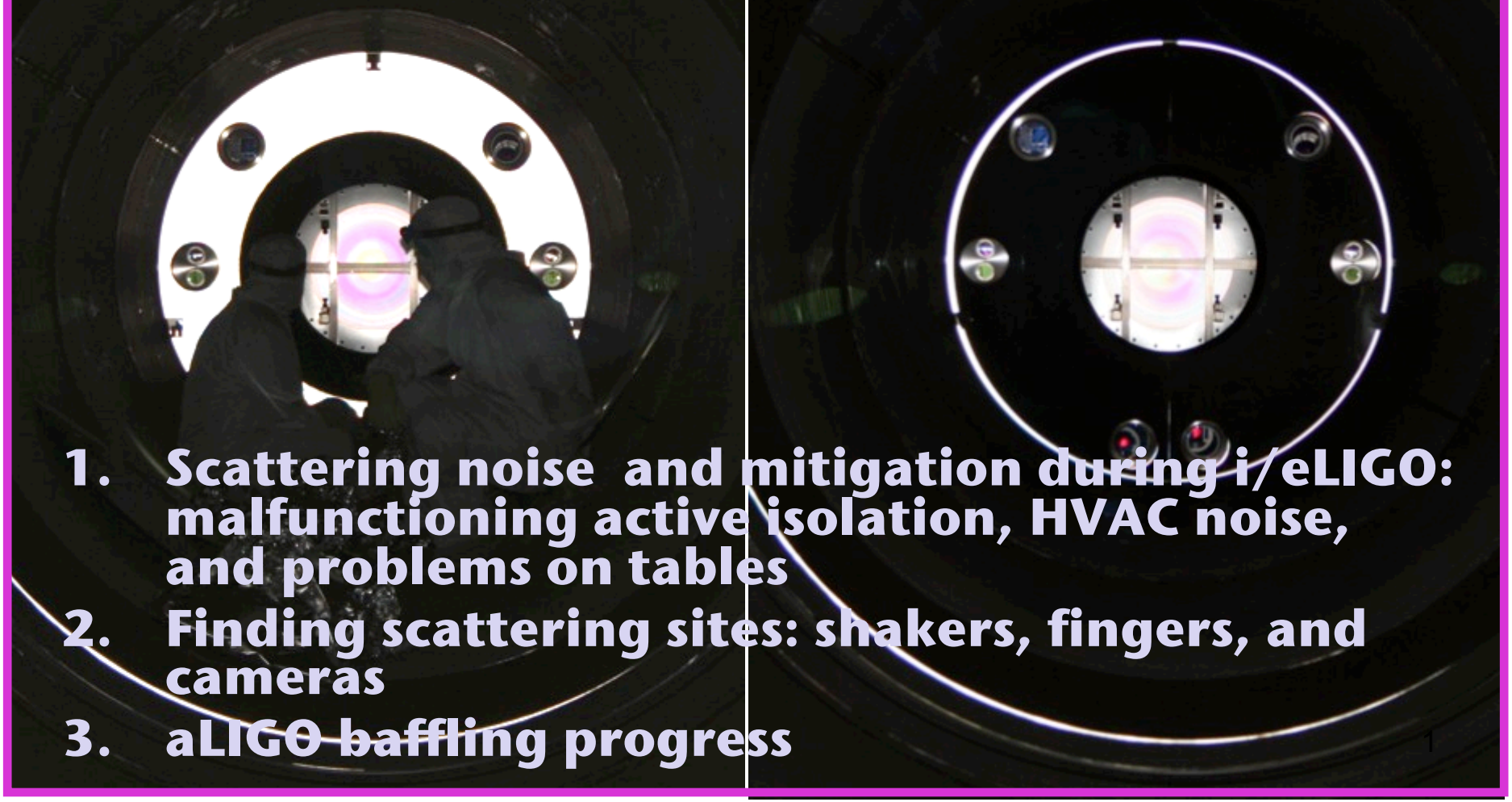
Identifying and mitigating scattering noise in LIGO

Robert Schofield (University of Oregon) LIGO-G1300624



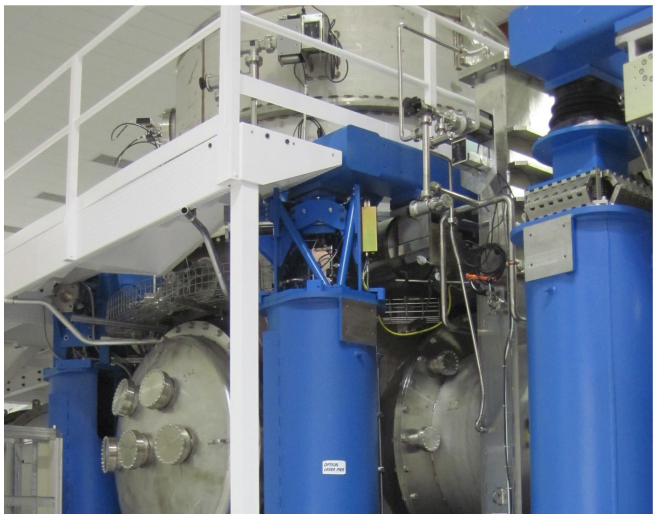
1. Scattering noise and mitigation during i/eLIGO: malfunctioning active isolation, HVAC noise, and problems on tables
2. Finding scattering sites: shakers, fingers, and cameras
3. aLIGO baffling progress

Noise in iLIGO and eLIGO that was attributed to scattering

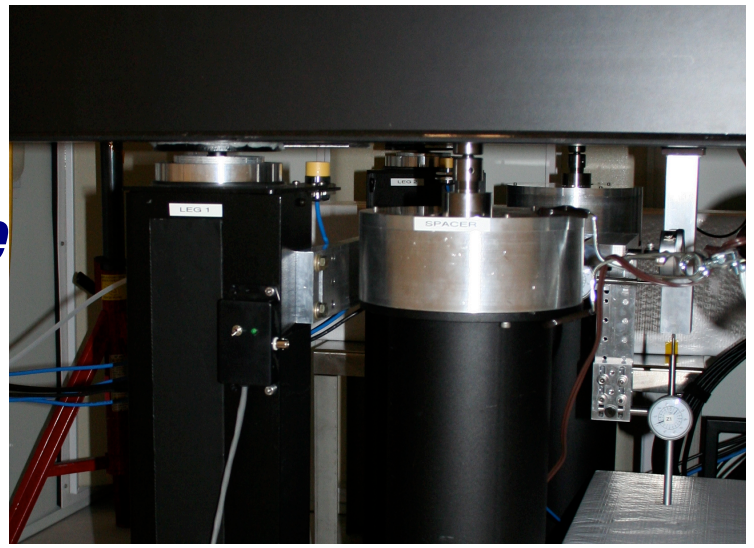
- ***Path length change large compared to wavelength: only observed when active isolation systems were malfunctioning.***
- ***Path length change small compared to wavelength but harmonics, not fundamental, were the biggest problems: HVAC noise***
- ***Path length change small compared to wavelength: many examples on optics tables***

Path length change exceeded wavelength

- Malfunction of external isolation system used to accommodate microseismic peak

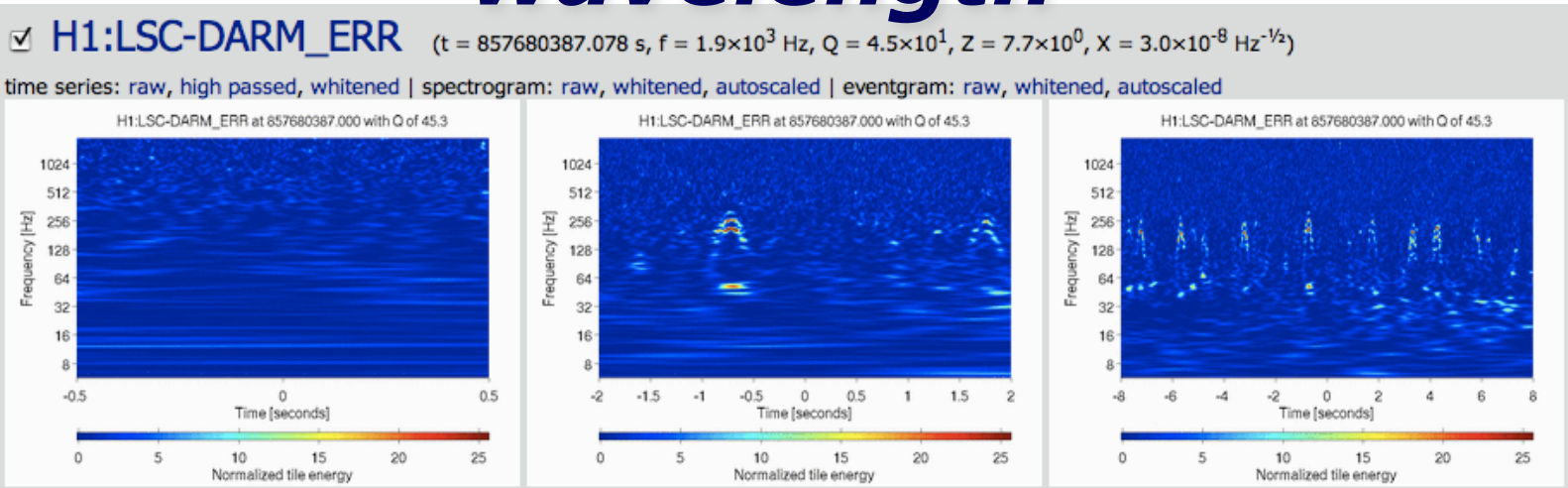


- Malfunction of optic table actuators

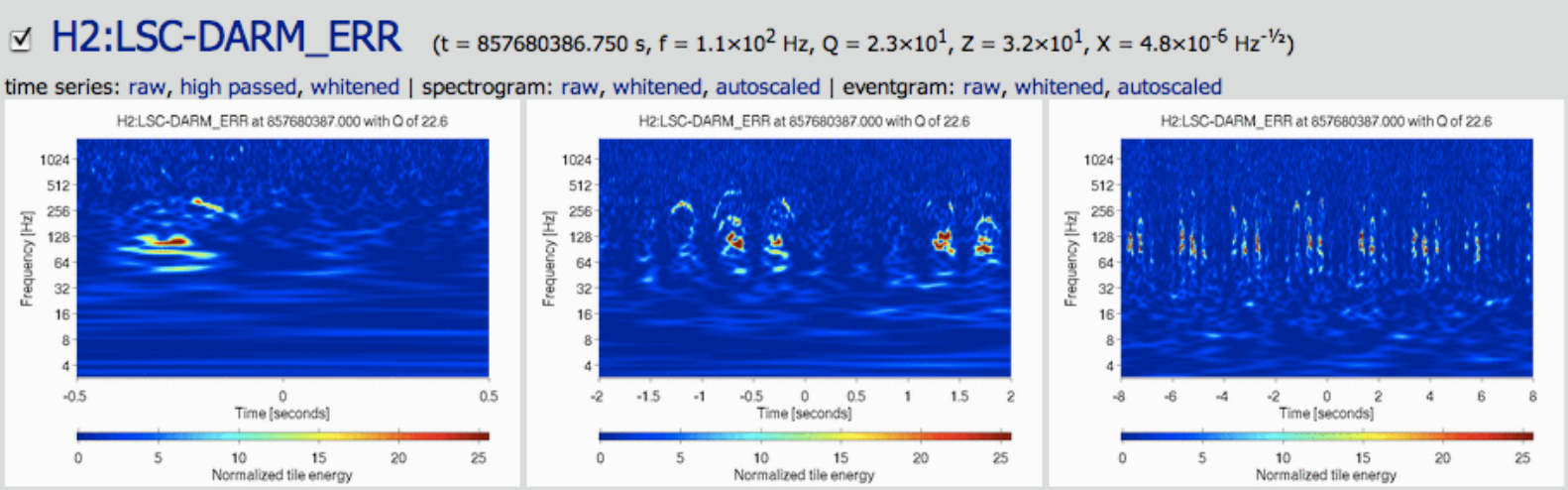


Path length change exceeds wavelength

H1



H2



These events during H2 malfunction (broken actuator moving test mass suspension). Show that H1-H2 back-scattering paths exist.

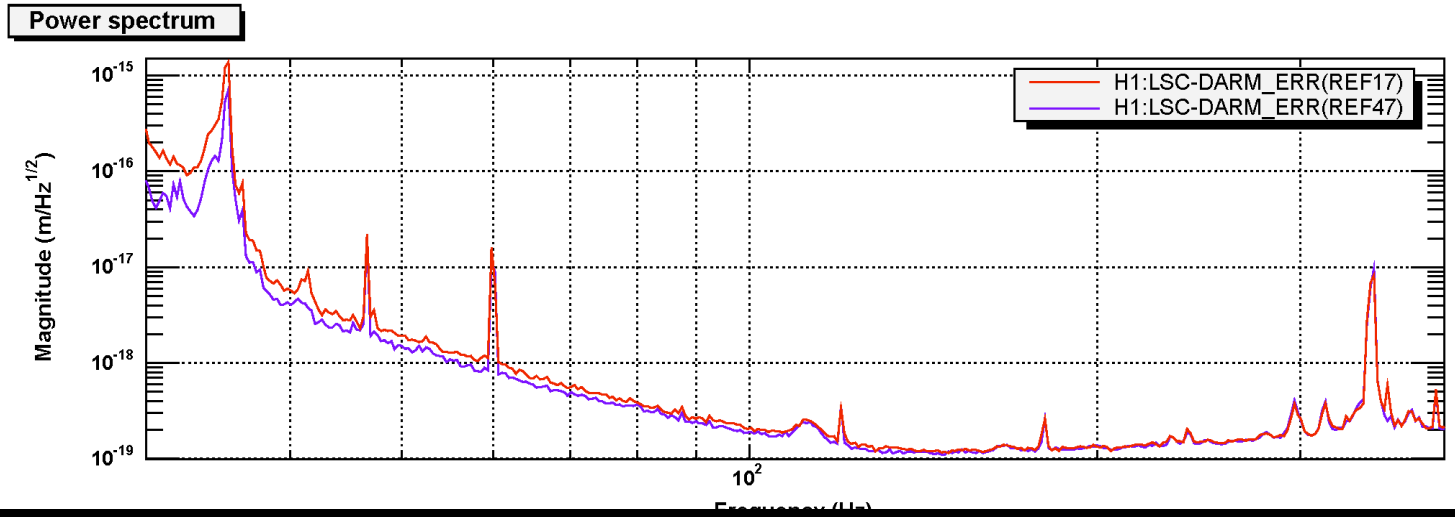
Noise in iLIGO and eLIGO that was attributed to scattering

- ***Path length change large compared to wavelength: only observed when active isolation systems were malfunctioning.***

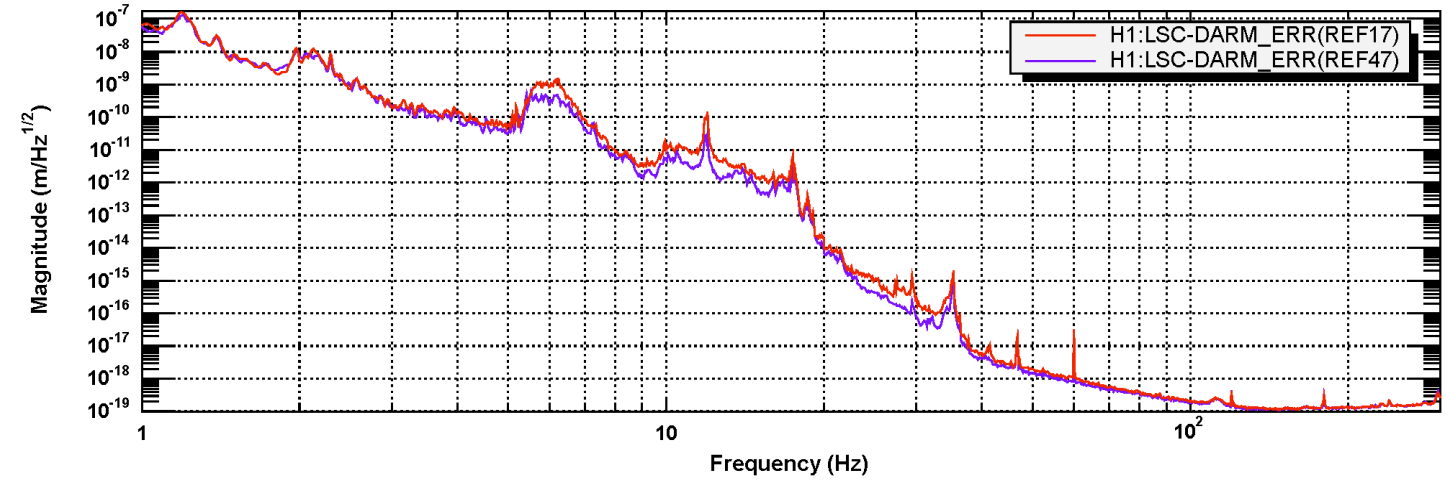
- ***Path length change small compared to wavelength but harmonics, not fundamental, were the biggest problems: HVAC noise***

- ***Path length change small compared to wavelength: many examples on optics tables***

Inspiral range increased by ~1Mpc when HVAC off



Blue: All site turbines and chiller pad equipment off; Red: normal



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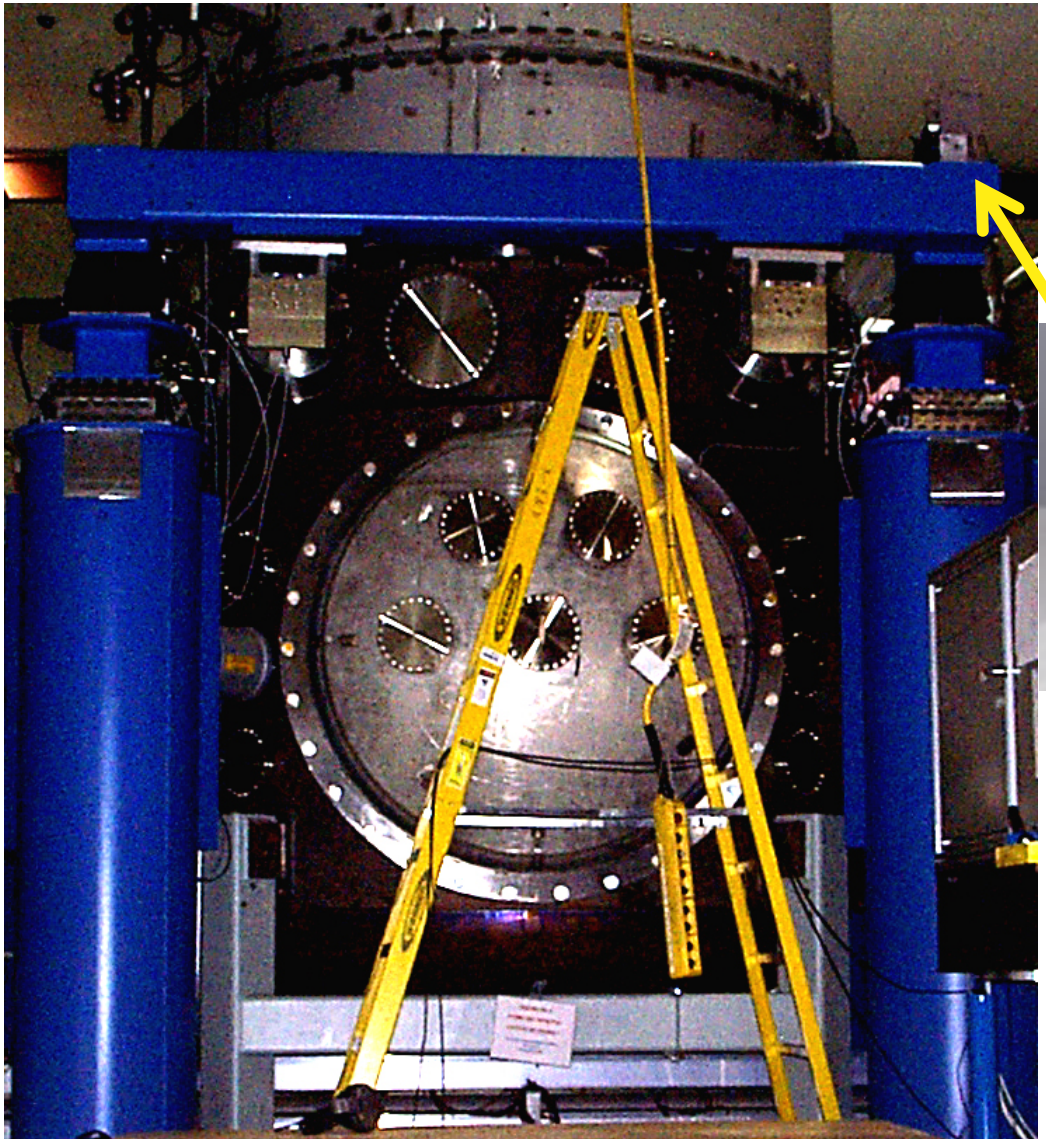
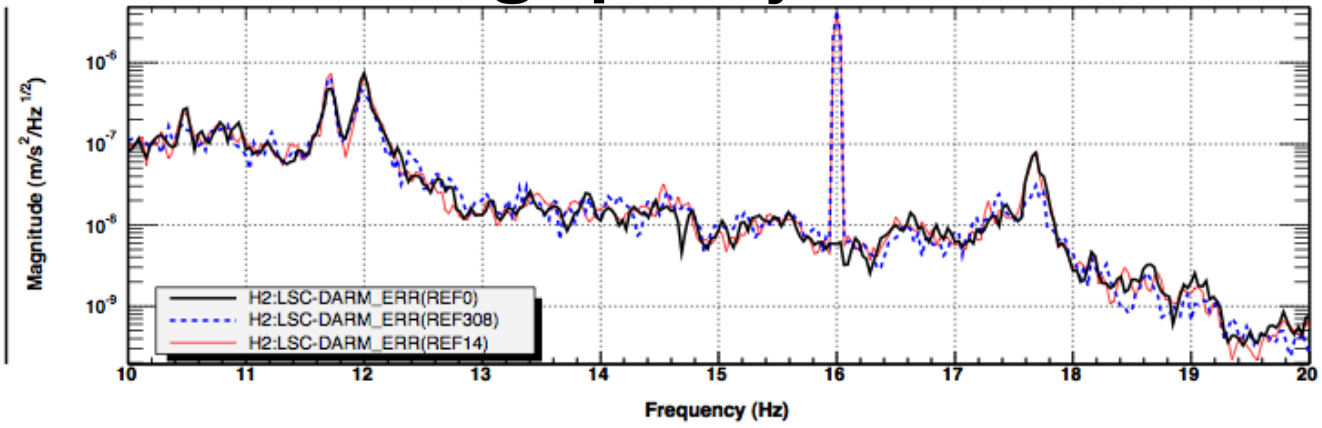
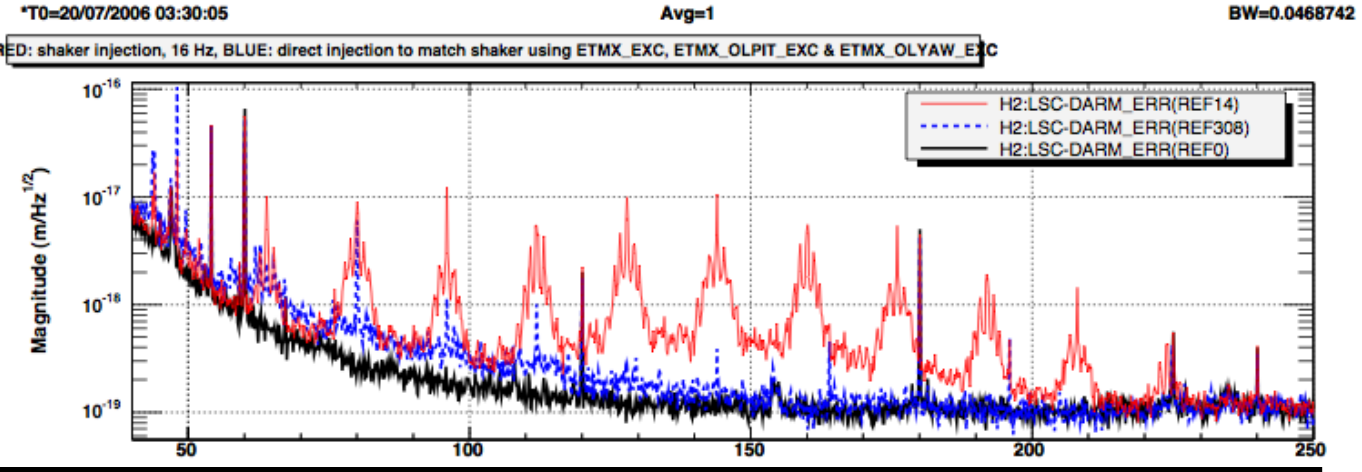
Shaking to study HVAC coupling



HVAC effect from shaking of optic support structures but not from shaking optic by itself

RED: shaker injection, 16 Hz;
BLUE: servo injections to match pitch, yaw and displacement from shaker injection

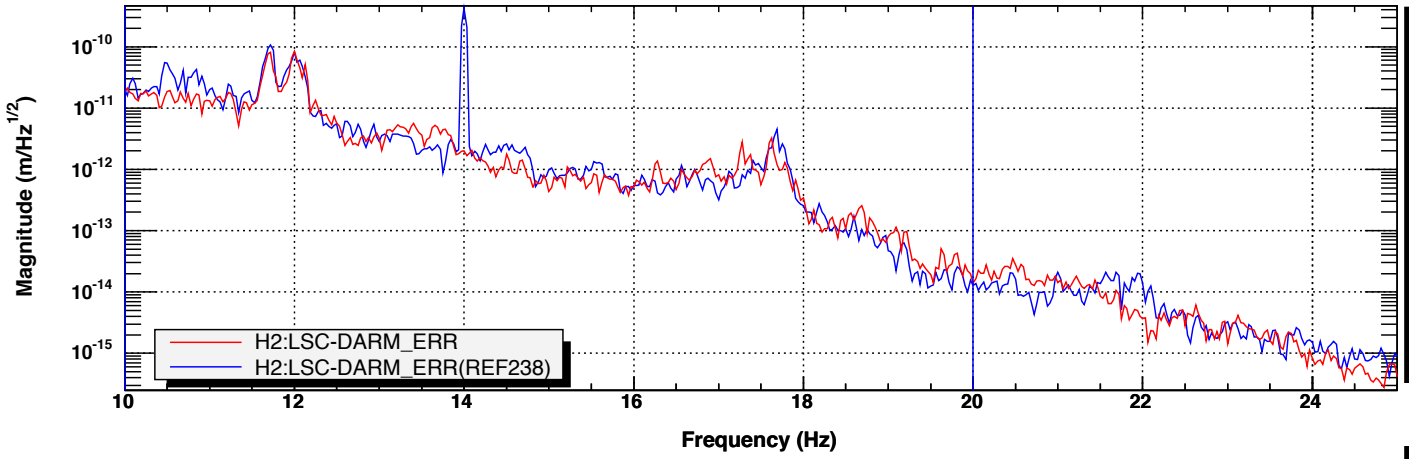




Noise from shaker injection was consistent with HVAC effect, but noise from test mass actuator injection was too small. This eliminated our Barkhaussen noise problem as the source of the HVAC effect and suggested scattering from optic support.

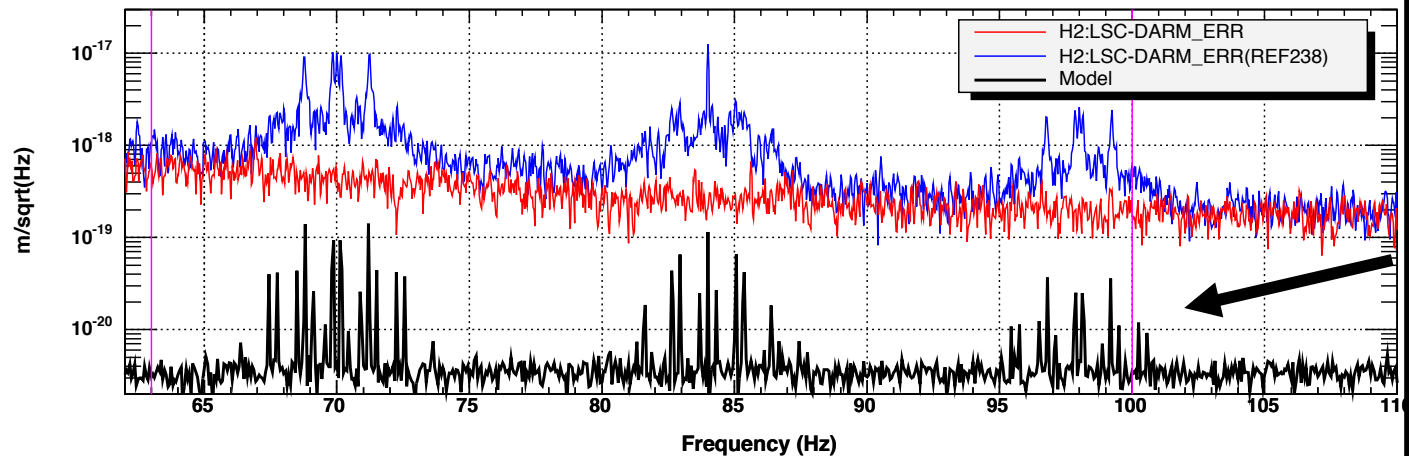
Shaker noise was consistent with simple scattering model

BLUE: 14 Hz shaking of BSC-5 blue crossbeam. 10-20 Hz rms: red, 4.2e-11, blue, 1.1e-10



*T0=20/07/2006 04:44:35 *Avg=1 BW=0.0468

backscattering model (BLACK) reproduces spectral features from injections (BLUE)



*T0=31/05/2008 00:59:06 *Avg=4 *BW=0.0468742

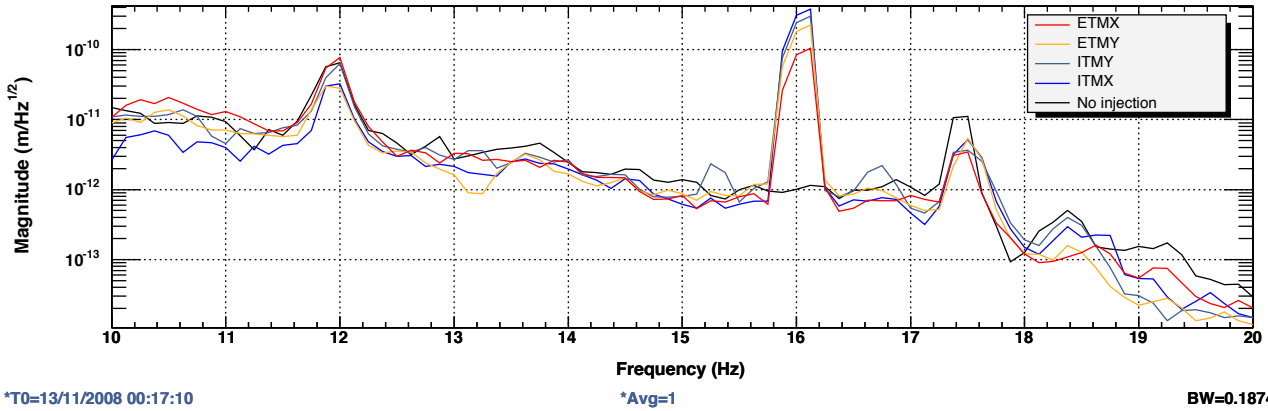
Both plots: GW Channel (DARM). RED: normal, BLUE: 14 Hz shaking

Black: model with proper amplitudes of 0.15 Hz microseismic peak, 1.2 Hz stack mode, and 14 Hz motion from shaker

Candidate site for HVAC coupling

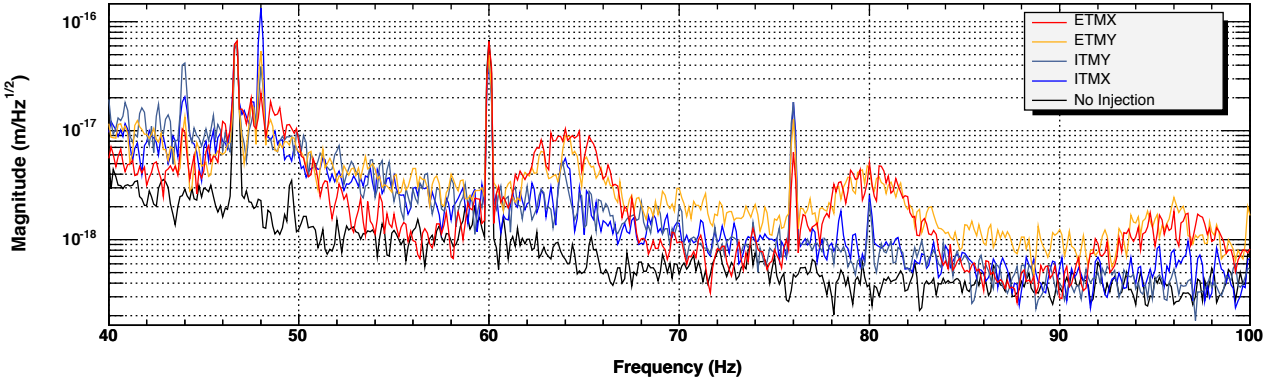
Shaking of each test mass structure indicated that worst locations had transmission monitors (with reflective supports)

H1 DARM_ERR: Shaking blue BSC cross beams at 16 Hz at different stations.

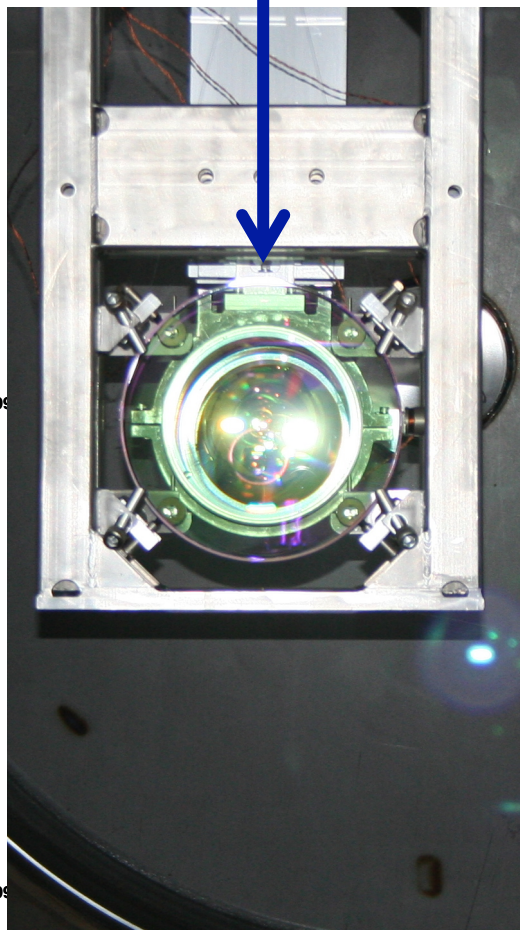


*T0=13/11/2008 00:17:10 *Avg=1 BW=0.187499

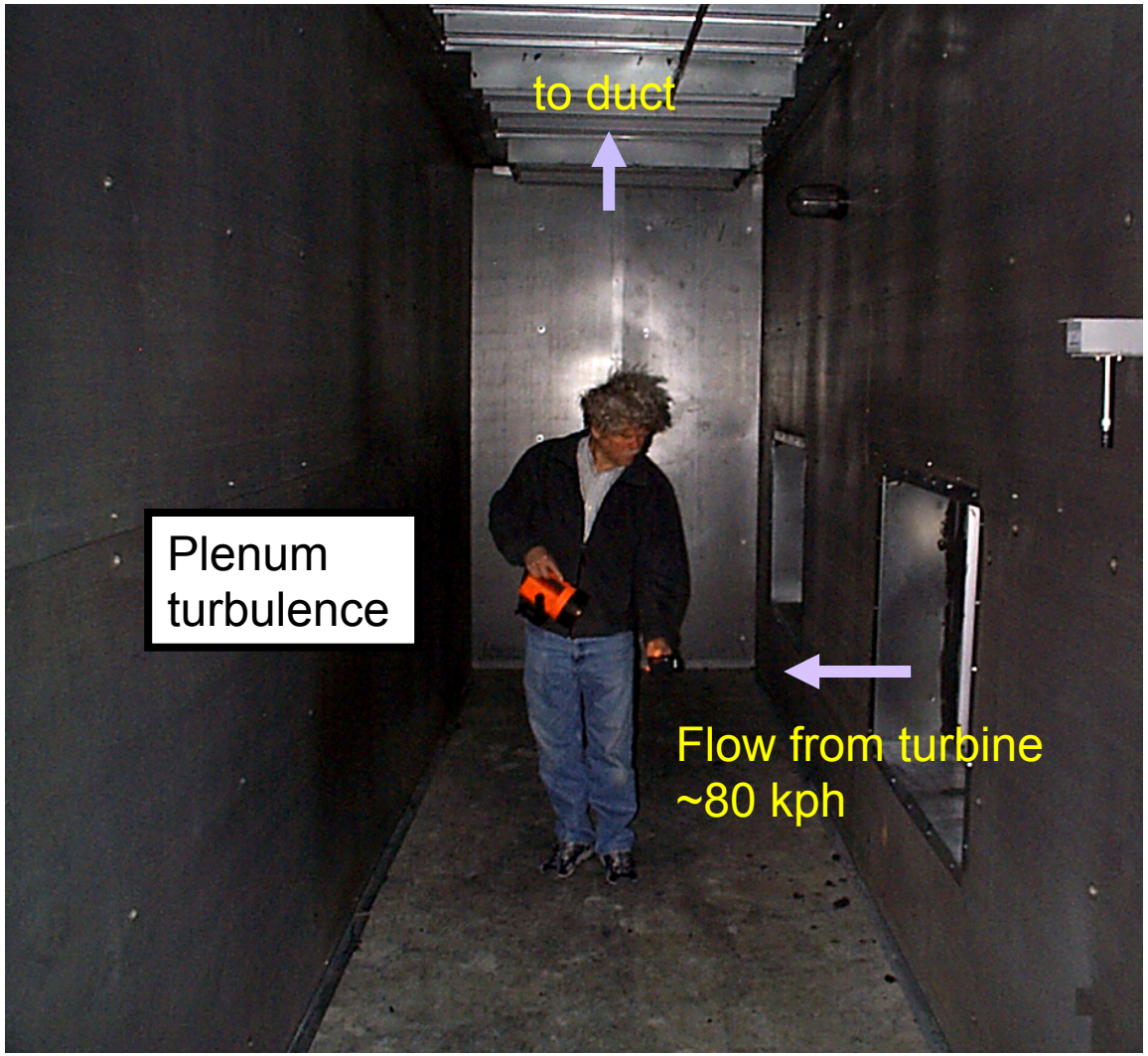
H1 DARM_ERR: upconversion peaks are dominated by intermodulation products of 16, 1.2 and 0.15 Hz. Worst site is ETMX, then ETMY.

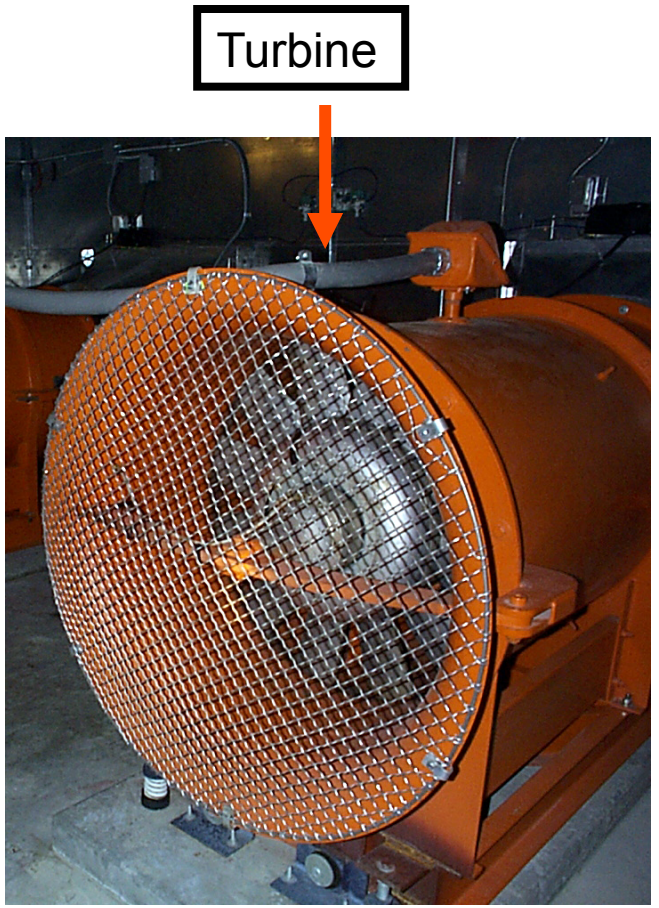


*T0=13/11/2008 00:17:10 *Avg=1 BW=0.187499

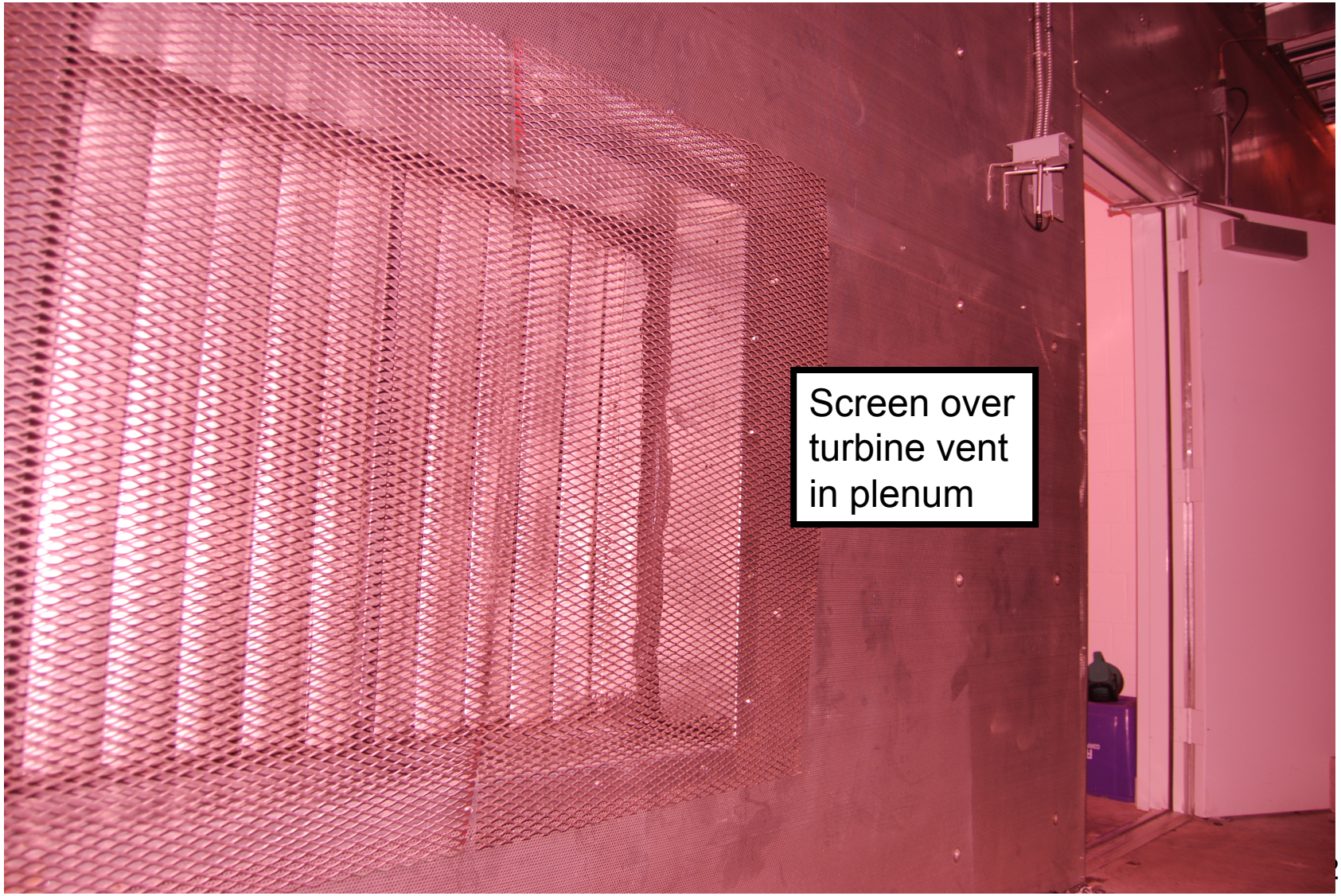


Broad-band seismic signal from HVAC was produced by plenum turbulence (noise did not require duct flow)





For eLIGO, HVAC shaking reduced by screens to break up large eddies. For aLIGO we will have better baffling and screens.



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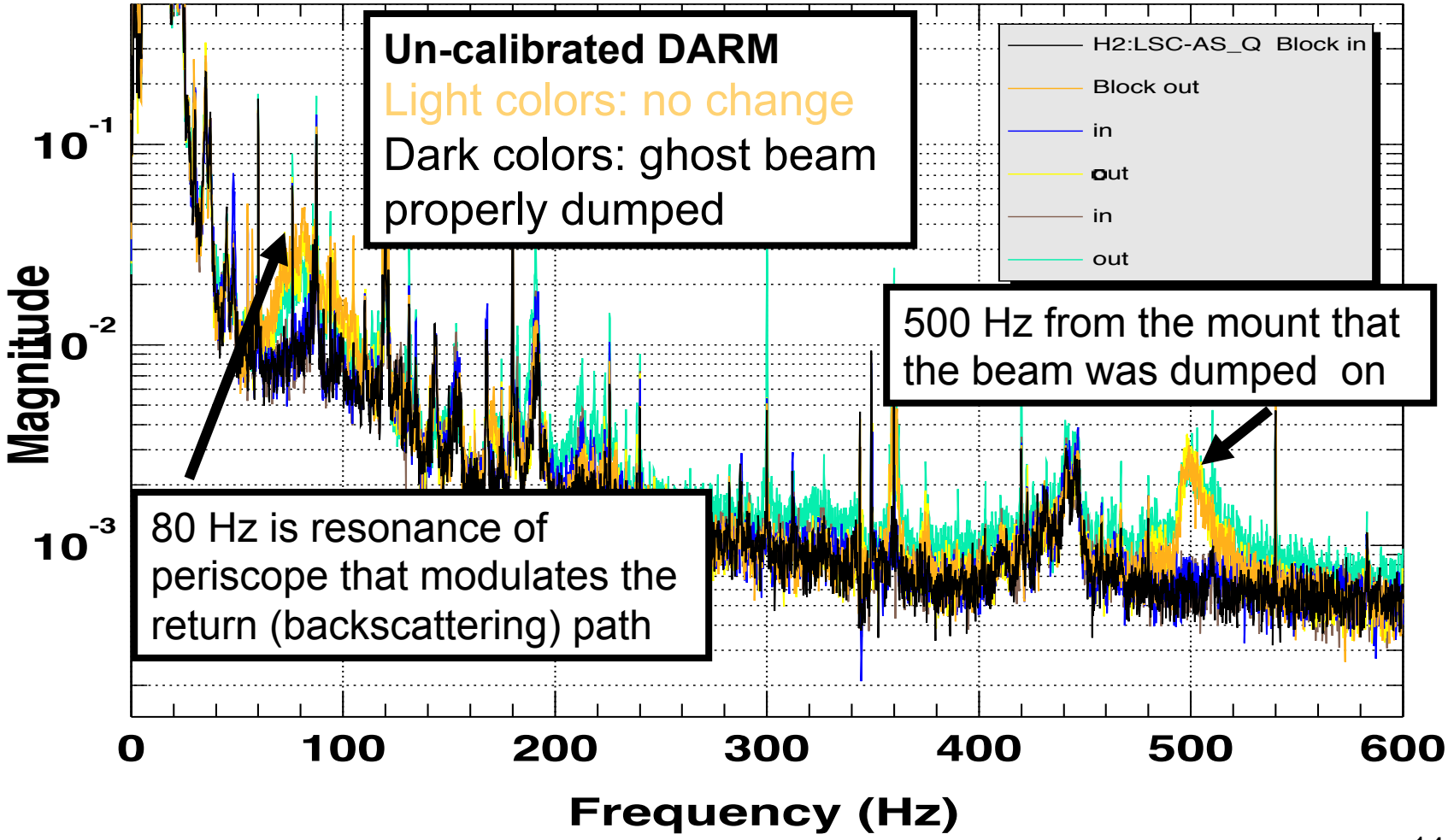
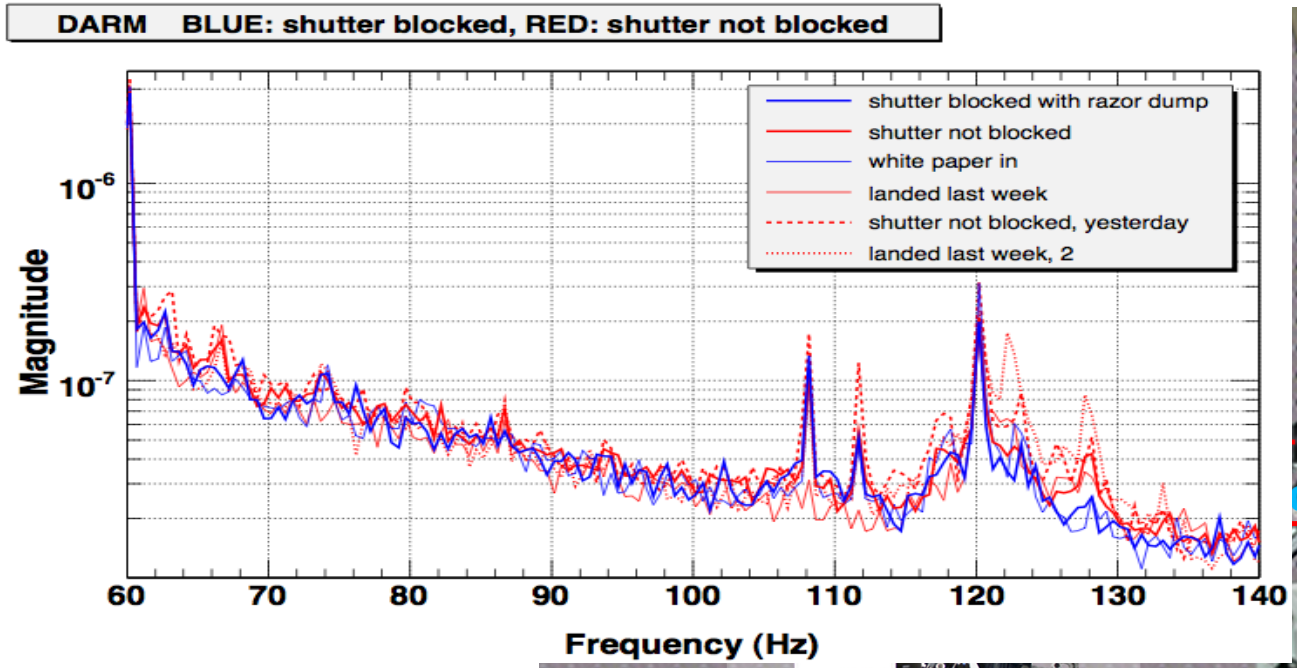
Backscattering from bright ghost beam dumped on optic mount

Damage is mostly due to fundamentals, not harmonics



Backscatter from unused S5 shutter makes DARM peaks in S6



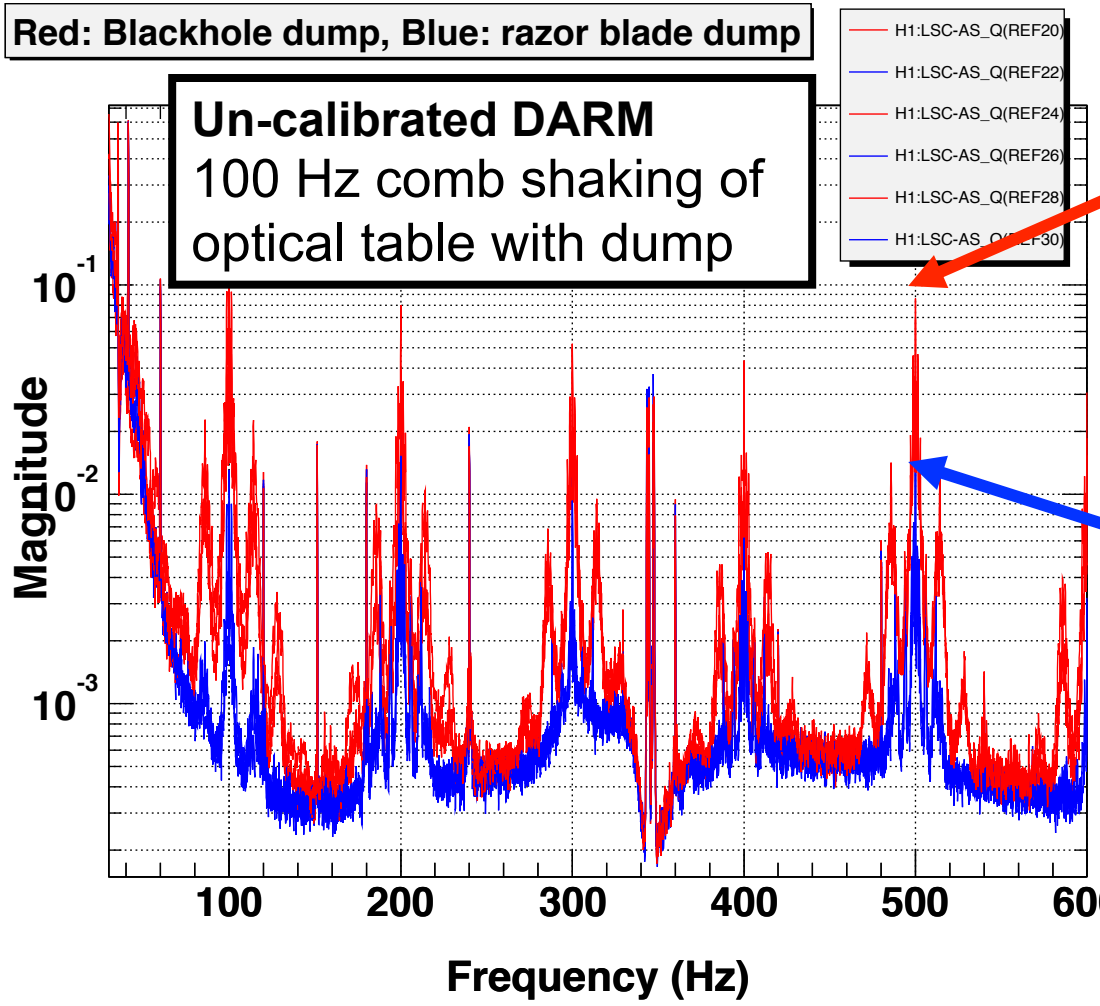
Backscattering shutter

Backscatter from bad beam dump

"Blackhole" dumps were about the same as white paper.

Red: Blackhole dump, Blue: razor blade dump

Un-calibrated DARM
100 Hz comb shaking of optical table with dump



BAD

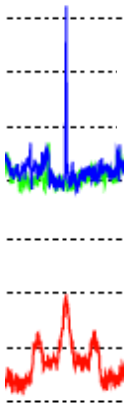
Black glass even better

Reminder: most of the vibration-related noise in LIGO was not from scattering

- ***We had to reduce acoustic noise in DARM by 3+ orders of magnitude. We did this based on indications that the coupling was mainly from clipping by optics on tables (EO shutters were worst), and beam motion on the photodiodes (which did not have uniform responses). We distinguished these coupling mechanisms from scattering using neutral density filters and irises as well as other techniques.***

- ***Our biggest source of noise from low frequency seismic motion was Barkhausen magnetic domain flipping noise.***

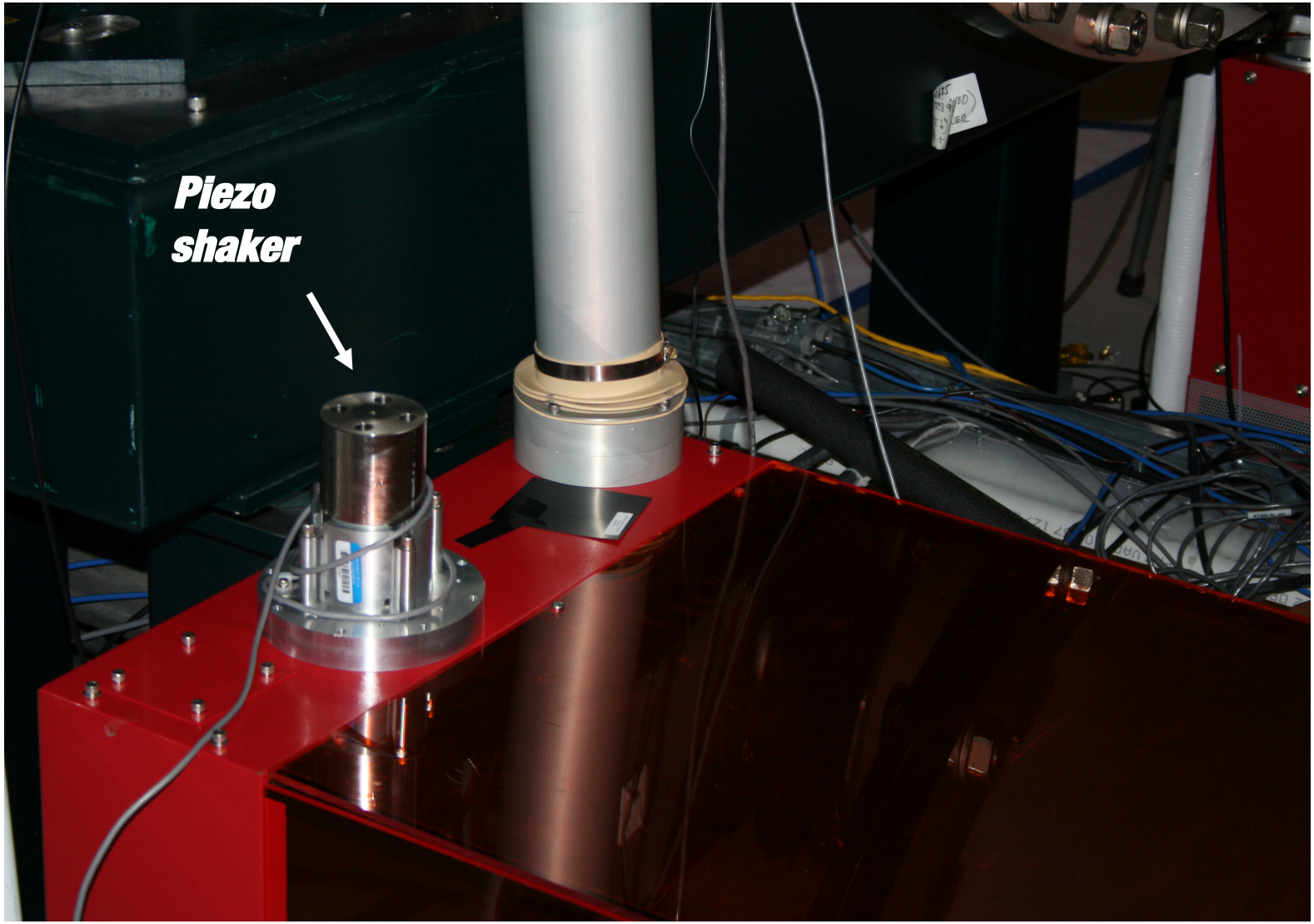
Quick and easy (but not perfect) check – since coupling with low frequency motion is very non-linear, scattering noise is very susceptible to bilinear upconversion, while for many non-scattering coupling mechanisms, a monochromatic environmental injection makes a sharp DARM line.



Microphone

DARM

Finding scattering sites: shakers

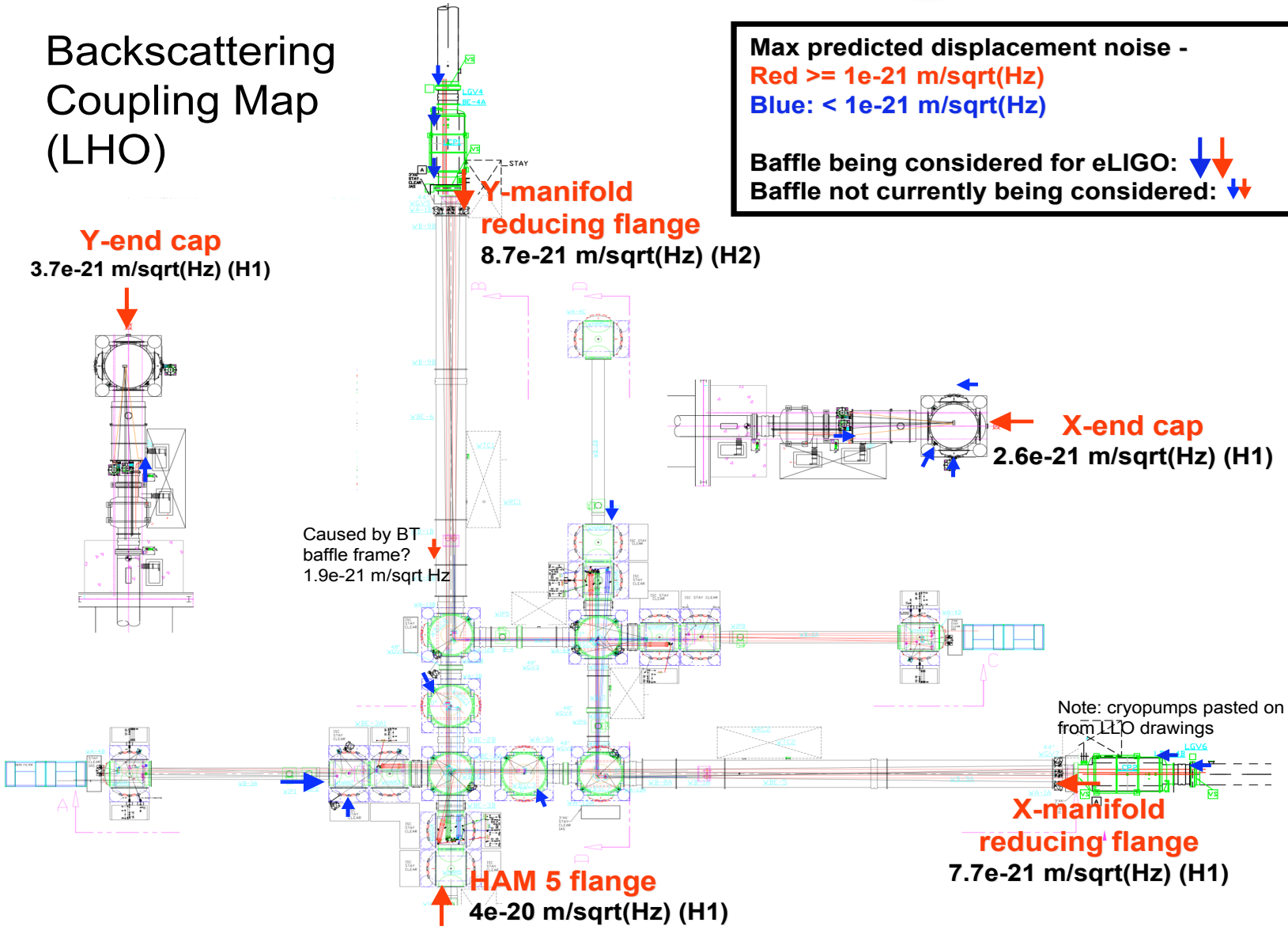


17 sites investigated

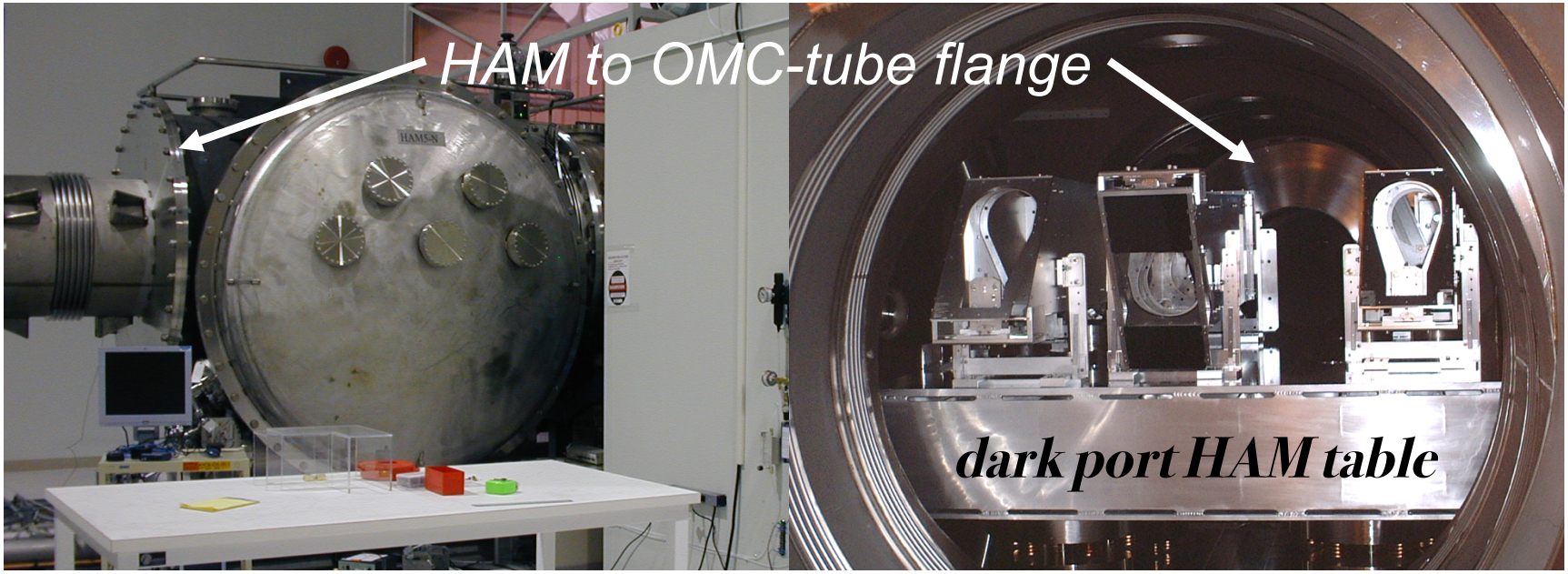
Backscattering Coupling Map (LHO)

Max predicted displacement noise -
Red >= 1e-21 m/sqrt(Hz)
Blue: < 1e-21 m/sqrt(Hz)

Baffle being considered for eLIGO:
Baffle not currently being considered:

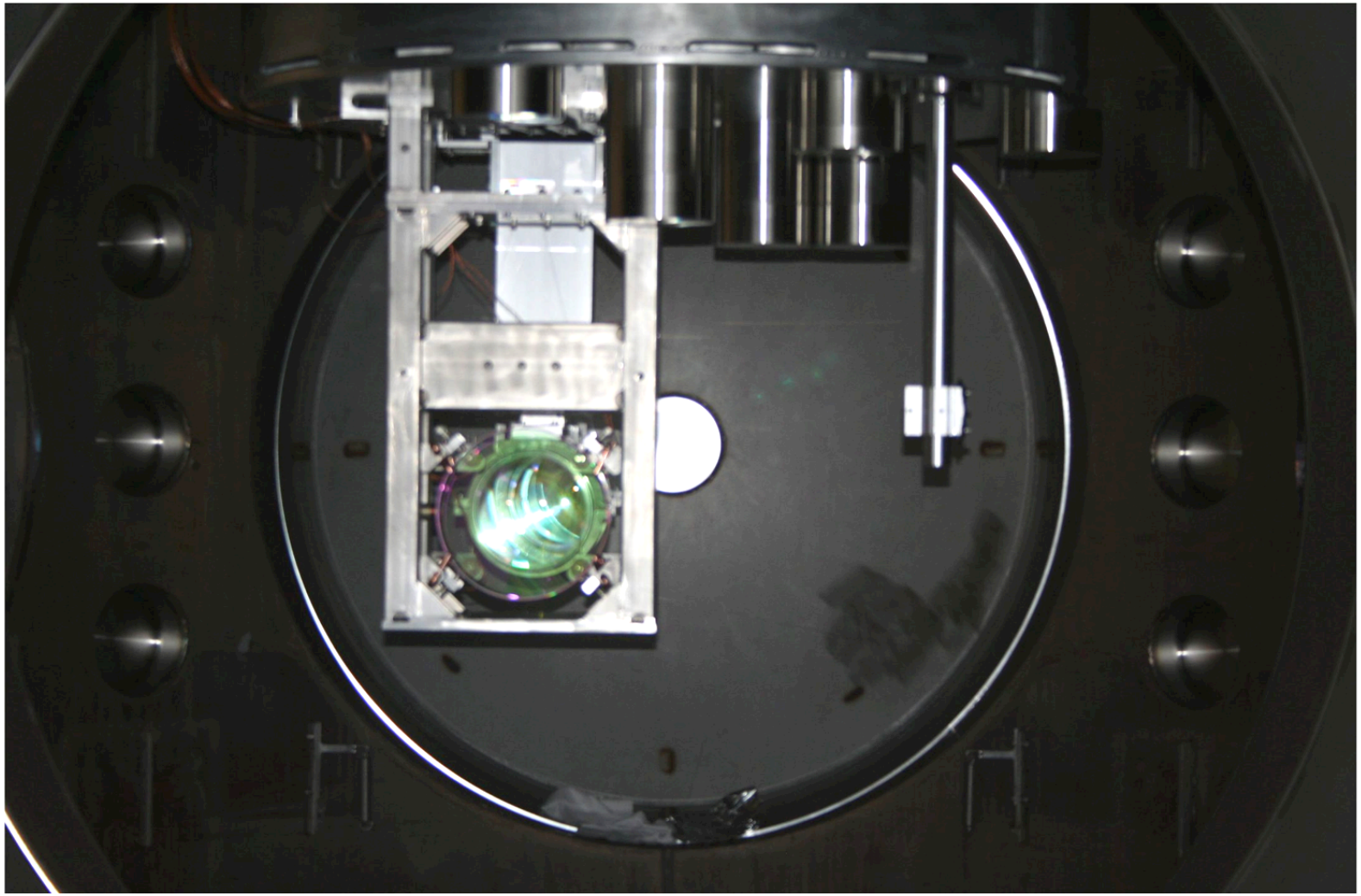


Worst back-scattering sites



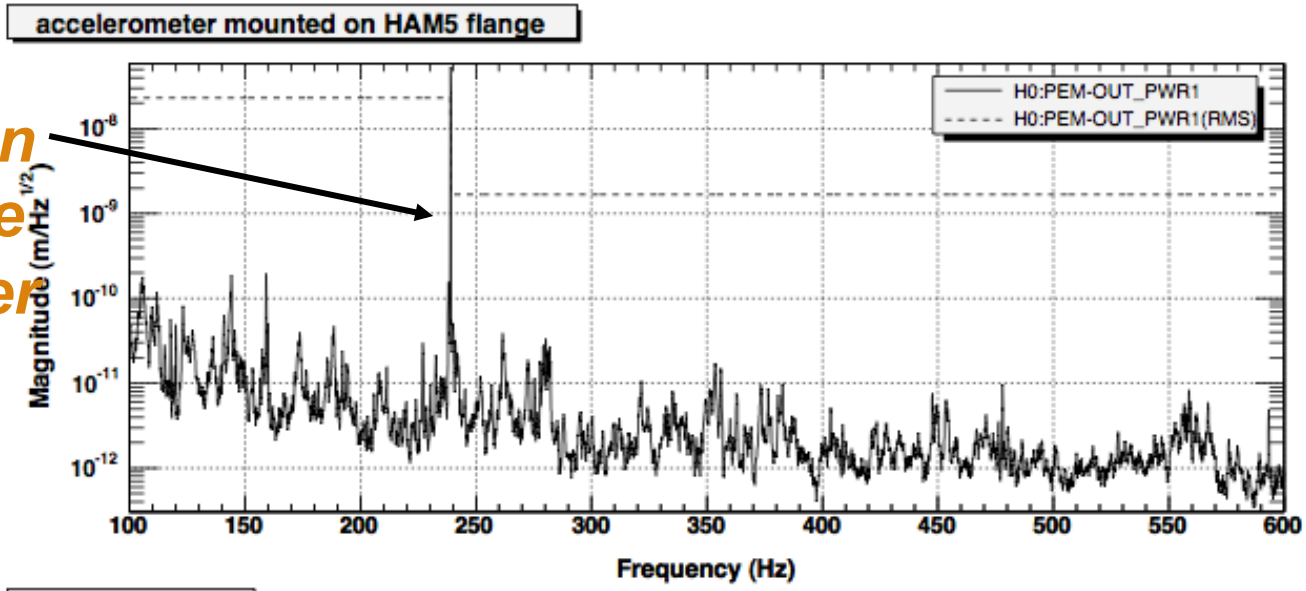
Worst sites

End cap of beam tube

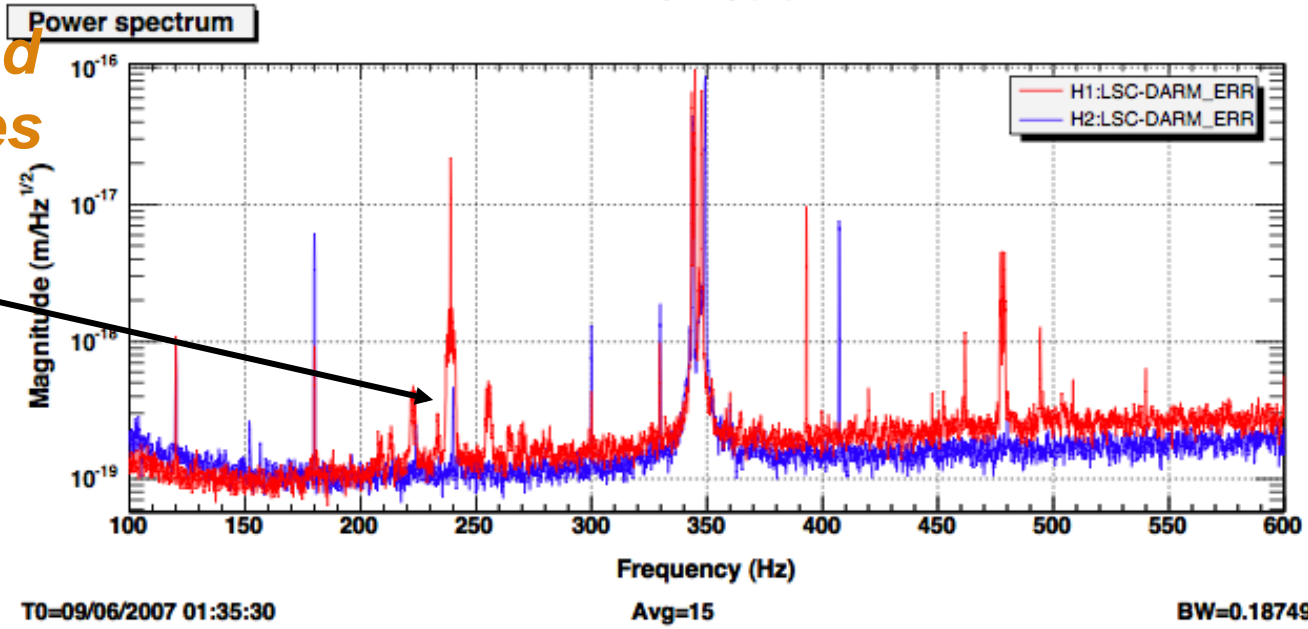


Back-scattering from HAM5 flange

Shaker peak in HAM 5 flange accelerometer spectrum



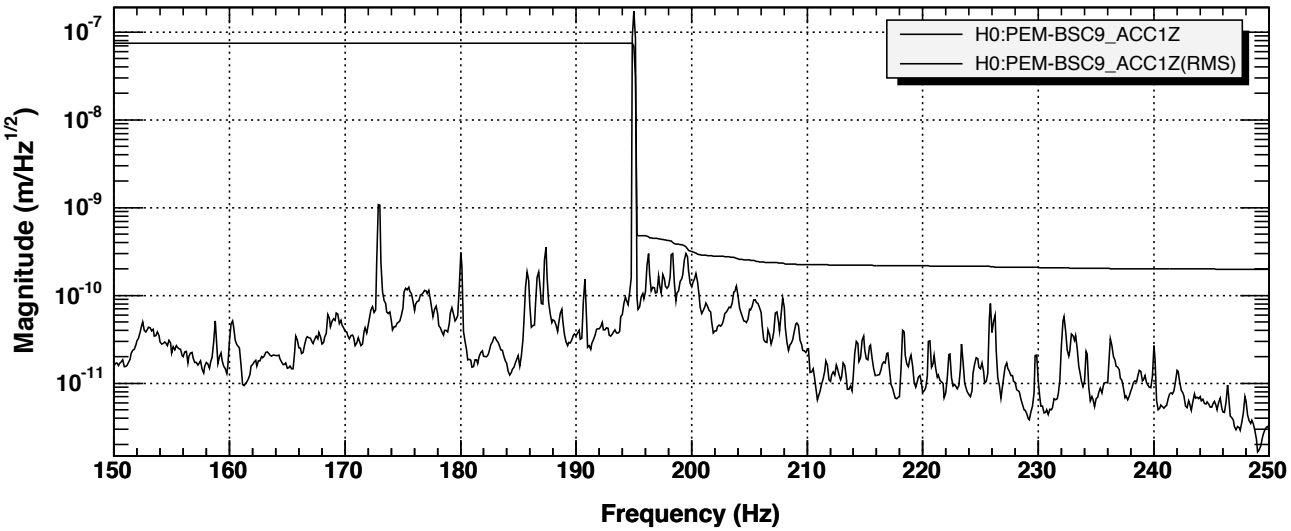
Back-scattered light produces H1 and H2 peaks



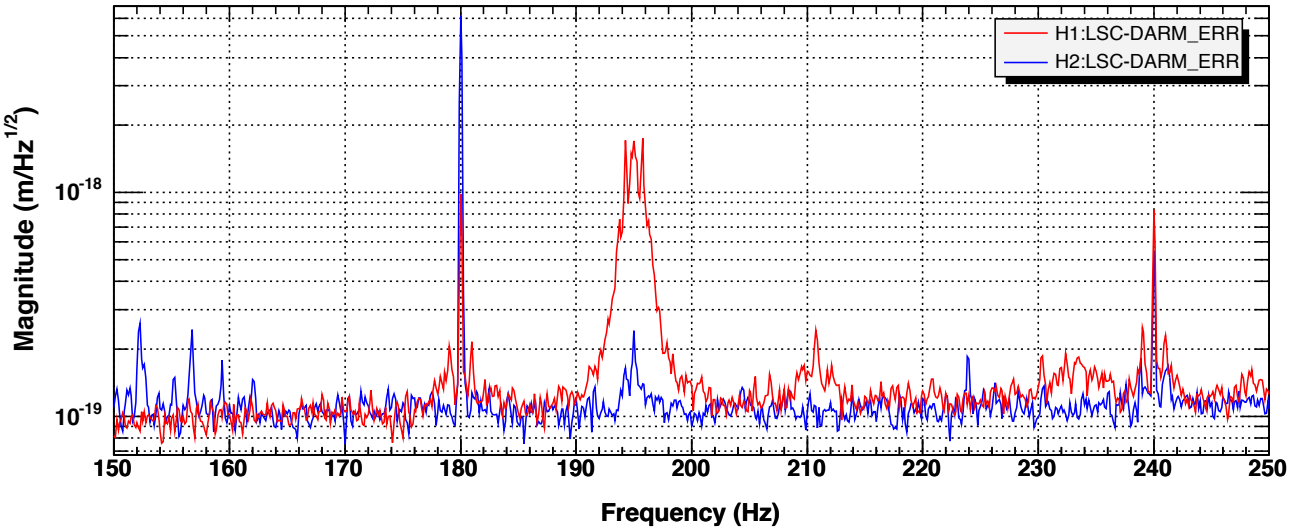
End cap of beam tube

Shaking evident on H2 even though the nearest component was 2km away

Accelerometer mounted near shaker on center port of BSC9 (EX) end door

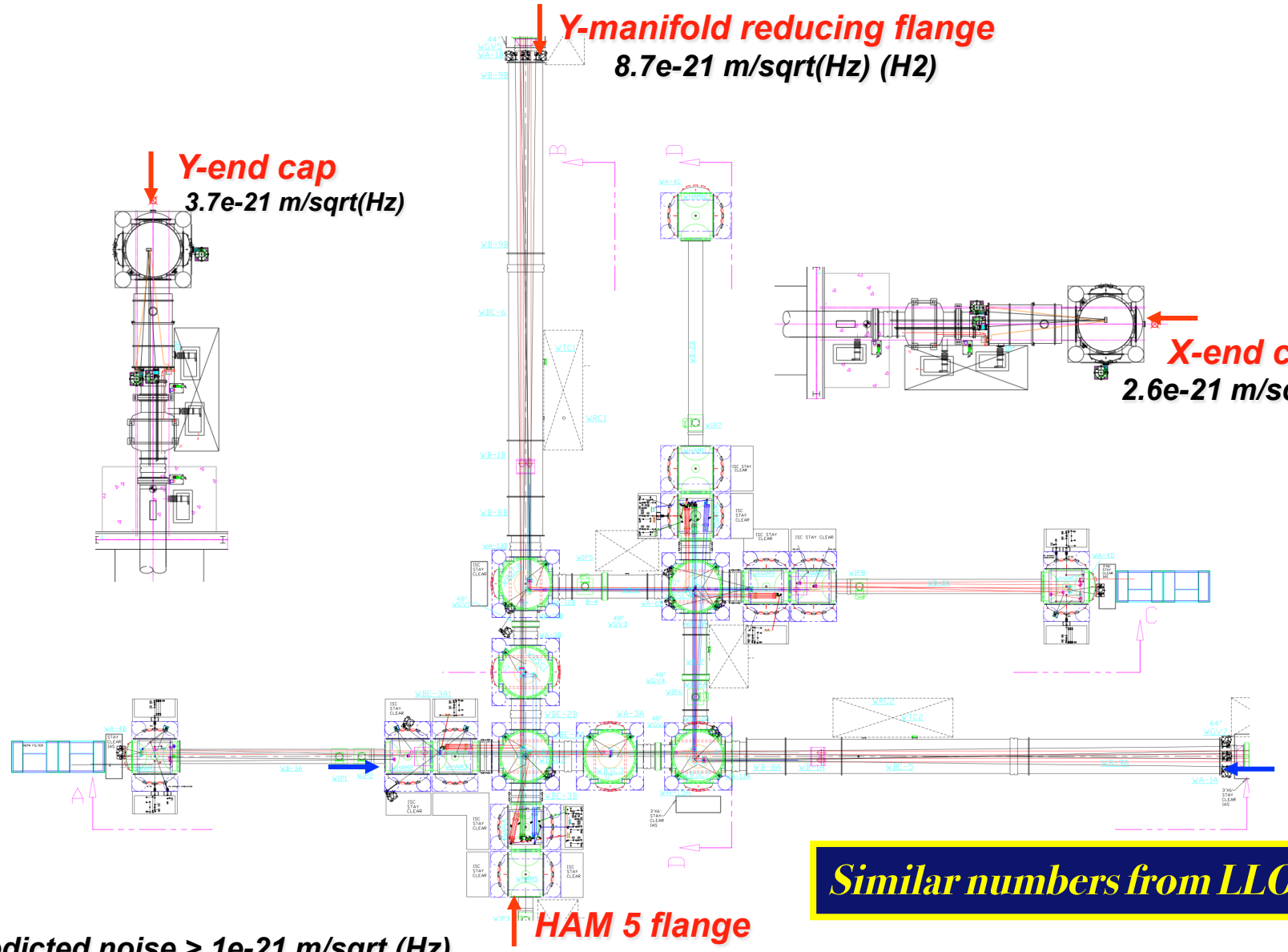


Backscattering into H1 and H2



T0=18/05/2007 23:54:30 Avg=30 BW=0.187499

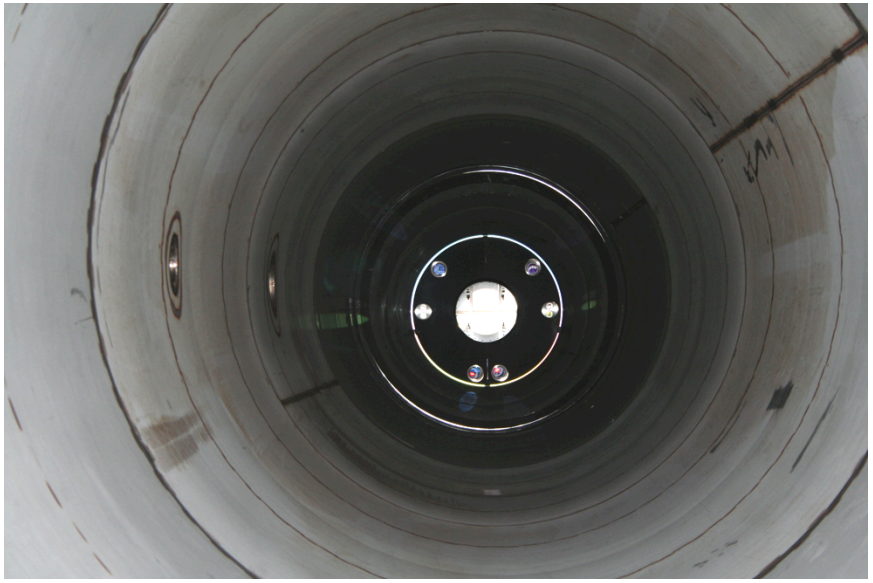
Worst* scattering sites (↓); proposed S6 baffles (↓,↓)



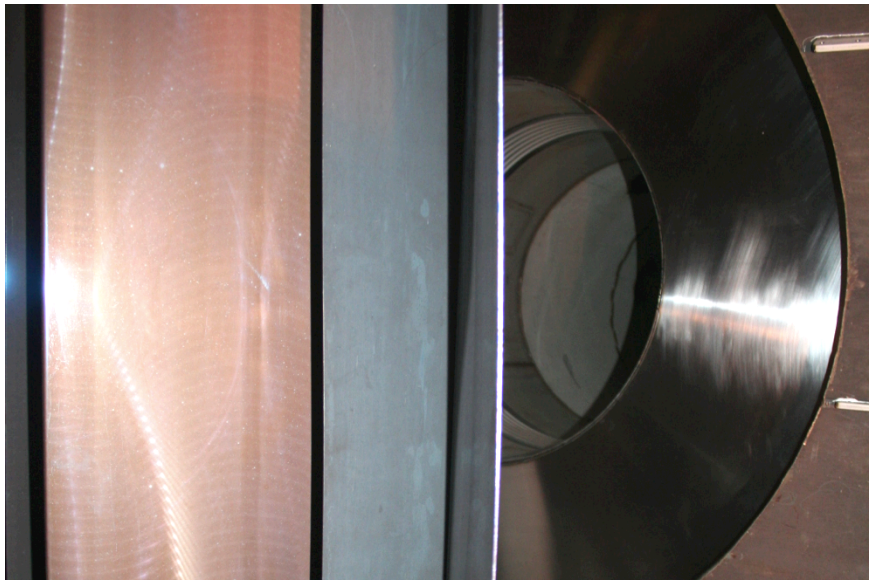
Similar numbers from LLO

* Predicted noise > 1e-21 m/sqrt (Hz)

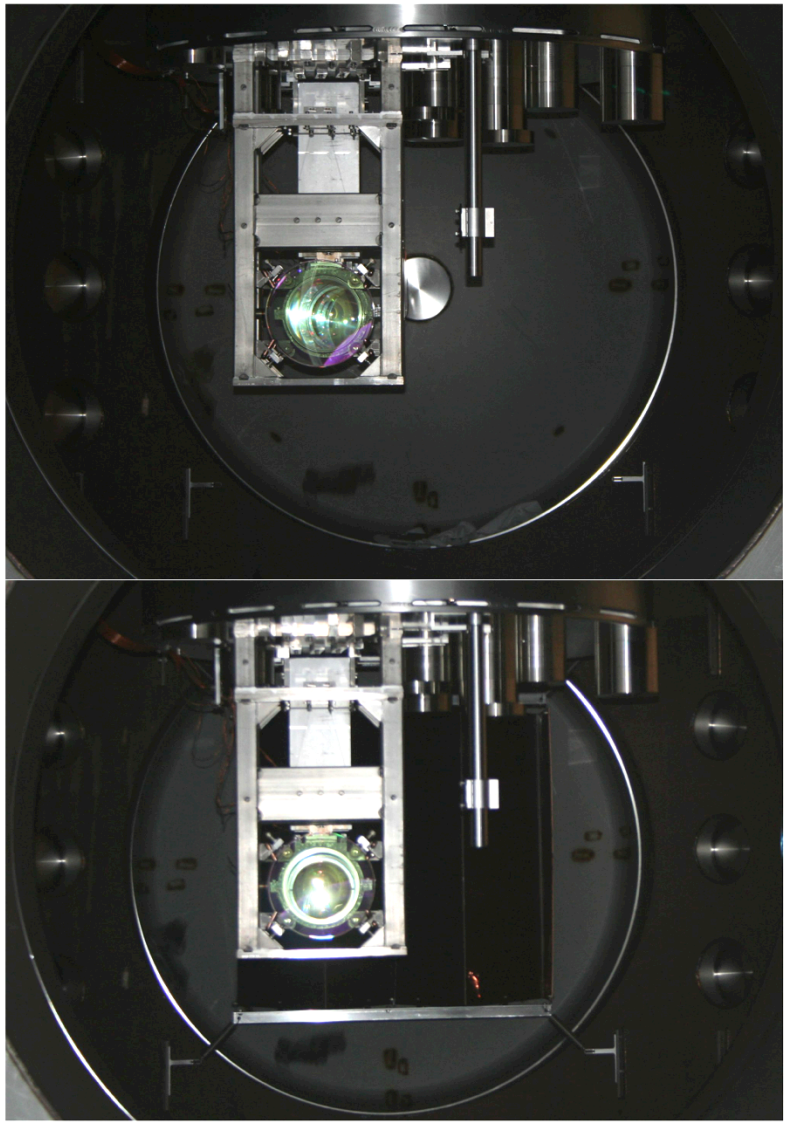
Y-manifold baffle



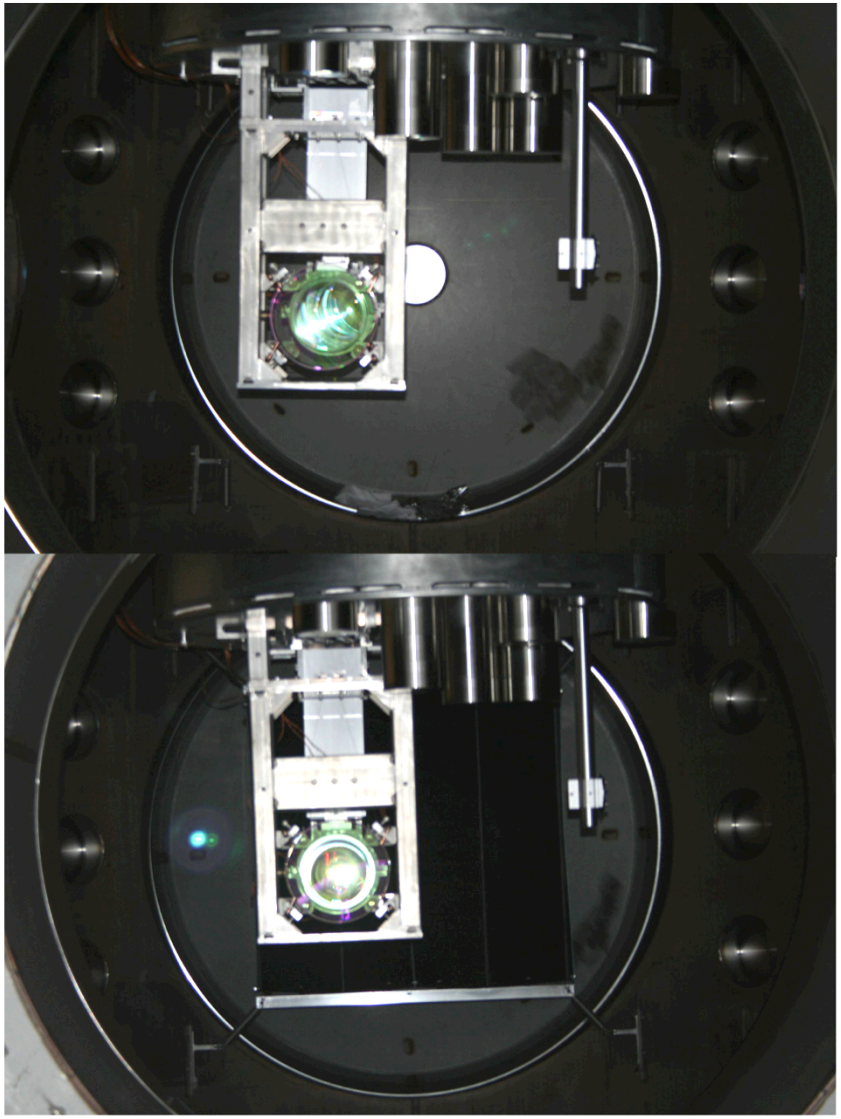
HAM5 baffle



X-endcap baffle



Y-endcap baffle

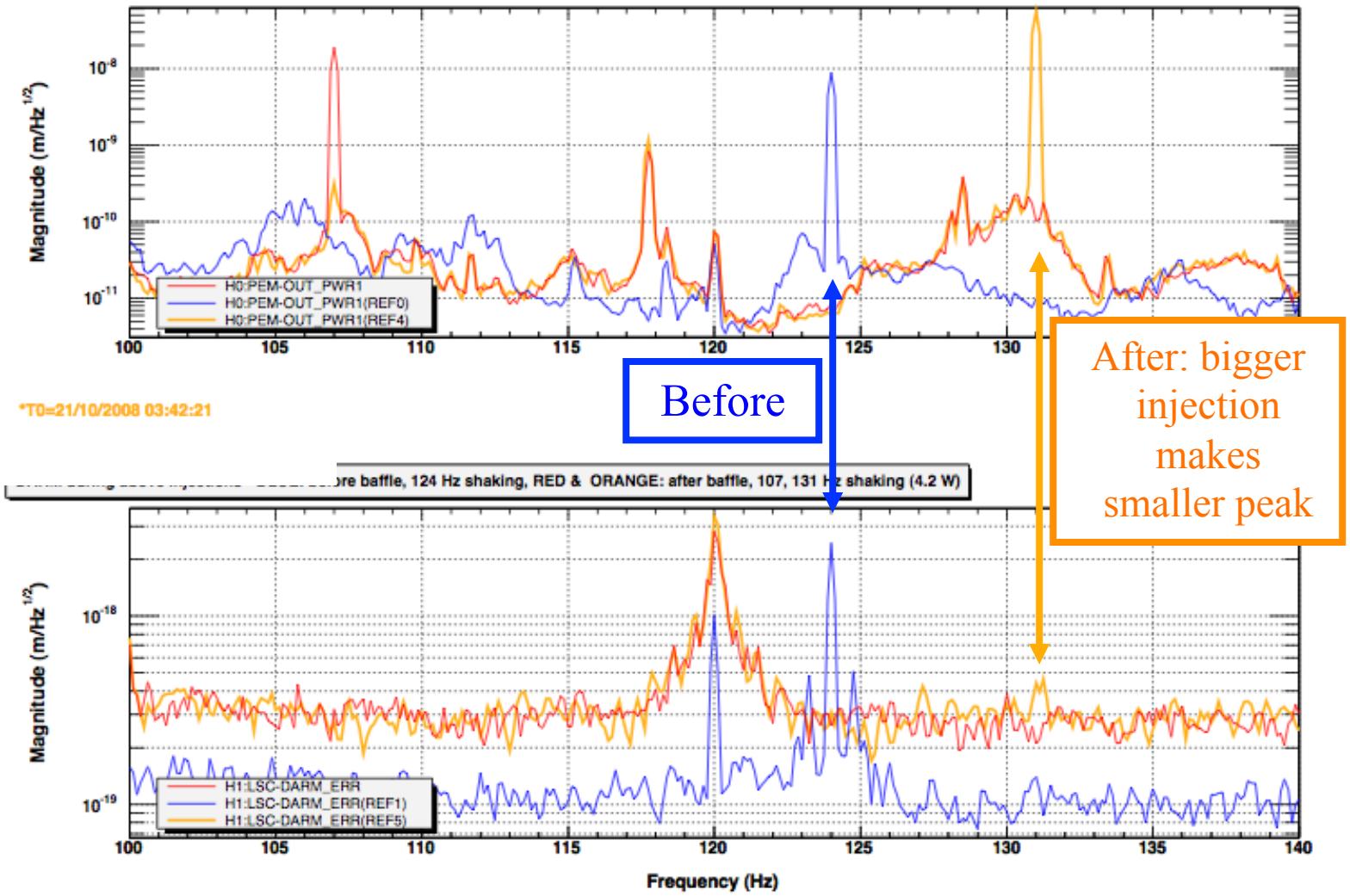


Baffling worked

HAM5 baffle check

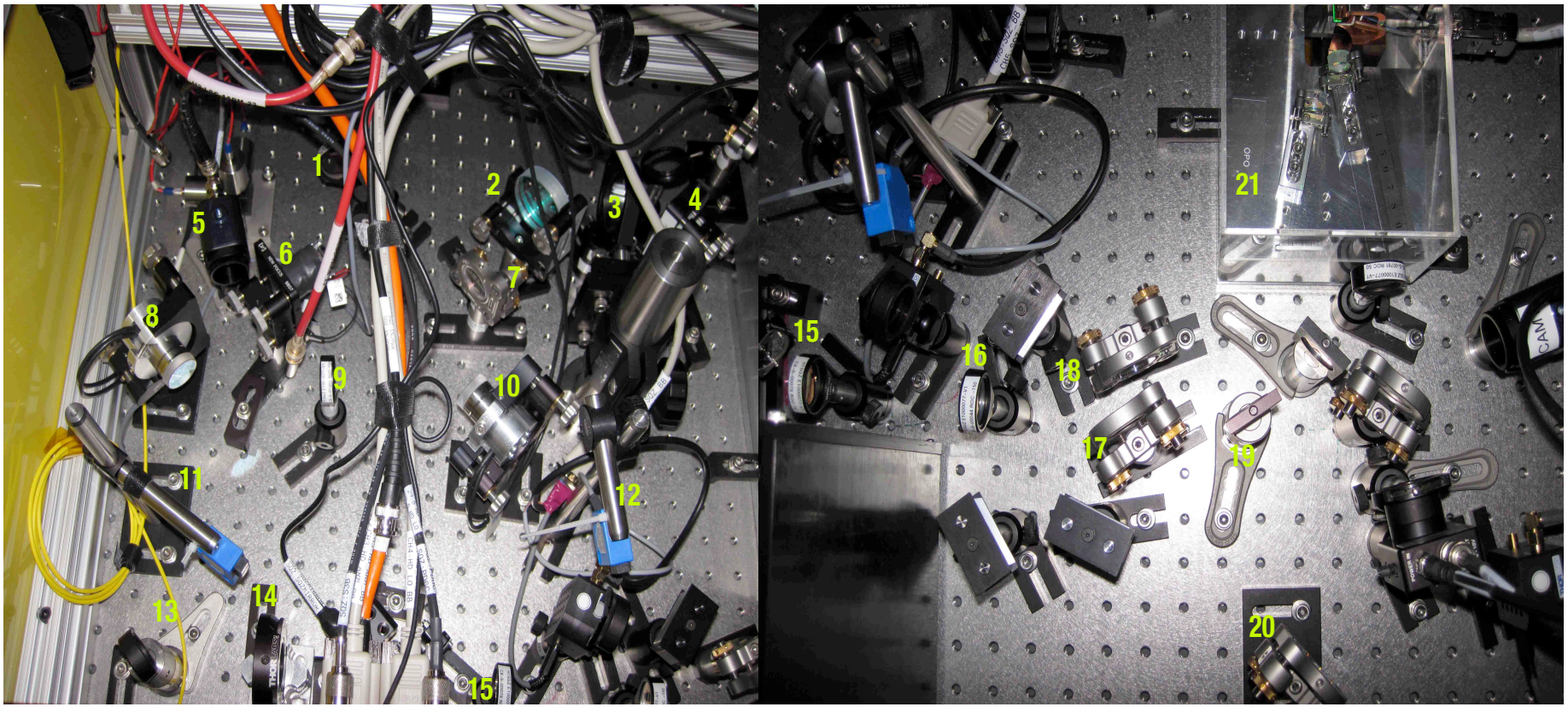
Acceler-ometer

DARM



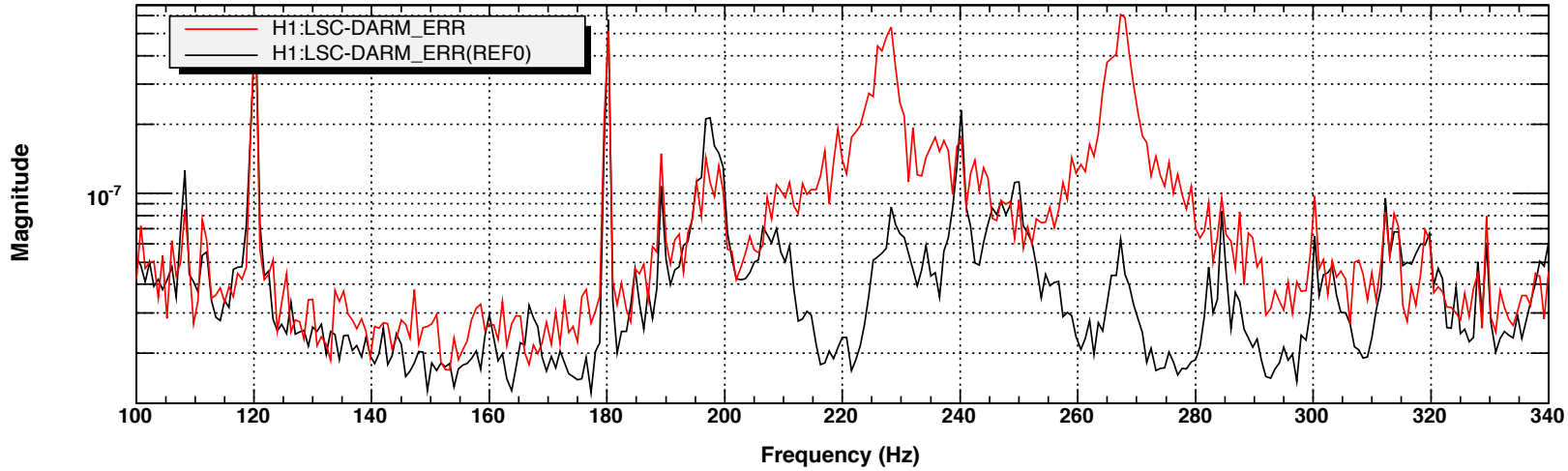
Finding scattering sites: bowing or plucking

Squeezing at LHO: we bowed numbered optics using finger ridges.
With Sheila Dwyer and Sheon Chua



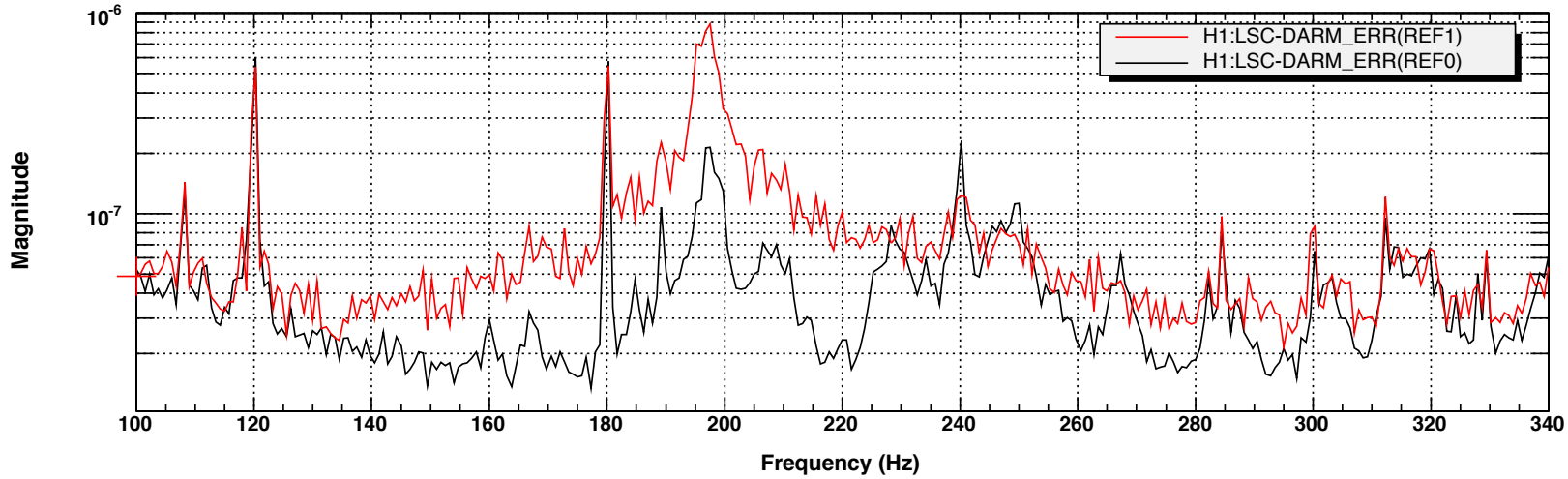
Identifying optics peaks in DARM

BLACK: nominal DARM, RED: bowing optic 10



*T0=12/11/2011 21:28:21 *Avg=4/Bin=3 BW=0.374999

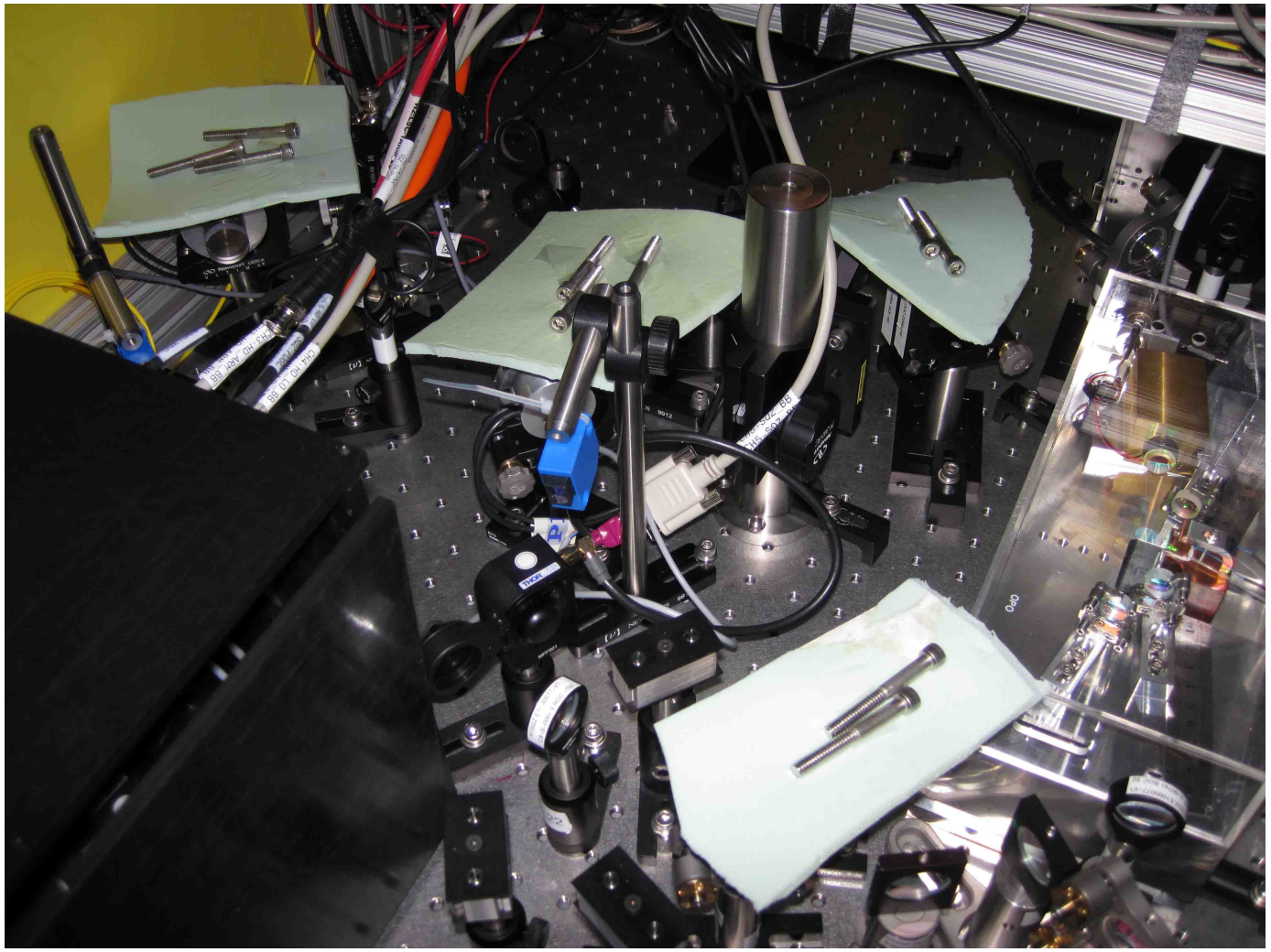
BLACK: nominal DARM, RED: bowing optic 18



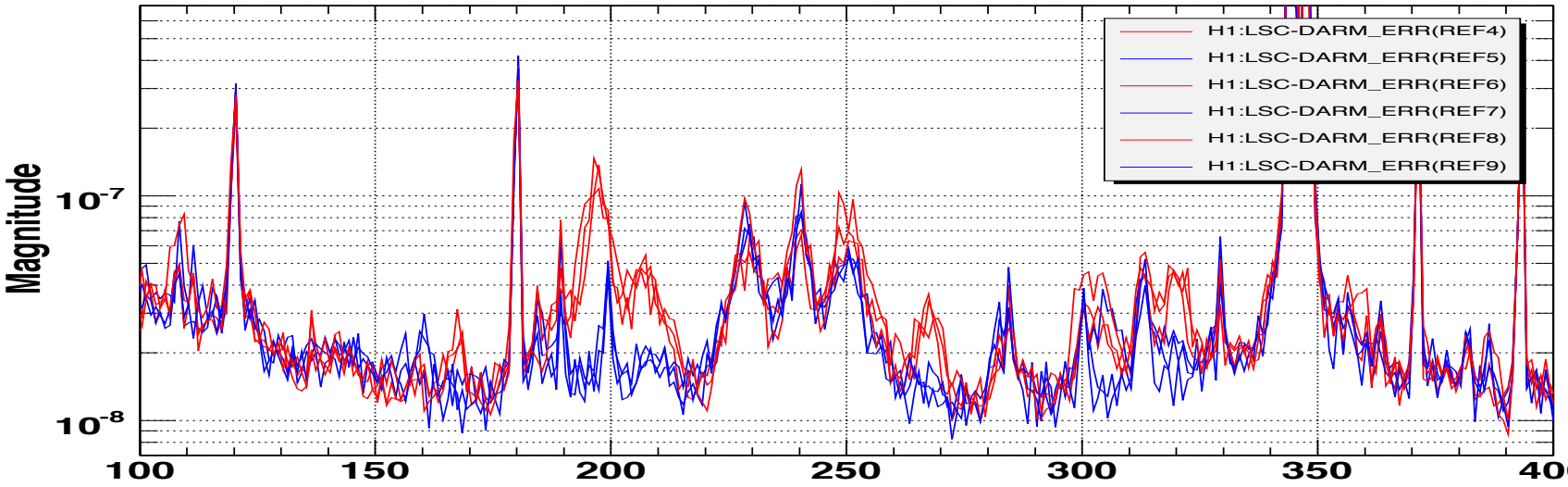
*T0=12/11/2011 21:34:59 Avg=55/Bin=3 BW=0.374999

Temporary solution

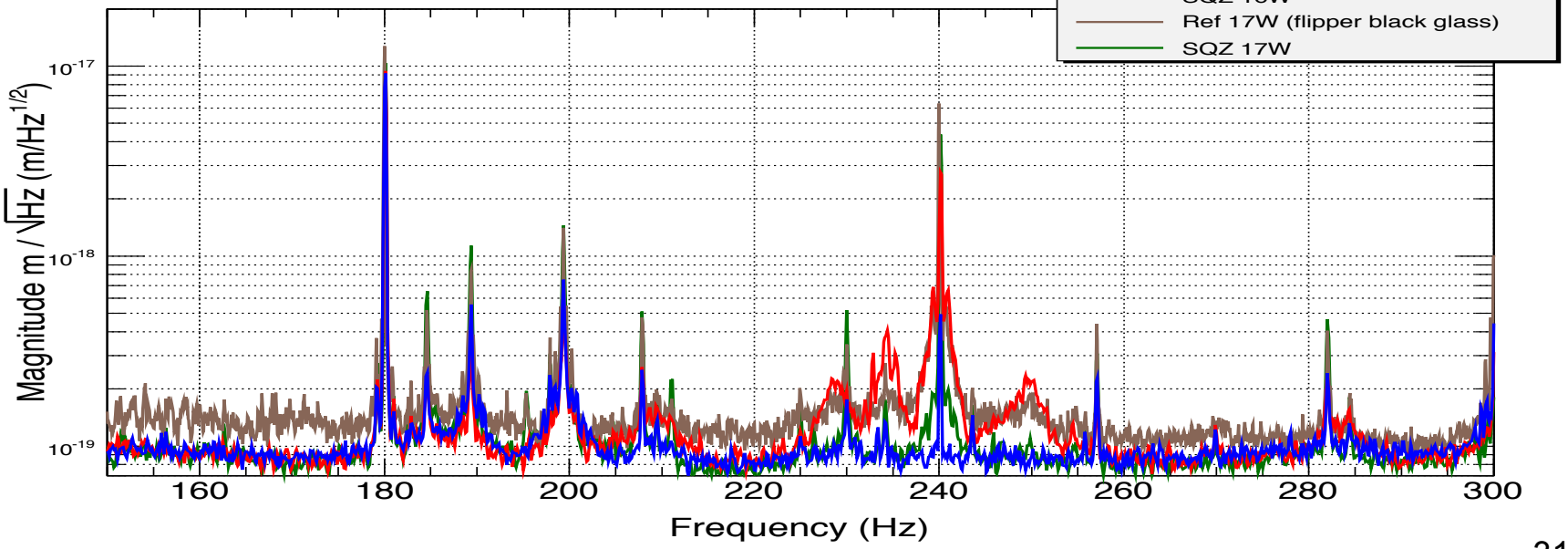
Weighted damping material set on top, rather than damping of individual optics (which would require redoing the beam path)



Peaks gone from DARM



DARM ERR, Clean rooms off

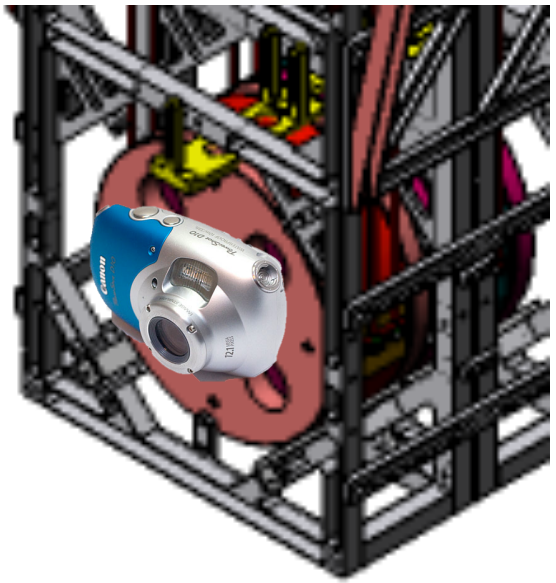


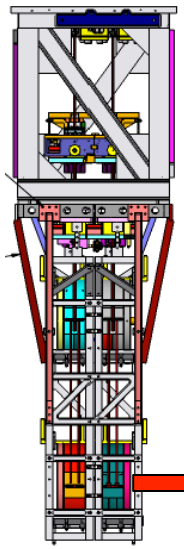
*T0=14/11/2011 03:51:00 Avg=122 *BW=0.187493

Finding scattering sites: camera techniques for glints

Using a camera with its flash near its lens to qualitatively observe sites that back-reflect, keeping in mind that angular distribution of light from flash can be very different..

- ***Beam spot view:*** *camera placed as near as possible to beam spot to observe any surfaces that retro-reflect light scattered from optic*



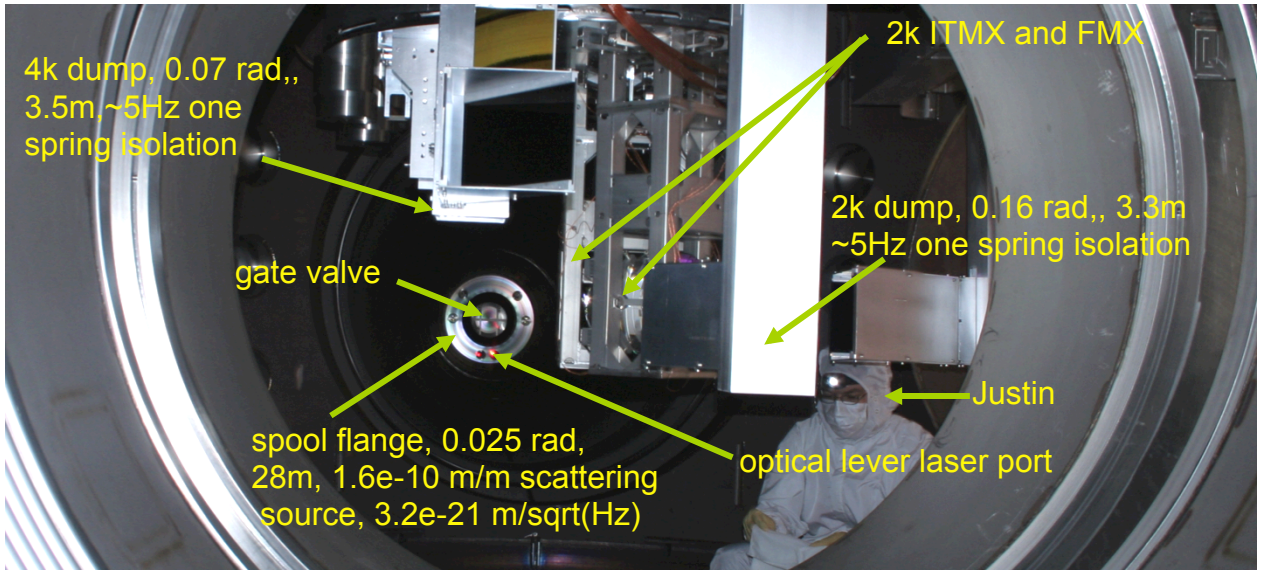


- ***Distant optic view:*** *camera placed far from optic, in beam path (flash reflects in optic), to observe glints that retro-reflect light scattered from distant optic*

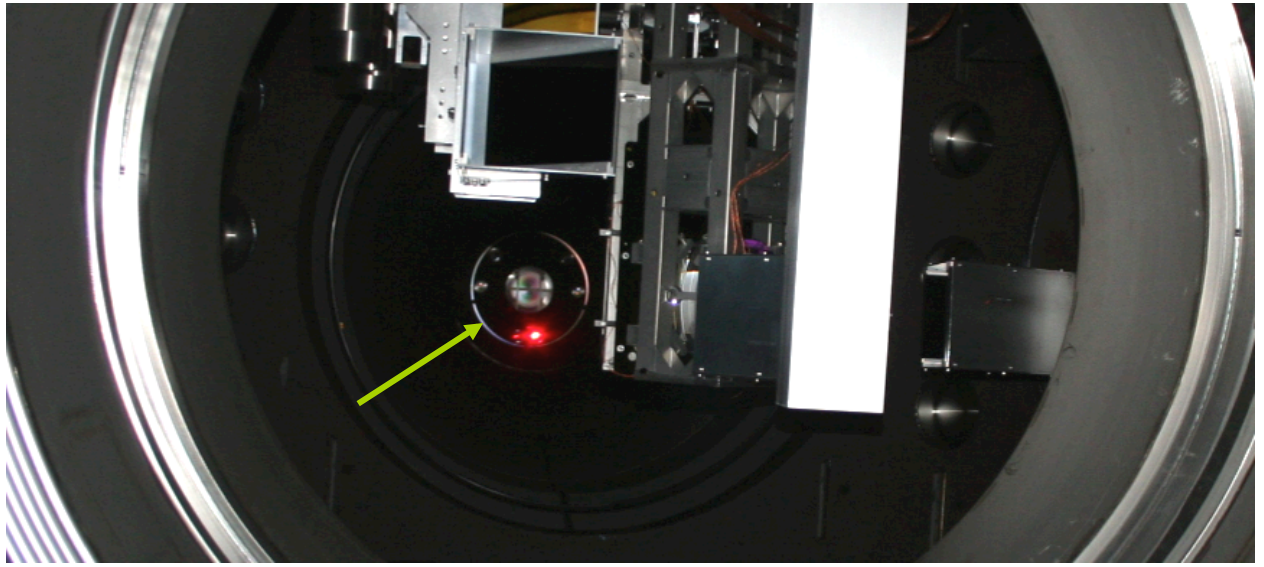
Beam spot view (iLIGO)

X-manifold - view from ITMX

Before



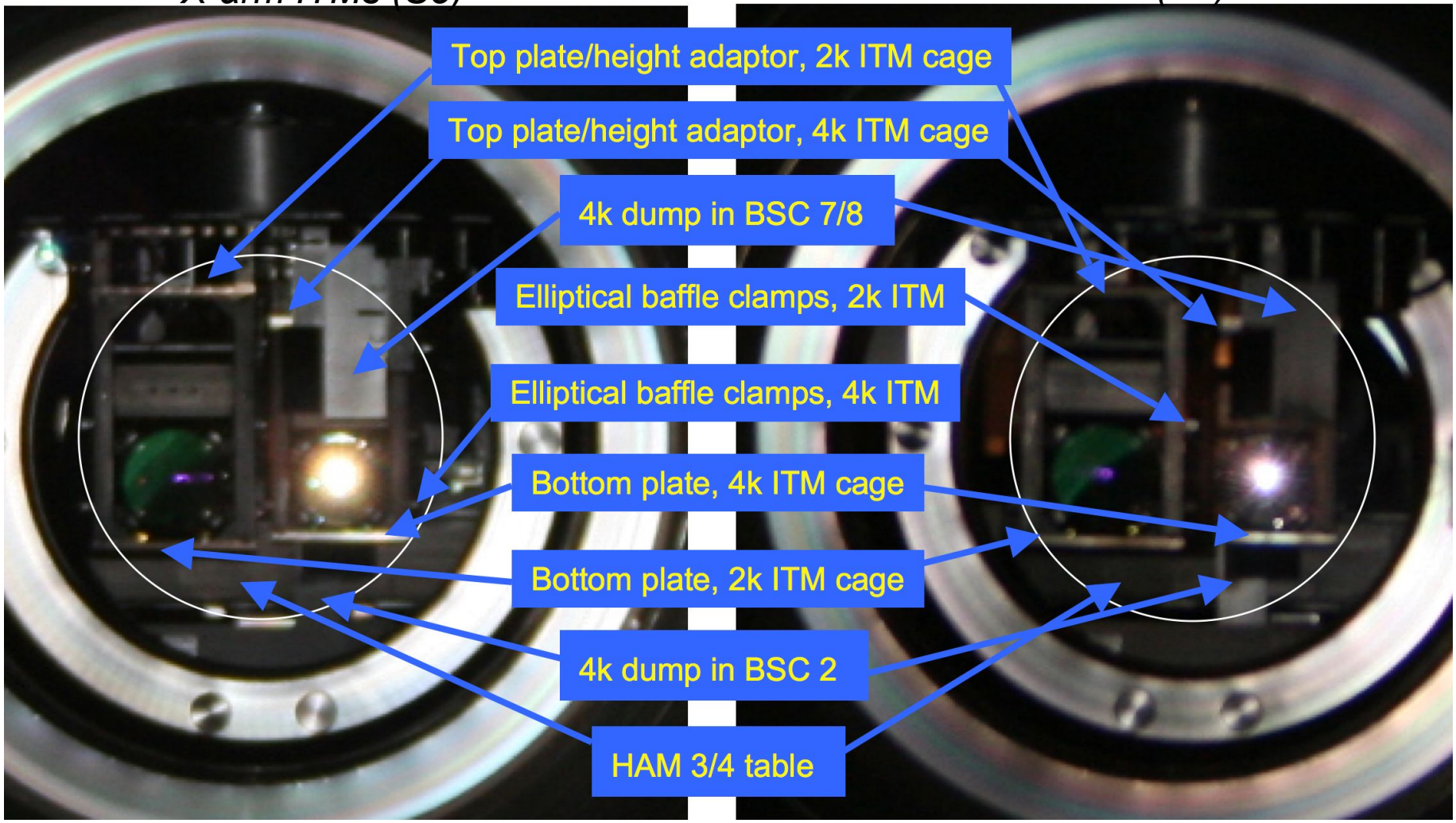
After



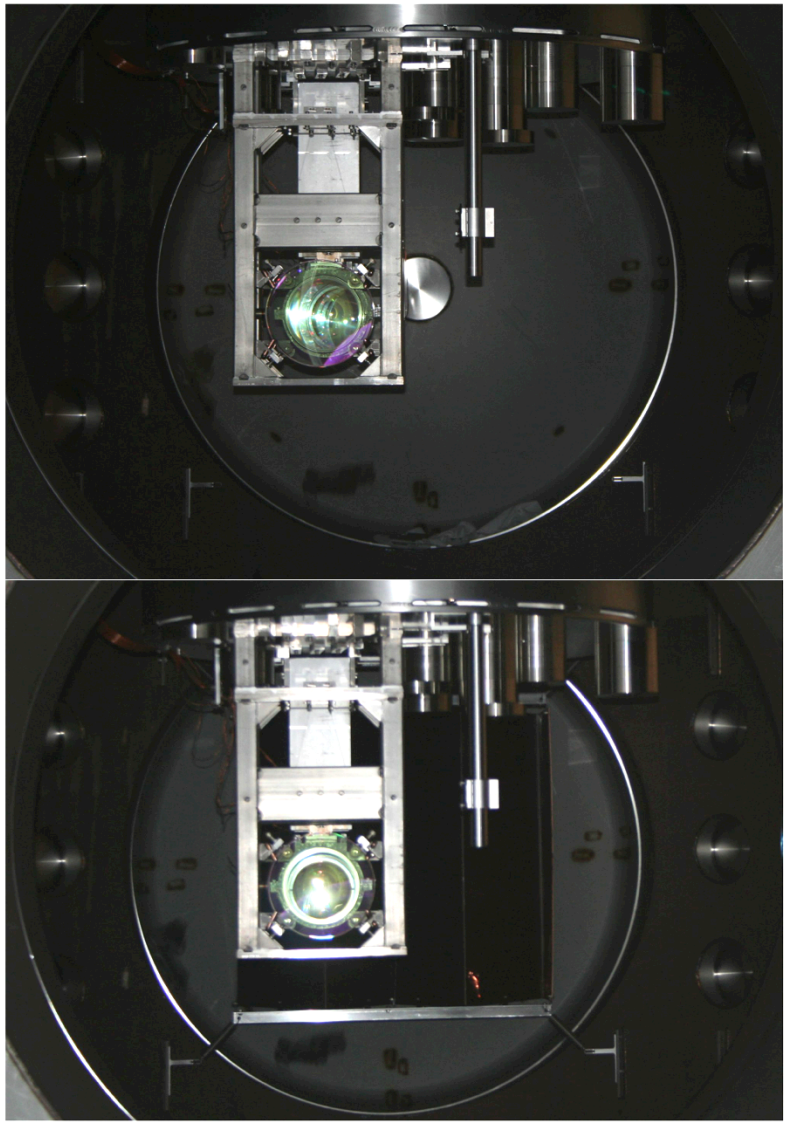
Distant optic view (iLIGO)

White circles: region visible to ETMs (approx. clear aperture)

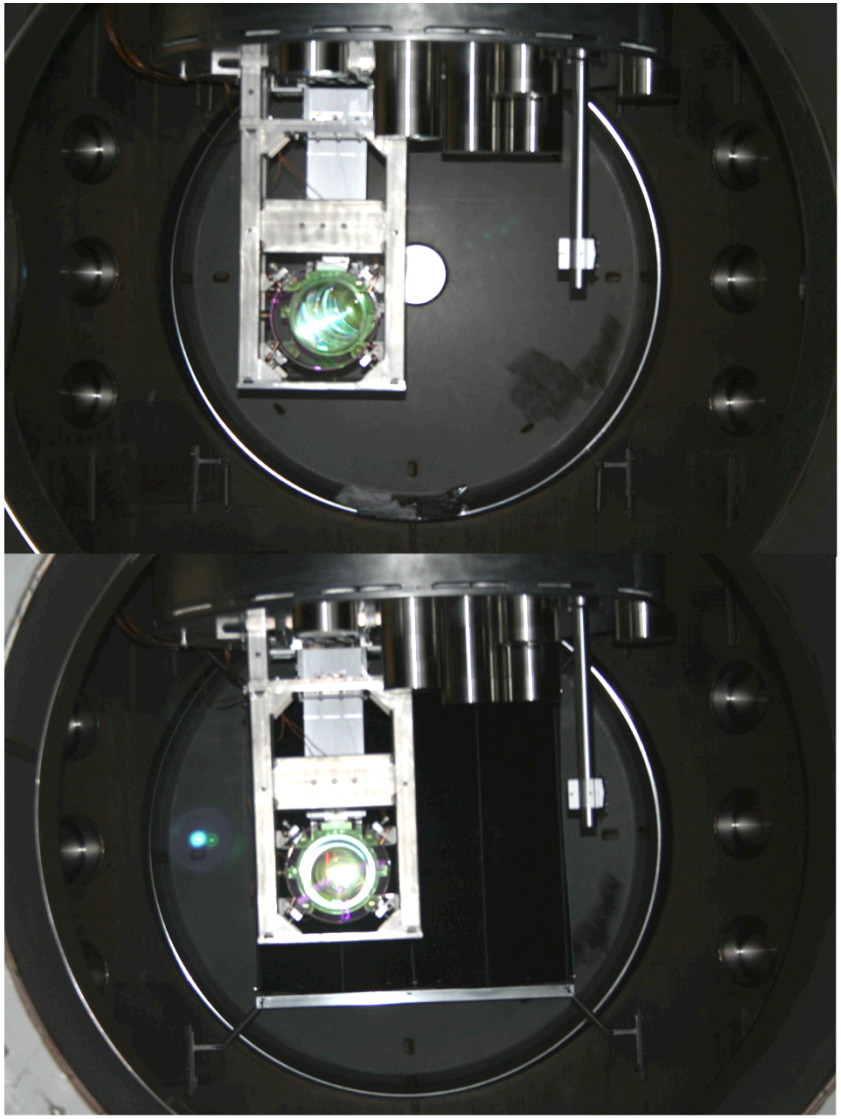
X-arm ITMs (S5) *Y-arm ITMs (S5)*



X-endcap baffle

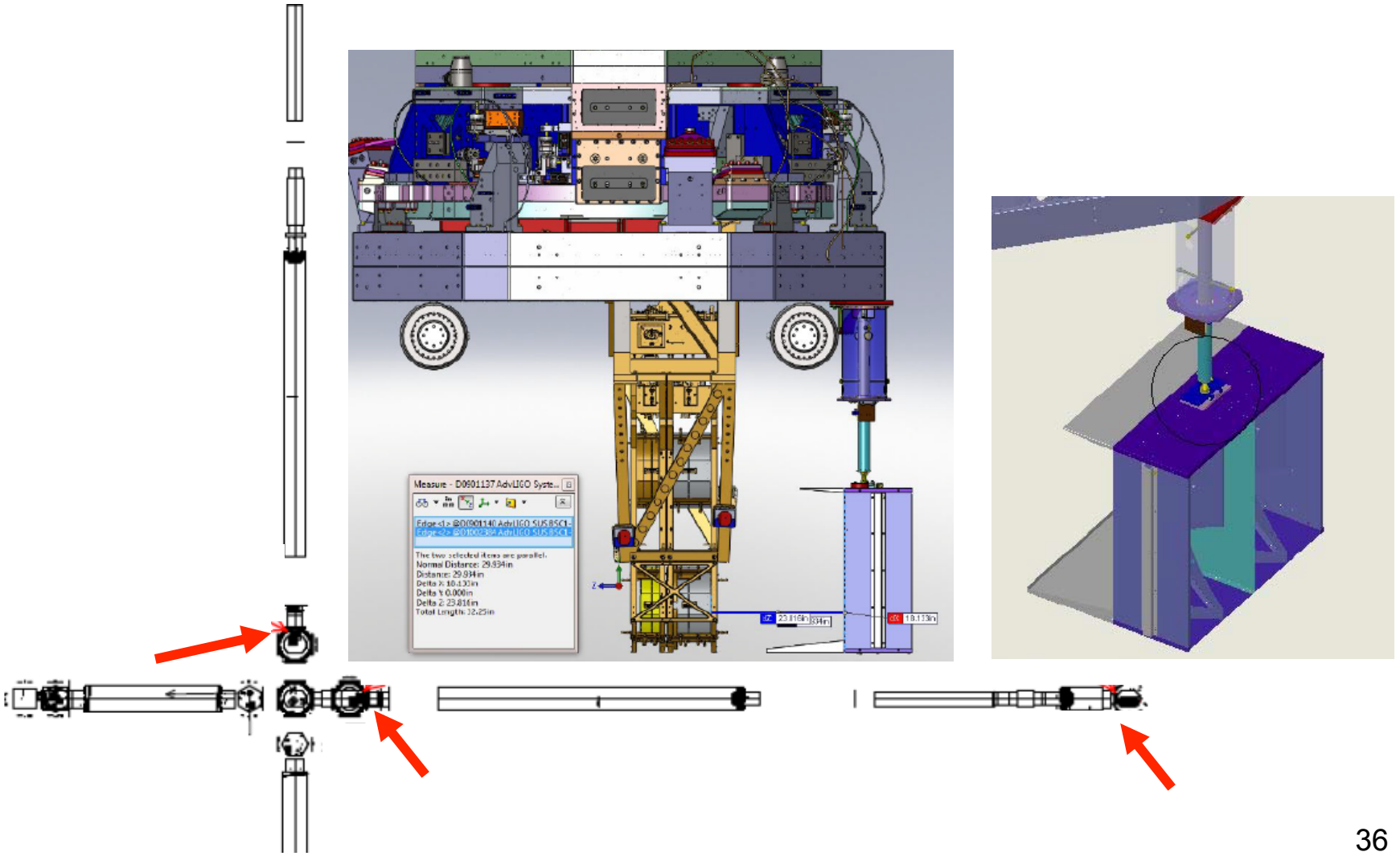


Y-endcap baffle



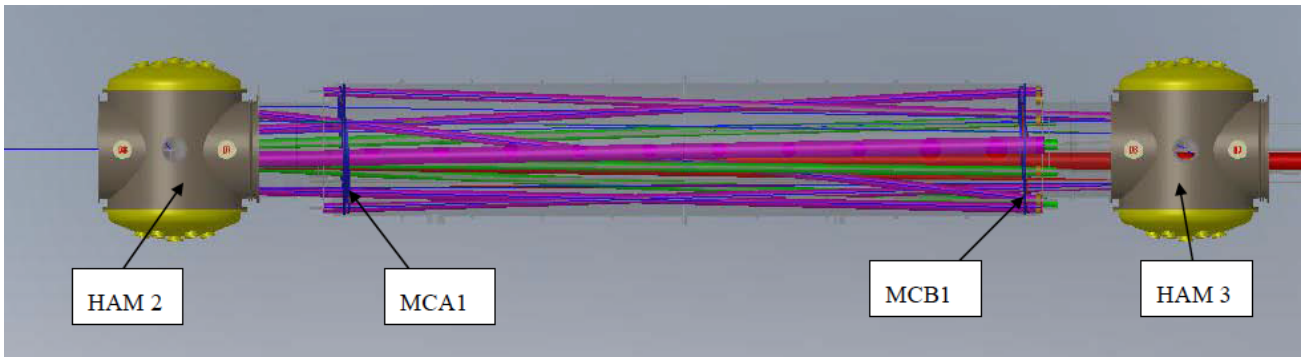
aLIGO Baffles

Arm cavity side of test masses, 1 spring + HEPI isolation, damped



aLIGO Baffles

Mode cleaner tubes, input and output, 1 spring isolation, damped



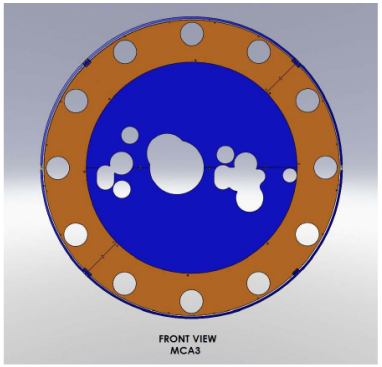
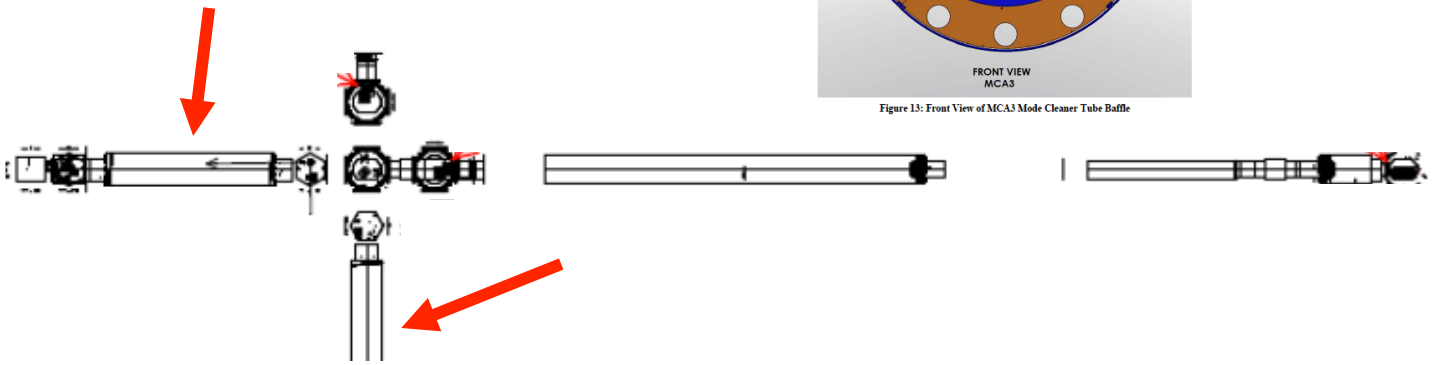
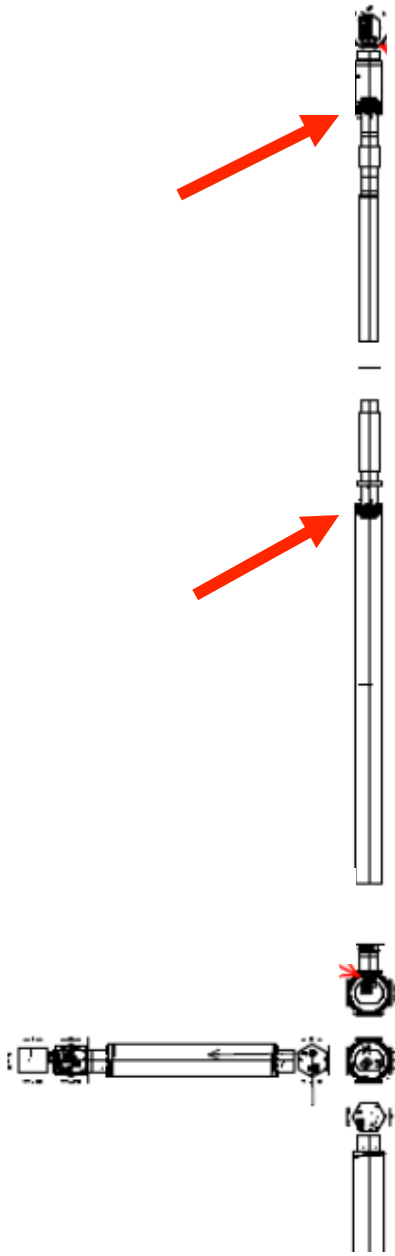


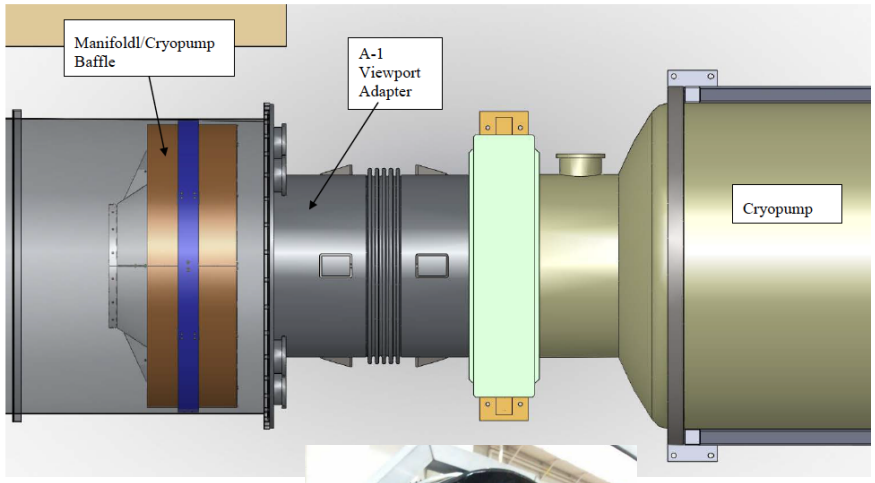
Figure 13: Front View of MCA3 Mode Cleaner Tube Baffle

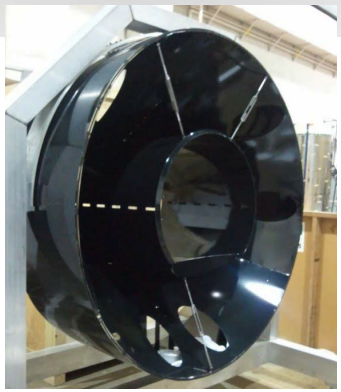


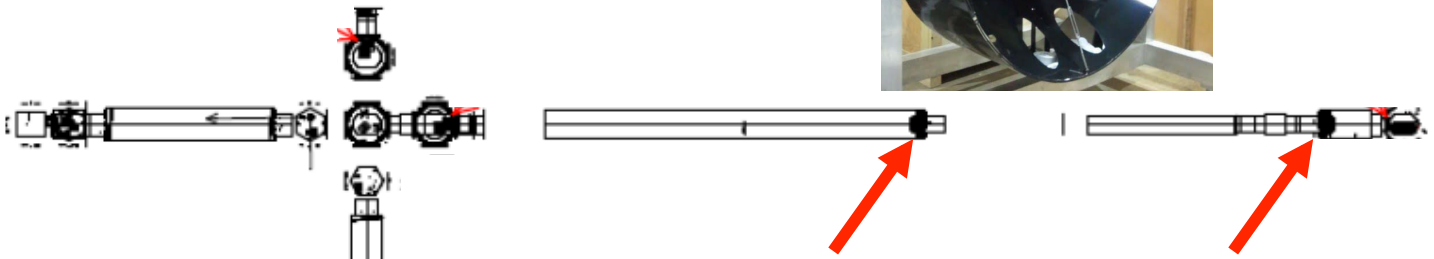
aLIGO Baffles

Cryopump, 1 spring isolation, damped









aLIGO Baffles

Input test mass elliptical, on beam splitter side, 1 spring + HEPI isolation, damped

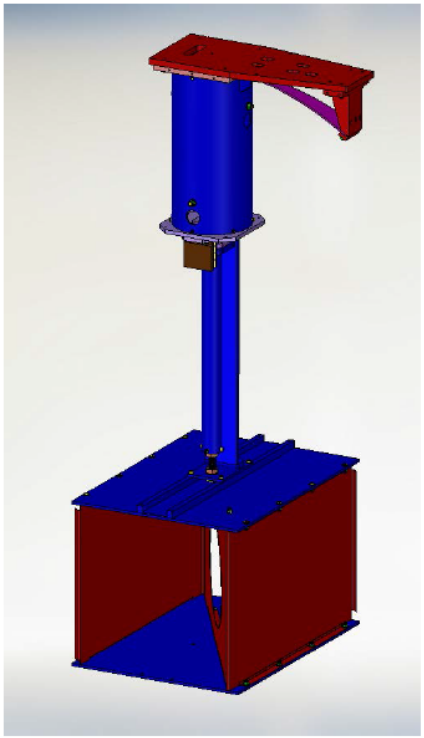
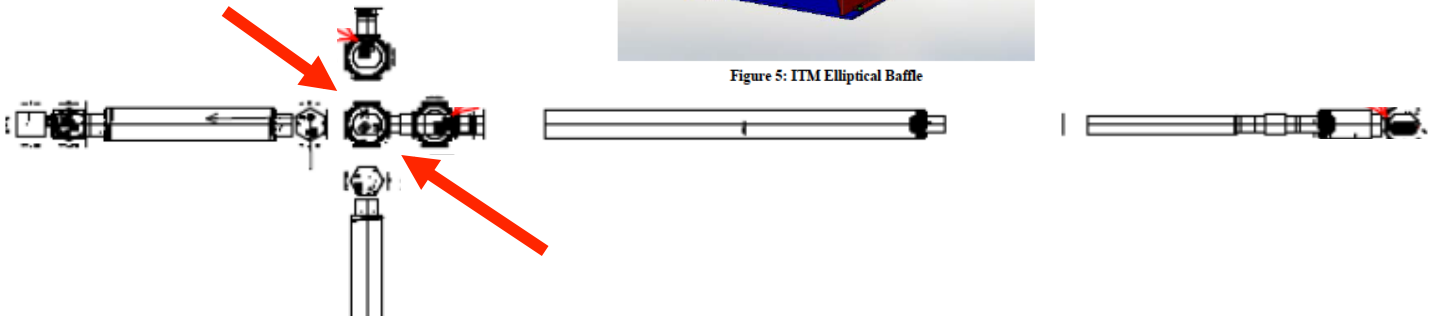


Figure 5: ITM Elliptical Baffle



aLIGO Baffles

Beam splitter elliptical, same isolation as active table

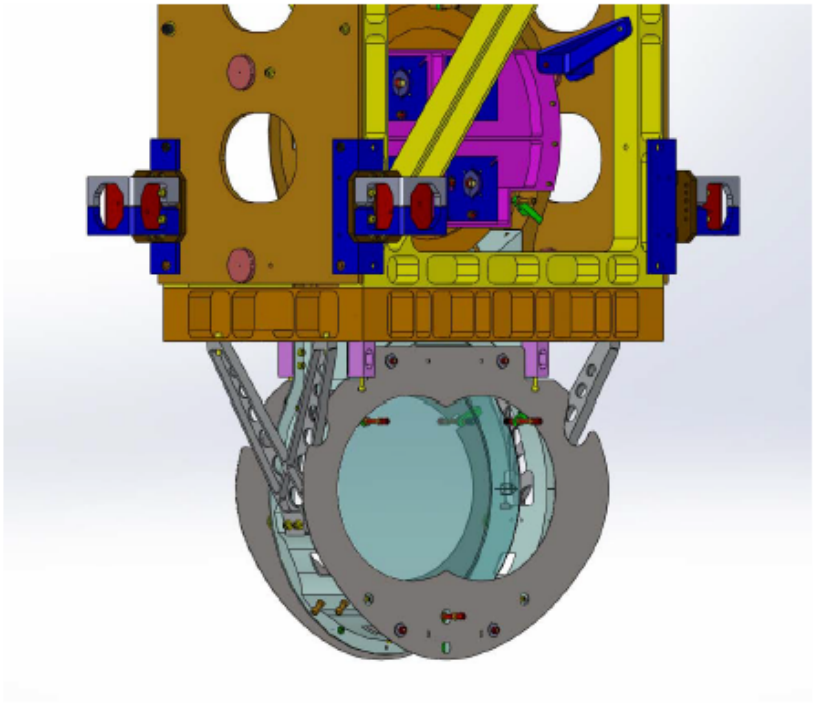
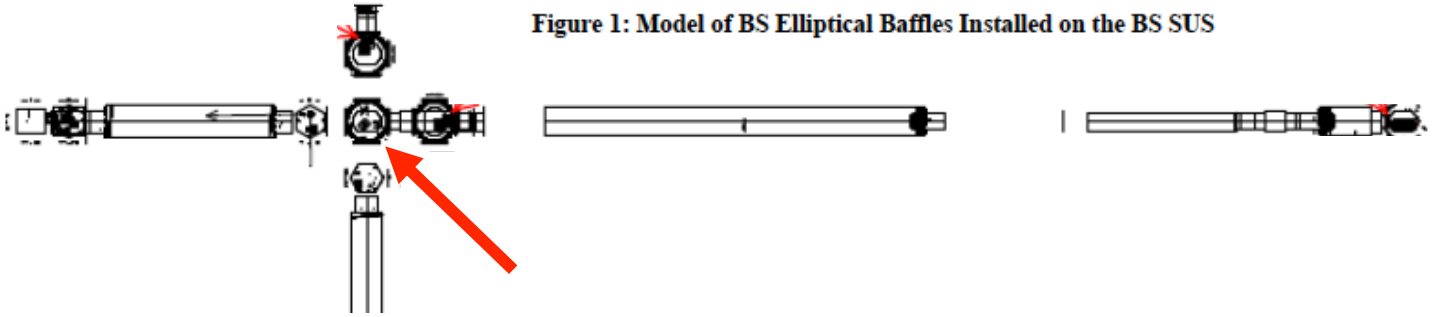


Figure 1: Model of BS Elliptical Baffles Installed on the BS SUS



aLIGO Baffles

Many input and signal recycling cavity baffles

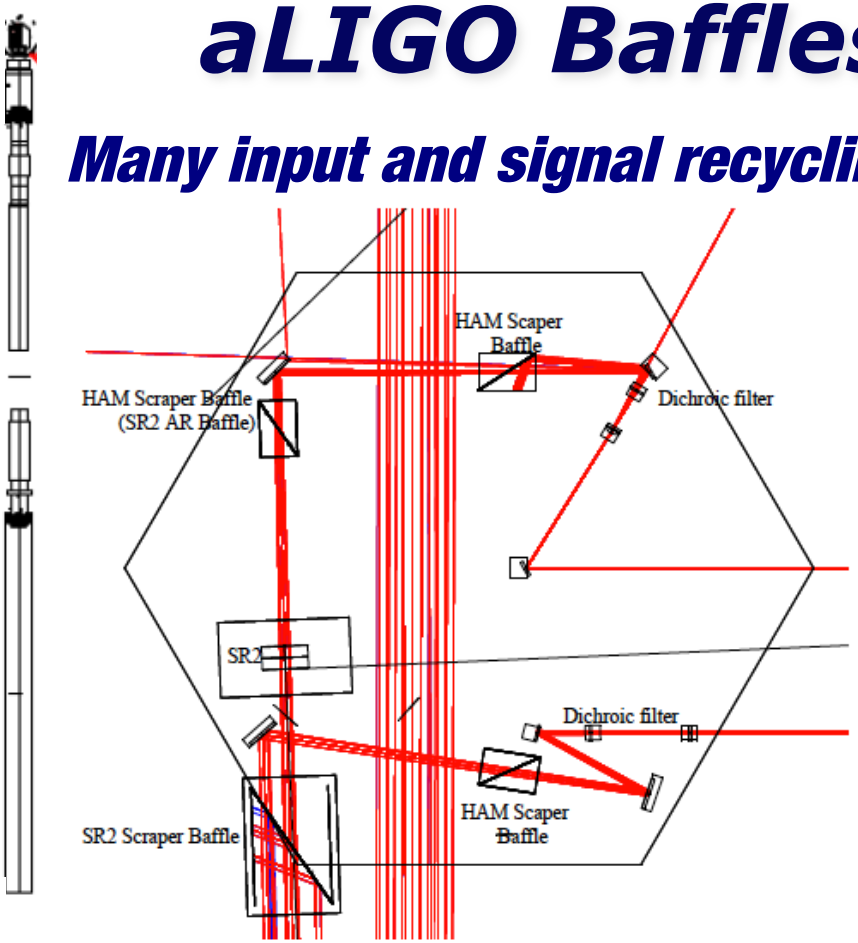


Figure 1: H1 & L1 HAM4: SR2 Scraper Baffle, SR2 AR Baffle, HAM Scraper Baffle

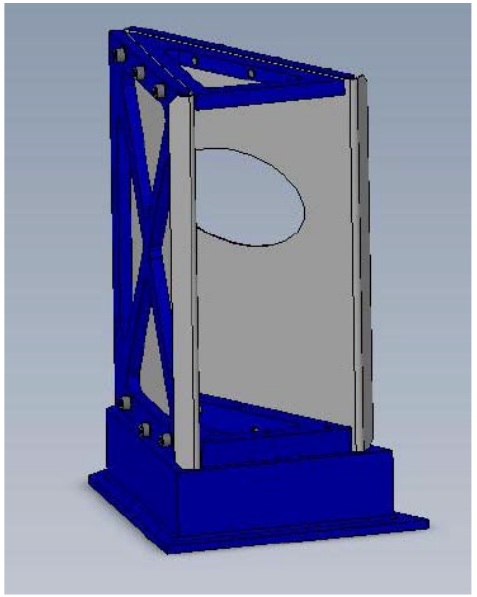
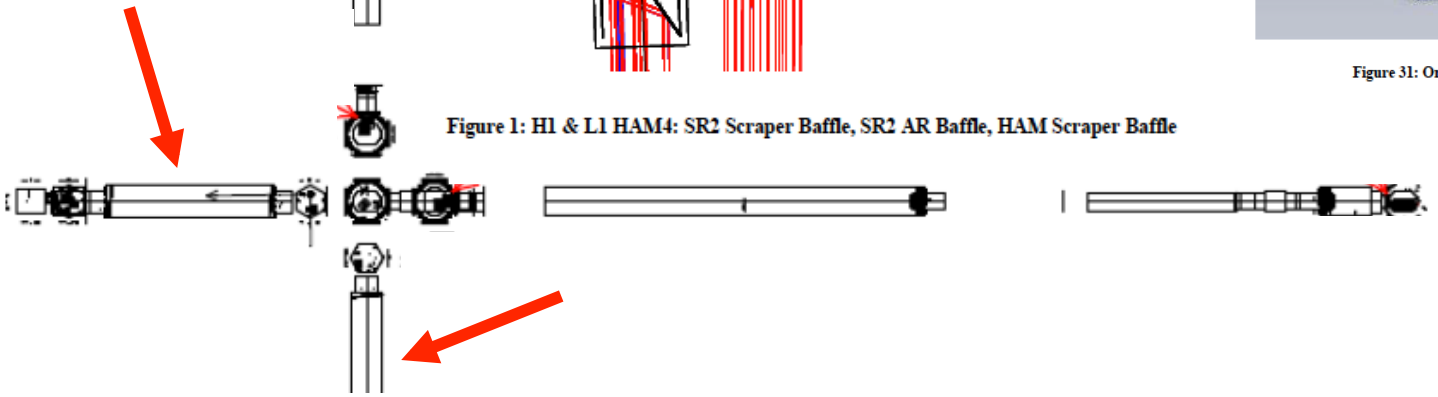
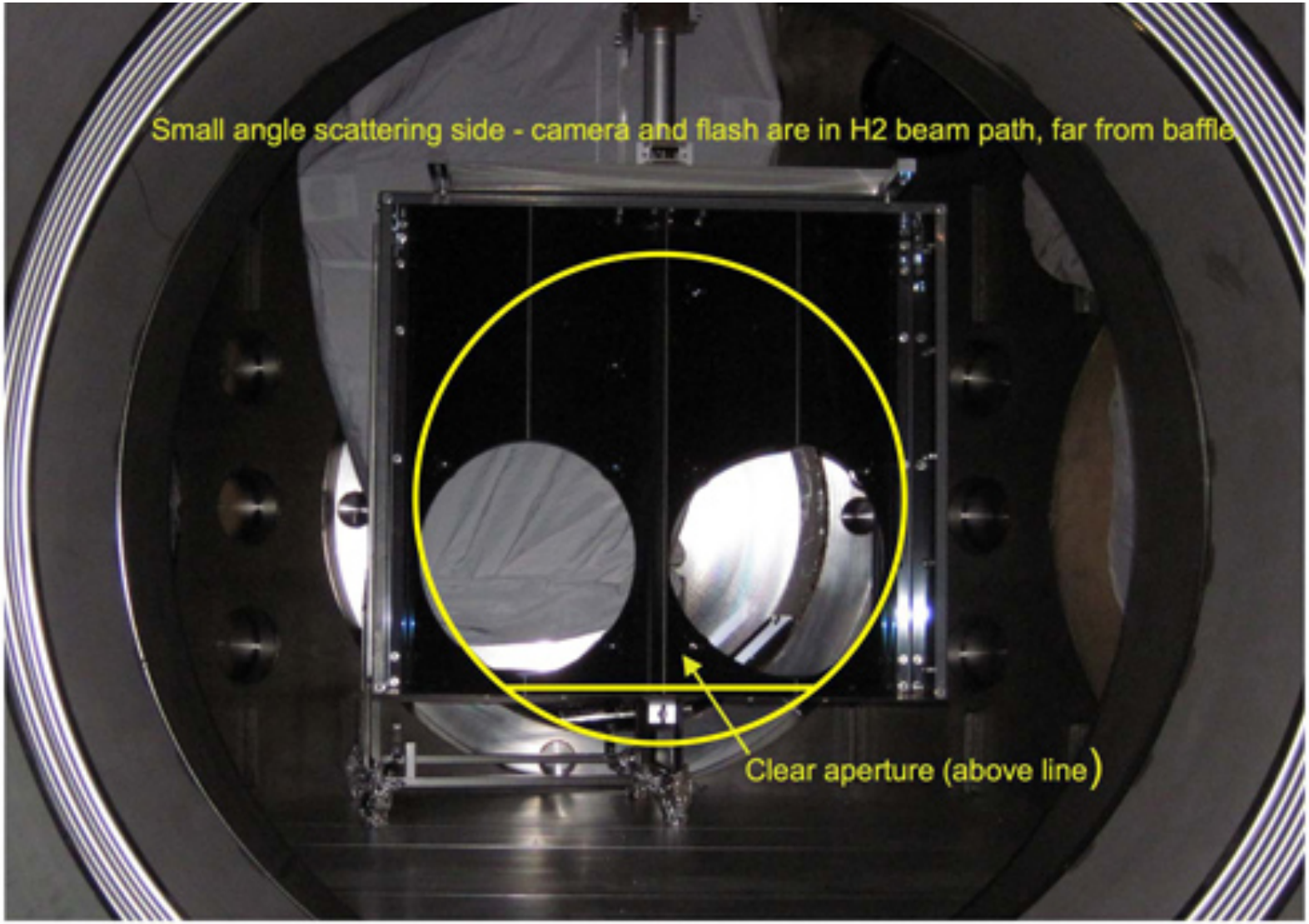


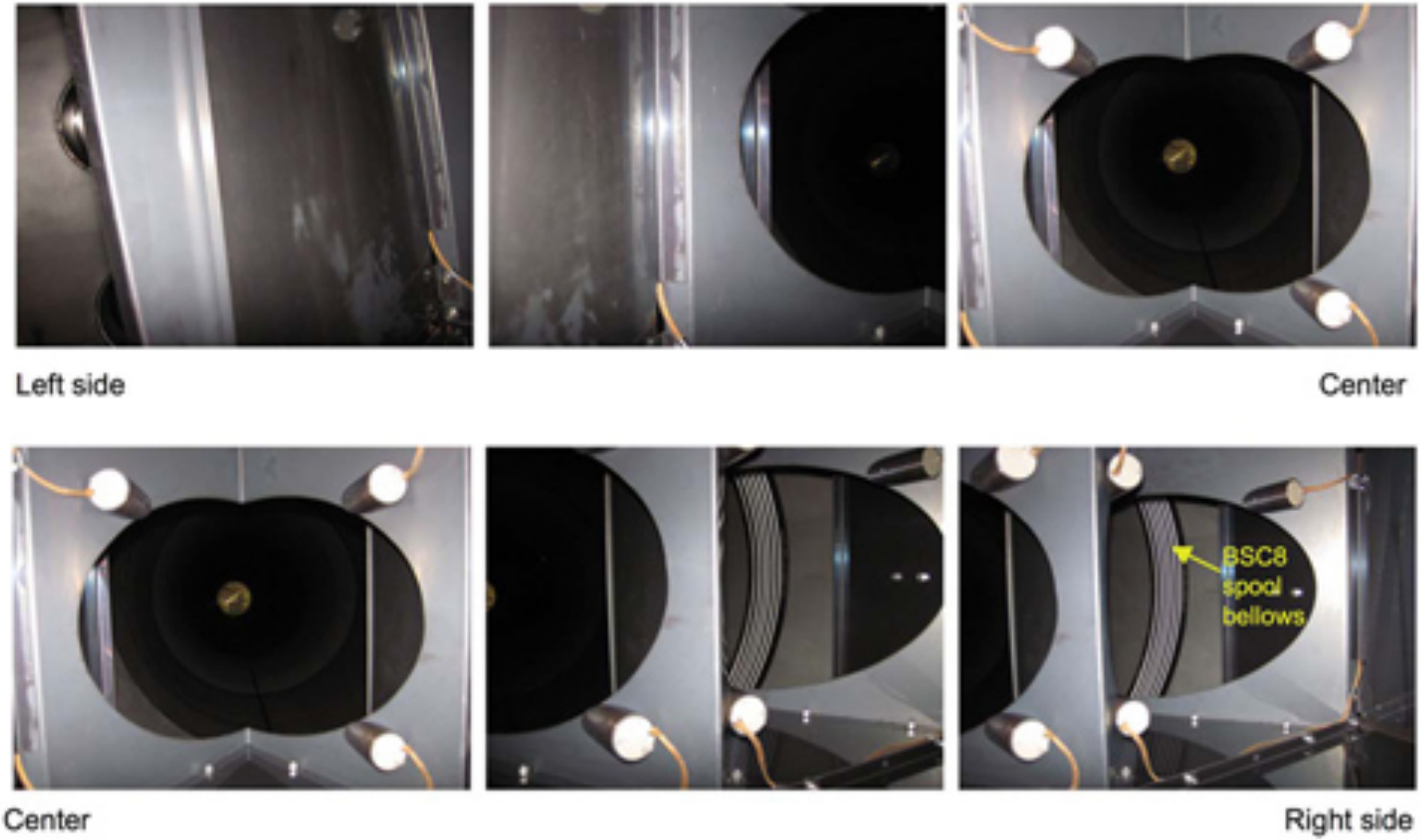
Figure 31: One-sided HAM Scraper Baffle



Distant optic view, baffle check (aLIGO, arm cavity-v1)



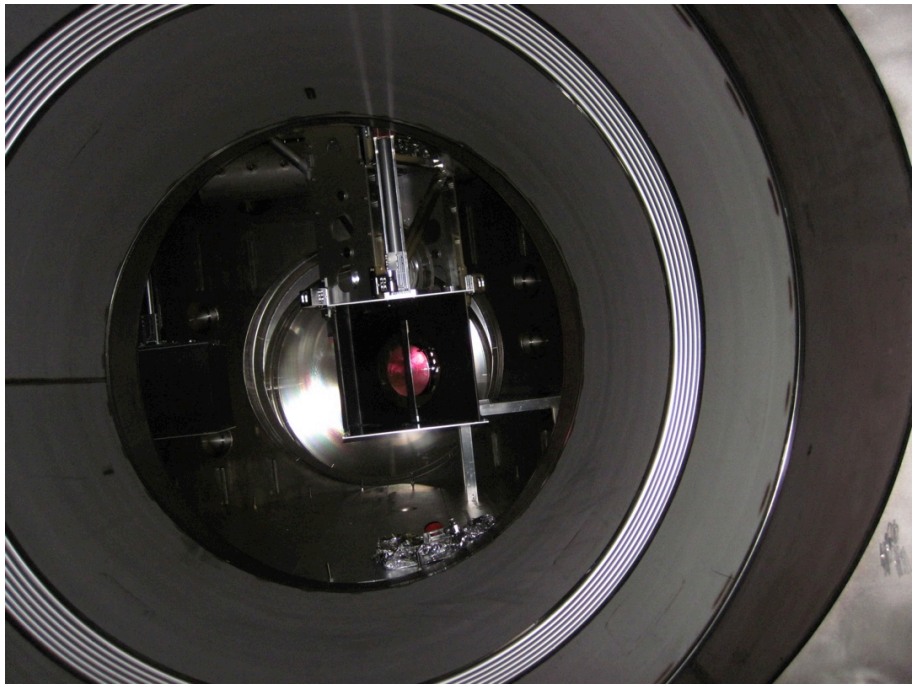
Beam spot view, baffle check (aLIGO arm cavity – v1)



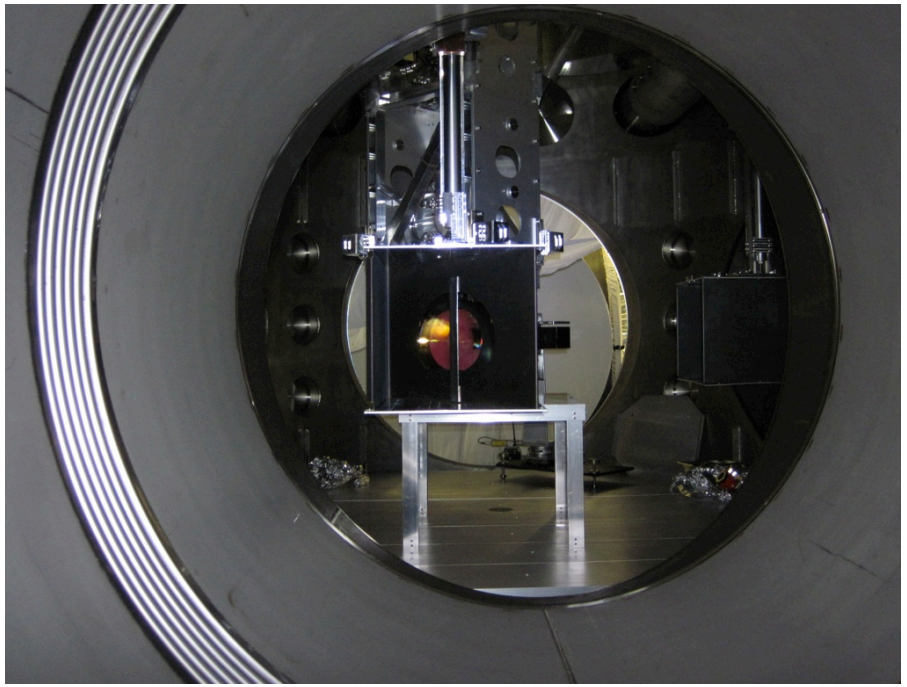
Beam spot view from back of ITM's

Looking towards beam splitter through ITM elliptical baffles

from ITMY



from ITMX



Beam spot view from beam splitter

Note bright reflection from ITM cage: we had not considered this – a baffle may be needed