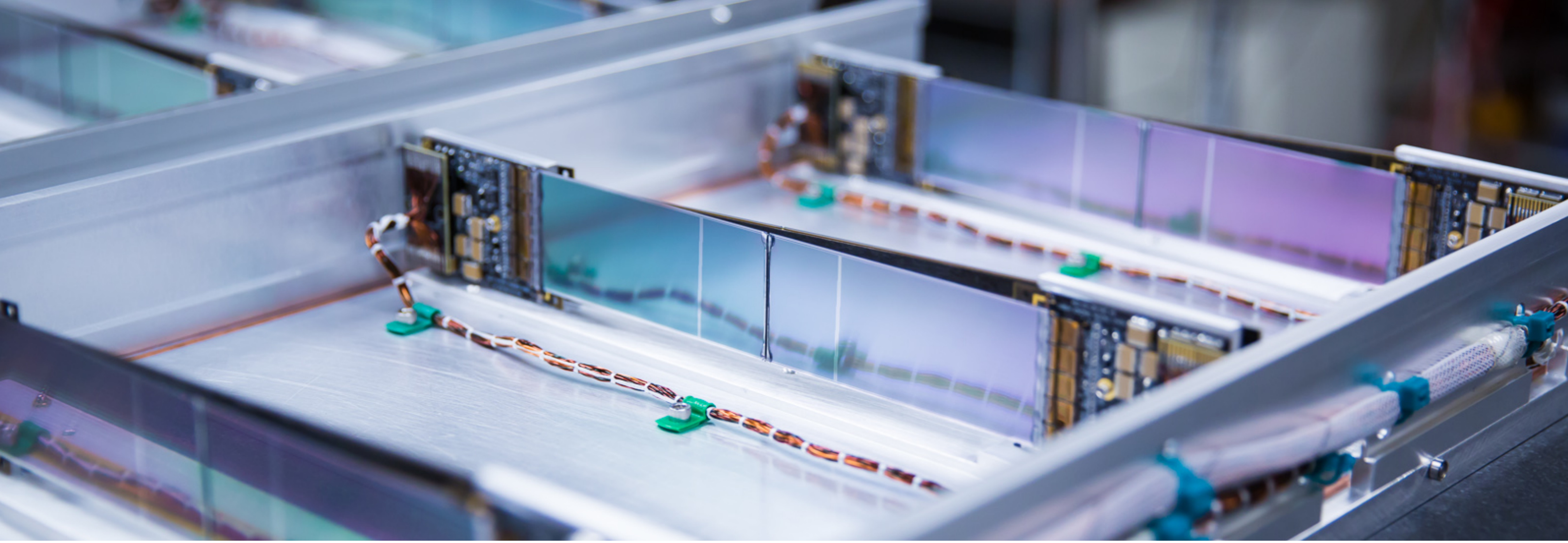


HPS:
SVT Upgrade for 2019

Tim Nelson - SLAC

HPS DOE Review

SLAC - January 18, 2019

U.S. DEPARTMENT OF ENERGY
Office of Science

SLAC NATIONAL ACCELERATOR LABORATORY

Outline

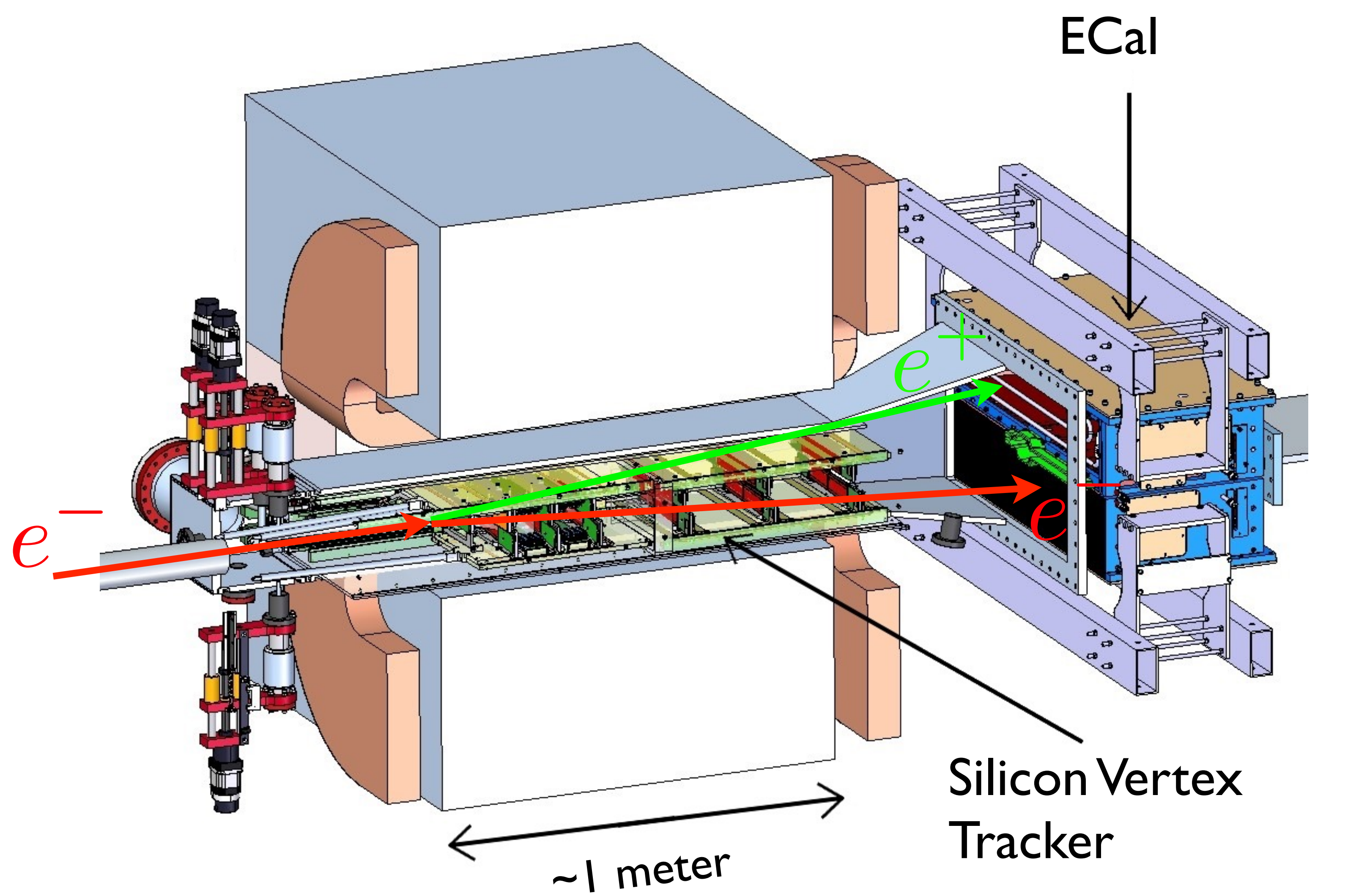
- Review of SVT and motivations for upgrade
- Conceptual design and expected performance
- Technical design and status of construction
- Schedule, budget, and resources

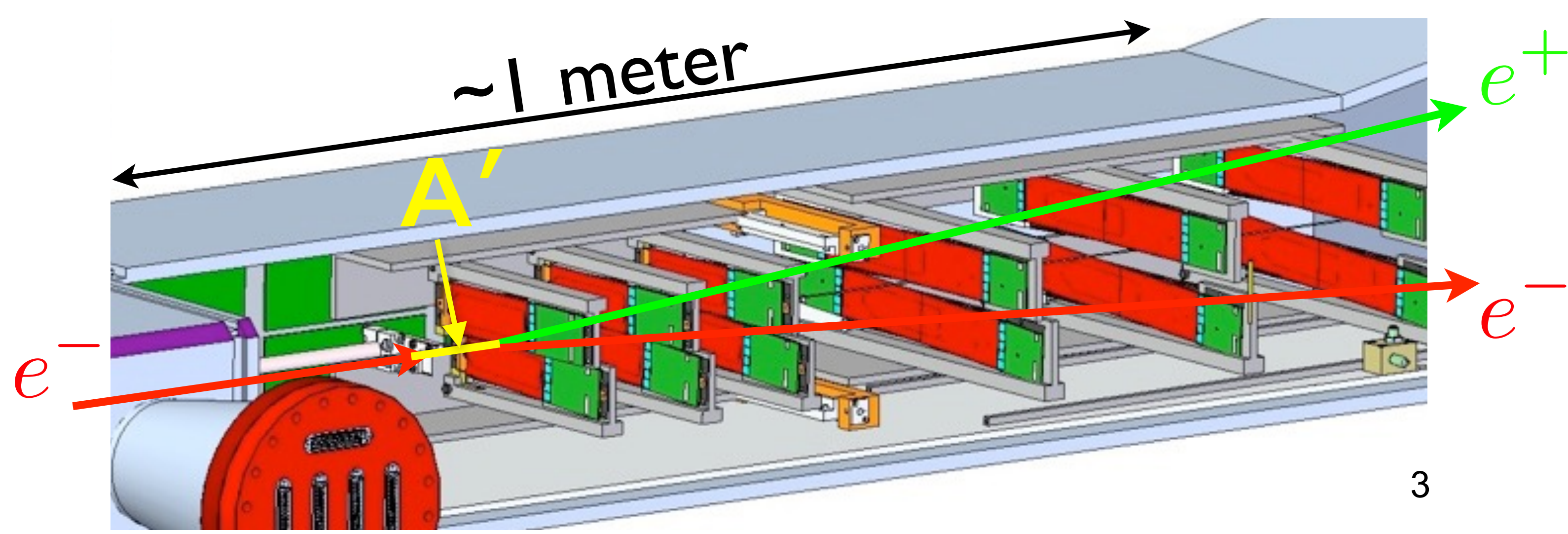
The HPS SVT

Compact e^+e^- spectrometer, immediately downstream of thin target in multi-GeV beam in Hall B.

- Low-mass, high-rate (up to 4 MHz/mm^2) silicon tracker (SVT) allows ***vertexing long-lived A′***. SVT must suppress SM tridents from target by factor ~10^7
- $PbWO_4$ ECal trigger eliminates 10's MHz scattered single e^-.

Short engineering runs in 2015 (1.7 days) and 2016 (5.4 days)



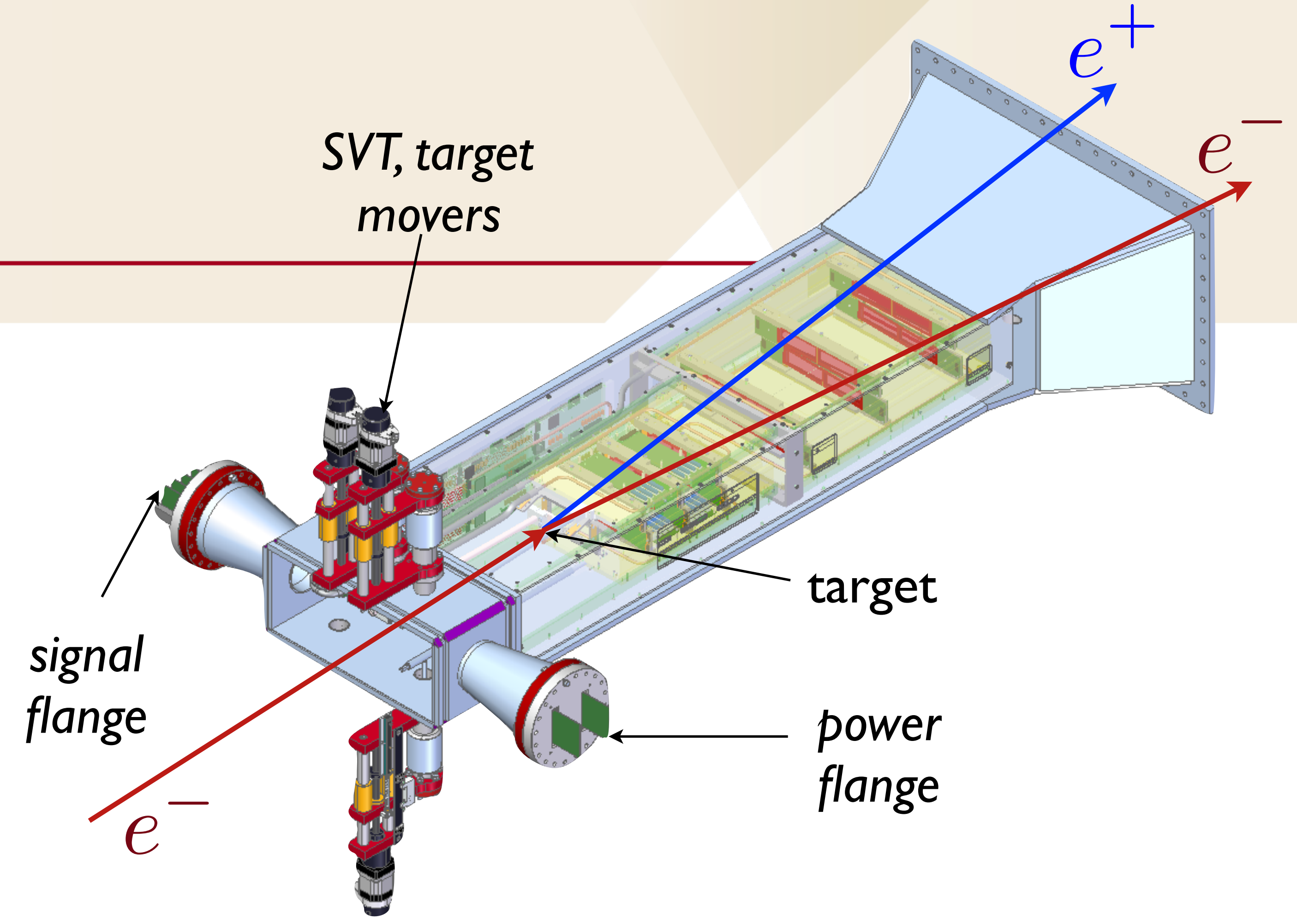


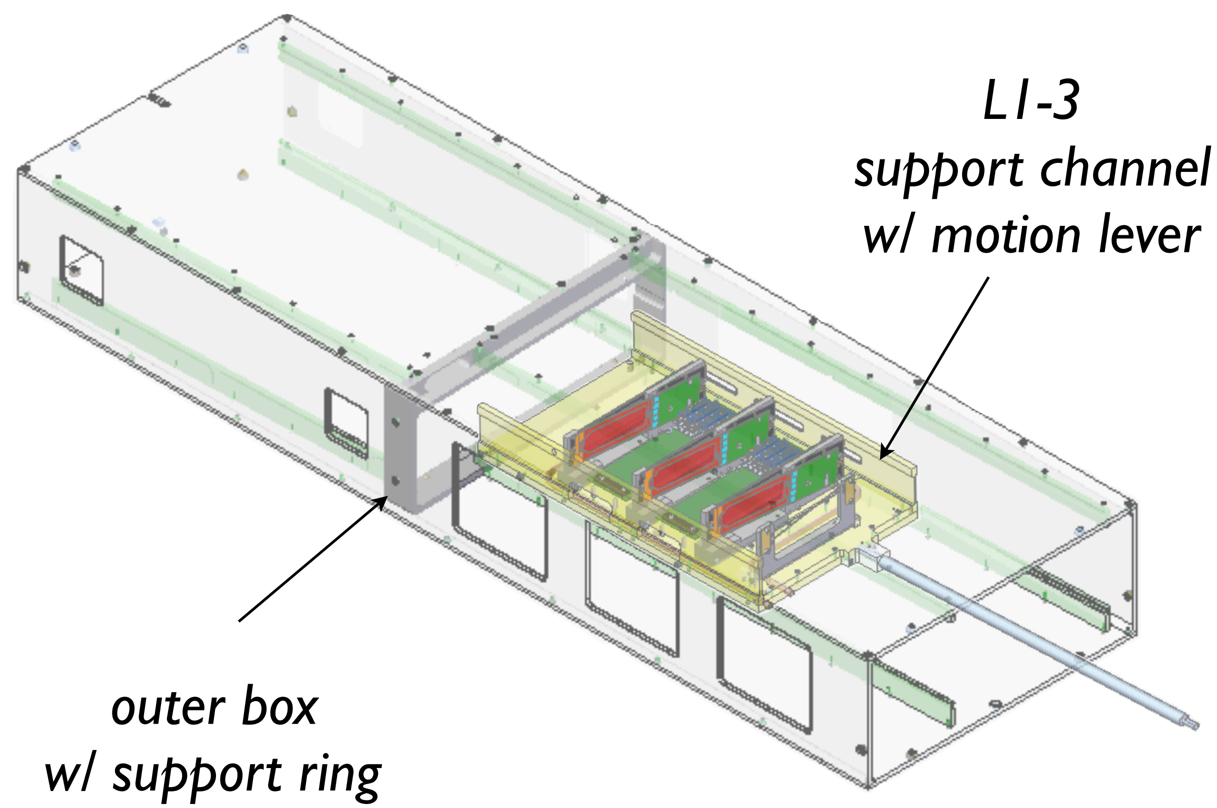
The HPS SVT

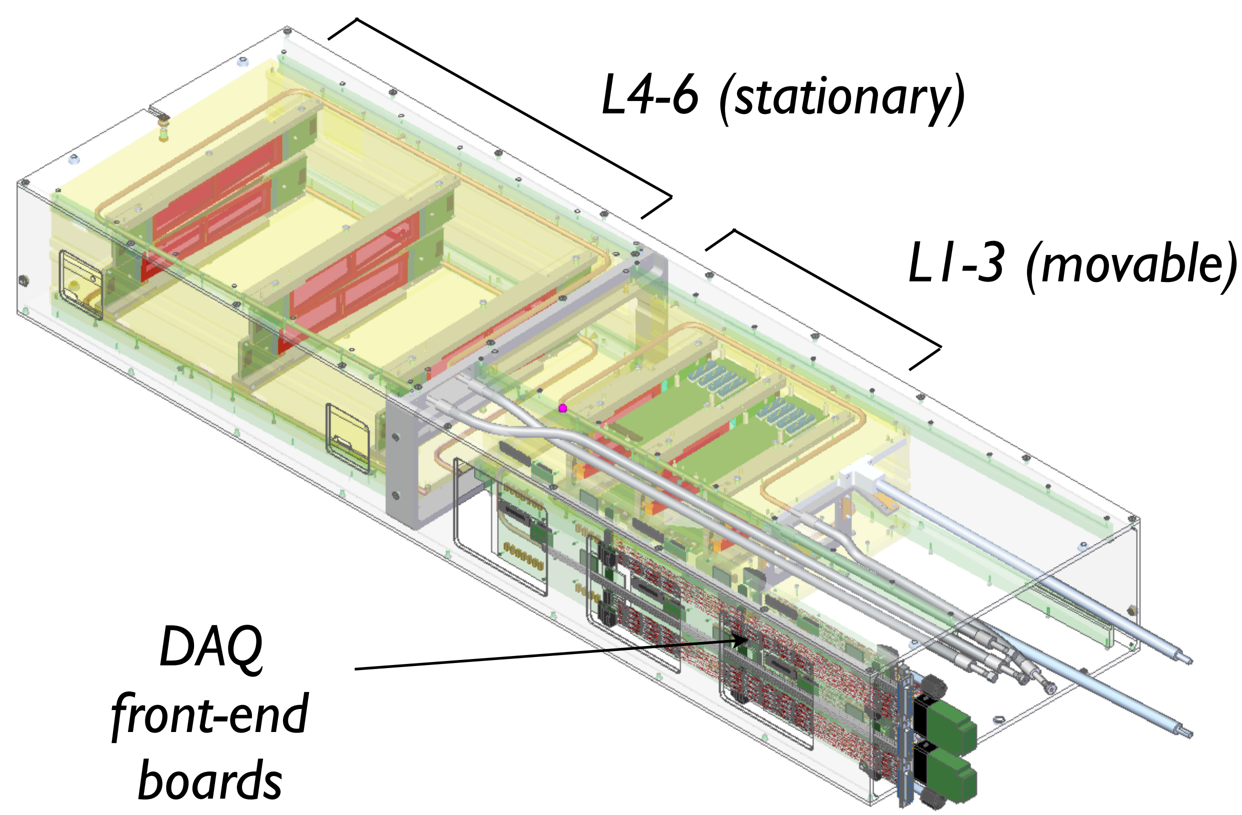
12 layers of silicon strips, each measures position ($\sim$6 μm) and time ($\sim$2 ns) *with 0.7% X_0 / 3d hit.*

Must operate in an extreme environment:

- beam vacuum and 1.5 T magnetic field
- sensor edges 0.5 mm from beam in L1 (15 mrad acceptance in all layers)
- must be actively cooled to -20 C
- ~100 gb/sec requires fast electronics



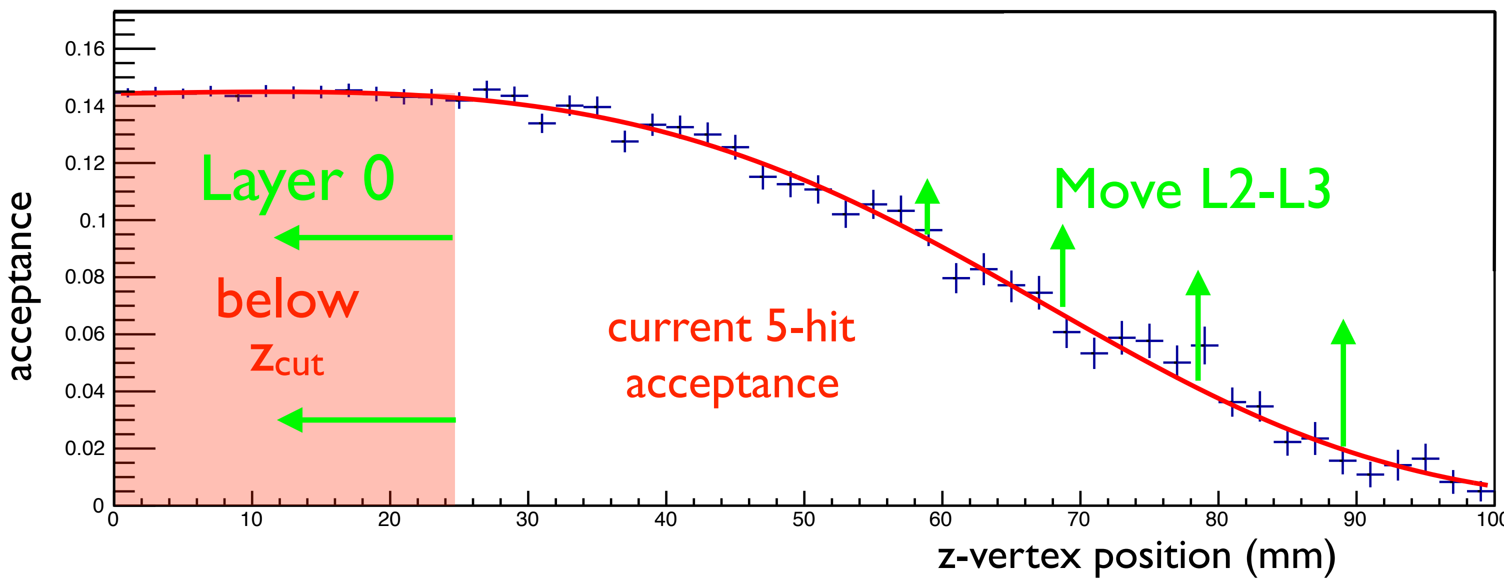


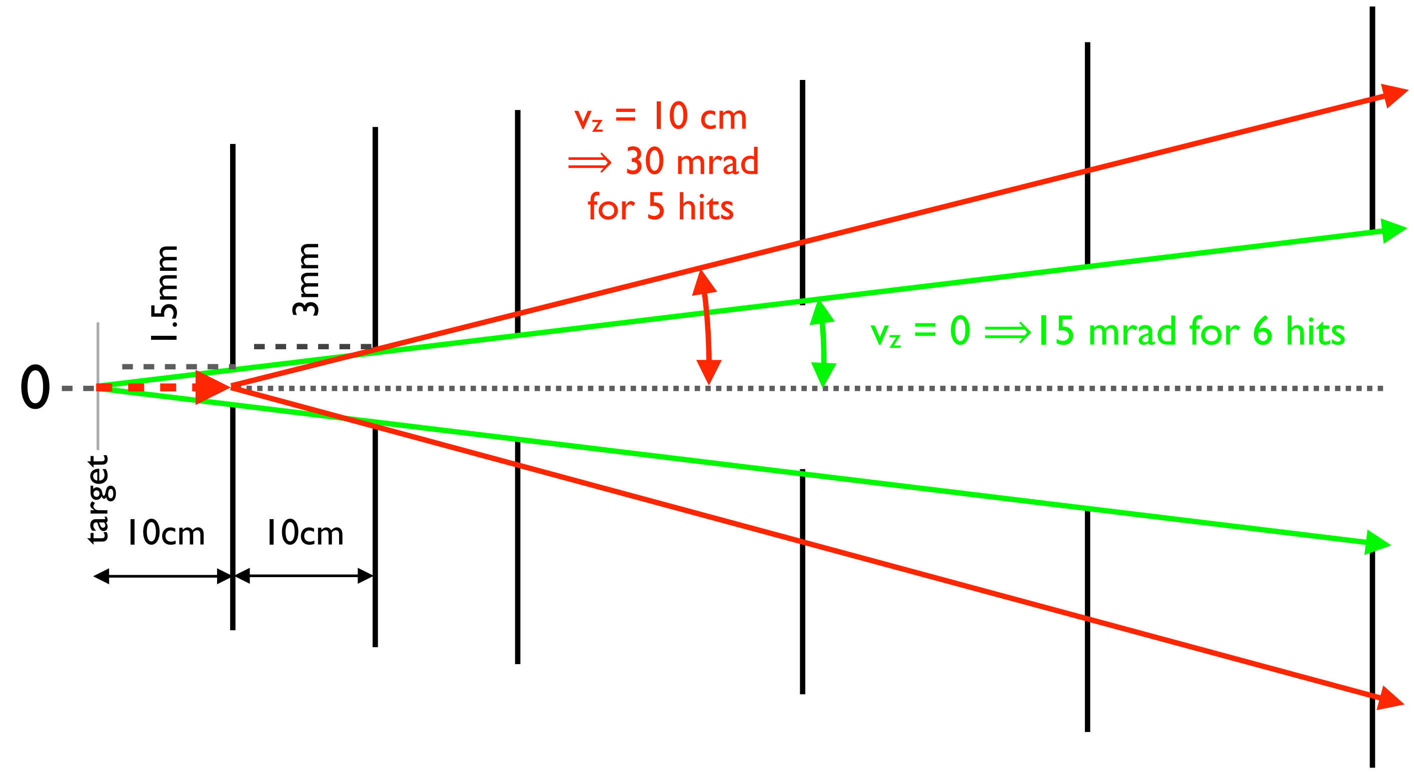


SVT Upgrade Motivations

Adding a new "Layer 0" closer to the target allows access to shorter decay lengths: large multiplier on acceptance for exponential decays.

Moving Layers 2 and 3 as close to beam as occupancy allows restores acceptance at longer decay lengths.





Conceptual Design

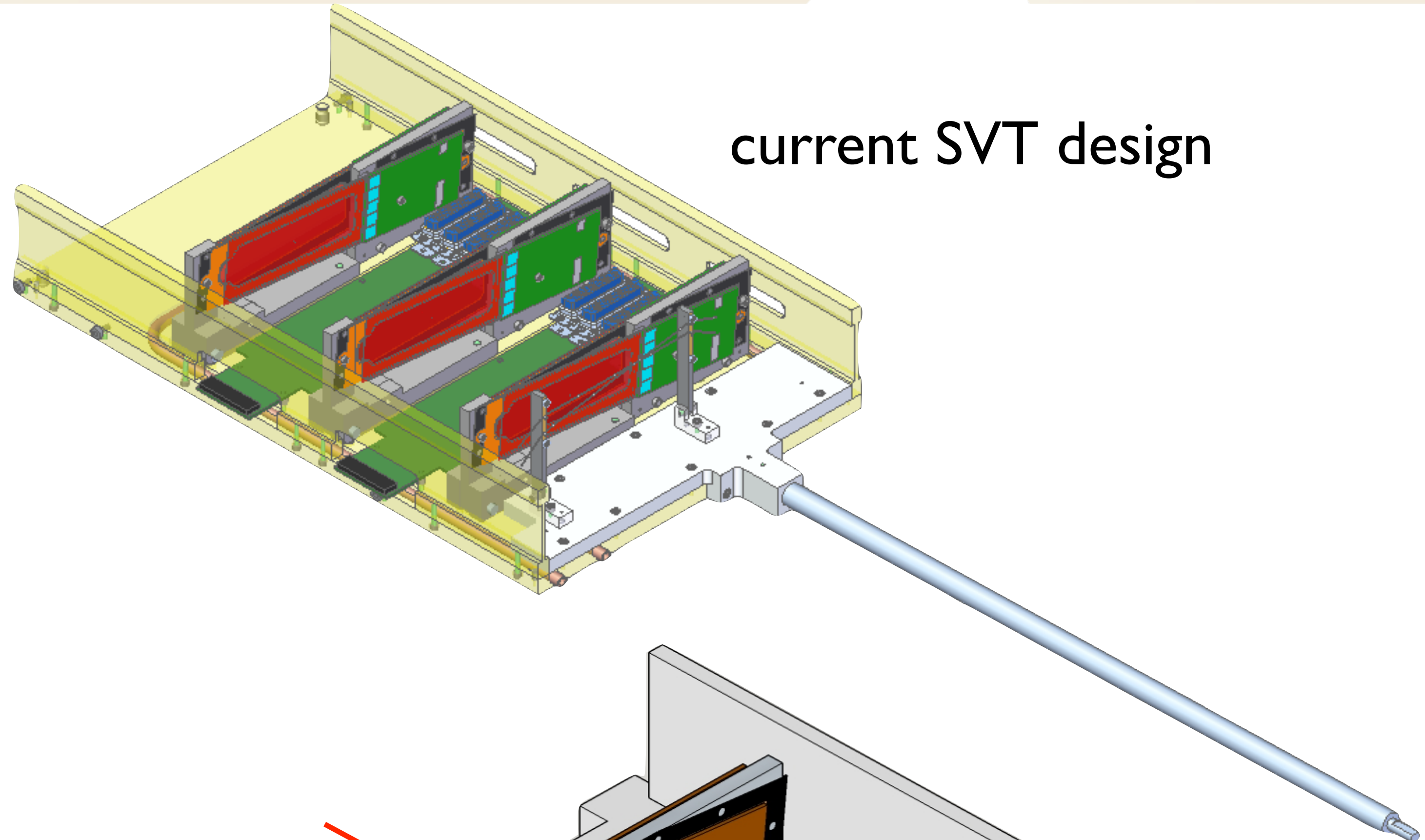
Layer 0 is similar in concept to other layers, but…

closer to target (5 cm vs. 10 cm for L1)

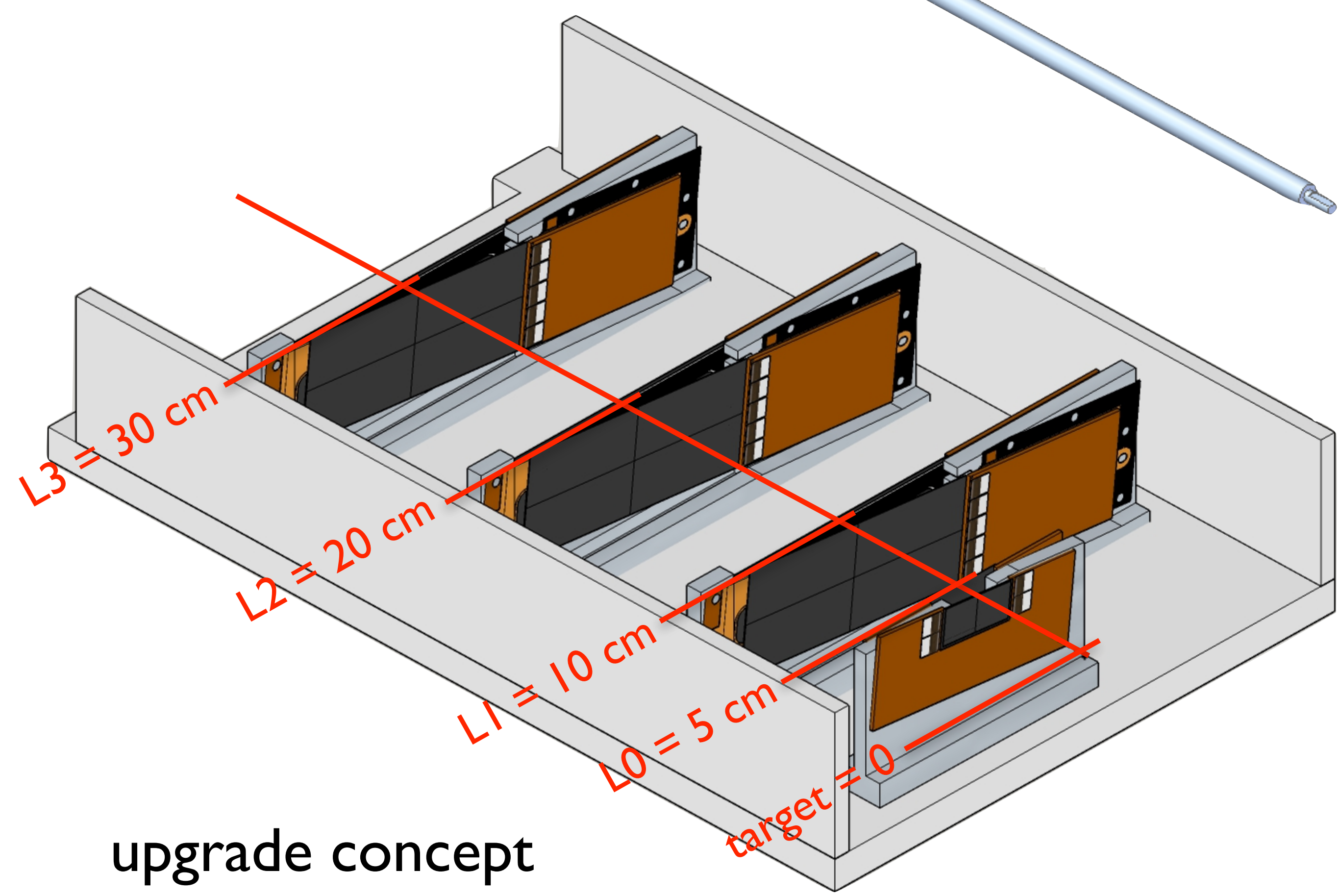
~half the material (0.4% X_0)

For same acceptance, must be proportionally closer to beam.

Moving L2 and L3 closer by small amount (700 microns) is simple matter of adding shims under modules.

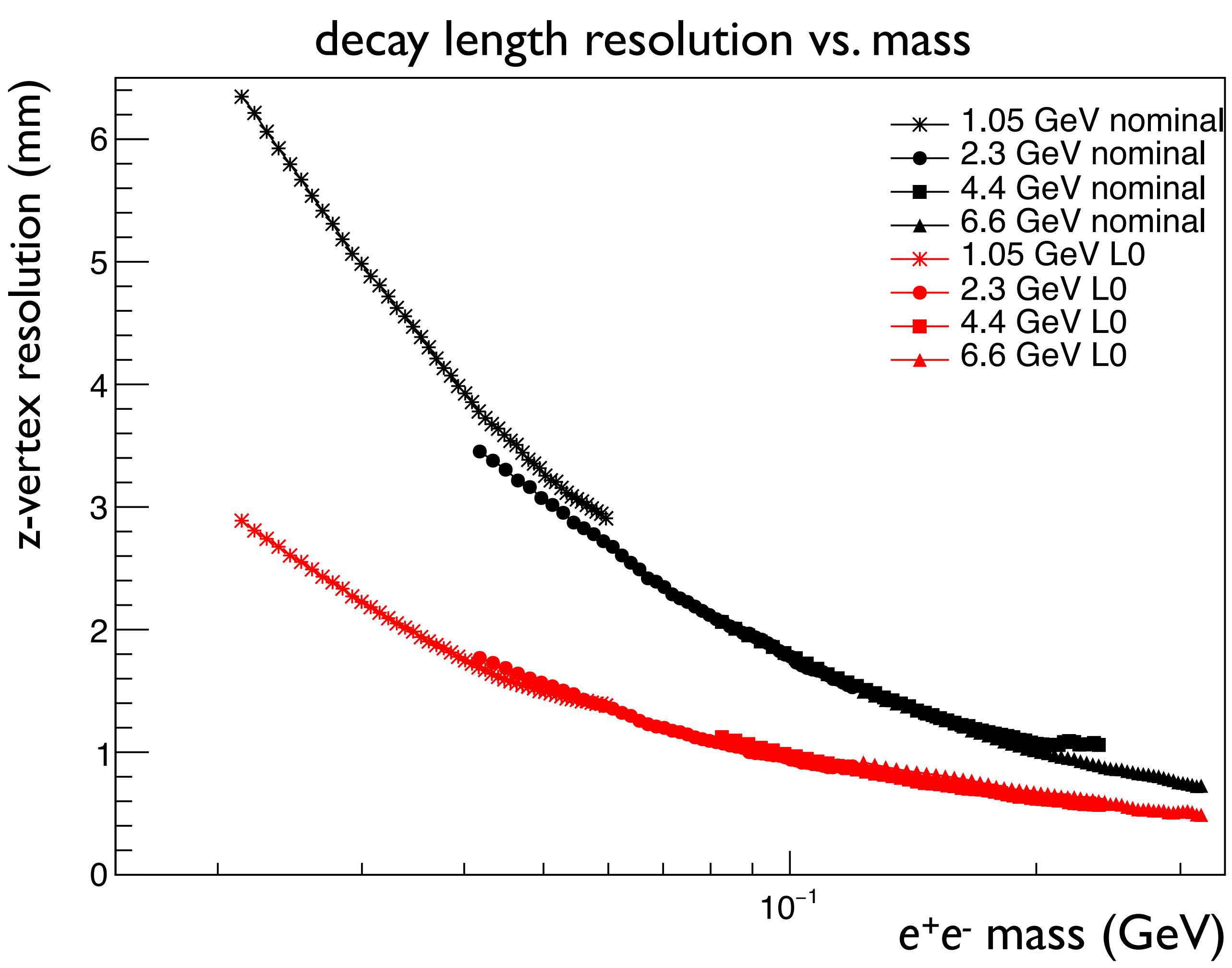


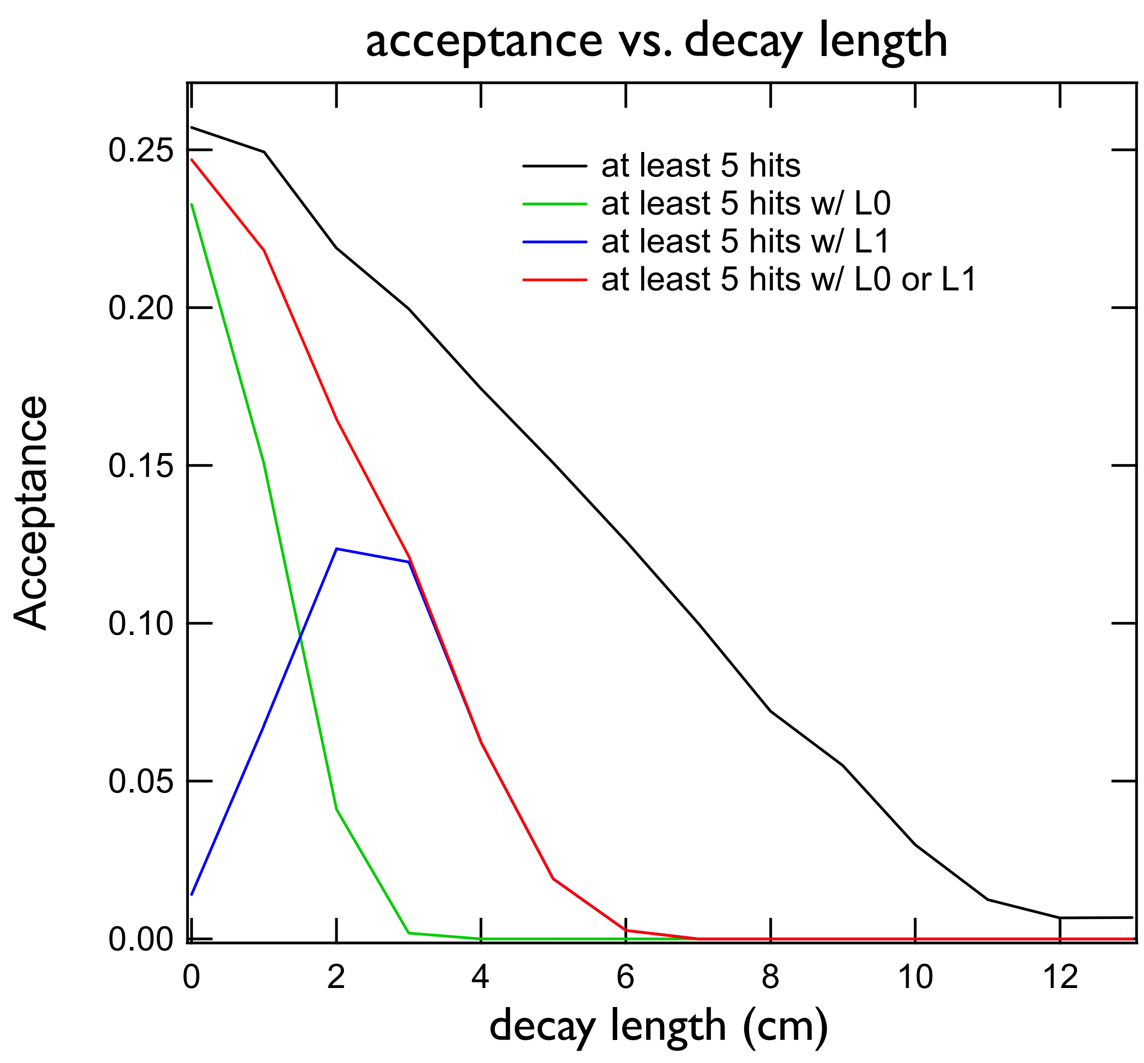
current SVT design



upgrade concept

Upgrade Improvements

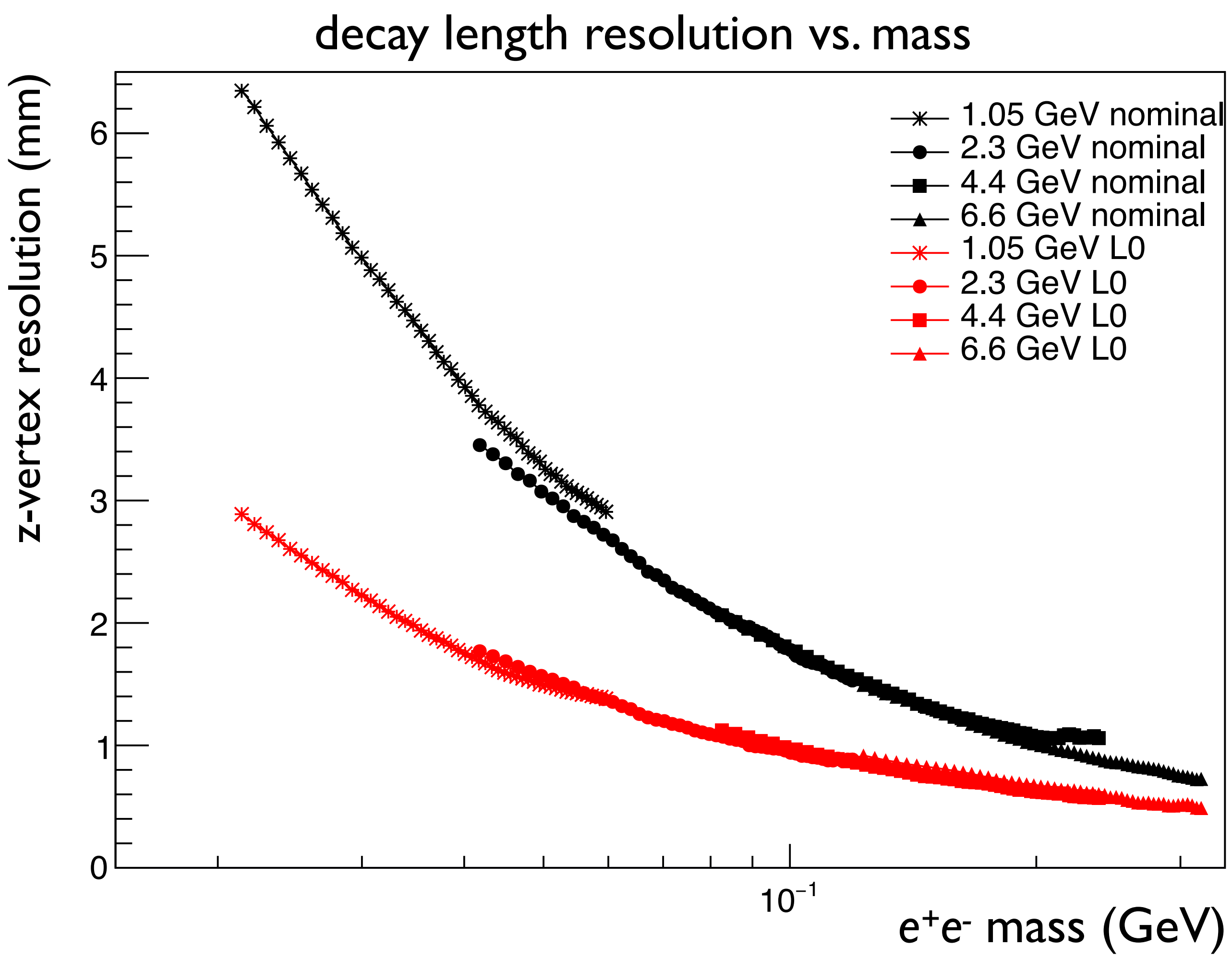


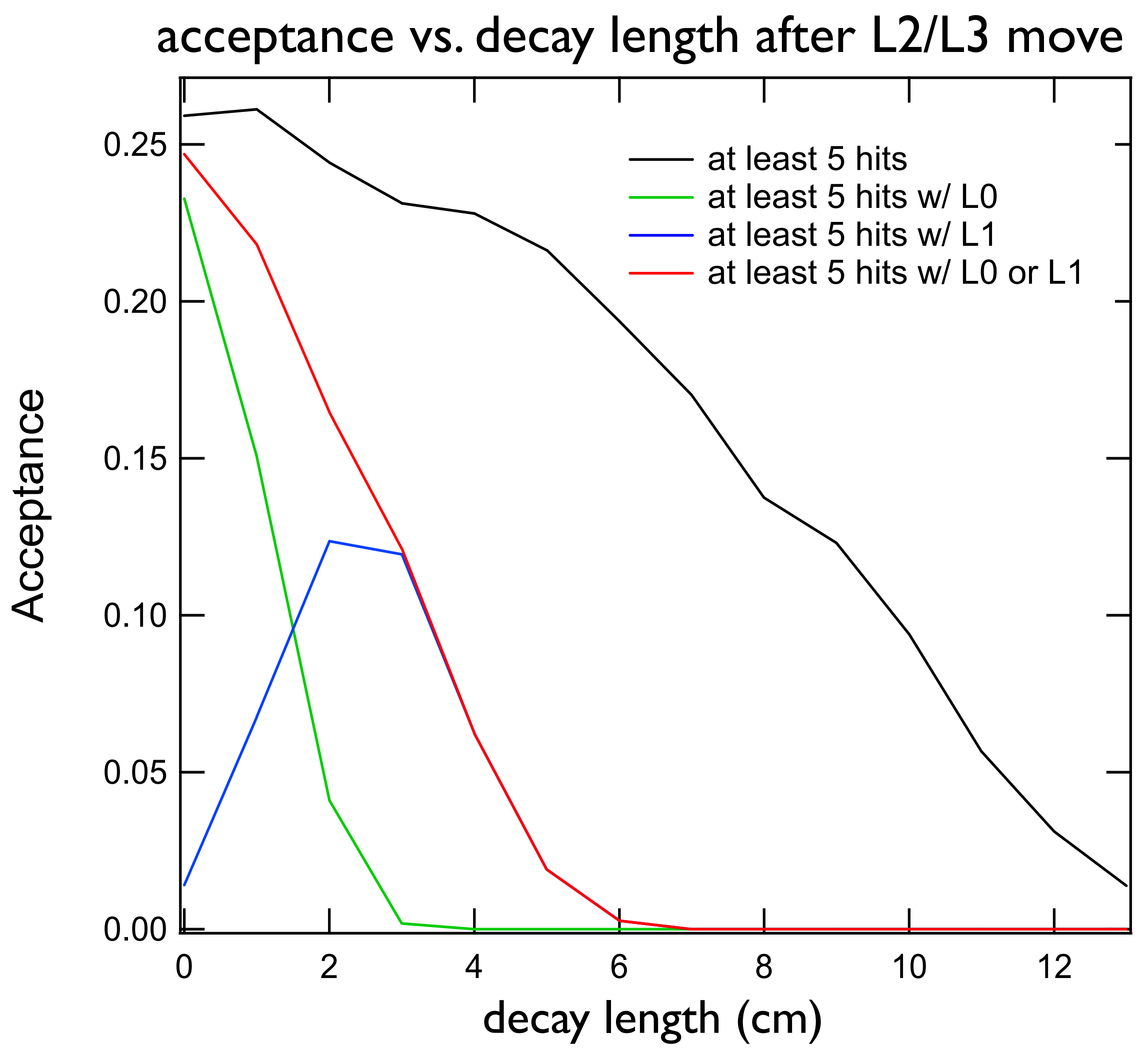


Vertex resolution improves roughly a factor of two.

Acceptance improves for long decay lengths

Upgrade Improvements





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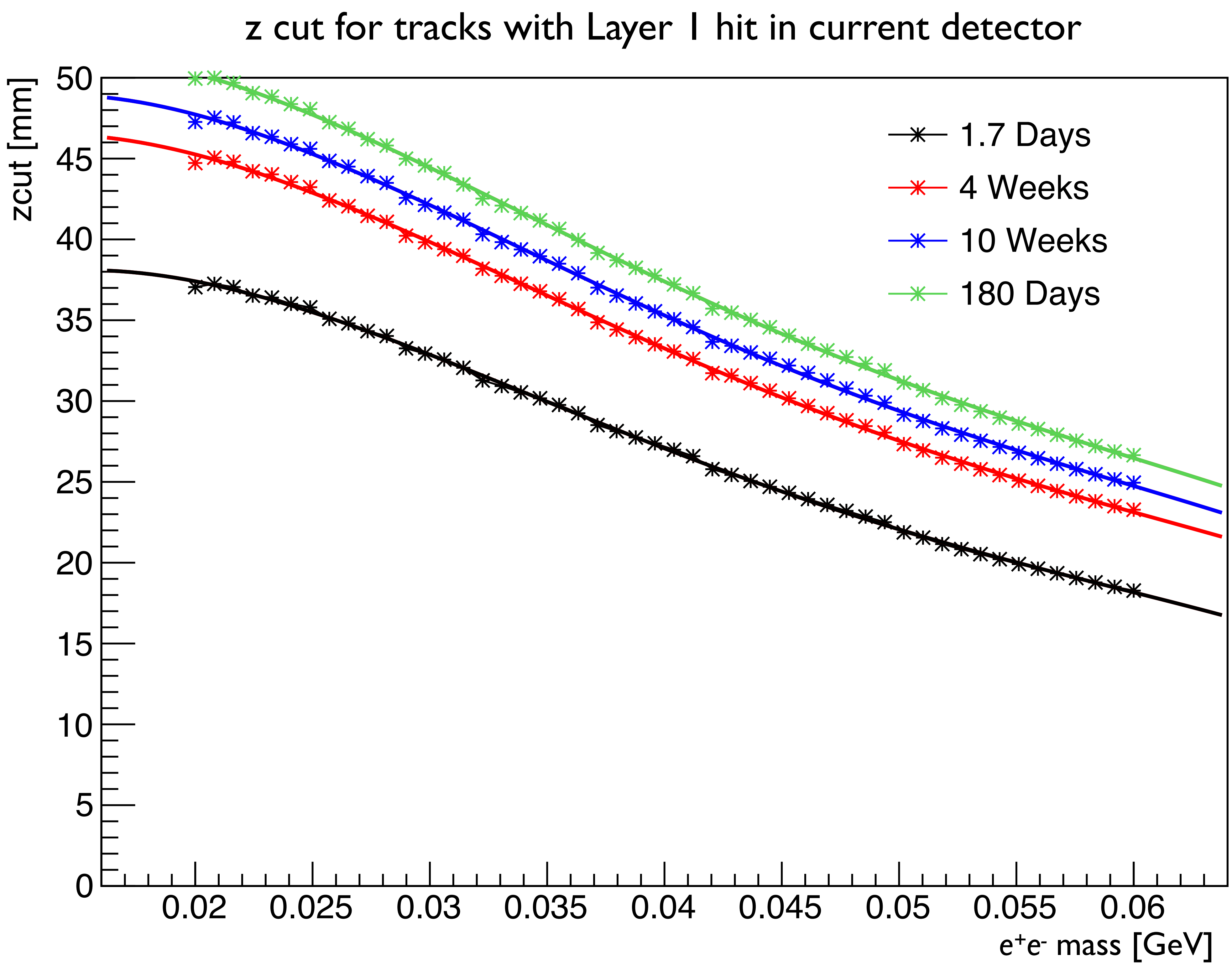
Cut on z vertex position for 0.5 Events Background

SLAC



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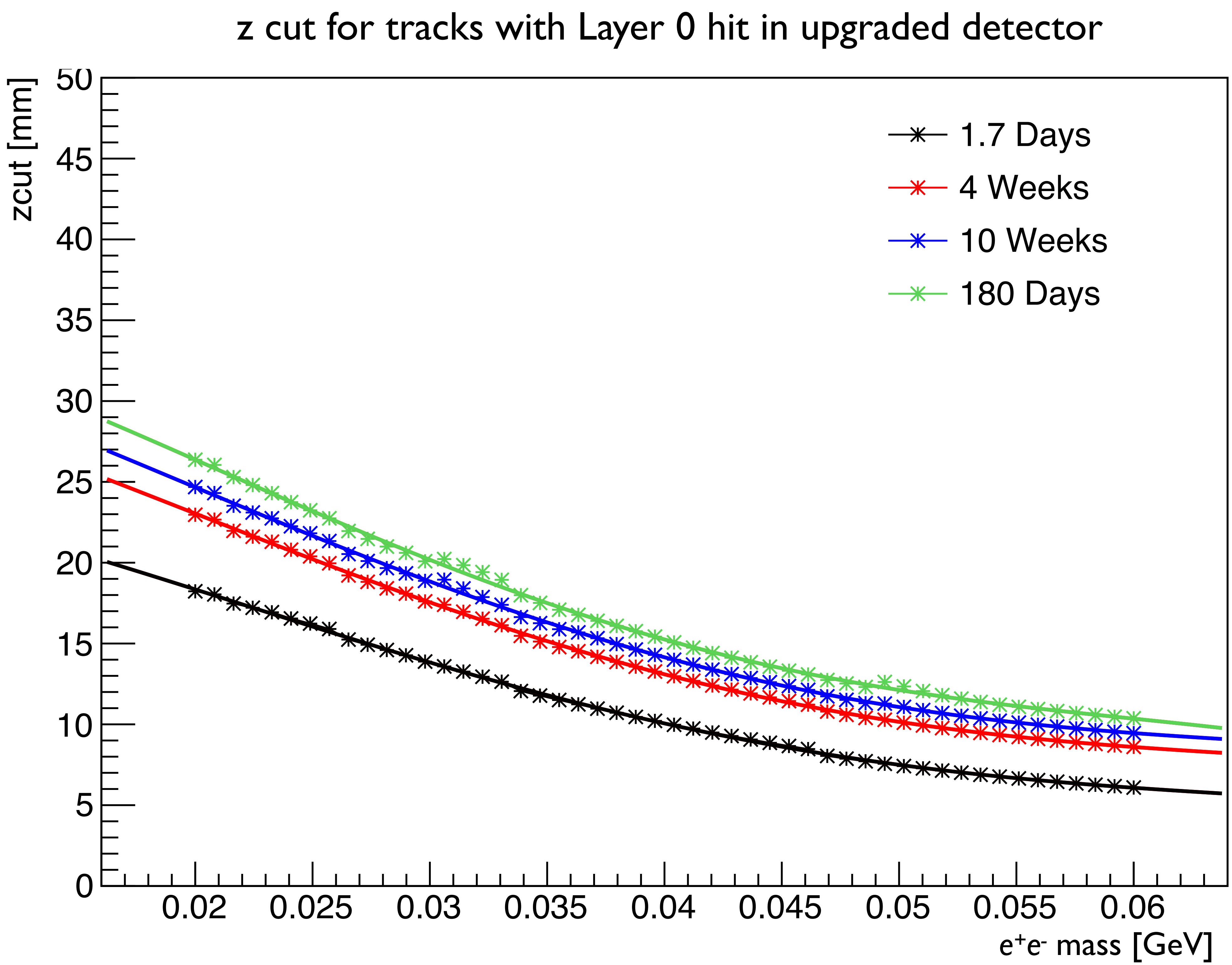
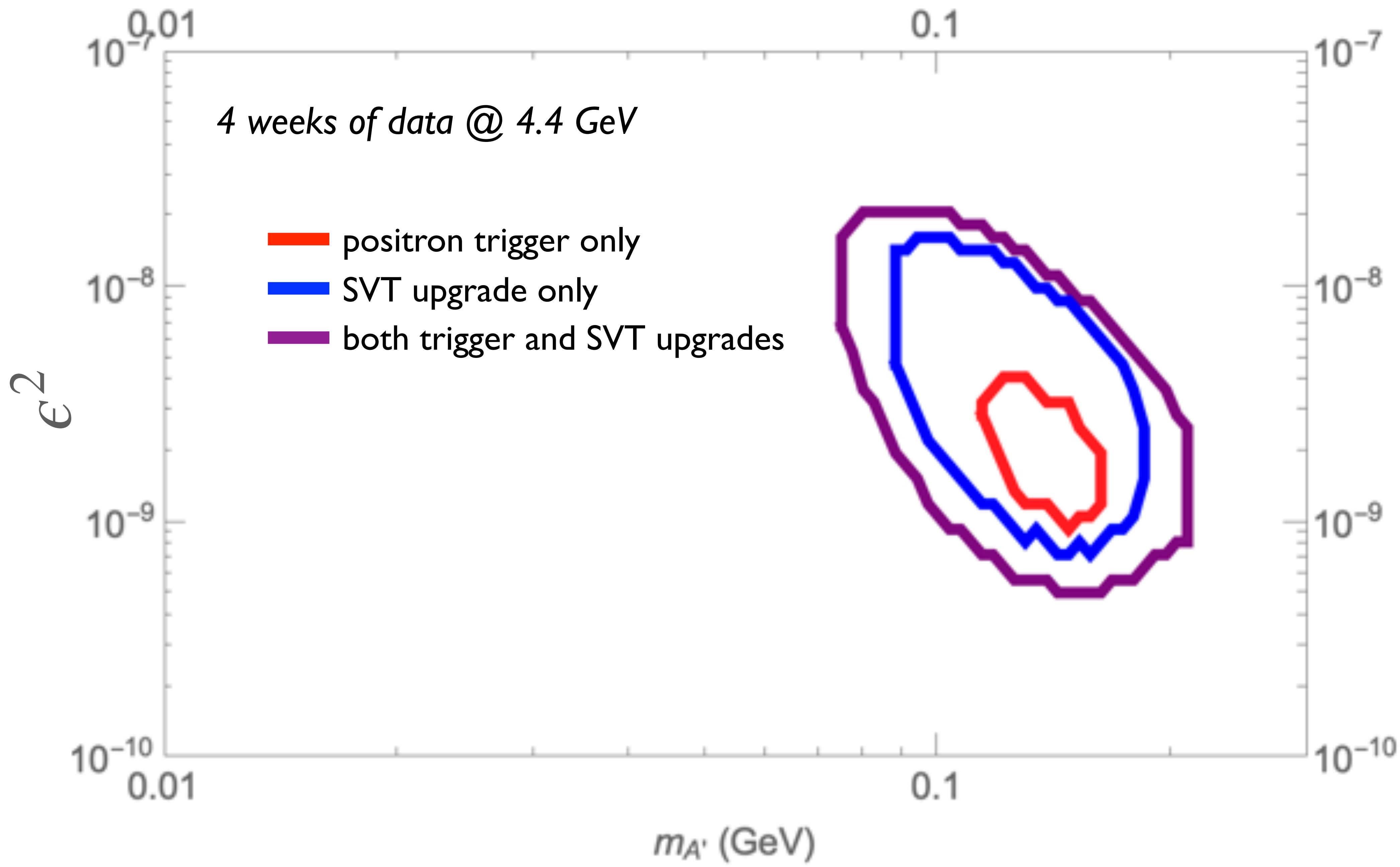


Upgraded Reach

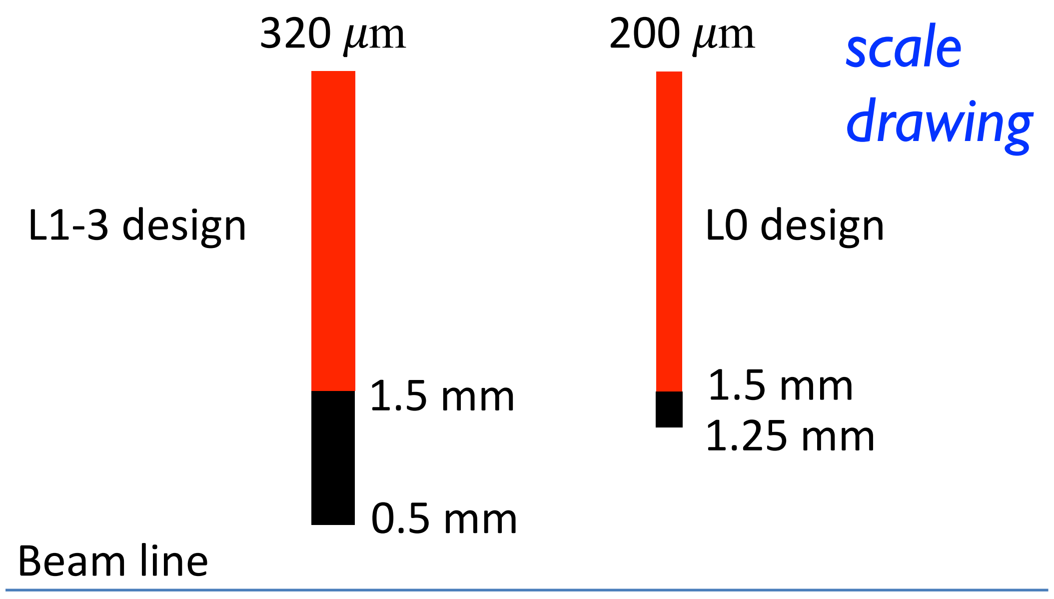


Layer 0 is biggest factor in restoring reach with the upgrades.

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?

Layer 0 design tolerates higher occupancy, would allow moving Layer 1 inward so that more long-lived particles will have an L1 hit.

Additional sensitivity from this change still being assessed but could be large.

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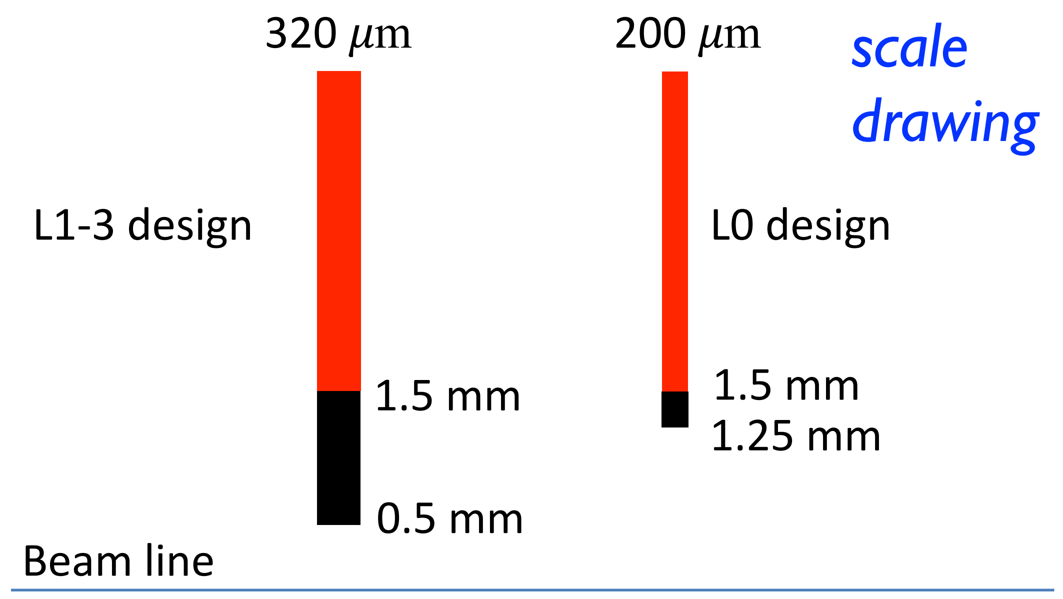
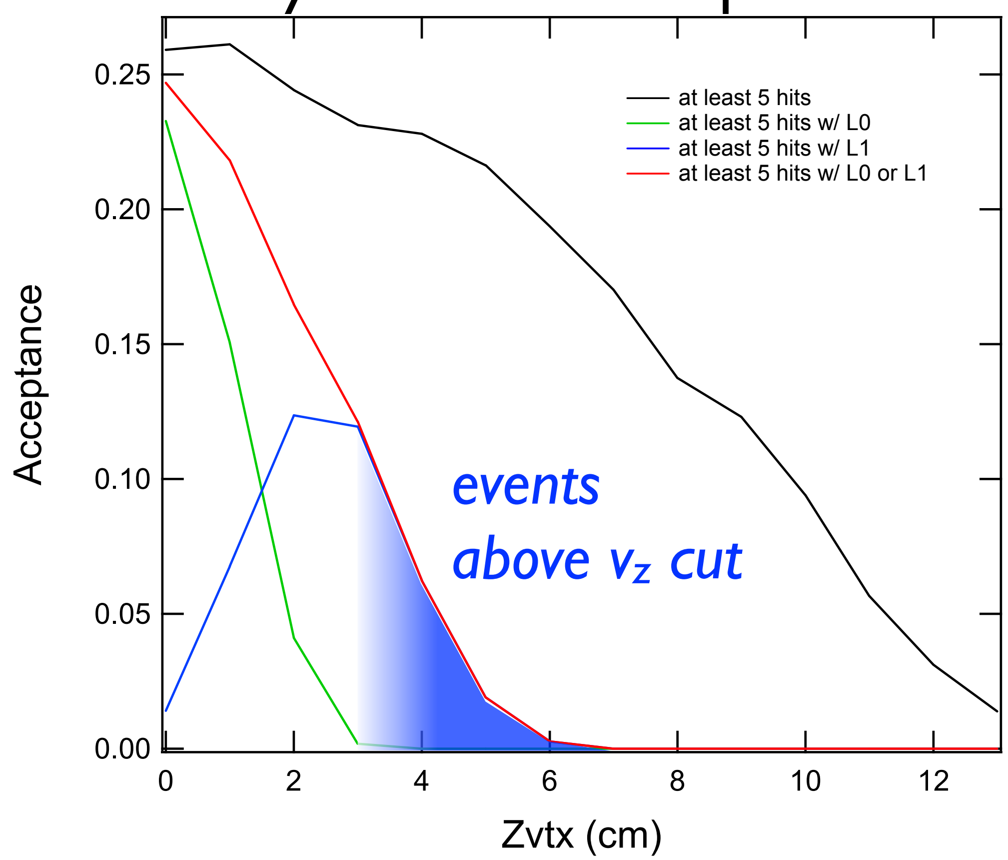
scale drawing



Layer 1 in nominal position



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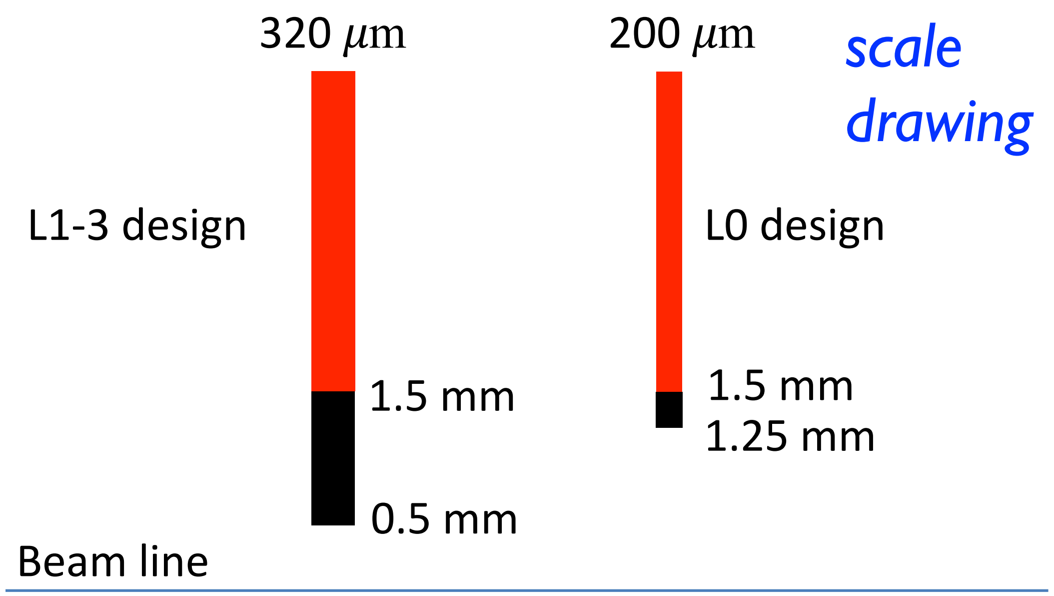
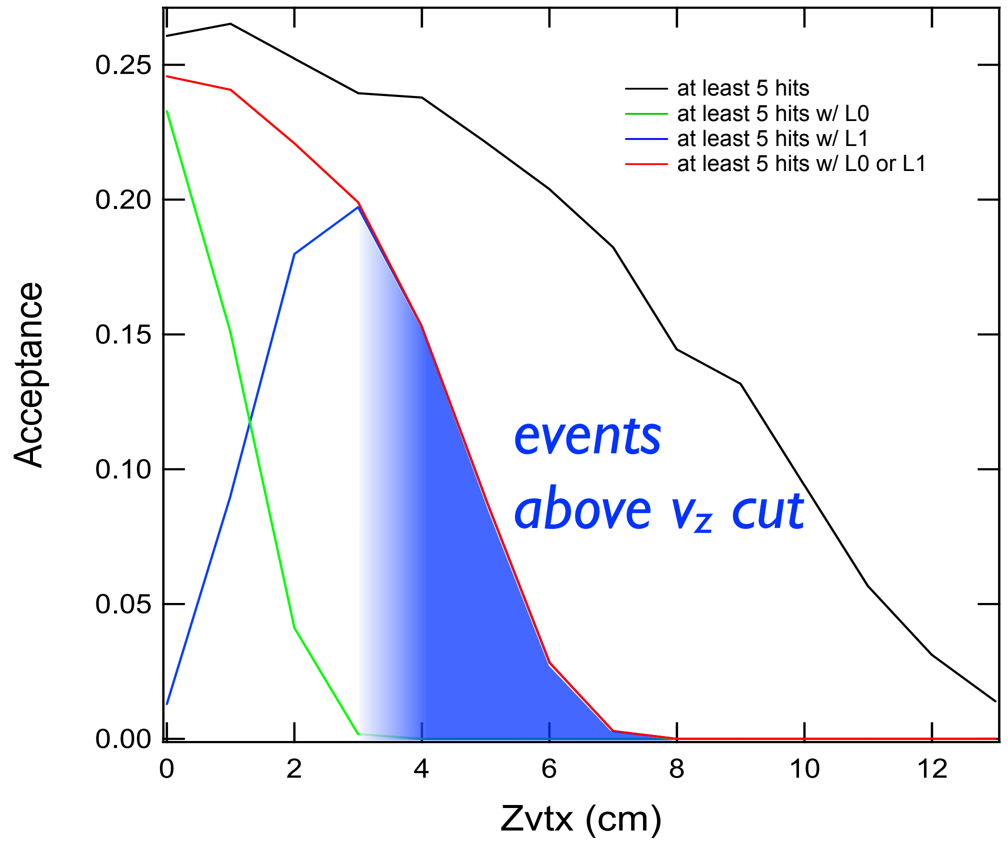
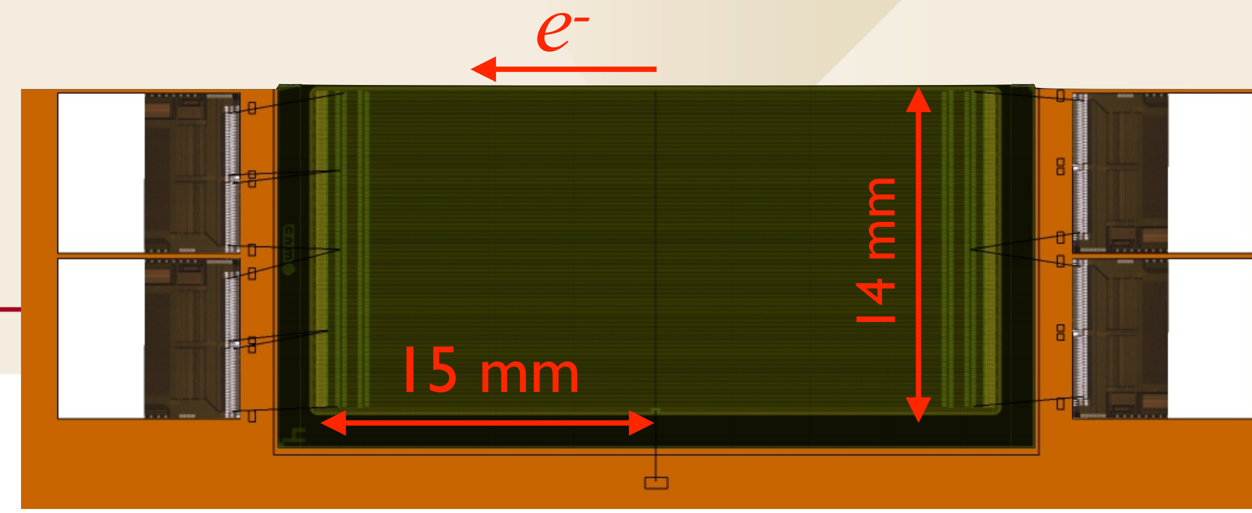


move L1 in 0.4 mm



Layer 0 Sensor Design



200 μm thick p⁺-in-n bulk Si

55 μm sense/readout pitch

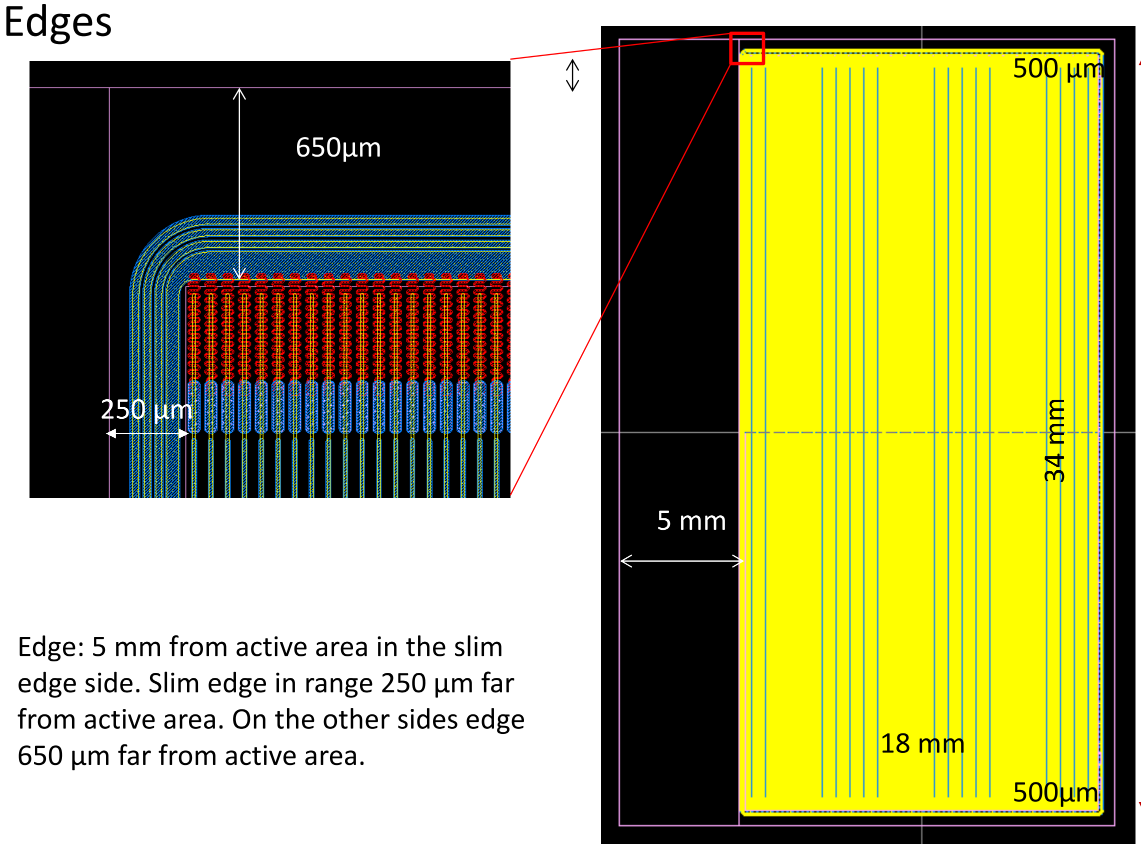
split into two 15 mm × 14 mm active areas, with short strips read out from both ends

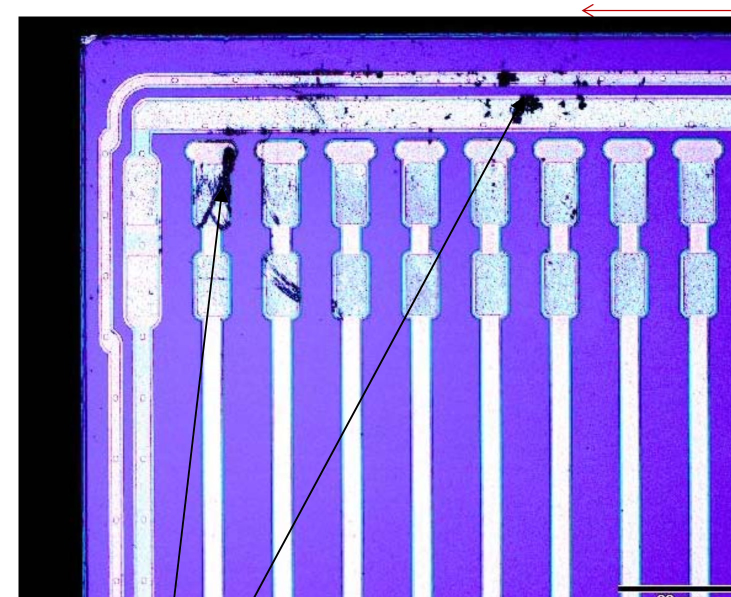
510 channels (2×255)

250 μm slim inactive edge allows placement closer to beam (scribe-cleave-passivate process)

~500V maximum bias voltage

Edges





Sensor Status

Sensors have defined the critical path

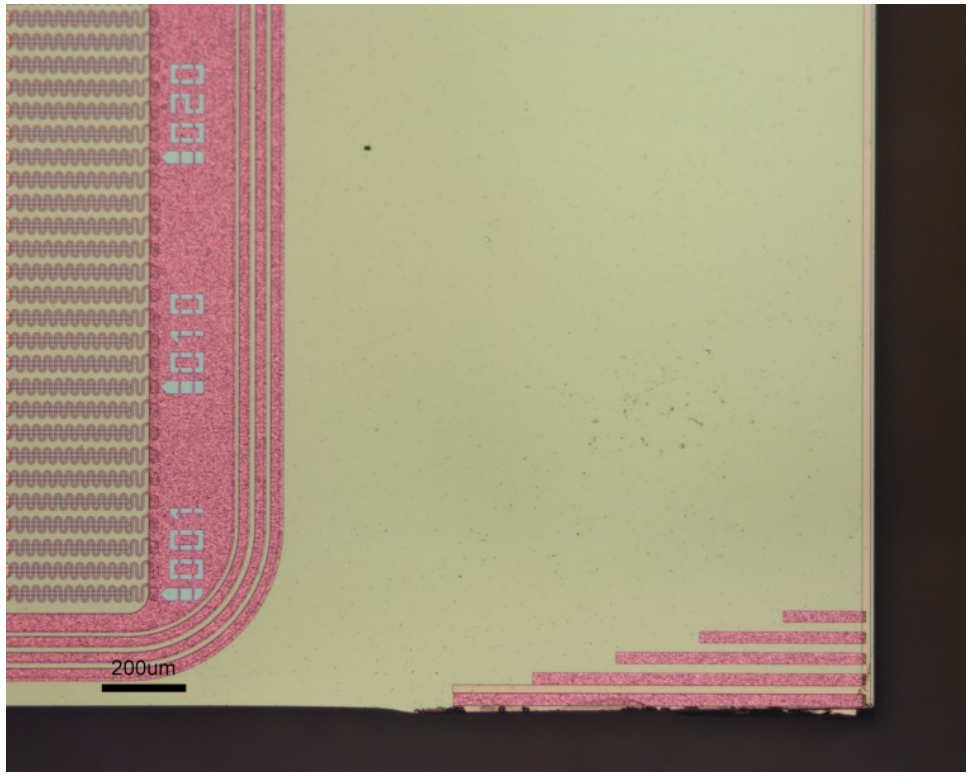
- Order for 20 units placed Oct. 2017 with CNM D+T
- Design finalized 1/19/18, fabrication started 2/5/18
- Projected delivery July → October → *December*
- Fabrication completed Nov. 9, tested/diced sensors available Dec. 4 for slim-edge cleaving
- First cleaved sensors now at UCSC and SLAC.

Results overall are good

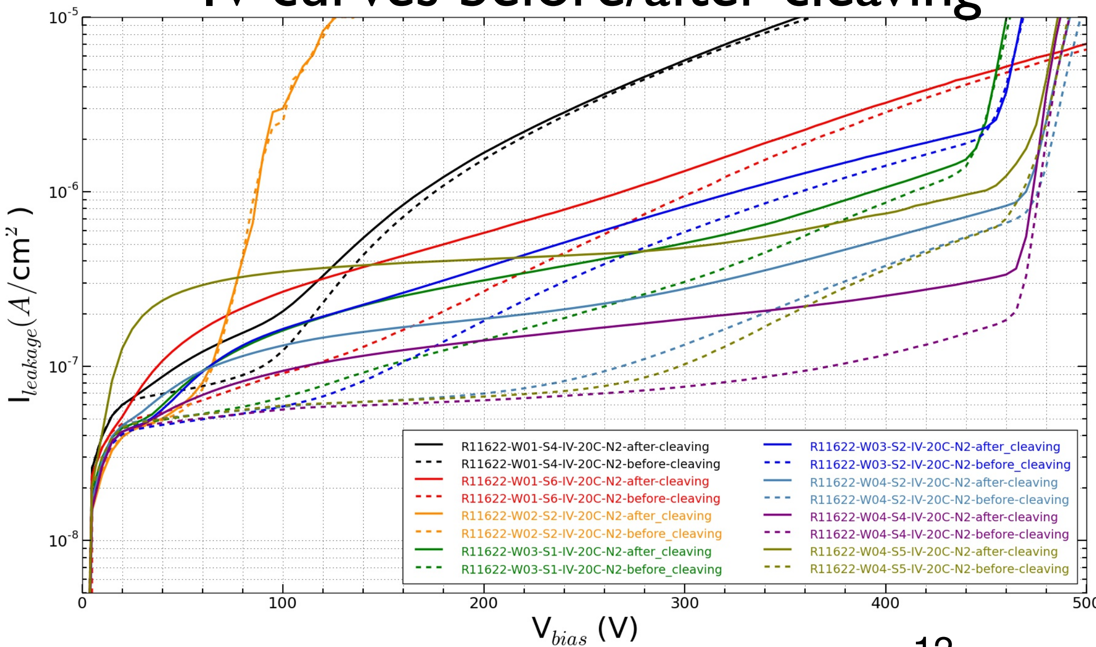
- depletion and IV characteristics as expected
- cleaving not significantly impacting breakdown
- factors determining yield:
  - pinhole spec (2%)
  - slim-edge thickness
  - ➡Modules used in L1 don't require slimmest edge
  - ➡Many pinholes outside acceptance

Can build good modules for L0 and L1 with these.

slim-edge cleaving



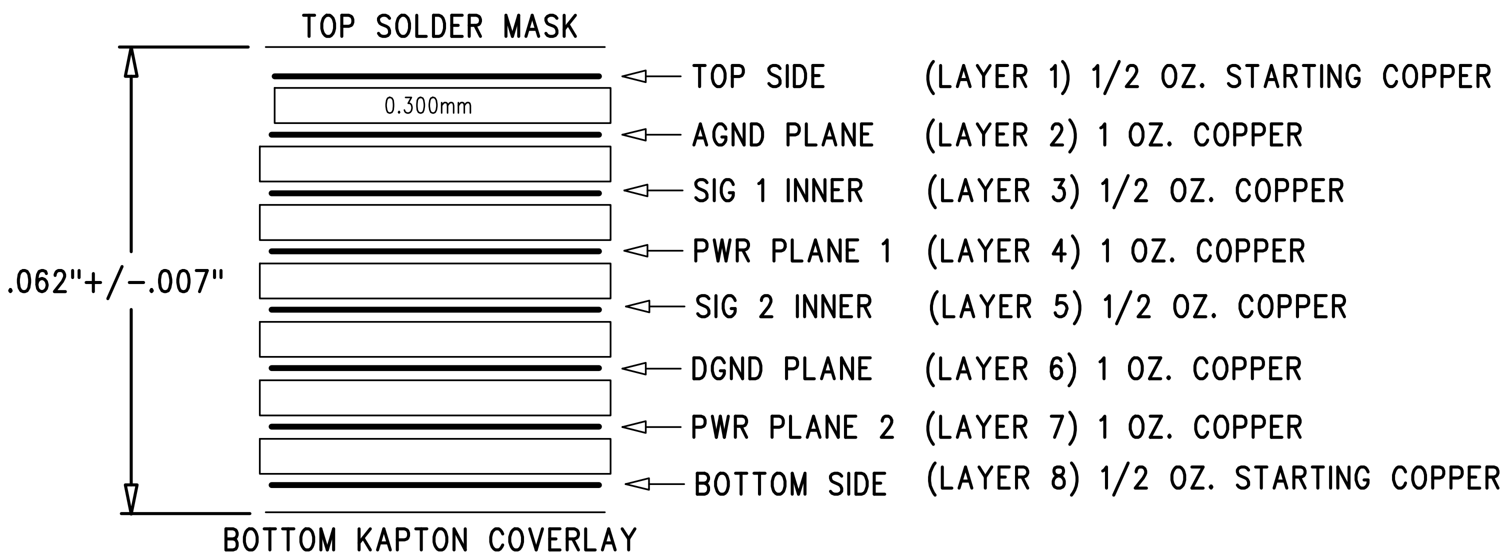
IV-curves before/after cleaving

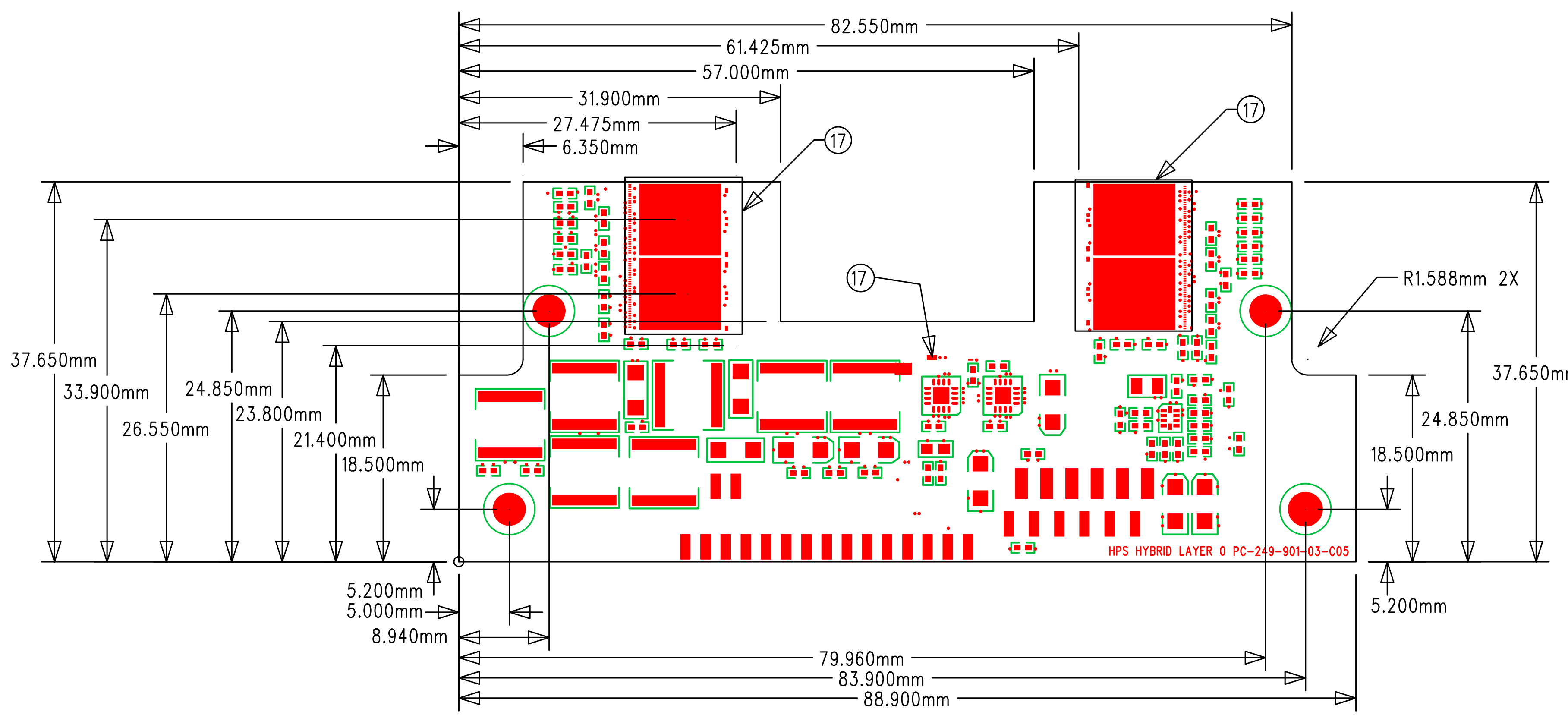


Layer 0 Hybrid Design

Schematic is simple modification to previous designs (one fewer APV25), but the layout is quite different.

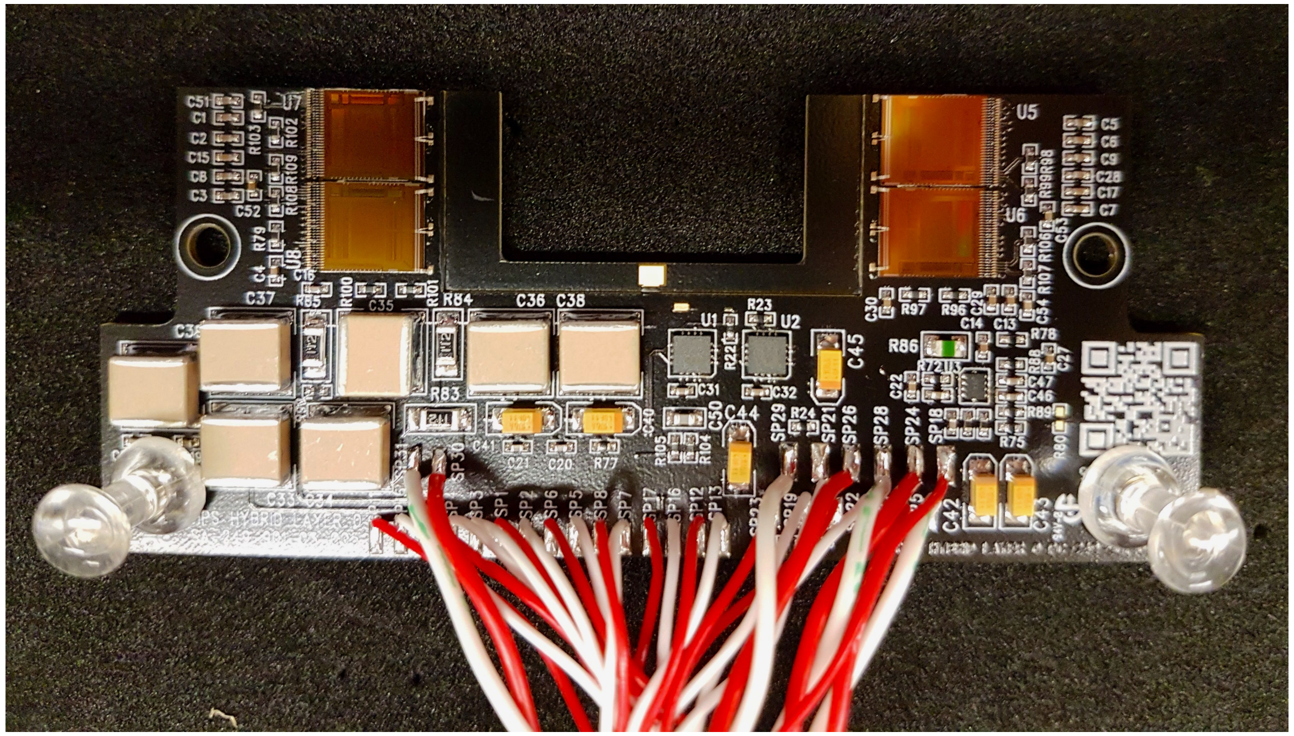
8-LAYER STACK-UP

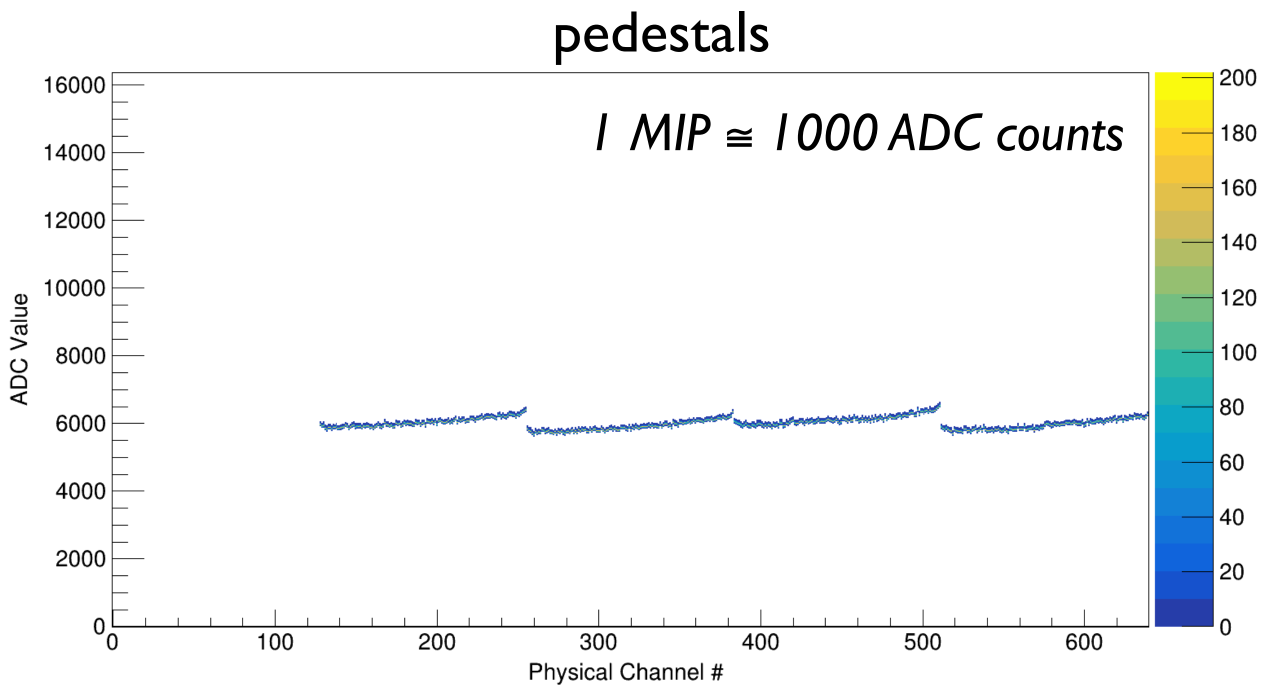


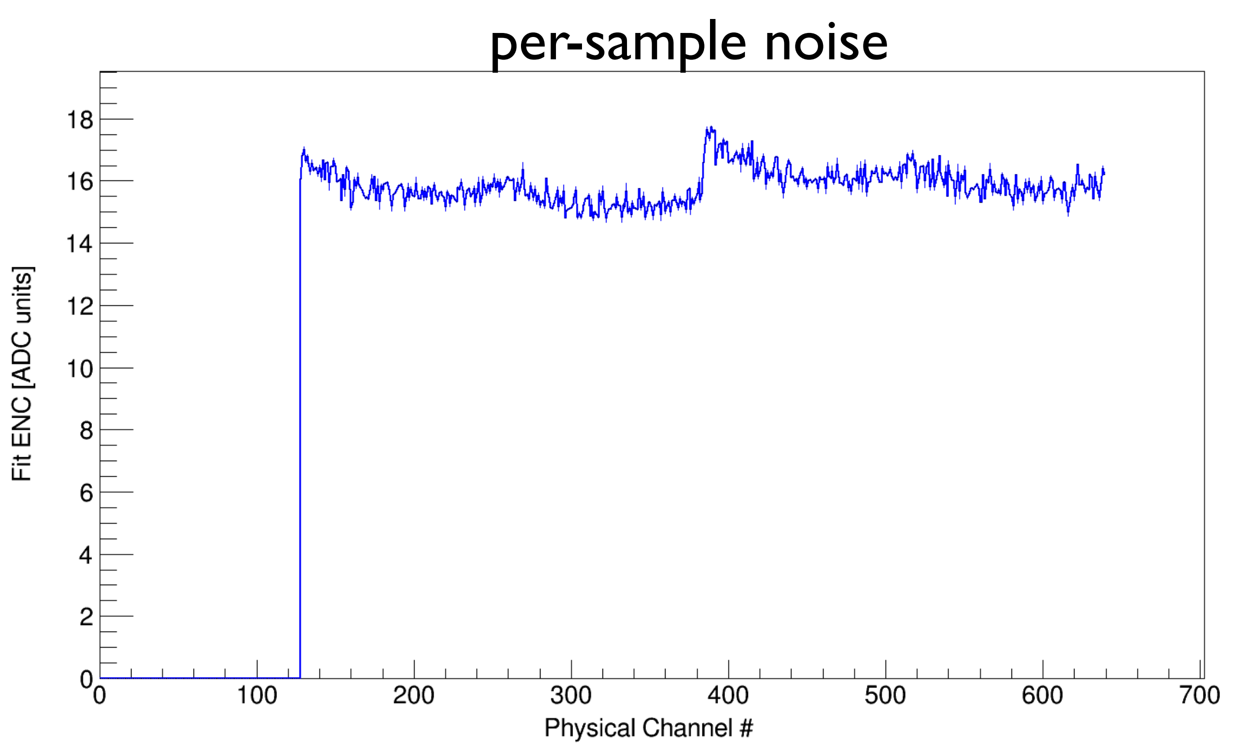


DRILL DRAWING

Layer 0 Hybrid Status and Performance



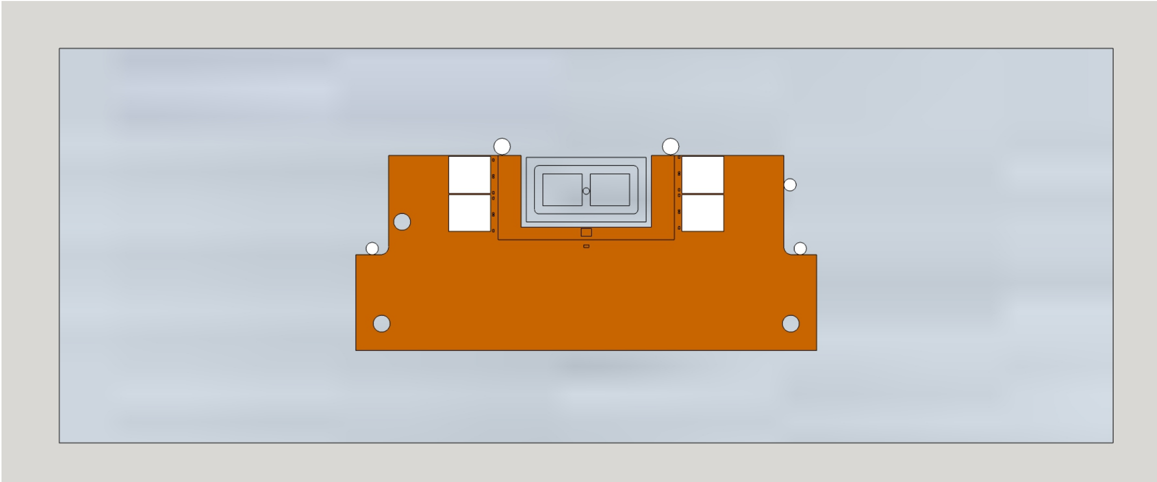


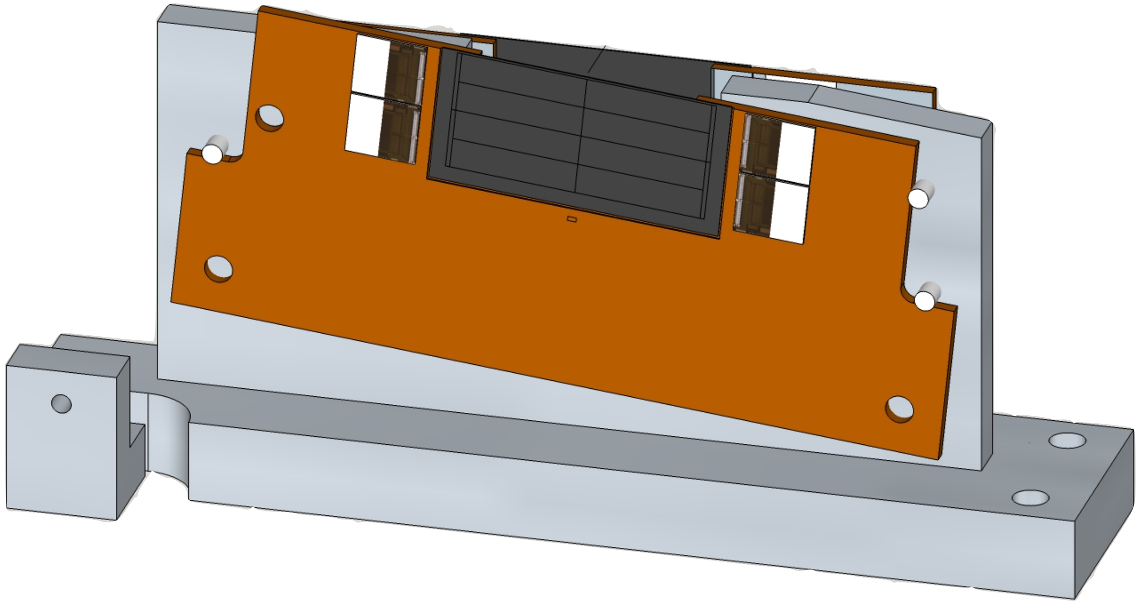


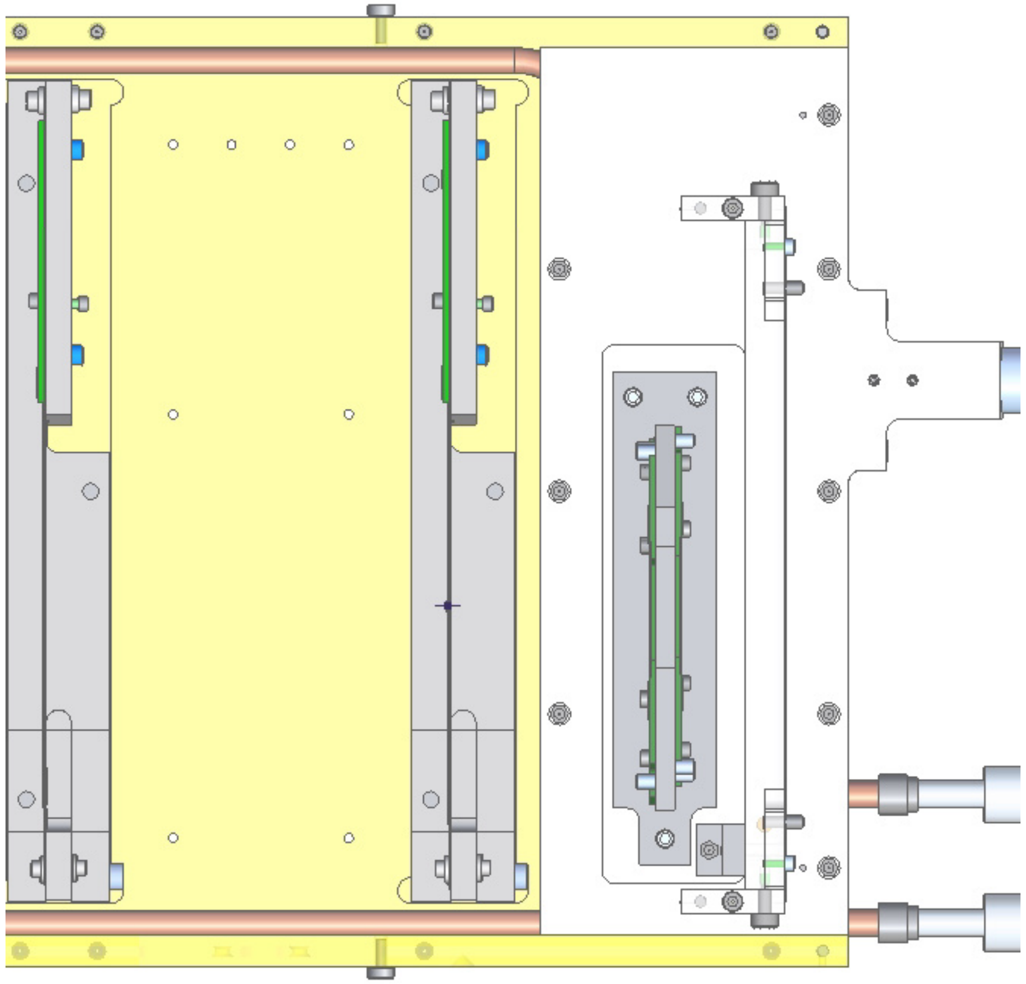
- Full run of hybrids received in early December.
- First production hybrid was assembled and tested at SLAC/UCSC before the holidays.
- Performance is as expected.
- Now loading and testing all hybrids

Layer 0 Mechanical Design

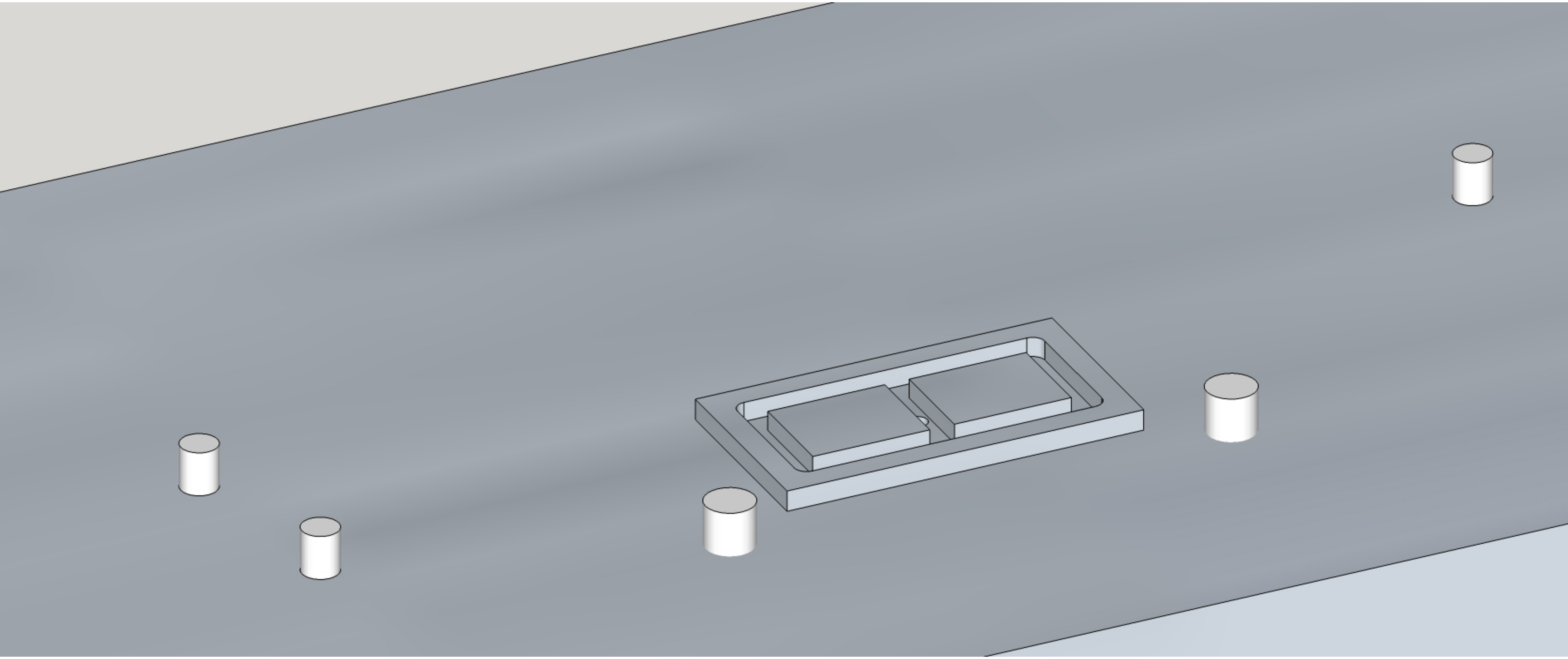
- module assembly fixture
- module support
- u-channel lever block
- storage/shipping/wirebonding fixtures







Layer 0 Module Design and Assembly



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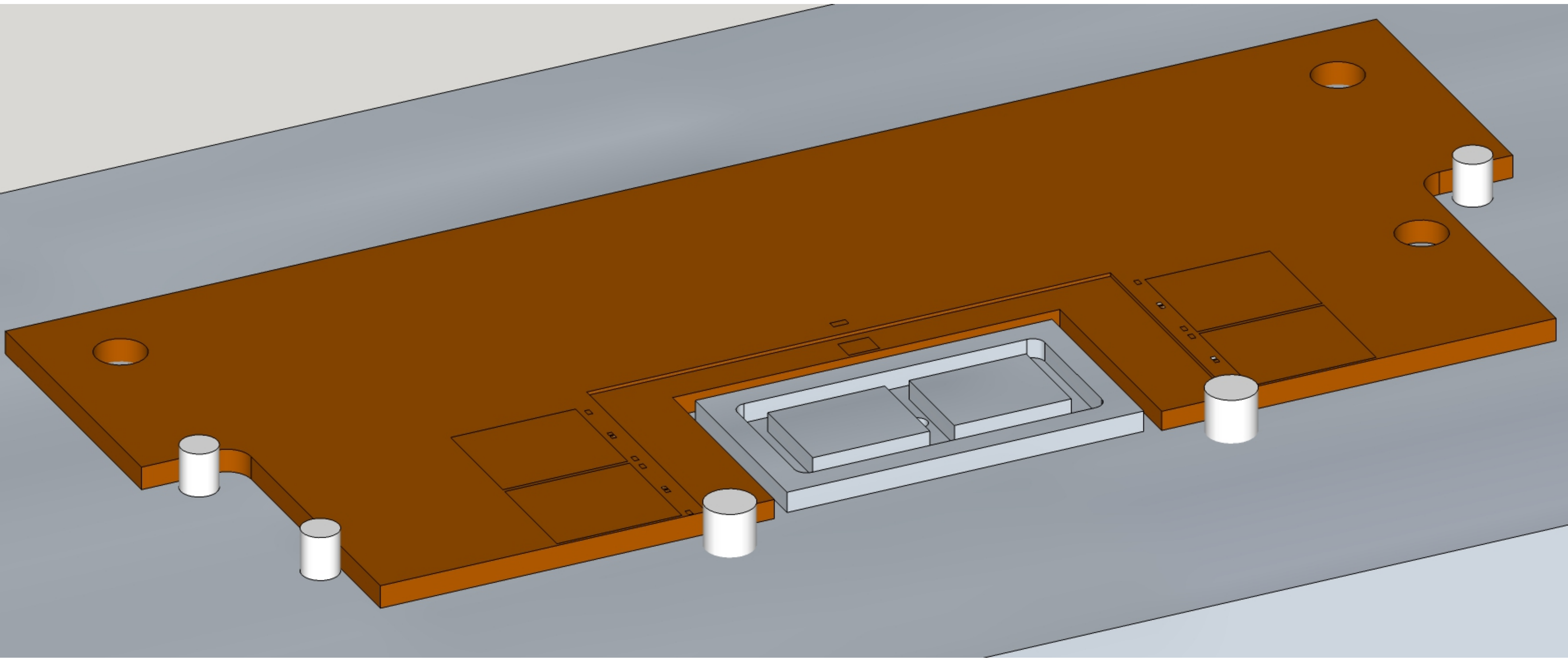

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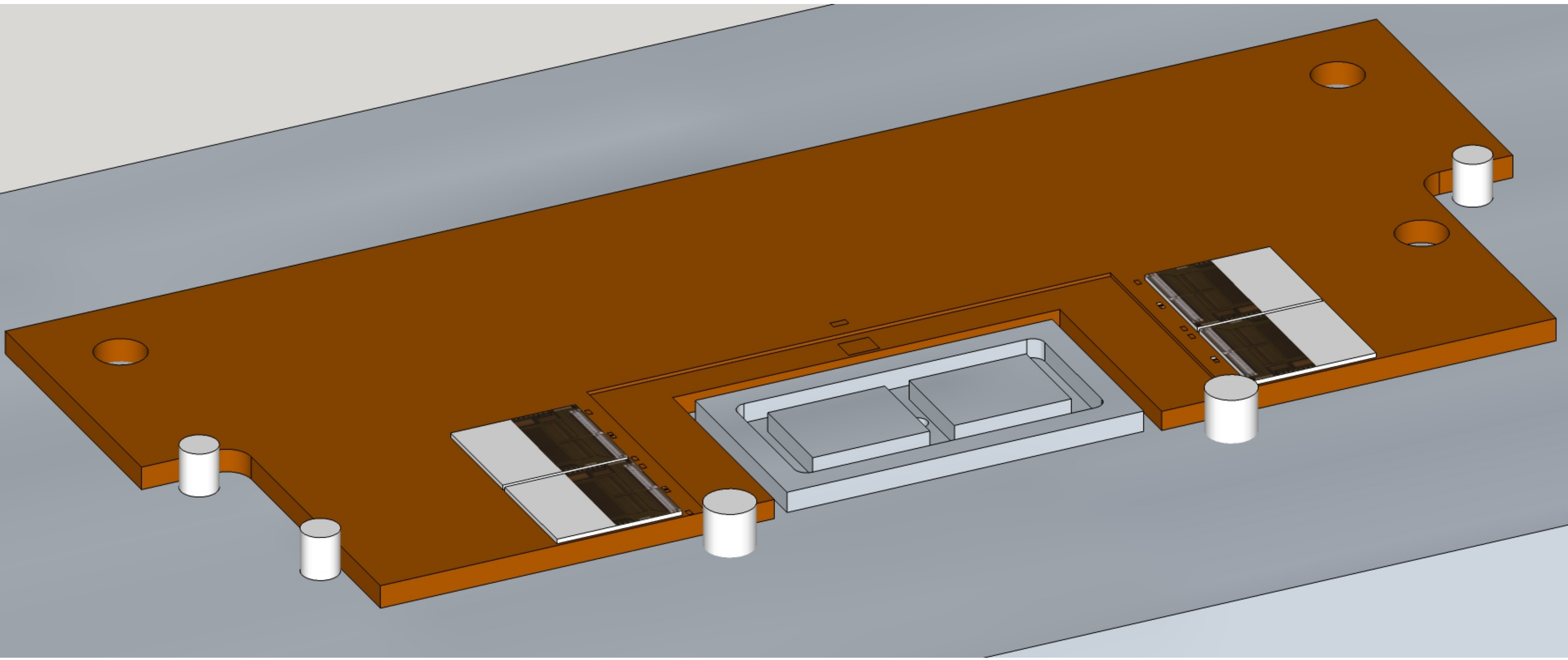

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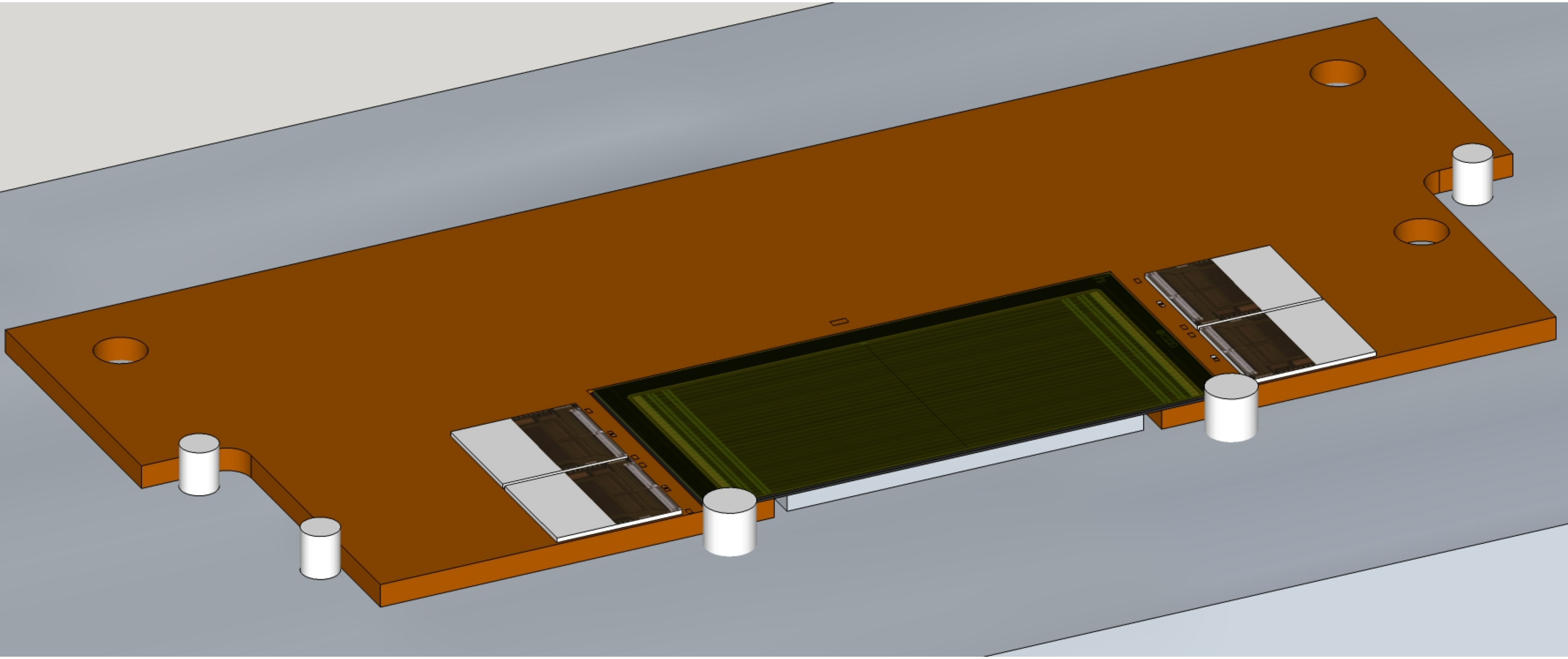

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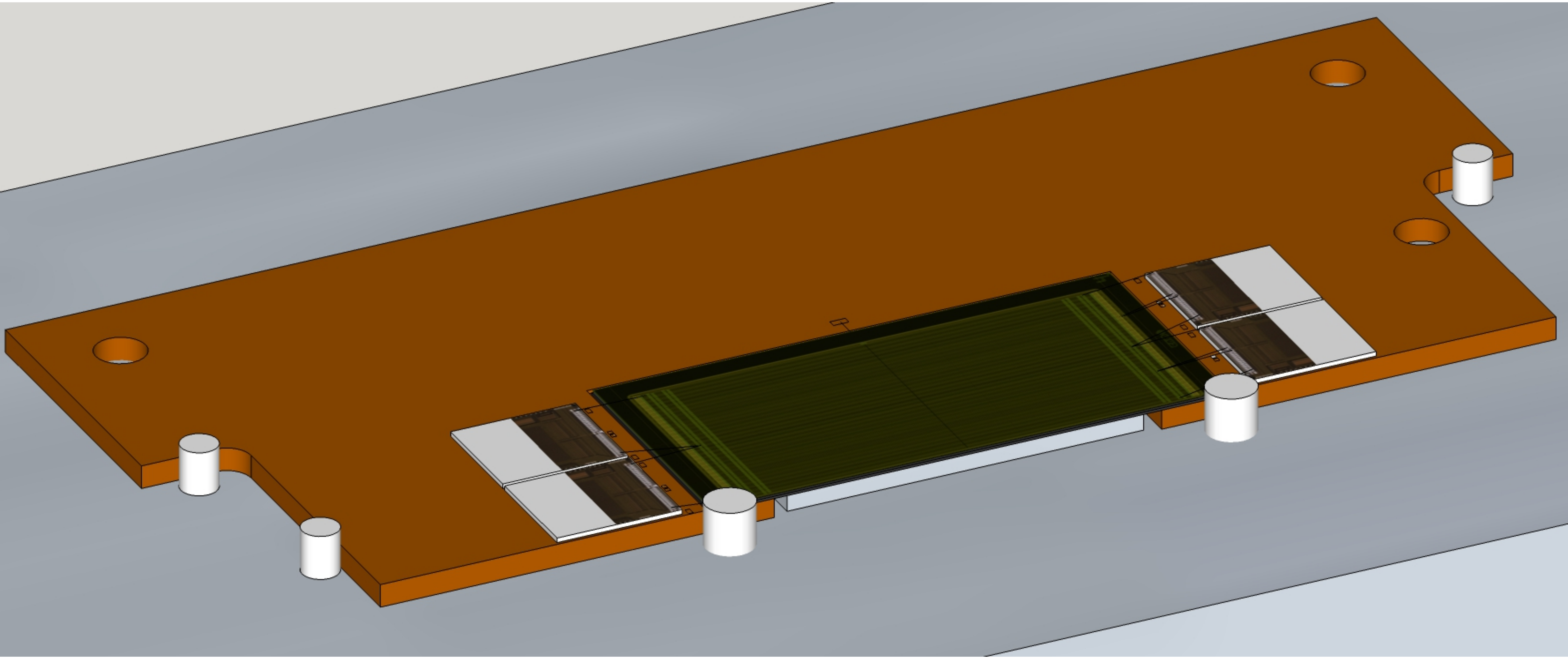
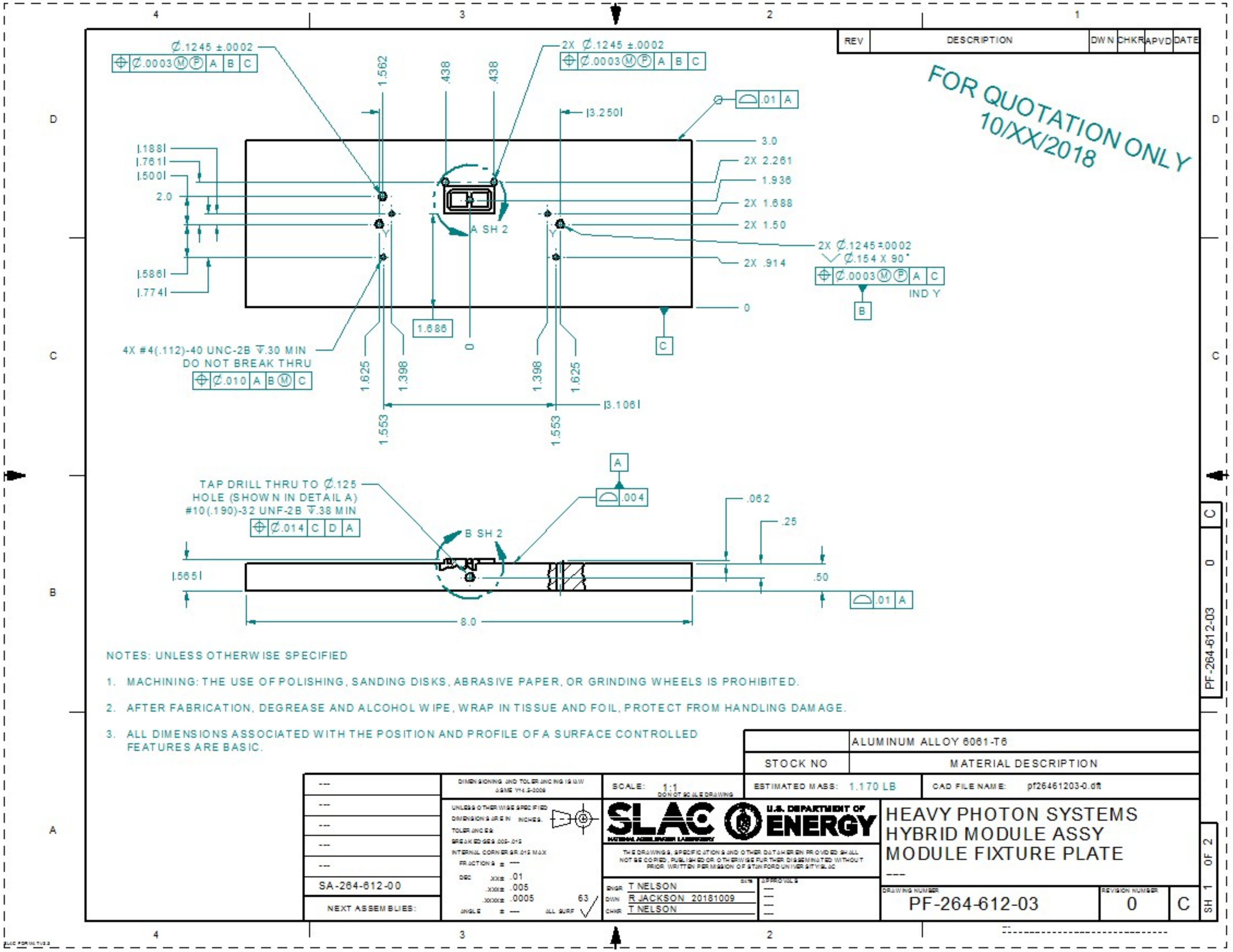


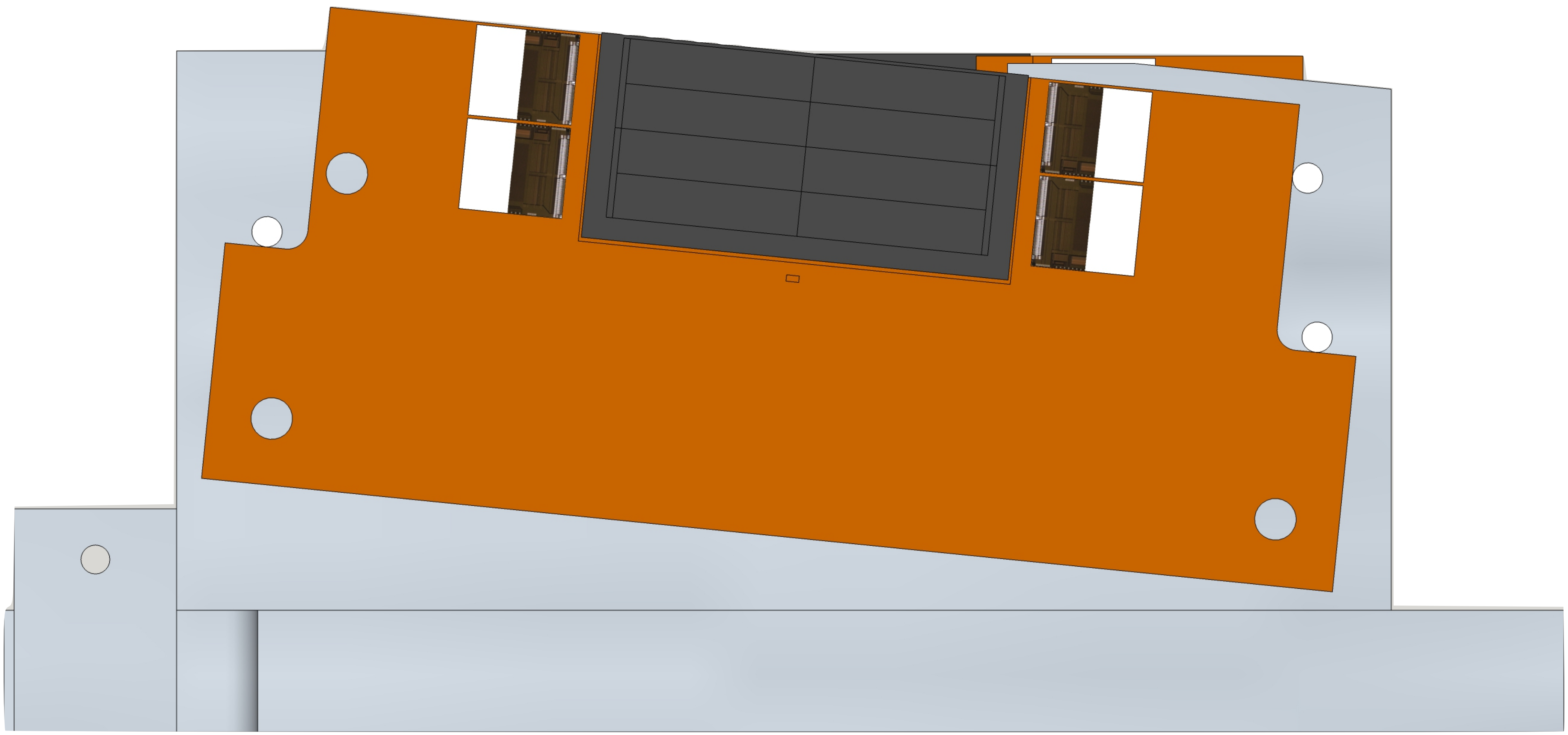
Layer 0 Module Assembly Fixture



Have a pair of these at SLAC. Setting up to begin sensor attachment.

Layer 0 Module Support

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



currently in fabrication

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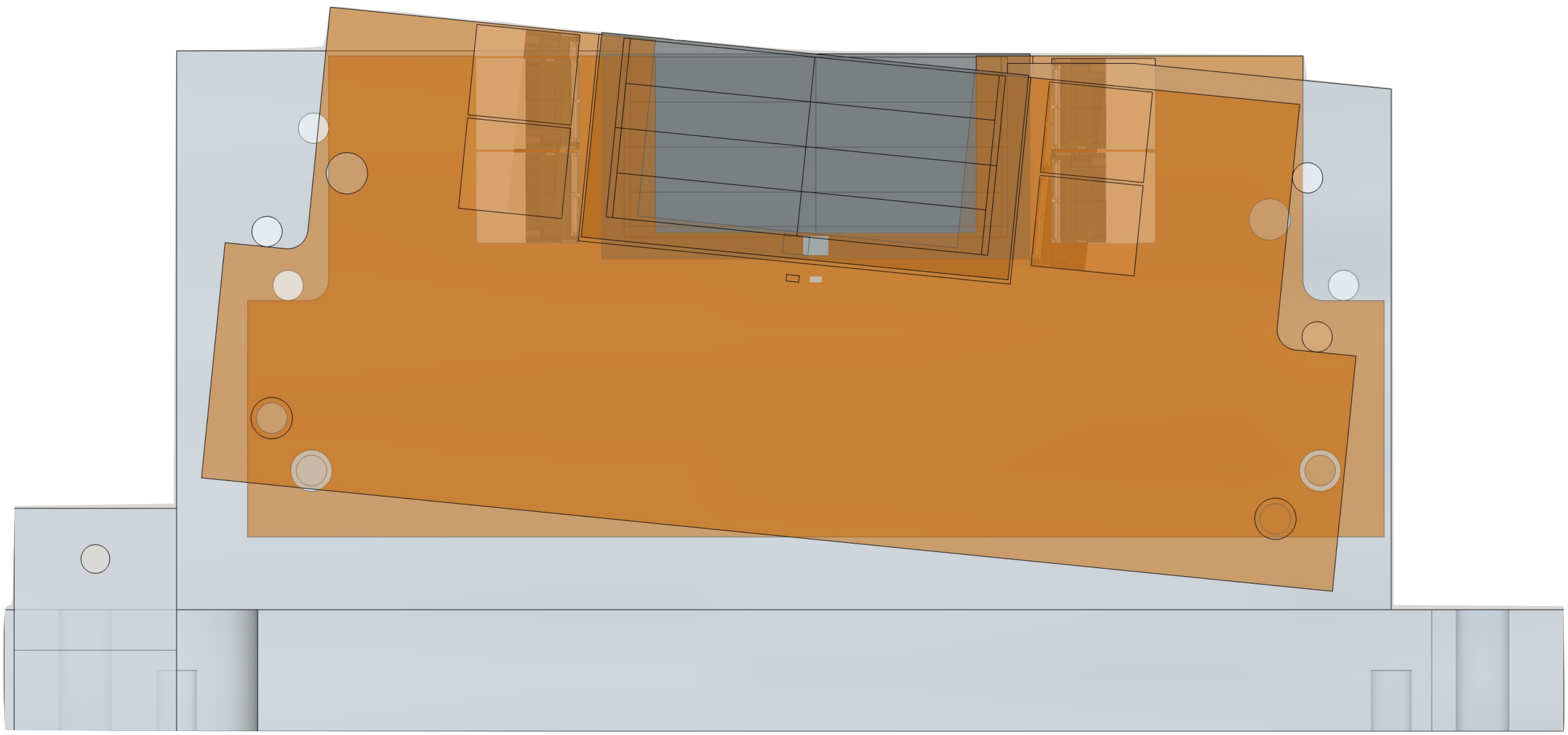
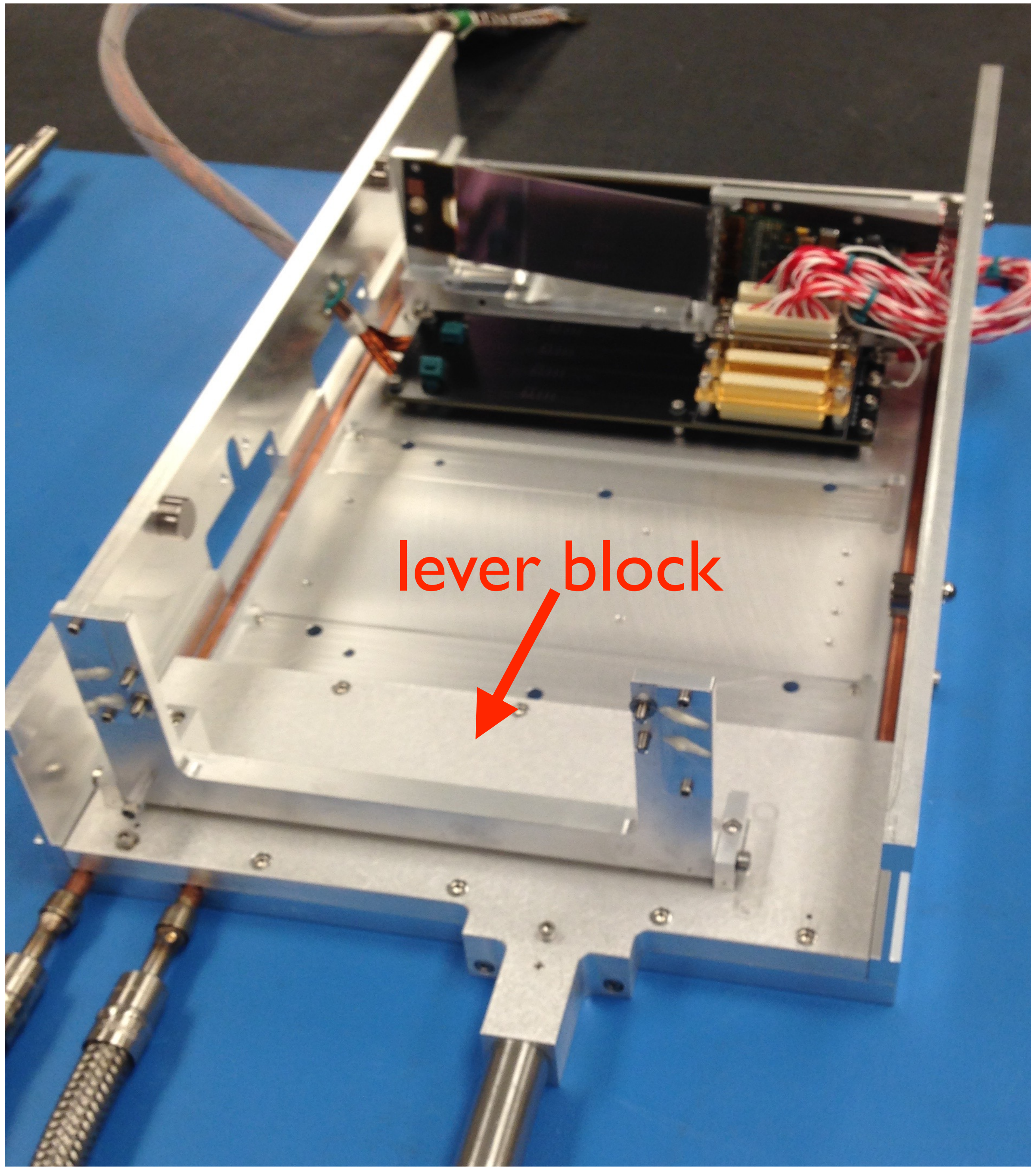
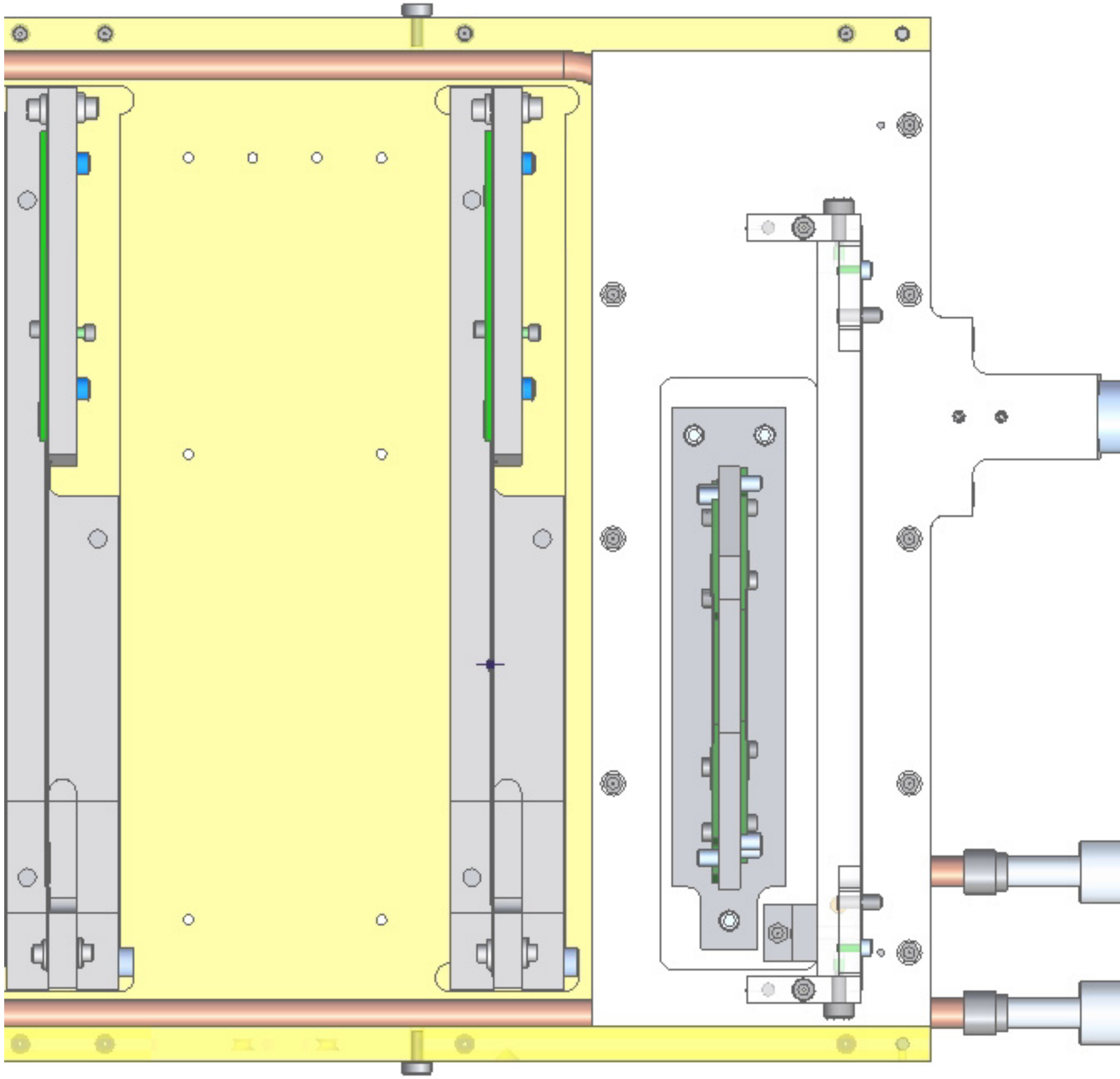


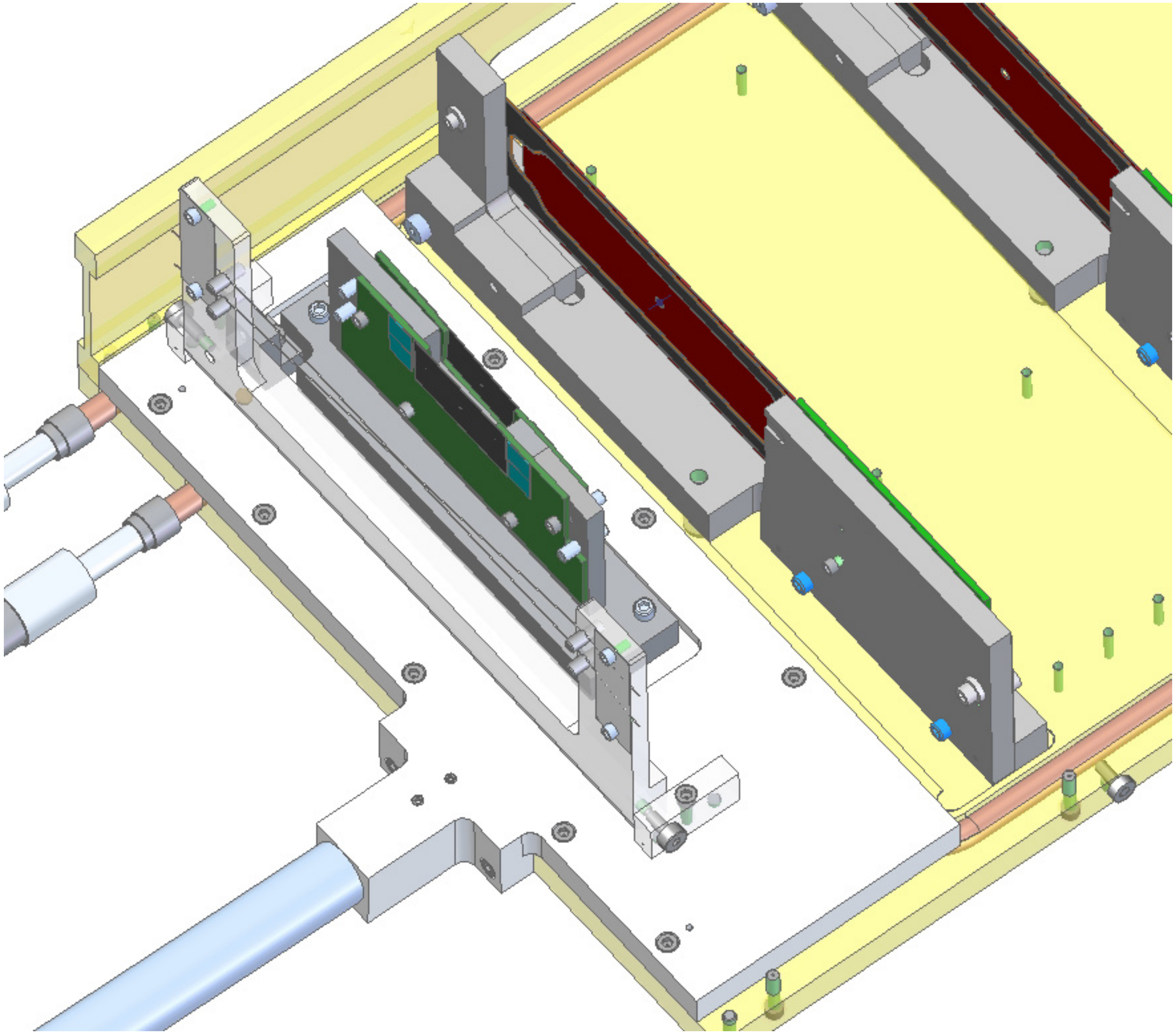
currently in fabrication

U-channel Lever Block





U-channel Lever Block and Layer 1 Replacement



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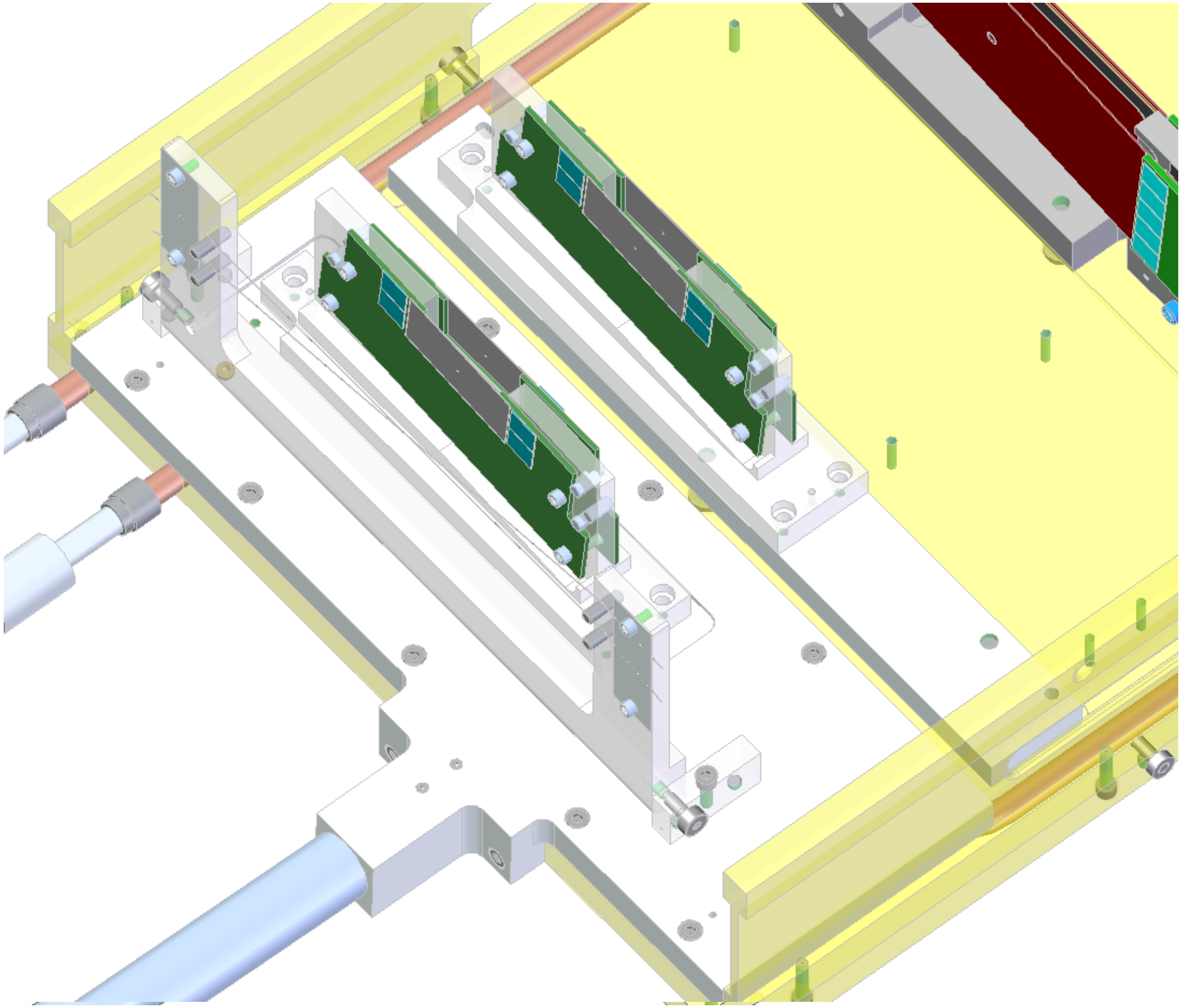
SLAC



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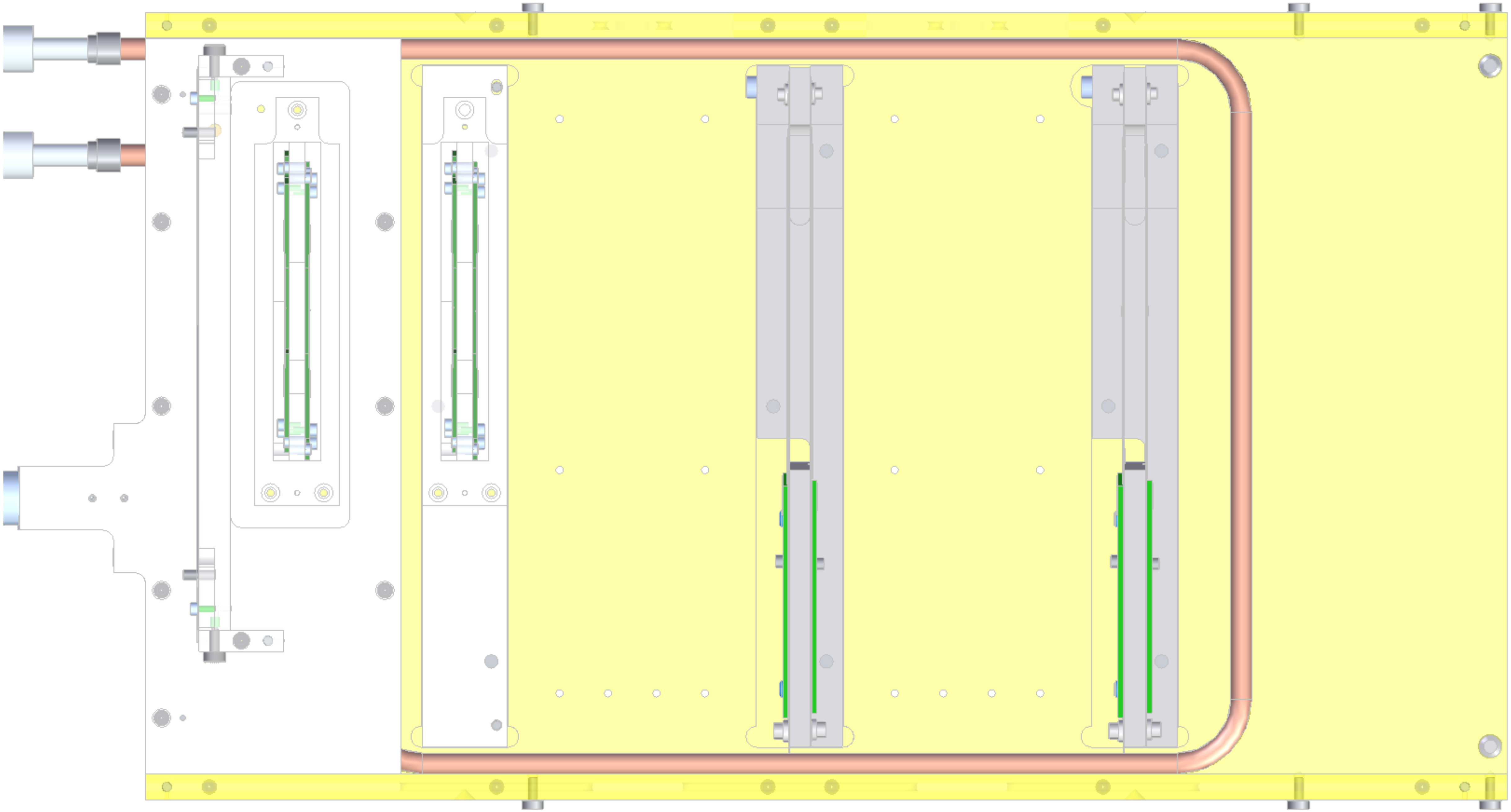
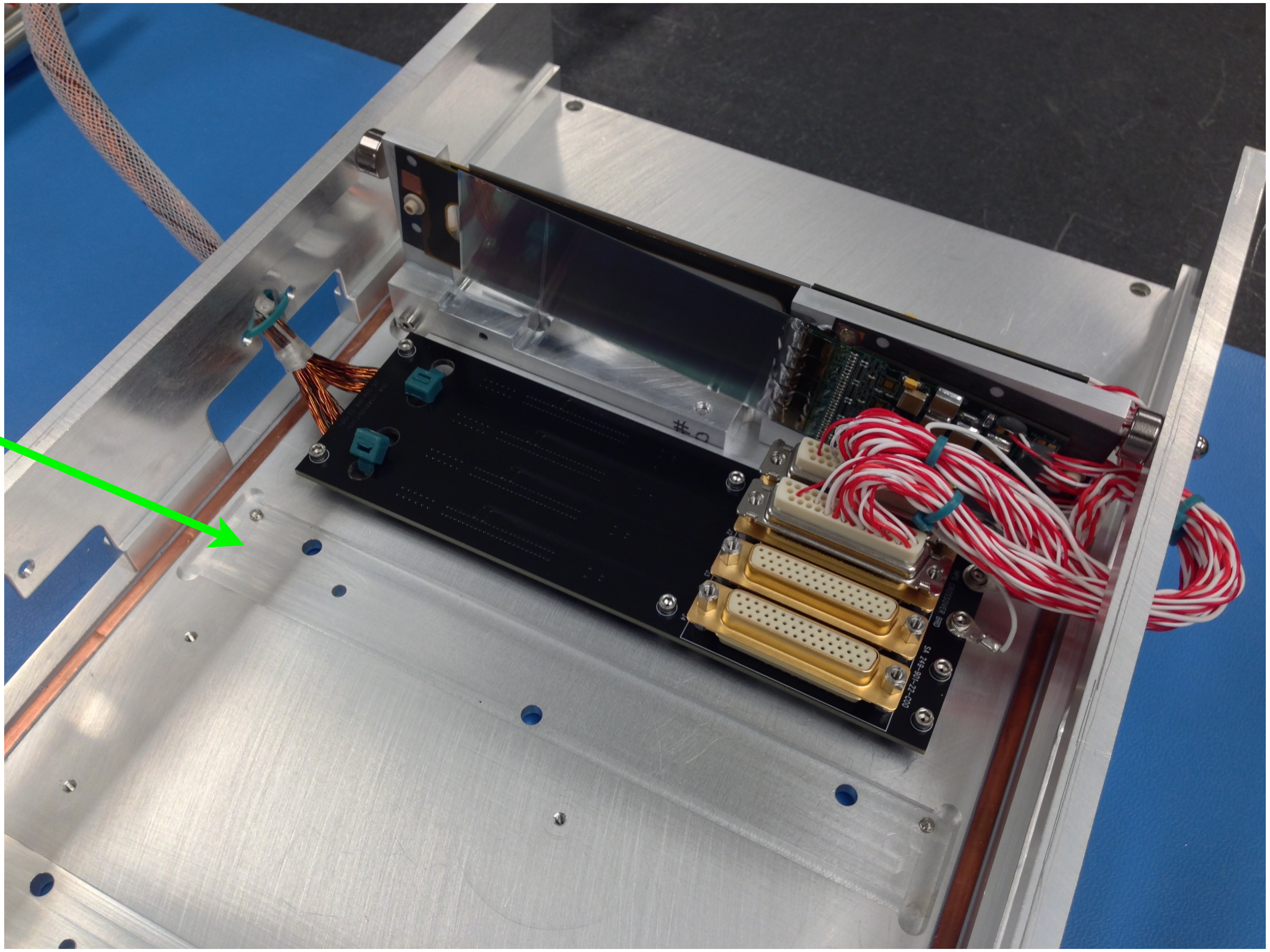


parts currently in fabrication

Moving Layers 2 and 3

standard shim stock of desired thickness with clearance holes

no changes to module mounting hardware are required

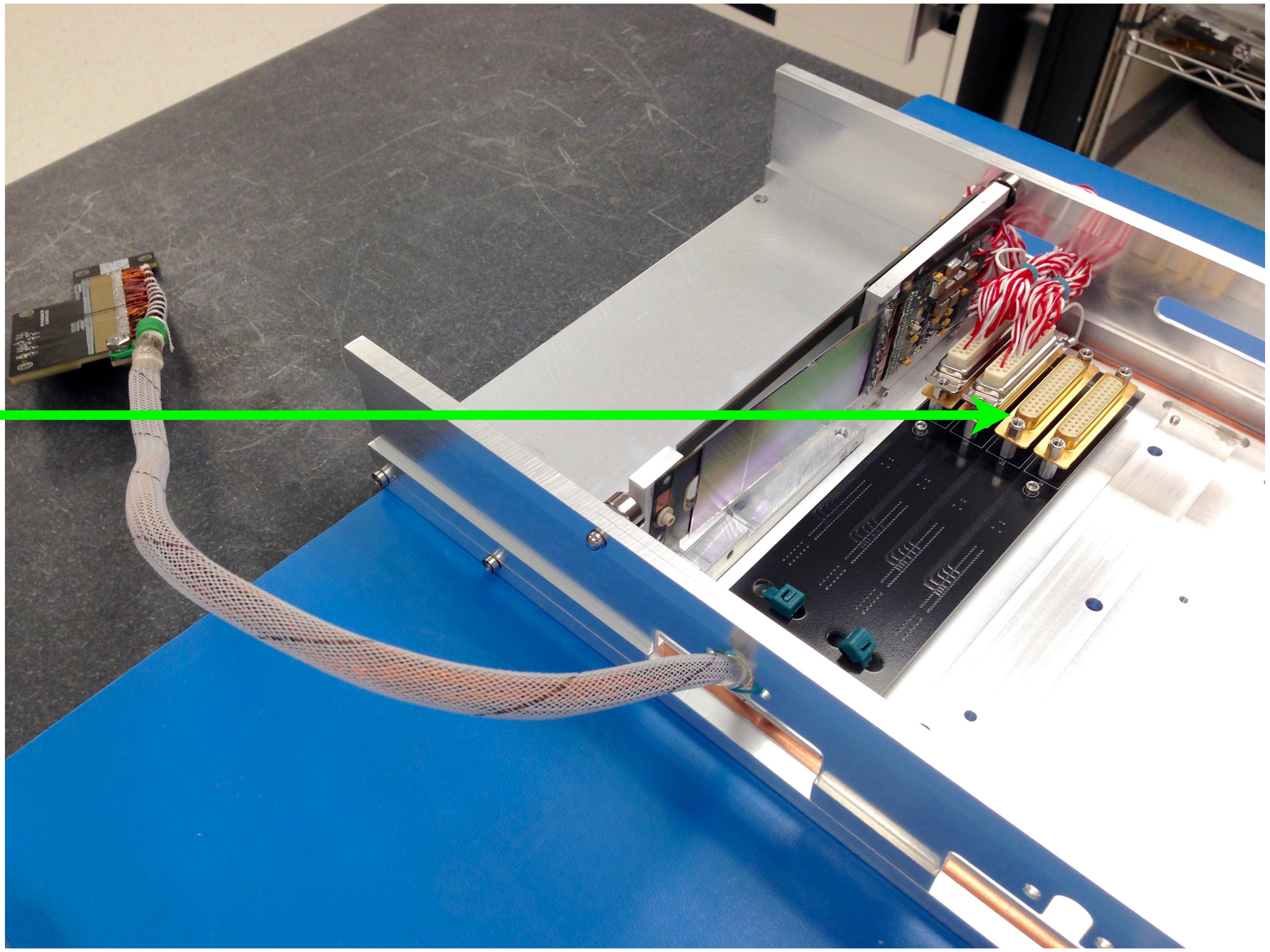


Layer 0 DAQ

Hybrids terminated with same connectors as L1-L3 modules, originally built for the HPS Test Run.

Open channels on crossover boards fully serviced by existing DAQ.

Only changes are to DAQ firmware/software to accommodate addition of data from Layer 0 modules.



Schedule

Item	Vendor/ Institution	Completion dates
Project Approved	SLAC	Complete
Sensor Masks Delivered and Sensor Fabrication Start	CNM	Complete
Sensors Fabricated	CNM	Complete
Hybrids Ready for Module Assembly	SLAC, UCSC	Complete
Sensors Processed, Tested, and Ready	UCSC	01/10/2019*
Detector Mechanics Complete	SLAC	02/15/2019
Modules Ready	SLAC, UCSC	03/18/2019
SVT Fully Assembled at SLAC	SLAC	04/08/2019
SVT Fully Assembled at JLAB	SLAC, JLAB	04/22/2019
SVT Installed and Ready for Beam – Project Complete	SLAC, JLAB	04/26/2019

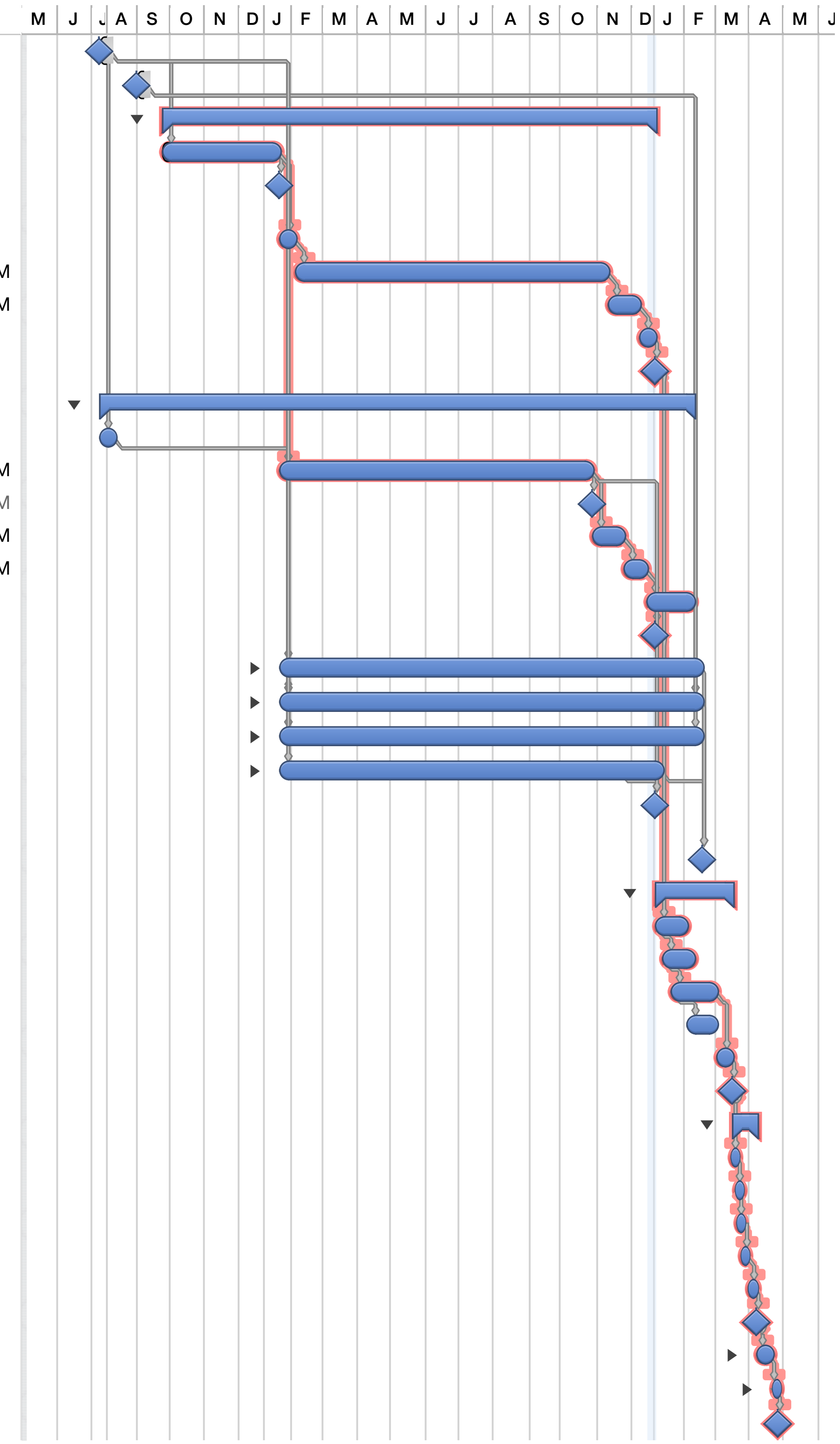
*** in progress — some sensors ready**

Sensor order not complete, but enough are available to begin production.

Sensor delays required compressing module testing and QA from 12 to 6 weeks.

Expect to install SVT at beginning of installation window in Hall B.

Title	End
1) Project Approved	7/10/17, 8:00 AM
2) Layers 1-3 @ SLAC	9/1/17, 6:00 AM
3) Sensors	1/7/19, 2:00 PM
3.1) Sensor Design	1/22/18, 2:00 PM
3.2) Sensor Design Complete	1/22/18, 2:00 PM
3.3) Mask Procurement	2/5/18, 2:00 PM
3.4) Sensor Fabrication	11/12/18, 2:00 PM
3.5) Sensor Processing	12/10/18, 2:00 PM
3.6) Sensor Testing	1/7/19, 2:00 PM
3.7) Sensors Ready	1/7/19, 2:00 PM
4) Hybrids	2/11/19, 2:00 PM
4.1) Schematics	8/11/17, 5:00 PM
4.2) Layout	10/29/18, 2:00 PM
4.3) Hybrid Layout Complete	10/29/18, 2:00 PM
4.4) Procurement	11/26/18, 2:00 PM
4.5) Assembly	12/17/18, 2:00 PM
4.6) Testing	2/11/19, 2:00 PM
4.7) Hybrids Ready	1/7/19, 2:00 PM
5) Module Supports	2/18/19, 2:00 PM
6) Layer 2-3 Shims	2/18/19, 2:00 PM
7) Lever Blocks	2/18/19, 2:00 PM
8) Assembly Fixtures	1/14/19, 2:00 PM
9) Mechanical Design Complete	1/7/19, 2:00 PM
10) Mechanics Complete	2/18/19, 2:00 PM
11) Module Assembly	3/18/19, 2:00 PM
11.1) Sensor Attachment	2/4/19, 2:00 PM
11.2) Wirebonding	2/11/19, 2:00 PM
11.3) Testing	3/4/19, 2:00 PM
11.4) Encapsulation	3/4/19, 2:00 PM
11.5) Mounting	3/18/19, 2:00 PM
11.6) Modules Complete	3/18/19, 2:00 PM
12) Final Assembly	4/8/19, 2:00 PM
12.1) U-channel assembly	3/20/19, 2:00 PM
12.2) Module mounting	3/22/19, 2:00 PM
12.3) Wireframe mounting	3/25/19, 2:00 PM
12.4) Final testing	4/1/19, 2:00 PM
12.5) Survey	4/8/19, 2:00 PM
12.6) Ready for shipping	4/8/19, 2:00 PM
13) Shipping	4/22/19, 2:00 PM
14) Installation	4/26/19, 2:00 PM
15) Project Complete	4/26/19, 2:00 PM



Budget

	Labor	M&S	Totals
Sensors	$5000	$37500	$42500
Hybrids	$64360	$10000.00	$74360.00
Modules	$75640	$10000.00	$85640.00
U-channels	$61640	$10000.00	$71640.00
Misc	$5000	$5000.00	$10000.00
TOTALS	**$211640**	**$72500.00**	**$284140.00**

The SVT upgrade is not funded by DOE
- *paid for with Stanford funds*
- *sensors purchased by M. Diamond w/ NERSC fellowship funds*

Currently $81K left in upgrade budget.

This is roughly on track, but without much contingency.

SVT Upgrade Resources

Responsibilities and personnel are largely the same as for SVT production:

SLAC - B84 cleanroom and "Group C" lab

hybrid design and assembly

mechanical design and assembly

Final QA and full system testing

Cameron Bravo (RA)
Rick Jackson (Mechanical Designer)
Matt McCulloch (Mechanical Tech)
Omar Moreno (RA)
Tim Nelson (staff scientist)
Ben Reese (Electrical Engineer)
Matt Solt (HPS grad student)
Adele Zawada (grad rotation student)
+ TID AIR Electronics Techs

UCSC - silicon assembly and wirebonding lab

APV25 mounting, wirebonding and QA of bare hybrids

sensor wirebonding and QA of modules

Vitaliy Fadeyev (Research Physicist)
Forest McKinney (Technician)
Alic Spellman (HPS grad student)

Summary

- A small upgrade to the HPS SVT significantly improves vertexing performance.
- Along with positron-only trigger, restores desired physics reach
- Key components are all in hand and project is in production by an experienced team.
- Very few contingencies remain for successful completion.
- Small numbers required will be completed in weeks and ready for installation for the summer run.

Extra Slides

Miscellaneous Items

Things that the upgrade Layer 0 does not change significantly:

The materials inside the vacuum chamber

The cooling envelope for the detector

Any operational procedures for the detector

Any equipment in Hall B (outside of the vacuum chamber)

The data volume produced by the detector

The software and techniques used to reconstruct the data

Commissioning Plan

Entire SVT will need to be tested after installation to ensure that everything works as expected. (must be done anyway after 2 years down!!)

With first beam, we will want to undertake careful scanning and running before moving the SVT in completely.

Previous experience will help us do this safely and quickly. Probably, this will not look very different from 2016 running, unless we see something unusual along the way.

One item that we will want to give attention to measuring beam halo with some ideas of how to identify the source and mitigate if larger than expected: not unique to Layer 0… Layer 1 has similar susceptibility.

Reduced Signal Primarily Impacts t0 Resolution

Currently S/N ~ 25 for 300 μm Si. Assume ⟹150μm:

- Structure is negligible, so material/2 means signal/2.
- To maintain t_0 resolution, must have S/N>20.

➡ need noise/2

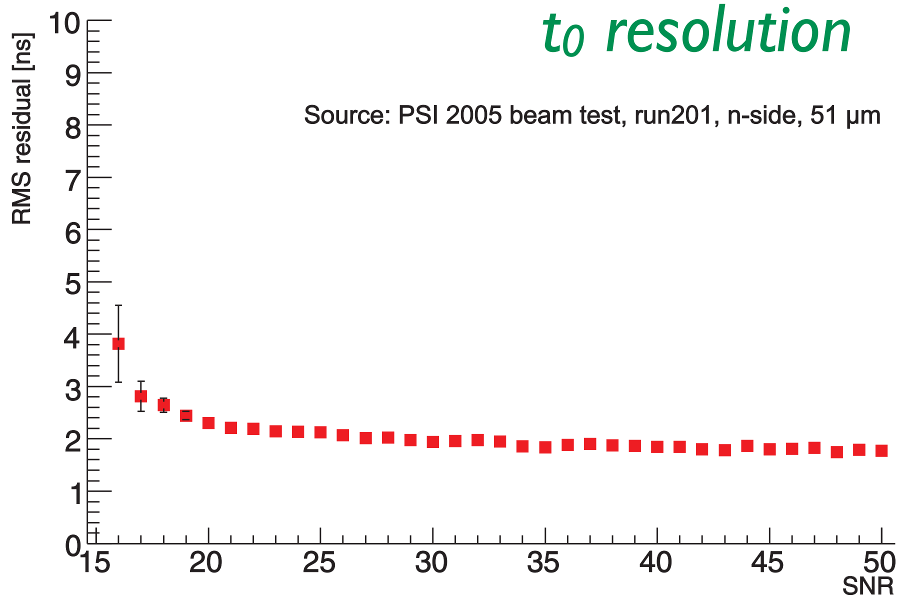
Noise characteristics of our sensors w/ APV25:

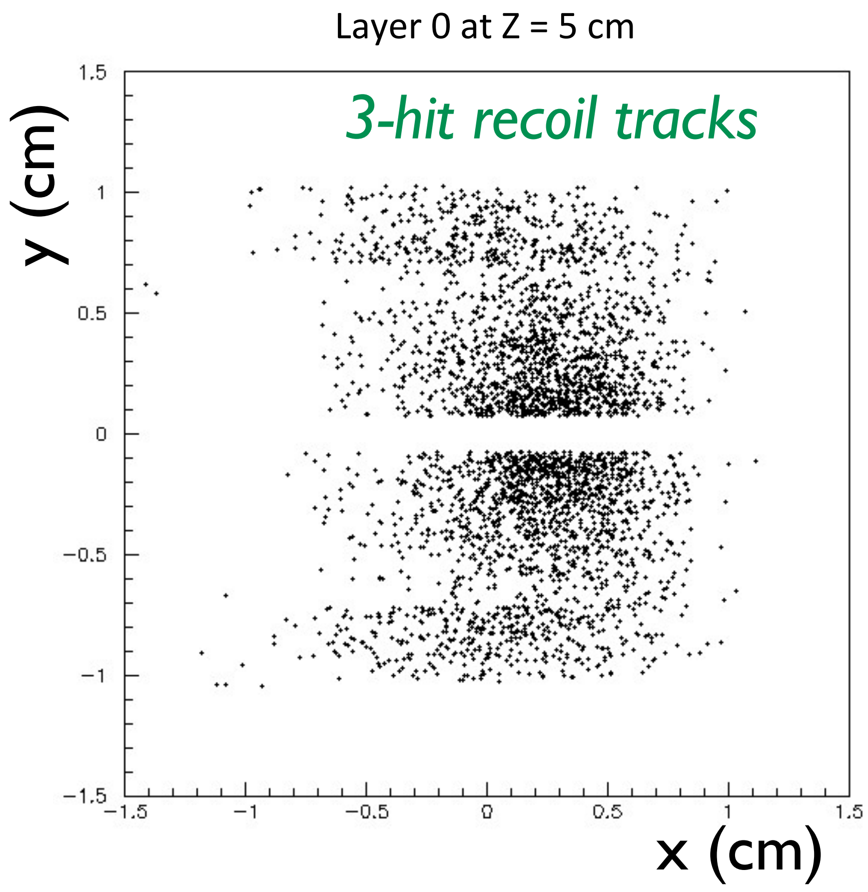
$$ENC \simeq 250+36C \oplus \alpha C(R_s)^{1/2} \; e^-$$

- currently C=12pf ⇒ ENC = 950 (C ≃1.2 pf/cm)
- need ENC ≲ 450 ⇒ strip length ≲ 3.5 cm.

Full acceptance for A′ daughters allows very short strips. Conservatively assume we want largest acceptance we could imagine for any purpose: 3-hit tracks from recoils.

⇒ Requires silicon only ~2 cm long: OK





Physics Backgrounds/Radiation

Must match 15 mrad coverage of Layer 1

- Naively, background flux at 15 mrad for z=5 cm is 4× that at current L1 at z=10 cm ($1/r^2$).
  However, strips don't sample areal density!
- Fast MC finds background occupancy in first strip for Layer 0 is ~2× current Layer 1 occupancy (~1%).

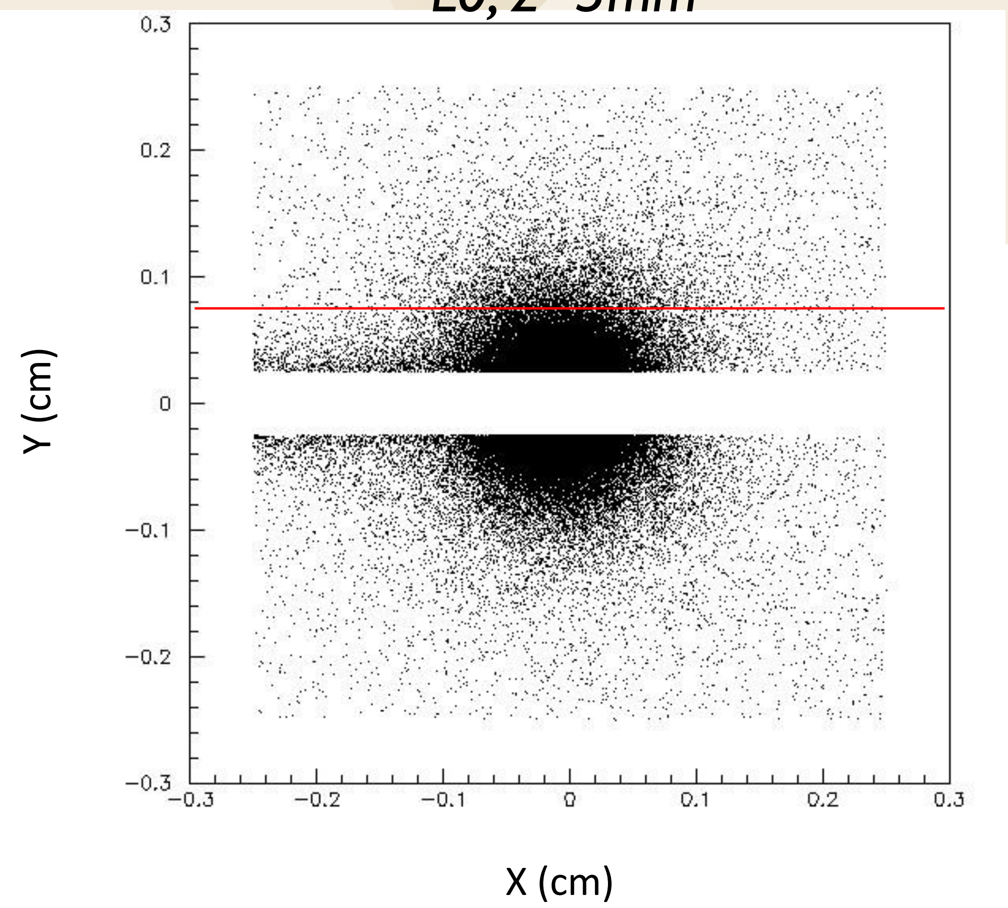
  Split the strips on the sensor in half electrically, reading out sensor from both ends. Cuts occupancy in half: OK.

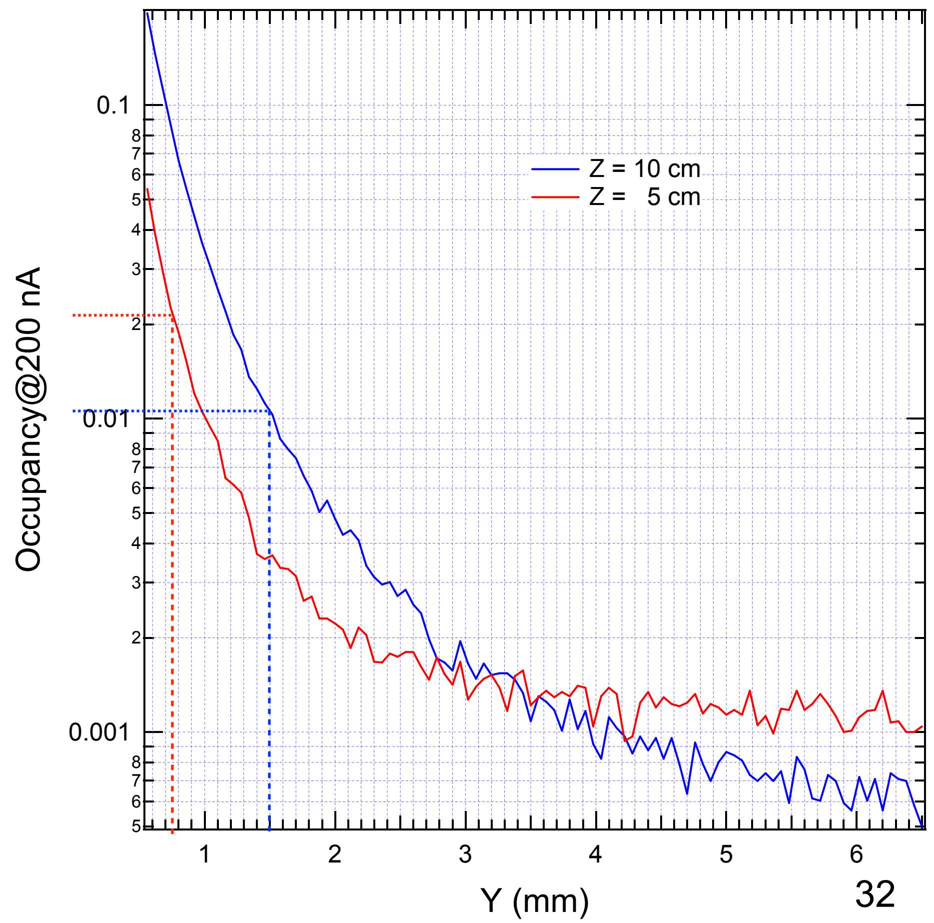
  For extra headroom on strip occupancy, eliminate capacitively-coupled sense strip present in other layers. (resolution is limited by multiple scattering anyway).

  These changes further reduce noise.
- Principal source of our radiation damage. Layer 0 could require replacement in as little as 3 months.

  Layer 0 can be easily replaced between runs.

L0, z=5mm





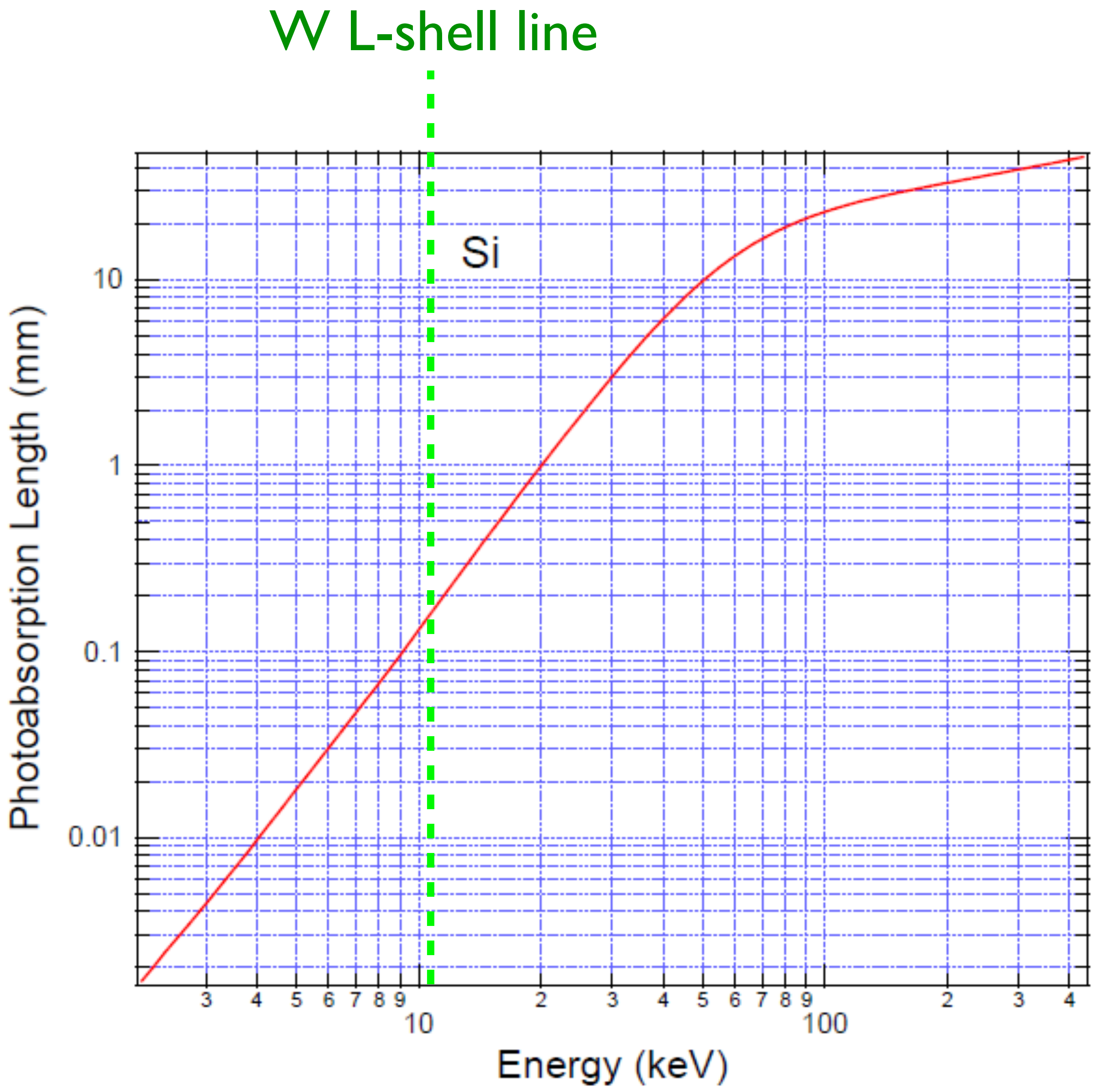
X-rays

Thresholds in current detector are roughly at the L-shell line from the tungsten target.

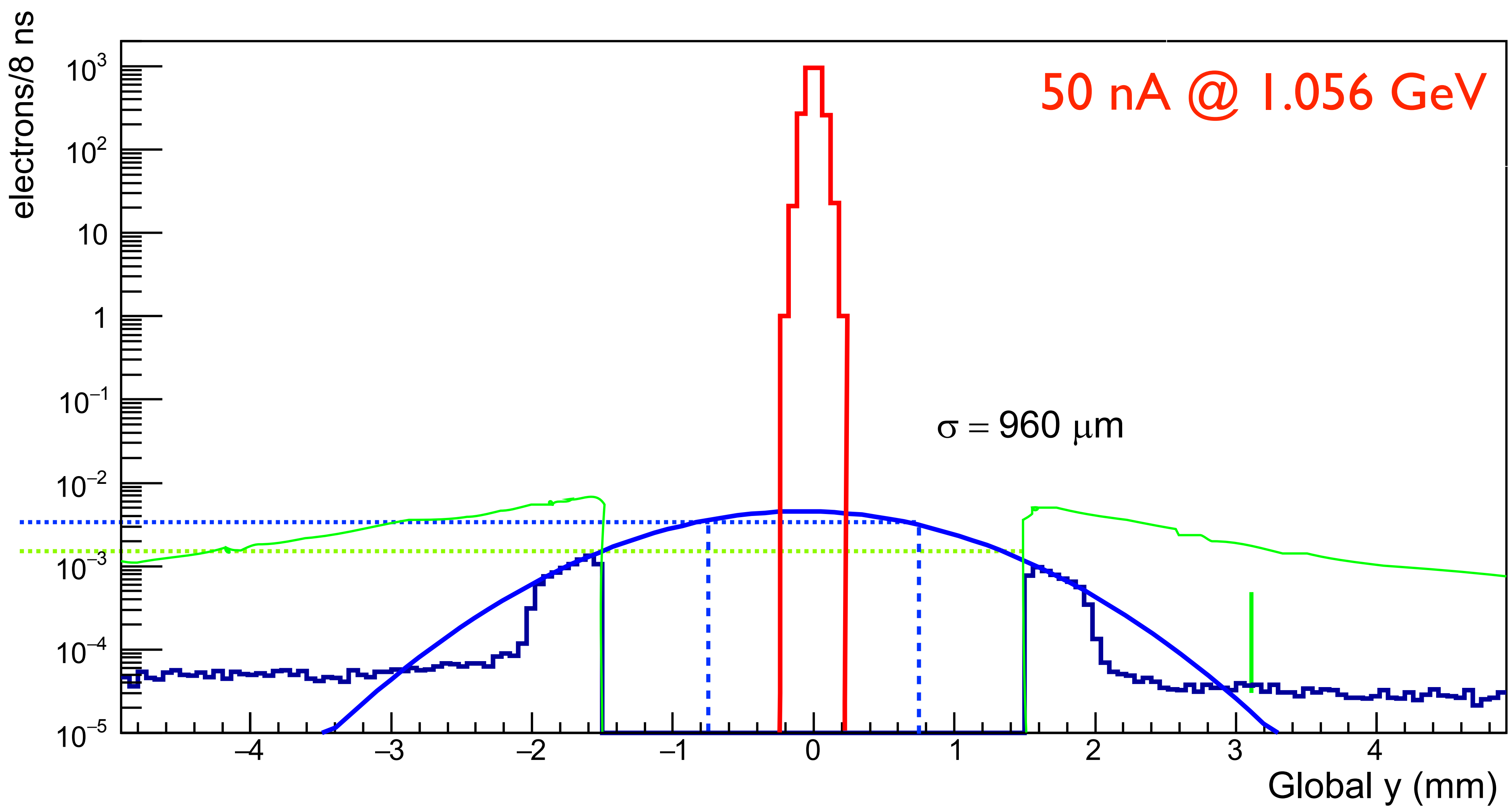
signal/2 ⇒ ~threshold/2

⟹ All L-shell x-rays that absorbed in Si will be above threshold.

- Small sensor means sensor actually has smaller solid angle than Layer 1.
- Thinner sensor means only about 2/3 of L-shell x-rays with be absorbed in sensor.
- Studies find that x-ray occupancy will be ~0.4 hits/sensor
  ⇒ 0.07% occupancy: OK



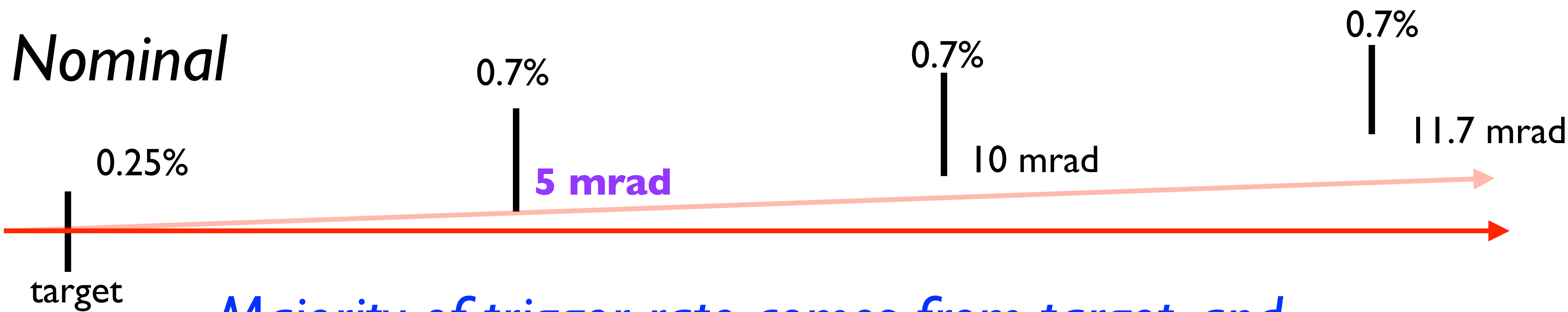
Beam Tails



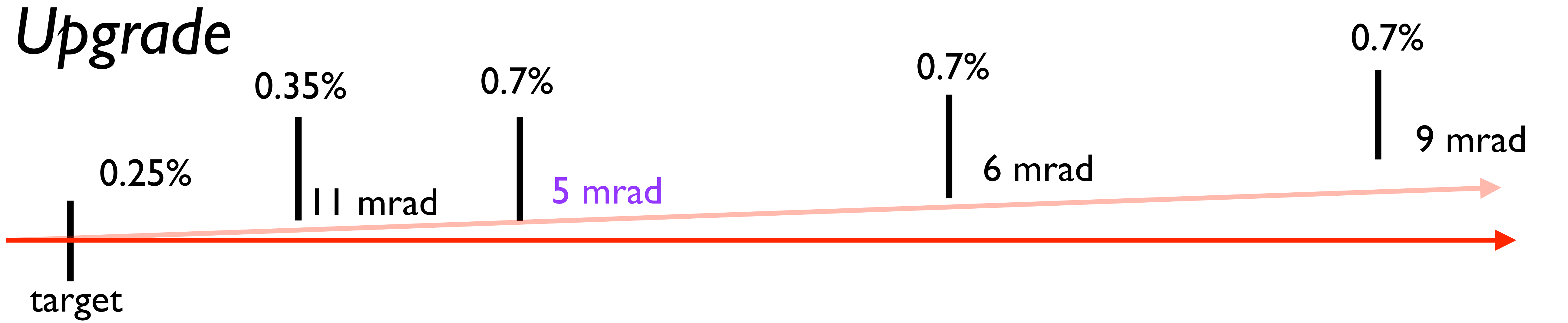
~*factor of 2*

- With innermost strip at 0.75mm, beam tails could be a more serious problem.
- Profile of tails measured in engineering run would predict roughly 2× tails at 0.75mm.
- Like physics occupancy, splitting readout strips in half cuts this in half. *OK at 50 nA.*
- *At 300 nA (4.55 GeV running), expect roughly 1% occupancy / 8 ns in both L0, L1.*
- *What will tails look like relative to previous? How can we protect ourselves?*

Material Distribution: Upgrade vs. Nominal



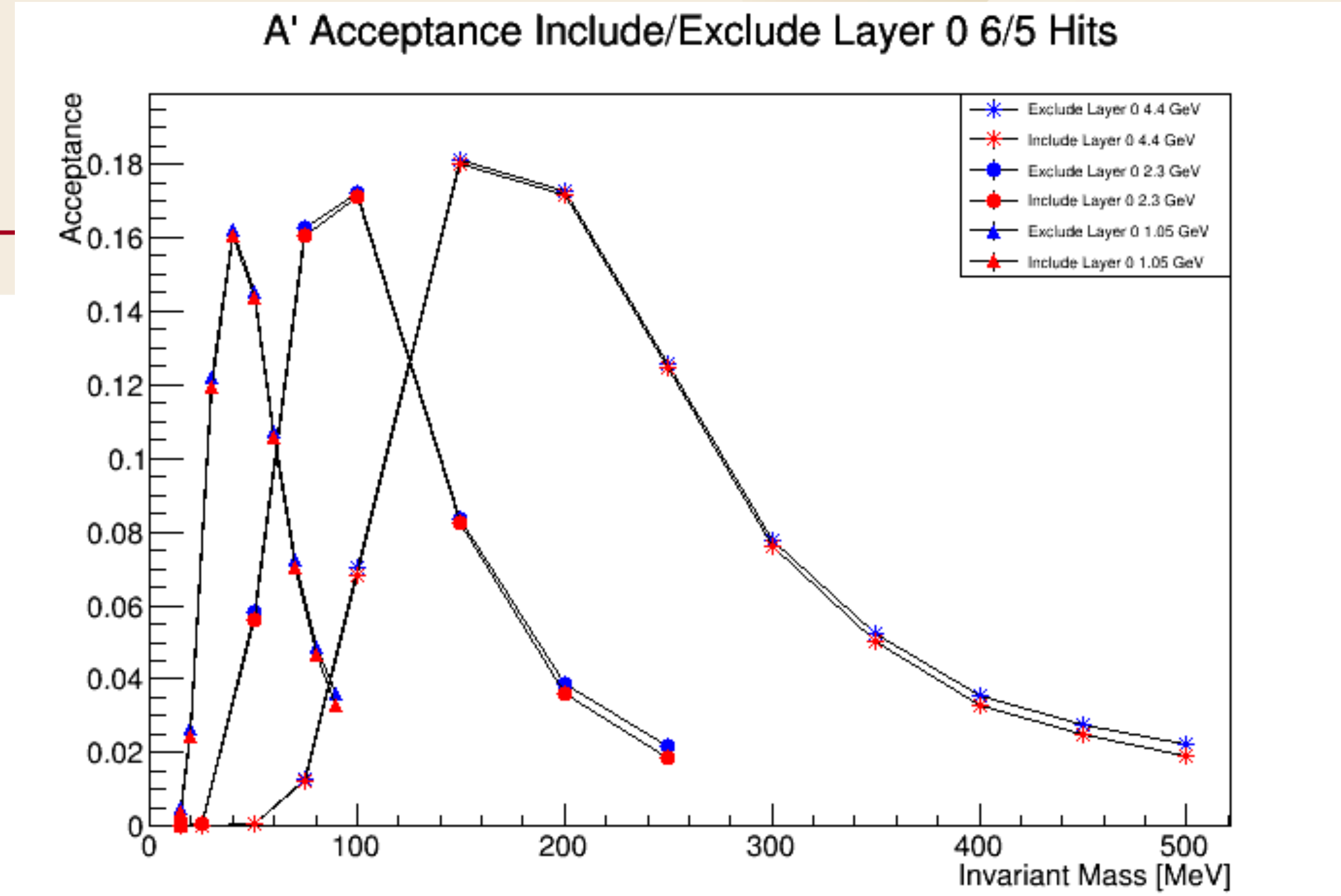
Majority of trigger rate comes from target, and…



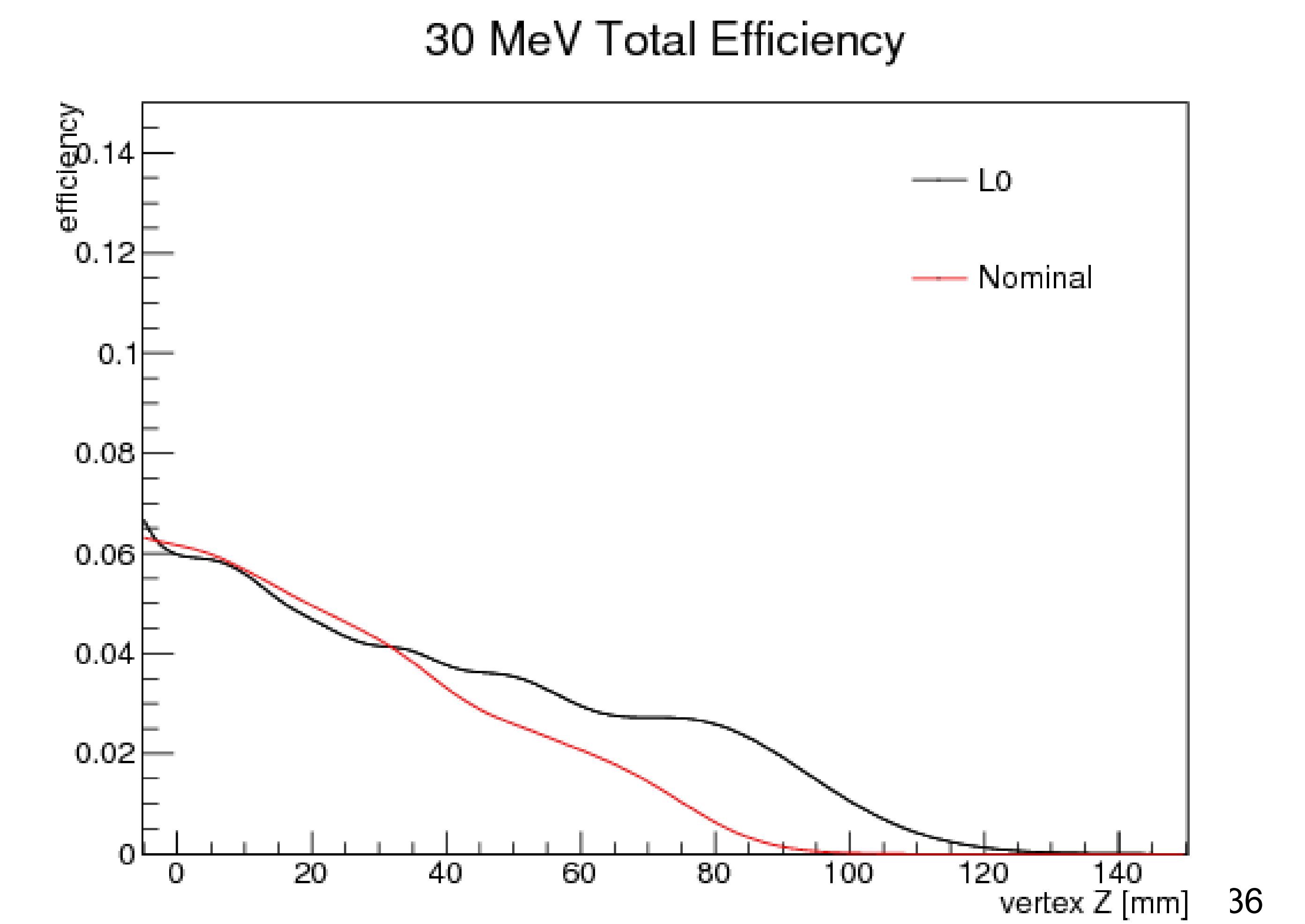
*upgrade does **not** add material at smaller scattering angles.*

Acceptance and Efficiency

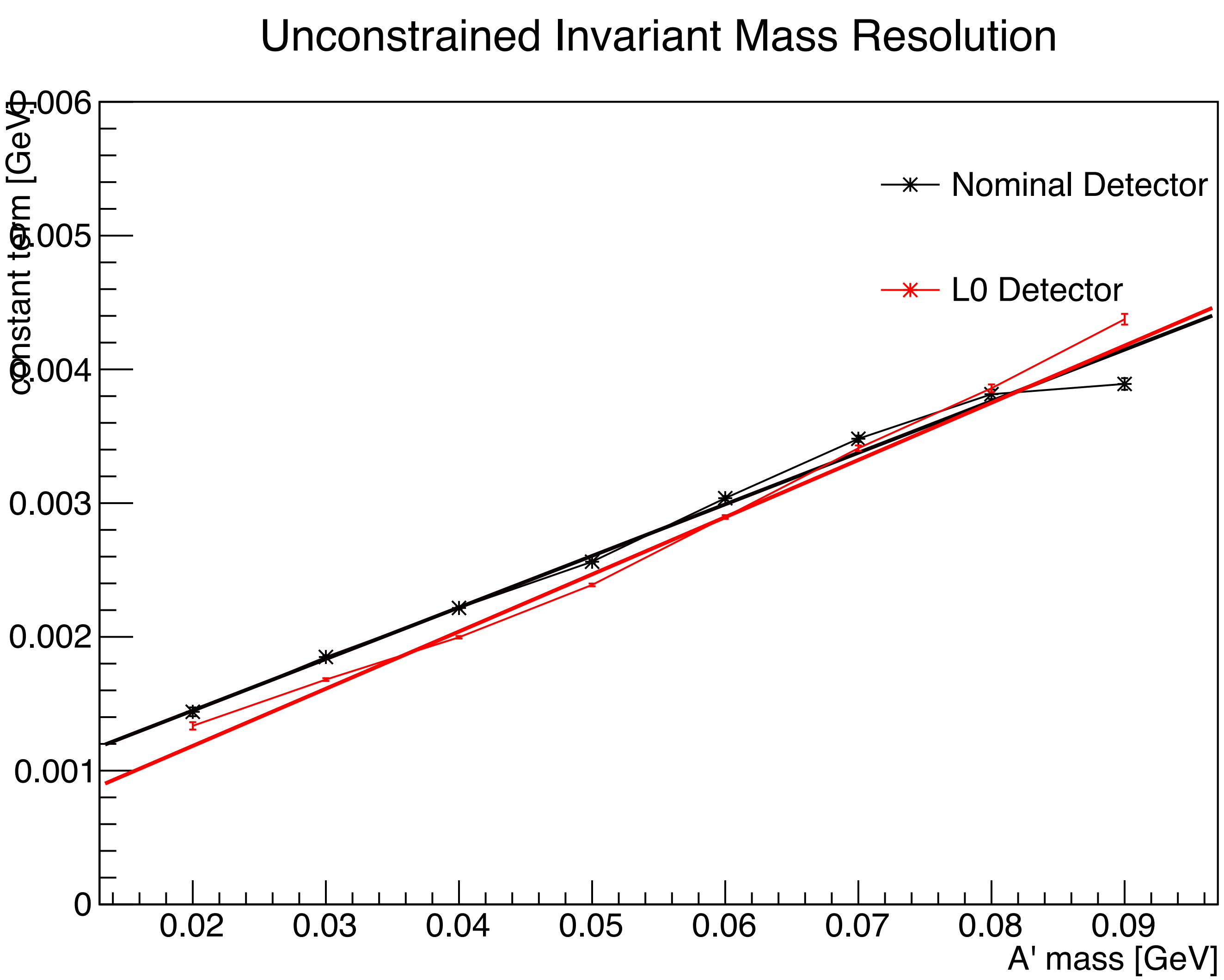
Layer 0 has full acceptance and good efficiency for tracks accepted by the rest of the tracker.

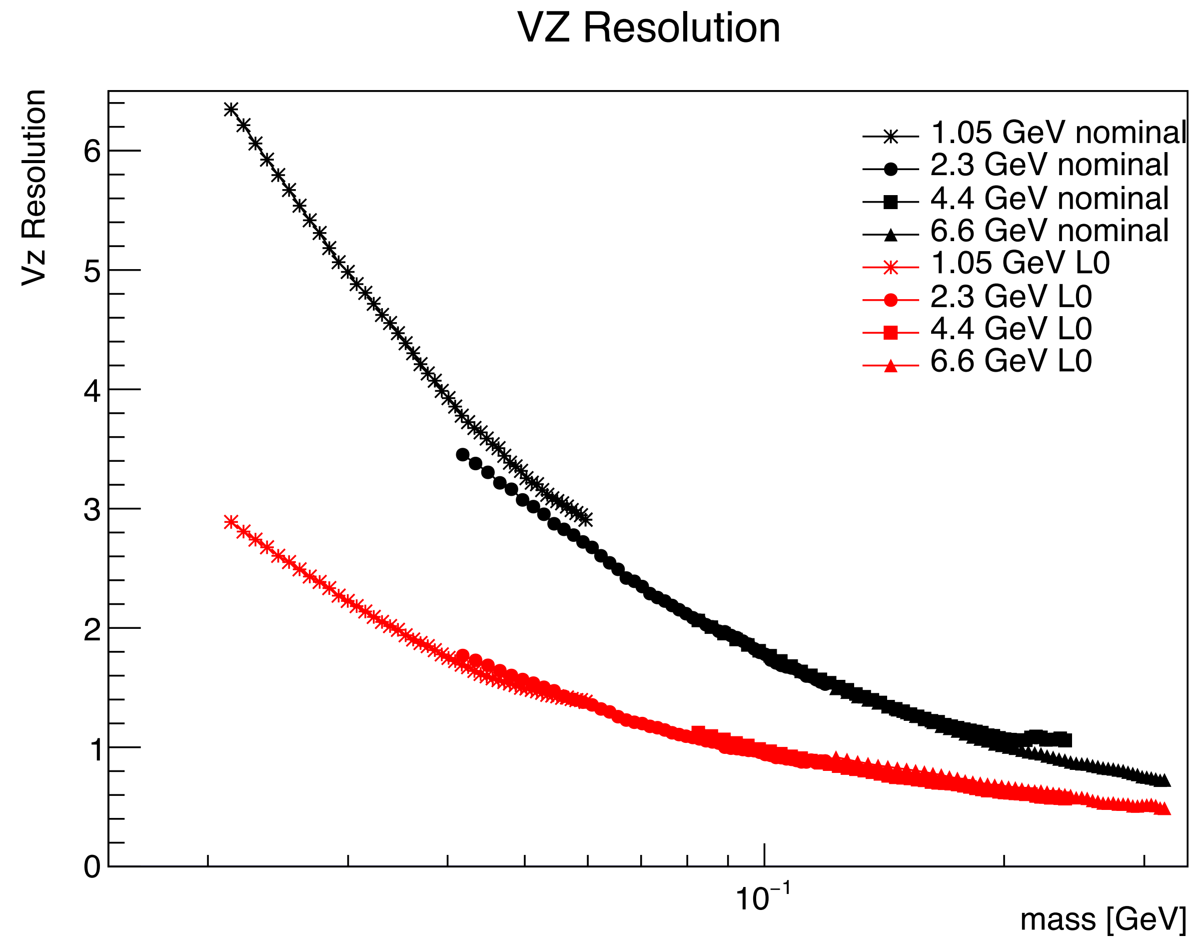


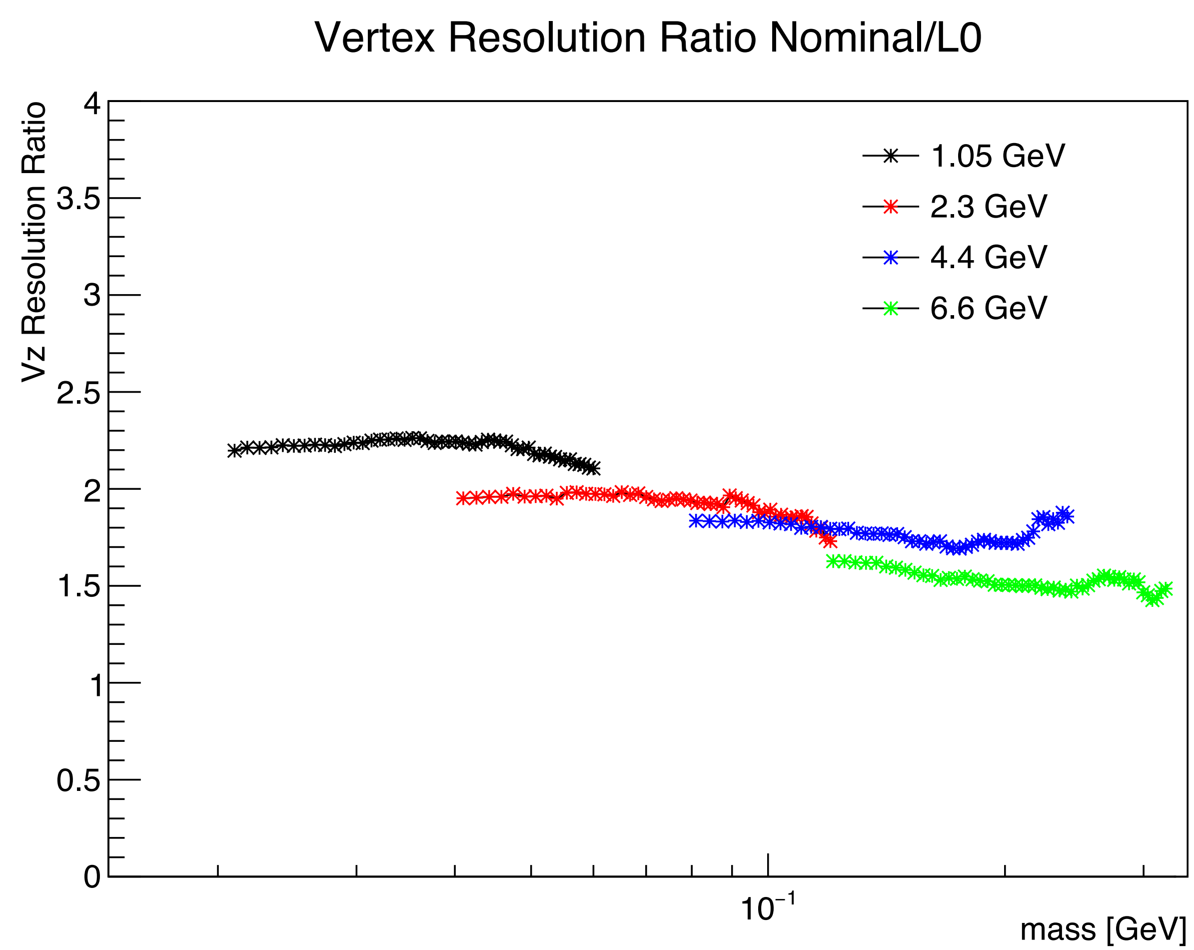
Moving Layers 2 and 3 inwards increases acceptance for long-lived A′ daughters as expected.



Resolutions



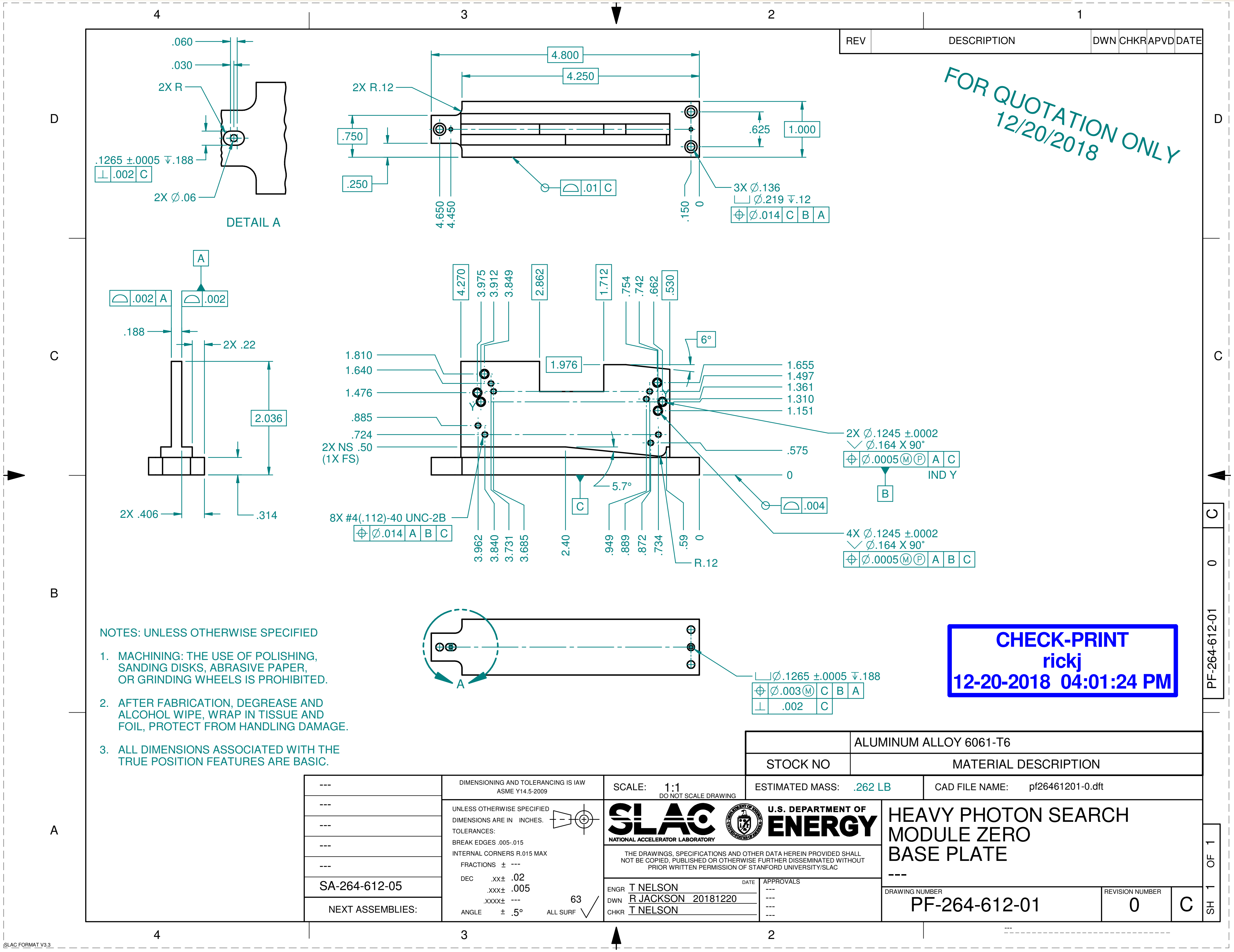




Mass resolution roughly unchanged (as expected)

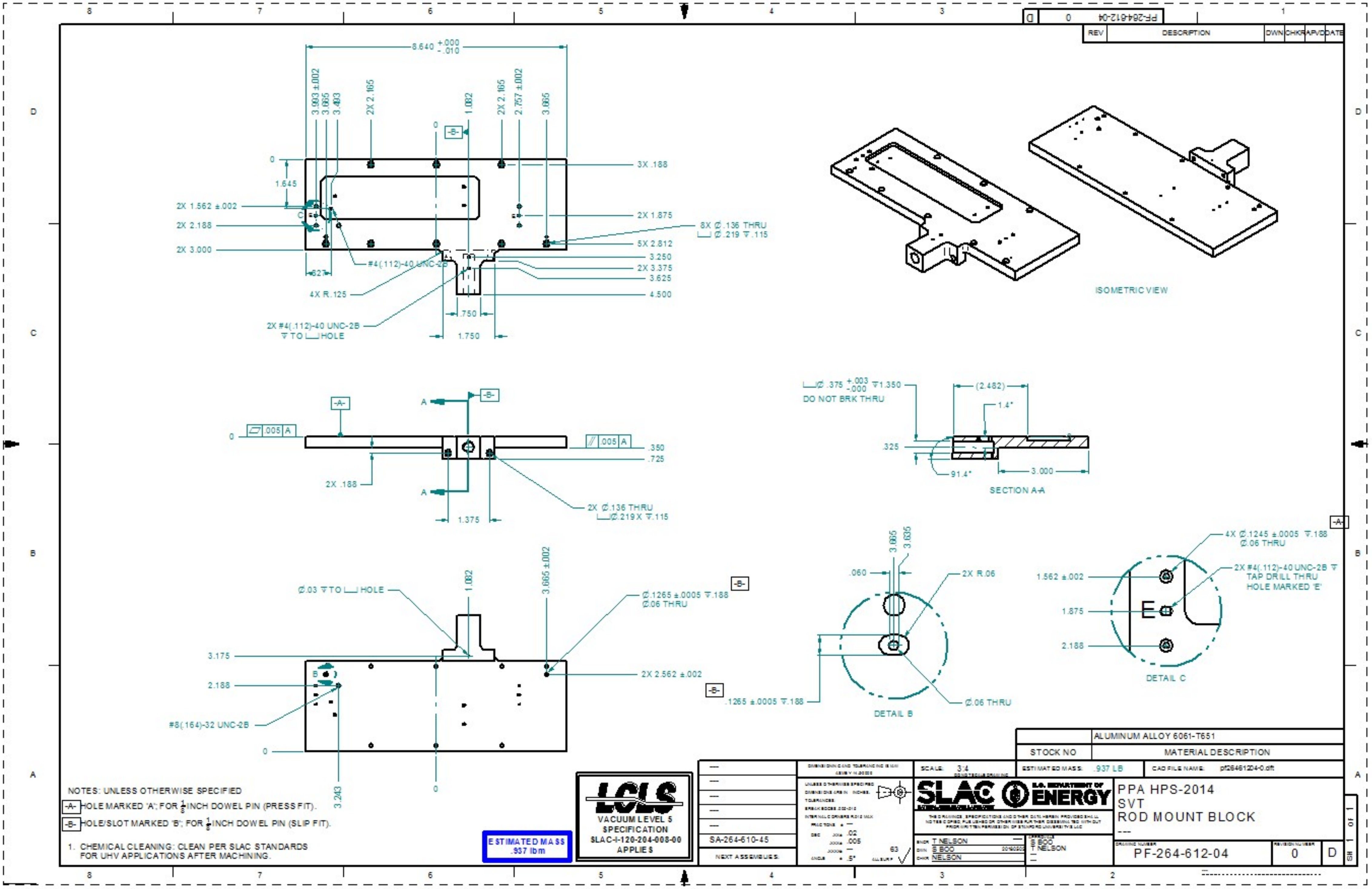
Vertex resolution improves roughly a factor of two, with some momentum dependence.

Layer 0 Module Support



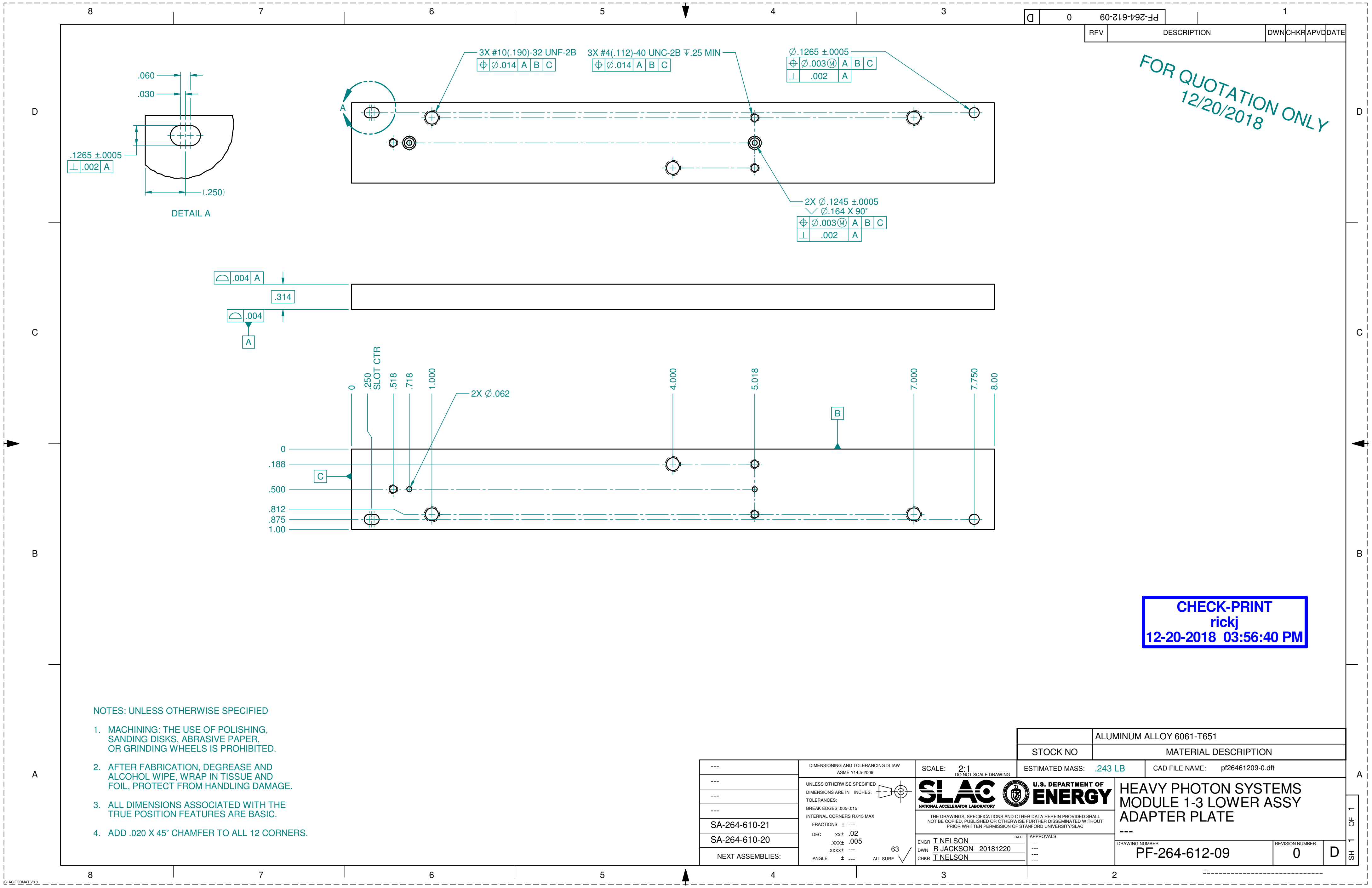
In fabrication

Lever Block



In fabrication

Layer 1 Adapter Plate



In fabrication

Clearance Checks