Hardware Burst Injections in Pre-S2 $\rightarrow$ S2

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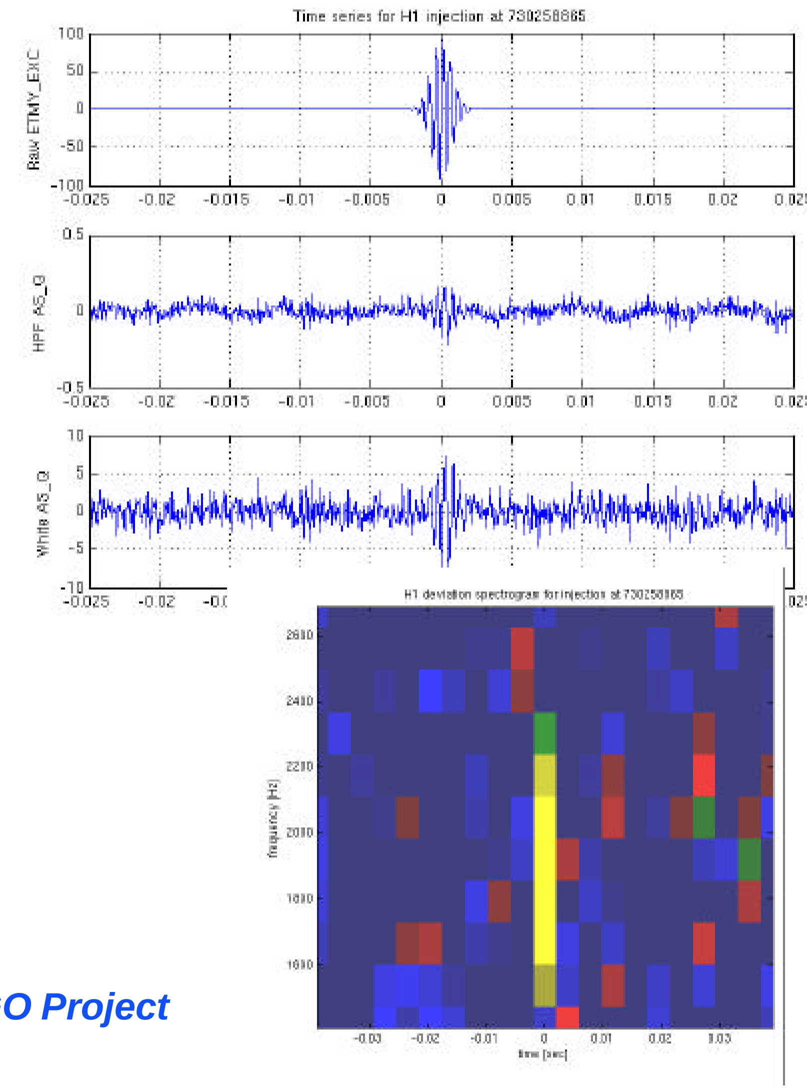
And WaveBurst results from
Sergei Klimenko, UFla
Igor Yakushin, LIGO-LLO

LSC meeting,
3/18/03



Goals of the Burst Injections

- test our understanding of the entire signal chain from
  - » GDS excitation point →
  - » displacements of test masses →
  - » data logged in LSC-AS_Q and related DM and common mode channels →
  - » entire burst search analysis chain.
- In particular, we need a quantitative comparison between signals injected into the IFO and signals injected into the datastream in software (in LDAS), to validate the efficiency calculation.
- Verify that we detect HW injected signals with SNR as expected
  - » Detection confidence
- Test our understanding of the dependence on source direction and polarization.

Injecting signals

The *awg, multiawgstream* and *SIStr* facilities developed by I. Leonor, P. Shawhan, D. Sigg are used to inject series of signals into the *LSC-ETMX_EXC*, and *LSC-ETMY_EXC*, or *DARM_CTRL_EXC* channels of the three interferometers.

The injections during S1, E9 and S2 were/are coordinated by M. Landry, P. Shawhan, S. Marka

Many thanks to all the developers for this immensely important and useful facility!

Original (ambitious) program: Burst_z and Burst_ang

Burst_z scan, into DARM or ETMX-ETMY:

- inject sine-Gaussians into all 6 end test masses, with durations of ~ 1 second, spaced 40 seconds apart.
- Scan 8 logarithmically-spaced central frequencies from 100 - 2000 Hz.
- Scan ~6 amplitudes from 1 to 100 times the nominal calibrated strain sensitivity at that central frequency.
- These 48 bursts should thus take 32 minutes.

Burst_ang scan, exciting both DARM and CARM, with IFO-IFO delays:

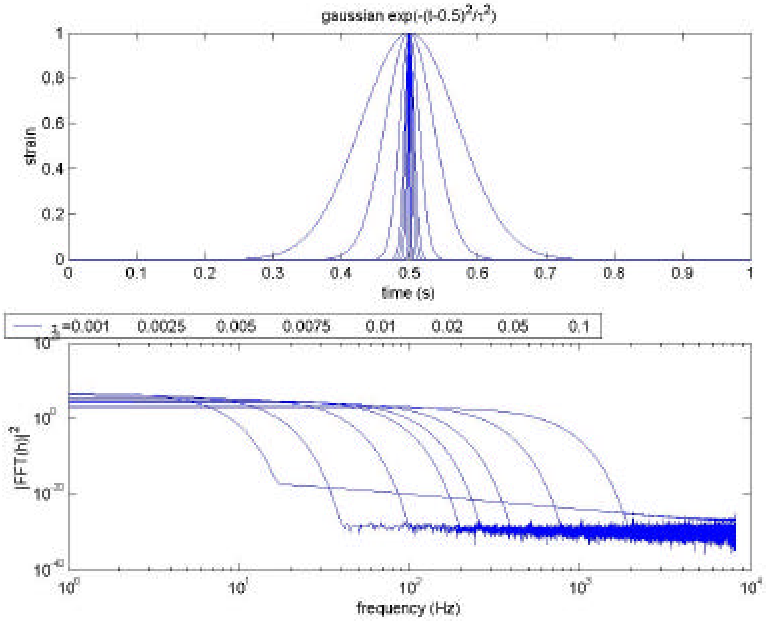
- Choose one central frequency and relatively large amplitude, and scan over 100 source directions and polarizations (5 in $\cos\theta$, 5 in φ, 4 in ψ; all with respect to the mean of the LHO/LLO zenith and orientation). This should take 67 minutes.

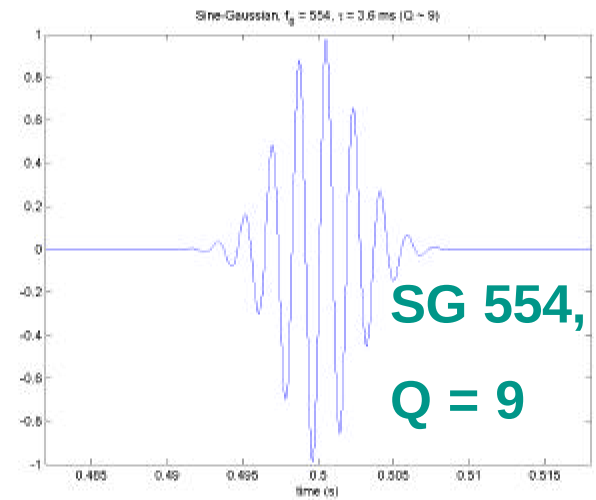
Waveforms, amplitudes

- Short, narrow-bandwidth signals (sine-Gaussians) provide the most direct and useful interpretation of IFO and data analysis responses. We envision a "swept-sine calibration" of sine-Gaussians of varying frequency, spanning the LIGO band of interest.
- Signal amplitudes should span the range from "barely detectable" to "large, but not so large as to excite a non-linear response". The IFO strain sensitivity varies over the frequency range of interest, so the amplitudes should vary as well.
- Signals are injected using the GDS excitation engine, which accepts 16384-Hz time series in units of counts to the coil driver. The frequency dependence of the test mass response must be taken into account.
- Each sine-Gaussian has $Q \sim 9$; total duration ~ Q/f_0

Frequency f_0 (Hz) Duration (msec)	100 90	153 58	235 38	361 25	554 16	850 11	1304 7	2000 4.5
Time from segment start t_0 (sec)	20	40	60	80	100	120	140	160

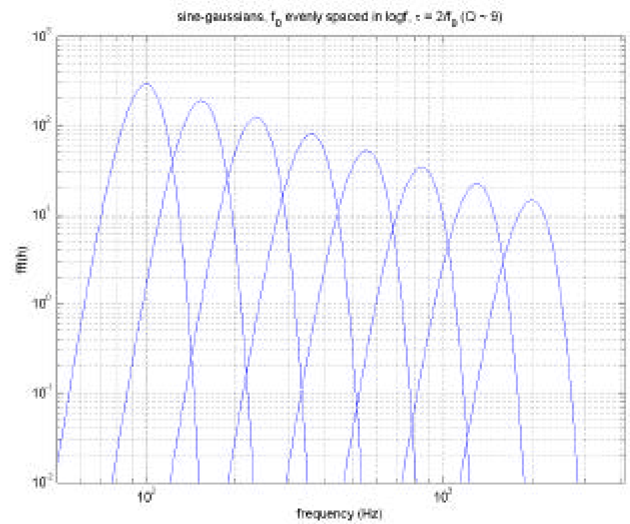
Ad-hoc signals: (Sine)-Gaussians





SG 554,

Q = 9



These have no astrophysical significance;

But are well-defined in terms of waveform, duration, bandwidth, amplitude

Schedule of Signal Injections During the S2 Run

```
Feb 14  2:48 CST,  0:48 PST #
Feb 18 23:00 CST, 21:00 PST
Feb 23 16:00 CST, 14:00 PST
Feb 25 18:00 CST, 16:00 PST *
Mar  2 14:00 CST, 12:00 PST
Mar  3 12:00 CST, 10:00 PST
Mar  7 2:00 CST,   0:00 PST
Mar 12 20:00 CST, 18:00 PST
Mar 15 24:00 CST, 22:00 PST *
Mar 19 23:00 CST, 21:00 PST
Mar 23  3:00 CST,  1:00 PST
Mar 25 22:00 CST, 20:00 PST
Mar 28 20:00 CST, 18:00 PST *
Apr  2 10:00 CST,  8:00 PST
Apr  5  4:00 CST,  2:00 PST
Apr  9 24:00 CST, 22:00 PST *
Apr 11 22:00 CDT, 20:00 PDT
* inserted during the run to make up for lost opportunities
  (sometimes the interferometers were just out of lock and injection was pointless or partial)
# The injection time was determined just before the injection
```

S, Marka,

P. Shawhan,

I. Leonor

Actually done and analyzed (so far):

- Groups of 8 SG's, varying amplitudes.
- Intra-run injections subject to IFO availability.

DATE	ETMx-ETMy	ETMx	ETMy
Feb 13 (pre-S2)	13 (H1,L1)	8 (H1,L1)	8 (H1,L1)
Feb 17	-	-	3 (H1,L1)
Feb 25	-	-	3 (H1,H2,L1)
Mar 2	-	-	3 (H1)
Mar 7	-	-	3 (H1,L1)
Mar 15	-	-	3 (H1,L1)
Mar 17	-	-	3 (H2)

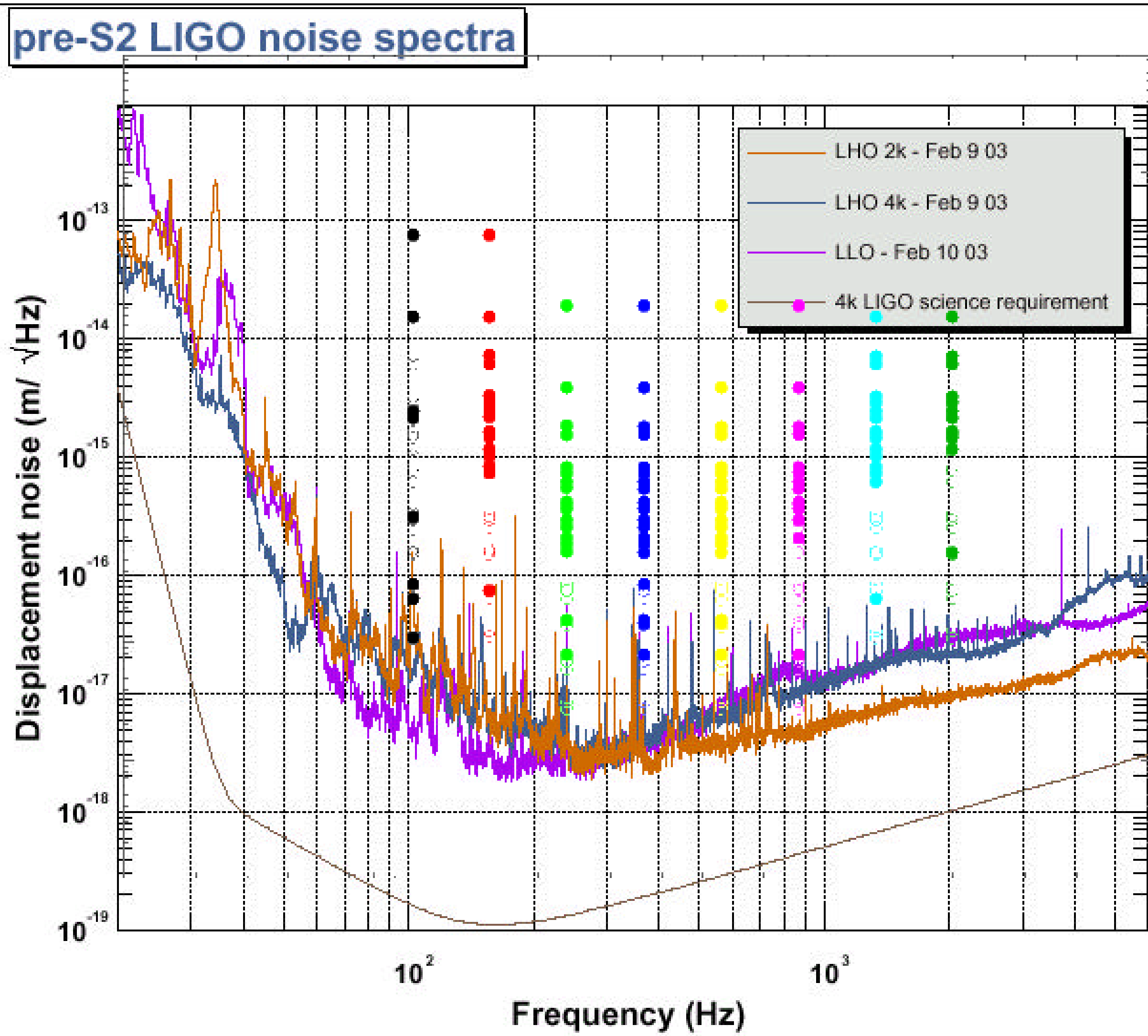
Signal amplitudes

# Time	Cfg	Waveform file	ETMX	ETMY	hpeak (strain)
729154547.000000	1	wfsg100Q9.dat	0.0107060	-0.0104160	3.0e-19
729154567.000000	1	wfsg153Q9.dat	0.0312080	-0.0303660	3.7e-19
729154587.000000	1	wfsg235Q9.dat	0.0227440	-0.0221300	1.1e-19
729154607.000000	1	wfsg361Q9.dat	0.0663000	-0.0645080	1.4e-19
729154627.000000	1	wfsg554Q9.dat	0.1932700	-0.1880460	1.7e-19
729154647.000000	1	wfsg850Q9.dat	0.5634020	-0.5481760	2.1e-19
729154667.000000	1	wfsg1304Q9.dat	6.5694940	-6.3919400	1.1e-18
729154687.000000	1	wfsg2000Q9.dat	19.1507320	-18.6331460	1.3e-18

The waveform files have a peak amplitude (at 0.5 secs) of 1.
You can read off the ETMx and ETMy signals, peak amplitude in counts. So:

|ETMx-ETMy| (in counts)
´ (~1 nm / ct) (DC calibration, approximate, varies from ~0.5-1.0)
´ (0.744/f0)^2 (pendulum response, where f0 is central SG frequency)
/ 4000 m (or 2000 m for H2)
will give you a peak amplitude in strain.

SG injections: frequencies, amplitudes

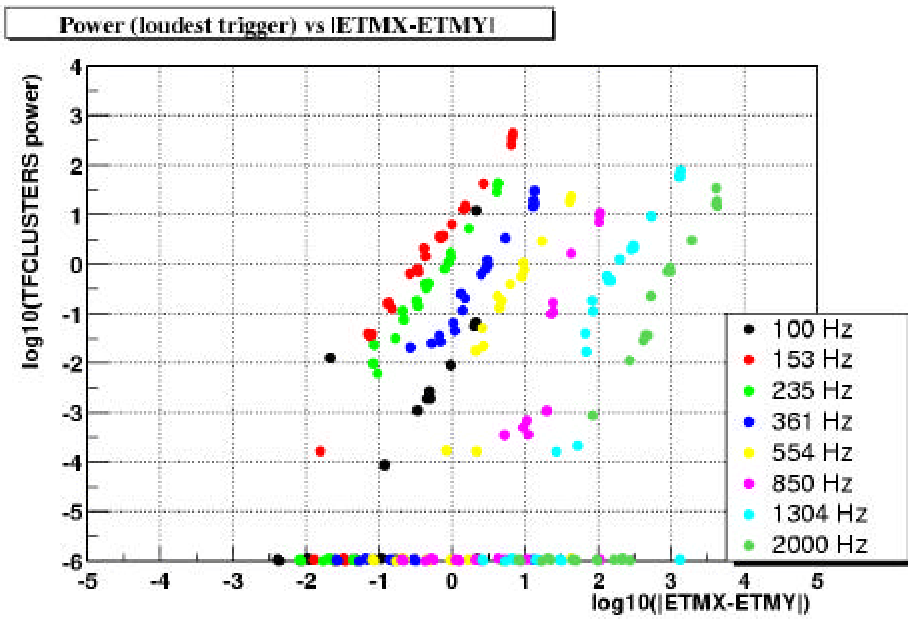


- SG central frequencies f_0 are color-coded
- Closed circles are detected bursts; Open circles are undetected (H1)

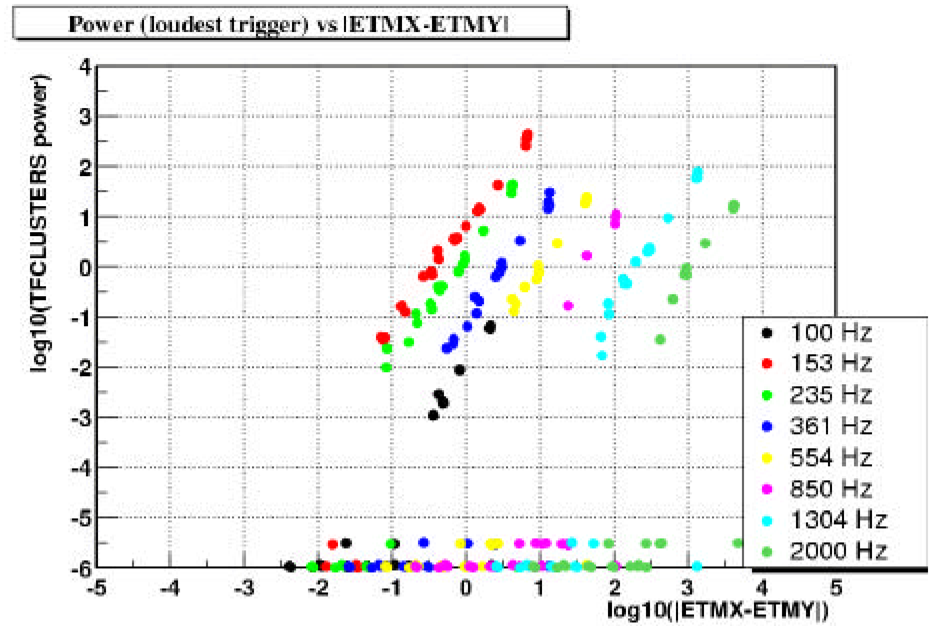
Analysis

- Data were analyzed through the standard Burst pipeline
- Pre-filtering in datacond, including 100 Hz HPF and whitening
  - » For the first few injection runs, HPF 150 Hz and S1 whitening
- Then, data from each IFO were passed through tfclusters and slope ETG's
- Each ETG returns triggers with start_time and trigger strength
- tfclusters also returns a central frequency
- Time resolution:
  - » tfclusters uses time bins of 1/8 second, start_time is quantized in those units (125 msec)
  - » Slope is expected to give < 50 msec resolution

Trigger power (tfclusters) Feb 13 injections



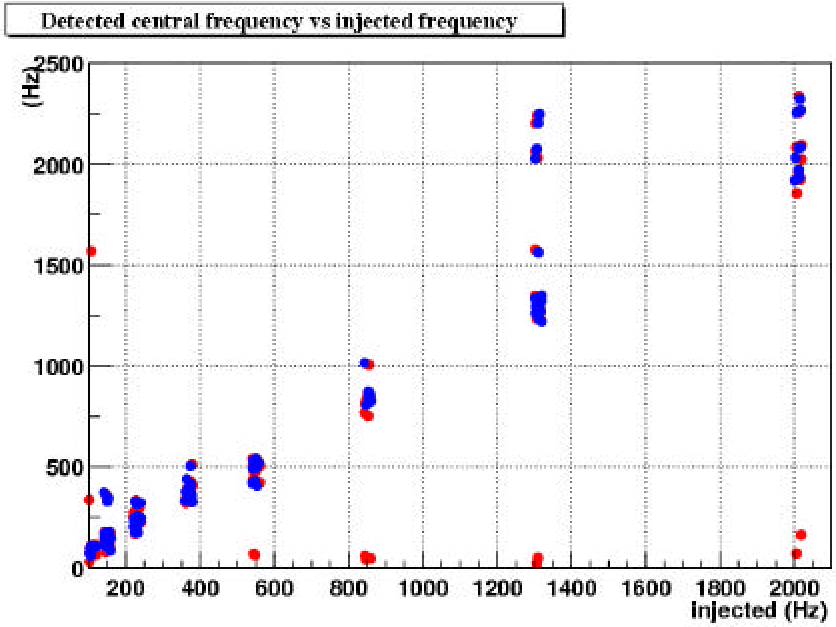
Before frequency consistency cut

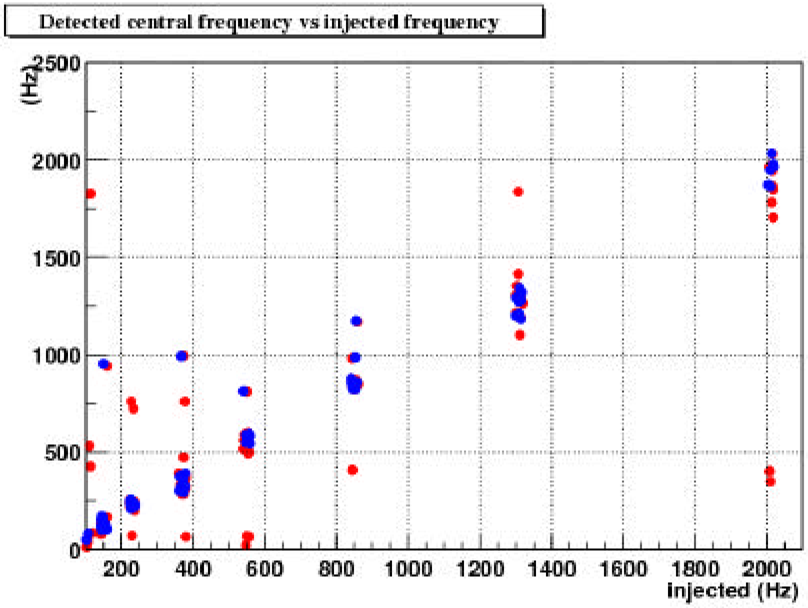


After frequency consistency cut

L. Cadonati

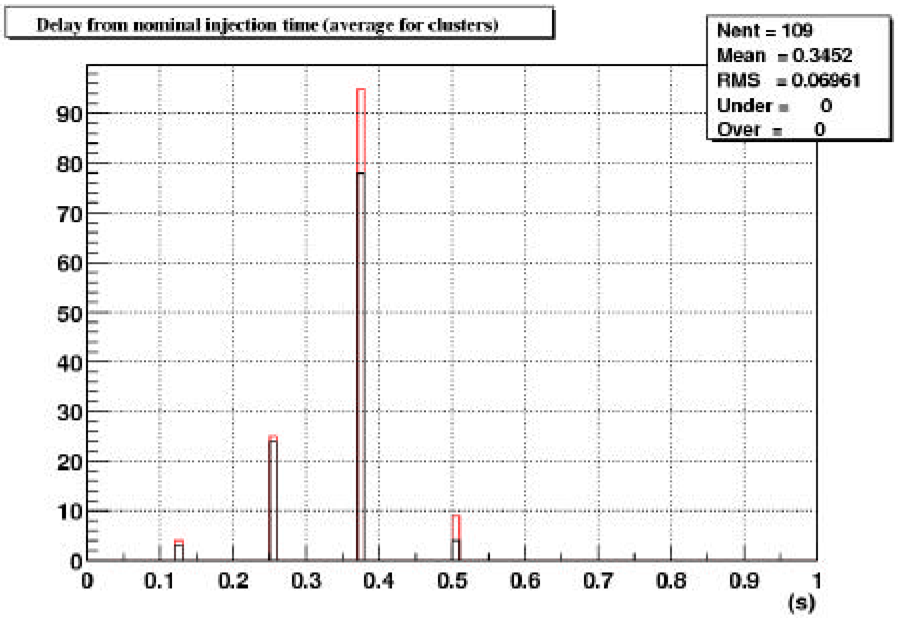
TFCLUSTERS central frequency vs injected frequency

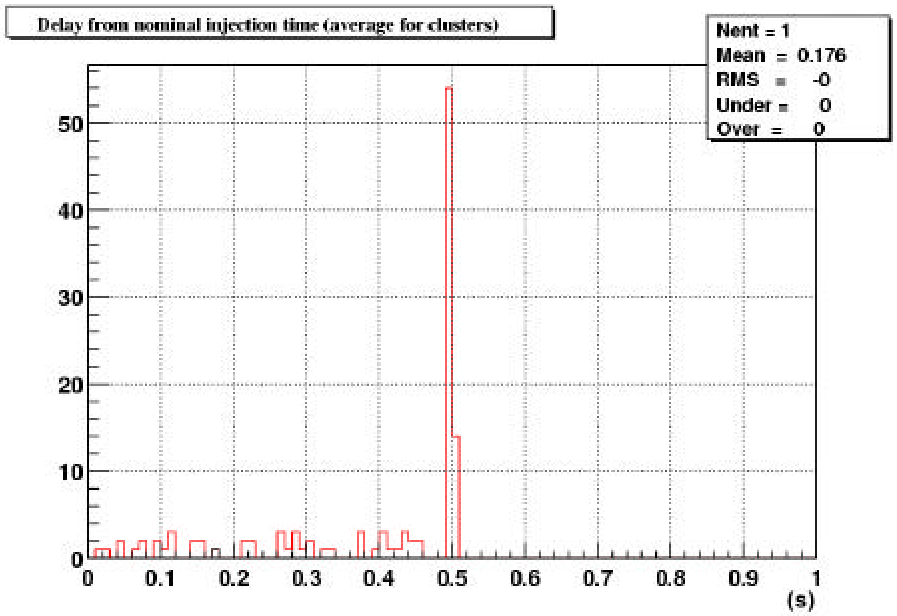




The red, off diagonal events are the ones rejected by the frequency cut (background noise).
The blue, off diagonal events have large bandwidth, covering the injected frequency, thus pass the frequency cut.

Timing accuracy





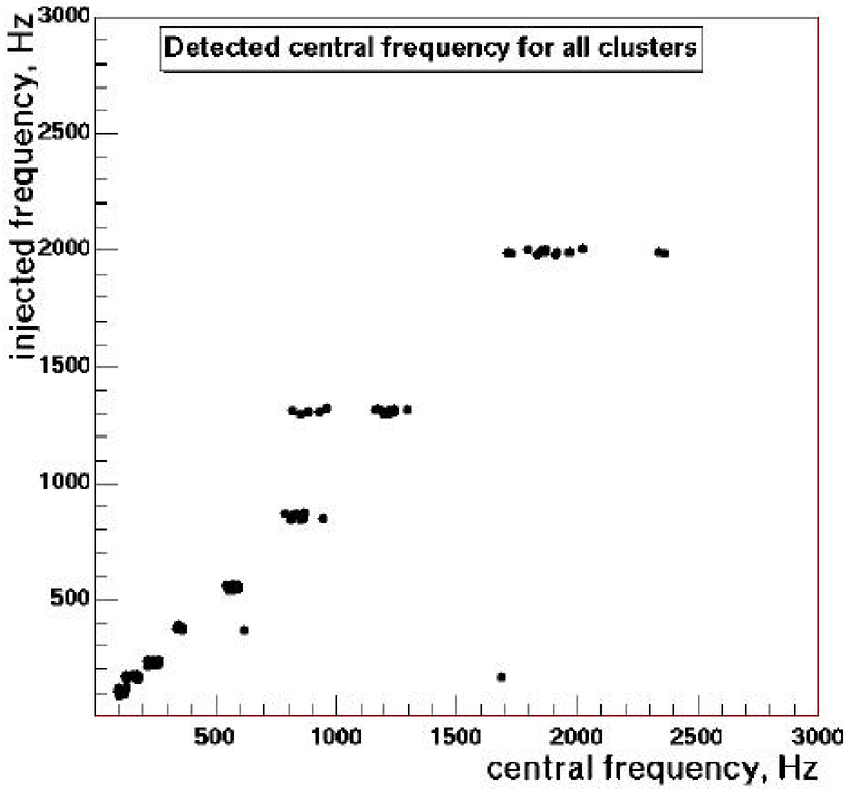
- Injection peaks at 0.5 secs, starts ~10's of msec before then
- Tfclusters (left) is quantized in bins of 1/8 sec.
- Slope (right) peak is 10 msec before 0.5 sec.

Results from WaveBurst

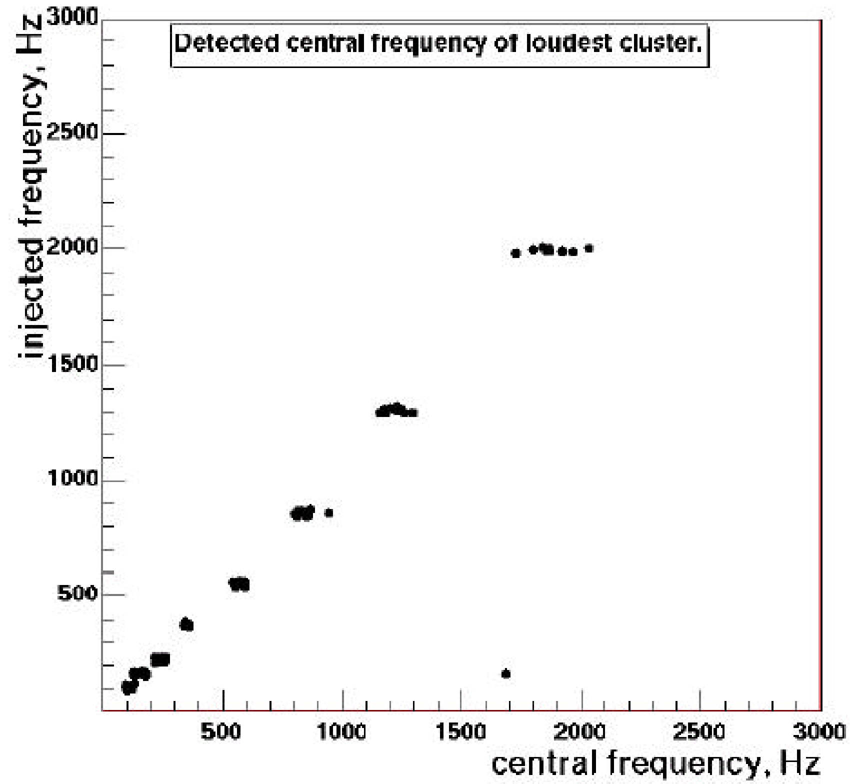
- WaveBurst DSO (S. Klimenko, I. Yakushin) cross-correlates data streams from 2 detectors in wavelet basis.
- Run on H1 and H2 detectors, using the 23 groups of 8 SG bursts from Feb 13, 2003
- Biorthogonal wavelet of 16^{th} order was used
- WaveBurst TF resolution of 1/32 sec x 16 Hz

Central frequency from WaveBurst

all clusters



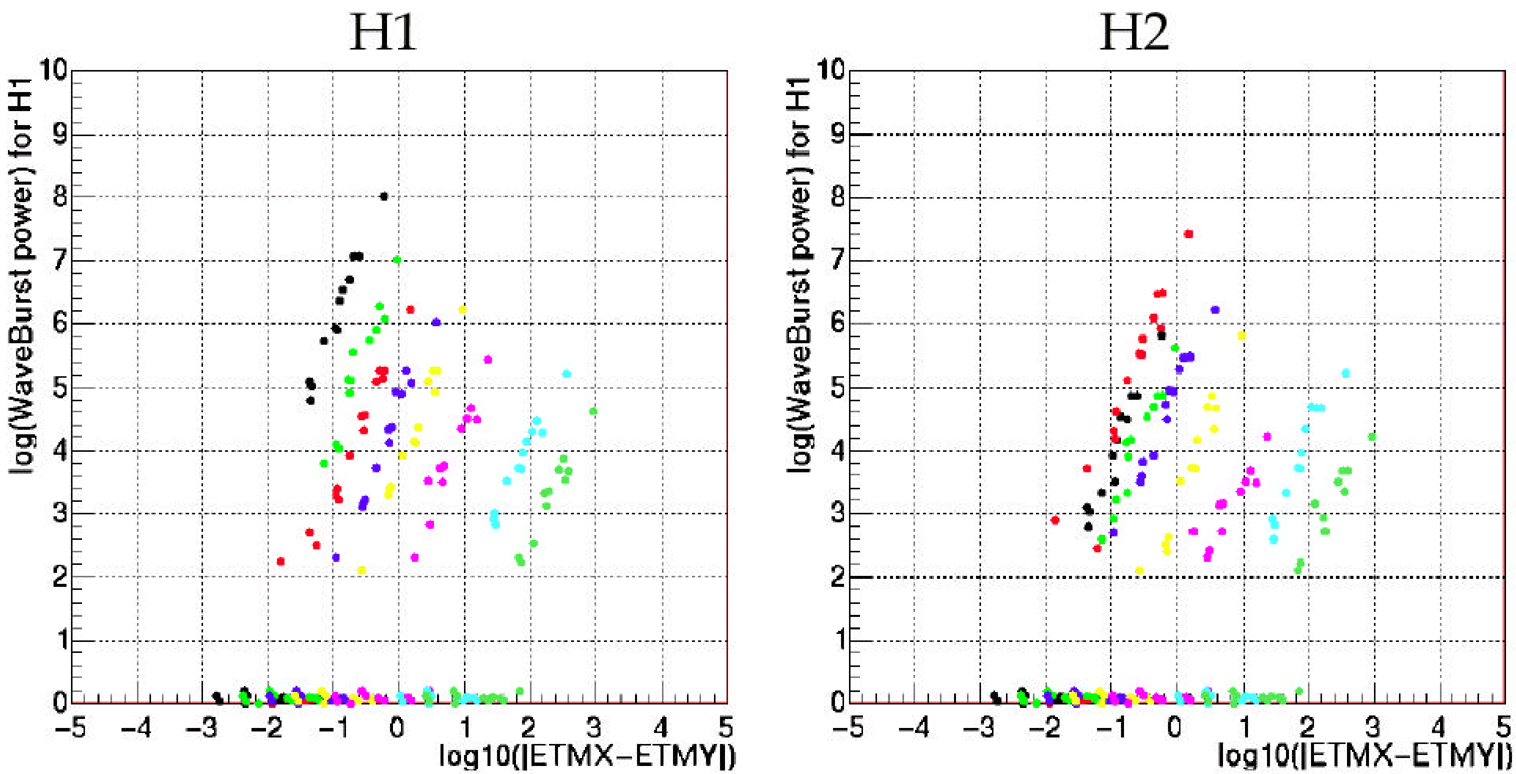
loudest clusters



WaveBurst power

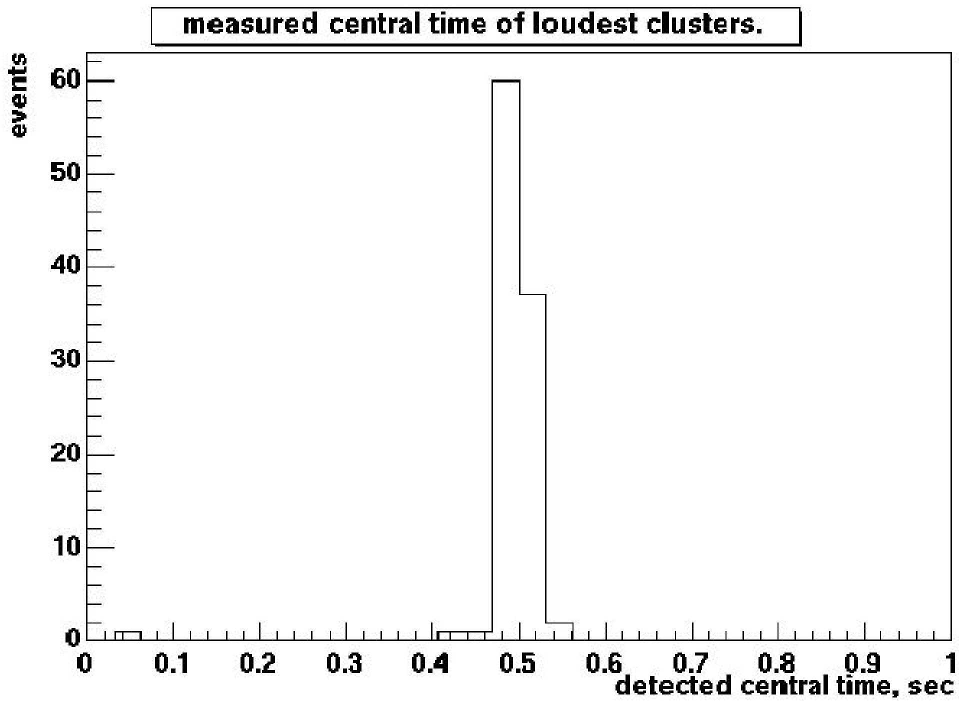
Power of loudest clusters

(100Hz and 153 Hz detection is limited by H2 IFO)

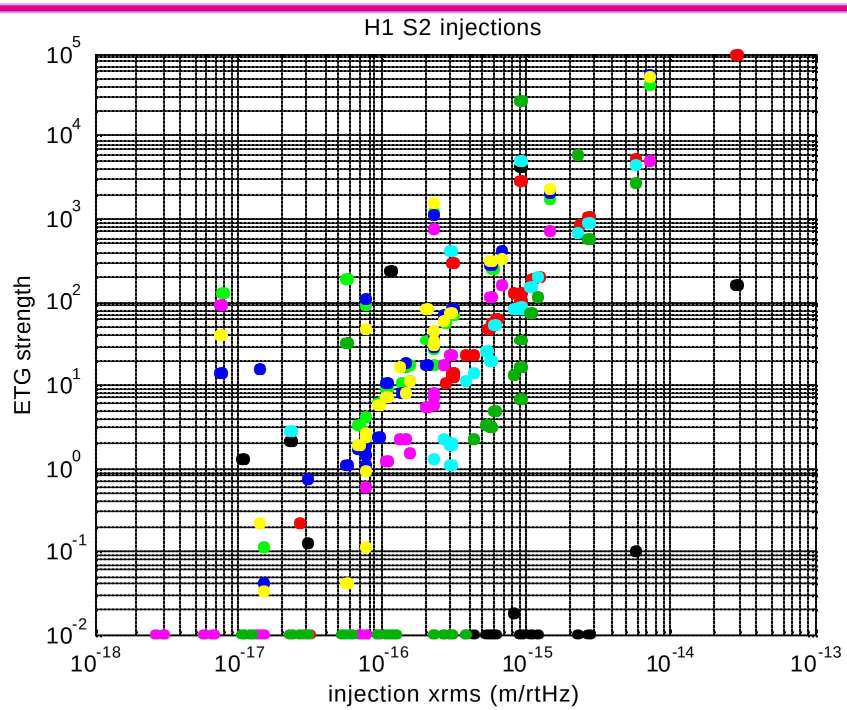


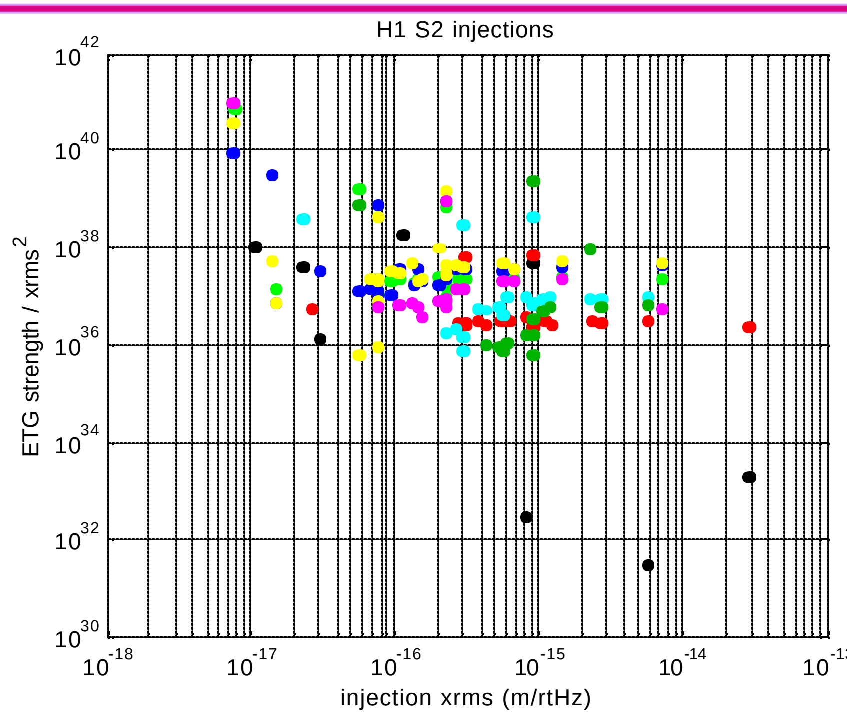
Central time of WaveBurst cluster

- **Bin width corresponds to the WaveBurst time resolution 1/32 sec**



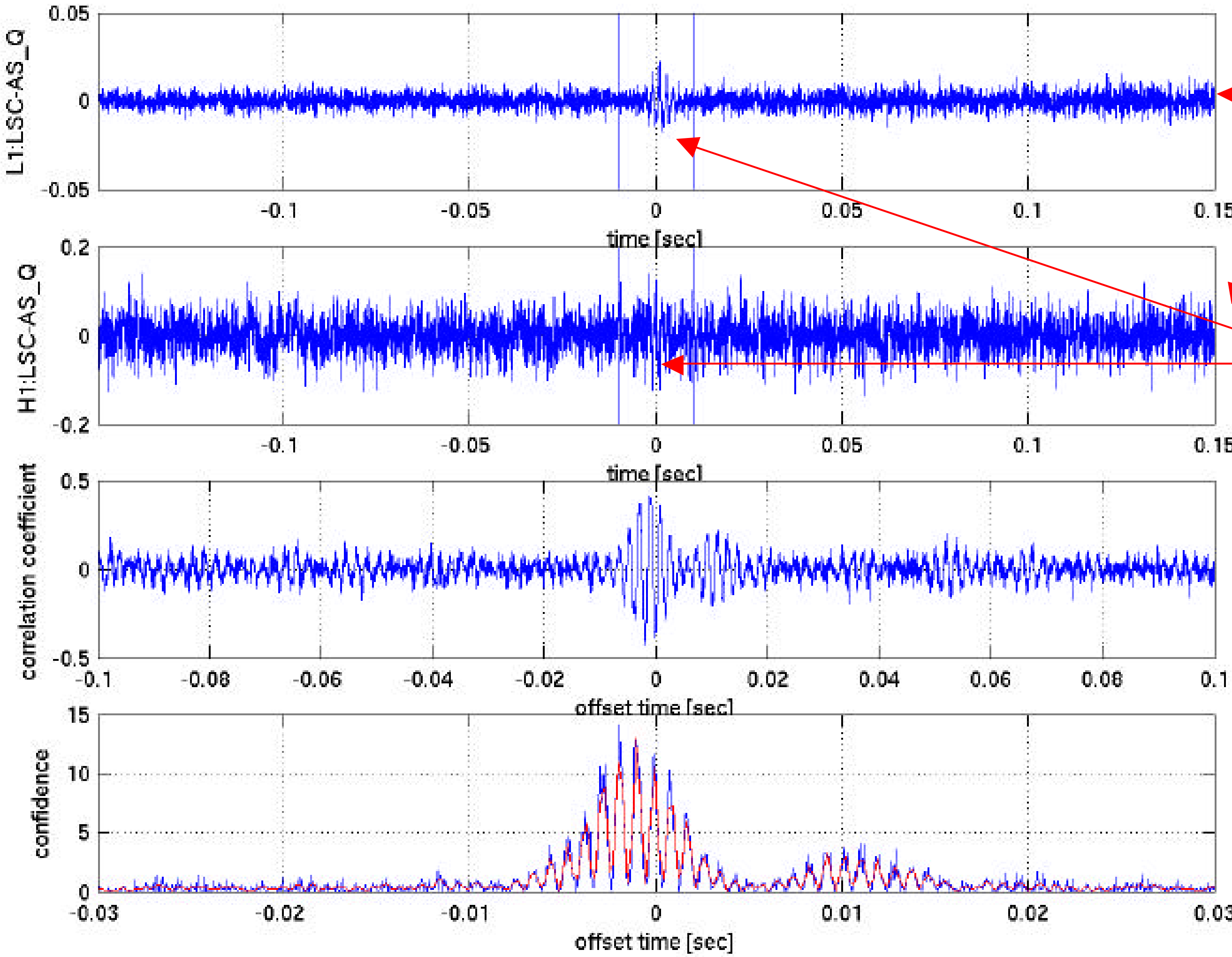
ETG strength ~ $xrms^2$





- There's a lot of scatter, but most injections indeed show strength ~ $xrms^2$
- Don't compare the different colors; they're different frequencies, and the IFOs have different sensitivities. The black dots are at 100 Hz, and we hpf'ed at 150 Hz!
- Still, a lot of signals were not found – under investigation!

H1 – L1 cross-correlation



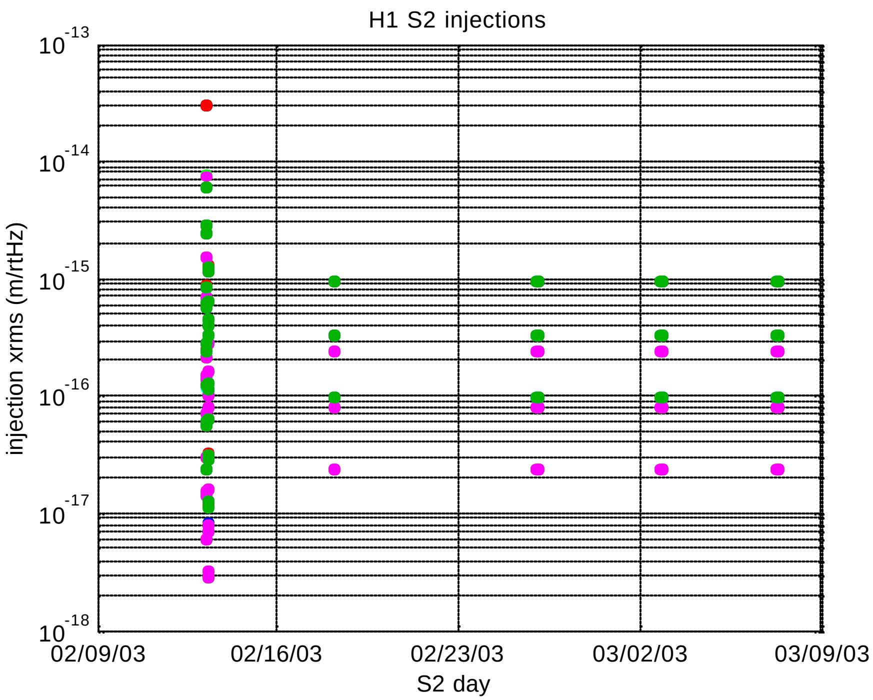
Filtered AS_Q data streams

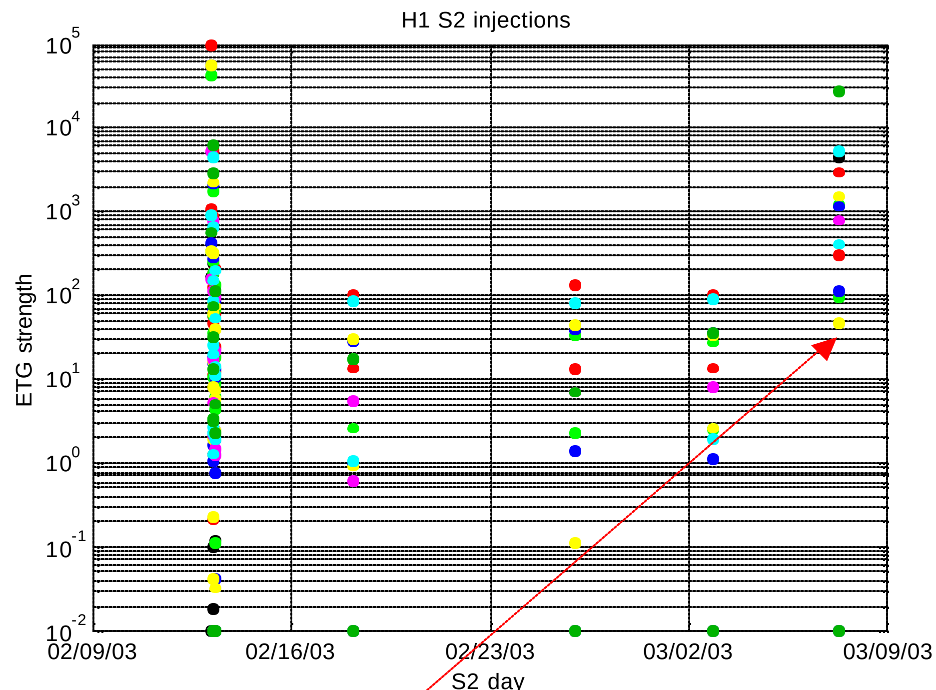
554 Hz SG at hrms ~ 2e-20 Injected in H1 and L1 simultaneously

Correlation coefficient and confidence

L. Cadonati

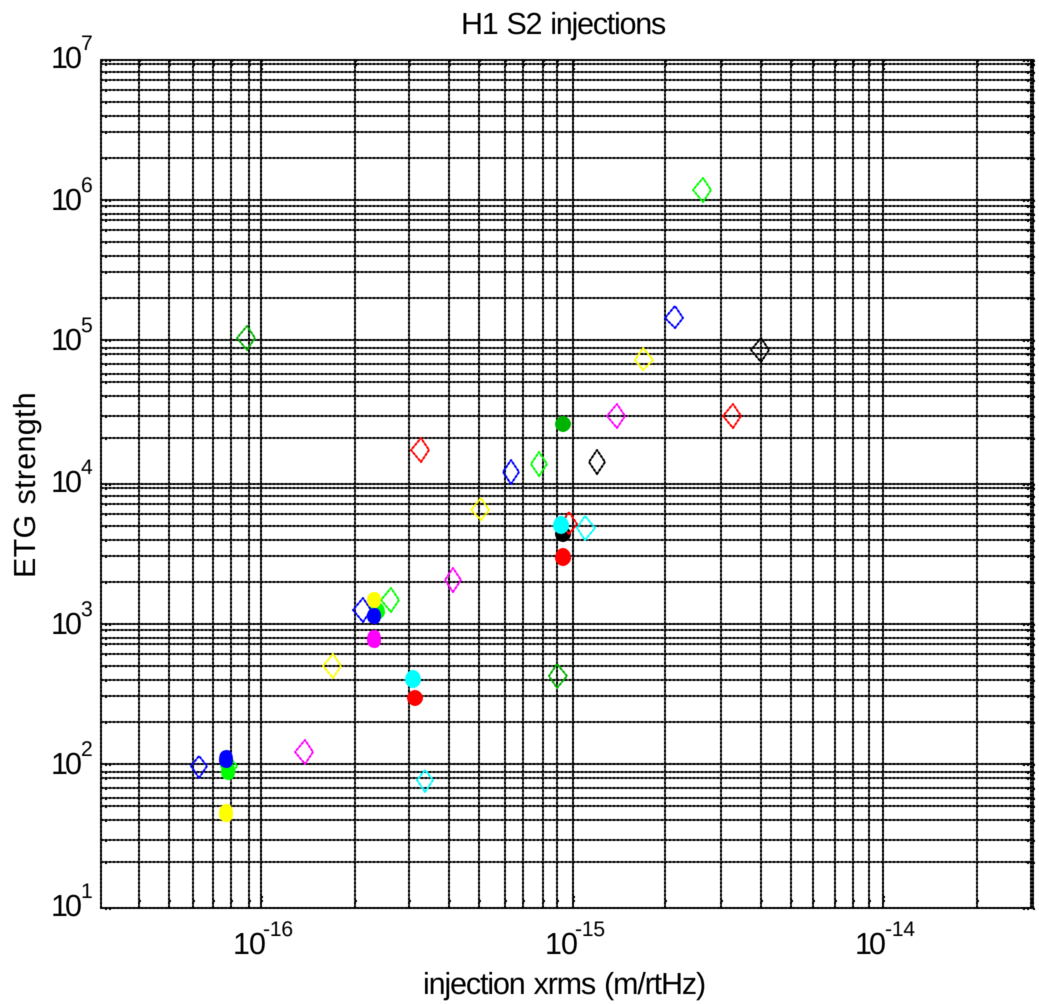
Intra-run injections and stability





- A much more limited set of injections are being done throughout S1.
- Oops! Used different pre-filtering for the 3/7/03 injections!
- Need to run with the new filters on all injections; trying to get the data and filters all available at one ldas…

Comparison with SW injections

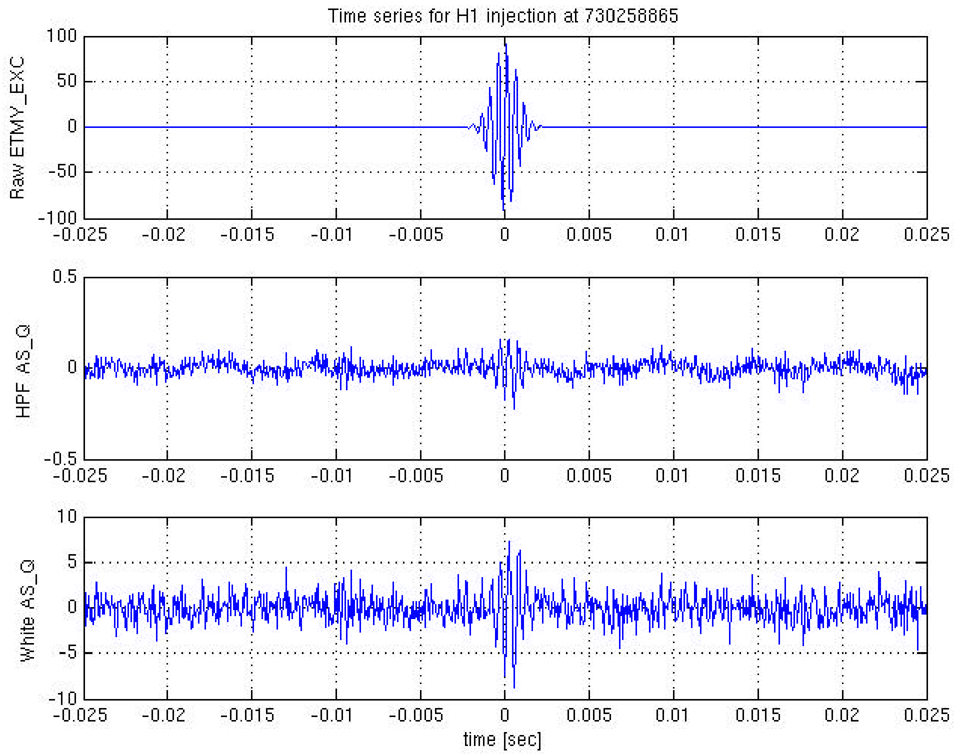


- Comparison currently only available for latest round of intra-run injections into H1.
- Solid points = HW
- Open diamonds = SW
- Find 45° line connecting points and diamonds of same color (f_0)?
- That's qualitative evidence that HW and SW injections with same (nominal) xrms are found by tfclusters with same strength.
- Much more work, statistics, etc, required to establish this quantitatively!

Why did tfclusters fail to see some of the louder injections?

This nice loud injection was not observed:

central time:	730258785.5
quality factor:	9
central frequency:	2 kHz
duration:	4.5 ms
bandwidth:	222 Hz
dac amplitude:	93.1658000 counts
displacement amplitude:	12.9 x 10^-15 m
strain amplitude:	3.22 x 10^-18
strain spectral density:	152 x 10^-21 Hz^-1/2



HW injections help to better tune algorithm parameters

Rectangular window,

No overlap,

8 Hz/125 msec bins

Hanning window,

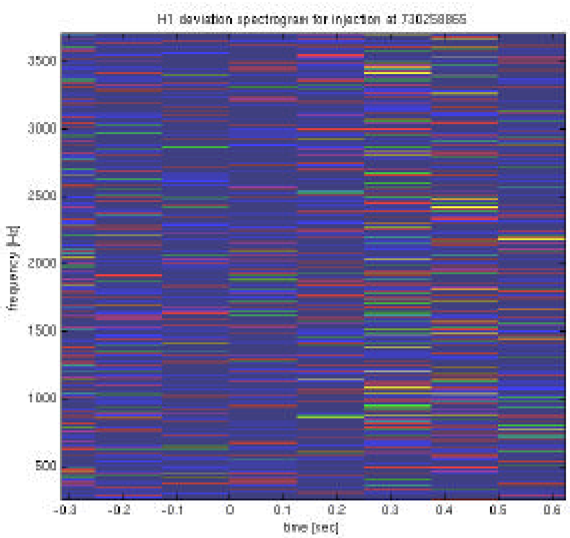
50% overlap,

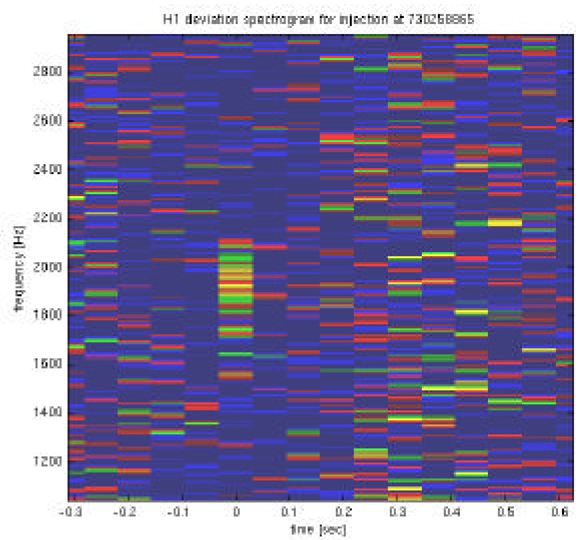
8 Hz/125 msec bins

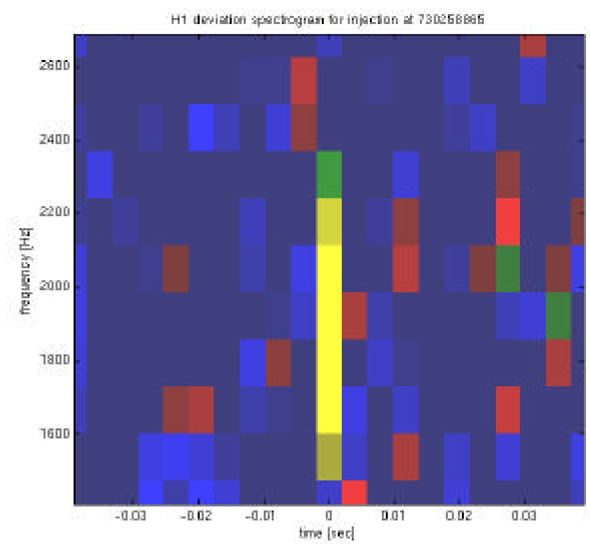
Hanning window,

50% overlap,

128 Hz/7.8 msec bins







- Need better windowing to reduce leakage, better binning to improve resolution for such short bursts
- Not yet verified that tfclusters detects these with these changes
- Could have seen this with SW injections, but the urgency of HW detection analysis made it happen!

Summary

- HW Burst injections, pre-S2 and during S2, are a powerful tool for honing algorithms, building confidence in detection ability, monitoring detection stability, finding problems
- Confirms ability to detect bursts at ~ expected level
- Comparison of HW and SW injections: qualitatively, in the right ballpark
- Failure to detect some signals with tfclusters is under investigation