Searching for GRB-GWB coincidence during LIGO science runs

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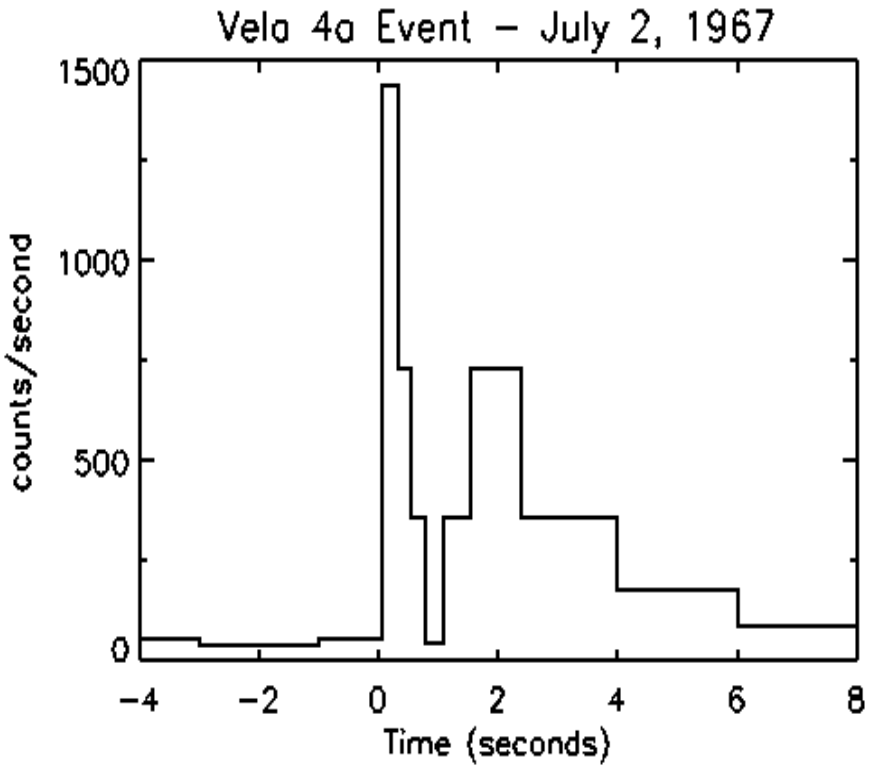
Motivation

- almost 40 years since GRBs were discovered
- past 15 years has been time of important “clues”
- isotropic and inhomogeneous distribution (BATSE); first optical, x-ray, radio counterparts; redshift measurements; association with core-collapse supernovae
- yet important questions remain as to origin, engine
- detection of coincident gravitational-waves would provide important information

The first GRB detected
(Klebesadel, Strong, Olson)



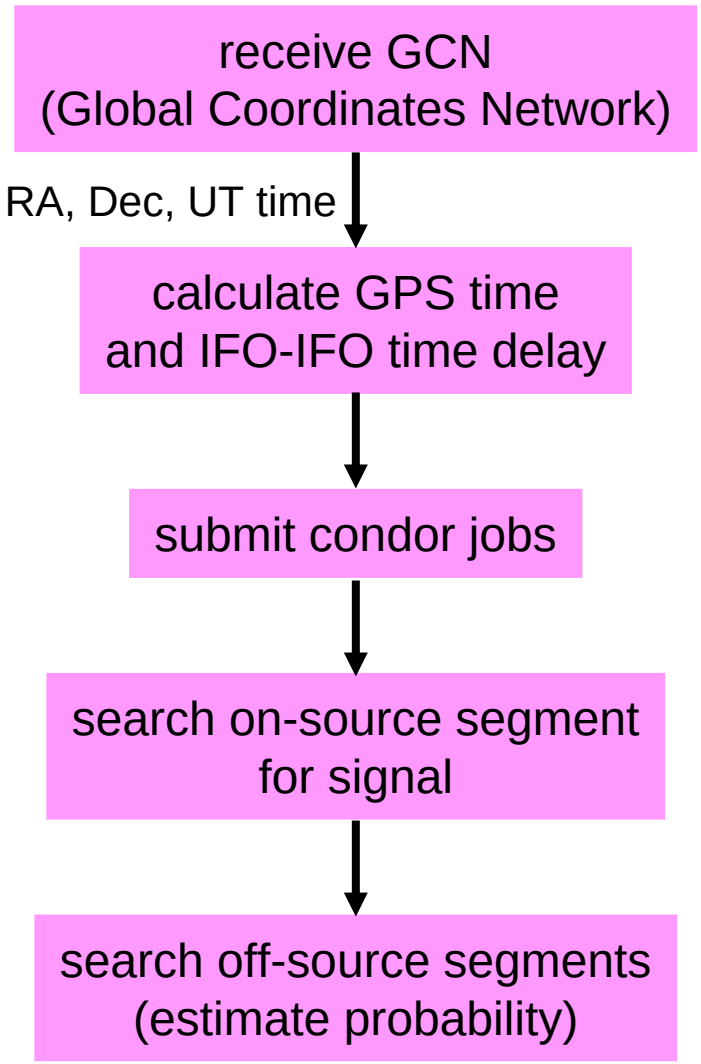
Motivation

- take advantage of readily-available and readily-accessible GRB triggers
  - some GRBs with measured redshifts z ~ 1, but most GRBs don't have measured redshifts
  - reduces trials of search
- use definite GRBs as triggers
- triggers are from Swift, HETE, INTEGRAL, others
- search optimized for short-duration GW bursts
  - ~1 to ~10 ms, e.g. supernova core-collapse models, late stage of inspiral mergers

Motivation

- Swift is up and running – ***"catching GRBs on the fly"***
  - "first GRB light" on December 17, 2004
  - has detected 23 GRBs since then
  - expected average rate of >100 GRBs per year
- prepare for S5 run
  - one year of coincident S5 run => ~100 GRB triggers
  - more triggers means nearby GRB triggers more likely

Sequence of events for search (new for S4)



TITLE: GCN GRB OBSERVATION REPORT
NUMBER: 3117
SUBJECT: Swift Detection of GRB 050319
DATE: 05/03/19 10:42:25 GMT
FROM: Hans Krimm at NASA-GSFC <krimm@milkyway.gsfc.nasa.gov>

Swift Detection of GRB 050319

H. Krimm (GSFC/USRA), M. Still (GSFC/USRA), S. Barthelmy, L. Barbier (GSFC), S. Campana (INAF-OAB), M. Capalbi (ASDC), M. Chester (PSU), J. Cummings (GSFC/NRC), E. Fenimore (LANL), N. Gehrels (GSFC), M. R. Goad, O. Godet (U.Leicester), J. Greiner (MPE), D. Grupe (PSU), D. Hullinger (GSFC/UMD), V. La Parola , V. Mangano (INAF-IASF/Palermo), C. Markwardt (GSFC/UMD), P. Meszaros, D. C. Morris, J. A. Nousek (PSU), K. Page (U.Leicester), D. Palmer (LANL), A. Parsons (GSFC), T. Sakamoto (GSFC/NRC), G. Sato (ISAS), M. Suzuki (Saitama), G.Tagliaferri (INAF-OAB), J. Tueller (GSFC)
report on behalf of the Swift-BAT and Swift-XRT teams:

At 09:31:18.44 UT, the Swift Burst Alert Telescope (BAT) triggered and located on-board GRB 050319. The burst was 37 degrees off the BAT boresight. The spacecraft executed an immediate slew and was on target by 09:32:45.53 UT at which time the XRT began taking data in Auto State. On-board software recognized a bright source at location

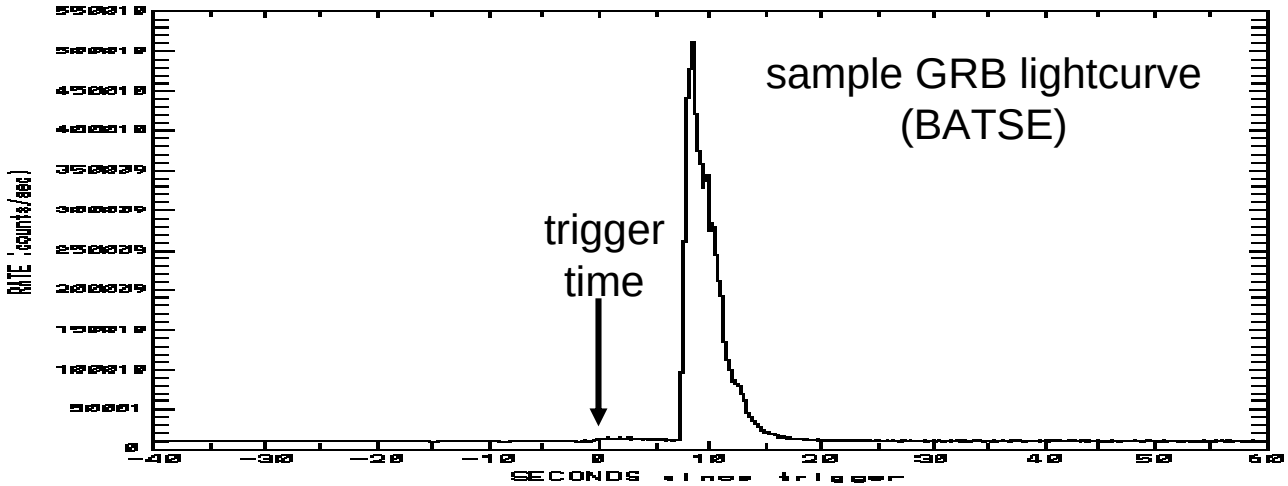
RA 154.2016d {+10h 16m 48s} (J2000),
Dec +43.5463d {+43d 32' 47"} (J2000)

We estimate an uncertainty of 7 arcseconds.

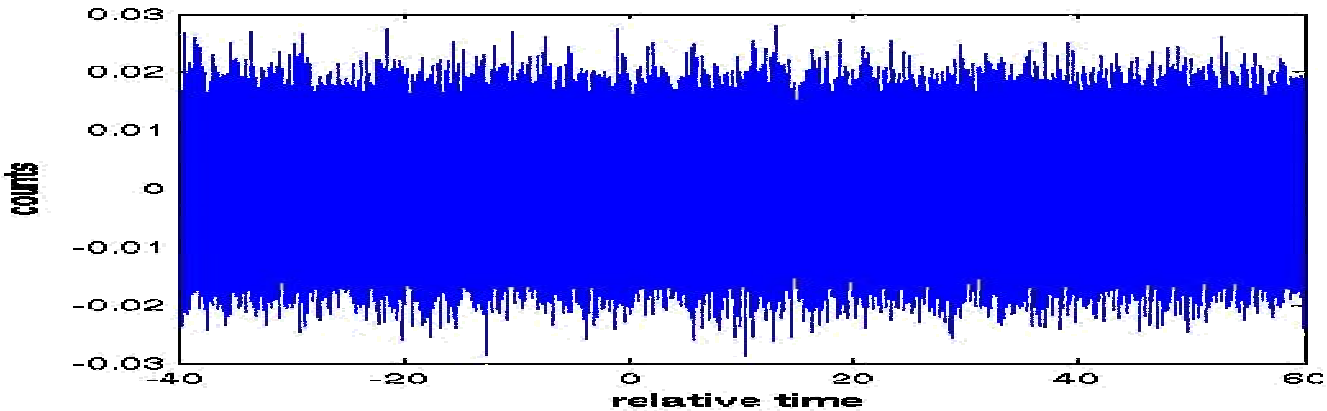
The burst lightcurve as seen in the BAT has a single peak with a fast rise, exponential decay. The estimated duration is 15 seconds. The peak count rate is 2,000 counts/second (15-350 KeV)

Search method -- crosscorrelation

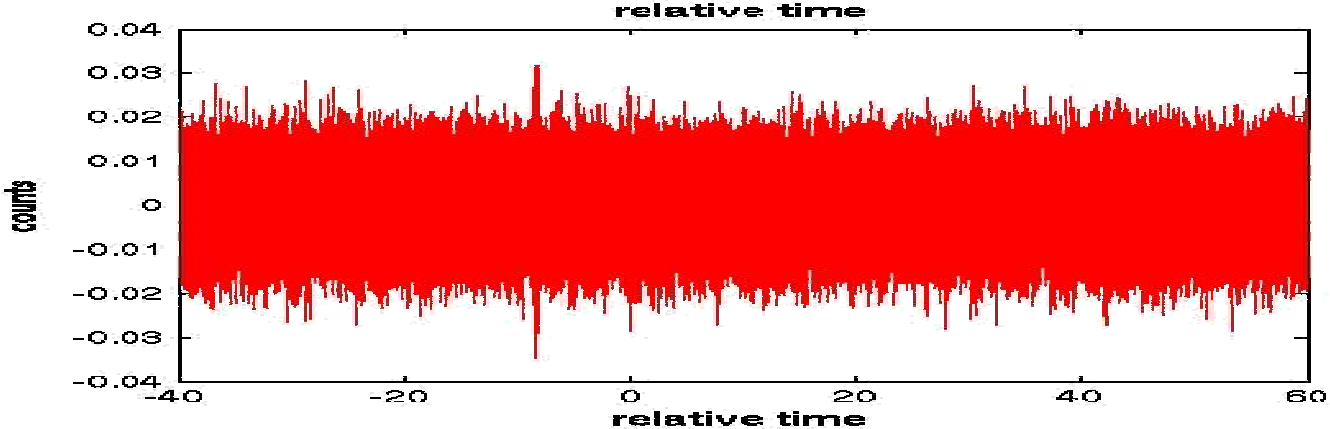
- each search segment is 180-seconds long, centered on GRB trigger time (less ~1.5 seconds at ends of segment)
- each 180-second segment conditioned (whitened and calibrated)
- use crosscorrelation windows of length 25 ms each, windows overlapping by half a window length
- calculate normalized crosscorrelation for each 25-ms second
- find largest crosscorrelation within each 180-second search segment, for H1-H2; find largest abs(cc) for H1-L1 and H2-L1 due to unknown polarization


sample GRB lightcurve
(BATSE)
trigger
time
RATE (counts/sec)
SECONDS since trigger

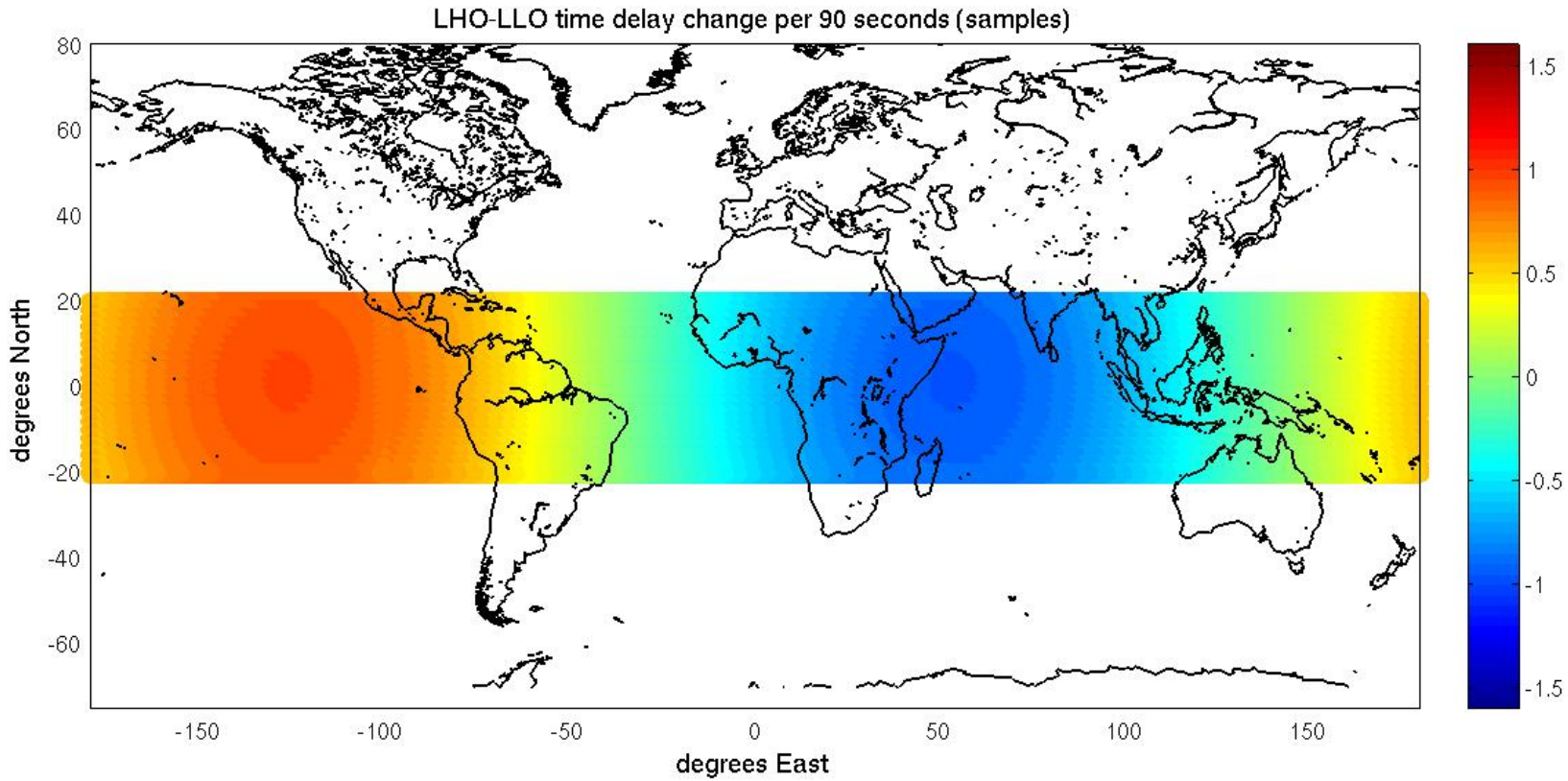
H1


counts
relative time

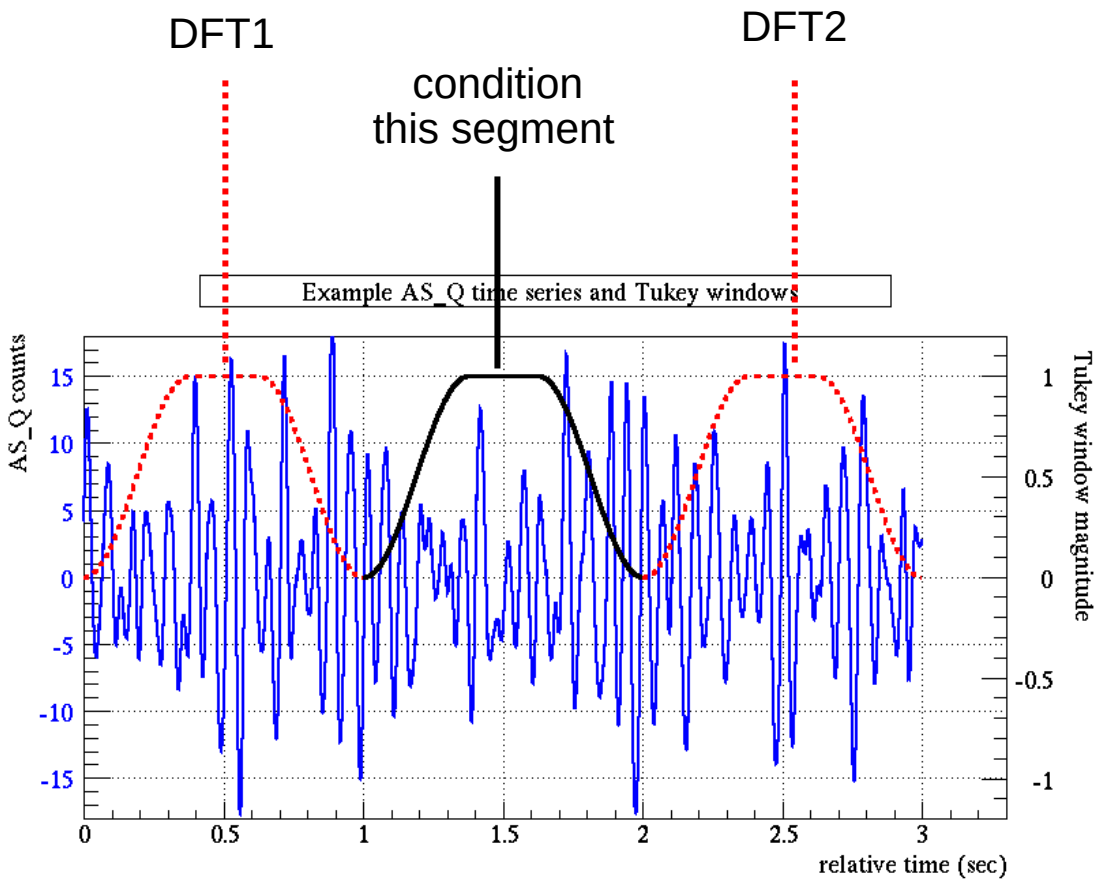
H2


counts
relative time

Time-of-flight delay change during on-source search

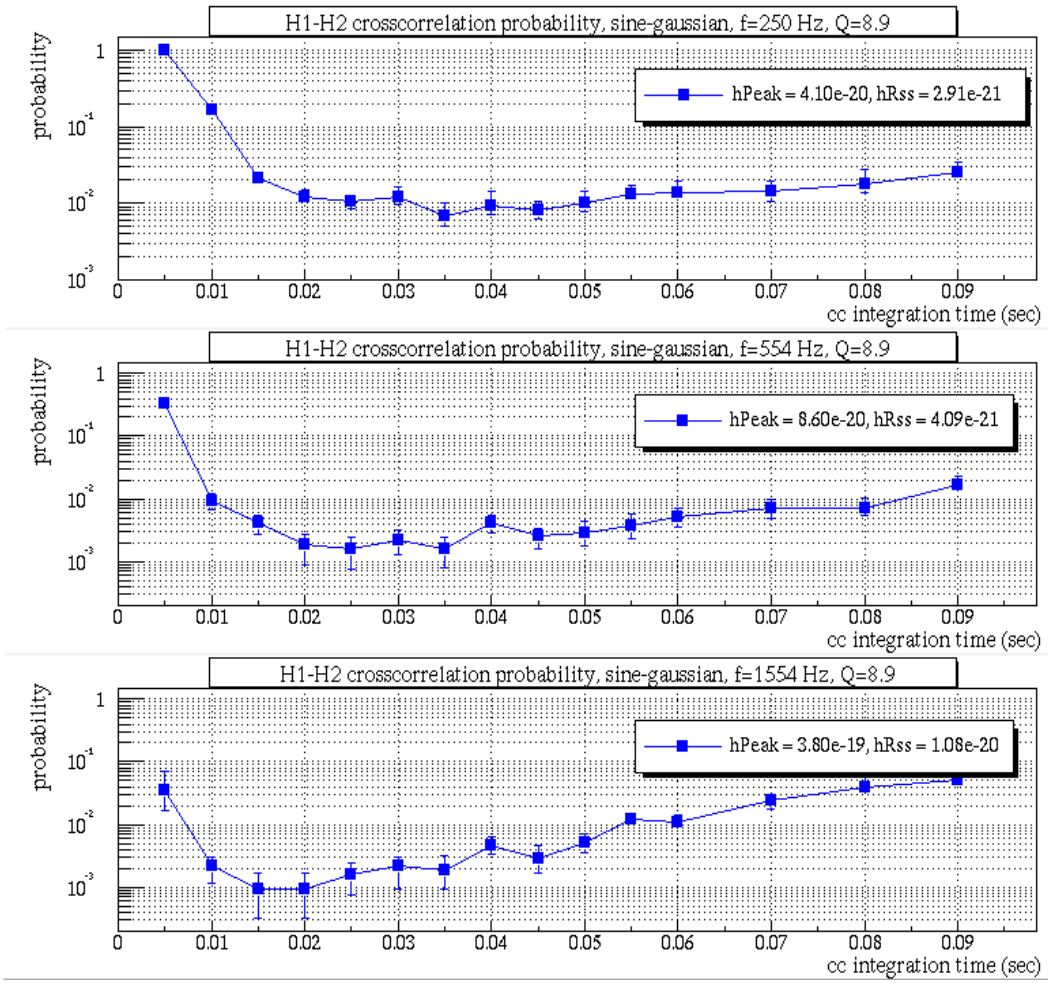


Data conditioning – whitening and phase correction



- data conditioning done in frequency domain
- data DFTed using 1-second Tukey windows
- adjacent 1-sec segments DFTed to determine factor for whitening in frequency domain
- whitening factor(f) = max(DFT1(f),DFT2(f))
- use phase calibration to correct signal phase

False alarm probability vs. integration length for short duration signals (~1 – ~10 ms)



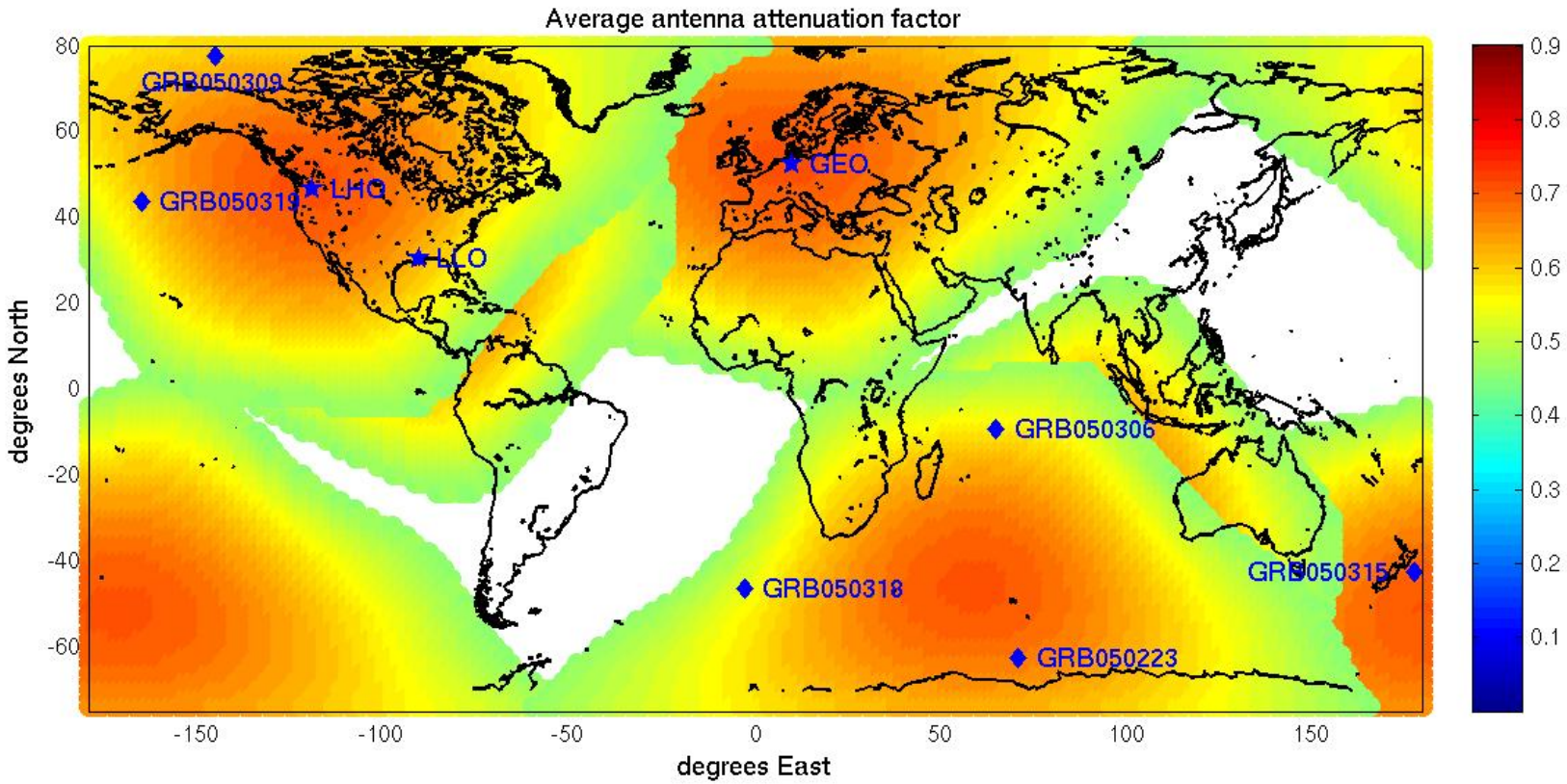
- probability for getting median of simulated on-source distribution, given off-source distribution
- probability takes into account trials in search
- probability is function of length of crosscorrelation window
- small window: 1/sqrt(N); more trials
- large window: more noise integrated

The S4/S3/S2 GRB Samples

- **S4: 6 GRBs** with at least double coincidence (2 with redshift)
  - 4 for H1-H2
  - 3 for H1-L1
  - 3 for H2-L1
- **S3: 11 GRBs** with at least double coincidence (0 with redshift)
  - 11 for H1-H2
  - 1 for H1-L1
  - 1 for H2-L1
- **S2: 29 GRBs** with at least double coincidence (3 with redshift)
  - 23 for H1-H2
  - 7 for H1-L1
  - 7 for H2-L1
- only well-localized GRBs considered for H1-L1, H2-L1 search

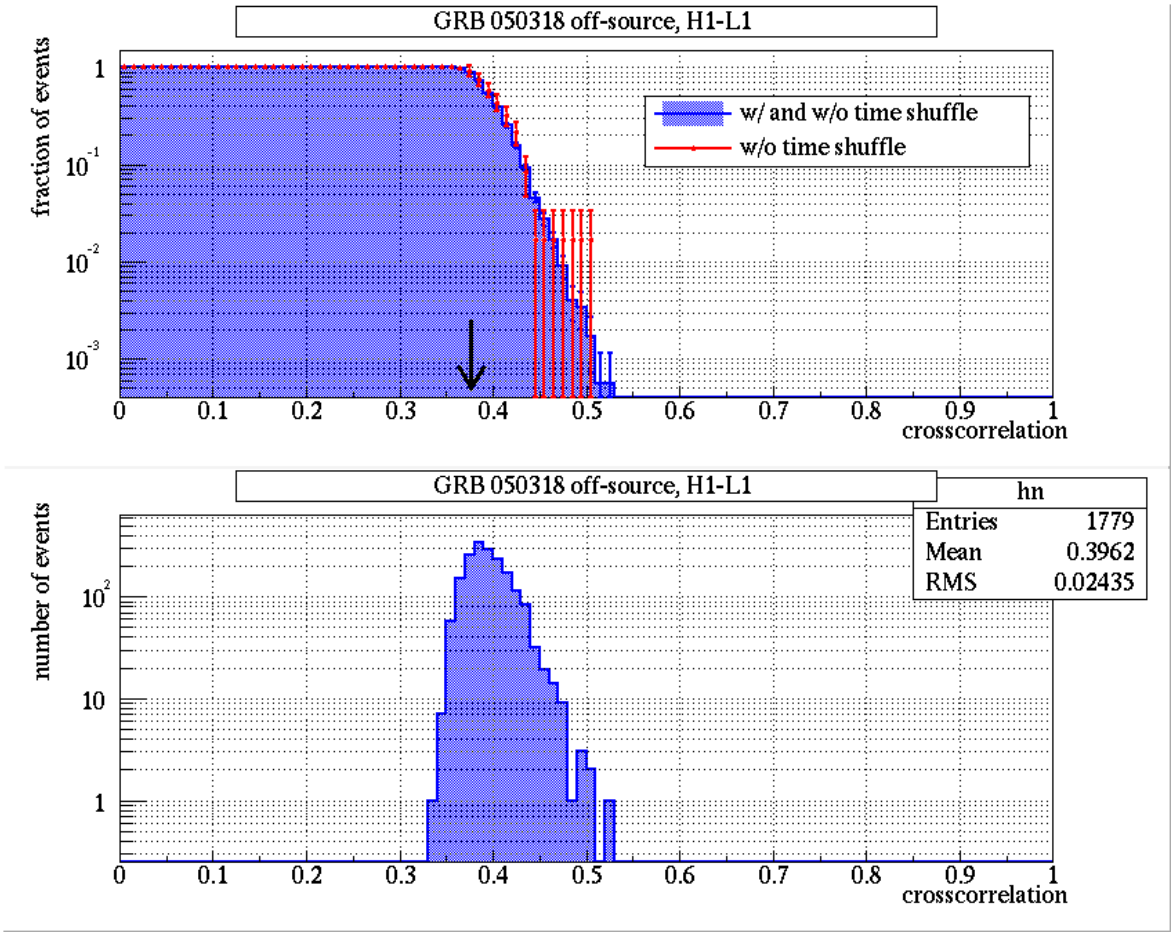
GRB Local Map for S4

$$\sqrt{\langle F_+^2 \rangle} = \sqrt{\langle F_\times^2 \rangle}$$



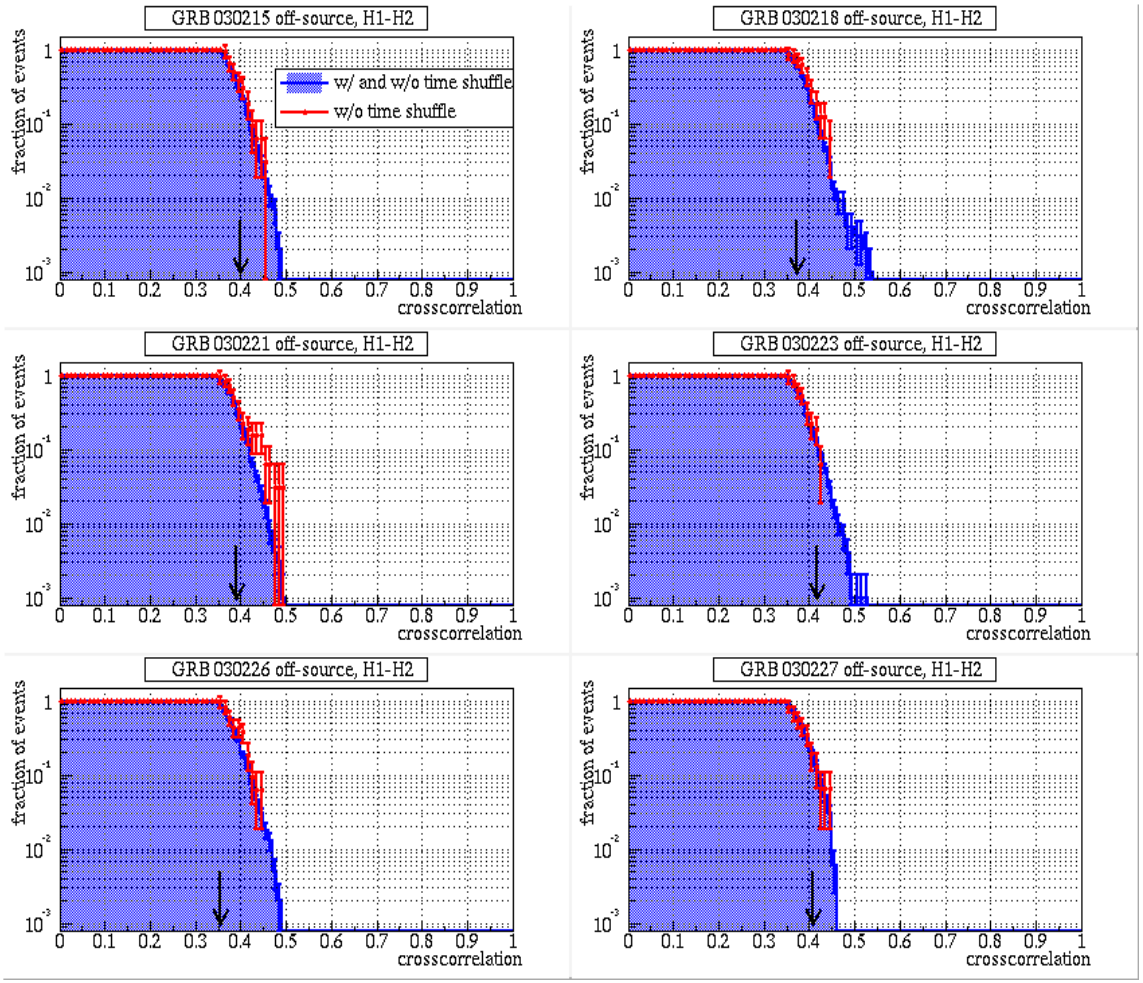
After-trials probability distribution

http://www.uoregon.edu/~ileonor/ligo/s4/grb/online/s4grbs_online.html

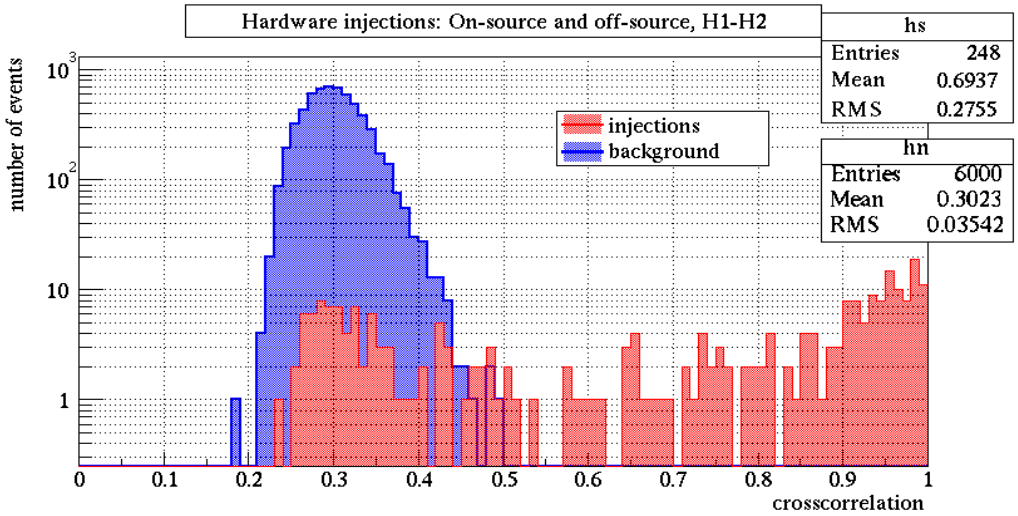


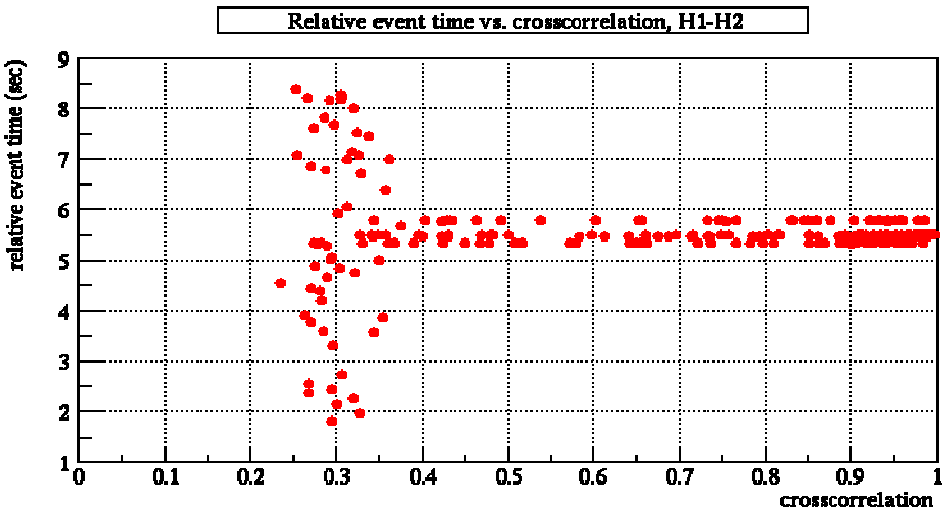
- local off-source distribution determined for each IFO pair for each GRB trigger
- distribution determined from searches within science segments occurring within a few hours of GRB trigger
- largest crosscorrelation found in each on-source search indicated by black arrow
- probability is estimated using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

S2 off-source distribution examples – H1-H2



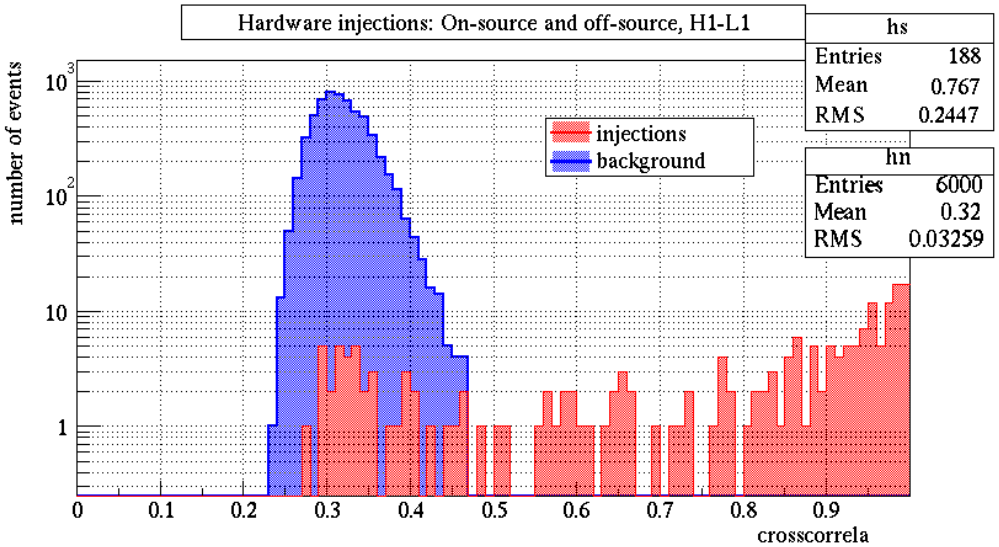
Hardware injections search (H1-H2)





- looked at hardware injections using 10-second search duration (spacing of injections) instead of 180 seconds
- significant fraction had cc above after-trials distribution
- detection times consistent with injection times

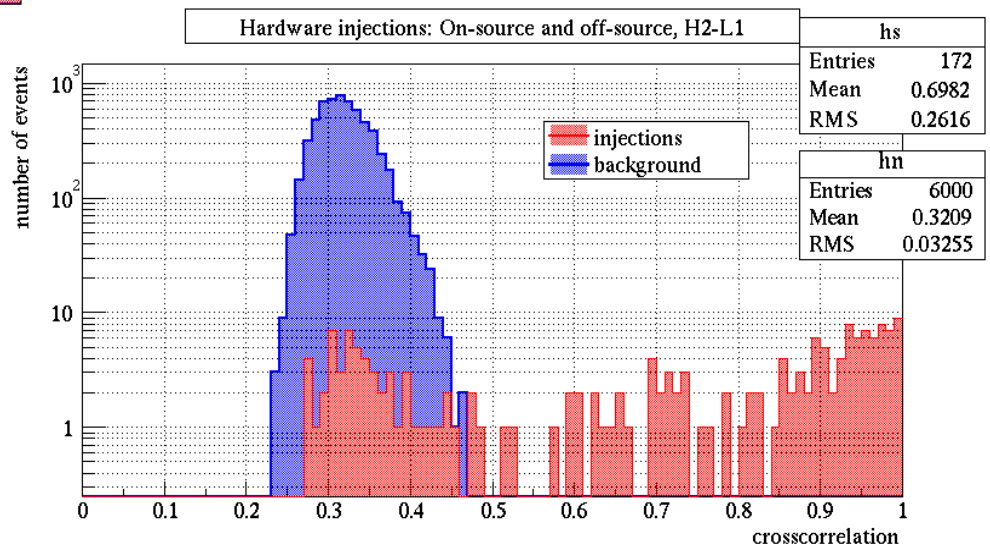
Hardware injections search (H1-L1, H2-L1)



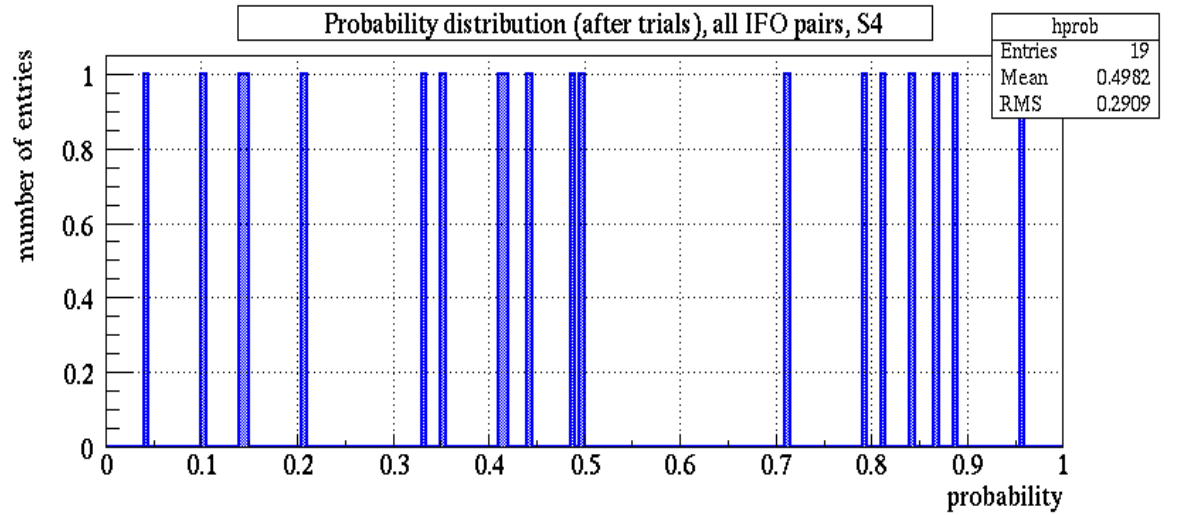
← H1-L1

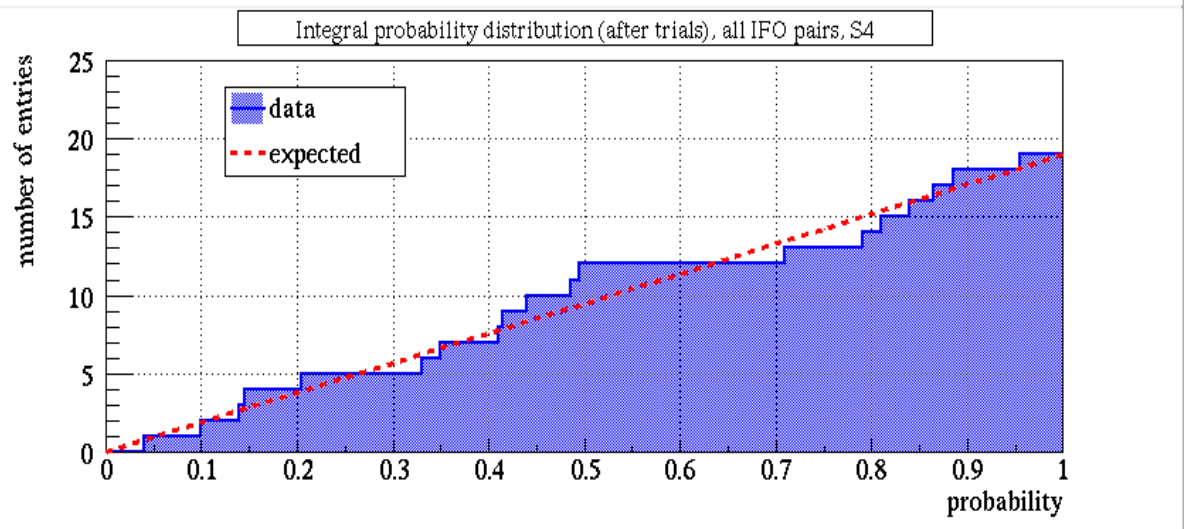
better "detection" rate than H1-H2 or H2-L1, as expected

H2-L1 →



What are the odds? Current S4 results



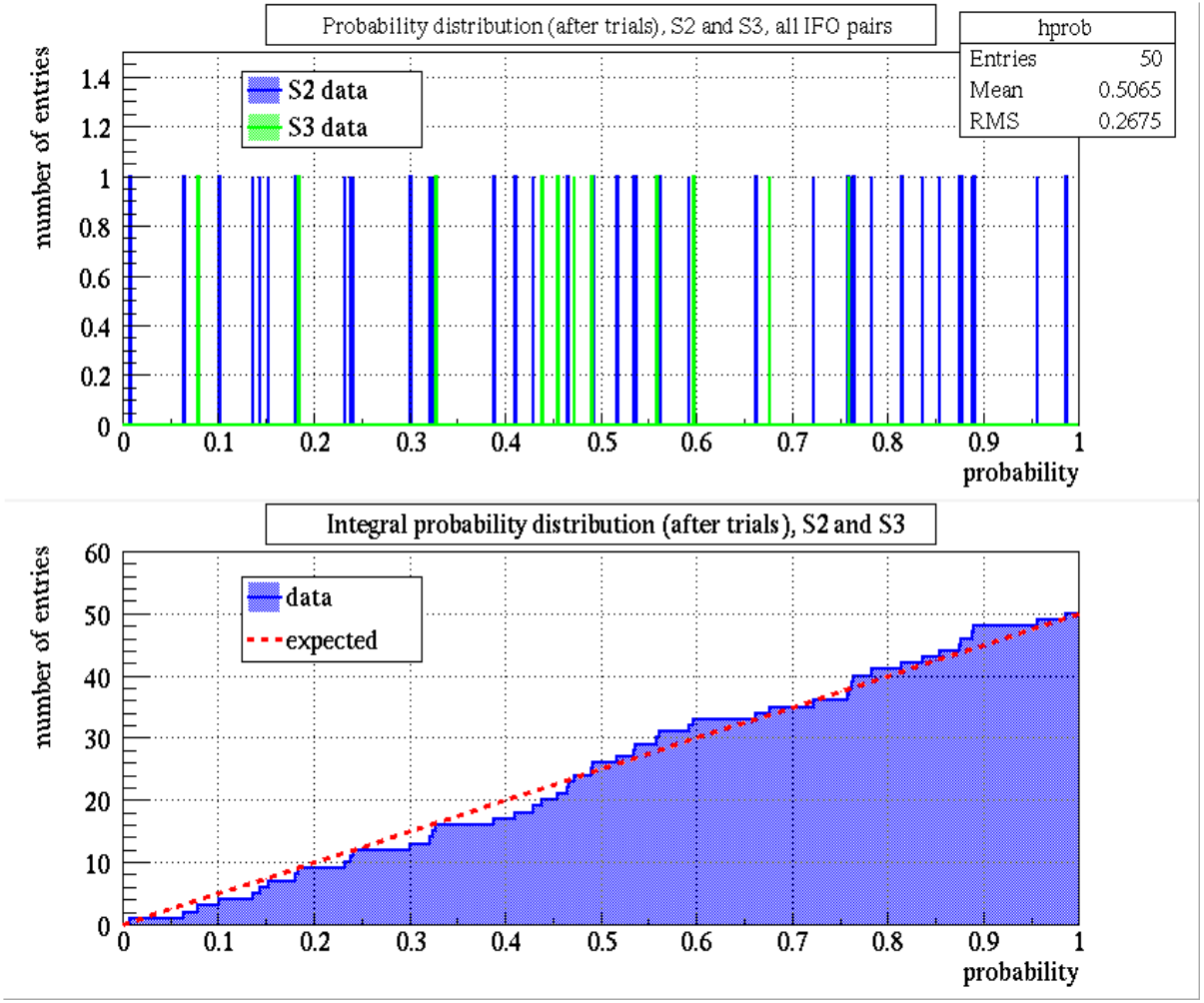


- calculate after-trials probability using off-source distribution
- test sample distribution using K-S test (Kolmogorov-Smirnov)
- probability that measured statistic will be larger under null hypothesis:

$$p = 0.70$$

- consistent with null hypothesis

What are the odds? Combined S2 and S3 probabilities



p = 0.81

Summary

- developed scheme for searching for GRB-GWB coincidence in near real time
- looking forward to S5 run with ~100 GRB triggers in one year of coincident run
- performed search for short-duration GW bursts coincident with S4, S3, and S2 GRBs using crosscorrelation method
- sample probability distribution consistent with null hypothesis