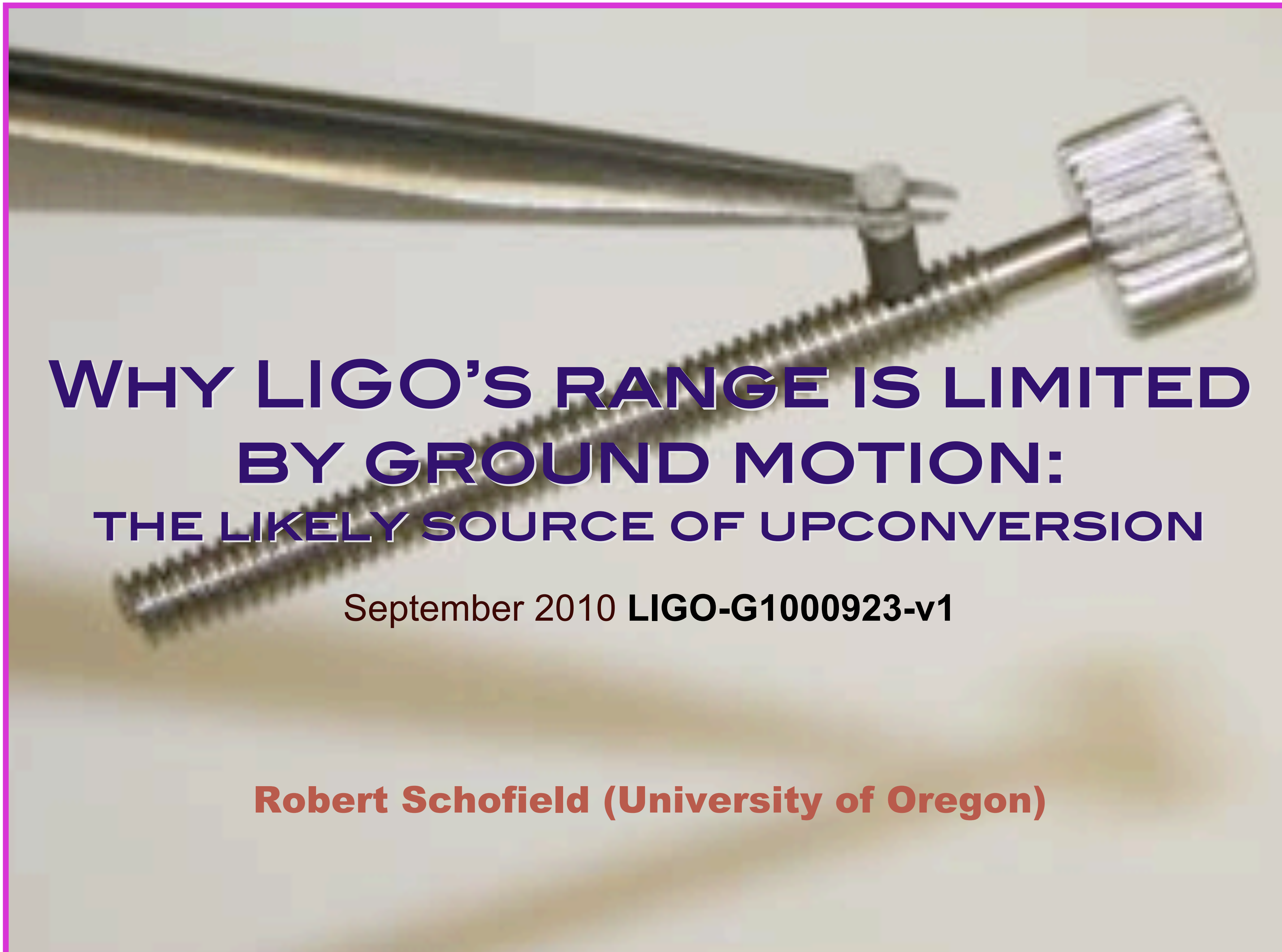


Why LIGO's range is limited by ground motion:
the likely source of upconversion

September 2010 **LIGO-G1000923-v1**

Robert Schofield (University of Oregon)

LHO upconversion before and after test mass magnet swap

and predicted PAM magnet forces

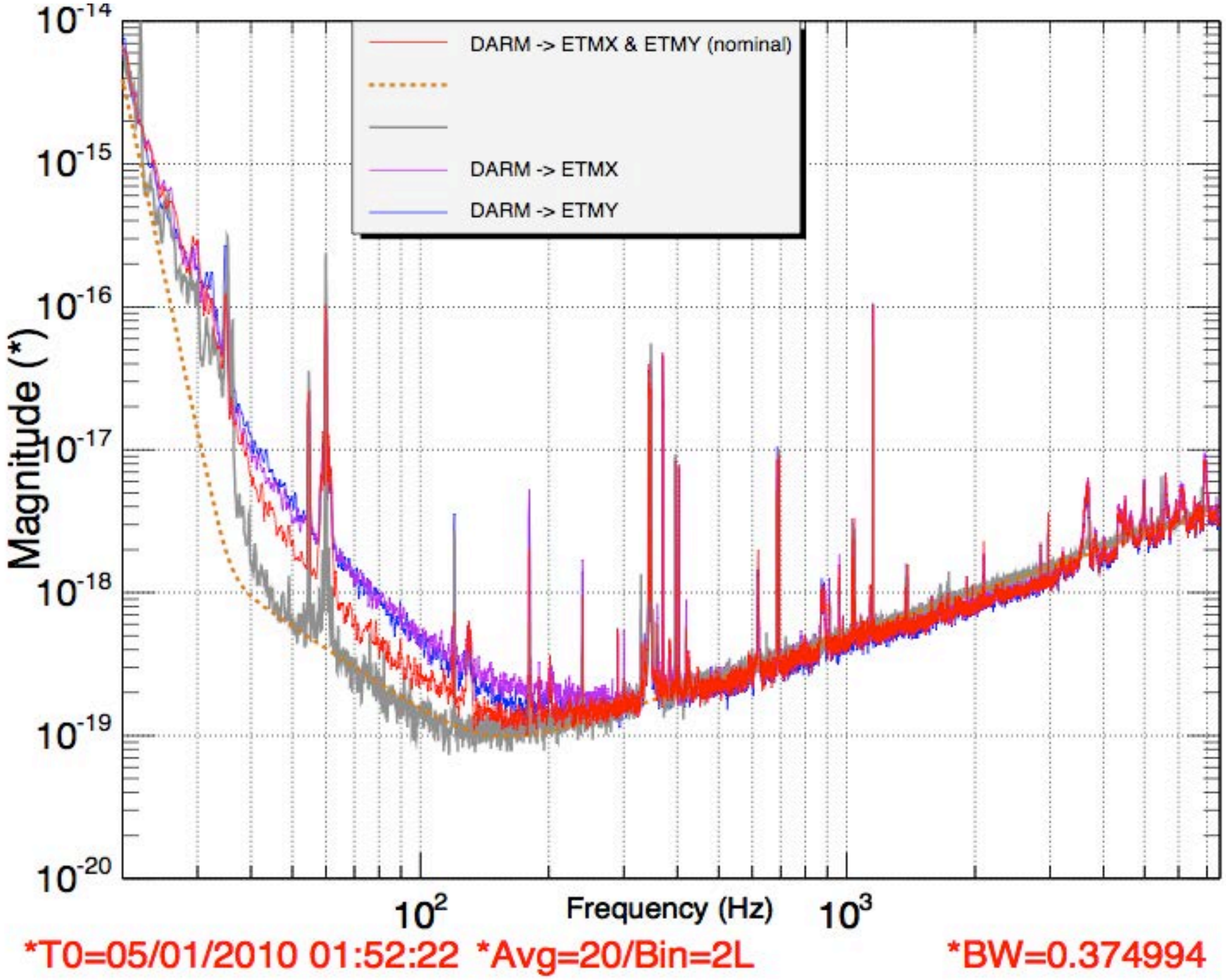
Test mass	Upconversion noise fit to A/f^4: pre-swap A	recent A	ratio	Predicted PAM magnet forces: before	after	ratio
ETMX	3.8e-12	b 5.6e-12	1.48	12	8.2	0.7
ETMX		a 6.5e-12	1.72			
ETMY	1.2e-11	c 1.2e-11	1.01	14	8.4	0.6
ETMY		b 1.1e-11	0.90			
ETMY		a 1.3e-11	1.06			
ITMX	3.5e-12	6.2e-12	1.76	24	4.4	0.2
ITMY	7.1e-12	5.3e-12	0.74	49	26	0.5

To test upconversion from individual test masses, directed LSC control to each test mass using Rana's resonant gain technique.

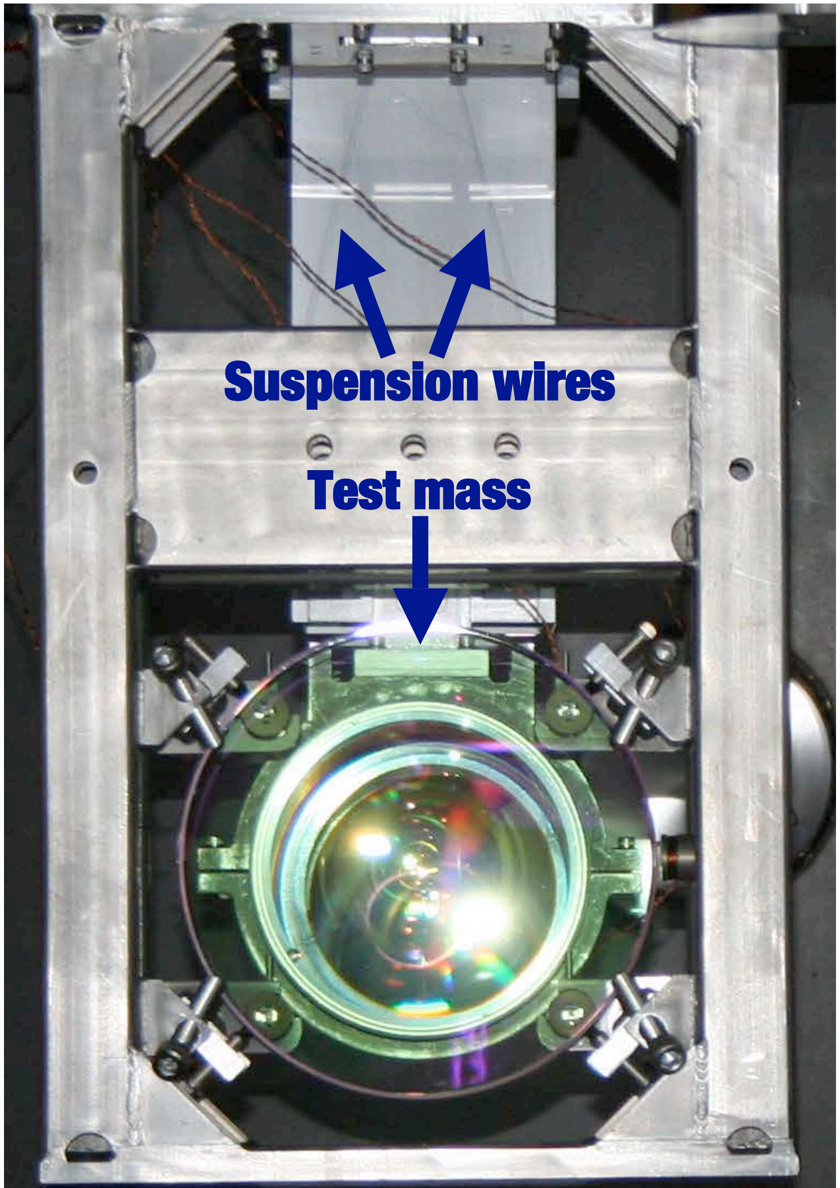
Take home message: TM magnet swap didn't reduce upconversion and no evidence that switching PAM magnets would have helped.

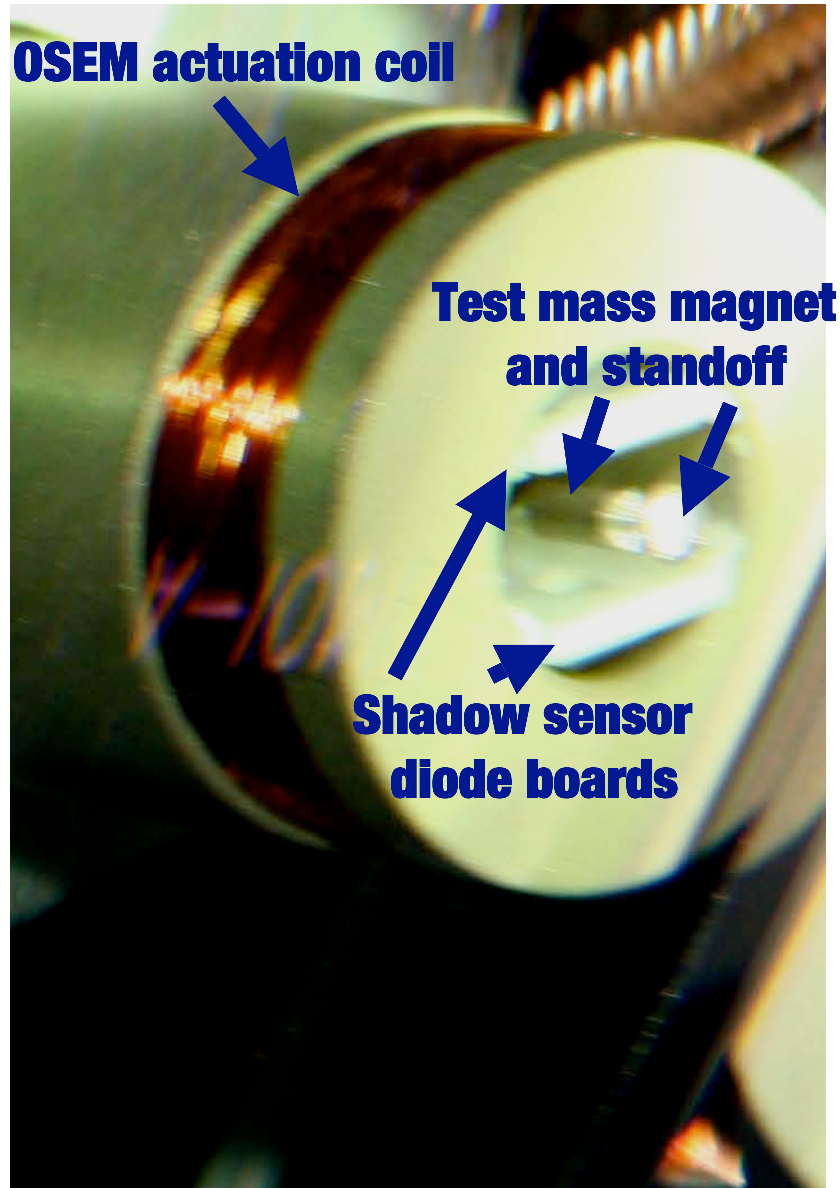
LLO results also indicate that PAM magnets did not dominate

At LLO, Test mass magnets were swapped on ETMY and ETMX and PAM magnets were swapped on ETMY. Post-swap upconversion same from each optic.



Mechanisms other than Barkhausen?



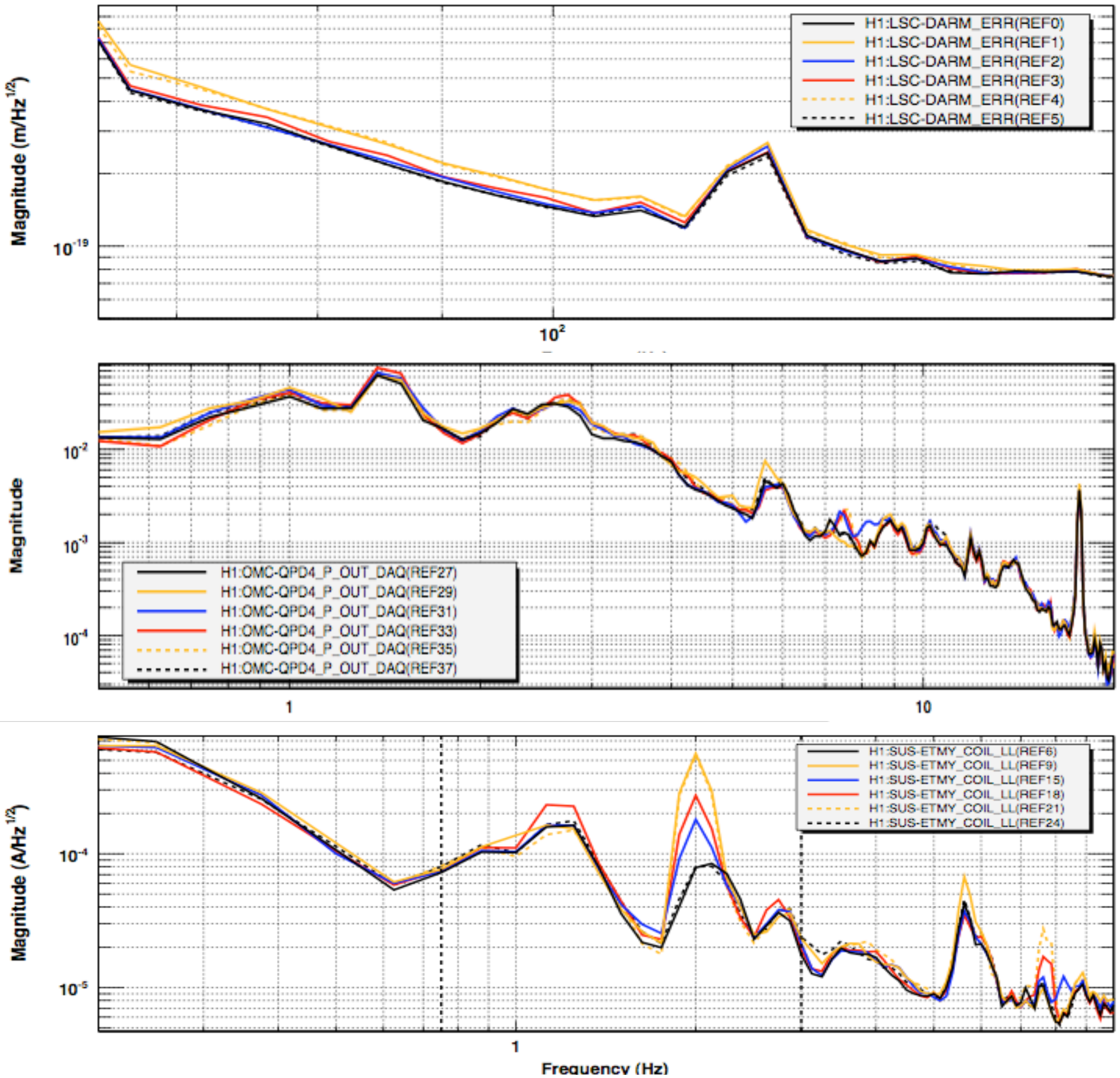


Upconversion goes with coil current not beam jitter

DARM upconversion region

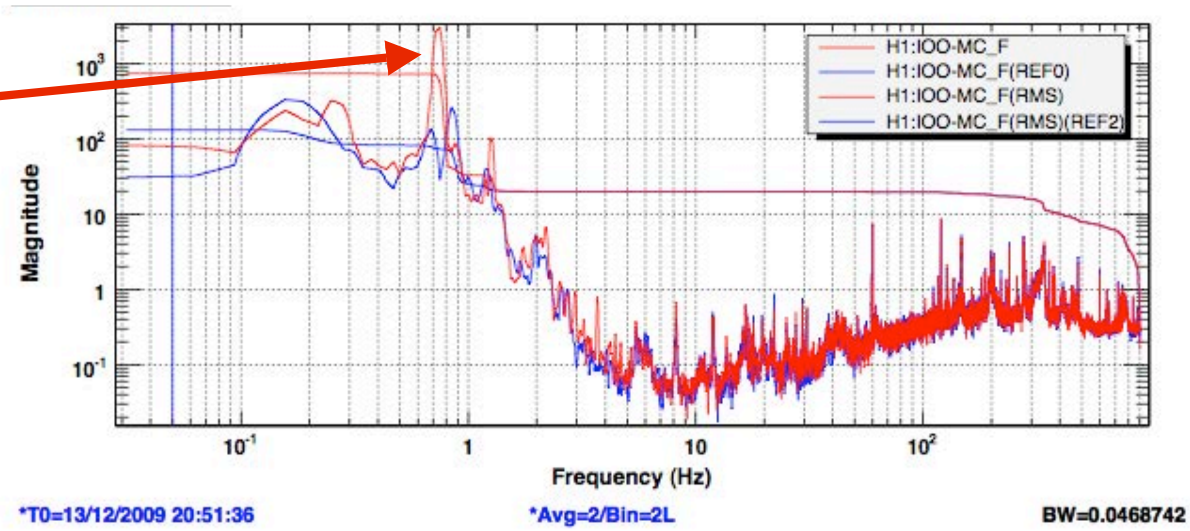
Low f beam jitter from OMC quad diodes (pitch)

Low f coil current

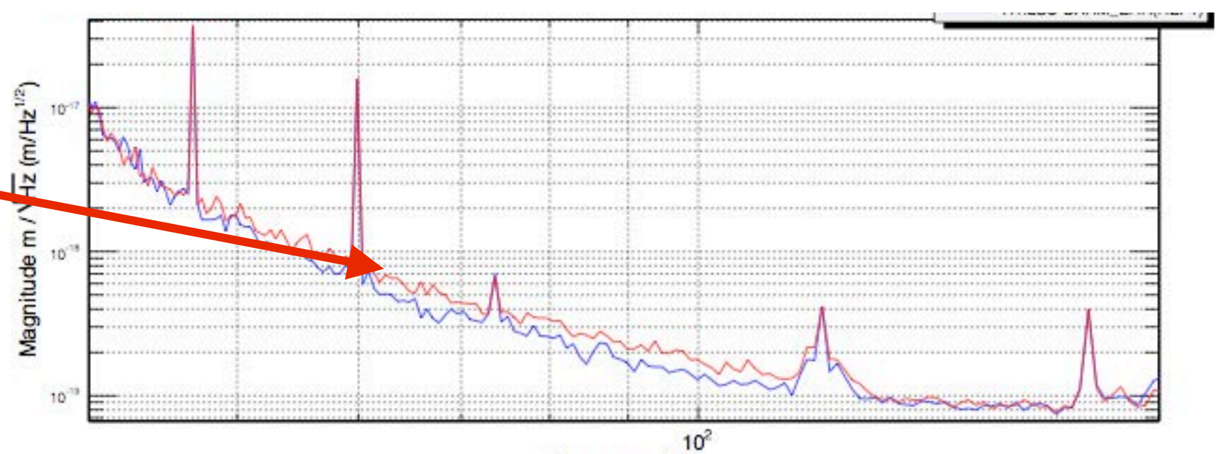


Upconversion goes with coil current not test mass motion

100 fold increase in common mode motion of test masses



Leads to small increase in upconversion predicted from small increase in coil current due to angular damping

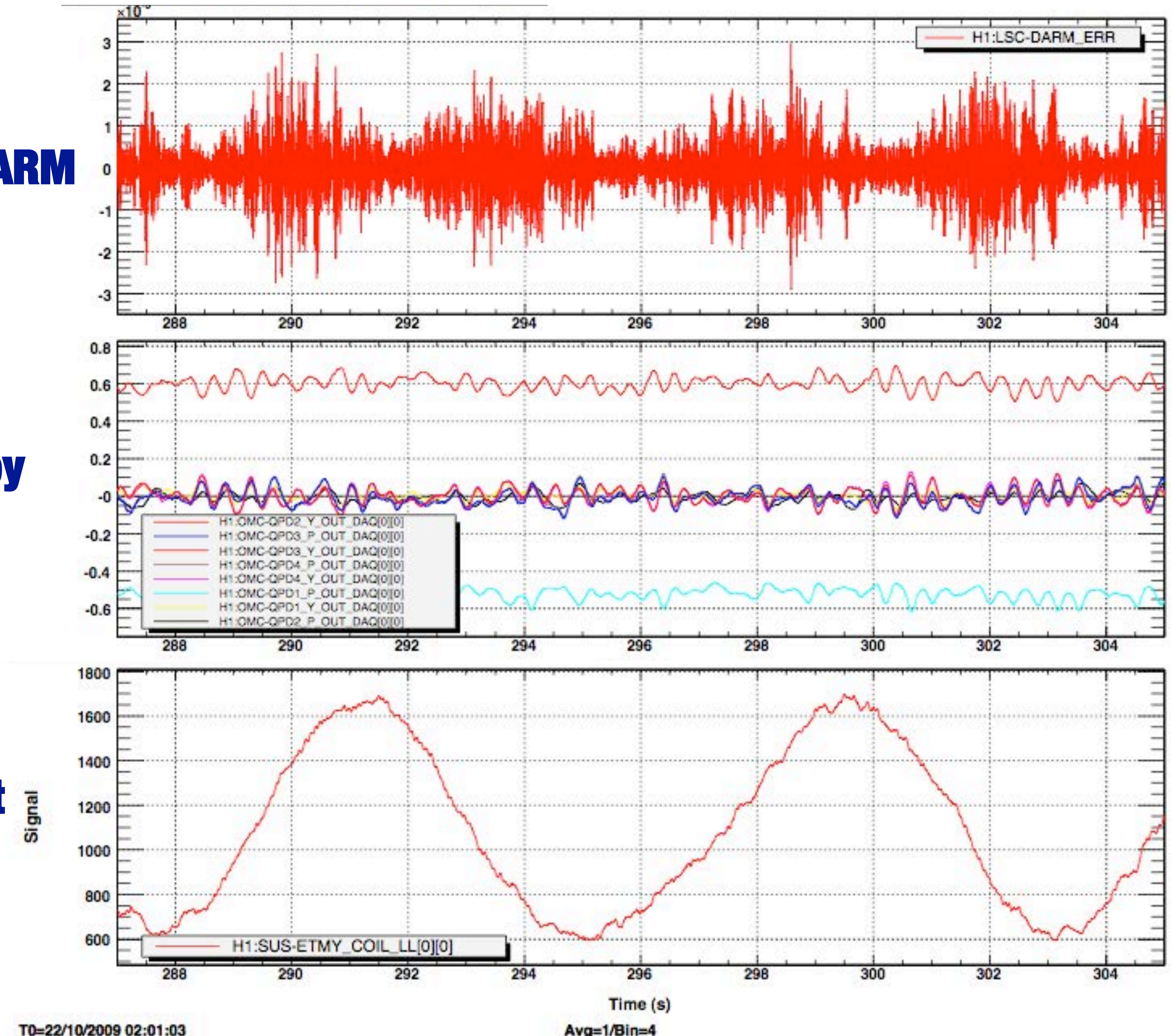


Upconversion bursts go with coil current not beam jitter

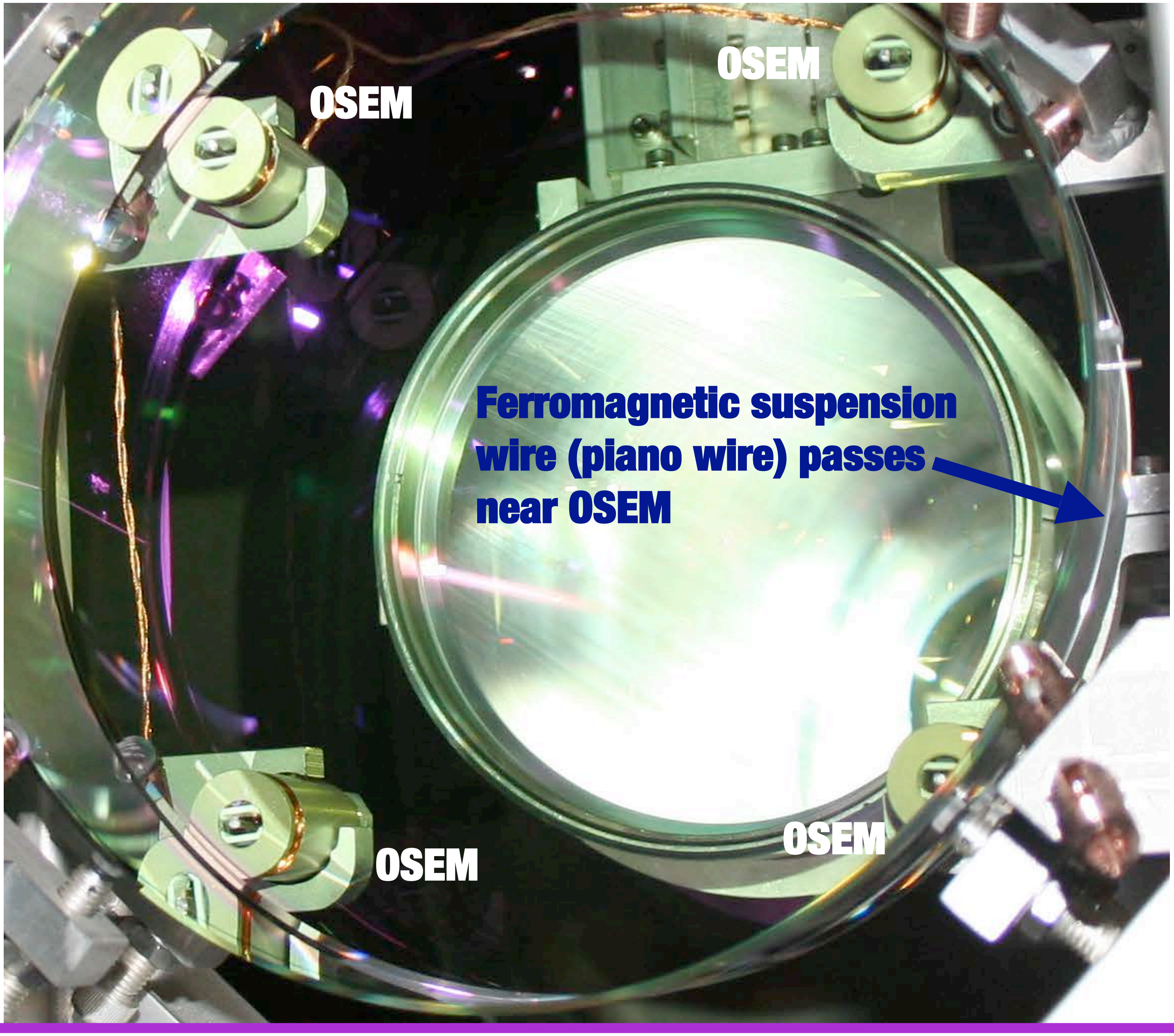
70 - 110 band of DARM

Beam jitter as seen by OMC quad diodes

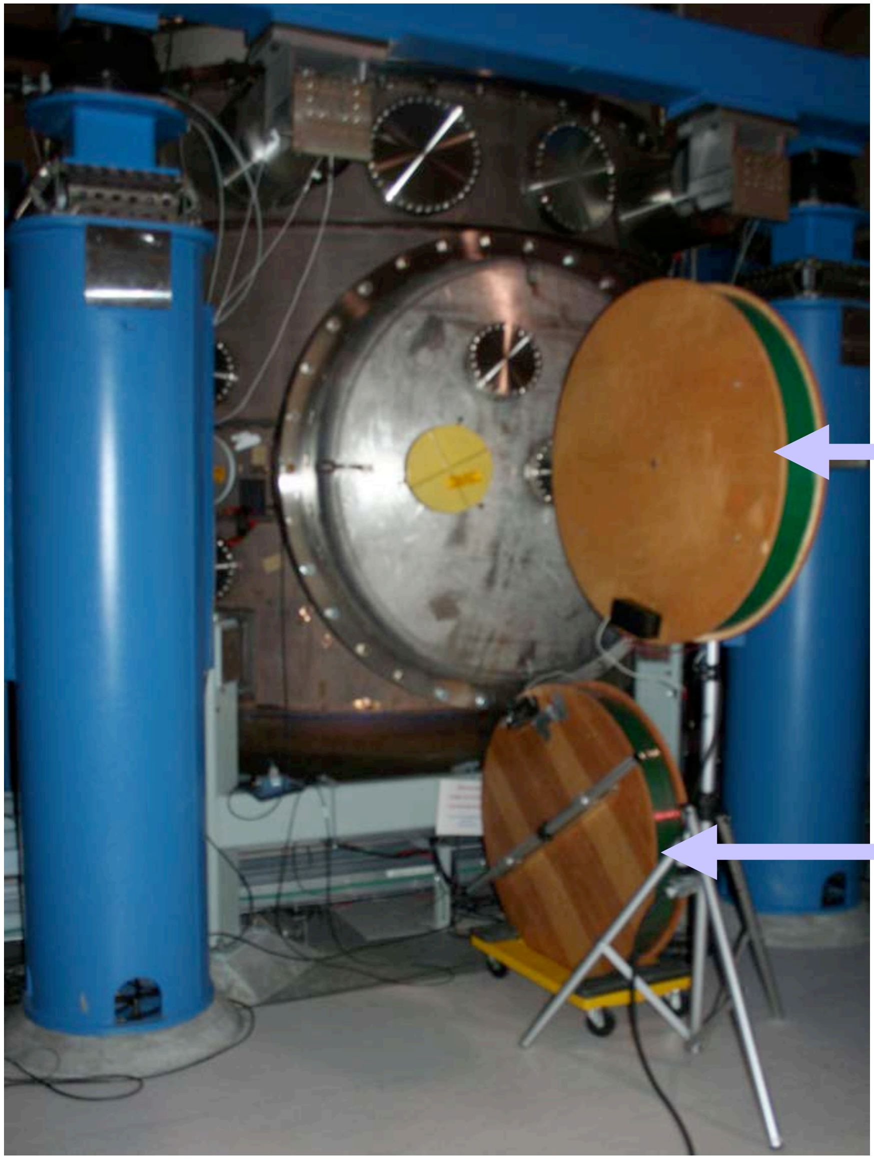
Actuation coil current



Barkhausen noise from suspension wire ?

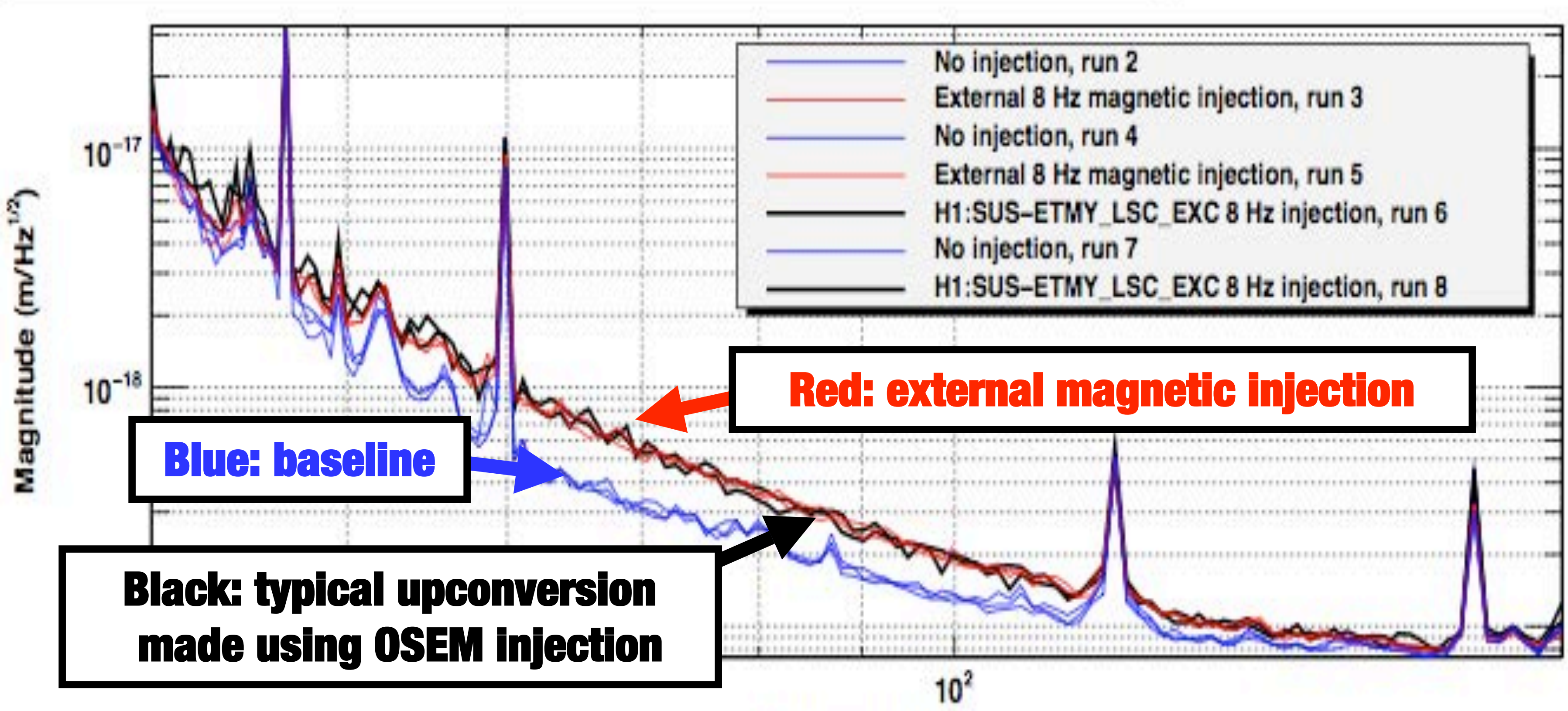


Can magnetic fields reproduce seismic upconversion ?



Coils in position at ITMY for injecting magnetic fields to test Barkhausen magnetic domain change noise hypothesis

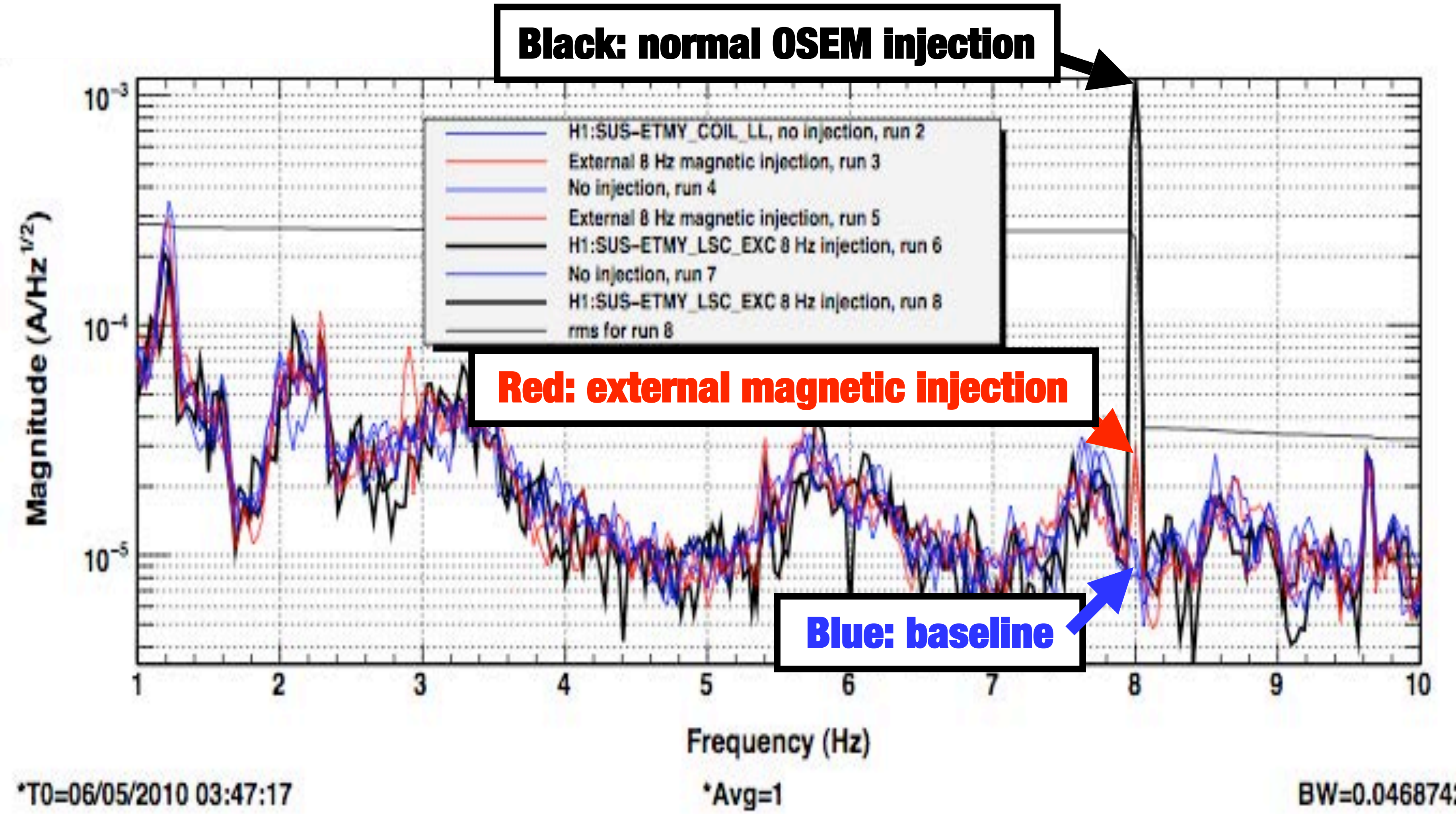
Upconversion from external 8 Hz magnetic injection



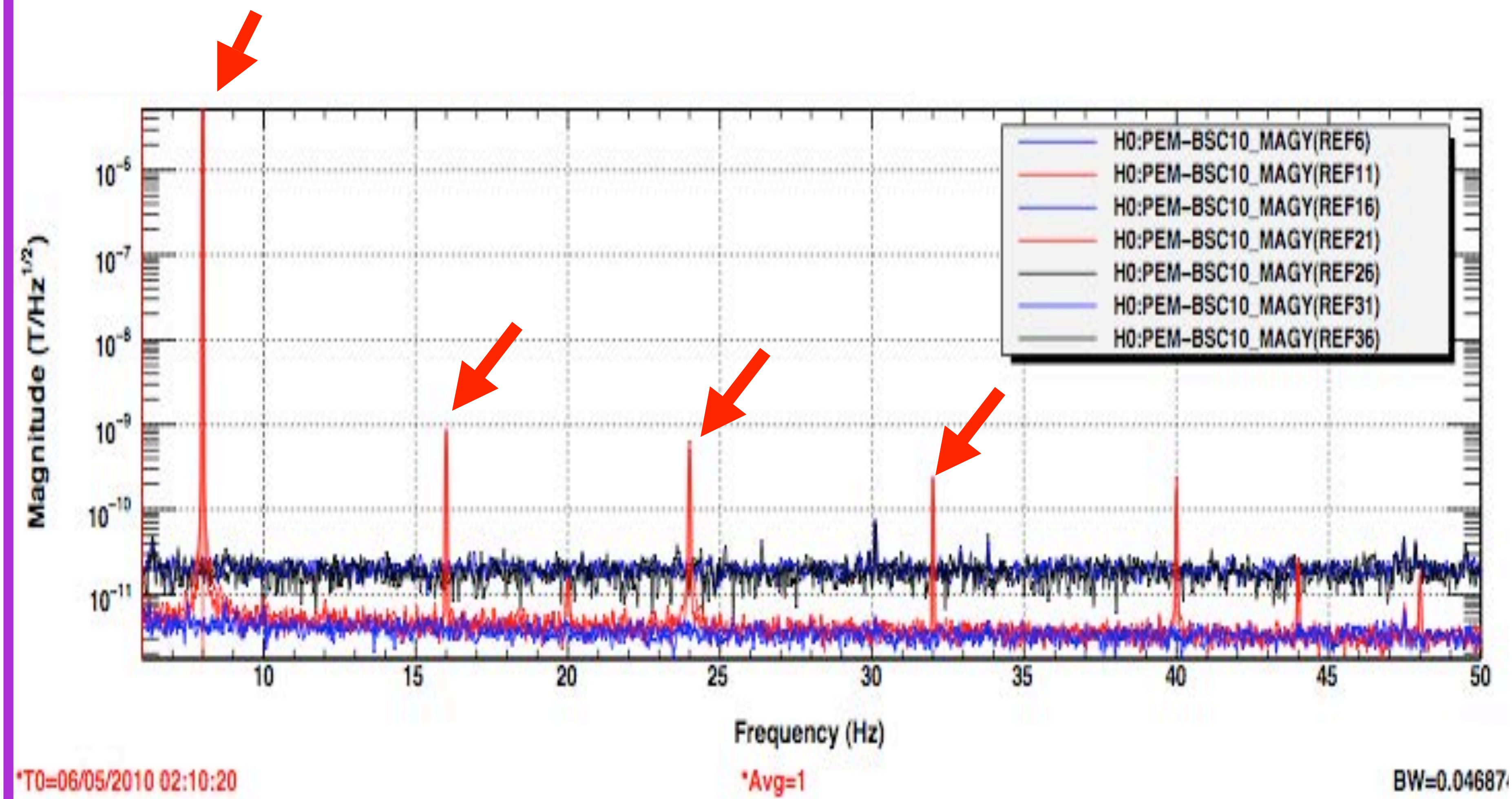
Reproduces spectral shape of seismic upconversion

Similar plot for 2 test masses, 3 injection frequencies

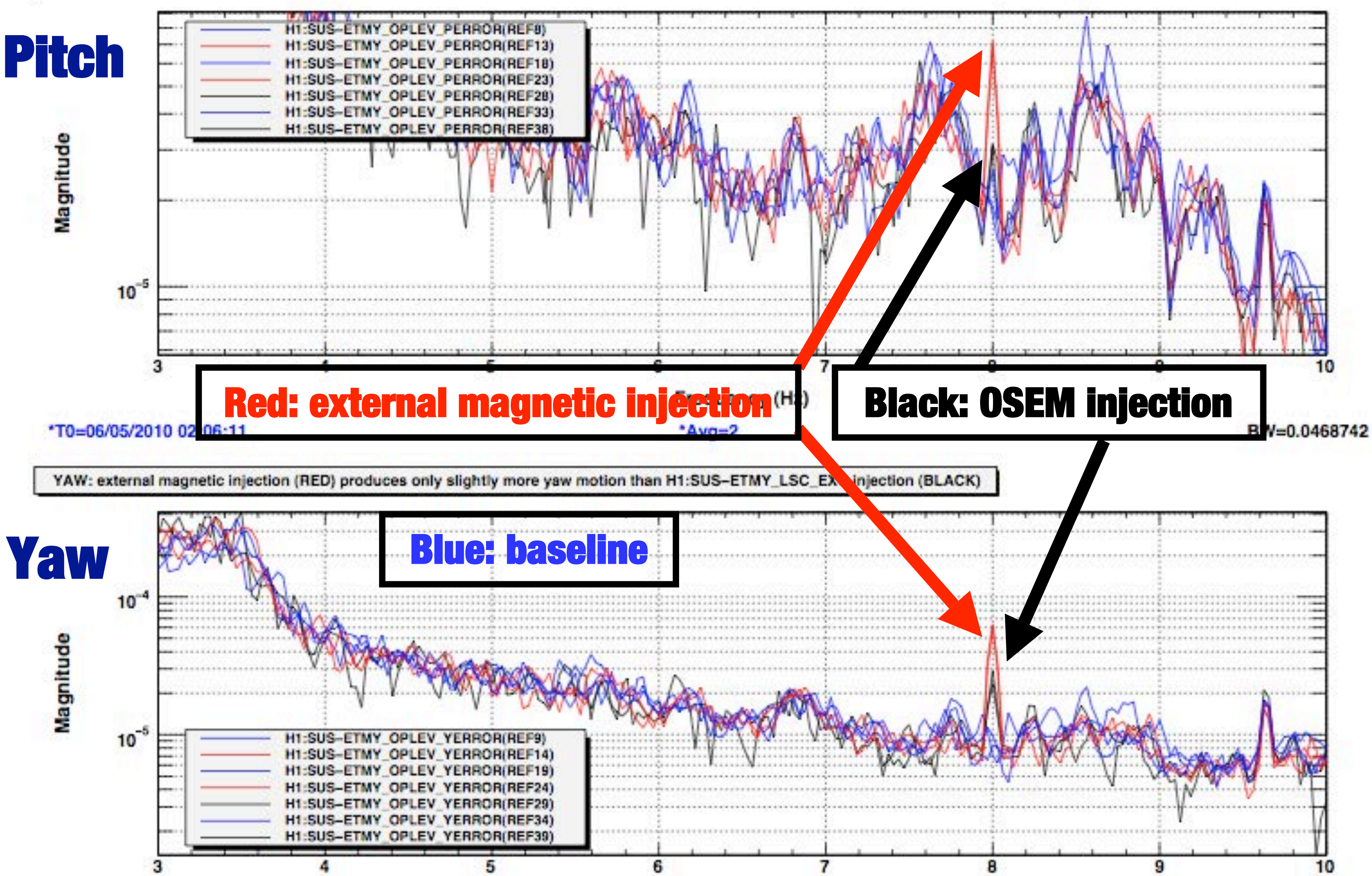
Check: coil current much smaller for external injection



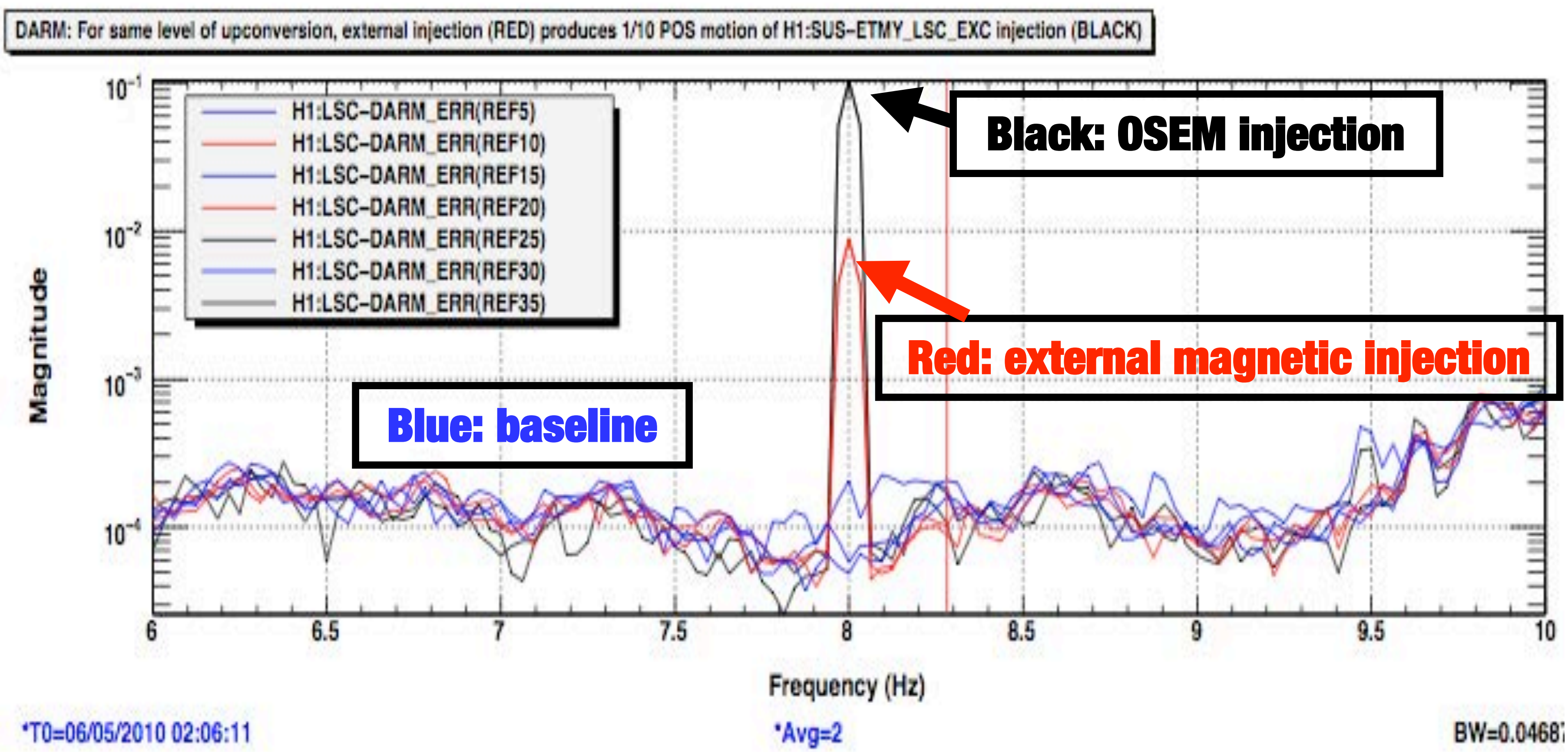
Check: only small magnetic fields at harmonics



Check: pitch and yaw motion for external injection is minimal



Check: beam line motion was 10x less than for OSEM injection



Location of Barkhausen noise source

Source is assumed to be located where magnetic fields from external and OSEM injections are equal, for equal upconversion

- **Not suspension wires, because externally generated field at wires was >100 times larger than OSEM field for same upconversion level**
- **Not other locations distant from OSEM (e.g. earthquake stops)**

External and OSEM fields match at OSEM center
for equal levels of upconversion

Estimated magnetic fields at center of OSEM coil

Location and frequency	From external coil	From OSEM coil	OSEM/external coil
ITMY 8 Hz	9.8 e-6 T	8.94e-6 T	0.91
ETMY 8 Hz	5.86e-6 T	5.50e-6 T	0.94
ETMY 4 Hz	1.06e-5 T	7.20e-6 T	0.68
ETMY 2.5 Hz	9.33e-6 T	1.11e-5 T	1.19

Determining fields to narrow location of noise source

Predicting fields inside BSC chamber from external coil

- Fields assumed to drop off as $1/r^3$
- Small correction for eddy current shielding (knee ~20 Hz)
- Measured at 6 external locations to test prediction (including opposite side of chamber)
- Magnetometer calibrated at 2.5, 4, 8 Hz
- Standard deviation of predicted/measured was 0.34, n=6

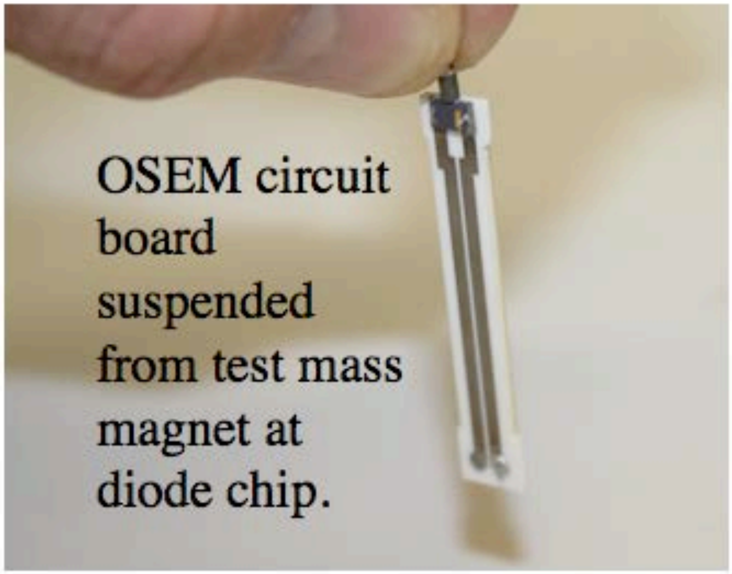
Determining fields to narrow location of noise source

Predicting fields from OSEM coil

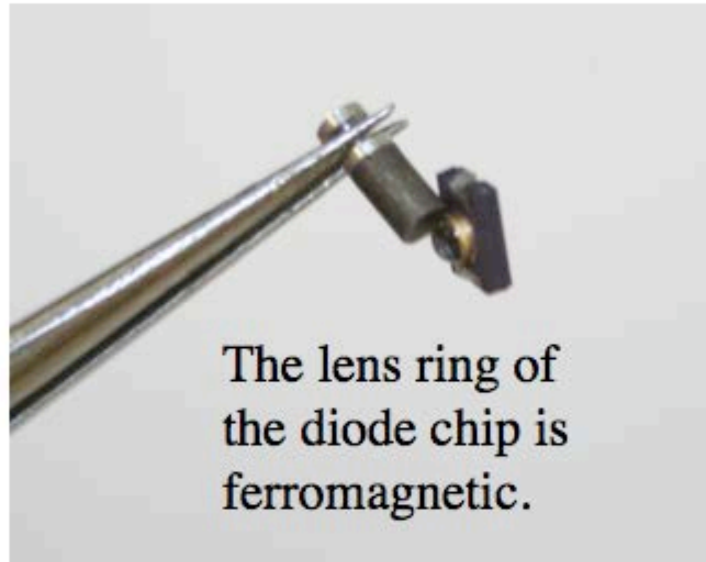
B_{center} = 4pi x 1×10^{-7} N I / sqrt($L^2 + 4R^2$)

N = number of turns in OSEM coil, 400 (unraveled and counted)
I = current through OSEM coil, from COIL channel, calibration: 6.67e-6 A/count
L = length of OSEM coil, 0.0047 (checked by measuring)
R = radius of OSEM coil, 0.01m (measured)

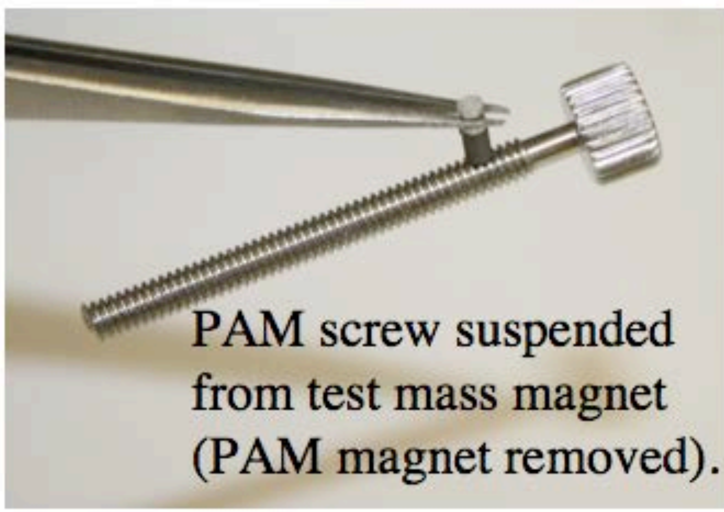
Ferromagnetic materials found near OSEM center



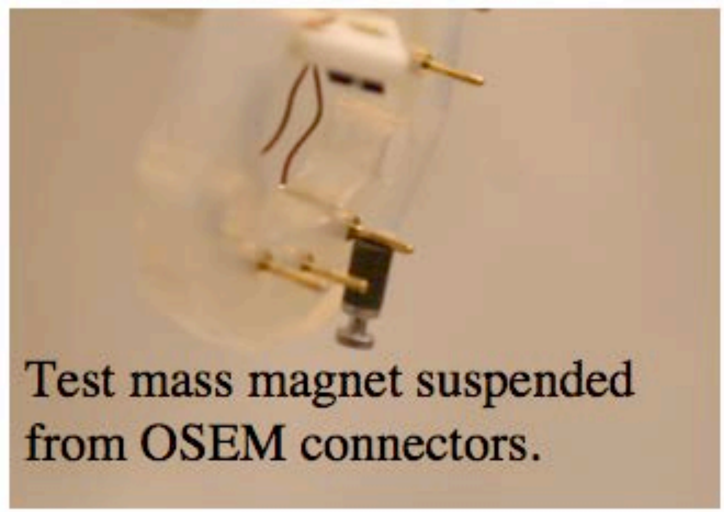
OSEM circuit board suspended from test mass magnet at diode chip.



The lens ring of the diode chip is ferromagnetic.



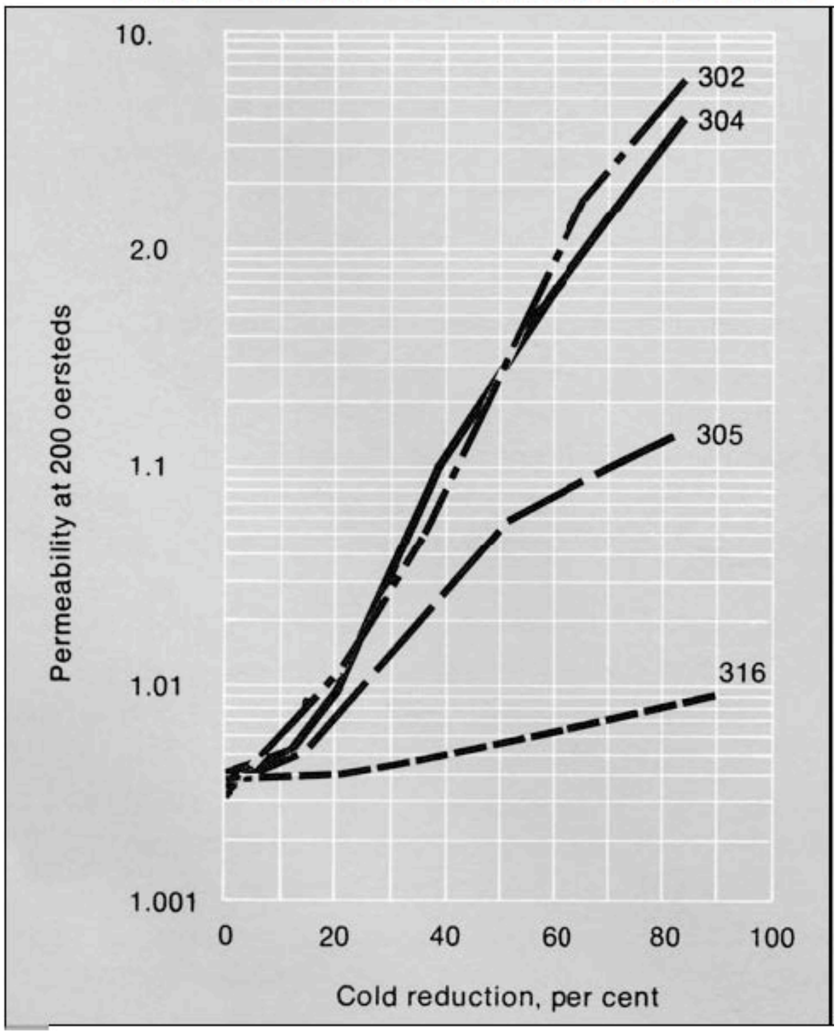
PAM screw suspended from test mass magnet (PAM magnet removed).



Test mass magnet suspended from OSEM connectors.

Fasteners can become magnetic when cold worked

Figure 7 **WHEN COLD WORKING IS EMPLOYED, SOME NORMALLY NON-MAGNETIC AUSTENITIC STEELS BECOME SUBSTANTIALLY MAGNETIC**



What about advanced LIGO?

Electrostatic control of test mass, magnetic control of penultimate mass, so noise will be filtered by test mass pendulum

Barkhausen upconversion should not limit adLIGO if:

- Displacement noise at penultimate test mass is no more than for iLIGO
- Noise is not greater at low frequencies than predicted from spectral shape at 100 Hz

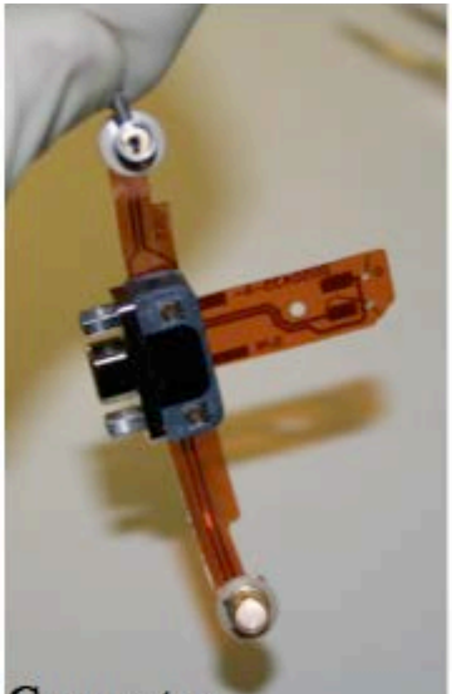
Ferromagnetic components in AOSEMs

Connector (with suspended test mass magnet)

Diode chips, both transmitter and receiver, can be suspended from magnet

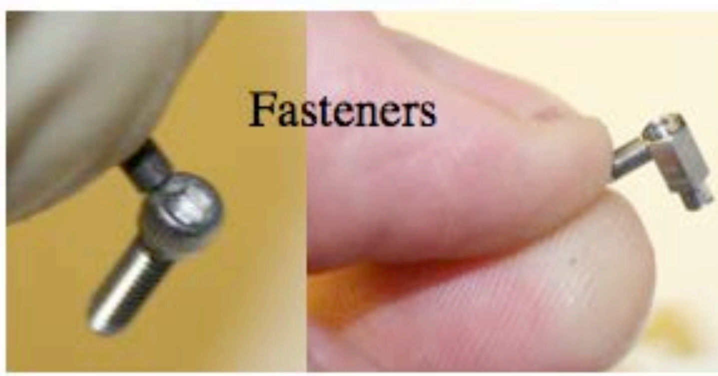
Fasteners

Ferromagnetic components in BOSEMs

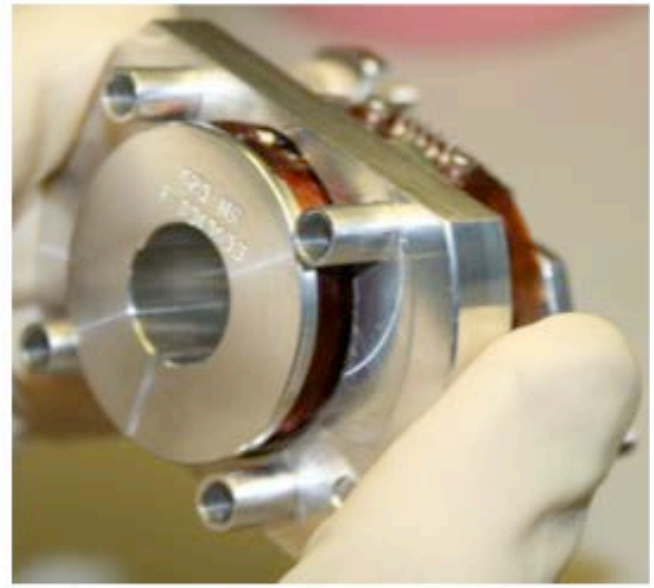


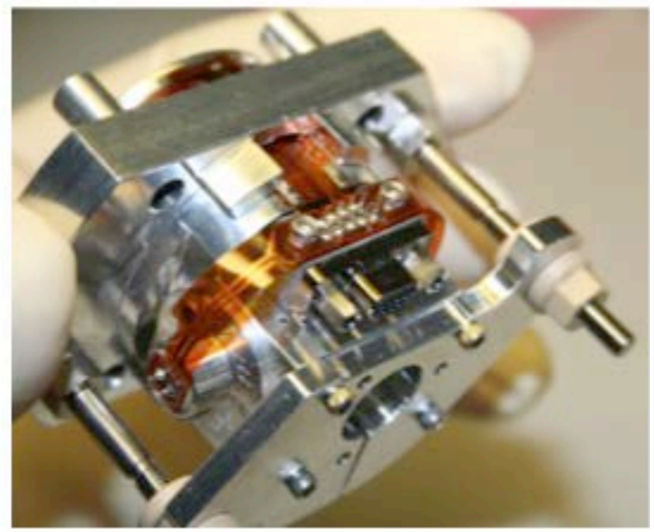
Connector, flexicircuit, LED and photodiode assembly suspended from test mass magnet

Connector (with suspended test mass magnet)



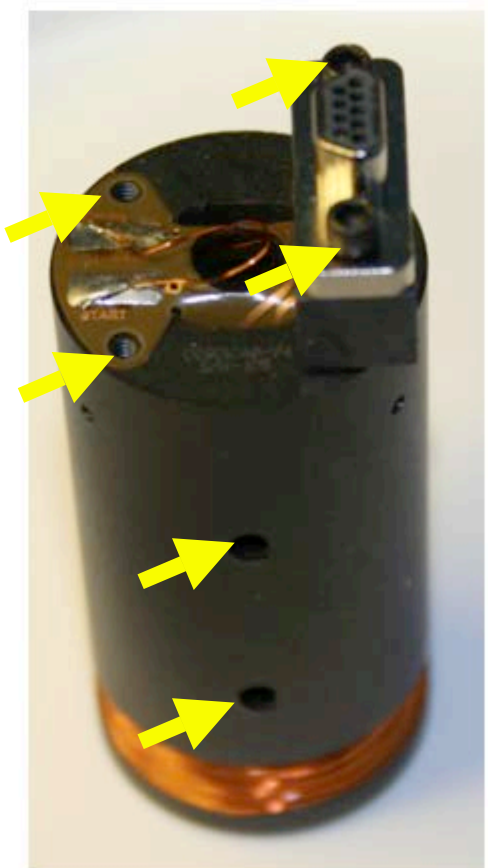
Fasteners

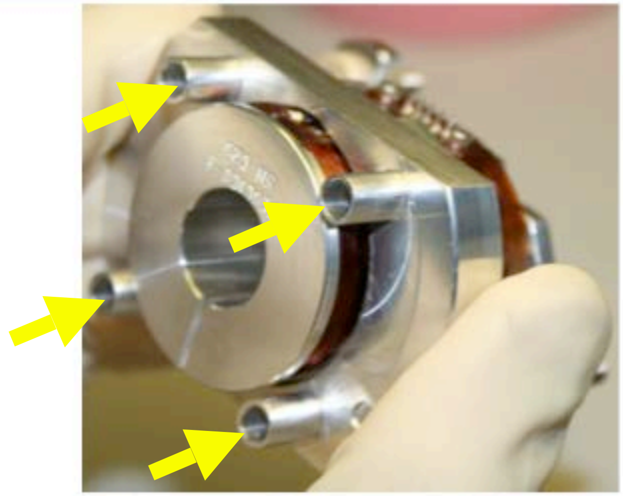


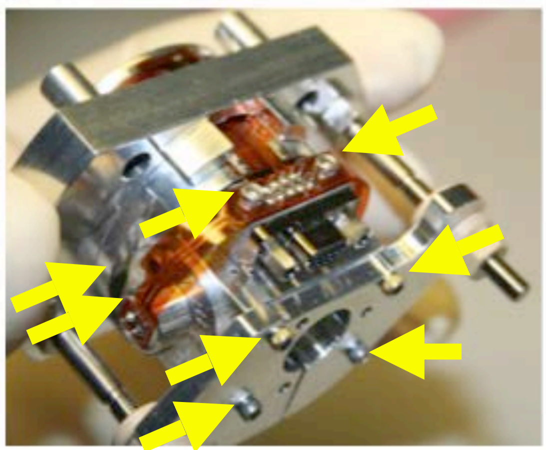


Risk reduction plan for adLIGO

- Use 316ss at indicated locations in all AOSEMs
- Replace the indicated fasteners in BS and FM BOSEMs







Summary

1) External magnetic injections were used to test the hypothesis that seismic upconversion is mainly Barkhausen magnetic domain noise.

2) External magnetic injections did produce upconversion and the spectral shape matched that of seismic upconversion.

3) For matched levels of upconversion, the OSEM and externally injected magnetic fields were estimated to be equal at the OSEM, suggesting that the source of the Barkhausen noise is in the OSEM.

4) Ferromagnetic parts were found inside the OSEMs, the largest was the PAM magnet screw.

5) A measurement of the Barkhausen noise from this screw should be made to confirm that it was the source of seismic upconversion.

6) Barkhausen noise is unlikely to limit adLIGO (test mass actuation is electrostatic) but to reduce risk, some screws in the penultimate mass magnetic actuators will be replaced with 316ss.