All-Sky Search for Gravitational Wave Bursts in LIGO S4 Data

Peter Shawhan, for the LIGO Scientific Collaboration

GWDAW
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Overview of the Search

- Searched triple-coincidence (H1+H2+L1) LIGO data for short (<1 sec) signals with frequency content in range 64–1600 Hz
- Used WaveBurst time-wavelet decomposition to generate triggers, followed by *r*-statistic cross-correlation tests
- Data quality cuts, significance cuts and veto conditions chosen largely based on time-shifted coincidences
- Preliminary results being presented today

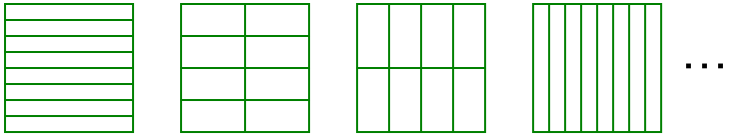
WaveBurst Trigger Generation

Definition of triple-coincidence data segments for analysis

- Basic data quality flags (no hardware injections, no ADC overflows, etc.)
- Discarded last 30 seconds before loss of lock
- Discarded segments shorter than 300 sec

WaveBurst processed all 3 DARM_ERR streams simultaneously

- Wavelet decomposition from 64–2048 Hz with 6 different resolutions from 1/16 sec × 8 Hz to 1/512 sec × 256 Hz



- Whitening, black pixel selection, cross-stream pixel coincidence, clustering
- Param. estimation: time, duration, frequency, h_{rss} (signal amplitude at Earth)

Found coincident clusters for true time series plus ~100 time shifts

- Initially –156.25 to +156.25 sec in 3.125-sec increments (excluding ±3.125)

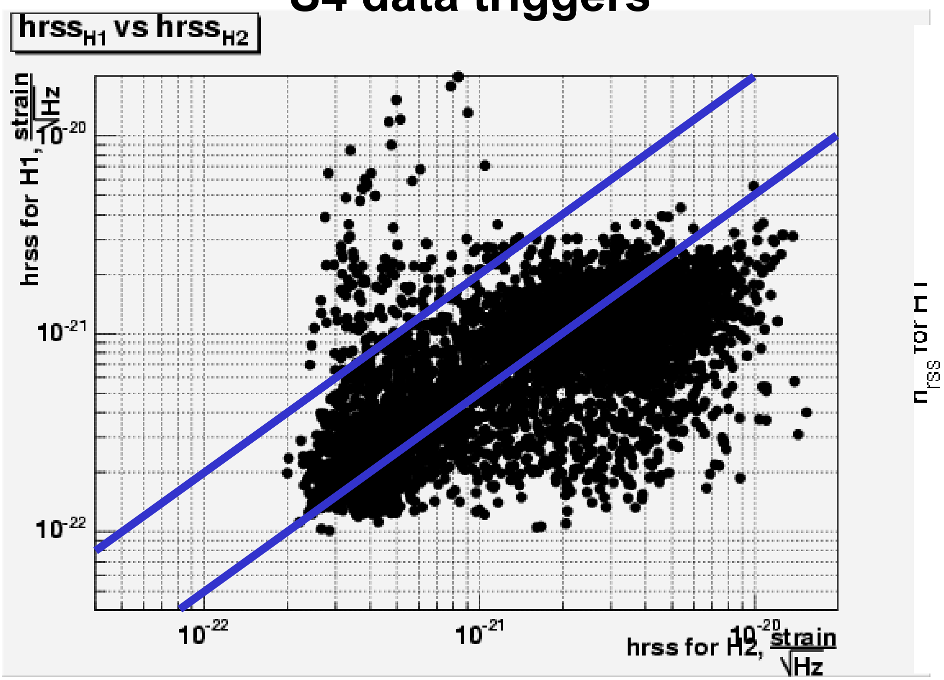
Initial cluster significance cut: GC>2.9
& frequency content cut: Required to overlap 64–1600 Hz band

H1/H2 Amplitude Cut

Based on calibrated h_{rss} estimated by WaveBurst

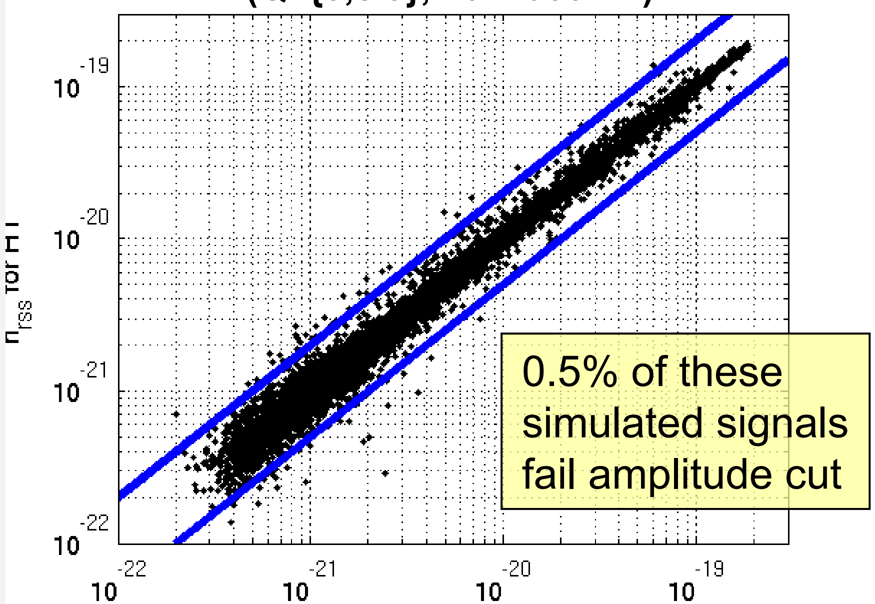
Require 0.5 < (H1/H2) < 2

S4 data triggers



Sine-Gaussians

(Q={3,8.9}, 70–1053 Hz)



r-Statistic Quantities

CorrPower run on raw data at times of WaveBurst triggers

Data conditioning

- Downsampled to 4096 Hz
- Bandpass filtered with 64 Hz & 1572 Hz corner frequencies
- Linear predictor filter used to whiten data
- Notch applied around 345 Hz to avoid violin modes

Statistics calculated by CorrPower

- Derived from normalized cross-correlations (*r*-statistic) for pairs of detectors
- Integration window lengths: 20, 50, 100 ms
- Relative time shifts: up to 11 ms for H1-L1 and H2-L1, 1 ms for H1-H2

Gamma : arithmetic mean of three pairwise confidences

R0 : signed correlation of H1 and H2 with zero relative time shift

- Require R0 to be positive

Data Quality Cuts

Some chosen *a priori*,
others based on efficiency studies with single-interferometer "glitch" triggers recorded by KleineWelle

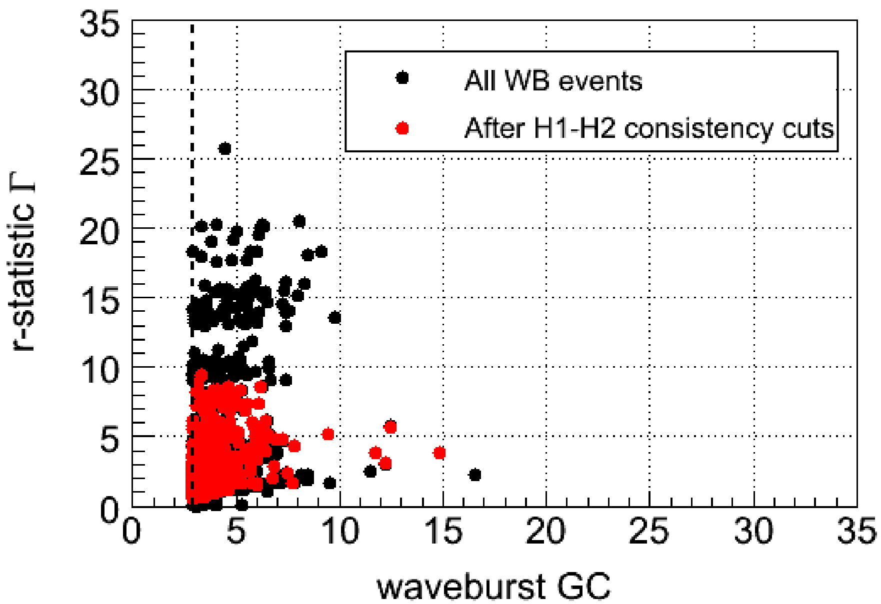
- Calibration line dropouts (1-second and single-sample)
- Dips in arm cavity stored light
- Elevated DC light level at antisymmetric port (H1 and L1)
- Elevated seismic noise in 0.9–1.1 Hz band at LHO
- Jet plane fly-over at LHO
- Wind over 35 mph [62 km/h] at LHO

Used to reject triggers

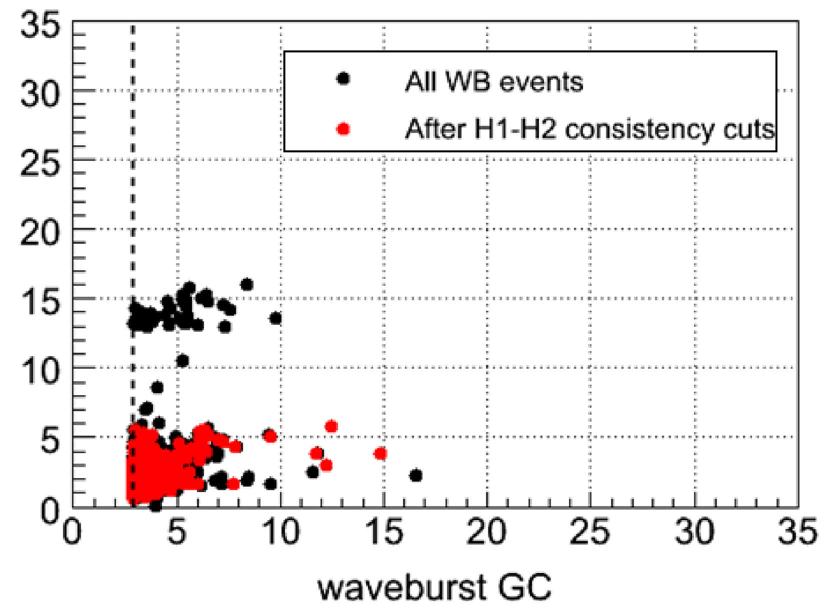
Net loss of observation time: 5.6%

Effect of Data Quality Cuts on Time-Shifted Coincidences

Minimal DQ cuts



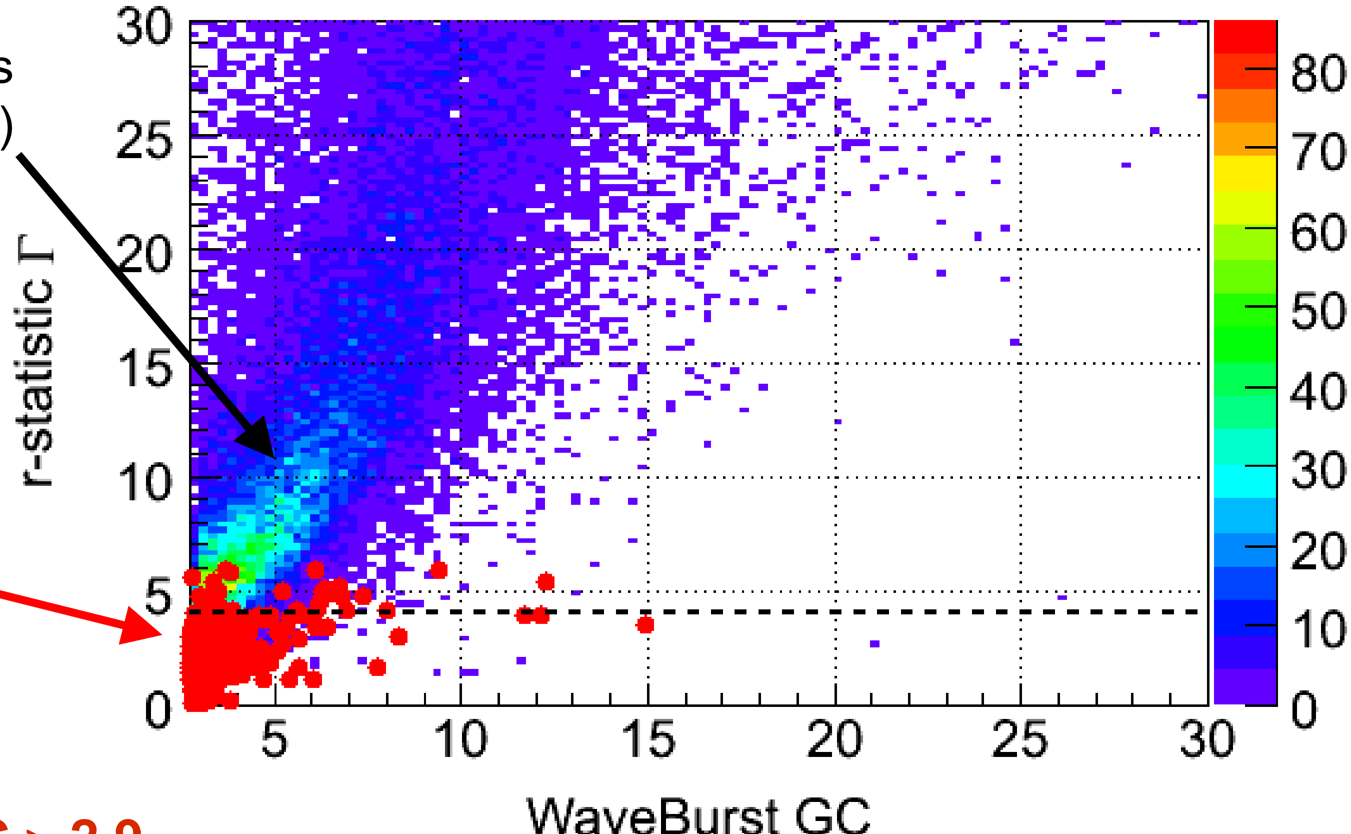
All DQ cuts



Choice of Final Significance Cuts

Simulated signals (sine-Gaussians)

Time-shifted coincidences



Final choices:
WaveBurst GC > 2.9
***r*-statistic Gamma > 4**

Chosen to make expected background low, but not zero

Auxiliary-Channel Vetoes

Used KleineWelle triggers generated from auxiliary channels

Triggers produced for many channels

Established "safe" veto conditions (minimum KleineWelle trigger significance)

Several channels found to be promising on a statistical basis, from comparison with samples of KleineWelle GW channel triggers

Decided to use an OR of veto conditions – but which ones?

Veto effectiveness found to be different for WaveBurst / *r*-stat triggers

Final choice of 7 veto conditions based largely on examining time-shifted WaveBurst / *r*-stat triggers with largest Gamma values

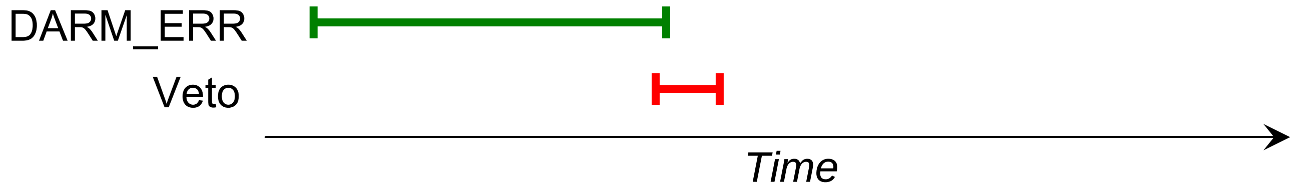
Able to veto 6 of the top 10, including:

- 2 with strong signals in accelerometers on H1 and H2 antisymmetric port optical tables
- 3 with glitches in H1 beam-splitter pick-off channels (H1:LSC-POB_I and/or H1:LSC-POB_Q)
- 1 with big signals in H2 alignment system

Deadtime from Veto Conditions

Deadtime depends on waveform and amplitude of GW signal

Veto logic uses trigger duration reported by WaveBurst,
looks for overlap with veto trigger



Loss of observation time is effectively the sum of DARM_ERR trigger duration (for a simulated signal) and veto trigger duration

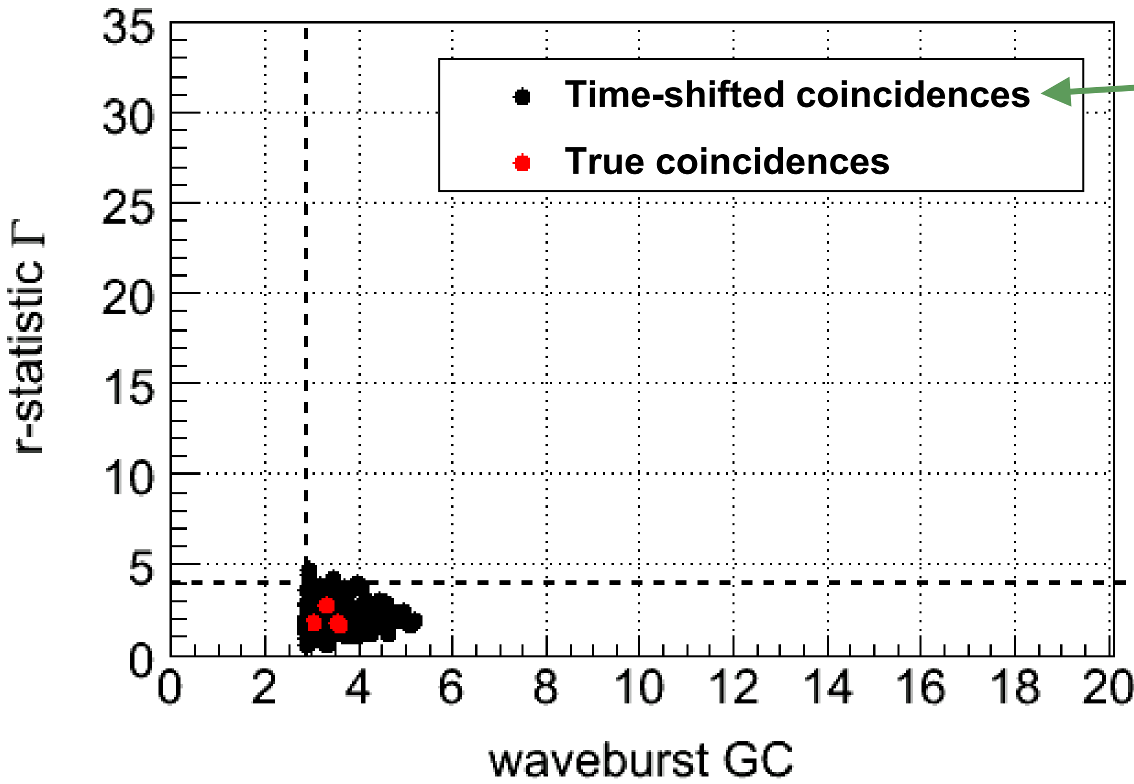
For waveforms simulated so far, effective deadtime is:

- less than 1% for signals near detection threshold,
- about 2% for very large signals

Count this against detection efficiency, not observation time

The Search Result

After opening the box …



Now a different set of time shifts: –250 to +250 sec in 5-sec increments

Background estimate: 3 events out of 77 effective S4 runs
⇒ ~0.04 events

No event candidates pass all cuts

Rate Upper Limit

Background rate estimate is not rigorous

Non-circular time shifts don't sample all times equally

Possible correlations introduced by data conditioning with common set of segments

So take background to be zero for purposes of setting a limit

(The conservative thing to do)

Calculate a frequentist one-sided upper limit (90% C.L.) based on zero events passing all cuts

$$R_{90\%} = \frac{2.303}{15.53 \text{ days}} = \mathbf{0.148 \text{ per day}}$$

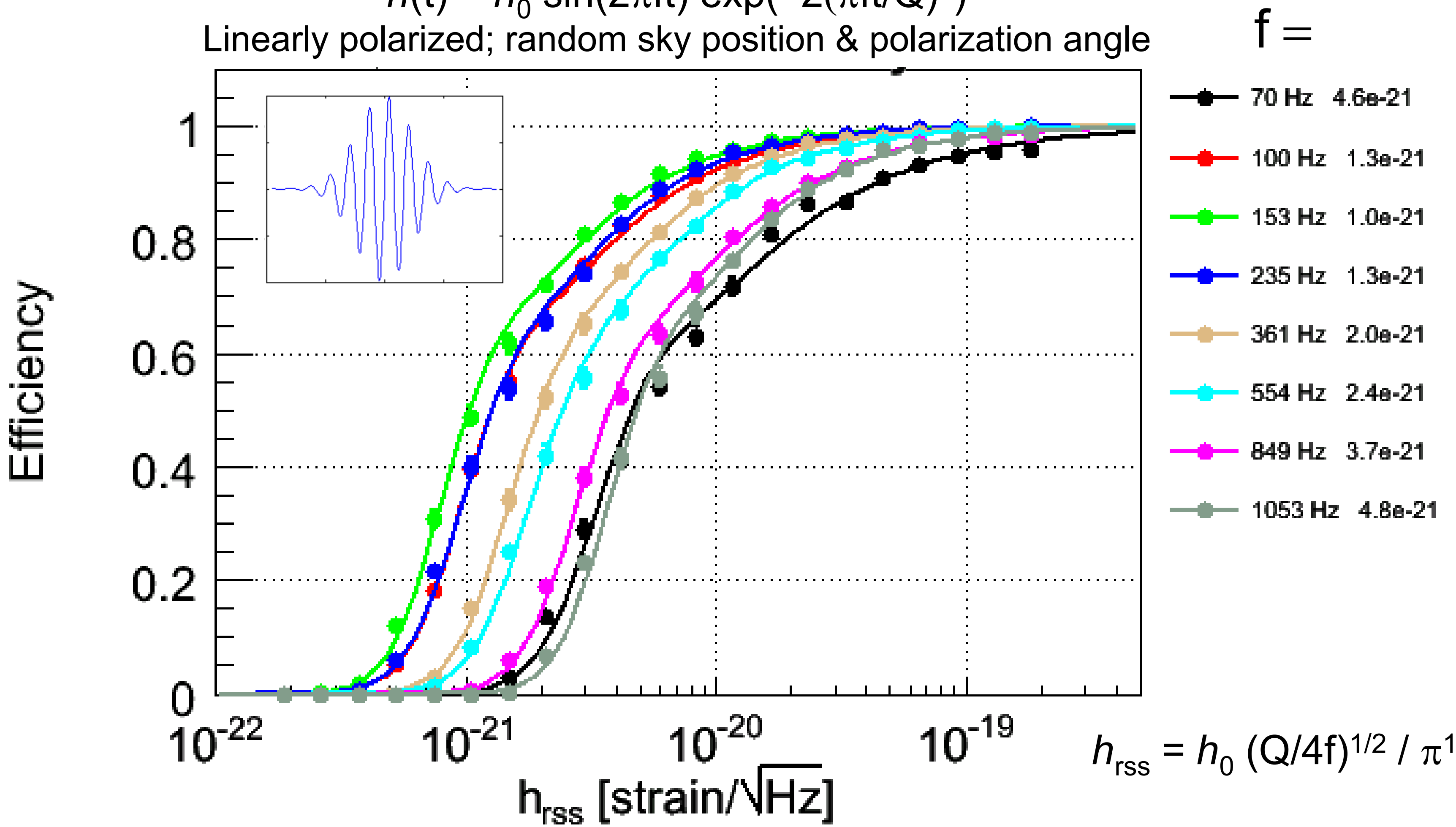
(S2 rate limit: 0.26 per day)

Efficiency Curve for Q=8.9 Sine-Gaussians (preliminary)

Caveats: preliminary calibration; auxiliary-channel vetoes *not* applied

$h(t) = h_0 \sin(2\pi ft) \exp(-2(\pi ft/Q)^2)$

Linearly polarized; random sky position & polarization angle



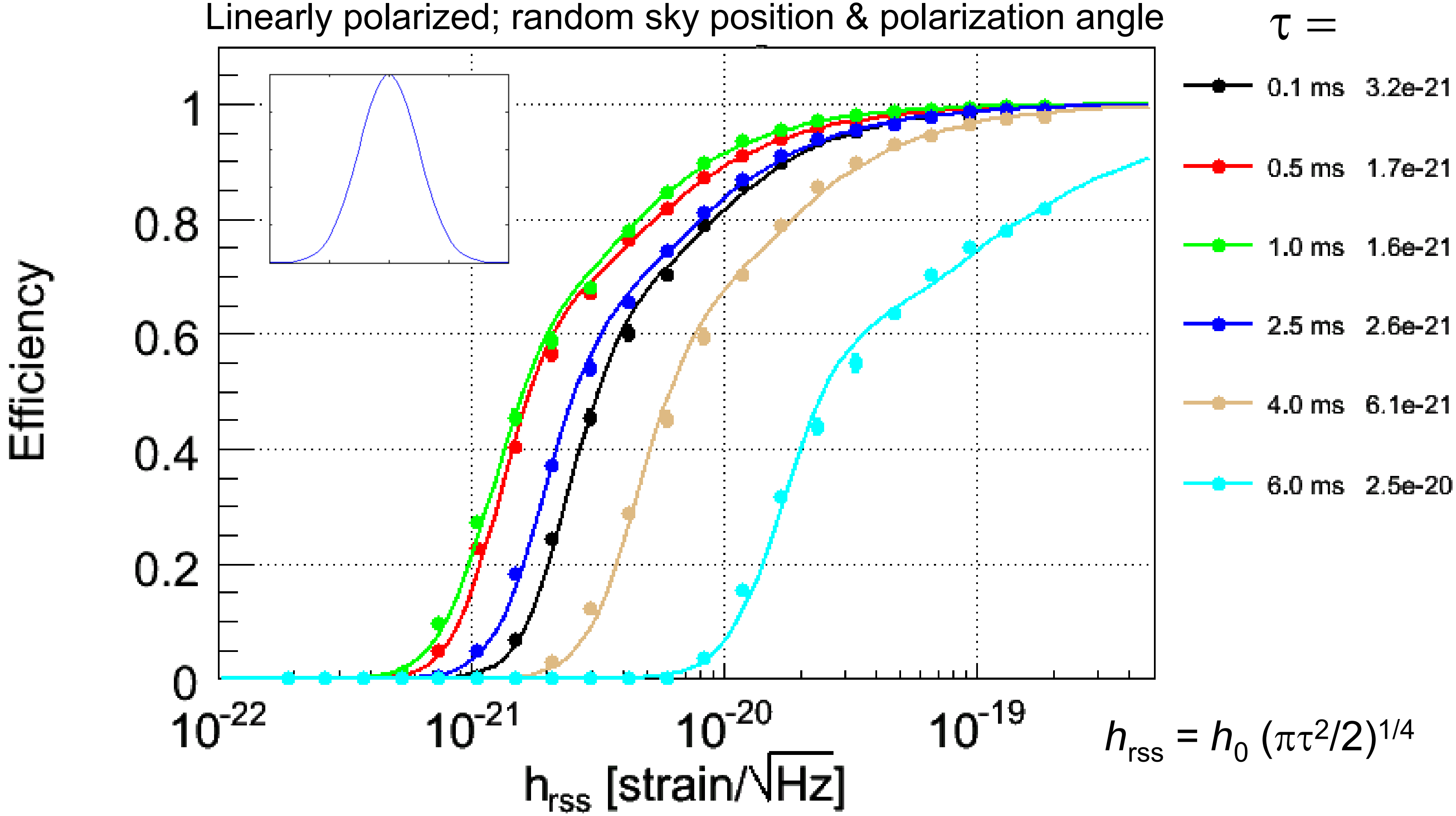
$h_{rss} = h_0 \, (Q/4f)^{1/2} / \pi^{1/4}$

Efficiency Curve for Gaussians
(preliminary)

Caveats: preliminary calibration; auxiliary-channel vetoes *not* applied

$h(t) = h_0 \exp(-t^2/\tau^2)$

Linearly polarized; random sky position & polarization angle



$h_{rss} = h_0\,(\pi\tau^2/2)^{1/4}$

Summary of Sensitivities
(preliminary)

h_{rss} at 50% detection efficiency, in units of 10^{-21}

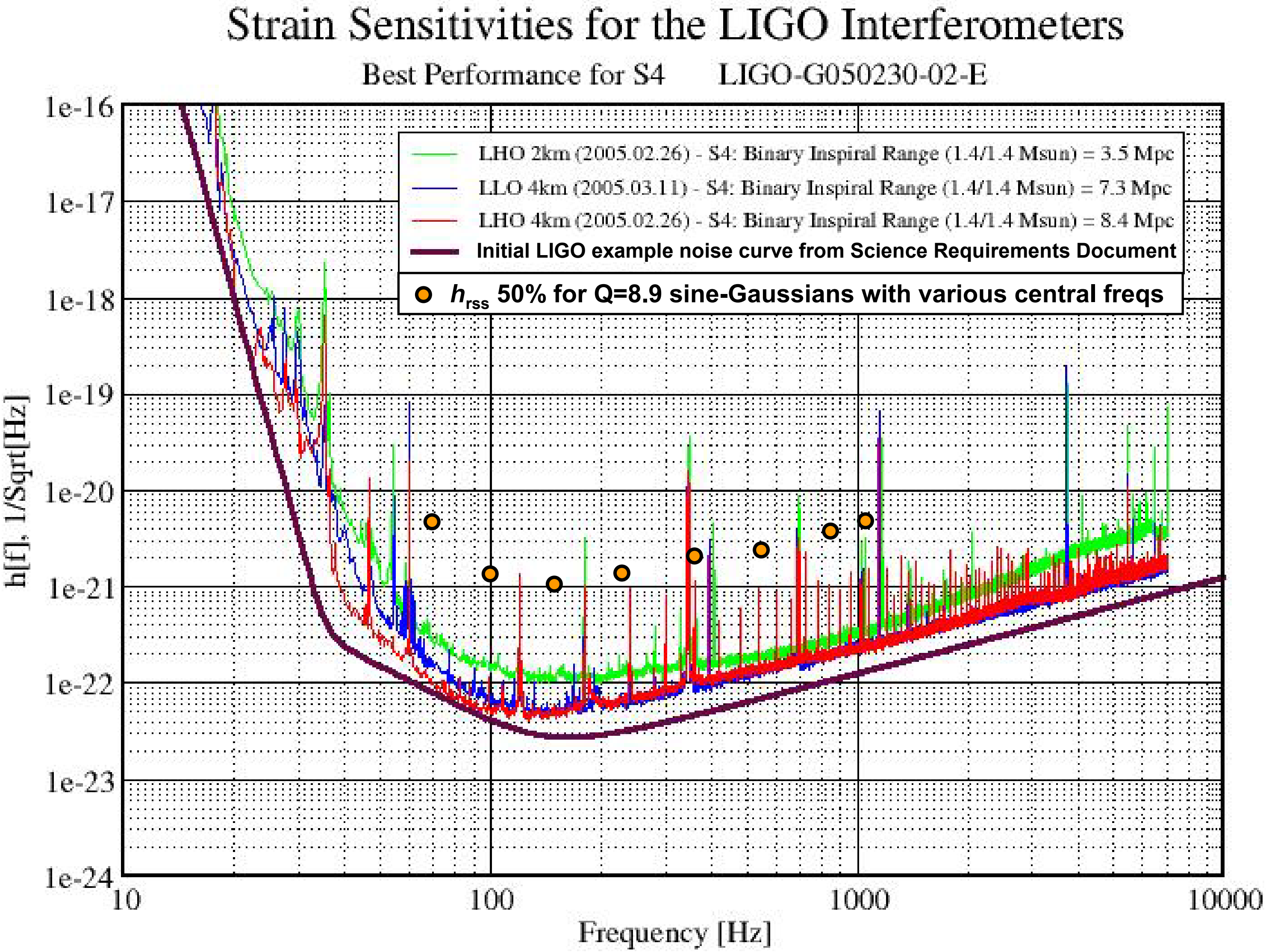
Caveat: prelim calibration, no vetoes

	Freq (Hz)		S3:	S2:
Sine-Gaussians with Q=8.9	70	**4.6**	–	–
	100	**1.3**	–	82
	153	**1.0**	–	55
	235	**1.3**	9	15
	361	**2.0**	–	17
	554	**2.4**	13	23
	849	**3.7**	23	39
	1053	**4.8**	–	–
	Tau (ms)			
Gaussians	0.1	**3.2**	18	43
	0.5	**1.7**	–	26
	1.0	**1.6**	–	33
	2.5	**2.6**	–	140
	4.0	**6.1**	–	340

S3 values from Amaldi6 presentation and proceedings: gr-qc/0511146

S2 values from Phys. Rev. **D** 72, 062001 (2005).

Summary of Sensitivities
(preliminary)



Summary

We are finishing up an all-sky untriggered burst search using S4 LIGO data

No event candidates pass all cuts

Upper limit on rate of detectable events:
0.15 per day (90% C.L.)

Sensitivity: several times better than S3

Preliminary