

Cosmic neutrino and the possibility of searching for W bosons with masses 30–100 GeV in underwater experiments

V. S. Berezinskiĭ and A. Z. Gazizov

Institute of Nuclear Research, USSR Academy of Sciences

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The possibility is discussed for searching for W bosons in underwater experiments with the aid of the resonant reaction $\bar{\nu}_e + e^- \rightarrow W^- \rightarrow \text{hadrons}$. The resonance production of W bosons manifests itself as a narrow peak in the energy spectrum of the underwater nuclear-electromagnetic cascades. For W -boson masses 30–100 GeV (resonant antineutrino energies $9 \times 10^{14} - 1 \times 10^{16}$ eV) the resonant effect should exceed by more than one order of magnitude the background due to the nonresonant neutrino events.

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The search for the W boson in underwater neutrino experiments is most effective with the aid of the Glashow resonant reaction^[1] $\bar{\nu}_e + e^- \rightarrow W^- \rightarrow \text{hadrons}$. The W -boson masses (m_W) from 30 to 100 GeV correspond to antineutrino energies $E_0 = m_W^2/2m_e$ from 9×10^4 to 1×10^{16} eV. The W -boson mass in the Weinberg model ($m_W \approx 70$ GeV) corresponds to an antineutrino energy 5×10^{15} eV. Neutrino fluxes of such energies, sufficient for the search for the W bosons, can be expected from extragalactic sources.^[2] The background due to atmospheric muons is negligibly small at such energies, and the resonant production of W

bosons manifests itself in a narrow peak in the spectrum of the hadron-induced showers, a peak due to other neutrino events ($\nu_\mu + N \rightarrow \mu + \text{hadrons}$, $\nu_\mu + N \rightarrow \nu_\mu + \text{hadrons}$, etc.).

The presently planned DUMAND experiment is aimed at registering high-energy muons and neutrinos at a 5 km depth in the ocean.^[3] The apparatus should consist of a grid of photomultipliers spanning a volume 10^9 m^3 . The particle detector is the ocean water itself in the space between the photomultipliers; in this reaction, in particular, the hadrons due to the $\nu_e e$ collisions will produce in water a nuclear-electromagnetic shower that emits Cerenkov light.

Even more effective registration of showers due to neutrinos with energies above 10^{16} eV under water is possible by an acoustic method.^[4]

The cross section of the reaction $\bar{\nu}_e + e^- \rightarrow W^- \rightarrow \text{hadrons}$ near resonance is described by the Breit-Wigner formula

$$\sigma = \frac{4\pi}{m_W^2} \frac{2J+1}{2j+1} \frac{\Gamma_l \Gamma_h}{(E_c - m_W)^2 + \Gamma^2/4} \quad (1)$$

where $J=1$ is the W -boson spin, $j=1/2$ is the electron spin, $\Gamma_l = (1/6\pi\sqrt{2})G_F m_W^3$ is the width of the lepton decay channel, $W \rightarrow l\nu$, G_F is the Fermi weak-interaction constant, Γ_h is the width of the hadron channel, and Γ is the total width. In the model of four colored quarks $\Gamma_h = 6\Gamma_l$ and $\Gamma_h \approx 3/4\Gamma$, if there are only two lepton decay channels $W \rightarrow e\nu$ and $W \rightarrow \mu\nu$.

At a W -boson mass $m_W \geq 30 \text{ GeV}$, the entire upper hemisphere above the installation is transparent to antineutrinos with resonance energy. Integrating over the power-law spectrum of the neutrinos with allowance for the cross section (1), we easily obtain the frequency of the appearance of resonant events $\bar{\nu}_e + e^- \rightarrow W^- \rightarrow \text{hadrons}$ in an installation with a total number of electrons N_e :

$$\nu_{\text{res}} = 3\sqrt{2}\pi^2 \gamma N_e G_F \Phi_{\bar{\nu}_e}^-(> E_0), \quad (2)$$

where γ is the exponent of the integral neutrino spectrum, and G_F corresponds to a cross section $4.4 \times 10^{-33} \text{ cm}^2$.

Thus, the frequency ν_{res} of the appearance of the resonant events determines the antineutrino flux at an energy below $E_0 = m_W^2/2m_e$ independently of the W -boson mass. The reason is that $\nu_{\text{res}} \sim \Phi_{\text{dtr}}(E_0) \Gamma_{\text{lab}} \sigma_{\text{max}}$, where $\Phi_{\text{dtr}}(E_0)$ is the differential spectrum of the antineutrinos, $\Gamma_{\text{lab}} = (m_W/m_e) \Gamma \sim G_F(m_W/m_e)$ is the width of the resonance in the l.s., and $\sigma_{\text{max}} \sim 1/m_W^2$ is the cross section at the maximum of the resonance. Recognizing that $E_0 = m_W^2/2m_e$ and that $\Phi_{\text{dtr}}(E_0) \times E_0 \sim \Phi(>E_0)$, we verify that the frequency of the appearance of resonance events is in fact independent of the W -boson mass.

The frequency of the appearance of resonant events ν_{res} (in yr^{-1}) with an energy release $E_0 = m_W^2/2m_e$ in an underwater volume V (in m^3) is connected with the integral antineutrino flux $\Phi_{\bar{\nu}_e}^-(> E_0)$ by the relation

$$\Phi_{\bar{\nu}_e}^-(> E_0) \approx 5.3 \times 10^{-15} \frac{1}{\gamma} \left(\frac{\nu}{10} \right) \left(\frac{10^9}{V} \right) \text{ cm}^2 \text{ sec}^{-1} \text{ sr}^{-1}. \quad (3)$$

In the case of neutrinos produced in proton-nucleon collisions (pp neutrinos^[2]) the electronic antineutrinos amount to 1/6 of all the neutrinos. At $\nu = 10 \text{ yr}^{-1}$, a

DUMAND installation with volume 10^9m^3 can register a flux of $3 \times 10^{-14} \text{cm}^{-2} \text{sec}^{-1} \text{sr}^{-1}$. For the Weinberg model we must have such a flux at an energy $5 \times 10^{15} \text{eV}$. According to^[2], this flux exceeds by two orders of magnitude the flux of neutrinos from normal galaxies. It is shown in^[2], however, that the real neutrino flux can be larger by three orders of magnitude than from normal galaxies.

The acoustic method of detecting high-energy neutrinos^[4] makes it possible to increase the effective volume of the installation by two orders of magnitude. In this case the W bosons can be observed even in the combined flux of anti-neutrinos from normal galaxies and from our galaxy. The background events relative to the resonant events are the reactions: $\nu_u + N \rightarrow \mu + \text{hadrons}$, $\nu_u + N \rightarrow \nu_u + \text{hadrons}$, $\nu_e + N \rightarrow e + \text{hadrons}$, $\nu_e + N \rightarrow \nu_e + \text{hadrons}$, $\nu_e + e \rightarrow \nu_e + e$, $\nu_u + e \rightarrow \mu + \nu_e$ and $\nu_u + e \rightarrow \nu_u + e$. The width of the resonance is only 5–6% of the resonant energy E_0 , and the width of the resolution of the underwater installations will apparently be much larger. We therefore stipulate as a condition for the observation of the W bosons that the frequency of the resonant events exceed the frequency of the background showers with energies $\geq E_0$ from the upper hemisphere. Then, taking into consideration all the above-named reactions we obtain the ratio of the frequency of the resonant events to the background events:

$$\frac{\nu_{\text{res}}}{\nu_{\text{backgr}}(\geq E_0)} = 1.3 \times 10^3 \left(\frac{10}{m_W} \right)^2, \quad (4)$$

where m_W is in GeV. The ratio (4) can be improved by discriminating additionally the background events in muon registration and by using only events inside the energy interval ΔE corresponding to the resolution of the apparatus. For $\bar{\nu}_e$ neutrinos^[2] the ratio (4) becomes worse because of the decrease of the relative number of $\bar{\nu}_e$ in the total neutrino flux. If the search for the W boson is carried out with the aid of muons ($\bar{\nu}_e + e^- \rightarrow W^- \rightarrow \mu^- + \bar{\nu}_\mu$), the number of which exceeds the frequency of the showers because of the large range of the muons, then the ratio (4) is decreased by an approximate factor of 25.

If neutrino oscillations^[5] occur and cause the transitions $\bar{\nu}_\mu \rightleftharpoons \bar{\nu}_e$, then the $\bar{\nu}_e$ flux and the ratio (4) increase. This effect is particularly important for $\bar{\nu}_e$ neutrinos.

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