Neutrino mass models at colliders in the ~~post-ESU 2020~~ Snowmass 2021 era

Rare Process Frontier Townhall Meeting

Richard Ruiz

Center for Cosmology, Particle Physics, and Phenomenology (CP3)
Universite Catholique de Louvain

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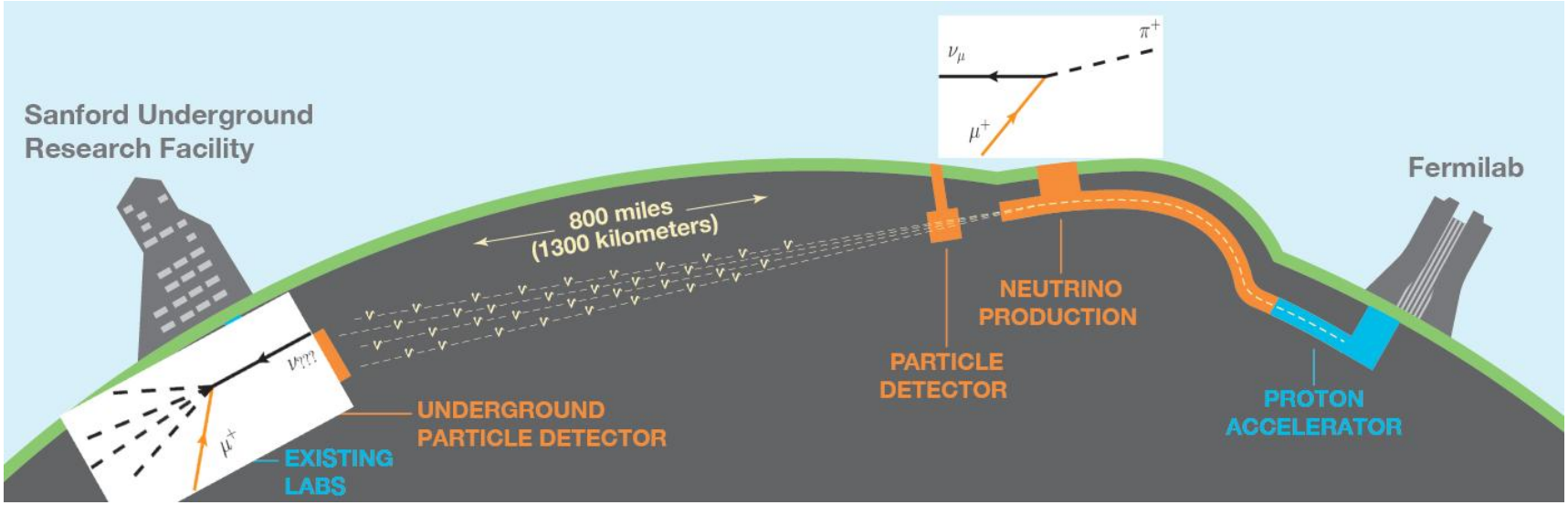
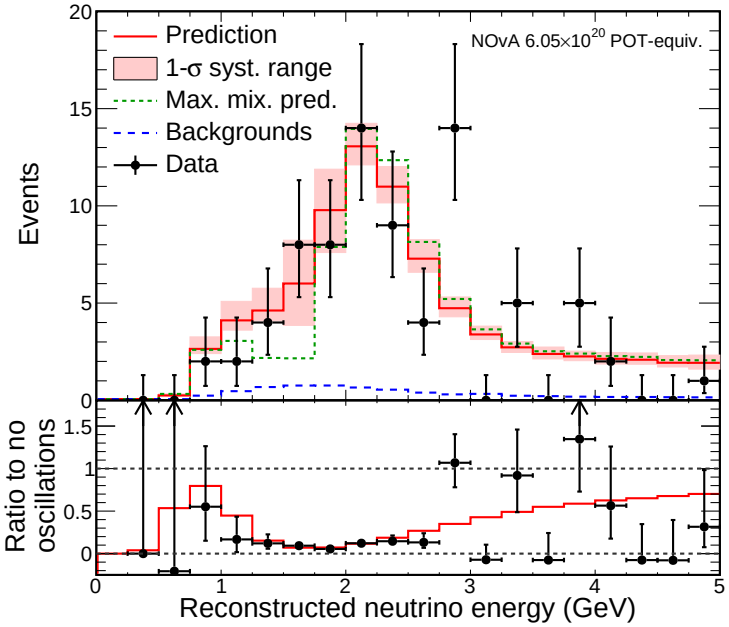
What is the physics / motivation for your LOI?

the big physics picture



In neutrino fixed-target expts, ν_μ beams from collimated $\pi^\pm$, then studied at near and far detectors



Deficit/disappearance of expected ν_μ (+apperance of ν_e/ν_τ) interpreted as $\nu_{\ell_1} \to \nu_{\rm mass} \to \nu_{\ell_2}$ transitions/oscillations [E.g. NOνA ν_μ disapp., 1701.05891]

$\Longrightarrow$ ν have mass!

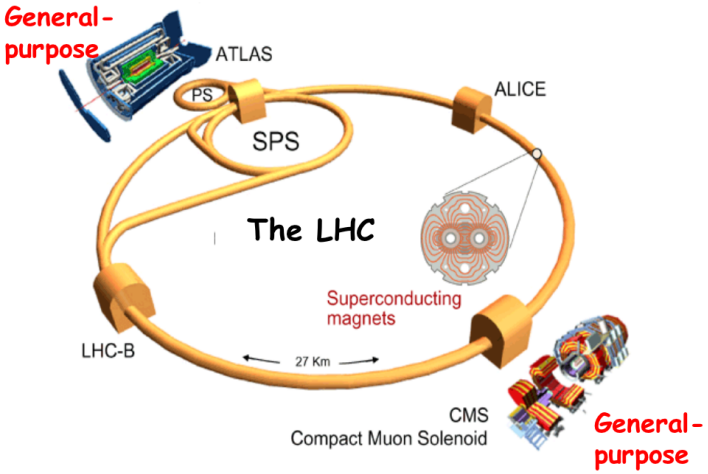
the medium picture

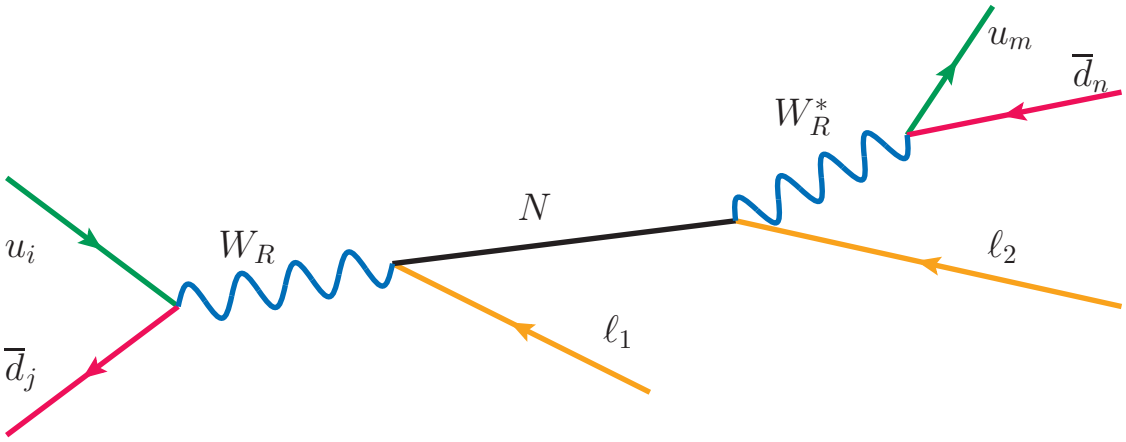
models that explain tiny neutrino masses (Seesaw models)

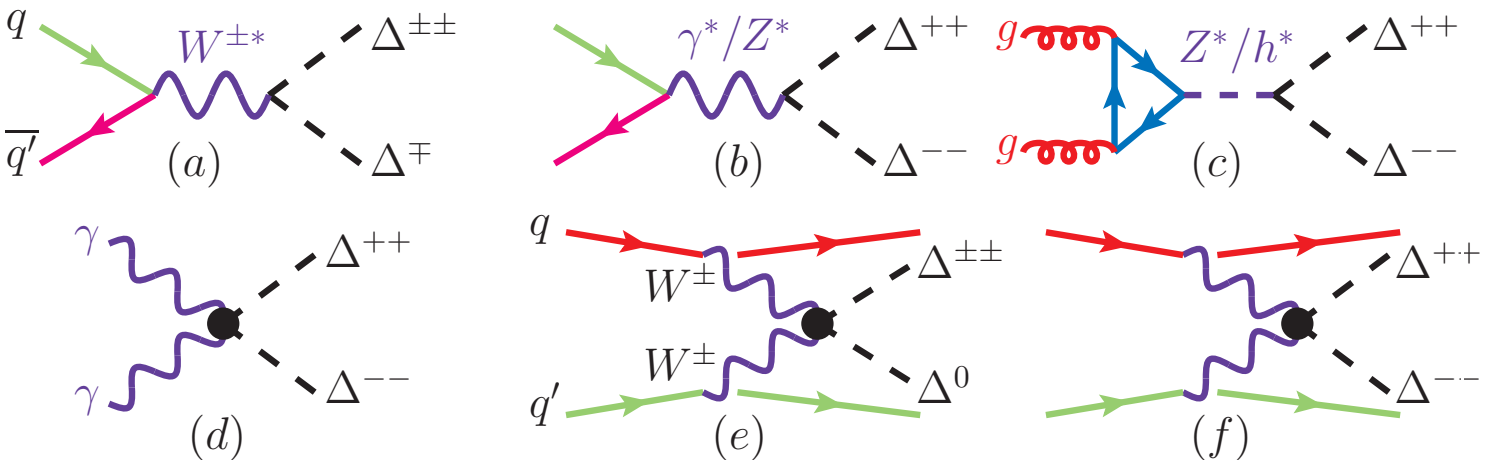
are testable

models that explain tiny neutrino masses (Seesaw models) are testable, especially at colliders

for a review, see w/ Y. Cai, T. Li, and T. Han [1711.02180] as well as w/ Pascoli, et al [1812.08750]







the little picture

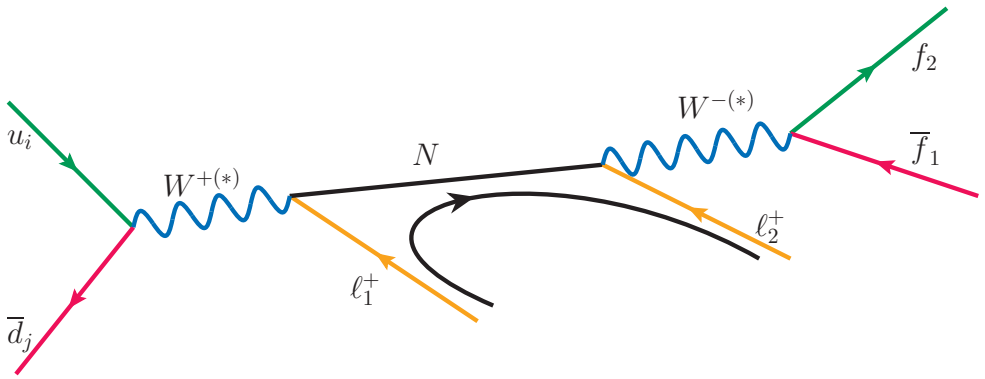
(our part!)

Snowmass 2013 inspired an effort to systematically modernize the collider phenomenology for Seesaw models

for example

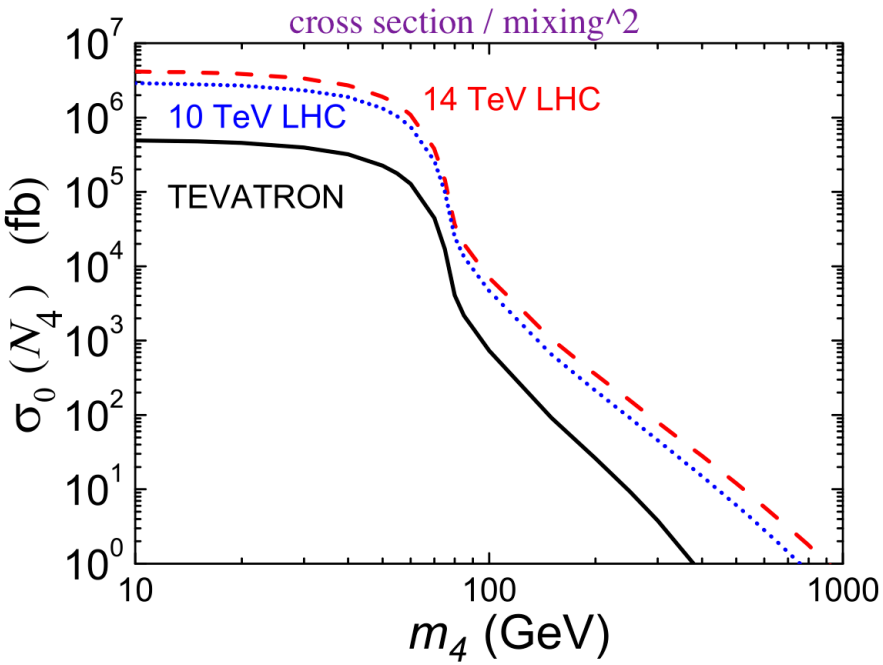
Historically, searches for N with $m_N > M_W$ relied on $(q\overline{q})$ annihilation

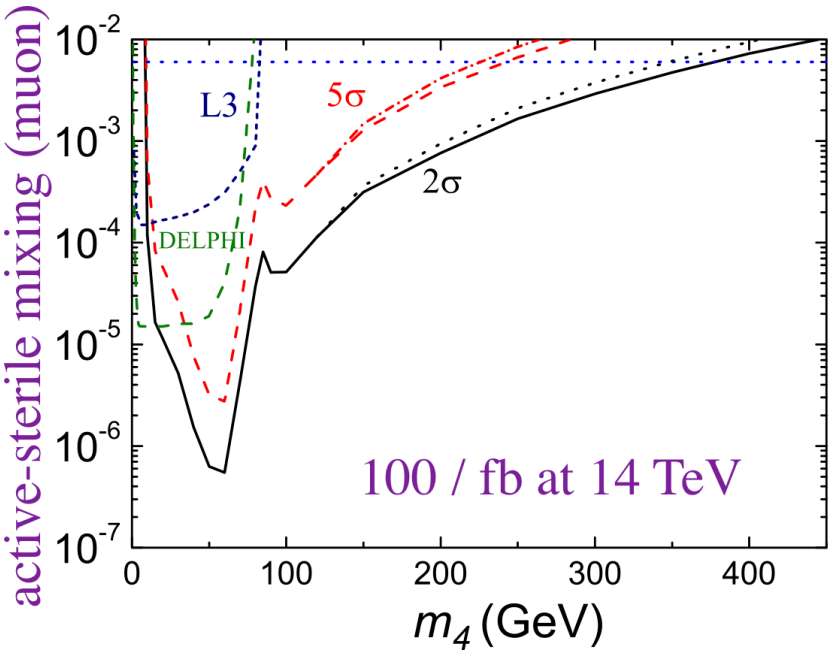
Keung & Senjanovic (PRL'83)



At the LHC, a canonical signature for N: $pp \to \ell_i^\pm \ell_j^\pm + nj +$ no MET

based on seminal works by K&S, del Aguila & Aguilar-Saavedra [0808.2468], and Atre, et al [0901.3589]



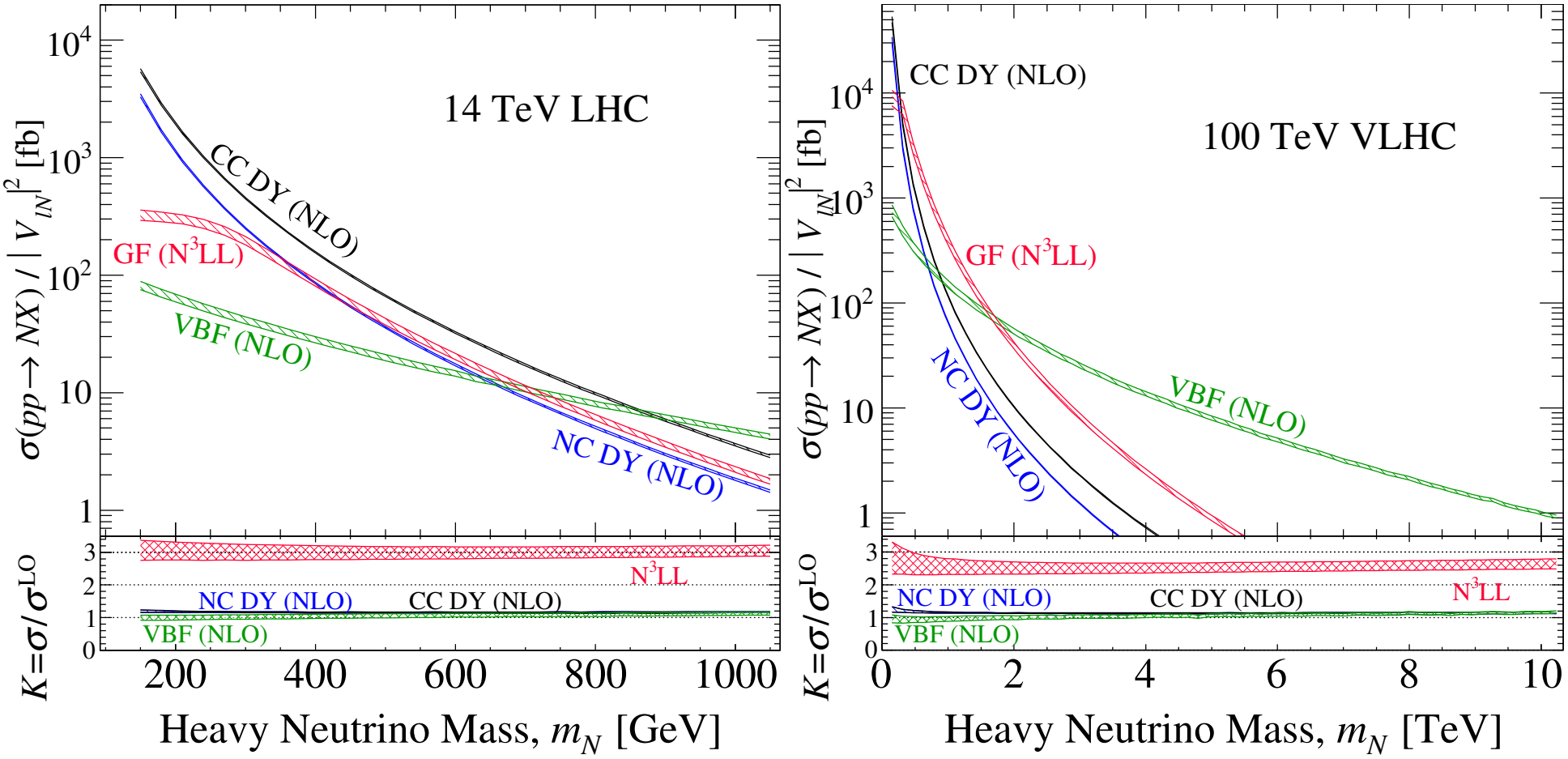


a lot has happened since 2013

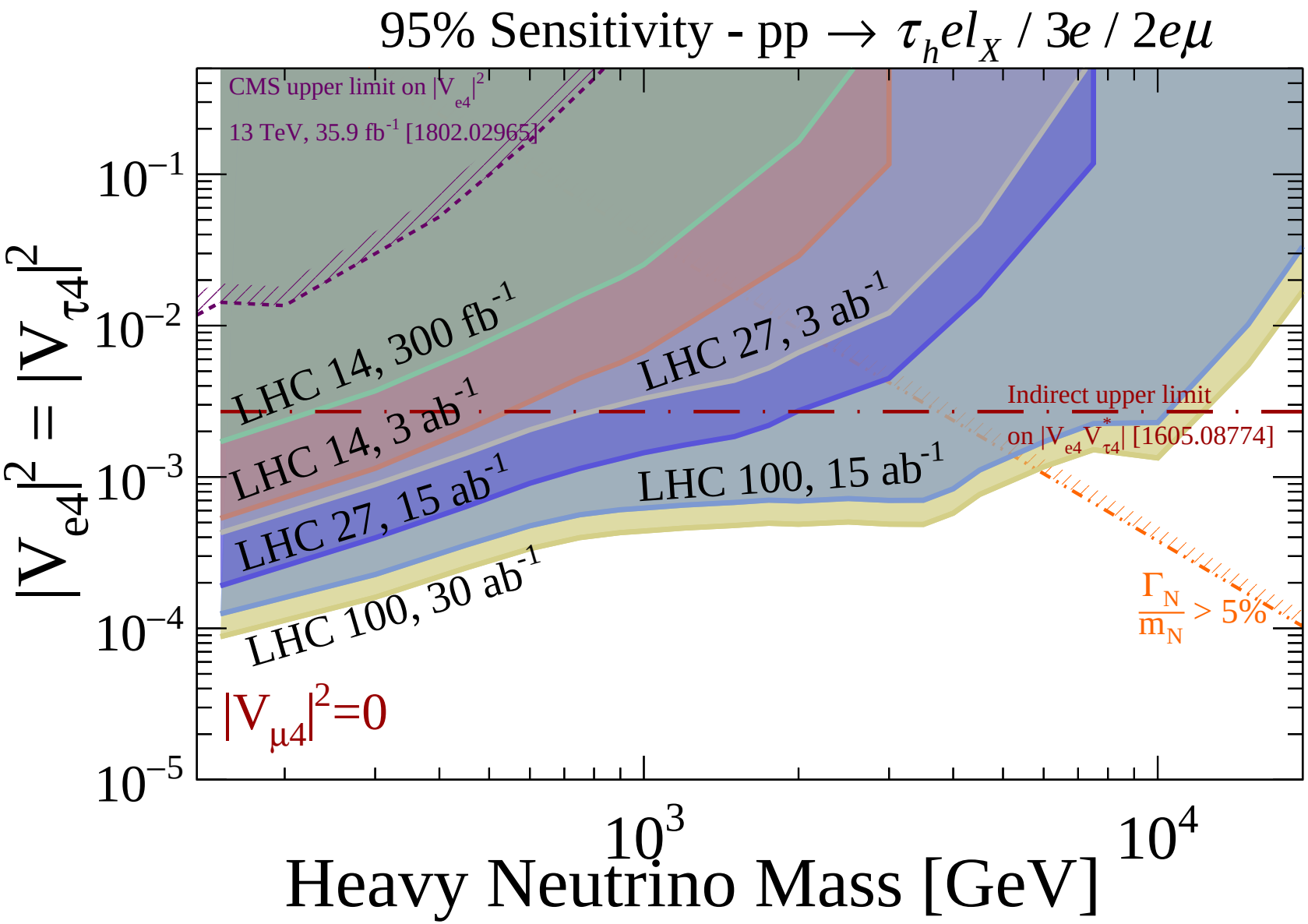
After lots of coffee and CPU hours

for details, see [1711.02180] and [1812.08750]

Plotted: Normalized production rate ($\sigma/|V|^2$) vs heavy N mass (m_N)



For $m_N = 10$ TeV and $|V_{\ell N}|^2 \sim 10^{-3}$, then at 100 TeV, one has $\mathcal{O}(30)$ VBF events after 30 ab^{-1}! If BR$\times\varepsilon\times\mathcal{A} \sim \frac{1}{3}$, then $\sqrt{N_{Obs.}} > 3\sigma$



Major improvements $\Longrightarrow$ $> 10\times$ better sensitivity to LNV + cLFV

Only a few results. See the big paper for various flavor, Dirac vs Majorana, and $\sqrt{s}$ permutations [1812.08750]

“What will you work on between now and Snowmass, and what is your schedule for developing a contributed paper?”

continue extending outlook for other models

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- Type I Seesaw - pseudo-Dirac and Majorana N ✓✓

  E.g. w/ Degrand, et al [1602.06957]; w/ Pascoli, et al [1812.08750]

- Type II Seesaw - exotically charged $\Delta^{\pm}, \Delta^{\pm\pm}$ ✓

  E.g. w/ Fuks and Nemevšek [1912.08975]

- Type III Seesaw - exotically charged $T^{\pm}, T^{0}$ (need to update)

  E.g. [1509.05416]

- Left-Right Symmetry - $W_R^{\pm}, Z_R$ + many other things ✓✓

  E.g. w/ Mitra, Scott, Spannowsky, Mattelaer [1607.03504; 1610.08985] Nemevšek, et al [1801.05813]

- $B - L$ Symmetry - $N + Z_{B-L}$ (need to updated for 100 TeV)

- All of the above - with τ_h final states (long term goal)

  E.g. w/ Pascoli, et al [1805.09335; 1812.08750]

Priority: over next six months, run the numbers for EFTs and W'/Z'

“What common data sets, joint efforts, etc. do you need?”

our simulation tools are public and folks are welcome to help!

- Ongoing efforts within `FeynRules` and `MadGraph` MC collaborations
- Mainstream tools with widespread use and technical support

Available UFOs[1] for neutrino mass models:

- Type I Seesaw - feynrules.irmp.ucl.ac.be/wiki/HeavyN (Request/use by ATLAS+CMS)
- Type II Seesaw - feynrules.irmp.ucl.ac.be/wiki/TypeIISeesaw (Request/use ATLAS)
- Left-Right Symmetry - feynrules.irmp.ucl.ac.be/wiki/EffLRSM (Request/use ATLAS)
- Generic W'/Z' feynrules.irmp.ucl.ac.be/wiki/WZPrimeAtNLO
- $+$ others
- Cannot find your favorite Seesaw model UFO? We should collaborate!

[1] UFOs encode Feynman rules for mainstream event generators, e.g. `MadGraph`, to simulate BSM (not just colliders)

“What would you like to come out of the Snowmass process?”

given the latest tools, newest analysis techniques,

and a better understanding of current ones,

what new information can the HL-LHC and successors provide

about the origin of tiny m_ν?

Thank you.