The HPS SVT

Tim Nelson - SLAC

HPS DOE Review

July 11, 2013

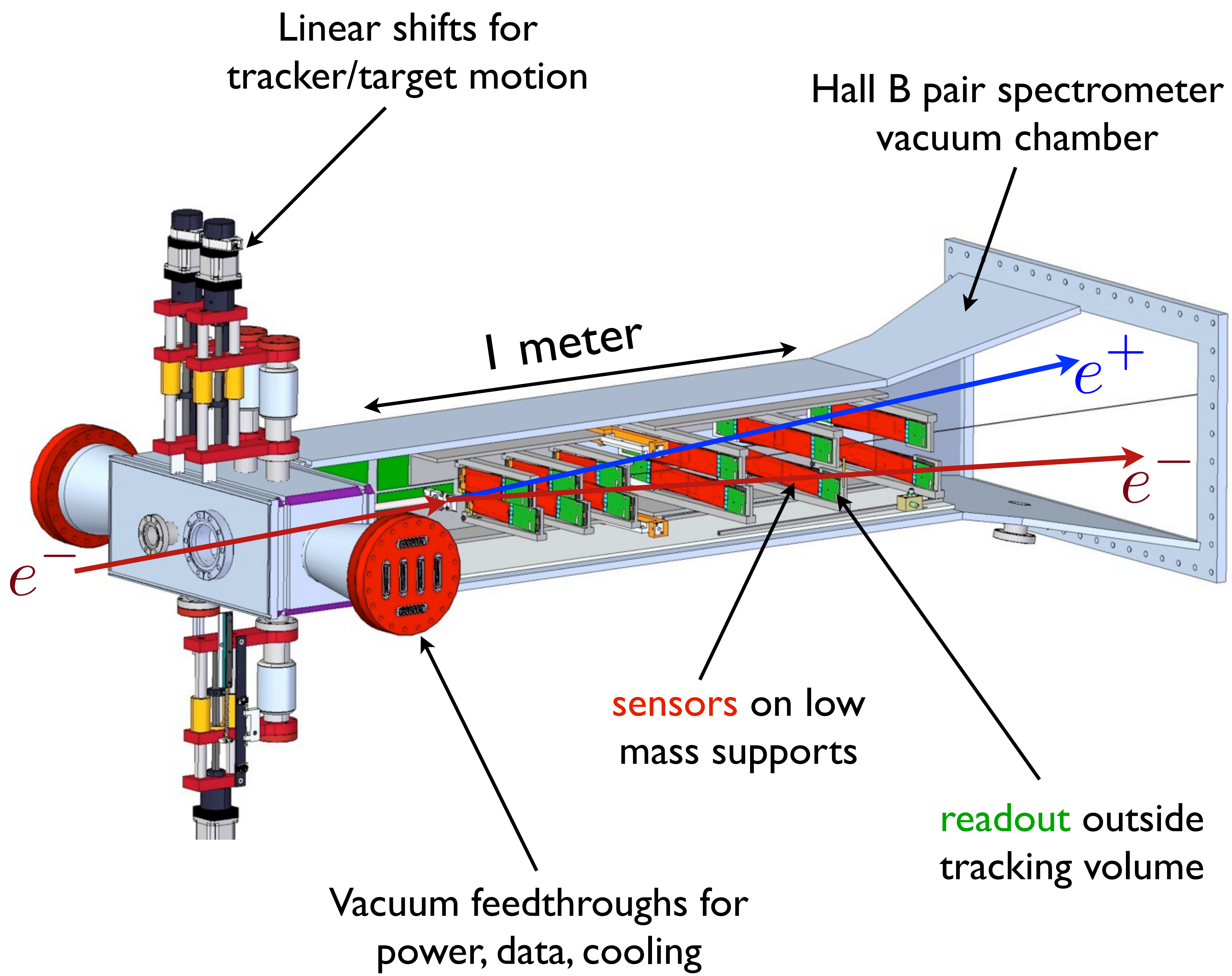
Outline

- 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

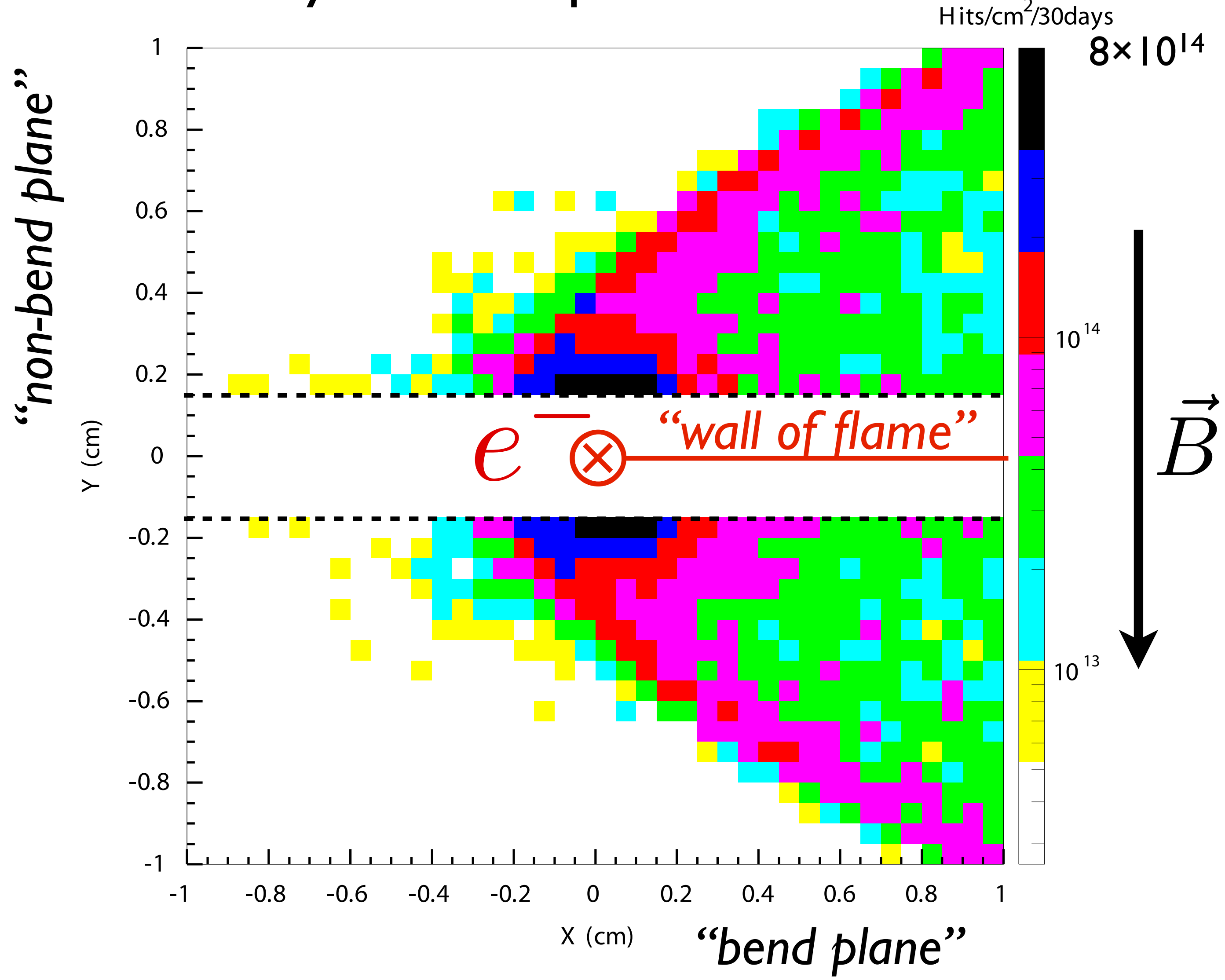
High-mass is simple in principle:
build it as big as you can afford!

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$^-$ ≅ 1.6×10^{14} neq. in 6 months of running

Layer 1 e$^-$ exposure / month



Sensor Selection

Also need...

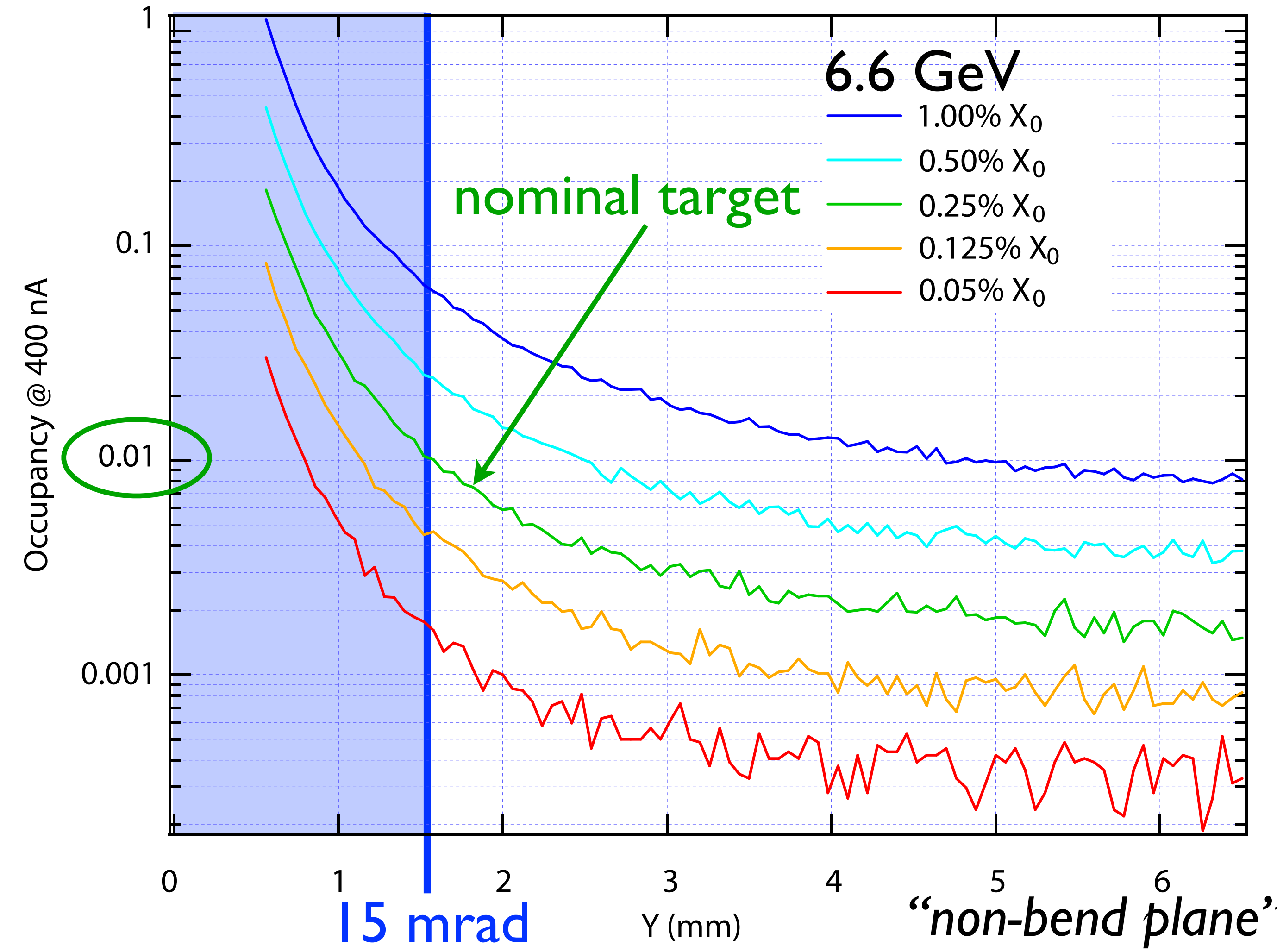
- < 1% X_0 per layer
- $\lesssim$ 50 μm single-hit resolution
  in both measurement coordinates
- < $1M for a complete system, soon!

~~MAPS~~?

~~Hybrid pixels~~?

➡ *Strip sensors (edges 500 μm from beam!)*

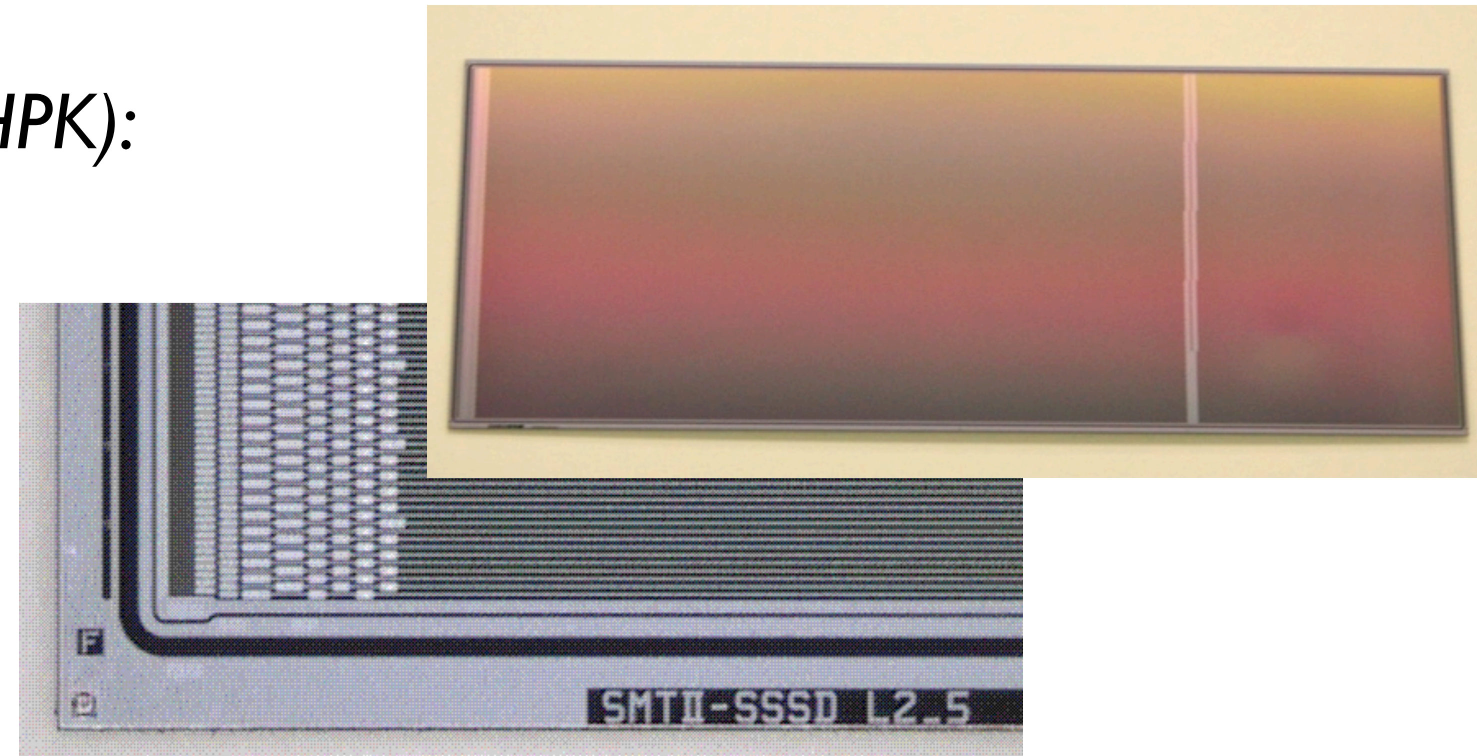
Layer 1 strip occupancy / 8 ns trigger window



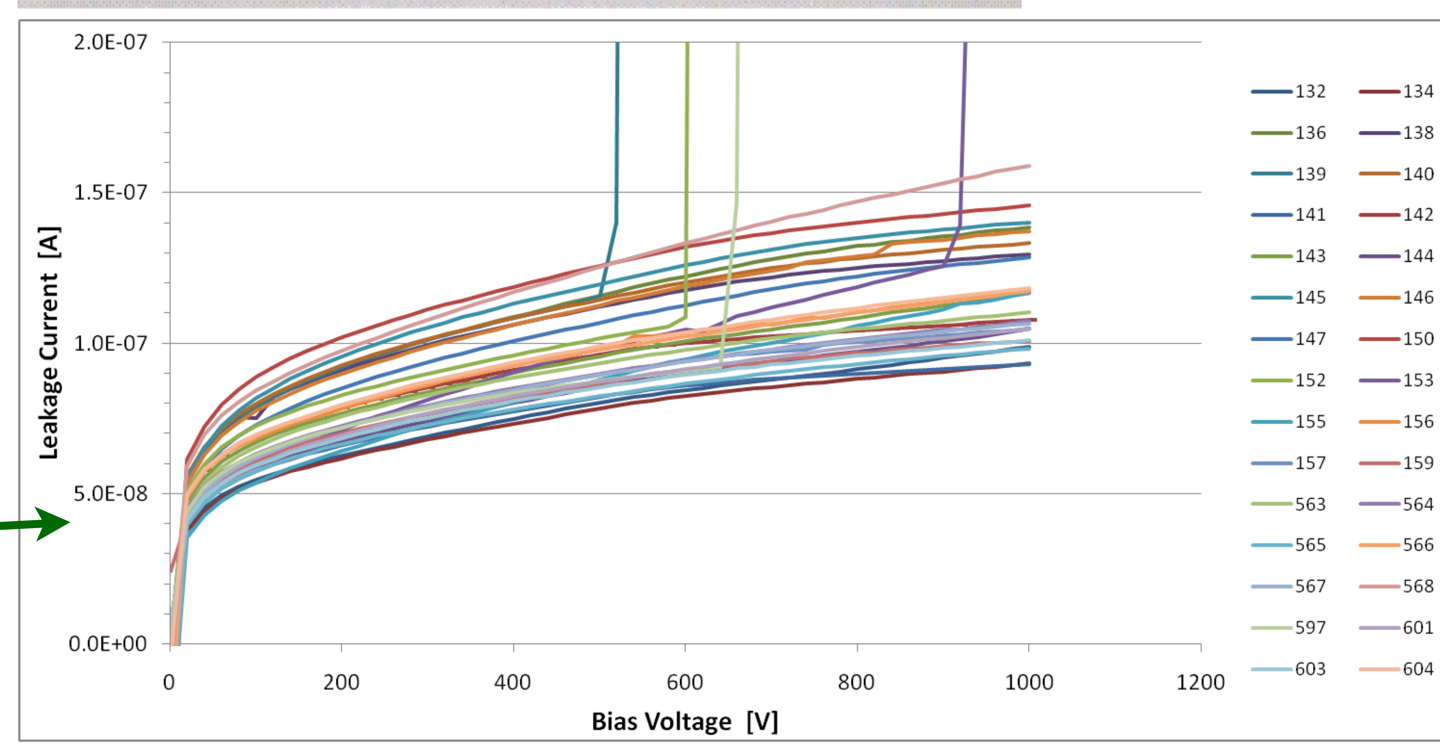
Silicon Microstrip Sensors

Production Tevatron RunIIb sensors (HPK):

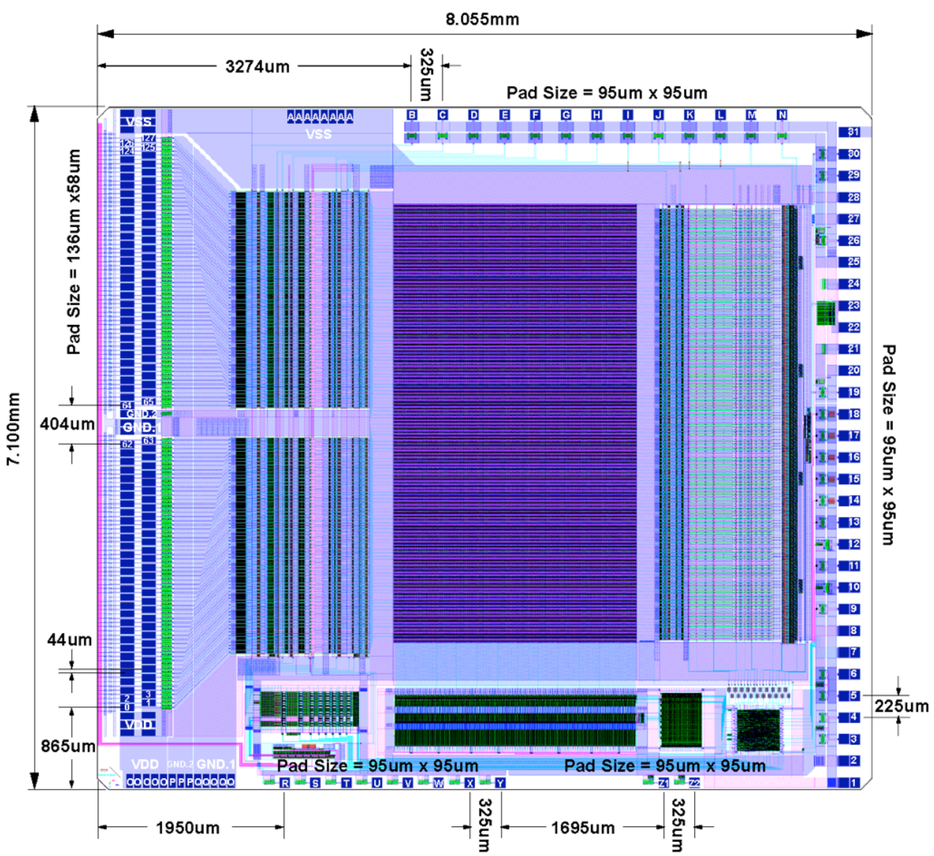
- Fine readout granularity
- most capable of 1000V bias:
  fully depleted for 6 month run.
- Available in sufficient quantities
- Cheapest technology
  (contribution from FNAL)



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%**



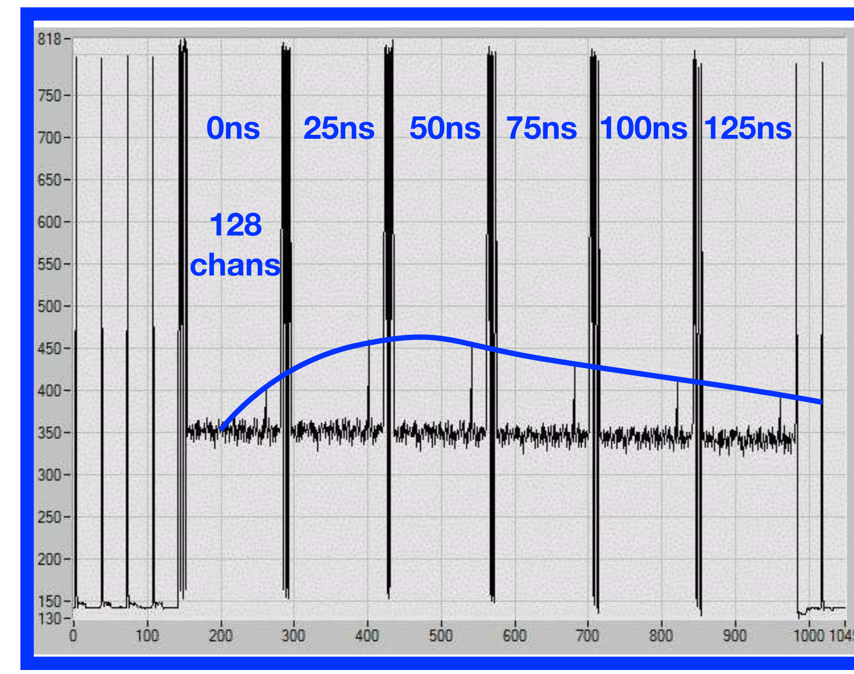
Front-end Electronics: APV25

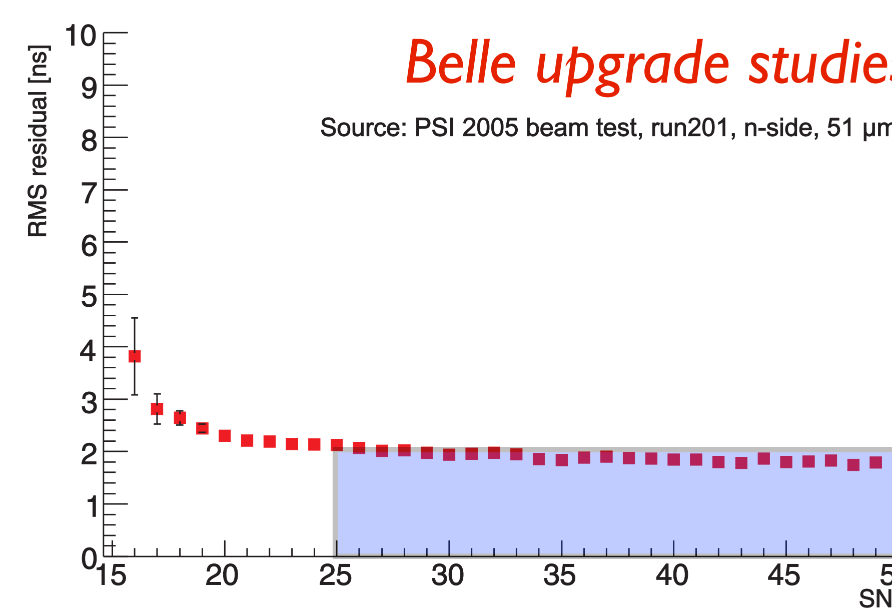


# Readout Channels	128
Input Pitch	44 µm
Shaping Time	50ns nom. (35ns min.)
Noise Performance	270+36×C(pF) e- ENC
Power Consumption	345 mW

Developed for CMS

- available (~~28~~ *15!* 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

A relatively large and expensive detector.

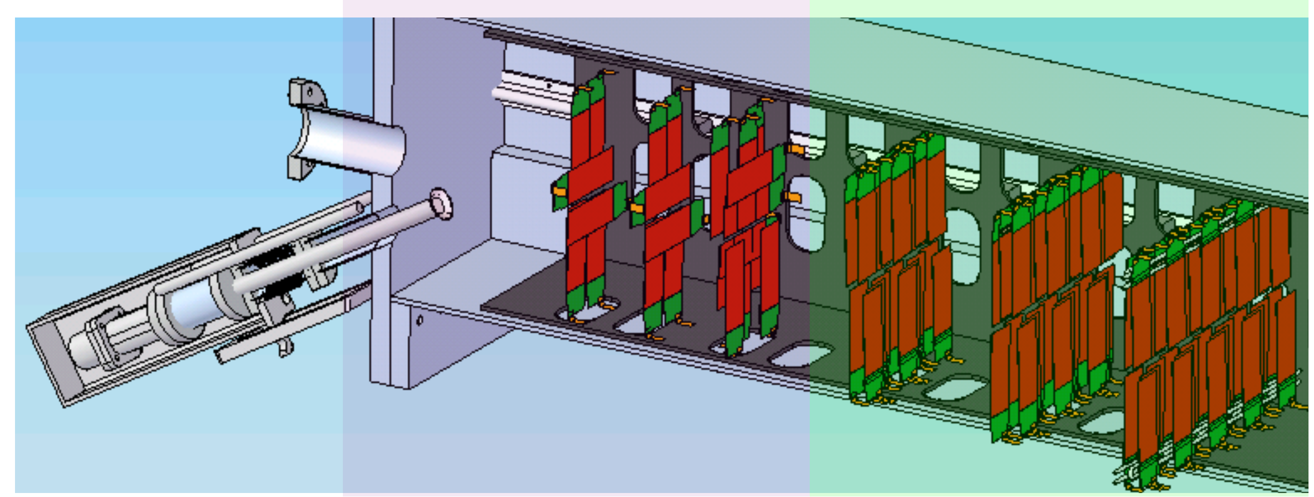
Requires large magnet, vacuum chamber and ECal also.

How do we prove this works?

	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

Vertexing | Pattern Recognition

M o m e n t u m

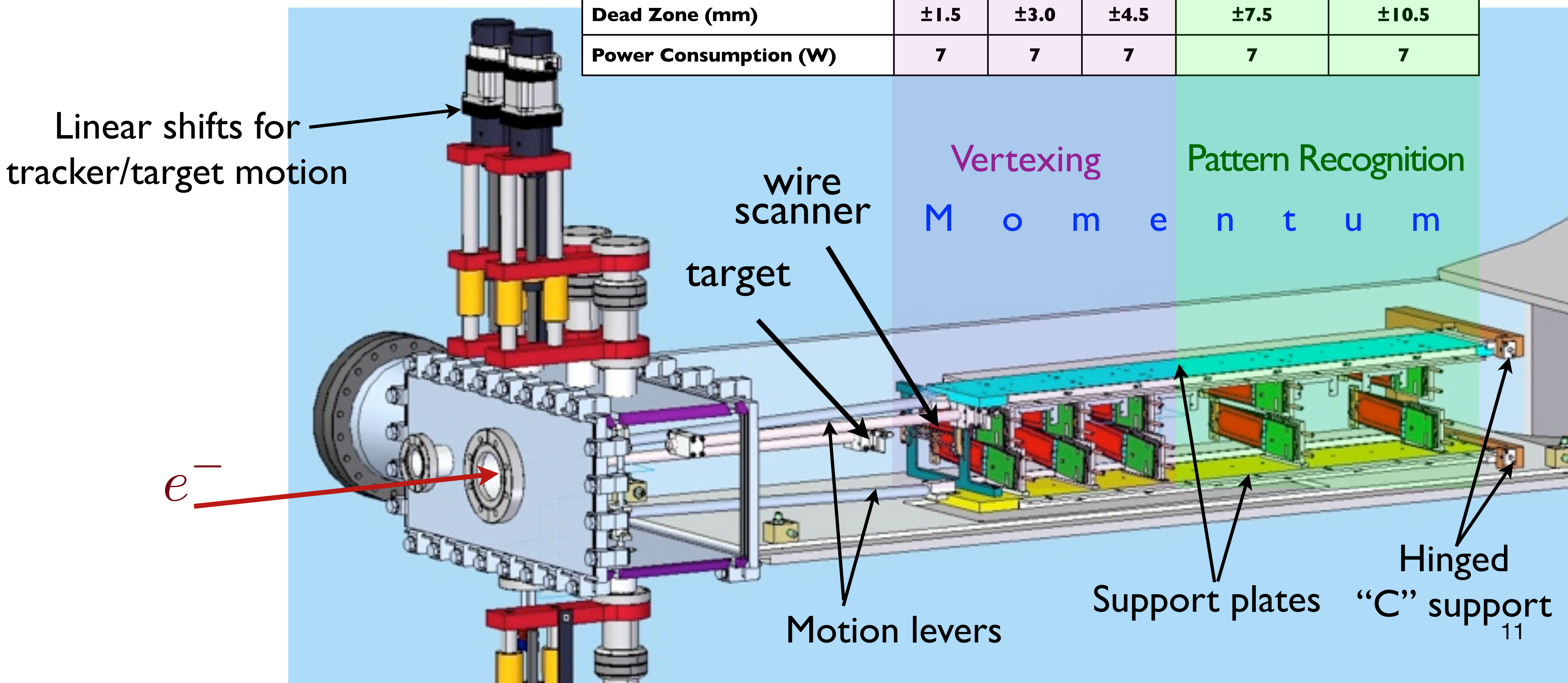


HPS Test SVT

Proposed 3/11, Installed 4/12

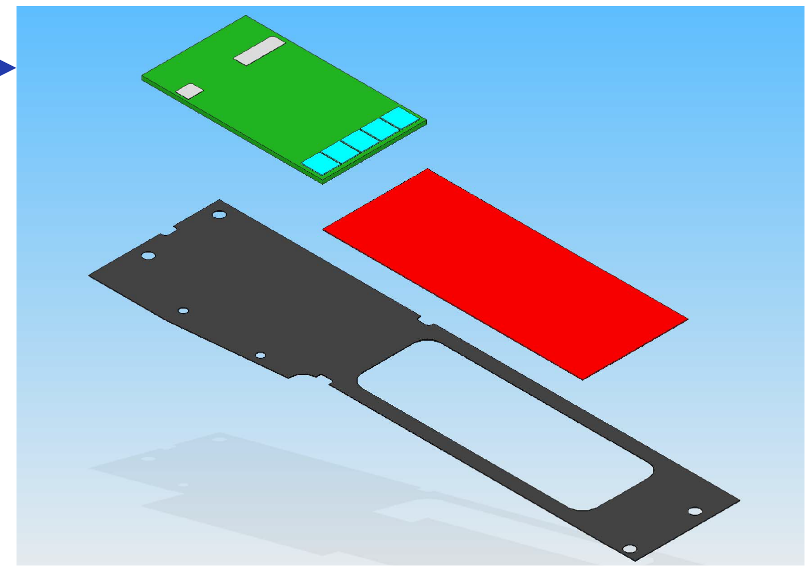
- Develop technical solutions
- Prove operational principles
- Capable of A' physics

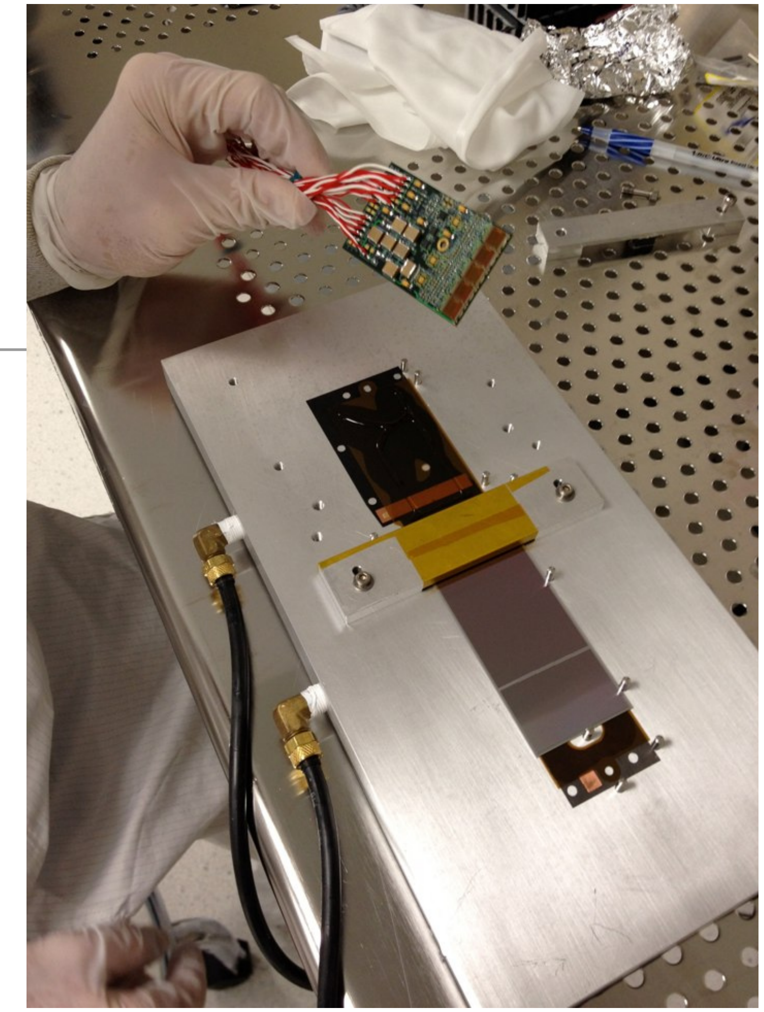
	Layer 1	Layer 2	Layer 3	Layer 4	Layer 5
z position, from target (cm)	**10**	**20**	**30**	**50**	**70**
Stereo Angle (mrad)	**100**	**100**	**100**	**50**	**50**
Bend Plane Resolution (μm)	**≈ 60**	**≈ 60**	**≈ 60**	**≈ 120**	**≈ 120**
Non-Bend Resolution (μm)	**≈ 6**	**≈ 6**	**≈ 6**	**≈ 6**	**≈ 6**
# 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

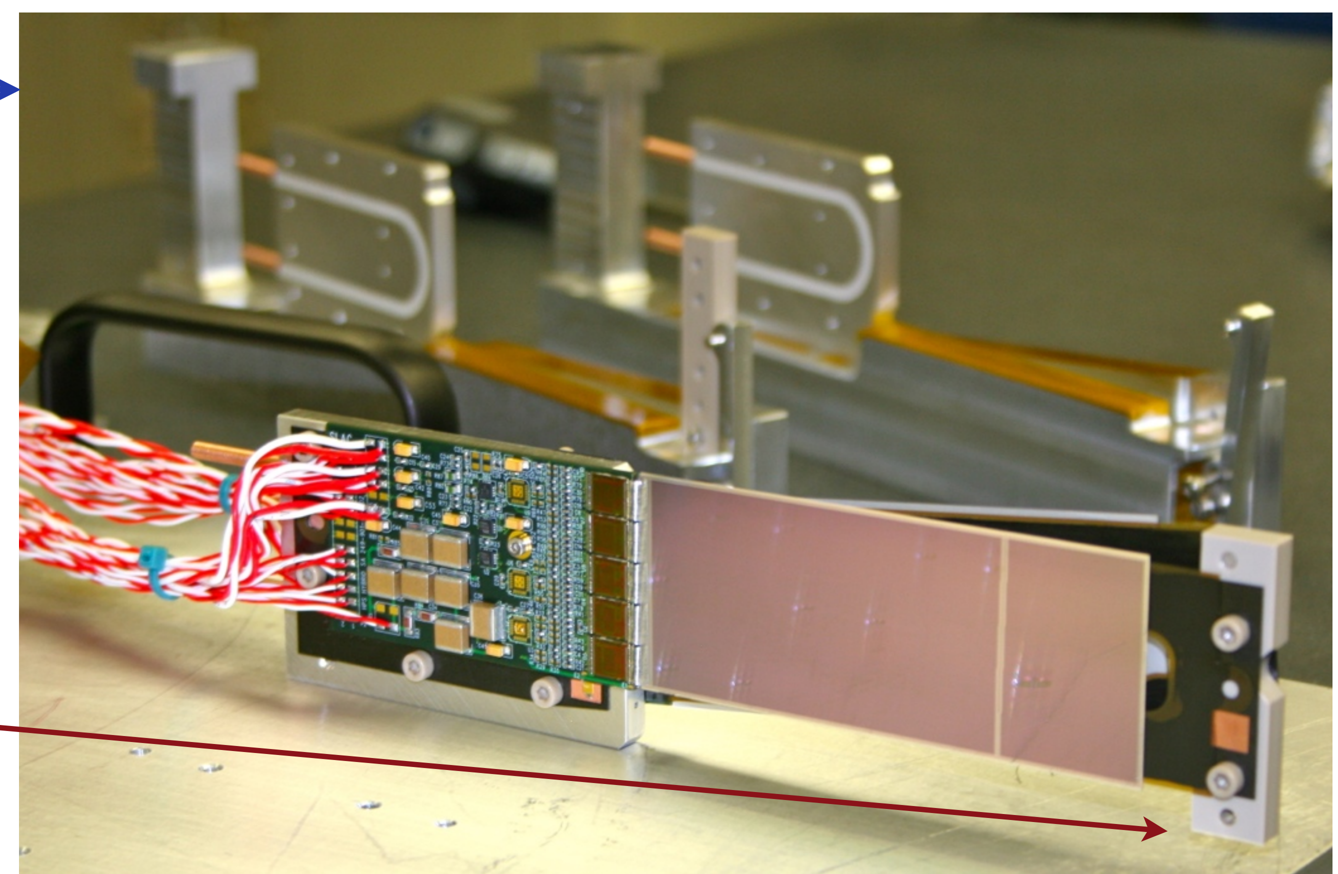
Half Module





- 0.17 mm thick CF frame (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

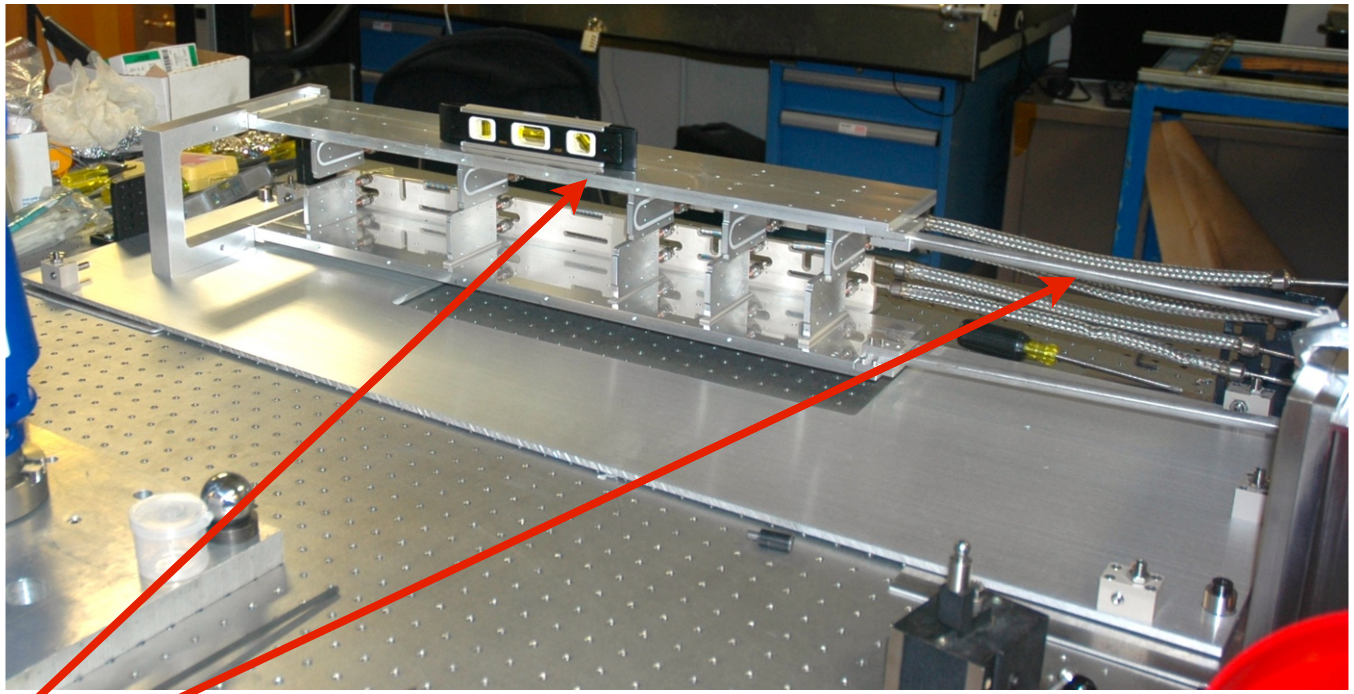
Limits flatness/stability of Si

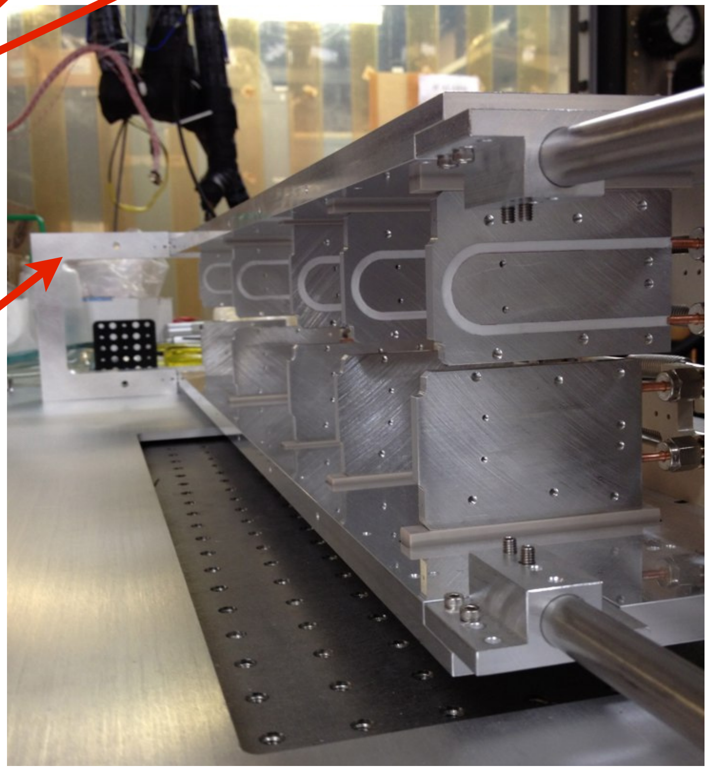
Test SVT Mechanics

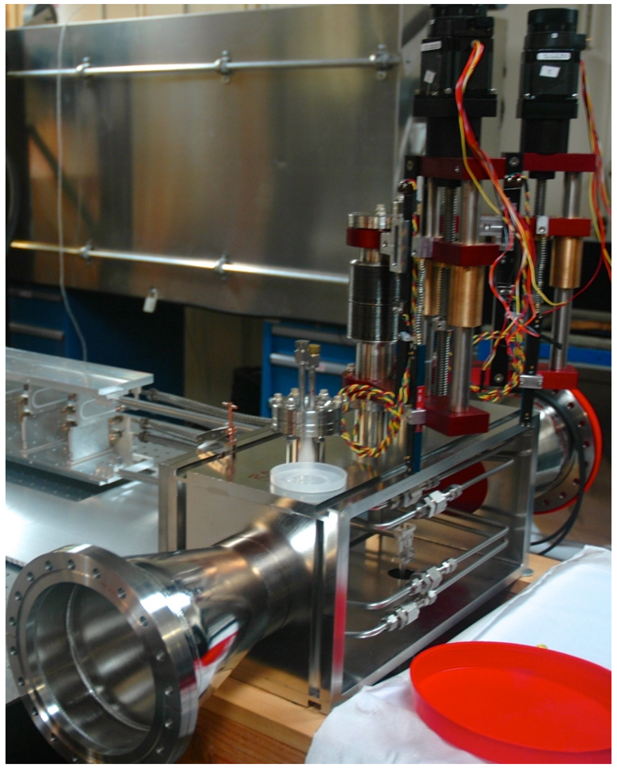
Cooling blocks mount on Al support plates with hinged "C-support" and motion lever

- 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 small roll in top plate.

Works, but can be improved upon

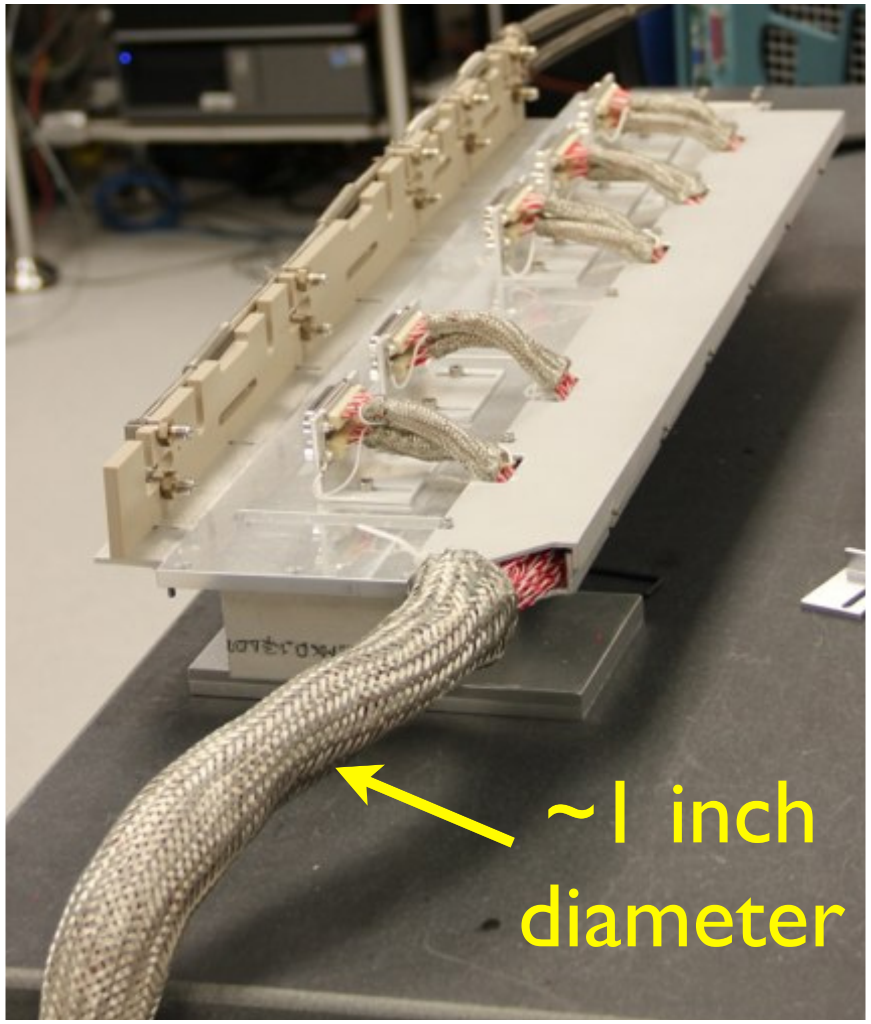


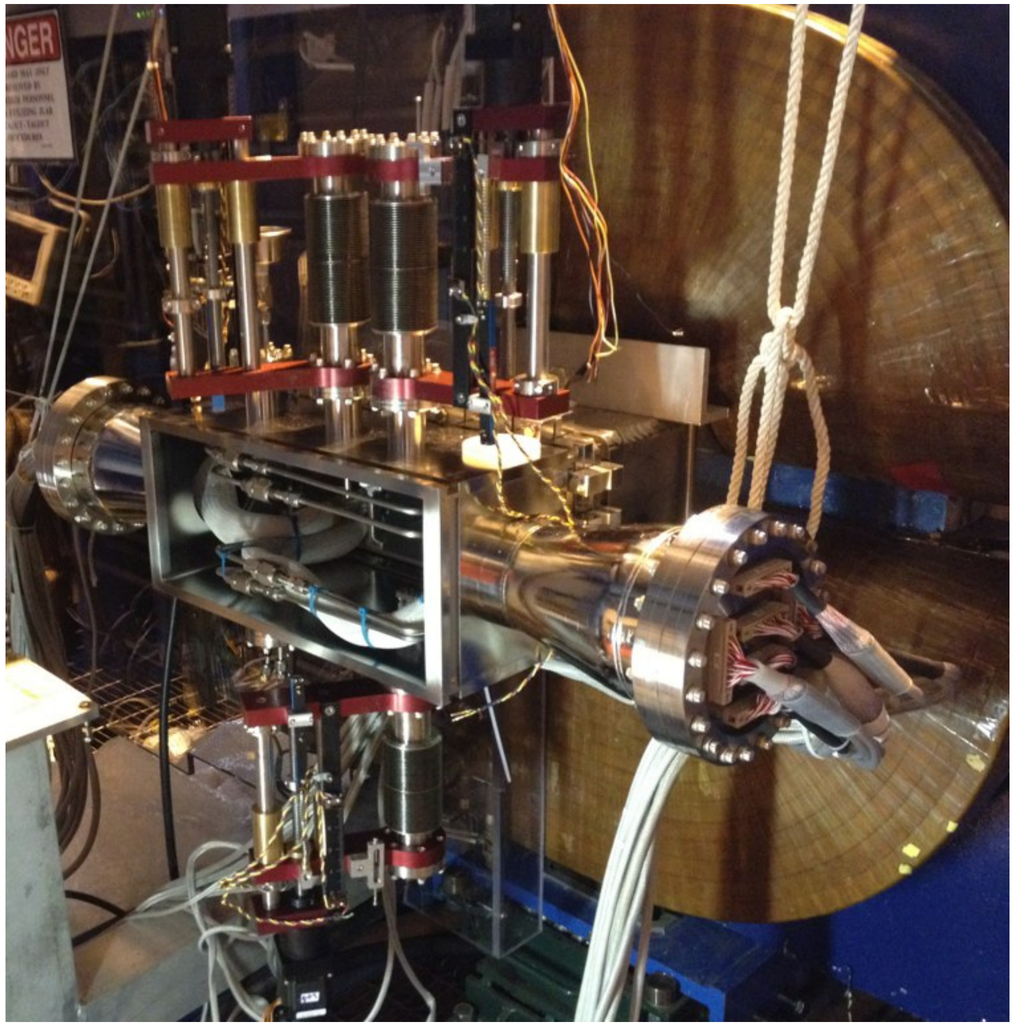




Test SVT Services

- 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



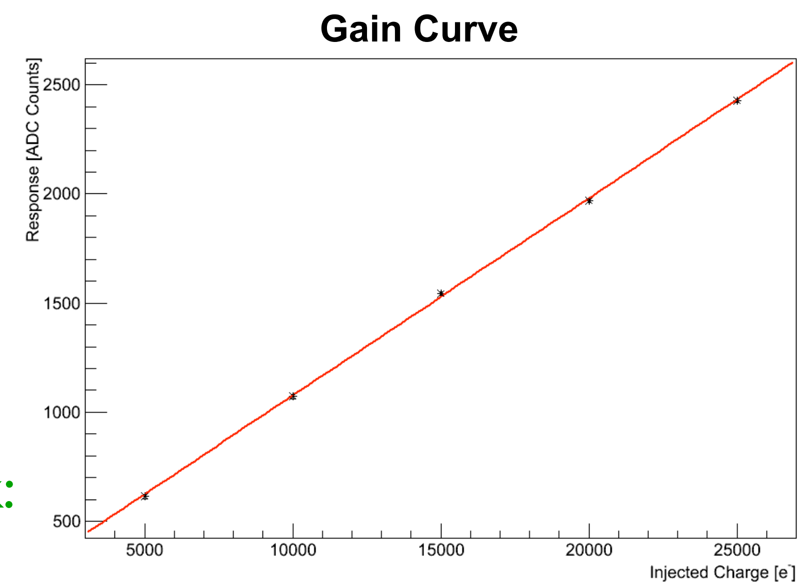


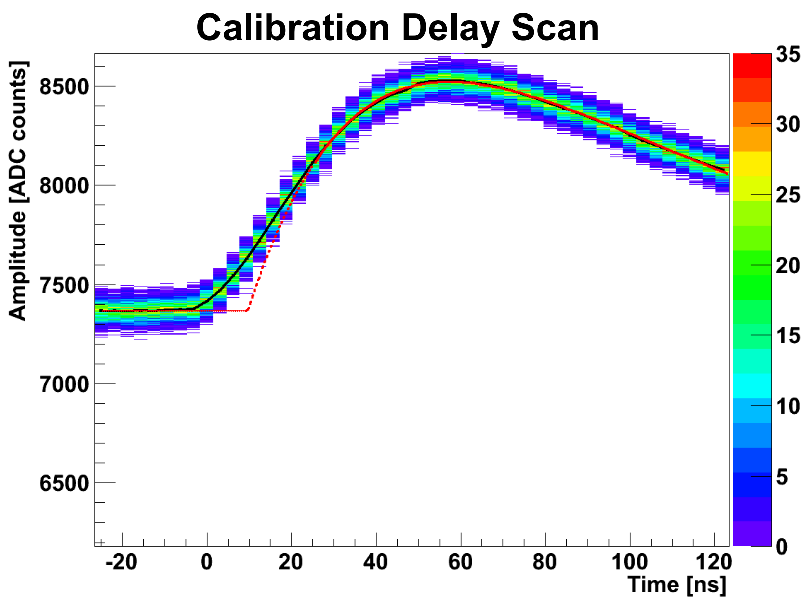
We got away with this, but it doesn't scale well to a larger detector.

Test SVT Assembly, Commissioning, Operation

At SLAC:

- Began with 165 APV25 (enough for 33 hybrids)
- 29/30 hybrids passed QA
- 28/29 half-modules passed QA
- Good noise, linearity, uniformity
- Assembly precision at cooling block: x-y ~10 μm, z ~ 25 μm
- Flatness (z) along sensor ~200 μm

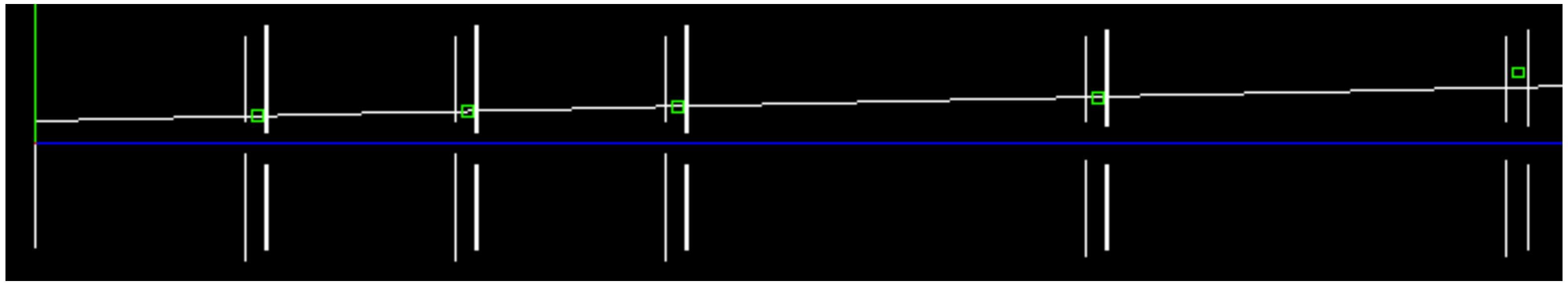




At JLab:

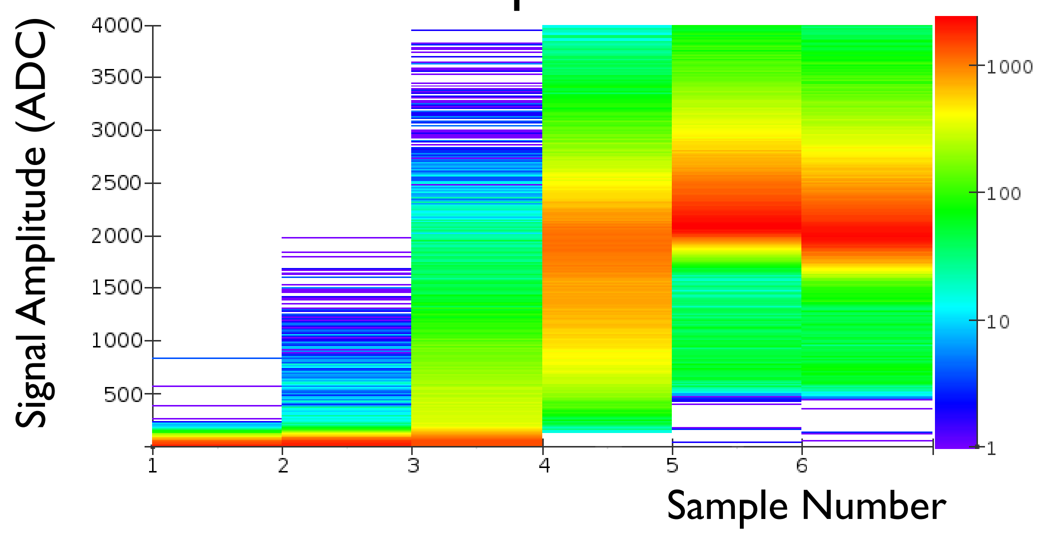
- Installed in Hall B on April 19 for parasitic photon run
- all chips responding
- no problems with vacuum

From: Graham, Mathew Thomas <mgraham@slac.stanford.edu>
Subject: tracks, I think...
Date: May 3, 2012 3:10:54 PM PDT

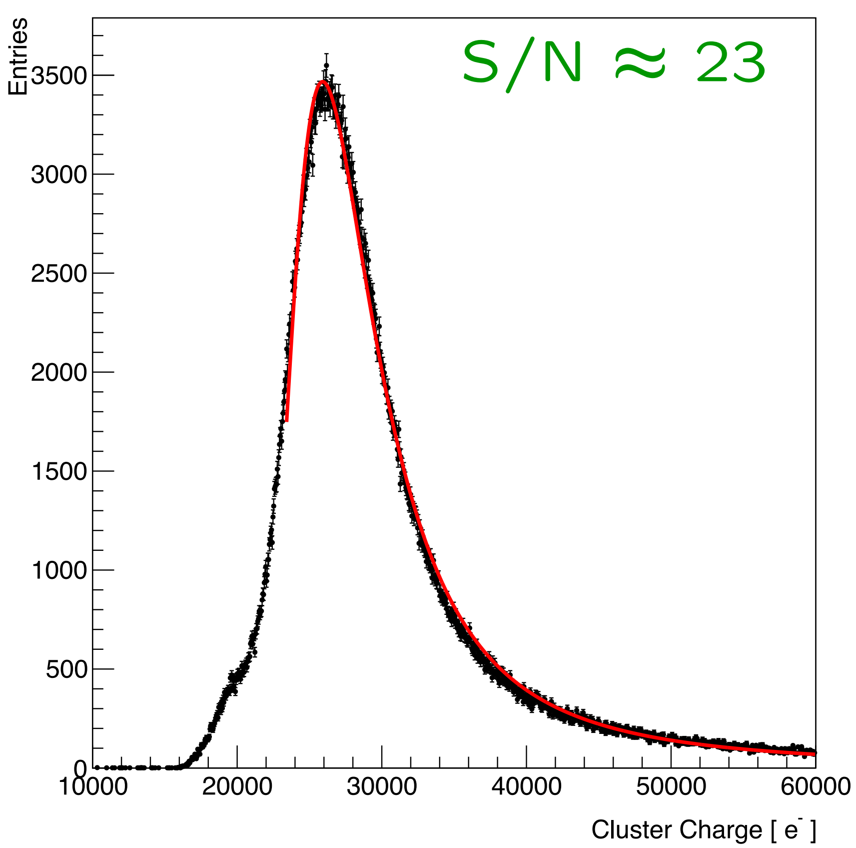


Test SVT Amplitude and Time Reconstruction

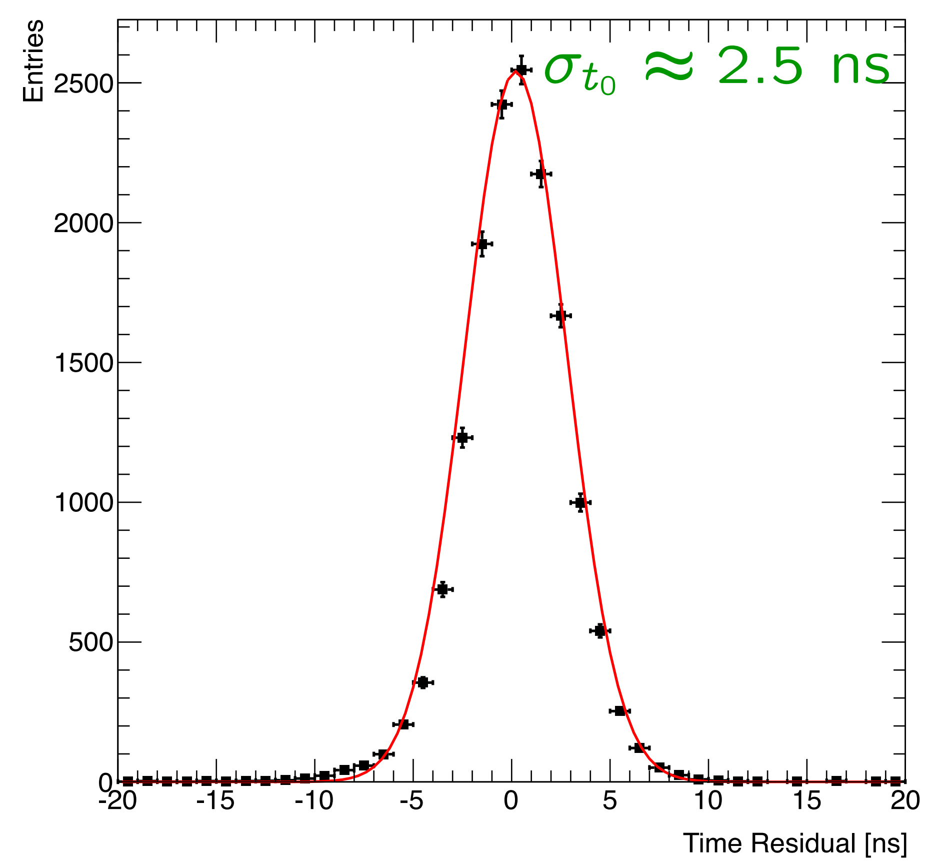
Raw Amplitude Data



Cluster Charge Reconstruction



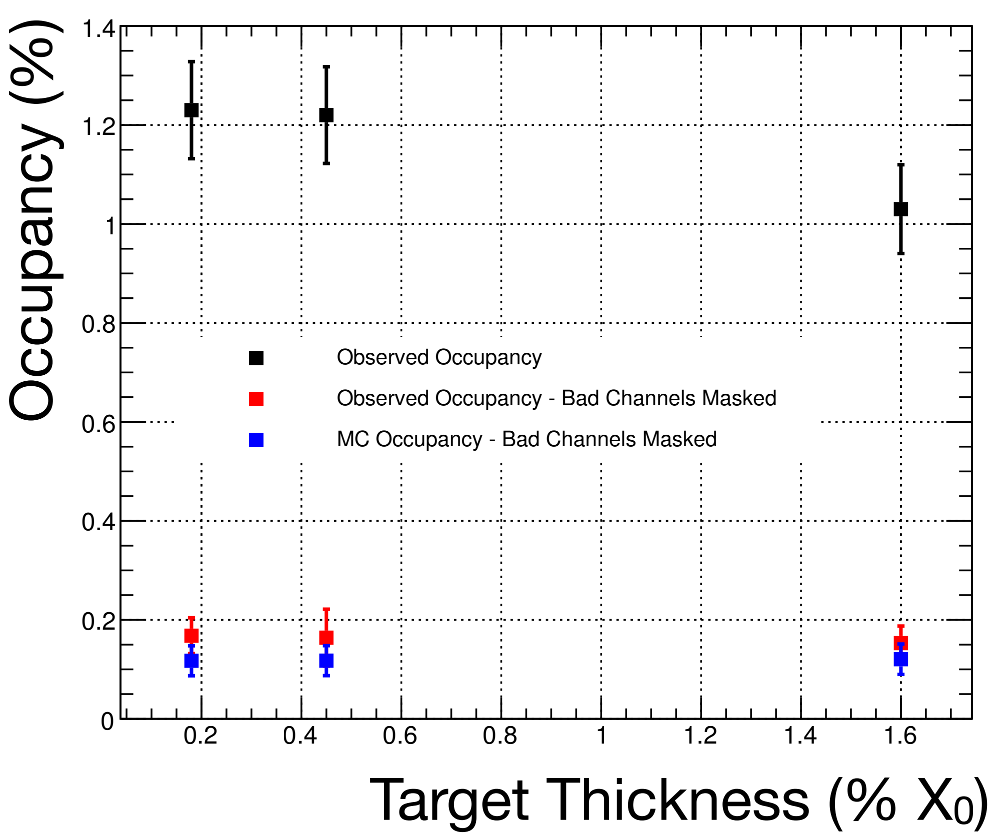
Hit Time Reconstruction

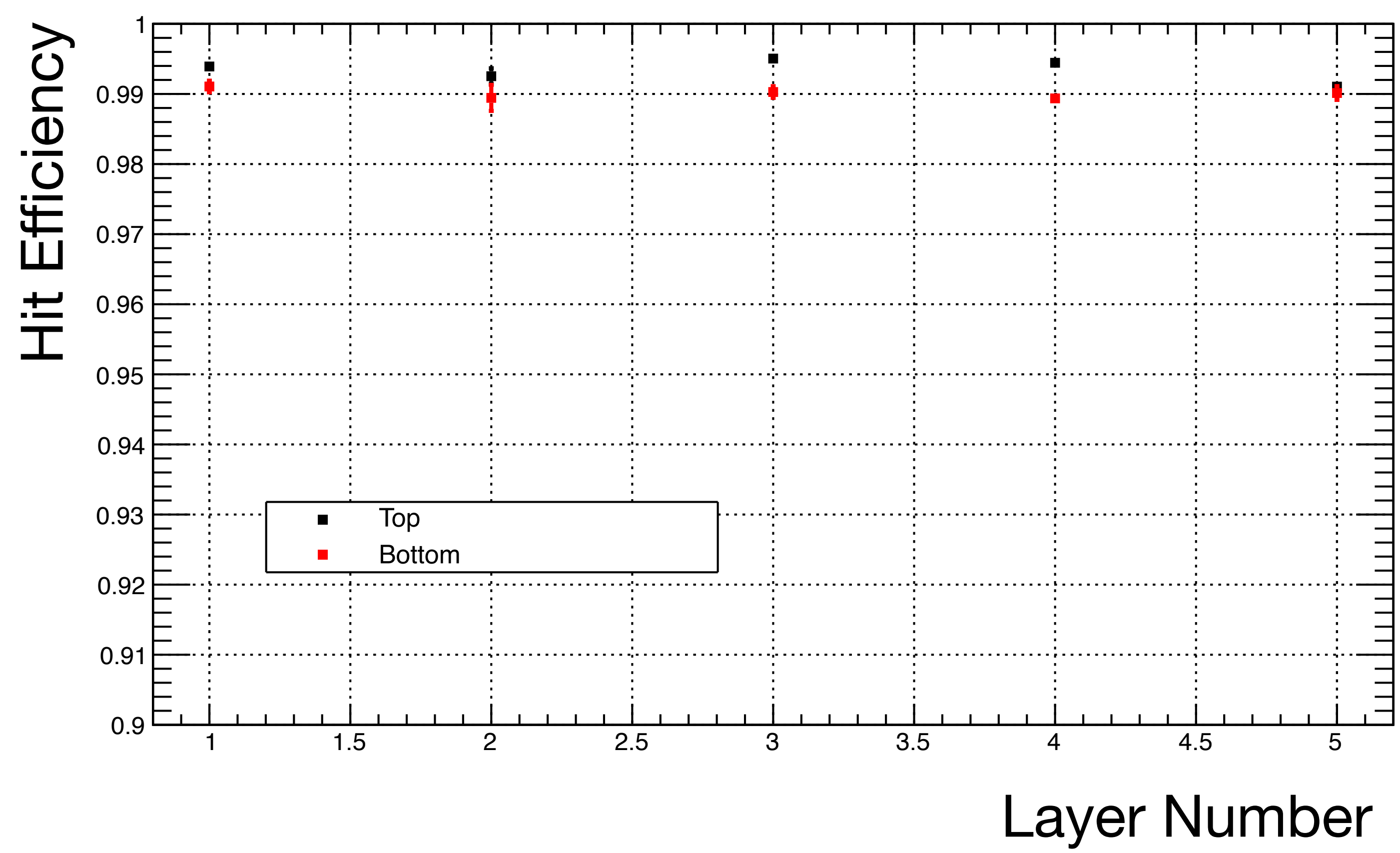


Test SVT Hit Occupancy and Efficiency

With noisy channels masked, occupancy is as expected...

and efficiency for finding hits on tracks is >99%.





HPS 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 efficiency, spatial and time resolution
- We can integrate SVT DAQ with JLab ECal DAQ and trigger
- *We can do better for the HPS SVT,*
  - Larger acceptance and better redundancy
  - Modules with flatter, colder sensors
  - Improved support rigidity
  - More reliable interconnect strategy
  - Fully tested and debugged DAQ

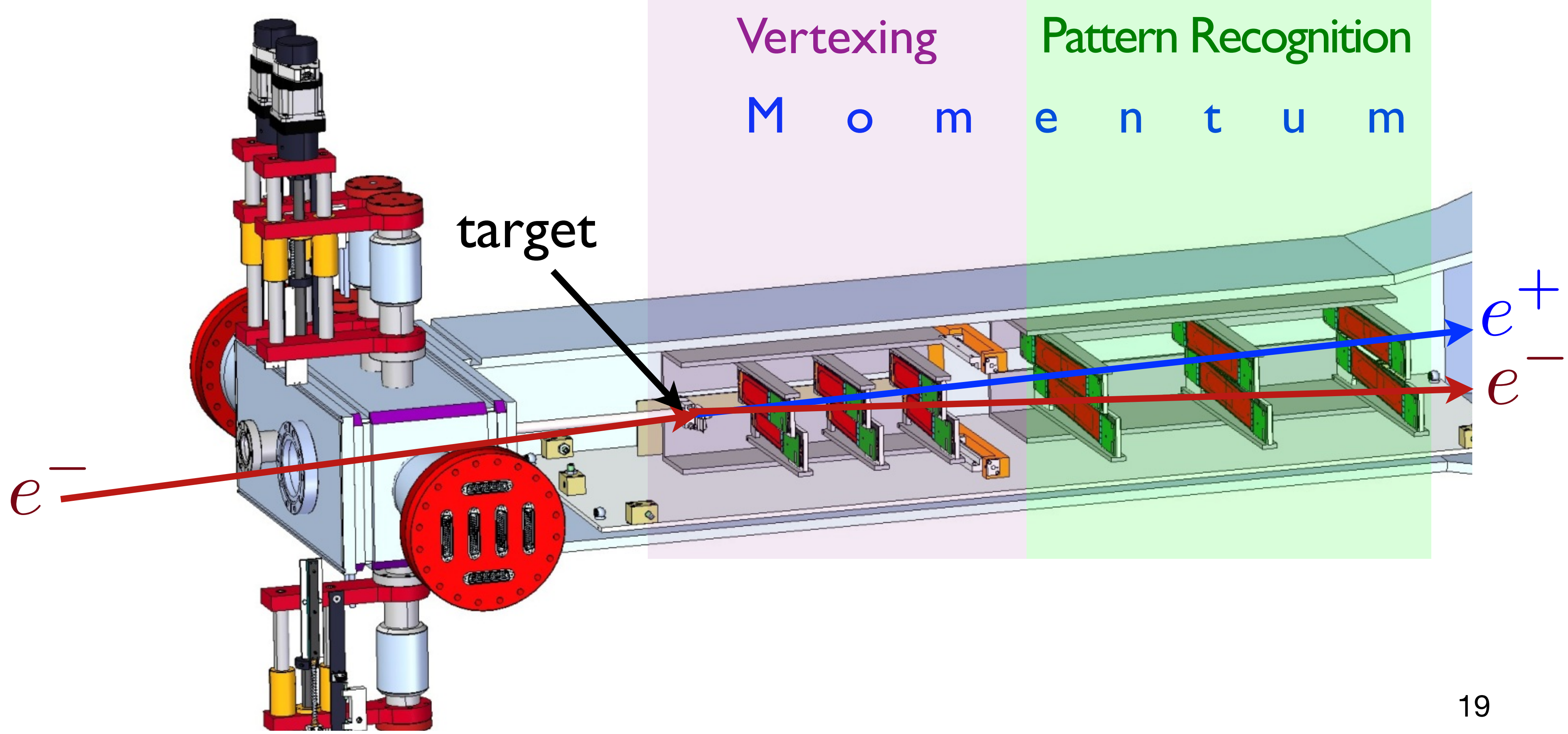
but it would be foolish to start from scratch!!

HPS SVT Layout

Evolution of HPS Test SVT

- Layers 1-3: same as HPS 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



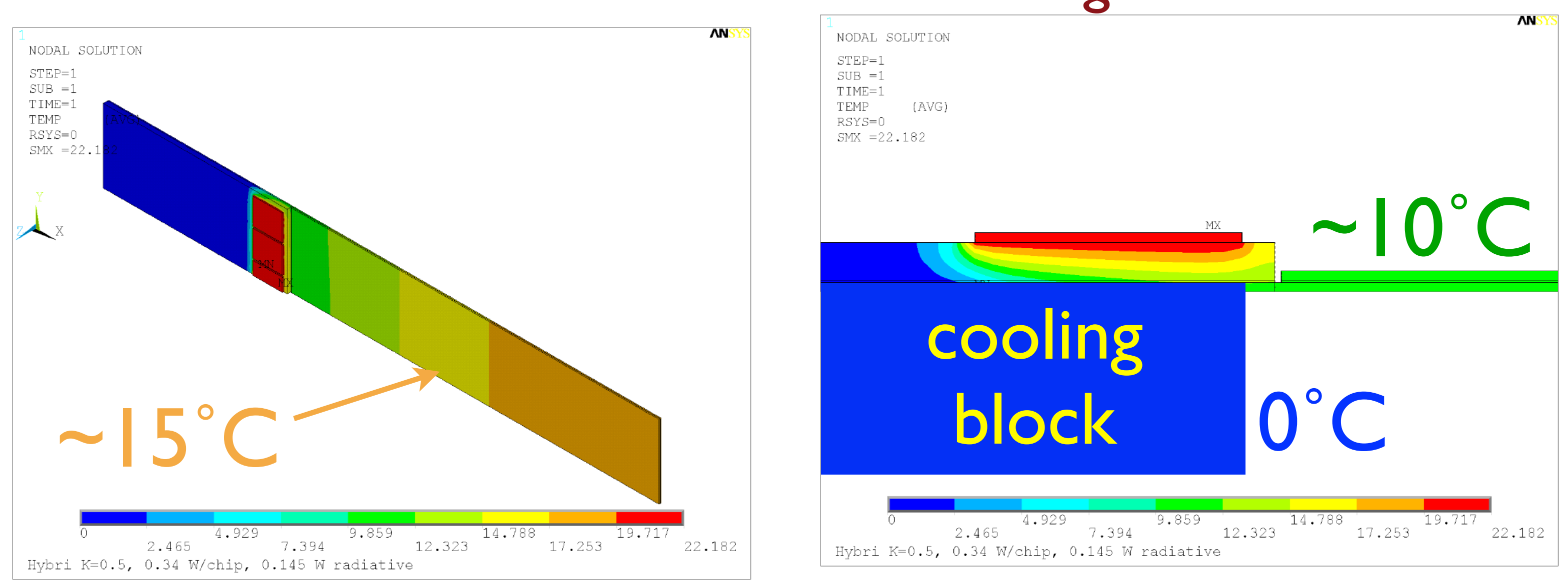
Layer 1-3 Modules

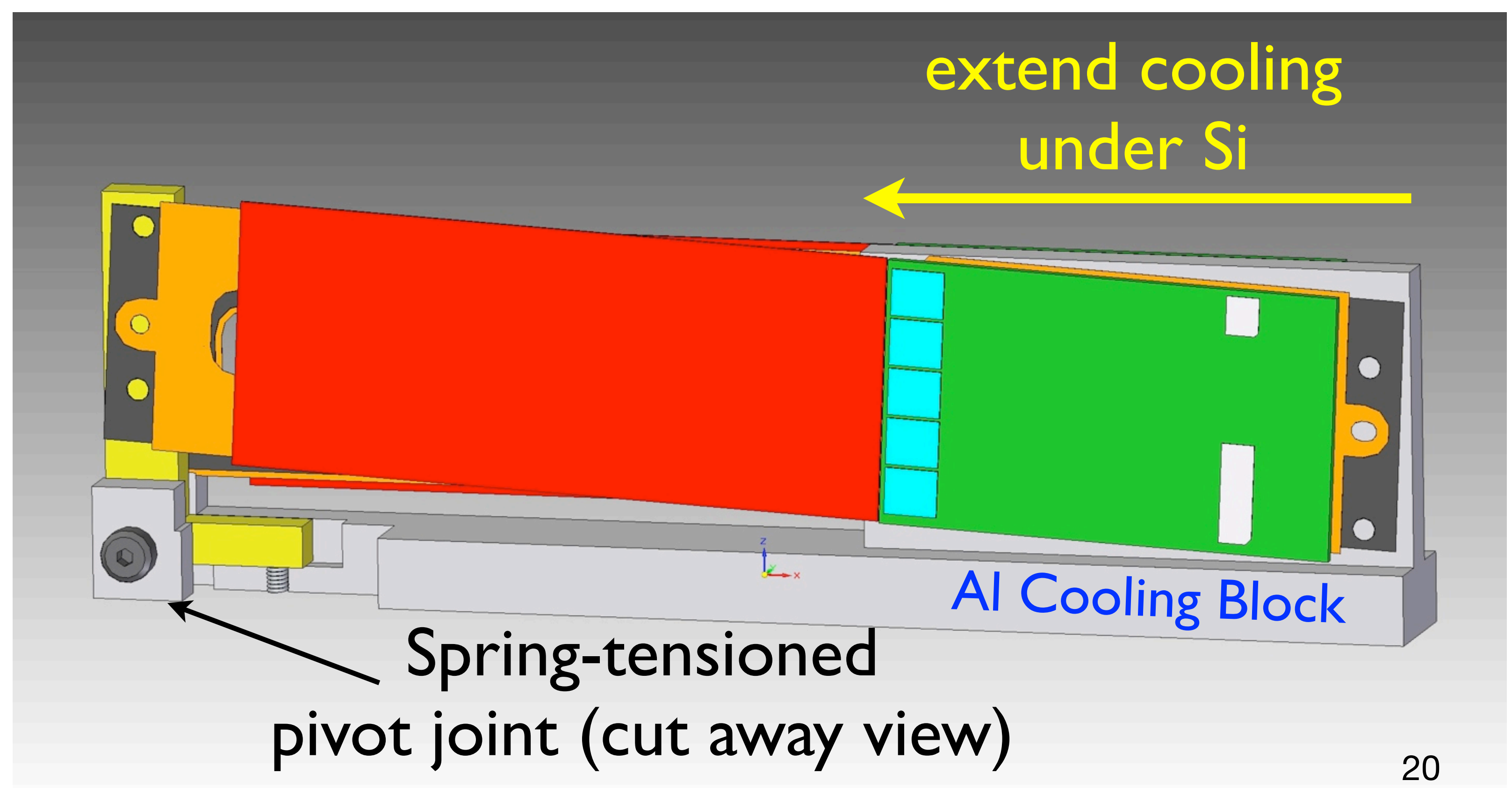
Reuse half-modules from HPS Test, but design better module supports: tension CF between cooled uprights.

- 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 low-risk R&D effort

HPS Test Sensor Cooling



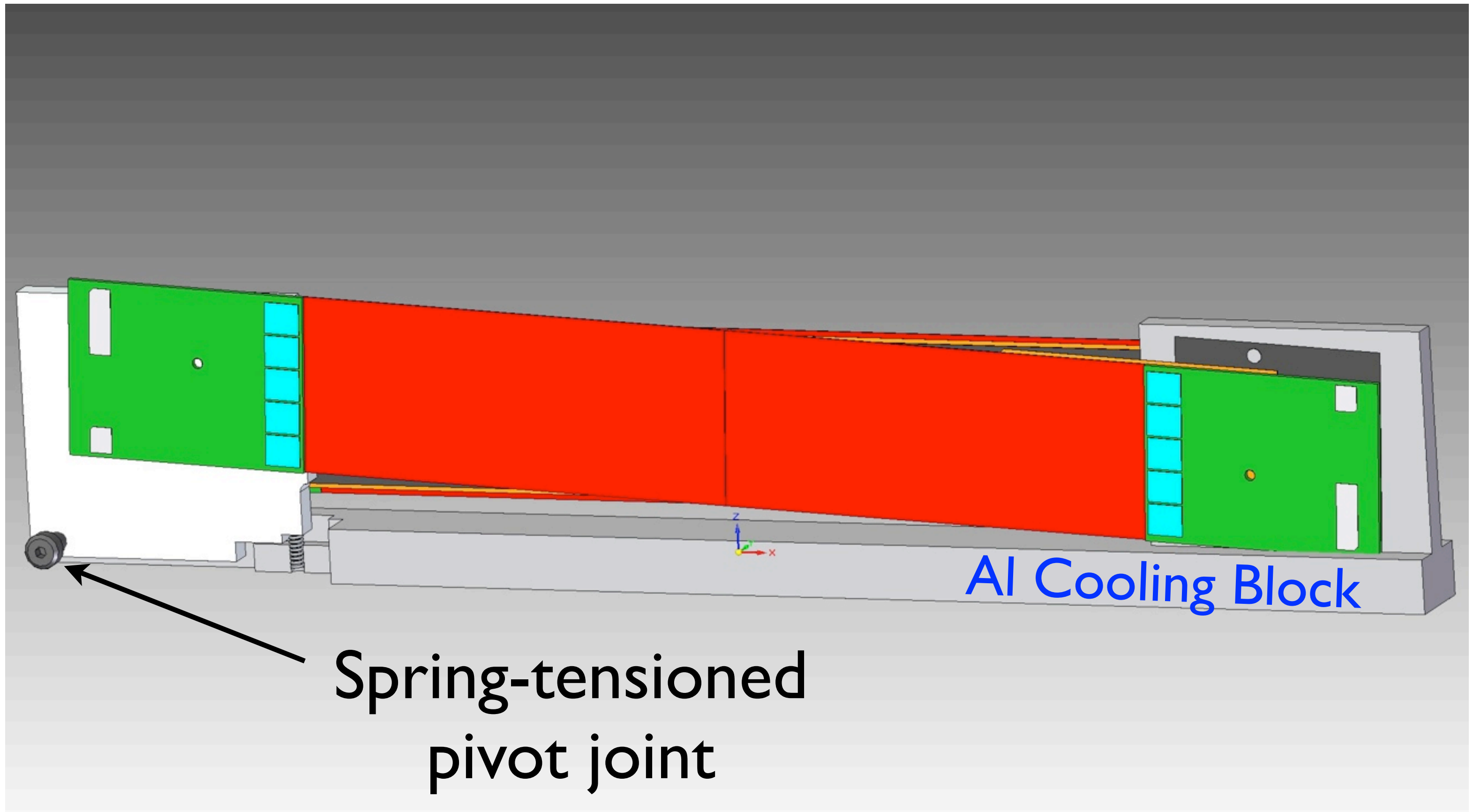


Layer 4-6 Modules

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 low-risk redesign of test run half-modules

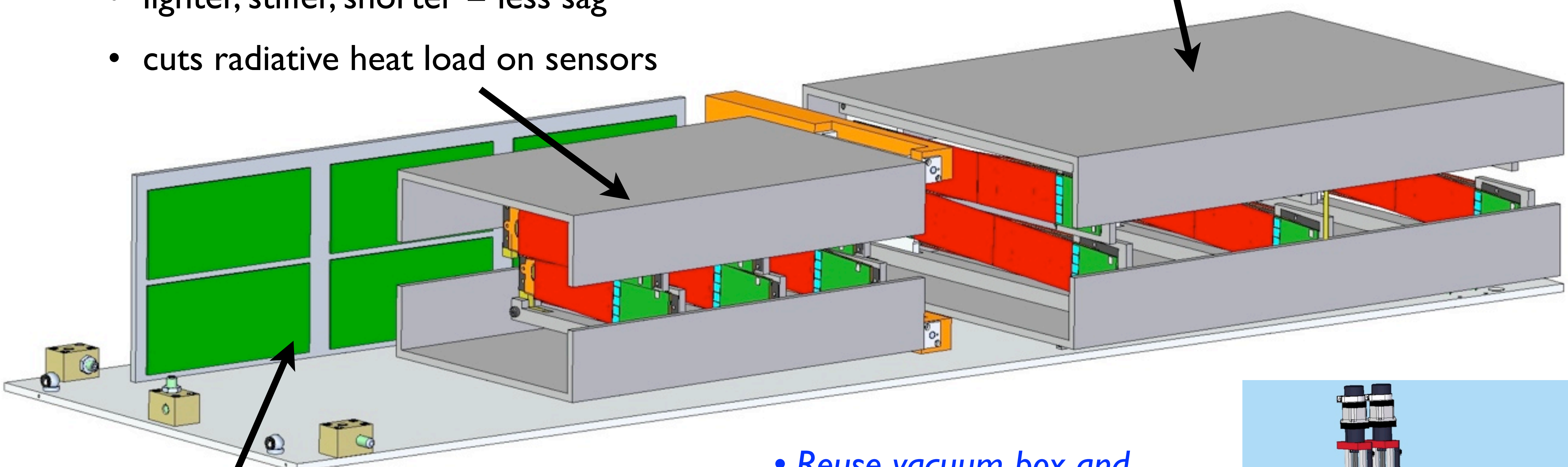


Support, Cooling and Services

Cooled support channels for L1-L3

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

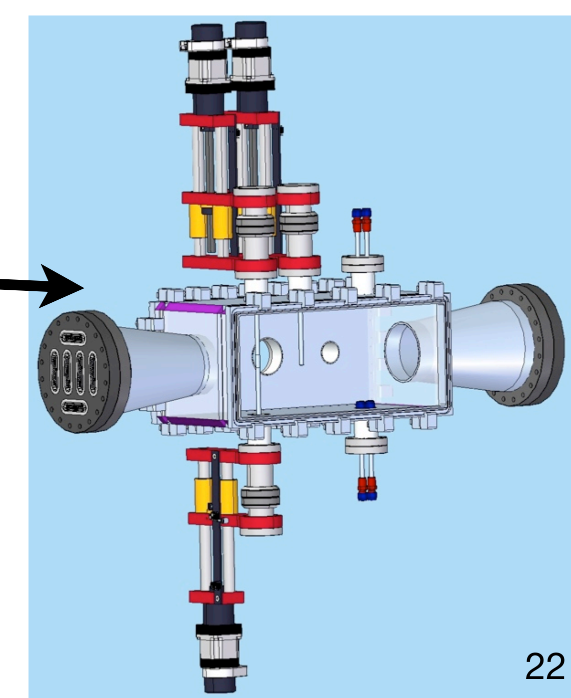
Cooled support channels for L4-L6 are stationary



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 - Hansson, Jaros, Maruyama, McCulloch, Nelson, Oriunno, Osier, Swift, Uemura

UCSC - Fadeyev, Grillo, McKinney, Moreno

FNAL - Cooper, FNAL Techs

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

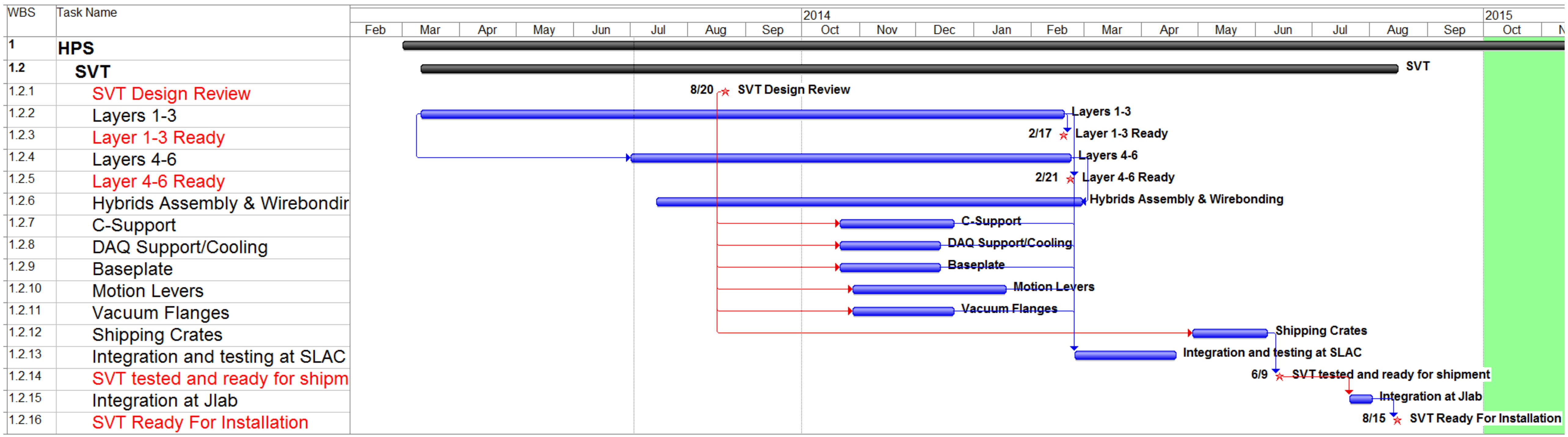
Project Budget

- *SVT "upgrades" have been designed around scope we understand; scope of the Test SVT*
- *Budget includes significant contingency beyond actual spending on similar items for Test SVT*

	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.

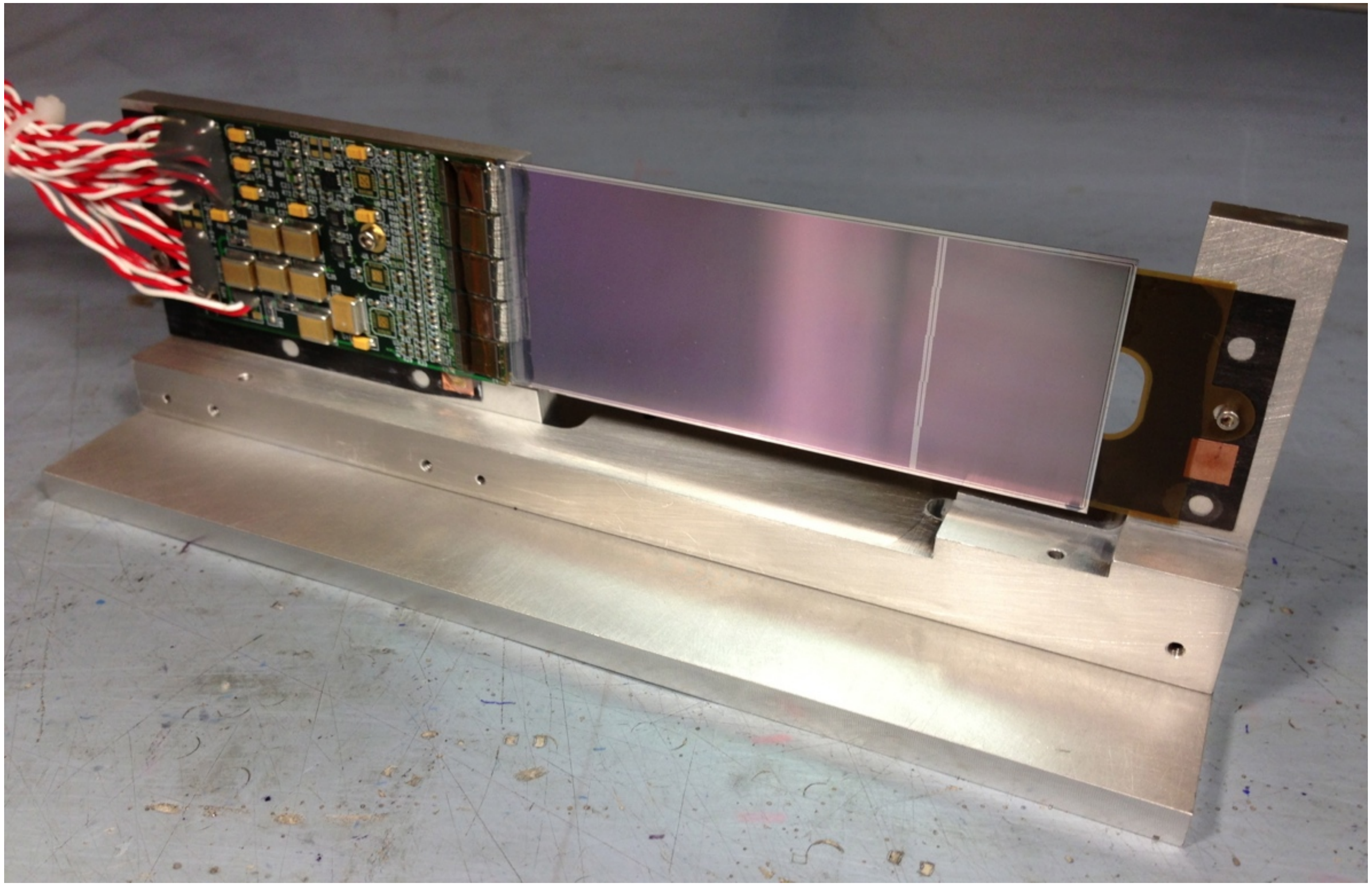
Schedule



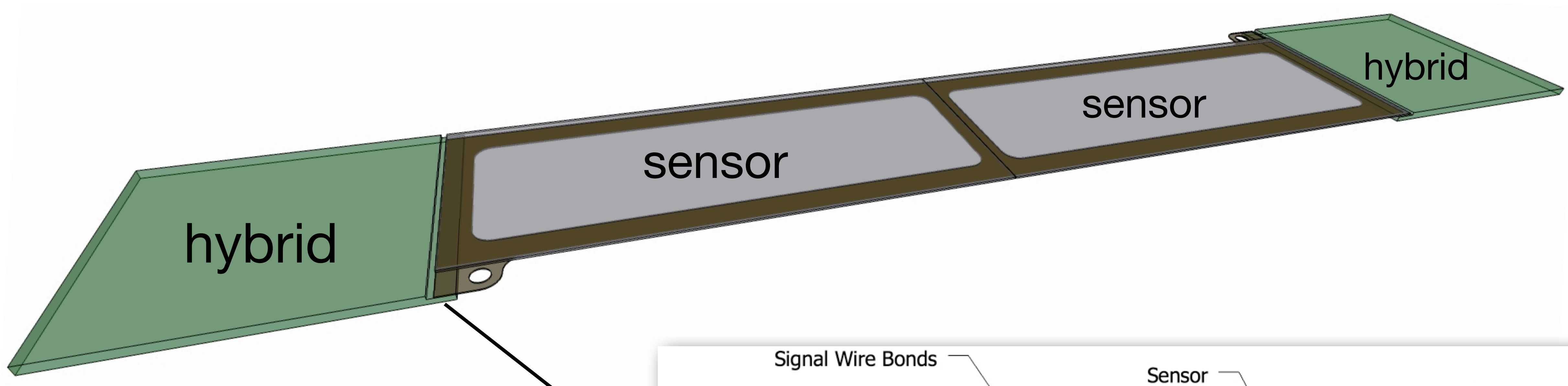
- Comfortable relative to schedule for HPS Test, but still quite busy
- Critical path hangs off of funding availability
- Tasks we must begin during "keepalive" period to keep them off critical path:
  - Design and prototyping of new module supports for Layers 1-3: *well underway*
  - Design and prototyping of new half-modules for Layers 4-6: *begun*
  - Early design work on new support plates and detector integration: *beginning in August*

Layer 1-3 Supports

- Prototype delivered to SLAC 10 days ago.
- Testing underway, looks good so far.
- Cost was $1100: budget is $1640 each. (16 total for all layers)
- If testing is successful, L1-L3 modules are essentially done.



Layer 4-6 Half-Module Design



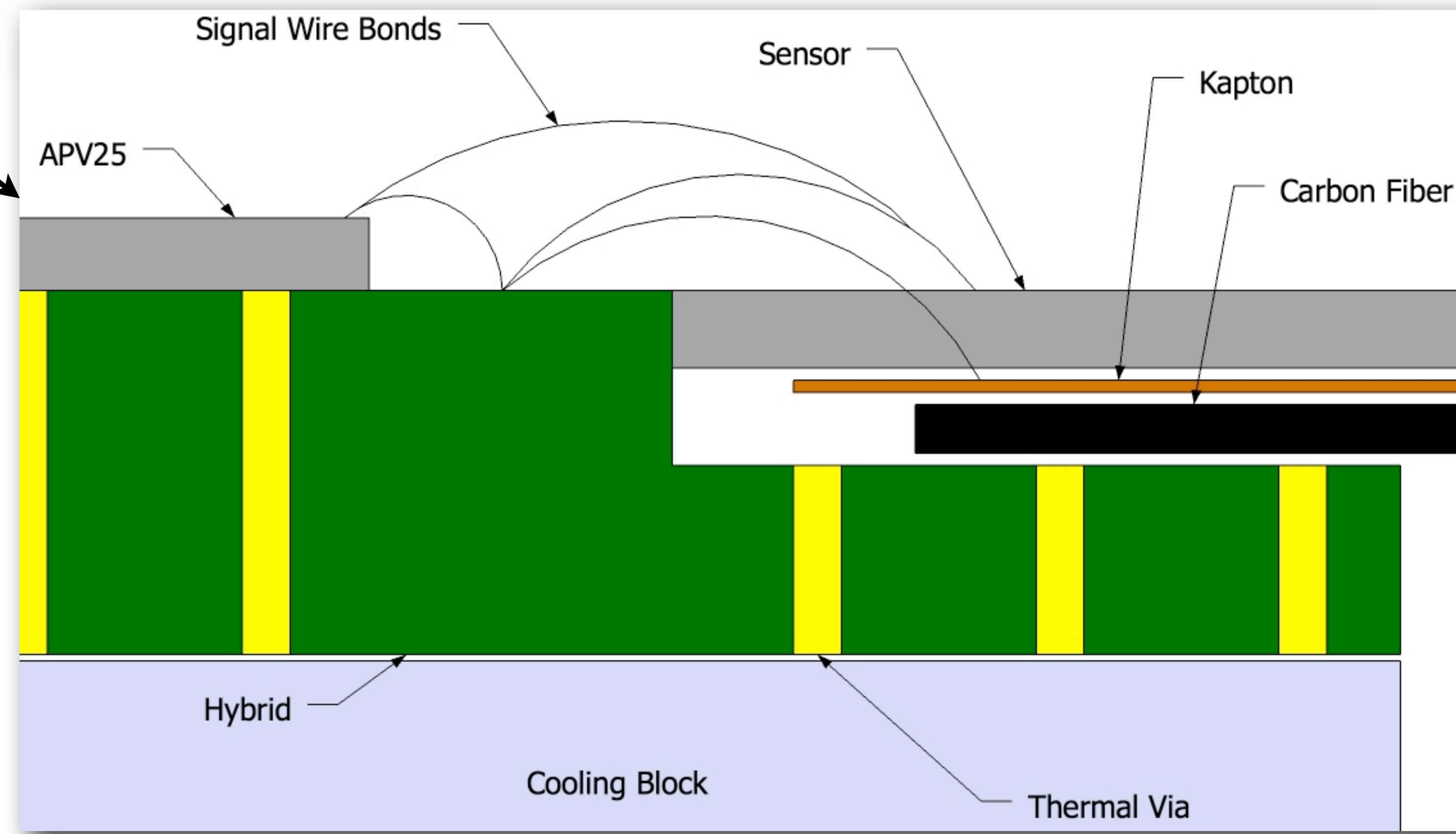
Similar to L1-L3 design, but...

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

➡ *simplifies assembly process*

➡ *separates heat path for silicon from APV heat loads*

➡ *easier wirebonding geometry and better support under bonds*

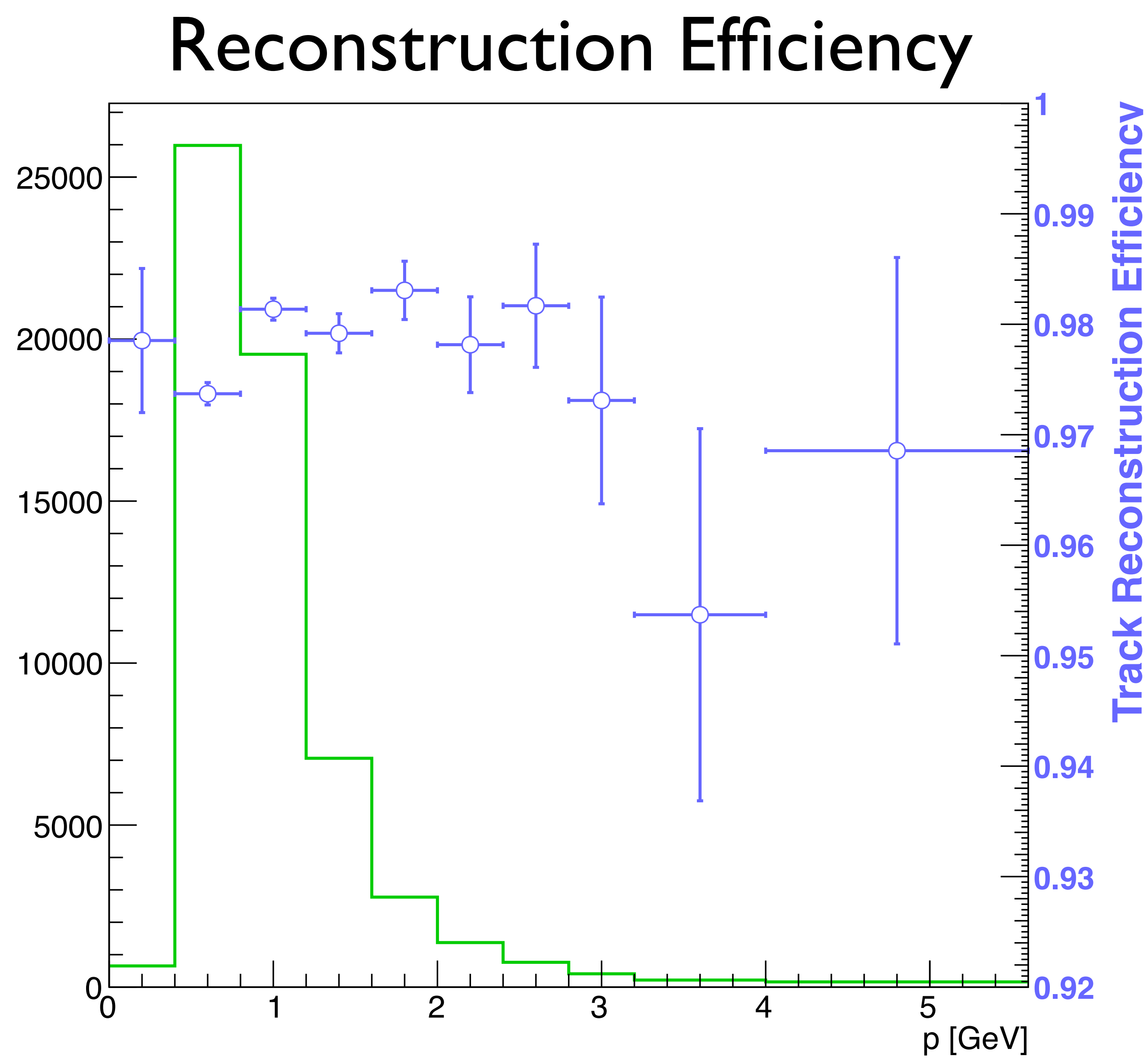


currently developing assembly fixture concept along with design details required for assembly.

Summary

- The HPS Test SVT got most things right and performed well
  - Met key performance goals 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
  - Minimal budget risk, which is generous relative to Test SVT actual costs.
  - Schedule risk is modest if funding becomes available at beginning of FY14.
  - First steps on critical path are underway.
- Together with upgraded DAQ, the new SVT should deliver expected physics reach.

Track Reconstruction Efficiency



Good reconstruction efficiency
even without full alignment