Optimal Filter Validation of S5 Hardware Injections

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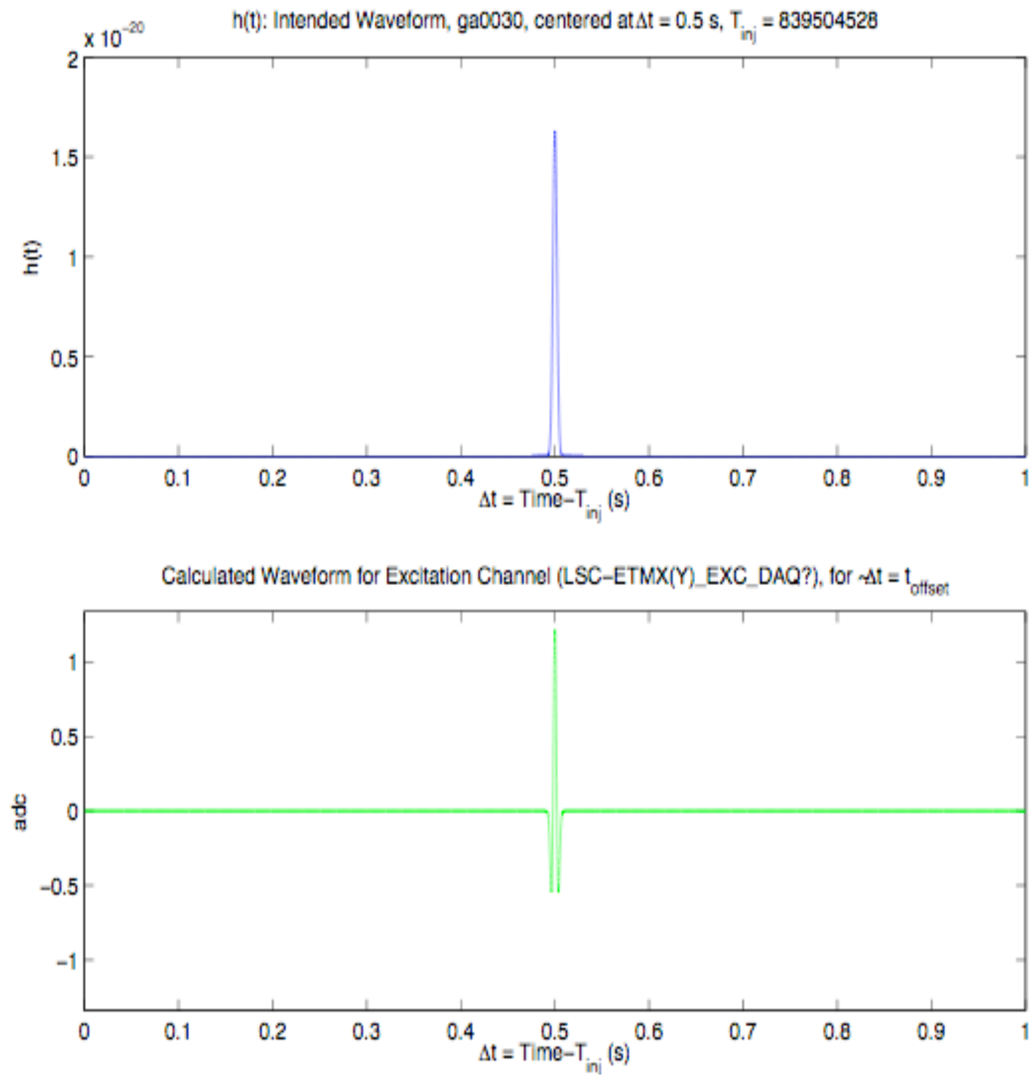
Optimal Filter: $h_{rss} = N \int_0^\infty \frac{\tilde{h}^*(f)\tilde{s}(f)}{S(f)} e^{-2\pi i f t} df$

- A standard method from classical signal processing.
- Known waveforms - Matched filter study.
- Optimized for the measured stationary noise of detector.
- It is also a *linear* measure of the strength;
  - Normalized it so that its numerical values is an unbiased estimate of the strength (hrss).
  - The response function mostly cancels , i.e., similar expressions for either DARM_ERR or h(t).

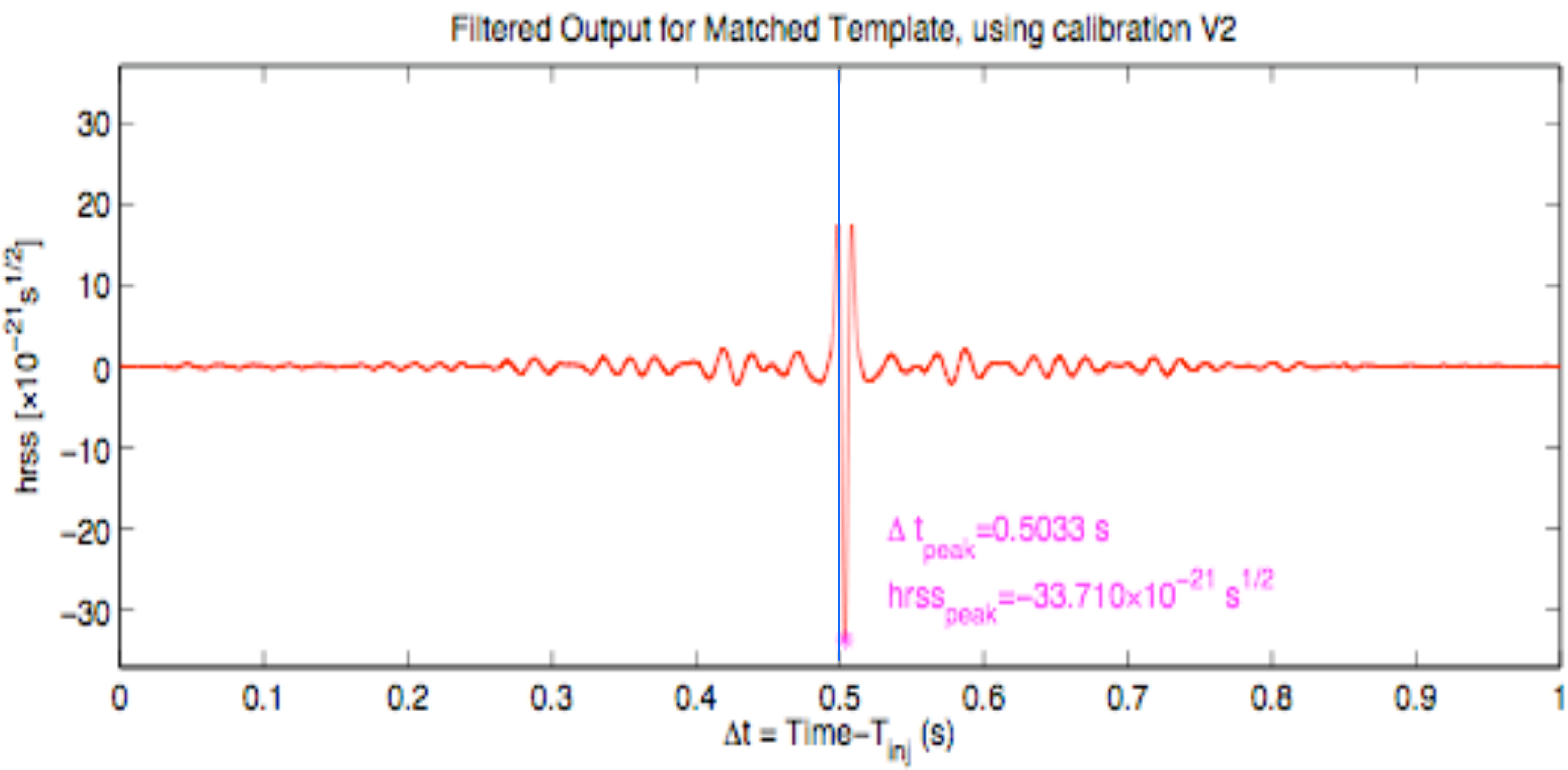
S5 Burst Hardware Injections

- Since Jan. 19, 2006
- 20 different burst waveforms (1s long)
- 12 Burstsets for S5 Hardware Injections
  - ➢ Burstsets 6~11, 18~20 (12~14) - Three waveforms (21s Long)
  - ➢ Burstset 21 (15): Sine-Gaussians with 11 Frequencies and 2 strength (106s long)
  - ➢ Burstset 22 (16): Gaussians with 4 widths and 2 strength. (36s long)
  - ➢ Burstset 23 (17): 19 burst waveforms with various hrss(excl. white noise burst) (96s long)
- Different hrss and time offset for each waveform
- Use response function (h(t) -> actuation(t)) to find the excitation function.



Optimal Filter on HW Injections

- Matlab scripts (python scripts for controlling jobs)
- Use DARM_ERR data
- Start with a waveform in strain h(t) (or template), then transform with the response function that takes h(t) -> DARM_ERR(t).
- Use the filtered output to measure peak hrss and peak time.



Validation of Injections

- Compare with injected hrss and time for each waveform;

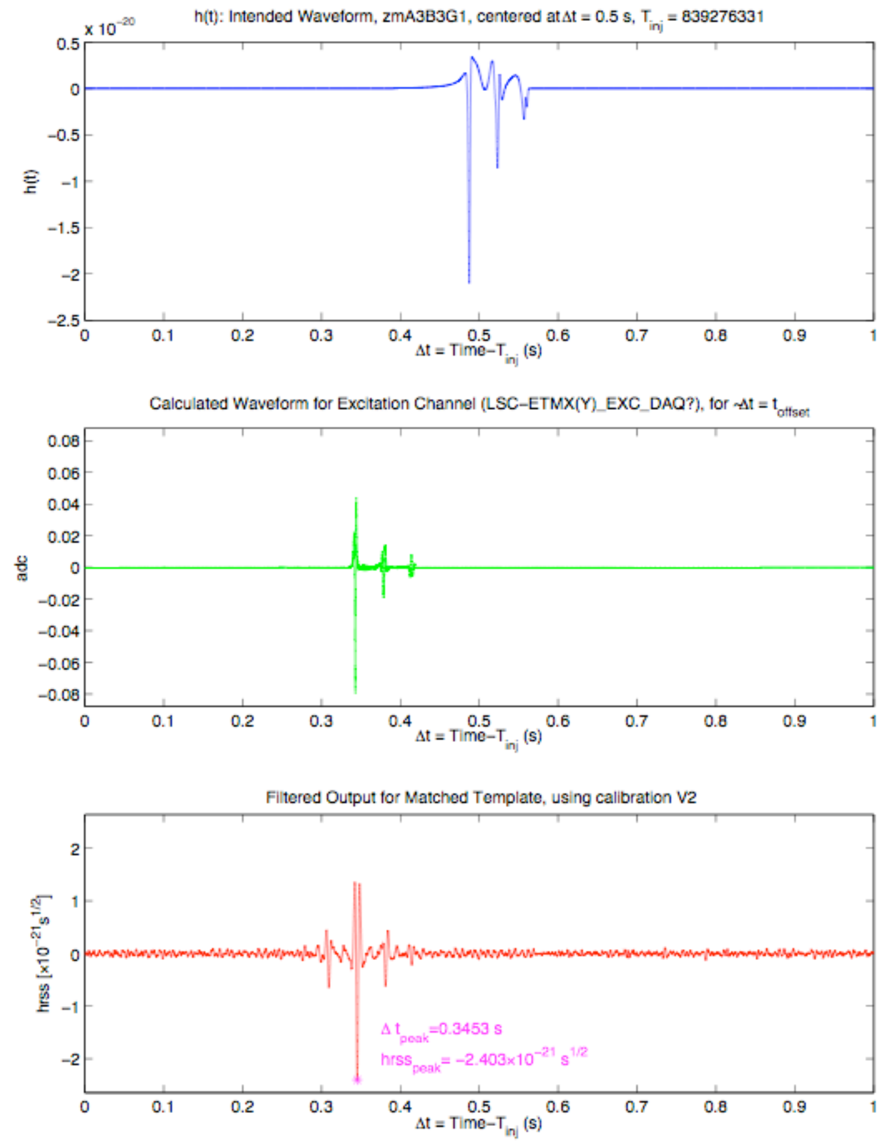
$$\epsilon_h \equiv \frac{hrss_{\text{injected}} - hrss_{\text{measured}}}{hrss_{\text{injected}}}$$

$$\delta(\Delta t) \equiv T_{\text{offset}} - T_{\text{peak}}$$

- For good injections,

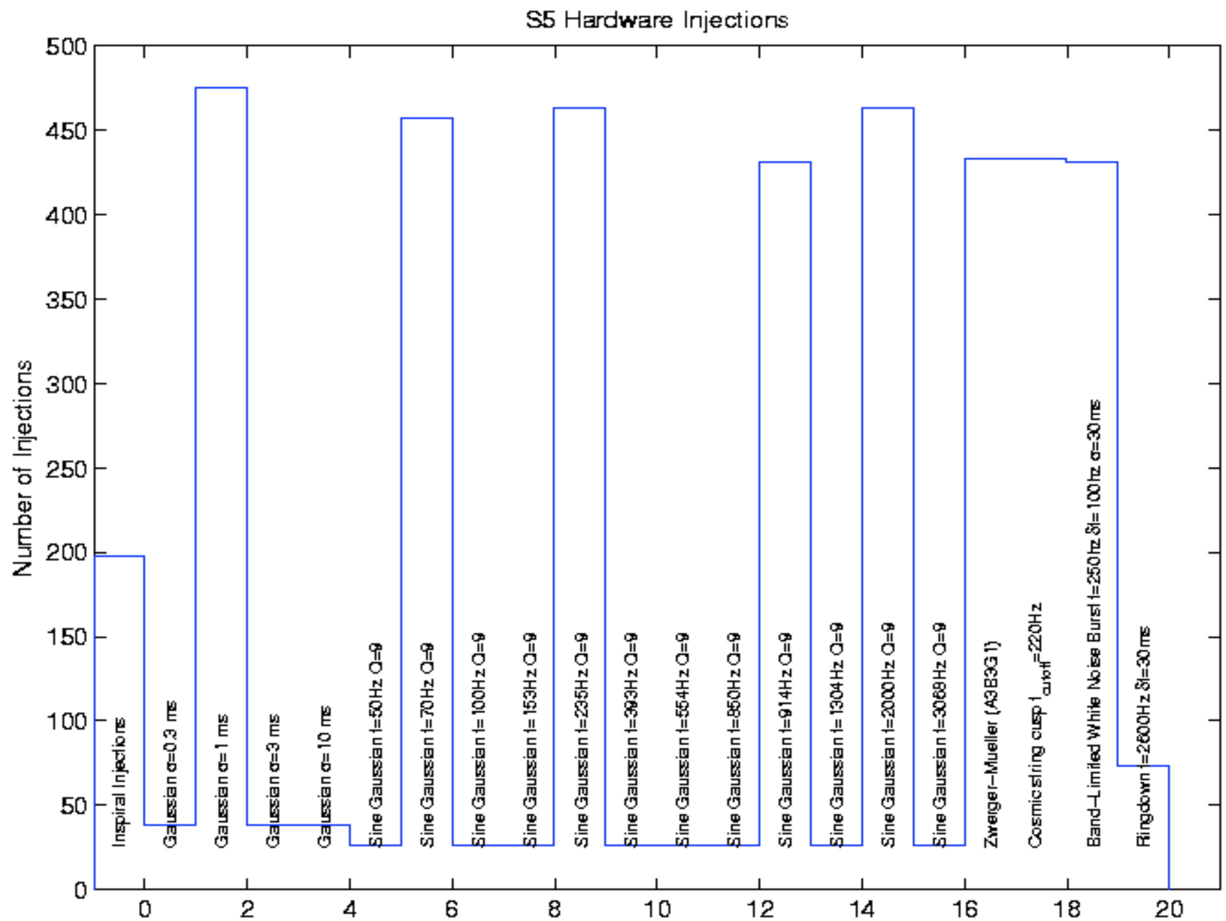
$$\epsilon_h < 0.6, \quad \delta(\Delta t) < 45ms$$

- Online analysis;
  - ➢ Running for last 4 months
  - ➢ Results available for scimon check in 1/2~1 hr after injections.



(LLO: http://ldas-jobs.ligo-la.caltech.edu/~sung/HardwareInjections/S5/html/HardwareInjection_S5.html)

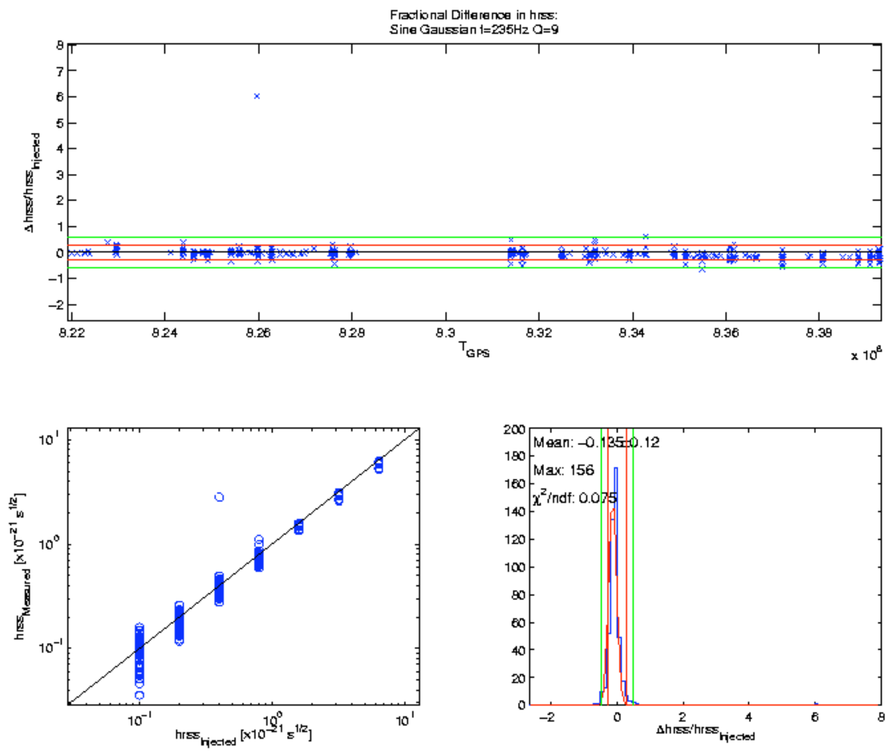
S5 Hardware Injections (H1)



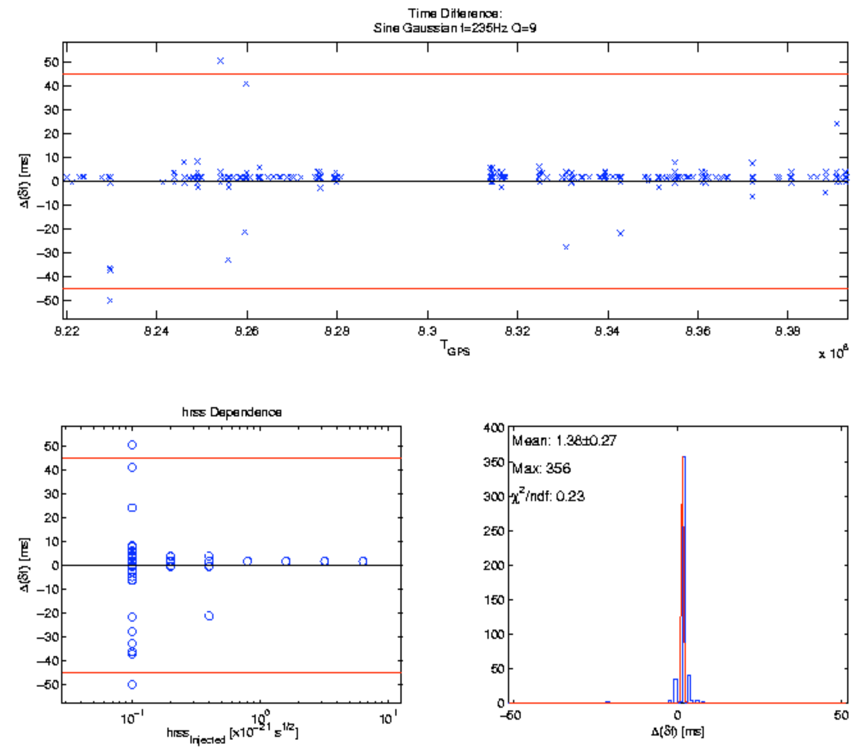
- Statistical study;
  - H1: http://ldas-jobs.ligo-wa.caltech.edu/~sung/HardwareInjections/S5/statistics/HWI_Statistics_H1.html
  - H2: http://ldas-jobs.ligo-wa.caltech.edu/~sung/HardwareInjections/S5/statistics/HWI_Statistics_H2.html
  - L1: http://ldas-jobs.ligo-la.caltech.edu/~sung/HardwareInjections/S5/statistics/HWI_Statistics_L1.html

Sine Gaussian 235Hz Q=9

- H1: 489 Injections
- $\epsilon_h = -0.14 \pm 0.12, \quad \delta(\Delta t) = -1.34 \pm 0.26ms$



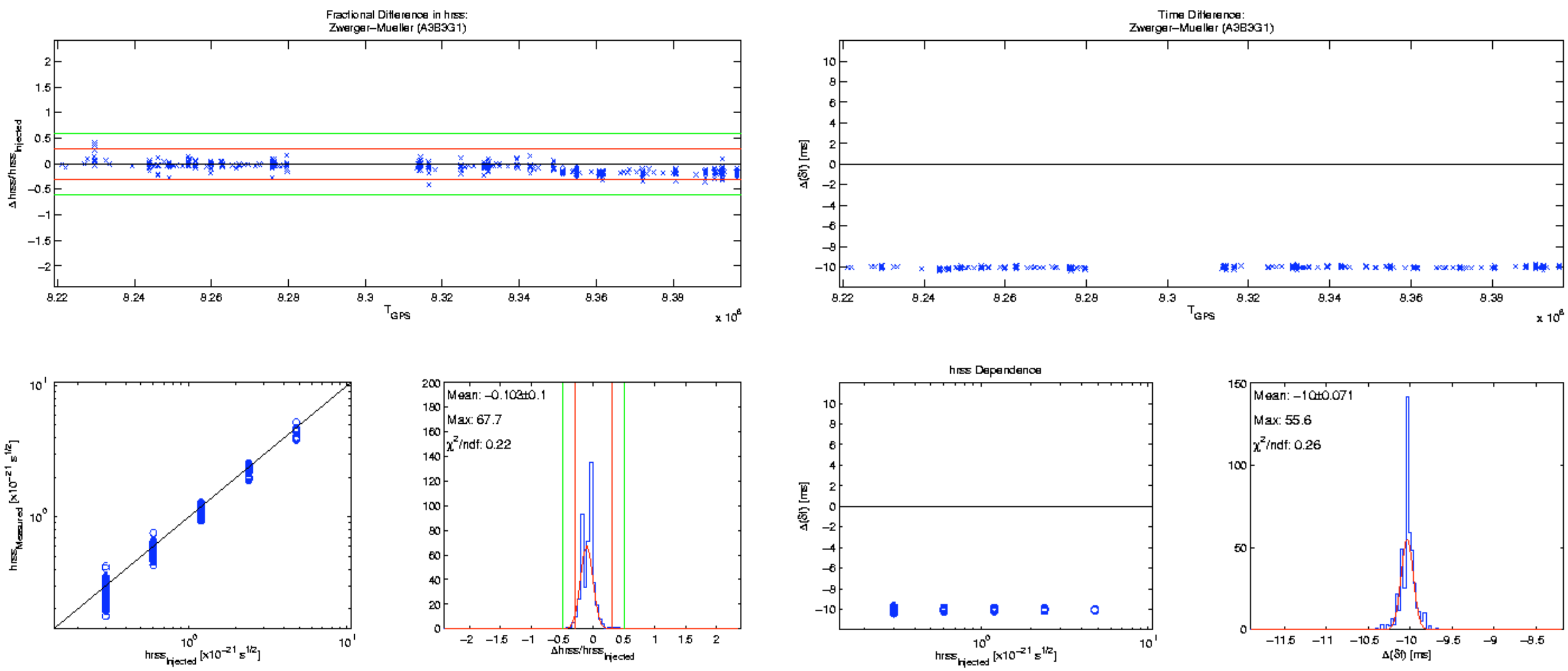
Hrss



Time

Zwerger-Mueller (A3B3G1)

- H1: 446 Injections
- $\epsilon_h = -0.10 \pm 0.09, \quad \delta(\Delta t) = -10.03 \pm 0.07ms$

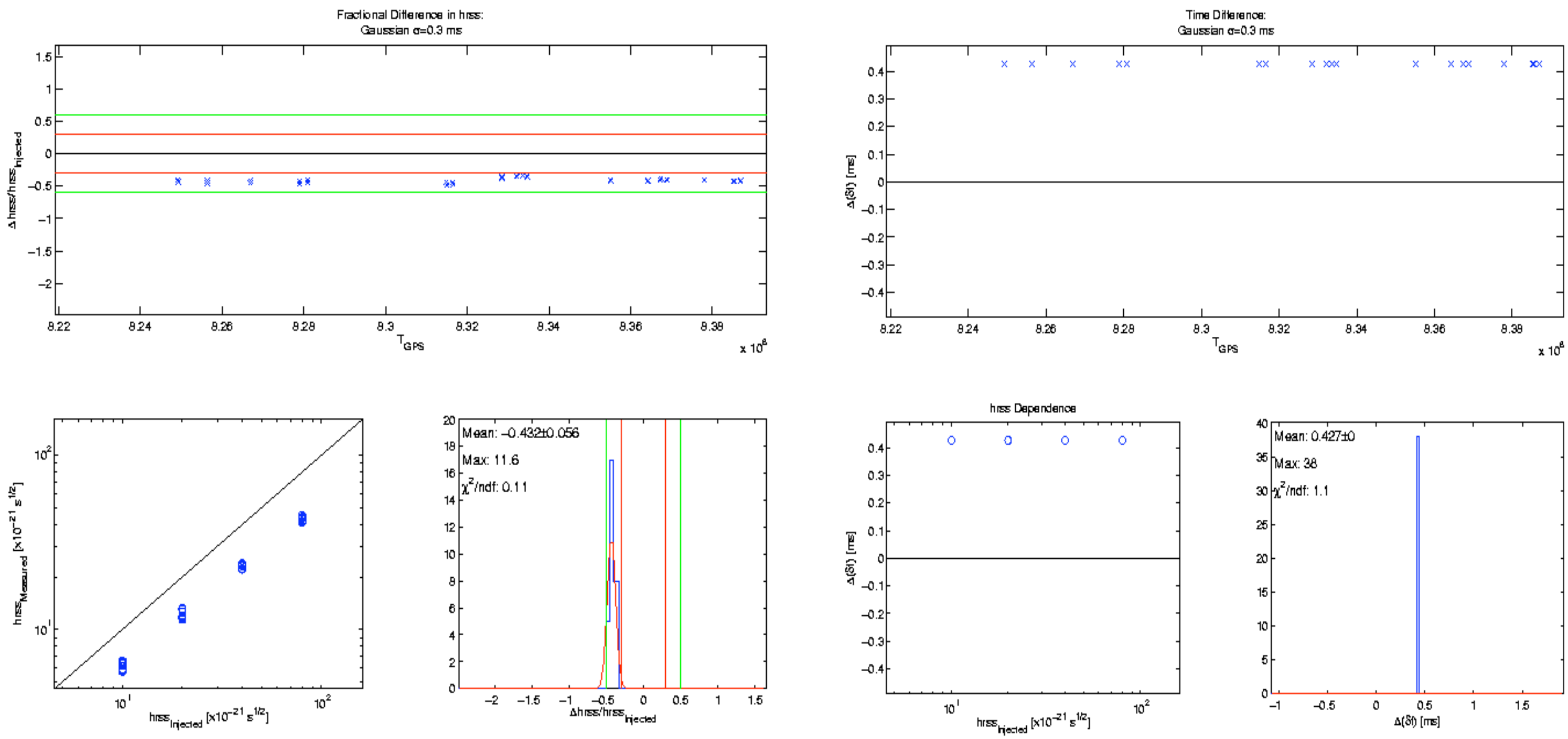


Hrss

Time

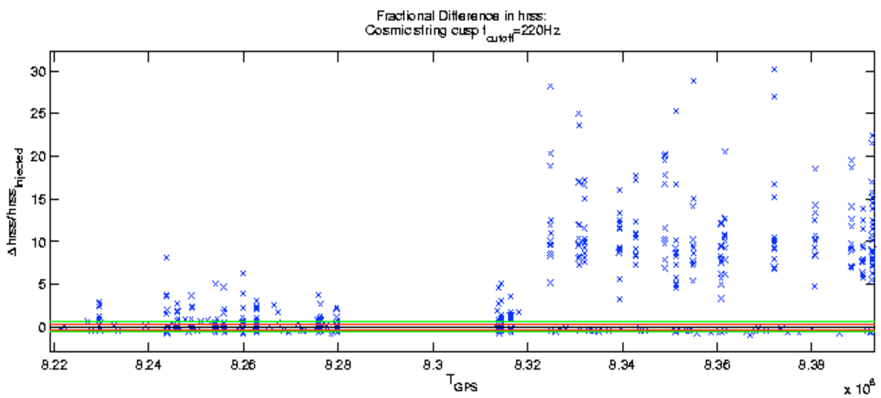
Gaussian with σ=0.3ms

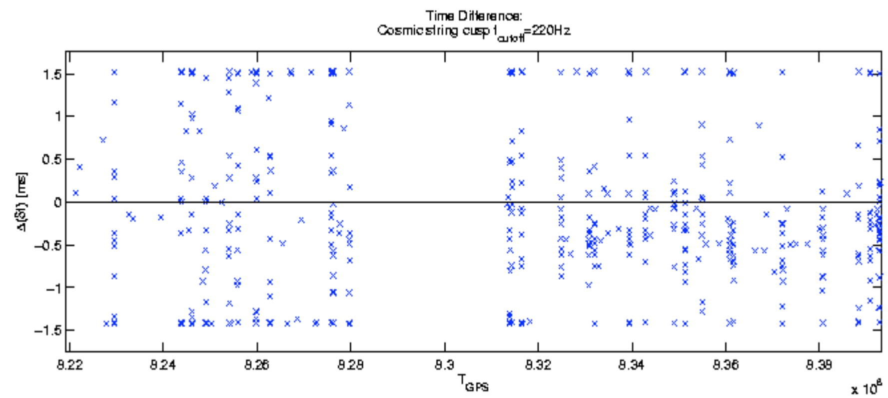
- H1: 38 Injections
- $\epsilon_h = -1.4 \pm 0.4, \quad \delta(\Delta t) = 6.0 \pm 0.9\ ms$

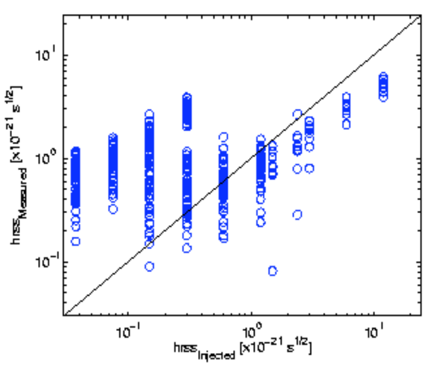


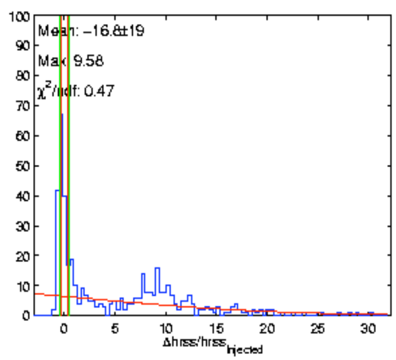
Cosmic String cusp

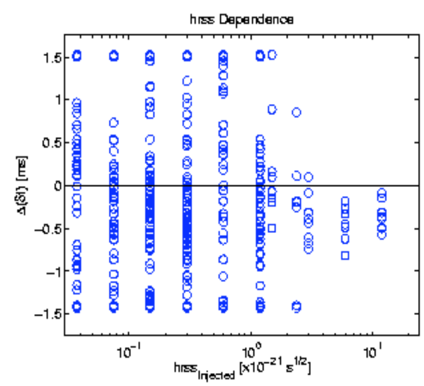
- H1: 433 Injections
- Trouble with low hrss injections.

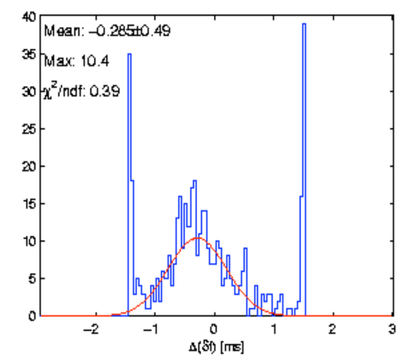






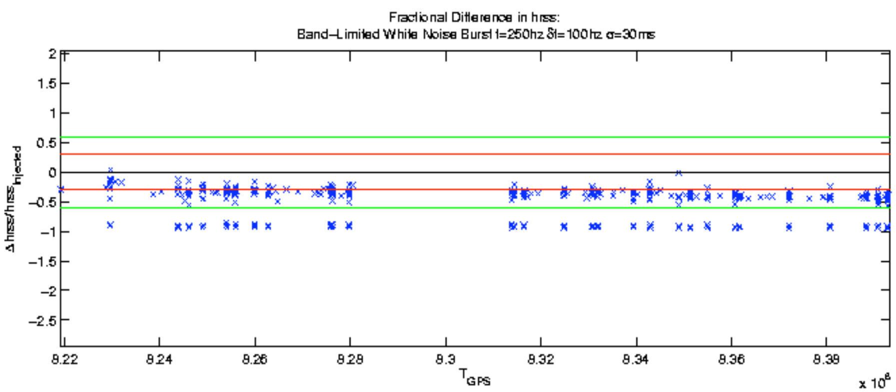


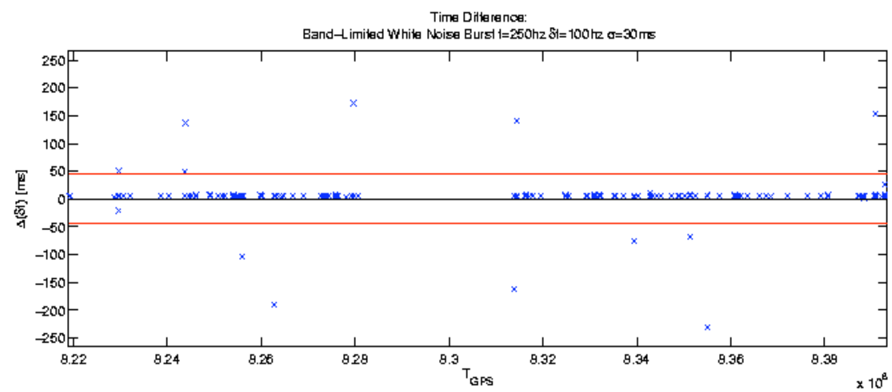


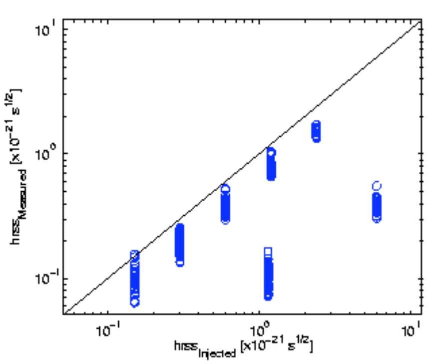


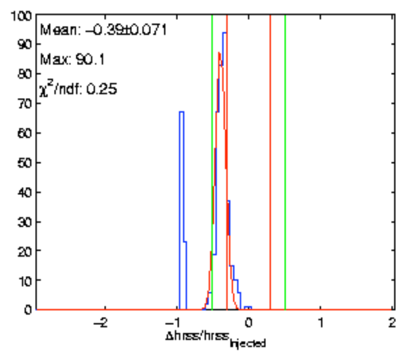
Band-Limited White Noise Burst

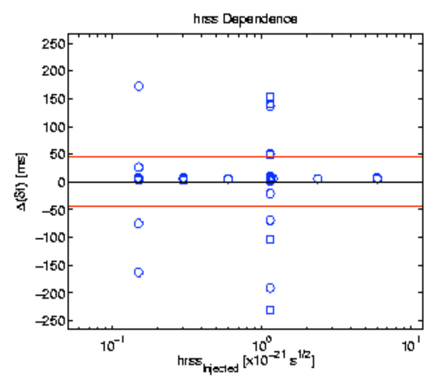
- H1: 431 Injections
- Double peak hrss distribution

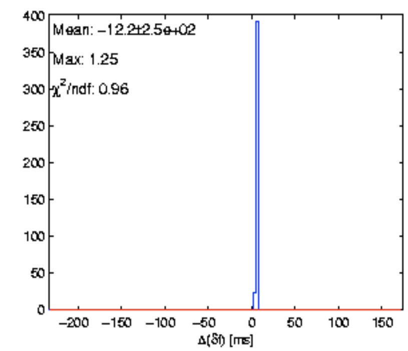






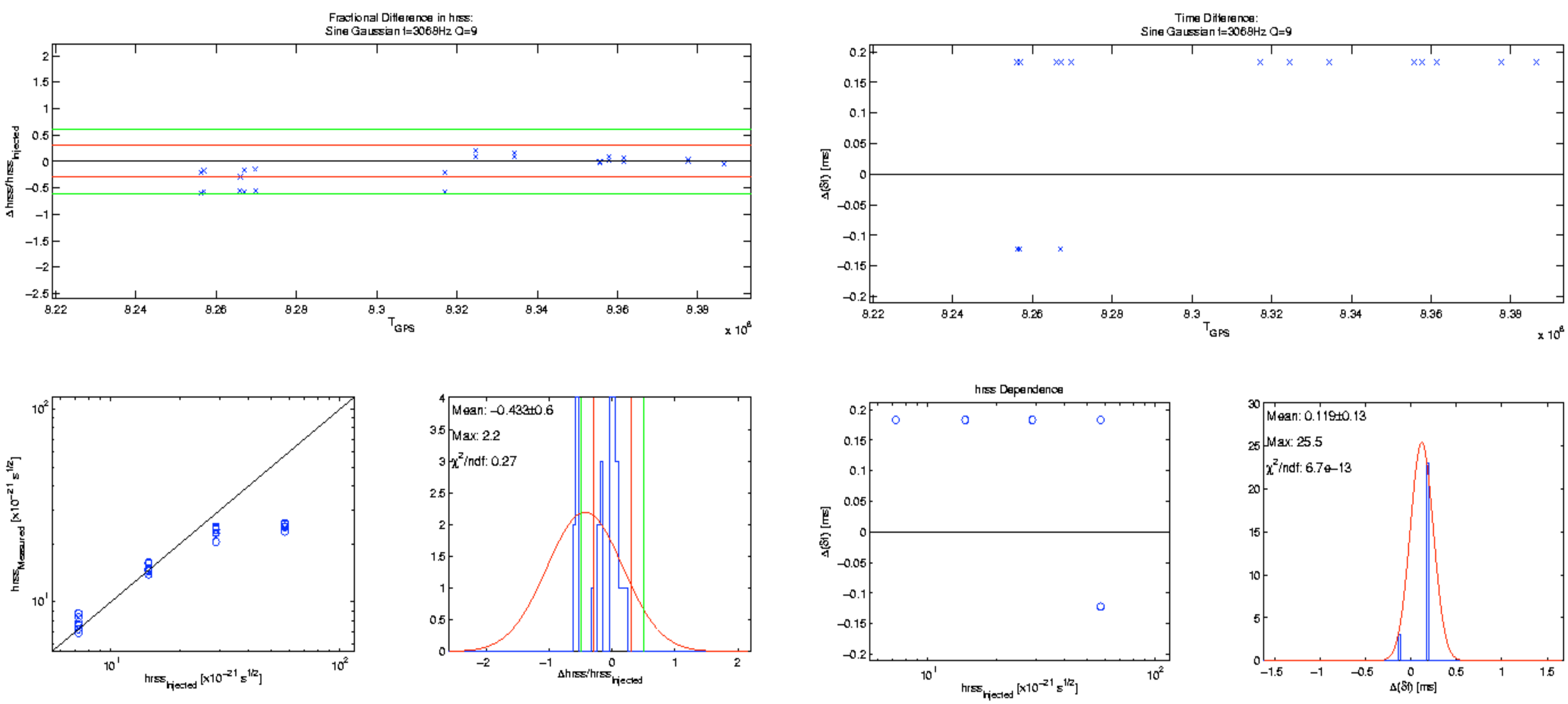






Sine Gaussian 3068Hz Q=9

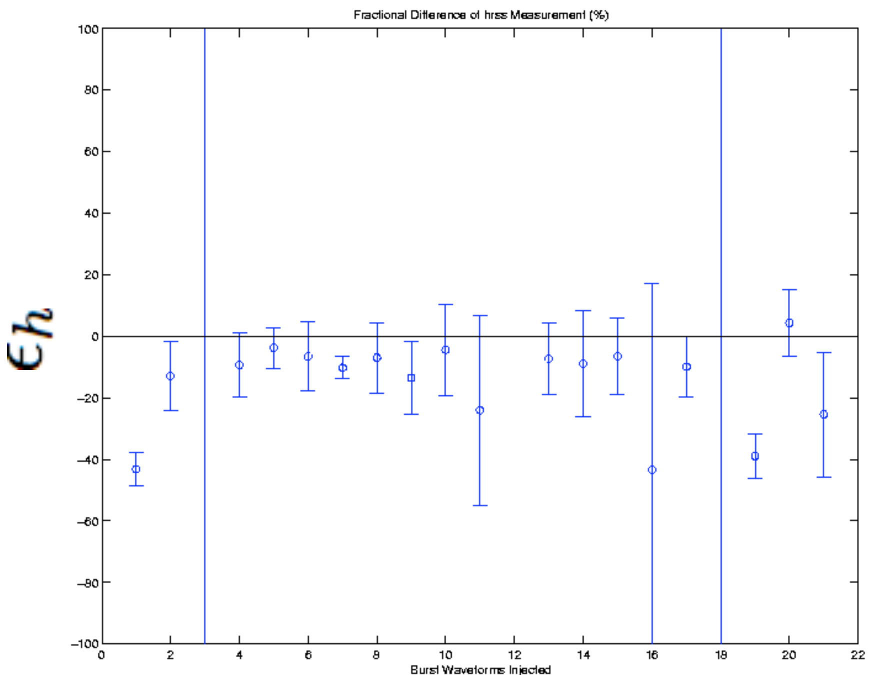
- H1: 26 Injections
- Saturation with high hrss injections



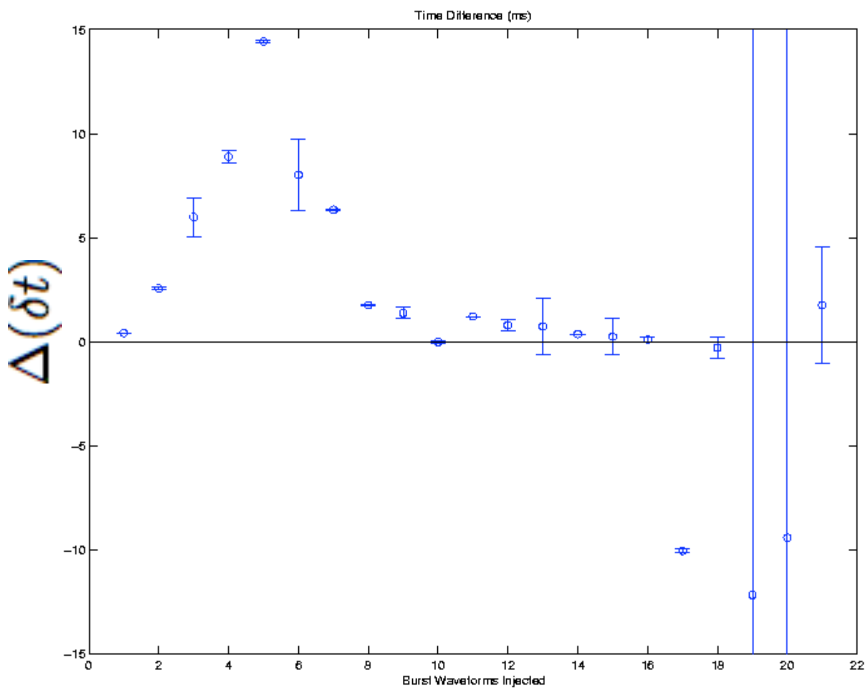
More discussion - http://ligo.phys.lsu.edu/sung/OptimalFilter/HardwareInjection/S5/HardwareInjections_Statistics.html

Hrss and Time for Waveforms

H1

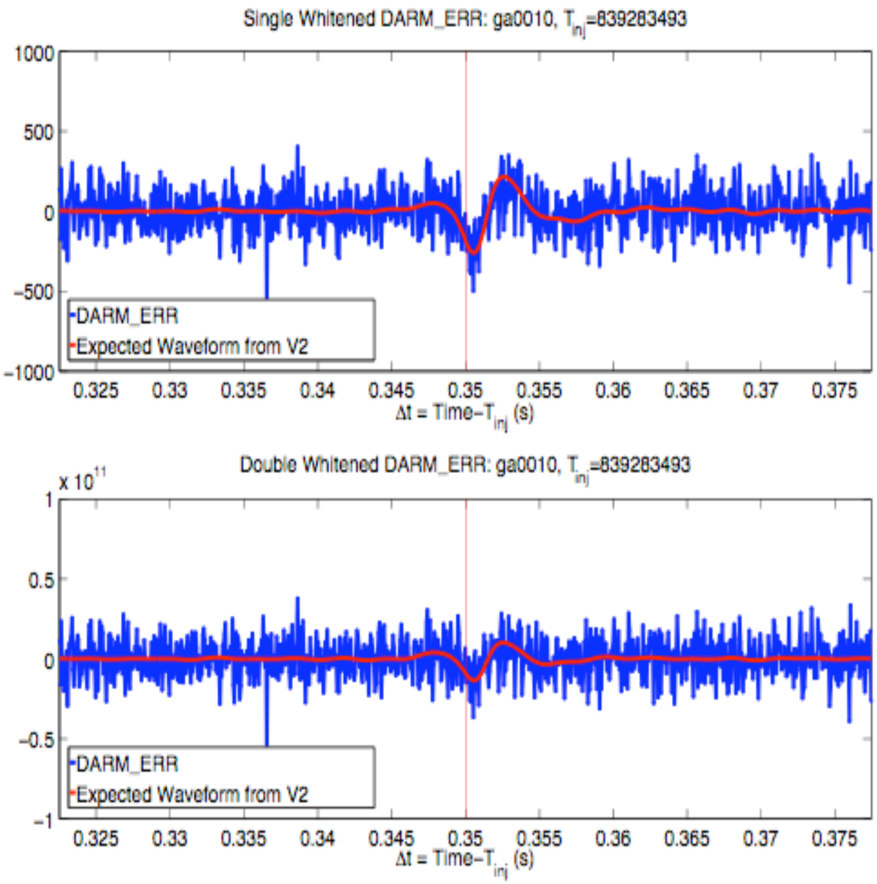


Waveforms

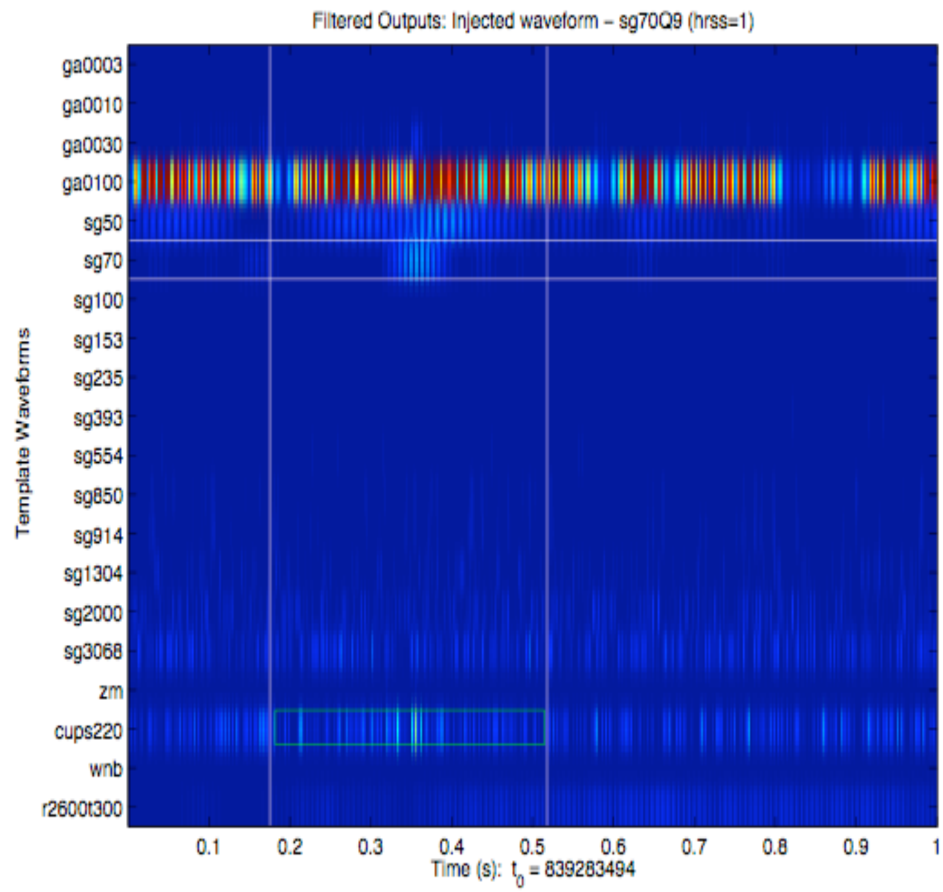


Waveforms

Extra Information



Comparison with Whitened Data



Mismatched Filters

Summary

- Prompt results from optimal filter study on hardware injections.
- General condition to validate burst injections; recently relaxed the condition for hrss measurements.
- Three waveforms with problems - a Gaussian (0.3ms), cusp, white noise burst.
- Saturation with Gaussian 3068Hz with early injections.
- Not much for Inspiral injections yet.