A search for low-energy Borexino's signals correlated with γ-ray bursts, solar flares and gravitational wave events

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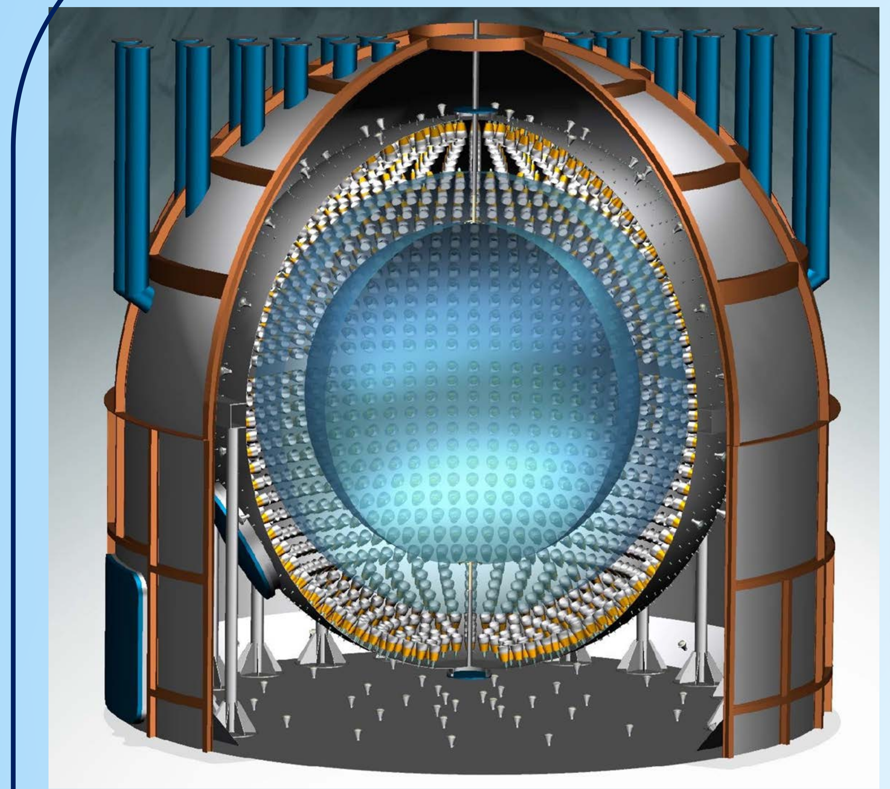
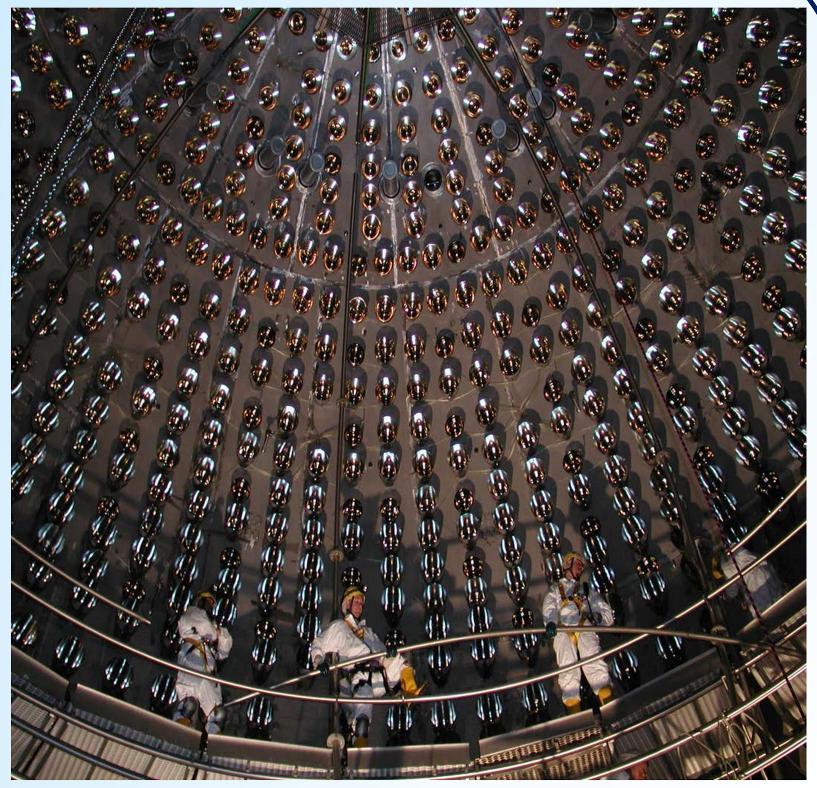
The Borexino detector





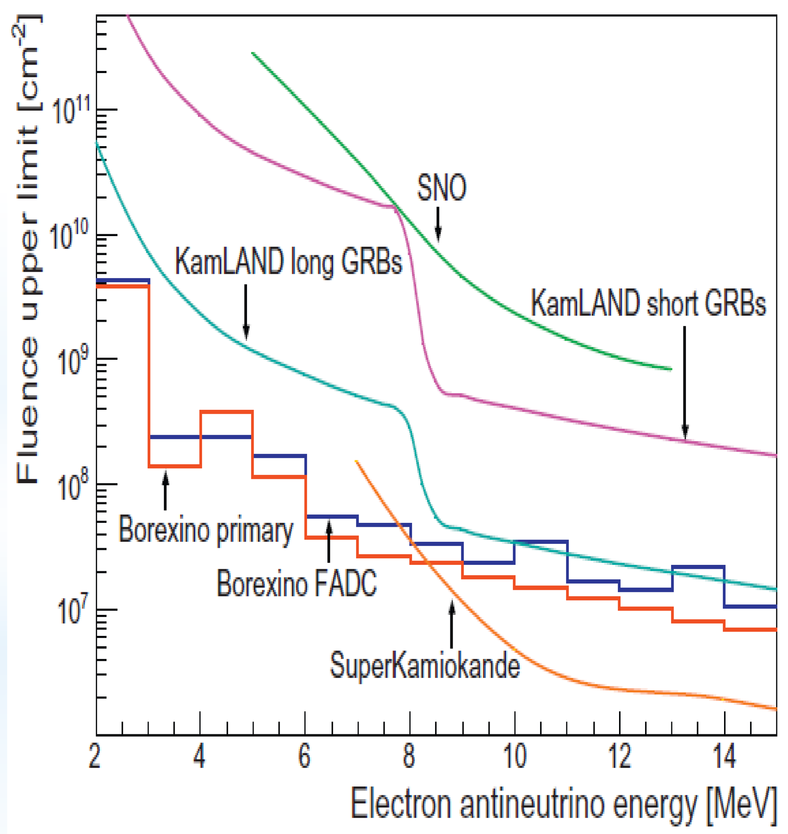
Borexino is a real-time detector for solar neutrino spectroscopy located at the Gran Sasso Underground Laboratory. Its main goal is to measure ***low-energy solar neutrinos*** via ***(ν,e)-scattering*** in an ultrapure liquid scintillator. At the same time, the extremely high radiopurity of the detector and its large mass allow it to be used to study other fundamental questions in particle physics and astrophysics. The energy resolution scales approximately as ***σ/E = 5% $E^{-1/2}$***. The position of an event is determined using a photon time of flight reconstruction algorithm. The space resolution of the events, as measured using ***^{214}Bi - ^{214}Po*** decay sequence, is ***13.2 cm.***

Abstract

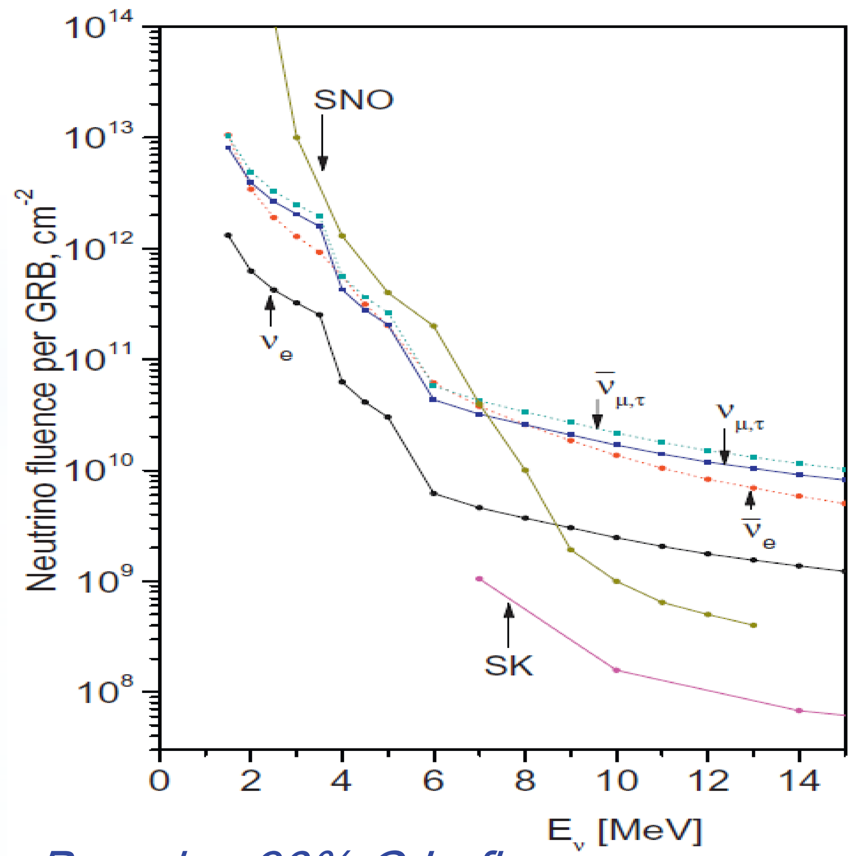
*The results of a low-energy neutrino search using the Borexino detector in coincidence with gamma-ray bursts (**GRB**), solar flares (**SF**) and gravitational wave (**GW**) events are presented. The correlated events with energies greater than 0.25 (1.0) MeV were looked for within a various time windows centered around the GRB, SF or GW detection time. As a result, we have obtained the best current upper limits on all flavor neutrino fluences associated with these astrophysical sources for neutrino energy below 5-7 MeV.[1-3].*

Upper limits on ν-fluence from GRBs

*Gamma ray bursts (GRBs) are among the most energetic events known in the Universe, with a typical apparent energy release of 10^{54} erg (or ~1 solar mass), assuming isotropic emission of energy. A search for neutrino and antineutrino events correlated with **2350(980)** gamma-ray bursts (GRBs) is performed with Borexino data collected between Dec 2007 and Nov 2015.*

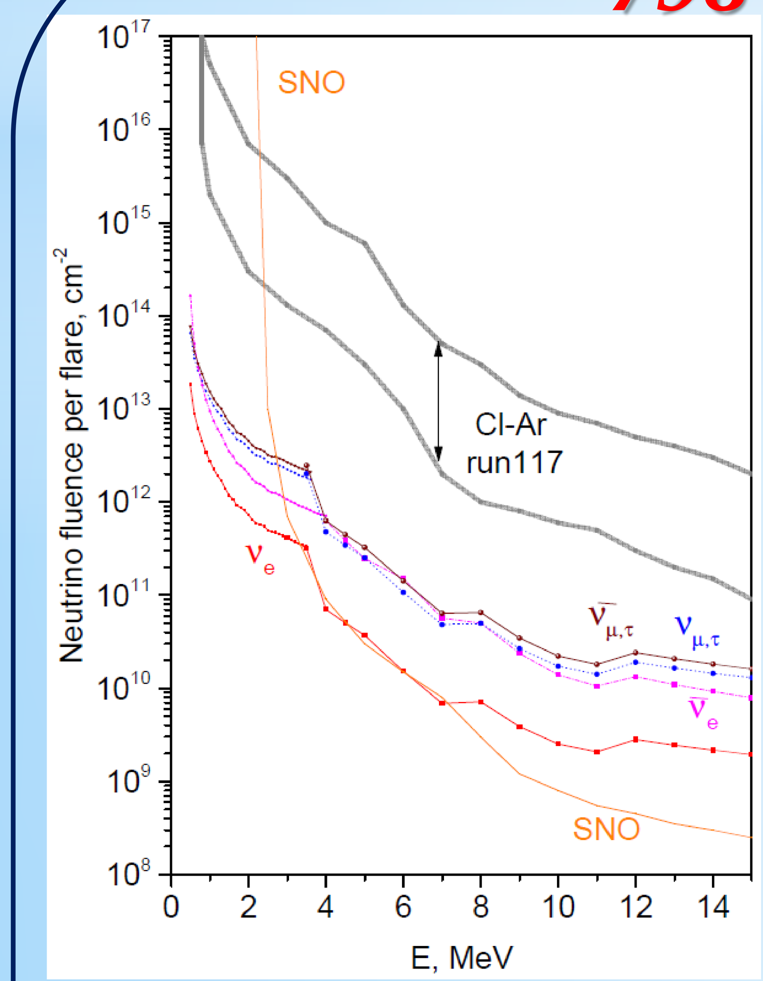


*Borexino fluence upper limits for electron antineutrinos from GRBs causing **inverse beta decay** in comparison with results from SK, SNO and KamLAND.*



*Borexino 90% C.L. fluence upper limits obtained through **neutrino-electron elastic scattering** for different neutrino flavors. Given are also the limits obtained by SNO and SK.*

798 Solar flares



Flares are caused by the restructuring of the solar magnetic field, which leads to the acceleration of protons and other charged particles and ions. Neutrinos could be generated in the decays of pions, which are abundantly produced in pp- and p-collisions in the flare's region.

*Borexino investigated **798 solar flares** as possible neutrino sources and obtain the strongest up-to-date limits on the fluence of neutrinos of all flavor neutrino below 3–7MeV. Assuming the neutrino flux to be proportional to the flare's intensity, we exclude an intense solar flare as the cause of the observed excess of events in **run 117** of the Cl-Ar Homestake experiment.*

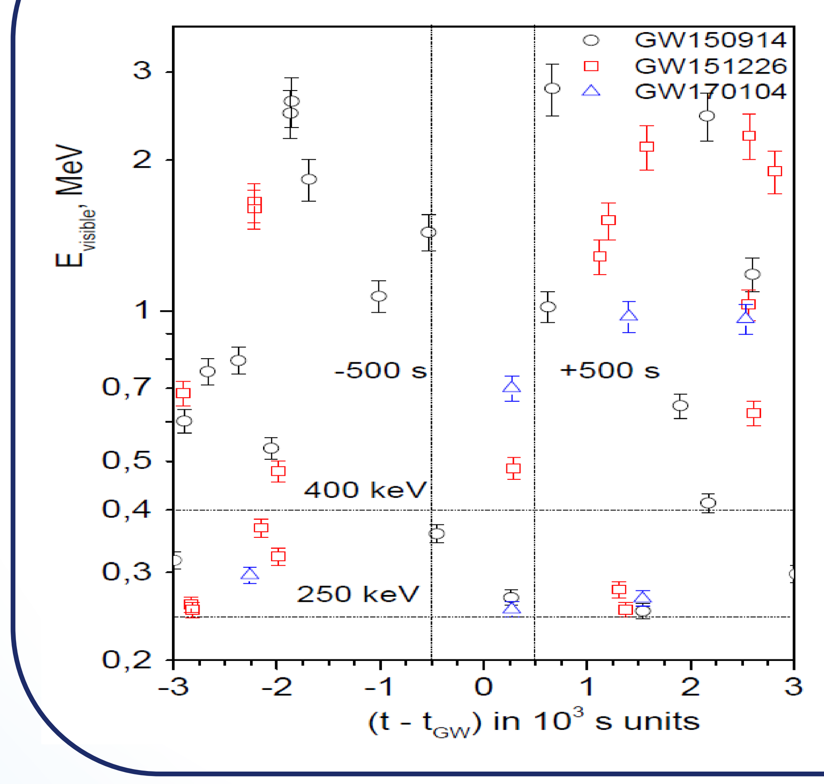
*Borexino 90% C.L. fluence upper limits obtained through neutrino-electron elastic scattering for ν_e, $\bar{\nu}_e$, $\nu_{\mu,\tau}$ and $\bar{\nu}_{\mu,\tau}$. In the plot the limits obtained for ν_e by SNO Coll. are labelled and the range of fluences that would have explained the **Cl-Ar** Homestake excess in run 117*

1. M. Agostini et al. (Borexino Coll.), ***Borexino's search for low-energy neutrino and anti-neutrino signals correlated with gamma-ray bursts***, Astroparticle Physics 86 (2017) 11–17

2. M. Agostini et al . (Borexino Coll.), ***A Search for Low-energy Neutrinos Correlated with Gravitational Wave Events GW 150914, GW 151226, and GW 170104 with the Borexino Detector.*** The Astrophysical Journal, 850:21, 2017

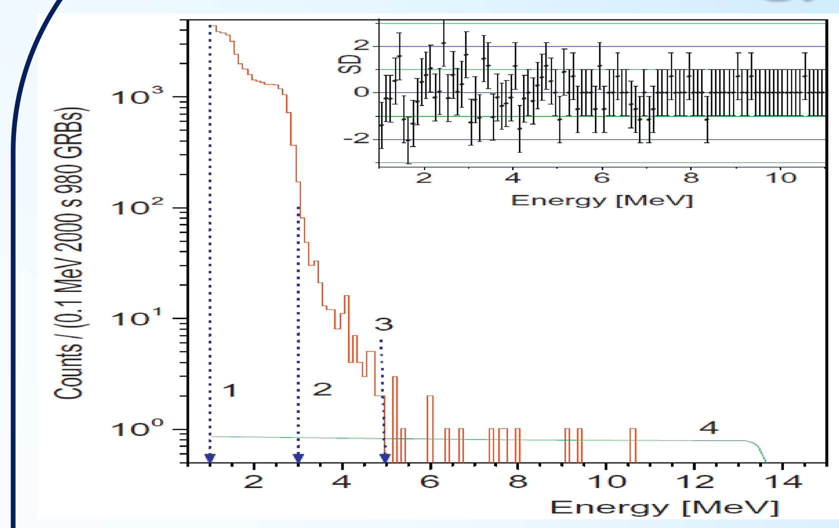
3. M. Agostini et al. (Borexino Coll.) ***Search for low-energy neutrinos from astrophysical sources with Borexino***, arXiv 1909.02422v1, to be appeared in Astroparticle Physics (2020)

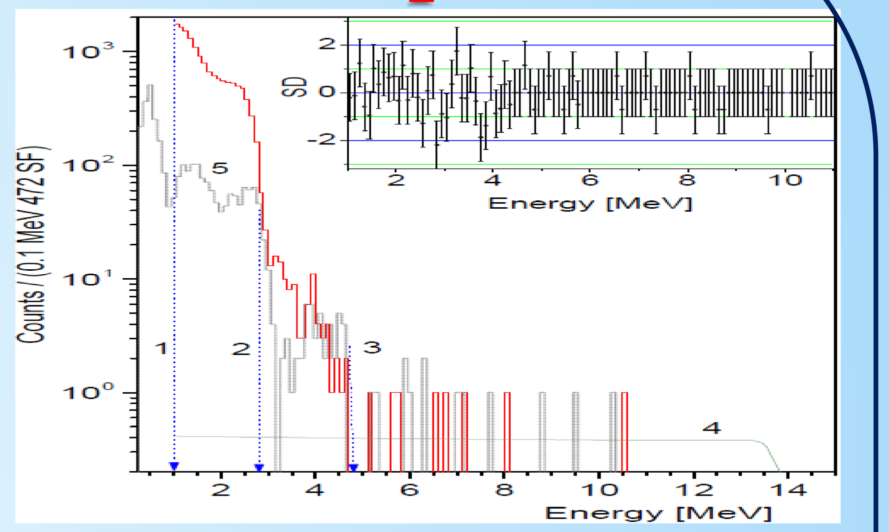
Borexino events within ±3000 s interval



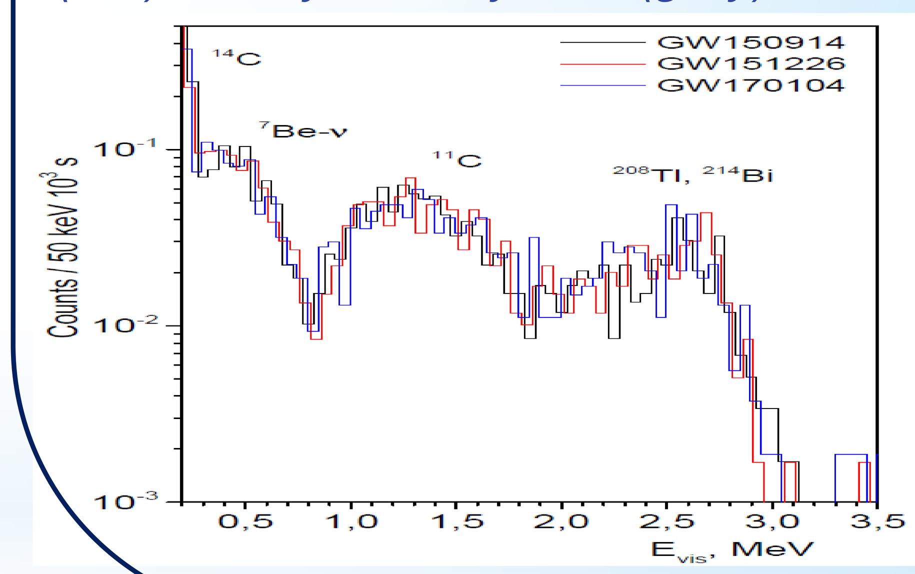
*Borexino events between **0.25 MeV** and **15 MeV** occurring within **±3000 s** of the GW150914 (black circles), the GW151226 (red squares) and the GW170104 (blue triangles) detection times. The **±500 s** time window covers the possible delay of a neutrino which propagates slower than GW as well as possible earlier emission of neutrinos due to poorly constrained details of BH-BH merger. Moreover, the choice is consist-ent with the time window chosen by ANTARES, Pierre Auger Observatory, KamLAND and S-K. All events are consistent with the expected solar neutrino and background count rate.*

Borexino energy and time spectra





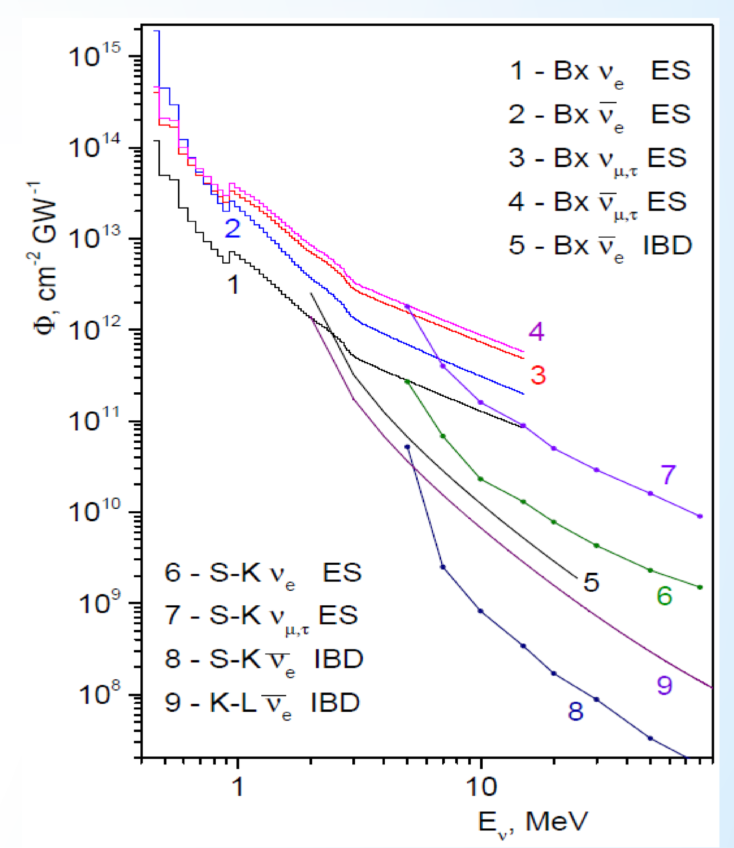
*Borexino energy spectrum of singles in correlation with **980 GRBs** (left) and **472 SFs** (right). In insets, the difference between spectra measured in GRB/SF time windows is shown in the units of standard deviations (SD). Line 4 shows the expected spectrum of recoil electrons for the fluence **1×10^{10} cm^{-2}** per one GRB/SF of 14 MeV neutrinos. Spectra of single events in correlation with SFs were measured by FADC system (red) and by DAQ system (grey).*



*The plot shows the main spectral components, such as recoil electrons produced in elastic scattering of solar neutrinos from **^{7}Be**, decays of cosmogenic **^{11}C** and external gamma events caused by decays of **^{214}Bi** and **^{208}Tl** outside fiducial volume. The spectra corresponding to the GW151226 and GW170104 are shifted to the left by 15 and 30 keV for illustrative purposes.*

Gravitational wave events

*The observation of GW events by the LIGO/VIRGO experiments triggered an intensive follow-up campaign with neutrino detectors. Using the unique features of the Borexino detector—outstanding low-level background and low-energy threshold—new limits on low-energy neutrino fluence correlated with **GW150914, GW151226** and **GW170104** events have been obtained.*



The upper limits on the fluence without oscillation for monoenergetic (anti-) neutrinos with energy E are calculated as follows:

$$\Phi = \frac{N_{90}(E_\nu, n_{obs}, n_{bkg})}{\epsilon N_e \sigma(E_{th}, E_\nu)}$$

*where **N_{90}** is the 90 % C.L. upper limit on the number of GW-correlated events in **(E_{th},E_ν)** range per single GW event, ε is the recoil electron detection efficiency, **N_e** is the number of electrons in the Borexino fiducial volume, **$\sigma(E_{th},E_\nu)$** is the total neutrino-electron cross-section integrated over the **(E_{th},E_ν)** interval.*

*Borexino 90% C.L. fluence upper limits obtained through neutrino-electron elastic scattering for **ν_e** (line 1), anti-**ν_e**(line 2), **$\nu_{\mu\tau}$**(line 3), anti-**$\nu_{\mu\tau}$**(line 4) and through inverse beta-decay for anti-**ν_e** (line 5). Given are also the limits obtained by Super-Kamiokande (line 6, 7, 8) and KamLAND (line 9).*