Search for gravitational wave bursts with LIGO

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LIGO Scientific Collaboration

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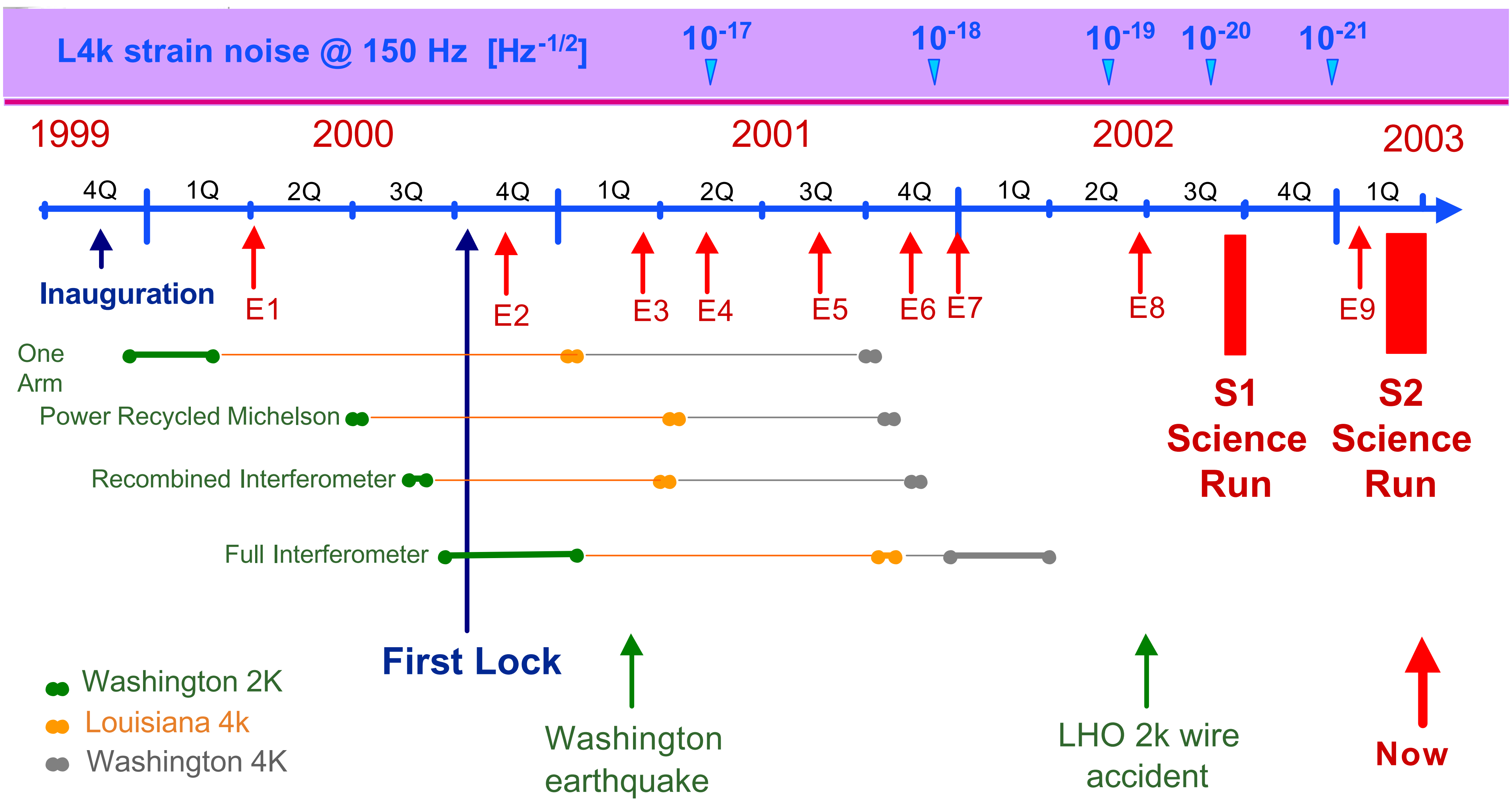
Outline

- LIGO commissioning and the S1 Science Run
- Burst search
- Analysis system
- S1 results
- S2 and beyond...

LIGO commissioning & S1: History



LIGO commissioning & S1: duty factors

- S1: 408 h (17 d)
- Single interferometers lock statistics:

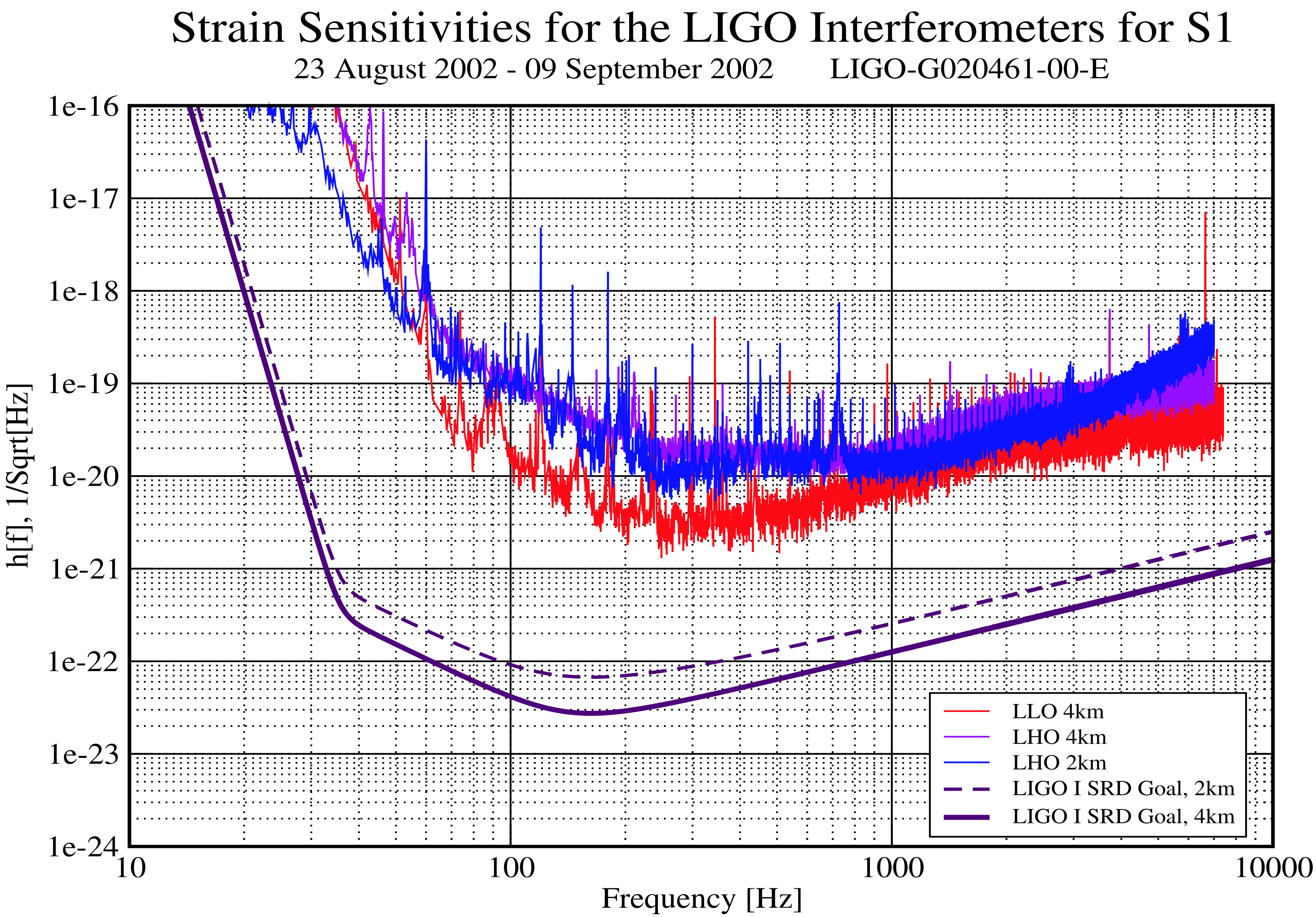
LHO 2k	298 h (73%)
LHO 4k	235 h (58%)
LLO 4k	170 h (42%)

- Double coincidences:

LHO 2k - LHO 4k	188 h (46%)
LHO 2k - LLO 4k	131 h (32%)
LHO 4k - LLO 4k	116 h (28%)

- Triple coincidence: 96 h (23%)

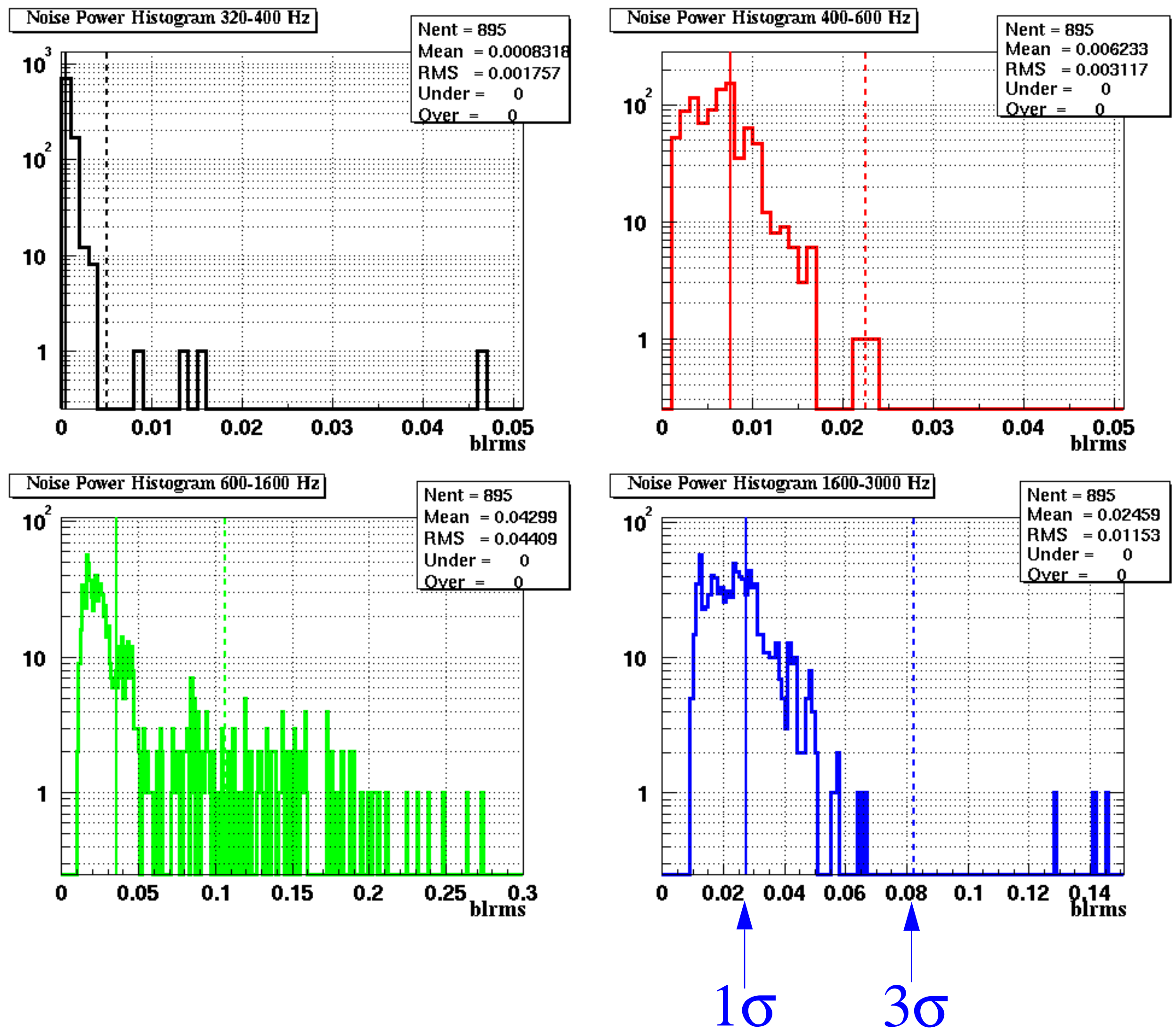
LIGO commissioning & S1: noise spectra



LIGO commissioning & S1: stationarity

- Noise power fluctuates widely
- Measure power in bands, apply ‘epoch veto’
- No GW could have produced such variations

H2:



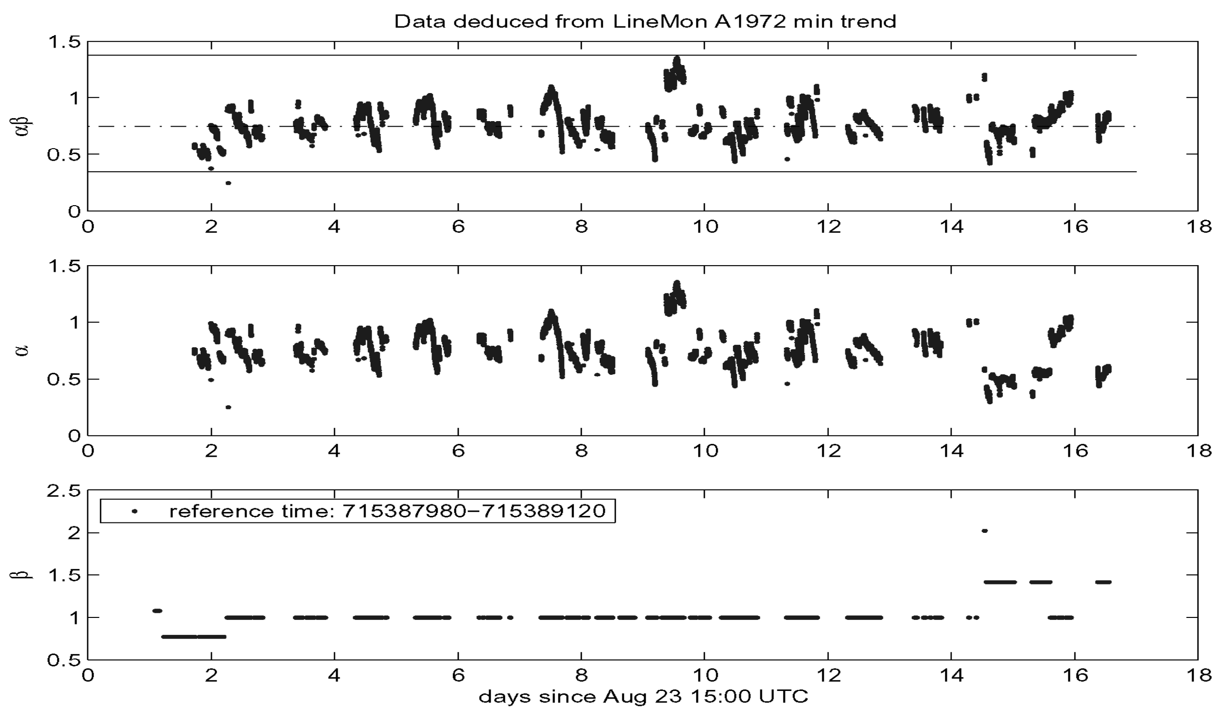
LIGO commissioning & S1: calibration

- Inject calibration lines, and parametrize

$$[\text{GW error signal}](f) = [\text{calibration signal}](f) \times \frac{[\text{sensing function}](f)}{1 + [\text{open-loop-gain}](f)}$$

as

$$\text{AS\_Q}(f) = X(f) \times \frac{\alpha C(f)}{1 + \alpha\beta H(f)}$$



LIGO commissioning & S1: data selection

- Three detectors locked (96 h, 23%)
- Playground + lock stretch boundaries (81 h, 20%)
- Epoch veto (55 h, 13%)
- Calibration (35.5 h, 8.7%)

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Burst search: motivations

- We don’t understand our detectors well enough yet to go after a detection: upper limits are more natural
- Four upper limit groups:
  - stochastic background
  - continuous waves
  - binary inspirals
  - bursts
- Some resources are shared between the UL groups: calibration, vetoes, LDAS, etc.
- Formal publications are on their way

Burst search: definition

- Our definition of a burst: short (< seconds) period of time where the data in our detectors is consistent with noise and a coherent gravitational wave signal
- We try to be sensitive to the broadest class of signals possible: no matched filtering
- As a natural consequence of our definition of a burst:
  - we must characterize the noise
  - we must calibrate our detectors
  - we should use as many detectors as possible in coincidence
- We try to answer: "What is the largest rate and amplitude of a certain type of bursts that are consistent with our data?"
  - all the science is hidden in the definition of what we mean by "certain type"; e.g. interpreted vs. uninterpreted rates
  - the way we build the analysis pipeline implicitly affects the types of bursts we can detect

Burst search: methodology

- Want to construct an analysis system that measures:
  - ››the number N_{GW} of GW candidates
  - ››the expected number N_B of false detections
  - ››the fraction ε of bursts from a certain population that can be detected
- N_{GW} and N_B, together with the assumption that we have Poisson statistics, give a limit λ on the rate of GW bursts detectable by our analysis system
- λ/ε gives a limit on the rate of GW bursts from the population used to measure ε

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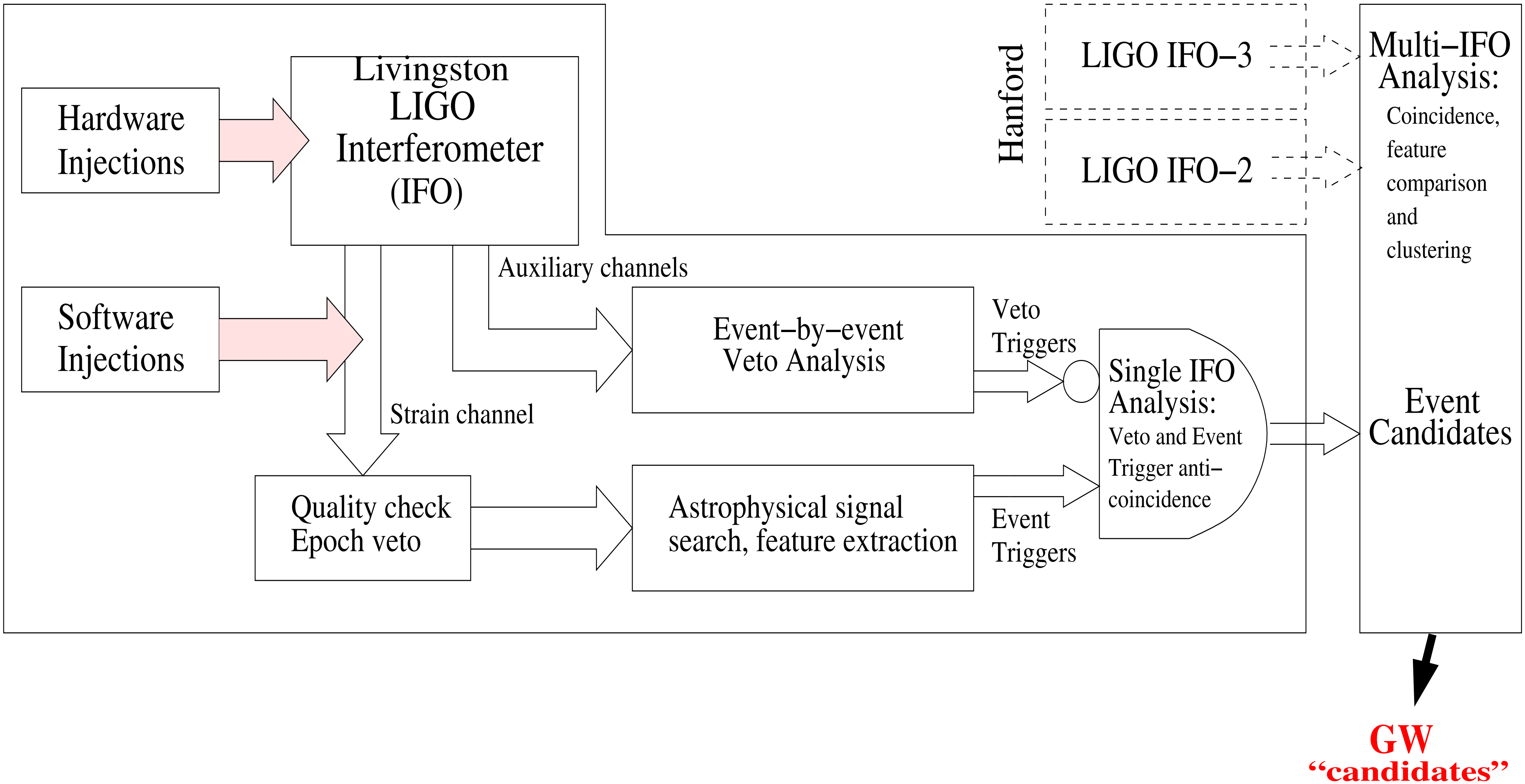
Analysis system: analysis pipeline

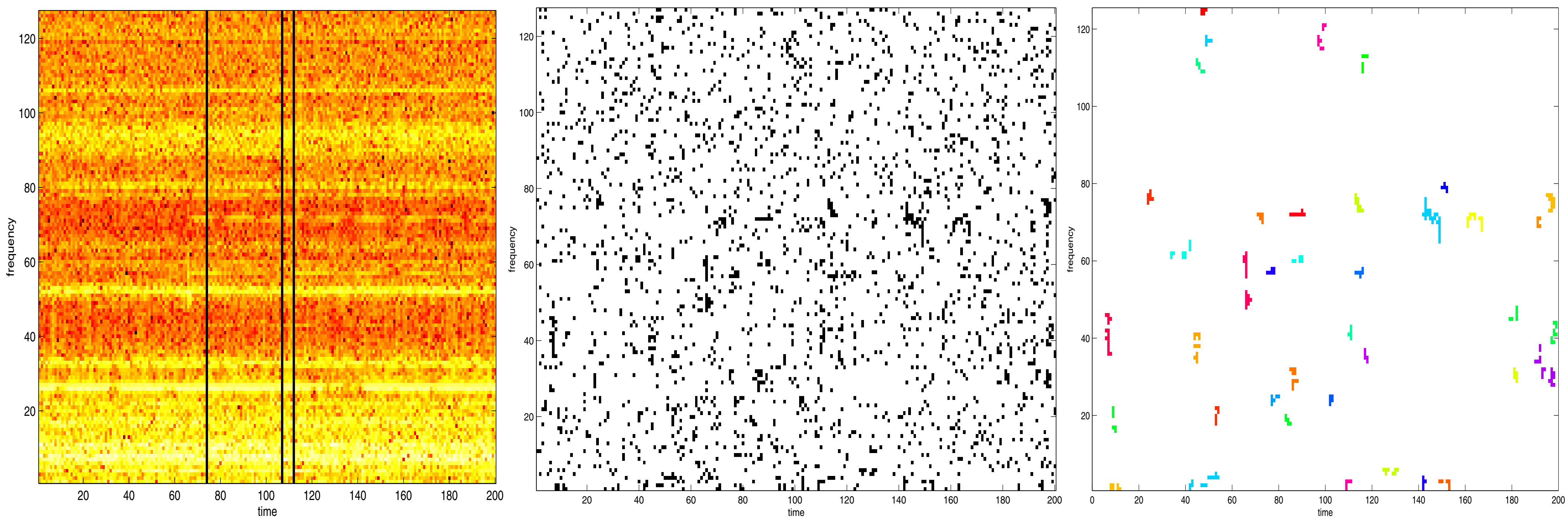


Analysis system: event trigger generators

- ETG: transform a time series into a list of events
  - TFCLUSTERS: time-frequency + clustering
  - SLOPE: time domain filter

LIGO

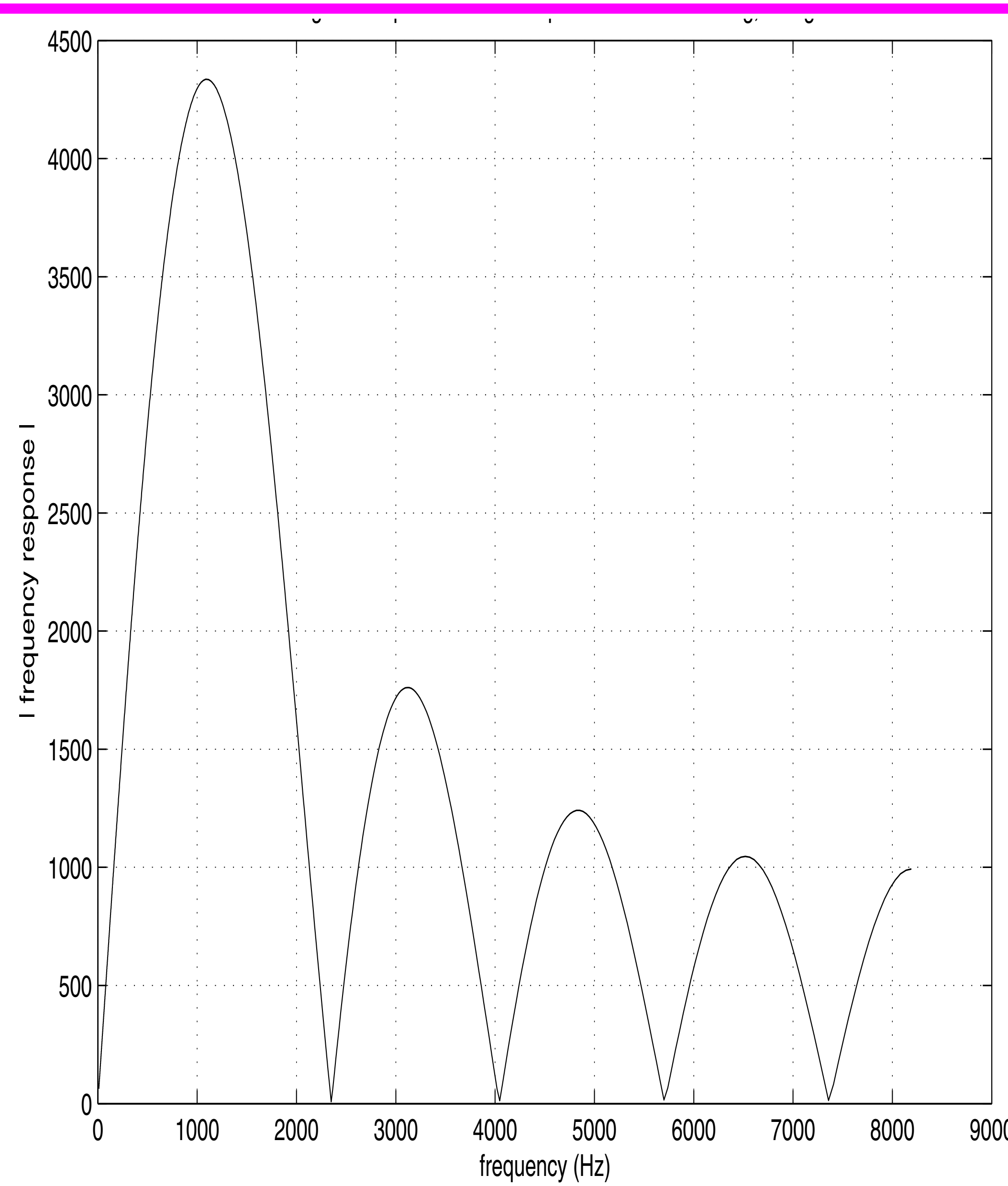
Analysis system: TFCLUSTERS



- Compute spectrogram (125 ms time resolution); threshold on power, get uniform black pixel probability (fit to Rice distribution)
- Look at clusters in black and white image; threshold on size or on size and distance for pairs of clusters
- Get start time, duration, bandwidth, cluster size, cluster shape, power distribution

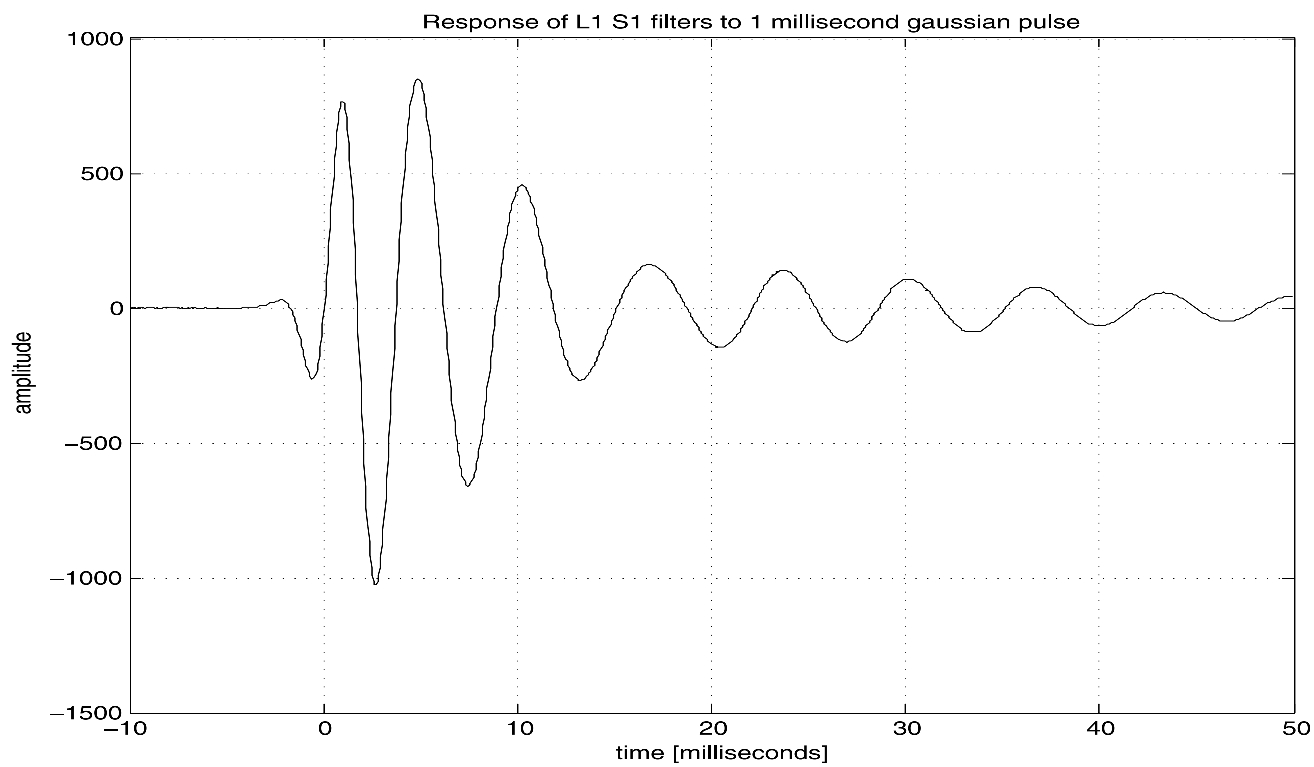
Analysis system: slope

- Convolve data with a ramp symmetric about zero, of duration 0.61 ms (10 points at 16384 Hz)
- Look for threshold crossings
- Cluster crossings on 2.9 ms timescale
- Arnaud et al., Phys. Rev. D 59, 082002 (1999)
  Pradier et al., Phys. Rev. D 63, 042002 (2001)



Analysis system: data conditioning

- Slope and (to a lesser extent) TFCLUSTERS are sensitive to the correlations in the input noise
- High-pass filter (150 Hz corner frequency)
- Rough whitening
- Significant ringing is problematic for time coincidences



Analysis system: vetoes

- Run simple glitch finder on auxiliary channel
- Look for significant correlation with GW channel using a time-lag analysis
- Environmental channels are not necessary as vetoes
- A few instrumental channels are good vetoes
  - I phase of error signal for the differential mode
  - Michelson interferometer control signal
  - error signal for the common mode (laser frequency noise)
- With the diagnostics performed during S1, we couldn’t demonstrate that the instrumental channels would never see a strong GW
- No vetoes were used in our analysis

Analysis system: coincidences

- Most powerful way to reduce false rates is to use triple coincidences
- Slope: 50 ms time window (10 ms light travel time + 40 ms ringing)
- TFCLUSTERS: 500 ms time window (4 times 125 ms resolution) and 80 Hz frequency window
- Clustering of triplets within 0.5 s of each other
- Coincidence analysis retains all GW signals detected by the ETGs

Analysis system: tuning

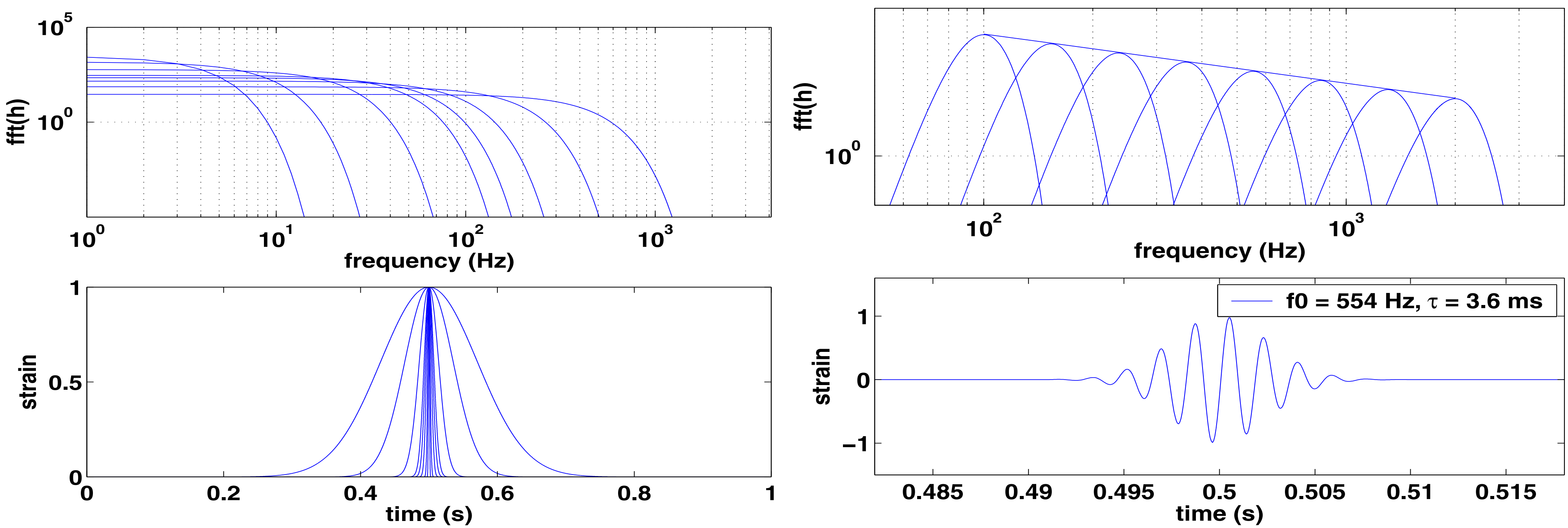
- Defined a playground dataset for optimizing the pipeline (9.3 h of triple coincidence)
- Playground is uniformly distributed in time, not in other aspects of the data (non-stationarities)
- Tuned ETG thresholds to have ~1 false coincidence in all S1

Analysis system: background

- Assuming a small GW rate, we create ‘fake’ datasets by time shifting the event lists from each interferometer with respect to each other
- The two detectors at Hanford are somewhat correlated, so the shift is only between the Hanford and the Livingston sites
- Averaged over lags from -100s to +100s

Analysis system: efficiency

- The efficiency is measured by injecting a waveform in software, with various values of its amplitude
- Each waveform is injected at the zenith of each detector, with optimal orientation; get sky average in post-processing
  - ››this computationally efficient method can only handle linearly polarized signals
- We used Gaussian pulses and Sine-Gaussian waveforms



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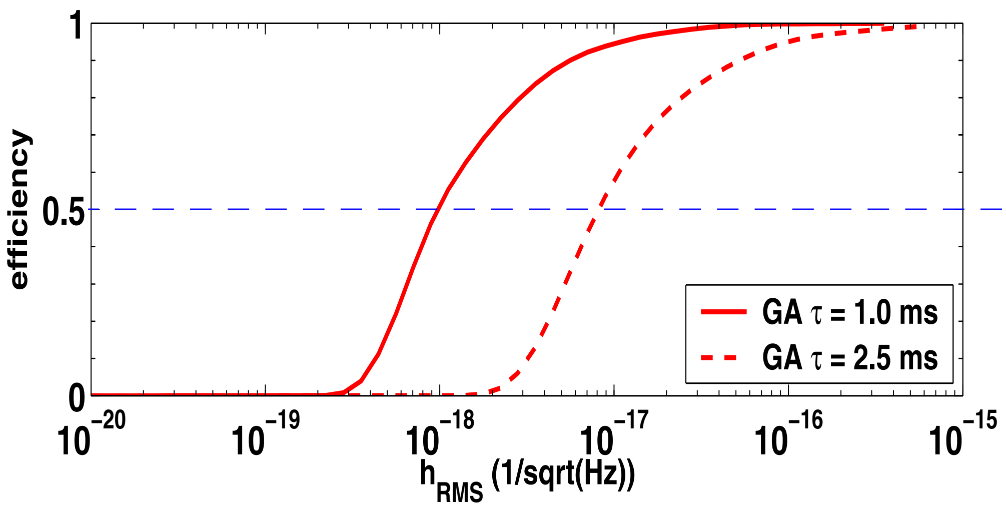
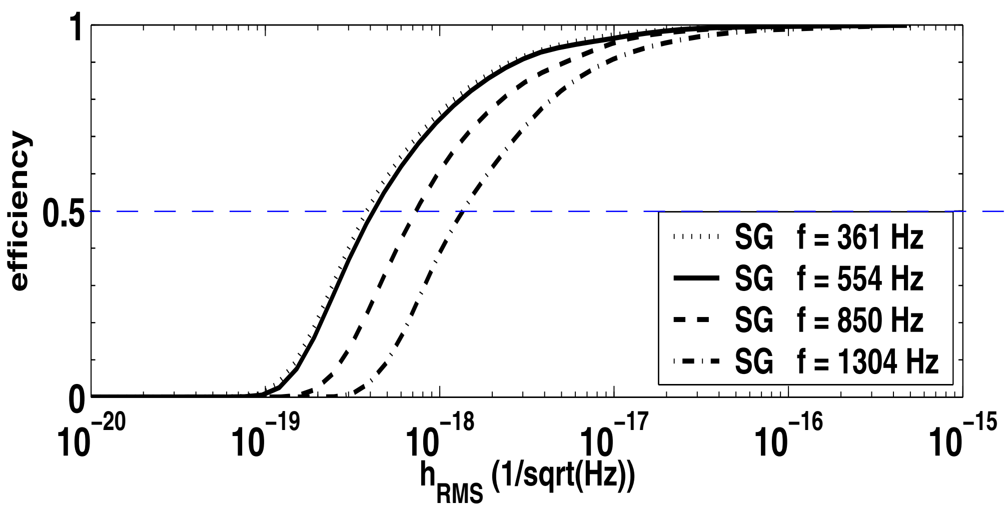
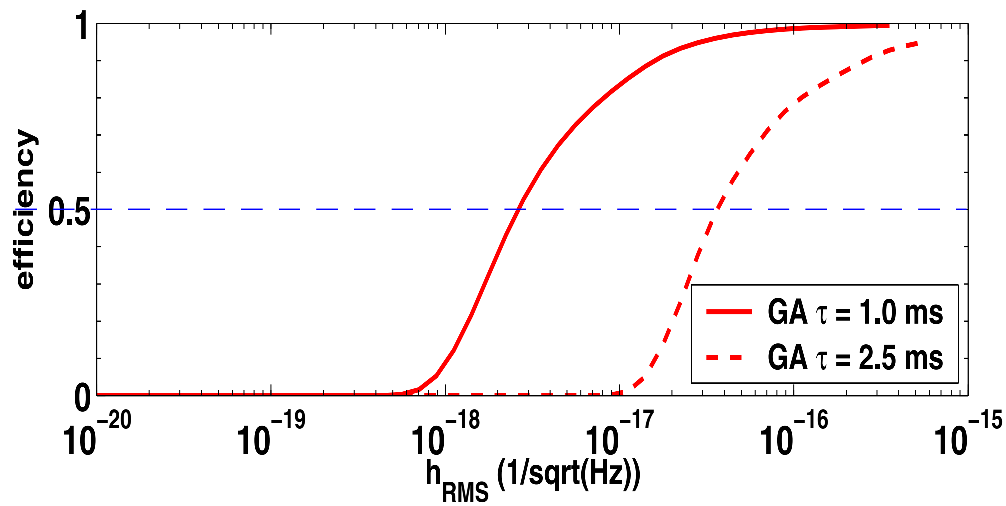
S1 results: efficiency

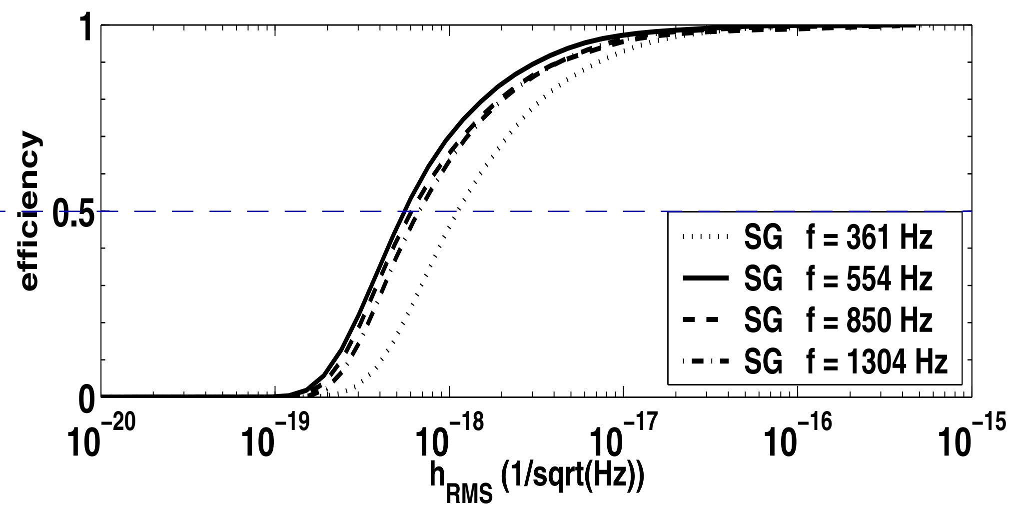
TFCLUSTERS





SLOPE

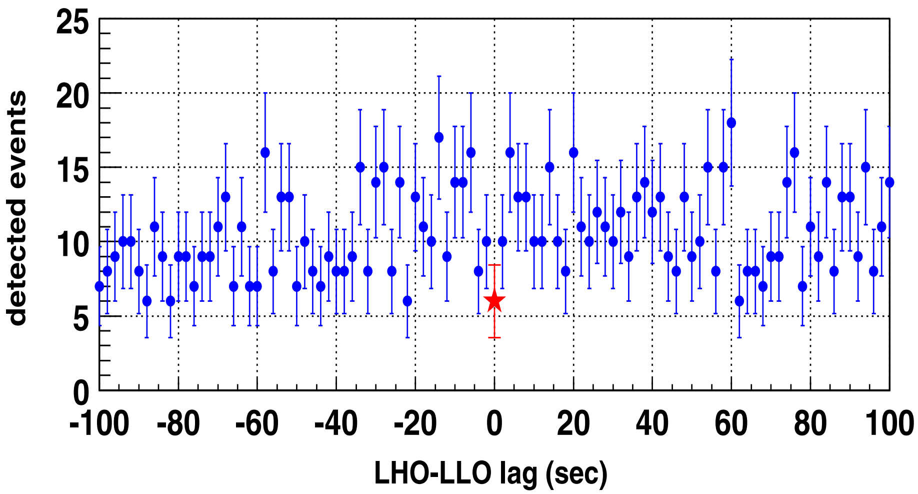


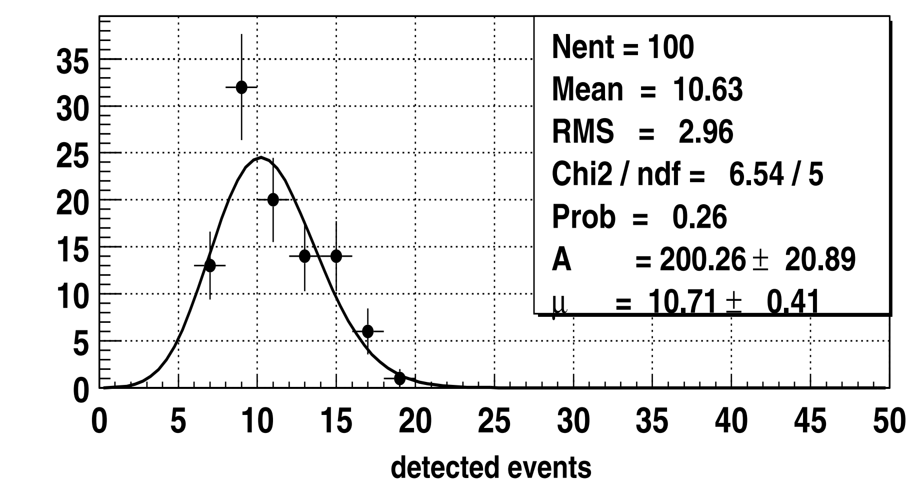


Efficiency for triple coincidences, averaged over position and polarization

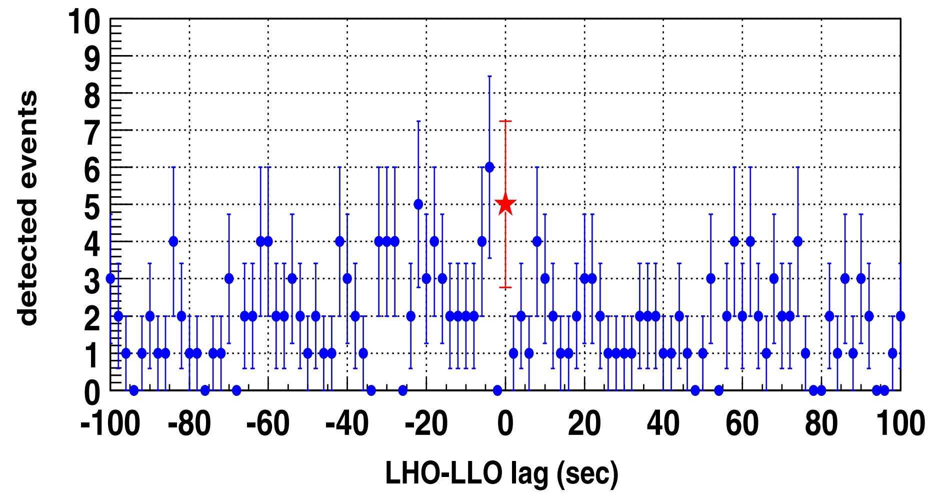
S1 results: background

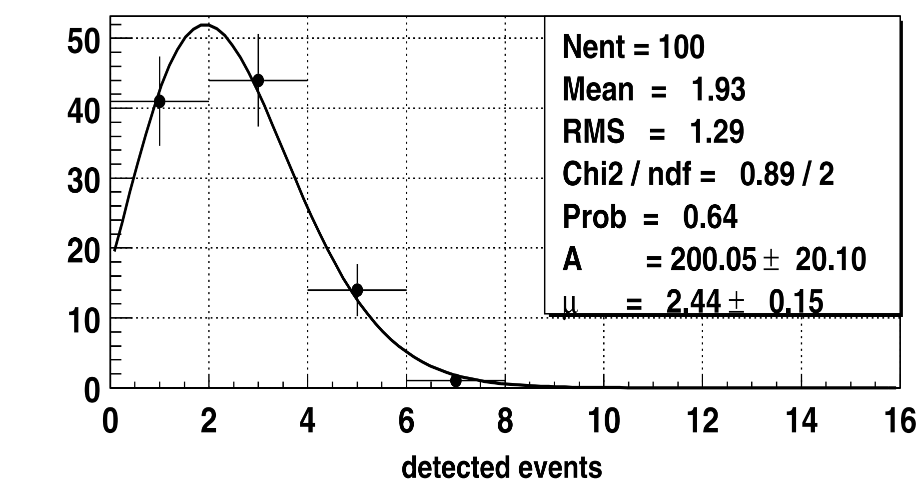
TFCLUSTERS





SLOPE





Time-shifted triple coincidence events

S1 results: upper limits

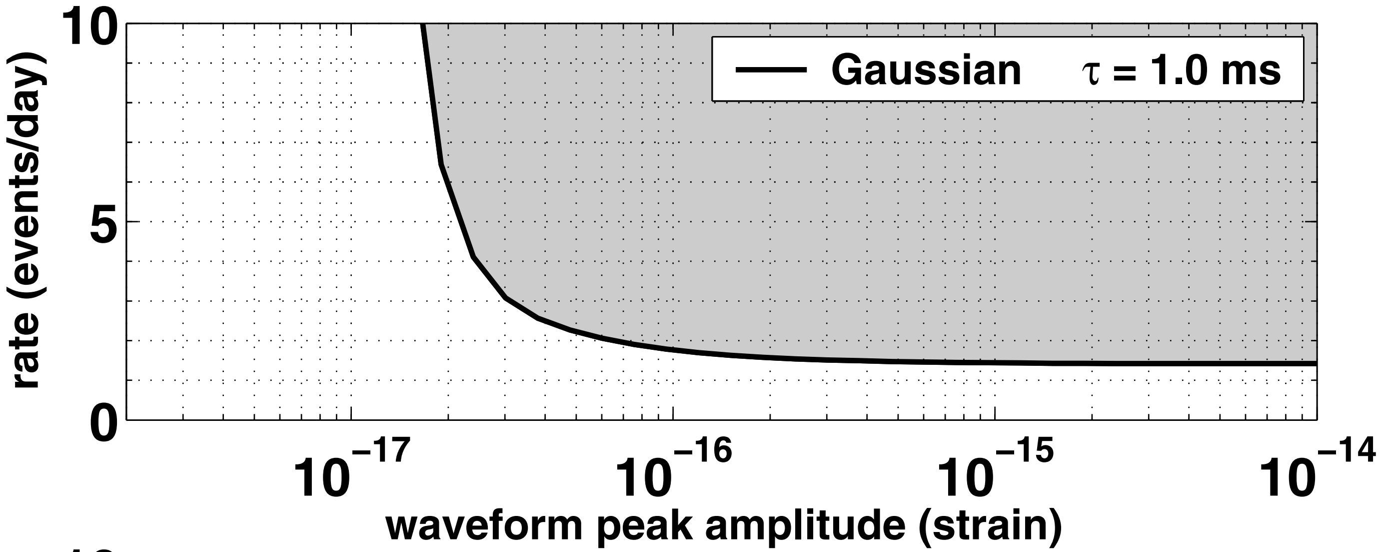
- Use Feldman-Cousins ordering principle to get Frequentist confidence interval
  - 90% confidence level
  - marginalize over Poisson error in background estimation (small effect)

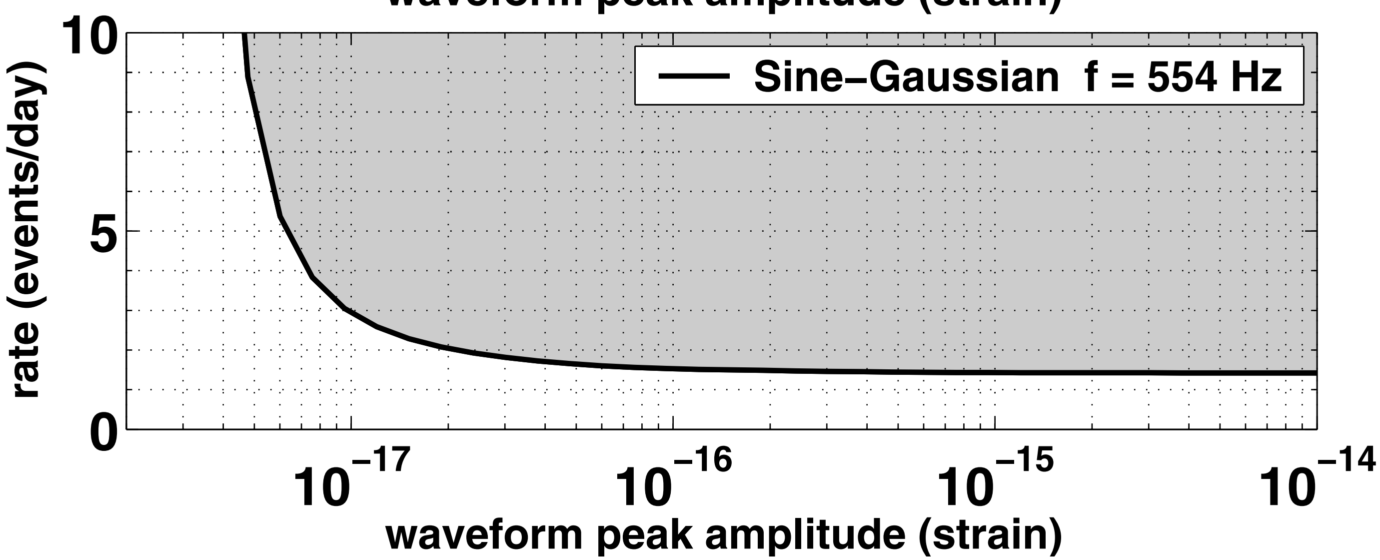
	TFCLUSTERS	SLOPE
# coincidences	6	5
mean background	10.7 +/- 0.4	2.5 +/- 0.2
confidence interval event number	[0, 2.1]	[0.5, 8.0]
UL on rate	1.4 per day	5.4 per day

- Inconsistency of Slope confidence interval with zero: a result of our inability to model all the non-stationarities and to understand perfectly our detectors. Hence, upper-limit.

S1 results: interpreted limits

90% confidence regions for TFCLUSTERS





S1 results: systematic errors

- 20% uncertainty on efficiency from calibration errors (included in results)
- Unknown (small?) uncertainty in possible non-representativeness of data used in simulations
- Small uncertainty in triple coincidence efficiency estimation (trivial to get rid off with more CPU cycles)
- Small uncertainty in background estimation procedures

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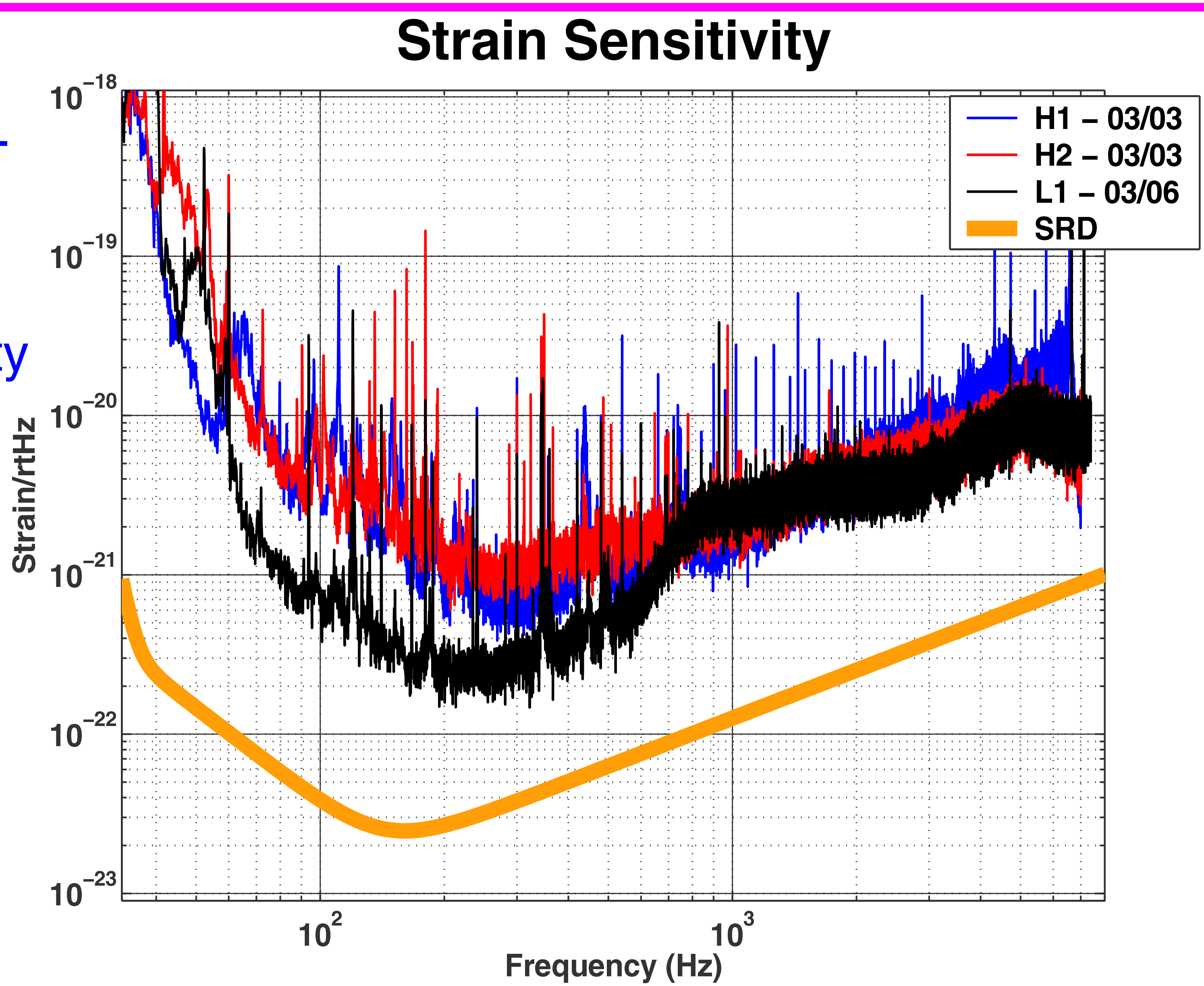
S2 and beyond: data

- 8 weeks of data (similar duty factors as S1)
- good sensitivity
- improved stability



S2 and beyond: analysis

- We need better handling or significant reduction of non-stationarities (glitches, longer trends, ...)
- We could do much better in detection efficiency
  - ››fine tuning and extensions of existing ETGs
  - ››new ETGs (wavelets, time domain, ...)
  - ››more complete coincidences (amplitude, tighter timing, time-frequency shapes, ...)
  - ››coherent post-coincidence analyses (cross correlations, coherent power filters, ...)
  - ››use more detectors (GEO, TAMA, Virgo, bars)
- We should make scientific interpretation easier
  - ››more realistic or interesting waveforms in simulations
  - ››use pointing to target particular objects or regions
- S3 now planned for the Fall of 2003: goal of similar sensitivities for all interferometers
- *We plan to transition to a detection mode of operation by early 2004*