Search Method for Coincident Detection of Events in Time and Direction in the Datastreams of LIGO and the IceCube Neutrino Detector

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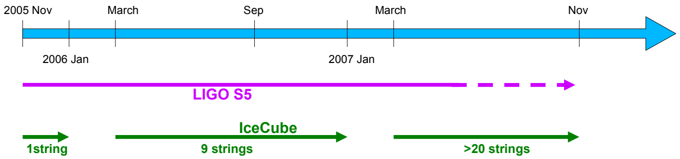
Neutrino observatories such as IceCube are capable of detecting neutrinos originating from a wide range of astrophysical sources. High energy neutrinos from cosmological distances, likely associated with very energetic astrophysical sources (such as GRBs, AGNs, etc.), are expected to interact with the IceCube detector in a way that allows the determination of their arrival time and direction. Our method shall examine IceCube's neutrino events and the gravitational wave candidates of the LIGO detector network which are coincident in time and direction during LIGO's fifth science run. Rings corresponding to the possible gravitational wave source direction are determined via a similar method to the one originally developed for searches for gravitational wave repeaters*. Each ring, corresponding to an event candidate, is then matched to the direction of time-coincident IceCube events. With typically ~2 neutrino events per day, the background coincidence rate will be low, and the association between GWs and neutrinos can be addressed either statistically or on an event by event basis. The method is capable of confident detection of gravitational waves and of extending each detector's scientific reach.

1 Expected overlap of observing time



2 Trigger rate

Triggers are produced by LIGO standard event trigger generators (e.g. Q-pipeline). Based on triggers during the first portion of S5 (November 17-May 2 (167 days)) the expected low threshold trigger rates are

- ~900,000(H2) - 1,400,000((L1) - 2,800,000(H1) single detector trigger events (depends on detector)→ ~ 1 event in every 5 -13 seconds
- ~28,000 time double coincidences for H1 and L1 → ~ 1 event in every 10 minutes
- ~15,000 time and frequency double coincidences → ~ 1 event per 18 minutes
- ~8,300 unique time, frequency and Q-plane double coincidences → ~ 1 event in every half an hour
- ~47 triple time-frequency-Q coincidences for L1-H1-H2 → ~ 1 event in every three days

The current IceCube neutrino rate of ~2 events per day is expected to increase in March 2007 when the next step of detector commissioning is finished (~ 5 events per day).

3 Event Direction

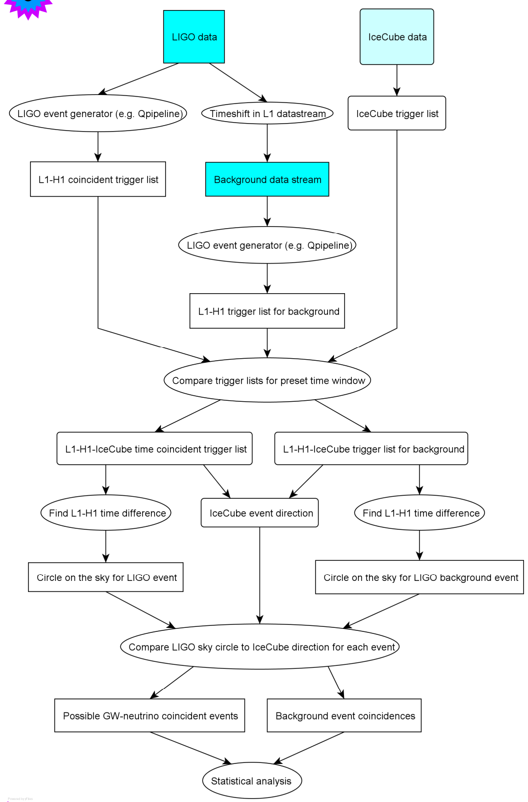
- IceCube event direction can be determined to better than 2 degrees. IceCube is sensitive to neutrino events which originate from the Northern hemisphere.
- Using the two LIGO detectors in the best case scenario one might determine a ~1 degree thick circle (1 σ) on the sky corresponding to each event candidate. Assuming that coincident triggers produce a uniform distribution of time shifts between H1 and L1 only 5.6% of coincident events would have a probability of zero of originating in the northern celestial hemisphere.
- For the LIGO-VIRGO network the directional sensitivity will improve significantly and there will be two allowed directions on the sky instead of the circle.

4 Proposed analysis procedure

1. Generate coincident LIGO trigger list via LIGO event generators (e.g. Q-pipeline)*
2. Compare GW trigger list with the list of neutrino events from IceCube for a given time window.
3. For GW events overlapping in time with IceCube events find sky positions on the celestial sphere (ring) that may have produced GWs consistent with the coincident LIGO triggers (L1-H1). For plotting the ring, apply a procedure similar to the one developed for searches of gravitational wave repeaters.*
   - To find the time difference between L1 and H1 trigger events correlate the conditioned L1 and H1 data streams.
   - Using this time difference and the sidereal time of the event we plot a ring, with a width determined by the precision in the time difference, via triangulation.
4. We shall consider LIGO-IceCube events coincident in direction if the IceCube 90% directional confidence patch touches or overlaps the 90% confidence belt of the LIGO ring or LIGO-VIRGO patches.
5. The LIGO-IceCube coincident (in time and direction) event rate is compared with (background) event rate obtained via the same procedure using time shifted L1 datastreams.

*See GWDAW-11 poster titled "Search for Gravitational Wave Repeaters" by John Dwyer et al.
*Q-pipeline - See talk by S. Chatterji

5 Proposed analysis pipeline



6 Analysis input parameters

We can control or optimize:
- time-window chosen
  This depends on the inherent uncertainty on the delay between GW and neutrino emission for the given astrophysical source.
- GW trigger rate can be controlled via changing the trigger threshold in the ETG

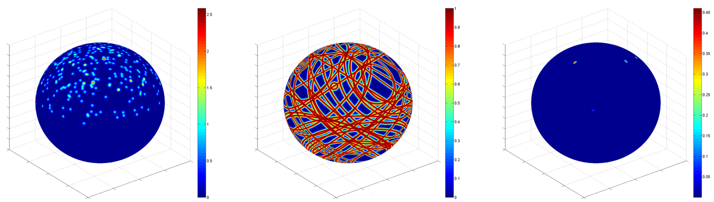
We have no or little control on:
- GW angular resolution, ultimately determined by the signal SNR and waveform type
- neutrino event angular resolution, determined by IceCube instrumental parameter
- observed neutrino rate, however it is expected to increase as the commissioning of IceCube is progressed

7 Estimated lower bounds on the rate of GW-neutrino coincident events

Monte Carlo simulation results for:
- six months of GW-neutrino coincident observing time
- neutrino rate is set for 2 events per day
- angular resolution of IceCube is fixed at 2 degrees (+/- 1 σ)
- the thickness of the LIGO ring is set at 2 degrees (+/- 1 σ)
- three different GW trigger rates are considered
  - -1 event in every 3 days, corresponding to the expected rate of triple (L1-H1-H2) coincidences
  - -10 events per day
  - -1 event in every half an hour, corresponding to the expected rate of double (L1-H1) coincidences
- vary the neutrino-GW trigger time window logarithmically

GW rate /day	Δt(neutrino-GW) (s)	neutrino-GW coincidences / 6 months
0.333	100	4×10^{-3}
	10	4×10^{-4}
	1	4×10^{-5}
	0.1	4×10^{-6}
10	100	1×10^{-1}
	10	1×10^{-2}
	1	1×10^{-3}
	0.1	1×10^{-4}
48	100	6×10^{-1}
	10	6×10^{-2}
	1	6×10^{-3}
	0.1	6×10^{-4}

8 Simulated sky distributions and event recovery example



- The left sky map shows 360 simulated neutrino events with 2 degrees of angular resolution (expected for 6 months of IceCube observations). The events are distributed on the northern hemisphere.
- The center map shows 60 simulated rings with 2 degrees widths for a network of two GW detectors.
- The right sky map shows recovered events coinciding in time, with the position of the neutrino event having some overlap with the ring corresponding to the GW event. The map was produced for 100 time coincidences (corresponding to 2 and half years of observation with 2 neutrino events per day and one GW event in every half an hour).

9 Conclusions

We present a simple approach for finding correlation between high-energy neutrino events and the gravitational wave data stream. The estimated low probability of coincidence between the data streams for coincident taking periods is encouraging. The result's dependence on input parameters such as GW-neutrino trigger time window is significant, therefore it requires further investigations. The ultimate goal, the correlation analysis of gravitational wave data and IceCube events is promising and should be pursued further.

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