NEUTRAL EXOTICA AT FASERν AND SND@LHC

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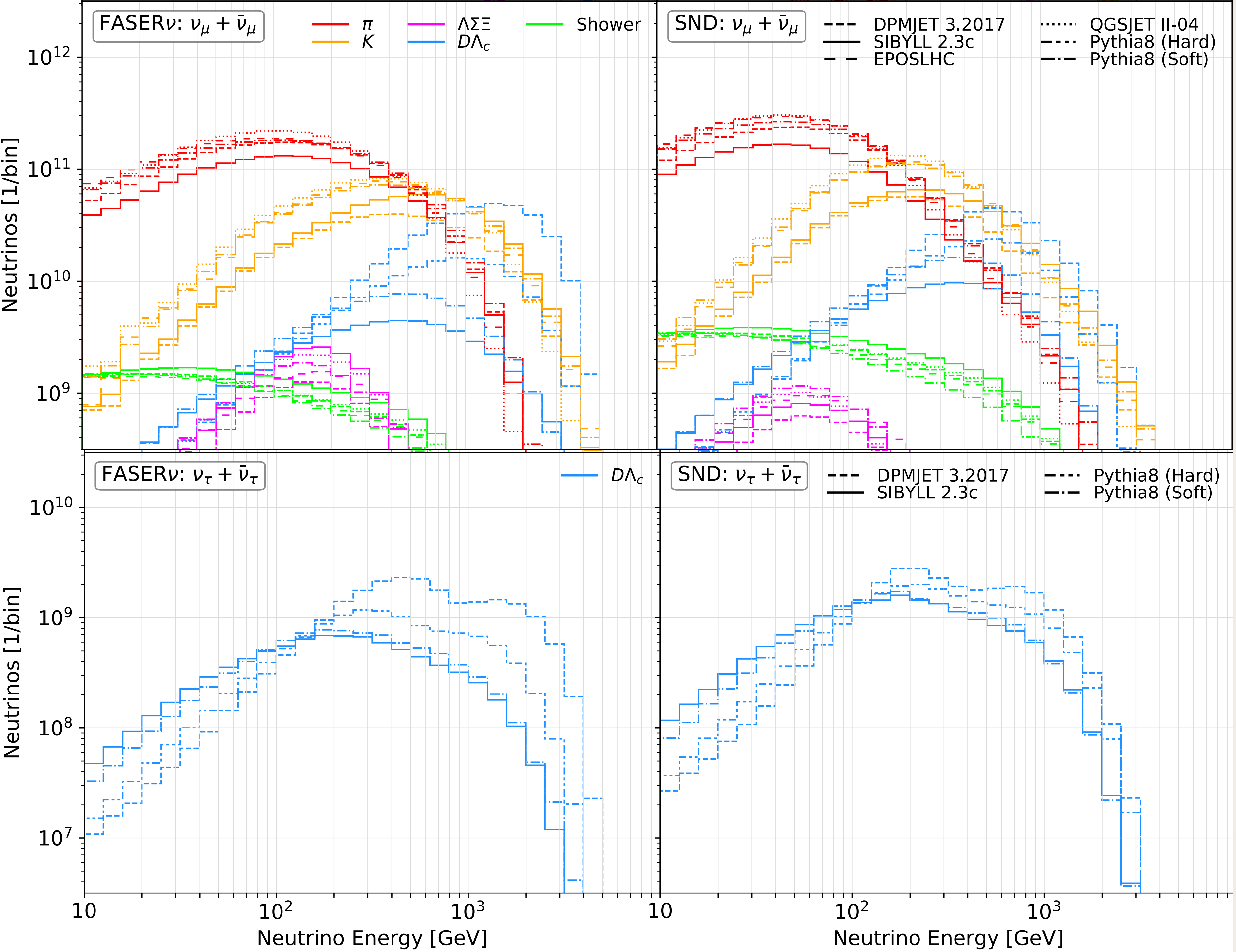
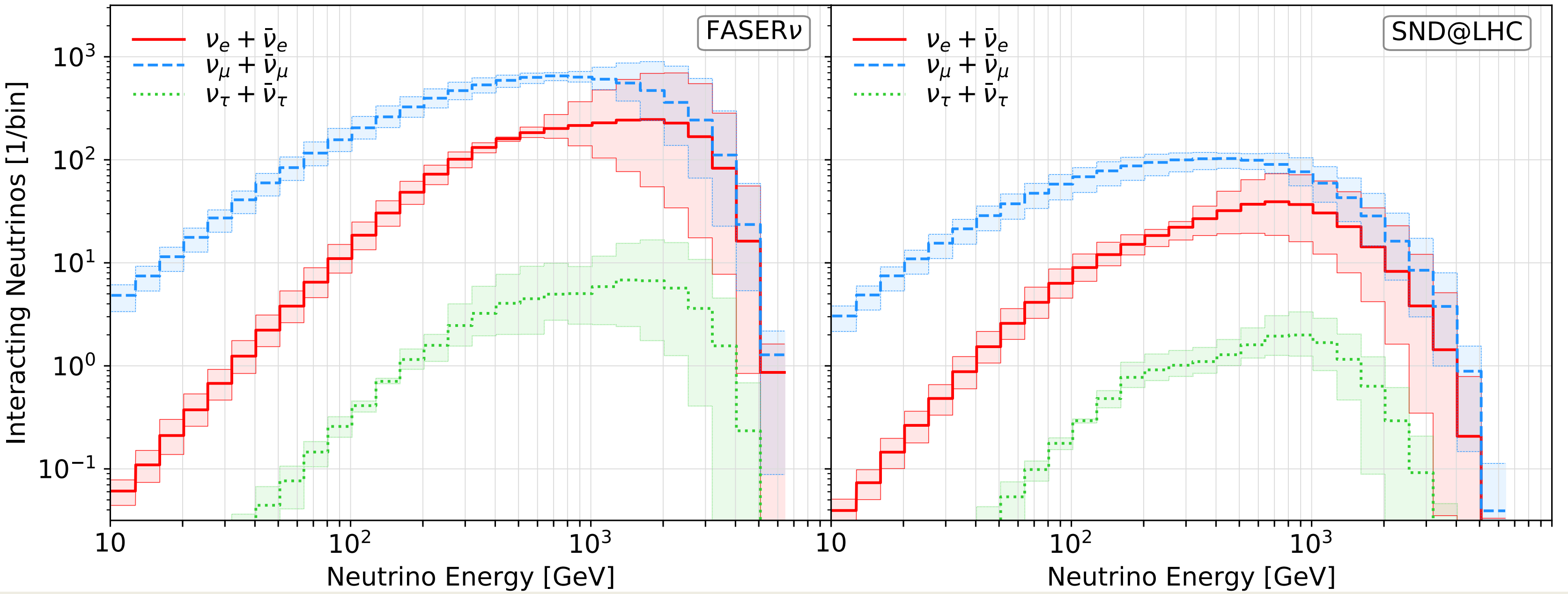


Kling, "Forward Meutrino fluxes at the LHC," 2105.08270

Traces of new physics in neutrino scattering

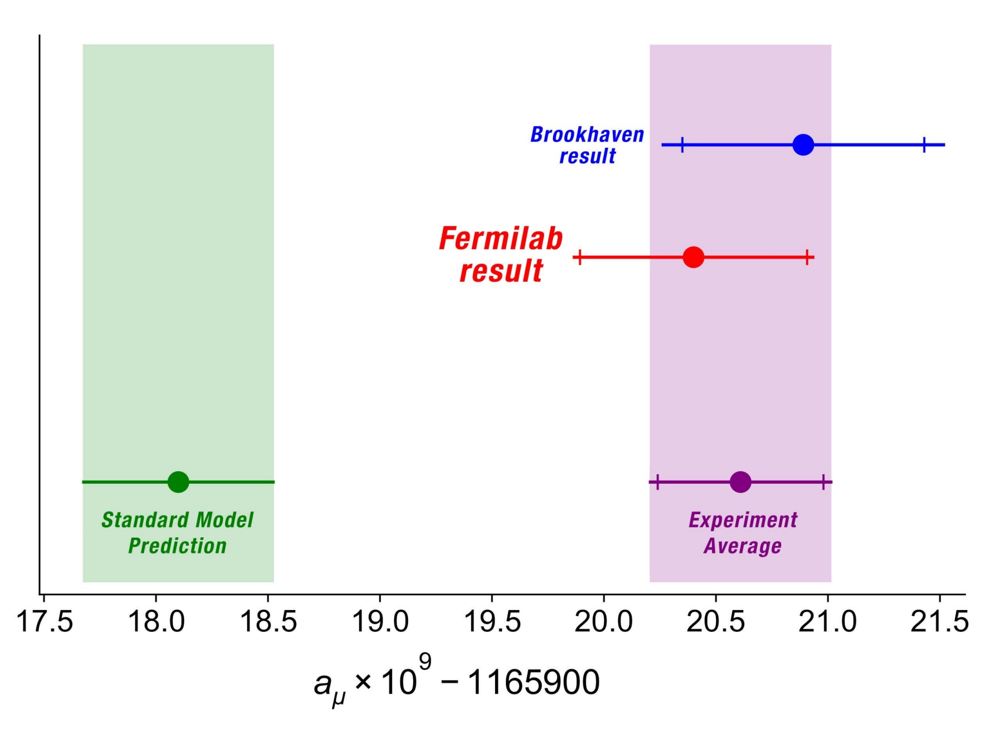
- A. Falkowski, M. González-Alonso, J. Kopp, Y. Soreq and Z. Tabrizi, EFT at FASERν, 2105.12136.
- A. Ismail, R. Mammen Abraham and F. Kling, Neutral current neutrino interactions at FASERν, Phys. Rev. D 103 (2021) 056014 [2012.10500].
- F. Kling, Probing light gauge bosons in tau neutrino experiments, Phys. Rev. D 102 (2020) 015007 [2005.03594].
- P. Bakhti, Y. Farzan and S. Pascoli, Discovery potential of FASERν with contained vertex and through-going events, JHEP 04 (2021) 075 [2010.16312].
- Y. Jho, J. Kim, P. Ko and S.C. Park, Search for sterile neutrino with light gauge interactions: recasting collider, beam-dump, and neutrino telescope searches, 2008.12598.
- K. Jodłowski and S. Trojanowski, Neutrino beam-dump experiment with FASER at the LHC, JHEP 05 (2021) 191 [2011.04751].
- A. Ismail, S. Jana and R.M. Abraham, Neutrino Up-scattering via the Dipole Portal at Forward LHC Detectors, 2109.05032.

Large flux of muon neutrinos



Kling, "Forward Meutrino fluxes at the LHC," 2105.08270

Hints for new couplings of second generation leptons



Anomalous magnetic moment of muon

B. Abi *et al.*, [Muon g-2], ``Measurement of the Positive Muon Anomalous Magnetic Moment to 0.46 ppm,'' PRL **126** (2021) no.14, 141801

Our model

$$\Phi = \begin{bmatrix} \Phi^+ \\ \Phi^0 \end{bmatrix} \qquad N$$

S. Ansarifard and Y. Farzan,
``Neutral Exotica at FASERν and SND@LHC,"
[arXiv:2109.13962 [hep-ph]].

$$Y_\alpha \bar{N} \Phi^T c L_\alpha + Y_d \bar{d} \Phi^\dagger Q + Y_u \bar{u} \Phi^T c Q + \text{H.c.}$$

$$\Downarrow$$

$$G_u \bar{N}_R \nu_\mu \bar{u}_L u_R + G_d \bar{N}_R \nu_\mu \bar{d}_R d_L + G_L \bar{N}_R \mu_L \bar{d}_R u_L + G_R \bar{N}_R \mu_L \bar{d}_L u_R + \text{H.c.}$$

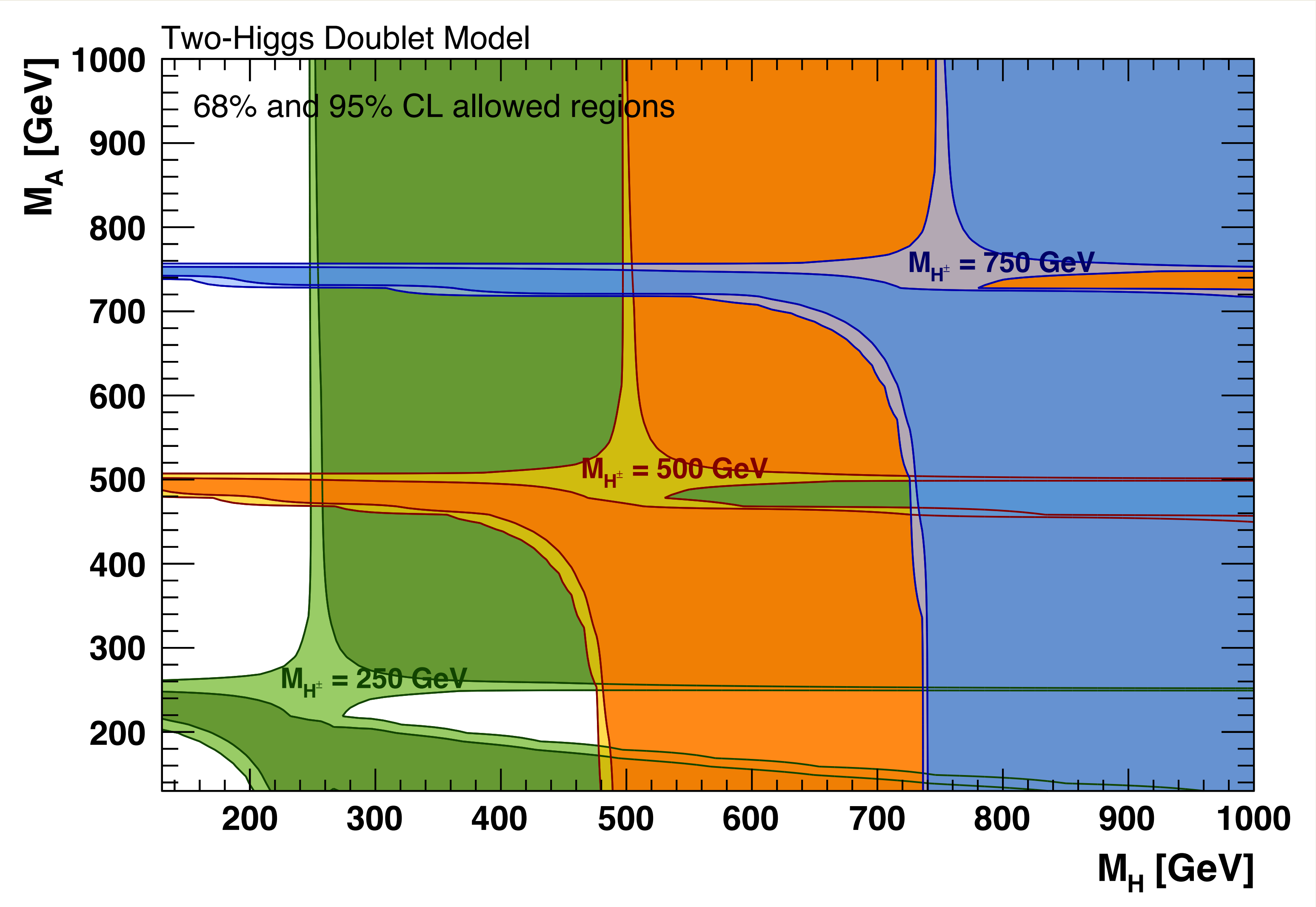
$$G_u = \frac{Y_\mu Y_u^*}{m_{\Phi^0}^2}, \ G_d = -\frac{Y_\mu Y_d}{m_{\Phi^0}^2}, \ G_L = \frac{Y_\mu Y_d}{m_{\Phi^+}^2}, \ \text{and } G_R = \frac{Y_\mu Y_u^*}{m_{\Phi^+}^2}.$$

Imposing global U(1)

$$\Phi \to e^{i\alpha}\Phi, \quad L_\mu \to e^{-i\alpha}L_\mu, \quad \mu_R \to e^{-i\alpha}\mu_R, \quad N \to N, \quad u \to e^{i\alpha}u, \quad \text{and} \quad d \to e^{-i\alpha}d,$$

Dirac or Majorana

- Coupling only first generation quarks
- Coupling to only second generation leptons
- Smallness of masses of u and d quarks
- No loop induced neutrino mass



oblique S, T, U parameters.

J. Haller et al., (Gfitter group),
"Update of the global electroweak fit and constraints on two-Higgs-doublet models,''
Eur. Phys. J. C **78** (2018) no.8, 675

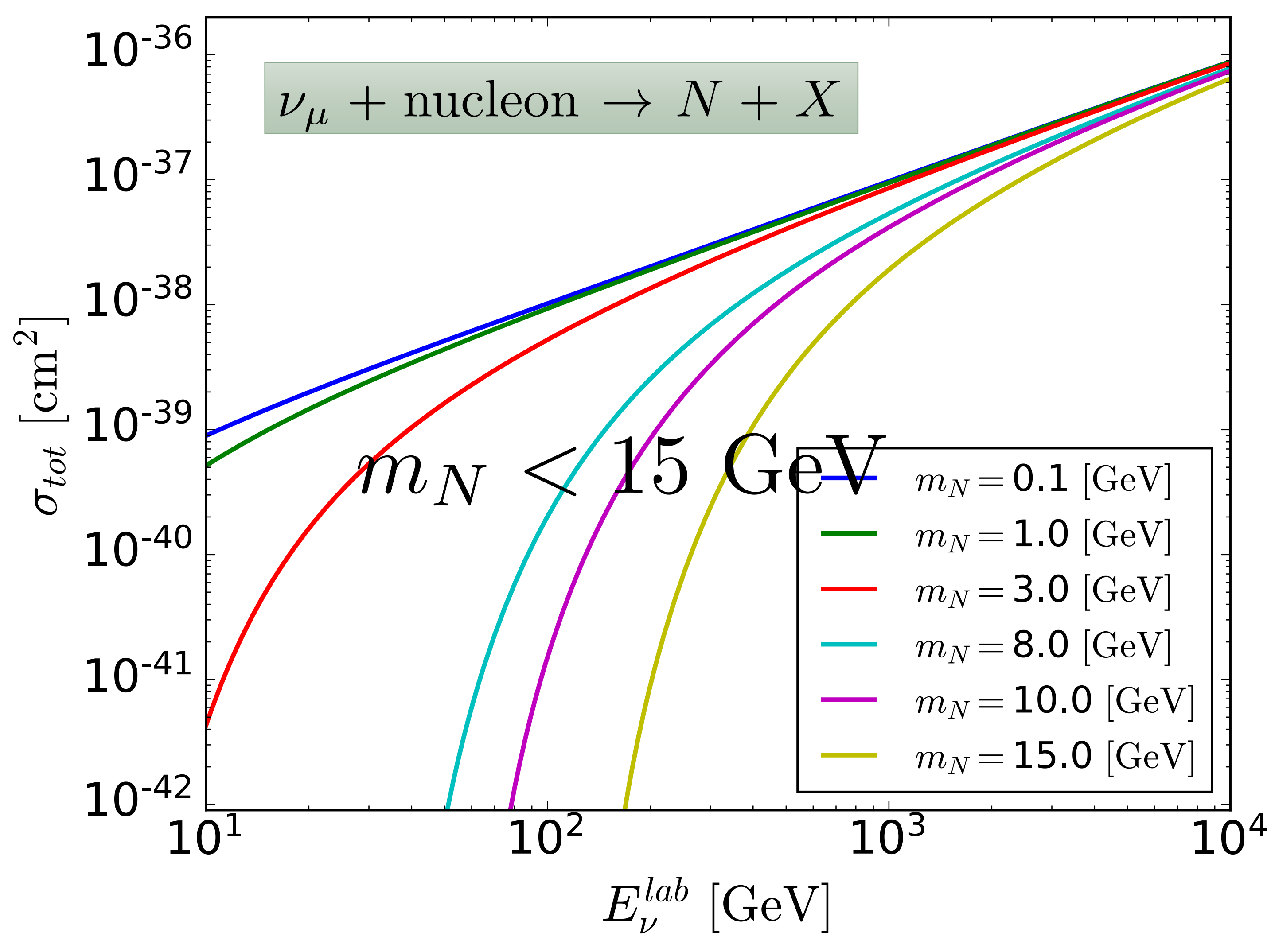
Effective coupling

$$G_u \bar{N}_R \nu_\mu \bar{u}_L u_R + G_d \bar{N}_R \nu_\mu \bar{d}_R d_L + G_L \bar{N}_R \mu_L \bar{d}_R u_L + G_R \bar{N}_R \mu_L \bar{d}_L u_R + \text{H.c.}$$

$(g-2)_\mu$

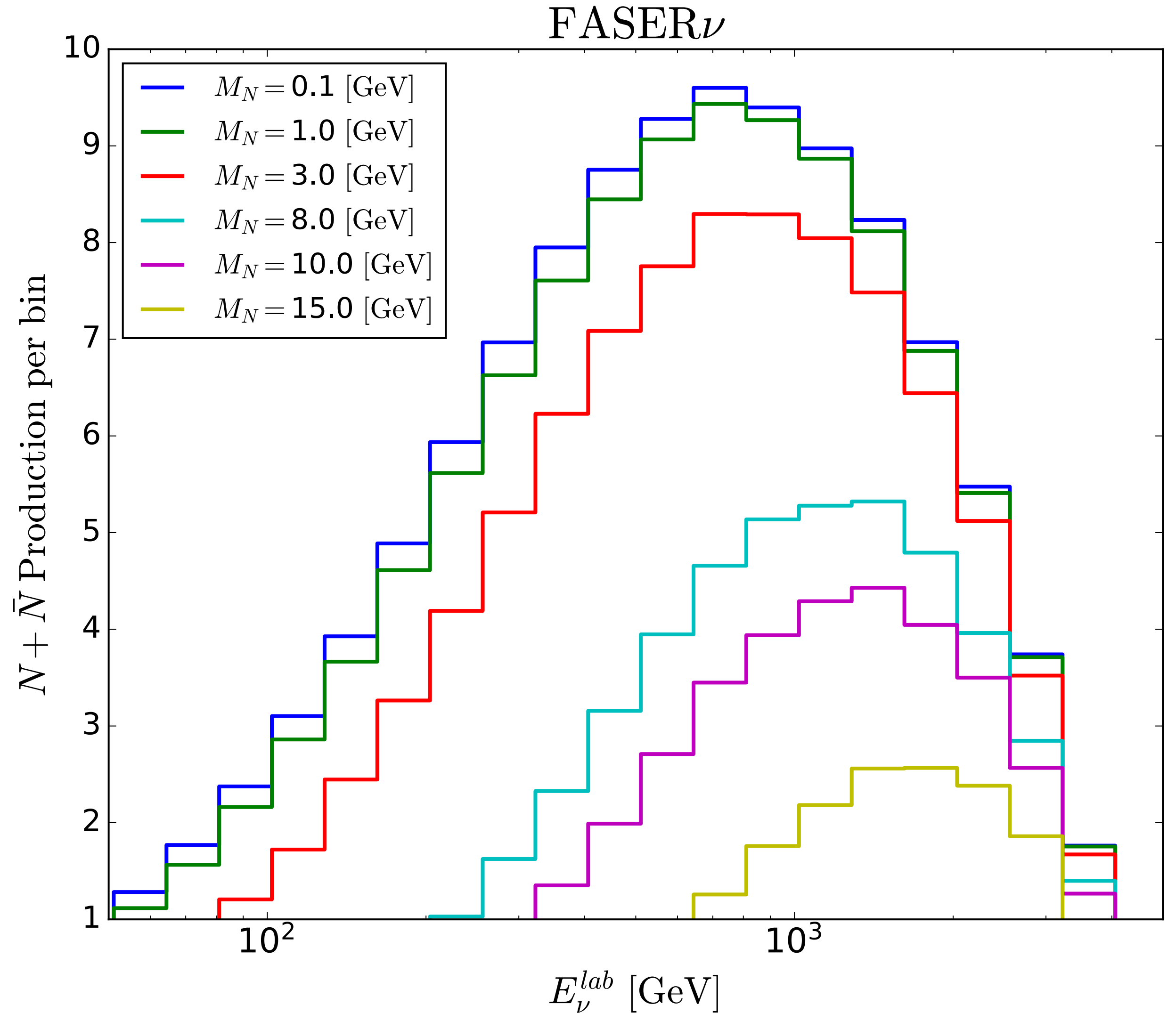
$$Y_u \sim Y_d \sim 0.3,\ Y_\mu \sim 3 \text{ and } m_{\Phi^0} \sim m_{\Phi^+} \sim 300 \text{ GeV},$$

$$G_u \sim G_d \sim G_L \sim G_R \sim 10^{-5} \text{ GeV}^{-2}.$$



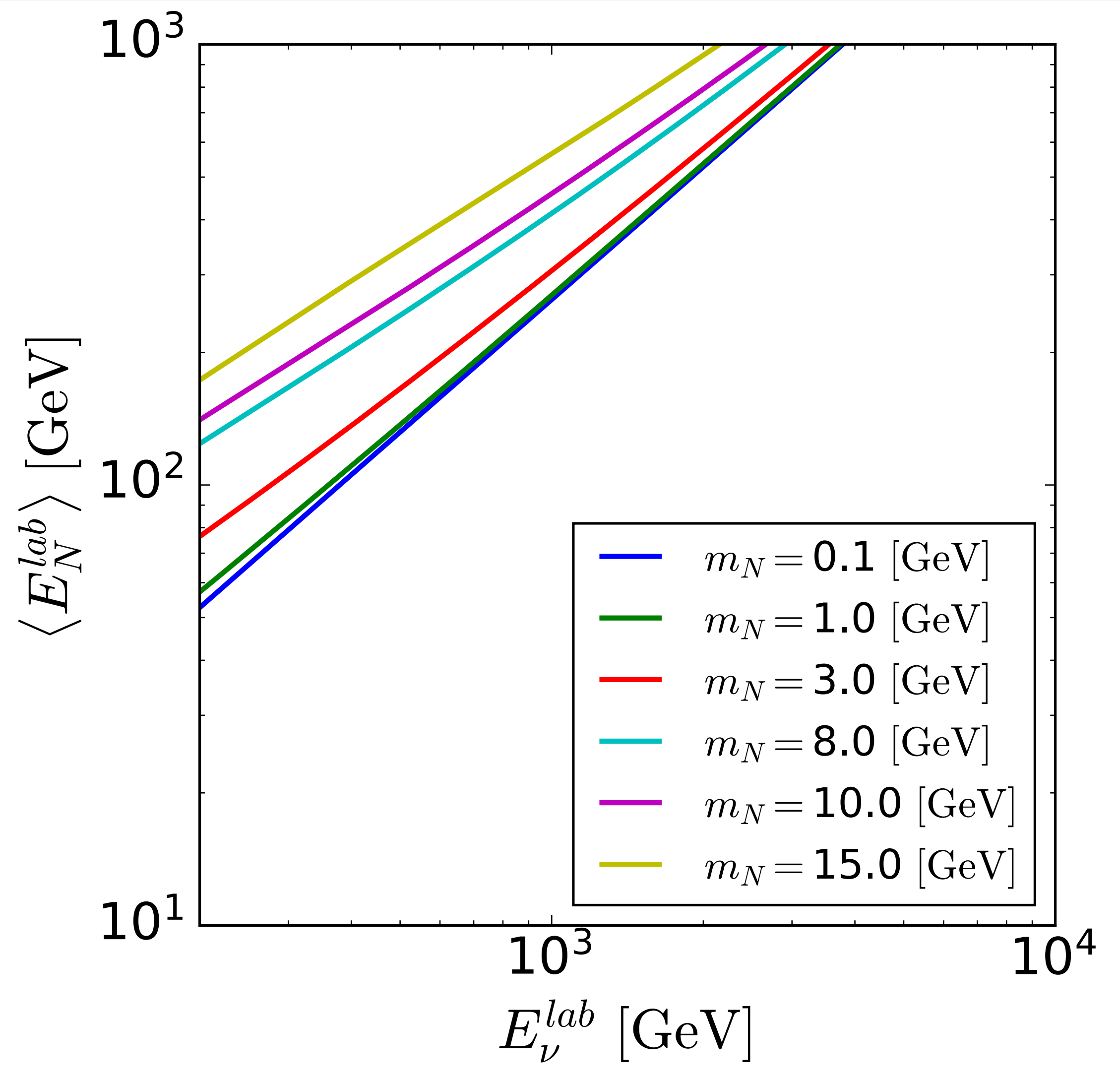
$$G_u = G_d = 10^{-5}\ \mathrm{GeV}^{-2}.$$

S. Ansarifard and Y. Farzan, ``Neutral Exotica at FASERν and SND@LHC," [arXiv:2109.13962 [hep-ph]].

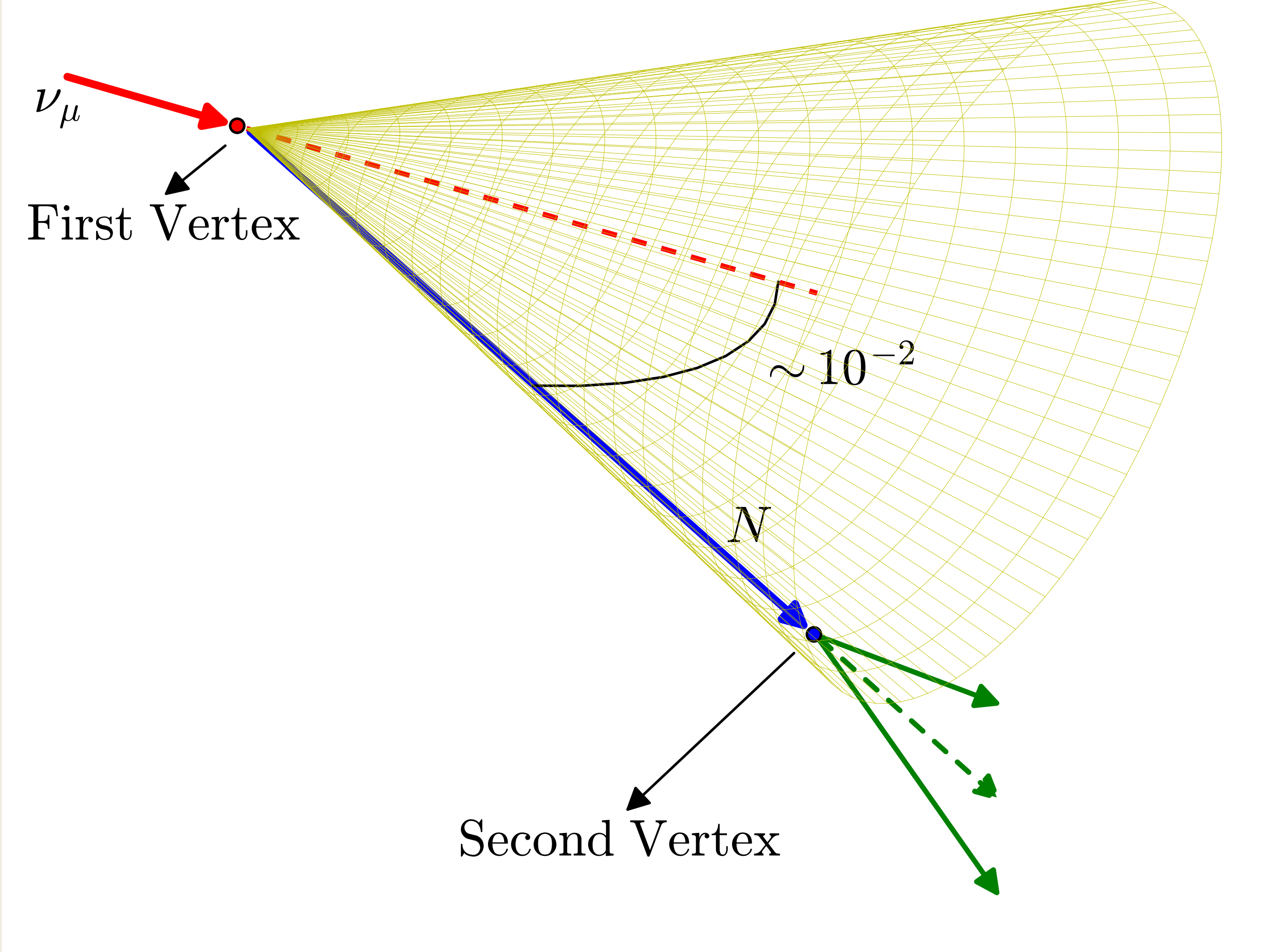


Number	$N+\bar{N}$					
m_N GeV	0.1	1	3	8	10	15
SND@LHC	19	18	13	5	3	1
FASERν	113	109	90	46	35	17
FASERν2	7685	7394	6045	3019	2229	1015

$m_N < 15$ GeV

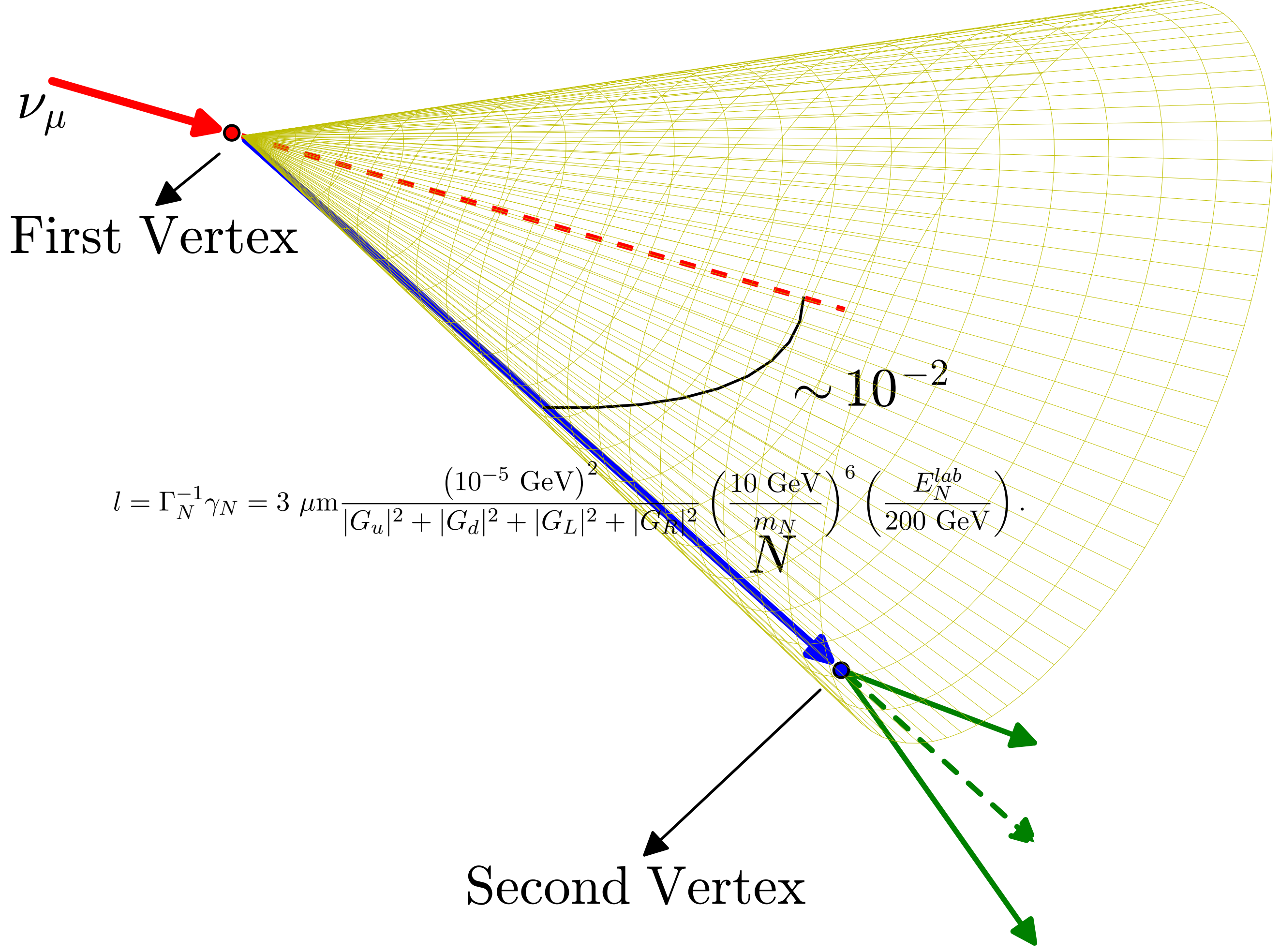


10^3
10^2
10^1
10^3
10^4
$\langle E_N^{lab} \rangle$ [GeV]
E_ν^{lab} [GeV]
$m_N = 0.1$ [GeV]
$m_N = 1.0$ [GeV]
$m_N = 3.0$ [GeV]
$m_N = 8.0$ [GeV]
$m_N = 10.0$ [GeV]
$m_N = 15.0$ [GeV]



$$\Gamma(N \to \nu_\mu u\bar{u}) = \frac{|G_u|^2}{|G_d|^2}\Gamma(N \to \nu_\mu d\bar{d}) = \frac{|G_u|^2}{|G_L|^2 + |G_R|^2}\Gamma(N \to \mu u\bar{d}) = \frac{G_u^2 m_N^5}{1024\pi^3}$$

$$l = \Gamma_N^{-1}\gamma_N = 3\ \mu\text{m}\frac{\left(10^{-5}\ \text{GeV}\right)^2}{|G_u|^2 + |G_d|^2 + |G_L|^2 + |G_R|^2}\left(\frac{10\ \text{GeV}}{m_N}\right)^6\left(\frac{E_N^{lab}}{200\ \text{GeV}}\right).$$



$$l = \Gamma_N^{-1}\gamma_N = 3\ \mu\text{m}\frac{(10^{-5}\ \text{GeV})^2}{|G_u|^2+|G_d|^2+|G_L|^2+|G_R|^2}\left(\frac{10\ \text{GeV}}{m_N}\right)^6\left(\frac{E_N^{lab}}{200\ \text{GeV}}\right).$$

First vertex: NC vertex

Second vertex: NC or CC vertex

Accidental background

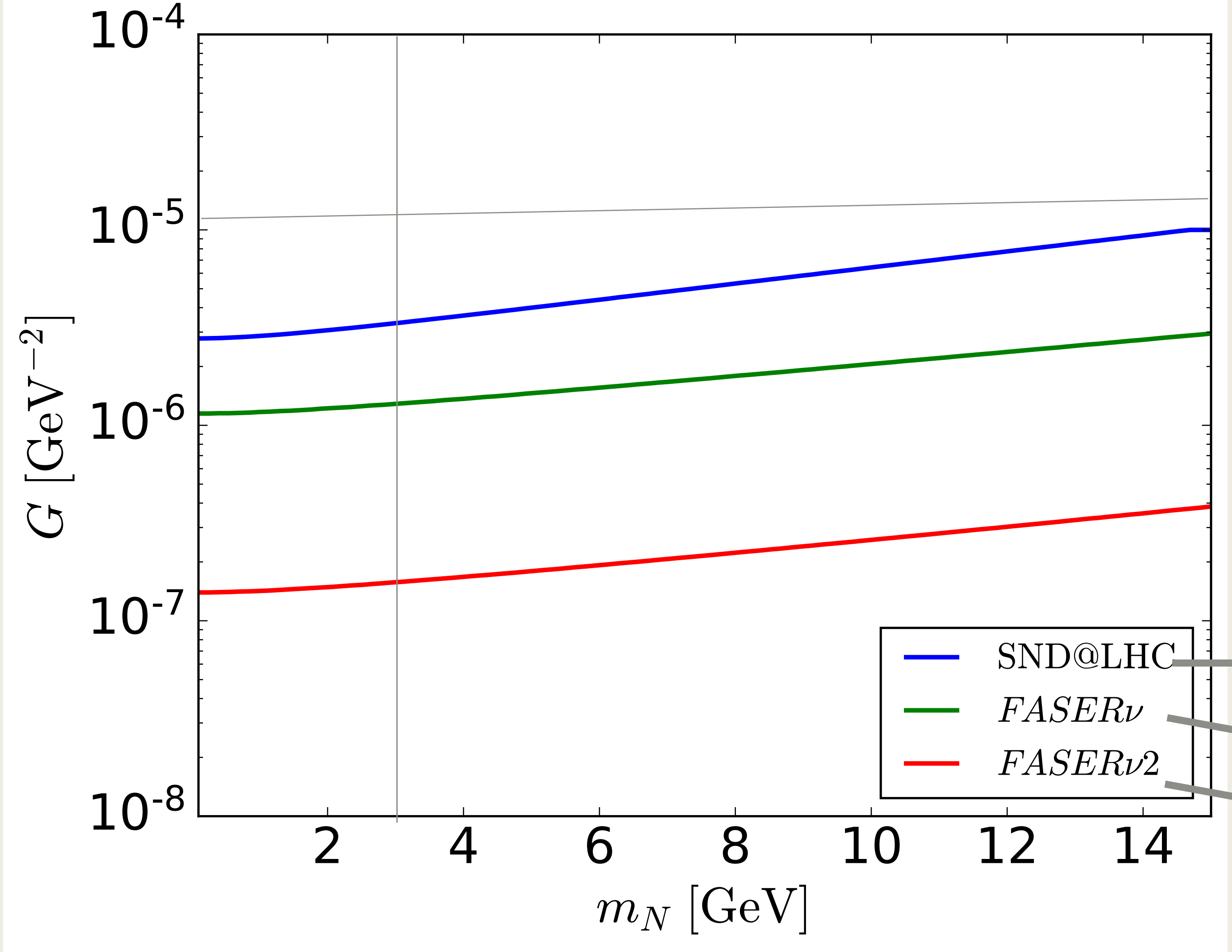
$m_N = 15$ GeV ⇨ $l = 0.4\ \mu\text{m} \simeq \sigma_{pos}$

$m_N = 2$ GeV ⇨ $l = 10$ cm

⇩

$$\mathcal{N}_{NC}^2 \times p/2 \sim 0.02 \text{ and } \mathcal{N}_{NC} \times \mathcal{N}_\mu \times p \sim 0.12.$$

$$l^3 \propto (2\ \text{GeV}/m_N)^{18}.$$



$$G_u = G_d$$

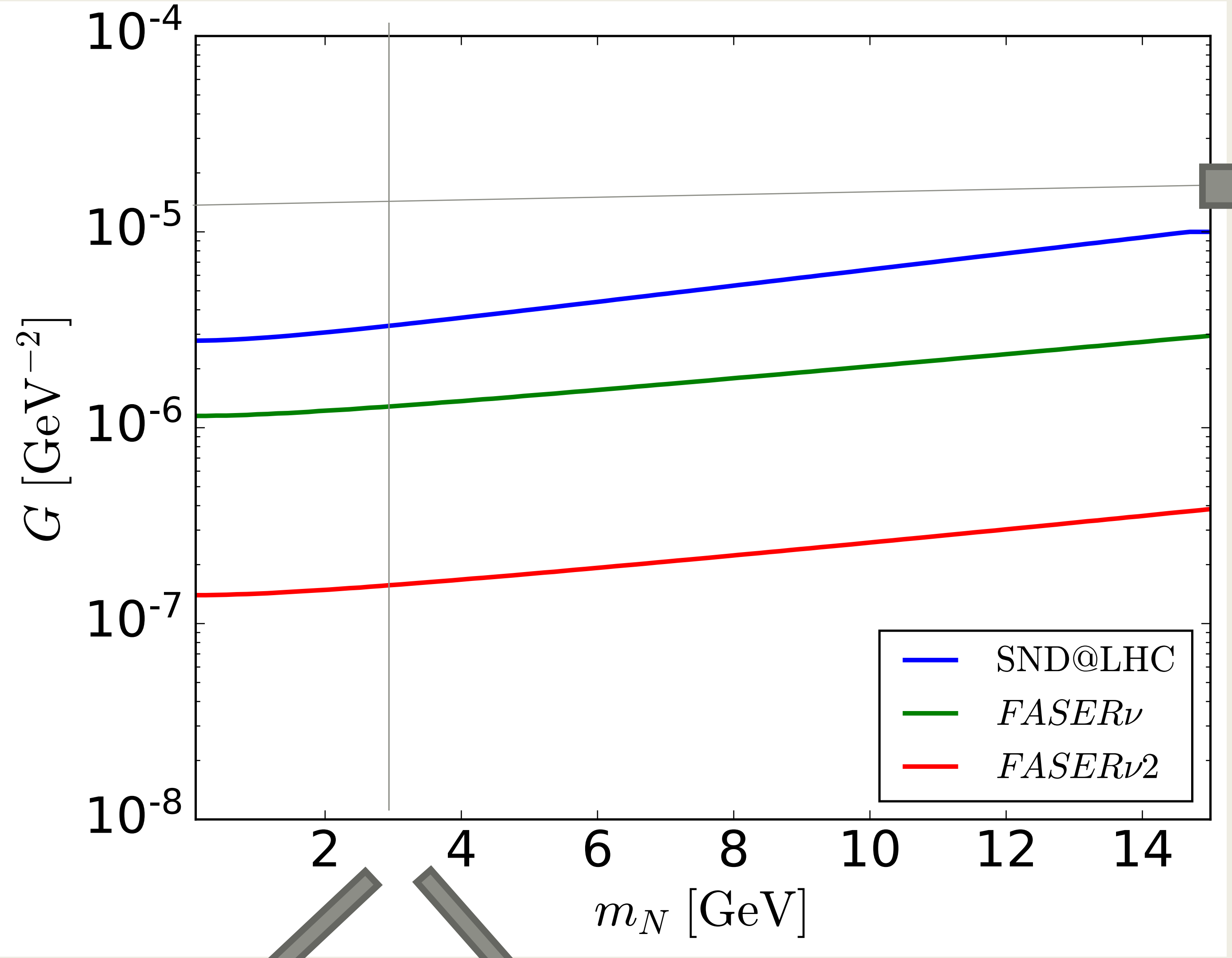
150 fb^{-1} and 3000 fb^{-1}

SND@LHC → 850 kg

FASERν → 1.2 tons

FASERν2 → 10 tons

S. Ansarifard and Y. Farzan, ``Neutral Exotica at FASERν and SND@LHC," [arXiv:2109.13962 [hep-ph]].



Indirect limit: perturbativity of couplings
And lower bound on mediator mass

NOMAD
bound

NuTeV displaced vertex not resolvable

Reanalysis of PDF

CMS and ATLAS

Φ can be pair produced via electroweak interaction

~ 10 fb

$\Phi^0 \to N\bar{\nu}_\mu$ and $\Phi^+ \to N\mu^+$

$$\Gamma(N \to \nu_\mu u\bar{u}) = \frac{|G_u|^2}{|G_d|^2}\Gamma(N \to \nu_\mu d\bar{d}) = \frac{|G_u|^2}{|G_L|^2 + |G_R|^2}\Gamma(N \to \mu u\bar{d}) = \frac{G_u^2 m_N^5}{1024\pi^3}$$

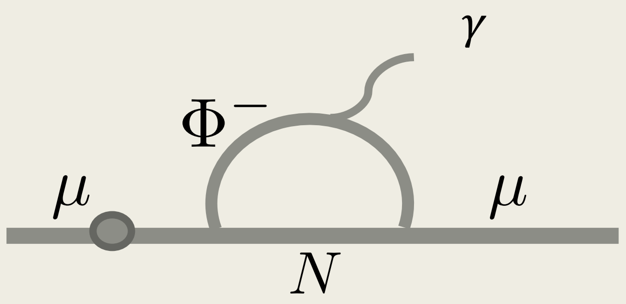
Forward experiments → Customized search in ATLAS and CMS data

Majorana vs Dirac

$\Phi^+ \to \mu^+ N \to \mu^+\mu^+ d\bar{u}$ → Same sign lepton → Majorana

Contribution to Muon Magnetic dipole moment

$$Y_\mu \bar{N} \Phi^T c L_\mu$$



$$\Delta a_\mu = \delta\left(\frac{g-2}{2}\right) = \frac{Y_\mu^2}{16\pi^2}\frac{m_\mu^2}{m_{\Phi^+}^2} K(m_N^2/m_{\Phi^+}^2),$$

$$K(t) = \frac{2t^2+5t-1}{12(t-1)^3} - \frac{t^2 \log t}{2(t-1)^4}.$$

For $m_N^2/m_{\Phi^+}^2 \to 0,\ K \to 1/12$

L. Lavoura, General formulae for f(1) —> f(2) gamma, Eur. Phys. J. C 29 (2003) 191

Contribution to Muon Magnetic dipole moment

Contribution from minimal model: $$\Delta a_\mu = \delta \left(\frac{g-2}{2}\right) = 5 \times 10^{-10} \left(\frac{Y_\mu}{3}\right)^2 \left(\frac{300\ \text{GeV}}{m_{\Phi+}^2}\right)^2 .$$

Four or Five times smaller

$$a_\mu(Exp) - a_\mu(SM) = (25.1 \pm 5.9) \times 10^{-10}$$

B. Abi *et al.*, [Muon g-2], ``Measurement of the Positive Muon Anomalous Magnetic Moment to 0.46 ppm,'' PRL **126** (2021) no.14, 141801

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Four or Five times smaller

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Four copies of scalar doublet → Effective coupling × 4 → Data × 16

Four copies of N → Interesting phenomenology

Chain leptonic decays of N

Model with multiple sterile neutrinos

$$Y_{\alpha i}\bar{N}_i\Phi^T cL_\alpha + \text{H.c.}$$

$$G^\mu_{ij}(\bar{N}_i\mu)(\bar{\mu}N_j) + G^\nu_{ij}(\bar{N}_i\nu_\mu)(\bar{\nu}_\mu N_j)$$

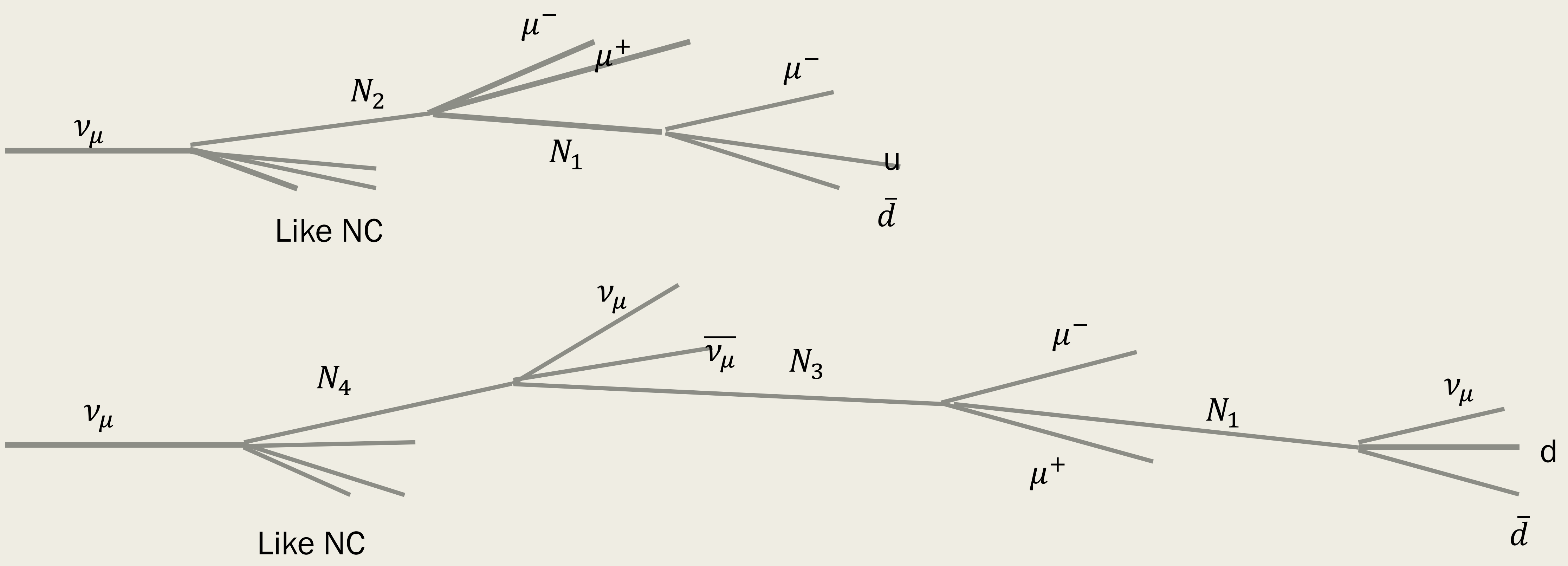
$$G^\mu_{ij} = \frac{Y_{\mu i}Y^*_{\mu j}}{m^2_{\Phi^+}} \quad \text{and} \quad G^\nu_{ij} = \frac{Y_{\mu i}Y^*_{\mu j}}{m^2_{\Phi^0}} + \text{H.c.}$$

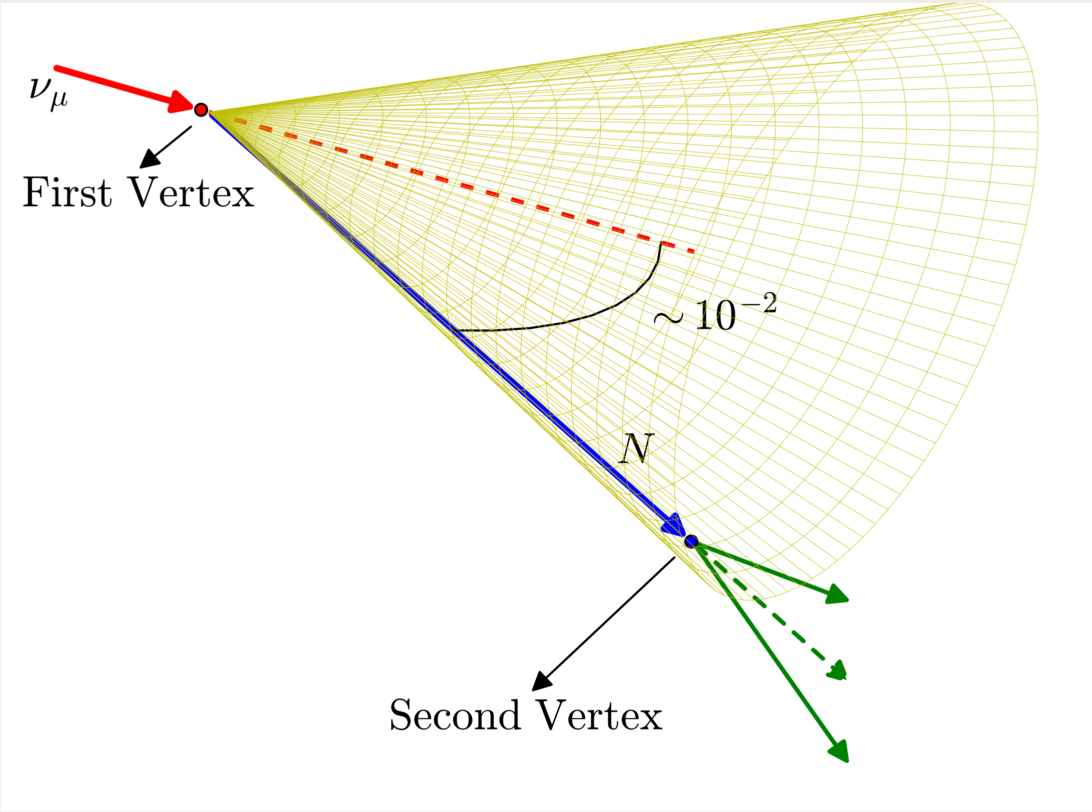
$Y_{\mu i} \sim Y_{\mu j} \sim 3$ and $m_{\Phi^+} \sim m_{\Phi^0} \sim 300$ GeV, $\Rightarrow$ $G^\nu_{ij} \sim G^\mu_{ij} \sim 10^{-4}\ \text{GeV}^{-2}$.

$Y_{\mu i} \gg Y_u, Y_d$: $N_i \to N_j\mu\bar{\mu}$ and $N_i \to N_j\nu_\mu\bar{\nu}_\mu$.

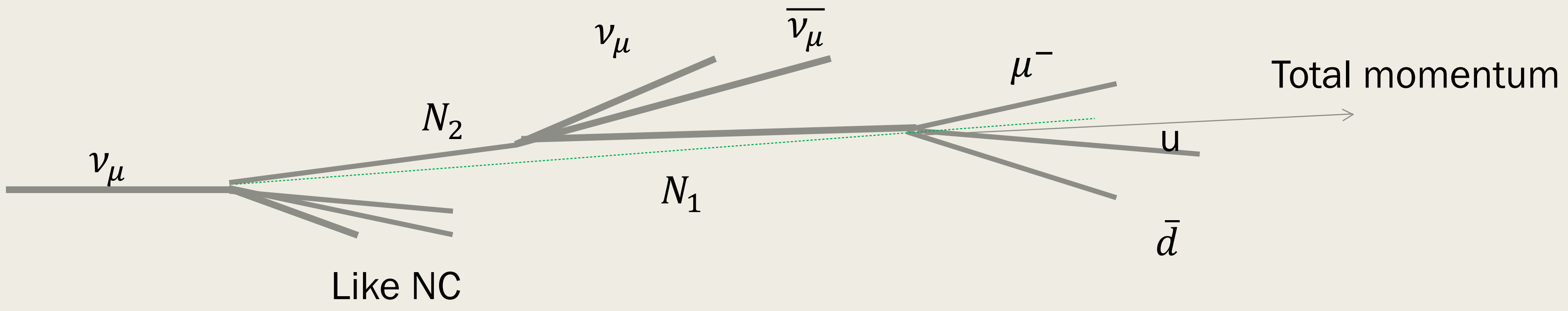
The lightest N_i decays into ν+two jets or μ+two jets

Signals at forward experiments




ν_μ
First Vertex
$\sim 10^{-2}$
N
Second Vertex

Missing transverse momentum

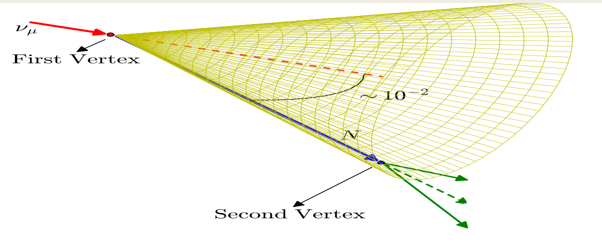


Summary

- Forward experiments can test $G_u \bar{N}_R \nu_\mu \bar{u}_L u_R + G_d \bar{N}_R \nu_\mu \bar{d}_R d_L$

$$m_N < 15 \text{ GeV}$$

- Signature of minimal model:



Alert for CMS and ATLAS

- CMS and ATLAS→ nature of N (Majorana vs Dirac)

Summary

- Contribution to muon magnetic moment, ¼ of deviation
- Extending model to include more N
- Chain decays of N at forward experiments with multiple muon emission