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What do we learn from HNL collider searches?

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PheNumenal

EXCELENCIA SEVERO OCHOA

Why Heavy Neutral Leptons?

Spin
1/2

Color
single

Isospin
single

Charge
0

Mass
how dare you!?

Social life
not much

Curriculum Vitae

Heavy Neutral Leptons

Heavy neutrinos, right-handed neutrinos, sterile neutrinos

Work experience

- Neutrino masses

Other skills

- Osc. anomalies
- Dark matter
- Baryogenesis
- Cooking

Searches for HNL

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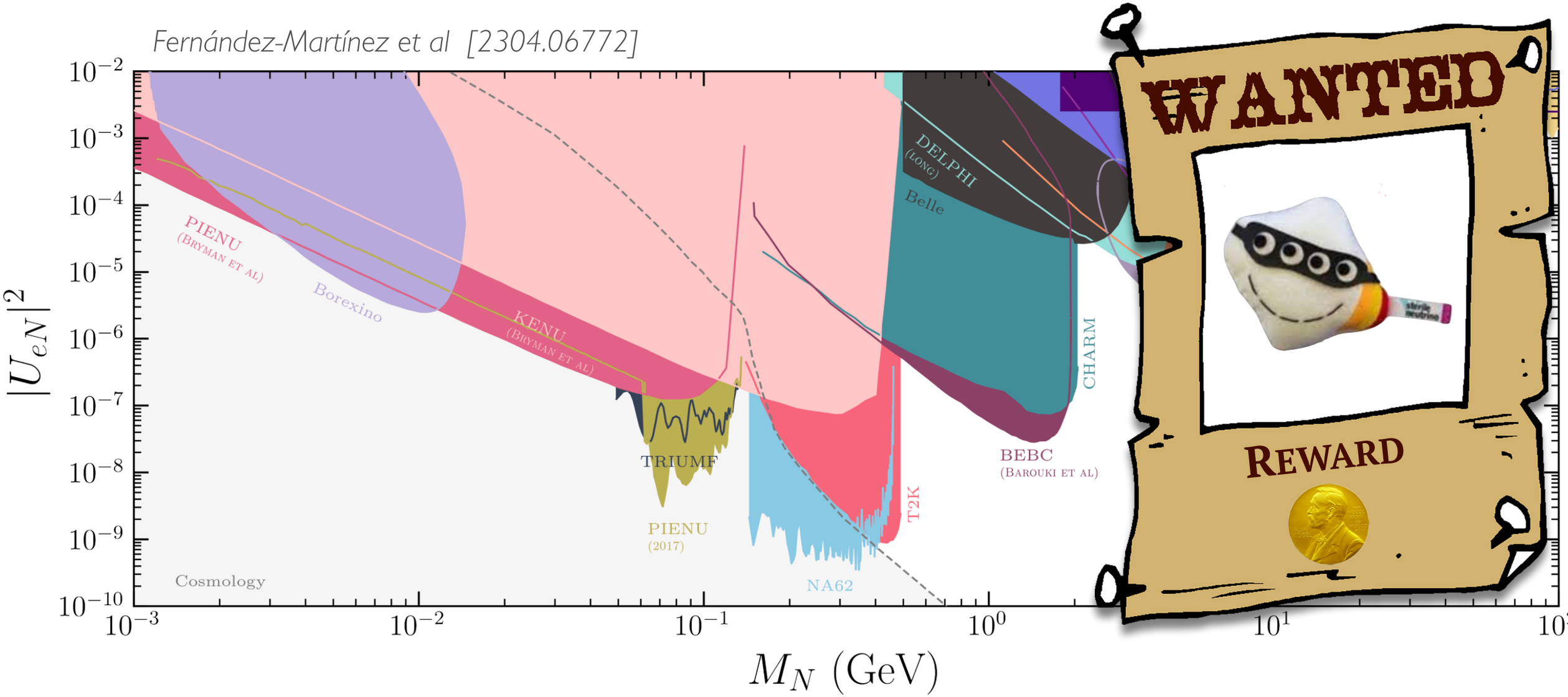
Fernández-Martínez et al [2304.06772]



Which Masses for colliders?

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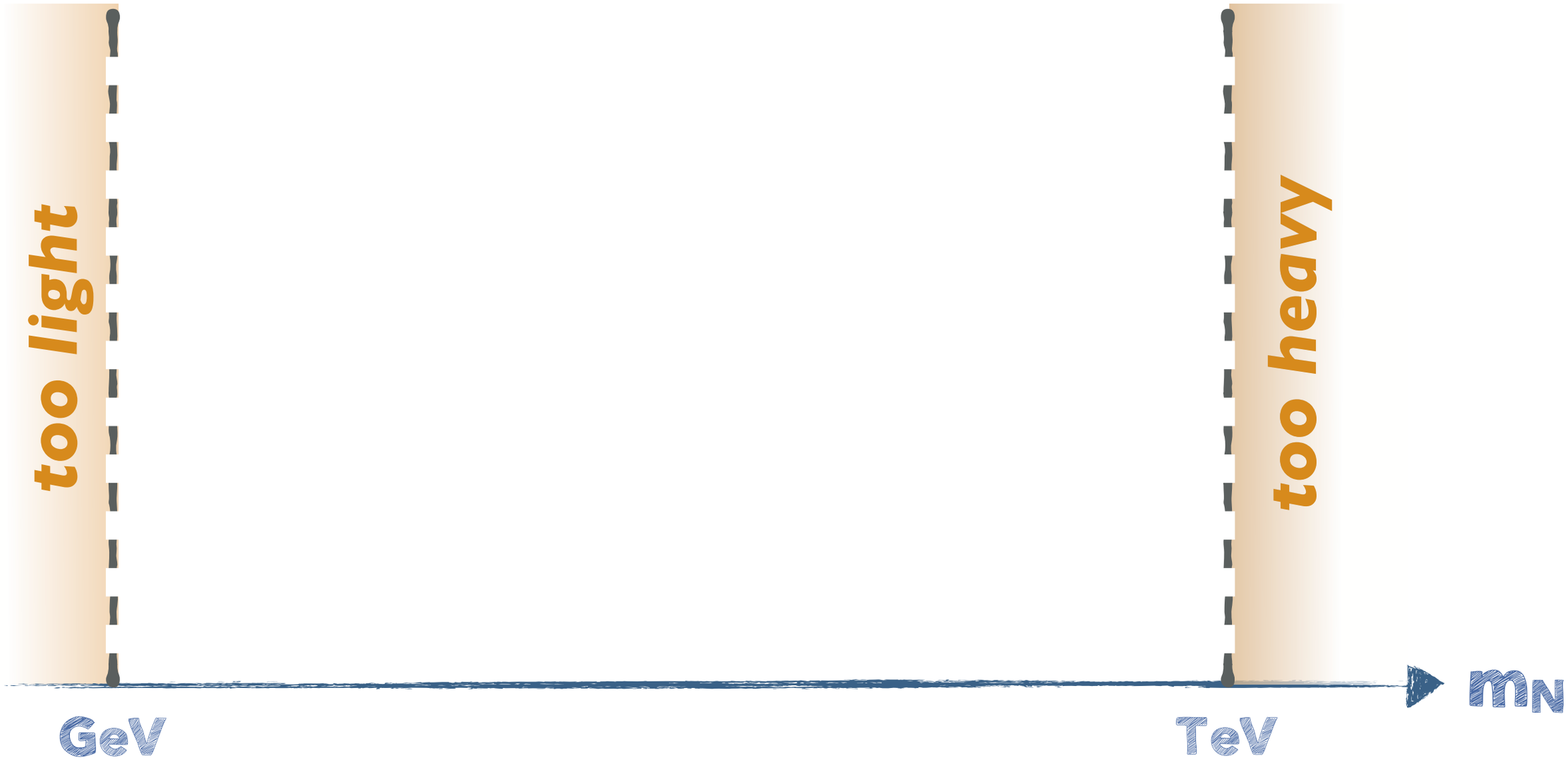
better via flavor and EWPO, talk by Daniel Naredo



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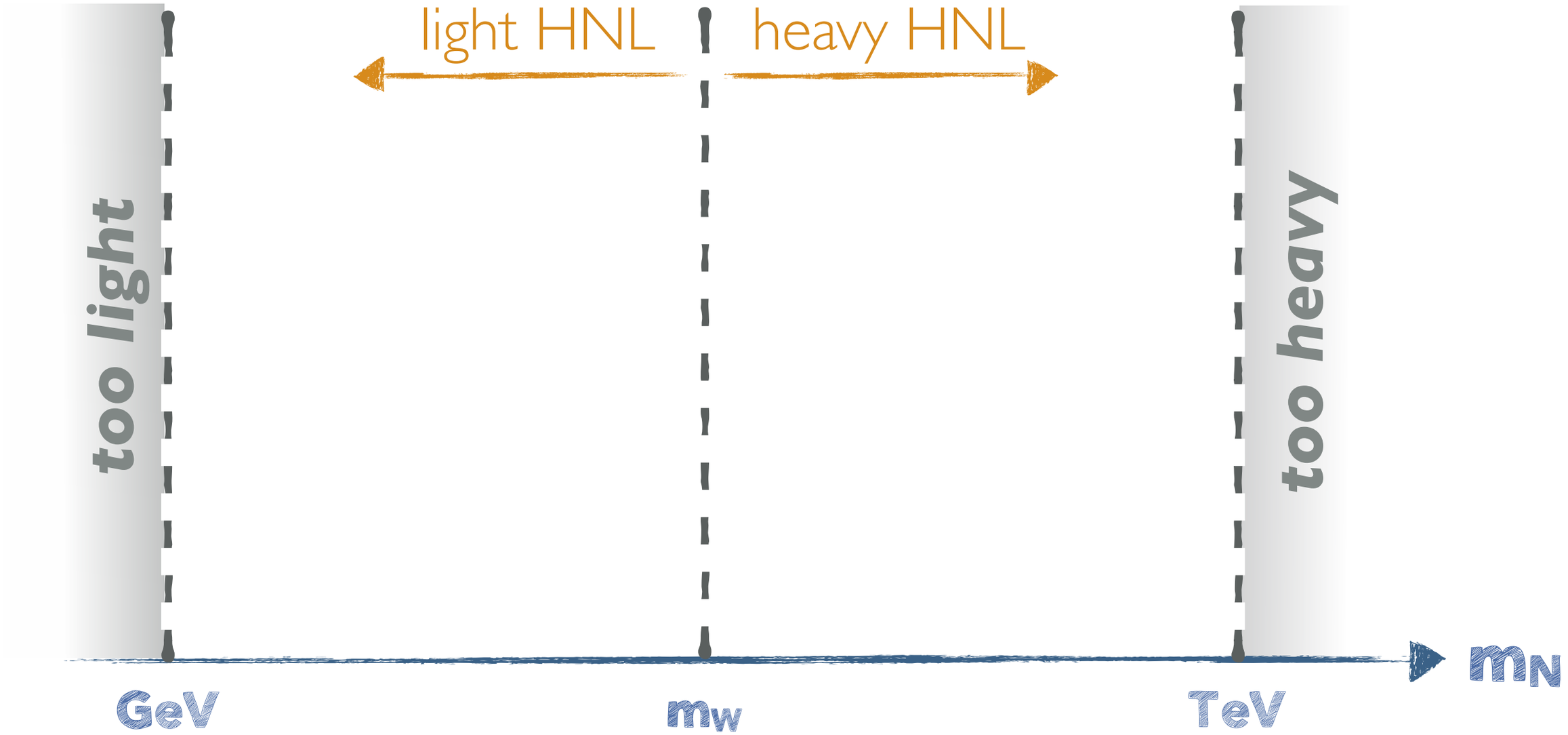

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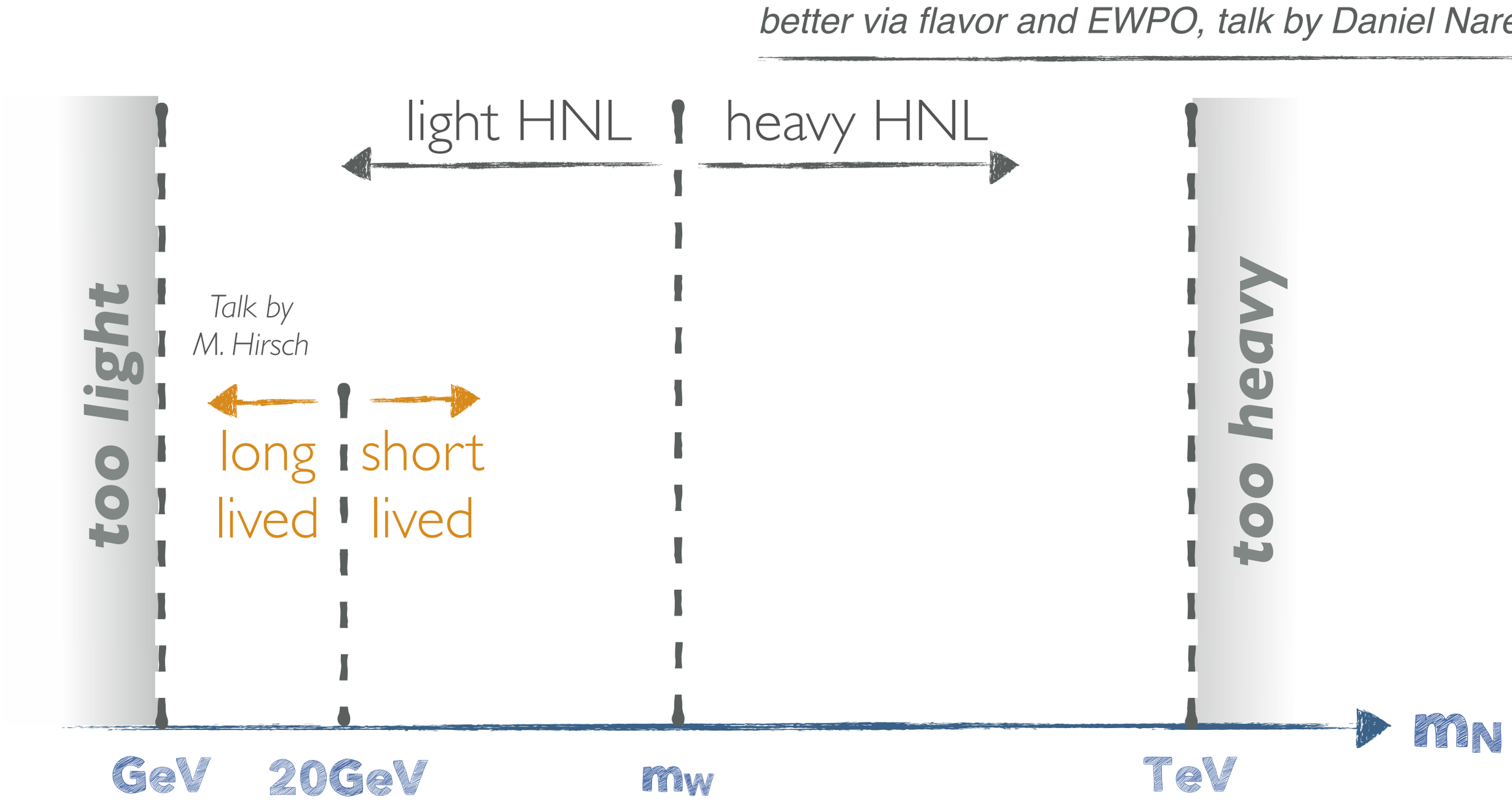

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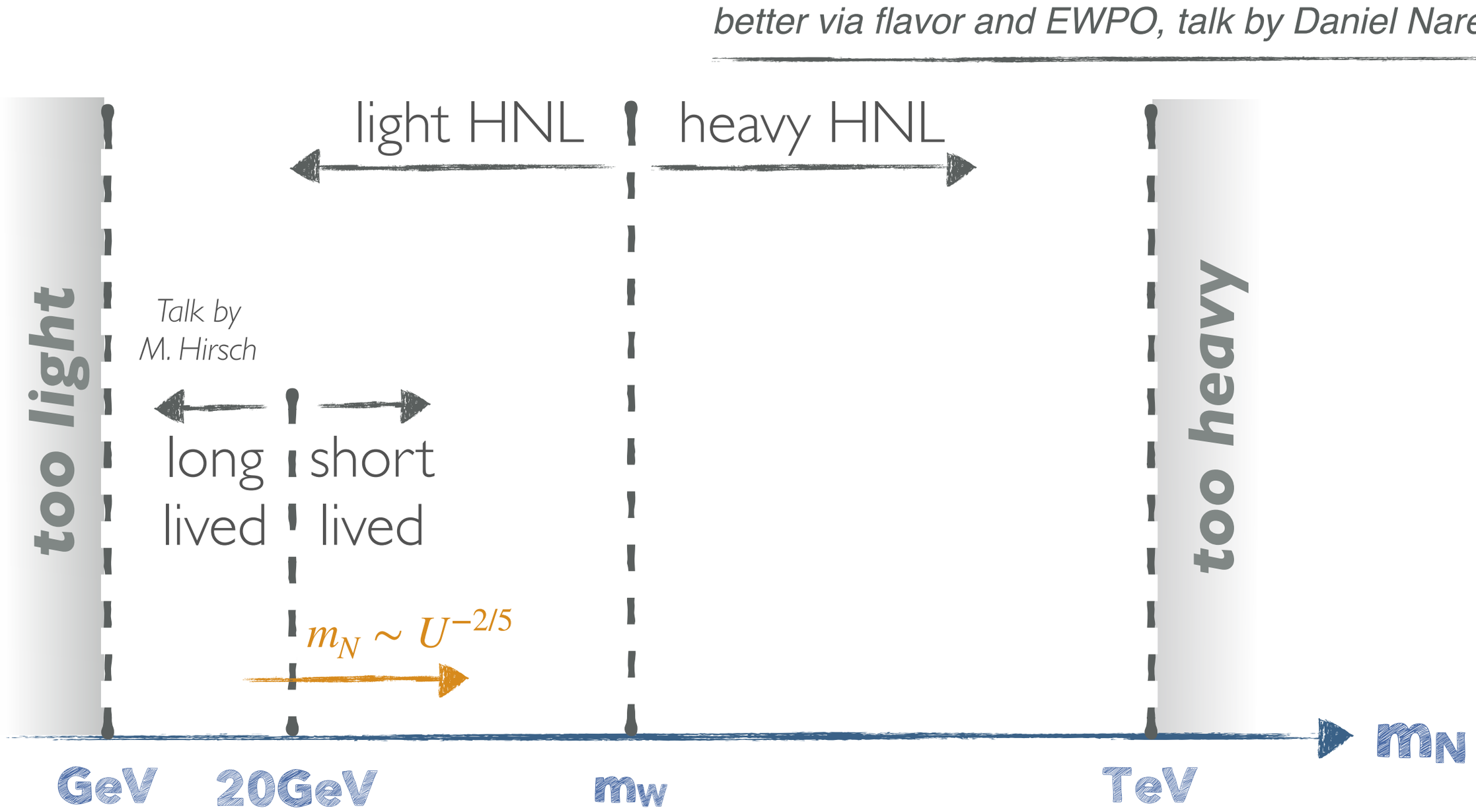
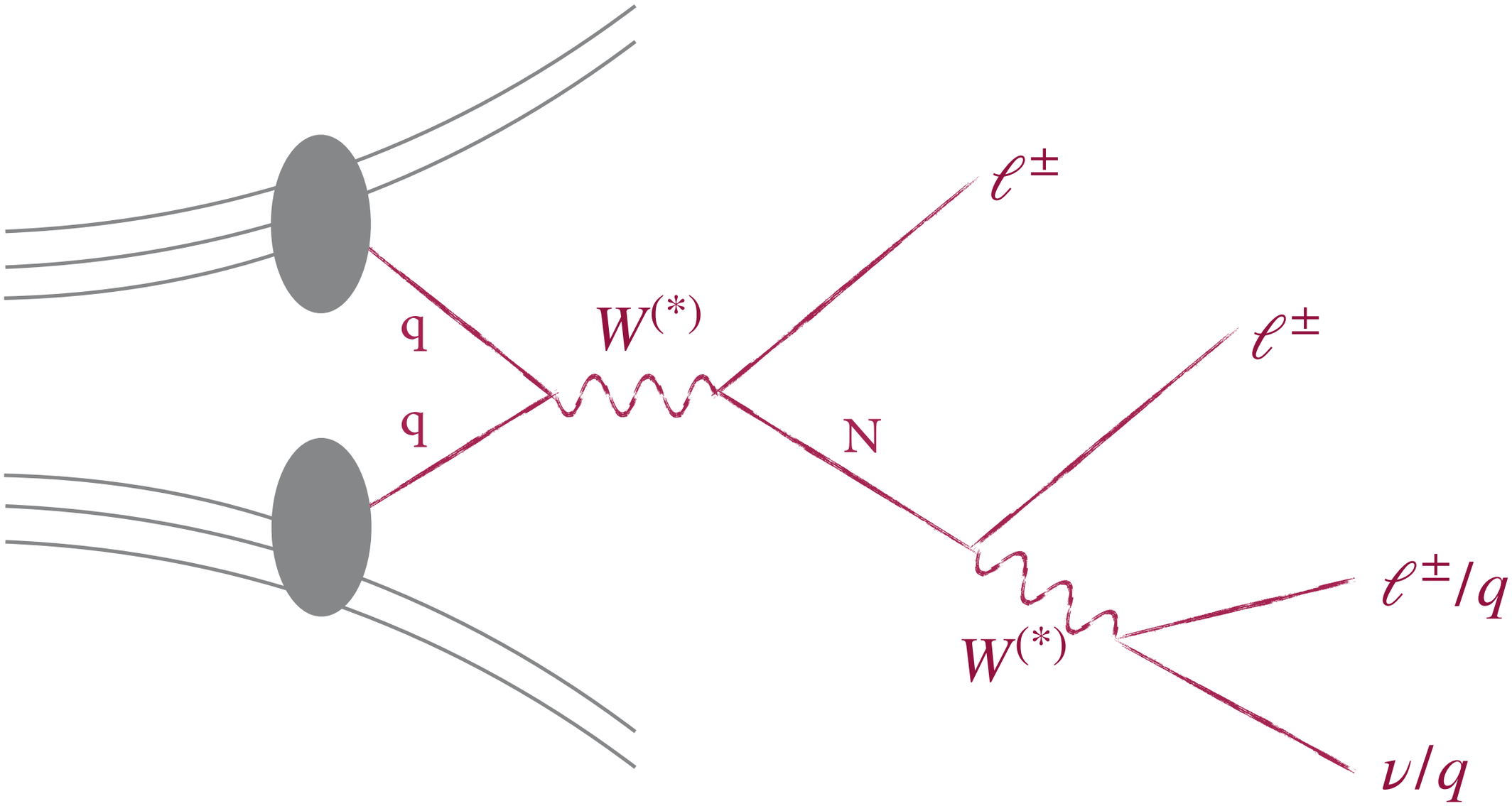


HNL Production and Decay at LHC



Several Channels at LHC

- *Same Sign Dilepton channel* — LNV—

$$pp \to W^{(*)} \to \ell^{\pm} N \to \ell^{\pm}\ell^{\pm} + nj$$

- *Opposite Sign Dilepton channel* — LNC—

$$pp \to W^{(*)} \to \ell^{\pm} N \to \ell^{\pm}\ell^{\mp} + nj$$

- *Trilepton channel* — LNV?—

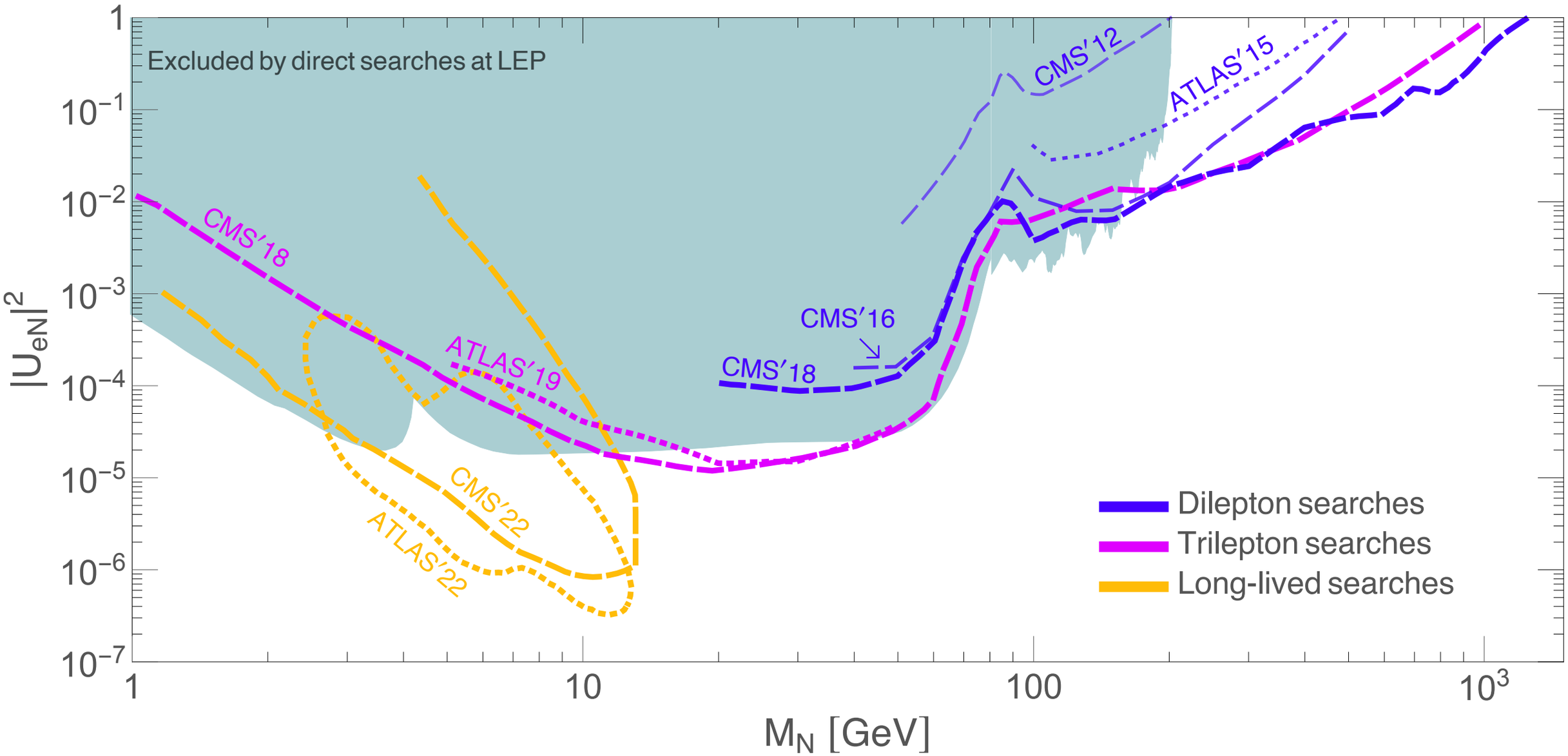
$$pp \to W^{(*)} \to \ell^{\pm}_{\alpha} N \to \ell^{\pm}_{\alpha}\ell^{\pm}_{\beta}\ell^{\mp}_{\gamma}\nu$$

- *Displaced vertices* — LNV?—

$$pp \to W^{(*)} \to \ell^{\pm}_{\alpha} N \quad // \quad N \to \ell^{\pm}_{\beta}\ell^{\mp}_{\gamma}\nu$$

Current Status

Abada, Escribano, XM, Piazza [2208.13882]



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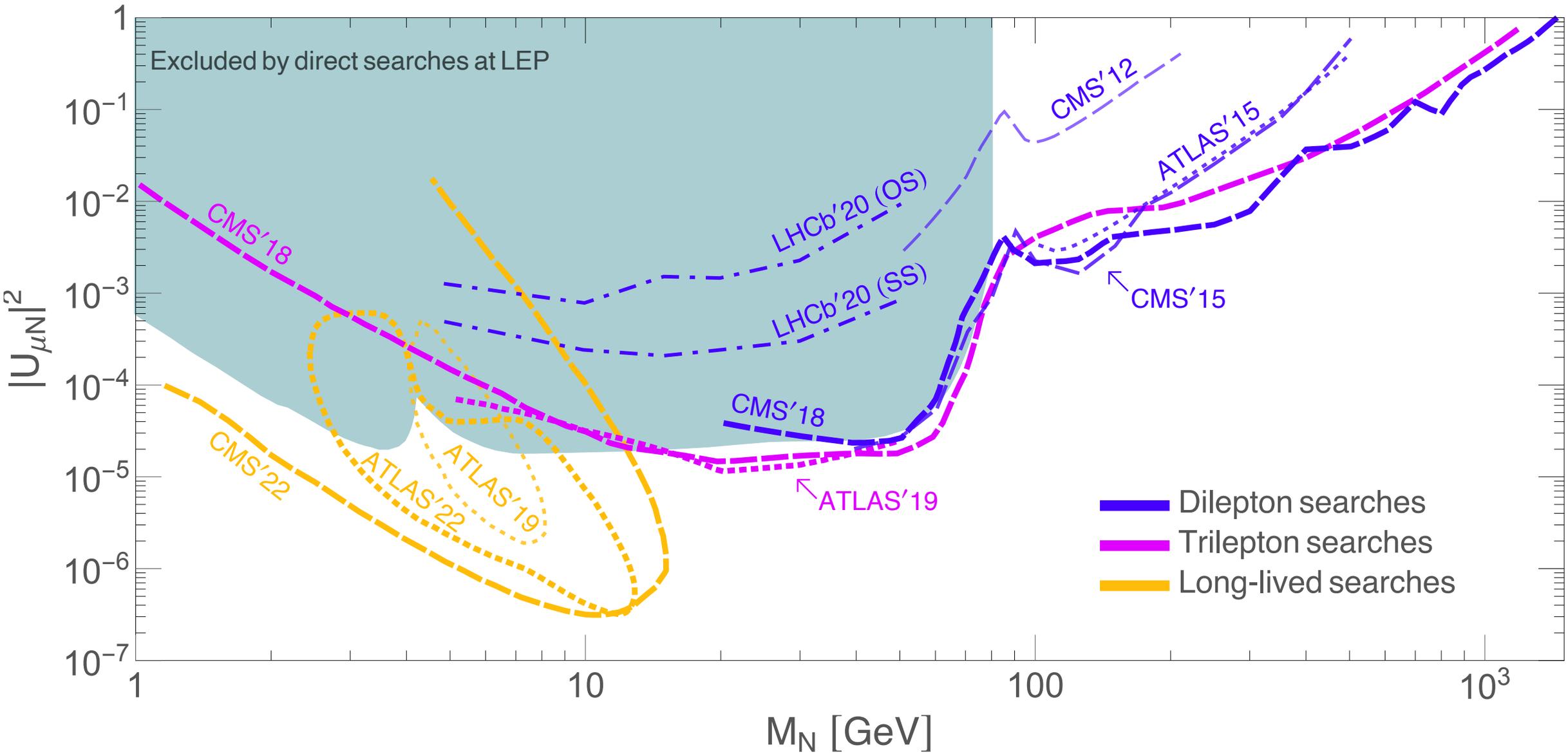
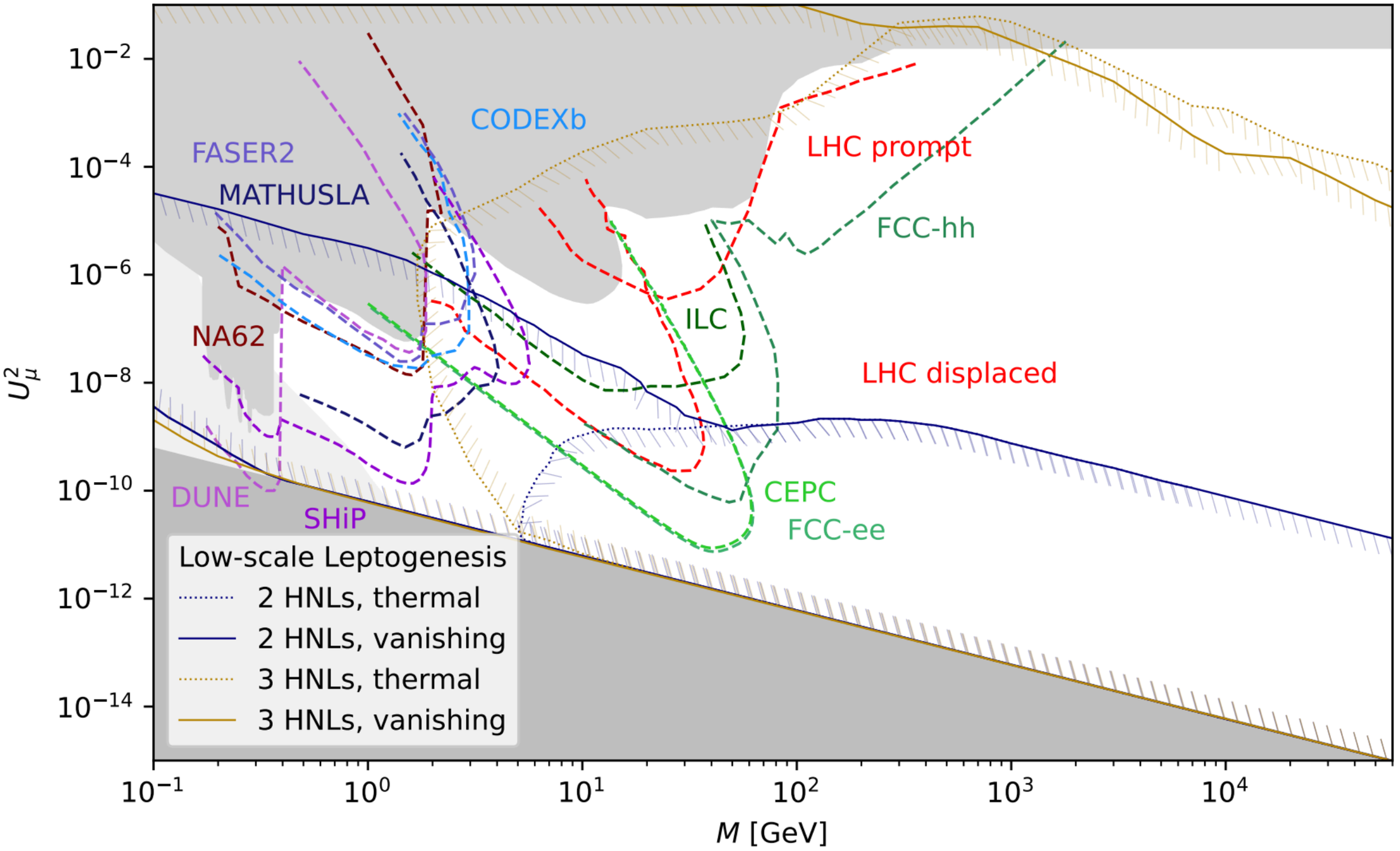


Future Collider Landscape

Abdullahi et al [2203.08039]



What do we learn from these analyses?

— Are we testing any Realistic Model? —

- *Exp searches consider HNL mixing to 1 flavor at a time*

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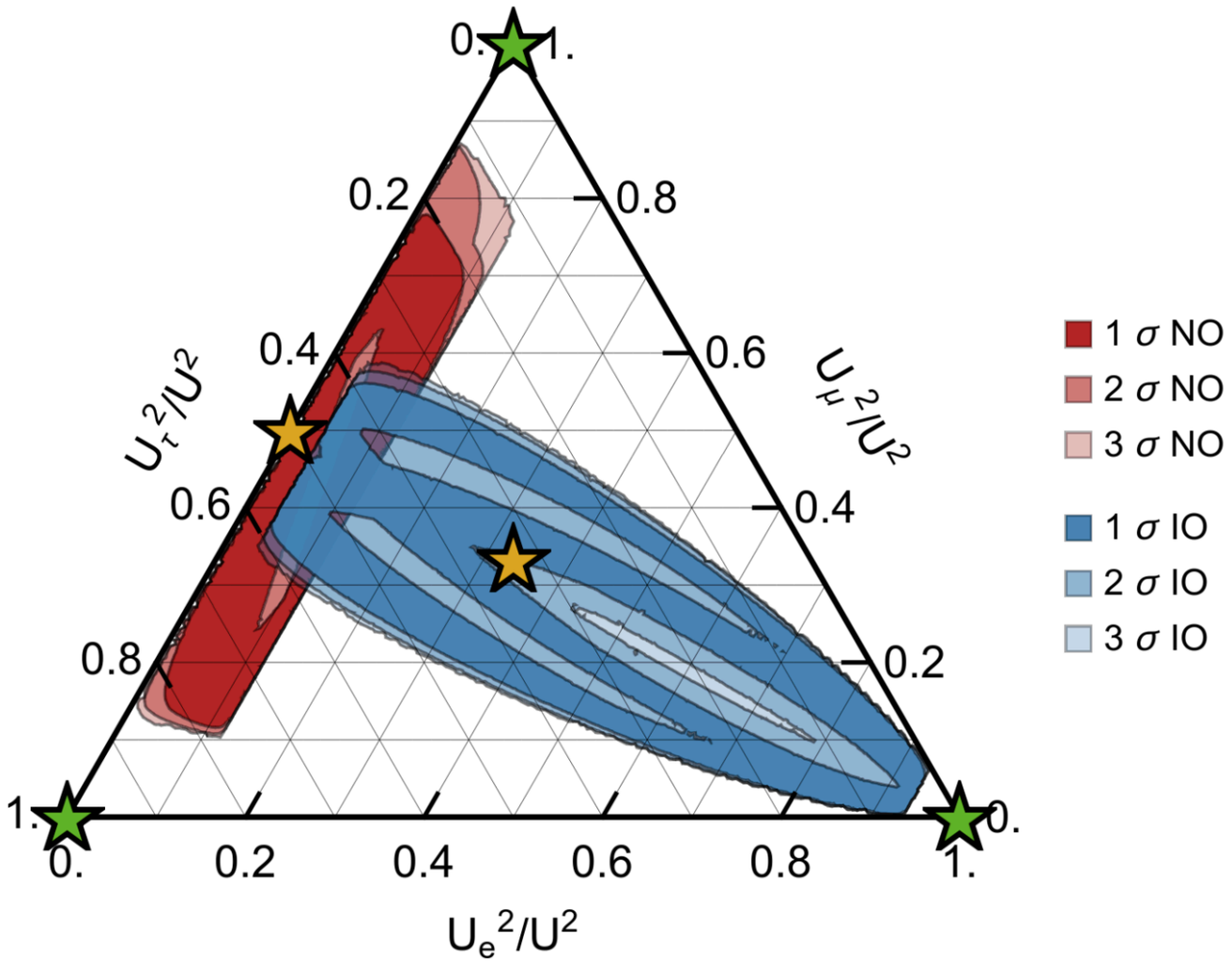

Alternative 1. New benchmarks matching flavor patterns for minimal models

— Drewes et al [2207.02742] —

What do we learn from these analyses?

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Alternative 2.
recast

Dileptons

Trileptons

Displaced Vertices

What do we learn from these analyses?

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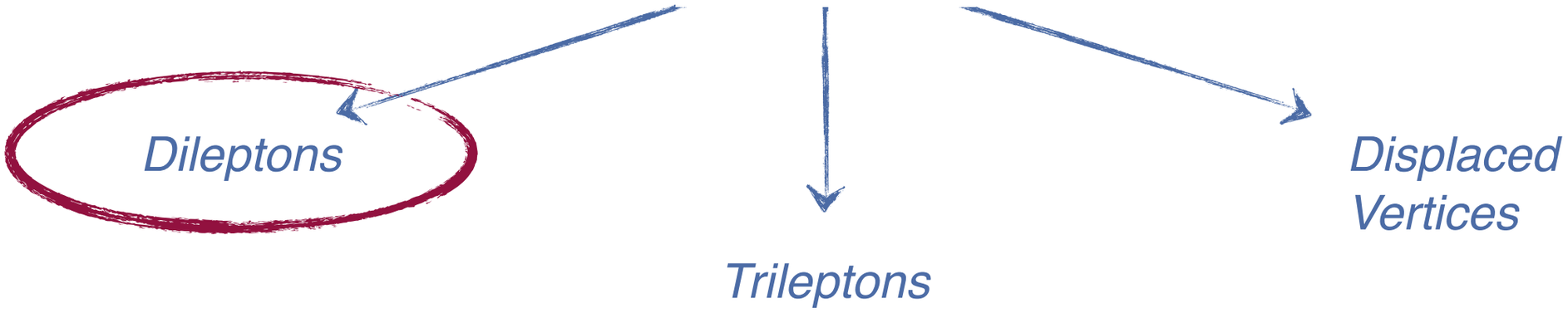
recast



Single Flavor Dominance

- *Setting bounds on, e.g.* $pp \to \mu\mu jj$

$$\sigma(pp \to \mu N) \times \mathrm{BR}(N \to \mu jj)$$

$$\downarrow$$

$$|U_{\mu N}|^2 \, \mathrm{BR}(N \to \mu jj)$$

$$\downarrow$$

$$|U_{\mu N}|^2$$

Single Flavor Dominance

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hep-ex →

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Mixing to a single flavor ←

hep-ph →

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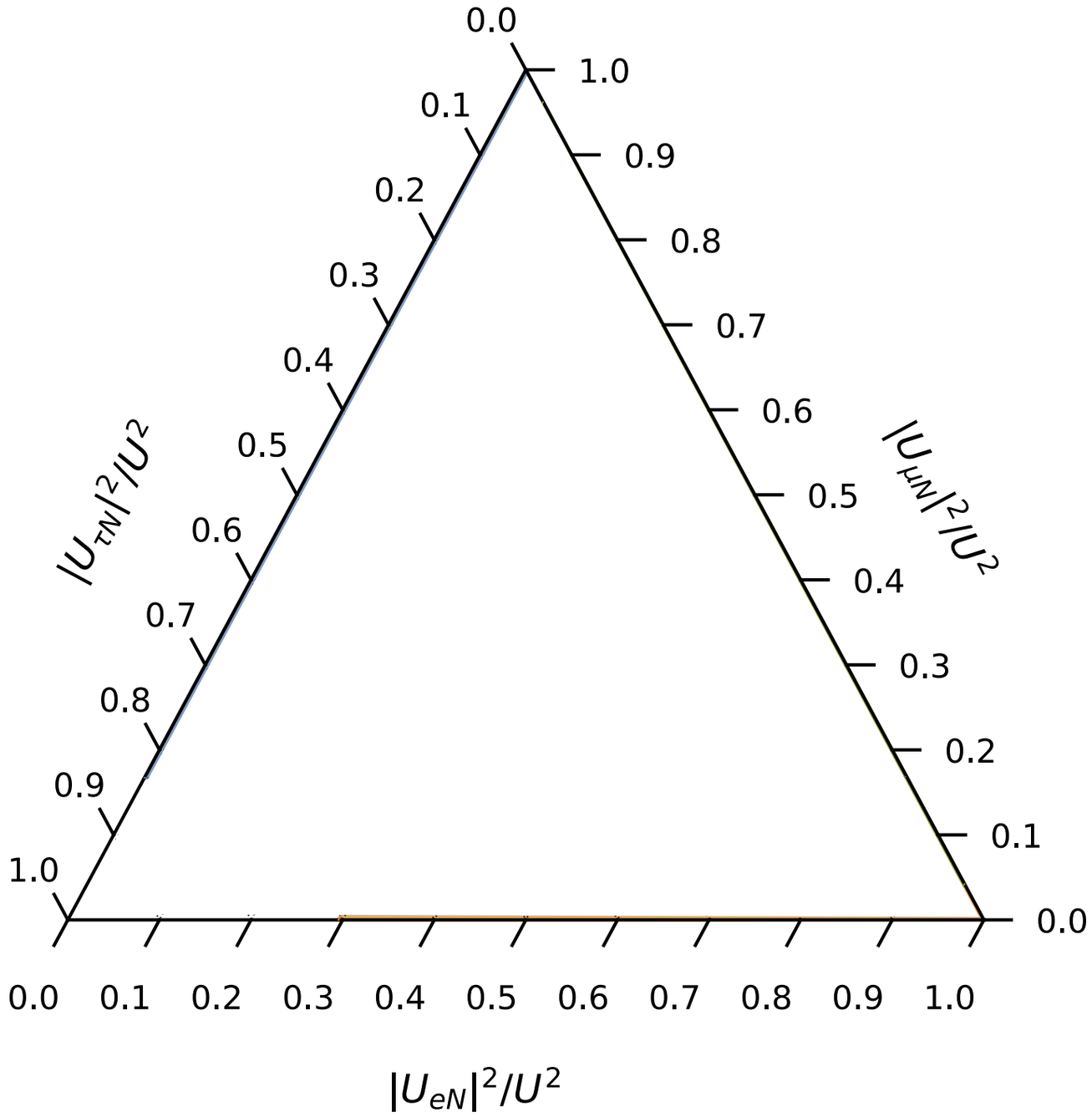
Recast — dileptons

— Abada, Escribano, XM, Piazza [2208.13882]—

For a fixed mass and U^2

$M_N = 30$ GeV, $U^2 = 10^{-3}$

- $\mu^\pm\mu^\pm$, CMS '18
- $e^\pm e^\pm$, CMS '18
- $e^\pm\mu^\pm$, CMS '18



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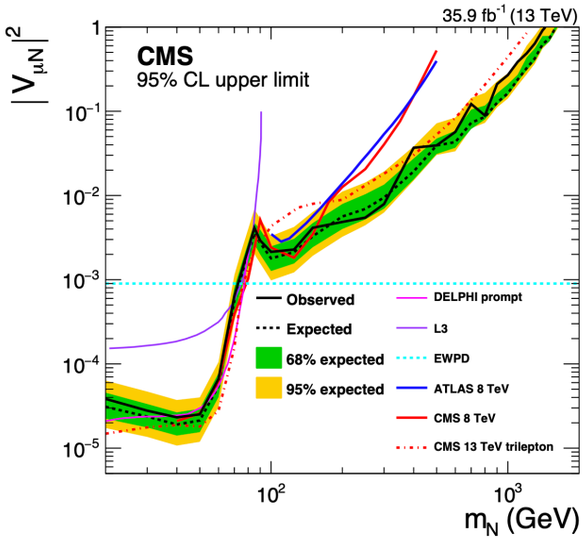

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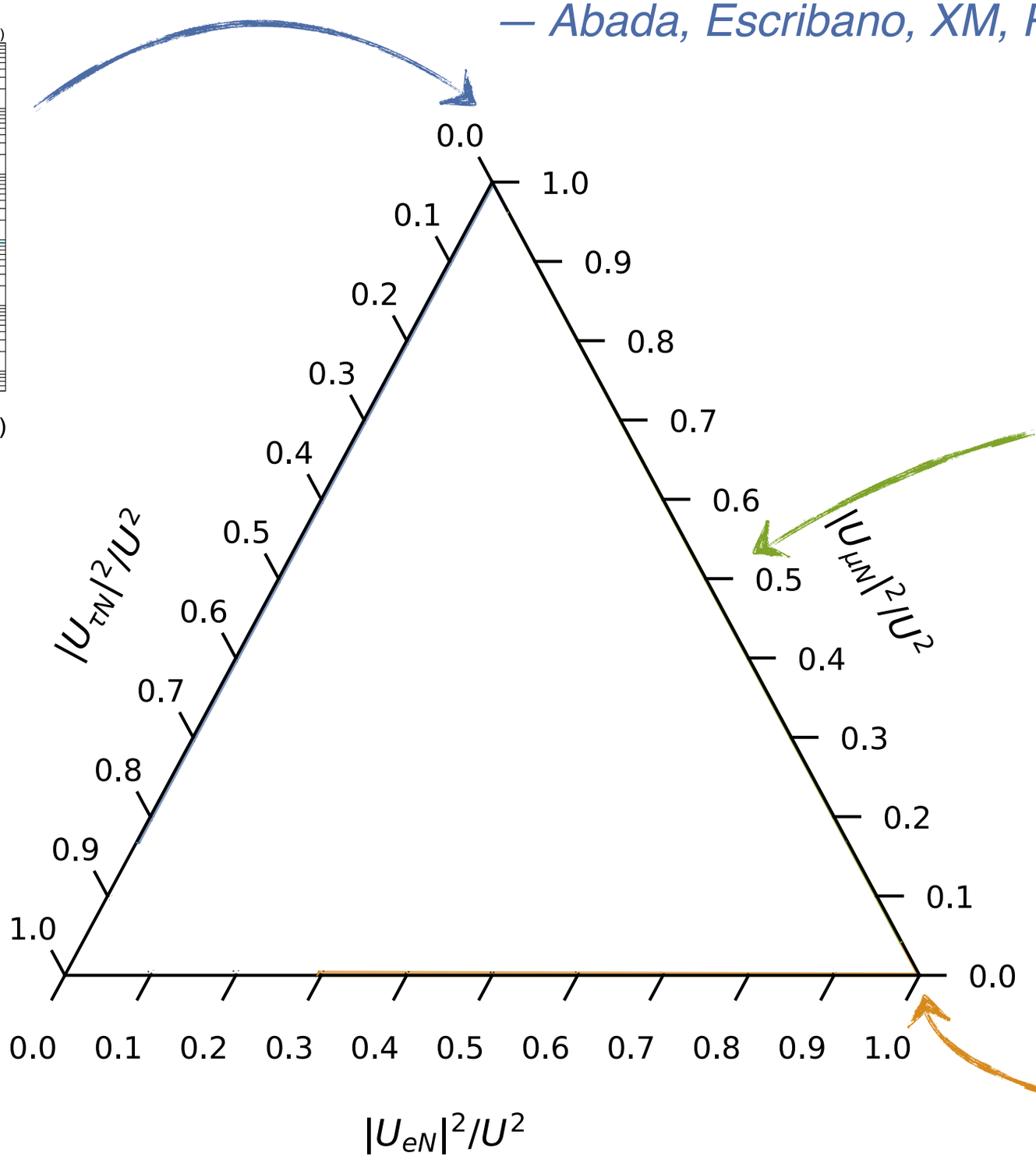

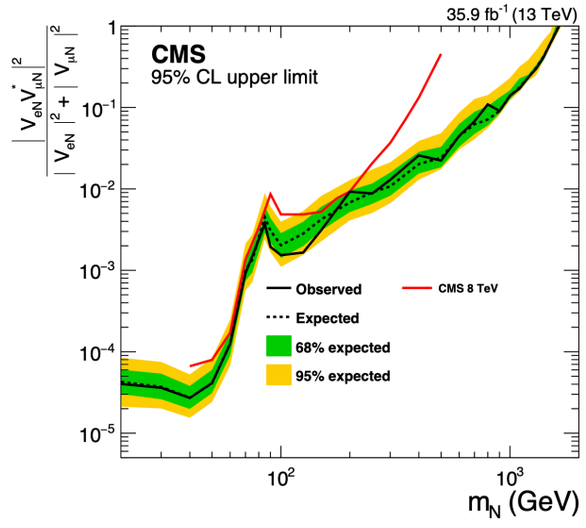

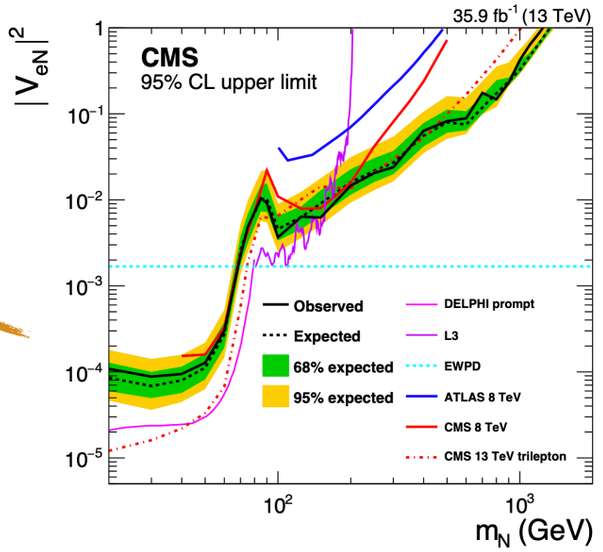

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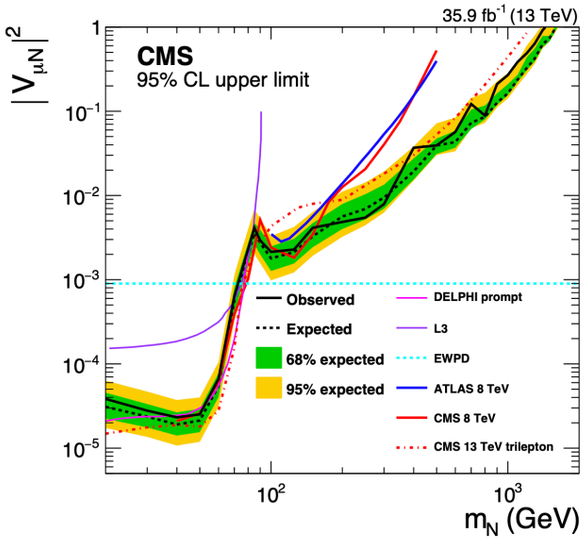

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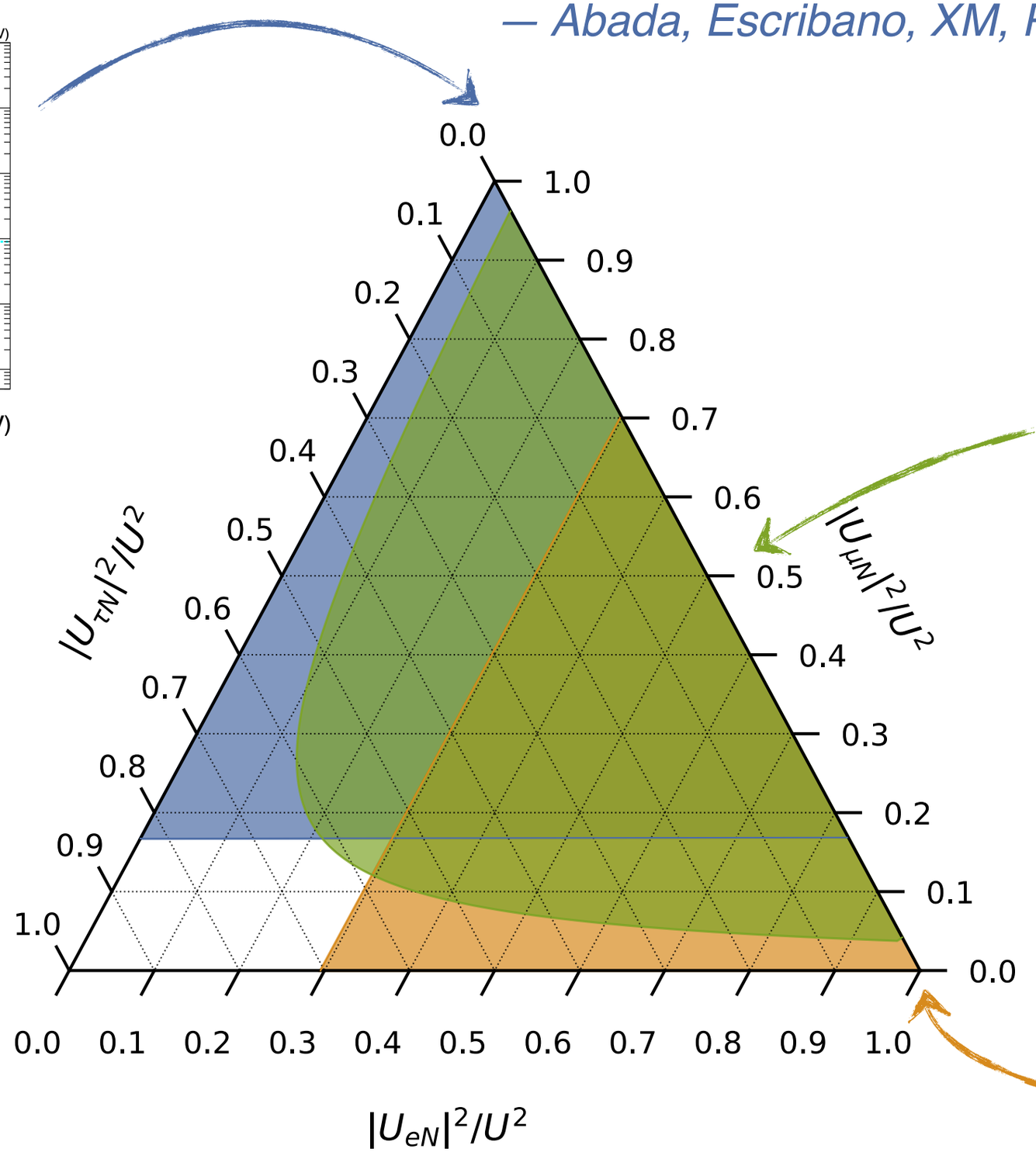

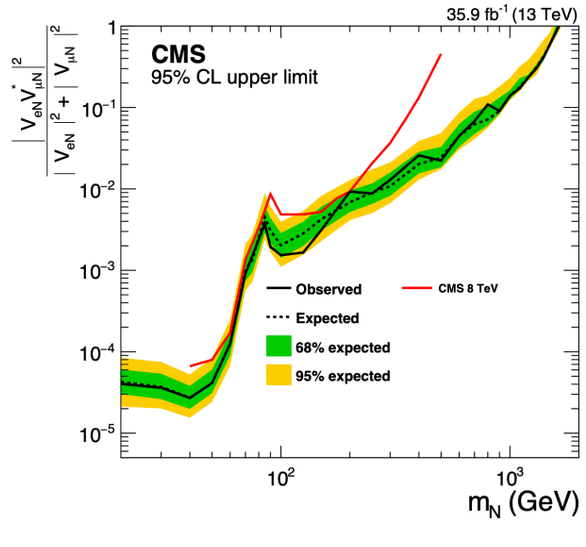

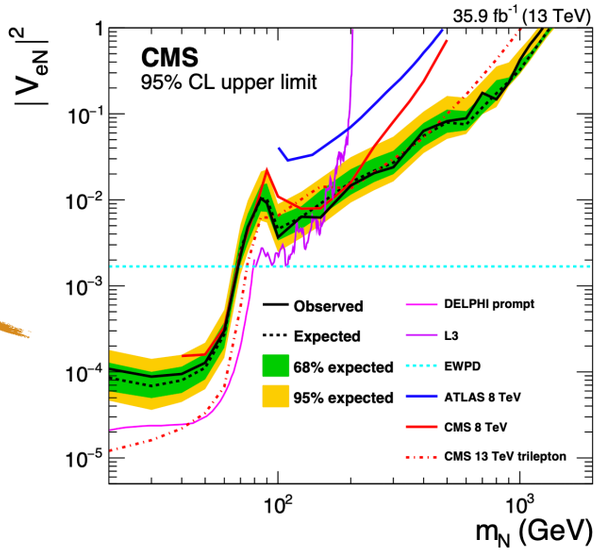

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Alternative 2.
recast

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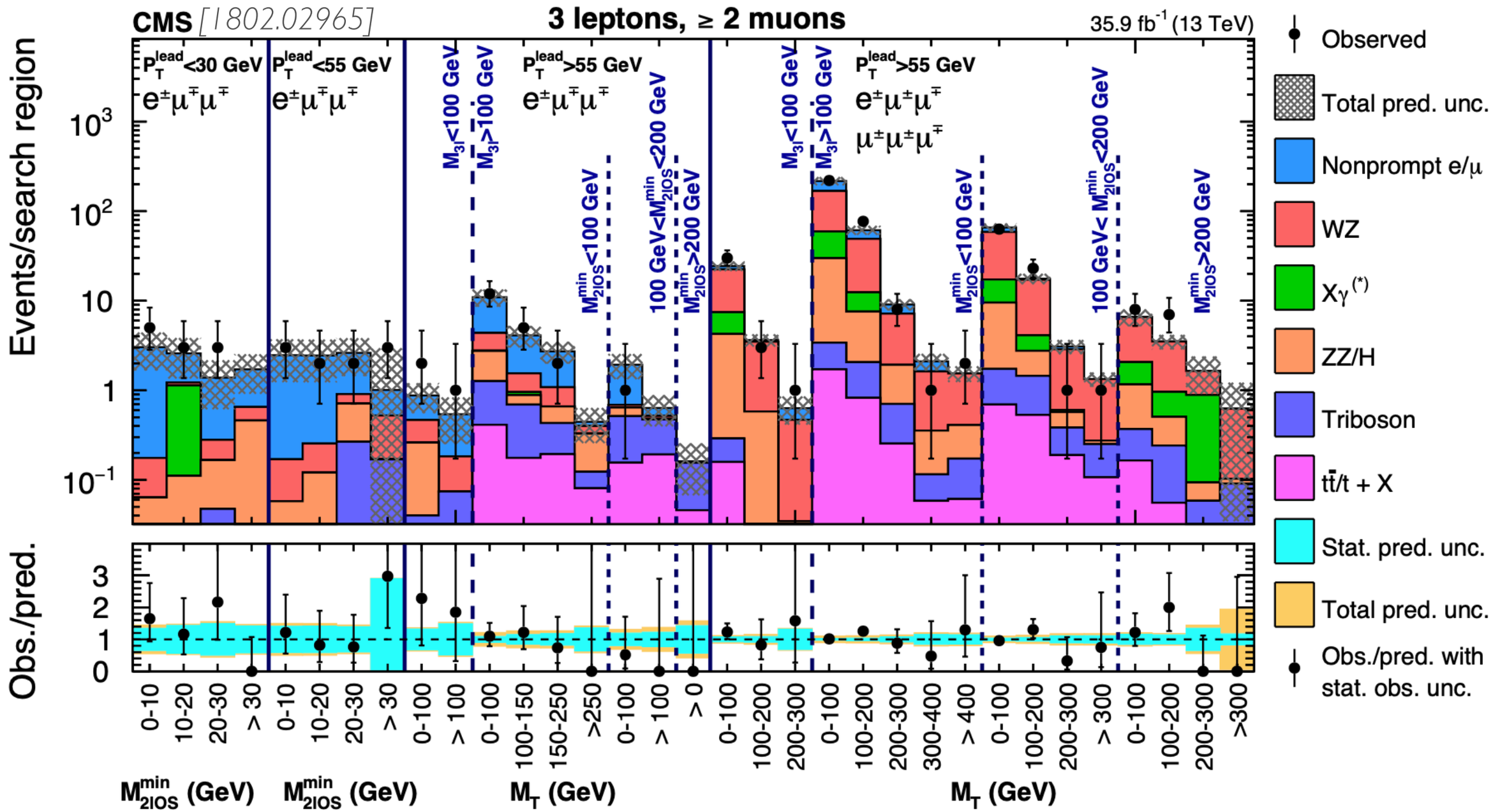
Trileptons

Displaced Vertices

$$|U_{\alpha N}|^2 \, \mathrm{BR}(N \to \ell_\beta jj)$$

Recast — Trileptons



Recast — Trileptons

- *Setting bounds on, e.g.* $pp \to \mu\mu e\nu \oplus \mu\mu\mu\nu$

$$\sigma(pp \to \mu N) \times \mathrm{BR}(N \to \mu e\nu) \;\oplus\; \sigma(pp \to \mu N) \times \mathrm{BR}(N \to \mu\mu\nu)$$

$$|U_{\mu N}|^2 \mathrm{BR}(N \to \mu e\nu) \;\oplus\; |U_{\mu N}|^2 \mathrm{BR}(N \to \mu\mu\nu)$$

$$|U_{\mu N}|^2$$

— *see also Tastet et al [2107.12980] —

Recast — Trileptons

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*Mixing to a single flavor**

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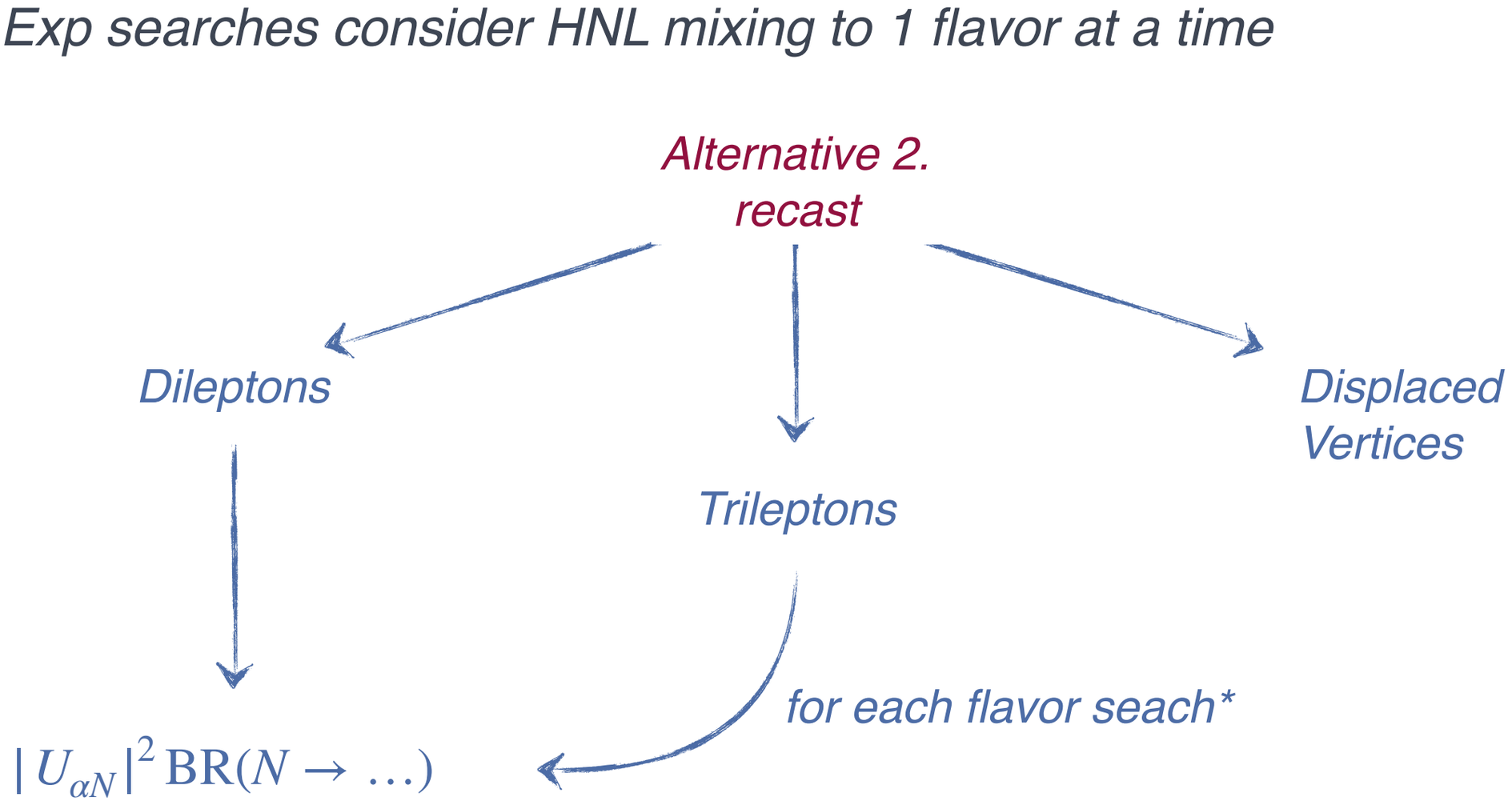

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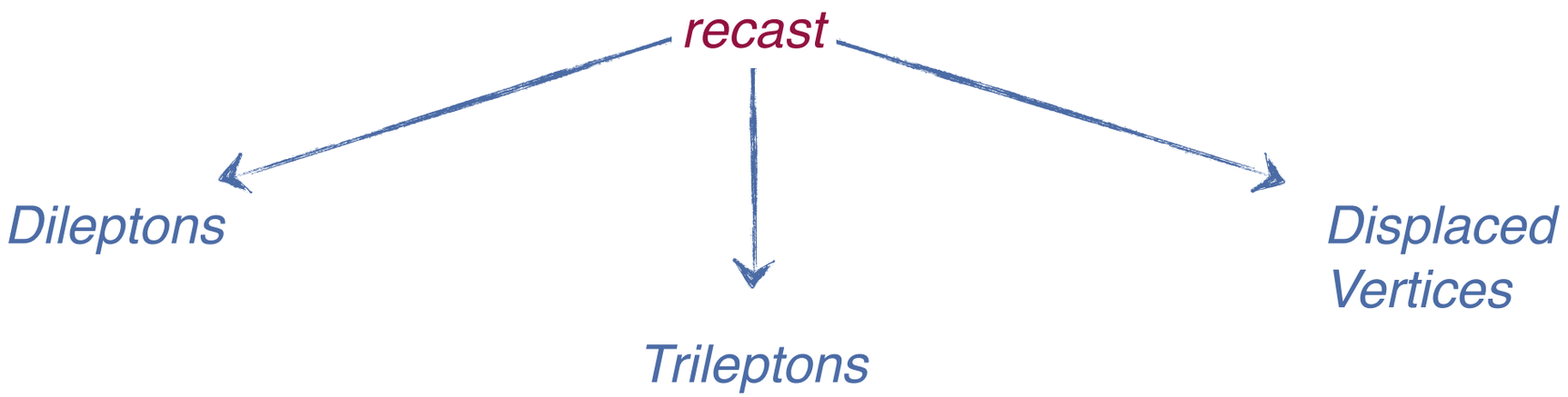

- *LHC is sensitive to very large mixings*

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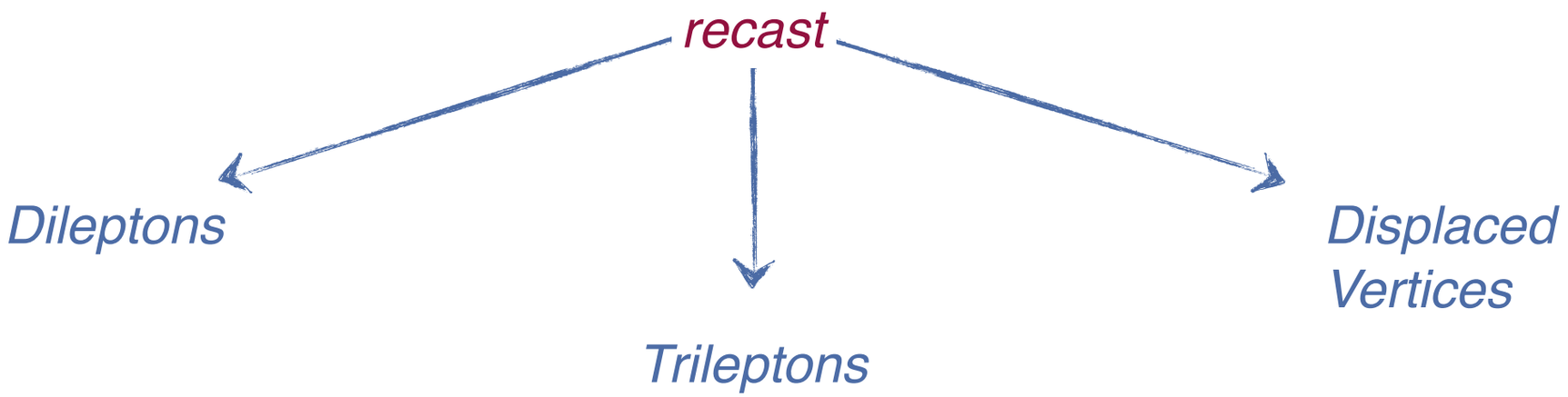


- *LHC is sensitive to very large mixings*

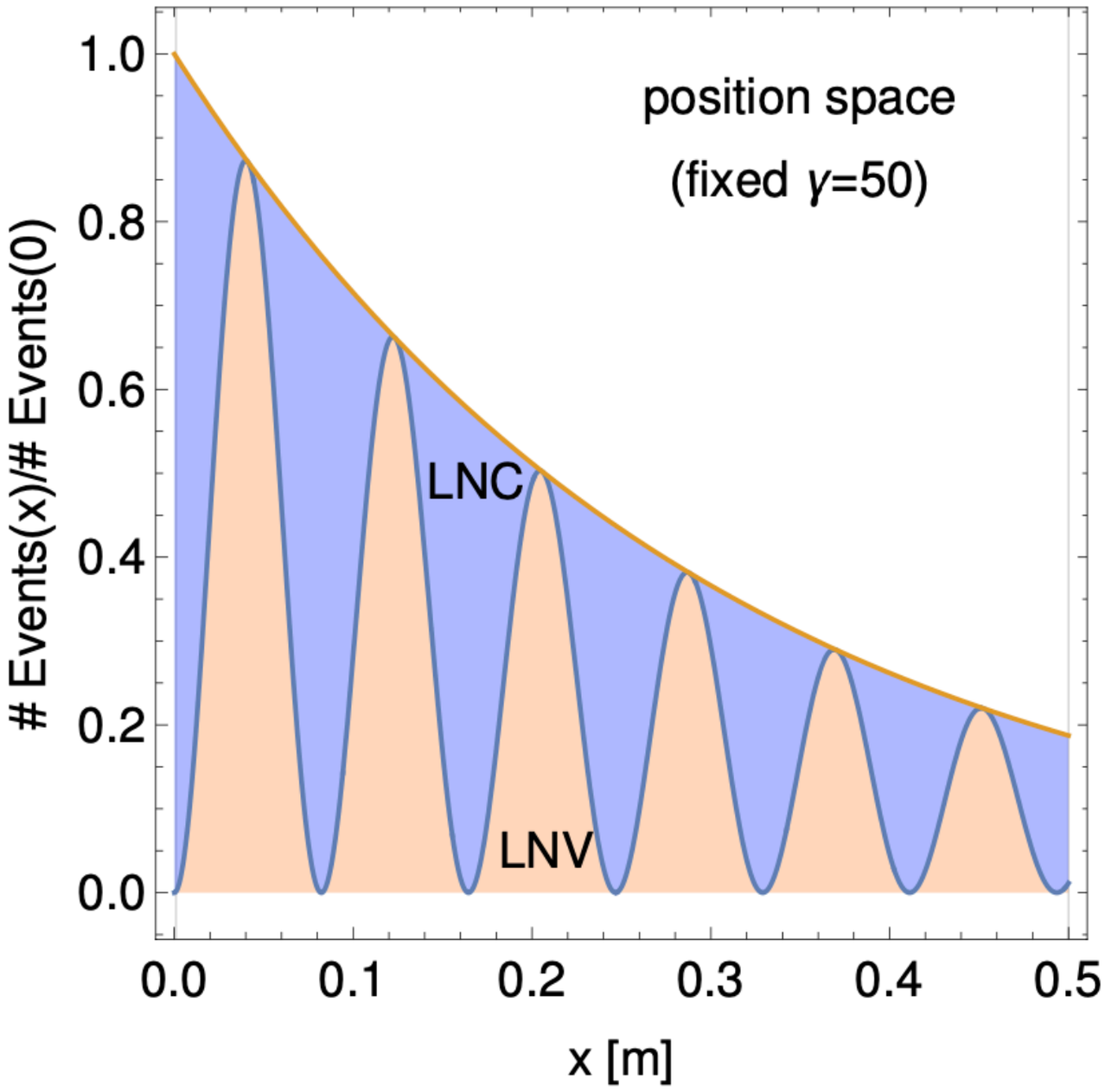
Calls for Symmetry Protected Low-Scale Seesaws ⟶ *LNV @ LHC???*

— talk by Stefan Antusch —

LNV in Symmetry Protected Scenarios

- *Potential oscillations between HNLs*

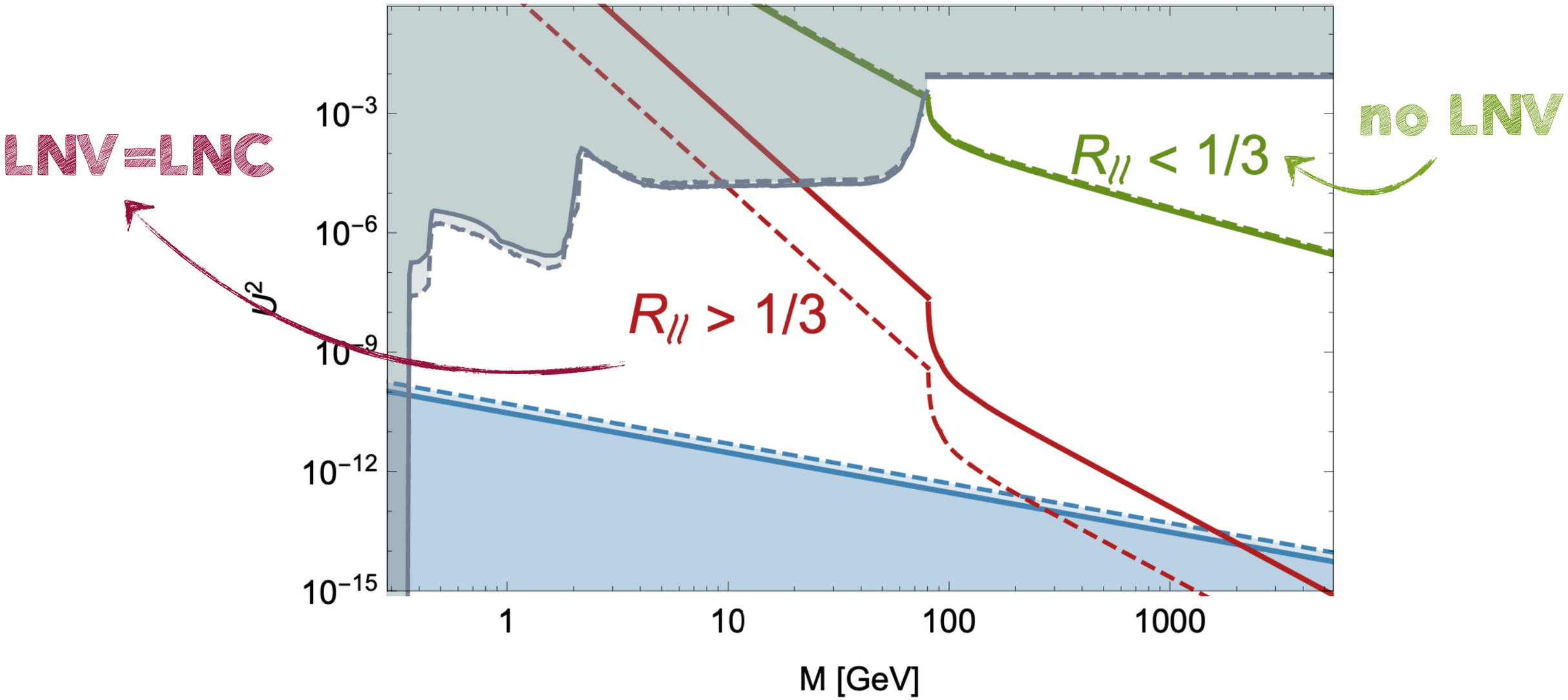
— Antusch et al [1709.03797] —



LNV in Symmetry Protected Scenarios

- *Connected to active neutrino masses*

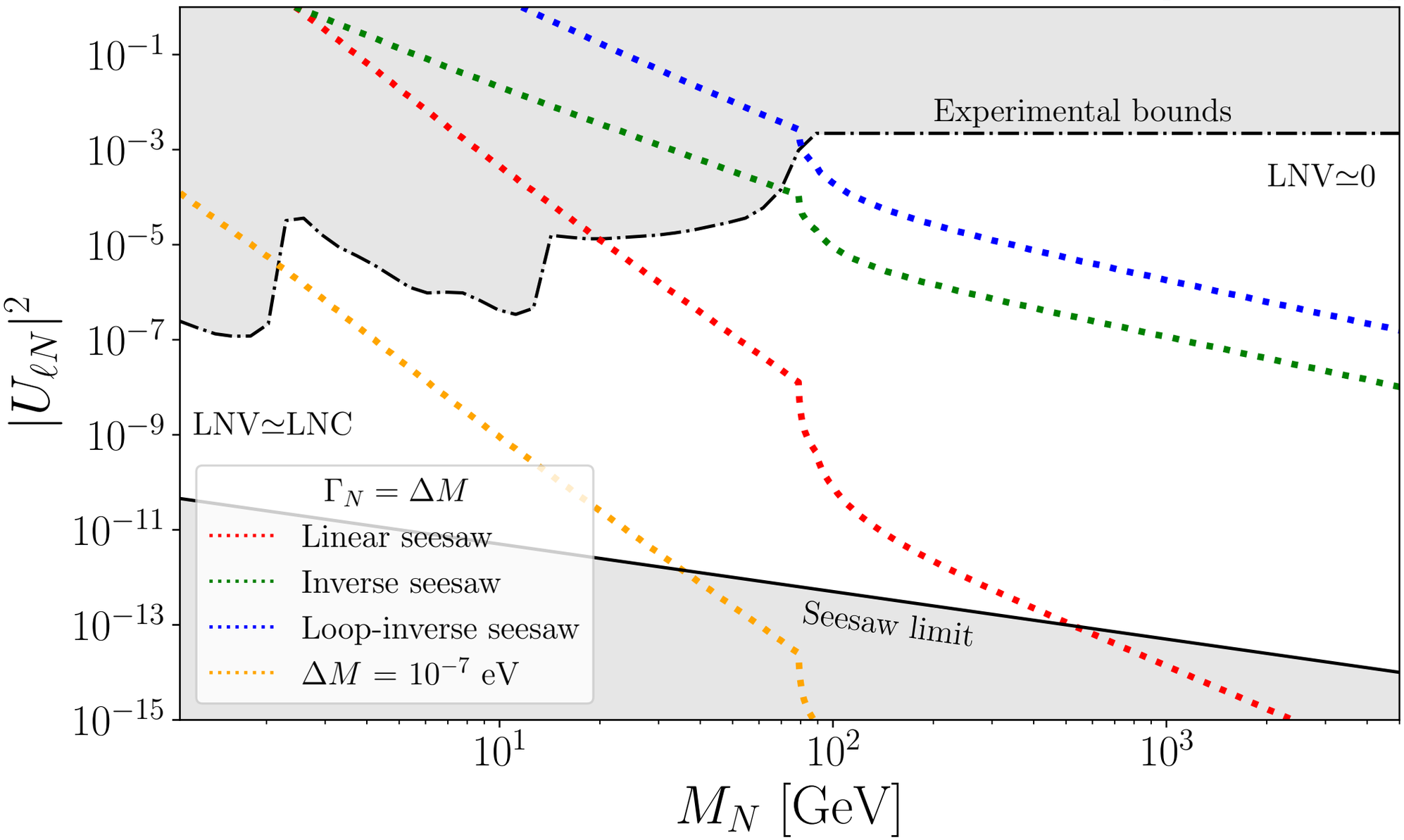
— Drewes et al [1907.13034] —



LNV in Symmetry Protected Scenarios

- *Discriminate between low-scale seesaws*

Fernández-Martínez, XM, Naredo-Tuero [2209.04461]



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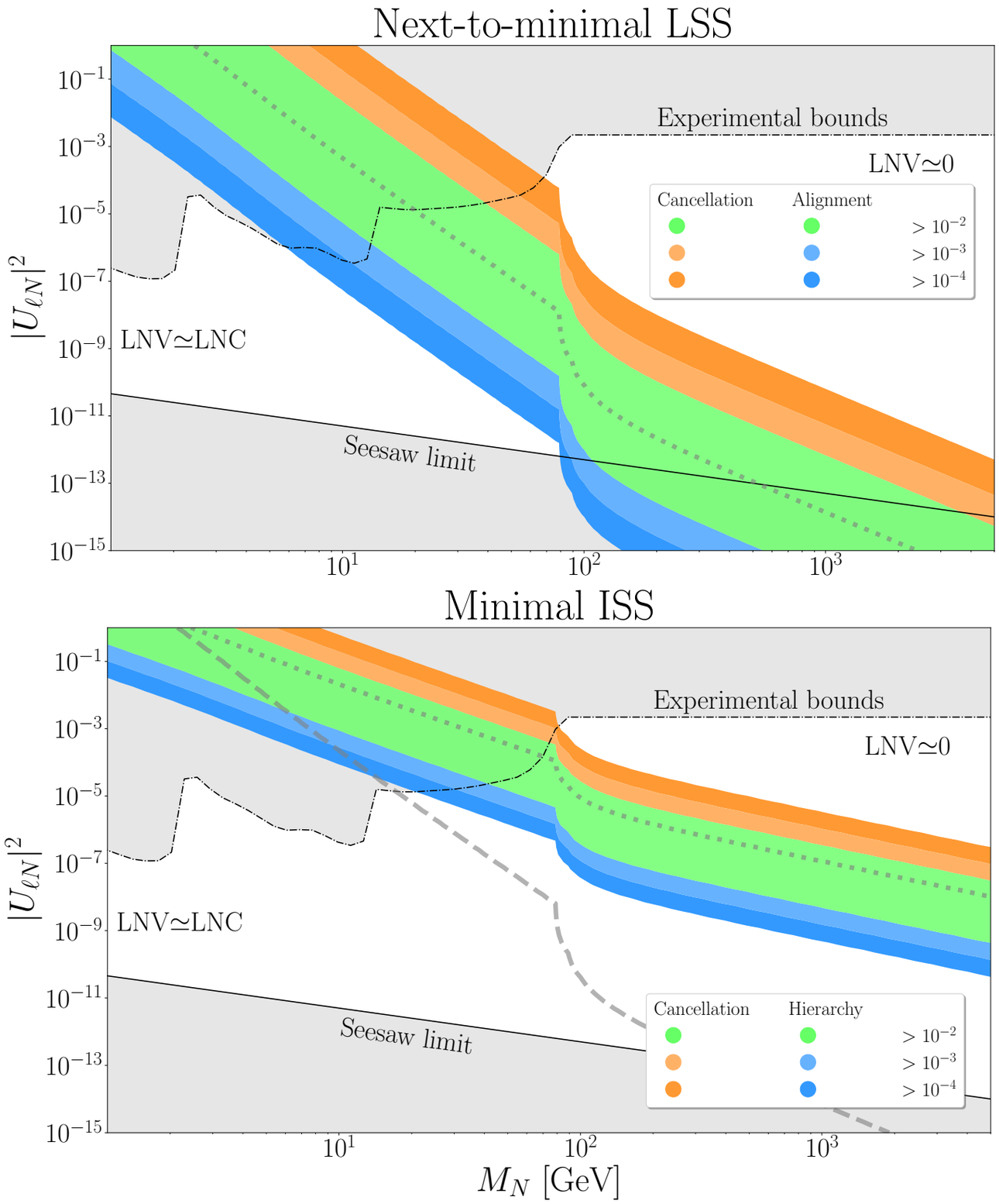

Summary

- *Colliders are good places to search for HNLs*

  — LEP, LHC and more to come —

- *LHC is already improving LEP*

- *Analyses are improving*

  — trileptons, DV, OS dileptons —

- *Still things to be improved*

  — going beyond single mixing hypothesis —

- *LNV signals still relevant for symmetry protected scenarios*

  — help discriminating low-scale seesaws —

Thank you!

Funded by the European Union's Horizon Europe Programme under the Marie Skłodowska-Curie grant agreement no. 101066105-PheNUmenal. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or the European Research Executive Agency (REA). Neither the European Union nor the granting authority can be held responsible for them.

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PheNUmenal

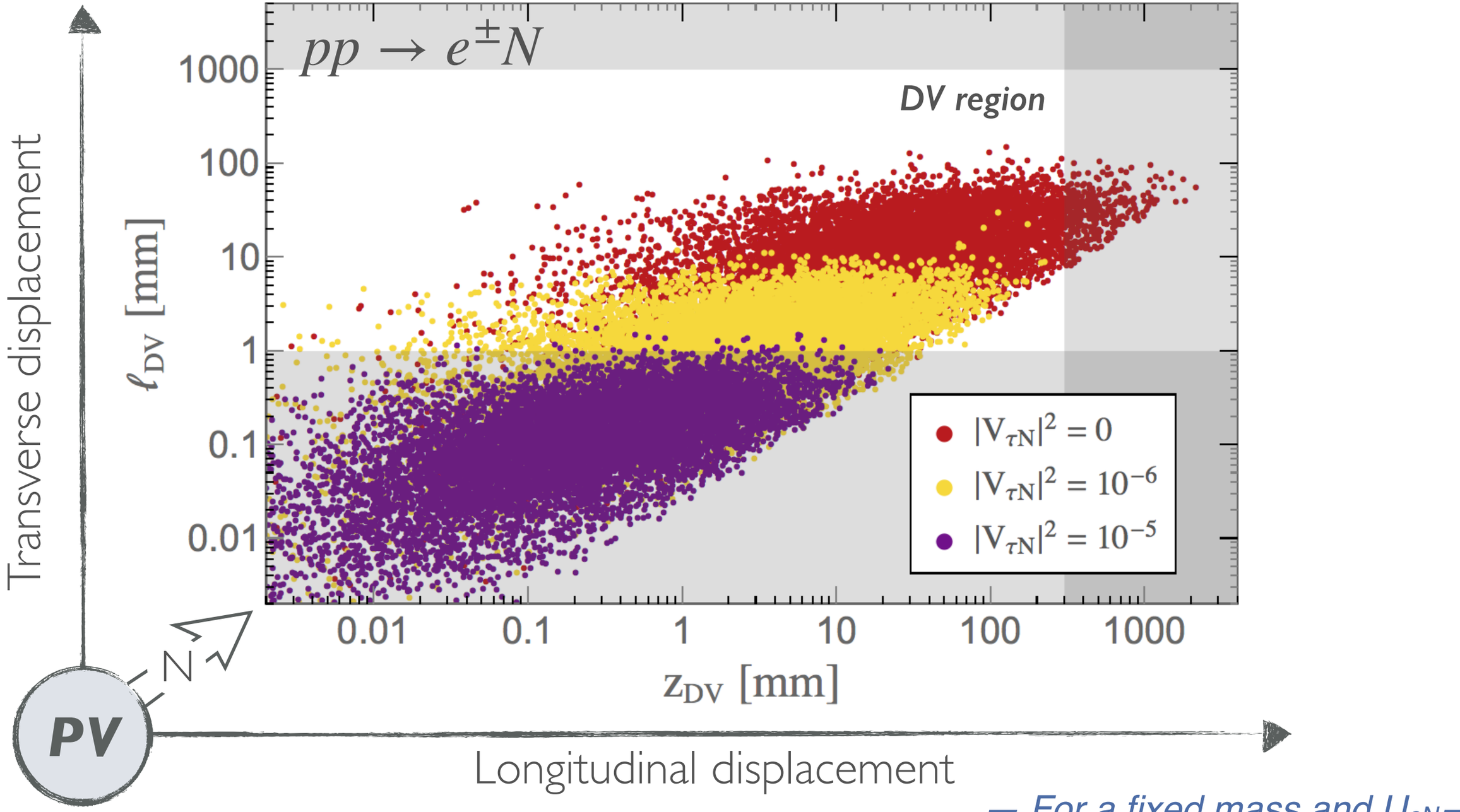
EXCELENCIA SEVERO OCHOA

Back up

Recast — Displaced Vertices

- *The efficiency is highly mixing-pattern dependent*

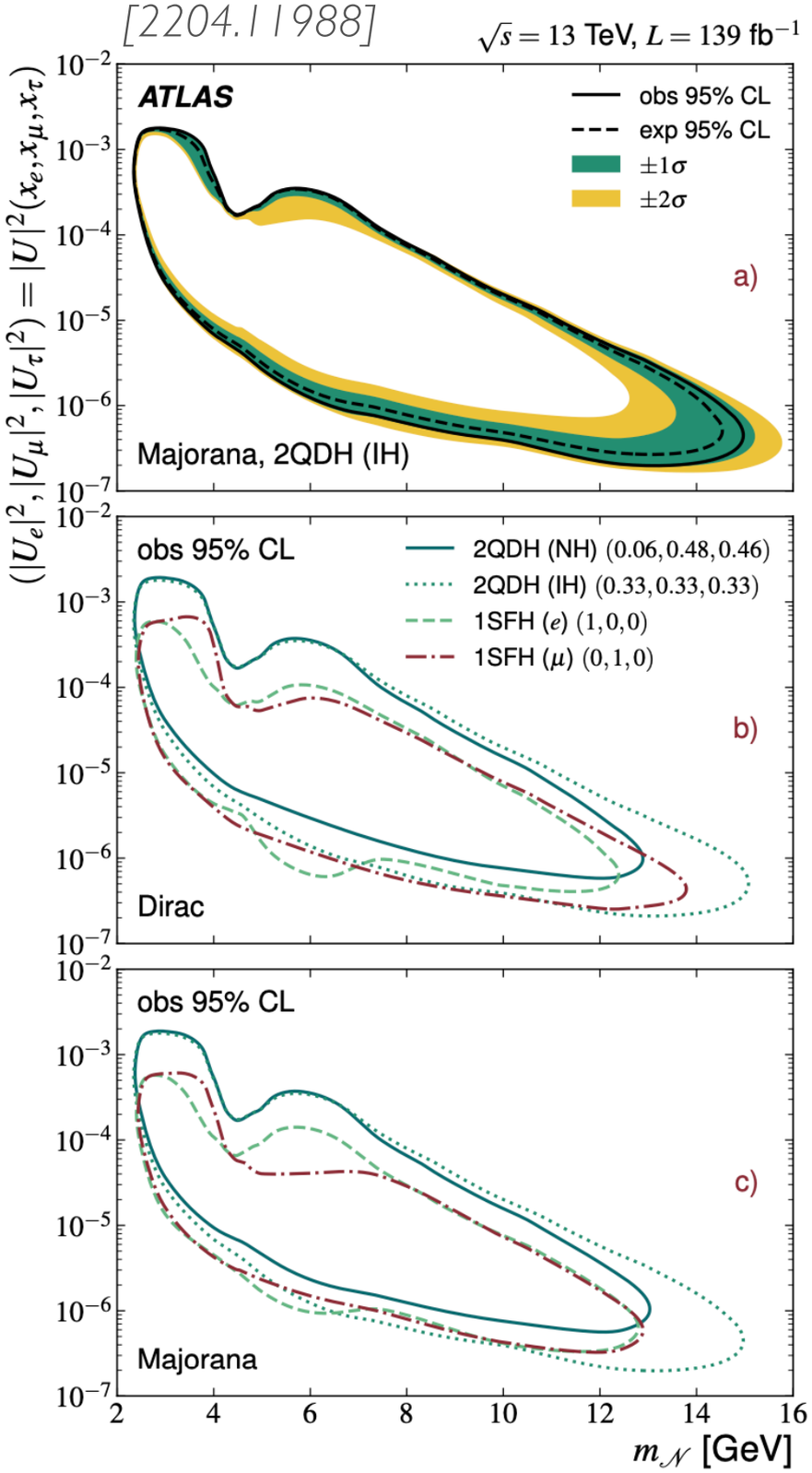
— Abada, Bernal, Losada, XM [1807.10024] —



— For a fixed mass and U_{eN} —

Single Mixing — DV

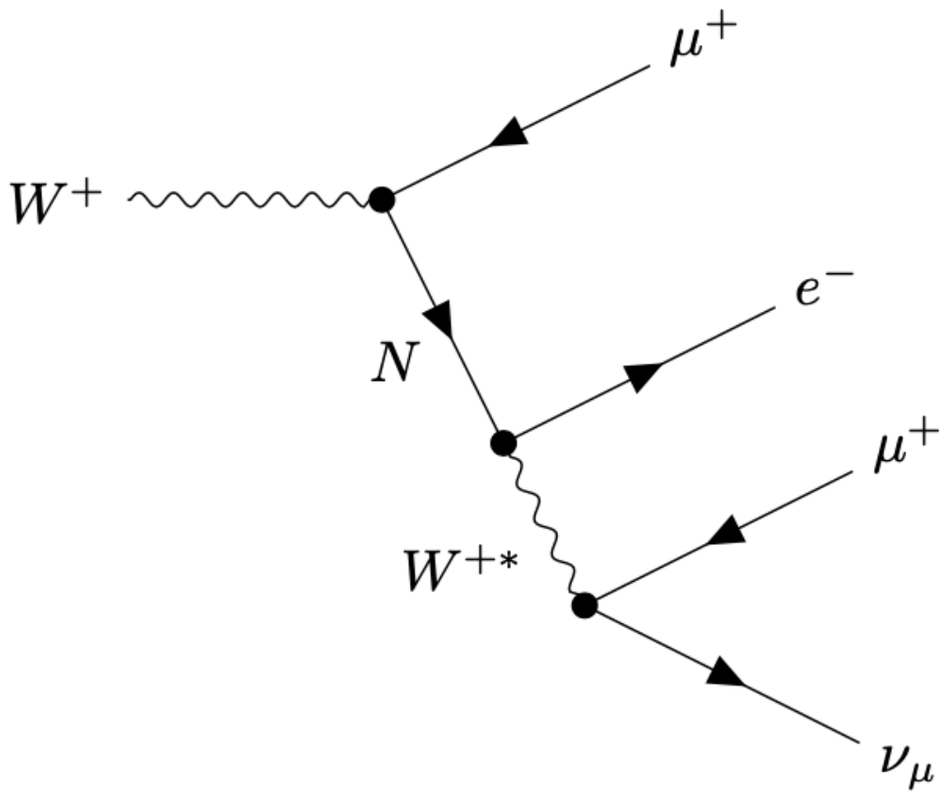
[2204.11988]



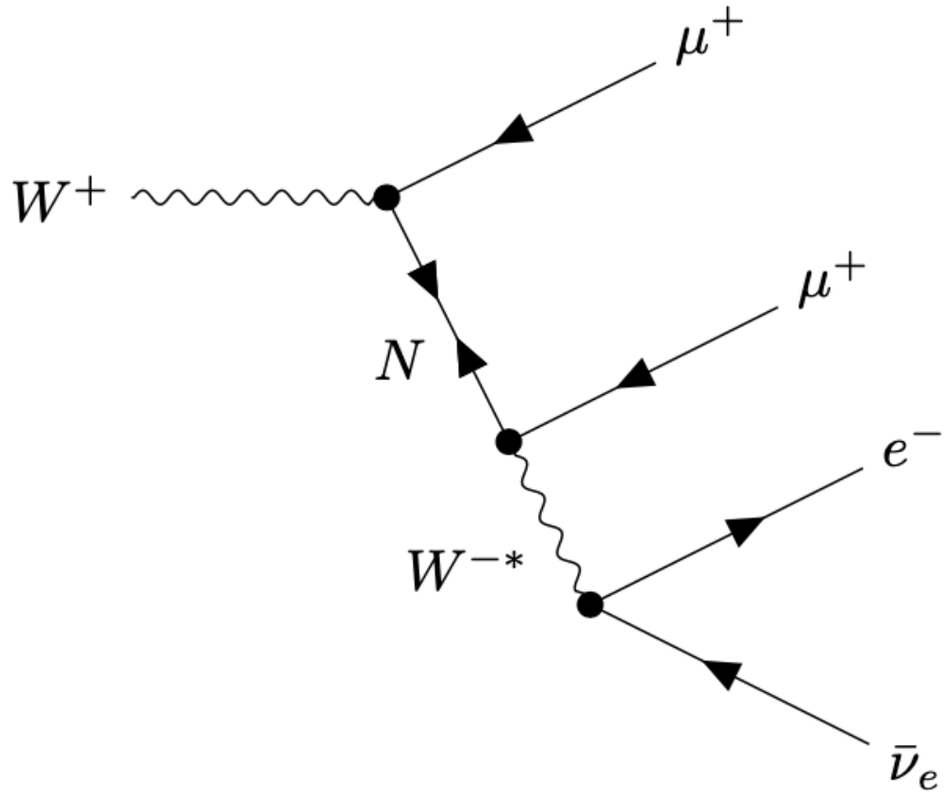
Recast — Trileptons

— *Tastet et al [2107.12980]* —

- *More mixings, more diagrams*



(a) LNC

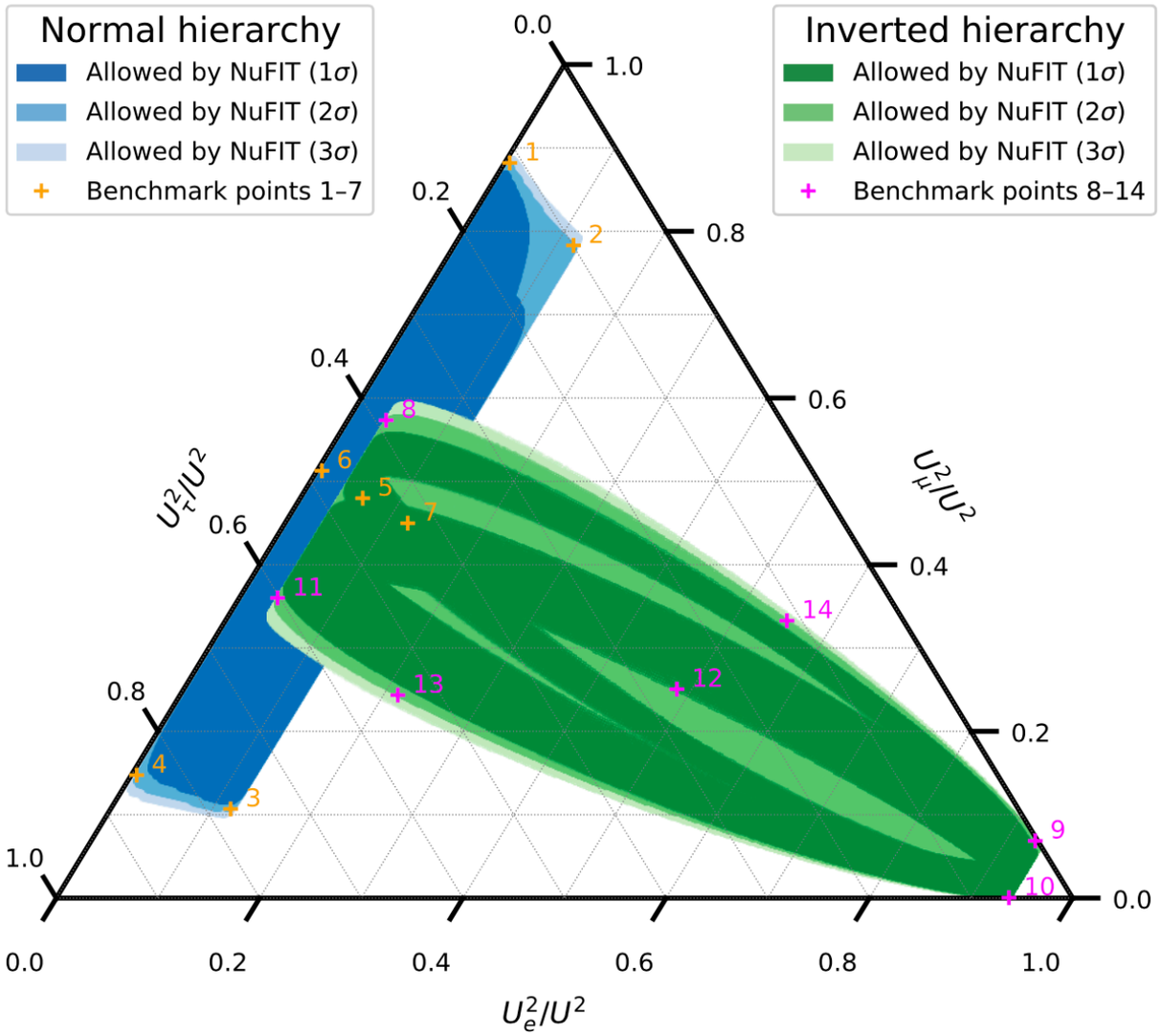


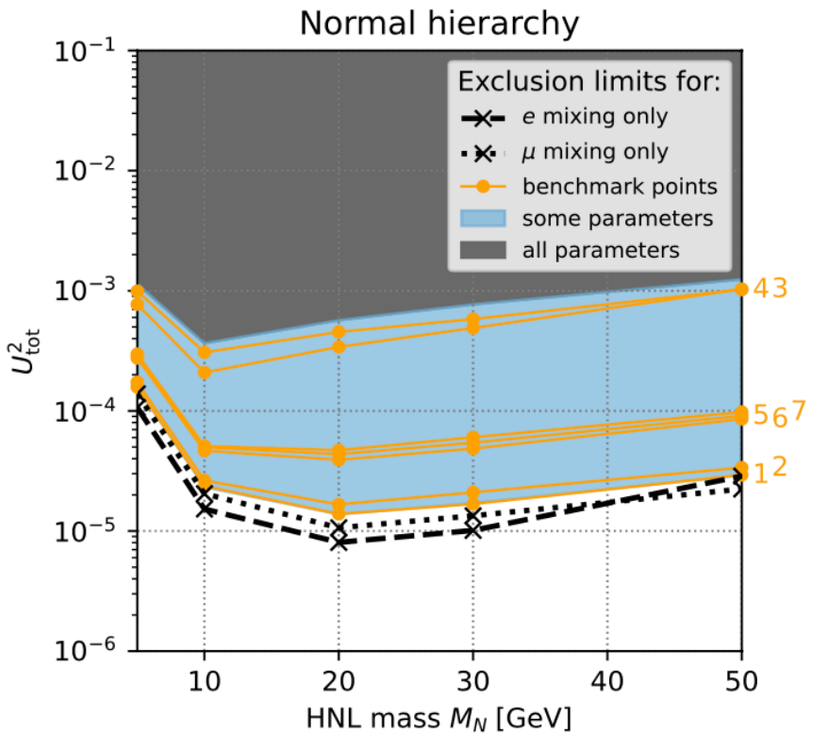
(b) LNV

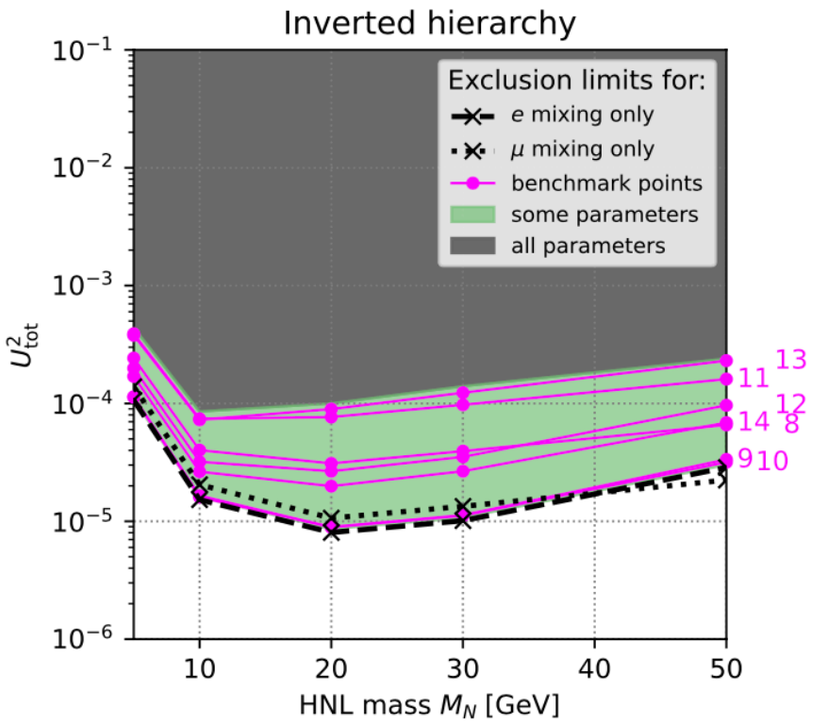
Recast — Tileptons

- *Simplest realistic framework*

— Tastet et al [2107.12980] —

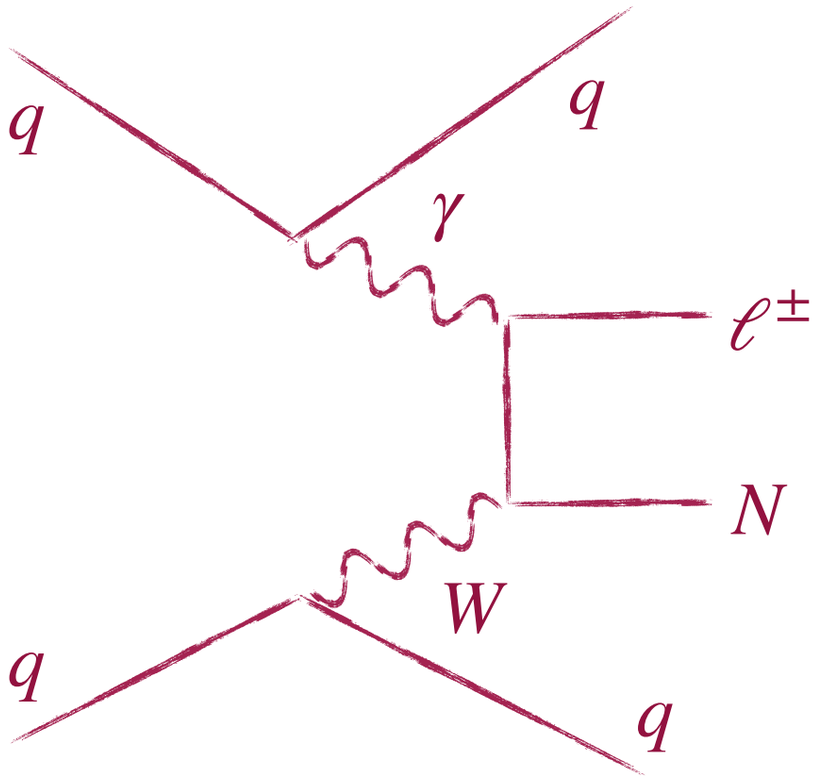




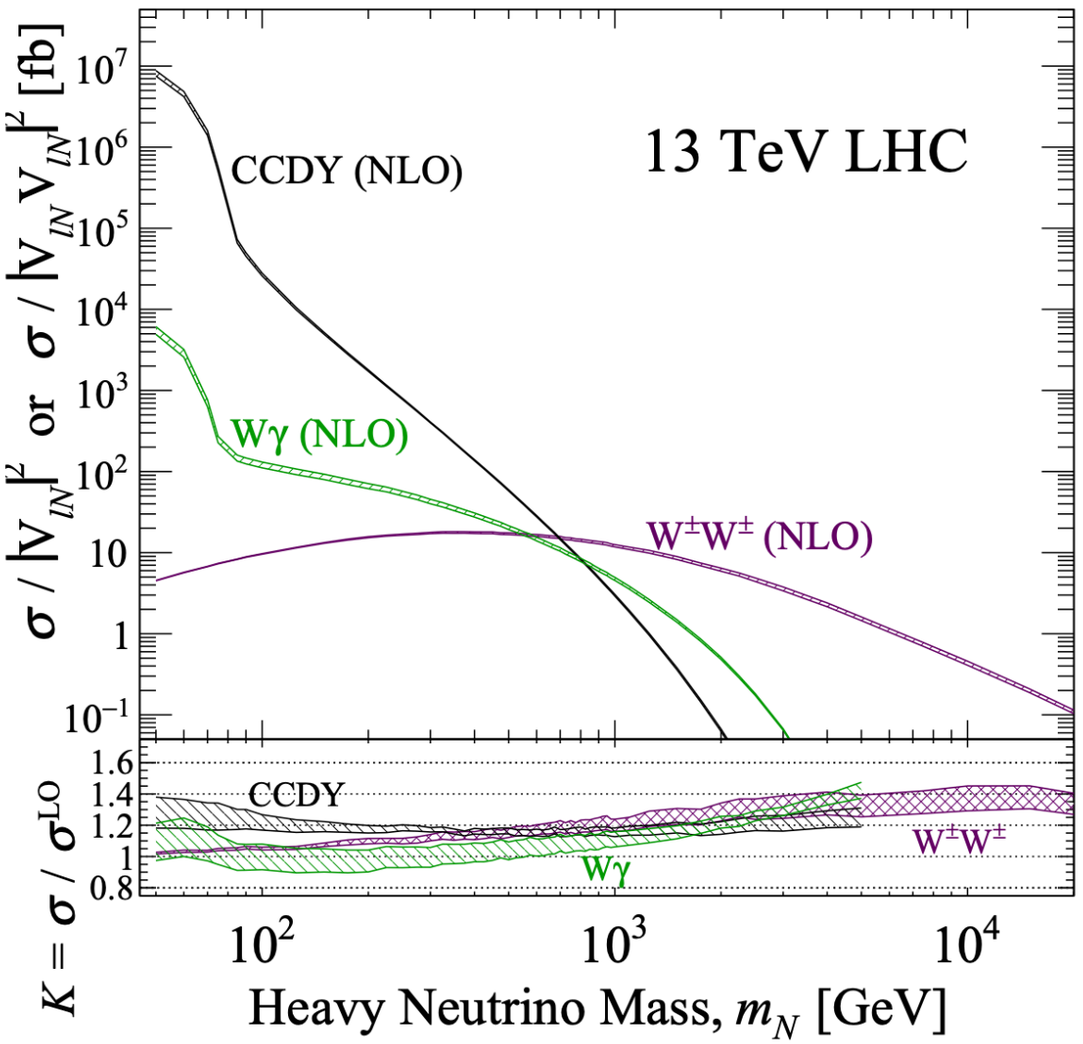


HNL Production

- *Dominant diagrams: Drell-Yan W and Z (and Higgs?)*
- *For higher masses, also Vector Boson Fusion*



Fuks et al. [2011.02547]

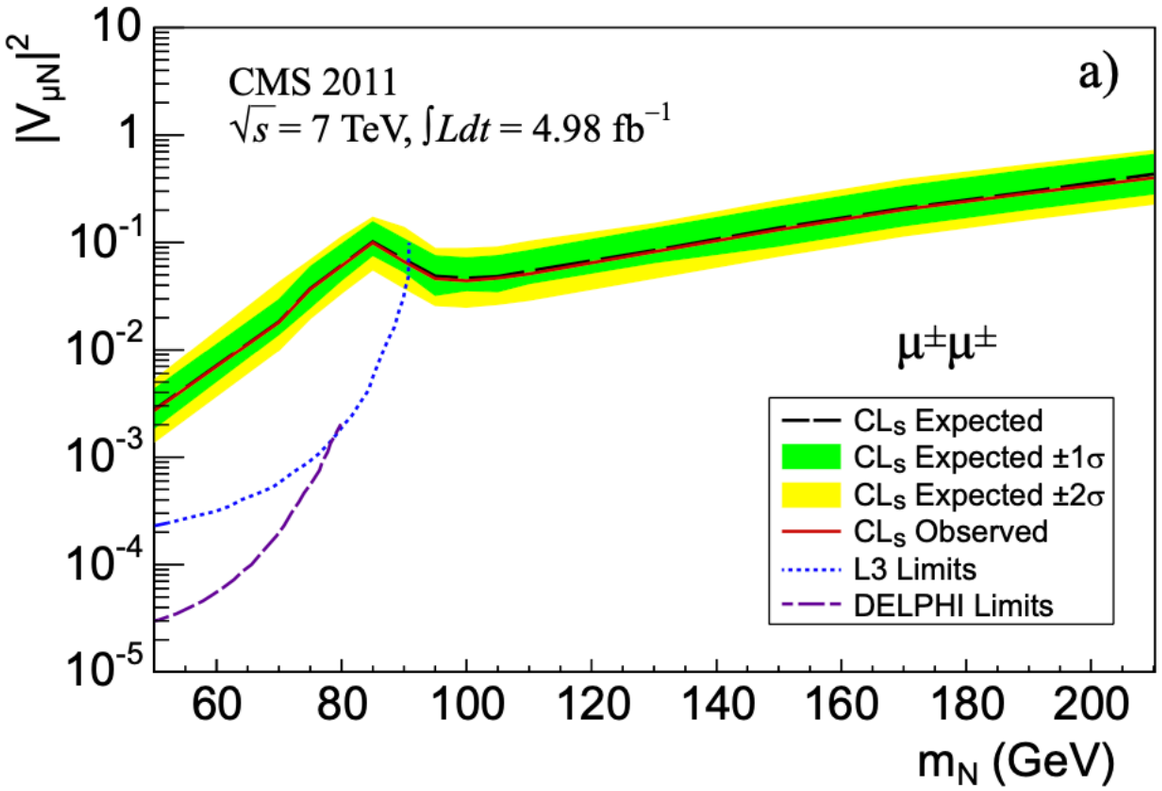


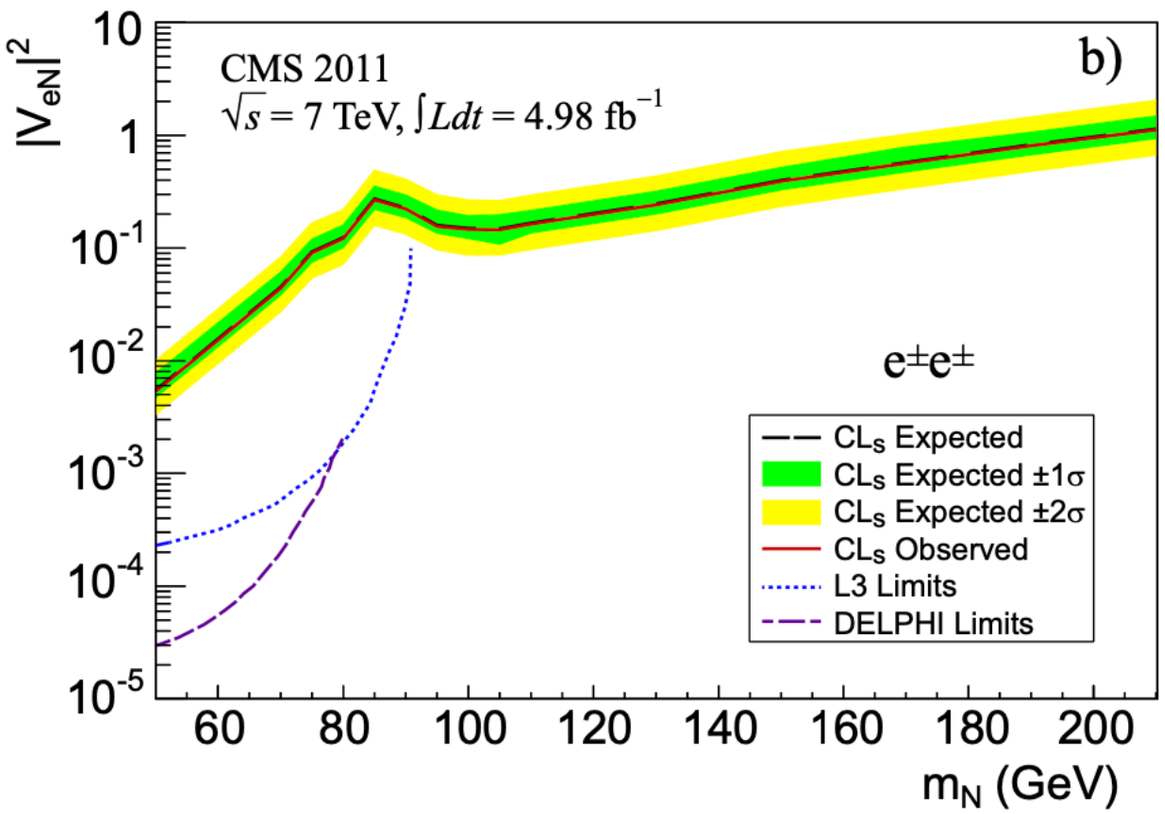
Di-leptons at LHC

- *Same sign dilepton channel* — *LNV signature*—

$$pp \to W^{(*)} \to \ell^{\pm} N \to \ell^{\pm}\ell^{\pm} + nj$$

[1207.6079]



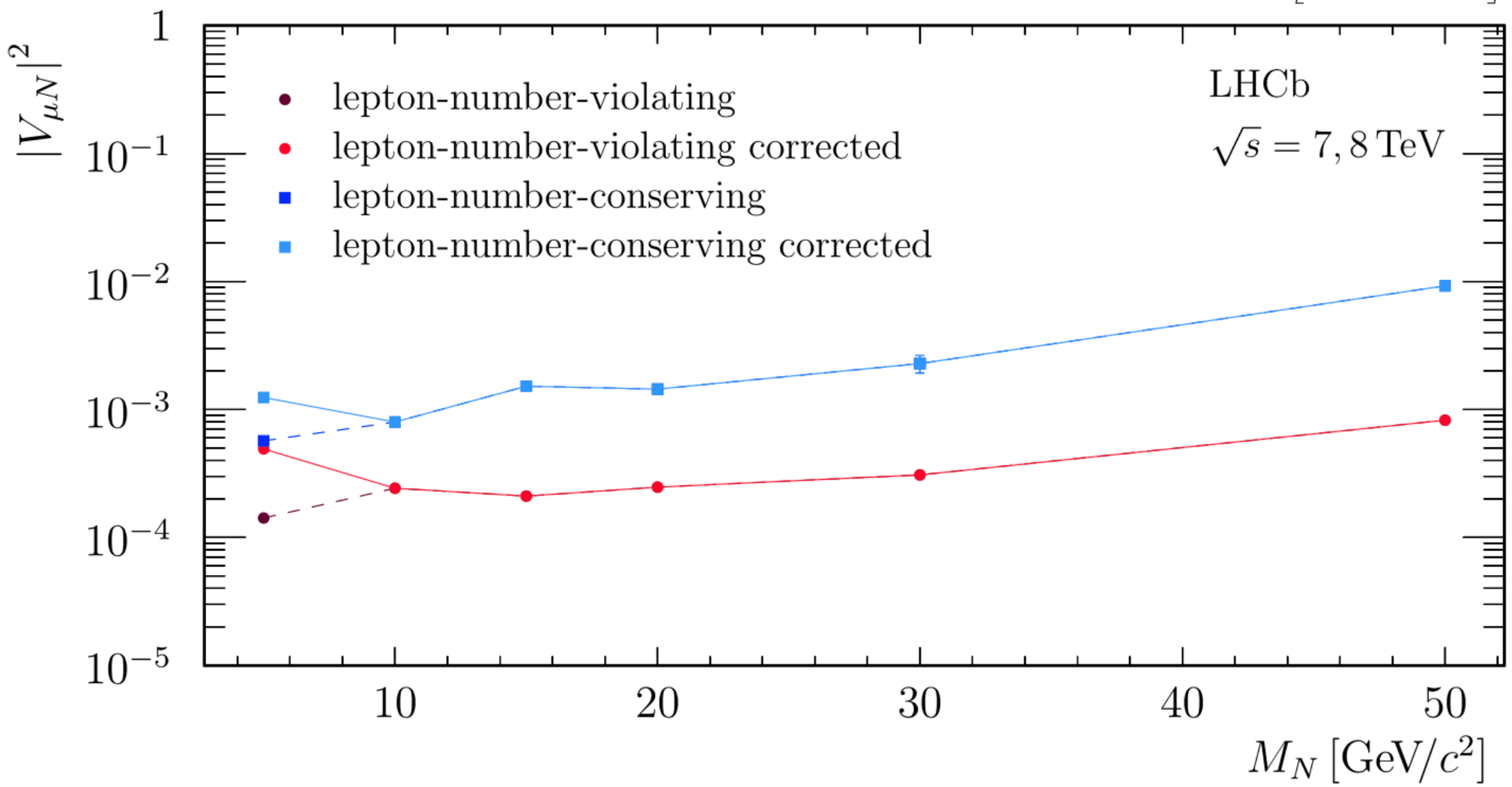


Di-leptons at LHC

- *LNC searches are also possible*

$$pp \to W^{(*)} \to \ell^{\pm} N \to \ell^{\pm}\ell^{\mp} + nj$$

[2011.05263]

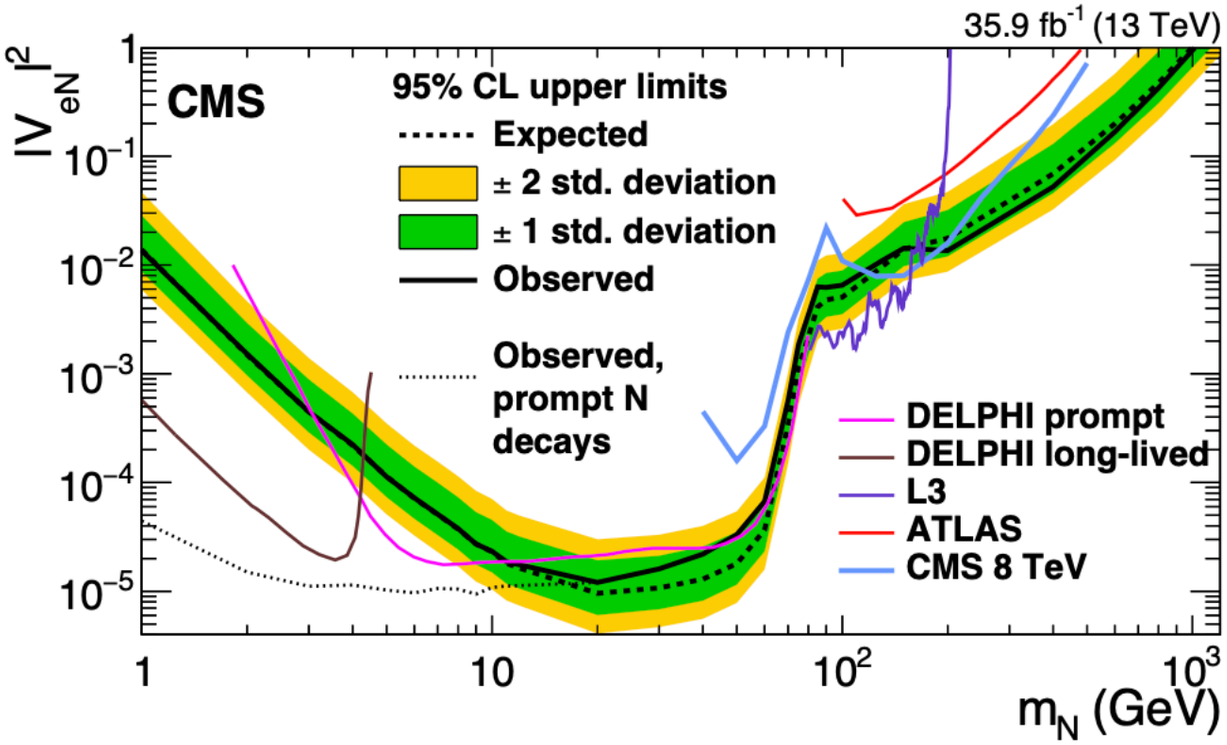


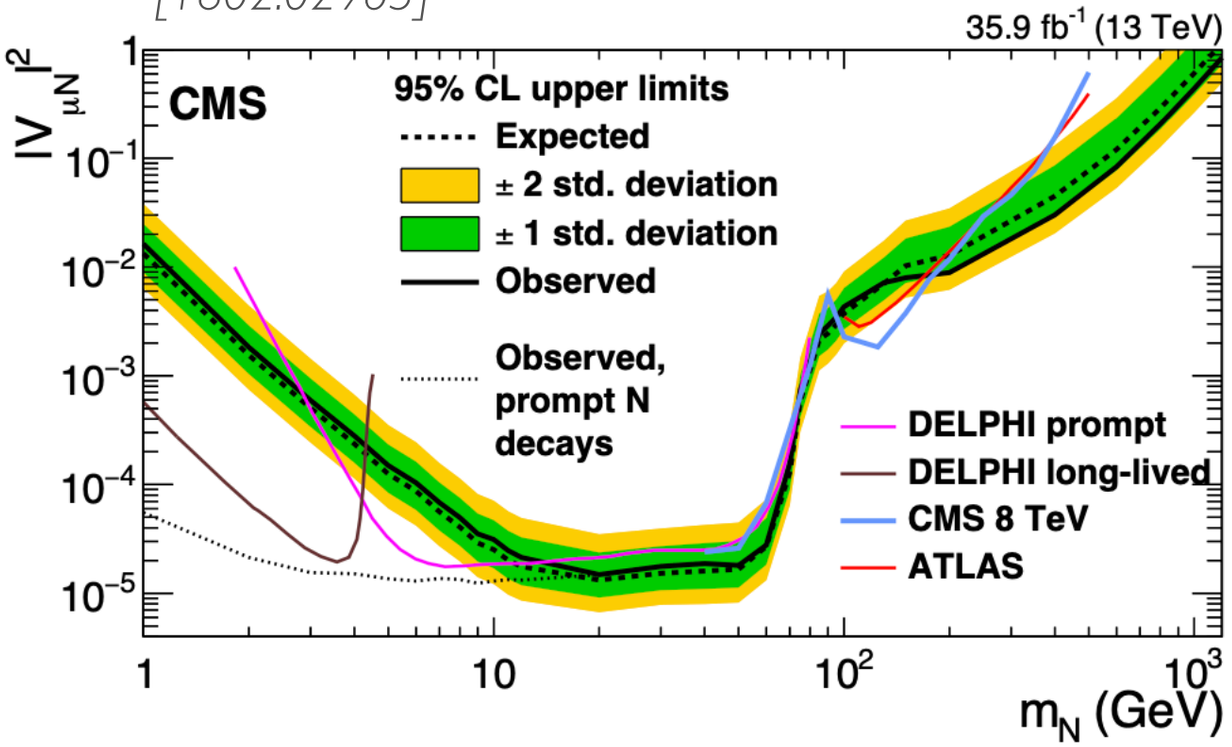
Tri-leptons at LHC

- *Trilepton* — *LNV signature?*—

$$pp \to W^{(*)} \to \ell^{\pm}_{\alpha} N \to \ell^{\pm}_{\alpha} \ell^{\pm}_{\beta} \ell^{\mp}_{\gamma} \nu$$

[1802.02965]



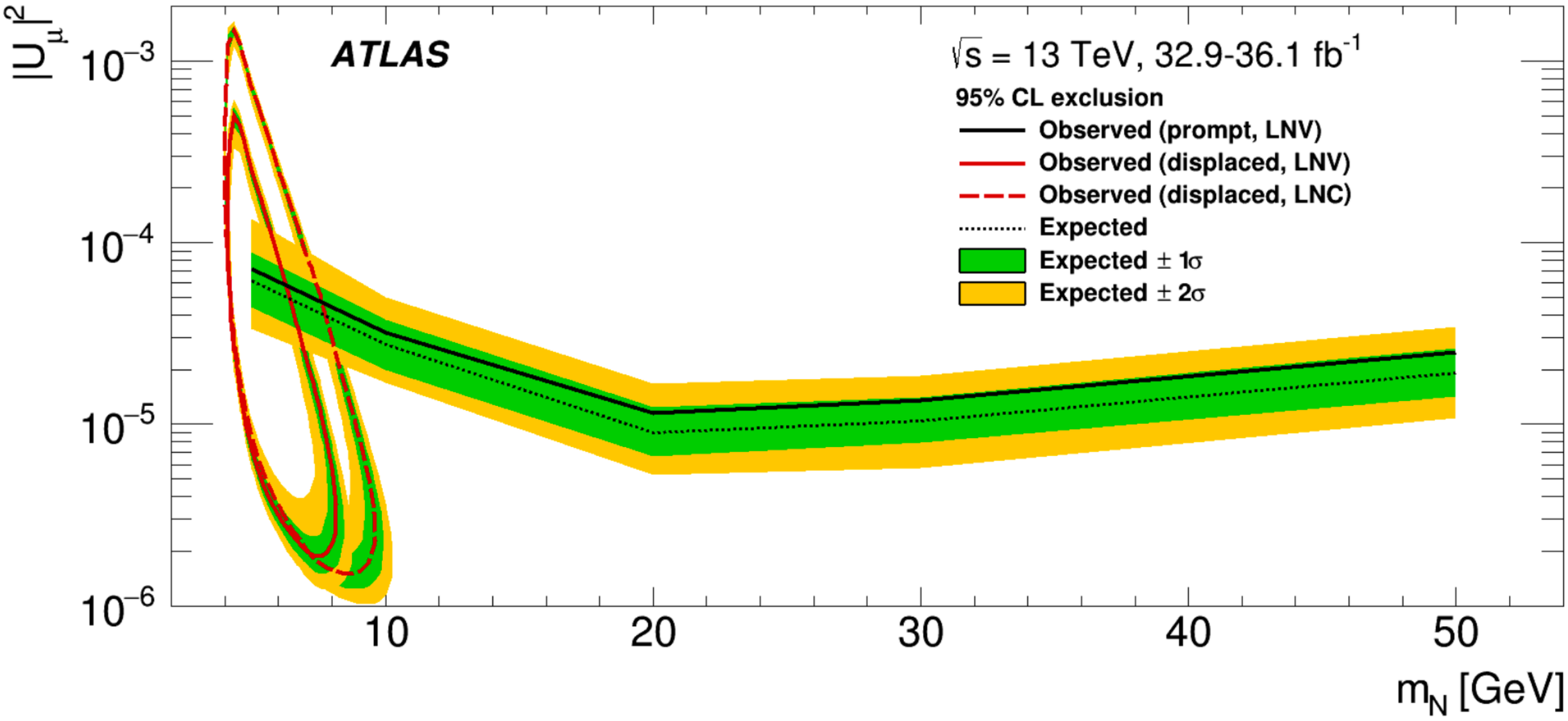


Long-Lived at LHC

- *Displaced Vertices* — *LNV signature?*—

$$pp \to W^{(*)} \to \ell^{\pm}_{\alpha} N \quad // \quad N \to \ell^{\pm}_{\beta} \ell^{\mp}_{\gamma} \nu$$

[1905.09787]

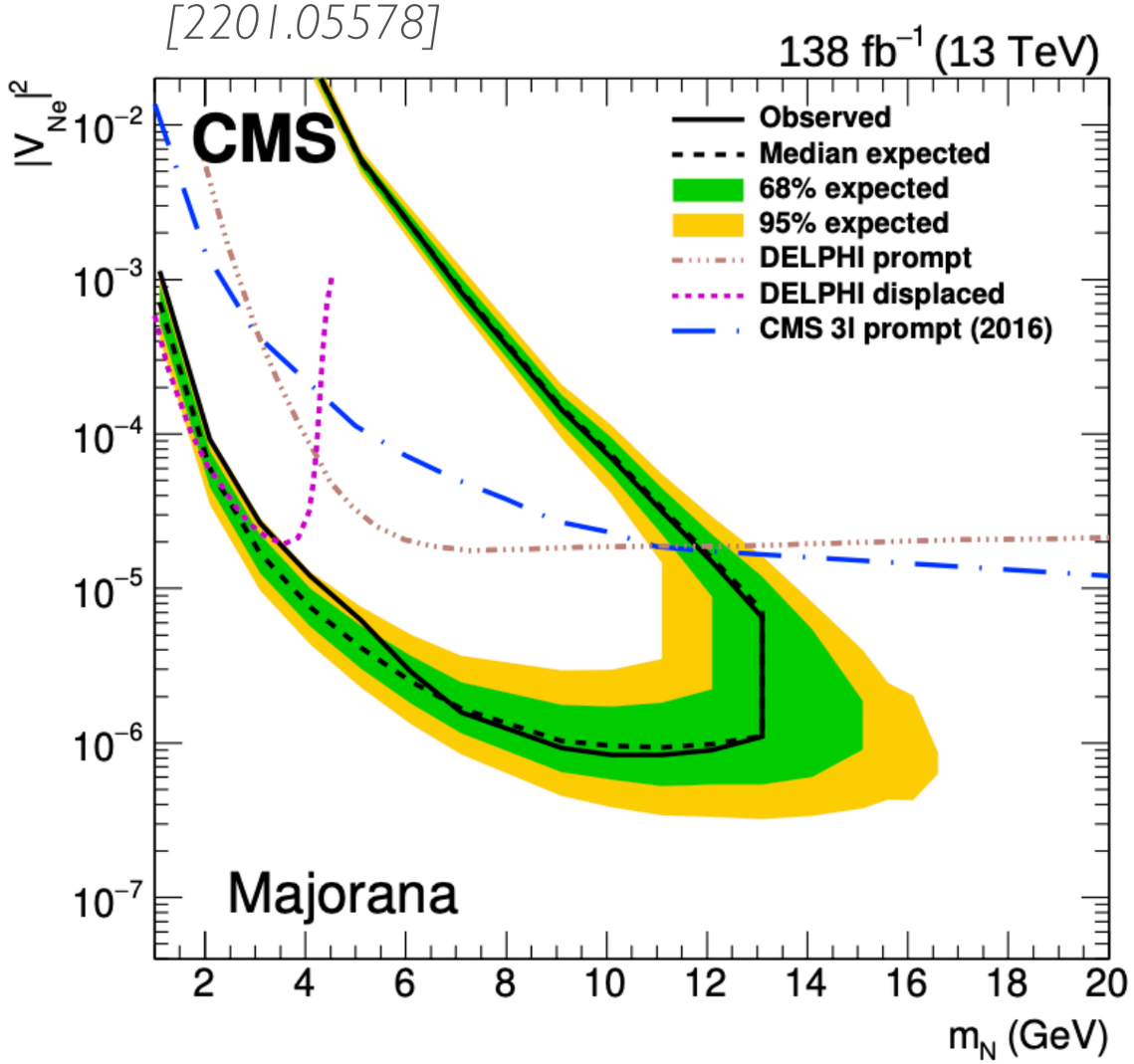


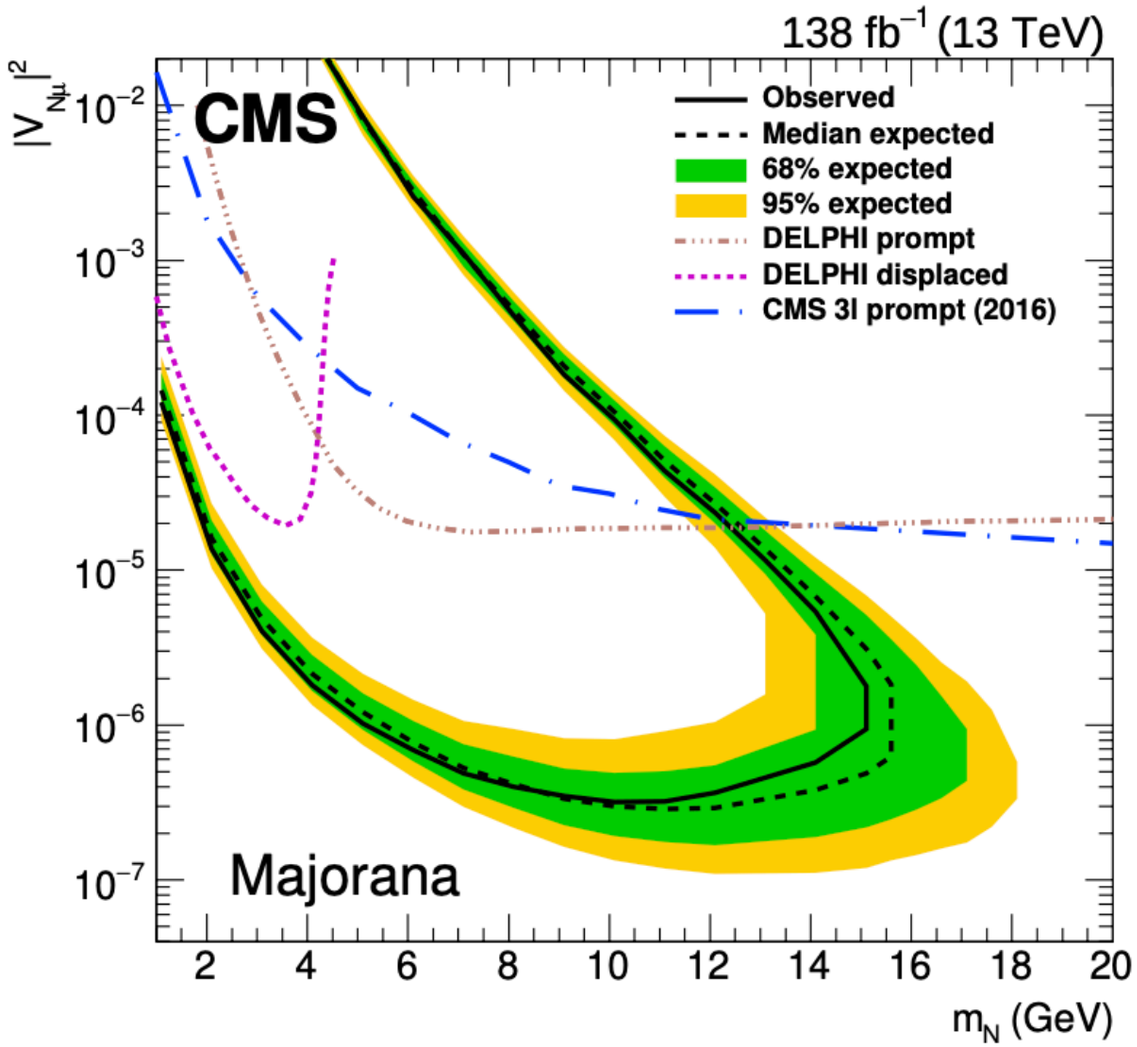
Long-Lived at LHC

- *Displaced Vertices* — *LNV signature?*—

$$pp \to W^{(*)} \to \ell^{\pm}_{\alpha} N \quad // \quad N \to \ell^{\pm}_{\beta} \ell^{\mp}_{\gamma} \nu$$

[2201.05578]



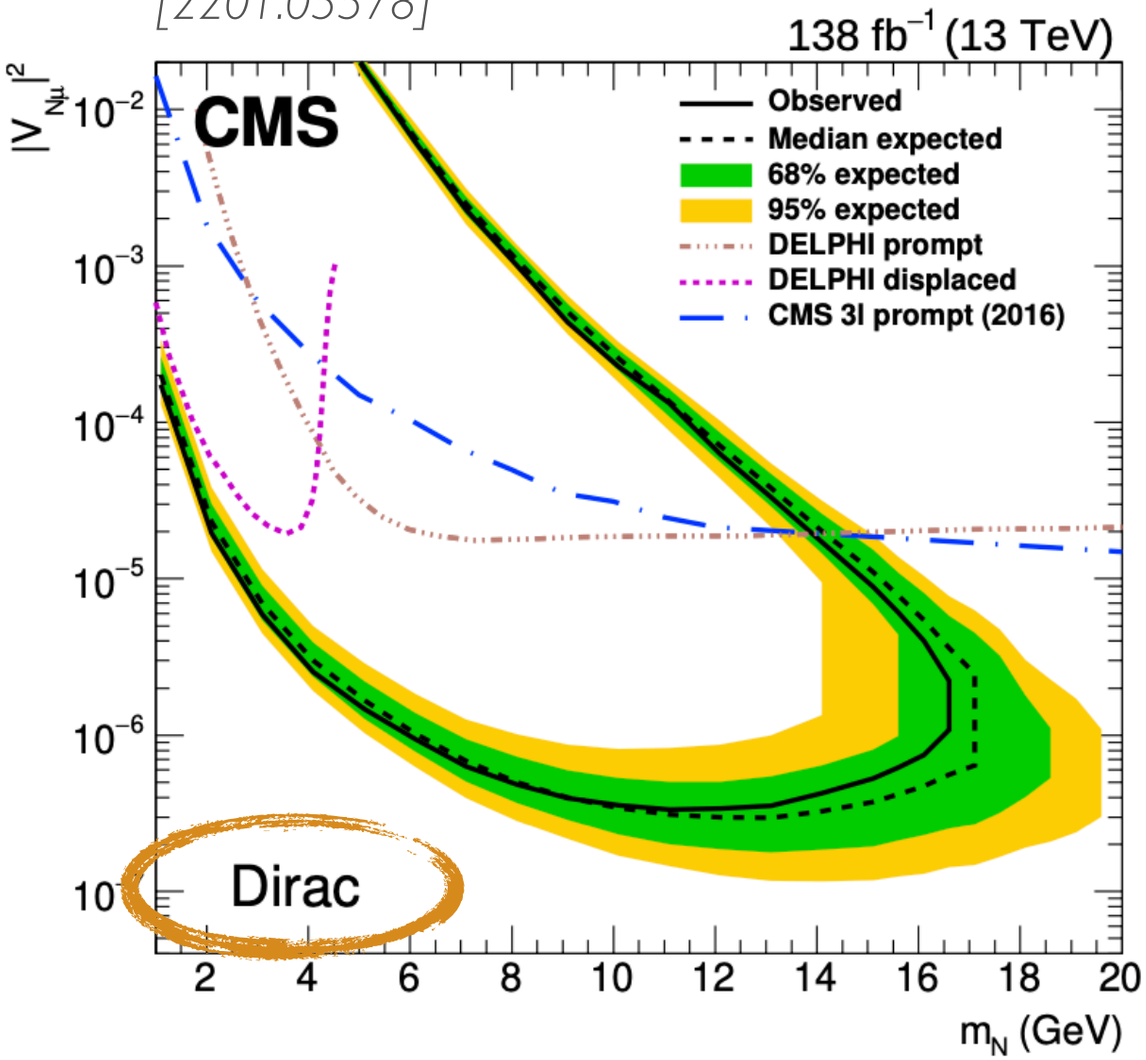


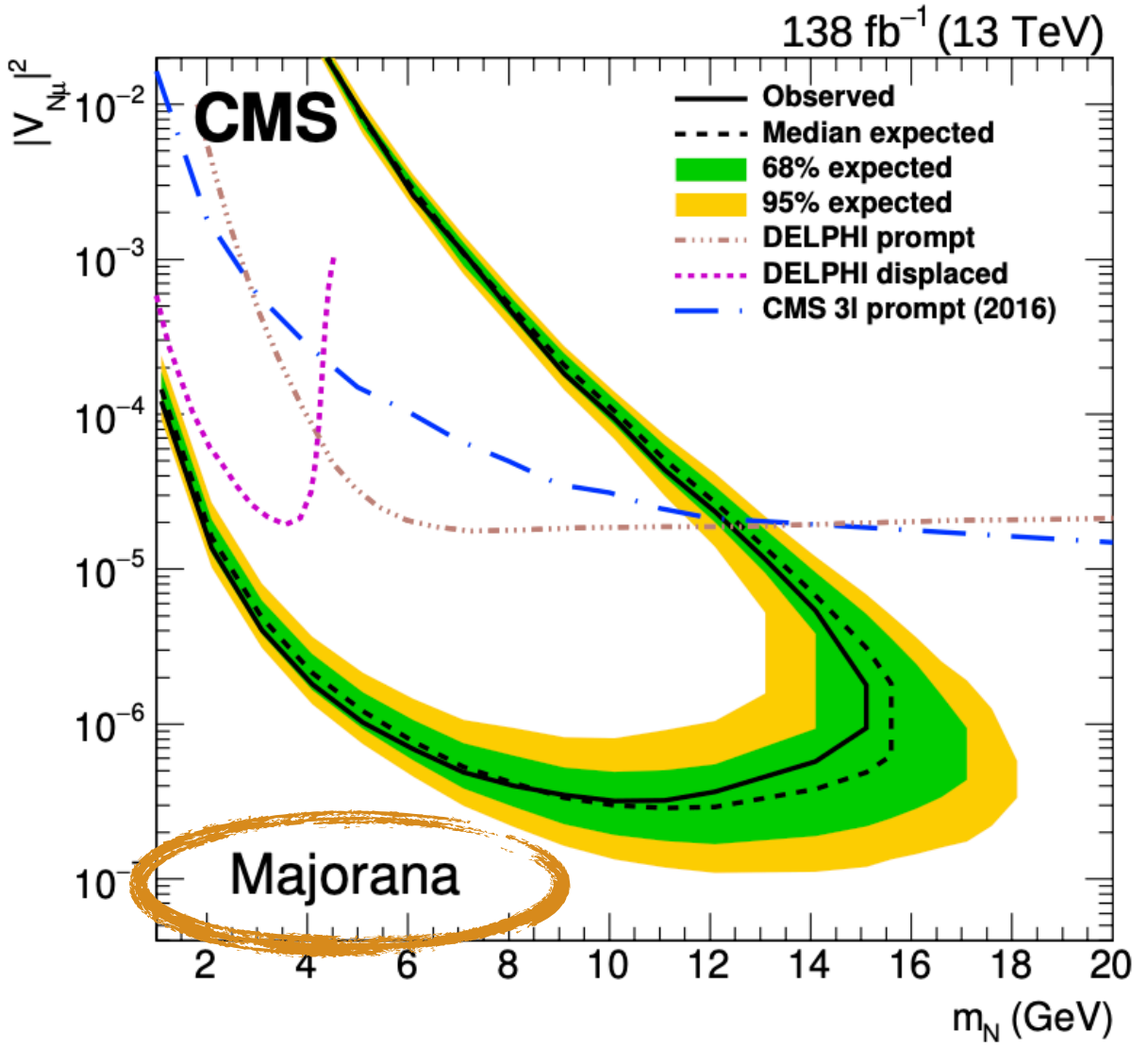
Long-Lived at LHC

- *Displaced Vertices* — *LNV signature?*—

$$pp \to W^{(*)} \to \ell^{\pm}_{\alpha} N \quad // \quad N \to \ell^{\pm}_{\beta} \ell^{\mp}_{\gamma} \nu$$

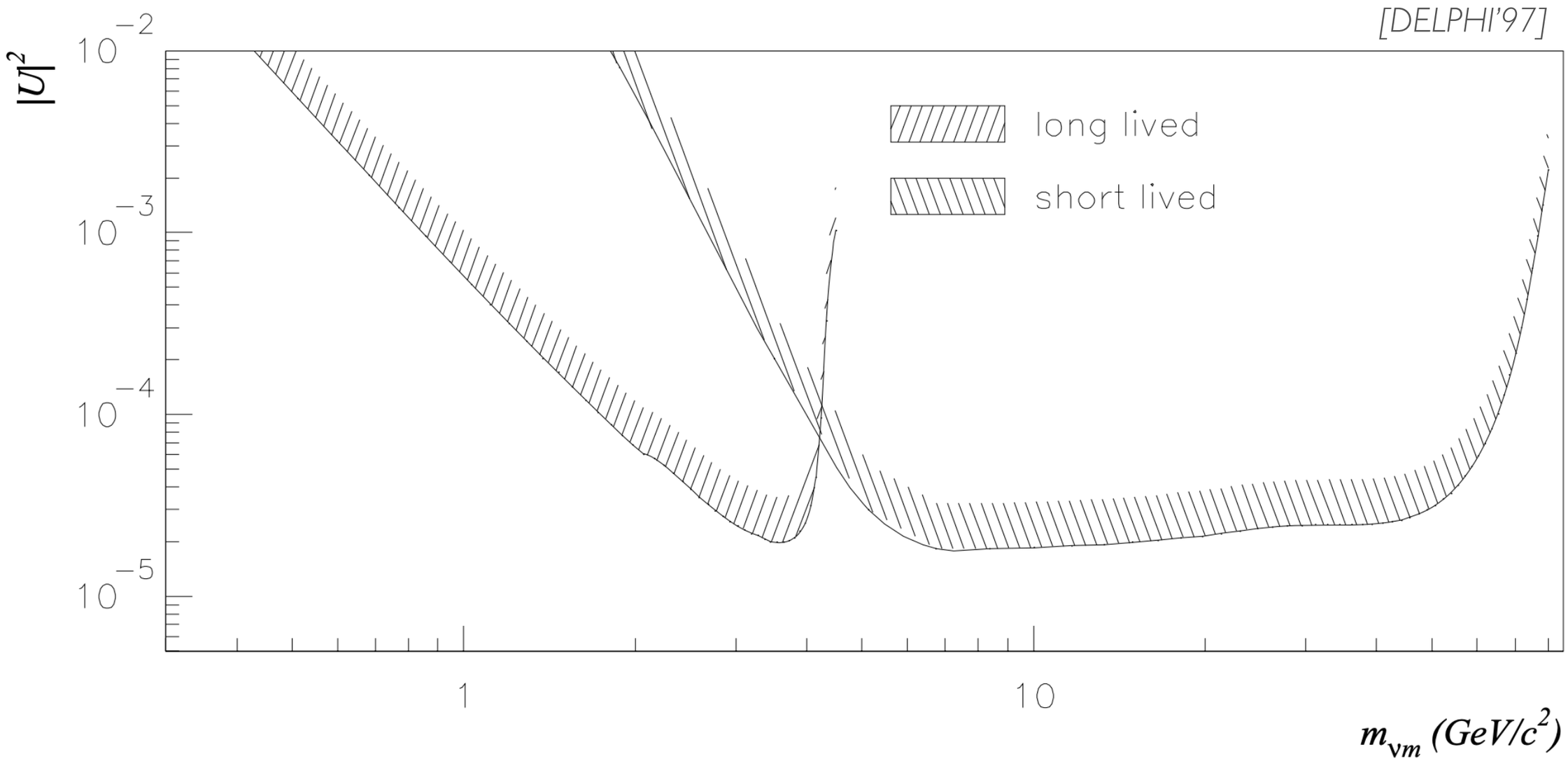
[2201.05578]



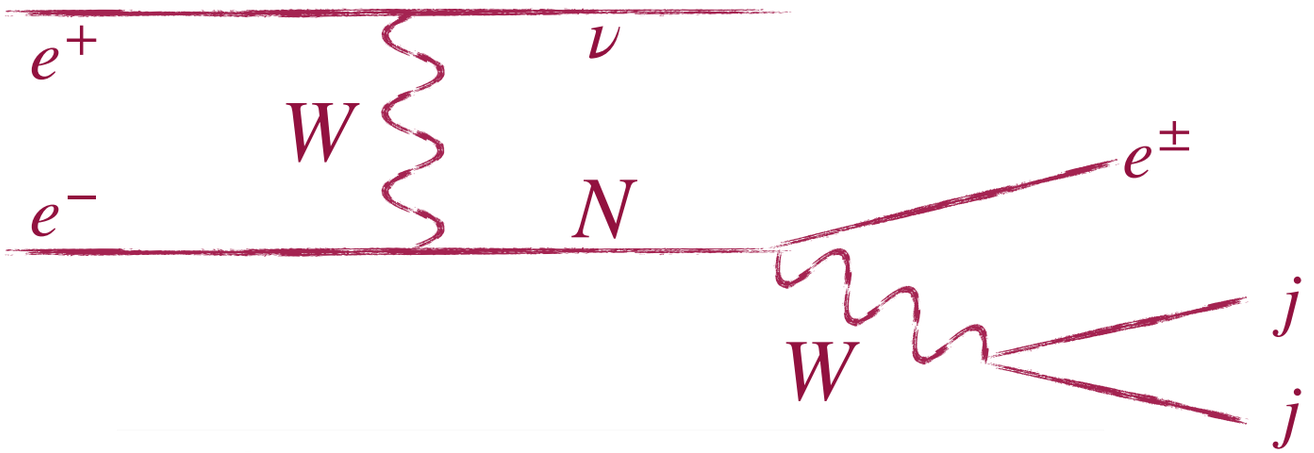


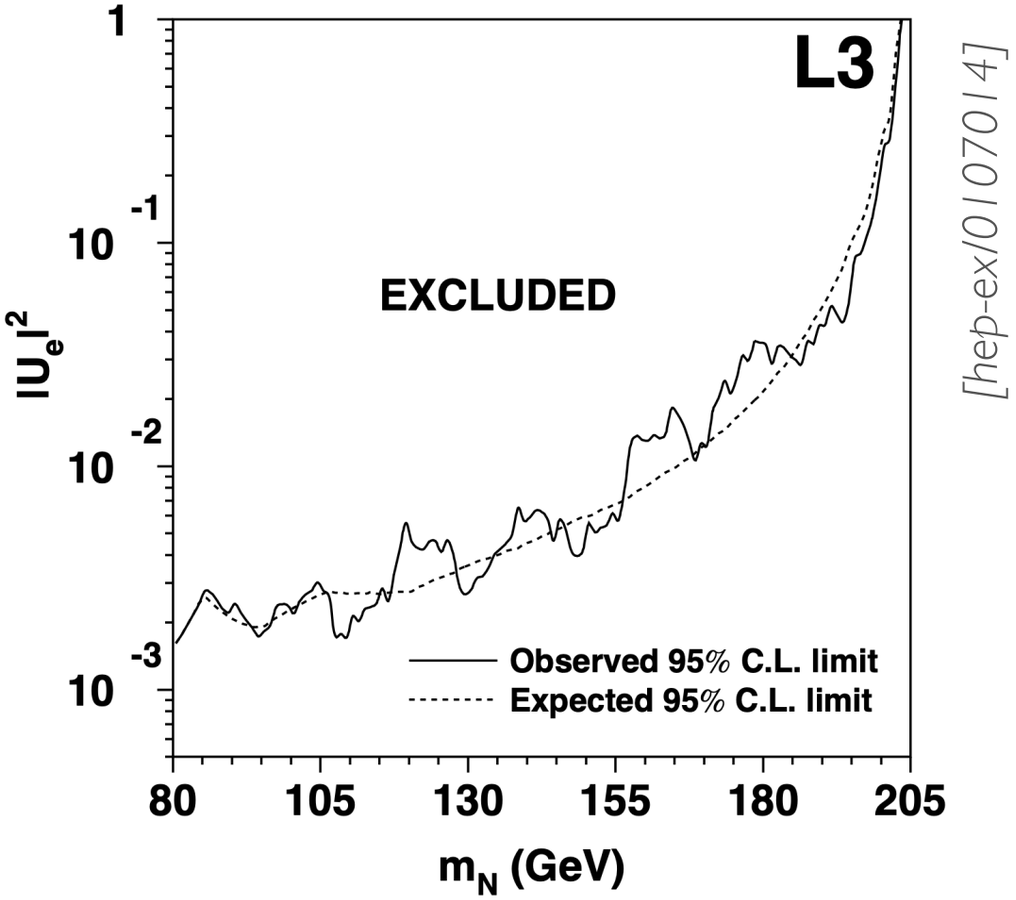
- *Light HNL: Drell-Yan Z (on-shell)* — *Sensitive to all flavor mixings*—

$$e^+e^- \to Z \to \nu N \to \nu l/\ell + nj$$



- *Heavy HNL: t-channel W* — *Sensitive to electron mixing*—





[hep-ex/0107014]