

Спиновый свет нейтрино: переходы между различными массовыми состояниями

Объединенный Семинар ОИЯИ и
МГУ по физике нейтрино.
Магнитный момент нейтрино

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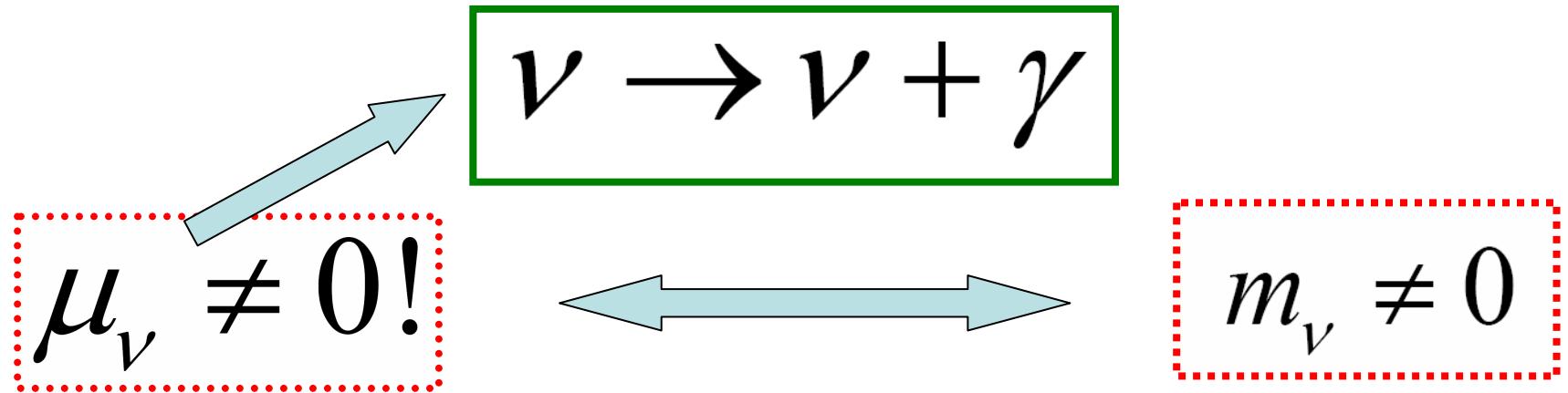
ОИЯИ - 2 ноября 2010



- A. Grigoriev, A. Lokhov, A. Studenikin, A. Ternov
“Spin light in neutrino transition between
different mass states in matter”

arXiv:1003.0630 [hep-ph]

New mechanism of electromagnetic radiation by neutrino in matter



Recent review of neutrino electromagnetic properties see:

C. Giunti, A. Studenikin,
Phys.Atom.Nucl. 72, 2151 (2009)

Spin Light of Neutrino in matter

(gamma-rays for relativistic neutrinos $\omega \sim 1/3 E_\nu$)

- A.Lobanov, A.Studenikin, Phys.Lett.B; **564** (2003) 27; **601** (2004) 171
 A.Studenikin, A.Ternov, Phys.Lett.B **608** (2005) 107
 A.Grigoriev, A.Studenikin, A.Ternov, Phys.Lett.B **622** (2005) 199

$$m_i = m_f$$

Neutrino radiative decay in vacuum

$$\begin{array}{c} \nu_i \rightarrow \nu_j + \gamma \\ \downarrow \qquad \downarrow \\ m_i \qquad m_j \end{array}$$

was also considered before:

S. Petcov, Nucl. Phys. 25 (1977) 641

G. Zatsepin, A. Smirnov, Nucl. Phys. 28 (1978) 6

A. De Rujula and S. L. Glashow, Phys. Rev. Lett. 45 (1980) 942

P. Pal, L. Wolfenstein, Phys.Rev.D 25 (1982) 766

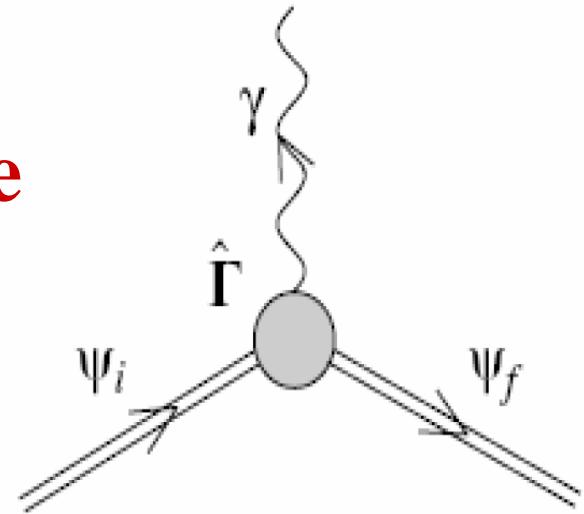
C. Giunti, C.W. Kim, W.P. Lam, Phys.Rev.D 43 (1991) 164

$$\nu_i \rightarrow \nu_j + \gamma$$

$$m_i \neq m_j$$

SLν

Neutrinos weak interaction with matter is taking into account: we use exact wave functions for the initial and final neutrinos in presence of matter



- γ is coupled to **neutrinos** by transition magnetic moment μ_ν
- high density of matter $n \sim 10^{37} \div 10^{40} \text{ cm}^{-3}$
(neutron stars)
- relativistic neutrinos

Modified Dirac Equation

$$\left\{ i\gamma_\mu \partial^\mu - \frac{1}{2} \gamma_\mu (1 + \gamma^5) f^\mu - m \right\} \Psi(x) = 0.$$

$$f^\mu = \frac{G_F}{\sqrt{2}} (n_n, 0, 0, 0)$$

for unpolarized and matter at rest

neutrino energy spectrum

matter density parameter

$$\alpha = \frac{1}{2\sqrt{2}} G_F \frac{n_n}{m}$$

$$E_\varepsilon = \varepsilon \sqrt{(p - s\alpha m)^2 + m^2} + \alpha m$$

neutrino momentum

S is neutrino helicity

$\varepsilon = \pm 1$ *defines positive and negative energy solutions*

n_n *is neutron number density*

A. Studenikin, A. Ternov Phys.Lett. B 60 (2005) 107

A. Studenikin, J.Phys. A:Math.Theor. 41 (2008) 16402

Total rate

Parameters:

$$\frac{\alpha m_i}{p_i}, \quad \frac{m_i}{p_i}, \quad \frac{m_i^2 - m_f^2}{p_i^2}$$

matter density parameter

$$V_i \rightarrow V_j + \gamma$$

$$m_i \quad m_j$$

$$\frac{1}{2\sqrt{2}} \tilde{G}_F n \sim 1 \text{ eV}$$

for

$$n = 10^{37} \text{ cm}^{-3}$$

$$\Gamma = 4 \mu^2 \alpha^3 m_i^3 \left[1 + \frac{3}{2} \frac{m_i^2 - m_f^2}{\alpha m_i p_i} + \frac{p_i}{\alpha m_i} \right]$$

$$\frac{\alpha m_i}{p_i} \gg 1, \quad \frac{m_i}{p_i} \ll 1, \quad \frac{m_f}{p_i} \ll 1, \quad \frac{m_i^2 - m_f^2}{p_i^2} \ll 1$$

Ultrahigh density

$$\Gamma = 4 \mu^2 \alpha^2 m_i^2 p_i \left(1 + \frac{\alpha m_i}{p_i} + \frac{m_i^2 - m_f^2}{\alpha m_i p_i} + \frac{3}{2} \frac{m_i^2 - m_f^2}{p_i^2} \right)$$

$$\frac{m_i}{p_i} \ll \alpha \ll \frac{p_i}{m_i}$$

High density

$$\Gamma = 1.87 \cdot \mu^2 p_i^3 \left(\frac{m_i^2 - m_f^2}{p_i^2} \right)^3$$

$$\frac{\alpha m_i}{p_i} \ll \frac{m_i^2}{p_i^2}$$

Heavy neutrino

$$\Gamma \sim m_i^5$$

Conclusions

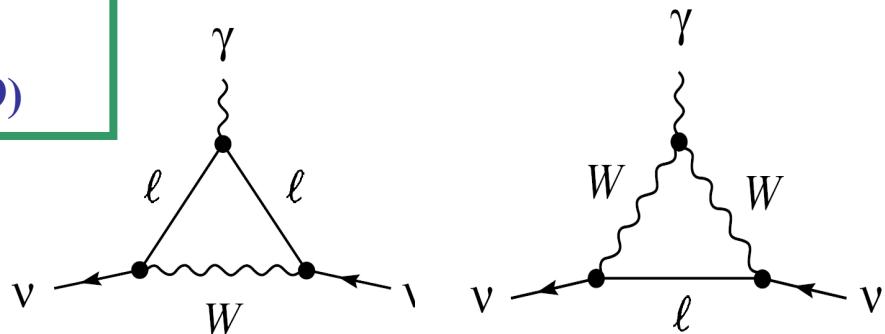
- The theory of spin light of neutrino in matter is now generalized for the case of neutrino transition between two different mass states (originally $SL\nu$ was considered for the case of equal masses of neutrino in initial and final states)
- The rate of the process provided by the transition magnetic moment is of the same order as provided by the diagonal one
- The energy spectrum of $SL\nu$ for the case of relativistic neutrino moving in dense matter span up to the range peculiar for gamma-rays
- In the case of ultra-relativistic neutrino energies and high densities of matter (astrophysical applications) the neutrino mass difference gives subdominant effect
- In the case of low neutrino energies and low densities of matter in the leading order our result is in agreement with
 - A. De Rujula and S. L. Glashow; G. Zatsepin, A. Smirnov;
S. Petcov; P. Pal, L. Wolfenstein
- The rate of $SL\nu$ is determined by the value of neutrino effective magnetic (transition) moment

SLν

Neutrino magnetic moment

Recent review of neutrino electromagnetic properties see:

C. Giunti, A. Studenikin,
Phys. Atom. Nucl. 72, 2151 (2009)



Theory SM
with massive
neutrino

$$\mu_{ij}^D = \frac{eG_F m_i}{8\sqrt{2}\pi^2} \left(1 + \frac{m_j}{m_i}\right) \sum_{l=e,\mu,\tau} U_{1l} U_{2l} F(r_l)$$

U_{ij} - mixing matrix

$$\mu_{ii}^D \approx 3.2 \times 10^{-19} \left(\frac{m_i}{1 \text{ eV}}\right) \mu_B$$

K. Fujikawa and R. E. Shrock, Phys. Rev. Lett. 45, 963 (1980)

Experiment

$$\mu_\nu \leq 3.2 \times 10^{-11} \mu_B$$

GEMMA collaboration

A.G. Beda *et al.*, in *Particle Physics on the Eve of LHC*, Ed. by A. Studenikin (World Sci., Singapore, 2009), p. 112,
arXiv:0906.1926

It is possible to have

$$\tau = \frac{1}{\Gamma} \ll \text{age of the Universe ?}$$

SL ν

For ultra-relativistic ν

with momentum $p \sim 10^{20} eV$

and magnetic moment $\mu \sim 10^{-10} \mu_B$

in very dense matter $n \sim 10^{40} cm^{-3}$

from

$$\Gamma_{SL\nu} = 4\mu^2 \alpha^2 m_\nu^2 p$$

$$p \gg m_{plasmon}$$

recently also
discussed by
**A.Kuznetsov,
N.Mikheev, 2006**

A.Lobanov, A.Studenikin, PLB 2003; PLB 2004

A.Grigoriev, A.Studenikin, PLB 2005

A.Grigoriev, A.Studenikin, A.Ternov, PLB 2005

$$\alpha m_\nu = \frac{1}{2\sqrt{2}} G_F n (1 + \sin^2 \theta_W)$$

it follows that

$$\tau = \frac{1}{\Gamma_{SL\nu}} = 1.5 \times 10^{-8} s$$