BSM Physics @ FASERν from the Neutrino Nucleon Scattering

NuINT 2022, The 13th International Workshop on Neutrino-Nucleus Interactions in the Few GeV Regions

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Based On: 10.1007JHEP12(2021)209, arXiv:2205.11077

Talk OutLine

1, Introduction to FASERν Detector

2, Non-standard neutrino and Z′ interactions at the FASERv

3, Constraining the Active-to-Heavy-Neutrino Z' transitional magnetic moments at FASERν

4, FPF

5, Summary

Motivation

“High energy collisions at the High-Luminosity Large Hadron Collider (LHC) produce a large number of particles along the beam collision axis, outside of the acceptance of existing LHC experiments.”

Neutrinos at the LHC

There is a huge flux of neutrinos in the forward direction, mainly from π, K and D meson decay. ATLAS provides an intense and strongly collimated beam of TeV-energy neutrinos along beam collision axis.

The neutrino beam passes through the side tunnels TI12 and TI18, about ~500 m downstream from ATLAS and shielded by ~100 m of rock from the IP, providing a natural location for LHC neutrino experiments.

FASER: ForwArd Search ExpeRiment at the LHC

The Forward Search Experiment at the LHC, has the potential to detect collider neutrinos for the first time .

FASERν is a newly approved detector whose main mission is to detect the neutrino flux from the collision of the proton beams at the ATLAS Interaction Point during the run III of the LHC in 2022-2025.

FASERv is an emulsion neutrino detector, consisting of 730 layers of emulsion films interleaved with tungsten plates as target. The total target mass is about 1.2 ton.

Detector				Number of CC Interactions		
Name	Mass	Coverage	Luminosity	$\nu_e+\bar{\nu}_e$	$\nu_\mu+\bar{\nu}_\mu$	$\nu_\tau+\bar{\nu}_\tau$
FASERν	1 ton	$\eta \gtrsim 8.5$	150 fb^{-1}	901 / 3.4k	4.7k / 7.1k	15 / 97
SND@LHC	800kg	$7 < \eta < 8.5$	150 fb^{-1}	137 / 395	790 / 1.0k	7.6 / 18.6
FASERν2	20 tons	$\eta \gtrsim 8.5$	3 ab^{-1}	178k / 668k	943k / 1.4M	2.3k / 20k
FLArE	10 tons	$\eta \gtrsim 7.5$	3 ab^{-1}	36k / 113k	203k / 268k	1.5k / 4k
AdvSND	2 tons	$7.2 \lesssim \eta \lesssim 9.2$	3 ab^{-1}	6.5k / 20k	41k / 53k	190 / 754

charged current neutrino interactions occurring the detector (Sibyll 2.3d and DPMJet 3.2017.)

Arxiv: 2109.10905v1

FASERν will give us an opportunity to measure ν-N cross-section in the ~ [100GeV – few TeV] range.

FASERv will record topology/kinematics of interaction

FASERν: Neutrino spectra

The LHC neutrino beam is broad, with mean energies around 1 TeV, exceeding the energies of all other artificial neutrino sources.

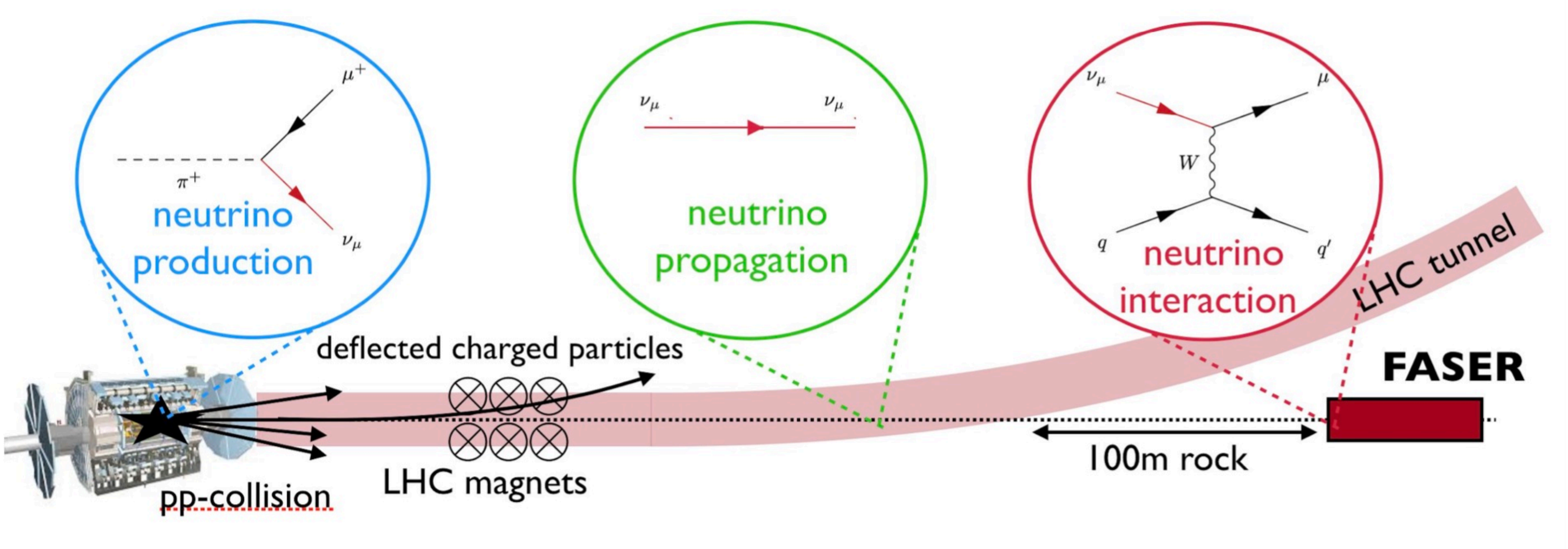
It originates from a variety of sources: pion, kaon, hyperon and charm decays.

It contains all neutrinos and anti-neutrinos of all three flavour.

Source: 10.1103/PhysRevD.104.113008

LHC Neutrino Physics Potential

What can we do learn from those neutrinos?



Source: arXiv:2109.10905v1

Non-standard neutrino and Z′ interactions at the FASERν

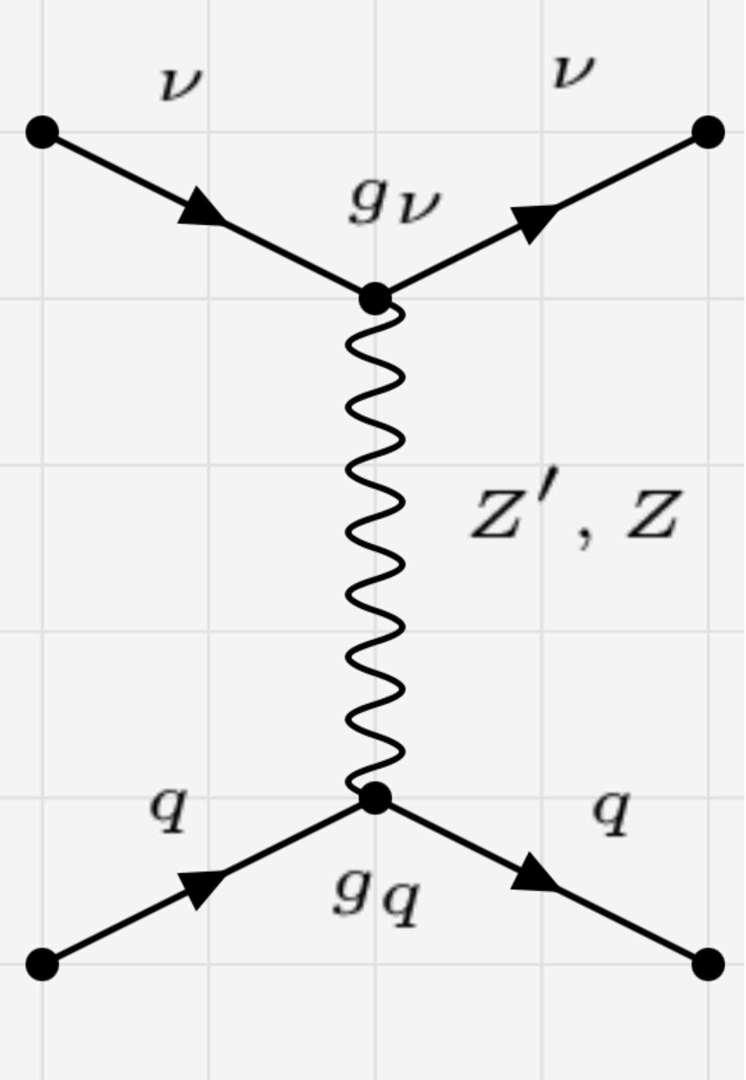
K. Cheung, C. J. Ouseph and T. Wang, JHEP12(2021), 209 doi:10.1007JHEP12(2021)209[arXiv:2111.08375 [hep-ph]]

$$\mathscr{L}_{NC} = -2\sqrt{2}G_F \sum_{f,P,\alpha,\beta} \epsilon^{f,P}_{\alpha\beta} \left(\bar{\nu}_\alpha \gamma^\mu P_L \nu_\beta\right) \left(\bar{f}\gamma_\mu P f\right)$$

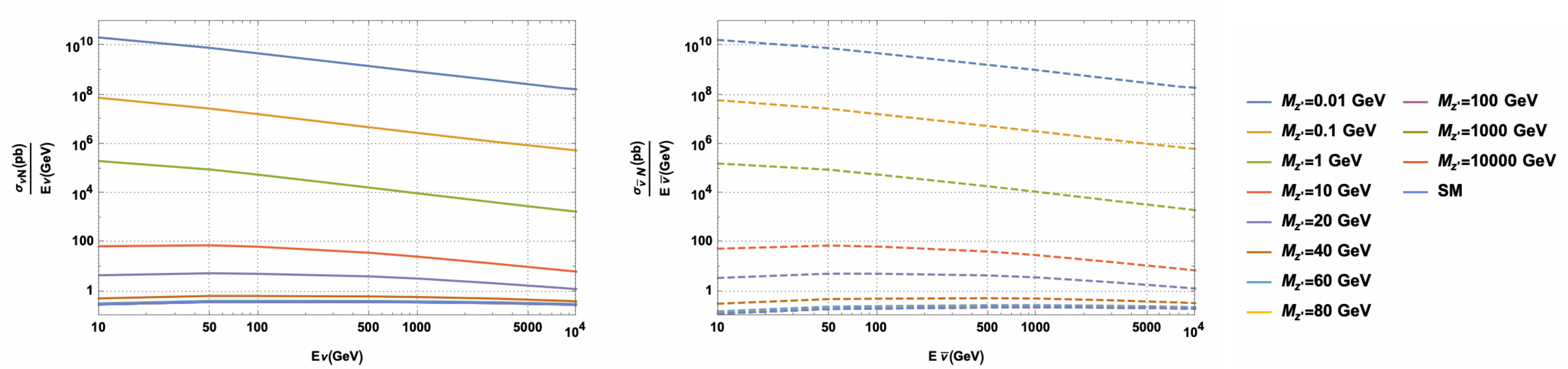
$$\mathscr{L}_{Z'} = -\left(g_\nu \bar{\nu}\gamma^\mu P_L \nu \; + \; g_q \bar{q}\gamma^\mu q\right) Z'_\mu$$

$$\sum |\mathscr{M}|^2 = 4\hat{u}^2 |M^{\nu q}_{LL}|^2 + 4\hat{s}^2 |M^{\nu q}_{LR}|^2$$

$$M^{\nu q}_{L\beta}\left(\nu(p_1)q(p_2) \to \nu(k_1)q(k_2)\right) = \frac{e^2 g^\nu_Z g^{q_\beta}_Z}{\sin^2\theta_w \cos^2\theta_w} \frac{1}{\hat{t} - M_Z^2} + \frac{g_\nu g_{q_\beta}}{\hat{t} - M_{Z'}^2}$$



$$\sigma_{\nu N} = n\sigma_{\nu n} + p\sigma_{\nu p}$$



K. Cheung, C. J. Ouseph and T. Wang, JHEP12(2021), 209 doi:10.1007JHEP12(2021)209[arXiv:2111.08375 [hep-ph]]

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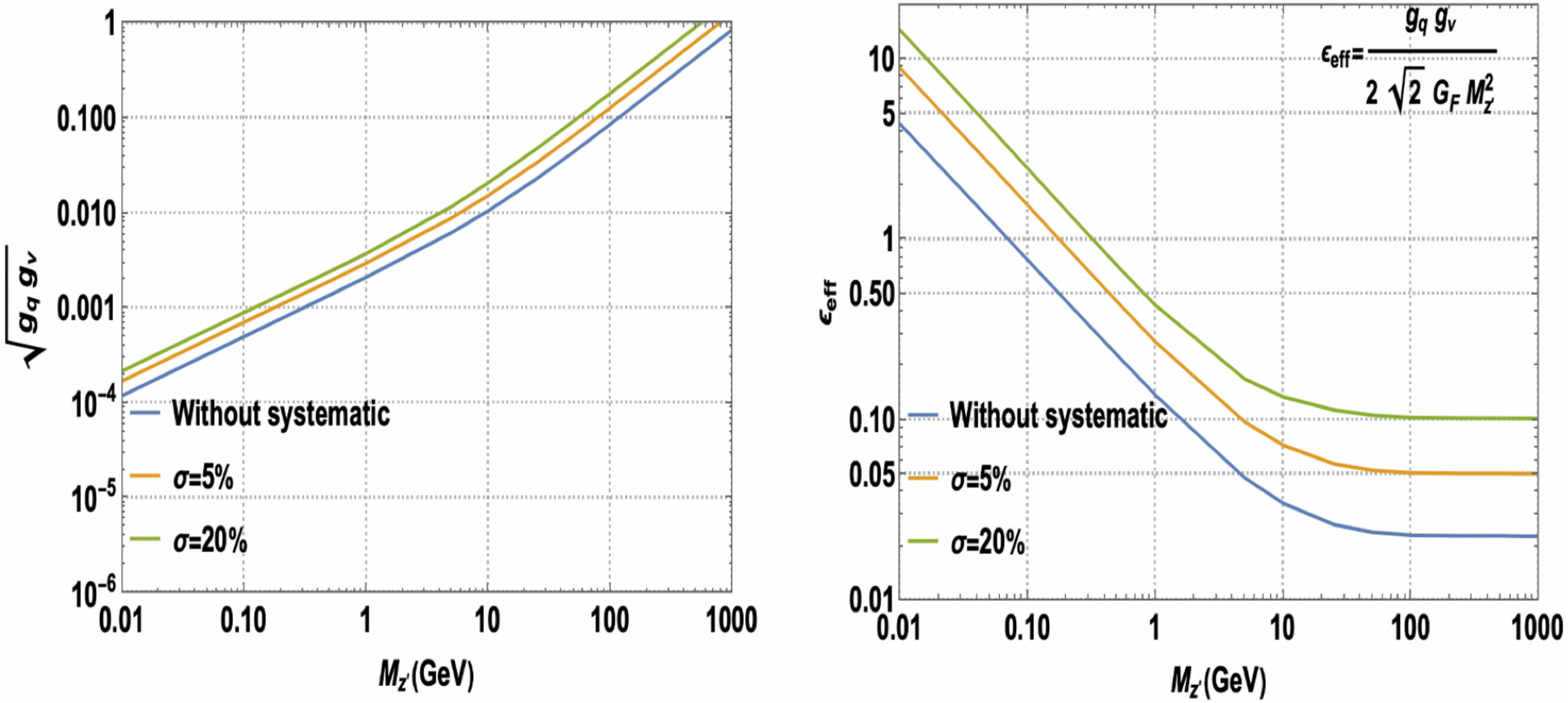
$$\chi^2(g_q g_\nu,\alpha) = \min_{\alpha}\left[\frac{(N_{BSM}^{\nu_e}-(1+\alpha)N_{SM}^{\nu_e})^2}{N_{BSM}^{\nu_e}} + \frac{(N_{BSM}^{\nu_\mu}-(1+\alpha)N_{SM}^{\nu_\mu})^2}{N_{BSM}^{\nu_\mu}} + \frac{(N_{BSM}^{\nu_\tau}-(1+\alpha)N_{SM}^{\nu_\tau})^2}{N_{BSM}^{\nu_\tau}} + \left(\frac{\alpha}{\sigma_{norm}}\right)^2\right]$$

The sensitivity of FASERν detectors to Z'

$N_{BSM} = N_{Z'} + N_{int} + N_{SM}$.

α is the nuisance parameters,

σ_{norm} is the systematic uncertainties from the flux and detector



K. Cheung, C. J. Ouseph and T. Wang, JHEP12(2021)

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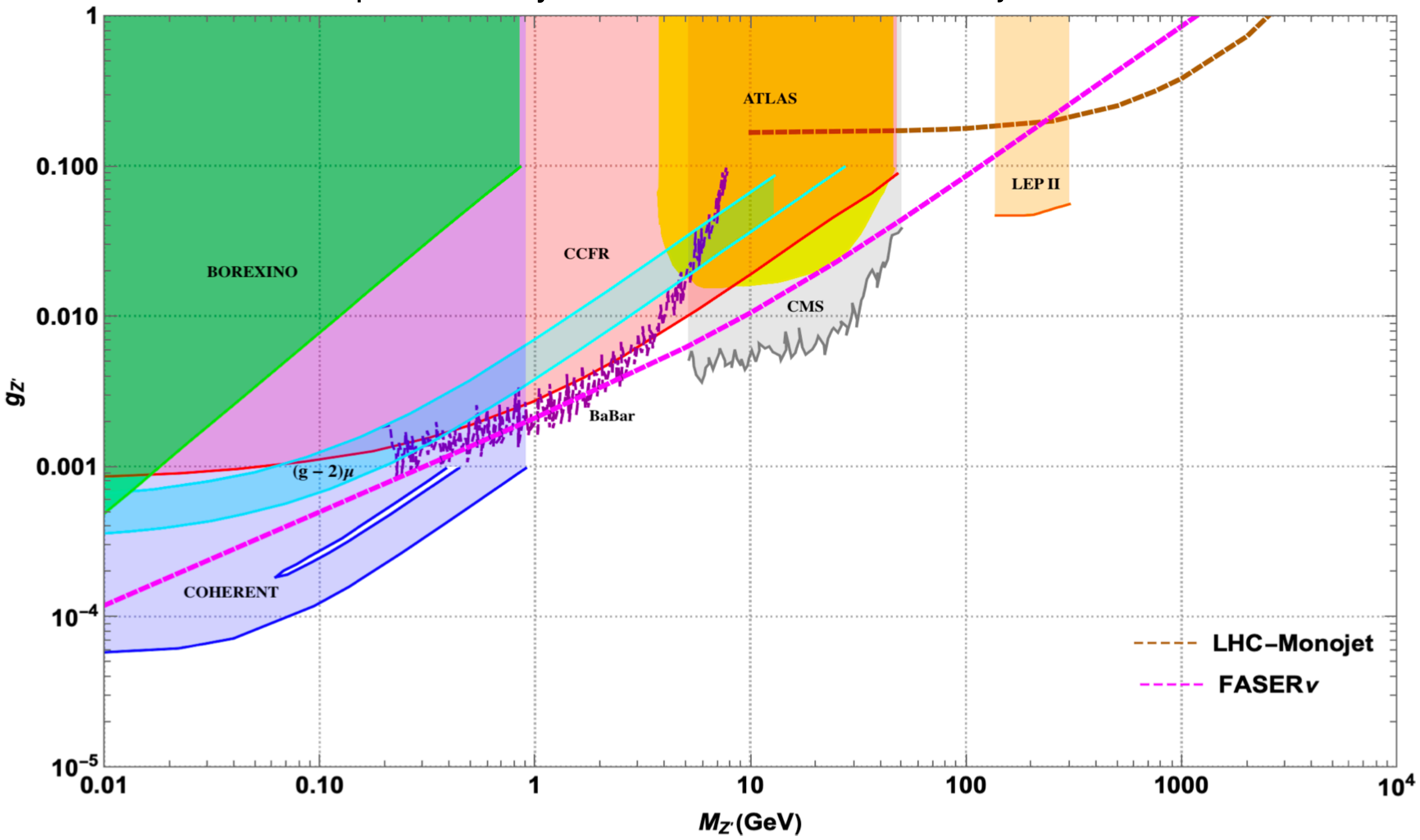
Complementarity of FASERν with LHC Monojet Results



K. Cheung, C. J. Ouseph and T. Wang, JHEP12(2021)

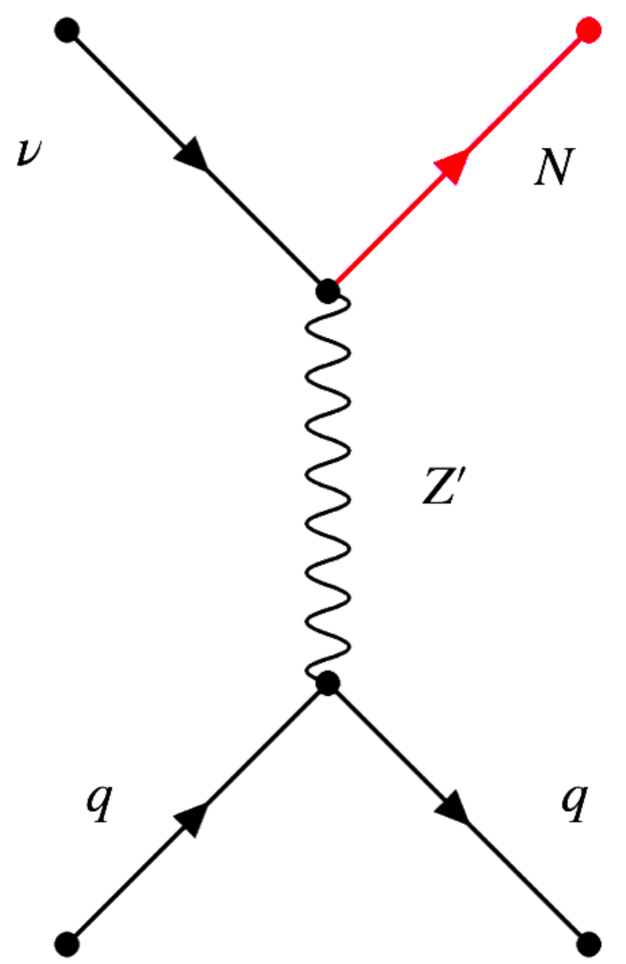
Constraining the Active-to-Heavy-Neutrino Z' transitional magnetic dipole moment at FASERν

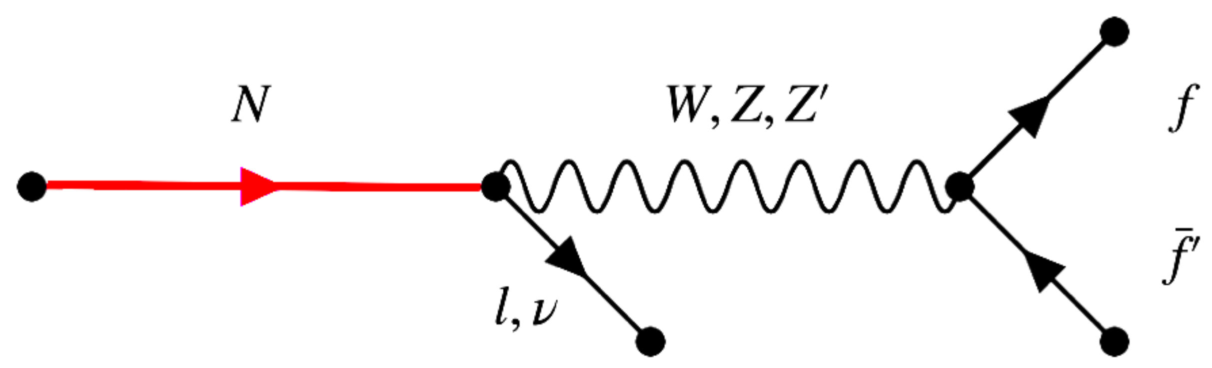
arXiv:2205.11077 (Submitted to JHEP)

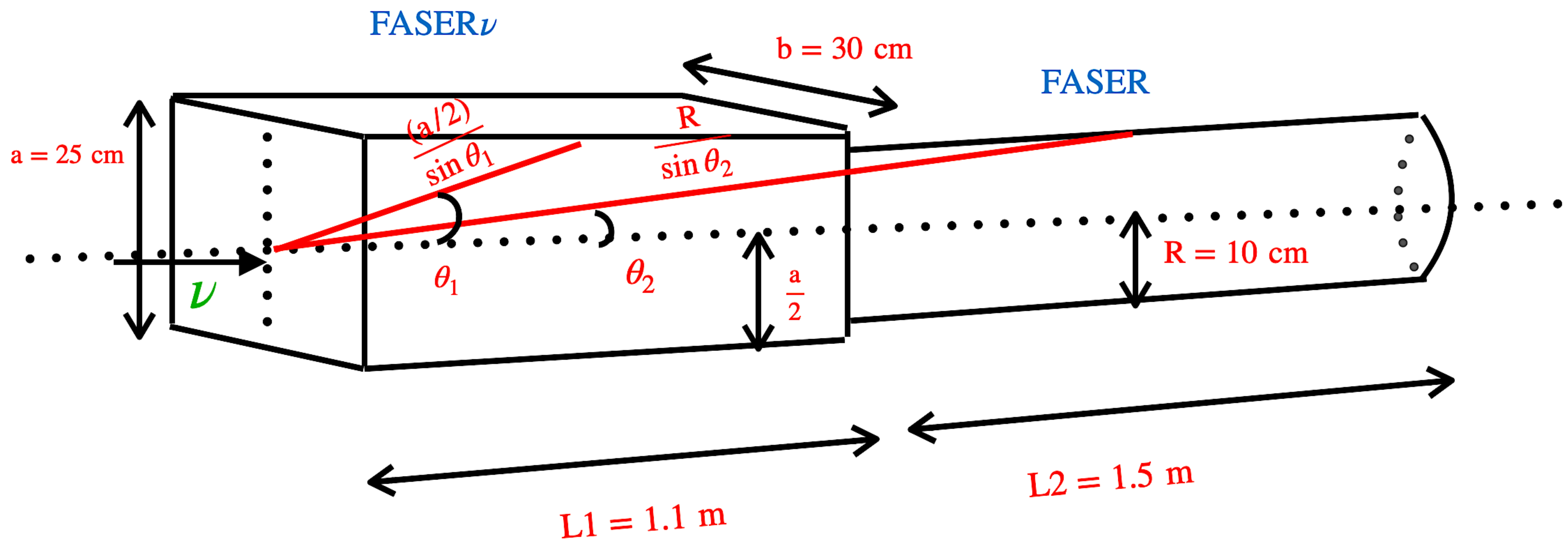
Active-to-Heavy Neutrino Z’ Transitional Magnetic Moment Interactions

$$\mathscr{L}_{\rm eff} = \sum_{\alpha=e,\mu,\tau}\left[\omega_{\nu_\alpha}\overline{N}\sigma^{\mu\nu}\nu_\alpha Z'_{\mu\nu} - \frac{g}{\sqrt{2}}V_{\alpha N}\overline{N}\gamma^\mu P_L l_\alpha W^+_\mu - \frac{g}{c_{\rm w}}V_{\alpha N}\overline{N}\gamma^\mu P_L \nu_\alpha Z_\mu + {\rm H.c.}\right] - \sum_{\rm q,\nu,l}\left[{\rm g_q}\bar{\rm q}\gamma^\mu{\rm q} + {\rm g}_\nu\bar{\nu}\gamma^\mu{\rm P_L}\nu + {\rm g_l}\bar{\rm l}\gamma^\mu{\rm l}\right]{\rm Z}'_\mu$$

$$\omega_{\nu_\alpha} \sim \frac{e\,.\,vev}{\Lambda^2}$$







Recasting transtional Magnetic moment μ_{ν_α} to transtional Magnetic type moment ω_{ν_α}

The bound of μ_{ν_α} comes from NOMAD and LEP, $\mu_{\nu_e}, \mu_{\nu_\tau} \leq 1.5 \times 10^{-7} \mu_B$, $\mu_{\nu_\mu} \leq 5 \times 10^{-9} - 1.4 \times 10^{-7}\, \mu_B$, for

$\mathrm{M_N} = 1 - 10$ GeV, where μ_B is the Bohr magneton.

$$\omega_{\nu_\alpha} \simeq \frac{(1\,\mathrm{GeV})^2 + M_{Z'}^2}{(1\,\mathrm{GeV})^2} \times \mu_{\nu_\alpha}$$

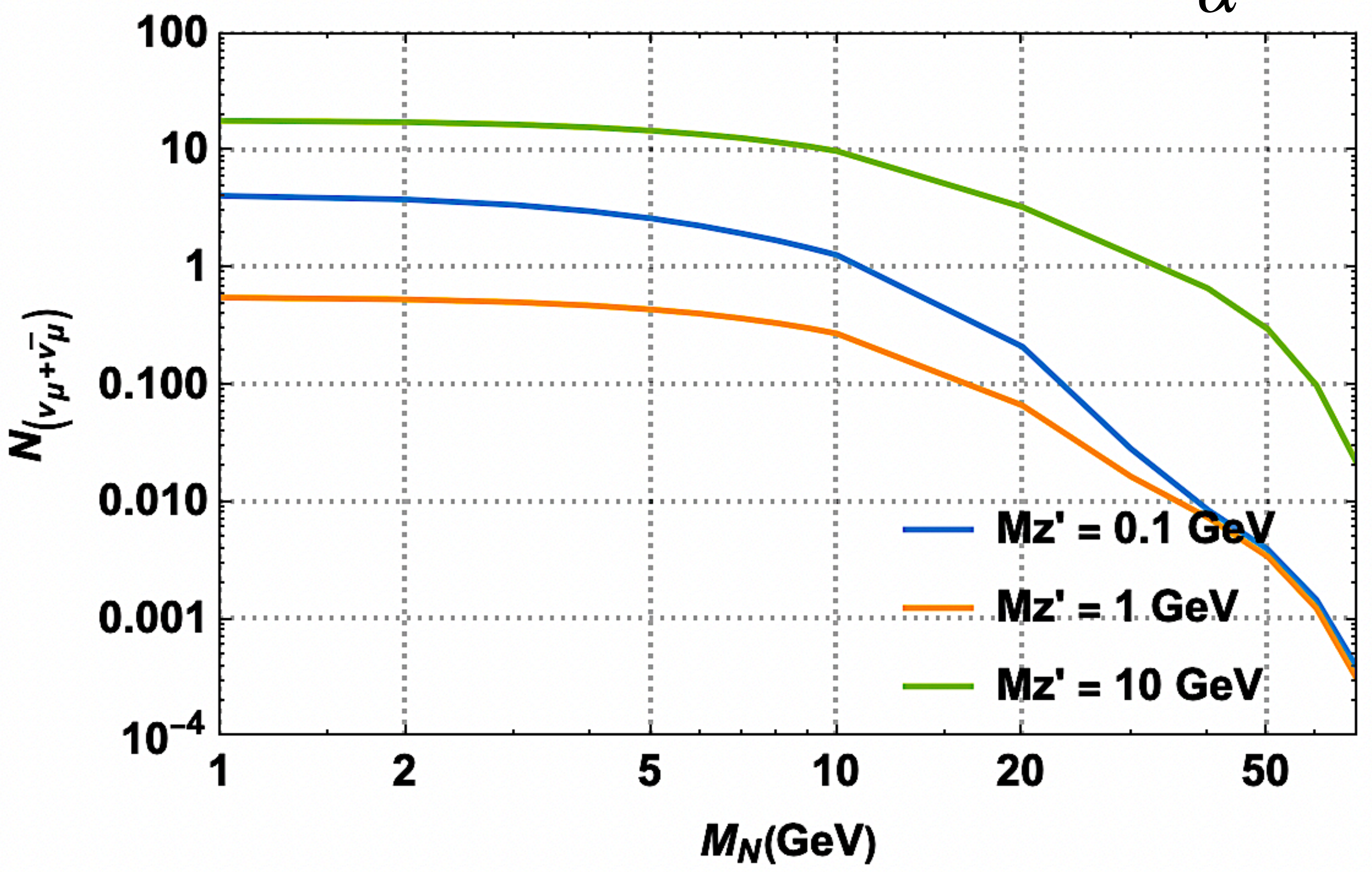
$$\omega_{\nu_\alpha} \overline{N} \sigma^{\mu\nu} \nu\, Z'_{\mu\nu} \longrightarrow \mu_{\nu_\alpha} \overline{N} \sigma^{\mu\nu} \nu\, F_{\mu\nu}$$

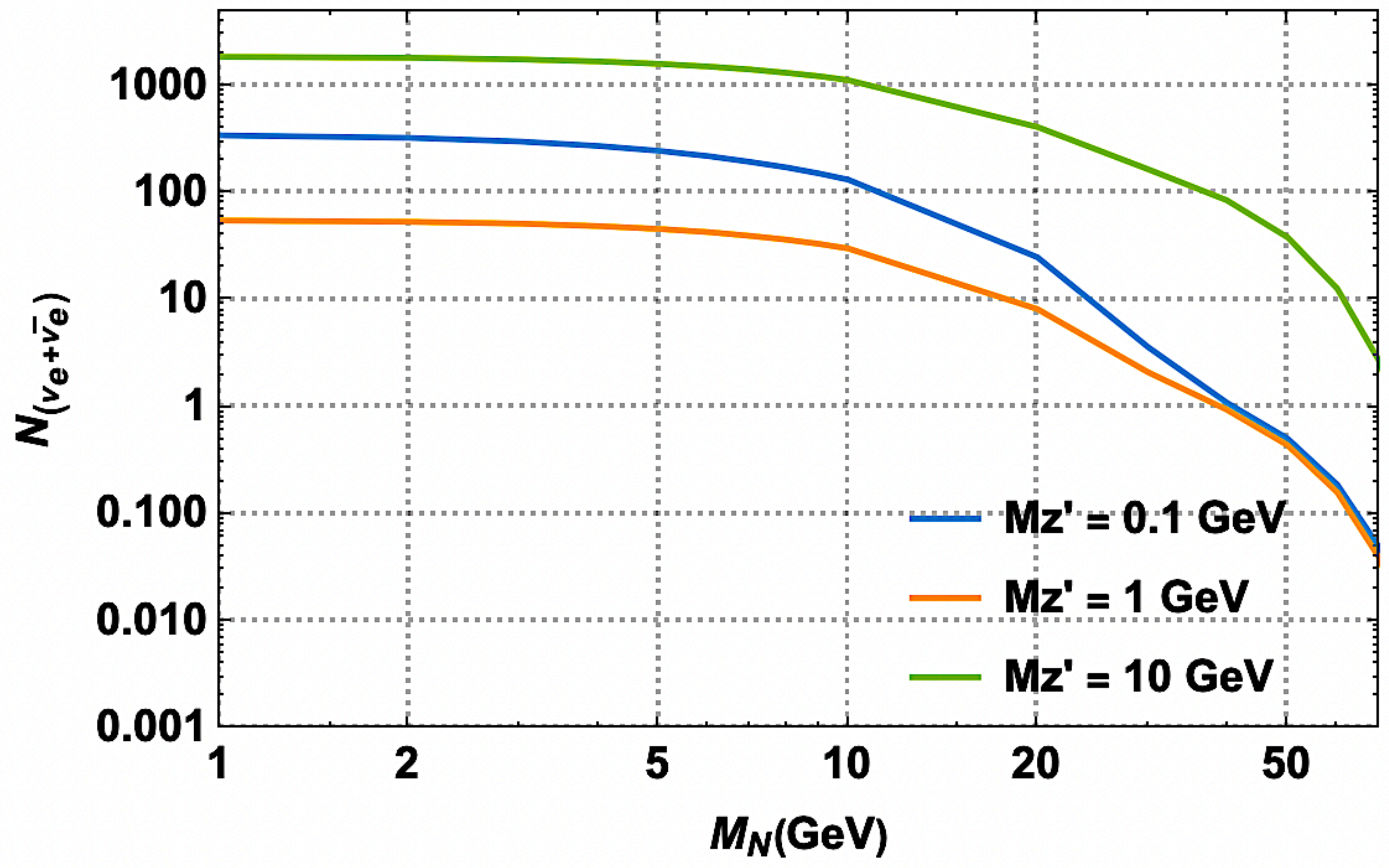
we assume the square of momentum transfer in the photon propagator is about $(1\mathrm{GeV})^2$.

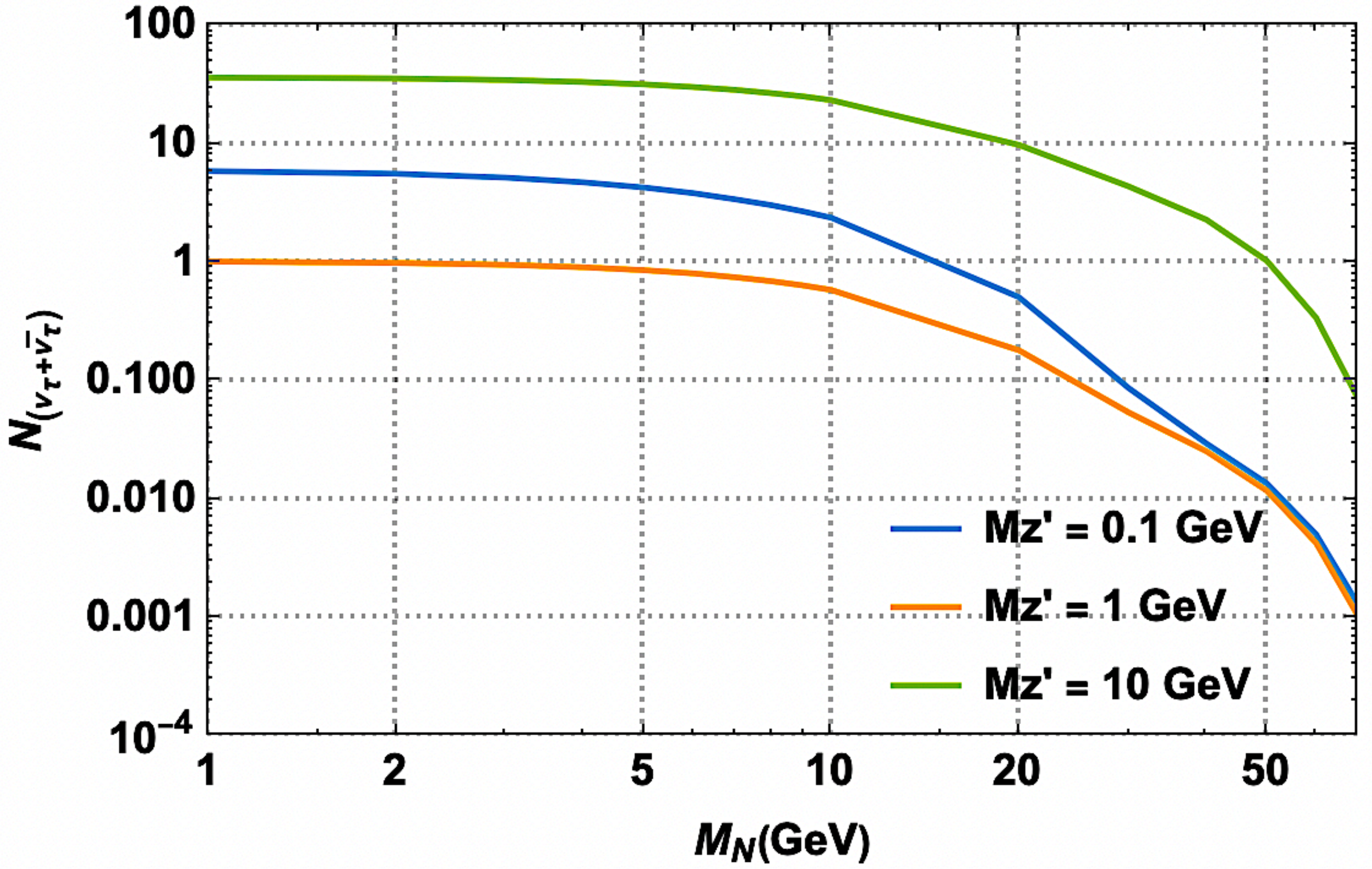
$M_{Z'}$(GeV)	ω_{ν_μ}	ω_{ν_e}	ω_{ν_τ}
0.1	$4.10 \times 10^{-9} \mu_B$	$1.39 \times 10^{-7} \mu_B$	$1.39 \times 10^{-7} \mu_B$
1	$8.12 \times 10^{-9} \mu_B$	$2.76 \times 10^{-7} \mu_B$	$2.76 \times 10^{-7} \mu_B$
10	$4.10 \times 10^{-7} \mu_B$	$1.39 \times 10^{-5} \mu_B$	$1.39 \times 10^{-5} \mu_B$

Heavy Neutrino events at FASERν

$$\nu_\alpha A \to N A'$$



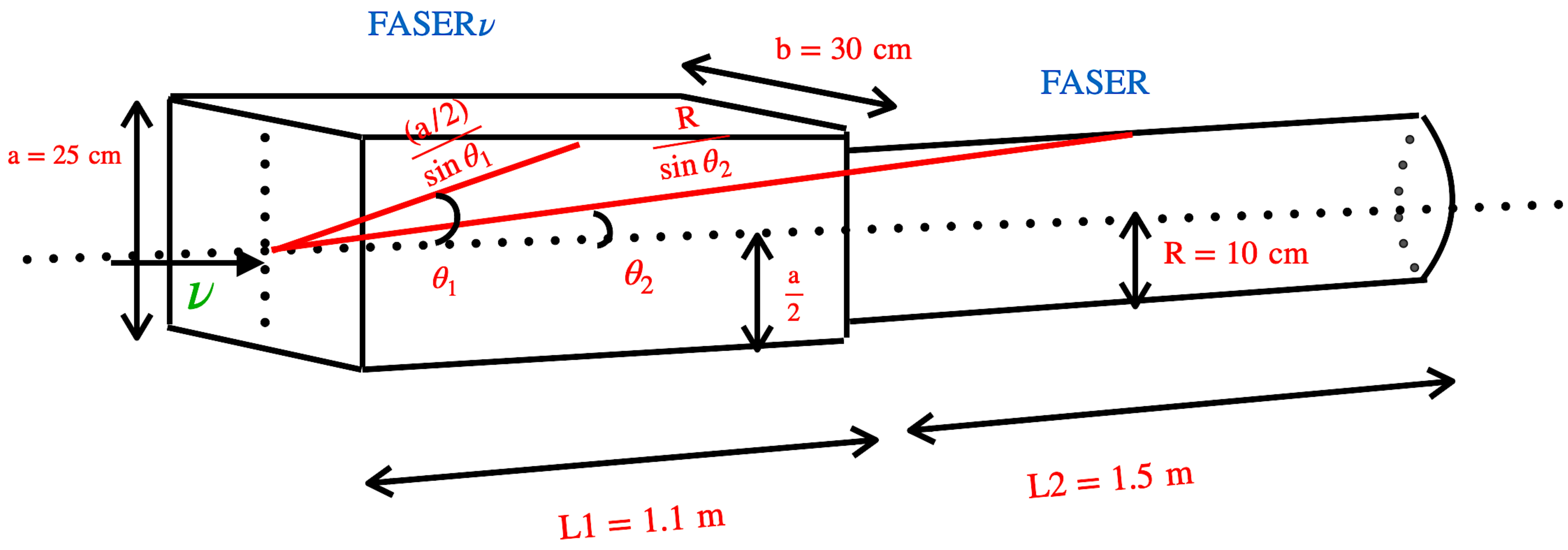




FASERν Sensitivity towards Transition Magnetic Moment Type Interactions

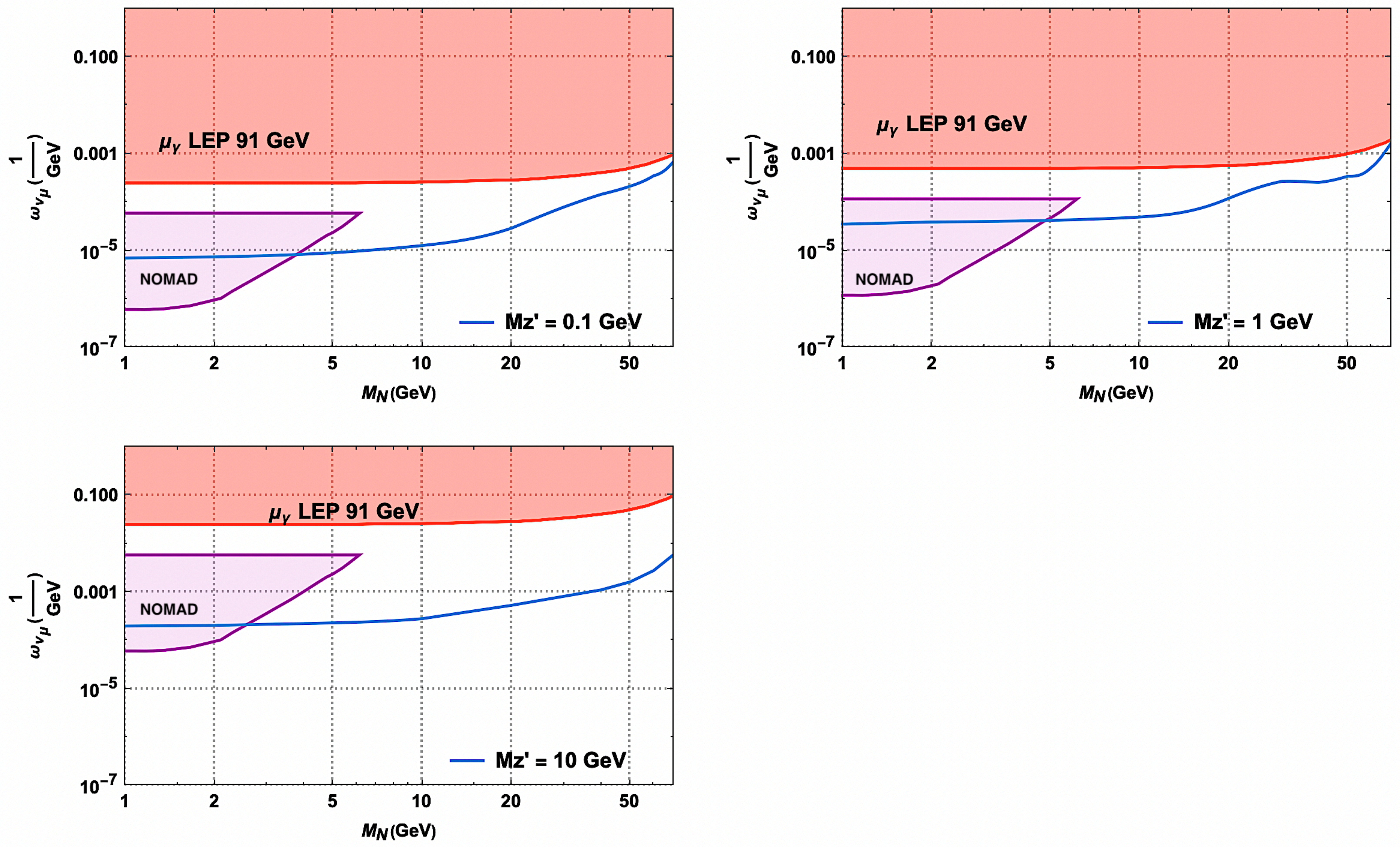
$$N_\alpha^{\rm detc} = N_\alpha^{\rm Prod}(\nu_\alpha A \to NA') \times \mathscr{P}_{detc} \times {\rm BR}(N \to \nu_\alpha\ l+\ \ l-)$$

$$\mathscr{P}_{\rm detc} = 1 - \exp(\frac{-d}{\beta c \tau}) \quad d = L1 + L2$$



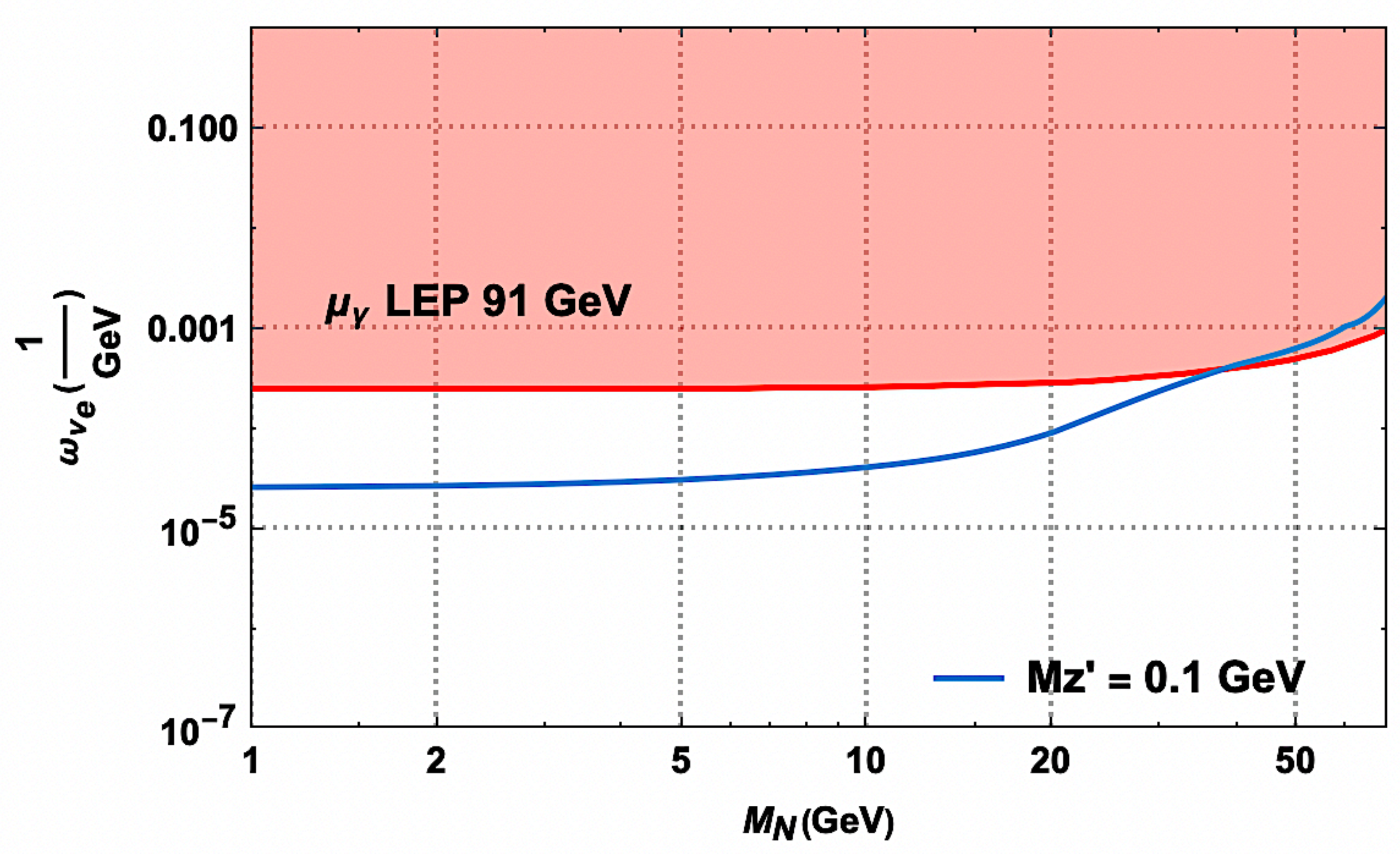
Bench Mark Model 1

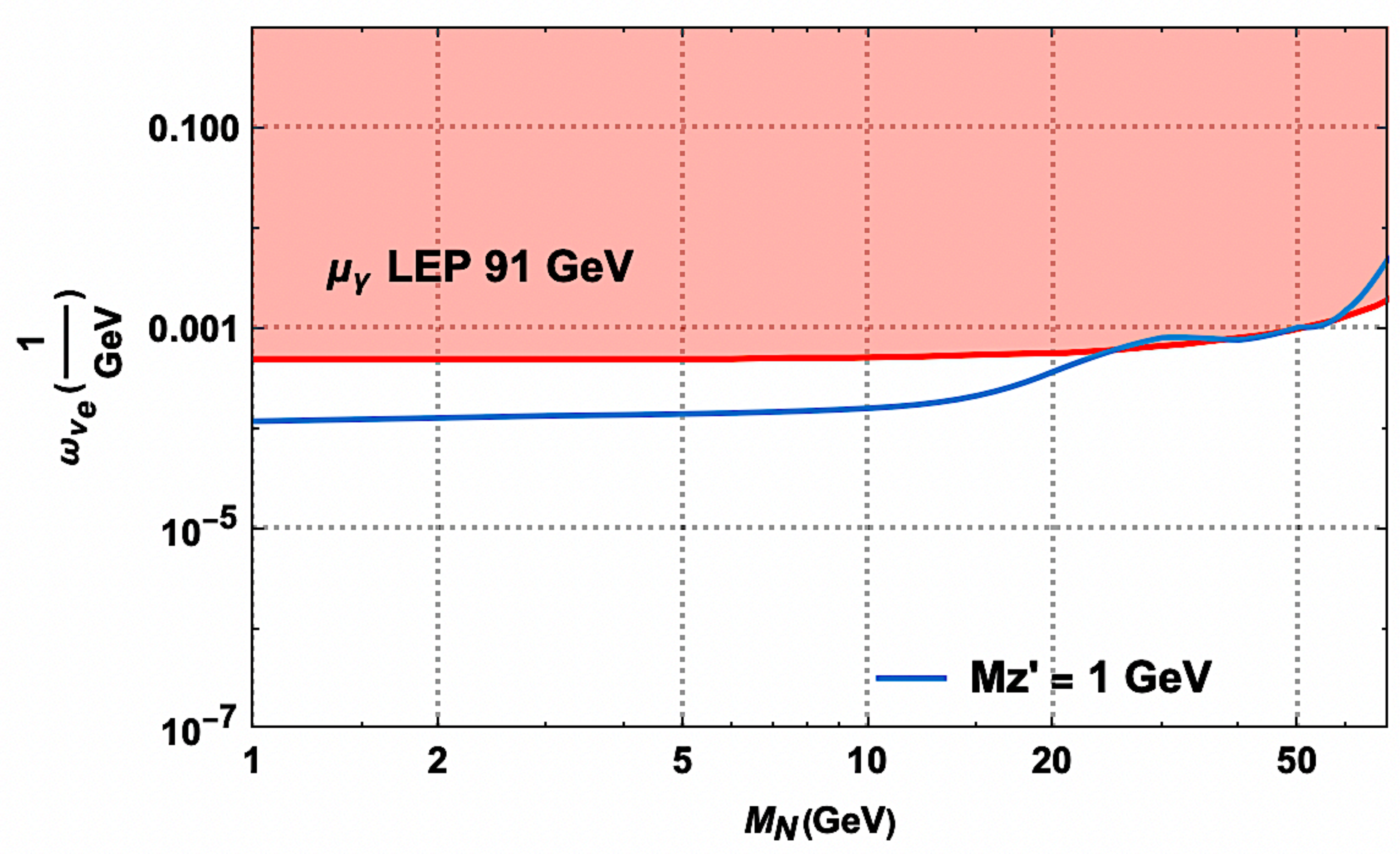
Heavy Neutrino Only coupled to L_μ Doublet

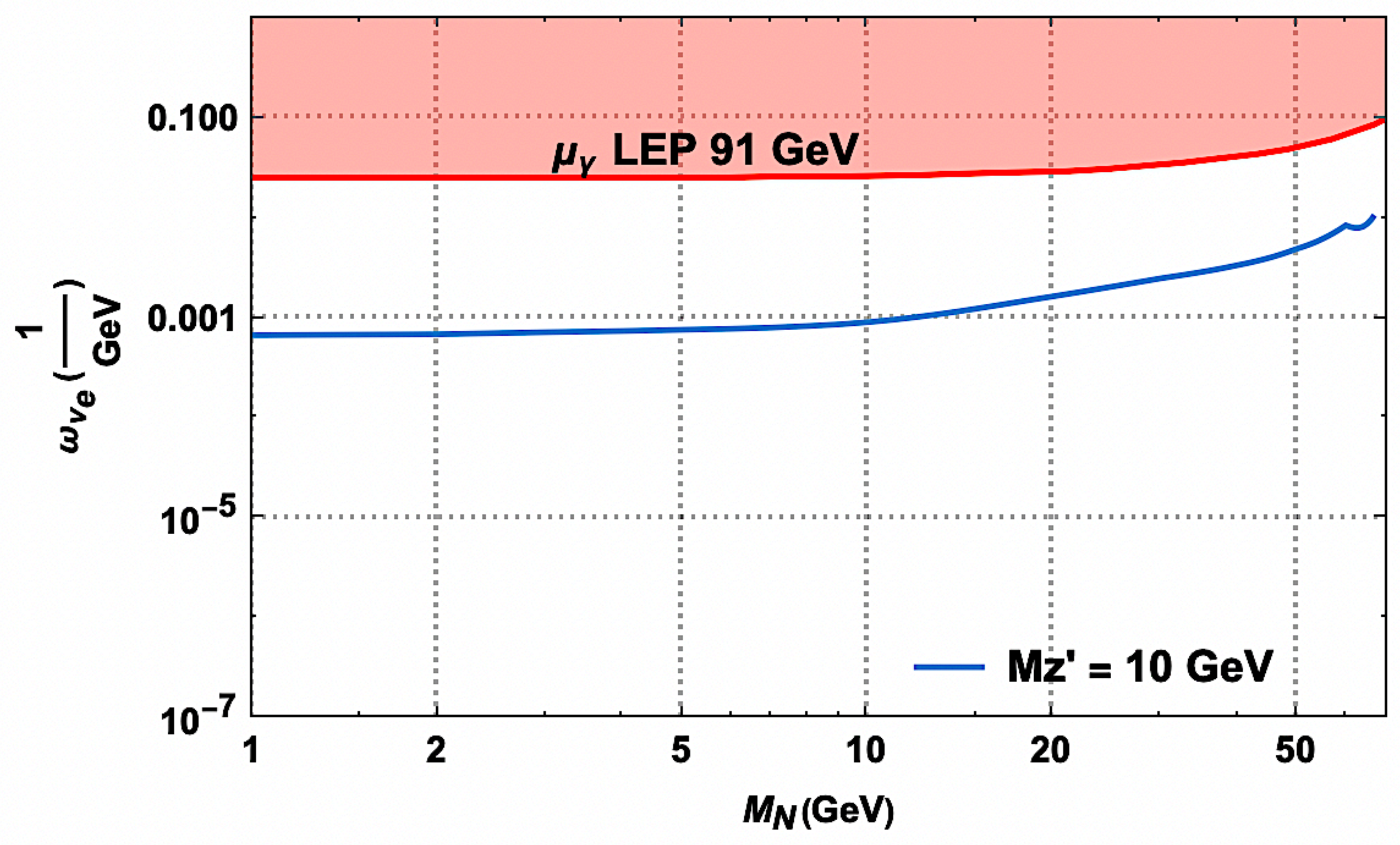


Bench Mark Model 2

Heavy Neutrino Only coupled to L_e Doublet

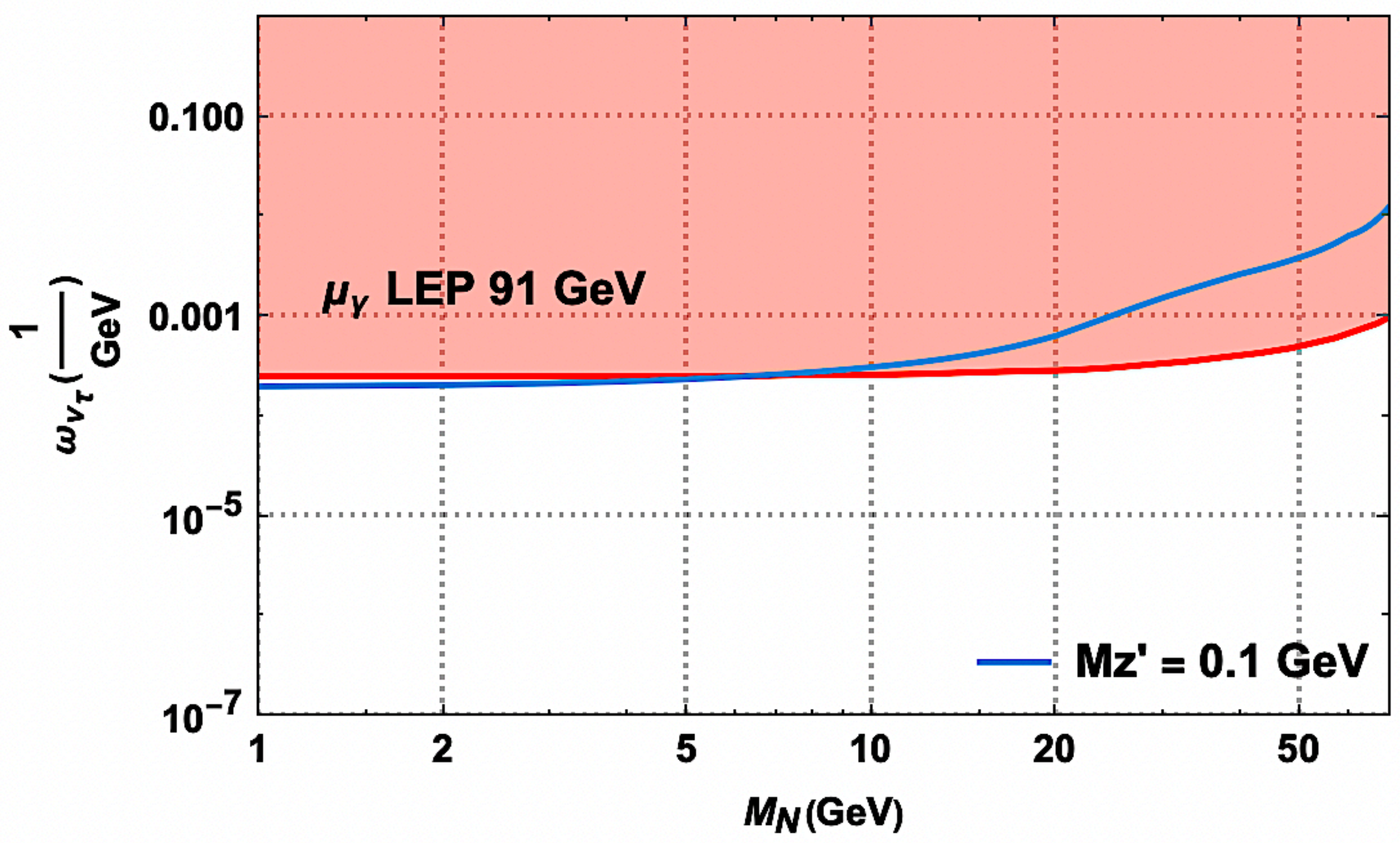


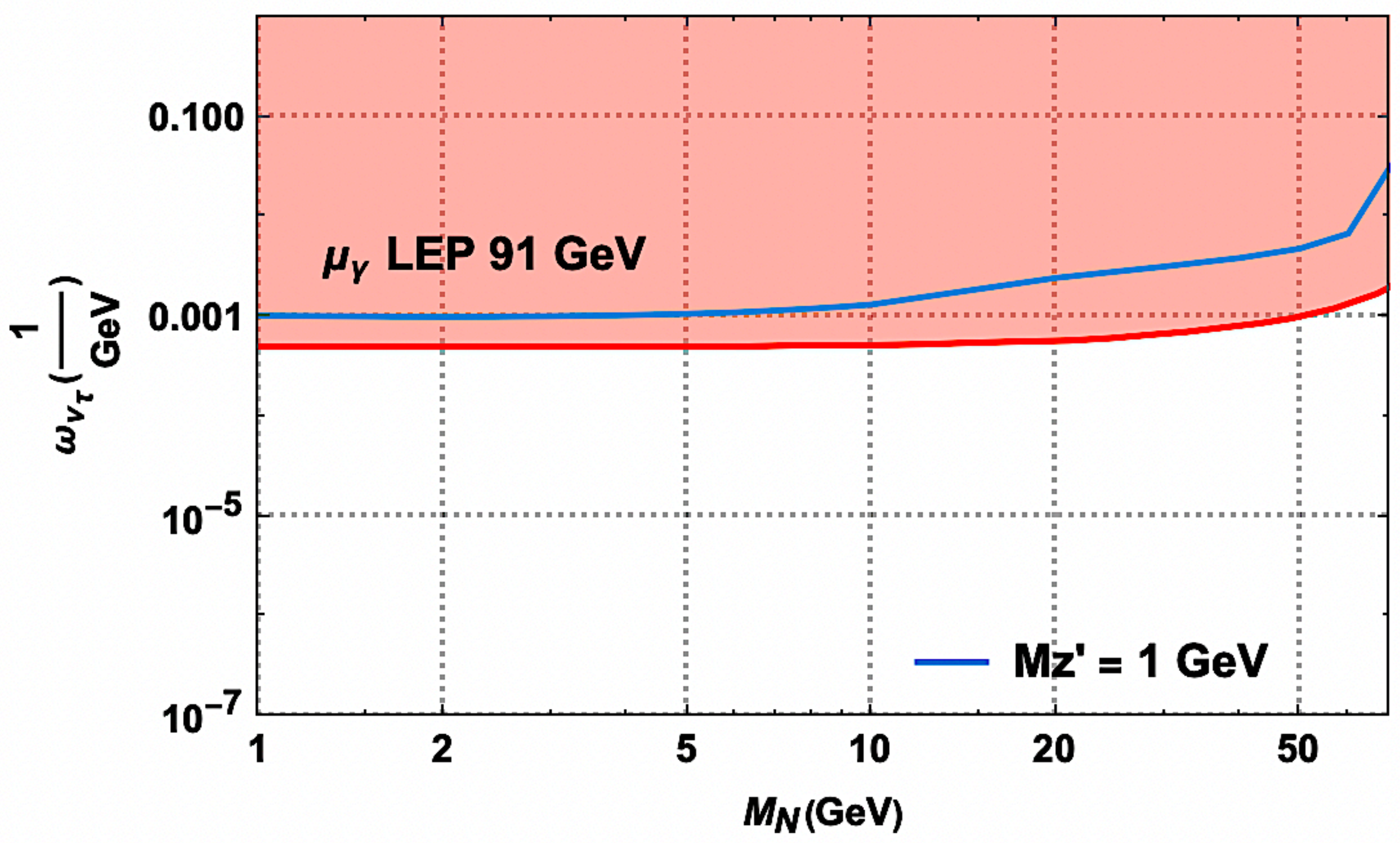


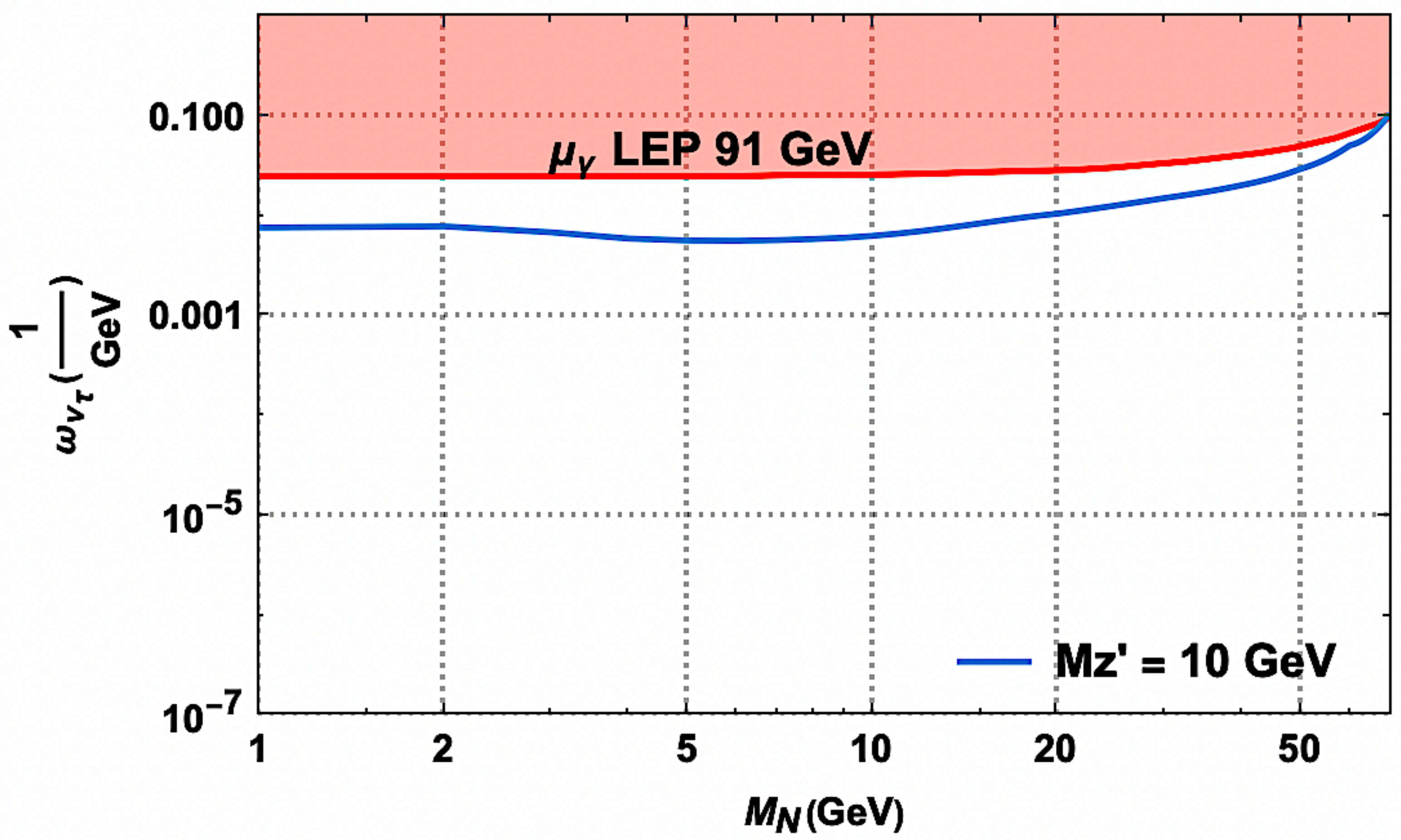


Bench Mark Model 3

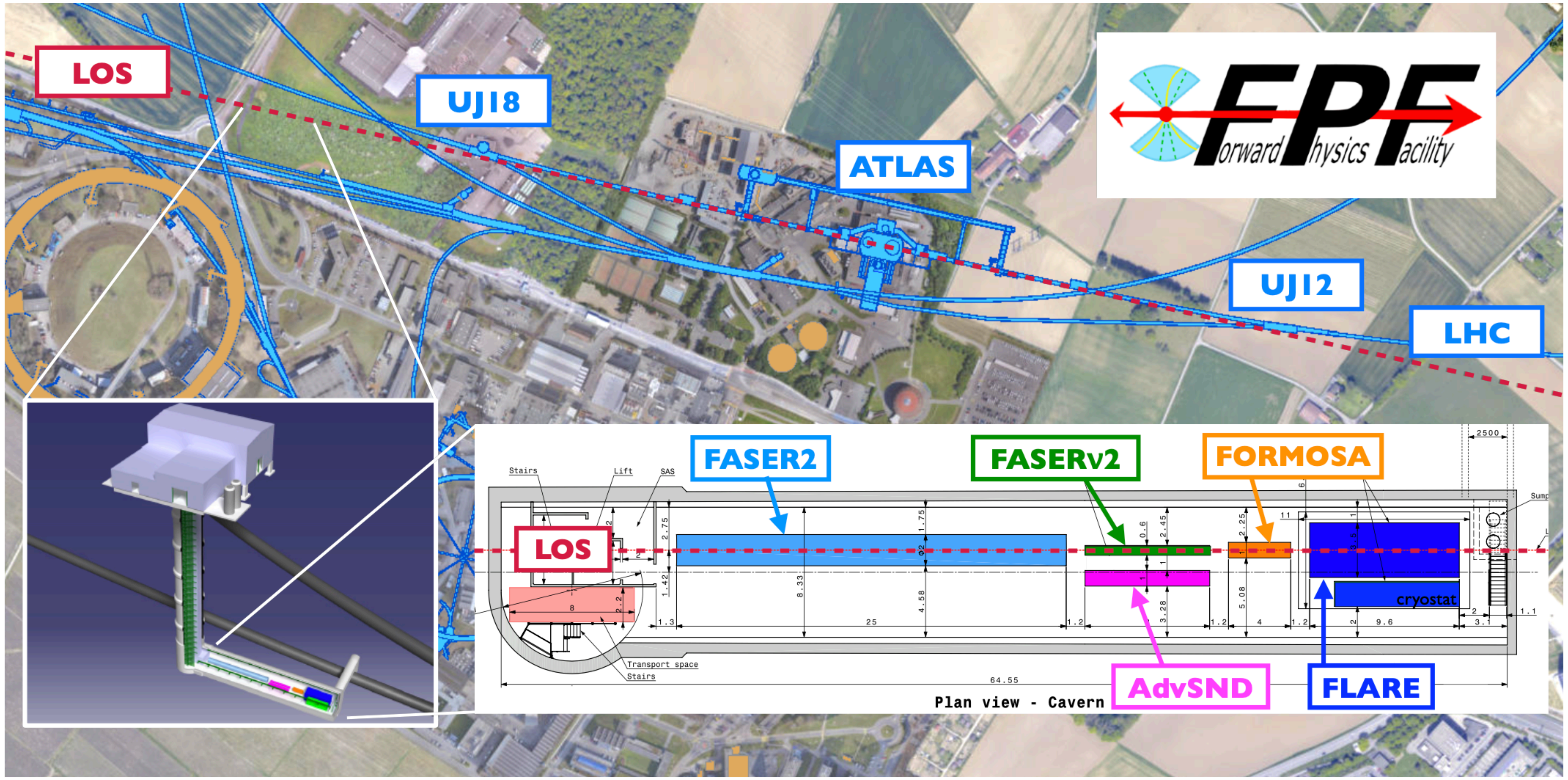
Heavy Neutrino Only coupled to L_τ Doublet







Forward Physics Facility (FPF)



Source: arXiv:2109.10905v1

FASER2: a magnetic spectrometer and tracker, will search for light and weakly-interacting states, including long-lived particles, new force carriers, axion-like particles, light neutralinos, and dark sector particles.

FASERν2: Upgraded version of FASERν

AdvSND: Upgraded version of SND@LHC

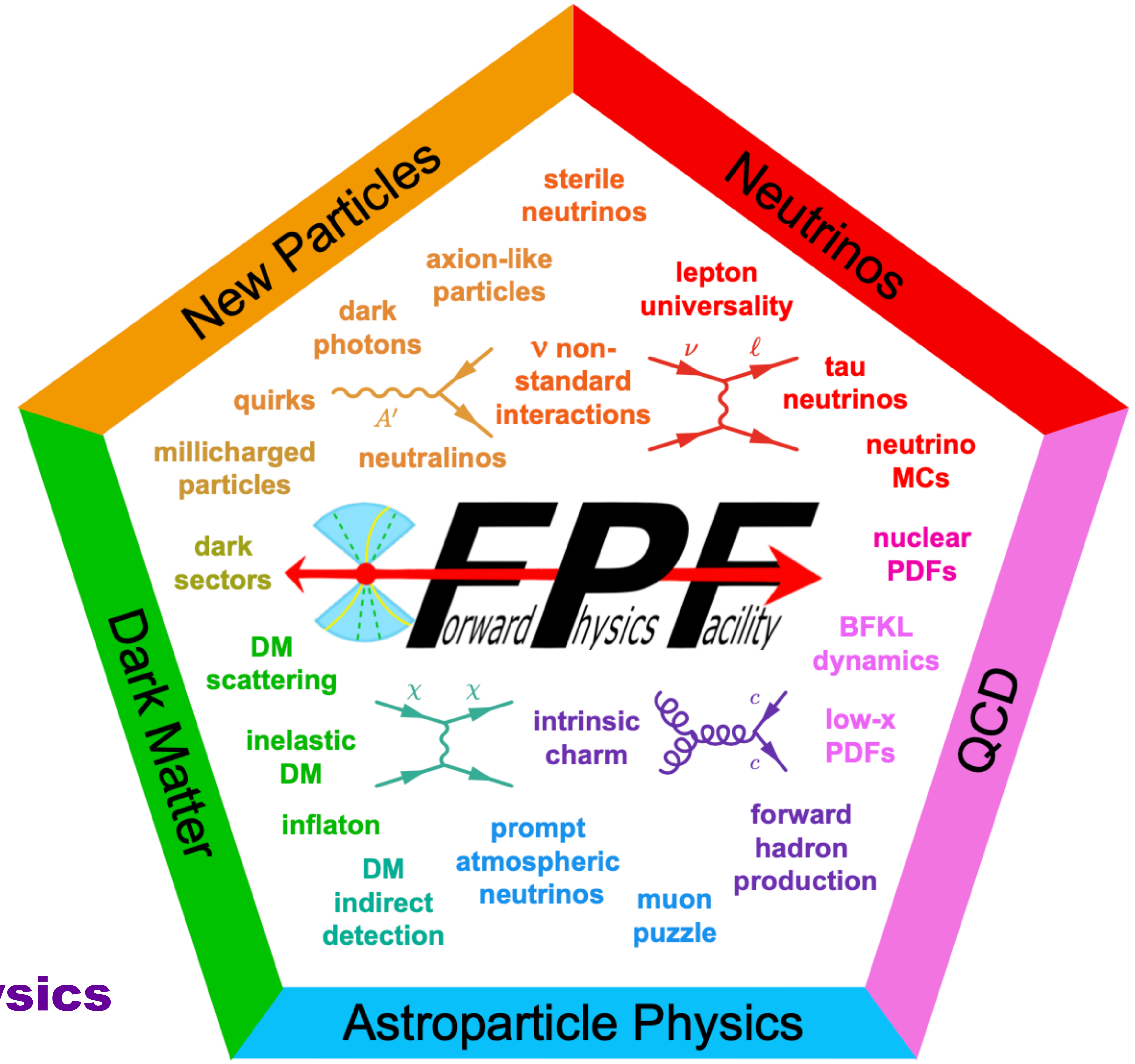
FORMOSA: a detector composed of scintillating bars, will provide world-leading sensitivity to millicharged particles and other very weakly-interacting particles across a large range of masses.

FLARE: a proposed 10-tonne-scale noble liquid detector, will detect neutrinos and also search for light dark matter.

Summary

We Explore the discovery potential of FASERν for the new physics Interactions

Physics abounds in the forward region of the LHC. Many detectors have been proposed in the forward region, such as FASER2, FASERv2, AdVSND@LHC, FLArE(10 tons, 100 tons), and FORMOSA. My goal is to study different NP interactions using these proposed detectors.



Source: arXiv:2109.10905v1

- **Sensitivities on dark photon from the Forward Physics Experiments (arXiv:2208.04523) - (accepted in JHEP)**
- **Probing the $L_\mu - L_\tau$ Model in Neutrino Trident Production at the Forward Physics Facility (In Preparation)**
- **LeptoQuark search at the forwards physics Experiments (In Preparation)**

FASERν and SND@LHC just started to take data in LHC's forward direction

The FPF is proposed to continue this program during the HL LHC era

Thank You . . .

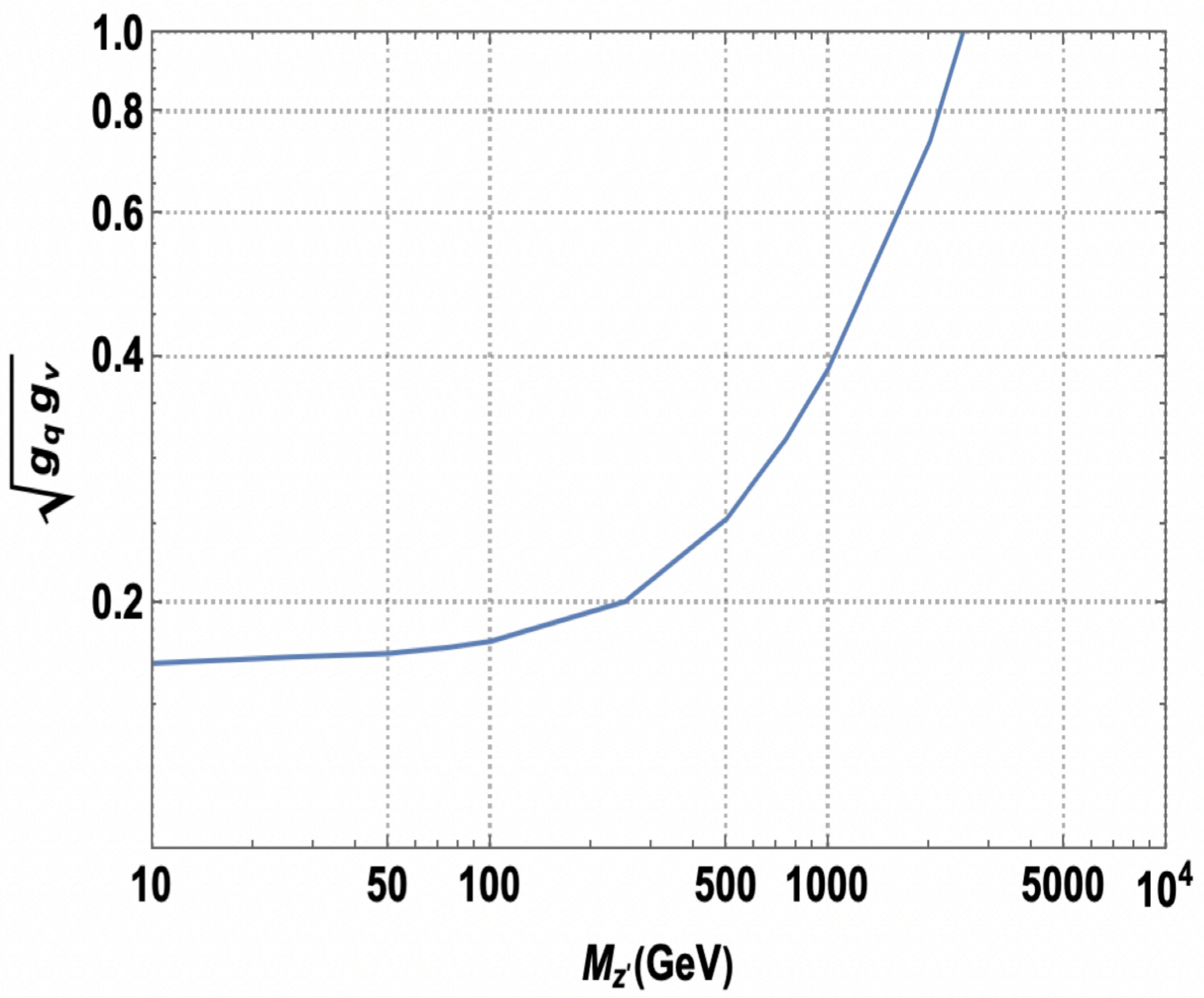
Backup Slides

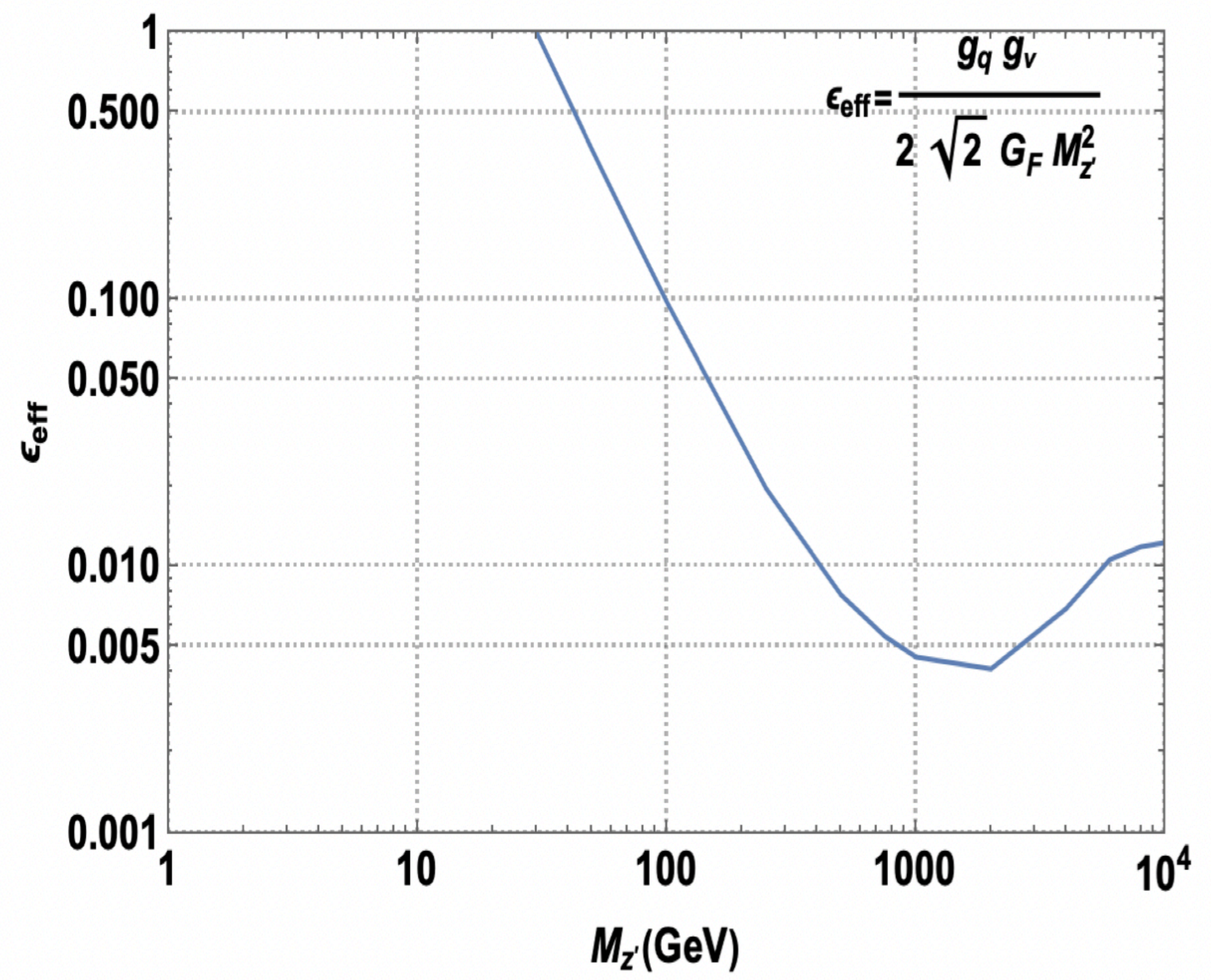
Effects of Z′ on the monojet production @ LHC

$$pp \to Z' + j \to \nu\nu + j$$

We follow closely the experimental cuts outlined in the ATLAS paper in order to directly use their upper limits on the monojet production cross sections.

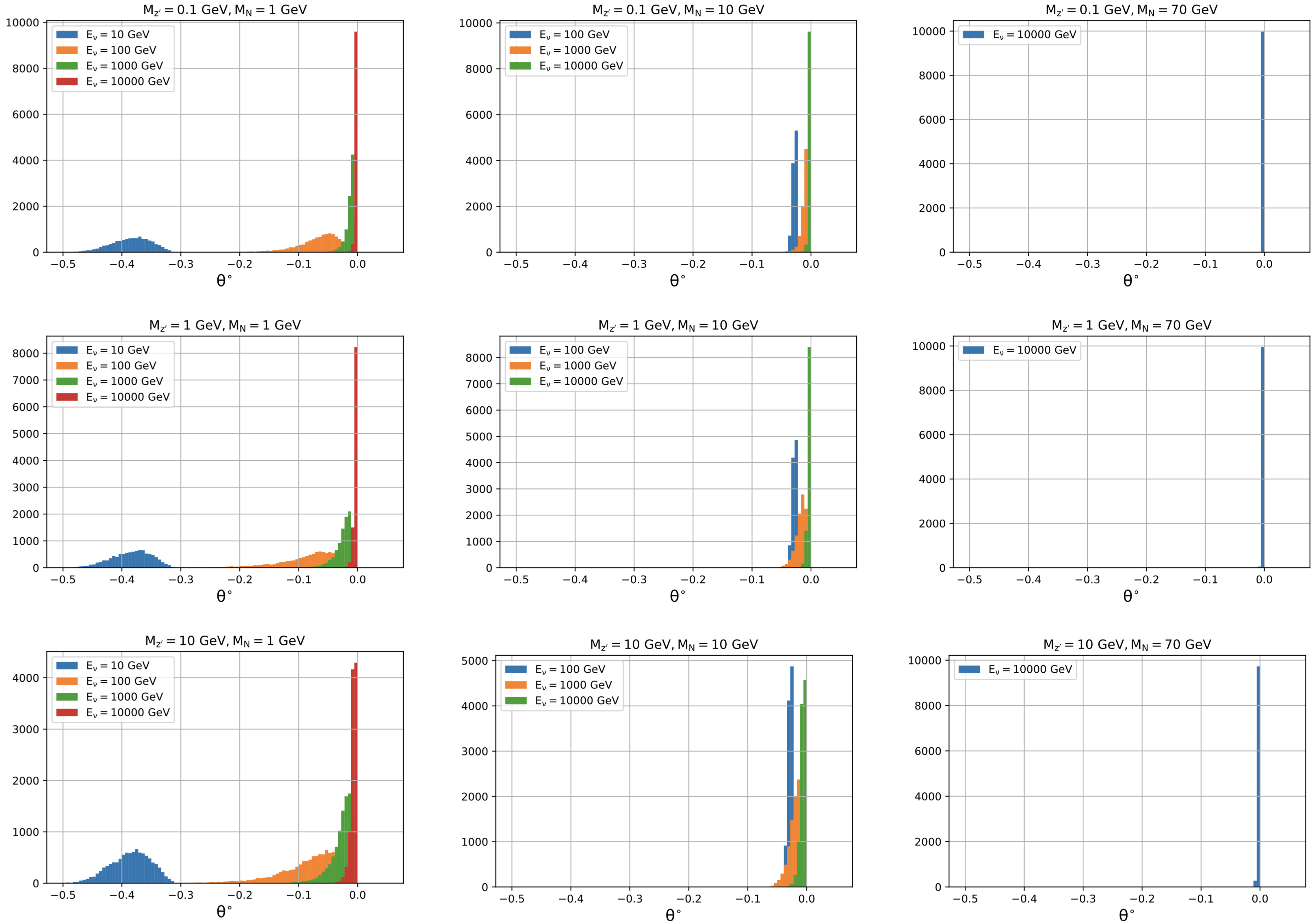
ATLAS paper results was based on the monojet search at 13 TeV with an integrated luminosity of 139 fb−1 [*Phys. Rev. D* **103** (2021) 112006 [arXiv:2102.10874]]



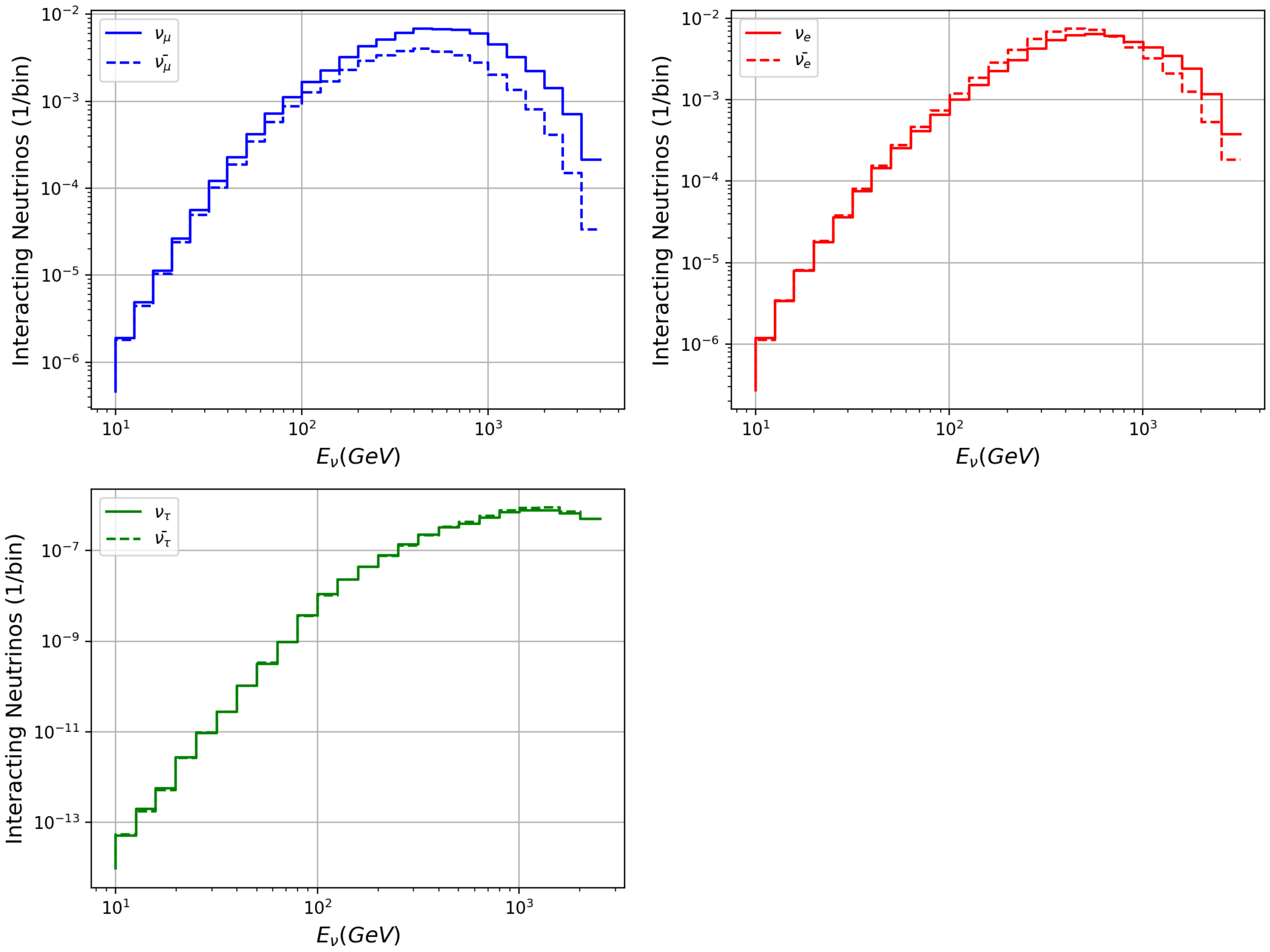


K. Cheung, C. J. Ouseph and T. Wang, JHEP12(2021)

Angular distribution of Heavy Neutrino

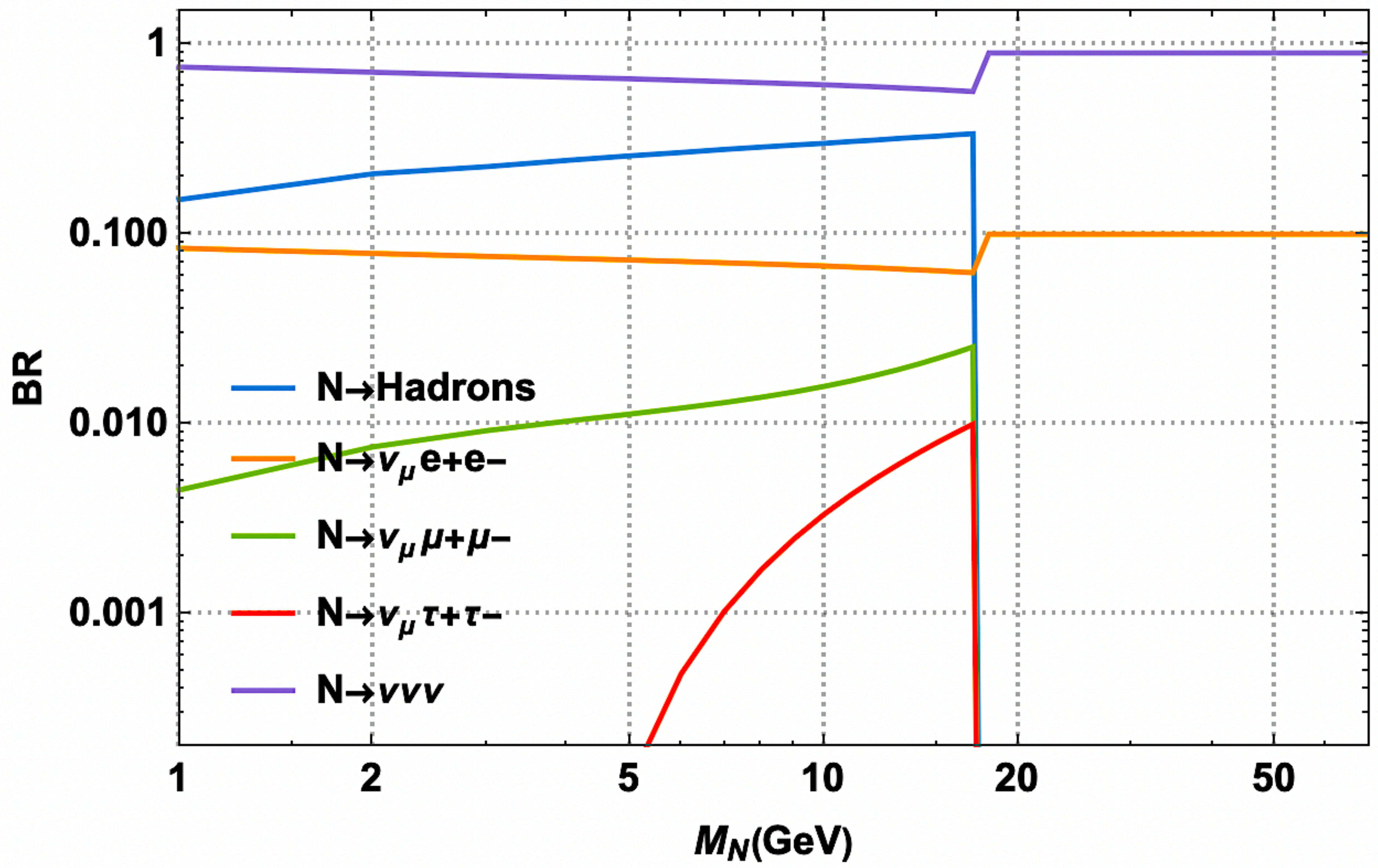


Trident BG

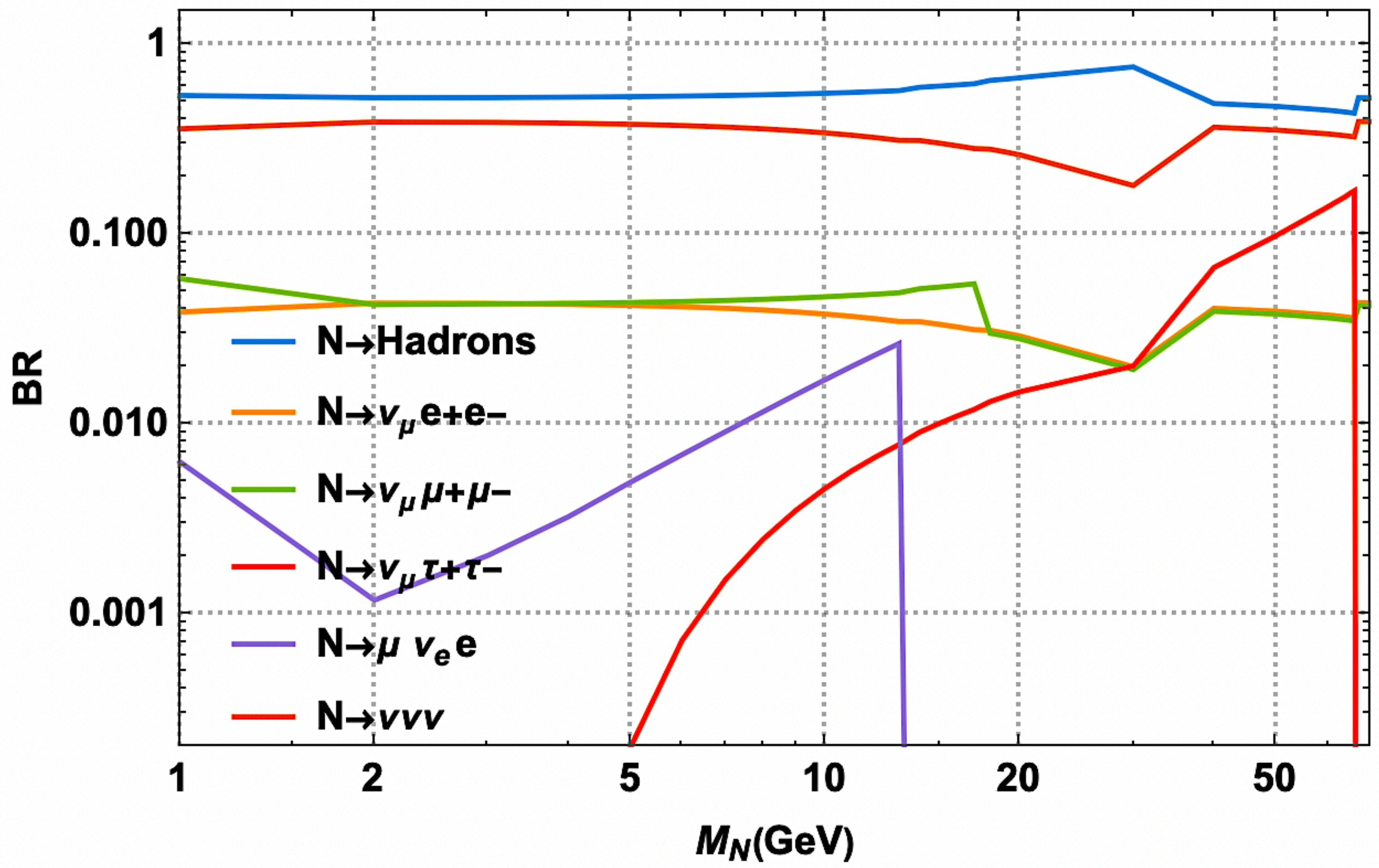


ν_μ
$\bar{\nu_\mu}$
ν_e
$\bar{\nu_e}$
ν_τ
$\bar{\nu_\tau}$
Interacting Neutrinos (1/bin)
$E_\nu(GeV)$

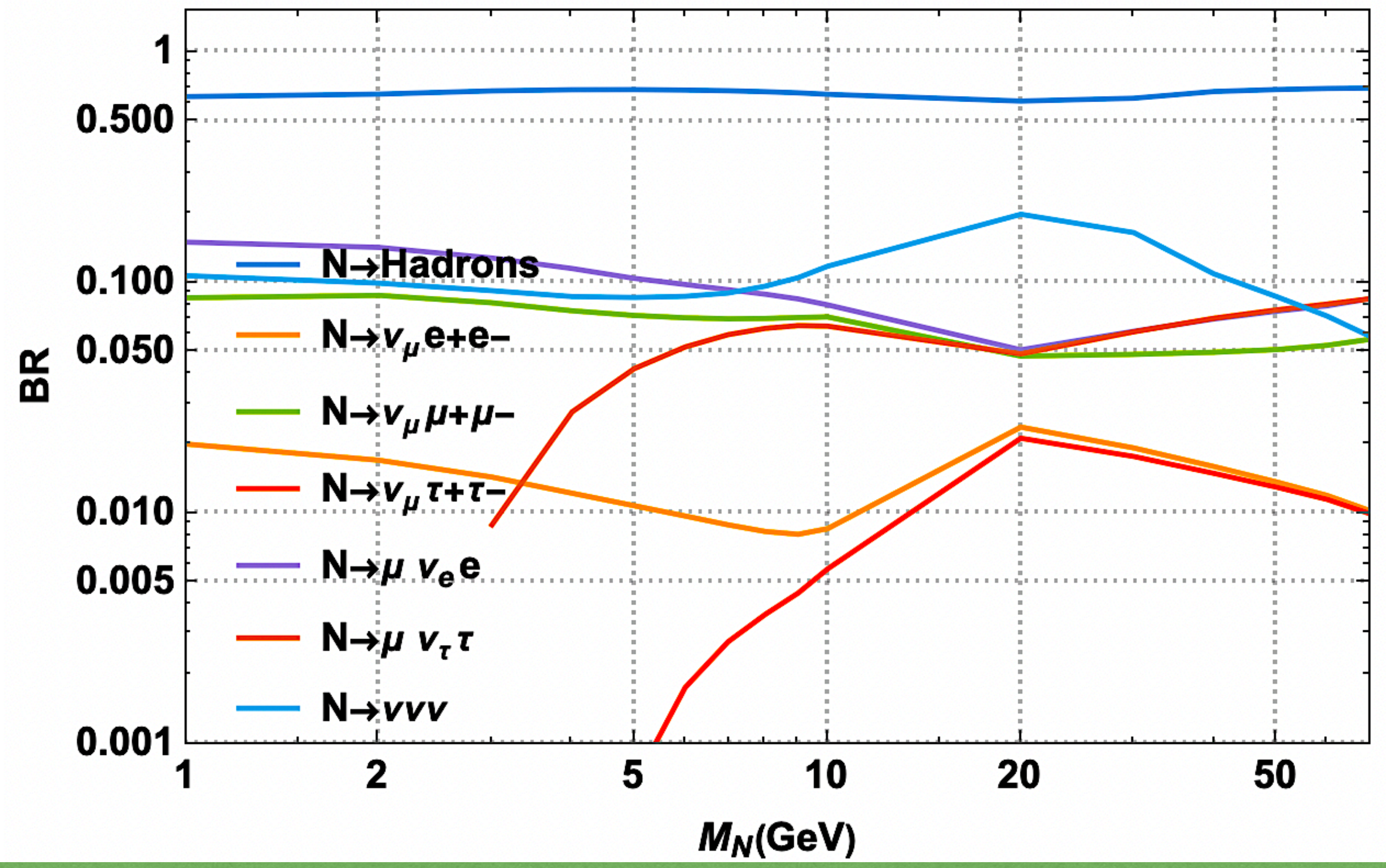
BR-BM-I



N→Hadrons
N→ν_μe+e−
N→$\nu_\mu\mu$+μ−
N→$\nu_\mu\tau$+τ−
N→$\nu\nu\nu$
BR
M_N(GeV)

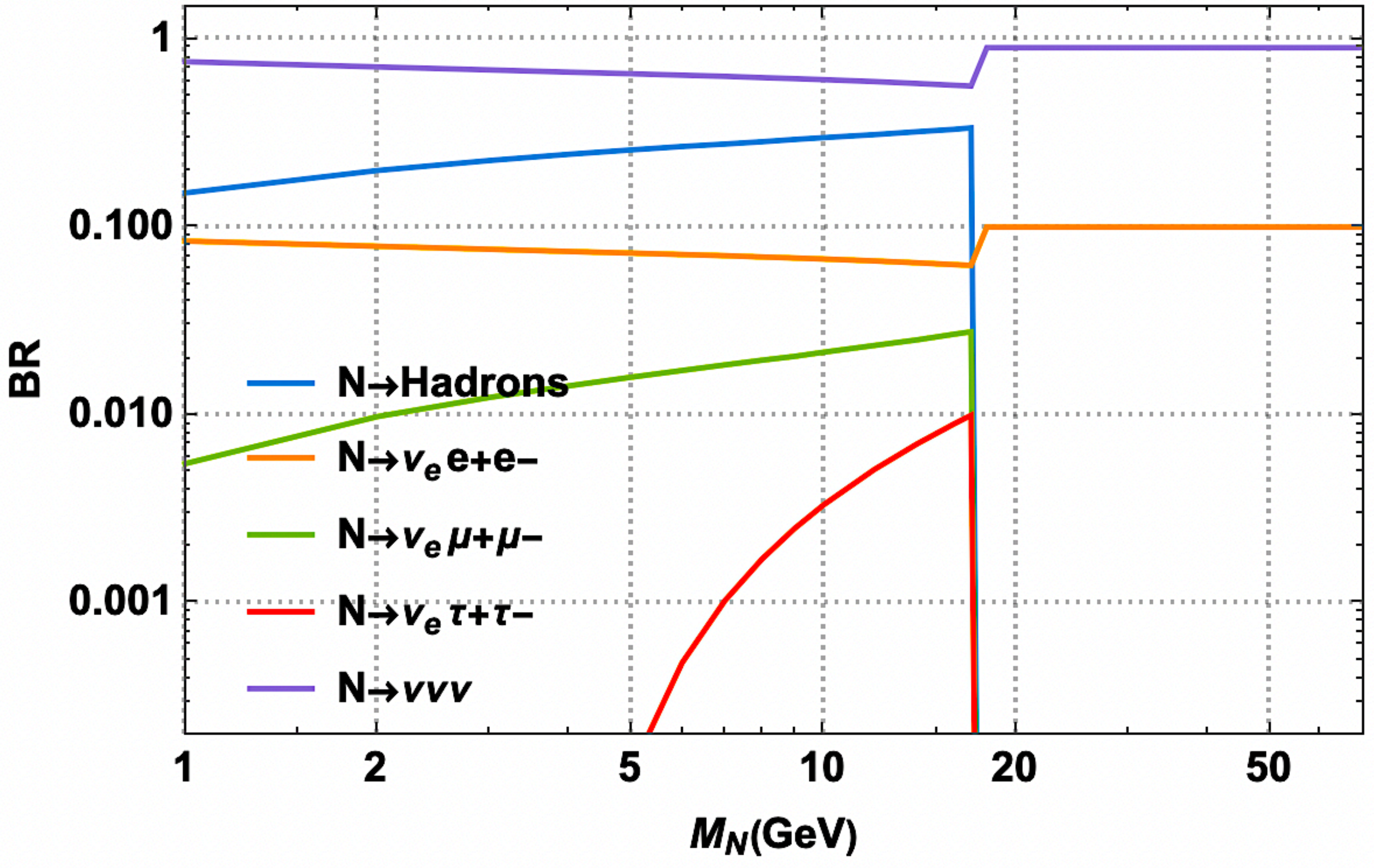


N→Hadrons
N→ν_μe+e−
N→$\nu_\mu\mu$+μ−
N→$\nu_\mu\tau$+τ−
N→μ ν_e e
N→$\nu\nu\nu$
BR
M_N(GeV)

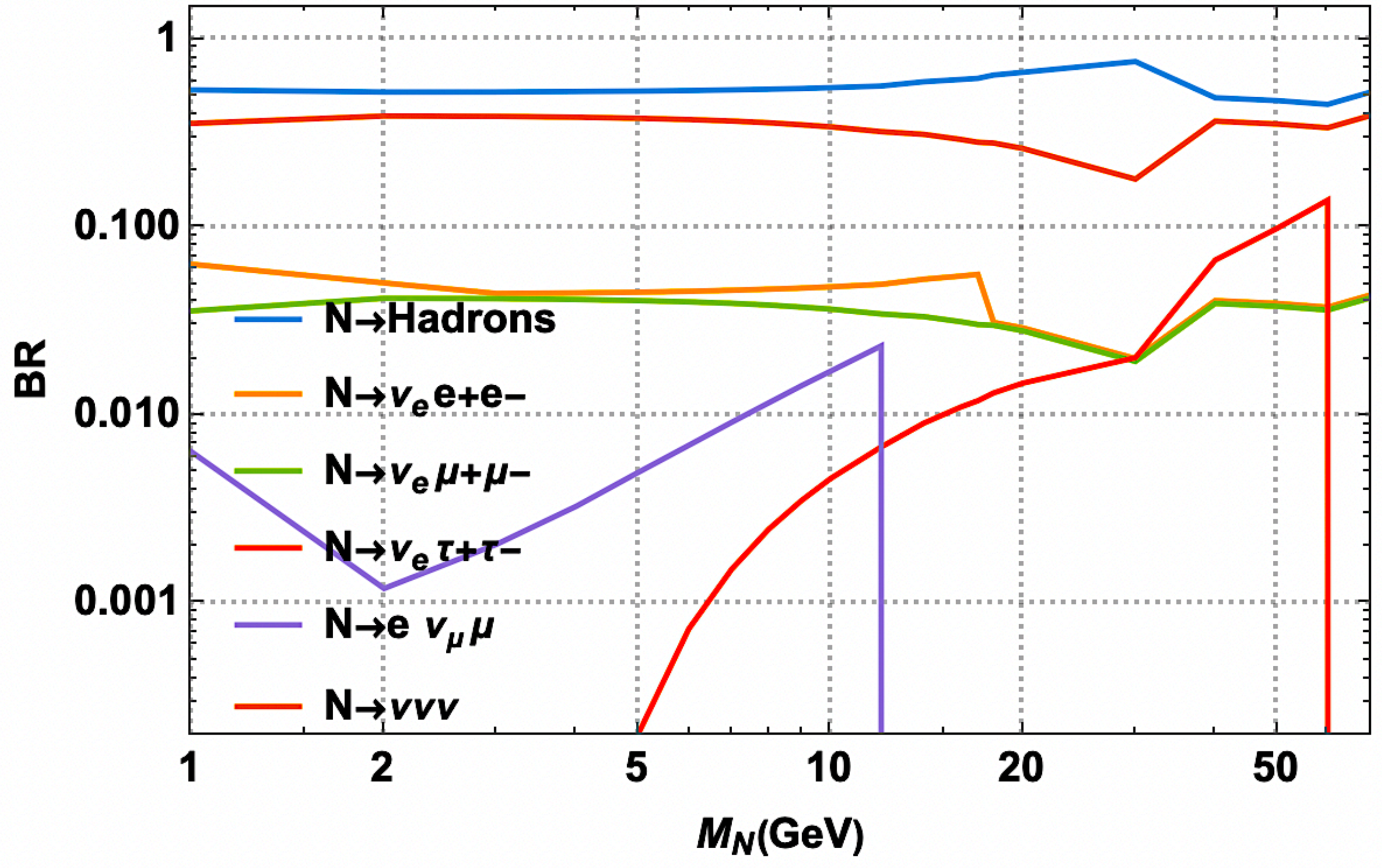


N→Hadrons
N→ν_μe+e−
N→$\nu_\mu\mu$+μ−
N→$\nu_\mu\tau$+τ−
N→μ ν_e e
N→μ ν_τ τ
N→$\nu\nu\nu$
BR
M_N(GeV)

BR-BM-II



BR
M_N(GeV)
N→Hadrons
N→ν_ee+e−
N→$\nu_e\mu$+μ−
N→$\nu_e\tau$+τ−
N→$\nu\nu\nu$



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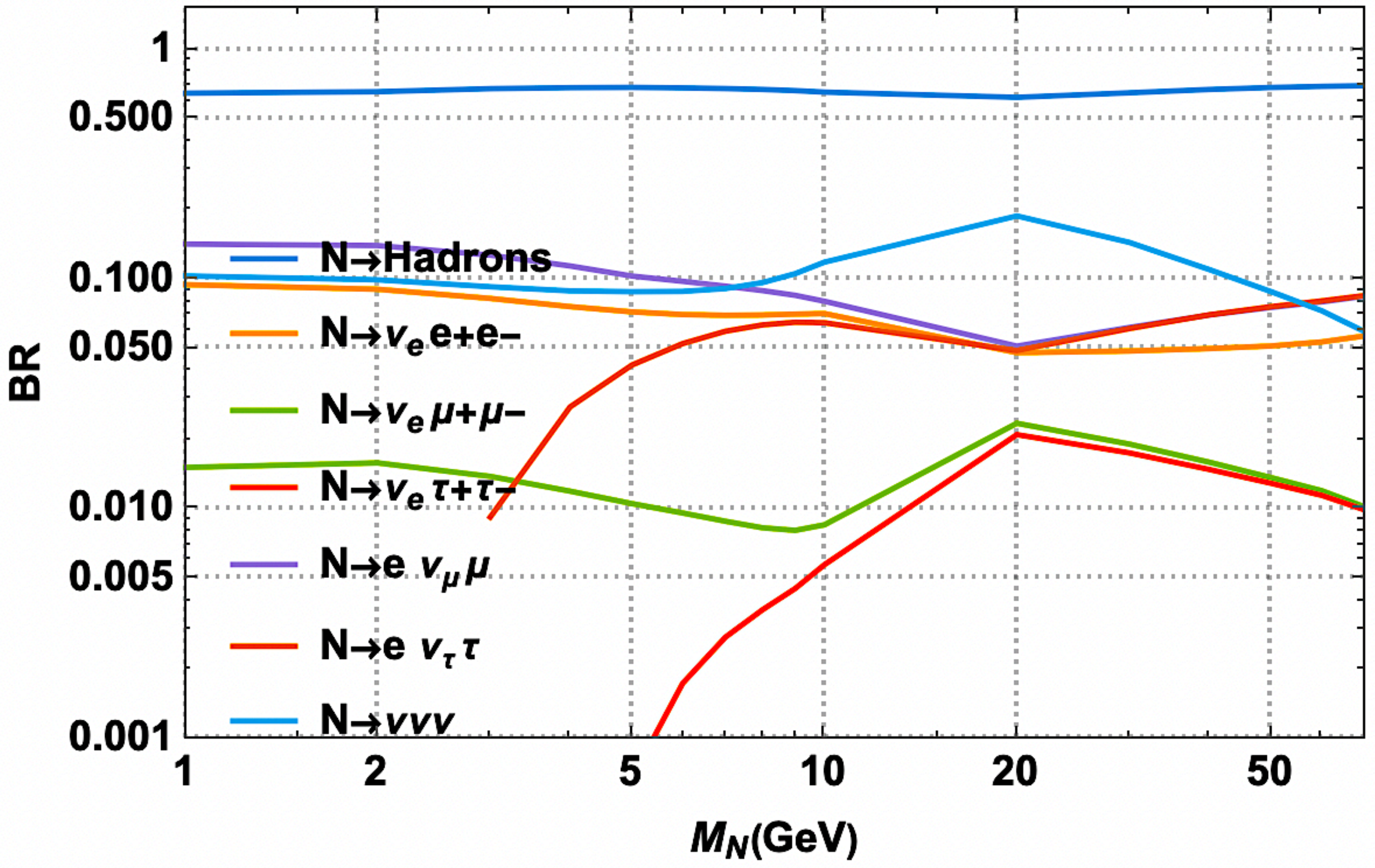
M_N(GeV)
N→Hadrons
N→ν_ee+e−
N→$\nu_e\mu$+μ−
N→$\nu_e\tau$+τ−
N→e $\nu_\mu\mu$
N→$\nu\nu\nu$



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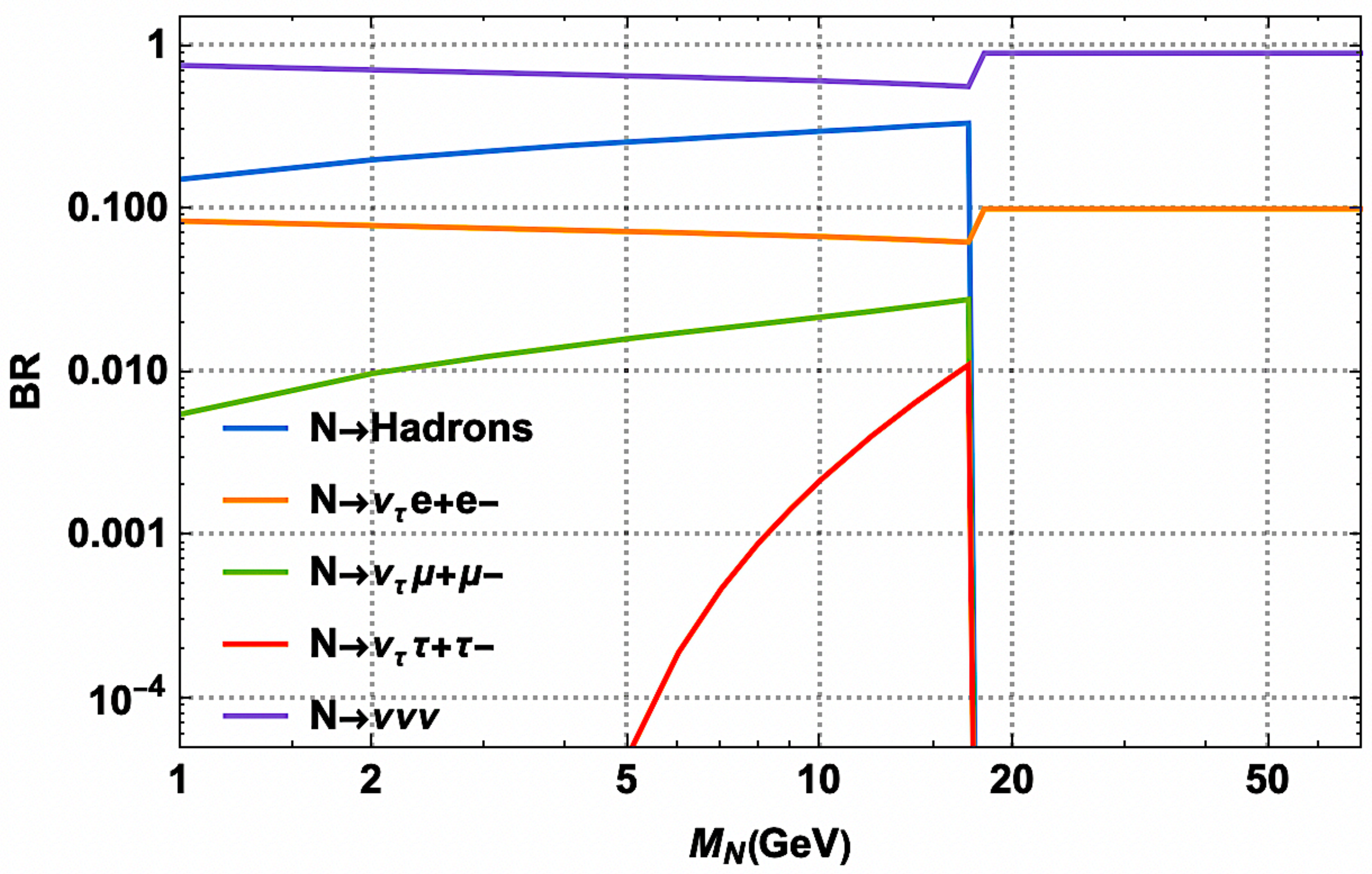
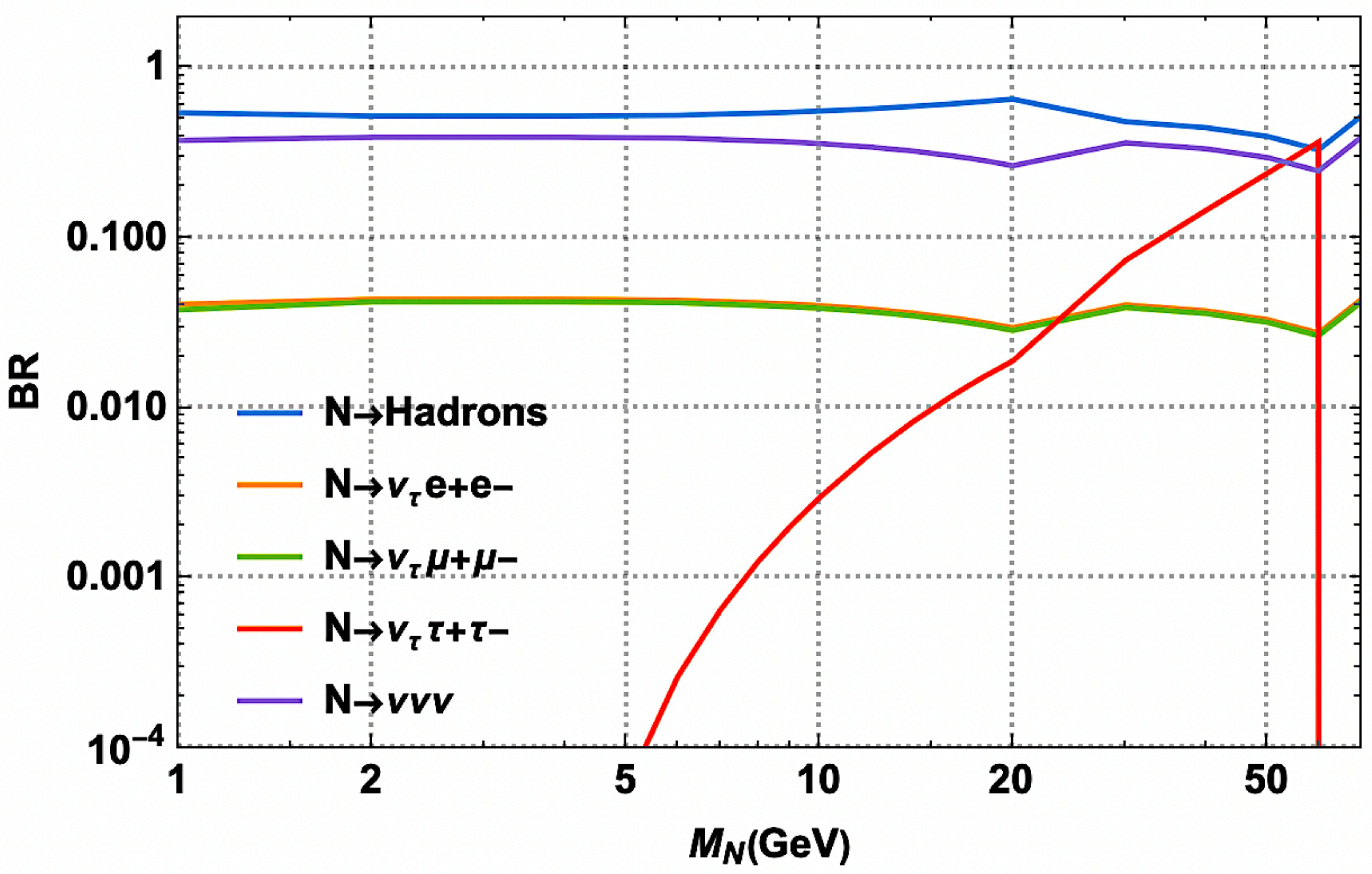
M_N(GeV)
N→Hadrons
N→ν_ee+e−
N→$\nu_e\mu$+μ−
N→$\nu_e\tau$+τ−
N→e $\nu_\mu\mu$
N→e $\nu_\tau\tau$
N→$\nu\nu\nu$

BR-BM-III


BR
M_N(GeV)
N→Hadrons
N→ν_τe+e−
N→$\nu_\tau\mu$+μ−
N→$\nu_\tau\tau$+τ−
N→$\nu\nu\nu$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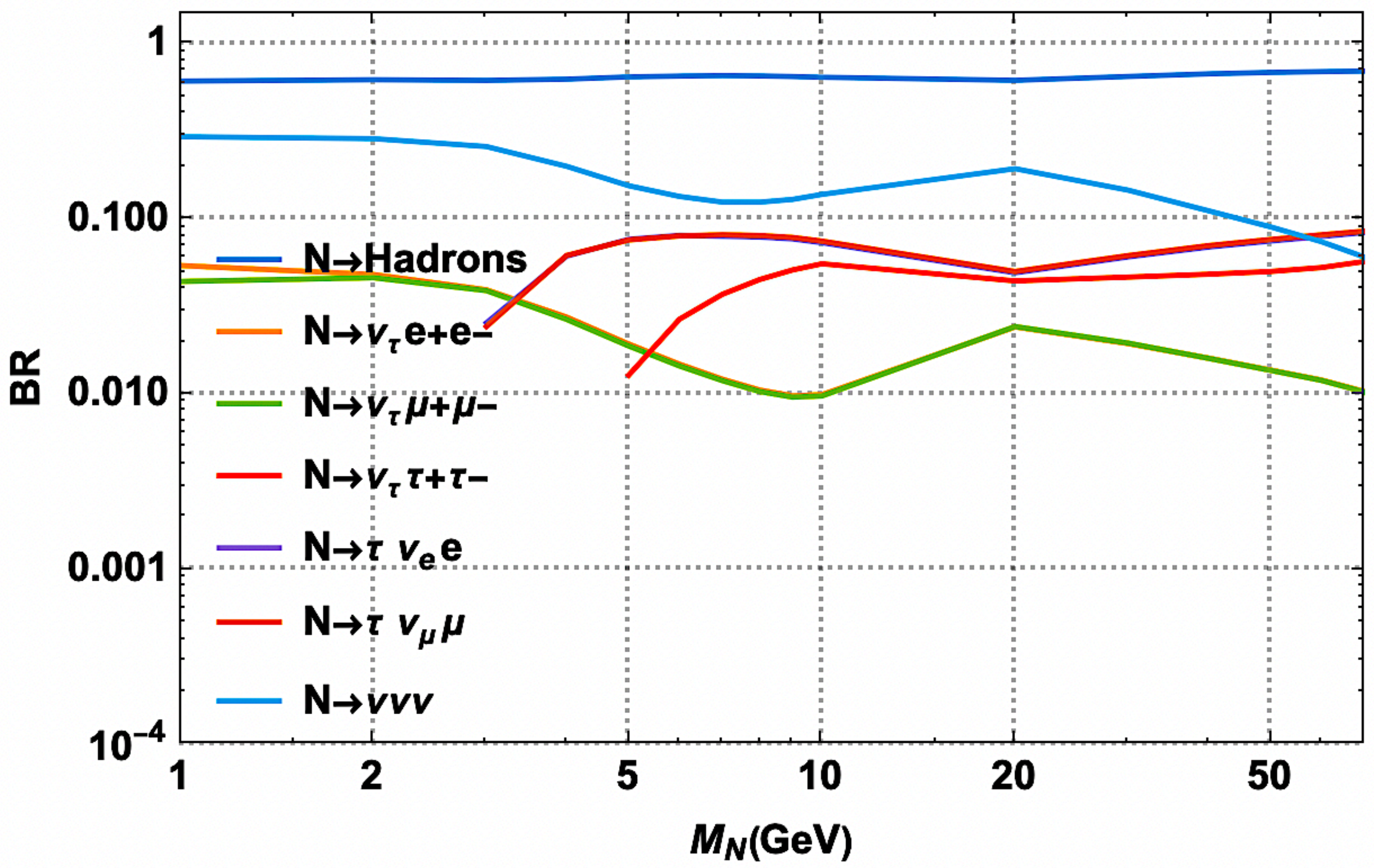
M_N(GeV)
N→Hadrons
N→ν_τe+e−
N→$\nu_\tau\mu$+μ−
N→$\nu_\tau\tau$+τ−
N→$\nu\nu\nu$


BR
M_N(GeV)
N→Hadrons
N→ν_τe+e−
N→$\nu_\tau\mu$+μ−
N→$\nu_\tau\tau$+τ−
N→τ ν_ee
N→τ $\nu_\mu\mu$
N→$\nu\nu\nu$

decay length