QED process in Very Special Relativity

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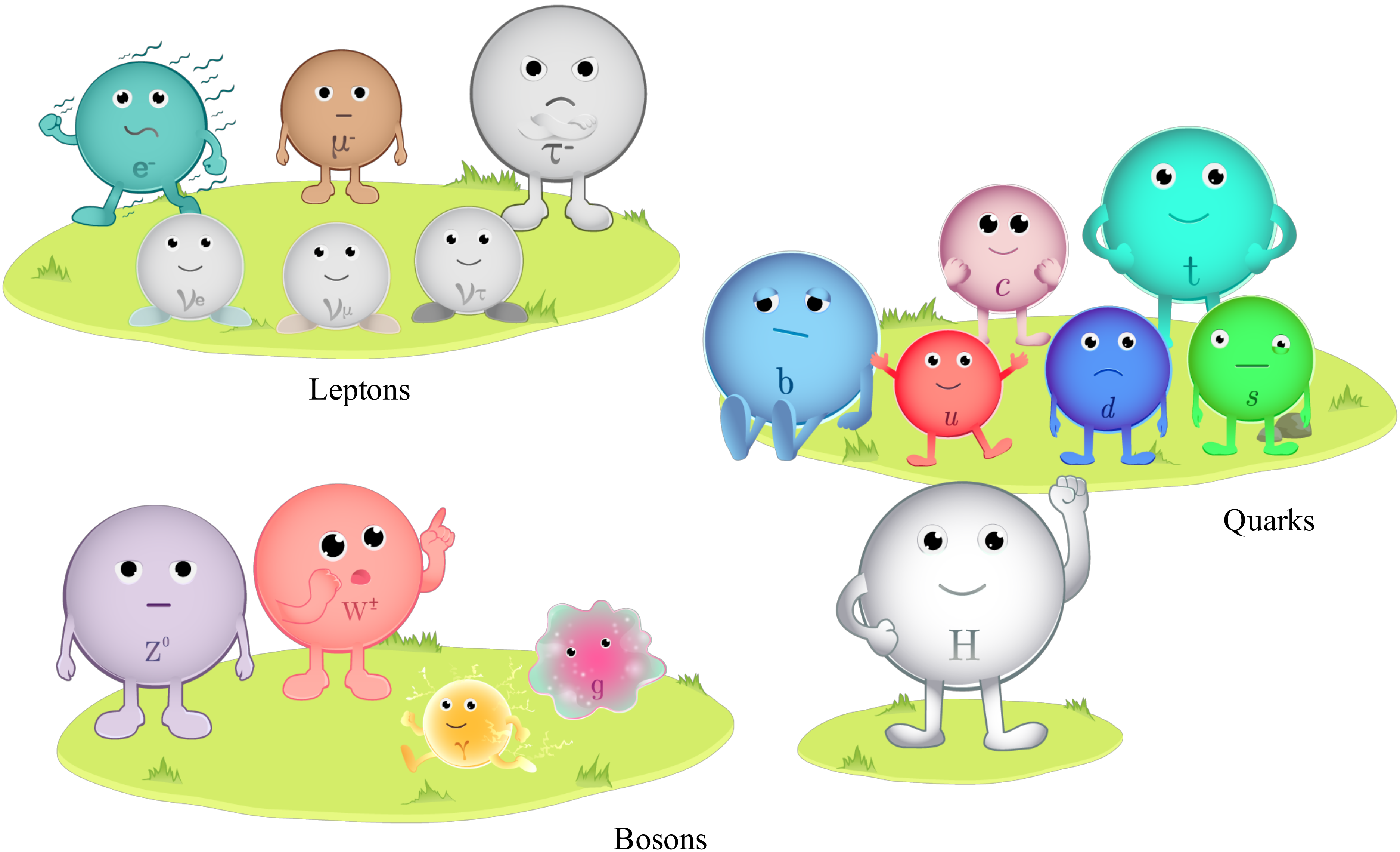
Outline

- VSR Framework
  - What is VSR
  - QED in VSR and Feynman Rules
- Photon-Photon Scattering
- Conclusions


Leptons
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e⁻
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e⁻
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Leptons
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Quarks
Z⁰
W±
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g
Bosons
H

How do I get mass?

Very Special Relativity

Andrew G. Cohen* and Sheldon L. Glashow†
Physics Department, Boston University
Boston, MA 02215, USA
(Dated: Jan 26, 2006)

Phys.Rev.Lett. 97 (2006) 021601

A Lorentz-Violating Origin of Neutrino Mass?

Andrew G. Cohen* and Sheldon L. Glashow†

Physics Department, Boston University

Boston, MA 02215, USA

(Dated: April 12,2006)

arXiv:hep-ph/0605036

Using SIM(2) an important feature is the following null vector

$$n \to (1, 0, 0, 1)$$

It transforms as

$$n \to e^{\phi} n$$

This allows us introduce new terms as

$$\frac{n \cdot p_1}{n \cdot p_2}$$

It is not Lorentz invariant but VSR

A privileged direction is part of the theory

VSR Equation for Neutrino:

$$\left(\not{p} - \frac{m^2}{2} \frac{\not{n}}{n \cdot p} \right) \nu = 0$$

Dispersion relation:

$$p^2 = m^2$$

The QED lagrangian is

$$\mathcal{L} = \mathcal{L}_{\text{fermion}} + \mathcal{L}_{\text{gauge}} + \mathcal{L}_{\text{GF}}$$

with

$$\mathcal{L}_{\text{fermion}} = \bar{\psi}\left[i\left(\not{D} + \frac{1}{2}m^2\frac{\not{n}}{n\cdot D}\right) - M\right]\psi$$

$$\mathcal{L}_{\text{gauge}} = -\frac{1}{4}F_{\mu\nu}F^{\mu\nu} - \frac{m_\gamma^2}{2}(n^\alpha F_{\mu\alpha})\frac{1}{(n\cdot\partial)^2}(n_\beta F^{\mu\beta})$$

$$\mathcal{L}_{\text{GF}} = -\frac{1}{2\xi}(\partial^\mu A_\mu)^2$$

and

$$D_\mu = \partial_\mu - ieA_\mu$$

The QED lagrangian is

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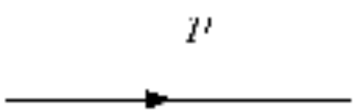
$$\mathcal{L}_{\rm GF} = -\frac{1}{2\xi}(\partial^\mu A_\mu)^2$$

and

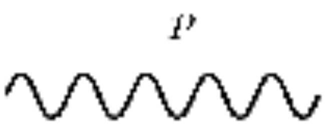
$$D_\mu = \partial_\mu - ieA_\mu$$

Here, a photon mass is allowed!
It doesn’t break gauge invariance!

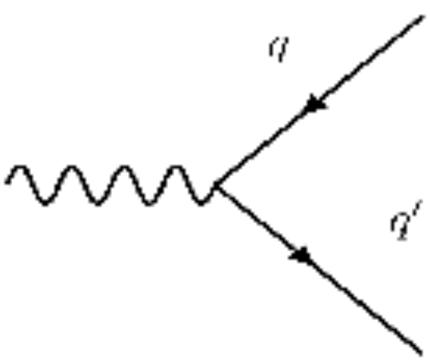
Feynman Rules



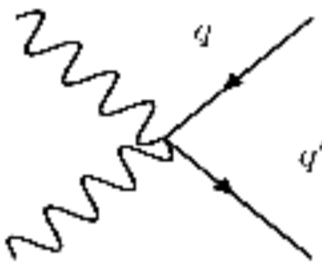
$$i\frac{\not p + M - \frac{m^2}{2}\frac{\not n}{n\cdot p}}{p^2 - M^2 - m^2 + i\varepsilon}$$



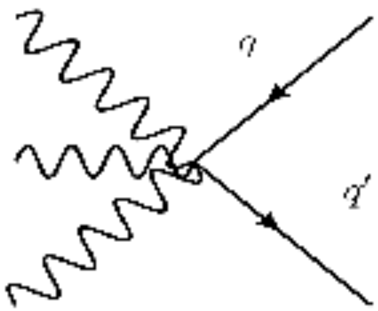
$$-i\frac{g_{\mu\nu}}{p^2 + i\varepsilon}$$



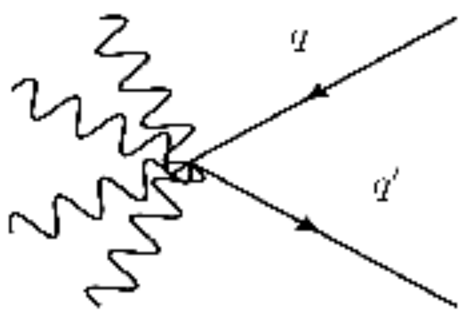
$$-ie\left(\gamma_\mu + \frac{1}{2}m^2\frac{\not n n_\mu}{n\cdot q n\cdot q'}\right)$$



$$-ie^2\frac{1}{2}\not{n}m^2\frac{n_\mu n_\nu}{n\cdot q\, n\cdot q'}\left(\frac{1}{n\cdot(p+q)}+\frac{1}{n\cdot(p'+q)}\right)$$



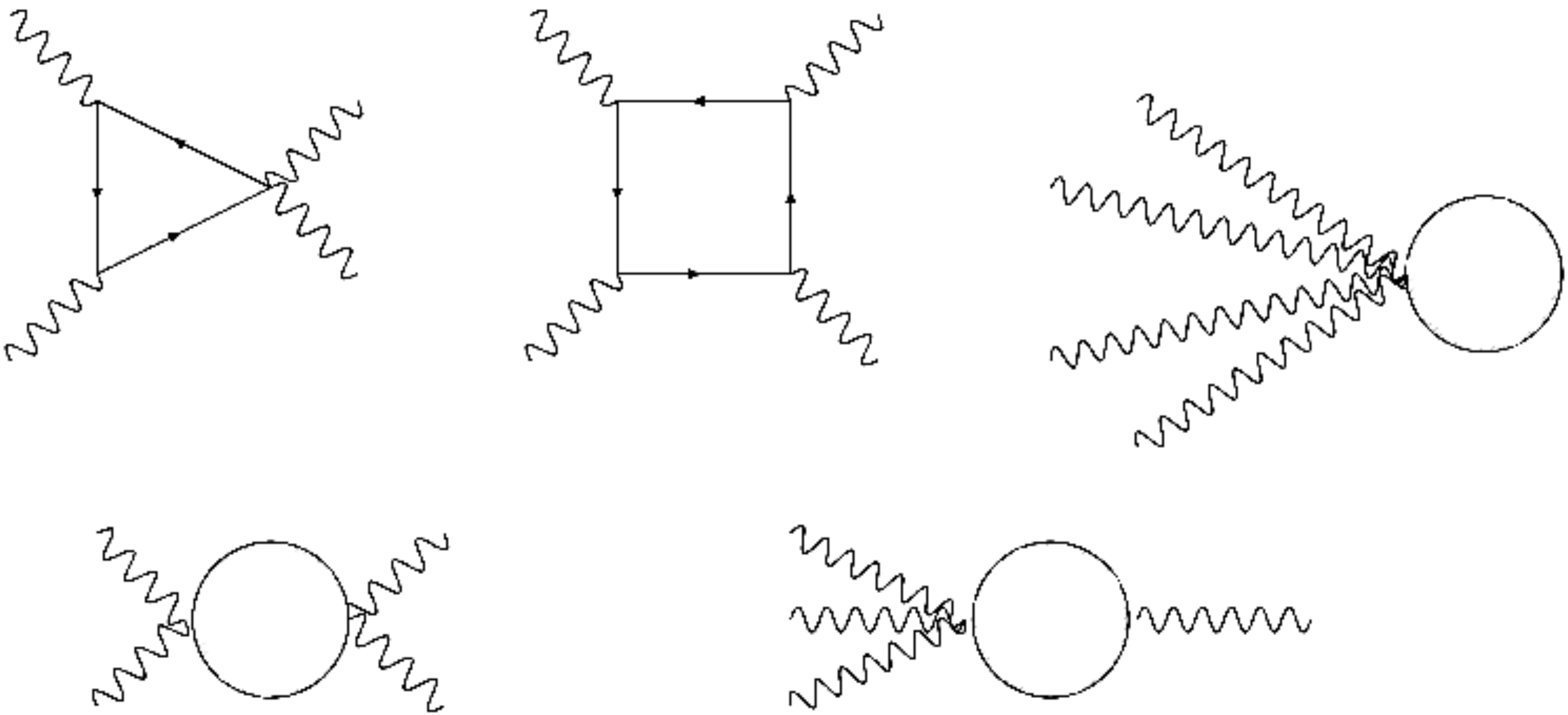
$$-ie^3\frac{1}{2}\not{n}m^2\frac{n_\mu n_\nu n_\rho}{n\cdot q\, n\cdot q'}\left[\left(\frac{1}{n\cdot(p_3+q)}+\frac{1}{n\cdot(p_2+p_3+q)}\right)+\text{perm.}\right]$$



$$-ie^4\frac{1}{2}\not{n}m^2\frac{n_\mu n_\nu n_\rho n_\sigma}{n\cdot q\, n\cdot q'}\left[\left(\frac{1}{n\cdot(p_4+q)}+\frac{1}{n\cdot(p_3+p_4+q)}+\frac{1}{n\cdot(p_2+p_3+p_4+q)}\right)+\text{perm.}\right]$$

Photon-Photon Scattering

Bounds in the neutrino mass with Photon-Photon Scattering in Very Special Relativity (Paper in preparation).



We consider the low energy regime.

We keep only the dominant term in m^2

The integrals with $\frac{1}{n \cdot p}$ are solved using the Mandelstam-Leibbrandt prescription.

Physical Review D 93, 065033 (2016)

We introduce a new null vector that satisfies

$$n_\mu \to \lambda n_\mu, \qquad \bar{n}_\mu \to \frac{1}{\lambda}\bar{n}_\mu, \qquad \lambda \in \mathbb{R} - \{0\}$$

We have checked the Ward identity is satisfied

$$k_\mu \Pi^{\mu\nu\rho\sigma} = 0$$

Euler-Heisenberg modified equation

$$\mathcal{L}_{EH} = \frac{e^4}{M_e^4 \pi^2} \left[\frac{1}{1440} (F_{\mu\nu} F^{\mu\nu})^2 + \frac{7}{5760} (\tilde{F}_{\mu\nu} F^{\mu\nu})^2 + \frac{m^2}{8} \left(\frac{\bar{n}^\mu}{n \cdot \partial} \varphi_\mu \right)^2 \varphi_\nu \varphi^\nu \right]$$

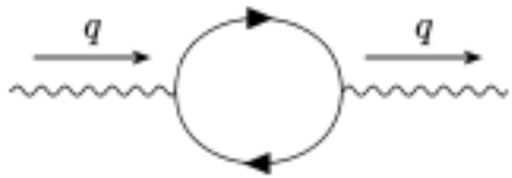
con

$$\tilde{F}_{\mu\nu} = \varepsilon_{\alpha\beta\mu\nu} F^{\alpha\beta}$$

$$\varphi_\nu = n^\mu F_{\mu\nu}$$

The new null vector breaks the SIM(2) invariance

In the two legs case

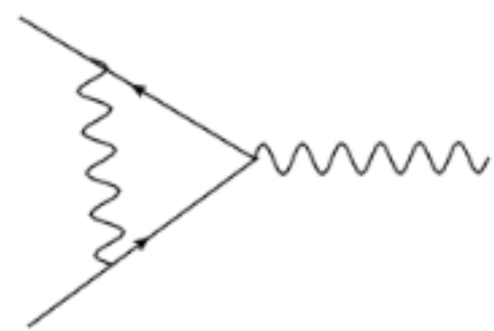


We choose $\bar{n}$ as

$$\bar{n}_\mu = -\frac{q^2}{2(n\cdot q)^2} n_\mu + \frac{1}{n\cdot q} q_\mu$$

Ward identity shows us to use the same $\bar{n}$ for all integrals

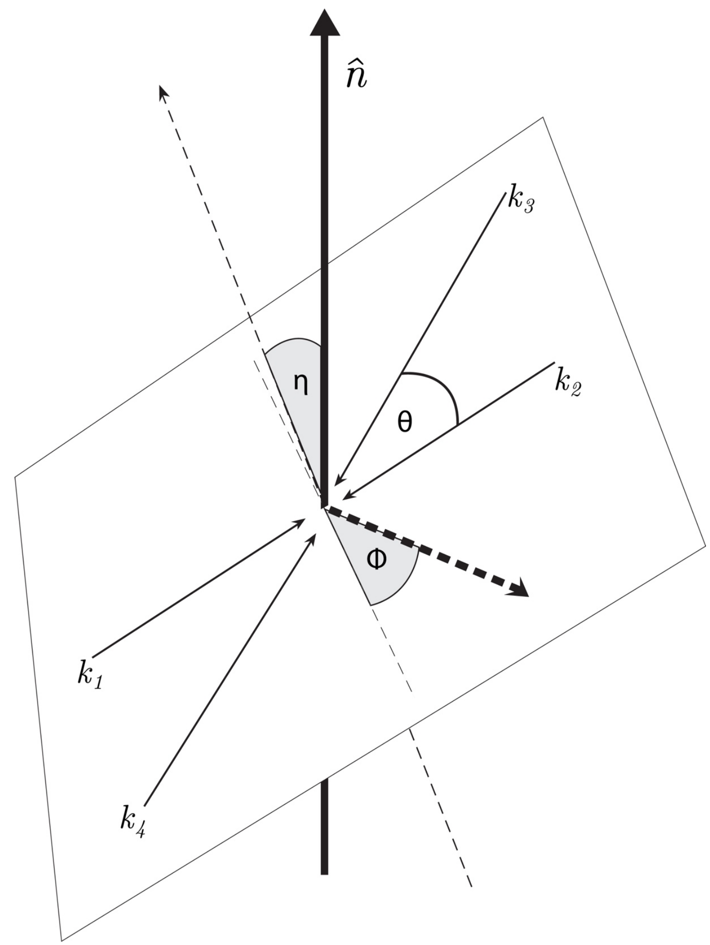
But we can choose different for



In the four legs case

$$\bar{n}_\mu = -\frac{(k_1+k_2+k_3)^2}{2(n\cdot(k_1+k_2+k_3))^2}n_\mu + \frac{k_{1\mu}+k_{2\mu}+k_{3\mu}}{n\cdot(k_1+k_2+k_3)}.$$

Using this diagram



The unpolarized cross section is

$$\frac{d\sigma}{d\Omega} = \frac{\alpha^4\omega^4}{(180\pi)^2 M_e^8}(139\omega^2(3+\cos^2\theta)^2 + 1800m^2\sin^2\theta).$$

$$\sigma = \frac{\alpha^4\omega^4(973\omega^2 + 750m^2)}{10125 M_e^8 \pi}.$$

There is not signal of privileged direction!

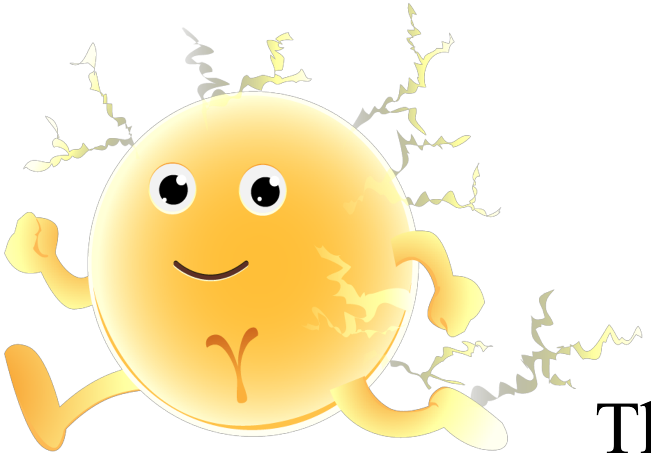
Using the cross section we can get an upper bound in the neutrino mass. Using PVLAS data experiment, for an energy of $1.17\ \mathrm{eV}$ and

$$\sigma < 4.6 \times 10^{-62}\ m^2$$

the upper bound was $6360.07\ \mathrm{eV}$

Conclusions

- The cross section in the photon-photon scattering is independent of n using the dominant terms. Maybe taking more terms we could see the dependency, but it will be small.
- Current bounds in the photon-photon scattering can give an upper bound for the neutrino mass in VSR, but the bounds are too high to give a prediction.



Thanks!