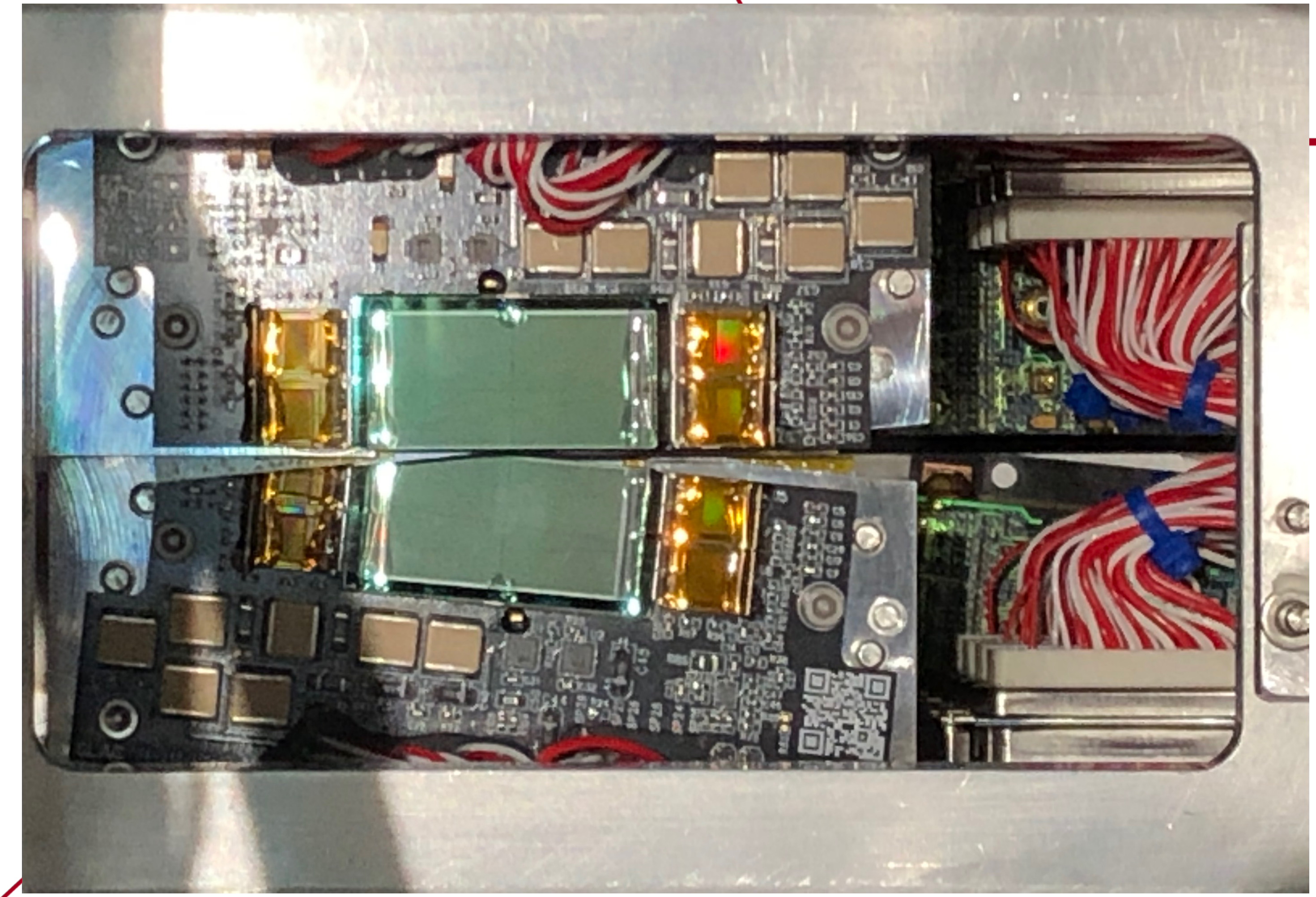
The SVT for 2019:
Status, Commissioning and Operations



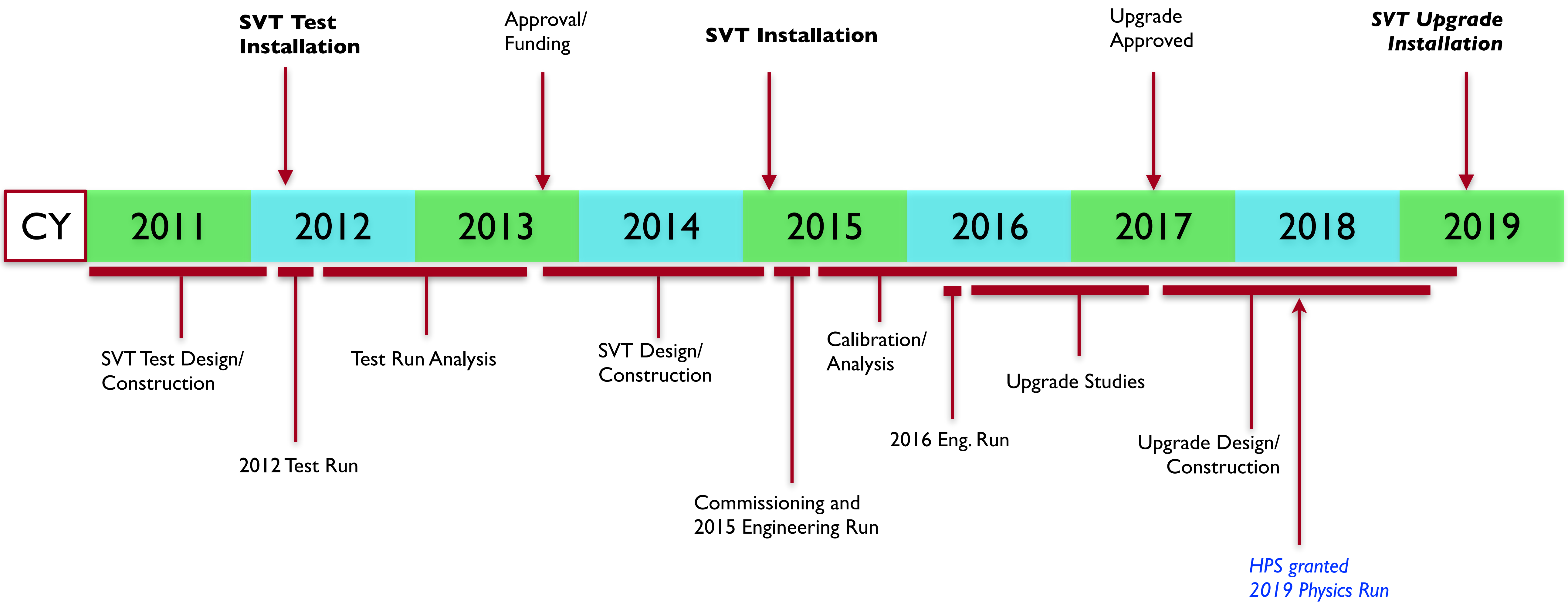
Tim Nelson
HPS Collaboration Meeting @ JLab
May 29, 2019

Outline

- SVT Overview and History, 2011-2018
- The SVT Upgrade for 2019
- 2019 Installation
- 2019 Commissioning and Operations
- SVT into the future…

SVT Overview and History, 2011-2019

The HPS SVT, 2011-2018



*This is the **third** generation of HPS, and the SVT*

HPS Test Run SVT

Test Run began a design evolution.

Early concepts for the SVT…

- used typical small angle stereo arrangement in L4-6 (axial w.r.t bend plane) and 90-degree stereo in L1-3.
- LARGE, required large magnet and vacuum chamber

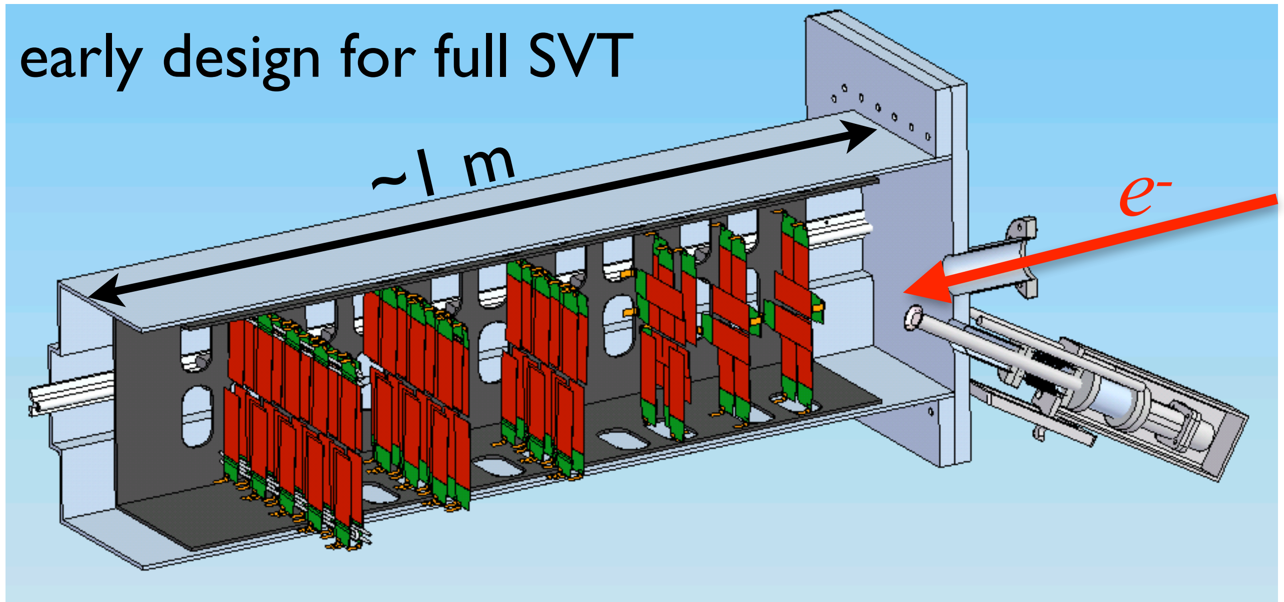
Existing magnet/chamber at JLab motivated a smaller detector.

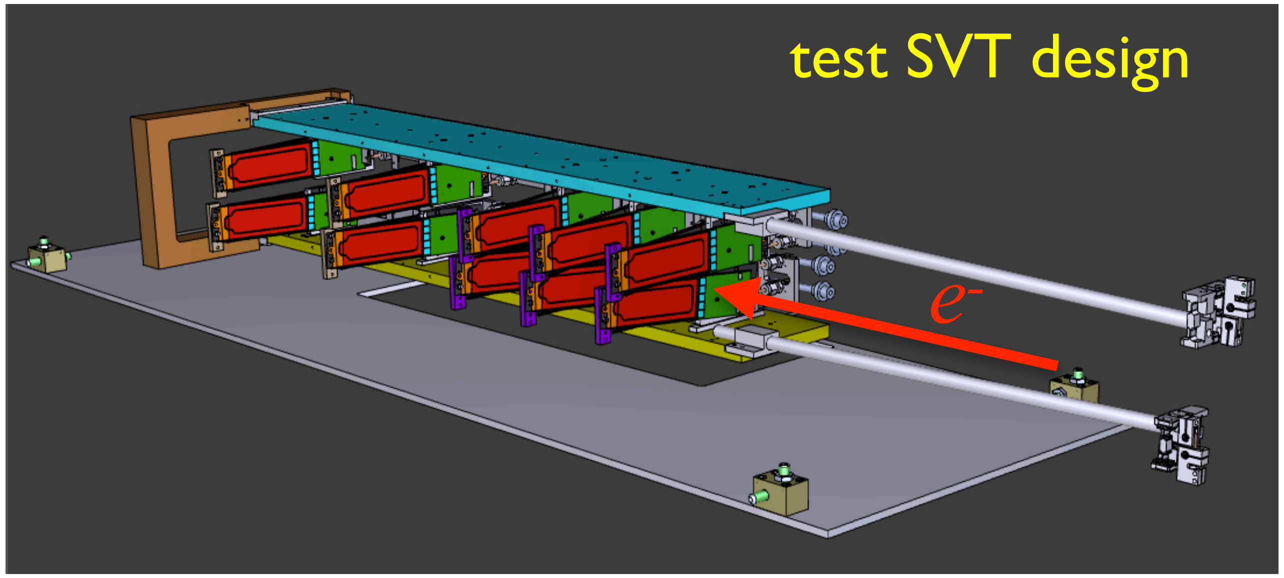
- simpler mechanics
- less coverage
- change to unusual axial/stereo arrangement

Studies showed minimal impact on physics

- important acceptance - low mass - is close to beam
- given MS, bend plane resolution can be modest
- vertexing power is in vertical plane anyway because dead zone between top and bottom selects low-mass pairs with large p_y/p_x.

We have kept this overall outline!

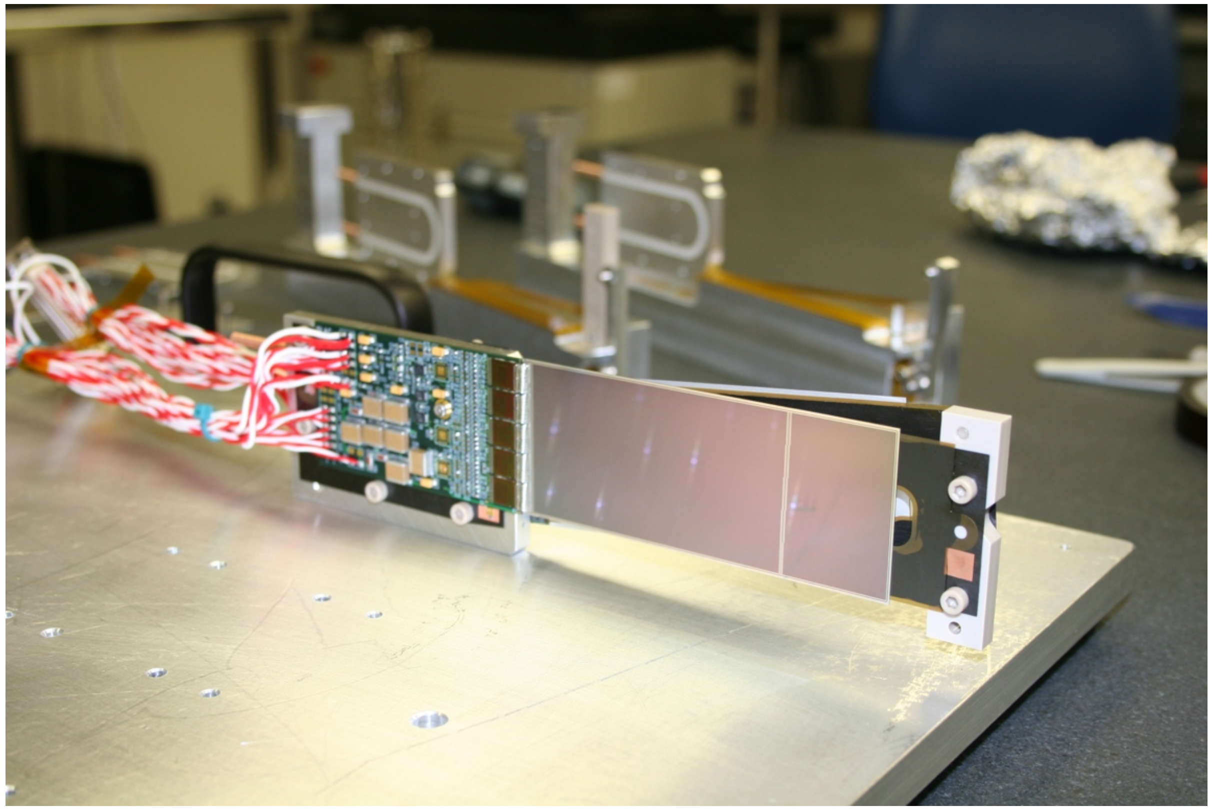


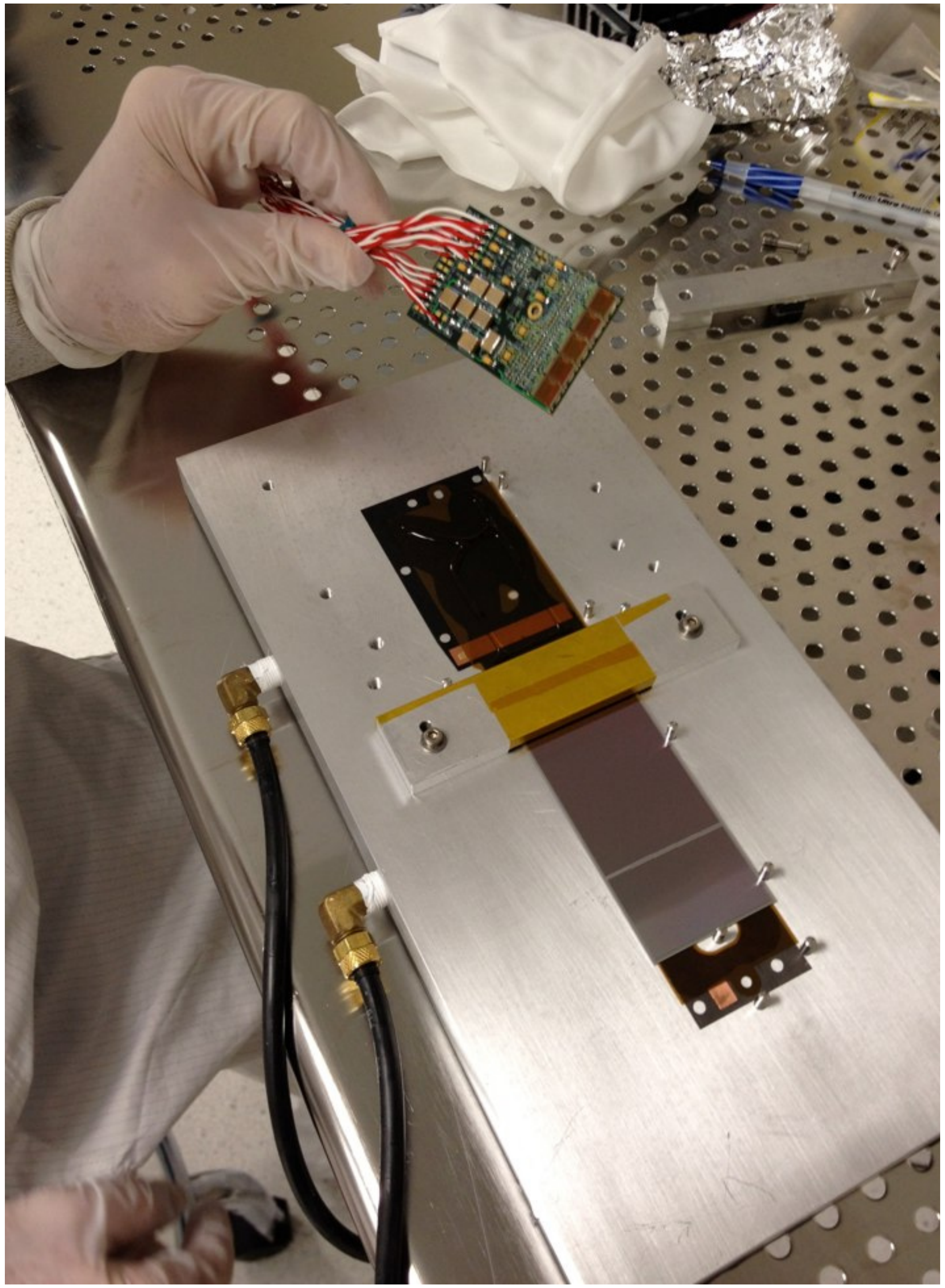


SVT Test Run: Modules

From zero to installation in one year:

- HPK sensors from DØ Run2b project
- APV25 FE ASICs from CMS
- Basic hybrid/DAQ/module designs
- Soldered pigtail with known vacuum compatible wires and stainless DB44 connectors was a quick and simple solution

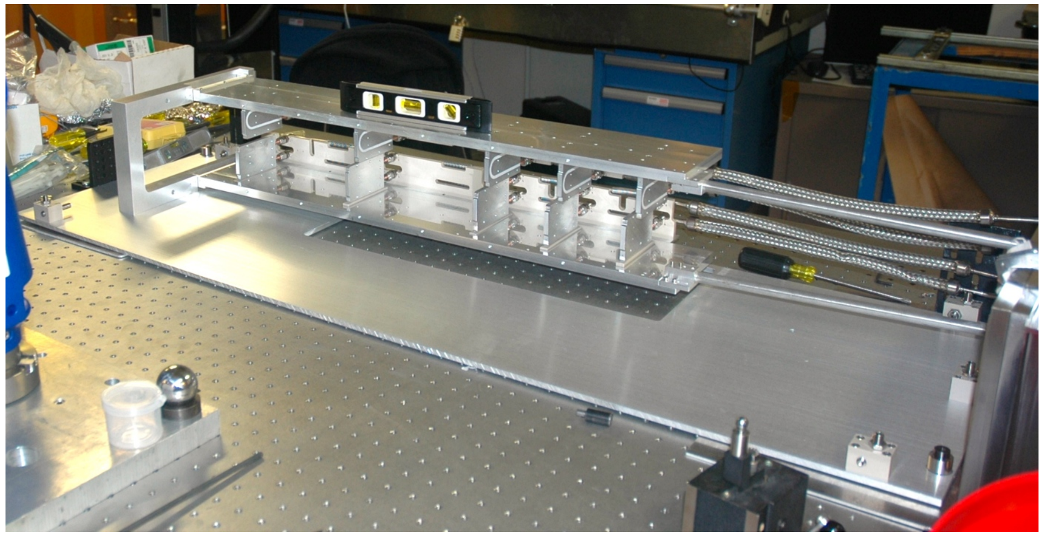




SVT Test Run:
Support, Cooling and DAQ

Infrastructure was somewhat crude.

- individually cooled modules:
  low flow, poor cooling for sensors
- skinny "support plates" and "C-support":
  structures suffered significant static sag
- analog signals from APV25 driven out
  through flange to RCE DAQ ~3 m away
  - reflections required FIR filter
    implemented in RCE DAQ (Sho!)
  - RCE still too close for comfort -
    SEB of ATCA power supplies from beam
- CAEN supplies from CDF nearly unusable

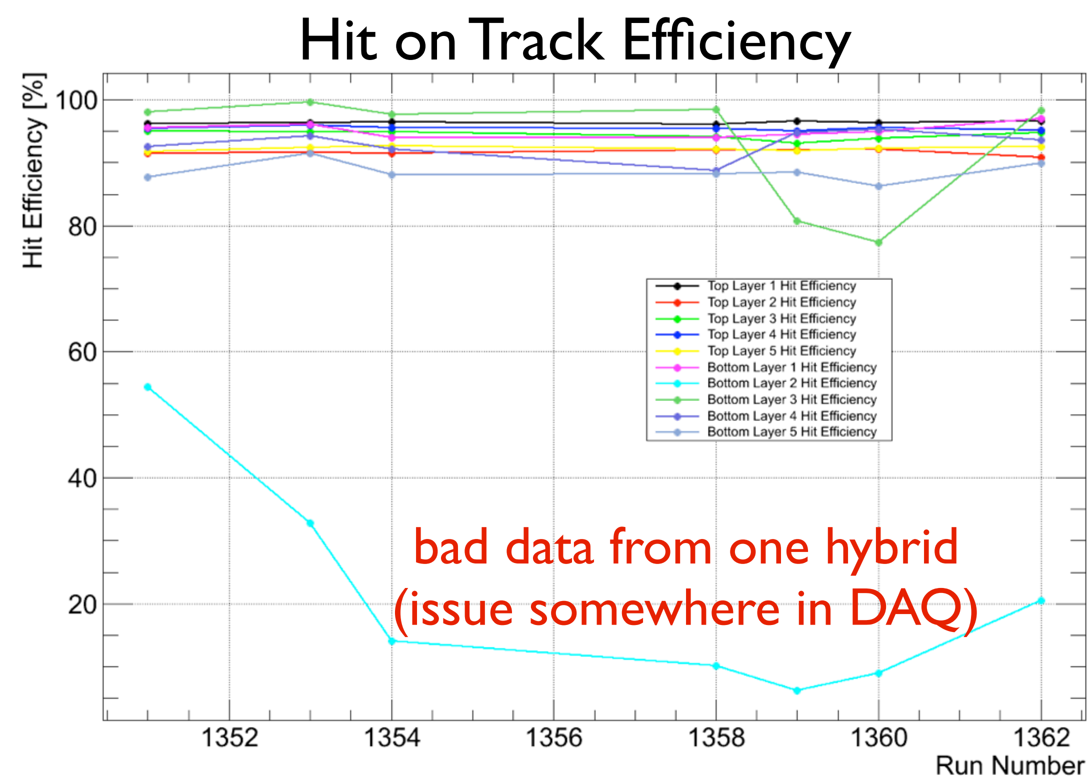


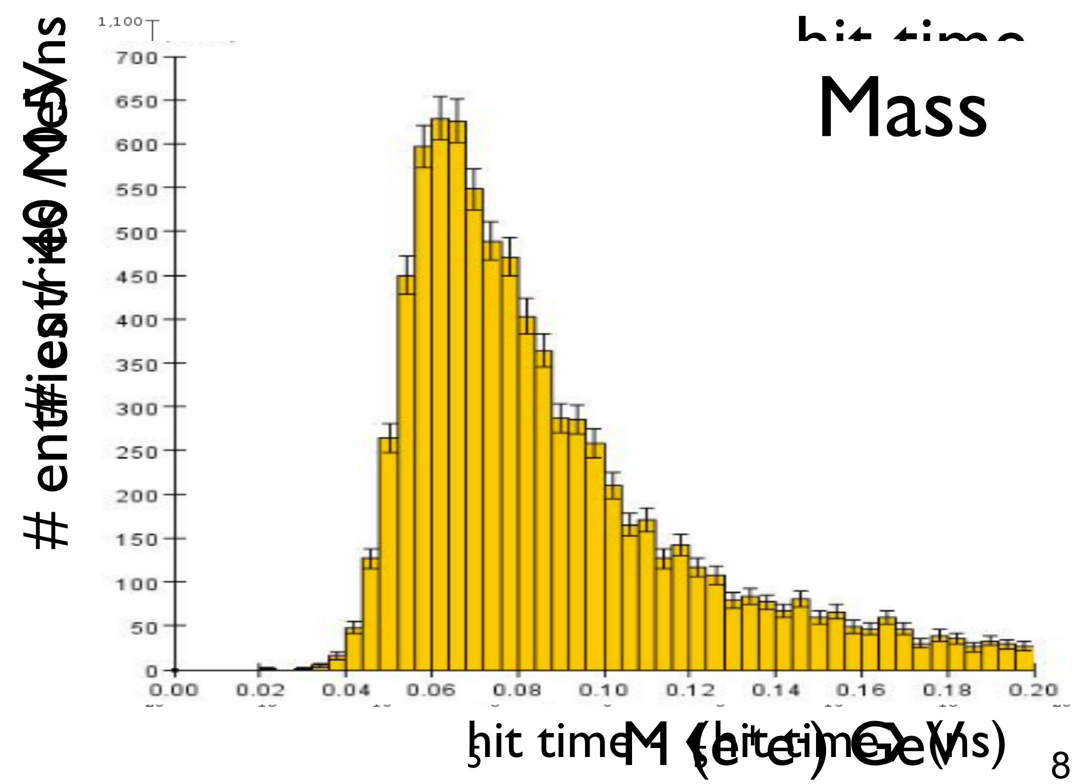
SVT Test Run Results

But it did the job.

- Proved S/N and time resolution expectations
- Modules were very good - 30 built with 90% having fewer than 0.5% bad channels
- Detector worked well on beam and in vacuum, proving the overall concept
- Measured the rate of scattered electrons close to beam that dominated occupancy, not simulated correctly by GEANT at the time.

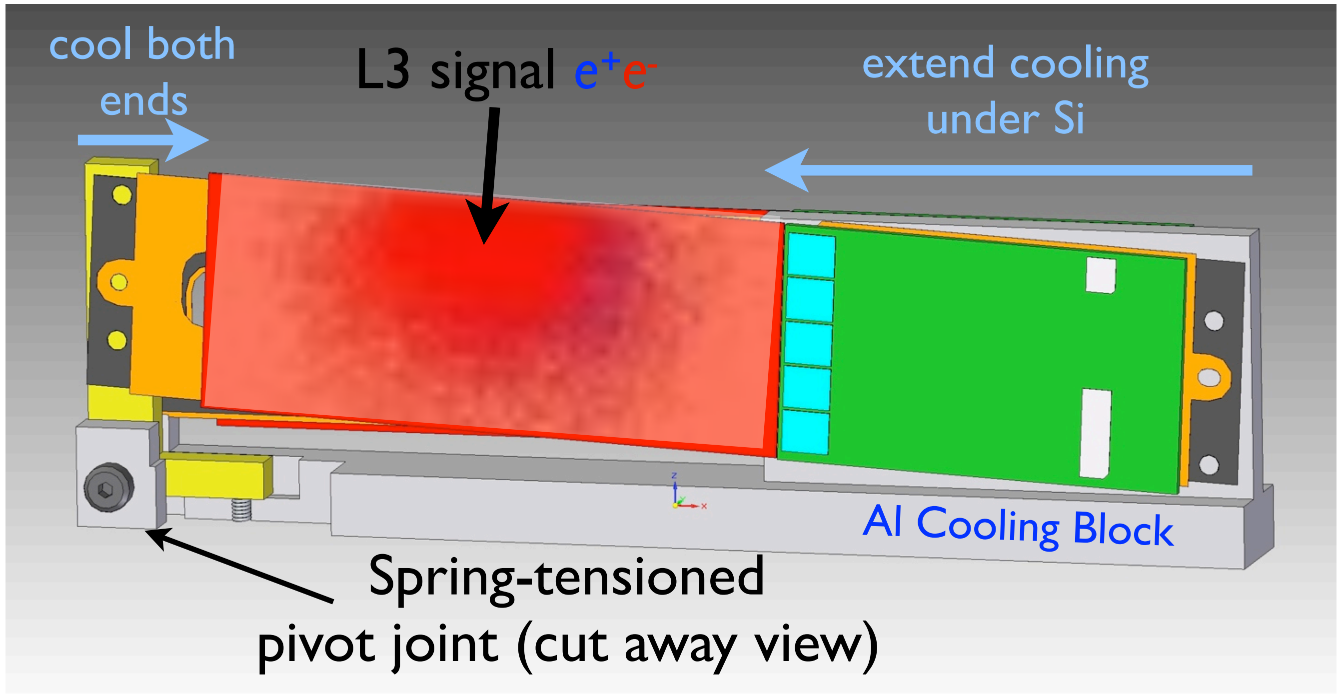
Motivated the approach of keeping what worked well and improving the rest for the full experiment.





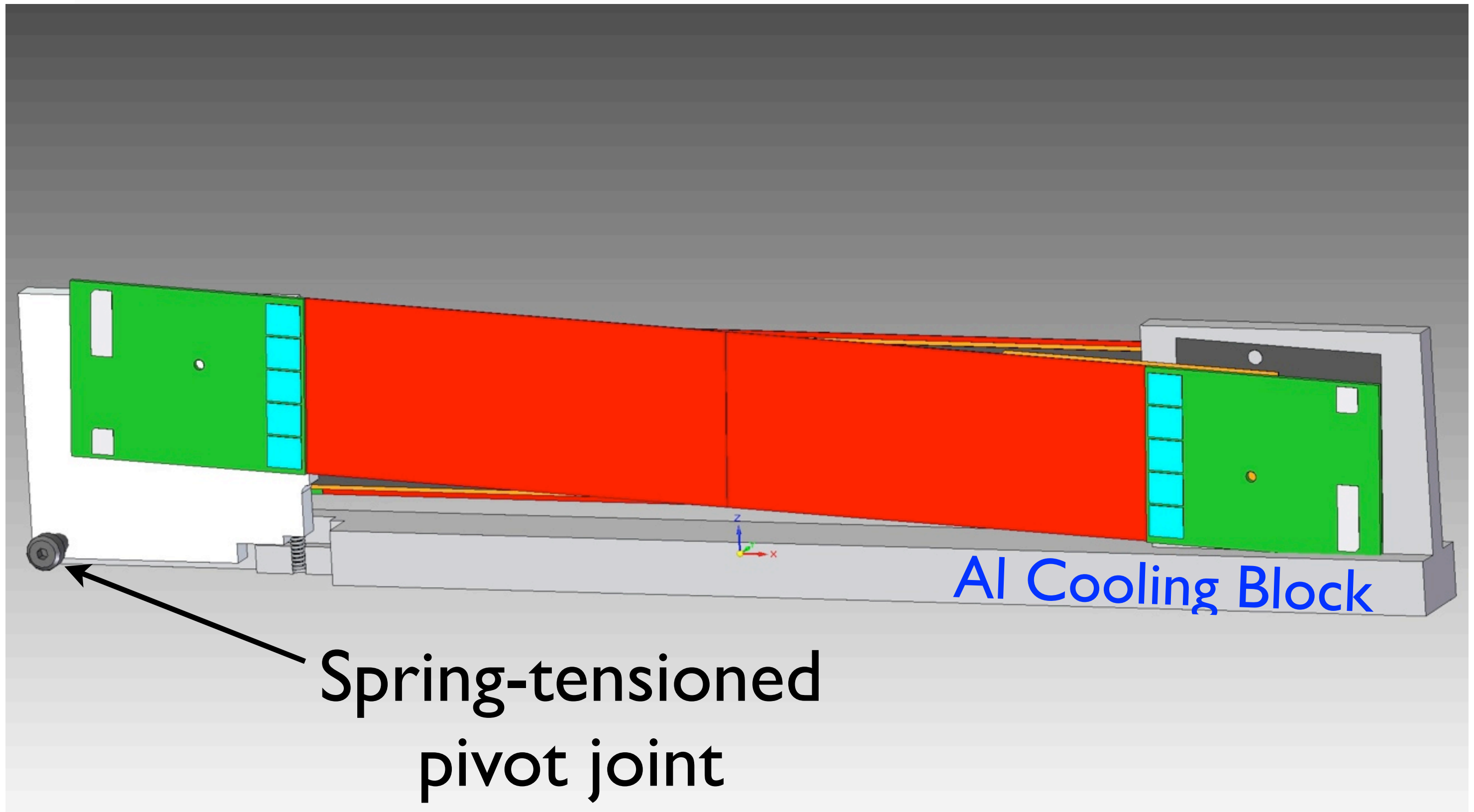
HPS SVT Modules

Reuse half-modules from HPS Test, but with improved module supports: tension CF between cooled uprights.



Extend concept to L4-L6 to allow same material budget for longer modules.

Eliminated pigtails in favor of cleaner solution, low-profile Samtec connectors



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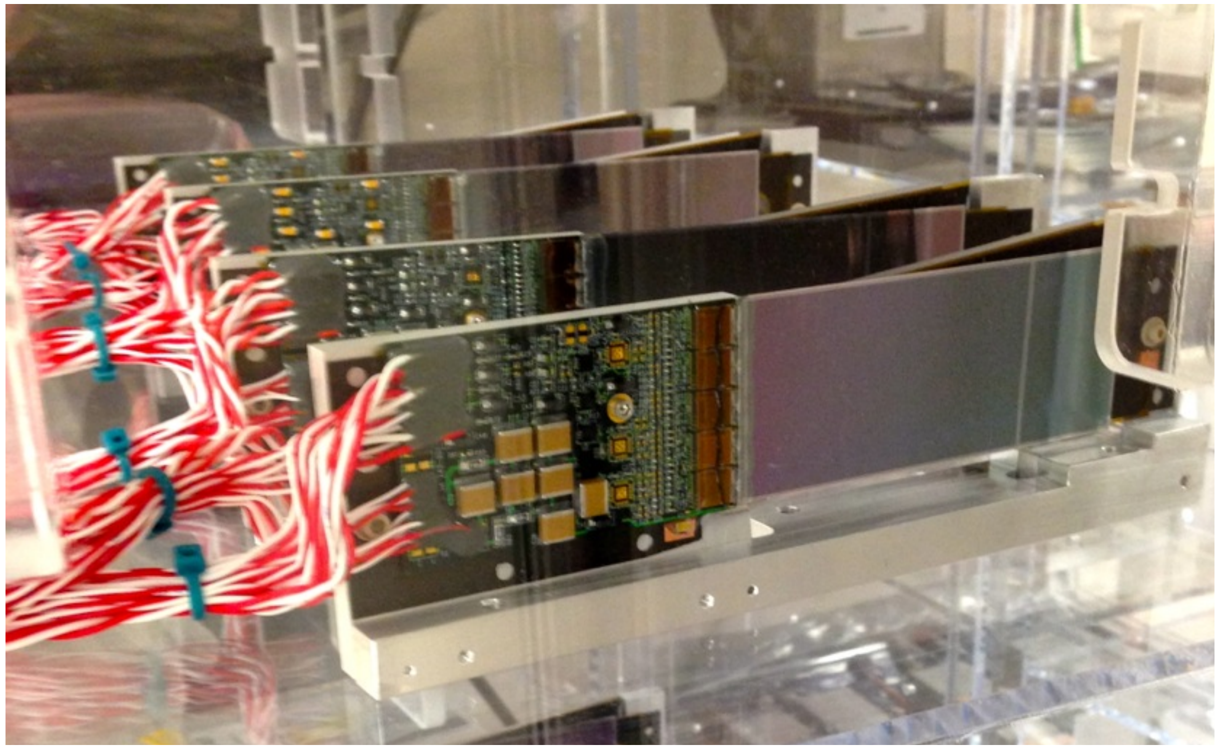

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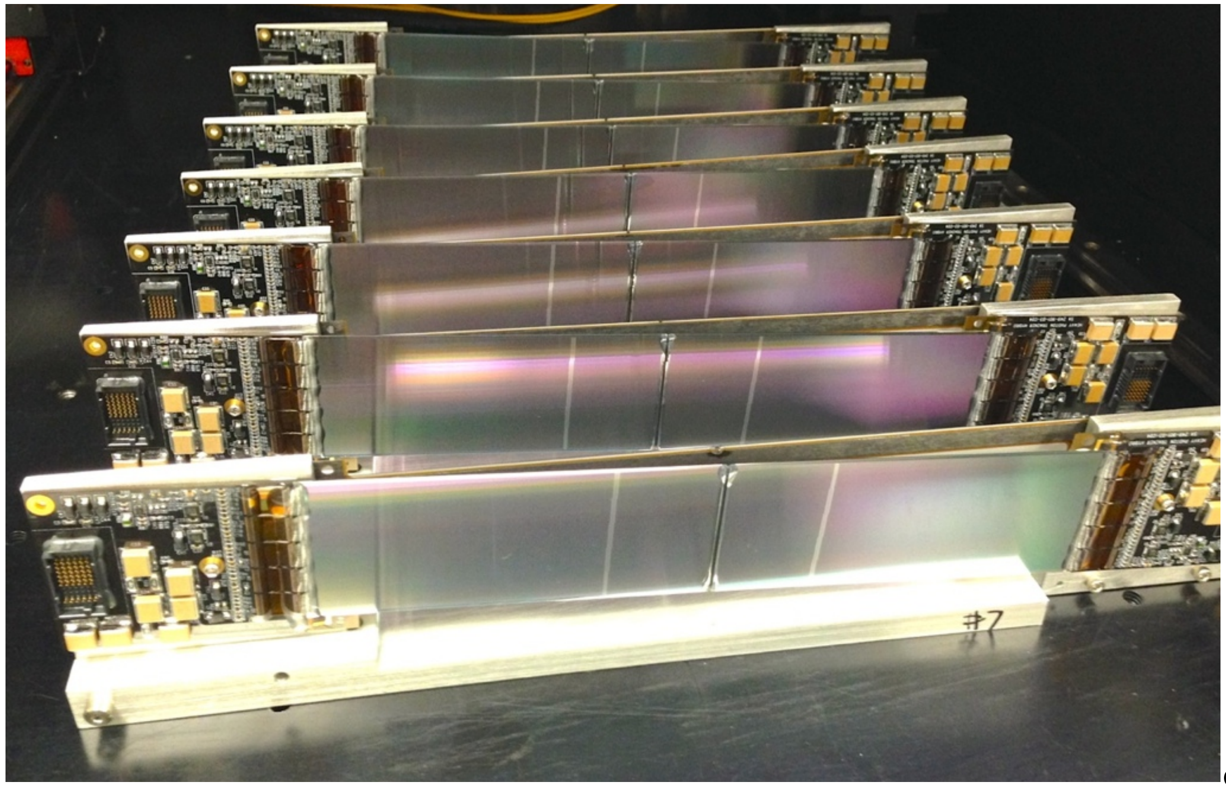
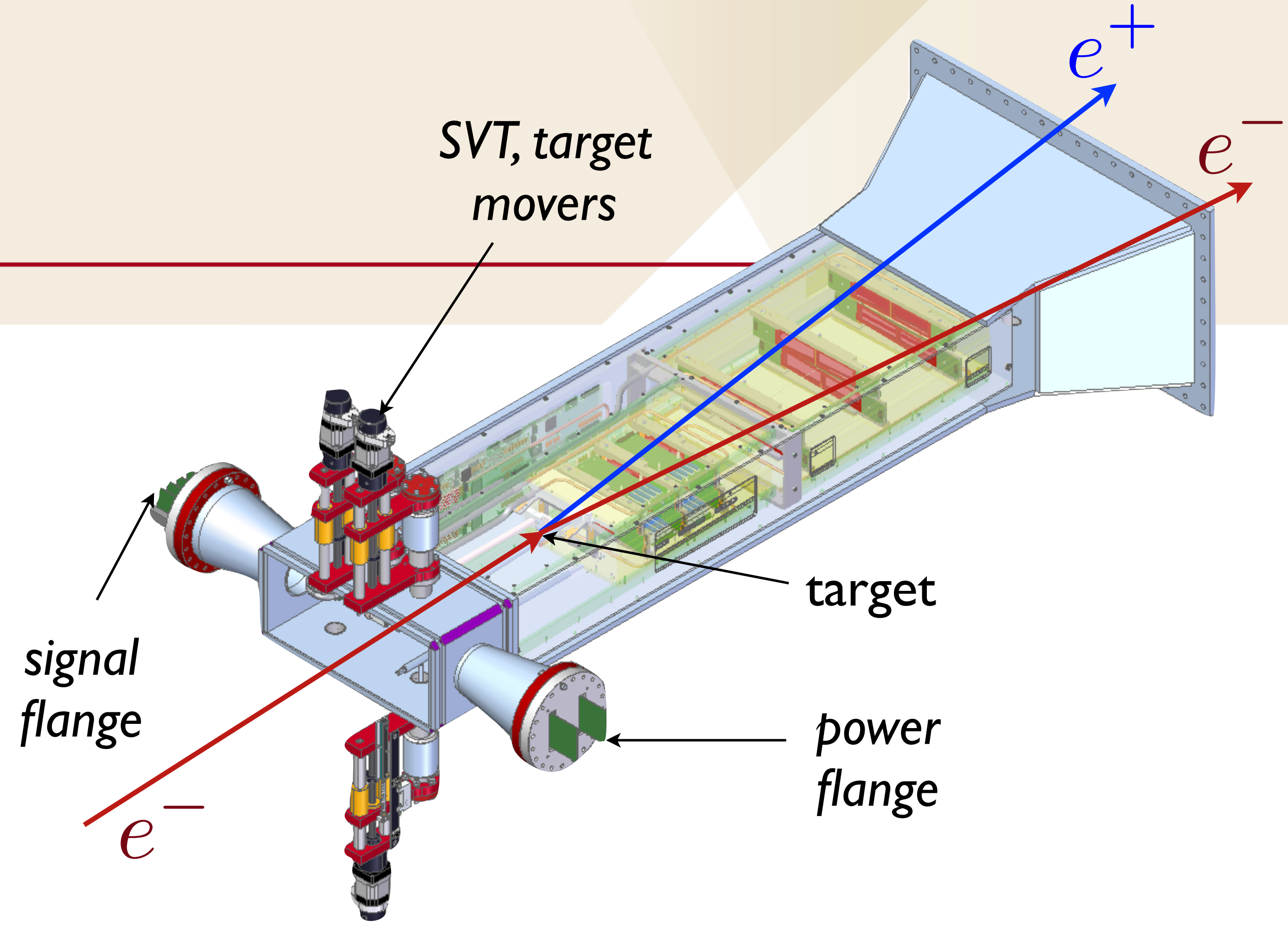


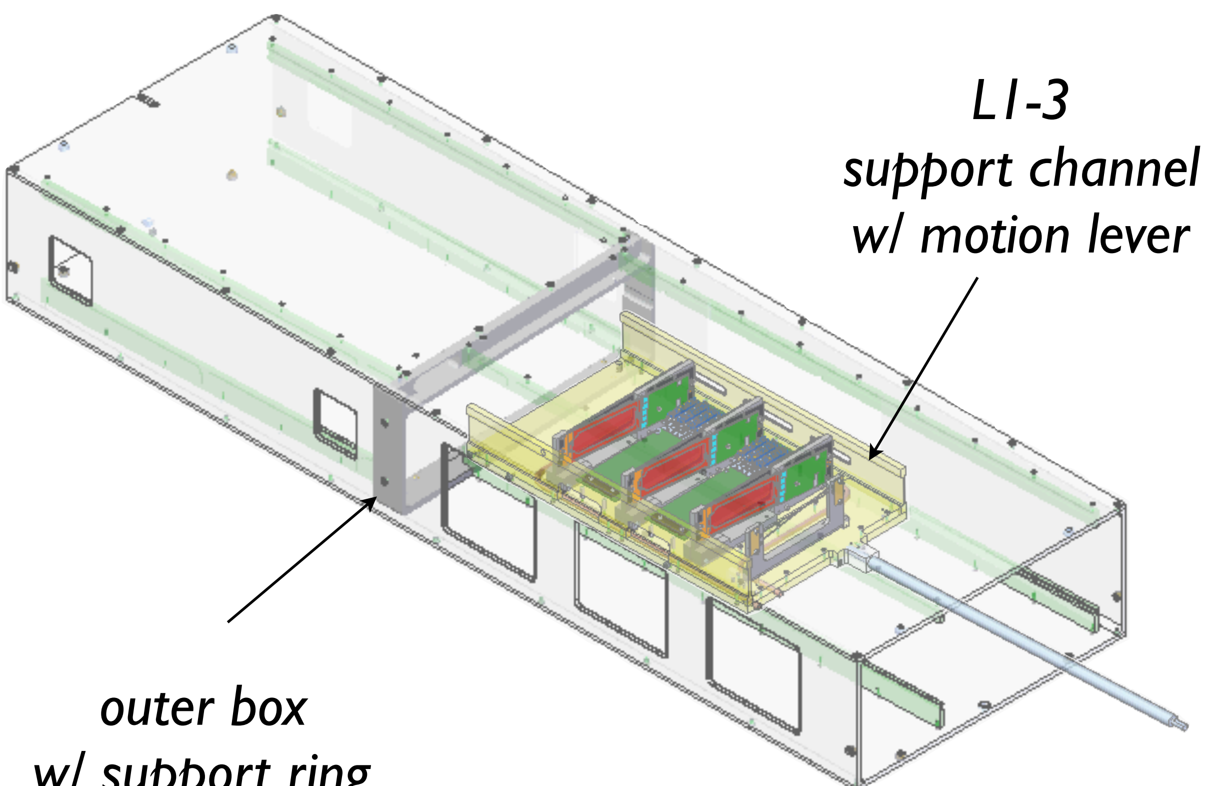
The HPS SVT for 2015-2016

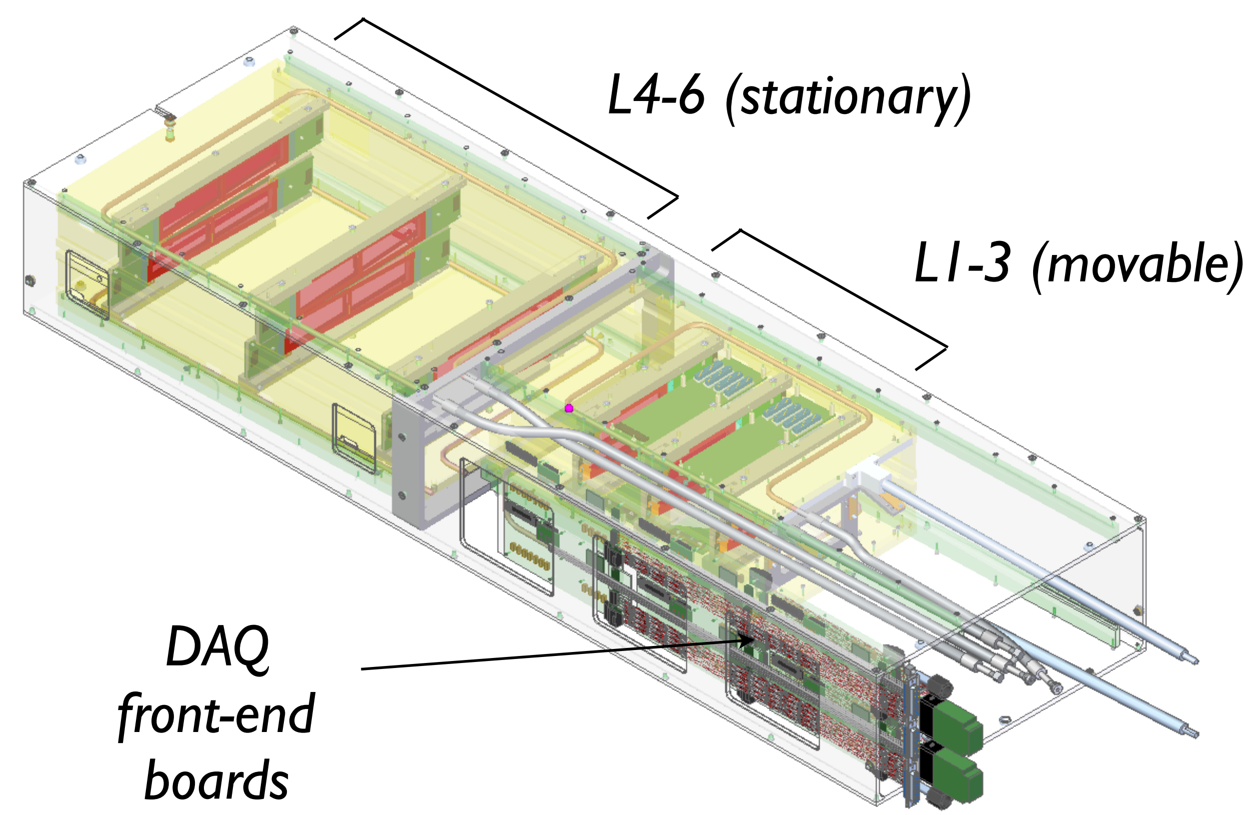
6 layers of silicon strips, each measures position (~6 μm) and time (~2 ns) with 0.7% X_0 / 3d hit.

Must operate in an extreme environment:

- beam vacuum and 1.5 Tesla magnetic field
  ⇒ constrains materials and techniques
- sensor edges 0.5 mm from electron beam in L1
  ⇒ must be movable, serviceable
- sensors see large dose of scattered electrons
  ⇒ must be actively cooled to -20 °C
- 23004 channels can output >100 gb/sec
  ⇒ requires fast electronics to process data





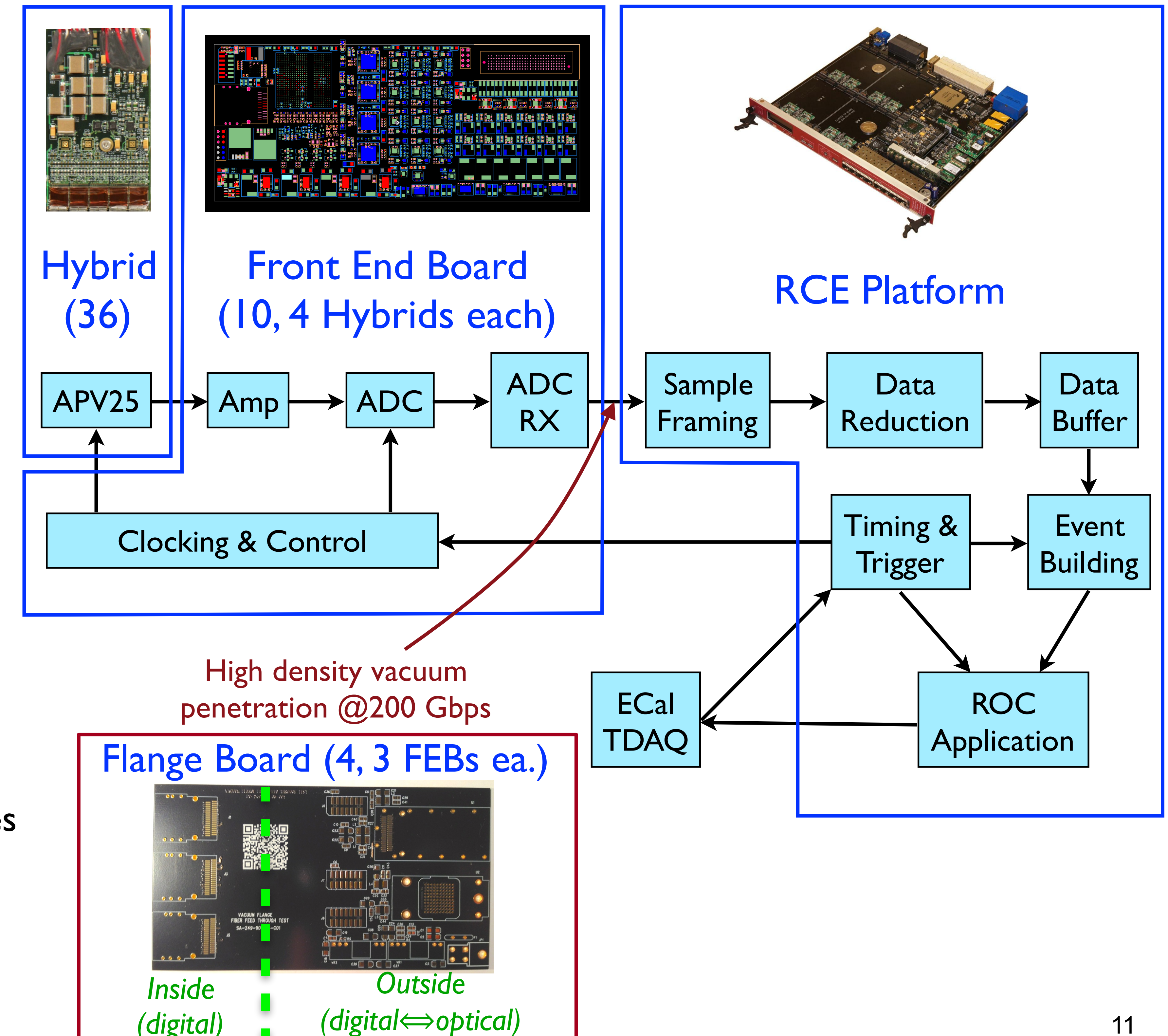


HPS SVT DAQ for 2015-2016

SLAC

- Hybrids hosting 5 CMS APV25 each
- In-vacuum ADC, voltage generation and power distribution/control on Front End Boards
- Penetration for digital signals via high-density PCB through flange. Optical conversion on outside of flange.
- Firmware support for APV25 burst trigger mode (50 kHz trigger rate for 6 samples)
- Wiener MPOD power supplies

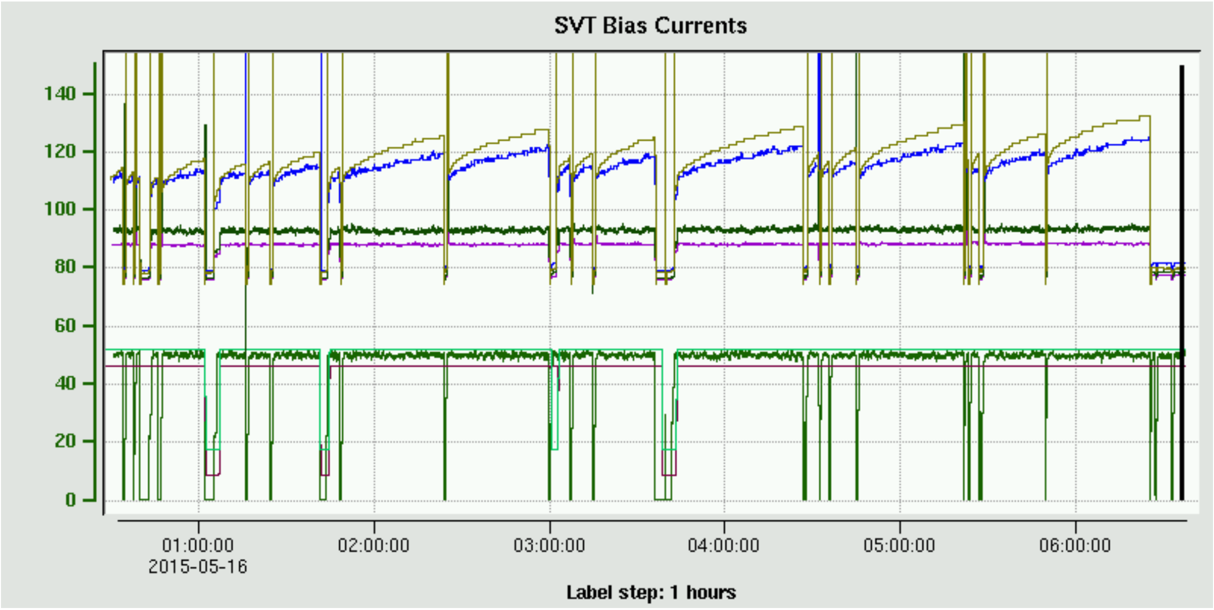
Much more powerful and flexible than test run DAQ.



2015 and 2016 Operations

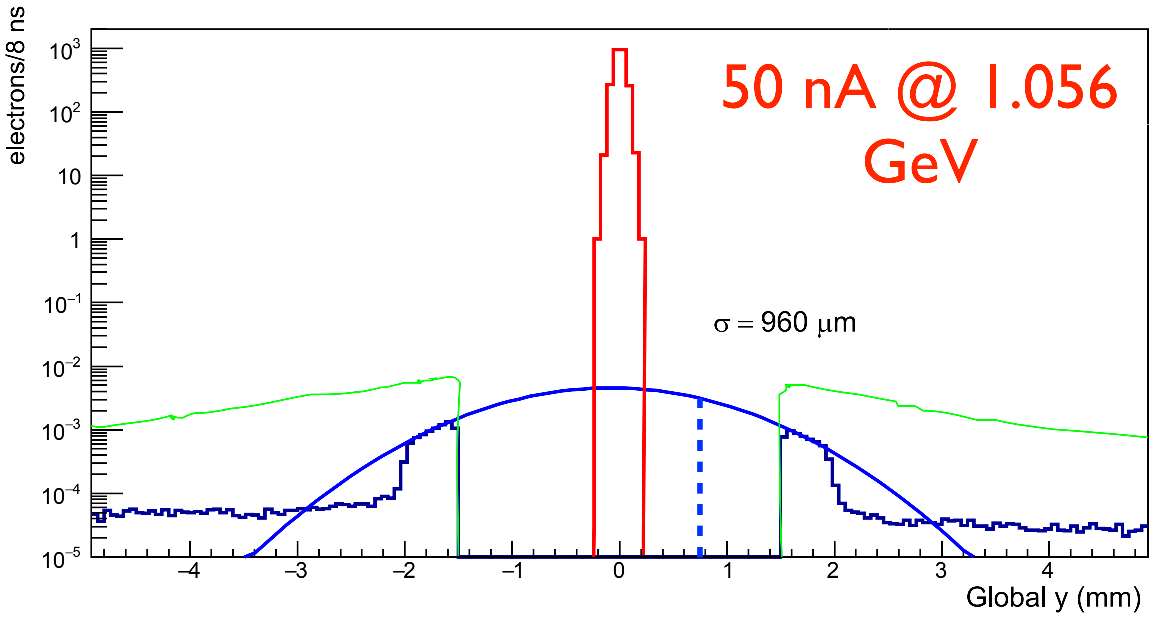
Expected observations

- increases in bias currents from bulk damage
- SEU counts in FEB FPGA monitors, but no clear instances of data corruption



Unexpected observations

- surface currents from x-rays in L1 front side.
- beam tails
- low-charge hits (from high noise) in samples acquired during readout of header (observed at CMS also)
- Problems w/ corruption of SD cards in RCE. *Mitigated by DAQ updates.*



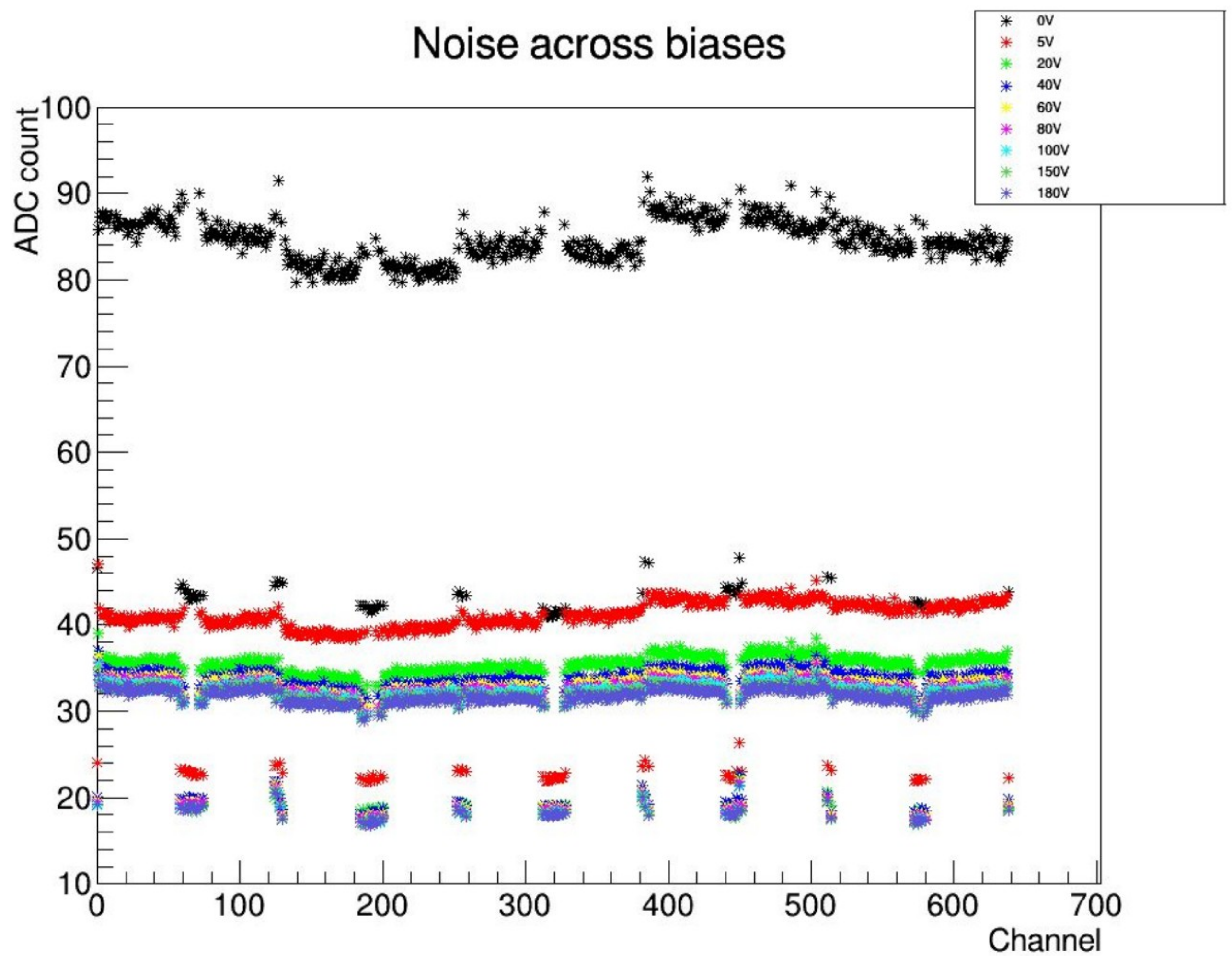
Issues Between 2015 and 2016 Runs

After 2015 run, detector warmed up and put on nitrogen purge for beamline work

A few months later, cooled down again, tested, and put on hibernation at ~0C with switch to HFE7500 to minimize reverse annealing of radiation damage.

Some sections of low-noise channels observed, only on back side of Layer 6 (facing ECal), in the middle of each APV and between APVs.

Those remained stable during/after 2016 run, but some additional similar channels in L1-3, away from beam, again after 2016 run.



study by To Chin You

Wirebond Damage

Cameron's investigations indicate wire bond damage

- Removed Sylgard and wire bonds from one sensor and re-bonded.
- Channels are recovered.

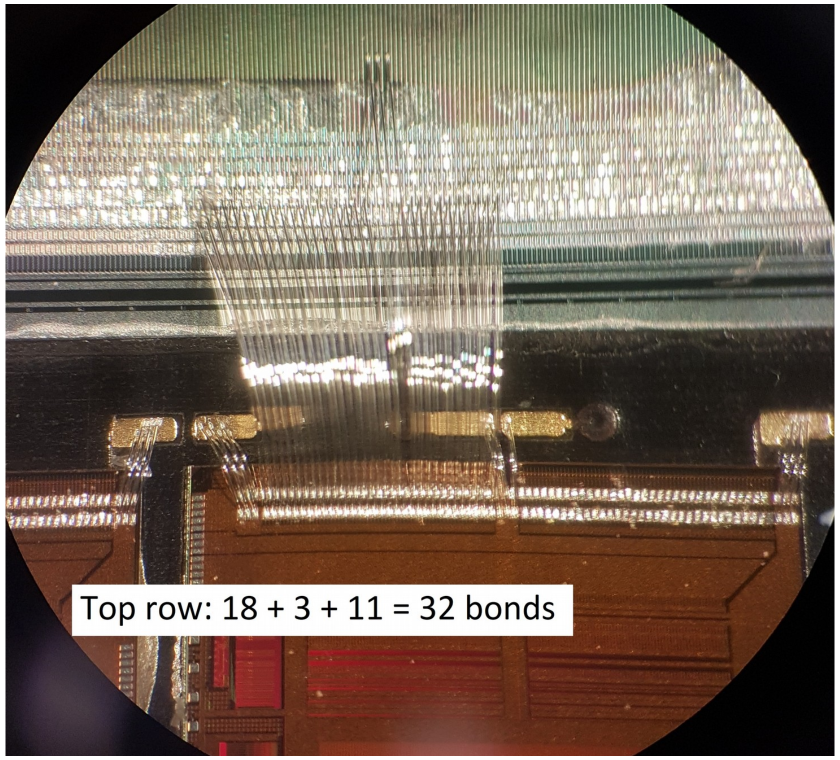
Less clear exactly what caused this

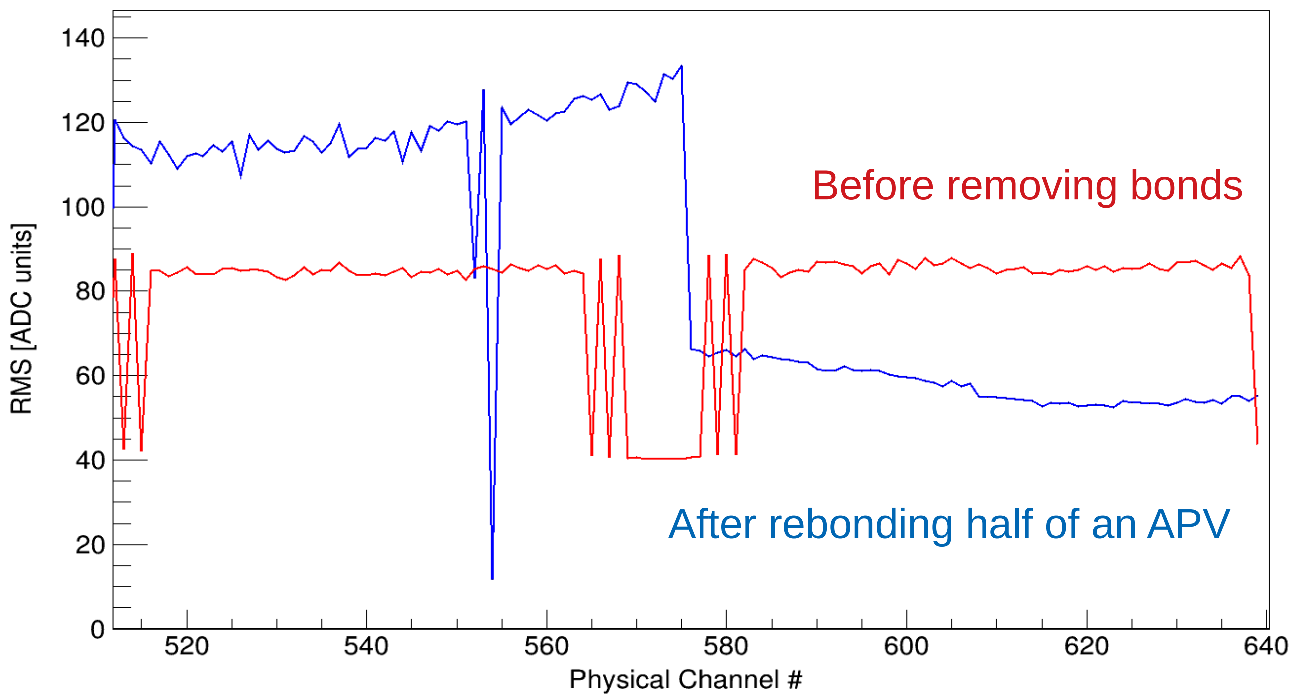
- Sylgard (esp. 186) is tried-and-true material for >30 years. Problems have been rare and involved unusual geometries (not like ours)
- CMS and ATLAS ***had*** recently decided that Sylgard was 100% trusted solution for upgrades.
- Everyone now looking at this more carefully
- CMS starts to see problems with 80C swings.

Localization suggests more than one causative agent

- Entire back of L6 - pump oil contamination? (crude test show ~1% swelling)
- Occasional outer edges of L1-3 - CTE stress (40 C swing gives ~1% differential)

Al-1%Si bond wire breaks at about 1% elongation…





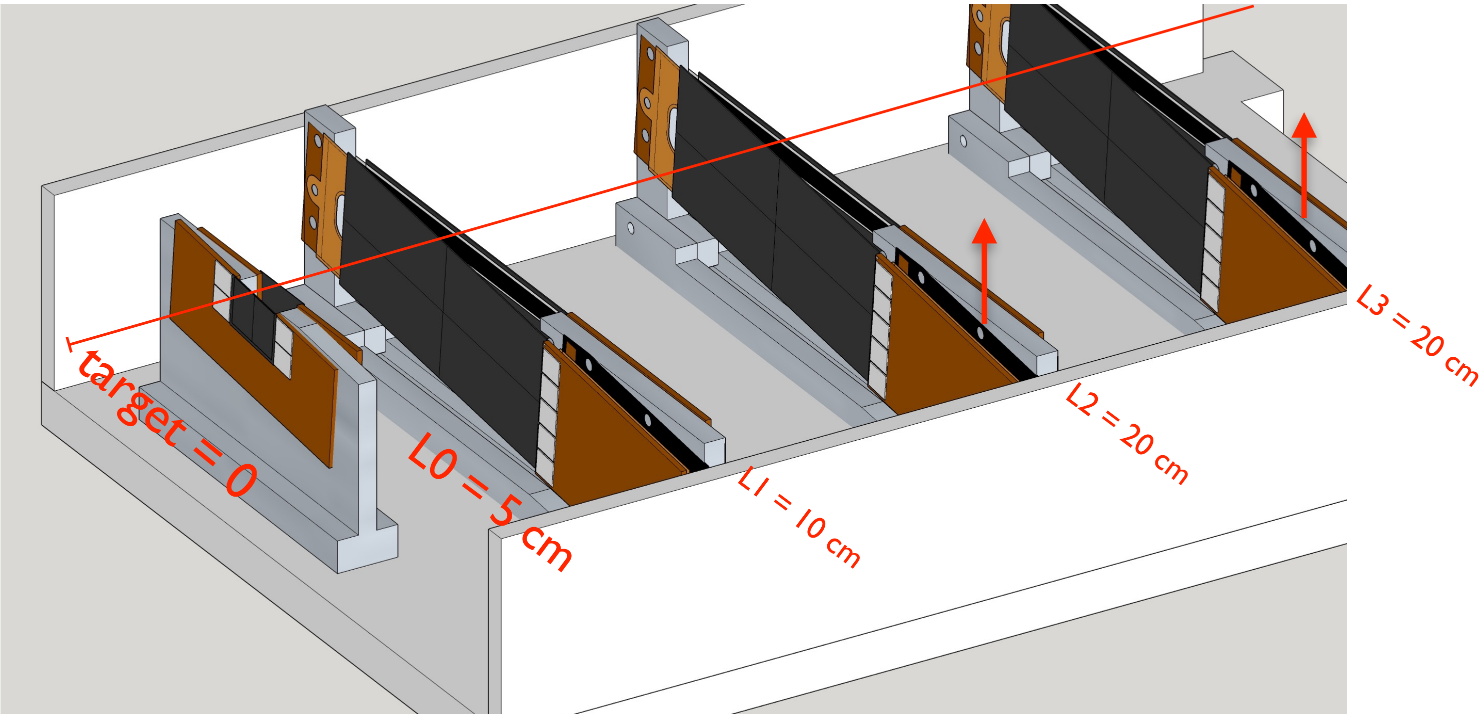
The SVT Upgrade for 2019

SVT Upgrade

Addition of Layer 0, similar in concept to other layers, but…

half the distance to target (5 cm)

roughly half the material (0.4% X_0)



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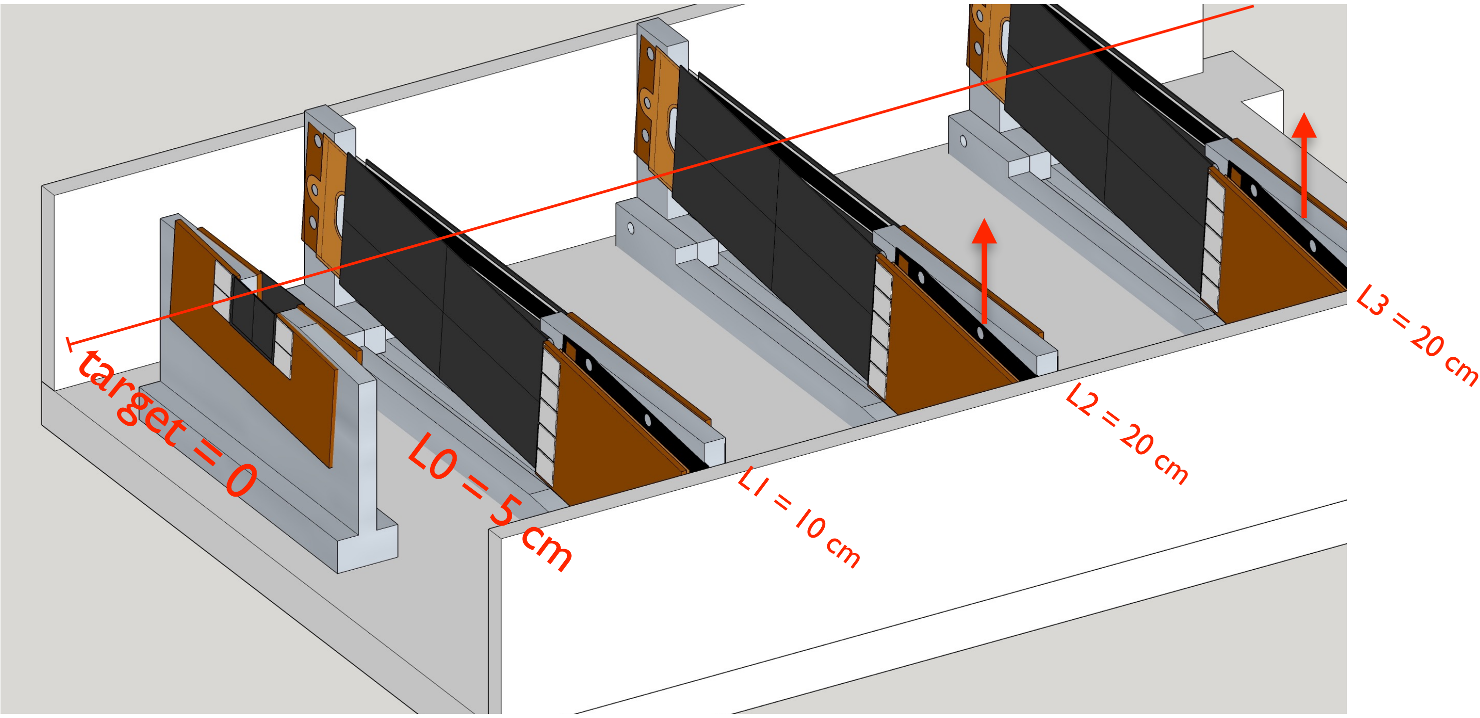
…greatly improves vertex resolution.



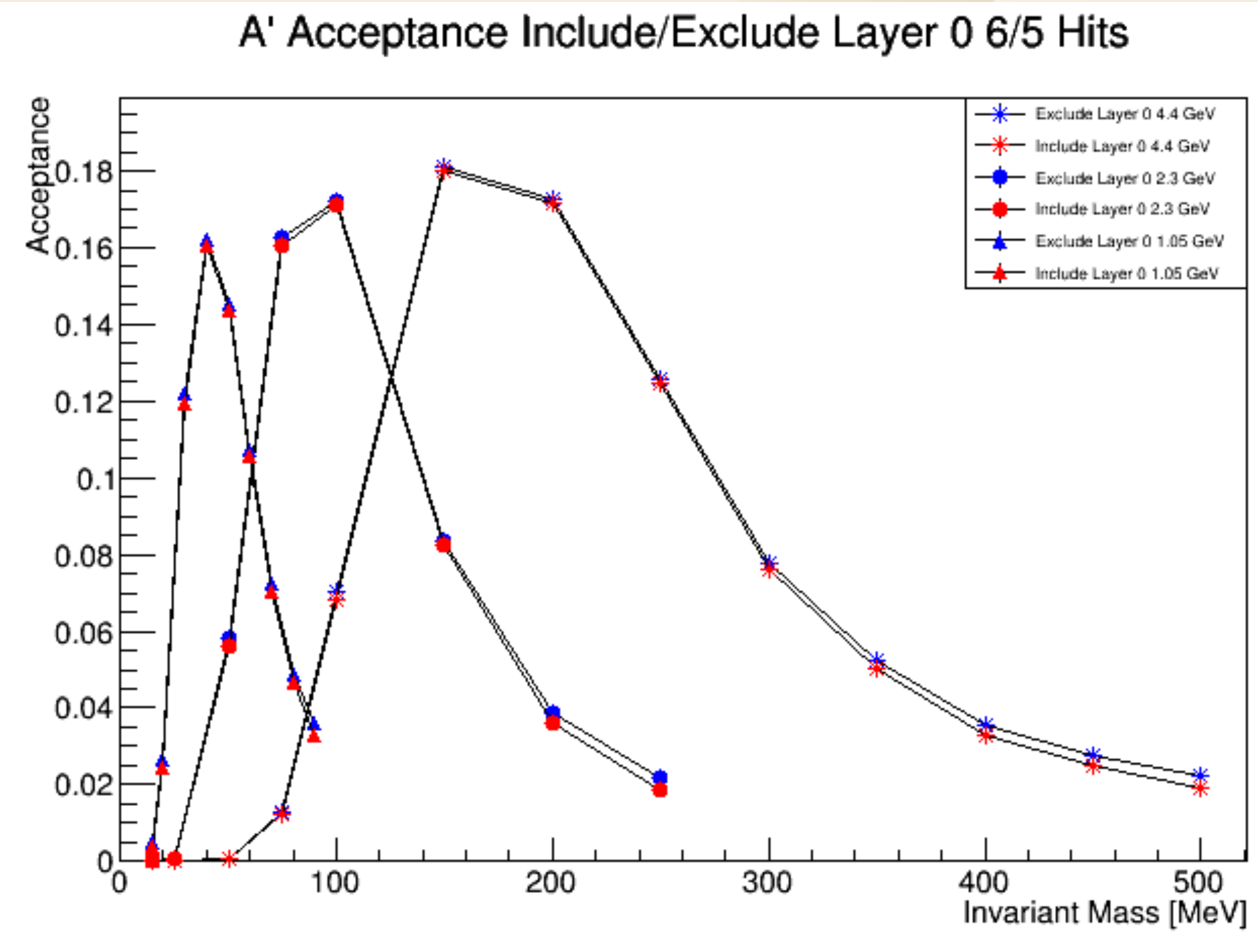
Moving L2 and L3 inward towards beam maximizes acceptance for long-lived A′

Occupancy is acceptable (similar to L1) for 0.7mm move

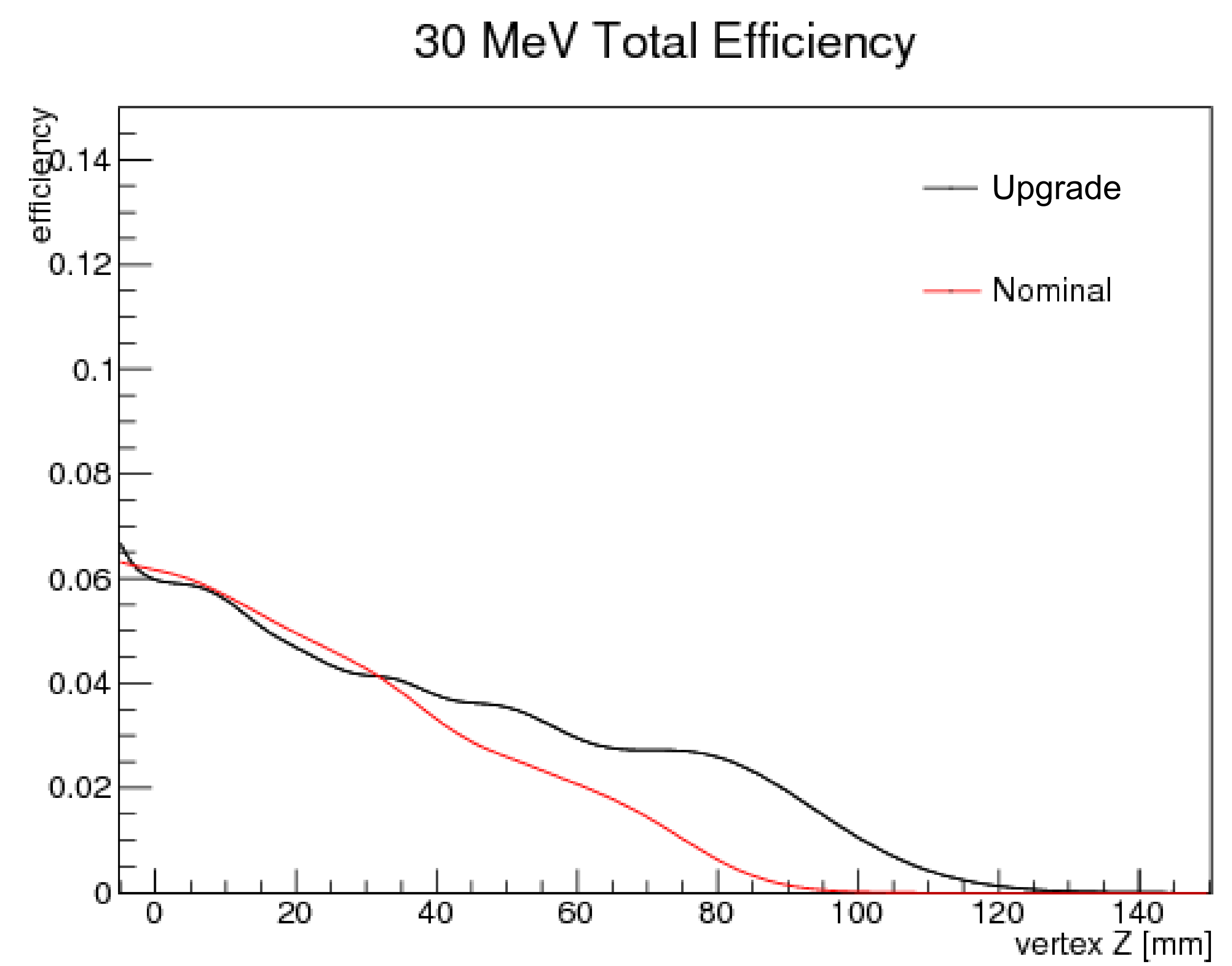
Easily accomplished with the addition of thin shims under L2, L3 supports

Acceptance and Efficiency

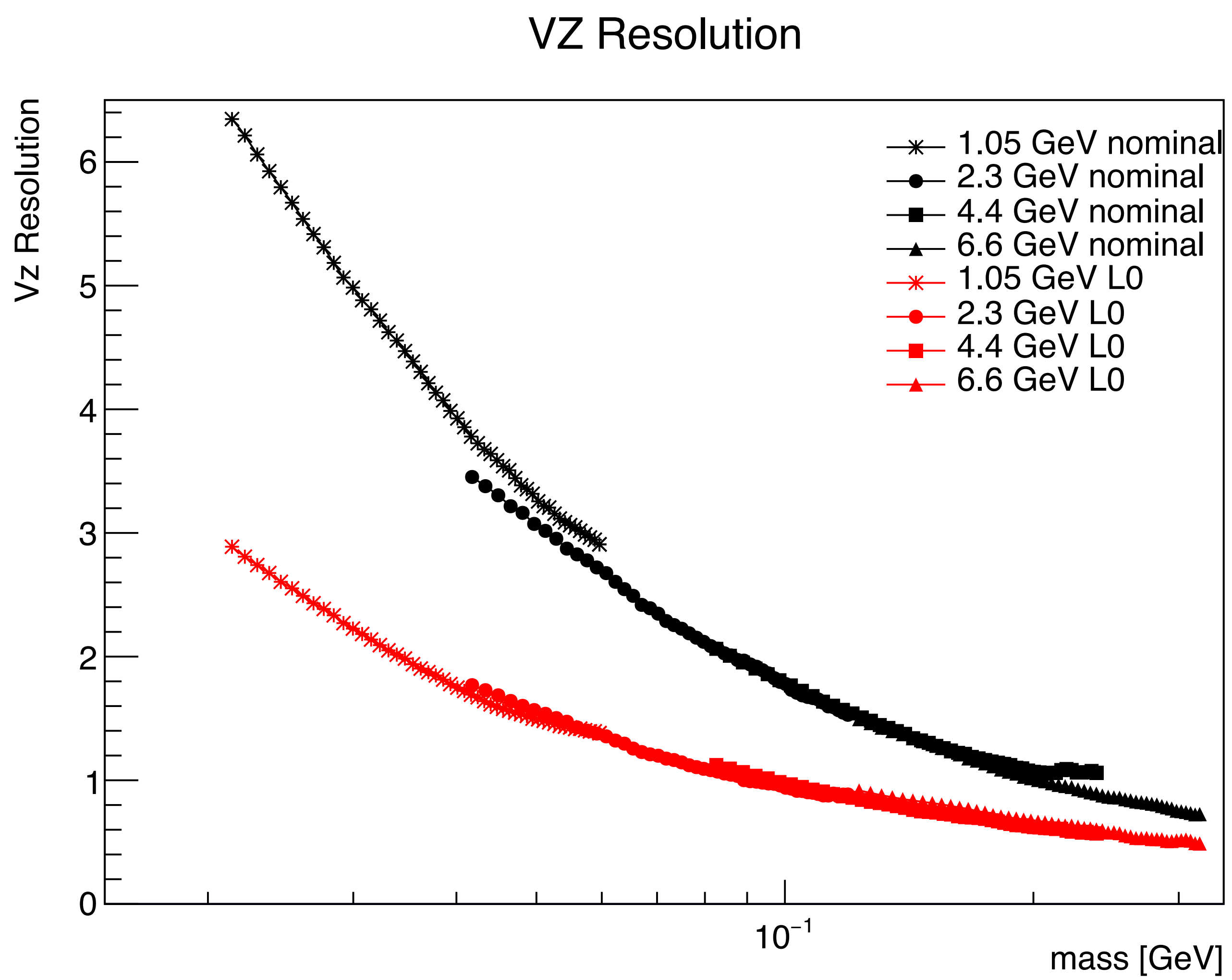
Layer 0 has full acceptance and good efficiency for tracks accepted by the rest of the tracker.

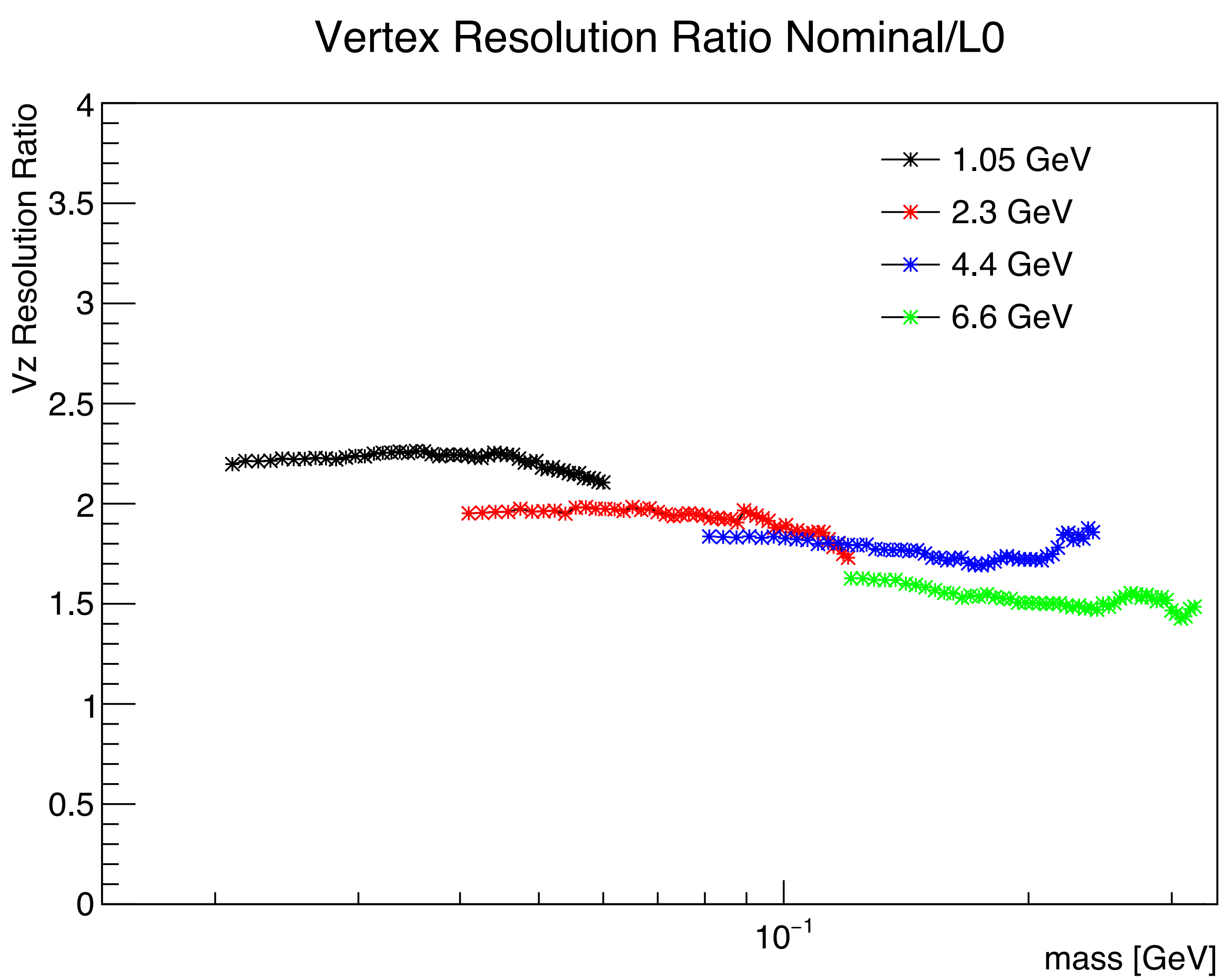


Moving Layers 2 and 3 inwards increases acceptance for long-lived A′ daughters as expected.

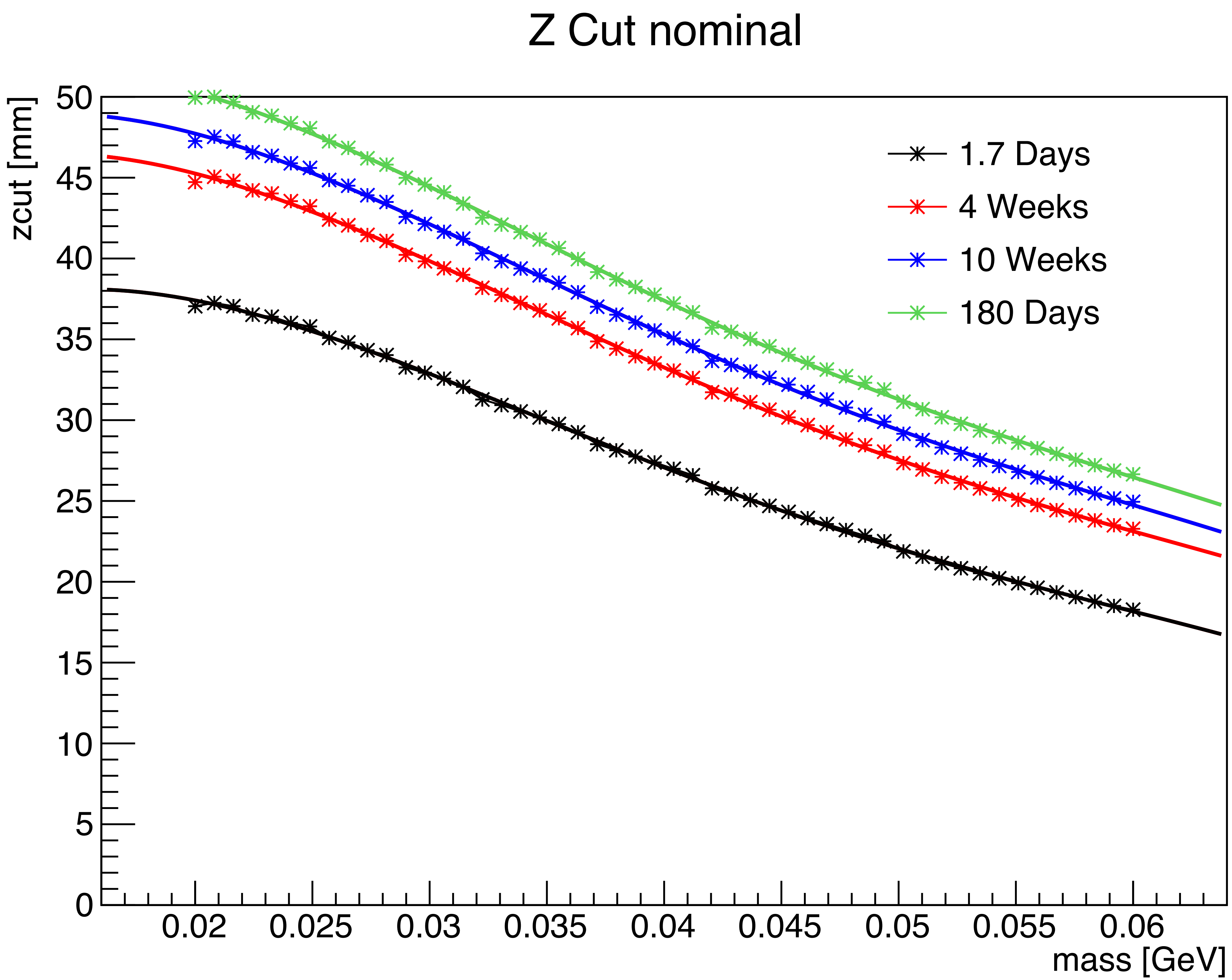


Vertex Resolution





Z Cut for 0.5 Events Expected Background



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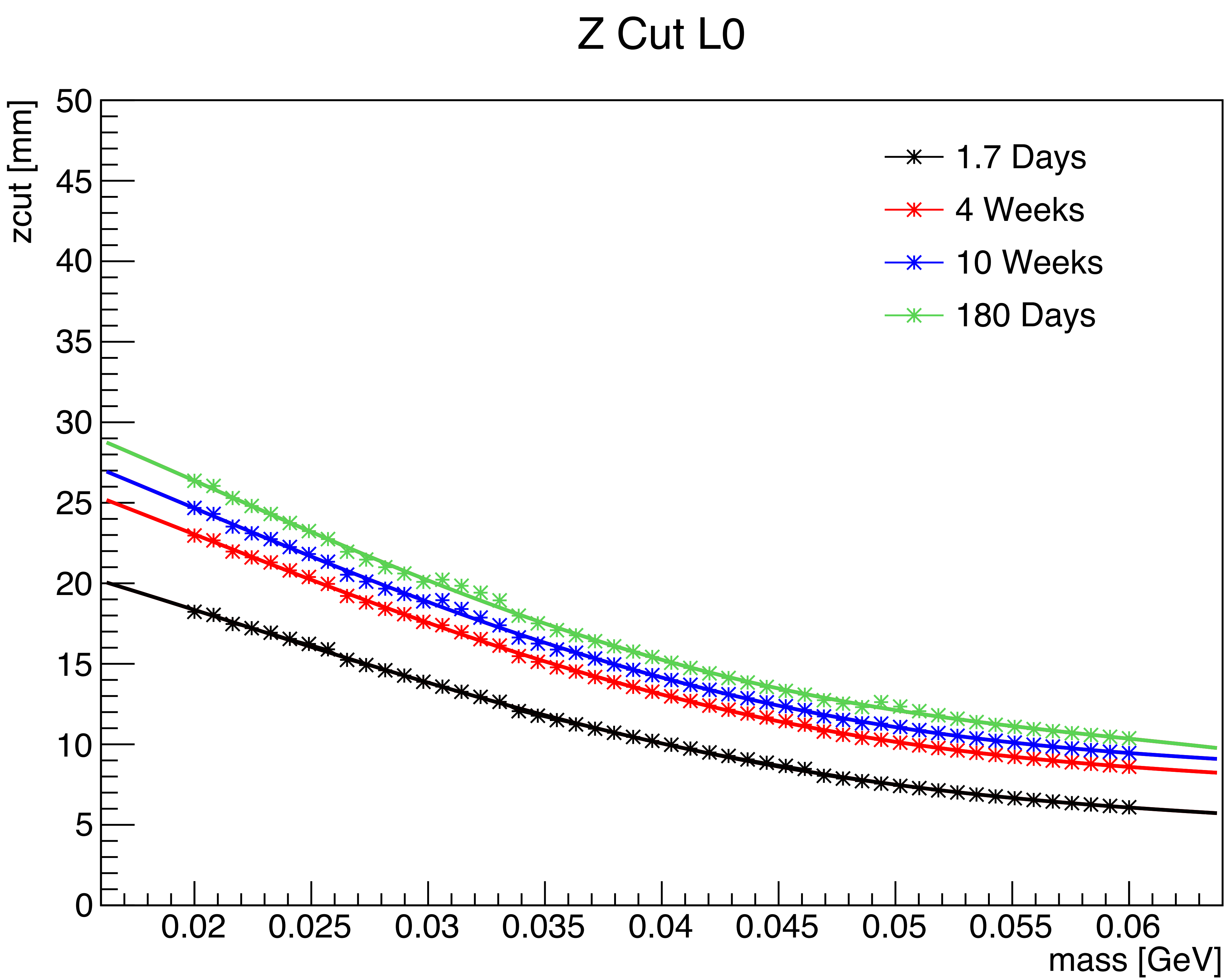
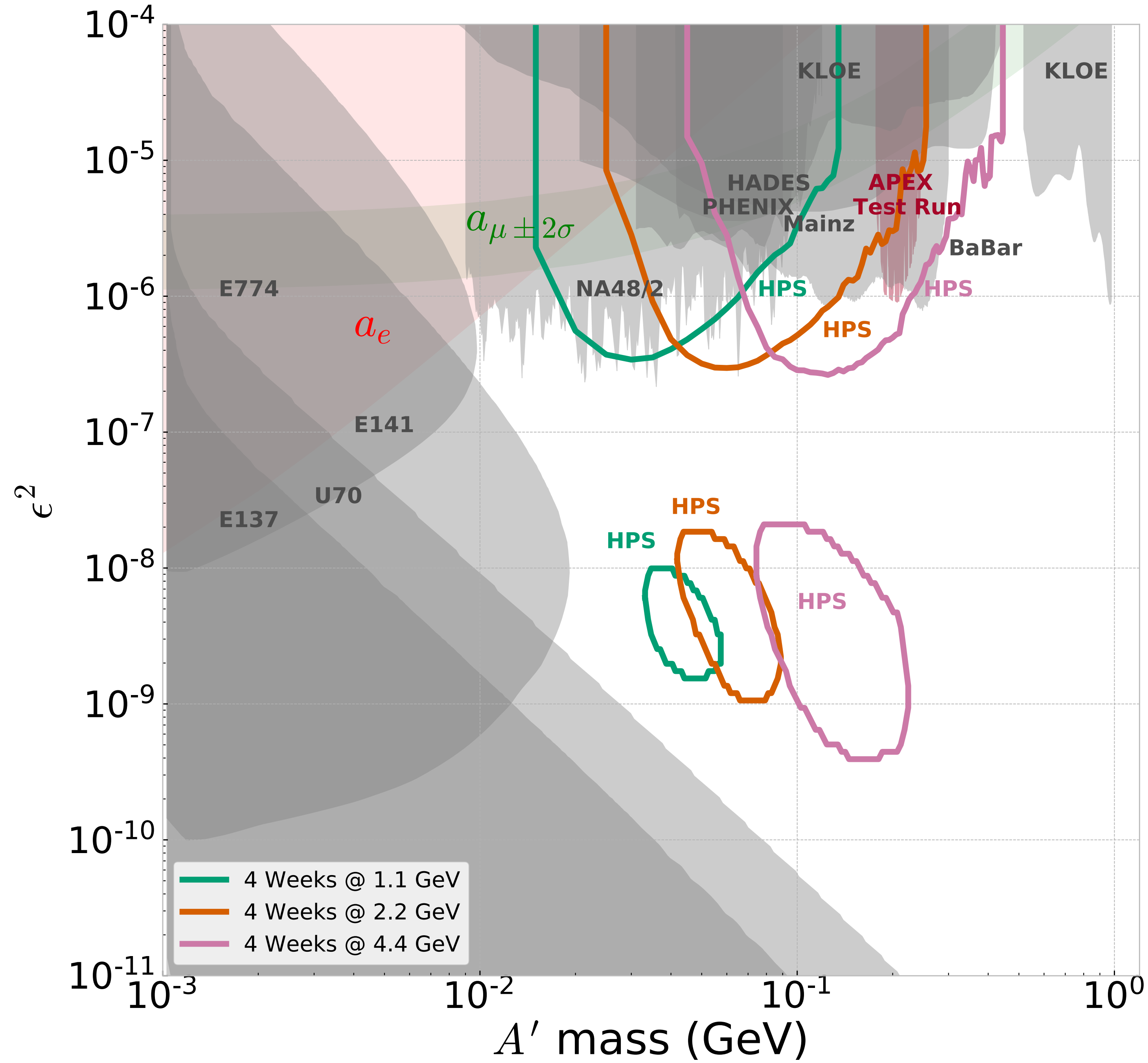


Upgraded Reach



Layer 0 is critical to improving sensitivity with the upgrades.

Option: Replacement of Layer 1

Inactive silicon at the edge of Layer 1 creates some difficult backgrounds

- conversion of wide-angle brems
- tridents from scattered electrons

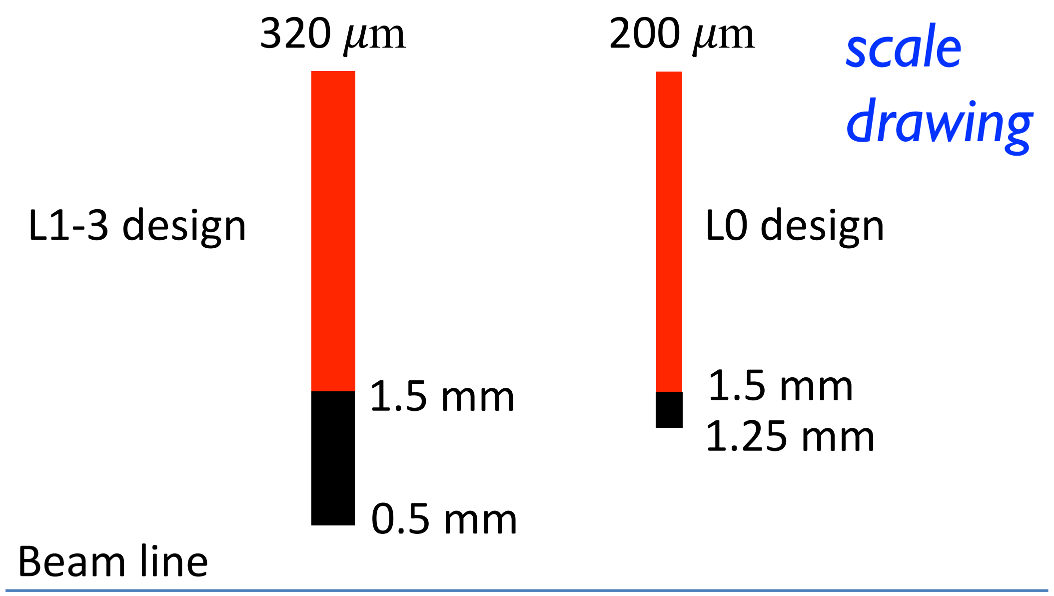
Layer 1 operates near the occupancy limit, but most of Layer 1 area has no useful occupancy

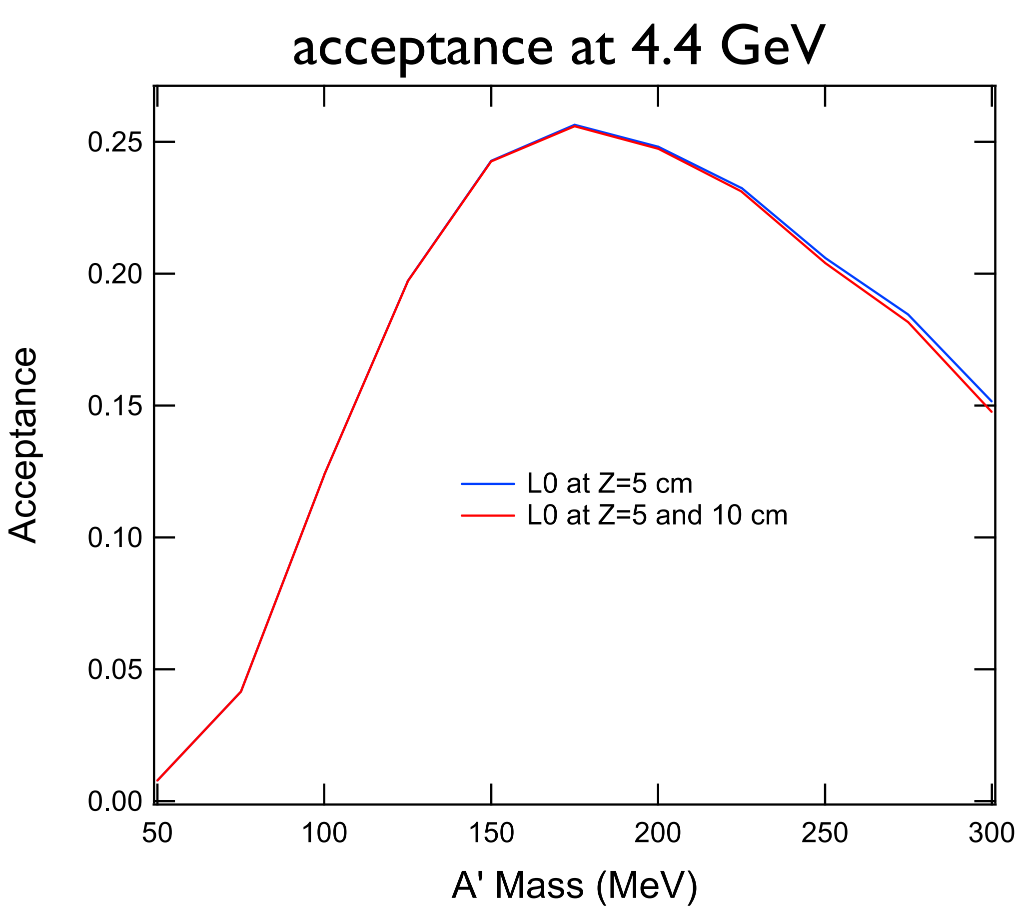
⇒Replace Layer 1 with Layer 0 modules?

Also allows moving Layer 1 inward to more closely match L2/L3 acceptance so more long-lived particles will have an L1 hit.

- Layer 1 can be moved in by 0.4 mm.
- Allowed for this possibility in conceptual design

Additional sensitivity from this change still not assessed but could be large.





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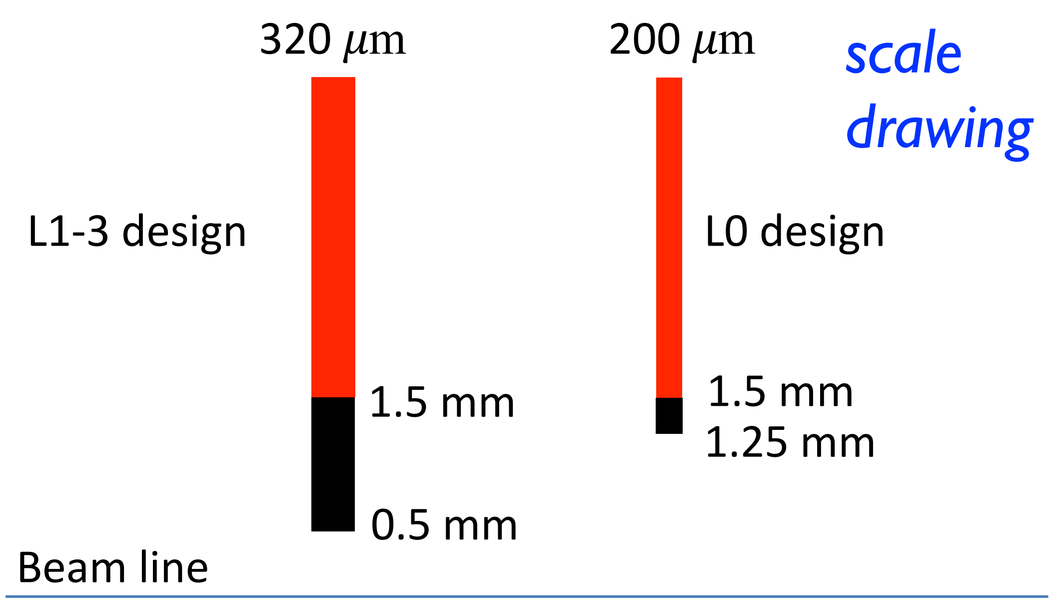

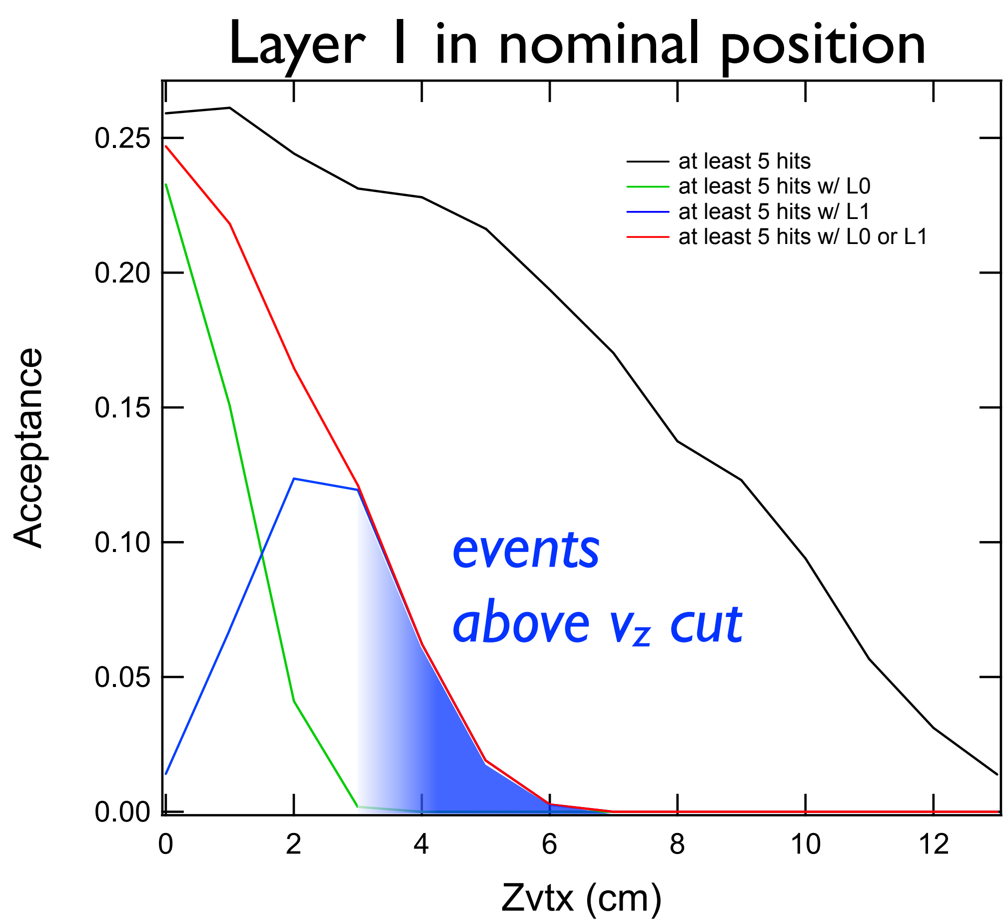

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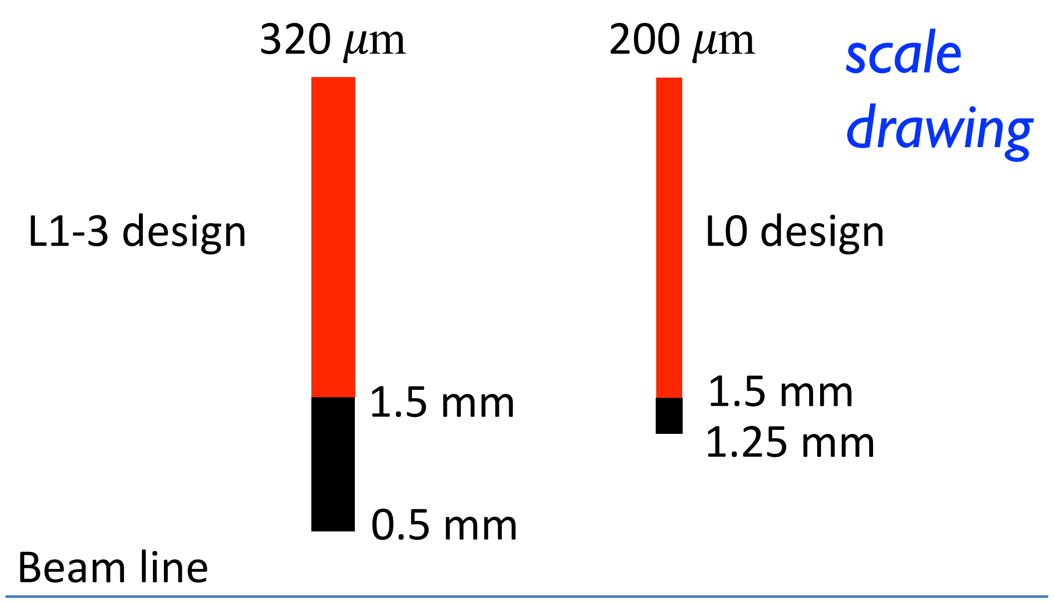
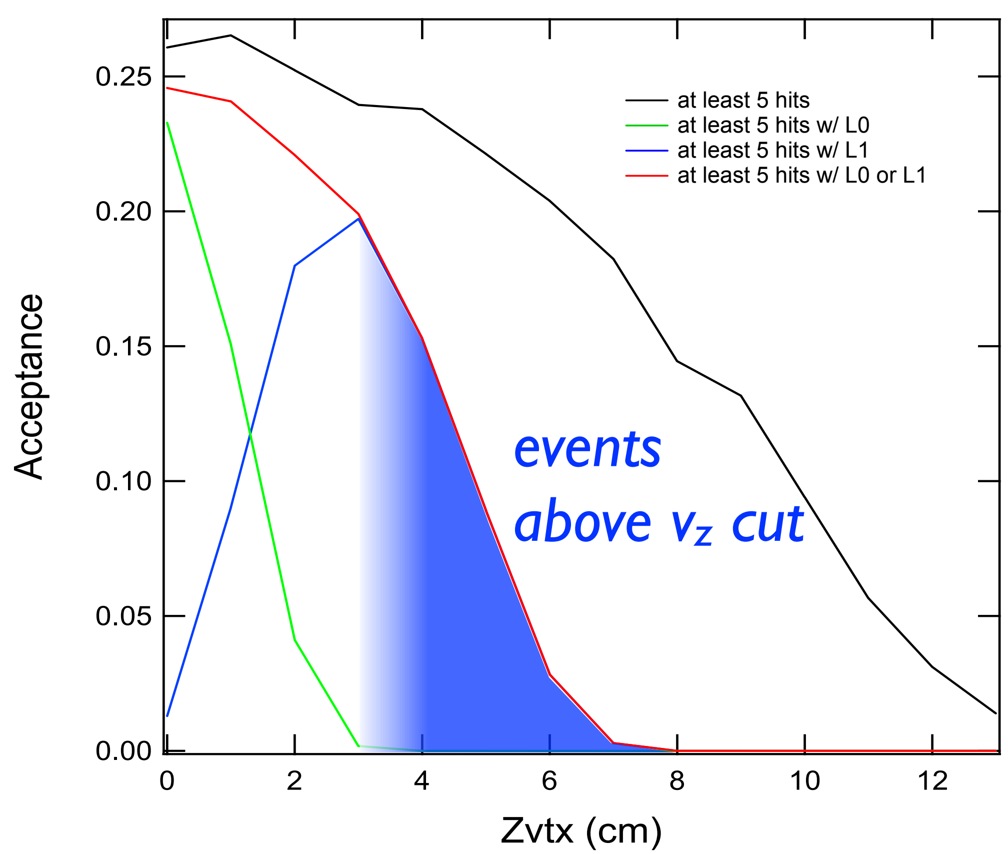


move L1 in 0.4 mm



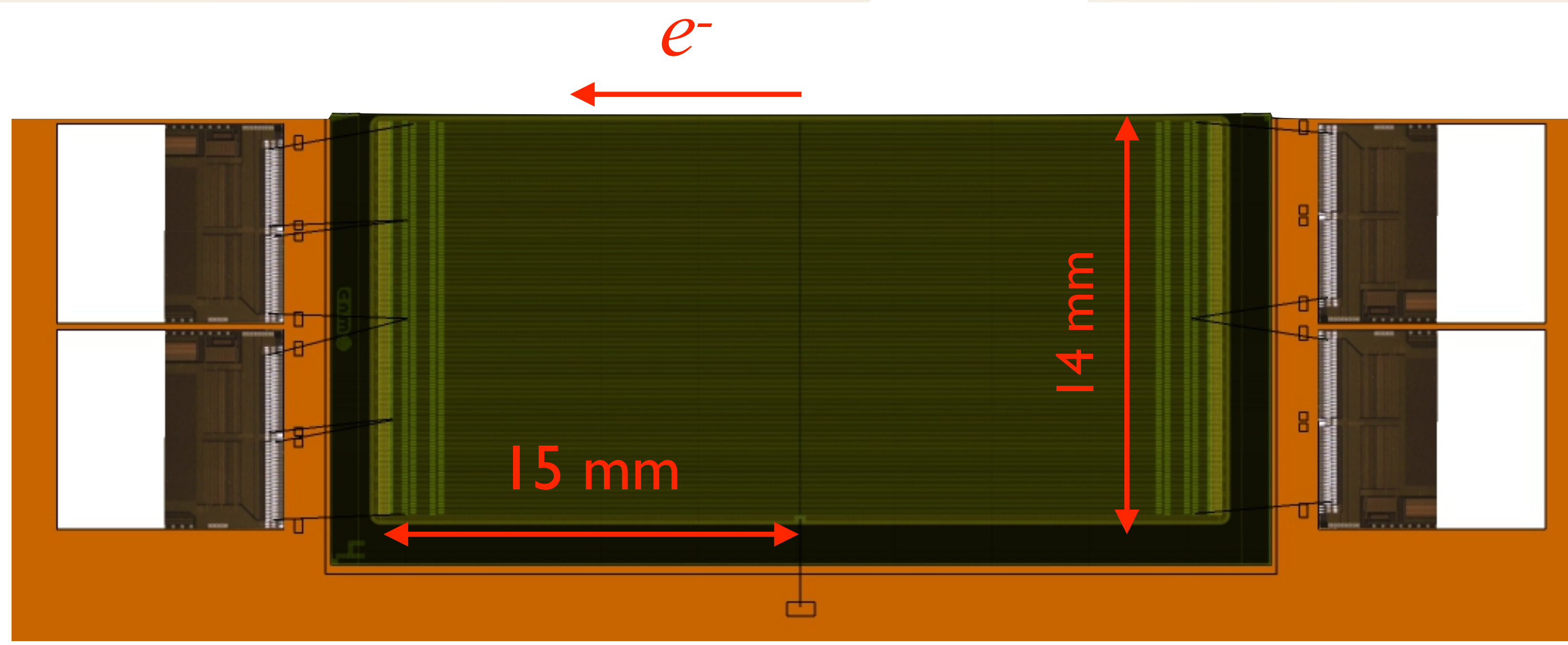
Layer 0 Sensor

Design specifications:

- thickness: 200 um
- sense/readout pitch: 55 um
- active areas: 2×(15 mm × 14 mm)
  (shorts strips reduce noise and physics occupancy to acceptable levels)
- # channels: 510 (2×255)
- slim edge: 250 um
  (Sensor edge 500 um from beam gives same acceptance as L1)
- breakdown voltage: 500V
- rate of bad channels: <1%

Vendor, CNM, missed on all three criteria

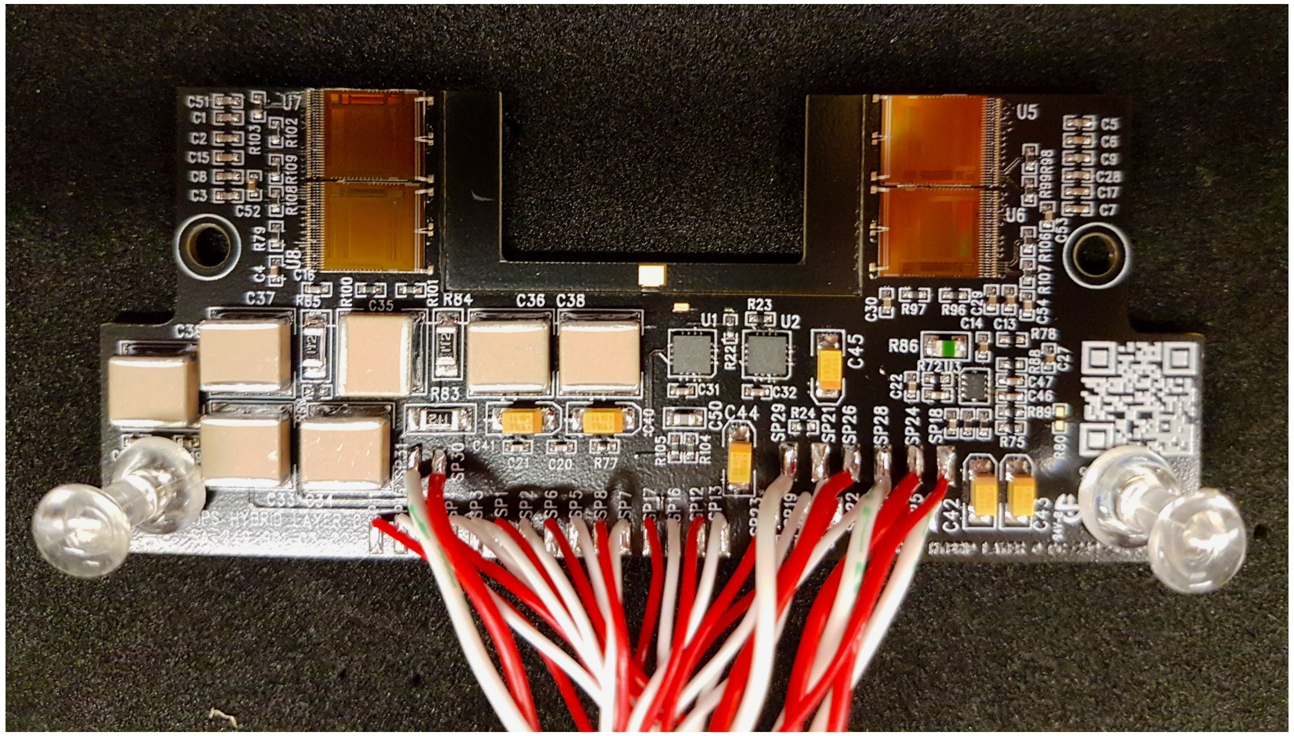
- Selected best slim edges (300-400 microns)
- Selected best breakdown voltages (250-400V)
- Developed bad channel criteria based on whether they were in our acceptance in L0/L1 (≲2% in acceptance).

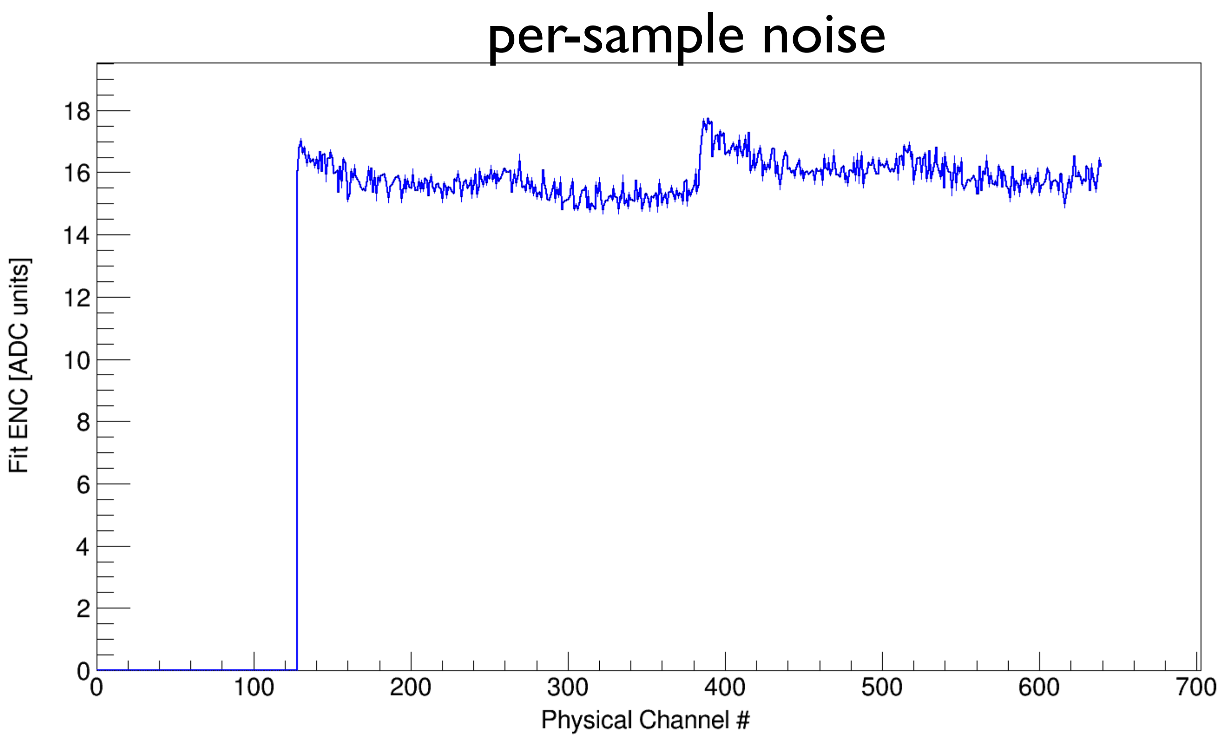


Layer 0 Hybrids

Hybrids utilize same basic schematic but very different layout.

- Received hybrids in early December
- First production hybrid was assembled and tested at SLAC/UCSC before the holidays.
- Expected performance for a bare hybrid, roughly 500 e^- noise.
- No major surprises during hybrid assembly and loading
- Note use of pigtail like Test Run modules used in Layers 1-3. Allows plug-and-play DAQ using spare capacity.





Layer 0 Half-Module Production

First module, using low-quality sensor, also went together well

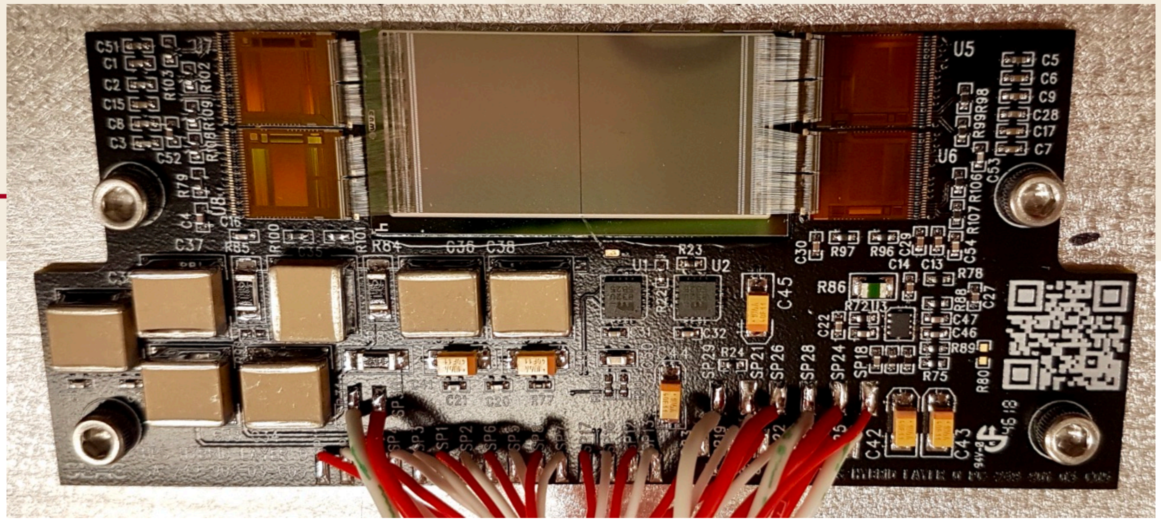
Noise as expected: ~700 e^-

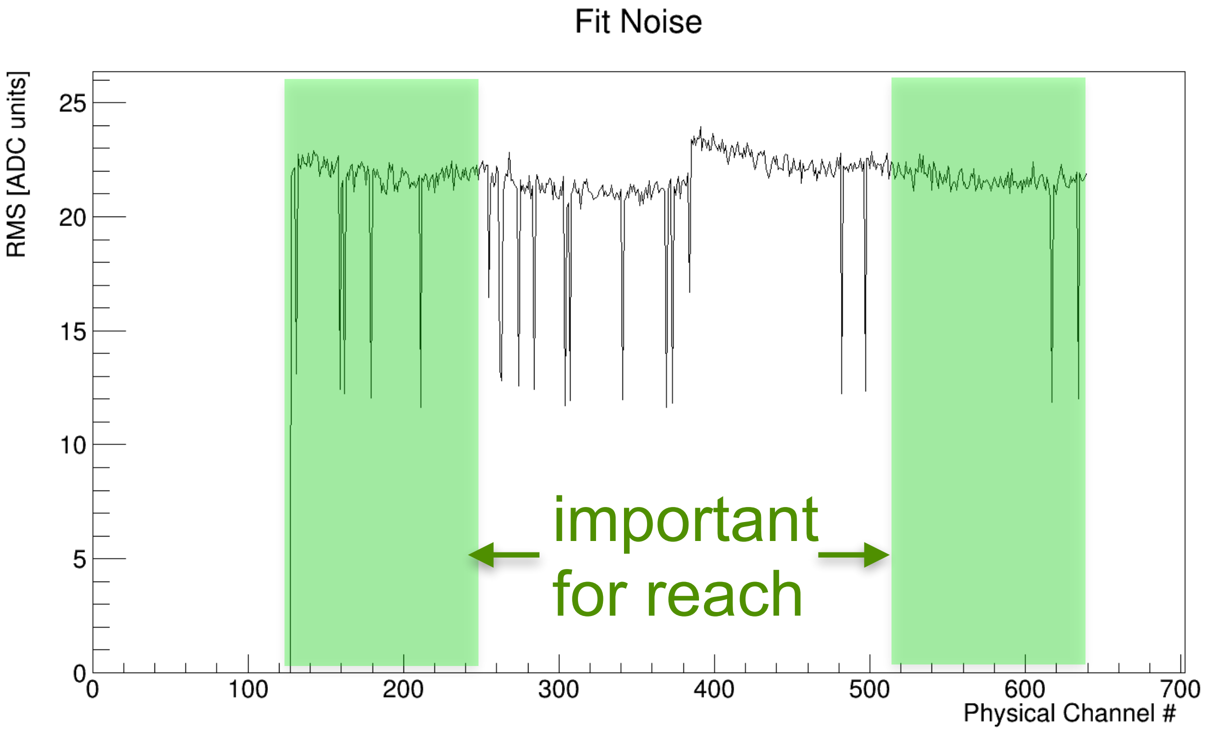
Encountered many unreported bad channels (pinholes)

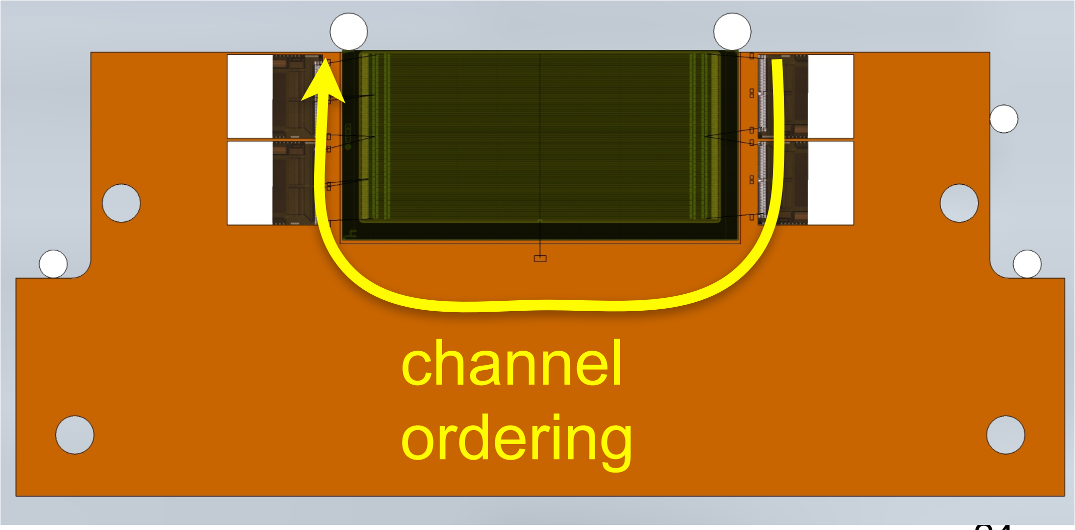
Some sensors had bad channel lists with no correspondence to *any* sensor that we could identify.

and then…

L0 M0 ("the gimp")







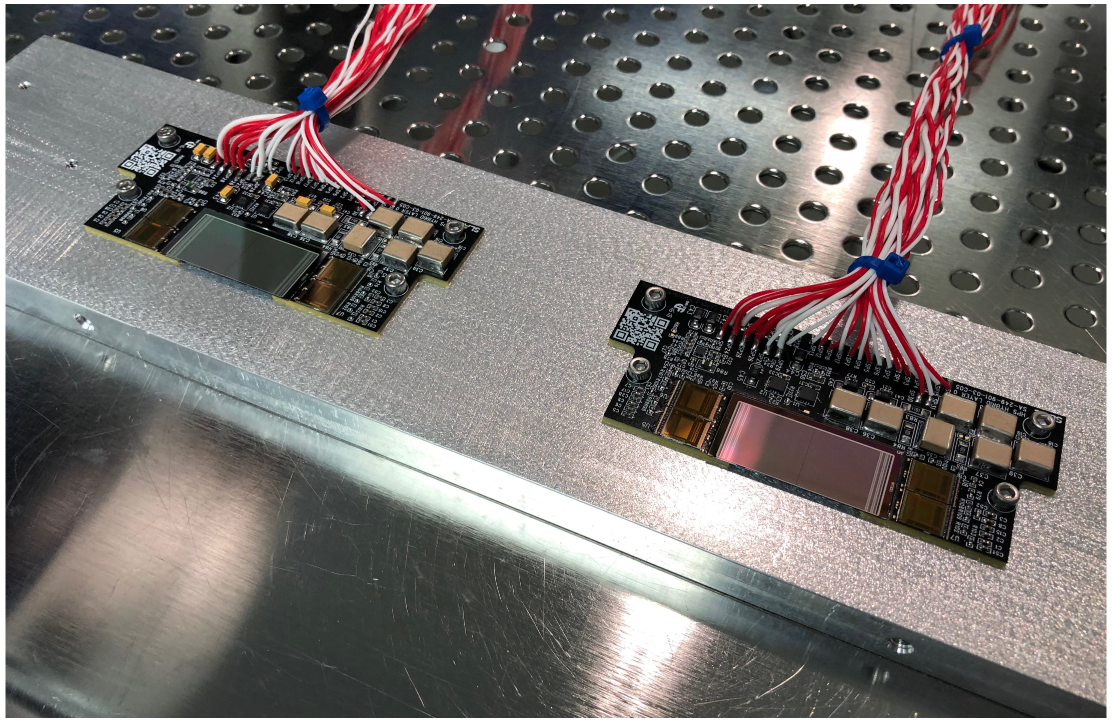
Layer 0 Sensors - First Shipment

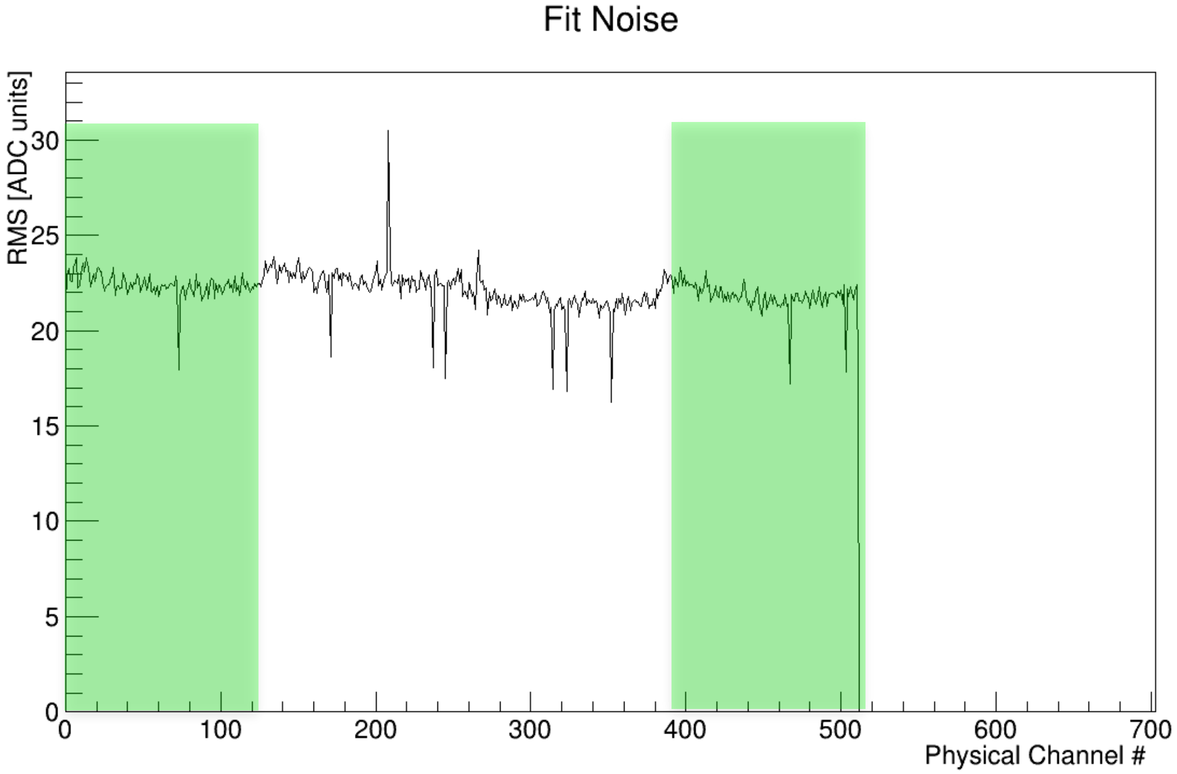
Packed for shipping in light-hold Gel-packs!

Layer 0 Half-Module Production

SLAC

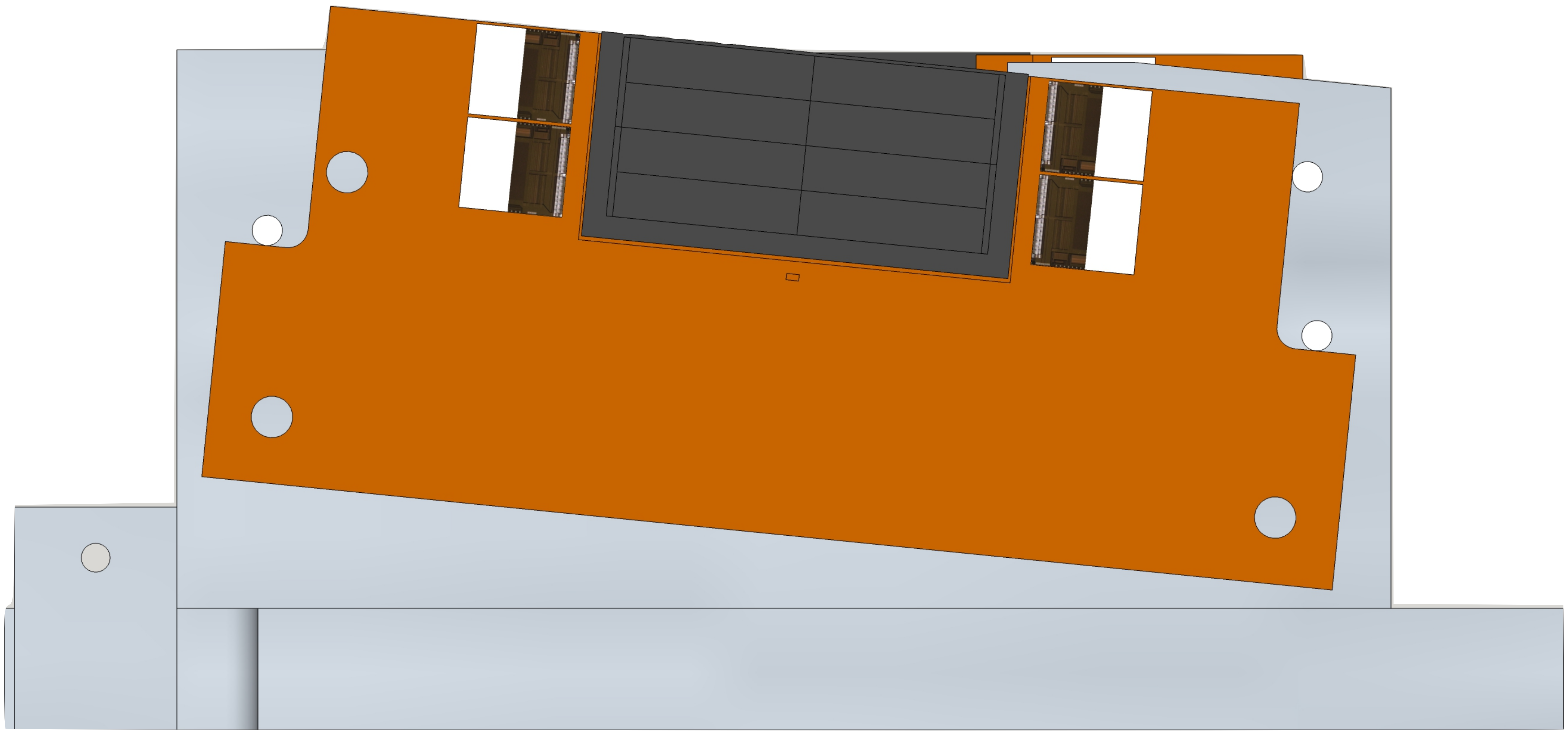
- First sensor shipment, poorly processed, some damaged due to improper packaging.
- Spent all time contingency understanding mitigations before instructing vendor on final processing and shipping remainder
  - ensuring our procedures not doing damage
  - baking sensors to grow oxide
  - investigate of alternate cleaving techniques
- Second shipment better. Of 20 modules built, 10 meet quality requirements, 8 of those use sensors from second shipment!
- Numbers allow L0 and replacement of L1, with bad channel rate of 1-2% (2015 detector was 1/10000) and *one* good spare stereo pair.
- Module production/testing completed 4/19, 1 month later than scheduled





Layer 0 Full Module Design

Similar to, but simpler than other layers: a solid Al cooling block.



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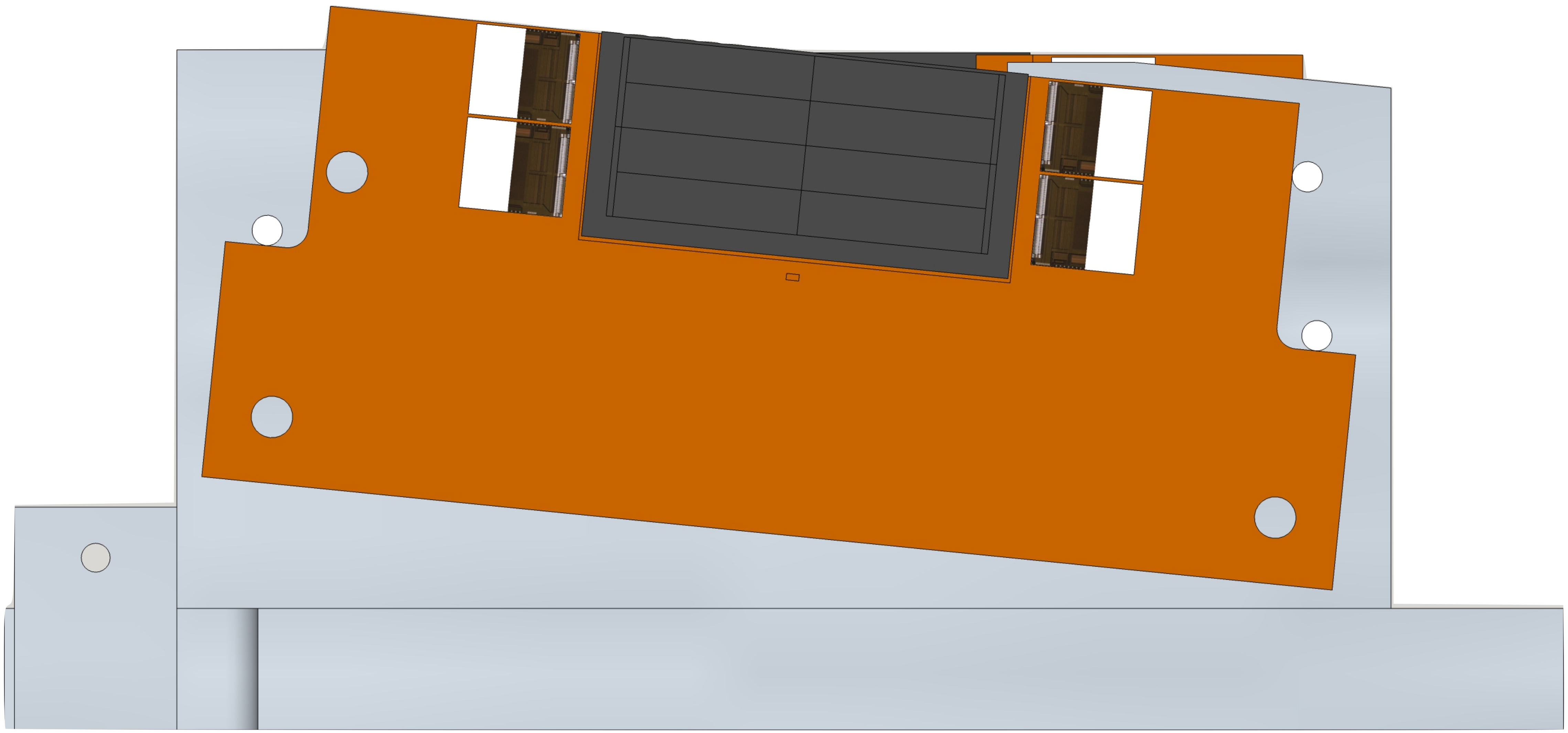

Angular acceptance of cooling block begins at 300 mrad, outside of SVT acceptance and where rate of brems is suppressed by >6 orders of magnitude.

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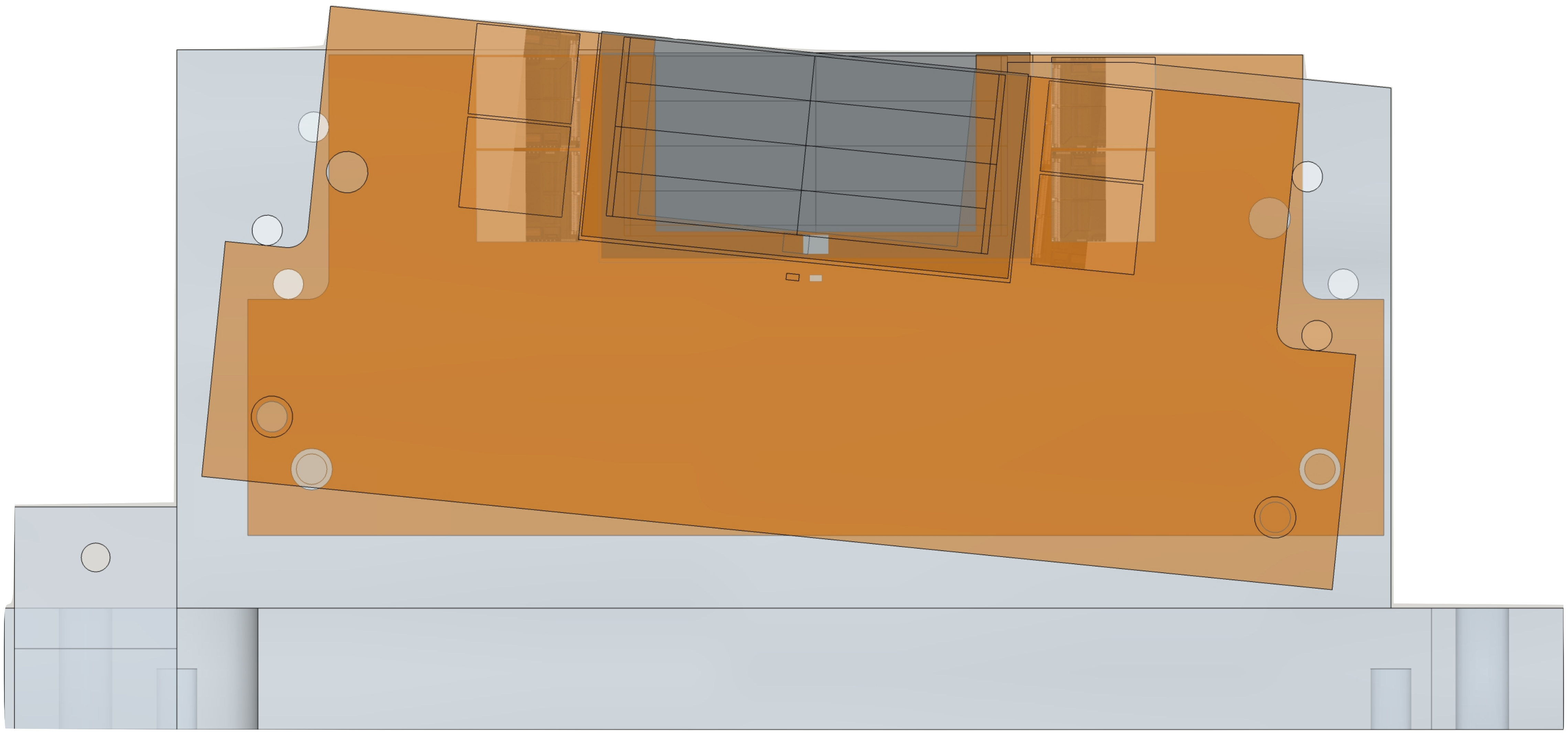

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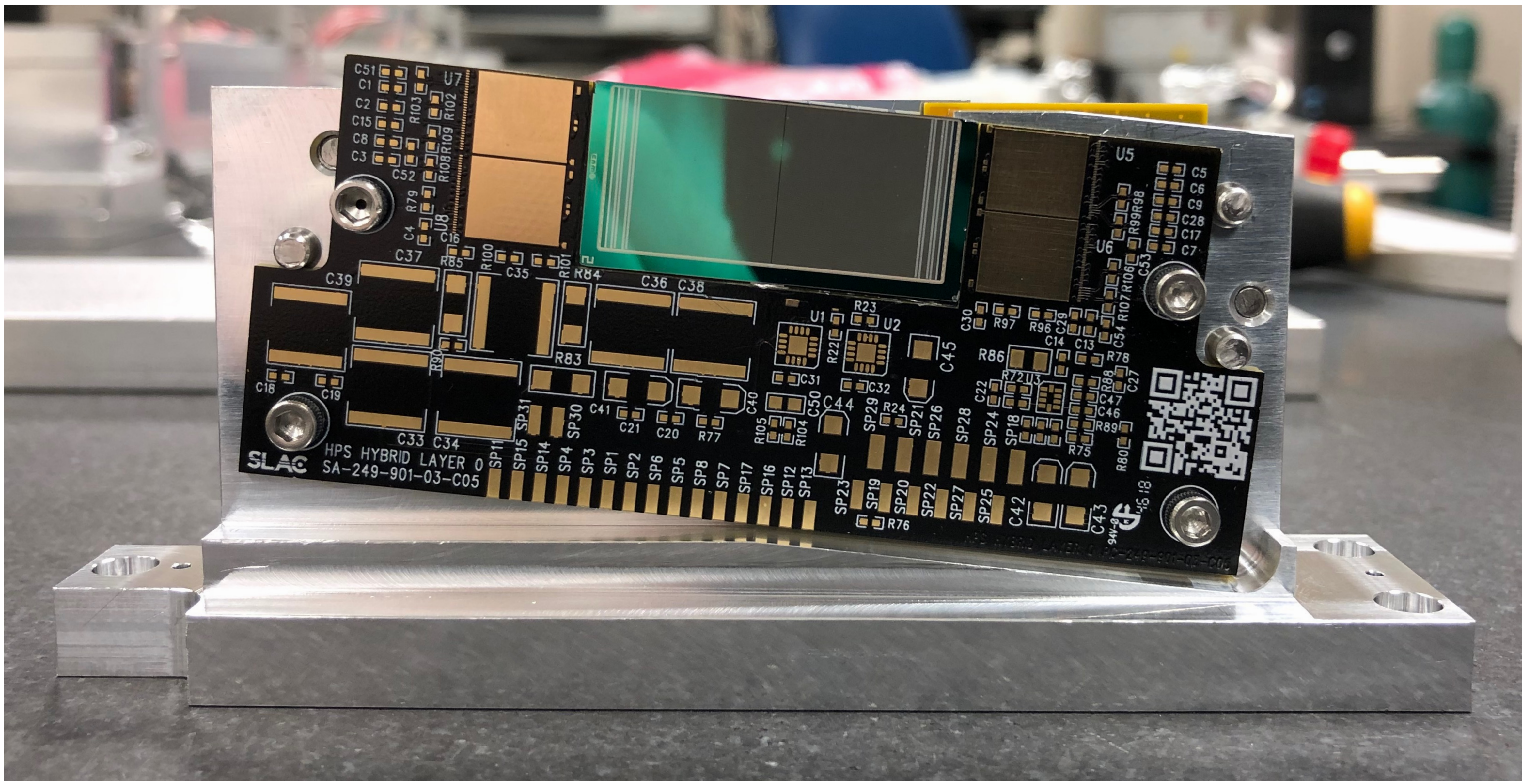
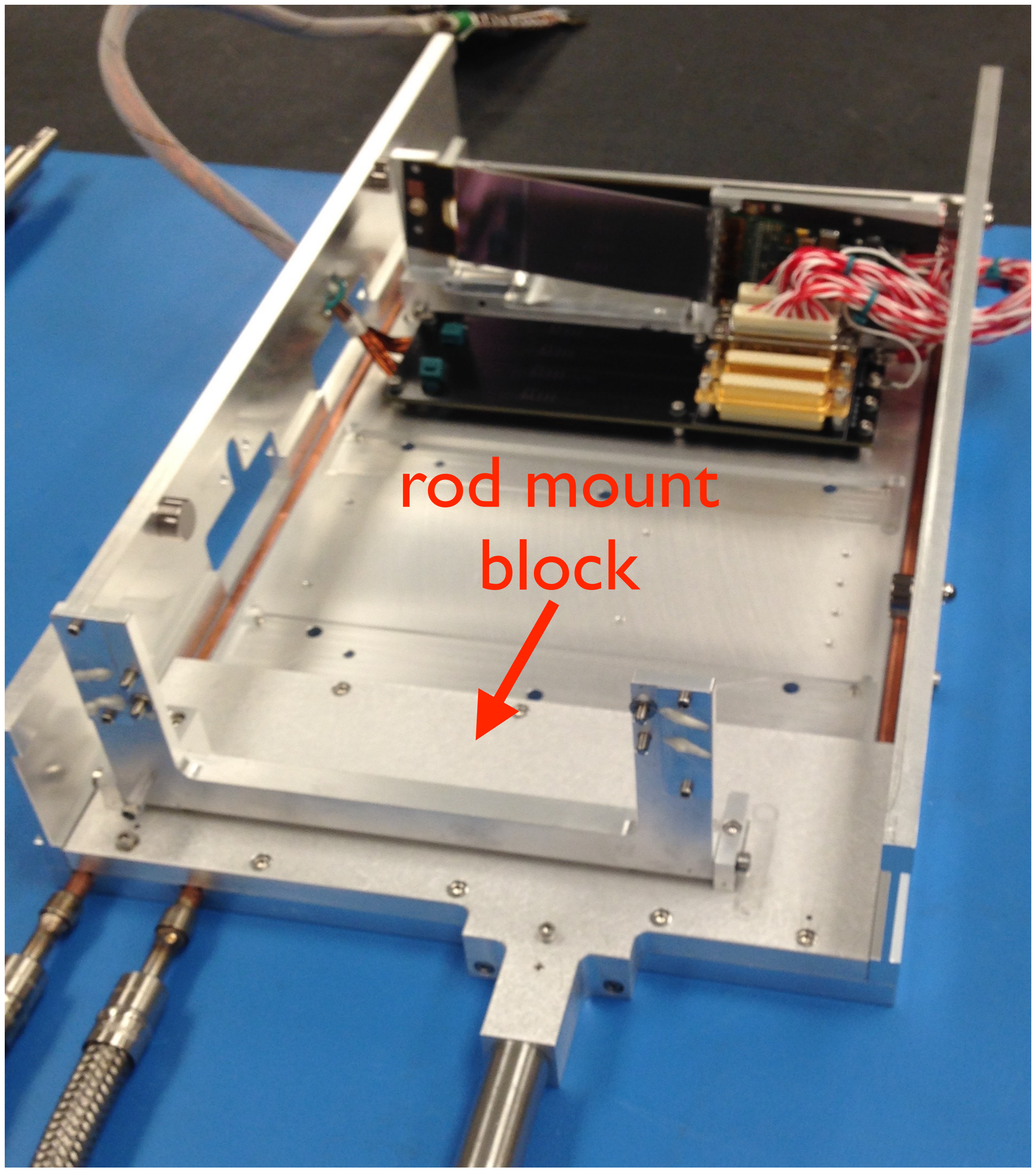
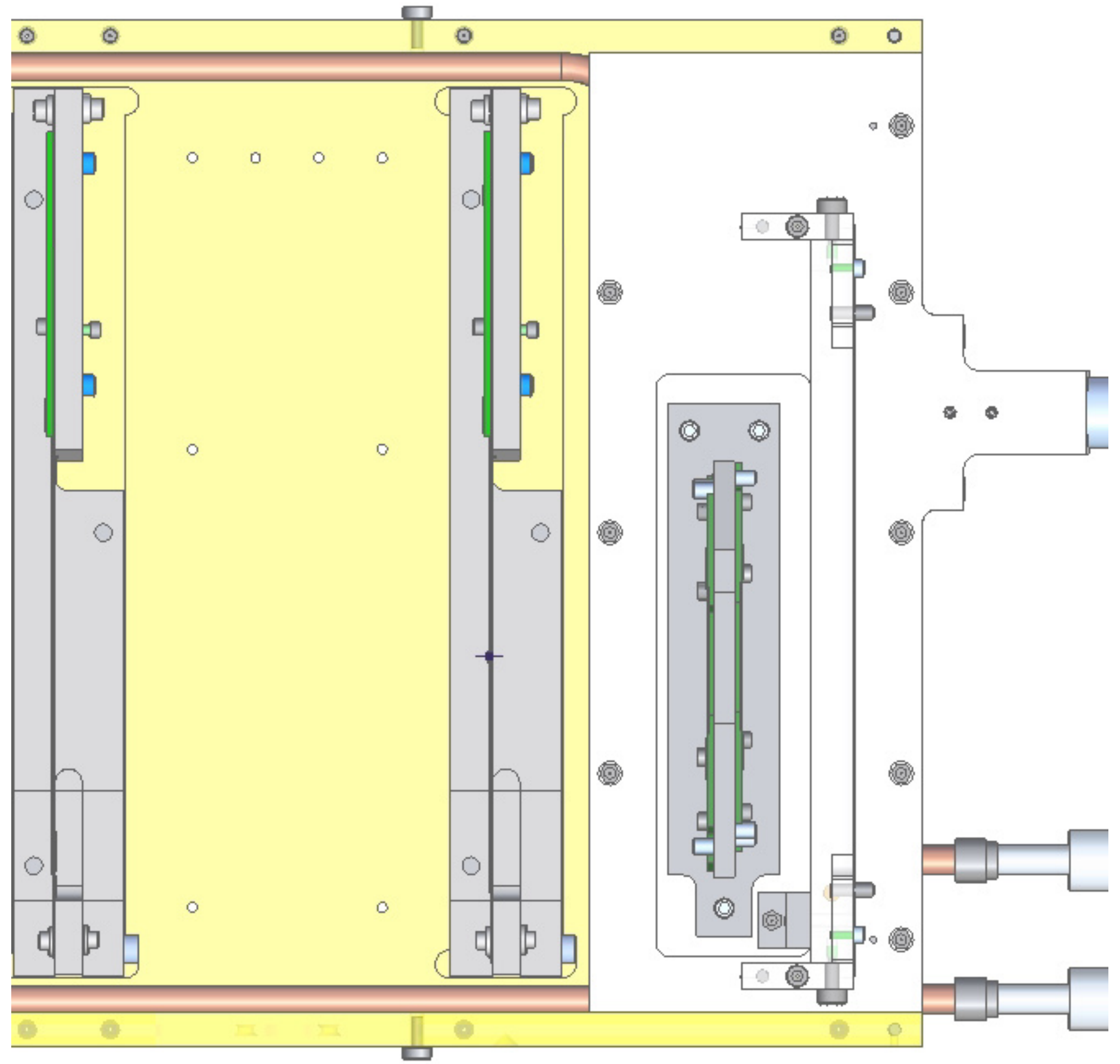


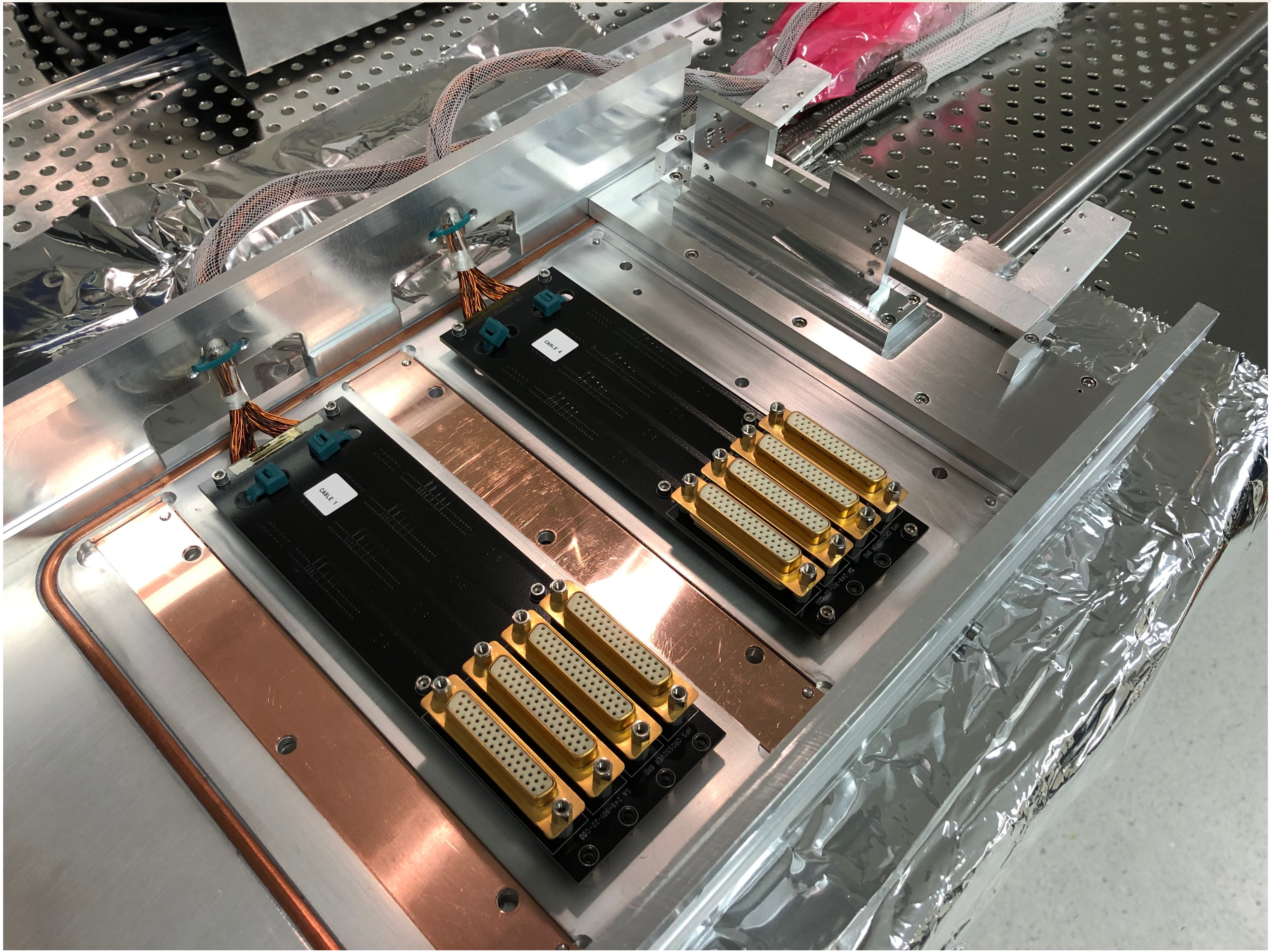
Angular acceptance of cooling block begins at 300 mrad, outside of SVT acceptance and where rate of brems is suppressed by >6 orders of magnitude.

Changes to Support Structure





Changes to Support Structure



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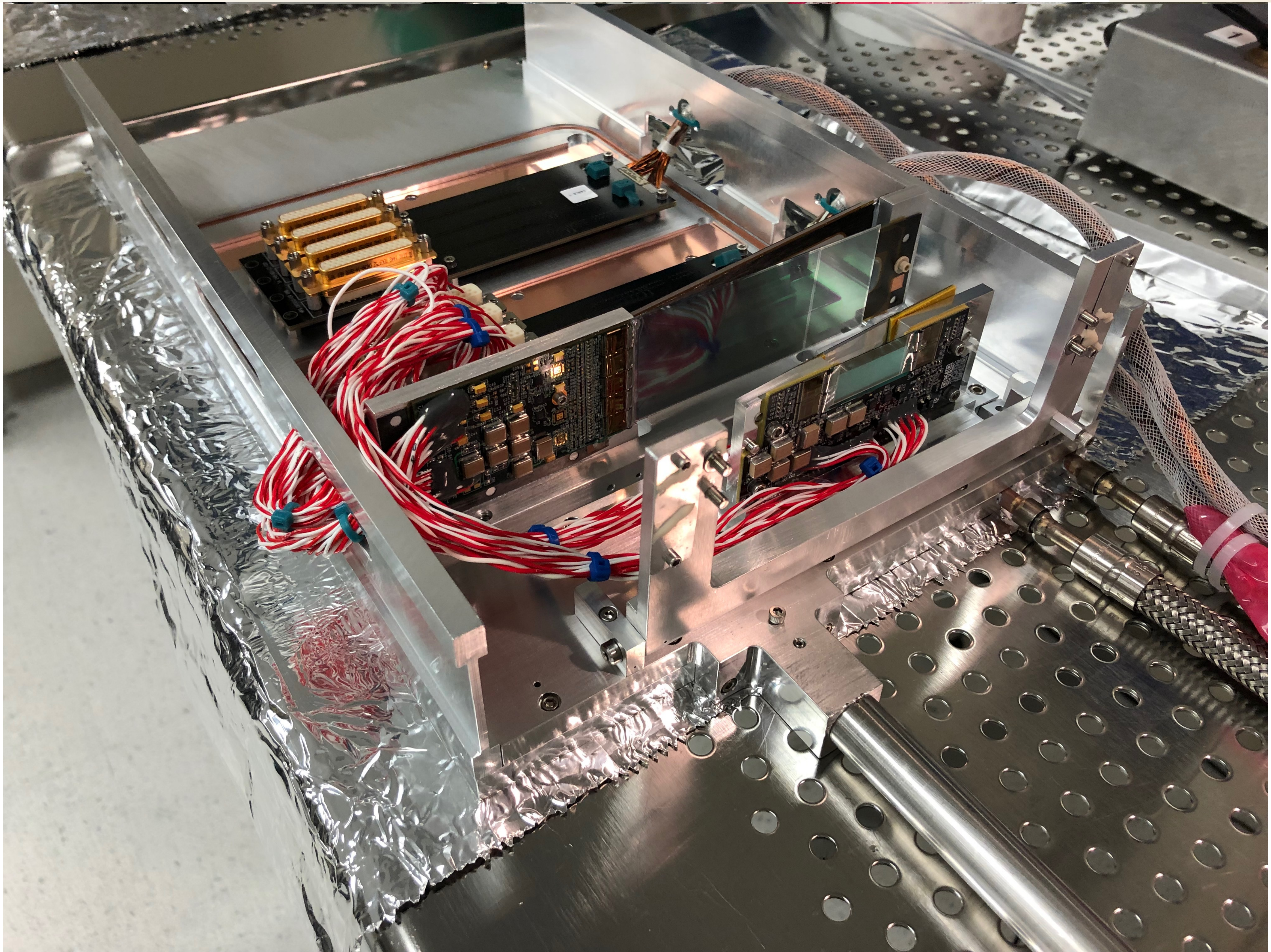
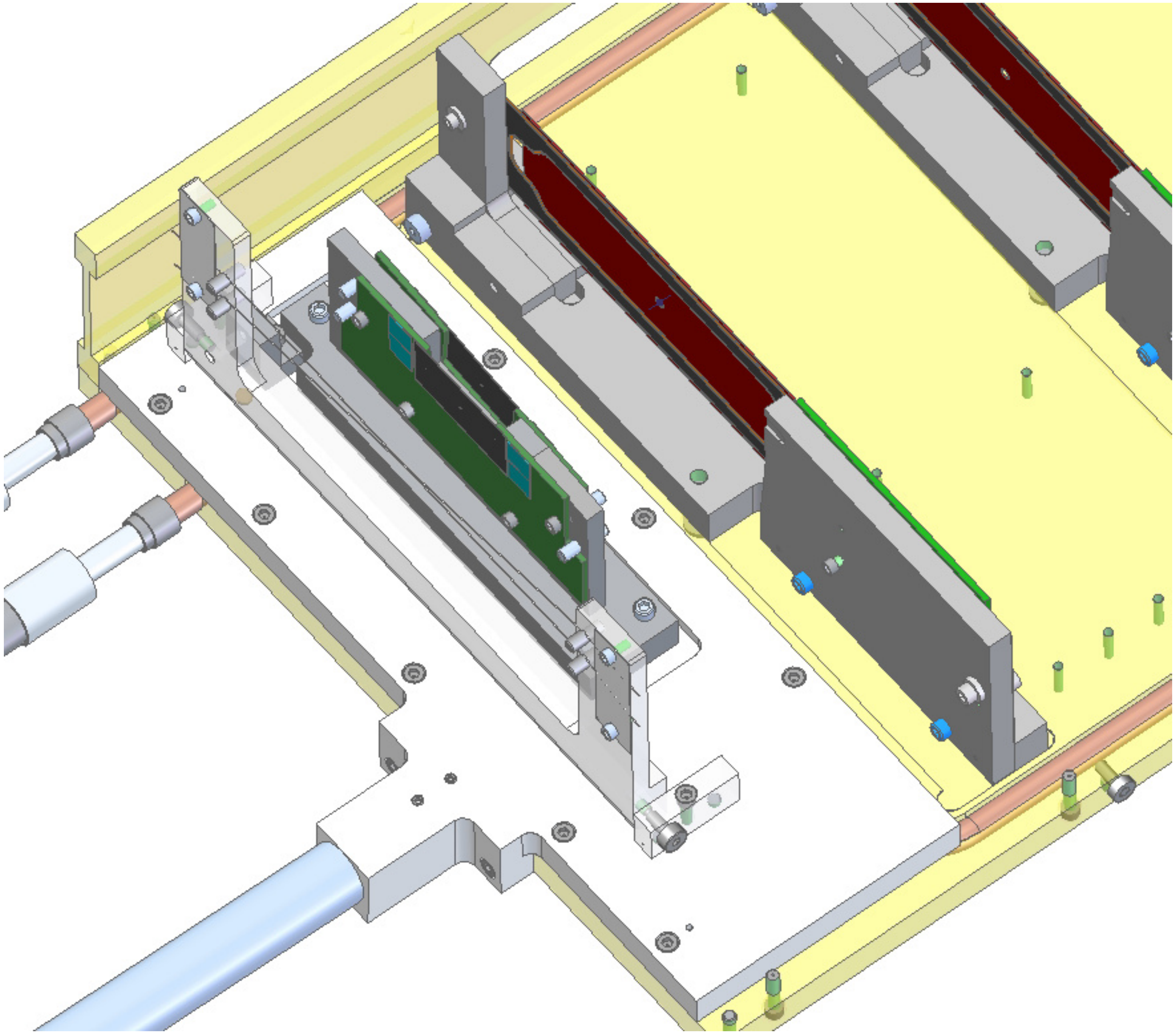
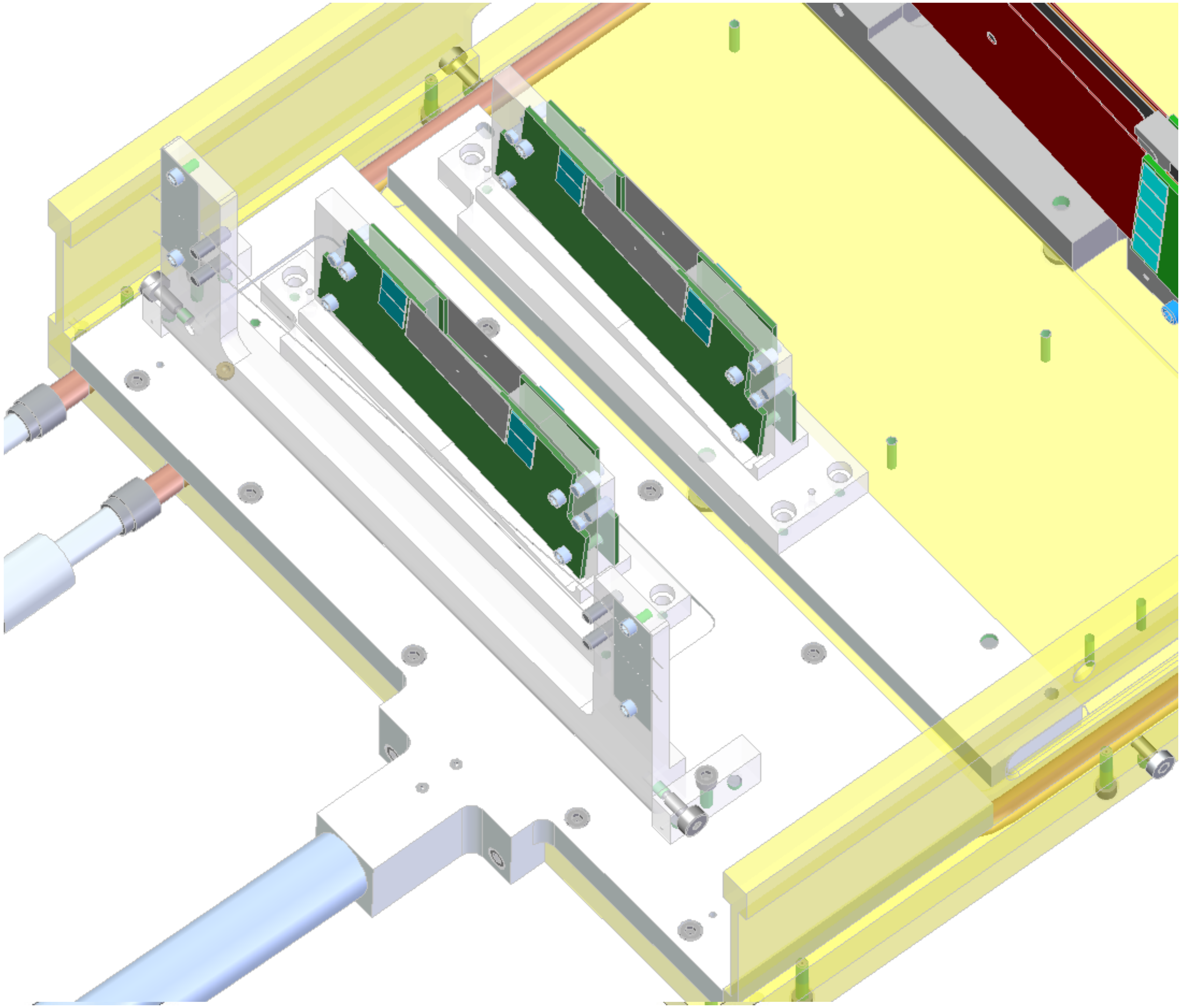


U-channel Lever Block and Layer 1 Replacement



U-channel Lever Block and Layer 1 Replacement



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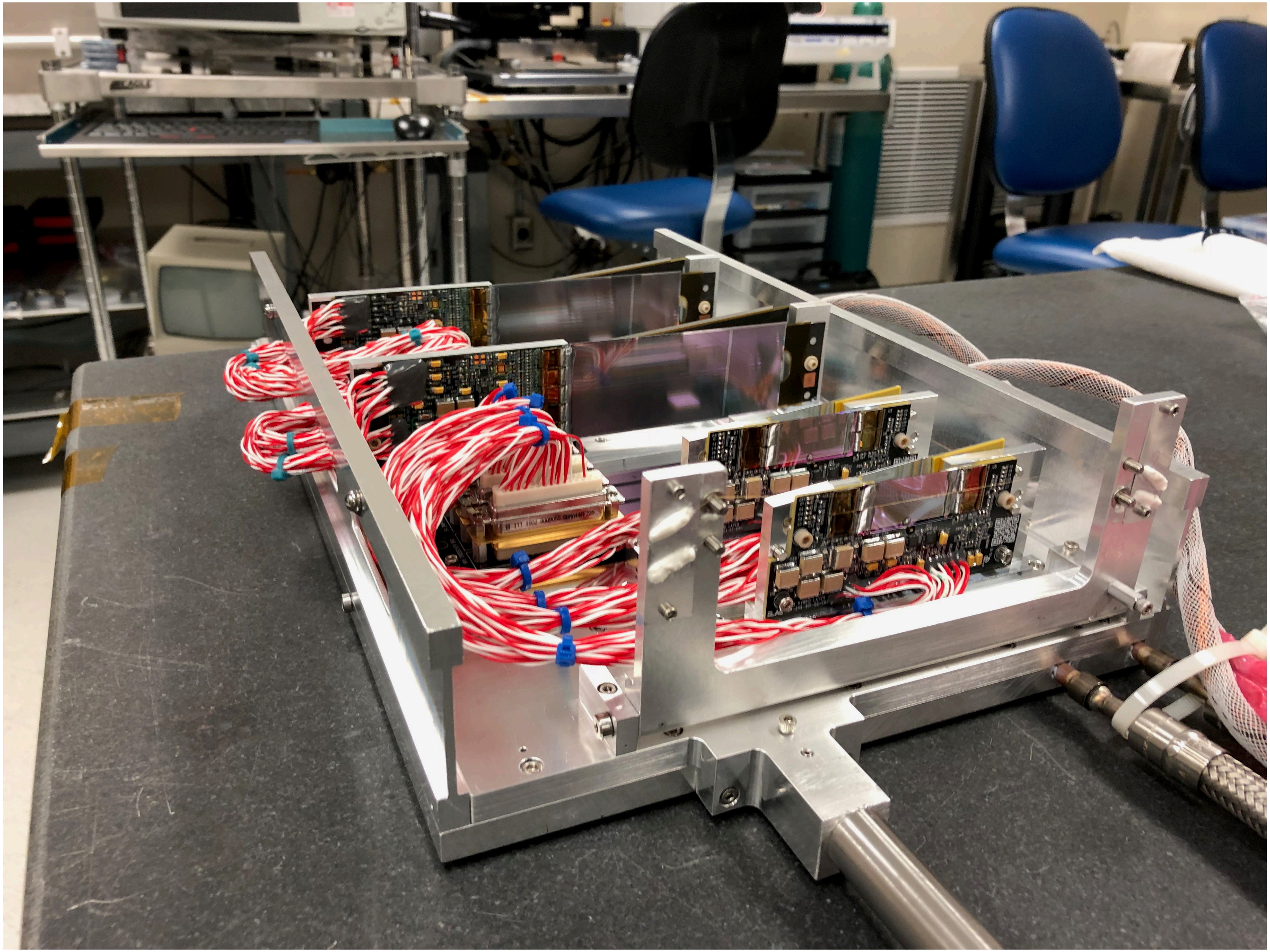


SVT Survey and Testing

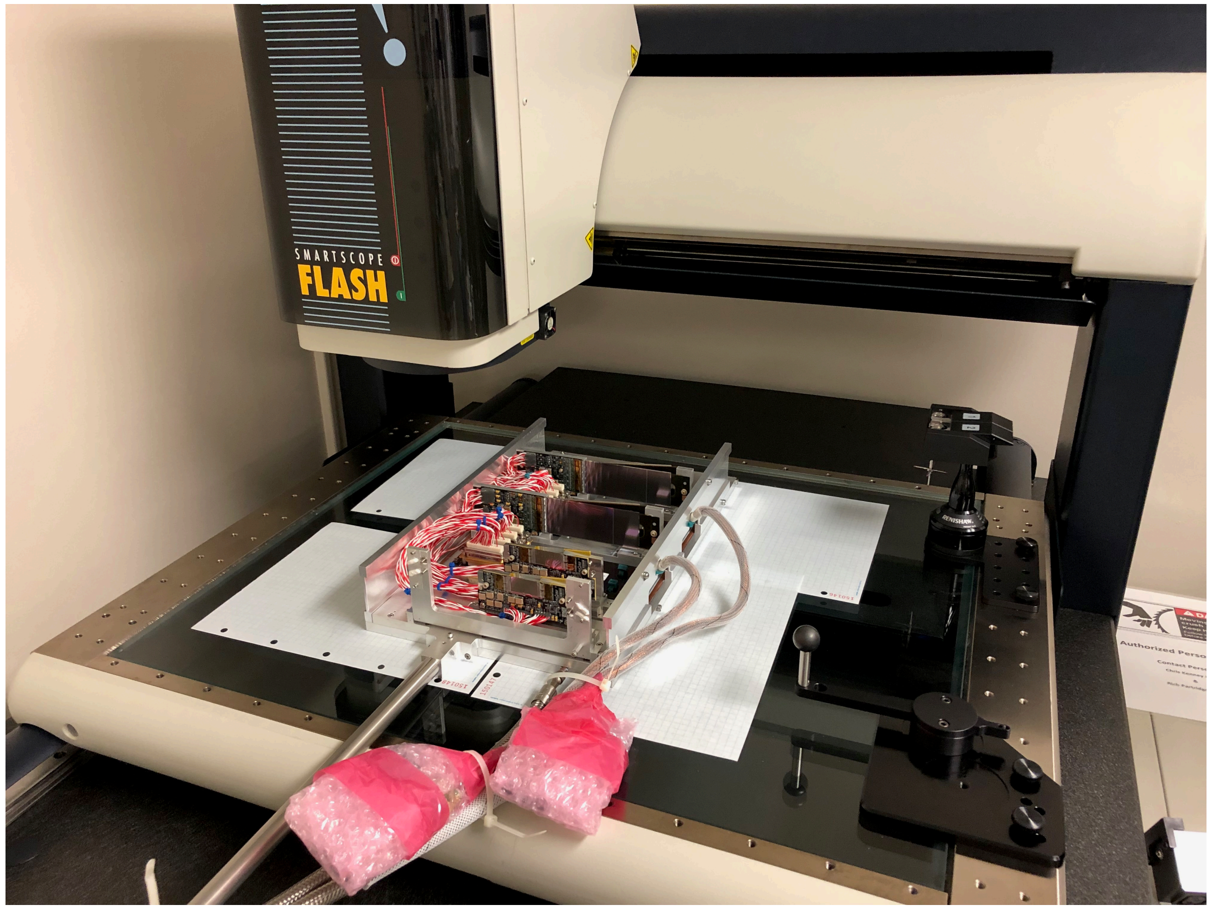
U-channels should return to same positions on kinematic mounts.

Want to establish locations of sensors relative to ideal within U-channel

First look finds positions and precisions roughly as expect
(considering doubled stack up from previous module mounting scheme.)

Wires also surveyed, similarly close to expected positions.

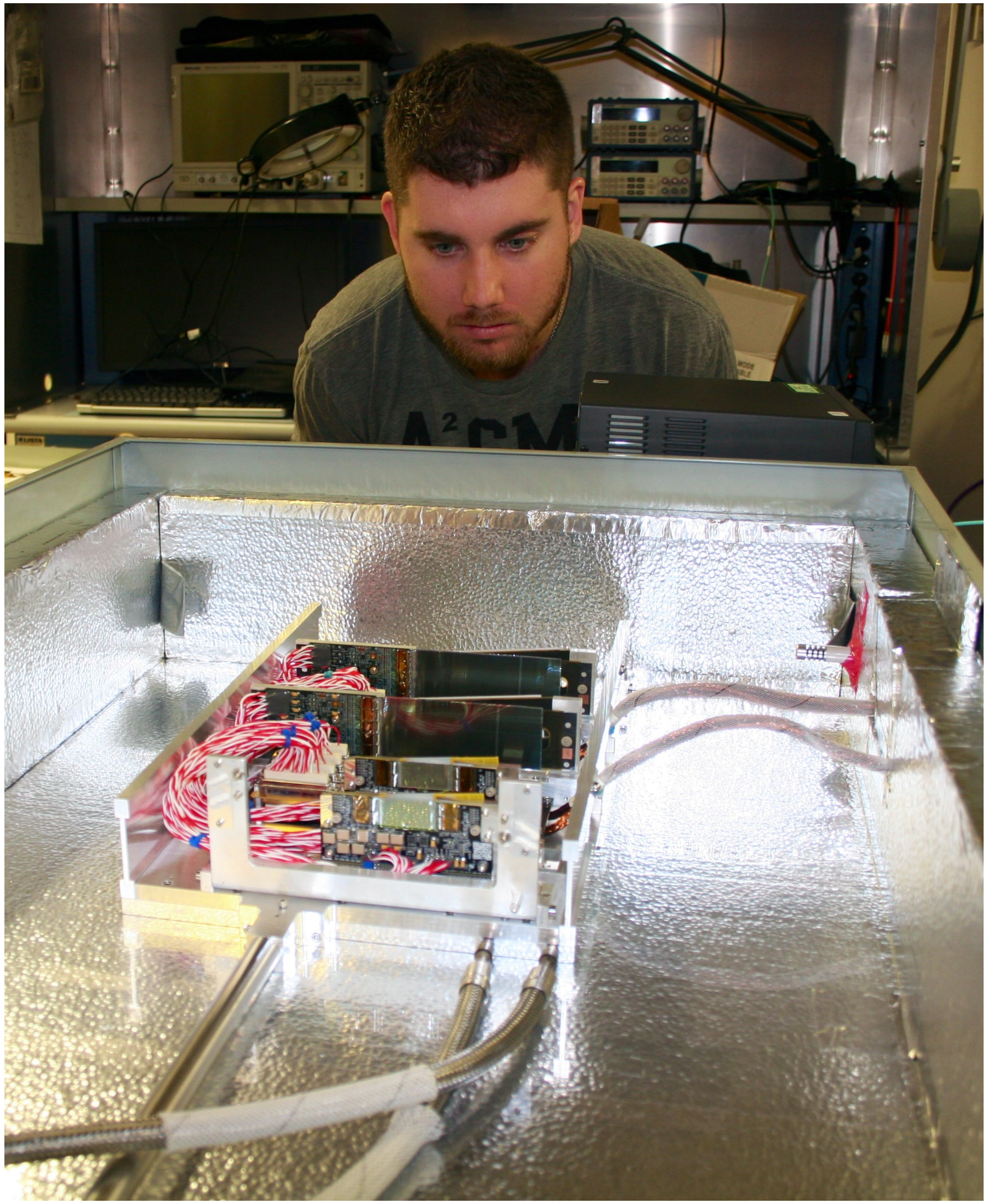
More work to do to define the exact locations of the silicon and the wire, needs to be pursued in advance of moving in the SVT.

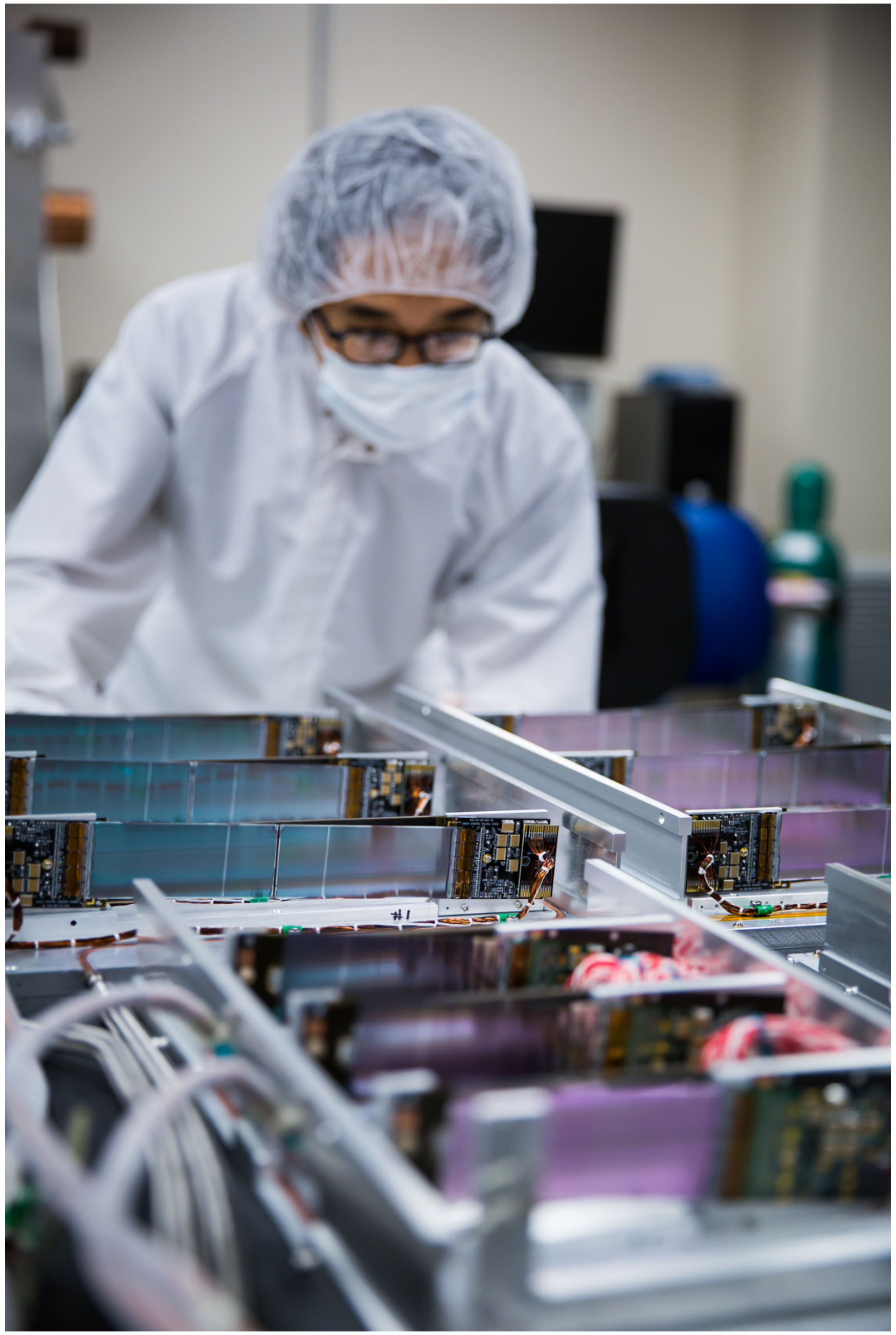


Sensor	Deviation from design elevation in U-channel
L0 axial top	-49
L1 axial top	80
L2 axial top	59
L3 axial top	66
L0 axial bot	-52
L1 axial bot	-99
L2 axial bot	-8
L3 axial bot	40

SVT Survey and Testing

Final testing in cold box at SLAC





2019 SVT Installation

2019 SVT Installation

SLAC

Installation Plan: (10 days from 5/6-5/15)

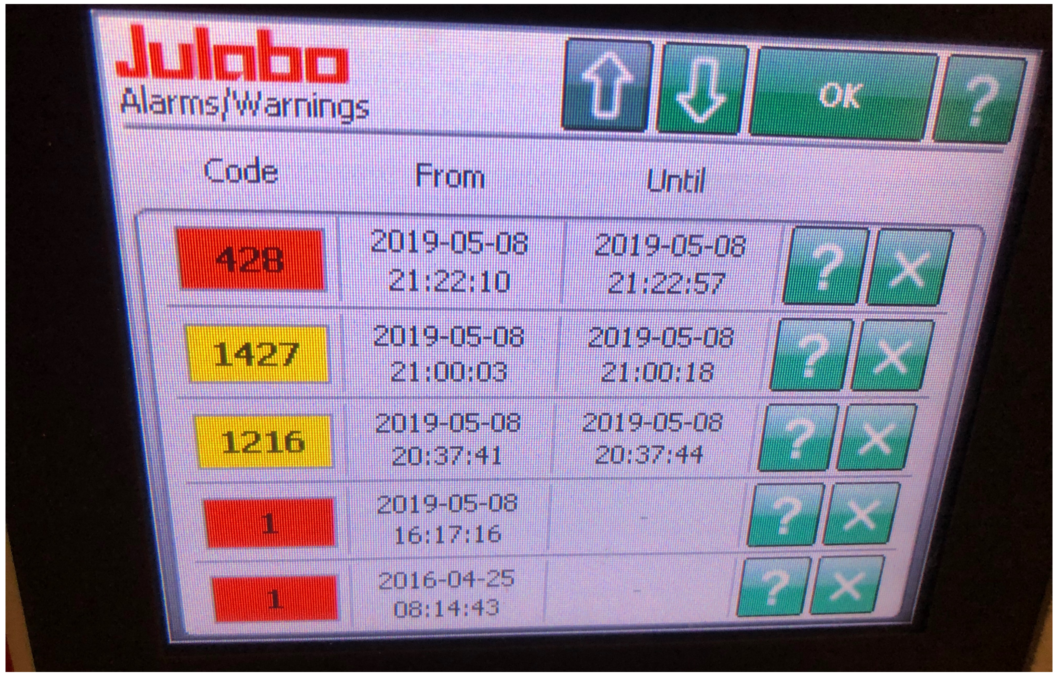
1. Test health of all DAQ chain to FEBs (last test during SVT extraction in Fall 2017). If damaged can decide repair in-situ or extract full SVT
2. Test health of L4-6. If no damage outside of Layer 6, replace in-situ, otherwise extract full SVT.
3. Install upgraded Layer 0-3 U-channels
4. Connect L0-3 to DAQ and motion system
5. Connect SVT cooling
6. Test full SVT and begin integration and commissioning with JLab TDAQ.

Piece of cake.

2019 SVT Installation

Installation ~~Plan~~ Reality:

- FEB chiller contaminated with algae (limited testing until day 3)
- Not receiving data from **2** FEBs: L4b and L23t
- One of four Wiener MPOD LV supplies not working, and half of Weiner crate is blacked out.
- SVT chiller runs but won't cool, starts delivering errors.
- L4-6 looked as expected on arrival



TWO Bad FEBs!?

The SVT FEB is an incredibly complex device due to space constraints.

- Services 4 hybrids, 20 APV25
- Analog and digital power distribution and control
- APV25 configuration and control
- APV25 analog amplification, digitization, and signal processing
- Dimensions 4”×7”, 20 layer PCB, designed to output up to 20 Gbps.

Only 15 FEBs were made (one panel of boards). Cost: $10-$15K each

Being complicated and delicate, FEBs break often when handled and most have been reworked many times.

However, these had been quite stable once in the system.

There was only one perfect spare at SLAC - it was damaged in April in a site-wide power surge (also made L0-3 full testing difficult.)

One
~~TWO~~ Bad FEBs!?

The L23 FEB was served by a flange channel that had failed (also rare!)

- Flange still had a spare working channel (one other broken before 2015 installation)
- Also have a complete spare, tested data flange at JLab in EEL

SLAC scrambled to repair a FEB, shipped to Stepan's house on Saturday. It's not perfect.

Plan, to swap perfect FEB in L6b to L4b, put spare in L6b, faced a critical decision:

Remove the entire SVT and work in the EEL?

- extraction/reinstallation is time consuming, not without risks
- EEL offers a clean, controlled work environment, but no DAQ, power, cooling for testing.

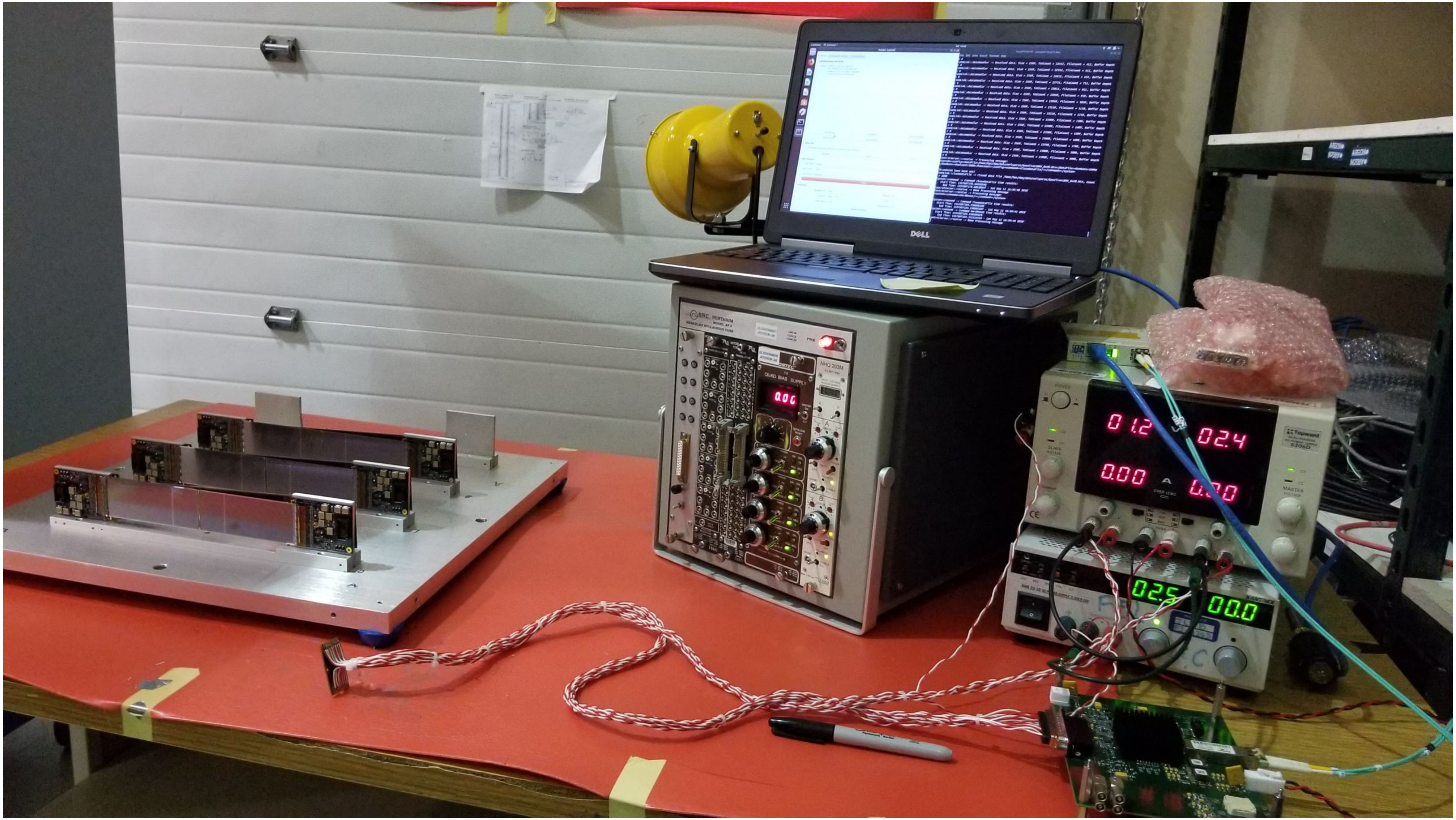
Work in Hall B?

- FEB cooling plate extraction/reinstallation **extremely** challenging work (not done since 2015)
- If successful saves time, allows testing with full SVT infrastructure

Decided overall risk was lower removing the FEB cooling plate, so created an orderly work space in front of the alcove for L6 and FEB replacement work

Extraction and Installation of FEB Cooling Plate (Tim/Matt)

Testing L4-6 Spares (Omar/Cam)

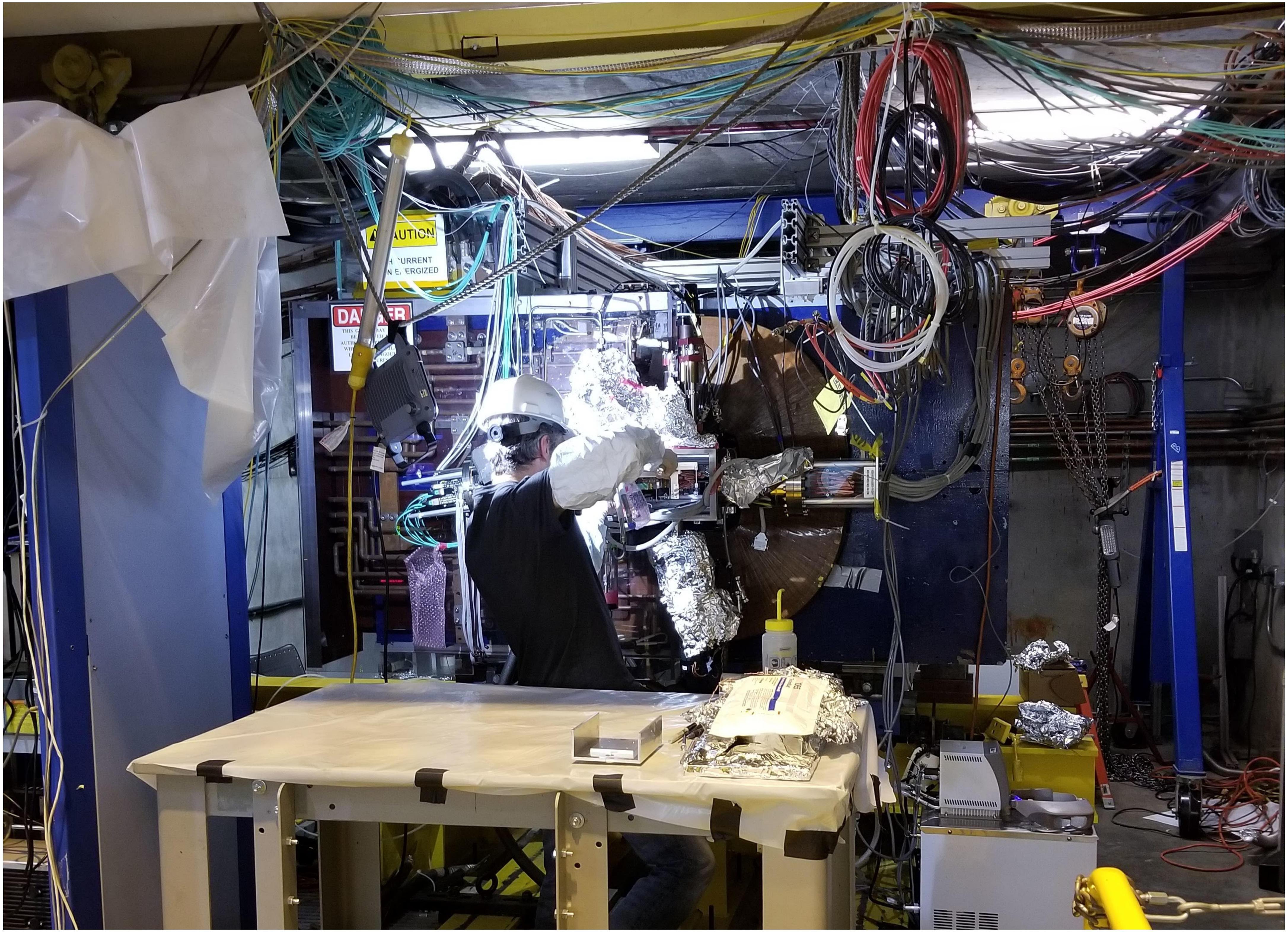


L6 Module Rework (Tim) and FEB Replacement (Omar)

SLAC

L0-3 Installation (Finally!)

SLAC



Other Problems Had Easier Solutions

Wiener MPOD:

Swapped in spare in crate. Created another problem: supply had not been set up correctly, caused testing failures that took more time to figure out.

SVT Chiller:

New 208 3-phase plug installed in alcove for chiller had been connected to a bad breaker. Chiller is OK plugged into old location with extension.

FEB Chiller:

Replaced with spare chiller and cleaned out lines. Still plan to run with filter to completely clean system.

One Major Surprise

It was our understanding there were complete services for four more hybrids in the chamber.

True for the DAQ, but not for the sensor HV! Only 36 HV lines, no spares!

The "correct" solution is probably >$50K

- custom PS cables and rewiring of the SVT power breakout box
- new power flange board fabrication and assembly
- a complete new power flange assembly and internal cabling
- modifications to the FEB cooling plate "ocotpus"

The option available during installation, jumper to place both L0 sensors on one HV bias line and both L1 sensors on the other, would likely have been the only design choice from the start.

Post-Installation Work/Status

Survey/alignment completed.

- Magnet could not be returned to previous position (2 mrad yaw!)
- SVT support box had to be moved 2.5mm right at upstream end
- Scope pointed along beamline used to create reference for SVT motors using SVT wires.

Testing status on leaving JLab:

- All APV25 sync, except three on imperfect FEB in L6b.
- During final testing, one hybrid in L4b has trouble syncing. After switching FEB assignment between L4b and L4t, both *appear* to sync fine.

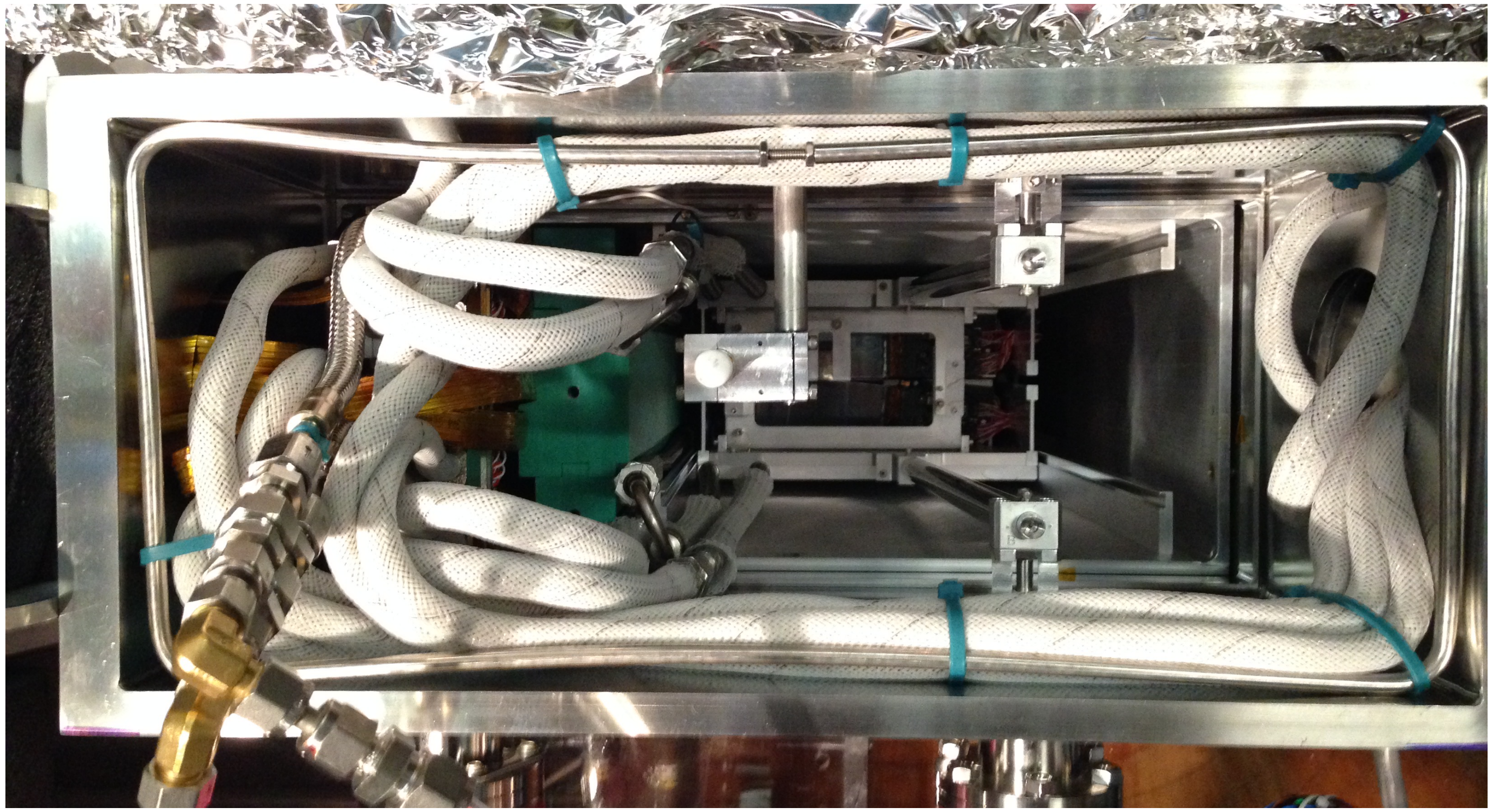
After further testing at SLAC:

- There are 5 chips served by bad FEB channels in L6.
- L4b gets flakier, still under investigation, but not very hopeful.
- Noise appears higher than expected. Need to (re-)verify grounding scheme is as before.

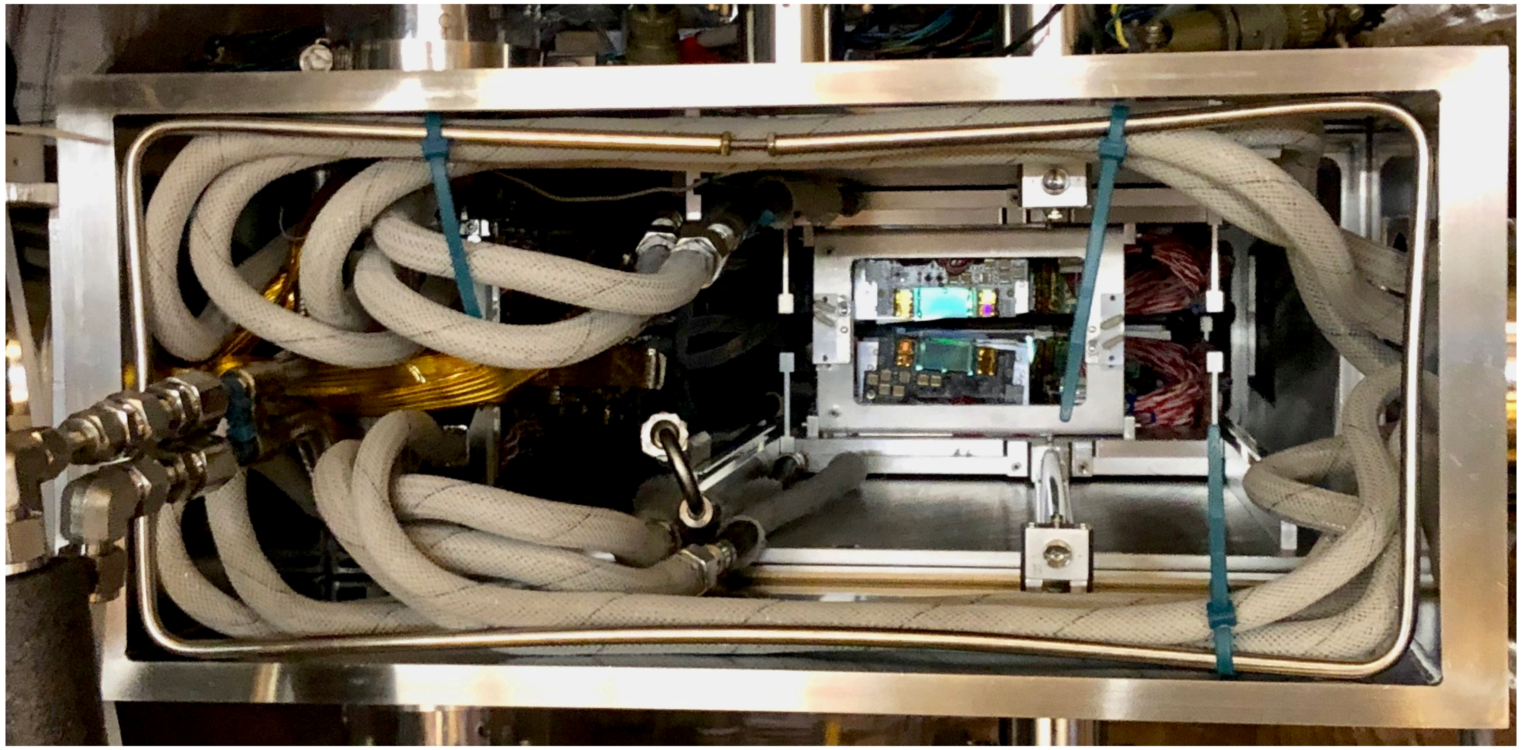
Intervention in L4b is a very big deal. Cannot consider this until we have a smoothly operating integrated DAQ. We are not close yet.

Current Status

2015



2016



Work for The Next Days (5/30-6/4)

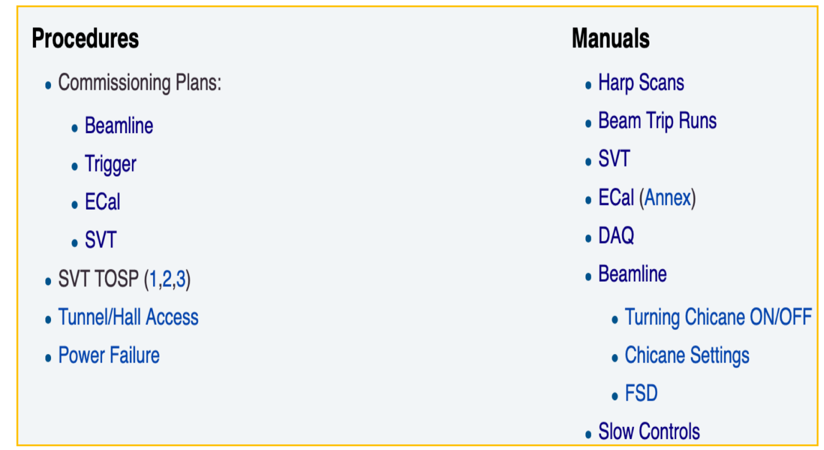
1. Installation of the target motor and target
2. Finish SVT motor setup
3. Installation of neutron shielding.
4. Close the data flange.
5. Close front flange.
6. Connect FEB cooling to feedthrough and close FEB cooling flange.
7. replace broken RTD on SVT manifold output.
8. Insulation of SVT cooling lines.
9. Clean up control connections to chiller and make RTD connections.
10. Pump down

Plan to complete this by early next week.

2019 Commissioning and Operations

Preparing for Operations

https://wiki.jlab.org/hps-run/index.php/The_HPS_Run_Wiki



SLAC will have at least one SVT hotshot (Cameron, Tim, Matt, Omar) at JLab from now until regular shifts begin.

DAQ testing and integration work continues - see Cameron's talk

Work to do to shake down cooling, controls and motion system, update operations documents and manuals in advance of the run.

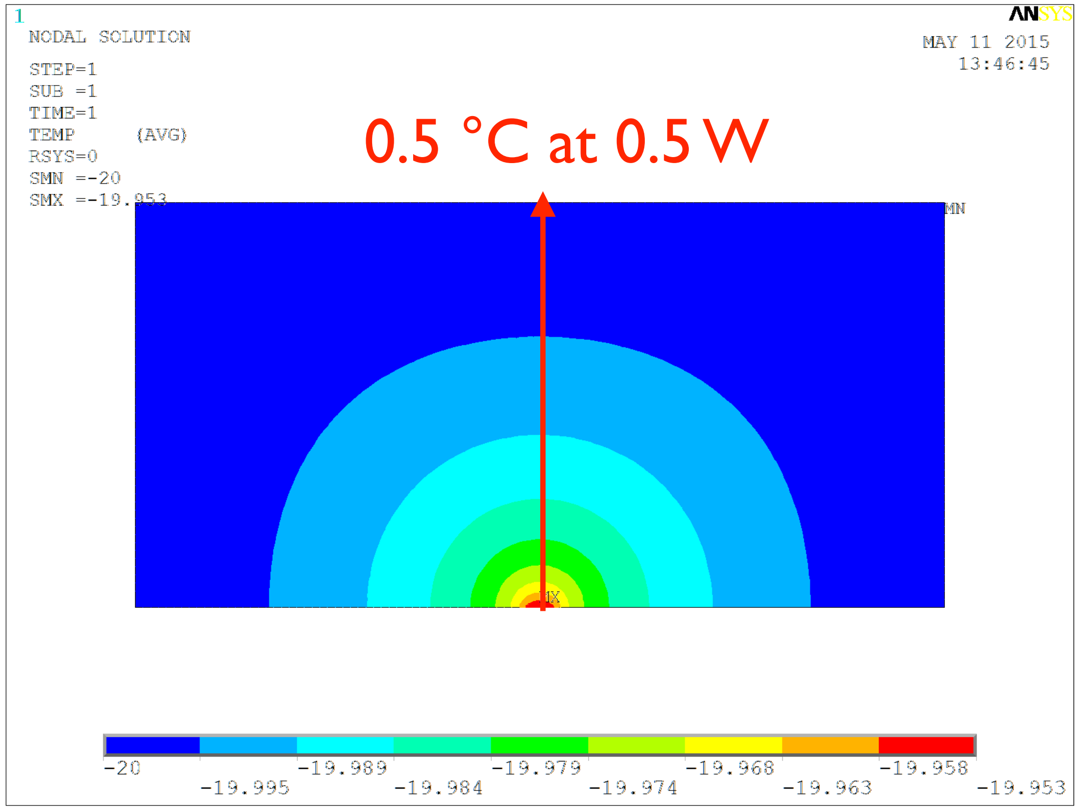
Monitoring app needs tweaks to add plots for Layer 0, but otherwise is same. Need final geometry and DAQ map to ensure reconstruction works with first beam!

Plenty here to keep us all busy.

Operational Procedures

With concerns about cooling-induced wirebond damage, want to run SVT only cold enough to prevent thermal runaway.

$$P = IV, I \propto 2^{\frac{T}{7^{\circ}C}}$$



We will want a somewhat careful approach with the SVT, similar to what was used before moving SVT in first time in 2015 (minus long beam studies)

- Motor calibration uncertainties
- Wire/SVT alignment uncertainties
- ***Uncertainties in how different sensor technology will behave in this environment.***

Considerations for special runs:

- no field: coverage of L0, L1 very different from before - need to check
- no target: almost instant feedback on beam tails
- bias scans: need to begin watching for under-depletion of older sensors

Last Thoughts: SVT Into the Future

We are very lean on L0 module spares

- We can make more, and very likely much better.
- We have been kind to CNM…
- Hybrids relatively cheap, more APV25 available
- Have clear plan for better slim-edge cleaving

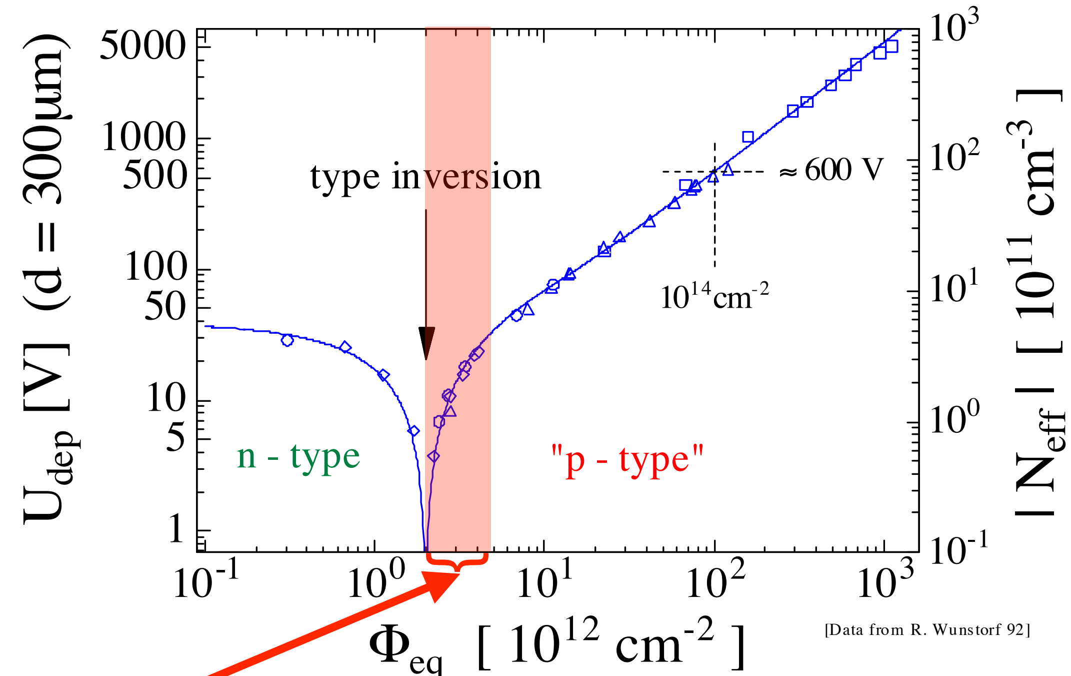
We need a deeper pool of FEB spares

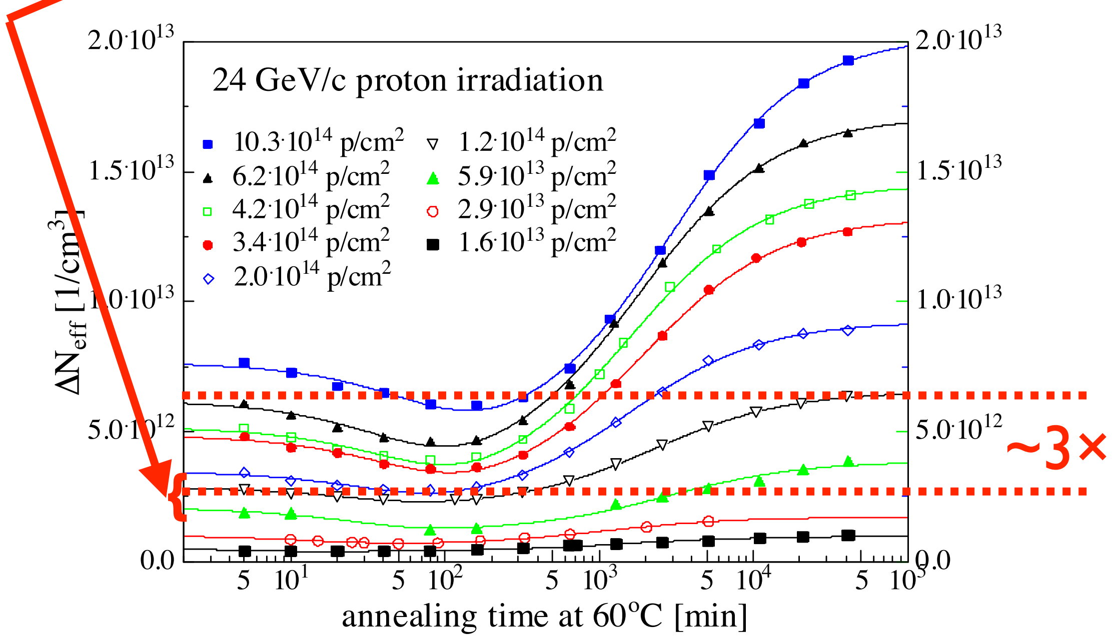
- The FEBs have become an unacceptable single-point of failure
- They're expensive, but we don't work without them

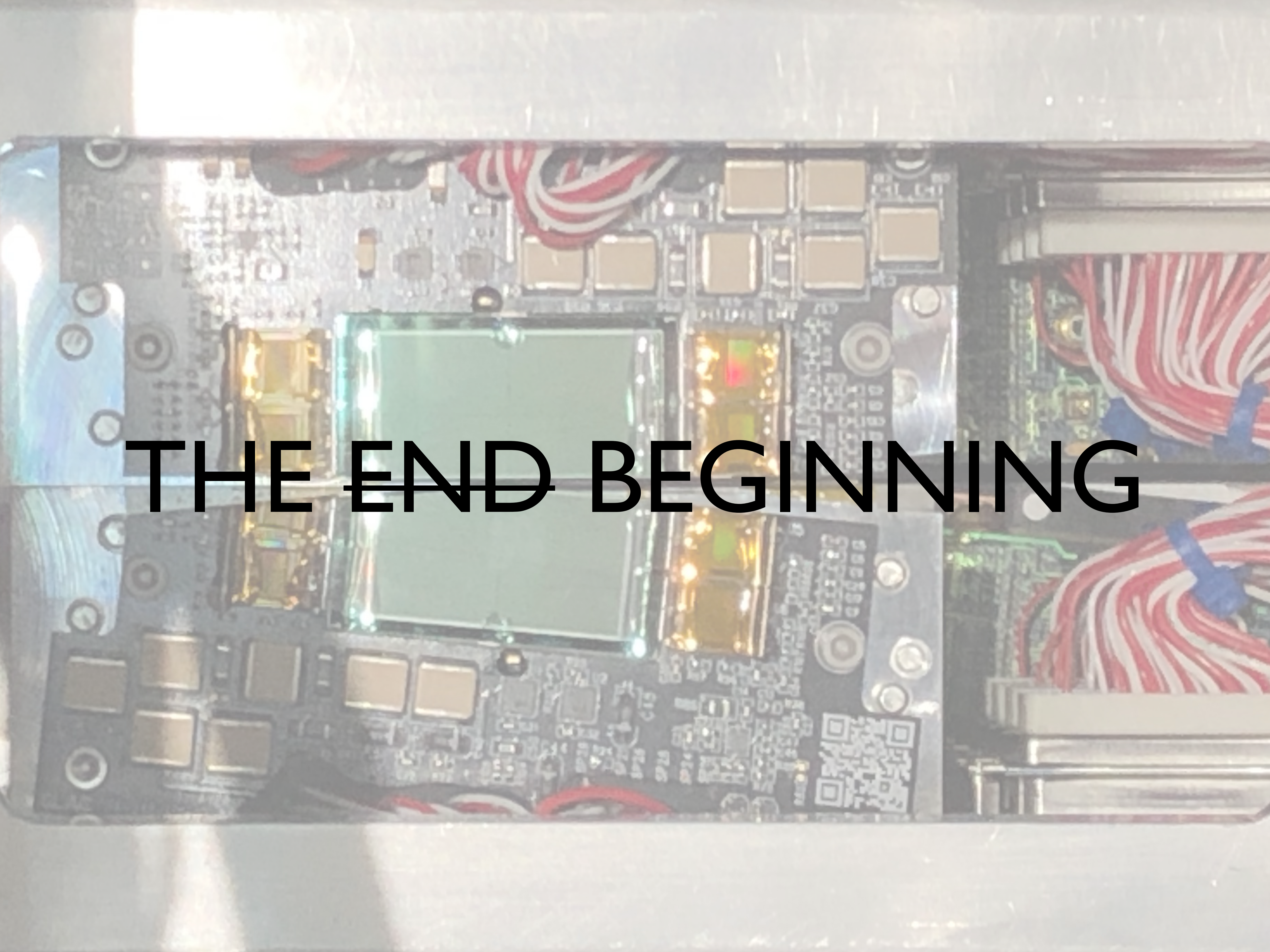
Cooling

- SVT ***must*** be kept cold after the 2019 run.
- A short (2-week) warm up is optimal
- Otherwise, detector needs to be at 0C or colder to minimize reverse annealing of defects.

"hottest" part of L1-3 sensors

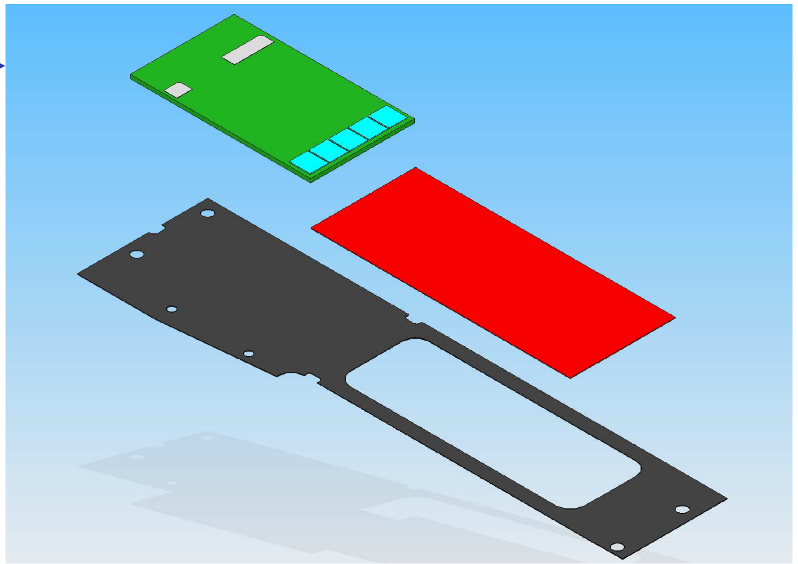


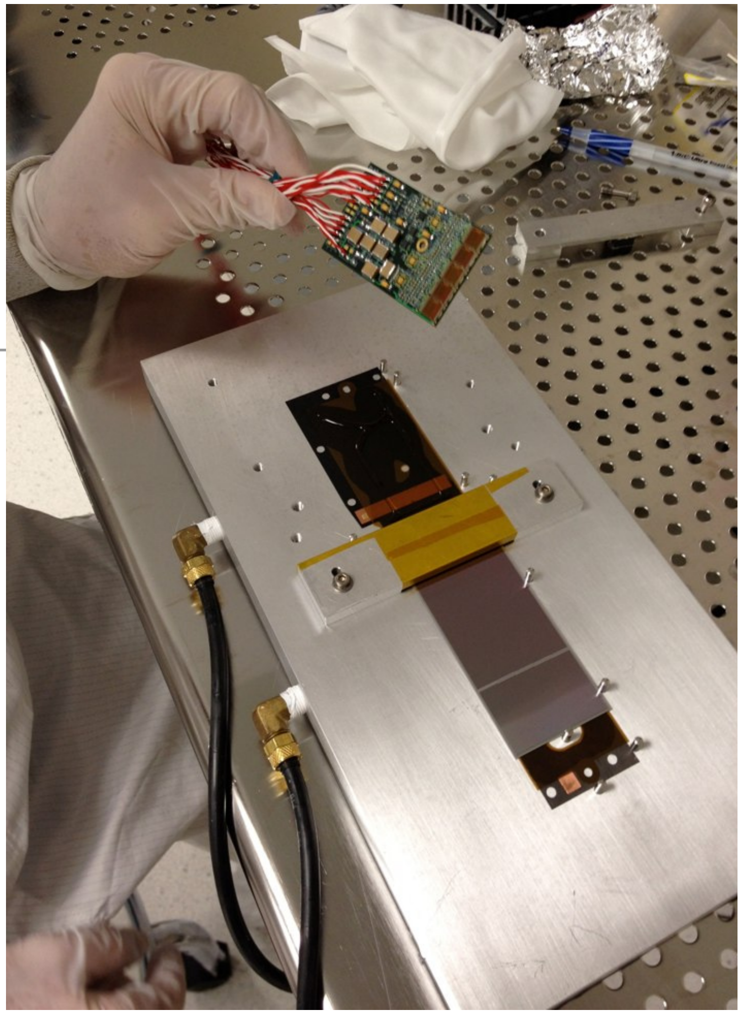



THE ~~END~~ BEGINNING

Test SVT Modules

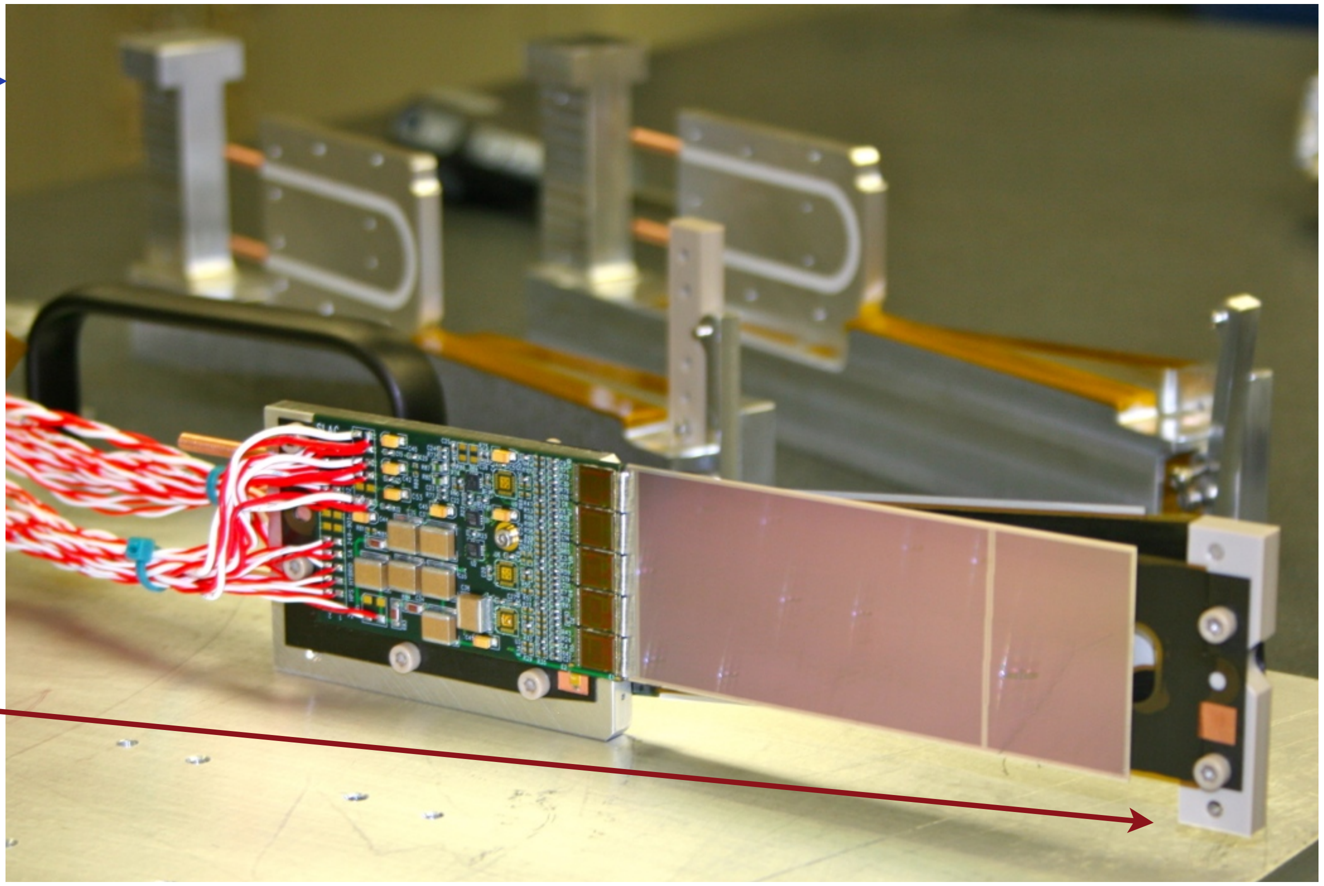
Half Module





- 0.17 mm thick CF frame (FE grounded, HV passivated)
- FR4 hybrid with 5 APV25, short twisted-pair pigtail cable
- single sensor

Full module



- Two half-modules back-to-back on Al cooling block w/ Cu tubes
- glue-less assembly with PEEK spacer block and hardware

➡ *0.7% X_0 average per layer*

➡ *Limits flatness of Si to ~200 μm*

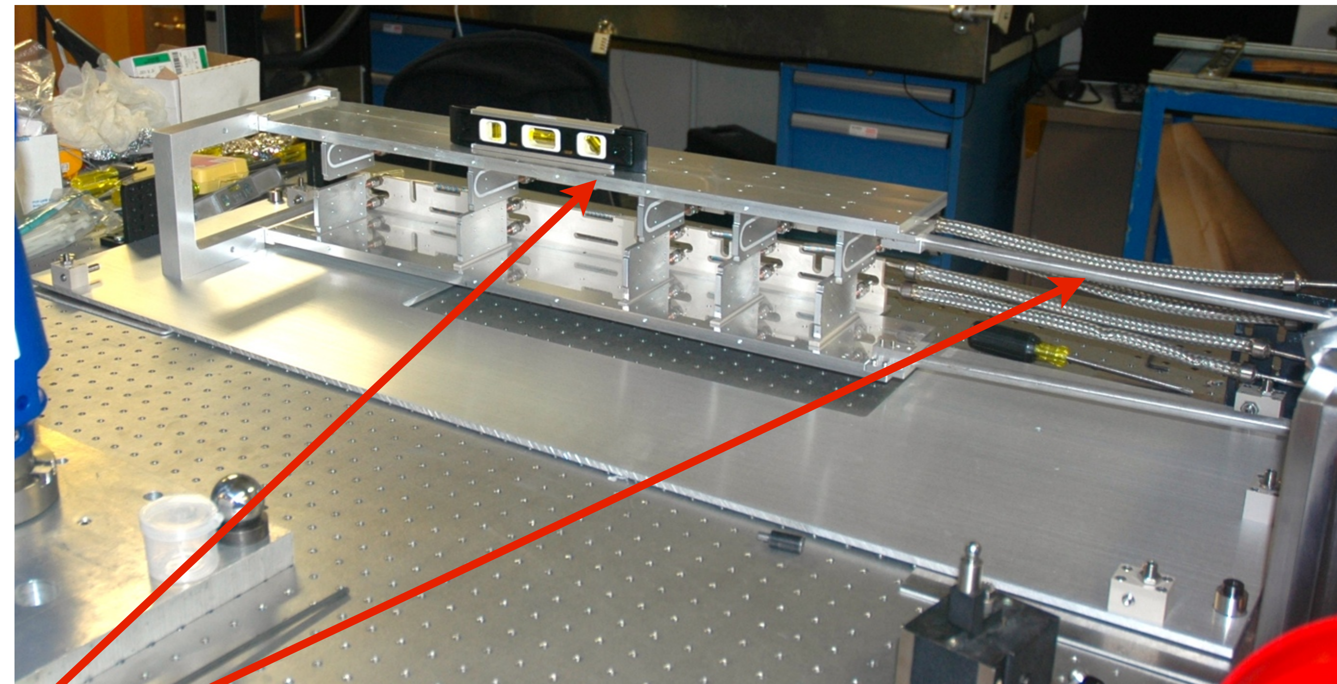
➡ *Compromised cooling limits radiation tolerance*

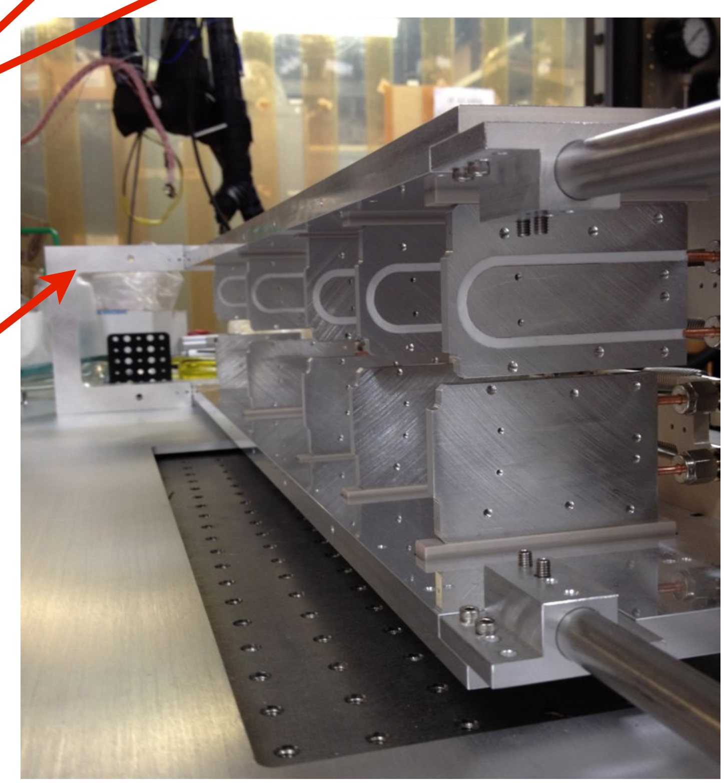
Test SVT Mechanics

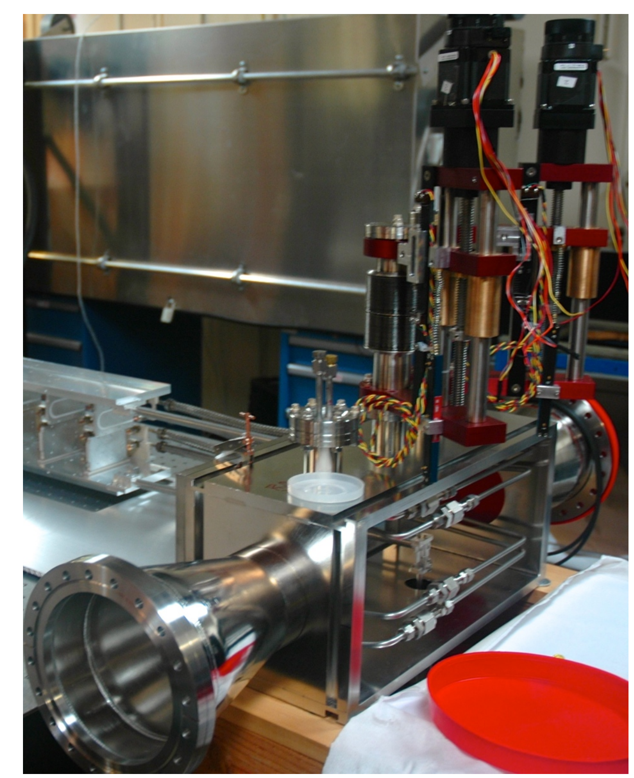
Cooling blocks mount on Al support plates with hinged "C-support" and motion lever

- Provide solid mounting for modules, routing for services, and simple motion for tracker
- PEEK pedestals create 15 mr dead zone, provide some thermal isolation
- Support plates + motion levers ~1.5 m long: sag dominates x-y imprecision (300 μm)
- Load on C-support introduces significant roll in top plate.

Works, but can be improved upon

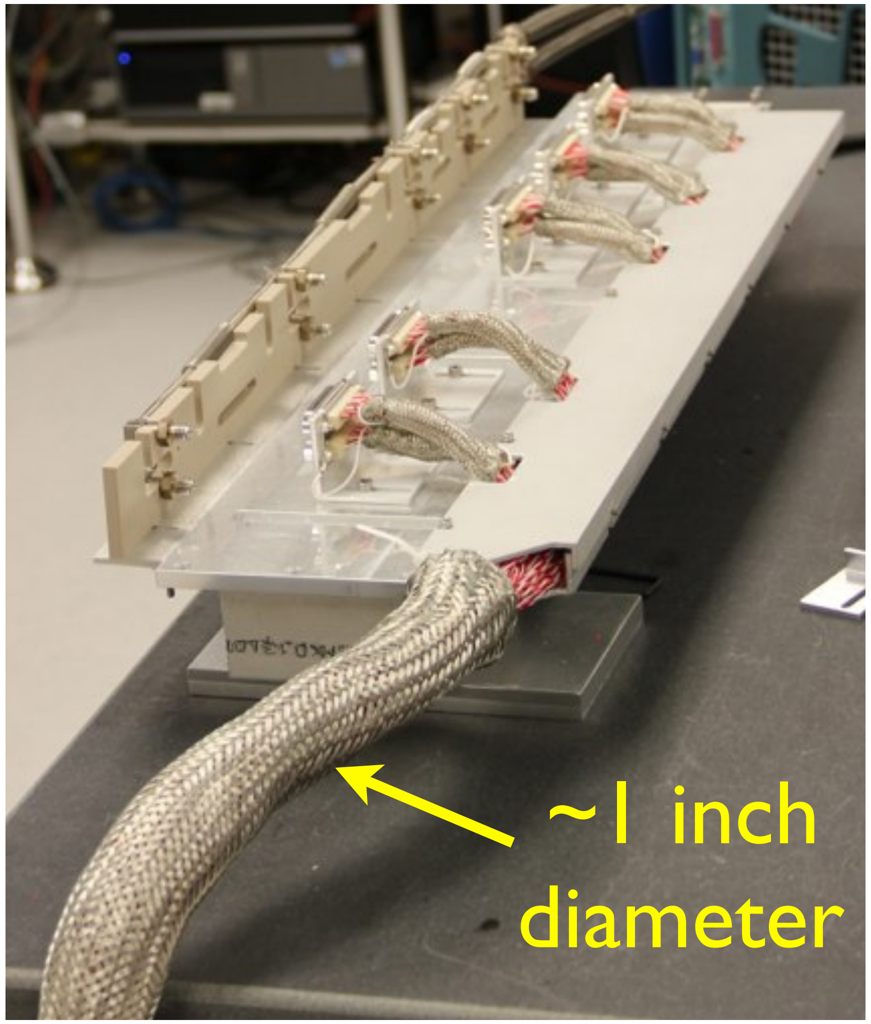


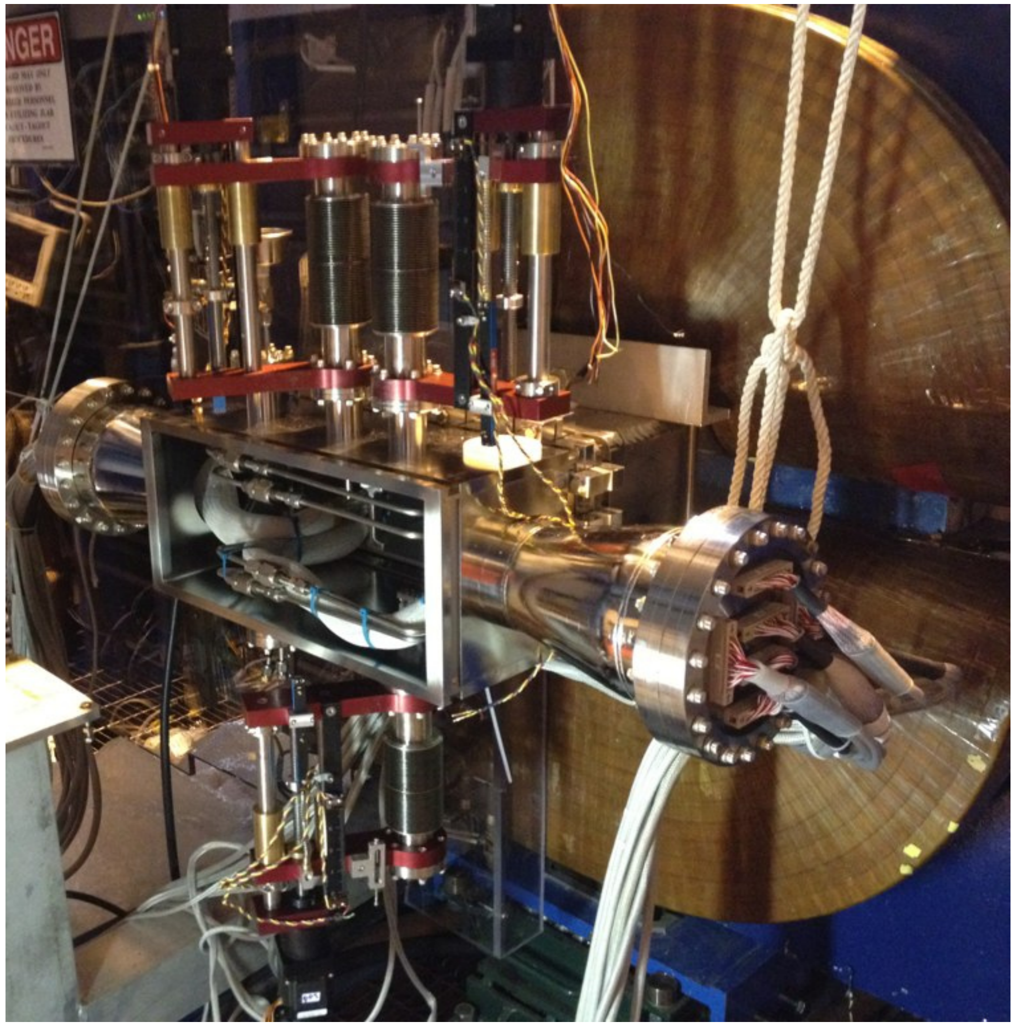




Test SVT Services

- Borrowed CDF SVXII power supplies (very crufty) and JLab chiller (limited to > 0˚C)
- Intricate welded cooling manifolds with 2 compression fittings/module
- 600 wires into vacuum chamber for power and data (3600 total pairs of connector contacts): recovered three sensors with internal connectivity problems after assembly/installation at JLab





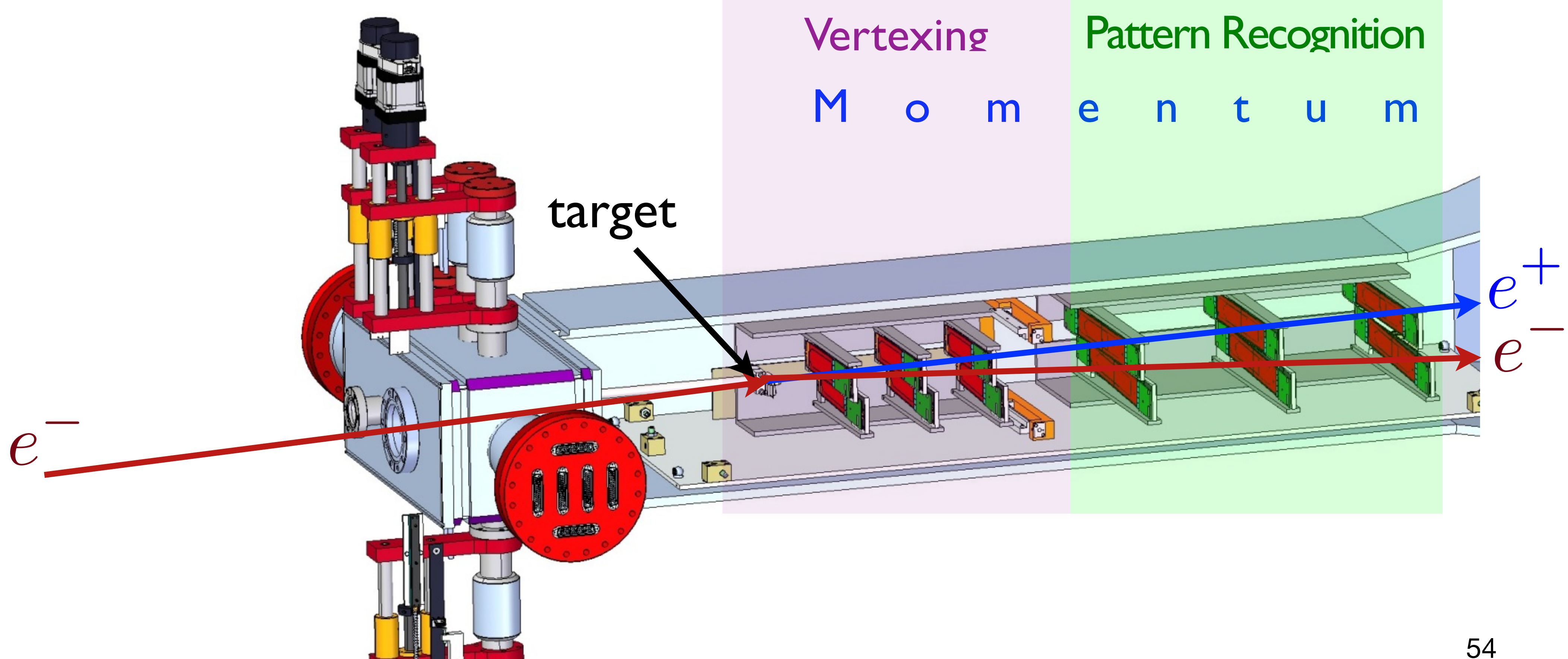
We got away with this, but it doesn't scale well to a larger detector.

HPS SVT Layout Changes

An evolution of Test SVT Layout

- Layers 1-3: same layout as Test SVT
- Layers 4-6: double width to match ECal acceptance and add extra hit.
- 36 sensors & hybrids
- 180 APV25 chips
- 23004 channels

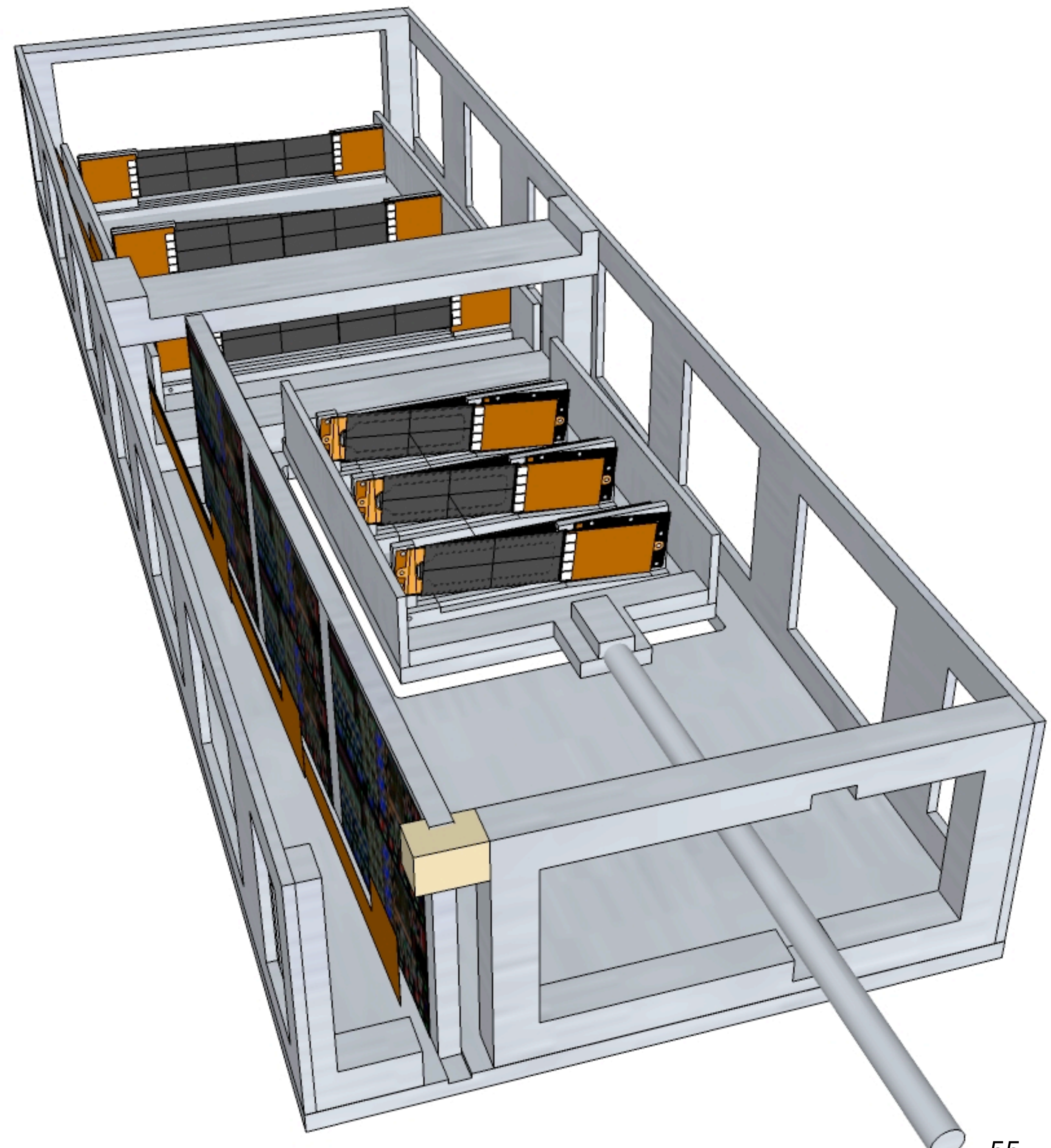
	Layer 1	Layer 2	Layer 3	Layer 4	Layer 5	Layer 6
z position, from target (cm)	10	20	30	50	70	90
Stereo Angle (mrad)	100	100	100	50	50	50
Bend Plane Resolution (μm)	≈ 60	≈ 60	≈ 60	≈ 120	≈ 120	≈ 120
Non-bend Resolution (μm)	≈ 6	≈ 6	≈ 6	≈ 6	≈ 6	≈ 6
# Bend Plane Sensors	2	2	2	4	4	4
# Stereo Sensors	2	2	2	4	4	4
Dead Zone (mm)	±1.5	±3.0	±4.5	±7.5	±10.5	±13.5
Power Consumption (W)	7	7	7	14	14	14



SVT Support Box Design

Developing detailed designs

- Rigid SVT support box
- adjustable, 3-point, kinematically mounted u-channels slide in like drawers, are removable from ends
- Survey features on box and each channel at kinematic mount points
- FEB cooling plate slides out from upstream end
- polyimide flex cables for data and power (1 pigtail + 4 longer cable designs)



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