Probing neutrino emission at GeV energies from compact binary mergers with IceCube

Gwenhaël de Wasseige, Imre Bartos, Krijn de Vries, Erin O’Sullivan
Compact binary mergers

Interferometers

A neutrino detector
Compact binary mergers

**Ingredients**

- BBH
- BNS and NSBH

01, 02 and 03

Interferometers

A neutrino detector
Which neutrinos do we look for?
Which neutrinos do we look for?

Graph showing different types of neutrino fluxes vs. neutrino energy (eV). Key categories include:
- Cosmological $\nu$
- SuperNova burst (1987A)
- Supernova Remnant
- Atmospheric $\nu$
- High-energy astrophysical $\nu$
- Cosmogenic $\nu$

Authors: A. Keivani, R. Hussain, M. Colomer Molla
Which neutrinos do we look for?
How could GeV neutrinos be produced?

\[ p + p, n \rightarrow \pi^+ \rightarrow \mu^+ + \nu_\mu \]
\[ \mu^+ \rightarrow e^+ + \nu_e + \bar{\nu}_\mu \]
\[ \pi^0 \rightarrow 2 \gamma \]
\[ \pi^- \rightarrow \mu^- + \bar{\nu}_\mu \]
\[ \mu^- \rightarrow e^- + \bar{\nu}_e + \nu_\mu \]

Give extra information on source environment

Maouloud, GDW, Ahlers, Bustamante, van Elewyck, PS2-129
How to detect GeV neutrinos?

Astrophysical neutrino

Not $\nu_\mu$ CC interaction

Detected event

PeV neutrino

How to detect GeV neutrinos?
Simulated event

GeV neutrino
Simulated event

GeV neutrino
Let's do the event selection together!
Astrophysical neutrino

Atmospheric muon

High luminosity

Low luminosity

Pure noise

GeV neutrino

Non-causally connected hits

Causally connected hits
Atmospheric muon

GeV neutrino

Pure noise

Rate = 0.02 Hz

(Initial rate: kHz)
How to detect a GeV neutrino signal?

Time window of interest

Control region

# of events

Time

8 hours

Increase?
Did we find GeV neutrinos?

“Spiraling Black Holes”
(Artist's conception)
Did we find GeV neutrinos?

- **3 BNS + 1NSBH mergers**
  Search for a prompt signal
  \([t_0, t_0+3] \text{ s}\)

- **6 BBH mergers**
  Search in an extended time windows
  \([t_0-500, t_0+500] \text{ s}\)

"Spiraling Black Holes"
(Artist's conception)
Did we find GeV neutrinos?

- **3 BNS + 1NSBH mergers**
  Search for a prompt signal
  
  \[ [t_0, t_0+3] \text{ s} \]
<table>
<thead>
<tr>
<th>Event</th>
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<th>EM counterpart?</th>
<th># of (\nu) events in ([t, t+3s])</th>
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<tbody>
<tr>
<td>BNS170817</td>
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Upper limit on the fluence at Earth:

$$1.84 \times 10^7 \text{ neutrinos } \text{MeV}^{-1} \text{cm}^{-2}$$

in the 3 seconds integrated over 3 flavours
Comparison with other neutrino searches

<table>
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<th>$[t, t +3s]$</th>
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Comparison with other neutrino searches

![Graph showing comparison of neutrino search results.](image-url)
Did we find GeV neutrinos?

- 3 BNS + 1NSBH mergers
  Search for a prompt signal $[t_0, t_0+3]$ s

- 6 BBH mergers
  Search in an extended time windows $[t_0-500, t_0+500]$ s

“Spiraling Black Holes”
(Artist's conception)
Did we find GeV neutrinos?
Did we find GeV neutrinos?
Did we find GeV neutrinos?

In the 5% tail
We have searched data collected by the Fermi Large Area Telescope (LAT) for possible high-energy (E > 100 MeV) gamma-ray emission in spatial/temporal coincidence with the LIGO/Virgo trigger G288732.

At the time of the trigger (T0 = 2017-06-08 02:01:16.492 UTC, 518580081.492 MET), none of the LIGO Bayestar probability map was in the LAT field of view. Part of the region entered the LAT field of view 70 seconds after T0, and we reached 100% cumulative coverage within ~6.5 ks after the trigger. We define "instantaneous coverage" as the integral over the region of the LIGO probability map that is within the LAT field of view at a given time, and "cumulative coverage" as the integral of the instantaneous coverage over time.

We performed a search for a transient counterpart within the 90% contour of the LIGO map in the time window from T0 to T0 + 10 ks, and no significant new sources are found above a Test Statistic (TS) of 25. On this time scale, the highest significance excess found was at R.A.,Dec.=128.11, 43.39, (J2000) with a localization error of 0.24 degrees (90% c.l.), with a TS of 23, corresponding to a pre-trial significance of 4.8 sigma. Given the number of trials involved, the post trial significance of this excess is estimated to be ~3.5 sigma. The location of the candidate was occulted by the Earth at the time of the LIGO trigger, and came into the FoV at ~1200 s after T0.

A Swift ToO observation has been requested to initiate follow-up observations at the location of this candidate source and we encourage additional follow-up observations.
Take-home message

- Search for GeV neutrino counterpart…
  …with IceCube!

- Two different searches
  - \([t, t+3s]\) for BNS and NSBH
  - \([t-500s, t+500s]\) for BBH

- No significant detection

- Many events in O3
  - Systematic follow-up of BNS and NSBH
  - Stacking analysis for BBH at the end of the run
How to detect neutrinos?

Cherenkov radiation

Dielectric medium

ν

e, μ, τ

1 km³

~ 5000 sensors or Digital Optical Modules (DOMs)
How to detect neutrinos?

Dielectric medium

Cherenkov radiation

ν, e, μ, τ

ν, μ
Did we find GeV neutrinos?

Upper limit on the fluence at Earth:

$$5 \times 10^4 \text{ neutrinos MeV}^{-1} \text{ cm}^{-2}$$

in the 1000 seconds integrated over 3 flavours.