HNL Production From New Gauge Interactions at Forward Physics Facilities

By: Francis Burk

PIKIMO 2026

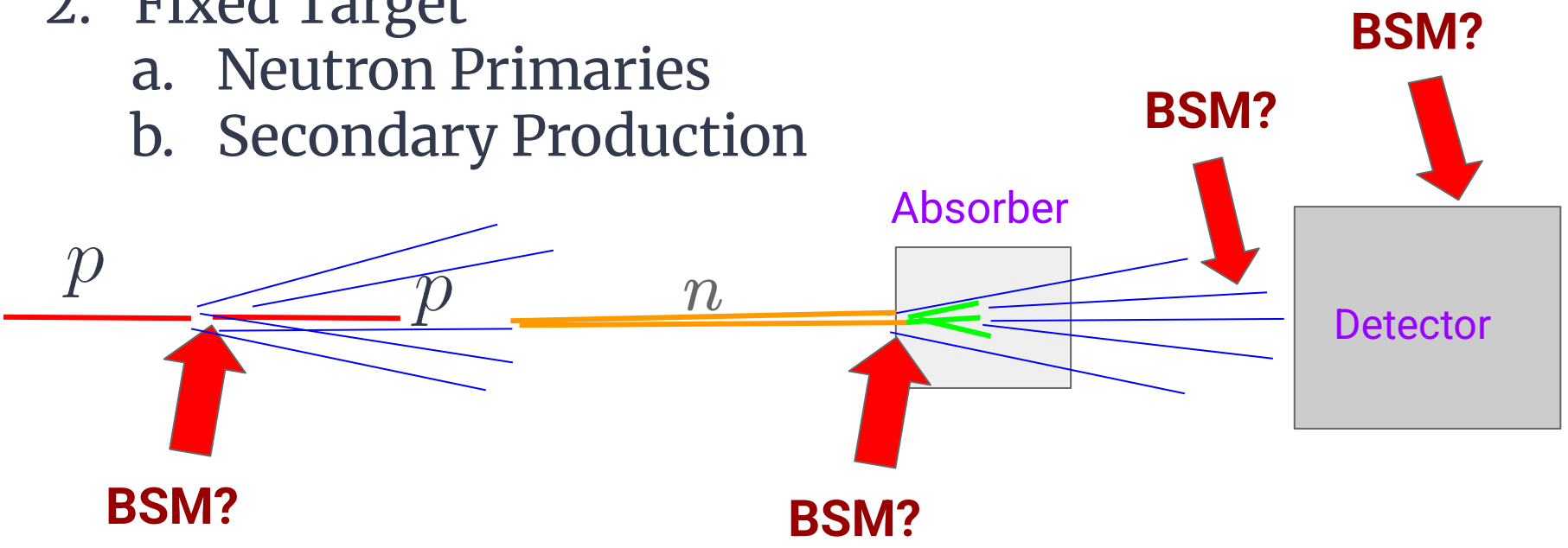
Coauthors: P.S. Bhupal Dev, Bhaskar Dutta, Tao Han, Aparajitha Karthikeyan, Doojin Kim

[2610.30240]

Sources of BSM Physics using LHC Forward Physics?

1. ATLAS IP
2. Fixed Target
   a. Neutron Primaries
   b. Secondary Production

Schematic Picture:



1. Event Production

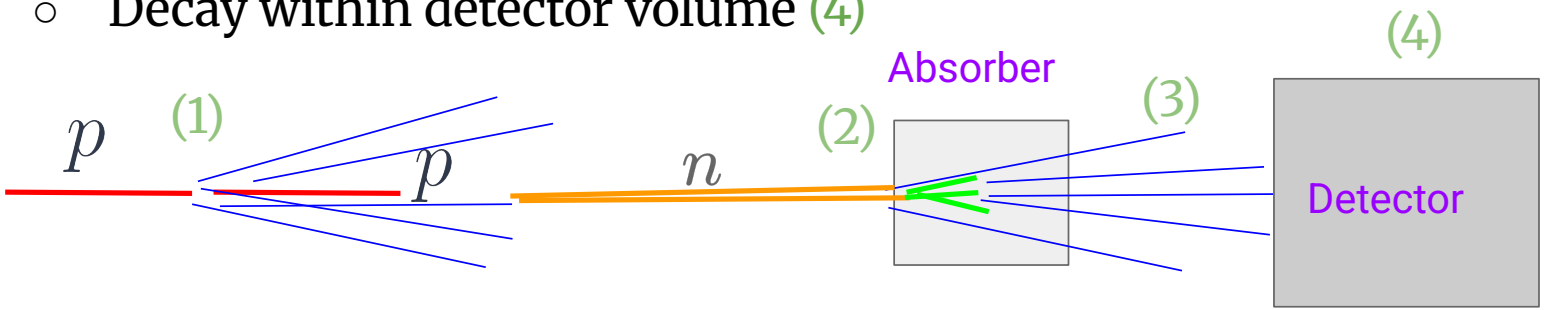
- Event Production rate:

Process Cross Section

Integrated Luminosity

$$N = \sigma \mathcal{L}$$

- Additional considerations:
  - Beam-Beam Collision (1)
  - Fixed Target (2)
  - Long-lived particles (3)
  - Decay within detector volume (4)



How far can we take an HNL and Z’ at Forward Physics Facilities?

2. HNLs from a Z'

Interaction terms

$$\mathcal{L}_X \supset -\frac{1}{4}F'_{\mu\nu}F'^{\mu\nu}+\frac{1}{2}m^2_{Z'}Z'_\mu Z'^\mu+g_X Z'_\mu\left(\sum_f \bar{f}\gamma^\mu(g_{V,f}+g_{A,f}\gamma_5)f+\bar{N}\gamma^\mu(g_{V,N}+g_{A,N}\gamma_5)N\right)$$

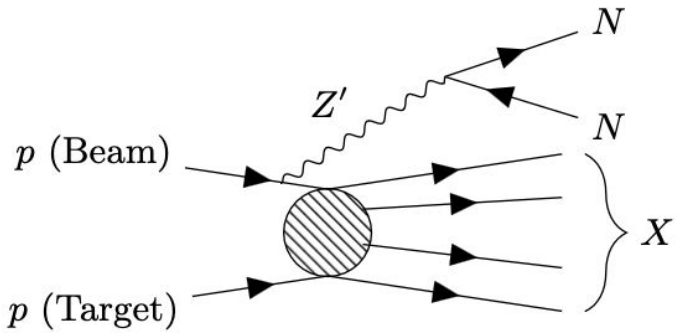
	$g_{V,q}$	$g_{A,q}$	$g_{V,l}$	$g_{A,l}$	$g_{V,N}$	$g_{A,N}$
$U(1)_{B-L}$	1/3	0	−1	0	0	−1
$U(1)_{B-3L_\tau}$	1/3	0	−3	0	0	−1
$U(1)_B$	1/3	0	0	0	0	−1

Rescale results for other similar U(1) models

Contributing Production Modes

3. Proton Bremsstrahlung Production

- Use Quasi-Real ISR
- Compute by sampling:



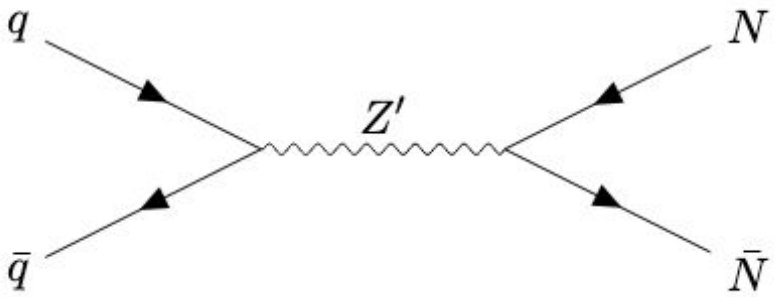
[2410.08981]

$$d\sigma^{p_N p_t \to V f} = \omega_N(z, p_T^2) dz dp_T^2 \times \sigma_{pp}^{\mathrm{NSD}}(s')$$

Splitting function for Z’

3. Drell-Yan Production

- Focus on resonant production of HNLs
- Generate events using WHIZARD



4. Benchmark Experiments

- Studied various experimental scenarios:
  - FASER
  - FASERν
  - FASER2
  - FASERν2

Experiment	Baseline	Transverse size	Fiducial decay length	Luminosity
FASER [6, 50]	480 m	$R = 10$ cm	1.5 m	343 fb^{-1}
FASERν [48, 50]	$\sim$ 480 m	25×30 cm^2	1.0 m	240 fb^{-1}
FASER2 [49, 51, 52]	$\sim$ 650 m	2.6×1 m^2	10 m	3 ab^{-1}
FASERν2 [53, 54]	$\sim$ 640 m	40×40 cm^2	6.6 m	3 ab^{-1}

5. Final States:

- Flavor alignments:

$$(|U_e|^2, |U_\mu|^2, |U_\tau|^2) = |U|^2 \left(\frac{1}{3}, \frac{1}{3}, \frac{1}{3}\right)$$

$$(|U_e|^2, |U_\mu|^2, |U_\tau|^2) = |U|^2 (0, 0, 1)$$

- Studied three types of final states
  - $N \to \nu \ell^+ \ell^-, \quad \ell \in \{e, \mu\}$ Focus for this talk
  - $N \to \nu \pi^0, \quad \pi^0 \to \gamma\gamma,$
  - $N \to \ell^\pm + \text{ hadrons}, \quad \ell \in \{e, \mu, \tau\}$

5. Background Considerations (1):

FASER/
FASER2:

$$E_{e^+e^-} > 100 \text{ GeV}, \qquad E_{\mu^+\mu^-} > 100 \text{ GeV}$$

[2405.07330]

$$E_\gamma > 100 \text{ GeV}, \qquad \Delta_{\gamma\gamma} \gtrsim 200 \ \mu\text{m},$$

[1]

$$E_{\text{vis.}} > 100 \text{ GeV}$$

[1811.12522]

1: J. Boyd, The faser w-si high precision preshower technical proposal, Tech. Rep. , CERN, Geneva (2022)

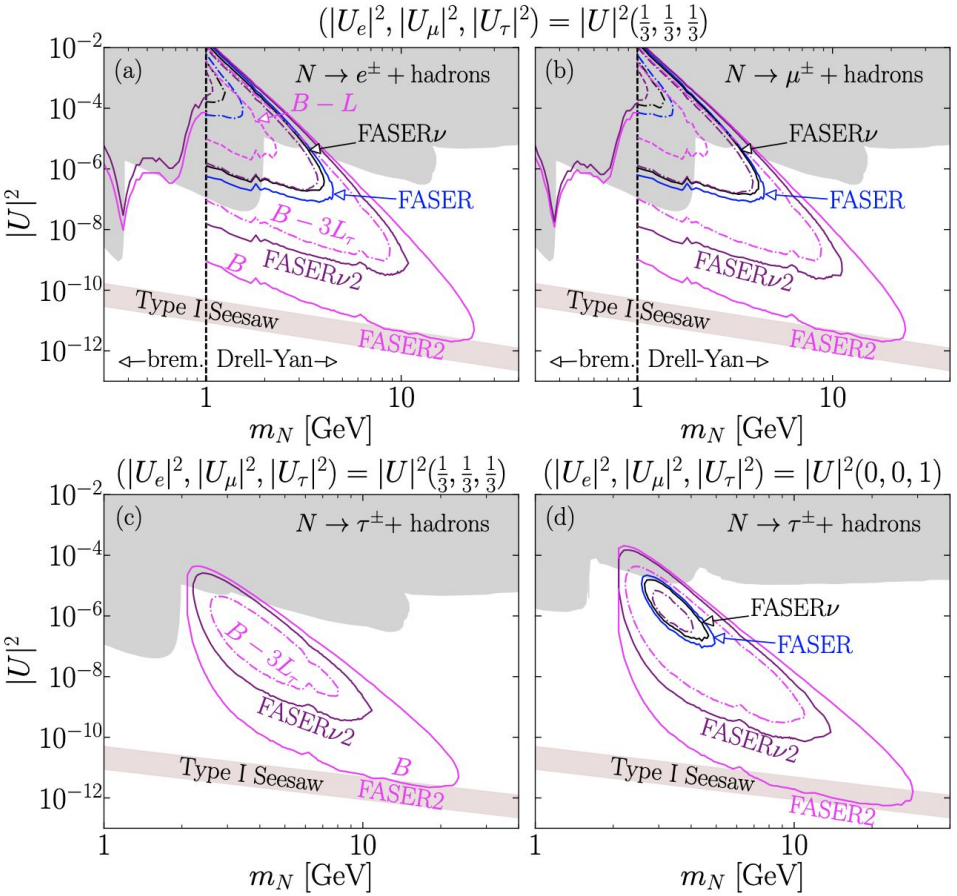
FASERν/
FASERν2:

$$E_{e^\pm} > 200 \text{ GeV}, \qquad E_{\mu^\pm} > 100 \text{ GeV}, \qquad E_{\tau^\pm} > 100 \text{ GeV}$$

electron ID : 70% muon ID: 86% tau ID: 75%

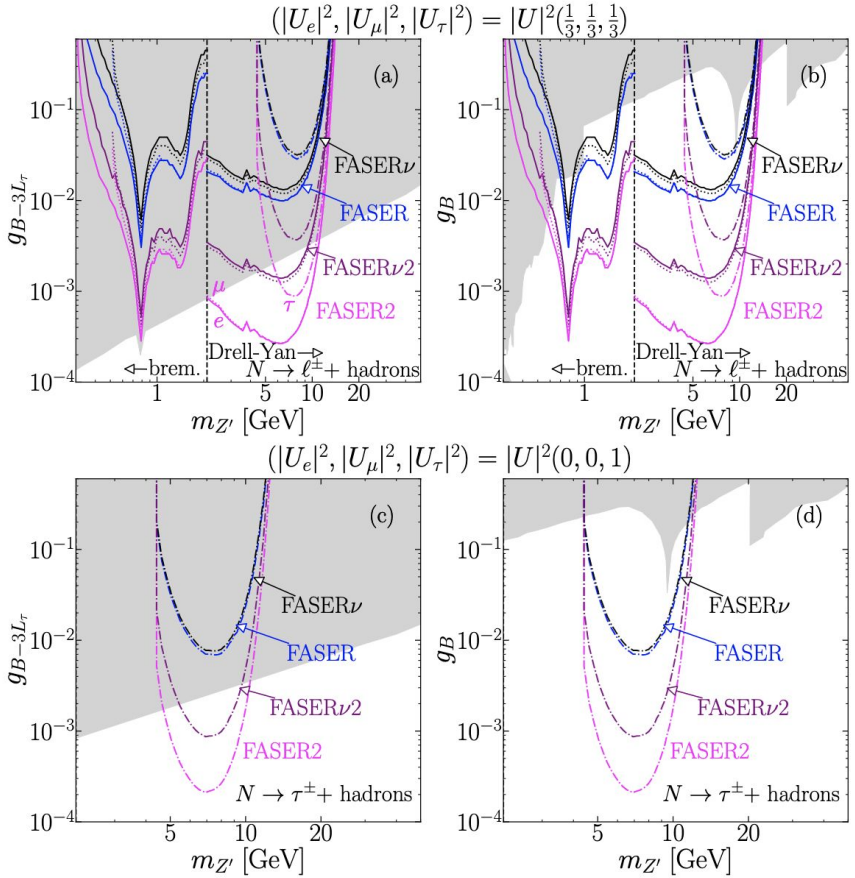
[2606.18517, 1908.02310, 2309.10417]

6. Sensitivities: HNL Mixing Angle:



	$B-L$	$B-3L_\tau$	B
gx	10^{-4}	10^{-3}	10^{-2}

6. Sensitivities: Gauge Coupling



$$|U|^2 = 10^{-7}$$

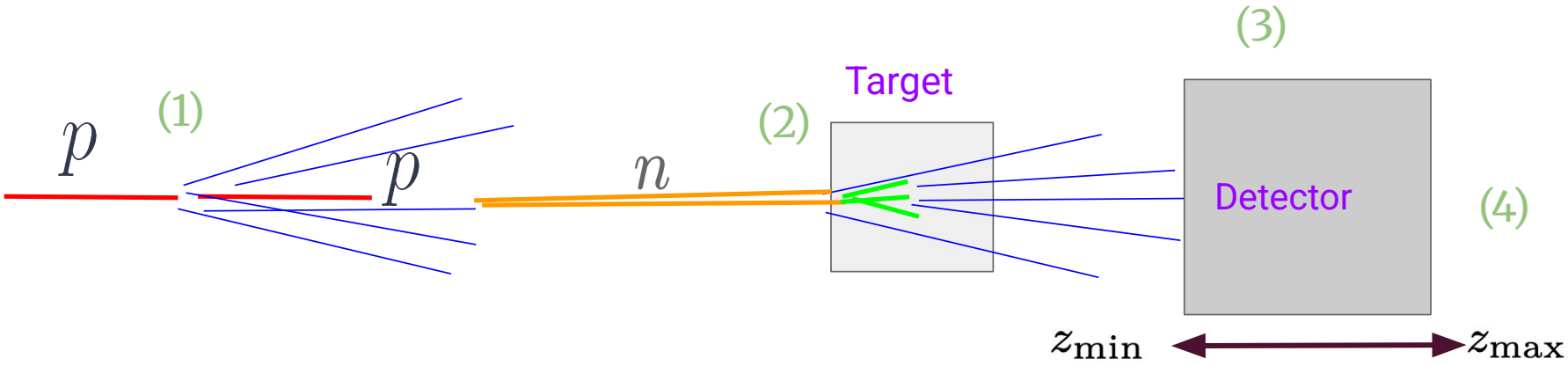
$$|U|^2 = 10^{-6}$$

Answer: HNL and Z’ can probe well outside of the excluded limits!

Conclusions/Outlook:

- Within our kinematically accessible region for some benchmarks, FASER2 may probe the Type I Seesaw band in all three lepton flavors
- First to show testable HNLs at FASERν

Thanks for coming to my talk!



Focus on ATLAS IP Production:

$$N_{\text{events}} = \sigma(X) \times \mathcal{L} \quad (1)$$

$$\text{eff} = m\Gamma \int_{z_{\min}}^{z_{\max}} dz \sum_{\text{events} \in \text{geom.}} \frac{e^{-z(m/p_z)\Gamma}}{N_{\text{MC}}\, p_z} \quad (3)$$

$$N_{\text{Detected}} = N_{\text{events}} \times \text{BR}(X \to \text{final states}) \times \text{eff}_f \quad (4)$$

Decays: Z’ (1)

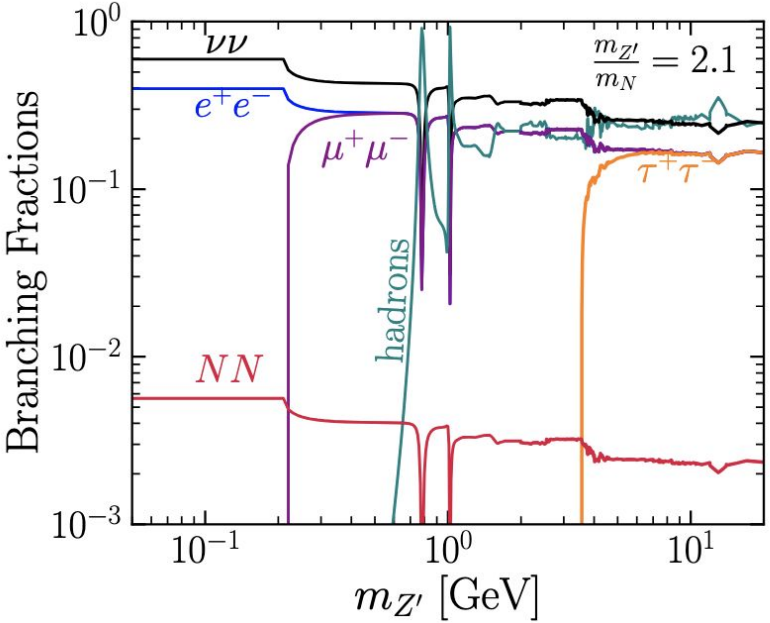
$$\Gamma(Z' \to f\bar{f}) = \frac{N_c}{S}\frac{g_X^2 m_{Z'}\beta_f}{12\pi}\left[(g_{V,f}^2 + g_{A,f}^2)\beta_f^2 + g_{V,f}^2\frac{6m_f^2}{m_{Z'}^2}\right]$$

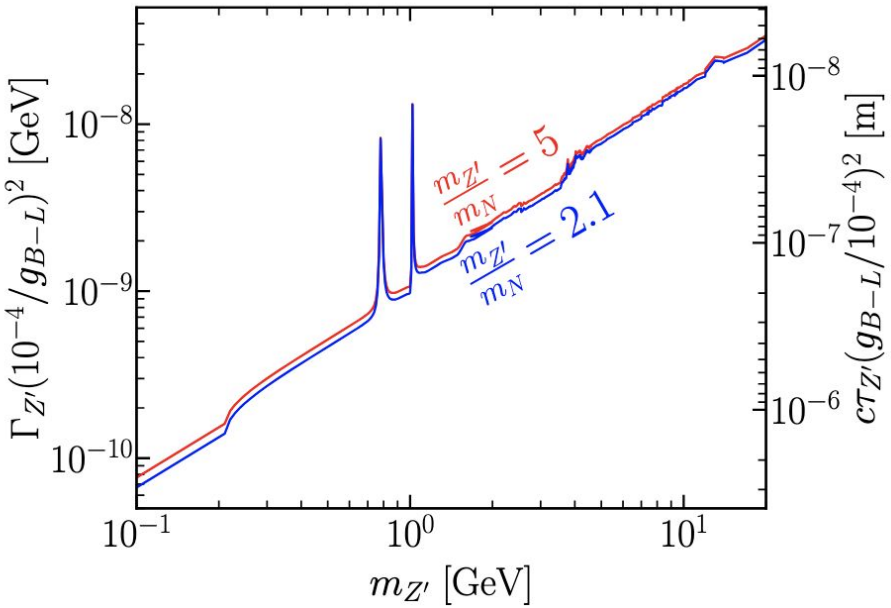
$$\Gamma(Z' \to NN) = \frac{g_{B-L}^2 m_{Z'}}{24\pi}\beta_N^3,$$

$$\Gamma(Z' \to \text{hadrons}) = \frac{\sum_q \Gamma(Z' \to q\bar{q})}{\sum_q Q_q^2 F_q} R(m_{Z'})$$

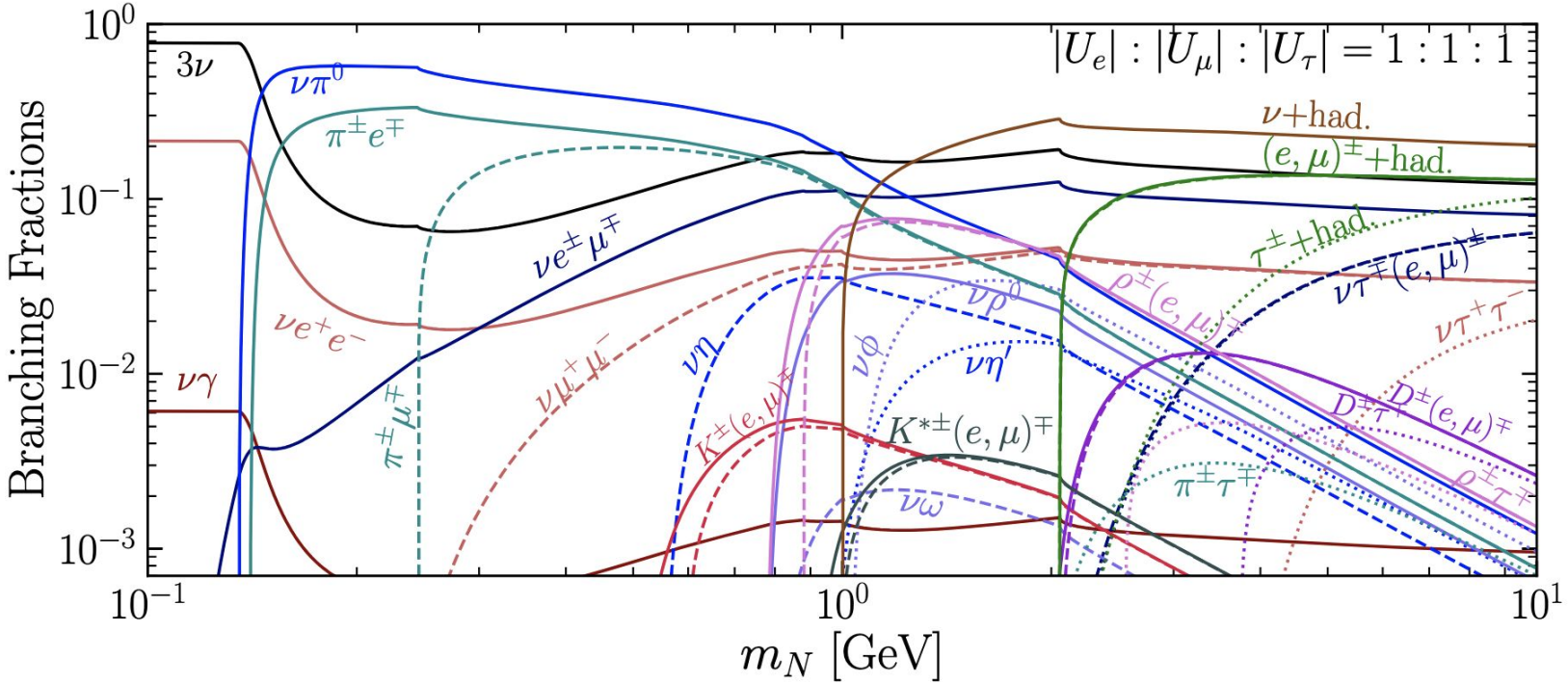
Decays: Z' (2)

$U(1)_{B-L}$

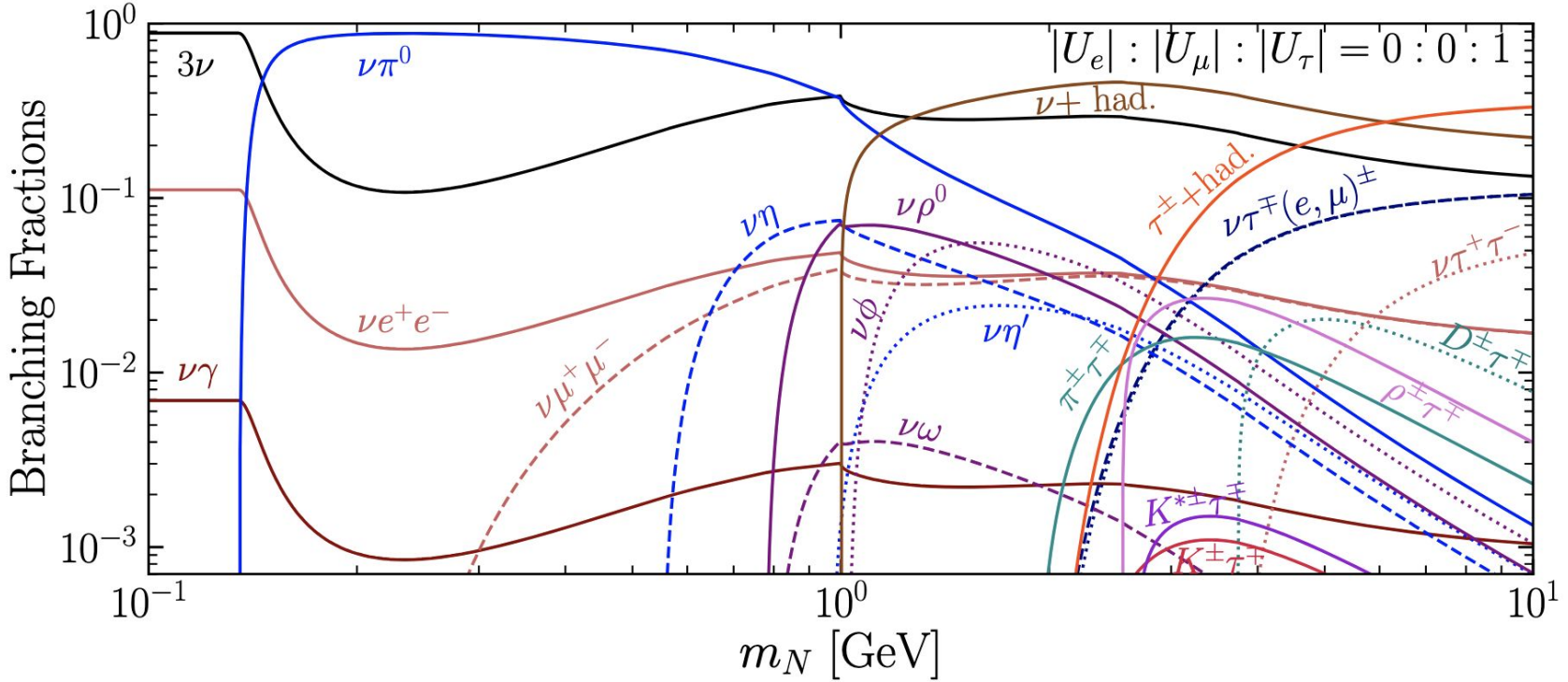




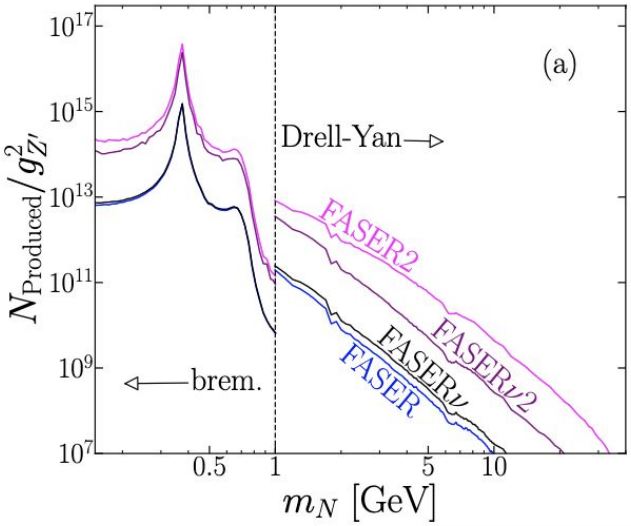
Decays: HNL (1)

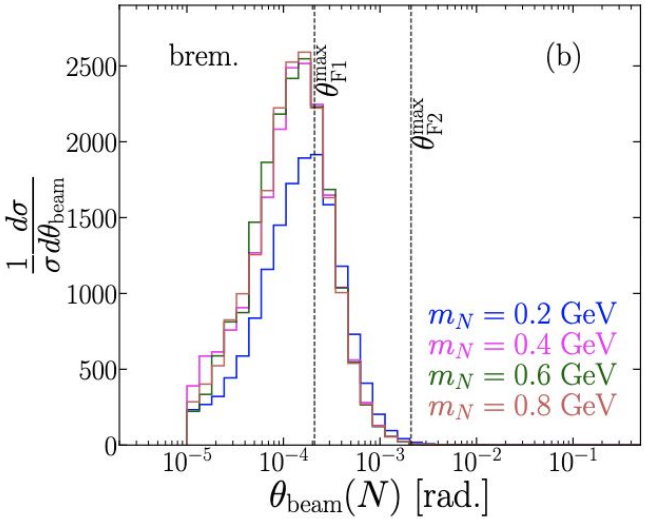

$|U_e| : |U_\mu| : |U_\tau| = 1 : 1 : 1$
Branching Fractions
m_N [GeV]
10^0
10^{-1}
10^{-2}
10^{-3}
10^{-1}
10^0
10^1
3ν
$\nu\pi^0$
$\pi^\pm e^\mp$
$\nu e^\pm \mu^\mp$
$\nu e^+ e^-$
$\nu\gamma$
$\pi^\pm \mu^\mp$
$\nu\mu^+\mu^-$
$\nu\eta$
$K^\pm(e,\mu)^\mp$
$\nu\phi$
$\nu\rho^0$
$\nu\eta'$
$K^{*\pm}(e,\mu)^\mp$
$\nu\omega$
ν+had.
$(e,\mu)^\pm$+had.
$\tau^\pm$+had.
$\rho^\pm(e,\mu)^\mp$
$\nu\tau^\mp(e,\mu)^\pm$
$\nu\tau^+\tau^-$
$D^\pm\tau^\mp$
$D^\pm(e,\mu)^\mp$
$\pi^\pm\tau^\mp$
$\rho^\pm\tau^\mp$

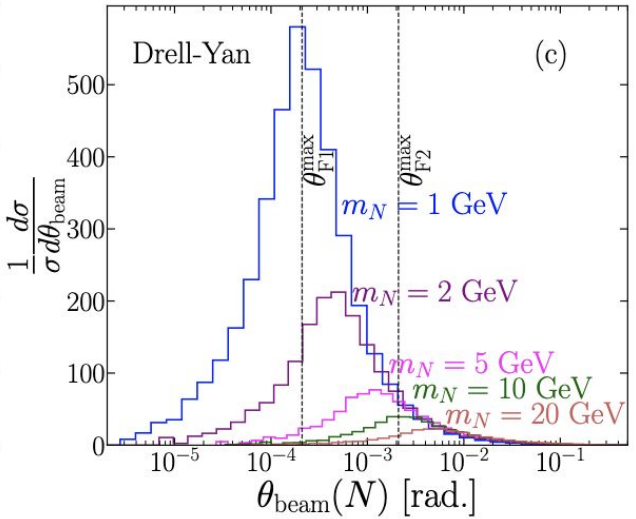
Decays: HNL (2)


$|U_e| : |U_\mu| : |U_\tau| = 0 : 0 : 1$
3ν
$\nu\pi^0$
ν+ had.
$\tau^\pm$+had.
$\nu\tau^\mp(e,\mu)^\pm$
$\nu\eta$
$\nu\rho^0$
νe^+e^-
$\nu\gamma$
$\nu\mu^+\mu^-$
$\nu\phi$
$\nu\eta'$
$\nu\tau^+\tau^-$
$\pi^\pm\tau^\mp$
$D^\pm\tau^\mp$
$\rho^\pm\tau^\mp$
$\nu\omega$
$K^{*\pm}\tau^\mp$
$K^\pm\tau^\mp$
Branching Fractions
m_N [GeV]
10^0
10^{-1}
10^{-2}
10^{-3}
10^{-1}
10^0
10^1

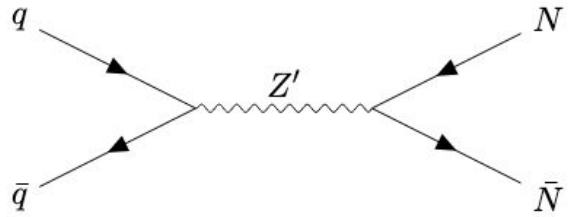
4. HNL Production:







3. Drell-Yan Production

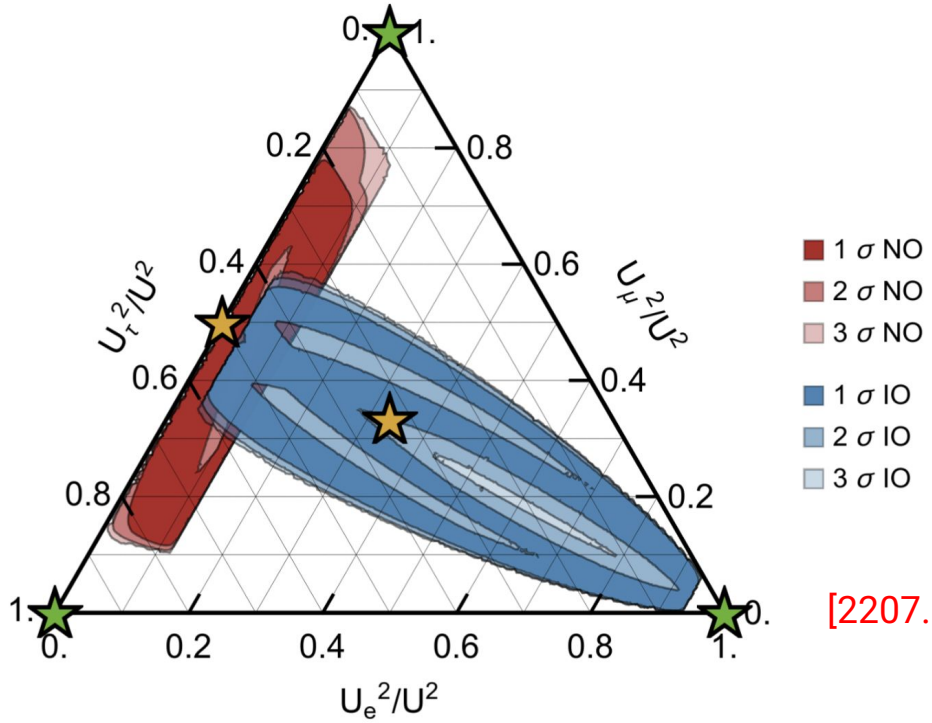


- s-channel production of HNLs
  - Such processes studied previously [1604.06099]
  - Scales as g^2_{B-L} during resonance

$$\sigma(pp \to Z' \to NN) = \frac{g^4_{B-L}}{1944\Gamma_{Z'}} \frac{\beta^3_N m_{Z'}}{s} \cdot \frac{1}{2} \sum_{q,\bar{q}} \int_{m^2_{Z'}/s}^{1} \frac{dx_2}{x_2} \left[f_q\left(\frac{m^2_{Z'}}{x_2 s}, m^2_{Z'}\right) f_{\bar{q}}(x_2, m^2_{Z'}) + (q \leftrightarrow \bar{q}) \right]$$

$$\equiv \mathcal{L}_{q\bar{q}}$$

HNL Flavor Alignment

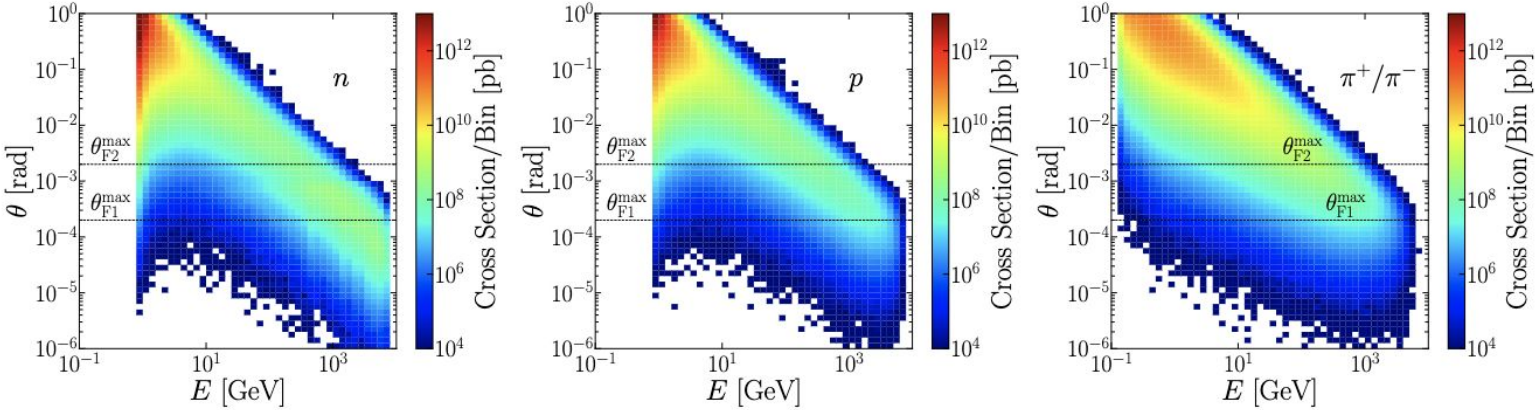


[2207.02742]

Backup: Recasting Collider Limits

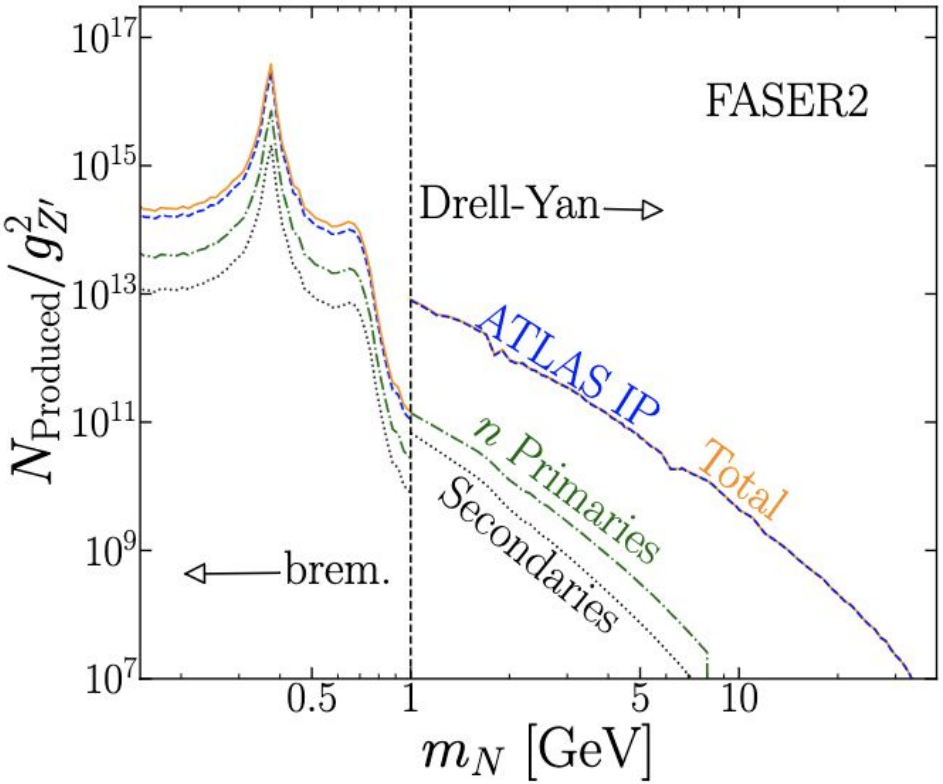
$$\sigma(pp \to \ell_\alpha^\pm \ell_\alpha^\pm + \text{jets}) \propto U^2 |\varepsilon_\alpha|^4,$$
$$\sigma(pp \to \ell_\alpha^\pm \ell_\beta^\pm + \text{jets}) \propto U^2 |\varepsilon_\alpha|^2 |\varepsilon_\beta|^2,$$
$$\sigma(pp \to \ell_\alpha^+ \ell_\alpha^+ \ell_\alpha^- + \not{E}_T) \propto U^2 |\varepsilon_\alpha|^4,$$
$$\sigma(pp \to \ell_\alpha^+ \ell_\alpha^+ \ell_\beta^- + \not{E}_T) \propto U^2 |\varepsilon_\alpha|^2 \left(|\varepsilon_\alpha|^2 + |\varepsilon_\beta|^2\right),$$
$$\sigma(pp \to \ell_\alpha^+ \ell_\alpha^- \ell_\beta^+ + \not{E}_T) \propto U^2 |\varepsilon_\alpha|^2 \left(|\varepsilon_\alpha|^2 + 3|\varepsilon_\beta|^2\right)$$

Backup: Fixed-Target (1)

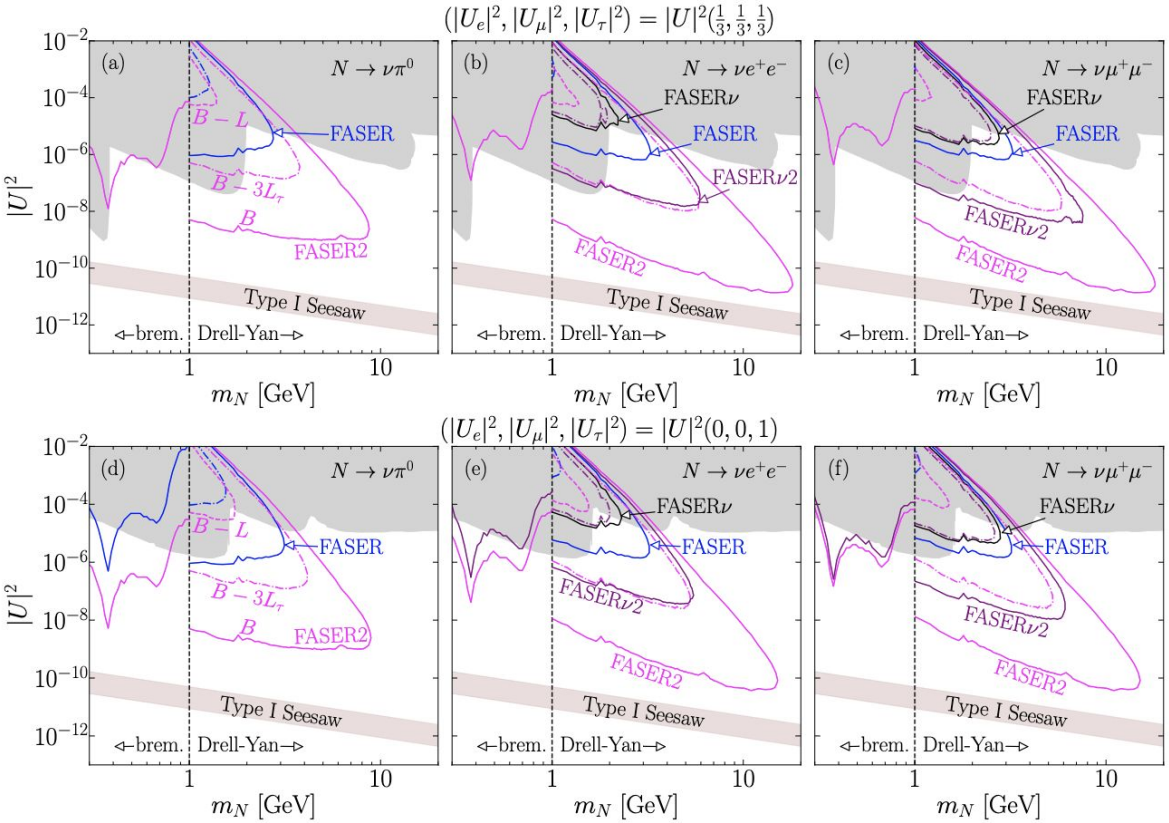


$$N_{\text{Detected}} = \text{HOT} \times A^{1-\alpha_h} \frac{\sigma(hp \to X)}{\sigma_{hp}(s)} \times \text{BR}(X \to \text{final state}) \times \text{eff}_f$$

Backup: Fixed-Target (2)

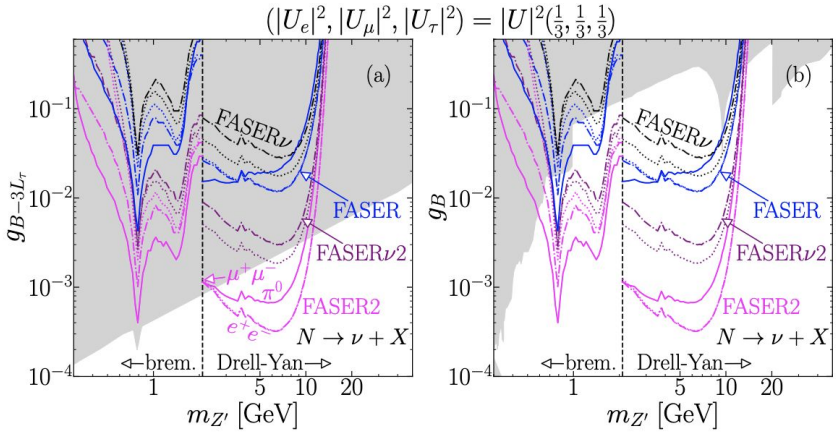


Backup: Sensitivities: HNL Mixing Angle:

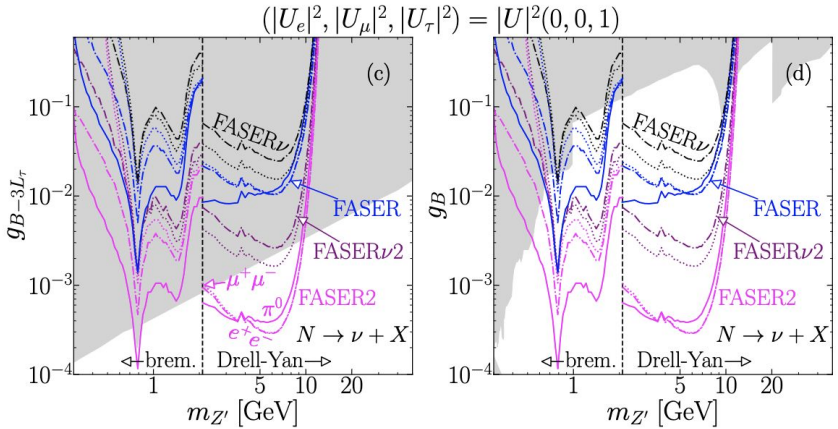


	$B-L$	$B-3L_\tau$	B
g_X	10^{-4}	10^{-3}	10^{-2}

Backup: Sensitivities: Gauge Coupling

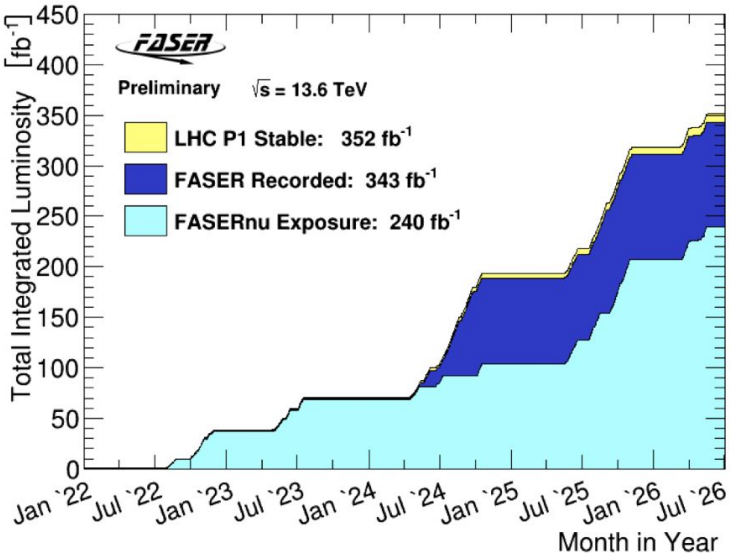


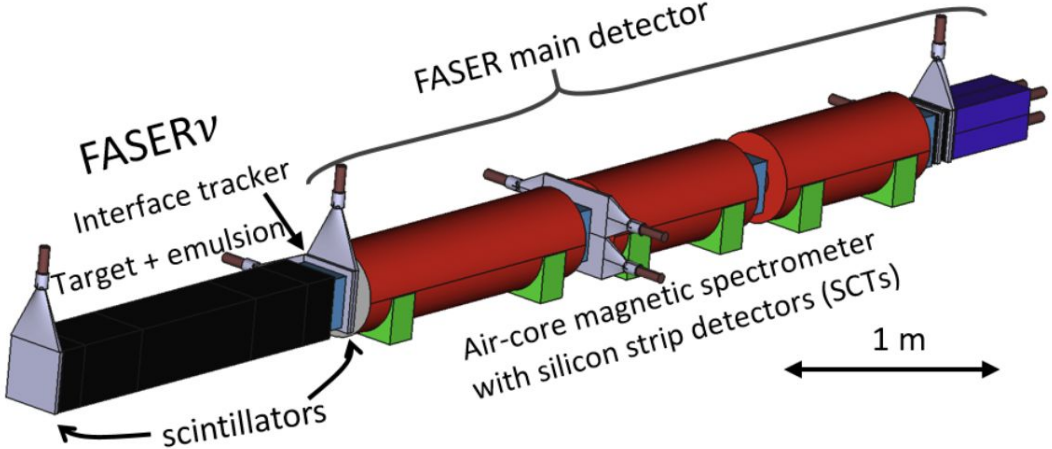
$$|U|^2 = 10^{-7}$$



$$|U|^2 = 10^{-6}$$

Backup: FASERν/ FASER

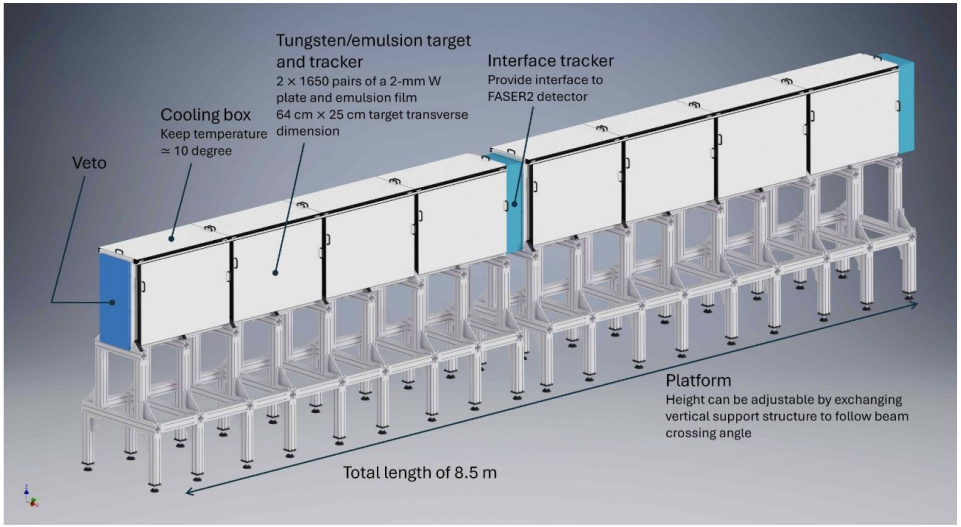


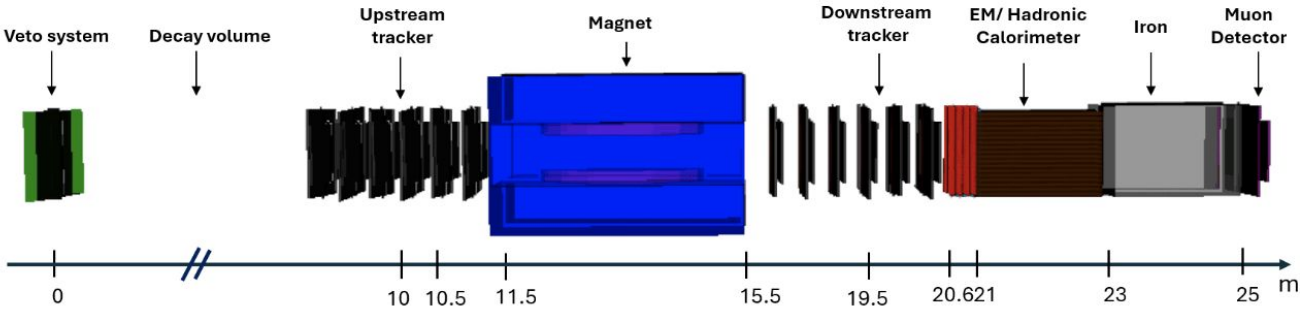


D'Onofrio, University of Liverpool, 10/27/2026

[2001.03073]

Backup: FASERν2/ FASER2





[2510.26260]