Confidence Test for Waveform Consistency of LIGO Burst Candidate Events

Laura Cadonati
LIGO Laboratory
Massachusetts Institute of Technology

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Preface

The LIGO Burst Search pipeline uses *Event Trigger Generators* (ETGs) to flag times when "something anomalous" occurs in the strain time series

$\Rightarrow$ burst candidate events (Δt, Δf, SNR)

Events from the three LIGO interferometers are brought together in coincidence (time, frequency, power).

In order to use the full power of a coincident analysis:

- » Are the waveforms consistent? To what confidence?
- » Can we suppress the false rate in order to lower thresholds and dig deeper into the noise?

Cross correlation of coincident events

Assigning a Correlation Confidence to Coincident Candidate Events

Pre-process

1. Load time series from 2 interferometers (2 sec before event start)
2. Decimate and high-pass ⇒ 100-2048Hz
3. Remove predictable content (effective whitening/line removal): train a linear predictor filter over 1 s of data (1 s before event start), apply to the rest.
   - ⇒ emphasis on transients, avoid non-stationary, correlated lines.
4. Apply an r-statistic test to quantify the correlation between interferometer pairs

r-statistic

$$r = \frac{\sum_i (x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum_i (x_i - \bar{x})^2} \sqrt{\sum_i (y_i - \bar{y})^2}}$$

Linear correlation coefficient or normalized cross correlation for the two series $\{x_i\}$ and $\{y_i\}$

NULL HYPOTHESIS: the two (finite) series $\{x_i\}$ and $\{y_i\}$ are uncorrelated

⇒ Their linear correlation coefficient (**Pearson's r**) is normally distributed around zero, with $\sigma = 1/\mathrm{sqrt}(N)$ where N is the number of points in the series (N >> 1)

$$S = \mathit{erfc}\left(|r|\ \mathrm{sqrt}(N/2)\right)$$

double-sided significance of the null hypothesis

i.e.: probability that |r| is larger than what measured, if $\{x_i\}$ and $\{y_i\}$ are uncorrelated

$$C = -\log_{10}(S)$$

confidence that the null hypothesis is FALSE ⇒ that the two series are correlated

Delay and Integration Time

What delay?

Shift $\{y_i\}$ vs $\{x_i\}$ and calculate: r_k ; S_k ; C_k
…then look for the maximum confidence C_M
Time shift for C_M = delay between IFOs
Shift limits: ±10 ms (LLO-LHO light travel time)

$$r_k = \frac{\sum_i (x_i - \bar{x})(y_{i+k} - \bar{y})}{\sqrt{\sum_i (x_i - \bar{x})^2} \sqrt{\sum_i (y_{i+k} - \bar{y})^2}}$$

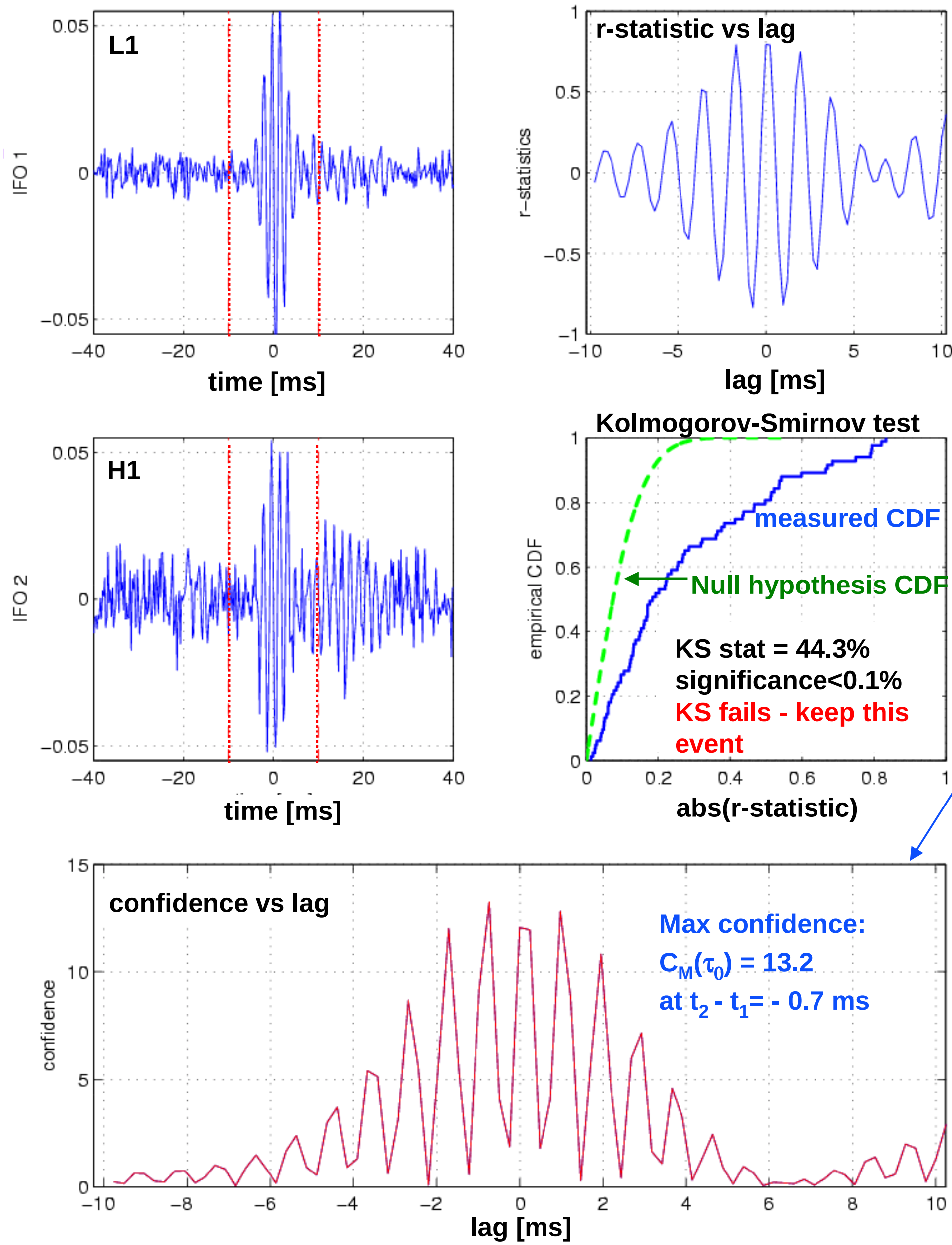
Integration time τ:

How long?

- » If too small, we lose waveform information and the test becomes less reliable
- » If too large, we wash out the waveform in the cross-correlation

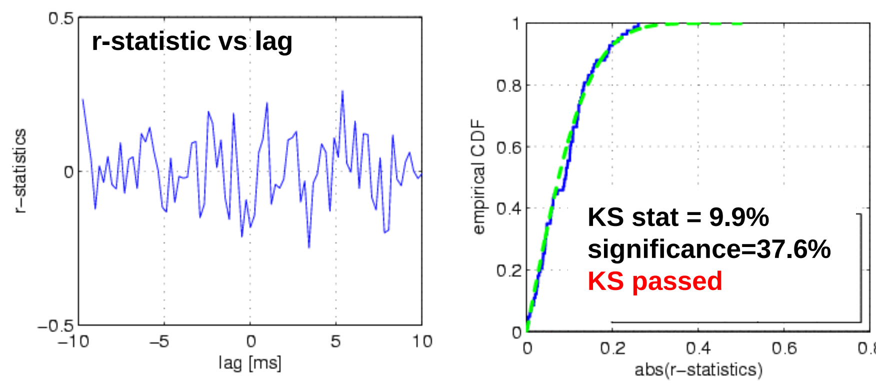
Test different τ's and do an OR of the results **(20ms, 50ms, 100ms)**

Simulated Sine-Gaussian Q=9, f_0=554Hz (passed through IFO response function)



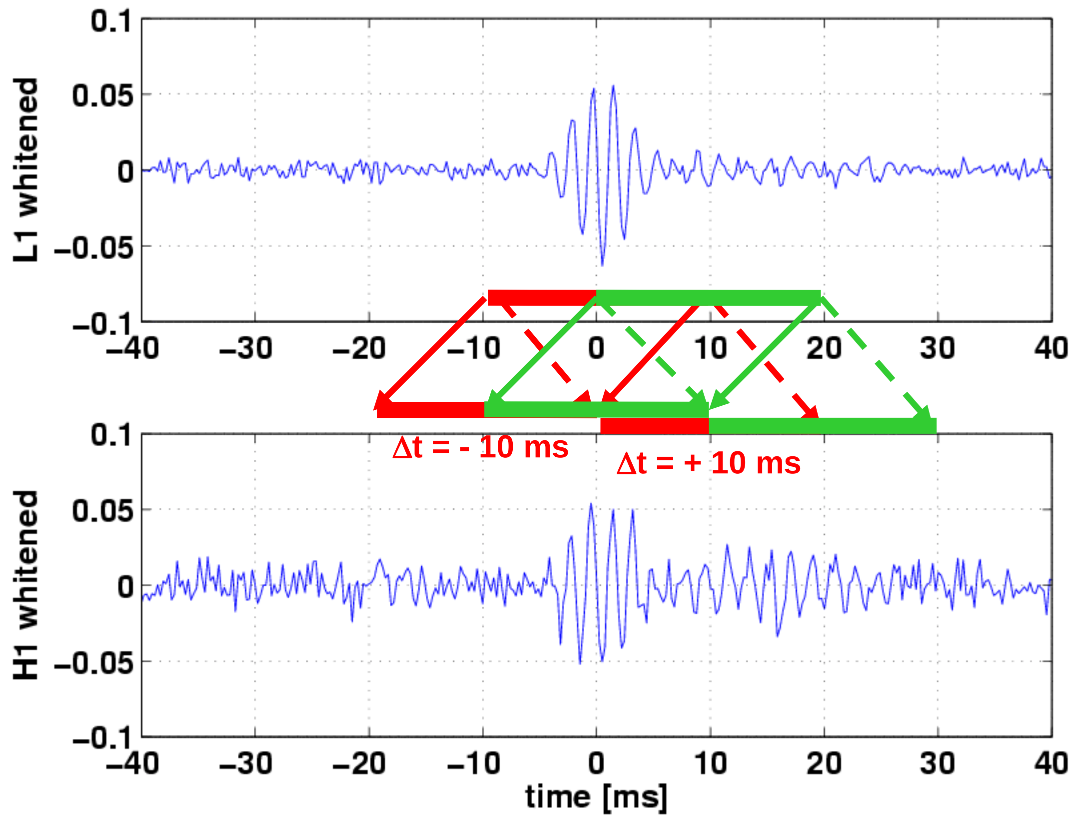
- L1-H1 pre-processed waveforms and r-statistic plot
  - integration time τ = 20 ms,
  - centered on the signal peak time.
- a Kolmogorov-Smirnov (KS) test states the $\{r_k\}$ distribution is NOT consistent with the null hypothesis.
  - » there is less than 0.1% probability that this distribution is due to uncorrelated series.
- On to the calculation of the confidence series and of its maximum C_M (j)

Noise only (no added signal)

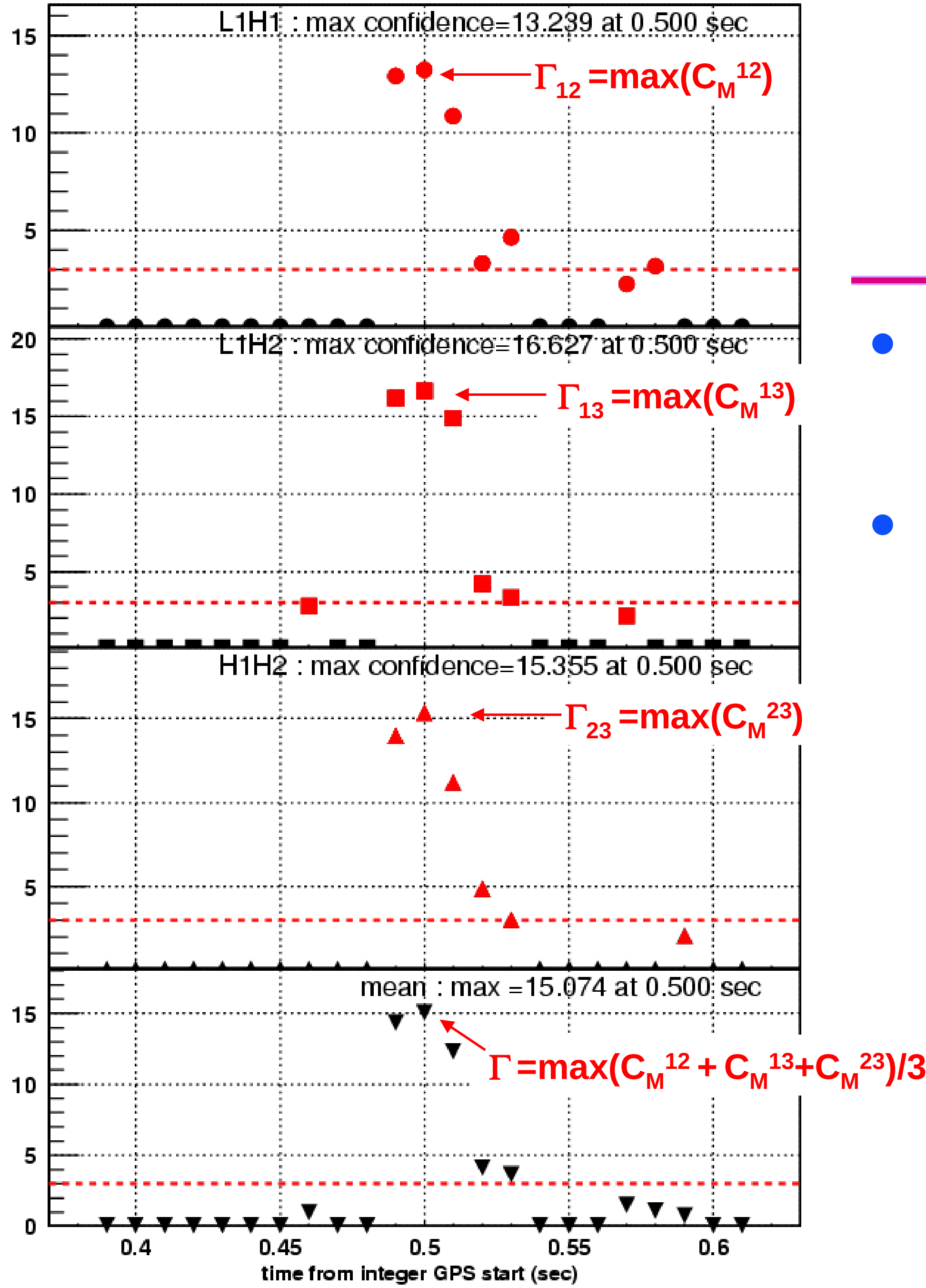


Scanning the Trigger Duration ΔT

- Partition trigger in $N_{sub}=(2\Delta T/\tau)+1$ subsets and calculate C_M (j) (j=1.. N_{sub})
- Use $\Gamma_{ab} = \max_j(C_M(j))$ as the correlation confidence for a pair of detectors over the whole event duration



$C_M(j)$ plots



- Each point: max confidence $C_M(j)$ for an interval τ wide (here: $\tau = 20$ms)

- Define a cut (pattern recognition?):
  - 2 IFOs:
  - $\Gamma = \max_j(C_M(j)) > \beta_2$
  - 3 IFOs:
  - $\Gamma = \max_j(C_M^{12} + C_M^{13} + C_M^{31})/3 > \beta_3$

In general, we can have $\beta_2 \neq \beta_3$

$\beta = 3$: 99.9% correlation probability

Sample Performance

Test on 26 simulated events:
Sine-Gaussians f_0=361 Hz or f_0=554 Hz ; Q=9
Gaussians τ = 1ms
ETGs as in S1 (~1 Hz single rate)
h_0=signal peak amplitude with 50% efficiency for triple coincidence event analysis (S1-style)
β_3=3 cut in the r-statistics test

Out of the 26 test points:
No background event passes the r-statistic test

All pass r-statistics test for $h_{peak} \geq h_0$

$\Rightarrow$ background suppression at no cost for sensitivity (so far)

$\Rightarrow$ETG thresholds can be lowered (sensitivity increase?)

Summary & Outlook

r-statistic test for cross correlation in time domain – allows to:

» Assign a confidence to coincidence events at the end of the burst pipeline

» Verify the waveforms are consistent

» Suppress false rate in the burst analysis, allowing lower thresholds

In progress:

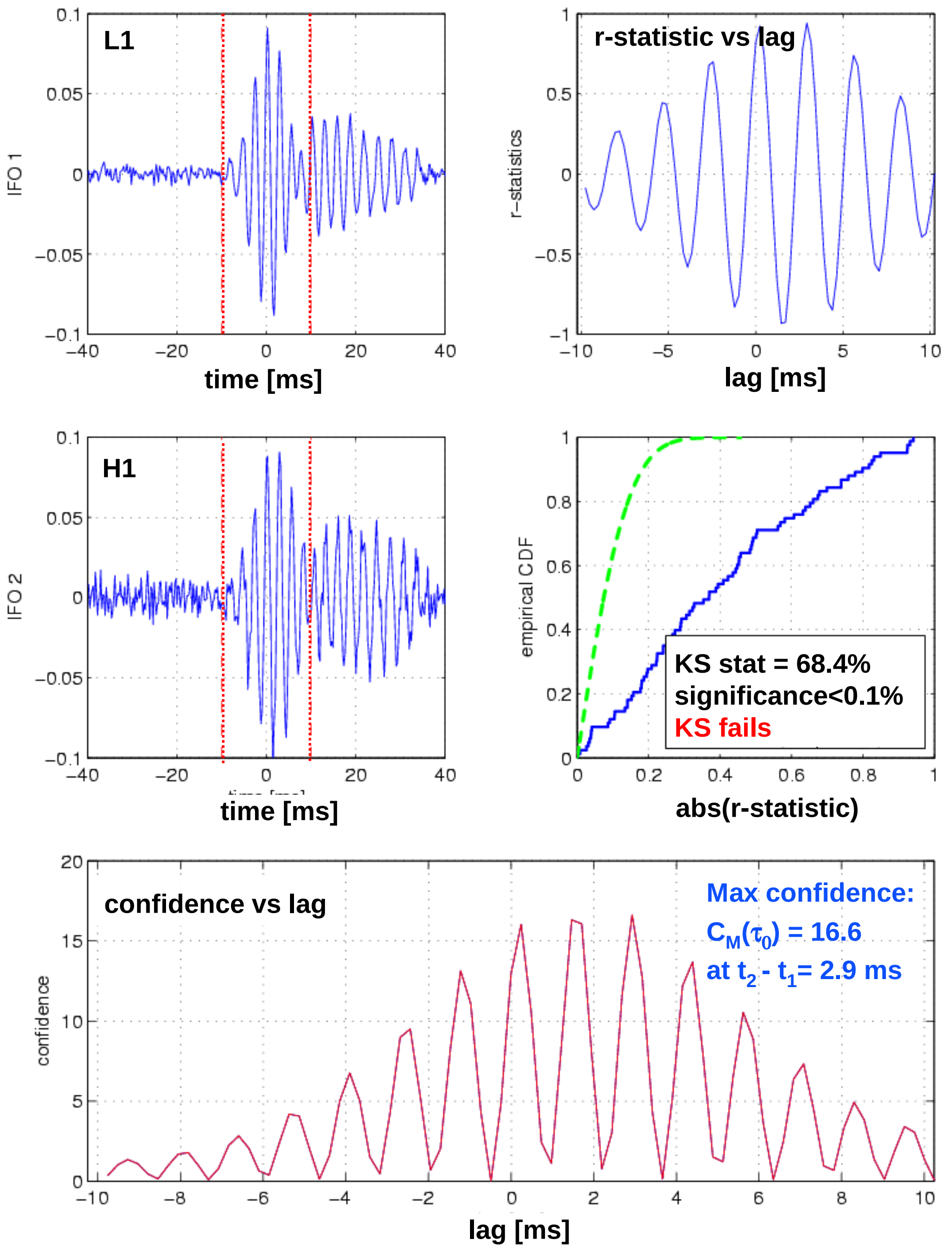
» Method tune-up on hardware injections

» Ongoing investigation with simulated signals

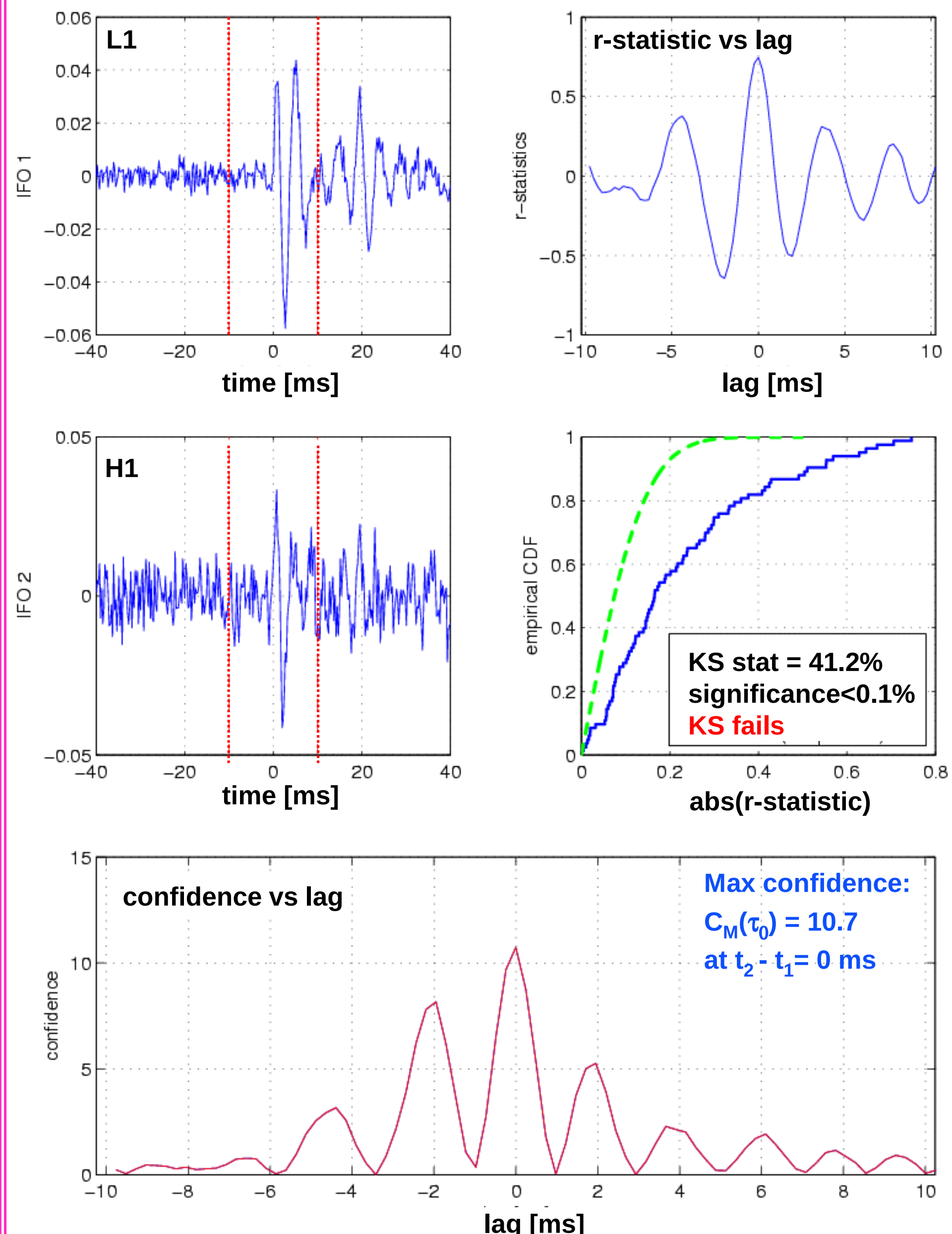
» Exploring implementation in frequency domain

» Coordination of the test implementation with the externally triggered search (see talk by Mohanty)

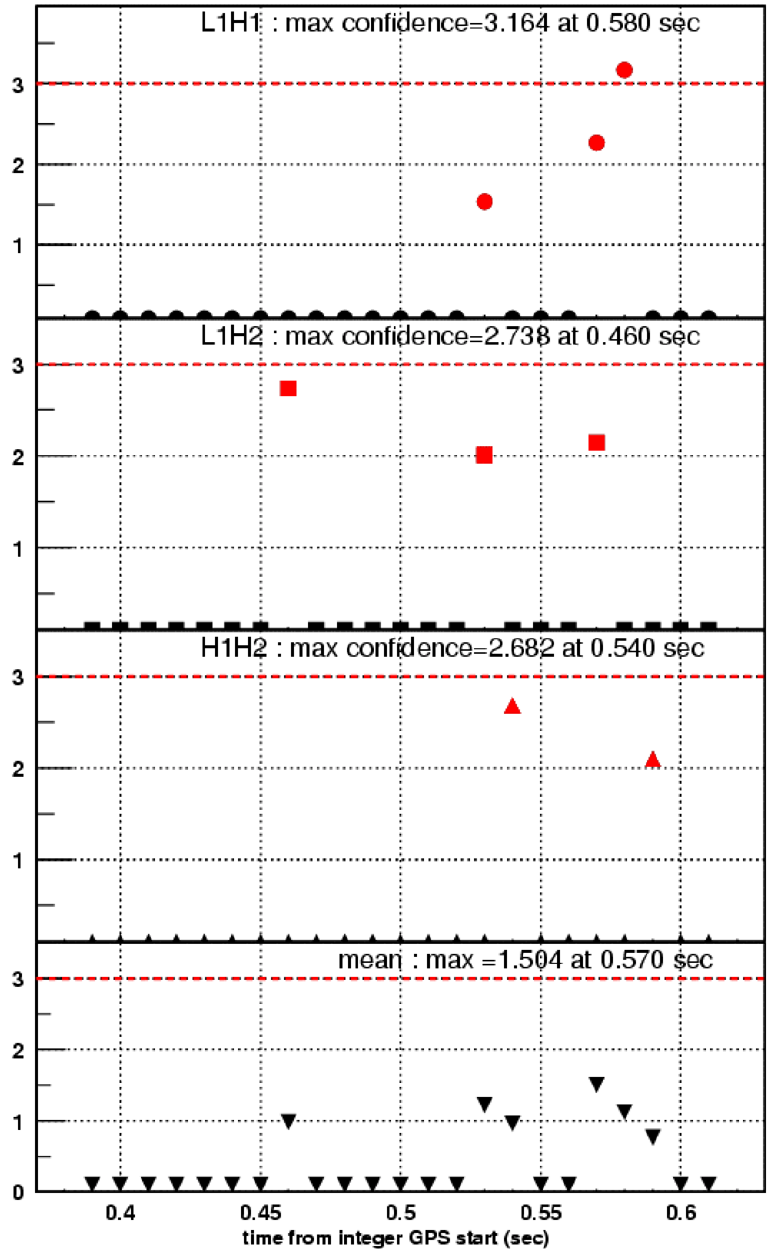
Simulated Sine-Gaussian Q=9, f_0=361Hz (passed through IFO response function)



Simulated 1 ms Gaussian (passed through IFO response function)



Background



Added signal (50% efficiency level)