BSM Physics at FASERν

The Future is Illuminating 2nd NCTS TG2.1 Hsinchu Hub Workshop

June 28 - 30, 2022, NTHU, Hsinchu, TW

Ouseph C.J.

Department of Physics, National Tsing Hua University, Taiwan

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

OutLine

1, Introduction to FASERν Detector

2, Non-standard neutrino and Z ' interactions at the FASERν and LHC

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

4, The future detectors

Neutrinos at the LHC

Neutrinos detected from many sources, but not from colliders (until 2018) *[Phys.Rev.D 104 (2021) 9, L091101].*

But 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.

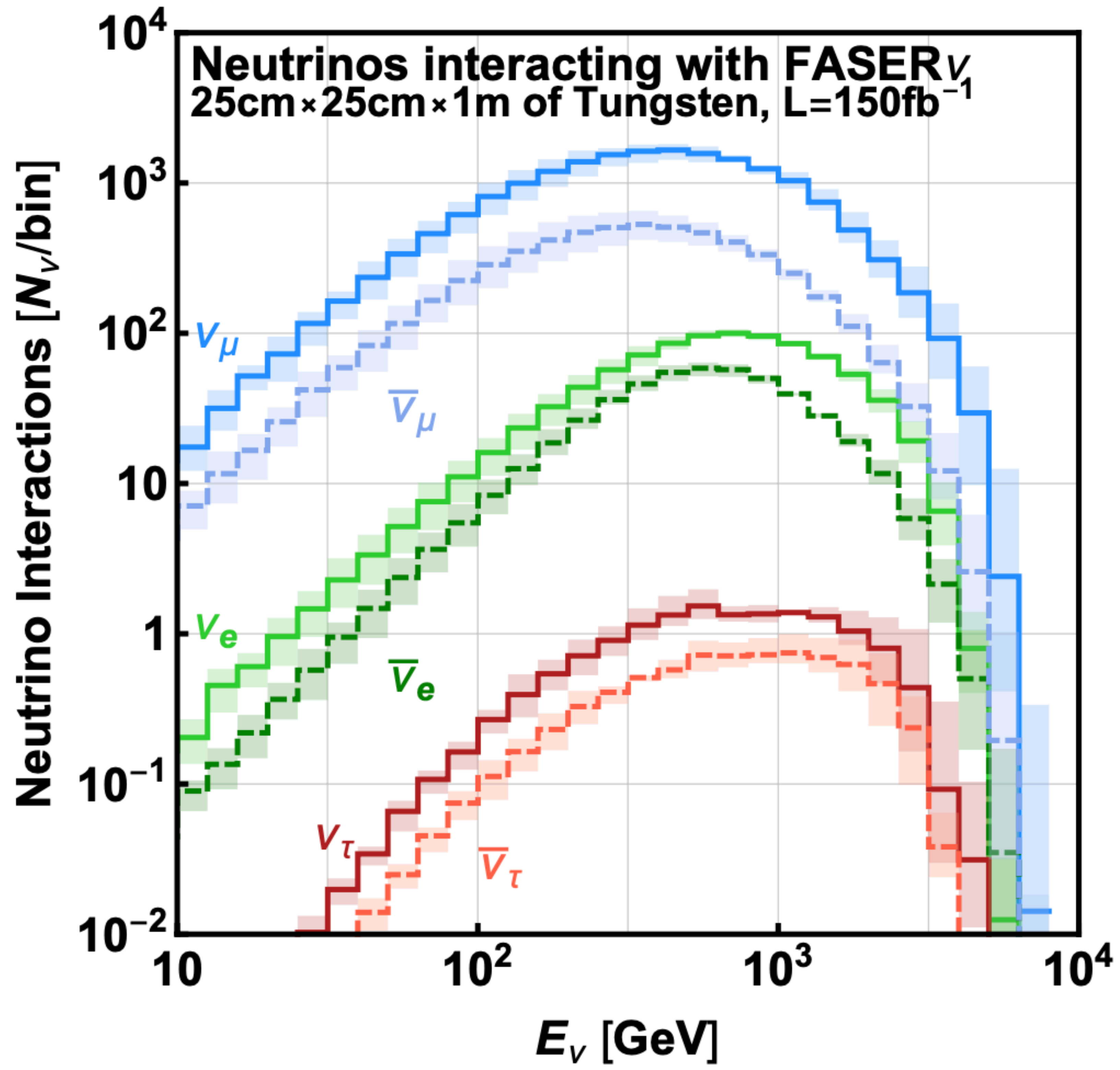
Source: Eur.Phys.J. C80 (2020) no.1, 61

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 2022-2024.

FASERν is an emulsion neutrino detector, consisting of 1000 layers of emulsion films interleaved with tungsten plates as target. The total target mass is about 1.2 ton.



source: Eur.Phys.J. C80 (2020) no.1, 61

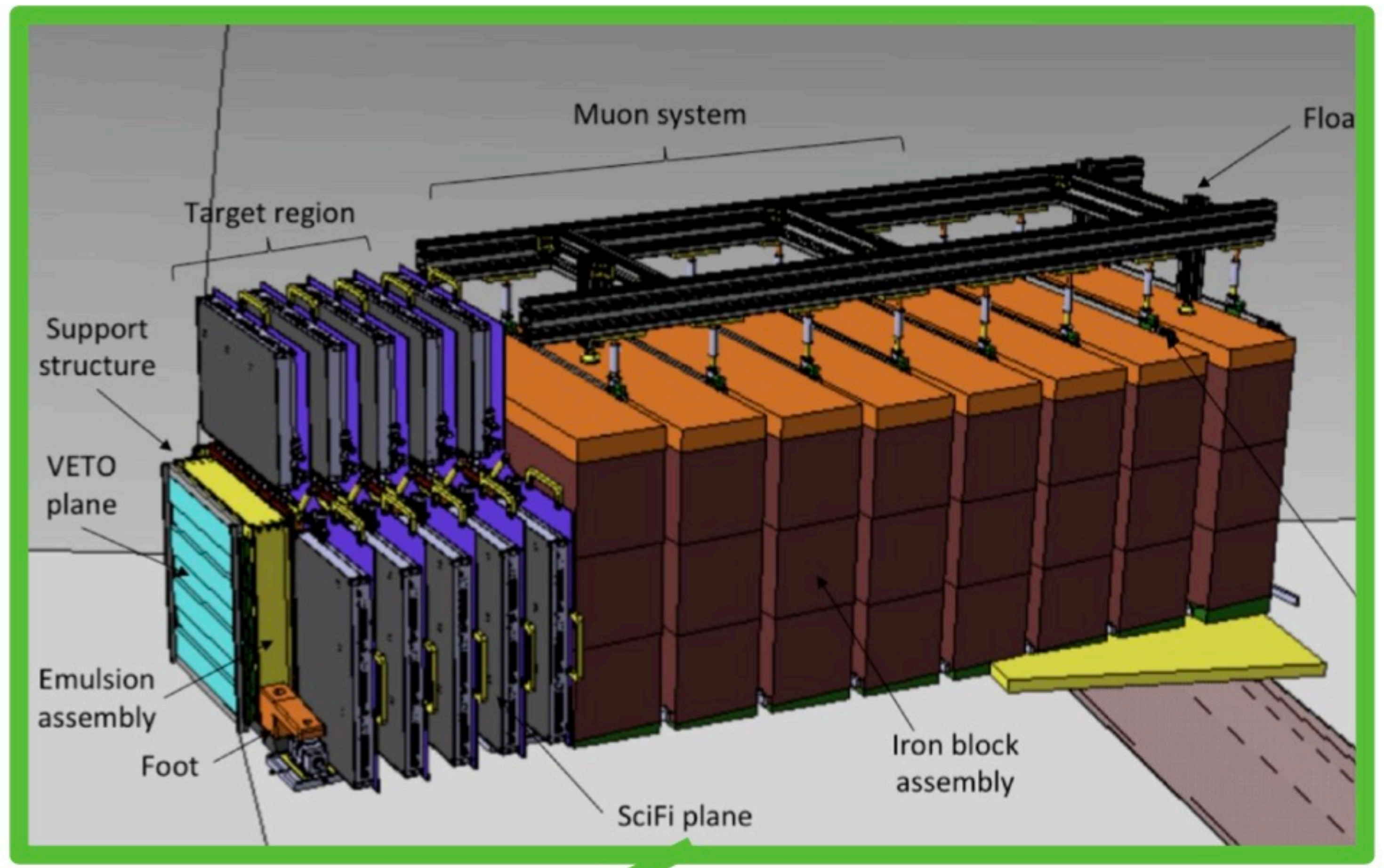
FASERν will give us an opportunity to measure ν-N cross-section in the ~ [100GeV – few TeV] range.

FASERν will record topology/kinematics of interaction

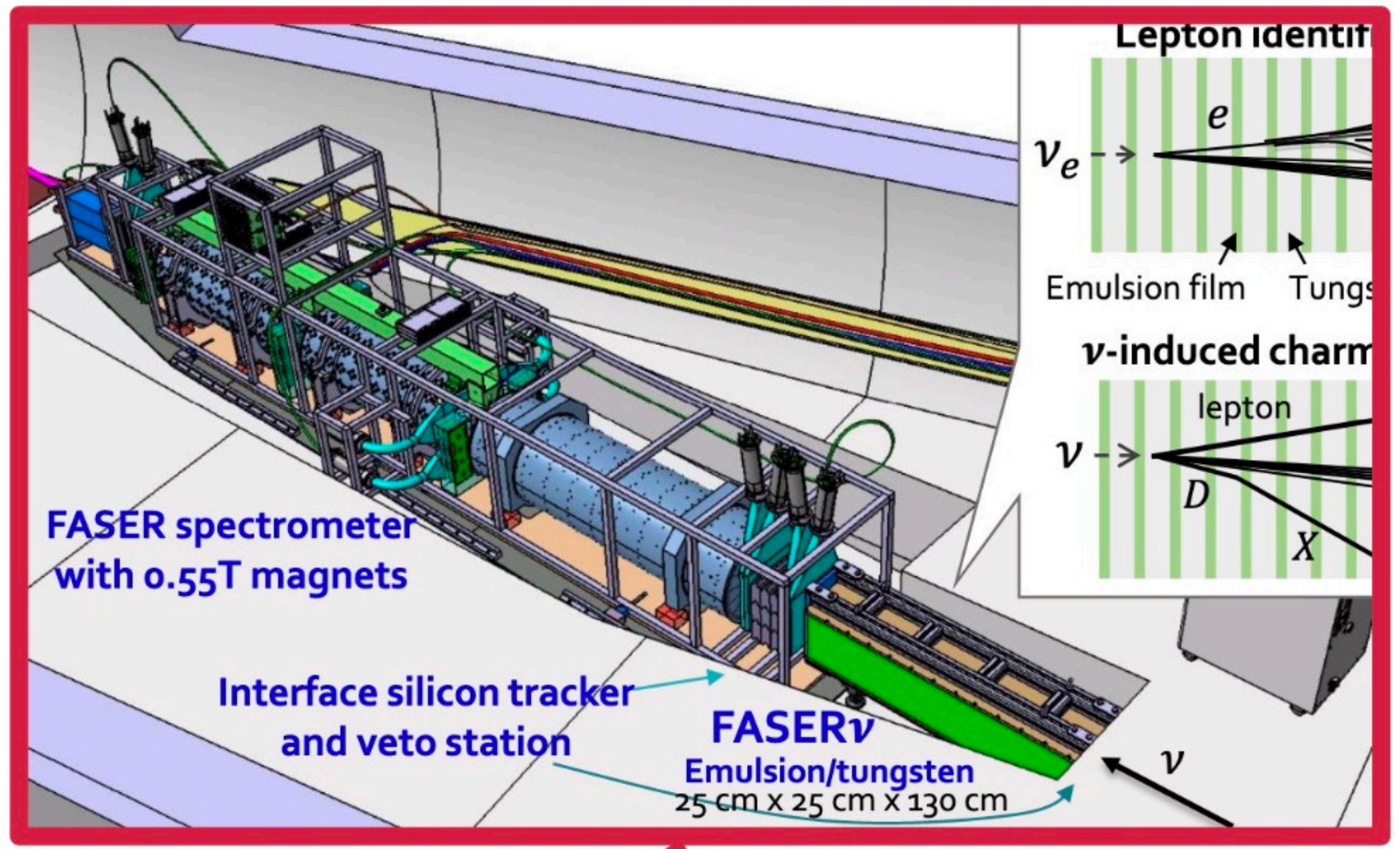
Neutrinos at the LHC

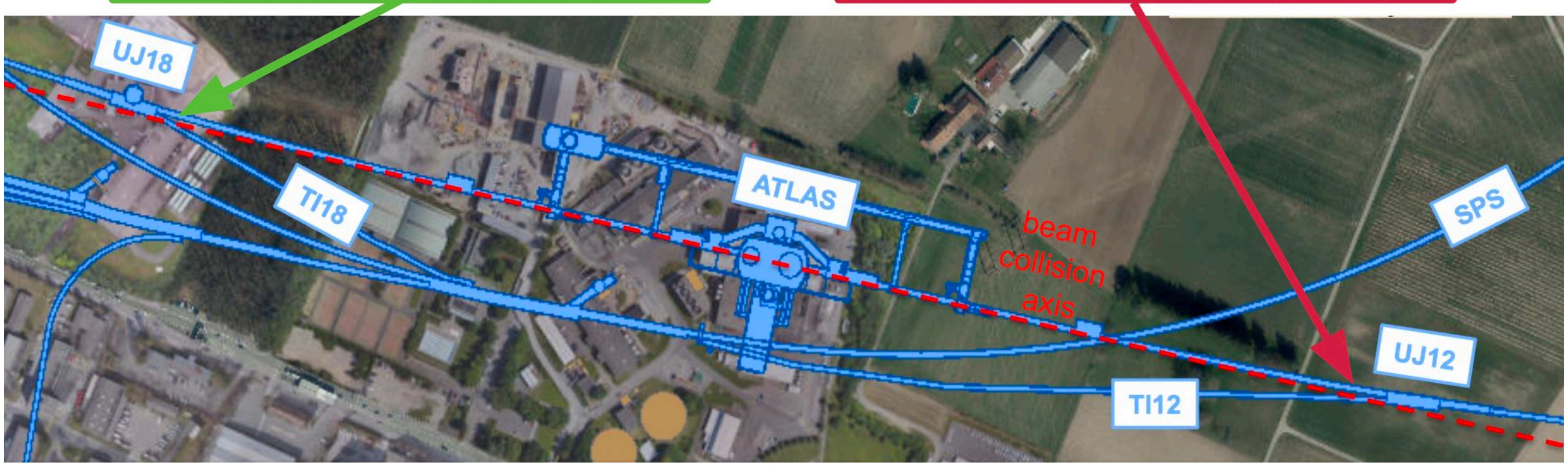
Two collaborations have propose neutrino experiments at the LHC.

SND@LHC (proposed)



FASERnu (approved and funded)





Source: arXiv:2109.10905v1

FASERν: Neutrino spectra

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

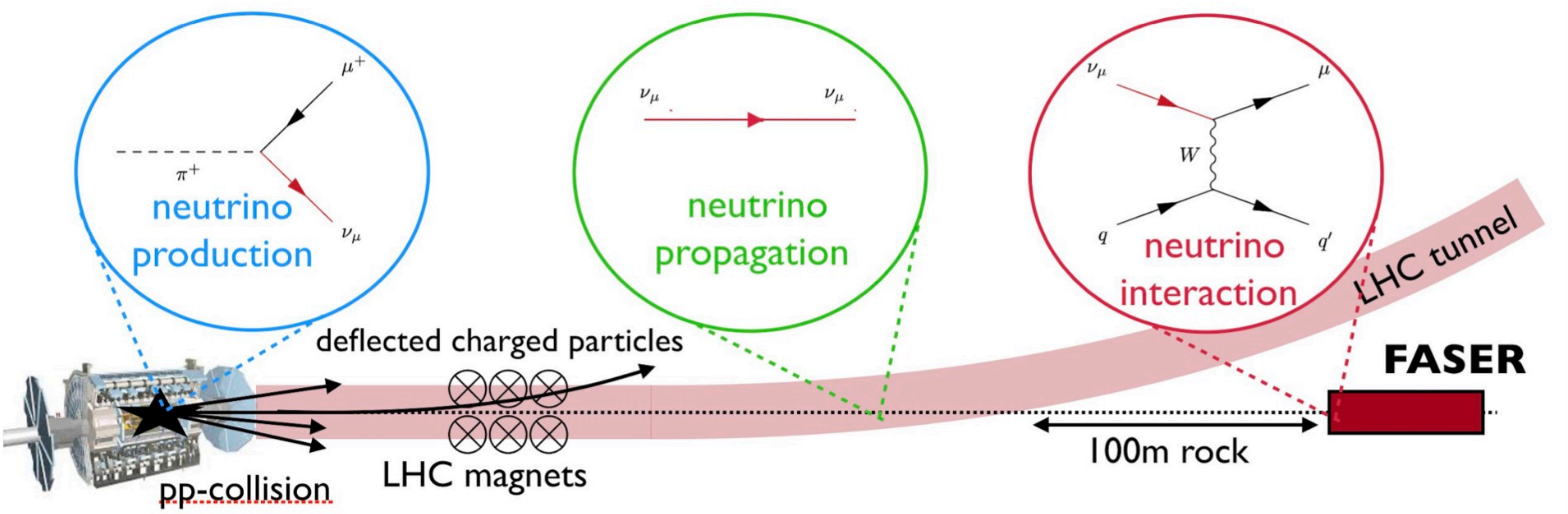
It originates from a variety of sources: pion, kaon, hyperon and charm decays.

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?

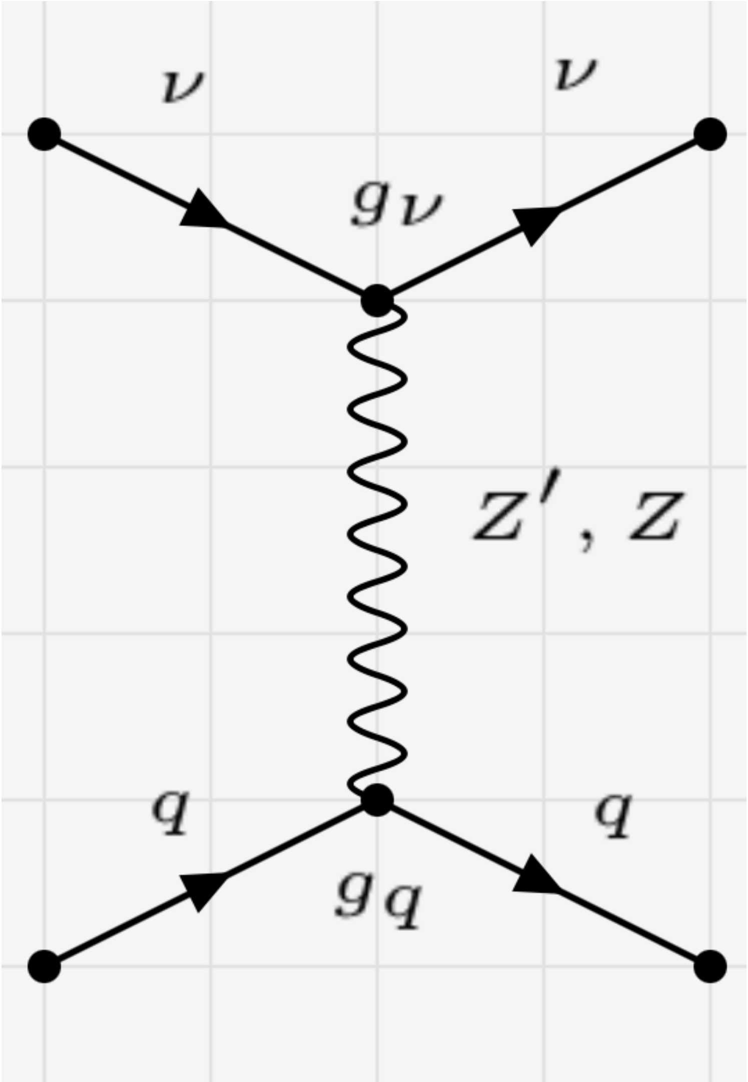


Source: arXiv:2109.10905v1

Non Standard Neutrino and Z' Interaction @ FASERν

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

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



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

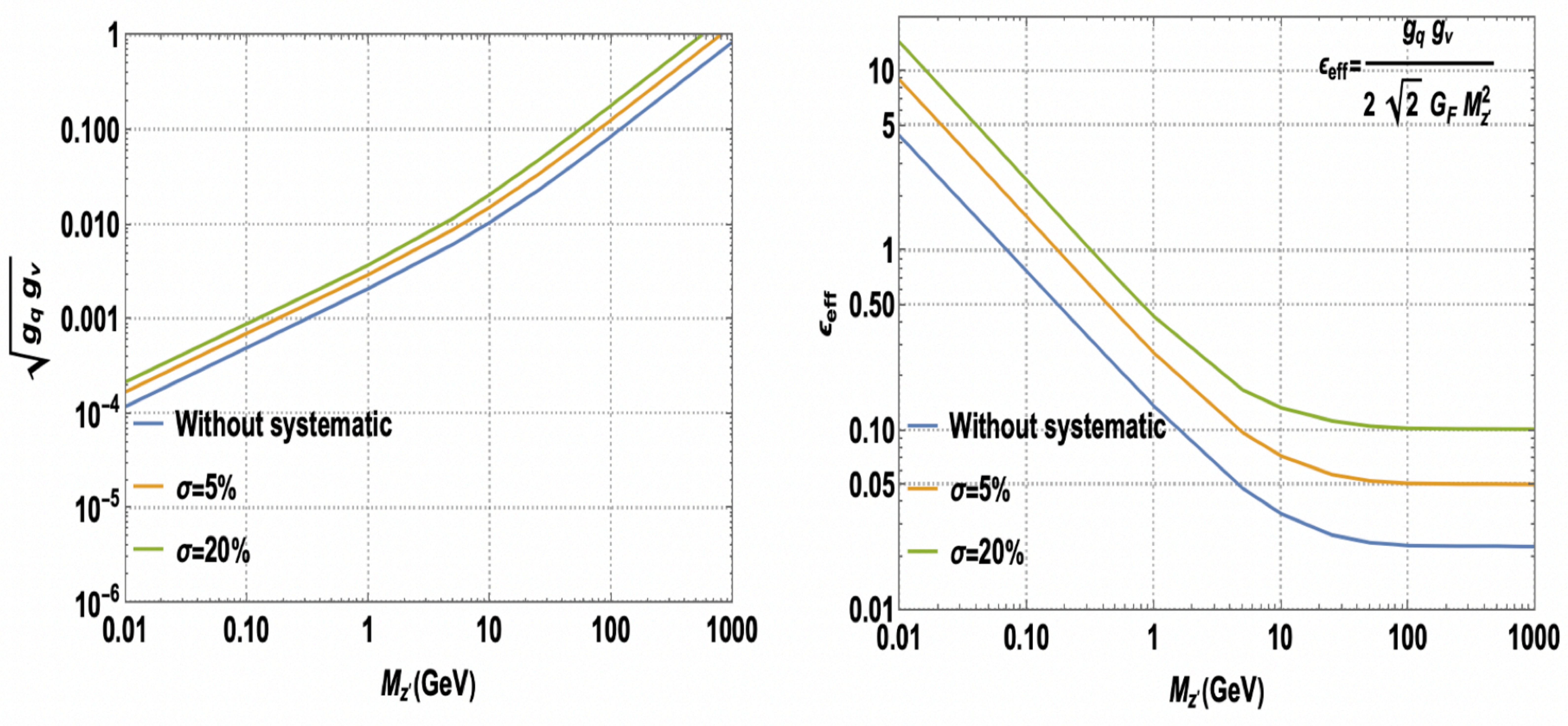
Cont'd

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

FASERν detector's neutrino scattering sensitivity to the Z$'$ at 95% C.L.

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

α is the nuisance parameters, with the uncertainties σ_{norm}, take into account normalization uncertainties from the flux and detector.



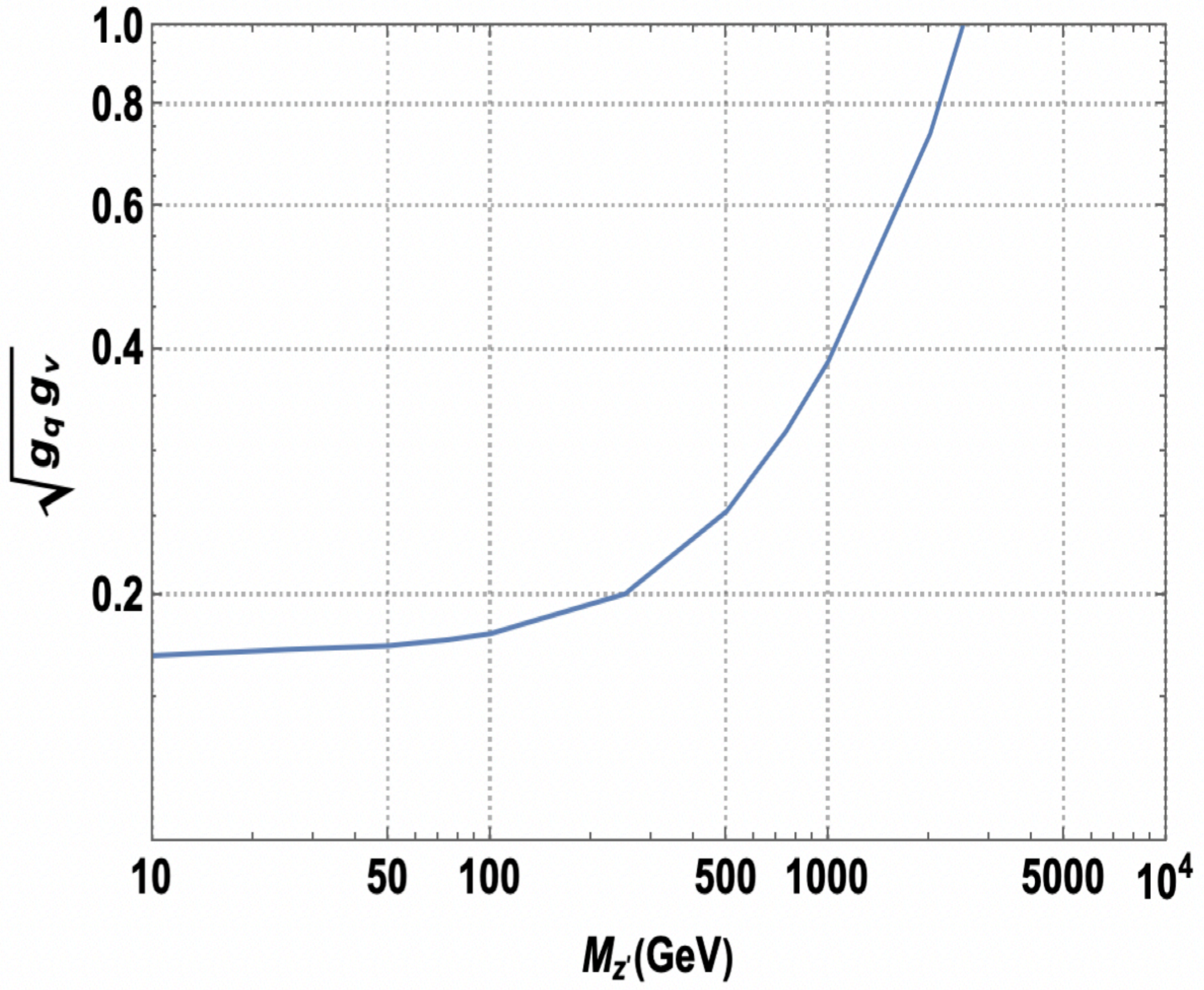
K. Cheung, C. J. Ouseph and T. Wang, JHEP12(2021)

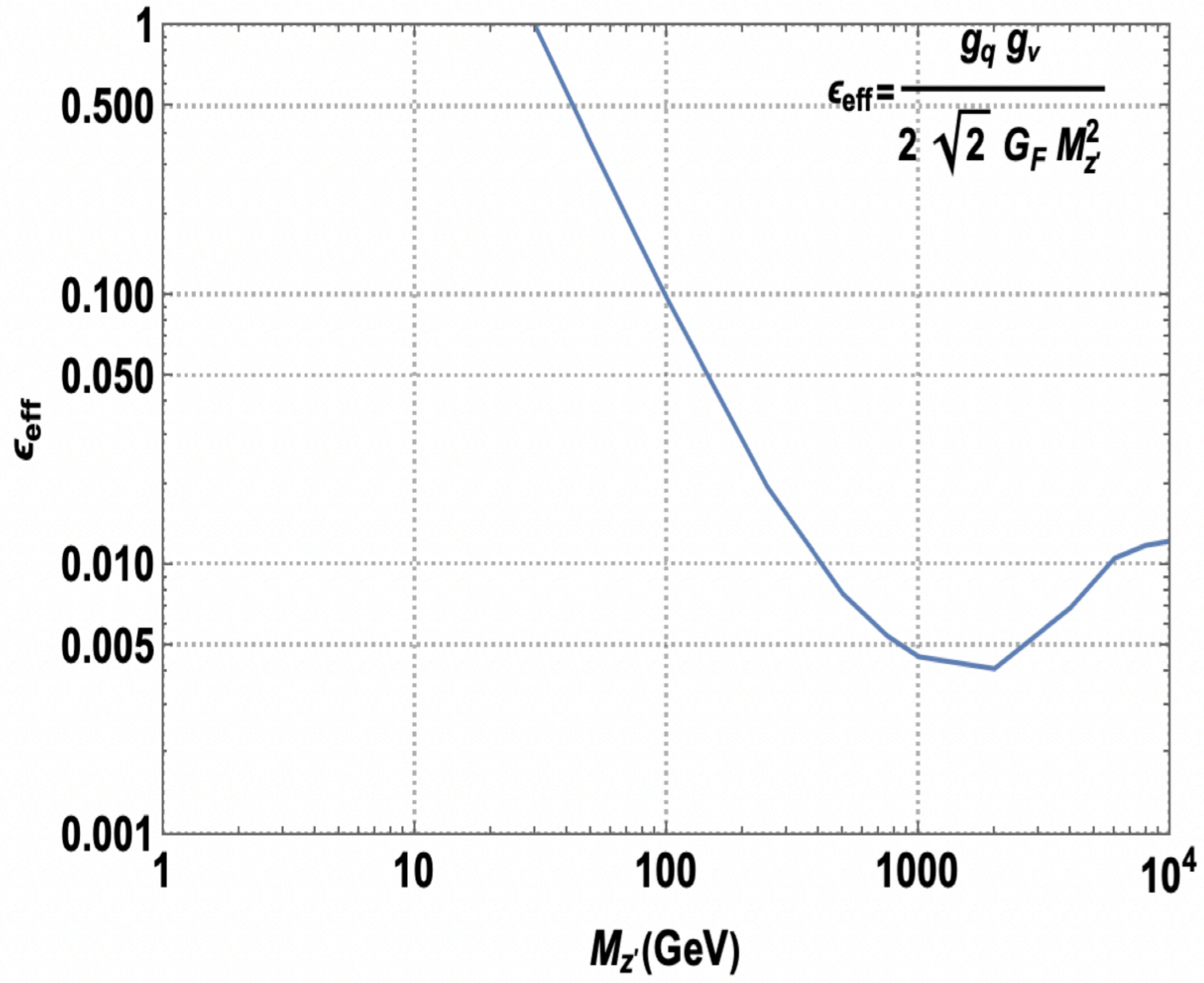
Effects of Z' on the monojet production @ LHC

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

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.

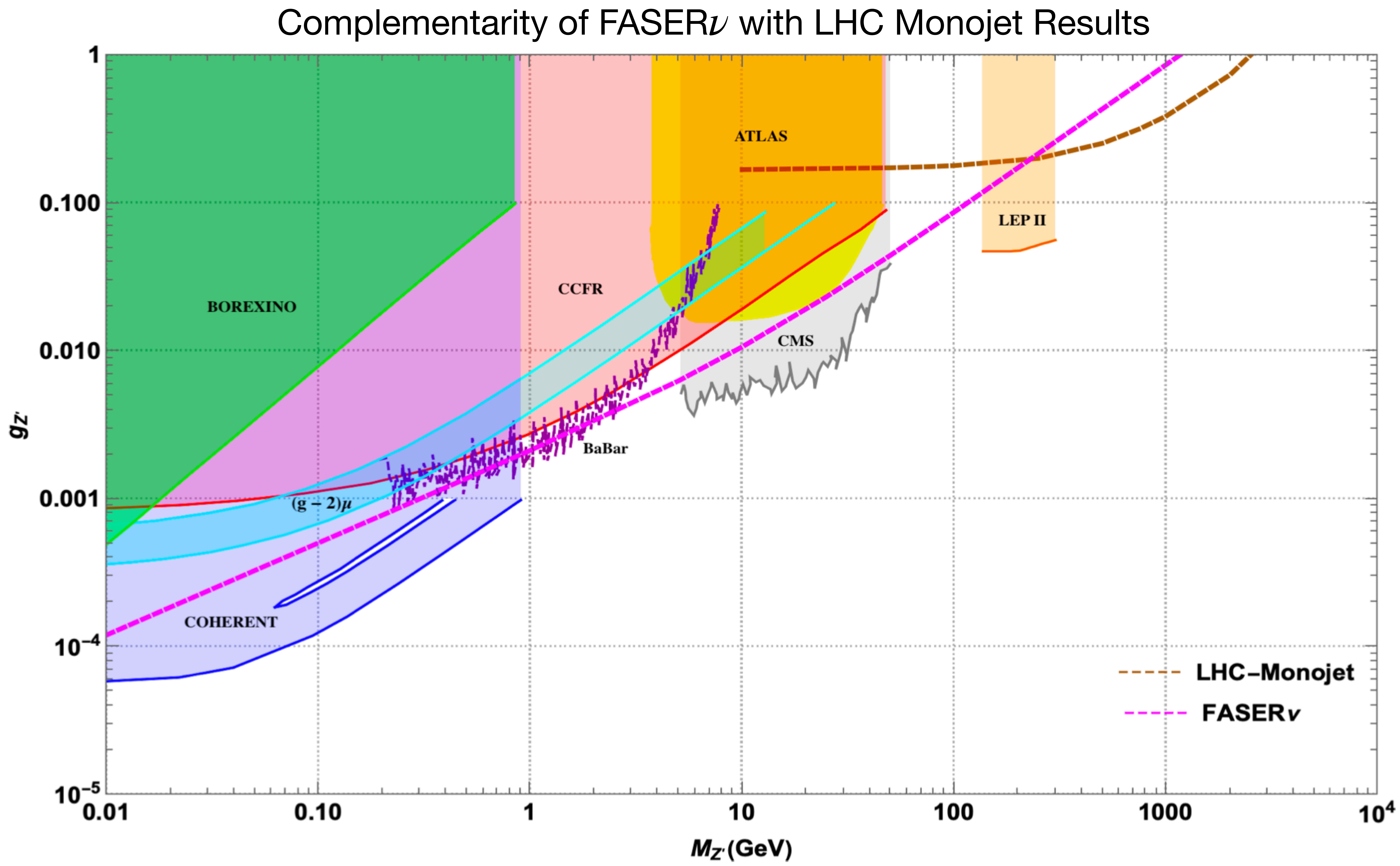
ATLAS paper results was based on the monojet search at 13 TeV with an integrated luminosity of 139 fb−1 [*Phys. Rev. D* **103** (2021) 112006 [arXiv:2102.10874]]





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

Cont'd

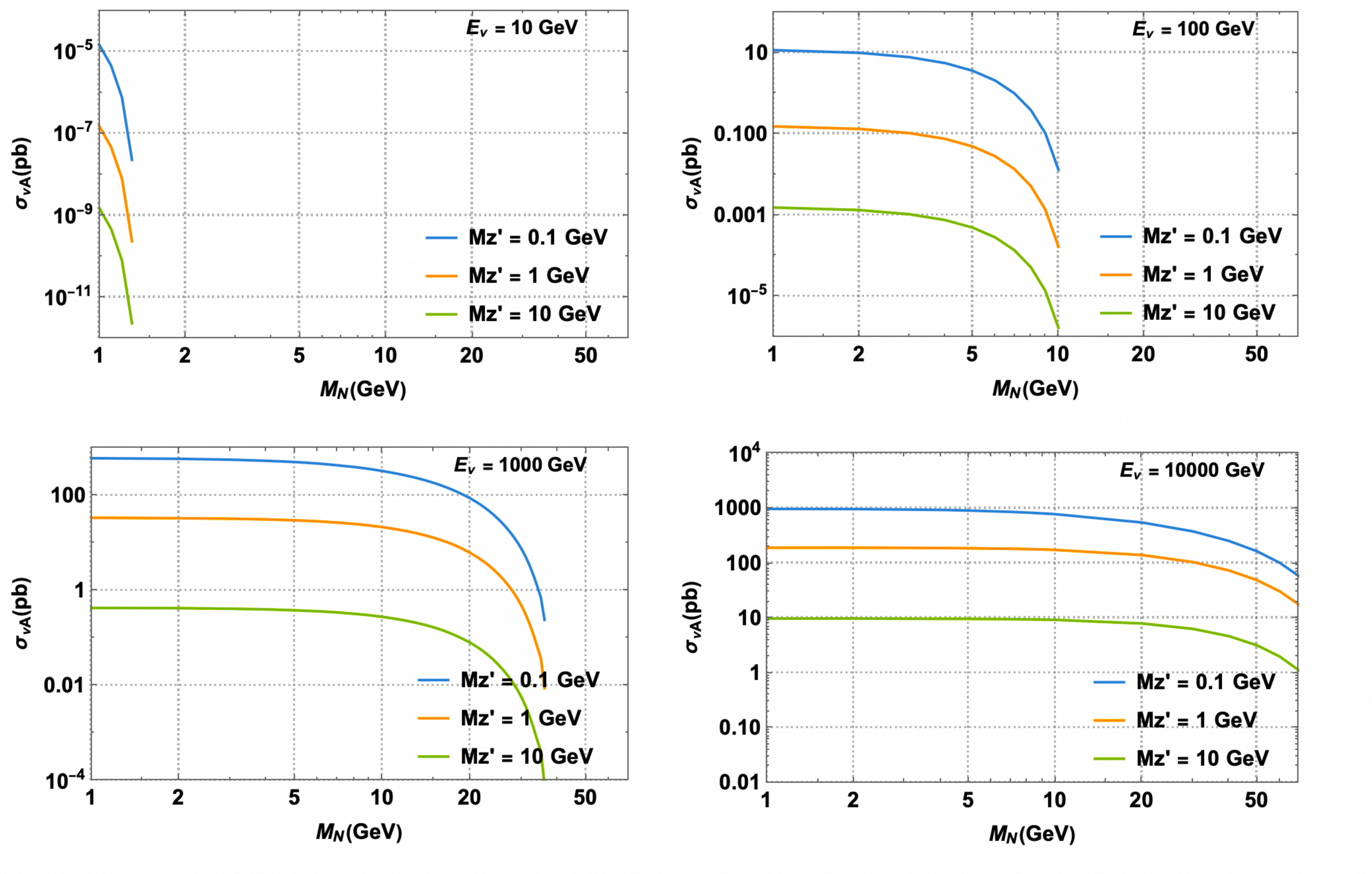


K. Cheung, C. J. Ouseph and T. Wang, JHEP12(2021)

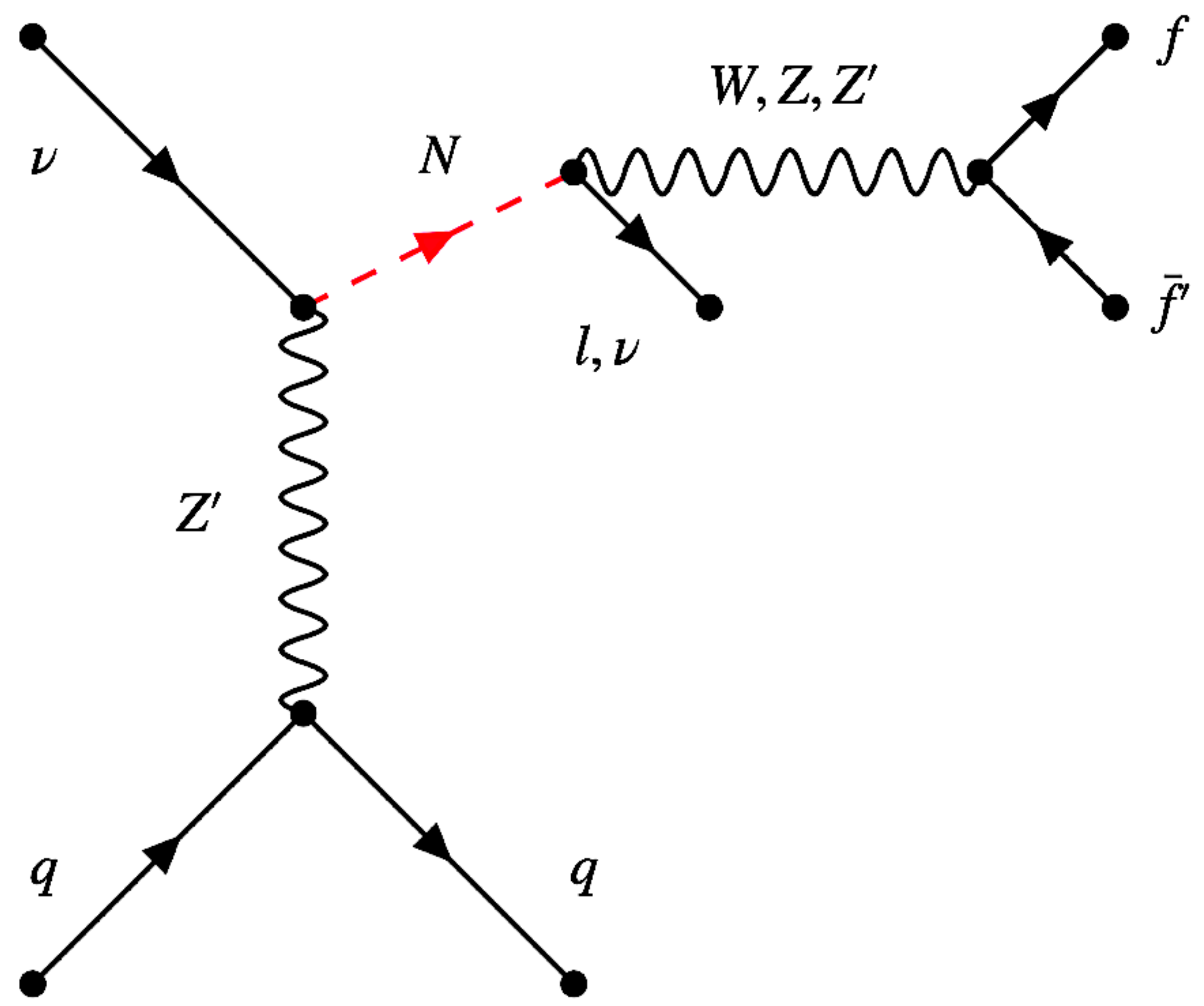
Constraining the Active-to-Heavy-Neutrino transitional magnetic moments Type Interactions associated with the Z' interactions at FASERν.

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

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



arXiv:2205.11077



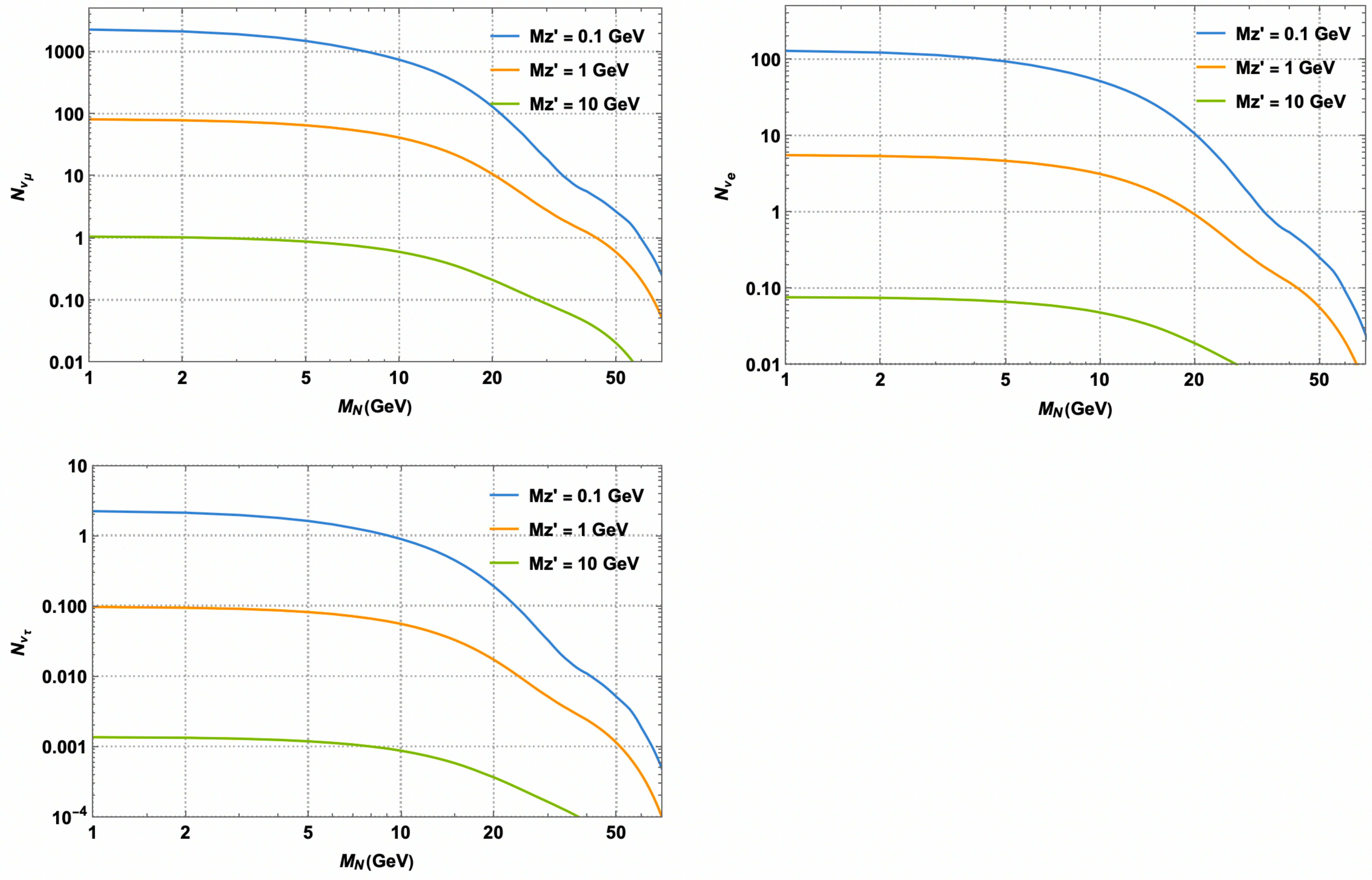
arXiv:2205.11077

FASERν Sensitivity towards Transition Magnetic Moment type interactions

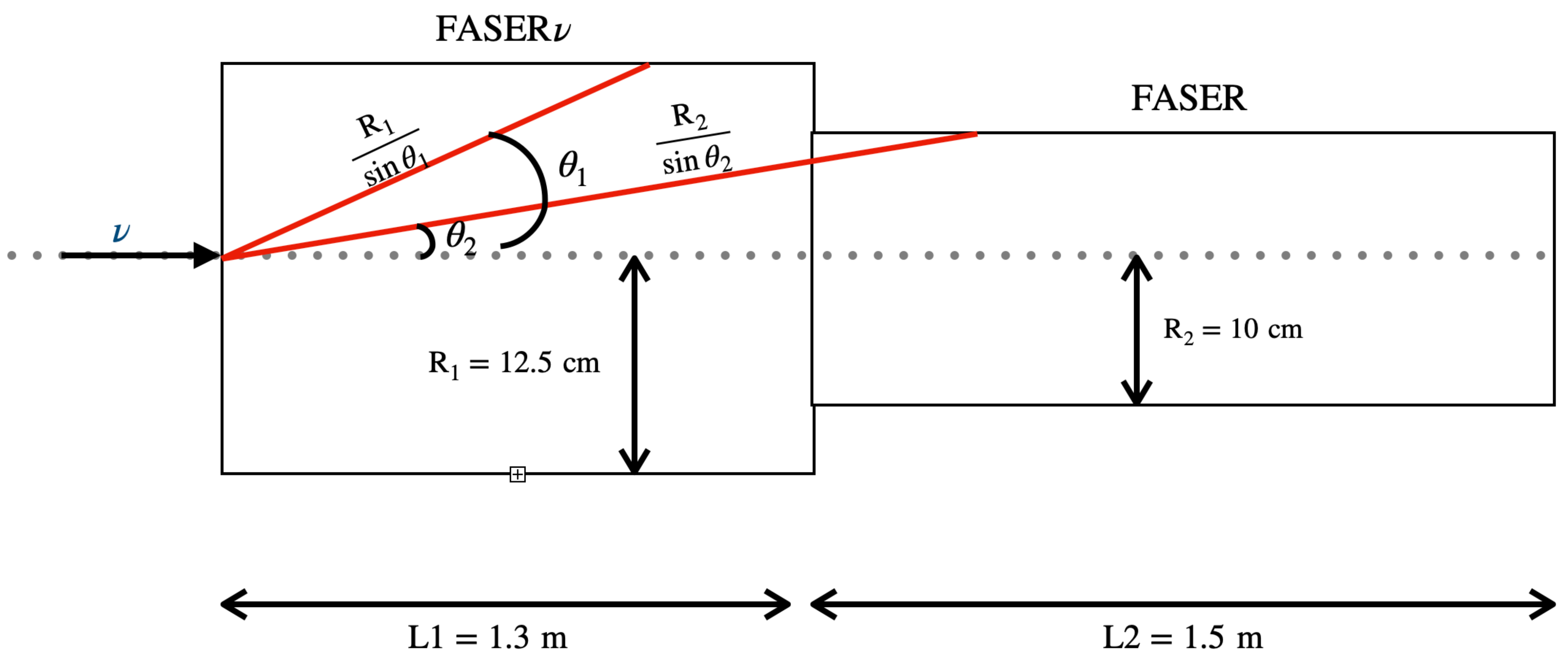
$$N^{\rm detc}_{\nu_\alpha} = N_{\nu_\alpha}(\nu_\alpha A \to NA) \times \mathscr{P}_{detc} \times {\rm BR}(N \to \nu_\alpha\ X\ X)$$

$$\mathscr{P}_{\rm detc} = 1 - \exp(\frac{-d}{\beta c \tau}) \qquad d = \min(\Delta, \frac{R}{\sin\theta})$$

$N_{\nu_\alpha}(\nu_\alpha A \to NA)$



arXiv:2205.11077



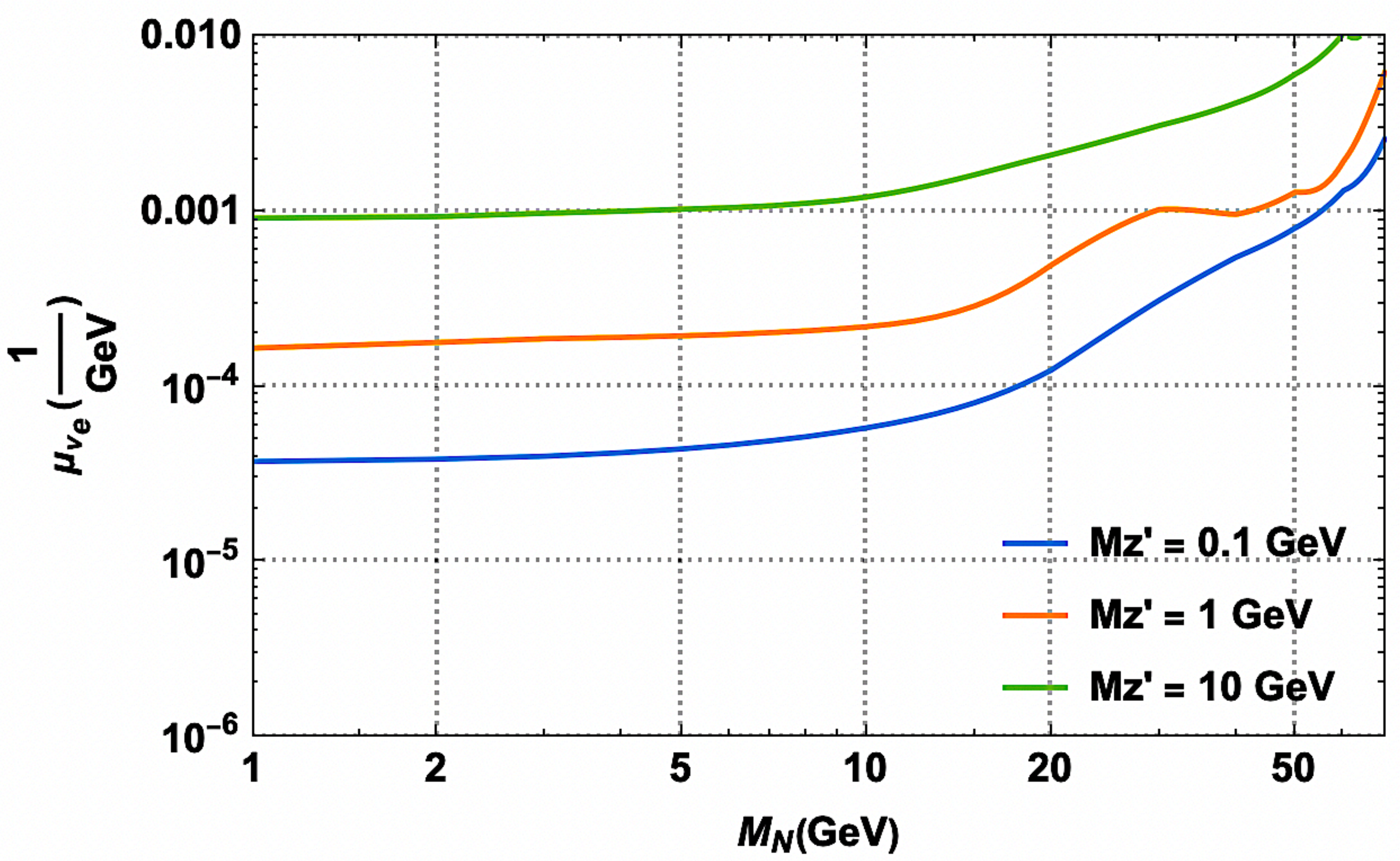
arXiv:2205.11077

Cont'd BM-I

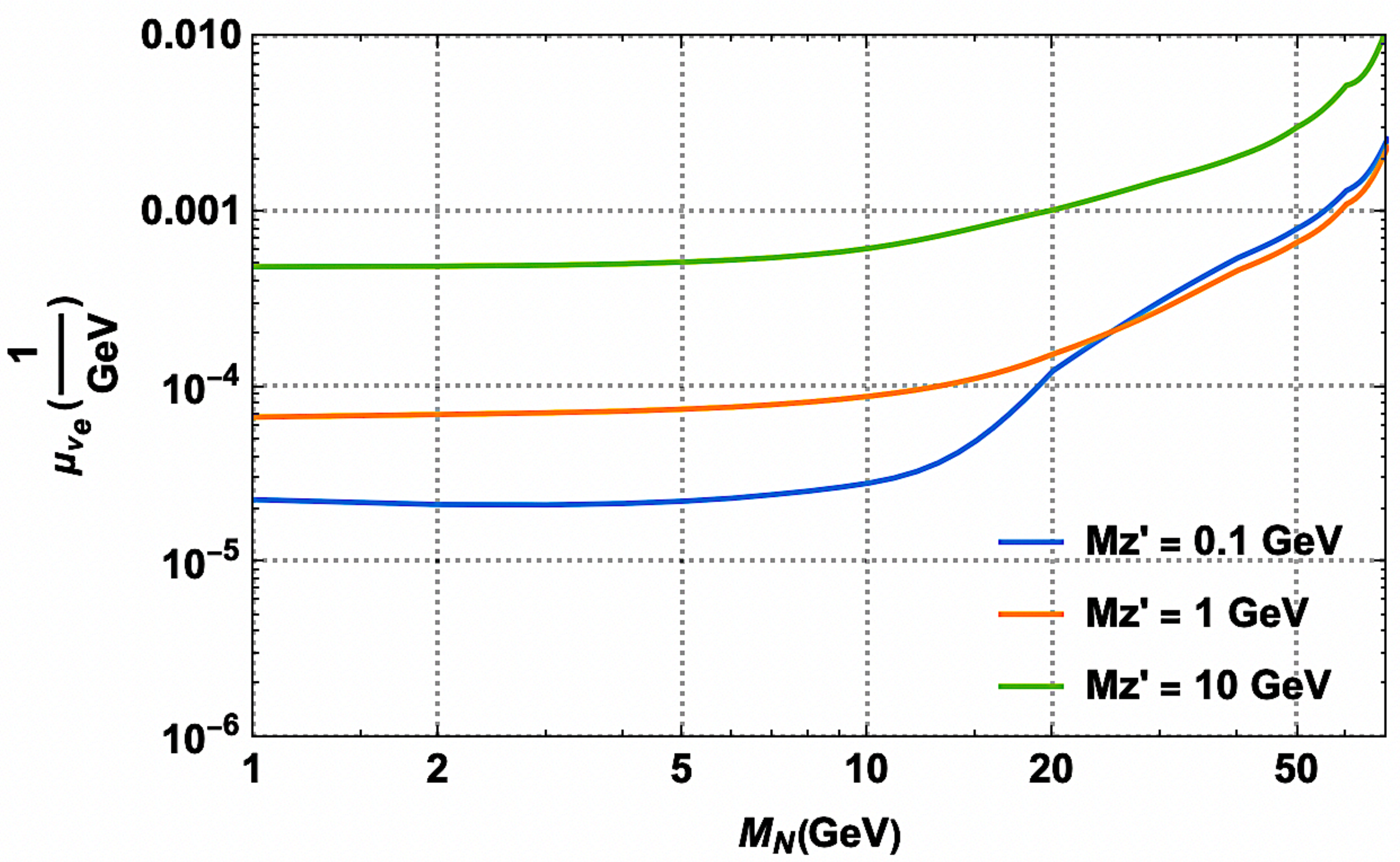
Heavy Neutrino Coupled with L_e Doublet,

$$\mu_{\nu_\mu} = \mu_{\nu_\tau} = 0$$
$$V_{\mu N} = V_{\tau N} = 0$$

Final state consist of charged leptons only



Final states consist of charged leptons and quark only



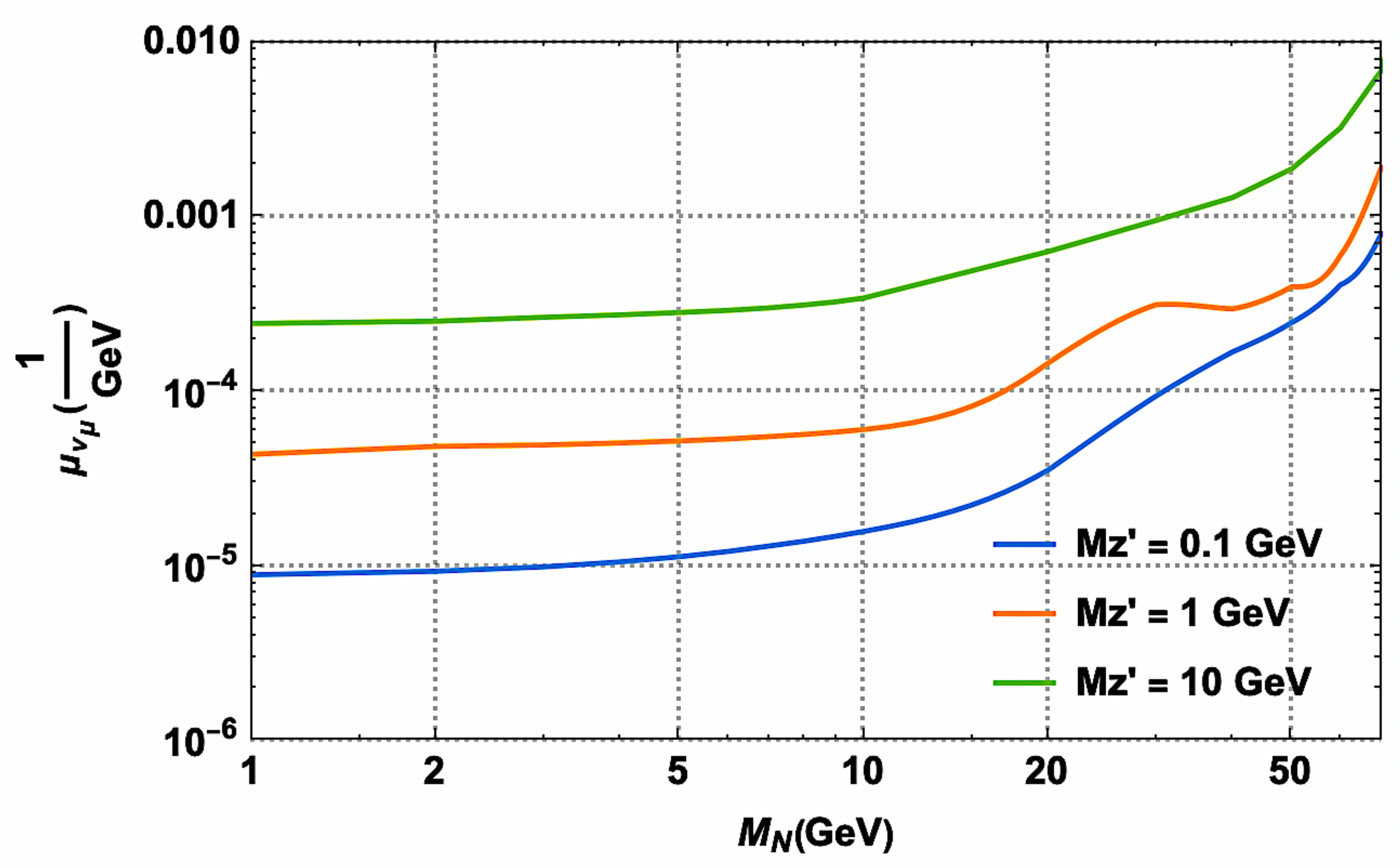
arXiv:2205.11077

Cont’d BM-II

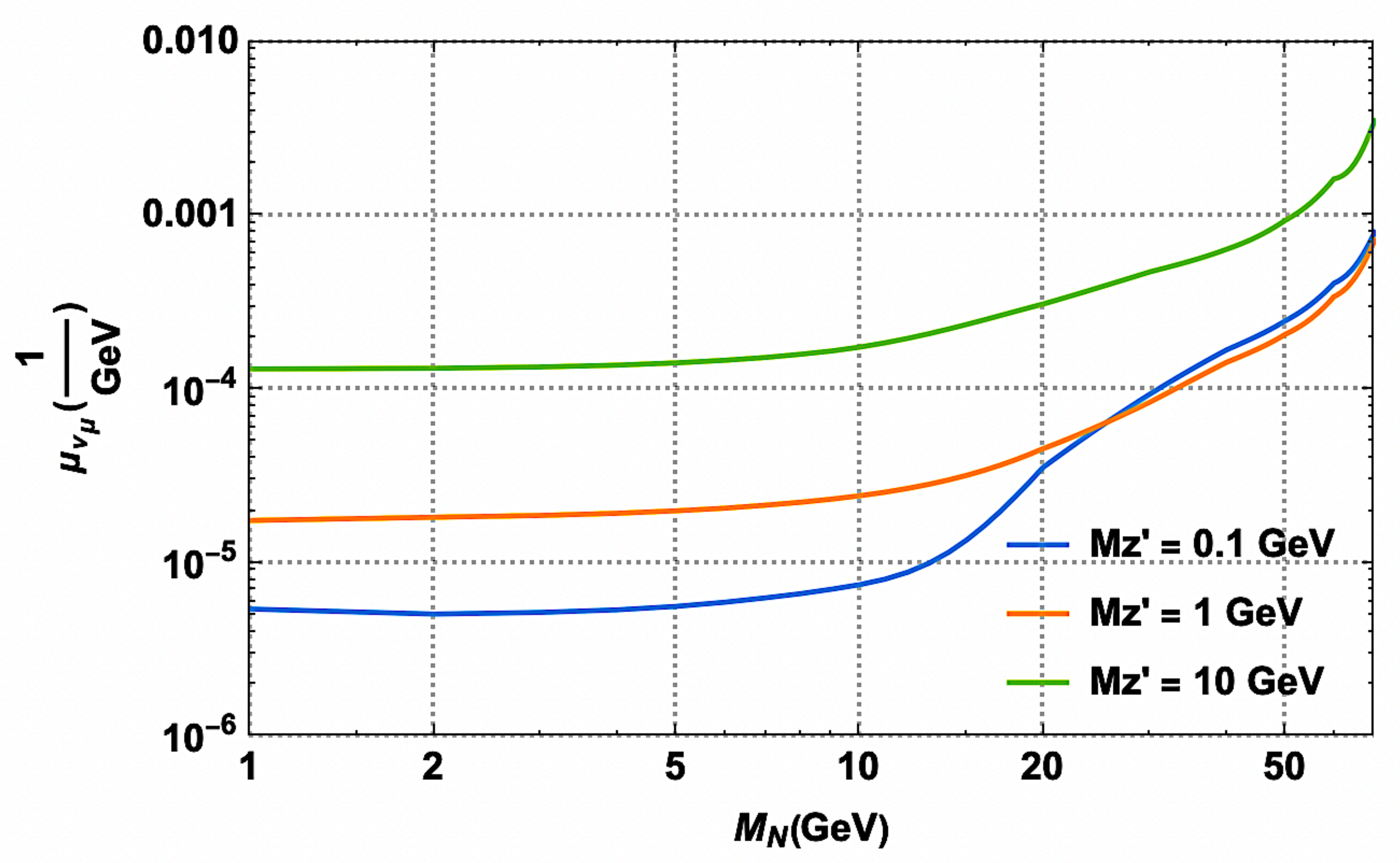
Heavy Neutrino Coupled with L_μ Doublet,

$$\mu_{\nu_e} = \mu_{\nu_\tau} = 0$$
$$V_{eN} = V_{\tau N} = 0$$

Final state consist of charged leptons only



Final states consist of charged leptons and quark only



arXiv:2205.11077

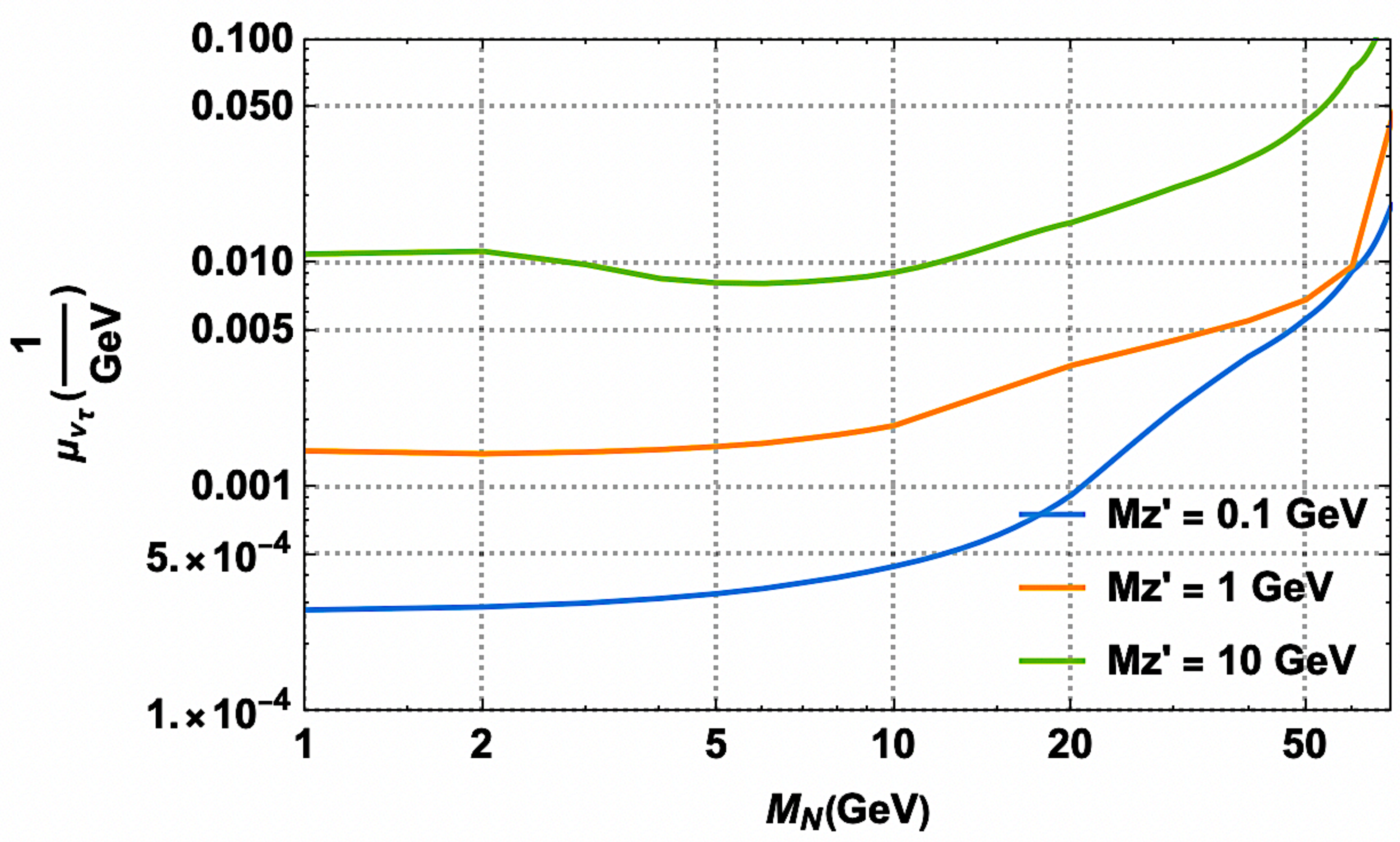
Cont'd BM-III

Heavy Neutrino Coupled with L_τ Doublet,

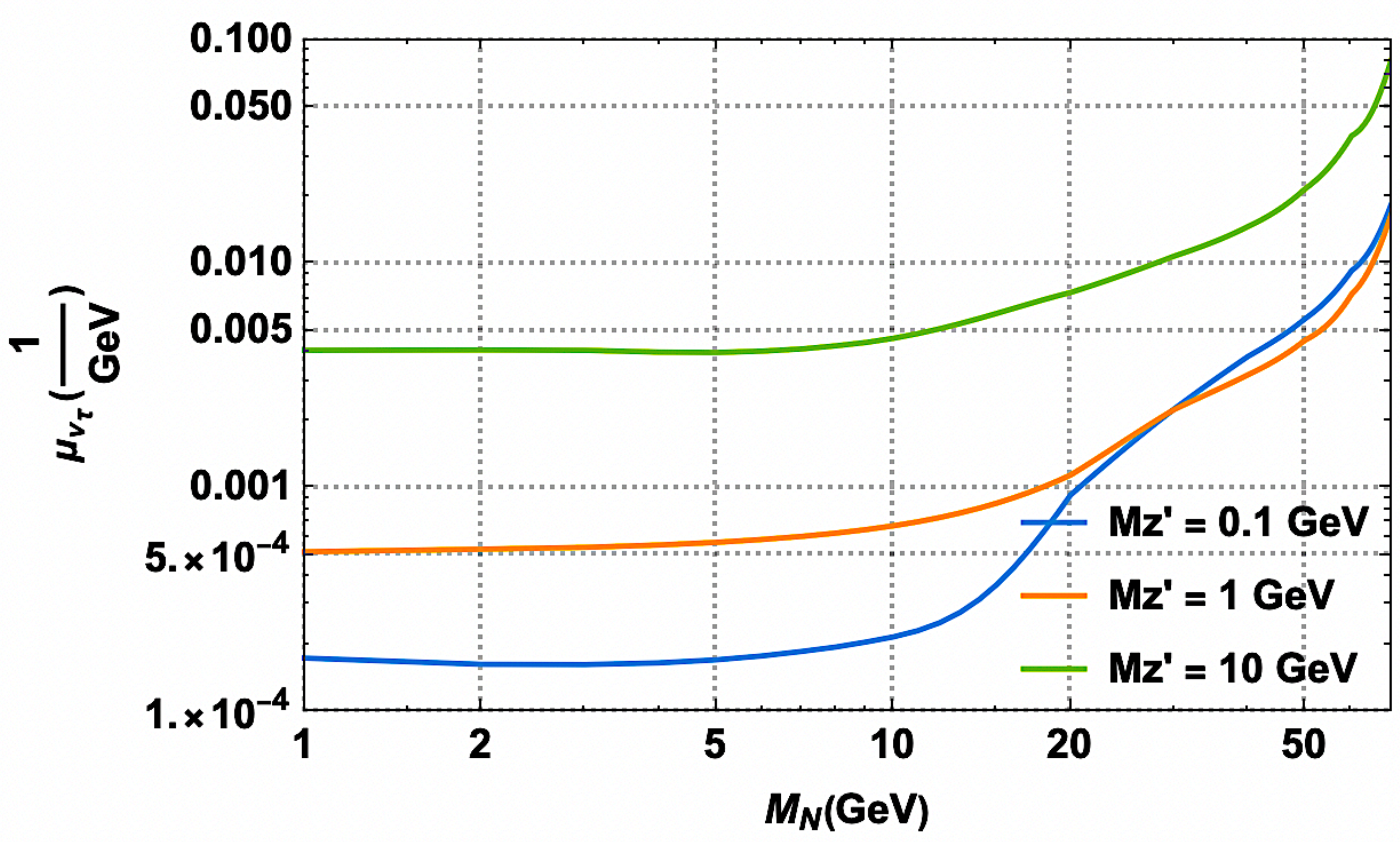
$$\mu_{\nu_\mu} = \mu_{\nu_e} = 0$$

$$V_{\mu N} = V_{eN} = 0$$

Final state consist of charged leptons only

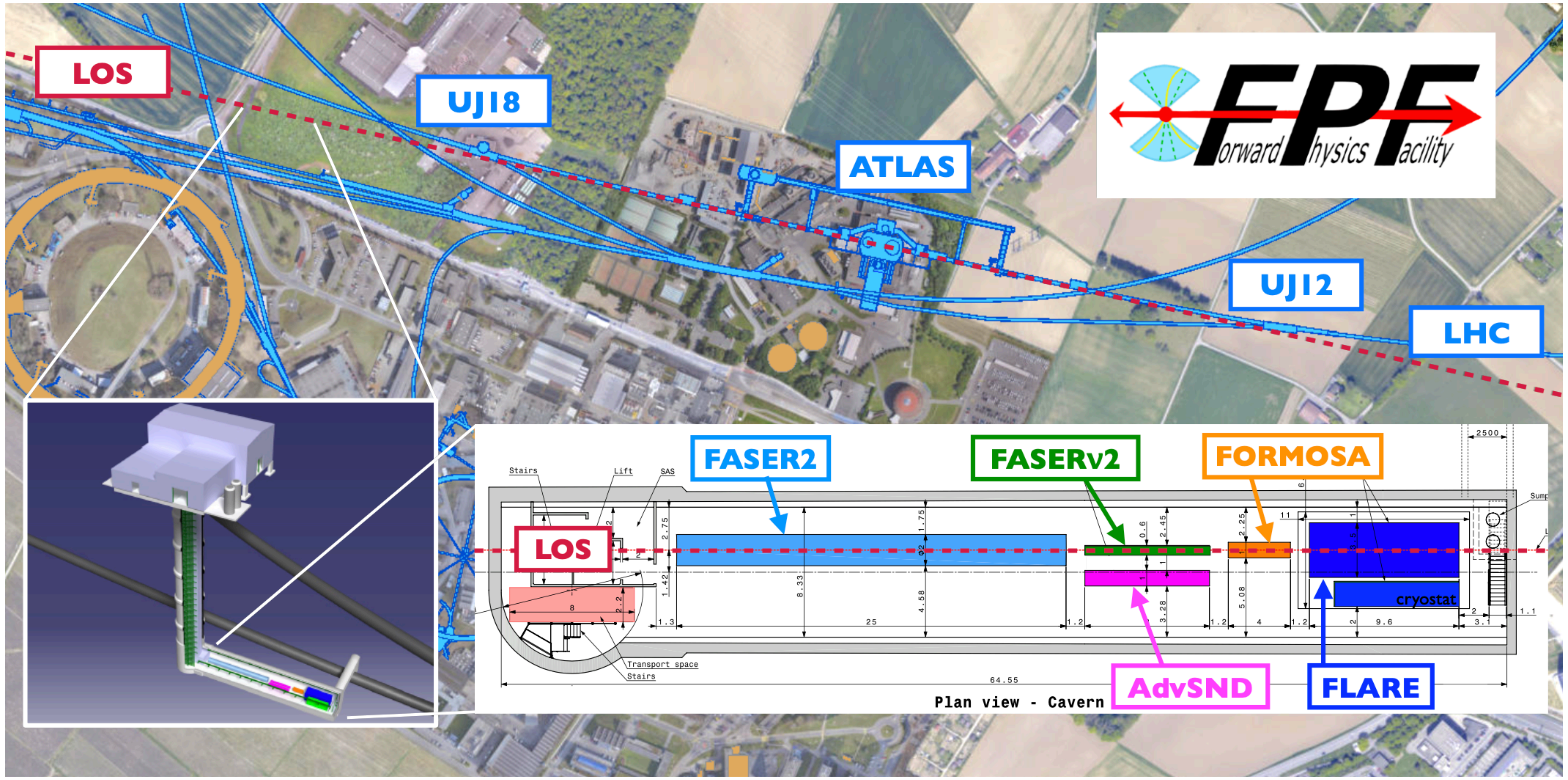


Final states consist of charged leptons and quark only



arXiv:2205.11077

The Future Detectors - 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.

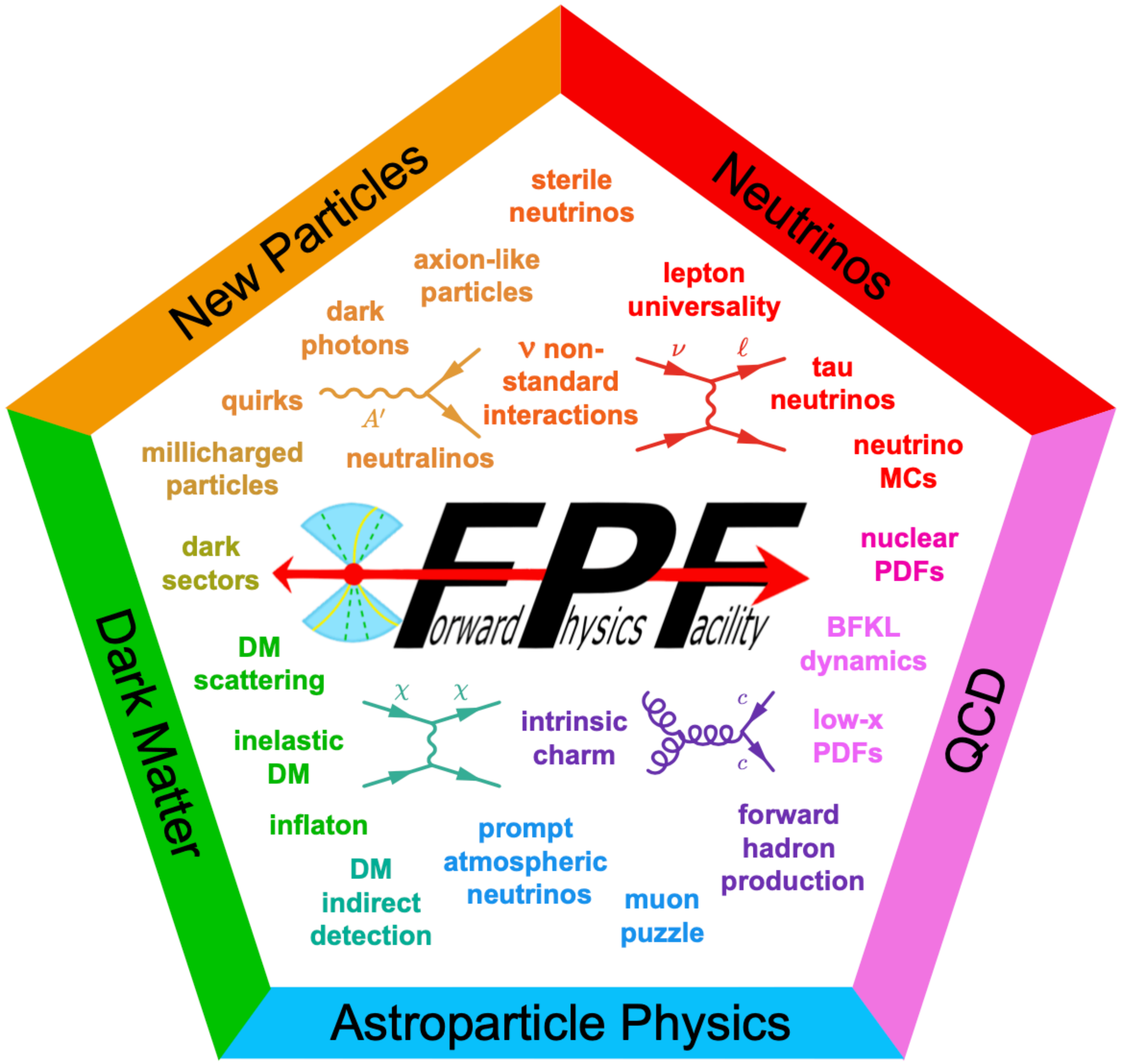
FASERν2: Upgraded version of FASERν

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.

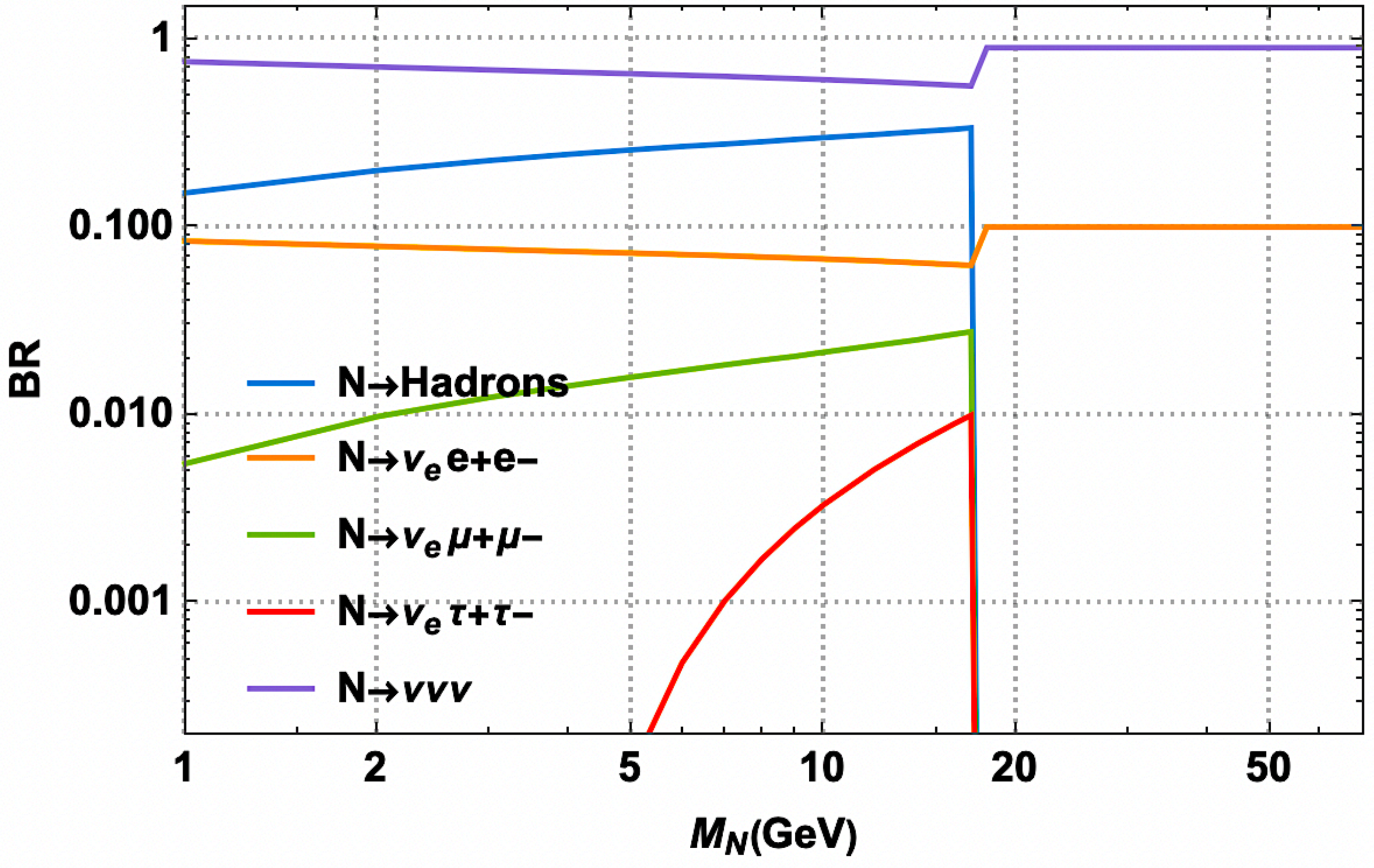
FLARE: a proposed 10-tonne-scale noble liquid detector, will detect neutrinos and also search for light dark matter.

Thank You . . .

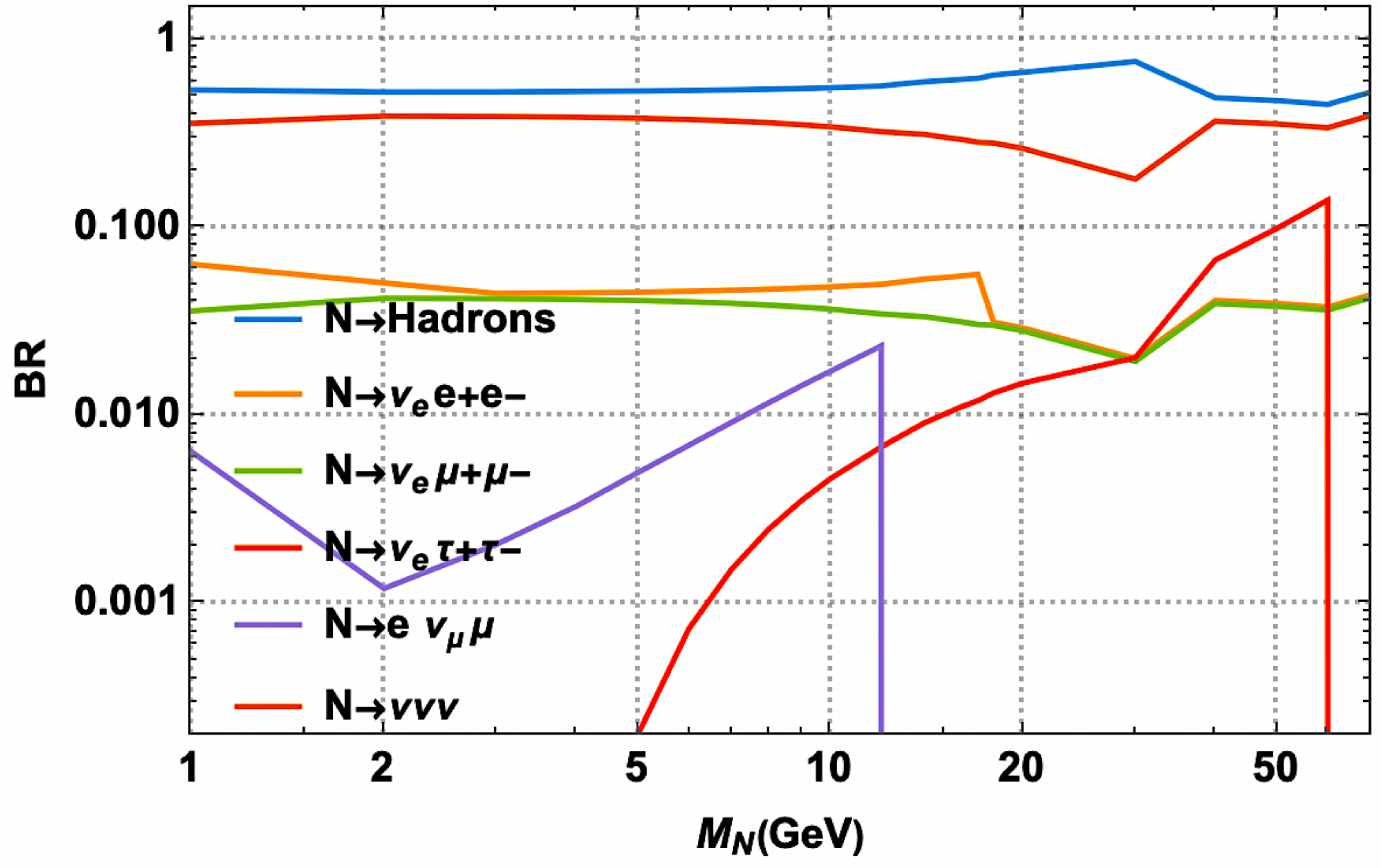


Source: arXiv:2109.10905v1

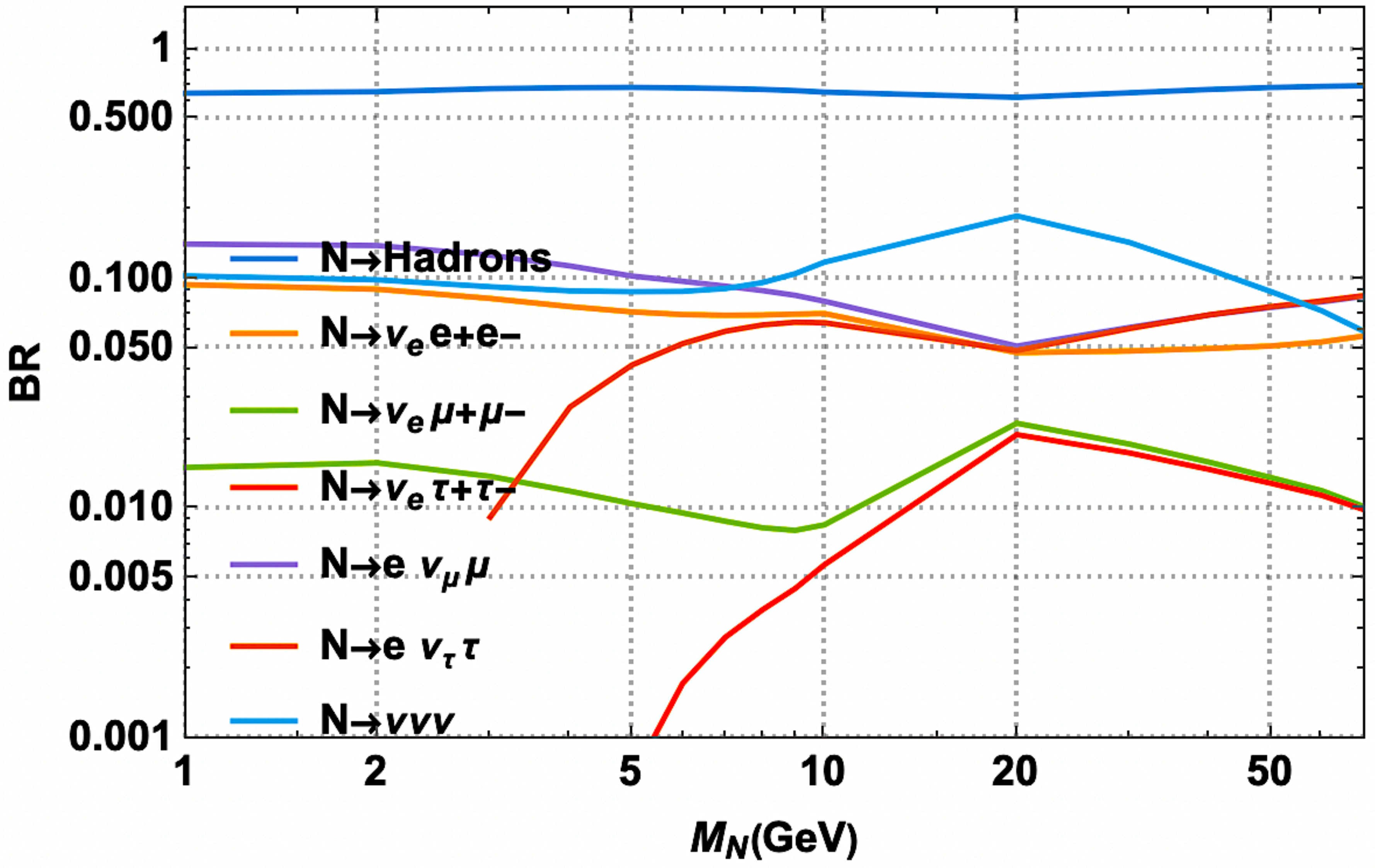
BR-BM-I



BR
1
0.100
0.010
0.001
N→Hadrons
N→ν_ee+e−
N→$\nu_e\mu$+μ−
N→$\nu_e\tau$+τ−
N→$\nu\nu\nu$
1
2
5
10
20
50
M_N(GeV)

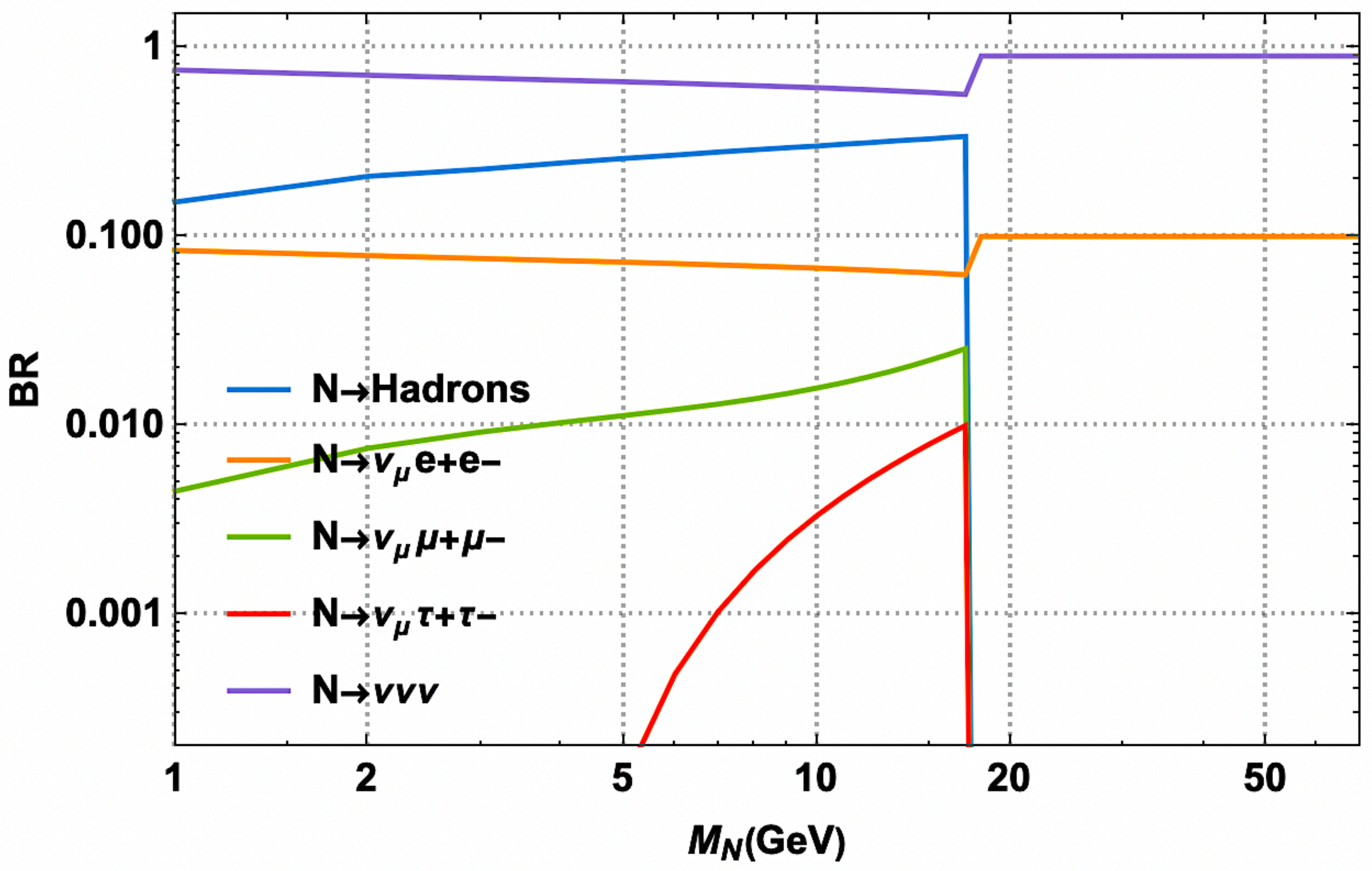


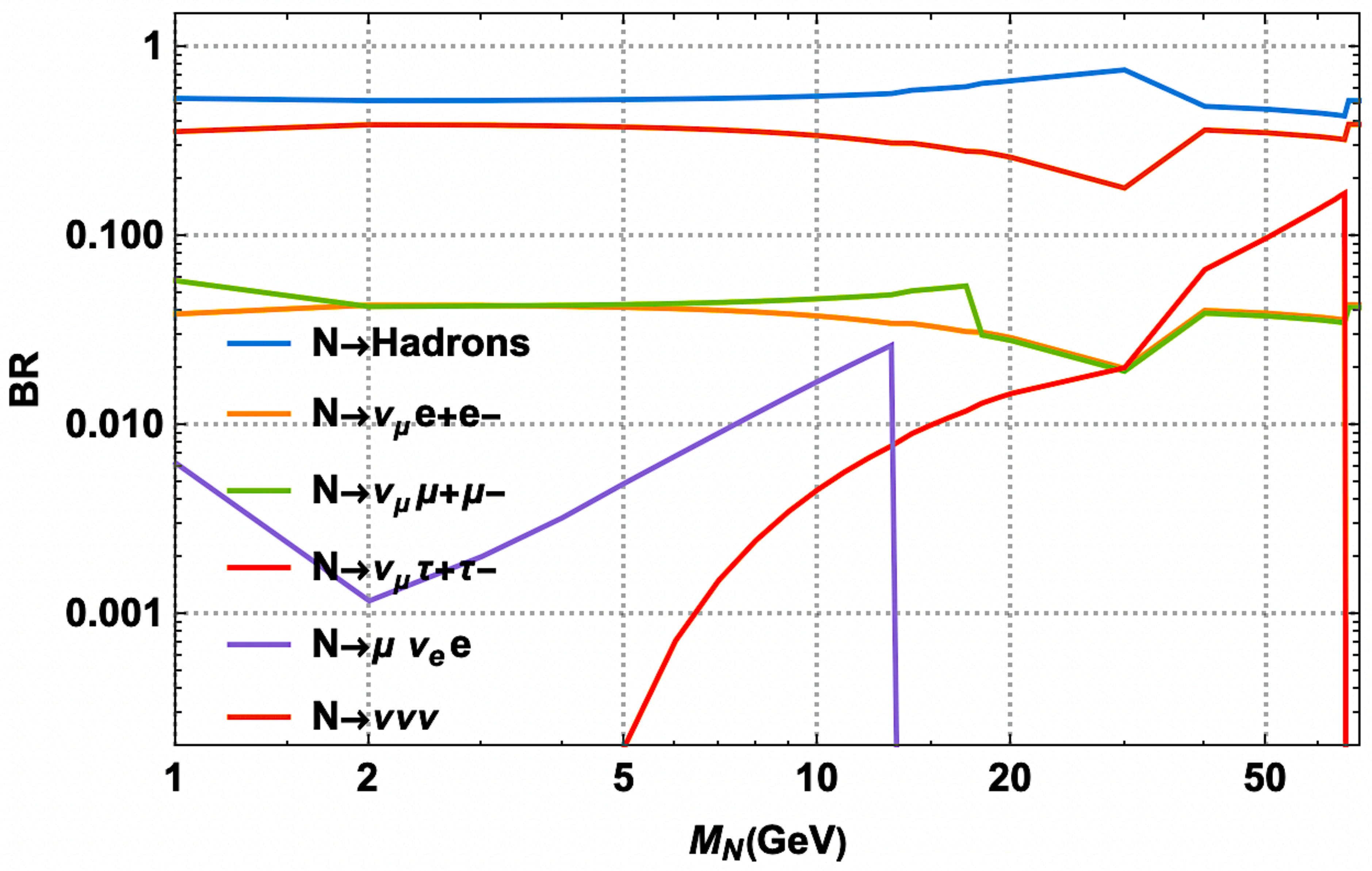
BR
1
0.100
0.010
0.001
N→Hadrons
N→ν_ee+e−
N→$\nu_e\mu$+μ−
N→$\nu_e\tau$+τ−
N→e $\nu_\mu\mu$
N→$\nu\nu\nu$
1
2
5
10
20
50
M_N(GeV)

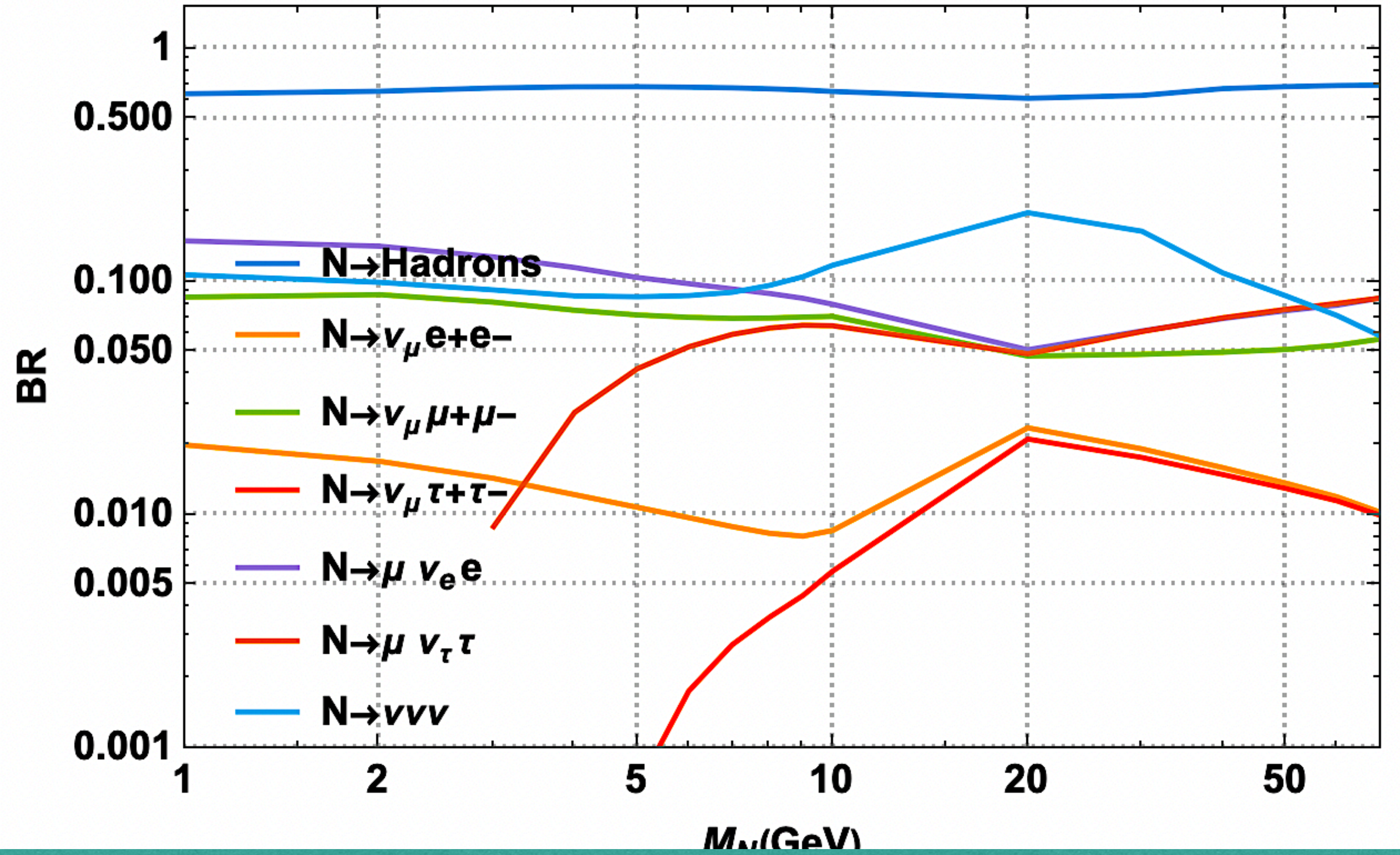


BR
1
0.500
0.100
0.050
0.010
0.005
0.001
N→Hadrons
N→ν_ee+e−
N→$\nu_e\mu$+μ−
N→$\nu_e\tau$+τ−
N→e $\nu_\mu\mu$
N→e $\nu_\tau\tau$
N→$\nu\nu\nu$
1
2
5
10
20
50
M_N(GeV)

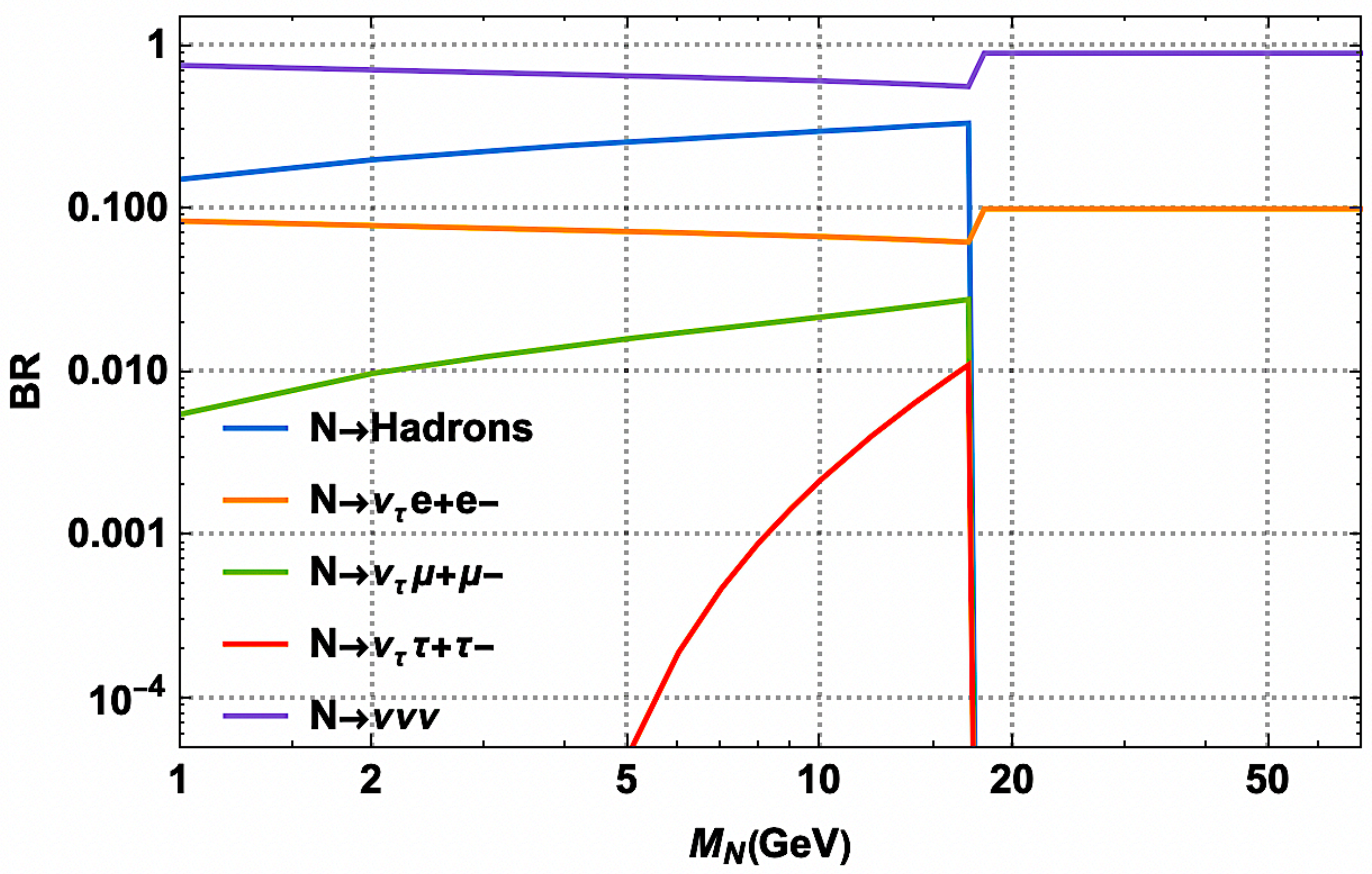
BR-BM-II


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

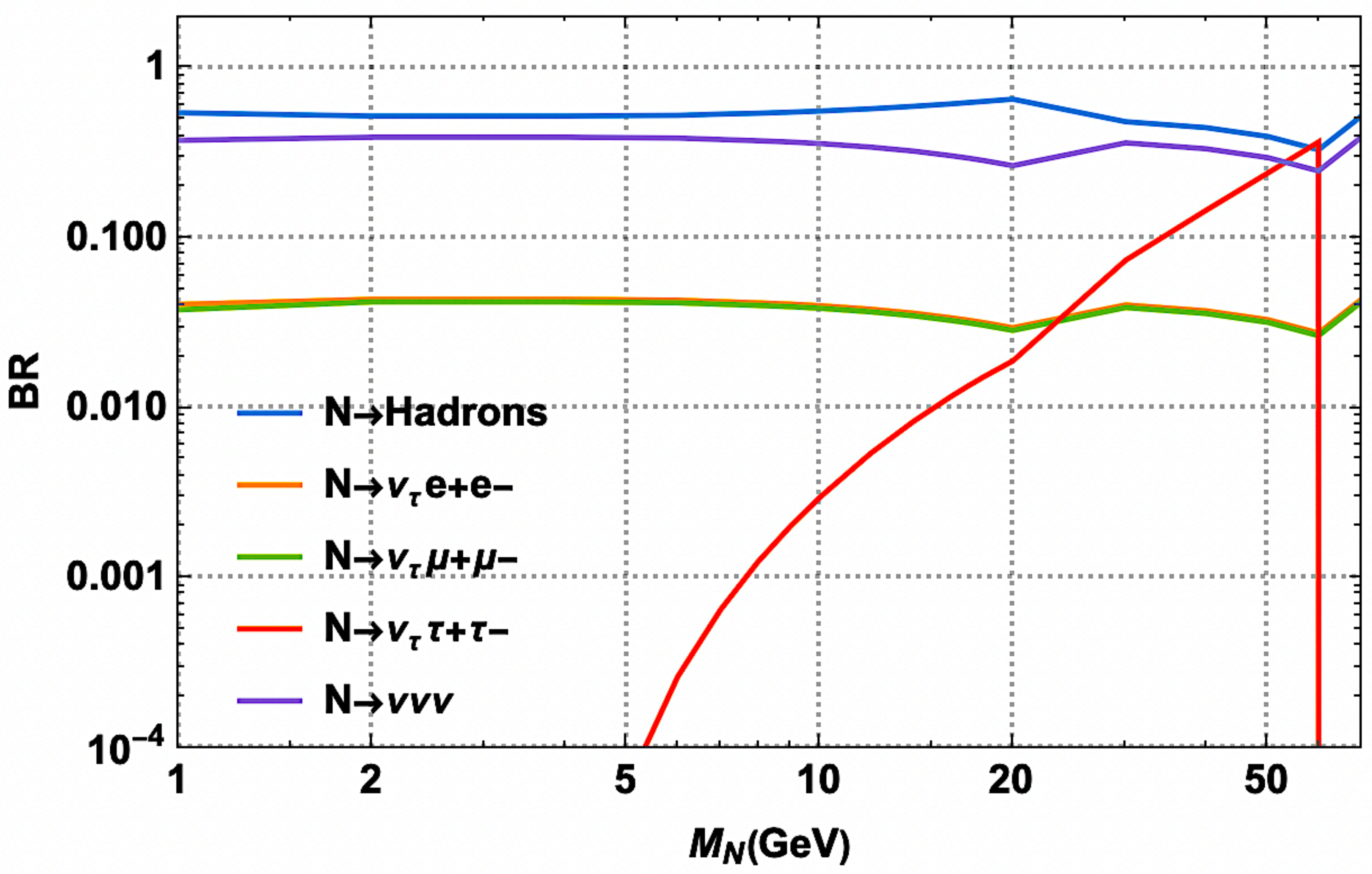

N→Hadrons
N→ν_μe+e−
N→$\nu_\mu\mu$+μ−
N→$\nu_\mu\tau$+τ−
N→μ ν_ee
N→$\nu\nu\nu$
BR
M_N(GeV)


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

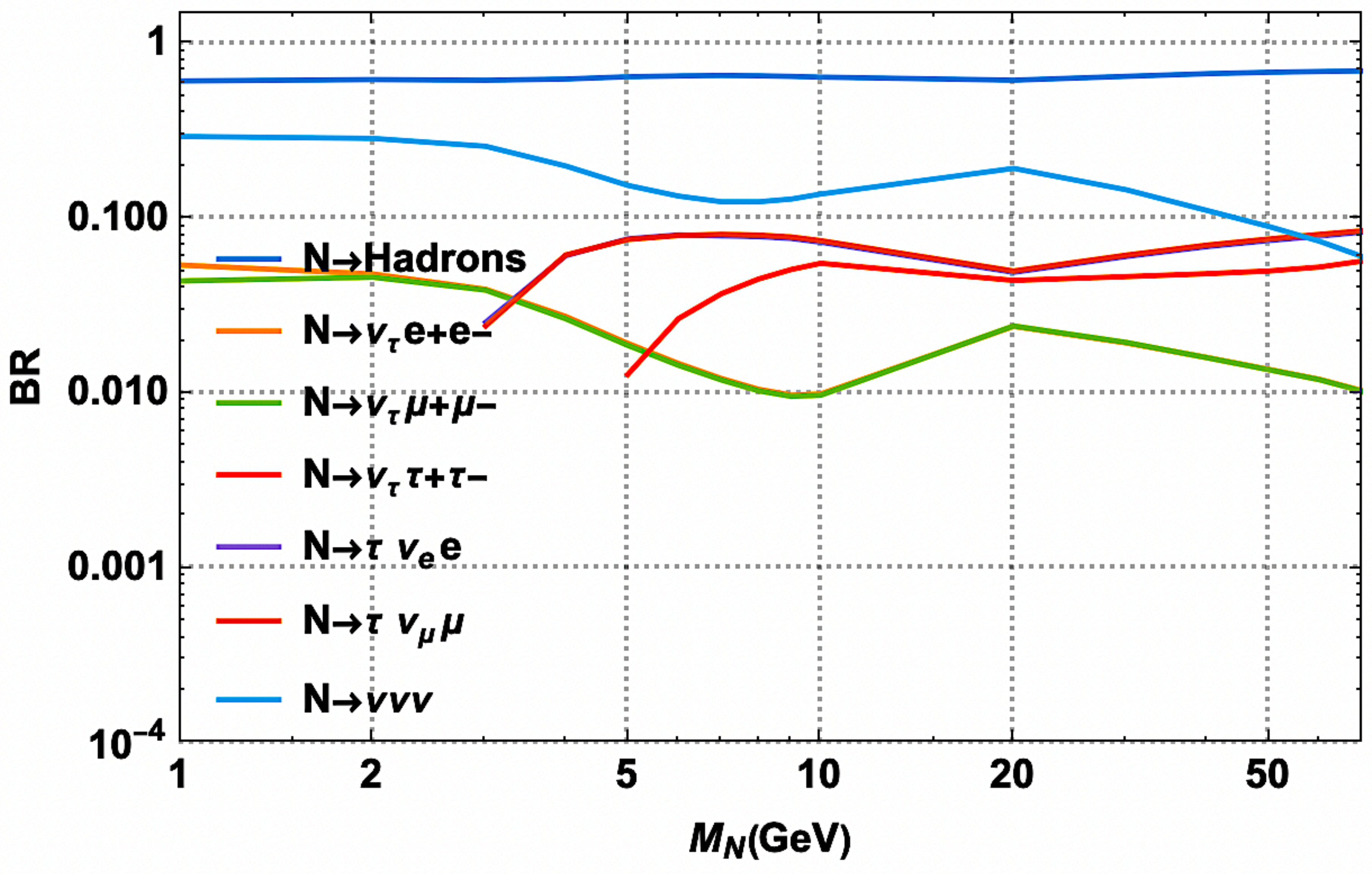
BR-BM-III



BR
1
0.100
0.010
0.001
10^{-4}
N→Hadrons
N→v_τe+e−
N→$v_\tau\mu$+μ−
N→$v_\tau\tau$+τ−
N→vvv
1 2 5 10 20 50
M_N(GeV)



BR
1
0.100
0.010
0.001
10^{-4}
N→Hadrons
N→v_τe+e−
N→$v_\tau\mu$+μ−
N→$v_\tau\tau$+τ−
N→vvv
1 2 5 10 20 50
M_N(GeV)



BR
1
0.100
0.010
0.001
10^{-4}
N→Hadrons
N→v_τe+e−
N→$v_\tau\mu$+μ−
N→$v_\tau\tau$+τ−
N→τ v_ee
N→τ $v_\mu\mu$
N→vvv
1 2 5 10 20 50
M_N(GeV)

Angular Distribution of M_N