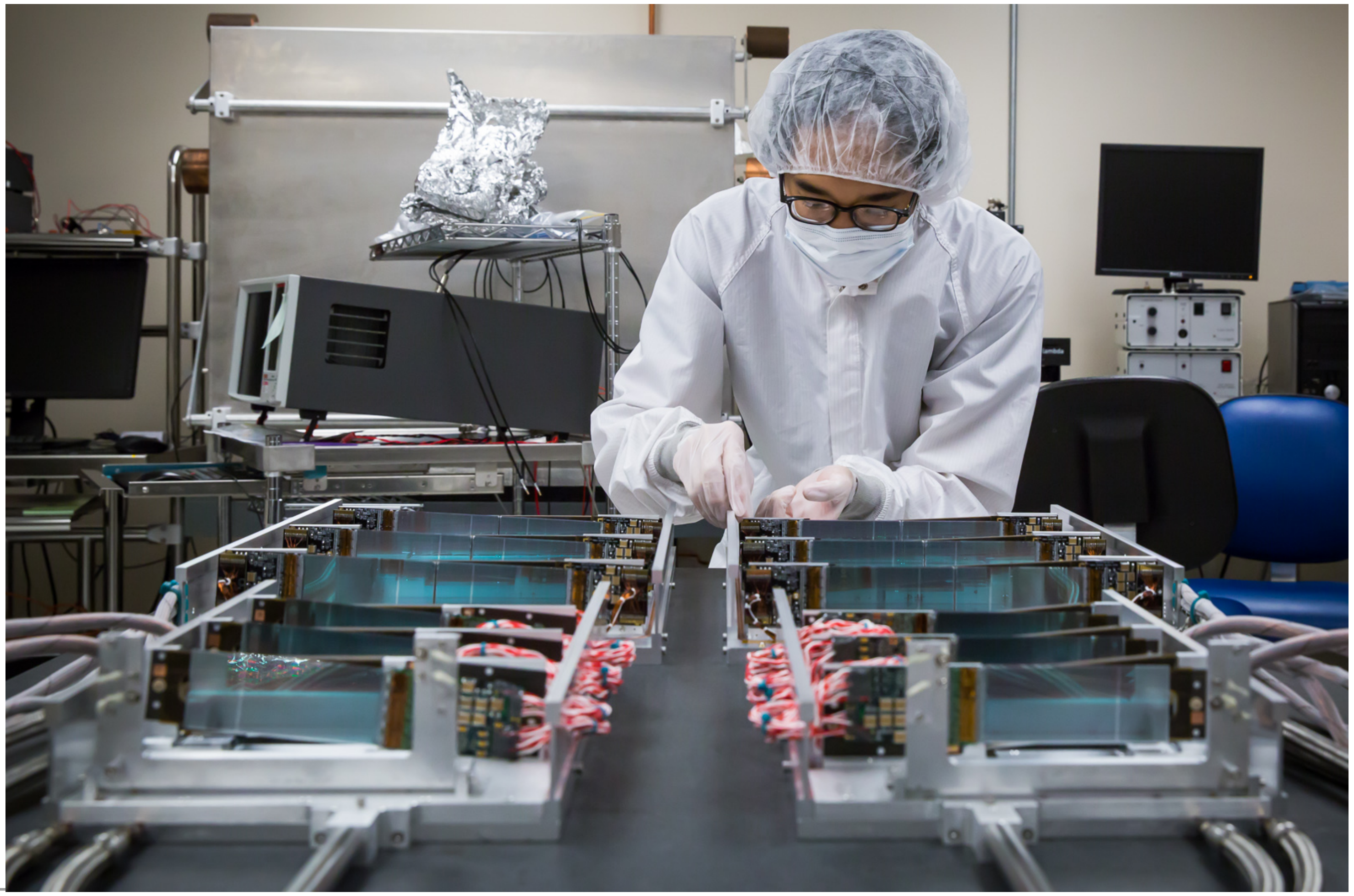
# SVT Upgrade

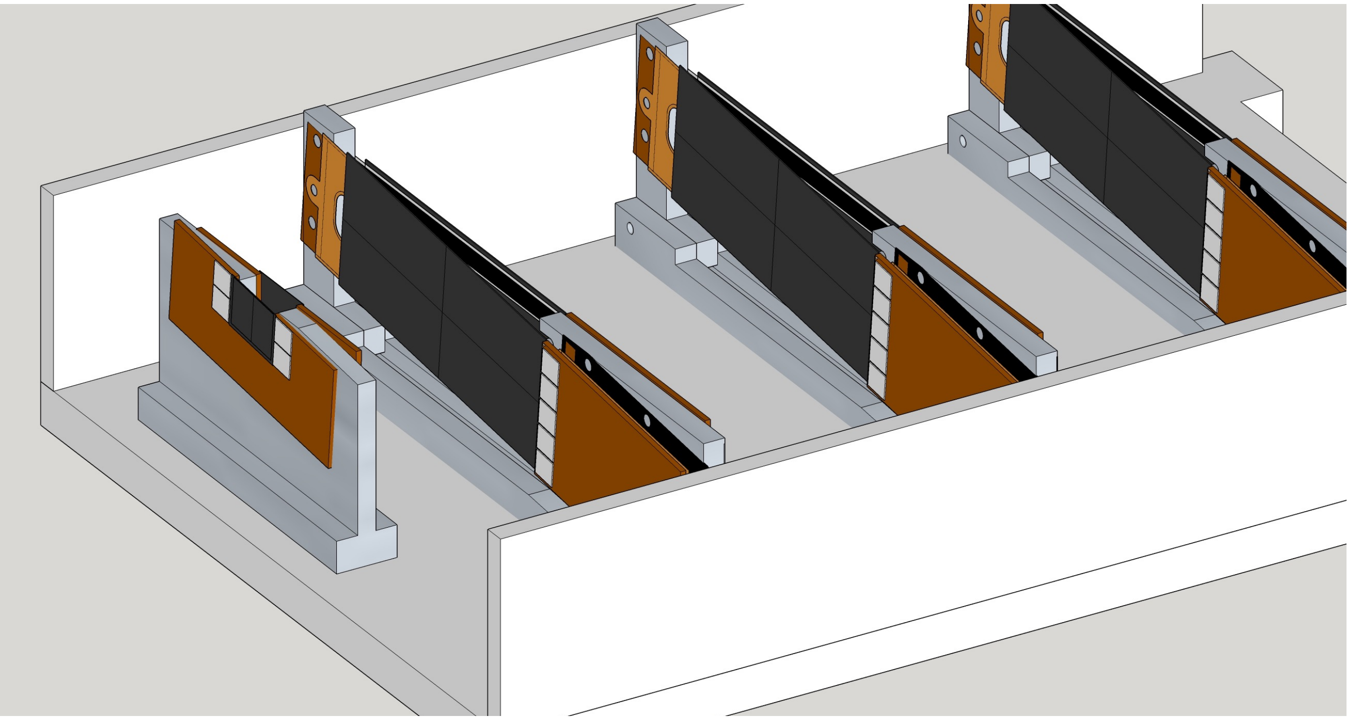
*and Preparing for 2019*



**Tim Nelson - SLAC**

*HPS Collaboration Meeting*

*May 22, 2017*



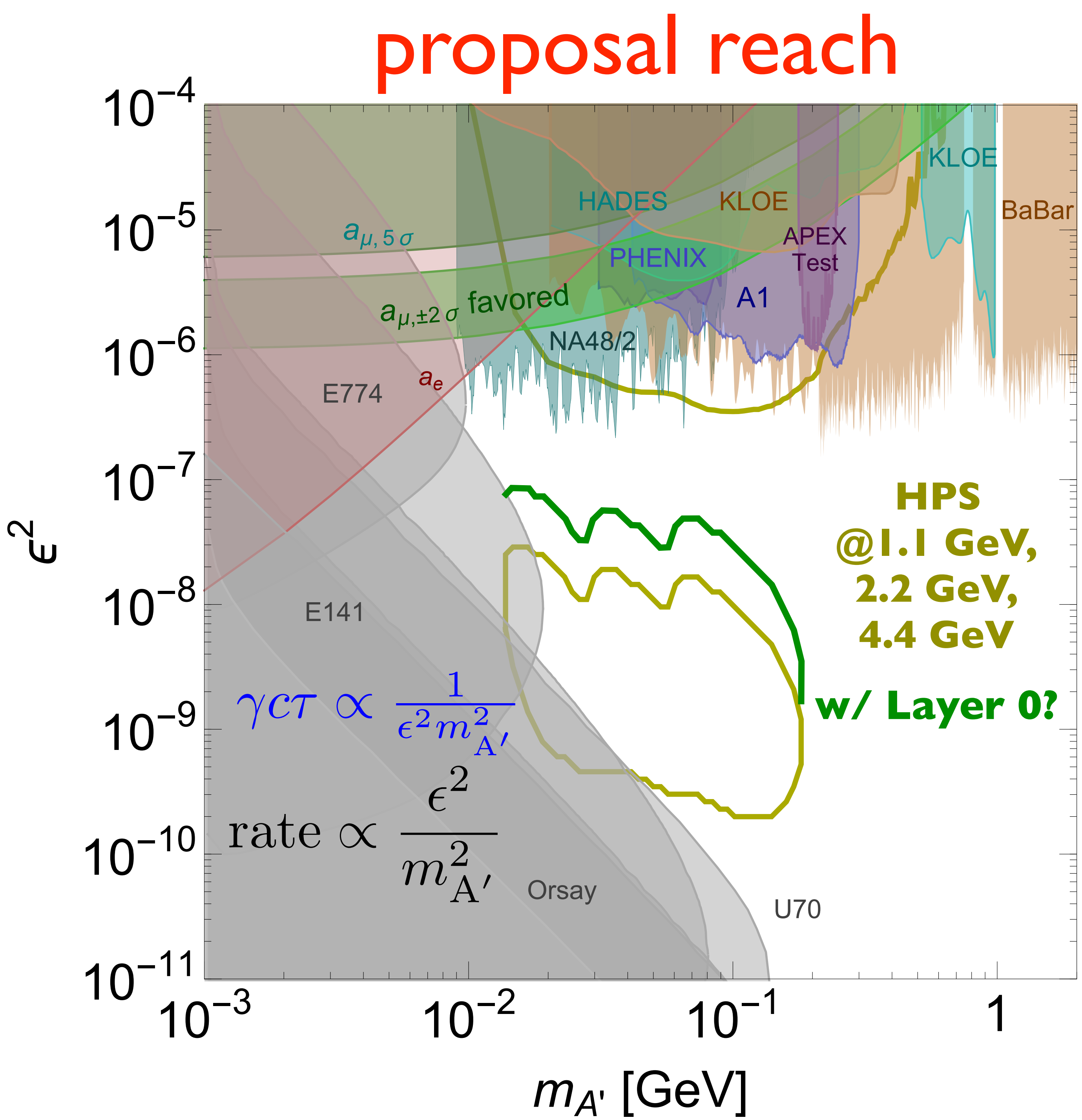
# Outline

- Review of SVT upgrade: motivations, requirements, performance
- Project Status
  - Sensors
  - Readout electronics
  - Mechanics
  - Schedule update
- Preparing to run in 2019
  - Updates to SVT DAQ platform (RCE DAQ)
  - Starting up the HPS detector and DAQ after three years (!)

# Motivations

*Addition of Layer 0*

- conceived and largely designed before errors in proposal reach were uncovered.
- purpose was to expand vertex reach, especially upwards into "Mont's Gap."



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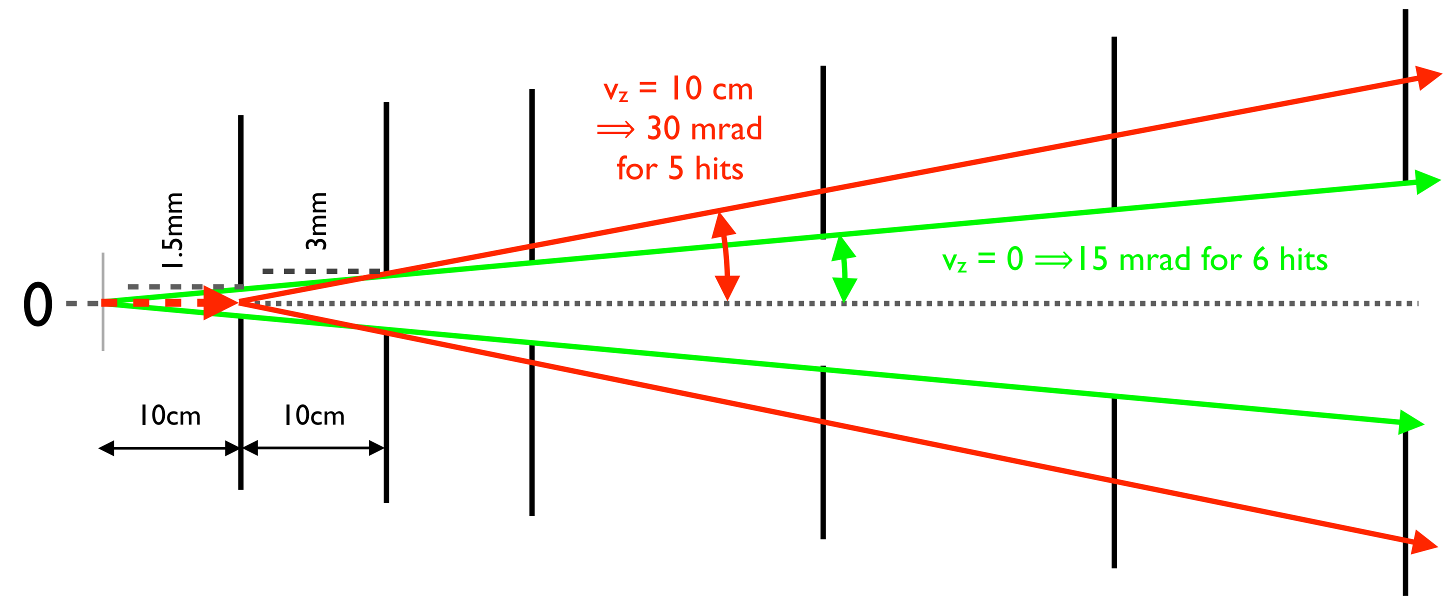
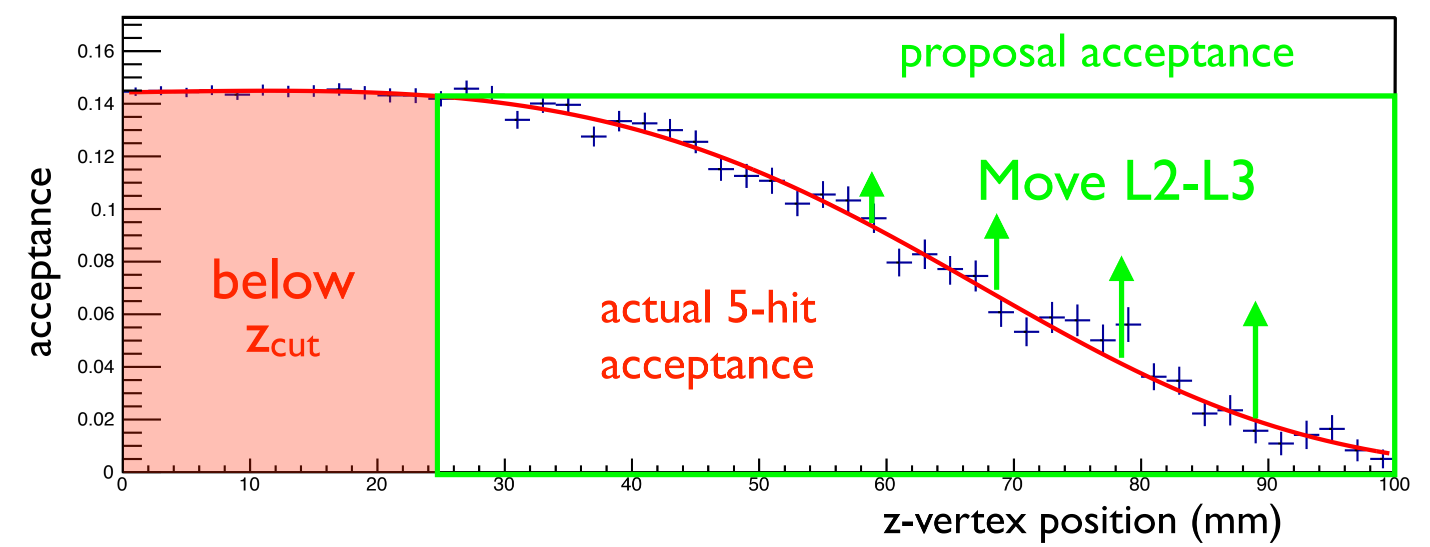



## *Move of Layers 2 and 3*

- dependence of acceptance on z-vertex position was not included in proposal estimates and therefore never explored
- Moving Layers 2 and 3 towards y=0 recovers some of the lost acceptance.



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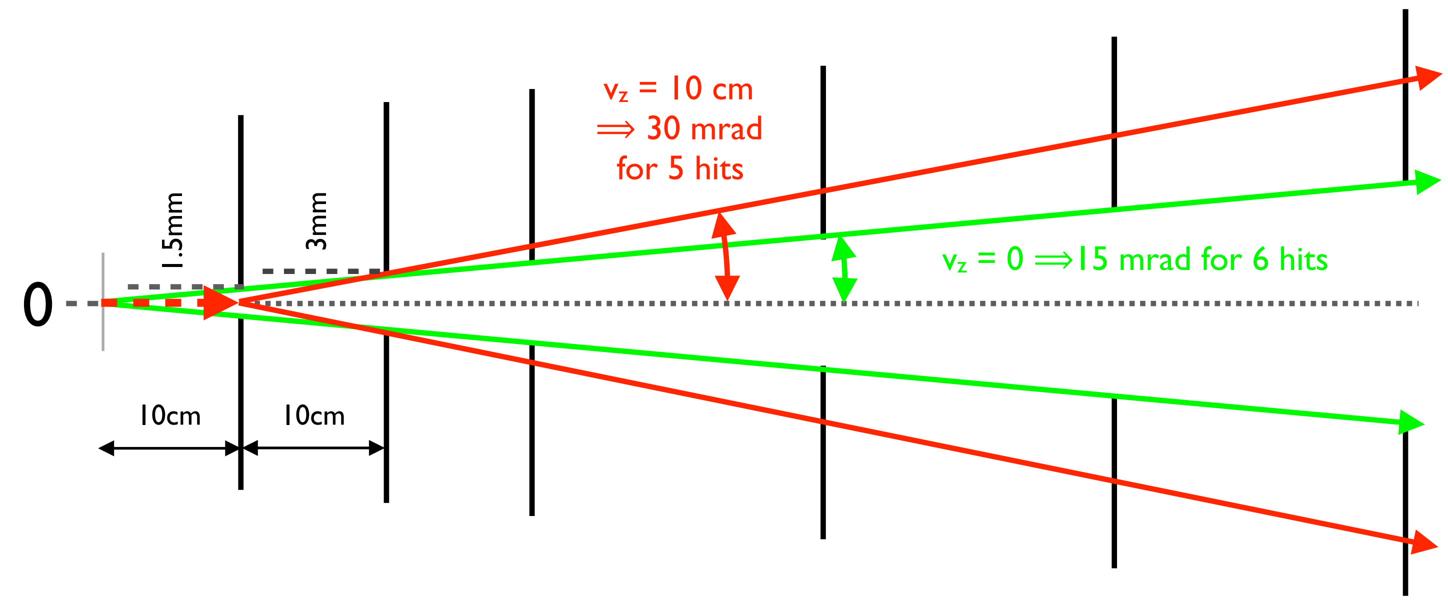


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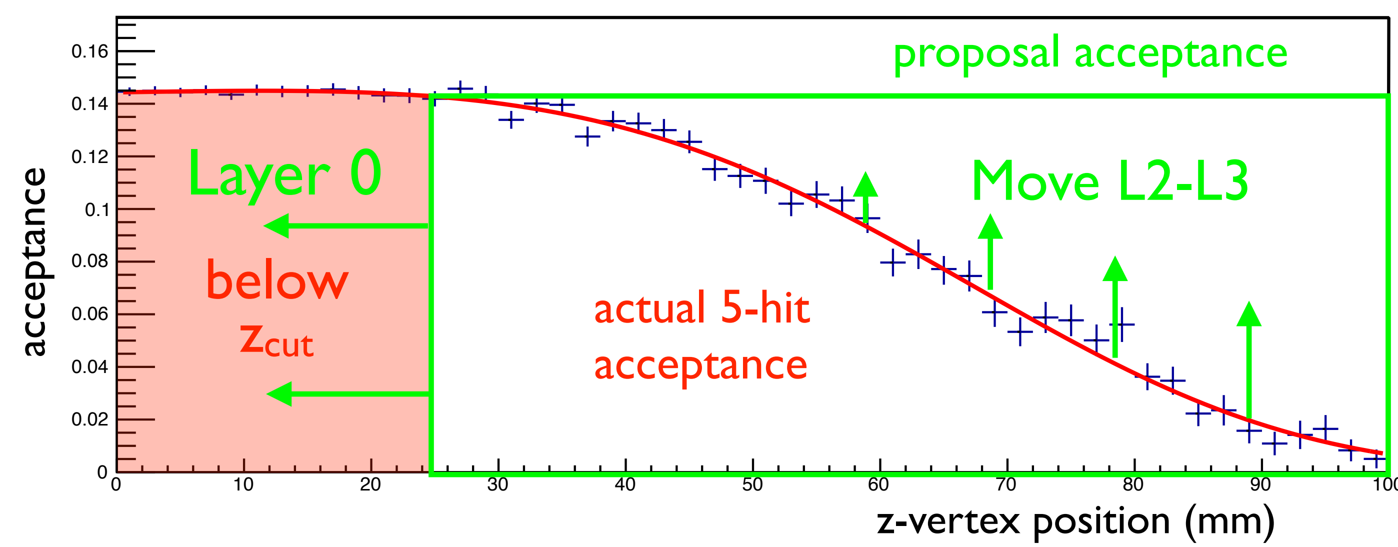
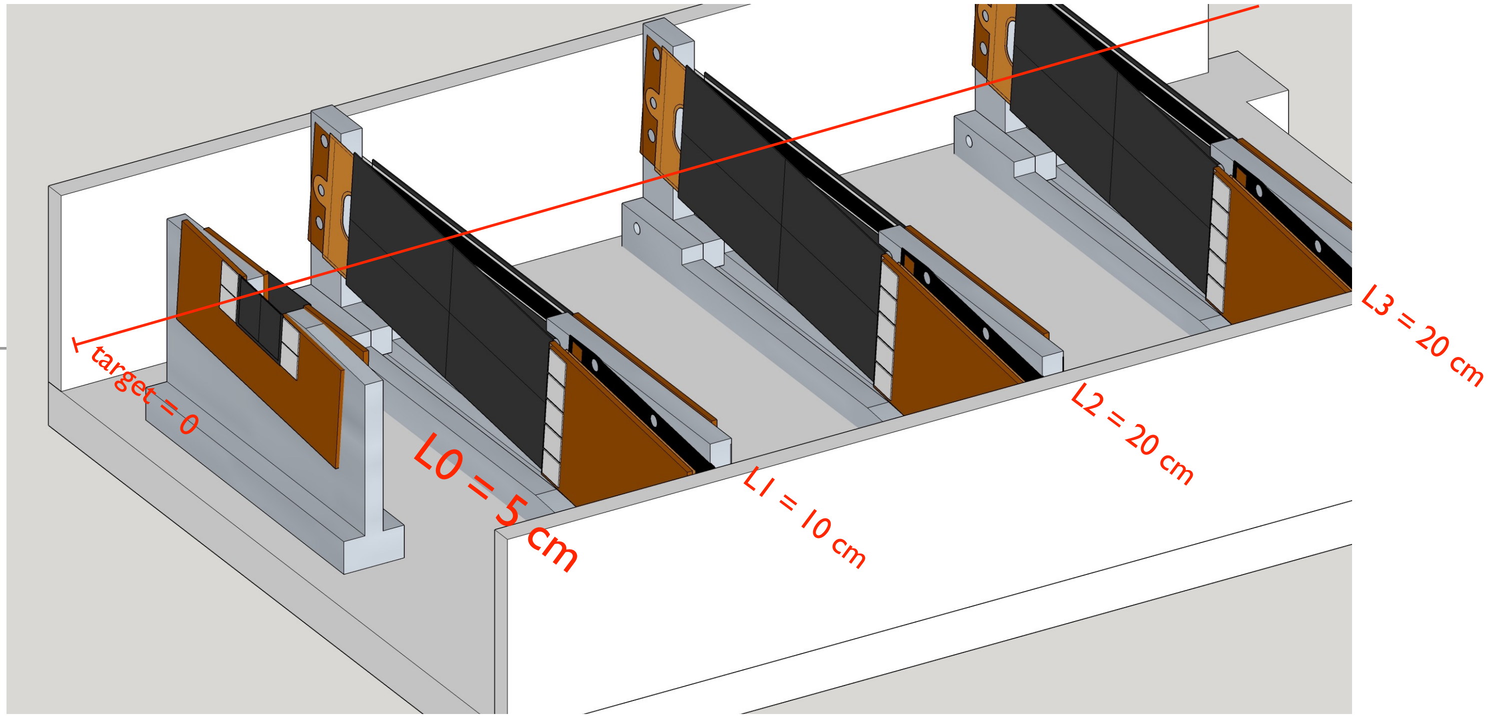



*Addition of Layer 0 takes on new importance in light of corrections to reach estimates.*

# Proposed Design

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- half the distance to target (5 cm)
- roughly half the material (0.4% $X_0$)

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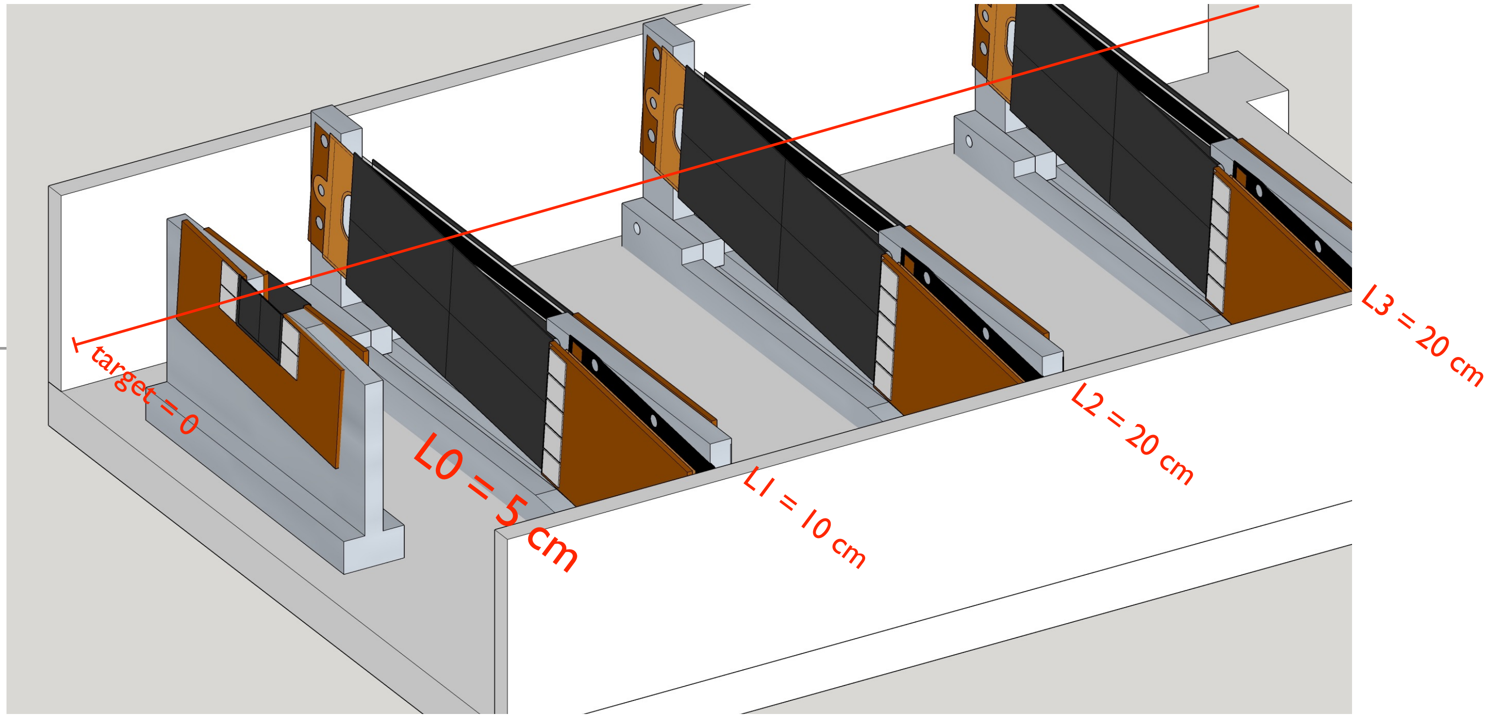


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- Being closer to target increases backgrounds and radiation.
- L-shell x-ray sensitivity from lower thresholds creates additional occupancy.
- Proximity of active region to beam means greater sensitivity to beam tails.

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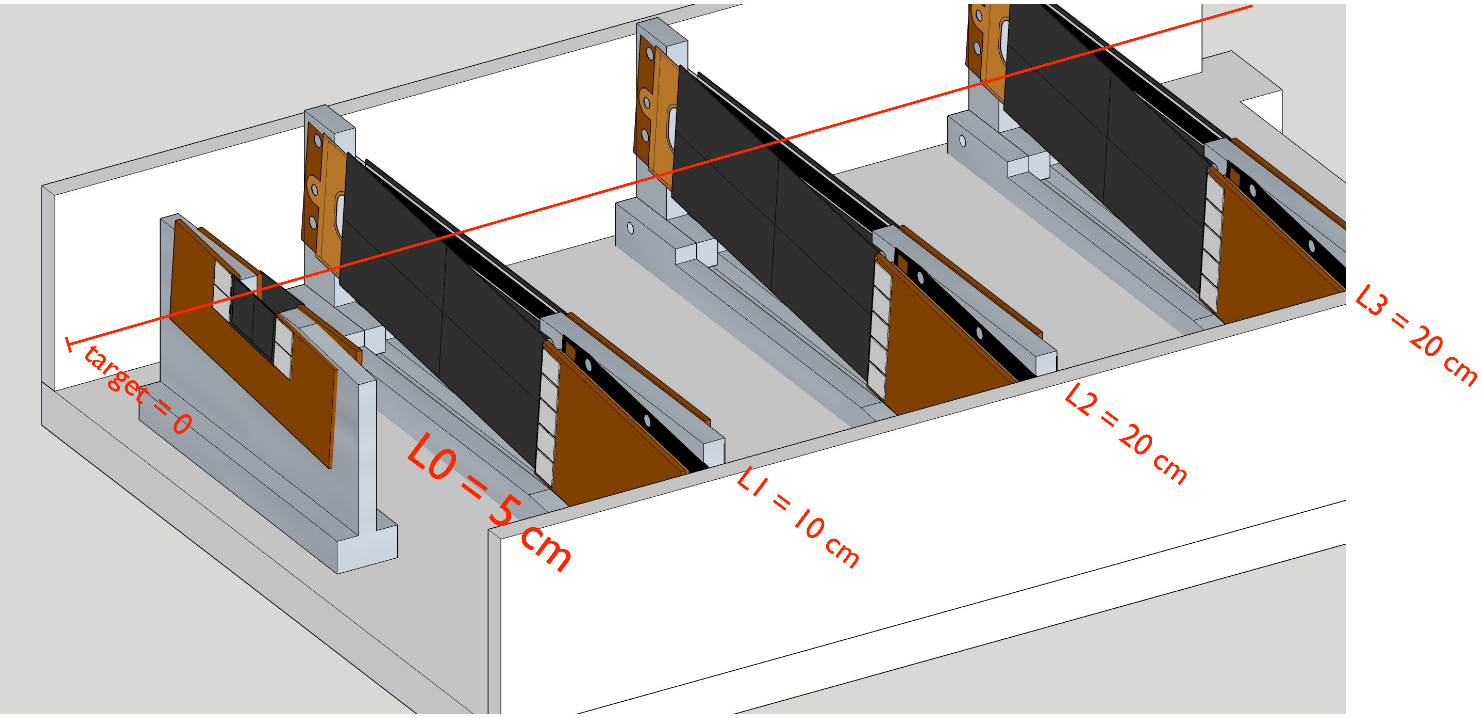


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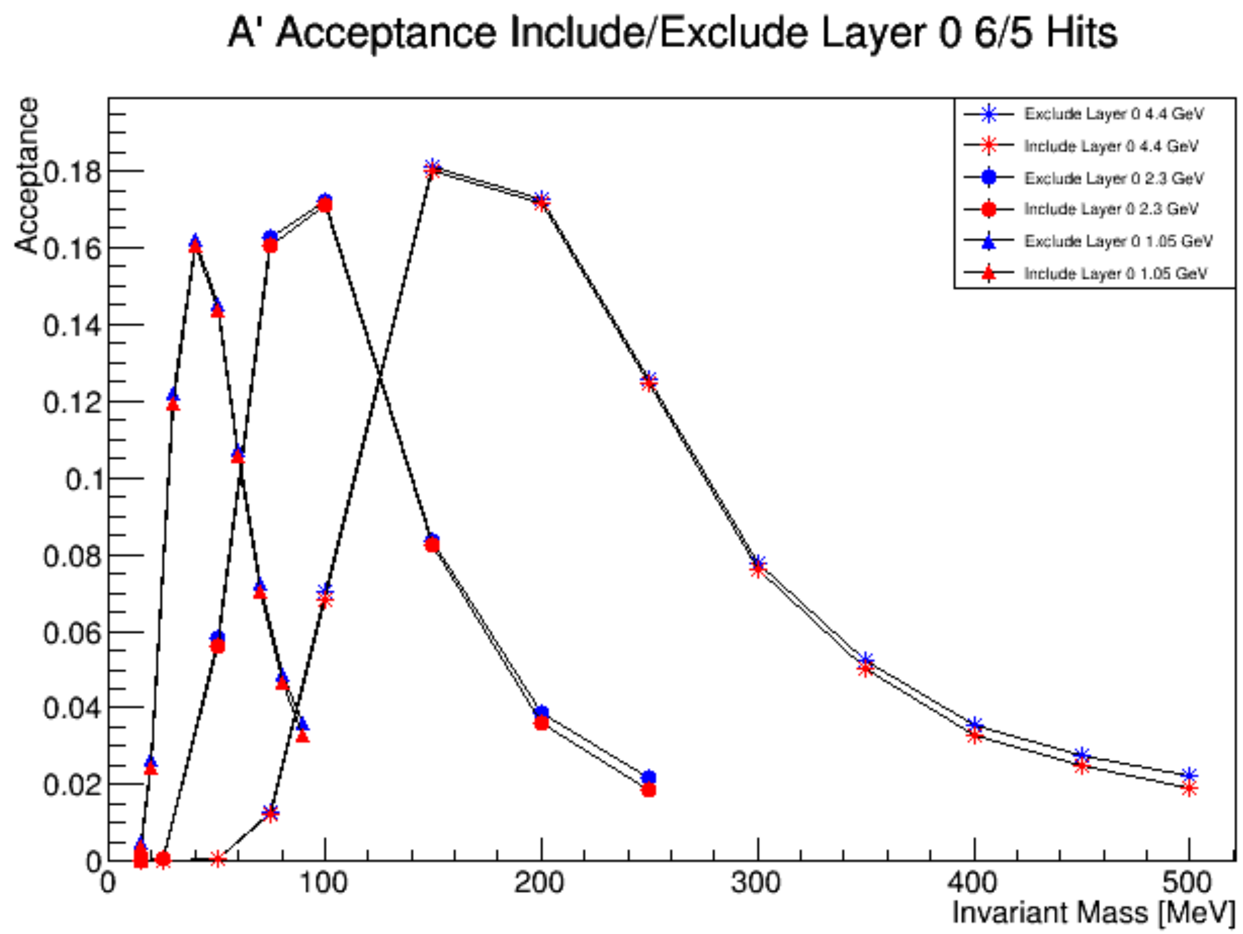
*Moving L2 and L3 is completely independent and very low impact.*

- Thin shims under module supports move L2 and L3 by 0.8 mm towards y=0.
- Adding these when modules are remounted for L0 modifications is trivial.

# Acceptance and Efficiency

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



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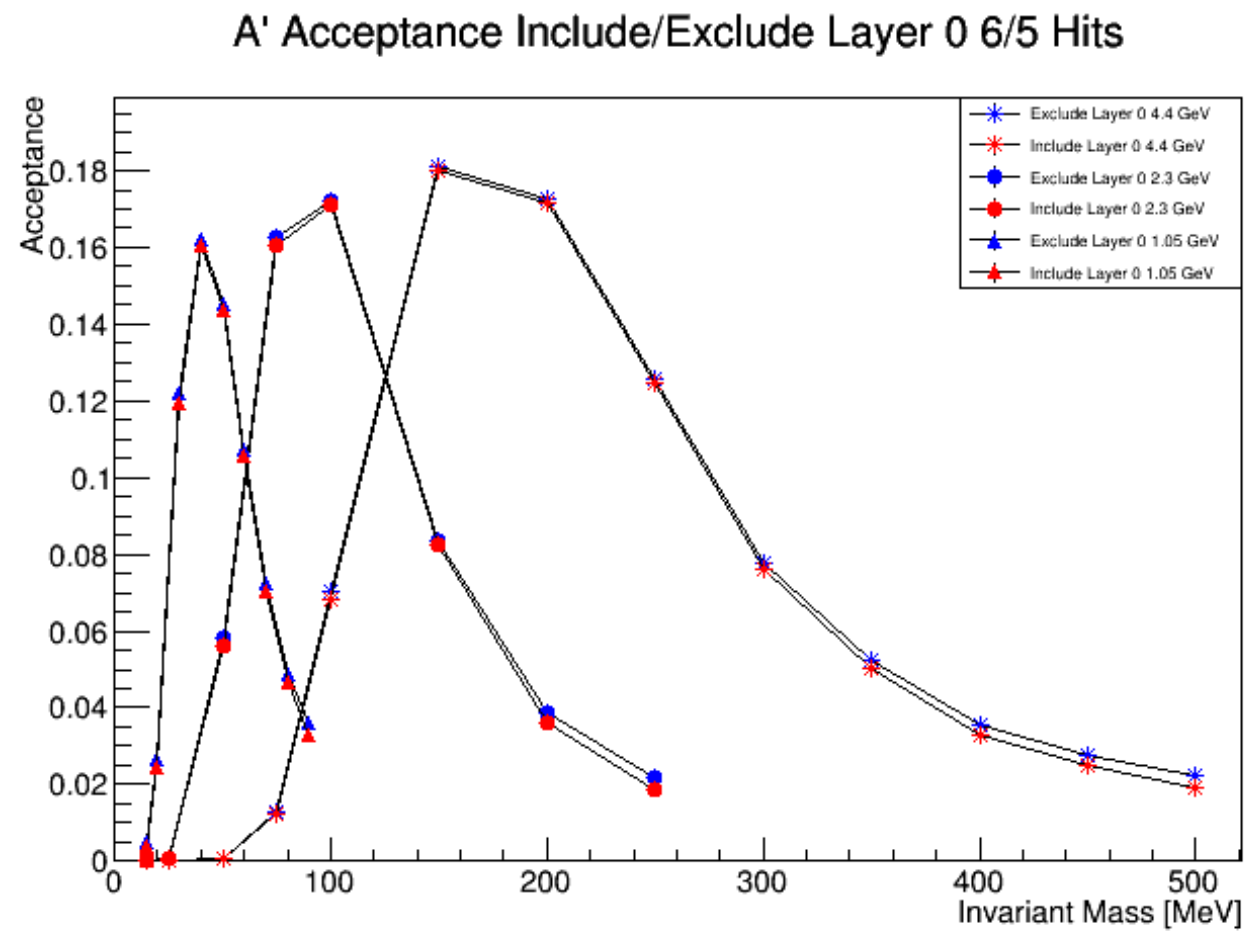
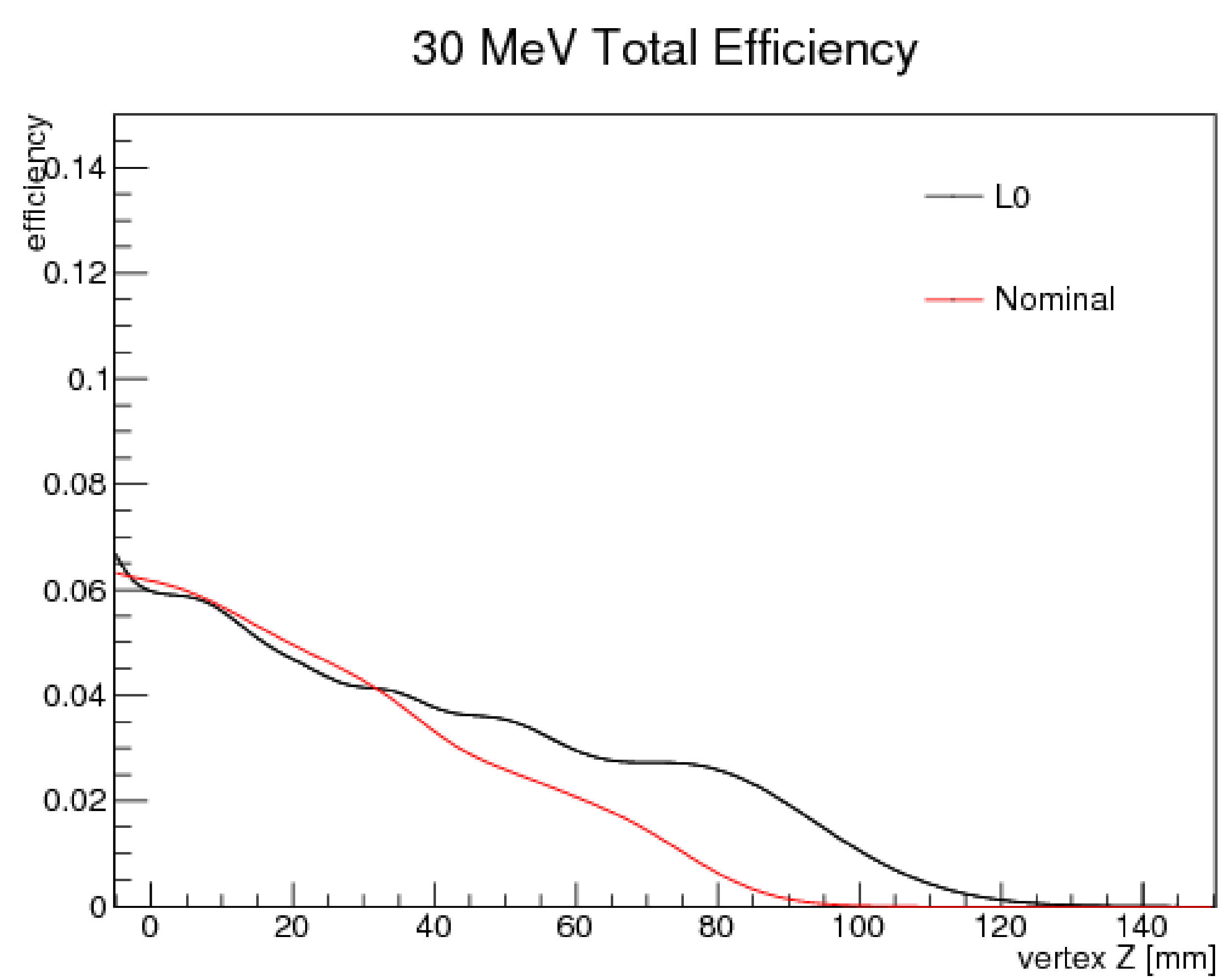
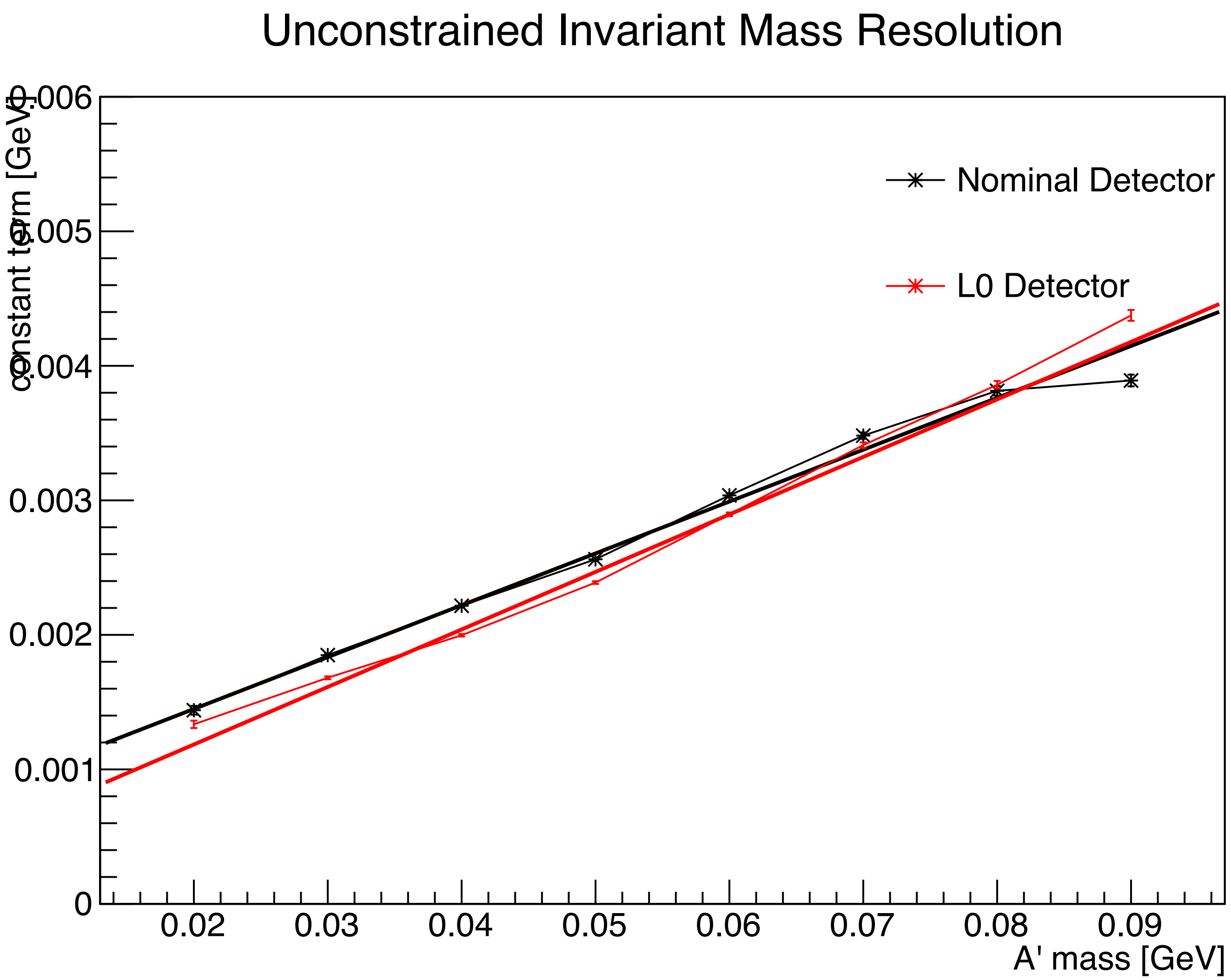



*Moving Layers 2 and 3 inwards increases acceptance for long-lived A′ daughters as expected.*



# Resolutions




*Mass resolution roughly unchanged (as expected)*

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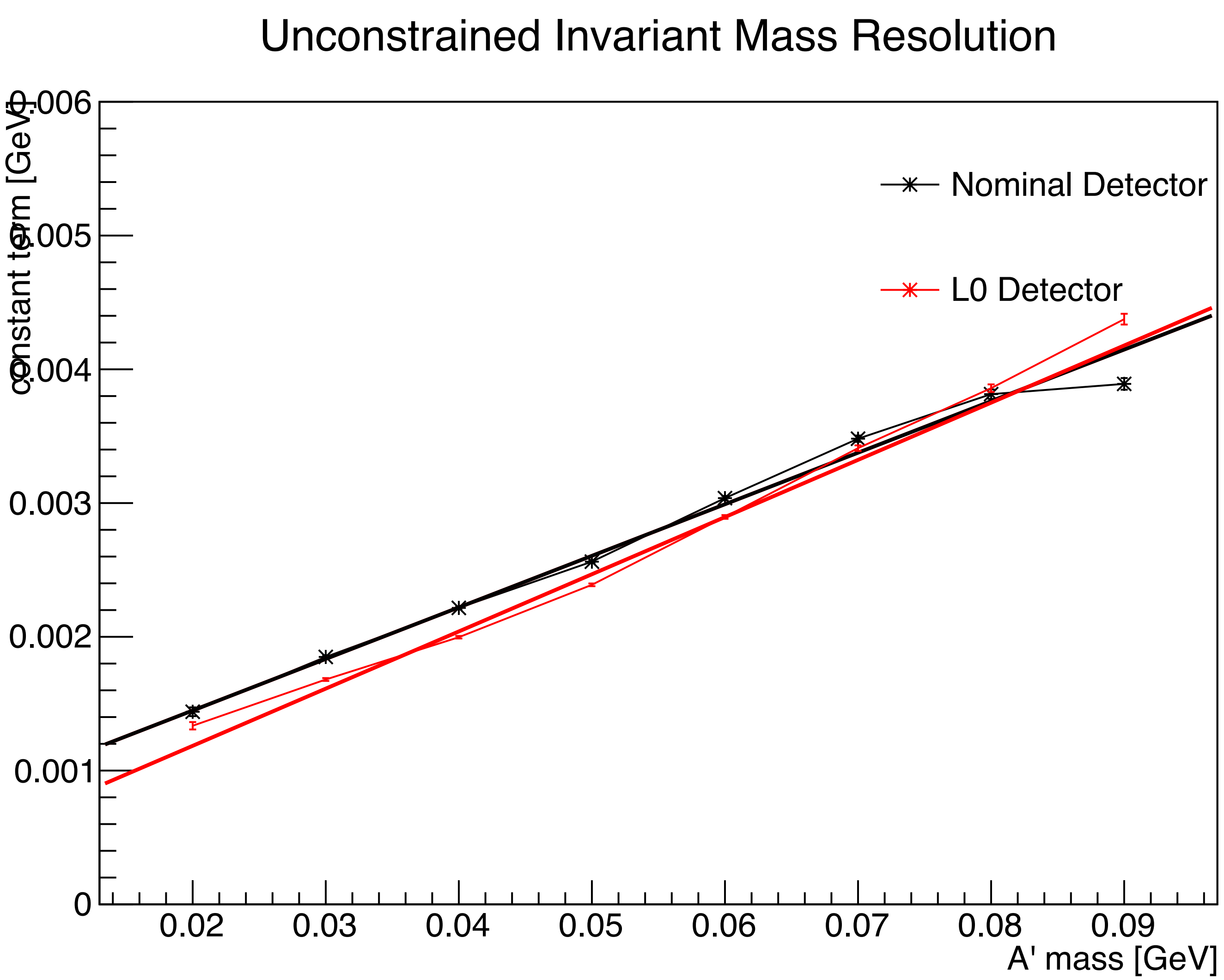
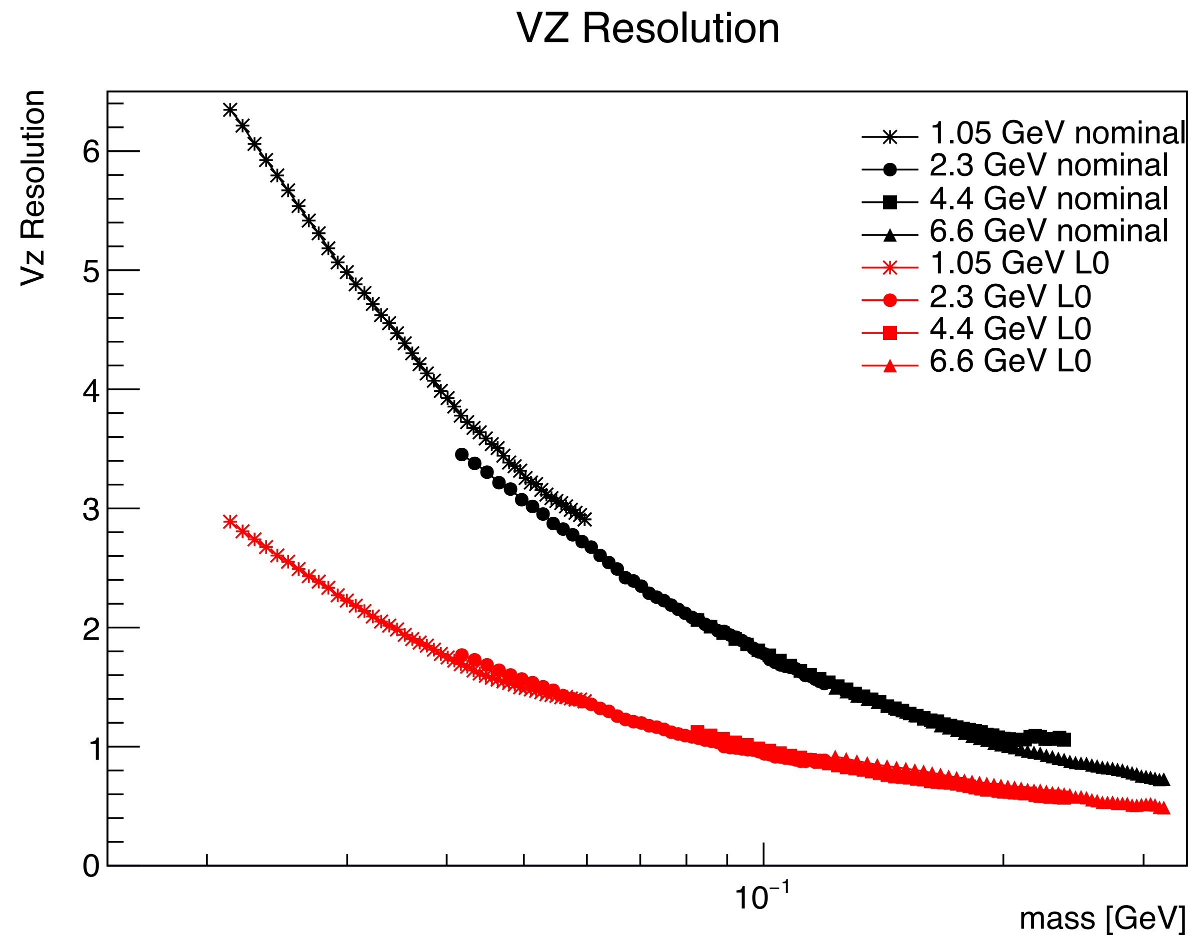
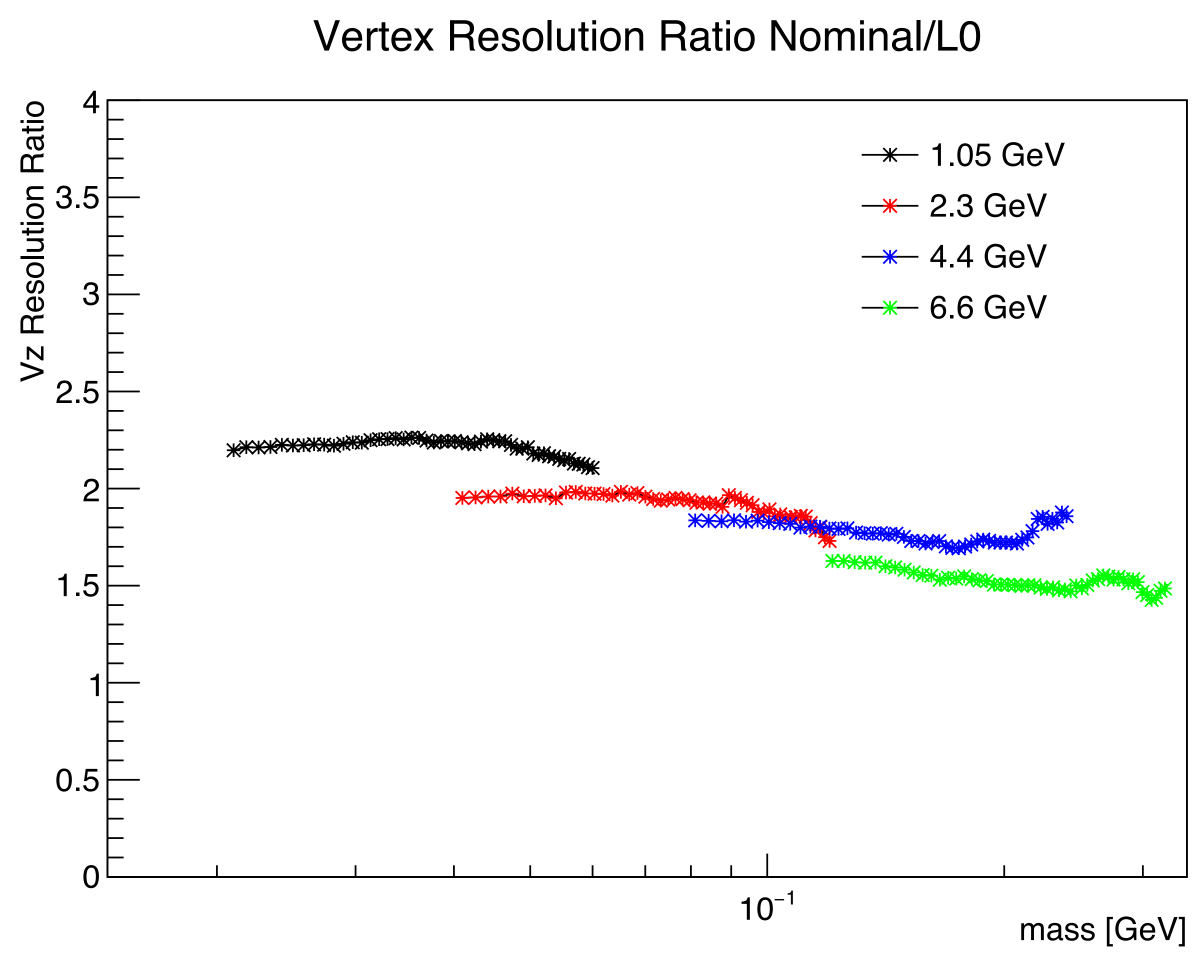


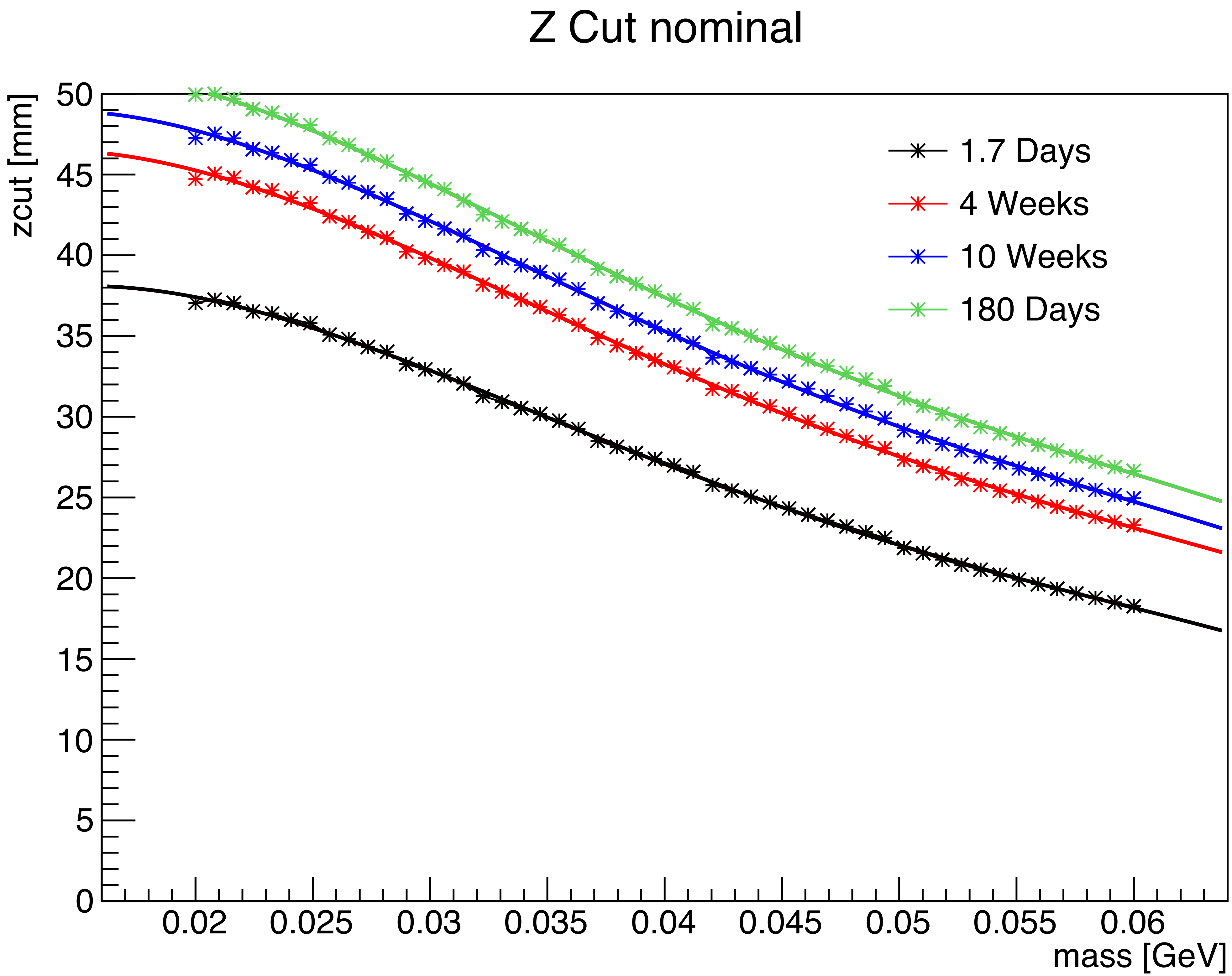




*Mass resolution roughly unchanged (as expected)*

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

# Z Cut for 0.5 Events Expected Background



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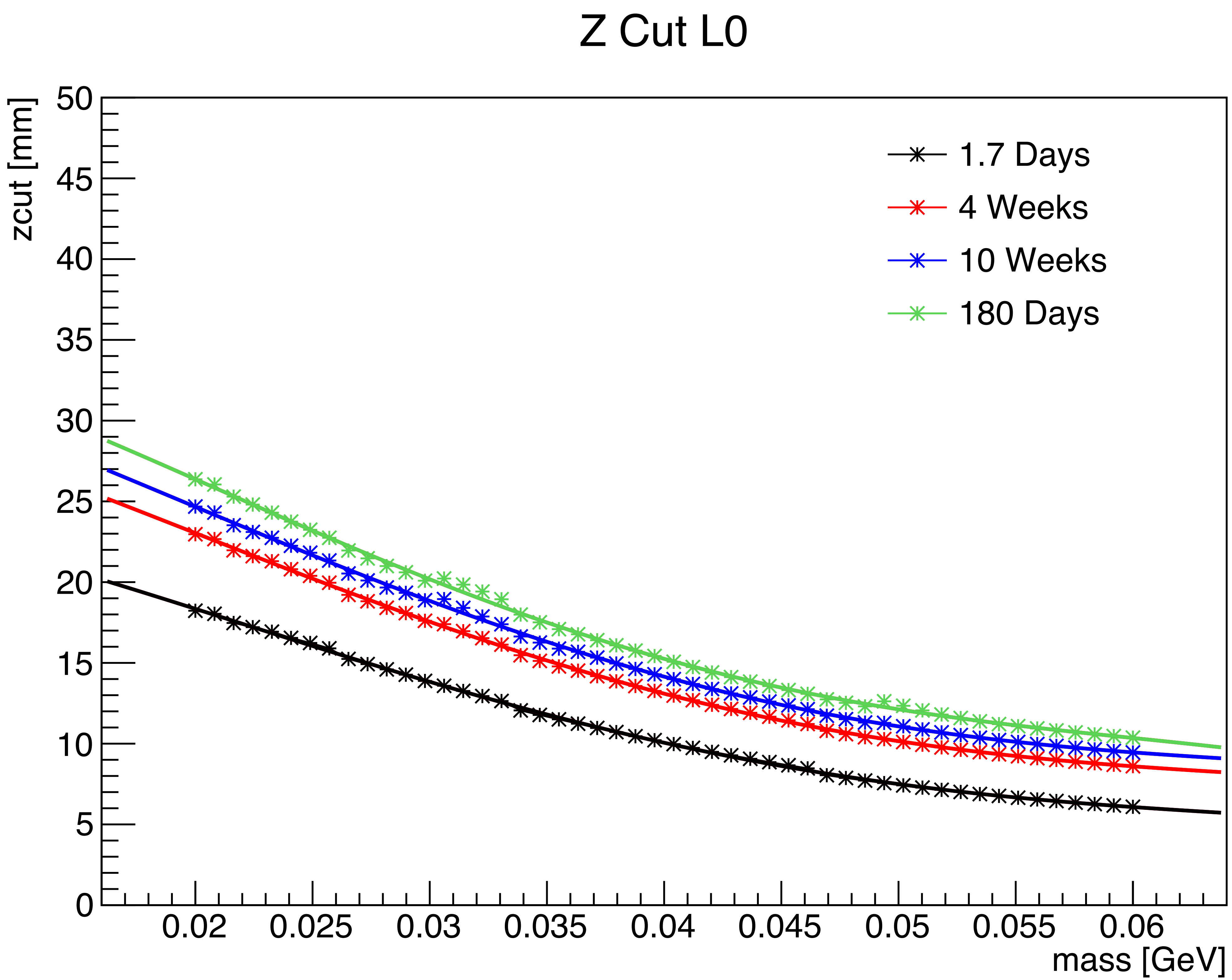
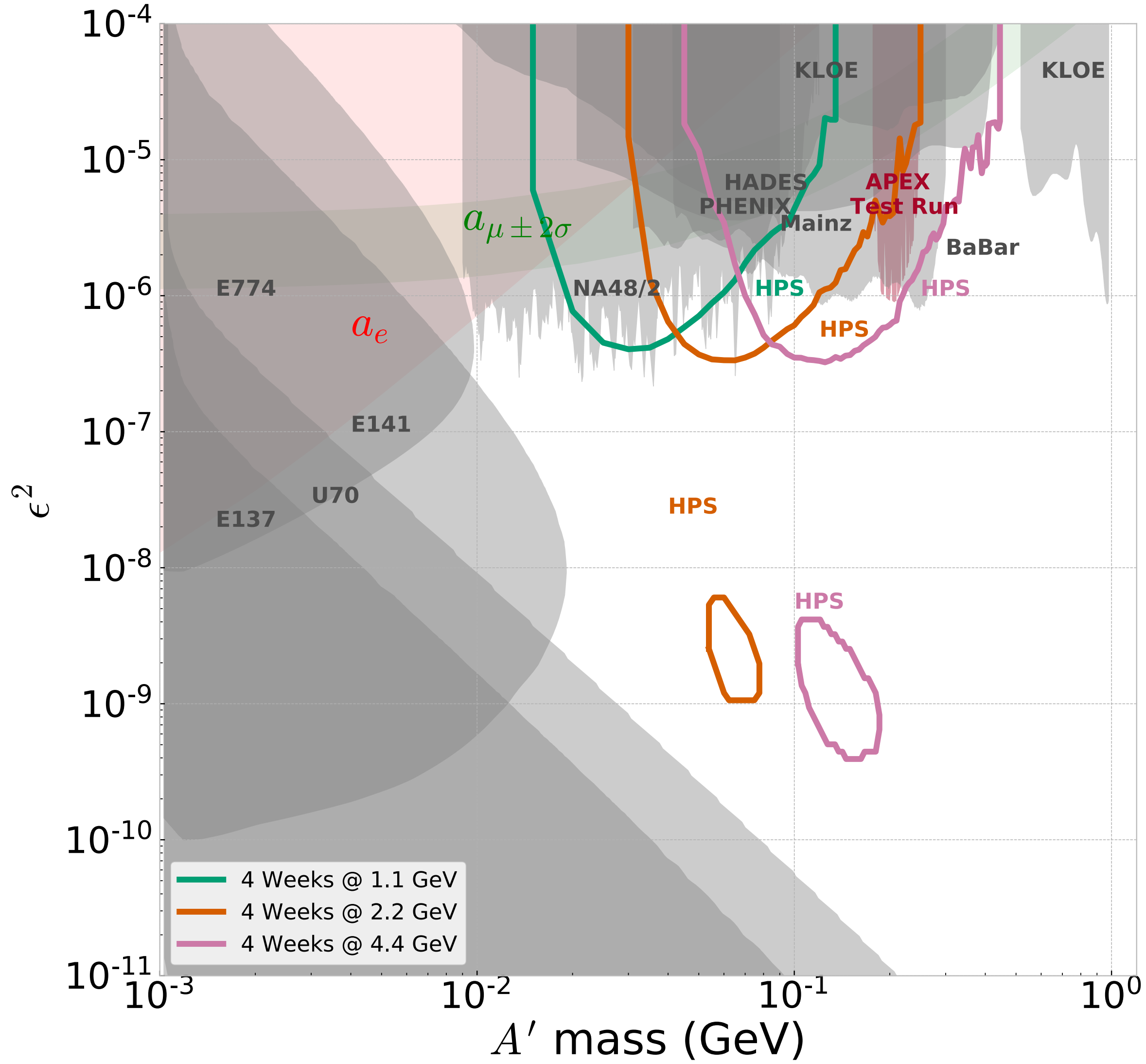
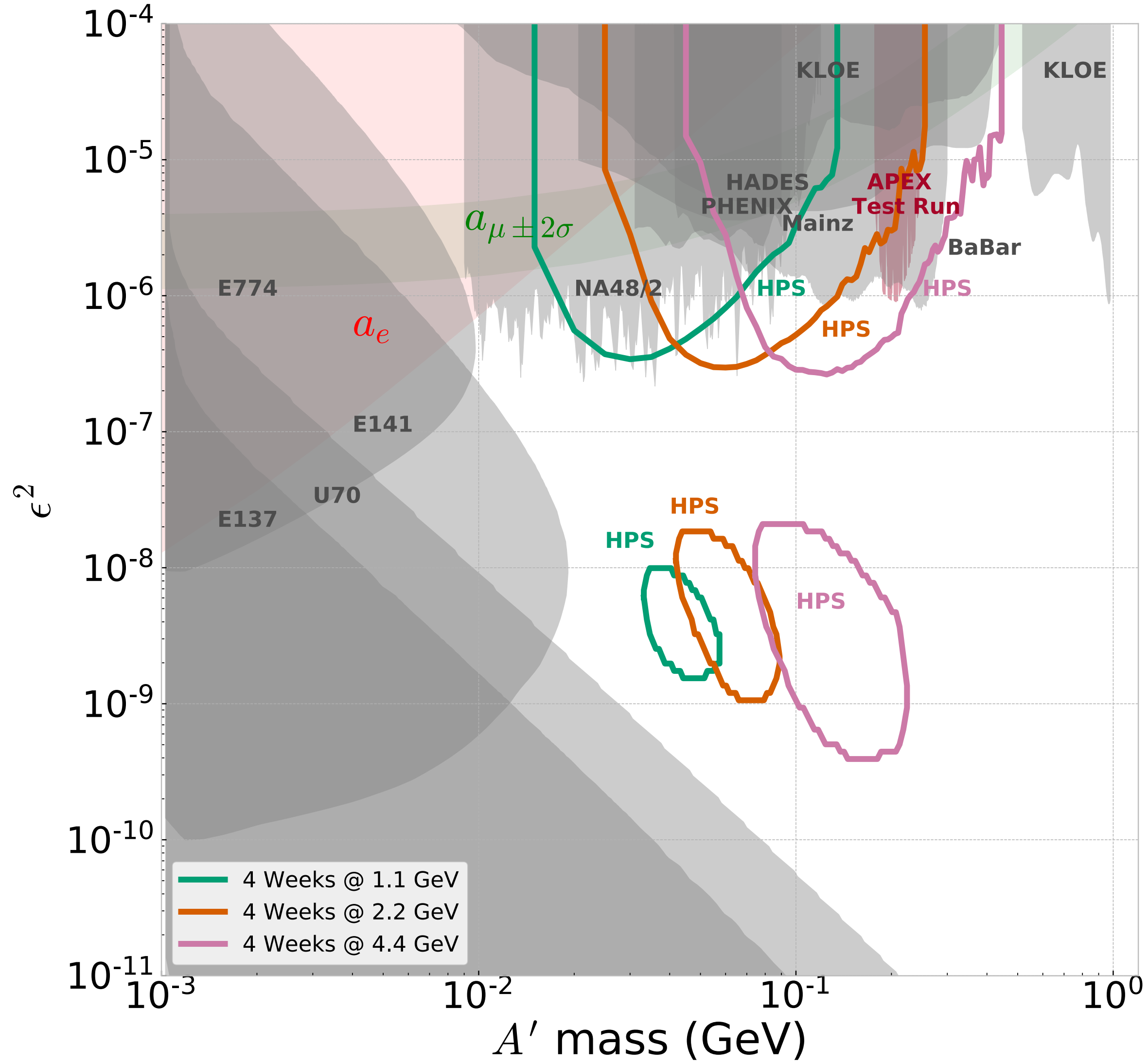


# Impact on Reach

## w/ positron hodoscope




## + SVT upgrade




*The majority of the SVT improvement is from adding Layer 0*

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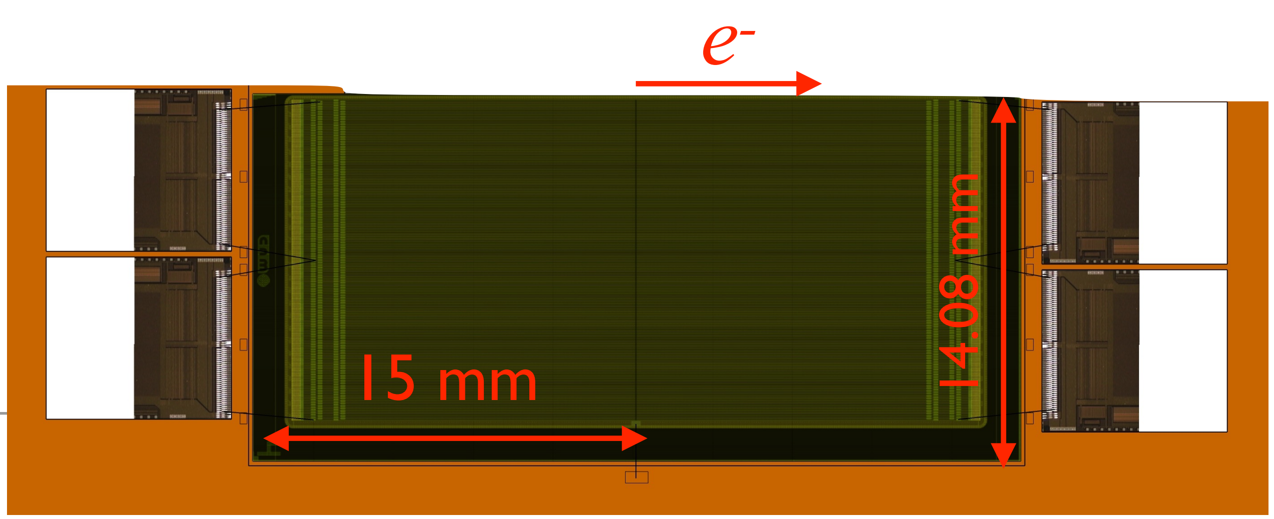
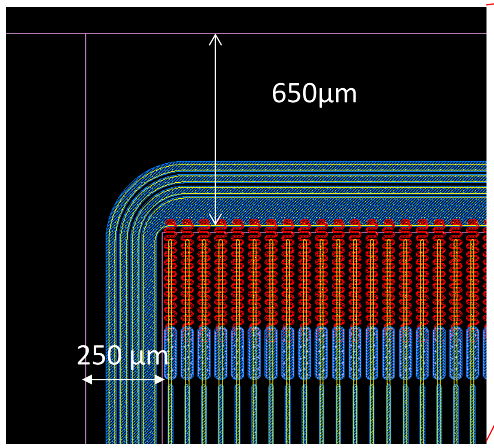
  - Investigating apparent module damage from previous runs
  - Starting up detector and DAQ for first time in three years

# Layer 0 Sensor Design

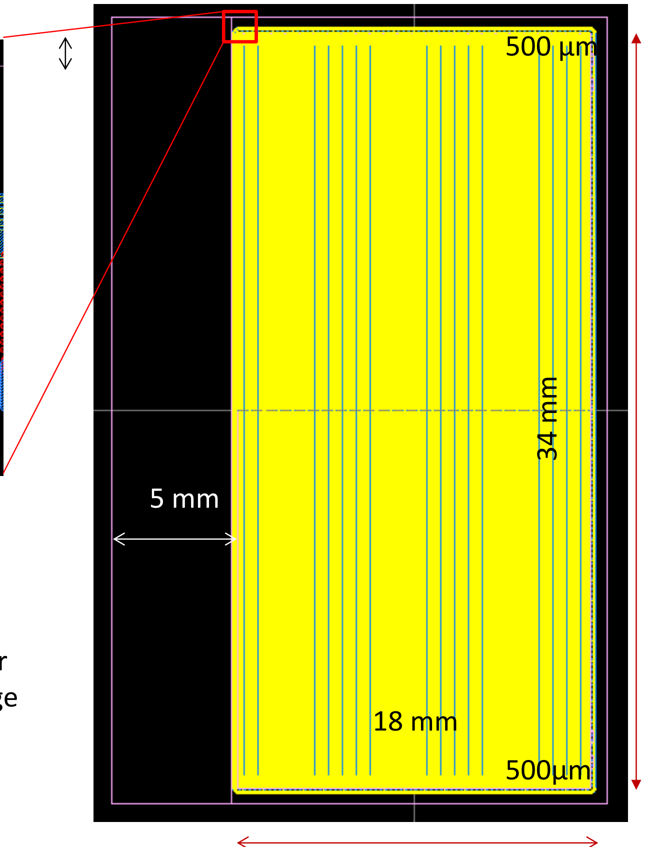


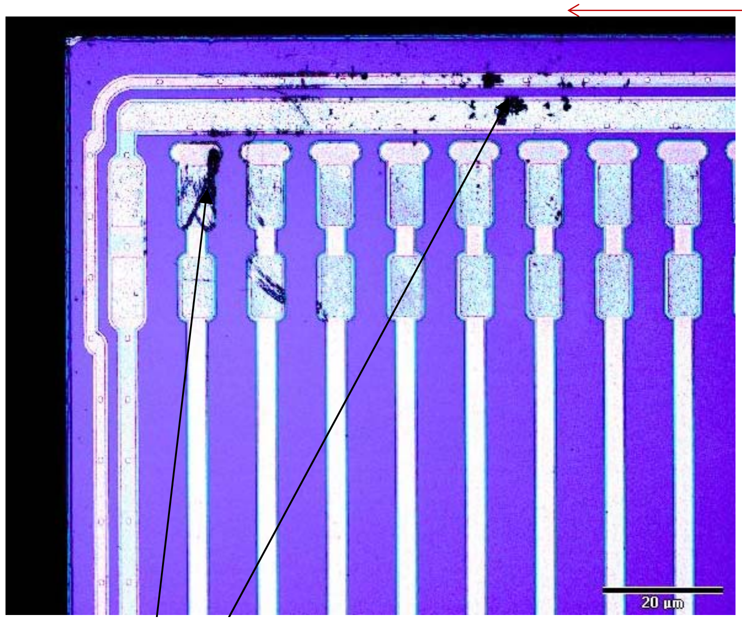

- thickness: 200 um
- sense/readout pitch: 55 um
  *(no capacitively coupled intermediate strip: reduces occupancy, improves two-hit resolution, reduces capacitance and strip resistance)*
- active areas: 2×(15 mm × 14.08 mm)
- # channels: 510 (2×255)
- slim edge: 250 um, similar to sensors already processed this way by UCSC.
  *(means edge of sensor will be same distance from beam as current Layer 1)*
- max bias voltage: 500V *(will test/select best sensors)*

Edges




Edge: 5 mm from active area in the slim edge side. Slim edge in range 250 µm far from active area. On the other sides edge 650 µm far from active area.



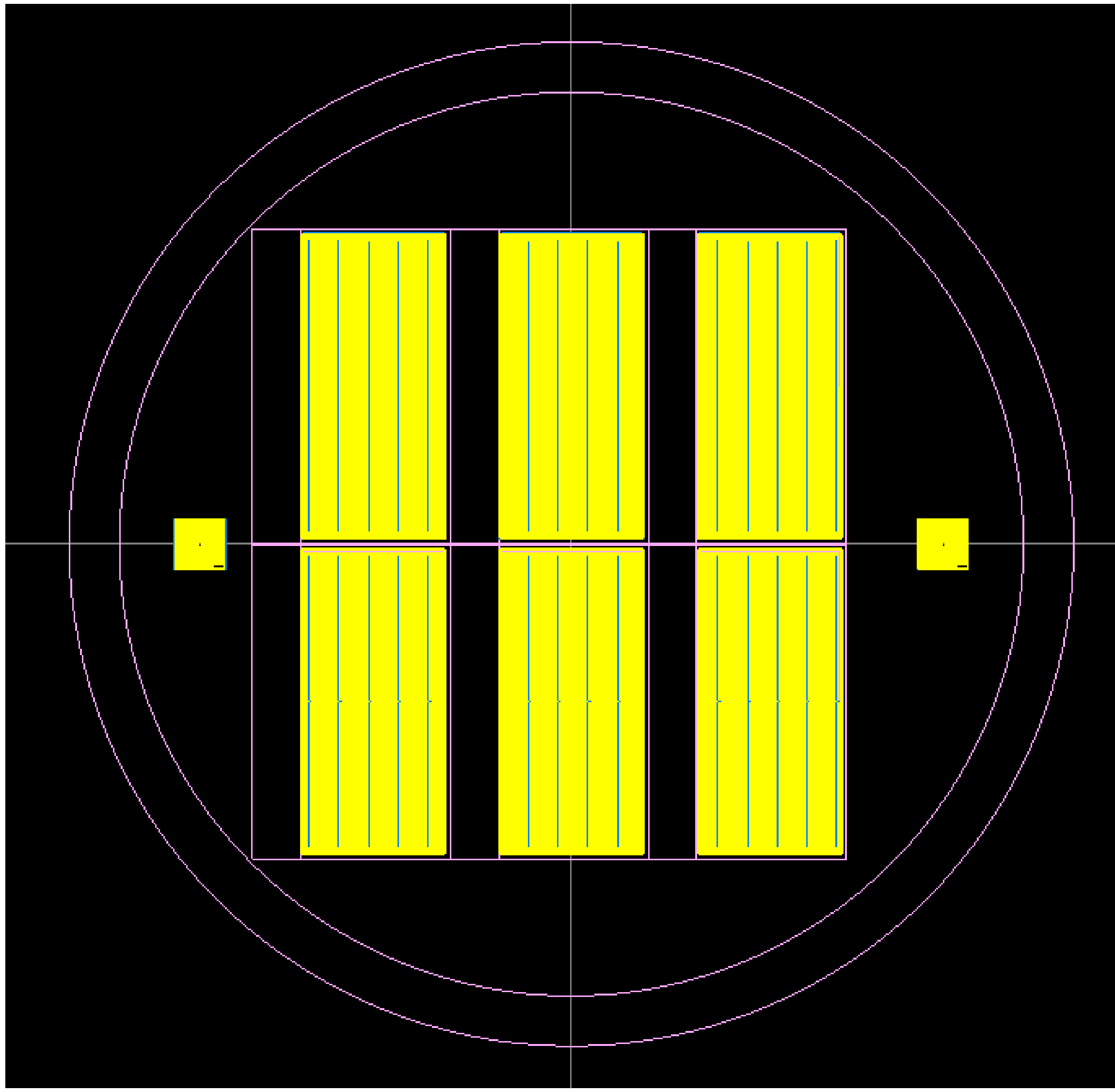



# Sensor Status

*Sensors have defined the critical path for Layer 0*

- Order with CNM D+T placed last October
- Sensor design finalized on 1/19/18,
  ⇒ *a required input for mechanical design*
- Fabrication began on 2/5/18
- Projected delivery date mid-July, now late July.
  ⇒ *Chance of slippage until after August.*

  Discussing with vendor whether we can help with slim-edge processing to get early delivery of first 10 sensors.

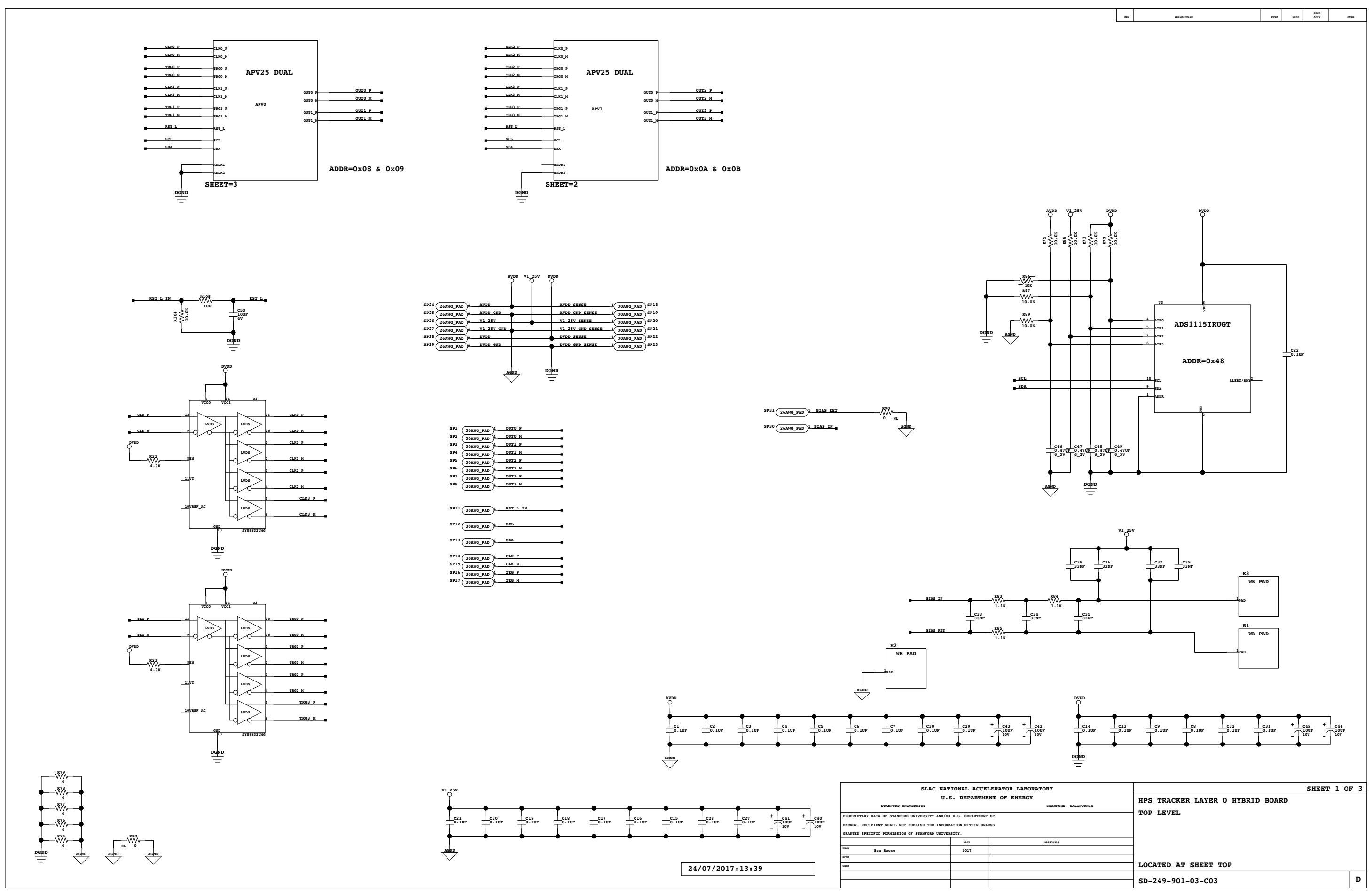


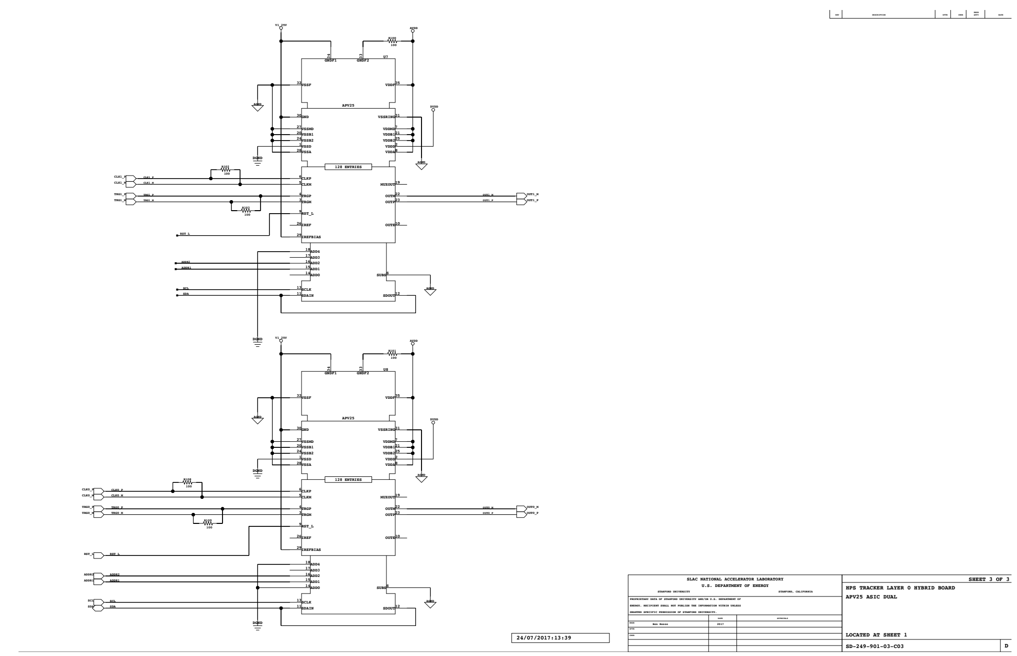
*Meanwhile, focus is on ensuring the critical path after sensor arrival is clear.*

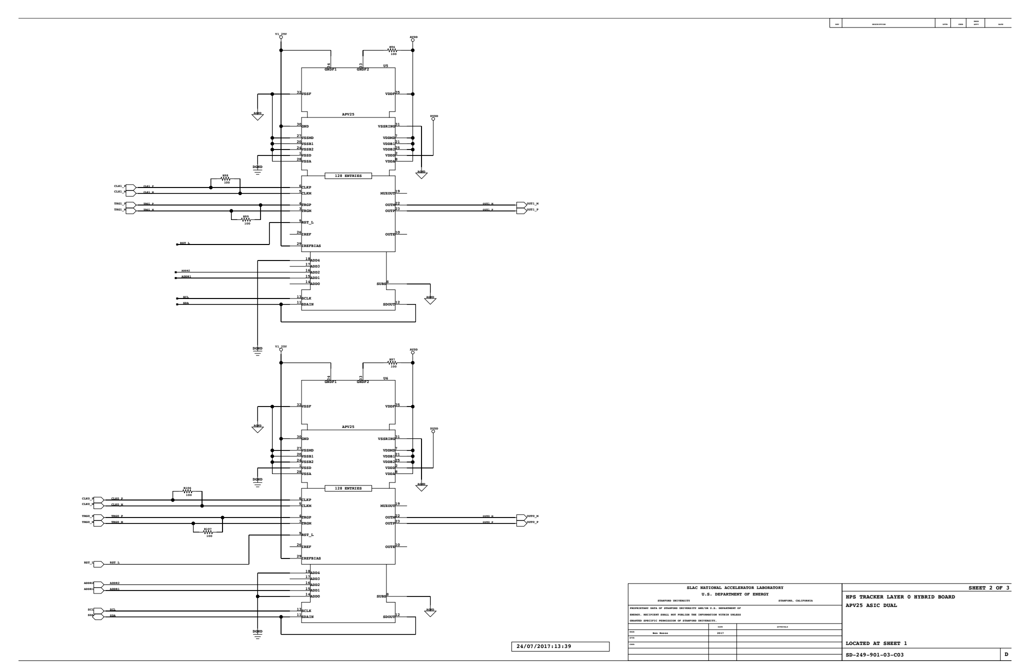
# Layer 0 Readout Design

Hybrid schematic a simple modification of existing designs (one fewer APV25)

Schematic was reviewed/approved in the fall.





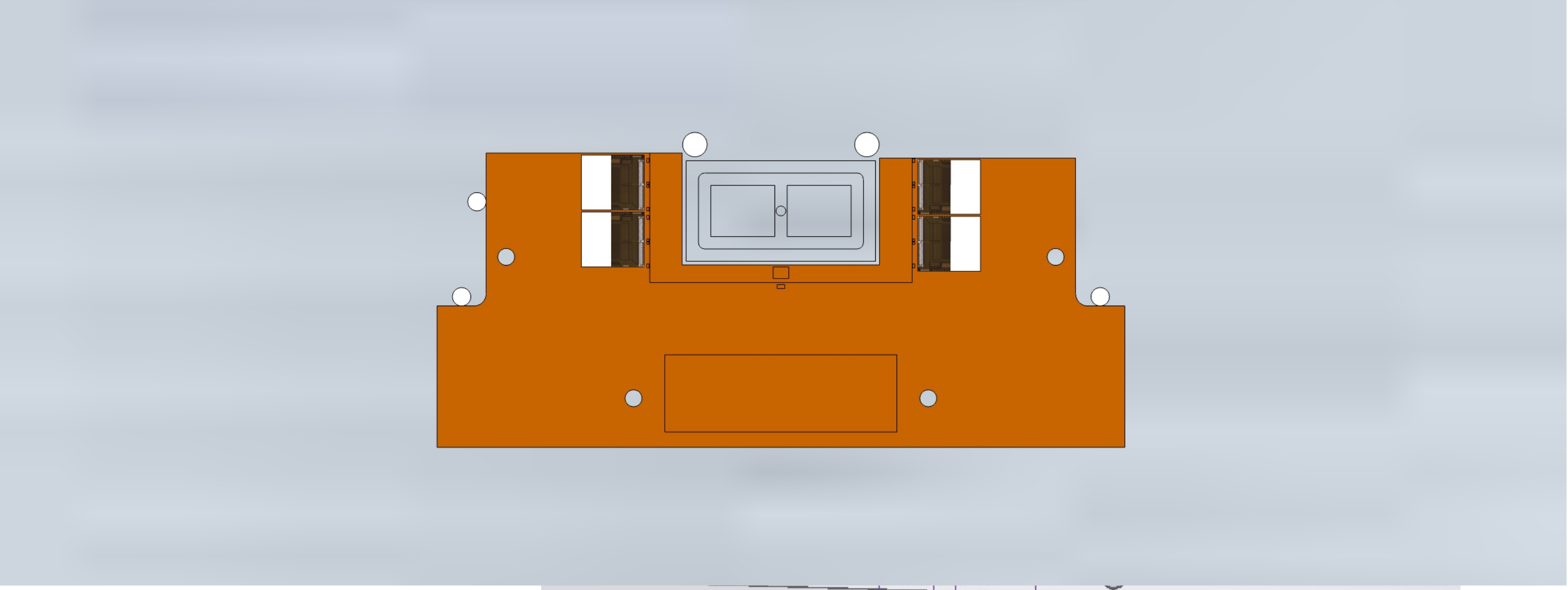


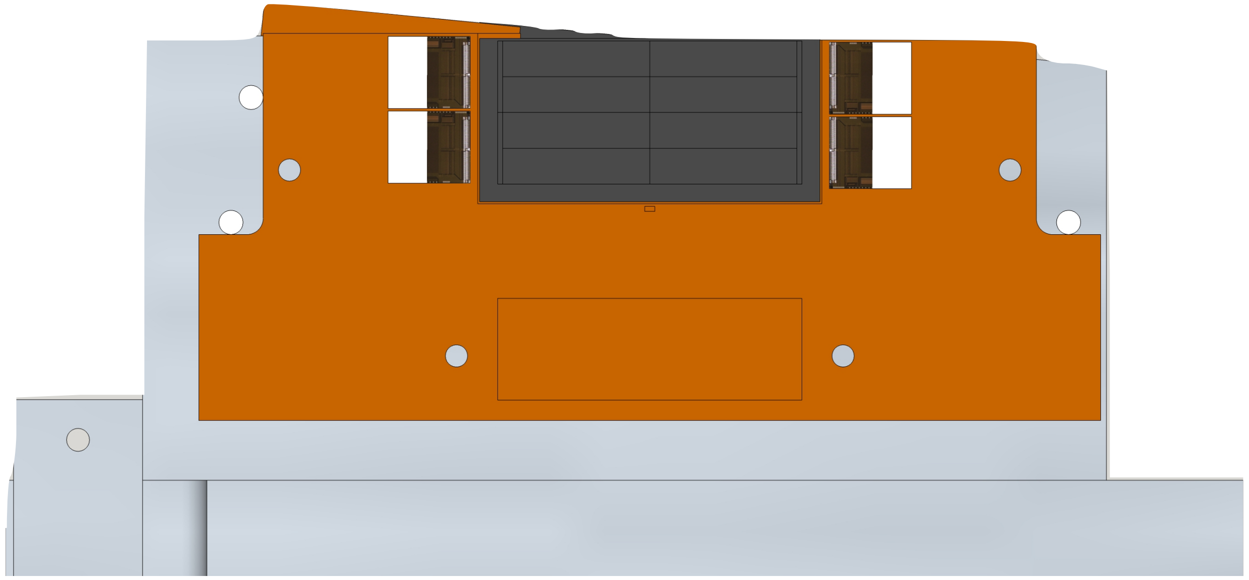
Once sensor design was defined, mechanical design could be completed.

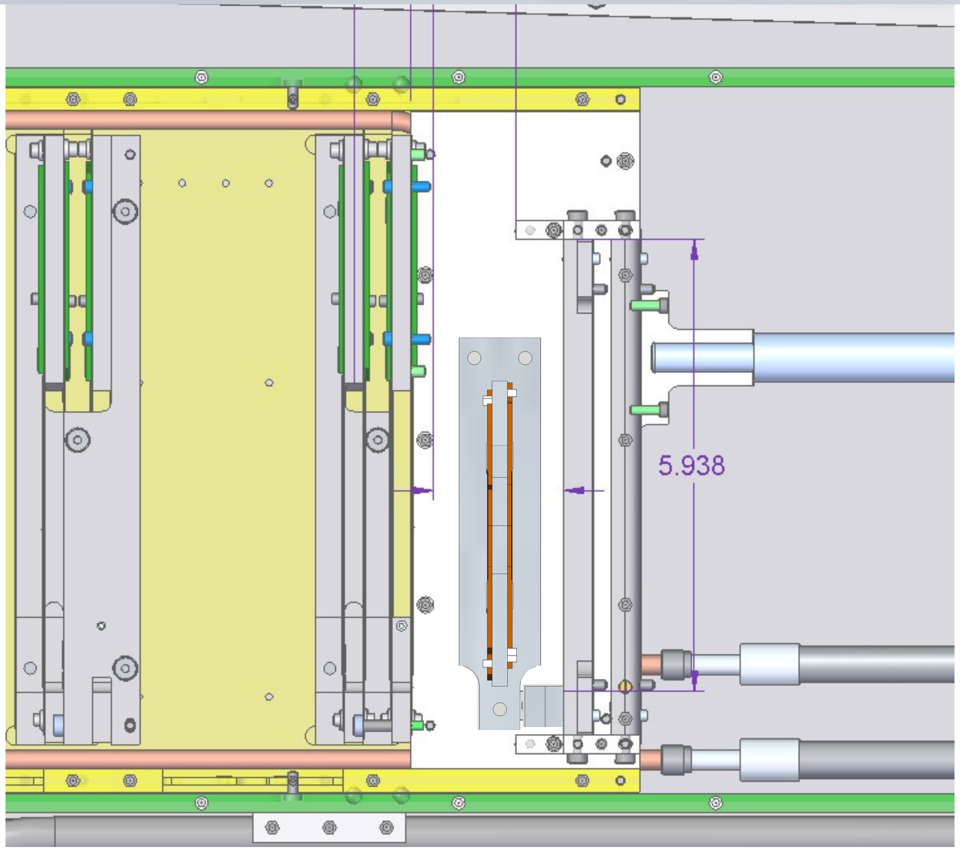
# Layer 0 Mechanical Design

*Key mechanical elements*

- hybrid
- module assembly fixture
- module support
- u-channel lever block
- wireframe stop







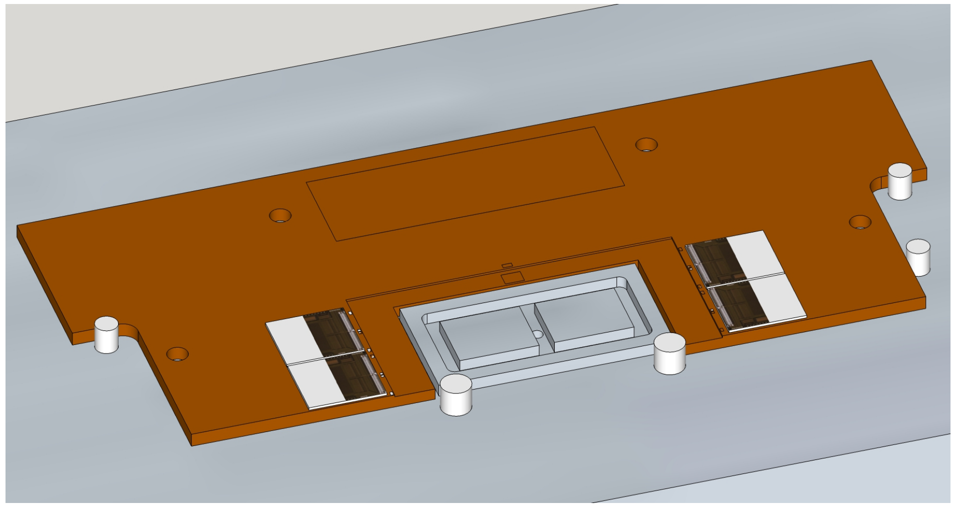
# Layer 0 Hybrid and Fixture Design

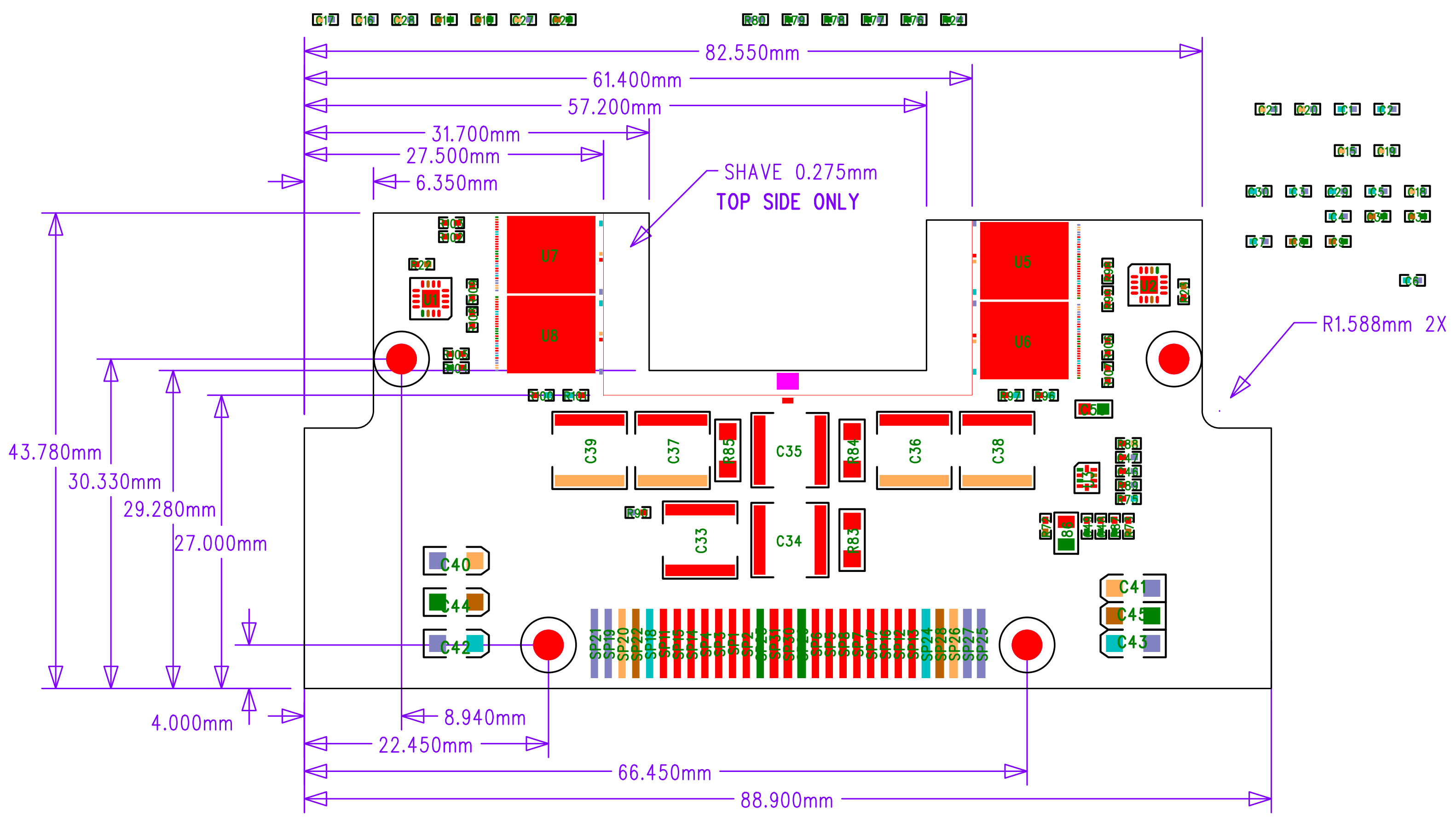
Layout is very different from previous designs, sensor placed in a window along one edge.

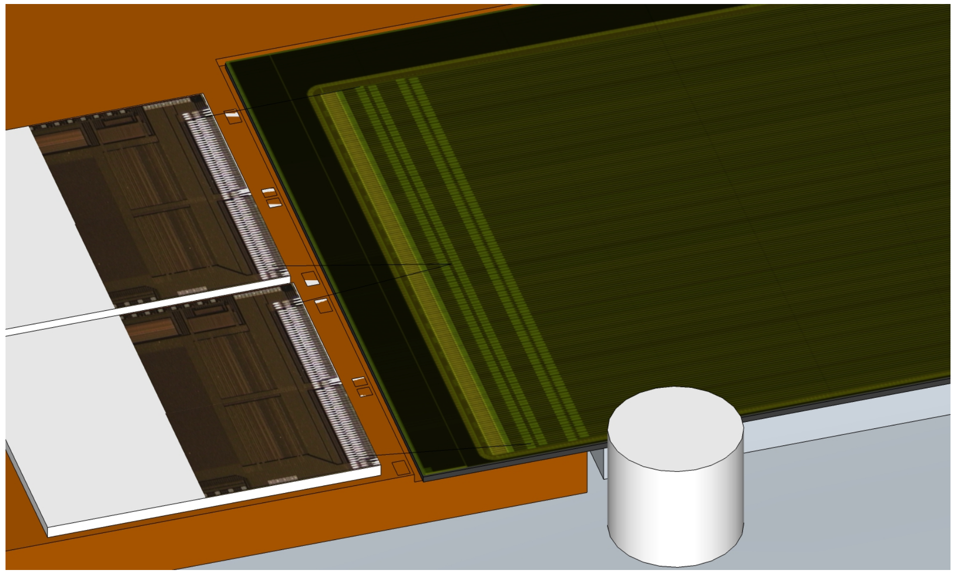
No CF support - heat path to edge of sensor is very short.

Tensioned silicon approach used in rest of SVT not required here due to small dimensions.

*Hybrid is currently in layout. A change in one dimension is required to accommodate connection location.*

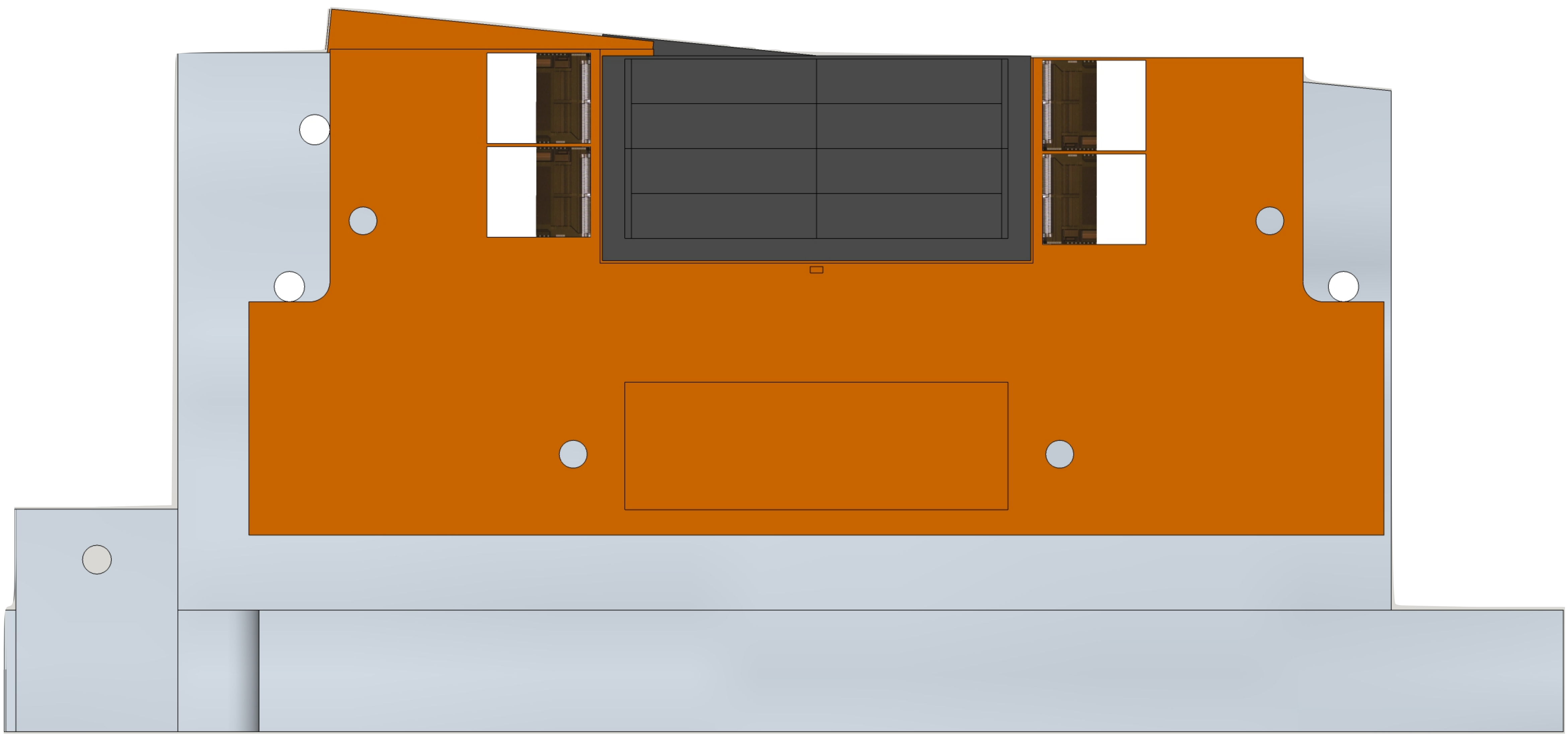




# Layer 0 Module Support

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



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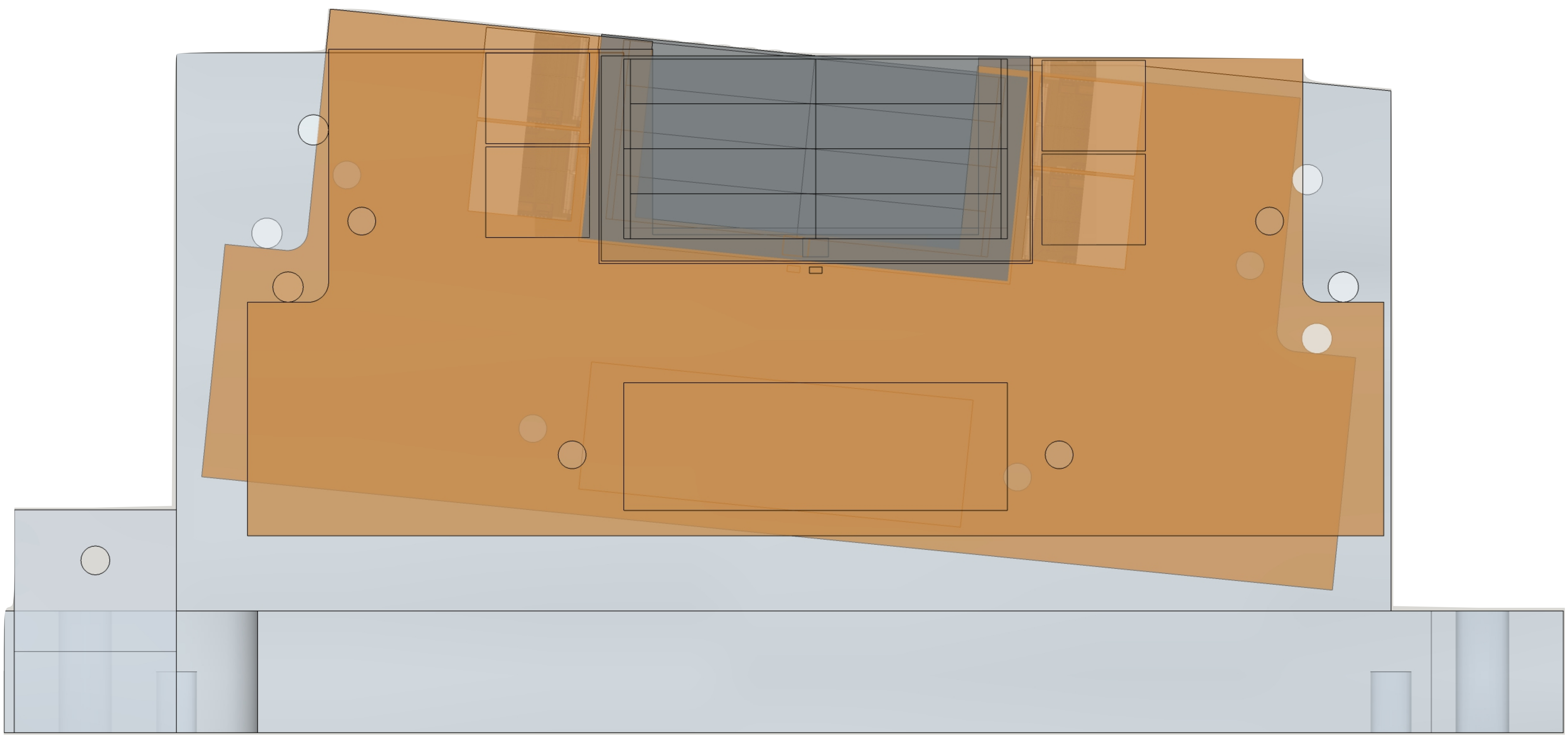
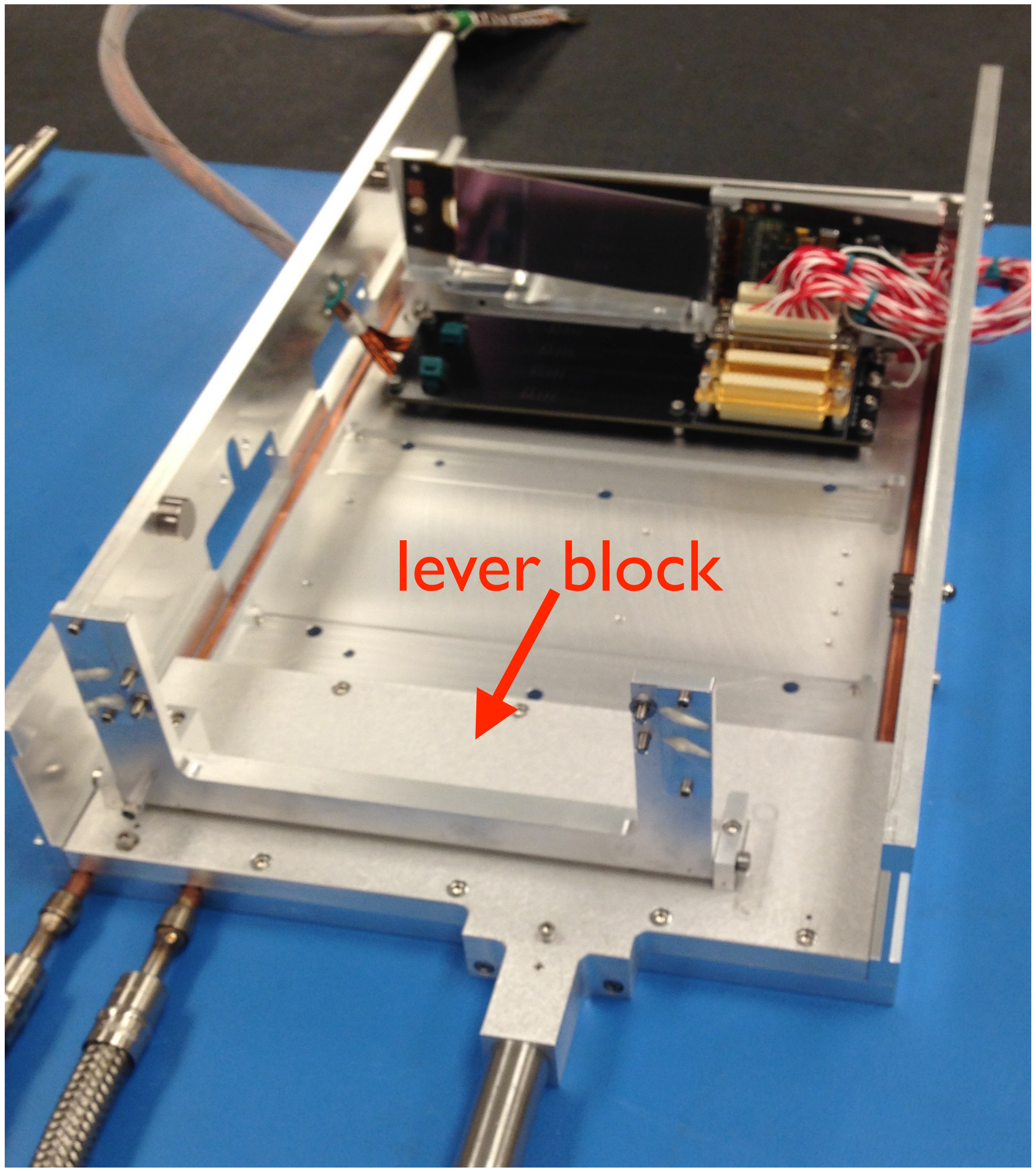
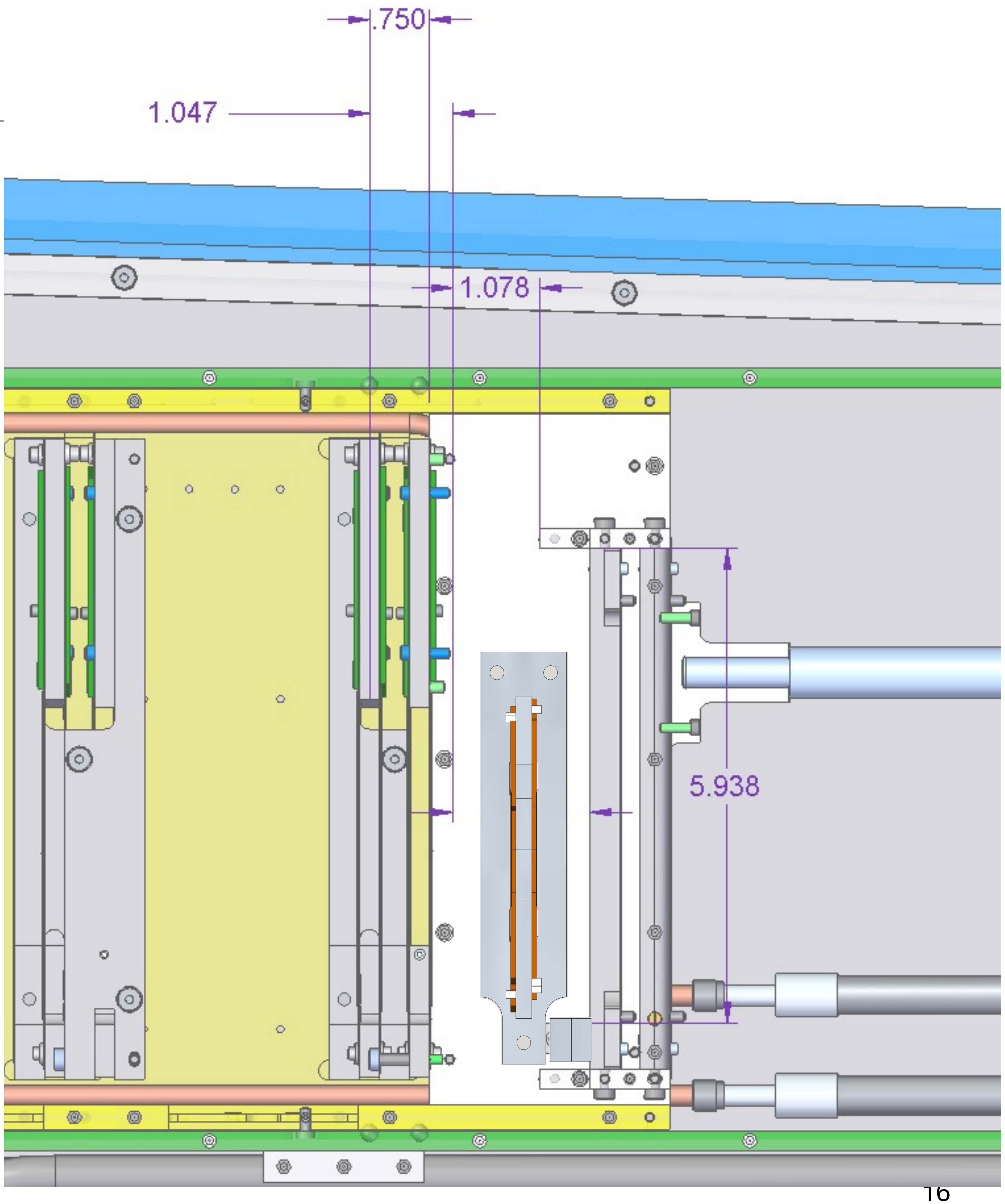


Angular acceptance of cooling block begins at 300 mrad, outside of SVT acceptance and where rate of brems is suppressed by >6 orders of magnitude.

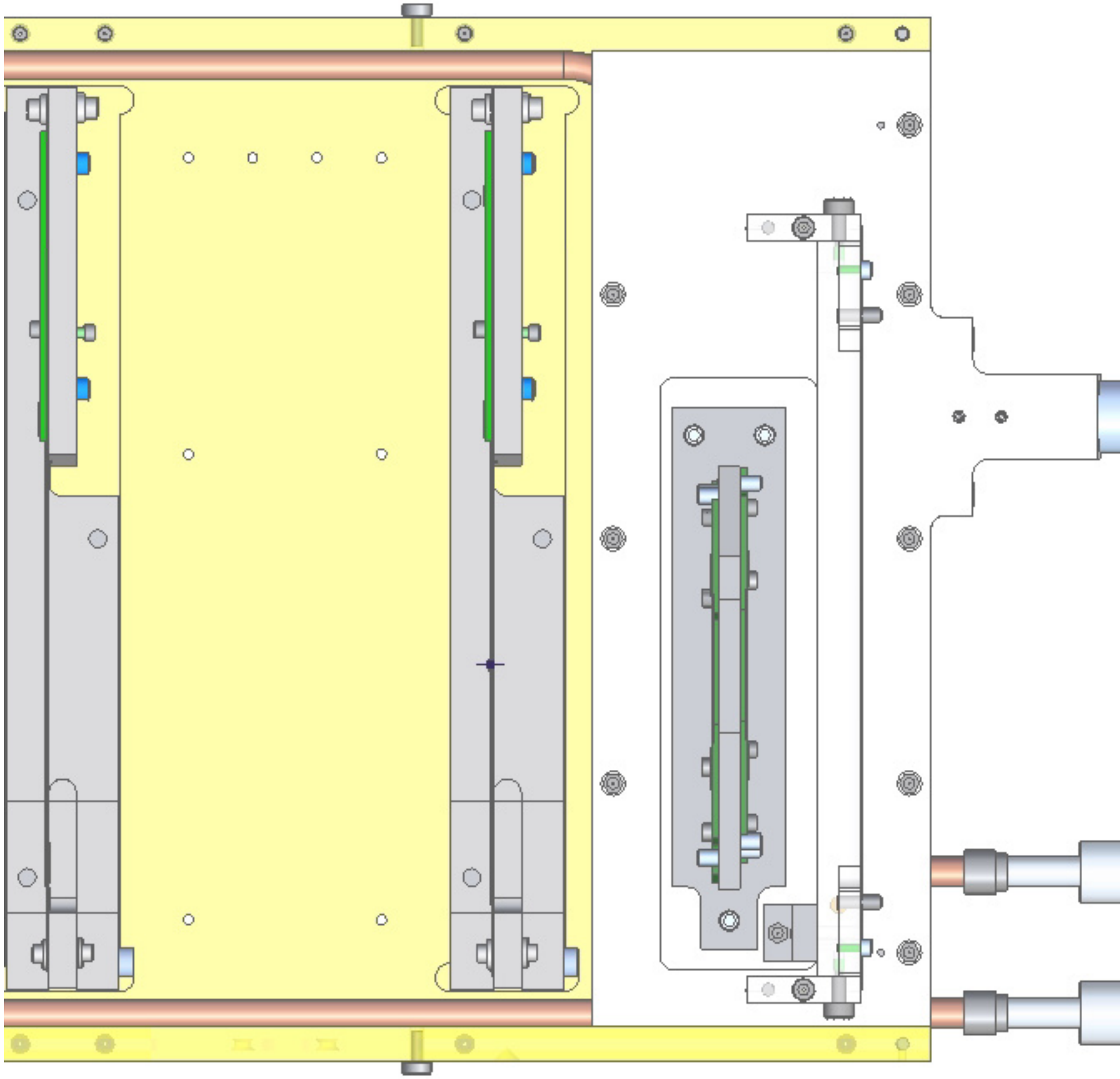
# U-channel Lever Block



# Support Design Status

- All mechanical elements incorporated into SVT model
- Everything fits and appears to be possible to install



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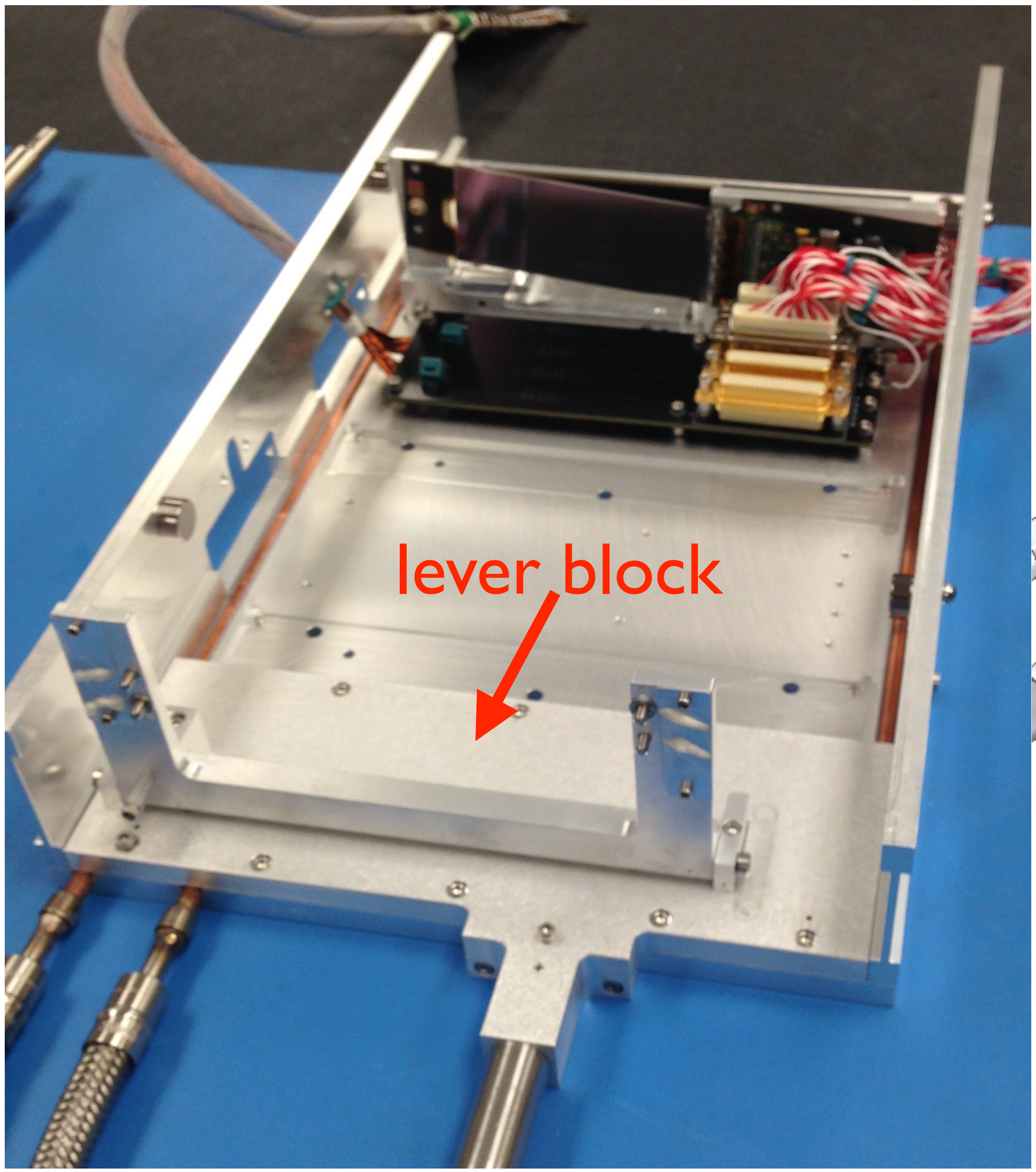


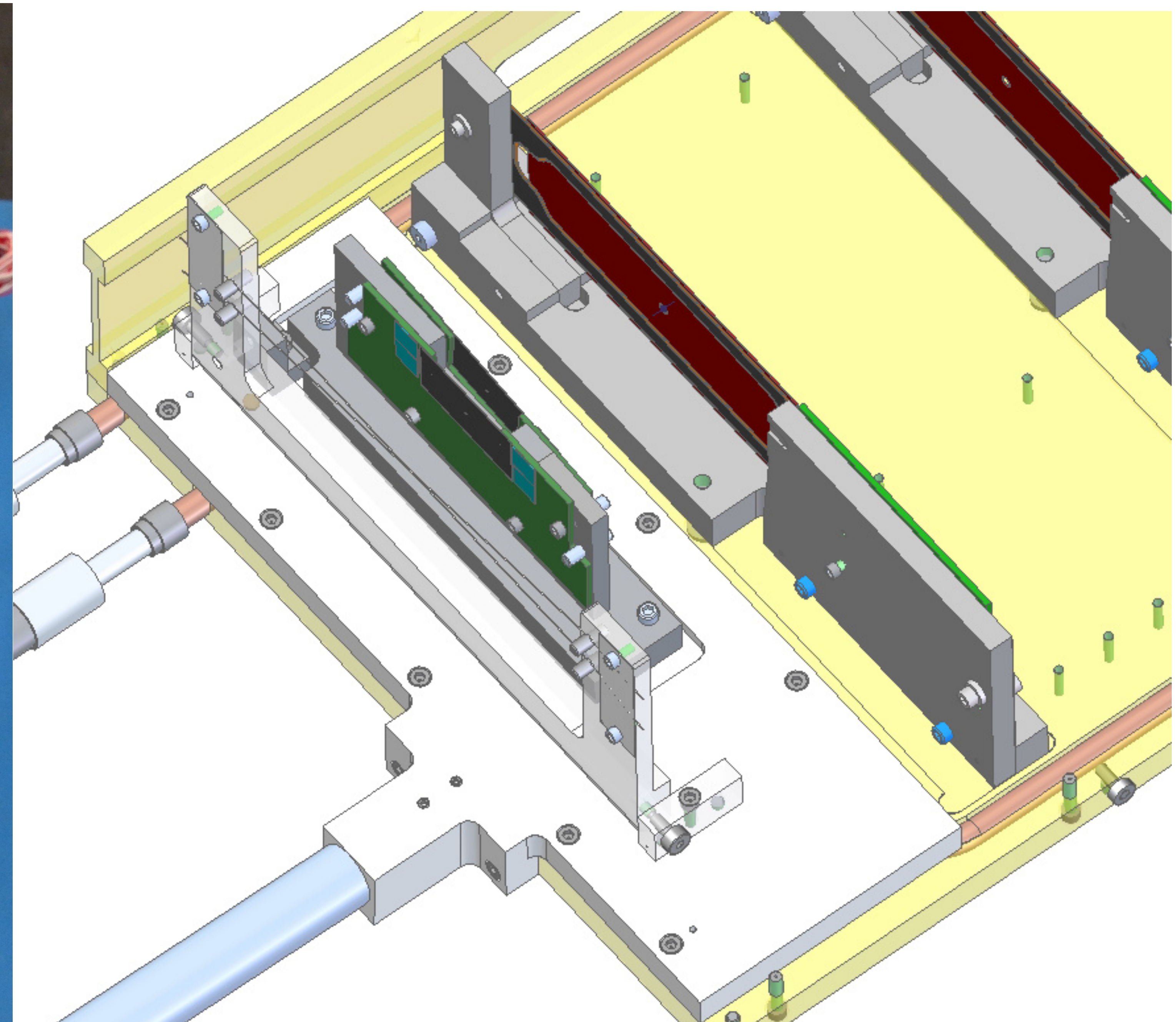

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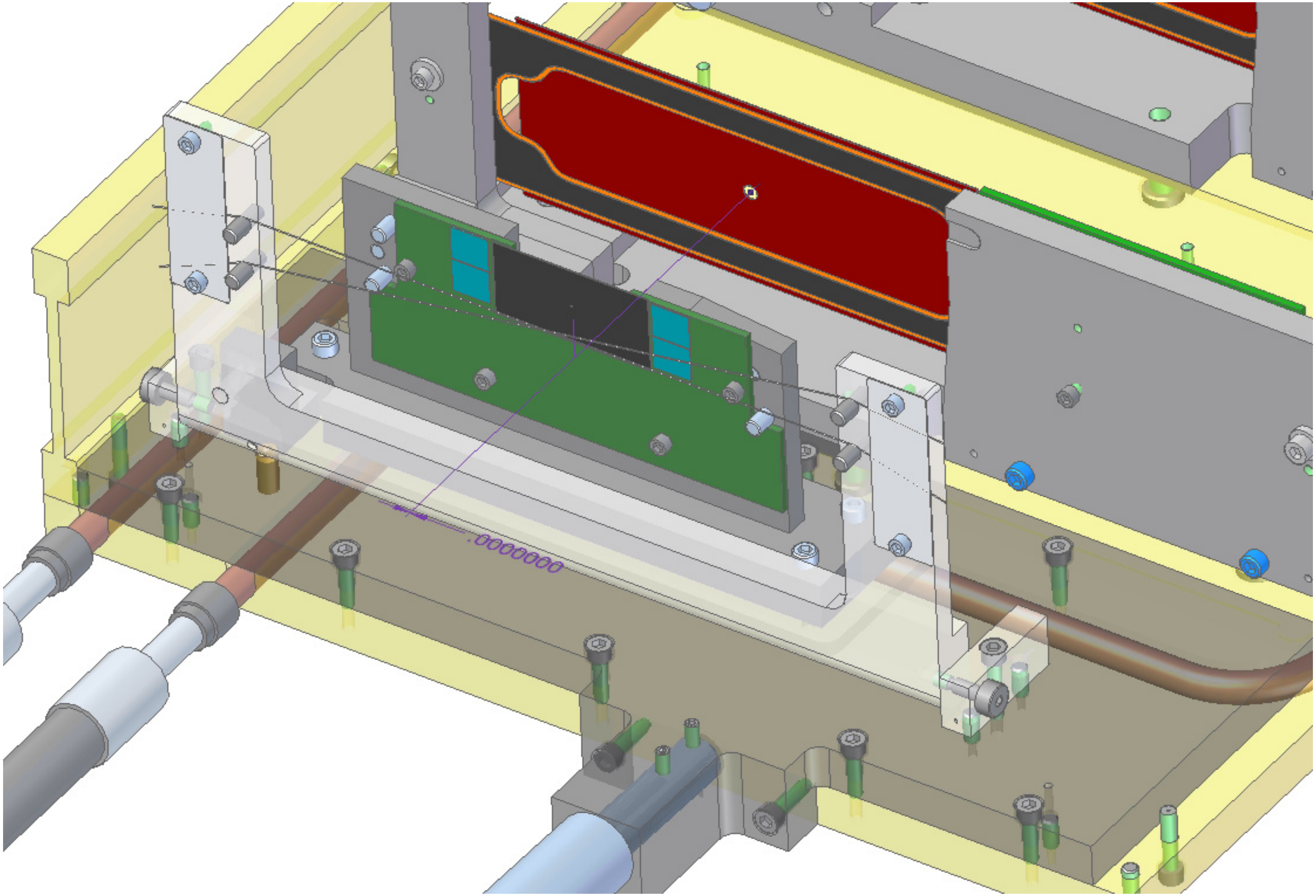
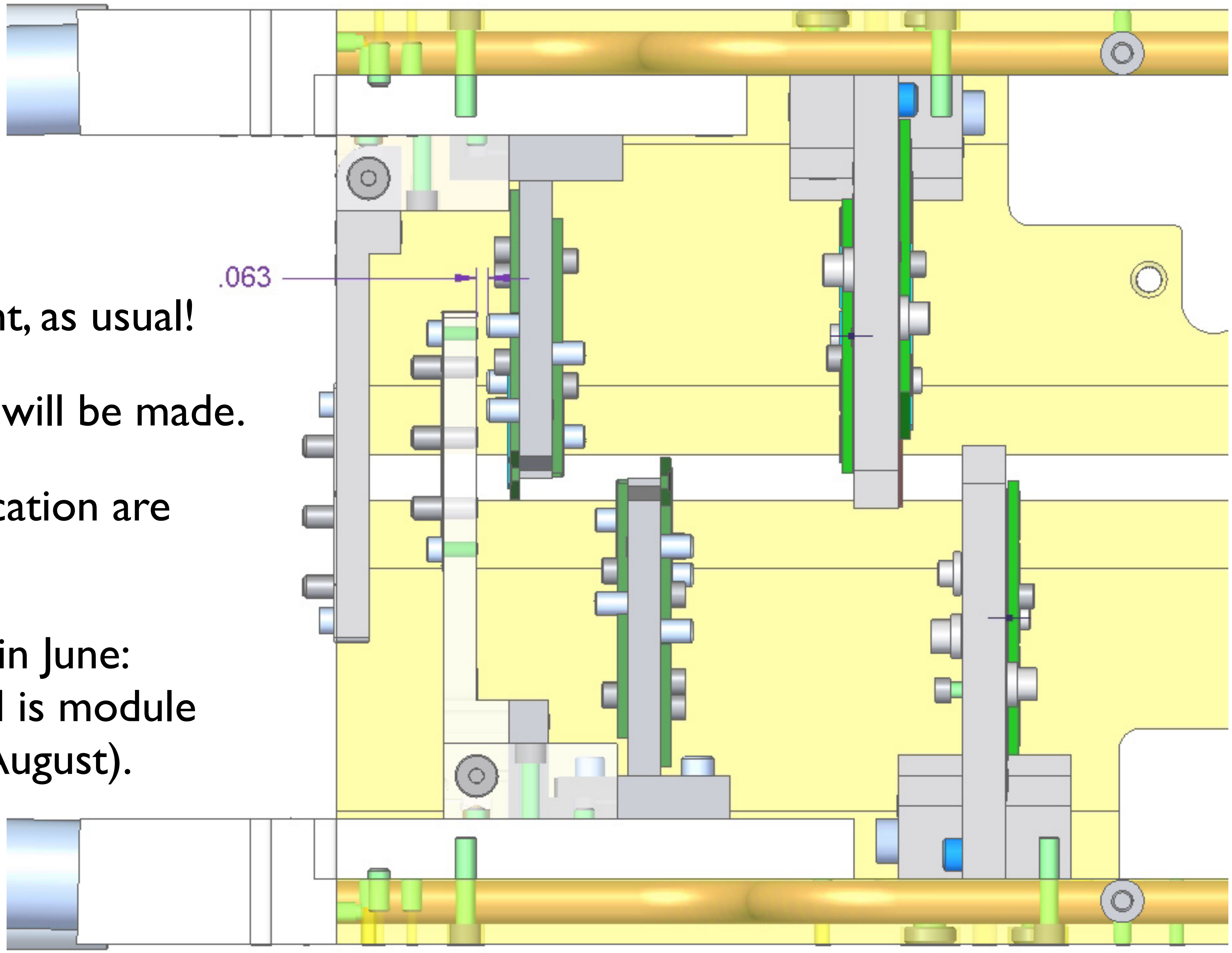


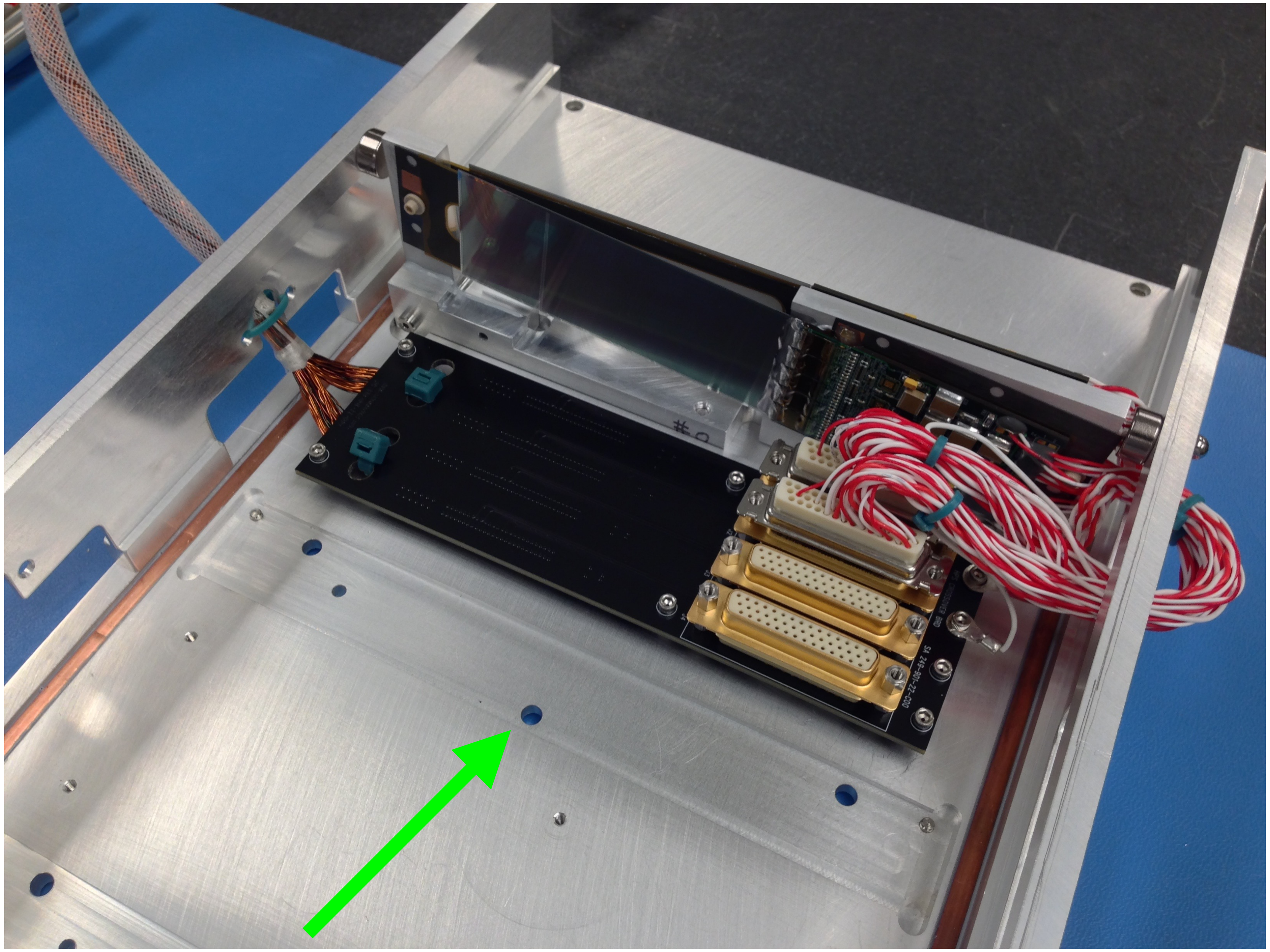
# Support Design Status

- Clearances are tight, as usual!
- Some adjustments will be made.
- Drawings for fabrication are being produced.
- Fabrication begins in June: first piece required is module assembly fixture (August).



# Moving Layers 2 and 3

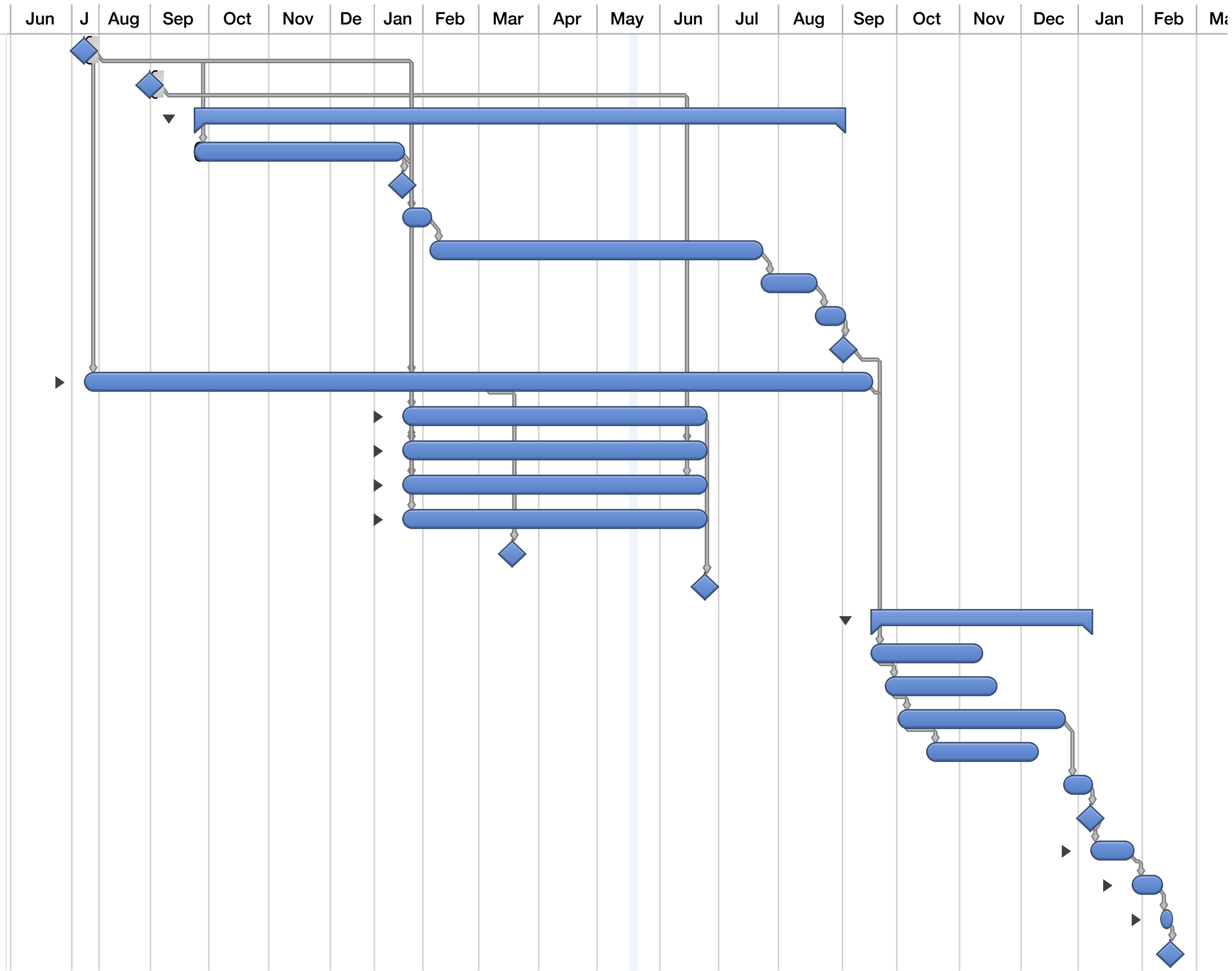
- Modules will be removed from U-channels for addition of Layer 0
- Shims can be added when modules are re-installed
- Requires only machining of standard shim stock of desired thickness with clearance holes
- Shims are thin enough that no changes to module mounting hardware are required
- We can easily decide at a very late date whether, and how much, to move L2 and L3.



# Schedule

Initial schedule last spring had installation before holidays.  Now 2/15/2019.

| Title | End | Duration |
|---|---|---|
| 1) Project Approved | 7/10/17, 8:00 AM | |
| 2) Layers 1-3 @ SLAC | 9/1/17, 6:00 AM | |
| **3) Sensors** | 9/3/18, 2:00 PM | 47w 5h |
| 3.1) Sensor Design | 1/22/18, 2:00 PM | 15w 5h |
| 3.2) Sensor Design Complete | 1/22/18, 2:00 PM | |
| 3.3) Mask Procurement | 2/5/18, 2:00 PM | 2w |
| 3.4) Sensor Fabrication | 7/23/18, 2:00 PM | 24w |
| 3.5) Sensor Processing | 8/20/18, 2:00 PM | 4w |
| 3.6) Sensor Testing | 9/3/18, 2:00 PM | 2w |
| 3.7) Sensors Ready | 9/3/18, 2:00 PM | |
| **4) Hybrids** | 9/17/18, 2:00 PM | 57w 5h |
| **5) Module Supports** | 6/25/18, 2:00 PM | 22w |
| **6) Layer 2-3 Shims** | 6/25/18, 2:00 PM | 22w |
| **7) Lever Blocks** | 6/25/18, 2:00 PM | 22w |
| **8) Assembly Fixtures** | 6/25/18, 2:00 PM | 22w |
| 9) Mechanical Design Complete | 3/19/18, 2:00 PM | |
| 10) Mechanics Complete | 6/25/18, 2:00 PM | |
| **11) Module Assembly** | 1/7/19, 2:00 PM | 16w |
| 11.1) Sensor Attachment | 11/12/18, 2:00 PM | 8w |
| 11.2) Wirebonding | 11/19/18, 2:00 PM | 8w |
| 11.3) Testing | 12/24/18, 2:00 PM | 12w |
| 11.4) Encapsulation | 12/10/18, 2:00 PM | 8w |
| 11.5) Mounting | 1/7/19, 2:00 PM | 2w |
| 11.6) Modules Complete | 1/7/19, 2:00 PM | |
| **12) Final Assembly** | 1/28/19, 2:00 PM | 3w |
| **13) Shipping** | 2/11/19, 2:00 PM | 2w |
| **14) Installation** | 2/15/19, 2:00 PM | 4d |
| 15) Project Complete | 2/15/19, 2:00 PM | |




*Slippage from delays in the sensor order.*

*Time could be made up time in module assembly and testing - budgeted at 4 months here.*

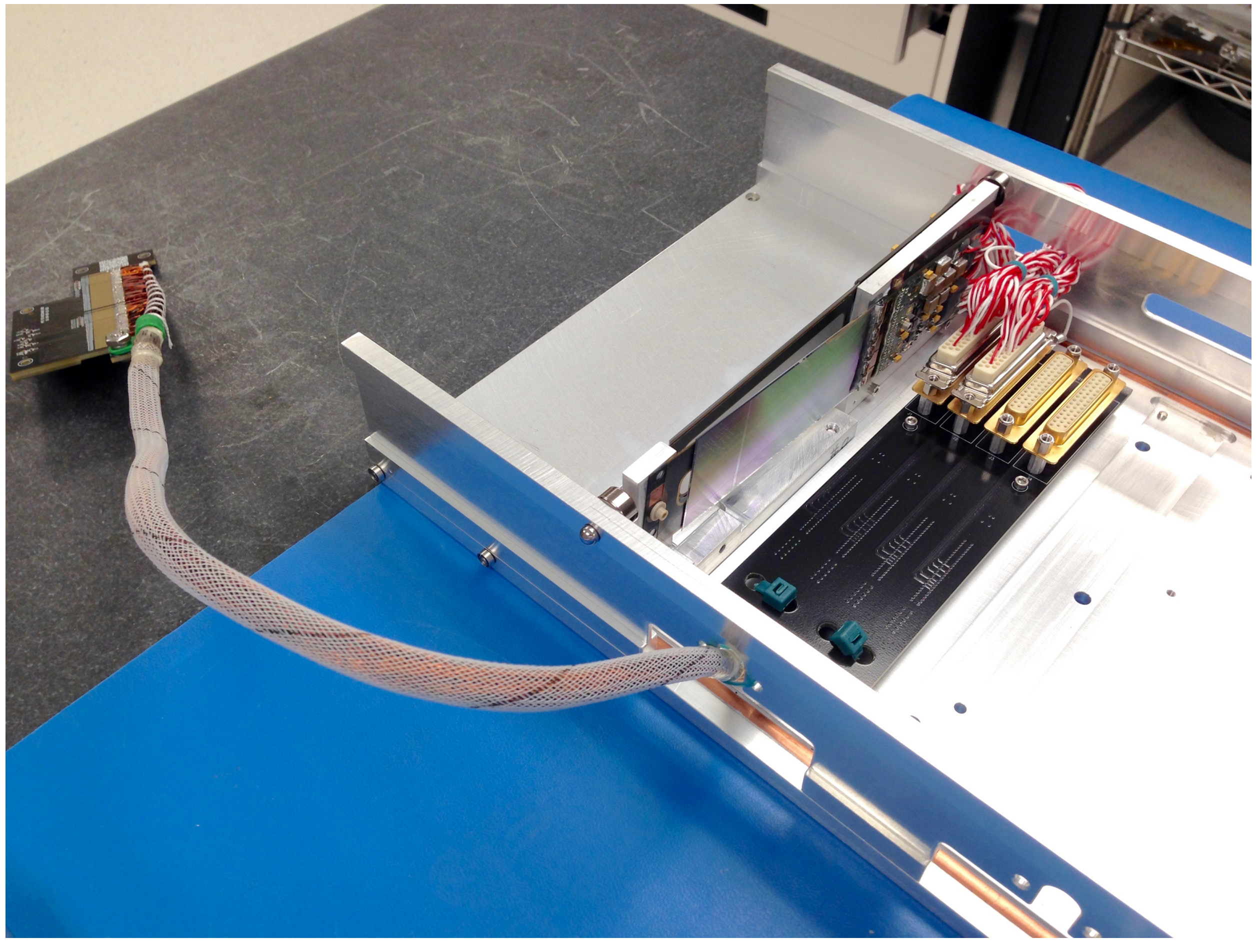
# Layer 0 DAQ

Hybrids will use soldered pigtails terminated in non-magnetic D-sub connectors, as in L1-L3 modules originally built for the HPS Test Run.

Open channels on crossover boards fully serviced by existing DAQ.

Getting pigtails routed to these connectors will be tricky.

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



# Updates to SVT DAQ

## SLAC RCE DAQ, used by SVT, transitioning to a new generation.

- Update FPGA firmware
- Upgrade DAQ software
- Deploy new firmware and software on Test Stand
- Deploy new firmware and software on RCE Crate at JLab

## Some significant improvements

- Adds bootloader to FEB PROM - allows FEB re-flash if primary image is corrupted
- New Python/C++ framework for communicating with FPGAs, Rogue
- New Xilinx PCI-E card makes it possible to plug a FEB directly to PC of test stand, test stand uses same firmware image as full RCE DAQ.
- Can add capability to calibrate/operate without CODA, useful for testing and debugging.

*Once work is done at SLAC, we will deploy and shake down at JLab.*

# Bringing the HPS Detector Back to Life

- The detector, both SVT and ECal, will have been sitting for three years next spring!
- We had some apparent damage in the SVT. We have spares for replacement but it is important to understand what went wrong and time is running out for that work.
- Bringing up physical plant - power, cooling, controls, monitoring - can have issues.
- A bigger concern is the DAQ
  - There will have been many changes to DAQ infrastructure, both SVT and JLab DAQ during that time
  - Some key experts have moved on.
  - We have failed to produce a stable DAQ for the first weeks of previous runs.

*We need to push hard and early to develop better stress tests and operational procedures to make sure we have solid DAQ from the first day of the run!*

# Summary

- SVT upgrade will significantly improve vertexing reach of HPS
- Together with positron-only trigger, reach from future runs will be dramatically improved.
- Project is well-defined in scope, design and resources required.
- Project is underway with good progress on the critical path.

*There is still lots of hard work ahead for the upgrades, but also to prepare for 2019 running!*

# Extra Slides

# Full Simulations of Upgrade Performance

*Prior to the ERR last June, reach was re-estimated with full simulation given lessons learned from analyzing 2015 data.*

*The same techniques were used, in parallel, to estimate reach for both current (AKA "Nominal") and upgraded (AKA "L0") detector configurations.*

# Full Simulations of Upgrade Performance

*Prior to the ERR last June, reach was re-estimated with full simulation given lessons learned from analyzing 2015 data.*

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*Fundamentals*

- occupancies
- acceptance/efficiency
- resolutions (vertex/mass)

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*Fundamentals*

- occupancies
- acceptance/efficiency
- resolutions (vertex/mass)

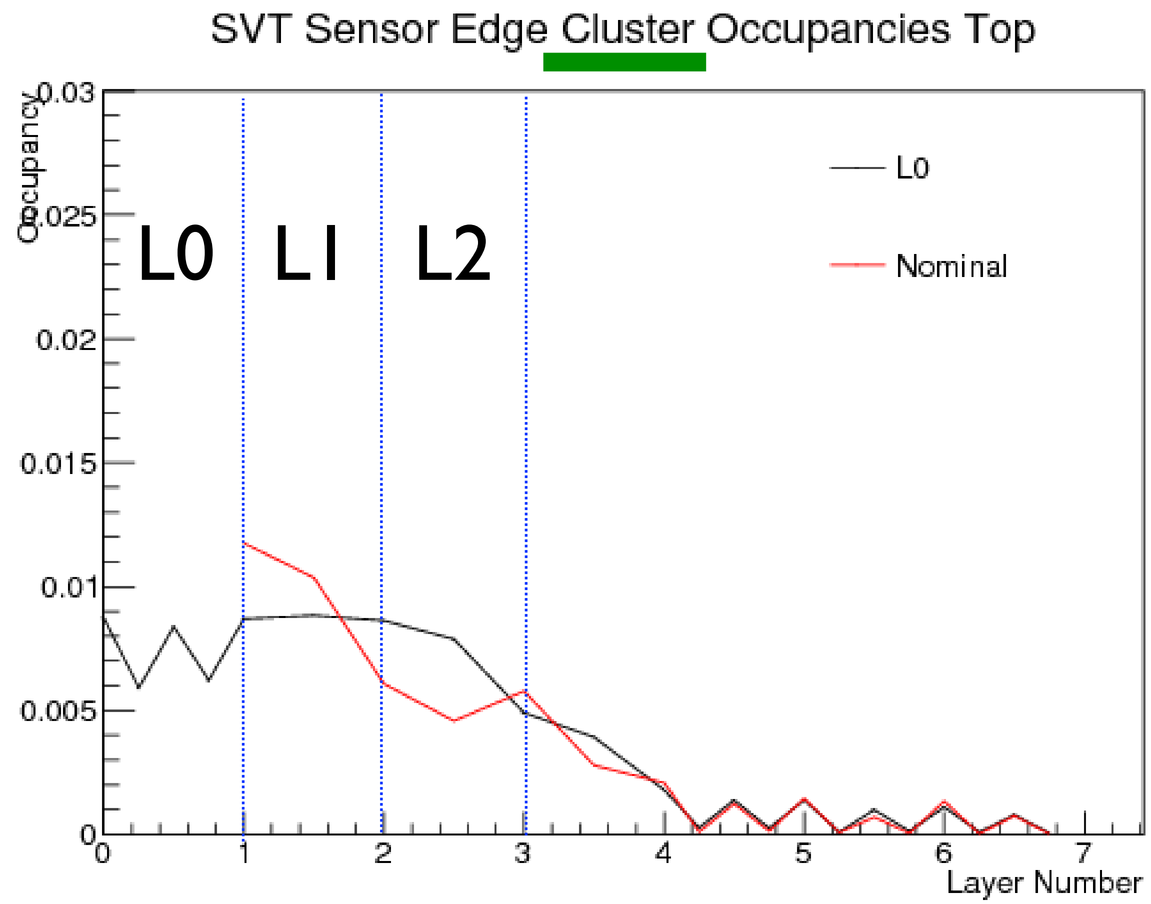
*Reach estimates*

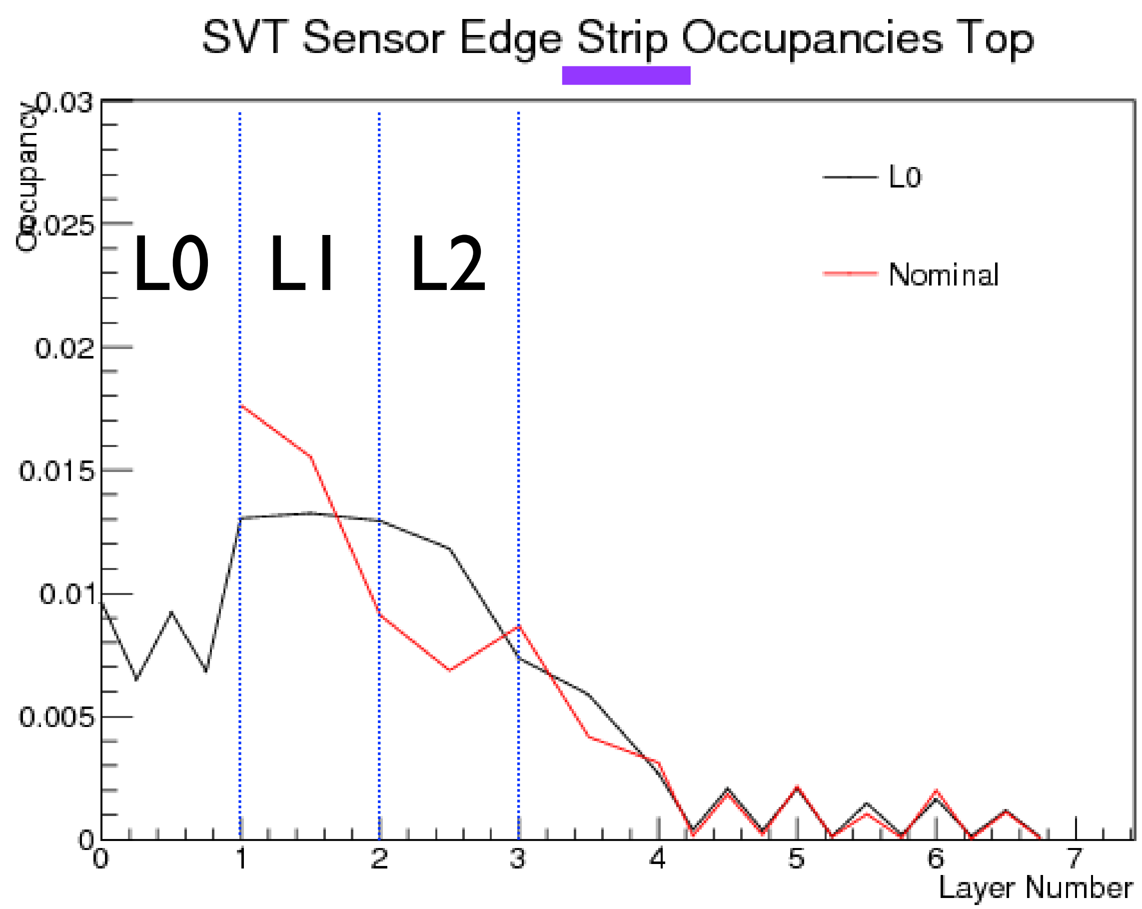
- z cuts required to achieve 0.5 background events
- Reach with/without SVT Upgrade @ 1.1 GeV, 2.2 GeV, 4.4 GeV

# Occupancies

*Nominal (current detector)*

- L1 > L2



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*L0 (upgraded detector)*

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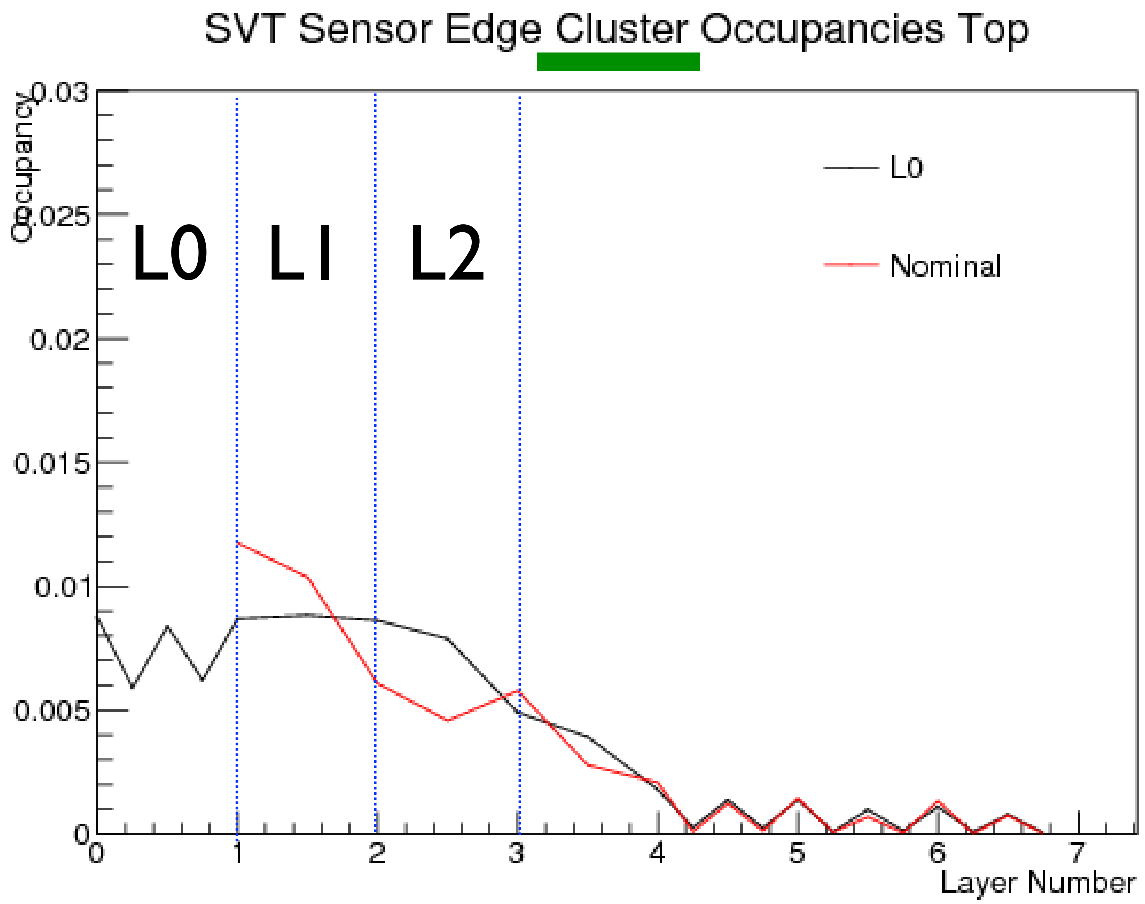


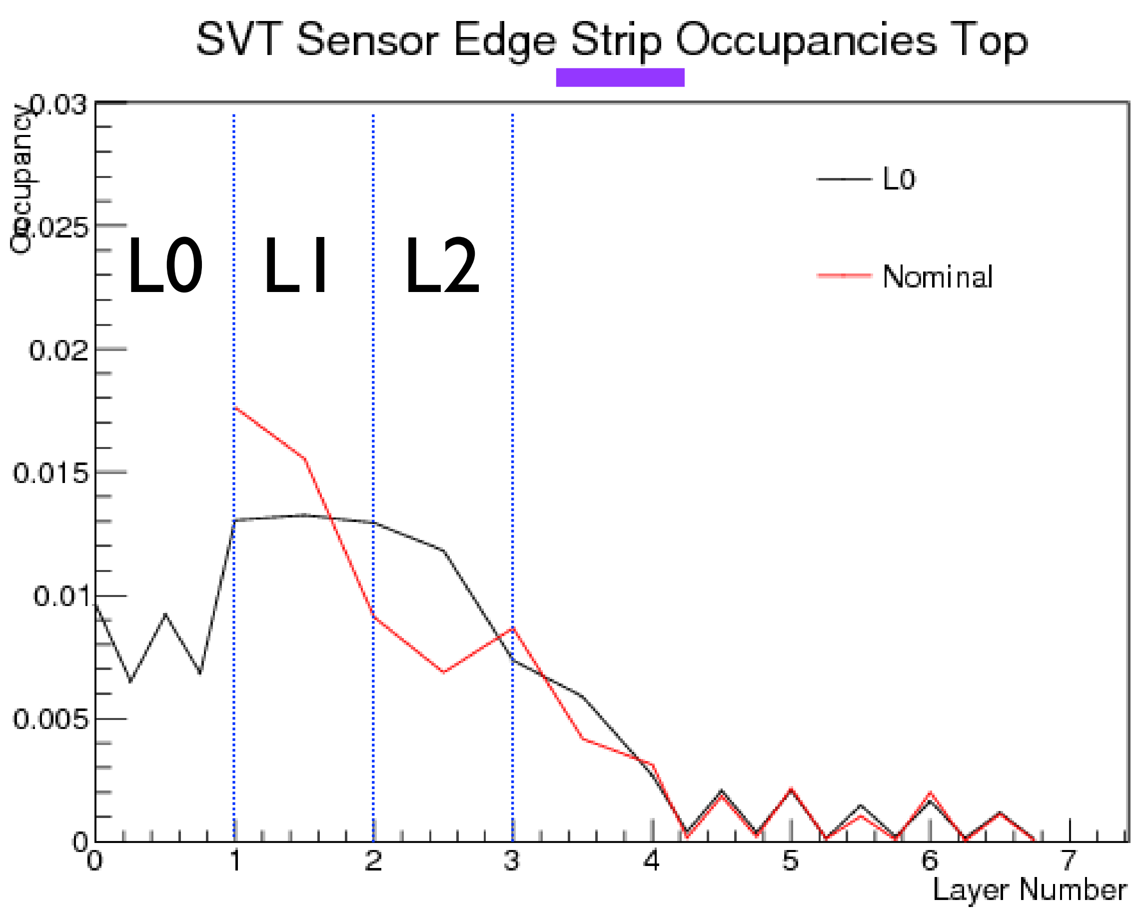

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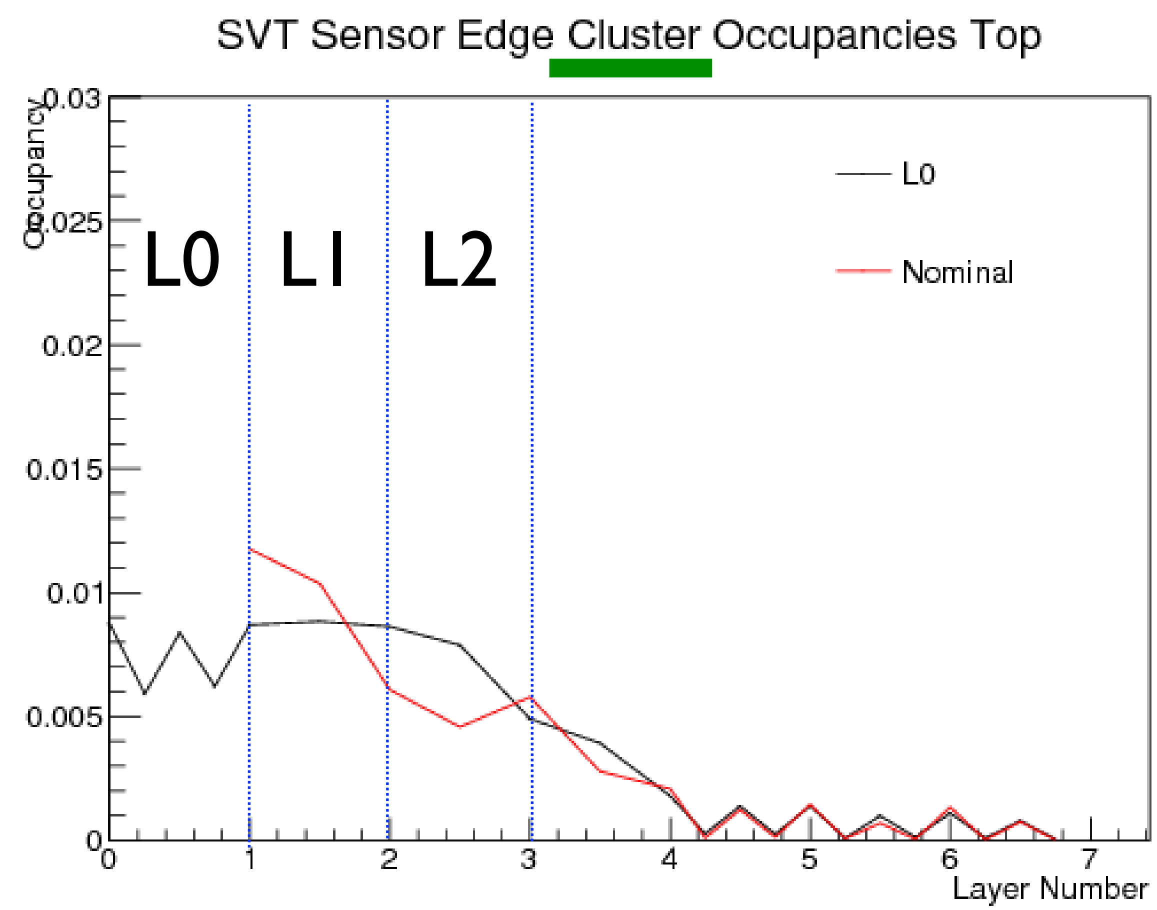
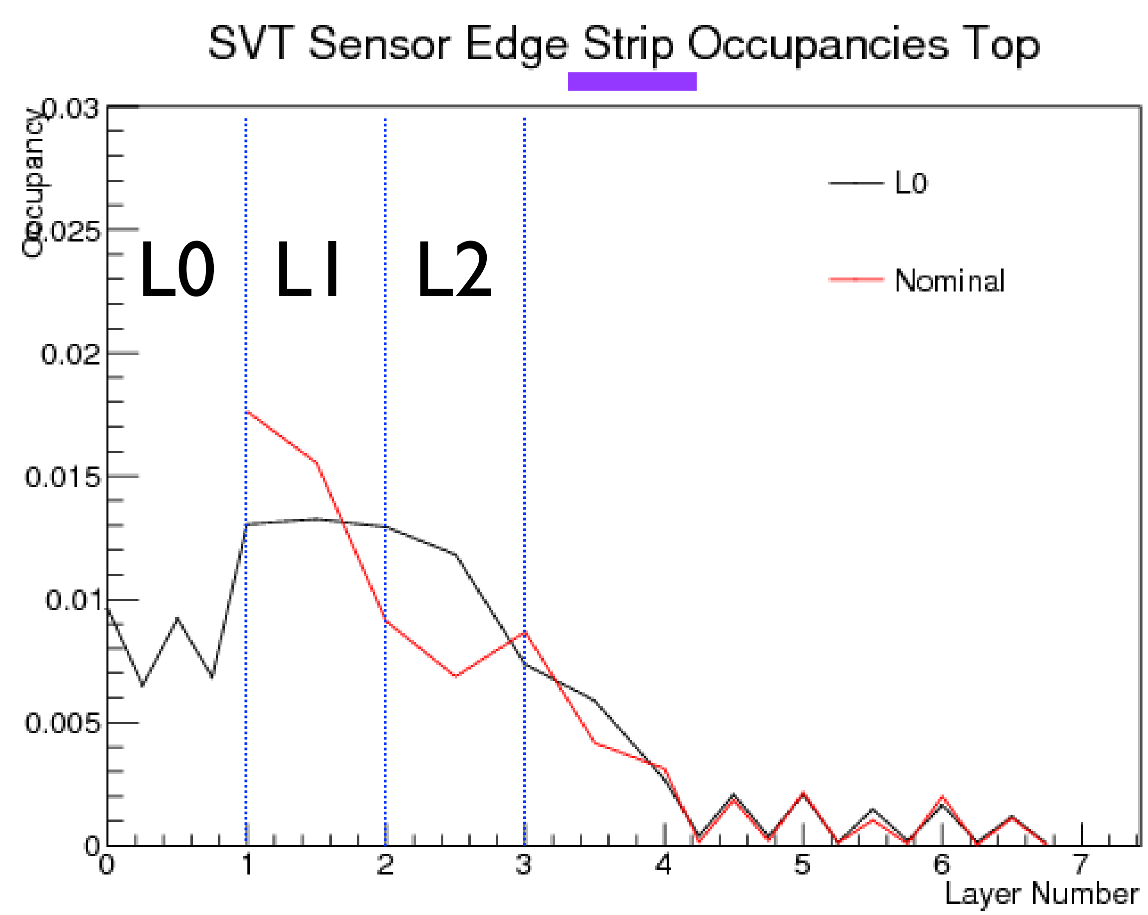


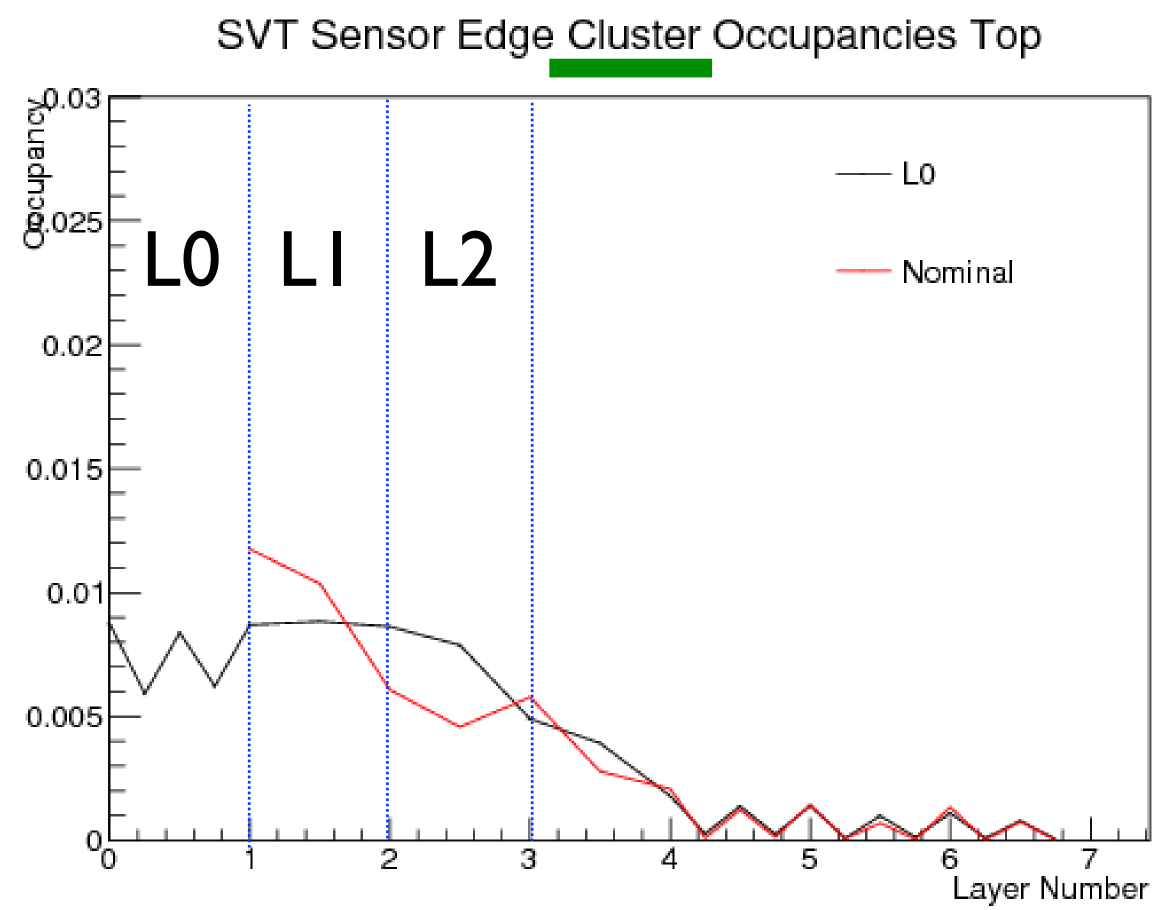
# Occupancies

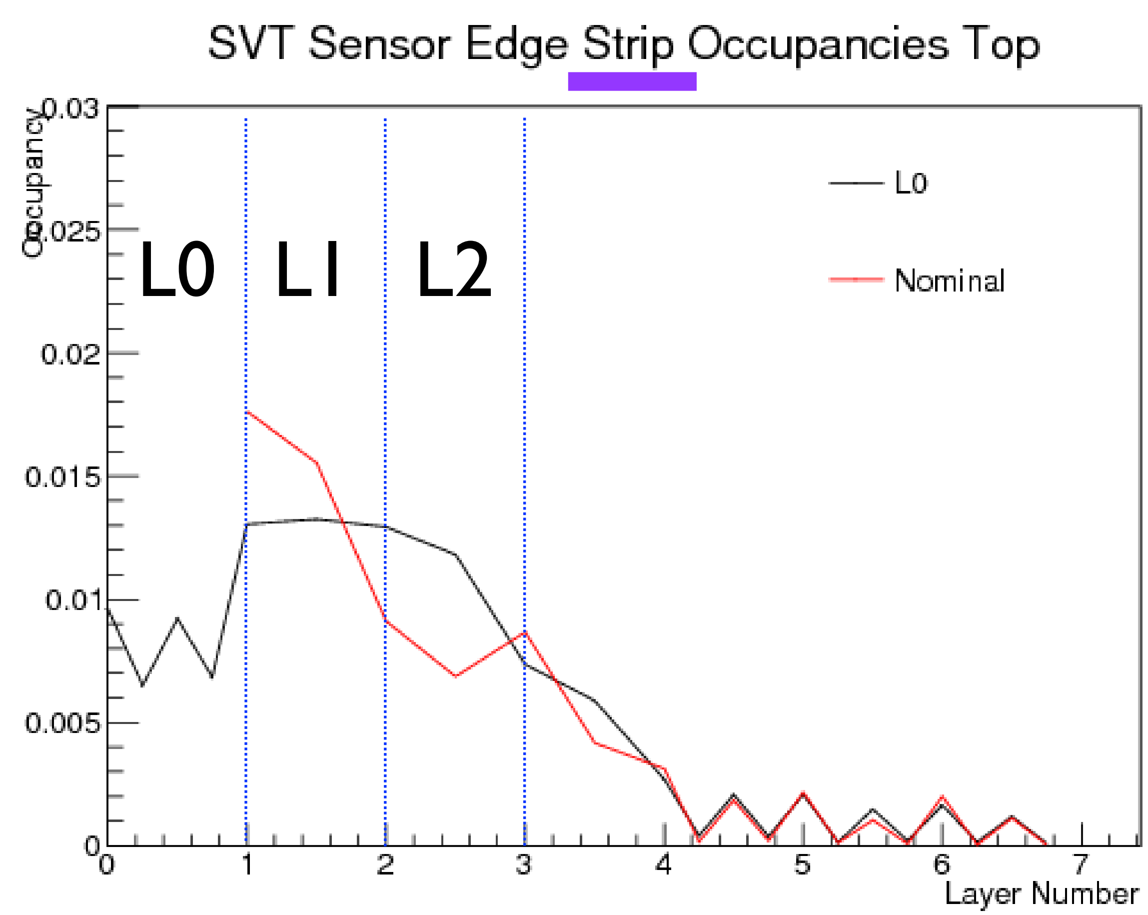
*Nominal (current detector)*

- L1 > L2

*L0 (upgraded detector)*

- L1 ~ L2 (by design)
- Particle occupancy (cluster occupancy) of L0 ~ L1 (by design)
- Strip occupancy of L0 < L1 (by design) because no capacitively-coupled sense strips
    - Mean cluster size in L0 is ~1.1 strips
    - Mean cluster size in L1 is ~1.6 strips



# Manpower and Resources

## *Hybrids, module electronics and DAQ*

- Ben Reese is overseeing hybrid design and layout.
- Vitaliy, Forest, and Mike at UCSC on design, chip loading, wire bonding and testing

## *Labor for mechanics*

- Designer Stephen Boo - Shawn Osier available to consult.
- Matt McCulloch will assist with assembly.

## *Facilities*

- L1-3 U-channels are small enough to do work in Building 84 cleanroom at SLAC.

# Budget

New Sensor: $43K

- Labor
    - Processing: $5K
- M&S: : $38K

New Hybrid: $74K

- Labor
    - Design: $29K
    - Assembly: $19K
    - Testing: $17K
- M&S: : $10K

New Modules: $86K

- Labor
    - Design: $33K
    - Assembly: $34K
    - Testing: $8K
- M&S: $10K

Modifications to mechanical support (includes L2 and L3 Move): $72K

- Labor
    - Design: $33K
    - Assembly: $20K
    - Testing: $8K
- M&S: $10K

Shipping and Installation: $10K

GRAND TOTAL: $284K

| | 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** |

# 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.

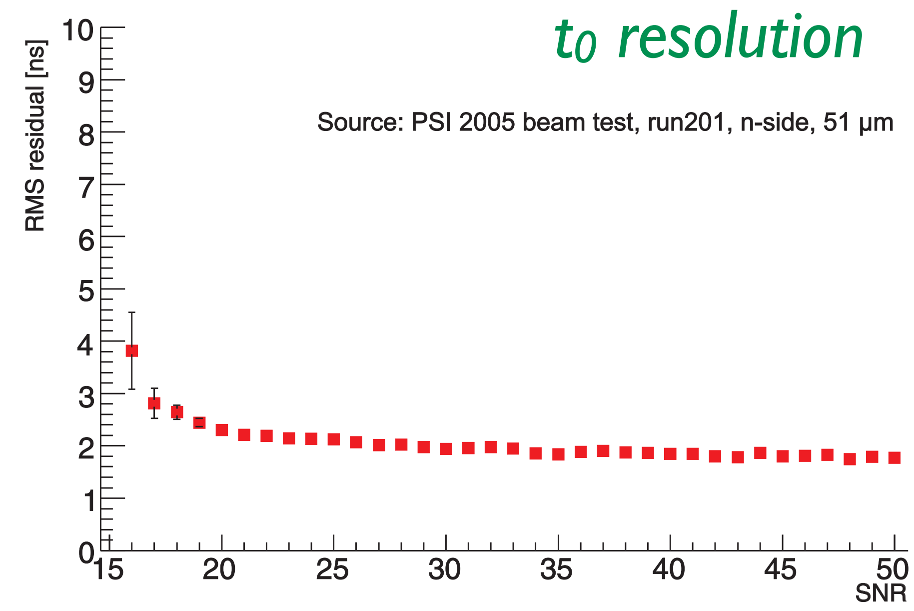
One item that we will want to give attention to measuring beam halo with some ideas of how to identify the source and mitigate if larger than expected: not unique to Layer 0… Layer 1 has similar susceptibility.

# Reduced Signal Primarily Impacts $t_0$ 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



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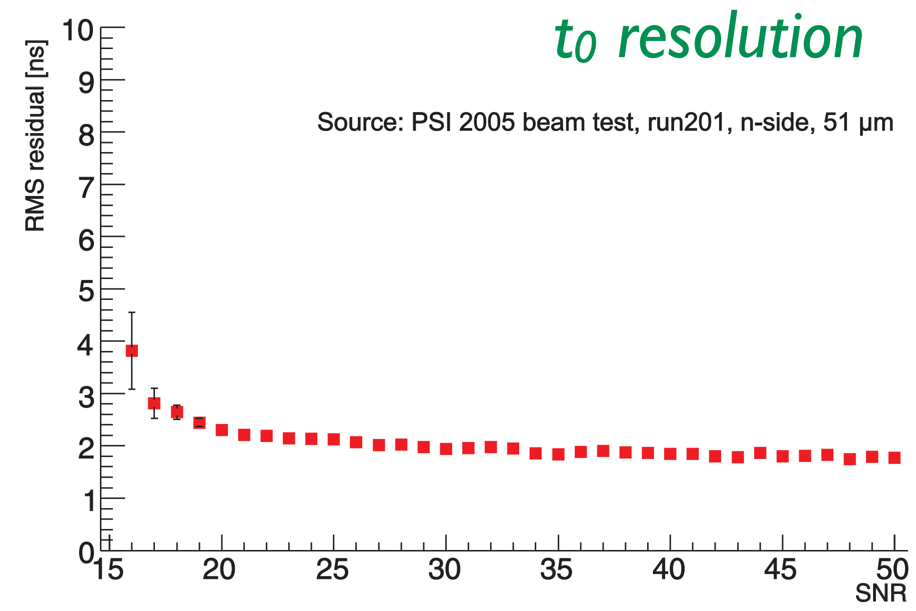


*Noise characteristics of our sensors w/ APV25:*

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

- currently C=12pf ⇒ ENC = 950 (C ≃1.2 pf/cm)
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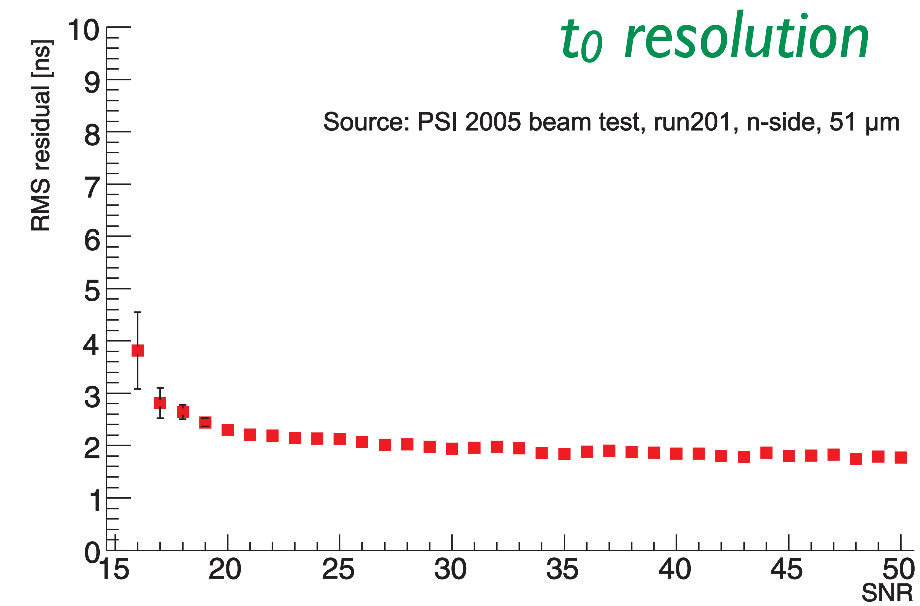
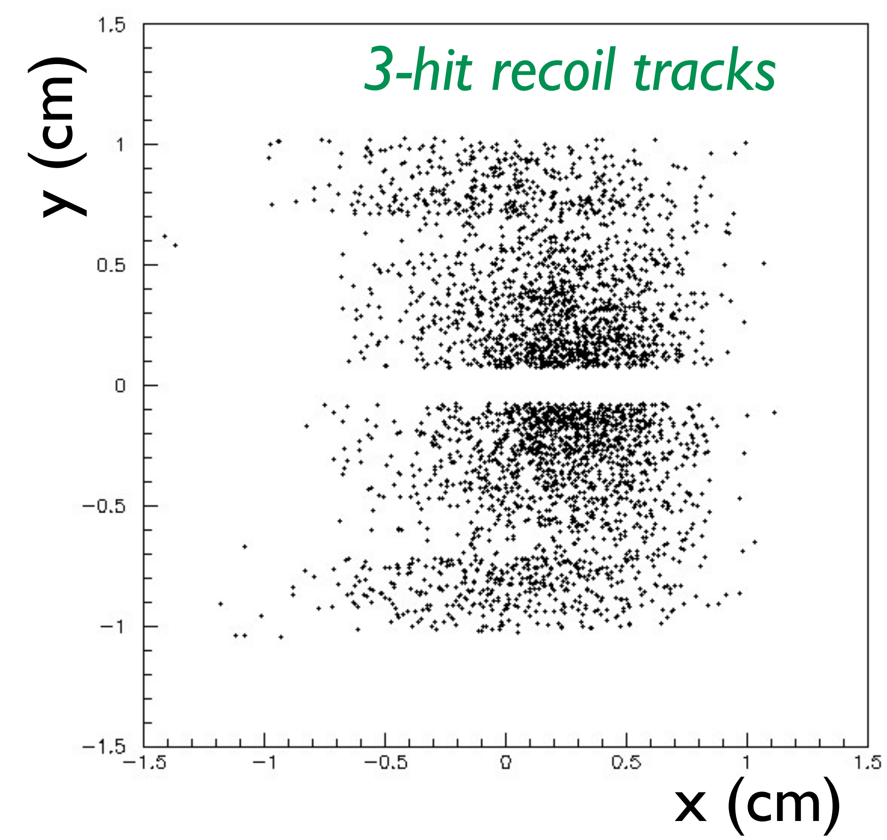
*Full acceptance for A′ daughters allows very short strips. Conservatively assume we want largest acceptance we could imagine for any purpose: 3-hit tracks from recoils.*

⇒ *Requires silicon only ~2 cm long: OK*




Layer 0 at Z = 5 cm

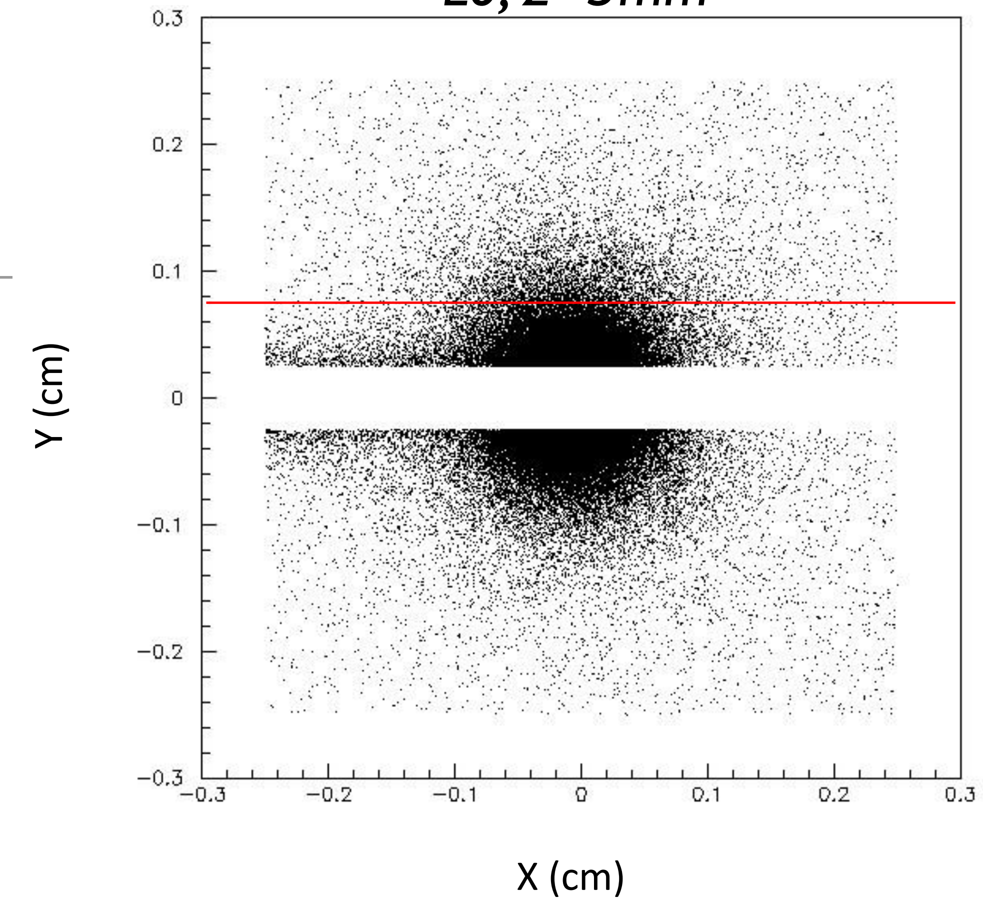


# Physics Backgrounds/Radiation

*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!*

L0, z=5mm



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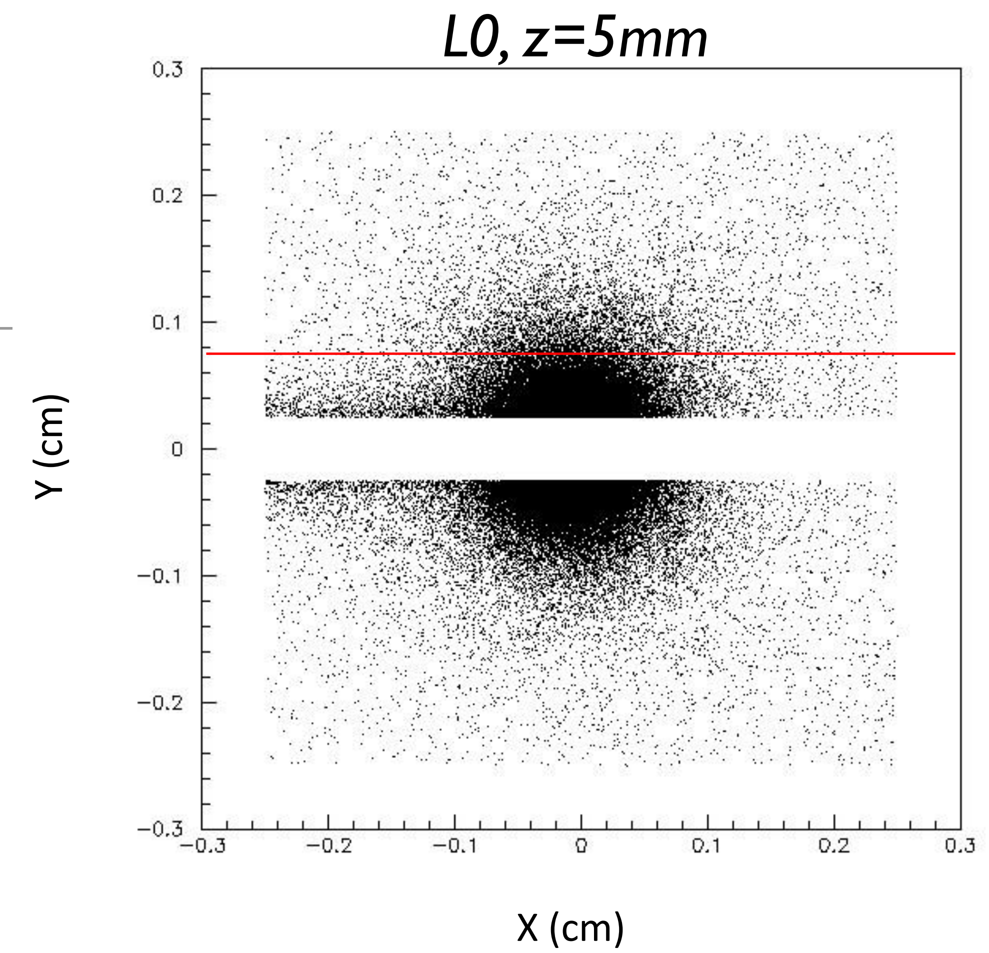
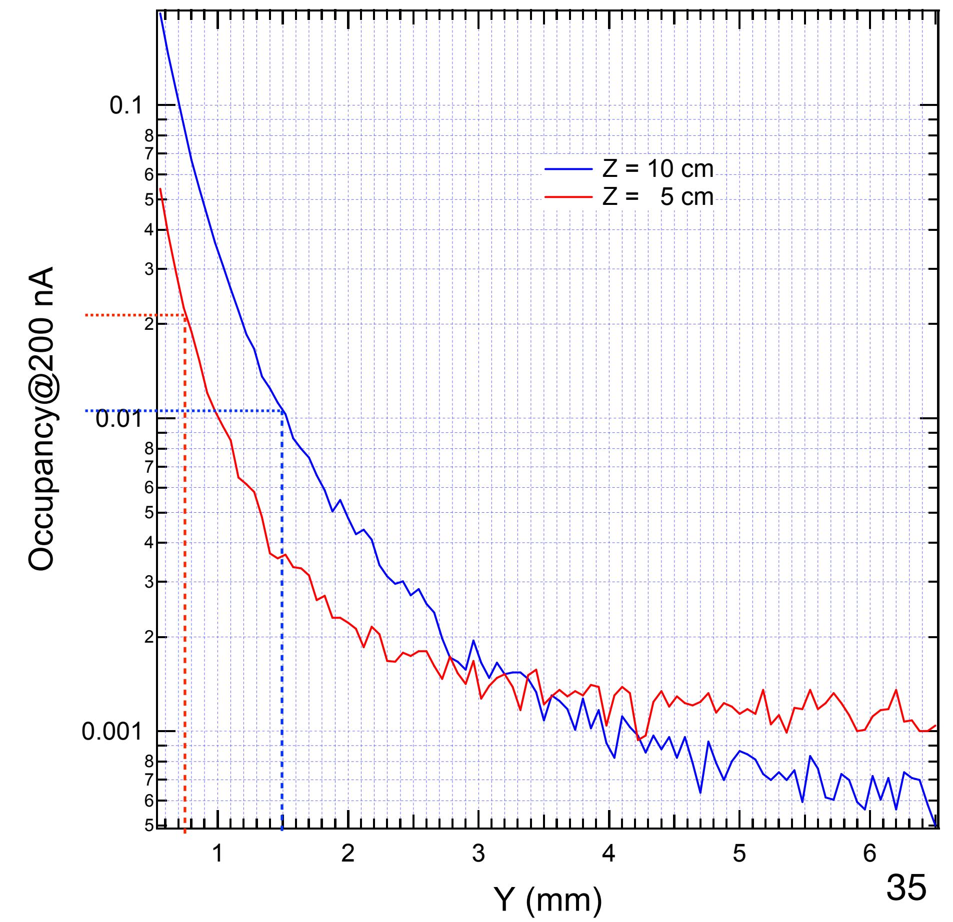
- Fast MC finds background occupancy in first strip for Layer 0 is ~2× current Layer 1 occupancy (~1%).

*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.*



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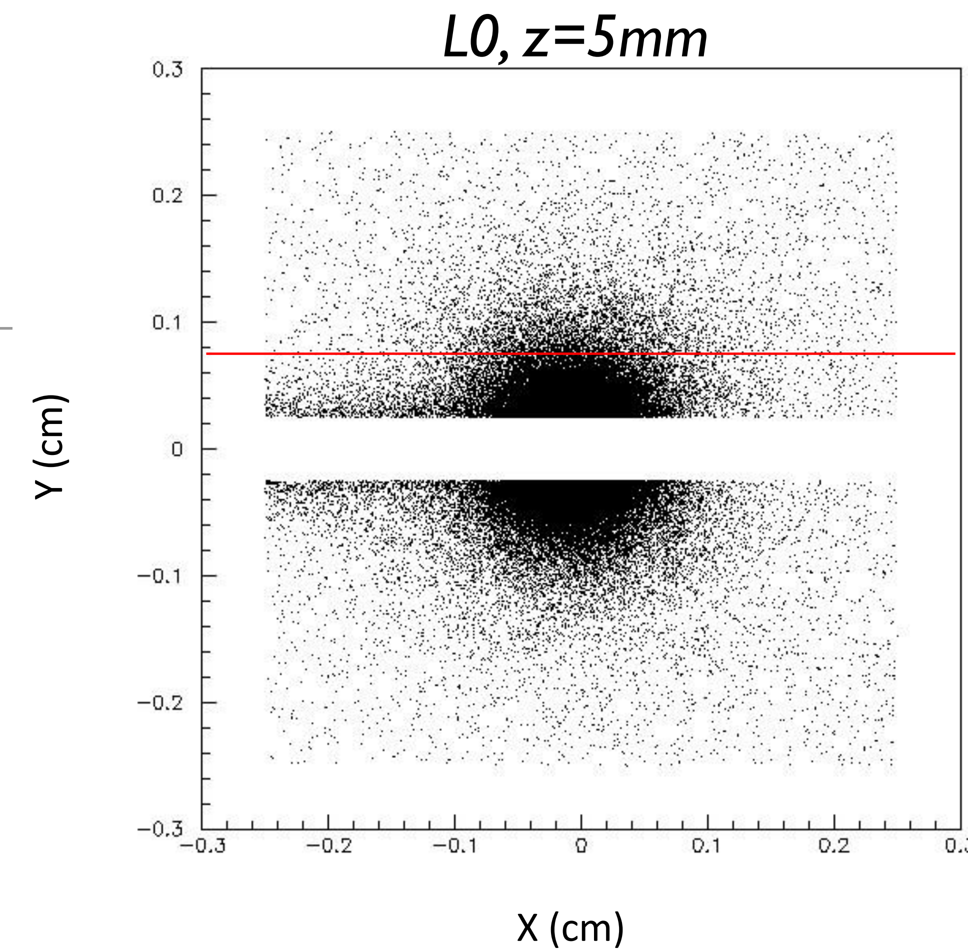
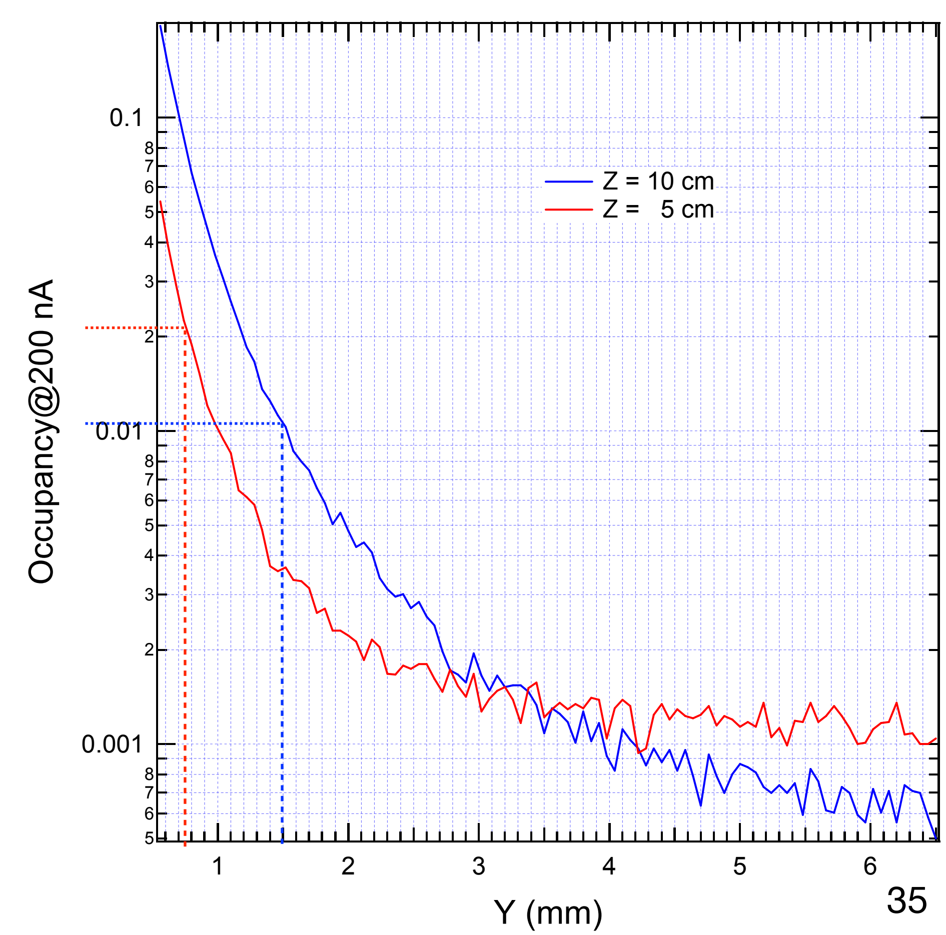
  *For extra headroom on strip occupancy, eliminate capacitively-coupled sense strip present in other layers. (resolution is limited by multiple scattering anyway).*

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

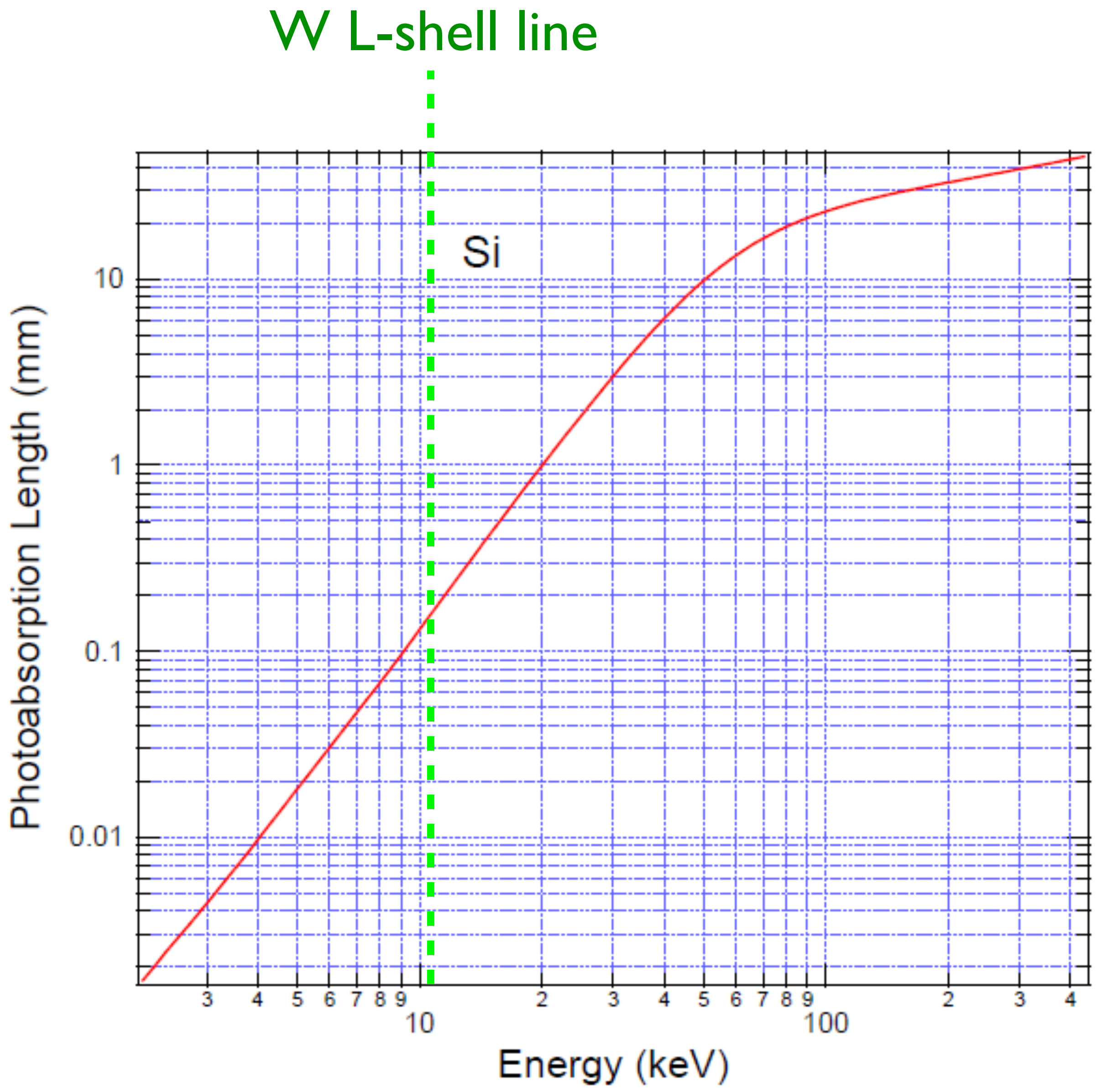
  *Layer 0 can be easily replaced between runs.*



# X-rays

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



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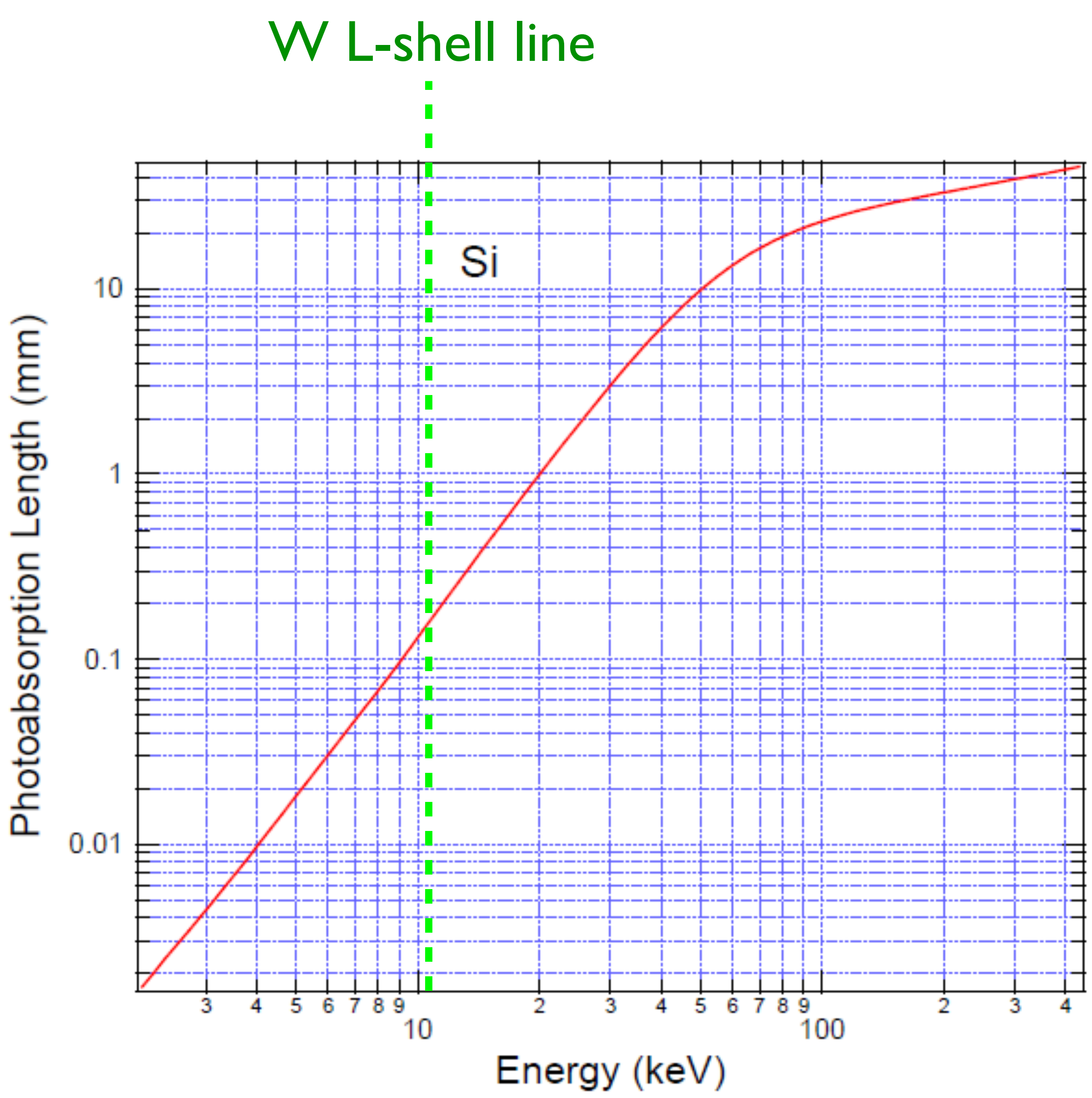

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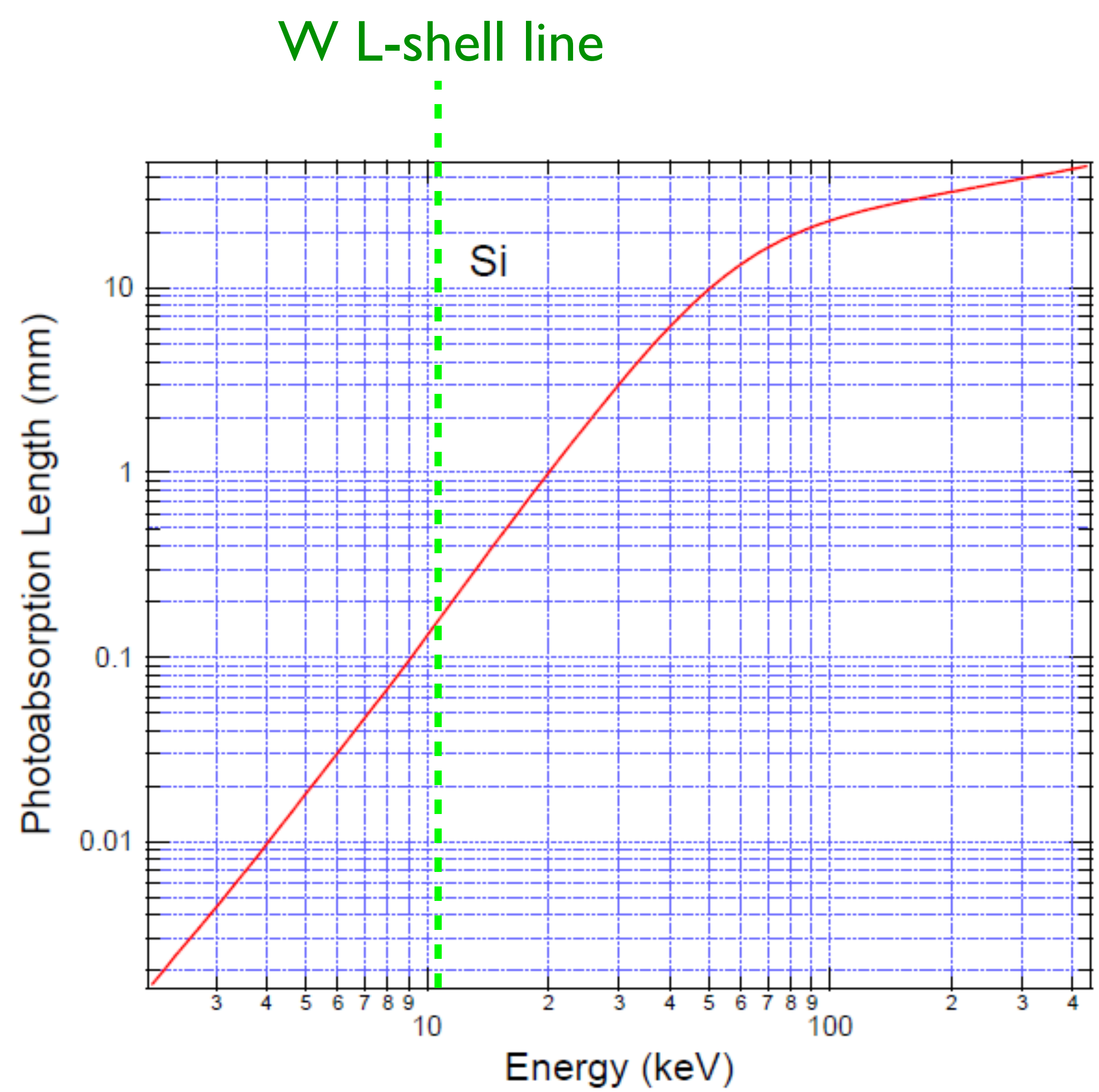
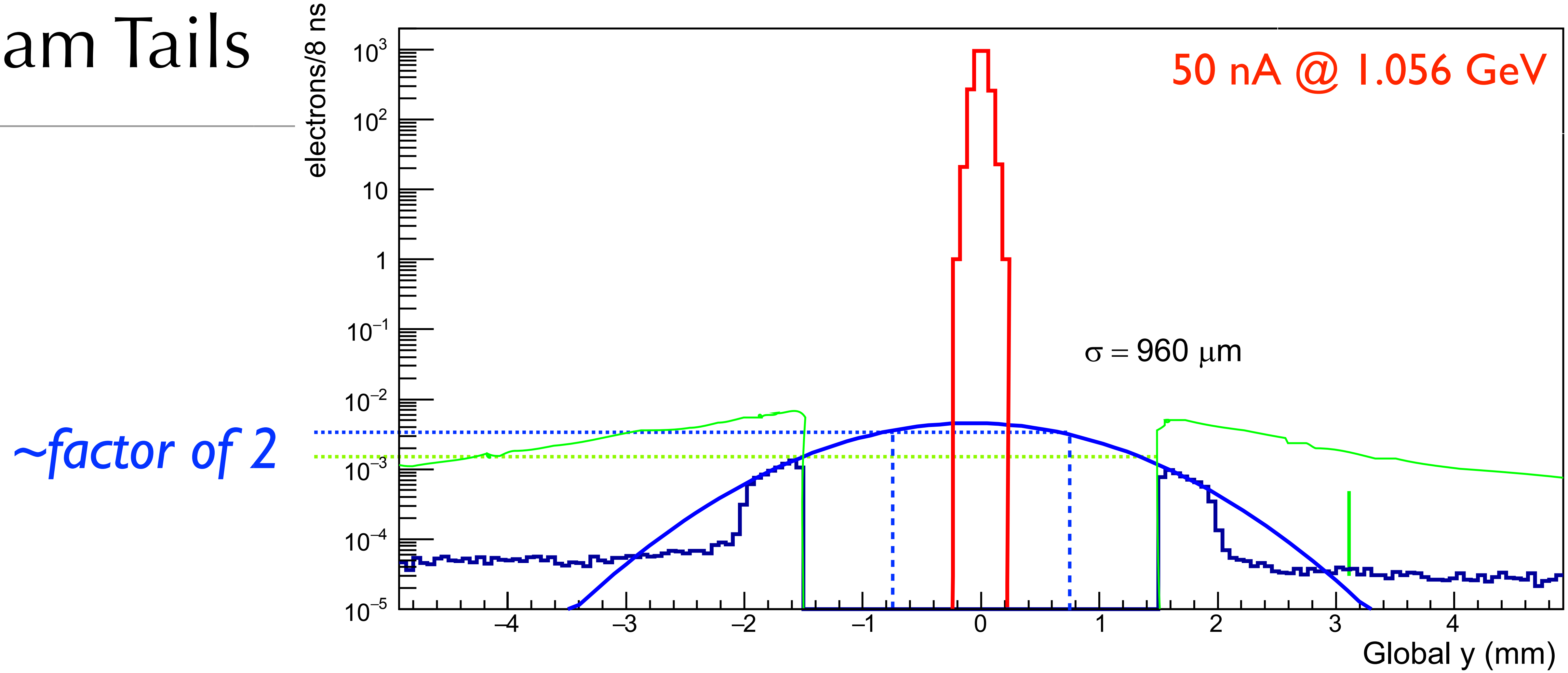
- Small sensor means sensor actually has smaller solid angle than Layer 1.
- Thinner sensor means only about 2/3 of L-shell x-rays with be absorbed in sensor.
- Studies find that x-ray occupancy will be ~0.4 hits/sensor
  ⇒ 0.07% occupancy: OK

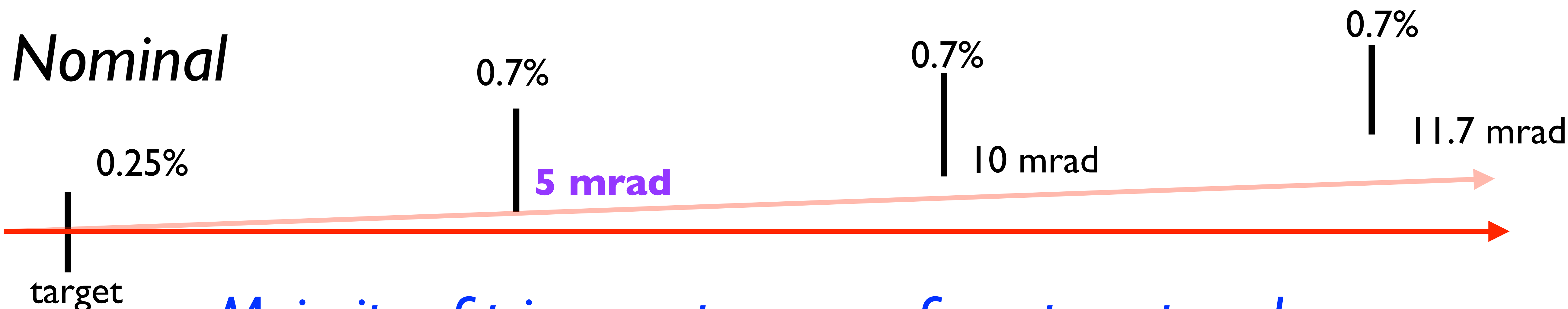


# Beam Tails




- 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 300 nA (4.4 GeV running), expect roughly 1% occupancy / 8 ns in both L0, L1.*
- *Expect that tails generated by beam-gas in poor vacuum through tagger will be improved.*

# Material Distribution: Upgrade vs. Nominal




*Majority of trigger rate comes from target, and…*

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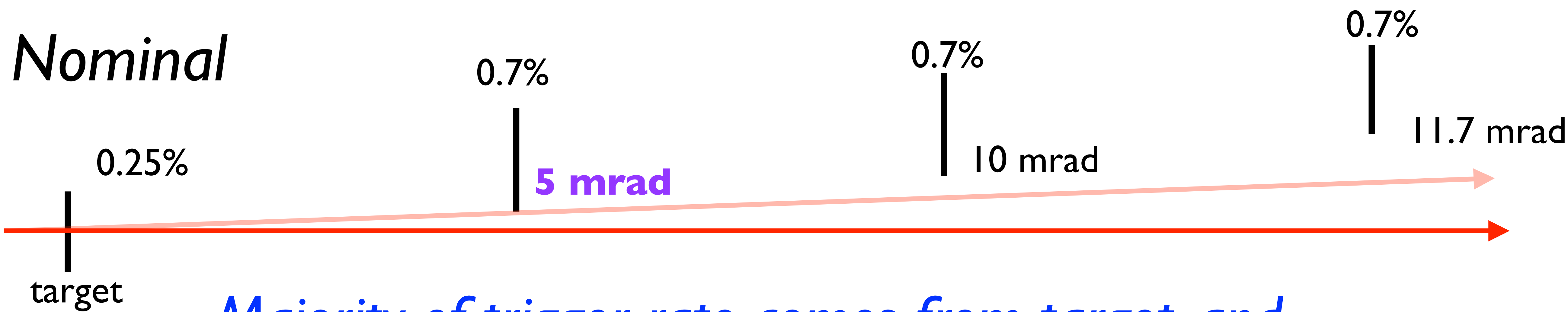


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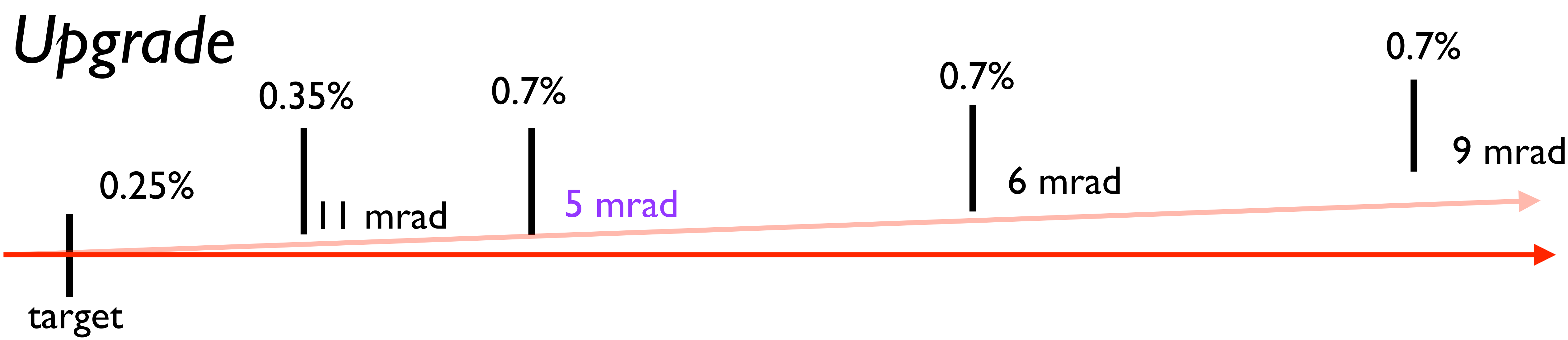
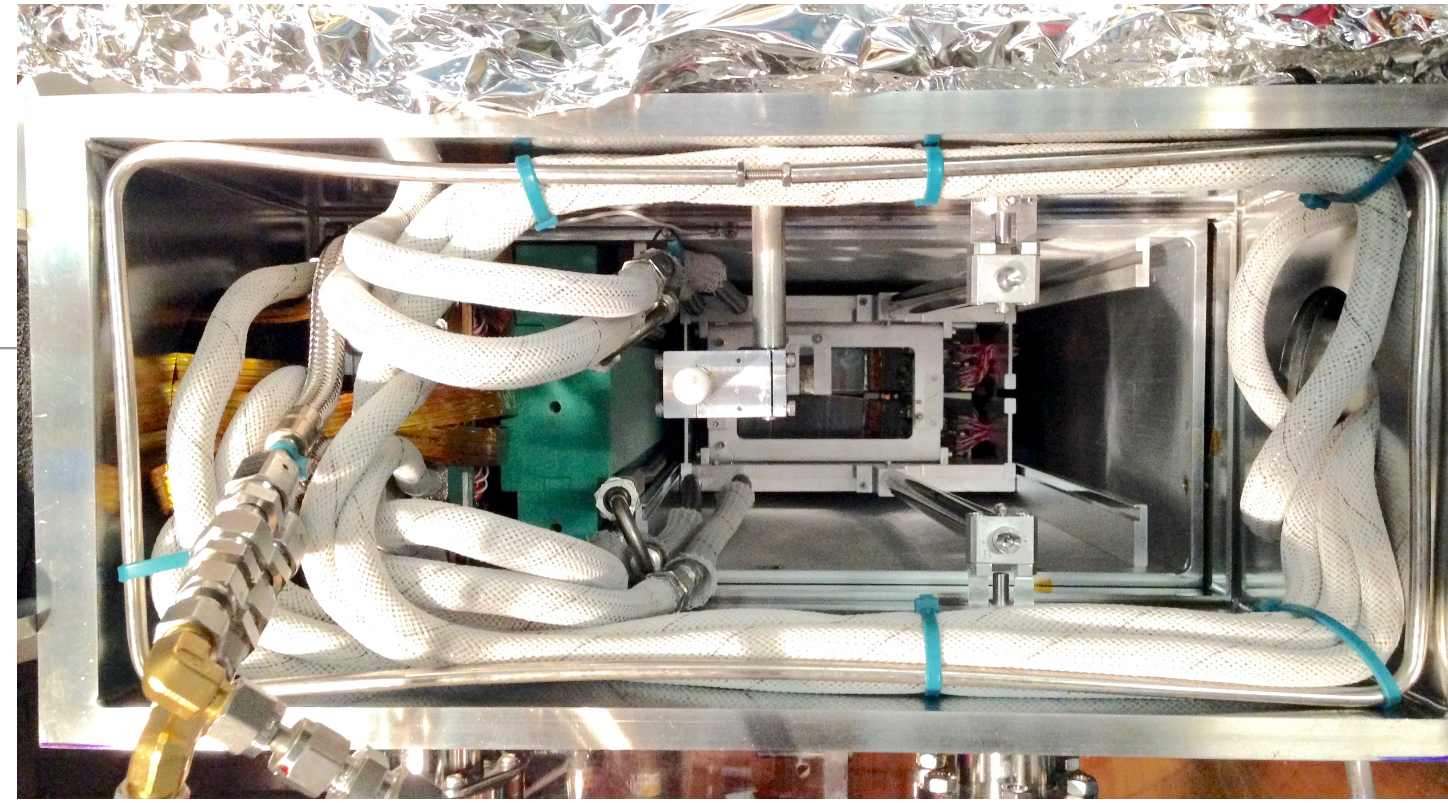
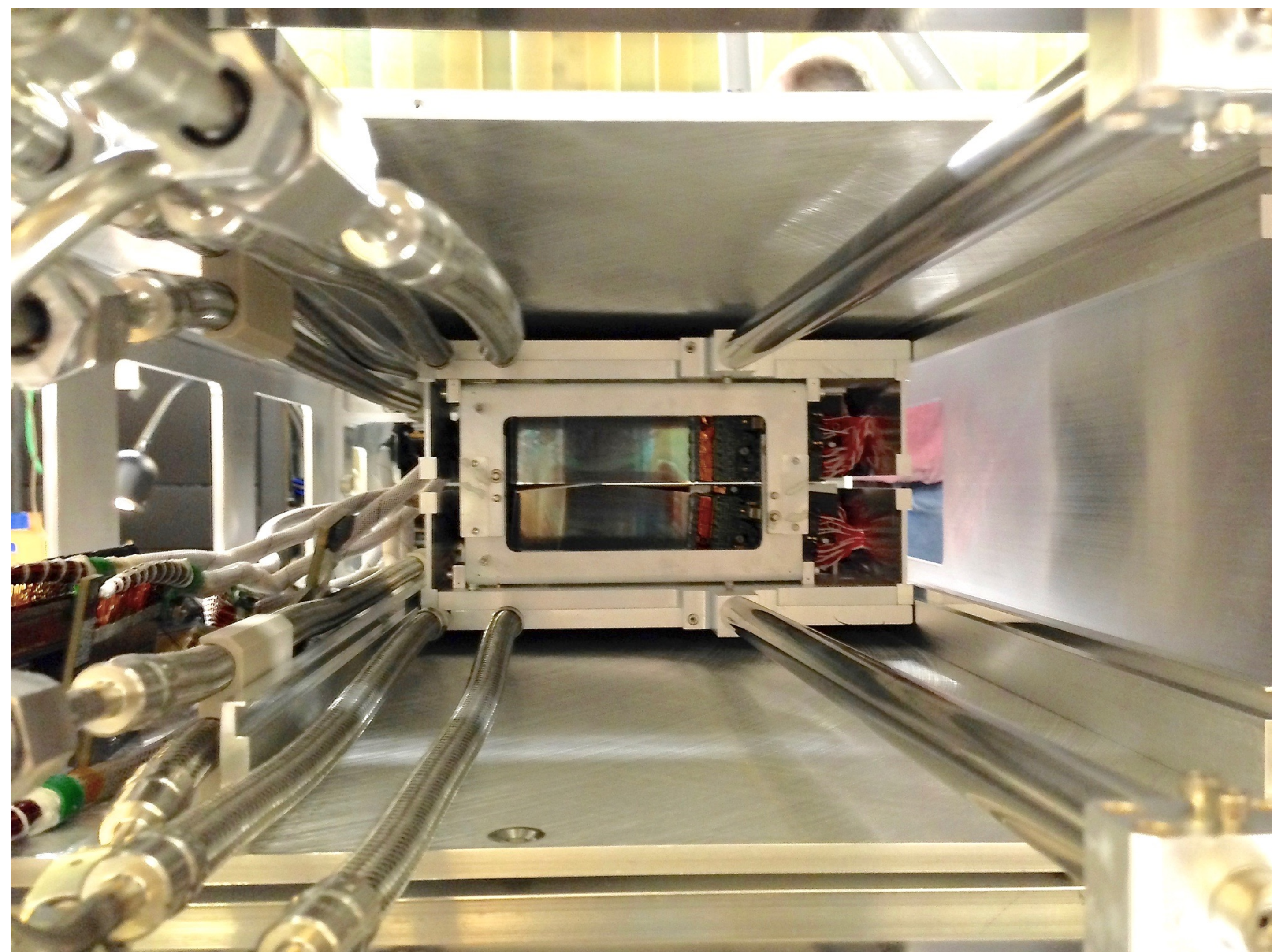



*upgrade does **not** add material at smaller scattering angles.*

# Removal, Installation and Serviceability

- Layer 1-3 U-channel designed for extraction without removing entire SVT (<1 day)
- If necessary, Layer 0 could be removed or replaced in alcove.
- Will extract U-channel for shipping back to SLAC in Aug.





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# Contingency Plans

*Layer 0 worst case scenario: it doesn't work*

- Degradation in vertex resolution is ~5%
- Layer 0 can be removed in 1 day down.

*Layer 2-3 worst case scenario: strips closest to the beam have occupancies high enough to create rare pattern recognition failures*

- Those strips could be ignored in analyzing the data