LLP and neutrino mass models at the high luminosity LHC.

Juan Carlos Helo
in collaboration with Martin Hirsch

Forward Physics Facility Kickoff Meeting November, 2020

-Heavy neutral fermions at the high-luminosity LHC, Helo, Hirsch, Wang. JHEP 07 056 (2018)
-Long-lived charged particles and multilepton signatures from neutrino mass models Arbelaez, Cottin, Helo Hirsch *Phys.Rev.D* 101 (2020) 9, 095033

LLP and neutrino mass models

Seesaw: Sterile neutrinos

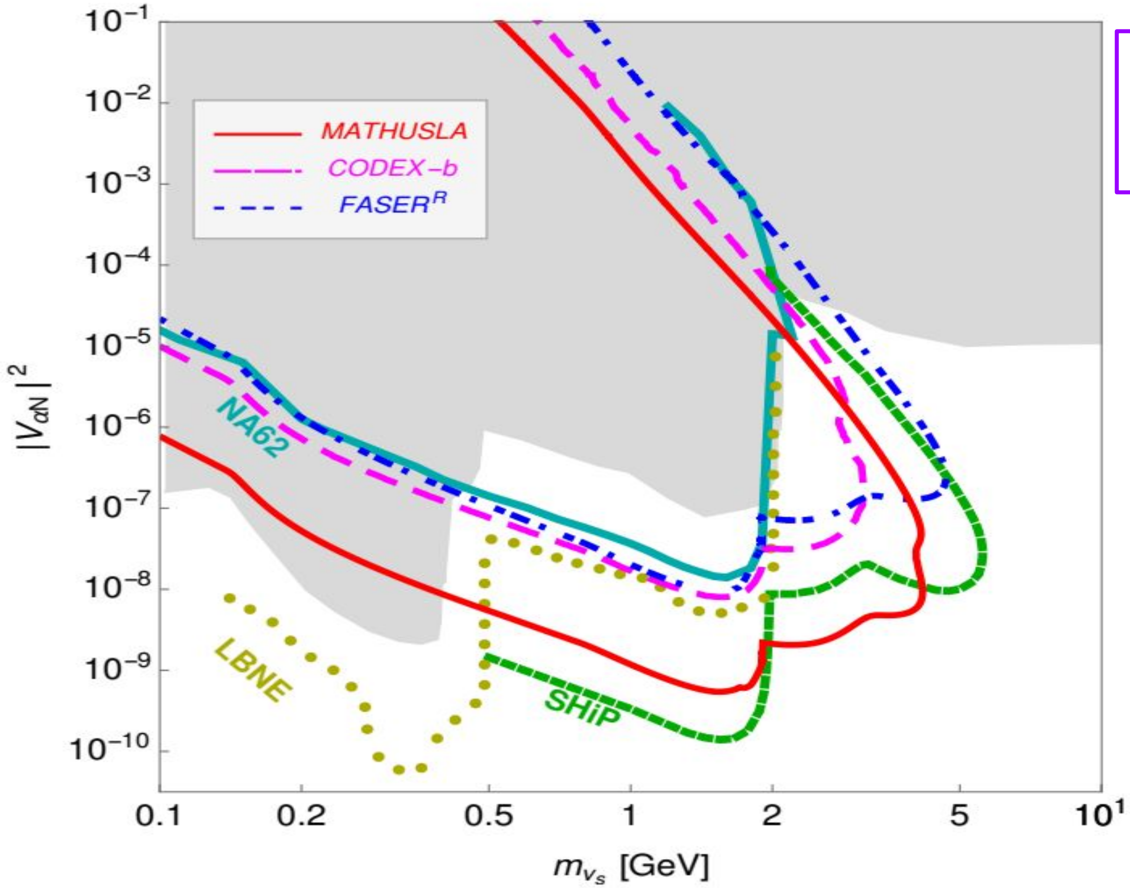
Susy with RPV: Light neutralinos

1-loop models: Multi-charged particles

Type-I Seesaw Minkowski; Gellman, Ramon, Slansky; Yanagida; Glashow; Mohapatra, Senjanovic

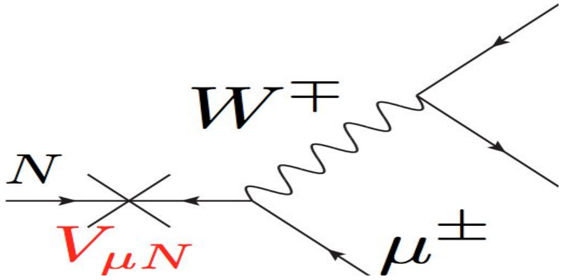
Low scale seesaw:
Mohapatra and Valle, Phys. Rev. D34, 1642 (1986).
Akhmedov, Lindner, Schnapka, and Valle, Phys.Lett. B368, 270),
Akhmedov, Lindner, Schnapka, Valle, Phys.Rev. D53, 275,

Helo, Hirsch, Wang. JHEP 07 056 (2018)



$$|V_{\alpha N_j}|^2 \simeq 5\times 10^{-11}\left(\frac{m_\nu}{0.05\mathrm{eV}}\right)\left(\frac{1\mathrm{GeV}}{M_N}\right)$$

See talks by: Guanghui Zhou
Yongsoo Jho
Sumit Ghosh



Susy with RPV : Light neutralinos

$$W = \lambda_{ijk}\hat{L}_i\hat{L}_j\hat{E}^c_K + \lambda'_{ijk}\hat{L}_i\hat{Q}_j\hat{D}^c_K + \epsilon_i\hat{L}_i\hat{H}_u$$

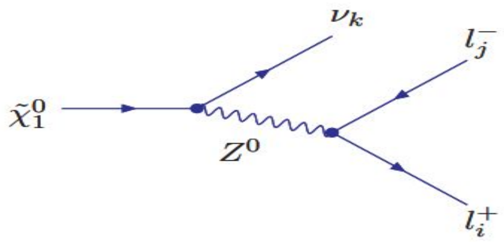
Here we consider: $pp \rightarrow Z^0 \rightarrow \chi^0_1\chi^0_1$

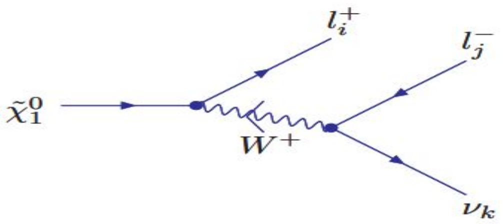
$$\Gamma(\chi^0_1) \sim \frac{g^4}{512\pi^3}\left(\frac{m_\nu}{m_{SUSY}}\right)\left(\frac{m^5_{\chi^0_1}}{m^4_W}\right)$$

W. Porod, M. Hirsch, J. Romao, and J. W. F. Valle, Phys. Rev. D63, 115004 (2001), arXiv:hep-ph/0011248.

M. Hirsch, M. A. Diaz, W. Porod, J. C. Romao, and J. W. F. Valle, Phys. Rev. D62, 113008 (2000).

$$M_{SUSY} = 1TeV,\ m_{\chi^0} = 40GeV,\ \mathbf{m}_\nu = \sqrt{\Delta(m^2_{Atm})} \quad \rightarrow \quad c\tau_{\chi^0} \sim 150m$$



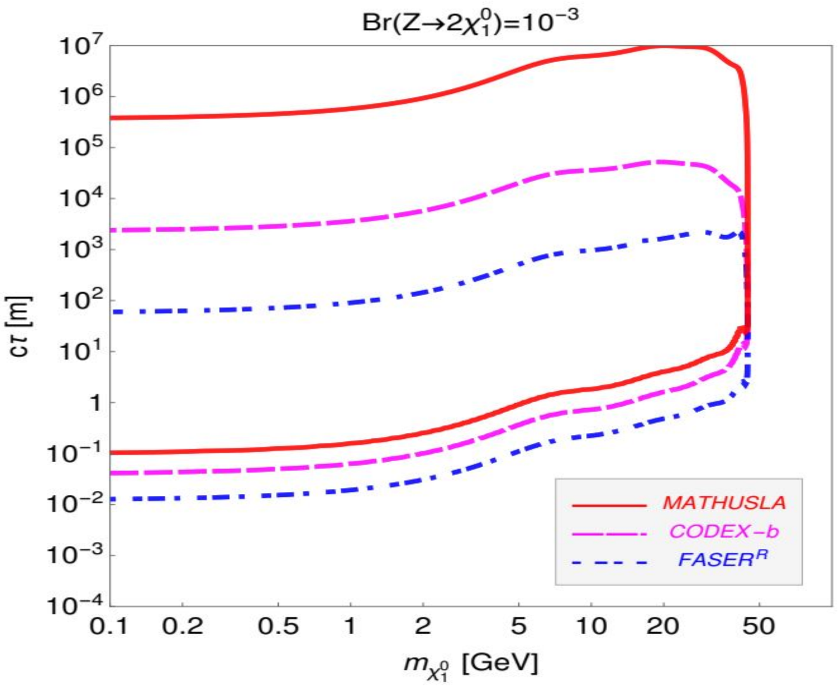


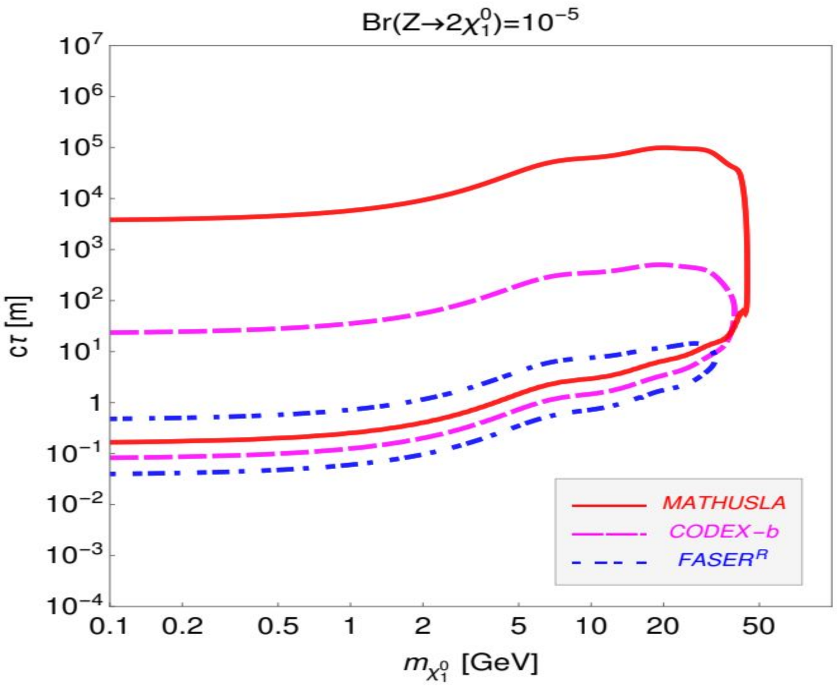
Susy with RPV : Light neutralinos

See also Dreiner's talk

For the bilinear RPV models these experiments cover large parts of the range of the half-life predicted theoretically from the observed neutrino masses!.

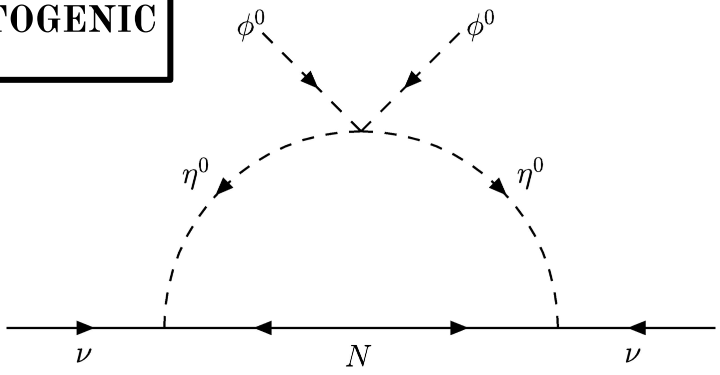
Helo, Hirsch, Wang. JHEP 07 056 (2018)





1-loop models:

SCOTOGENIC



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

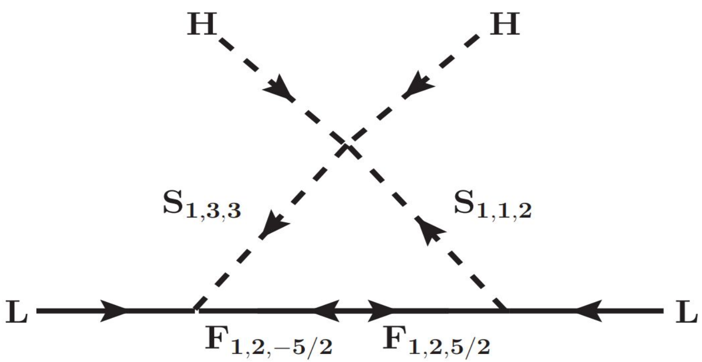
Additional symmetry to the SM $SU(2)_L \times U_Y \times Z_2$

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

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

2 Dark Matter Candidates !

OUR MODEL



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

No additional symmetries to the SM

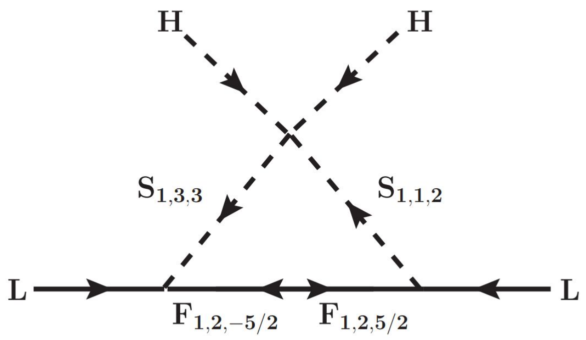
$$S_{1,1,2} = S_1^{2+}$$

$$S_{1,3,3} = (S_3^{4+}, S_3^{3+}, S_3^{2+})$$

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

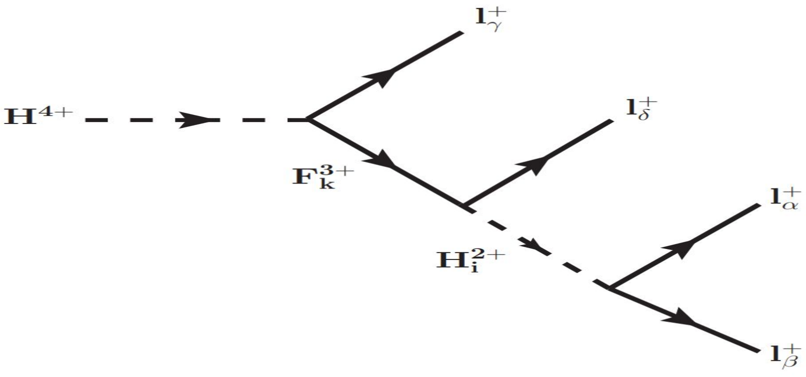
No Dark Matter Candidates

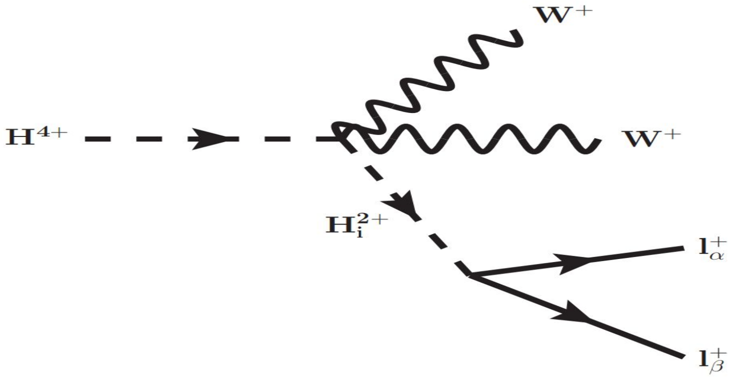
OUR MODEL



Since the model uses only non-singlet states
All beyond SM particles can in principle be produced at the LHC!

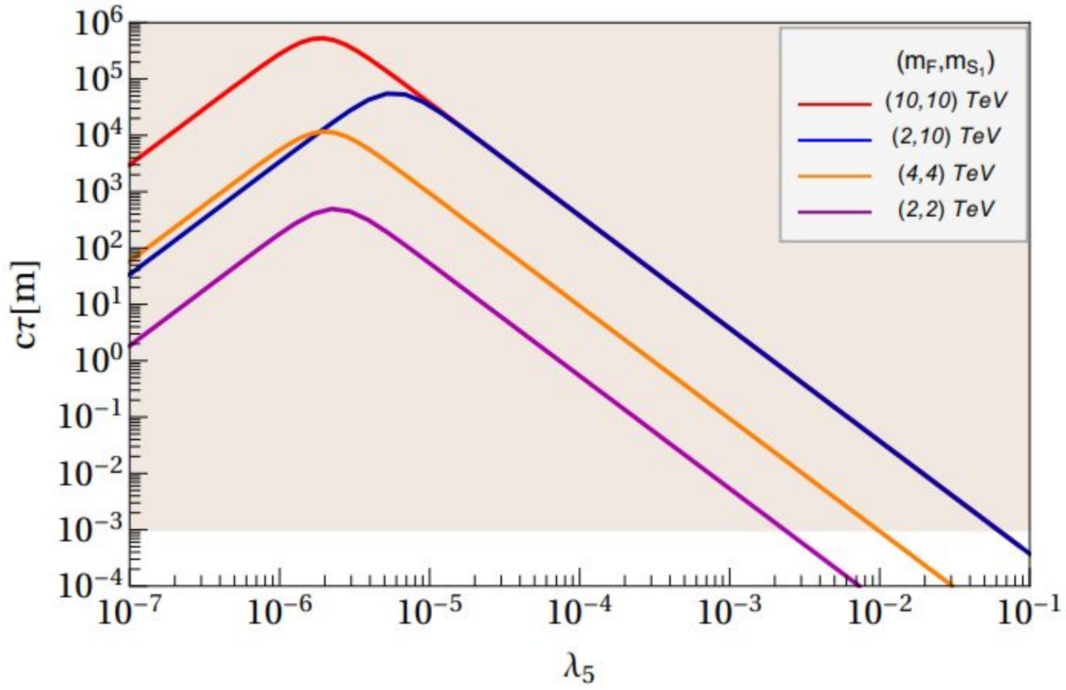
Decays of the 4-charge scalar

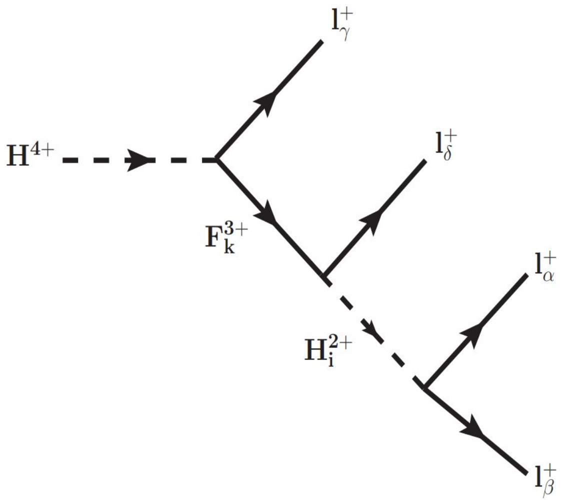




Long-Lived Multi-Charged Particles:

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





MoEDAL-MAPP sensitivity:
R. Maselek, K. Sakurai and M.Hirsch, work in progress

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

Conclusions

We have discussed 3 concrete models that can explain the observed neutrino masses (a) light sterile neutrinos (b) the lightest neutralino in R-parity violating supersymmetry and © 1-loop model with multi-charged particles.

For sterile neutrinos, FASER and CODEX-b show similar sensitivities. Here, FASER compensates its smaller detection volume by taking advantage of the fact that D-mesons (and to some degree B-mesons) are produced mostly in the forward direction.

For the case of neutralinos in RPV SUSY we have found that FASER, CODEX-b and MATHUSLA can cover interesting parts of the parameter space of these models, if the lightest neutralino has a mass in the range of a few GeV up to mZ/2. In particular, for bilinear RPV models these experiments cover large parts of the range of $c\tau$ predicted theoretically from the observed neutrino masses.

Finally 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. A new proposed experiments, such as MoEDAL-MAPP, located at the Forward direction might be also sensitive to these particles.

Thanks!!