Non-trivial discrimination between the Scotogenic model and the Inert Doublet model

(Looking for the difference between Tweedledum and Tweedledee)

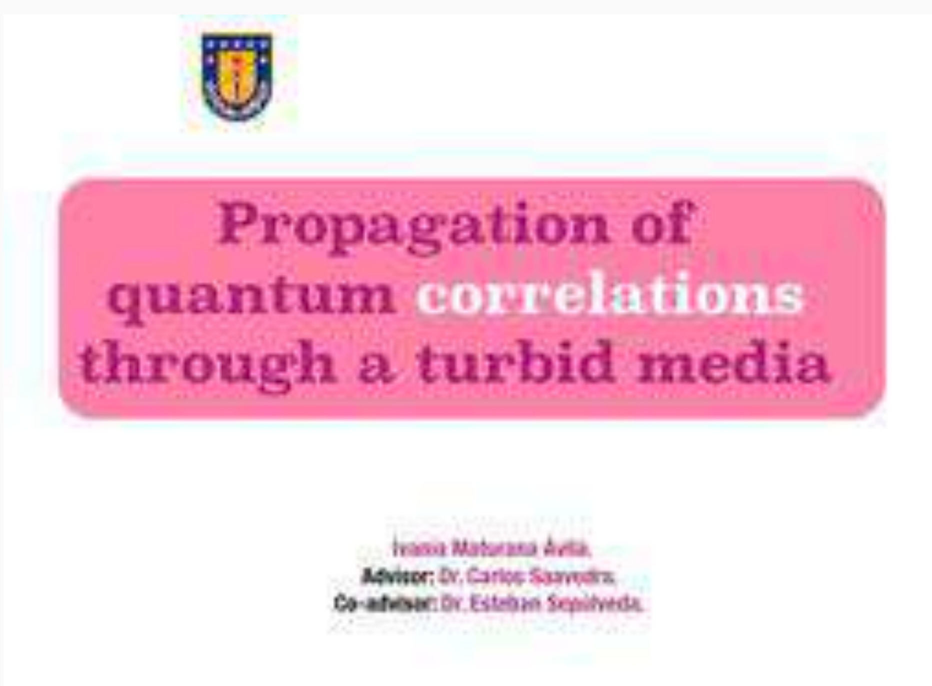
October 18 - IFIC

Who am I?

Antofagasta

Santiago

Concepción



The Cast

Ivania Maturana

Sebastian Urrutia

Professor MAD

Nicolás Rojas

The SM

Gauge Bosons

Quarks

Leptons

The SM problems

- Is there a theory that describes all the fundamental forces?
- Why are there 3 generations of quarks and leptons with different scales of mass?
- Why Higgs mass is so small?
- What is dark matter?
- How the neutrinos acquire mass?

This is not a work about finding a solution to the SM questions

The SM problems

- Does exist a theory that describes all the fundamental forces?
- Why are there 3 generations of quarks and leptons with different scales of mass?
- Why Higgs mass is so small?
- What is dark matter?
- How the neutrinos acquire mass?

We want to find a physical observable that help us to discriminate between both models.

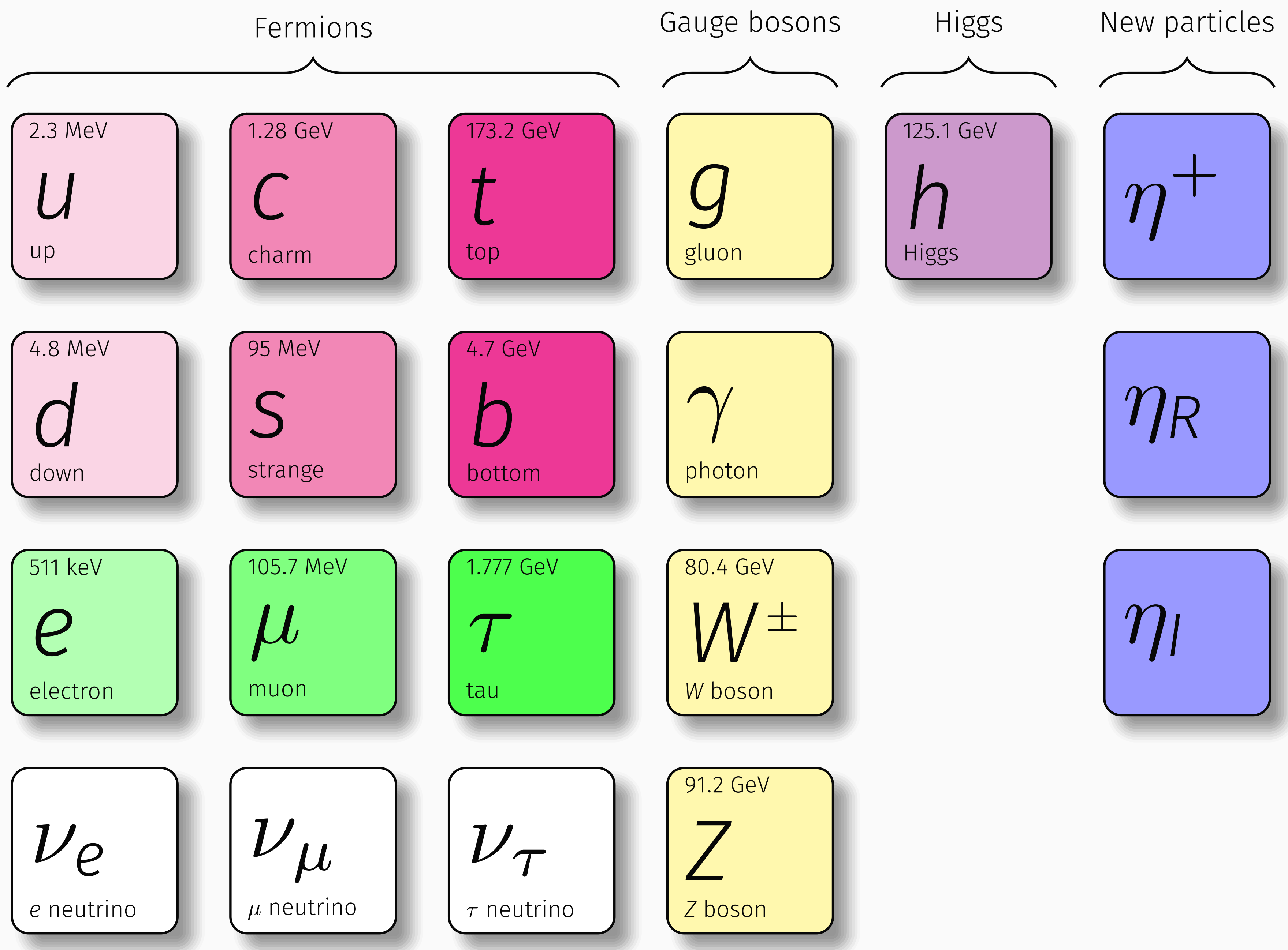
Inert doublet model

vs

Scotogenic Model

Why?

The inert doublet model



We can extend the SM adding two doublets charged under SU(2). The name of this model is THDM (1). The Inert doublet model adds a Z_2 symmetry or a stabilizing symmetry. The new symmetry acts in the new particles of the model as follows

$$\begin{aligned} \eta &\rightarrow -\eta \\ SM &\rightarrow SM \end{aligned} \quad (1)$$

The scalar potential is

$$\begin{aligned} V &= m_1^2\phi^\dagger\phi + m_2^2\eta^\dagger\eta + \lambda_1(\phi^\dagger\phi)^2 + \lambda_2(\eta^\dagger\eta)^2 + \lambda_3(\phi^\dagger\phi)(\eta^\dagger\eta) \\ &+ \lambda_4(\phi^\dagger\eta)(\eta^\dagger\phi) + \frac{\lambda_5}{2}[(\phi^\dagger\eta)^2 + (\eta^\dagger\phi)^2], \end{aligned} \quad (2)$$

where m_1^2, m_2^2 and λ_{1-5} are reals.

Expanding the fields around the vacuum, we will get

$$\begin{aligned} \phi &= \begin{pmatrix} 0 \\ (v+h)/\sqrt{2} \end{pmatrix}, \\ \eta &= \begin{pmatrix} \eta^+ \\ (\eta_R + i\eta_I)/\sqrt{2} \end{pmatrix}. \end{aligned} \quad (3)$$

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(1) G. C. Branco et all. 10.1016/j.physrep.2012.02.002

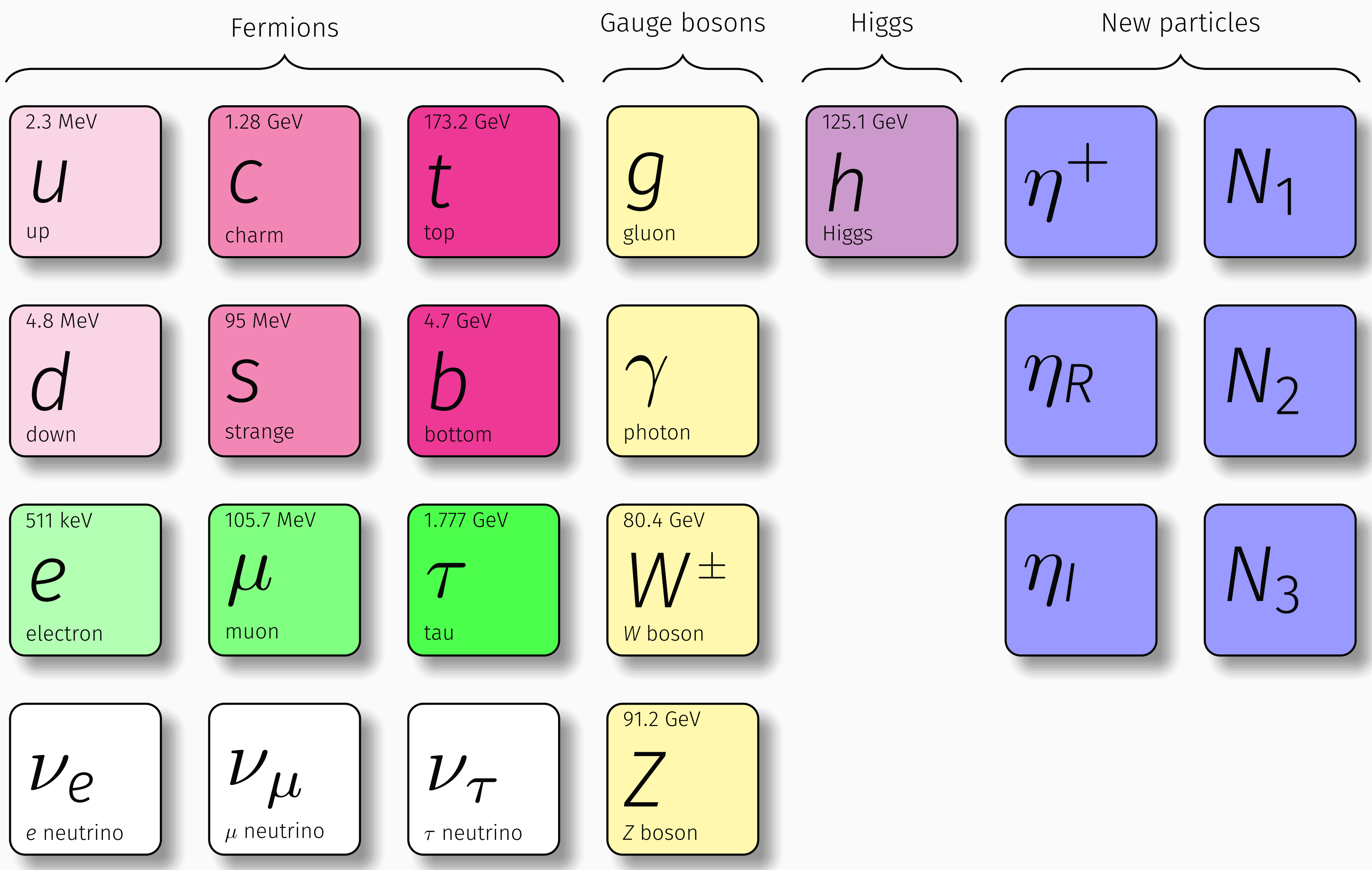
The mass terms of the physical states are

$$\begin{aligned} {m_\phi}^2 &= 2\lambda_1 v^2, \\ {m_\pm}^2 &= m_2^2 + \frac{\lambda_3}{2} v^2, \\ {m_R}^2 &= m_2^2 + \frac{\lambda_3}{2} v^2 + \left(\frac{\lambda_4 + \lambda_5}{2}\right) v^2, \\ {m_I}^2 &= m_2^2 + \frac{\lambda_3}{2} v^2 + \left(\frac{\lambda_4 - \lambda_5}{2}\right) v^2. \end{aligned} \tag{4}$$

In addition, the parameters of our model have the next constrains

$$\begin{aligned} \lambda_{1,2} &> 0 \\ \lambda_3 &> -\sqrt{\lambda_1 \lambda_2} \\ \lambda_3 + \lambda_4 - |\lambda_5| &> -\sqrt{\lambda_1 \lambda_2} \\ \lambda_4 + \lambda_5 &< 0 \\ \lambda_5 &< 0 \end{aligned} \tag{5}$$

The scotogenic model



The Scotogenic model (1) introduce a new Z_2 symmetry, the same that was introduced in the Inert Doublet model and will act over the fields like

$$\begin{aligned} N_{1,2,3} &\rightarrow -N_{1,2,3} \\ \eta &\rightarrow -\eta \\ SM &\rightarrow SM \end{aligned} \tag{6}$$

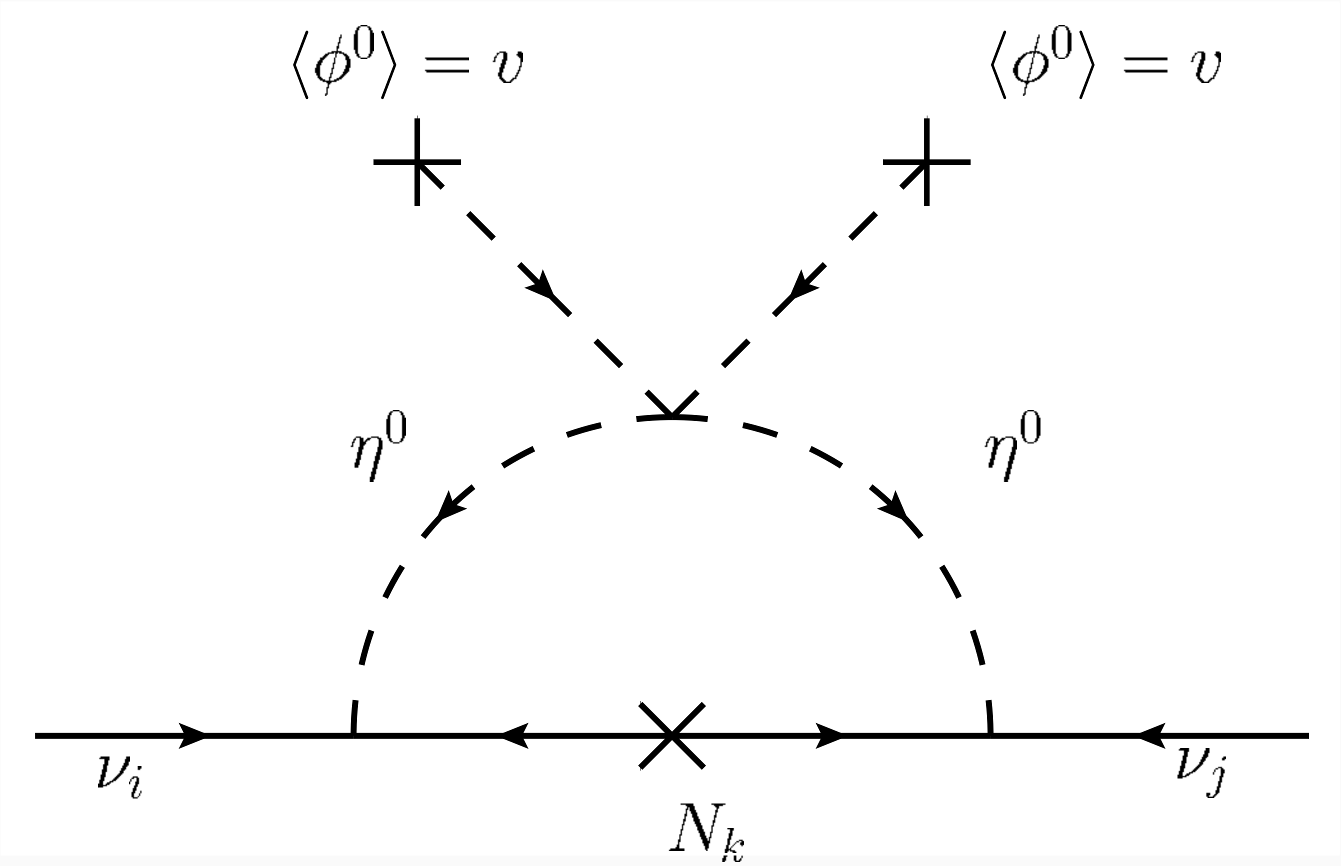
The model will generate neutrino masses at one loop. Comparing the model with the SM, the new fields/tems that will appear in the Lagrangian are

1. $\eta \approx (\mathbf{2}, 1/2)$.
2. $N_i \approx (\mathbf{1}, 0)$, that will have a Majorana mass term given by $-\frac{1}{2}\tilde{\bar{N}}^i M_{ij} N^{jc}$, with M_{ij} a matrix.
3. The Yukawa coupling $L_{Yukawa} \supset -h_{ij}\bar{N}^i_R \tilde{\eta}^\dagger l^j_L + h.c.$ (with $\tilde{\eta} = i\sigma_2\eta^*$).

(1) Ernest Ma. 10.1103/PhysRevD.73.077301

The neutrino masses will be given by the new term

$$M_{\nu,ij} = \frac{h_{ik}h_{jk}}{16\pi^2} N_k \left[\frac{m_R^2}{m_R^2 - N_k^2} ln \frac{m_R^2}{N_k^2} - \frac{m_I^2}{m_I^2 - N_k^2} ln \frac{m_I^2}{N_k^2} \right]. \quad (7)$$



Radiative seesaw mechanism

Breaking of Z2

We found the RGEs (1) for the Scotogenic model, where the most important for us is

$$Dm_2^2 = 6\lambda_2 m_2^2 + 2(2\lambda_3 + \lambda_4)m_1^2 + m_2^2\left[2T_\nu - \frac{3}{2}(g_1^2 + 3g_2^2)\right] - 4Tr(M_N M_N^* h h^\dagger), \quad (8)$$

where $T_\nu = Tr(h^\dagger h)$.

The last equation shows that the parameter m_2^2 could acquire negative values. If that happens the Z_2 symmetry will be broken (2). Taking in account some considerations we realized and study of the Z_2 breaking considering different mass values for N and η :

1.- The mass of the light neutrinos, the vev and the mixing angles will not change so much in the different scales of energy, where the fermionic fields N are introduced.

2.- Firstly we considered $[M_1, M_2, M_3] = [900, 1500, 5000]$ GeV.

(1) A. Merle, M. Platscher. 10.1103/PhysRevD.92.095002

(2) A. Merle, M. Platscher. 10.1007/JHEP11(2015)148

Numerical analysis

The steps were:

- We calculated the values of the coupling h with a parametrization (1) at the scale of 5000 GeV.

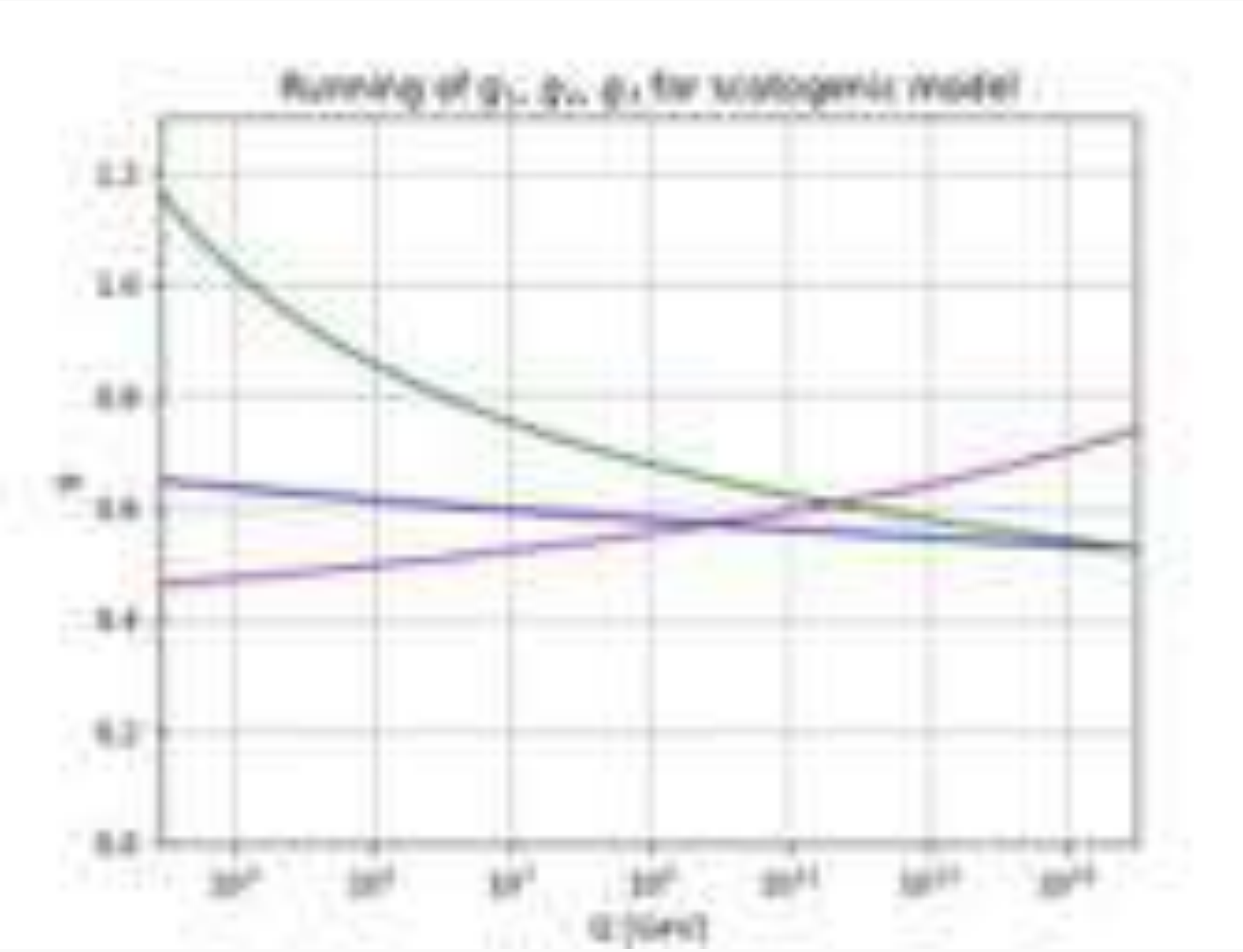
$$h = \sqrt{\Lambda}^{-1} R \sqrt{\hat{m}_\nu} U^\dagger \qquad (9)$$

$$\Lambda_i = \frac{M_{N_i}}{(4\pi)^2}\left[\frac{m_R^2}{m_R^2 - M_{N_i}^2} log\left(\frac{m_R^2}{M_{N_i}^2}\right) - \frac{m_I^2}{m_I^2 - M_{N_i}^2} log\left(\frac{m_I^2}{M_{N_i}^2}\right)\right]$$

- The parameters g_1, g_2, g_3, Y_e, Y_u, Y_d, λ_1 and m_1^2 were evolved from 90 GeV scale up to 5000 GeV scale where we save their values.

- Having all the RGEs of the model, we evolved it from 5000 GeV to GUT scale and we go back from 5000 GeV to 90 GeV.

(1) T. Toma, A. Vicente. 10.1007/JHEP01(2014)160


Running of g1, g2, g3 for scotogenic model
1.2
1.0
0.8
0.6
0.4
0.2
0.0
Q [GeV]

Results

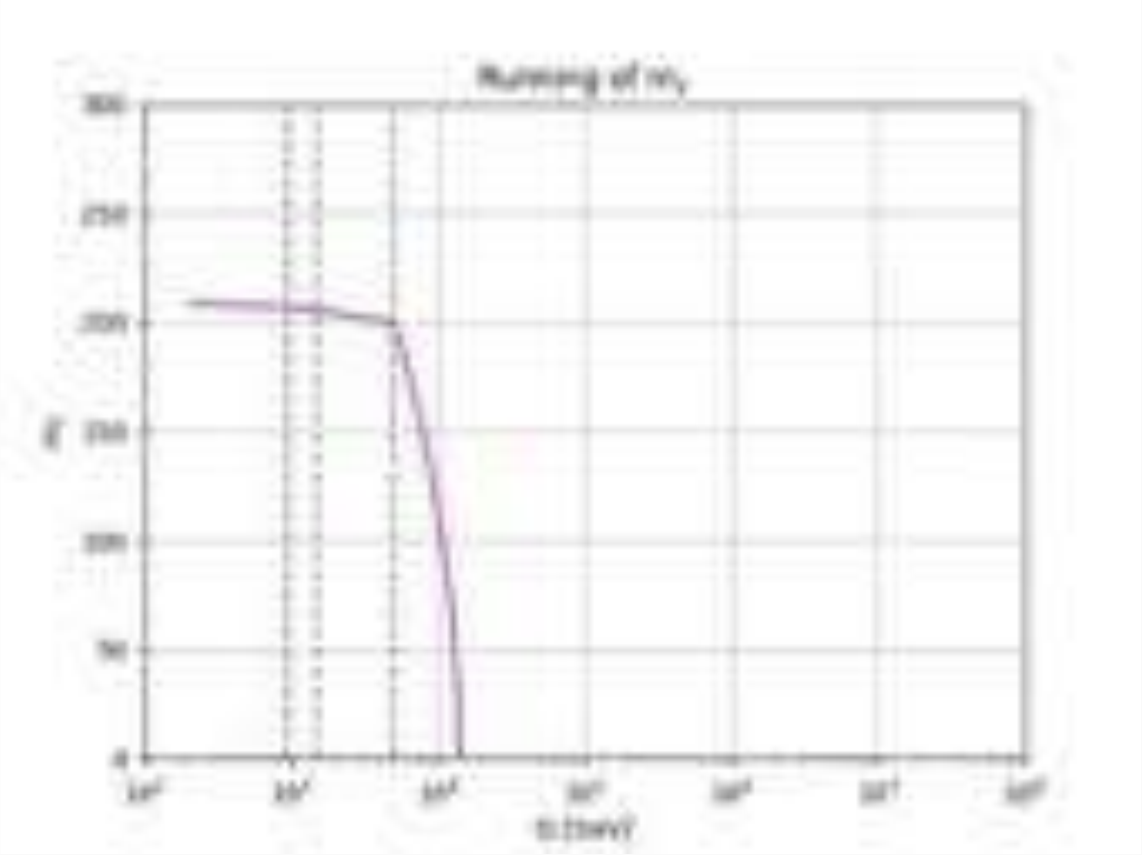


Figure: Plot for $m_2 = 200$ GeV

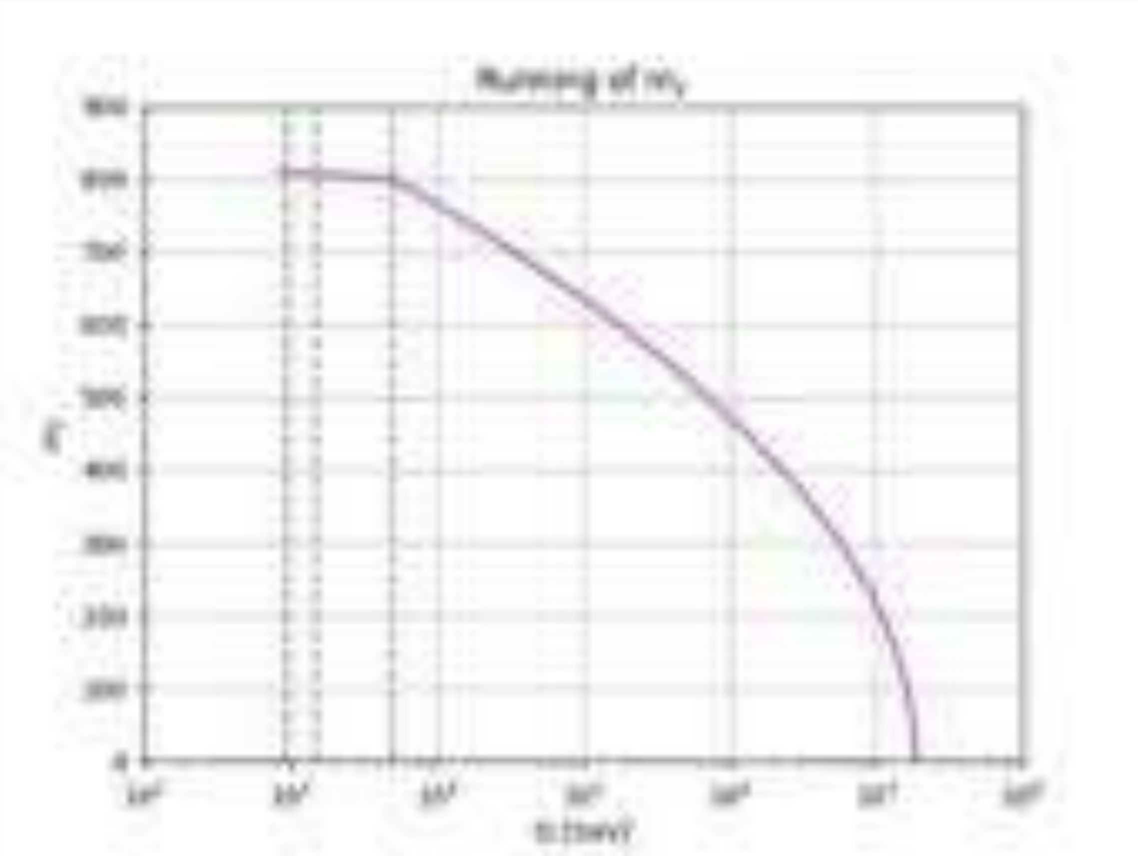


Figure: Plot for $m_2 = 800$ GeV

Changing the mass values for the fermions N and fixing the mass $m_2 = 800$ GeV, we have

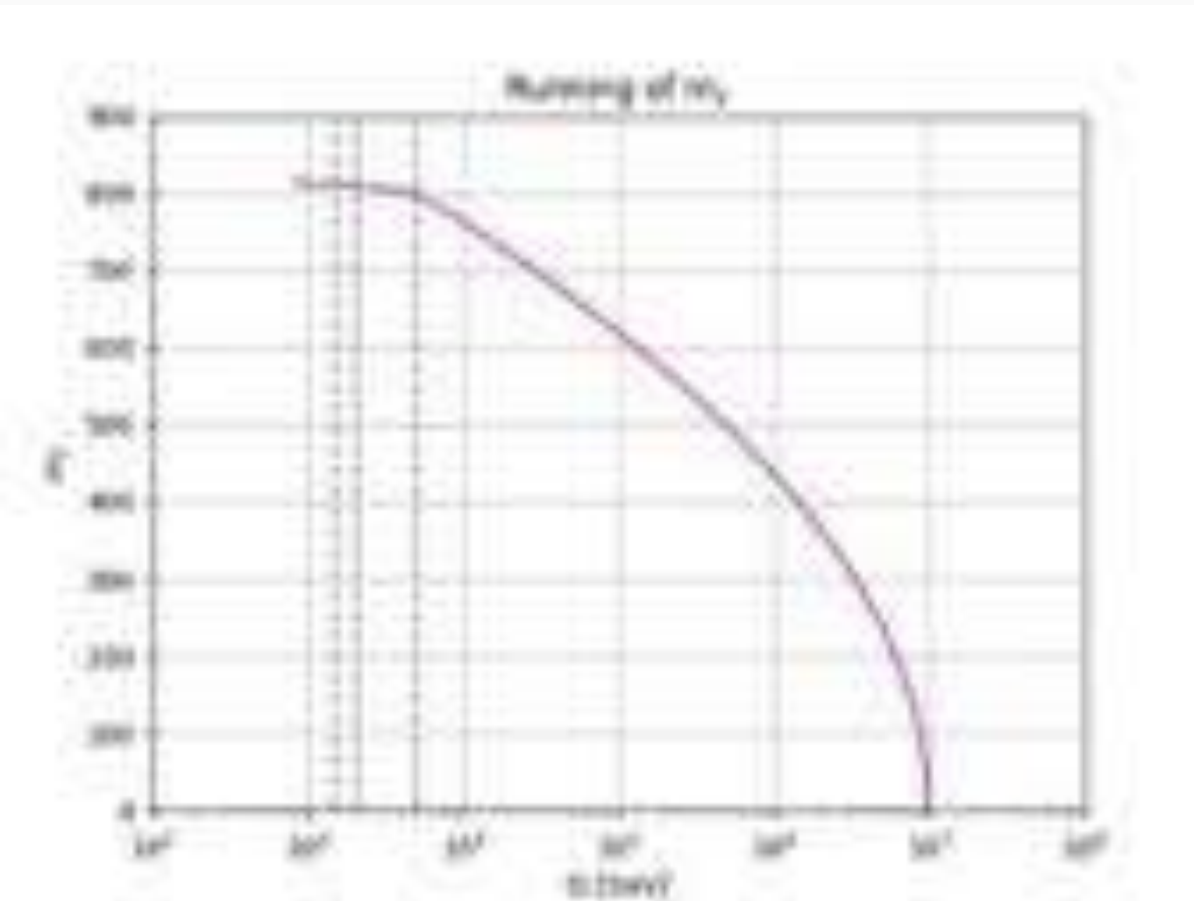


Figure: Plot when $[M_1, M_2, M_3] = [1500, 2000, 5000]$ [GeV]

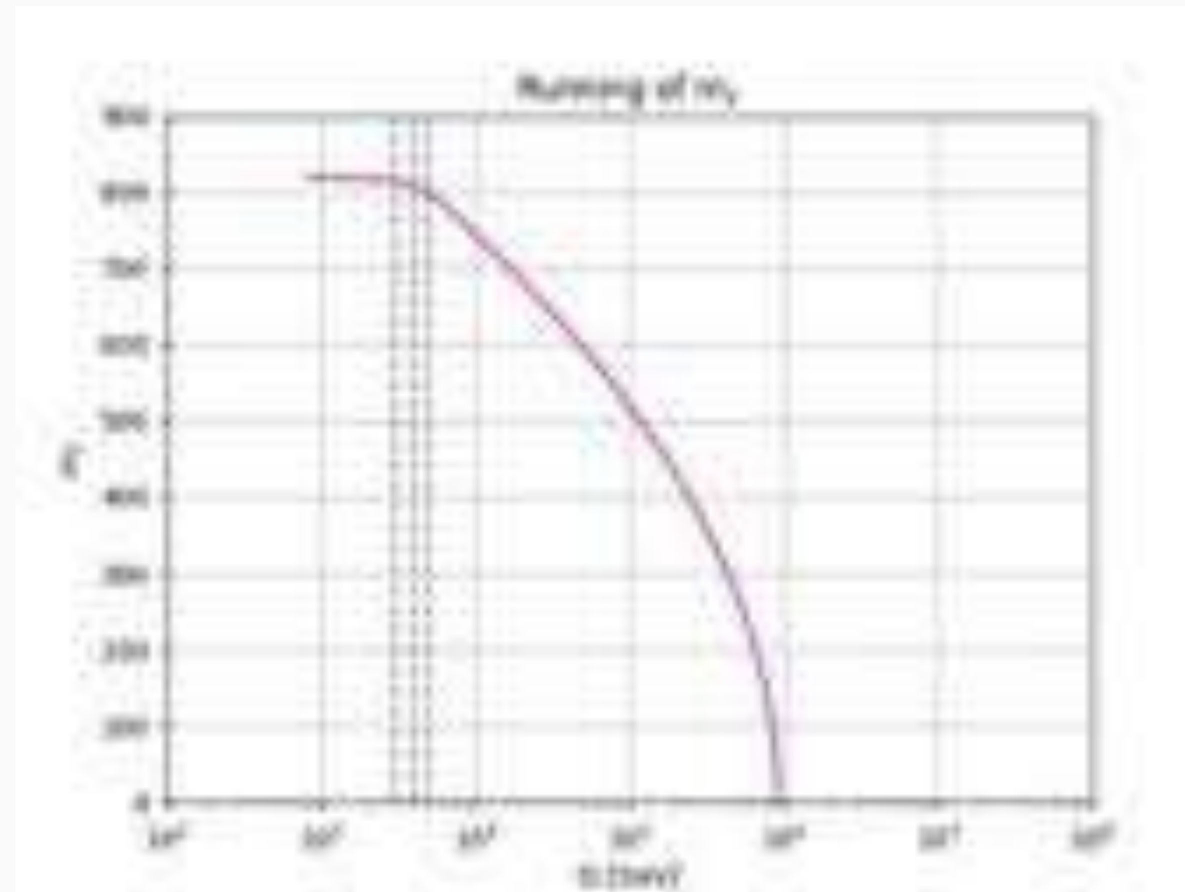
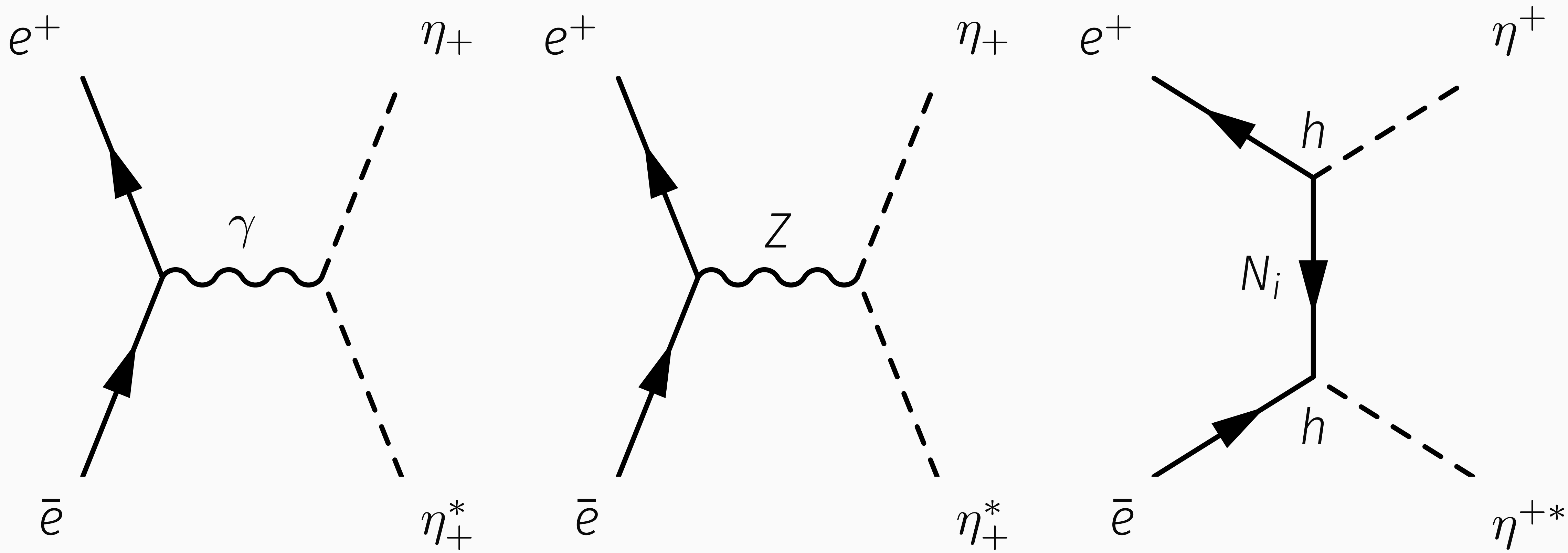
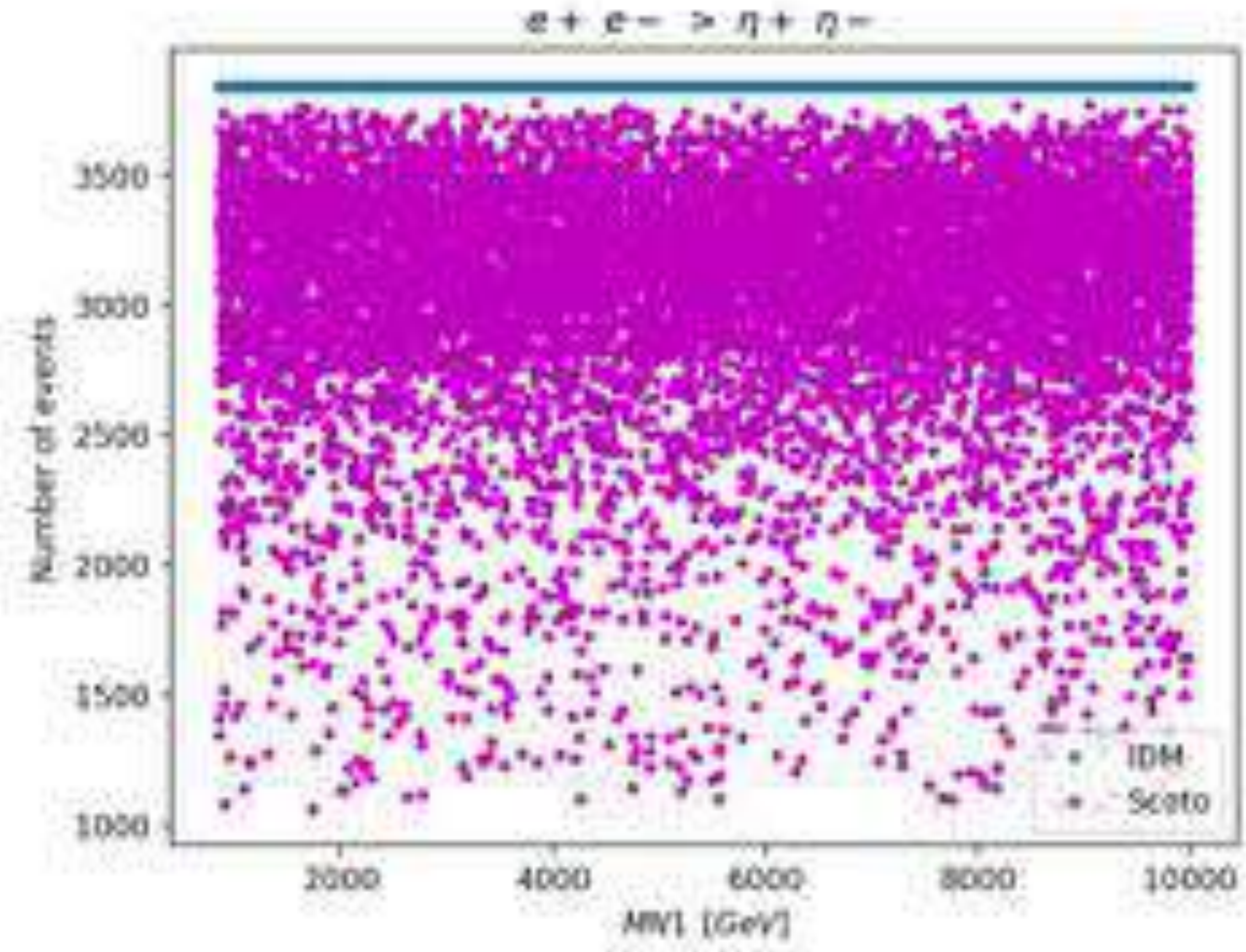


Figure: Plot when $[M_1, M_2, M_3] = [3000, 4000, 5000]$ [GeV]

Finding the observable

$\sigma_{e^+e\Rightarrow\eta^+\eta^-}$





$MN_1, MN_2 = [850, 10000] GeV$

$MN_3 = 10000$ GeV.

$m_2 = 800$ GeV.

$m_R = 799{,}99$ GeV.

$m_I = 800{,}00$ GeV.

$m^+ = 801{,}88$ GeV.

$m^2_{\nu_1} = [0, 0{,}001]$ eV.

$\lambda_1 = 0{,}26$

$\lambda_2 = [0, 0{,}5]$.

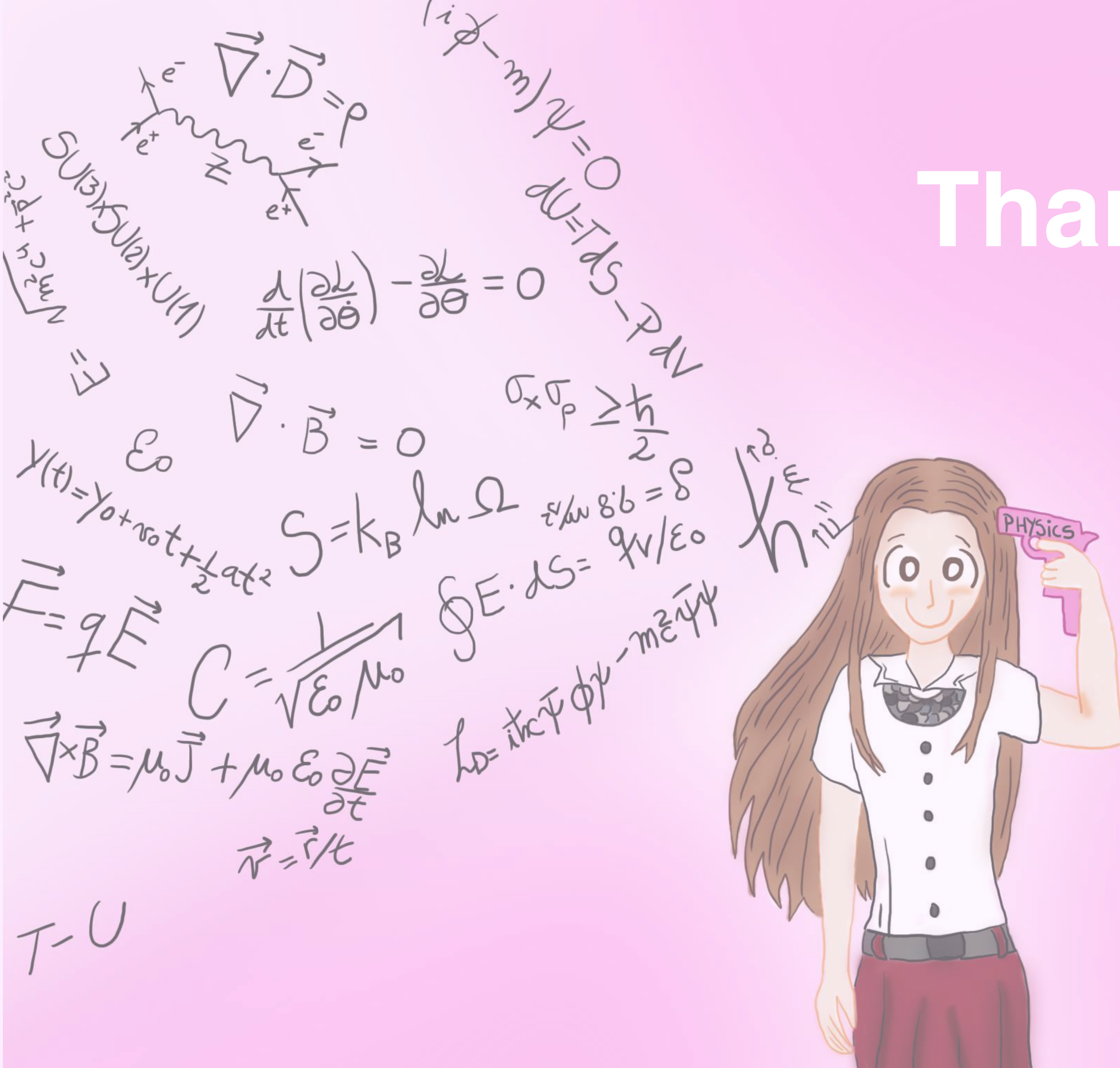
$\lambda_3 = 0{,}1$.

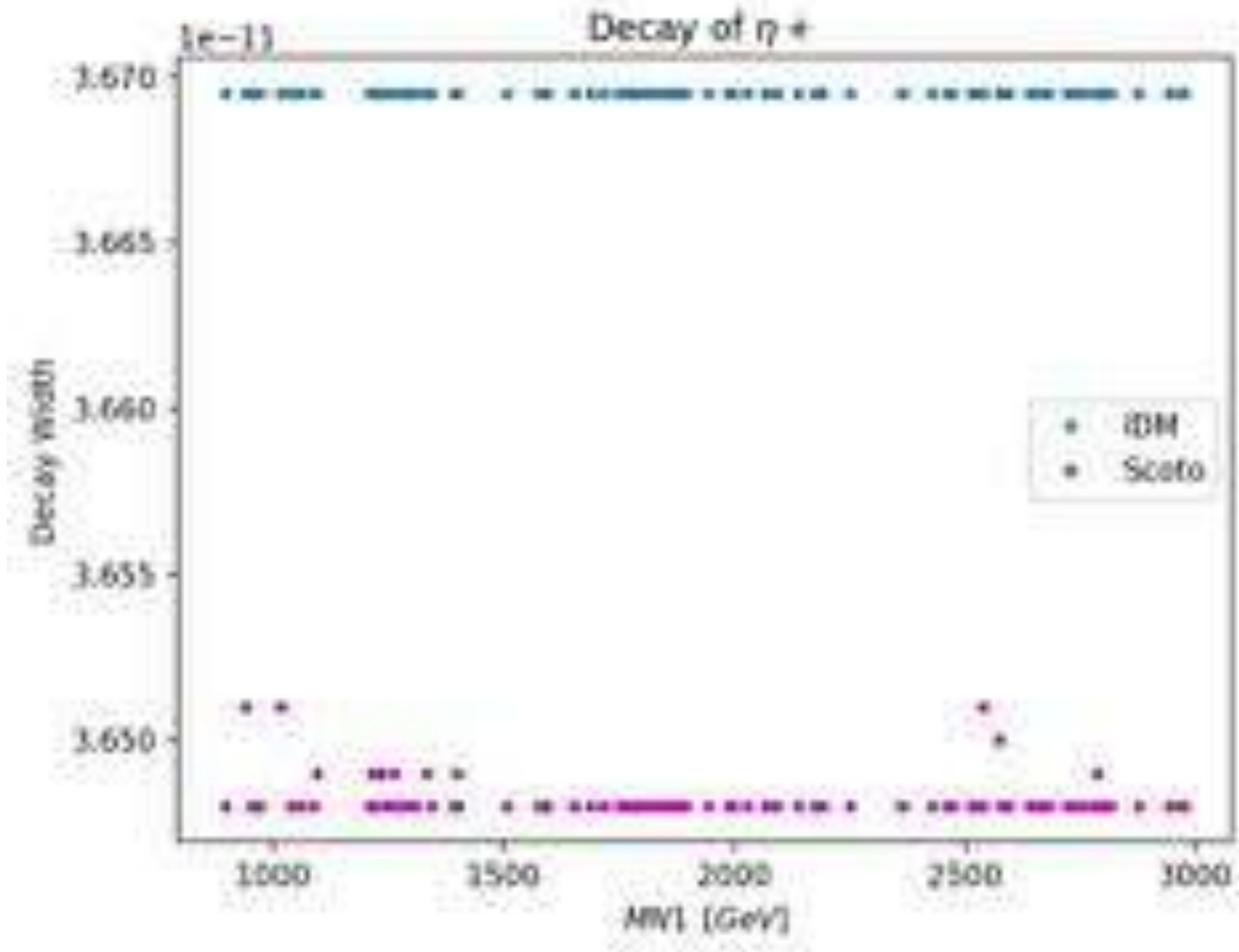
$\lambda_4 = -0{,}1$.

$\lambda_5 = 10^{-9}$.

(1) Sylbain Blunier. et all. 10.1103/PhysRevD.95.075038

Thanks!





Decay of η +
1e−11
3.670
3.665
3.660
3.655
3.650
Decay Width
IDM
Scoto
1000
1500
2000
2500
3000
MN1 [GeV]

Número Leptónico (L)

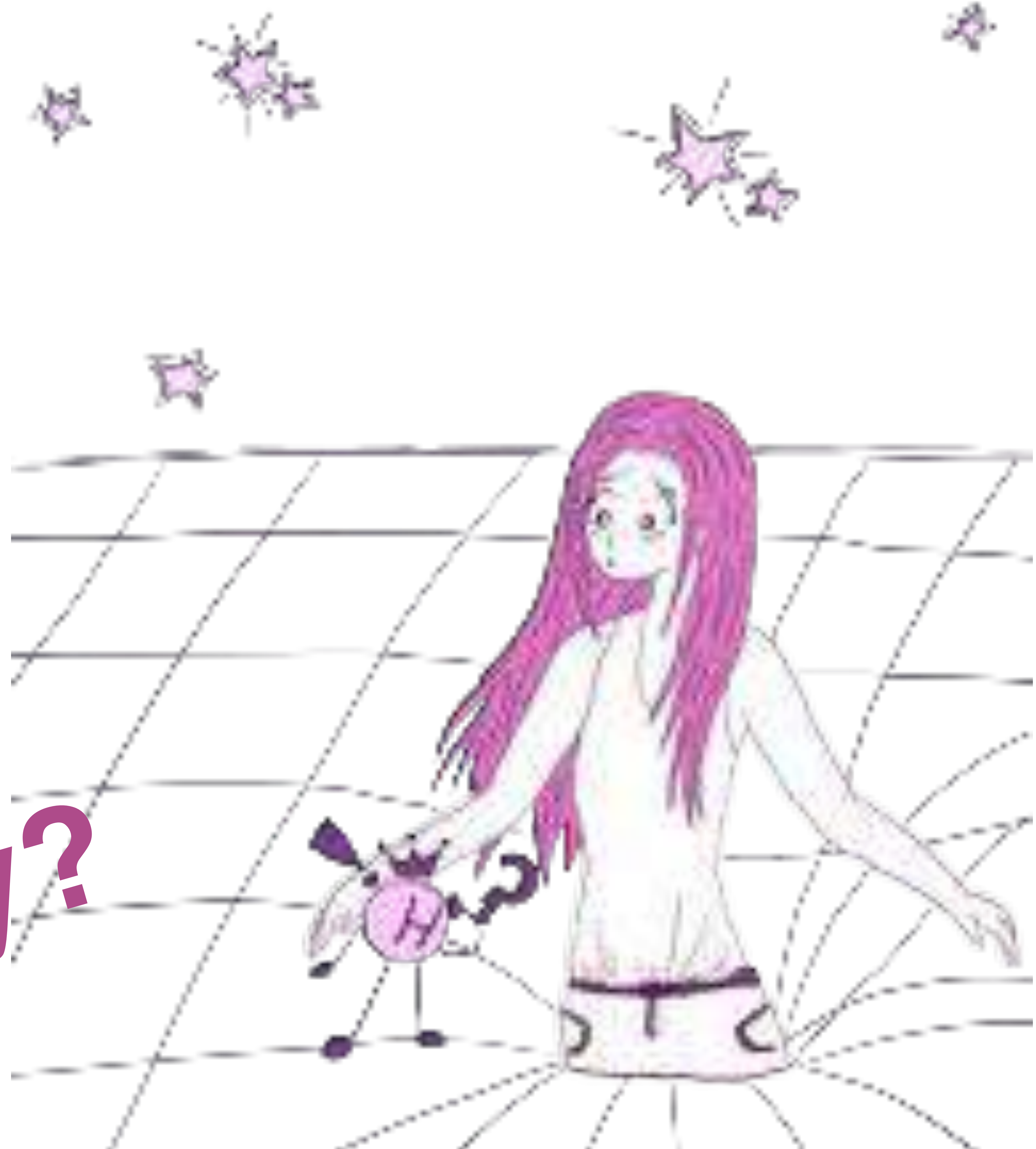
$$\left.\begin{array}{r} L_{SM} = 0 \\ L_\phi = 0 \\ L_\eta = 0 \\ L_N = 1 \end{array}\right\} \quad -\frac{1}{2}\bar{N}_R^i M_{ij} N_R^{j\,c} + h.c.$$

$$\left.\begin{array}{r} L_{SM} = 0 \\ L_\phi = 0 \\ L_\eta = 0 \\ L_N = 0 \end{array}\right\} \quad L_Y \supset -h_{ij}\bar{N}_R^i \tilde{\eta}^\dagger l_L^j + h.c$$

$$\left.\begin{array}{r} L_{SM} = 0 \\ L_\phi = 0 \\ L_\eta = 1 \\ L_N = 0 \end{array}\right\} \quad \frac{\lambda_5}{2}[(\eta^\dagger\phi)^2 + h.c.]$$

The SM “problems"

- Does exist a theory that describes all the fundamental forces?



Gravity?