Search for Neutrino Signals from Regions of Localization of Gravitational-Wave Events

V. B. Petkov[1,2], I. M. Dzaparova[1,2,3], M. M. Kochkarov[1], A. N. Kurenya[1], Yu. F. Novoseltsev[1], R. V. Novoseltseva[1], P. S. Striganov[1,3], I. B. Unatlokov[1], and A. F. Yanin[1,3]

[1] Institute for Nuclear Research, Russian Academy of Sciences, Moscow, Russia,
[2] Institute of Astronomy, Russian Academy of Sciences, Moscow, Russia
[3] Sternberg Astronomical Institute, Lomonosov Moscow State University, Moscow, Russia
vpetkov@inr.ru

Abstract. Using data of the Baksan Underground Scintillation Telescope (BUST) we have made a search for muon neutrinos and antineutrinos with energies above 1 GeV from the regions of localization of reliably observed gravitational-wave events. No neutrino signals from gravitational-wave events have been detected in the interval of ±500 s at the BUST. The upper limits on integral fluxes of muon neutrino and antineutrino from the sources of gravitational waves are derived.

Keywords: gravitational waves; neutrinos
DOI:10.26119/978-5-6045062-0-2_2020_370

1 Introduction

Interest in the search for high energy neutrinos, on the scale of GeV and above, among other things, is due to the fact that the flux of such neutrinos is expected from any merger of a compact object with the remnant of a neutron star or a merger that occurs in a significant concentration of gas (Fraija 2016). To date, during three observing runs, the LIGO and Virgo gravitational wave detectors have reliably detected fourteen gravitational-wave events (Abbott et al. 2019, 2020a,b,c). The detection of gravitational-wave events initiated the search for their astrophysical sources. With the exception of the GW170817 no reliable signals have been detected from the gravitational-wave bursts. The GW170817 event was identified with the GRB 170817A gamma-ray burst detected by the Fermi gamma-ray burst monitor; electromagnetic radiation in a wide wavelength range was later detected (Abbott et al. 2017). Neutrino signals from the gravitational-wave events were sought in a wide energy range from 0.5 MeV to $\sim 2.5 \cdot 10^{10}$ GeV and for different types of neutrinos at the ANTARES and IceCube neutrino telescopes, Pierre Auger extensive air shower array, and Borexino, KamLAND, Super-Kamiokande and BUST detectors (Adrián-Martínez et al. 2016; Aab et al. 2016; Albert et al. 2017a,b,c; Gando et al. 2016; Abe et al. 2016, 2018; Albert et al. 2019; Petkov et al. 2018, 2019). No common sources of GWs and neutrinos have been identified so far.

2 Experiment

The BUST is located in Baksan Valley (North Caucasus, Russia) within an underground laboratory at an effective depth of 850 m of water equivalent. It is a multi-purpose instrument designed for a wide range of studies into physics of cosmic rays and elementary particles, and neutrino astrophysics (Alekseev et al. 1979). The BUST design allows one to identify trajectories of the muons crossing the telescope and to determine the muon arrival direction. When detecting muons from the lower hemisphere ($\theta > 90°$) one can exclude the background from muons penetrating underground (since all known components of cosmic rays are absorbed at a depth of several kilometers of rock), if the flux of back-scattered muons from above is less than the neutrino effect at the telescope depth. For the BUST depth the muon background is totally excluded when zenith angles are $\theta > 100°$. When an object is located in the upper hemisphere one can also search for muon neutrinos in the given time interval, provided that the muon background for a given direction is small, i.e., for directions with sufficiently large thickness of matter. Separation of arrival directions of muons between the upper and lower hemispheres is realized using the time-of-flight method. The threshold energy of muon neutrinos detected by the BUST is determined by energy losses of muons crossing the telescope, and it is equal to 1 GeV for the used selection criteria.

3 Search for Muon Neutrinos from GW Events

The search of muon neutrinos associated with gravitational-wave events was performed in time interval of ± 500 s, as the maximum interval between the gravitational wave and the neutrino from cosmic gamma-ray bursts Baret et al. (2011). No neutrino signals from all fourteen reliably observed gravitational-wave events have been detected at the BUST in this interval. For the three of them (GW170817, GW170818, GW190814) the regions of localization were completely outside of field of view of the BUST. From the fact of absence of

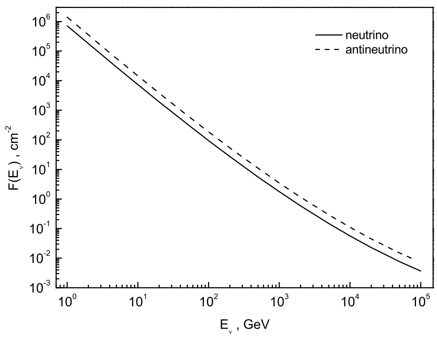

Fig. 1. The upper limits on integral fluxes of muon neutrinos and antineutrinos from GW150914 for the time interval ± 500 s as functions of their energy (for monoenergetic spectrum).

neutrino signals from the sources the upper limits (90% confidence level) on integral fluxes of muon neutrinos/antineutrinos were derived as functions of their energy assuming monoenergetic spectrum:

$$F(E_\nu, \theta, \phi) = \frac{n_{90}}{\epsilon S_\nu(E_\nu, \theta, \phi)}, \tag{1}$$

where $n_{90} = 2.3$, and $\epsilon = 0.84$ is the portion of neutrino events from a point-like source within a circle of radius $5.0°$. $S_\nu(E_\nu, \theta, \phi)$ is the effective area of detection of muon neutrino/antineutrino with energy E_ν and direction (θ, ϕ). The value of S depends on neutrino interaction cross-section and area of the BUST at this direction. The limits are derived separately for muon neutrino and antineutrino, because interaction cross-sections are different for muon neutrinos and antineutrinos (Hayato 2009), so that their effective areas of detection are different too. As example, figure 1 presents the upper limits on integral fluxes of muon neutrinos and antineutrinos from GW150914 as functions of their energy for monoenergetic spectrum.

Acknowledgments. The reported study was funded by RFBR, project number 19-29-11027. The work is performed with the Baksan Underground Telescope, Unique Scientific Facility of the Common Use Center Baksan Neutrino Observatory. This work was also partially supported by RFBR grant 17-52-80133.

Bibliography

Aab, A., Abreu, P., Aglietta, M., et al. 2016, Phys. Rev. D, 94, 122007
Abbott, B. P., Abbott, R., Abbott, T. D., et al. 2020a, ApJ, 892, L3
Abbott, B. P., Abbott, R., Abbott, T. D., et al. 2019, Physical Review X, 9, 031040
Abbott, B. P., Abbott, R., Abbott, T. D., et al. 2017, ApJ, 848, L12
Abbott, R., Abbott, T. D., Abraham, S., et al. 2020b, Phys. Rev. D, 102, 043015
Abbott, R., Abbott, T. D., Abraham, S., et al. 2020c, ApJ, 896, L44
Abe, K., Bronner, C., Hayato, Y., et al. 2018, ApJ, 857, L4
Abe, K., Haga, K., Hayato, Y., et al. 2016, ApJ, 830, L11
Adrián-Martínez, S., Albert, A., André, M., et al. 2016, Phys. Rev. D, 93, 122010
Albert, A., André, M., Anghinolfi, M., et al. 2017a, European Physical Journal C, 77, 911
Albert, A., André, M., Anghinolfi, M., et al. 2017b, Phys. Rev. D, 96, 022005
Albert, A., André, M., Anghinolfi, M., et al. 2019, ApJ, 870, 134
Albert, A., André, M., Anghinolfi, M., et al. 2017c, ApJ, 850, L35
Alekseev, E. N., Alekseeva, L. N., Chudakov, A. E., et al. 1979, in International Cosmic Ray Conference, Vol. 10, International Cosmic Ray Conference, 282
Baret, B., Bartos, I., Bouhou, B., et al. 2011, Astroparticle Physics, 35, 1
Fraija, N. 2016, Journal of High Energy Astrophysics, 11, 29
Gando, A., Gando, Y., Hachiya, T., et al. 2016, ApJ, 829, L34
Hayato, Y. 2009, Acta Phys. Polon. B, 40, 2477
Petkov, V. B., Boliev, M. M., Butkevich, A. V., et al. 2019, arXiv e-prints, arXiv:1907.05183
Petkov, V. B., Novoseltseva, R. V., Boliev, M. M., et al. 2018, Soviet Journal of Experimental and Theoretical Physics Letters, 107, 398