The Glashow Resonance in Neutrino–Photon Scattering

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Outline

1. Introduction
2. W boson production in $\nu\gamma$ scattering: The Standard Model
3. W boson production in $\nu\gamma$ scattering: The parton model
4. Experimental consequences
5. Conclusions

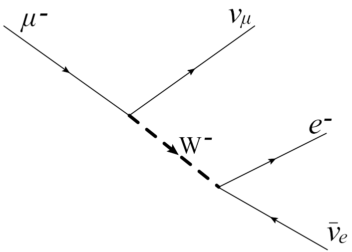
PHYSICAL REVIEW VOLUME 118, NUMBER 1 APRIL 1, 1960

Resonant Scattering of Antineutrinos

SHELDON L. GLASHOW*
Institute for Theoretical Physics, Copenhagen, Denmark

(Received October 26, 1959)

The hypothesis of an unstable charged boson to mediate muon decay radically affects the cross section for the process $\bar{\nu}+e \to \bar{\nu}+\mu^-$ near the energy at which the intermediary may be produced. If the boson is assumed to have K-meson mass, the resonance occurs at an incident antineutrino energy of $\sim 2\times 10^{12}$ ev. The flux of energetic antineutrinos produced in association with cosmic-ray muons will then produce two muon counts per day per square meter of detector, independently of the depth and the orientation at which the experiment is performed.



muon decay

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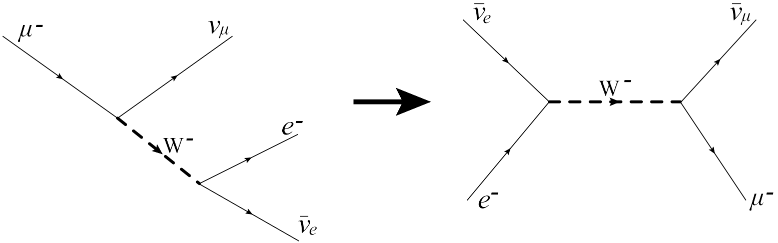
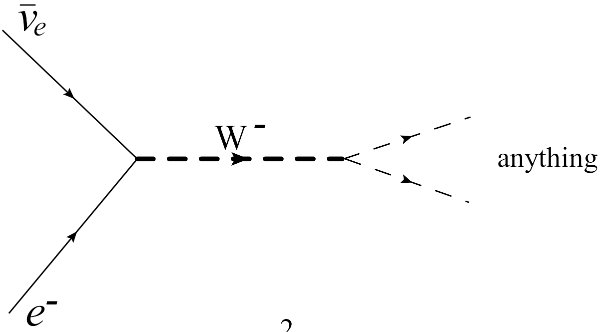


muon decay

resonant scattering at $s=m_W^2$

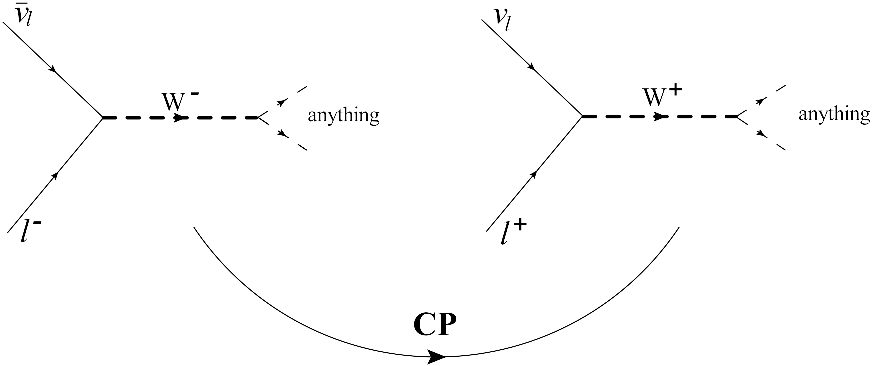
The Glashow Resonance



$$s=m_W^2$$

The Glashow Resonance

$$l = e,\ \mu,\ \tau$$



The s-channel reaction $\bar{\nu}_e + e^- \to W^-$ takes a unique place.

Electrons are present in matter while positrons, muons and tau leptons are not.

The Glashow resonance can be observed in large volume neutrino telescopes. The incident neutrino energy in the laboratory reference frame is very high:

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

.

The IceCube Neutrino Telescope –a kilometer-scale detector at the South Pole– investigates this energy region but no convincing evidence for the Glashow resonance is found to date.
So far the Glashow resonance is not experimentally observed.

The Glashow resonance still remains an important prediction and its observation would be a crucial test of the Standard Electroweak Theory.

Exclusive single W boson production in $\nu\gamma$ scattering

CP invariant interaction

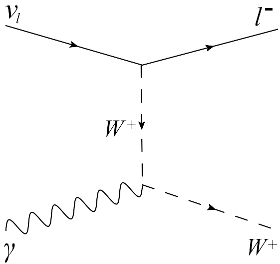
$$\begin{tikzcd}[column sep=huge] \nu_l + \gamma \longrightarrow l^- + W^+ \arrow[r, bend right, "\mathbf{CP}"] & \bar{\nu}_l + \gamma \longrightarrow l^+ + W^- \end{tikzcd}$$

$$\begin{tikzcd}[column sep=huge] \left|\mathrm{M}(\nu_l + \gamma \longrightarrow l^- + W^+)\right|^2 \arrow[r, phantom, "="] \arrow[r, bend right, "\mathbf{CP}"] & \left|\mathrm{M}(\bar{\nu}_l + \gamma \longrightarrow l^+ + W^-)\right|^2 \end{tikzcd}$$

The Standard Model

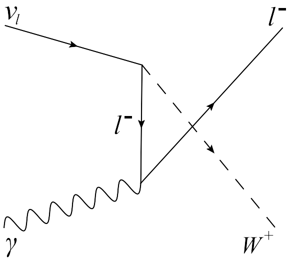
$$\nu_l + \gamma \longrightarrow l^- + W^+$$

$$M =$$



t-channel

$$+$$



u-channel

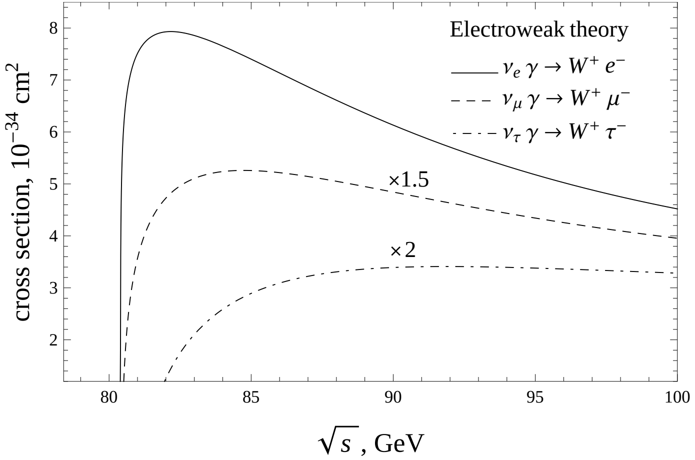
D. Seckel, Phys. Rev. Lett. 80 (1998) 900.

The LO cross section for $\nu_l \gamma \to W^+ l^-$:

$$\sigma_l = \sqrt{2}\alpha G_F \left\{ 2\left(1 - \frac{m_W^2}{s}\right)\left(1 + \frac{2m_W^4}{s^2} - \frac{m_W^4}{s^2}\ln\left[\frac{s}{m_W^2}\right]\right) + \frac{m_W^2}{s}\left(1 - \frac{2m_W^2}{s} + \frac{2m_W^4}{s^2}\right)\ln\left[\frac{(s - m_W^2)^2}{m_l^2 s}\right]\right\}.$$

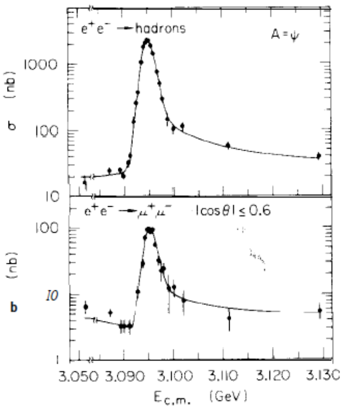
[D. Seckel, Phys. Rev. Lett. 80 (1998) 900]
[I. Alikhanov, Phys. Lett. B 710 (2012) 149]

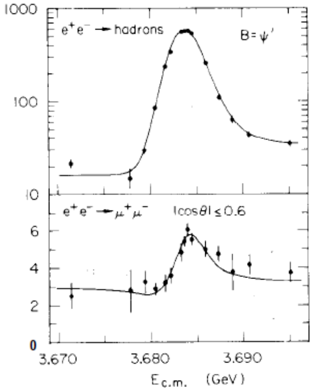
The LO cross section for $\nu_l \gamma \to W^+ l^-$:



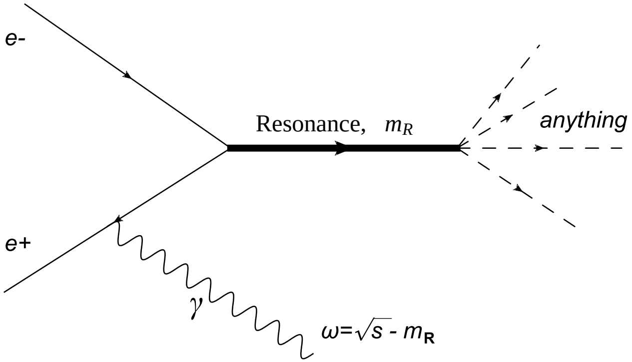
$e^+e^- \rightarrow J/\Psi, \Psi(2S)$

B. Richter, Nobel Lecture, 1976



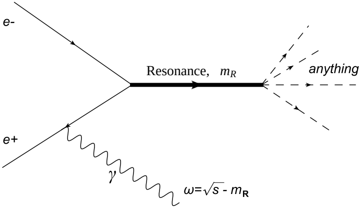


Initial state radiation in e^+e^- annihilation into a resonance



A "radiative tail" appears to the right of the resonance maximum. The emitted photon carries away the energy excess and turns thus back the electron–positron pair to the resonance energy. The suppression due to the extra factor α is compensated by the resonance denominator.

[Ioffe B.L., Khoze V.A., Lipatov L.N., Hard processes 1. Phenomenology Quark–parton model, 1984]



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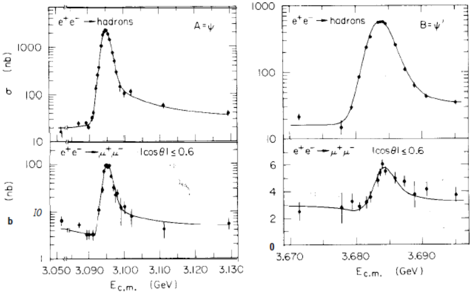
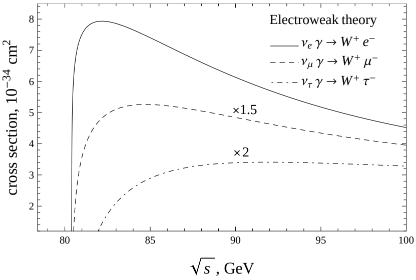
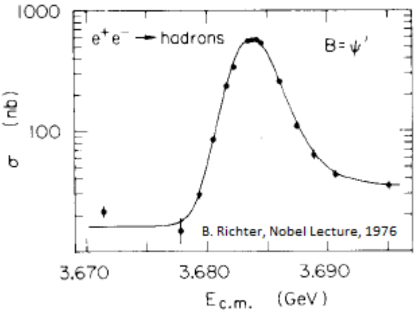
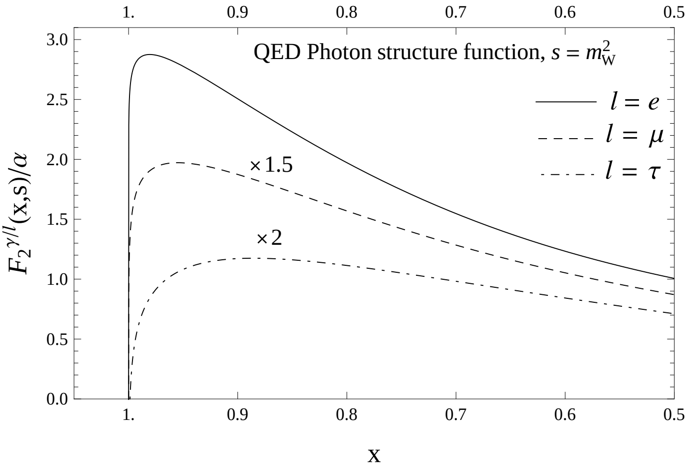


Initial state lepton emission in $\nu_l \gamma \to W^+ l^-$?



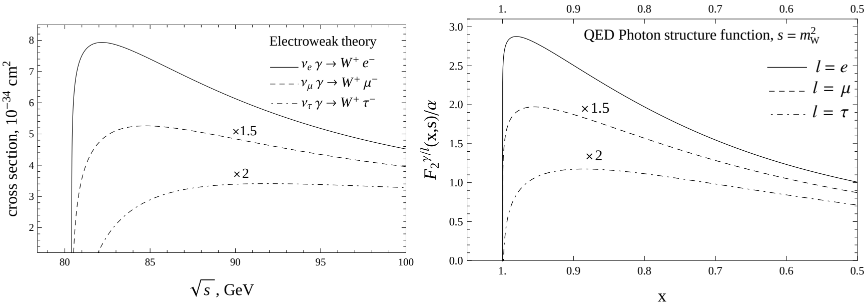


The photon structure function

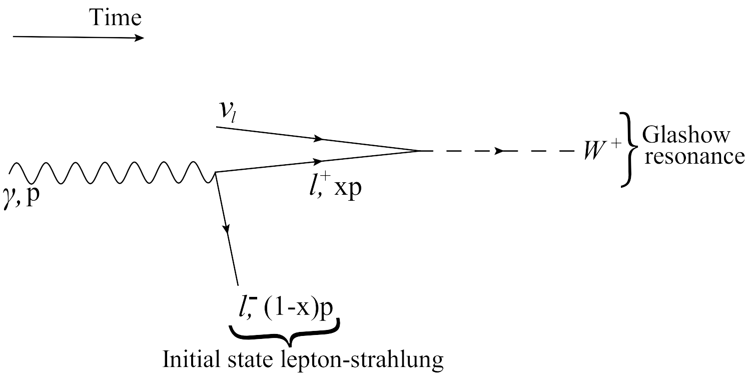


[R. Nisius, Phys. Rept. 332 (2000) 165]

The photon structure function



$\nu_l\gamma \to W^+l^-$ in the parton model



$$\sigma_l = \int_0^1 \frac{dx}{x} F_2^{\gamma/l}(x,s)\sigma_{\nu l\to W}(xs).$$

$\nu_l \gamma \to W^+ l^-$ in the parton model

$$\sigma_l = \int_0^1 \frac{dx}{x} F_2^{\gamma/l}(x,s)\sigma_{\nu l \to W}(xs).$$

In the narrow width approximation:

$$\sigma_{\nu l \to W}(xs) = 2\sqrt{2}\pi G_F \tau \delta(x-\tau), \;\; \tau = m_W^2/s,$$

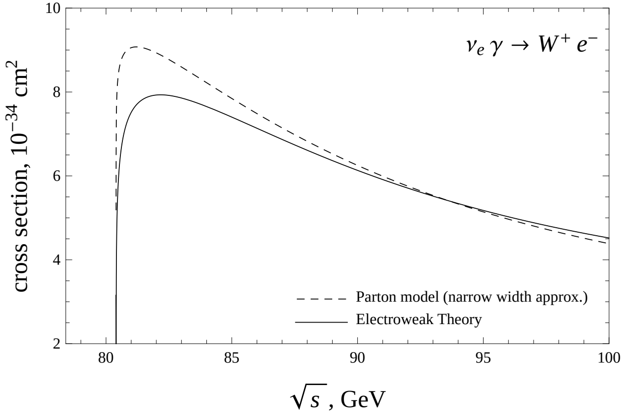
$$\sigma_l = 2\sqrt{2}\pi G_F F_2^{\gamma/l}(\tau, s).$$

The Glashow resonances project out the corresponding structure functions of the photon $F_2^{\gamma/l}(x,s)$ in the cross sections σ_l.

$\nu_e\gamma \to W^+e^-$ in the parton model

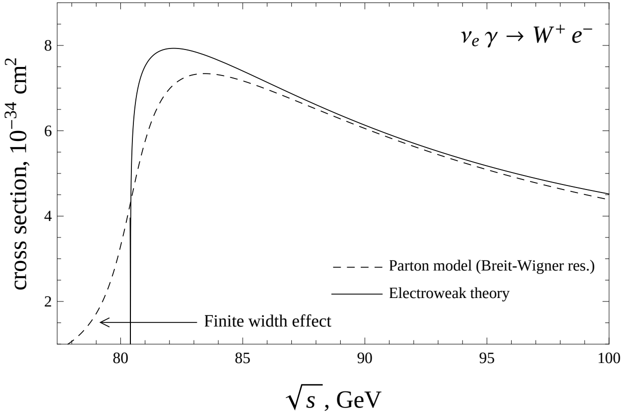
$$\sigma_e = 2\sqrt{2}\pi G_F F_2^{\gamma/e}(\tau, s).$$

For example,



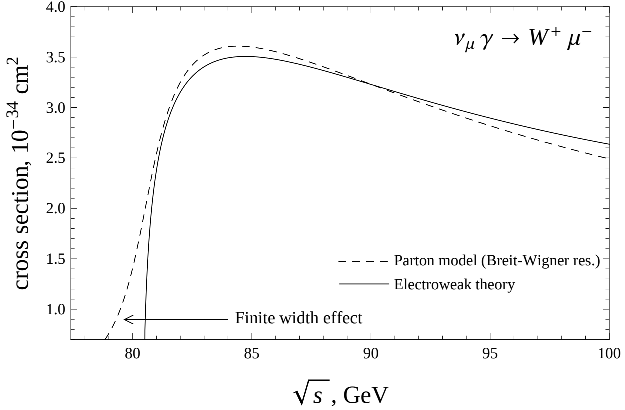
The Breit–Wigner formula provides a more realistic description than the narrow width approximation:

$$\sigma_e = 24\pi\Gamma_{W\to\nu e}\Gamma\int\limits_0^1 \frac{dx}{x}\frac{F_2^{\gamma/e}(x,s)}{(xs-m_W^2)^2+m_W^2\Gamma^2},$$



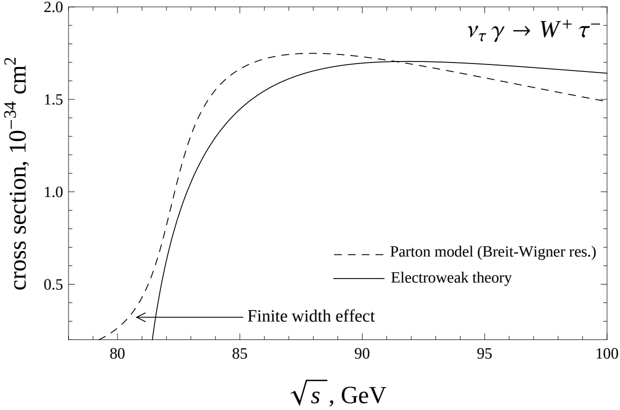
The Breit–Wigner formula provides a more realistic description than the narrow width approximation:

$$\sigma_\mu = 24\pi\Gamma_{\mathrm{W}\to\nu\mu}\Gamma \int\limits_0^1 \frac{dx}{x} \frac{F_2^{\gamma/\mu}(x,s)}{(xs-m_W^2)^2+m_W^2\Gamma^2},$$

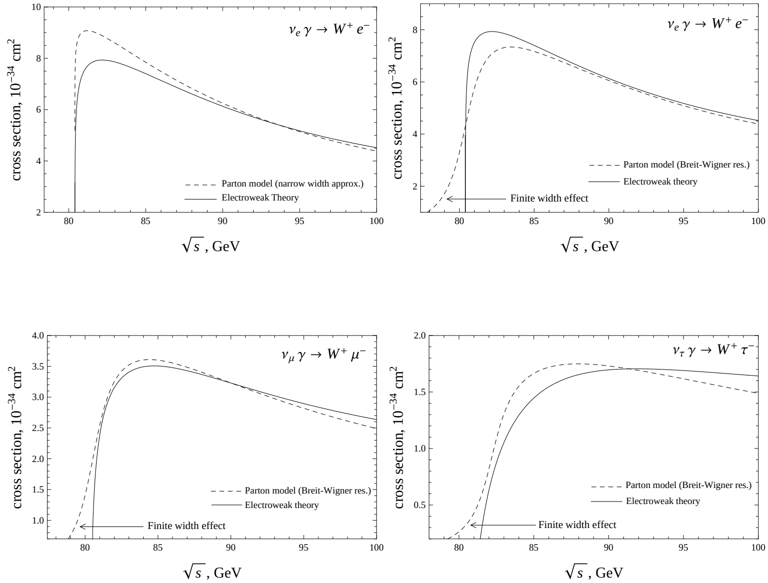


The Breit–Wigner formula provides a more realistic description than the narrow width approximation:

$$\sigma_\tau = 24\pi\Gamma_{\mathrm{W}\to\nu\tau}\Gamma \int\limits_0^1 \frac{dx}{x}\frac{F_2^{\gamma/\tau}(x,s)}{(xs - m_W^2)^2 + m_W^2\Gamma^2},$$



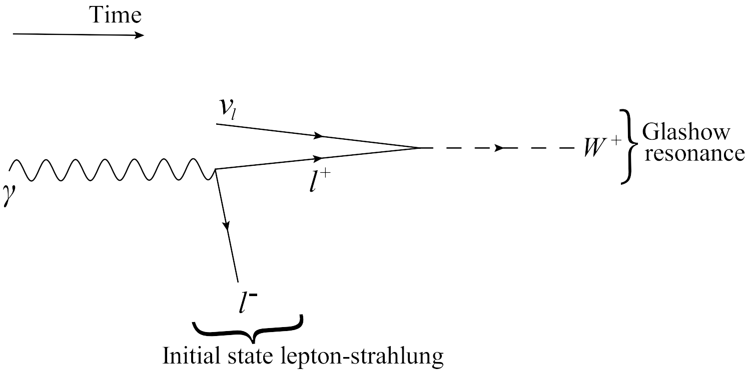
$\nu_l \gamma \to l^- W^+$ in the parton model



The Standard Model strongly suggests that the reactions $\nu_l \gamma \to l^- W^+$ proceed through initial state lepton emission.

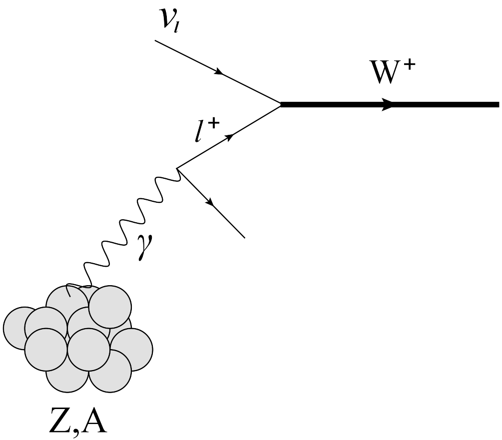
Hypothesis: The on-shell W bosons in $\nu_l \gamma \to l^- W^+$ are the Glashow resonances.

$$\nu_l + \gamma \longrightarrow l^- + W^+$$

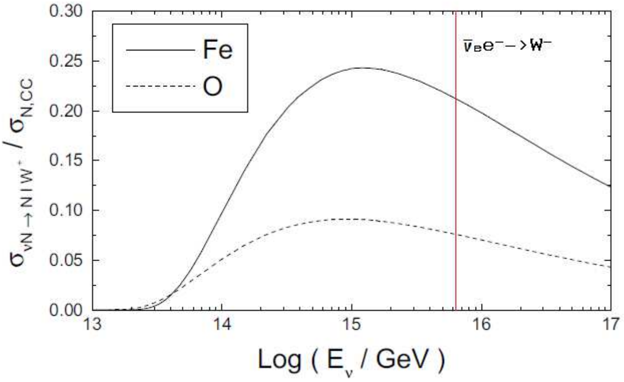


Scattering off nuclei

The equivalent photon approximation



The Glashow resonance may have already been produced in the IceCube neutrino detector at energies far below 6.3×10^{15} eV.



[D. Seckel, Phys. Rev. Lett. 80 (1998) 900]

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The event rate distribution:

$$\frac{dN}{dE_\nu} = nt\Omega \sum_{l=e,\mu,\tau} \sigma_{Nl} \Phi_{\nu_l + \bar{\nu}_l}, \tag{1}$$

where n is the number of target nuclei in the effective volume of the detector, t is the time of exposure, Ω is the solid angle, $\Phi_{\nu_l + \bar{\nu}_l}$ is the flux of neutrinos and antineutrinos of flavor l.

The number of events at IceCube:

$$n = 1.3 \times 10^{37},$$

$$t = 662 \text{ days},$$

$$\Phi_{\nu+\bar{\nu}} = 6.62 \times 10^{-7} (E_\nu)^{-2.3} \, \mathrm{GeV}^{1.3} \mathrm{cm}^{-2} \mathrm{s}^{-1} \, \mathrm{sr}^{-1},$$

1:1:1 neutrino flavor ratio.

L. A. Anchordoqui *at al.*, arXiv:1312.6587.

8 ± 1 events

Conclusions

1. Exclusive single W boson production production in $\nu\gamma$ scattering at $s \approx m_W^2$ is analyzed.

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5. The Glashow resonance can be probed not only for $\bar{\nu}_e$ but also for the other neutrino flavors, ν_μ and ν_τ.

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5. The Glashow resonance can be probed not only for $\bar{\nu}_e$ but also for the other neutrino flavors, ν_μ and ν_τ.
6. The Glashow resonance may have already been produced in the IceCube neutrino detector at $E_\nu \propto 50$ TeV.

Thank You!