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Heavy neutrino searches at the LHC with displaced vertices.

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Comhep III, Colombia
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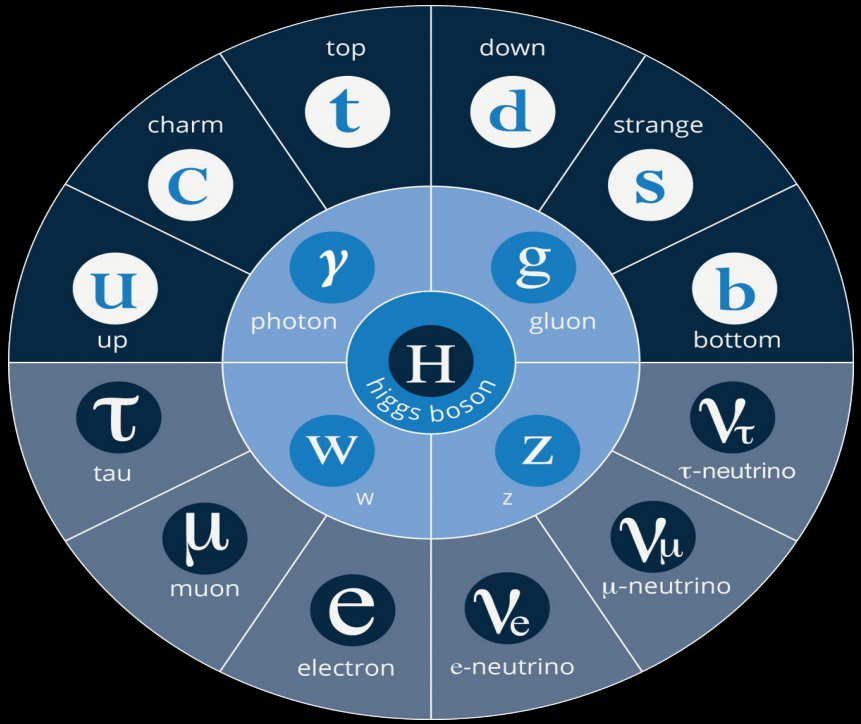
Heavy neutrino searches at the LHC with displaced vertices. J. C. Helo, M. Hirsch, S. Kovalenko. Published in Phys.Rev. D89 (2014)
Displaced vertices as probes of sterile neutrino mixing at the LHC. G. Cottin, J. C. Helo, M. Hirsch. Published in Phys.Rev. D98 (2018) no.3, 035012
Searches for light sterile neutrinos with multitrack displaced vertices. G. Cottin, J. C. Helo, M. Hirsch. Published in Phys.Rev. D97 (2018) no.5, 055025

The Standard Model

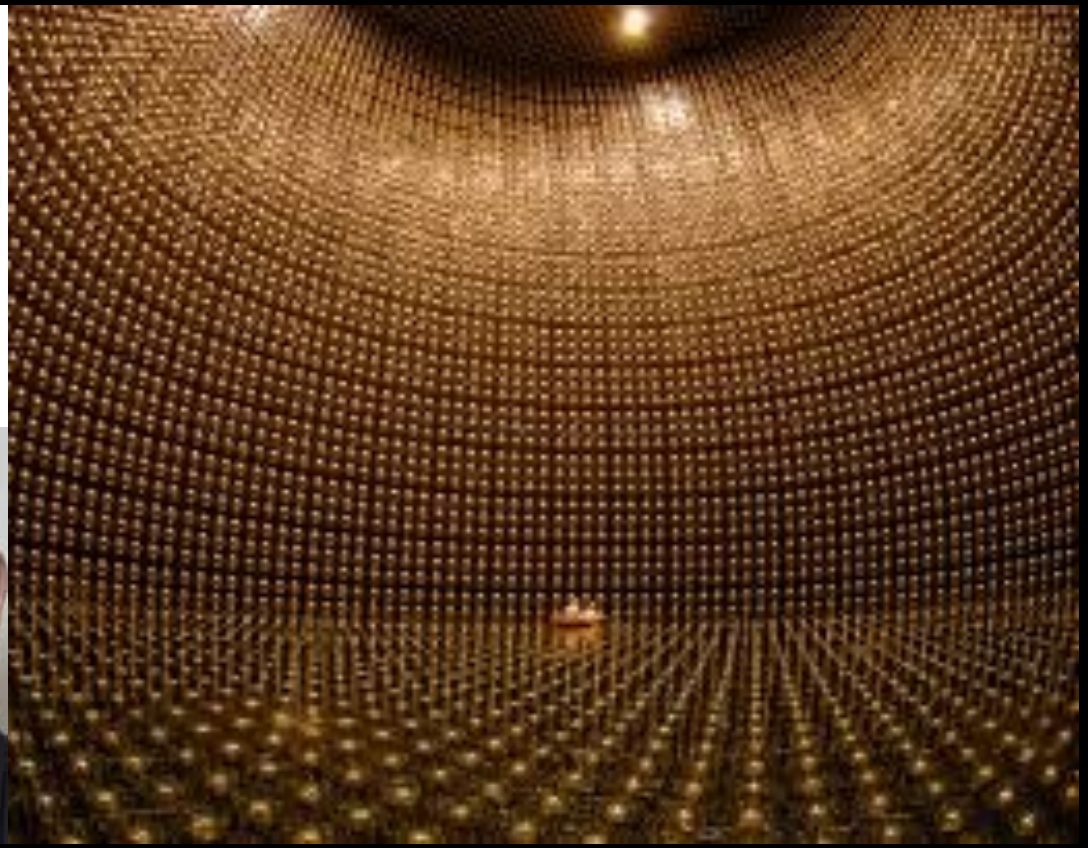
The Standard Model of Matter and its Interactions

Experiments at CERN have tested the Standard Model with remarkable accuracy !!!



Source : https://atlas.cern/discover/physics

Evidence for BSM physics BEYOND the Standard Model



Super Kamiokande neutrino detector

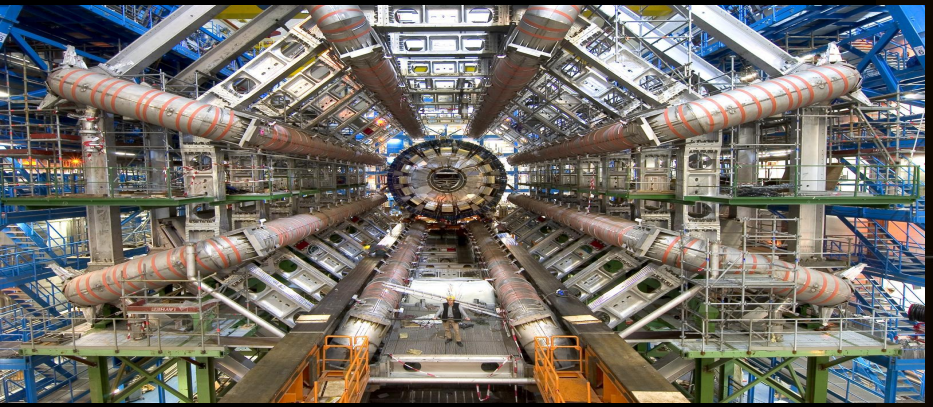
Neutrino mass models

Sterile Neutrinos : Standard Model + N (Singlet)

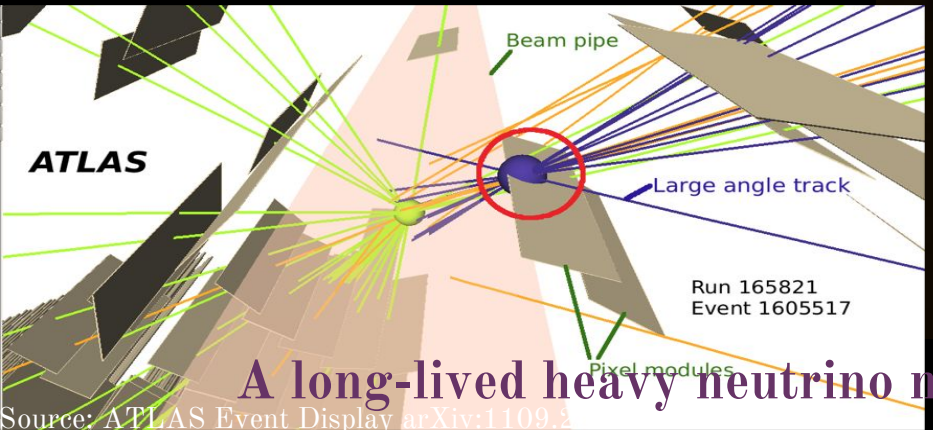
Left-Right Symmetry : N (Doublet)

Source: FermiLab

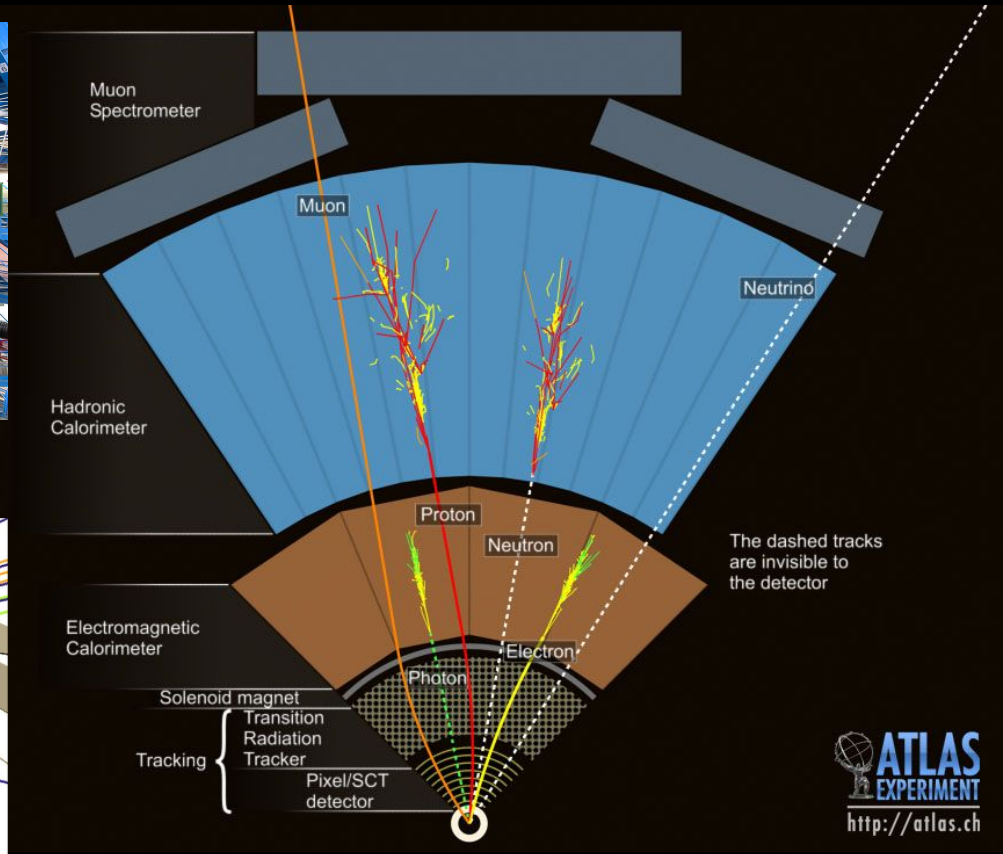
The LHC and the origin of neutrino masses?



Heavy neutrino searches at the LHC with displaced vertices. J. C. Helo, M. Hirsch, S. Kovalenko. Published in Phys.Rev. D89 (2014)



Source: ATLAS Event Display arXiv:1109.2



A long-lived heavy neutrino may appear at the LHC !

Multitrack displaced vertices search

G. Cottin, J. C. Helo, M. Hirsch. Phys.Rev. D97 (2018) no.5, 055025 - Phys.Rev. D98 (2018) no.3, 035012

We have proposed a search inspired by the ATLAS multitrack displaced vertex analysis which is sensitive to displaced vertex signature inside the inner tracker. We trigger on the prompt lepton coming from the decay of the W boson, impose cuts on the neutrino displaced vertex its decanday products, and apply vertex-level efficiencies made public by ATLAS.

The following selections are imposed: (with these selections we are still in a zero backg. region, **ATLAS, arXiv:1710.04901**).

1. One prompt lepton (as reconstructed above) with $pT > 25$ GeV.

2. Decay position of the DV contained within transverse distance $rDV < 300$ mm, and $|zDV| < 300$ mm. The distance between the interaction point and the decay position must be bigger than > 4 mm.

3. Decay products must be charged (i.e tracks) with $pT > 1$ GeV and transverse impact parameter $|d0| > 2$ mm.

4. The number of selected tracks Ntrk must be at least 3. The invariant mass of the DV mDV must be $\geqslant 5$ GeV, and assumes all tracks have the mass of the pion.

5. Parametrized selection efficiencies are applied depending on the displaced vertex distance (within 4 and 300 mm, between the pixel and the SCT), number of tracks and mass.

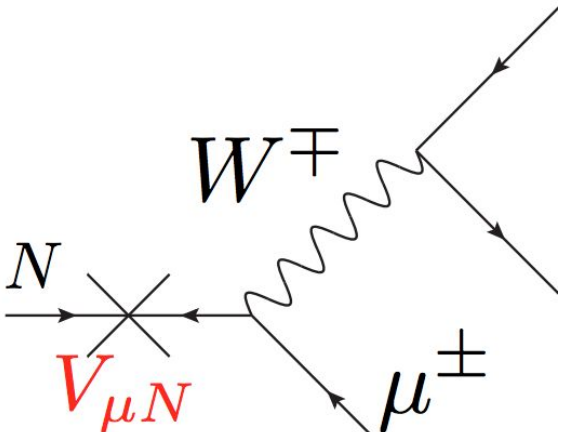
6. DV efficiency: parametrized selection efficiencies are implemented depending on the displaced vertex distance, number of tracks and mass "https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/PAPERS/SUSY-2016-08/hepdata_info.pdf,(2017).

Sterile Neutrinos : Standard Model + N

Seesaw:
P. Minkowski, Phys. Lett. 67B (1977)
R. N. Mohapatra and G. Senjanovic, Phys. Rev. Lett. 44 (1980)
J. Schechter and J. W. F. Valle, Phys. Rev. D22, 2227 (1980)

$$pp \to W^{\pm} \to N l^{\pm}$$

$N \to l^{\pm} q\bar{q}$
$N \to l'^{\mp} l^{\pm} \nu_l$
$N \to \nu_l q\bar{q}$



$$c\tau_N \sim 3.7 \left(\frac{1\,\text{GeV}}{m_N} \right)^5 \left(\frac{0.1}{|V_{lN}|^2} \right) \text{ [mm]}$$

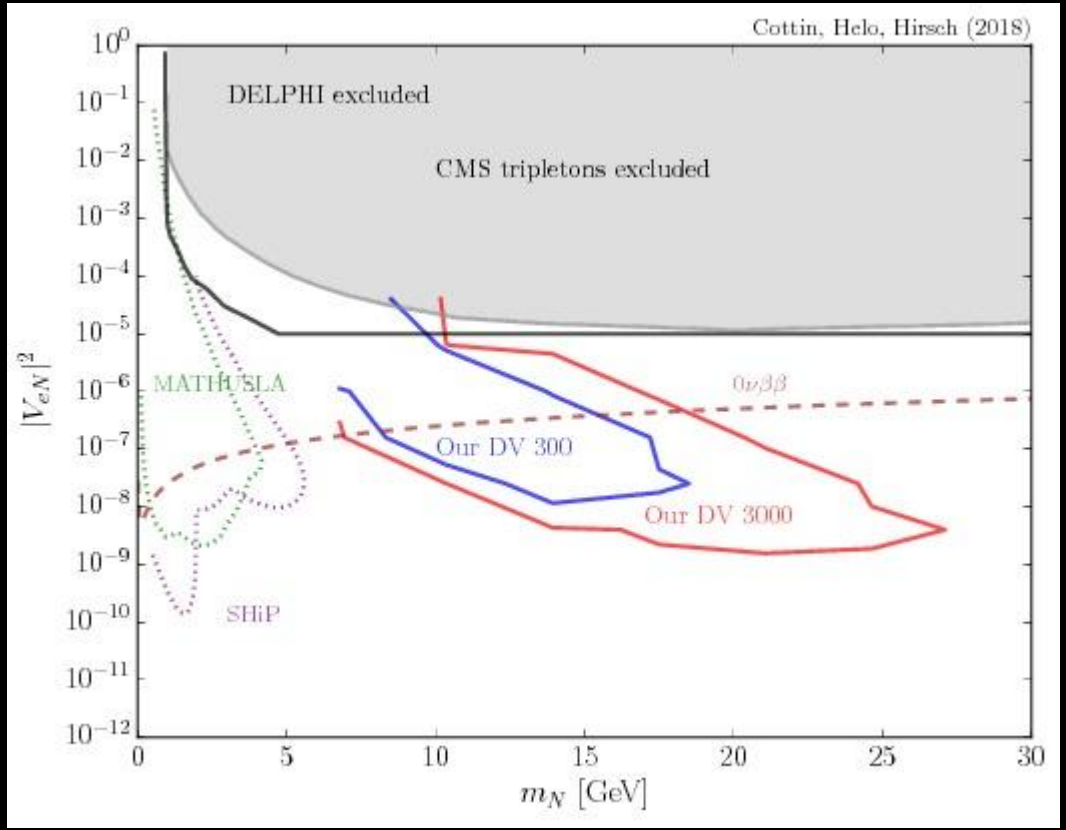
Sterile N mixes with SM neutrino.
Large lifetime due to off-shell decay

The LHC can probe this model with a displaced vertex search strategy and reach regions of parameter space that other searches and even other experiments can NOT !!

$$pp \to W^{\pm} \to Nl^{\pm}$$

$$N \to l^{\pm} q\bar{q}$$

$$N \to \nu_l q\bar{q}$$



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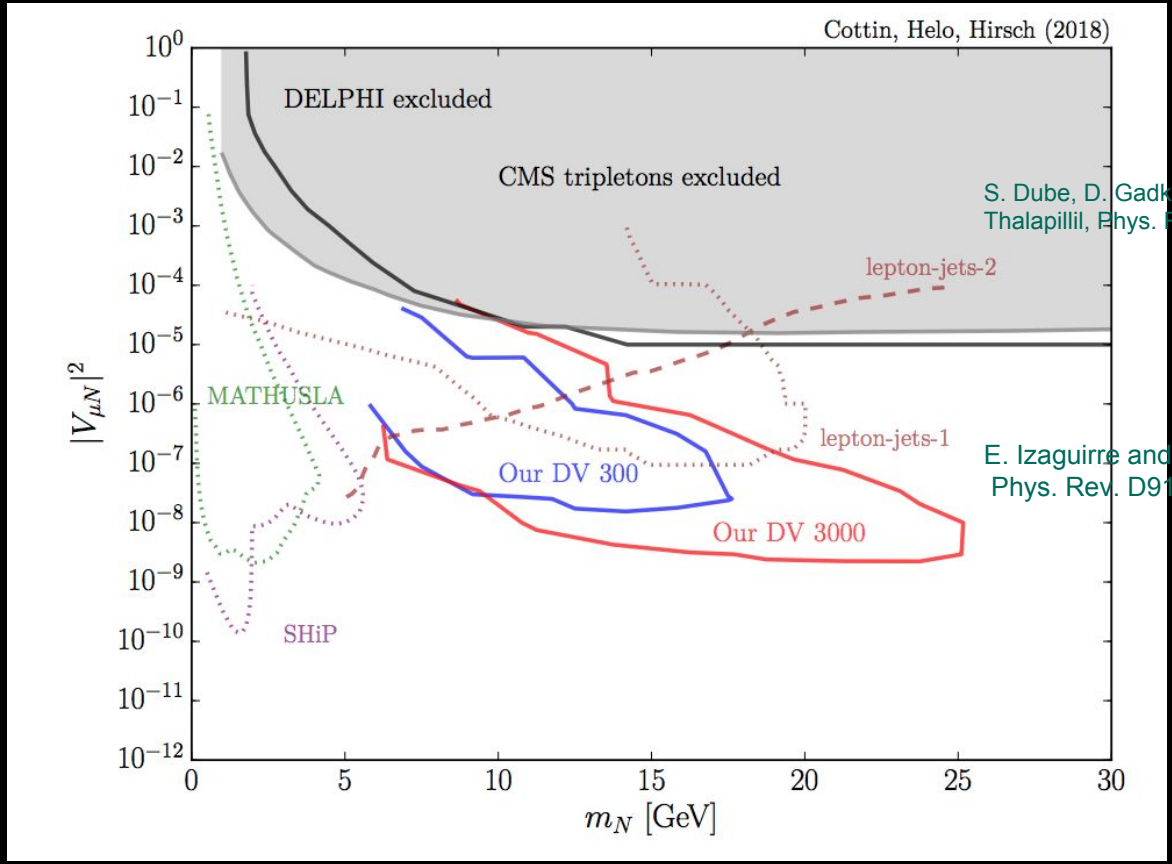

S. Dube, D. Gadkari, and A. M. Thalapillil, Phys. Rev.D96, 055031 (2017)

E. Izaguirre and B. Shuve, Phys. Rev. D91, 093010 (2015)

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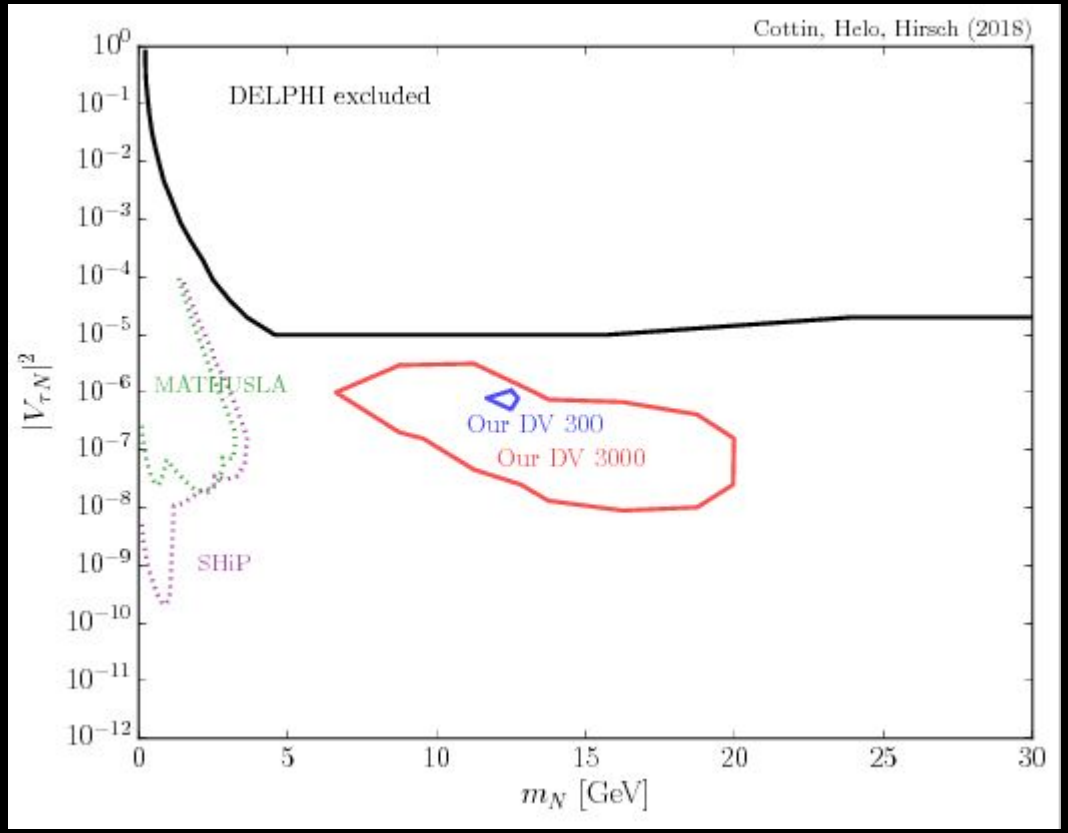
$$N \to \nu_l q\bar{q}$$

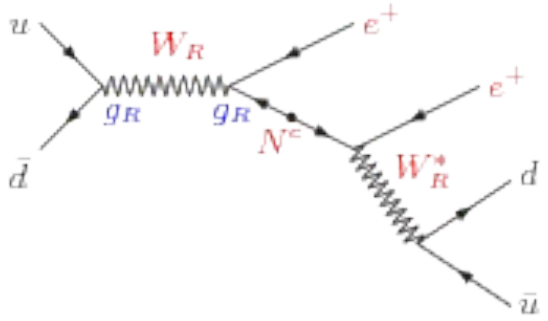
Experimental limits for tau mixing have not been addressed yet at the LHC.

The parametrized selection efficiencies provided by ATLAS assumes all decay products are prompt from the DV, they are not directly applicable to the case when there is a tau lepton coming from the displaced vertex.

For taus we implement a basic reconstruction following (ATLAS) Eur. Phys. J.C75, 303 (2015)

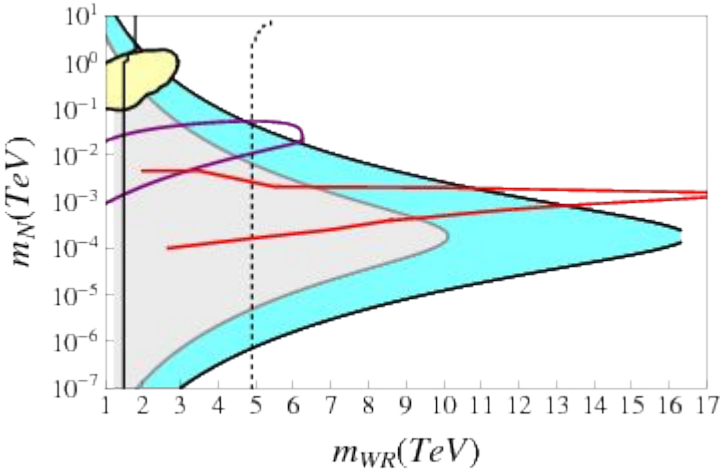


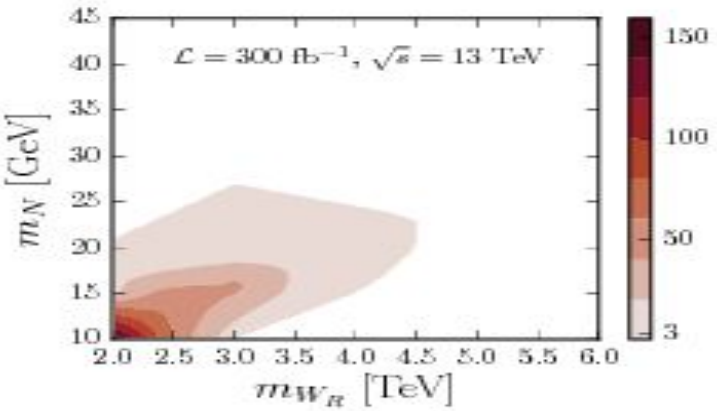
Left-Right Symmetry :

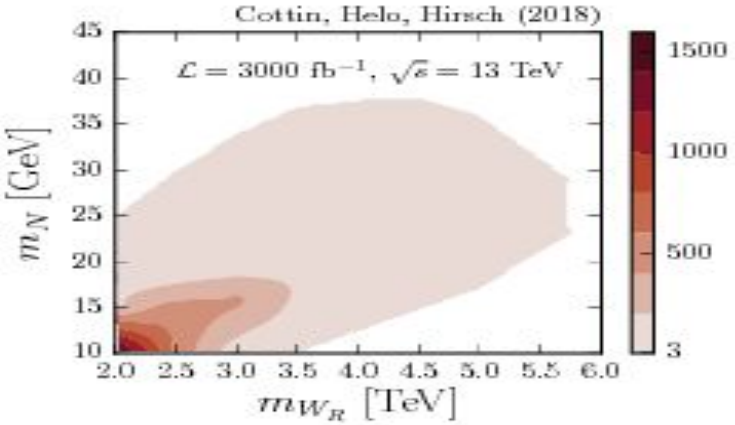


Keung & Senjanovic, 1983
Phys. Rev. Lett. 50, 1427

Dib, Castillo, Helo, Kovalenko, Ortiz
Phys.Rev. D92 (2015) no.1, 013001







Conclusions

We study the potential of the LHC to probe heavy neutrinos with a displaced vertex strategy motivated by current multitrack DV searches at the 13 TeV LHC

Our tracker based DV search for light sterile neutrinos unique, as it has no competition from other experiments within $5\ \text{GeV} < \text{mN} < 30\ \text{GeV}$.

Finally, the sensitivity of this displaced strategy at the LHC is complementary to that of future fixed-target experiments, such as SHiP, or the MATHUSLA surface detector.

Thanks

Multitrack displaced vertices search

G. Cottin, J. C. Helo, M. Hirsch. Phys.Rev. D97 (2018) no.5, 055025 - Phys.Rev. D98 (2018) no.3, 035012

(ATLAS), (2017), arXiv:1710.04901 originally triggers on missing transverse momenta in the event to be bigger than 250 GeV. In this work, we propose to trigger on the prompt lepton , as in our model there is little or no missing transverse momenta. Apart from the trigger requirement, we fully recast the multitrack analysis.

The following selections are imposed: (with these selections we are still in a zero backg. region, **ATLAS, arXiv:1710.04901**).

1. One prompt lepton (as reconstructed above) with $pT > 25$ GeV.

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