8.701

Introduction to Nuclear and Particle Physics

Markus Klute - MIT

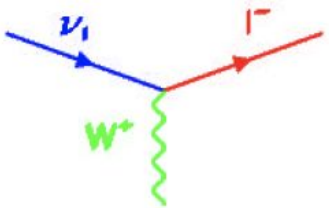
8. Neutrinos

8.1 In the Standard Model

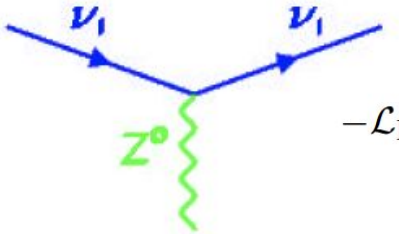
Neutrinos in the Standard Model

Neutrinos Massless

Interacts with W and Z bosons



$$-\mathcal{L}_{\mathrm{CC}} = \frac{g}{\sqrt{2}} \sum_{\ell} \bar{\nu}_{L\ell} \gamma^{\mu} \ell_L^- W_{\mu}^+ + \mathrm{h.c.}$$



$$-\mathcal{L}_{\mathrm{NC}} = \frac{g}{2\cos\theta_W} \sum_{\ell} \bar{\nu}_{L\ell} \gamma^{\mu} \nu_{L\ell} Z_{\mu}^0$$

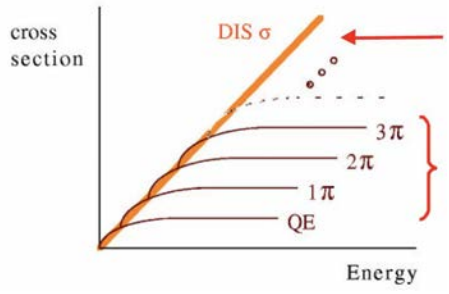
Have three flavors (electron, muon, and tau)

Neutrinos are left-handed (Anti-neutrinos are right-handed)

Neutrino-Nucleon Processes

- Charged - Current: $W^{\pm}$ exchange
  - Quasi-elastic Scattering:
    (Target changes but no break up)
    $\nu_\mu + n \rightarrow \mu^- + p$
  - Nuclear Resonance Production:
    (Target goes to excited state)
    $\nu_\mu + n \rightarrow \mu^- + p + \pi^0$ (N^* or Δ)
    $n + \pi^+$
  - Deep-Inelastic Scattering:
    (Nucleon broken up)
    ν_μ + quark $\rightarrow \mu^-$ + quark'

- Neutral - Current: Z^0 exchange
  - Elastic Scattering:
    (Target doesn't break up or change)
    $\nu_\mu + N \rightarrow \nu_\mu + N$
  - Nuclear Resonance Production:
    (Target goes to excited state)
    $\nu_\mu + N \rightarrow \nu_\mu + N + \pi$ (N^* or Δ)
  - Deep-Inelastic Scattering
    (Nucleon broken up)
    ν_μ + quark $\rightarrow \nu_\mu$ + quark



Linear rise with energy

Resonance Production

Neutrino-Nucleon Scattering

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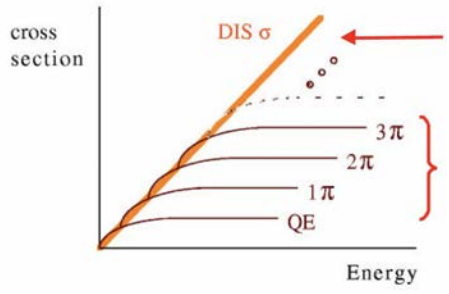
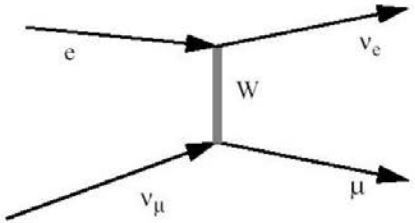
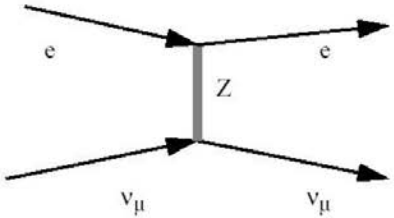


Linear rise with energy

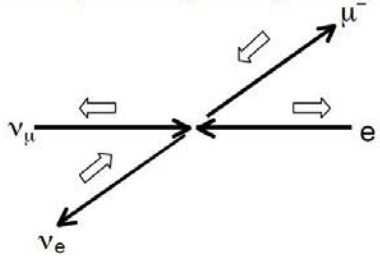
Resonance Production

Neutrino-Electron Scattering





- Inverse μ–decay: $\nu_\mu + e^- \rightarrow \mu^- + \nu_e$
  - Total spin J=0 (Helicity conserved)



  - Point scattering $\Rightarrow \sigma \propto s = 2m_e E_\nu$

$$\sigma_{TOT} = \frac{G_F^2 s}{\pi} = 17.2 \pm 10^{-42}\, cm^2 / GeV \cdot E_\nu (GeV)$$

- Elastic Scattering: $\nu_\mu + e^- \rightarrow \nu_\mu + e^-$
  - Point scattering $\Rightarrow \sigma \propto s = 2m_e E_\nu$
  - Electron coupling to Z^0
    - (V-A): $-1/2 + \sin^2\theta_W$ J = 0
    - (V+A): $\sin^2\theta_W$ J = 1

$$\sigma_{TOT} = \frac{G_F^2 s}{\pi}\left(\frac{1}{4} - \sin^2\theta_W + \frac{4}{3}\sin^4\theta_W\right)$$

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