Fermilab

Mu2e Cosmic Ray Veto: 8.7: CRV Module Fabrication

Craig Group
L3 Manager and CAM for CRV Fabrication
10/21/2014

CRV Fabrication Team

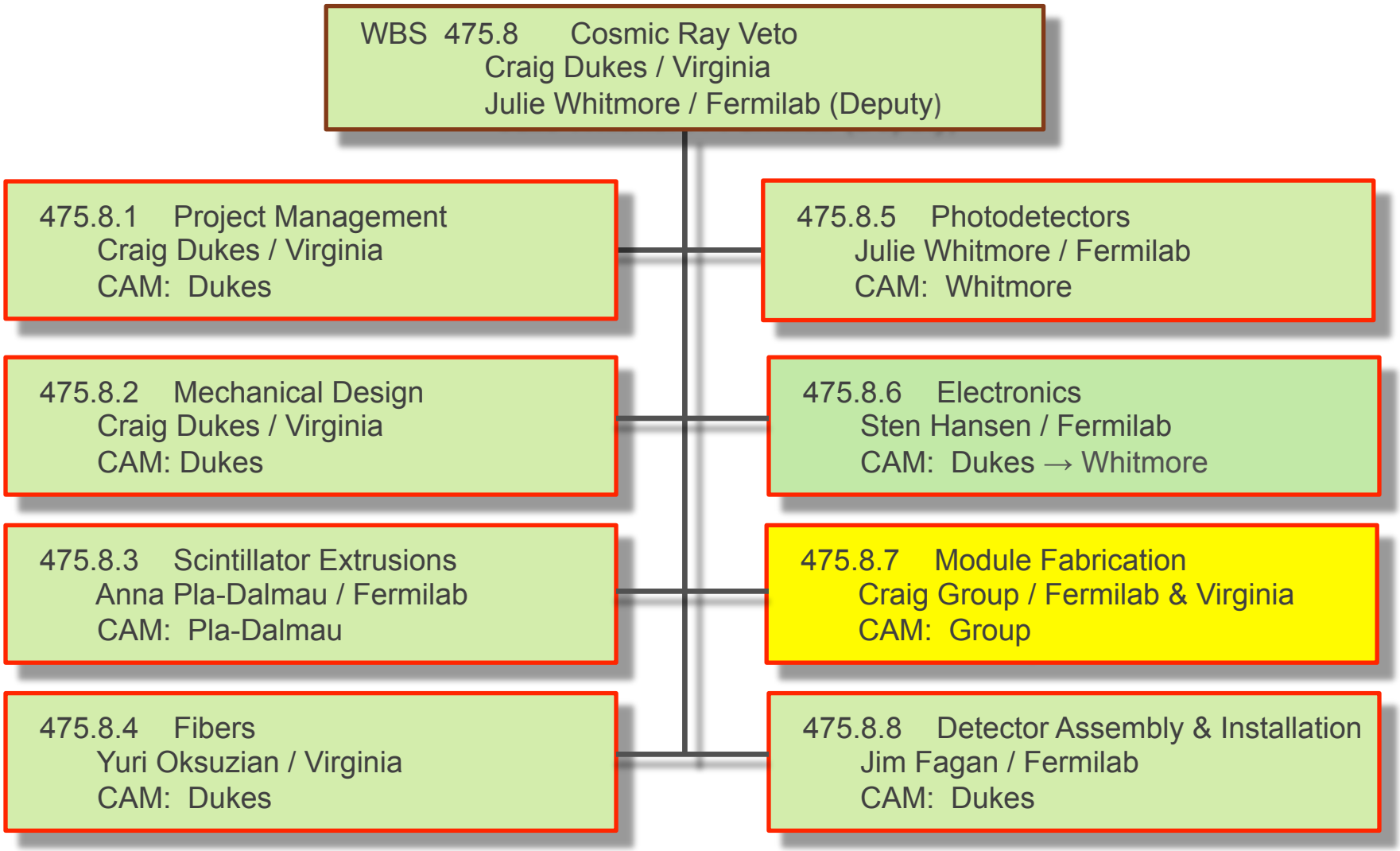
- Craig Group – CAM and L3 Manager
  - Joint UVA faculty and Fermilab scientist position.
  - Ph.D. in 2006 – U. Florida on CDF
  - Also on NOvA experiment
  - Involved in CRV R&D since 2009

- Richard Bomgardner– Lead Technician
  - B.S. Physics
  - Several years experience as each: electrician, scientist, and machinist.

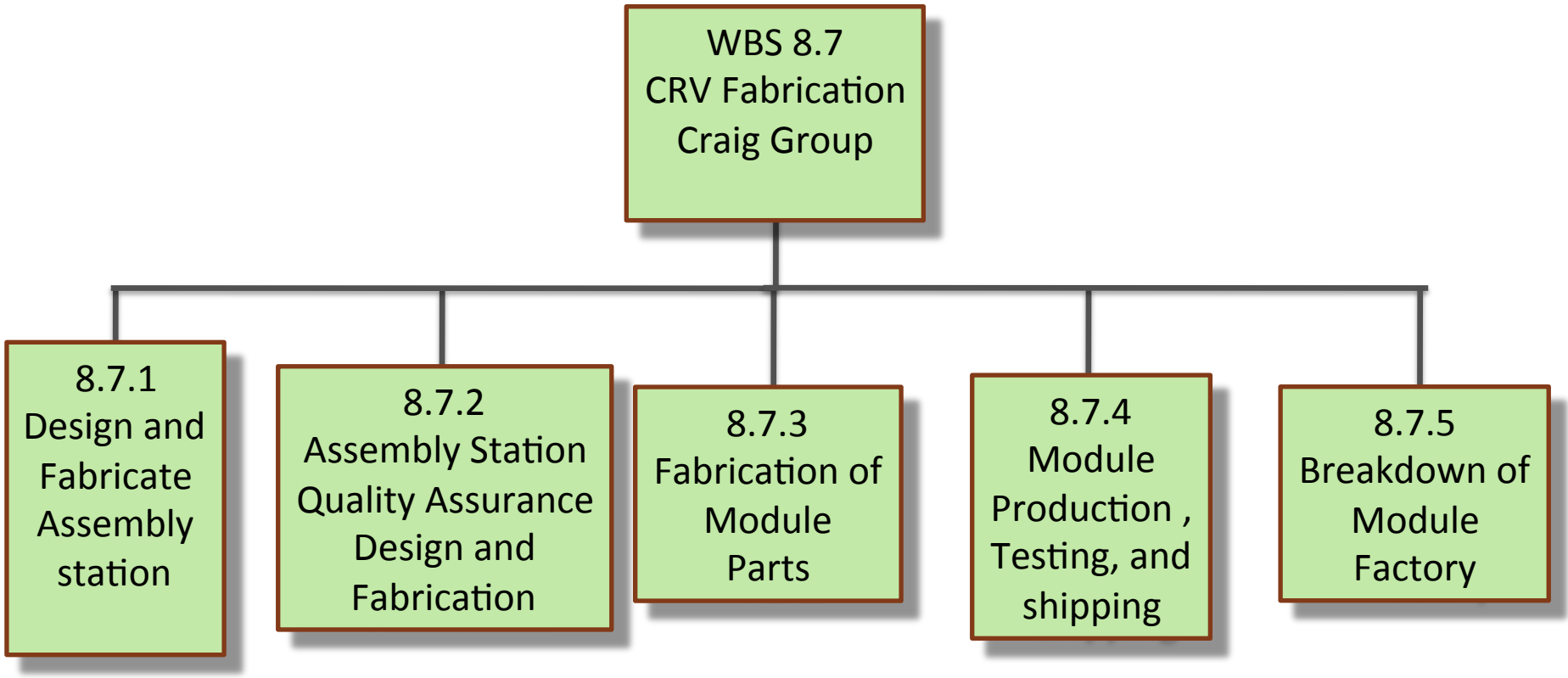
Outline

- Organizational Breakdown
- Overview of Module Production Factory
- Quality Assurance
- ES&H
- Schedule and Remaining Work Before CD3
- Cost Table
- Cost Breakdown
- Quality of Estimate
- Labor Resources by Fiscal Year
- Schedule

Organization



Organizational Breakdown



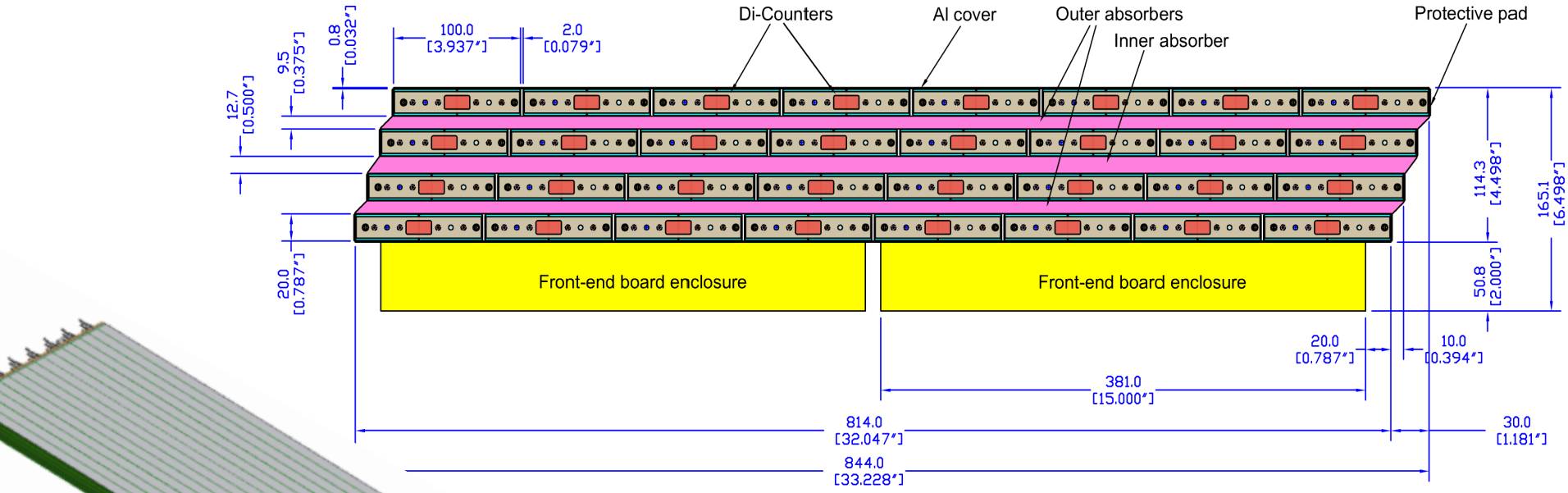
WBS Dictionary for 8.7

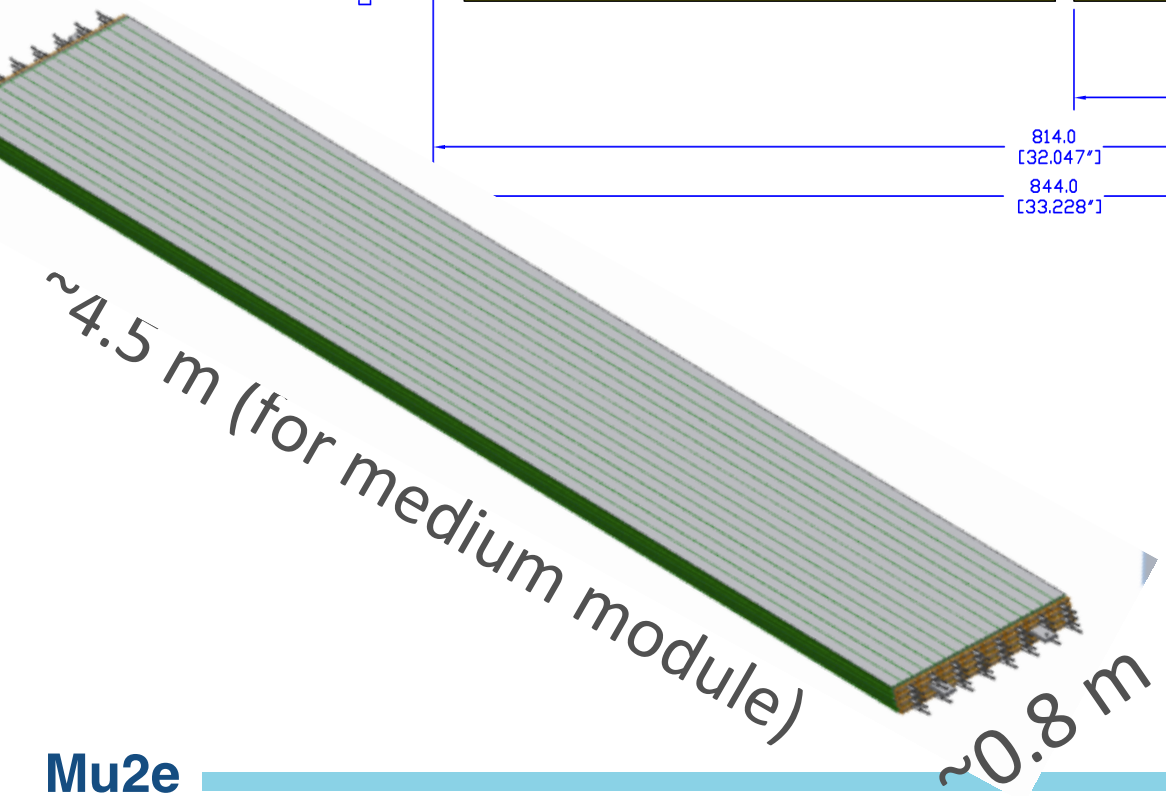
- **475.08.07.01 Design and Fabricate Assembly Station**: This set of activities cover the design and fabrication of the equipment needed to fabricate the counters and modules.
- **475.08.07.02 Assembly Station Quality Assurance Design and Fabrication**: This set of activities cover the design and fabrication of the quality assurance jigs needed to test the counters and modules during and after assembly.
- **475.08.07.03 Fabrication of Module Parts**: This task covers the fabrication of the all the parts needed for the assembly of the counters and the modules, save the extrusions, fibers, photodetectors, and electronics.
- **475.08.07.04 Module Production, Testing, and Shipping**: This task covers all aspects of the counter and module assembly, testing, and shipping. It includes non-working mechanical prototype modules, pre-production modules, and production modules.
- **475.08.07.05 Breakdown of Module Factory:** This task covers the decommissioning of the module fabrication factory.

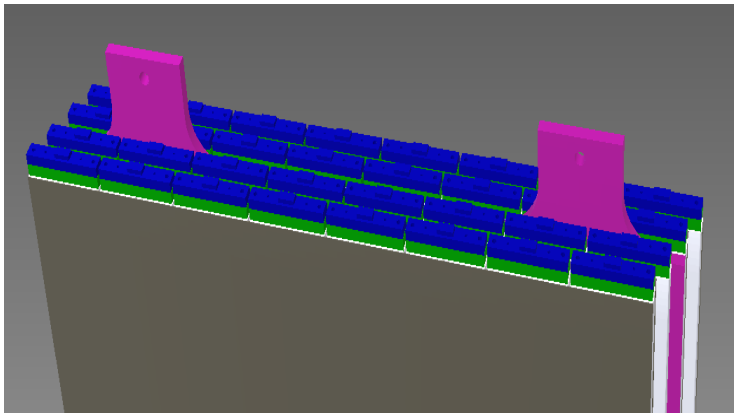
CRV Fabrication Overview

- Fabrication: assemble scintillator extrusions, wavelength-shifting fibers, and photodetectors into working modules.
- QA at each assembly step – large component of labor effort.
- 82 modules of 7 different sizes, as well as 9 spare modules.
- Scintillator lengths range from 0.9 m for the cyro modules to 6.6 m for the extra-long modules.
- Module widths for 16 (8) counters for normal (narrow) width modules is ~80 cm (40 cm).
- The “extra long” modules weigh about 2000 lbs

Reminder: Basic CRV Module







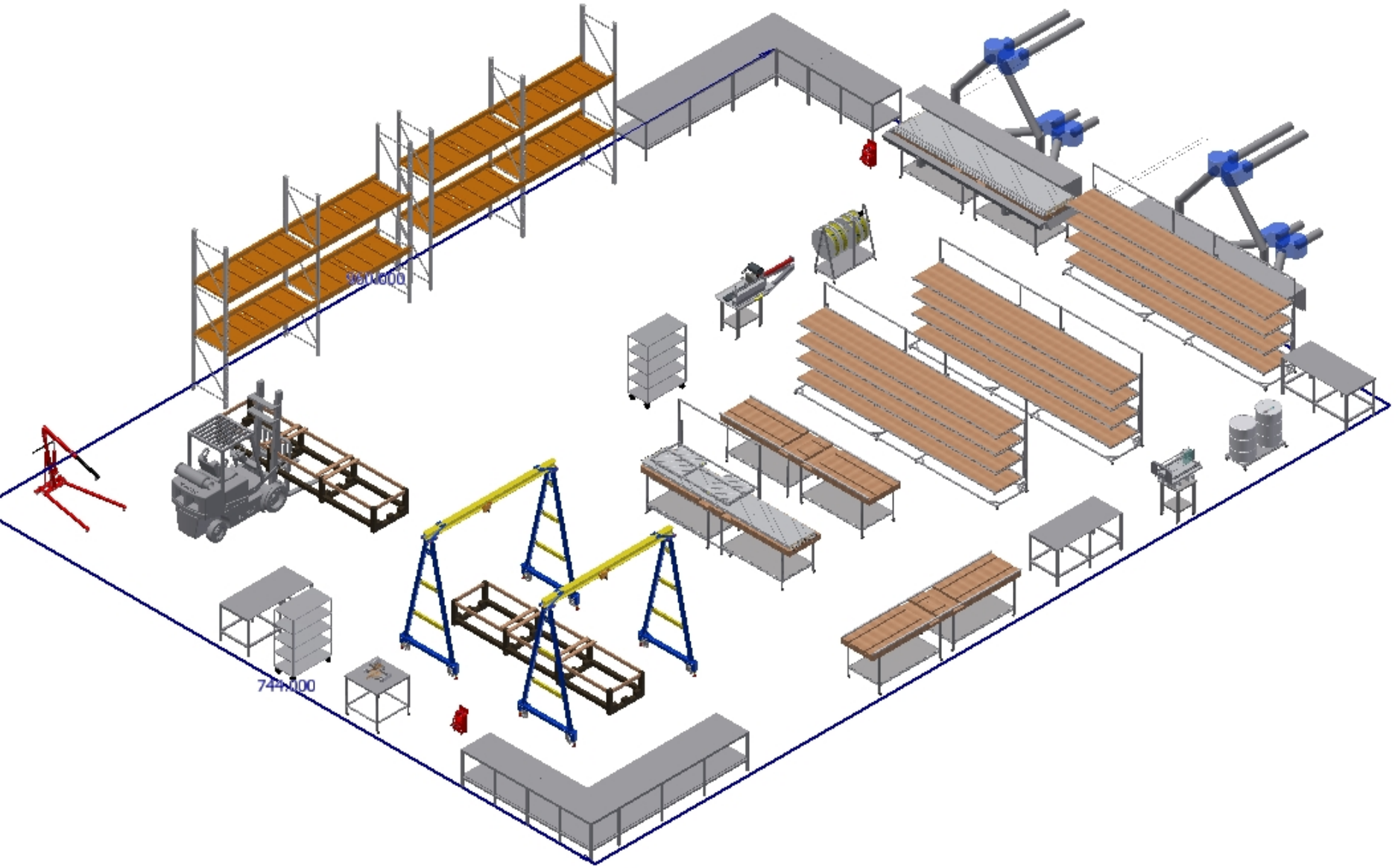
Overview (continued)

- Factory space will be rented near UVA.
- Materials shipped to UVA factory.
- Di-counters assembled with fiber, manifolds and SiPMs. Di-counter QA performed.
- Modules assembled from di-counters, epoxy, and aluminum sheets. Module QA performed.
- Modules crated and shipped to Fermilab.
- During peak production factory will be capable of producing 6 modules per month.

Note: we have a “pilot” production phase for the first 10% of the production modules in which we estimate that fabrication will proceed at 50% of the peak rate.

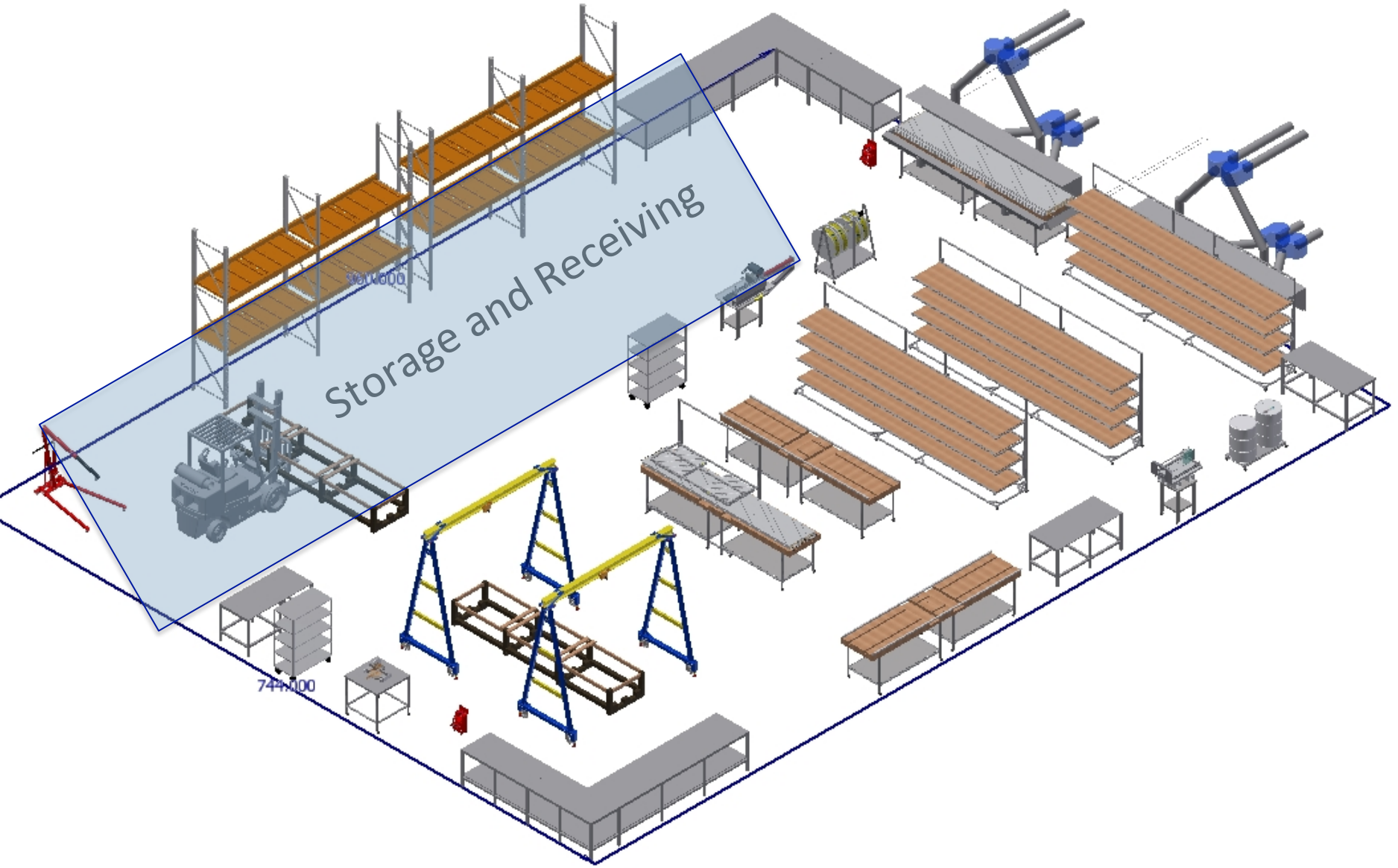
Module Factory

5000 ft^2



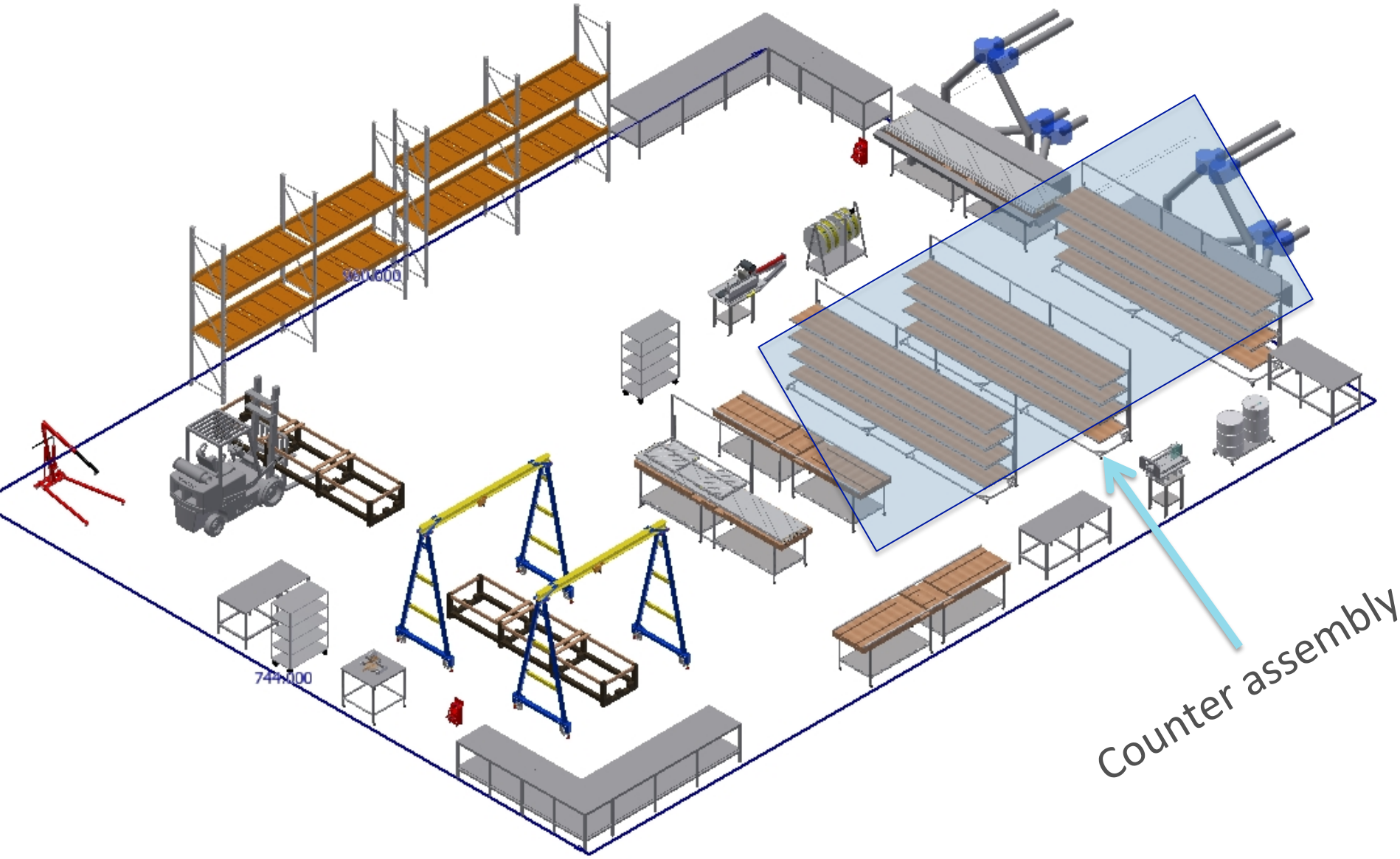
Module Factory

5000 ft^2



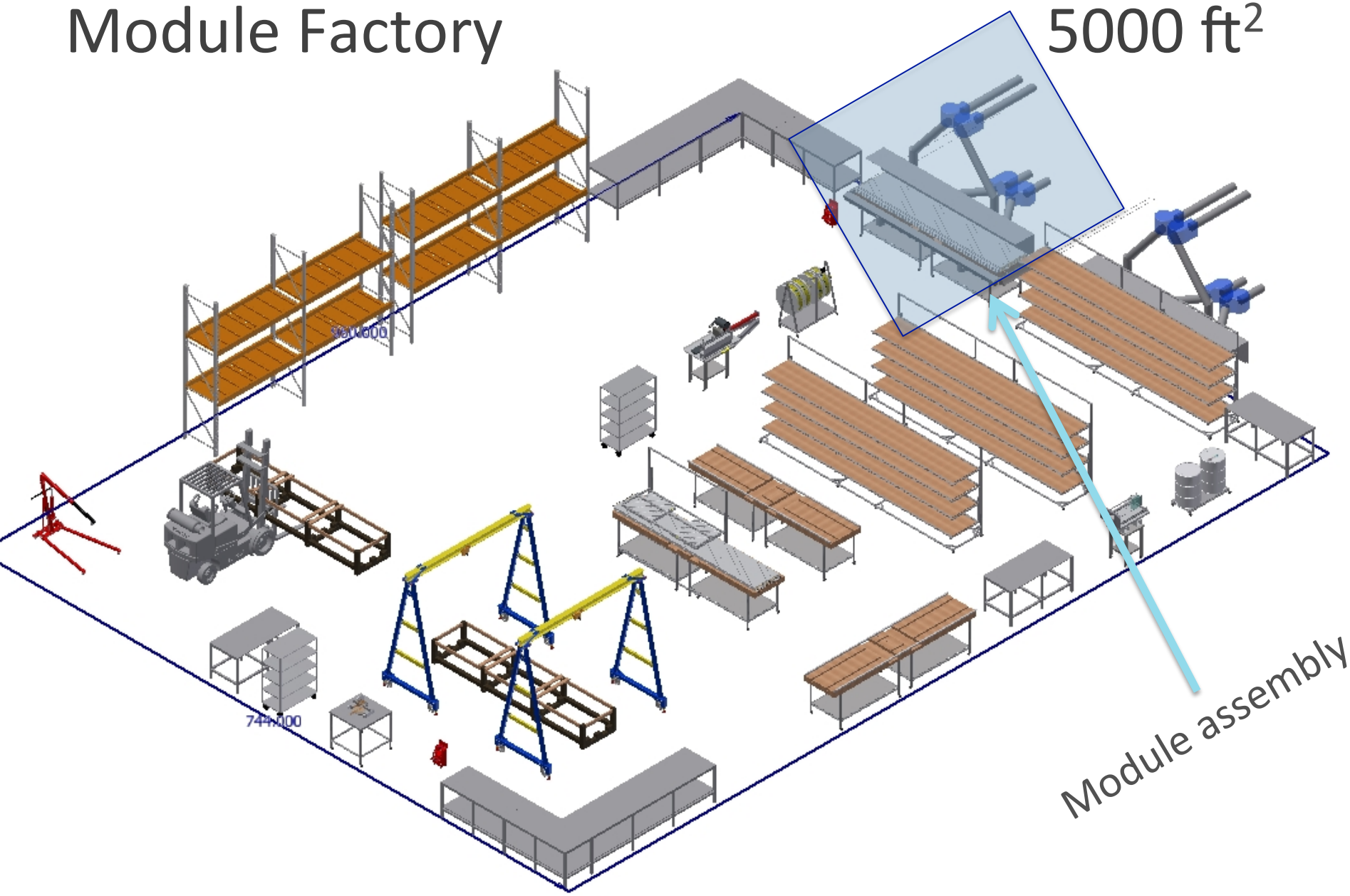
Module Factory

5000 ft^2



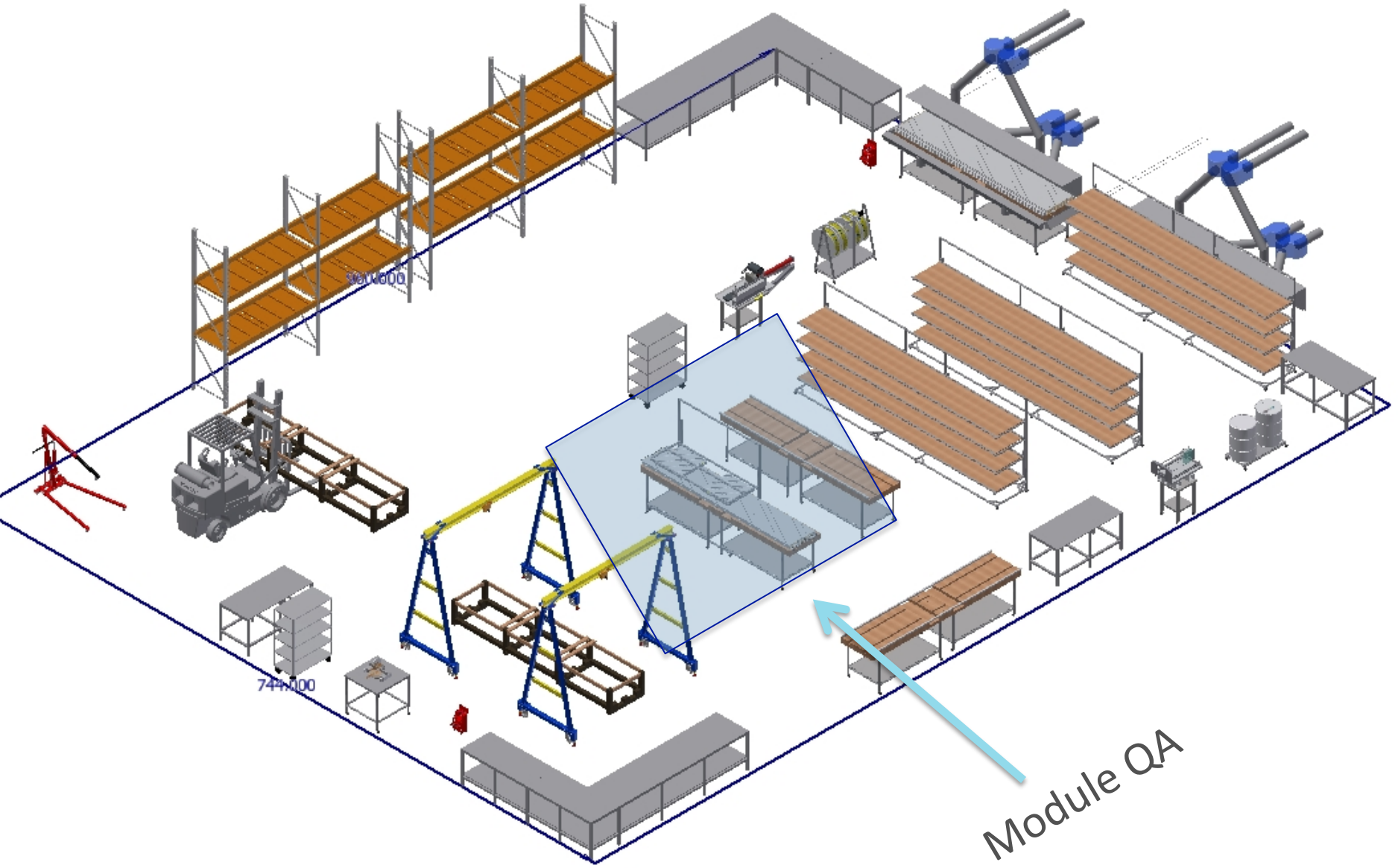
Module Factory

5000 ft^2



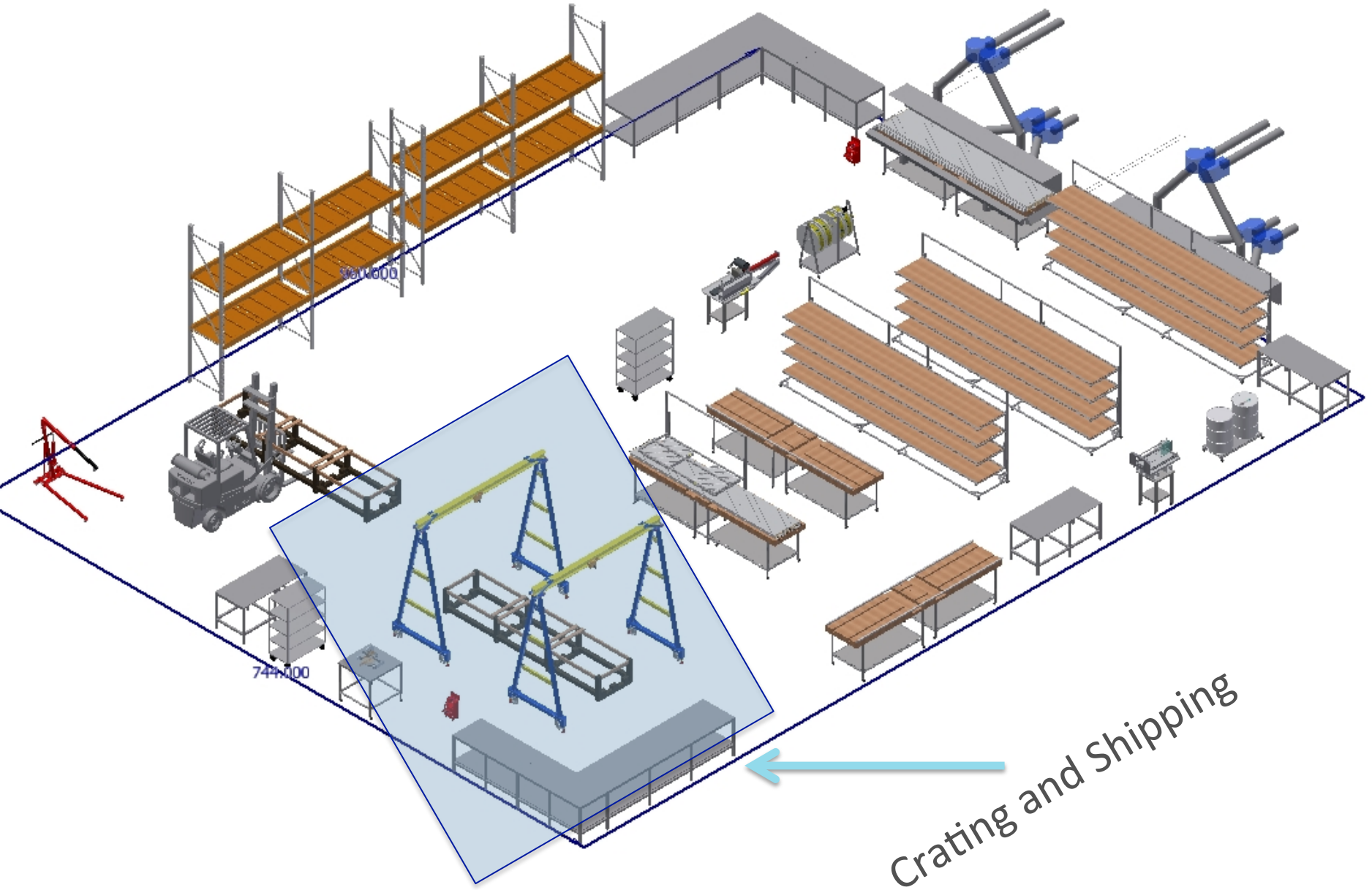
Module Factory

5000 ft^2



Module Factory

5000 ft^2



Required Space

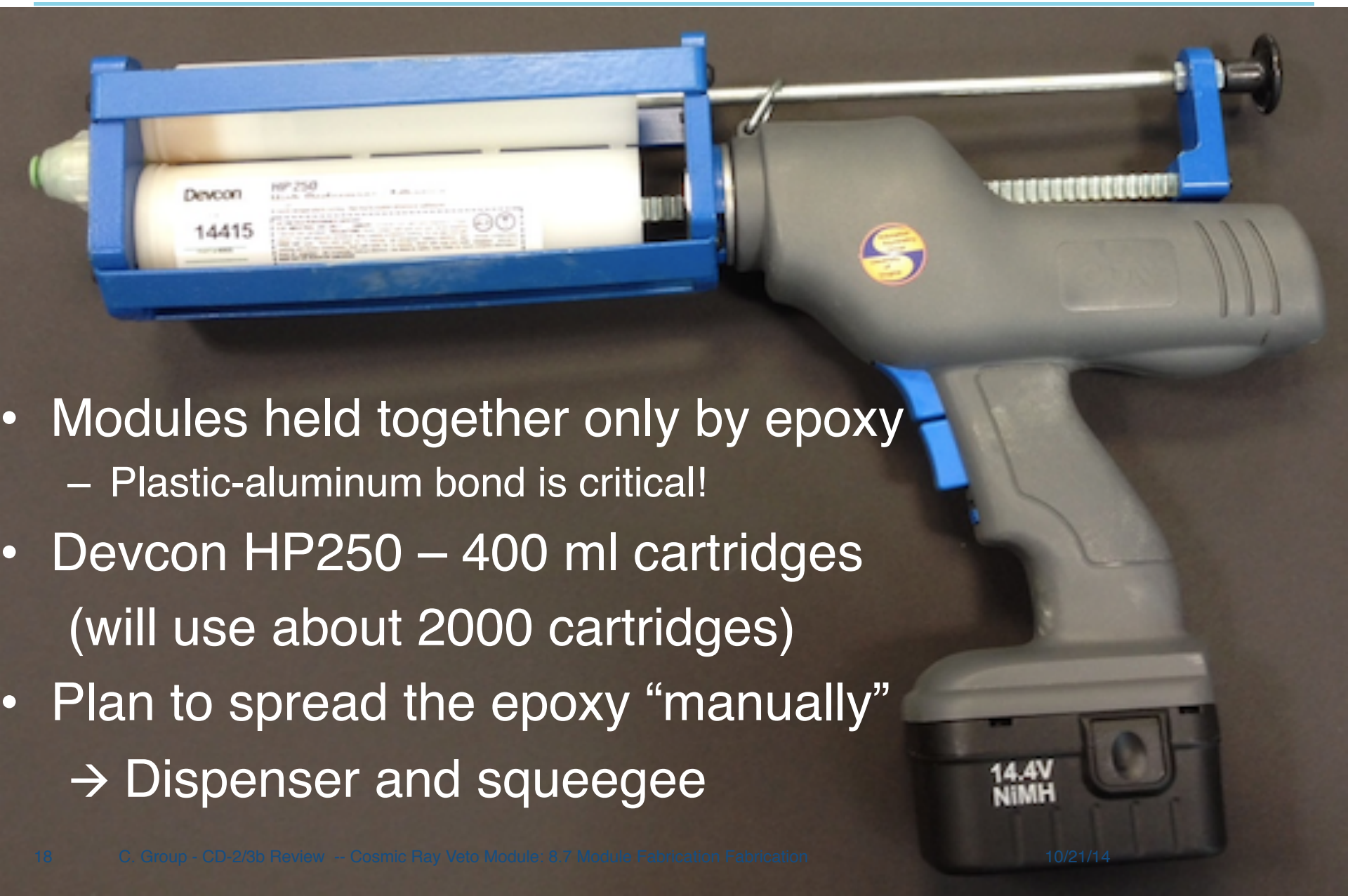
Required space	
Storage/receiving	1500 ft^2
Counter assembly/QA	900 ft^2
Module assembly	400 ft^2
Module QA test stand	400 ft^2
Crating/shipping	1000 ft^2
Total production space	4200 ft^2
Target space	5000 ft^2

Ideally, we would have 5000 square feet of space in the module factory.
(Less space would be possible, but would stretch the fabrication timeline)

Factory Notes

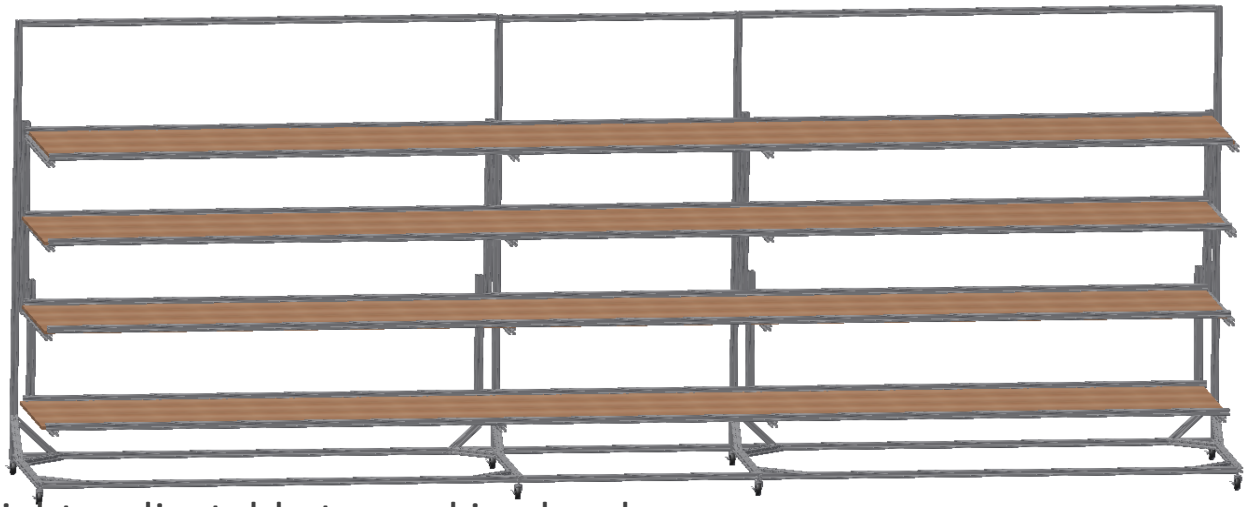
- Plan is to rent industrial space. ~$1/ft^2/month
- Discussion ongoing at UVA to find space on campus.
  - May provide an opportunity to reduce cost.
  - Finding space at UVA is an opportunity and listed in the risk registry.
- All major components will be on locking casters to maximize flexibility of available space.
- Counter Assembly Tables and Module Assembly Tables will be moved to vent hoods for epoxy application steps.

Epoxy



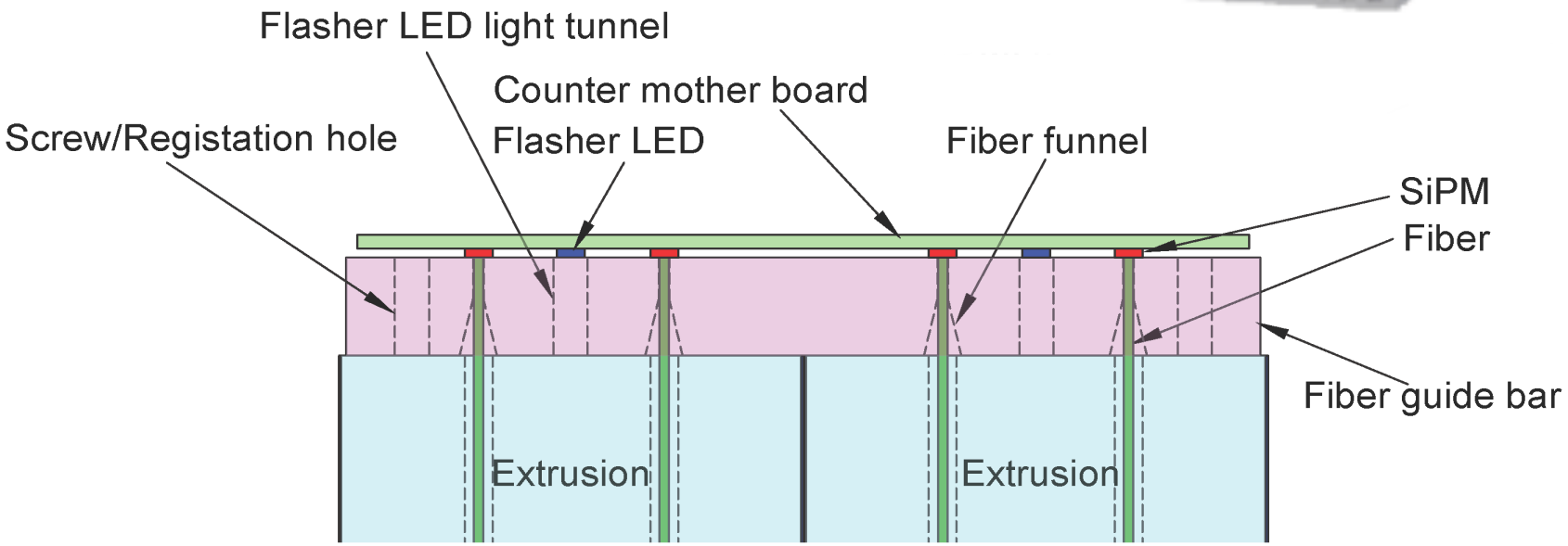
- Modules held together only by epoxy
  - Plastic-aluminum bond is critical!
- Devcon HP250 – 400 ml cartridges
  (will use about 2000 cartridges)
- Plan to spread the epoxy “manually”
  → Dispenser and squeegee

Counter Assembly Table



- Shelf heights adjustable to working level.
- One shelf to assemble di-counters for each module layer
  - Epoxy di-counter pairs (overnight cure required)
  - Di-counter pairs cut to length with chop saw
  - Install fiber
  - Epoxy fiber guide bar (3 day cure required for FGB)
  - Fly cut FGB with fibers (one 0.015" trim cut and one 0.004" polish cut)
  - Fiber QA to test cut/polish (details in QA section)
    - Digital photo with 80x microscope
    - Fiber light transmission tester
  - Bar-counter interface will be painted using black latex-enamel paint.

Di-counter Assembly



Chop Saw and Fly Cutter

To be modified with cross-slide stage for 36” travel so that full module layer can be cut at once.

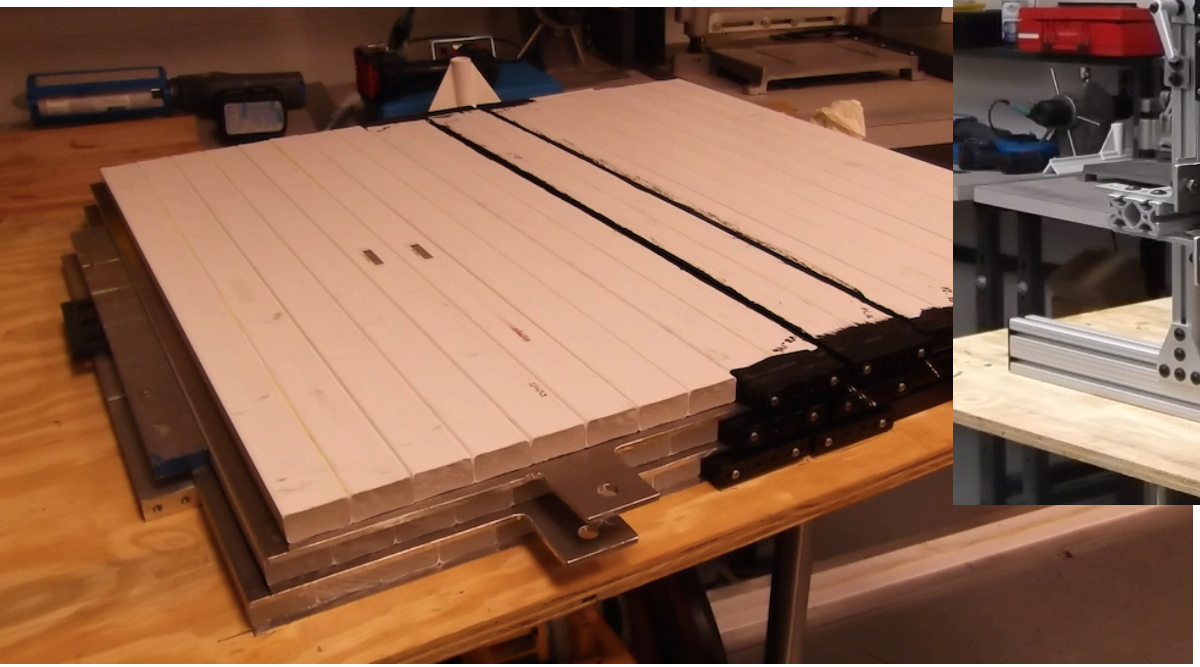
Module Assembly Table

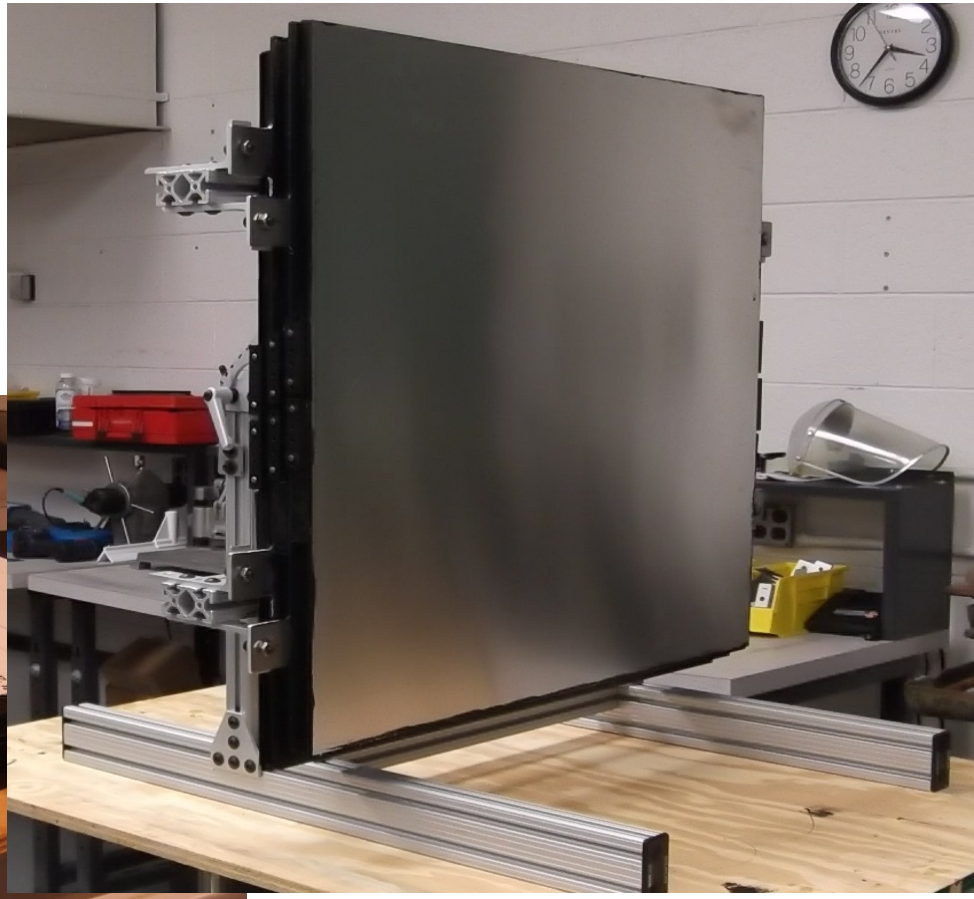
Simple table for module assembly
-- Base: two heavy-duty machine tables with locking casters
-- 80/20 frame attaching the two tables
-- 2"x6" lumber frame and ¾” plywood top
--The table has guides (module glue jig) to locate the counter pairs onto the aluminum absorber plates and to offset counter layers 10 mm from each other
-- Vacuum lifter (with crane or gantry hoist) required for handling aluminum sheets and completed modules

Module Assembly Steps

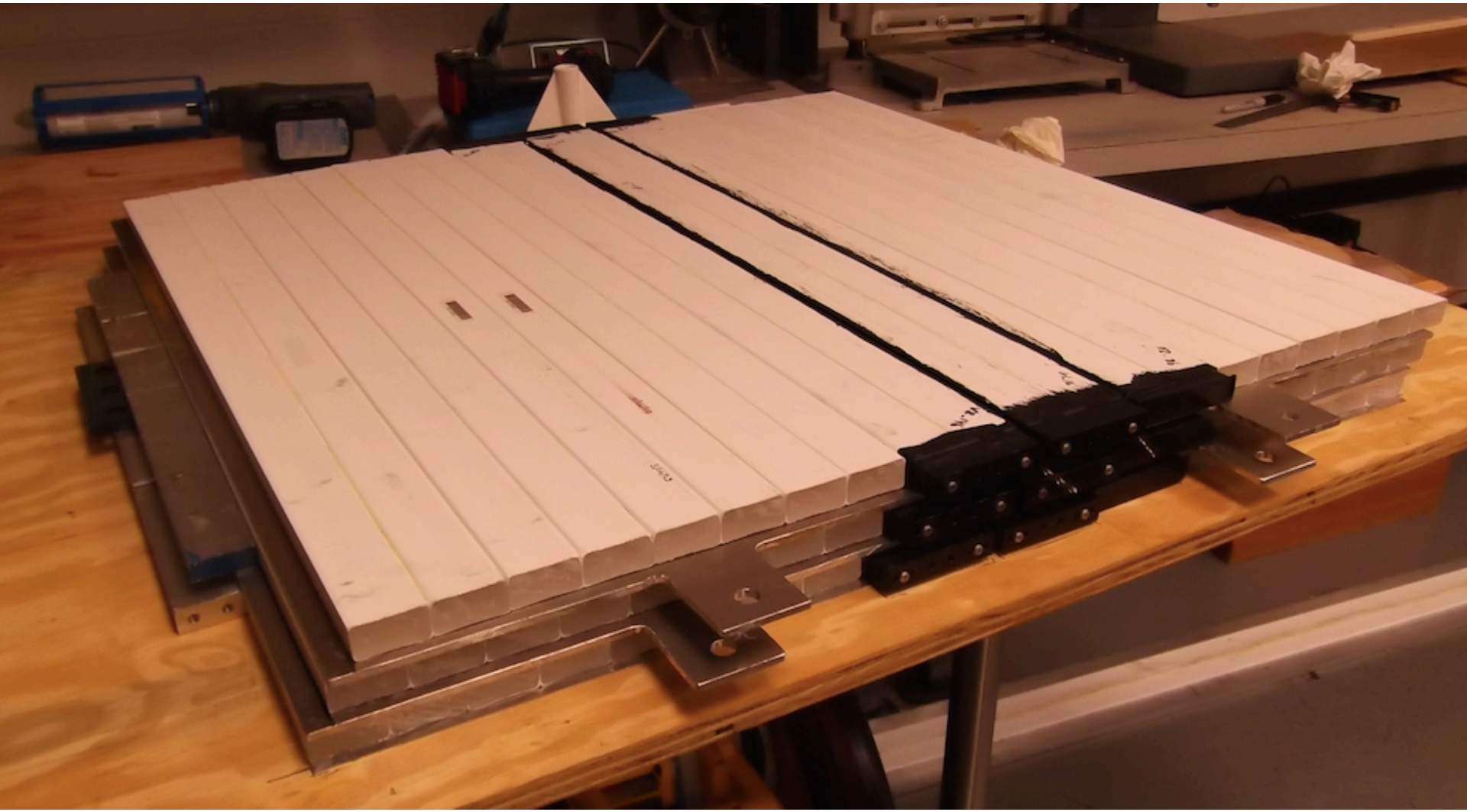
- Aluminum cover (0.032"-thick) placed on table and epoxy spread to a uniform ~0.010" thickness (or 0.005” on each interface).
- Di counters are placed and spaced carefully so that edge counters are aligned with aluminum edges (8 di counters for normal-width module)
- Epoxy spread to a uniform ~0.005" thickness on di-counter layer
- AL absorber (0.250"-thick) placed onto the wet di-counter layer and positioned using the module glue jig.
- Repeat previous steps to build up 4 layers.
- Aluminum cover (0.032"-thick) is placed onto the wet di-counter layer and positioned with using the module glue jig.
- A plywood weight is placed on top to provide light contact pressure while curing (3 day cure required).

Test Beam Prototype Assembly





Test Beam Prototype Assembly

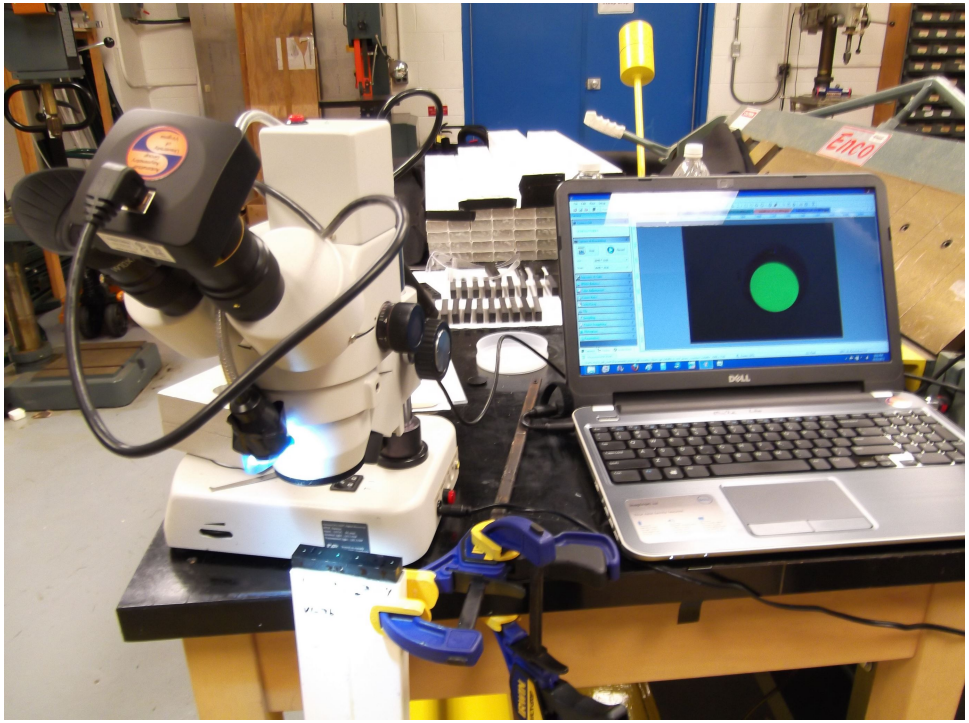


QA at the Fabrication Factory

- Counters:
  - →Digital photo with 80x microscope
  - →Fiber light transmission tester
- Modules:
  - →PE yield measurement with CSC cosmic ray test stand
- QA checklist in QAP (DocDB 4165 – attachment 3)

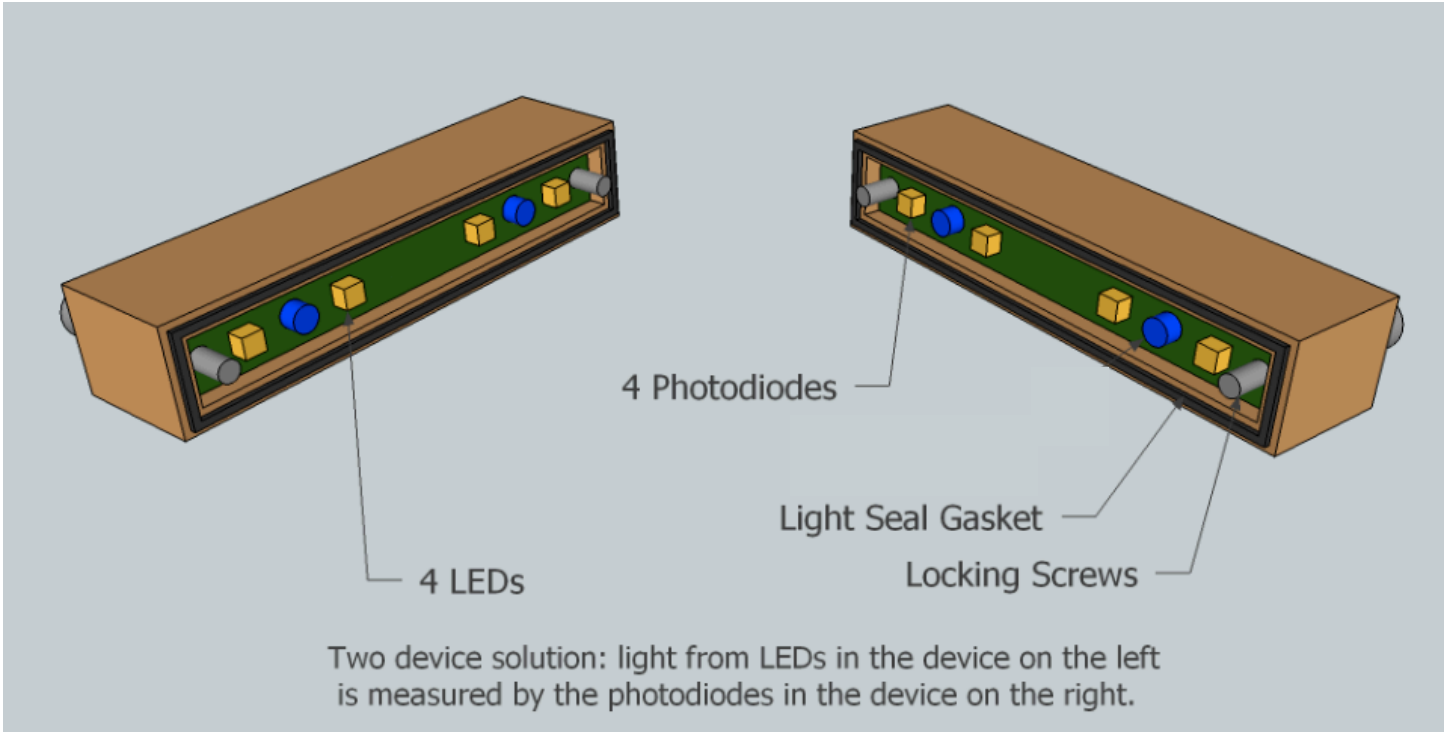
Counter QA

- Counters can't be "unglued", so QA is critical at the counter assembly step.
- Optical QA via digital image with 80x microscope.
- Image will be stored for each fiber cut.



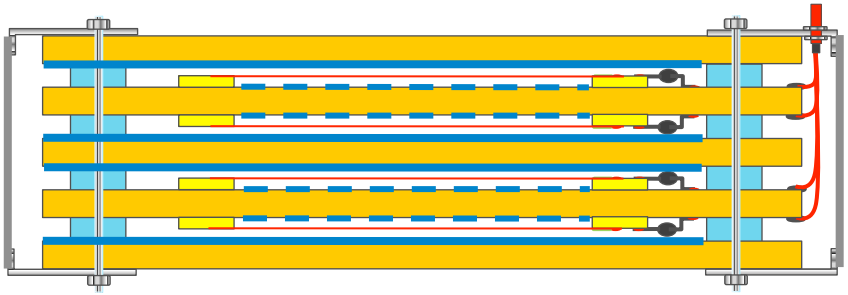
Counter QA

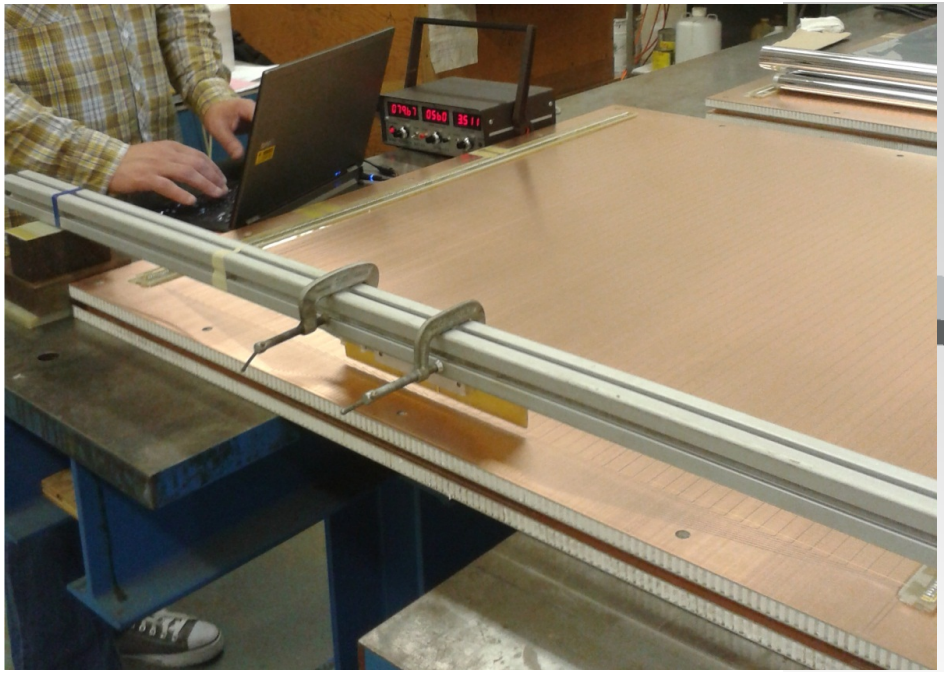
- Counters can't be "unglued", so QA is critical at the counter assembly step.
- Fiber tester: to be designed/fabricated by Dean Shooltz who built similar devices for NOvA.

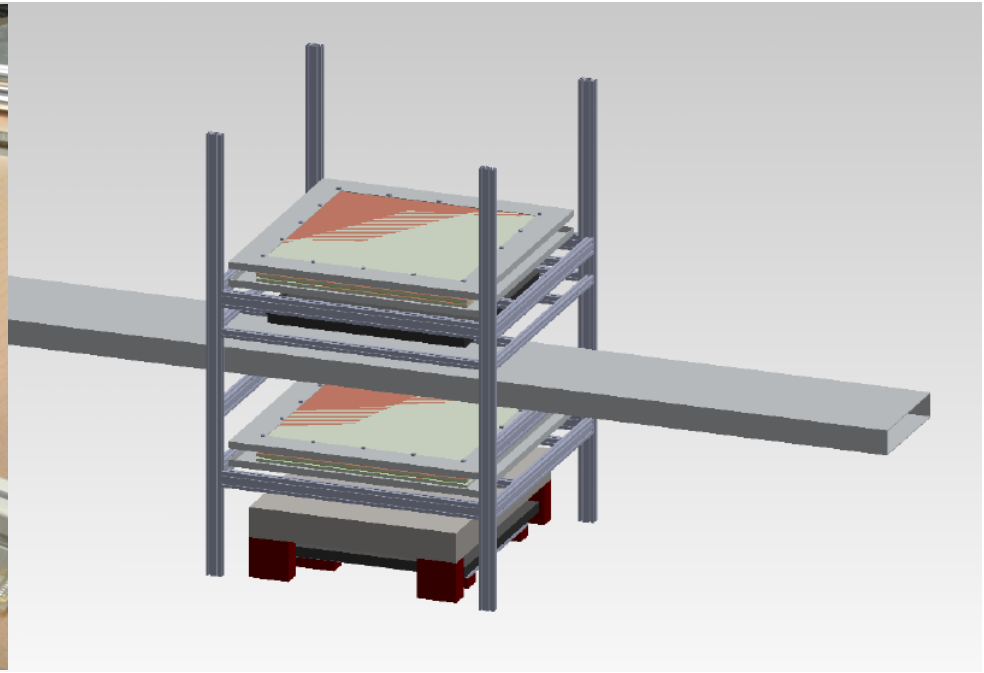


Module QA: CSC Test Stand

- A CSC prototype is being assembled that will be converted into a cosmic ray test stand for module QA.
- Winding complete
- HV/noise tests ongoing

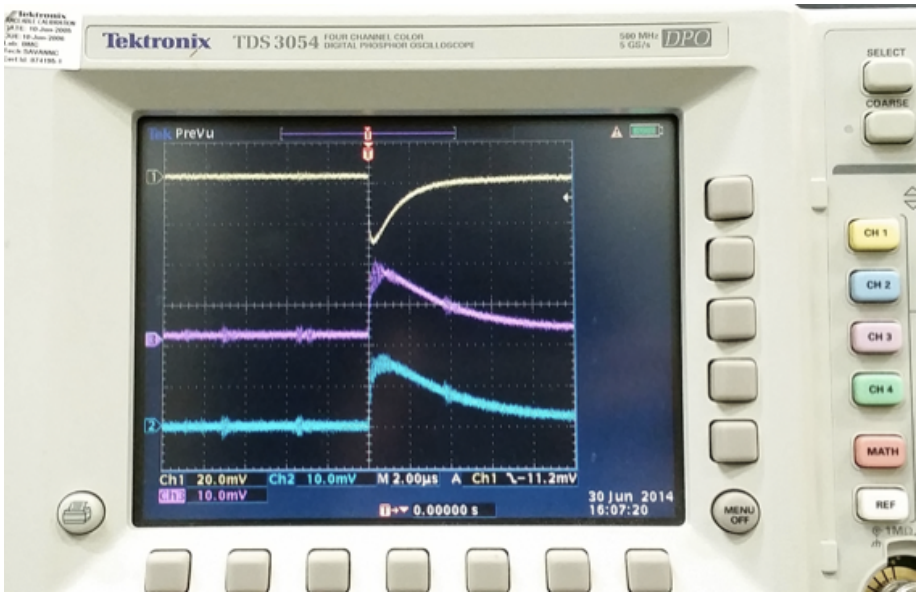






Test Stand Plan

- 1x1 m^2 active area
- Test stand will employ:
  - two multi-layer CSCs
  - gas system (Ar-CO2)
  - Trigger: large scintillation counter (for minimum energy confirmation)
  - Readout electronics
- PE yeild will be measured from each module end
- 10-hour runs will yield several hundred thousand cosmic ray muons
- Test procedure will be optimized using module prototypes
- Chamber commissioning is going well…



Cathode strips register signal from cosmic-ray trigger.

QA Checklist

Mu2e CRV Module Factory Quality Assurance Program
Rev-2- 04/04/2014

Mu2e DocDB: 4150

UNIVERSITY of VIRGINIA

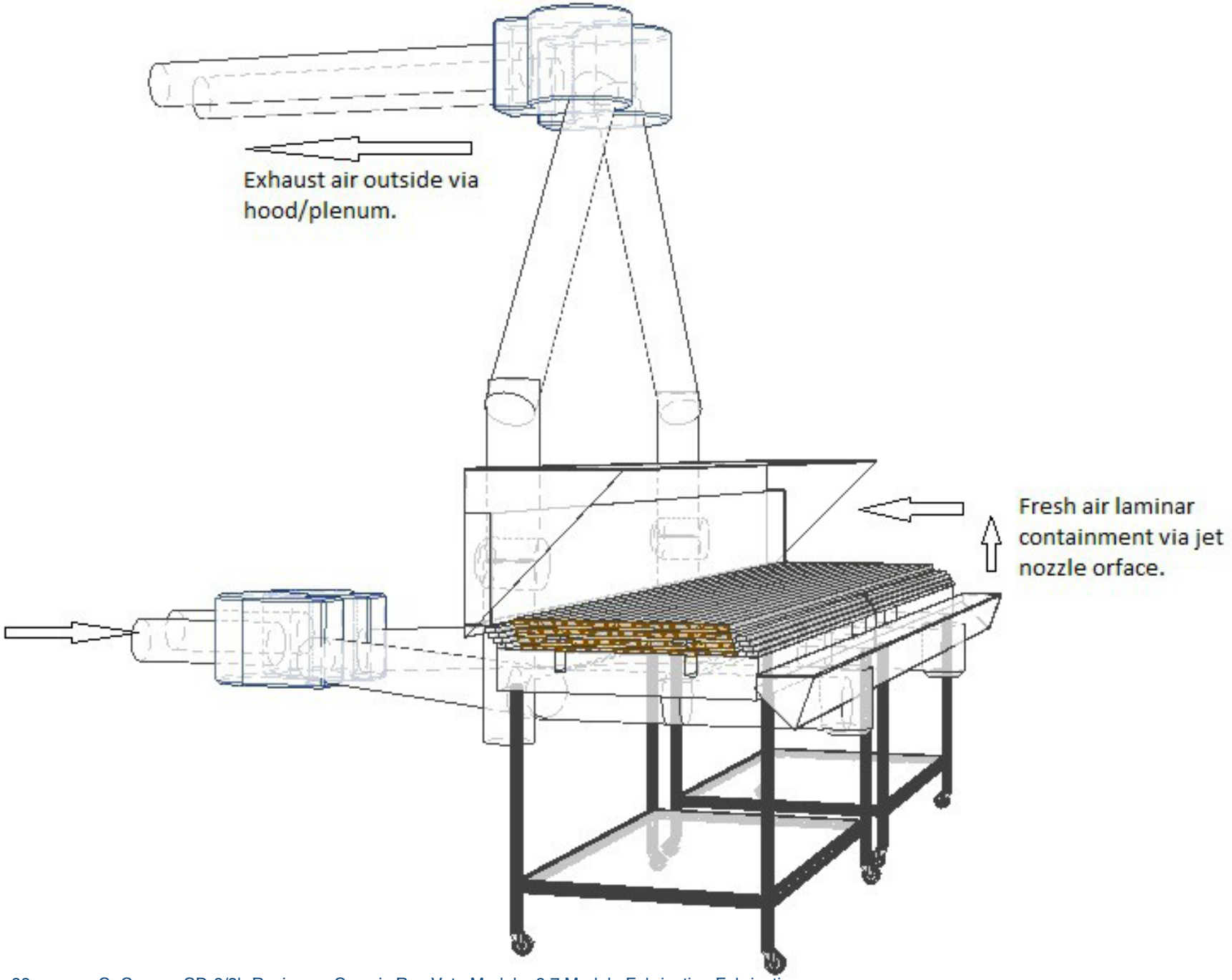
ATTACHMENT 3: CRV Module Factory QA Checklist:

Summary of additional QA checks:

- Scintillator extrusions - dimensional tolerances, defect free, test hole with spare fiber.
- Devcon HP 250 Epoxy - Glue test protocol, peel, shear, durability, hardness.
- Fiber guide bars (FGB) - dimensional tolerances, defect free.
- Counter motherboards (CMB) - dimensional tolerances, electronics tests.
- SiPM mounting blocks (SMB) - dimensional tolerances, defect free.
- Front end boards (FEB) - dimensional tolerances, electronics tests.
- Aluminum absorbers - dimensional tolerances, defect free.
- Light-tight paint and bumpers - defect free.
- …

Safety at the Module Factory

- Safety plans are also covered by the QAP (DocDB 4150)
- There are several hazards in the module factory: high voltage, compressed gas, epoxy fumes, power and other sharp tools…
- All employees must study and sign the UVA standard operating procedures (SOP) document to begin work.
- Each employee will be trained in all current OSHA, Fermilab and UVA ES&H safety guidelines for identifying, mitigating and managing all relevant hazards at the job site.
- Operation of the chop-saw or fly-cutter or access to the machine shop will require UVA machine shop training.
- All epoxies contain some toxic chemicals, engineering controls will be employed to mitigate occupational exposure levels.
- Working closely with industrial hygienist at UVA to finalize ventilation plan


Exhaust air outside via hood/plenum.
Fresh air laminar containment via jet nozzle orface.

Epoxy Fumes

- A similar design will be adapted for the Counter Assembly Tables.
- Devcon HP250 does not contain MDA which is a known carcinogen often found in epoxy. We chose a “safer” epoxy.
- However, it does contain a suspected carcinogen, MBCHA, and other known toxins.
- A prototype ventilation system will be tested via air sampling while building prototype modules to ensure air contaminants are mitigated to acceptable levels.

Personnel at the Module Factory

- Technician Leader: Factory design, prototyping, factory management (QA/safety), documentation, fabrication, …
- Mechanical Technician: Assist in moving into factory, building assembly stations, and fabrication efforts.
- Undergraduates: tedious tasks in the module factory: cleaning/de-burring components, spreading epoxy, QA checklists, …
- Uncosted graduate students, postdocs, and faculty: commission the QA tools, establish metrics, and analyze data from QA measurements.

Personnel at the Module Factory

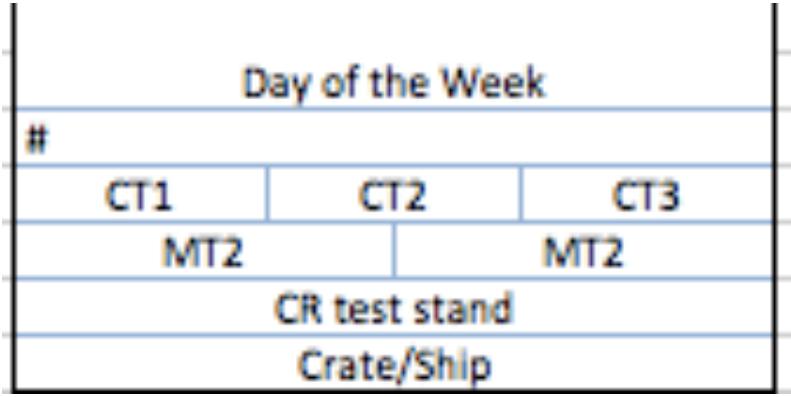
- About 7300 total hours of effort to fabricate, pack, and ship 91 modules to Fermilab.
- ~80 hours of fabrication effort per module.
- ~54 hours of tech effort per module for fabrication.
- With full-time effort, about 6 modules per month can be produced in the module factory.
- Example work flow to follow, more details in DocDB 4197.

Work flow at module factory

Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
			1 di-counter	2 fiber di-counter	3 cure fiber di-counter	4 cure cure
5 cure cure	6 flycut cure fiber	7 fiber QA flycut cure	8 manifold fiber QA cure	9 transition manifold cure transition	10 di-counter transition flycut module transition	11 cure
12 cure	13 fiber di-counter fiber QA cure module	14 cure fiber manifold transition cure tranistion	15 cure cure transition transition cure CR test stand	16 cure cure di-counter module cure Crate (1)	17 flycut cure fiber cure transition transition	18 cure cure
19 cure cure	20 fiber QA flycut cure CR test stand	21 manifold fiber QA flycut transition transition Crate(2)	22 transition manifold flycut transition CR test stand	23 di-counter transition fiber QA module transition Crate(3)	24 fiber di-counter manifold cure module	25 cure cure cure
26 cure cure cure	27 cure fiber transition cure transition	28 flycut cure transition transition CR test stand	29 fiber QA cure di-counter module transition transition Crate(4)	30 manifold cure fiber cure CR test stand	31 transition flycut cure cure transition Crate (5)	1 cure cure

Module 1
Module 2
Module 3
Module 4
Module 5
Module 6
Module 7
Module 8
Module 9
Module 10
Module 11
Module 12
Module 13
Module 14

Month 1
(DocDB 4197)



Work flow at module factory

Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
						1 cure cure
2 cure	3 di-counter fiber QA flycut transition module transition	4 fiber manifold fiber QA cure CR test stand	5 cure transition manifold transition cure Crate(6)	6 cure di-counter module cure	7 cure fiber cure transition transition	8 cure cure
9 cure cure	10 flycut cure transition transition QA test stand	11 fiber QA flycut di-counter transition module transition Crate (7)	12 manifold fiber QA fiber cure CR test stand	13 transition manifold cure transition cure Crate (8)	14 d-counter cure module cure	15 cure cure
16 d-counter cure	17 fiber flycut cure transition transition	18 cure transition fiber QA transition CR test stand	19 cure di-counter manifold transition module transition Crate (9)	20 cure fiber transition transition cure CR test stand	21 flycut cure di-counter module cure Crate (10)	22 cure cure cure
23 cure cure	24 fiber QA flycut fiber transition cure tranistion	25 manifold fiber QA cure cure CR test stand	26 transition manifold cure transition transition transition Crate (11)	27 di-counter transition cure module transition CR test stand	28 fibers di-counter flucut cure module Crate (12)	29 cure cure cure
30 cure cure cure	31 cure fibers fiber QA transition transition					

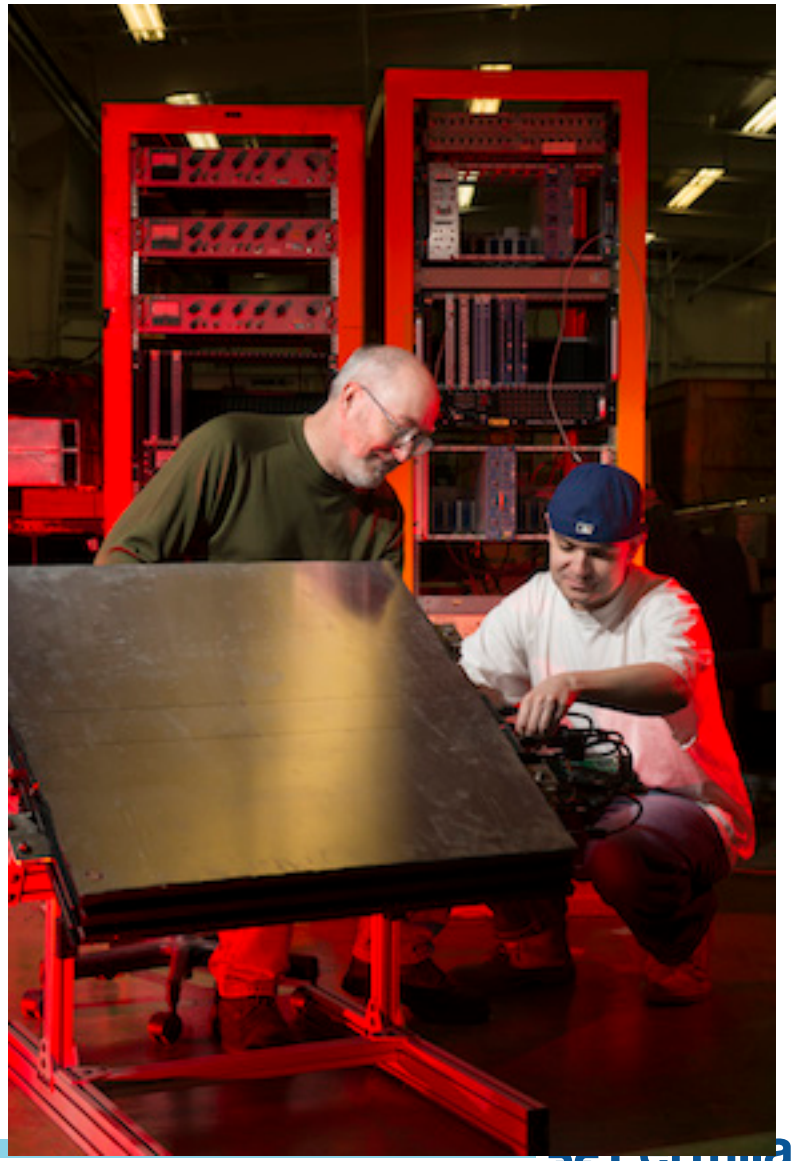
Module 12 crated in less than 2 months!

Month 2

Day of the Week		
#		
CT1	CT2	CT3
MT2	MT2	
CR test stand		
Crate/Ship		

- Module 1
- Module 2
- Module 3
- Module 4
- Module 5
- Module 6
- Module 7
- Module 8
- Module 9
- Module 10
- Module 11

Prototype Plan



- Past experience with “test beam” prototype
- Prototyping is critical for understanding ideal tooling and required tech hours

Prototype Plan

- Mechanical prototype (early FY15):
  - 4.7 m long; No electronics
  - Time and motion studies; handling modules
  - Test/practice epoxy application
- Two short (cryo-length) electronics prototypes (FY15):
  - Outfitted with electronics
  - Study mounting techniques
  - Test bed for electronics
- Two “pre-production” prototypes (FY16):
  - Outfitted with electronics
  - Production scintillation and fiber
  - Shipped to Fermilab to test installation and mounting procedures

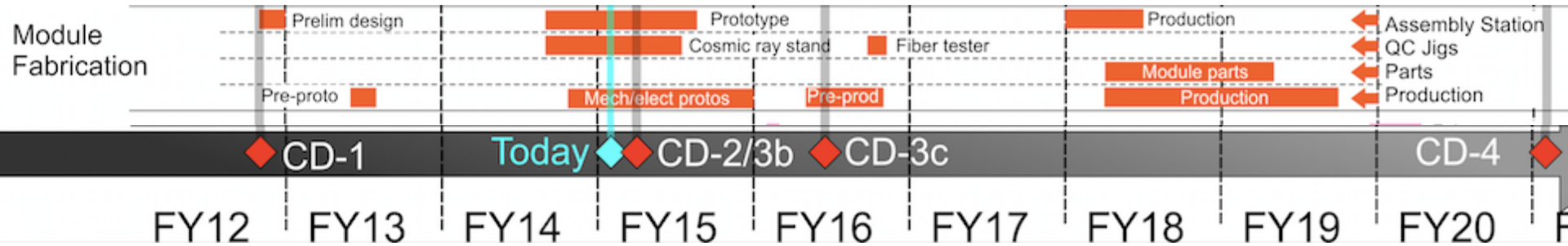
Shipping

- Plan for ~9 shipments (~10 modules per shipment)
- Plan for 2 modules per crate
- Crates will weigh about 4000 lbs
- Crates will be assembled at a local job shop
- Will consider shipping crates back to UVA.
- Crates designed to be stackable.

Shipping

- Crates will be loaded via fork lift
- Need access from side of truck
- Flatbed truck with tarps possible, but "Conestoga 2" seems ideal -- sliding tarp system:

Schedule and Remaining work before CD3

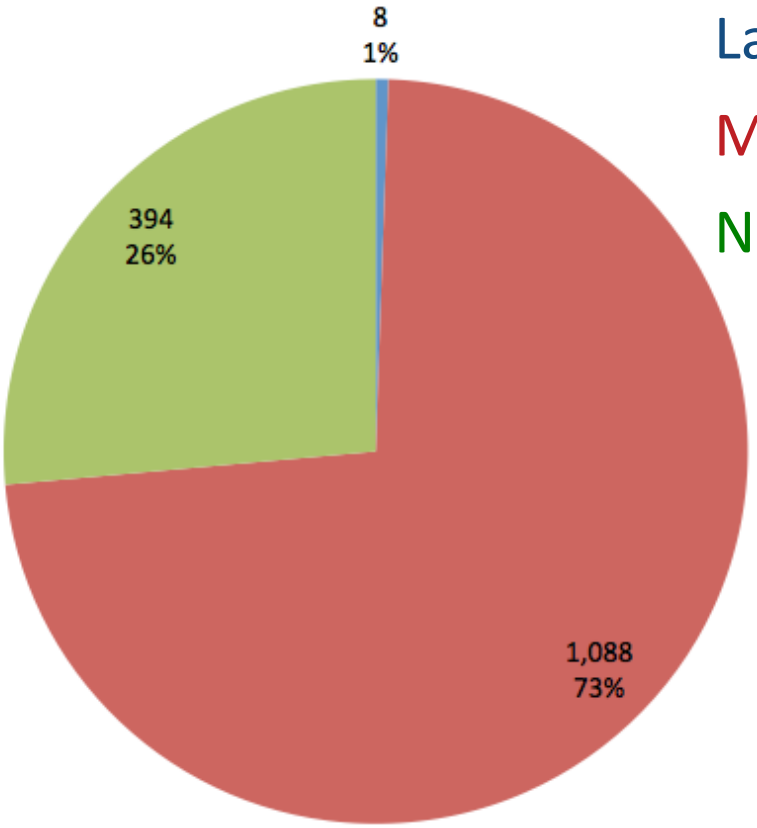


- Complete fabrication of prototype assembly stations
- Complete fabrication of cosmic ray test stand
- Produce “mechanical” prototype module
- Produce “short electronics” prototype module
- Produce “pre-production” prototype
- Test “pre-production” prototype
- Design and fabricate “pre-production” prototype shipping crate
- Ship “pre-production” prototype to Fermilab

Cost Table (Base Cost – AY k$)

	Base Cost (AY K$)					
	M&S	Labor	Total	Uncertainty (on remaining budget)	% Contingency (on remaining budget)	Total Cost
8.07.01 Design and fabricate assembly station	163		163	62	47%	225
8.07.02 Assembly Station Quality assurance design & fabrication	98	8	106	23	65%	129
8.07.03 Fabrication of Module Parts	454		454	93	21%	547
8.07.04 Module Production, Testing, Shipping	741		741	276	41%	1,018
8.07.05 Breakdown of Module Factory	26		26	11	43%	37
Grand Total	1,482	8	1,490	466	35%	1,956

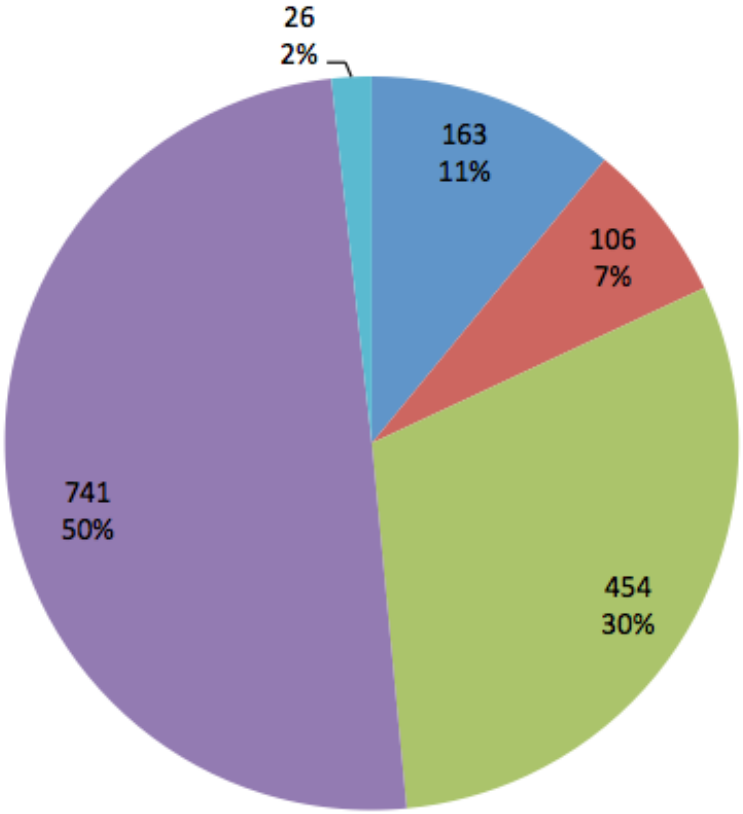
Cost Breakdown (Base Cost – AY k$)



Labor

Materials

Non-FNAL Labor



08.07.01

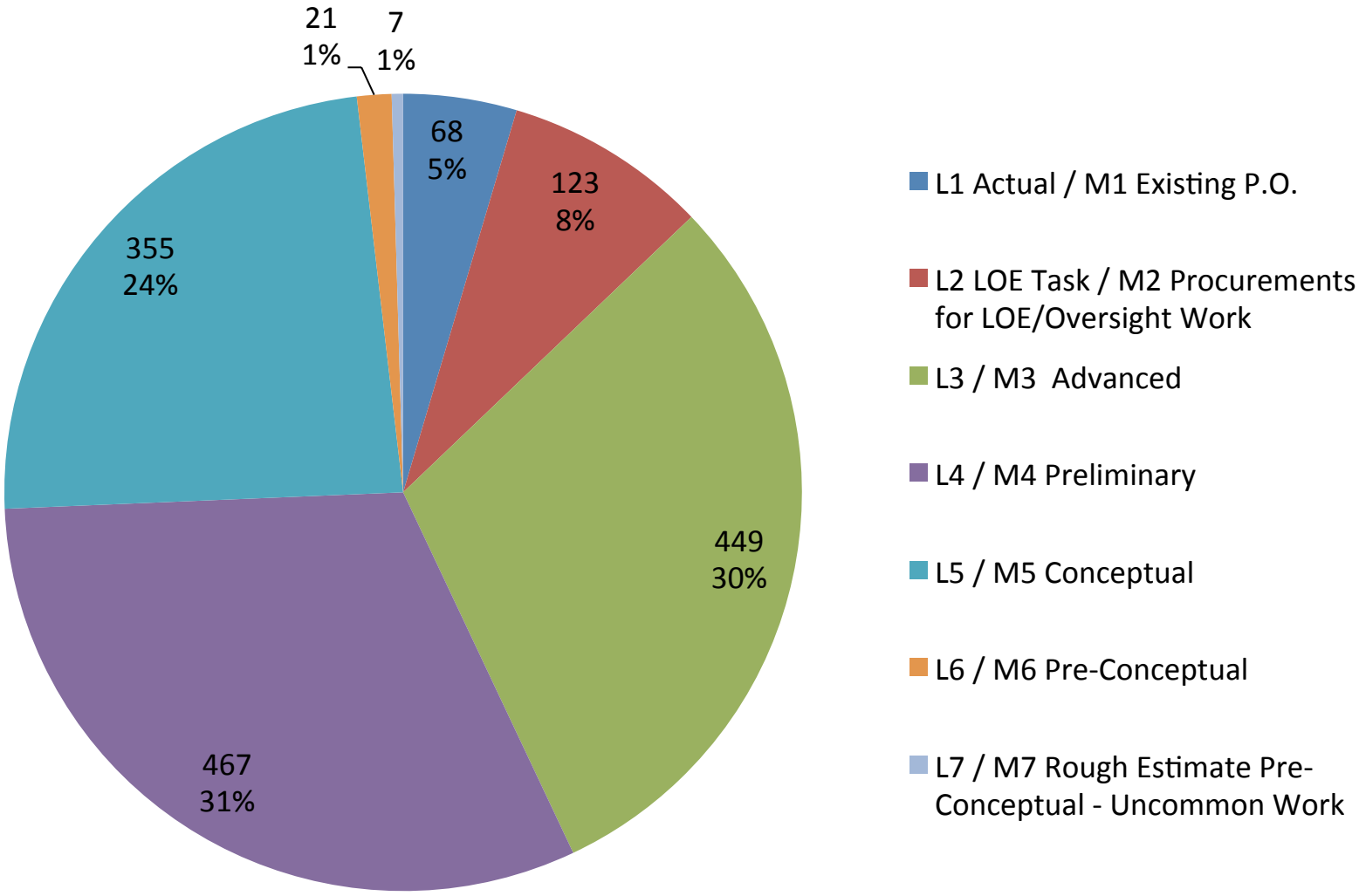
08.07.02

08.07.03

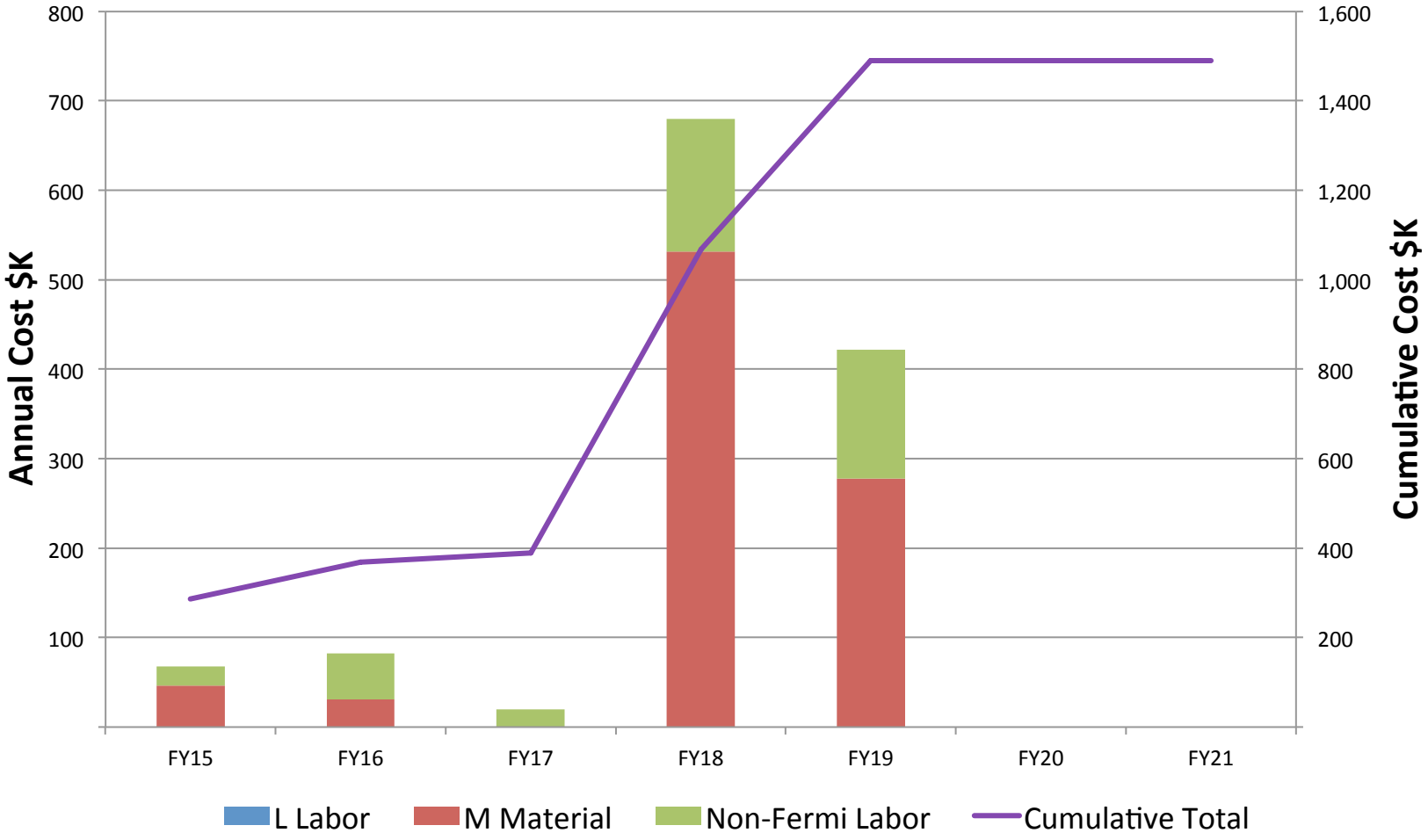
08.07.04

08.07.05

Quality of Estimate (Base Cost – AY k$)



Labor Resources by FY (Base Cost in AY K$)



Integration and Interfaces

- CRV fabrication is integrated with most other CRV L3s: design, fibers, electronics, extrusions, instillation…
- Many interfaces require coordination:
  - Fabrication procedure dependent on design
  - Components are shipped to module factory
  - QA of many parts done during fabrication
  - Completed modules shipped back
- All interfaces are internal to the CRV group.
- Discuss interfaces at weekly CRV meeting.
- Share documentation – same chapter for the TDR.

Major Milestones

- Oct. 2014: Cosmic Ray Test Stand Ready
- Dec. 2014: Approve mechanical prototype
- Feb. 2016: Approve pre-production prototype
- June 2019: Production modules complete
- Sept. 2019: Module factory breakdown complete

Summary

- Factory plan is complete and prototyping is ongoing...
- All factory components on castors -- flexibility is important--location won't be finalized until rental space is acquired.
- Prototype assembly will allow us to fine tune assembly plan.
- The cost and schedule are well understood, with contingency estimated to reflect estimate uncertainty.
- The CRV fabrication activity is ready for CD2 and has a clear plan to get to CD3.

Supplementary Material

Prototype Counter Assembly Table

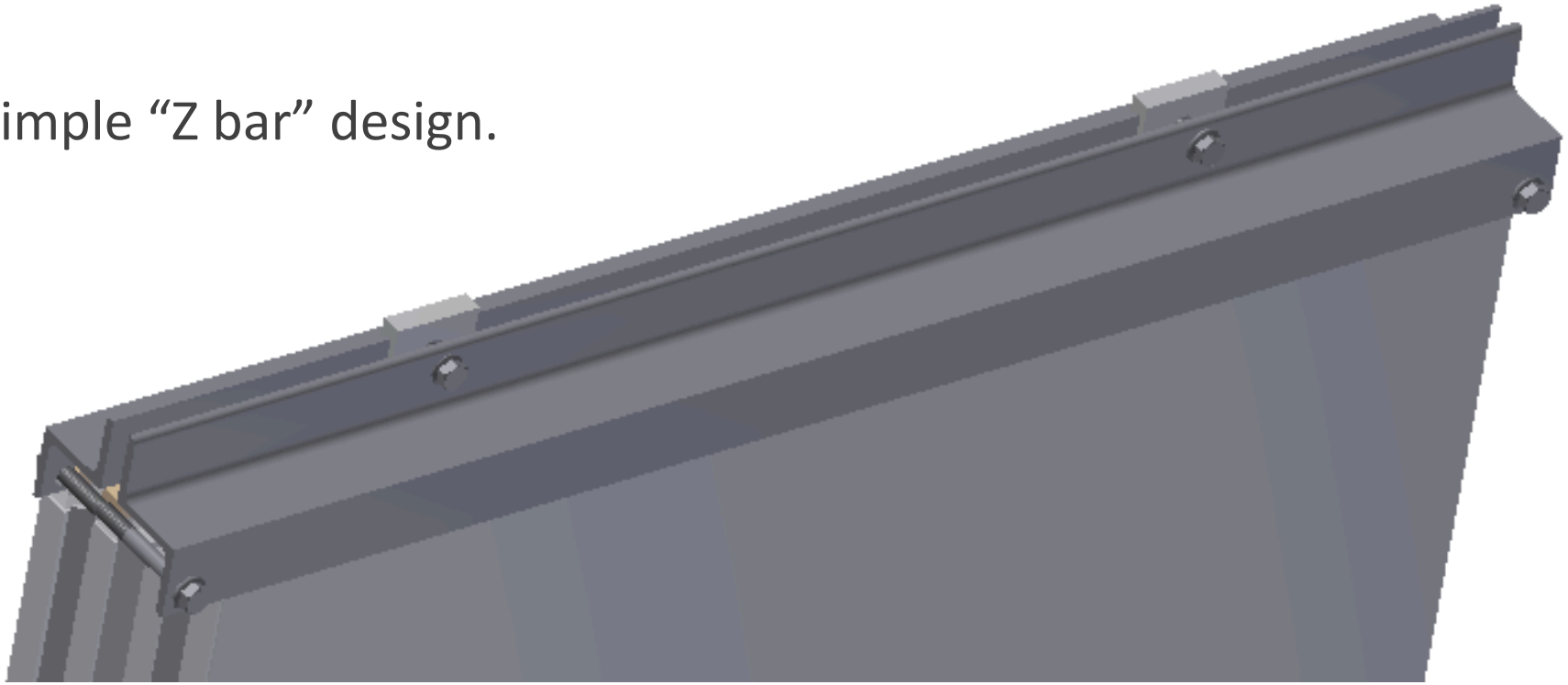
Up

M

Down

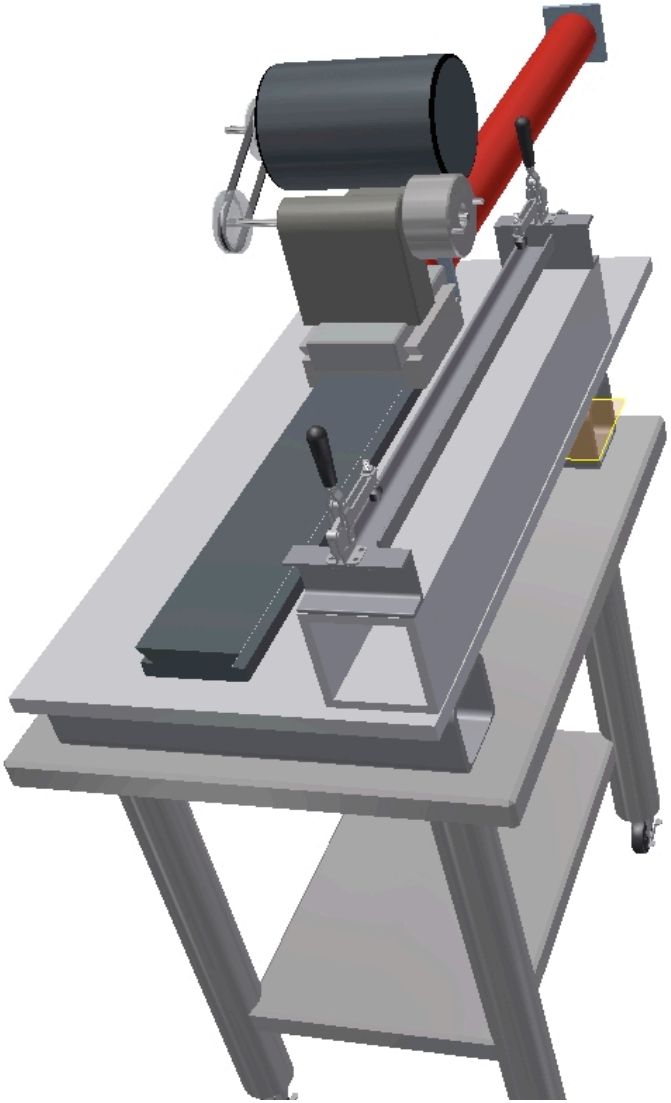
Module End Caps

Simple “Z bar” design.



To protect the sensitive module readout ends during transportation and handling.

Fly Cutter With 36” Slide…



Full Schedule