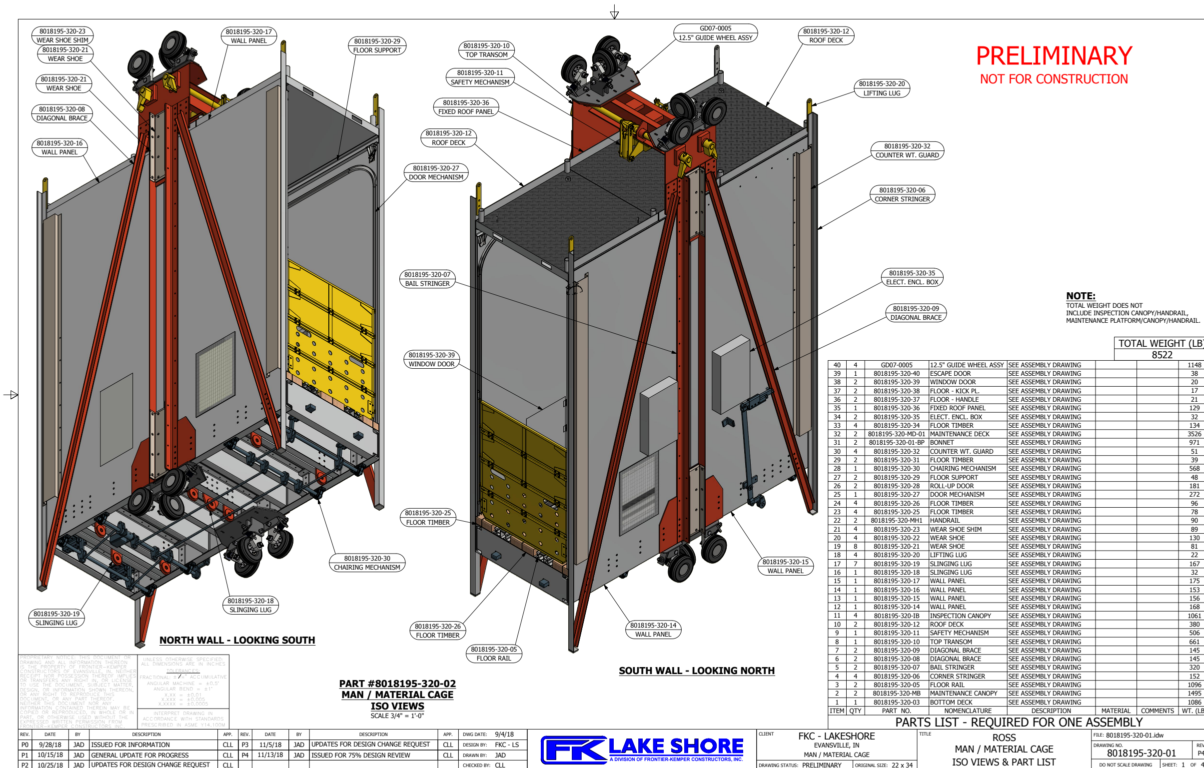

Figure 4 – Current cage design (75% drawing from Fall, 2018). Hook points are shown in red on the left panel.

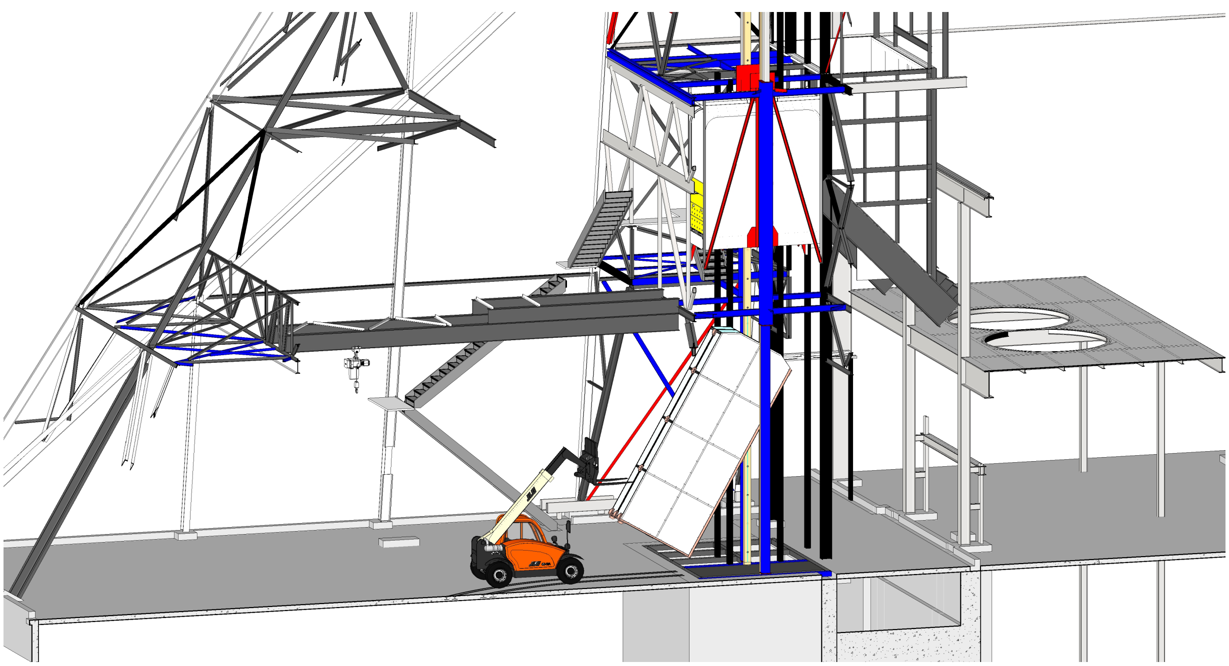

Figure 5 - A APA frame being rotated into the slung load position at SURF. (Justin Freitag)

Figure 6 - A ProtoDUNE-SP APA being rigged from horizontal to vertical using a similar technique at CERN.

Using the cage as a hoist and slowly adjusting the position of the boom of the telehandler as the cage raises, the frame is pulled into vertical and hangs as a slung load below the cage.[7] The crate includes mount points (swivel eyes) for the spreader beam, the cage cables, and the telehandler. The center of gravity of the loaded shipping frame is safely below the imaginary line between the two hook points so the load will be stable throughout this operation. This operation is nearly identical that that successfully used for rotating the ProtoDUNE-SP APAs into their vertical orientation at CERN (Figure 6). This operation needs to be repeated 75 times per detector module.

The lower cables stay with the load, will be hooked by the shaftman at the 4850 Level, and then attached to another telehandler to begin the unloading process. The loading process is reversed to remove the crate from the shaft (Figure 7). Note that underground the shipping frame is extracted on from the back of the cage inverted from its orientation on the surface. The shipping frame will be loaded onto a horizontal cart and secured.

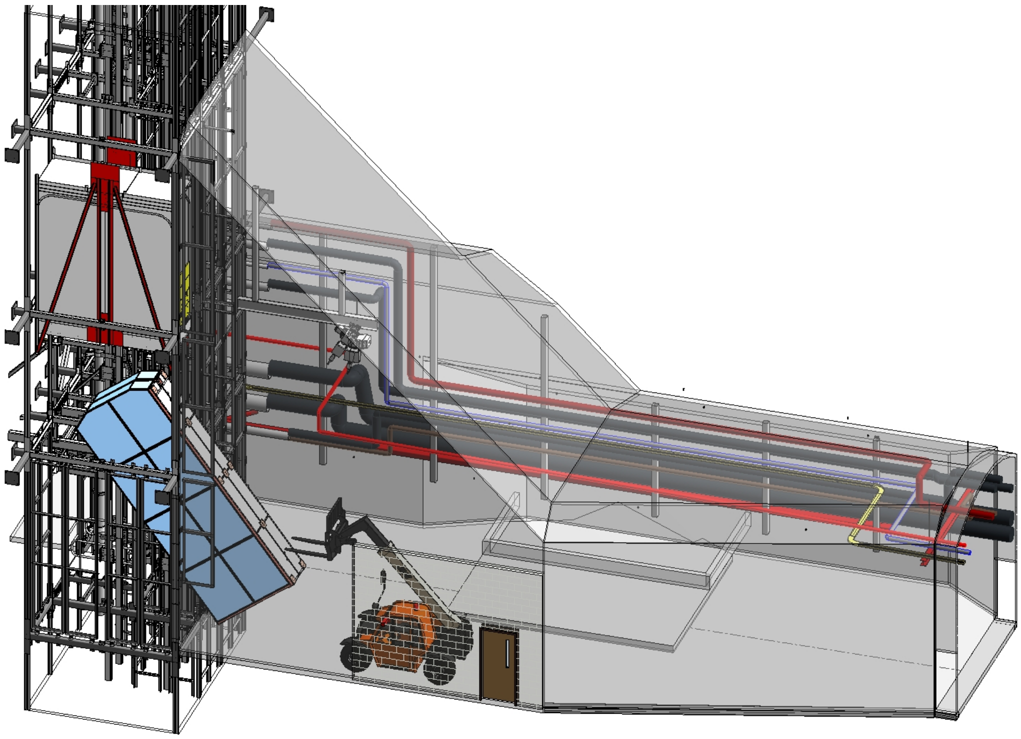

Figure 7 - unloading the APA frame at the lower shaft station. (Justin Freitag)

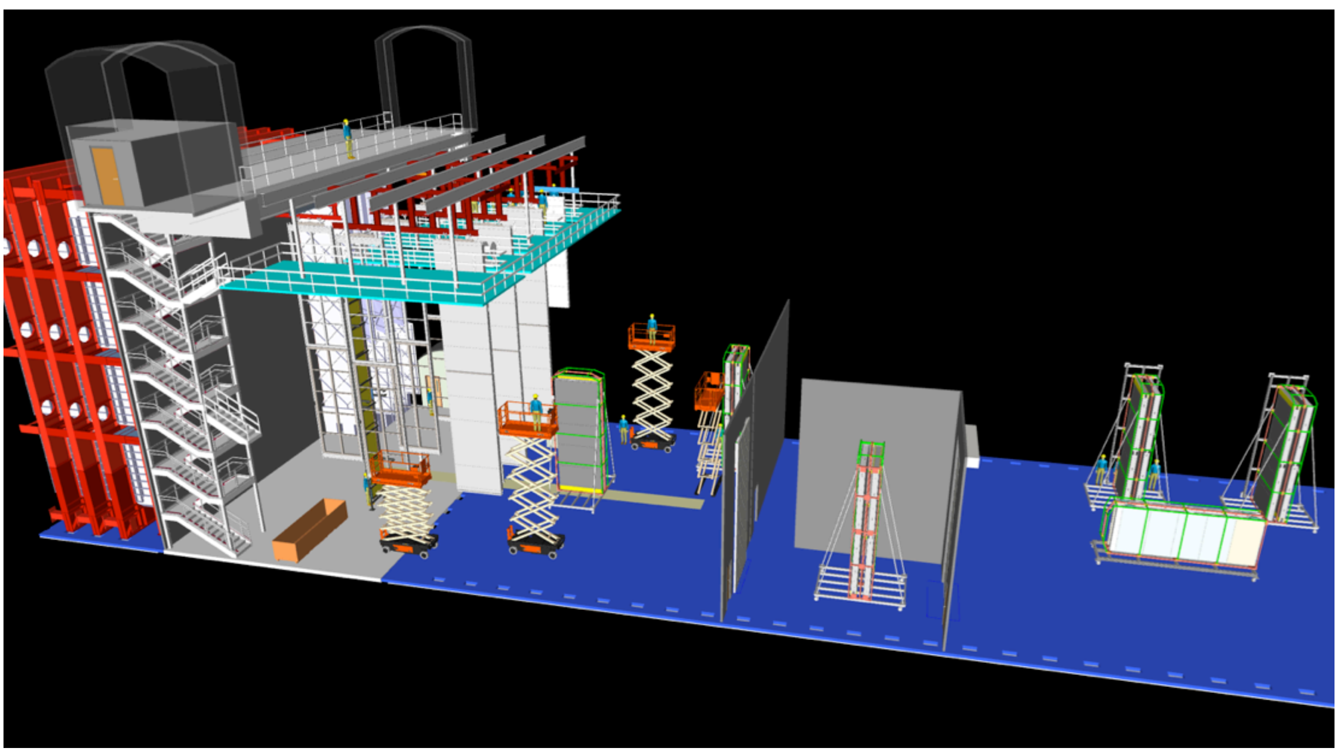

Figure 8 - Layout of the cavern and installation spaces indicating APA frames being stored vertically on carts, being moved into the SAS on a cart, readied and tested in the clean room, and being assembled after being removed from their frames. (Bill Miller)

Use case 6: transport to the cavern

The APA frames are hauled along the drift to the cavern using a powered vehicle that is still to be specified. They are then hooked to the cavern bridge crane with a spreader beam, the cart is released, and they are lowered to the 4910 level (hall floor). At this time they are rotated to the vertical position, landed on vertical APA carts, and secured. The rotation to vertical will be accomplished in an operation using two cranes using the same mounting locations as used it the cage loading and unloaded operations. The frames must allow for efficient and secure connections to the vertical carts (Figure 8). The APA frames are then move by pallet jack into a storage area in the cavern. Approximately one month of APAs should be stored as a buffer (12 APA shipping frames). The floor space required for storage will be determined by the final size of the vertical APA cart.

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

When needed for installation, the APAs (on their carts) will be rolled through a door into the SAS. Their outer packaging (side frames) is removed and the carts (esp. wheels) are cleaned. The APA shipping frame is then moved to the clean room's assembly area (Figure 9). The APAs will be tested for continuity, isolation, and wire tension in the clean room by removing small sections of the protective covers that expose the head boards during testing but continuing to protect the rest of the APA. The frames are designed so there is access to all of photodetector (PD) slots. The PDs are installed and cable management work is completed with the protection covers in place.

The two individual APAs are unloaded from the frame one at a time and loaded onto the assembly tower using the cavern bridge crane. The first APA is lifted from the frame using a lifting fixture by a monorail-mounted hoist and placed on a lower rail. The second APA is lifted from the frame using a lifting fixture by a monorail-mounted hoist and placed on an upper rail. This completes the APA operations with the shipping frame.

Except for at the very top, we are assuming that the protective covers stay on until the final steps of integration and photogrammetry/survey prior to insertion into the cold box. The design of the protective covers should not allow dropped objects to slip between the protective covers and the APA whilst the upper covers are removed.

Use case 8: Frames transported to the surface and to the warehouse

The 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. The wrapping materials will be bailed and shipped to the surface with other waste packaging. The removable side frames are reattached to the frames. The frames will be returned to the surface in the reverse of the operation that brought them underground and trucked back to the warehouse. Up to 25% of the pallets, shipping frames, and protective covers will be shipped back to the US APA factories for use on the second module. The remainder will be cut prior to transport to surface for loading into cage and scrapped for salvage.

Use case 9: Sampled above-ground cold testing at PSL

We will fully test the first 5 APA pairs from each factory at PSL including cold tests and wire tension tests. PSL modules they will be double shipped to/from SURF prior to these initial tests. During steadystate operations, 1 in every 10 APA pairs will also be sample tested at PSL. The APAs will be unloaded and completely stripped of packaging material for the cold tests. They must be repackaged and reloaded onto the frames for eventual shipping to SURF.

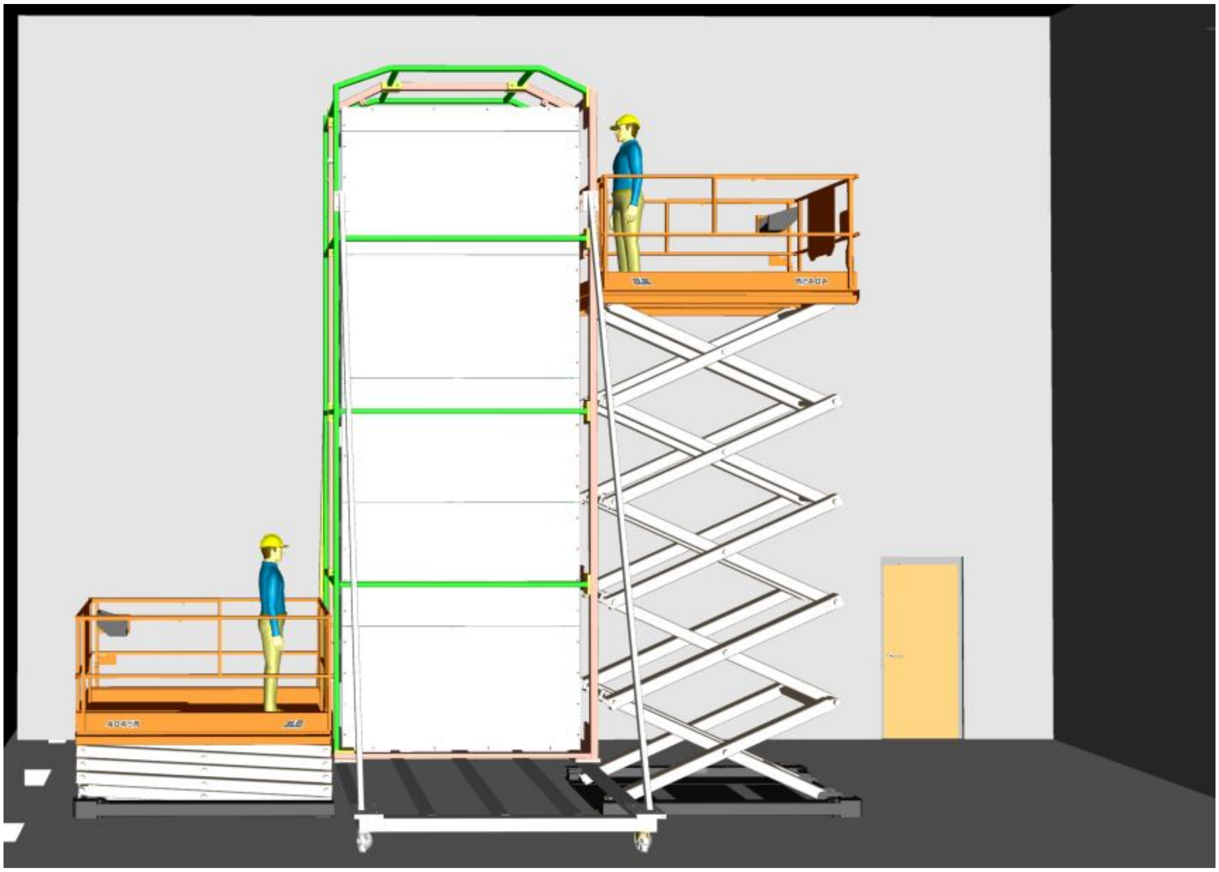

Figure 9 - APA shipping box located in cleanroom for testing and integration of PDs. (Bill Miller)

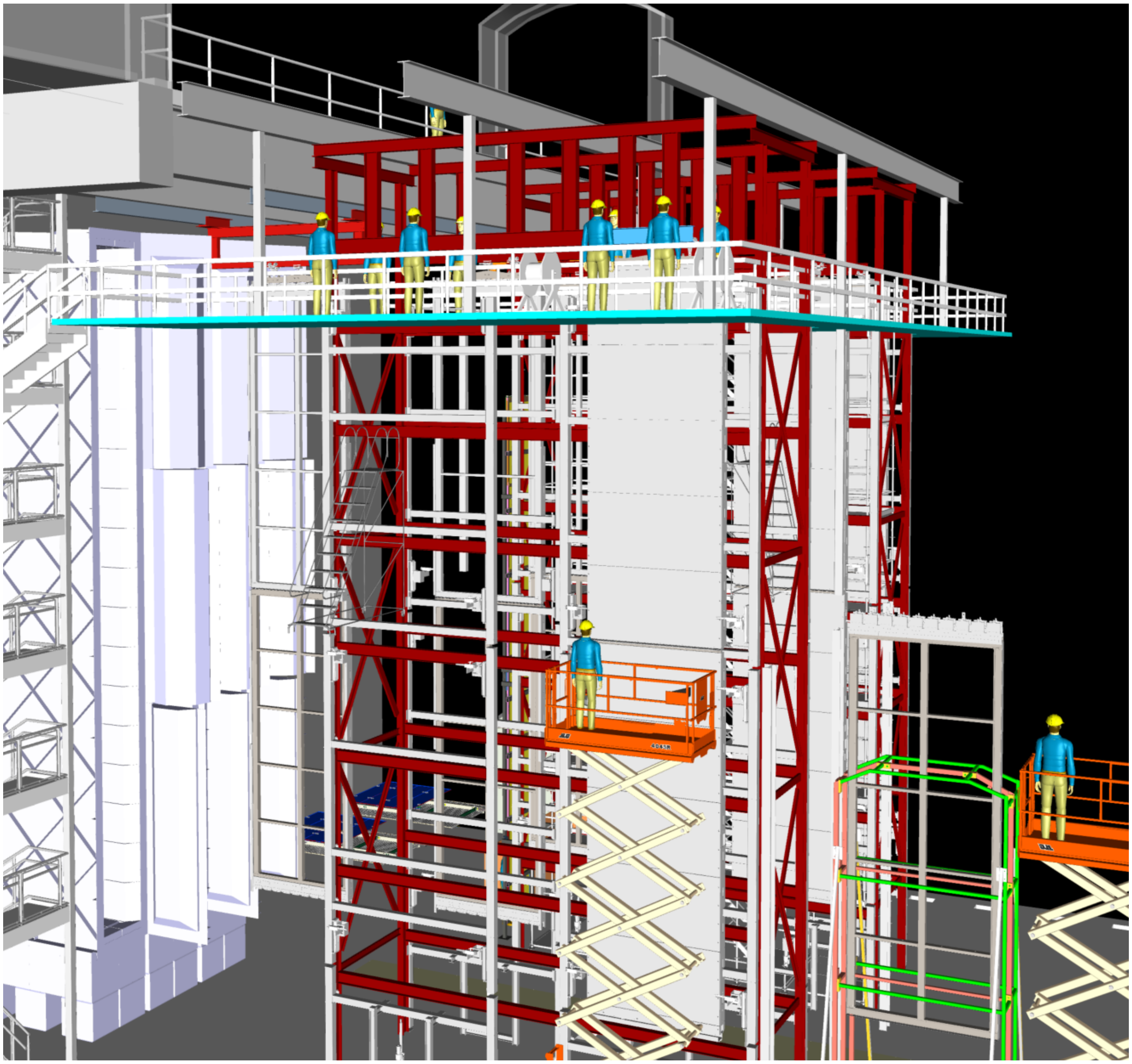

Figure 10 - An APA (shown without panels or wire planes) being removed from the shipping frame (shown in pink/green). (Bill Miller)

3 APA Shipping Frame Requirements

APA transport frame requirements derived from factories and shipping

- The transport frame should hold 2 APAs positioned end for end (a top and a bottom APA).
- The transport frame, in horizontal orientation, should allow transfer of a completed APA to the frame at the factories. It should be stable while secured to a horizontal cart when only one APA is installed.
- The transport frame must be sufficiently cleaned after fabrication and transportation to the factory prior to entry to the APA factory floor. Steel surfaces should be painted to facilitate cleaning.
- The side frames that wrap around the APAs should be made of aluminum (currently considering T-channel hardware), must be able captured by pockets to help mate to the frames while protecting the APA panels, and must be relatively efficient to secure in place.
- Frame must be designed with lifting points (or pockets) for slings and side-loading forklift pockets to allow loading onto flat bed trailers. The frames should also have end pockets to allow a fork truck or jack to engage and move the frames while on carts. Alternatively, these end pockets could be integrated in the two different cart designs.
- The transport frame should isolate the APAs from shock and vibration due to transportation and handling to as low as reasonably practicable. Note that the shaft's emergency braking system can give 2g in the vertical orientation, which should be considered as a static load on the isolation system.
- The APAs structures must not undergo more than 4g. As a minimum requirement the transmitted acceleration should be less than 4g peak measured at the APA for 7.6g for 11ms input in all 3 directions. This input is the maximum value taken from MIL-STD-810H Table 516.8-VII *Procedure II – Transportation shock test sequence*.
- For resilience to handling conditions the isolation system should be designed to minimise acceleration experienced by the APAs to less than 4g peak when exposed to a transit drop of at least 114mm (which equates to an instantaneous velocity change of 1.5m/s). A target transit drop value of 460mm is required to be in accordance with MIL-STD-810H, however, it is understood this may not be achievable within the allowable space constraints. Therefore the system should be designed to allow resilience to the highest drop possible up to this value. The drop should be assessed for all configurations of the lift sequence, i.e. drops on the long and short faces and the corner between them.
- Stresses within the transportation frame should be assessed such that they are within acceptable limits considering the maximum reaction forces applied by the isolation system (e.g. a spring system) for each load condition, as it likely these will be the highest forces experienced

by the frame. There should be no yielding of the system under any transportation or handling loads. Fatigue effects should be considered for vibration loads taken from suitable norms, for example MIL-STD-810H Paragraph 514.8.

- Sufficient internal clearances should be designed to accommodate the full stroke of the selected isolators in all 3 directions. This is critical to avoid collision between the APAs and the transport frame.

- The frame must meet appropriate requirements in the UK, EU, and US. Fermilab and CERN have classified the central structural frames as below-the-hook lifting fixture (ASME B30.20 code category A, service class 0 fixture). UK it is covered by *Lifting Operations and Lifting Equipment Regulations* 1998 (LOLER). As such, each frame will need its welds individually inspected and will be subject to specified load testing.

- The shipping frames should have instrumentation to indicate if the APAs were subjected to more than 4g during shipping.

- The first modes of the transportation frame/system should be computed and compared to the lowest modes of the APA frames. The design should incorporate in as much separation between transport frame modes and APA modes to ensure isolation.

- The removable side frames and protection panels must be designed to allow one panel to be removed to provide access to the head boards for testing and must be able to be reinstalled while the APA is mounted on the frame, with side frames in place, while oriented either horizontally or vertically. It must not be possible for hardware released in this process to accidentally fall inside the APA volume.

- The loaded frames must be able to be installed in wooden shipping crates (UK) or wrapped on pallets (US). The UK crates need to be less than 2.44m (8ft) in width to allow shipping without wide-load permitting in the US.

- The frames will be stored long-term in the SDWF and their shipping packaging should allow them be stable while stored on their sides in the warehouse. Consider desiccant within the plastic wrap to control for condensation during temperature extremes during shipping.

APA transport frame requirements derived from transport underground and to the cavern

- At the headframe, the shipping frame must be able to be unloaded from trailer by a spreader beam from an overhead crane (as in the factories).

- The frame must follow SURF shipping requirements as shown in DocDB-4781. Drawing F10071028 shows the maximum box size. The shaft is controlled by SDSTA and they approve all loads transferred into the shaft. Load specifications are shown documented in DocDB 4781 (Figure 11).[9]

- Maximum slug load weight not to exceed 13,000 lbs (5,896 Kg).
- Maximum length with 5’-6” curved radius on top corner 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 determined and approved by SDSTA

- The frame must be able to withstand rotation from landscape (up-side up) to vertical in the shaft, and be pulled out to landscape (up-side down) and loaded onto transport carts at the underground shaft station.

- The frame or cart must have mount points for a forklift to guide the crate down the drift to the cavern.

Transport frame requirements derived from underground storage, testing, integration

- Outside side protection panels must be removable. We assume a seal (plastic wrapping) over the side frames to protect the APA outside the cleanroom/SAS. We must be able to remove individual protection panels over the head boards during testing, and integration of PDs and cold electronics.

- The frame sides must be able to be removed from the frame while the crate is in the vertical orientation and allow the APAs to be lifted out of the frame.

- The APA shipping frame must be able to be rotated from horizontal to vertical using two independent cranes in the cavern.

- The frame will be stored in the main cavern in a vertical orientation attached to carts. It must be able to stable when stood on end and mounted to a rolling cart that brings the APA shipping frame into SAS and Cleanroom.

- Must be able to remove a single APA while the shipping frame is vertical in the cart and have the APA+cart remain stable.

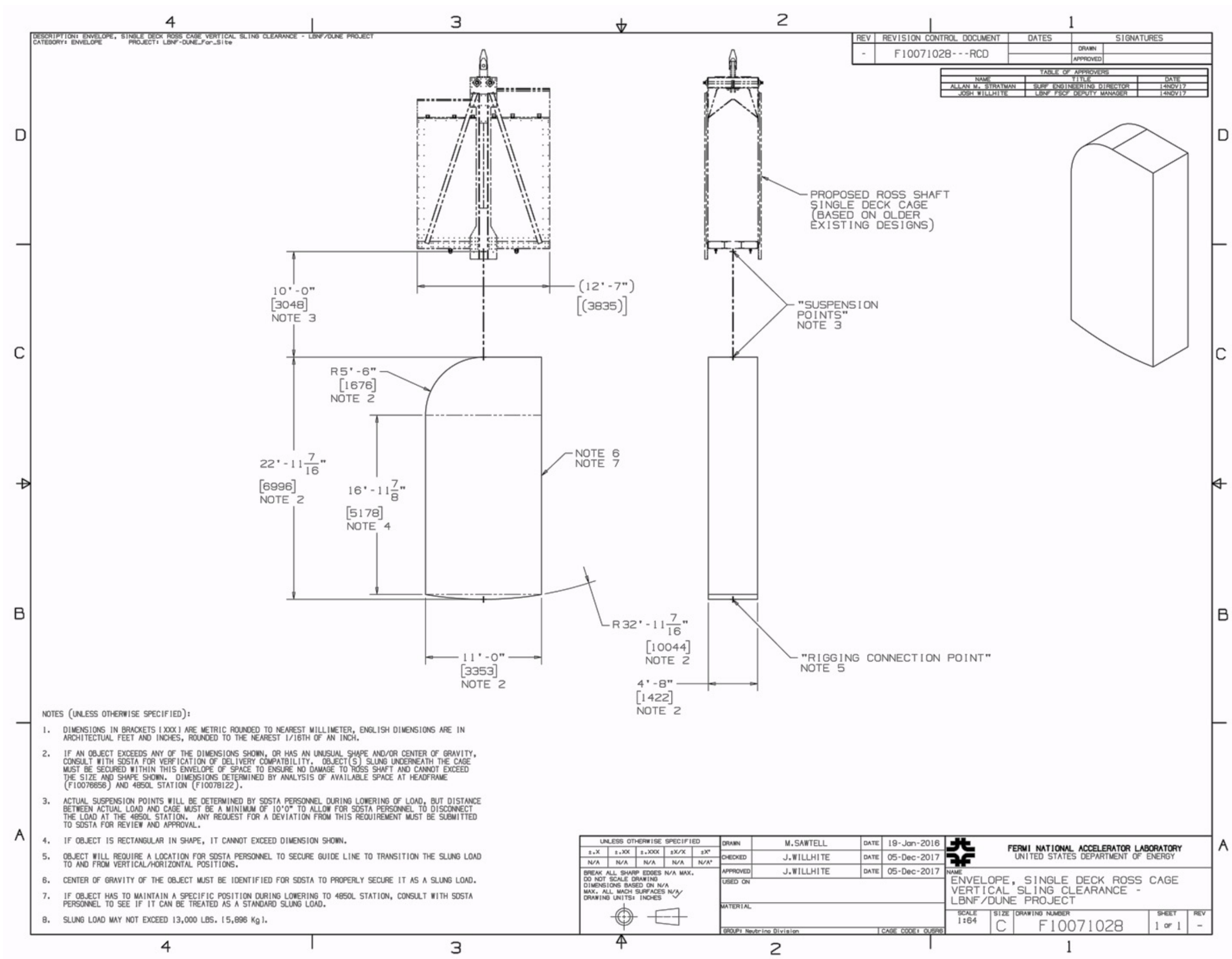

Figure 11 - Drawing F10071028 showing the maximum slung-load dimensions. (SDSD)

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[1] Crate drawing: https://edms.cern.ch/document/2157225/1

[3] The version of this used for the SBND APAs is described in the SBND-docdb-8886. https://sbn-docdb.fnal.gov/cgi-bin/private/ShowDocument?docid=8886

[4] A study by Jacob Nesbit and Dan Wenman (PSL) showed that above 4g the welds on the frames reach their available strength limit. This was presented at https://indico.fnal.gov/event/18815/contribution/10/material/slides/1.pdf

[5] Typical slung load procedures: https://indico.fnal.gov/event/18435/contribution/19

[7] Cage drawing: https://edms.cern.ch/document/2054597/1

[9] DocDB 4781-v13, "Drawings and Analysis of Vertical Slung Loads in the Ross Cage Shaft for SURF," Matt Sawtell (drawing F10071028).