Search for short duration gravitational waves coincident with S2 and S3 GRBs

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Motivation

- search for short-duration GW bursts coincident with gamma-ray burst triggers
  - ~1 to 10 ms, e.g. supernova core-collapse models, end of inspiral merger
- take advantage of readily-available and readily-accessible GRB triggers
- use definite GRBs as triggers
- triggers are from Interplanetary Network (IPN) (Konus-Wind, Ulysses, Mars Odyssey, others), INTEGRAL , HETE
- prepare for Swift triggers

The S2/S3 GRB Sample

- **S2: 29 GRBs** with at least double coincidence science segments
  - 23 for H1-H2
  - 7 for H1-L1
  - 7 for H2-L1
  - 11 for H1-H2-L1 (not all with well-defined positions)
- **S3: 11 GRBs** with at least double coincidence science segments
  - 11 for H1-H2 (only 8 if segments with seismic flags excluded)
  - 0 for H1-L1 (one GRB eliminated due to bad timing flag)
  - 0 for H2-L1 (one GRB eliminated due to bad timing flag)
- time delay taken into consideration for H1-L1, H2-L1 search
- only well-localized GRBs considered for H1-L1, H2-L1 search

➜ combine S2 and S3 results

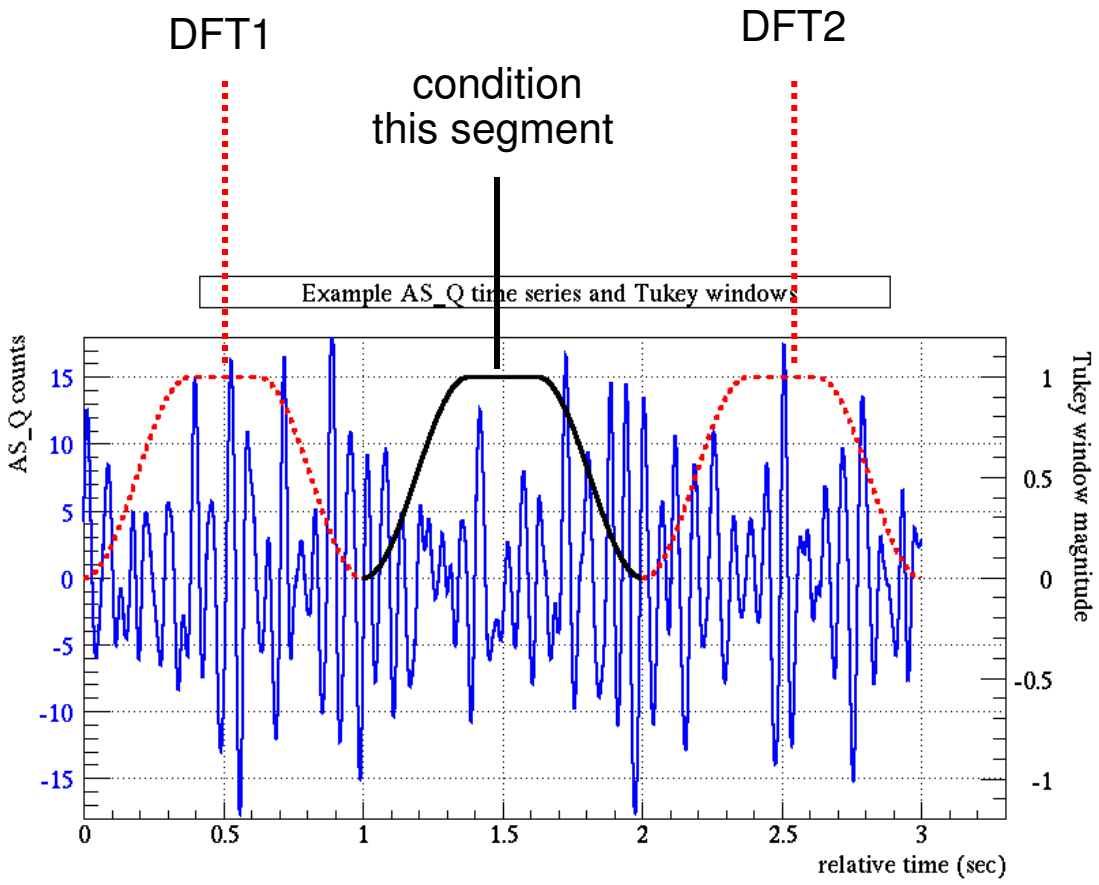
S2 and S3 GRBs with science mode segments (at least double coincidence)

date	z		GPS time	RA	DEC	error						IFO	
S2 GRBs:													
030215		12685	61912.00 17:11:52.00	729364325.00	--	--	--	--	--	--	HET	H2595	H1/H2/L1	7
030217		12687	9942.00 02:45:42.00	729485155.00	186.596	-11.850	0.019dA	50.00	1.2E-5	1.2E-6	IPN	1870/1872	H2/L1	27
030218		12688	42158.00 11:42:38.00	729603771.00	351.179	-41.826	55.834+/-0.019d	200.00	3.6E-5	1.9E-6	IPN	1874	H1/H2/L1	39
030221		12791	27974.00 07:46:14.00	729848787.00	--	--	--	--	--	--	HET	H2602	H1/H2/L1	55
030223		12693	35106.00 09:45:06.00	730028719.00	349.492	-41.979	22.224+/-0.137d	10.00	5.8E-6	4.9E-7	IPN	1877	H1/H2/L1	60
030226	1.986	12696	13591.99 03:46:31.99	730266404.99	173.254	25.900	0.033dCR	100.00	5.7E-6	1.2E-7	HET	1888	H1/H2/L1	68
030227		12697	31336.25 08:42:16.25	730370549.25	74.383	20.500	0.050dCR	20.00	n/m	6.0E-8	INT	1895/1896	H1/H2	89
030228		12698	73606.00 20:26:46.00	730499219.00	347.624	-42.117	84.182+/-0.157d	15.00	2.0E-6	4.9E-7	IPN	1918	H1/H2	107
030301		12699	73640.00 20:27:20.00	730585653.00	167.280	42.132	76.348+/-0.161d	30.00	1.1E-5	5.3E-7	IPN	1919	H1/H2	119
030307		12705	52320.00 14:32:00.00	731082733.00	345.309	-42.142	70.420+/-0.016d	3.00	4.7E-6	2.4E-6	IPN	1937	H1/H2	170
030308		12706	50769.00 14:06:09.00	731167582.00	--	--	--	--	--	--	HET	H2619	H1/H2	176
030317		12715	25133.00 06:58:53.00	731919546.00	342.016	-41.985	42.684+/-0.077d	20.00	1.6E-5	1.7E-6	IPN	1938	H1/L1	276
030320a		12718	36700.00 10:11:40.00	732190313.00	267.929	-25.317	0.083dCR	80.00	1.1E-5	6.7E-7	INT	1941/1943	H1/H2/L1	236
030320b		12718	67757.00 18:49:17.00	732221370.00	160.920	41.819	85.870+/-0.122d	150.00	1.2E-5	4.6E-7	IPN	1944	H1/H2	226
030323a		12721	31344.00 08:42:24.00	732444157.00	297.250	-12.500	2.000dCR	5.00	n/m	2.0E-7	INT	1970	H1/H2/L1	267
030323b	3.372	12721	79017.60 21:56:57.60	732491830.60	166.525	-21.900	0.020dA	26.00	1.1E-6	1.2E-9	HET	1956	H1/H2/L1	273
030324		12722	11562.80 03:12:42.80	732510775.80	204.296	-0.317	0.117dCR	8.70	1.6E-6	1.4E-7	HET	1954	H1/H2	249
030325		12723	51310.00 14:15:10.00	732636923.00	70.808	-19.133	0.527dCR	2.00	1.0E-6	1.0E-6	IPN	1962/1965/1969	H1/H2/L1	294
030326		12724	38621.00 10:43:41.00	732710634.00	292.967	-11.717	0.476dCR	10.00	3.5E-6	8.2E-7	IPN	1967	H1/H2/L1	304
030329		12727	12703.00 03:31:43.00	732943916.00	--	--	--	--	--	--	HET	H2651	H1/H2	291
030329a	0.168	12727	41834.67 11:37:14.67	732973047.67	161.208	21.517	0.033dCR	50.00	1.2E-4	7.0E-6	HET	1997/2026	H1/H2	292
030329b		12727	56055.35 15:34:15.35	732987268.35	160.626	-48.572	1.448dA	65.00	2.0E-5	1.0E-6	KON/IPN	2025/2055	H1/H2	294
030331		12729	20320.82 05:38:40.82	733124333.82	349.261	36.260	0.111dA	10.00	4.6E-6	1.3E-6	KON/IPN	2057/2061	H1/L1	428
030403		12732	13066.00 03:37:46.00	733376279.00	157.362	40.758	21.165+/-0.172d	30.00	5.1E-6	5.2E-7	IPN	2125	H1/L1(6s)	455
030405		12734	8248.00 02:17:28.00	733544261.00	248.275	-24.150	0.010dA	5.00	4.3E-6	1.0E-6	IPN	2126/2128	H1/H2/L1	387
030406		12735	81727.00 22:42:07.00	733704140.00	285.429	-68.083	0.021dA	65.00	1.3E-5	1.0E-6	IPN	2127	H1/L1	487
030410		12739	41022.00 11:23:42.00	734009035.00	216.716	-15.670	59.394+/-2.469d	0.30	n/m	n/m	IPN	2134	H1/H2	385
030413		12742	27277.00 07:34:37.00	734254490.00	198.604	62.350	0.461dCR	15.00	2.3E-6	4.7E-7	IPN	2135	H2/L1	494
030414		12743	49707.00 13:48:27.00	734363320.00	119.887	-48.583	0.632dCR	40.00	1.2E-5	8.6E-7	IPN	2138	H1/H2	411
S3 GRBs:														
031107	n/m	12950	66246.00 18:24:06.00	752264659.00	342.257	-9.639	50.513+/-0.446d	25.00	n/m	n/m	IPN	2448	H1/H2	58
031108	n/m	12951	51061.00 14:11:01.00	752335874.00	66.729	-5.930	0.444dA	22.00	2.5E-5	1.8E-6	IPN	2441	H1/H2	59
031109a	n/m	12952	40308.00 11:11:48.00	752411521.00	327.765	20.203	2.194dA	20.00	3.0E-6	n/m	HET/IPN	2452	H1/H2	66
031109b	n/m	12952	70138.00 19:28:58.00	752441351.00	4.265	-7.145	0.333dCR	480.00	1.1E-6	n/m	HET	2442	H1/H2/L1	35
031111a	n/m	12954	60313.00 16:45:13.00	752604326.00	71.764	18.086	0.0067dA	10.00	2.1E-6	1.1E-6	IPN/HET	2443	H1/H2	79
031114	n/m	12957	76071.00 21:07:51.00	752879284.00	270.780	6.199	1.500dA	12.00	2.2E-6	3.6E-7	IPN	2449	H1/H2	106
031123	n/m	12966	81674.00 22:41:14.00	753662487.00	--	--	--	--	--	--	HET	H2941	H1/H2	199
031127a	n/m	12970	68338.00 18:58:58.00	753994751.00	21.275	-60.447	70dCR	10.00	n/m	n/m	IPN	2461	H1/H2	232
031127b	n/m	12970	68356.00 18:59:16.00	753994769.00	350.166	-5.279	73.555+/-1.271d	70.00	n/m	n/m	IPN	2461	H1/H2	232
031130	n/m	12973	7488.00 02:04:48.00	754193101.00	171.881	4.499	58.501+/-0.403d	4.00	n/m	n/m	IPN	2457	H1/H2/L1	170
031220	n/m	12993	12596.74 03:29:56.74	755926209.74	69.893	7.374	0.346dCR	23.70	1.9E-6	n/m	HET	H2976	H1/H2	490

Search method -- crosscorrelation

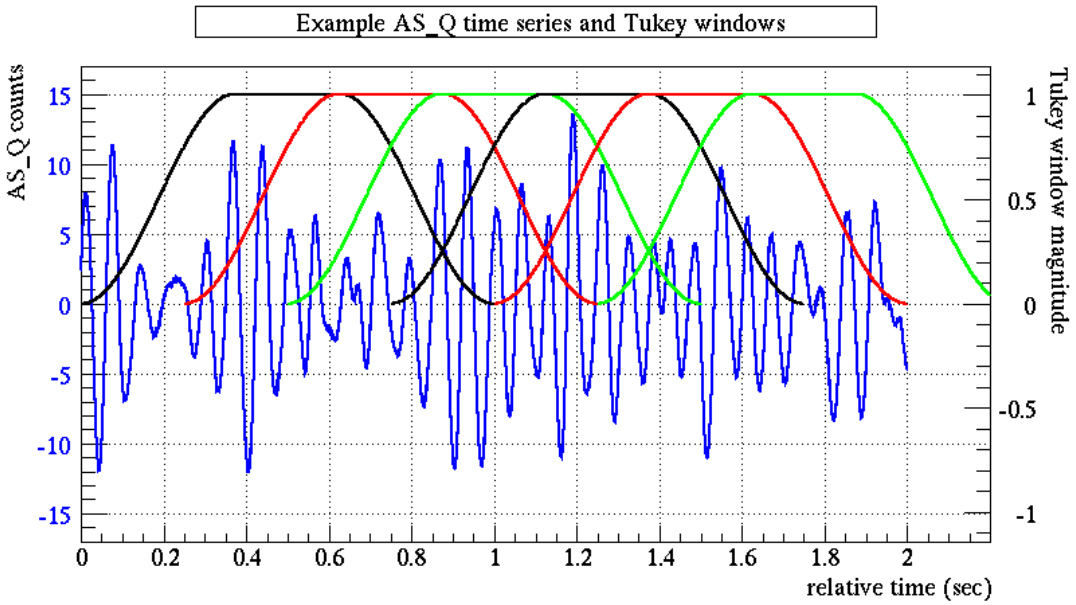
- each search segment is 160-seconds long (less ~1.5 seconds at ends of segment)
- each 160-second segment pre-conditioned
- use crosscorrelation windows of length 25 ms each, windows overlapping by half a window length
- calculate normalized crosscorrelation for each 25-ms second
- find largest crosscorrelation within each 160-second search segment; find largest abs(cc) for H1-L1 and H2-L1 due to unknown polarization
- use playground data to test pipeline and estimate sensitivity – playground data was long science segment not coincident with any GRB trigger

Data conditioning – whitening and phase correction



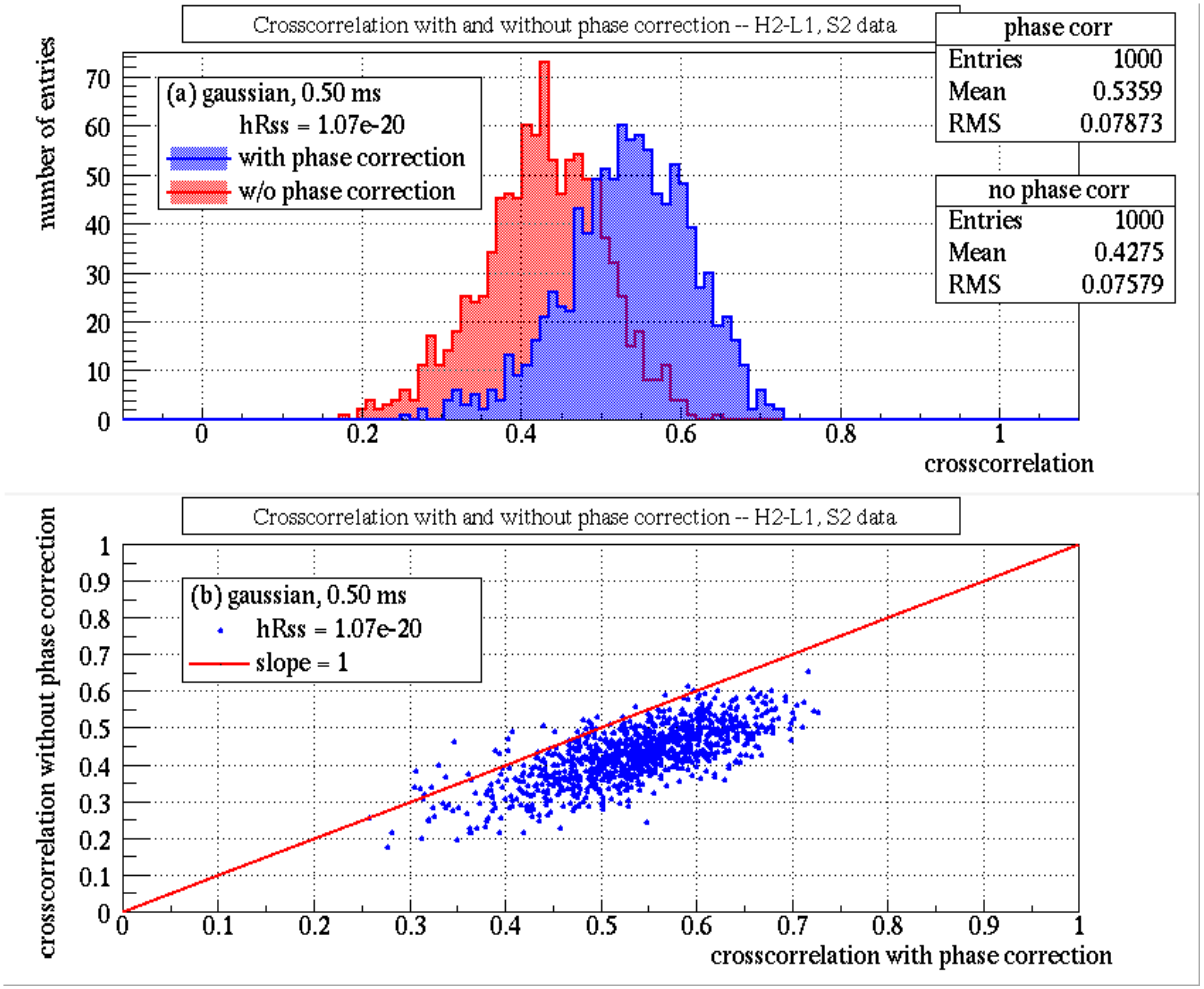
- data conditioning done in frequency domain
- data DFTed using 1-second Tukey windows
- adjacent 1-sec segments DFTed to determine factor for whitening in frequency domain
- whitening factor(f) = max(DFT1(f),DFT2(f))
- use phase calibration to correct signal phase

Data conditioning – overlapping Tukey windows, and "stitching"



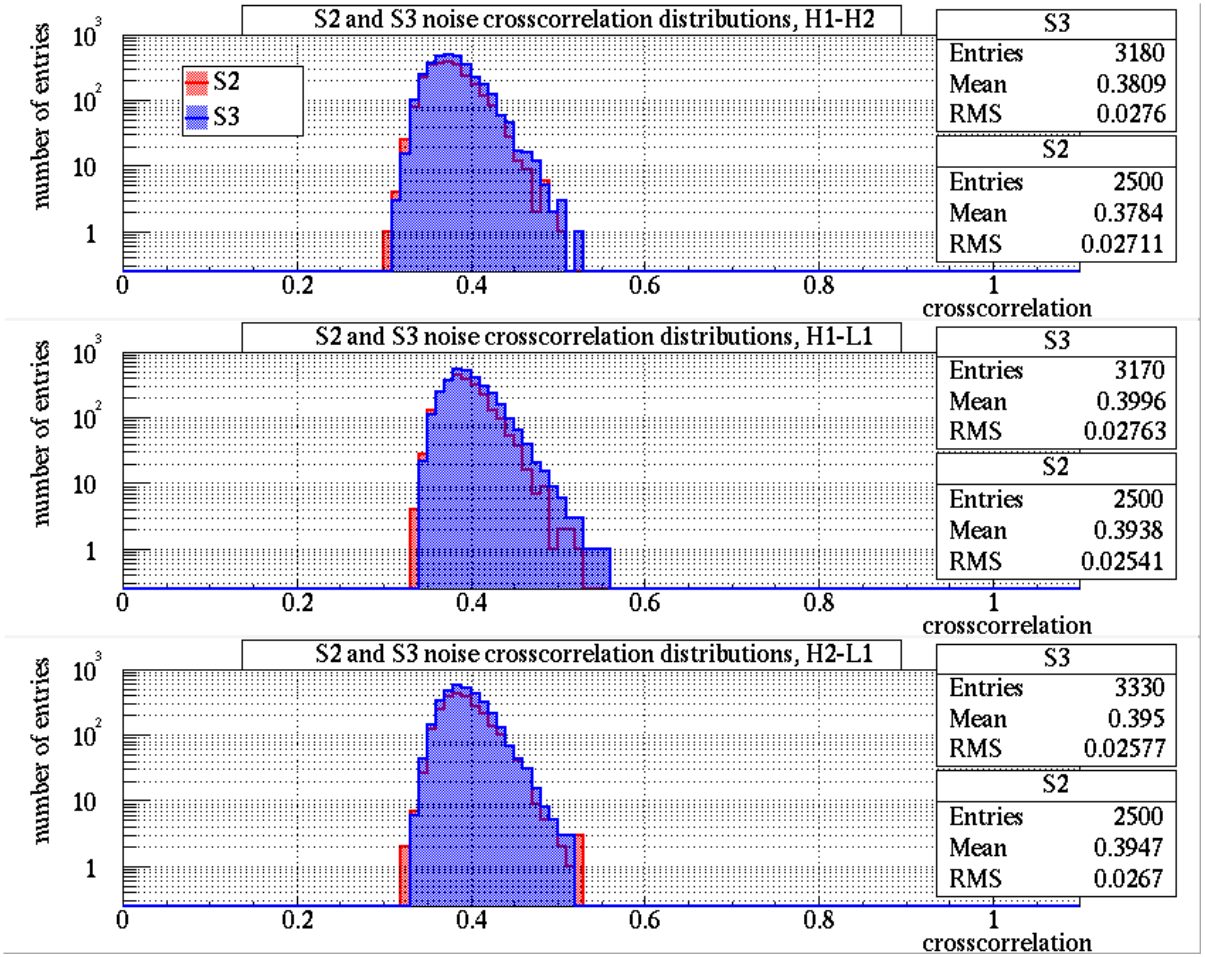
- data conditioning process repeated for each second
- perform inverse DFT to convert back to time domain
- keep only time segment corresponding to unattenuated section of window
- crosscorrelation calculated in time domain

Effect of phase correction on crosscorrelation

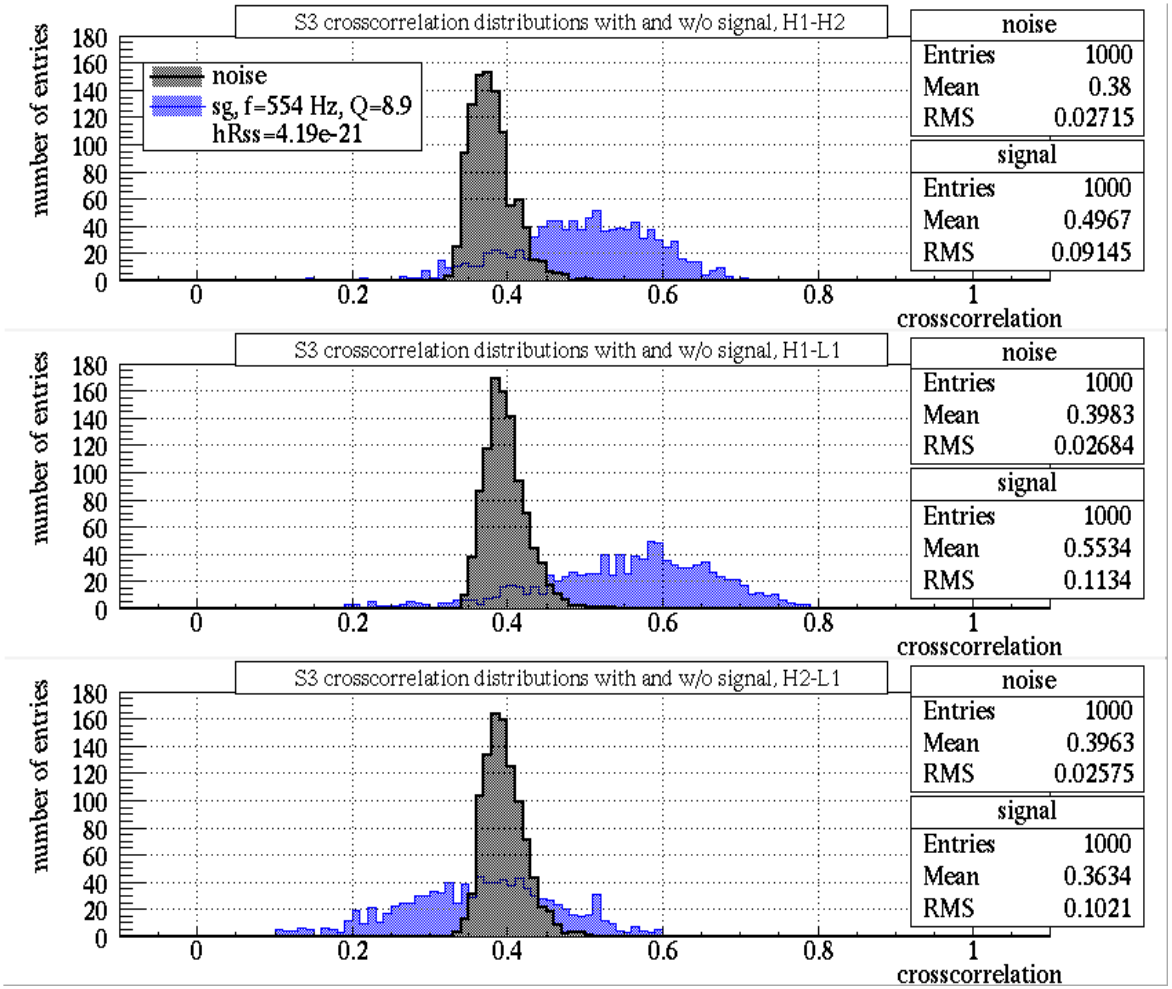


- S2 data, H2-L1 crosscorrelation
- effect of phase correction varies depending on time epoch and IFO pair
- large effect of phase on crosscorrelation not yet seen in S3 data

S2 and S3 noise crosscorrelation distribution examples (after trials)

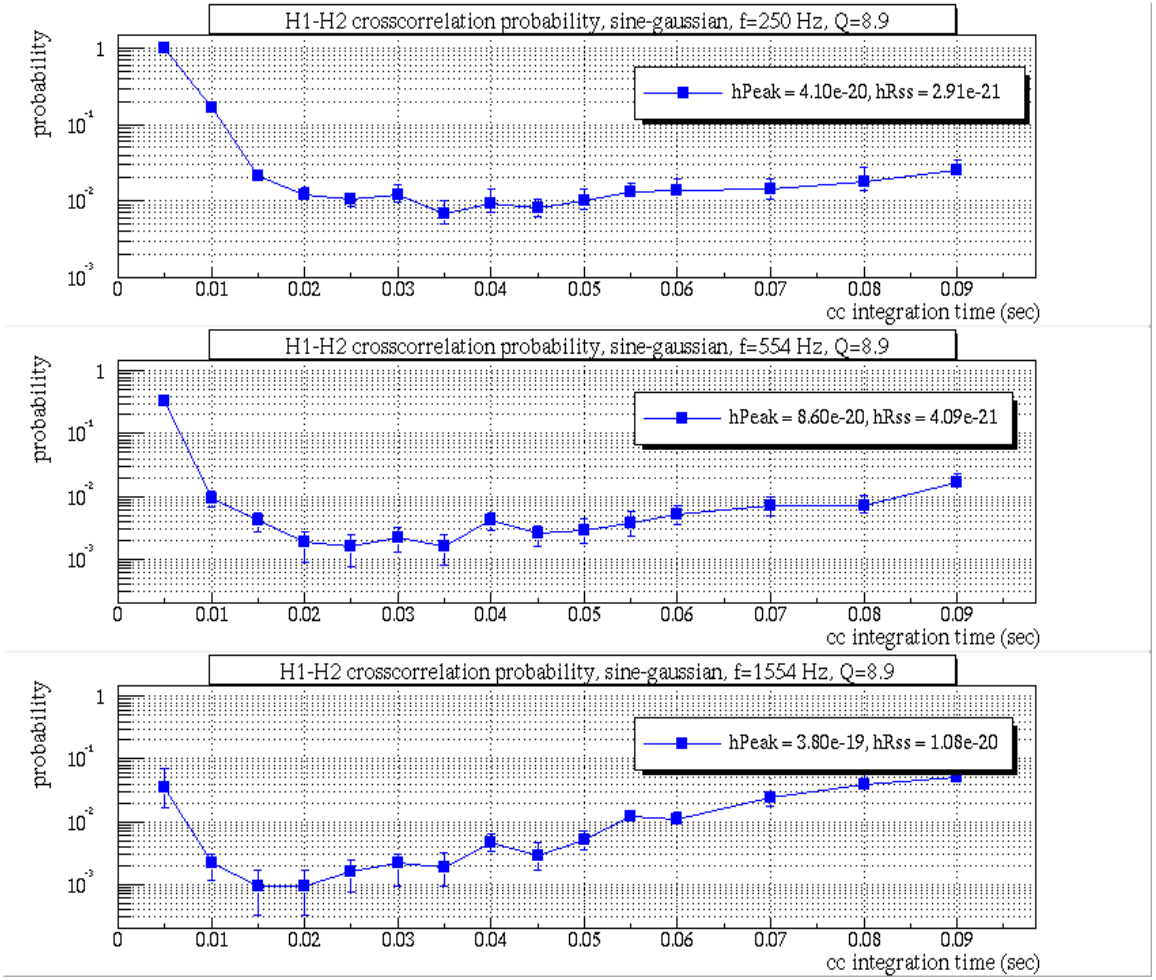


Crosscorrelation distributions – 'off-source' and 'on-source' examples



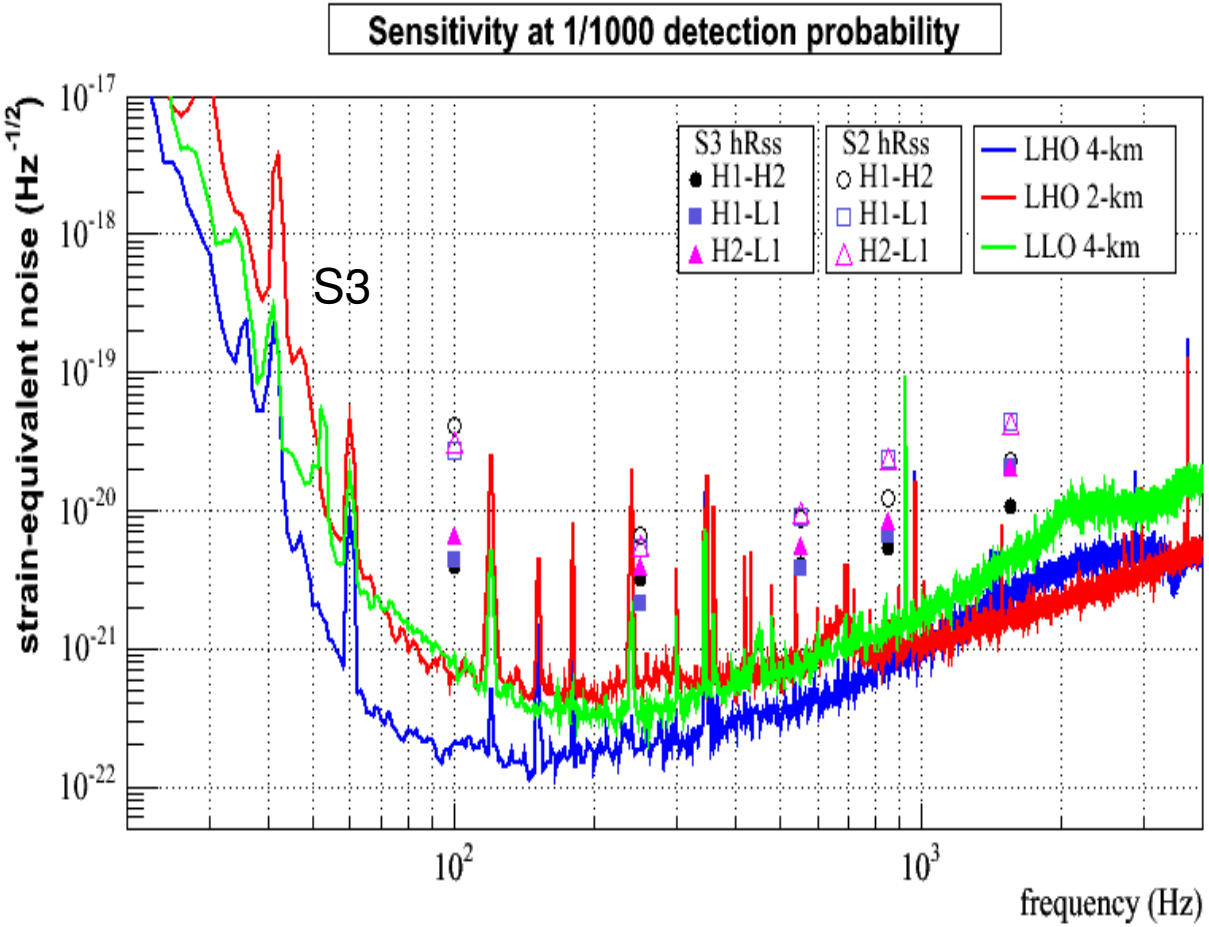
- S3 data
- on-source distributions derived from playground data with injections
- off-source segments were shuffled – each search segment from one IFO paired with all segments from other IFO

Detection probability vs. integration lengths for short duration signals (~1 – 10 ms)



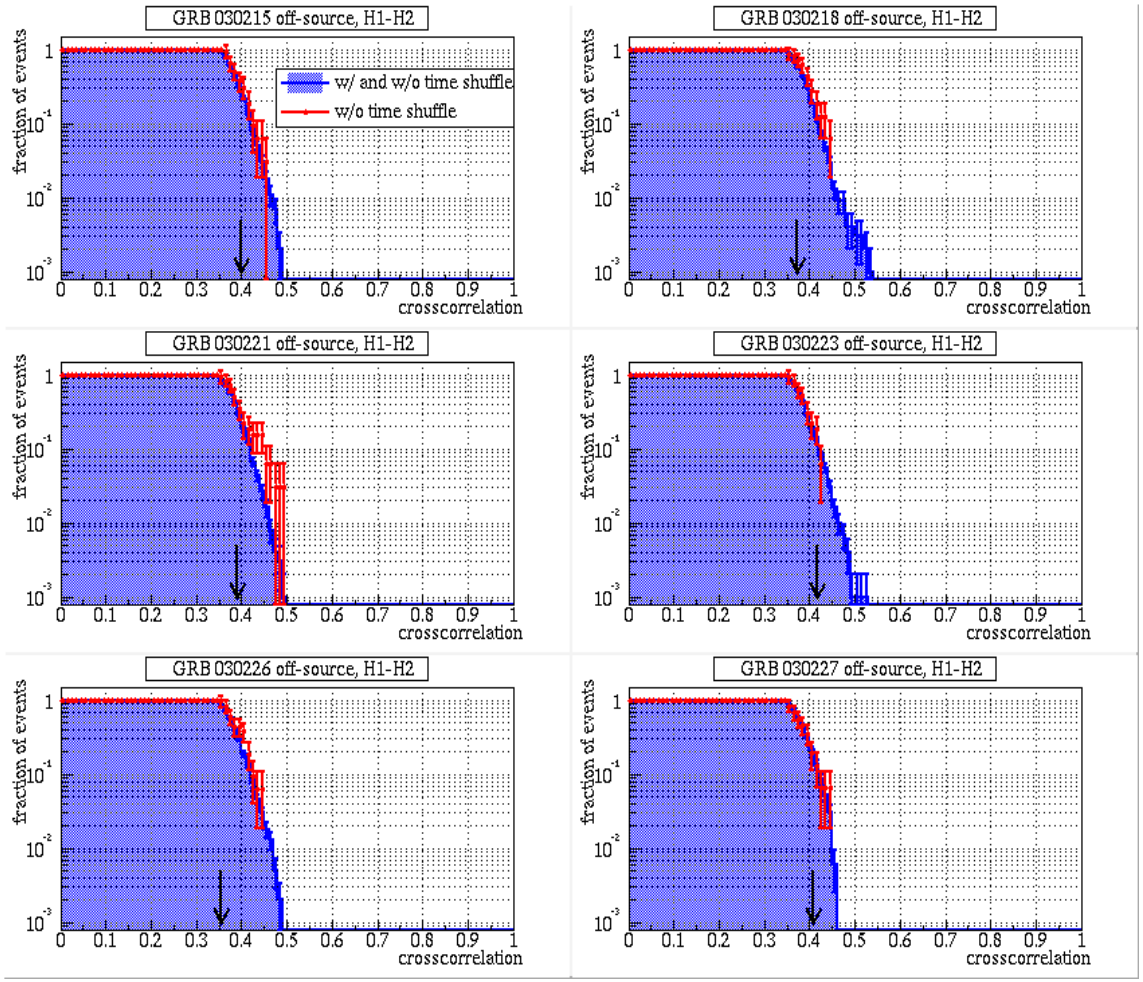
- probability for getting median of on-source distribution, given off-source distribution
- probability takes into account trials in search
- probability is function of length of crosscorrelation window
- small window: 1/sqrt(N), more trials
- large window: more noise integrated

S2 and S3 estimate of sensitivity to sine-gaussians



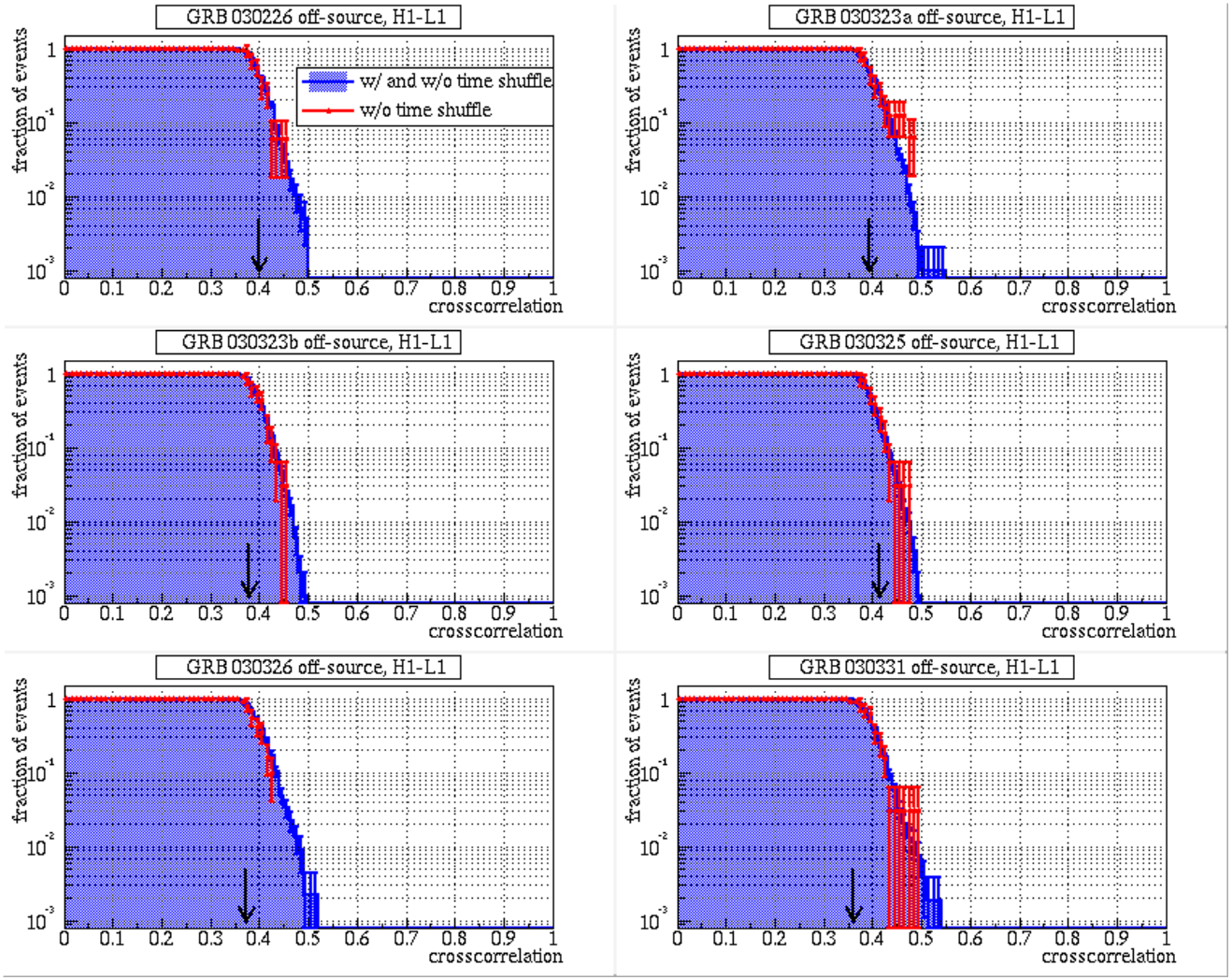
- sine-gaussians, Q = 8.9
- markers: hrss such that median of cc distribution with injections has a probability of 1/1000 given off-source distribution
- valid for 160-second search window, 25-ms crosscorrelation length

S2 off-source distribution examples – H1-H2

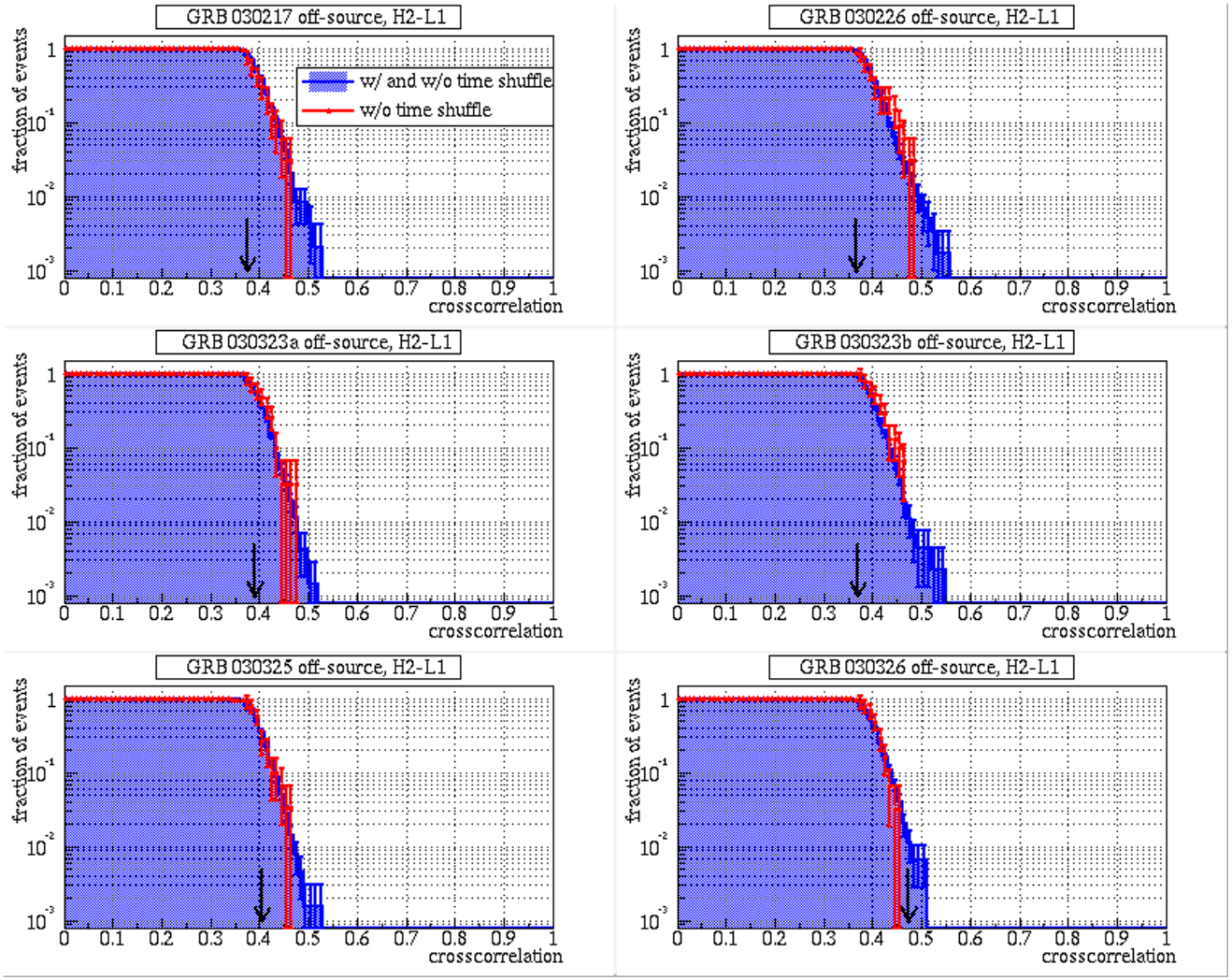


- local off-source distribution determined for each GRB trigger
- each distribution determined from searches within science segments occurring within a few hours of GRB trigger
- largest crosscorrelation found in each search included in distribution (indicated by black arrow)
- used data segments defined by burst group

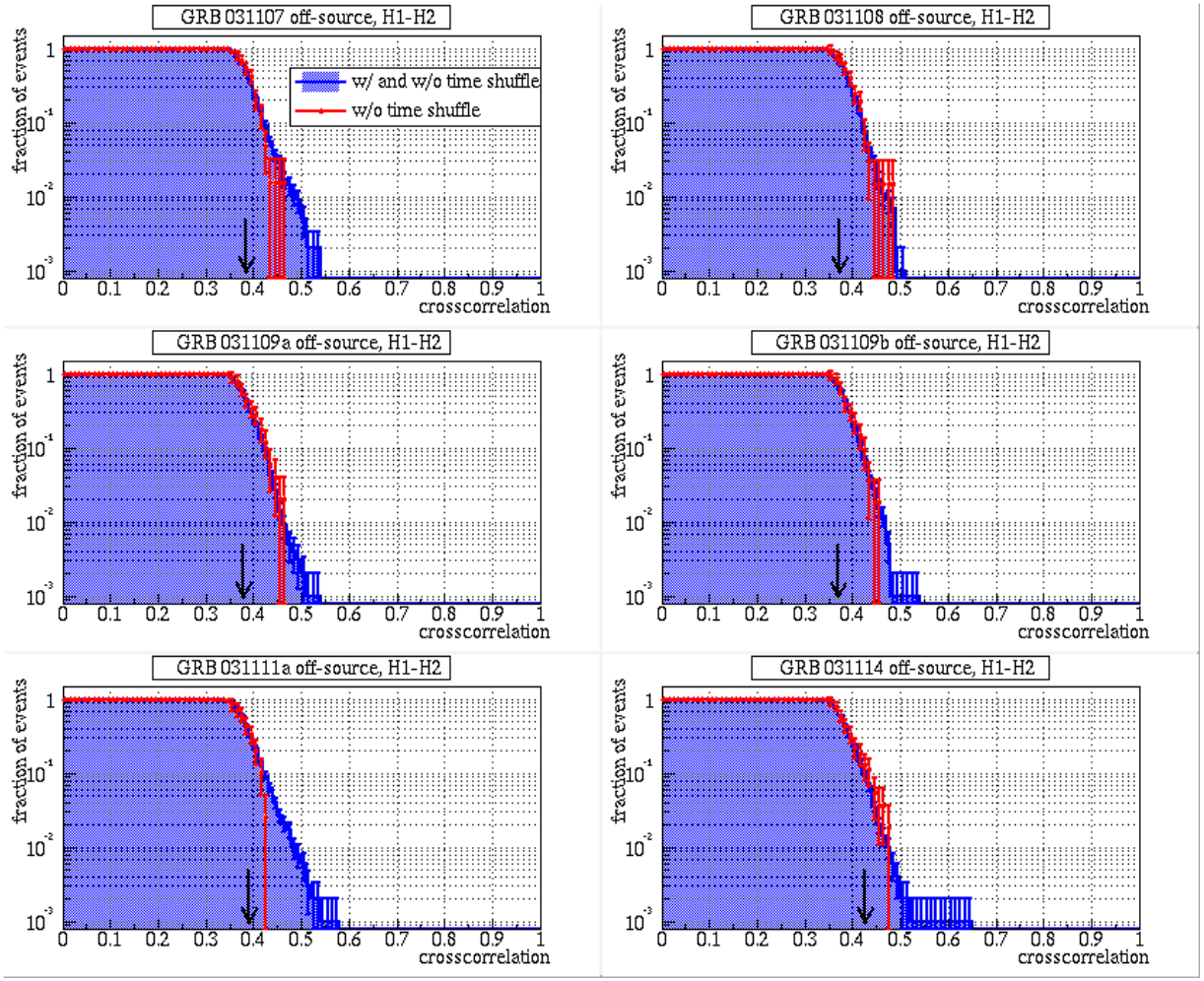
S2 off source distribution examples – H1-L1



S2 off-source distribution examples – H2-L1

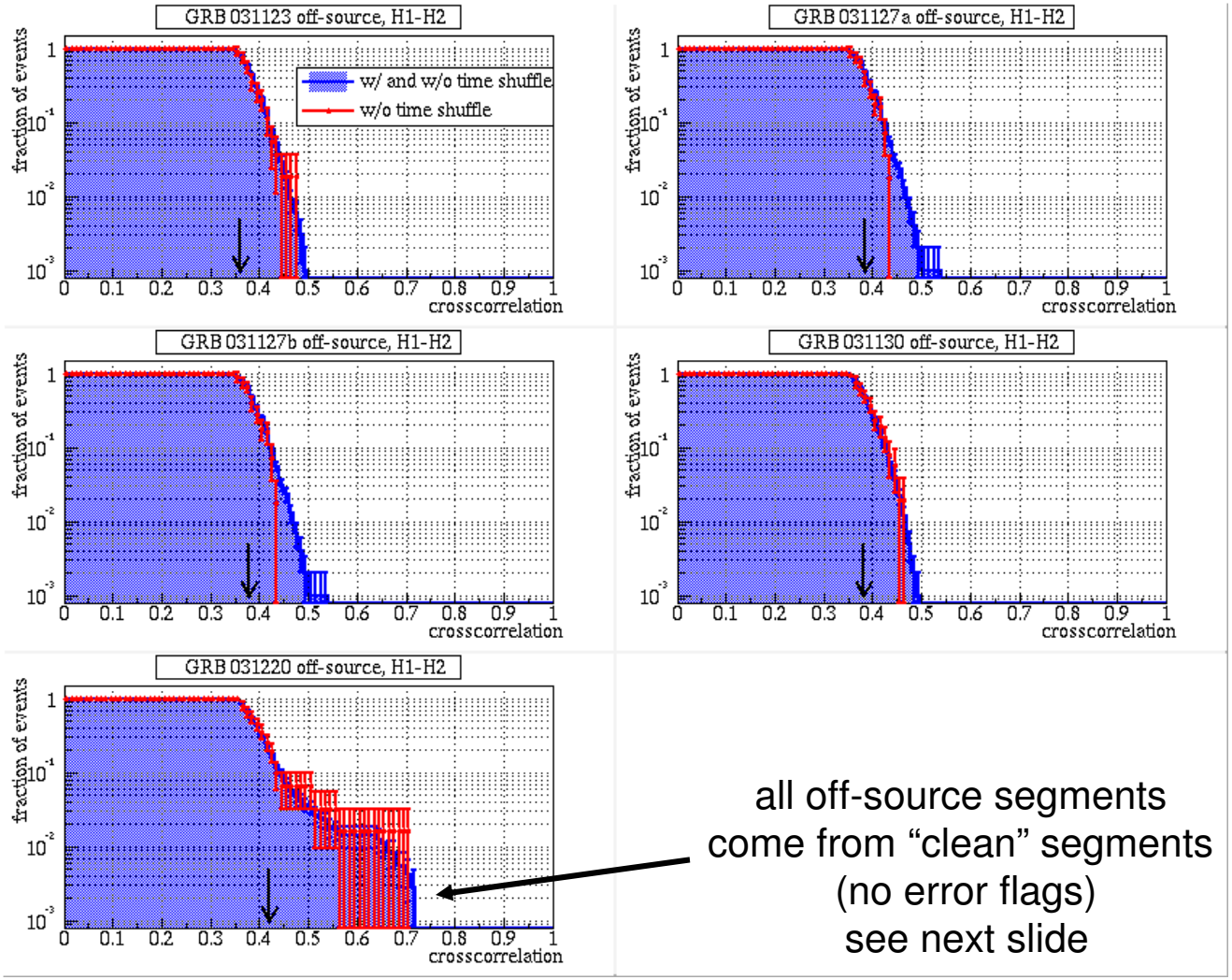


S3 off-source distribution examples – H1-H2



- v03 segments list allowed flags: DUST, SEISMIC_ELEVATED,
- note that S3 off-source distributions are very similar to S2 distributions
  - indicates robustness of crosscorrelation and pipeline

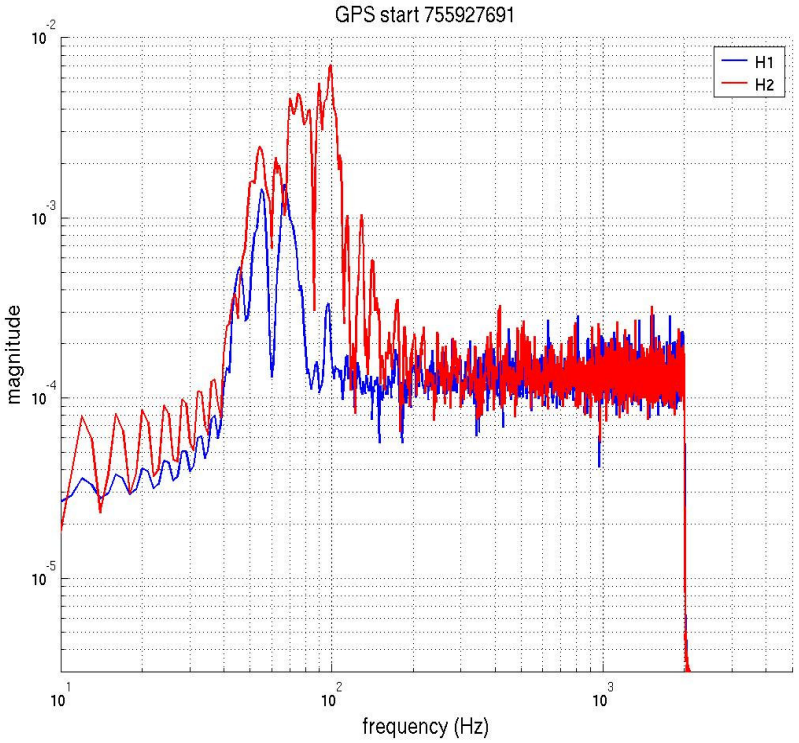
S3 off-source distribution examples – H1-H2



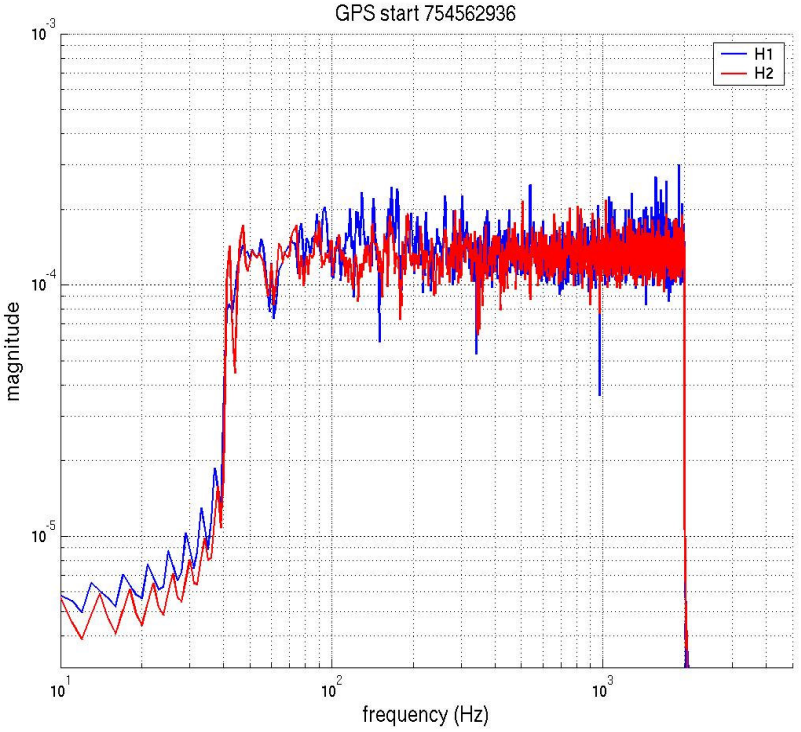
all off-source segments
come from “clean” segments
(no error flags)
see next slide

Example of off-source outlier (from conditioned AS_Q)

from loud segment

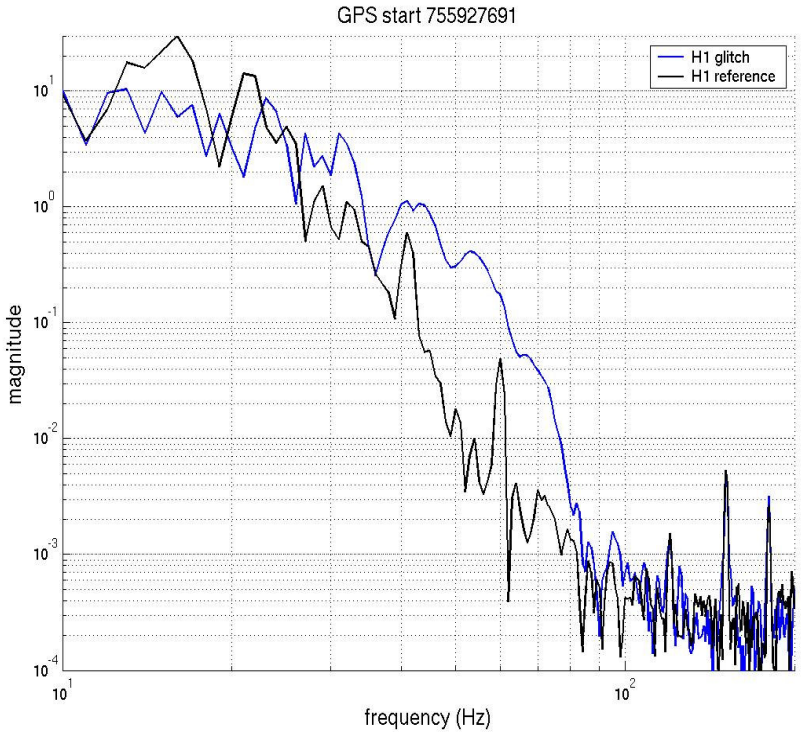


from playground data

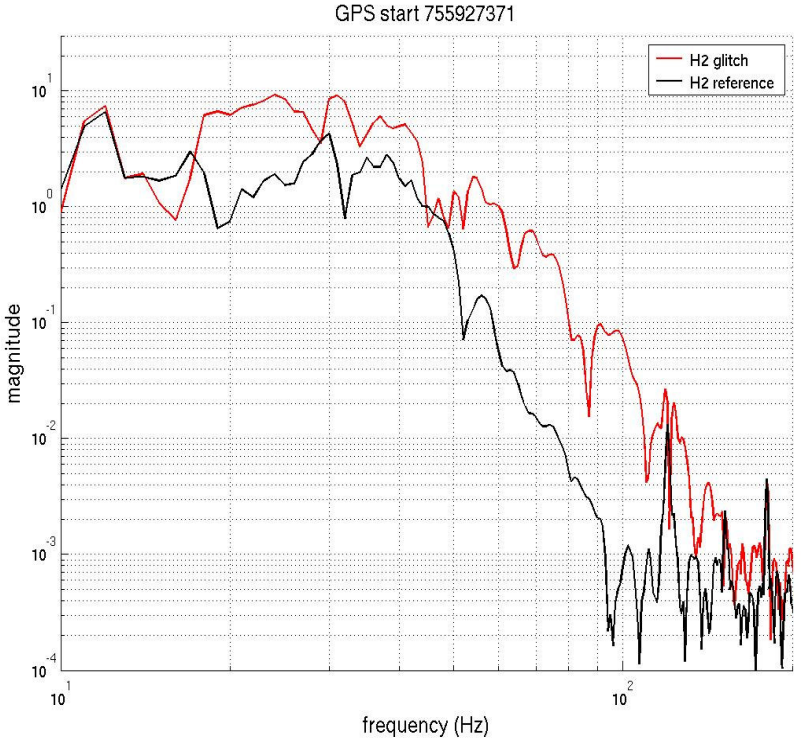


Example of off-source outlier (from raw AS_Q)

H1



H2

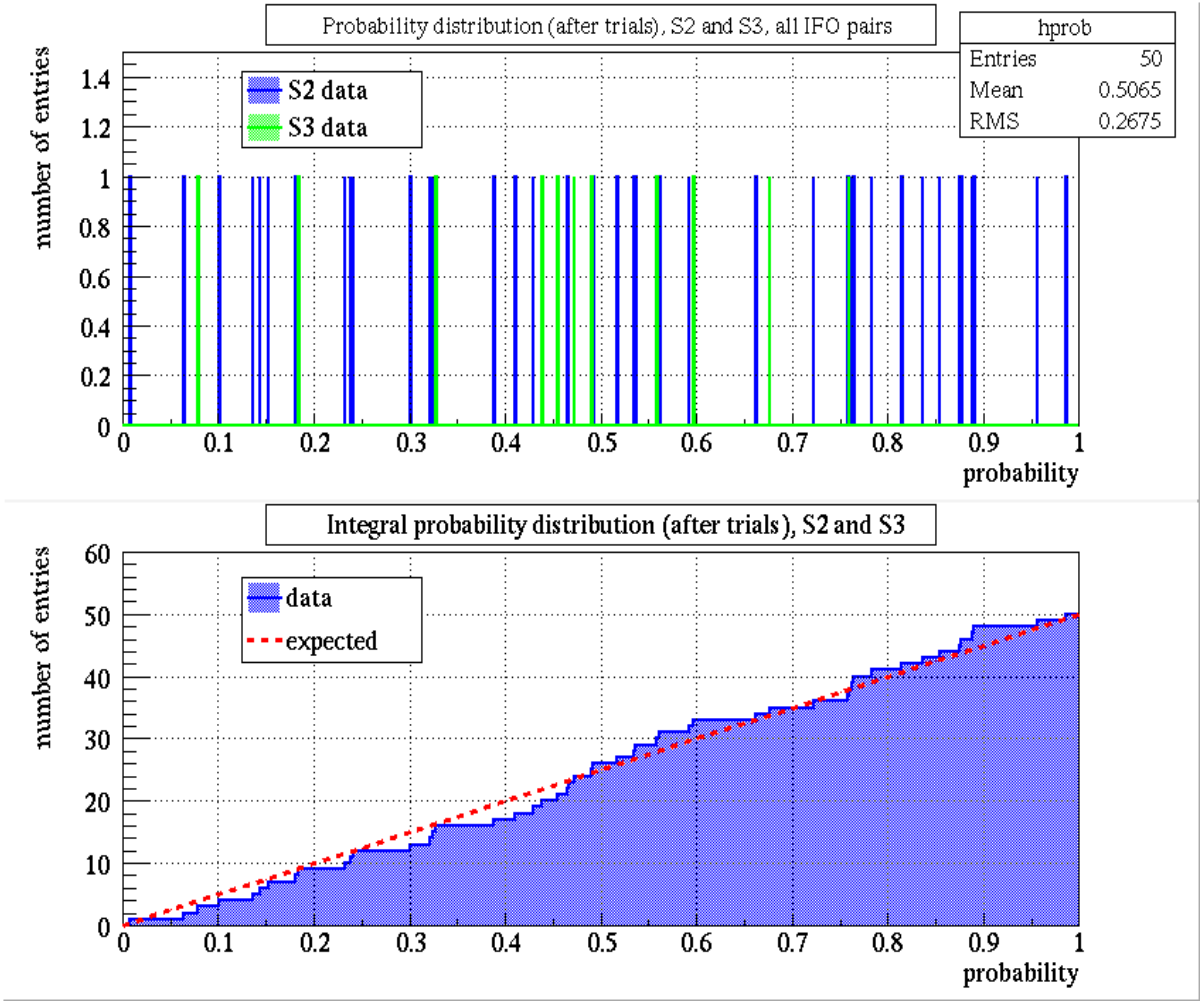


GPS times of some outliers

(outlier GPS in black, airplane GPS in blue)

755920143 (Dec 20 2003	1:49)	*some days had plane flags at this time of day
755922223 (Dec 20 2003	2:23)	
755922360 (Dec 20 2003	2:25)	airplane flag
755927211 (Dec 20 2003	3:46)	
755927371 (Dec 20 2003	3:49)	
755927691 (Dec 20 2003	3:54)	*some days had plane flags at this time of day
755928840 (Dec 20 2003	4:13)	airplane flag
755929210 (Dec 20 2003	4:20)	
755929370 (Dec 20 2003	4:22)	
755929560 (Dec 20 2003	4:25)	airplane flag
755930137 (Dec 20 2003	4:35)	
755930520 (Dec 20 2003	4:41)	airplane flag

What are the odds? Combined S2 and S3 probabilities

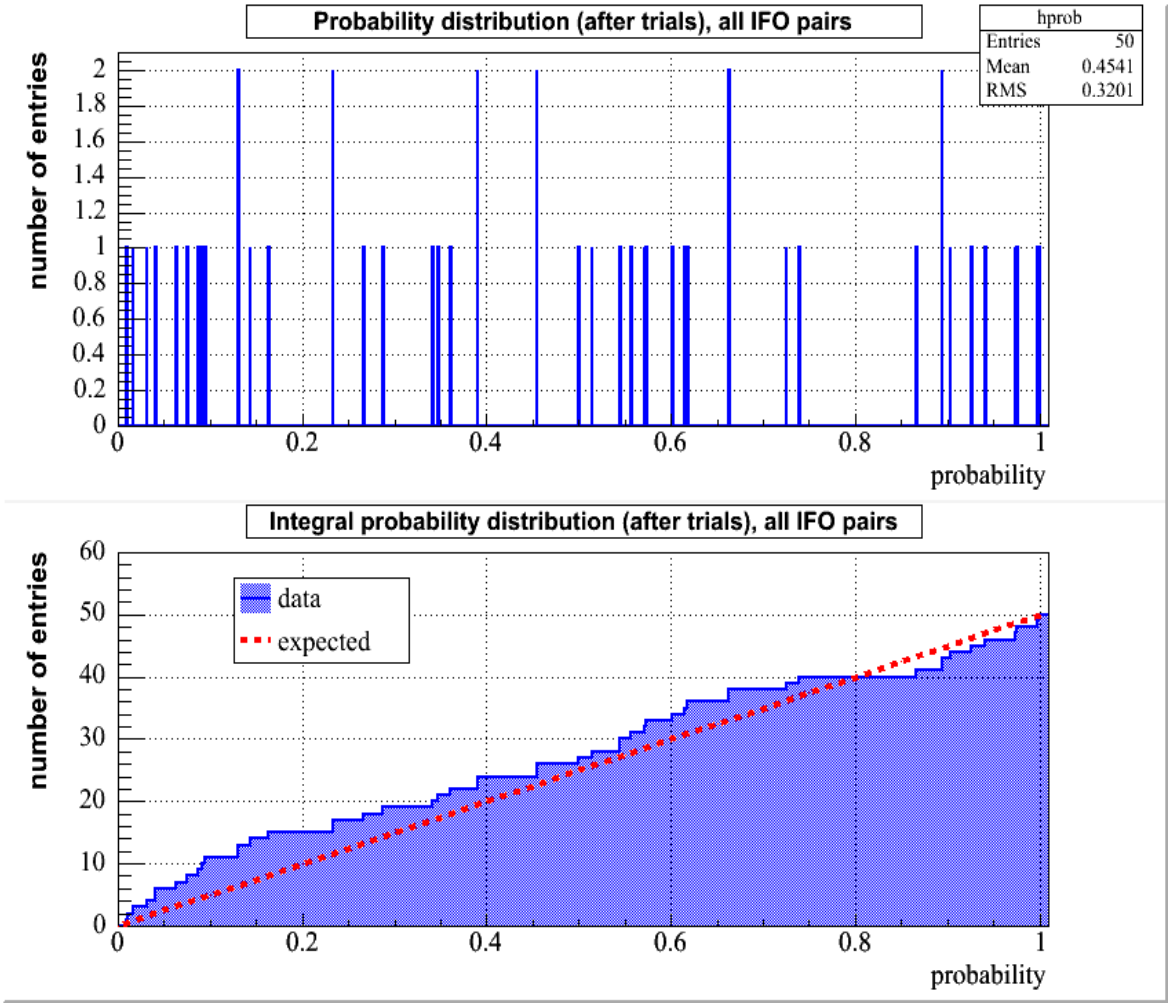


- calculate after-trials probability using off-source distribution
- test sample distribution using K-S test (Kolmogorov-Smirnov)
- probability that measured statistic will be larger under null hypothesis:

$$p = 0.81$$

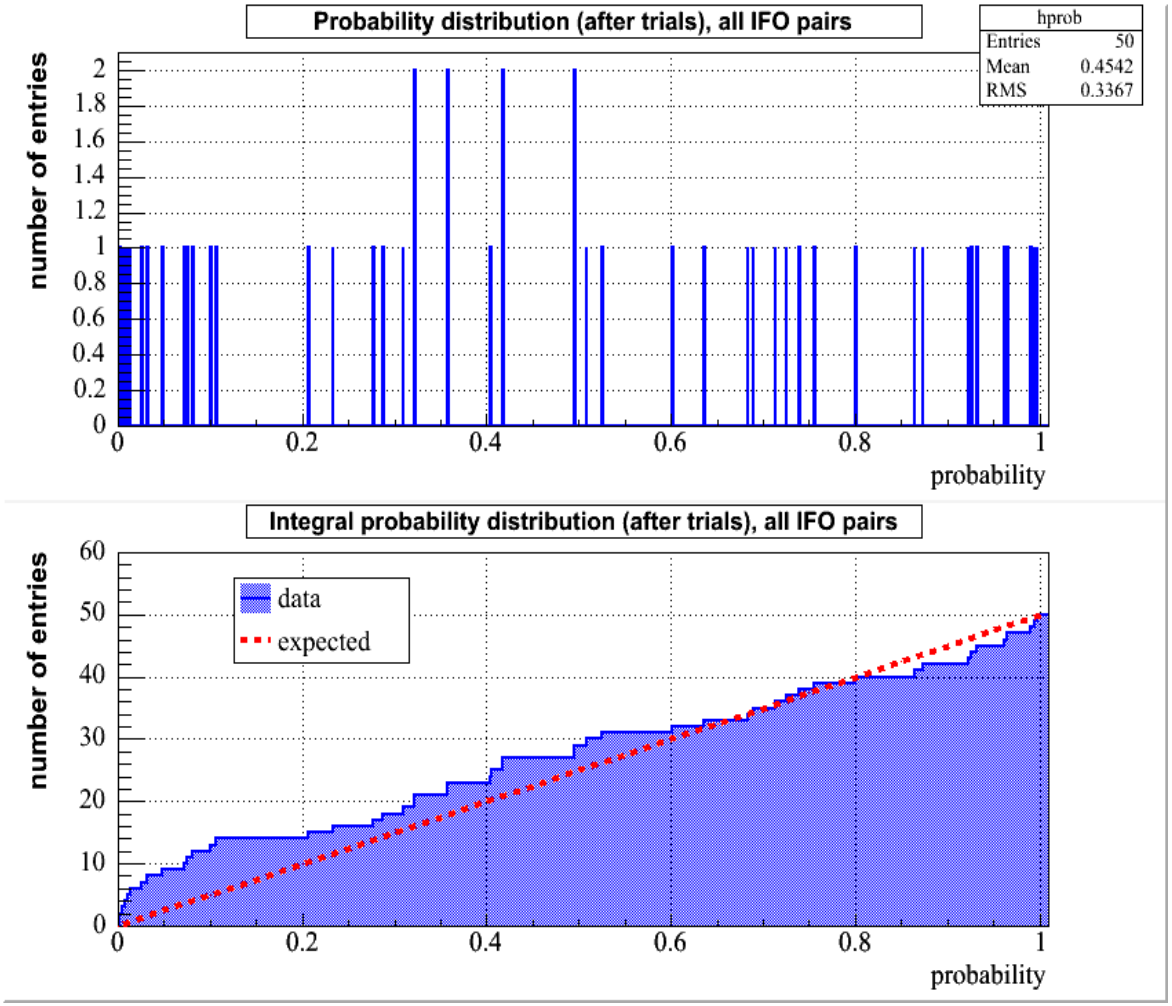
- consistent with null hypothesis

Example of probability distribution with injected signals



- inject signals into playground, sine-gaussian, f = 554 Hz, Q = 8.9, hRss = 2.6E-21
- K-S test: ***p = 0.15***

Example of probability distribution with injected signals



- inject signals into playground, sine-gaussian, f = 554 Hz, Q = 8.9, hRss = 2.6E-21
- K-S test: ***p = 0.026***

Summary

- performed search for short-duration GW bursts coincident with S2 and S3 GRBs using crosscorrelation method
- combined S2 and S3 results
  - there were much fewer S3 GRBs than S2 GRBs due to lockloss and also fewer triggers
- sample probability distribution consistent with null hypothesis
- large outliers seen in one GRB off-source period
  - S3 segments list probably needs refinement