Heavy Neutral Leptons without Prejudice

Based on
NB, K. Deka and M. Losada
arXiv:2311.18033, 2403.soon

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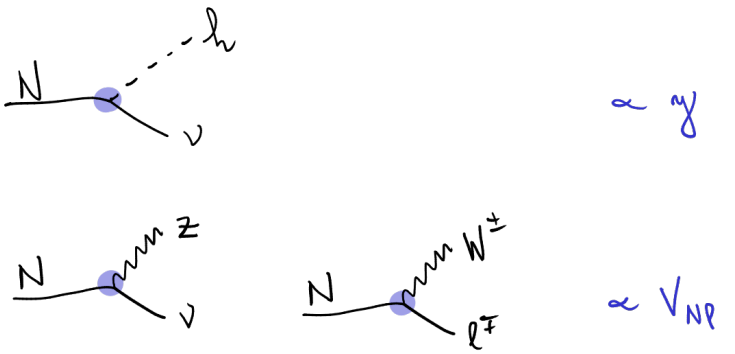
Heavy Neutral Leptons (HNLs)

HNLs (N) can play a fundamental role in

* neutrino masses
* leptogenesis
* dark matter

New free parameters:

* mass m_N
* Yukawa couplings y_{Ne}, $y_{N\mu}$, $y_{N\tau}$
* mixing angles V_{Ne}, $V_{N\mu}$, $V_{N\tau}$



Heavy Neutral Leptons (HNLs)

Mixing angles and Yukawa couplings are *typically* related

* Type-I seesaw

$$|V_{N\alpha}|^2 \simeq \left(|y_{N\alpha}| \frac{v}{m_N} \right)^2$$

* Scotogenic

$$y_{N\alpha} = 0 \qquad \text{but} \qquad V_{N\alpha} \neq 0$$

1. HNLs *only* couple to SM Higgs boson

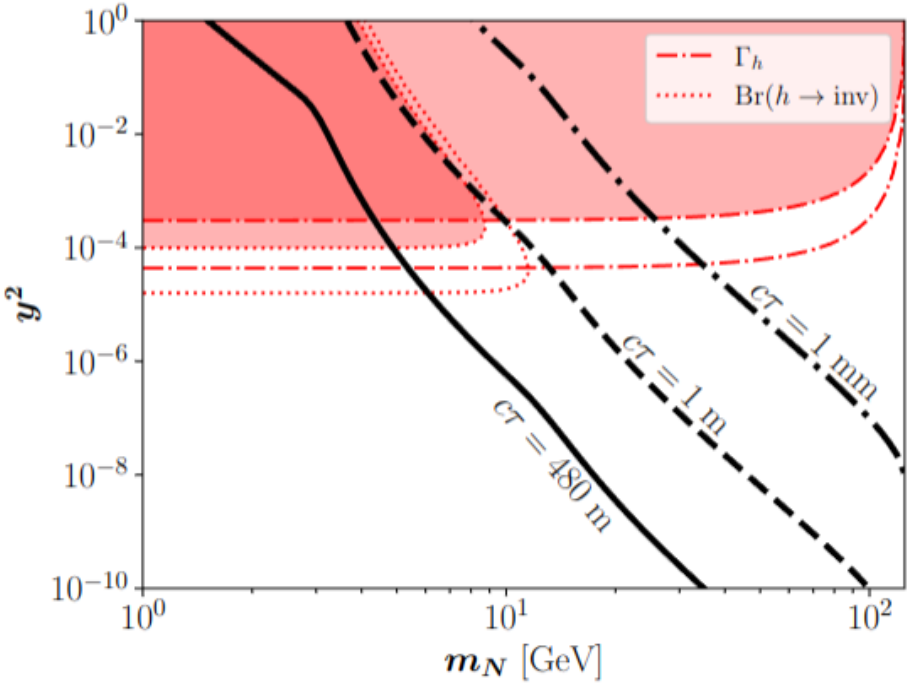
HNLs: Production and decay

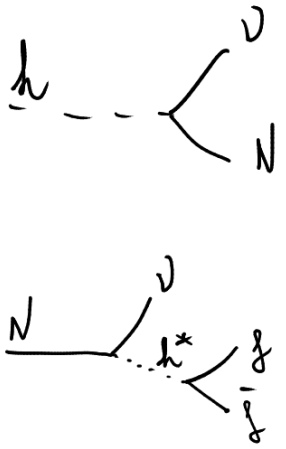
* Production through Higgs decays

$$\Gamma(h \to N\nu) = \frac{y^2}{8\pi} m_h \left[1 - \left(\frac{m_N}{m_h}\right)^2\right]^2$$

* Decays into 3-body final states

$$\Gamma(N \to \nu f \bar{f}) \propto y^2 \frac{m_f^2 \, m_N^5}{m_h^6}$$





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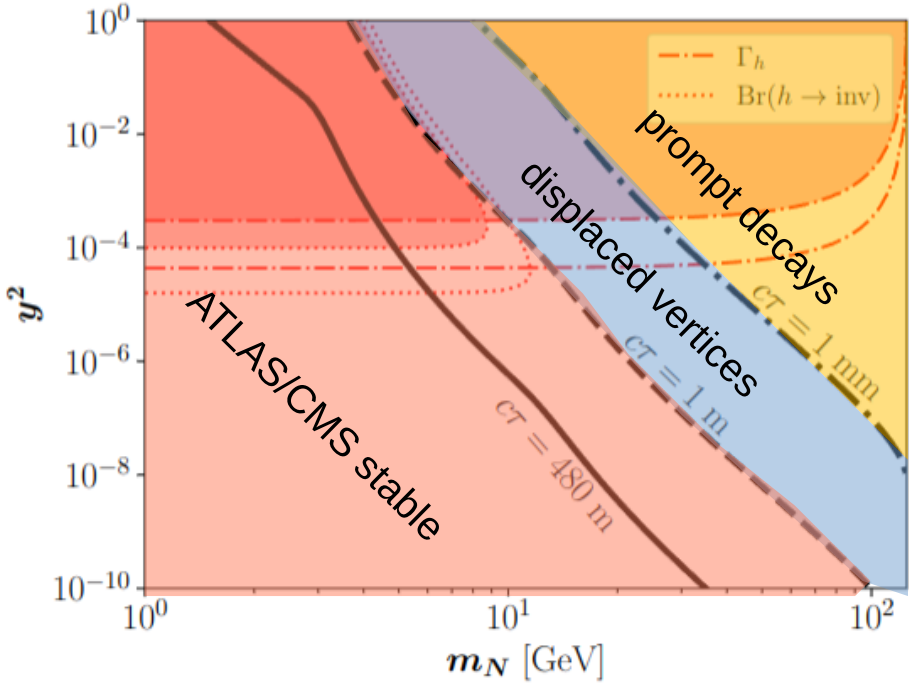

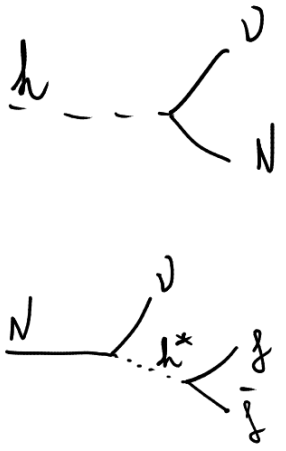

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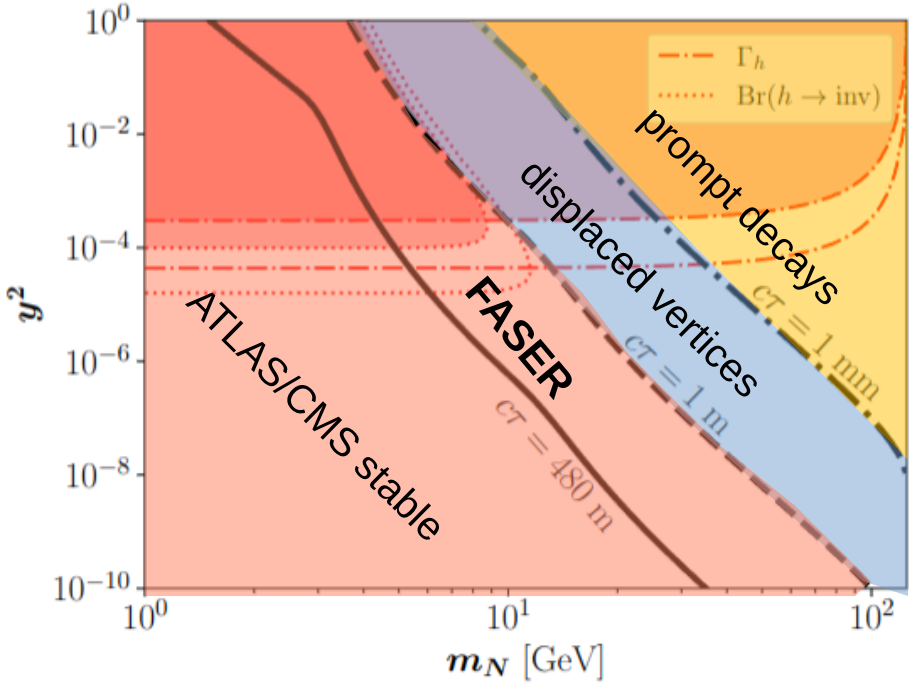

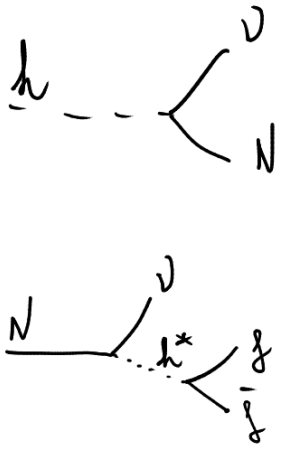

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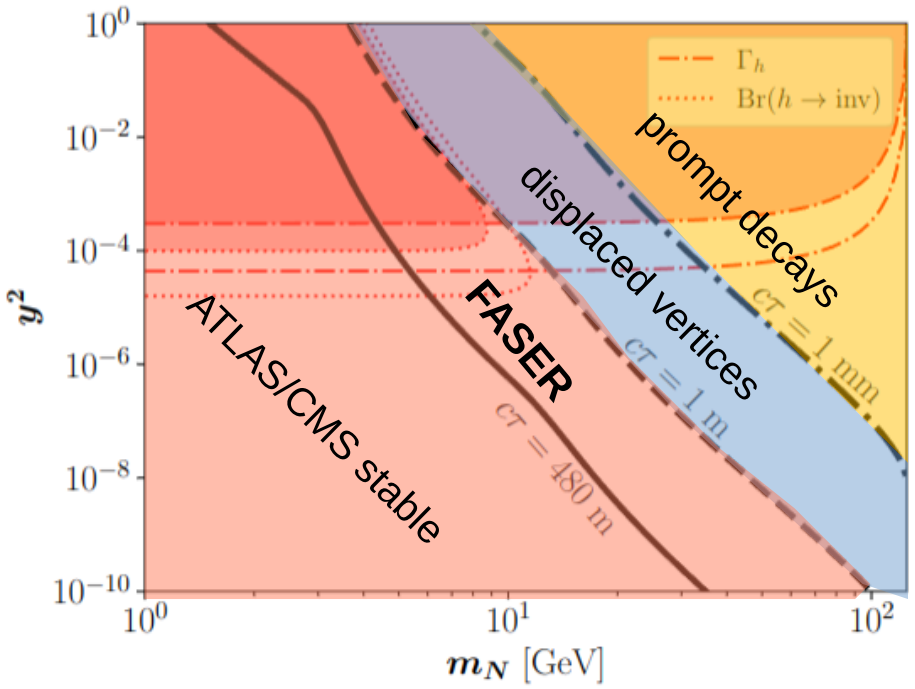
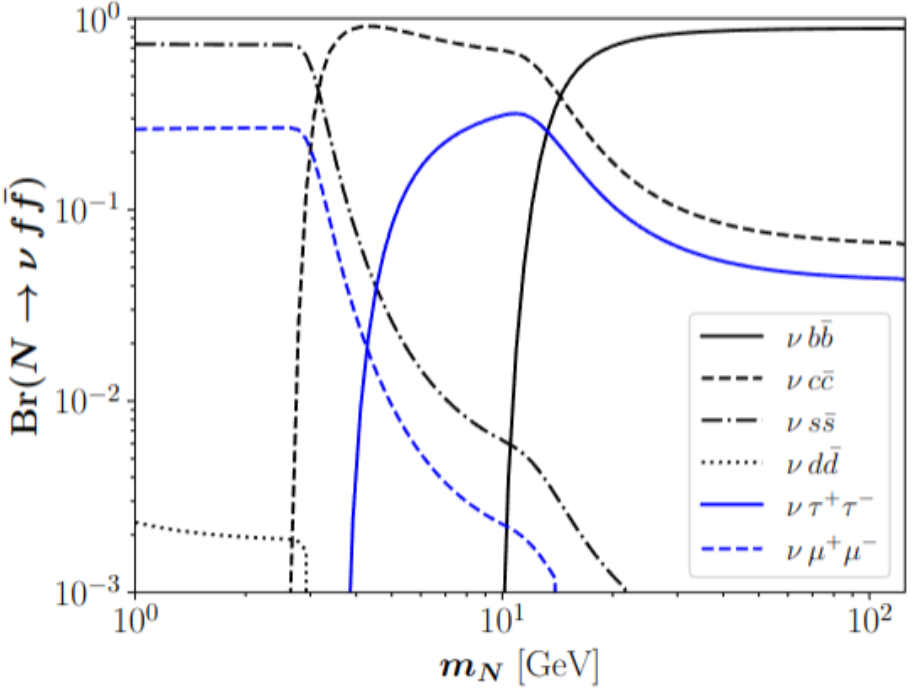
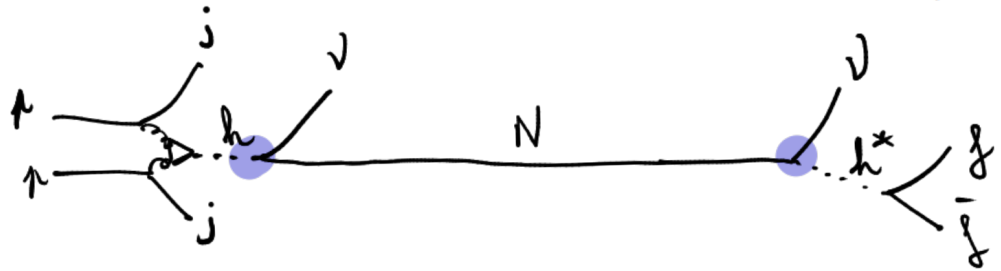




HNLs @ Far Detectors

HNLs from Higgs decays

Higgs inclusive production $\sigma \simeq 59.1$ pb at $\sqrt{s} = 14$ TeV $\mathcal{L} = 3$ ab^{-1}



* **FASER-2** $\Delta = 10$ m, $R = 1$ m

Probability of HNL decay inside the detector

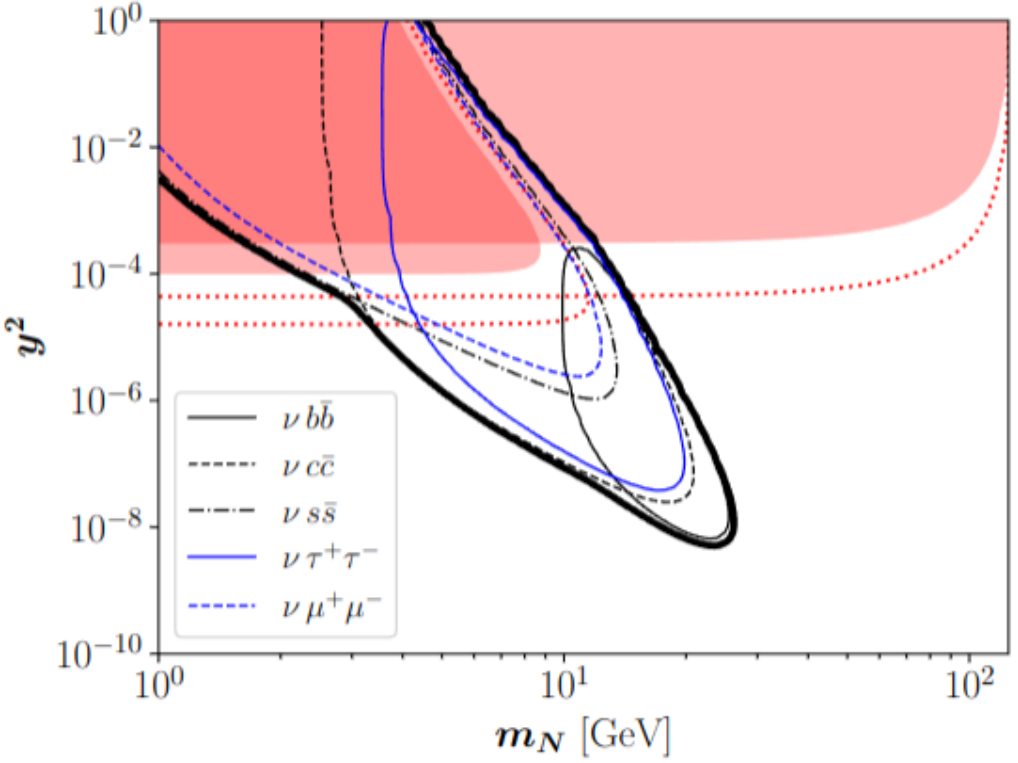
$$\mathcal{P} = \left[e^{-(L-\Delta)/d} - e^{-L/d}\right] \Theta\left[R - L \tan\theta\right]$$

$$d = c\tau\,\beta\,\gamma = c\tau\,\frac{|\vec{p}|}{m_N}$$

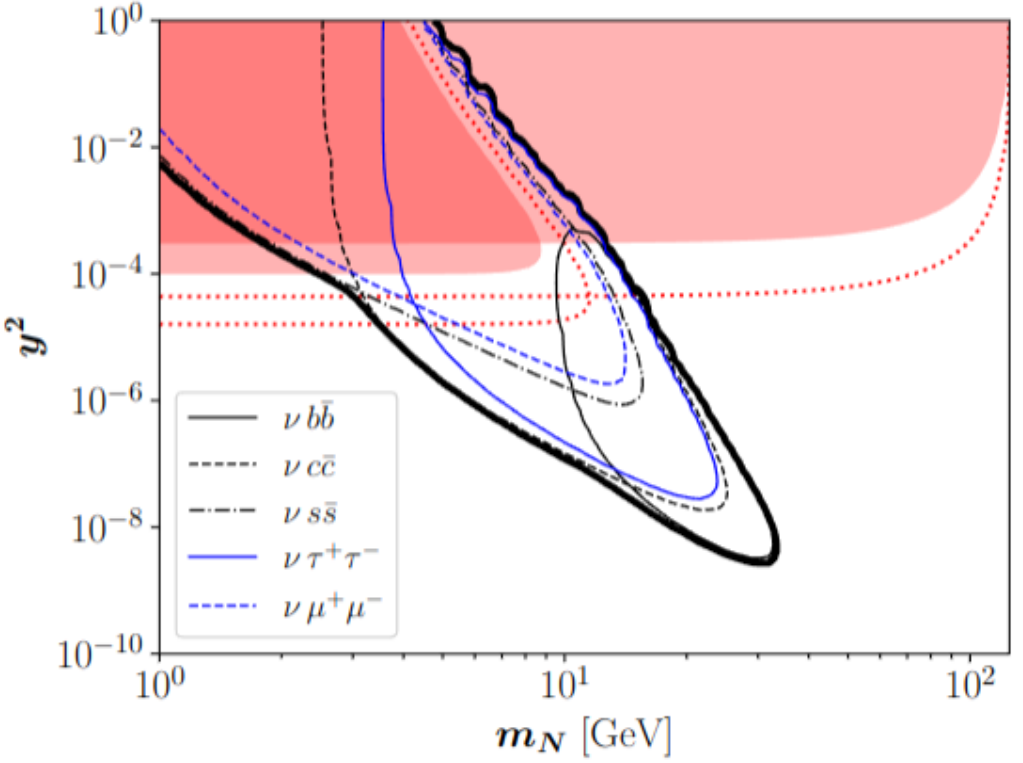
* MATHUSLA

HNLs @ Far Detectors

FASER-2

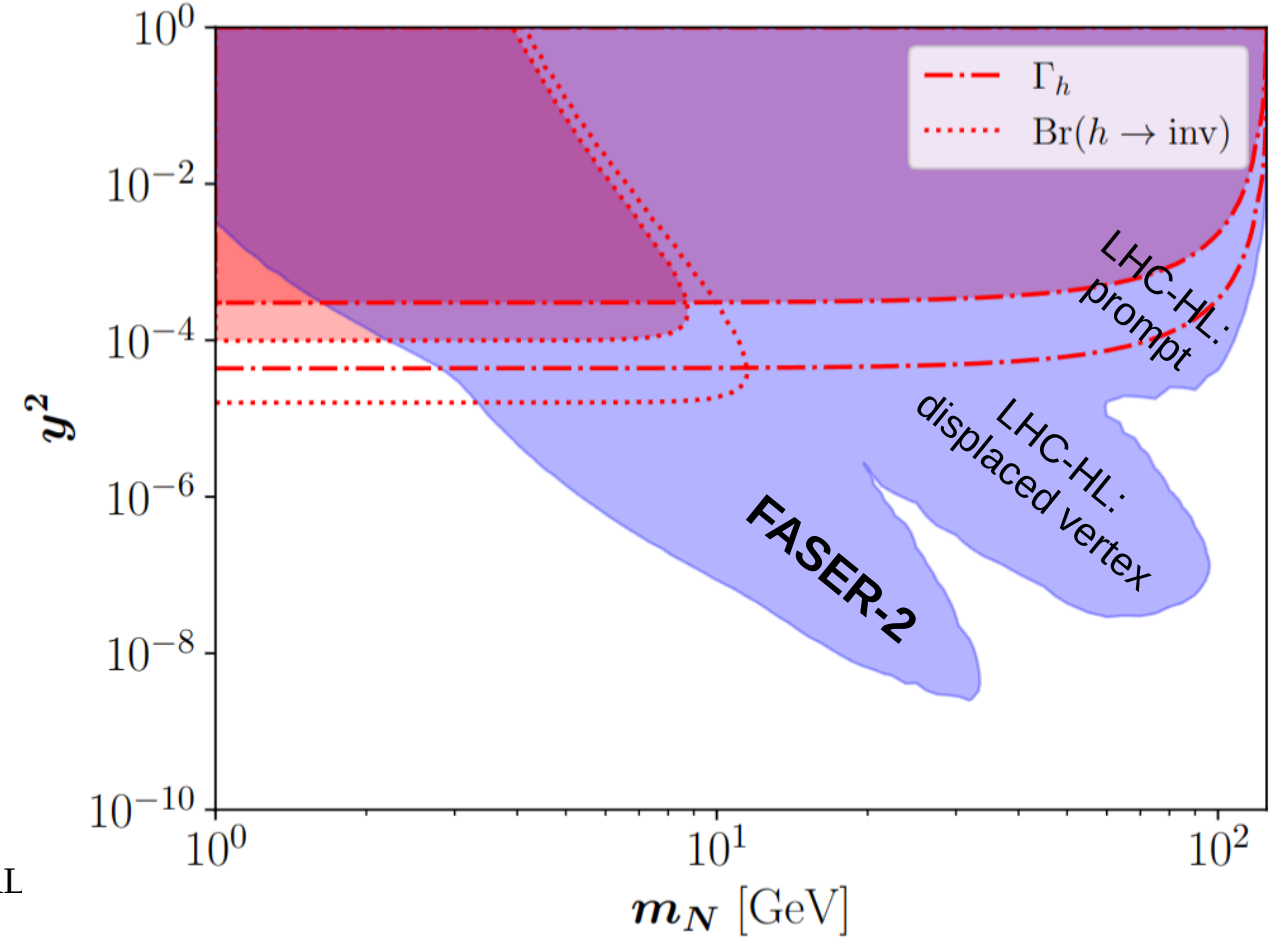


MATHUSLA



No background assumed: 3 events → 95% CL

HNLs Complementarity



2. HNLs *independent* Yukawas and Mixings

HNLs: Production and decay

* Production
from Higgs

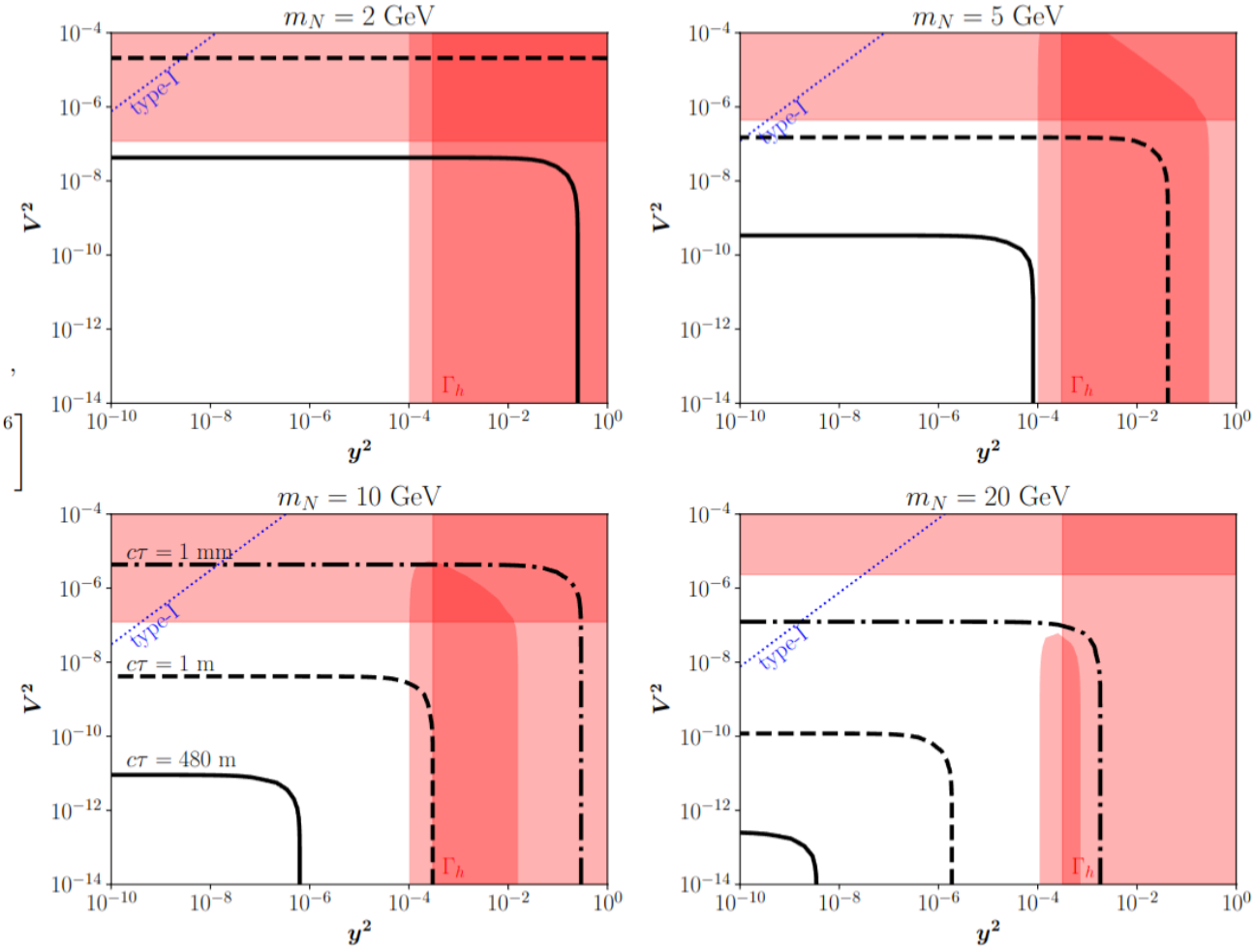
$$\Gamma(h \to N\nu) = \frac{y^2}{8\pi} m_h \left[1 - \left(\frac{m_N}{m_h}\right)^2\right]^2$$

from gauge bosons

$$\Gamma(W^\pm \to N l_\alpha^\pm) \simeq \frac{e^2 V_{N\alpha}^2}{96\pi s_W^2} m_W \left[2 - 3\left(\frac{m_N}{m_W}\right)^2 + \left(\frac{m_N}{m_W}\right)^6\right],$$

$$\Gamma(Z \to N\nu) = \frac{e^2 V^2}{96\pi c_W^2 s_W^2} m_Z \left[2 - 3\left(\frac{m_N}{m_Z}\right)^2 + \left(\frac{m_N}{m_Z}\right)^6\right]$$

* 3-body decays
through off-shell *Z*,*W* and *h*



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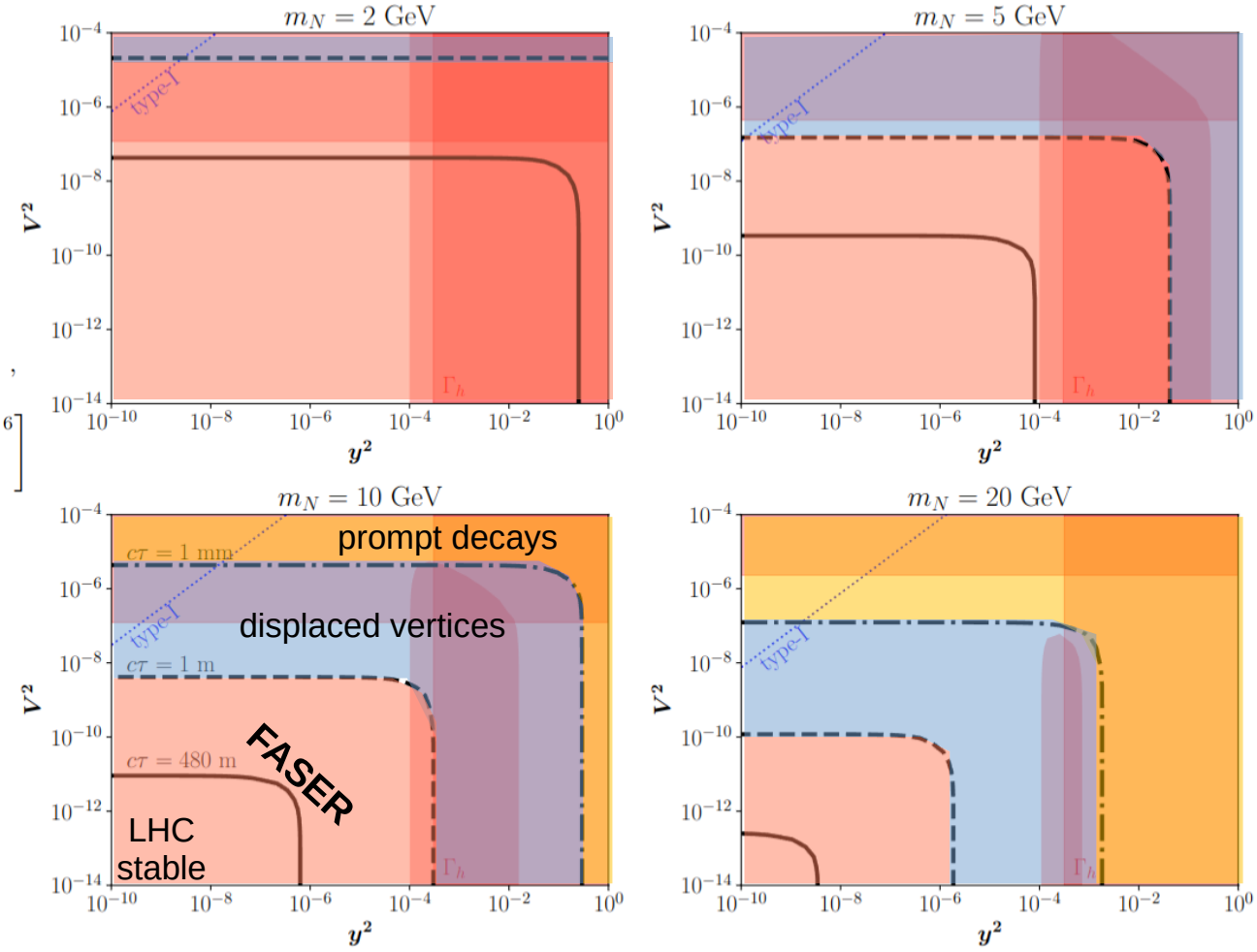
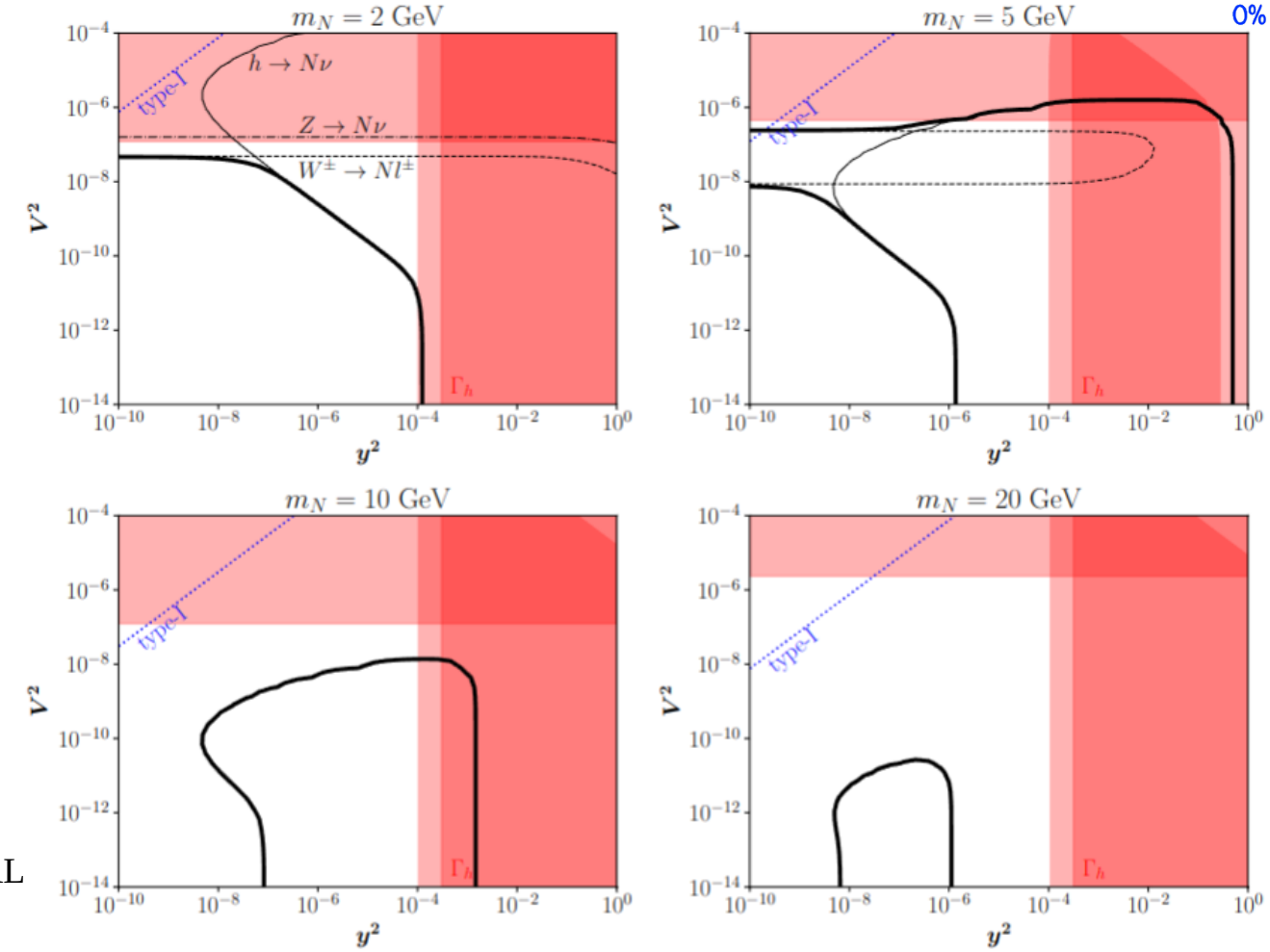


HNLs @ FASER-2


work in
progress
0%
100%


$m_N = 2$ GeV
$m_N = 5$ GeV
$m_N = 10$ GeV
$m_N = 20$ GeV
$h \to N\nu$
$Z \to N\nu$
$W^\pm \to Nl^\pm$
type-I
Γ_h
V^2
y^2

Conclusions & Outlook

- HNLs are cool (neutrino masses, leptogenesis, dark matter)
- The relation between Yukawa couplings and mixing angles is unknown
- Model-independent search: Yukawas and mixings as free parameters
- Complementarity: prompt decays, displaced vertices & long-lived particles
- FASER will play a key role in the search for HNLs
- Higgs sector has to be further tested

Muchas gracias!