Search for Gravitational Wave Bursts in LIGO Science Run 2 Data

John G. Zweizig
LIGO / Caltech
for the LIGO Scientific Collaboration

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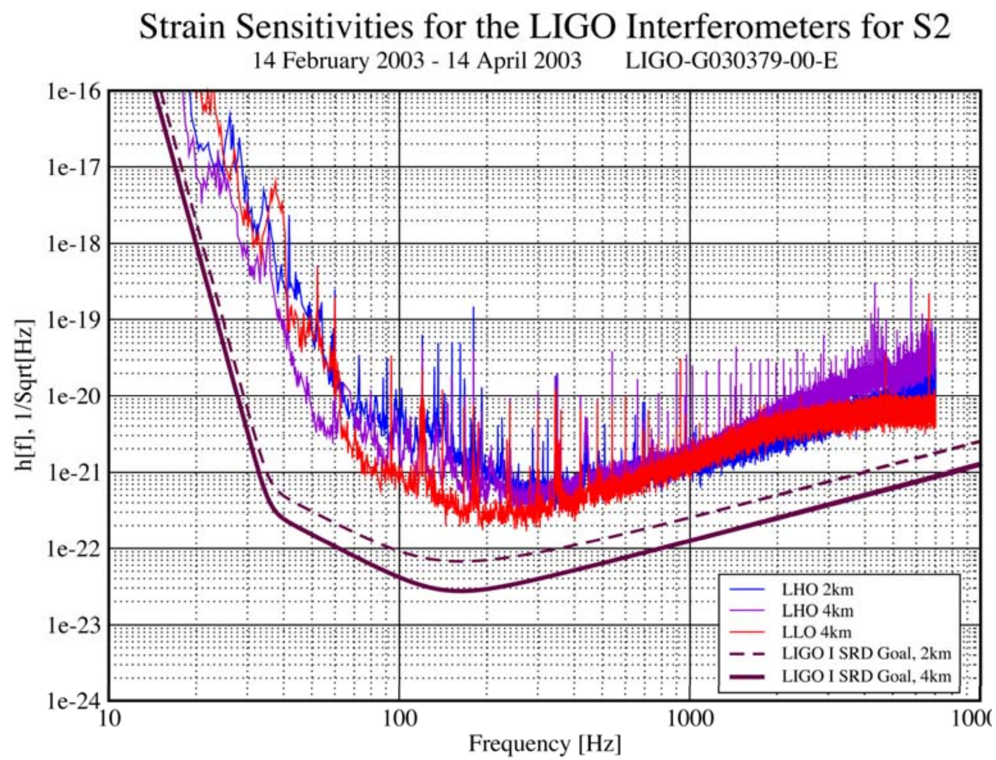
Science Run 2

Improvements over S1 important for Burst Search

- 60 days of running (vs. 19 in S1)
- ~318 hrs triple coincidence (34 in S1)
- Sensitivity ~1 order of magnitude better than S1.



S2 Science Mode Running

IFO	hrs	%
H1	1043.7	73.7
H2	821.8	58.0
L1	536.4	37.9
H1·H2·L1	318.0	22.5

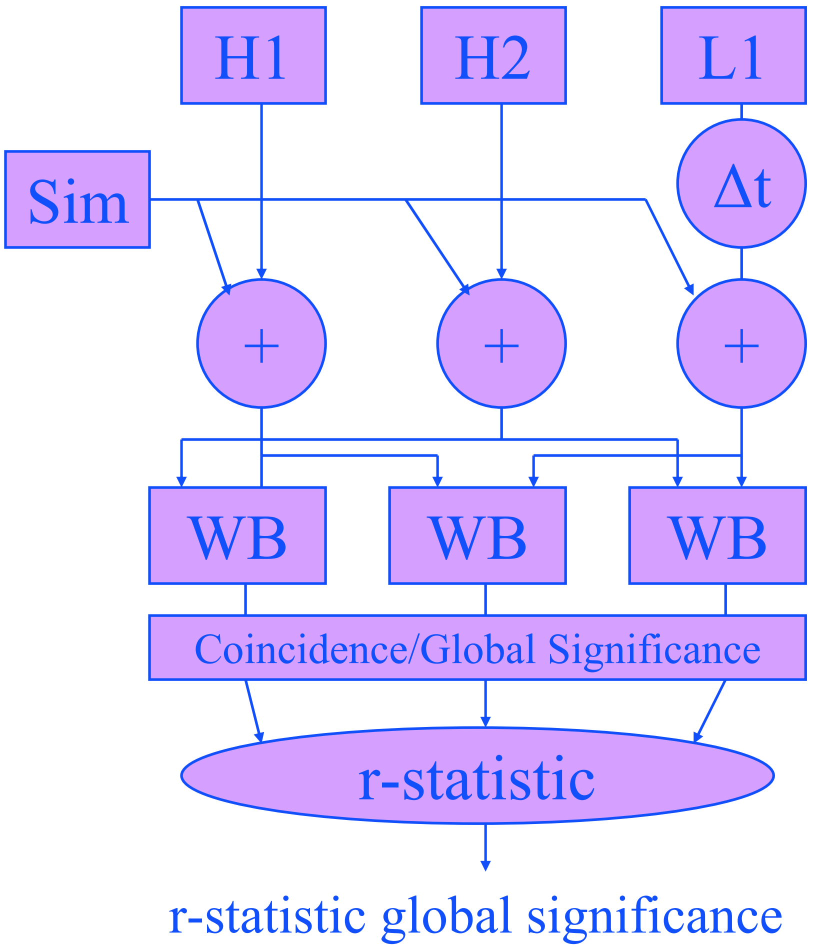
Data Selection

- Use triple coincidence science mode segments
- Data quality cuts eliminate sections with:
  - DAQ errors / Missing data
  - Non-standard/noisy IFO
  - Missing/unreliable calibration
- Pipeline inefficiencies:
  - Processing granularity
- No effective vetoes (significant reduction in single IFO triggers) found in playground.

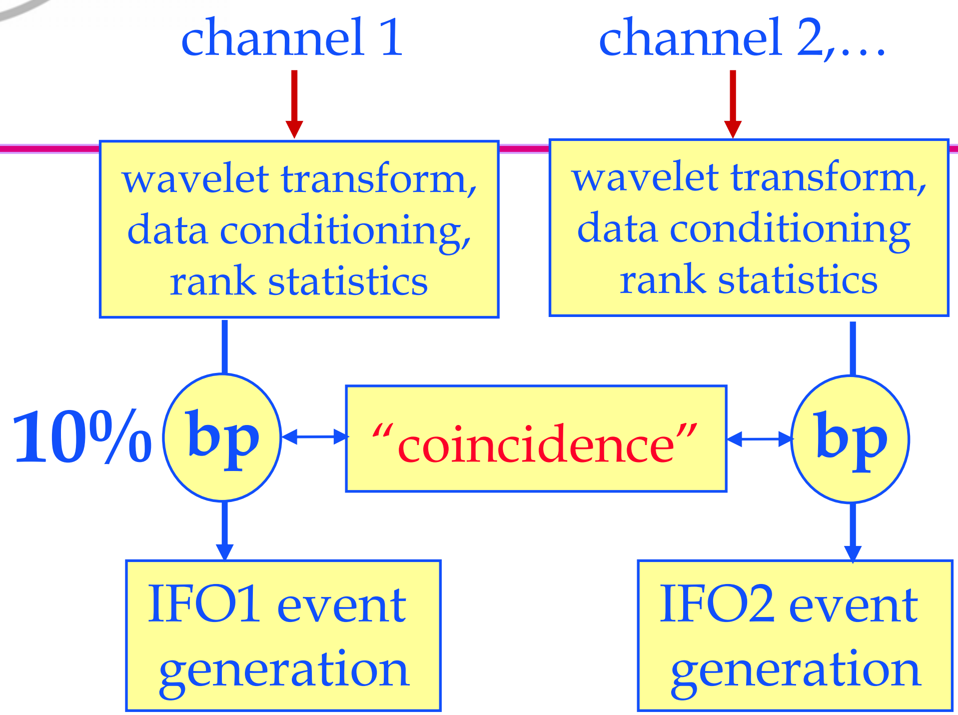
Criterion	hours	%
Total H1·H2·L1	318.0	100.0
After data quality	304.9	95.9
No playground	277.2	87.2
Pipeline	239.5	75.3
After Acoustic Veto	237.8	74.8

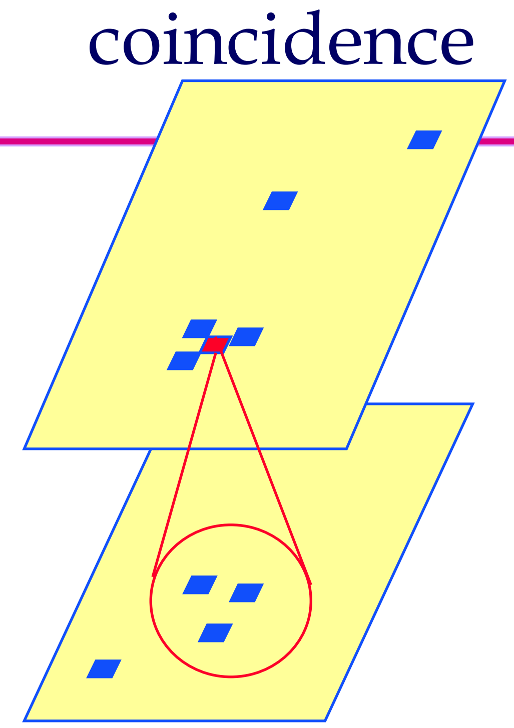
Analysis Pipeline

- Use all three LIGO interferometers (H1, H2, L1)
- Wavelet domain event search using WaveBurst (WB)
- Consistency check between IFO pairs using r-statistic test
- Search in frequency band 100-1100 Hz
- Tune analysis cuts using playground sample (~10% of triple coincidence data)
- Background estimate from time-shifted data
- Upper limit calculated from the upper bound of a Feldman-Cousins interval.



WaveBurst pipeline





$$\Delta f \times \Delta t = 64Hz \times 1/128\sec$$

band 64-4096 Hz

coincidence likelihood>1.5, cluster likelihood>4

Threshold on combined significance of triple coincidence events.

Ref: Class. Quantum Grav. 21 (2004) S1819;

r-Statistic Test

- Waveform consistency test using r-statistic
- $$r = \frac{\sum (x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum (x_i - \bar{x})^2 \sum (y_i - \bar{y})^2}}$$
- Effectively a measure of the cosine of an angle in signal space
- Significance: $C = erfc\left(\sqrt{\frac{r^2 N}{2}}\right)$
- Combine significance of IFO pairs $\Gamma = -\log_{10}\left(\prod_{i<j} C_{ij}\right)$
- Unknown incident direction (Δt), signal duration (τ)→search valid {Δt, τ} to maximize Γ.
- Reference: *L. Cadonati, Class. Quantum Grav. 21 S1695-S1703*

Pipeline Tuning

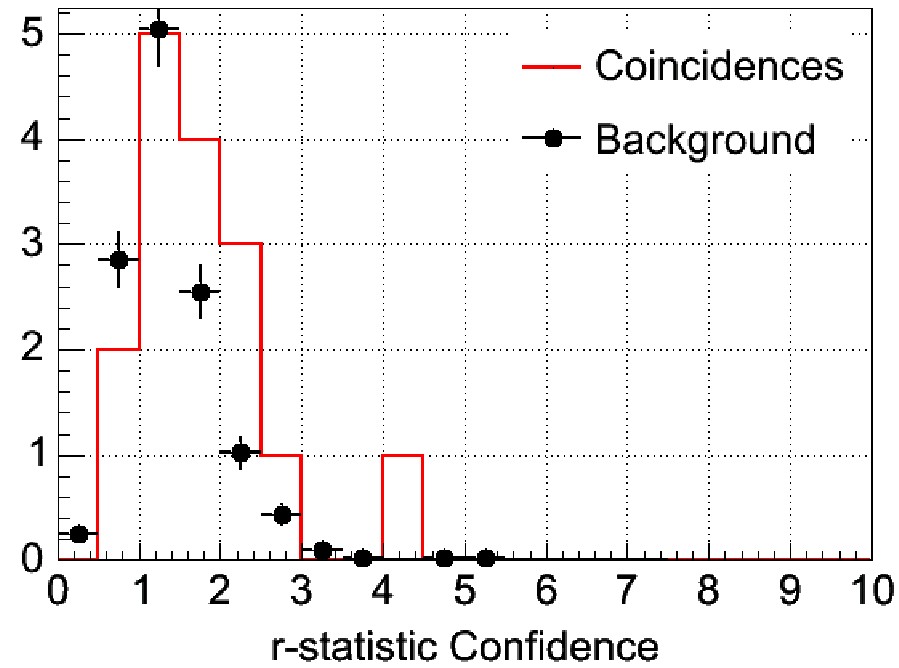
- Pipeline tuned on ~10% "playground" sub-sample (not used in final analysis)
- Search code global significance tuned to produce ~20μHz coincidence rate.
- r-Statistic aims at ~99% reduction in final rate. Threshold set to $\Gamma>4$.
- Expected background ~0.05 events.

Background Estimation

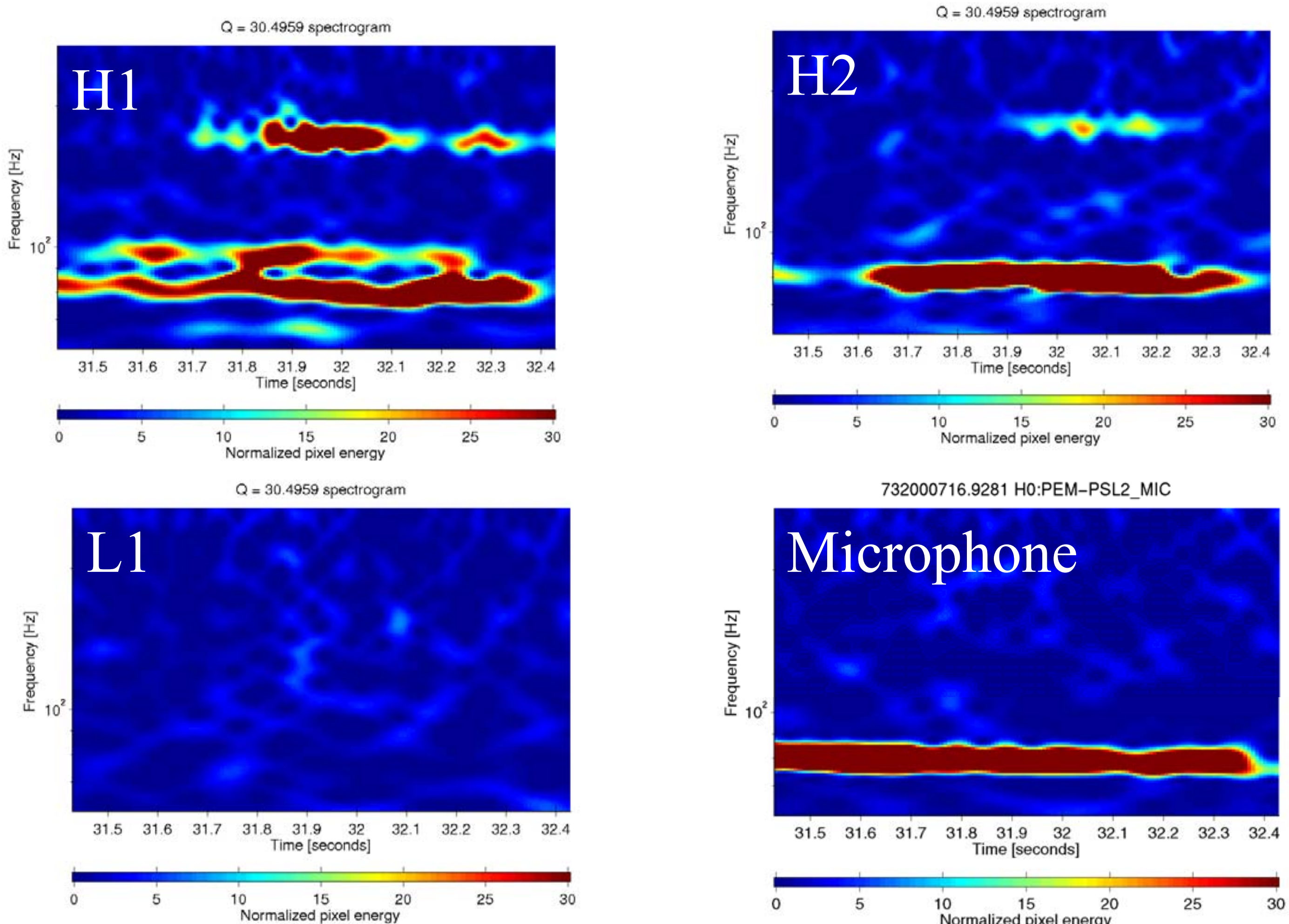
- Background estimated using time shifted 3-fold coincidences.
  - » LLO data shifted relative to LHO data
  - » 46 × 5s time shifts (5s ≤ |Δt| ≤ 115s)
  - » Data time shift internal to WaveBurst and r-statistic
- Identical pipeline, cuts for all shifted data

Detectable Burst Upper Limit

- Blind procedure gives one event candidate
  - » Event immediately found to be correlated with airplane over-flight
  - » Airplanes have been seen to in PEM channels for ~5 years.
  - » Acoustic mitigation before S3 reduced coupling.
- Background estimate is 0.05.
- Our Feldman Cousins 90% upper limit for one event would be 4.3



Airplane at LHO

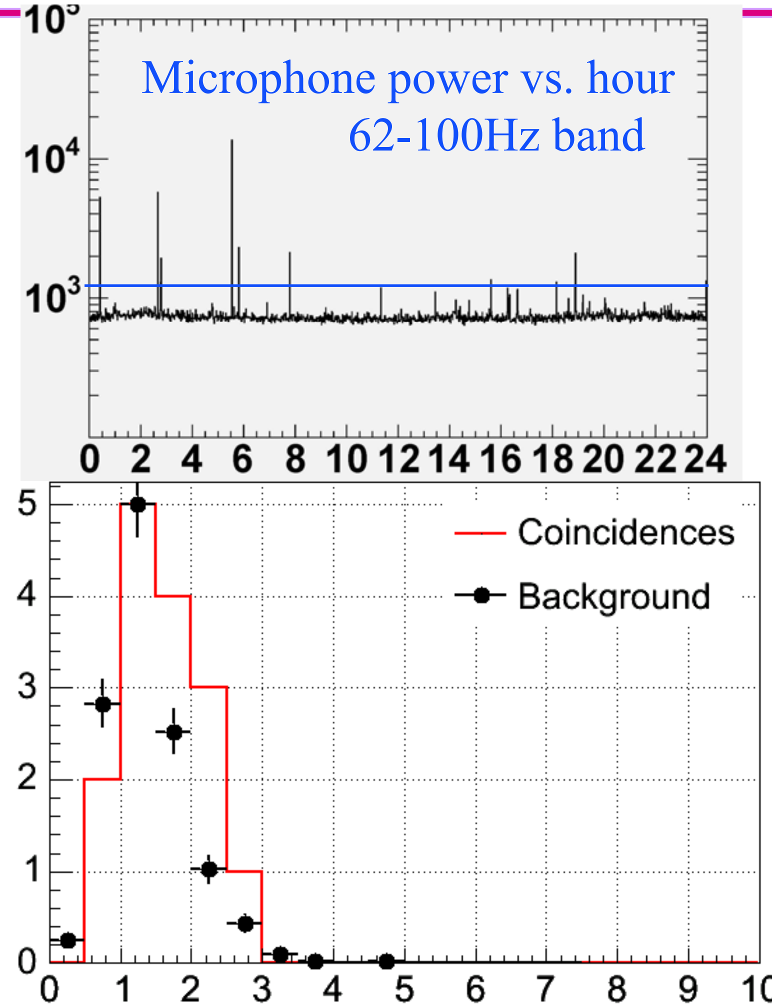


Statistical Issues

- LSC is currently debating whether we can make a statistically reliable confidence limit made after a post analysis veto.
- Statistical issues under discussion include:
  - » Does upper limit with "airplane" event adequately state the measurement we wish to make?
  - » Will post analysis veto necessarily cause under coverage?
  - » How does veto procedure affect background estimate?
  - » Simulation needs probability that a believable veto will be found for real GW events.
- We quote the 0 foreground event limit with a band of systematic uncertainty that includes the limit inferred from one event.

Acoustic Veto!

- Acoustic veto based on power in 65-115Hz band in H2 PSL table microphone.
- Vetoes ~0.7% of live-time
- Eliminates Δt=0 event and one background (Δt≠0) event.
- Feldman Cousins 90% upper limit for 0 events over a background of 0.05 is 2.4.
- Rate upper limit = $2.8\times10^{-6}s^{-1}$ =0.24/day.



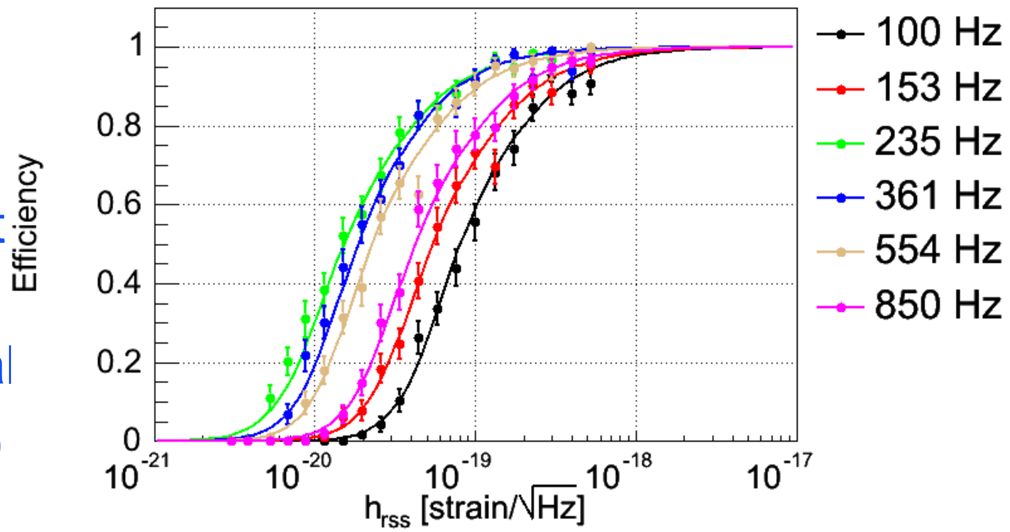
Rate Upper Limits vs h_{rss}

- We infer rate upper limits vs. strength for test wave-forms
  - » sine-Gaussians
  - » Gaussian
  - » Lazarus and Zwerger-Muller (not shown here)
- Use h_{rss} to indicate strength, where: $h_{rss} = \sqrt{\int |h(t)|^2 dt}$
- $$R(h_{rss}) = \frac{\eta}{\varepsilon(h_{rss}) \times T}$$
- We present results as a band limited by 0 → 1 foreground event
- Bands include 11% calibration uncertainty

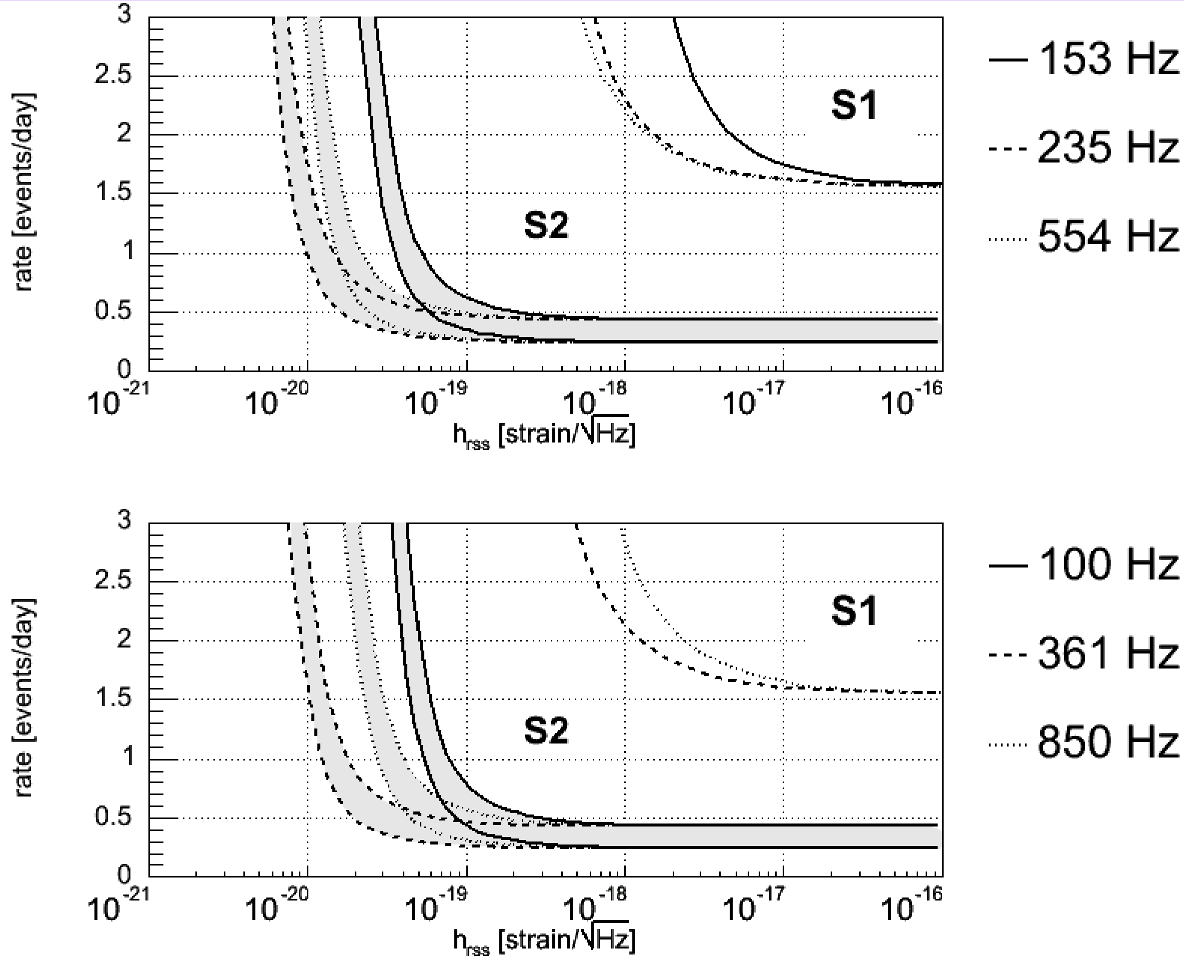
Detection Efficiency vs. h_{rss}

- Measure test waveform efficiencies vs. h_{rss}
  - » sine-Gaussian
  - » Gaussian
- Software injections: signal added to digitize IFO output
- Hardware injection: signals added to length servo signal
- All-sky (random orientation)
- Fit to asymmetric sigmoid

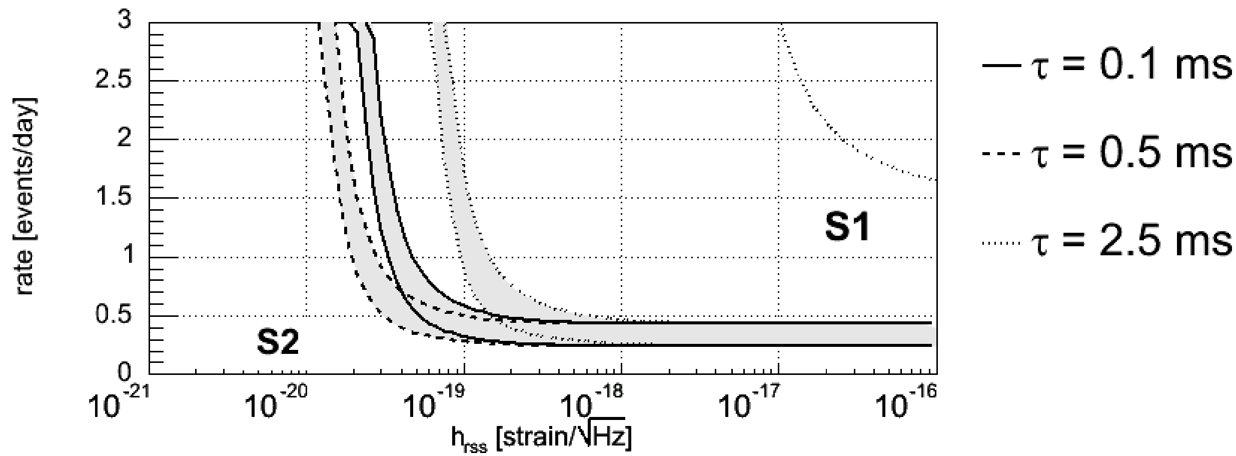
Q=9 sine-Gaussian Efficiencies

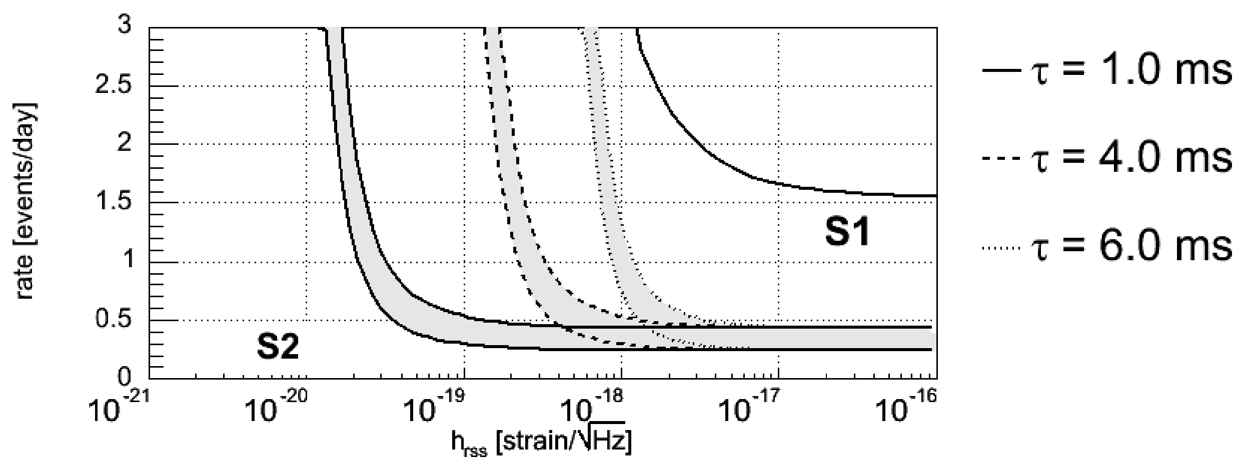


Rate vs. h_{rss} (Q=9 sine-Gaussians)



Rate vs. h_{rss} (Gaussians)





Summary

- LIGO S2 triple-coincidence data were searched for gravitational wave burst events.
- The analysis improved on the S1 untriggered pipeline
  - » A new wavelet-based search code was used.
  - » The r-statistic was used to test signal consistency in the 3 IFOs.
- One event remained at the end of the pipeline
  - » Event traced to an airplane flying over LHO
- An 90% confidence upper limit for detectable bursts in the 100-1100Hz band of 0.24/day was inferred from zero events (with systematic uncertainty extending to 0.43/day)
- Rate vs. strength curves were calculated for Gaussian and sine-Gaussian waveforms.