

Probing Lepton Number Violation and Majorana Nature of Neutrinos at the LHC

Dorival Gonçalves 
Oklahoma State University

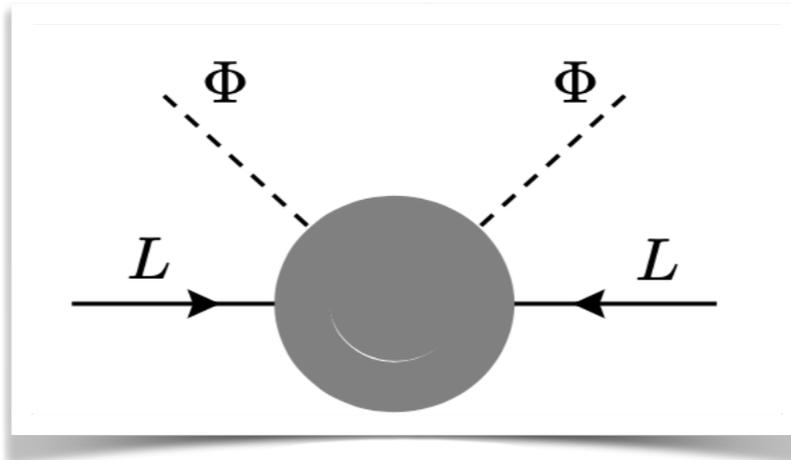
arXiv:2212.08025 K. Babu, R. Barman, DG, A. Ismail

Pittsburgh - 05.09.2023



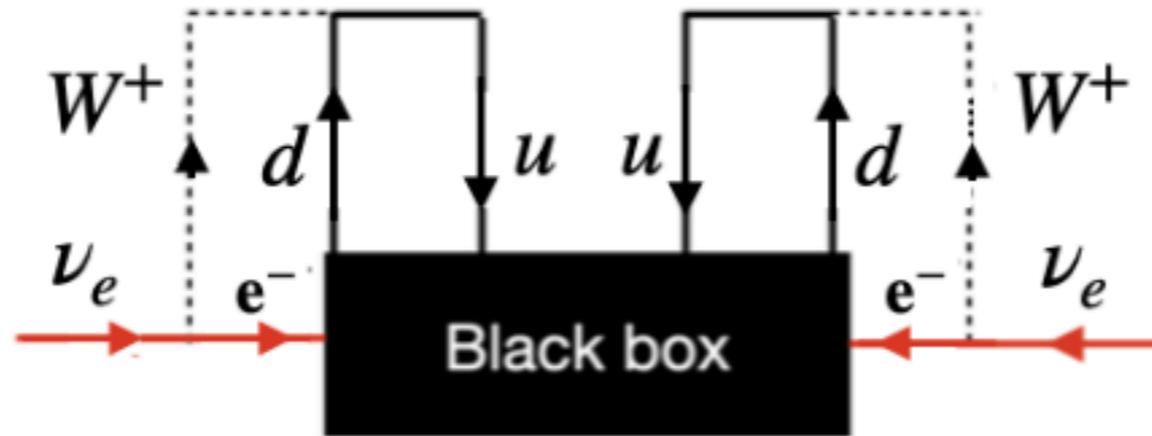
Motivation

- Existence of small but non-zero neutrino masses, as implied by the neutrino oscillation experiments, is clear evidence for BSM [See talk by K. Babu](#)
- ➔ Dirac vs Majorana neutrinos?
- ➔ Majorana neutrinos are arguably more natural

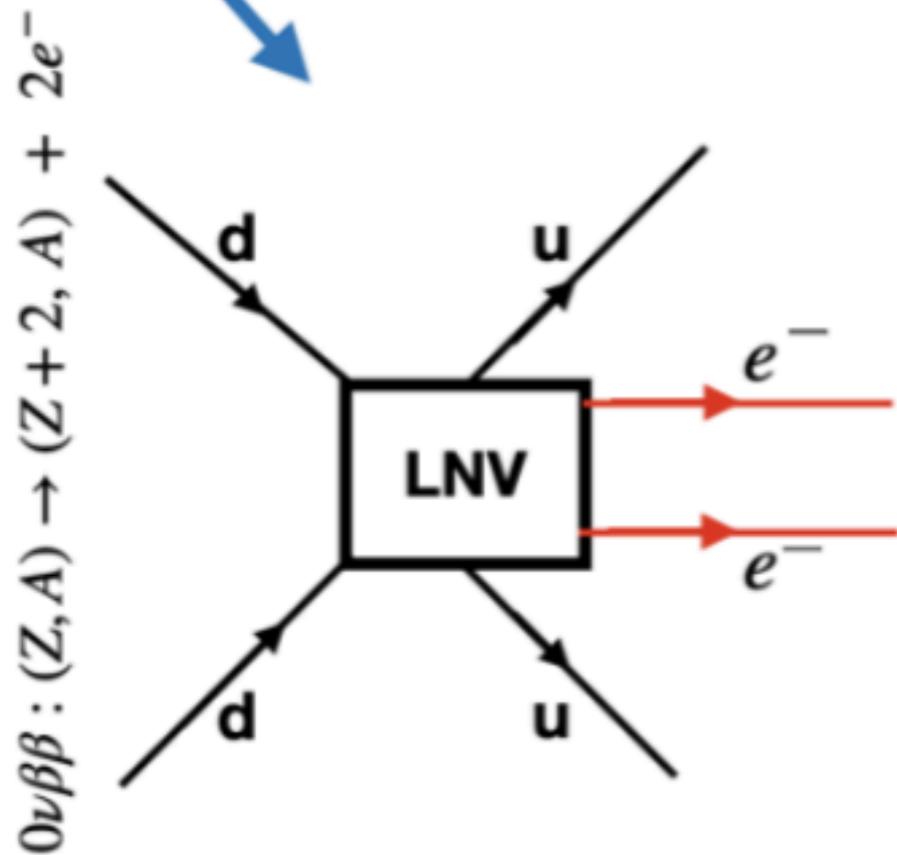


- ➔ A Majorana mass term for the neutrino would explicitly break LN by two units: $|\Delta L| = 2$
It may play crucial role in explaining the matter-antimatter asymmetry: Leptogenesis

Black box theorem at colliders



Schechter, Valle (1982)

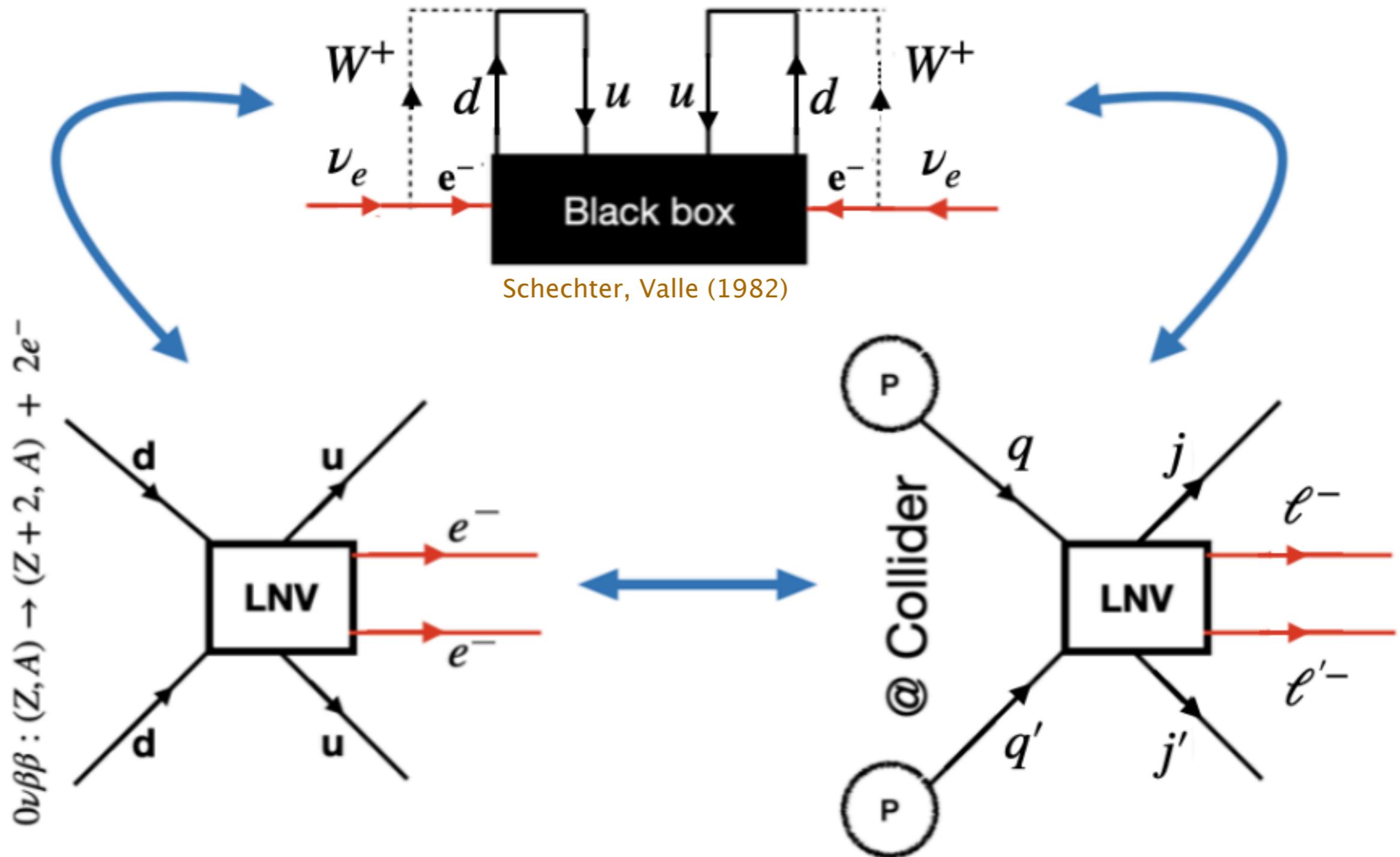


→ $^{76}\text{Ge} \quad T_{0\nu}^{1/2} \gtrsim 1.8 \times 10^{26} \text{ yr (GERDA)}$

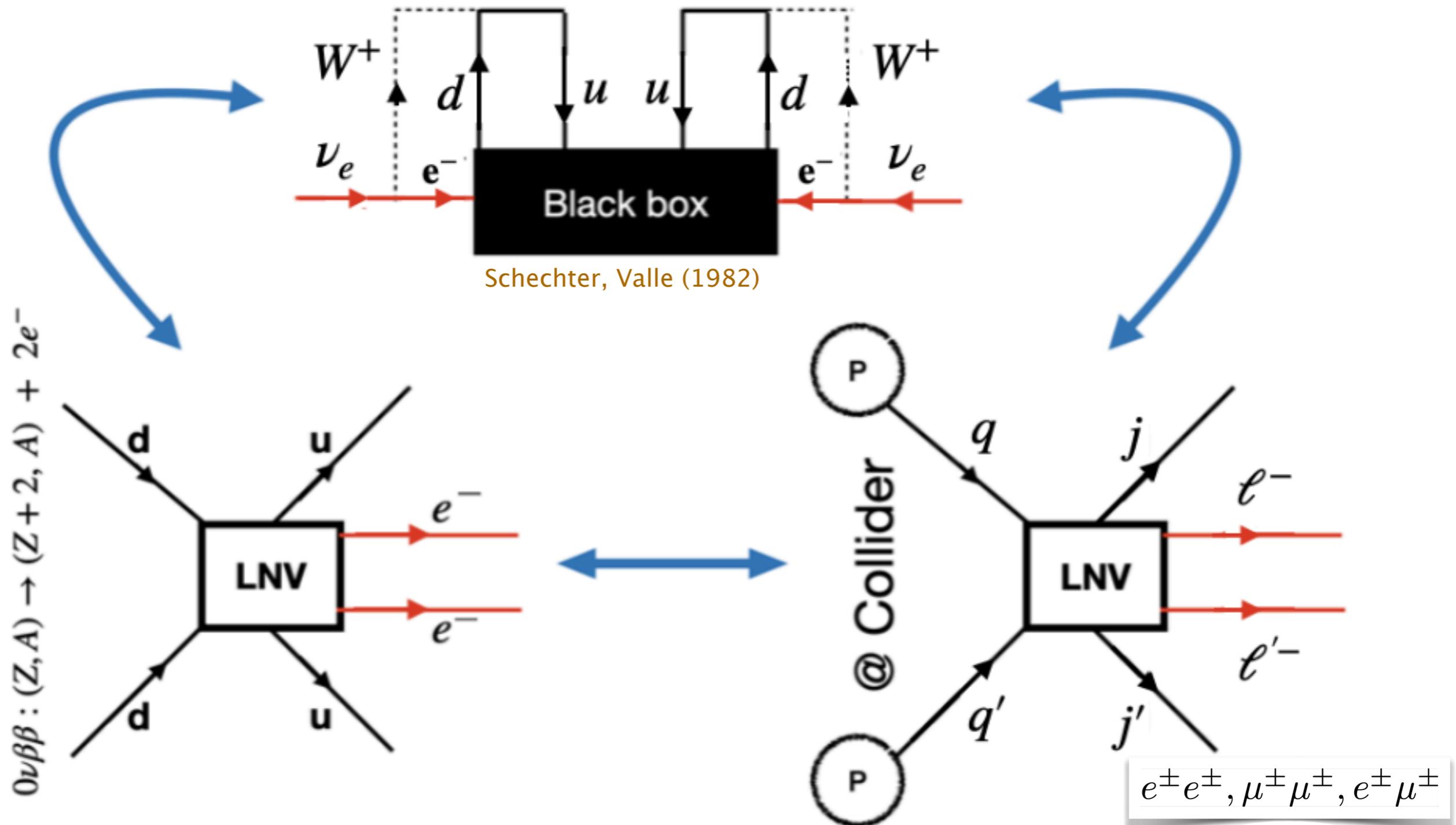
→ $^{136}\text{Xe} \quad T_{0\nu}^{1/2} \gtrsim 1.07 \times 10^{26} \text{ yr (Kamland-Zen)}$

→ $\langle m_{\beta\beta} \rangle \equiv \left| \sum_i U_{ei}^2 m_{\nu_i} \right| < (61 - 165) \text{ MeV}$

Black box theorem at colliders



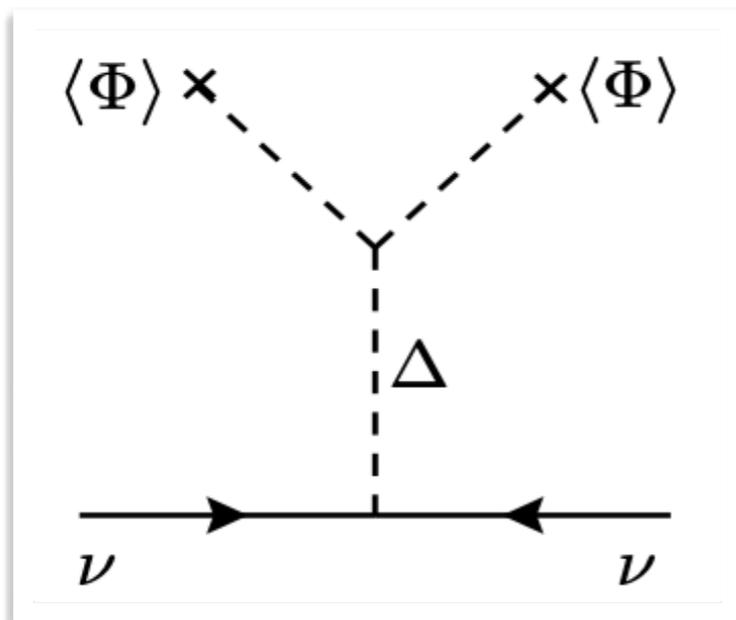
Black box theorem at colliders



➡ LNV observation at colliders would allow us to explore the underlying mechanism for such signal

Neutrino mass generation

Tree-level

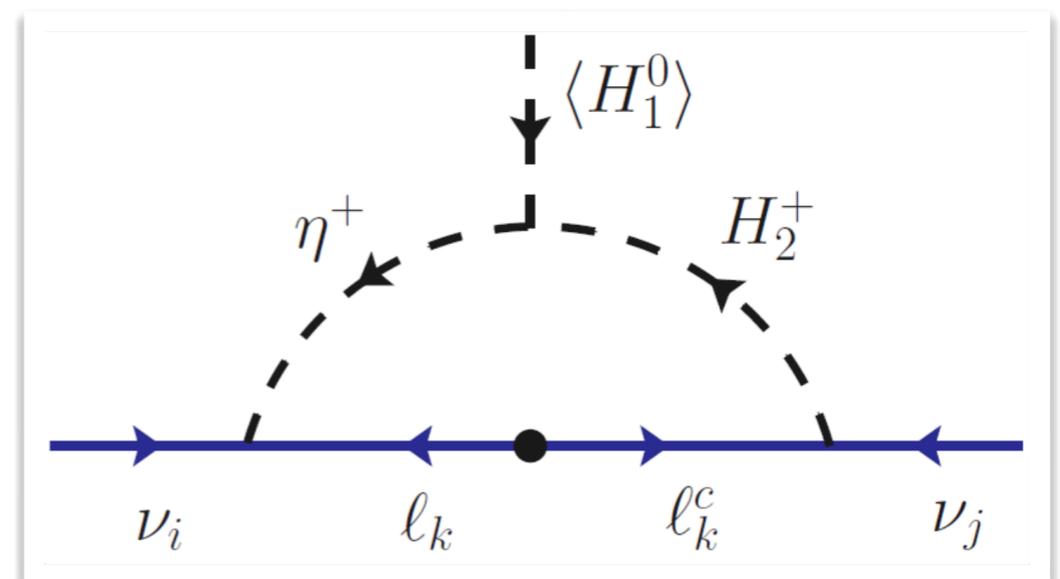


Type-II seesaw

Mohapatra, Senjanovic (1980); Schechter, Valle (1980)
Lazarides, Shafi, Wetterich (1981)

Pheno: Perez, Han, Huang, Li, Wang (2008)
Cai, Han, Li, Ruiz (2017)

Loop-induced



Zee model

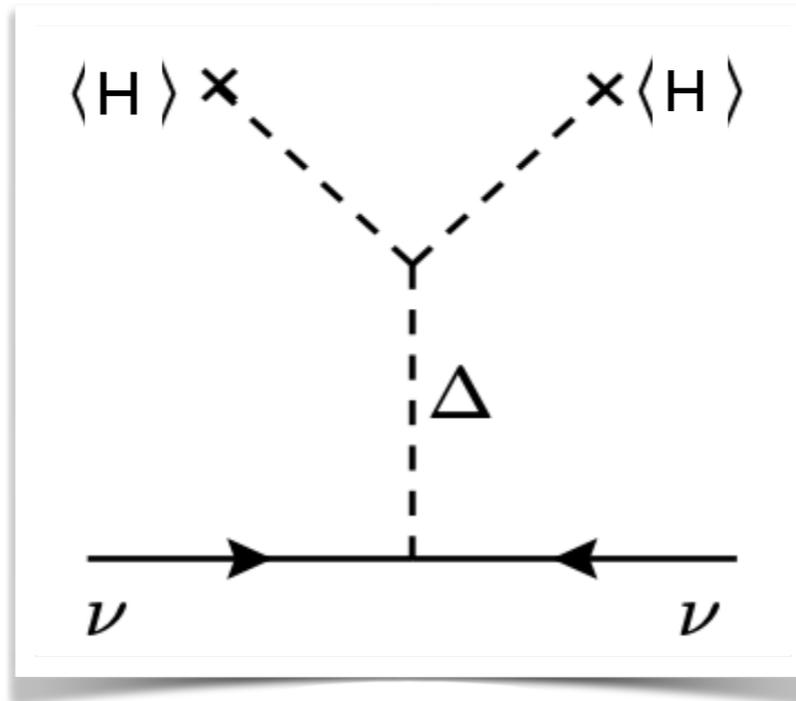
Zee (1980)

Pheno: Babu, Dev, Jana, Thapa (2019)

Type-II Seesaw

$\Delta(1, 3, 1)$

$$\mathcal{L} \supset -Y_\nu l_L^T C i\sigma_2 \Delta l_L + \mu H^T i\sigma_2 \Delta^\dagger H + \text{h.c.}$$



→ $v_\Delta = \mu v_0^2 / \sqrt{2} M_\Delta^2$

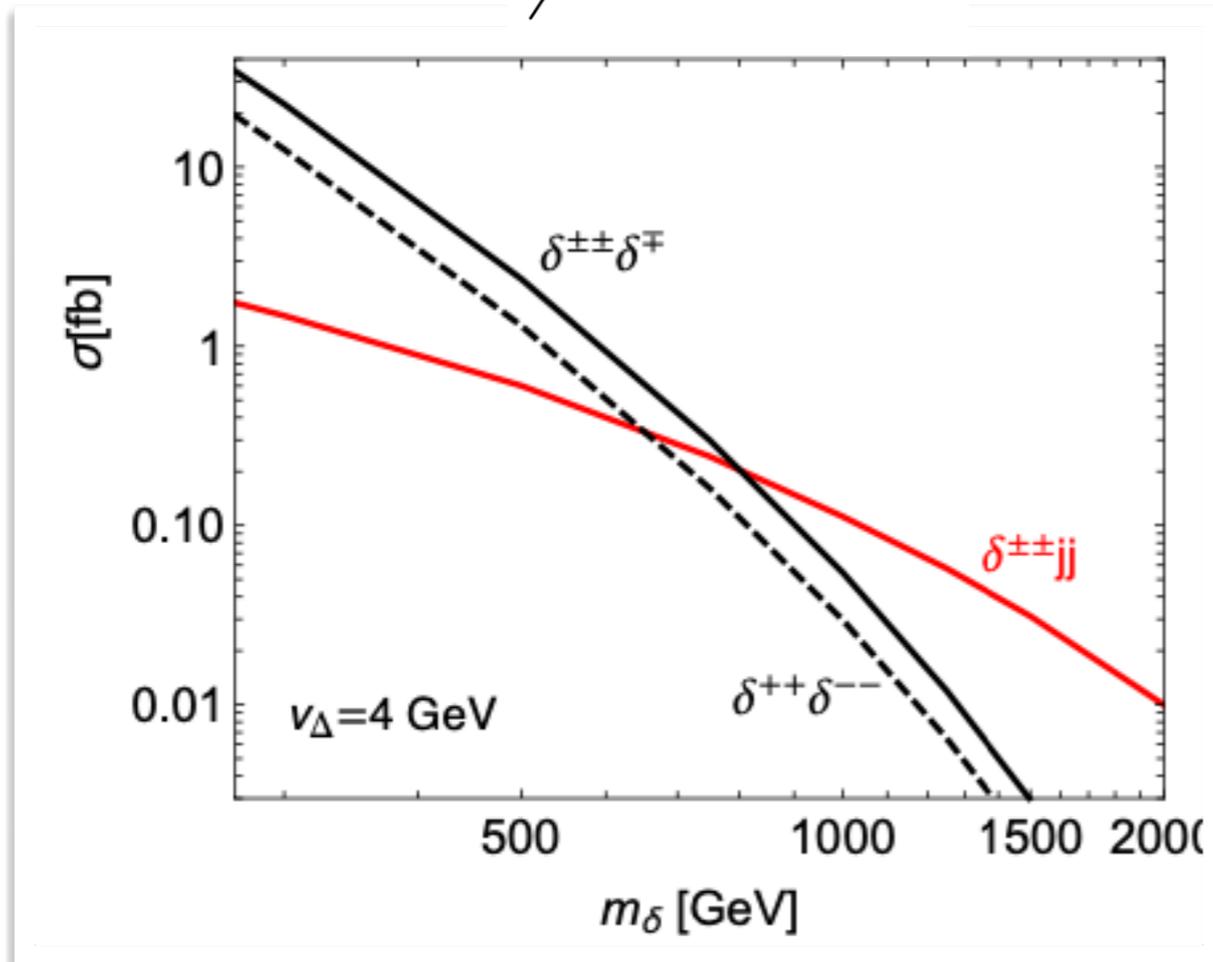
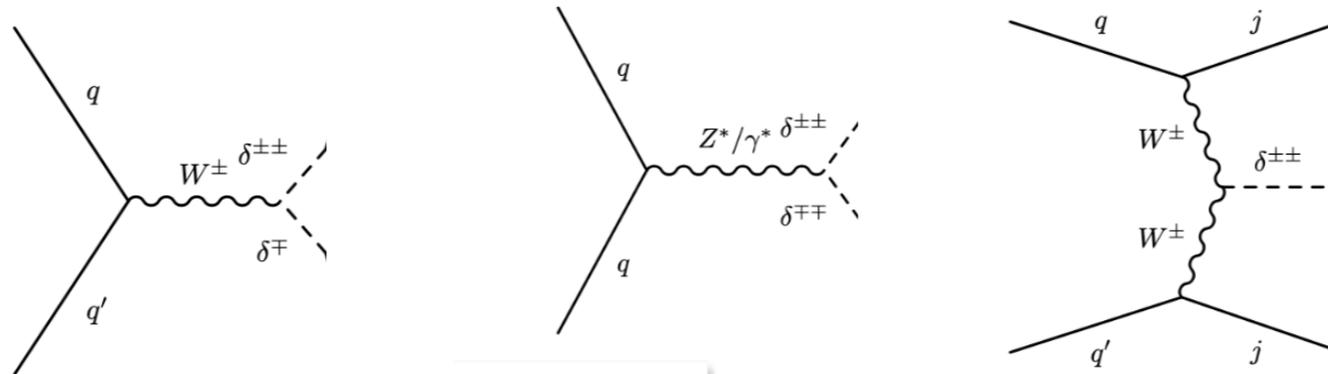
→ Majorana neutrino masses given by $m_\nu = \sqrt{2} Y_\nu v_\Delta$

Mohapatra, Senjanovic (1980); Schechter, Valle (1980); Lazarides, Shafi, Wetterich (1981)

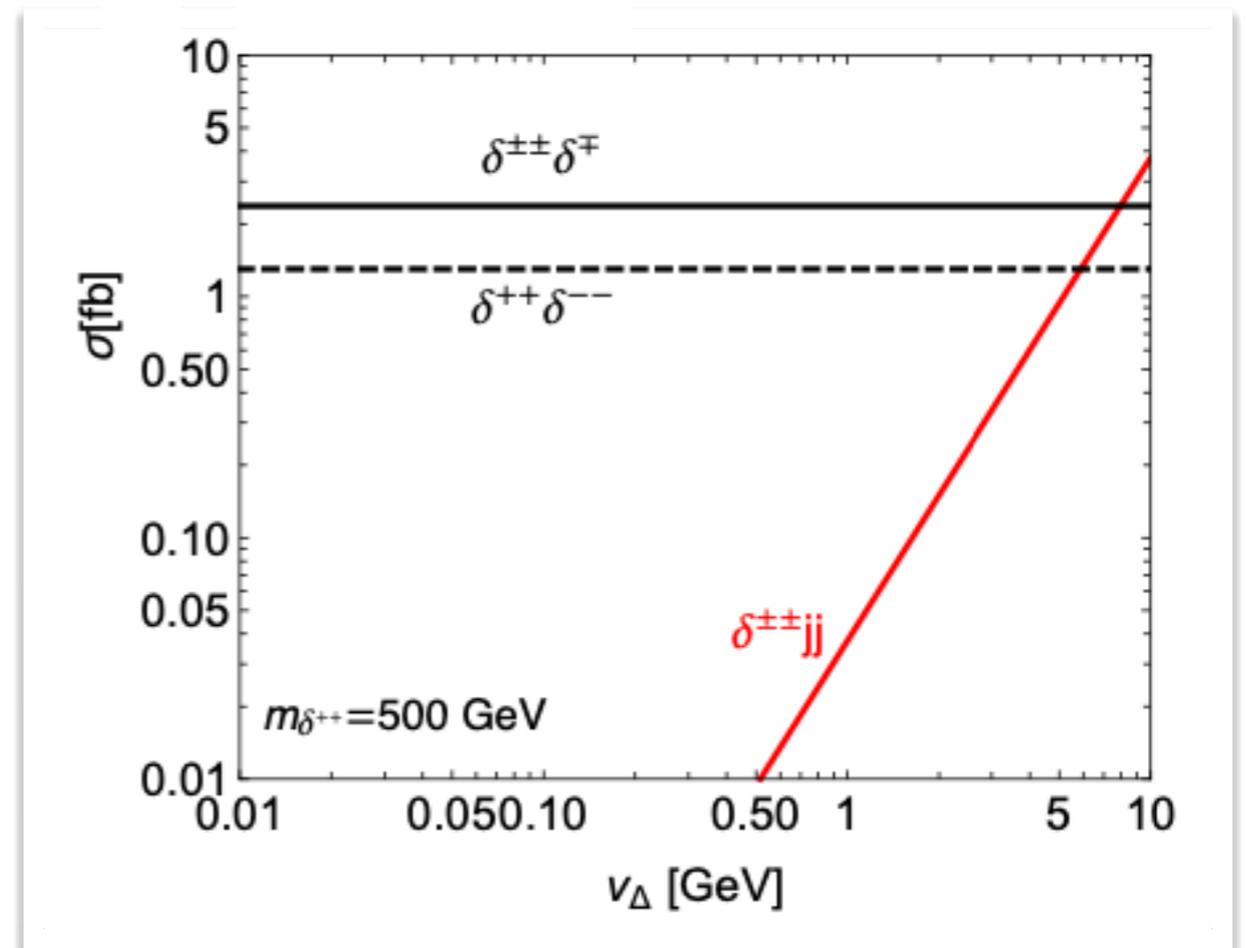
Type-II Seesaw

Δ can directly couple to SM gauge bosons (W^\pm , Z , γ)

Exciting signatures at the LHC [Perez, Han, Huang, Li, Wang \(2008\)](#); [Cai, Han, Li, Ruiz \(2017\)](#)

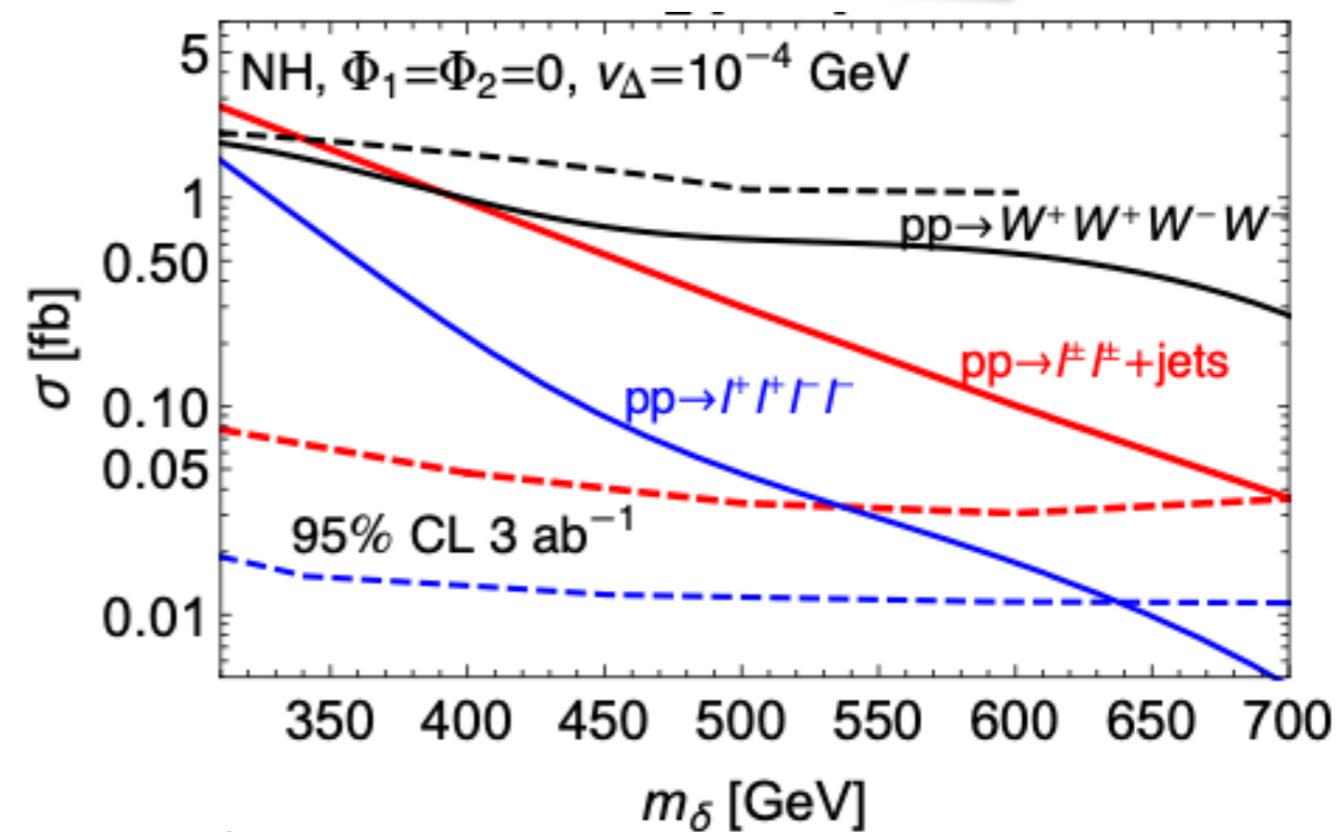
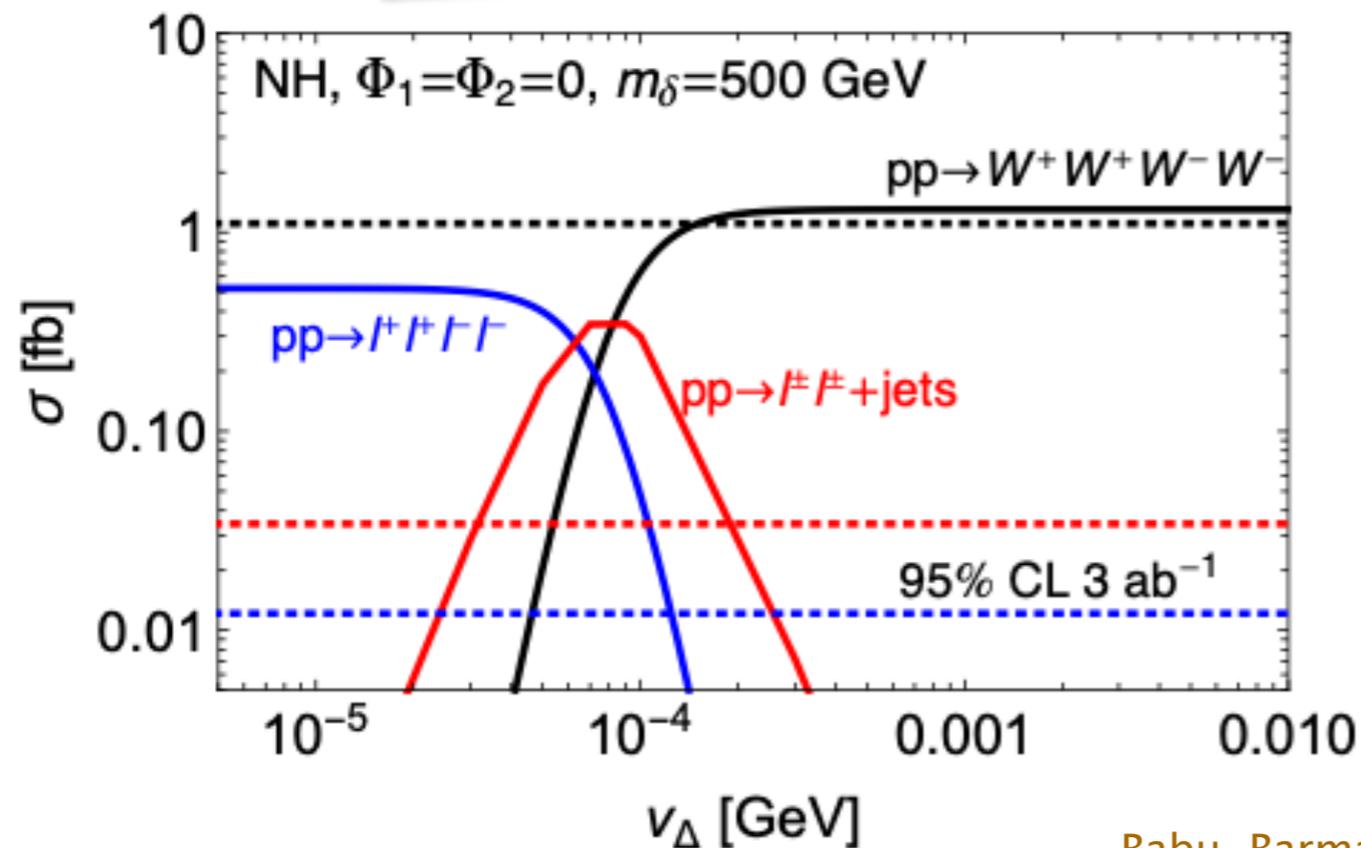
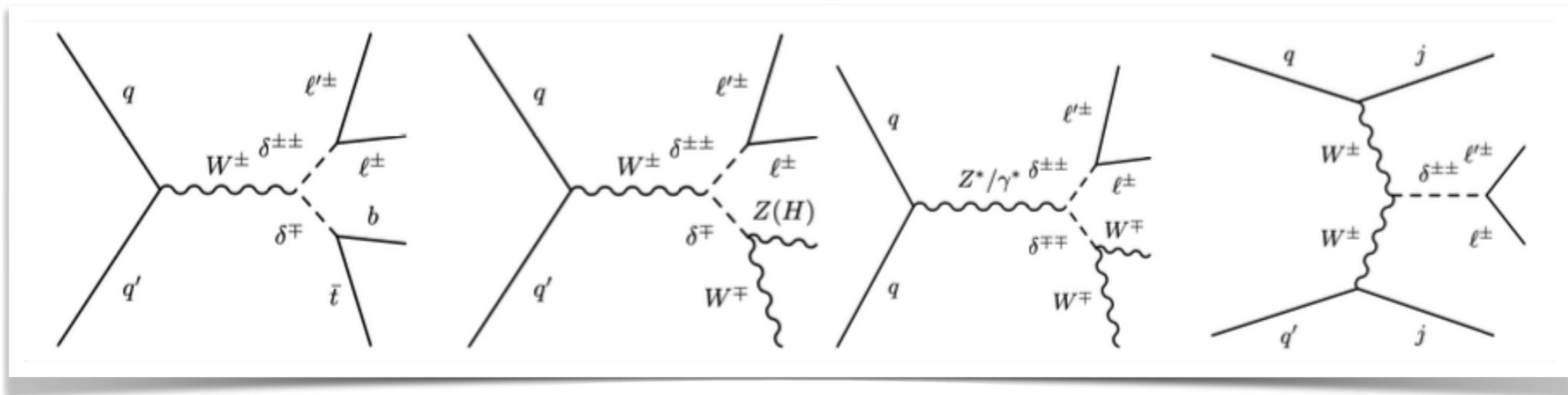


[Babu, Barman, DG, Ismail \(2022\)](#)



Type-II Seesaw: LNV signature

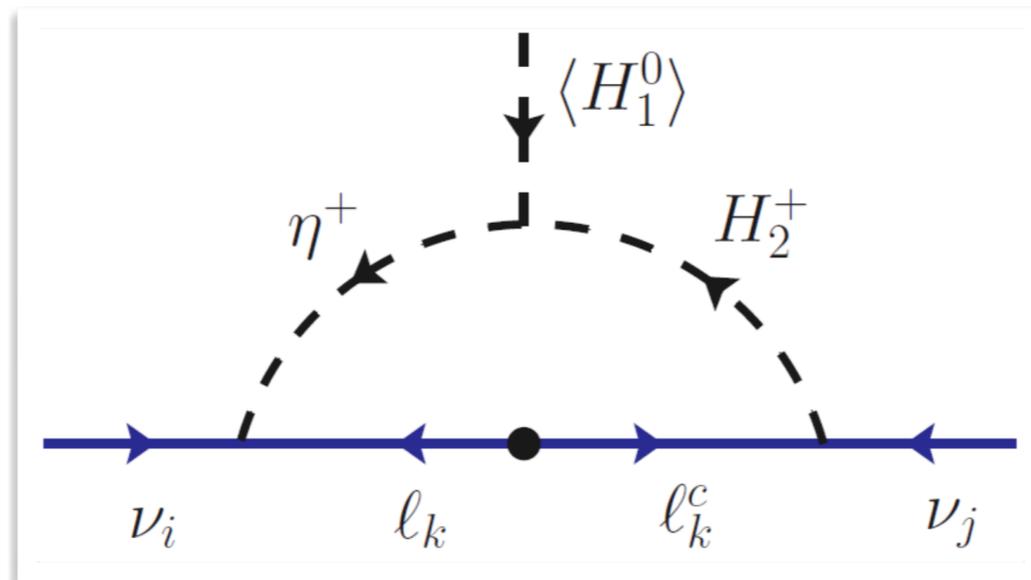
● LNV signature, $pp \rightarrow \ell^\pm \ell'^\pm + \text{jets}$, arise from all 3 leading production modes for $\delta^{\pm\pm}$



Babu, Barman, DG, Ismail (2022)

Zee Model

$H_2(1, 2, -1/2), \eta^+(1, 1, 1)$
 $-\mathcal{L}_Y \supset f_{\alpha\beta} L_\alpha^i L_\beta^j \epsilon_{ij} \eta^+ + Y_{\alpha\beta} \tilde{H}_2^i L_\alpha^j \ell_\beta^c \epsilon_{ij}$
 $+ \tilde{Y}_{u\alpha\beta} H_2^i Q_\alpha^j u_\beta^c \epsilon_{ij} + Y_{d\alpha\beta} \tilde{H}_2^i Q_\alpha^j d_\beta^c \epsilon_{ij} + h.c.$
 $V \supset \mu H_1^i H_2^j \eta^- \epsilon_{ij} + h.c.$



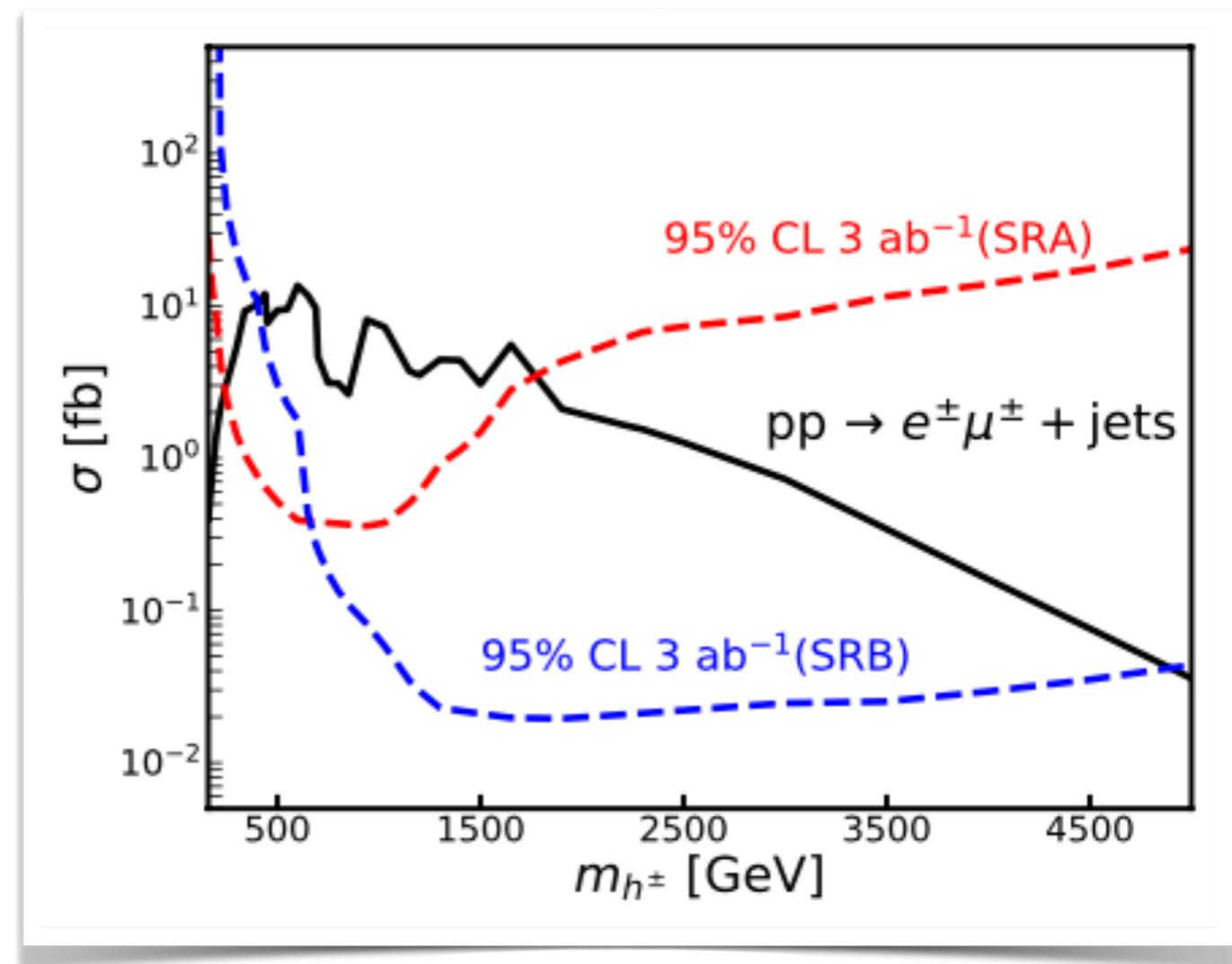
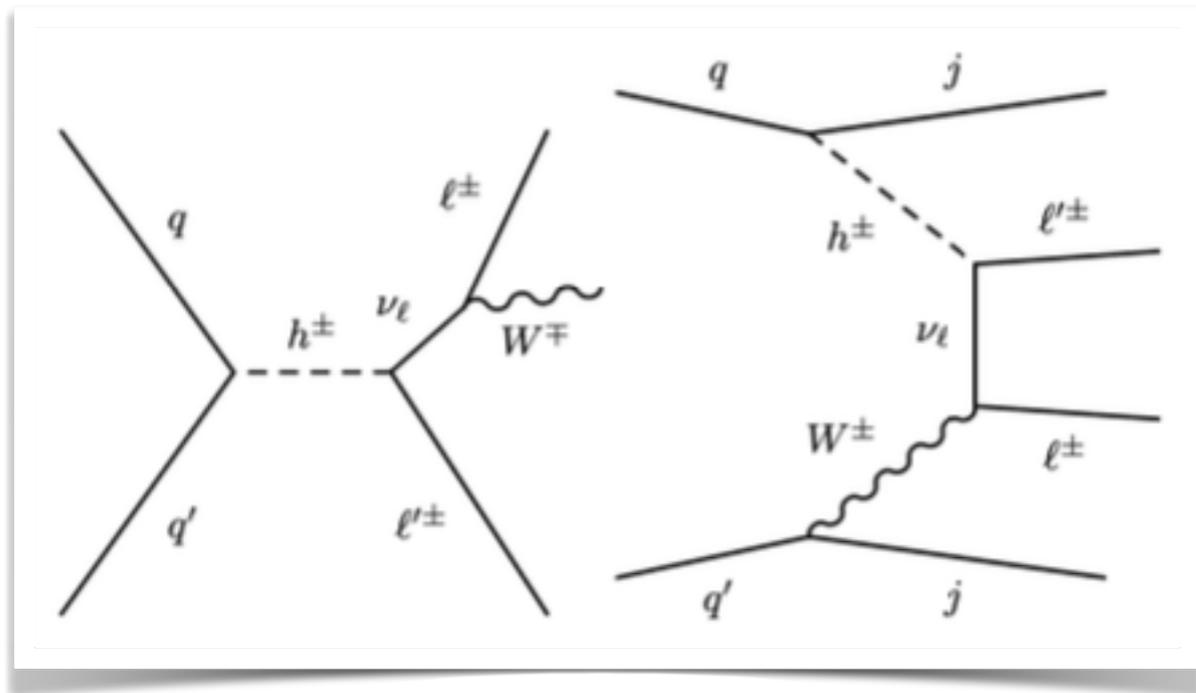
$\longrightarrow m_\nu = \kappa(f M_\ell Y + Y^T M_\ell f^T),$ where $\kappa = (1/16\pi^2) \sin 2\varphi \log(m_{h^+}^2/m_{H^+}^2)$

Zee (1980)

Zee Model: LNV signature

● LNV signature: $pp \rightarrow e^\pm \mu^\pm + \text{jets}$

Focus on parameter space region: $f_{e\mu} \sim \mathcal{O}(1) \gg f_{\mu\tau}, f_{e\tau}$

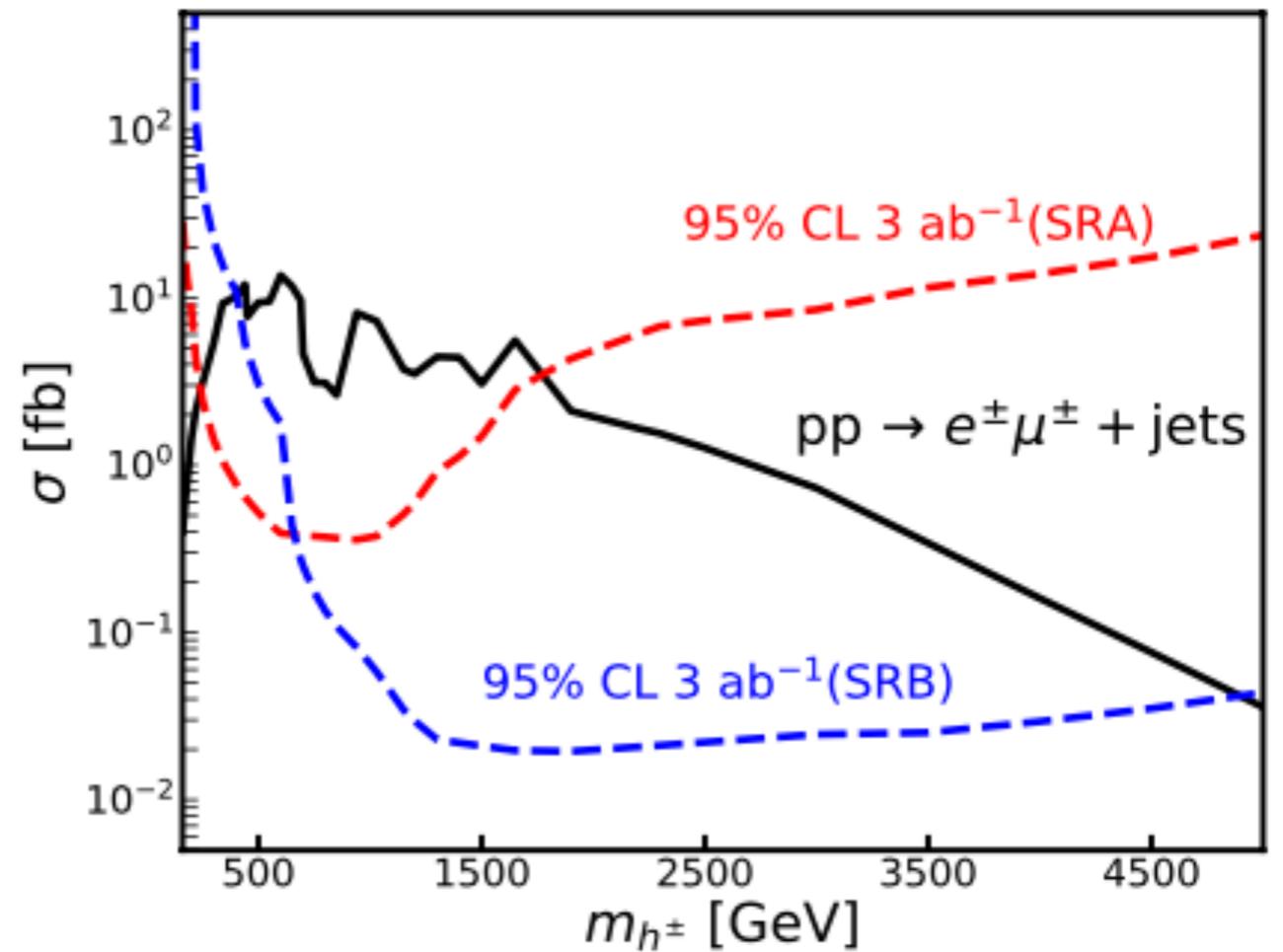
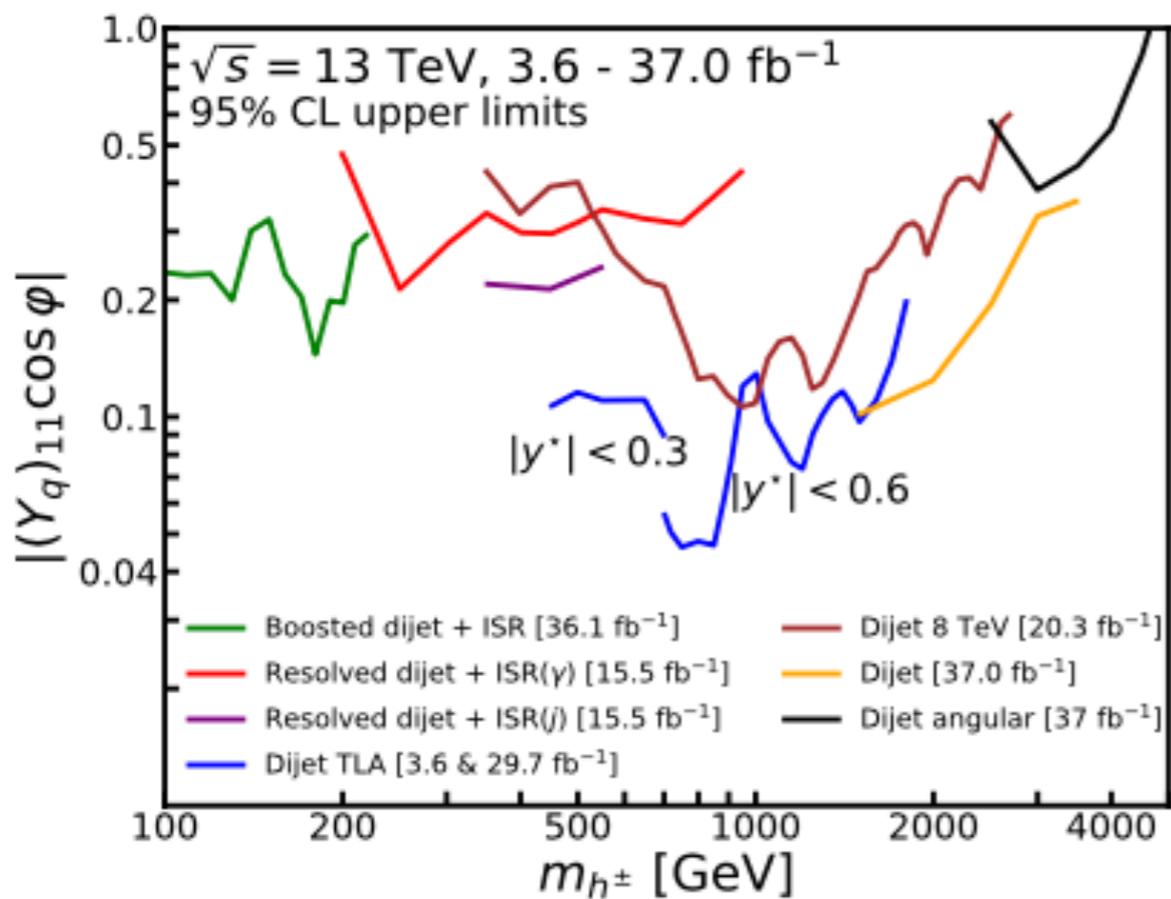


For a general pheno study of the Zee model see Babu, Dev, Jana, Thapa (2019)

Zee Model: LNV signature

● LNV signature: $pp \rightarrow e^\pm \mu^\pm + \text{jets}$

Focus on parameter space region: $f_{e\mu} \sim \mathcal{O}(1) \gg f_{\mu\tau}, f_{e\tau}$

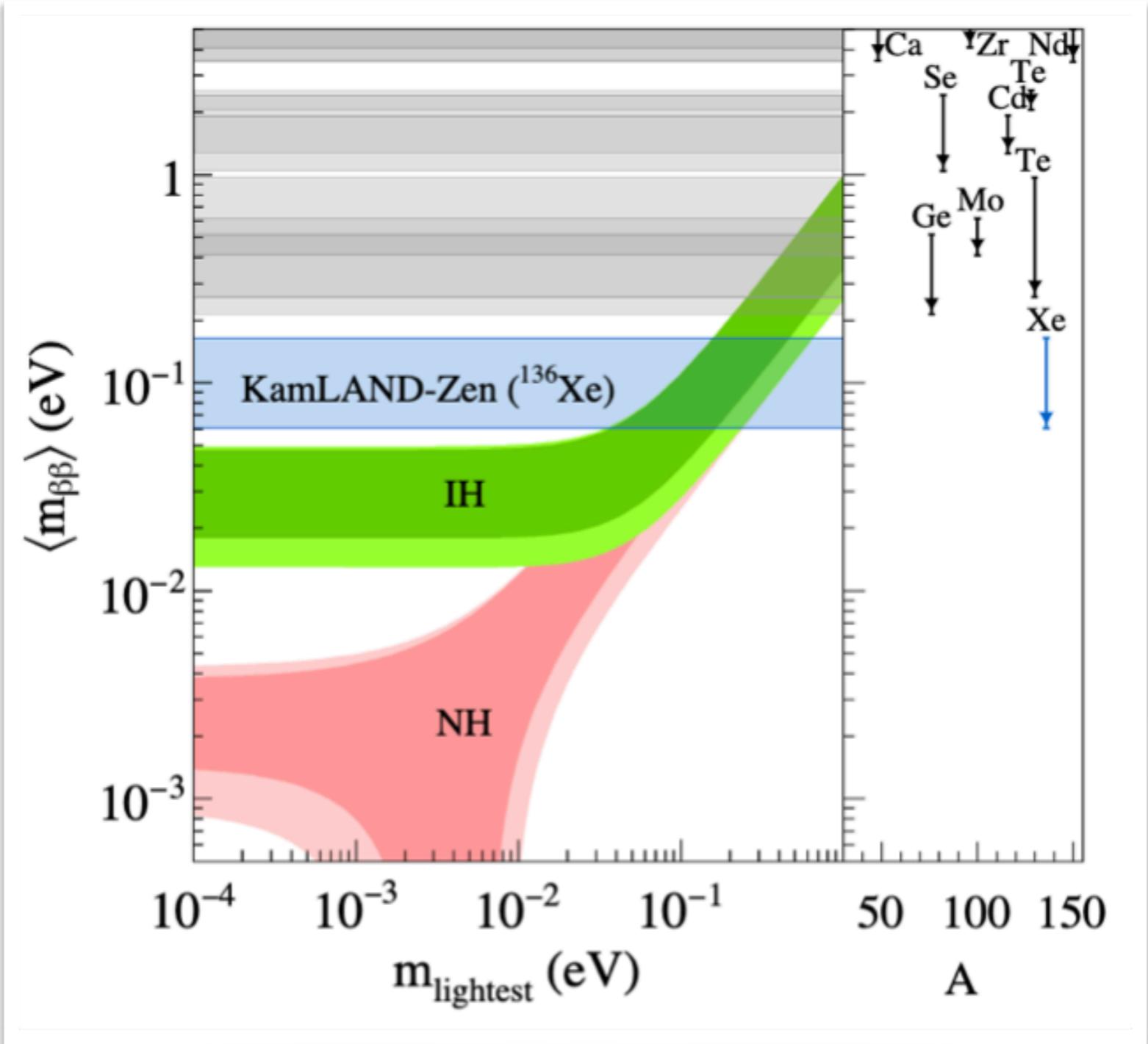


For a general pheno study of the Zee model see Babu, Dev, Jana, Thapa (2019)

Summary

- LHC has potential to probe LNV by two units which would provide evidence for Majorana neutrino
- Tree and loop-level models for mass generation may display LNV signature at the LHC
- ➔ Type-II seesaw: $pp \rightarrow \ell^\pm \ell'^\pm + \text{jets}$ complementary to standard 4ℓ and $4W$ searches at intermediate $v_\Delta \sim 10^{-4}$ GeV
- ➔ Zee model: $pp \rightarrow e^\pm \mu^\pm + \text{jets}$ will be able to probe LNV for wide range of masses $m_{h^\pm} = [0.3, 4.8]$ TeV

Backup



1605.02889