Seesaw and effective operators

Florian Bonnet

Laboratoire de Physique Théorique
Université Paris XI

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1 Introduction

ν are massless in the SM

- No Dirac mass: $m_D(\overline{\nu_L}\nu_R + \overline{\nu_R}\nu_L)$
  - no right-handed neutrino ν_R $\longrightarrow$ no $Y\widetilde{H}\overline{l_L}\nu_R + h.c.$

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$\longrightarrow$ Neutrinos are massless

Experimental data

Experimental observations of solar, atmospherical and terrestrial neutrinos showed their oscillations : *Strumia 06*

$$\begin{aligned}
\Delta m^2_{12} &= (8.0 \pm 0.3) \times 10^{-5} eV^2 \\
\left|\Delta m^2_{23}\right| &= (2.5 \pm 0.2) \times 10^{-3} eV^2 \\
\tan^2\theta_{12} &= 0.45 \pm 0.05 \\
\sin^2 2\theta_{23} &= 1.02 \pm 0.04 \\
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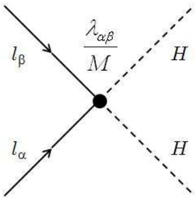
→ ν are massive
flavor mixing in the leptonic sector

Proof that there must be a Physic Beyond the SM

Adding heavy fields

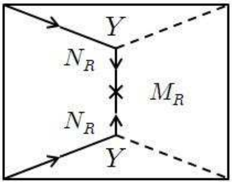
The heavy fields manifest in the low energy theorie by non-renormalisable operators.

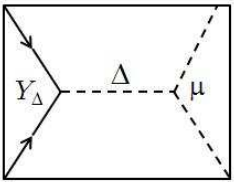


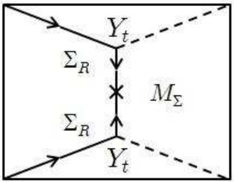
$$\frac{\lambda_{\alpha\beta}}{M}\overline{l^c_{L\alpha}}l_{L\beta}\widetilde{H}^*\widetilde{H}^\dagger \longrightarrow \frac{\lambda_{\alpha\beta}}{M}v^2\overline{\nu^c_{L\alpha}}\nu_{L\beta}$$

Majorana mass, violation of lepton lumber

Various realization of the seesaw







Type I

N_R singlet fermion

Gell-Man, Ramond, Slansky

Yanagida

Mohapatra,Senjanovic

Type II

Δ scalar triplet

Georgi,Glashow, Nussinov

Mohapatra, Senjanovic

Schechter, Valle

Ma, Sarkar

Type III

Σ_R triplet fermion

Ma,Hambye et al.

Bajc, Senjanovic

Abada, Antusch, Biggio, F.B. Gavela, in progress...

Effective theory

Developement of the Lagrangian into a serie of non-renormalizable operators when the heavy fields are integrated out

$$\mathcal{L}_{SM} + \mathcal{L}_{seesaw} \rightarrow \mathcal{L}_{eff} = \mathcal{L}_{SM} + \frac{1}{\Lambda}\mathcal{L}^{d=5} + \frac{1}{\Lambda^2}\mathcal{L}^{d=6} + \ldots$$

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$$\downarrow$$

$$\mathcal{O}_{Weinberg}$$

$$m_\nu$$

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$\frac{1}{\Lambda}\mathcal{L}^{d=5}$ ↓ $\mathcal{O}_{Weinberg}$, m_ν

$\frac{1}{\Lambda^2}\mathcal{L}^{d=6}$ ↓ ???

81 operators constructed with the SM fields

(Buchmuller & Wyler, 86)

Exemple : Type I

$$\mathcal{L}_{N_R} = i\overline{N_R}\partial\!\!\!/ N_R - \left(\overline{l_L}\tilde{\phi}Y_\nu N_R + \overline{N_R}Y_\nu^\dagger\tilde{\phi}^\dagger l_L\right) - \frac{1}{2}\left(\overline{N_R^c}MN_R + \overline{N_R}M^*N_R^c\right)$$

Effective Lagrangian

$$\mathcal{L}_{eff} = \mathcal{L}_{SM} + \frac{1}{M}\mathcal{L}^{d=5} + \frac{1}{M^2}\mathcal{L}^{d=6} + \ldots$$

$$\mathcal{O}_{Weinberg} \rightarrow m_\nu \simeq Y_\nu Y_\nu^\dagger \frac{v^2}{M}$$

$$\frac{1}{M^2}\mathcal{L}^{d=6} = \left(\overline{l_L}\tilde{\phi}\right) i\,\overrightarrow{\partial\!\!\!/}\, Y_\nu \frac{1}{M^2} Y_\nu^\dagger \left(\tilde{\phi}^\dagger l_L\right)$$ →Renormalization of kinetic energy

⇒Unitarity violation

Broncano, Gavela, Jenkins 02
Antusch, Biggio, Fernandez-Martinez, Gavela, Lopez-Pavon 06

Model of Seesaw de type II

$$\Delta = \begin{pmatrix} \Delta^{++} \\ \Delta^{+} \\ \Delta^{0} \end{pmatrix} \sim (1,3,2), \quad L_\Delta = -2$$

Yukawa term :

$$Y_{\Delta ij} \overline{(l_L)^c}_{ia} \, (l_L)_{jb} \, (i\tau_2\tau_\alpha)_{ab} \, \Delta^\alpha + h.c$$

Scalar terms:

$$\mu \phi_a^t \phi_b \, (i\tau_2\tau_\alpha) \left(\Delta^\dagger\right)^\alpha + h.c.$$
$$-M_\Delta^2 \Delta^\dagger \Delta - \tfrac{1}{2}\lambda_2 \left(\Delta^\dagger \Delta\right)^2$$
$$-\lambda_3 \left(\phi^\dagger \phi\right) \left(\Delta^\dagger \Delta\right)$$

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Masse :

$$m_\nu = Y_\Delta \frac{\mu}{M_\Delta^2} v^2$$

2 different scales μ, M_Δ

possibility for $Y_\Delta \sim \mathcal{O}(1)$

$M_\Delta \sim 1\ TeV$ ($\mu \sim 100\, eV$)

d=6 operators

in collaboration with Abada, Gavela, Hambye

$\frac{1}{2M^2} Y_{\Delta ij} Y^\dagger_{\Delta kl} \left(\overline{l_{Li}} \gamma^\mu l_{Lk}\right) \left(\overline{l_{Lj}} \gamma_\mu l_{Ll}\right)$ → Lepton Flavor Violation, constrains

$$\left.\begin{array}{l} -2\frac{\mu^2}{M_\Delta^4} \partial_\mu \left(\phi^\dagger \phi\right) \partial^\mu \left(\phi^\dagger \phi\right) \\ 2\lambda_3 \frac{\mu^2}{M_\Delta^4} \left(\phi^\dagger \phi\right)^3 \\ 4\frac{\mu^2}{M_\Delta^4} \left[\phi^\dagger D_\mu \phi\right]^\dagger \left[\phi^\dagger D_\mu \phi\right] \end{array}\right\} \rightarrow \text{EW precision data, coupling to bosons}$$

$-2\frac{\mu^2}{M_\Delta^4} \left(\phi^\dagger \phi\right) \left\{Y_e \bar{l} e_R \phi + Y_d \bar{q} d \phi - Y_u \bar{q} i \tau_2 u \phi + h.c.\right\}$ → top.....

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Scalar sector : EW precision data, ρ

The only contribution to ρ is coming from $4\frac{\mu^2}{M_\Delta^4}\left[\phi^\dagger D_\mu \phi\right]^\dagger \left[\phi^\dagger D_\mu \phi\right]$

$$\delta\rho = \frac{2v^2\mu^2}{M_\Delta^4} \to \left|\frac{\mu}{M_\Delta^2}\right| < 3 \times 10^{-5}\,\mathrm{GeV}^{-1}$$

to compare with

$$m_\nu = Y_\Delta \frac{\mu}{M_\Delta^2} v^2$$

For $m_\nu \sim 1\,\mathrm{eV}$ we get:

$$\frac{\mu}{M_\Delta^2} \;:\sim 10^{-15}\,\mathrm{GeV}^{-1} \to \sim 10^{-5}\,\mathrm{GeV}^{-1}$$

$$Y_\Delta \;:\quad 1 \quad \to 10^{-10}$$

Scalar sector : ILC (1)

$$a_1\mathcal{O}_{\phi,1} = 4\frac{\mu^2}{M_\Delta^4}.\frac{1}{2}\partial_\mu\left(\phi^\dagger\phi\right)\partial^\mu\left(\phi^\dagger\phi\right)\ ; \quad a_2\mathcal{O}_{\phi,2} = 6\lambda_3\frac{\mu^2}{M_\Delta^4}.\frac{1}{3}\left(\phi^\dagger\phi\right)^3$$

Barger & al. 03

- Modification of the scalar potential
- Renormalization of the kinetic term

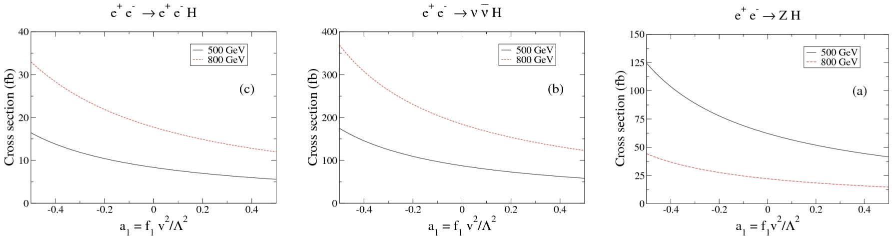
Consequences :

- Modification of HWW, HZZ, HHWW, HHZZ and HHH and HHHH couplings
- Modification of the single Higgs and Higgs pair production cross sections at ILC and CLIC

Scalar sector : ILC (2)

Single Higgs production / $a_1 = 4\frac{\mu^2}{M_\Delta^4}$

Barger & al. 03

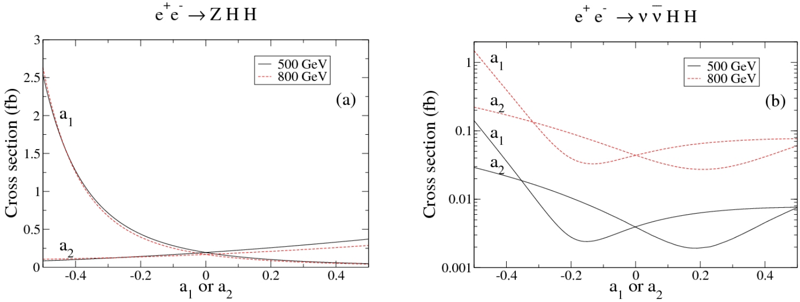


constrains by ρ : $a_1 = 4\frac{\mu^2}{M_\Delta^4} = 0.0004\pm^{0.0007}_{0.0004}$ $\longrightarrow$ very few deviation from SM

Any deviation observed$\Rightarrow$ New physics other than the triplet

Higgs pair production / $a_2 = 6\lambda_3 \frac{\mu^2}{M_\Delta^4}$

Barger & al. 03



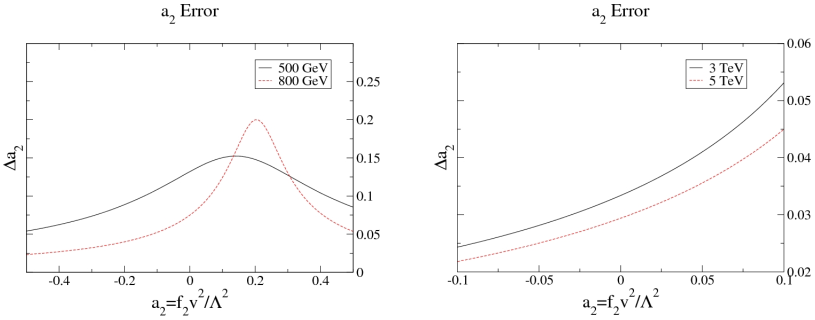
As a_1 is strongly constrained, the only deviation is due to $a_2 = 6\lambda_3 \frac{\mu^2}{M_\Delta^4}$

$\to$Mesurement of one parameter of the potential $\lambda_3 \left(\phi^\dagger\phi\right)\left(\Delta^\dagger\Delta\right)$

Scalar sector : ILC (4)

Mesurement of λ_3

Barger & al. 03



Conclusion (1)

Model

$$\Delta = \begin{pmatrix} \Delta^{++} \\ \Delta^{+} \\ \Delta^{0} \end{pmatrix} \sim (1,3,2), \quad L_{\Delta} = -2$$

5 non-renormalizable (d=6) operators which effects are:

- Lepton Flavor violation
- Modification of Higgs production cross section at ILC and CLIC
- Top's physics

Conclusion (2)

Seesaw Type II

- Future improvement on LFV measurement $\longrightarrow$ better knowledge on the $Y_{\Delta ij}$
- Observation of Δ^{--} at LHC $\rightarrow$ mass scale
- Future Linear Colliders $\rightarrow$ scalar potential, other source of NP

Seesaw Type III (Abada, Antusch, Biggio, F.B., Gavela , in progress.....)

......Thanks for your attention......