Long-lived-particles searches in low-scale seesaws

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Talk based on A.C, P. Hernandez, J. Lopez-Pavon, J. Salvado (to appear..)

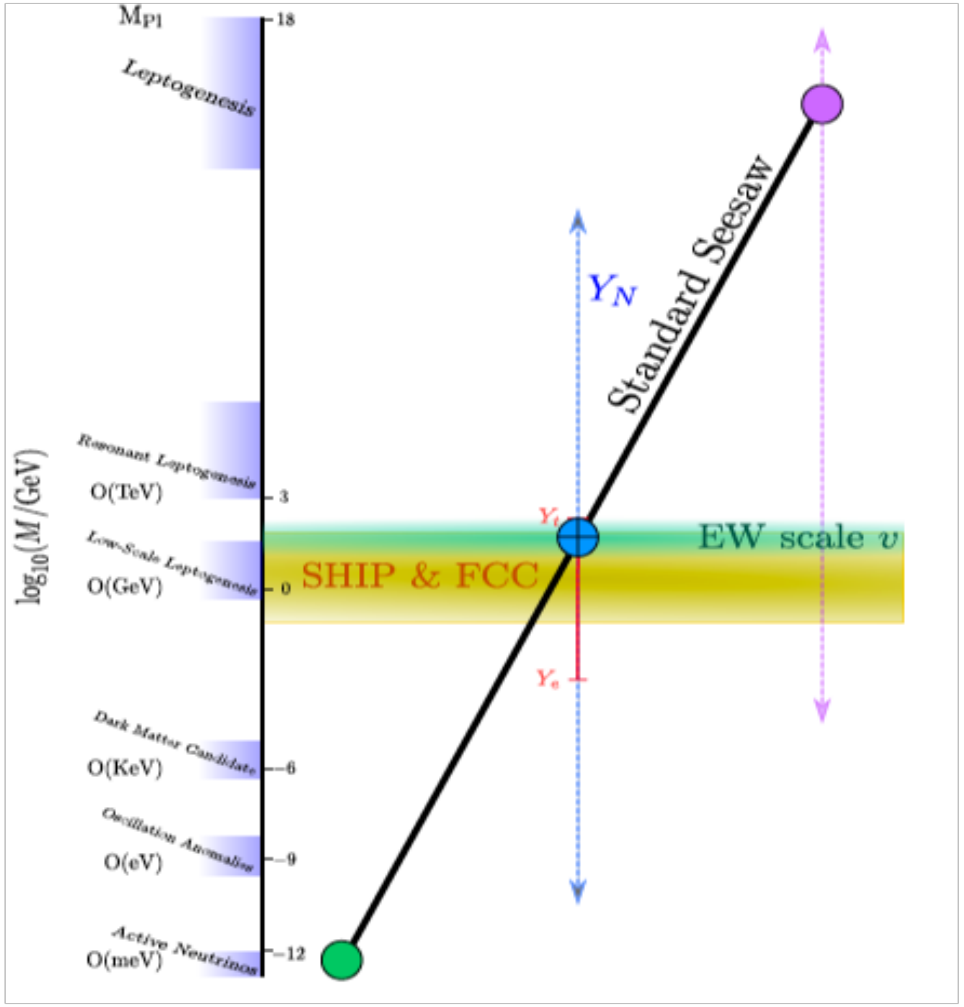
Cern 2017

Motivation

- $\mathcal{L}_{seesaw} = \mathcal{L}_{SM} - \sum_{\alpha,i} \overline{L_\alpha}\, Y^{\alpha,i} \tilde{\phi} N_i - \sum_{i,j=1}^{2} \frac{1}{2} \overline{N_i^C}\, M_N^{i,j} N_i + h.c$

P. Minkowski(1977), M. Gell-Mann, P. Ramond and R. Slansky (1979), T. Yanagida (1979), R.N. Mohapatra and G. Senjanovic (1980)

- Observed neutrino masses
- Explain Matter-Antimatter asymmetry via neutrino oscillations if $M_N \in [1, 10^2] GeV$
- Testable scenario in beam dump experiments and future colliders



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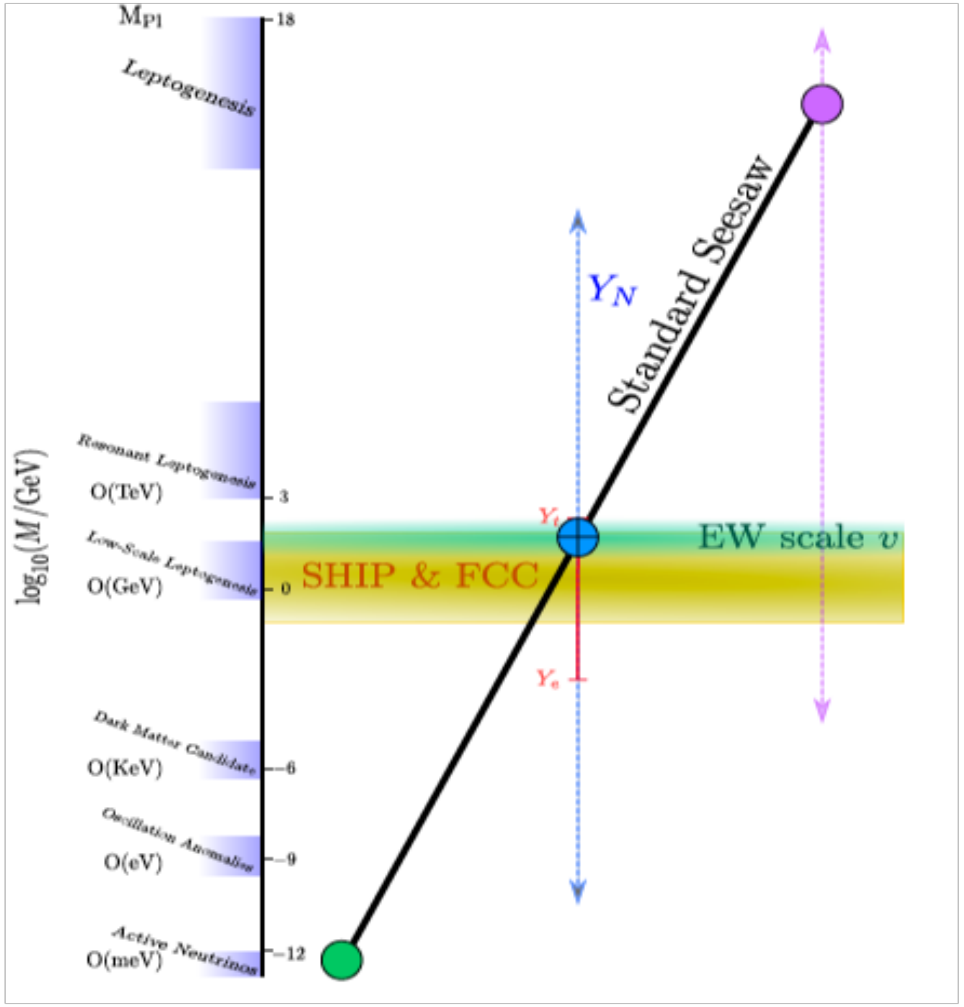

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E.K.Akhmedov, V.Rubakov, A.Y. Smirnov
Asaka, Shaposhnikov

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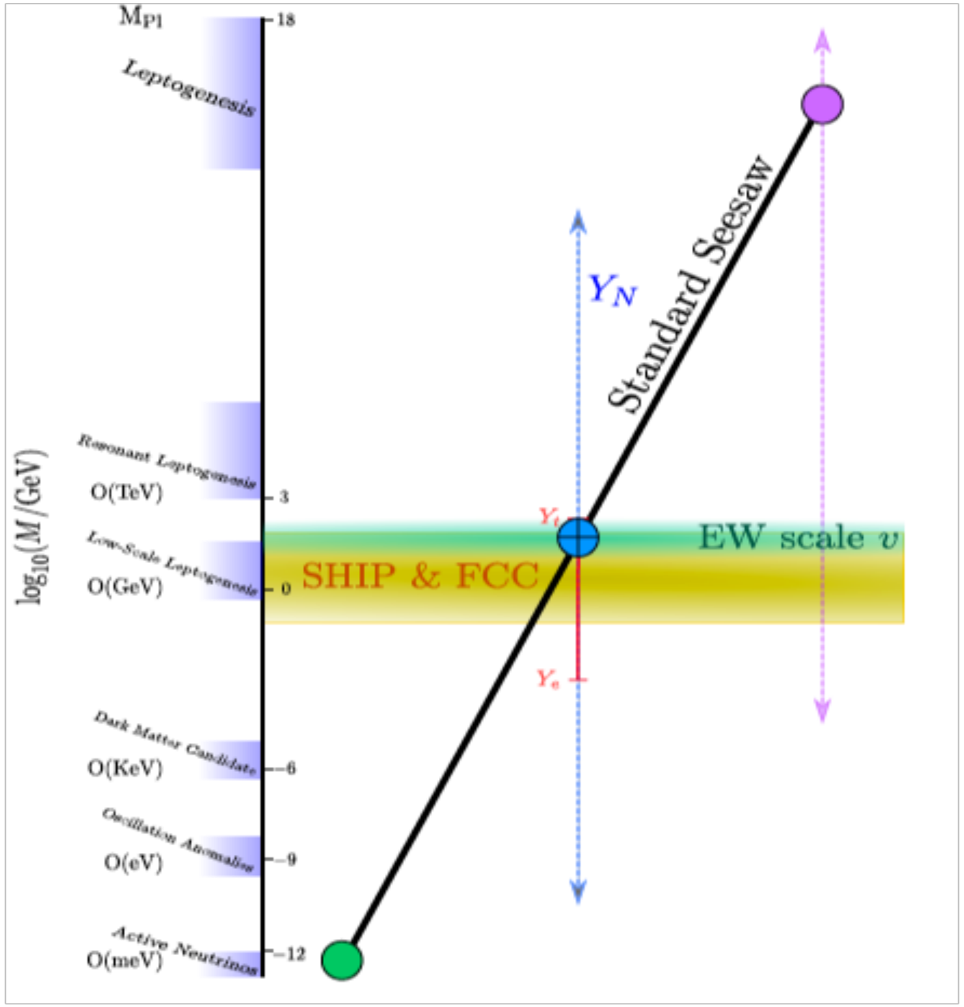

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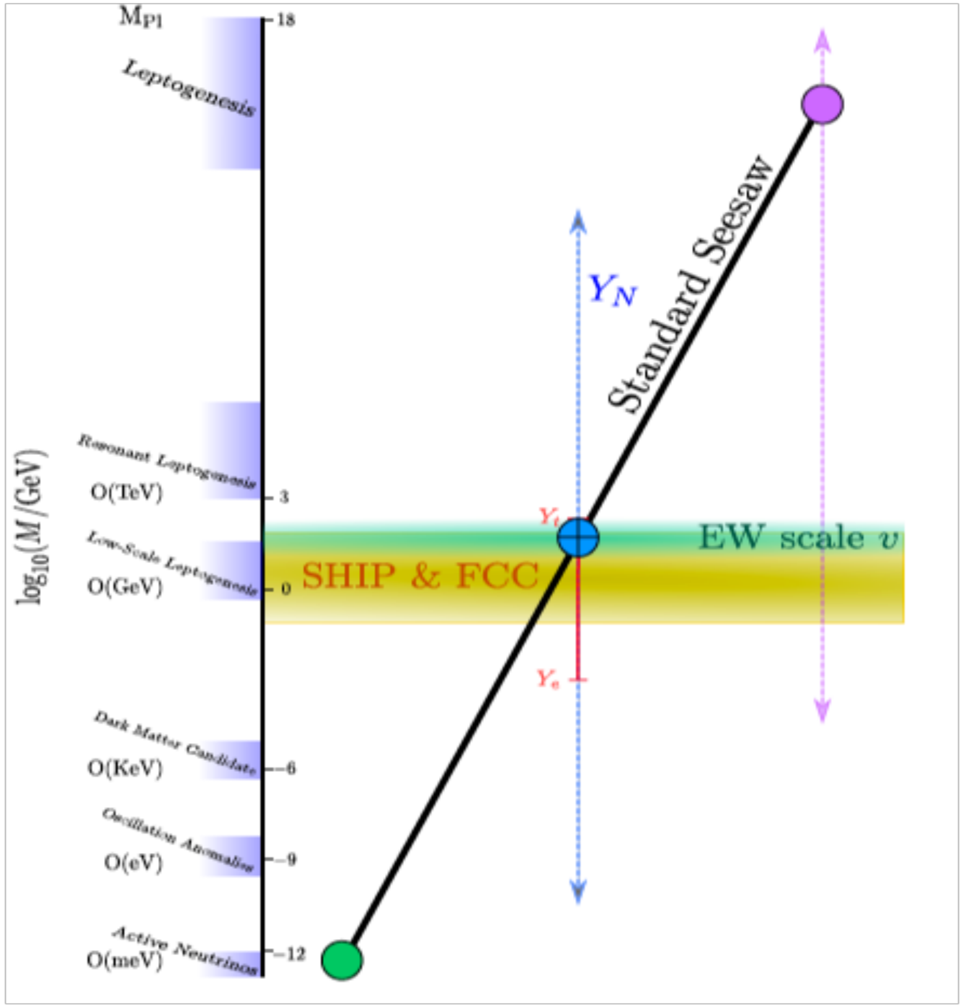
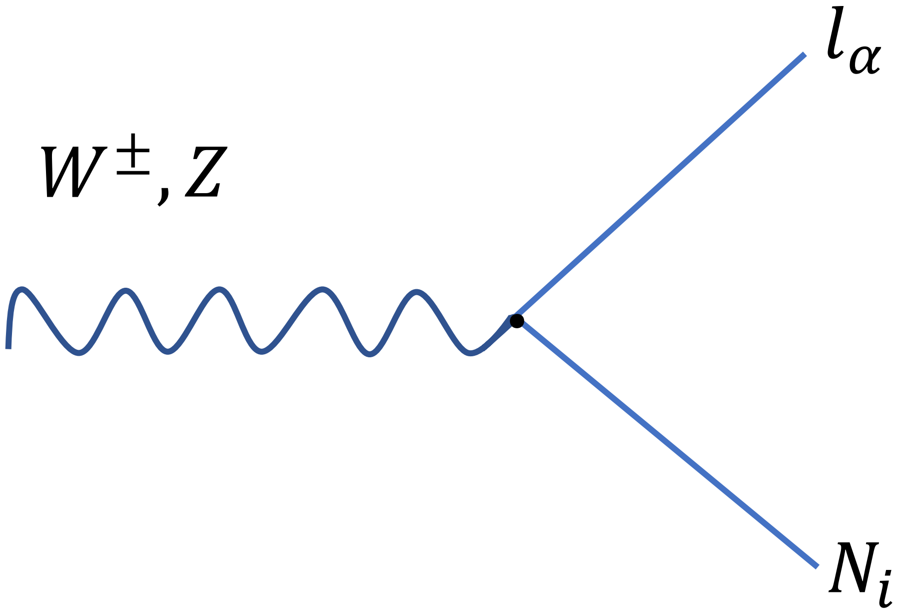


- light neutrinos masses

$$m_\nu \approx -\frac{v^2}{2} Y \frac{1}{M} Y^T$$

- two heavy states with mass M



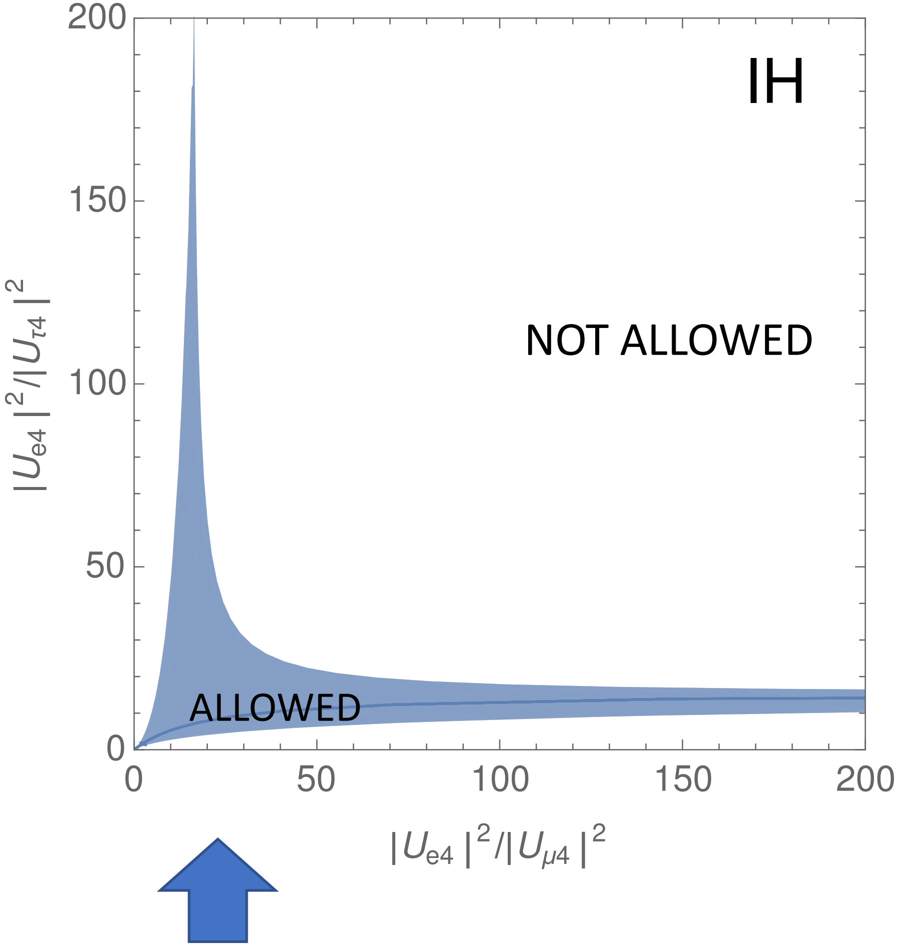
$\propto U_{\alpha i}$ *mixing between leptons and sterile neutrinos*

$$U_{\alpha i} = \frac{v}{\sqrt{2}} Y M^{-1} \approx \sqrt{\frac{m_\nu}{M}}$$

Strongly correlated to the light neutrino masses!!

High Predictivity

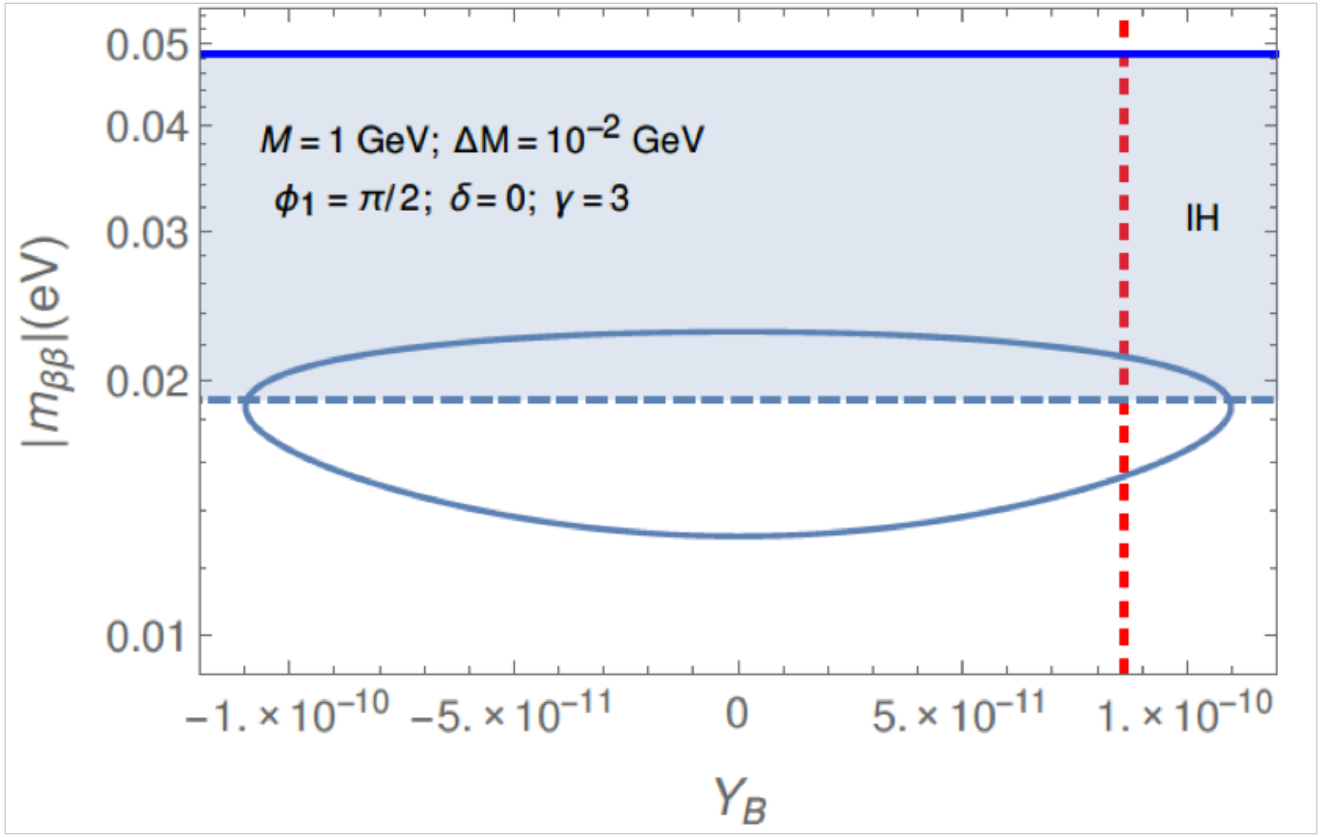
Flavour ratios of mixings



Strong constraints from light neutrinos masses and mixings

CP Phases (δ, ϕ)

Non trivial correlation between baryon asymmetry and neutrinosless double beta decay amplitude



P. Hernandez, M. Kekic, J. Lopez-Pavon, J. Racker and J. Salvado, JHEP 08 (2016) 157

A.C, P. Hernandez, J.Lopez-Pavon, M. Kekic, J.Salvado, 1611.05000

These predictions rely to a large extent on its minimality

To what extent can they be modified in the the presence of additional new physics?

Model independent approach: EFT

d=5 operators

- $O_W = \sum_{\alpha,\beta} \frac{(\alpha_W)_{\alpha,\beta}}{\Lambda} \overline{L_\alpha} \tilde{\phi} \phi^\dagger L_\beta^C$

- $O_{N\phi} = \sum_{i,j} \frac{(\alpha_{N\phi})_{i,j}}{\Lambda} \overline{N_i} N_j^C \phi^\dagger \phi$

- $O_{NB} = \sum_{i \neq j} \frac{(\alpha_{NB})_{i,j}}{\Lambda} \overline{N_i} \sigma_{\mu\nu} N_j^C B^{\mu\nu}$

S.Weinberg, Phys.Rev.Lett, 43(1979) 1566-1570
M.Graesser, Phys.Rev.D76 (2007) 075006
F. Del Aguila, S.Bar-Shalom, A.soni and J.Wudka, Phys. Lett. B670 (2009)

Model independent approach: EFT

- $O_W = \sum_{\alpha,\beta} \frac{(\alpha_W)_{\alpha,\beta}}{\Lambda} \overline{L_\alpha} \tilde{\phi} \phi^\dagger L_\beta^C$ ➡ Additional contribution to the light neutrino masses.
It can modify the predictions

- $O_{N\phi} = \sum_{i,j} \frac{(\alpha_{N\phi})_{i,j}}{\Lambda} \overline{N_i} N_j^C \phi^\dagger \phi$

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Model independent approach: EFT

- $O_W = \sum_{\alpha,\beta} \frac{(\alpha_W)_{\alpha,\beta}}{\Lambda} \overline{L_\alpha} \tilde{\phi} \phi^\dagger L_\beta^C$

- $O_{N\phi} = \sum_{i,j} \frac{(\alpha_{N\phi})_{i,j}}{\Lambda} \overline{N_i} N_j^C \phi^\dagger \phi$

New coupling to the Higgs

- $O_{NB} = \sum_{i \neq j} \frac{(\alpha_{NB})_{i,j}}{\Lambda} \overline{N_i} \sigma_{\mu\nu} N_j^C B^{\mu\nu}$

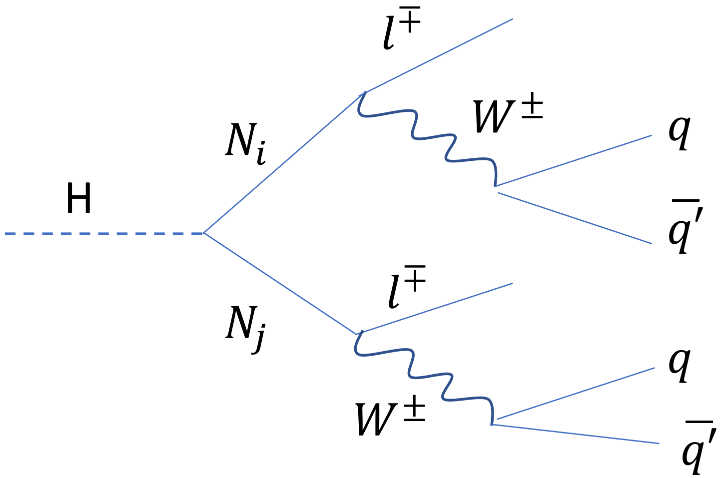
Higgs coupling

$$L \supset -\frac{v}{\sqrt{2}\Lambda} H \overline{N}^c \alpha_{N\phi} N + h.c.$$

$M_i \leq \frac{M_H}{2}$ → *Spectacular signal at LHC, pair of displaced vertices (DVs)*

MadGraph5, parton-level
Monte Carlo analysis

$$E_{C.M} = 13\ TeV, \mathcal{L} = 300\ fb^{-1}$$



semileptonic decays only

1. Search of displaced tracks in the inner tracker where at least one displaced lepton, e or μ, is reconstructed from each vertex

2. Search for displaced tracks in the muon chambers and outside the inner tracker, where at least one μ is reconstructed from each vertex

E.Accomando, L. Delle Rose, S.Moretti, E.Olaiya, C.Sheperd-Themistocleous (1612.05977)
CMS Collaboration, 1411.6977, CMS-PAS-EXO-14-012

Kinematical cuts:

- $p_T(l) > 26GeV$
- $|\eta| < 2$
- $\Delta R > 0.2$
- $\cos\theta_{\mu\mu} > -0.75$

$\mu\mu$	10 GeV	20GeV	30GeV	40 GeV
p_T	7.0%	6.8%	6.0%	4.7 %
η	4.7%	4.9%	4%	3.2%
ΔR	4.7%	4.9%	4%	3.2%
$\cos\theta_{\mu\mu}$	3.2%	3.6%	3.0%	2.7%

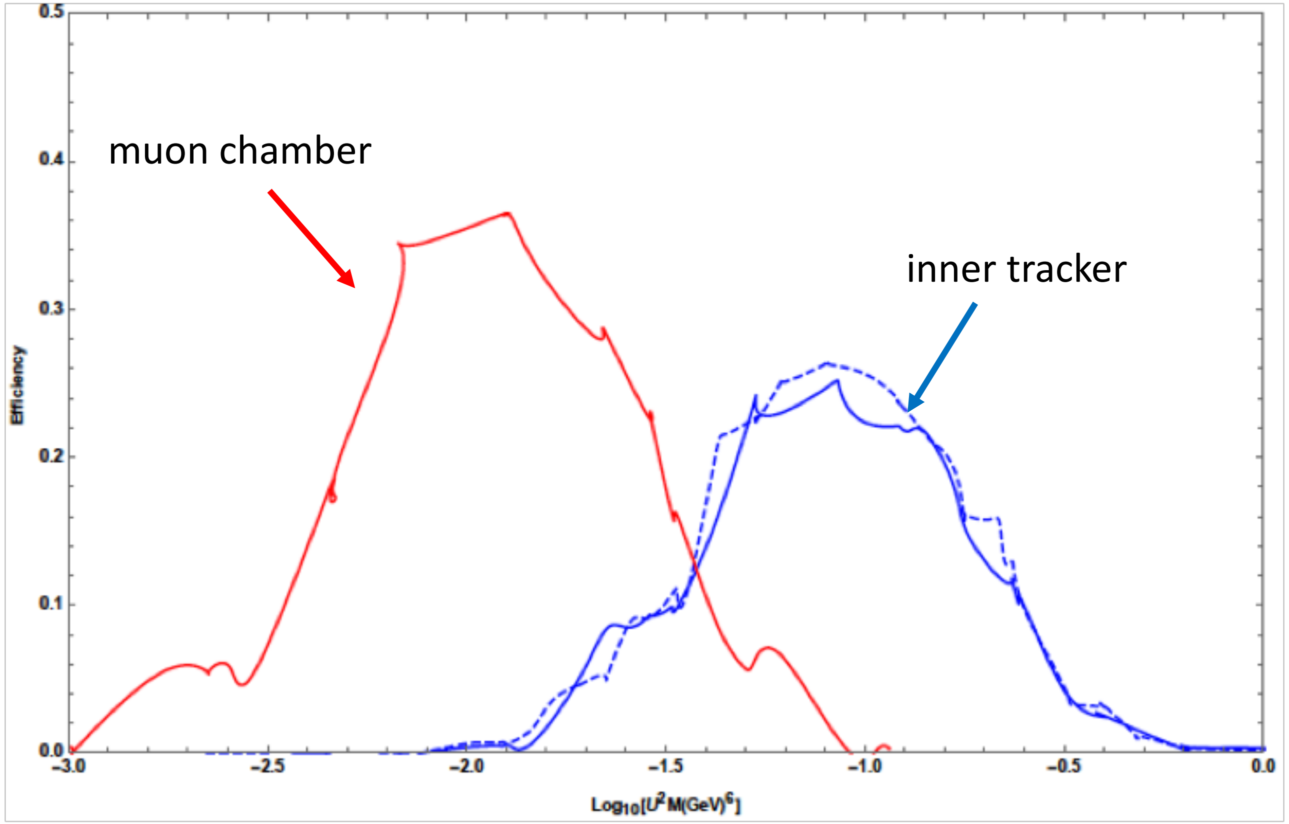
→ Sterile Neutrino Mass

Cuts associated to displaced tracks:

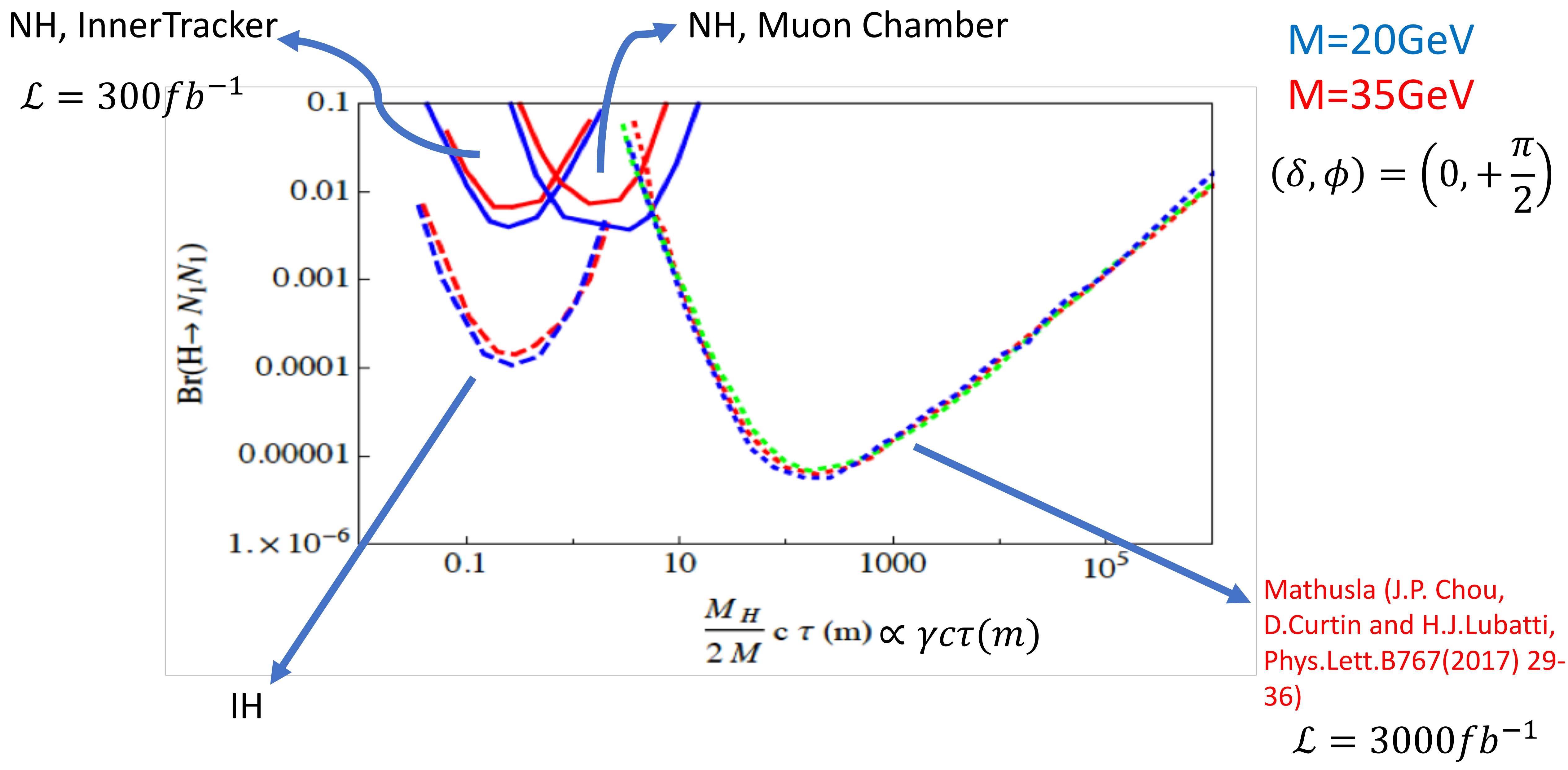
1. $10cm < |L_{xy}| < 50cm, |L_z| \leq 1.4m, \frac{d_0}{\sigma_d^t} > 12 (\sigma_d^t \approx 20\mu m)$ Inner Tracker (IT)

2. $|L_{xy}| < 5m, |L_z| \leq 8m, \frac{d_0}{\sigma_d^\mu} > 4 \left(\sigma_d^\mu \approx 2cm\right)$ Muon Chambers (MC)

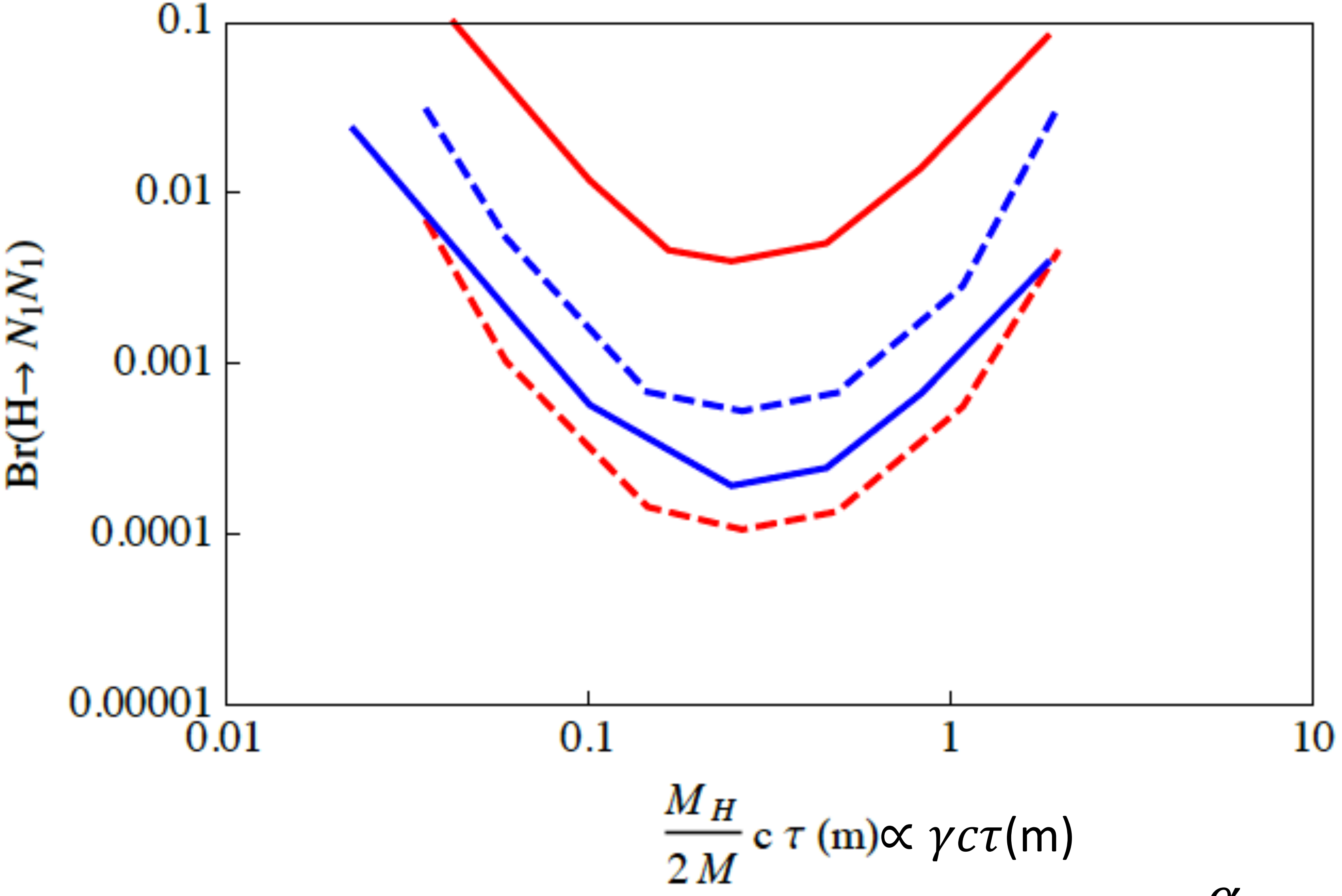
$$L^{-1} \propto U^2 M^6$$



L^{-1}



NH, InnerTracker
NH, Muon Chamber
M=20GeV
M=35GeV
$\mathcal{L} = 300fb^{-1}$
$(\delta, \phi) = \left(0, +\frac{\pi}{2}\right)$
0.1
0.01
0.001
0.0001
0.00001
$1.\times10^{-6}$
$Br(H \to N_1 N_1)$
0.1
10
1000
10^5
$\frac{M_H}{2M} c\,\tau$ (m) $\propto \gamma c\tau(m)$
IH
Mathusla (J.P. Chou, D.Curtin and H.J.Lubatti, Phys.Lett.B767(2017) 29-36)
$\mathcal{L} = 3000fb^{-1}$



$M_N = 20GeV$

Solid → *NH*
Dashed → *IH*

Blue → $(\delta, \phi) = \left(0, -\frac{\pi}{2}\right)$
Red → $(\delta, \phi) = \left(0, +\frac{\pi}{2}\right)$

$$\frac{\alpha_{N\phi}}{\Lambda} \leq 6\times(10^{-3} - 10^{-2})TeV^{-1}$$

Conclusion

- If the coefficients of the d=5 operators are all of the same order, the strongest bounds come from the bound on the lightest neutrino mass:

$$\left|\frac{\alpha_W v^2}{2\Lambda}\right| \leq O(1) m_{lightest} \leq 0.2 eV \rightarrow \frac{\alpha_W}{\Lambda} \leq 6\times 10^{-9} TeV^{-1}$$

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- If we want the predictions on flavour mixings not to be lost, the bounds are even stronger

$$\left|\frac{\alpha_W v^2}{2\Lambda}\right| \leq \sqrt{\Delta m_{sol}^2}$$

In the presence, instead, of large hierarchies $\alpha_W \ll \alpha_{N\phi} \sim \alpha_{NB}$ (that could be protected by global symmetries: $U(1)_L, MFV$)

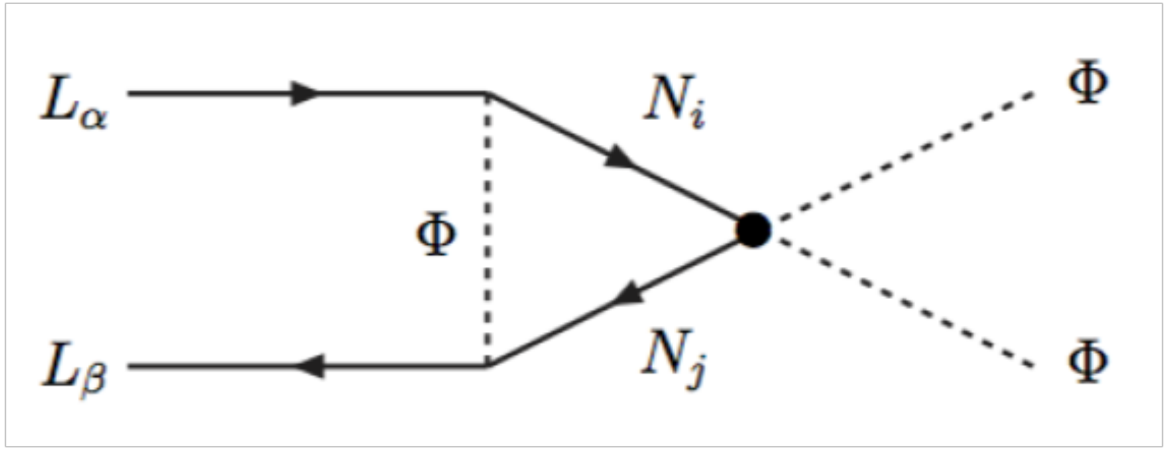
LHC ⇒ $$\left|\frac{\alpha_{N\phi} v^2}{\sqrt{2}\Lambda}\right| \leq 10^{-3} - 10^{-2} \rightarrow \frac{\alpha_{N\phi}}{\Lambda} \leq 6\times(10^{-3} - 10^{-2}) TeV^{-1}$$

$$\frac{\alpha_{NB}}{\Lambda} \leq 10^{-2} - 10^{-1} TeV^{-1}$$

A.Aparici, K.Kim, A.Santamaria and J.Wudka, Phys. Rev. D80(2009) 013010

Thanks for your attention

Radiative corrections



$$\delta\left(\frac{\alpha_W}{\Lambda}\right) \propto \frac{1}{4\pi^2}\frac{Y^2}{4}\frac{\alpha_{N\Phi}}{\Lambda}\log\frac{\mu^2}{M^2}$$

This contribution has to be equal or smaller than the tree-level contribution

$$\frac{\alpha_{N\phi}}{\Lambda} \lesssim \frac{2\cdot 10^{13}}{\log\frac{\mu^2}{M^2}}\left(\frac{10^{-6}}{U^2}\right)\left(\frac{\mathrm{GeV}}{M}\right)^2\frac{\alpha_W}{\Lambda}$$