

# LHC LLP Working Group Update: HNL Summary Plots

Dominique Trischuk, on behalf of the LHC LLP Working Group  
LHC BSM Working Group General Meeting  
LLP Session  
November 11, 2025



**University  
of Victoria**



LHC LLP Working Group, <https://lpcc.web.cern.ch/lhc-llp-wg>, at LPCC (LHC Physics Centre), conveners:

- CMS: Alberto Escalante del Valle
- ATLAS: Dominique Trischuk
- LHCb: Andrii Usachov and Gaia Lanfranchi
- FASER: Dave Casper
- MoEDAL: James Pinfold
- SND@LHC: Cristovao Vilela
- Theory: Andre Lessa

## **Goals of the WG:**

- Facilitate communication between the experimental and theoretical LLP communities
- Provide recommendations for benchmark models to be used in LLP interpretations
- Develop and/or validate MC tools for event generation (e.g. dark sector showers, library of models)
- Provide recommendations to experiments on how to best present the results and facilitate reinterpretation of LLP searches
- Discuss possible new search directions based on new input from theory and/or experiment



- LHC Summary plots in the context of a “Roadmap to summary plots and reinterpretation for LLP searches”:

1.  $H \rightarrow SS$  summary plots (Links from [ATLAS](#), [CMS](#))

2. **\*\*New\*\*** Reinterpretation rare Higgs decays in BC5 benchmark

- See previous [talk by A. Escalante Del Valle](#)



3. **\*\*New\*\*** HNL Summary plots (Links from [ATLAS](#), [CMS](#))

- [This presentation](#)

Please also see the [lhc bsm wg docs](#) for links to summary plots

# Roadmap to summary plots and reinterpretation



- Well-known problem that is not easy to compare LLP searches across different experiments, and it is not easy to reinterpret LLP searches
  - ▶ See [talk by E. Pompa Pacchi](#) next on gaps in experimental coverage & new signatures & [talk by A. Lessa](#) on reinterpretation material for LLP searches
- To address the problem, we identified an initial list (in 2022) of 5 benchmark scenarios, mainly based on existing LLP interpretations (details in this [presentation](#))
  1.  $H \rightarrow SS$ ;  $S \rightarrow bb, qq, \tau\tau$ , for hadronic searches 
  2. HNLs 
  3.  $H \rightarrow Z_D Z_D$ ; with  $B(Z_D)$  from Hidden Abelian Higgs model (HAHM), for leptonic searches
  4. GMSB SUSY
  5. RPV SUSY

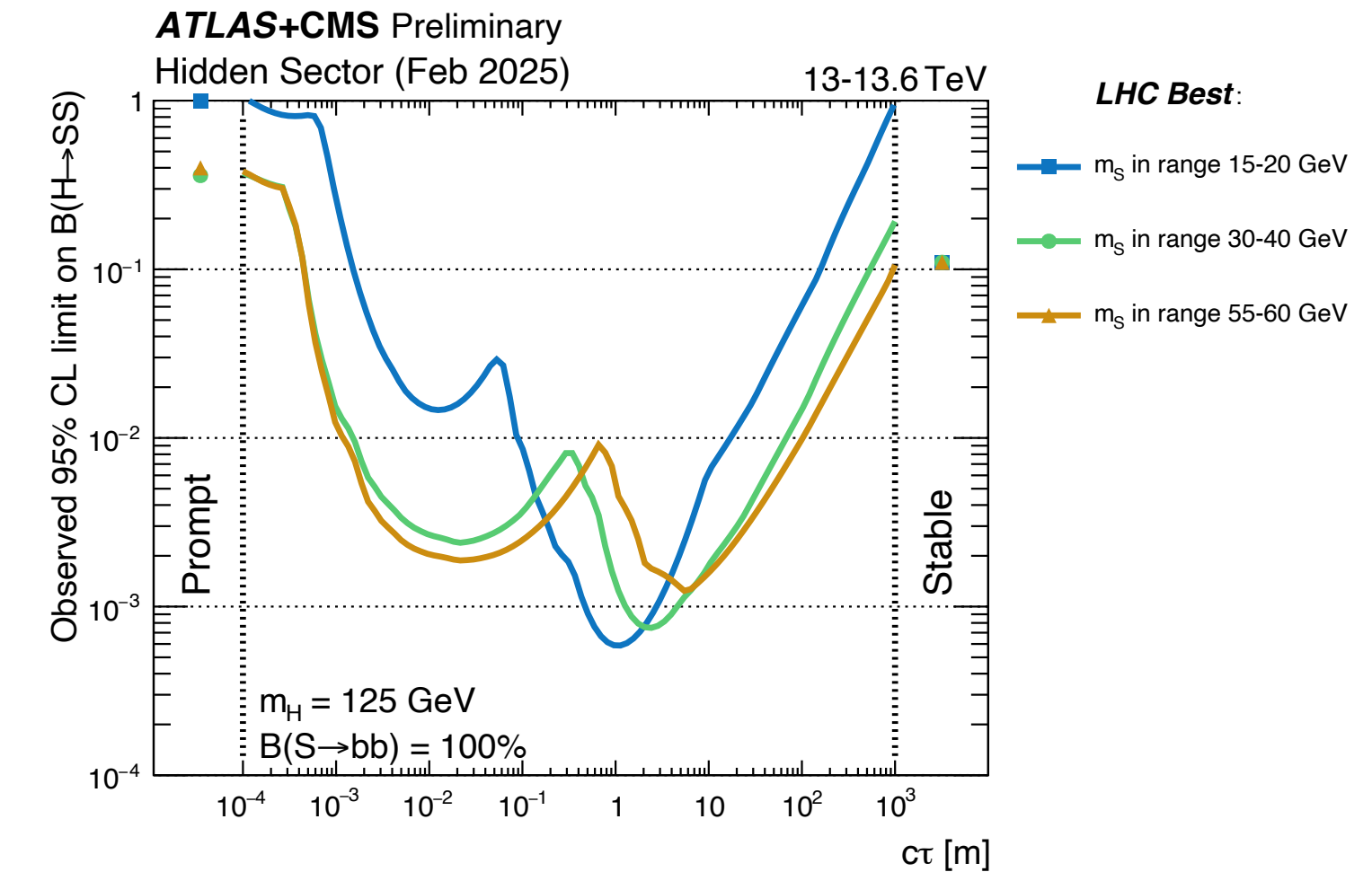
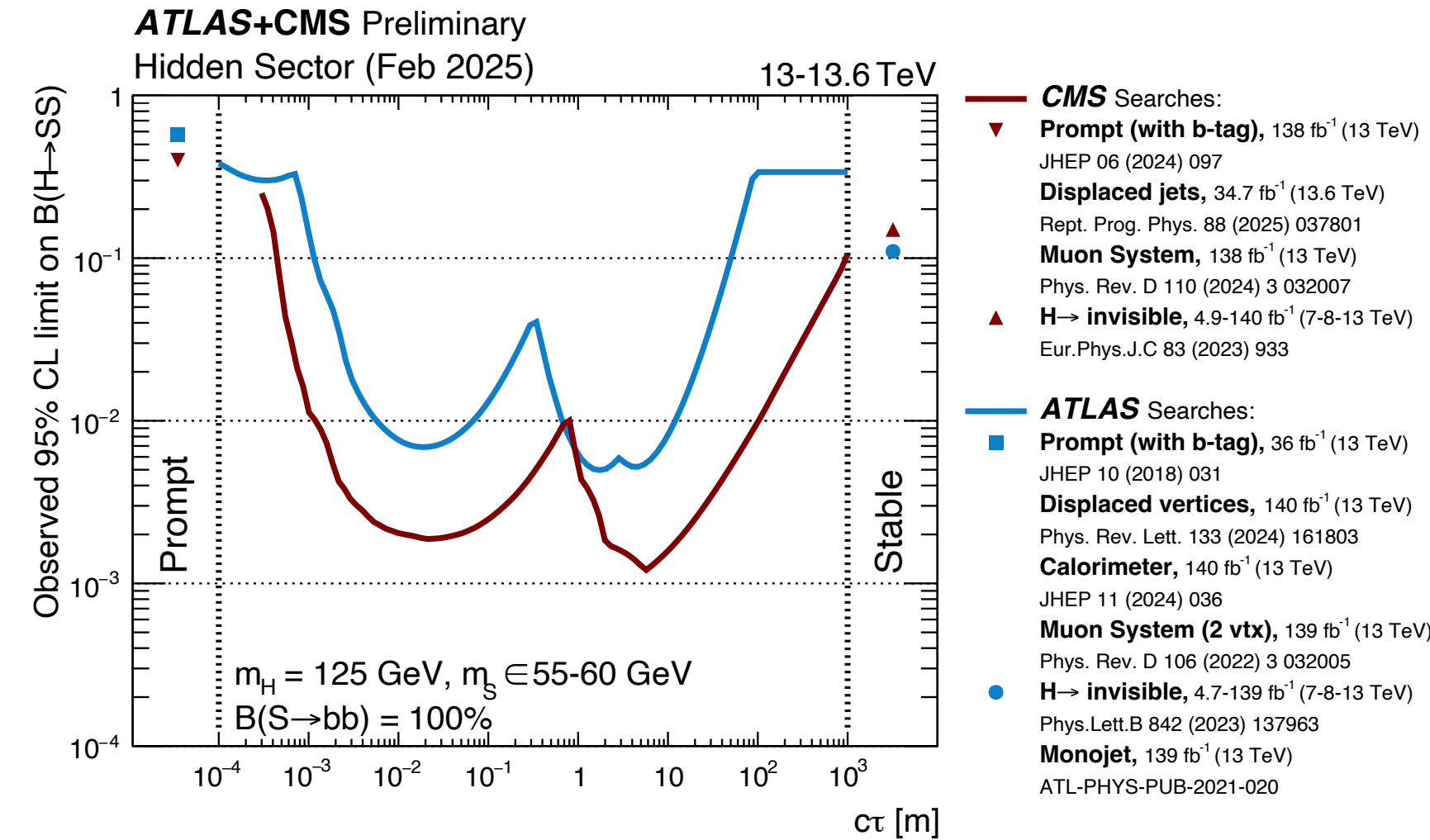
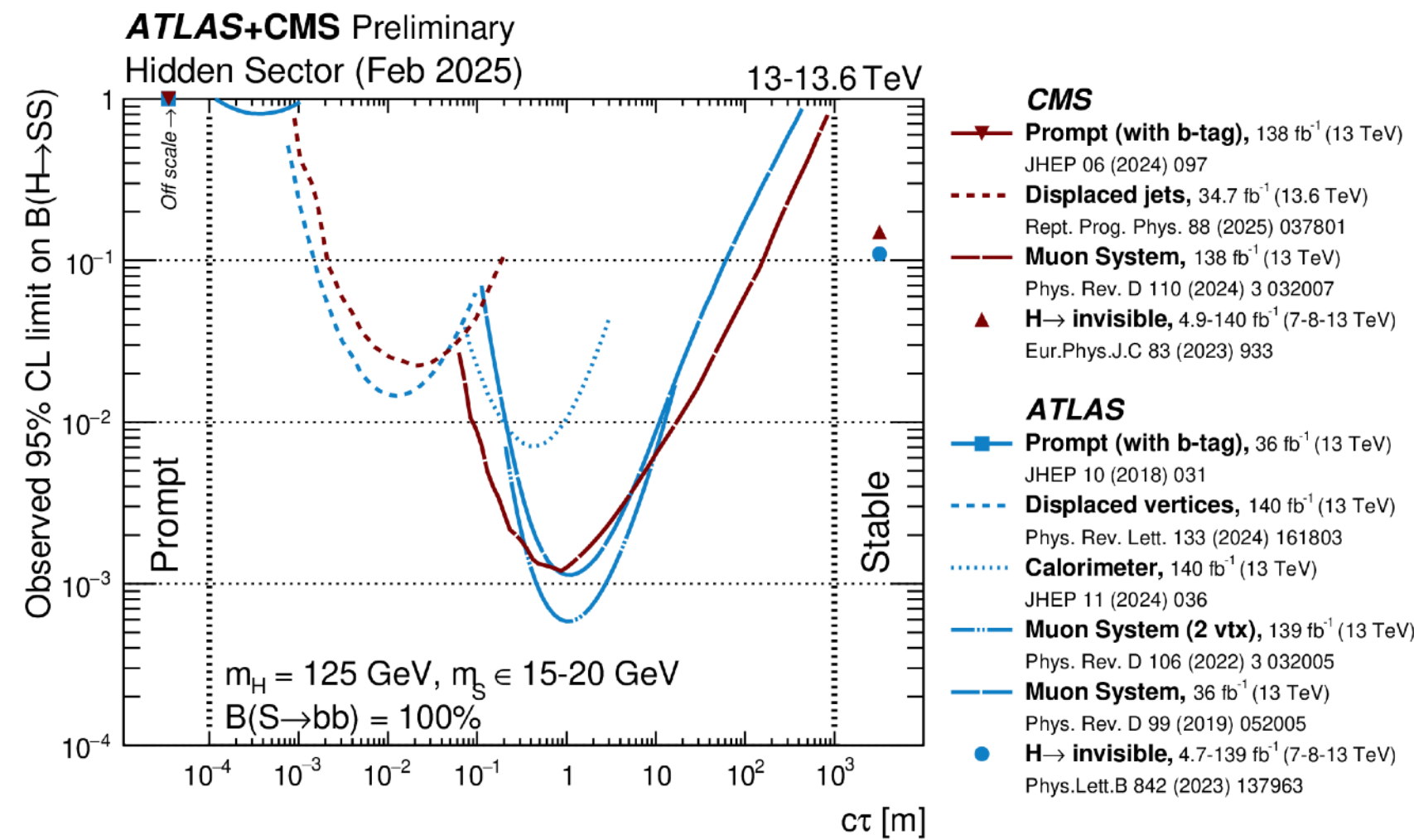
# Recap: HSS Summary Plots



**Most sensitive** individual ATLAS and CMS results

**Envelope** of the best exclusions for **each experiment**

**Envelope** of the best exclusions from CMS or ATLAS denoted as **“LHC “best”**

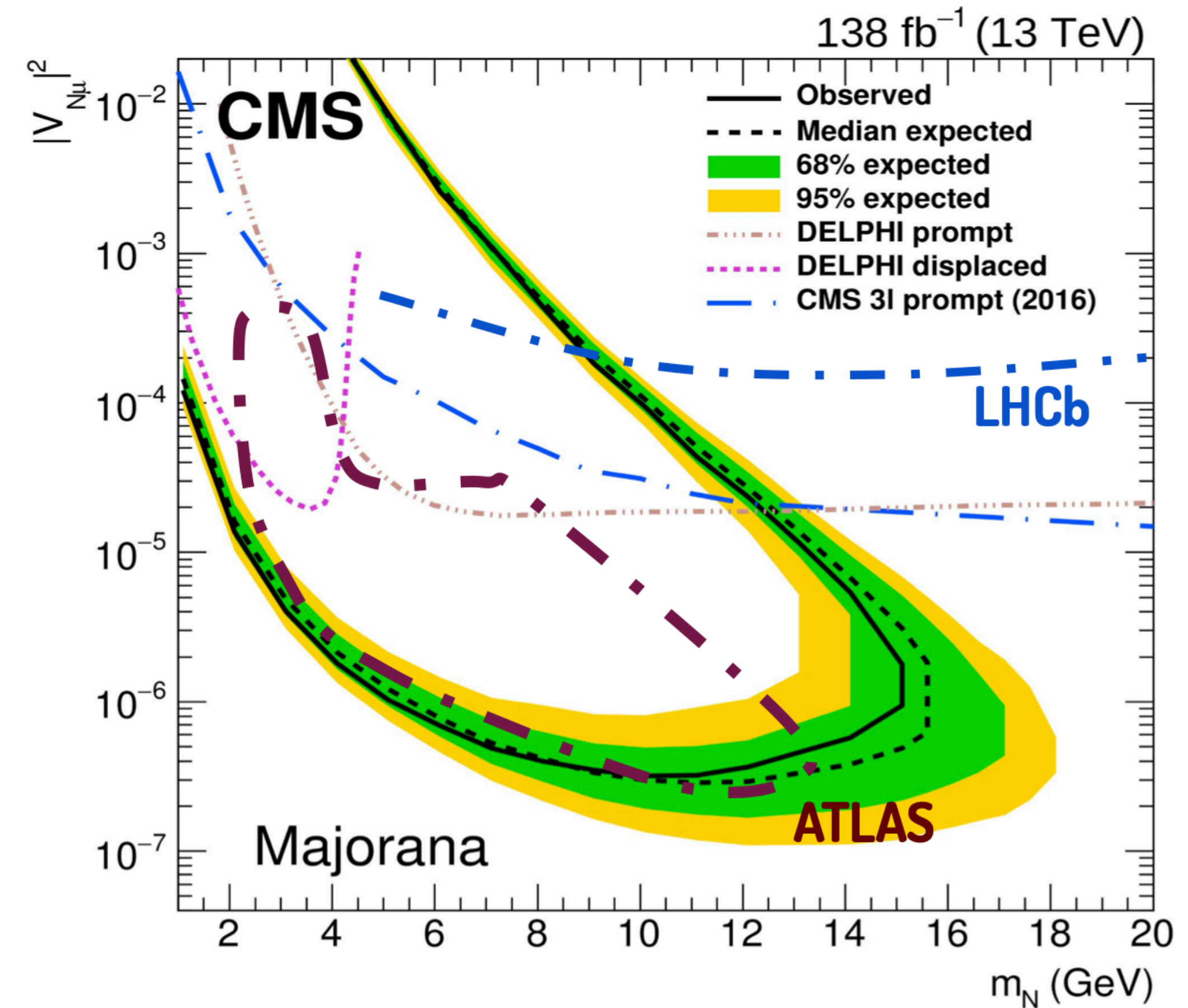
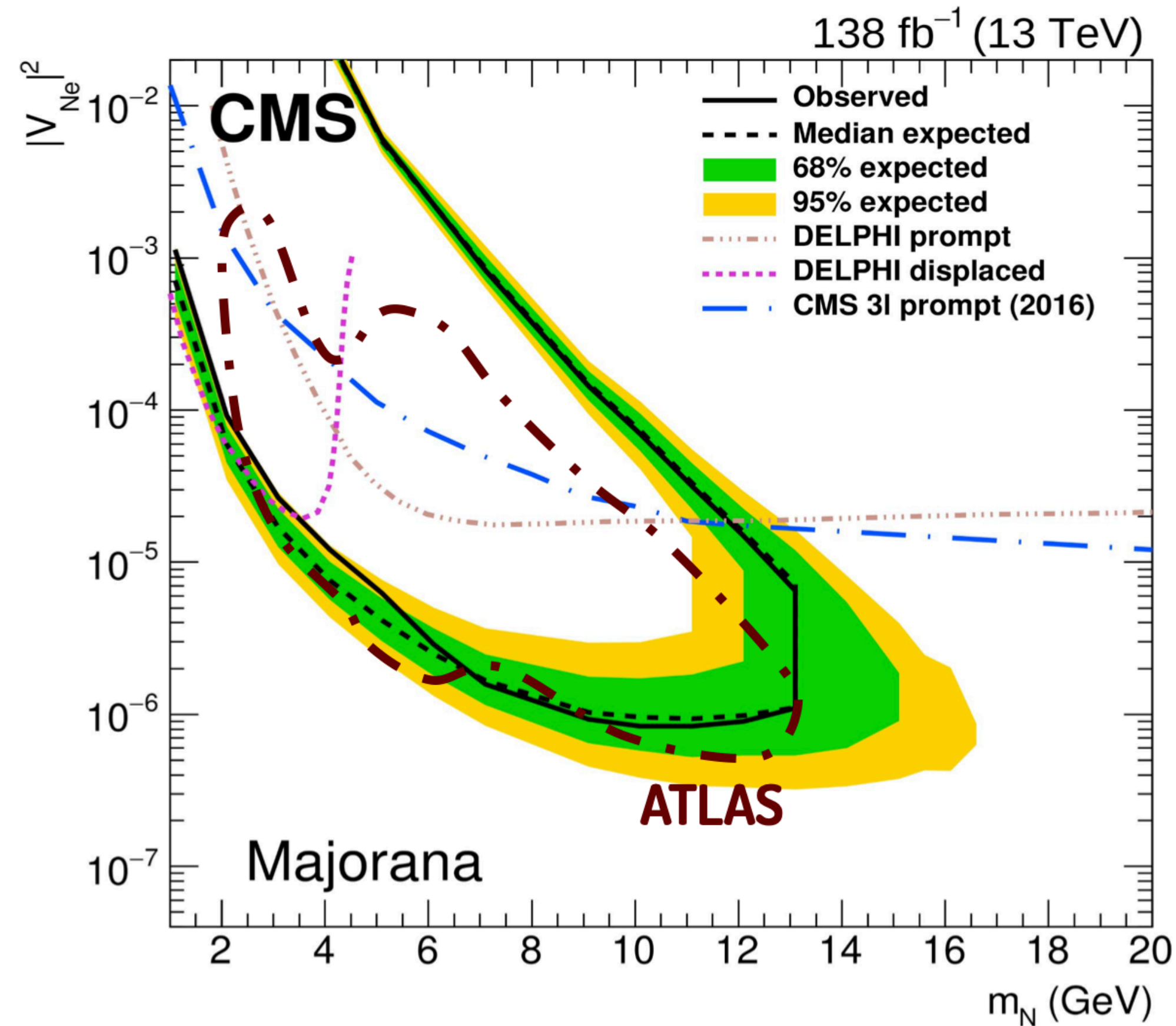


Link to the plots: [ATLAS](#), [CMS](#)

# Heavy Neutral Leptons



Hand-drawn comparison between **ATLAS**, **CMS**, **LHCb**, and **DELPHI** results

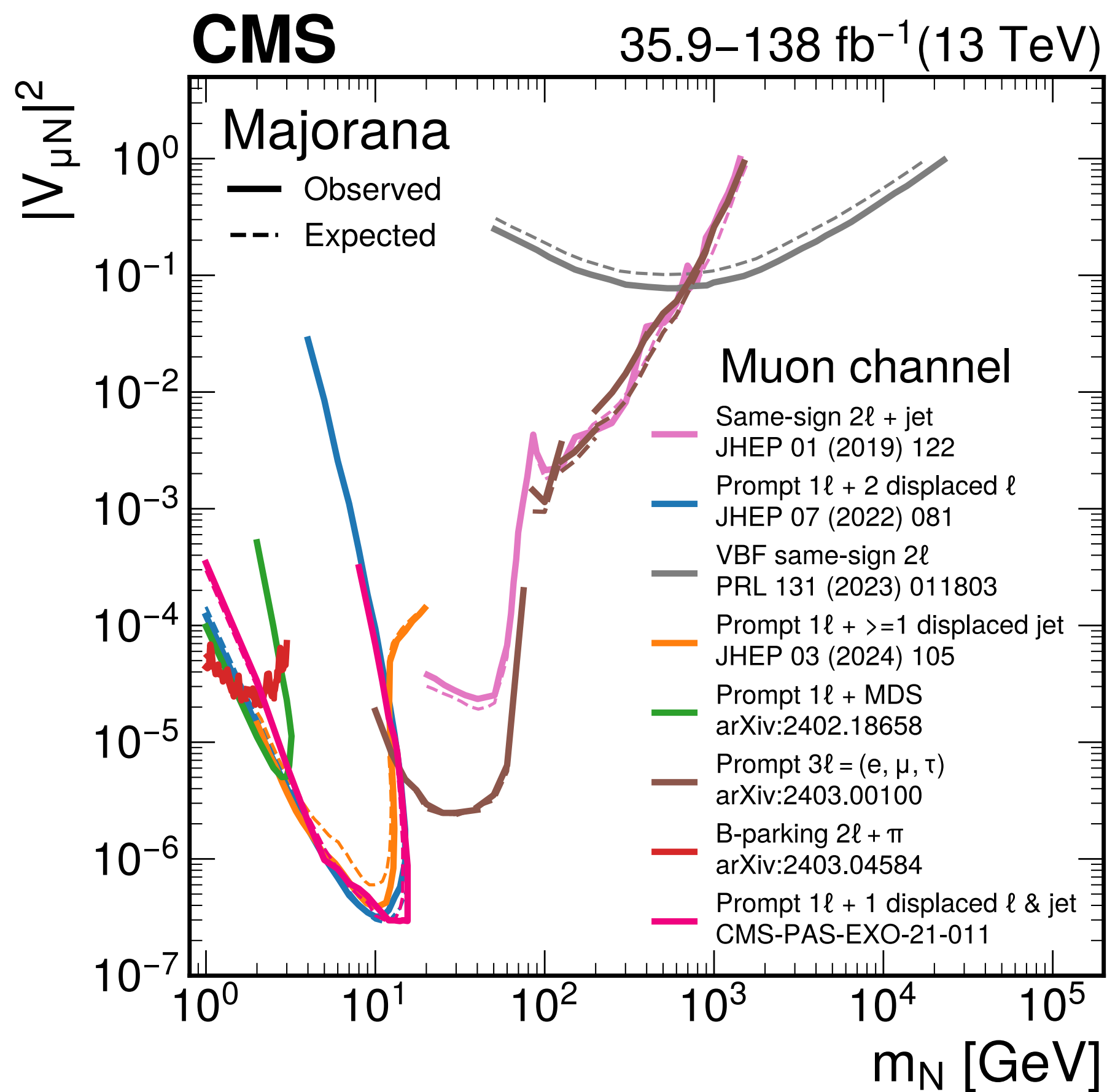


Summer 2022

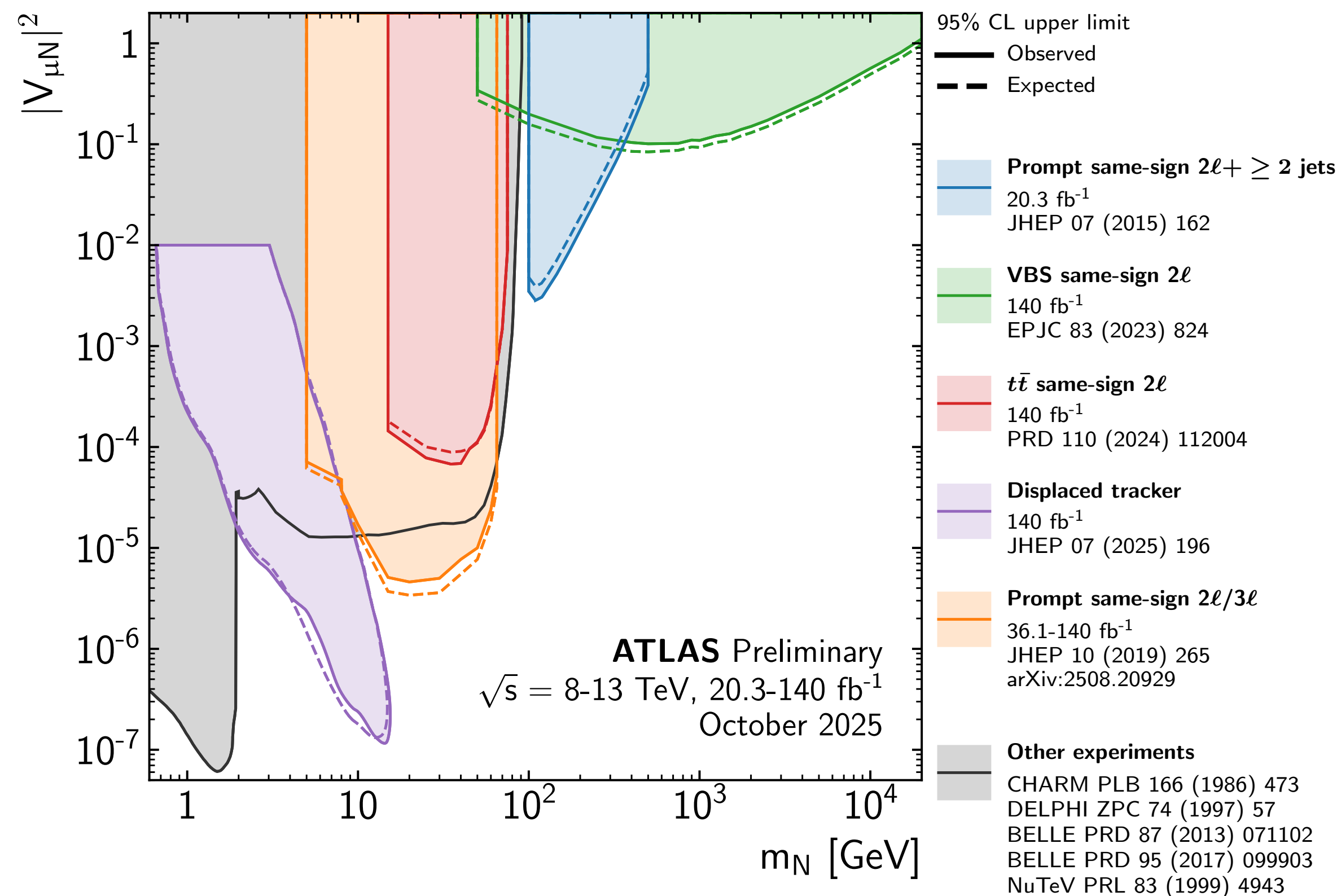
# Heavy Neutral Leptons



## CMS Summary Plots EXO-23-006



## ATLAS Summary Plots ATL-PHYS-PUB-2025-038



Spring 2024 - 2025

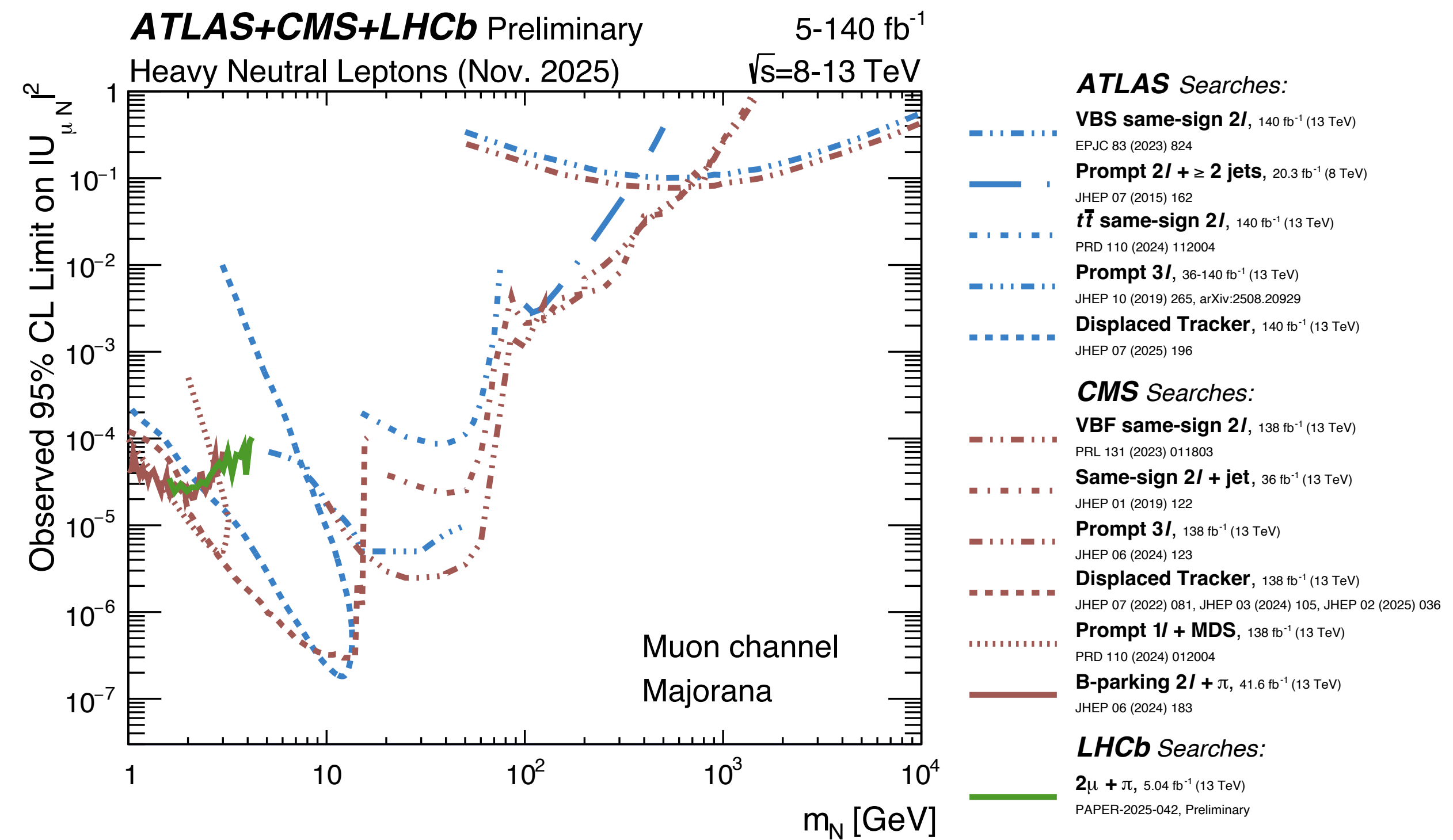
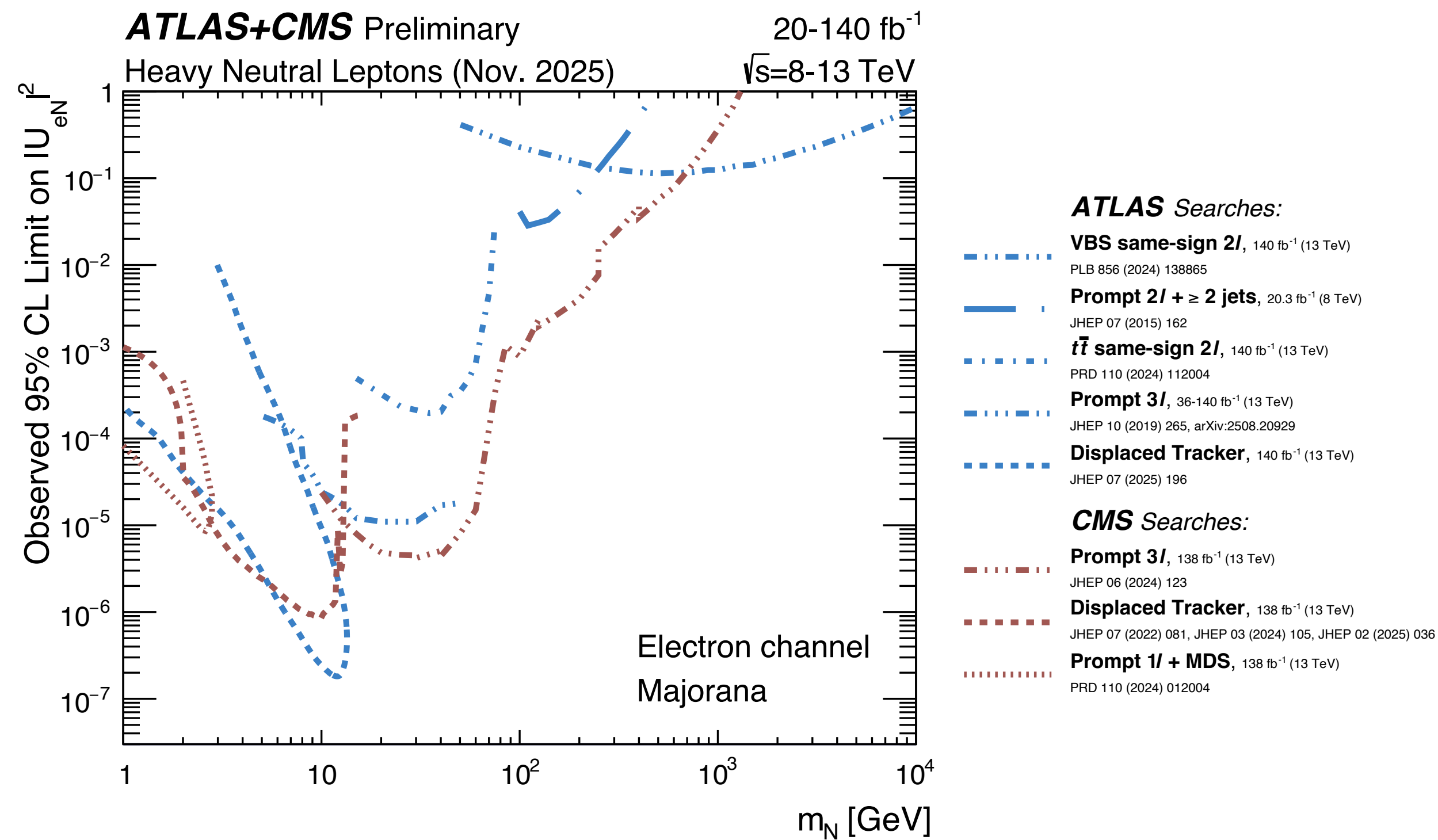
# HNL Summary Plots

Most sensitive individual ATLAS, CMS and LHCb results



## First generation lepton ( $|U_{eN}|^2$ )

## Second generation lepton ( $|U_{\mu N}|^2$ )



Links from [ATLAS](#), [CMS](#), [LHC BSM WG](#)

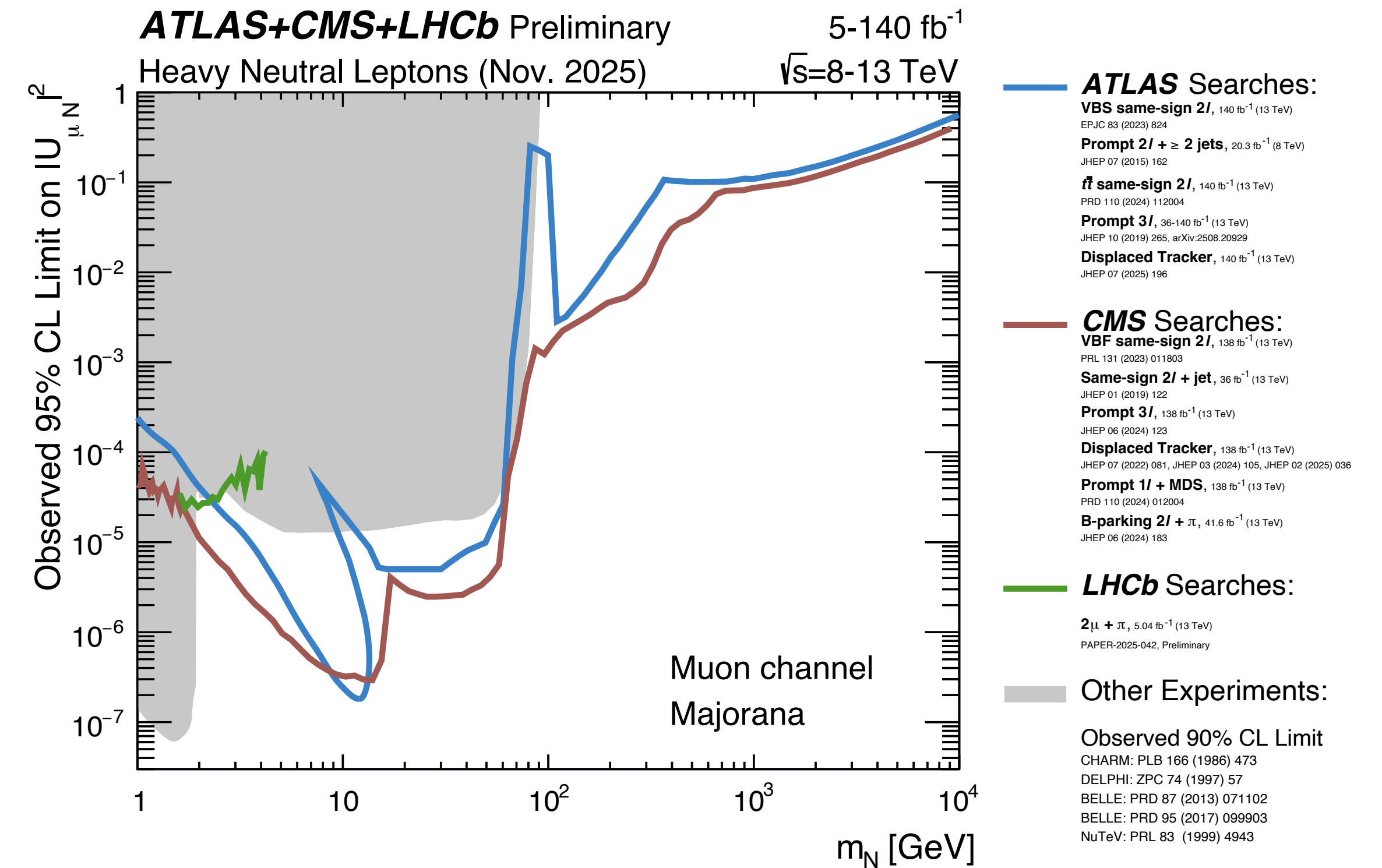
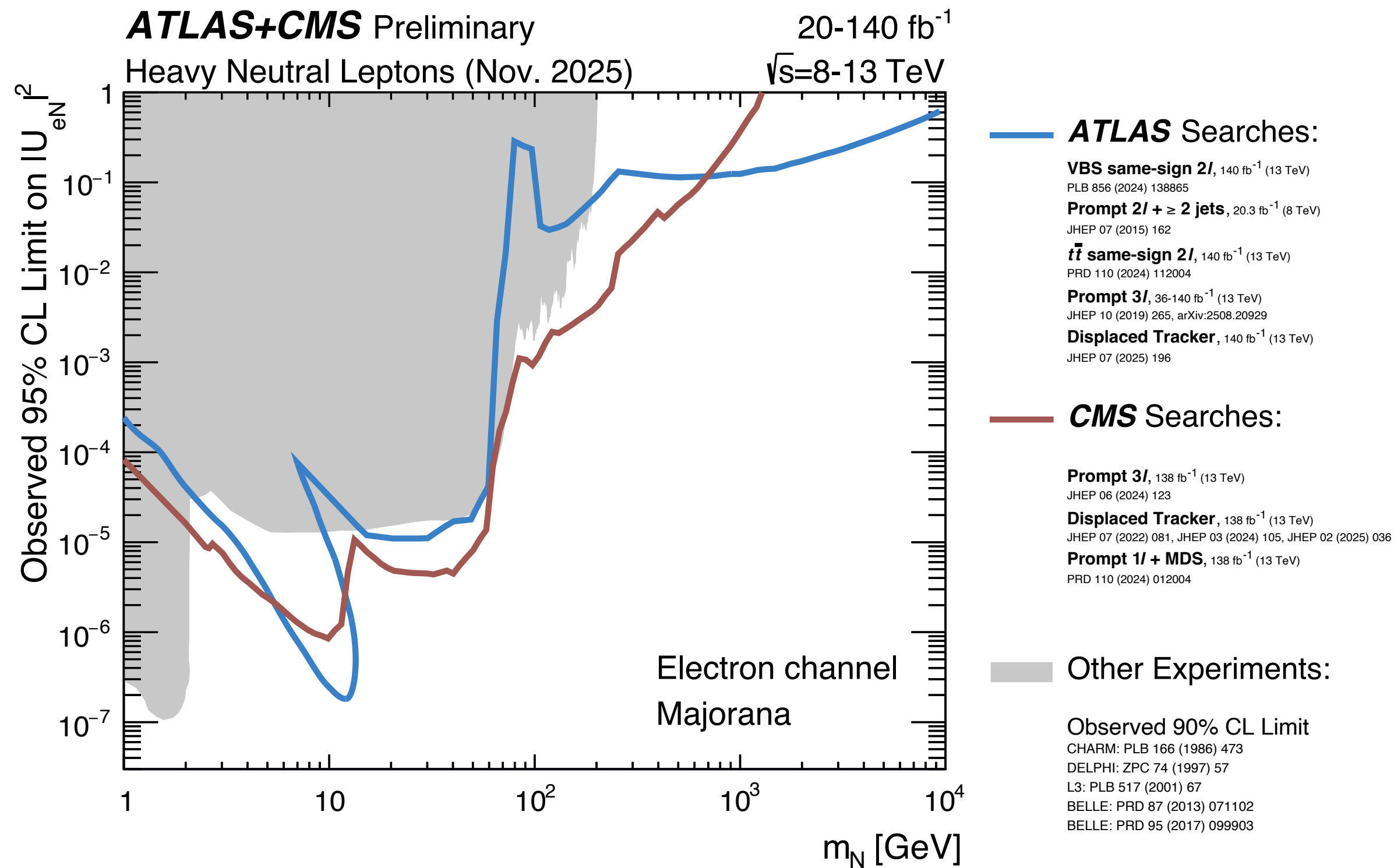
# HNL Summary Plots

Envelope of the best exclusions  
for each experiment



First generation lepton ( $|U_{eN}|^2$ )

Second generation lepton ( $|U_{\mu N}|^2$ )



\* included grey areas for regions excluded by other experiments to demonstrate unique parameter space probed at the LHC are unique

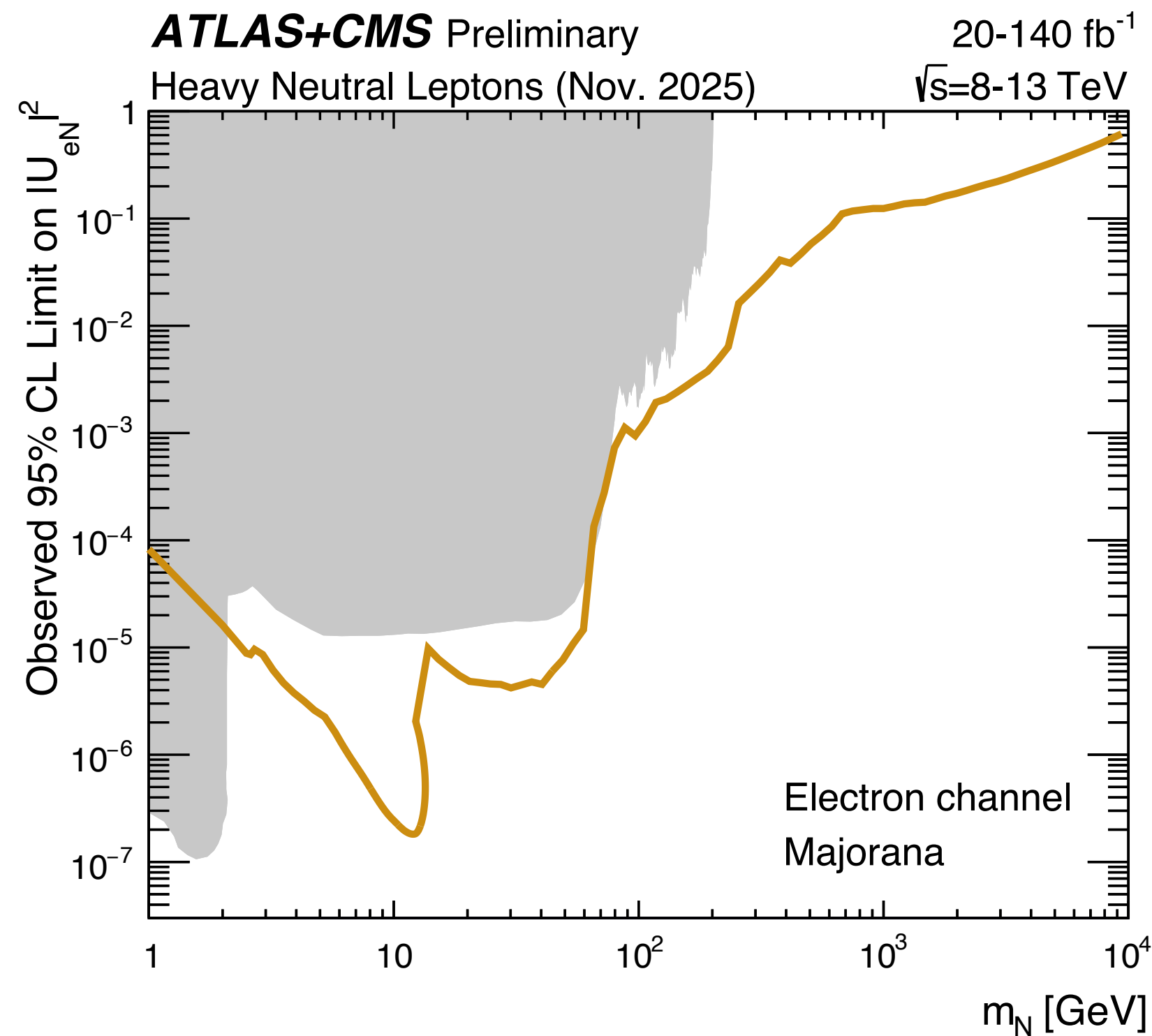
Links from [ATLAS](#), [CMS](#), [LHC BSM WG](#)

# HNL Summary Plots

Envelope of the best exclusions from CMS, ATLAS and LHCb denoted as “LHC “best”

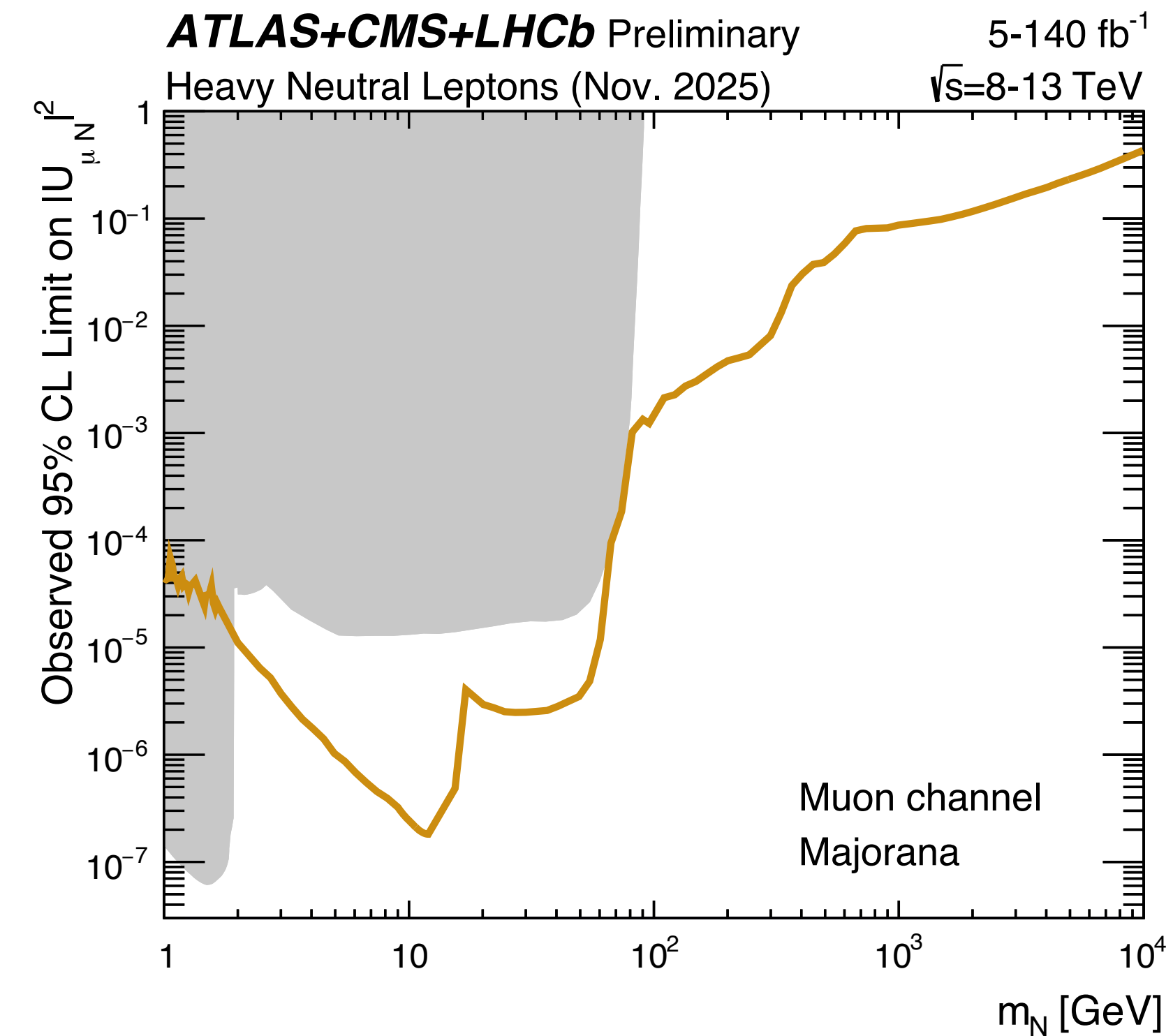


## First generation lepton ( $|U_{eN}|^2$ )



- LHC best
- ATLAS: PLB 856 (2024) 138865
  - ATLAS: JHEP 07 (2015) 162
  - ATLAS: PRD 110 (2024) 112004
  - ATLAS: arXiv:2508.20929
  - ATLAS: JHEP 10 (2019) 265
  - ATLAS: JHEP 07 (2025) 196
  - CMS: JHEP 06 (2024) 123
  - CMS: JHEP 02 (2025) 036
  - CMS: JHEP 07 (2022) 081
  - CMS: PRD 110 (2024) 012004
  - CMS: JHEP 03 (2024) 105
- Other Experiments:
- Observed 90% CL Limit
- CHARM: PLB 166 (1986) 473
- DELPHI: ZPC 74 (1997) 57
- L3: PLB 517 (2001) 67
- BELLE: PRD 87 (2013) 071102
- BELLE: PRD 95 (2017) 099903

## Second generation lepton ( $|U_{\mu N}|^2$ )



- LHC best
- ATLAS: EPJC 83 (2023) 824
  - ATLAS: JHEP 07 (2015) 162
  - ATLAS: PRD 110 (2024) 112004
  - ATLAS: arXiv:2508.20929
  - ATLAS: JHEP 10 (2019) 265
  - ATLAS: JHEP 07 (2025) 196
  - CMS: PRL 131 (2023) 011803
  - CMS: JHEP 01 (2019) 122
  - CMS: JHEP 06 (2024) 123
  - CMS: JHEP 02 (2025) 036
  - CMS: JHEP 07 (2022) 081
  - CMS: PRD 110 (2024) 012004
  - CMS: JHEP 03 (2024) 105
  - CMS: JHEP 06 (2024) 183
  - LHCb: PAPER-2025-042, Preliminary
- Other Experiments:
- Observed 90% CL Limit
- CHARM: PLB 166 (1986) 473
- DELPHI: ZPC 74 (1997) 57
- BELLE: PRD 87 (2013) 071102
- BELLE: PRD 95 (2017) 099903
- NuTeV: PRL 83 (1999) 4943

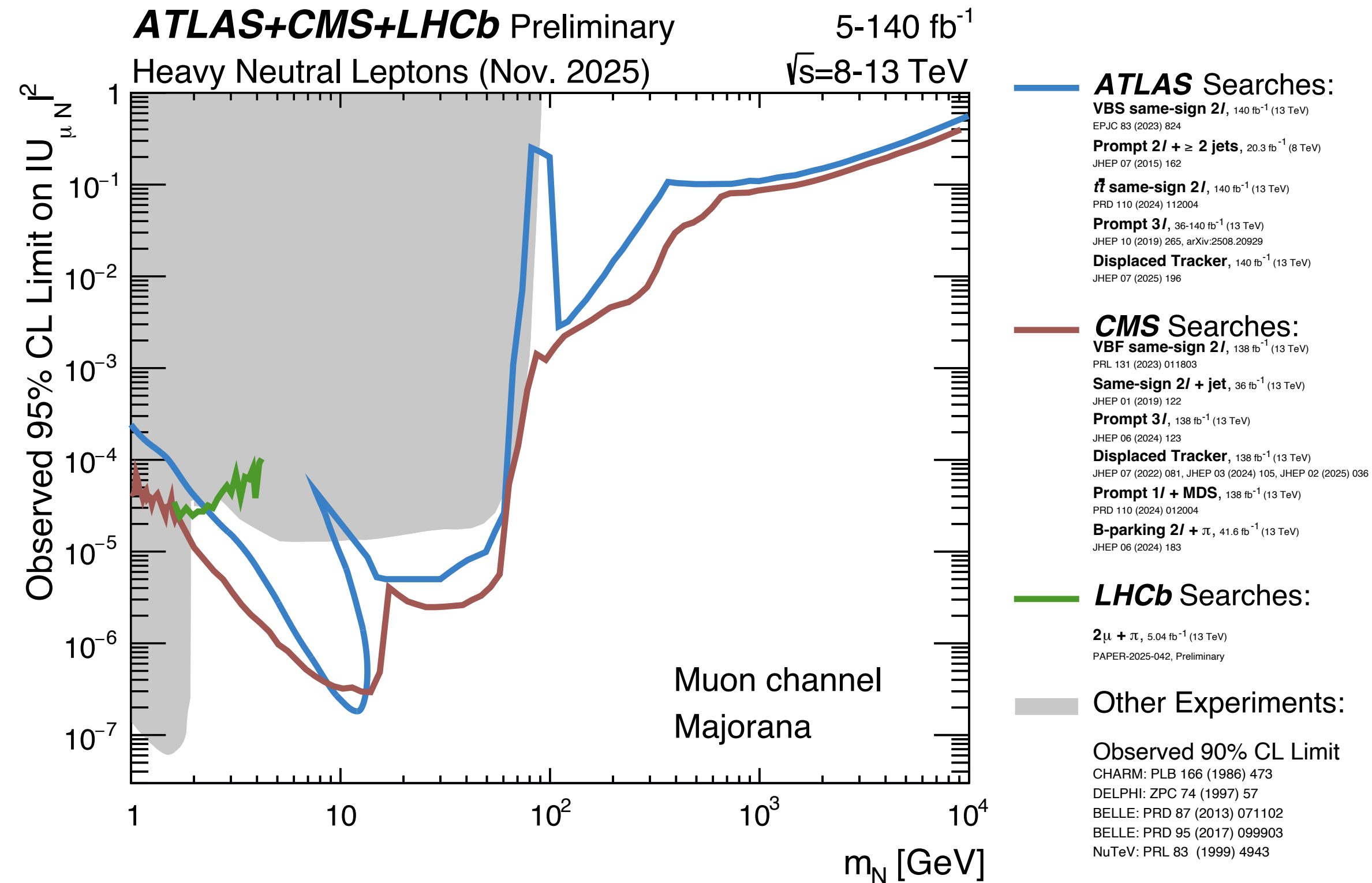
\* included grey areas for regions excluded by other experiments to demonstrate unique parameter space probed at the LHC are unique

Links from [ATLAS](#), [CMS](#), [LHC BSM WG](#)

# Summary



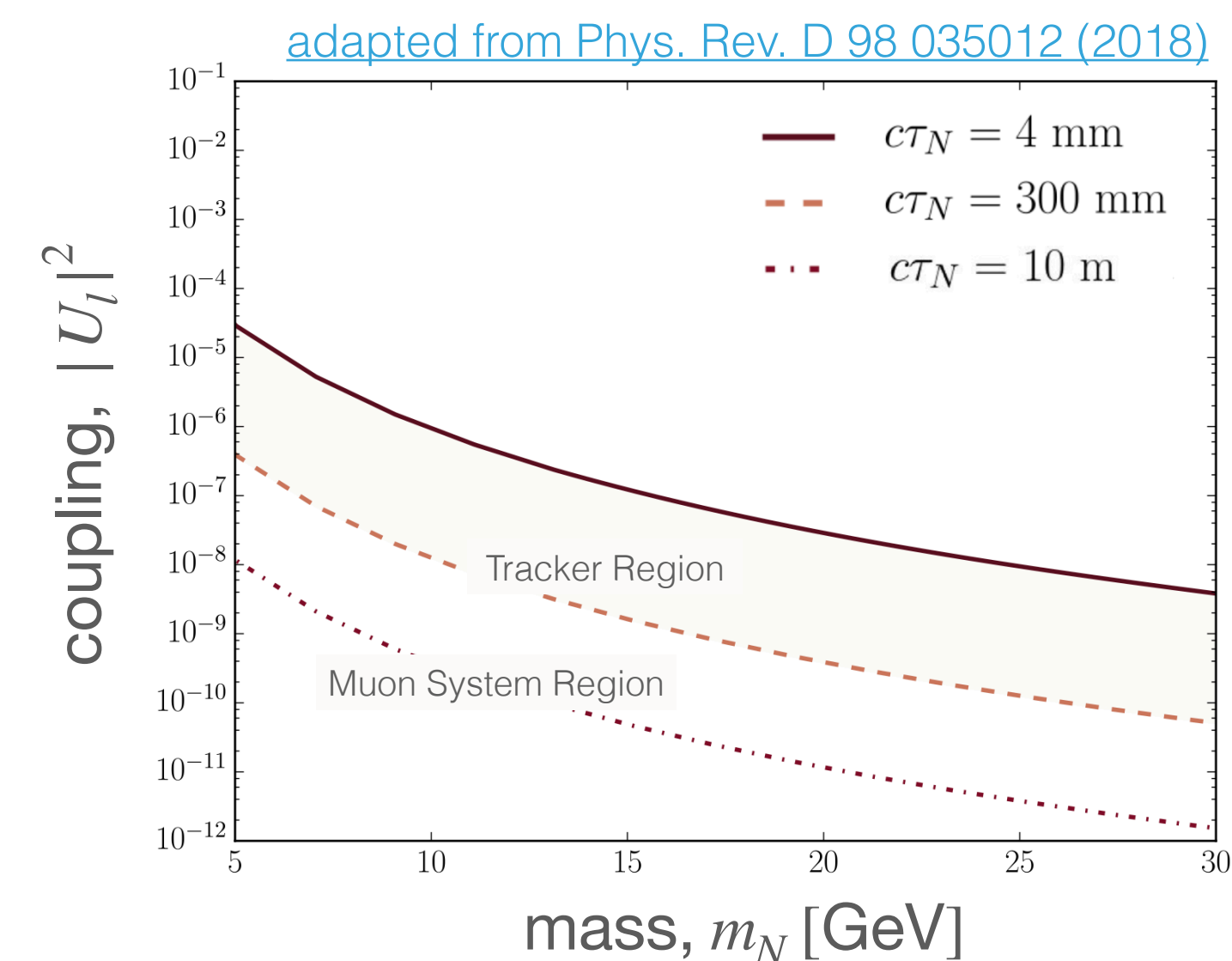
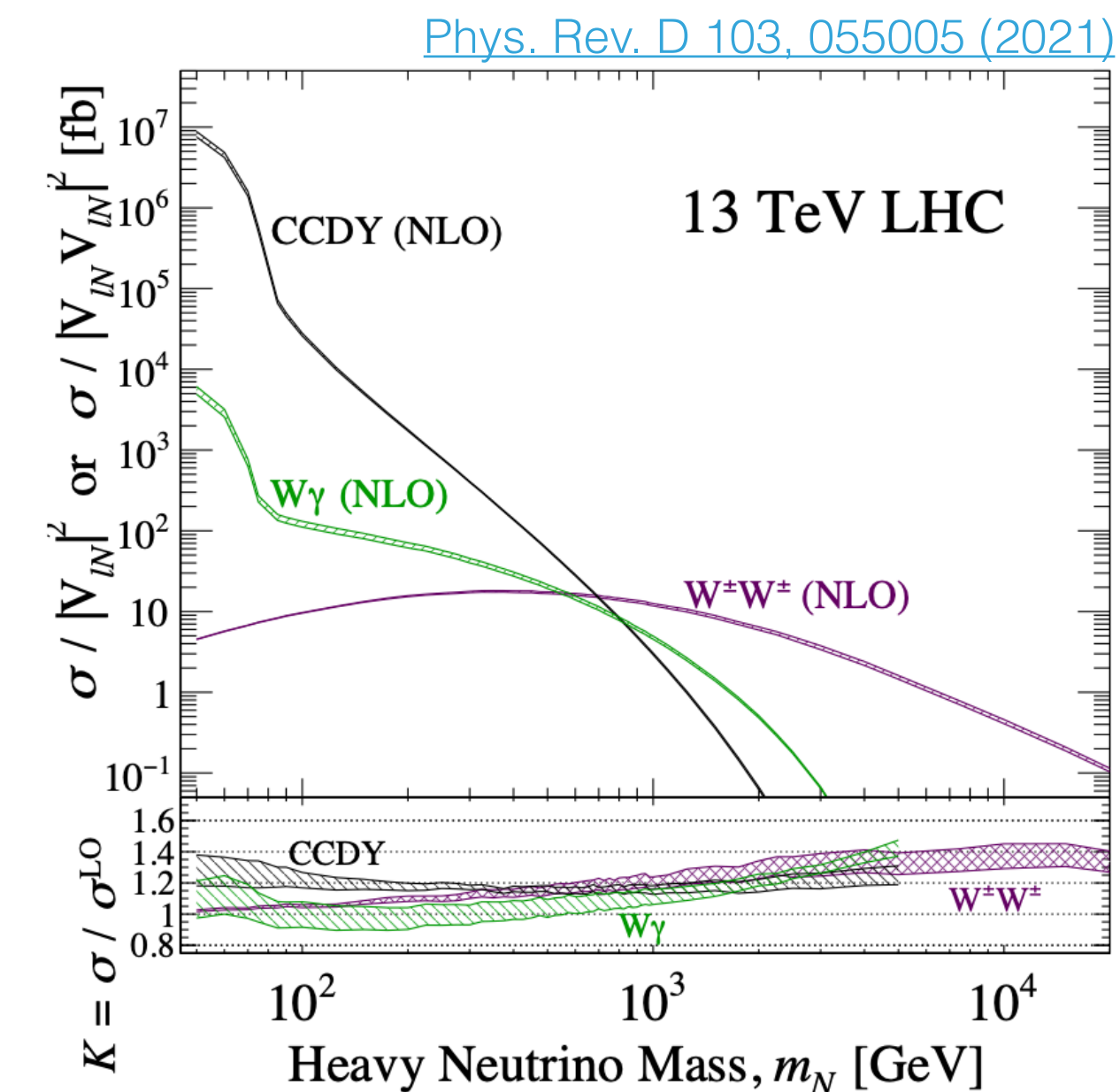
- In the context of a “Roadmap to summary plots and reinterpretation for LLP searches” a joint LHC summary plot effort is underway
- HNL summary plots presented for the first time today!
  - ▶ Also the first (?) example of joint ATLAS+CMS+LHCb summary plot (at least that I am aware of!)



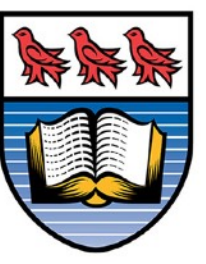
# Discussion 1



- Two examples now of summary plots across LHC experiments. With this in mind, when is a good moment to update the LHC LLP summary plots? They should not get outdated
- **Extensions** to HNL summary plots (could be done now):
  - ▶ Consider should 1st and 2nd generation mixing on the same plot to compare (e.g. muon vs electron channels)
  - ▶ Consider showing expected and observed limits
  - ▶ Consider doing a LHC best plot showing the cross-section of the different production modes of the HNL that are relevant for LHC searches or constant  $c\tau$  lines

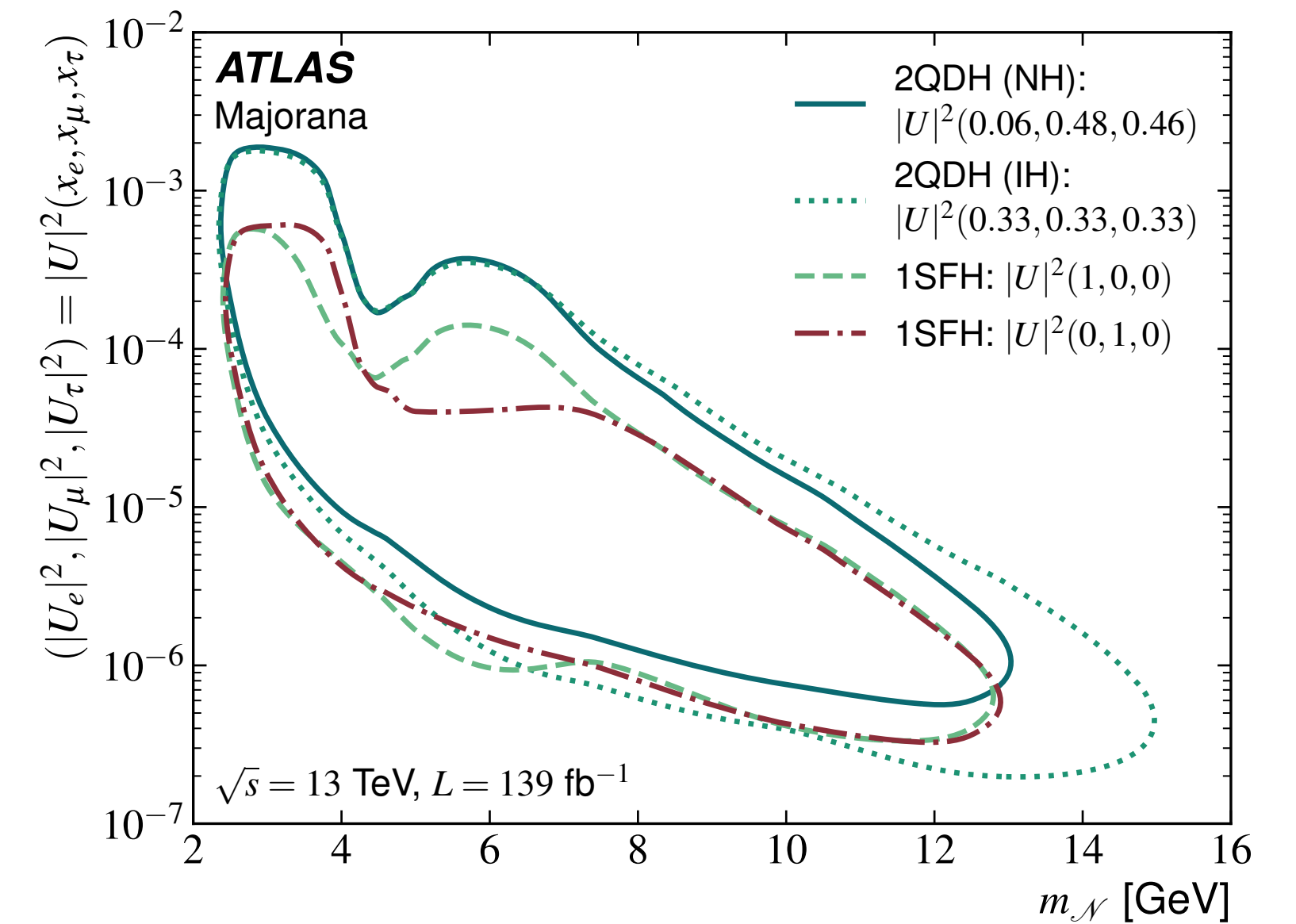
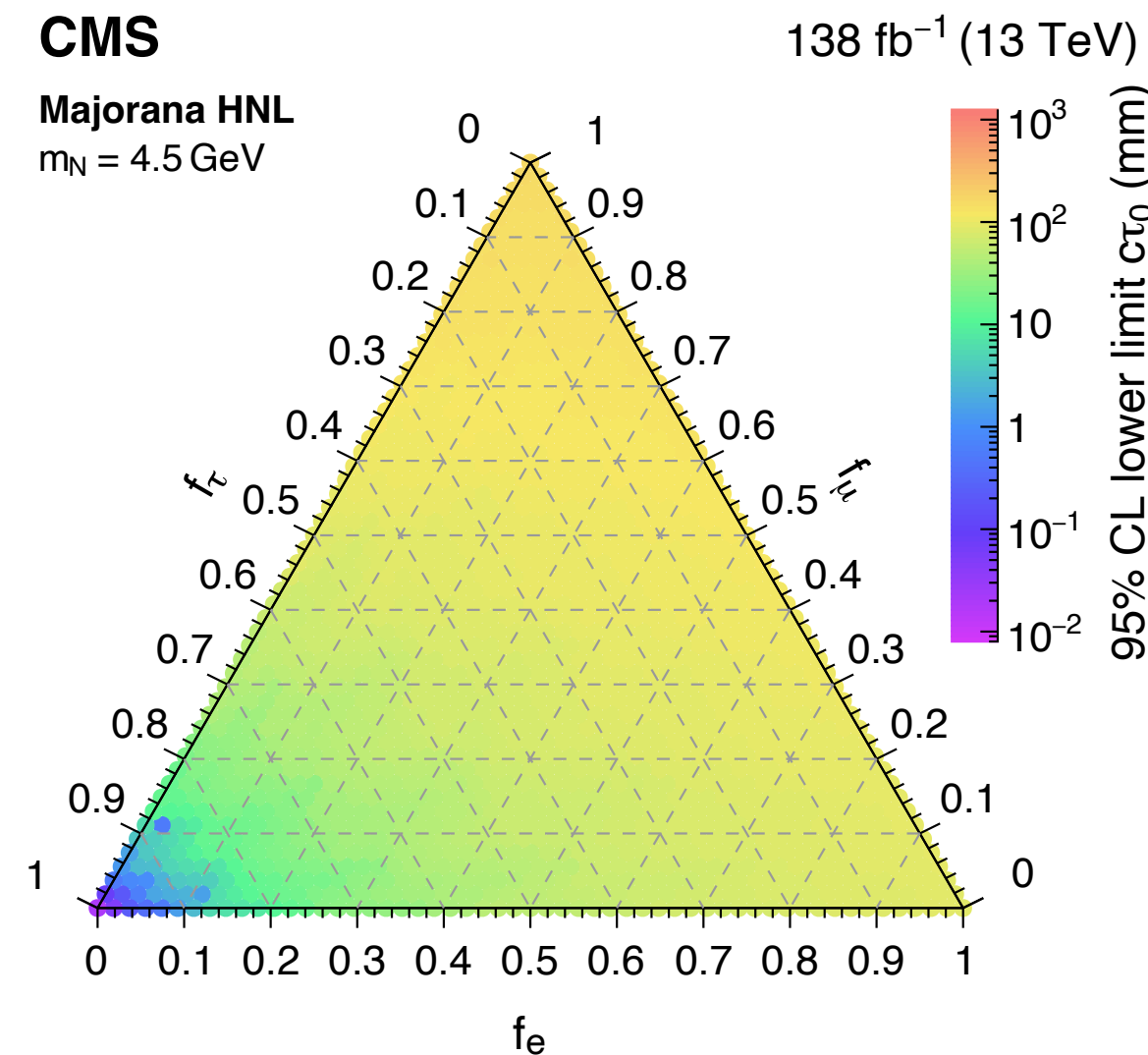
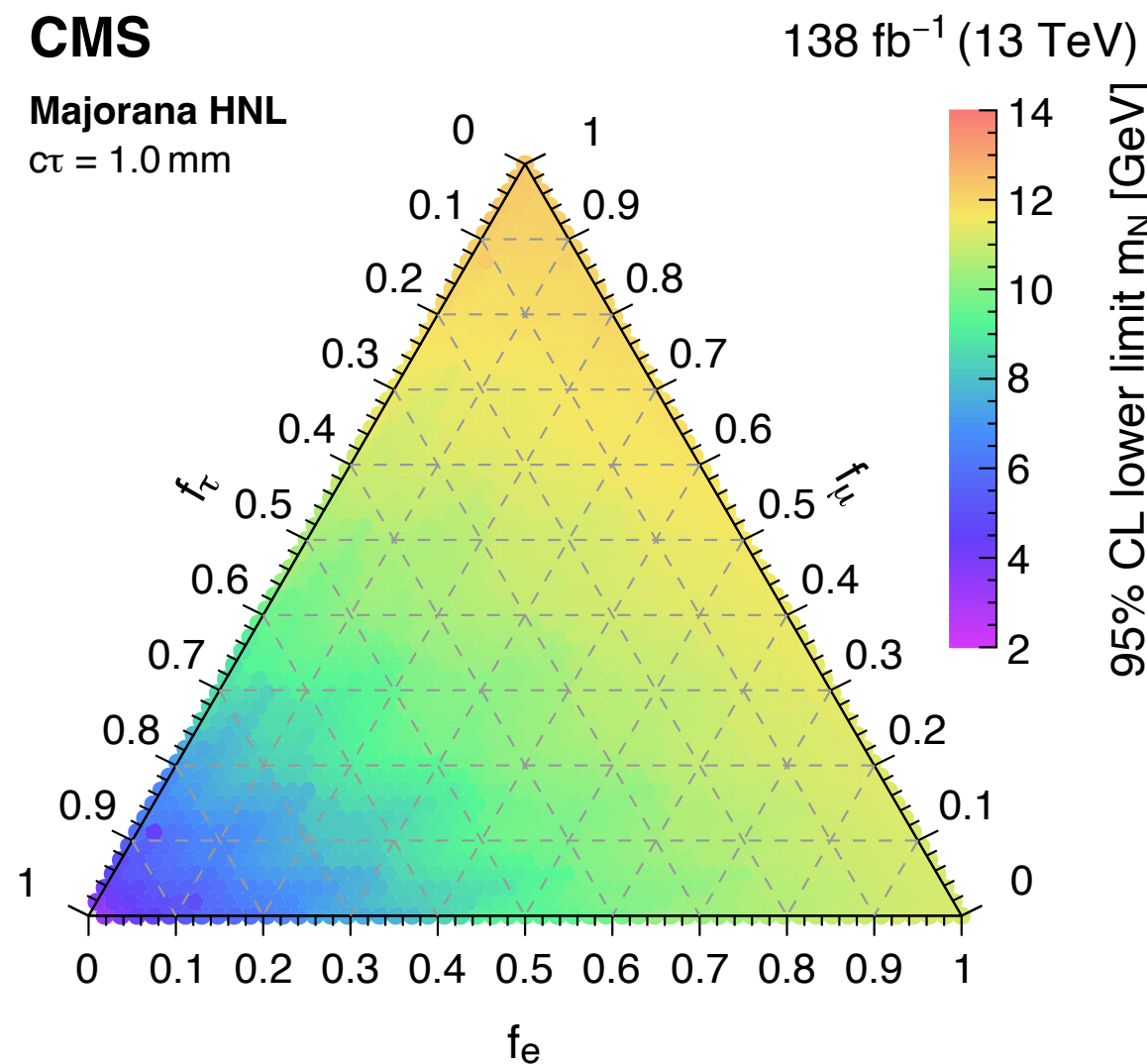
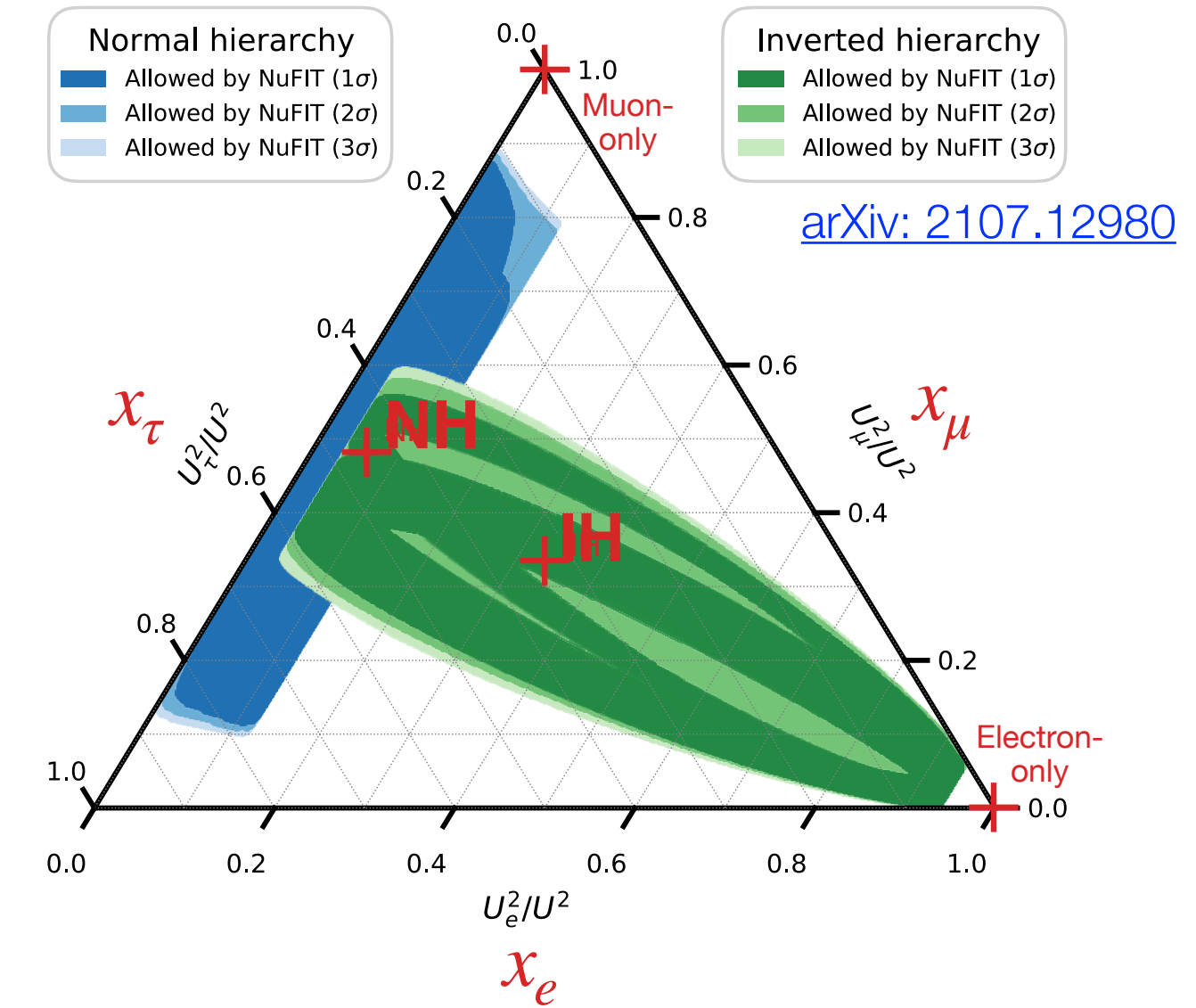


# Discussion 2



- **Extensions** to HNL summary plots (for the future):

- ▶ Extend to tau sector (missing input from ATLAS)
- ▶ Providing limits for realistic coupling scenarios
  - ATLAS examples with fixed mixing ratio; CMS examples with fixed mass/ $c\tau$  and varying mixing ratios
  - Not (currently) available for all searches
  - Should discuss and converge on benchmarks for the LHC?
  - Need ways to compare with the past (single-flavour mixing), but also more motivating to look at sensitivity to realistic models moving forward





- Thoughts on which benchmarks to next address? Original list from 2022 ~ ordered by complexity?

1.  ~~$H \rightarrow SS; S \rightarrow bb, qq, \tau\tau$ , for hadronic searches~~

2. ~~HNLs~~

3.  $H \rightarrow Z_D Z_D$ ; with  $B(Z_D)$  from Hidden Abelian Higgs model (HAHM), for leptonic searches

4. GMSB SUSY

5. RPV SUSY

- Other ideas?

# Backups

## Mixing scenario benchmarks:

- Simple model: One HNL with single-flavour mixing (1SFH)
  - ▶ **Muon-only** mixing ( $|U_\mu|^2$ )
  - ▶ **Electron-only** mixing ( $|U_e|^2$ )
- Realistic scenario: Two quasi-degenerate HNLs with  $m_1 \sim m_2$  (2QDH)
  - ▶ **Inverted hierarchy (IH)** mixing ( $|U|^2$ )
  - ▶ **Normal hierarchy (NH)** mixing ( $|U|^2$ )

$$|U|^2 = \sum_{\alpha=\mu,e,\tau} |U_\alpha|^2$$

$$x_\alpha = |U_\alpha|^2 / |U|^2$$

“Realistic” multi-flavour mixing models consistent with neutrino oscillations data

