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# Search for Gravitational-Wave Bursts (GWBs) Associated with Gamma-Ray Bursts (GRBs) Using LIGO Detectors

**LIGO-G060663-00-Z**

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# Outline of GRB-GWB search

- ❖ search for short-duration gravitational-wave bursts (GWBs) coincident with gamma-ray bursts (GRBs)
- ❖ use GRB triggers observed by satellite experiments
  - ❖ Swift, HETE-2, INTEGRAL, IPN, Konus-Wind
  - ❖ include both “short” and “long” GRBs
- ❖ search 180 seconds of LIGO data surrounding each GRB trigger (on-source segment)
- ❖ waveforms of GWB signals associated with GRBs are not known
- ❖ use **crosscorrelation** of two interferometers (IFOs) to search for associated GW signal

$$\mathit{crosscorr} = \frac{\sum_i x_i y_i}{\sqrt{\sum_j x_j^2} \sqrt{\sum_k y_k^2}}$$

correlated signal in two IFOs  
→ large crosscorr

- ❖ use **crosscorrelation lengths of 25 ms and 100 ms** to target short-duration GW bursts of durations ~1 ms to ~100 ms
- ❖ use bandwidth of 40 Hz to 2000 Hz

# The GRB sample for LIGO S2/S3/S4 runs

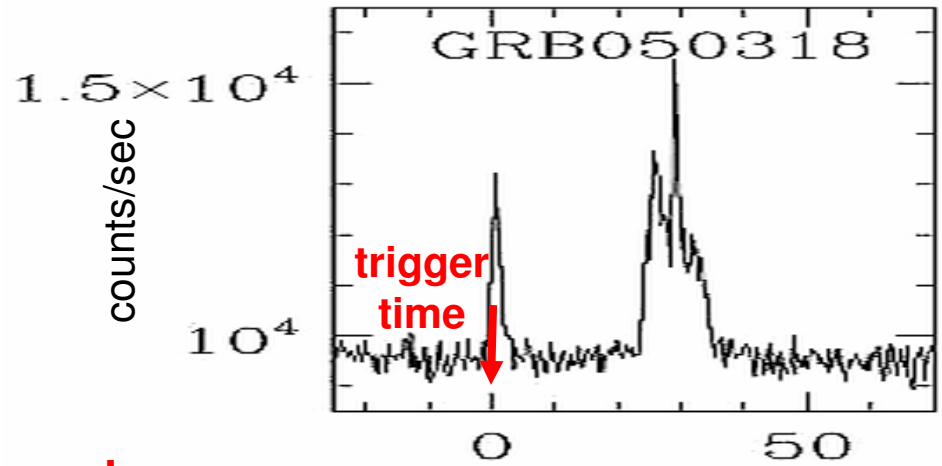
- ❖ **S2: 28 GRBs** with at least double coincidence LIGO data
    - ❖ 24 for LHO 4km – LHO 2km
    - ❖ 9 for LHO 4km – LLO 4km
    - ❖ 9 for LHO 2km – LLO 4km
  - ❖ **S3: 7 GRBs** with at least double coincidence LIGO data
    - ❖ 7 for LHO 4km – LHO 2km
    - ❖ 0 for LHO 4km – LLO 4km
    - ❖ 0 for LHO 2km – LLO 4km
  - ❖ **S4: 4 GRBs** with at least double coincidence LIGO data
    - ❖ 4 for LHO 4km – LHO 2km
    - ❖ 3 for LHO 4km – LLO 4km
    - ❖ 3 for LHO 2km – LLO 4km
- IPN, HETE-2, INTEGRAL, Konus-Wind (pre-Swift)
- start of Swift era

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## 59 LIGO on-source pairs analyzed

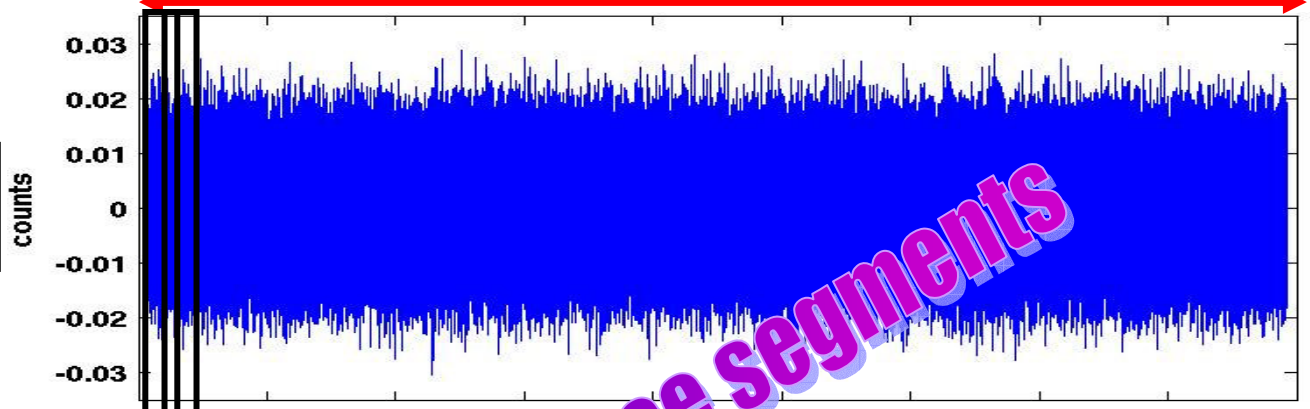
- ❖ only well-localized GRBs considered for LHO – LLO search

sample GRB  
lightcurve  
(Swift)

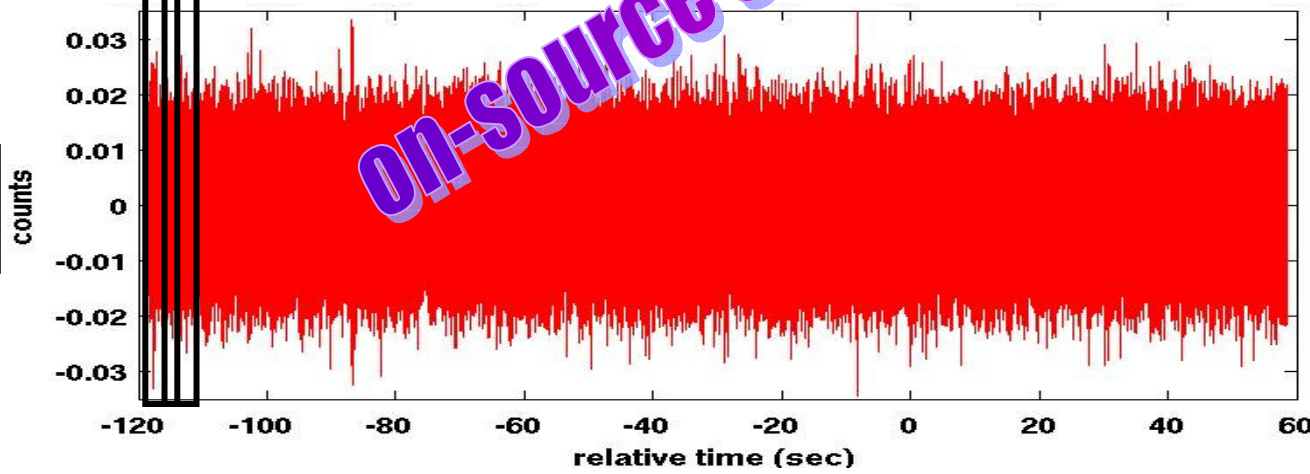


180 seconds

LIGO  
IFO 1



LIGO  
IFO 2

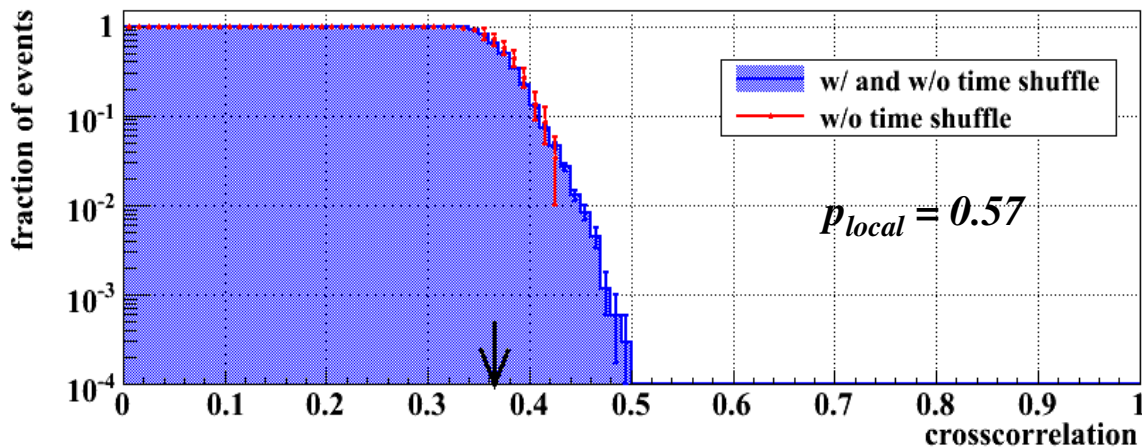
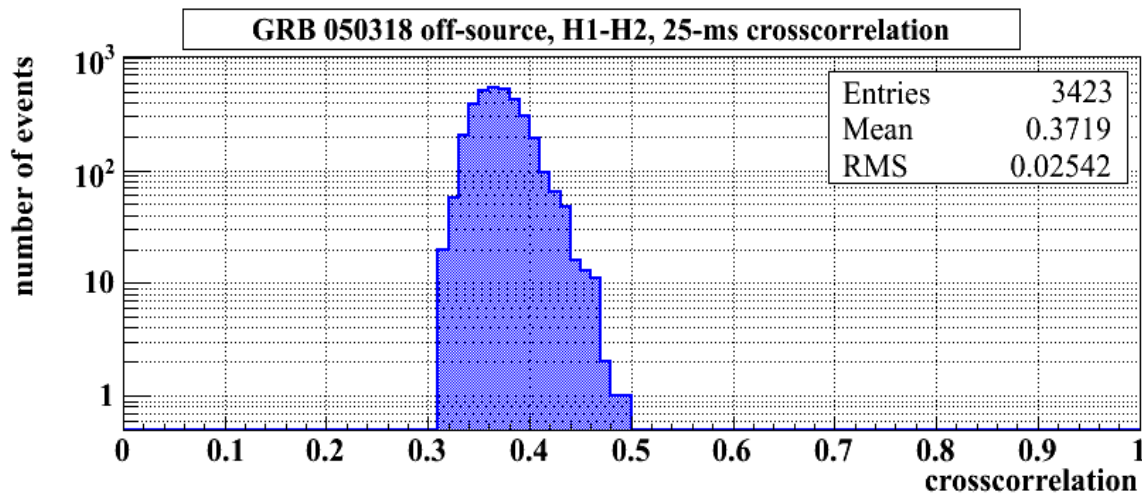


use 180-second  
LIGO on-source  
data surrounding  
GRB trigger

crosscorrelate  
output of two IFOs

look for largest  
crosscorrelation  
within 180-second  
on-source segment

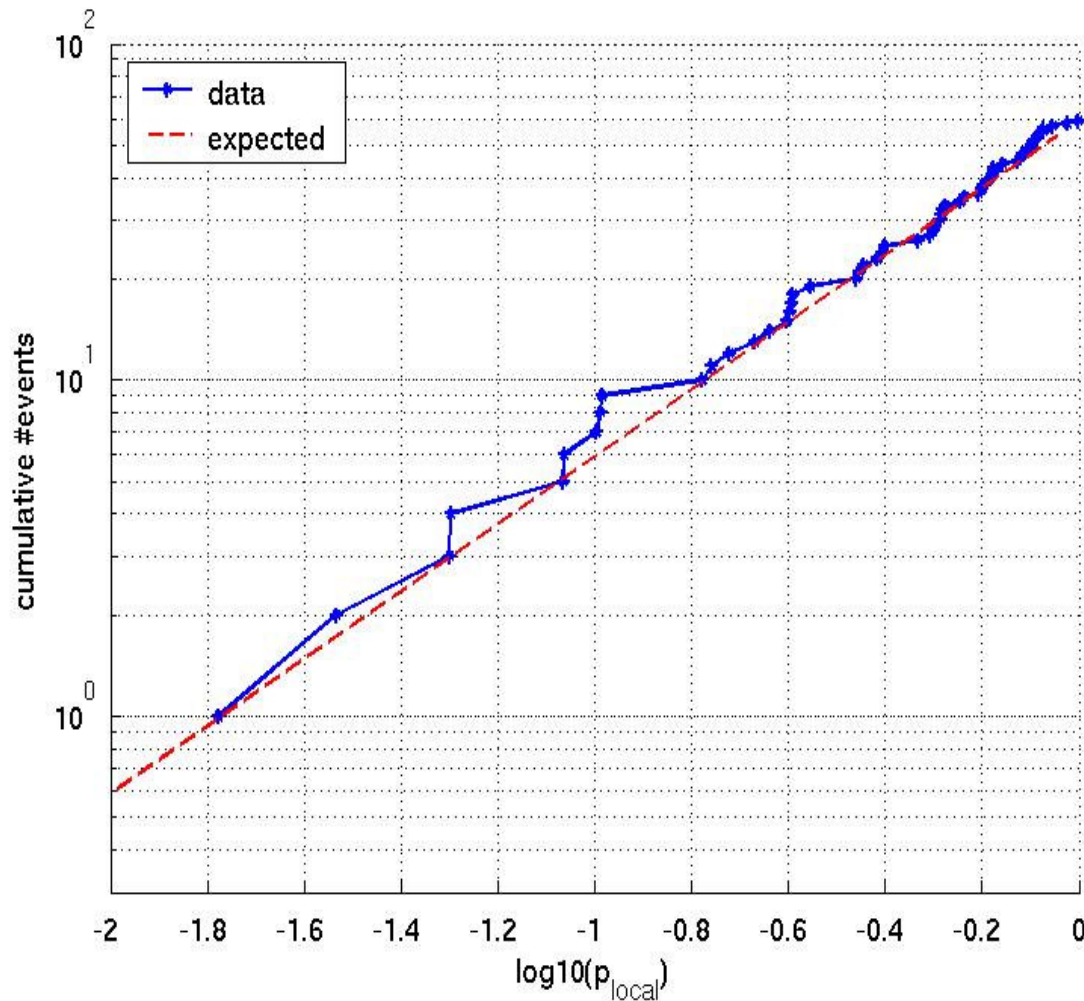
# Estimating probability of measured on-source largest crosscorr: Sample off-source distribution using 25-ms cc length



- ❖ apply search to off-source segments to obtain crosscorrelation distribution
- ❖ use time shifts to get enough statistics
- ❖ largest crosscorrelation found in on-source search indicated by black arrow
- ❖ **probability is estimated using this distribution**
- ❖ off-source crosscorrelation distribution is determined for each IFO pair for each GRB trigger

# Results: Cumulative distribution of local probabilities

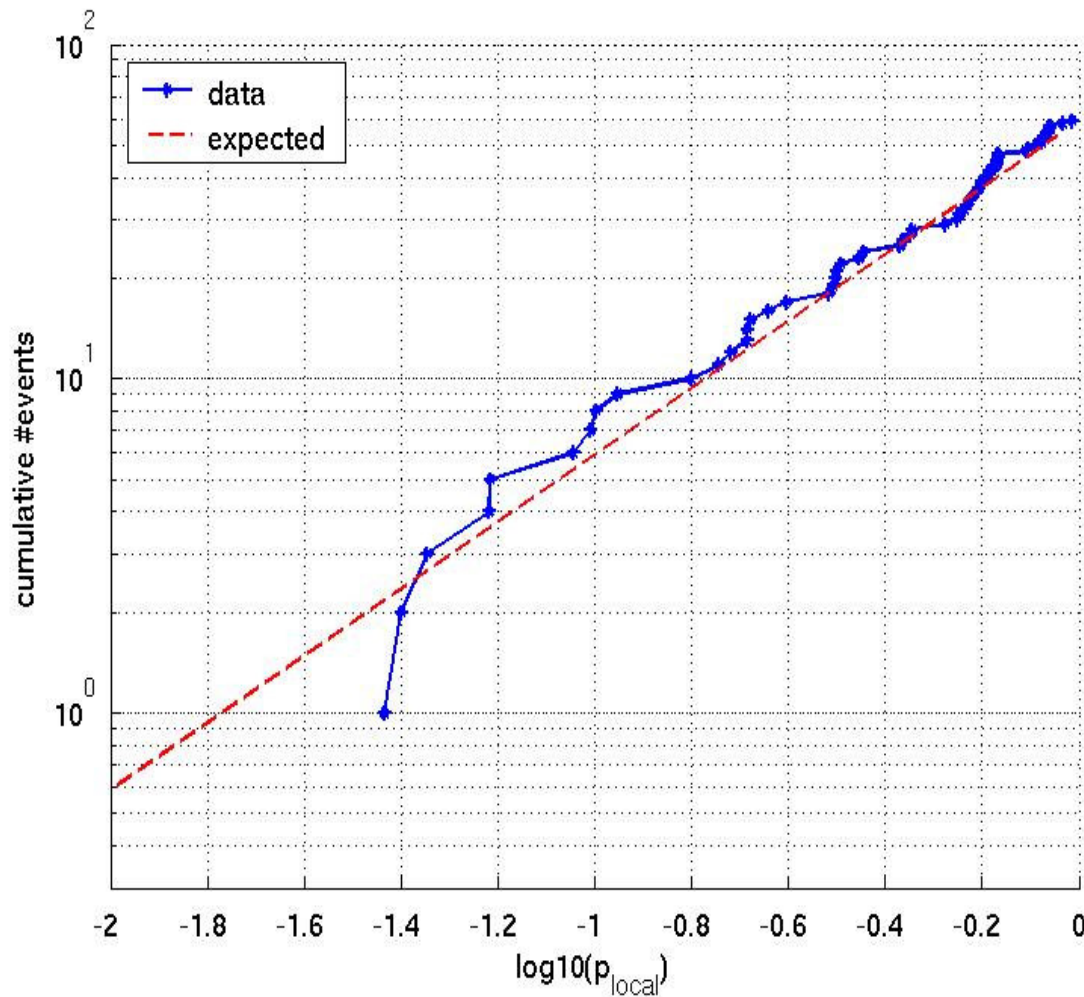
## 25-ms crosscorrelation length



- ❖ 59 entries -- includes all GRBs, all IFO pairs
- ❖ expected distribution of probabilities under null hypothesis is uniform from 0 to 1
- ❖ **no loud event from any GRB**
- ❖ perform statistical test on this distribution

# Results: Cumulative distribution of local probabilities

## 100-ms crosscorrelation length



- ❖ 59 entries -- includes all GRBs, all IFO pairs
- ❖ expected distribution of probabilities under null hypothesis is uniform from 0 to 1
- ❖ **no loud event from any GRB**
- ❖ perform statistical test on this distribution

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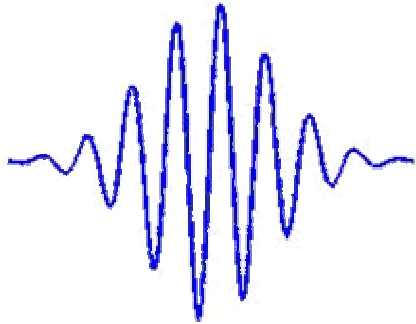
# Statistical tests

- ❖ **statistical search:** search for weak signals which, individually, would not comprise a detection, but together could have a detectable cumulative effect on measured distributions
- ❖ **binomial test:** search local probability distribution for deviation from expected distribution
- ❖ **rank-sum test:** test if medians of on-source crosscorrelation distribution and off-source crosscorrelation distribution are consistent with each other

***Result of tests: On-source and off-source crosscorrelation distributions are statistically consistent.  
Null hypothesis cannot be rejected.  
No GW signal seen from statistical search.***

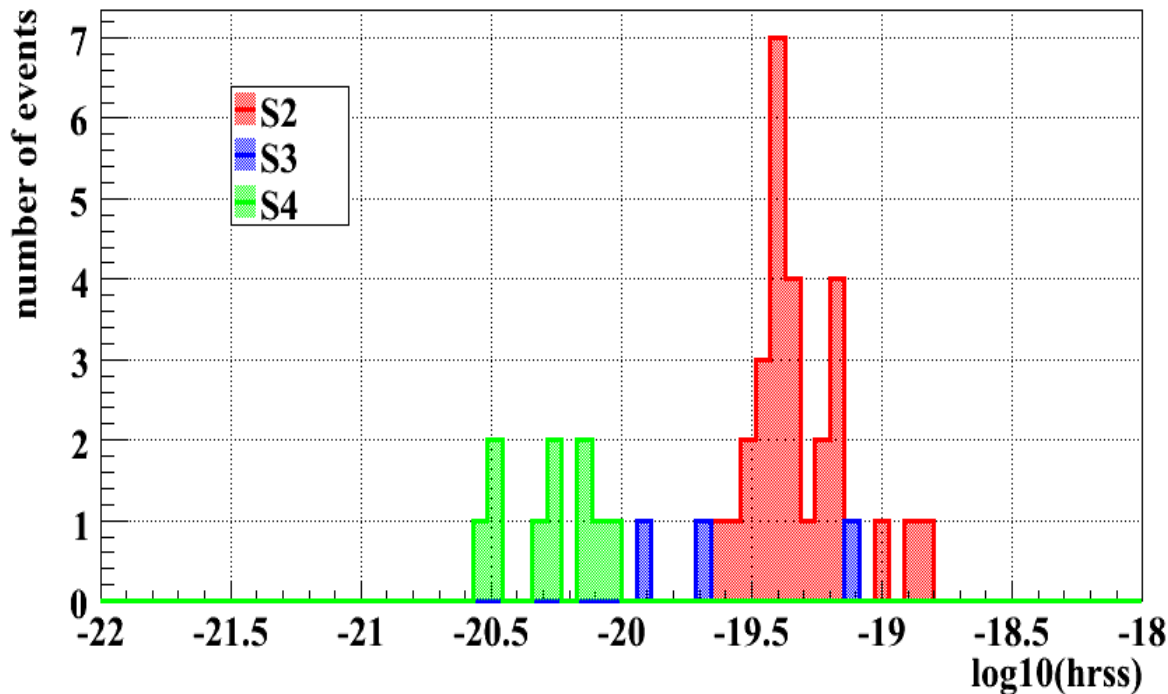


## S2/S3/S4 $h_{RSS}$ 90% upper limits for sine-gaussians



$$h_{RSS} = \sqrt{\int_{-\infty}^{+\infty} |h(t)|^2 dt}$$

hrss upper limits, 25-ms window, sine-gaussian, f=250 Hz, Q=8.9



- ❖ GW waveforms not known
- ❖ inject simulated sine-gaussians into data to estimate search sensitivity
- ❖ use linear polarization
- ❖ take into account antenna response of interferometers

❖ S2 best  $h_{RSS}$  limit (250 Hz):

❖  **$2.5E-20 \text{ Hz}^{-1/2}$**

❖ S3 best  $h_{RSS}$  limit (250 Hz):

❖  **$1.2E-20 \text{ Hz}^{-1/2}$**

❖ S4 best  $h_{RSS}$  limit (250 Hz):

❖  **$3.0E-21 \text{ Hz}^{-1/2}$**

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## S5 GRB-GWB Search: Preliminary Results

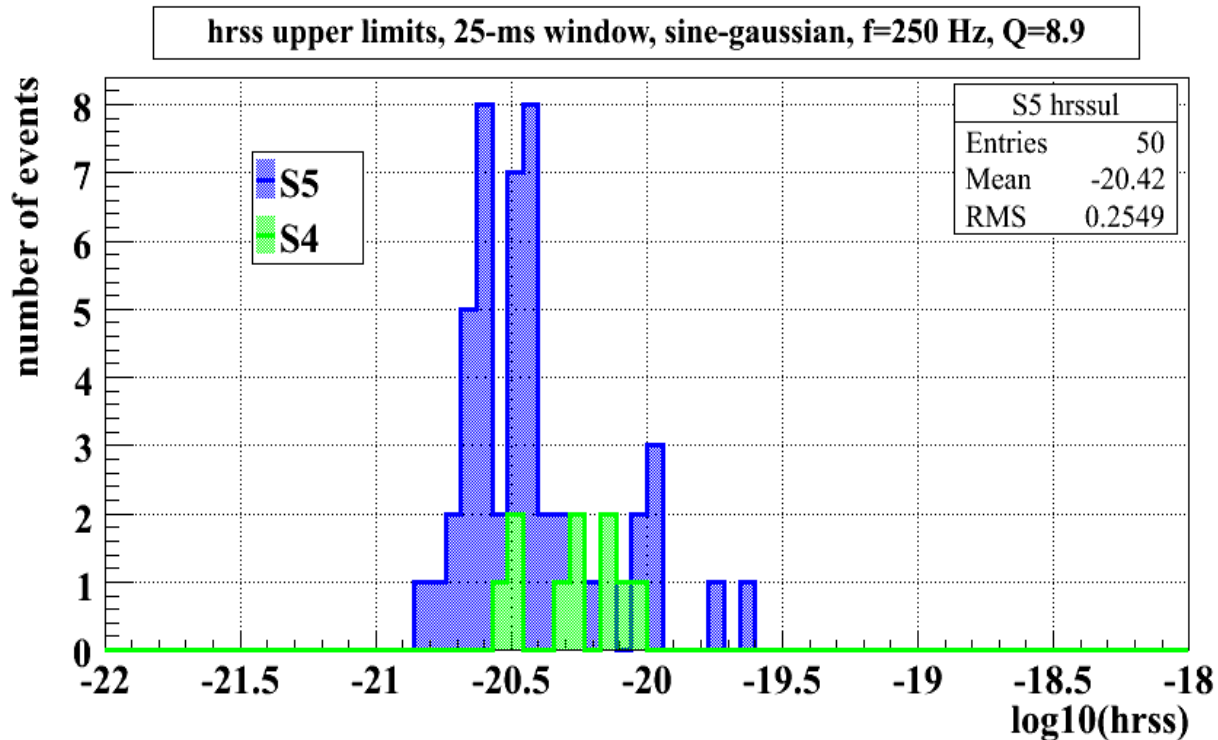
- ❖ Goal: One year of coincident science run at LIGO-1 design sensitivity
- ❖ currently ongoing
- ❖ commenced November 4, 2005

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## The GRB sample for LIGO S5 run

- ❖ 53 GRB triggers in 5 months of LIGO S5 run (as of April 10, 2006)
  - ❖ most from Swift
  - ❖ 16 triple-IFO coincidence
  - ❖ 31 double-IFO coincidence
  - ❖ 6 short-duration GRBs
  - ❖ 11 GRBs with redshift
    - ❖  $z = 6.6$ , farthest
    - ❖  $z = 0.0331$ , nearest
- ❖ performed GW burst search on this sample using same pipeline
  - ❖ No loud events seen that are inconsistent with expected probability distribution

# S5 GRB-GWB preliminary sensitivity: Upper limits on $h_{\text{rss}}$ at 250 Hz



- ❖ 90% UL on  $h_{\text{rss}}$
- ❖  $Q = 8.9$ ,  $f = 250$  Hz sine-gaussian
- ❖ S5 best  $h_{\text{rss}}$  (so far):

**1.5E-21 Hz<sup>-1/2</sup>**

# Relating $h_{rss}$ sensitivity to an astrophysical quantity

- ❖ Energy radiated by a source in gravitational waves:

$$E_{GW} \sim \frac{c^3}{G} D^2 f_c^2 h_{rss}^2$$

- ❖ We might expect to be sensitive to GW bursts out to a distance of:

$$D \sim 100 \text{ Mpc} \left( \frac{100 \text{ Hz}}{f_c} \right) \left( \frac{10^{-21} \text{ Hz}^{-1/2}}{h_{rss}} \right) \left( \frac{E_{GW}}{M_{\odot} c^2} \right)^{1/2}$$

factor depends on  
GW polarization,  
source position  
and orientation

S4:  $\sim 3\text{E-}21 \text{ Hz}^{-1/2}$   
S5:  $\sim 1.5\text{E-}21 \text{ Hz}^{-1/2}$

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## Summary

- ❖ We have performed a search for short-duration GW bursts associated with 39 GRBs detected by satellite experiments during dates of LIGO's S2, S3, and S4 runs
- ❖ We found no evidence for GW bursts associated with GRBs using this sample
- ❖ Using simulated sine-gaussian waveforms, we have estimated the search sensitivity and set 90% upper limits on the root-sum-square strain amplitude, with a **best  $h_{\text{rss}}$  limit for the S4 run of  $\approx 3.0\text{E-}21 \text{ Hz}^{-1/2}$  at 250 Hz**
- ❖ We are using the same method to search for GW bursts associated with GRBs detected by **Swift** (mostly) and other satellite experiments during LIGO's **ongoing S5 run**
- ❖ **The best S5 GRB-GWB sensitivity at 250 Hz, i.e. 90%  $h_{\text{rss}}$  upper limit, is  $\approx 1.5\text{E-}21 \text{ Hz}^{-1/2}$**