UHE neutrinos: current non-conservation, mass scales, saturation

R. Fiore and V.R. Zoller

ITEP, Moscow

UniCal, INFN, Italy

Diffraction 2010

Ultra High Energy (UHE) neutrino:

by definition, UHE corresponds to

$$E_\nu > 10^7 \text{ GeV}$$

A lot of interesting papers on

$$\sigma^{\nu N}(E_\nu)$$

with E_ν up to

$$10^{15} \text{ GeV}$$

scales - prodotti tipici

Massless approximation and DLLA

$$\sigma^{\nu N} = \frac{1}{s}\int^{s} dQ^2 \int_{x_0}^{1} \frac{dx}{x}\left(\frac{d\sigma}{dxdy}\right)$$

$$\frac{d\sigma}{dxdy} = \frac{G_F^2 s}{2\pi}\left(\frac{m_W^2}{m_W^2+Q^2}\right)^2 \left[(1-y)F_L + (1-y+\frac{y^2}{2})F_T\right]$$

$$\sigma^{\nu N} \propto \int dQ^2 \left(\frac{m_W^2}{m_W^2+Q^2}\right)^2 \exp\sqrt{C\log(1/x)\log\log Q^2}$$

W-propagator introduces cut-off. Then the scale is

$$Q^2 \sim m_W^2$$

when top enters the game

- The estimate

$$Q^2 \sim m_W^2$$

  is not unreasonable only for light flavors.

- The top-bottom current needs special care. The phenomenon of Charged Current Non-Conservation (CCNC) pushes the scale up to

$$\sim m_t^2$$

to be discussed:

- Charged Current Non-Conservation (CCNC) efects in UHE neutrino interactions.
- top-bottom current - new “hardness” scale
- scales and saturation

F_L as a carrier of CCNC effects

weak currents are not conserved...,but in what way?

For longitudinal/scalar W-boson in

$$W_L \to t\bar{b} \propto \varepsilon_L^\mu J_\mu \propto \partial_\mu J_\mu \propto m_t \pm m_b$$

Therefore,

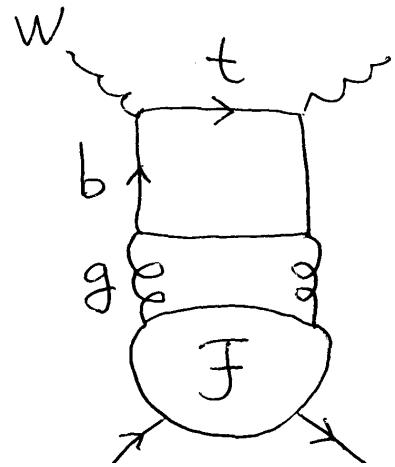
$$F_L \propto \varepsilon_L^\mu T^{\mu\nu} \varepsilon_L^\nu$$

provides a measure of CCNC effects.

to calculate $F_L = Q^2\sigma_L/4\pi^2\alpha_W$

one needs gauge invariant sum of diagrams like this

$\mathcal{F}$ - un-integrated gluon density
$\boldsymbol{\kappa}$ - gluon momentum
$z, \mathbf{k}$ - Sudakov's variables of t-quark



$$\frac{d\sigma_L(x,Q^2)}{dz d^2\mathbf{k}} = \frac{\alpha_W}{\pi}\int \frac{d^2\boldsymbol{\kappa}}{\boldsymbol{\kappa}^4}\alpha_S(q^2)\mathcal{F}(x,\boldsymbol{\kappa}^2)\left(V_S + A_S + V_P + A_P\right)$$

Two components: $t\bar{b}$-state with angular momentum $L=0$ and $L=1$: S-wave and P-wave.

- The appearance of P-wave - manifestation of CCNC

S-wave: $|W\rangle \to |t\bar{b}, L=0\rangle$

$$V_S(m_t, m_b) = \frac{1}{Q^2}\left\{2Q^2 z(1-z) + (m_t - m_b)\left[(1-z)m_t - z m_b\right]\right\}^2$$
$$\times \left(\frac{1}{\mathbf{k}^2 + \varepsilon^2} - \frac{1}{(\mathbf{k} - \boldsymbol{\kappa})^2 + \varepsilon^2}\right)^2$$

$$A_S(m_t, m_b) = \left(\frac{g_A}{g_V}\right)^2 V_S(m_t, -m_b)$$

$$\varepsilon^2 = z(1-z)Q^2 + (1-z)m_t^2 + z m_b^2$$

P-wave: $|W\rangle \to |t\bar{b}, L=1\rangle$

Scalar W $\to$ wrong helicities $\to$ suppression at $Q^2 \gg m_q^2$

$$V_P(m_t, m_b) = \frac{1}{Q^2}(m_t - m_b)^2 \left(\frac{\mathbf{k}}{\mathbf{k}^2 + \varepsilon^2} - \frac{\mathbf{k} - \boldsymbol{\kappa}}{(\mathbf{k} - \boldsymbol{\kappa})^2 + \varepsilon^2} \right)^2$$

$$A_P(m_t, m_b) = \left(\frac{g_A}{g_V} \right)^2 V_P(m_t, -m_b)$$

$$\varepsilon^2 = z(1-z)Q^2 + (1-z)m_t^2 + z m_b^2$$

This is higher twist but

$$Q^2 < m_W^2 \ll m_t^2$$

soft gluons, $\kappa^2 \lesssim k^2 + \varepsilon^2$, - DLLA

the DLLA (soft gluon) contribution to
the P-wave or CCNC component of

$$F_L = F_L^S + F_L^P$$

is dominated by highly asymmetric configurations with

$$z \sim 1 - \frac{m_b^2}{m_t^2 + Q^2}.$$

Then

$$F_L^P(x, Q^2) \simeq \frac{m_t^2}{m_t^2 + Q^2} \int_{m_b^2}^{m_t^2} \frac{d\varepsilon^2}{\varepsilon^2} \frac{\alpha_S(\varepsilon^2)}{3\pi} G(x, \varepsilon^2)$$

survival ability

- The CCNC effect

$$\propto m_t^2/(m_t^2+Q^2)$$

survives in UHE neutrino interactions because the W-propagator allows only “small” Q^2

$$Q^2 < m_W^2 \ll m_t^2$$

- It is enhanced by the gluon density factor $G(x, m_t^2)$.
- This CCNC-term is not a property of the interaction of $t\bar{b}$-dipole with the target but the property of the light-cone density of $t\bar{b}$-states (Fiore & VRZ 2008).

DLLA - lower estimate for CCNC

To DLLA the CCNC contribution to $\sigma^{\nu N}$ is estimated as

$$\sigma^{\nu N}_{CCNC} \simeq 0.43 \times 10^{-31}\, cm^2$$

for

$$E_\nu = 10^{12}\, cm^2$$

(the gluon density $G(x, k^2)$ from Ivanov and Nikolaev 2003)
The frequently used massless approximation for different gluon densities (E. Henly and J. Jalilian-Marian, 2006) gives for $E_\nu = 10^{12}$ GeV

$$0.2 \times 10^{-31} < \sigma^{\nu N} < 1.5 \times 10^{-31}\, cm^2$$

unitarity/saturation

In massless approximation (CCNC neglected) unitarity corrections to $\sigma^{\nu N}$ found to be 50 per cent effect (Kutak and Kwiecinski 2003): unitarity turns

$$\sigma_{CC}^{\nu N} \simeq 1. \times 10^{-31} cm^2$$

at $E_\nu = 10^{12}$ GeV into

$$\sigma_{CC}^{\nu N} \simeq 0.5 \times 10^{-31} cm^2$$

scales and saturation

Saturation depends on scale. First higher twist correction

$$\sim \frac{\alpha_S(Q^2)}{Q^2}\frac{G(x,Q^2)}{\pi R^2}$$

The CCNC hardness scale m_t^2 is much "harder": than the mass scale Q_0^2 for light flavors:

$$m_t^2 \gg Q_0^2 \lesssim m_W^2$$

the ratio of saturation corrections is apparently very small

$$\frac{\delta\sigma(CCNC)}{\delta\sigma(massless)} \sim \frac{Q_0^2}{m_t^2}\frac{\alpha_S(m_t^2)G(x,m_t^2)}{\alpha_S(Q_0^2)G(x,Q_0^2)} \ll 1$$

mini-conclusion

Saturation affects strongly the light quark contribution to $\sigma^{\nu N}$ but leaves the top-bottom CCNC term intact.

Conclusions

- The lower (DLLA) estimate for the CCNC contribution to $\sigma^{\nu N}$ presented for UHE neutrinos.
- Found that

$$\sigma^{\nu N}_{CCNC} \sim \sigma^{\nu N}(massless)$$

- Additional momentum to the CCNC effect in its competition with massless calculations gives the unitarity suppression which is much stronger for massless cross sections.