



Improving LIGO's stability and sensitivity: commissioning examples

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Recent commissioning efforts

□ Reliability & Stability

- Seismic retrofit at LLO: **Hydraulic External Pre-Isolator (HEPI)**

□ Sensitivity

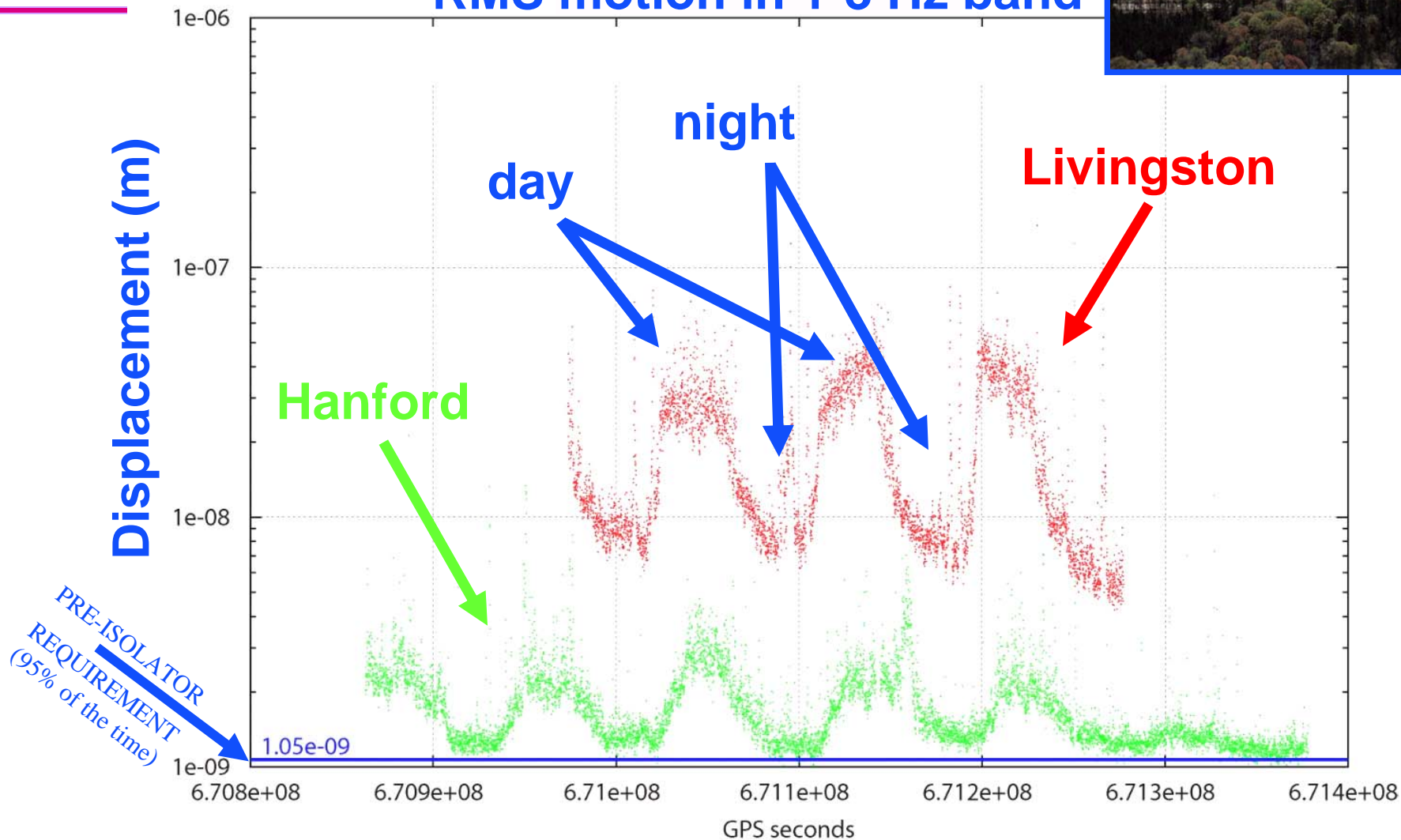
- Operate at high power: **achieve designed optical gain**
 - ❖ Laser power increase
 - ❖ Thermal compensation system (TCS)



Daily Variability of Seismic Noise



RMS motion in 1-3 Hz band





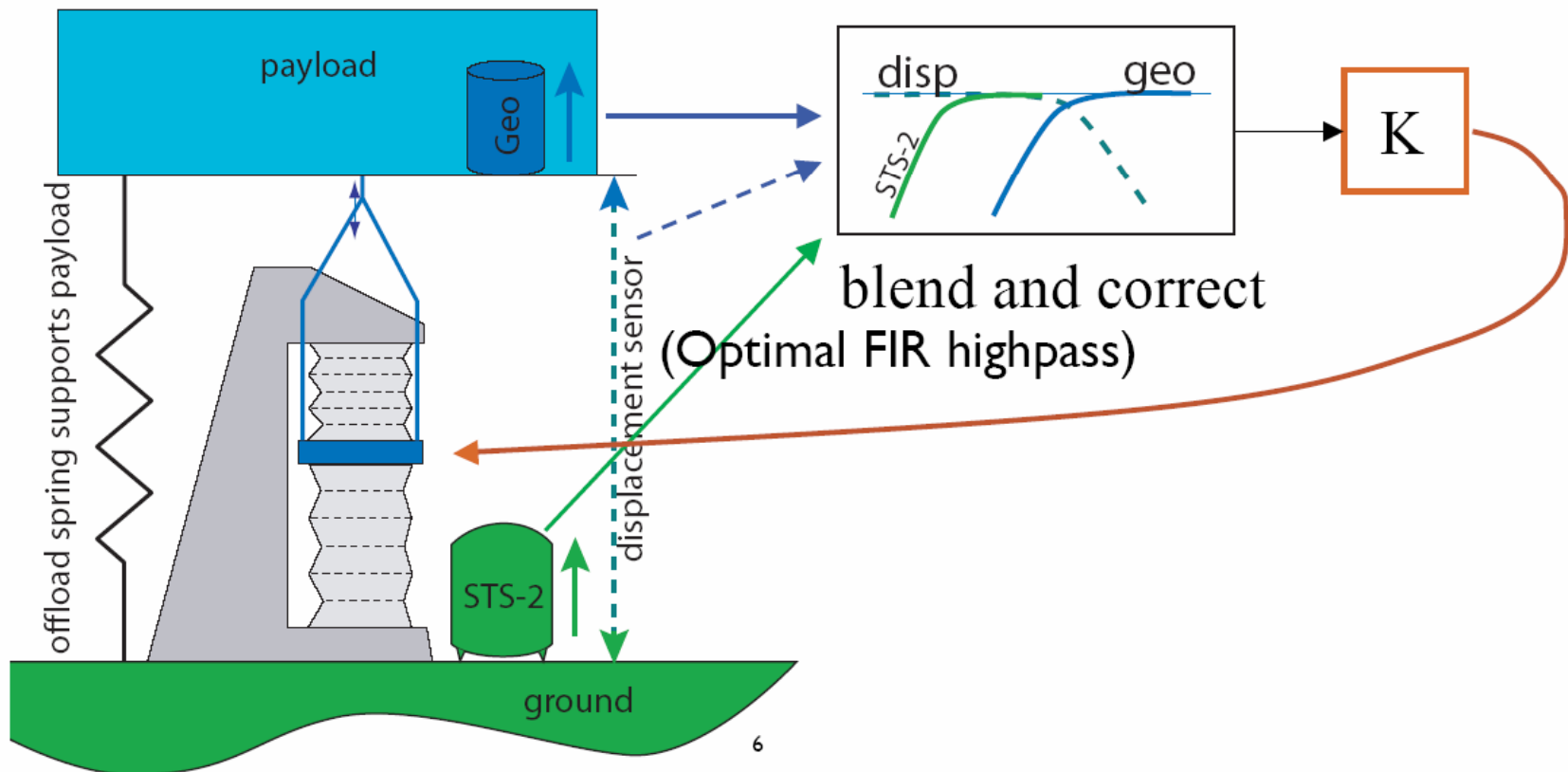
Hydraulic External Pre-Isolation: HEPI at LLO



Why has LLO been 'down' for half a year? An extra active seismic isolation stage has been installed at LLO, between the piers and the external seismic support structure.

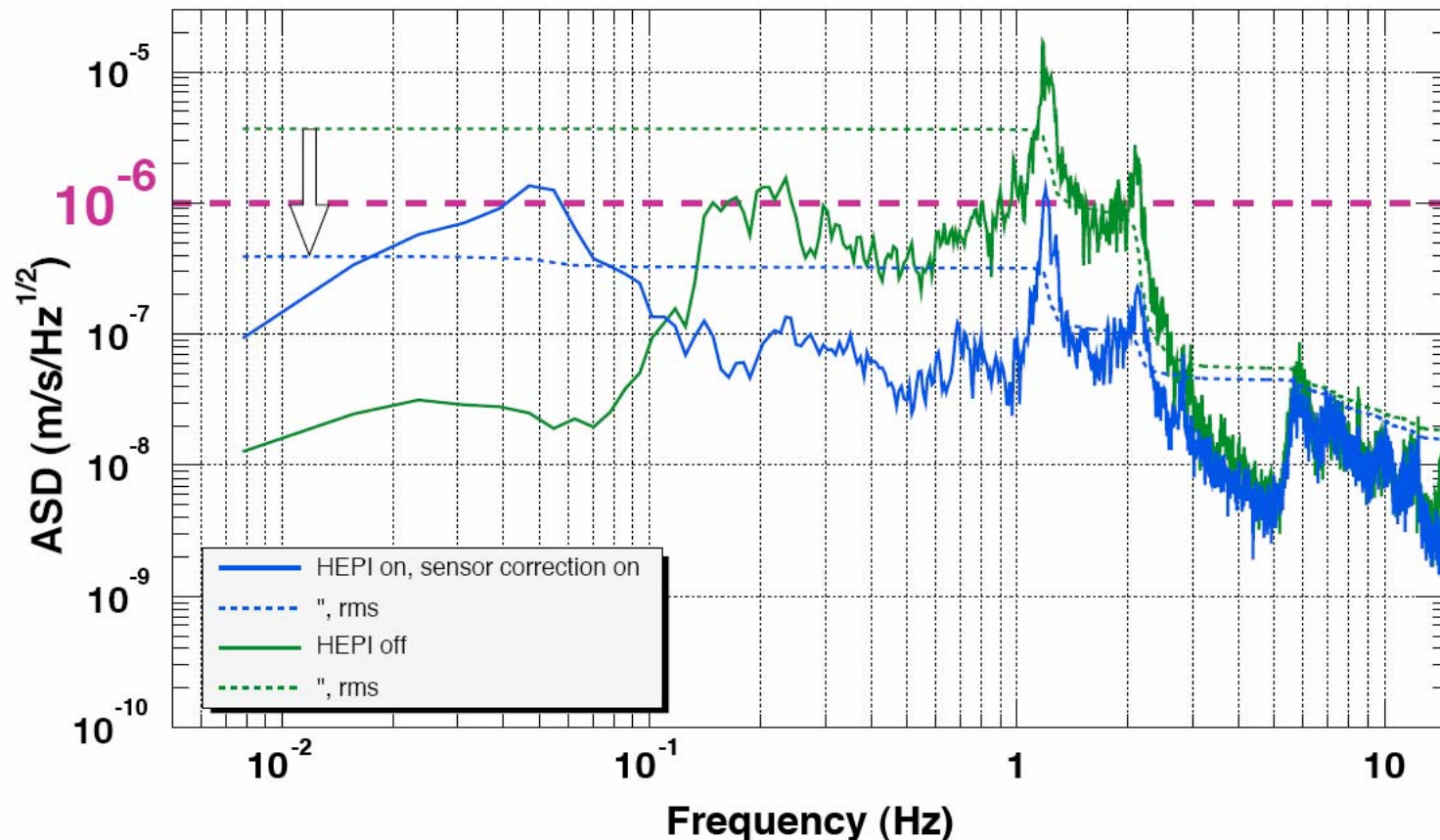
Low-frequency pre-isolation

- At each tank corner pier, there is a sensor/actuator set, vertical and horizontal.
- Each DOF controlled with respect to HEPI displacement sensors and geophones.
- Displacement sensor corrected for floor motion as measured by Streckeisen STS-2., in x, y, z DOF's.





X-arm length disturbance on a noisy afternoon



- Noisy afternoon of Aug 10, 2004 had a BLRMS ground velocity 1–3 Hz monitor value between the 90th and 95th percentiles.
- With HEPI in use, we expect the LLO detector to work on such a day, with a factor of 2 headroom.



HEPI summary

□ Remaining tasks

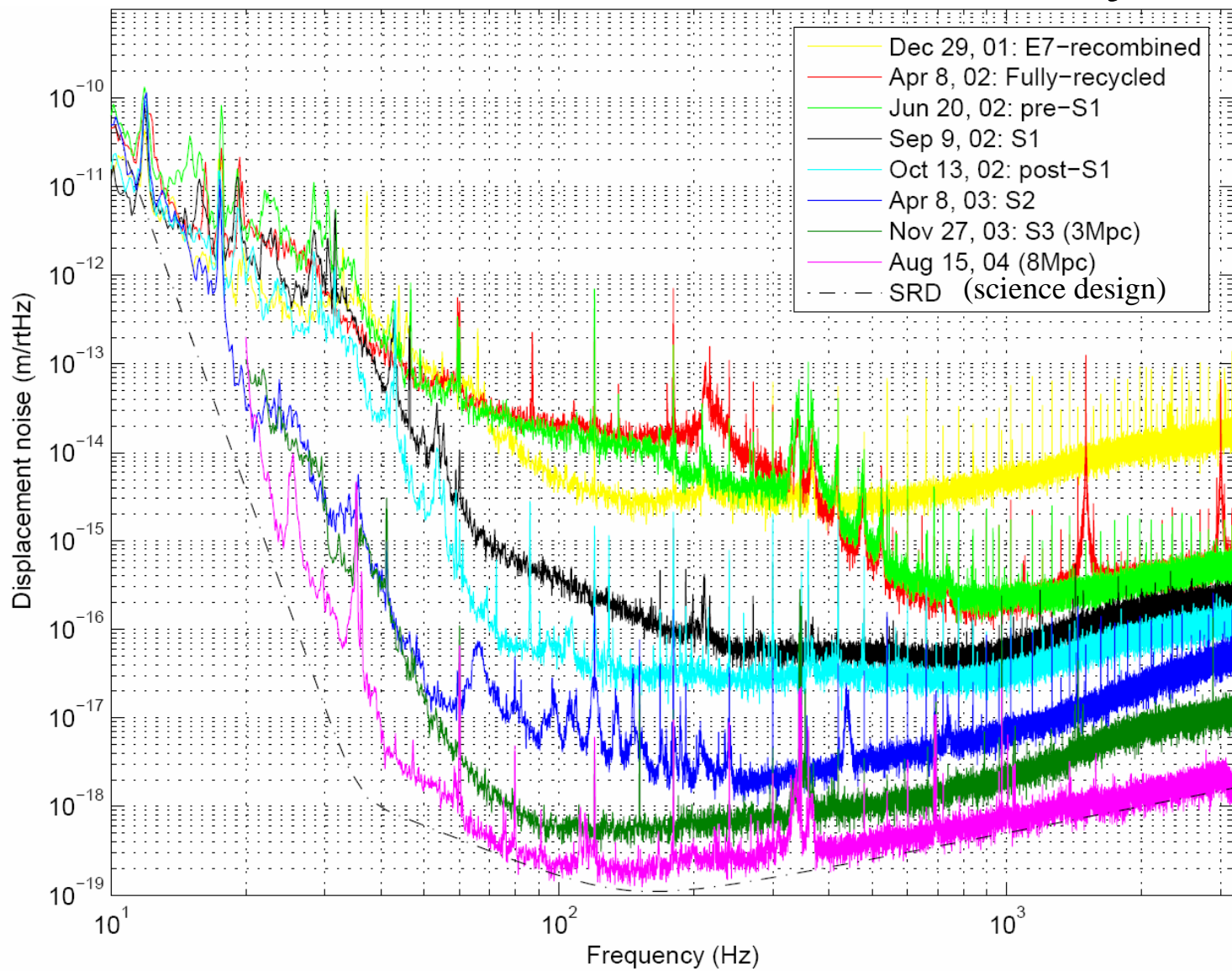
- Complete commissioning of final six chambers
- Sensor and whitening filter optimization
- Scripting, safeties, man-machine interface software

□ Summary

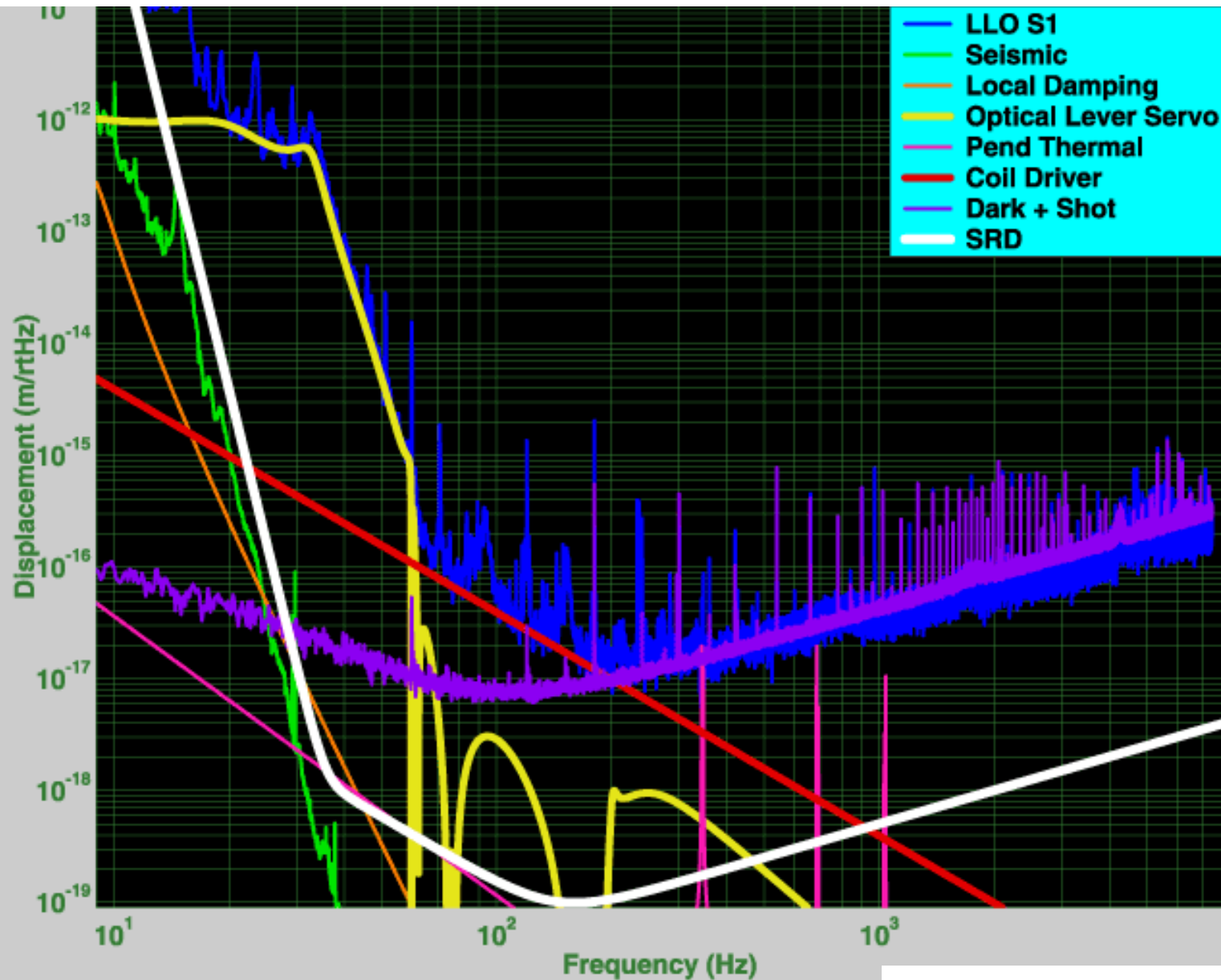
- All hardware installed
- Crucial one-arm test completed successfully
- LIGO will soon have two sites capable of night and day operation with reasonable duty cycle
- Pre-Isolator is first Advanced LIGO subsystem shown to work at required specification at observatory setting



LHO 4k noise history

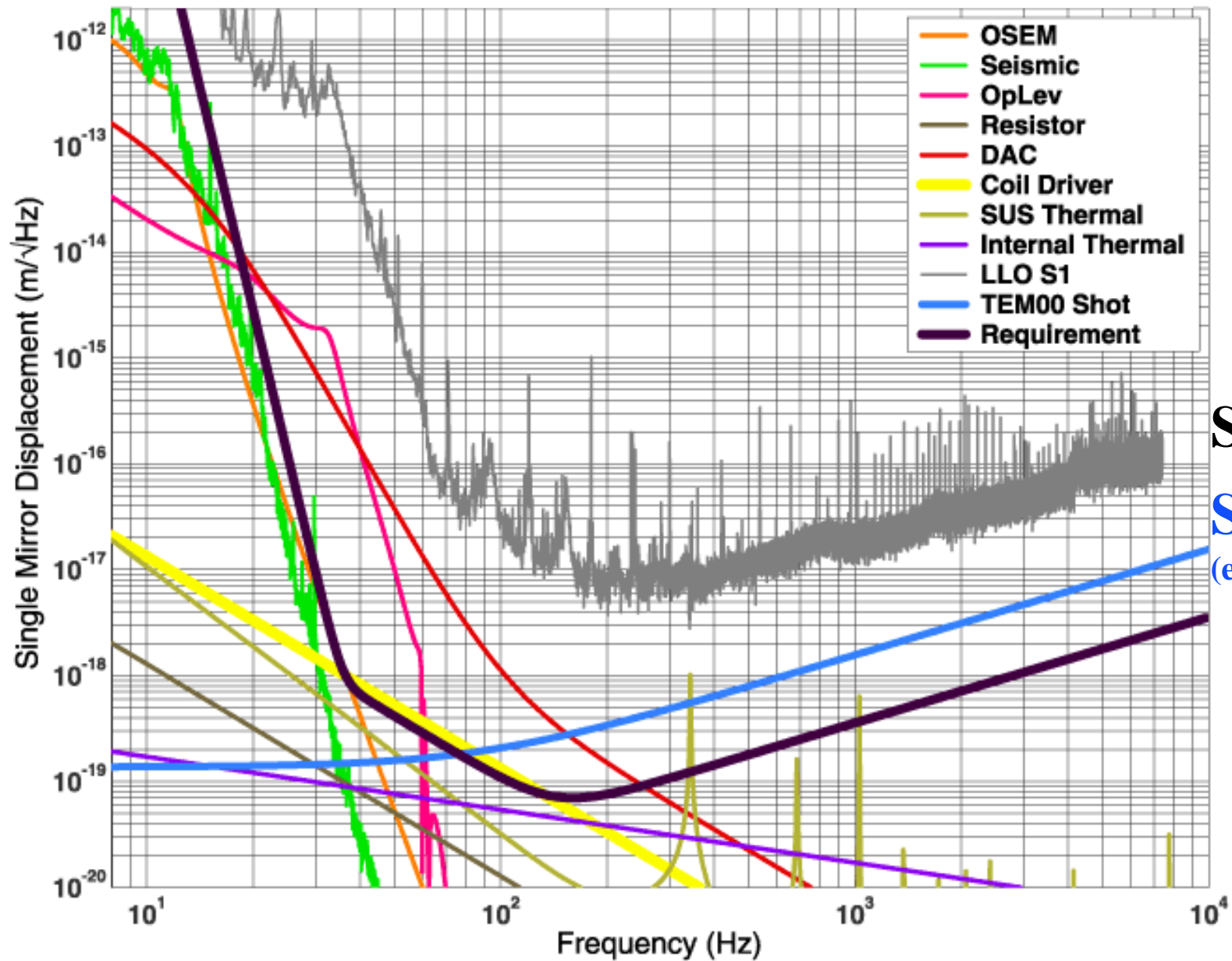


S1 Noise Component Analysis, LLO 4k



S1

Estimated Noise Limits for S2 (as planned in October 2002)



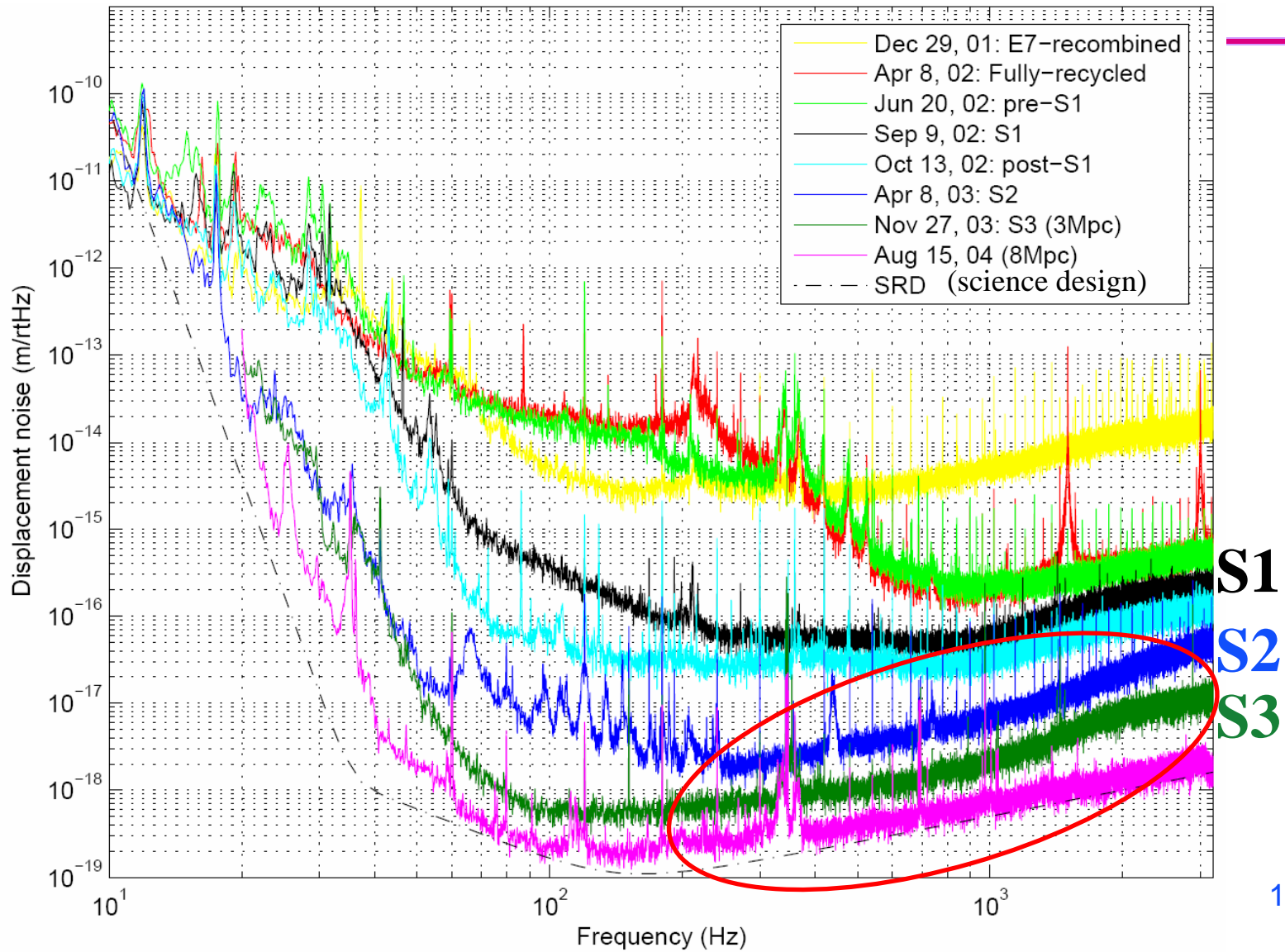
S1

S2

(expected)



LHO 4k noise history





What is shot noise?

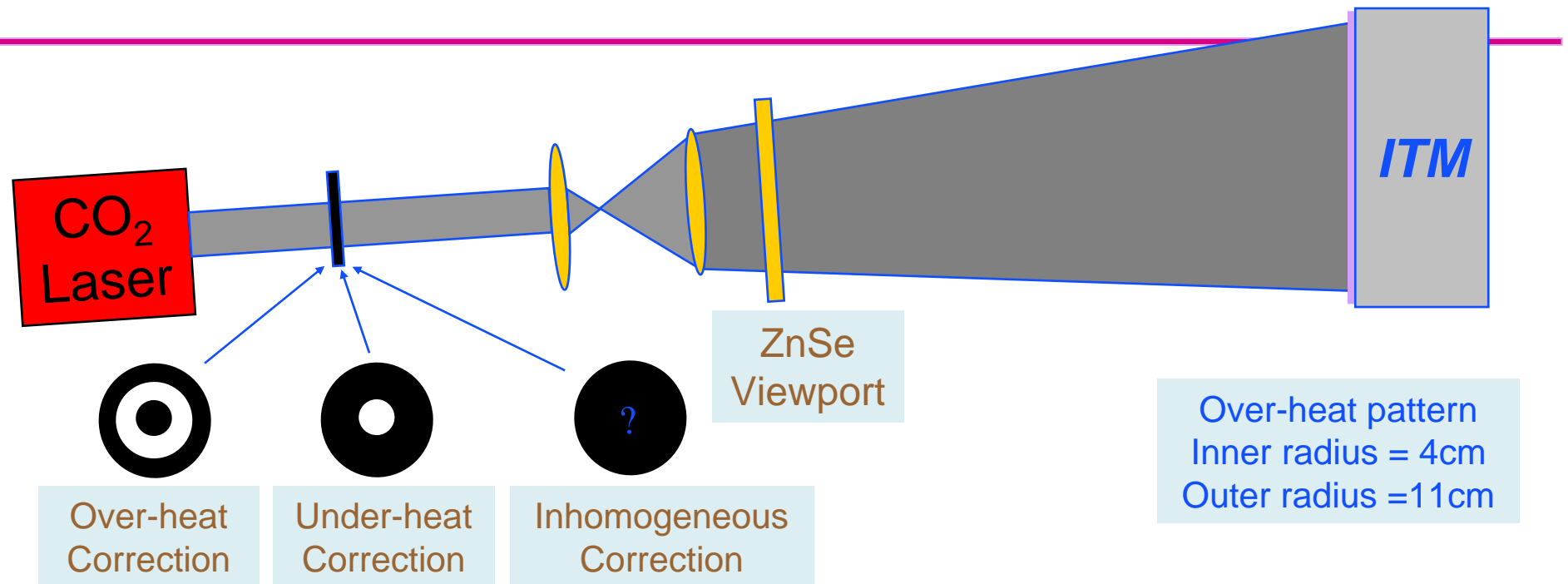
- ❑ Laser light comes in discrete packets of photons
- ❑ Stastical fluctuation in detected photons appears as length noise in an interferometer; Poisson statistics of light arrival times at the gravity-wave port photodiodes
- ❑ Strain noise decreases with the square-root of laser power



What can we do about shot noise?

- ❑ Increase laser power
 - Lasers refurbishing, now running at ~8W
 - ❖ Approximately 4W incident on interferometers
 - Input optics-train modified and aligned for better throughput
 - Additional photodiodes added to gravity-wave port
 - Additional power produces “thermal lensing” in interferometer optics
 - ❖ necessitates Thermal Compensation System (TCS)
- ❑ Ensure other high-frequency noise sources are reduced accordingly
 - E.g. “oscillator phase noise”

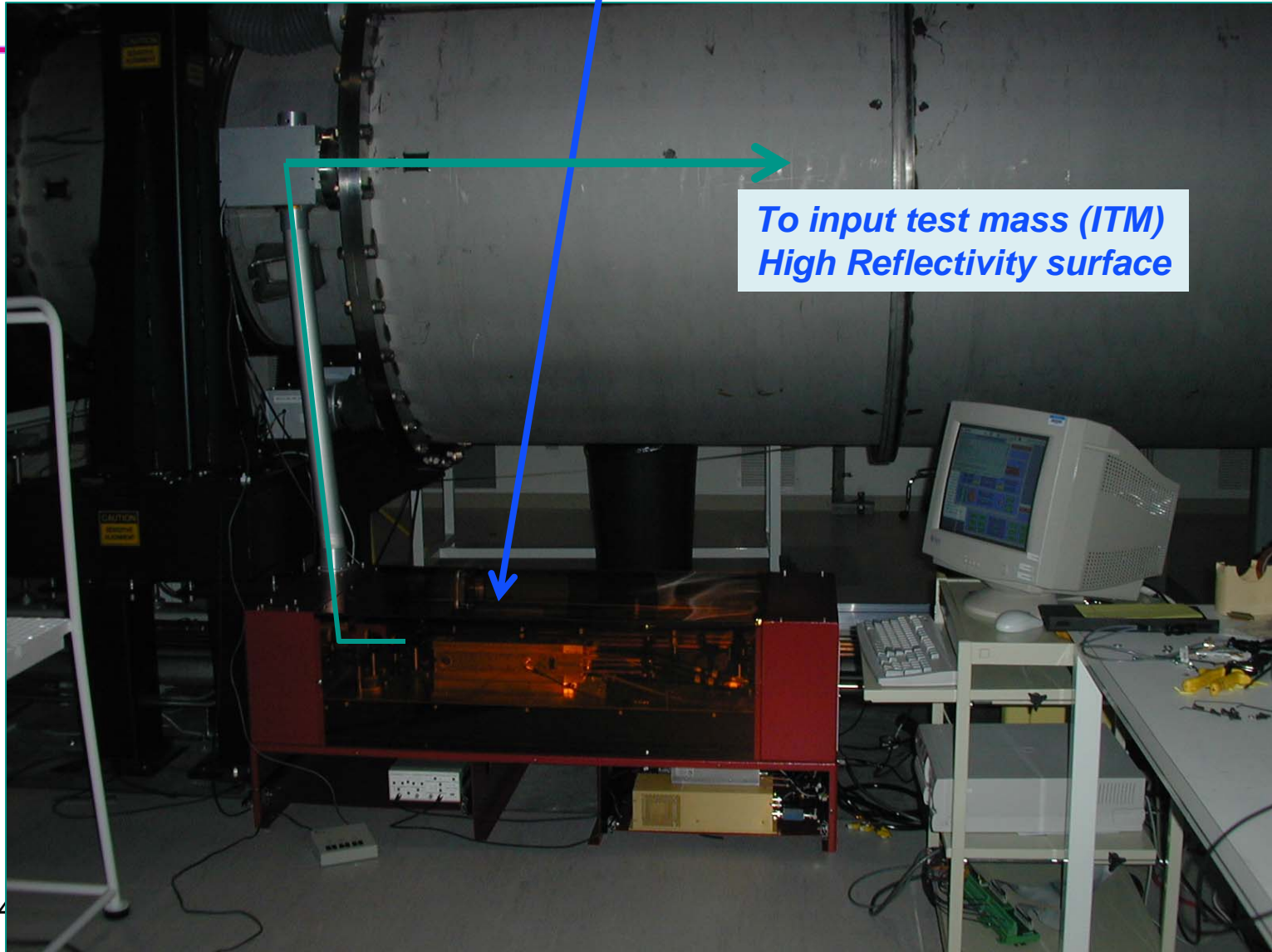
Thermal Compensation System (TCS)



- Require TCS to match input beam to the mode supported in arm cavities
- All systems installed



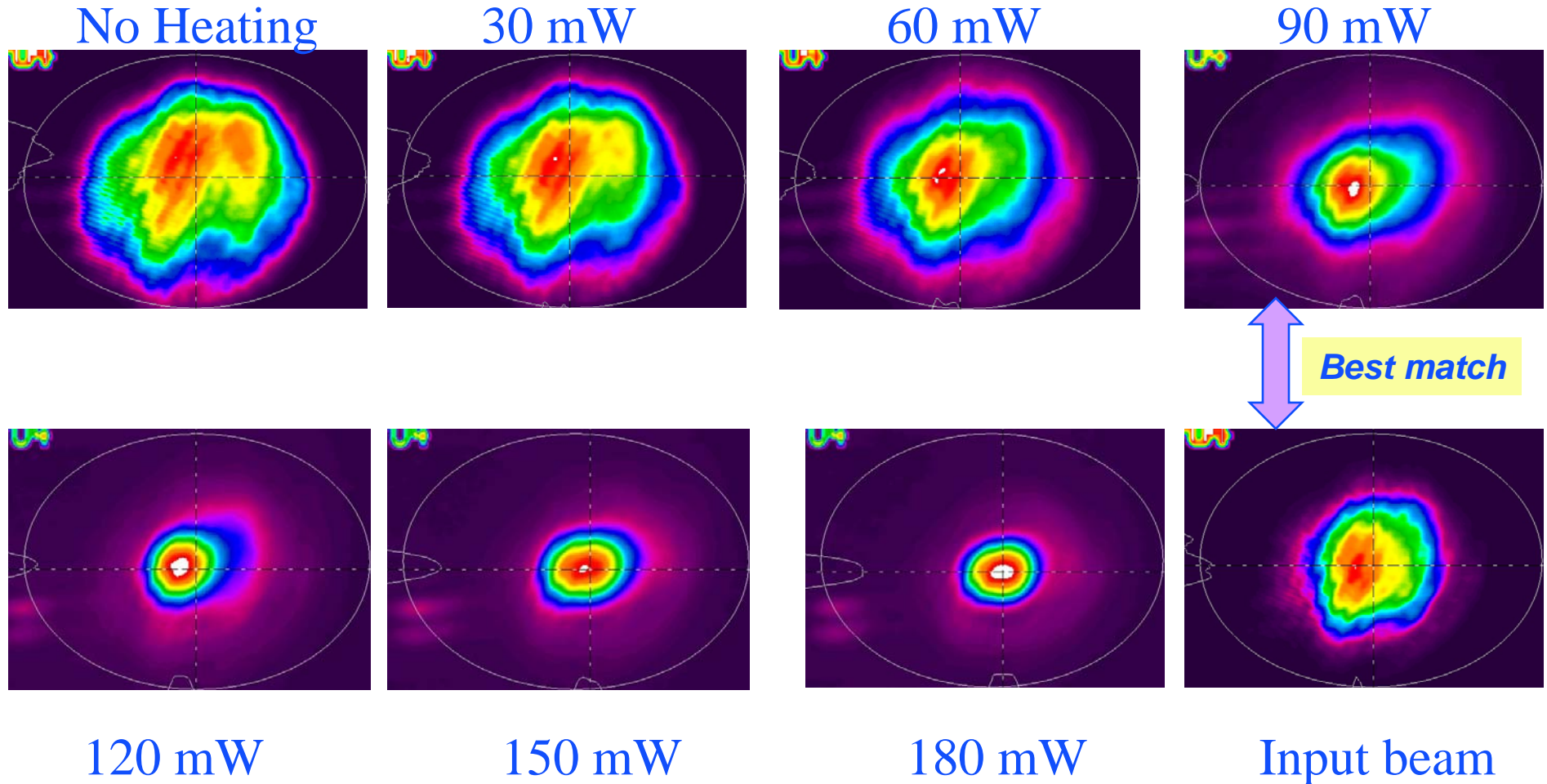
Two CO₂ lasers installed on H1



*To input test mass (ITM)
High Reflectivity surface*



TCS on the power recycled Michelson: beam images at gravity-wave port





High-frequency noise improvements

- Recent high-frequency noise improvement by factor of 2-4
- Thermal compensation required to support this gain in sensitivity (otherwise thermal lensing would limit such gains)

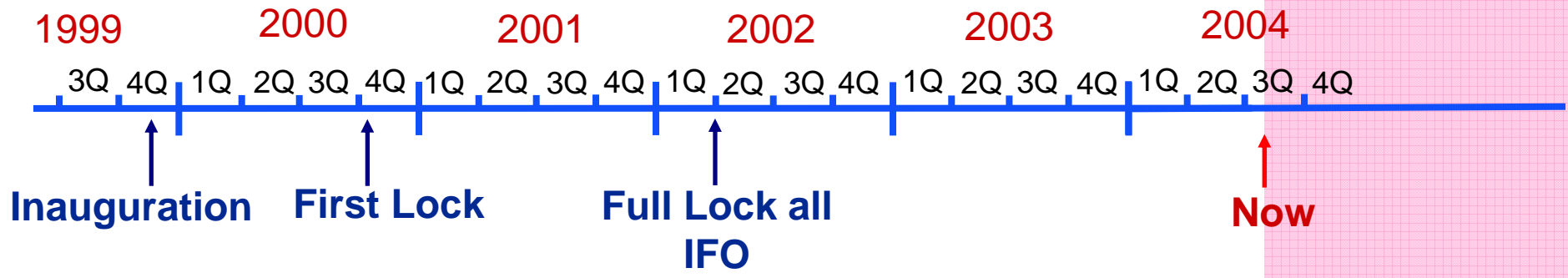


Parallel efforts

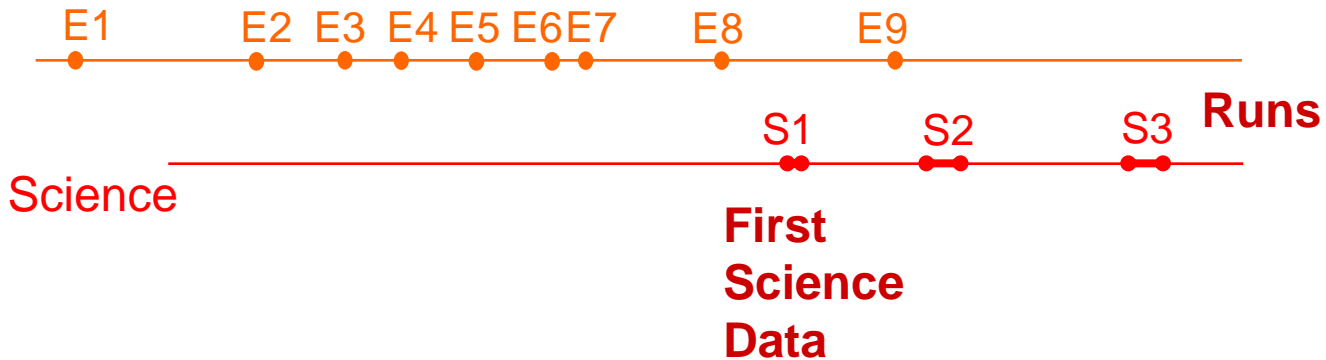
- Many other key commissioning efforts underway, including
 - Control of angular degrees-of-freedom (d.o.f.)
 - ❖ All 14 angular d.o.f. controlled on Hanford 4km interferometer
 - ❖ Input pointing into the interferometers controlled
 - Acoustic mitigation
 - Reducing control noise from other feedback systems in the interferometers



Time Line



Engineering





Looking ahead

- ❑ Livingston 4km interferometer:
 - Finish Hydraulic external pre-Isolator (HEPI)
 - Get good spectrum back
 - Implement improvements from LHO 4km interferometer
- ❑ Hanford 4km interferometer:
 - High power operations
 - “output mode cleaner” test version 2
 - New frequency and intensity stabilization, “common mode” boards, non-resonant sideband photodiodes on interferometer reflected output port
 - Optimize dewatering for new low-noise digital-to-analog converters
- ❑ Hanford 2km interferometer:
 - Implement improvements from the Hanford 4km interferometer
- ❑ Expect 4-6 week science run beginning Jan 2005
- ❑ On track to reach design sensitivity and begin an extended science run summer 2005