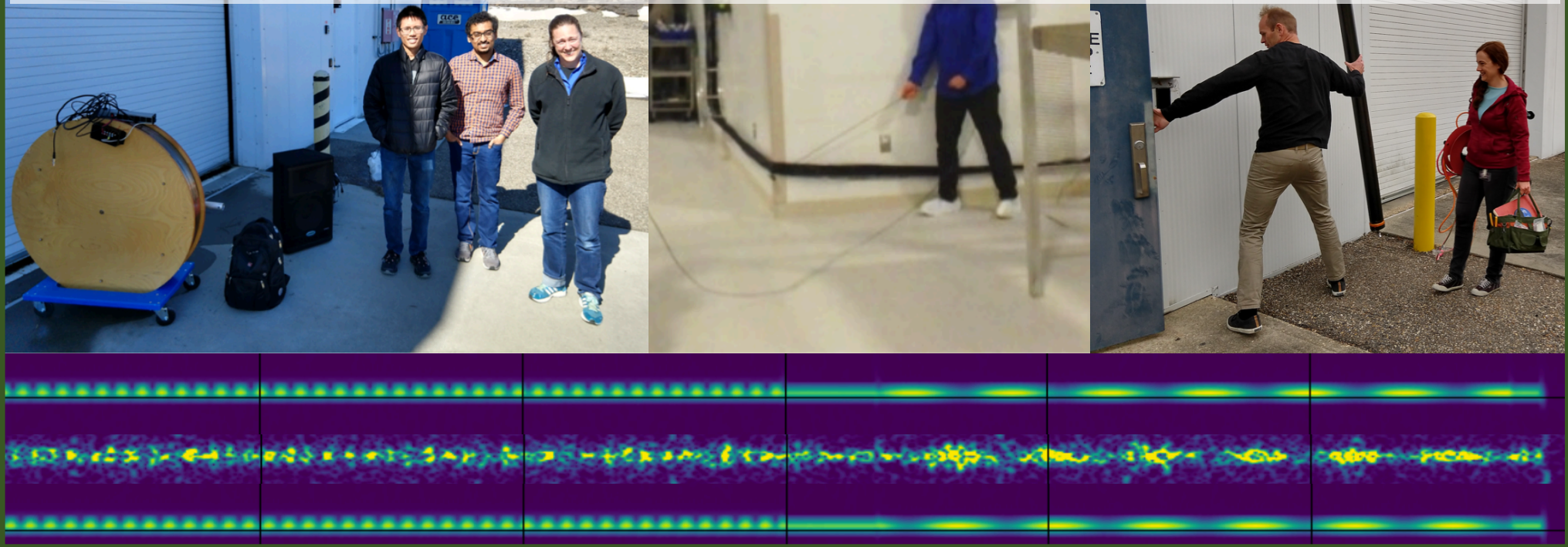
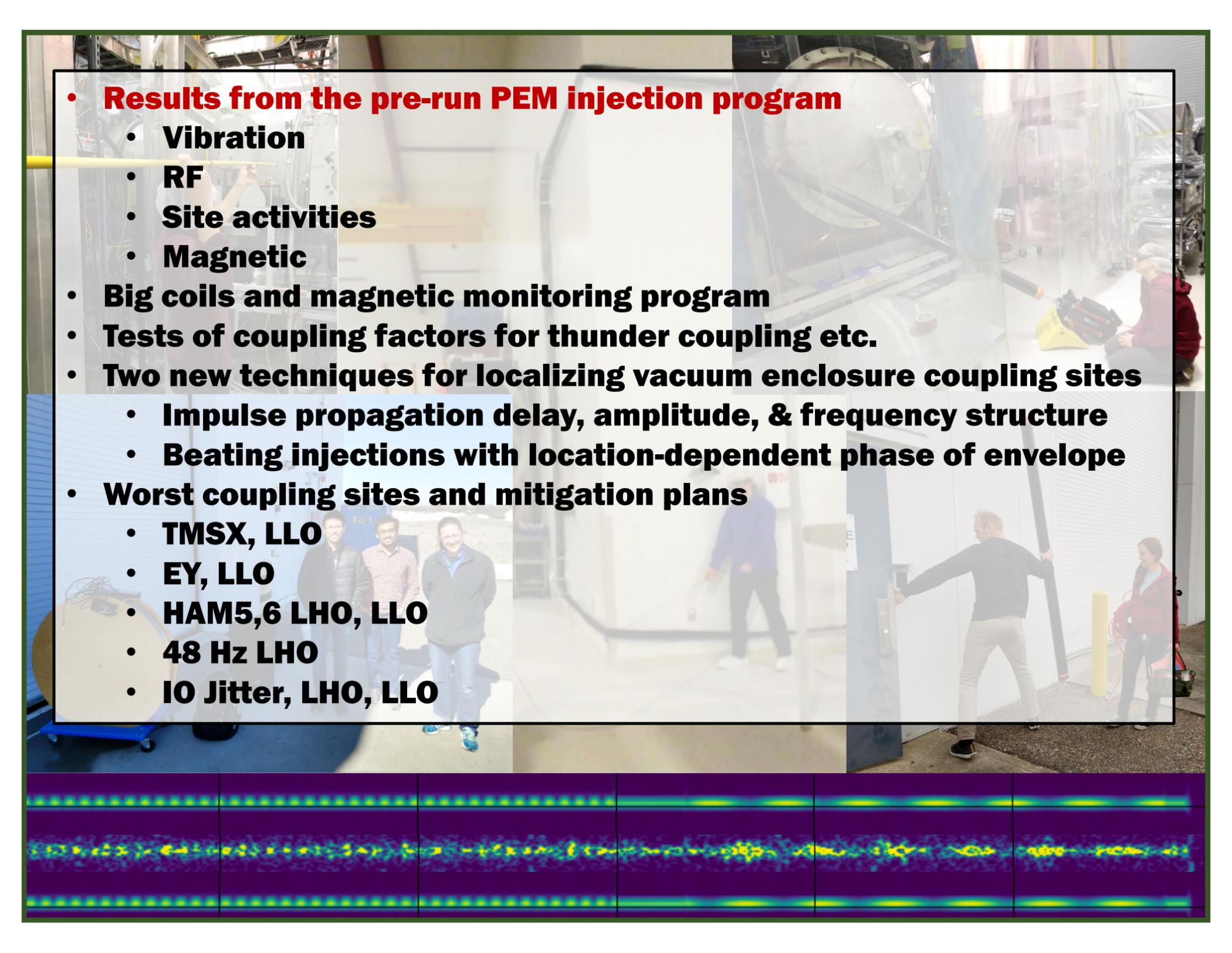




# August 2019 PEM update and new techniques for localizing scattering

Robert Schofield, Philippe Nguyen, Sharan Banagiri, Corey Austin, Kara Merfeld, Anamaria Effler, David Shoemaker, Siddharth Soni, Adrian Helmling-Cornell, Matthew Ball, DetChar

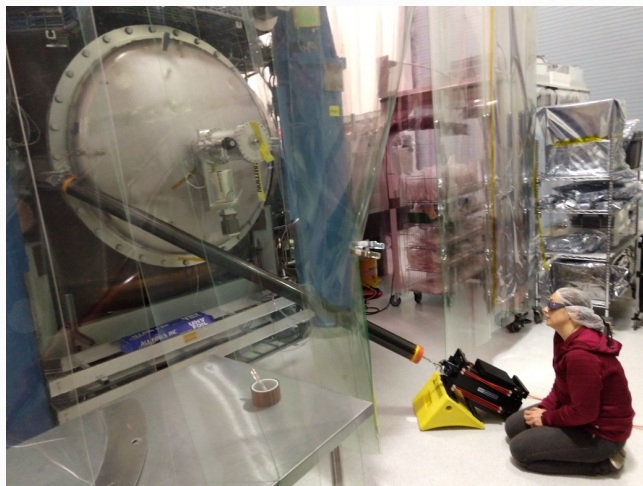
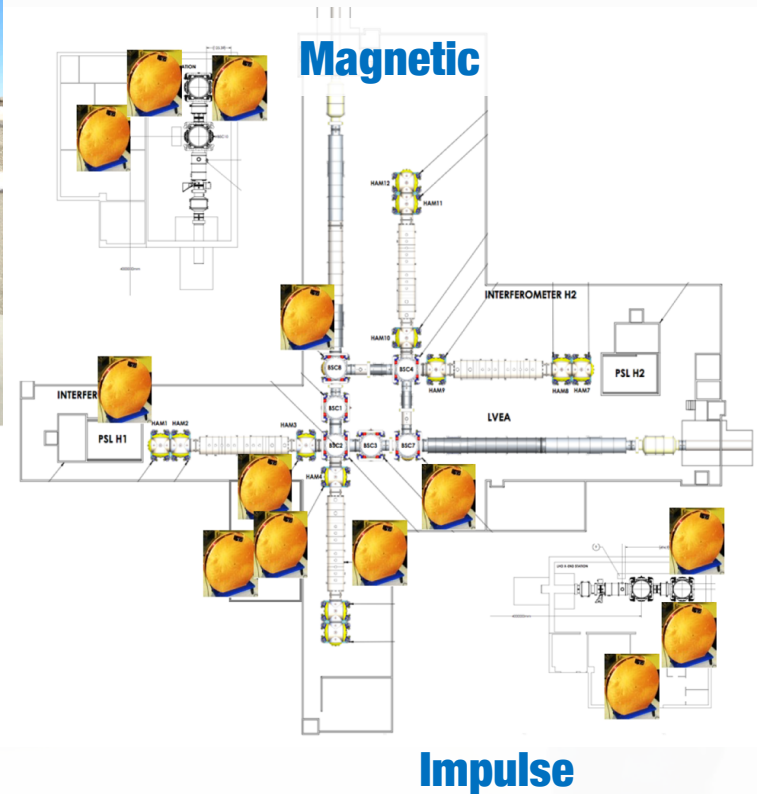
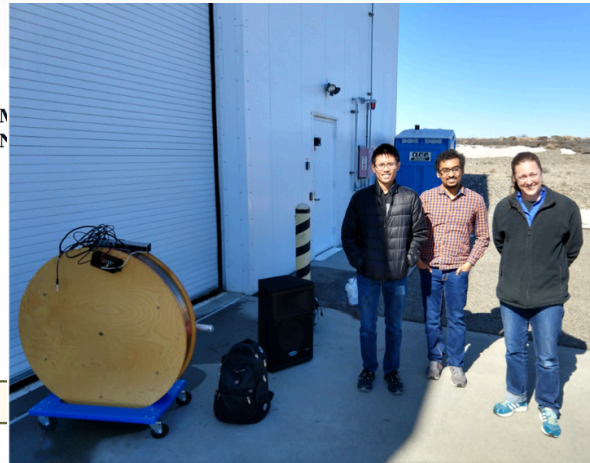
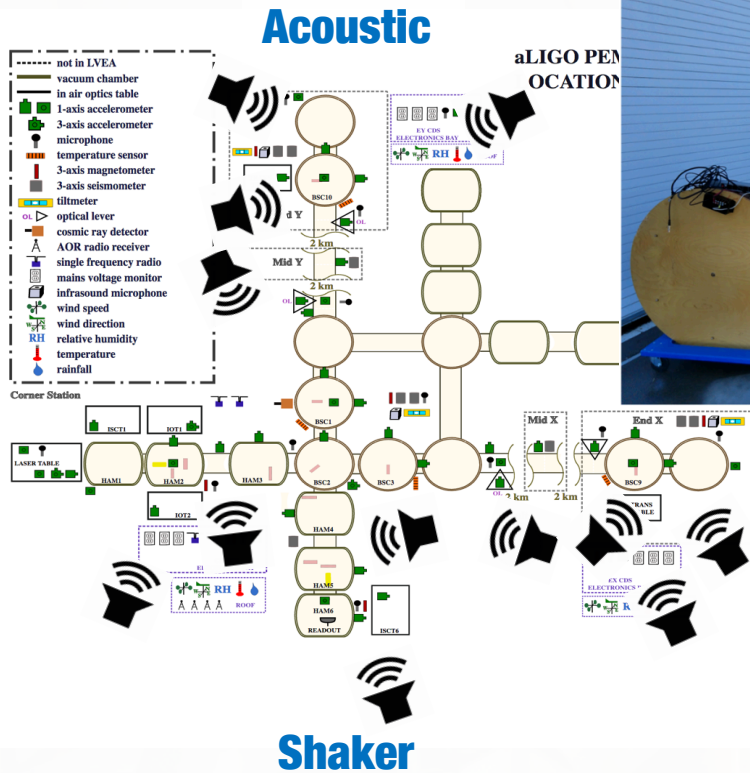


The background of the slide is a collage of several images. At the top left, a person is working on a large piece of equipment. In the center, there's a large, complex industrial machine, possibly a particle accelerator component. On the right, a person is kneeling and working on a piece of equipment. At the bottom left, three people are standing and smiling for a photo. At the bottom right, a person is pushing a large metal door. The bottom of the slide features a series of horizontal spectrograms or heatmaps showing frequency spectra over time, with various colored bands (yellow, green, blue) indicating different frequency levels.

- **Results from the pre-run PEM injection program**

- **Vibration**
- **RF**
- **Site activities**
- **Magnetic**
- **Big coils and magnetic monitoring program**
- **Tests of coupling factors for thunder coupling etc.**
- **Two new techniques for localizing vacuum enclosure coupling sites**
  - **Impulse propagation delay, amplitude, & frequency structure**
  - **Beating injections with location-dependent phase of envelope**
- **Worst coupling sites and mitigation plans**
  - **TMSX, LLO**
  - **EY, LLO**
  - **HAM5,6 LH0, LLO**
  - **48 Hz LH0**
  - **IO Jitter, LH0, LLO**

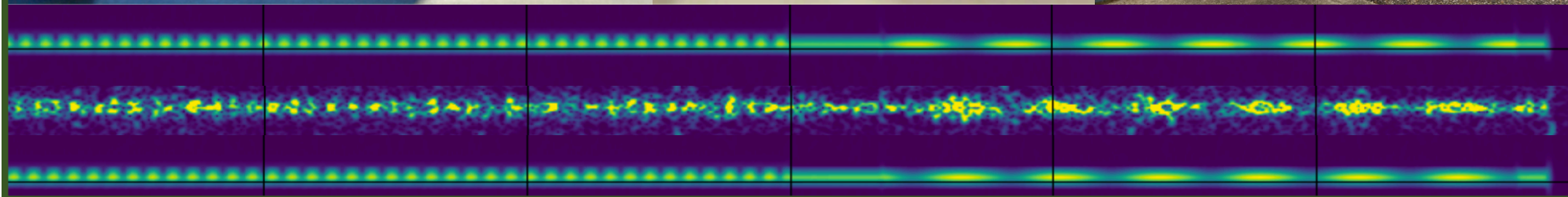
# PEM Injection Program



- **Results from the pre-run PEM injection program**

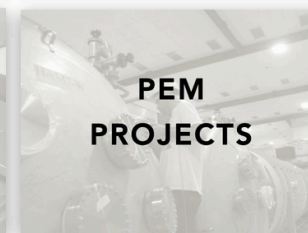
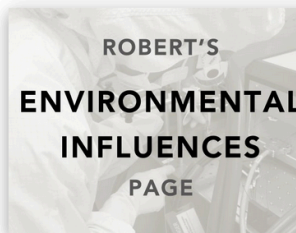
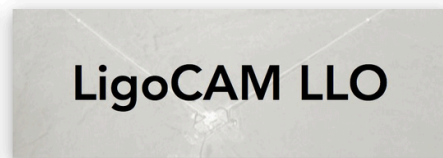
- **Vibration**

- RF
- Site activities
- Magnetic
- Big coils and magnetic monitoring program
- Tests of coupling factors for thunder coupling etc.
- Two new techniques for localizing vacuum enclosure coupling sites
  - Impulse propagation delay, amplitude, & frequency structure
  - Beating injections with location-dependent phase of envelope
- Worst coupling sites and mitigation plans
  - TMSX, LLO
  - EY, LLO
  - HAM5,6 LHO, LLO
  - 48 Hz LHO
  - IO Jitter, LHO, LLO



# Results at: PEM.LIGO.ORG

## PEM Central



Count coupling functions for easy estimate of signal in DARM

## All Channels A-Z

[Click here to see all PEM channel coupling functions](#)

Physics units coupling functions

## Channels Sorted By Location and Coupling Type

Interferometer	LHO						LLO					
Station	CS		EX		EY		CS		EX		EY	
Coupling Type	<a href="#">Vibrational</a>	<a href="#">Magnetic</a>	<a href="#">Vibrational</a>	<a href="#">Magnetic</a>	<a href="#">Vibrational</a>	<a href="#">Magnetic</a>	<a href="#">Vibrational</a>	<a href="#">Magnetic</a>	<a href="#">Vibrational</a>	<a href="#">Magnetic</a>	<a href="#">Vibrational</a>	<a href="#">Magnetic</a>

## Jitter Coupling Plots

[Click here to see jitter coupling functions](#)

Site-wide summary

## Site-Wide Summary Plots

[Click here to see site-wide coupling functions](#)

## Documentation

All the coupling functions here were generated using the pemcoupling code.

[Click here for the git repo \(LIGO credentials required\)](#)

[Click here for the documentation](#)

Last updated May 2019 by Philippe Nguyen (philippe.nguyen@ligo.org)

## PEM Coupling Functions - Site-Wide Summary Plots

These plots were generated using the [pemcoupling-sitewide](#) tool.

### LHO - Magnetic

Estimated Ambient: [Plot Data](#)

Coupling Function: [Plot Data](#)

### LHO - Vibrational

Estimated Ambient: [Plot Data](#)

Coupling Function (accelerometers only): [Plot Data](#)

### LLO - Magnetic

Estimated Ambient: [Plot Data](#)

Coupling Function: [Plot Data](#)

### LLO - Vibrational

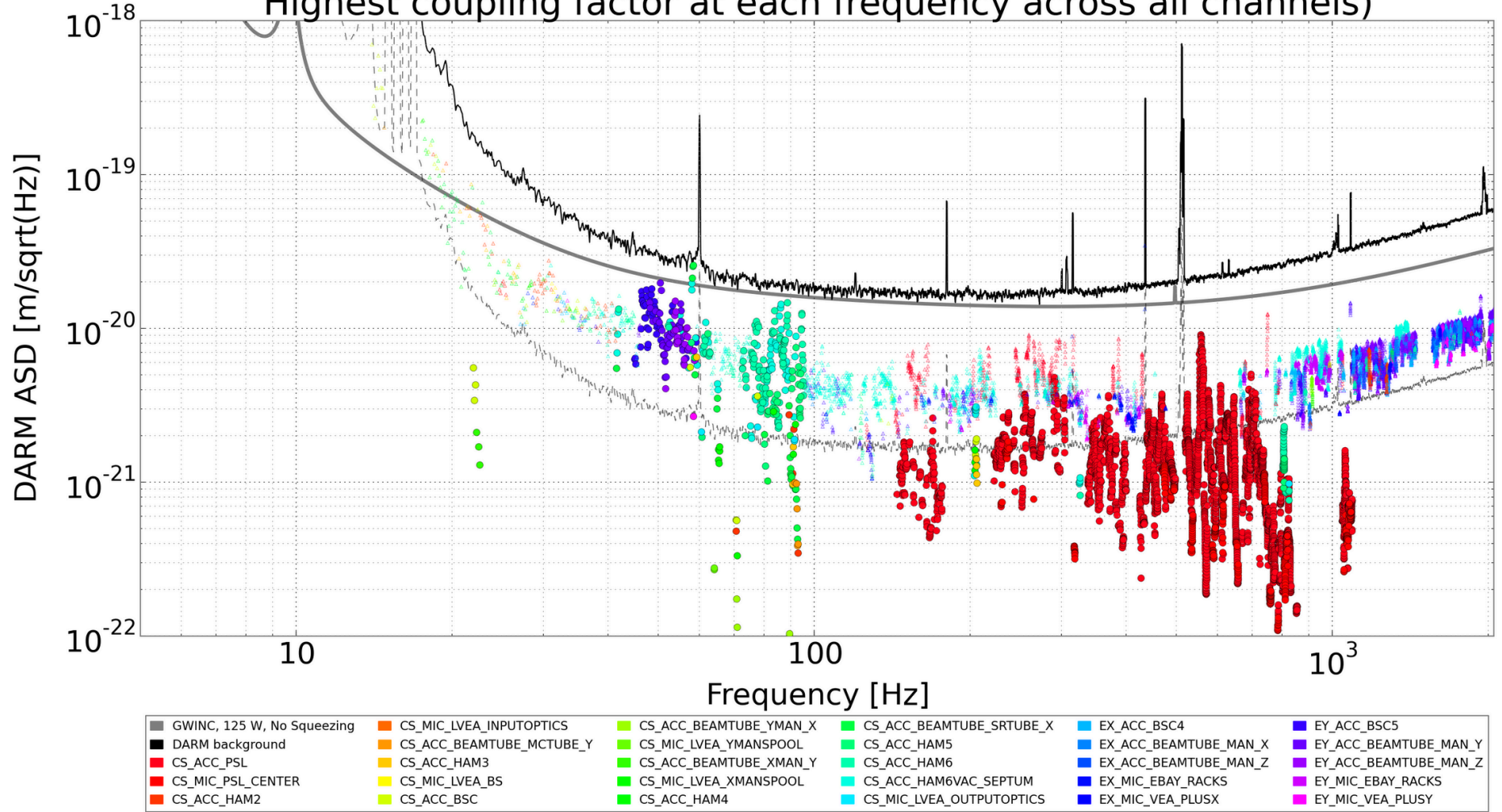
Estimated Ambient: [Plot Data](#)

Coupling Function (accelerometers only): [Plot Data](#)

Last updated May 2019 by Philippe Nguyen ([philippe.nguyen@ligo.org](mailto:philippe.nguyen@ligo.org))

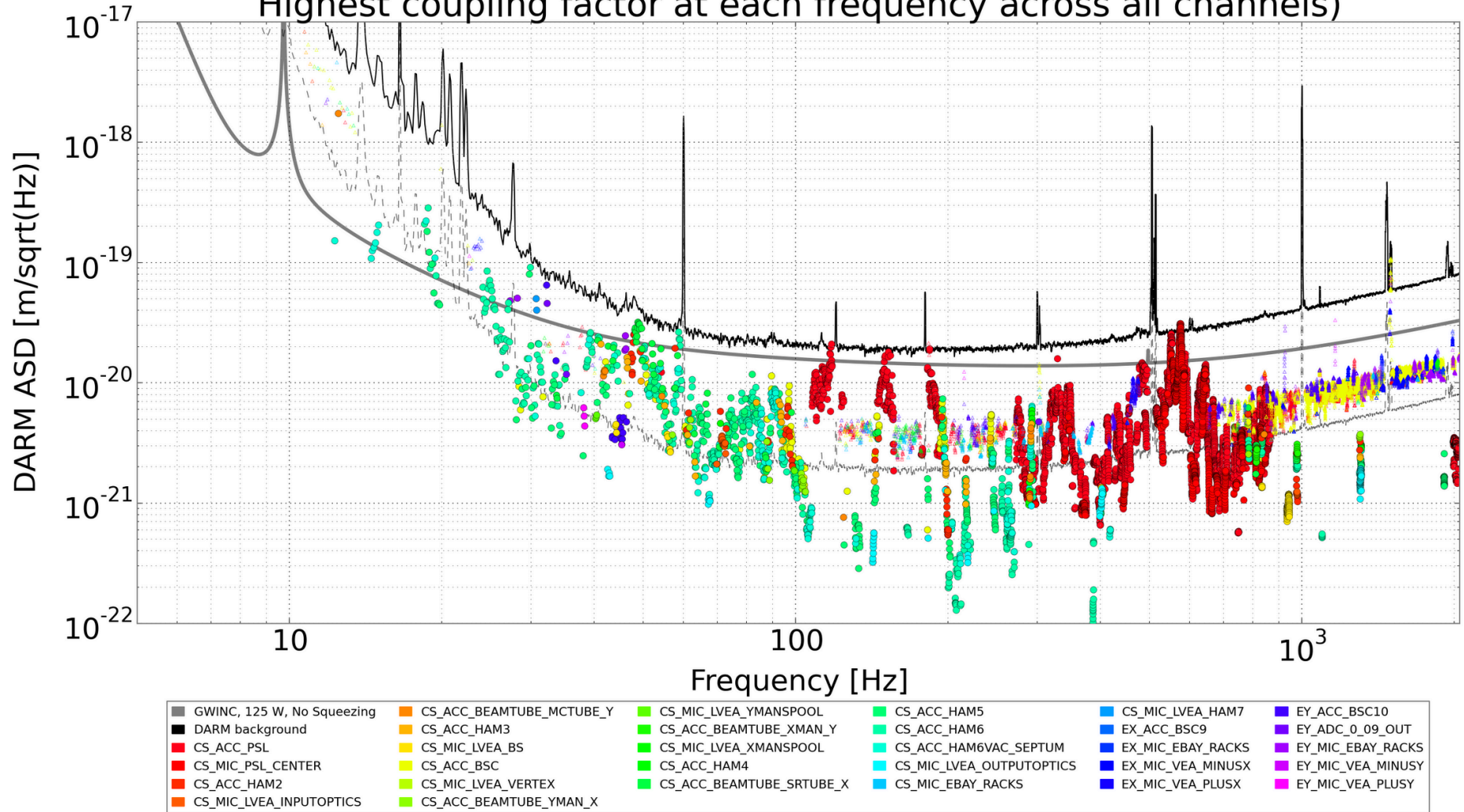
## L1 Vibrational - Estimated Ambient

Highest coupling factor at each frequency across all channels)



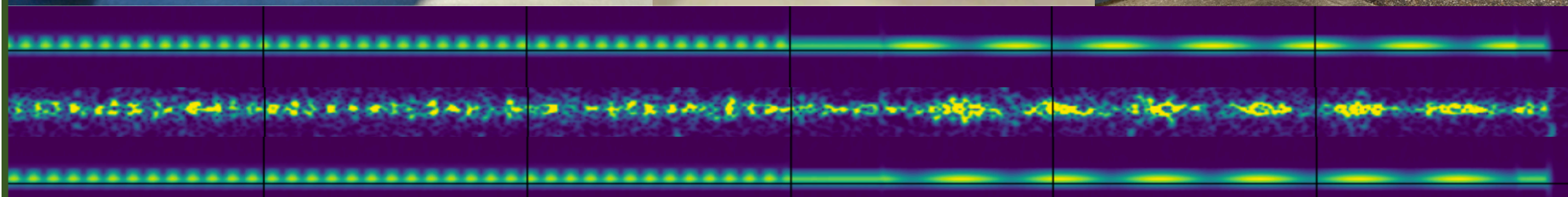
Ambient estimates are made by multiplying coupling factors by injection-free sensor levels. CIRCLES indicate estimates from measured coupling factors, i.e. where the injection signal was seen in the sensor and in DARM. TRIANGLES represent upper limit coupling factors, i.e. where a signal was seen in the sensor but not in DARM. For some channels, at certain frequencies the ambient estimates are upper limits because the ambient level is below the sensor noise floor.

# H1 Vibrational - Estimated Ambient (Highest coupling factor at each frequency across all channels)



Ambient estimates are made by multiplying coupling factors by injection-free sensor levels. CIRCLES indicate estimates from measured coupling factors, i.e. where the injection signal was seen in the sensor and in DARM. TRIANGLES represent upper limit coupling factors, i.e. where a signal was seen in the sensor but not in DARM. For some channels, at certain frequencies the ambient estimates are upper limits because the ambient level is below the sensor noise floor.

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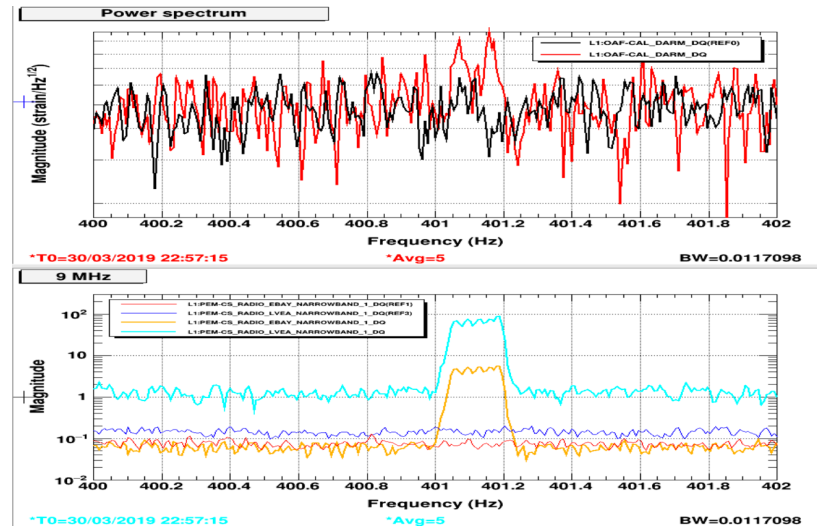
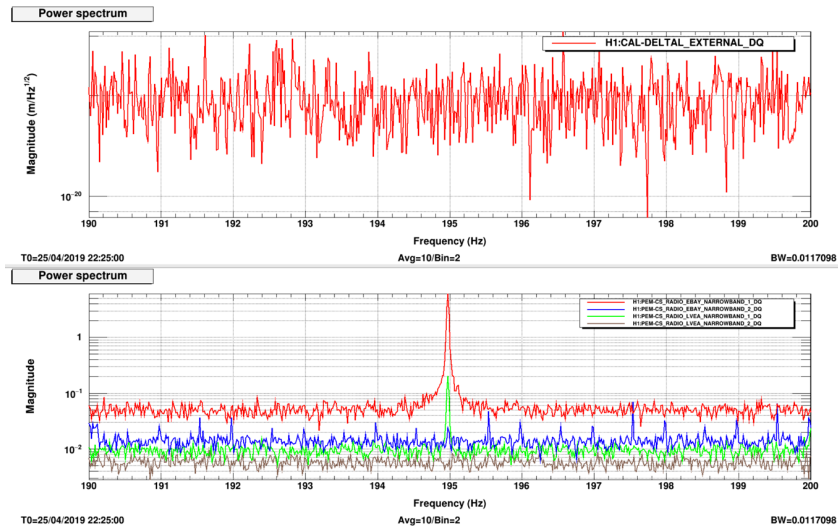


# Radio channels detect external 9 & 45 MHz RF with at least 100 times SNR of DARM

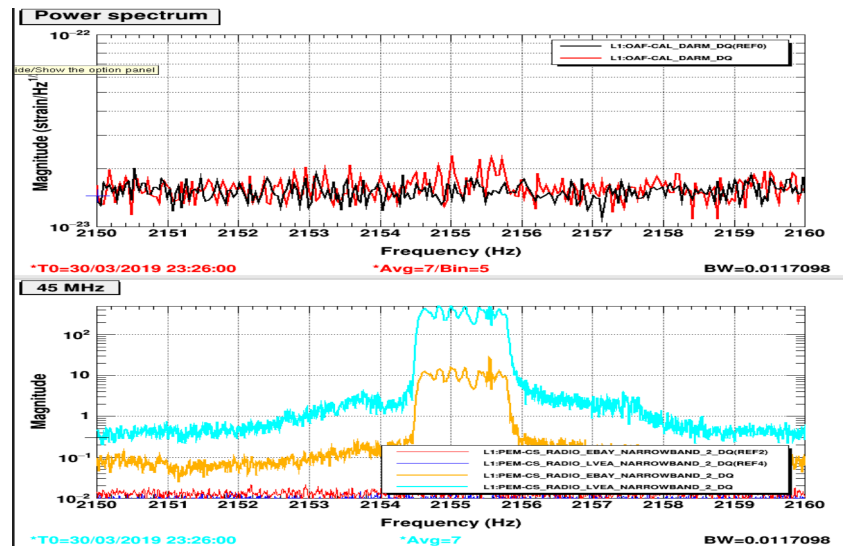
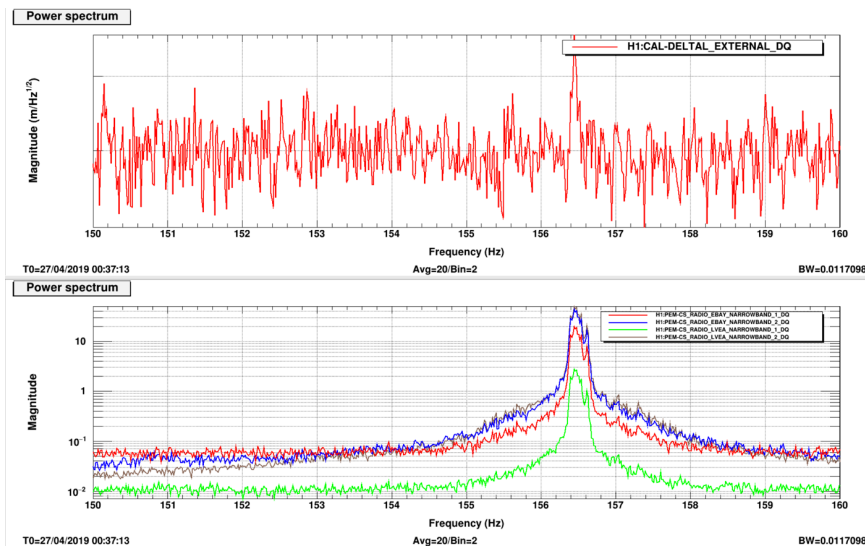
LHO

LLO

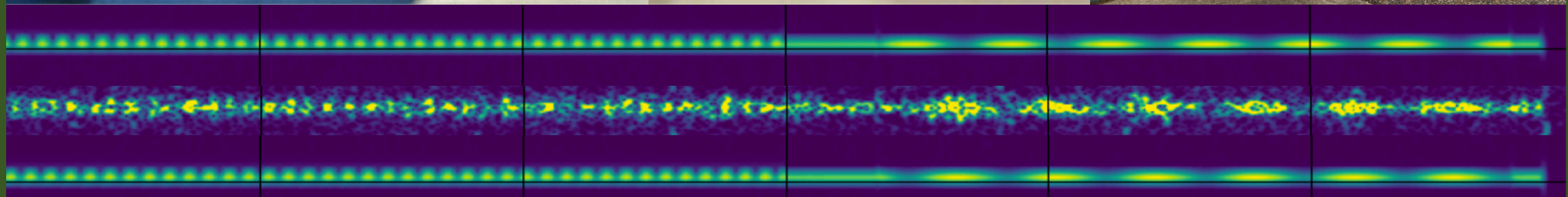
9 MHz



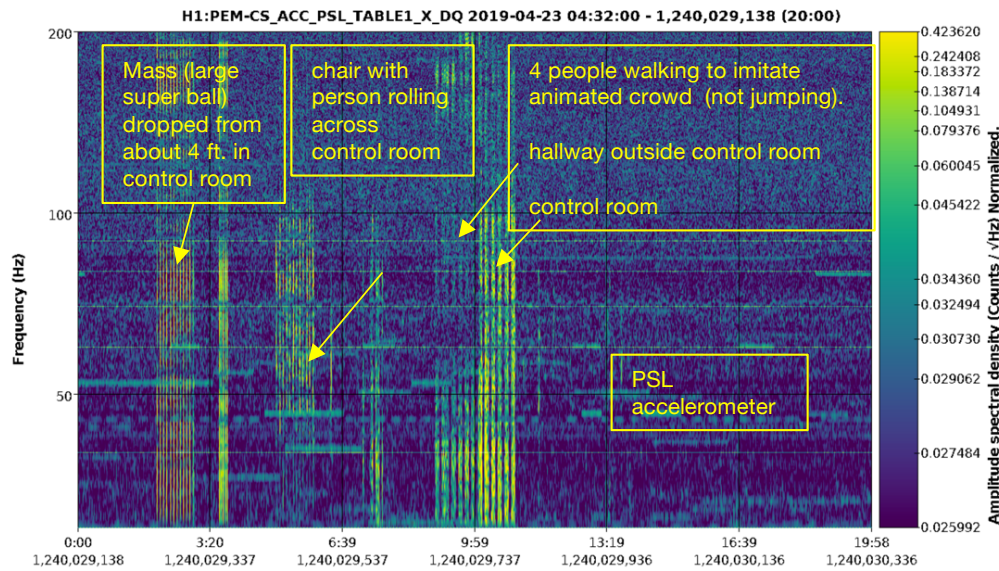
45 MHz



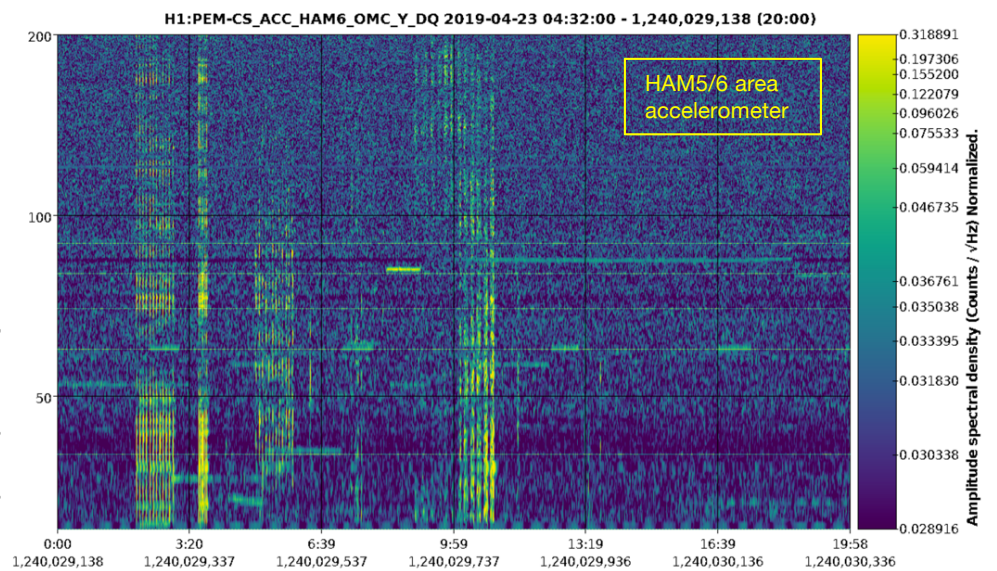
- **Results from the pre-run PEM injection program**
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  - **48 Hz LHO**
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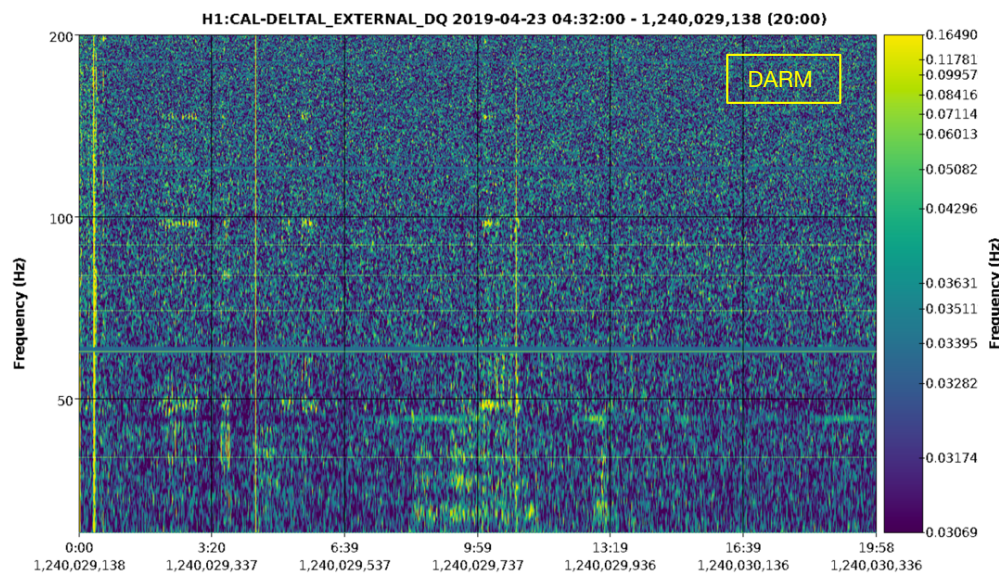
# Heavy stepping tours, rolling chairs in control room, dropping a few pounds, show in H1 DARM



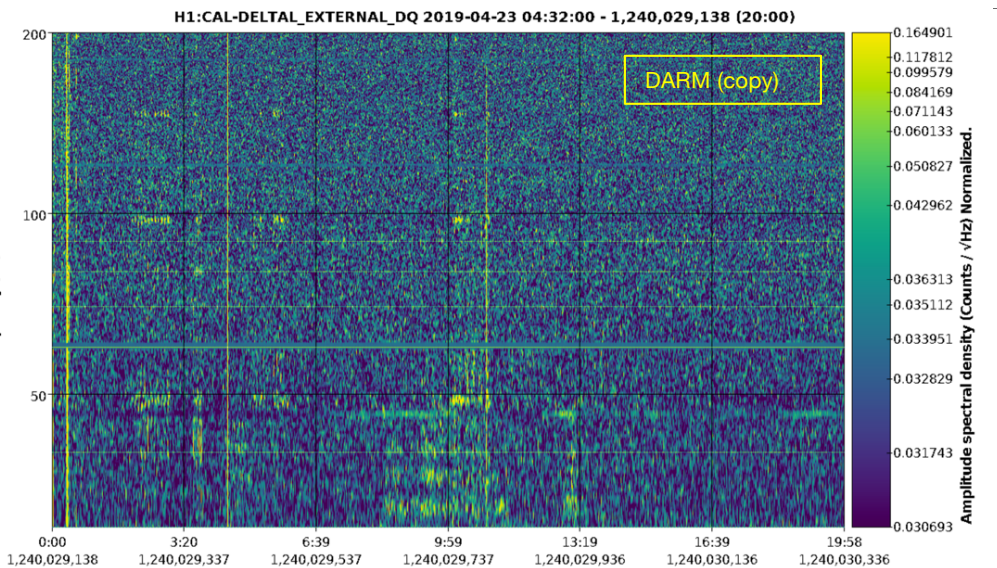
Fs=4,096Hz, sec/fft = 2.00, overlap = 0.90, fft length=8,192, #-FFT = 5986, bw = 0.50, in samples = 4,915K, up = 1.00, low = 0.20



Fs=4,096Hz, sec/fft = 2.00, overlap = 0.90, fft length=8,192, #-FFT = 5986, bw = 0.50, in samples = 4,915K, up = 1.00, low = 0.20

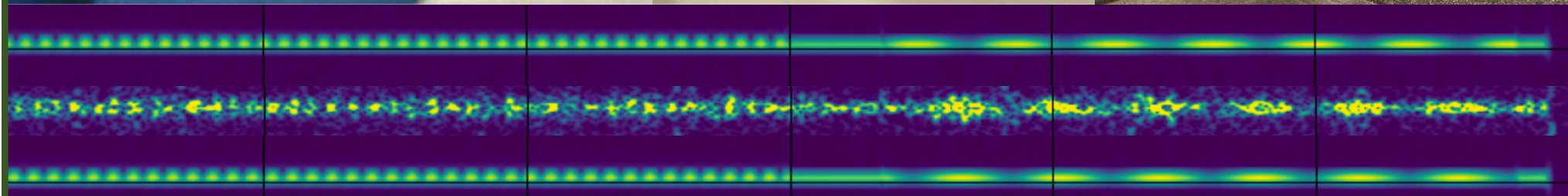


Fs=16,384Hz, sec/fft = 2.00, overlap = 0.90, fft length=32,768, #-FFT = 5991, bw = 0.50, in samples = 19,661K, up = 1.00, low = 0.20



Fs=16,384Hz, sec/fft = 2.00, overlap = 0.90, fft length=32,768, #-FFT = 5991, bw = 0.50, in samples = 19,661K, up = 1.00, low = 0.20

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## PEM Coupling Functions - Site-Wide Summary Plots

These plots were generated using the [pemcoupling-sitewide](#) tool.

### LHO - Magnetic

Estimated Ambient: [Plot Data](#)

Coupling Function: [Plot Data](#)

### LHO - Vibrational

Estimated Ambient: [Plot Data](#)

Coupling Function (accelerometers only): [Plot Data](#)

### LLO - Magnetic

Estimated Ambient: [Plot Data](#)

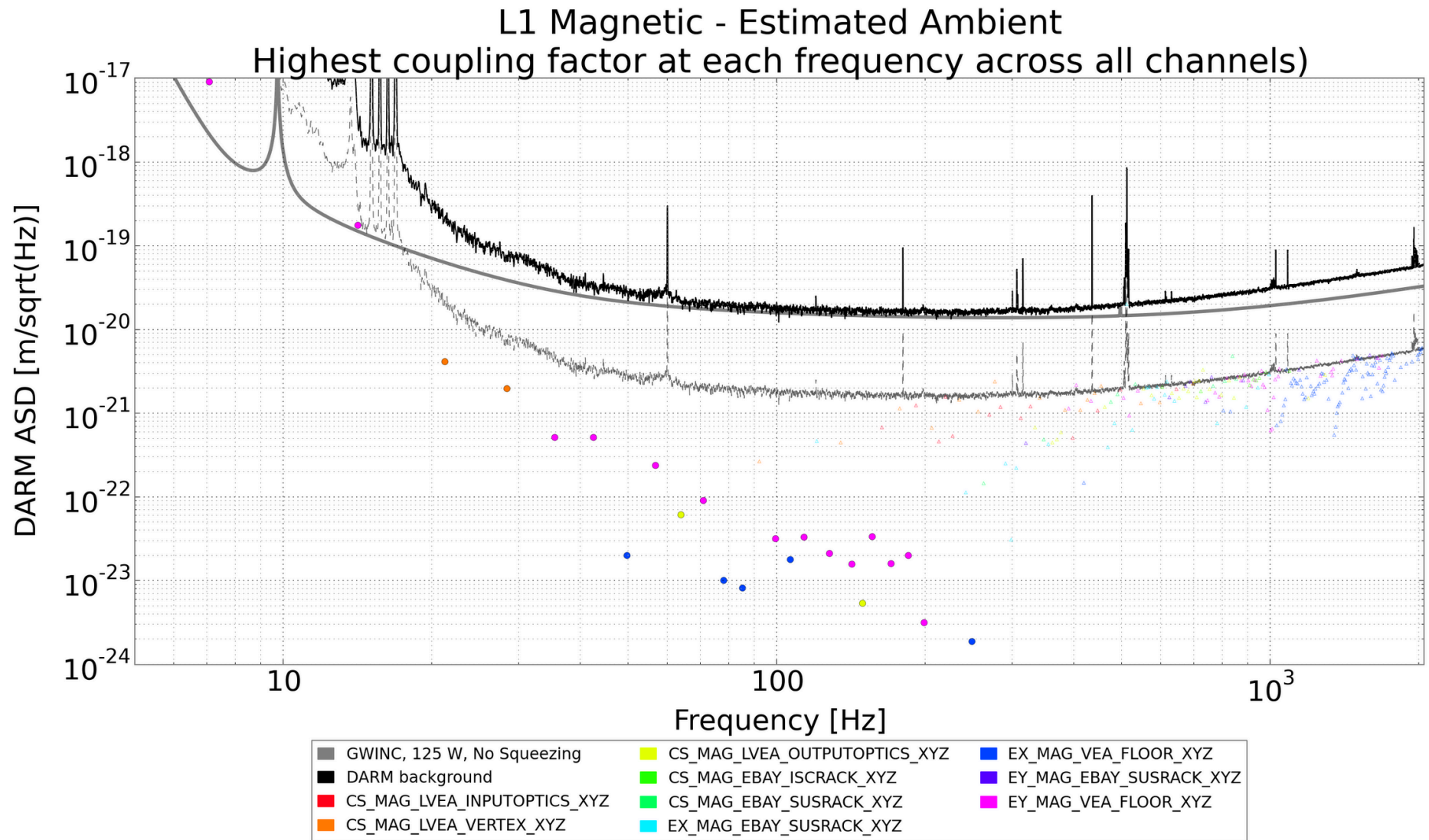
Coupling Function: [Plot Data](#)

### LLO - Vibrational

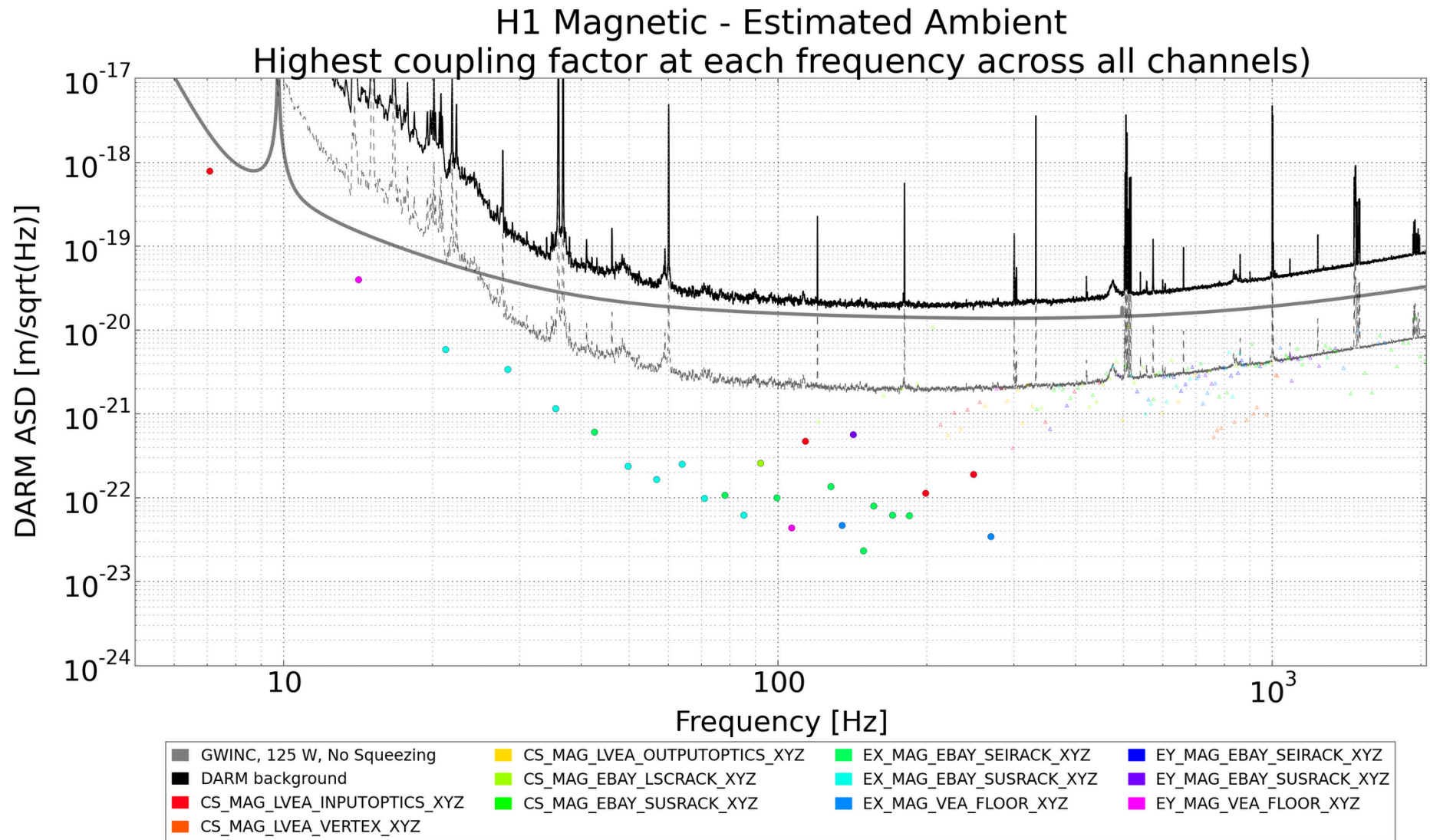
Estimated Ambient: [Plot Data](#)

Coupling Function (accelerometers only): [Plot Data](#)

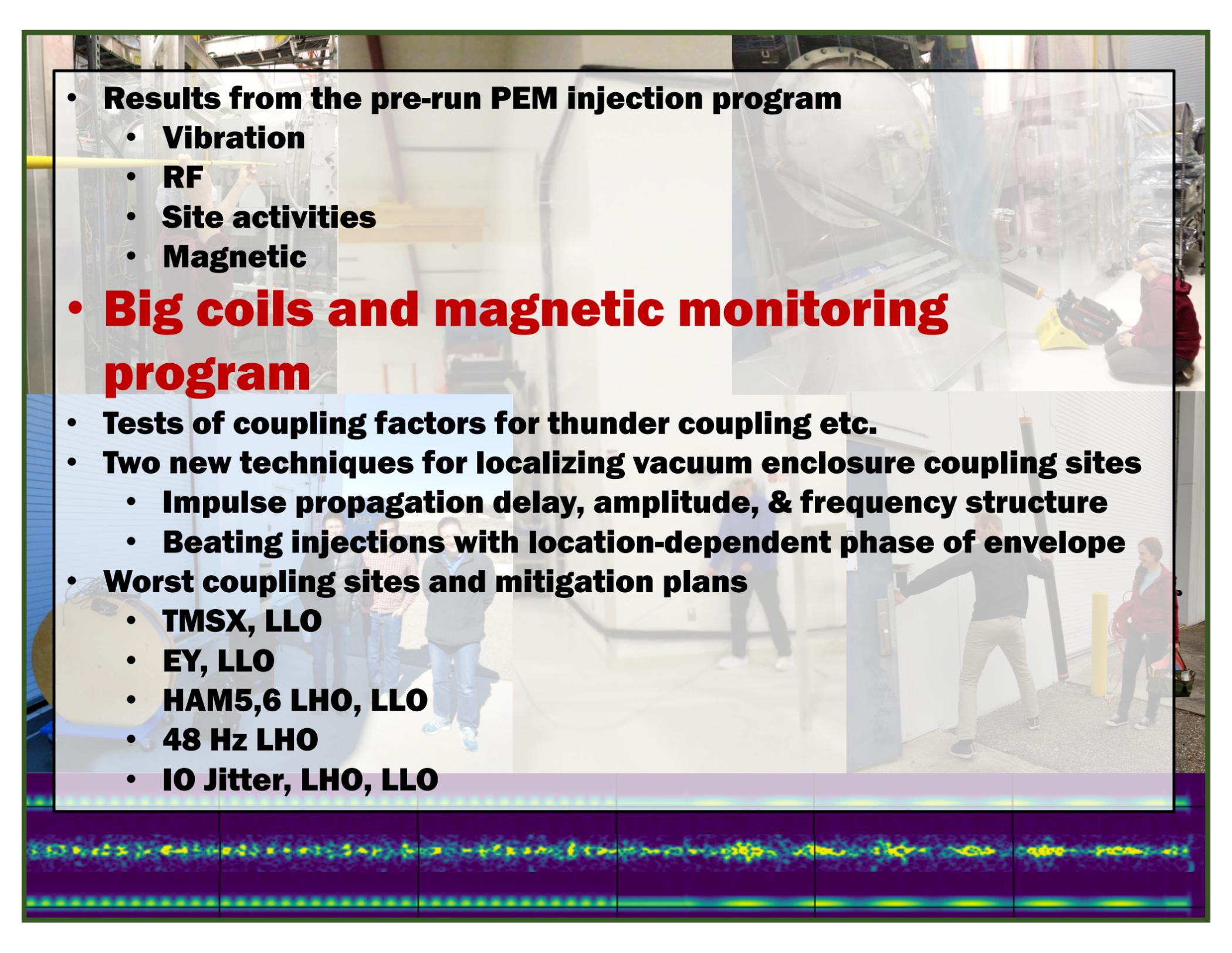
Last updated May 2019 by Philippe Nguyen ([philippe.nguyen@ligo.org](mailto:philippe.nguyen@ligo.org))



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The background of the slide is a collage of several images. At the top left, a person is working on a large piece of machinery. To the right, a large cylindrical object, possibly a vacuum chamber, is shown. Below these, there are images of people standing in a laboratory or industrial setting, and a person working on a large blue cabinet. At the bottom of the slide, there is a horizontal strip of colorful, abstract patterns resembling a spectrum or data visualization.

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# First coils at LHO & LLO

LHO CS

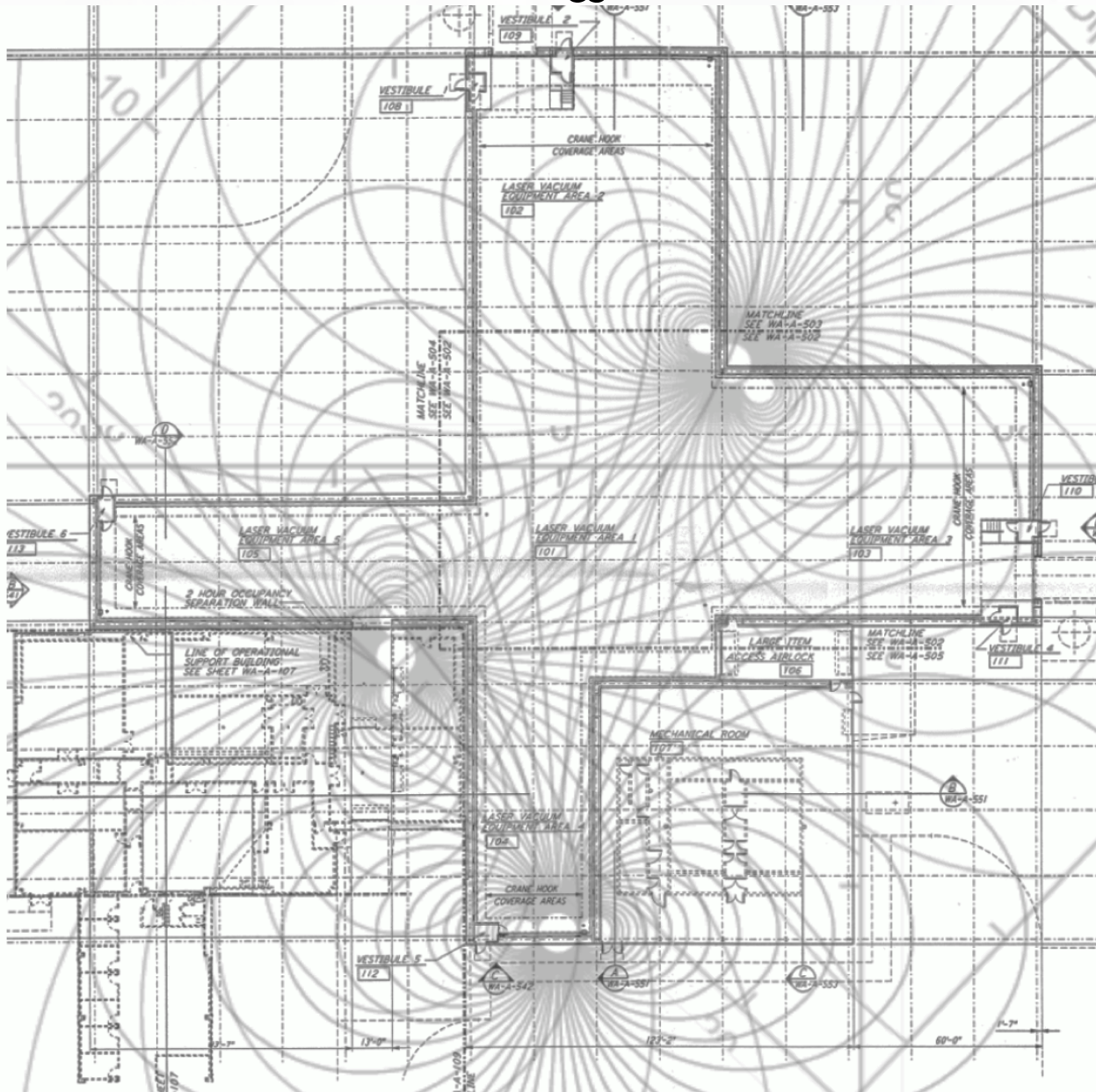


LLO EX

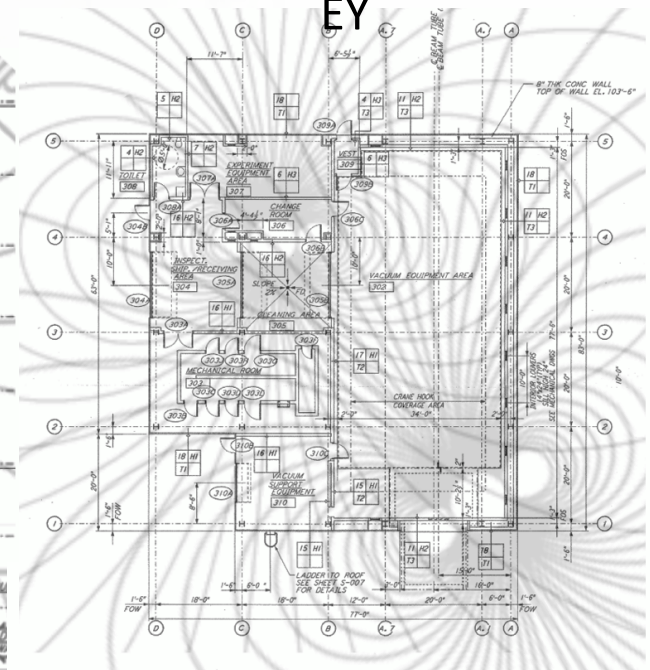


## Proposed coil locations

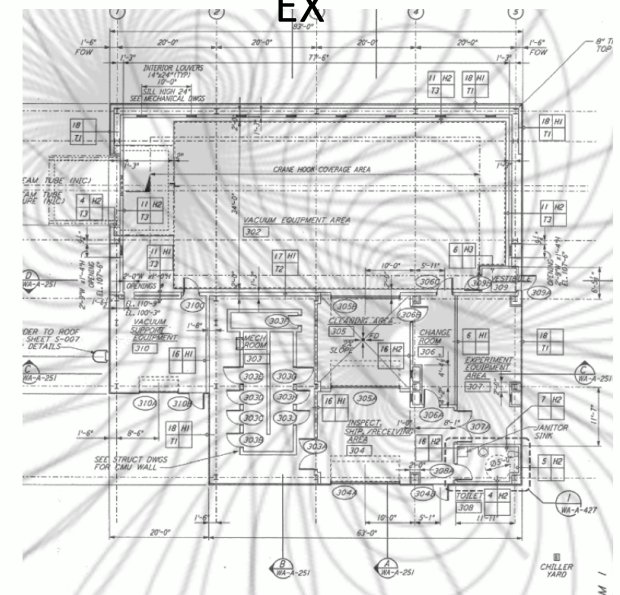
CS



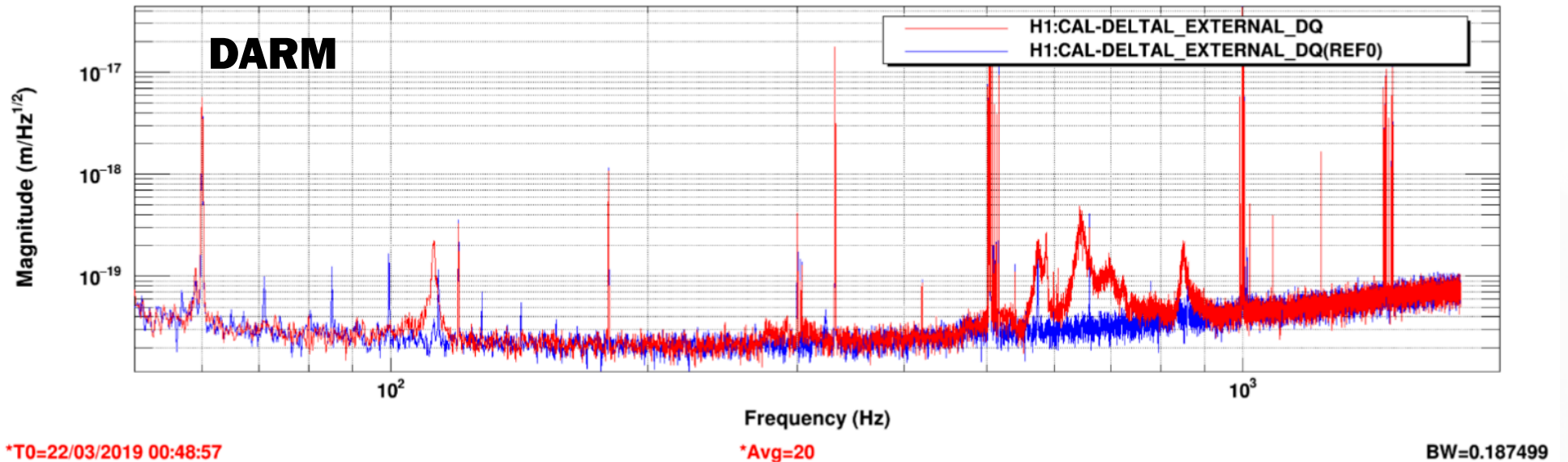
EY



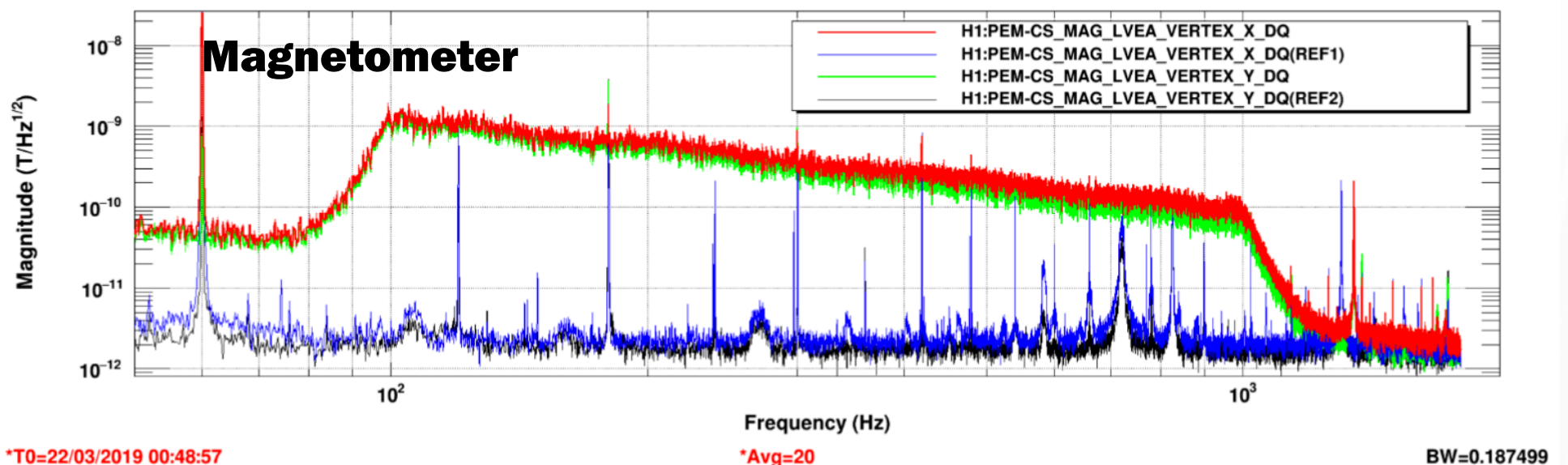
EX



# Broad band injection shows magnetic resonances



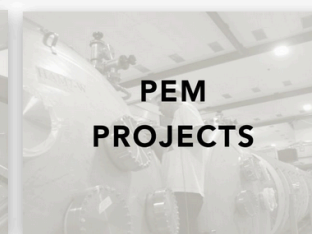
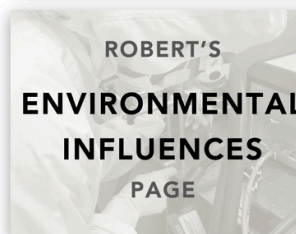
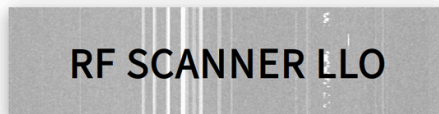
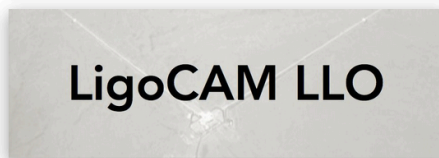
Power spectrum



# Weekly magnetic injection results

(Philippe N.)

## PEM Central



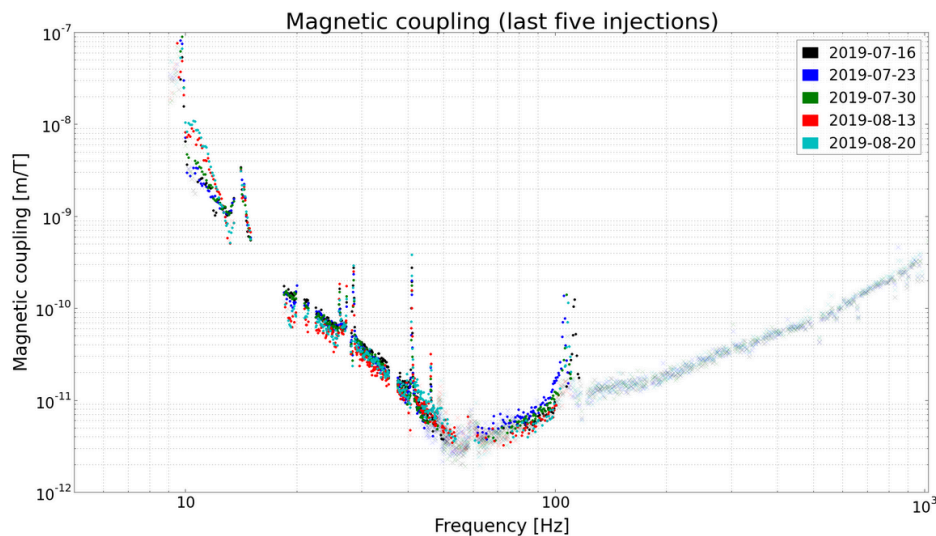
# Weekly magnetic injection

## LHO Weekly Magnetic Monitoring

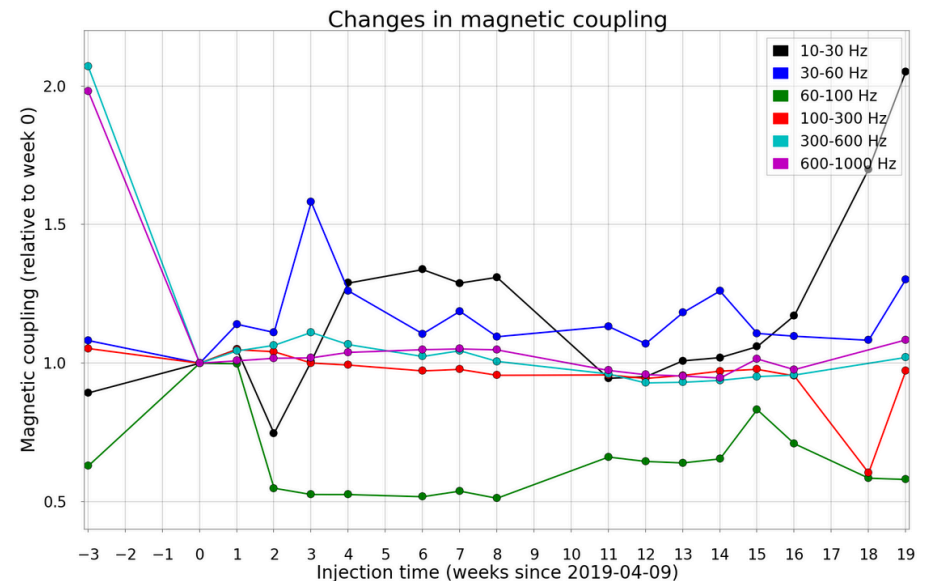
This is a summary page for the monitoring of magnetic coupling at LHO. The coupling functions shown here are measured using the Tuesday morning magnetic injections detailed in [aLog 48212](#) and [T-1900053](#). The drop-down menu at the top of page links to each individual injection, if there was one. No page is created if the injection is aborted, the injection is performed when the IFO was not locked, or the analysis code fails to run.

All coupling functions here were measured with the [pemcoupling code](#). See the [documentation](#) and [G-1800121](#) for more details.

Coupling functions measured from the last five injections.



Changes in magnetic coupling in multiple frequency bands, relative to the coupling measured from the earliest injection.



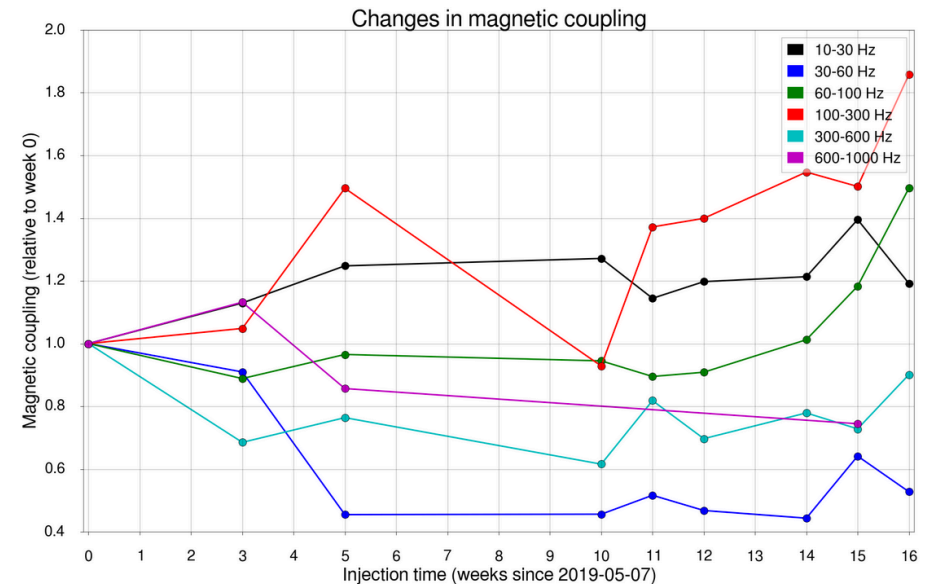
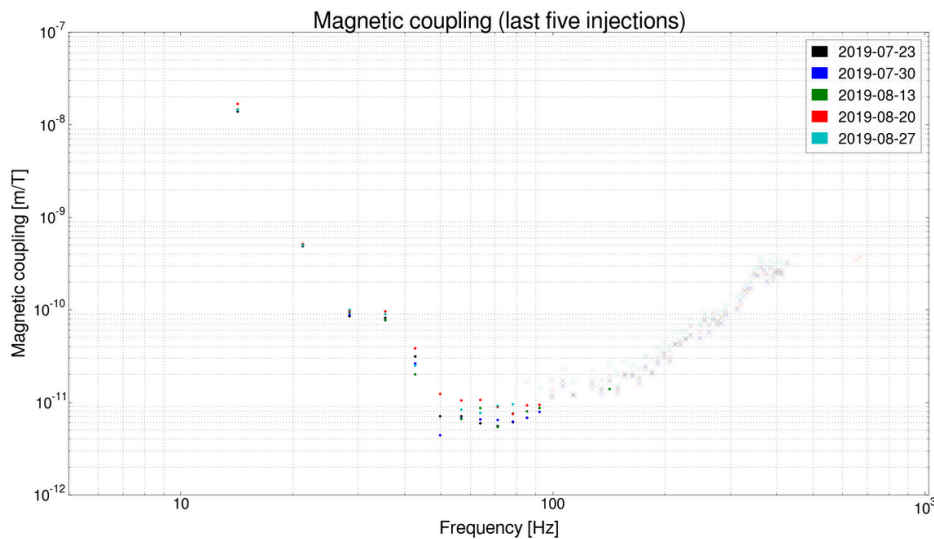
## LLO Weekly Magnetic Monitoring

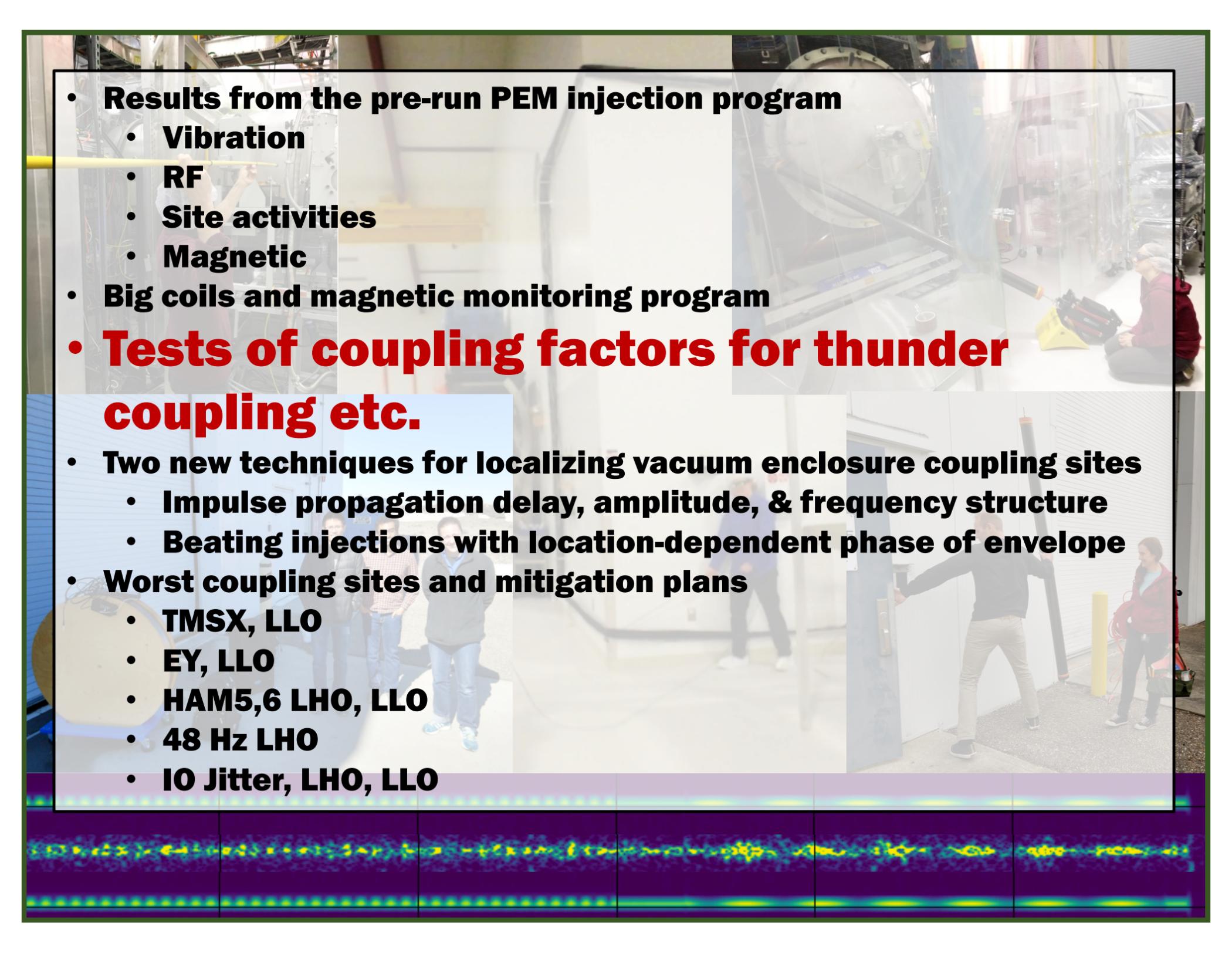
This is a summary page for the monitoring of magnetic coupling at LLO. The coupling functions shown here are measured using the Tuesday morning magnetic injections detailed in [aLog 48212](#) and [T-1900053](#). The drop-down menu at the top of page links to each individual injection, if there was one. No page is created if the injection is aborted, the injection is performed when the IFO was not locked, or the analysis code fails to run.

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  - **48 Hz LH0**
  - **IO Jitter, LH0, LLO**

# **Effects of environment on DARM are consistent with PEM coupling functions**

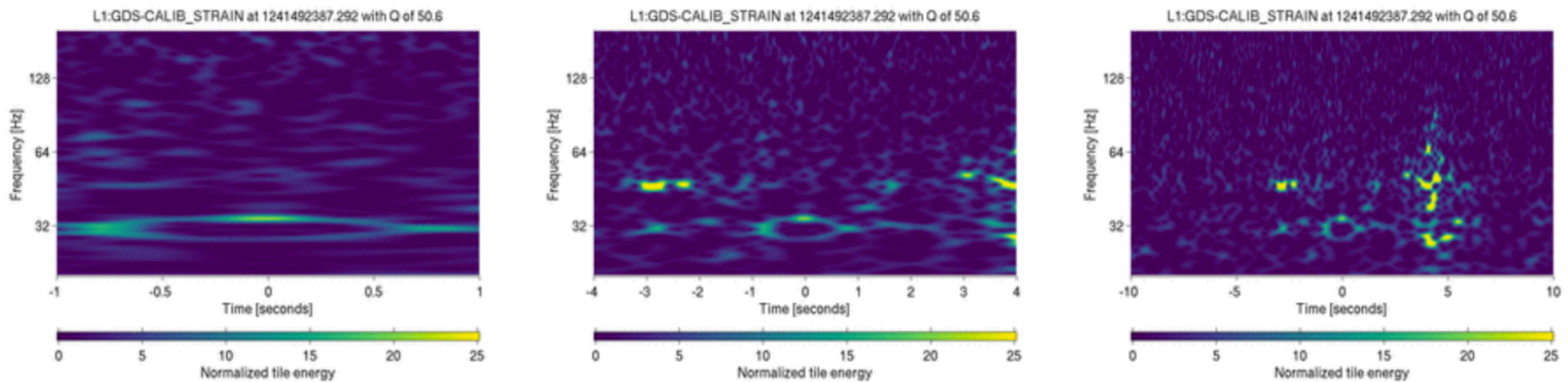
- 1. Range reduction from LHO HVAC is roughly predicted from estimates for HAM5/6.**
- 2. Range reduction from rain at LHO is roughly consistent with PEM coupling functions, though underestimated by 2 at 48 Hz**
- 3. Range reduction from wind at LHO is roughly consistent with PEM coupling functions.**
- 4. LLO DARM glitch from thunder near S190510g is correctly predicted from PEM injection coupling functions.**

# Thunder associated with S190510g in DARM and accelerometer

## ✓ L1:GDS-CALIB\_STRAIN

most significant tile:  $t = 1241492384.438$  s,  $f = 46.6$  Hz,  $Q = 50.6$ ,  $Z = 6.6 \times 10^1$ ,  $X = 7.5 \times 10^{-23}$  Hz $^{-1/2}$ , SNR = 11.5

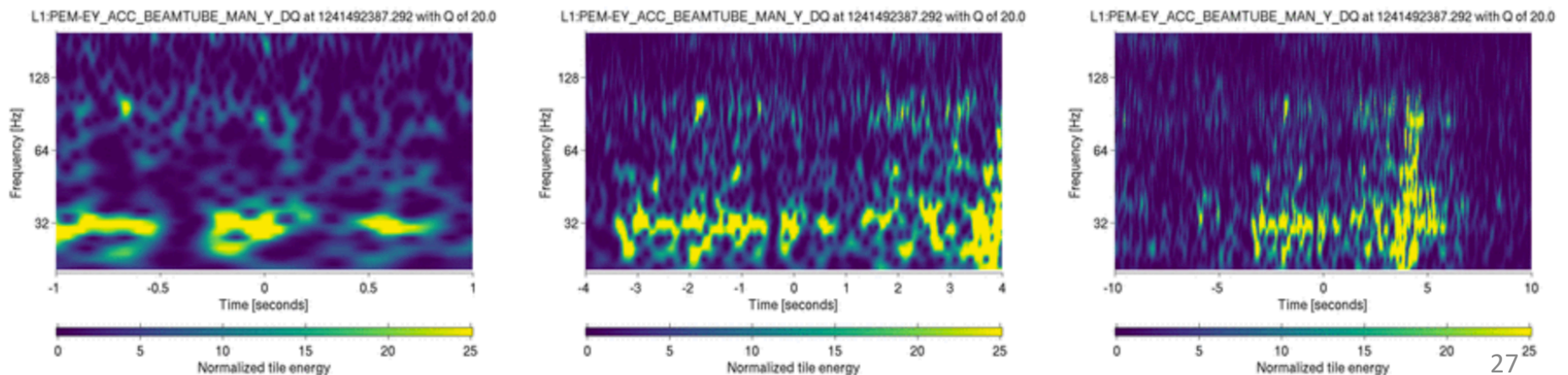
time series: raw, high passed, whitened | spectrogram: raw, whitened, autoscaled | eventgram: raw, whitened, autoscaled



## ✓ L1:PEM-EY\_ACC\_BEAMTUBE\_MAN\_Y\_DQ

most significant tile:  $t = 1241492390.906$  s,  $f = 30.9$  Hz,  $Q = 20.0$ ,  $Z = 3.2 \times 10^2$ ,  $X = 6.2 \times 10^1$  Hz $^{-1/2}$ , SNR = 25.4

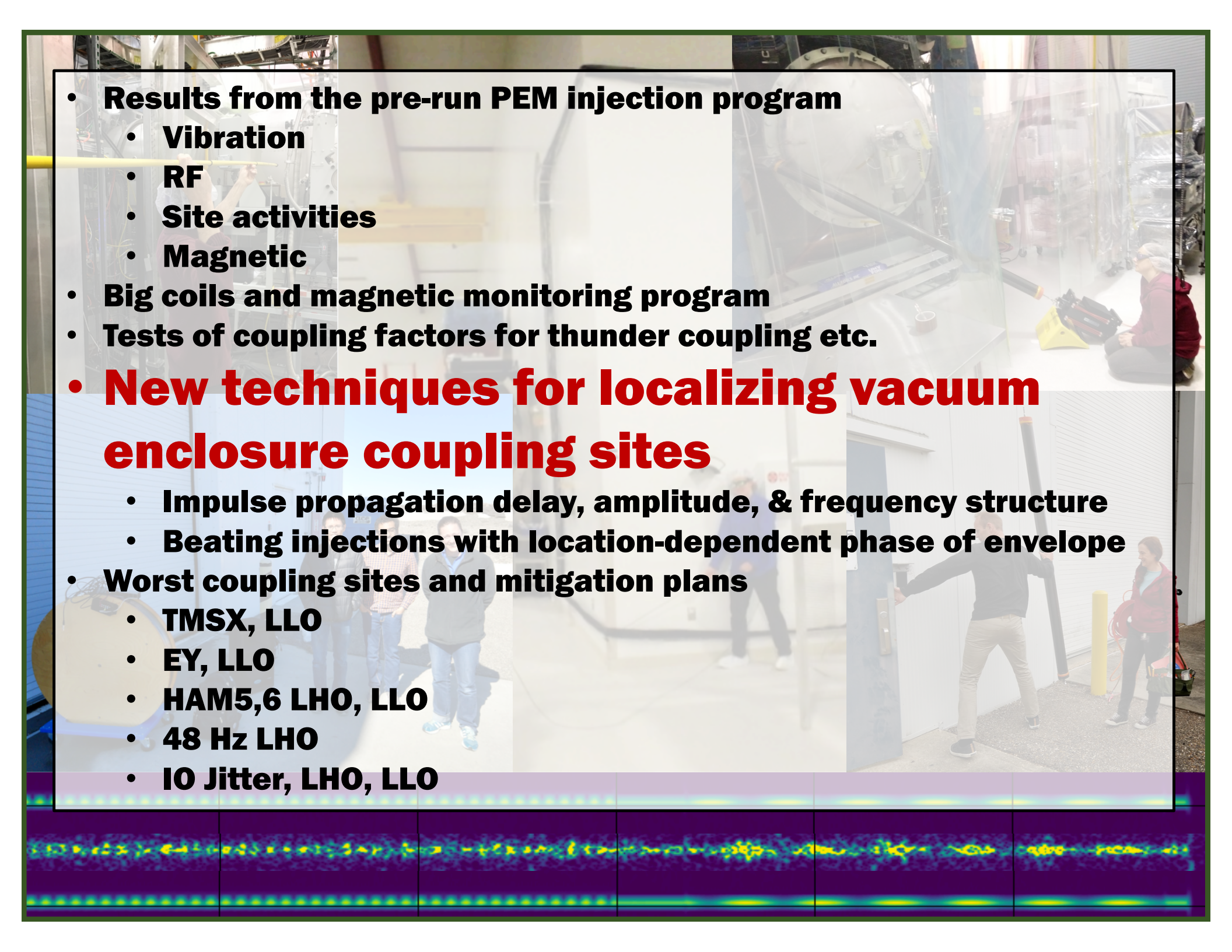
time series: raw, high passed, whitened | spectrogram: raw, whitened, autoscaled | eventgram: raw, whitened, autoscaled



# Automated DQR results: signal in DARM is well predicted

Channel	Peak frequency	Peak amplitude	Coupling function at peak freq	Coupling function flag	Estimated DARM amplitude	DARM background	Estimated amplitude / bkgd
L1:PEM-EY_ACC_BEAMTUBE_MAN_Y_DQ	30.9	6.2e+01	1.7e-20	Upper Limit	1.0e-18	7.6e-20	13.85
L1:PEM-EY_ACC_BSC5_ETMY_X_DQ	47.3	3.7e+01	7.6e-21	Measured	2.8e-19	3.4e-20	8.31
L1:PEM-EY_ACC_BSC5_ETMY_Y_DQ	47.3	9.6e+01	2.9e-21	Measured	2.7e-19	3.4e-20	8.17
L1:PEM-EY_ACC_VEA_FLOOR_Z_DQ	32.7	1.3e+01	3.0e-20	Upper Limit	3.9e-19	5.9e-20	6.70
L1:PEM-EY_ACC_BEAMTUBE_MAN_Z_DQ	47.3	3.9e+01	5.0e-21	Measured	2.0e-19	3.4e-20	5.89
L1:PEM-EX_ACC_BSC4_ETMX_X_DQ	28.1	2.2e+01	1.4e-20	Upper Limit	3.1e-19	7.2e-20	4.33
L1:PEM-EY_ACC_OPLEV_ETMY_X_DQ	56.9	4.2e+01	2.7e-21	Measured	1.2e-19	2.8e-20	4.19
L1:PEM-CS_ACC_BEAMTUBE_MCTUBE_Y_DQ	37.9	1.6e+01	9.3e-21	Upper Limit	1.5e-19	4.1e-20	3.58
L1:PEM-EY_ACC_BSC5_ETMY_Z_DQ	32.7	1.3e+01	1.5e-20	Upper Limit	2.0e-19	5.9e-20	3.48
L1:PEM-EY_MIC_VEA_PLUSY_DQ	48.2	9.2e+01	1.2e-21	Measured	1.1e-19	3.1e-20	3.39
L1:PEM-CS_ACC_ISCT1_REFL_Y_DQ	38.8	1.0e+01	6.9e-21	Upper Limit	7.1e-20	4.0e-20	1.78
L1:PEM-EX_ACC_BSC4_ETMX_Z_DQ	26.8	3.5e+00	4.9e-20	Upper Limit	1.7e-19	1.1e-19	1.56
L1:PEM-EX_ACC_OPLEV_ETMX_Y_DQ	37.2	3.6e+00	2.1e-20	Upper Limit	7.5e-20	4.9e-20	1.52
L1:PEM-CS_ACC_LVEAFLOOR_HAM1_Z_DQ	24.5	1.7e+00	9.8e-20	Upper Limit	1.7e-19	1.2e-19	1.42
L1:PEM-EX_MIC_EBAY_RACKS_DQ	21.6	2.0e+01	1.2e-20	Upper Limit	2.5e-19	1.8e-19	1.37
L1:PEM-EX_ACC_VEA_FLOOR_Z_DQ	26.8	3.5e+00	3.9e-20	Upper Limit	1.4e-19	1.0e-19	1.31
L1:PEM-CS_ACC_BSC1_ITMY_Y_DQ	23.9	1.4e+01	1.1e-20	Upper Limit	1.5e-19	1.3e-19	1.21
L1:PEM-CS_ACC_HAM2_PRMY_DQ	34.6	3.9e+00	1.5e-20	Upper Limit	5.8e-20	5.0e-20	1.16
L1:PEM-CS_ACC_PSL_PERISCOPE_X_DQ	39.9	1.4e+00	3.4e-20	Upper Limit	4.6e-20	4.2e-20	1.10
L1:PEM-EY_ACC_EBAY_FLOOR_Z_DQ	44.2	1.3e+01	2.8e-21	Upper Limit	3.6e-20	3.5e-20	1.03

**Similar automated calculations are made for every PEM trigger around candidates**

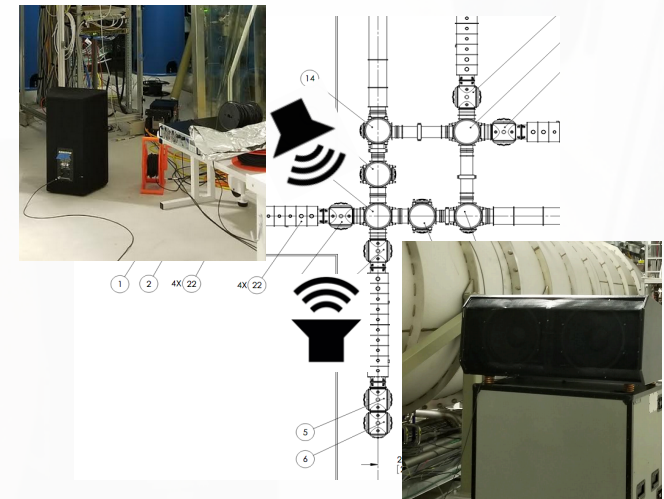
- 
- The background of the slide is a collage of several images. At the top left, a person is working on a large piece of machinery. In the top right, a person is kneeling on the floor next to a large, complex machine. In the center, a group of people are standing in a large, open industrial space. At the bottom right, a person is standing next to a large, white, cylindrical object. The bottom of the slide features a series of horizontal bands with a colorful, abstract pattern, possibly representing a data visualization or a decorative element.
- **Results from the pre-run PEM injection program**
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# I. New techniques for localizing vacuum enclosure coupling

**When you shake HAM5, HAM6 and other places shake also, so other techniques are needed to narrow potential coupling sites**

**1. Impulse injections at multiple sites, monitor DARM and accelerometers for consistency of propagation delays, amplitude ratios, and resonance structure.**

**2. Beating injections producing location-dependent phase of beat-envelope. Coupling site is near accelerometer that best matches phase of beat-envelope in DARM. **Better for narrow-band coupling****



# 1. Impulse injected onto vacuum enclosure at multiple sites

**a. consistency between accelerometer and DARM arrival times**

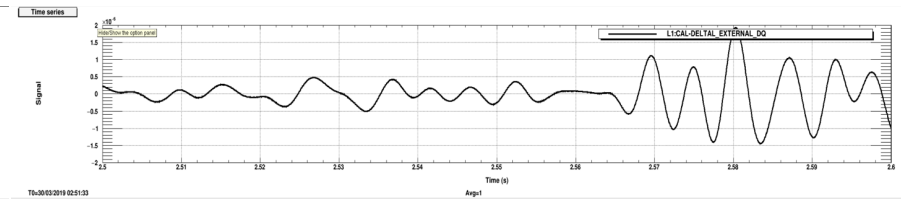
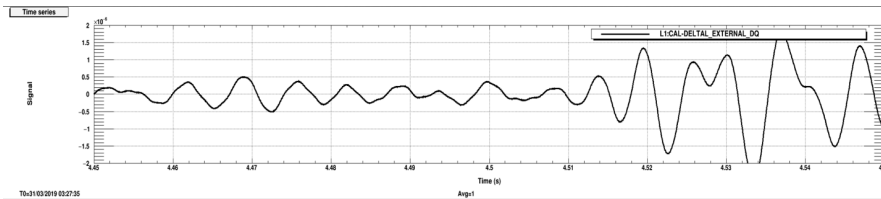
**b. consistency between accelerometer/DARM amplitude ratios**

**c. consistency between accelerometer and DARM frequency structure**

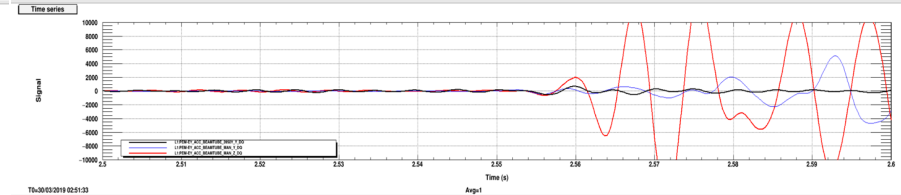
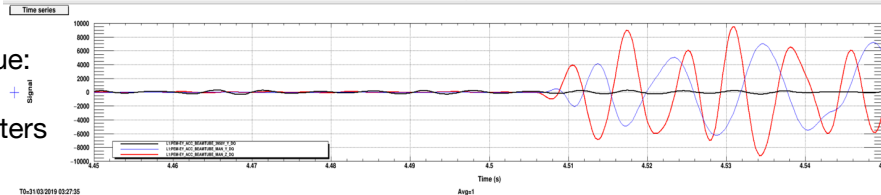
Soft hammer strike on -Y reduction flange, 70-200 Hz band

Soft hammer strike on end cap, 70-200 Hz band

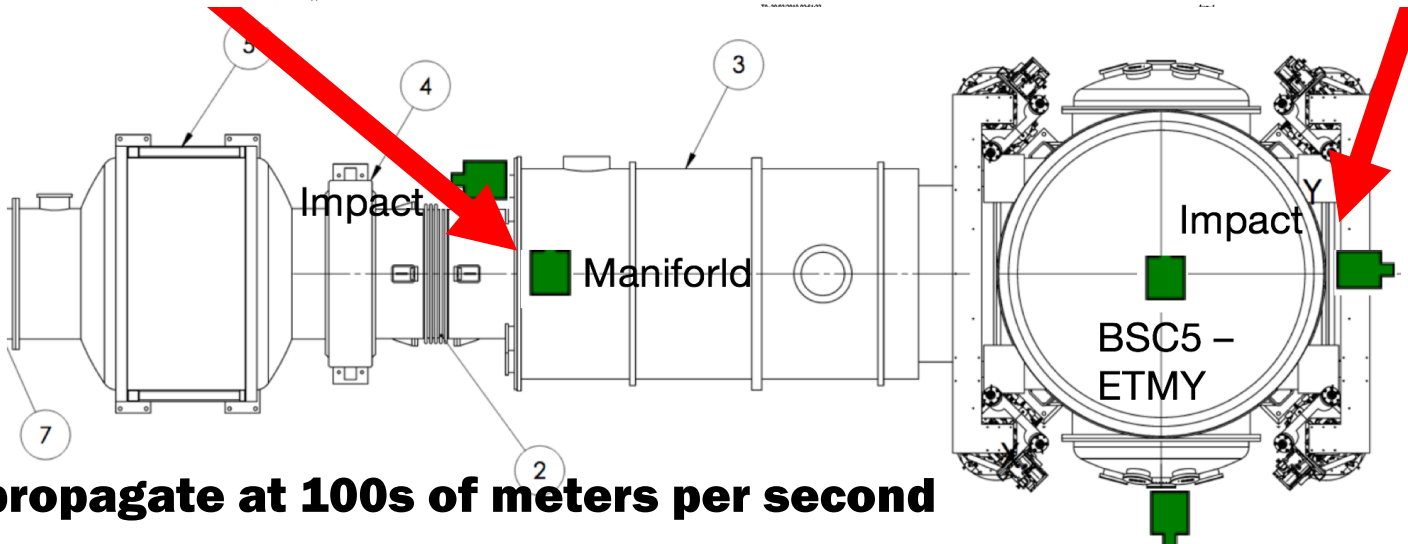
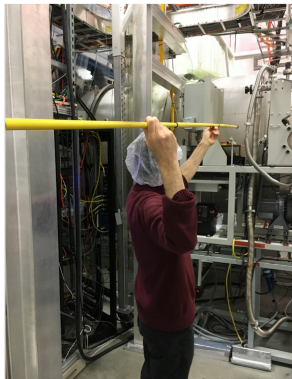
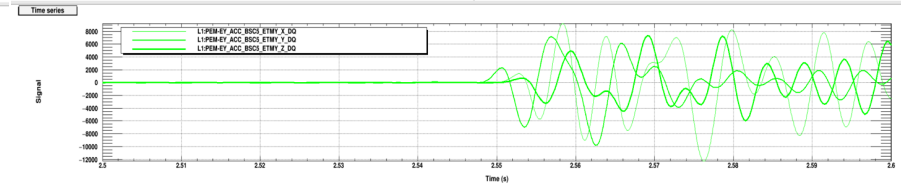
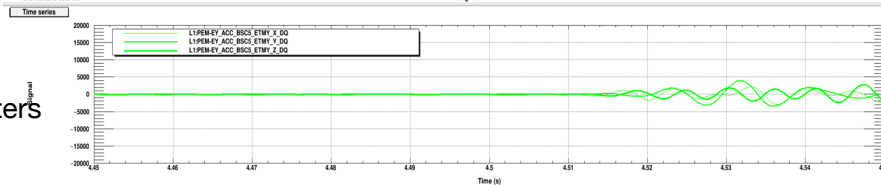
DARM



Red and Blue:  
manifold  
+  
accelerometers

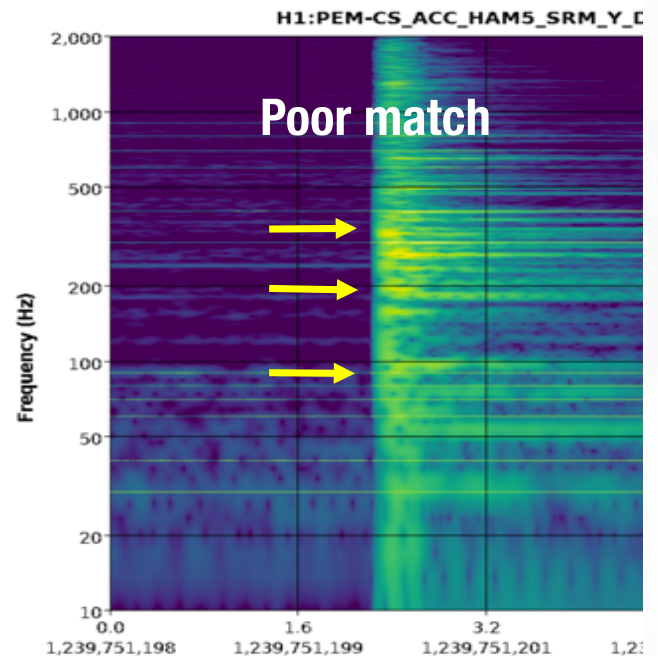
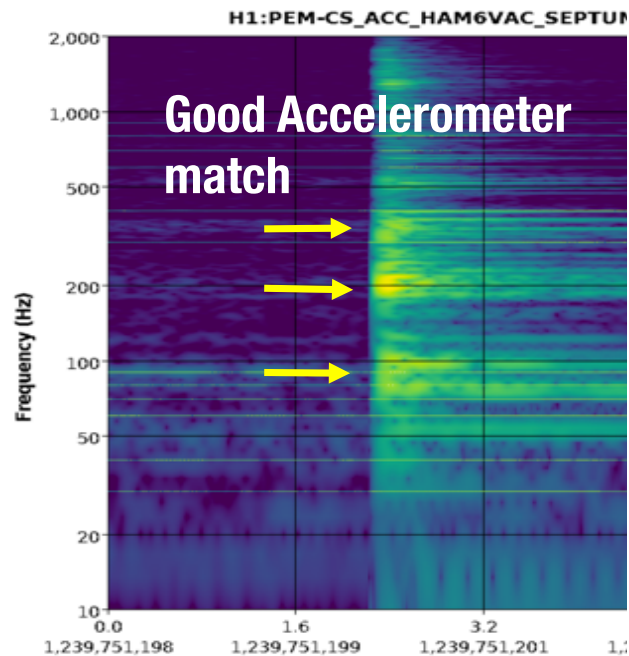
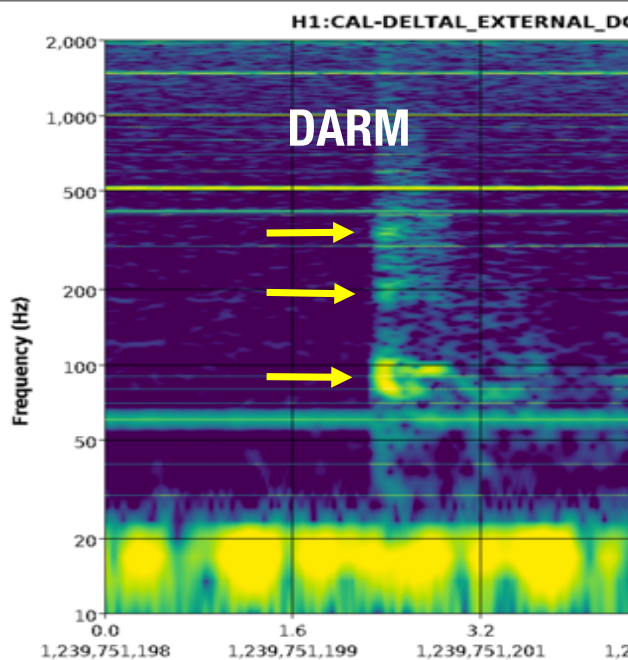


BSC 5  
accelerometers



**Impulses propagate at 100s of meters per second**

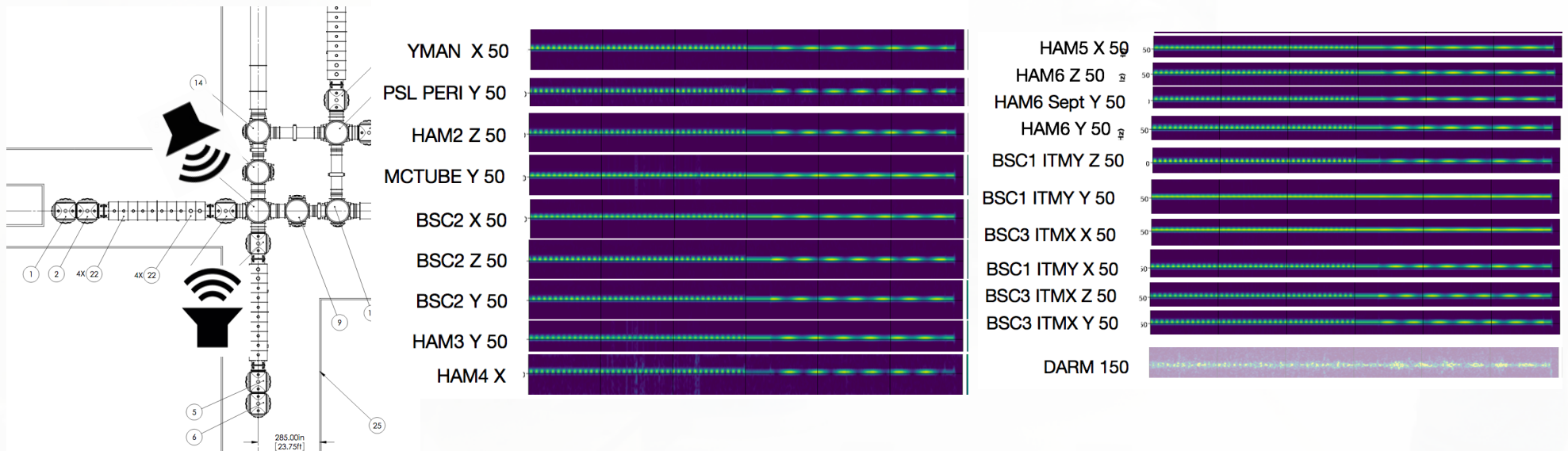
- 1. Impulse injected onto vacuum enclosure at multiple sites**
  - a. consistency between accelerometer and DARM arrival times**
  - b. consistency between accelerometer/DARM amplitude ratios**
  - c. consistency between accelerometer and DARM frequency structure**



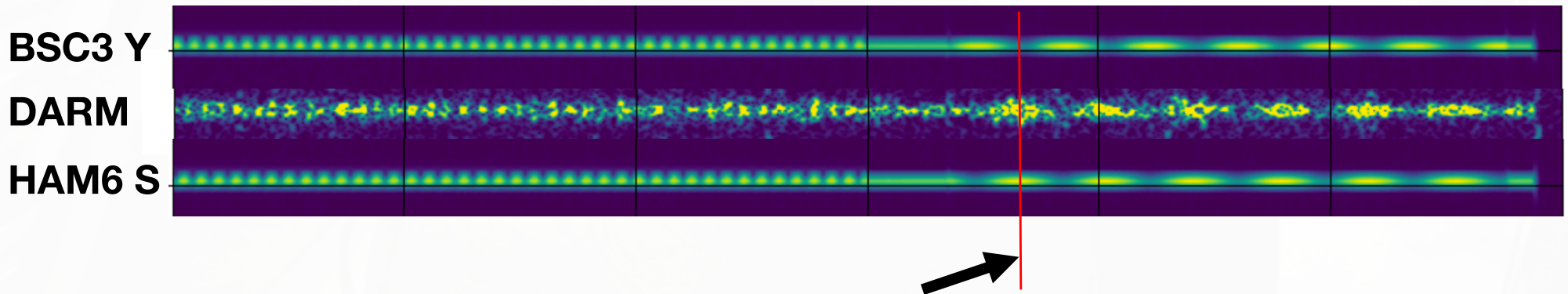
## 2. Separated beating injections to produce location-dependent beat-envelope phase

### a. Accelerometer and DARM consistency for acoustic injections

### b. Accelerometer and DARM consistency for vacuum enclosure



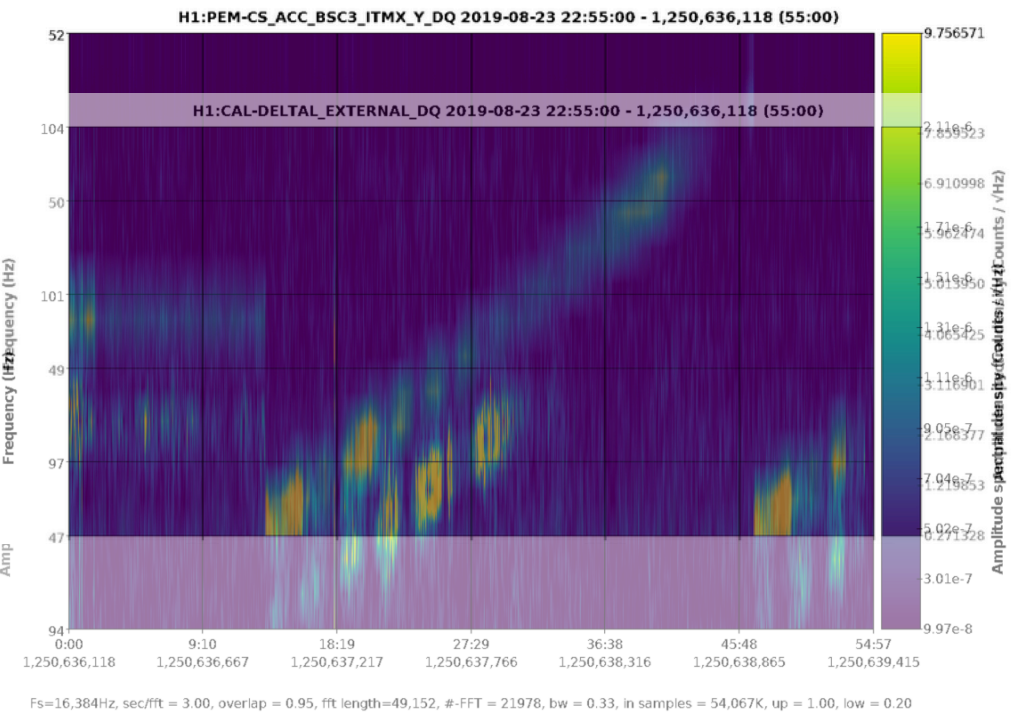
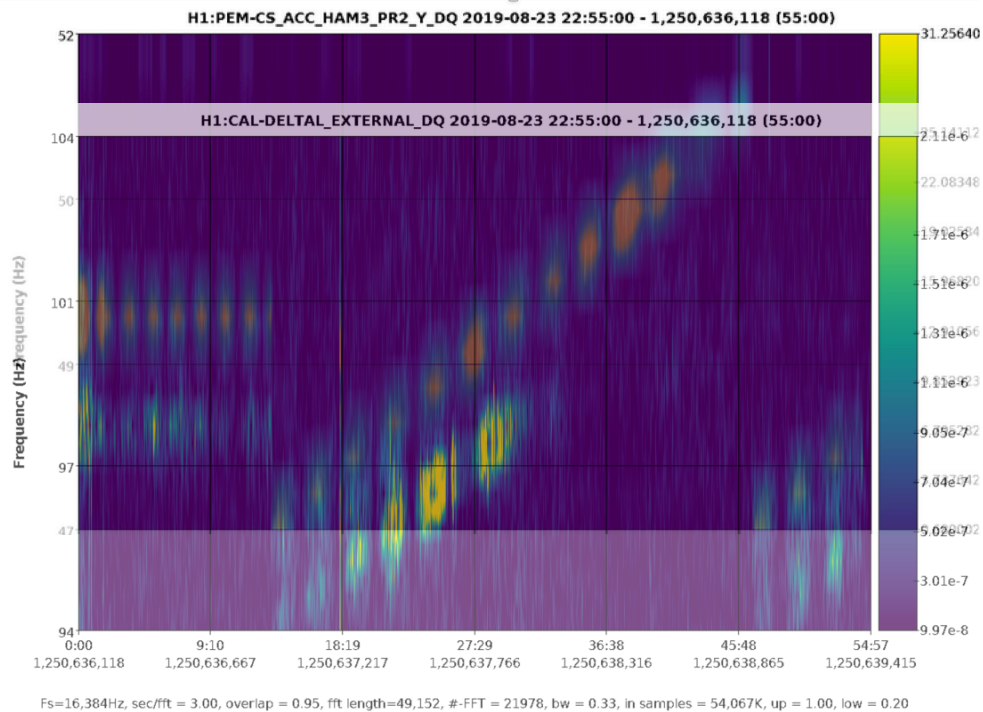
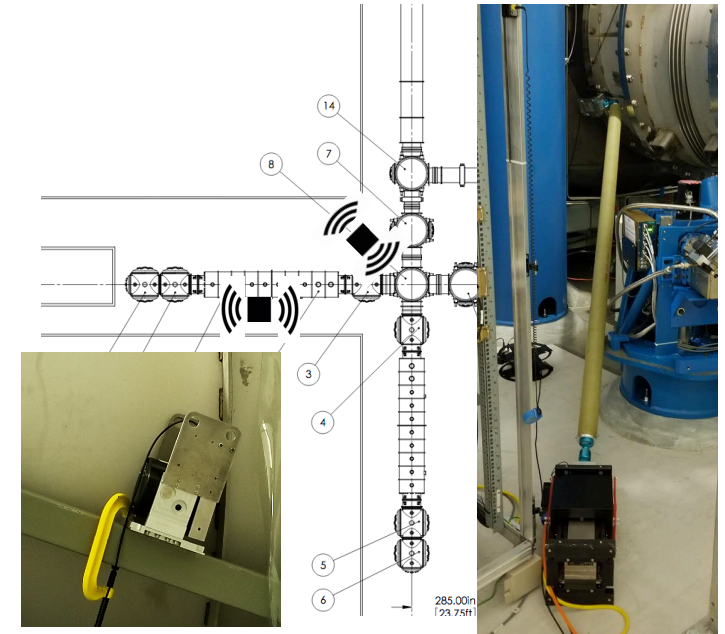
Strips of spectrograms with 20s 50, 50.05 Hz beats followed by 50, 50.01 Hz 100s beats



BSC3 accelerometer doesn't match DARM envelope but HAM6 septum does

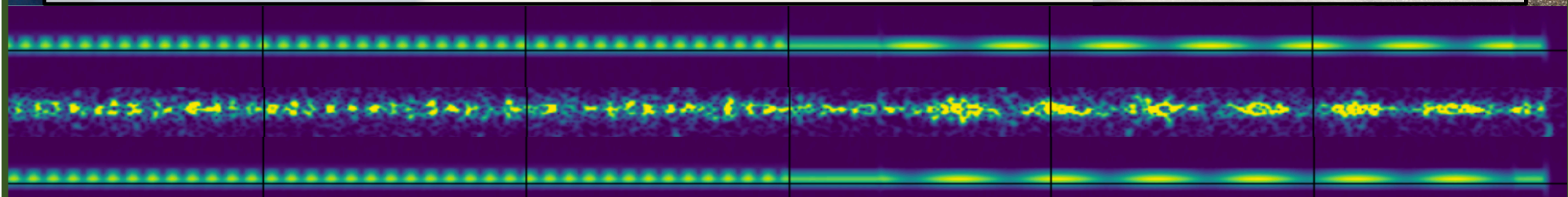
## 2. Double injections to produce location-dependent beat-envelope phase

- a. Accelerometer and DARM consistency for acoustic injections
- b. Accelerometer and DARM consistency for vacuum enclosure shaking



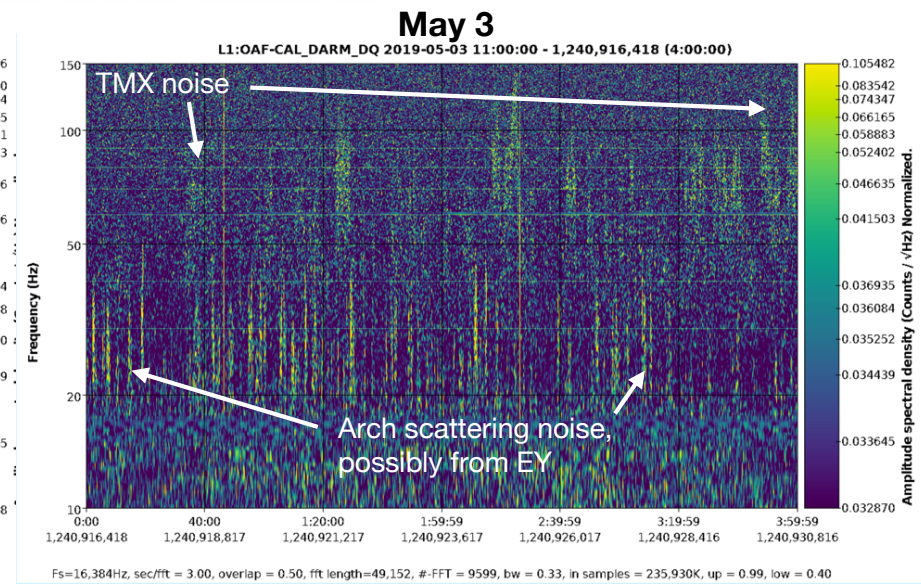
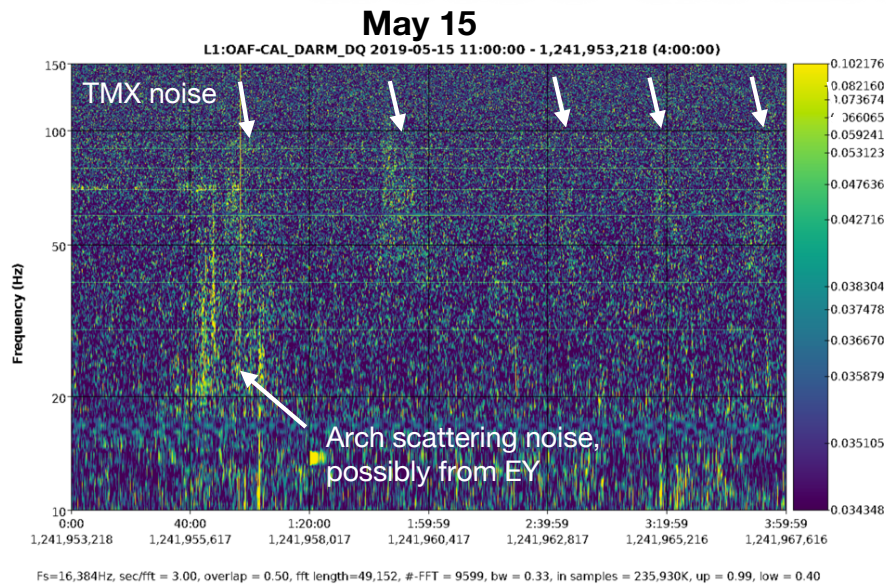
Frequency sweep to reduce chance of accidental alignment for non-coupling locations

- **Results from the pre-run PEM injection program**
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  - **IO Jitter, LH0, LLO**

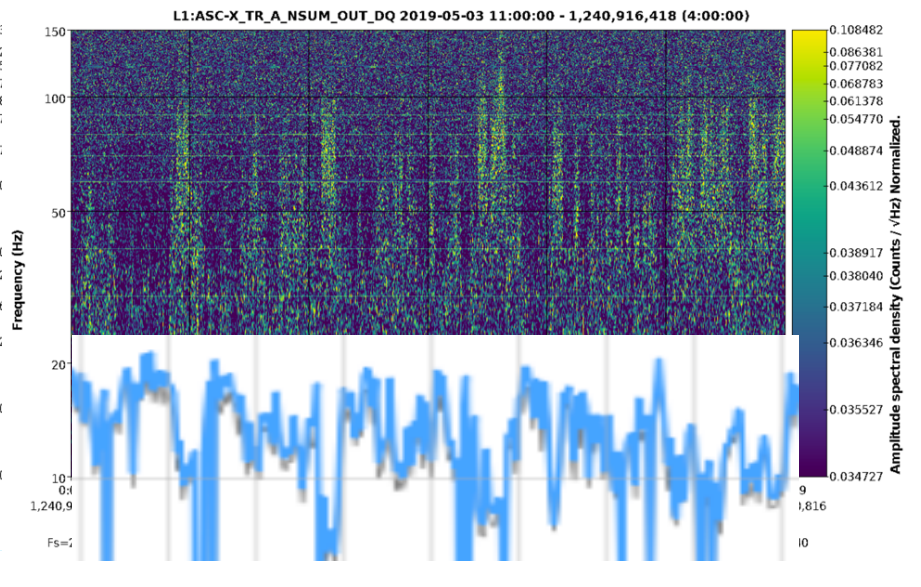
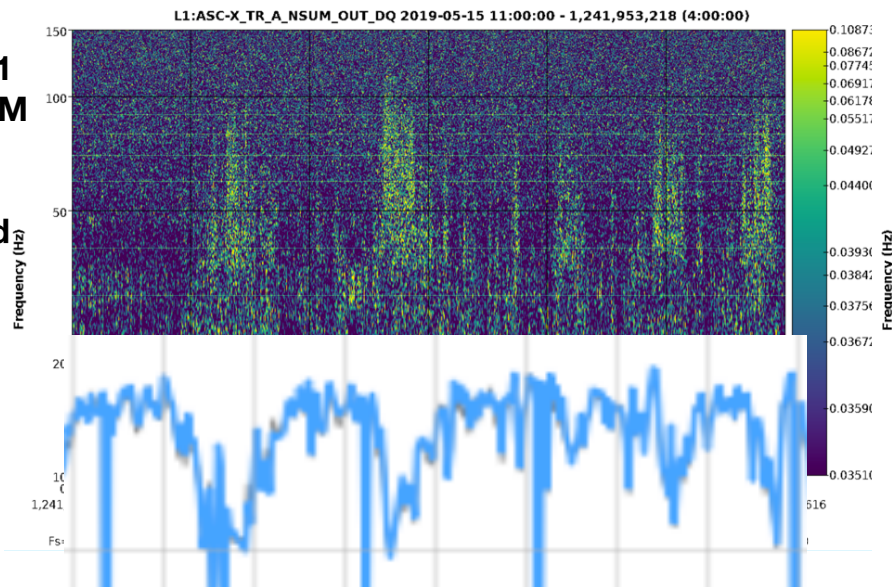


# Worst source of range drops: TMSX noise at EX at LLO

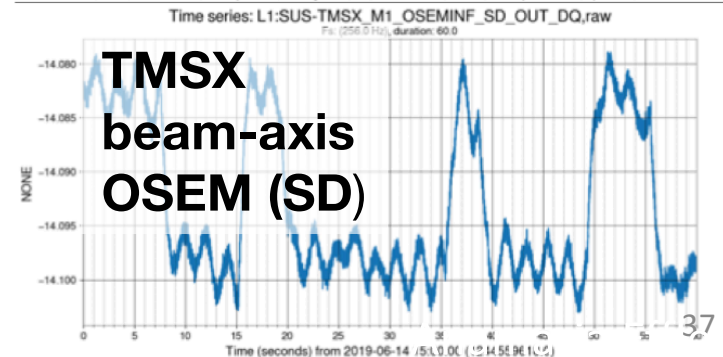
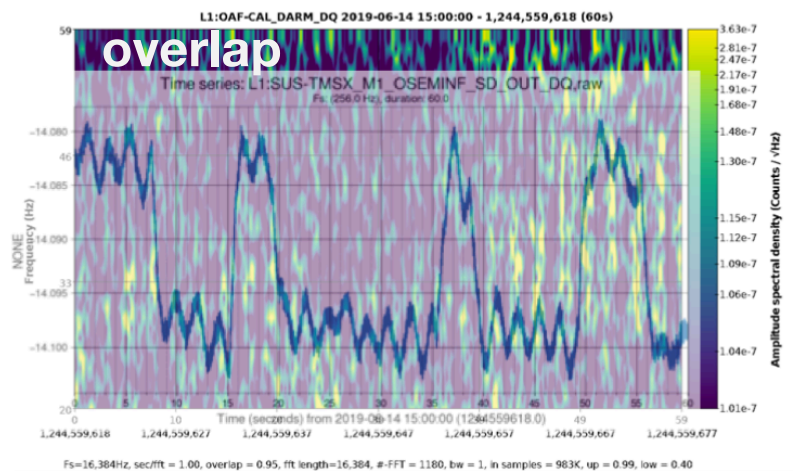
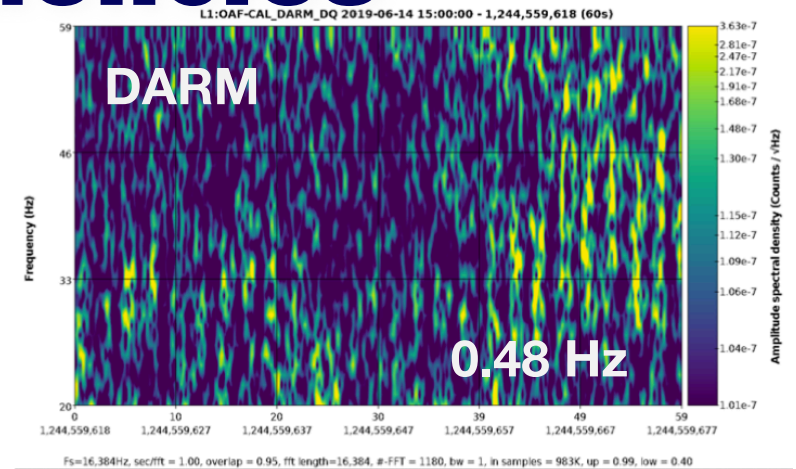
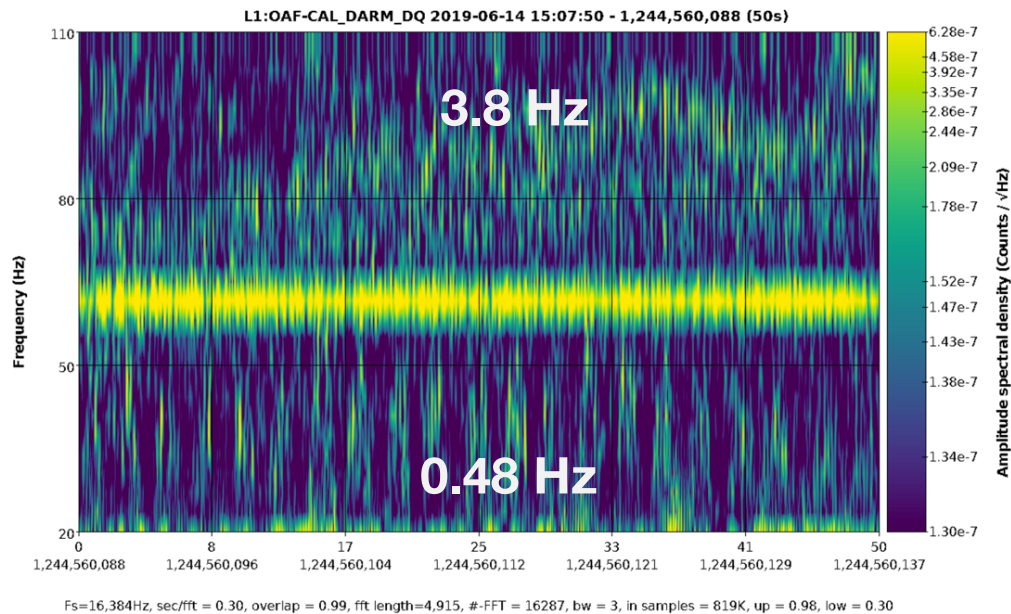
L1 DARM  
4 hours



TMX noise: L1  
X\_TR\_A\_NSUM  
signal from  
transmission  
monitor quad  
photodiode

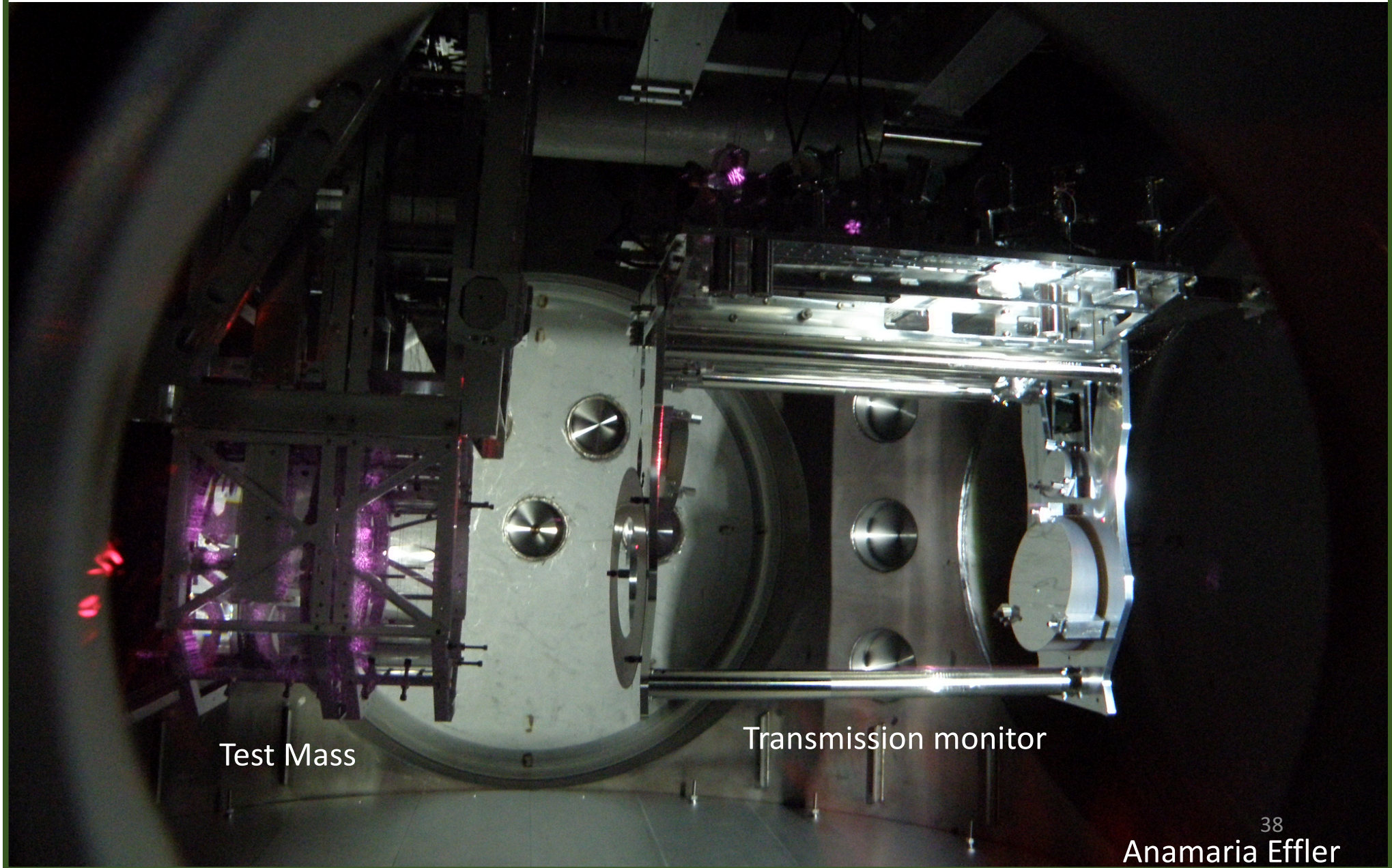


# Noise in DARM modulated at TMSX suspension frequencies



Angular motion of the TMSX could produce high frequencies in DARM if the scattered light only couples back into the arm cavity over a couple of percent of the angular range (i.e. intensity noise from varying mode matching).

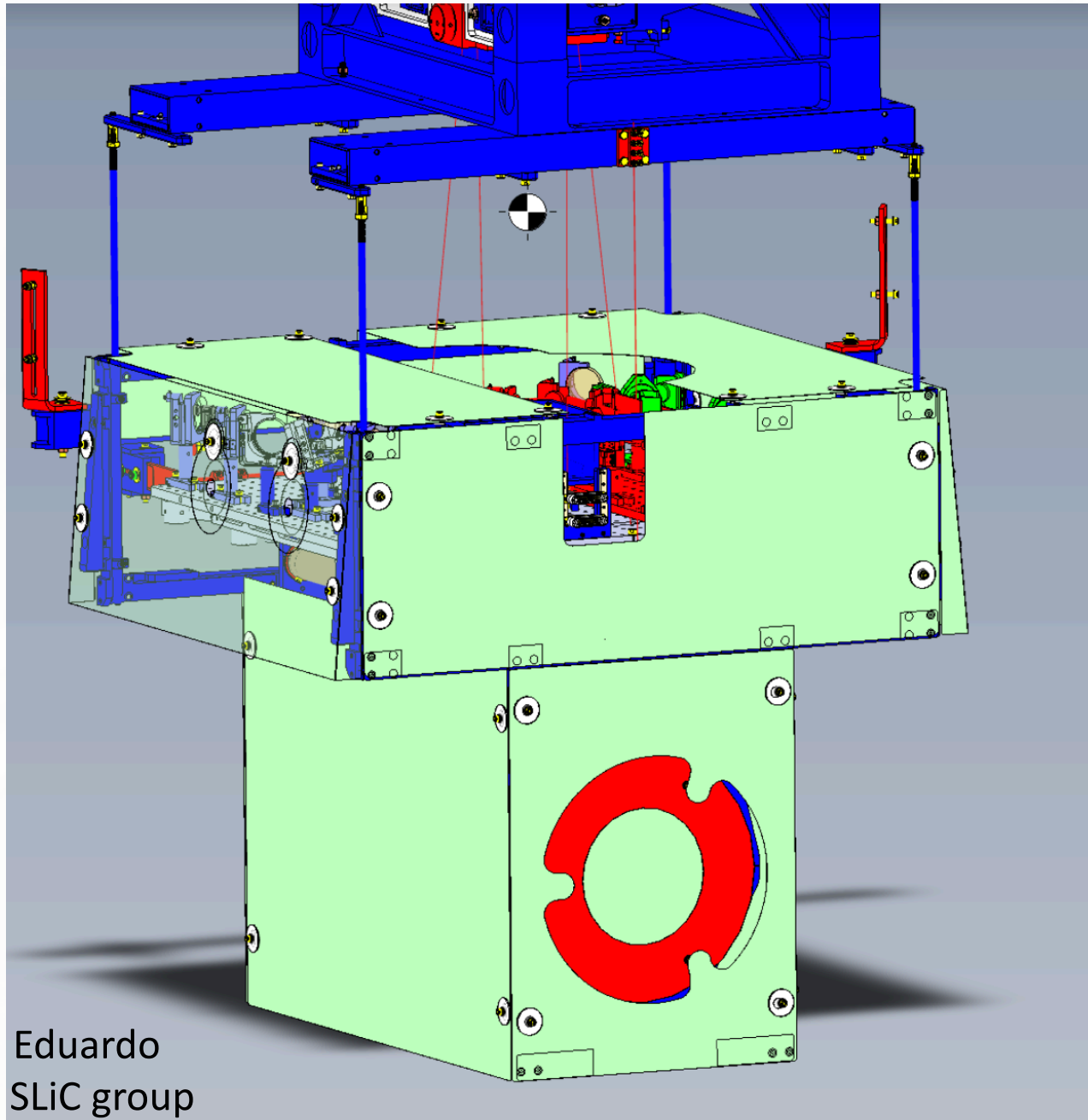
# Transmission monitor during lock



Test Mass

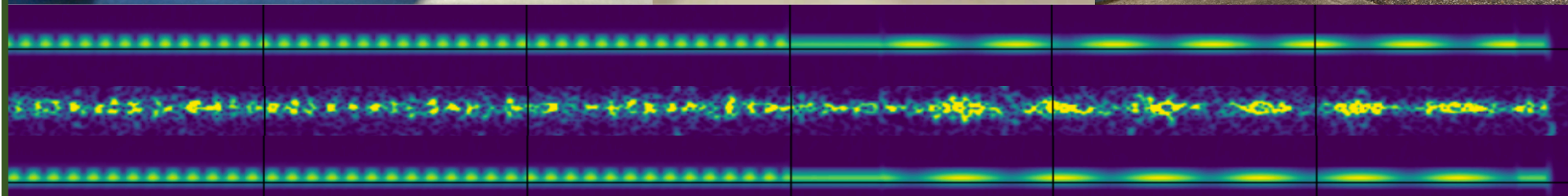
Transmission monitor

# TMS shroud



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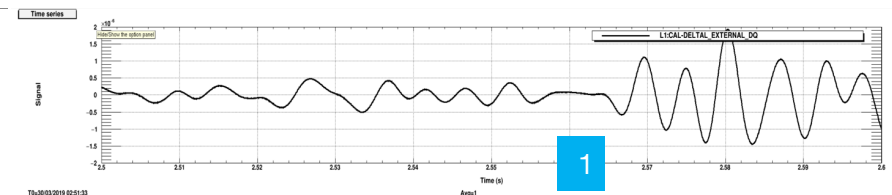
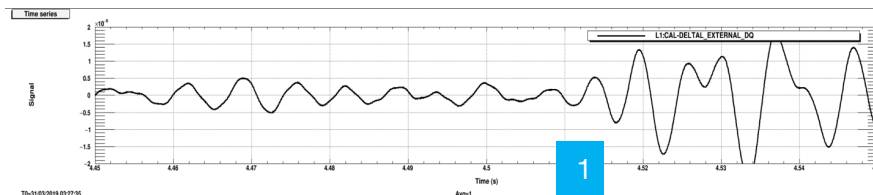
# Impulse injections suggest EY coupling site is in manifold near P-cal periscope

Figure 1b. LLO EY: accelerometer signals are most consistent with coupling site in manifold

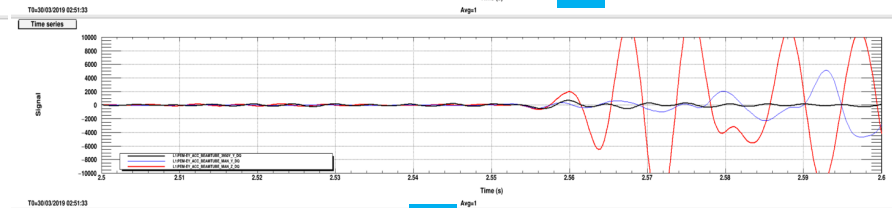
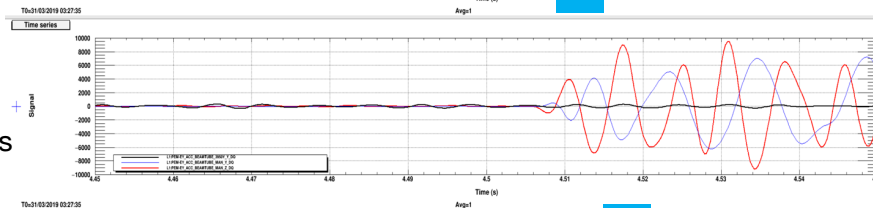
Soft hammer strike on -Y reduction flange, 70-200 Hz band

Soft hammer strike on end cap, 70-200 Hz band

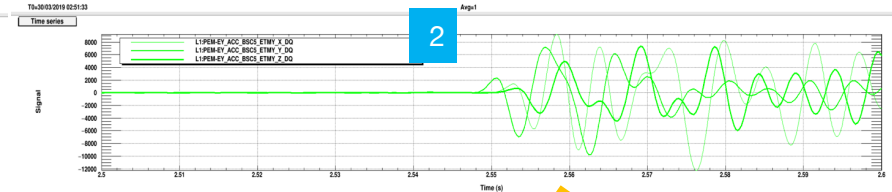
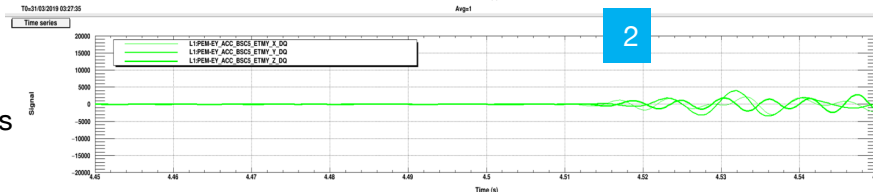
DARM



Red and Blue:  
manifold  
accelerometers



BSC 5  
accelerometers

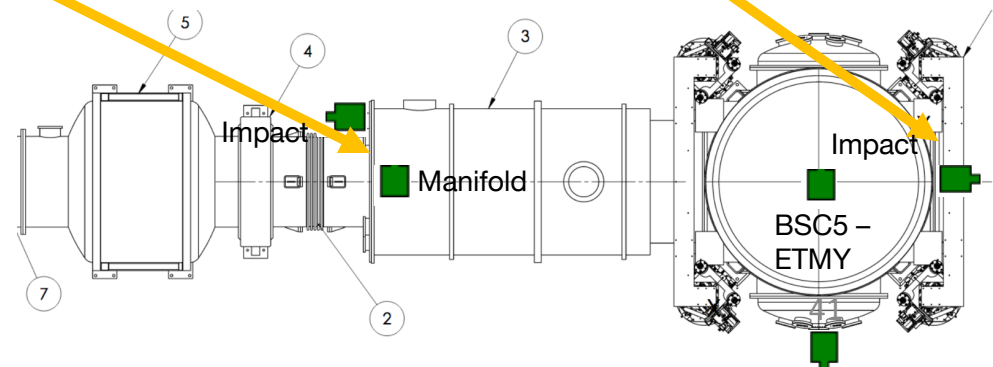


1

DARM time and amplitude are consistent with red and blue manifold accelerometers: DARM crosses 1 about the same time red or blue cross 8000 for these and other impulses

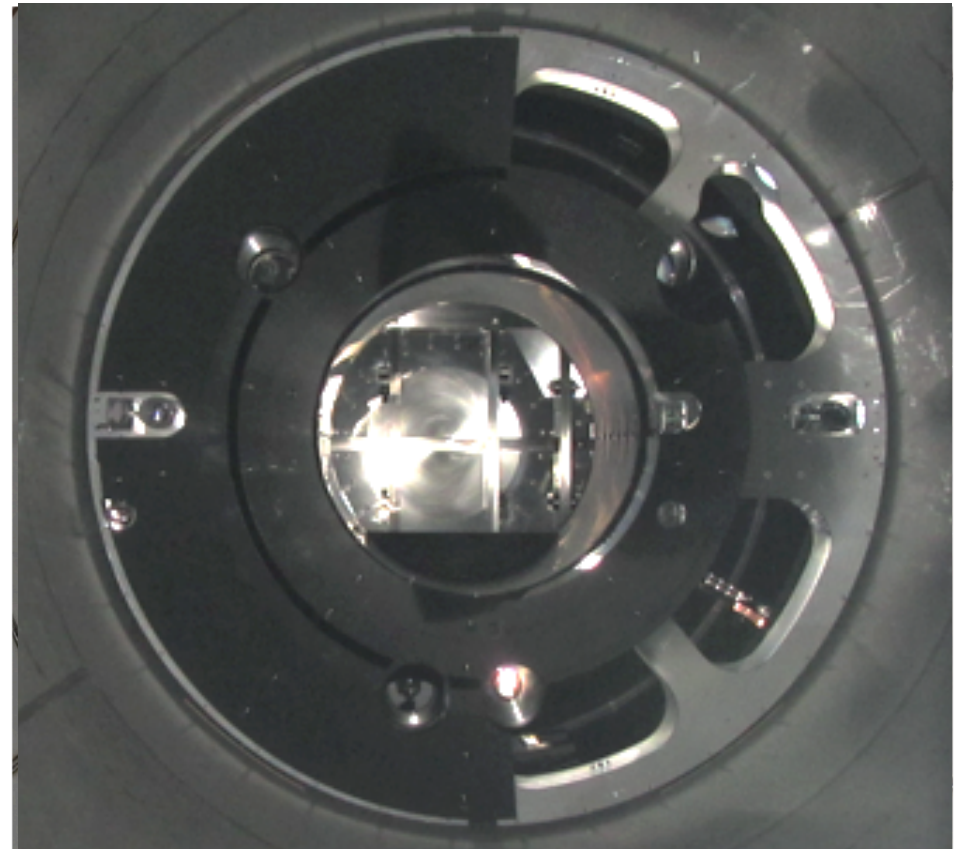
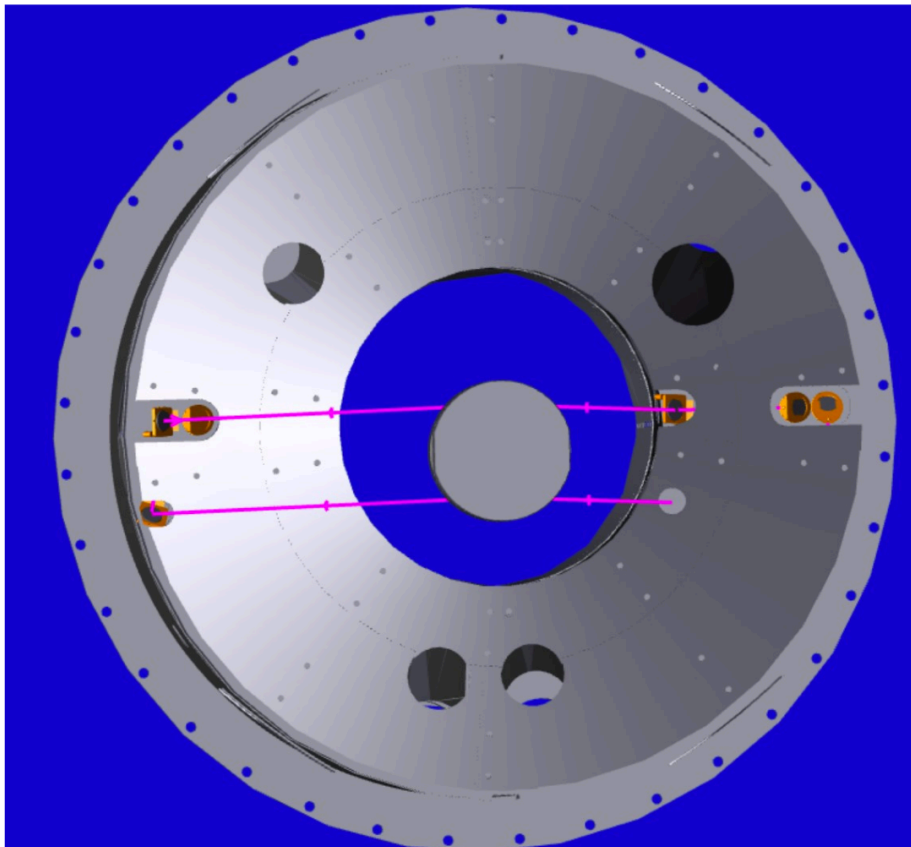
2

Green BSC chamber accelerometers are not consistent in time or amplitude with DARM signal



# Plans: complete P-cal periscope baffling

P-cal end-X view generated by Zemax (left – all solid). Right – real world

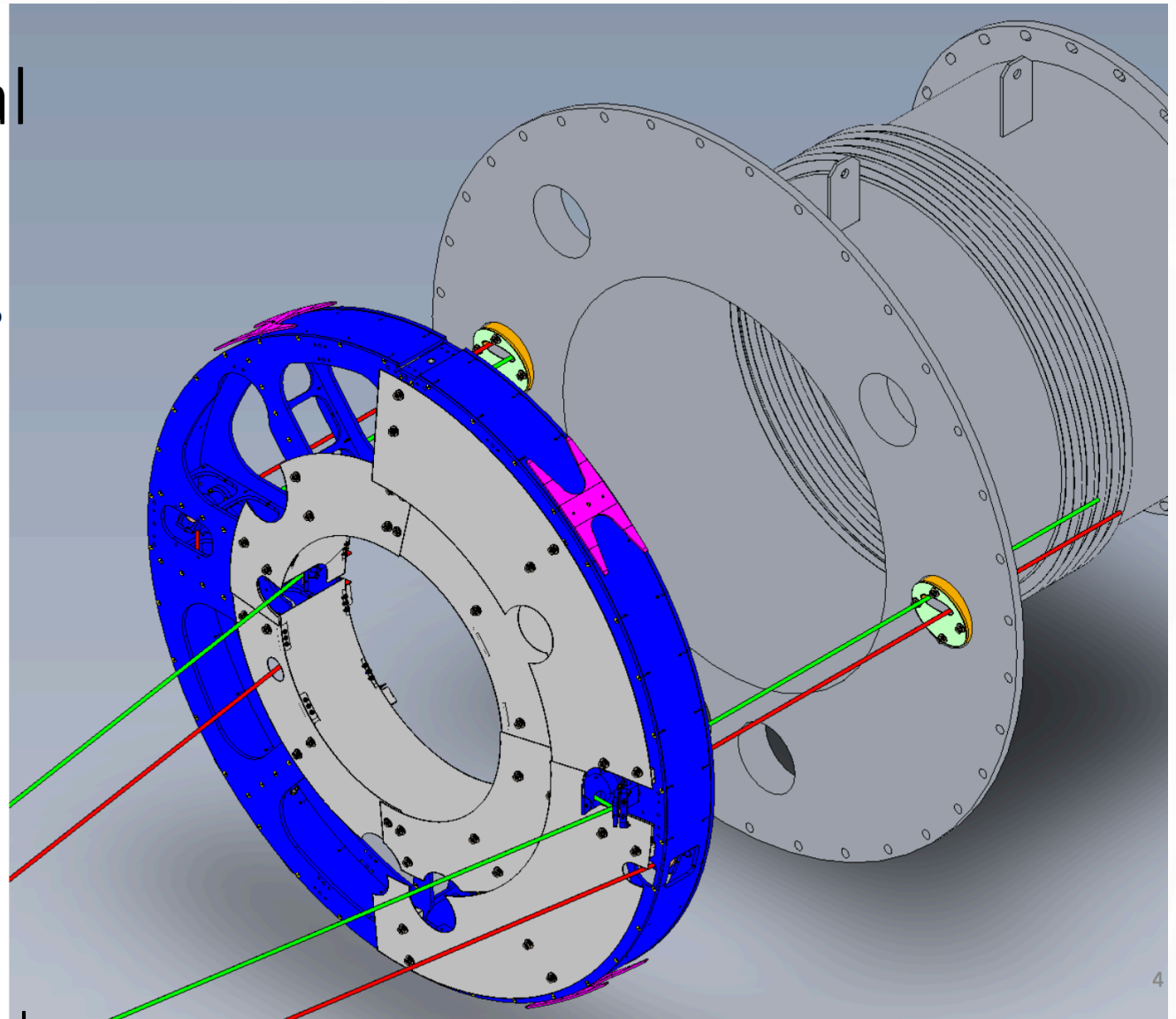
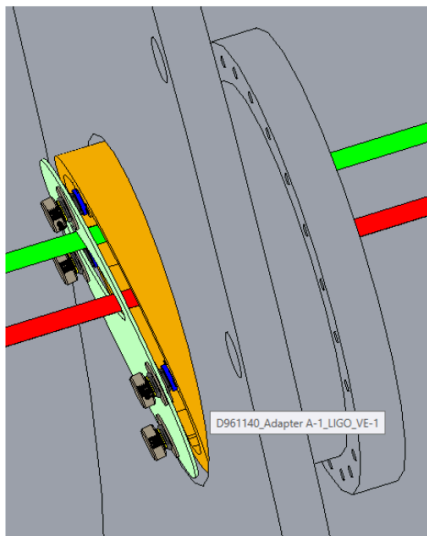


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# Nozzle baffles

## 3.Nozzles pcal

- pitched down
- will it fit through the VP?
- what VP to cover? Apertures?



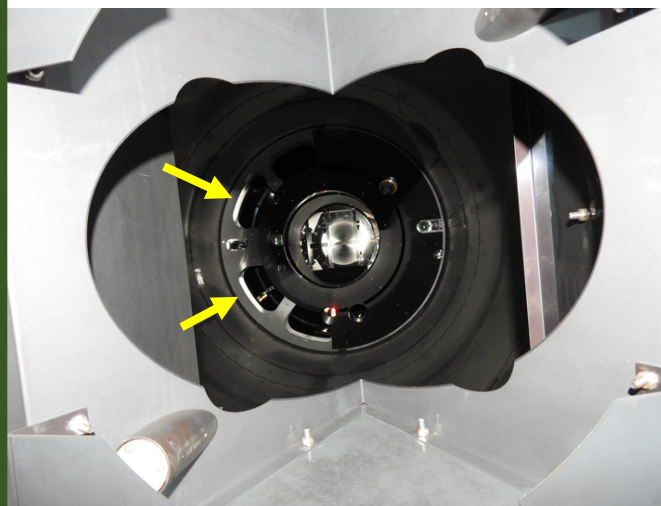
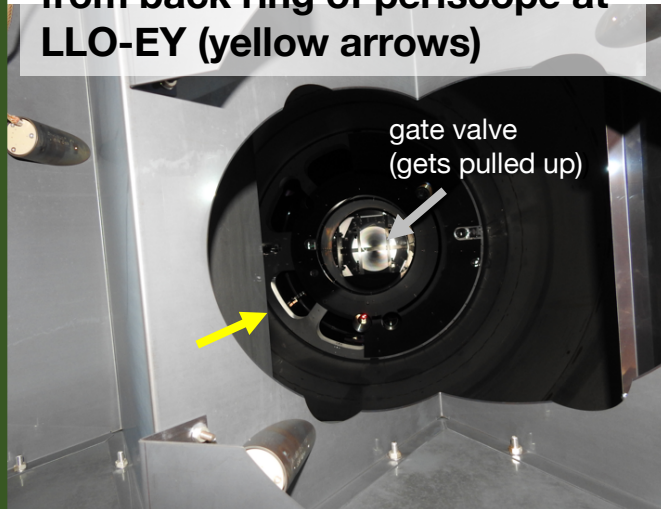
<https://dcc.ligo.org/LIGO-D1800212>

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# But reflections from LLO EY periscope are not unique

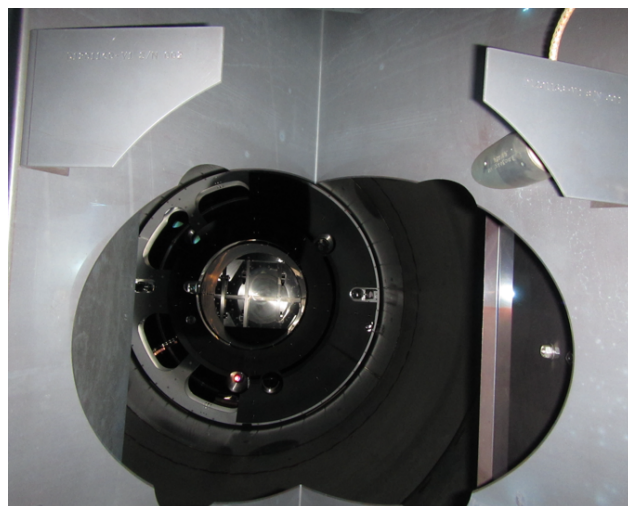
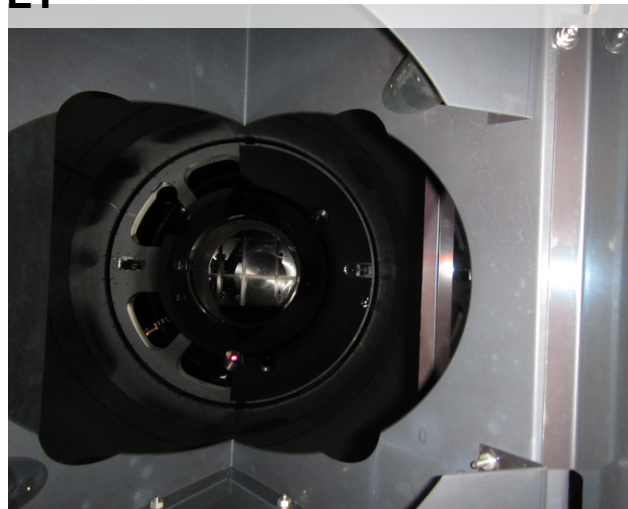
LLO EY (2 views)

Fairly bright retro reflections from back ring of periscope at LLO-EY (yellow arrows)



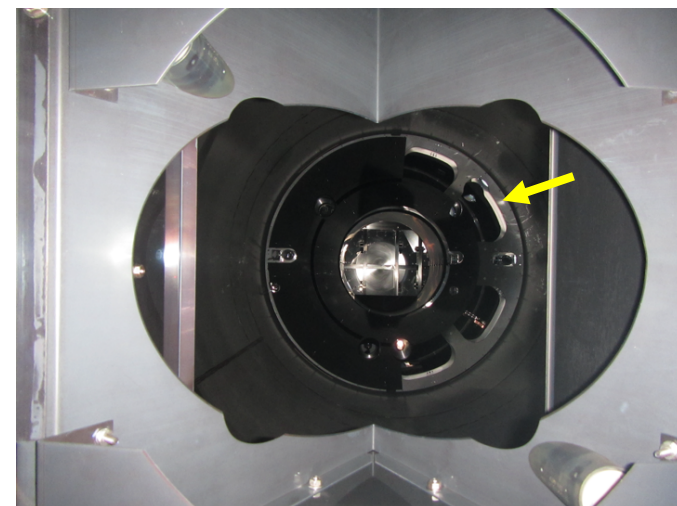
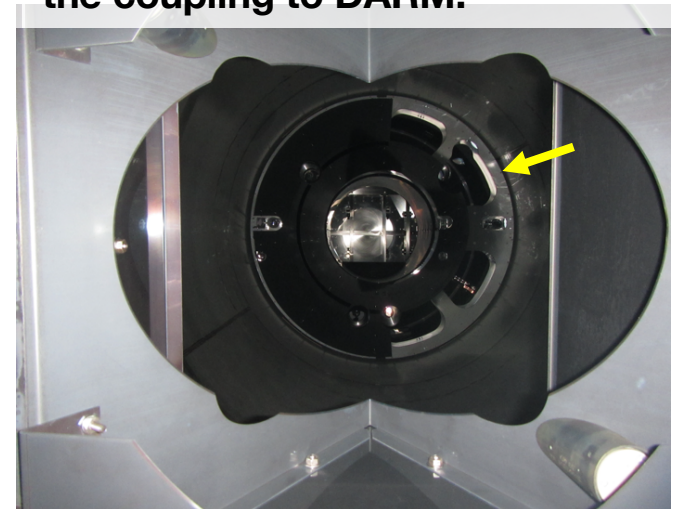
LHO EY (2 views)

Similar glints can be seen at LHO EY

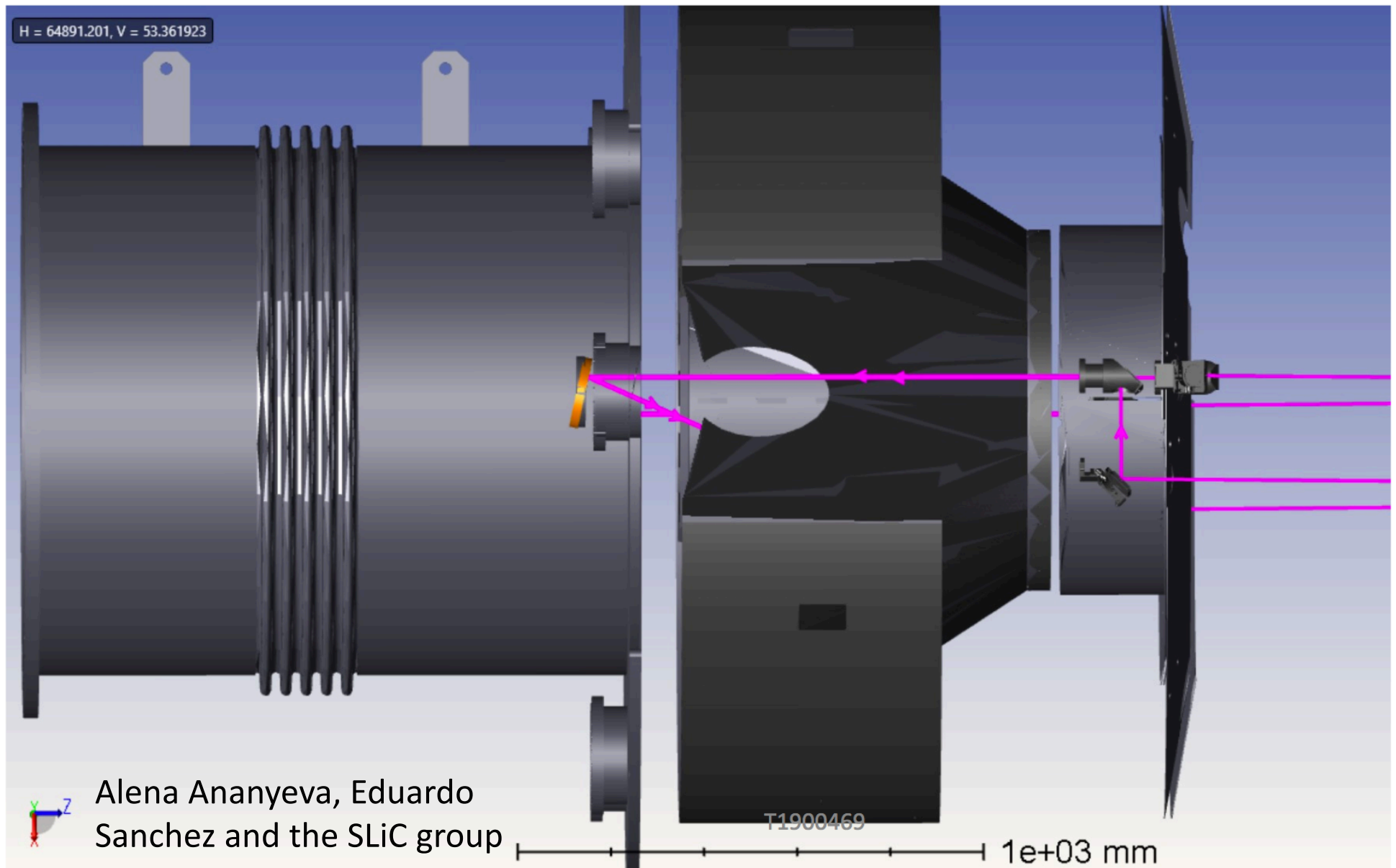


LHO EX (2 views)

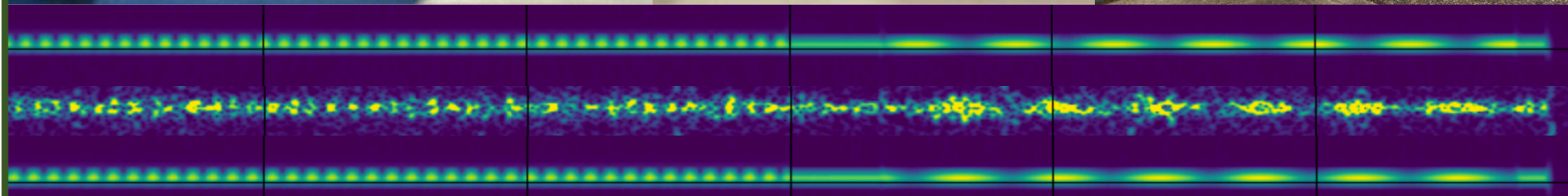
LHO EX has similar glints, without the coupling to DARM.



# Angle P-cal beam windows so they won't retro-reflect

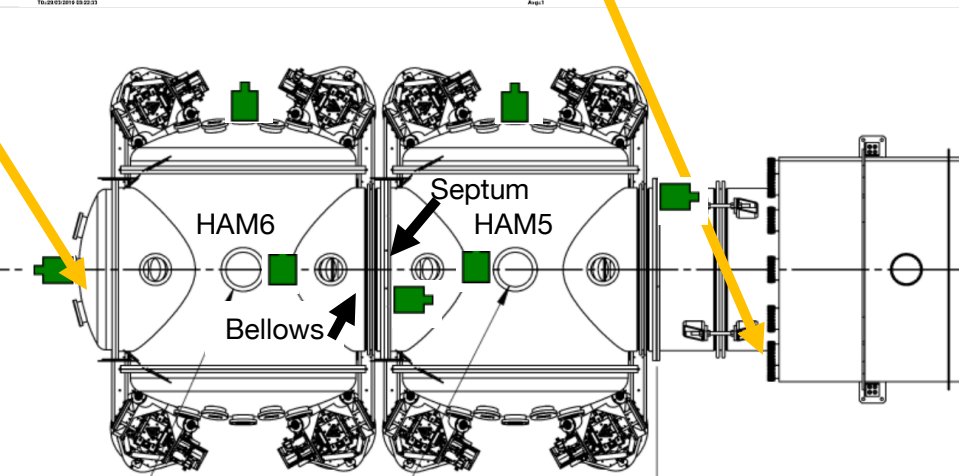
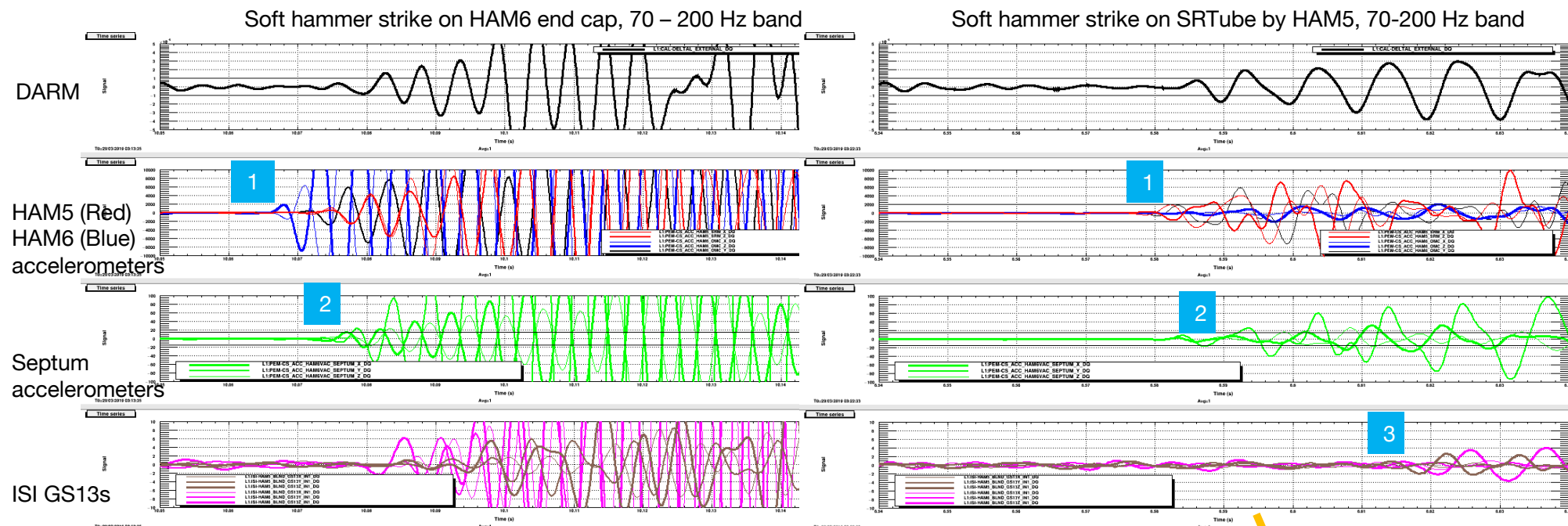


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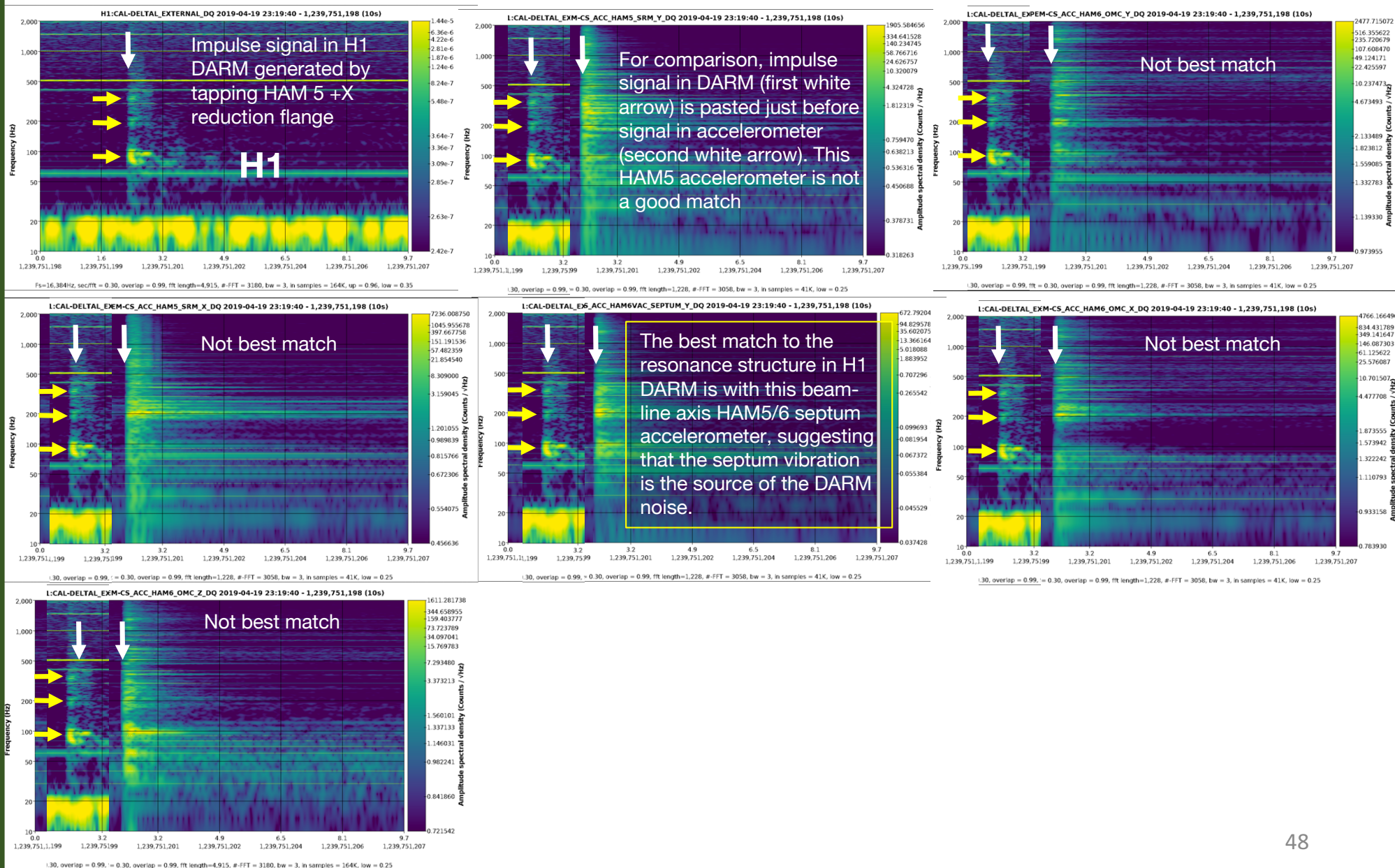


# Impulse injections suggest coupling at LLO & LHO HAM5/6 septum

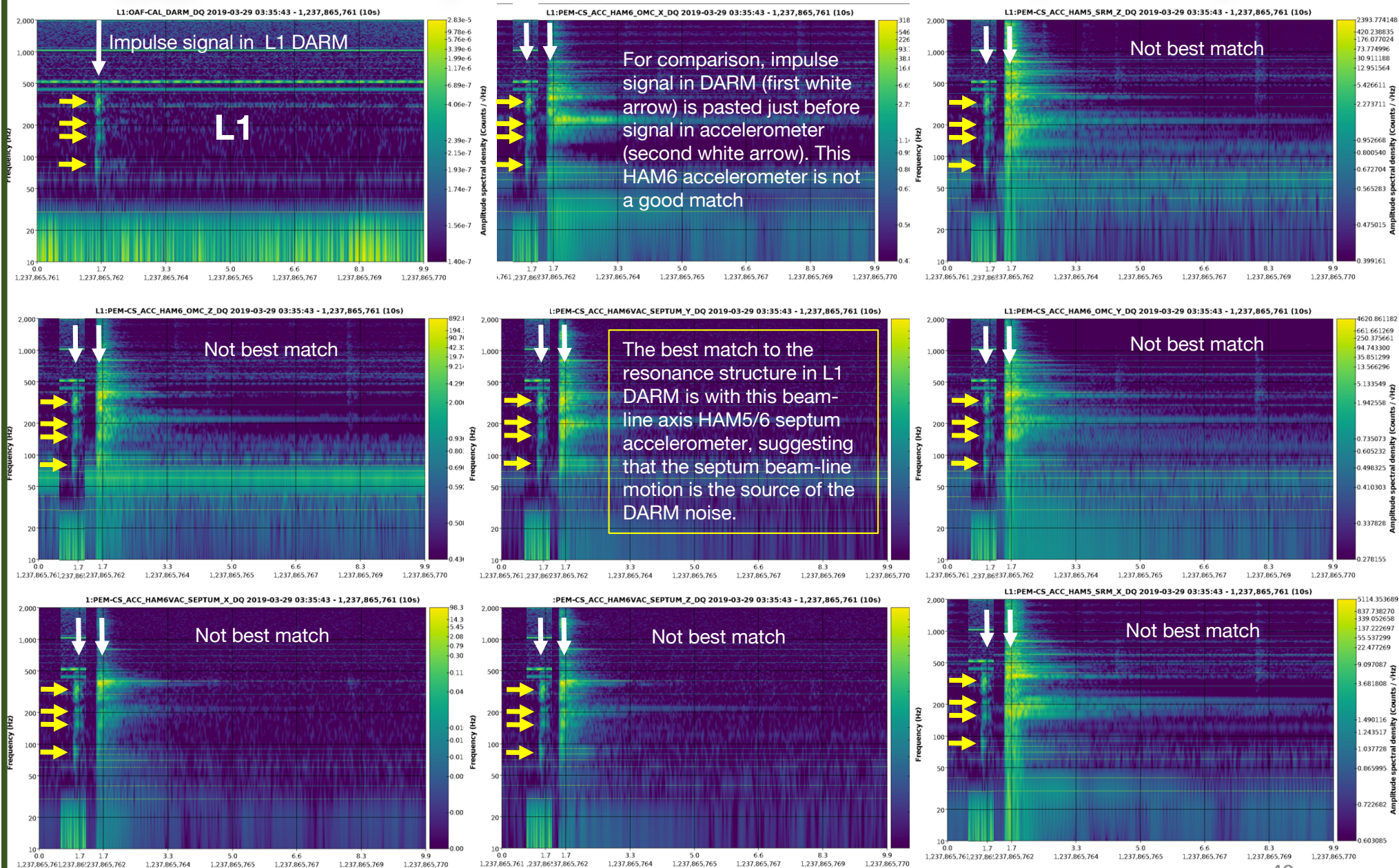
Figure 1a. L1 coupling time and amplitude consistent with septum or HAM5 walls, not HAM6 walls or ISI tables



# Impulse injection resonance structure suggest coupling at LHO HAM5/6 septum

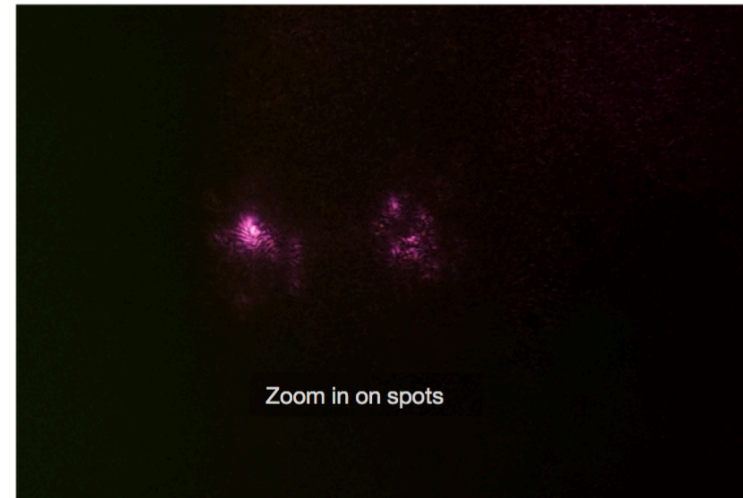
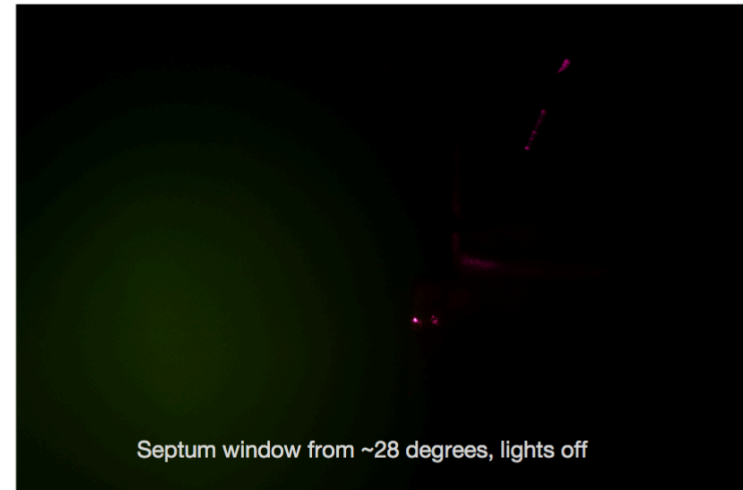
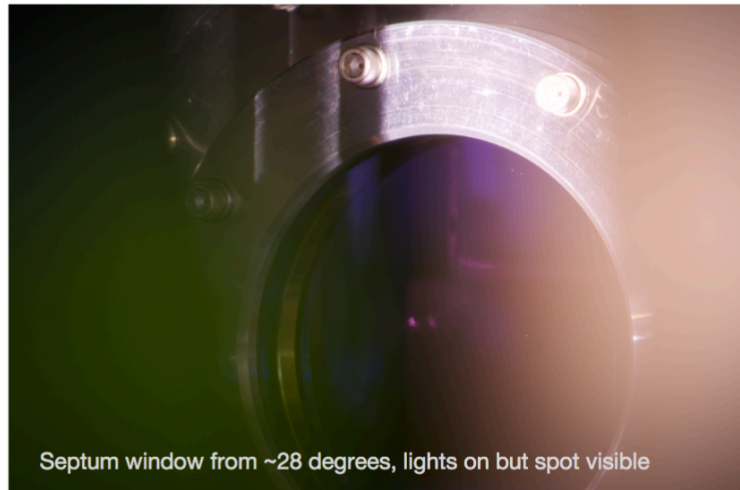


# Impulse injection resonance structure suggest coupling at LLO HAM5/6 septum

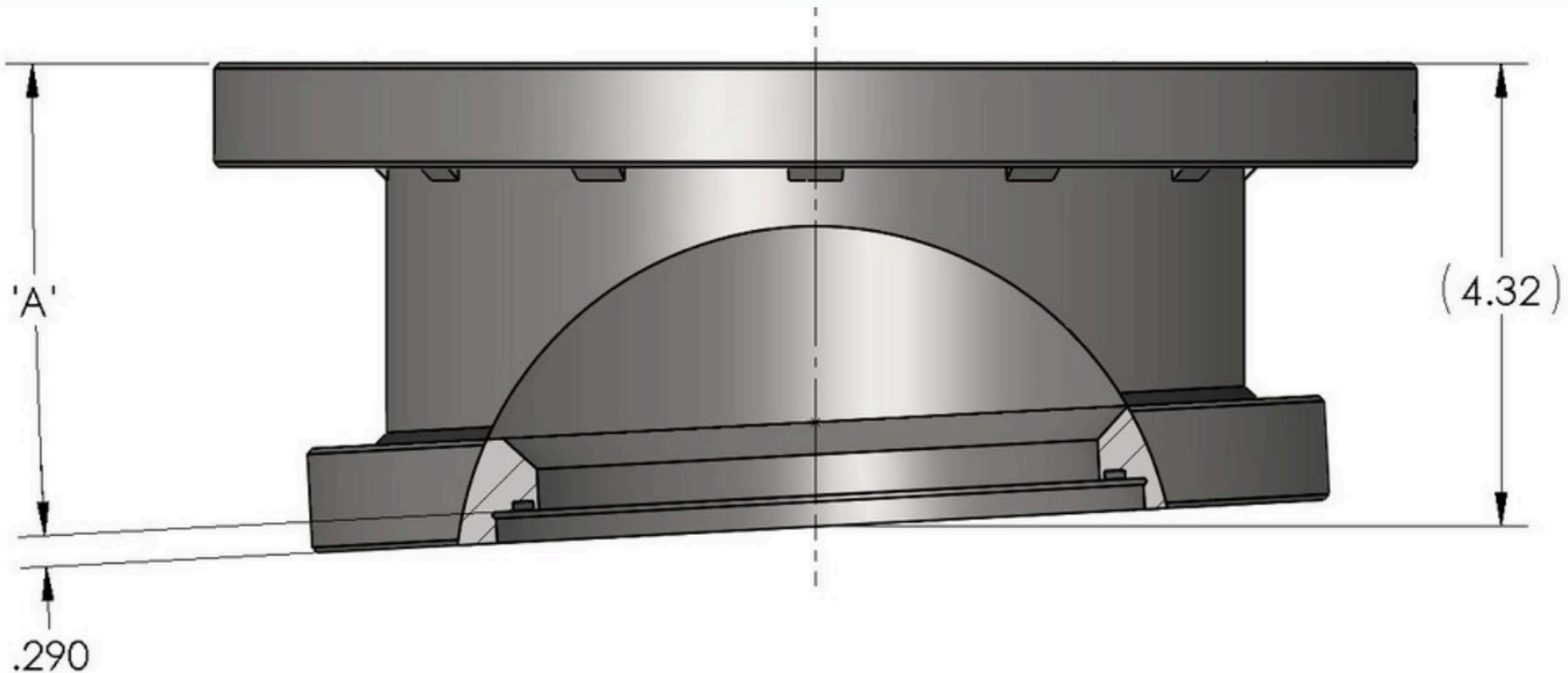


# **HAM5/6 coupling at the septum window?**

## **Scatter from beam spot seen at LHO but not LLO**



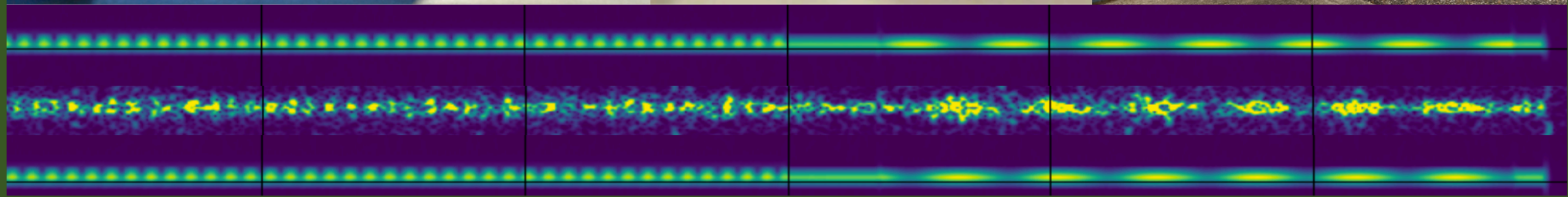
# Angled septum ports to be installed in October vent



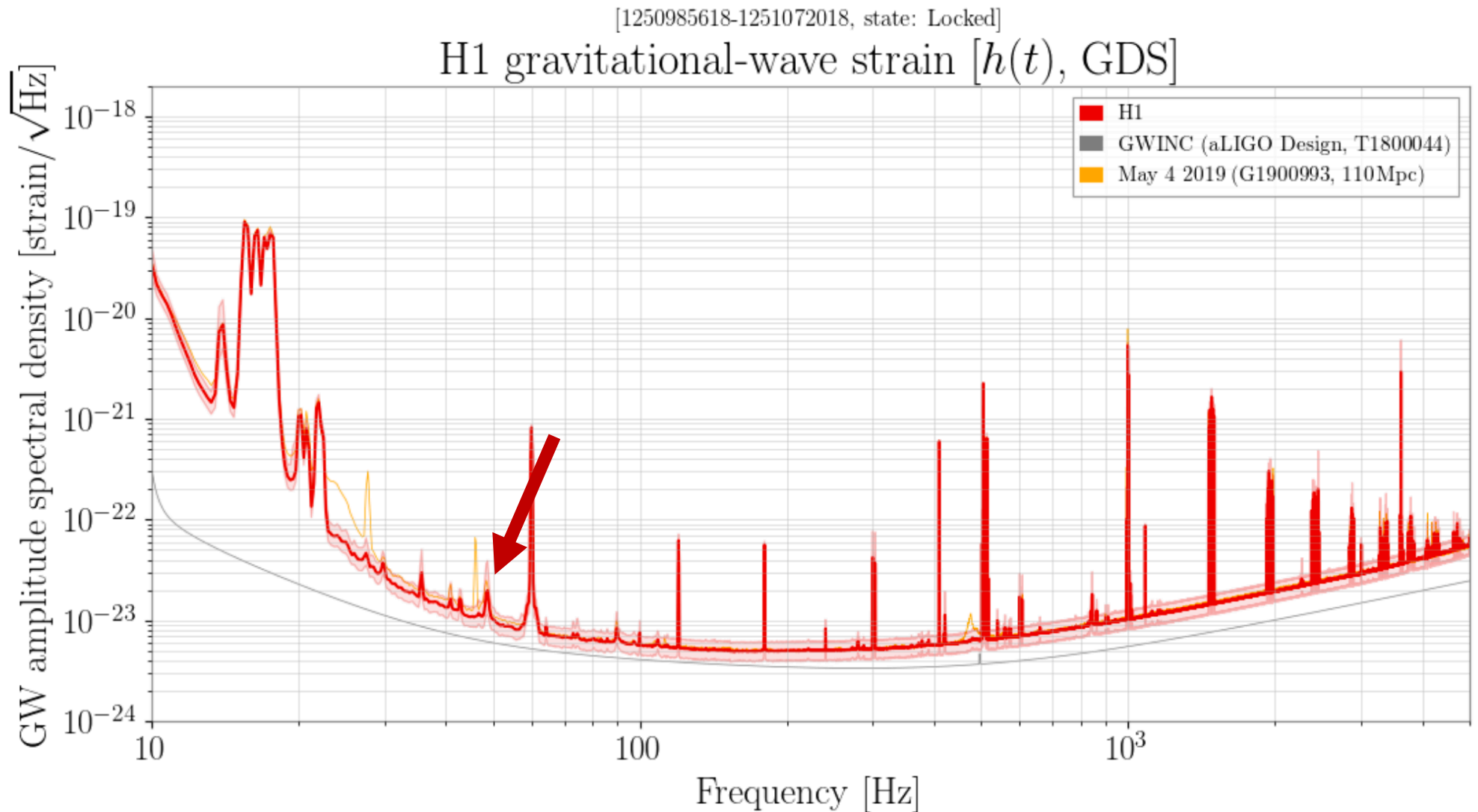
PART NUMBER	DIM 'A' (DEGREE)	ANGULAR TOLERANCE	USED ON
D1900239-01	5	$\pm 0.25^\circ$	LLO
D1900239-02	2.9		LHO

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  - **48 Hz LHO**
  - **IO Jitter, LHO, LLO**

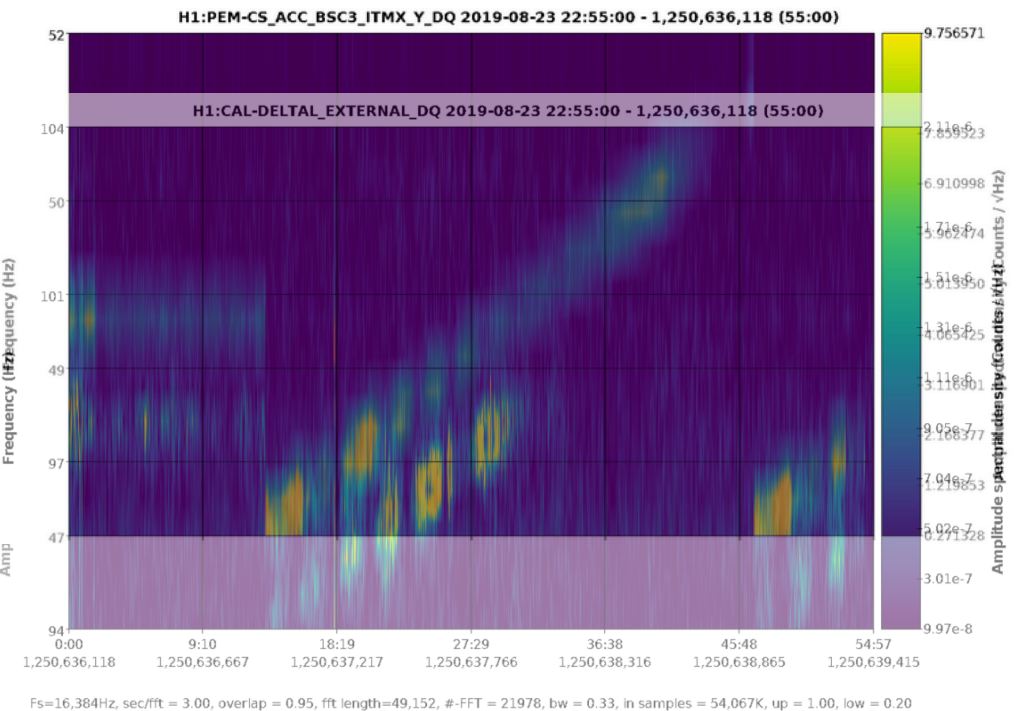
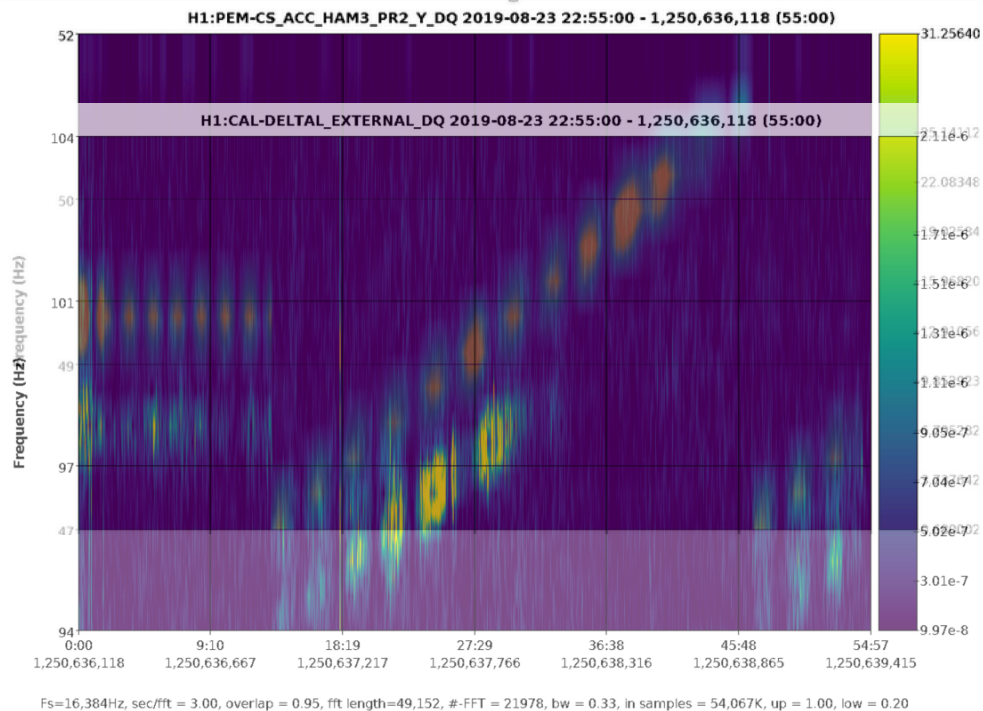
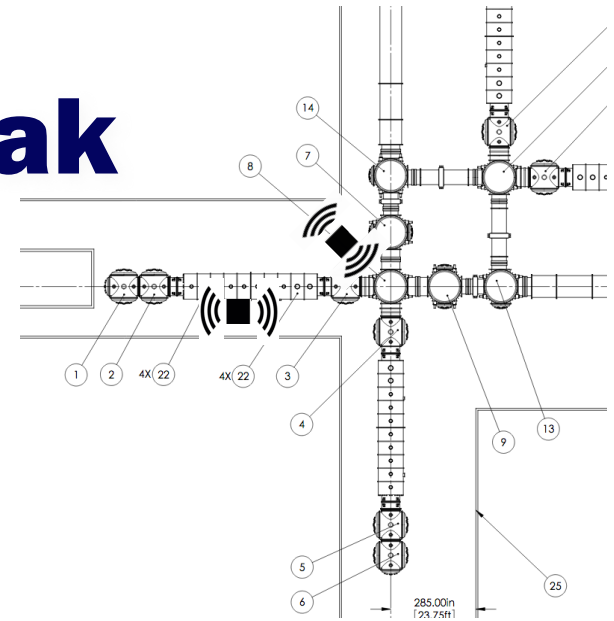


# LHO 48 Hz peak



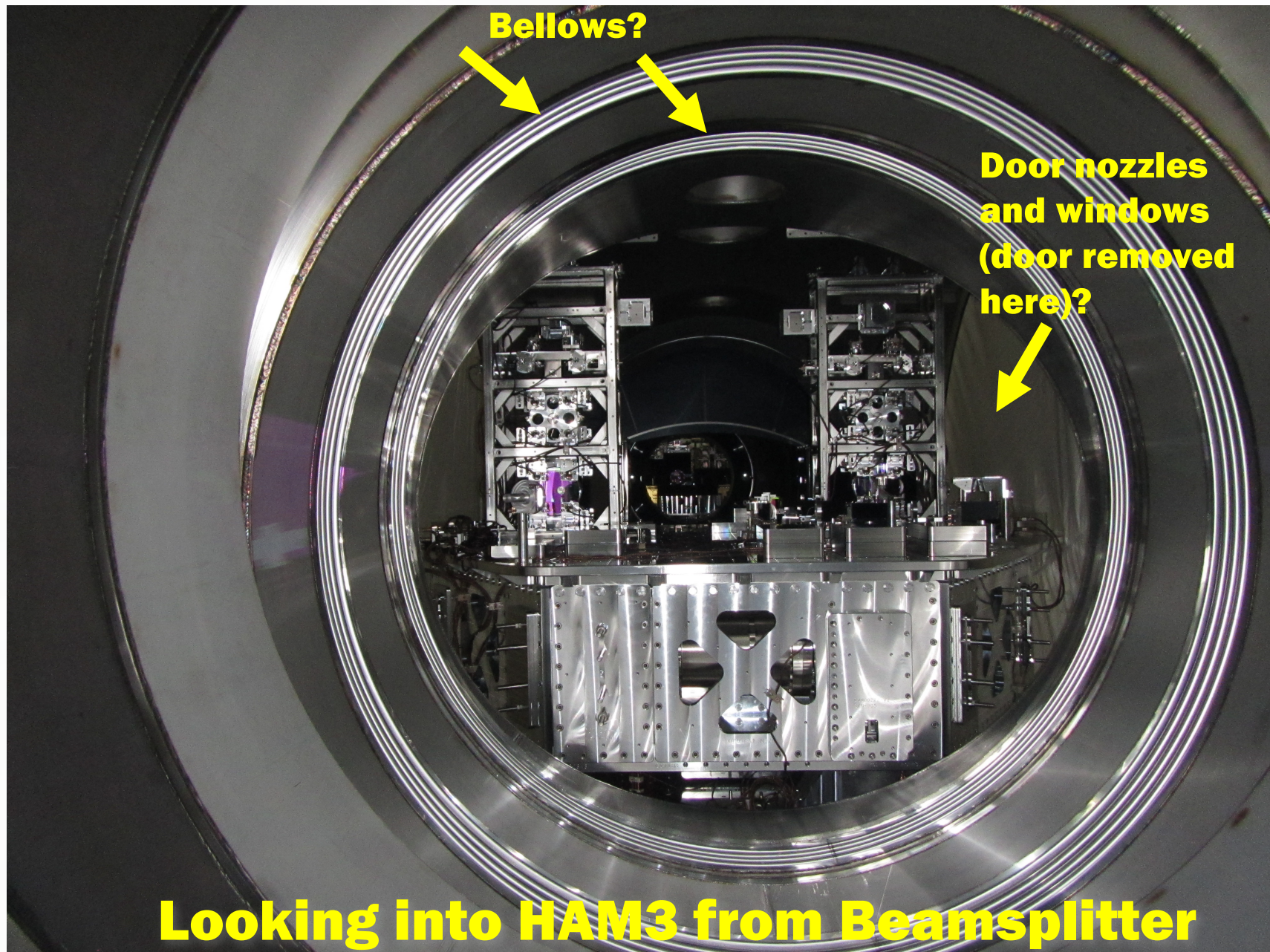
# LHO 48 Hz peak

1. **Shaker injections: some sensitivity at BSC2**
2. **Impulse injections: point towards vertex, but hard to tell because too short**
3. **Beating shaker injections: HAM3 area most consistent with DARM**

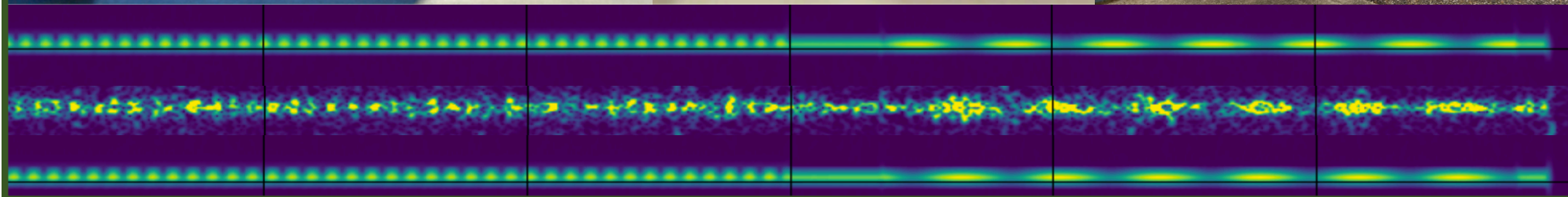


Frequency sweep to reduce chance of accidental alignment for non-coupling locations

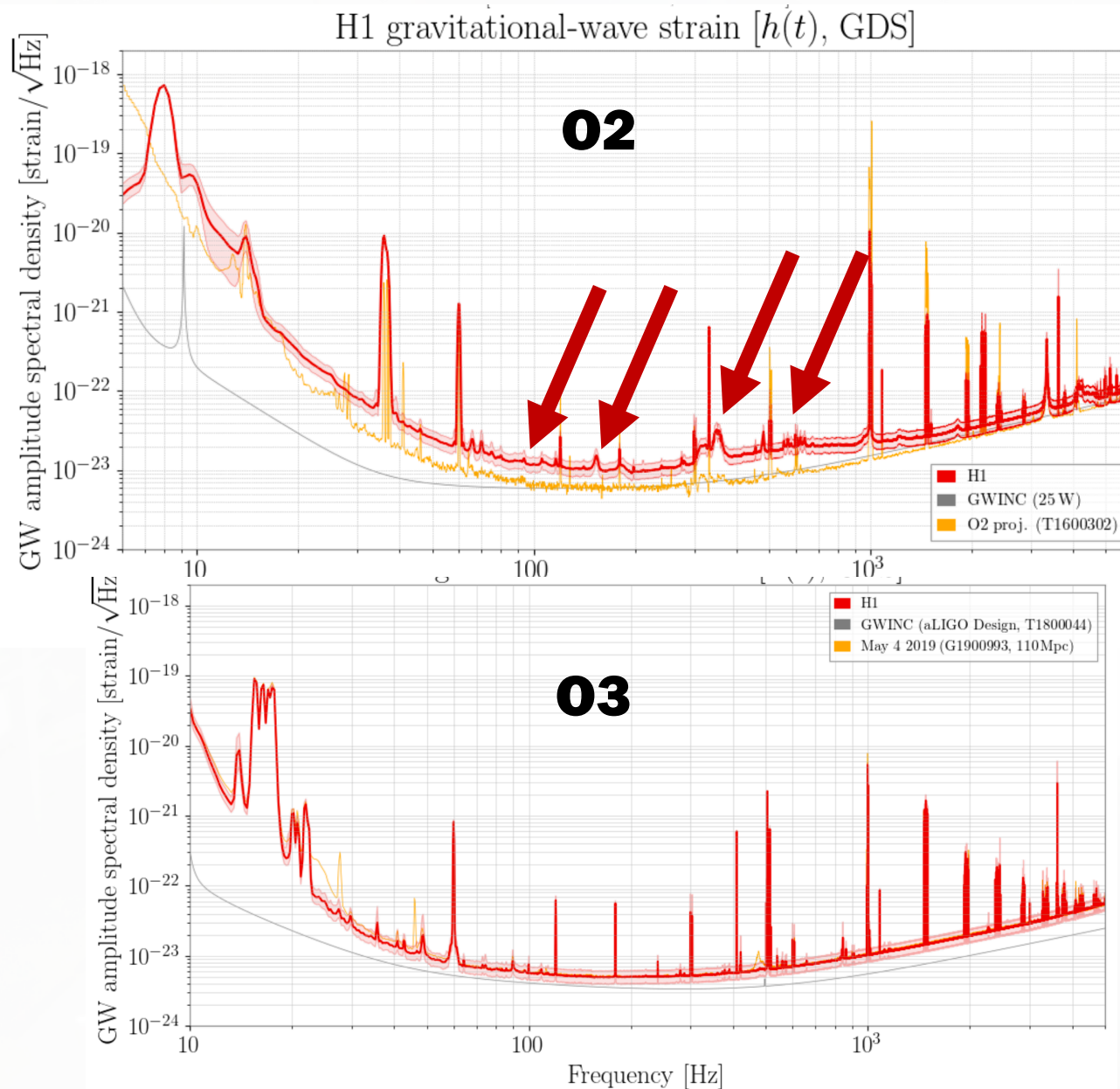
# Scattering from HAM3?



- **Results from the pre-run PEM injection program**
  - **Vibration**
  - **RF**
  - **Site activities**
  - **Magnetic**
- **Big coils and magnetic monitoring program**
- **Tests of coupling factors for thunder coupling etc.**
- **Two new techniques for localizing vacuum enclosure coupling sites**
  - **Impulse propagation delay, amplitude, & frequency structure**
  - **Beating injections with location-dependent phase of envelope**
- **Worst coupling sites and mitigation plans**
  - **TMSX, LLO**
  - **EY, LLO**
  - **HAM5,6 LHO, LLO**
  - **48 Hz LHO**
  - **IO Jitter, LHO, LLO**



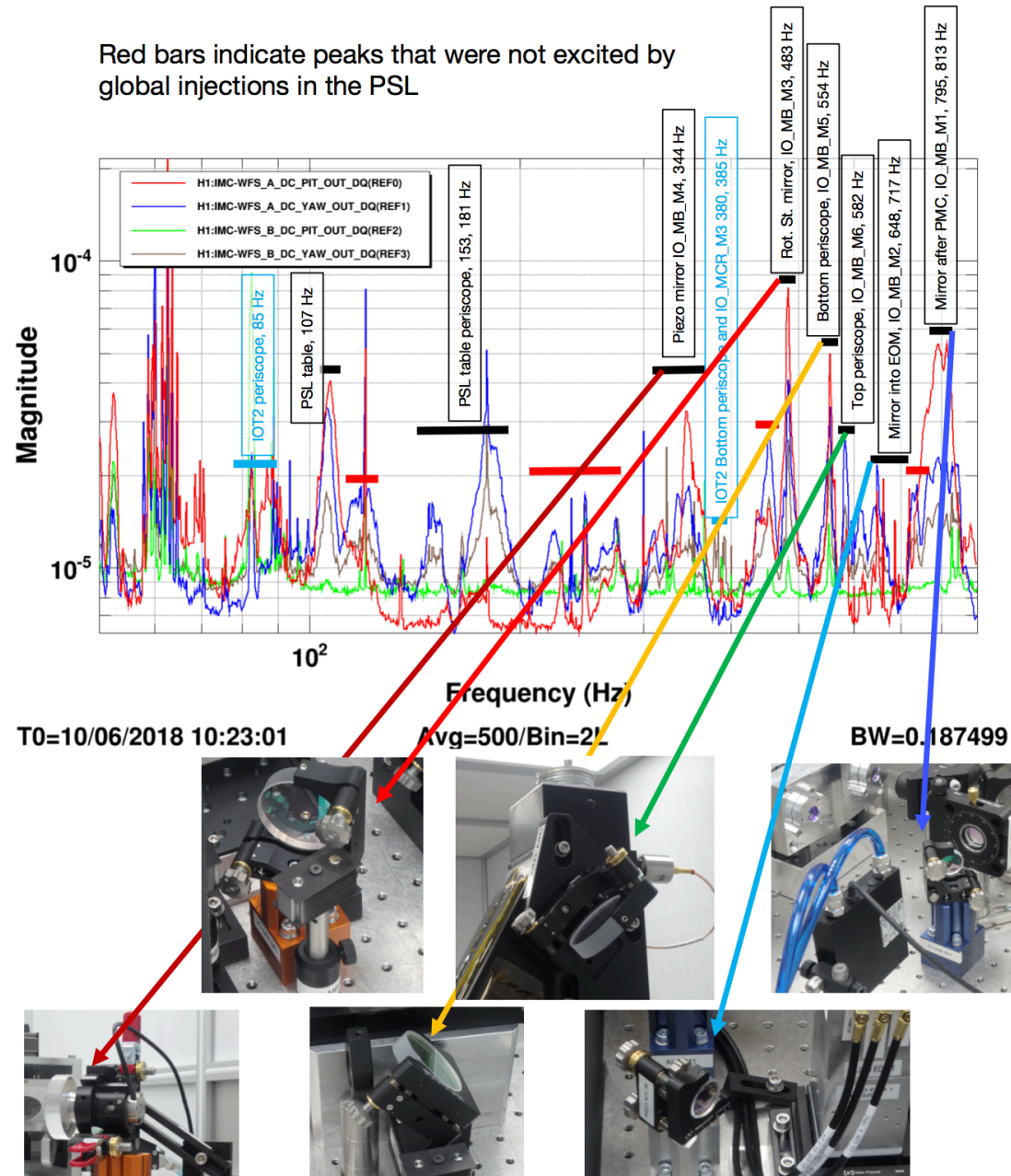
# Reduction in jitter mainly due to reduced cooling water, some from optic damping



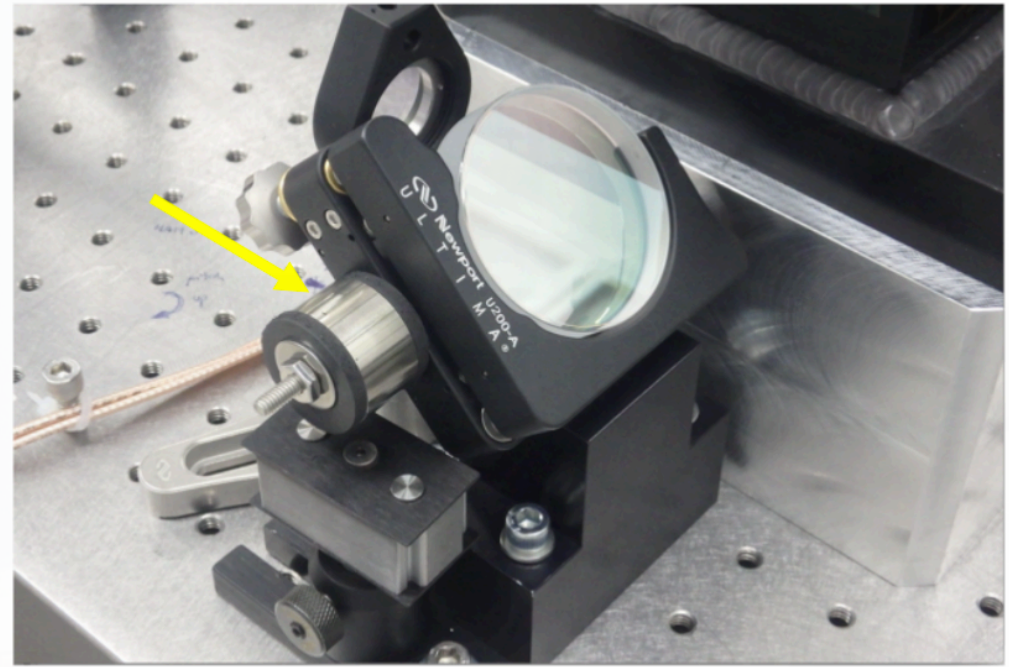
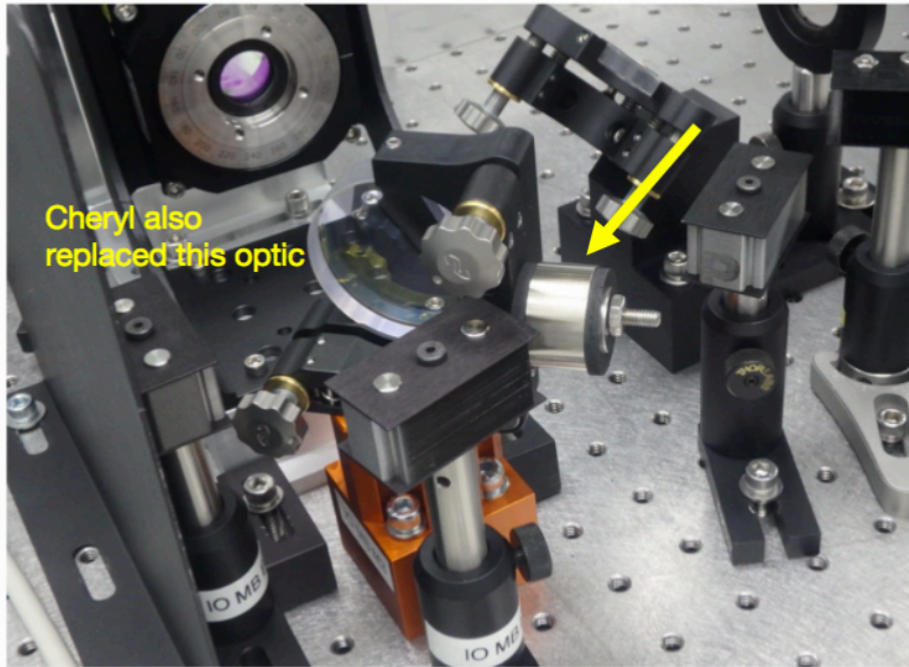
# Identifying sources of jitter peaks

## Identification of peaks in the IMC WFS DC spectra

Red bars indicate peaks that were not excited by global injections in the PSL



# 5 minute optic damping system



50gm add-on mass  
D020351 v2

1/8" Viton hand-  
made washer

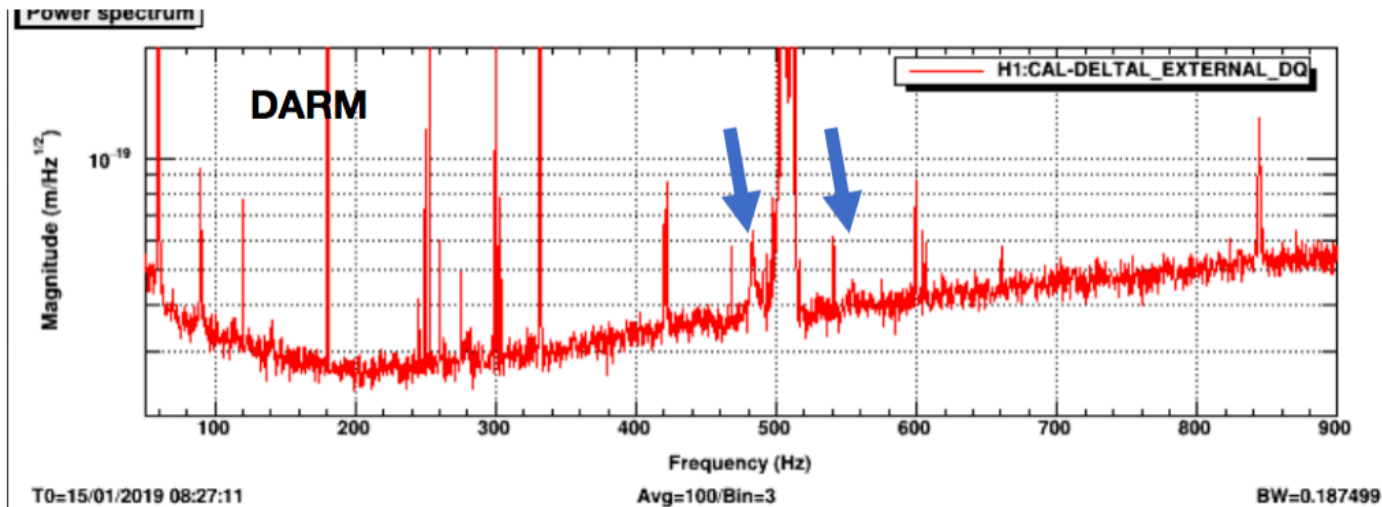
1/8" Viton hand-  
made washer

1.5" 8-32 (I left it a little long  
in case I wanted to add mass)

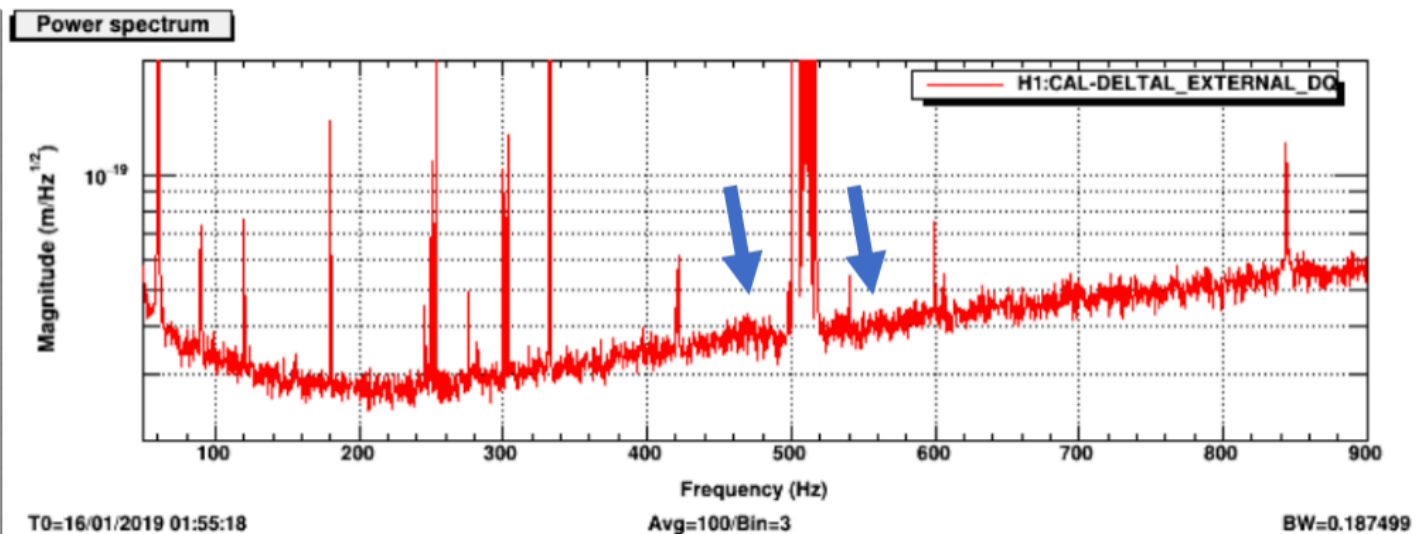


# Optic damping difference

Before damping

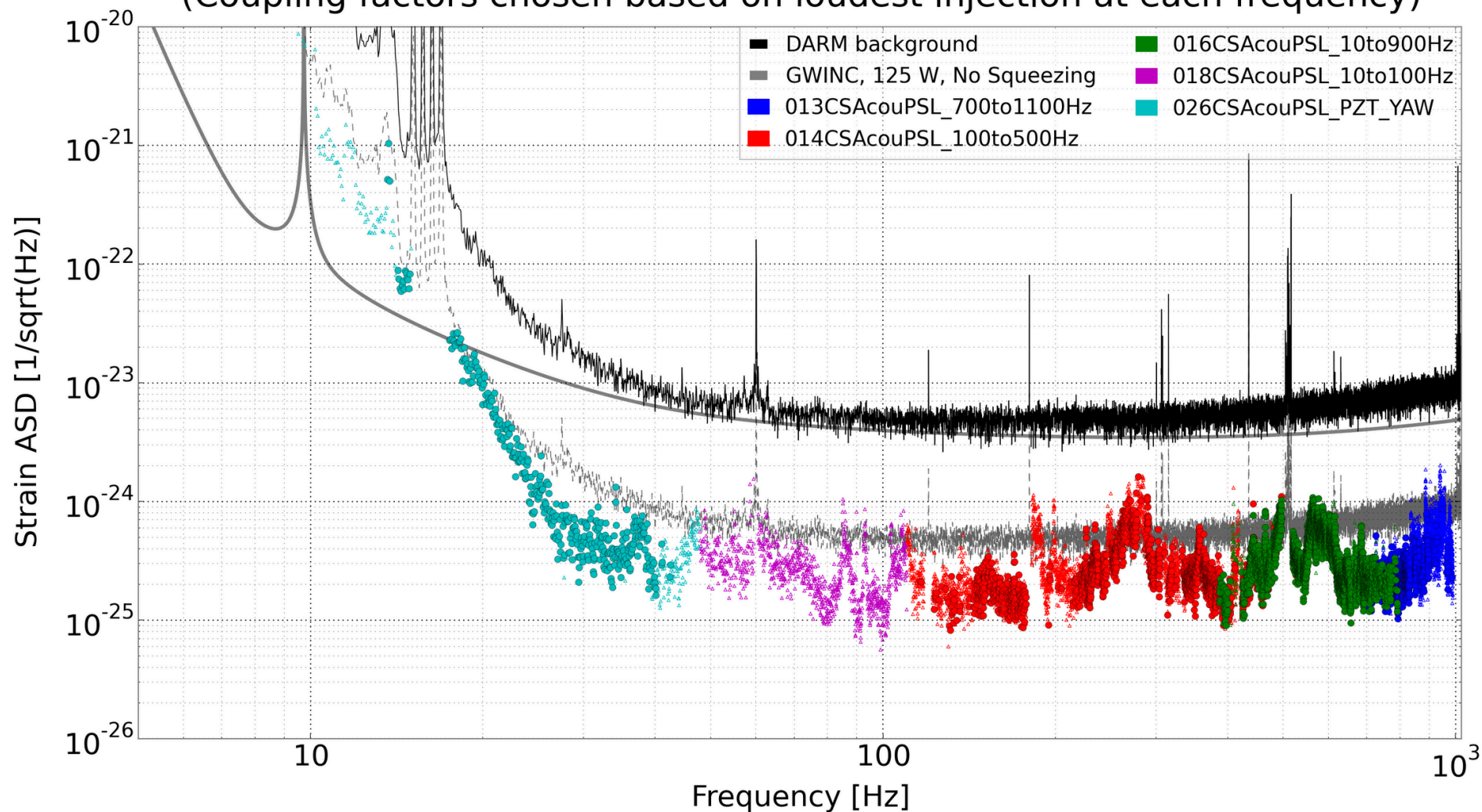


After damping



# Current LLO jitter noise

L1:IMC-WFS A I PTYAW QUADSUM - Composite Estimated Ambient  
(Coupling factors chosen based on loudest injection at each frequency)



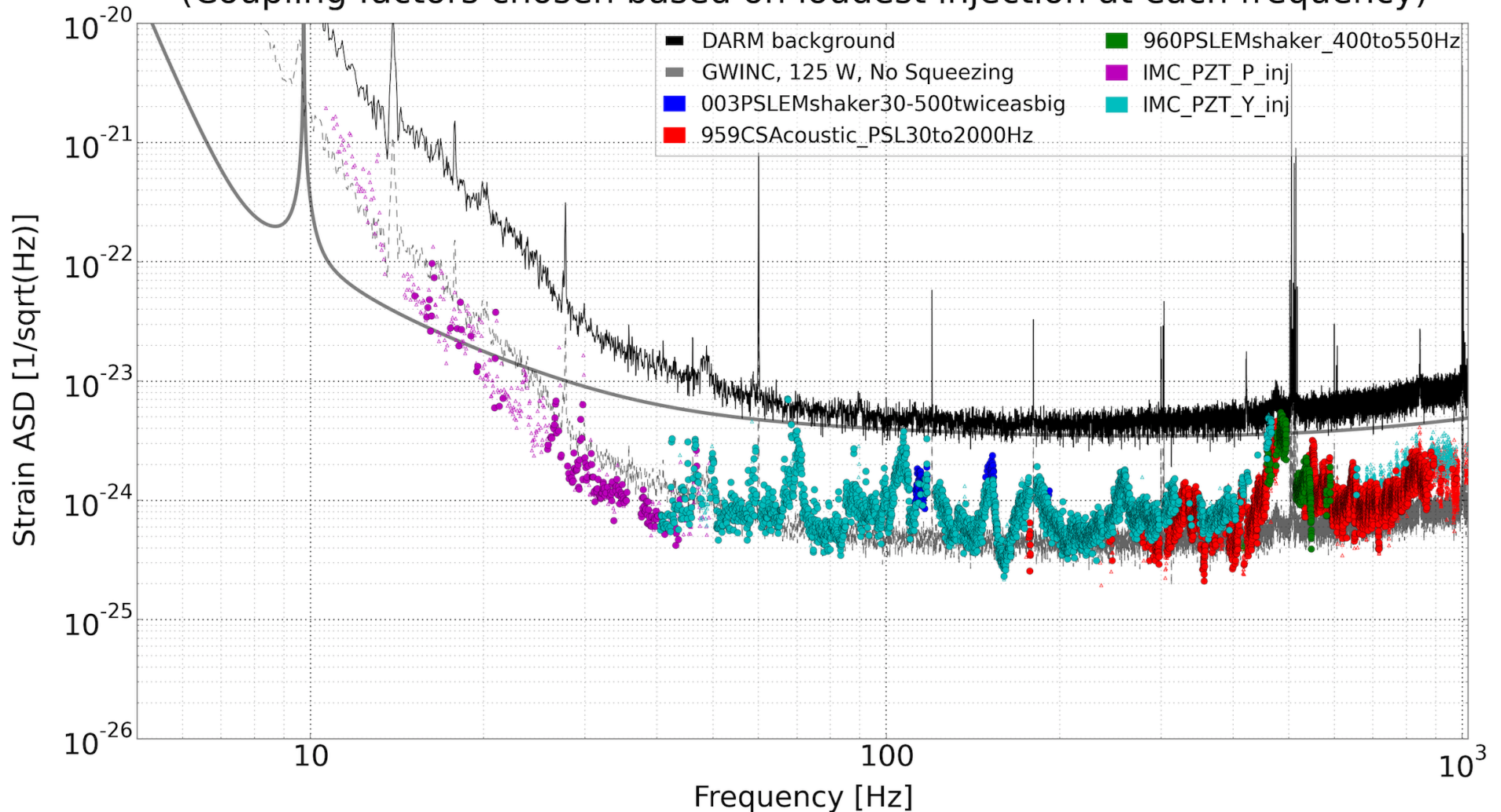
Ambient estimates are made by multiplying coupling factors by injection-free sensor levels.

CIRCLES indicate estimates from measured coupling factors, i.e. where the injection signal was seen in the sensor and in DARM.

TRIANGLES represent upper limit coupling factors, i.e. where a signal was not seen in DARM.

# Current LHO jitter noise

H1:IMC-WFS A DC PITYAW QUADSUM - Composite Estimated Ambient  
(Coupling factors chosen based on loudest injection at each frequency)



Ambient estimates are made by multiplying coupling factors by injection-free sensor levels.

CIRCLES indicate estimates from measured coupling factors, i.e. where the injection signal was seen in the sensor and in DARM.

TRIANGLES represent upper limit coupling factors, i.e. where a signal was not seen in DARM.

- **Results from the pre-run PEM injection program**
  - **Vibration**
  - **RF**
  - **Site activities**
  - **Magnetic**
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  - **HAM5,6 LH0, LLO**
  - **48 Hz LH0**
  - **IO Jitter, LH0, LLO**

