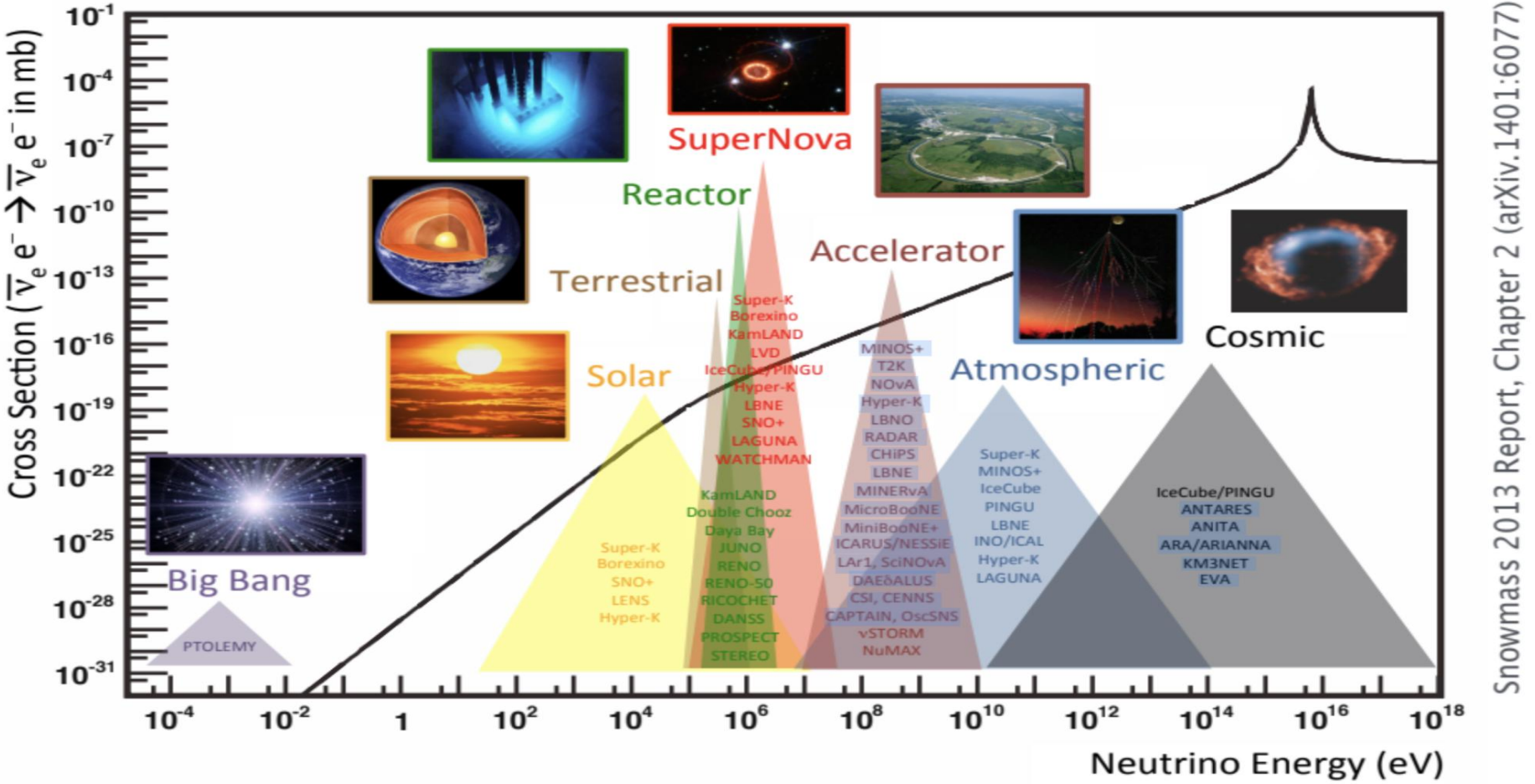
With support from Fondecyt 1201673 and Iniciativa Programa Milenio code ICN2019_044

Long-lived Multi-charged particles and neutrino mass models

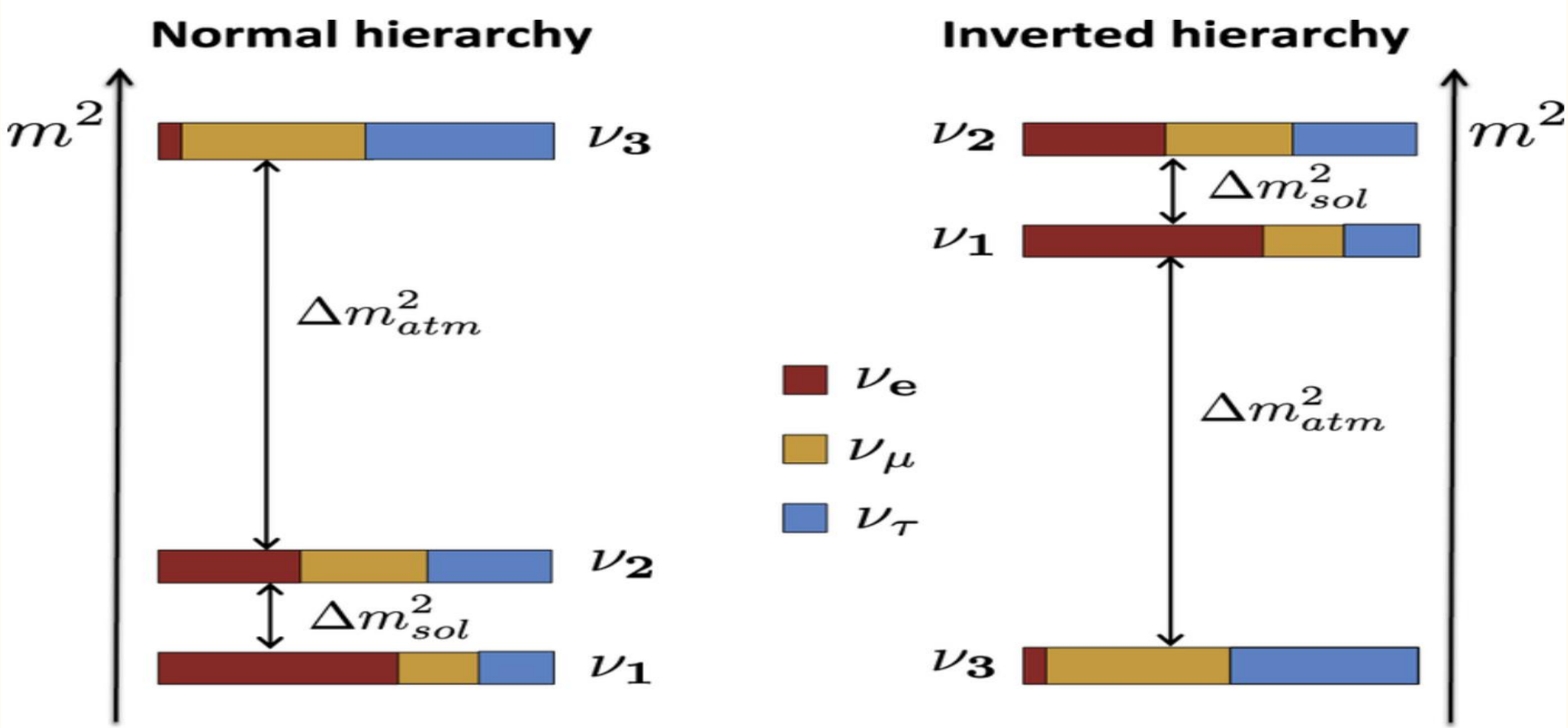
Juan Carlos Helo.

Phys.Rev.D 101 (2020) 9, 095033 Cottin, Arbelaes, Hirsch, Helo

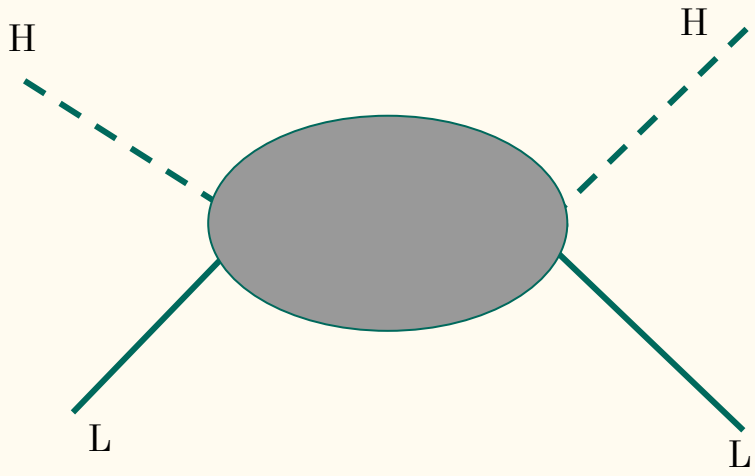
Neutrinos are everywhere!

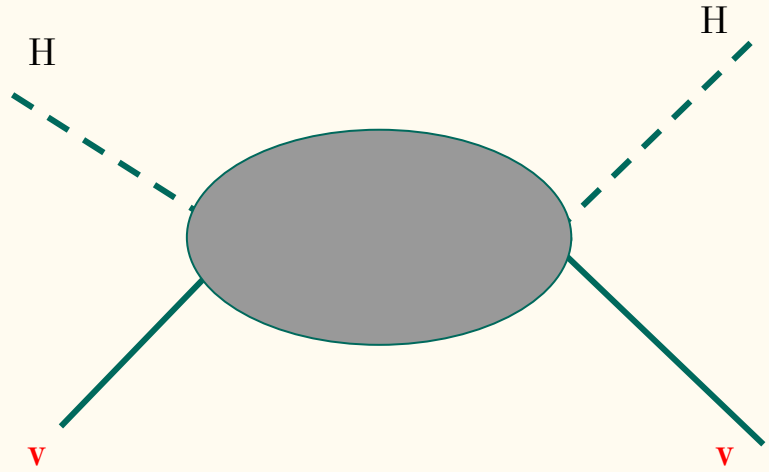


Snowmass 2013 Report, Chapter 2 (arXiv.1401:6077)


Normal hierarchy
m^2
ν_3
Δm^2_{atm}
ν_2
Δm^2_{sol}
ν_1
ν_e
ν_μ
ν_τ
Inverted hierarchy
ν_2
Δm^2_{sol}
ν_1
Δm^2_{atm}
ν_3
m^2

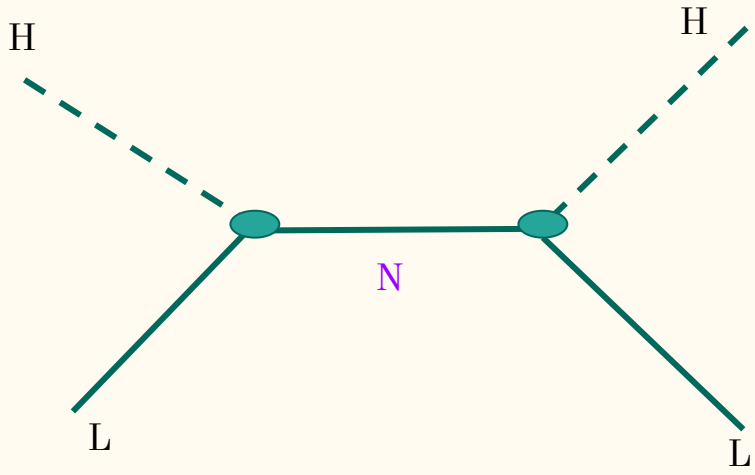
Weinberg operator. Neutrinos are Majorana

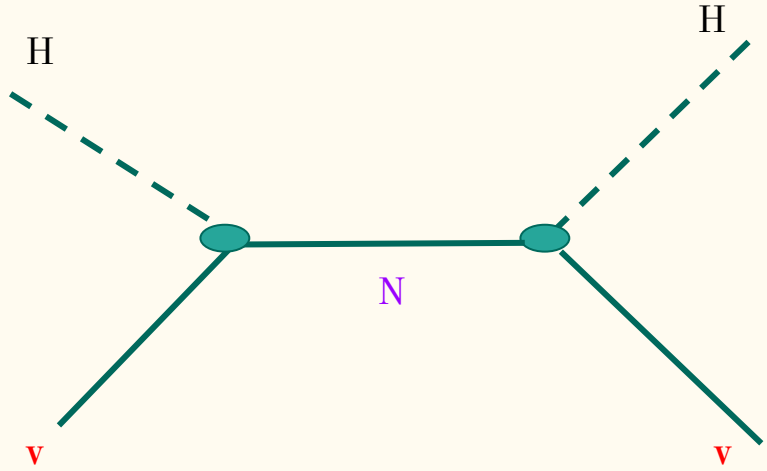




Weinberg operator. Neutrinos are Majorana

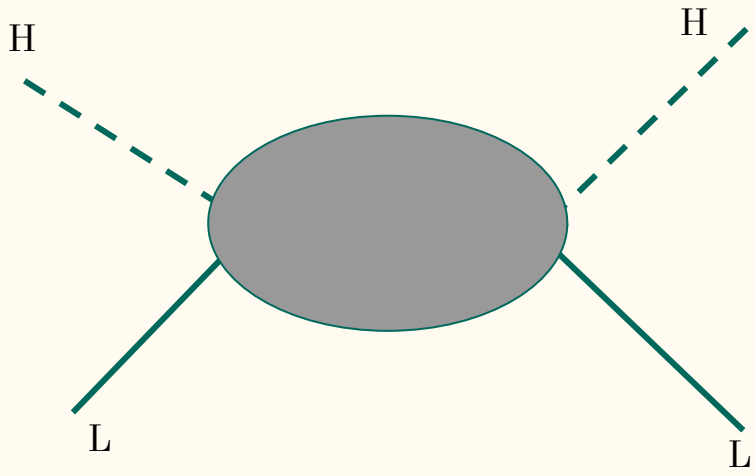
Seesaw Tipo I.

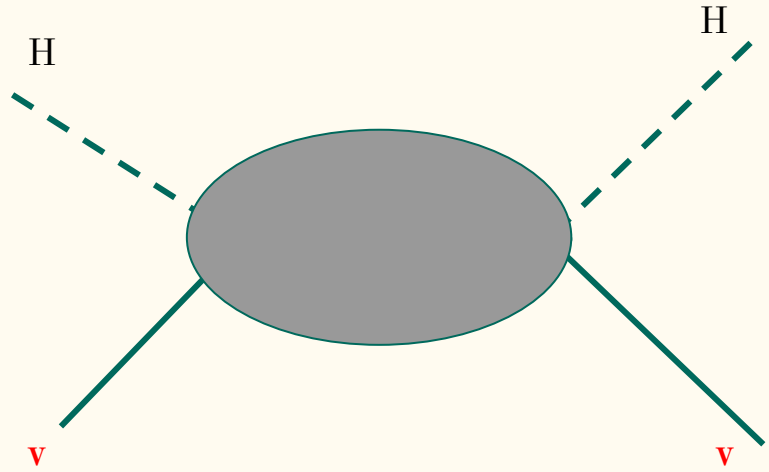


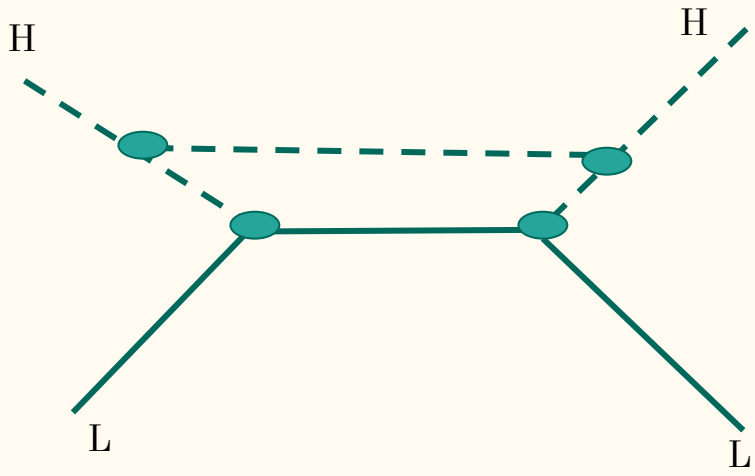


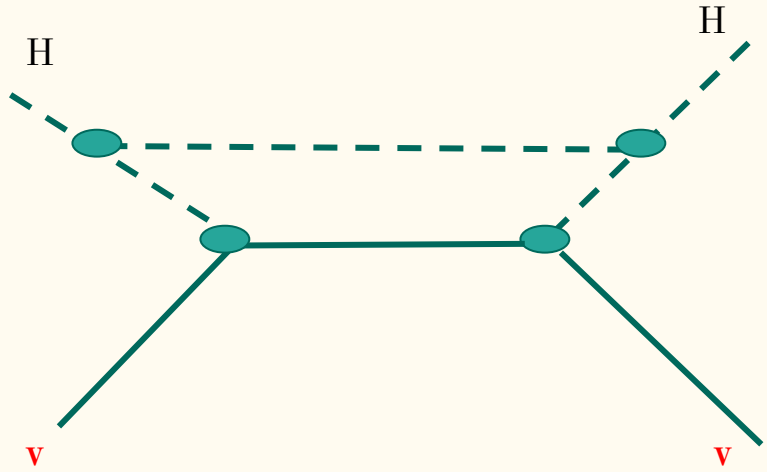
See Tomorrow Giovanna‘s talk

Weinberg operator. Neutrinos are Majorana





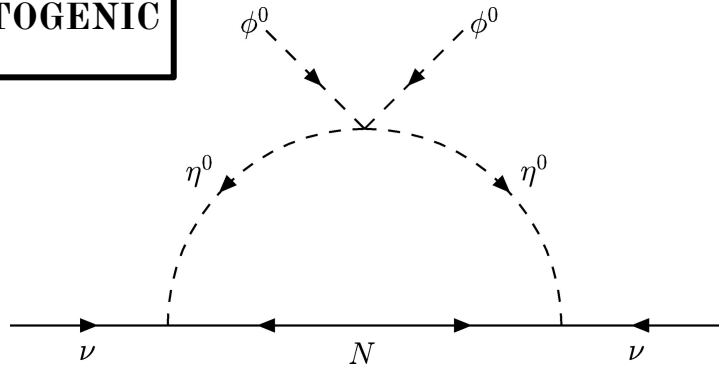




- *JHEP* 08 (2022) 023 Arbelaez, Hirsh, Cepedello, Kovalenko, Helo
- *JHEP* 07 (2012) 153 Ota, Bonnet, Winter, Hirsch

1-loop models:

SCOTOGENIC



E. Ma, Phys. Rev. D73 (2006) 077301,

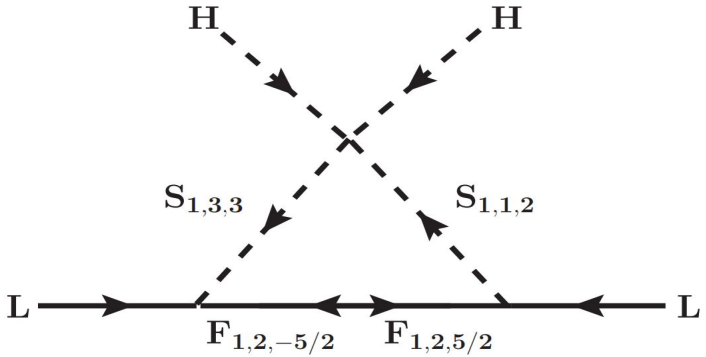
Additional symmetry to the SM $SU(2)_L \times U_Y \times Z_2$

$$(\nu_i, l_i) \sim (2, -1/2; +), \quad l_i^c \sim (1, 1; +), \quad N_i \sim (1, 0; -),$$

$$(\phi^+, \phi^0) \sim (2, 1/2; +), \quad (\eta^+, \eta^0) \sim (2, 1/2; -).$$

2 Dark Matter Candidates !

OUR MODEL



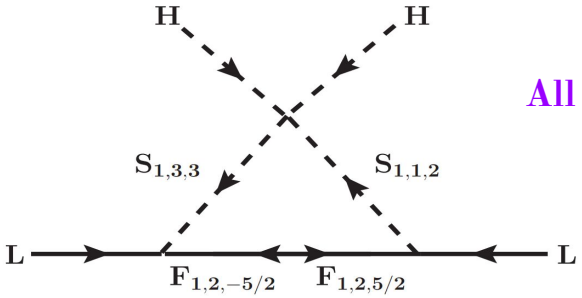
Arbelaez, Cottin, Helo Hirsch *Phys.Rev.D* 101 (2020) 9, 095033

No additional symmetries to the SM

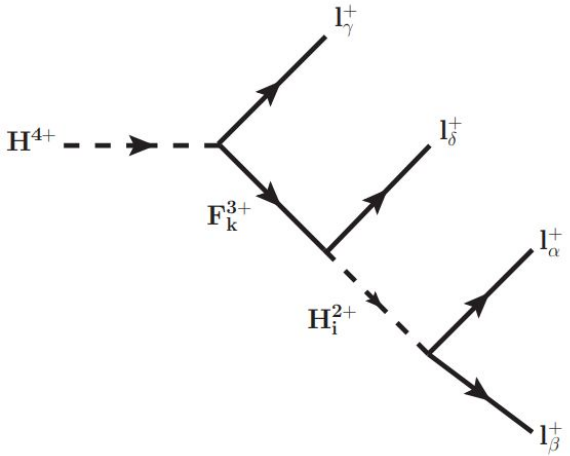
$$S_{1,1,2} = S_1^{2+}$$
$$S_{1,3,3} = (S_3^{4+}, S_3^{3+}, S_3^{2+})$$
$$F_{1,2,5/2} = (F^{3+}, F^{2+})$$

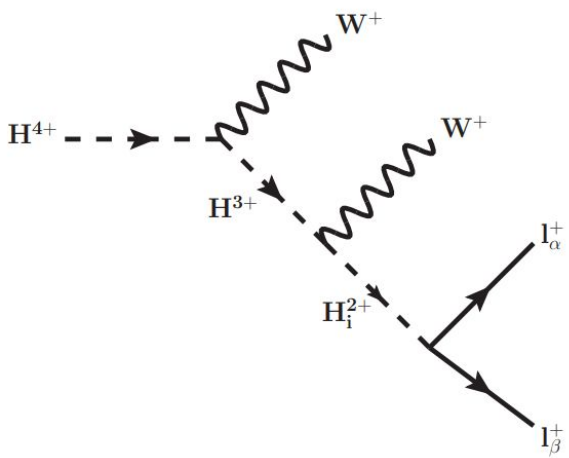
No Dark Matter Candidates

OUR MODEL



All these particles will decay to SM particles with at least two same-sign leptons!





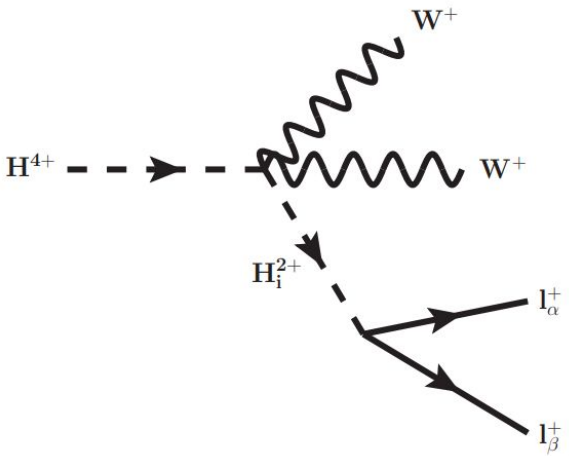
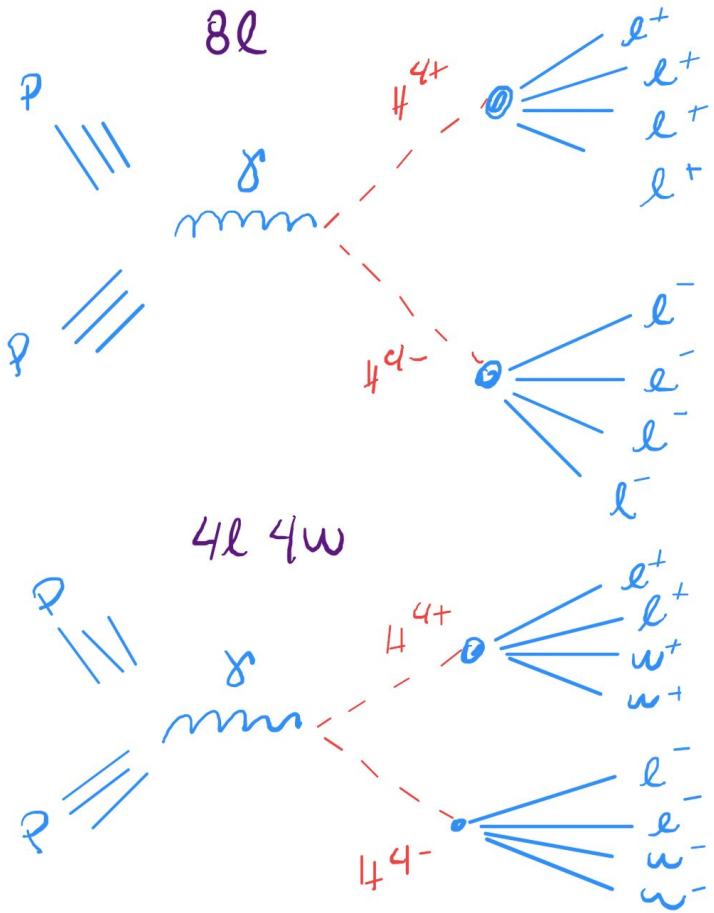
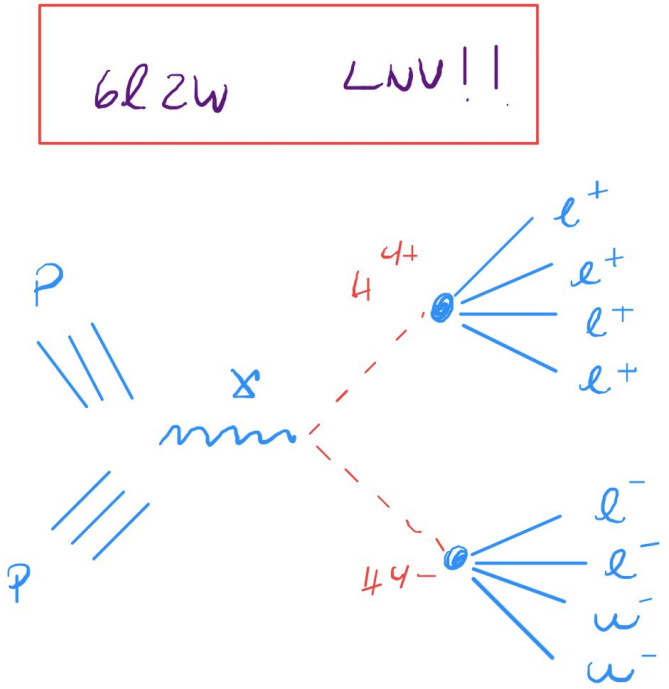


FIG. 2: Feynman diagrams for the decays $H^{4+} \to l_\gamma^+ l_\delta^+ l_\alpha^+ l_\beta^+$ and $H^{4+} \to W^+W^+ l_\alpha^+ l_\beta^+$. .

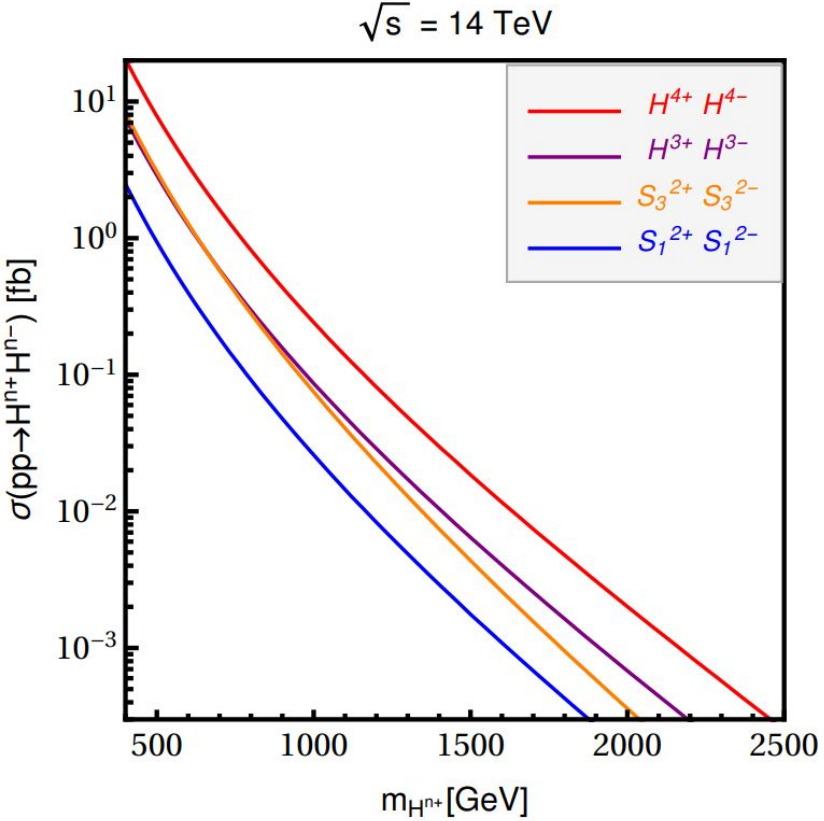
We define LNV multi-lepton events as final states with at least Four charged leptons!.

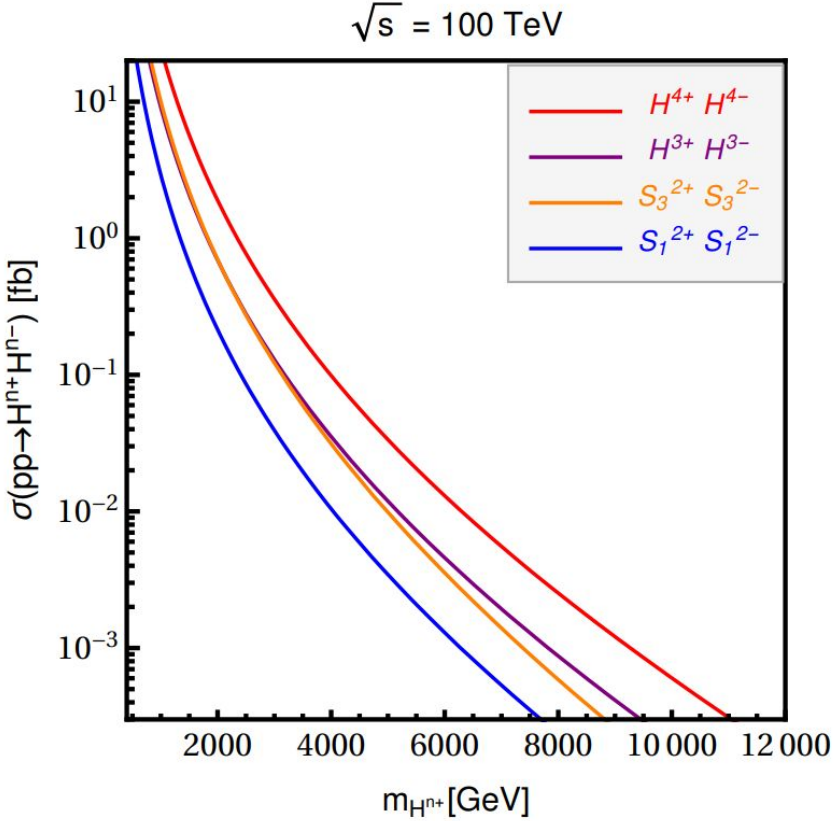
In our model multi-lepton events have larger rates than di-lepton events!





Pair production of MCP is dominated by photon-photon fusion diagrams for large scalar masses.

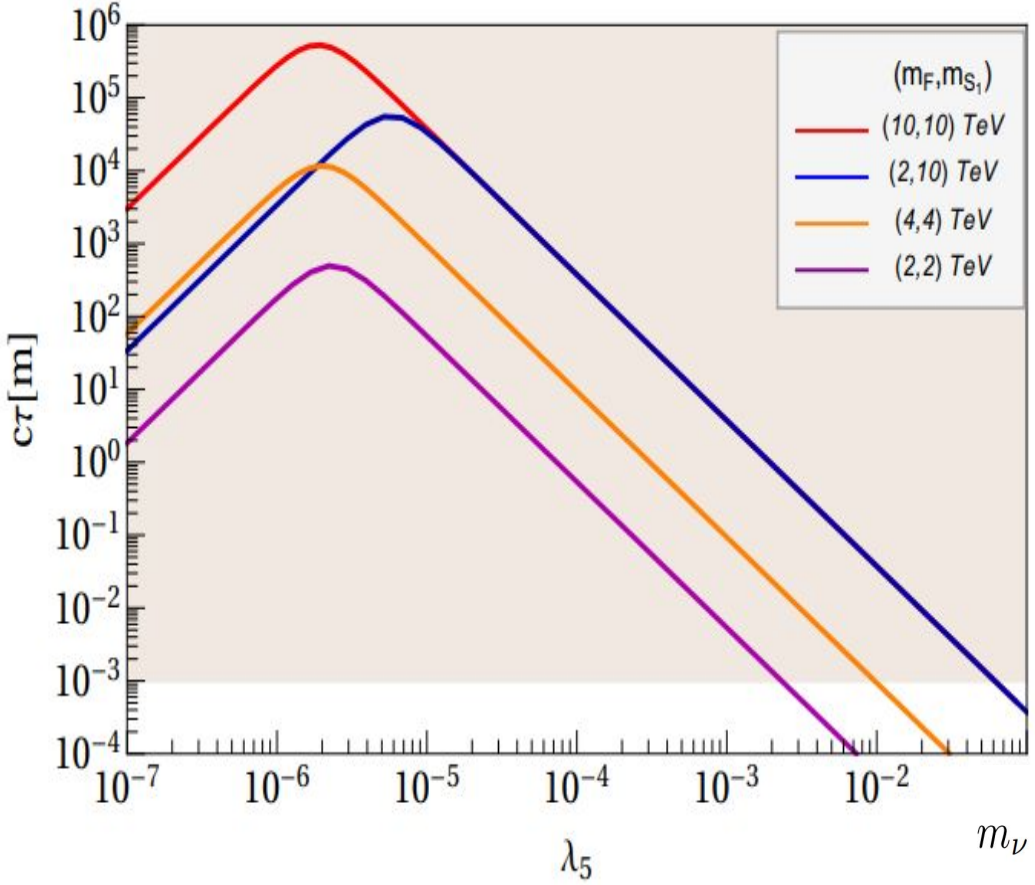


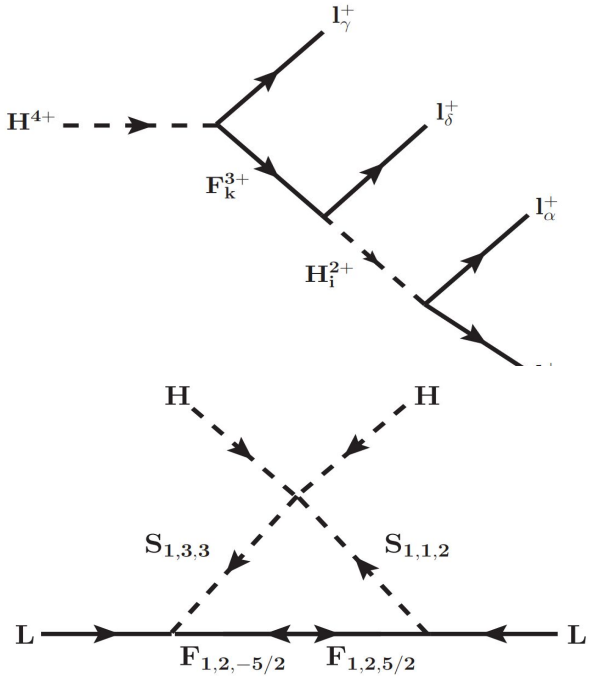


We have used LUXqed17_plus_PDF4LHC15_nnlo_100 PDFs. See Manohar, Nason, Salam, Zanderigui. Phys. Rev. Lett. 117 (2016) 242002

Long-Lived Multi-Charged Particles:

Smallness of the observed neutrino masses, together with the high multiplicity of the final states, lead to Long-Lived Multi-Charged Particles!!!





$$m_\nu \simeq 0.05 \left(\frac{\lambda_5}{10^{-6}}\right)\left(\frac{h_F}{10^{-2}}\right)\left(\frac{h_{\bar{F}}}{10^{-2}}\right)\left(\frac{1\ \text{TeV}}{\Lambda}\right)\ \text{eV}$$

Current limits: Non of existing searches covers exactly the multi-lepton signals!

$c\tau >$ detector size. MCP based on only 36 /fb

ATLAS collaboration, M. Aaboud et al.,Phys. Rev. D99 (2019) 052003,

Based on the anomalously large ionization of MCP that are long-lived enough to reach the muon spectrometer $M_{H^{4+}} > 980$ GeV. Limits only applies for $c\tau$ larger than 10m!

$c\tau =$ 1 mm -1 m detector size. Displaced vertices - Disappearing tracks.

CMS collaboration, Phys. Rev. Lett. 114 (2015) 061801, [1409.4789].
CMS collaboration, Search for displaced leptons in the e-mu channel, CMS-PAS-EXO-16-022.
ATLAS collaboration, G. Aad et al.Phys. Rev. D92 (2015) 072004, [1504.05162].
CMS collaboration, A. M. Sirunyan et al., JHEP 08 (2018) 016, [1804.07321].
ATLAS collaboration, M. Aaboud et al.,, JHEP 06 (2018) 022, [1712.02118].
J. A. Evans and J. Shelton,, JHEP 04 (2016) 056, [1601.01326].
R. Mahbubani, P. Schwaller and J. Zurita, JHEP 06 (2017) 119, [
ATLAS collaboration, M. Aaboud et al., Phys. Rev. D97 (2018) 052012, [1710.04901].
ATLAS collaboration, M. Aaboud et al.,Phys. Rev. D99 (2019) 052003,

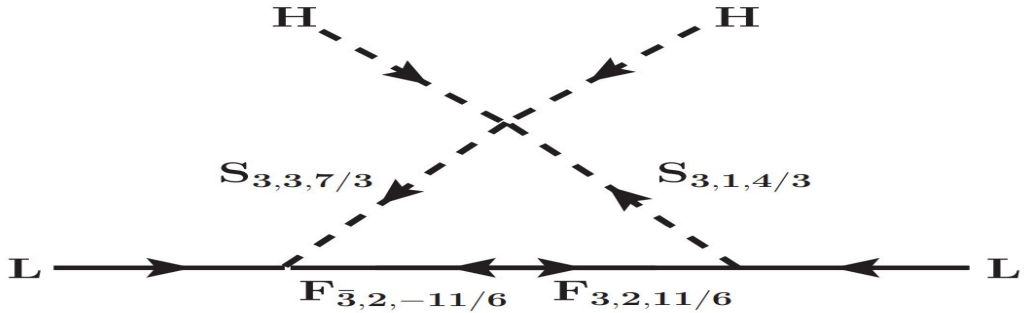
Displaced vertex and disappearing tracks searches can give limits to our model

$c\tau <$ 1mm. Promt decays

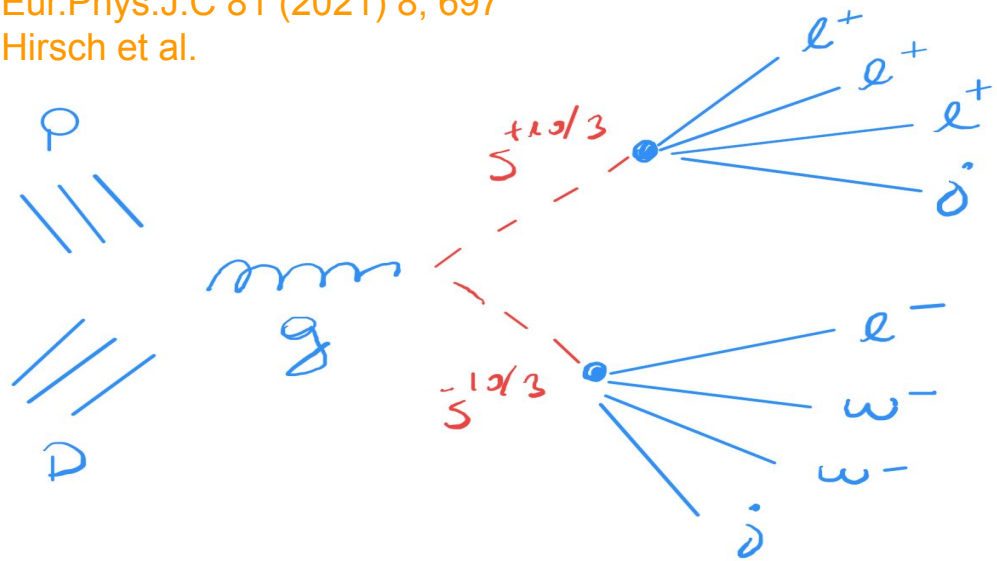
CMS collaboration, A. M. Sirunyan et al., Search for physics beyond the standard model in multilepton final states in proton-proton collisions at $\sqrt{s} = 13$ TeV JHEP 03 (2020) 051

For the parameter region of our model where the scalars decay promptly, various “seesaw-searches” can give limits to our model.

Other models can be constructed that leads To exotic multi-lepton signals!



Eur.Phys.J.C 81 (2021) 8, 697
Hirsch et al.



LNV!
4ℓ 2W 2j

$S_{33\frac{7}{3}} = (S^{4/3}, S^{7/3}, S^{10/3})$

all with color!!

Conclusions

We discussed 1-loop neutrino mass model which does not require additional symmetries to be the leading contribution to neutrino masses. We showed that in this approach multi-charged particles which are Long-lived naturally appears as a consequence of the smallness of neutrino masses and the high multiplicity of the final states. These particles have masses up to 10 TeV.

Different searches can be sensitive to our model: from searches of stable MCP, to displaced vertex signals, depending on the half-life of the new particles.

Multi-leptons signals can arise in our model. In particular we have discussed the possibility of having multi-lepton LNV final states at the LHC.

Other interesting models can be built that lead to multi-lepton signatures. We have showed another possibility that leads to Long-lived colored Multi-charge particles.


thank you

Backup