Application of the Q Pipeline to LIGO's fifth science run

With an emphasis on follow-up consistency tests to increase detection confidence

Shourov K. Chatterji

for the LIGO Scientific Collaboration

11th Gravitational Wave Data Analysis Workshop

Potsdam, Germany

2006 December 21

LIGO-G060618-00-Z

Single detector Q Pipeline

- Multiresolution time-frequency search for statistically significant excess signal energy
- Projects whitened data onto an overlapping basis of sinusoidal Gaussians characterized by central time, central frequency, and Q (ratio of central frequency to bandwidth)
- The template bank is constructed using a maximum mismatch approach similar to the matched filtering approach
- The search is equivalent to a matched filter search for waveforms that are sinusoidal Gaussians *after* whitening
- The reported normalized energy Z is a measure of event significance and is simply twice the squared SNR ρ that would be reported by a matched filter search

Collocated detector Q Pipeline

- The two LIGO Hanford detectors (H1H2) can be combined to form two new detector data streams

H+ The optimal linear combination that maximizes the signal to noise ratio of potential signals.

$$H_+ = \left(\frac{1}{S_1} + \frac{1}{S_2} \right)^{-1} \left(\frac{H_1}{S_1} + \frac{H_2}{S_2} \right)$$

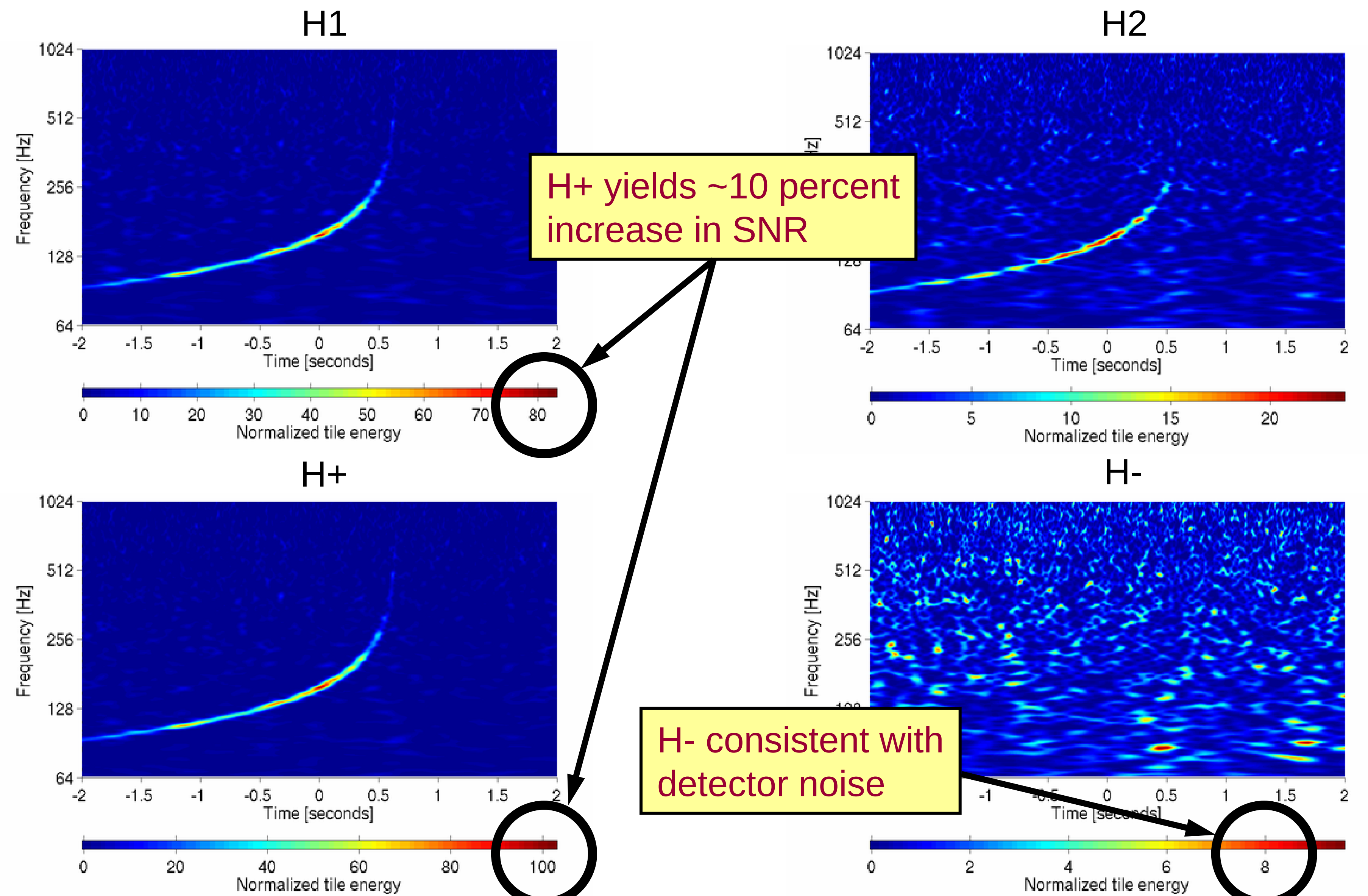
  - Frequency dependent weighting factors are inversely proportional to power spectral density S in each bin
  - Resulting SNR is the quadrature sum of SNRs

H- The null stream, which should be consistent with noise in the case of a true gravitational-wave

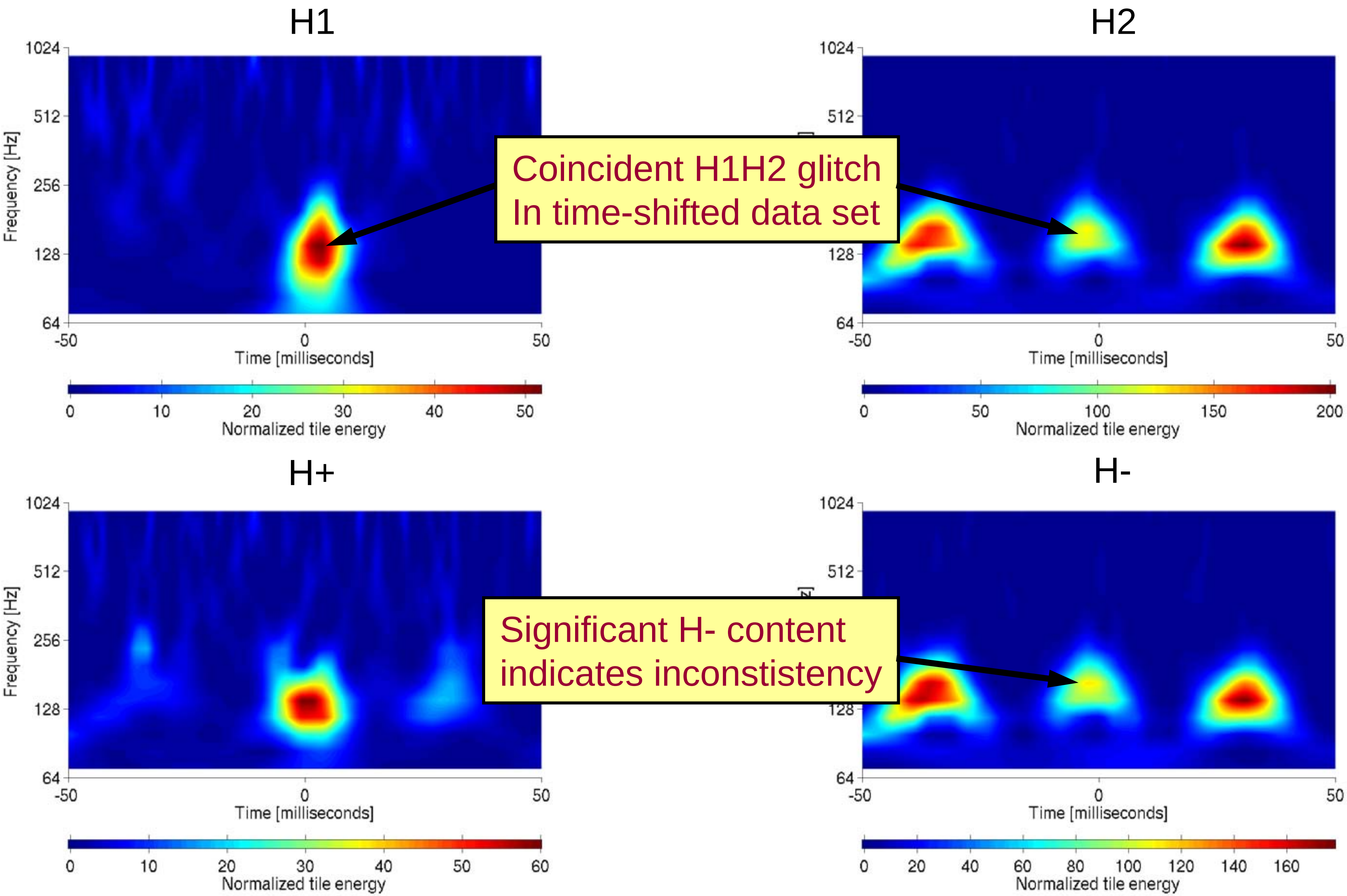
$$H_- = H_1 - H_2$$

  - Frequency independent weighting factors

H1H2 example: Inspiral at 5 Mpc



H1H2 example: time shifted glitch



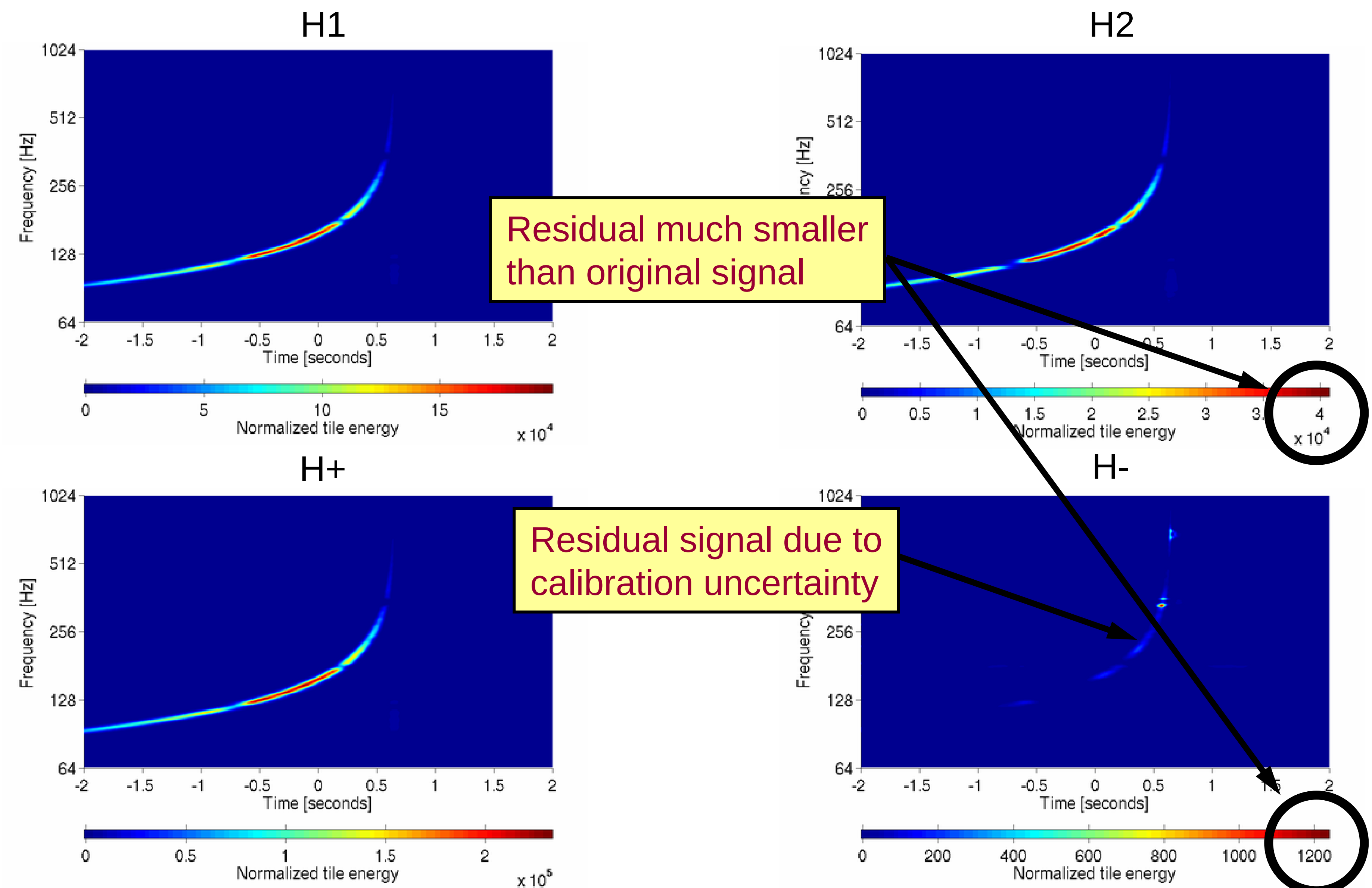
Collocated detector Q Pipeline

- Calibration uncertainty can produce a significant residual null stream signal for strong gravitational waves
- Compare null stream significance with the significance expected on the assumption of uncorrelated detectors

$$Z_0 = \frac{Z_1 S_1 + Z_2 S_2}{S_1 + S_2}$$

- Veto significant H+ events that are coincident with a significant H- event
  - H- events are significant if $Z_- > \alpha + \beta Z_0$
  - Veto H+ events within 1 second of strong H- events
  - Veto H+ events overlapping in time and frequency with weaker H- events

H1H2 example: Inspiral at 0.1 Mpc



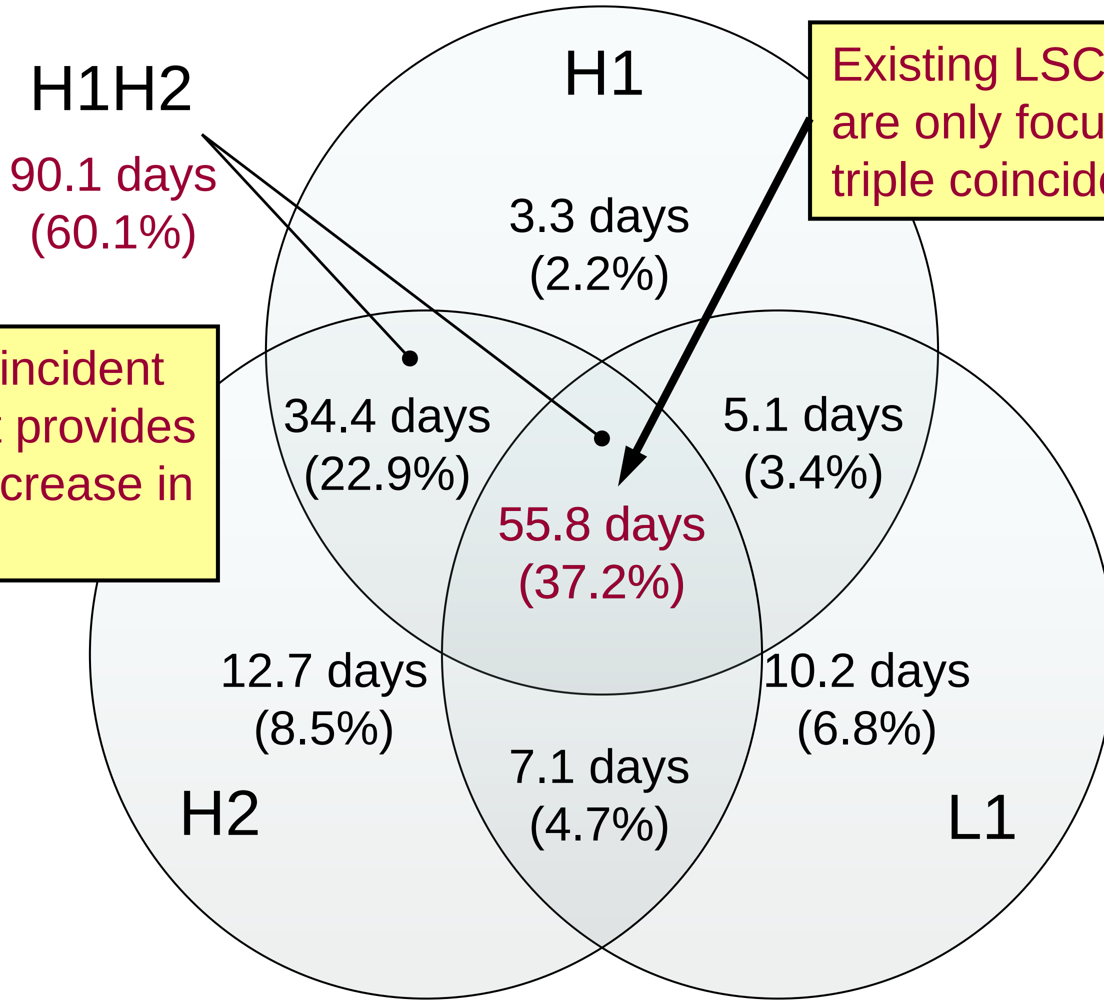
S5 Q Pipeline search

- There are two primary components of this analysis
  - H1H2 double coincident search for combined excess signal energy followed by H1H2 null stream consistency test
  - H1H2L1 triple coincident search for time frequency coincidence between H1H2 triggers and L1 triggers
- Upper limits will be determined using the loudest event statistic
- The most significant ~100 events will be followed up
  - Scan auxiliary detector and environmental channels for statistically significant signal content in coincidence with gravitational-wave signal
  - Fully coherent test for consistency with a direction on the sky if data is available from a sufficient number of detectors

S5 livetime and duty cycle

The double coincident H1H2 data set provides a significant increase in duty cycle

Existing LSC burst searches are only focus on the H1H2L1 triple coincident data set



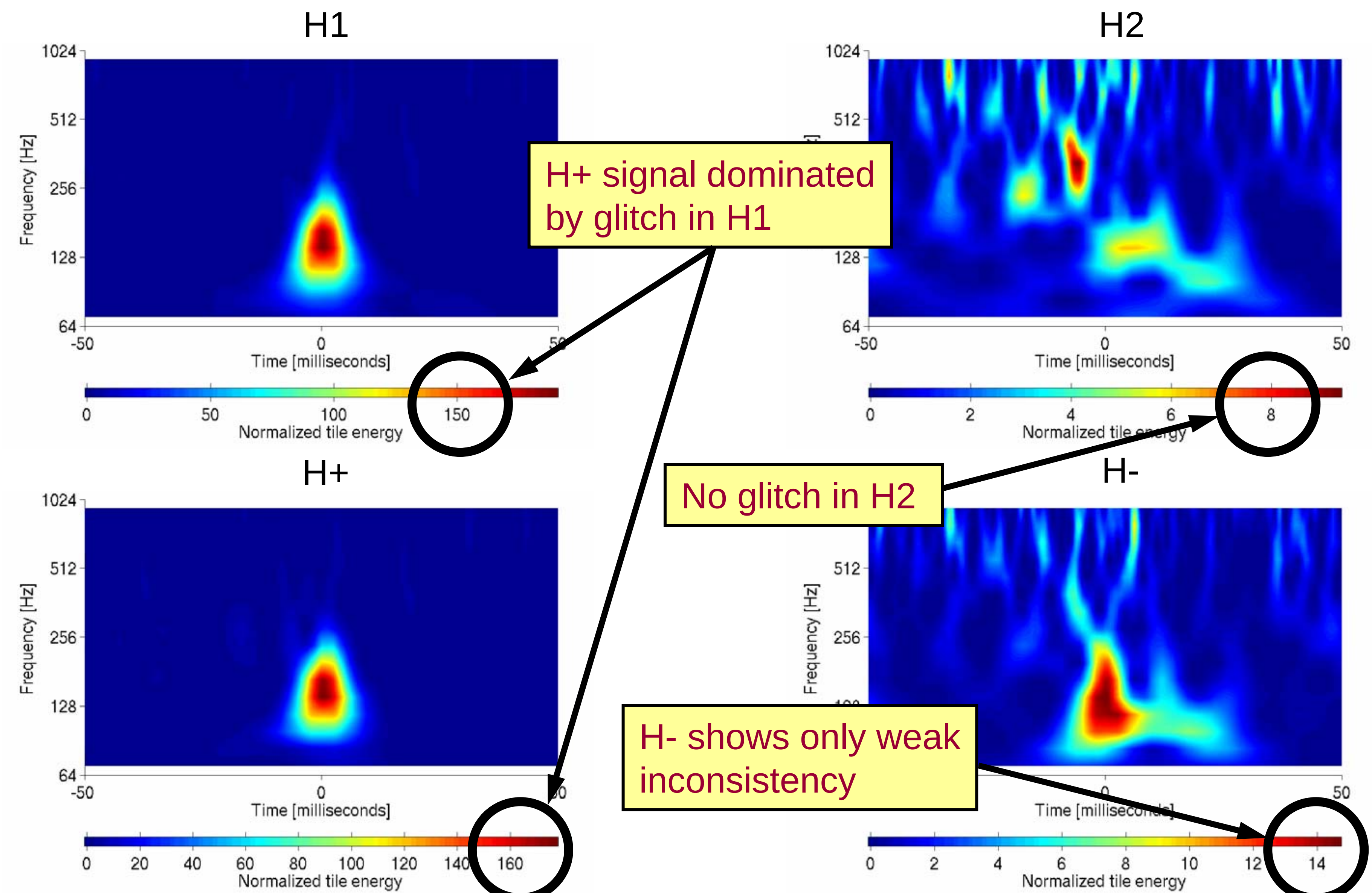
Livetime in days through April 3, 2006

Science mode duty cycle relative to start of S5 at LHO

Effect of H1H2 null stream veto

WORK IN PROGRESS

Most significant time lag H1H2 event



Effectiveness of coherent searches

- Null stream veto limited by least sensitive detector
  - Successfully vetoes coincident H1H2 glitches
  - Successfully vetoes H2 only glitches
  - Successfully vetoes strong H1 only glitches that were strong enough to have been seen in H2
  - Avoids false dismissal of gravitational waves that are strong enough to been seen in H1 but not H2
- At best, the coherent sum provides a $\sqrt{N}$ improvement
  - Only if all N detectors have equal sensitivity
  - Only if all N detectors see the same signal
- Due to the presence of glitches, coherent null streams may provide a much greater improvement in sensitivity and detection confidence than the coherent sum

Effect of common environment

- The H1 and H2 detectors share a common environment
  - Cross-correlation reveals coherent noise
  - Time shifted coincidence tests reveal increased coincidence at zero time shift
- What is the risk that coincident H1 and H2 glitches also pass the null stream consistency test?
- Use the LIGO S4 run as a playground data set

WORK IN PROGRESS

Example S5 H1H2 sensitivity

- Estimate the sensitivity to sinusoidal Gaussian injections in time shifted data after application of null stream veto
- Threshold at significance of loudest time shifted event
- This assumes that the loudest zero time shift event has similar significance
- Tuning in progress

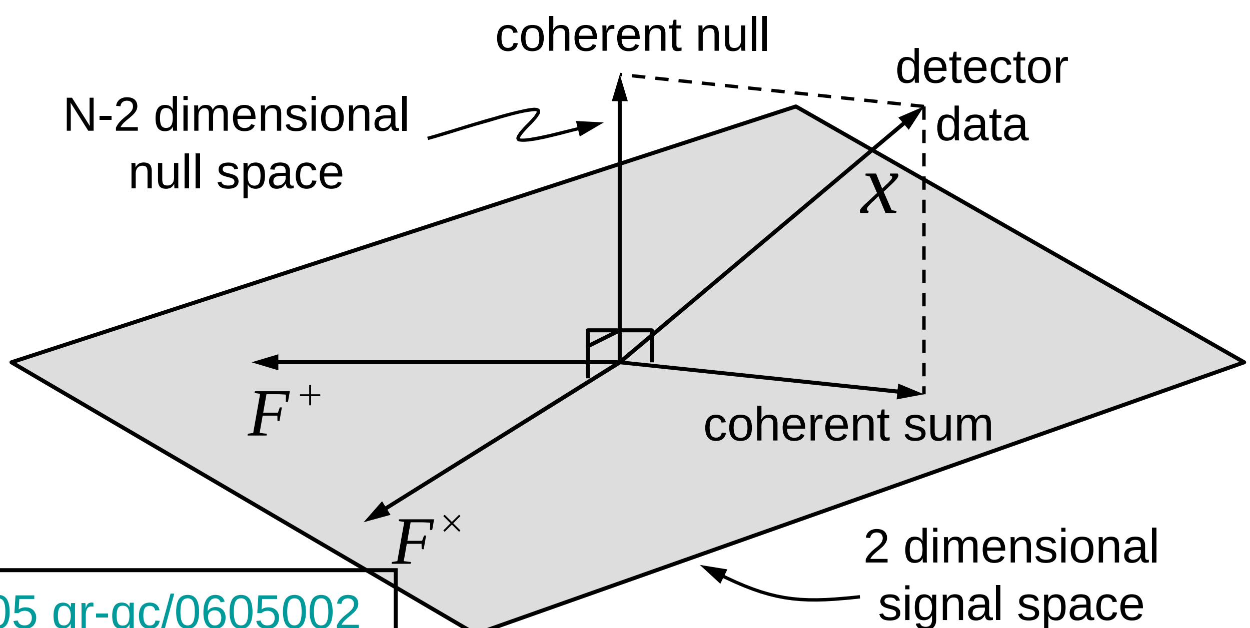
WORK IN PROGRESS

Generalized coherent follow-up

- A fully coherent follow-up to candidate events can be performed when data is available from three or more non-aligned detectors
- Analogous to collocated H1H2 analysis
  - Produce linear combination of time-shifted detector data that maximizes the signal to noise ratio of potential signals
  - Produce linear combination(s) that contain no signal
  - Compare null streams with expected null stream based on the assumption of uncorrelated detector data
- Produce consistency sky maps
- Again, the greatest benefit comes from null stream tests

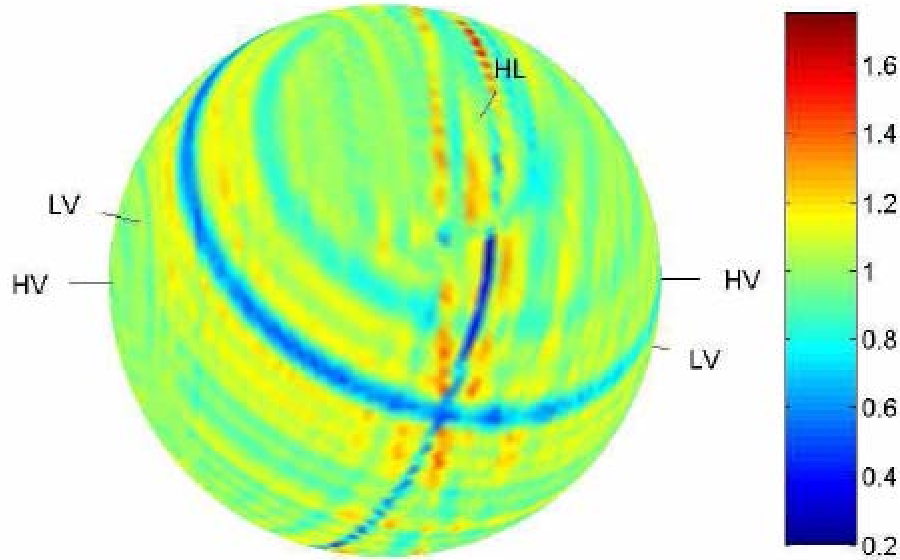
Generalized coherent follow-up

$$\begin{bmatrix} x_1 \\ x_2 \\ \vdots \\ x_N \end{bmatrix} = \begin{bmatrix} F_1^{+} & F_1^{\times} \\ F_2^{+} & F_2^{\times} \\ \vdots & \vdots \\ F_N^{+} & F_N^{\times} \end{bmatrix} \begin{bmatrix} h_+ \\ h_\times \end{bmatrix} + \begin{bmatrix} n_1 \\ n_2 \\ \vdots \\ n_N \end{bmatrix}$$

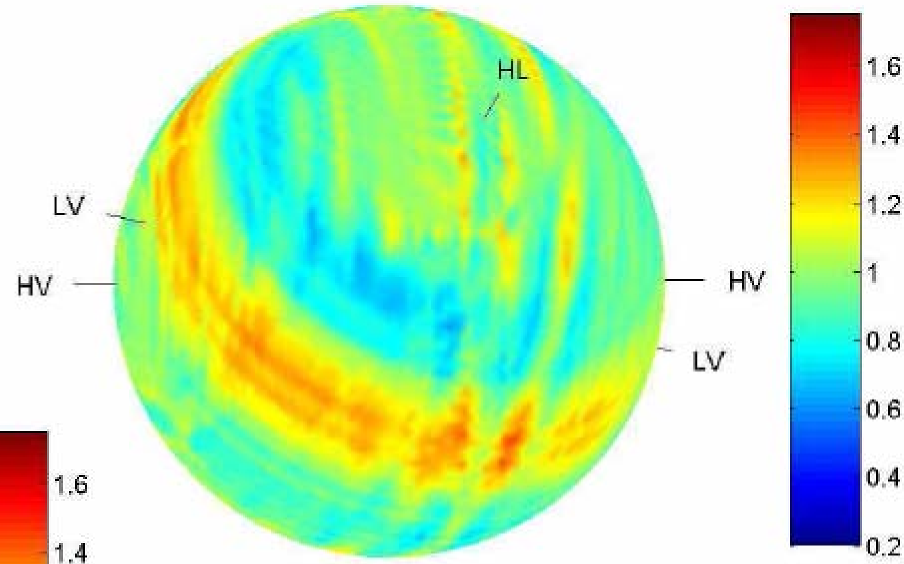


Phys.Rev. D74 (2006) 082005 gr-qc/0605002

Example consistency sky maps



Simulated gravitational-wave burst



Simulated coincident glitch

Phys.Rev. D74 (2006) 082005, gr-qc/0605002

Scan for anomalous detector behavior

- The QScan utility scans for anomalous detector behavior
- Searches for statistically significant signal content in numerous auxiliary detector and environmental channels
- Applies the Q Pipeline methodology
- Provides guidance to the search for vetoes
    - Cannot distinguish causal vs. accidental coincidence
    - Should be combined with follow-up statistical studies
- Helps diagnose coupling mechanisms or data corruption
- Results presented as web based report [example]

Comments

- The Q Pipeline provides three tools beyond single detector analysis that can significantly improve performance and increase detection confidence
  - Collocated H1H2 consistency tests
  - Coherent consistency tests using three or more non-aligned detectors (nearing completion)
  - Analysis of auxiliary detector and environmental channel data for anomalous detector behavior
- The collocated H1H2 search is a planned first step in coherent hierarchical pipeline
  - Powerful veto for glitches
  - Does not require H2 detection
  - Preserves detection efficiency
  - Computationally inexpensive