Excitation of the Glashow resonance without neutrino beams

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Motivation

The neutrino sector is a promising area to search for new physics beyond the Standard Model.

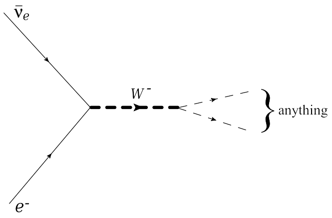
However, one encounters serious challenges on the way to investigate high mass final states

$$\nu + (e, N) \rightarrow X, \ \ (m_X^2 \gtrsim m_W^2).$$

Performing experiments in the laboratory frame requires neutrino beams of very high energies. On the other hand, one has also to measure huge energy deposits in a detector.

The Glashow resonance

Predicted by Sheldon Glashow in 1959, but still requires unambiguous experimental confirmation. Using the $\bar{\nu}_e$-component of cosmic rays annihilating on electrons in matter



Berezinsky and Gazizov, JETP Lett. 25 (1977) 254.

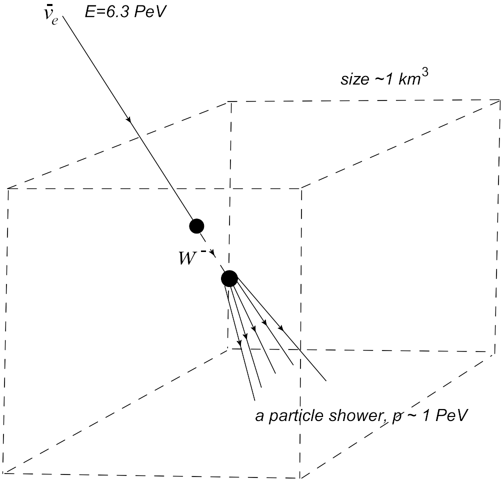
Neutrinos have to posses energies in the PeV region:

$$E_\nu = \frac{m_W^2}{2m_e} \approx 6.3 \times 10^{15} \ \text{eV} = 6.3 \ \text{PeV}.$$

The corresponding neutrino flux is relatively low in this region.

Searches in large-volume water/ice detectors (IceCube, Baikal-GVD, KM3NeT)

After over a decade of observations just a few events in the PeV region have been detected.



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Detection of a particle shower at the Glashow resonance with IceCube

The IceCube Collaboration

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This article has been updated

Abstract

The Glashow resonance describes the resonant formation of a W^- boson during the interaction of a high-energy electron antineutrino with an electron[1], peaking at an antineutrino energy of 6.3 petaelectronvolts (PeV) in the rest frame of the electron. Whereas this energy scale is out of reach for currently operating and future planned particle accelerators, natural astrophysical phenomena are expected to produce antineutrinos with energies beyond the PeV scale. Here we report the detection by the IceCube neutrino observatory of a cascade of high-energy particles (a particle shower) consistent with being created at the Glashow resonance. A shower with an energy of 6.05 ± 0.72 PeV (determined from Cherenkov radiation in the Antarctic Ice Sheet) was measured.

Is it possible to probe the Glashow resonance without preparing (anti)neutrino beams?

We suggest a positive answer to the question above.
Namely, the resonance could occur as

$$e^+e^- \to W^-\rho^+.$$

The radiative return with photons

The radiative return in QED allows us to measure the process

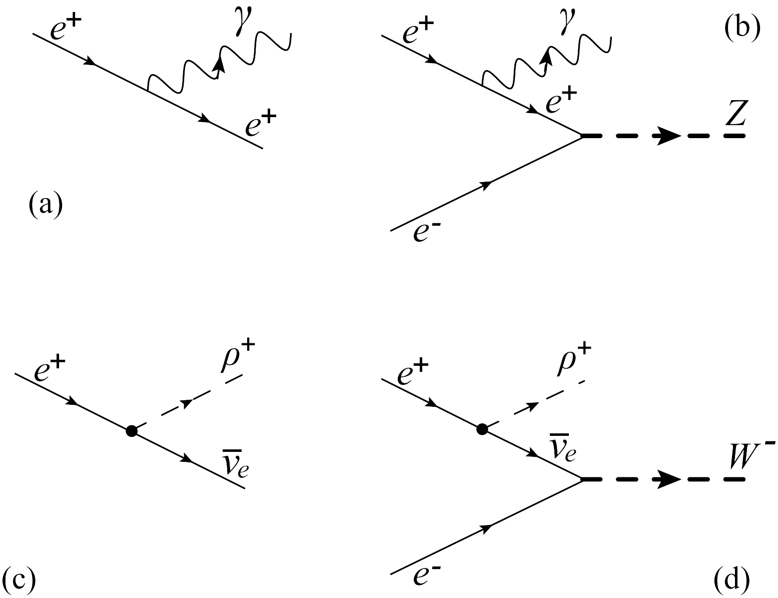
$$e^+e^- \to X$$

at fixed cms energy $\sqrt{s}$ for a wide range of masses of the final state X through the reaction

$$e^+e^- \to X\gamma.$$

For example, the pion formfactor by KLOE Collaboration, 2005.

The radiative return with relatively light charged mesons



The radiative return with relatively light charged mesons

Due to the condition $\sqrt{s} \gg m_\rho$ one can regard the meson as a massless particle and therefore factorize the process $e^+e^- \to W^-\rho^+$ into two subprocesses.

$$\mathcal{M}_\gamma = e\,[\bar{u}_e \gamma^\sigma u_e]\,\varepsilon^*_\sigma,$$

$$\mathcal{M}_\rho = \frac{G_F}{\sqrt{2}} V_{ud}\, f_\rho\, m_\rho \left[\bar{u}_e \gamma^\sigma (1-\gamma^5) u_\nu\right] \epsilon^*_\sigma.$$

The cross section for $e^+e^- \longrightarrow W^-\rho^+$

$$\sigma_{ee\to W\rho}(s) = \int F^{(\rho)}_{\nu/e}(x,s)\,\sigma_{\nu e\to W}(xs)\,\mathrm{d}x,$$

where

$$F^{(\rho)}_{\nu/e}(x,Q^2) = \frac{(G_\rho G_F)^2}{8\pi^2}\frac{1+x^2}{1-x}\log\left(\frac{Q^2}{m_\rho^2}\right)$$

and

$$\sigma_{\nu e\to W}(s) = \sqrt{8\pi^2}G_F m_W^2\delta(s-m_W^2).$$

The cross section for $e^+e^- \to W^-\rho^+$

The final result reads

$$\sigma_{ee\to W\rho}(s) = \frac{G_\rho^2 G_F^3}{\sqrt{8\pi^2}} \frac{r + r^3}{1 - r} \log\left(\frac{s}{m_\rho^2}\right),$$

where $r = m_W^2/s$.

One can see the pole in the denominator as well as the logarithmic enhancement typical for the radiative return.

CP conjugate of the Glashow resonance and its copy for muons

CP conjugate: $\nu_e e^+ \to W^+$.
The copy for muons: $\nu_\mu \mu^+ \to W^+$.
Today, these processes are widely believed to be unobservable at neutrino telescopes. However, at lepton colliders they seem to become accessible to experiment study through

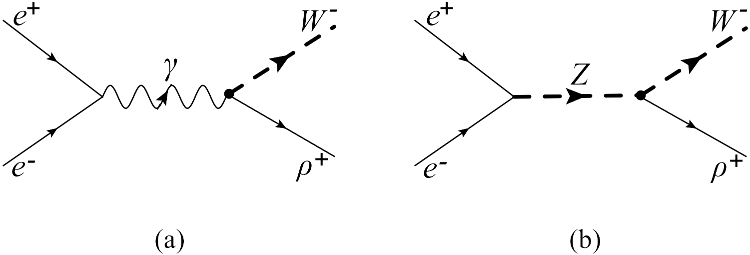
$$e^+ e^- \to W^+ \rho^-$$

and

$$\mu^+ \mu^- \to W^+ \rho^-.$$

Nonresonant (background) channels

In principle, the vertices $\gamma W \rho$ and $Z W \rho$ may arise in effective theories like, e.g., vector meson dominance extended to weak interactions.



However there are at least two independent reasons of suppression of such a background: i) the s-channel exchange leads to the $1/s^2$ behaviour of the cross section; the couplings $\gamma W \rho$ and $Z W \rho$ are constrained by the non-observation of the decay modes $W^\pm \to \gamma \rho^\pm$ and $Z \to W^\pm \rho^\mp$.

Experimental observation

Future high-luminosity lepton colliders as, for example, CEPC and FCC-ee, seem to be promising for excitation of the Glashow resonance in laboratory conditions.

Number of $e^+e^- \to W^\mp\rho^\pm$ and $e^+e^- \to W^\mp D_s^{*\pm}$ events at collider experiments assuming integrated luminosity of 10 ab^{-1}. Two different values of the decay constants are used for each channel.

Channel	Decay const. f_{ρ,D_s^*} (MeV)	No. of events $\sqrt{s} = 91$ GeV	No. of events $\sqrt{s} = 125$ GeV
$ee \to W\rho$	219	2.0	0.3
$ee \to W\rho$	490	10.3	1.6
$ee \to WD_s^*$	240	–	2.3
$ee \to WD_s^*$	391	–	6.0

More than 10 events per year could be obtained. For comparison, the current event rate at IceCube that uses the natural (cosmic) neutrino beam is less than 1 event per year in the PeV region.

Conclusions

1. We have suggested a meson analogue of the radiative return. Emission of a positively charged meson from the initial state not merely carries away a fraction of the collision energy but converts the incident e^+ into $\bar{\nu}_e$.
2. This allowed us to factorize the reaction $e^+e^- \to W^-\rho^+$ into two processes and thus put forward a Glashow resonance interpretation of the underlying physics. Similar channels with muons and other mesons have also been considered.
3. Future high-luminosity lepton colliders seem to be promising for excitation of the Glashow resonance, its CP conjugate and its copy for muons at cms energies of order of 100 GeV.
4. The proposed approach is versatile and can be applied to other reactions with massive final states. More details and references are given in arXiv:2504.02820.