Update of the Heavy Photon Search (HPS) Experiment at Jefferson Lab

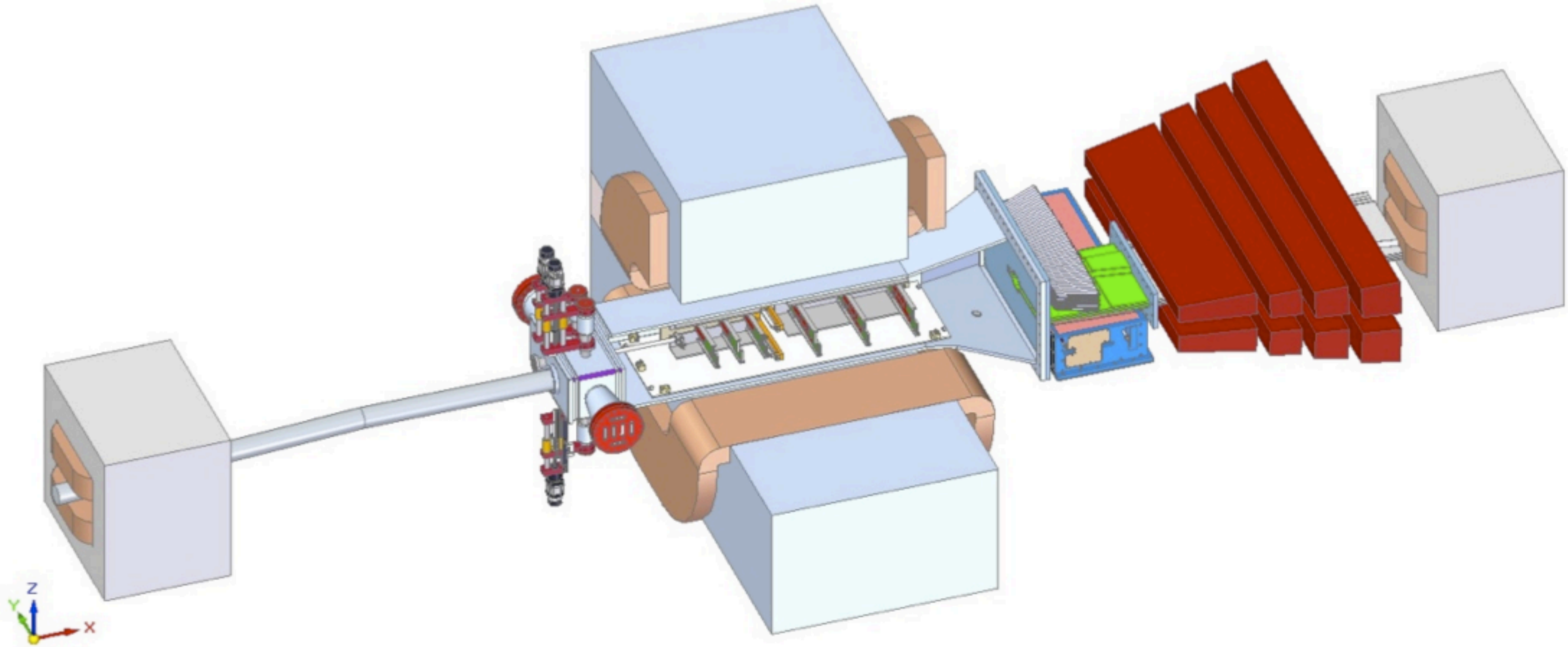
Holly Szumila-Vance
On behalf of the Heavy Photon Search Collaboration

Old Dominion University, Department of Physics
22 April 2014

HPS Implementation at JLab

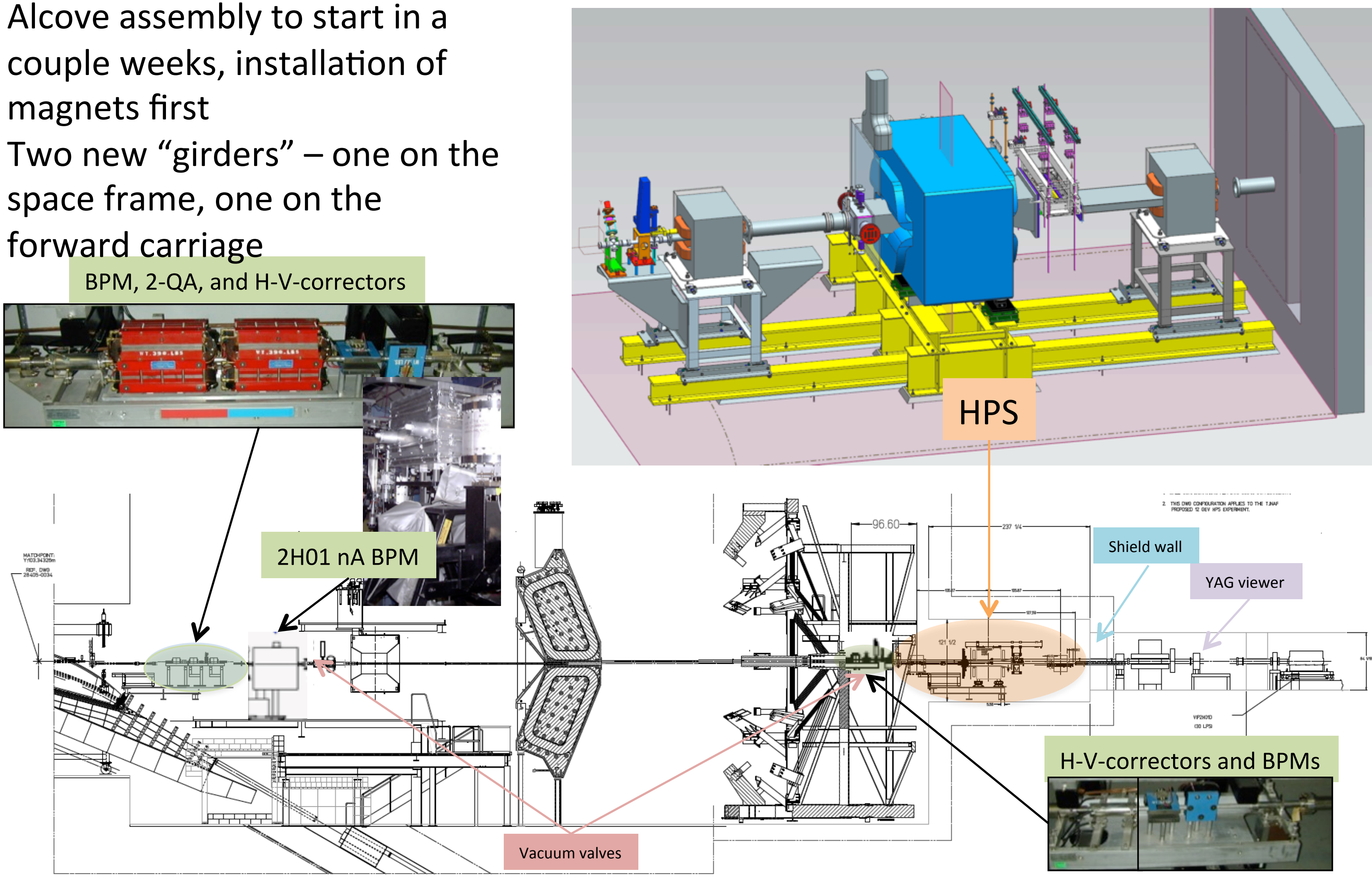
- HPS Engineering run in FY15:
  - Beam delivery to Hall-B possible after RF separators are commissioned (November 3rd, 2014)
  - Concurrently, assembly of CLAS12 Torus magnet and other detectors
  - HPS running cannot conflict with assembly of the CLAS12 Torus coils
- DOE review July 2013 approved HPS proposal, recommended funding in FY14-16 (only 3 recommendations and all on project management side)
- Funding came in mid-November, detector construction started
  - JLab received funds for beamline, slow controls, Ecal and trigger and DAQ
  - SLAC received funds for SVT, SVT DAQ, and software
  - Substantial funding from Italian and French collaborations
- Conducted internal reviews for all detector subsystems, including software
- Schedule:
  - Installation, September of 2014
  - Beamline commissioning, October 2014
  - Engineering run through spring of 2015

HPS Detector

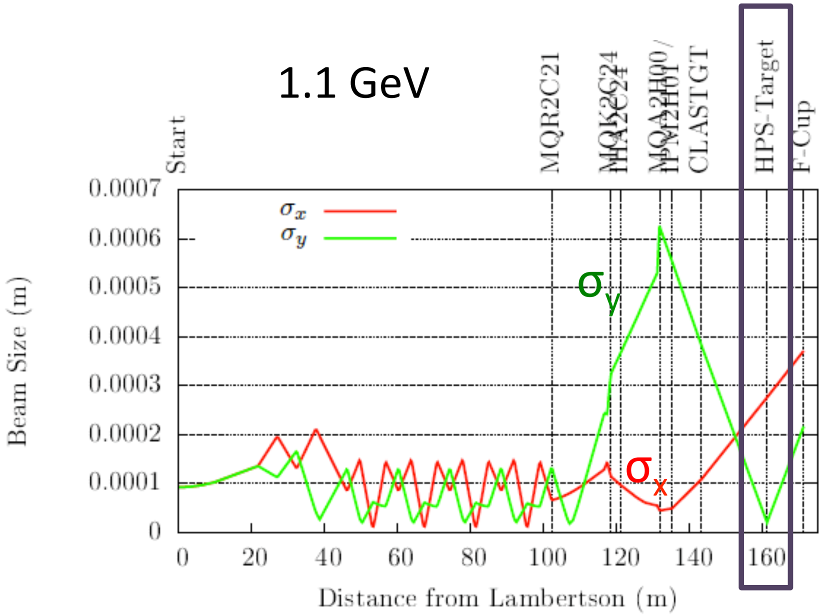


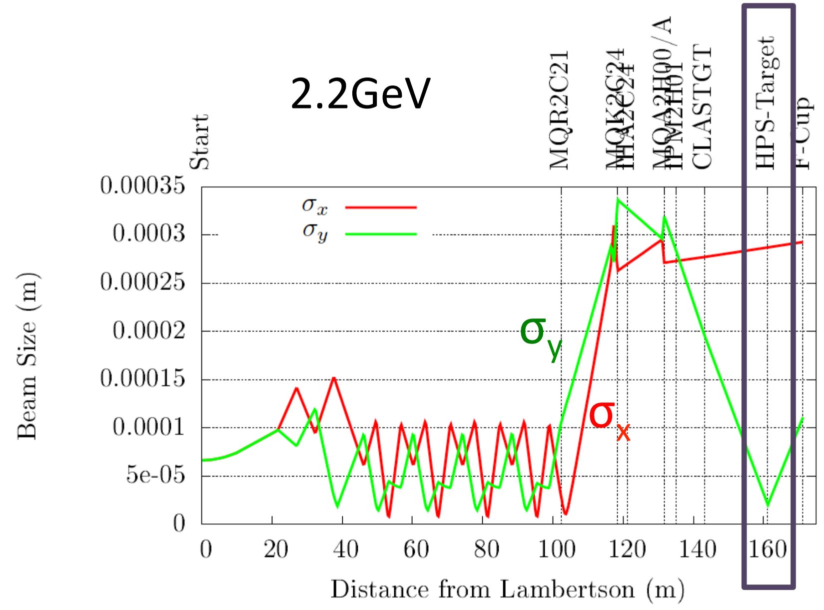
HPS Beamline

- Downstream of CLAS12
- Alcove assembly to start in a couple weeks, installation of magnets first
- Two new "girders" – one on the space frame, one on the forward carriage



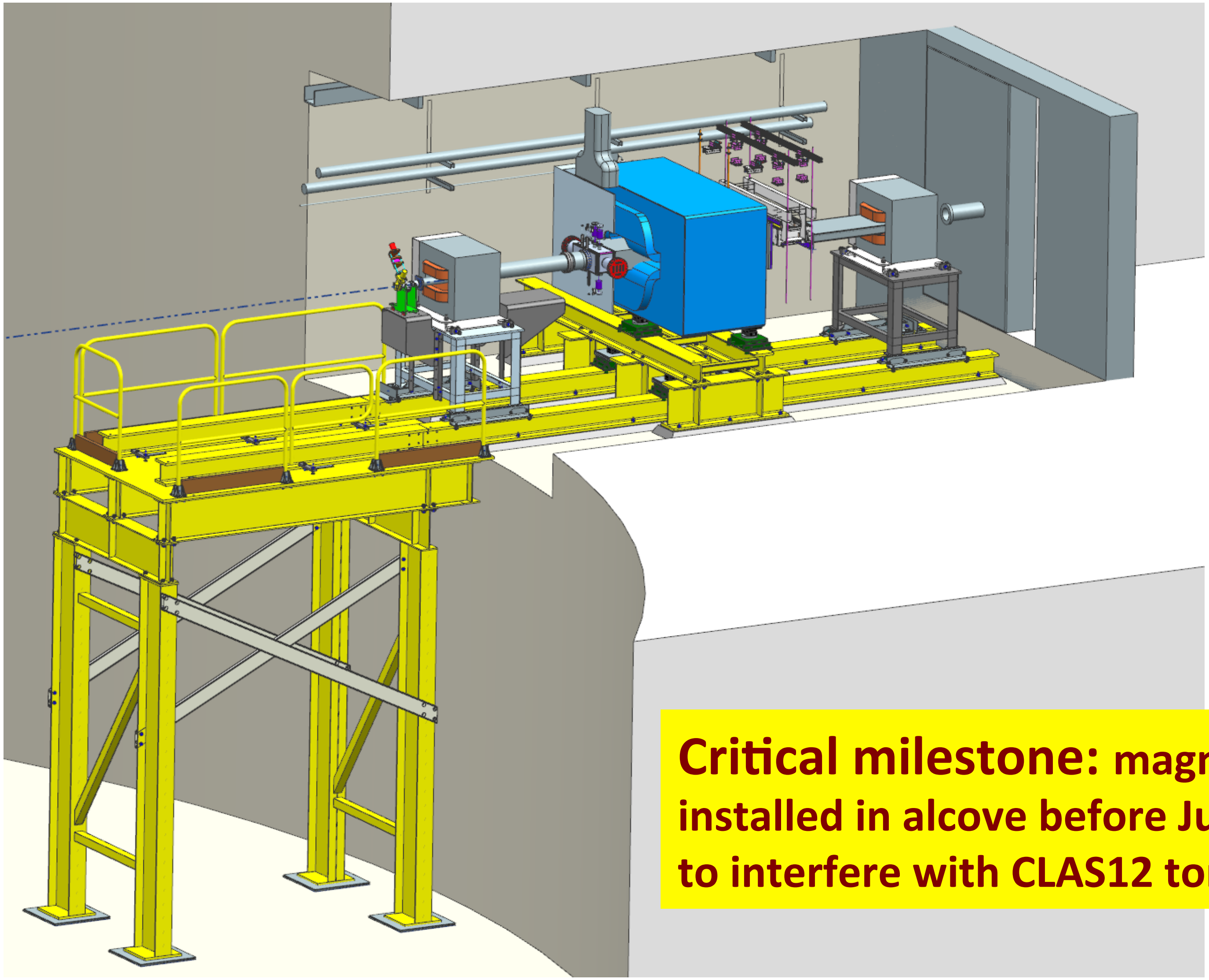
New Beamline Optics Design





Parameter	Requirement			Unit
E	1100	2200	6600	MeV
$\delta E/E$	$< 10^{-4}$			
Current	< 200	< 400	< 500	nA
Current Instability	< 5			%
σ_x	< 300			μm
σ_y	< 50			μm
Position Stability	< 30			μm
Divergence	< 100			μrad
Beam Halo ($> 5\sigma_Y$)	$< 10^{-5}$			

HPS chicane design status



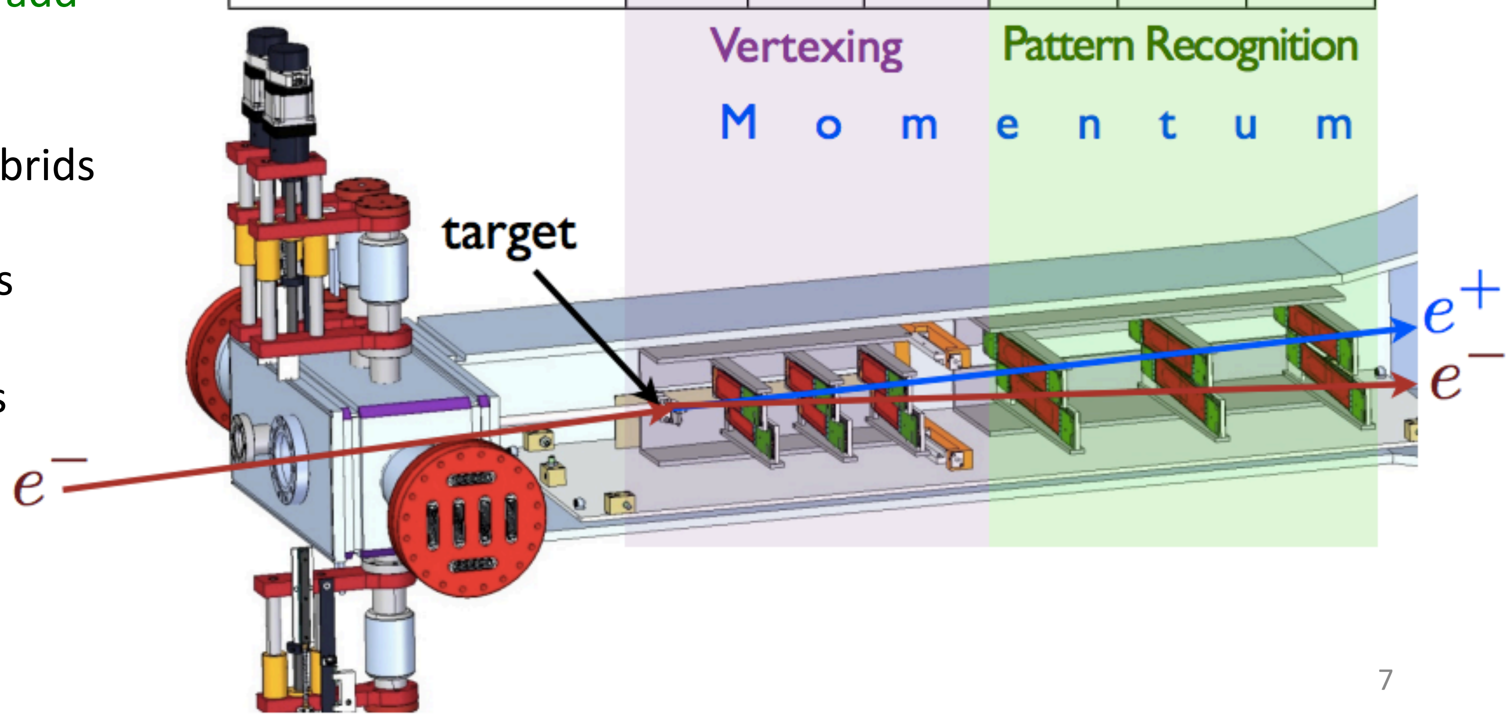
Critical milestone: magnets must be installed in alcove before June 2014 not to interfere with CLAS12 torus assembly

Updates to Silicon Vertex Tracker (SVT)

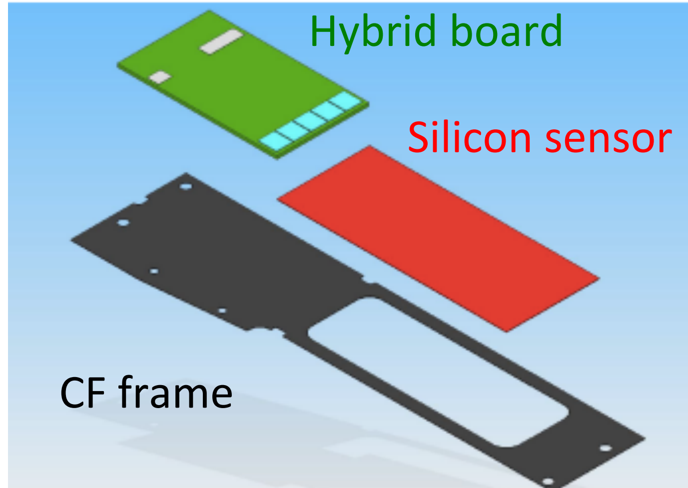
Evolution of HPS Test SVT:

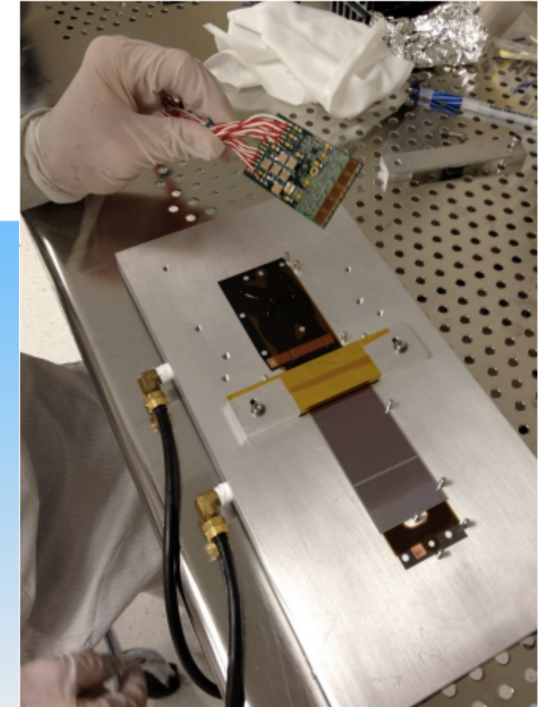
- Layers 1-3: same half-modules and layout as HPS Test SVT
- Layers 4-6: double width to match Ecal acceptance and add extra layer
- 36 sensors & hybrids
- 180 APV25 chips
- 23,004 channels

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



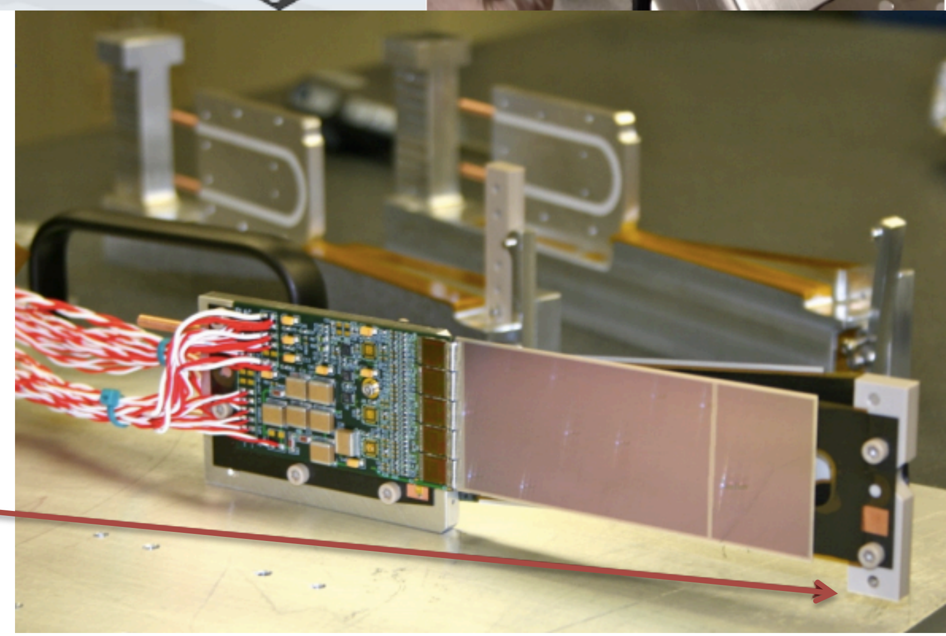
SVT Module Components





Half Module

- 0.17 mm thick CF frame
- Hybrid board with 5 APV25 chips
- Short twisted pair pigtail cable
- Single sensor



Full Module

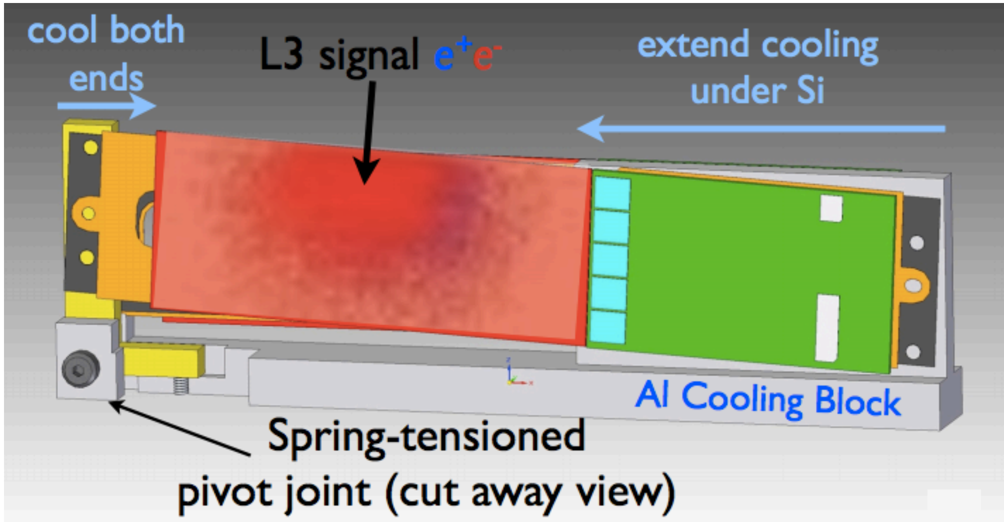
- Two half-modules back-to-back on Al cooling block
- Glue-less assembly with PEEK spacer block and hardware

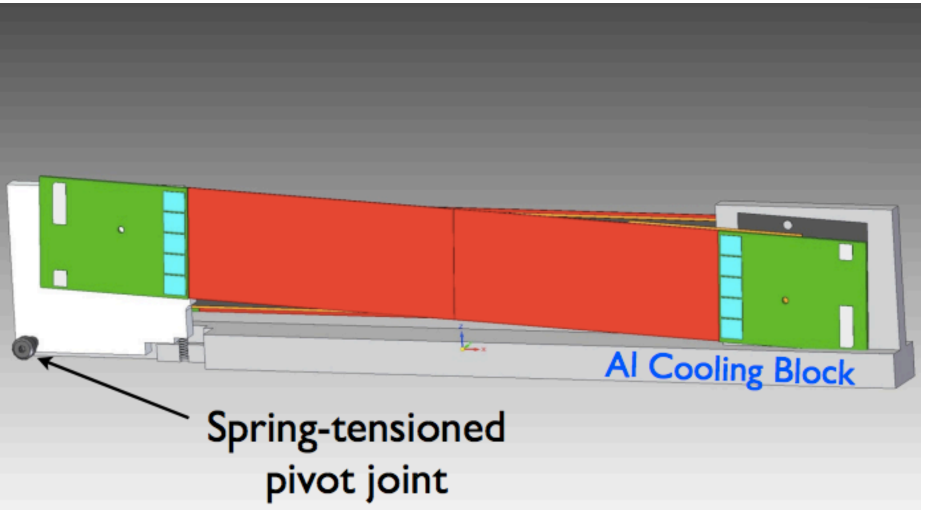
- 0.7% X_0 average per layer
- Limits flatness of Si to ~200 µm
- Compromised cooling limits radiation tolerance

Layer Modules

Layers 1-3: Reuse half-modules from HPS Test Run with changes to supports

- Better cooling at both ends of sensor
- Support at both ends ensures overall straightness
- Spring pivot with low-viscosity thermal compound keeps CF under tension





Layers 4-6: Build new "double-ended" half-modules

- Similar carbon fiber frame
- Shorter hybrid design omits unnecessary components, uses flex pigtails
- Ends of CF/Si supported by hybrid

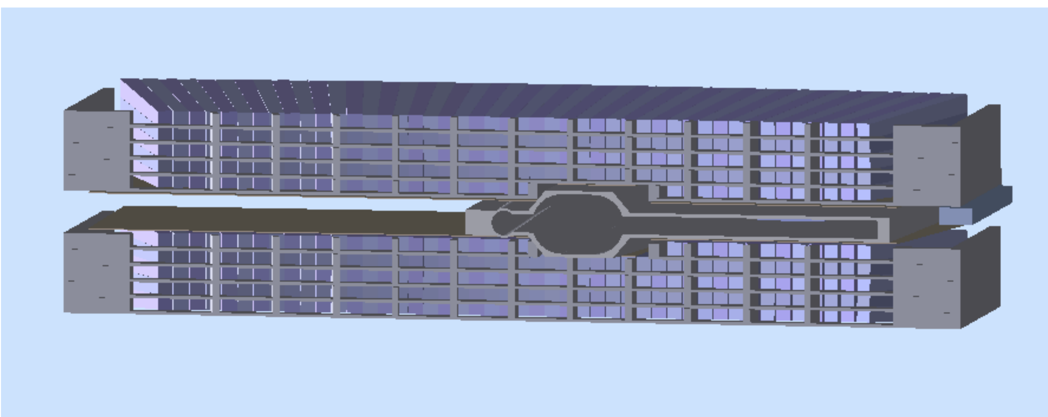
SVT Progress Report

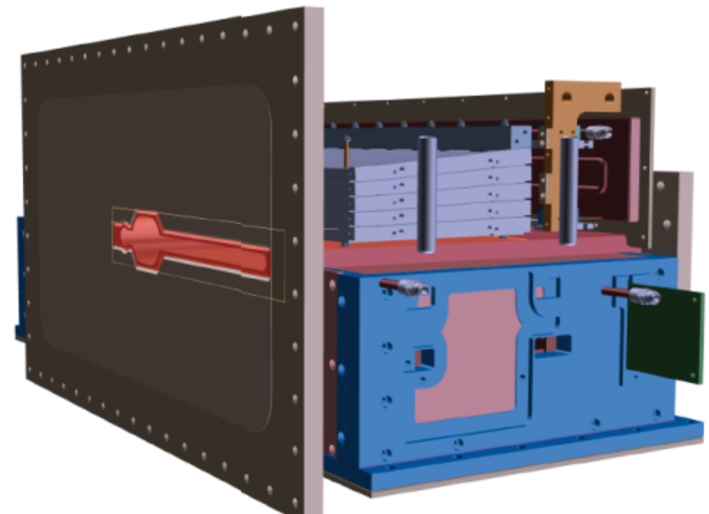
- Hardware Production:
    - L4-6 Hybrids working (APV25 Front end readout). Ready for module construction.
    - Second L4-6 Module (detector+support+hybrid) built and tested. Works! Production run to begin soon.
    - Engineering design of support box and u-channel support is complete (holds modules, cooling, data and power connections)->fabrication to begin in May
- Electronics and DAQ:
    - Second version of hybrid (to correct minor wiring error) produced and tested, bonding to first double-width modules
    - Testing electronics boards:
        - Front End Board (digitizing signal, data transfer from hybrids, distributes power)
        - Flange Board (transfers signals from Front End Board to optical fibers, provides HV)
    - Cluster on Board (COB) delivered and fully functional
        - Interface between COB and data transmitted from the experiment to undergo testing later this month

Electromagnetic Calorimeter

Test Run ECal:

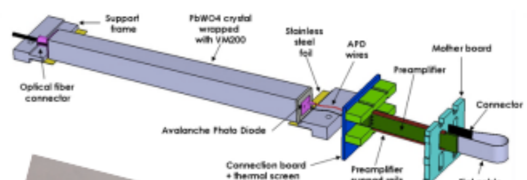
- 442 Scintillating $PbWO_4$ crystals ($1.3 \times 1.3\ cm^2$ cross section, 16 cm long)
- Crystals arranged in each half by rectangular formation of 5 layers, 4 layers have 46 crystals and 1 closest to beam has 37
- Readout by JLAB FADC250; pulse height, spatial and timing info

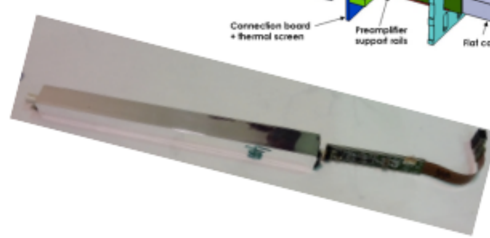




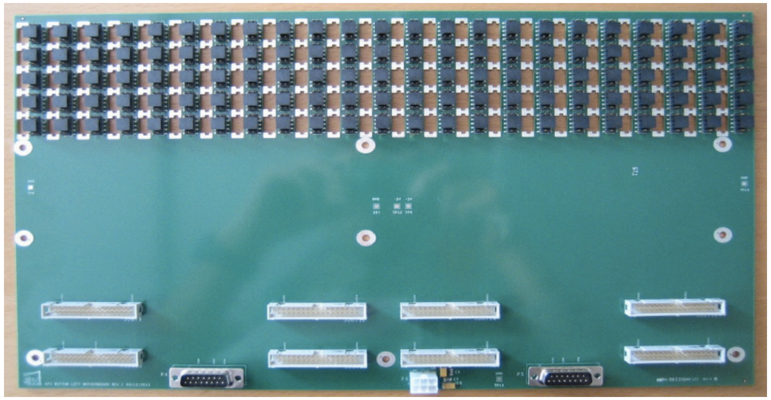
Changes from Test Run (electronics):

- Motherboards
- Preamplifiers
- LED Monitoring System
- Large Area Avalanche Photodiodes



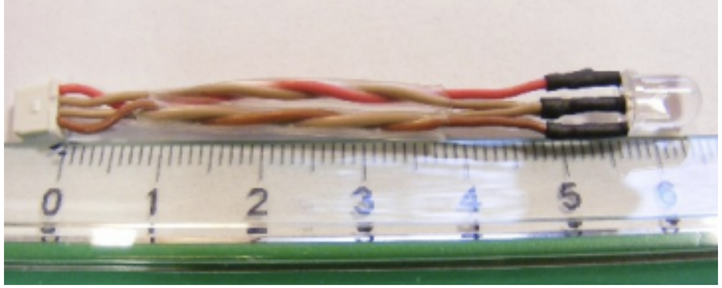


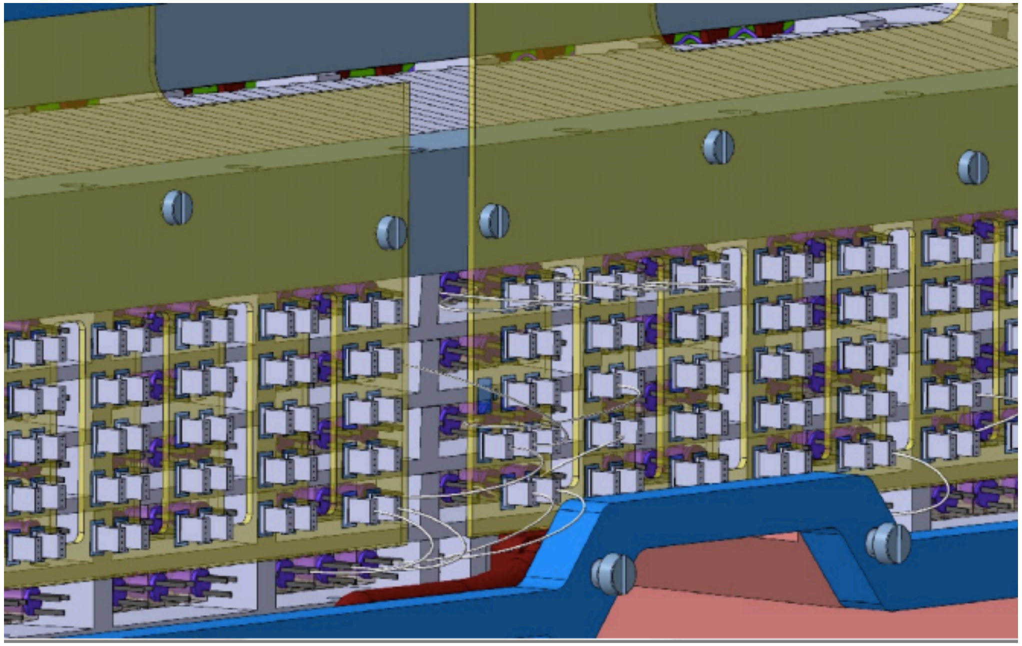
ECal Updates



Motherboards:
- 115 (106) channels for left (right) MB
- Tested at INFN, low electronic cross talk (0.02%)
- Ready to be installed in the detector

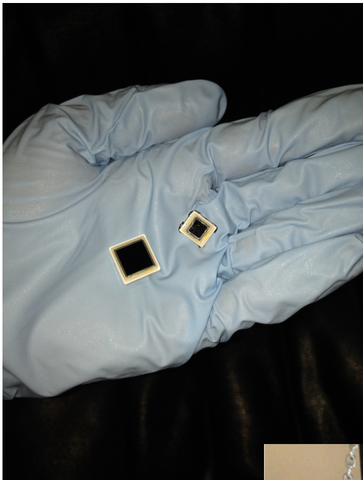
Preamplifiers:
- Faster
- Less noise
- Production is ongoing at IPNO





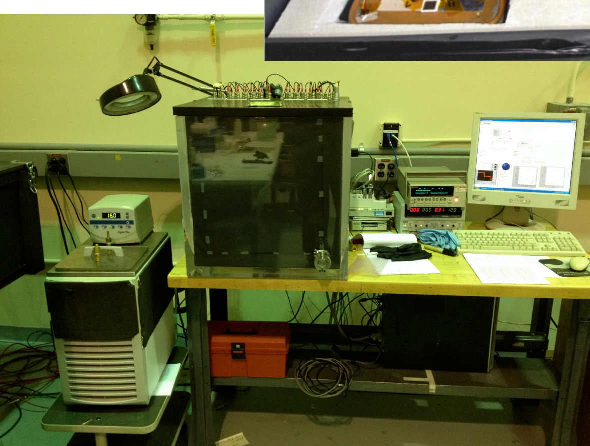
LED Monitoring System:
- LEDs will be placed in front of each crystal
- Calibration and testing

Large Area APDs for ECal Upgrade



Replace old APDs (5x5 mm^2) with new APDs (10x10 mm^2) bought by IPNO and INFN from Hamamatsu

- Remove old APDs (done)
- Test and Benchmark new APDs (60% done)
- Glue and test new APDs on crystals (started)



Test and Benchmark of APDs:

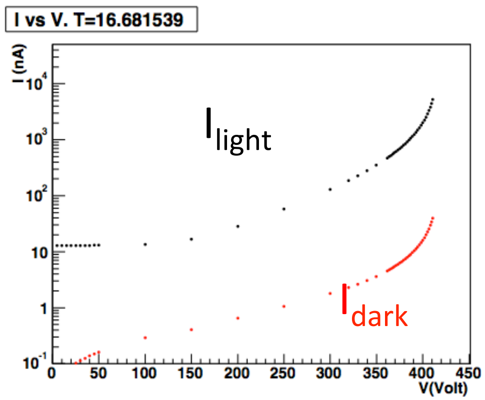
- Measure Current with LED on (light) and LED off (dark) on new APD for three different temperatures (20°C,18°C,16°C) and voltage range (0 V to just below breakdown V):

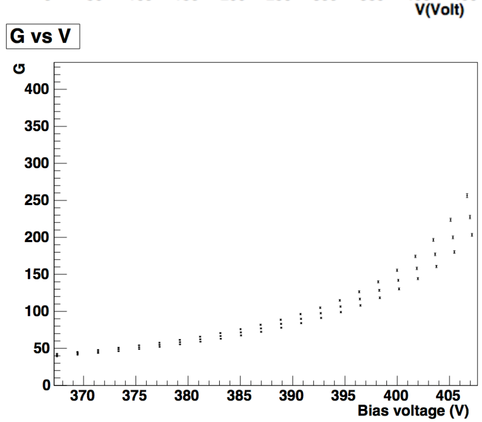
$$Gain = \frac{(I_{light} - I_{dark})_{V,T}}{(I_{light} - I_{dark})_{V=25,T}}$$

- Check for correct behavior:
  - I_{dark} and I_{light} vs V_{bias}
  - I_{dark} vs Gain (linear)
  - Gain dependence on V and T

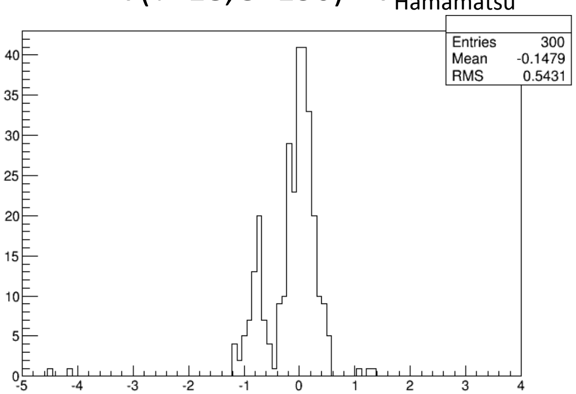
Testing and Benchmarking LAAPDs

Diagnostics:



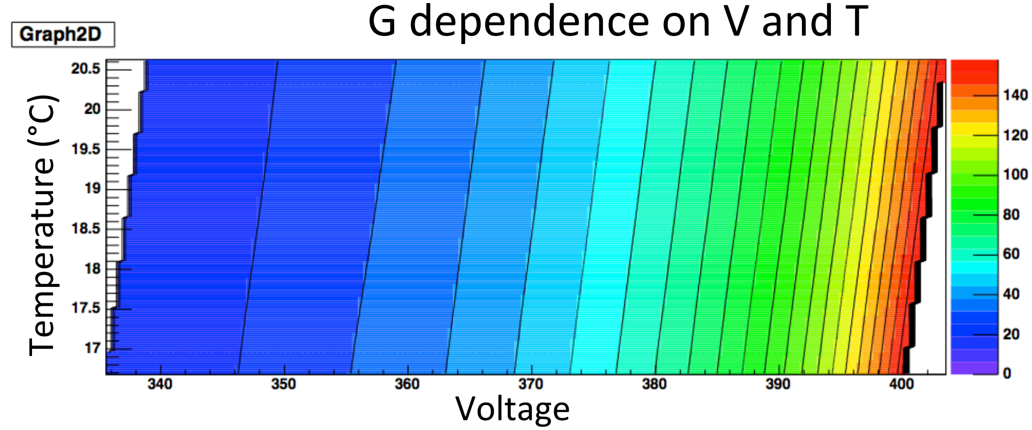


$V(T=18, G=150) - V_{Hamamatsu}$



Bilinear behavior of gain: $G = \alpha V - \beta T$

G dependence on V and T

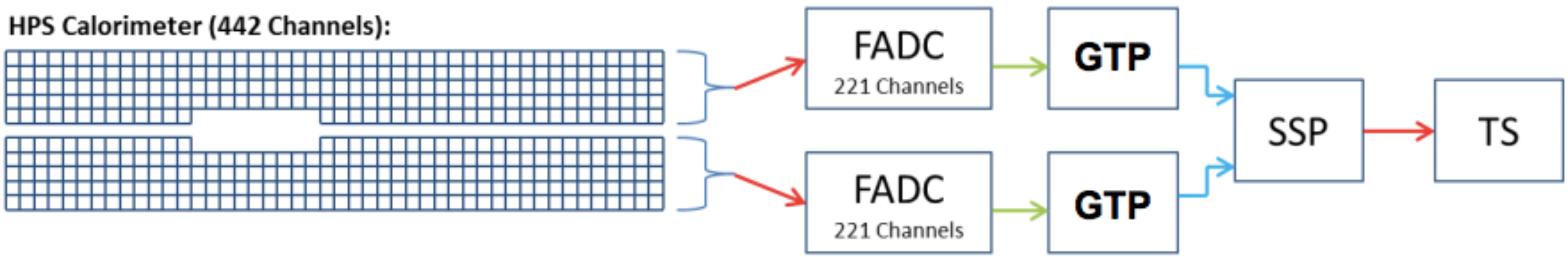


Grouping of APDs for Motherboards:

Goal: Match groups of APDs for common HV

1. Test grouped APDs (Hamamatsu, based on HV at G=150, T=18°C)
2. Remove APDs with large gain fluctuations for changes of V and T (α/β) or poor performance
3. Group APDs as closely as possible (goal is <0.5 V)

Trigger Overview



FADC (Flash Analog-to-Digital Converter)

- 250 Msps, 12 bit pulse digitizer for: Readout & Trigger (energy, timing)

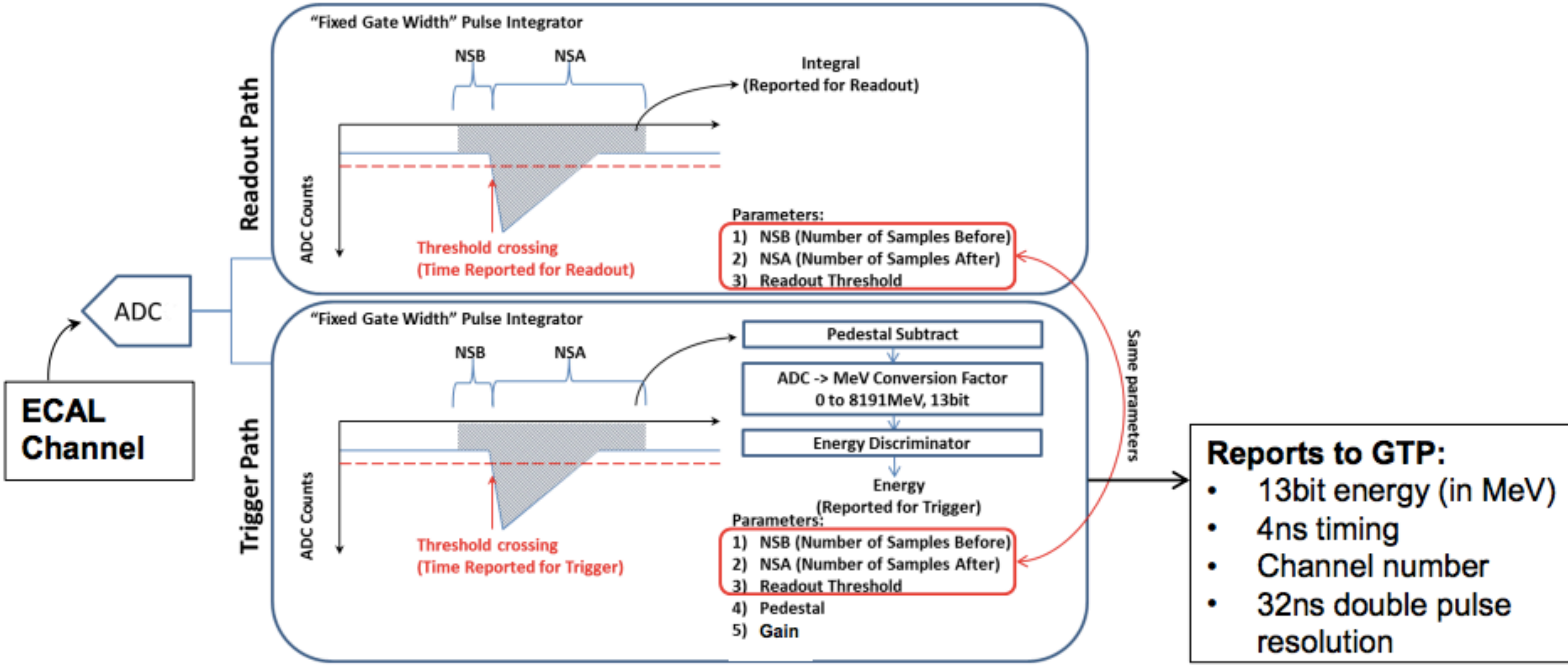
GTP (Global Trigger Processor)

- Collects pulse data from all FADC channels in crate
- Searches for clusters on half (top or bottom) in ECal
- Sends cluster energy, time, position, hit count to SSP

SSP (Sub-System Processor)

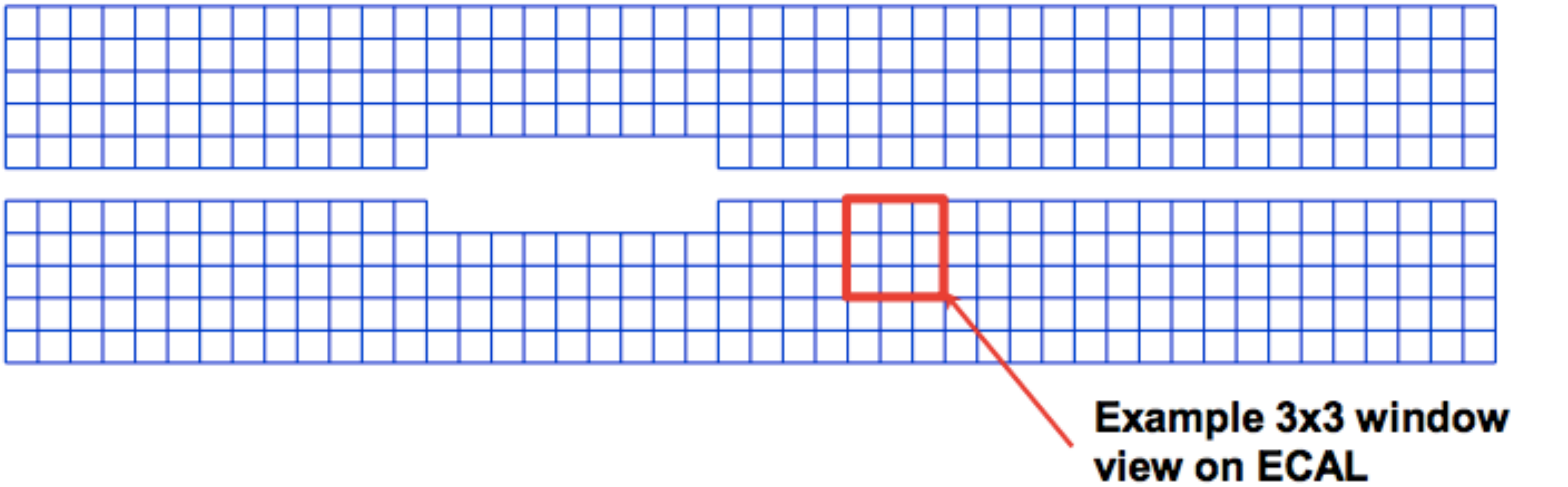
- Collects clusters from top & bottom halves of ECal from GTP
- Cuts on individual clusters: energy, hit count
- Cuts on paired clusters: energy sum/difference, coplanarity, distance-energy
- Delivers trigger signals to TS (Trigger Supervisor) for readout

FADC Pulse Processing



- After threshold event occurs in crystal, no other hits will be registered in this crystals for 8 clock cycles (32 ns)
- Both pedestal and gain require calibration to determine parameters
- When not above threshold for a clock cycle, zero energy is reported instead

GTP-Cluster Processing



Clusters:

- Find local maximum in both space and time
- Sum energies of seed hit (maximum channel) and neighbors (3x3)
- Integrate over specified time window
- Must exceed minimum energy for both its seed hit and total energy

Sub-System Processor (SSP)

Trigger cuts on clusters:

- Energy sum $$E_{\min} \leq E_{top} + E_{bot} \leq E_{\max}$$
- Pair coincidence time $$\left|t_{top} - t_{bot}\right| \leq \Delta t_{\max}$$
- Energy difference $$\left|E_{top} - E_{bot}\right| \leq \Delta E_{\max}$$
- Energy slope $$E_{least} + R_{\min} \times F_{energy} \leq Threshold$$
- Coplanarity
- Number of component hits $$N_{hit} \leq N_{threshold}$$

Note: E_{min},E_{max}, Δt_{max}, ΔE_{max}, F_{energy}, coplanarity angle, and $N_{threshold}$ are all programmable parameters

Trigger and Slow Controls

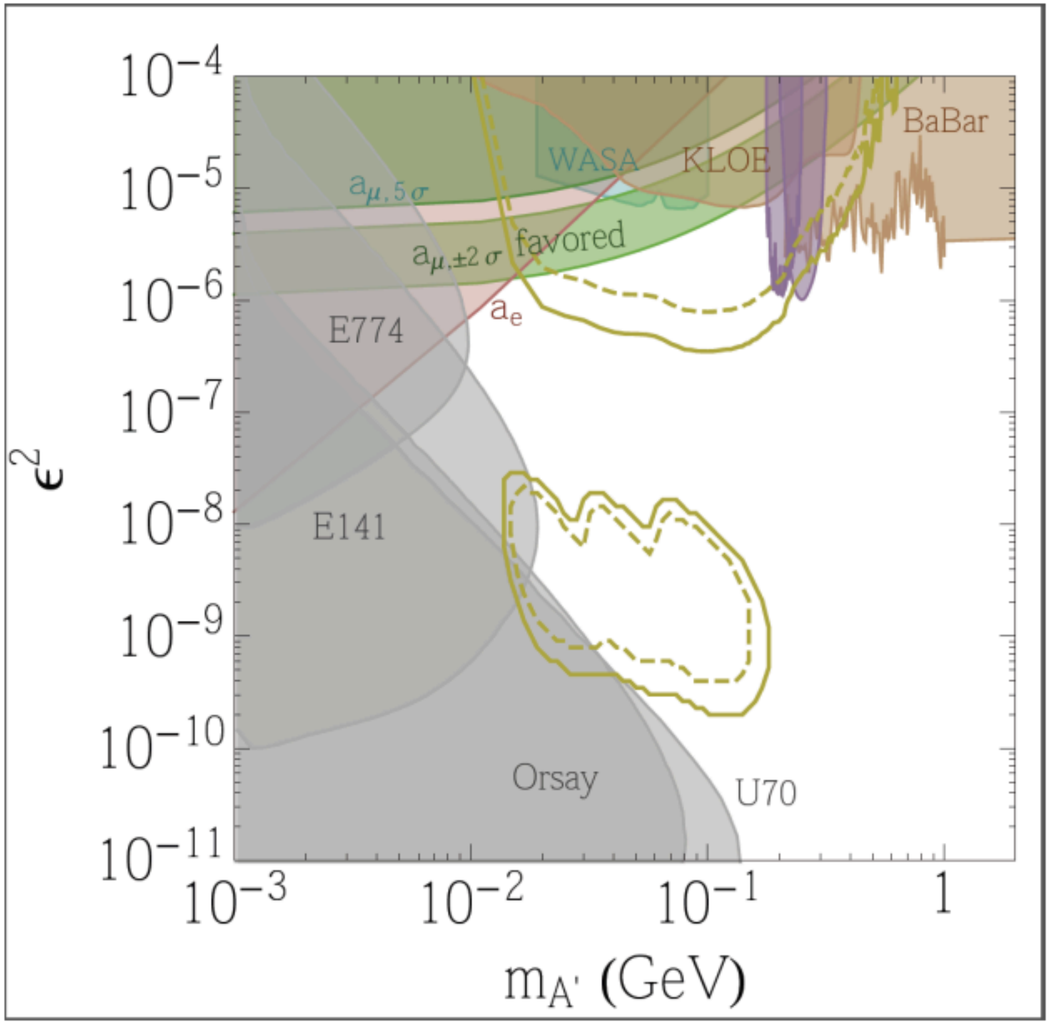
TDAQ:

- Already has all components (FADCs and trigger elements which use FADC) since they are produced and tested for CLAS12
- Firmware and overall system integration is underway

Slow controls:

- New design for implementation of HPS beam interlock and motor controllers for linear shifts (precise positioning for SVT and SVT target)
- EPICS Input/Output Controller for SVT voltage controls has been configured and is running on Hall B server, alarms screens for SVT voltages nearly complete
- Slow controls for ECal nearly identical to test run
- Stepper motor controllers for SVT and target motion control have been purchased and cables fabricated

HPS Reach



1 week at 1.1 GeV:
- 50 nA
- 0.125% X_0 W target

2 weeks at 2.2 GeV:
- 250 nA
- 0.125% X_0 W target

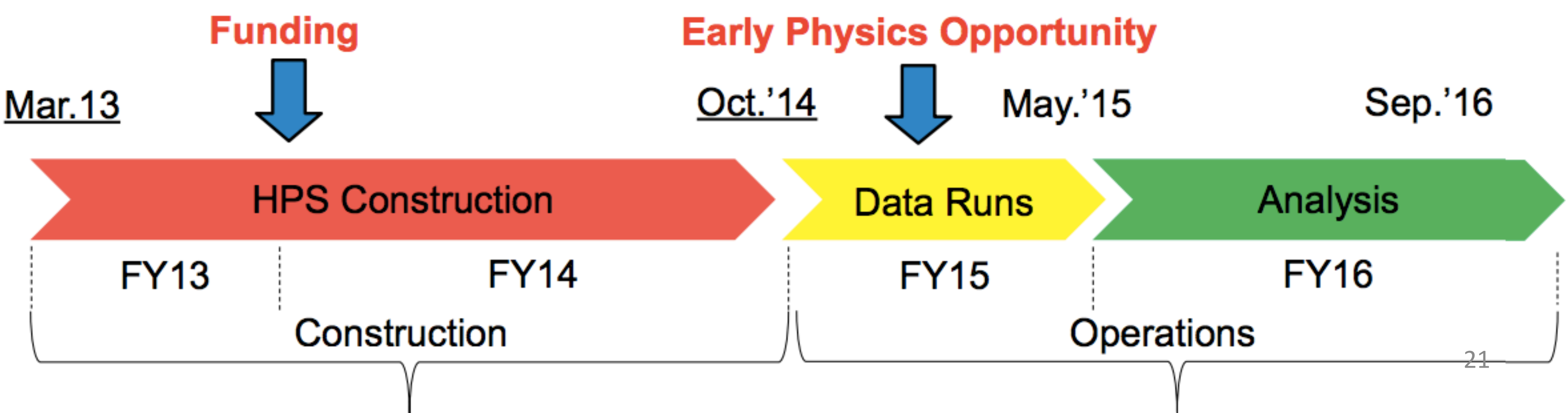
2 weeks at 4.4 GeV:
- 350 nA
- 0.25% X_0 W target

Solid line shows 2 sigma limits, dashed line shows 4.5 sigma limits
2014-2015 run includes 1 week at 1.1 GeV, 2 weeks at 2.2 GeV (optional additional 4.4 GeV)

Current Status

- HPS Test Run Paper
- Hardware commissioning goal August 2014
- Software:
  - Development along all fronts (monitoring, clustering, alignment, magnetic field mapping, HPS Monte Carlo)
  - Mock Data Challenge:
    - Develop analysis code and techniques
    - Test infrastructure for simulating, analyzing, and reconstructing a large dataset
    - Head start for physics results

HPS will be first experiment to run in Hall B!



Jefferson Lab: S. Boryarinov, V. Burkert, C. Cuevas, A. Deur, H. Egiyan, L. Elouadrihi, A. Freyberger, F.X. Girod, S. Kaneta, V. Kubarovsky, N, Nganga, B. Raydo, Y. Sharabian, S. Stepanyan, M. Ungaro, B. Wojtsekhowski

SLAC: P. Hansson Adrian, C. Field, N. Graf, M. Graham, G. Haller, R. Herbst, J. Jaros, J. McCormick, K. Moffeit, T. Nelson, H. Neal, A Odian, T. Maruyama, M. Oriunno, S. Uemura, D. Walz

UCSC: A. Grillo, V. Fadeyev, O. Moreno

University of New Hampshire: M. Holtrop, K. Slifer, S.K. Phillips, K. McCarty

William and Mary: K. Griffioen, S. Paul

Old Dominion University: L. Weinstein, S. Bueltmann, H. Szumila-Vance

Glasgow University: E. Buchanan, B. McKinnon, D. Sokhan

FNAL: W. Cooper

Hebrew University: G. Ron

INFN Catania: E. Lenora, M. DeNapoli, N. Randazzo, S. Aiello

INFN Genova: A. Celentano, M. Battaglieri, M. Osipenko, R. DeVita, S. Fegan,

INFN Padova: G. Simi

INFN Sassari: M. Carpinelli, V. Sipala

INFN Torino: D. Calvo, A. Filippi

INFN U. Rome: A. Rizzo, A. D’Angelo

YerPhI: N. Dashyan, N. Gevorgyan, R. Paremuzyan, H. Voskanyan

Stony Brook University: R. Essig

Rutgers University: Y. Gershtein

Perimeter Institute: N. Toro, P. Schuster

IPN Orsay: G. Charles, R. Dupre, B. Guegan, M. Guidal, P. Rosier

Idaho University: M. Khandaker

Schedule Changes:

1. Hall B beam line installation/restoration "Off Project Item": Upstream tunnel work (Restore Moller Polarimeter – *work started*, Remove "Radiator Long" & install short, 2" beampipe, Restore Vacuum beam line.) **Work will be completed by August 2014.**
2. Magnet and Power Supplies: **Will be completed by Summer 2014.**
3. Check HPS vacuum chambers: ***ECal vacuum chamber*** *has been check, flanges are perpendicular to the mid plane +/- 1mm. Next is to mount it on the analyzing magnet vacuum chamber and check the overall alignment, but this we may do after it will be moved to alcove.* **Work will be completed by Summer 2014.**

HPS chicane move and connection in alcove:

Will happen in March - June 2014.

- Design of major parts of the magnet supports are complete
- Drawings will be ready for purchasing components in December
- Most of beam line elements use existing support stands for magnets.

There will be a short time window between the end of detector installation on the forward carriage in Hall-B and the start of CLAS12 torus assembly when we can move forward carriage upstream and can install magnet support system (alcove platform) and all three chicane magnets in alcove.

Critical milestone: magnets must be installed in alcove before June 2014 not to interfere with CLAS12 torus assembly.

Two New Girders:

- **Downstream Guider that holds 2 BPMs and Horizontal – Vertical Correctors:** Girder ensures stable beam on target. Design work in progress.
- **Upstream Girder holds new quads and correctors:** The upstream girder will have quads and correctors. Design work in progress.

SVT Update

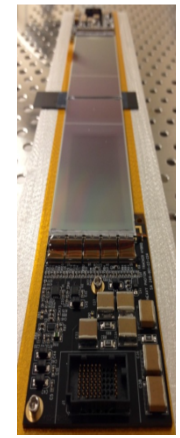
- **L4-6 Hybrids** (APV25 front end readout) working. Ready for module construction.

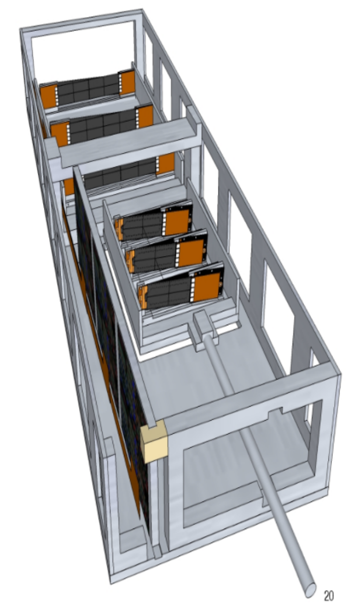
- **Second L4-6 Module** (detector+support+hybrid) built and tested. Works! Production run begins soon.

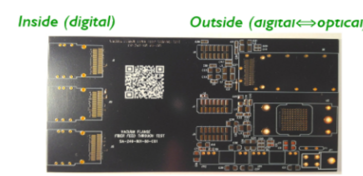
- **Support structure design** ~ complete. Fabrication begins mid-May. 4-6 weeks late.
  * Robust and reproducible module support
  * Mechanics for moving assembly close to beam
  * Module and electronics cooling
  * Holds FE electronics

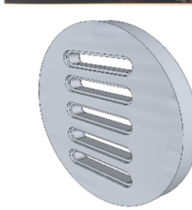
- **Flange Board and Flange** provide vac feed-through for power, signal, and HV. Board and feed-through successfully tested.

- **Precision movers being commissioned**









SVT Cooling

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

- better cooling and cooling at 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

HPS Test Sensor Cooling