

HYDROSTATIC LEVELING SYSTEMS AT THE ADVANCED PHOTON SOURCE



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ABSTRACT

- Maintaining the upgraded APS alignment tolerances is challenging due to ground motion and settlement.
- APS is deploying two hydrostatic leveling systems (HLSs) to:
 - monitor vertical displacement
 - transfer elevation over long distances
- The storage ring HLS system includes 110 sensors to measure:
 - relative floor motion at each insertion device front end
 - global floor motion throughout the storage ring tunnel
- A second HLS system with 2 sensors will transfer X-ray source-point elevations to the Long Beamline Building (LBB), about 200 meters away.
- The presentation covers:
 - the design of both systems
 - their intended applications
 - the current deployment status
- Since neither system is fully operational yet, the presenters welcome discussion and feedback from those with relevant commissioning and operational experience.

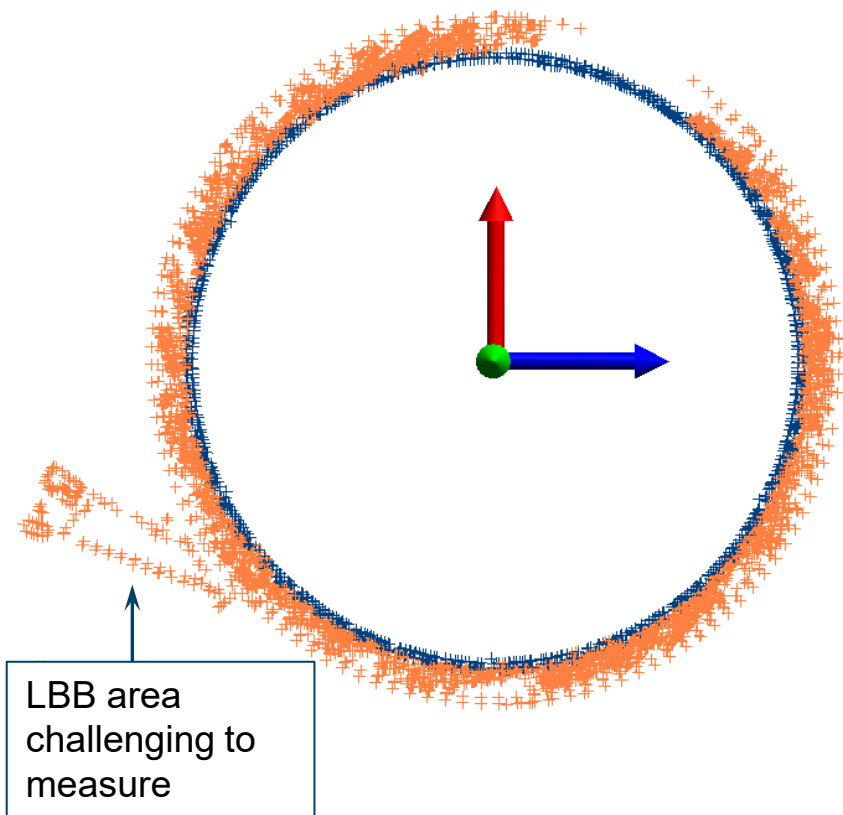
APS COORDINATE SYSTEM

- The Advanced Photon Source (APS) reference surface is a Gaussian sphere fitted to Clarke's ellipsoid at 41.7° north latitude, approximating the local gravity field with a radius of 6,371-km.
- The APS design lattice is expressed in a right-handed Cartesian system aligned with and tangent to the geodetic system at the origin, where beam elevation is 228.1712-m (MSL). Origin is storage ring radius point.
- The Cartesian plane departs from the geodetic surface with increased distance from the origin.
- For the storage ring (≈ 175 -m radius), the deviation is ~ 2.42 -mm constant; for the LINAC, PAR, and booster and experiment hall, it is variable.
- Compensation for systematic curvature effect is applied to all accelerator and beamline component positioning.



NASA Goddard Space Flight Center
Image by Reto Stöckli

APS CONTROL NETWORKS



Primary Storage Ring Tunnel Network

1305 monuments

Single data set

Most precise - Two-face tracker measurement

Storage ring alignment tolerance

30 to 100- μm rms

Secondary Experiment Hall Networks

>6100 monuments

Multiple data sets

Less precise - Best-fit to primary network

Beamline alignment tolerance

250- μm rms

APS CONTROL NETWORKS

- 3-D control networks measured using Leica AT403 Laser Trackers and Digital Levels.
- One-dimensional leveling networks integrated - increase confidence in geodetic elevation data
 - Digital automatic level
 - Invar bar code leveling staffs
 - Leveling adjustment software (Infinity)
- Primary 3-D Network +1-D elevation adjustment performed using NETOBS* software
- Secondary networks adjusted in USMN
 - Best-fit to Primary Network
 - Fitted to 1-D elevation data

*NETOBS Free Download at:
<https://frib.msu.edu/user-facilities/downloads/netobs>

LBB-HLS



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LONG BEAMLINE BUILDING (LBB)

Two ~200-meter-long beamlines pass through multiple spaces and corridors - conventional line-of-sight surveying difficult.

Advantages of a Hydrostatic Leveling System (HLS):

- Significantly reduces Survey effort
- Provides higher accuracy with lower uncertainty
- References gravity equipotential surface
- Does not require a clear line of sight
- Eliminates optical refraction errors



20-ID

High-Energy X-ray
Microscope
(HEXM)

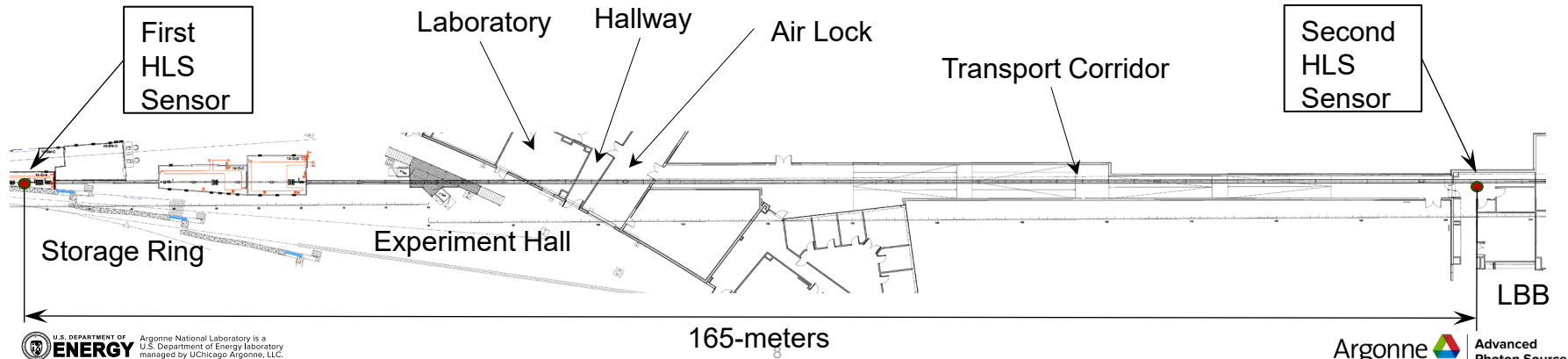
19-ID

In-Situ Nanoprobe
(ISN)



LBB-HLS

- 19-ID beam transport provides a stable support structure
- 165-m of 2" PVC pipe along x-ray beam transport
- Pipe leveled to ± 2 -mm, half-filled with water
- Two sensor heads – one at each end
- Storage ring elevation transferred to first HLS sensor
- Second HLS sensor in LLB serves as a high-precision benchmark



MECHANICAL DESIGN CONSIDERATIONS

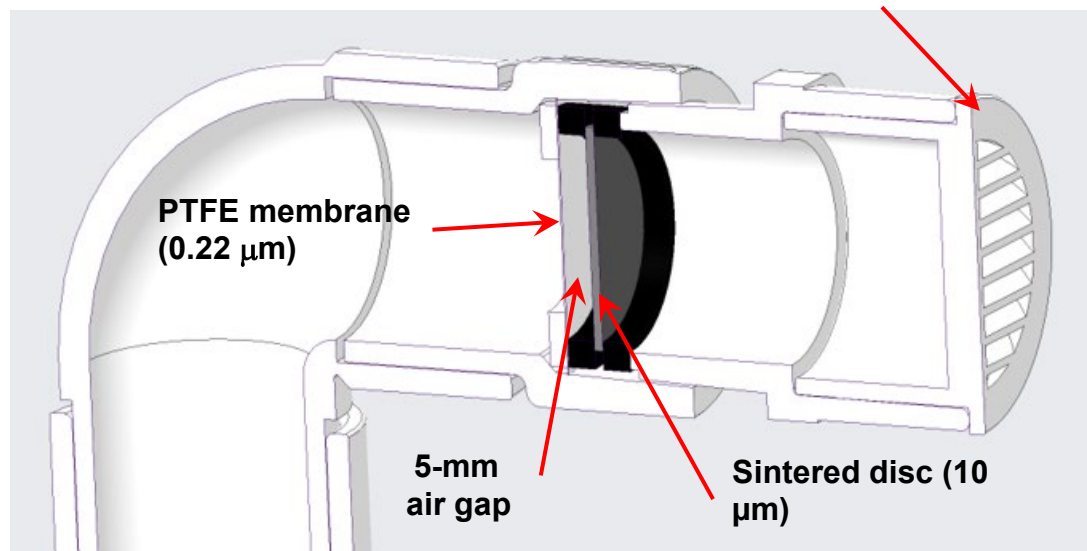
- Moderate CTE requires thermal displacement mitigation. Change of 5°C = $\sim 4\text{-mm}$ displacement over 15-m.
 - ✓ 90-degree bends fitted with flexible couplings at wall pass-throughs and around 19ID B and C enclosures
 - ✓ expansion couplings every 30-m on longer runs; constraints at midpoints; max expansion length 15-m



AIR FILTRATION AND CONTAMINATION PREVENTION

Prevention of contamination with biota such as bacteria, molds and algae in the HLS piping system is important.

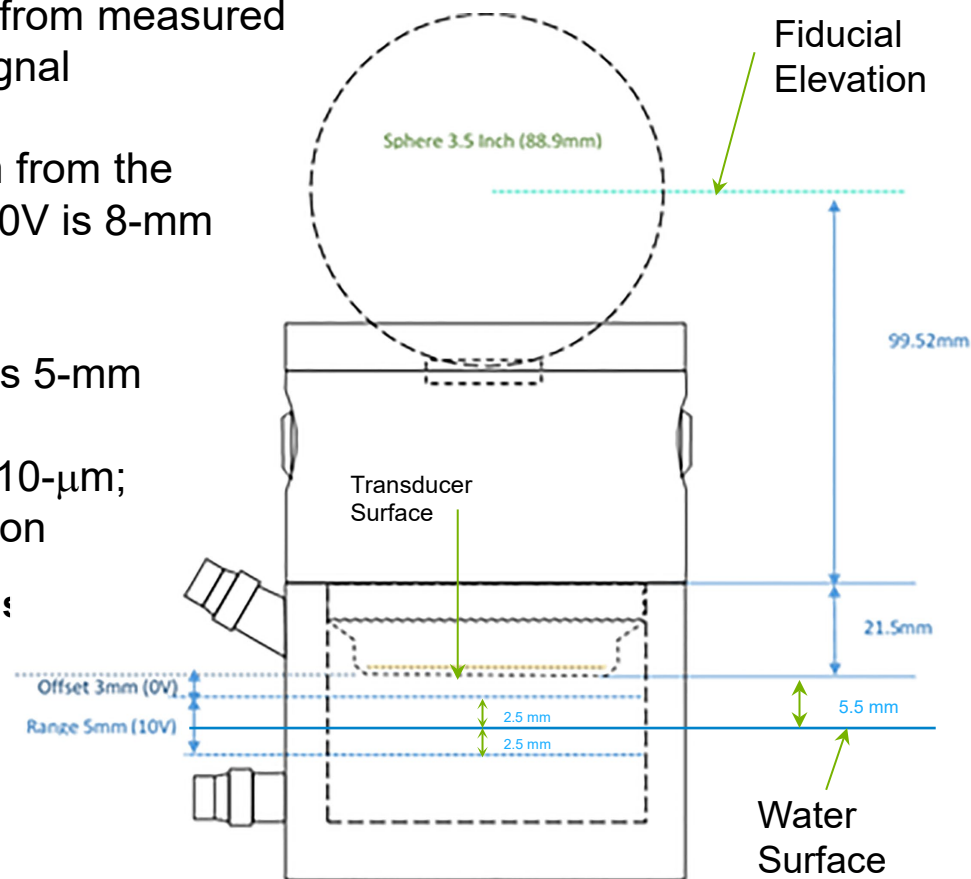
- Interior of the piping cleaned, disinfected and kept free of contamination during assembly.
- Long-term prevention of contamination includes filling the system with distilled water and incorporating air filtration at the vents.



- A single vent to equilibrate pressure within the pipe with the ambient air pressure. Vent filtration includes sintered disc and PTFE membrane. Two auxiliary vents for drain/fill process only.
- Biocides may be added if contamination becomes an issue.

HLS MEASUREMENTS

- Distance determined from measured transducer voltage signal
- 0 Volts is offset 3-mm from the transducer surface; 10V is 8-mm from the transducer
- Measurement range is 5-mm
- Sensor accuracy is $\sim 10\text{-}\mu\text{m}$; resolution is sub-micron
- Storage ring elevation is transferred to the US sensor
- LBB elevation is measured from DS sensor $\sim 165\text{-m}$ away



Sensor H7E4-020

Results	
Voltage (V)	Distance (mm)
0.0027866	-0.0001
0.48581	0.2498
0.9689	0.4987
1.4571	0.7492
1.9476	0.9998
2.4386	1.2496
2.9295	1.4983
3.4261	1.7481
3.9239	1.9985
4.4236	2.2499
4.923	2.4993
5.4264	2.7499
5.9288	2.9993
6.4324	3.2486
6.9372	3.4979
7.4451	3.7482
7.9535	3.9983
8.4626	4.2485
8.9706	4.4978
9.4807	4.7483
9.9895	4.9983

Sensor H7E4-022

Results	
Voltage (V)	Distance (mm)
-0.0034094	-0.0018
0.47991	0.2481
0.96362	0.4971
1.4517	0.7474
1.9422	0.9979
2.4336	1.248
2.9243	1.4967
3.4203	1.7472
3.9179	1.9977
4.4175	2.2482
4.9167	2.4978
5.4195	2.7481
5.922	2.9977
6.425	3.247
6.9295	3.4962
7.437	3.7464
7.9452	3.9966
8.4544	4.2469
8.9622	4.4962
9.4722	4.7465
9.9821	4.9966

STORAGE RING HLS



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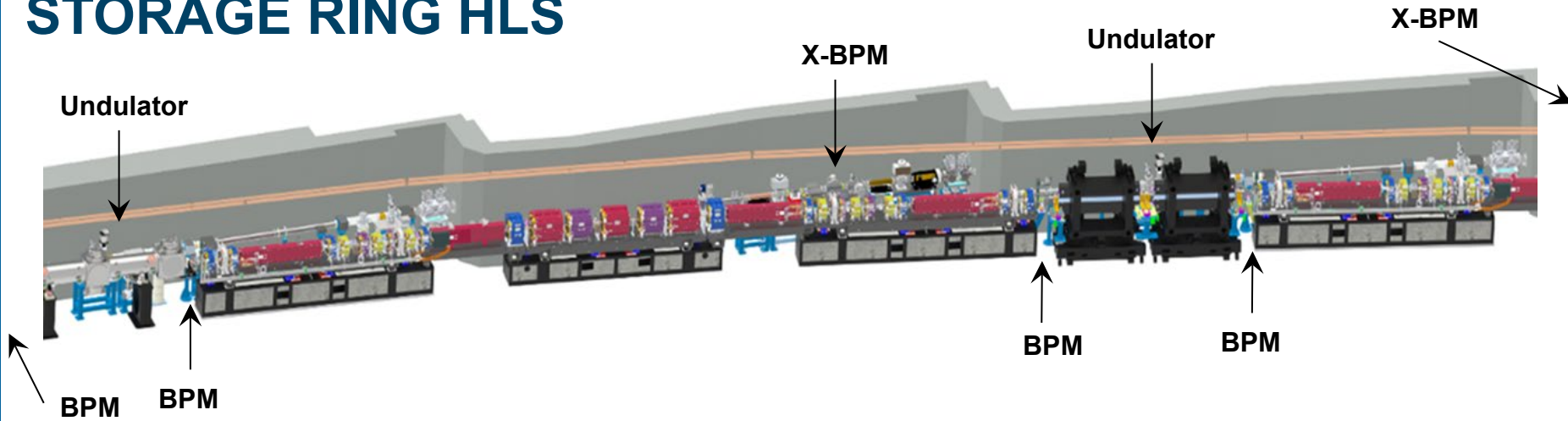
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STORAGE RING HLS

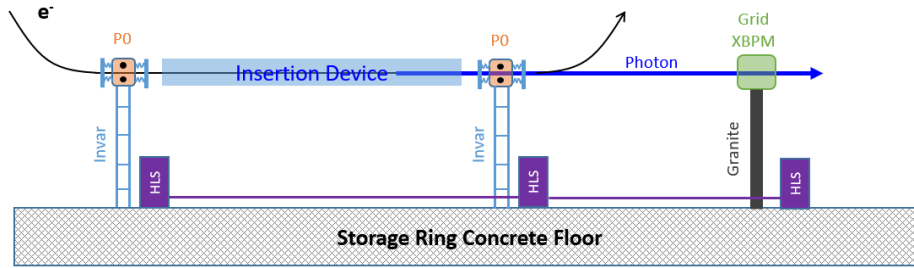
- APS storage ring tunnel infrastructure relatively stable vertically – settlement rate significantly reduced over ~35 years. **However;**
- Alignment tolerances for APS Upgrade storage ring considerably more challenging than original APS – new machine less tolerant of settlement and seasonal displacements
- Monitor relative vertical positions of two e⁻ beam BPM's and one X-BPM for each of 35 insertion device beamlines (3 sensors per beamline) to correlate floor motion with motion of critical beam-monitoring devices: electron beam BPMs, photon beam xBPMs

STORAGE RING HLS



- Initial installation will independently monitor each beamline with flexibility to interconnect all sensors in the future. Adjacent sectors use the same electronics rack (double sector configuration).
- Separate water and air lines employed – 12-mm ID tubing used. Future interconnection could be challenging. Half-full pipe may be necessary.
- Sensor heights adjusted to common elevation to maximize measurement range.

HLS SYSTEM AND SPECIFICATION



- 3 sensors per Insertion Device Frontend (IDFE)
- Total of 35 IDFE's
- 5 extra sensors in RF / Injection area

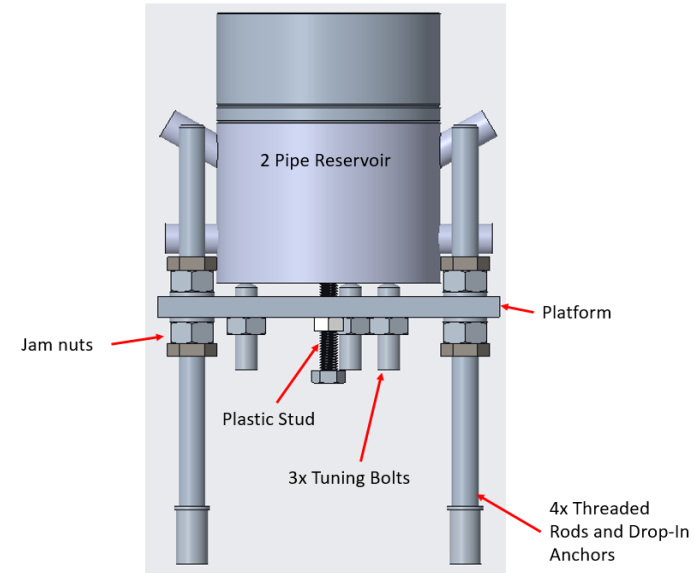
Total **110 HLS** sensors in Storage Ring

BPM supports are Invar CTE = 1.2 ppm/°C

Grid XBPM support is granite CTE = 4.0 to 9.0 ppm/°C

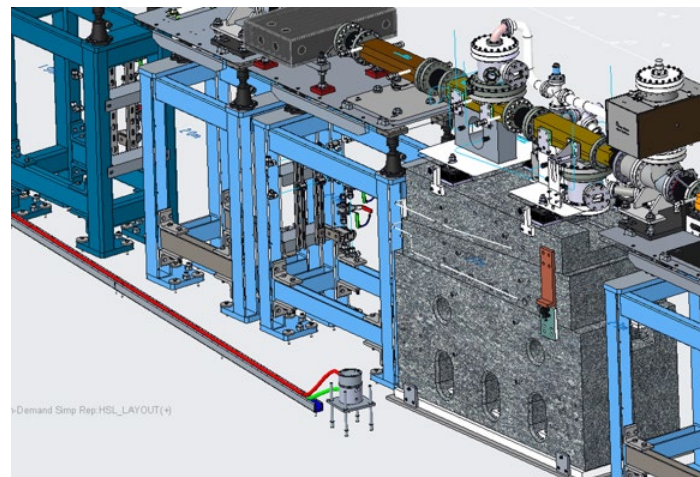
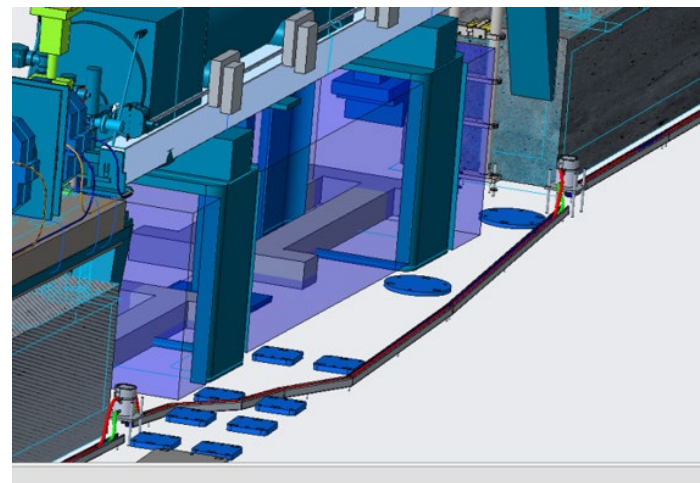
Storage Ring tunnel temperature stability 22.2 +/- 0.1°C

Parameter	Specification	Condition
Resolution	50 nm RMS	0.01 Hz
DC stability	500 nm RMS	1 week



SYSTEM LAYOUT

- 35 ID Front Ends (IDFEs), 3 sensors per IDFE
- Sensors near upstream BPM, downstream BPM, GRID xBPM (~20 m from source)
- 5 extra sensors in Zone-F sectors
- Total: 110 measurement locations
- Local networks join via valves into global ~1.1 km ring network
- Why: captures local and global floor motion
- Enables comparison of floor motion at primary diagnostics



EXPECTED PERFORMANCE

- Prototype met 50 nm resolution @ 0.01 Hz, 500 nm stability/week
— APS-U 2-pipe aims for similar performance
- HLS data supports evaluating long-term motion and correlating BPM/xBPM drift
- Helps understand stability limits over days
- Bottom line: A diagnostic tool to monitor and eventually improve the long-term beam stability.
- Key point: the HLS helps distinguish true floor motion from other sources of beam-position drift

EPICS INTERFACE



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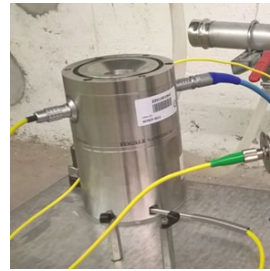
APS EPICS INTERFACE

- HLS sensors read from the controllers through via **Experimental Physics and Industrial Control System (EPICS)** software application
- EPICS application was developed by diagnostics group for storage ring monitoring – same application to be used for LBB-HLS
- Automated Data logging and reduction

HLS_DS2Sec.d

HLS Double Sector

Ria Rack	Sensor Location	Height(mm)	Temperature(C)	Height w/o Dilution
S21 RiaCh1	BP0	5.406506	25.442374	5.008854
S21 RiaCh2	AP0	0.400987	24.923966	0.046955
S21 RiaCh3	XBPM	5.382363	25.137236	5.013857
S21 RiaCh4	BP0	5.478912	26.164797	5.010884
S21 RiaCh5	AP0	0.415519	24.139403	0.135197
S21 RiaCh6	XBPM	5.333706	24.630199	5.012832



```
#####
### MainS = Sector the Ria Box locate
### Riach = the channel ID on Ria Box
### Sector = Sector the HLS sensor locate
### Sensor = The Sensor order from upstream to downstream
### BpmName = The Bpm next to sensor
### NextPV = FLK of this PV, normally it goes to TempSaveVoltM for next sensor in this template e.g. S02-HLS:SNR2:TempSaveVoltM
### NextPV = for the last one, it goes to the first PV in RiaBpm Diff.template, e.g. S02-HLS:Delta2_2M
### CalLH = Temperature sensor's Calibration Coefficient; To Td = TdV
### CalLHx = Height sensor's Calibration Coefficient; H= H0+ H1V+ H2V^2 +H3V^3
### H0 = Height of sensor base above floor
### H0100 = Height of pipe bottom from floor

file db/RiaBpm.Cali.template {
  pattern
  (MainS RiaCh Sector Sensor BpmName NextPV CalLH1 CalLH2 CalLH3 CalLH4 Hsensor Hpipe)

#H7E4-015
( S09 1 S08 SNR1 BP0 S08-HLS:SNR2:TempSaveVoltM 0.5031 -0.00120 +0.000001 -0.001 0.10 -260.0 )
#H7E4-016
( S09 2 S08 SNR2 AP0 S08-HLS:SNR3:TempSaveVoltM 0.5029 -0.00112 +0.000077 -0.001 0.10 -260.0 )
#H7E4-014
( S09 3 S08 SNR3 XBPM S09-HLS:SNR1:TempSaveVoltM 0.5037 -0.00118 +0.000078 -0.001 0.10 -260.0 )
#H7E4-012
( S09 4 S09 SNR1 BP0 S09-HLS:SNR2:TempSaveVoltM 0.5028 -0.00111 +0.000077 -0.001 0.10 -260.0 )
#H7E1-015
( S09 5 S09 SNR2 AP0 S09-HLS:SNR3:TempSaveVoltM 0.5036 -0.00115 +0.000074 -0.000 0.10 -260.0 )
#H7E1-015
( S09 6 S09 SNR3 XBPM S08-HLS:Delta2_2M 0.5030 -0.00115 +0.000074 -0.000 0.10 -260.0 )

#####
#####The Diff Height= Sensor1-Sensor2
#####The BpmName is the Bpm next to Sensor1
##### Next PV goes to the StatusEncDec is Main Sector, e.g. S03-HLS:CTLR:StatusEncDec
##### If for Sector 36,37,38,39 this will not be called!!
file db/RiaBpm.Diff.template {
  pattern
  (Sector Sensor1 Sensor2 BpmName1 BpmName2 NextPV)
  (S08 1 2 BP0 AP0 S08-HLS:Delta2_3M)
  (S08 2 3 AP0 XBPM S09-HLS:Delta2_2M)
  (S09 1 2 BP0 AP0 S09-HLS:Delta2_3M)
  (S09 2 3 AP0 XBPM S09-HLS:CTLR:StatusEncDec)
}
```



EPICS application developed for HLS by SuYin Grass Wang

ACKNOWLEDGEMENTS & REFERENCES

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LBB-HLS:

Michael Bosek: HLS installation assistance

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Su Yin Grass Wang: EPICS support

Luis Diaz: Design and Drafting

William Turner: Design and Drafting

Storage Ring HLS:

Dino Karas: ME support of the HLS system

Su Yin Grass Wang: EPICS support

Ken Kishbaugh and the diagnostics tech team:
Installation and acceptance testing

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1. **Earth Image (slide 5, slide 24):** NASA Goddard Space Flight Center Image by Reto Stöckli (land surface, shallow water, clouds). Enhancements by Robert Simmon (ocean color, compositing, 3D globes, animation). Data and technical support: MODIS Land Group; MODIS Science Data Support Team; MODIS Atmosphere Group; MODIS Ocean Group Additional data: USGS EROS Data Center (topography); USGS Terrestrial Remote Sensing Flagstaff Field Center (Antarctica); Defense Meteorological Satellite Program (city lights).

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21

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