



Commissioning, part I

the EMC and HEPI retrofits at LLO

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Progress on **ElectroMagnetic Compatibility** Retrofit Phase I *power, grounding, digital EMI containment* (M. Zucker)

- **Power & line interference**
 - Replaced switching power supplies w/linears (*LI, HI, H2*)
 - Segregated digital (+ telcom, video) functions away from analog (*LI, HI*)
 - Introduced isolated balanced technical power (*LI Ex, Ey, vertex in prog*)
- **EMI containment**(*LI Ex, LI Ey... LI vertex in prog*)
 - Shielded Racks, x-connects and VME crates, EMI filters, new cabling, feedthroughs
 - Relocated racks & fans to isolated rooms--> *acoustic isolation*
- **Ancillary improvements**
 - Improved analog protocols for new designs (HEPI, FSS, ISS, RFPD, etc.)
 - EMC planning and testing integrated in design & prototype process
 - EMC testing part of commissioning at observatories
- **Incorporating lessons learned while propagating to HI, H2**

New EMC-compliant racks



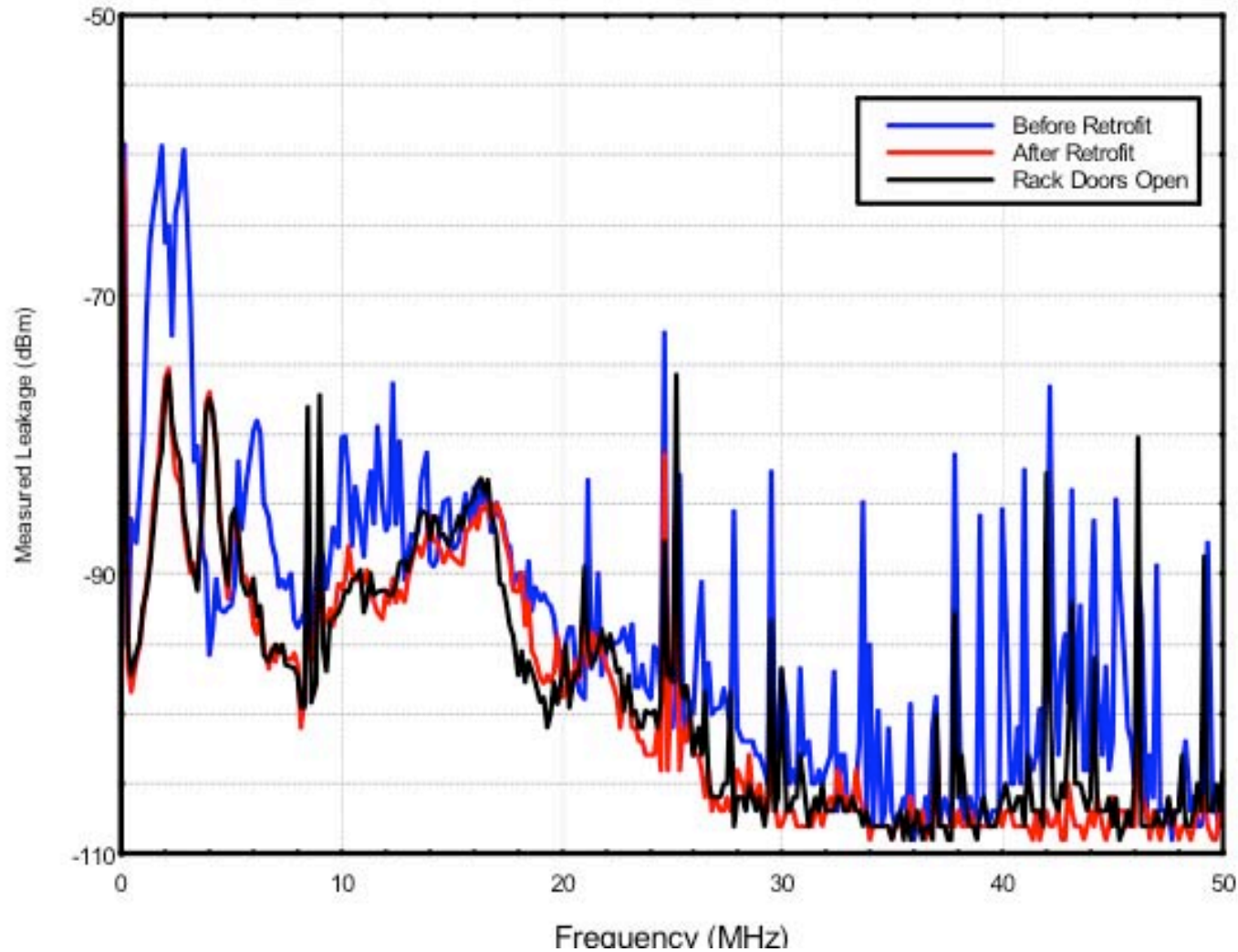
HEPI for LVEA



Y end station, sealed up

Effect of shielded racks/crates on HF radiation

Low Frequency RFI Results EY July 04



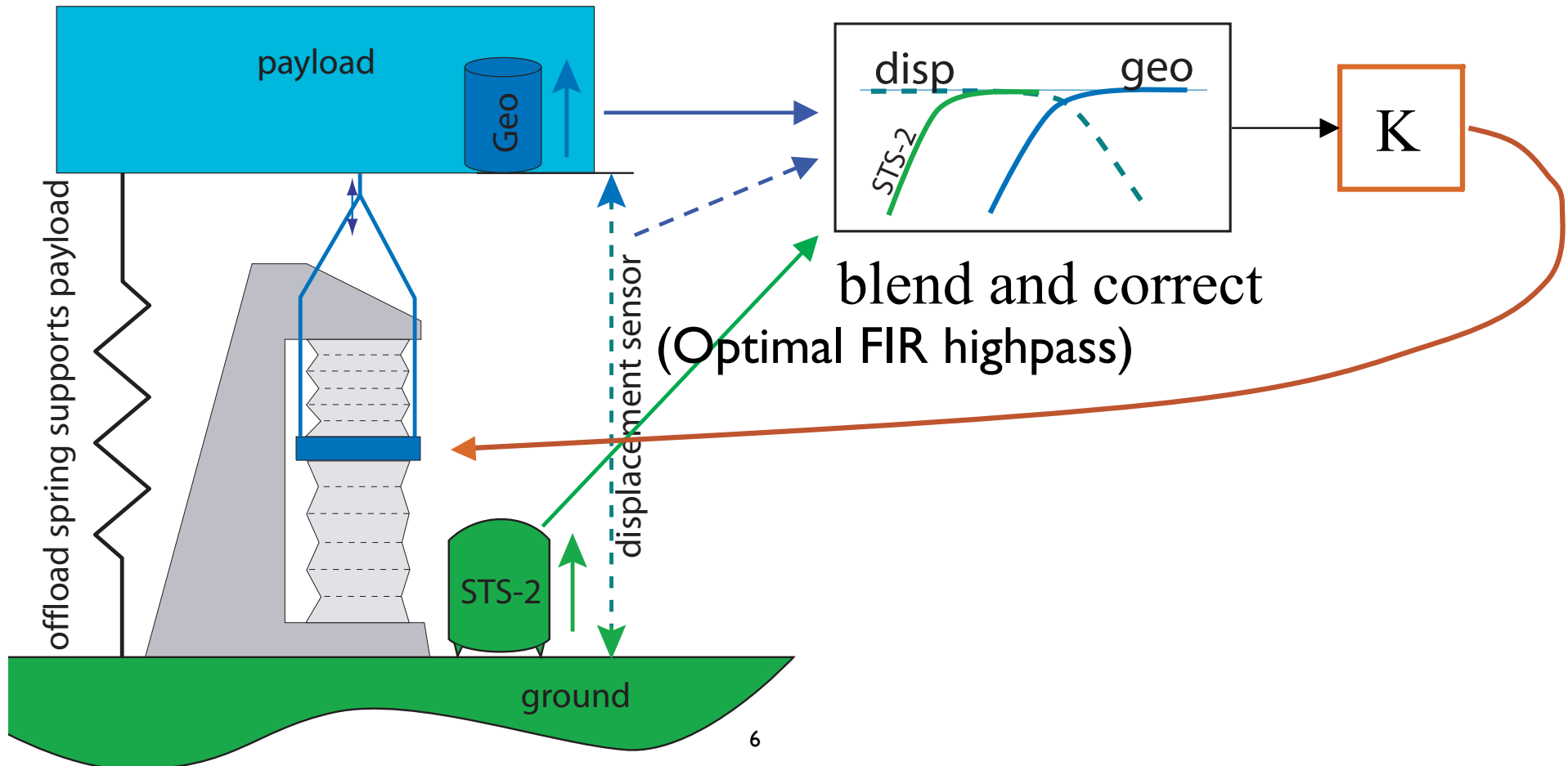
Hydraulic External Pre-Isolation (HEPI) stage



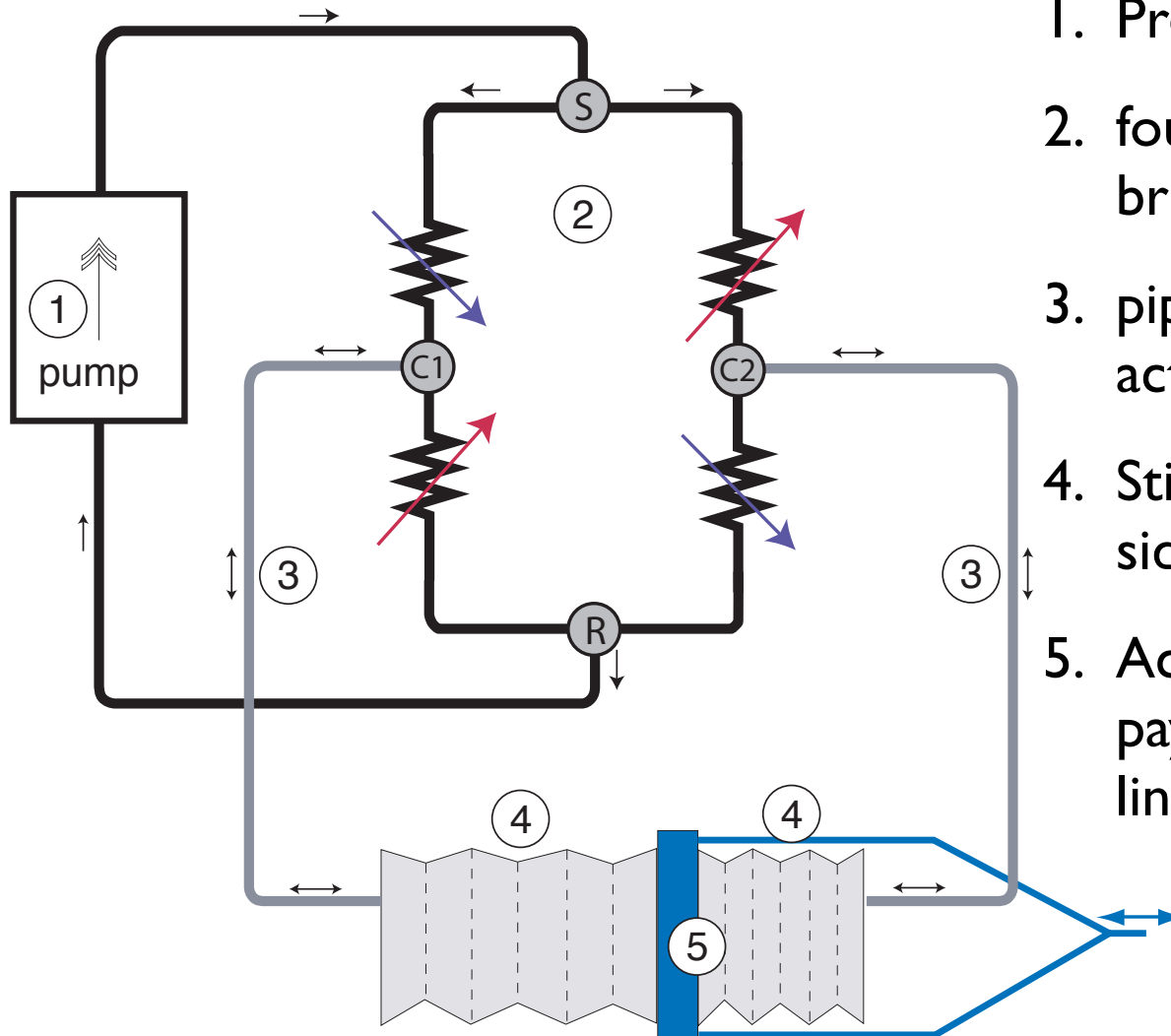
Why has LLO been 'down' for half a year? An extra active seismic isolation stage has been installed at LLO, between the piers and the external seismic support structure.

Low-frequency pre-isolation

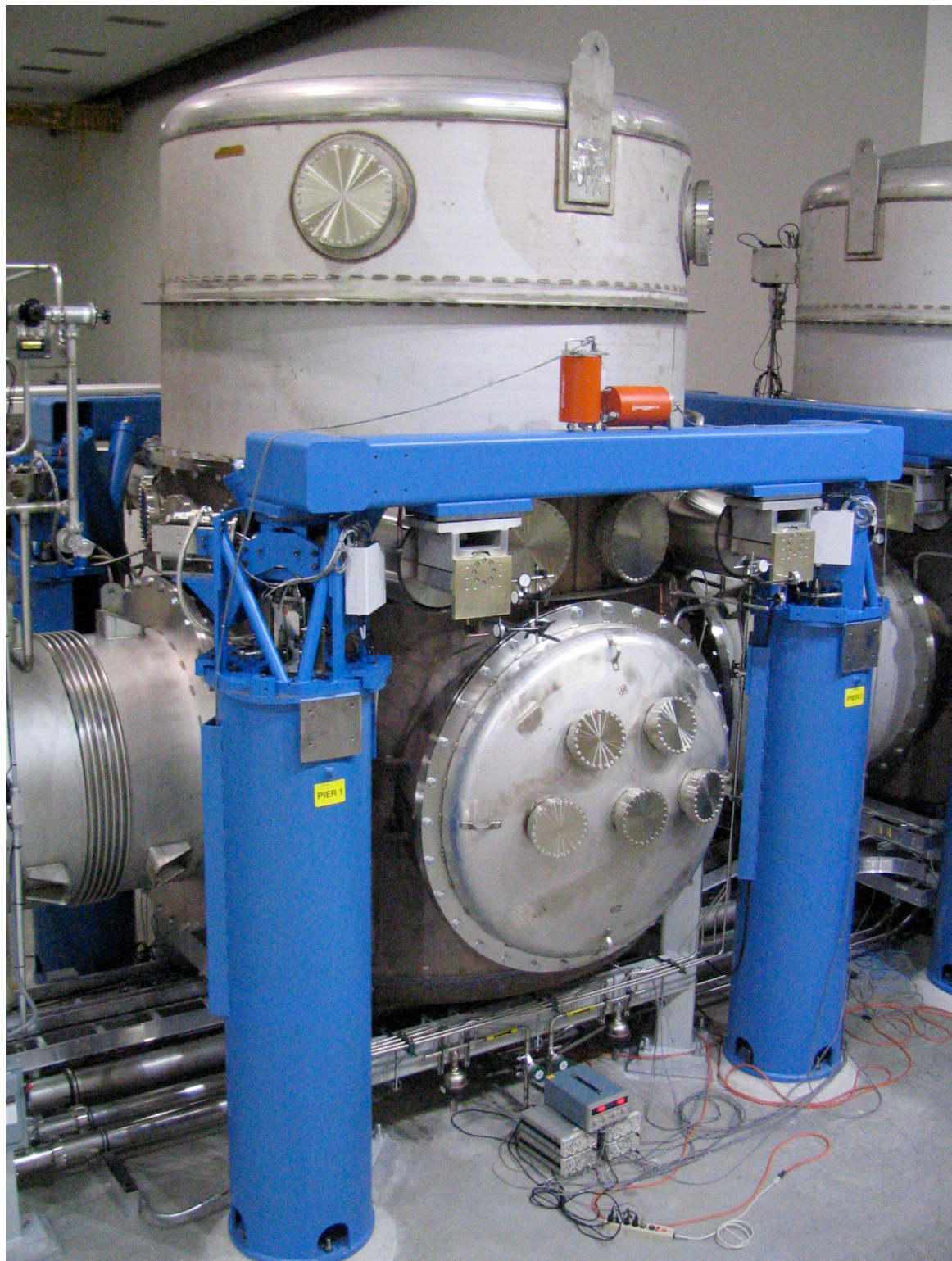
- At each tank corner pier, there is a sensor/actuator set, vertical and horizontal.
- Each DOF controlled with respect to HEPI displacement sensors and geophones.
- Displacement sensor corrected for floor motion as measured by Streckeisen STS-2., in x, y, z DOF's.



Hydraulic bridge actuation



1. Pressure-stabilized pump.
2. four-valve flow-resistance bridge.
3. pipes connect bridge to actuator.
4. Stiction-free bellows on each side of actuated plate.
5. Actuated plate connected to payload through I-DOF linkage.



Commissioning procedure

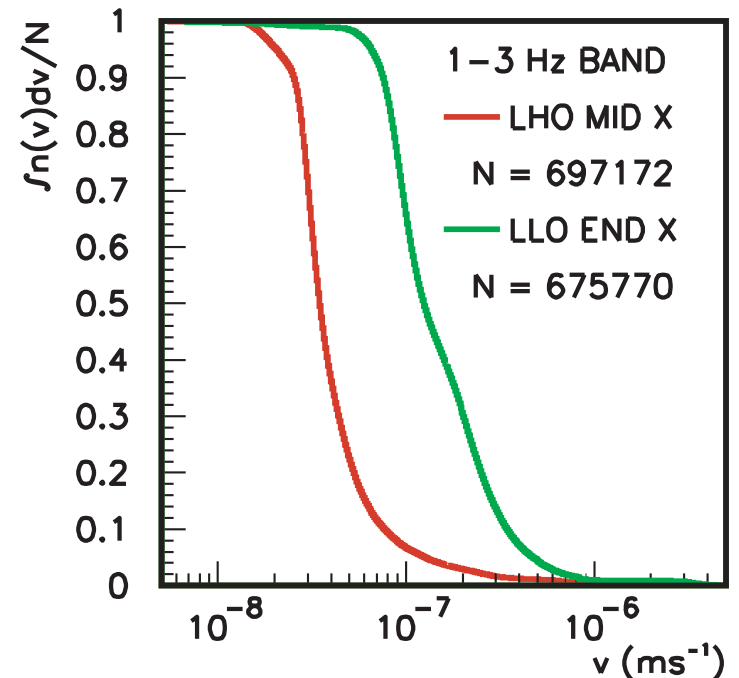
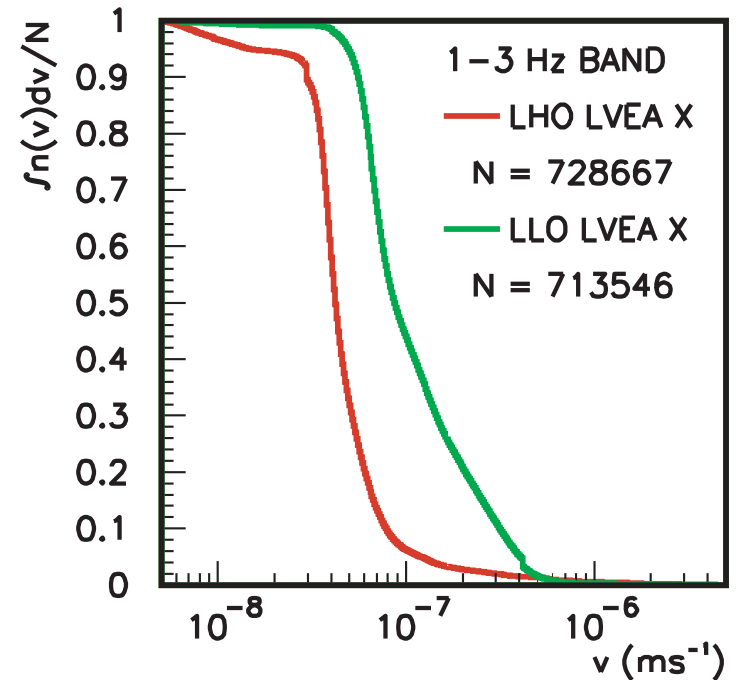
1. Manual sensor & actuator check-out, platform alignment.
2. Automated system identification of 8 input, 16 output, plant.
3. Feedback servo design and implementation for x , y , z , rx , ry , rz and two overconstrained DOFs.
4. Sensor correction sys-id, using portable witness geophones.
5. Sens. correction filter design and implementation for x , y , z .

Band-limited rms velocity monitor statistics

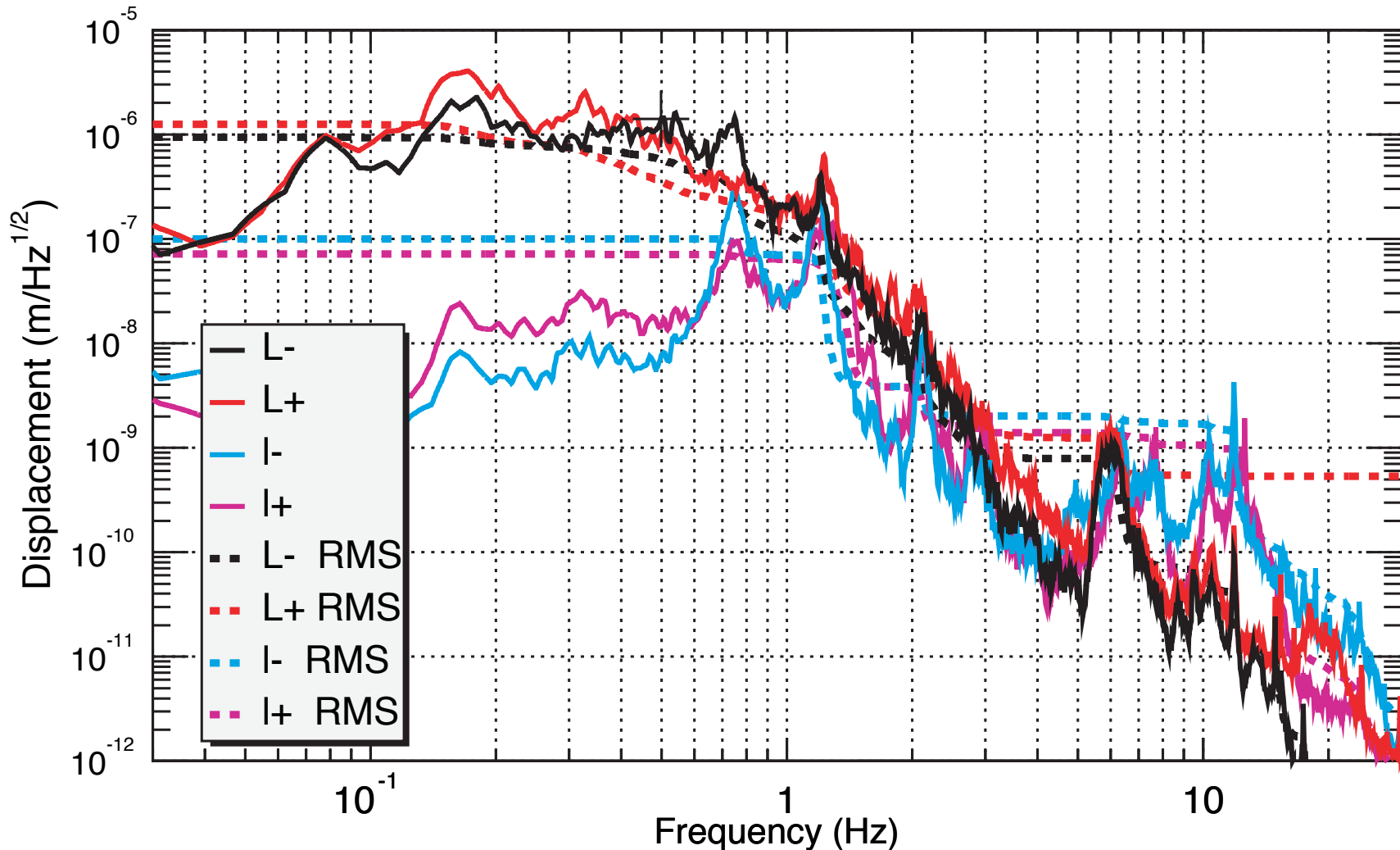
- Analysis of 600+ days of BLRMS data from LIGO PEM seismometers: E. Daw et al, Class. Quantum Grav. **21**, 2255-2273. (2004)
 - ▶ 1–3 Hz: 4–7 x higher at LLO.
 - ▶ 0.3–1 Hz: 5–7 x higher at LLO.
 - ▶ 0.1–0.3 Hz: 3 x higher at LLO.

example: 1–3 Hz 90th percentile values

site	chan	90%, $\mu\text{m/s}$	llo/lho
LLO	lvea x	0.31	4.0
	lvea y	0.29	3.6
	ex x	0.34	4.5
	ey y	0.75	7.3
LHO	lvea x	0.078	
	lvea y	0.083	
	mx x	0.077	
	my y	0.10	

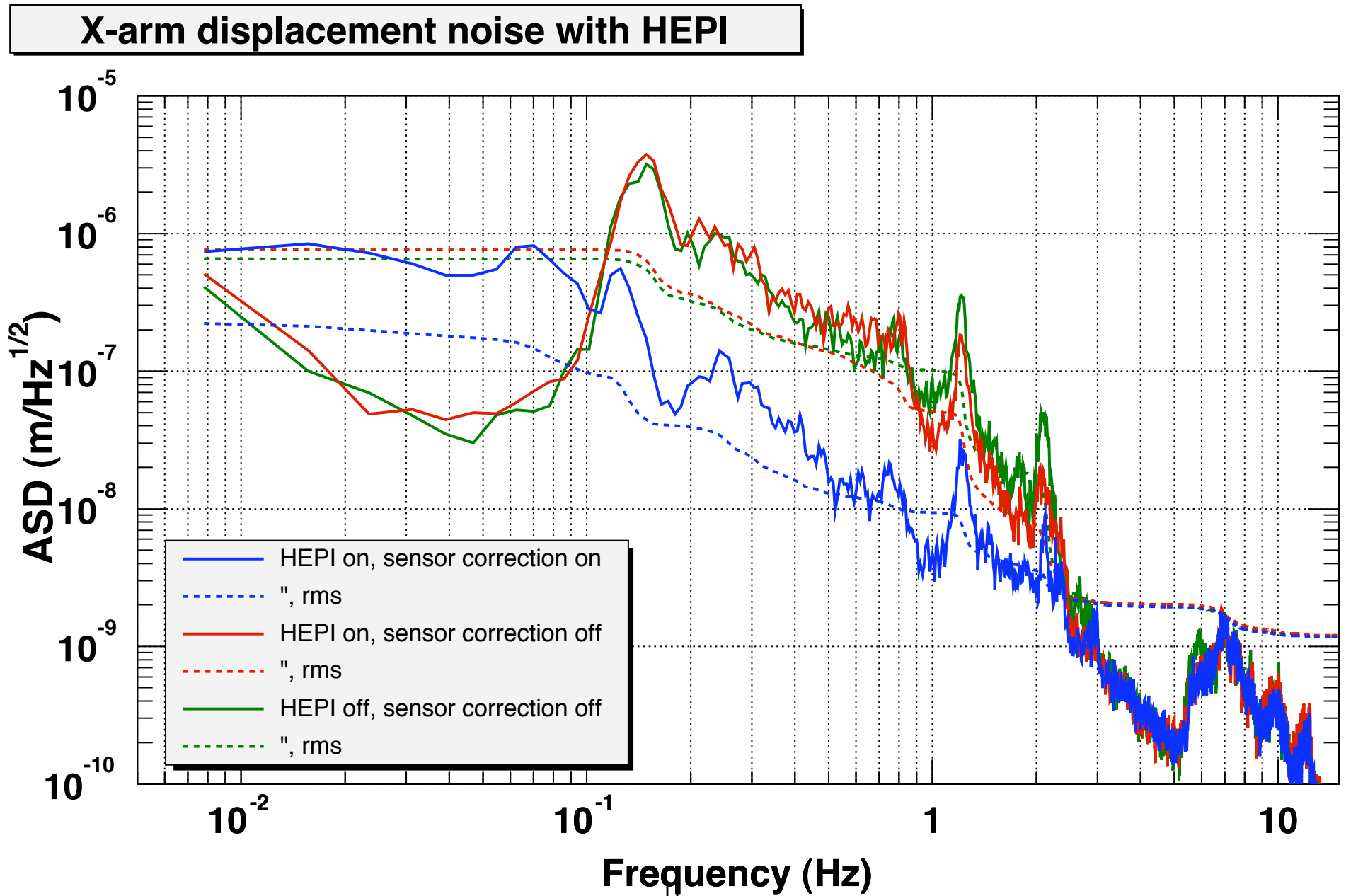


Detector disturbance levels

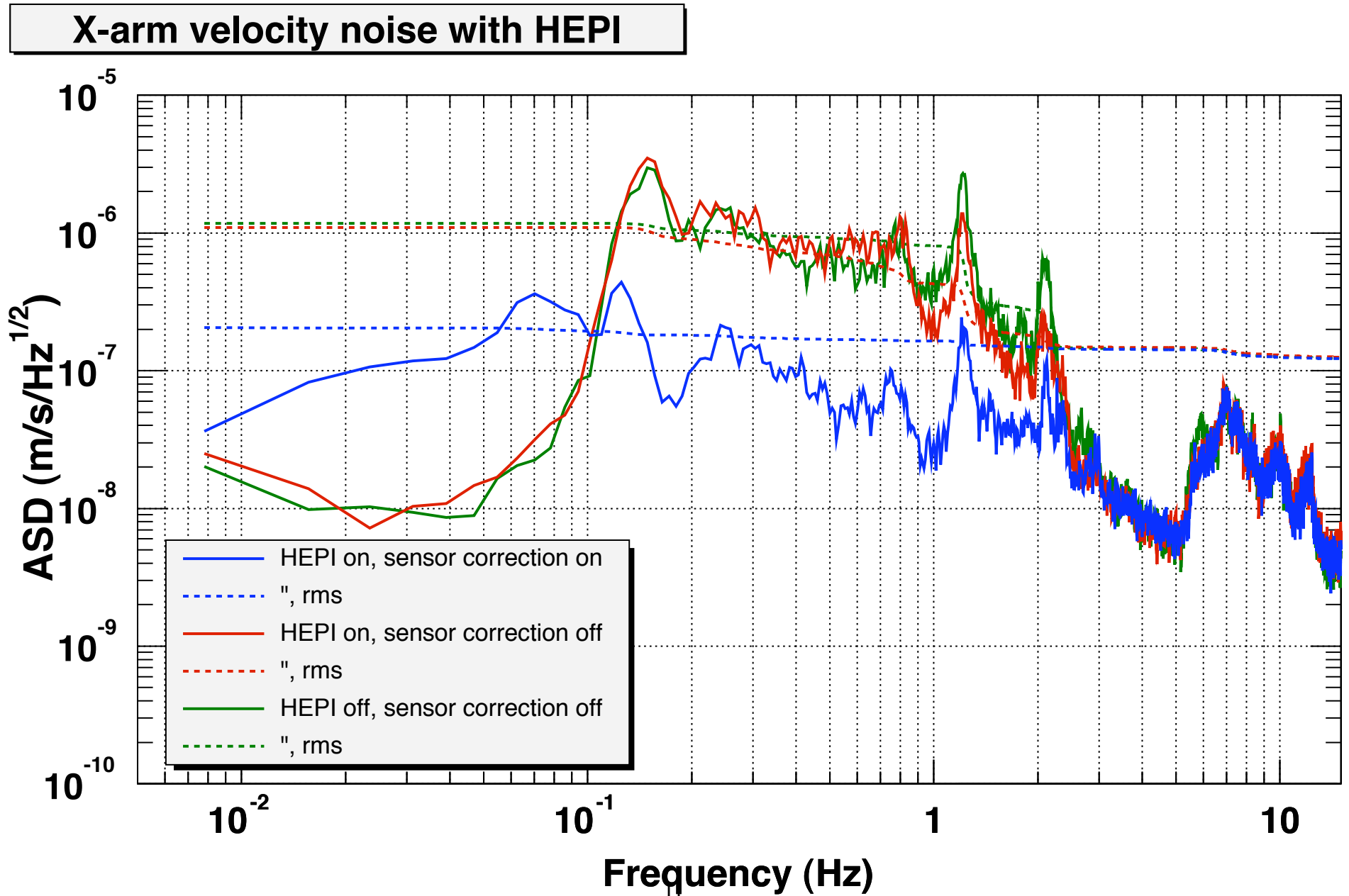


- Data from R.Adhikari's MIT Ph.D. thesis (2004) of the LLO detector.
- Bulk of RMS disturbance comes from 0.1–2.1 Hz band. 1 μm rms is consistent with detector operation. Also, 1 $\mu\text{m/s}$ rms velocity is the practical limit for reliable lock acquisition.

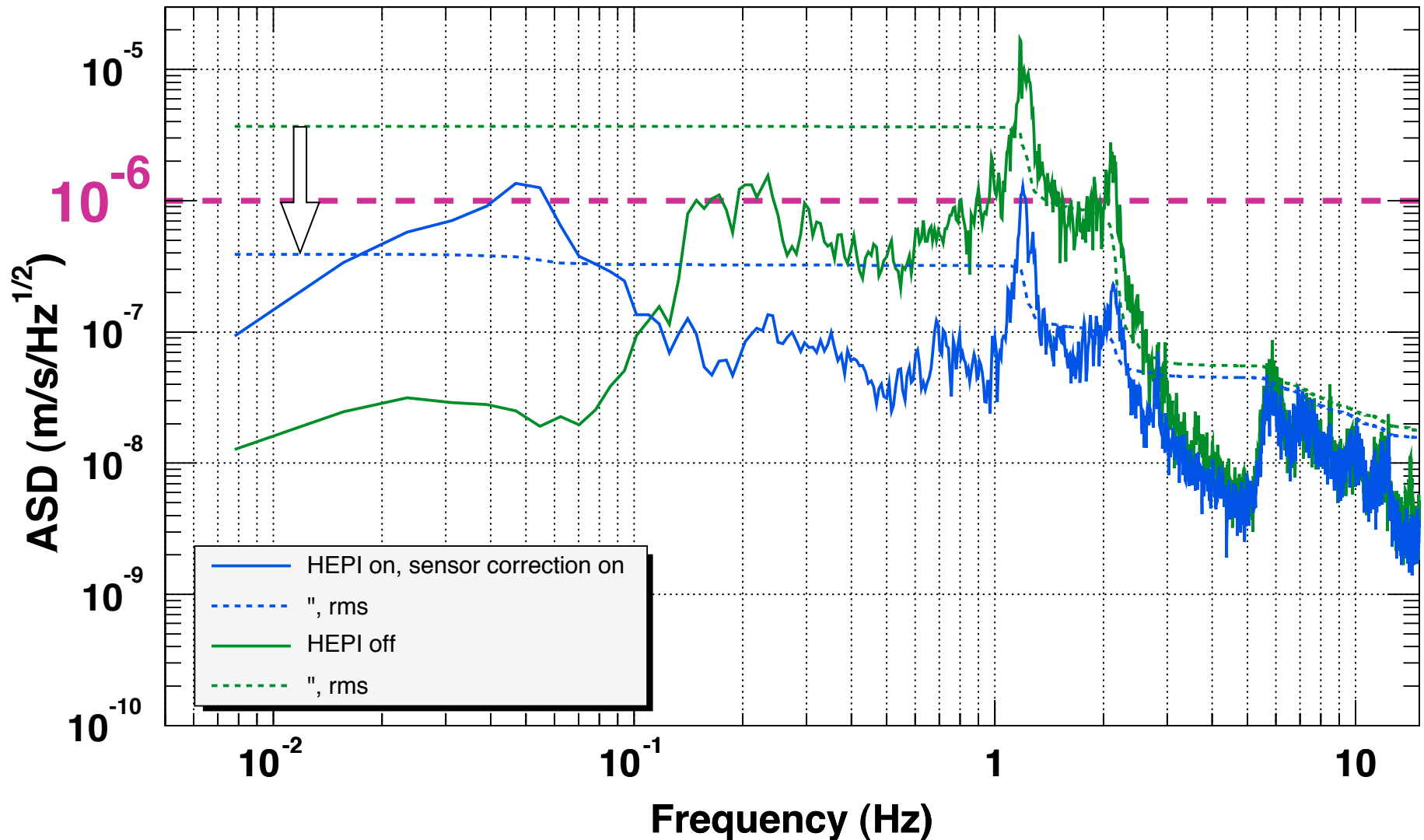
X-arm length disturbance, quiet evening



X-arm length disturbance, quiet evening



X-arm length disturbance, 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.

Remaining tasks

- Complete basic functionality on 6 more payloads
- Optimized sensor gains and whitening to make saturation less likely during extreme storms.
- Lock/unlock scripts, interfaced with watchdog function, to automate HEPI operation.
 - ▶ 3-stage watchdog, switches among servo & sensor correction, servo only, offset only, or HEPI off.
 - ▶ Simplified operator's EPICS screen.

Conclusions (HEPI)

- LIGO will soon have *two sites capable of day & night operation* with reasonable duty cycle.
- First *Advanced LIGO (sub-)subsystem* shown to work at design specification in the observatory setting.

Development history

- *Decades of R&D* on quiet hydraulics with Dan DeBra at Stanford, focussing on use of laminar flow oil to actuate machine tool assemblies.
- Recent development & *prototyping of zero-stiction balanced bellows quiet hydraulic actuators*, by DeBra, Hardham, Lantz et al, intended for use in Advanced LIGO pre-isolation stage. 2-DOF test stand experiment.
- Study by Hua et al of effective *control filter techniques* for ‘sensor correction’ active seismic isolation at sub-hertz frequencies.
- *Design of third-generation actuator*, payload suspension springs, and external housing for HEPI by Hardham, Hammond, Mason, Kern, Lacour, etc.
- *Tests at LASTI* (ongoing) by Mason, Hardham, Coyne, Lantz, Mittleman, Ottaway, Sarin, Macinnis, etc. New ‘safe’ fluid in use, tested at CIT.
- *Re-implementation of control system* and electronics for LIGO/VME environment and GDS by Bork, Sarin, Abbott(s), etc.
- *Mass production and installation* at LLO, by Kern, Abbott, Spjeld, Lacour, Traylor, Overmier, Mailand, Hanson, Carter, and many more.
- *Hardware/software commissioning at LLO* by Abbott, Traylor, Overmeir, Hanson, Fyffe, Wooley, Sellars, Parameswariah, etc.
- *Controls commissioning/ testing at LLO* by Mittleman, O’Reilly, Coyne, Lantz, Giaime, Frolov, etc.