Search for Short-Duration GW Bursts Coincident with S2/S3/S4 Gamma-Ray Bursts

S5 GRB-GWB Search: First Results

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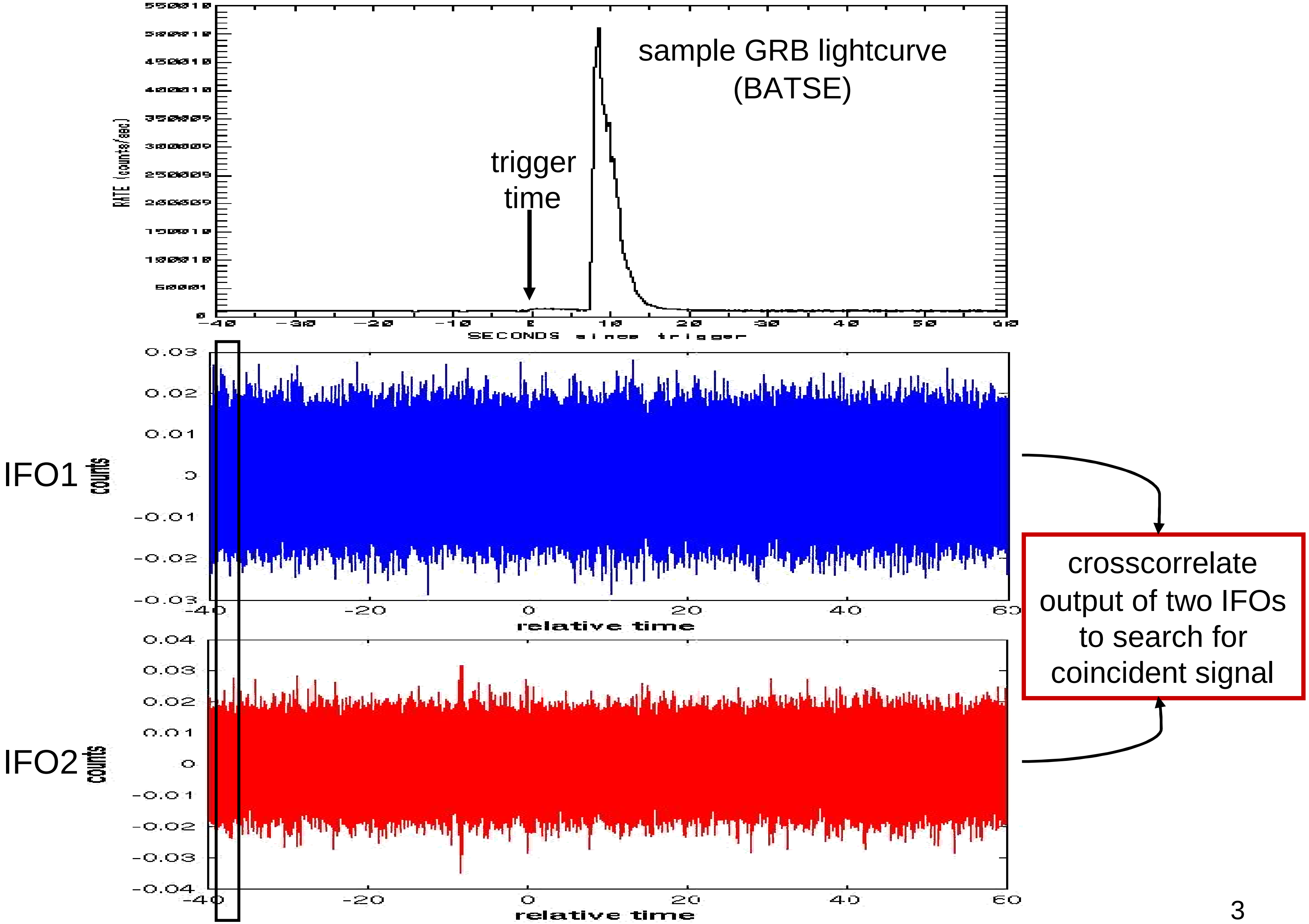
The S4/S3/S2 GRB Sample (after DQ cuts)

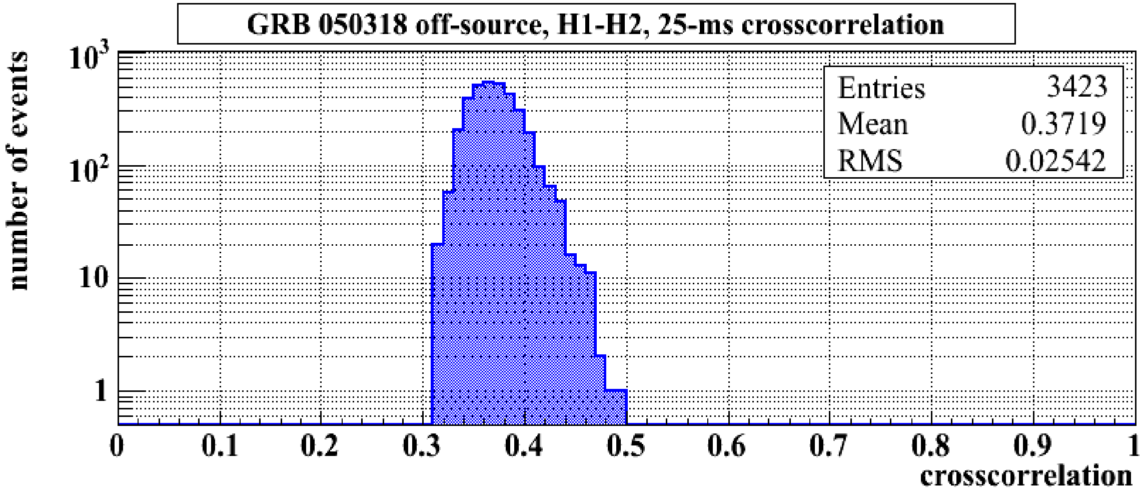
- **S4: 4 GRBs** with at least double coincidence
  - 4 for H1-H2
  - 3 for H1-L1
  - 3 for H2-L1
- **S3: 7 GRBs** with at least double coincidence
  - 7 for H1-H2
  - 0 for H1-L1
  - 0 for H2-L1
- **S2: 25 GRBs** with at least double coincidence
  - 21 for H1-H2
  - 8 for H1-L1
  - 8 for H2-L1
- only well-localized GRBs considered for H1-L1, H2-L1 search

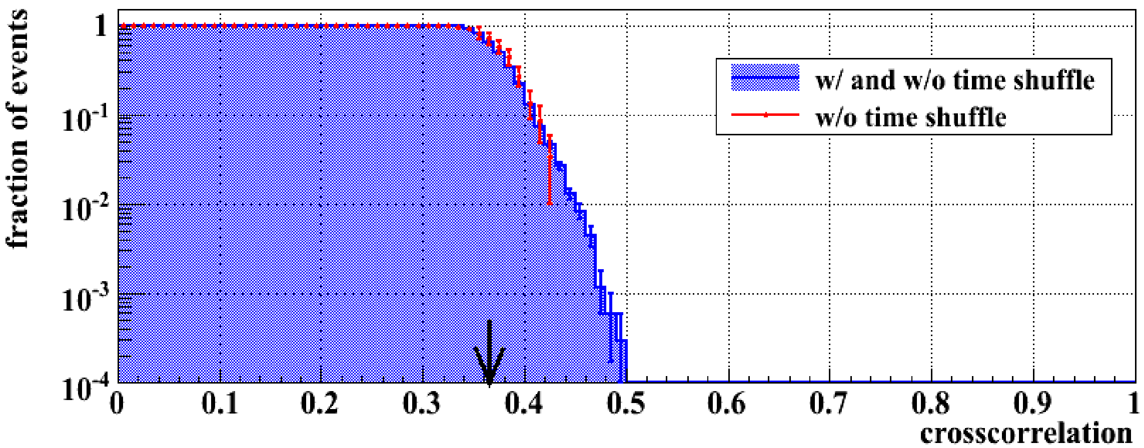

sample GRB lightcurve
(BATSE)
trigger
time
RATE (counts/sec)
SECONDS since trigger
IFO1
counts
relative time
IFO2
counts
relative time
crosscorrelate
output of two IFOs
to search for
coincident signal

Search method – crosscorrelation (targets short-duration bursts)

- each on-source search segment is 180-seconds long, 120 seconds before trigger time, 60 seconds after
- each 180-second segment conditioned (whitened, phase-calibrated, bandpassed)
- use crosscorrelation windows of lengths 25 ms and 100 ms each, windows overlapping by half a window length
- calculate normalized crosscorrelation for each 25-ms or 100-ms window
- find largest crosscorrelation within each 180-second on-source search segment for H1-H2; find largest abs(cc) for H1-L1 and H2-L1 due to unknown polarization

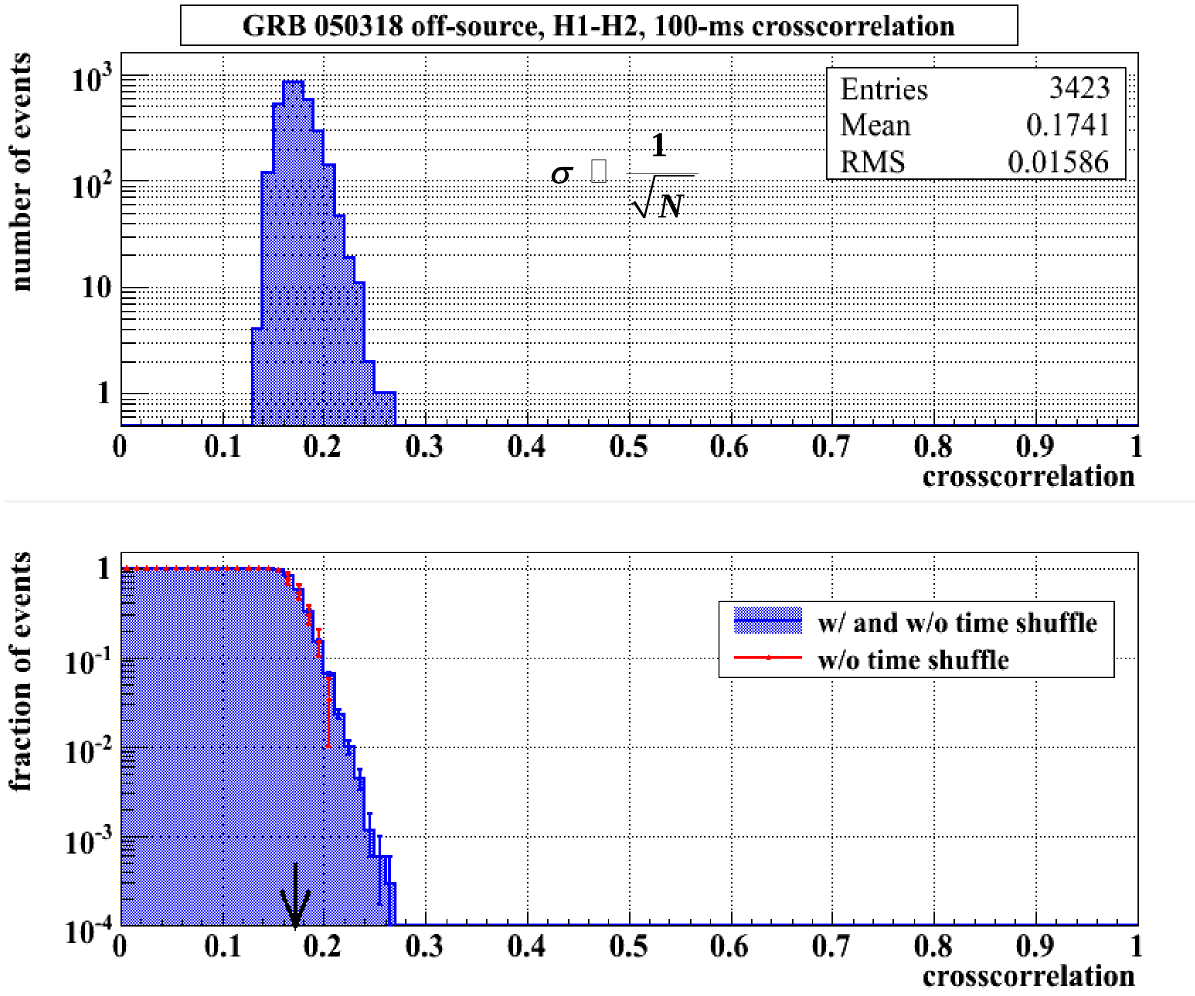
Estimating probability of measured on-source statistic: sample off-source distribution using 25-ms cc length





- local off-source distribution determined for each IFO pair for each GRB trigger
- distribution determined from searches within science segments occurring within a few hours of GRB trigger
- use time shifts to get enough statistics
- largest crosscorrelation found in on-source search indicated by black arrow
- probability is estimated using this distribution

Estimating probability of measured on-source statistic: sample off-source distribution using 100-ms cc length



- local off-source distribution determined for each IFO pair for each GRB trigger
- distribution determined from searches within science segments occurring within a few hours of GRB trigger
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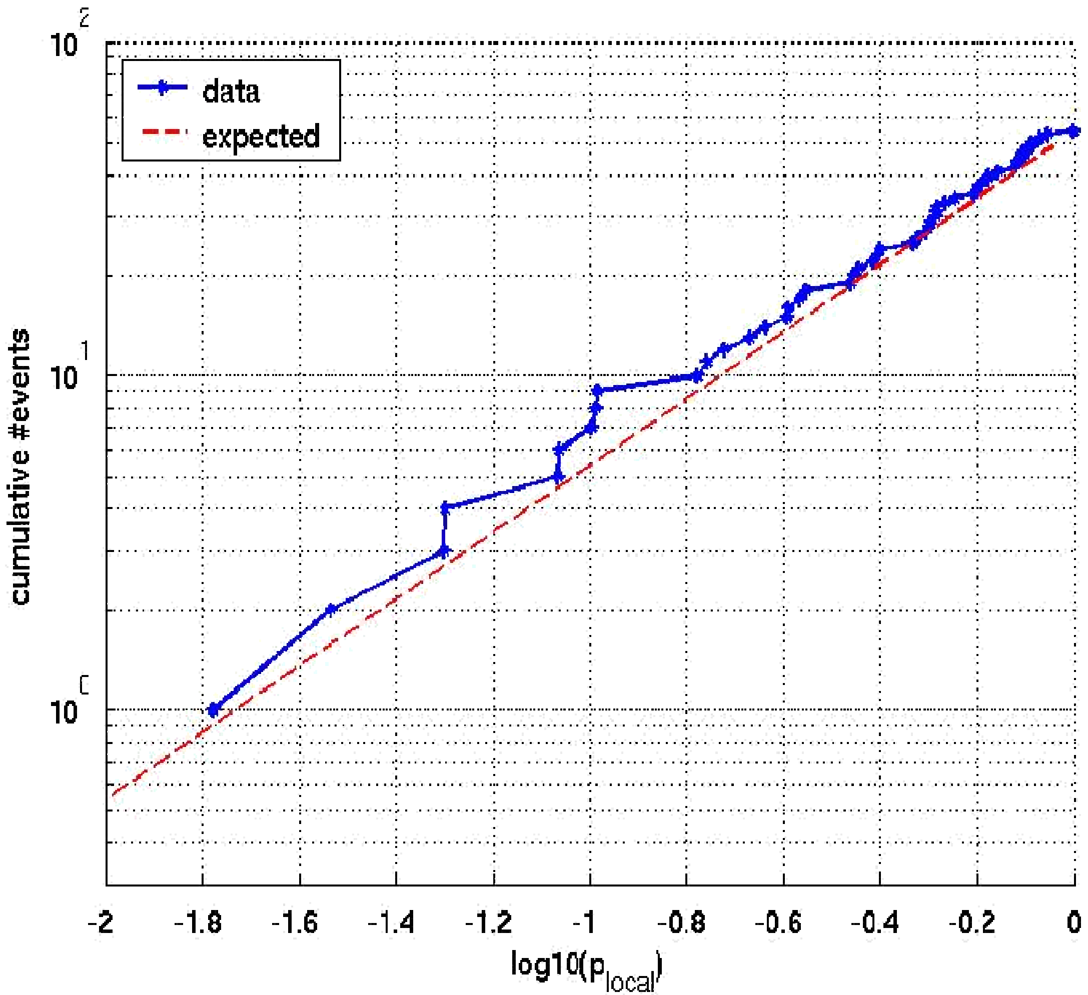
Results: Cumulative distribution of local probabilities

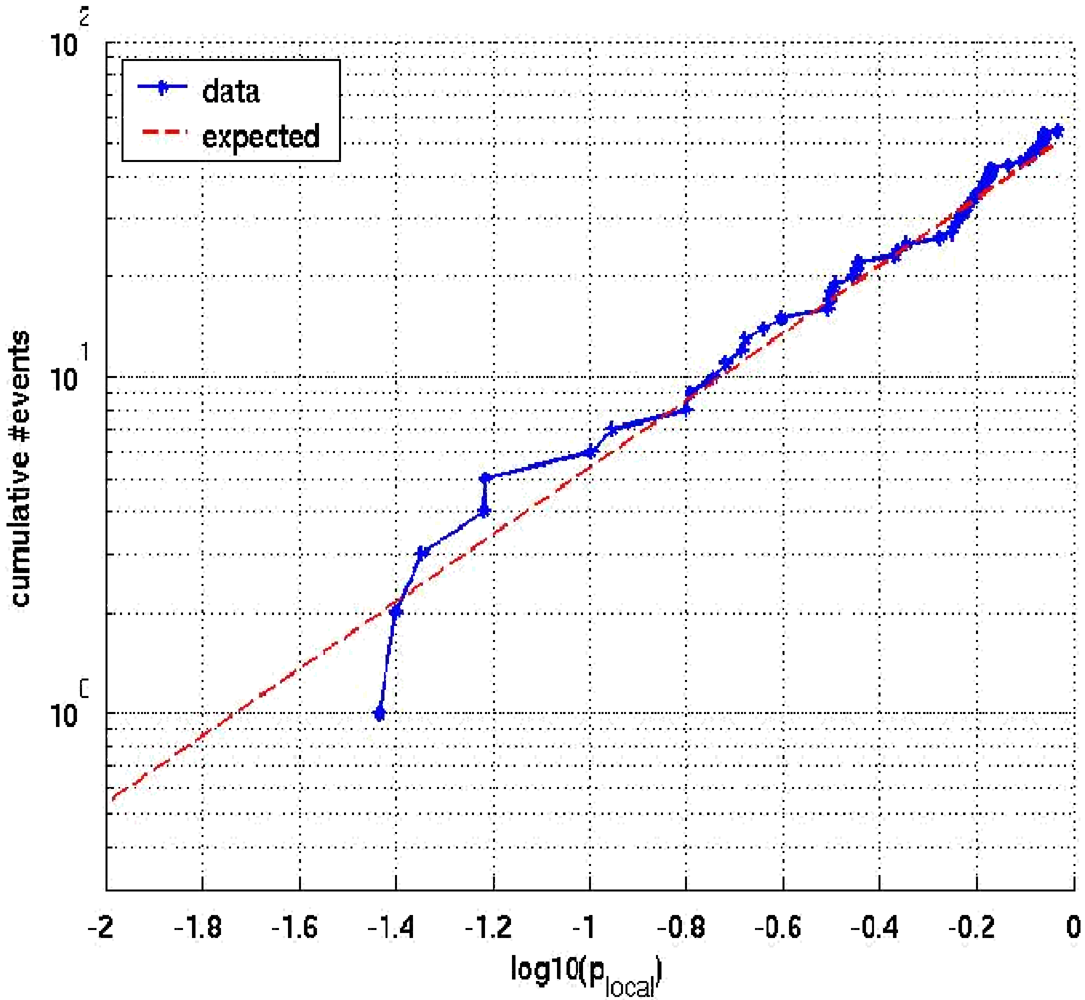
25-ms crosscorrelation length



- 54 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
- test this distribution against null hypothesis

Results: Cumulative distribution of local probabilities

100-ms crosscorrelation length



- 54 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
- test this distribution against null hypothesis

Statistical tests

- statistical search: search for weak signals which, individually, would not comprise a detection, but together could have a cumulative effect

- use binomial test to search local probability distribution for excess: probability for getting i or more events as least as significant as p:

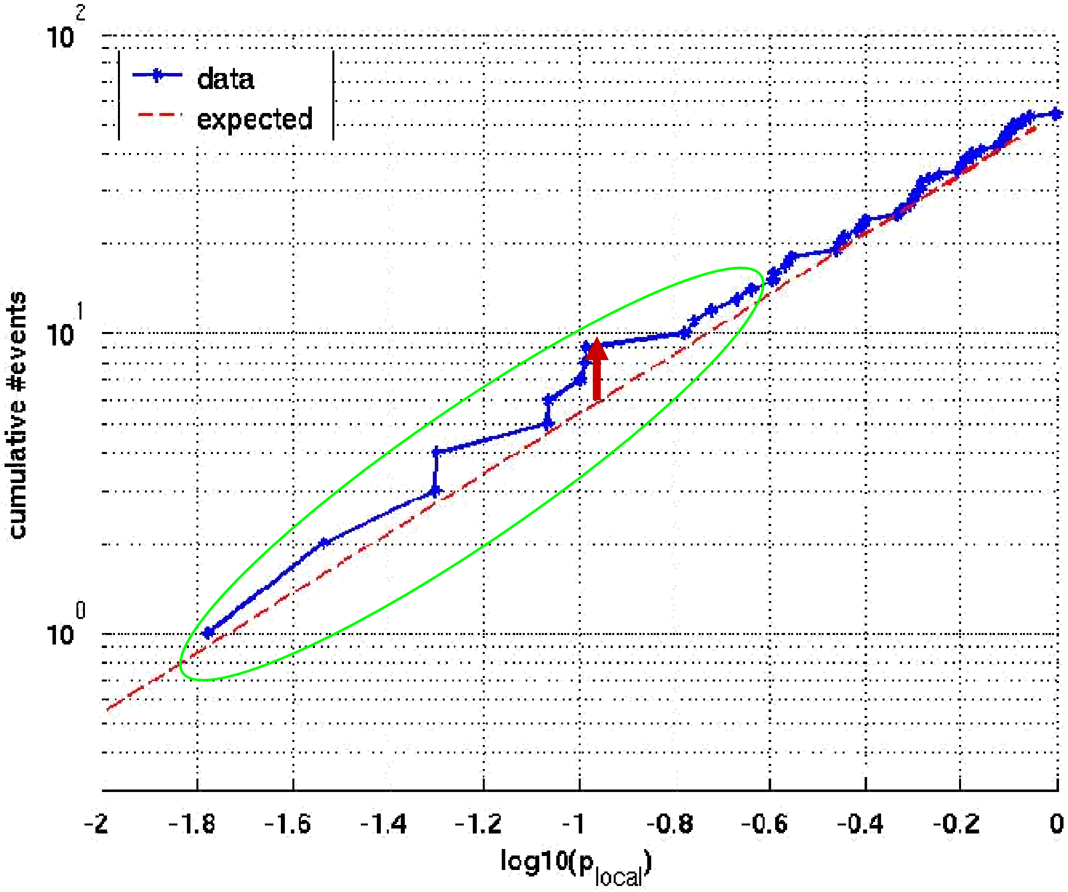
$$P_{\geq i}(p) = P_i(p) + P_{i+1}(p) + P_{i+2}(p) + \ldots$$

$$P_i(p) = \frac{N!}{i!(N-i)!} p^i (1-p)^{N-i}$$

- $P_i(p)$ gives probability for observing i events at least as significant as p in N searches (i.e. number of on-source measurements)
- for a single loud event, $P_{\geq 1}(p) = Np$, for $p \ll 1$

- ranksum test: test if medians of on-source crosscorrelation distribution and off-source crosscorrelation distribution are consistent with each other

Testing the tail of a probability distribution:
25-ms crosscorrelation length

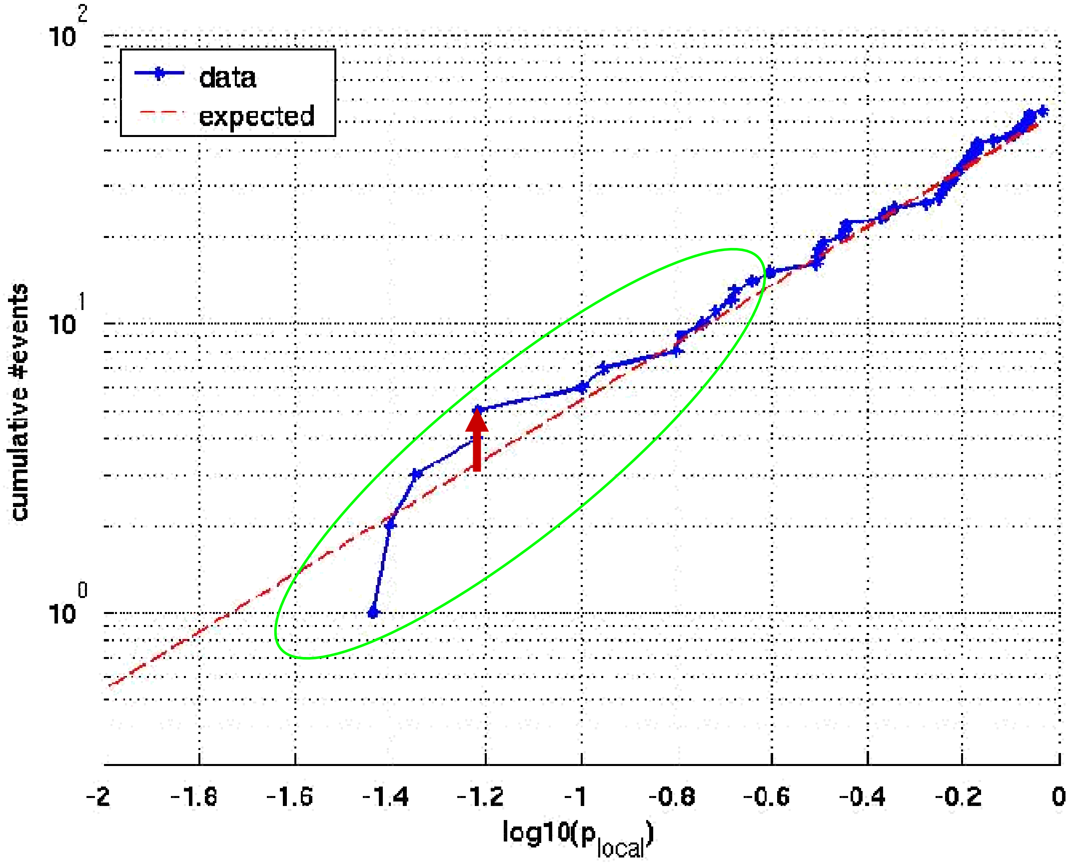


search 25% of distribution
(14 most significant events)

the binomial test finds the most significant excess in the tail of the distribution to be 9 events with $p \leq 0.1036$

binomial probability
$P_{\geq 9}\,(p_9) = 0.102$

Testing the tail of a probability distribution:
100-ms crosscorrelation length

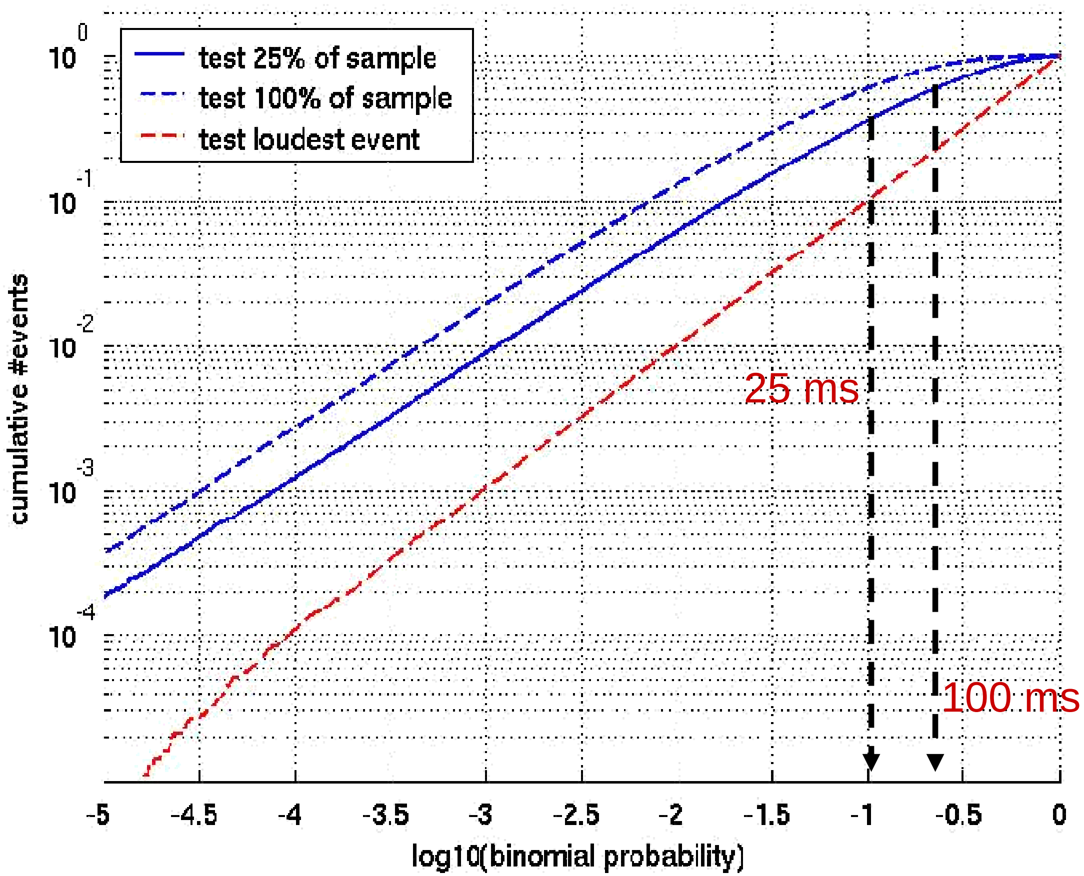


search 25% of distribution
(14 most significant events)

the binomial test finds the most significant excess in the tail of the distribution to be 5 events with p ≤ 0.0608

binomial probability
$P_{\geq 5}(p_5) = 0.230$

Distribution of binomial probability statistic under null hypothesis



- simulate probabilities using randomly-generated numbers from 0 to 1
- use same method to examine tail of each trial
- takes into account trials in searching the tail
- significance of measured statistic, $P_{\geq 9}(p_9)$ = 0.102

≈ 0.35 ,   25-ms window

i.e. under null hypothesis, **1 in 3** sets of 54 probabilities will result in $P \leq$ 0.102

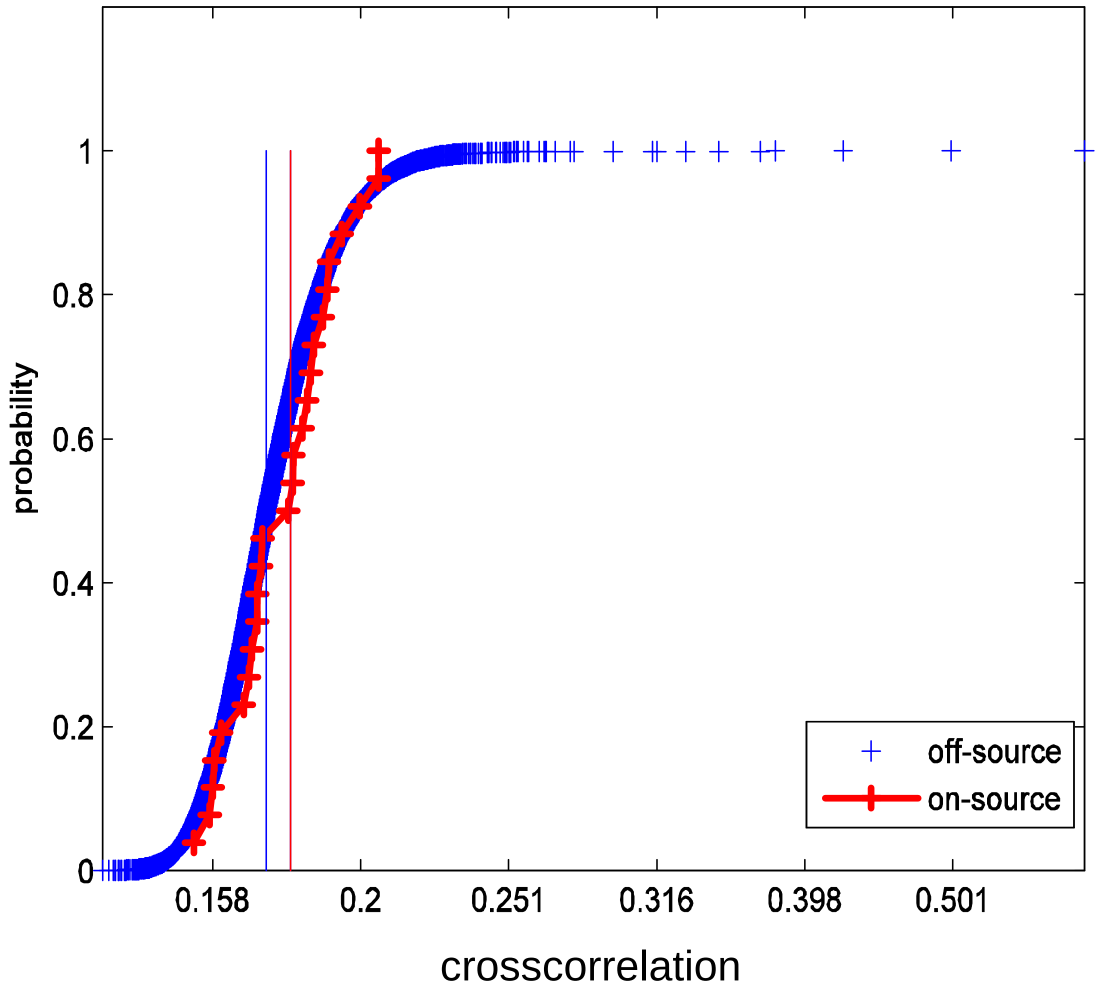
- $P_{\geq 5}(p_5)$ = 0.230

≈ 0.6 ,   100-ms window

i.e. **1 in 1.7** sets of 54 probabilities

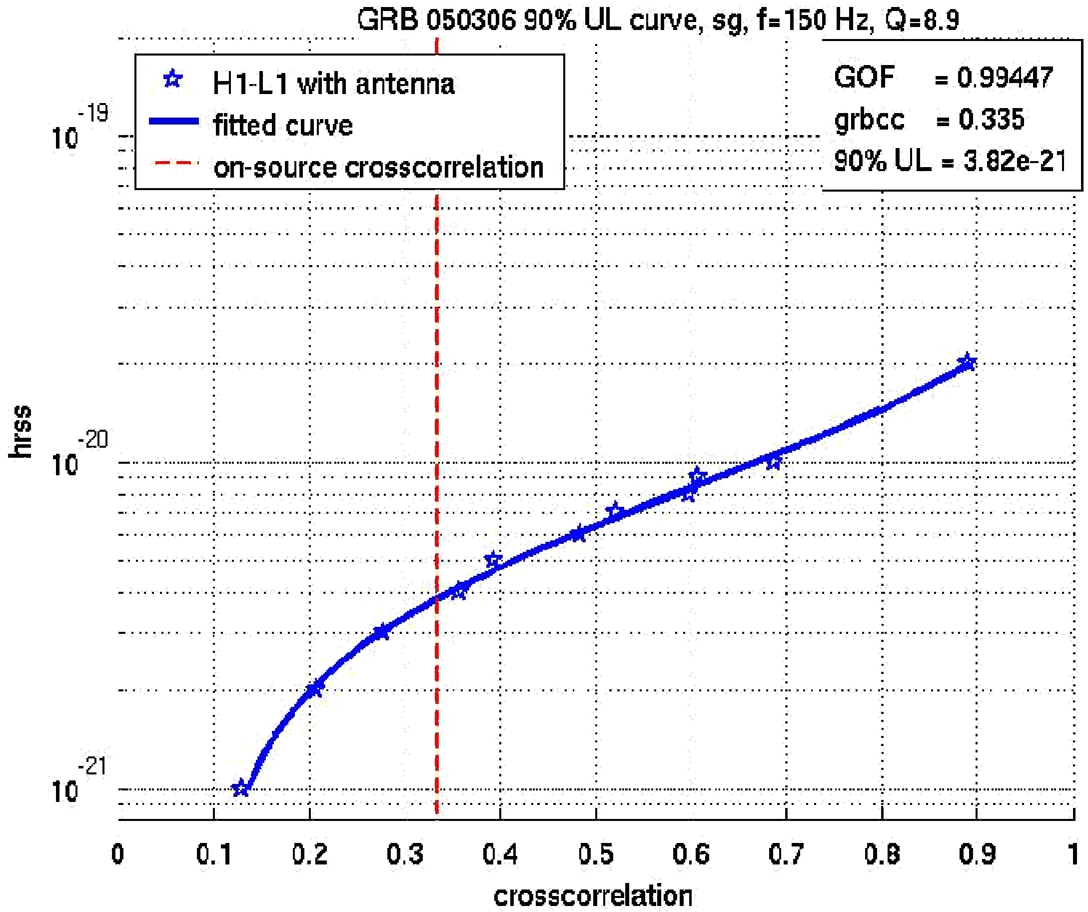
- both consistent with null hypothesis

Ranksum test



- compare medians of on-source and off-source crosscorrelation distributions
- significance under null hypothesis is 0.22

Setting hrss upper limits : GRB 050306 (example)



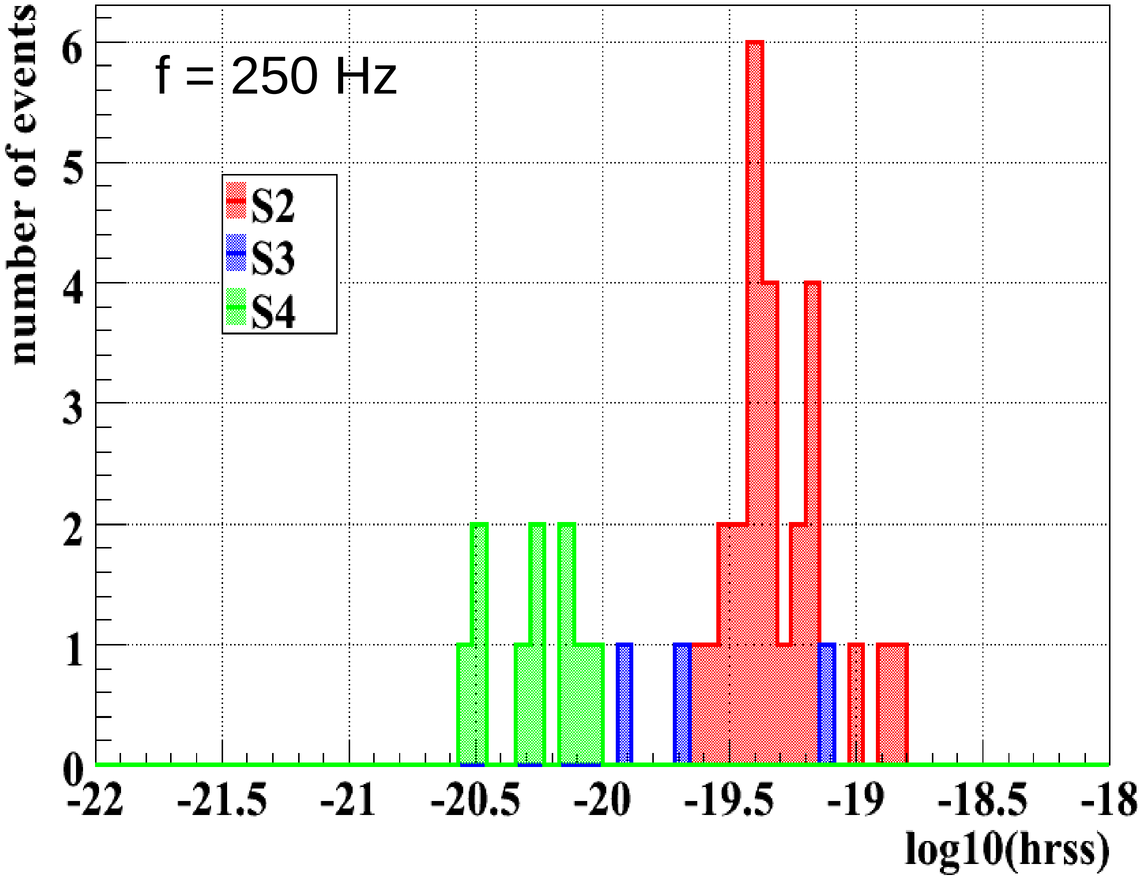
- injected signal:

$$h(t) = F_+(\theta,\Phi,\Psi)h_+(t)$$

- source position (θ,Φ) is known
- Ψ is unknown ➔ use random values for injections
- upper limits are on hrss of $h_+(t)$
- used standard recipe for constructing (frequentist) upper limit curves
- used maximum cc value found in on-source segment to get upper limit (different for each IFO pair)

e.g. 3.8e-21 for H1-L1 (90%)

S2/S3/S4 hrss upper limits for sine-gaussians, Q = 8.9



- S4 best hrss limit (150 Hz):
  - **2.6E-21 Hz$^{-1/2}$**
- S3 best hrss limit (150 Hz):
  - **1.2E-20 Hz$^{-1/2}$**
- S2 best hrss limit (250 Hz):
  - **2.6E-20 Hz$^{-1/2}$**

Relating hrss sensitivity to an astrophysical quantity

- Energy radiated in GW:

$$E_{GW} = Mc^2 \propto D_L^{\,2} h_{rss}^{\,2}$$

- If there is a nearby GRB trigger…

For example, at distance of GRB with smallest measured redshift: z = 0.0084, D_L = 35 Mpc (GRB 980425/SN1998bw), an S4 hrss sensitivity of 3E-21 Hz$^{-1/2}$ for 250-Hz, Q=8.9 sine-gaussian, will correspond to an energy release in GW of

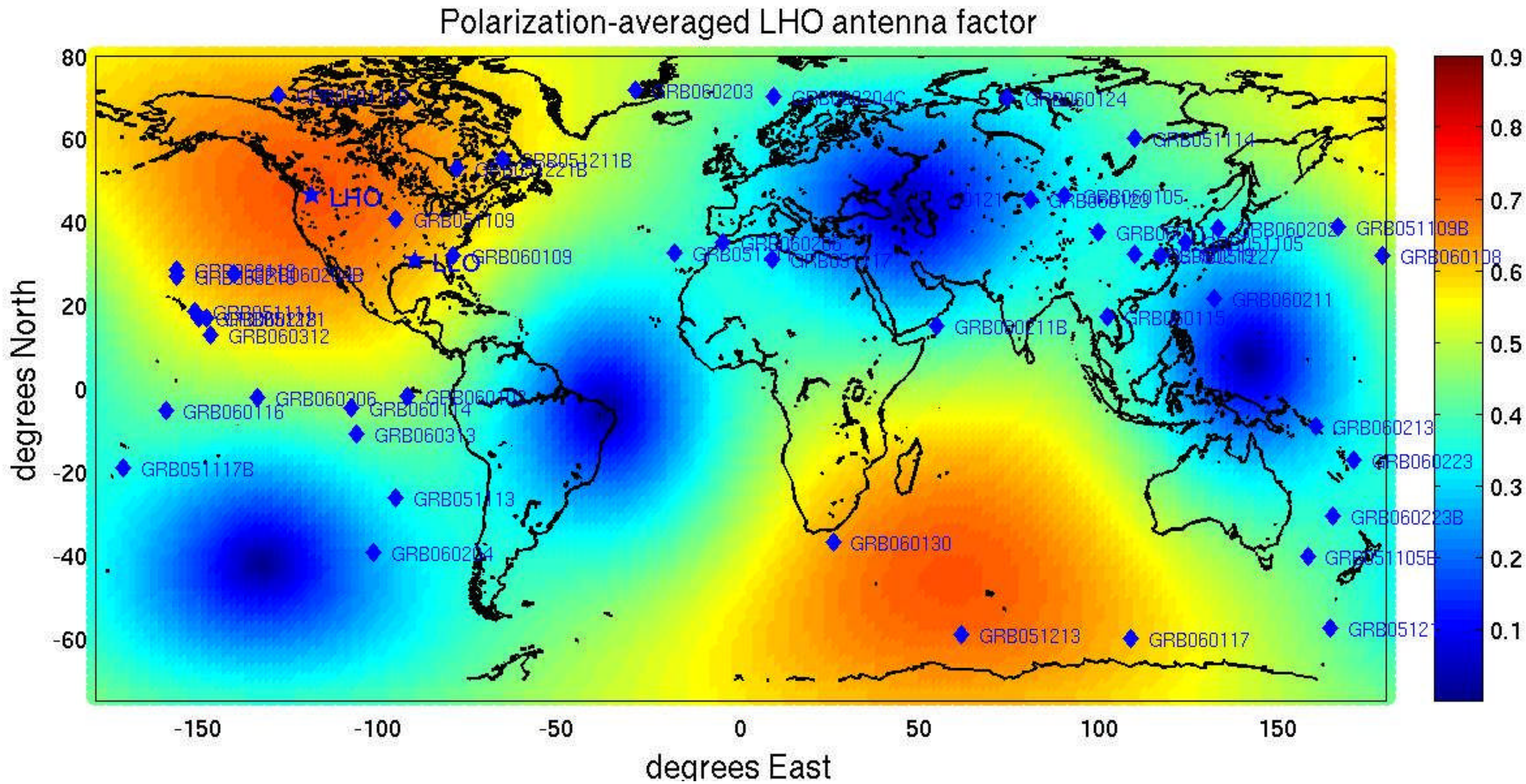
$$M \sim 10\, M_{\odot} \quad \text{at 35 Mpc}$$

or

$$M \sim 1\, M_{\odot} \quad \text{at 11 Mpc}$$

S5 GRB-GWB Search: First Results

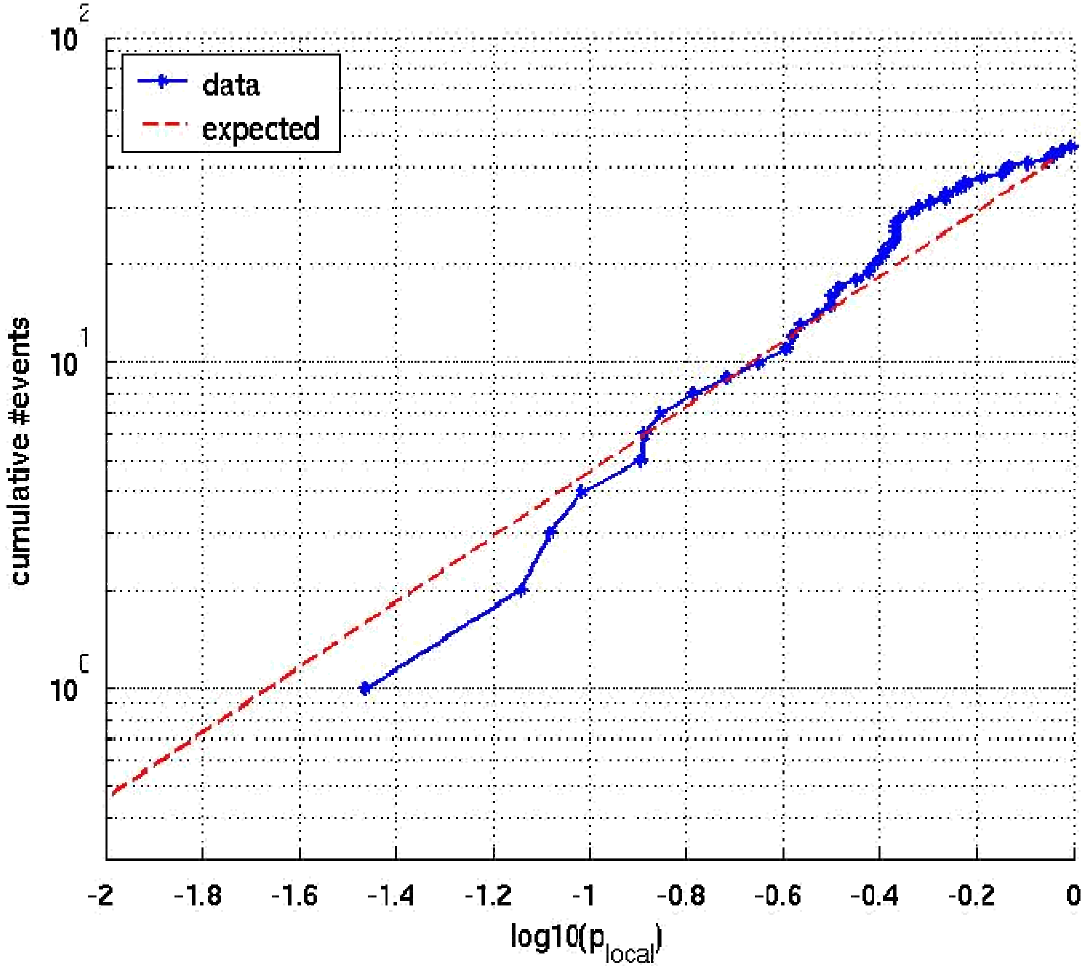
Positions of GRBs in local sky



Stats

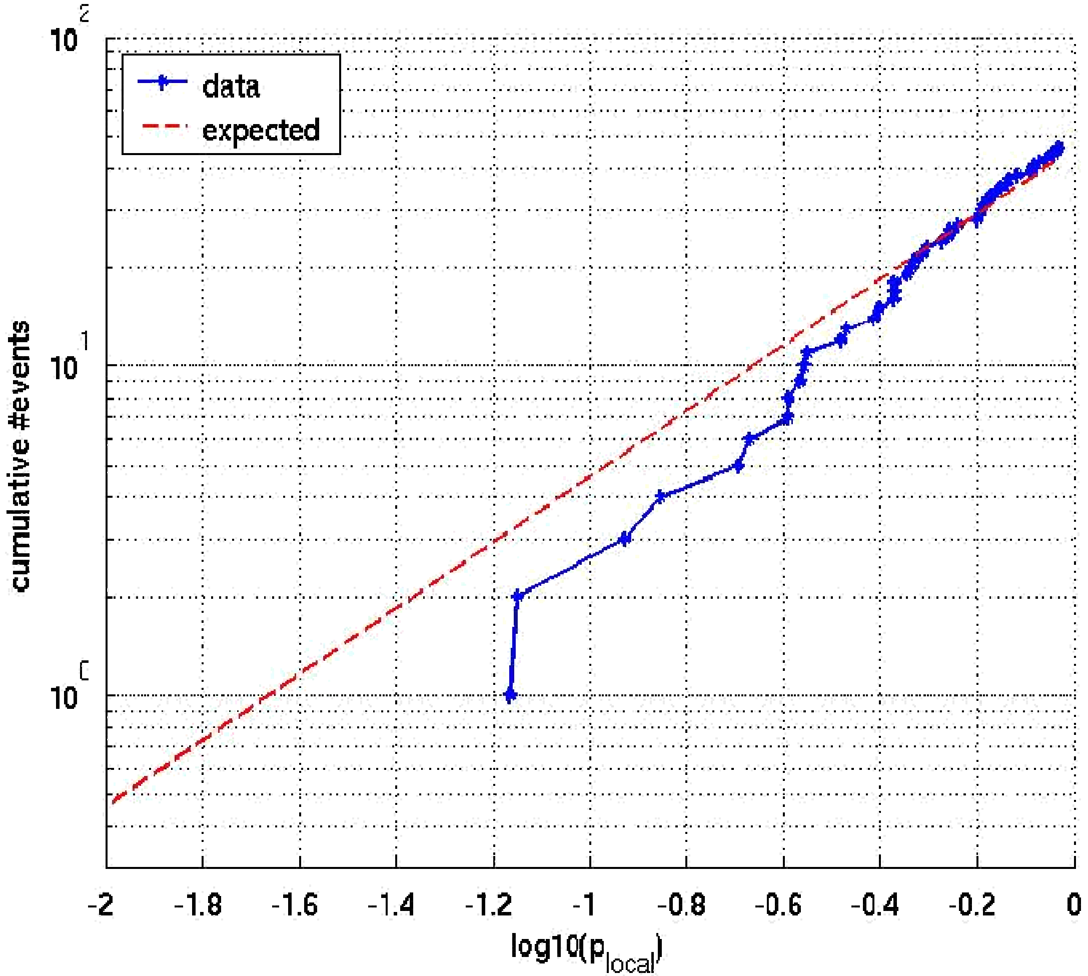
- 50 GRB triggers in 4.5 months (as of today)
  - **most from Swift**
  - **rate right on target! ~10 GRBs per month**
  - **16 triple-coincidence**
  - **28 double-coincidence**
    - **26 H1-H2**
    - **17 H1-L1**
    - **17 H2-L1**
  - **6 short-duration GRBs**
  - **11 GRBs with redshift**
    - **z = 6.6, farthest**
    - **z = 0.0331, nearest**

S5 cumulative distribution of local probabilities: 25-ms crosscorrelation length (no DQ cuts!)



- cut GRBs with z > 0.5
- 46 on-source segments
- no loud events; no excess at tail
- "bump" at low probabilities
- statistics?
- detector artefact?
- will DQ cuts make this disappear?
- binomial probability is ~7E-3
- significance under null hypothesis is ~1E-2

S5 cumulative distribution of local probabilities: 100-ms crosscorrelation length (no DQ cuts!)

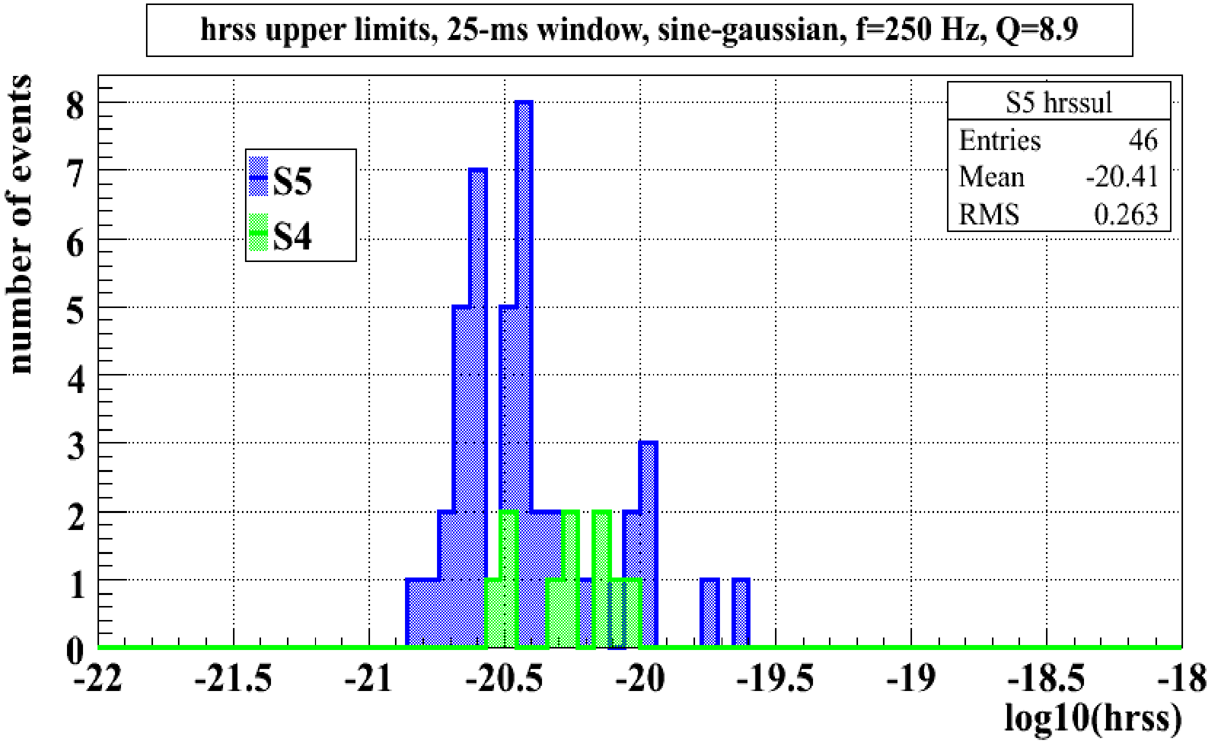


- "bump" not seen here
- no loud events
- no excess at tail

S5 GRB-GWB Search

- No loud events seen that are inconsistent with expected probability distribution

S5 upper limits on hrss



- 90% UL on hrss
- Q=8.9, f=250 Hz sine-gaussian
- S5 best hrss (so far): 1.5E-21 $Hz^{-1/2}$
- S5 peak hrss: 3.2E-21 $Hz^{-1/2}$
- S5 mean hrss: 3.9E-21 $Hz^{-1/2}$

$M \sim 3M_{\odot}$ at 35 Mpc

$M \sim 1M_{\odot}$ at 20 Mpc

Online pages

- S5 GRB triggers list:

  http://www.uoregon.edu/~ileonor/ligo/s5/grb/online/S5grbs_list.html

- S5 preliminary GRB-GWB search results (no DQ cuts):

  http://ldas-jobs.ligo-wa.caltech.edu/~grbxcorr/ligo/s5/grb/online/search/S5grbs_search.html