Weak Magnetism for charged current neutrino nucleon interaction

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September 25, 2014

Weak magnetism gives due to large anomalous magnetic moment of nucleons gives additional tensor coupling

$$\gamma_\mu \left(g_V + g_A \gamma_5\right) - \frac{F_2}{2M} \sigma_{\mu\rho} q^\rho$$

$$F_2 = 3.706 \quad \text{for} \quad n \leftrightarrow p$$

Additional terms in matrix element $\left\langle |M|^2 \right\rangle$

$$\begin{aligned}\left\langle |M|^2 \right\rangle = & \left[(g_A + g_V)^2 + 2 g_A F_2 \right] (P_\nu \circ P_n)(P_e \circ P_p) \\ & + \left[(g_A - g_V)^2 - 2 g_A F_2 \right] (P_\nu \circ P_p)(P_e \circ P_n) \\ & + \left[g_A^2 - g_V^2 \right] (P_\nu \circ P_e) M_n^* M_p^* \\ & + \left[2 g_V F_2 + \frac{F_2^2}{2} \right] (P_\nu \circ P_e)^2 \\ & + \left[\frac{F_2^2}{2} \right] \frac{1}{M^2} (P_\nu \circ P_e)(P_\nu \circ P_n)(P_\nu \circ P_p) \\ & + \left[\frac{F_2^2}{2} \right] \frac{1}{M^2} (P_e \circ P_\nu)(P_e \circ P_n)(P_e \circ P_p)\end{aligned}$$

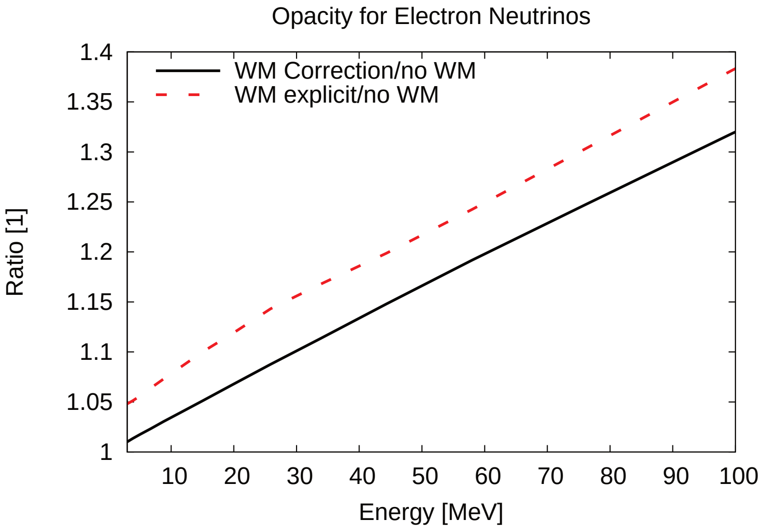
See [Horowitz,Li, PRD 61 (2000) 063002]

- In core collapse supernova Weak-Magnetism has been included in form of correction factors.
- Limiting case for non-reativistic nucleons
- $E_e = E_\nu \cdot \left[1 + \frac{E_\nu}{M_N}\left(1 - \cos\theta_{\nu,e}\right)\right]^{-1}$

See [Horowitz, PRD 65 (2002) 043001]

We have explicitely calculated the integration over the whole matrix element for relativitstic treatment of nucleons.
For method see [Steiner,Prakash,Lattimer, PLB 509 (2001) 10]

$T = 8$ MeV, $\rho = 3.35 \cdot 10^{13}$ g/cm^3, $Y_e = 0.042$, $U_n - U_p = 15.6$ MeV



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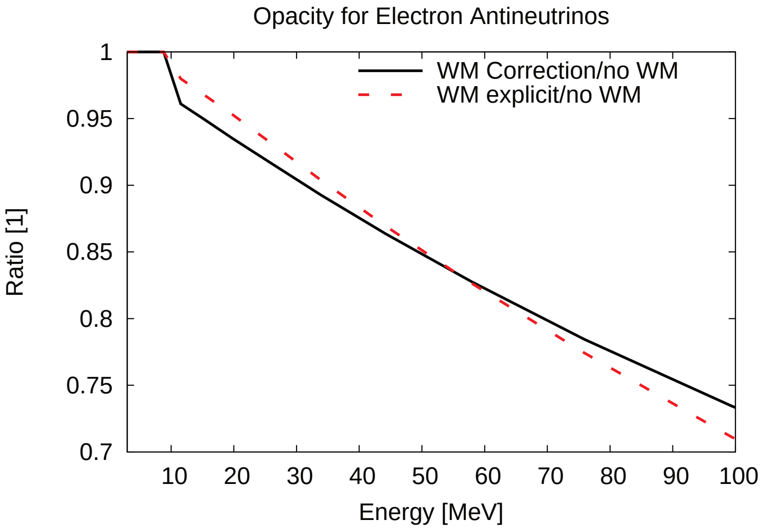
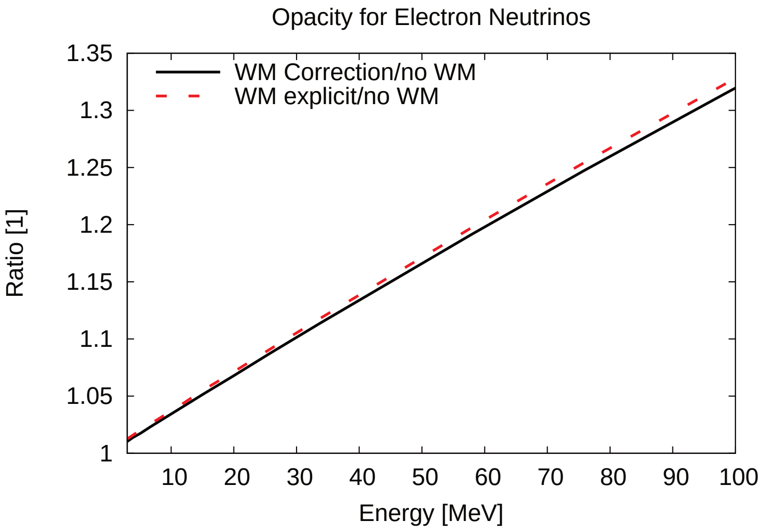


- Explicit calculation differs from correction factor
- Outgoing lepton energy not going to zero for incoming lepton energy going to zero
- Relative difference the largest for low energy neutrinos
- However: Good agreement for nucleosynthesis region

$T = 1$ MeV, $\rho = 1.0 \cdot 10^5$ g/cm^3, $Y_e = 0.48$



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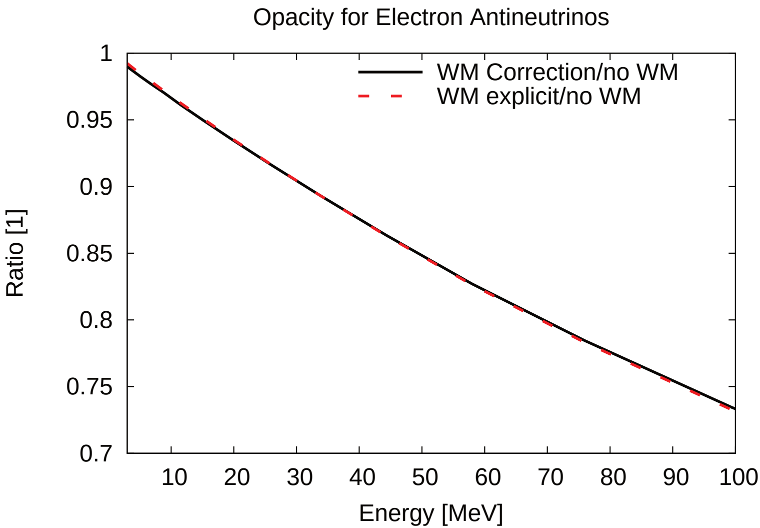

We have also calculated Weak Magnetism contribution for neutron decay

$$\left\langle |M|^2 \right\rangle = \left[(g_A + g_V)^2 + 2g_A F_2\right](P_\nu \circ P_n)(P_e \circ P_p)$$
$$+ \left[(g_A - g_V)^2 - 2g_A F_2\right](P_\nu \circ P_p)(P_e \circ P_n)$$
$$+ \left[g_A^2 - g_V^2\right](P_\nu \circ P_e)\, M_n^* M_p^*$$
$$+ \left[-2g_V F_2 - \frac{F_2^2}{2}\right](P_\nu \circ P_e)^2$$
$$+ \left[\frac{F_2^2}{2}\right]\frac{1}{M^2}(P_\nu \circ P_e)(P_\nu \circ P_n)(P_\nu \circ P_p)$$
$$+ \left[\frac{F_2^2}{2}\right]\frac{1}{M^2}(P_e \circ P_\nu)(P_e \circ P_n)(P_e \circ P_p)$$

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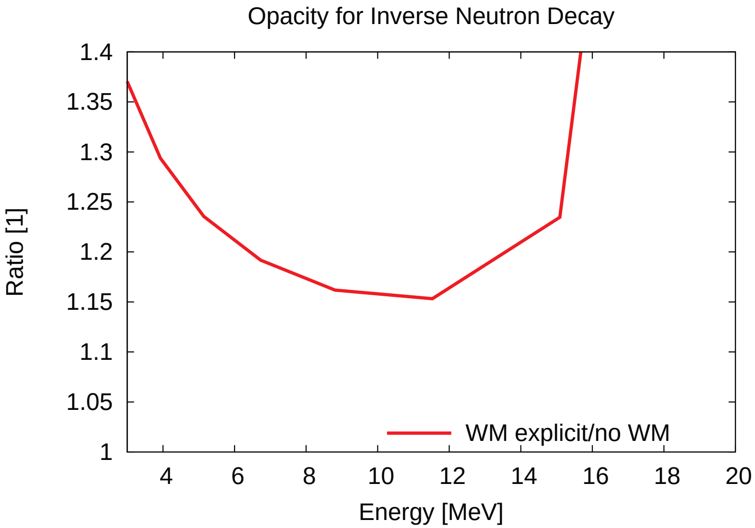

- We have also calculated Weak Magnetism contribution for $\nu_\mu + n \to \mu^- + p$
- One gets additional contributions proportional to m_μ^2/m_N^2

$$\left\langle |M|^2 \right\rangle_{m_\mu} = \left[-\frac{3}{2} g_V F_2 + \frac{F_2^2}{2m_N^2} \left(-\frac{3}{4} {m_N^*}^2 - \frac{1}{4} {m_n^*}^2 + \frac{1}{4} Q - \frac{1}{8} m_\mu^2 \right) \right] \cdot \left(P_\nu \circ P_e \right) m_\mu^2 + \left[\frac{F_2^2}{8} \right] \frac{m_\mu^2}{m_N^2} \left(P_\nu \circ P_e \right)^2 + \left[\frac{F_2^2}{2} \right] \frac{m_\mu^2}{m_N^2} \left(P_\nu \circ P_e \right) \left(P_\nu \circ P_n \right) - \left[\frac{F_2^2}{2} \right] \frac{m_\mu^2}{m_N^2} \left(P_\nu \circ P_n \right)^2$$

with $\quad Q = {m_n^*}^2 - {m_p^*}^2$

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