Low energy neutrinos from gamma-ray bursts: experimental search status

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Abstract. Gamma-ray bursts (GRBs) are the most energetic known events in the Universe. Though gamma-ray telescopes observe about one GRB event per day, the nature of this phenomenon is not yet totally understood. Many theoretical models predict emission of neutrinos of all types in a wide energy range. In this talk we review experimental searches of GRB neutrinos in MeV energy range. The searches of this kind had been performed by several experiments: SuperKamiokande, SNO and KamLAND. Also the similar study is now in progress in Borexino collaboration.

1. Introduction
Gamma-ray bursts are one of the most spectacular and bright objects in the Universe which produce great amount of energy in a short period of time. This phenomenon has been staying the relevant problem in modern astrophysics for several decades. GRBs were explored for the first time in the 60s of previous century, but still their nature is not well-known, there is no full information about GRB engine and all processes occurring in its center. According to the most popular theoretical models we can observe GRBs due to merging of two massive objects (two neutron stars or neutron star and black hole) [1] or core collapse of massive, rapidly rotating star [2]. These models predict that significant part of produced energy is taken away by neutrinos of all flavors. Thus, search for neutrinos in a wide energy range correlated in time with GRBs can help to understand better this kind of events.

Neutrinos of all types were previously searched for in several experiments. IceCube [3], ANTARES [4], AMANDA [5], Baikal [6] and SuperKamiokande [7] collaborations have searched for neutrinos and antineutrinos in the TeV and PeV energy range. Search for MeV neutrinos was performed by SuperKamiokande [7], SNO [8] and KamLAND [9] and is now in progress in Borexino collaboration.

The average rate of observed GRBs is about 1 event per day. GRBs are detected by several satellites, such as Swift, Fermi, Integral and more. There are two admitted types of GRBs concerning their duration. Short GRBs have duration less than 2 seconds and are presumed to be connected with merging of two objects, duration of long bursts is from 2 to 1000 seconds, in theoretical models they are commonly connected with core collapse of massive star.

In this report we review all performed experimental searches for low energy neutrinos (MeV energy range) from GRBs.
2. Review of experimental searches for neutrinos emitted in GRBs

As it was said before searches for MeV neutrinos and antineutrinos were done by SuperKamiokande, SNO and KamLAND neutrino experiments. These detectors have different construction and properties and have opportunity to detect neutrinos via different reactions. Moreover, methods applied for analysis are also different. Detailed descriptions of analysis performed and results obtained by all collaborations are presented below.

2.1. SuperKamiokande

SuperKamiokande is a 50 kiloton water Cherenkov detector located in the Kamioka Mine near the city of Hida, Gifu Prefecture, Japan. The main goals of this experiment are the search for proton decay, studies of solar and atmospheric neutrinos, and watching for supernovae.

Search for neutrinos from GRBs was performed by SuperKamiokande in 2002 [7]. Detector is able to register neutrino in the wide energy range, analysis for low energy (7-80 MeV) and high energy (200 MeV-200 GeV) was made independently. In this work all GRBs registered from April 1996 to May 2000 were considered, the BATSE online catalog [10] was used as GRBs data base. SuperKamiokande collaboration made an assumption that neutrinos in GRBs had been ejected simultaneously with light. Three time windows were chosen for analysis: ±10, ±100 and ±1000 seconds centered on the GRB time. Besides, 24-hour period before the moment of GRB registration was splitted into 24 time windows to search for neutrino signal excess within these windows. It was made in order to search for neutrinos that may precede GRB’s photons as it was observed in 1987 during supernovae explosion. There was no evidence of neutrinos correlated with GRBs in this analysis. The fluence upper limits were set for neutrinos and antineutrinos with 90% confidence level. Since there is no one definite model of GRBs and therefore neutrino spectrum is not known, limits on neutrino fluence were expressed in terms of ”Green’s function” fluence for mono-energetic neutrinos.

2.2. SNO

SNO detector contained 1 kiloton of pure heavy water. It was the experiment located in Creighton Mine in Sudbury, Ontario, Canada and was designed to detect neutrinos from the Sun.

Analysis of correlations between GRBs and neutrino signal in detector was performed by SNO in 2014 [8], they have used Swift satellite [11] data as the source of information about GRBs. Available energy for SNO detector to register neutrinos is in range from 5 to 13 MeV. Two time windows were chosen. The first window is 3 hours prior to GRB time (in assumption that neutrinos produced before the photons, the same as for SN 1987a) and the second window is 3 hours after the moment of GRB registration (in order to detect neutrinos from GRB’s afterglows and additionally to consider delay between neutrinos and photons due to non-zero neutrino mass). The excess of signal above the background was not showed up. The same as for SuperKamiokande results, the fluence upper limits were obtained for all neutrinos and antineutrinos (in terms of ”Green’s function” fluence for mono-energetic neutrinos).

2.3. KamLAND

KamLAND is liquid scintillator neutrino detector located in the underground laboratory near Toyama, Japan. KamLAND experiment is performing researches of neutrino oscillations, reactor, solar and geoneutrinos.

KamLAND collaboration has published results of the search for electron antineutrino associated with GRBs in 2015 [9]. Electron antineutrinos in this analysis were detected via inverse beta-decay reaction. GRB events detected by Swift, Fermi, Integral, AGILE and more satellites were used. Analysis was independently made for short and long GRBs. Data taking period consists of two periods: from August 2002 to September 2011 (antineutrino events with
energies from 7.5 to 100 MeV were searched in first period) and from September 2011 to June 2013 (lower limit for energy range was shifted to 0.9 MeV). Time windows for correlation search are different for each GRB and depend on GRB duration, also in estimation of time windows durations difference between times of registration of light and neutrinos was considered. No time coincidences of neutrino signal and GRB were found. The fluence upper limit for electron antineutrino was estimated (in terms of "Green’s function" fluence for mono-energetic neutrinos).

3. Results comparison
Let us compare results from experiments described above.

![Figure 1. Fluence upper limits versus neutrino energy, results of SuperKamiokande and SNO collaborations [8]. Lines connecting points are guide to the eyes only.](image1)

![Figure 2. Fluence upper limits versus electron antineutrino energy, results of SuperKamiokande, SNO and KamLAND collaborations [9]. Lines connecting points are guide to the eyes only.](image2)

From figure 1 can be seen that the strongest limits for all neutrino types for energy above 7 MeV were obtained by SuperKamiokande. The best result for energy lower then 7 MeV for all neutrino types except electron antineutrinos was obtained by SNO. And as it can be seen in figure 2 for the electron antineutrinos with energy 2-7 MeV the strongest limit is the KamLAND’s one.

4. Borexino
Borexino is liquid scintillator detector located at the Laboratori Nazionali del Gran Sasso (LNGS), near the town of L’Aquila, Italy. The main aim of Borexino is to measure fluxes of solar neutrinos, also Borexino allows to detect atmospheric and geoneutrinos, and neutrinos from different astrophysical sources.

Analysis of GRBs and neutrinos coincidences is now in progress in Borexino collaboration. IceCube data base [12] is used as catalog of GRBs in period from December 2007 to February 2015. There are two independent DAQ systems in Borexino, both of them are used in analysis. Fluence upper limits for neutrinos and antineutrinos are going to be obtained in energy region from 2 to 20 MeV in order to compare with another results.

5. Conclusion
Experimental searches for low energy neutrinos from GRBs have a long history and though no proof of existence of such kind of neutrino was found, modern neutrino detectors help to learn
more about GRB phenomenon by setting limits on fluences for all types of neutrinos.

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