Detector and Cassette Assembly Plan

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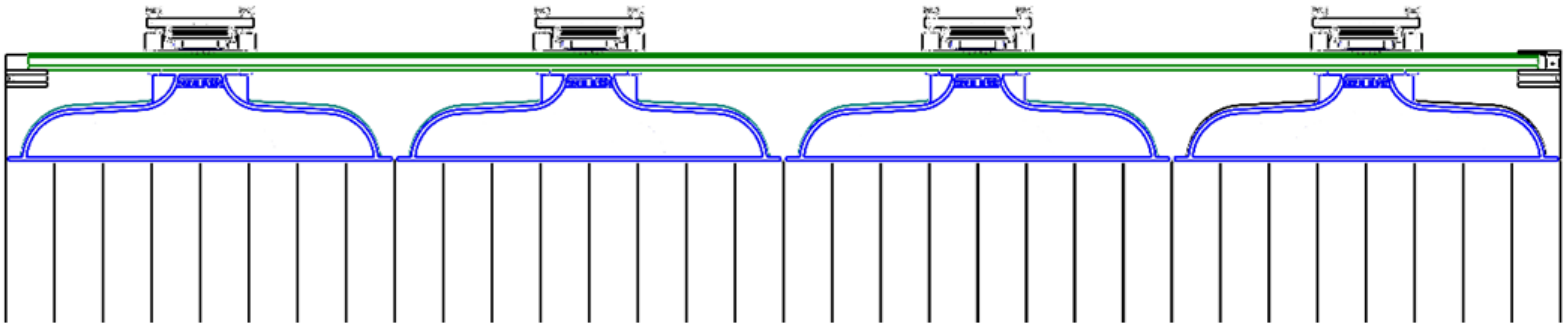
Module fabrication process

- The module fabrication process planning relied on the MINOS and Mu2e experience. Many of the pictures (not drawings) shown here are from those experiments.
- Each module is designed to house 32 extruded scintillator bars arranged within a light-tight aluminum case, and WLS fibers for efficient light collection.
- Each module is built out of 4 groups of 8 counters whose fibers go to a manifold and an optical connector. The scintillator bars within each module are encased in a light-tight aluminum light case.



Step 1. Prepare the scintillator bars

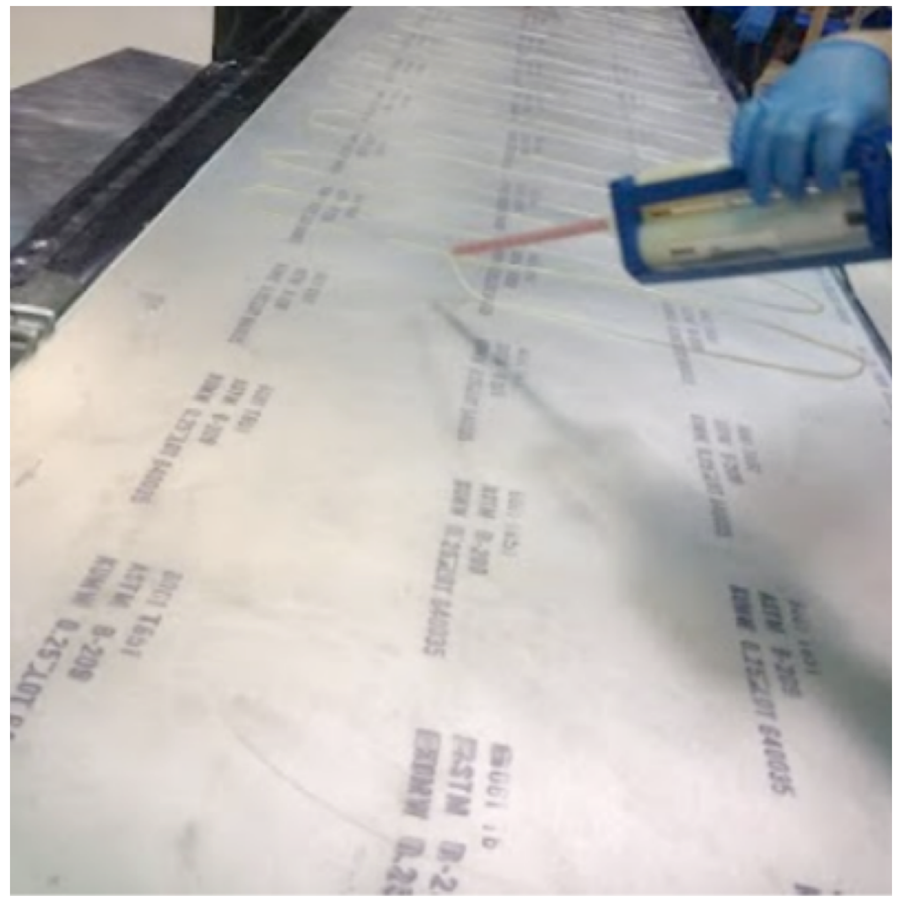
- Scintillators are inspected visually and dimensionally.
- A number of scintillators are loaded into a custom cut off rack.
- Scintillators are cut to the same length with a cut off saw.
- The fiber holes (one per scintillator bar) are then chamfered at each end using a center point drill.

Mu2e scintillator bars preparations

Step 2. Assemble Scintillator Bars on Bottom Light Case

- A **bottom aluminum light case is cut** to the required width, and flanges are formed to create a shallow enclosure for securing scintillator bars on a custom assembly table. The bars are placed before gluing when the flanges are formed to ensure proper sizing. A dummy cap is placed at the bottom for alignment.
  - Orientation and location is noted and then the scintillator bars are removed.
- Epoxy is spread on the plate. The 32 scintillator bars are arranged edge-to-edge within the bottom enclosure and bonded using epoxy.
- **The manifolds are added.** Alignment of the manifold with the holes in the scintillator bars is checked by threading from the manifold to the bars.
- Dead weights, clamps, and/or vacuum bonding apparatus are used to ensure even adhesion during curing.
- The assembly is bagged and placed under vacuum while epoxy sets. The assembly is left to **cure for 24 hours**.

MINOS bottom case cutting and flange forming

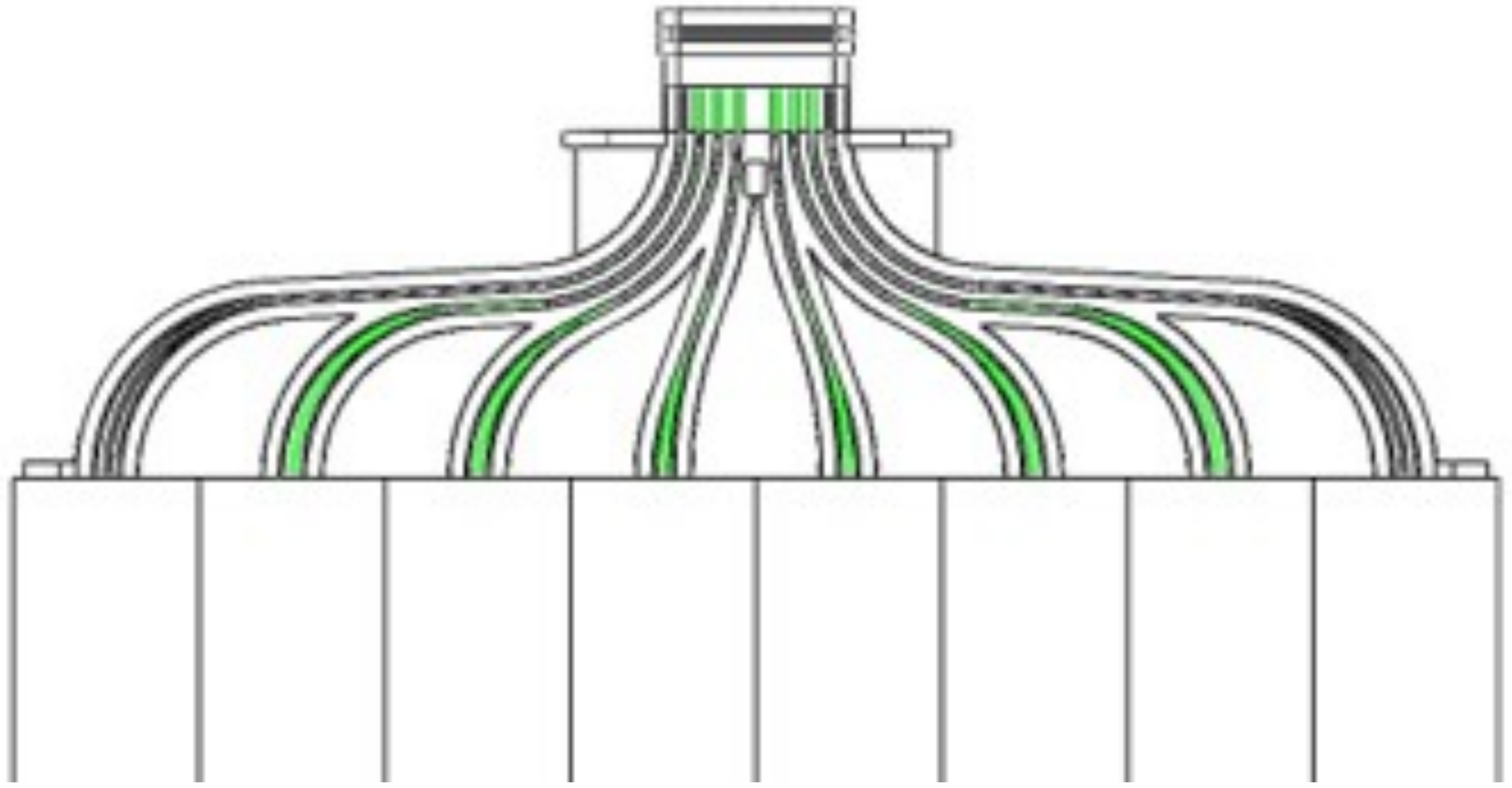


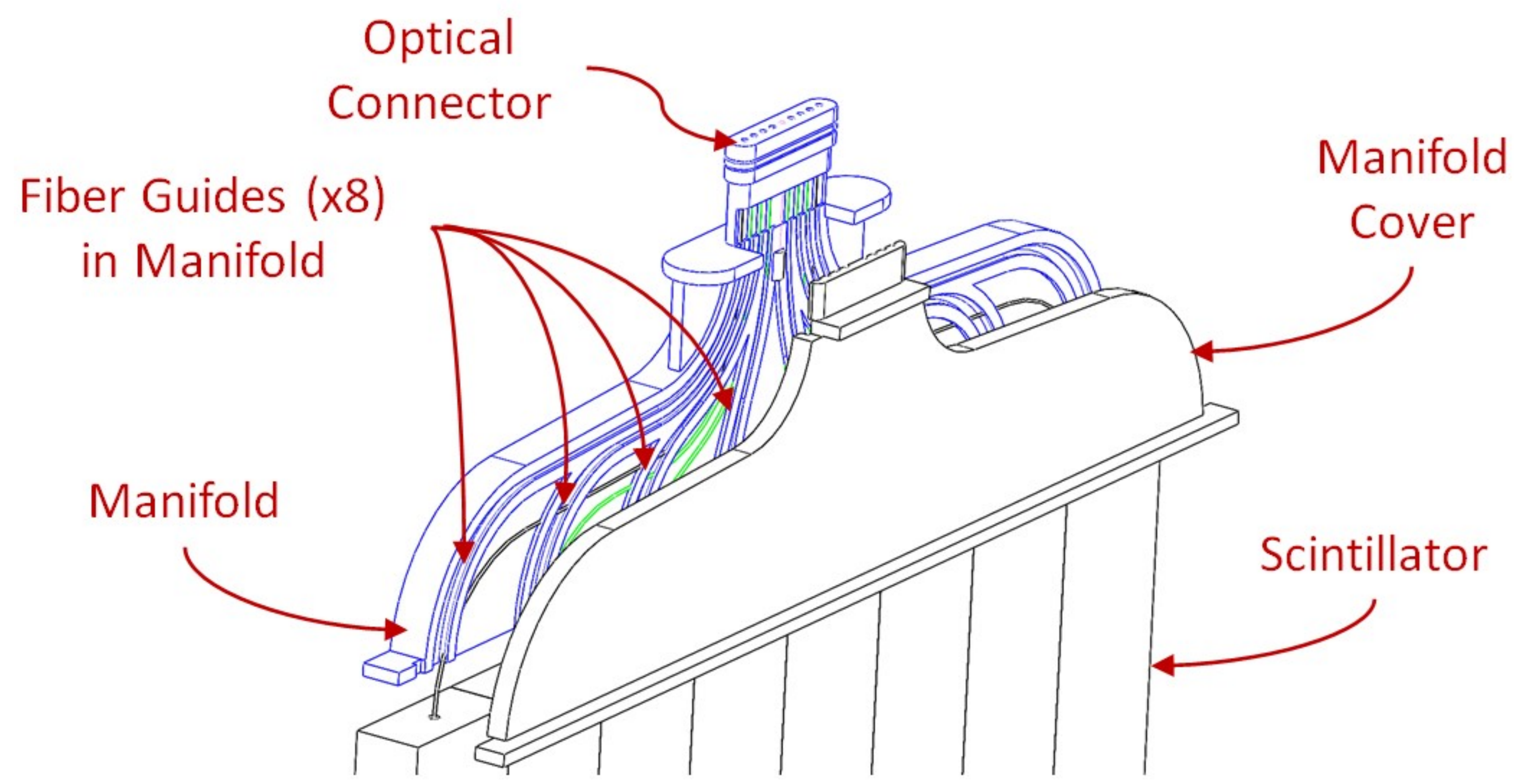
Mu2e applying epoxy to bottom case

MINOS bottom case vacuum bonding

Step 3. Fiber Installation and Potting

- Fibers are removed from the spool mounted to a fiber spool cart and are cut to length based on the module orientation.
- **WLS fibers are threaded** through the central holes of the scintillator bars and into the manifold and placing a transparent cover to ensure the fibers stay in the manifold. There are 4 such manifolds for each module.
- **Fibers are potted into the optical connector** using an epoxy compound to ensure stability and light-tightness.
- A temporary protective cover block over the end of the fibers is then installed.
- **Manifold covers are installed** (epoxied) to protect and secure the fibers during curing. The potting and manifold covers epoxy are allowed to cure in step 5.





Step 4. Intermediate Quality Control Test

- Before final assembly of a module a **fiber transmission test is performed**. This test could be performed using LED blocks from the bottom end of the fiber and checked on the connector side.

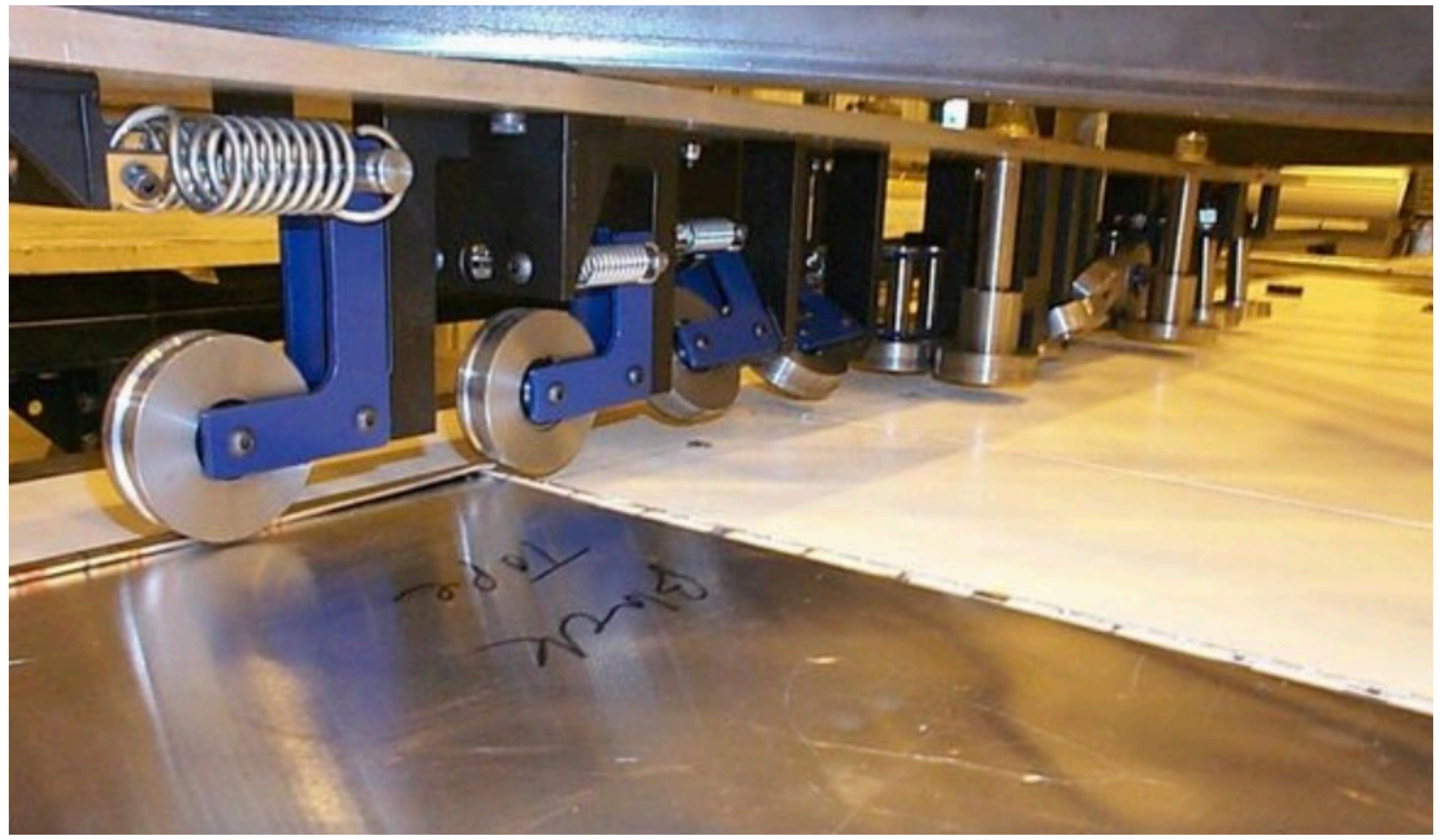
Step 5. Light Case Closure

- **Top light case is cut** to width and flanges are formed to match size of assembly.
- Adhesive is applied to the top scintillator bars and manifold cover, and the top aluminum light case is installed over the scintillator bars.
- The assembly is bagged and placed under vacuum while the epoxy sets. The assembly is left to **cure for 24 hours**.


MINOS upper light case installation

Step 6. Final Assembly and Light Tightening

- **The top and bottom light case flanges are crimped** together to form a labyrinth seal, ensuring light-tightness.
- **Top and bottom caps, snout seals, and variable-width seal caps** are installed to secure the assembly.
- Sealant is injected at designated ports along the edges and snout interfaces to eliminate potential light leaks.
- The assembly is moved to a storage rack and left to **cure for 24 hours**.


MINOS crimping in action


MINOS storage racks in the process of curing

Step 7. Flycut to Polish the Fiber Ends

- A hot knife is used to cut the fibers flush with the connector. The face of **the connector is flycut**.

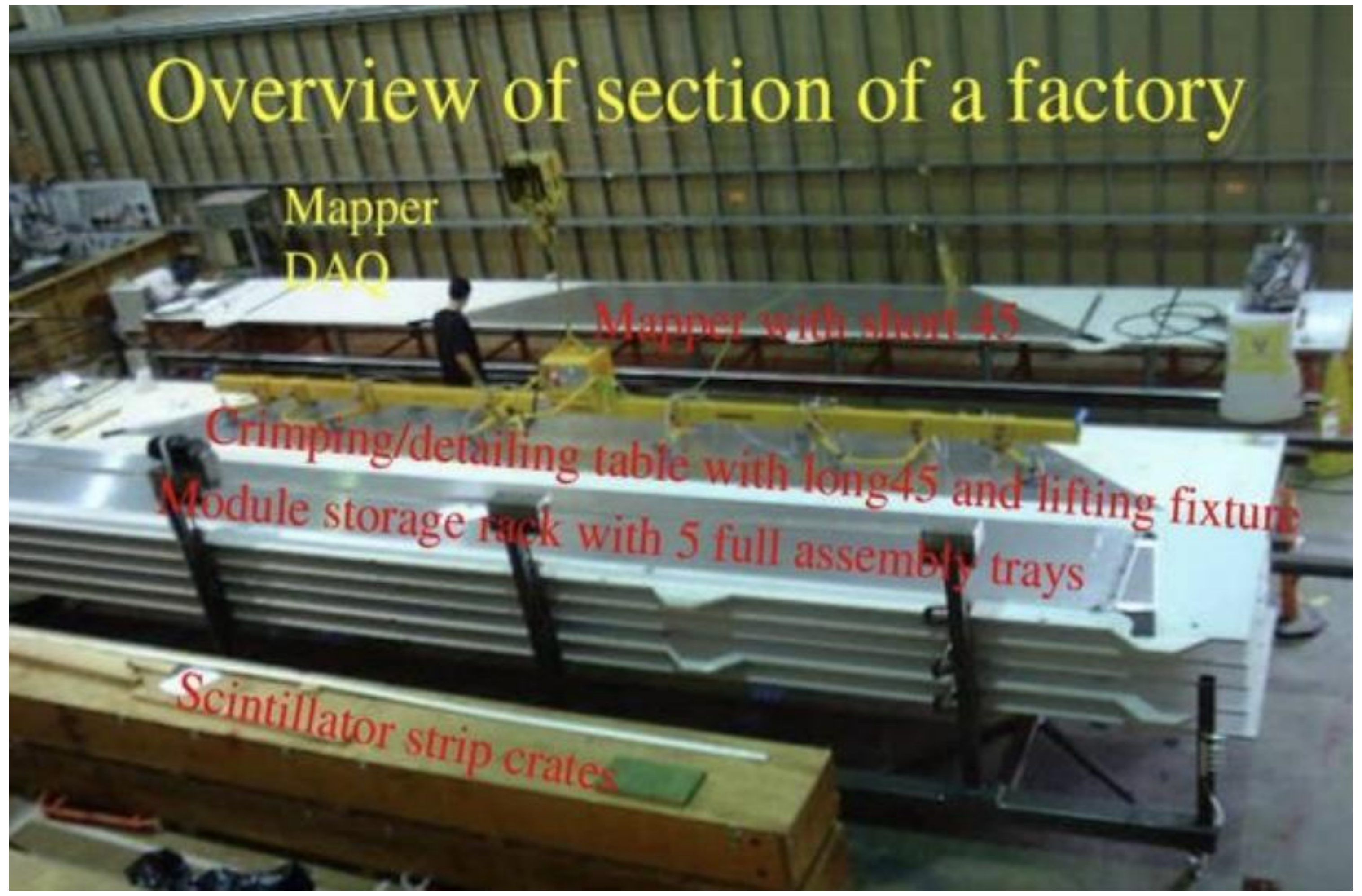
MINOS flycutting of fibers

Step 8. Final Quality Control Tests

- Measurements are made on each module to ensure that it meets dimensional tolerances, including straight angle corners and parallel sides.
- The completed module undergoes **quality assurance testing**, including functional tests with light injection to verify optical alignment and light-tight integrity.
- The response of each module to minimum ionizing particles will be studied using a cosmic ray test stand.

Module Production Timelines

- **Module production will occur at two primary fabrication sites**: the University of Minnesota (UMN) and Florida State University (FSU). Each site is expected to produce 300 modules, with the entire production timeline estimated under 24 months.
  - Previous estimates that included time-motion studies for a previous version of the design estimated 22 months.
- **Each module requires approximately 72 hours for complete curing**, with up to six modules assembled simultaneously per site.



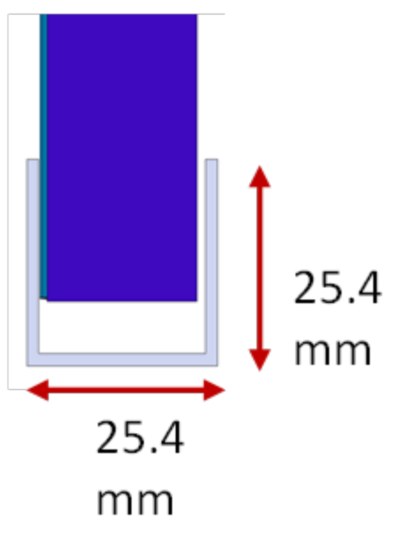
UMN MINOS module factory

Facilities and Shipping

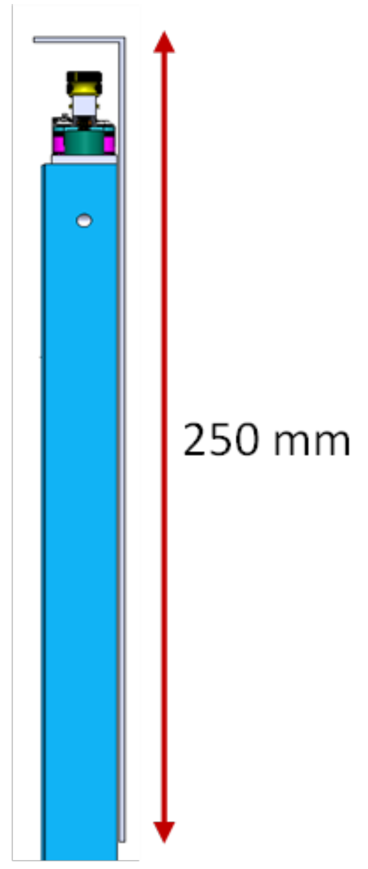
- Each module assembly station occupies approximately 5 m x 3.2 m, with space allocated for storage and quality assurance. Building six modules simultaneously requires a total space of approximately 96 square meters which would be reduced if storage racks would be used for curing.
  - At the University of Minnesota, space has been secured for a factory in the Physics and Nanotechnology building. The same labs were used previously for construction of the straw tube tracker for mu2e, and will meet the space requirements for such a factory. At Florida State University, suitable spaces are being identified.
- Completed modules are packed securely for transport to Fermilab, where they will be assembled into cassettes. The modules will be stored and shipped flat in crates. Modules will be removed from the crates via vacuum lifter. Modules are strong and stiff enough to be raised from a horizontal to vertical position without additional stiffening.

Cassette Assembly and Transportation

- Due to their size, cassettes will be constructed at Fermilab, reducing the risk and logistical challenges of transporting such large objects.
- As the cassette construction requires periods of waiting while epoxy cures, the plan is to have multiple cassettes being built and tested in parallel.
  - This requires space to construct at least three cassettes at the same time.
- Each cassette requires six modules, which will be moved to a construction table using a vacuum lifter.
- The exact process will depend on whether the cassette will be a U/V layer or a Y layer.
  - In particular, for the Y cassettes, the construction process is slightly different, as there are no wedge spacers needed, no top assembly needed and the module relative orientation is different. I will describe the U/V layer as it is the more complex one.

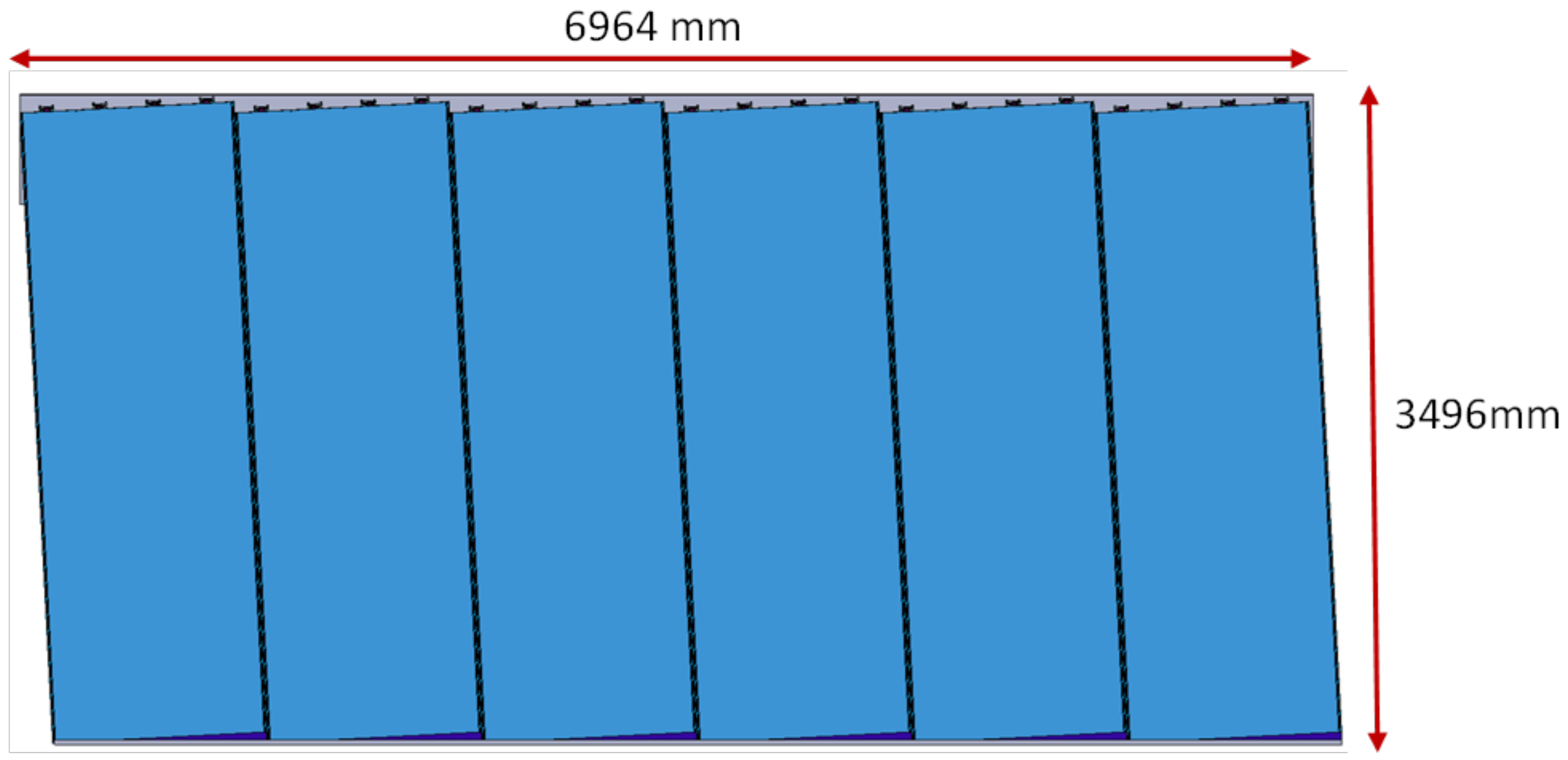


Bottom U-Channel



Top L-Bracket

3° Wedge



Assembled Cassette

Might need to be replaced

Step 1. Build top assemblies with cable storage

- Cable arms are attached to L-bracket with bolts and epoxy, and clamped in place.
- Assembly is left to cure overnight.
- Cables are carefully formed into a bundle with the correct lengths available at each end.
- Bundled cables are laid in cable arm, and attached with zipties.
- Top assemblies can be stored in a rack until needed for a cassette.

Step 2: Install wedges

- Epoxy is applied along bottom edge of a module, and a 3-degree wedge is held firmly against it with clamps.
- The module is left to cure overnight.

Step 3: Attach modules together

- Six modules are laid on an assembly table and the bottom edges of all wedges are aligned against a straight edge.
- Shims are added as needed to ensure the module edges are aligned with one another.
- Epoxy is applied in between all module edges, and rigid bars are placed on top to ensure modules remain `in plane’.
- A narrow air bag is placed along one edge, and inflated to provide compression for the epoxy.
- The assembly is left to cure overnight.

Step 4: Install top and bottom channels

- Epoxy is applied inside the lower U-channel, which is then fitted over the bottom edge of all modules.
- The channel is clamped in place.
- A top assembly is installed along the top edge, and clamped in place for epoxy to set.
- The cassette is left to cure overnight.

Step 5: Form ground connections and QA/QC

- Copper tape is placed along the full width of a cassette at the top and bottom to form a good electrical connection and ensure light cases are grounded.
- Protective covers are removed from optical connectors, and the mating connectors are installed.
- Cables are connected to mating connectors.
- A mobile QA/QC cart will be brought to the cassette table, to test modules in groups of two (one test per cable bundle).
- Dimensional measurements are made.

Cassette construction timeline and space req

- For U/V cassettes, the six-module assembly requires two 24-hour cure times, with additional curing time for the wedges and for the L-brackets. The latter two can occur in parallel and do not require a full 7 m x 3 m assembly table.
- For a Y-cassette, the six-module assembly also requires two 24-hour cure times, with no steps occurring before or in parallel.
- Each cassette construction table will be designed to function as part of a transportation frame (or more likely, the top surface of a construction table will form part of a transportation frame).
- After a cassette is built and tested, the rest of the transportation frame will be attached, so the cassette can be rotated into the orientation it will be inserted into the detector.
- Cassettes then remain in this vertical orientation through to final detector installation, at which point the transportation frame will be returned to the facility to be re-used.
- This means each construction station needs two or three of these fixtures (depending on how many need to be stored between assembly and installation), so another cassette can be constructed while one is installed.

Cassette Installation

- Cassettes will be brought underground in their transportation frames, which will in turn be held against the side of the steel and lined up with the steel gaps.
- A small winch will be placed on the opposite side of the relevant gap, approximately half way between the coils.
- The winch will allow a cable to be run along the support rail, such that it can be attached to a small metal ring on the cassette side.
- The winch will then pull the cable, pulling the cassette along the rail.
- Due to the winch being placed higher than the cassette attachment, some vertical force will be taken up by the winch cable, reducing the probability of sticking or snagging on the rail.
- Once the cassette is in place, a ground connection will be formed between it and the support structure, and clamps will be placed to prevent any lateral motion.

Would be nice to have drawing

Charge questions related to this talk