The HPS SVT

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HPS collaboration meeting

JLab - June 4, 2013

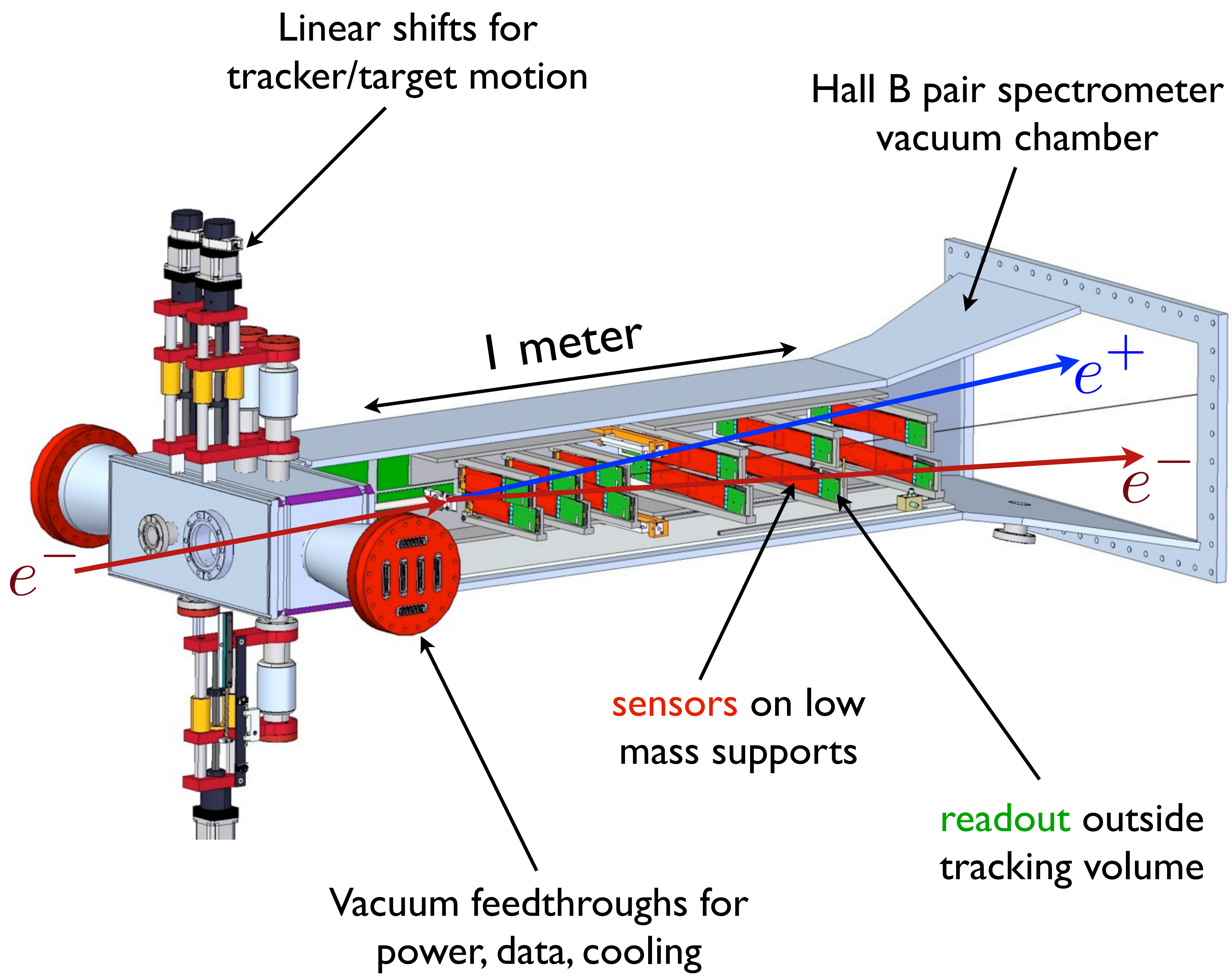
Outline

- Overview of SVT and requirements
- Key components
- Where we've been: HPS Test SVT
- Where we're going: HPS SVT
- How we'll get there.

The HPS SVT...

- *provides estimates of trajectories of low-momentum charged particles*
  - Momentum at production vertex - candidate A' mass
  - Vertex position - candidate A' lifetime
- *minimizes multiple scattering effects that dominate uncertainties in these estimates*
  - Material is the primary enemy
  - Requirements for single-hit and alignment precision are modest
- *optimizes acceptance by instrumenting as close to scattered primary beam as possible*
  - Operation in vacuum
  - Radiation tolerance
  - Fast trigger and DAQ
  - Excellent hit timing

SVT Overview



Optimizing Acceptance

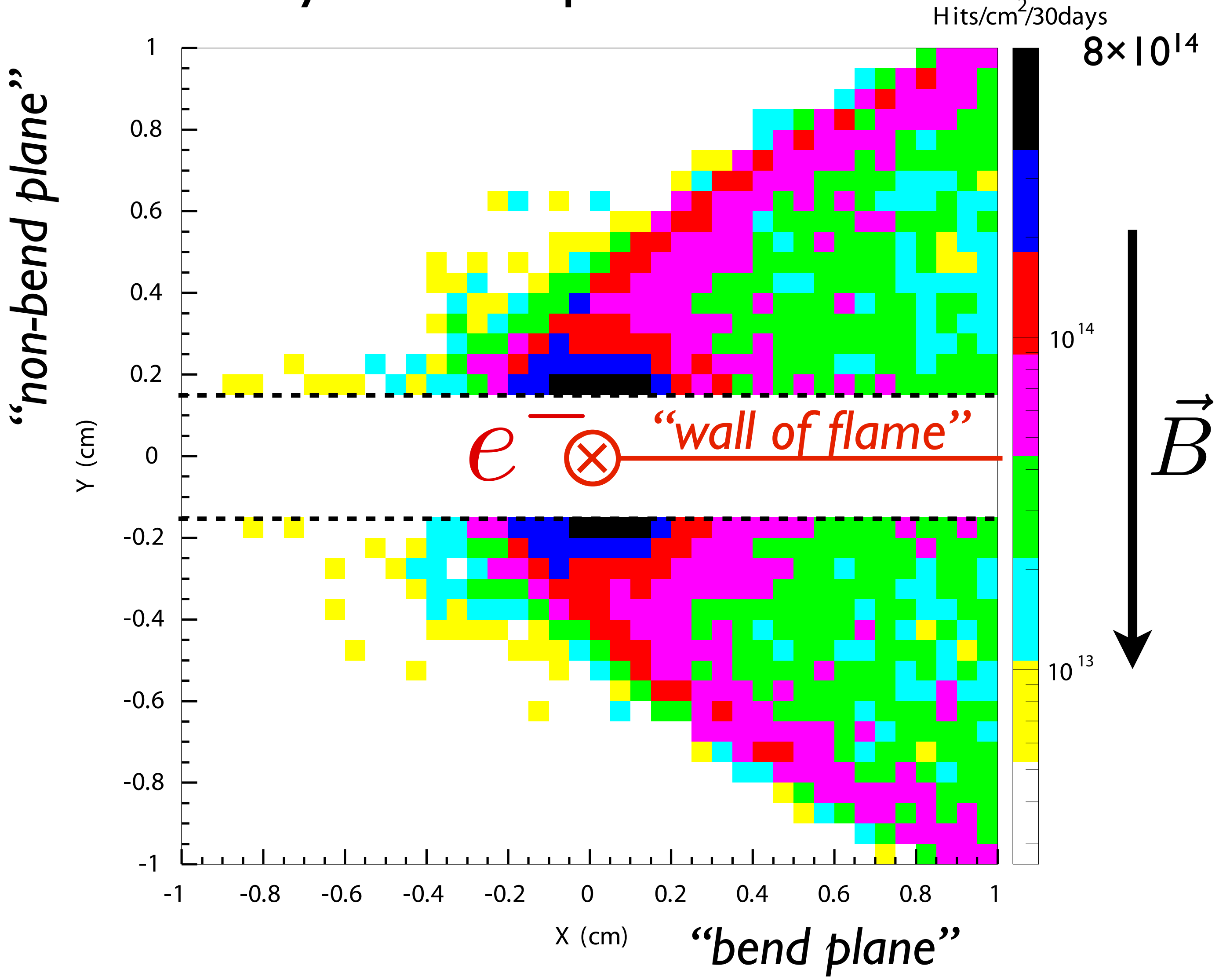
High-mass is simple in principle:
build it as big as you can afford!

Low-mass is harder:
requires acceptance very close to beam

At 15 mrad, 10 cm from target (L1):

- Active detector ~1.5 mm from beam
- Peak occupancy ~4 MHz/mm^2
- Fluence 4.8×10^{15} e^- $\cong$ 1.6×10^{14} neq. in 6 months of running

Layer 1 e^- exposure / month

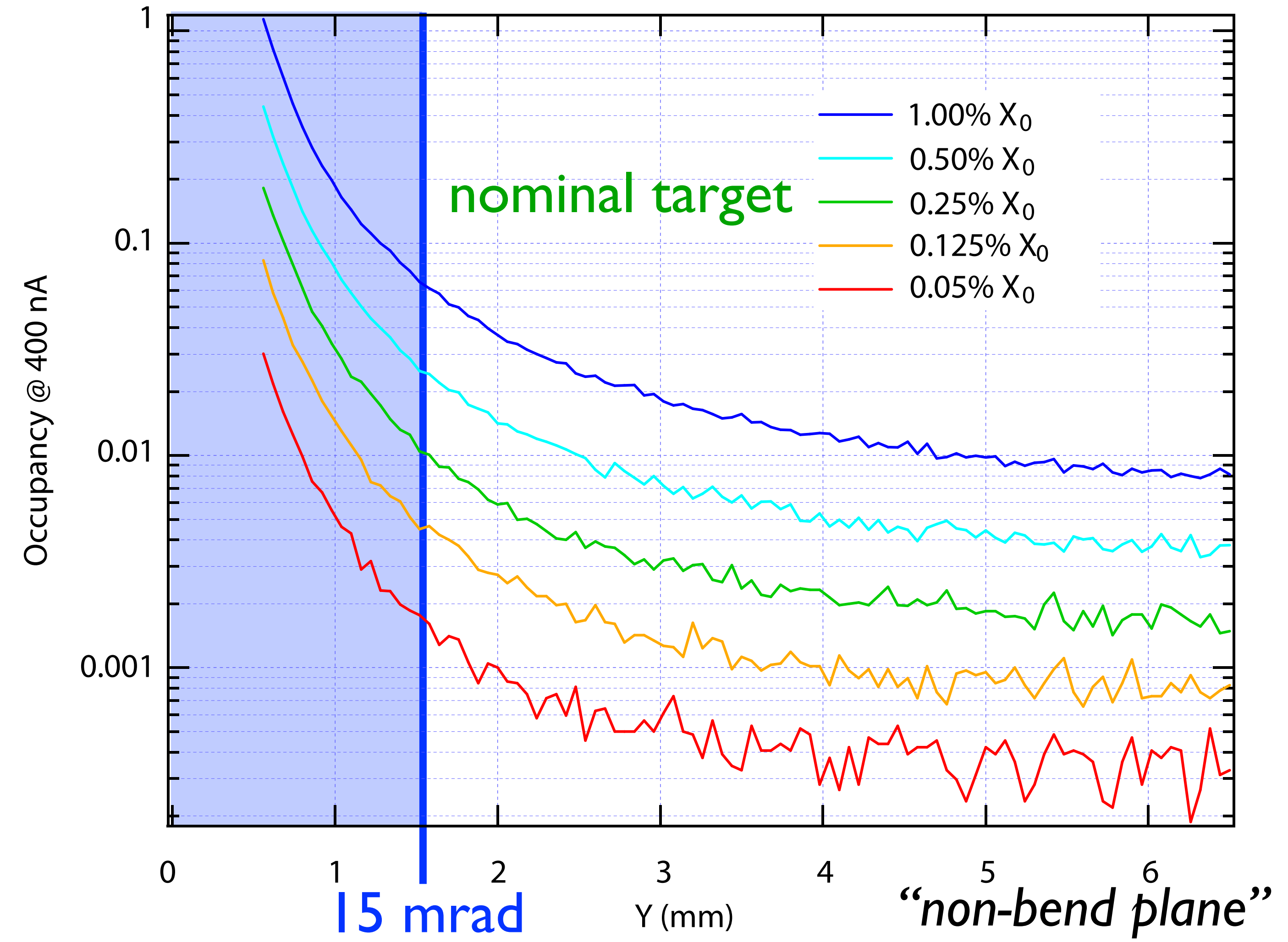


Sensor Selection

Also need...

- < 1% X_0 per layer
- <50 μm single-hit resolution in both measurement coordinates
- <$1M for a complete system, soon!
  - ~~MAPS~~?
  - ~~Hybrid pixels~~?
  - ➡ *Strip sensors (edges 500 μm from beam!)*

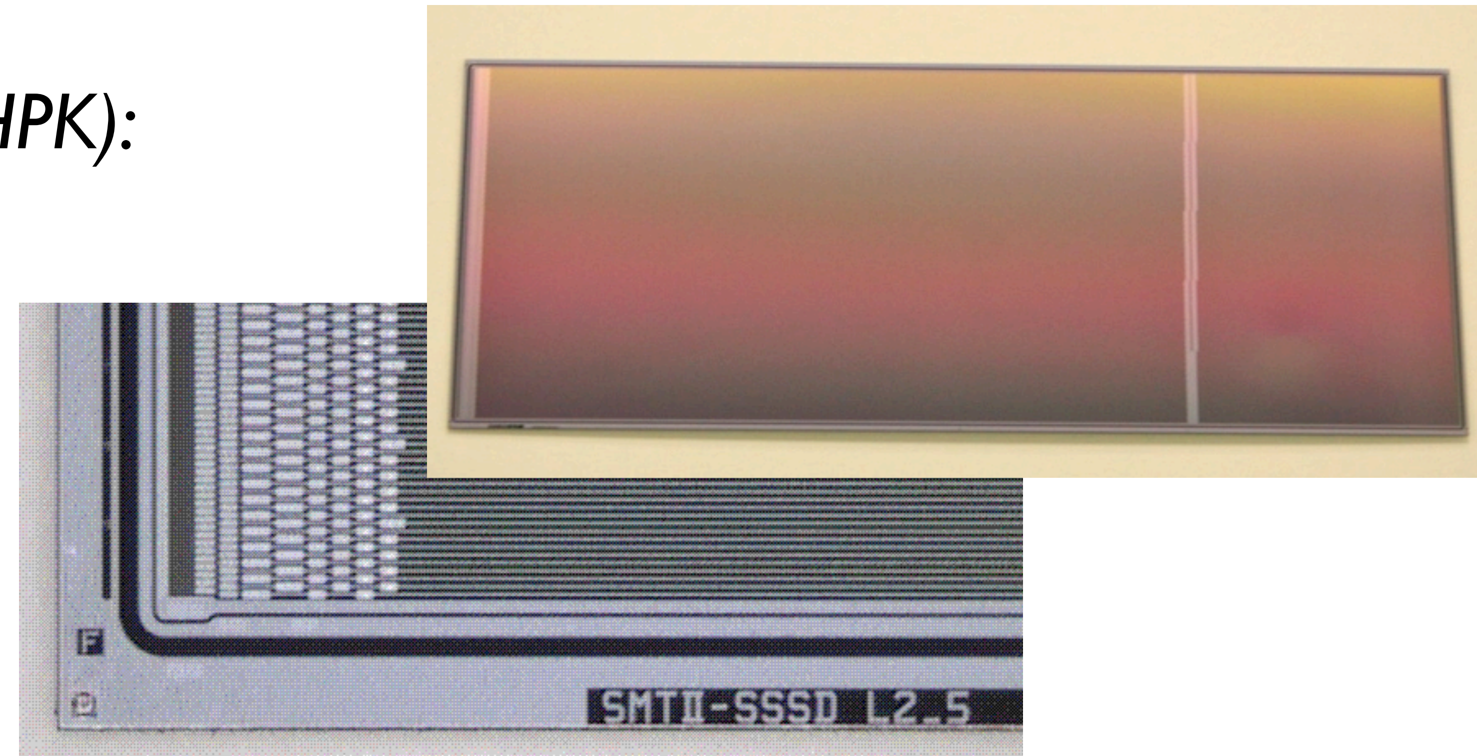
Layer 1 strip occupancy / 8 ns trigger window



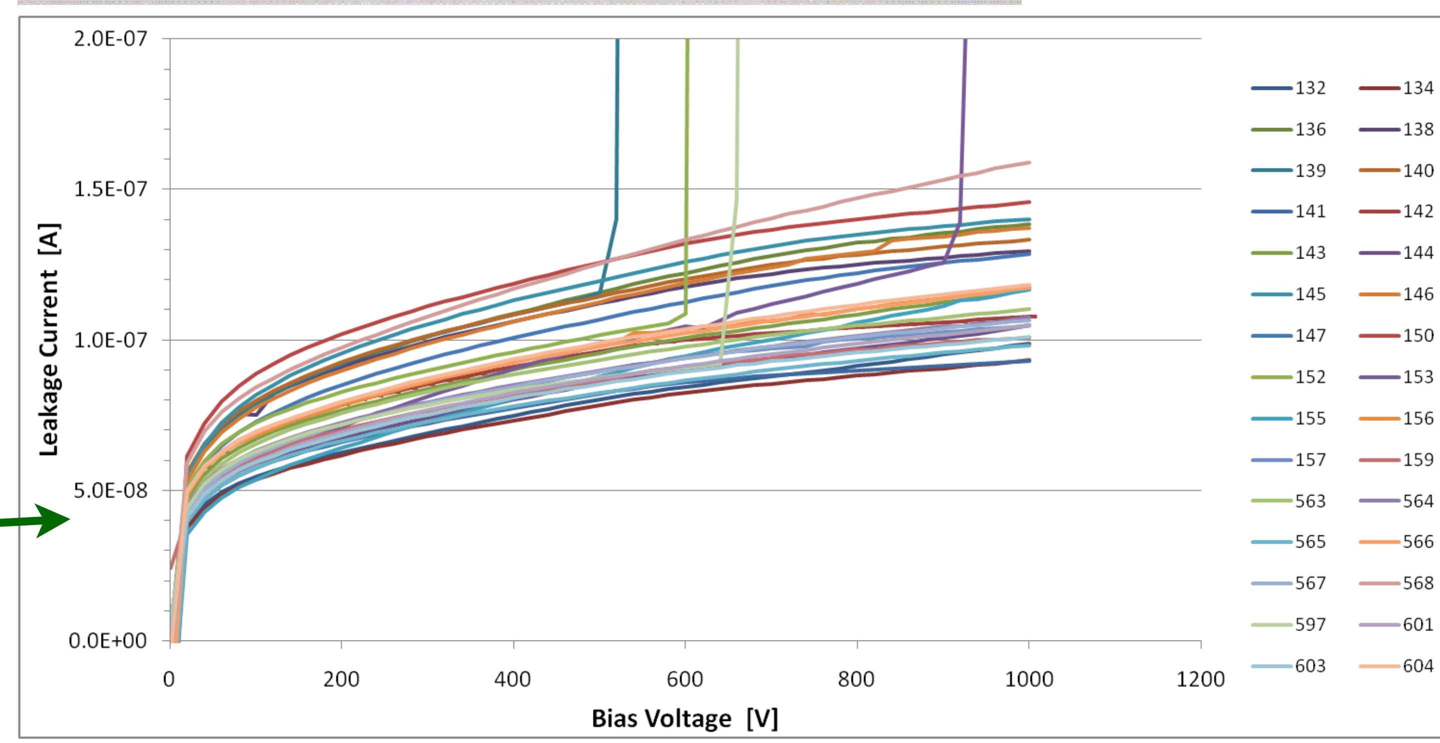
Silicon Microstrip Sensors

Production Tevatron RunIIb sensors (HPK):

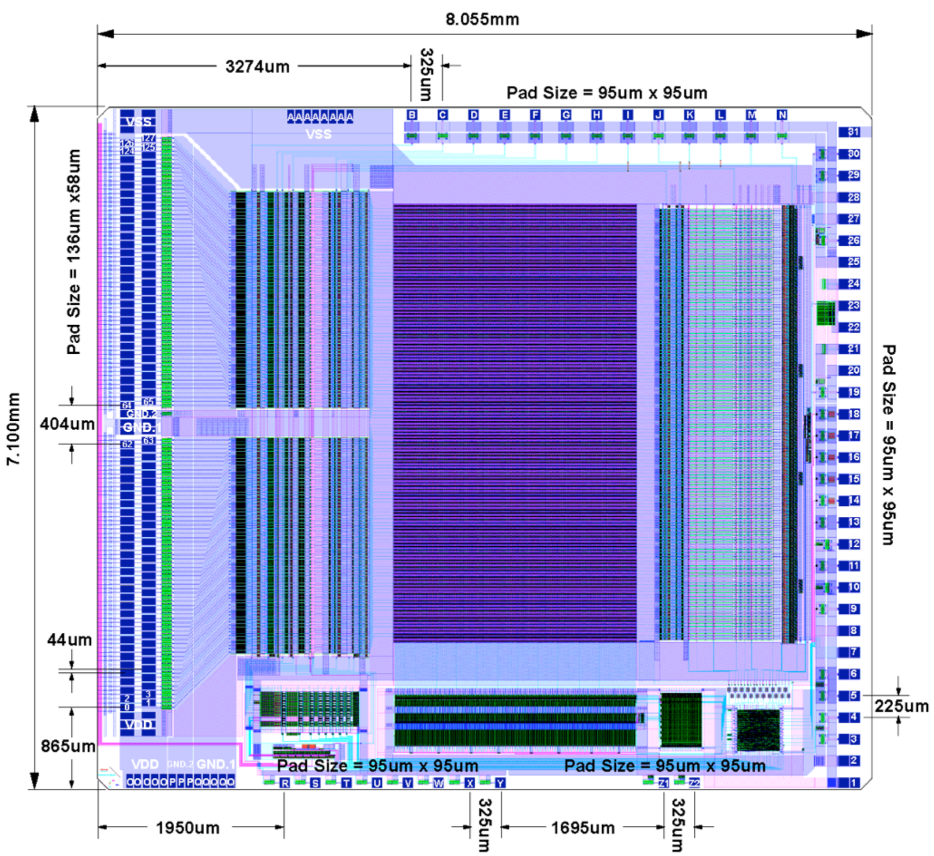
- Fine readout granularity
- most capable of 1000V bias: fully depleted for 6 month run.
- Available in sufficient quantities
- Cheapest technology *(contribution from FNAL)*



Technology	**<100>, p+ in n, AC-coupled**
Active Area (L×W)	**98.33 mm × 38.34mm**
Readout (Sense) Pitch	**60μm (30μm)**
Breakdown Voltage	**>350V**
Interstrip Capacitance	**<1.2 pF/cm**
Defective Channels	**<0.1%**



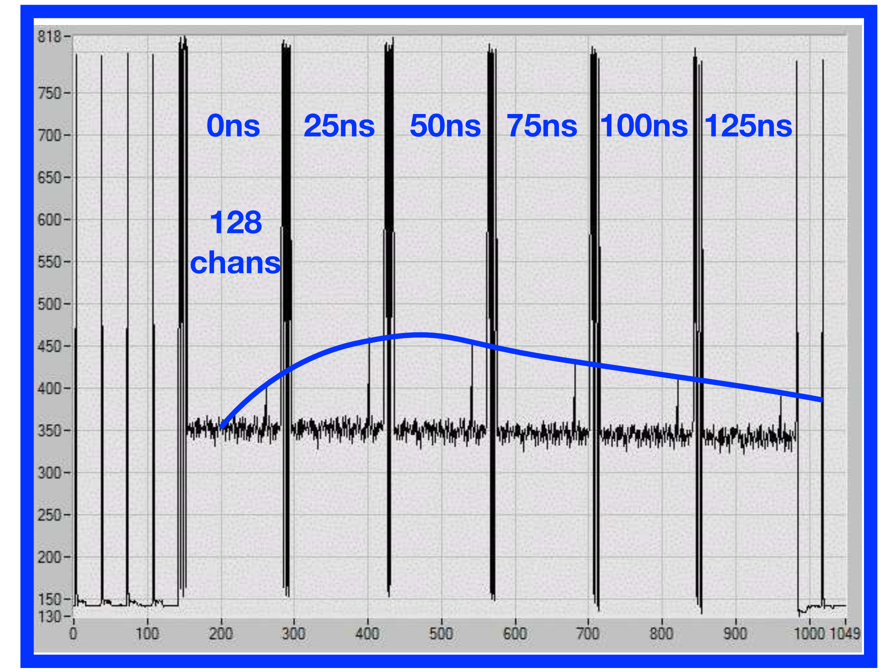
Front-end Electronics: APV25

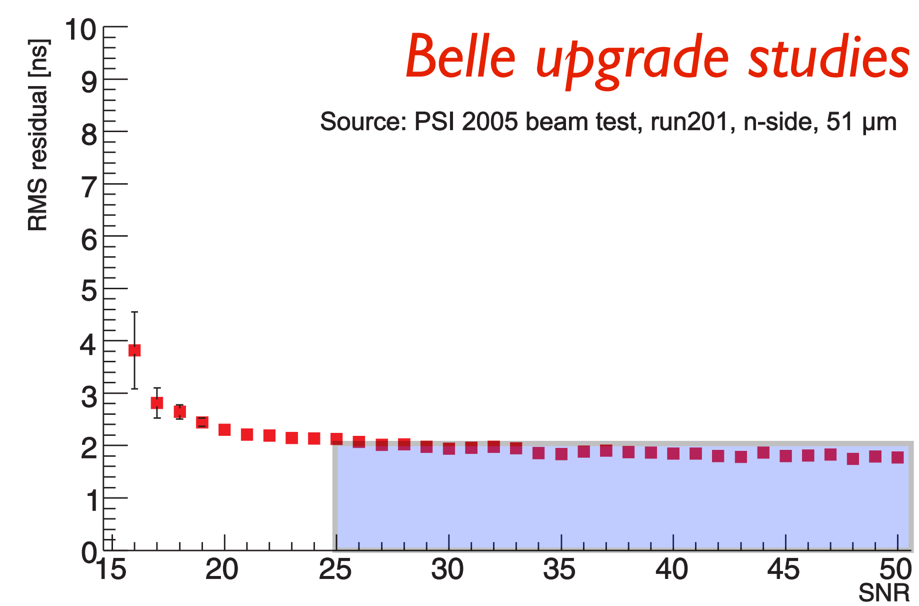


# Readout Channels	**128**
Input Pitch	**44 μm**
Shaping Time	**50ns nom. (35ns min.)**
Noise Performance	**270+36×C(pF) e⁻ ENC**
Power Consumption	**345 mW**

Developed for CMS

- available (28 CHF/ea.)
- radiation tolerant
- fast front end (35 ns shaping time)
- low noise (S/N > 25)
- "multi-peak" readout
- ~2 ns t_0 resolution!





Optimizing Detector Layout

Using SLIC/lcsim framework for simulation and reconstruction of both MC and data

- Detailed model of detector response for MC
    - Silicon charge deposition/collection
    - Time response and multi-peak readout of APV25 front end
    - Time-sequenced overlay of backgrounds
- Same hit and track reconstruction tools for both MC and data
    - Amplitude, time reconstruction, and clustering of hits
    - Track finding and fitting
    - Can produce MC using constants established with data

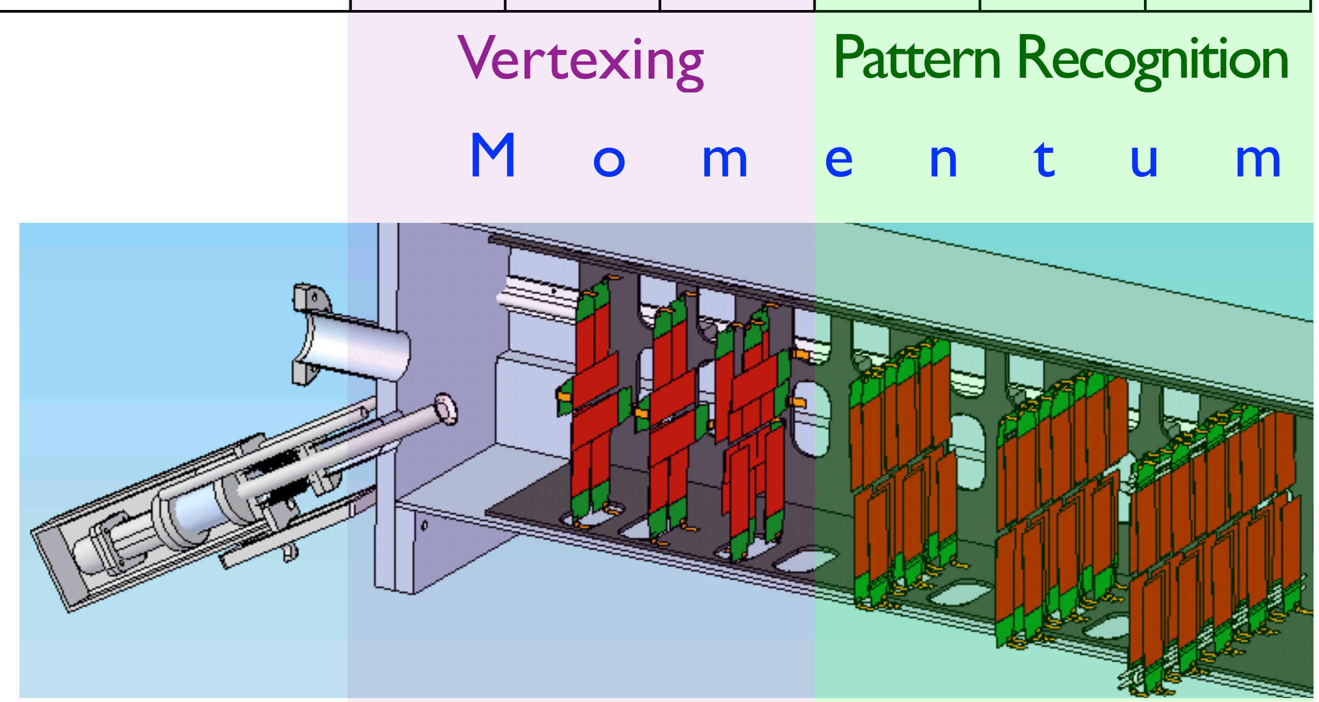
This high level of detail is critical for establishing vertex reach (10^{-7} prompt rejection!)

Initially Proposed Layout

A no-compromises approach with best possible mass and vertexing resolution over large acceptance

- 106 sensors & hybrids
- 530 APV25 chips
- 67840 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	90 deg.	90 deg.	90 deg.	50 mrad	50 mrad	50 mrad
Bend Plane Resolution (µm)	≈ 6	≈ 6	≈ 6	≈ 6	≈ 6	≈ 6
Stereo Resolution (µm)	≈ 6	≈ 6	≈ 6	≈ 120	≈ 120	≈ 120
# Bend Plane Sensors	4	4	6	10	14	18
# Stereo Sensors	2	2	4	10	14	18
Dead Zone (mm)	±1.5	±3.0	±4.5	±7.5	±10.5	±13.5
Power Consumption (W)	10.5	10.5	17.5	35	49	63



A relatively large and expensive detector.

Requires large magnet, vacuum chamber and ECal also.

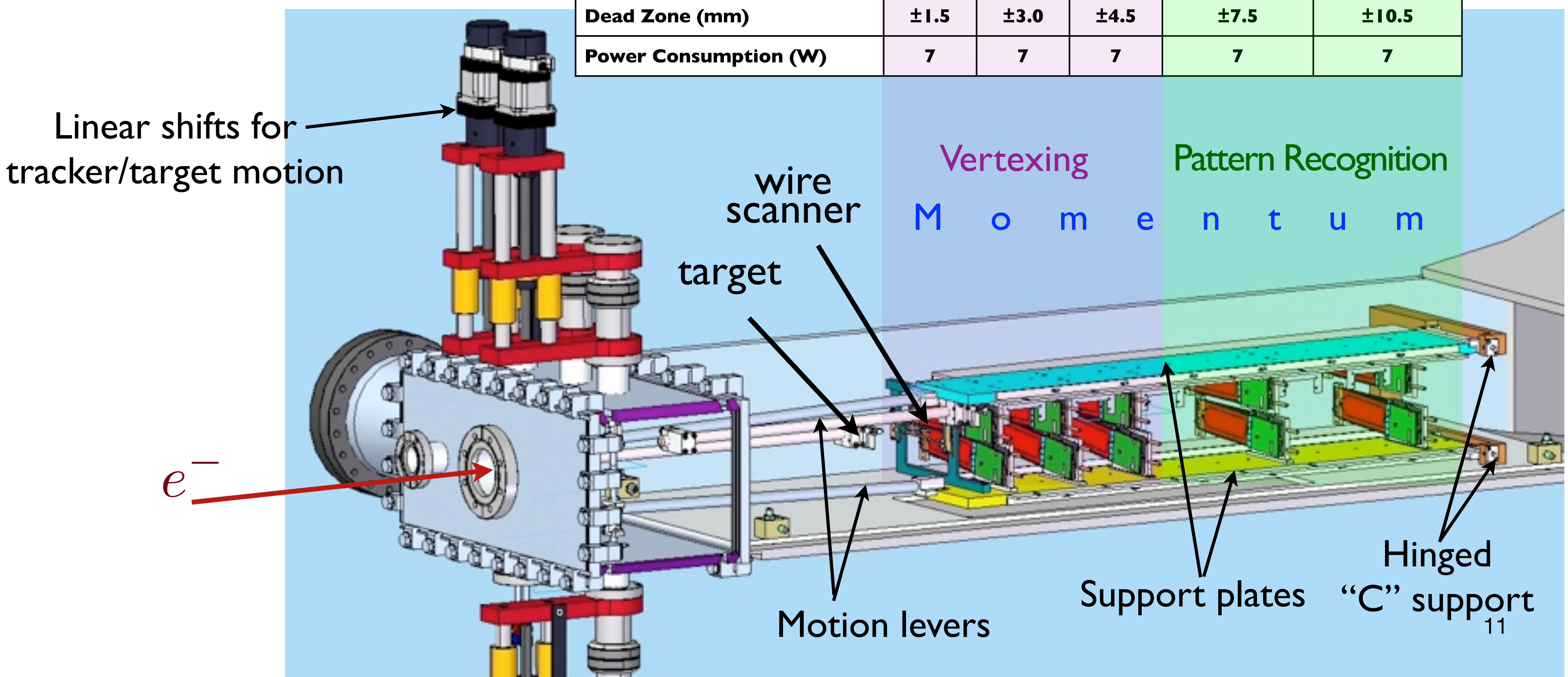
Could we get started with less?

HPS Test Run

Proposed 3/11, Installed 4/12

- Develop technical solutions
- Prove operational principles
- Capable of A′ physics

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



Test SVT Modules

Half Module

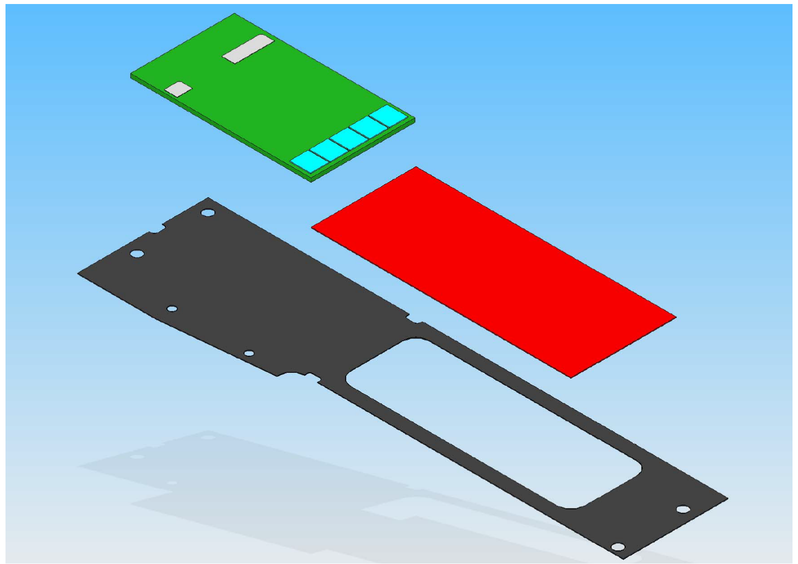
- 0.17 mm thick CF frame *(FNAL)* (FE grounded, HV passivated)
- FR4 hybrid with 5 APV25, short twisted-pair pigtail cable
- single sensor

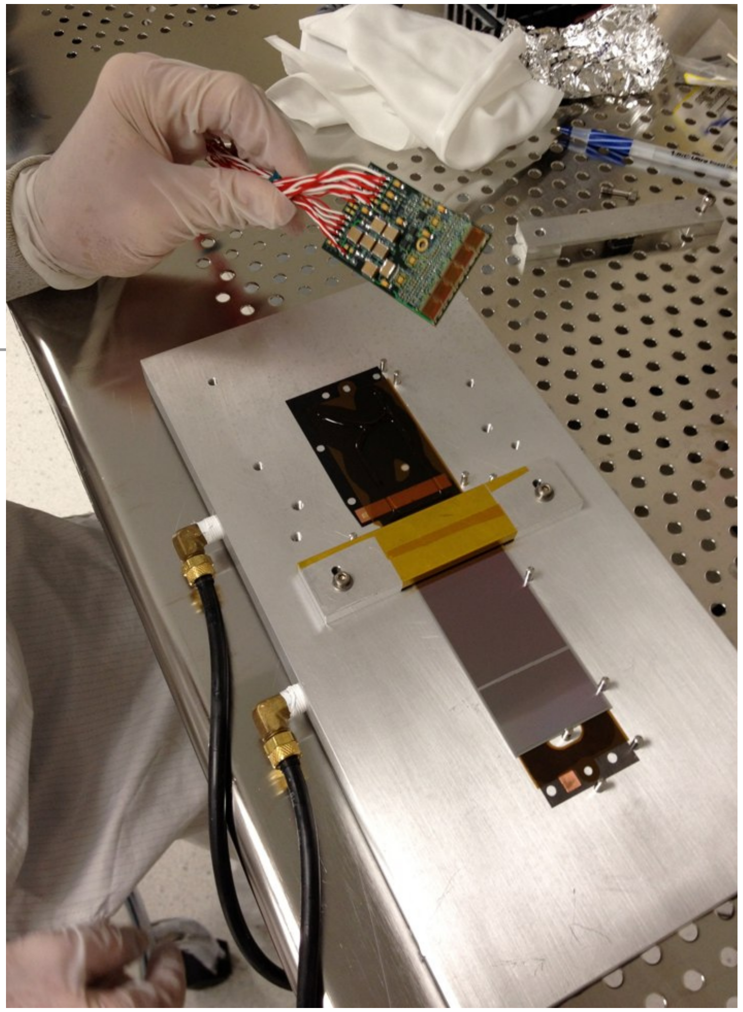
Full module

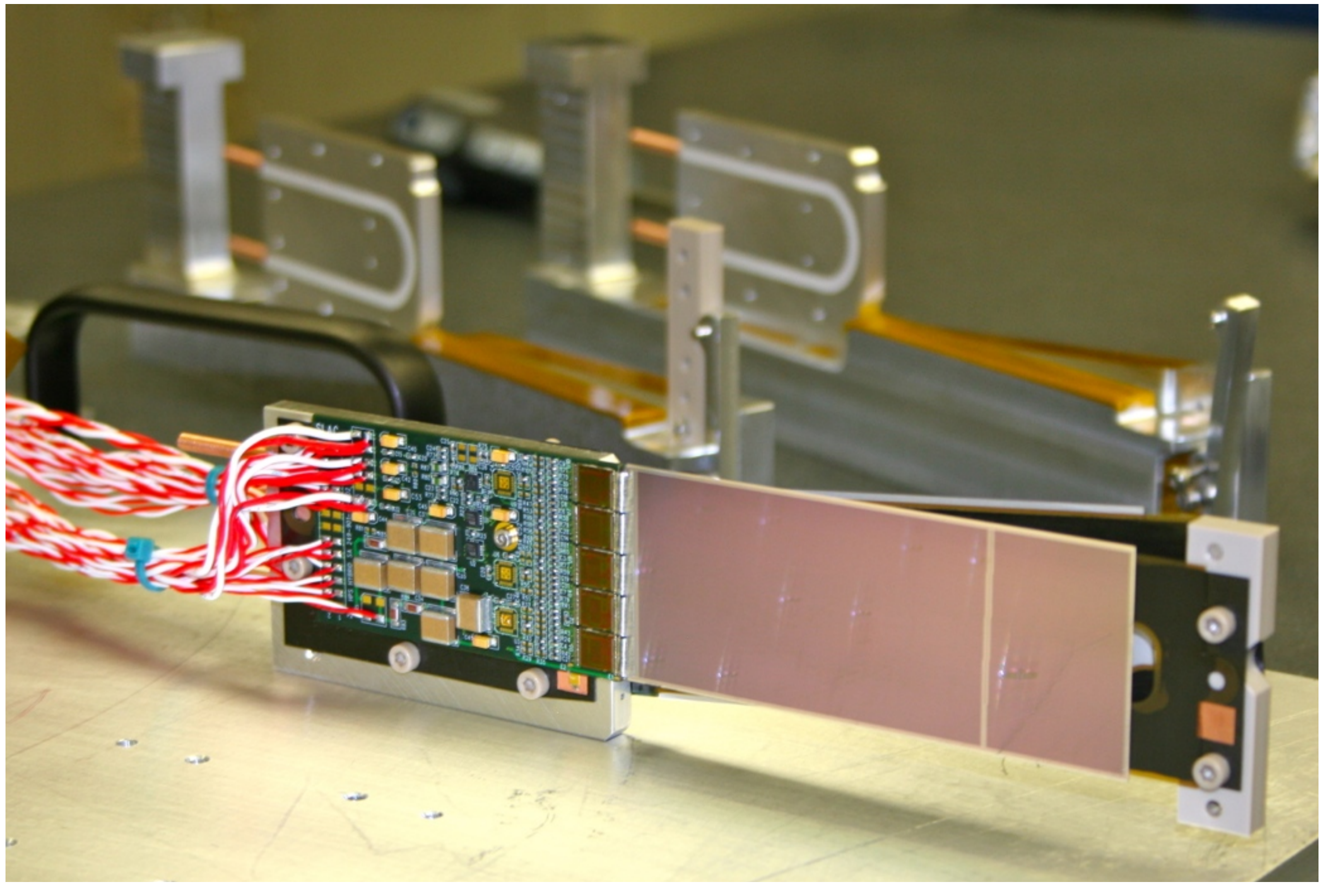
- Two half-modules back-to-back on Al cooling block w/ Cu tubes
- glue-less assembly with PEEK spacer block and hardware

0.7% X_0 average per layer

Limited flatness/stability of Si

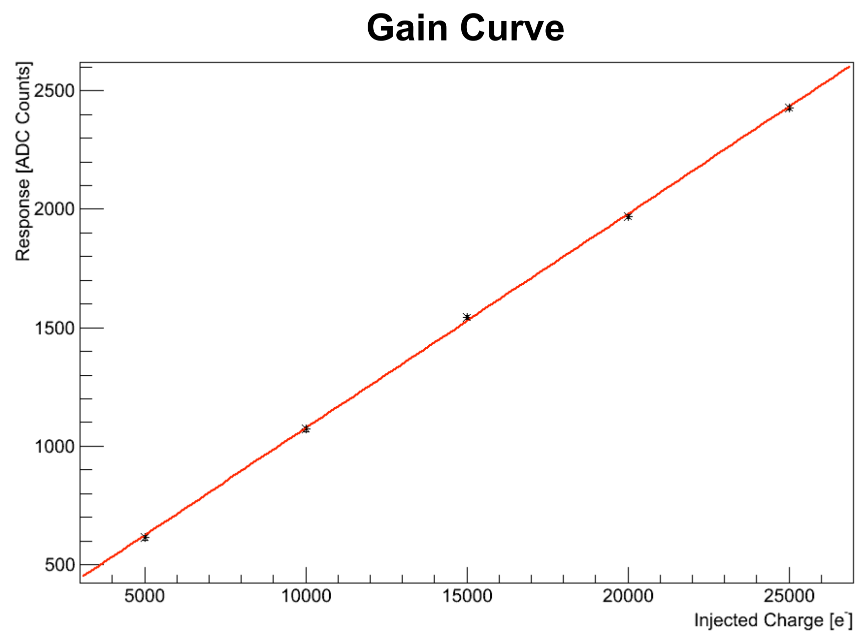


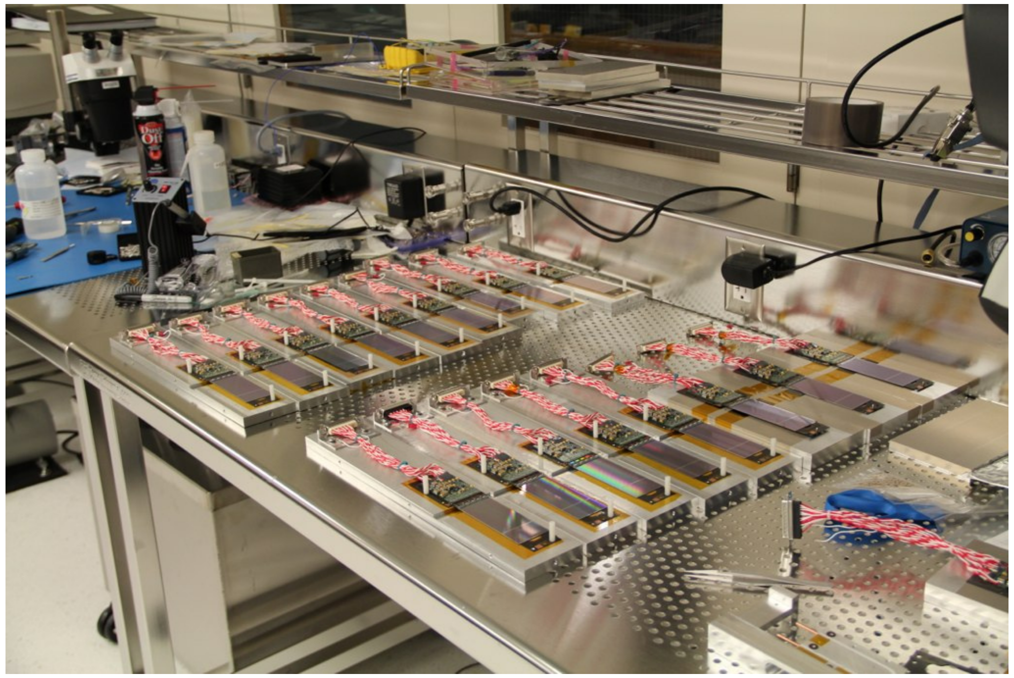


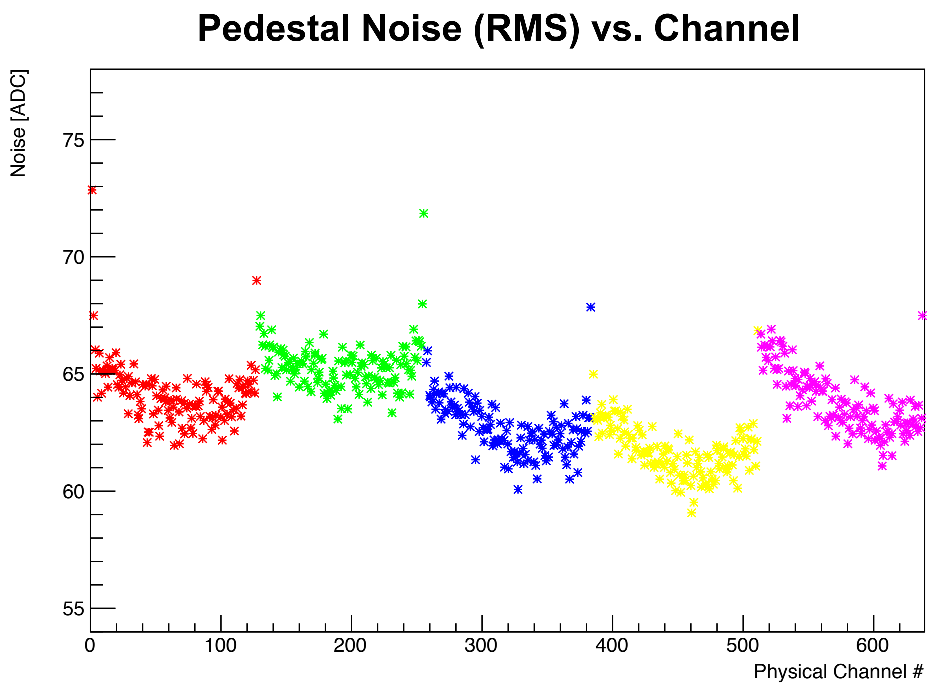


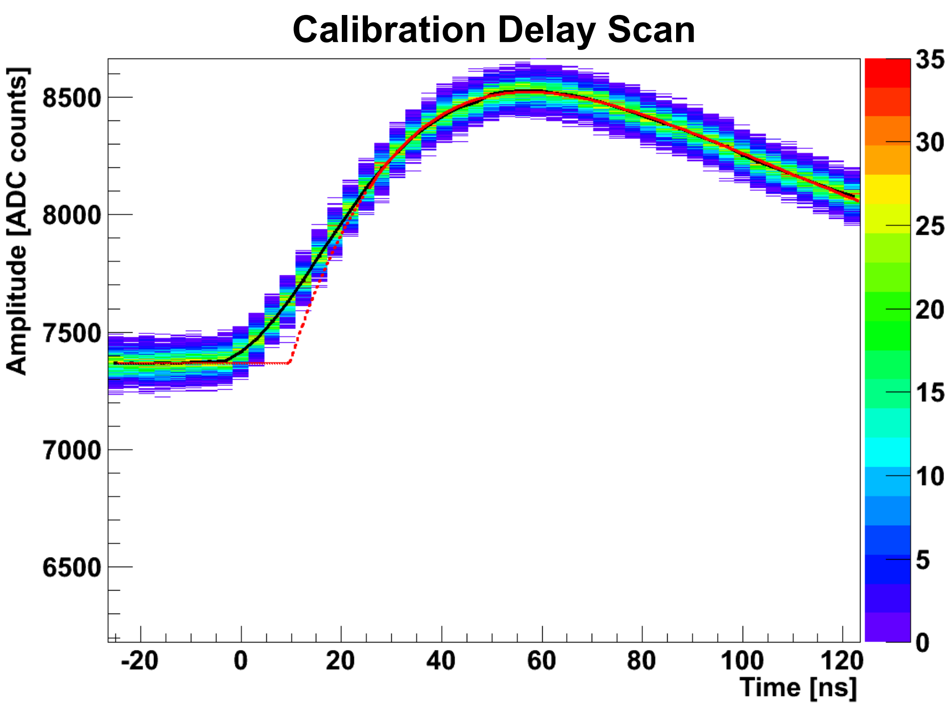
Module Construction, Testing and Qualification

- Began with 165 APV25 (enough for 33 hybrids)
- 30 production hybrids, 29 passed QA
- 29 half-modules, 28 passed QA
- S/N ~ 25 with Si load
- t_0 resolution = 2.5 ns
- Good linearity and uniformity
- Assembly precision at cooling block: x-y ~10 μm, z ~ 25 μm
- Flatness (z) along sensor only ~200 μm







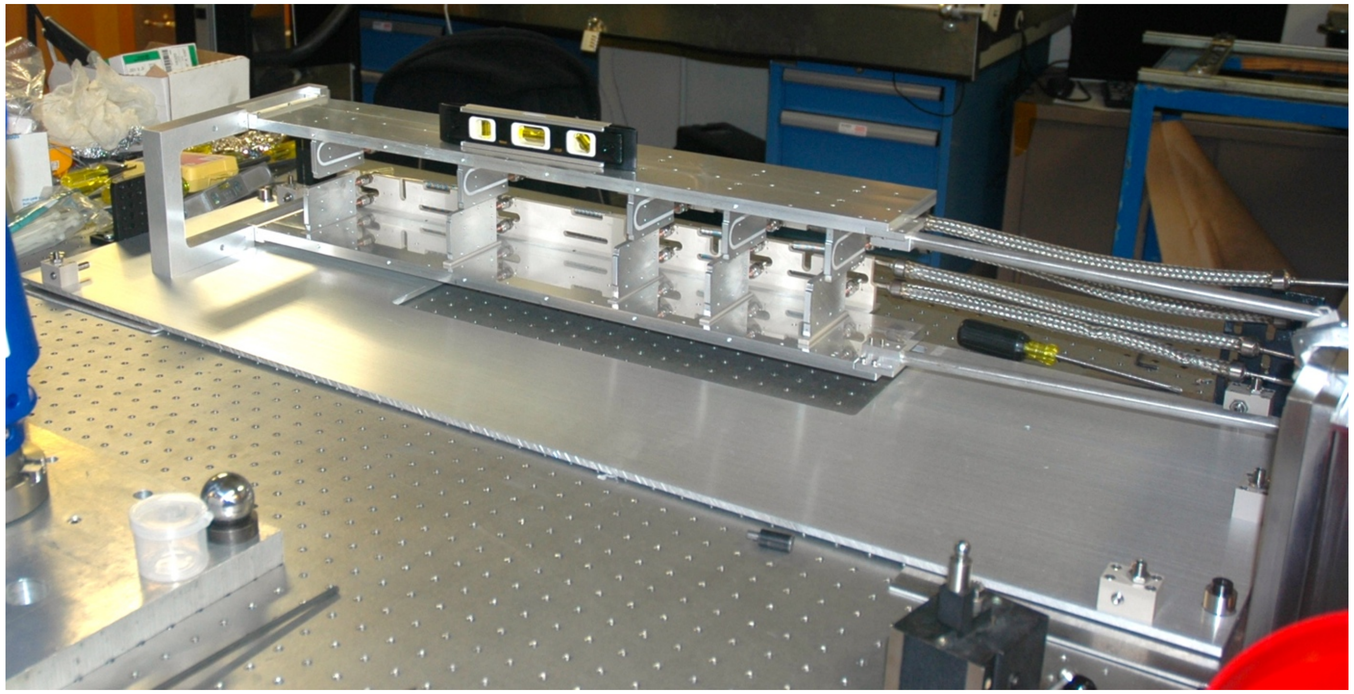


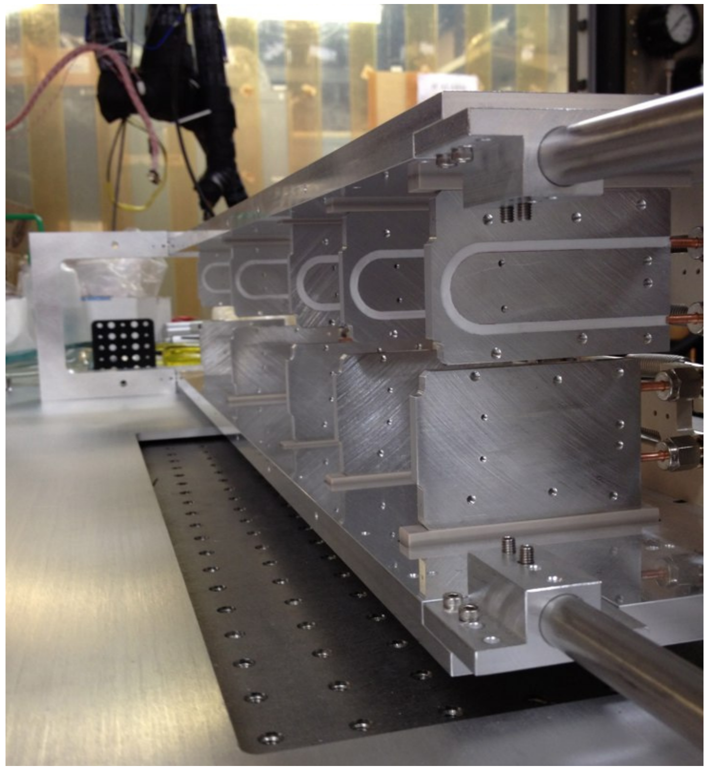
HPS Test SVT Mechanics

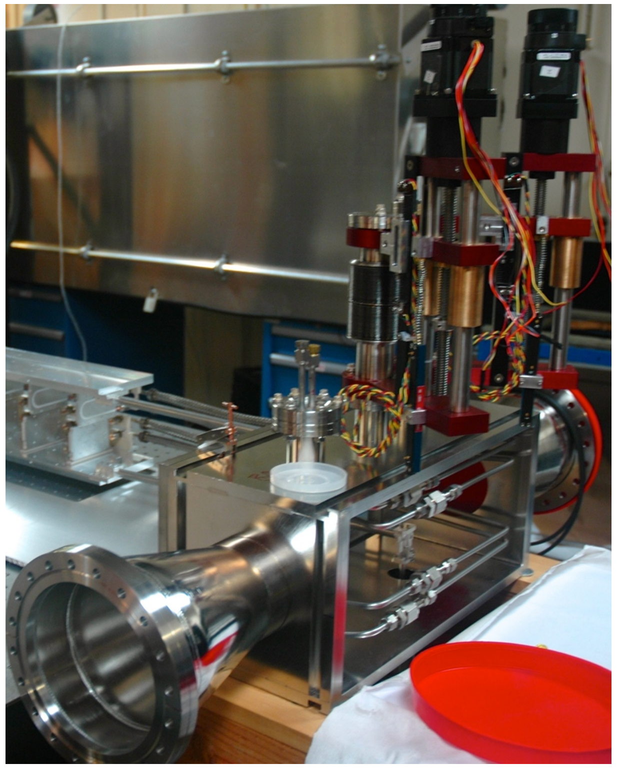
Cooling blocks mount on Al support plates with hinged C-support and motion lever

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

Adequate, but could be improved upon

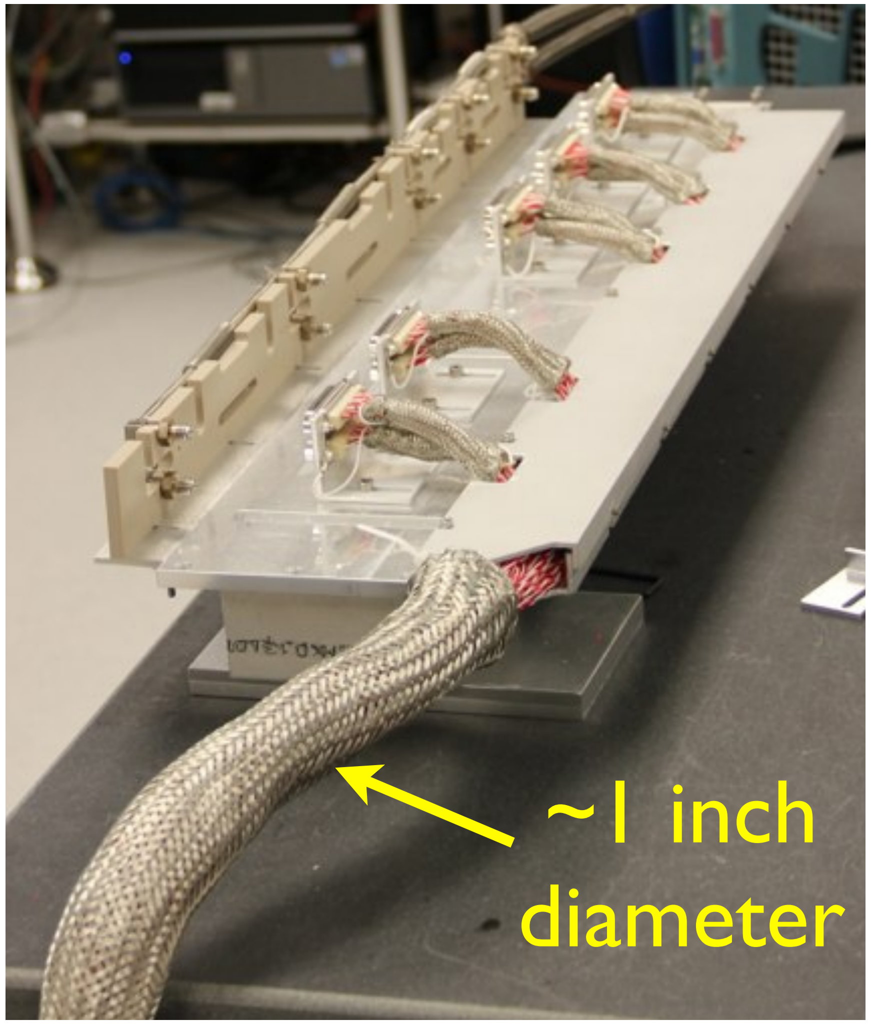


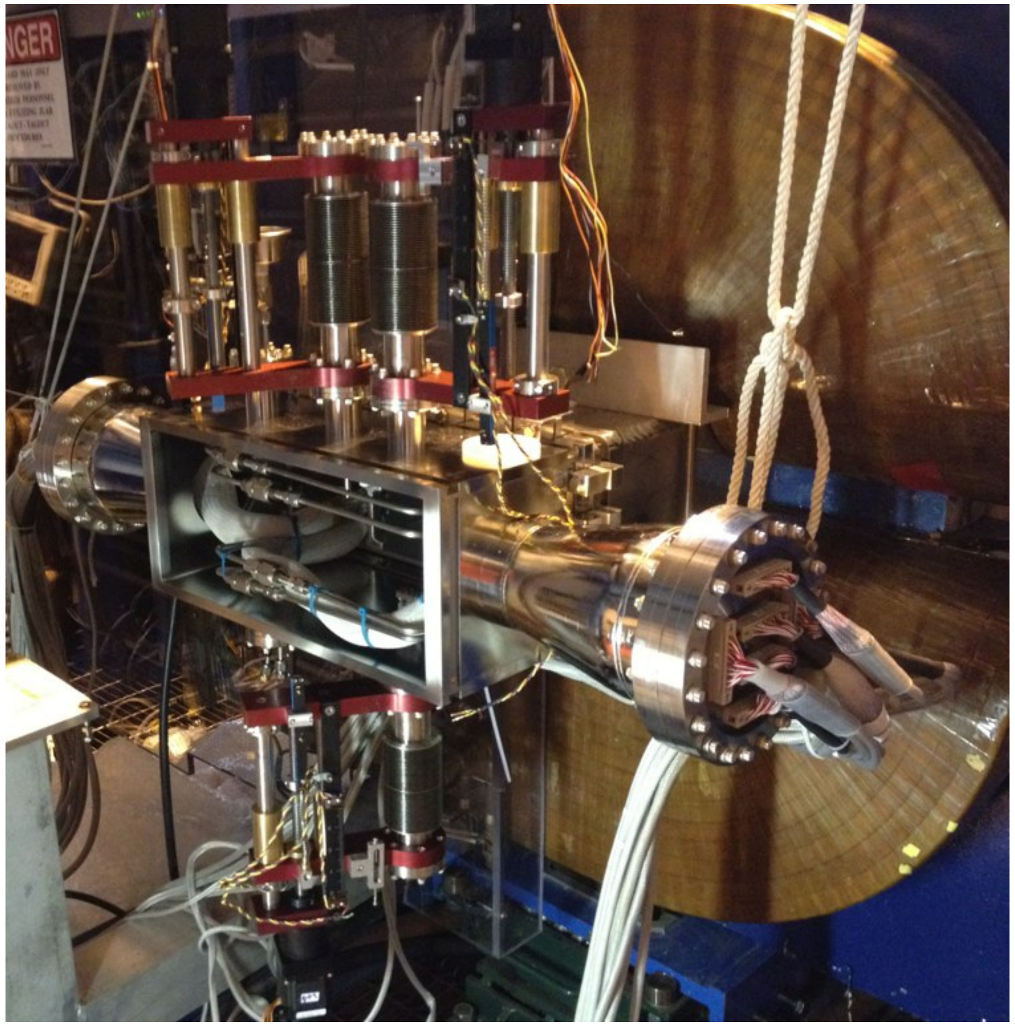




Test SVT Services

- Borrowed CDF SVXII power supplies (very crufty) and JLab chiller (limited to > 0˚C)
- Complicated, 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.

Test SVT Lessons Learned

- We can build a movable, liquid cooled tracker that operates in beam vacuum
- We can build tracker with 0.7% X_0 per 3-d measurement
- We can build a tracker with required hit efficiency and t_0 resolution
- We can integrate SVT DAQ with JLab ECal DAQ and trigger
- *We can do better,*
    - Layout: Larger acceptance and better redundancy
    - More reliable interconnect strategy (required for larger tracker)
    - Modules with flatter, colder sensors
    - Improved support rigidity
    - Fully tested and debugged DAQ

but it would be foolish to start from scratch!!

HPS SVT Layout

Evolution of HPS Test

- Layers 1-3: same as HPS Test
- 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
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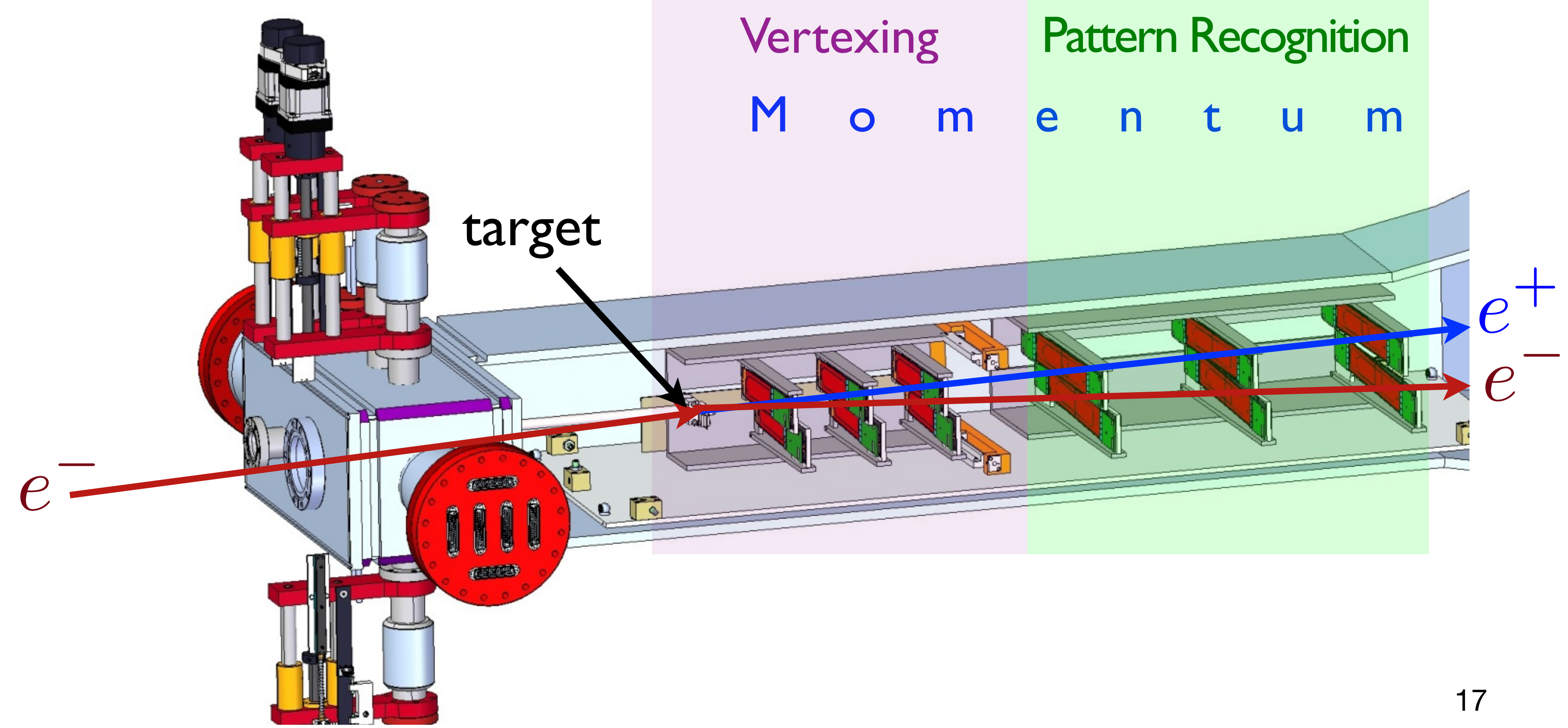
Dead Zone (mm)	±1.5	±3.0	±4.5	±7.5	±10.5	±13.5
Power Consumption (W)	7	7	7	14	14	14



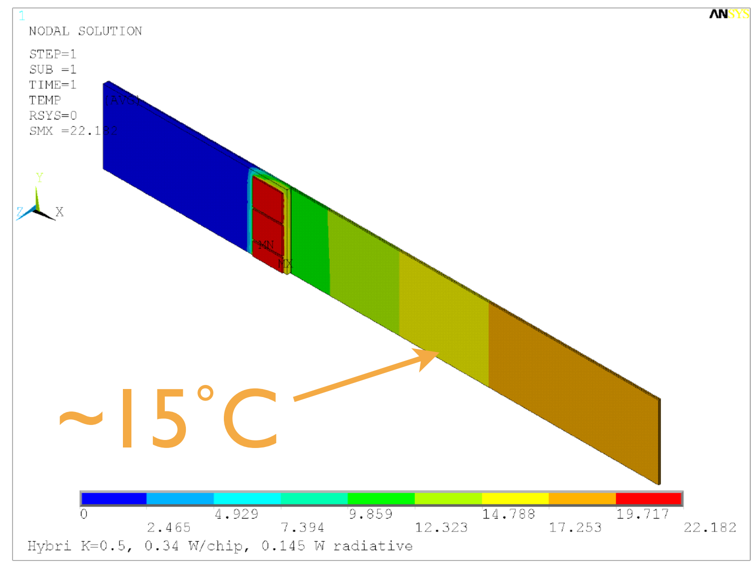
Layer 1-3 Modules

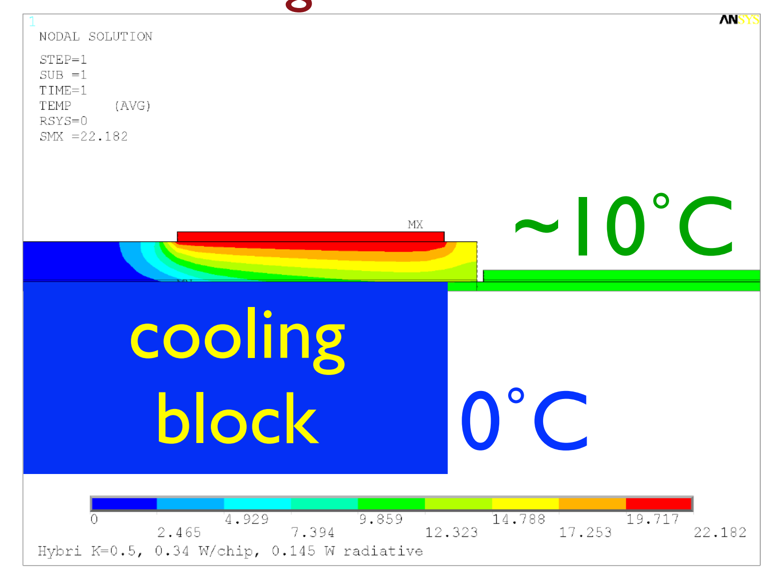
Reuse half modules from HPS Test, but design better module supports: tension CF between cooled uprights.

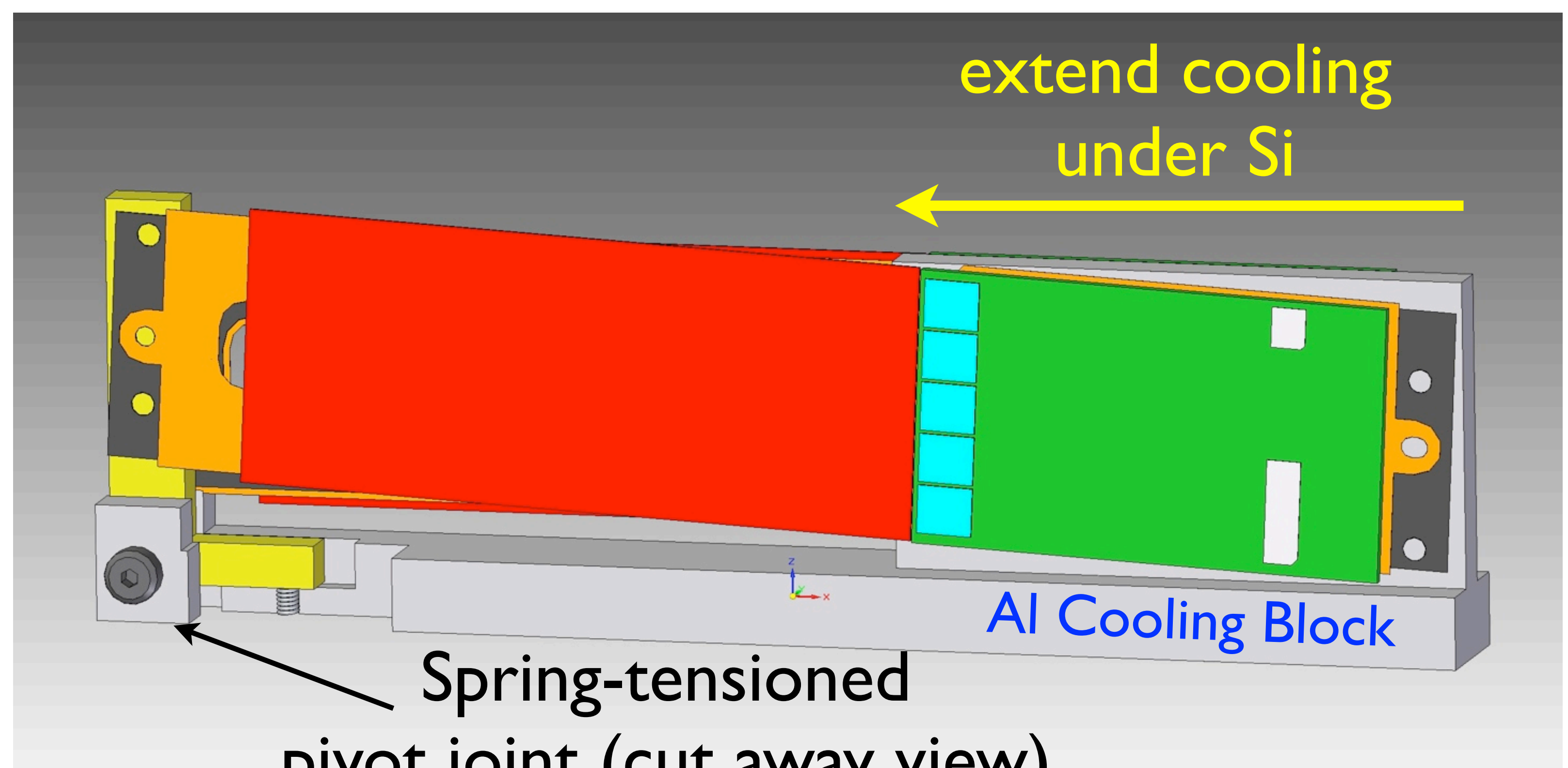
- better cooling to both ends of sensor reduces Δt to "hot spot" by ~80%
- support at both ends ensures overall straightness
- spring pivot with low-viscosity thermal compound keeps CF under tension:
    - stiffens/flattens half module
    - absorbs 60 μm differential contraction during 30˚C cooldown

A small, well-defined R&D project

HPS Test Sensor Cooling





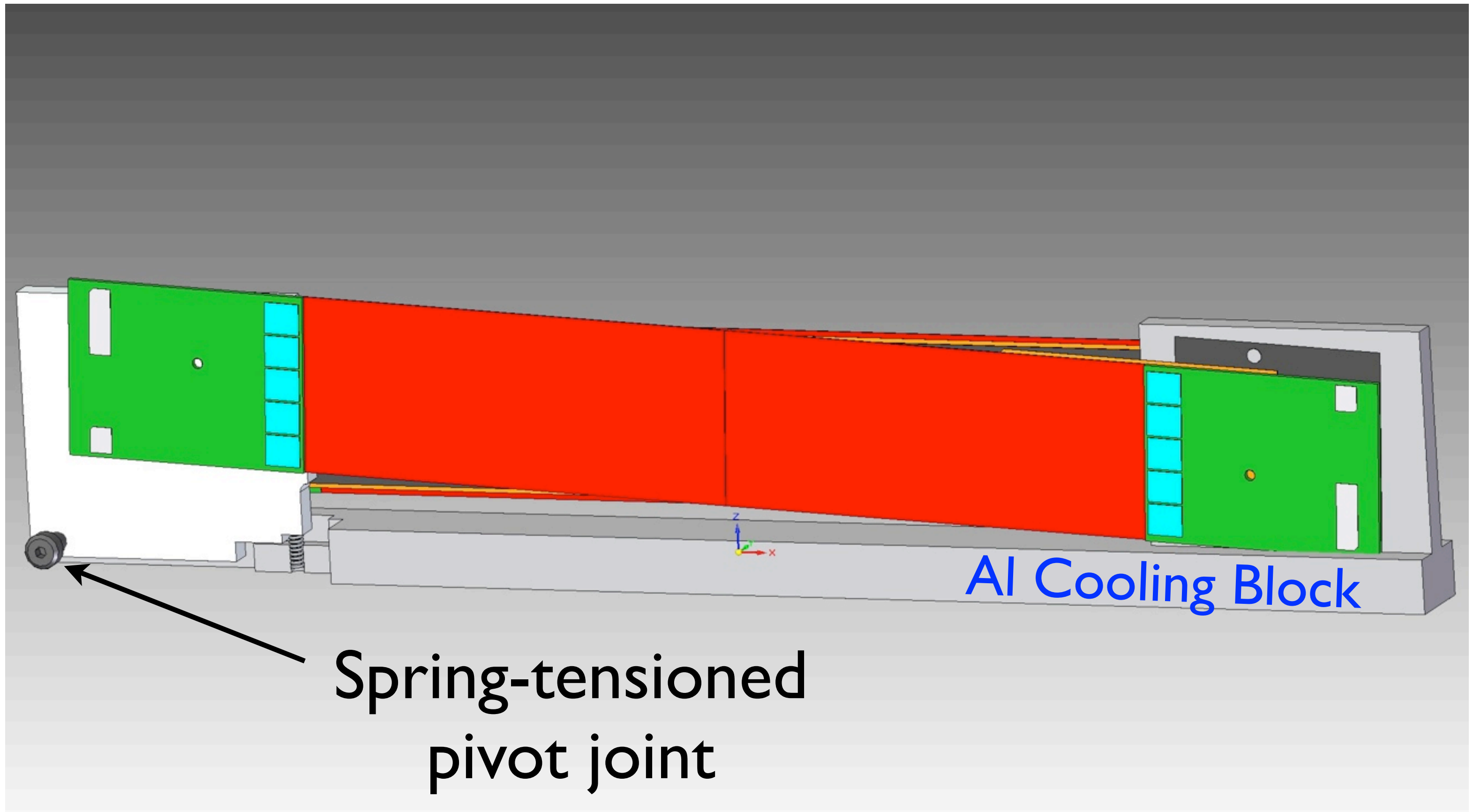


Layer 4-6 Modules

Extending concept to L4-L6 allows same material budget for long modules.

- Build new "double-ended" half-modules using same techniques as HPS Test.
  - similar CF frame, kapton passivation
  - shorter hybrid design omits unnecessary components, uses flex pigtails

A project similar in scope to building HPS Test modules

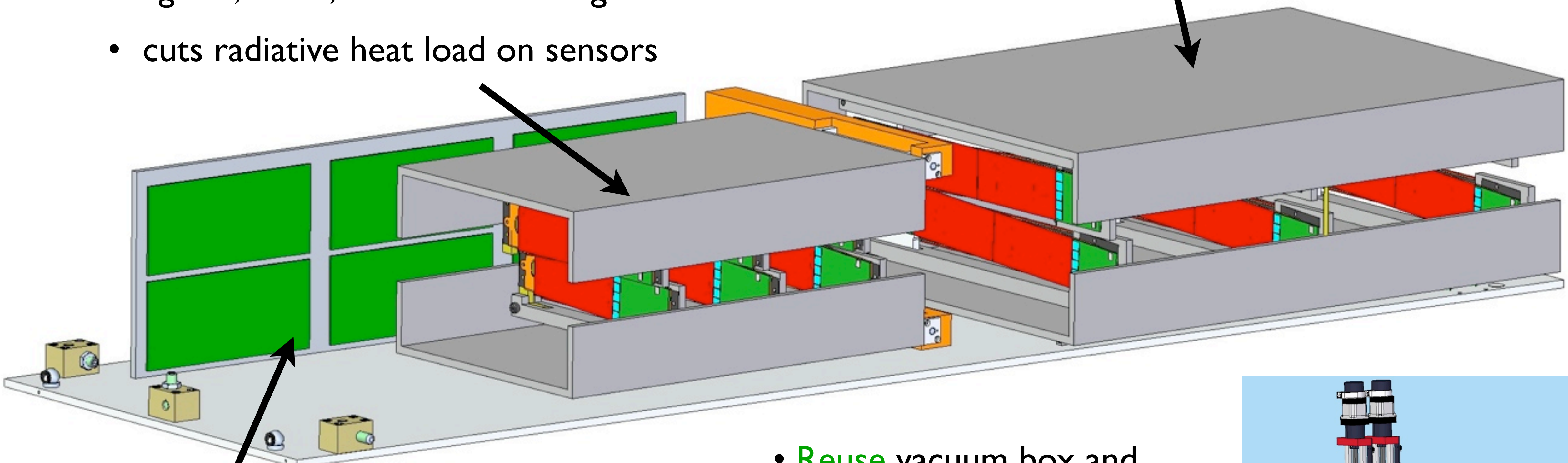


Support, Cooling and Services

Cooled support channels for L1-L3

- *reuse c-support, motion levers*
- lighter, stiffer, shorter = less sag
- cuts radiative heat load on sensors

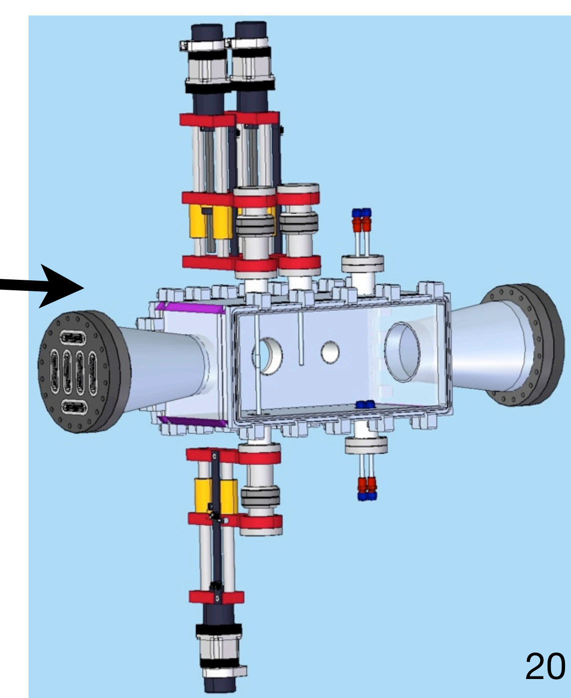
Cooled support channels for L4-L6 are stationary



DAQ/power inside chamber on cooling plate

- Reduces readout plant
- Low-neutron region (upstream, e^{+} side)
- Board spacing minimizes flex cable designs

- Reuse vacuum box and linear shifts with new vacuum flanges
- New chiller operable to -10°C with 1°C stability.
- Use new Wiener MPODs for power



Roles and Responsibilities

Same tasks and personnel as Test SVT

SLAC - Graham, Hansson, Jaros, Maruyama, McCulloch, Nelson, Oriunno, Uemura

UCSC - Fadeyev, Grillo, McKinney, Moreno

FNAL - Cooper

CF frames
- Fabrication
- Machining
- Passivation

Hybrids
- Loading
- APV25 attach
- Wirebonding
- Testing

Sensors
- Qualification

Half Modules
- Hybrid attachment
- Sensor attachment
- HV Wirebonding
- Signal wirebonding
- Testing

Module Supports
- Fabrication
- Assembly

Modules
- Module assembly
- Final testing
- Survey

Support Channels
- Machining
- Assembly
- Cooling installation
- Cable installation
- Survey

Tracker Halves
- Module installation
- Service dressing
- System testing
- Survey

Base Plate
- Plate machining
- C-support fab./inst.
- Lever fab./inst.
- Fiducial fab/inst
- Survey

Project Budget

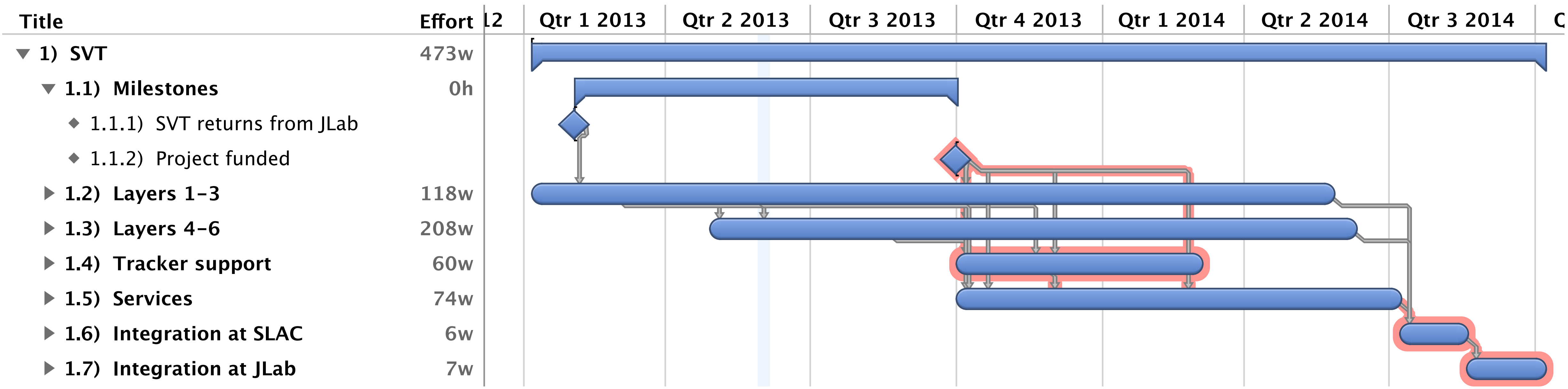
- *SVT "upgrades" have been designed around scope we understand; scope of the Test SVT*
- *Budget includes significant contingency beyond what was actually spent on HPS Test*

	Labor (w/ cont.)	Material (w/ cont.)	Total (w/ cont.)	Capital Eq.
Layers 1-3	$66K	$37K	$103K	$103K
Layers 4-6	$107K	$86K	$193K	$175K
Support, Cooling, Vacuum	$143K	$20K	$163K	$107K
Testing, Shipping, Integration	$136K	$61K	$197K	$154K
Total	$452K	$204K	$656K	$539K

Biggest items are completely new modules for Layers 4-6 and testing/integration at SLAC.

Schedule

Comfortable padding relative to schedule for HPS Test but still quite busy with funding delay.

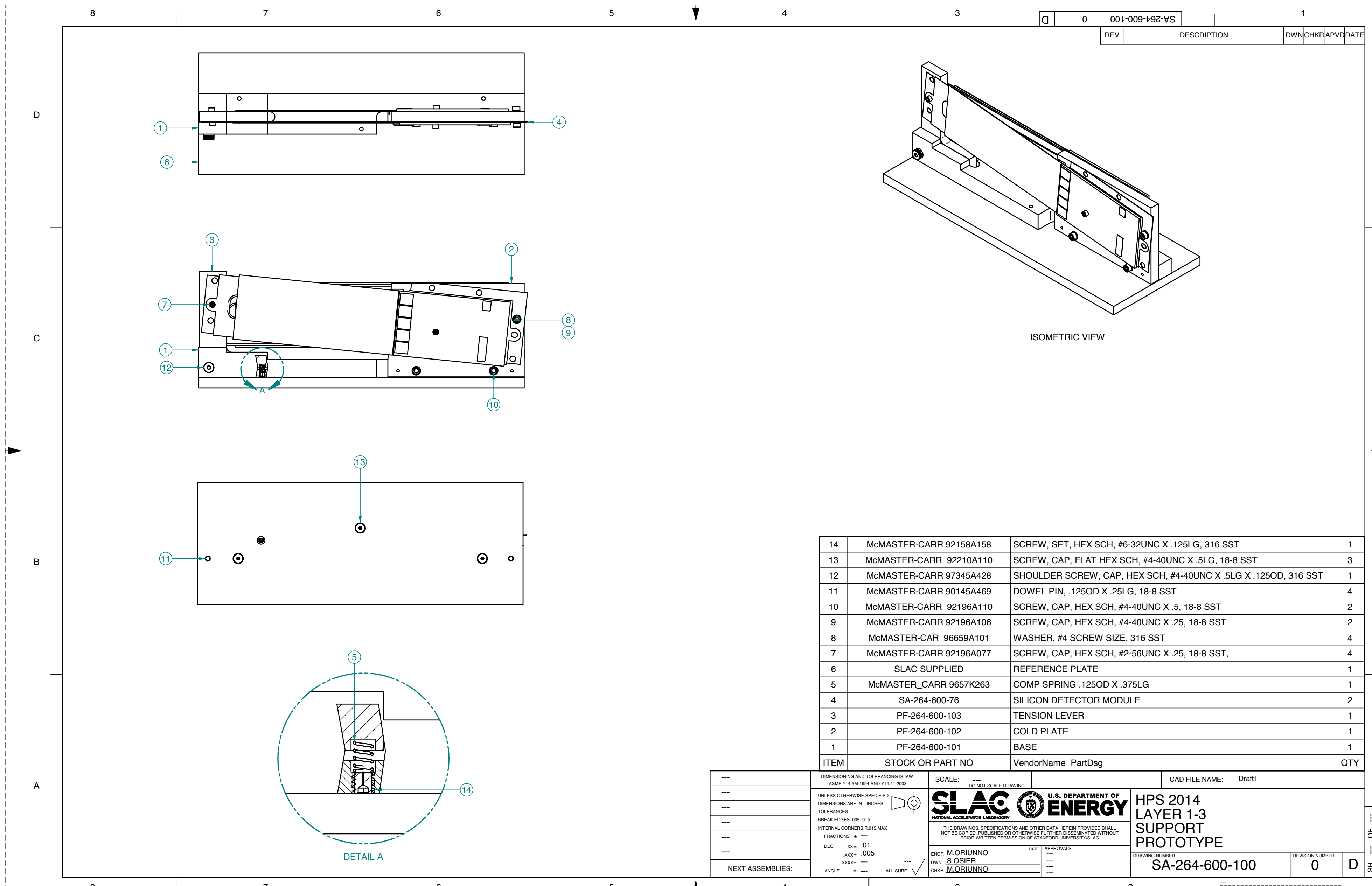


Three critical tasks during "keepalive" period:

- Development and production of new supports for Layers 1-3: *well underway*
- Development and prototyping of new half-modules for Layers 4-6: *begun*
- Early design work on new support plates: *not yet started*

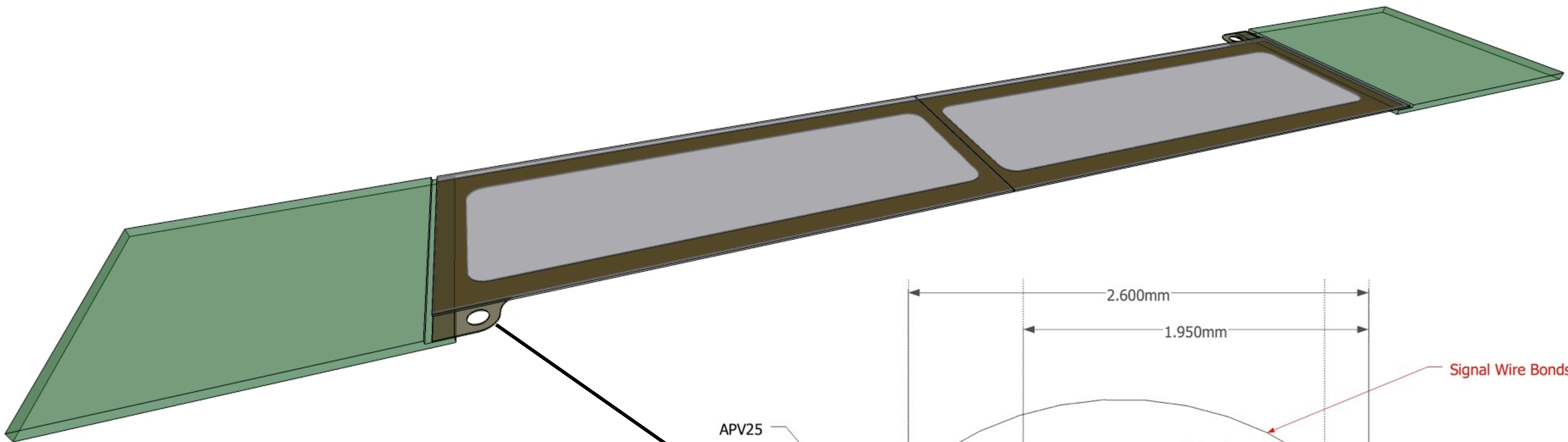
Layer 1-3 Supports

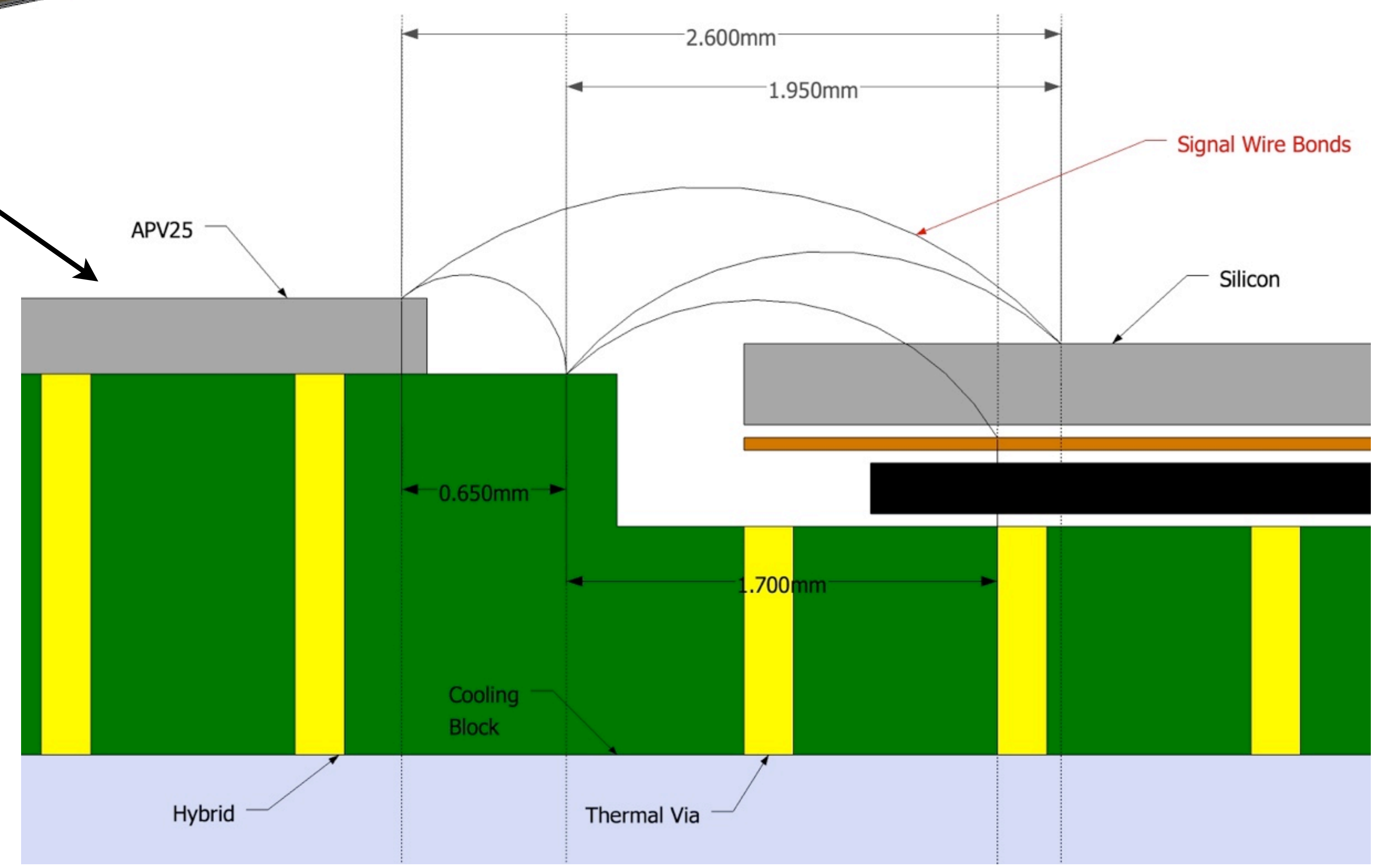
- Drawings for prototype are complete.
- 1 week turn at SLAC for ~$3K could begin tomorrow.
- Have bid from outside shop of $1K (3 weeks)
- Want prototype before review!



ITEM	STOCK OR PART NO	VendorName_PartDsg	QTY
14	McMASTER-CARR 92158A158	SCREW, SET, HEX SCH, #6-32UNC X .125LG, 316 SST	1
13	McMASTER-CARR 92210A110	SCREW, CAP, FLAT HEX SCH, #4-40UNC X .5LG, 18-8 SST	3
12	McMASTER-CARR 97345A428	SHOULDER SCREW, CAP, HEX SCH, #4-40UNC X .5LG X .125OD, 316 SST	1
11	McMASTER-CARR 90145A469	DOWEL PIN, .125OD X .25LG, 18-8 SST	4
10	McMASTER-CARR 92196A110	SCREW, CAP, HEX SCH, #4-40UNC X .5, 18-8 SST	2
9	McMASTER-CARR 92196A106	SCREW, CAP, HEX SCH, #4-40UNC X .25, 18-8 SST	2
8	McMASTER-CAR 96659A101	WASHER, #4 SCREW SIZE, 316 SST	4
7	McMASTER-CARR 92196A077	SCREW, CAP, HEX SCH, #2-56UNC X .25, 18-8 SST,	4
6	SLAC SUPPLIED	REFERENCE PLATE	1
5	McMASTER_CARR 9657K263	COMP SPRING .125OD X .375LG	1
4	SA-264-600-76	SILICON DETECTOR MODULE	2
3	PF-264-600-103	TENSION LEVER	1
2	PF-264-600-102	COLD PLATE	1
1	PF-264-600-101	BASE	1

Layer 4-6 Half-Module Design





Similar to L1-L3 design, but...

- ends of CF/Si supported by hybrid
- bias supply on Kapton passivation
- CF ground by silver epoxy between Cu pad on CF and thermal vias

➡ separate heat path for silicon

➡ 30% shorter wire bonds with better support under bonding region on Si

currently developing assembly fixture concept along with design details required for assembly.

Summary

- The HPS Test SVT got most things right and performed well
  - Met key performance parameters for material, position and time resolution.
  - Less-than 100% coverage mostly resulted from lack of time for testing/debugging.
  - Acceptance, redundancy, mechanical precision, and cooling could be improved.
- Modest upgrades to the Test SVT can address all of these
  - Project scope is, by design, very similar to that for HPS Test SVT
  - Schedule and budget are much less aggressive than for HPS Test
  - First steps on critical path are underway.
- Together with upgraded DAQ, the new SVT should deliver expected physics reach.