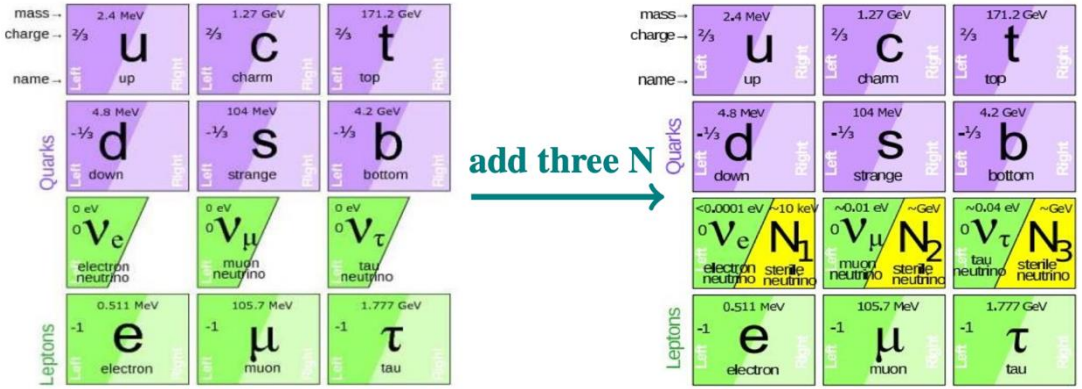
PPG BSM: HNLs

Annapaola De Cosa (ETH Zürich)
Roberto Franceschini (Roma Tre U. and INFN)
Lesya Shchutska (EPFL)
on behalf of the PPG BSM WG

Heavy neutral leptons (HNLs)

- right-handed neutrinos N are an example of fermionic “dark sector”

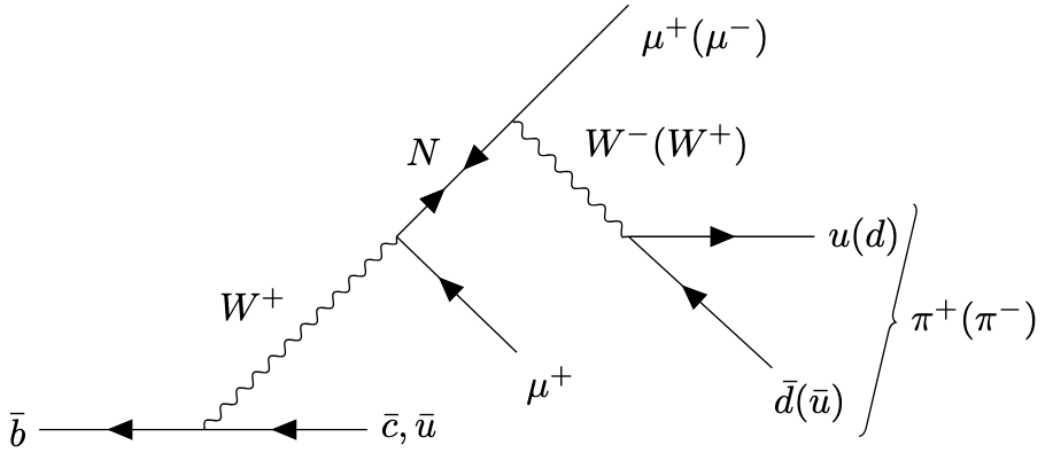


M. Shaposhnikov et al

- νMSM – a minimal extension of the SM by adding N_1, N_2, N_3
- provides a **dark matter particle N_1**:
  - very long-lived, decays visibly as $N_1 \rightarrow \nu\gamma$
- N_2 and N_3 can explain the **matter dominance of the Universe**
- N_2 and N_3 can be found with conventional detectors at colliders

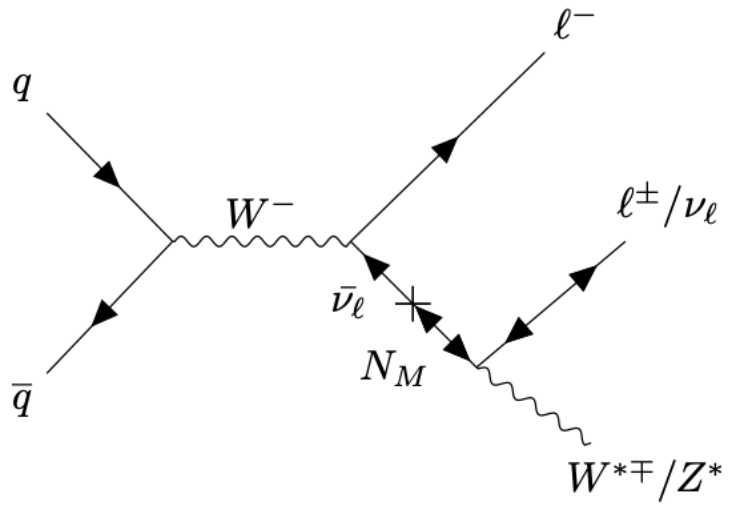
HNLs at colliders

Production in hadron decays



Explored by the beam-dump experiments,
neutrino experiments, B-factories, LHC experiments

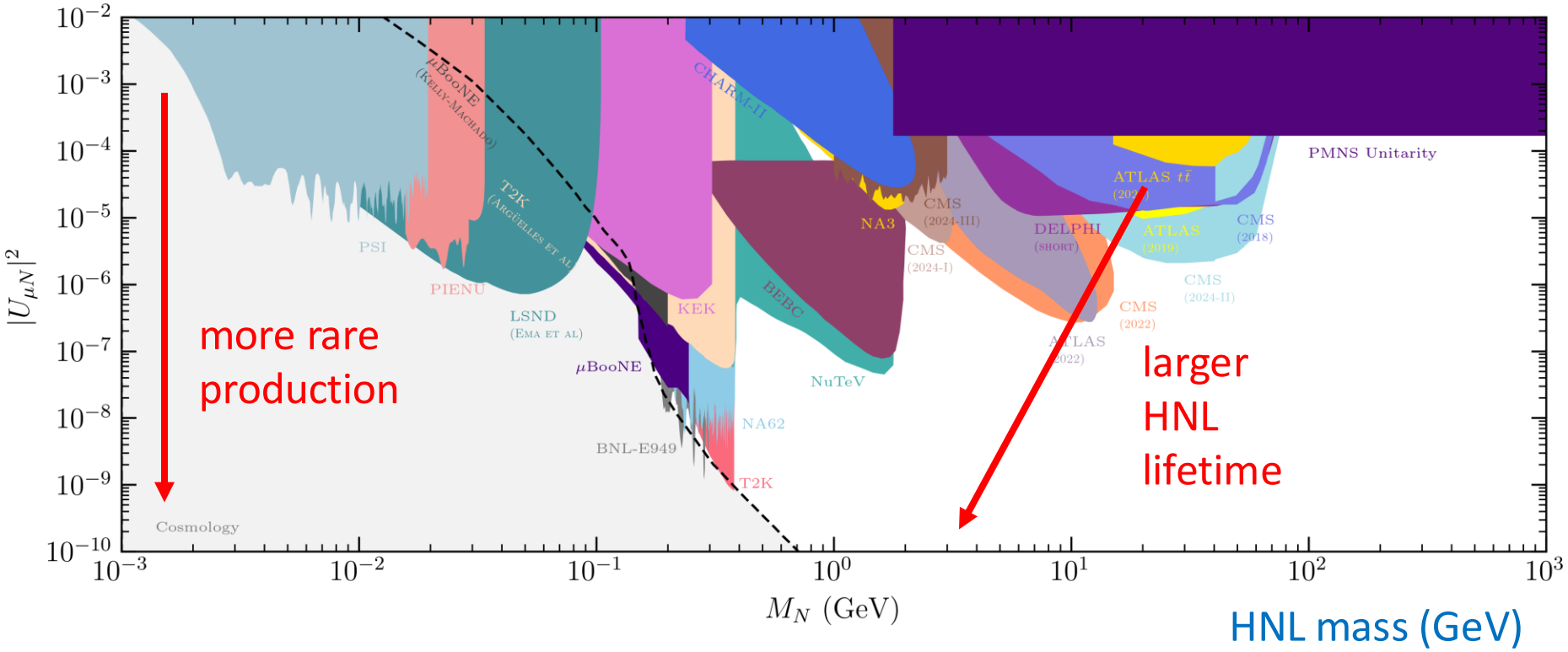
Production in on-shell boson decays or boson-mediated



Explored by the LHC experiments,
future electron, muon and hadron colliders

Allowed parameter space of HNLs

feeble interaction:
mixing with
active neutrinos



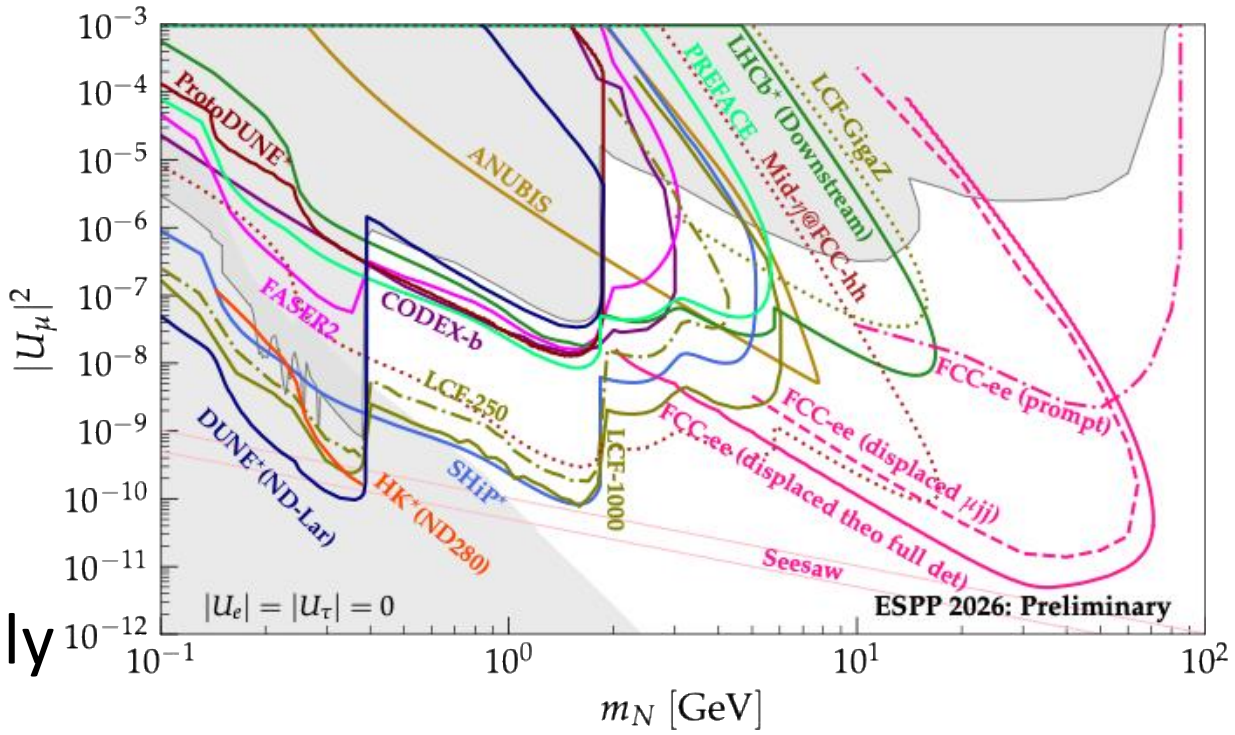
- the value of mixing with active neutrinos is constrained from cosmology and seesaw mechanism
- can be as low as 10^{-12}
- both prompt and displaced signatures in a detector have to be considered
- exploring all allowed parameter space is not possible with just one instrument

Heavy Neutrino Limits

Muon-coupling-dominance U_e:U_μ:U_τ = 0:1:0

- low masses (below *b* mass) dominated by beam-dump experiments:
  - SHiP
  - LCF beam dump

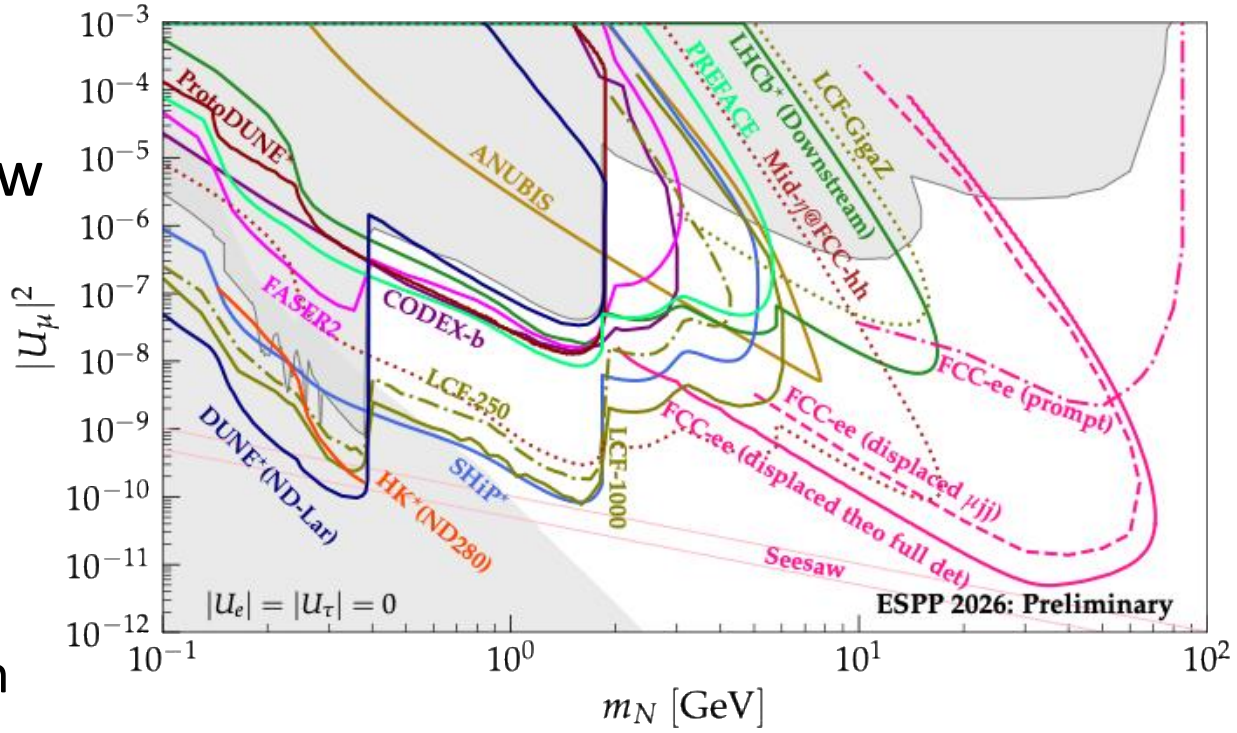
  or off-axis, shielded detectors:
  - FASER2
  - CODEX-b
- below the kaon mass (but cosmologically disfavored): near detectors of neutrino facilities:
  - DUNE
  - Hyper-K



PBC BC7 U_e:U_μ:U_τ = 0:1:0

Muon-coupling-dominance U_e:U_μ:U_τ = 0:1:0

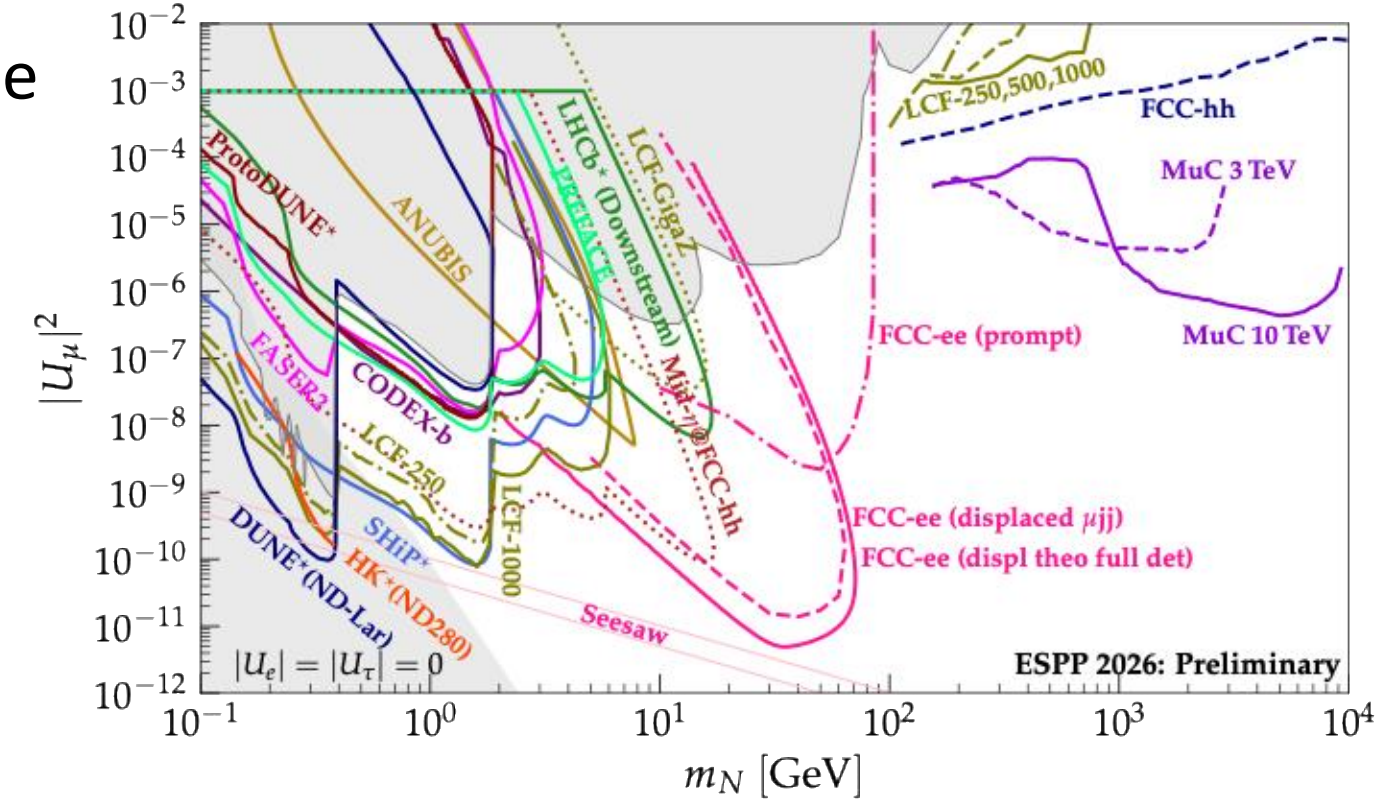
- intermediate masses (below Z boson) dominated by the FCC-ee at the Z-pole
  - both for prompt and displaced searches
- hadron-collider-based experiments allow going above *b* mass:
  - (HL-)LHC exps., e.g. LHCb (Downstream)
  - ANUBIS
  - PREFACE
- full FCC-hh reach is still to be explored:
  - mid-η@FCC-hh shows a potential for a dedicated LLP detector outside of the main FCC-hh experiment
- as dedicated detectors target displaced HNLs, the reach is limited to ~20 GeV



PBC BC7 U_e:U_μ:U_τ = 0:1:0

Muon-coupling-dominance U_e:U_μ:U_τ = 0:1:0

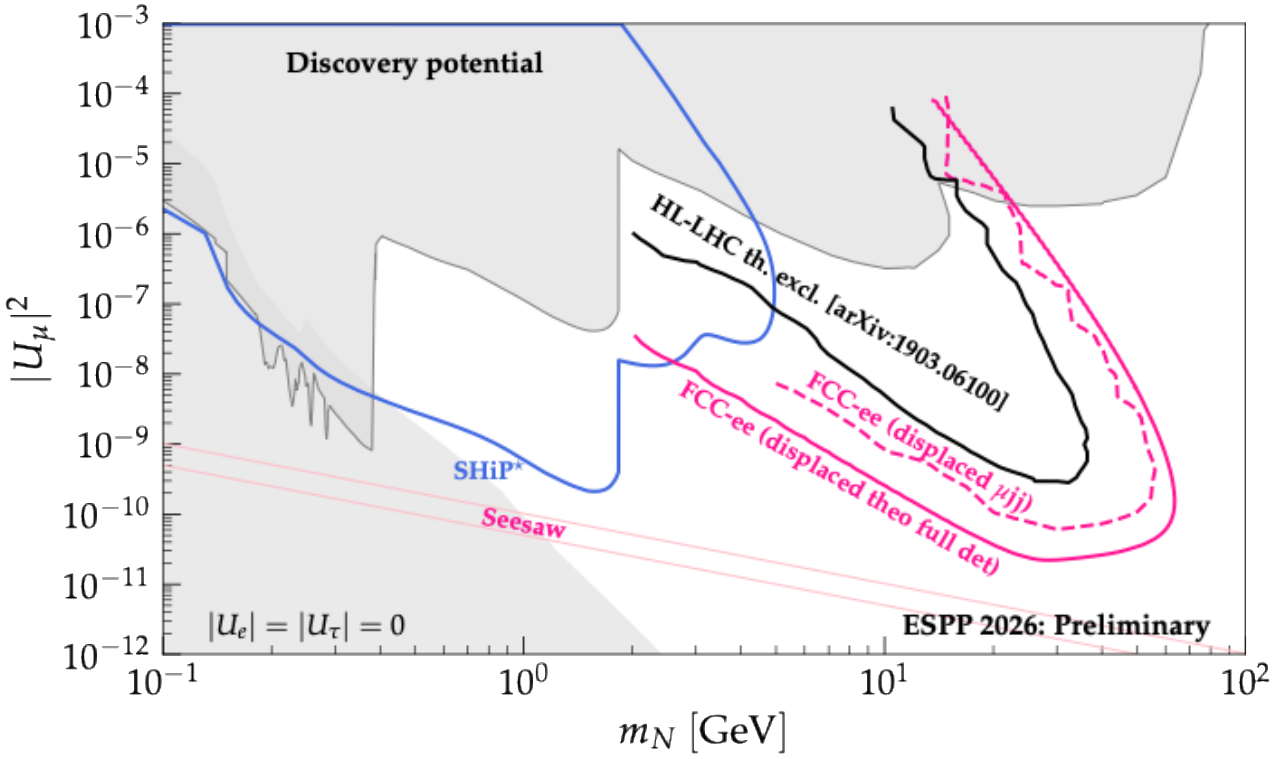
- masses above 100 GeV become accessible with high-energy colliders:
  - LCF-250, 500, 1000
  - FCC-hh
  - muon collider



PBC BC7 U_e:U_μ:U_τ = 0:1:0

Discovery potential

- A significant part of the allowed parameter space below 100 GeV is within the discovery reach of
  - SHiP
  - FCC-ee at the Z-pole
- More than an order of magnitude in coupling strength for a discovery post-HL-LHC!



PBC BC7 U_e:U_μ:U_τ = 0:1:0

Summary

- HNLs are comprehensively searched by facilities throughout the entire experimental spectrum of particle physics and cosmology:
  - neutrino, beam-dump, collider experiments, including dedicated detectors
- Existing LHC experiments allow probing interesting parameter space for intermediate masses
- Ultimate sensitivity for masses up to 5 GeV is ensured by **SHiP,** and up to 90 GeV can be delivered by the **FCC-ee**
  - In case of discovery, these experiments will be able to study HNL parameters
  - **FCC-hh** has an immense potential as a neutrino source to be explored
- Higher masses require going to new energy frontiers with a lepton or hadron collider

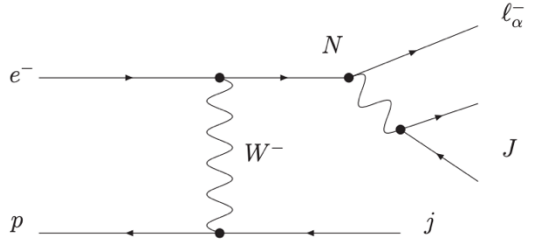
Considered inputs

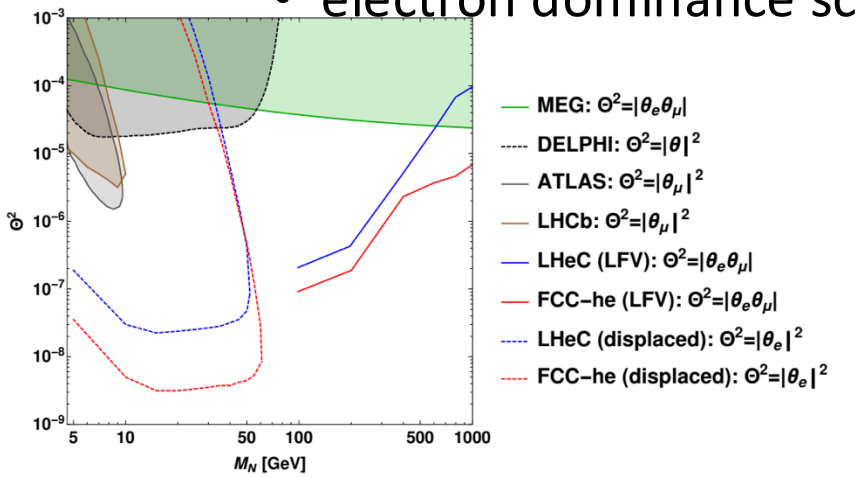
- 19: The Forward Physics Facility at the Large Hadron Collider
- 44: Proposal for a shared transverse LLP detector for FCC-ee and FCC-hh and a forward LLP detector for FCC-hh: only tau dominance (BC8), not used
- 81: Discovery potential of LHCb Upgrade II
- 118: The DUNE Science Program
- 140: LC vision: input adapted to provide BC7 (muon dominance)
- 141: The ECFA Higgs/Electroweak/Top Factory Study
- 145: SHiP experiment at the SPS Beam Dump Facility
- 207: The Muon Collider
- 235: Summary Report of the Physics Beyond Colliders Study at CERN
- 214: The Large Hadron electron Collider (LHeC) as a bridge project for CERN: only electron (BC6), or electron-muon dominance, not used
- 227: Prospects for physics at FCC-hh
- 233: FCC Integrated Programme Stage 1: The FCC-ee
- 242: Prospects in BSM physics at FCC
- 247: FCC Integrated Programme Stage 2: The FCC-hh

LHeC input on HNLs: electron dominance

- The Large Hadron electron Collider (LHeC) as a bridge project for CERN
  - https://indico.cern.ch/event/1439855/contributions/6461616/
  - “Portals (dark photon, dark higgs, HNLs, axions, ALPs): see Briefing Book 2020”
  - “Constraints can be placed on ALPs, see Fig. 14 [1], and also section 8.4.4 in [8].”

- [8] arXiv:2007.14491
- HNLs are taken from [653] arXiv:1908.02852
  - interpretations are for electron dominance or with equal electron-muon couplings
  - no muon dominance by construction
- [654] arXiv:1811.04291
  - electron dominance scenarios





LC sensitivity to high-mass HNL: electron case

- For the electron dominance scenario, much higher sensitivity to high-mass HNLs:
  - dominated by t-channel W exchange for electron coupling
- Considered scenarios:
  - 2 ab^{-1} at 250 GeV, 4 ab^{-1} at 500 GeV and 8ab^{-1} at 1TeV
  - use $e^-_L e^+_R$ data only (900 fb^{-1}, 1.6 ab^{-1}, 3.2 ab^{-1}, respectively)