The effective neutrino approximation

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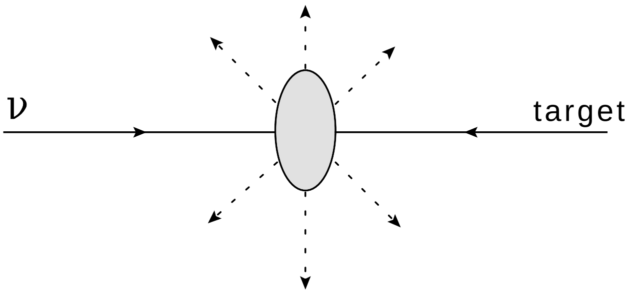
2000+ meters above sea level

Motivation:

How to probe neutrino-induced reactions at laboratory conditions?



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How to probe neutrino-induced reactions at laboratory conditions?

Preparing neutrino beams.

Neutrino sources:

1. Neutrinos from unstable particle decays: mesons $\to X + \nu$.
2. Neutrinos from cosmic rays.

How to probe reactions induced by neutrinos?

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Problems:

- Uncertainties in the neutrino energy spectrum.
- The lepton flavor composition of the ν-beam.
- Collimation of the ν-beam.
- Fixed target experiments only.

Restrictions of the fixed target experiments.

1. Very high energies are needed for probing heavy final states.
2. The targets are electrons and quarks only.

What about the following processes?

$$\nu + \nu \to \text{anything.}$$

$$\nu + e^{+} \to \text{anything.}$$

$$\nu + \mu^{\pm} \to \text{anything.}$$

...

How can they be studied experimentally?

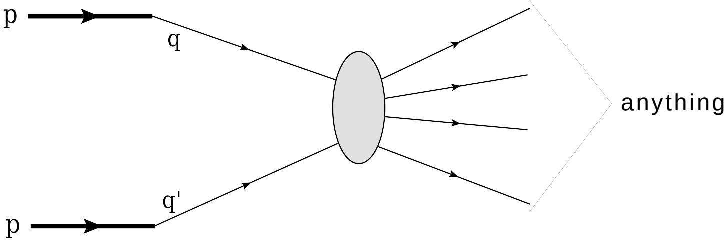
How do we study quark-induced reactions?

We do not collide quarks but hadrons.

The quark–parton model:

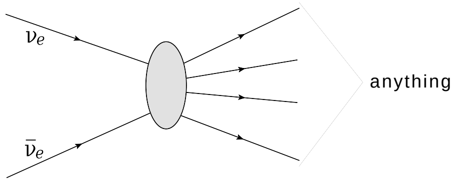
there is a certain probability that a hadron will manifest itself as a quark. The corresponding probability densities (the quark distribution functions) are calculable.

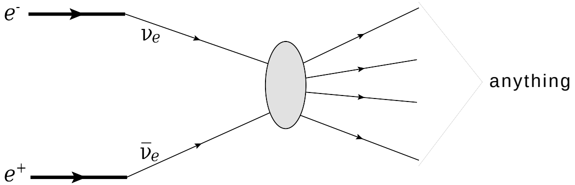
The quark–parton model



$$\sigma_{pp}(s) \propto \int f_q(x) f_{q'}(y) \hat{\sigma}_{qq'}(xys)\, dx dy.$$

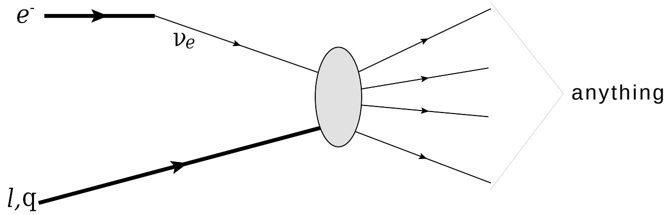
The effective neutrino approximation





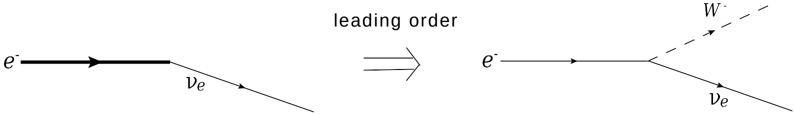
$$\sigma_{ee}(s) \propto \int f_\nu(x) f_{\bar{\nu}}(y) \hat{\sigma}_{\nu\bar{\nu}}(xys)\,dxdy.$$

$$\nu + l, q \rightarrow \text{anything.}$$



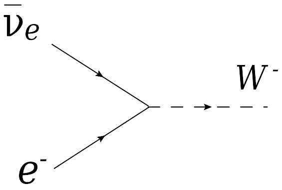
$$\sigma_{el}(s) \propto \int f_\nu(x) \hat{\sigma}_{\nu l}(xs) dx.$$

The distributions of the effective neutrinos in charged leptons are also calculable.



$$f_{\nu_e}(x) = \frac{\alpha}{8\pi \sin^2\theta_W} \left[\frac{1 + \left(x + m_W^2/s\right)^2}{1 - x - m_W^2/s} \ln\left(\frac{Q_{\max}^2 + m_W^2}{Q_{\min}^2 + m_W^2} \right) \right].$$

The Glashow resonance: $\bar{\nu}_e + e^- \to W^-$ (Glashow, 1959).



Annihilation of cosmic neutrinos on atomic electrons in a detector:

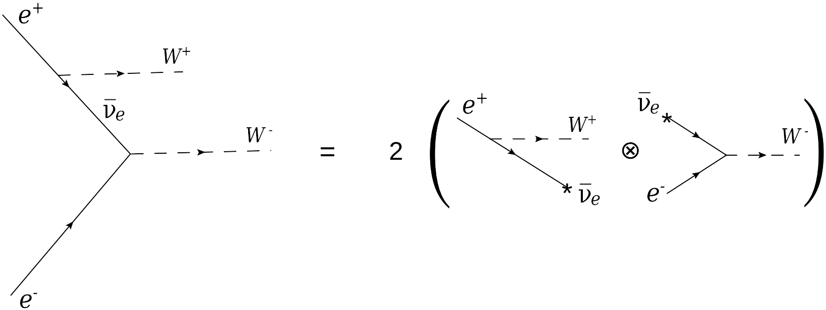
$$E_\nu = \frac{m_W^2}{2m_e} \approx 6.4 \times 10^{15} \text{ eV}.$$

Searches for the resonance at the IceCube Neutrino Observatory.

Not yet observed!

The Glashow resonance in electron–positron collisions:

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



$$\sigma_{WW}(s) = 2 \int_{m_W^2/s}^{1} f_{\bar{\nu}_e}(x)\hat{\sigma}_{\bar{\nu}_e e \to W}(xs)dx.$$

The Glashow resonance in electron–positron collisions.

$$\sigma_{WW}(s) = 2 \int_{m_W^2/s}^{1} f_{\bar{\nu}_e}(x)\hat{\sigma}_{\bar{\nu}_e e \to W}(xs)dx.$$

This equation links the process $e^+e^- \to W^+W^-$ to the Glashow resonance.

The Glashow resonance in electron–positron collisions.

Comparison of the effective neutrino approximation (ENA) with the exact result:

$$\lim_{m_W^2/s \to 0} [\sigma_{WW}^{ENA}(s) - \sigma_{WW}^{Exact}(s)] = 0.$$

Conclusion: The process $e^+e^- \to W^+W^-$ asymptotically is a sum of the Glashow resonance and its CP conjugate. Observable at collider energies (~ 100 GeV) $\ll 10^{15}$ eV.

Summary

We propose to exploit the concept of effective (equivalent) particle in studies of neutrino interactions. The effective neutrino approximation may provide a framework for probing neutrino-induced reactions at e^+e^- and ep colliders as well as at other lepton colliding facilities.

Advantages:

1. Well-established techniques of charged particle beam acceleration.
2. The possibility of variation of the collision energy in a wide range.
3. High luminosities can be achieved.
4. The interaction region is localized.

References

Details can be found in

arXiv:1812.07823, arXiv:1812.05578.

Thank you!