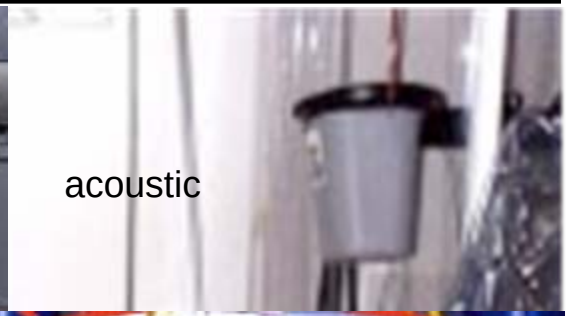
Environmental Coupling During S5

Robert Schofield (University of Oregon)

I. PEM injection overview
II. Acoustic/seismic coupling
III. Seismic upconversion
IV. Magnetic coupling
V. RF coupling
VI. S5 environmental coupling epochs
VII. High frequency PEM injections
VIII. Cost of suggested sensors for Hi-f

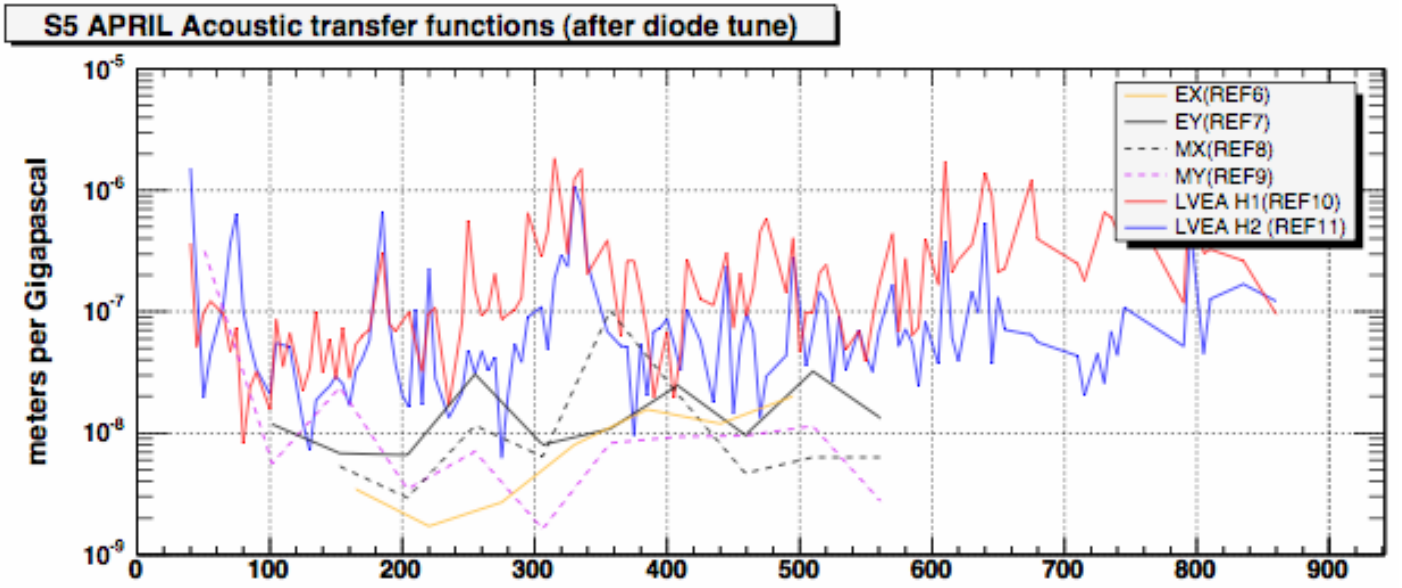
S5 PEM Injections

	LHO	LLO
Round 1:	Nov.-Dec. 2005	Dec. 2005
Round 2:	April-May 2006	Aug. 2006
Round 3:	October 2007	Oct. 2007

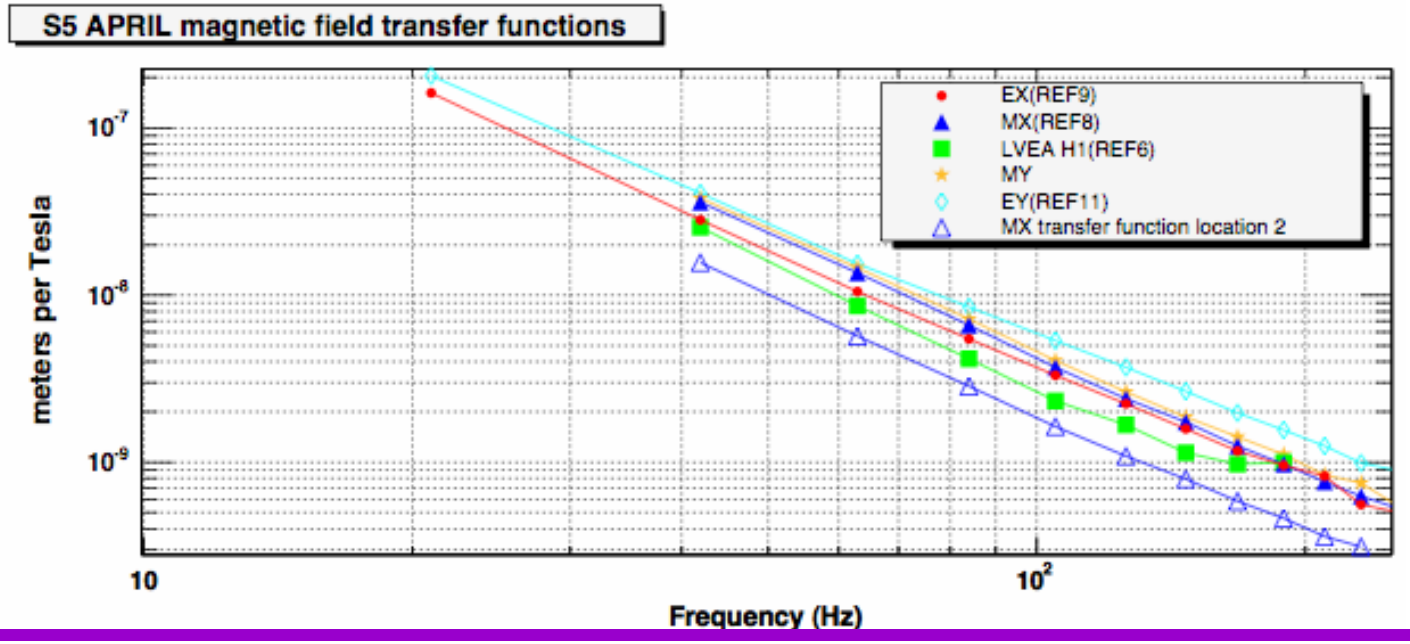


S5 PEM Injections: sample coupling functions

Acoustic



Magnetic



Limitations and successes of environmental coupling factors

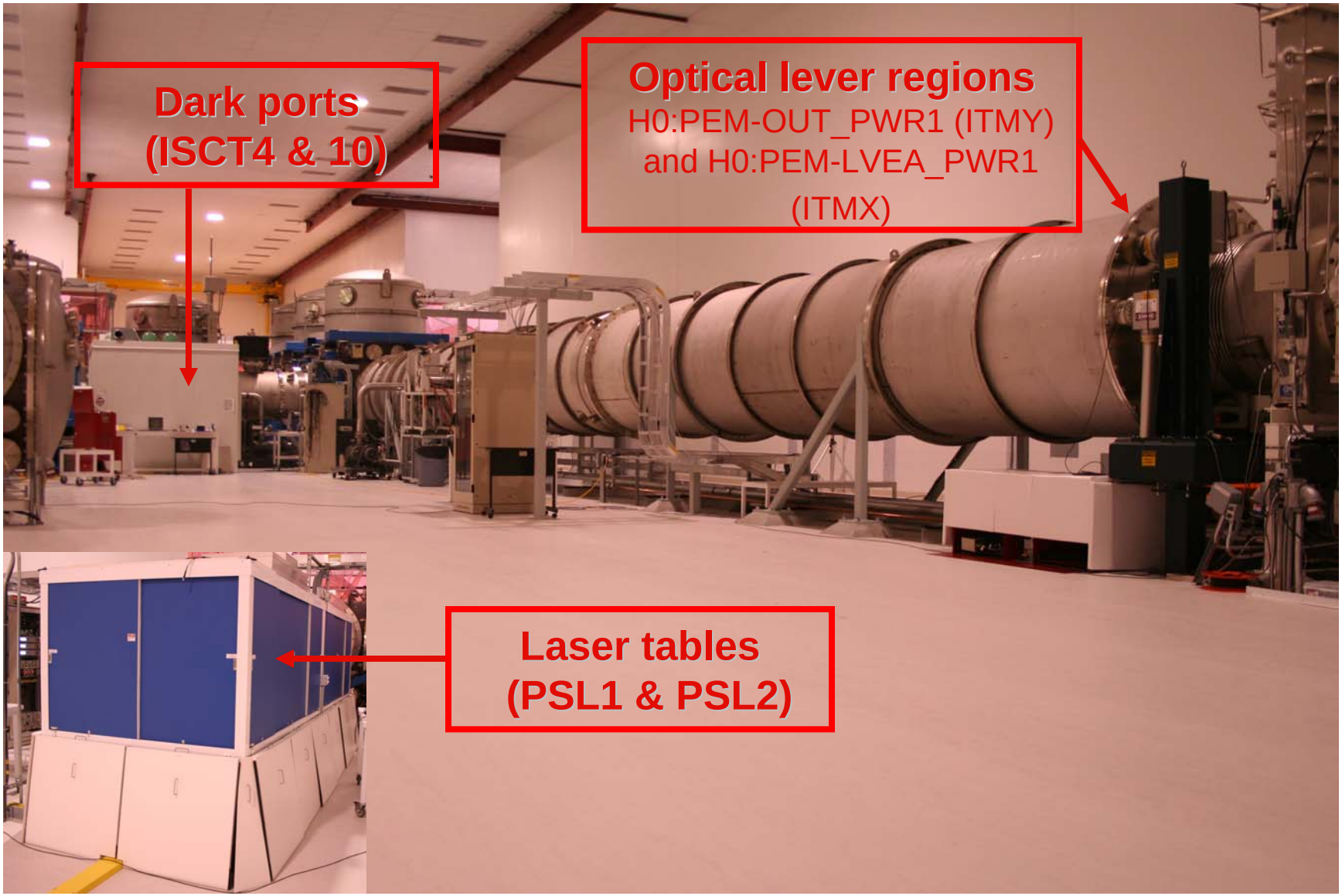
Limitations:

- Environmental source is closer to coupling site than to any sensor/no sensor near coupling site.
- Non-linear coupling
- Broken sensor channel
- Change in coupling

Successes:

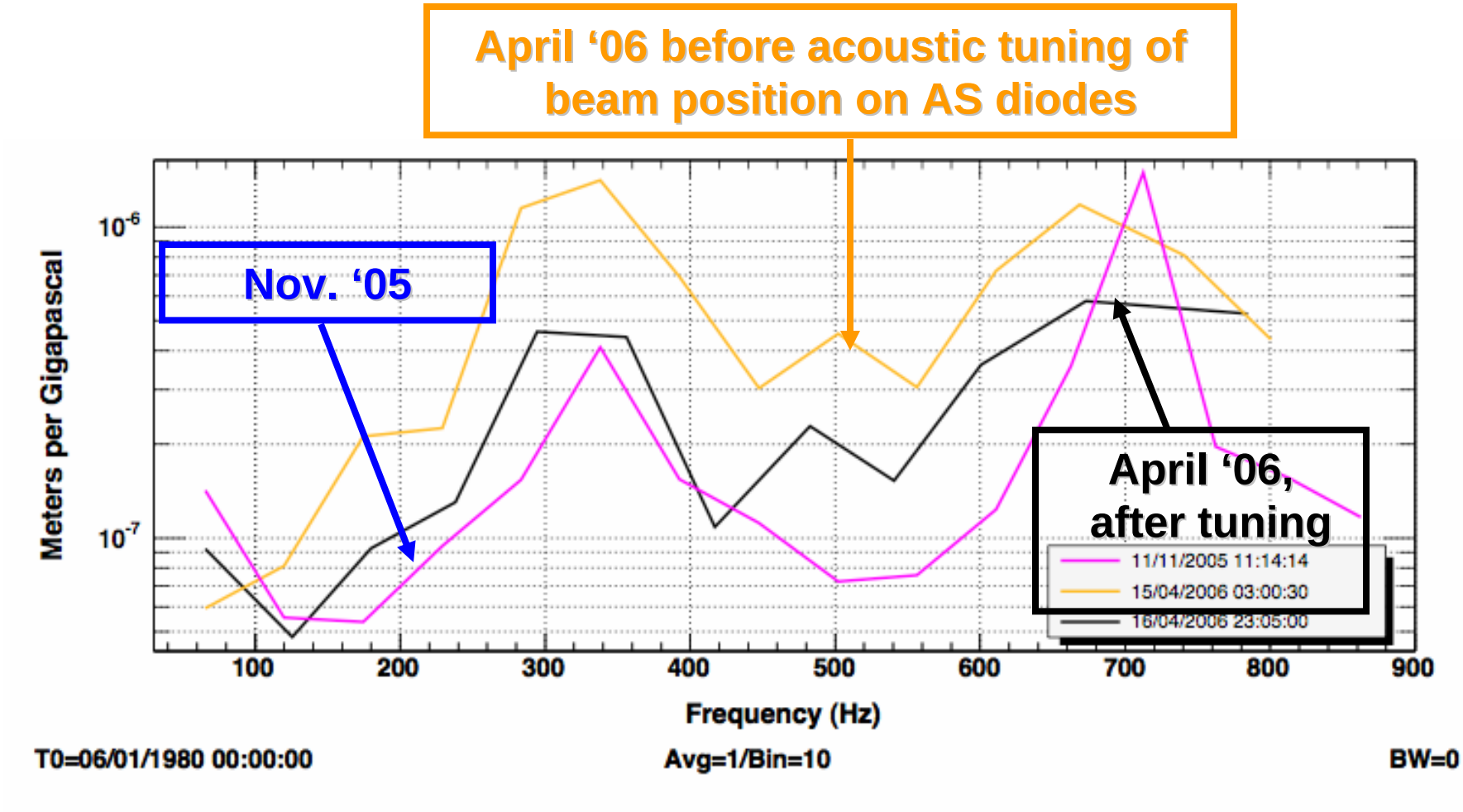
- Correctly predicted size of power grid events in DARM.
- Correctly predicted variation in 60 Hz H1 DARM peak with current in high-tension lines 2km from LHO.
- Correctly predicted size of magnetic features in DARM from rack magnetic fields, and other local sources.
- Correctly predicted size of many acoustic features in DARM from things such as PSL chillers.
- Correctly predicted the size of the famous airplane signal in DARM.

Main S5 LHO in-band acoustic/seismic coupling sites



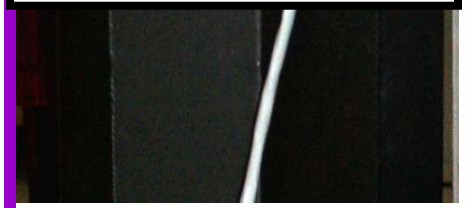
H1 acoustic coupling function variation

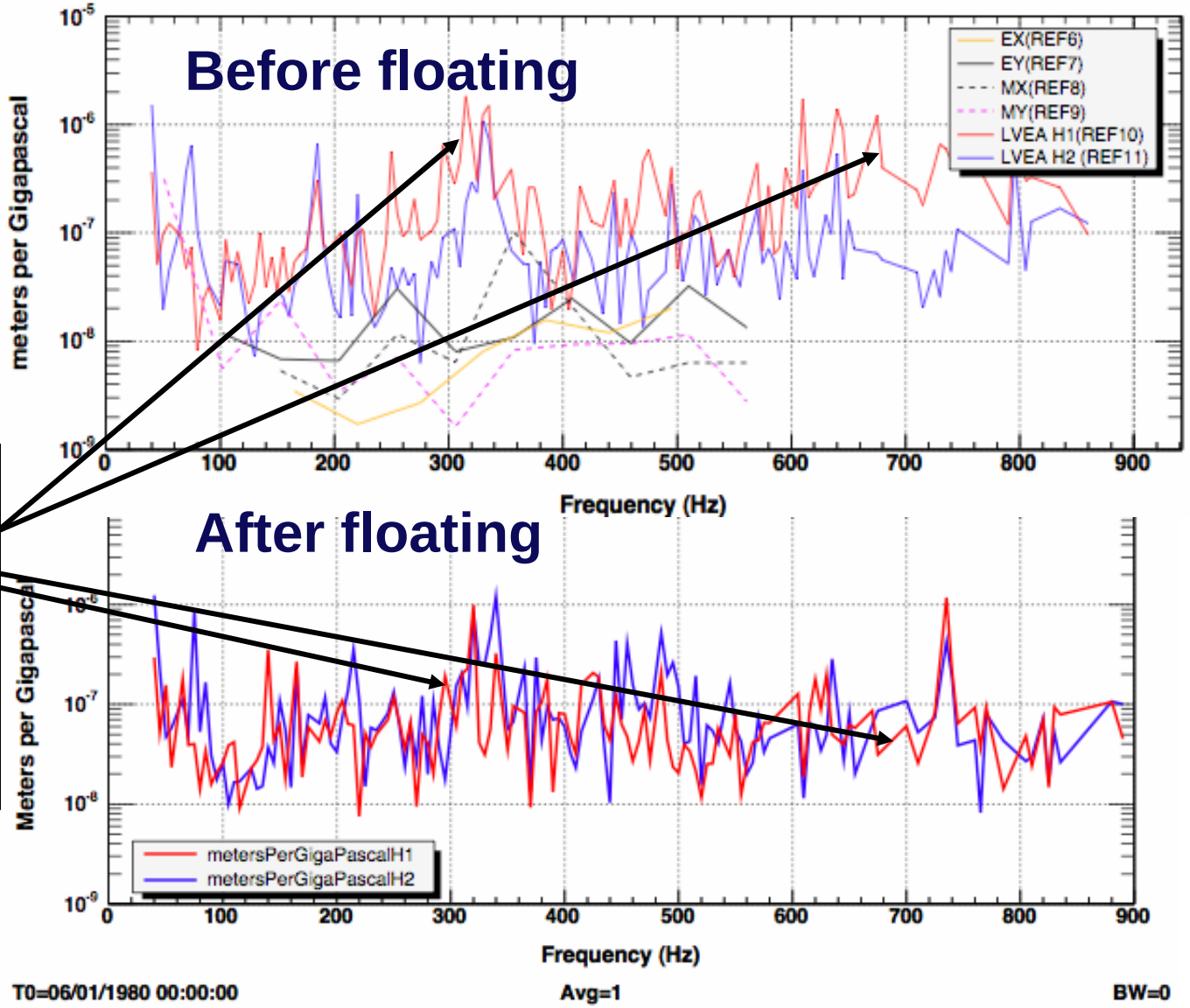
-this is the scale of variation that might not have been noticed



Reduction in H1 acoustic coupling from commissioning: “floating” of dark port

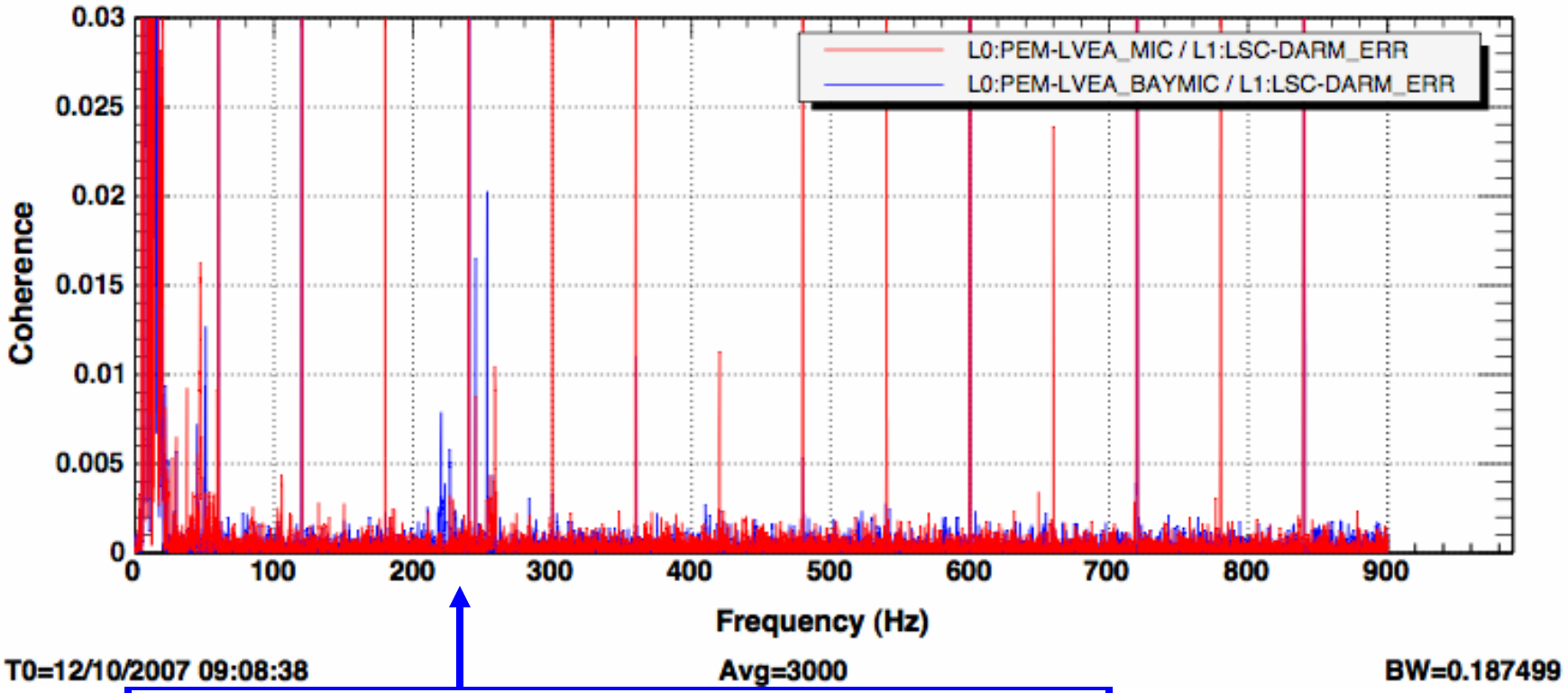
Red (H1) reduced to **blue (H2)** level or below





New acoustic coupling in LLO LVEA electronics bay

Red: LVEA_MIC, DARM Coherence



Blue: BAYMIC, DARM coherence

Summary of S5 acoustic coupling

H1 & H2:

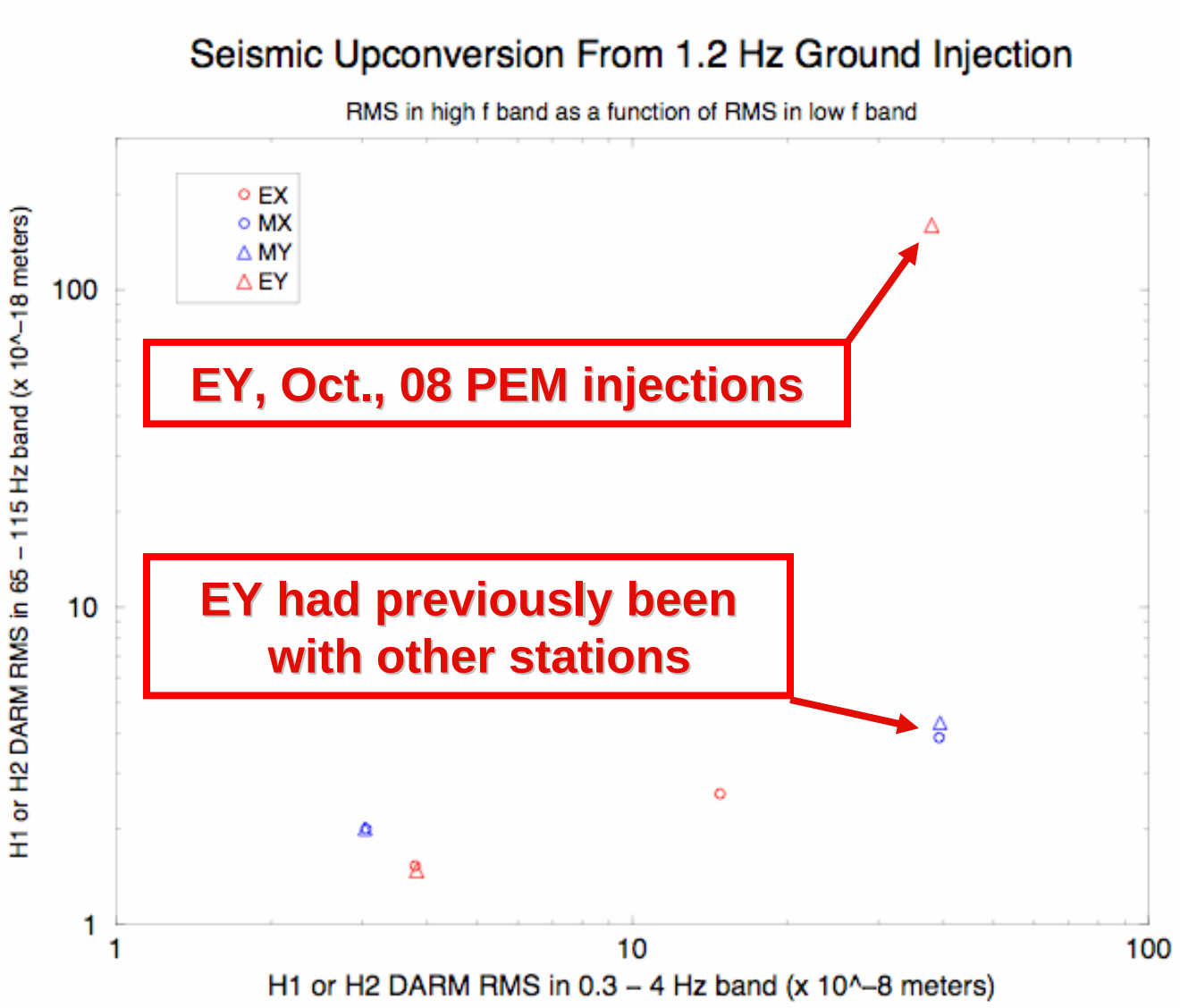
- Sound has to be 10-100 times louder than ambient sound background to appear in DARM, generally.
- Warning: there may be unknown periods of increased coupling.
- Main coupling sites (H1&H2): AS ports, ITM optical lever regions, PSLs. Sites are roughly equal. Thus acoustic coupling will not decrease much for AS diodes in vacuum.
- Important new ITM optical lever accelerometer channels, H0:PEM-OUT_PWR1 (H1 & H2 ITMY) and H0:PEM-LVEA_PWR1 (H1 & H2 ITMX).
- LVEA_MIC is the only sensor that reaches above 900 Hz. Ambient sound at 1200 Hz is predicted to produce displacement noise ~100 below DARM.

Summary of S5 acoustic coupling

L1:

- Similar to H1&H2: displacement noise from ambient sound level is 10 to 100 below DARM for the LVEA, end stations even lower.
- Acoustic coupling was detected in an electronics bay (LVEA) for the first time at the end of the run. Coupling level comparable to LVEA coupling.
- More sensitive to loud noises than H1&H2 - looses lock. As best as I could determine, the ITM optical lever regions are the worst coupling sites below a couple of hundred Hz.

Anomalous seismic upconversion at LHO EY

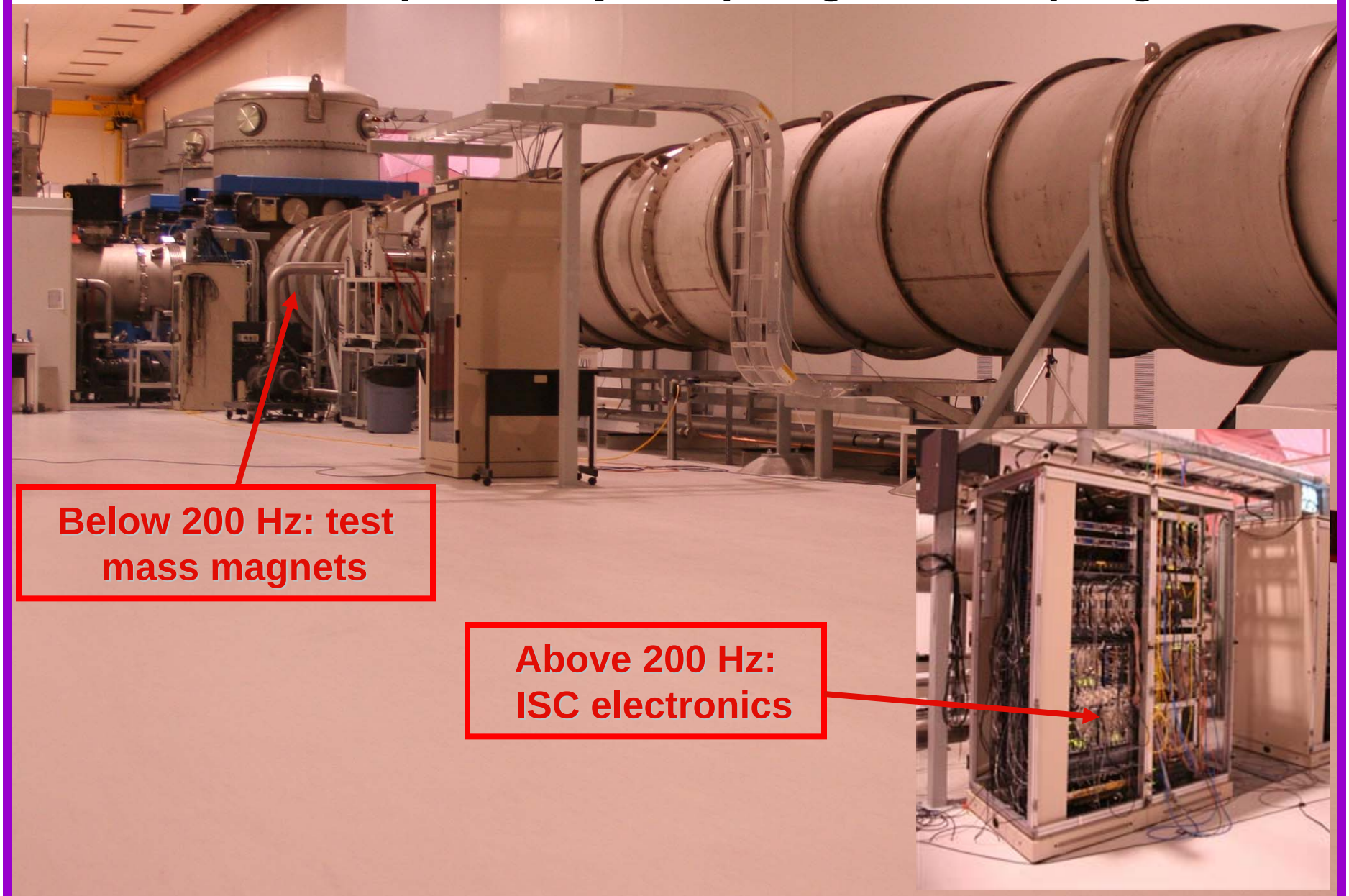


Summary of S5 low-f seismic coupling producing upconversion

H1 & H2:

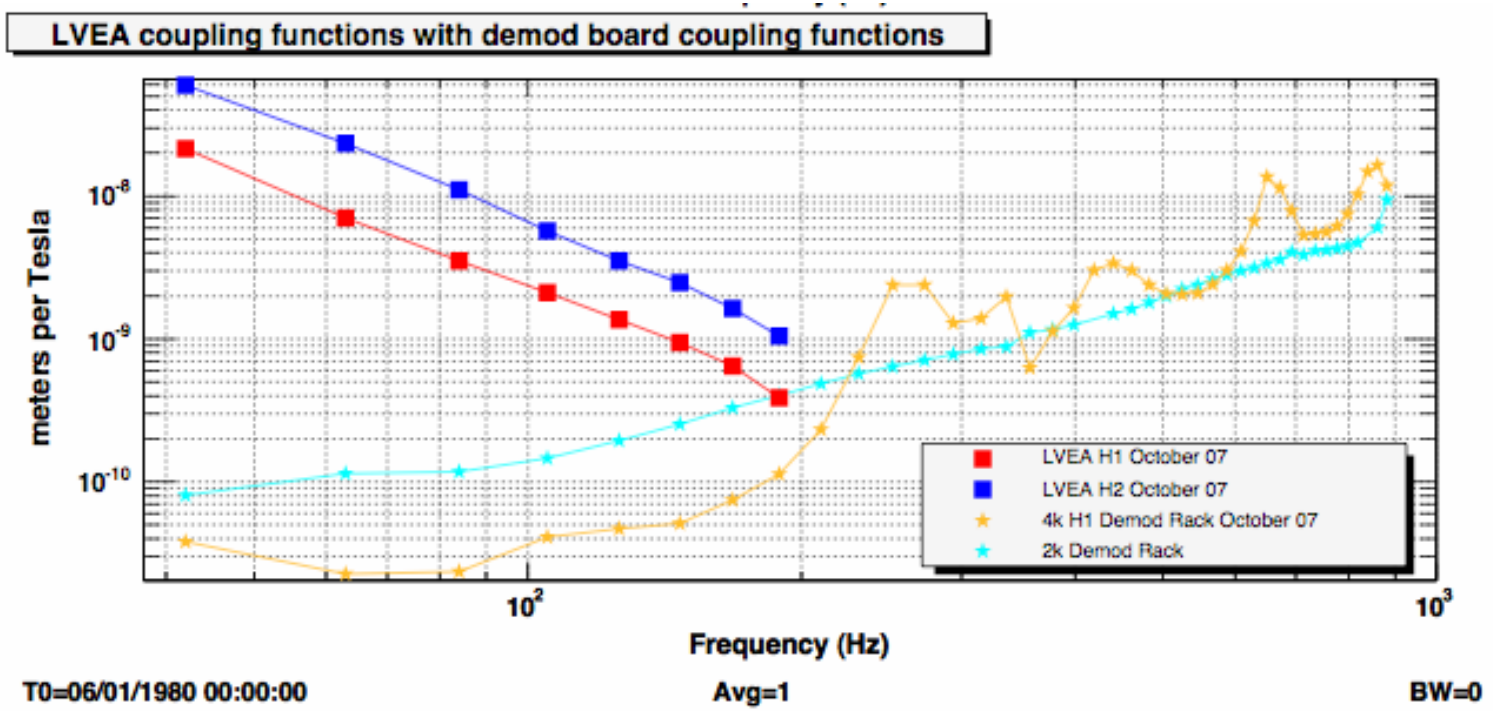
- **Close to the same at all four outstations (H1 & H2) for most of the run.**
- At EY (H1), changed late in run.

Main S5 LHO (and likely LLO) magnetic coupling sites



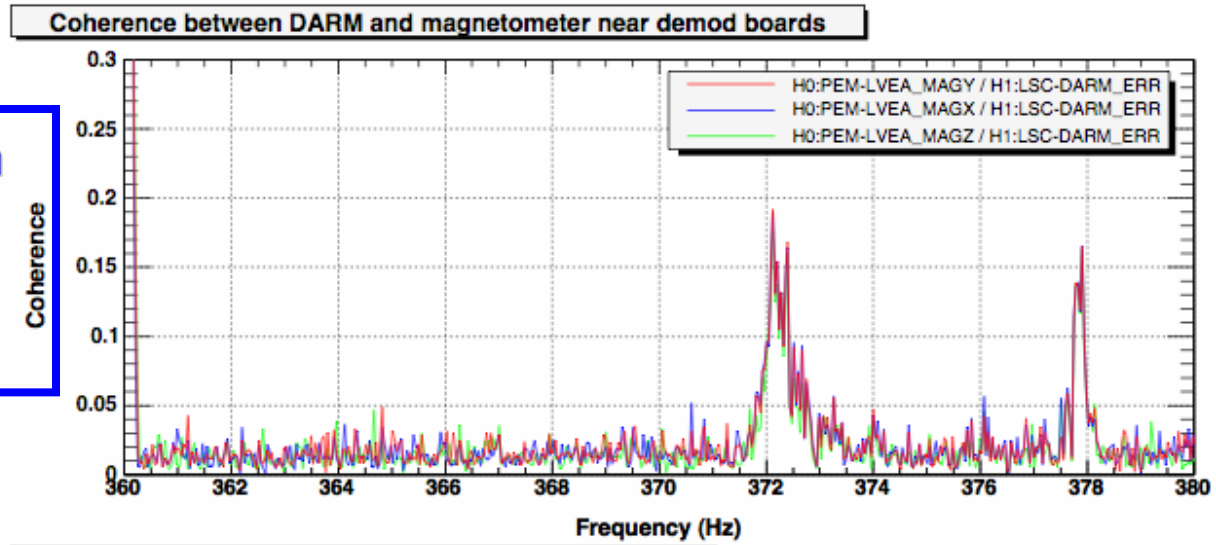
H1 magnetic transfer functions

Below 200 Hz from test mass magnets, above 200 Hz from coupling to ISC electronics



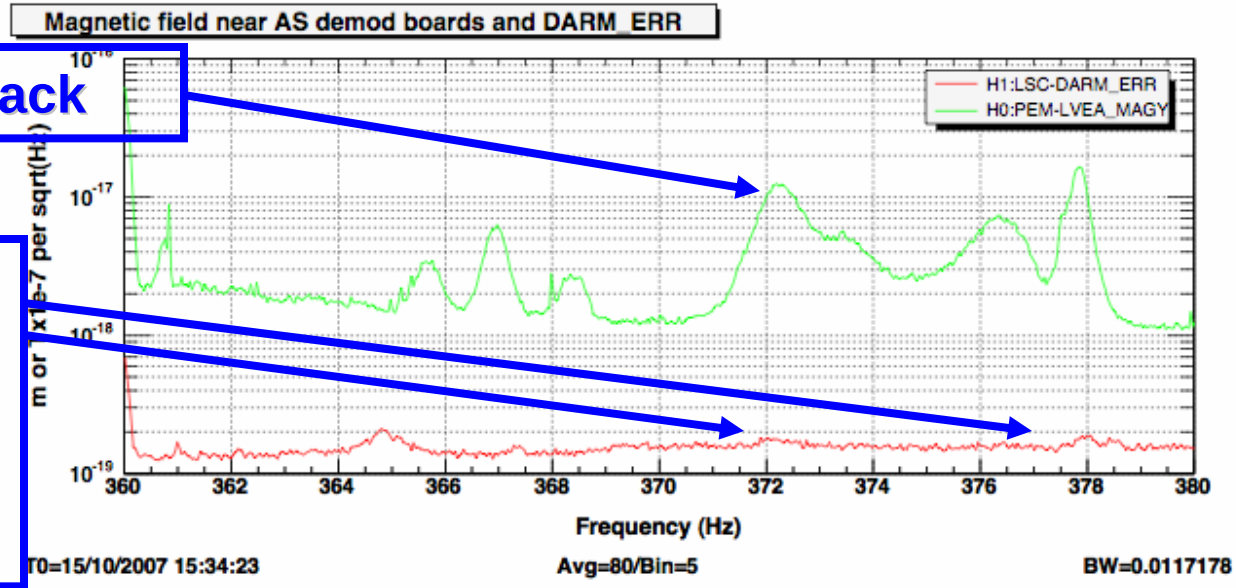
S5 features in DARM from rack magnetic fields

Coherence between DARM and magnetometer placed in rack

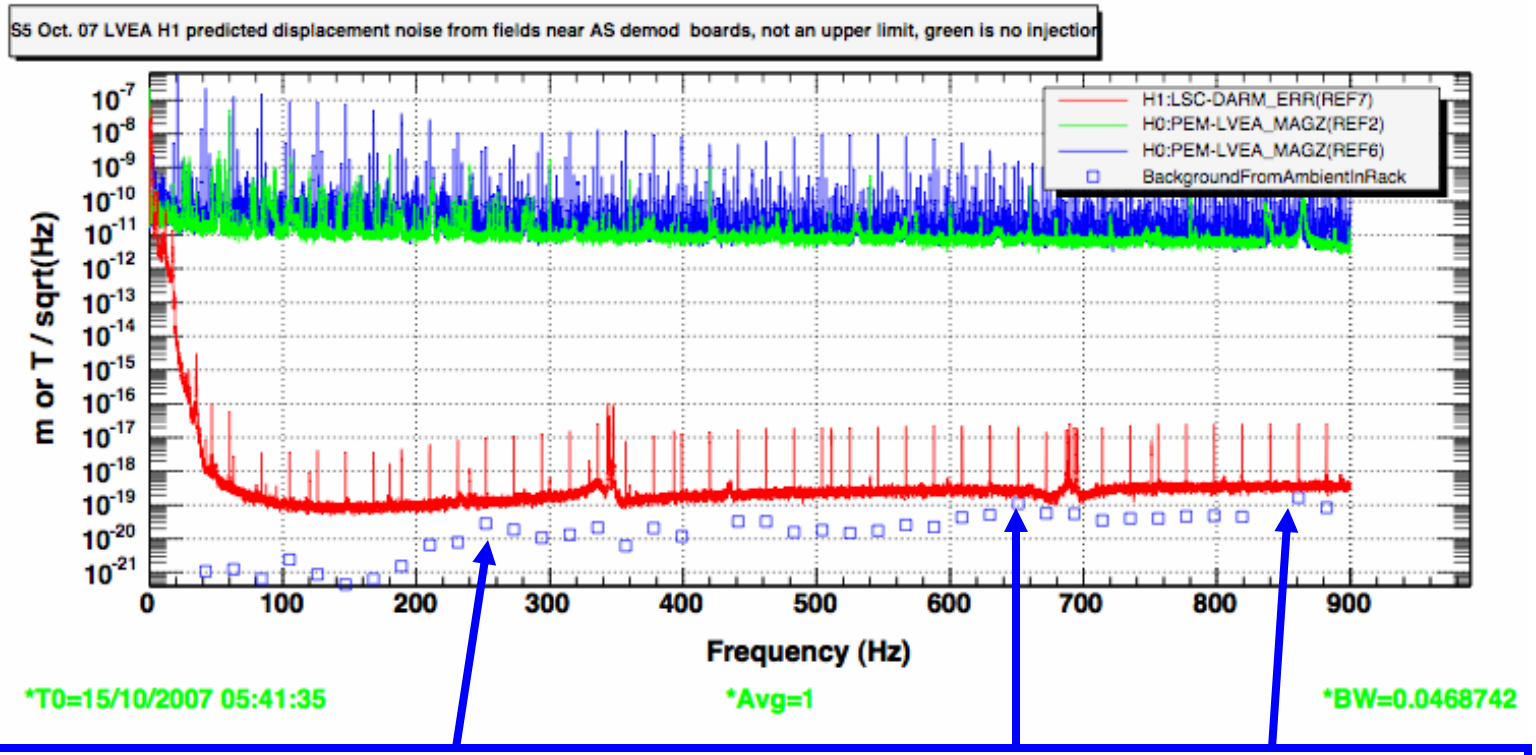


Magnetic field in rack

DARM with feature amplitude consistent with prediction from injections



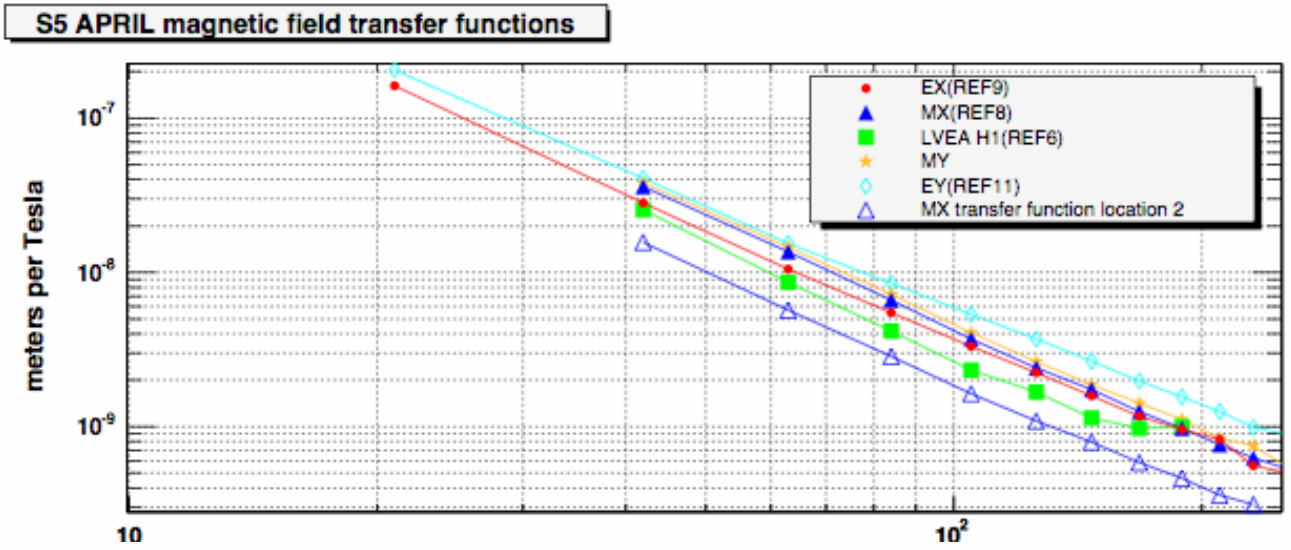
Magnetic field in racks was close to limiting H1 range. Rack magnetometers for S6?



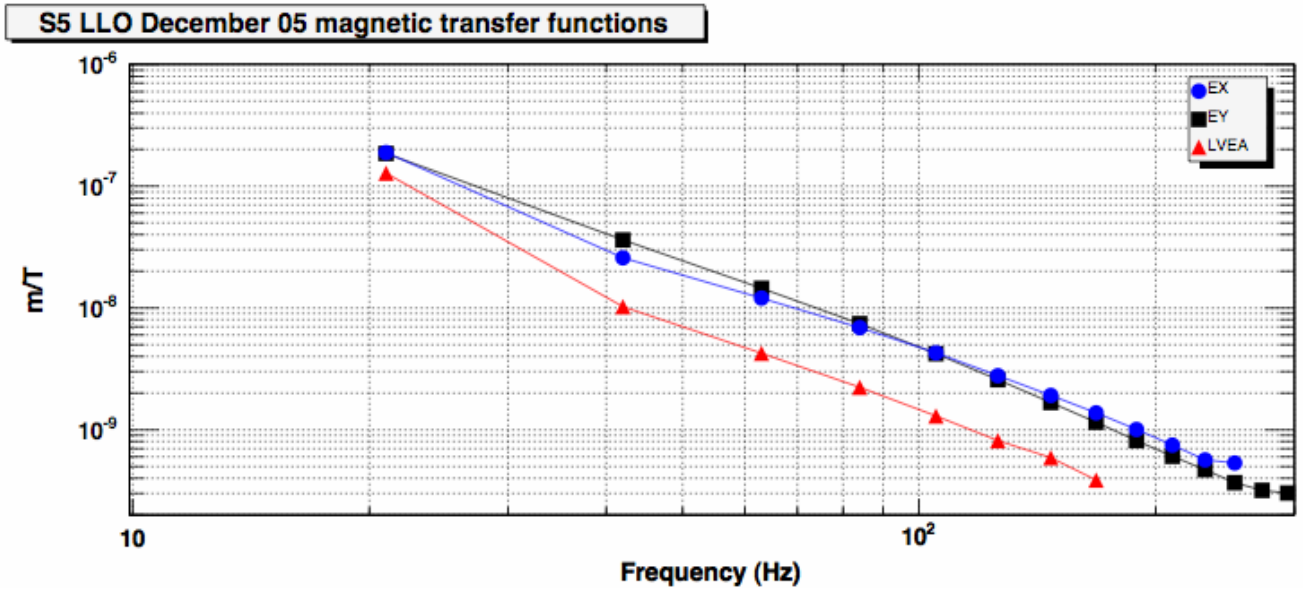
Predicted broad-band displacement noise from rack magnetic fields reaches within 2 of DARM floor

Magnetometer-DARM coupling factors are similar between sites

LHO

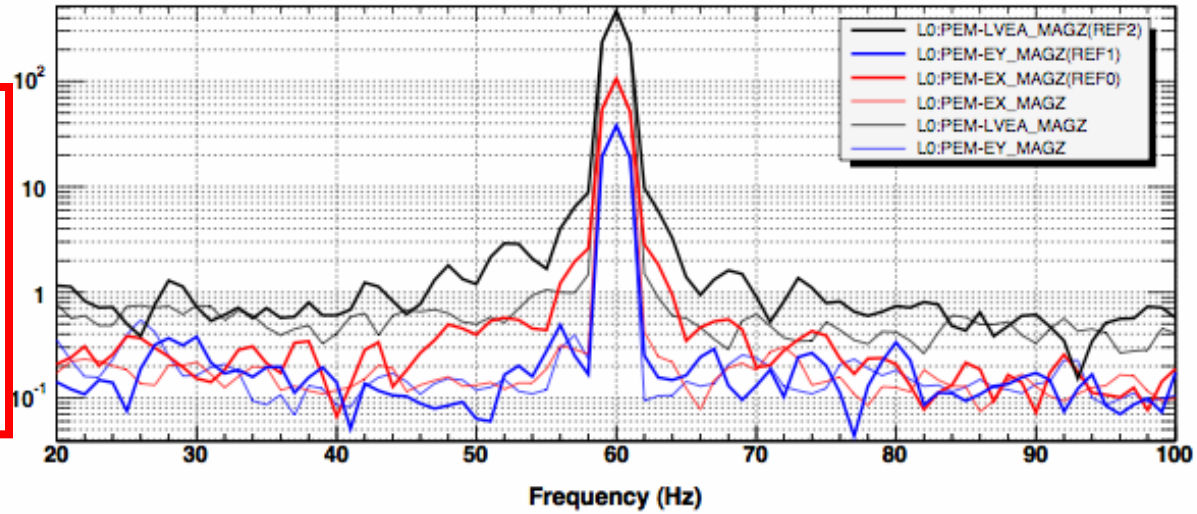


LLO



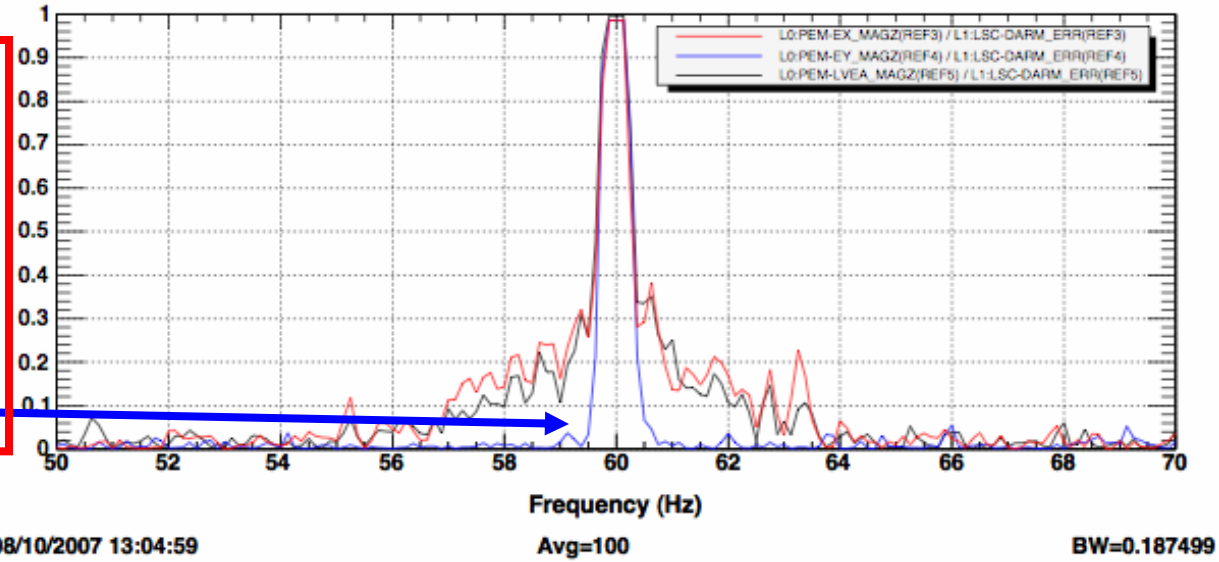
LLO crab-killing X-arm magnetic transients

Magnetometers, LVEA, EX, EY
Thick: during transient **Thin: between transients**



Coherence between DARM and magnetometers showing the long-term, crab killing effect of many X-arm transients

DARM - magnetometer coherence from repeated transients: No coherence with EY



T0=08/10/2007 13:04:59 Avg=100 BW=0.187499

Summary of S5 magnetic coupling

H1 & H2 :

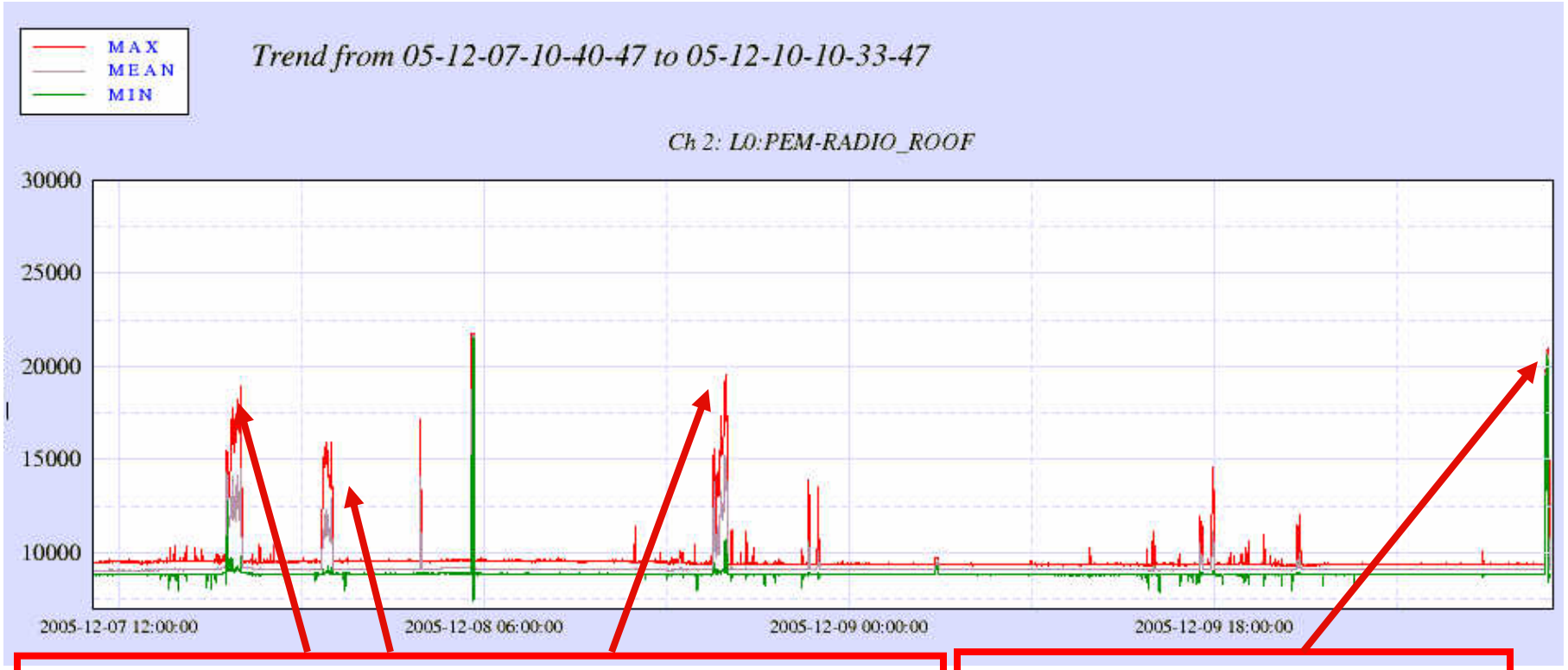
- Very little variation below 200 Hz (less than factor of 2)seen during run.
- Below 200 Hz the main coupling sites are the test mass magnets.
- Above 200 Hz, the strongest coupling sites are in the region of the AS demod boards, followed by the optic controllers.
- Some features in DARM are from magnetic fields inside the electronics racks.
- The coupling at the auxiliary channel demod boards appears to be nearly as bad as AS boards at low frequencies, so we might want to try some mitigation for eLIGO.
- Magnetometer at EY was mis-oriented between Sept. 4, 2007 and Oct 21, 2007.
- The 60 Hz peak in H1 & H2 DARM at level expected from magnetic coupling.
- 3 Hz sidebands of 60 Hz throughout run from the PSL chillers.

Summary of S5 magnetic coupling

L1:

- Coupling factors varied by less than 2 over the run.
- Coupling is within a factor of 4 of LHO.
- The 60 Hz peak in DARM is at a level expected from magnetic coupling of ambient fields.
- One set of 1 Hz side bands of 60 Hz was eliminated when remaining duct heater was turned off. A smaller set of 1 Hz sidebands are from the X&Y-arm TCS chillers, mainly X. From pulsed heat.
- Crab pulsar sensitivity is reduced by magnetic transients that appear simultaneously at the LVEA and EX, but not at EY.

Why radios are important veto channels



External sources, almost as loud as PEM injections, within a couple of MHz of 25 MHz (possibly Automatic Link Establishment)

RF PEM injections show up in DARM

Summary of S5 RF coupling

H1 & H2

- **Constant throughout S5**
- A peak in the radio channel needs to be a factor of about 100 above background before it shows up in DARM.

L1

- **Constant throughout S5**
- A peak in the radio channel needs to be a factor of about 100 above background before it shows up in DARM.
- Automatic Link Establishment signals may show up on DARM.

Environmental coupling epochs during S5

Bad sensor epochs not included, but new channels are.

H1

LVEA acoustic/seismic:

1. **Nov. 1 2005 - Apr. 14, 2006 Photo diode damage caused factor of 5 coupling variation in this period. Especially affects ISCT4_MIC and ISCT4_ACCX,Y,Z.**
2. **Apr. 14, 2006 - July 11 2006 Good running before addition of new channels.**
3. **July 11 2006 - Nov. 16, 2006 New channels at ITM optical levers (**H0:PEM-OUT_PWR1 (ITMY) and H0:PEM-LVEA_PWR1 (ITMX))
4. **Nov. 16 2006 - July 13 2007 ISCT4 floating reduced acoustic coupling in 300 and 700 Hz region by ~5, and reduced coupling of floor vibrations by about 10. Especially affects ISCT4_MIC and ISCT4_ACCX,Y,Z.**
5. **July 13 2007 - end of run Accelerometer added to HAM5 (**H0:GDS-TEST_32_1_12)

LVEA RF:

1. **Nov. 1 2005 - Jun. 11, 2006**
2. Jun. 11, 2006 - end of run **H1 radio channel added** H0:PEM-RADIO_LVEA_H1

Environmental coupling epochs during S5

Bad sensor epochs not included, but new sensors are.

H1(continued)

End stations acoustic/seismic:

1. **Nov. 1 2005 - Feb. 14, 2006**
2. **Feb. 14 2006 - end Coupling down by factor of 5 after transmitted port work. Especially affects BSC10_MIC, ACC and BSC9_MIC, ACC**
3. **?-end Seismic upconversion increase by >10 at EY. Affects EY_SEISX,Y,Z and DARM.**

H2

LVEA acoustic/seismic:

1. **Nov. 1 2005 - July 11, 2006**
2. **July 11 2006 - July 13, 2007 New channels at ITM optical levers (**H0:PEM-OUT_PWR1 (ITMY) and H0:PEM-LVEA_PWR1 (ITMX))
3. **July 13 2007 - July 18 2007 Accelerometer added to HAM5 (**H0:GDS-TEST_32_1_12)
4. **July 18 2007 - Aug. 15, 2007 Period of bad ISCT10 alignment. Especially affects ISCT10_MIC and ISCT10_ACCX,Y,Z.**
5. **Aug. 15 2007 - end**

Mid stations acoustic/seismic:

1. **Beginning - end**

Environmental coupling epochs during S5

bad sensor epochs not included

L1

LVEA acoustic/seismic:

1. **Beginning - April 28 2006 Before ISCT4 was isolated with rubber.**
2. **April 28 2006 - Aug. 22 2006 After ISCT4 on rubber. Especially affects ISCT4_MIC & _ACCX,Y,Z**
3. **Aug. 22 2006 - end Period of possible electronics bay coupling.** LVEA_BAYMIC important.

LVEA magnetic:

1. **Beginning - Aug. 22, 2006 Duct heater on, less sensitivity around 60 Hz**
2. **Aug. 22, 2006 - end Duct heater off. Affects LVEA_MAGX,Y,Z.**

End stations acoustic/seismic and magnetic:

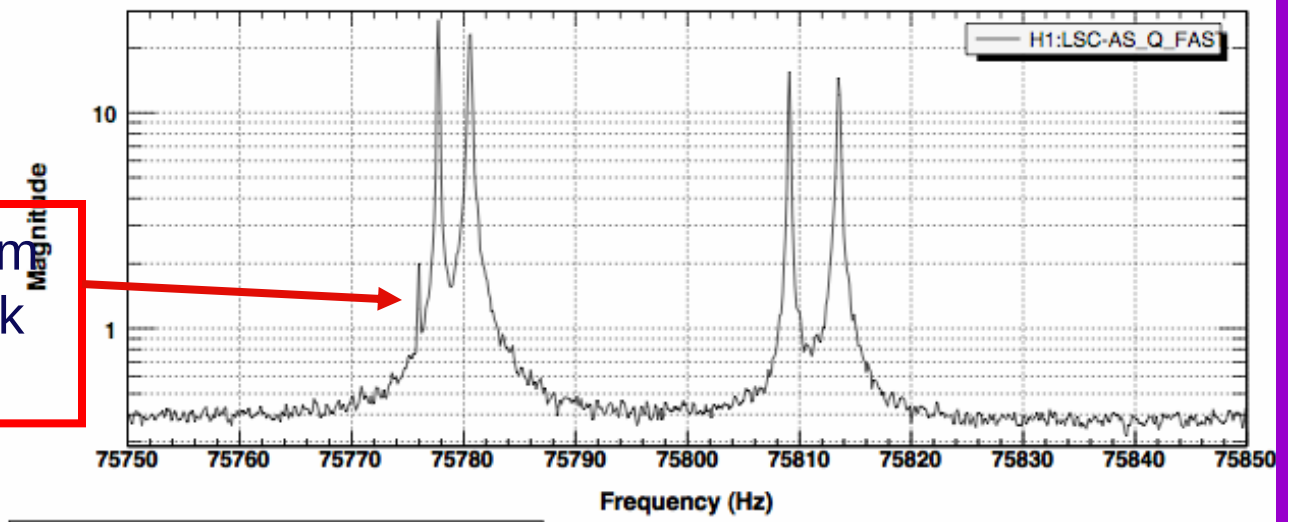
1. **Beginning-end**

New sensors added during S5

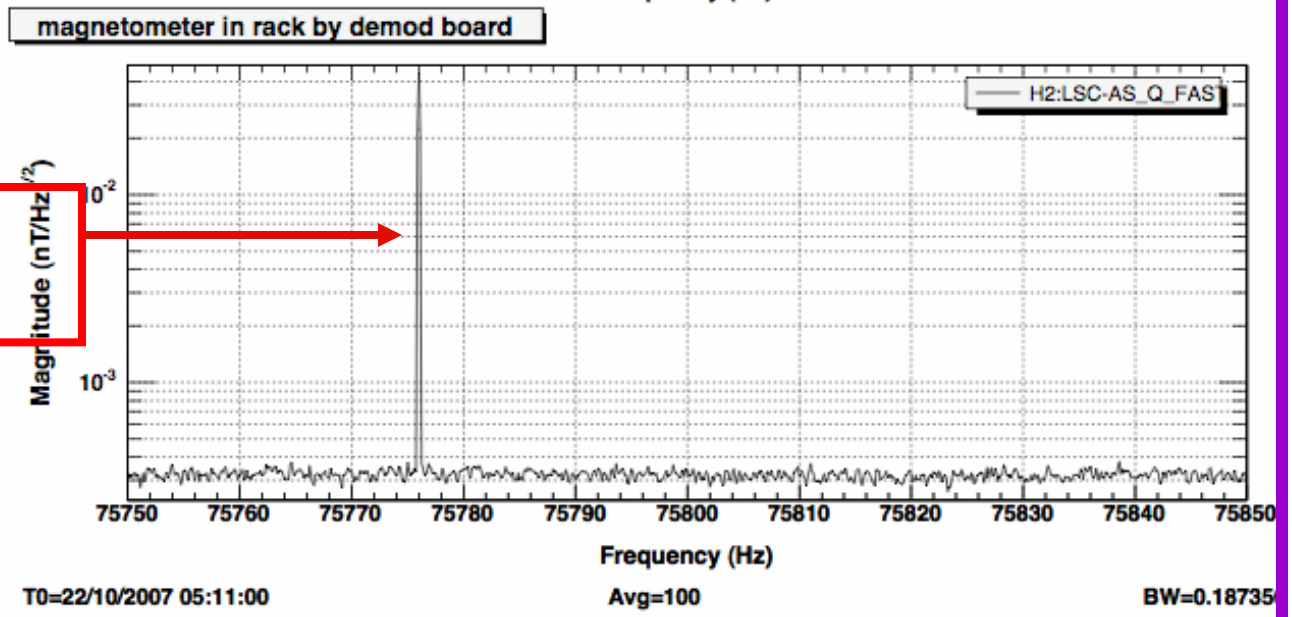
- H0:PEM-OUT_PWR1 (H1 and H2 ITMY optical lever accelerometers) July 11, 06
- H0:PEM-LVEA_PWR1 (H1 and H2 ITMX optical lever accelerometers) July 11, 06
- H0:GDS-TEST_32_1_12 accelerometer on HAM5-OMC flange July 13, 07
- H0:PEM-RADIO_LVEA_H1, Jun. 11, 06

HI-f magnetic coupling: rack magnetic peak in fast AS_Q at predicted level

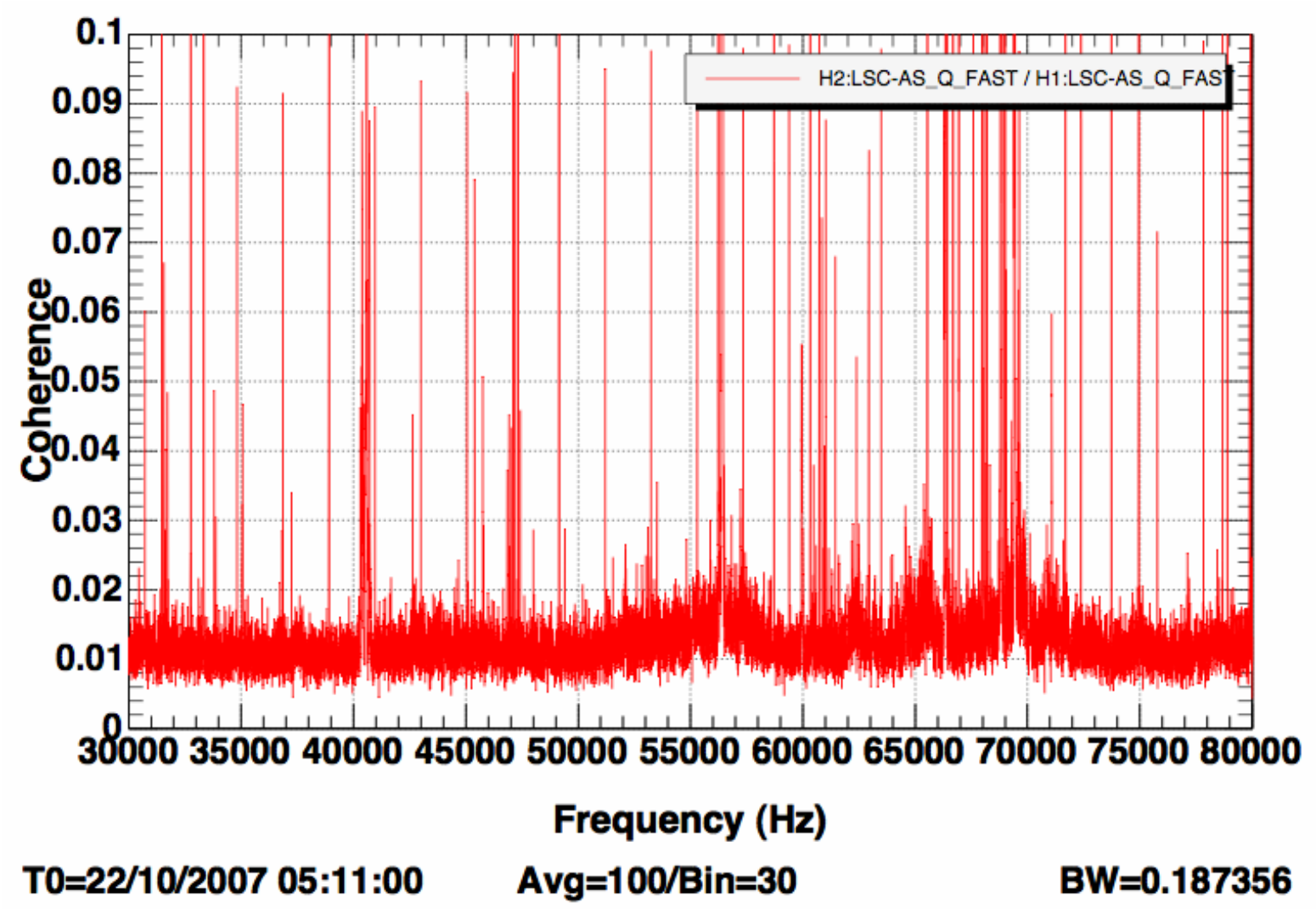
Peak in Hi-f AS_Q from magnetic field in rack



Peak in rack magnetometer



H1 hi-f AS_Q coherence with rack magnetometer



High frequency PEM injection summary

- Certain peaks in Hi-f AS_Q are produced by ambient magnetic fields
- Broad band magnetic noise was observed that should produce noise at up to 1/4 of the GW channel background.
- Ambient RF fields were observed that could produce noise above background in the GW channel, if they drifted into band.
- In contrast, ambient sound is expected to produce a noise floor that is several orders of magnitude below the hi-f GW channel floor.

What sensors would we want to have for Hi-f channel

- Magnetometers: 33 single axis (9 LHO LVEA, 6 LLO LVEA, 3 at each outstation), $330,000, or make them
- Microphones: (2 LVEA, 1 each outstation), $20,000
- Radio receivers: 1 each site, no extra cost
- Channels: 44 (mostly 2048)