Testing the models of neutrino mass at the high energy colliders

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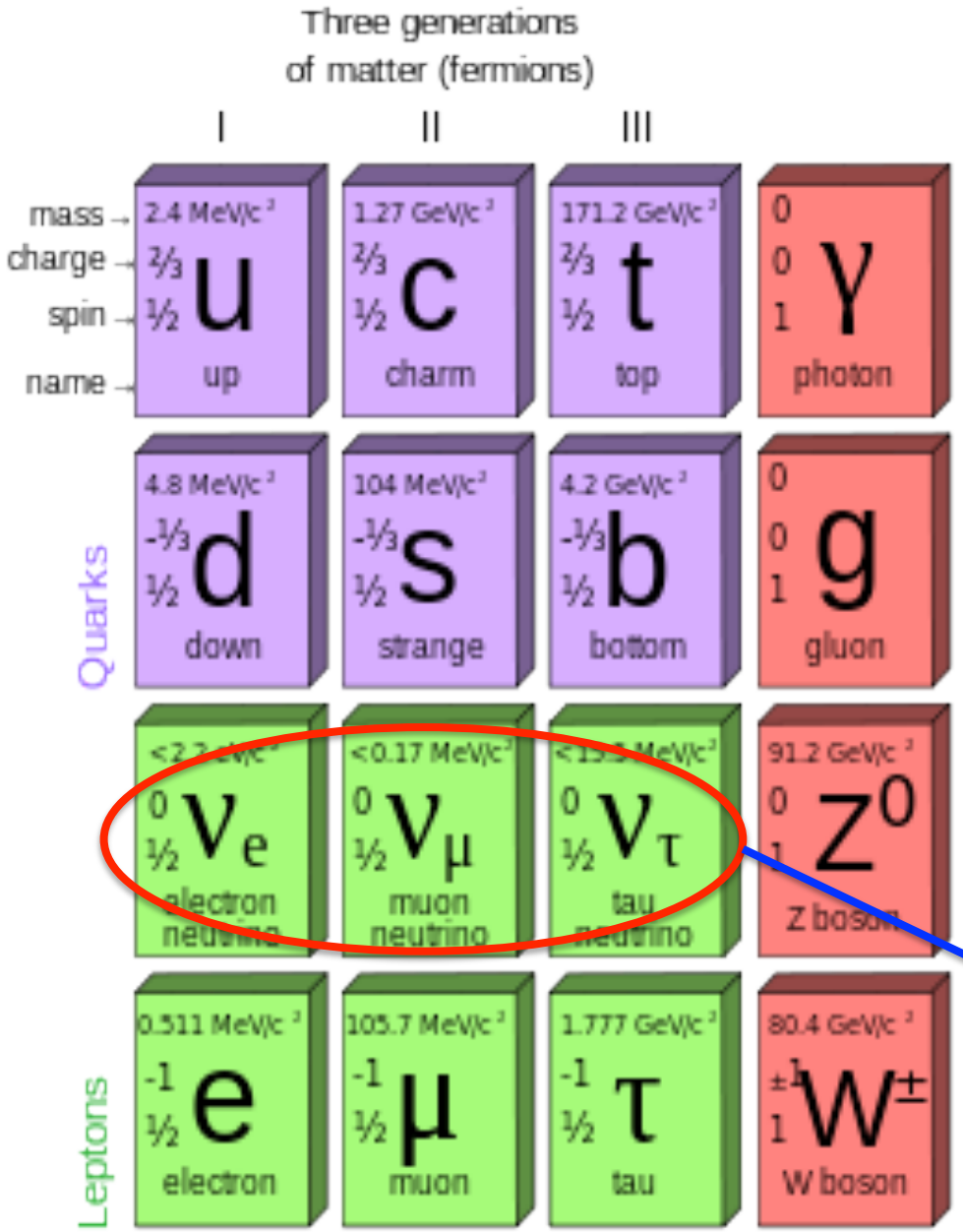
Seoul National University, 6th October, 2016

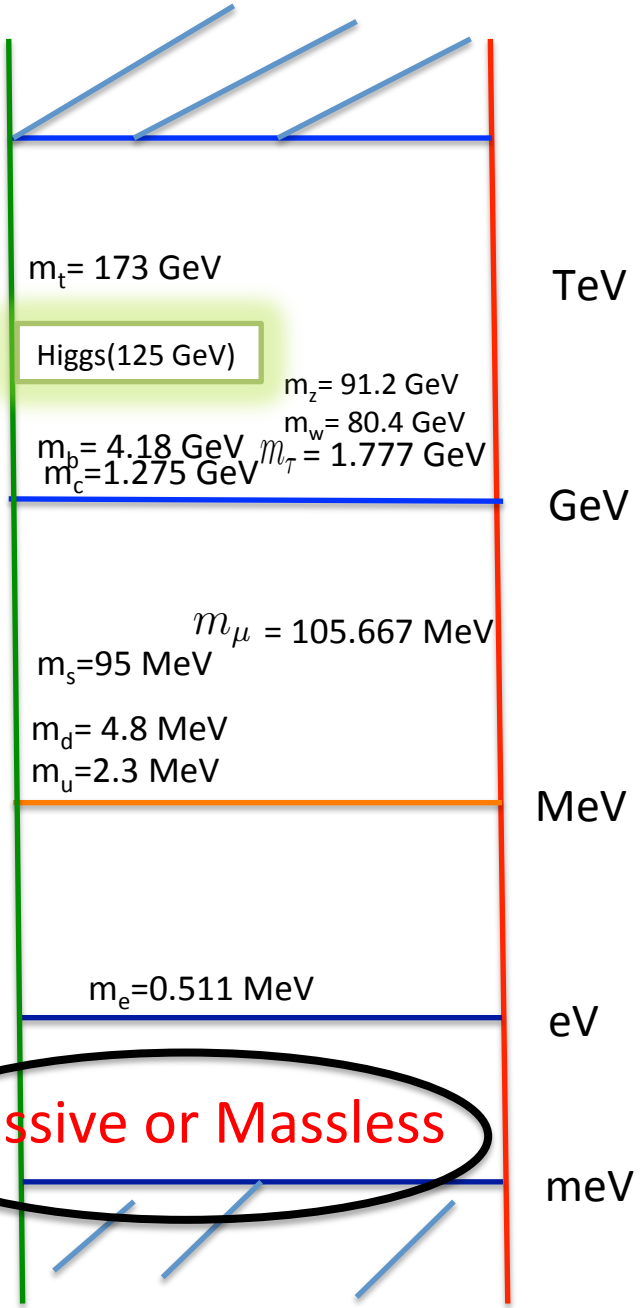
KIAS KOREA INSTITUTE FOR ADVANCED STUDY

SEOUL NATIONAL UNIVERSITY

한국중성미자연구센터 Korea Neutrino Research Center

Standard Model Particles





First evidence of the existence of the solar neutrino : Homestake / Ray-Davis Experiment

VOLUME 20, NUMBER 21 PHYSICAL REVIEW LETTERS 20 MAY 1968

SEARCH FOR NEUTRINOS FROM THE SUN*

Raymond Davis, Jr., Don S. Harmer,† and Kenneth C. Hoffman
Brookhaven National Laboratory, Upton, New York 11973
(Received 16 April 1968)

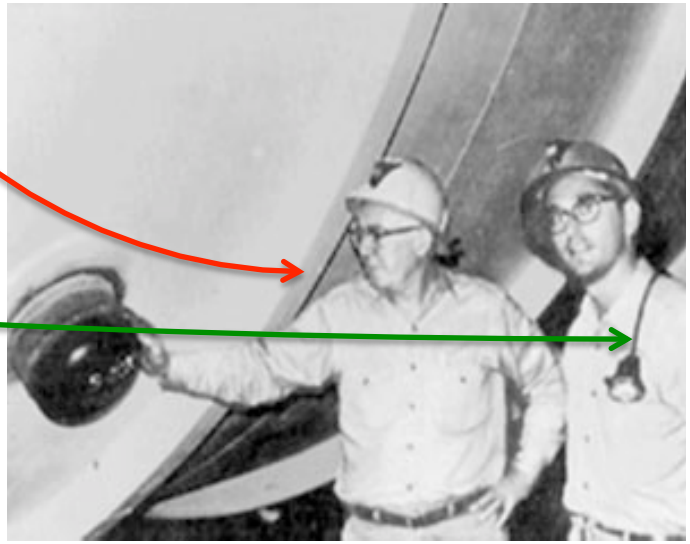
A search was made for solar neutrinos with a detector based upon the reaction $Cl^{37}(\nu, e^-)Ar^{37}$. The upper limit of the product of the neutrino flux and the cross sections for all sources of neutrinos was 3×10^{-36} sec^{-1} per Cl^{37} atom. It was concluded specifically that the flux of neutrinos from B^8 decay in the sun was equal to or less than 2×10^6 cm^{-2} sec^{-1} at the earth, and that less than 9% of the sun's energy is produced by the carbon-nitrogen cycle.

THE RATE OF THE PROTON-PROTON REACTION*

JOHN N. BAHCALL AND ROBERT M. MAY†
California Institute of Technology, Pasadena
Received January 31, 1968

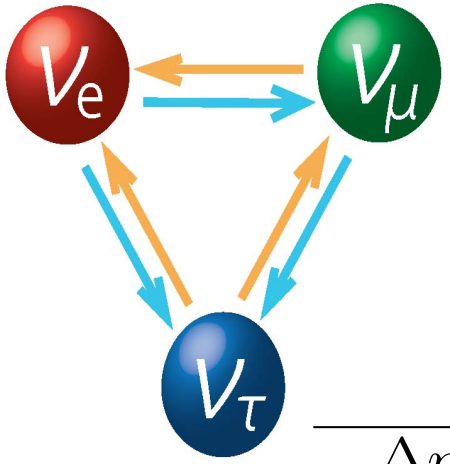
THE RATE OF THE PROTON-PROTON REACTION AND SOME RELATED REACTIONS

JOHN N. BAHCALL* AND ROBERT M. MAY†
California Institute of Technology, Pasadena, California
Received July 3, 1968



More Mysteries

Super- Kamiokande, Sudbury Neutrino Observatory 1999 ,
Neutrino oscillation between mass and flavor eigenstates



Neutrinos are very special



Neutrino oscillation data

Δm^2_{21}	$7.6 \times 10^{-5}\mathrm{eV}^2$	SNO
$\lvert\Delta m_{31}\rvert^2$	$2.4 \times 10^{-3}\mathrm{eV}^2$	Super − K
$\sin^2 2\theta_{12}$	0.87	KamLAND, SNO
$\sin^2 2\theta_{23}$	0.999	T2K
	0.90	MINOS
$\sin^2 2\theta_{13}$	0.084	DayaBay2015
	0.1	RENO
	0.09	DoubleChooz

Unresolved Issues

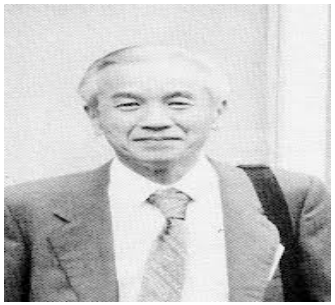
$$\begin{pmatrix} \nu_e \\ \nu_\mu \\ \nu_\tau \end{pmatrix} = U_{PMNS} \begin{pmatrix} \nu_1 \\ \nu_2 \\ \nu_3 \end{pmatrix}$$



Bruno Pontecorvo



Ziro Maki



Masami Nakagawa



Shoichi Sakata

$$= \begin{pmatrix} c_{12}c_{13} & s_{12}c_{13} & s_{13}e^{-i\delta} \\ -s_{12}c_{23} - c_{12}s_{23}s_{13}e^{i\delta} & c_{12}c_{23} - s_{12}s_{23}s_{13}e^{i\delta} & s_{23}c_{13} \\ s_{12}s_{23} - c_{12}c_{23}s_{13}e^{i\delta} & -c_{12}s_{23} - s_{12}c_{23}s_{13}e^{i\delta} & c_{23}c_{13} \end{pmatrix} \times diag\left(1, e^{i\rho}, e^{i\phi}\right)$$

We are looking for $\delta \neq 0$? Can we measure ρ and ϕ ?

Testing the UNITARITY of U_{PMNS}

Neutrino Mass : What Type



Ettore Majorana , (1906- ?)



Paul Dirac, FRS (1902-1984)

$$m_\nu \overline{\nu_L^c} \nu_L + \text{H. c.}$$

$$m_\nu \overline{\nu_R} \nu_L + \text{H. c.}$$



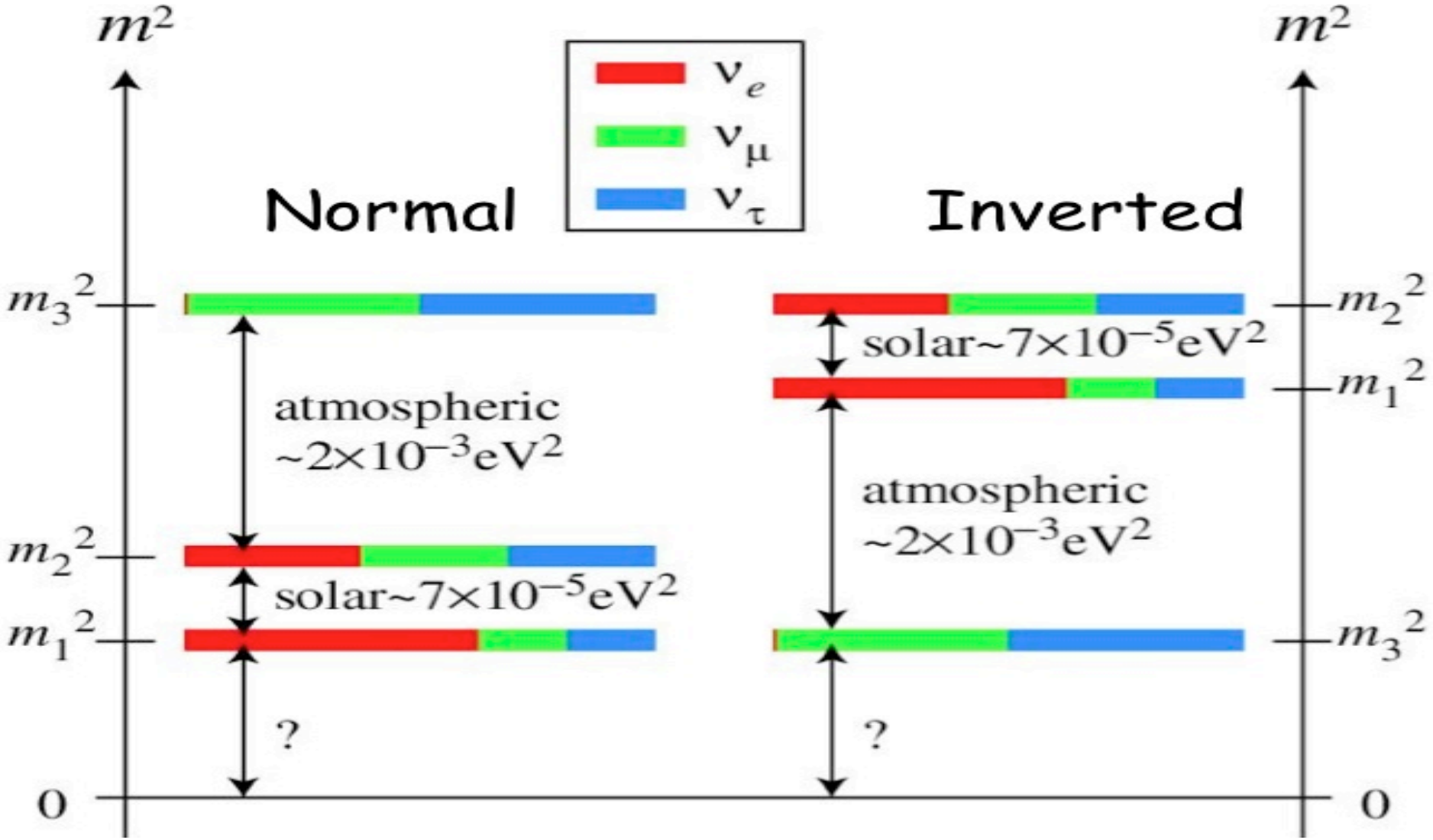
Fermion Number Violating



Fermion Number Conserving

Can be tested in neutrinoless double beta decay and collider experiments

Neutrino Mass Hierarchy : Yet to be FIXED



Can be fixed by the neutrino oscillation experiments

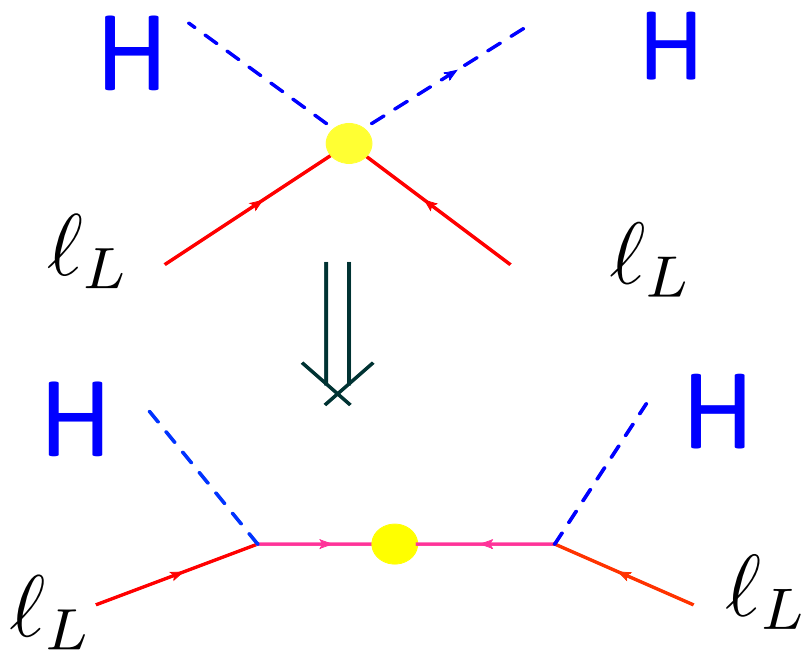
Birth of (a) new idea/ s : generation of neutrino mass

Weinberg Operator in SM (d=5), PRL 43, 1566(1979)

$$\frac{\overline{\ell_L} H \overline{\ell_L^c}^T H}{M}$$

within the Standard Model

The dimension 5 operator can be realized in the following ways



Majorana mass term is generated by the breaking of the lepton numbers by 2 units.

Seesaw Mechanism

Minkowski(1977), Yanagida (1979), Gell-Mann, Ramond, Slansky (1979), Glashow (1980), Mohapatra and Senjanovic (1980)

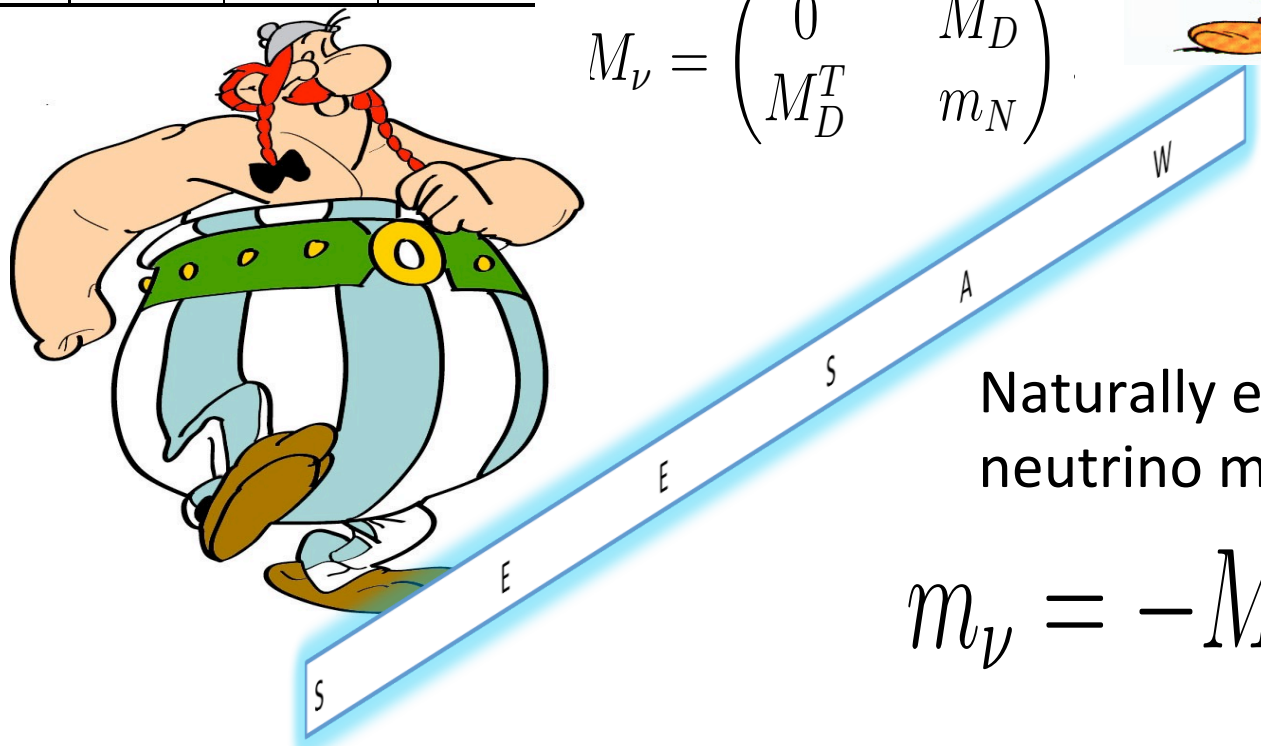
	SU(3)	SU(2)	$U(1)_Y$
$\ell_L = \begin{pmatrix} \nu_L \\ e_L \end{pmatrix}$	1	**2**	$-\frac{1}{2}$
e_R	1	1	-1
$H = \begin{pmatrix} H^0 \\ H^- \end{pmatrix}$	1	**2**	$-\frac{1}{2}$
N_R	1	1	0

$$\mathcal{L} \supset -Y_D^{\alpha\beta}\overline{\ell_L^\alpha} H N_R^\beta - \frac{1}{2} m_N^{\alpha\beta}\overline{N_R^{\alpha C}} N_R^\beta + H.c..$$

$$M_D = \frac{Y_D v}{\sqrt{2}}$$



$$M_\nu = \begin{pmatrix} 0 & M_D \\ M_D^T & m_N \end{pmatrix}$$



Naturally explains the small neutrino mass

$$m_\nu = -M_D m_N^{-1} M_D^T.$$

Inverse Seesaw Mechanism : Mohapatra(1986), Mohapatra & Valle (1986)

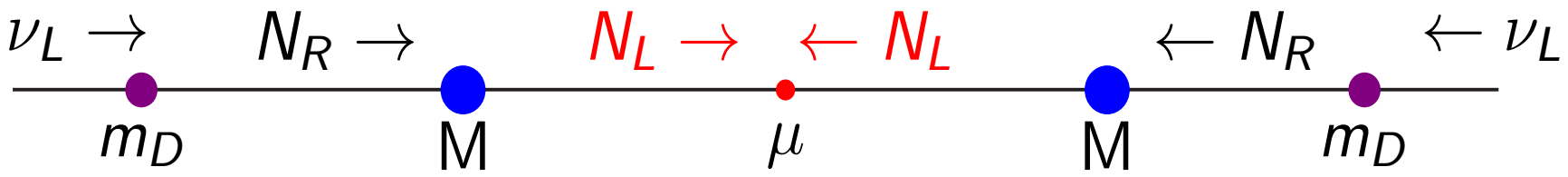
(see also Gogoladze, Okada, Shafi(PLB672 (2009) 235-239; Ghosh, Biswas, Mondal, Roy, Bhupal Dev, Pilaftsis, Senjanovic, Datta, Mitra, Rai, Lindner et. al., Han, Pascoli, Atre, Ruiz, Konar et. al., C. S. Kim et. al., F. del Aguila, J. A. Aguilar-Saavedra, R. Pittau, Antusch, Fischer, Nagata (arXiv:1601.05079 [hep-ph]))

	SU(2)	$U(1)_Y$
ℓ_L	**2**	$-1/2$
H	**2**	$-1/2$
N_R^j	**1**	0
N_L^j	**1**	0

Dirac Mass terms

Relevant Part of the Lagrangian $\mathcal{L}_{mass} \supset -\mu_{ij}\overline{((N_L)^c)^i}N_L^j - \boxed{m_{ij}\overline{N_R^i}N_L^j - Y_{D_{ij}}\overline{\ell_L^i}HN_R^j} + H.c.$

$$m_D = \frac{Y_D}{\sqrt{2}}v$$



$$M_\nu = \begin{pmatrix} 0 & m_D & 0 \\ m_D^T & 0 & M \\ 0 & M^T & \mu \end{pmatrix}$$

$$m_\nu = \left(m_D \mathbf{M}^{-1}\right)\mu\left(m_D \mathbf{M}^{-1}\right)^T$$

$$\mu \backsim \mathcal{O}(m_\nu)$$

$$m_D \mathbf{M}^{-1} \sim \mathcal{O}(1)$$

Light- heavy mixing could be large and Heavy neutrino can be produced at LHC

phenomenological constraints

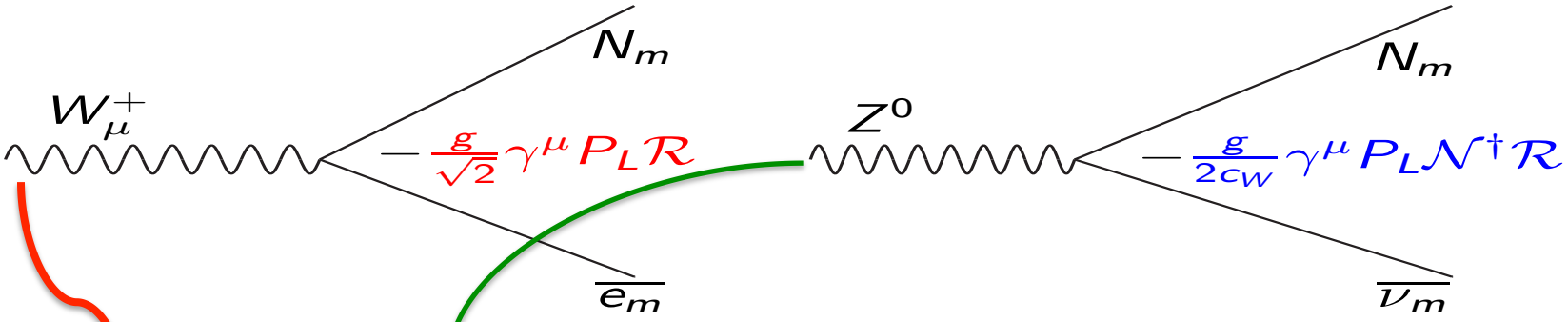
$$\mathcal{R} = m_D \mathbf{M}^{-1} \ll 1$$

Interaction of the heavy neutrinos with **W** and Z bosons

- Assuming, $\mathcal{R} = m_D \mathbf{M}^{-1} << 1$
- The flavour eigenstate (ν) in terms of the mass eigenstates

$$\nu \simeq \mathcal{N}\nu_m + \mathcal{R}N_m, \quad \mathcal{N} = (1 - \frac{1}{2}\mathcal{R}^*\mathcal{R}^T)U_{MNS}$$

- U_{MNS} is the usual neutrino mixing matrix to diagonalize m_ν as



$$\mathcal{L}_{CC} = -\frac{g}{\sqrt{2}} W_\mu \overline{e_m} \gamma^\mu P_L (\mathcal{N}\nu_m + \mathcal{R}N_m) + h.c.,$$

Very small

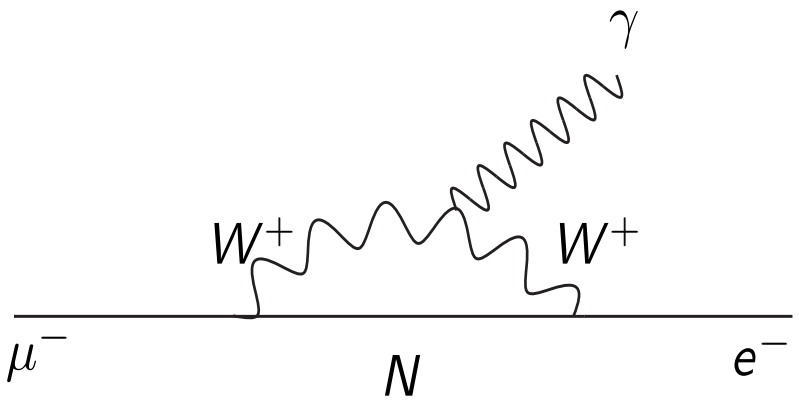
$$\mathcal{L}_{NC} = -\frac{g}{2c_w} Z_\mu \left[\overline{\nu_m}\gamma^\mu P_L(\mathcal{N}^\dagger\mathcal{N})\nu_m + \overline{N_m}\gamma^\mu P_L(\mathcal{R}^\dagger\mathcal{R})N_m\right]$$
$$- \frac{g}{2c_w} Z_\mu \left[\overline{\nu_m}\gamma^\mu P_L(\mathcal{N}^\dagger\mathcal{R})N_m + h.c.\right]$$

e_m, ν_m, N_m are the three generations of the leptons in the vector form.

Phenomenological Constraints on $\mathcal{N}$

Antusch et. al. JHEP 10 (2006) 084

The Lepton Flavour Violating (LFV) decays($l_i \to l_j \gamma;\ i,j = e,\mu,\tau$)



$\mu \to e\gamma$	$\mathcal{B}(< 5.7 \times 10^{-13})$	PRL 110, 201801 (2013)
$\tau \to e\gamma$	$\mathcal{B}\ (< 4.5 \times 10^{8})$	PLB 666, (2008)16-22
$\tau \to \mu\gamma$	$\mathcal{B}\ (< 12.0 \times 10^{-8})$	PLB 666, (2008)16-22

$Z \to l_i^+ l_i^-$ (LEP) **constraint**

CURRENT $\mathrm{B}(\mu^+ \to e^+\gamma) < 4.2 \times 10^{-13}$ arXiv:1605.05081

$$|\mathcal{N}\mathcal{N}^\dagger| = \begin{pmatrix} 0.994 \pm 0.00625 & < 1.5 \times 10^{-5} & < 8.76356 \times 10^{-3} \\ < 1.5 \times 10^{-5} & 0.995 \pm 0.00625 & < 1.046 \times 10^{-2} \\ < 8.76356 \times 10^{-3} & < 1.046 \times 10^{-2} & 0.995 \pm 0.00625 \end{pmatrix}$$

Strongest

$(1,2)$ element is constrained by	$\mu \to e\gamma$
$(1,3)$ element is constrained by	$\tau \to e\gamma$
$(2,3)$ element is constrained by	$\tau \to \mu\gamma$

Diagonal elements are constrained by LEP experiment

Fixing the Matrices $\mathcal{N}$ and $\mathcal{R}$

- We consider the two generations of heavy neutrinos

$$U_{MNS} = \begin{pmatrix} c_{12}c_{13} & s_{12}c_{13} & s_{13}e^{i\delta} \\ -s_{12}c_{23} - c_{12}s_{23}s_{13}e^{i\delta} & c_{12}c_{23} - s_{12}s_{23}s_{13}e^{i\delta} & s_{23}c_{13} \\ s_{12}s_{23} - c_{12}c_{23}s_{13}e^{i\delta} & -c_{12}s_{23} - s_{12}c_{23}s_{13}e^{i\delta} & c_{23}c_{13} \end{pmatrix} \times diag(1, e^{i\rho}, 1)$$

- We fix the parameters by the following neutrino oscillation data

$\sin^2\theta_{12}$	0.87
$\sin^2\theta_{23}$	1.00
$\sin^2\theta_{13}$	0.092
$\Delta m^2_{12} = m^2_2 - m^2_1$	$7.6 \times 10^{-5}\mathrm{eV}^2$
$\Delta m^2_{23} = \lvert m^2_3 - m^2_2 \rvert$	$2.4 \times 10^{-3}\mathrm{eV}^2$

Inverse Seesaw Case

- We study the Normal and Inverted hierarchies.
- The lightest mass eigenstate is massless. The diagonal mass matrices in the NH and IH cases are

$$D_{NH} = \mathrm{diag}\left(0, \sqrt{\Delta m^2_{12}}, \sqrt{\Delta m^2_{12} + \Delta m^2_{23}}\right), \qquad D_{IH} = \mathrm{diag}\left(\sqrt{\Delta m^2_{23} - \Delta m^2_{12}}, \sqrt{\Delta m^2_{23}}, 0\right)$$

We assume degenerate heavy neutrinos

$$M \to \begin{pmatrix} M & 0 \\ 0 & M \end{pmatrix} \qquad \mu \to \begin{pmatrix} \mu & 0 \\ 0 & \mu \end{pmatrix}$$

$$m_\nu = \mathcal{R}\mu\mathcal{R}^T = U^*_{MNS} D_{NH/IH} U^\dagger_{MNS}$$

Two typical cases :

a) Flavor non-diagonal (FND)

$\mu \sim \mu \mathbf{1}$ $m_D \sim \text{nondiag}(m_D)$

FND : 2 generations $N_{R_j}, N_{L_j}; j = 1, 2$

$$m_\nu = \frac{\mu}{M^2} m_D m_D = U^*_{MNS} D_{NH/IH} U^\dagger_{MNS}$$

$$m_D = \frac{M}{\sqrt{\mu}} U^*_{MNS} \sqrt{D_{NH/IH}}$$

$$\sqrt{D_{NH}} = \begin{pmatrix} 0 & 0 \\ (\Delta m^2_{12})^{\frac{1}{4}} & 0 \\ 0 & (\Delta m^2_{23} + \Delta m^2_{12})^{\frac{1}{4}} \end{pmatrix} \quad \sqrt{D_{IH}} = \begin{pmatrix} (\Delta m^2_{23} - \Delta m^2_{12})^{\frac{1}{4}} & 0 \\ 0 & (\Delta m^2_{23})^{\frac{1}{4}} \\ 0 & 0 \end{pmatrix}$$

b) Flavor diagonal (FD)

$m_D \sim m_D \mathbf{1}$

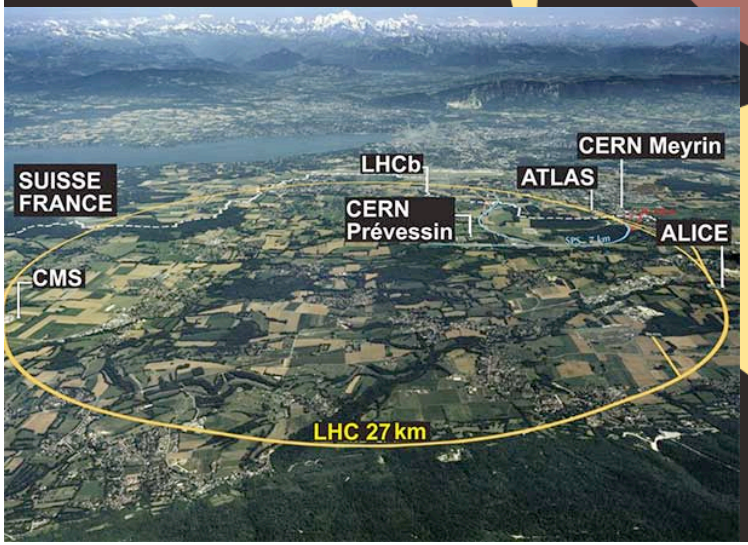
μ has Flavor structure

$$m_\nu = (\frac{m_D}{M})^2 \mu$$

$$= U^*_{MNS} D_{NH/IH} U^\dagger_{MNS}$$

Energy Frontier

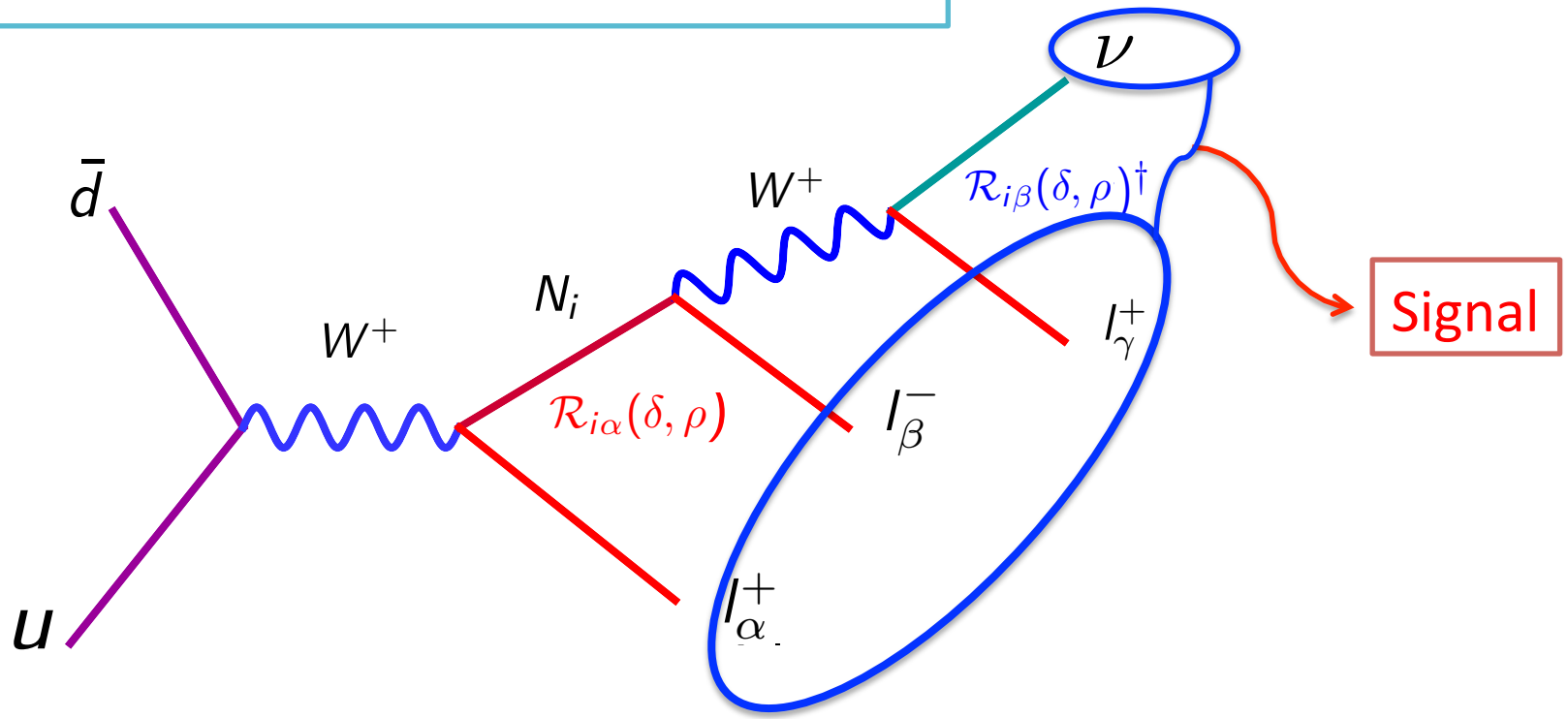
Large Hadron Collider/ Linear collider



Production of the heavy neutrinos at the High energy colliders

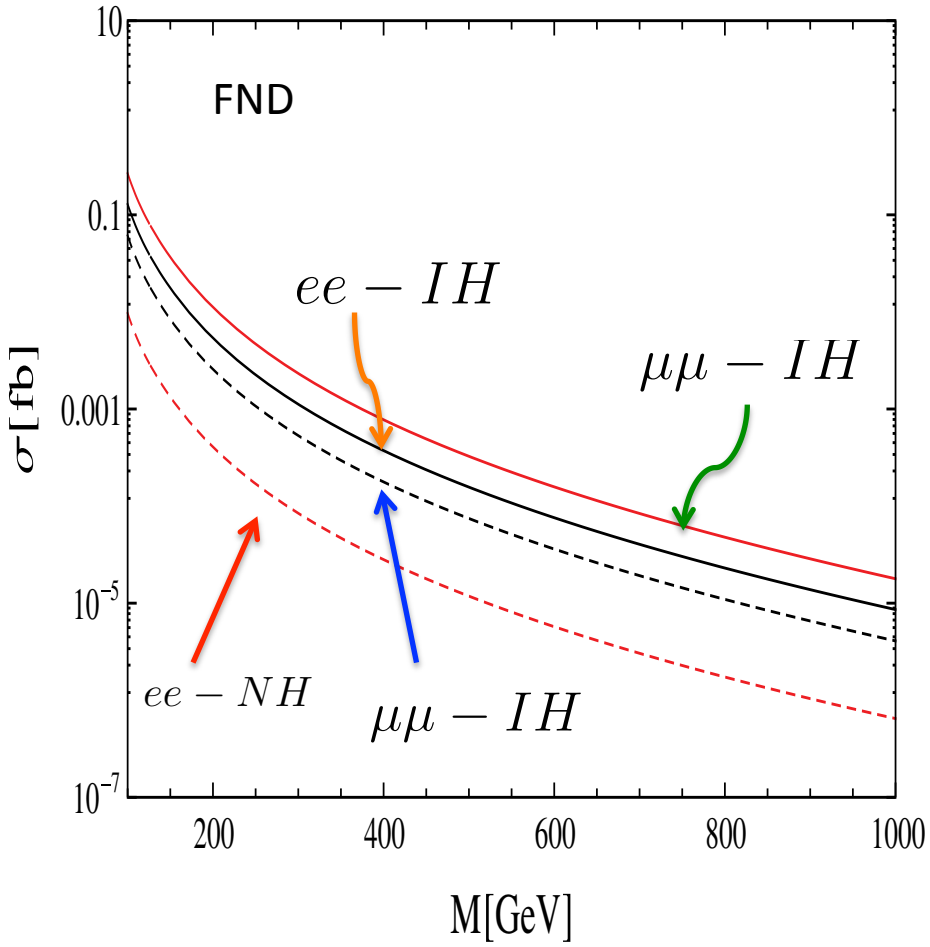
AD, Nobuchika Okada, Physical Review D88 (2013) 113001
AD and N Okada, in progress, arxiv:XXXX.XXXXX

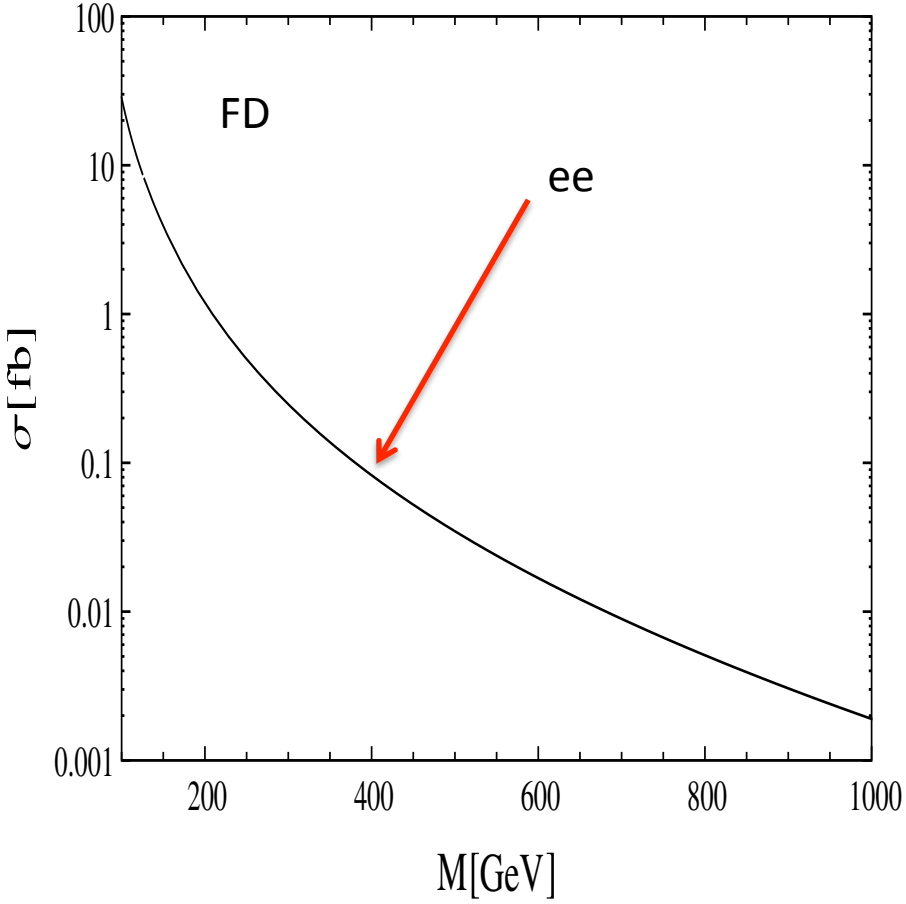
Heavy Neutrino Production at LHC



$$l^- = e, \mu$$

Mass of the heavy neutrino: 100 GeV, $\sqrt{s} = 14$ TeV





$\sqrt{s} = 14$ TeV. M= 100 GeV, Luminosity = 30 fb^{-1}

	ee	$\mu\mu$
FND (NH)	0.254	1.61
FND (IH)	7.00	3.38
FD	58.7	56.2
SM background	116.4	45.6

FD $_{ee}$ = 4.4 σ

FD $_{\mu\mu}$ = 5.6 σ

FND case is comparatively low

SM background, F. del Aguila, J. A. A. Savedra NPB 813 (2009) 22-90, PLB 672 (2009) 158-165

General Parameterization

Casas-Ibarra, NPB 618(2001)171-204

$$\mathcal{R}(\delta,\rho,x,y) = \frac{1}{\sqrt{\mu}} U^*_{MNS} \sqrt{D_{NH/IH}}\, O$$

$$O = \begin{pmatrix} cos(x+iy) & sin(x+iy) \\ -sin(x+iy) & cos(x+iy) \end{pmatrix}$$

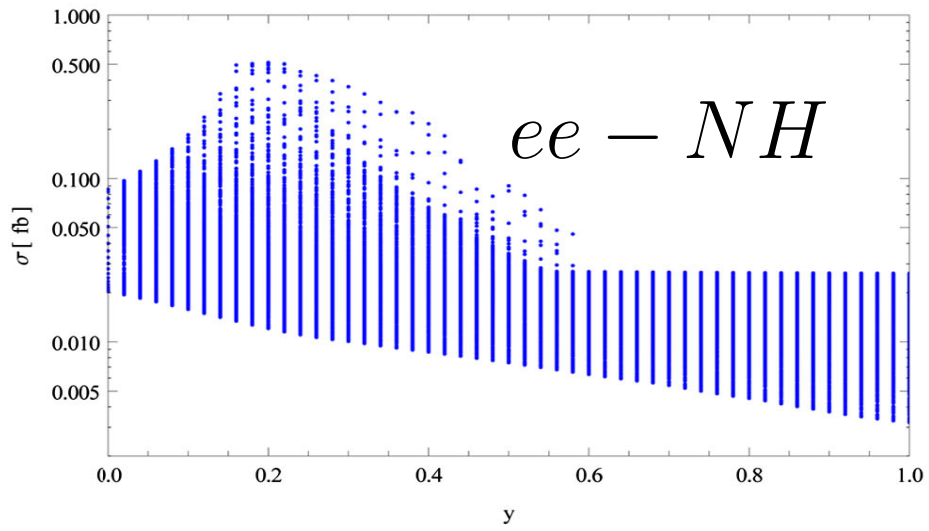
$$\mathcal{R}^*\mathcal{R}^T(\delta,\rho,y) = \frac{1}{\mu} U_{MNS} \sqrt{D_{NH/IH}}\, O^* O^T \sqrt{D_{NH/IH}}^T U^\dagger_{MNS}$$

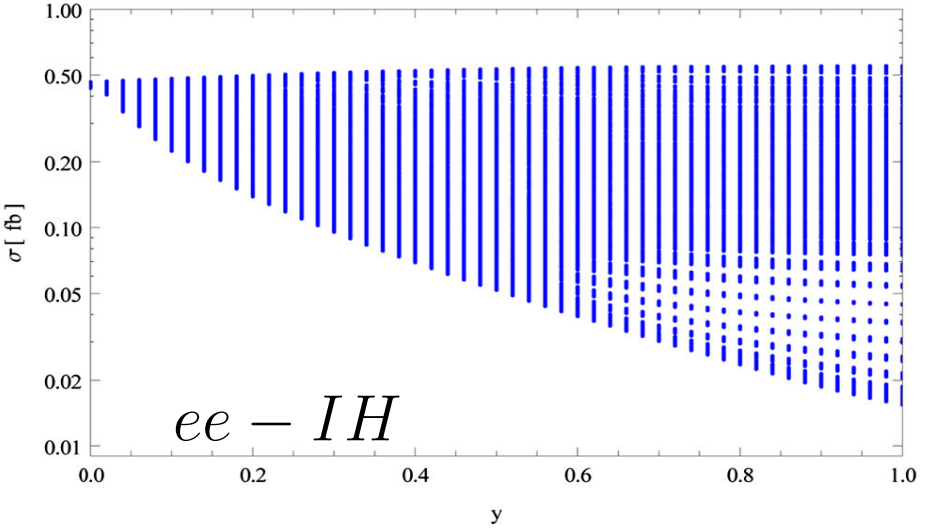
$$O^* O^T(y) = \begin{pmatrix} cosh^2 y + sinh^2 y & -2i\,coshy\,sinhy \\ 2i\,coshy\,sinhy & cosh^2 y + sinh^2 y \end{pmatrix}$$

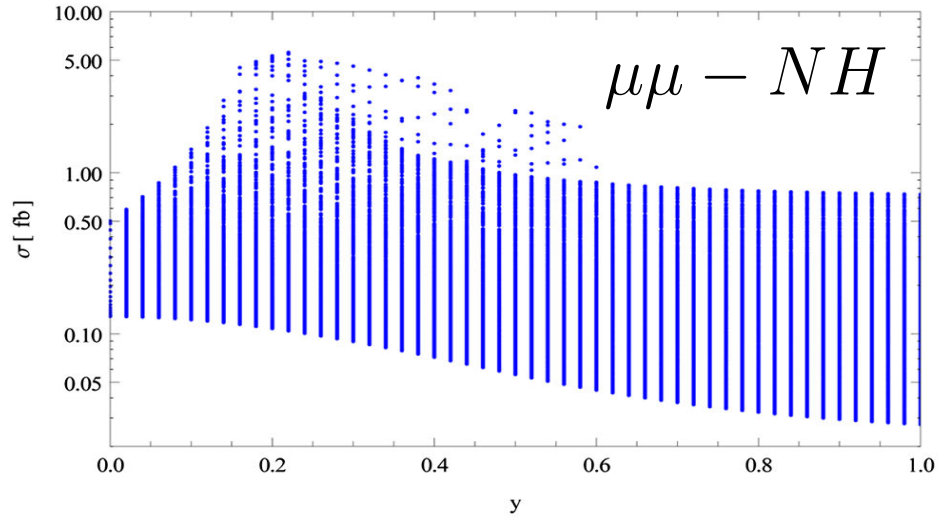
$$\mathcal{N}\mathcal{N}^\dagger \simeq \mathbf{1} - \mathcal{R}^*\mathcal{R}^{\mathbf{T}}$$

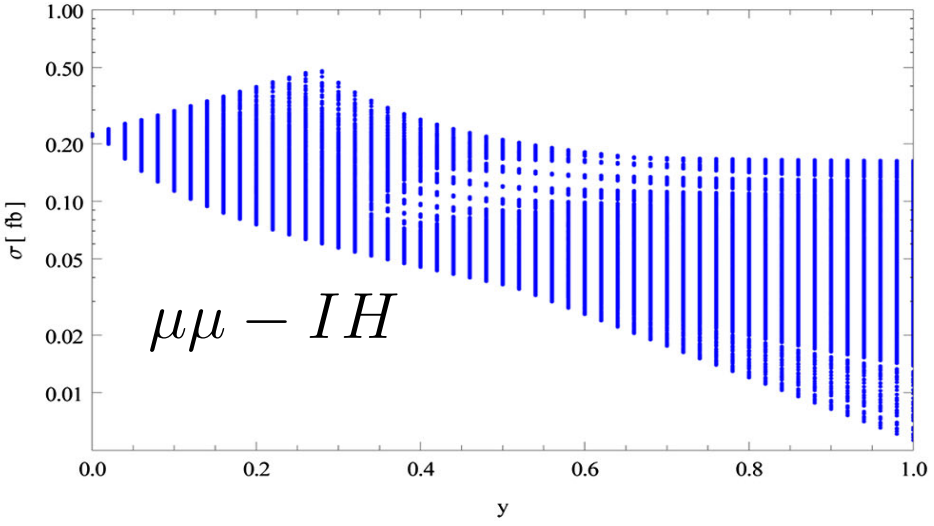
$\mathcal{R}^*\mathcal{R}^T$ is constrained by the LFV and LEP data

- The Dirac phase (δ) can be measured in future.
- Majorana phase (ρ) and y are independent of the oscillation data









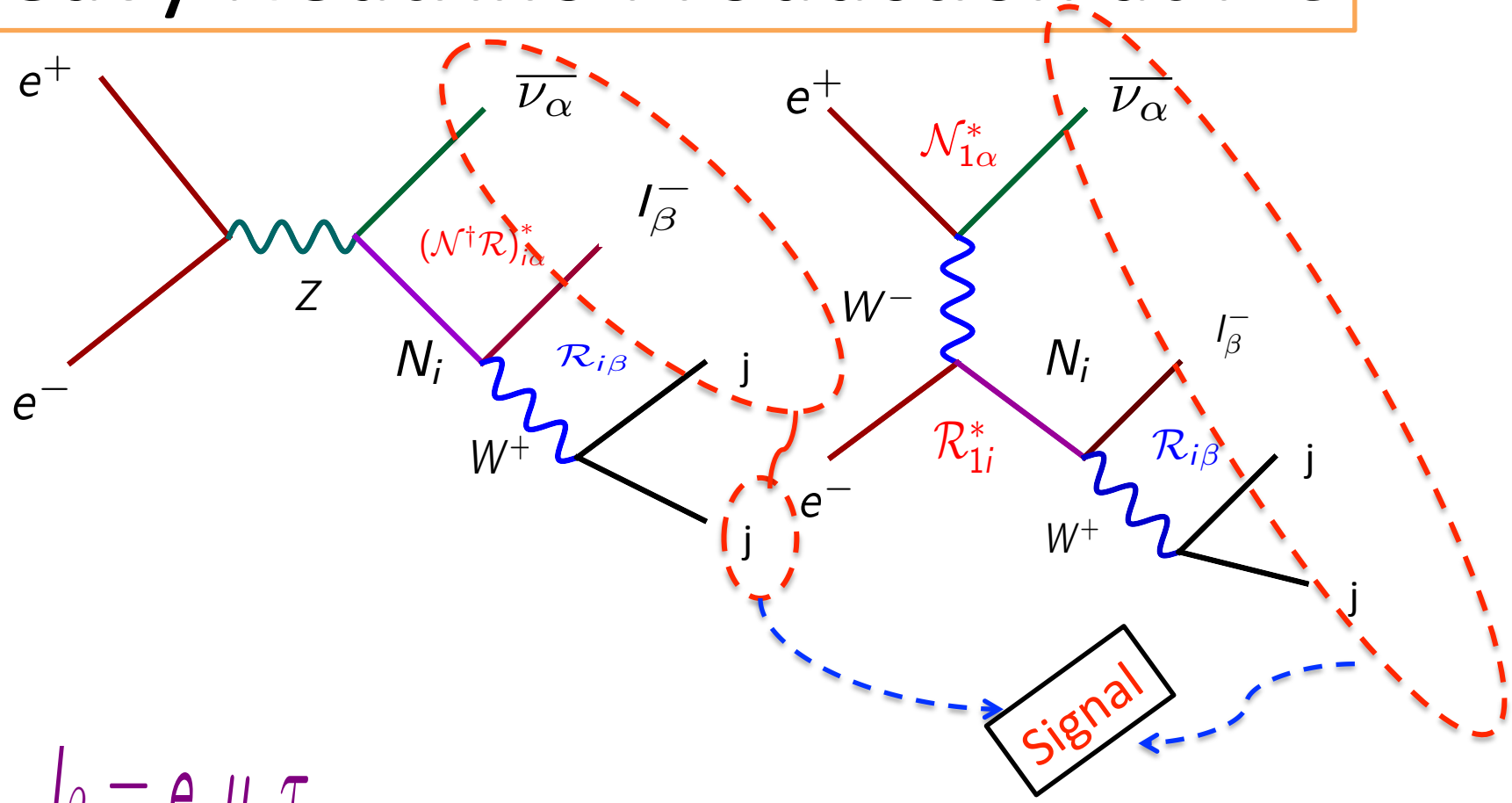
$\mu\mu$ -NH: 12 σ Other cases around 2 σ

$\sqrt{s} = 14$ TeV.M= 100 GeV, Luminosity = 30 fb^{-1}

FND: Cross section is enhanced by the general parameterization

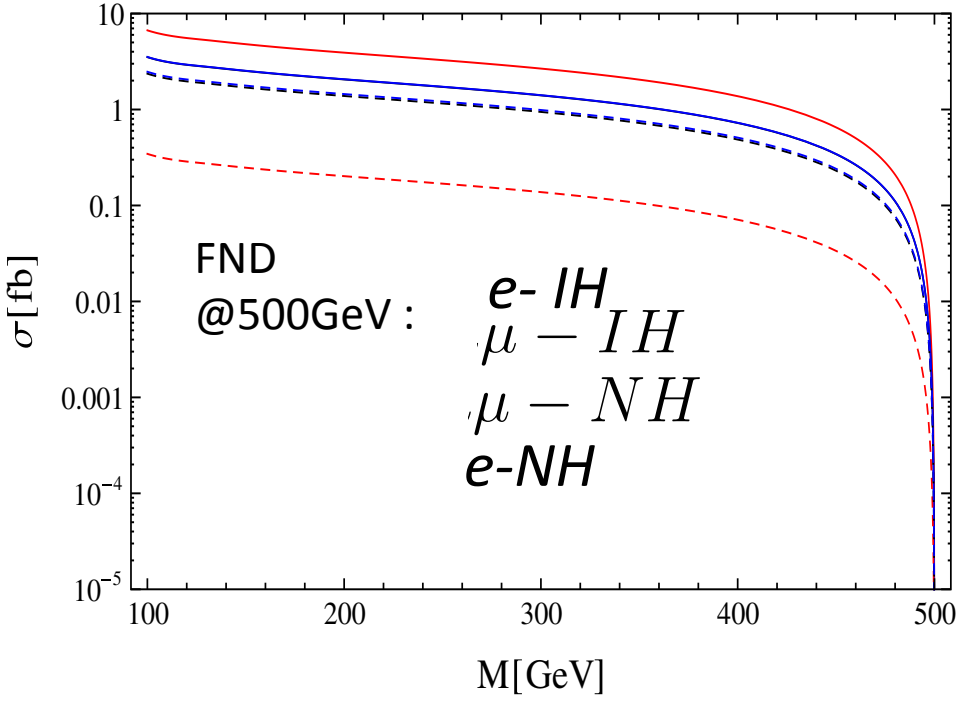
	ee	$\mu\mu$
NH	15.5	178.5
IH	17.3	14.3
SMBG	116.4	45.6

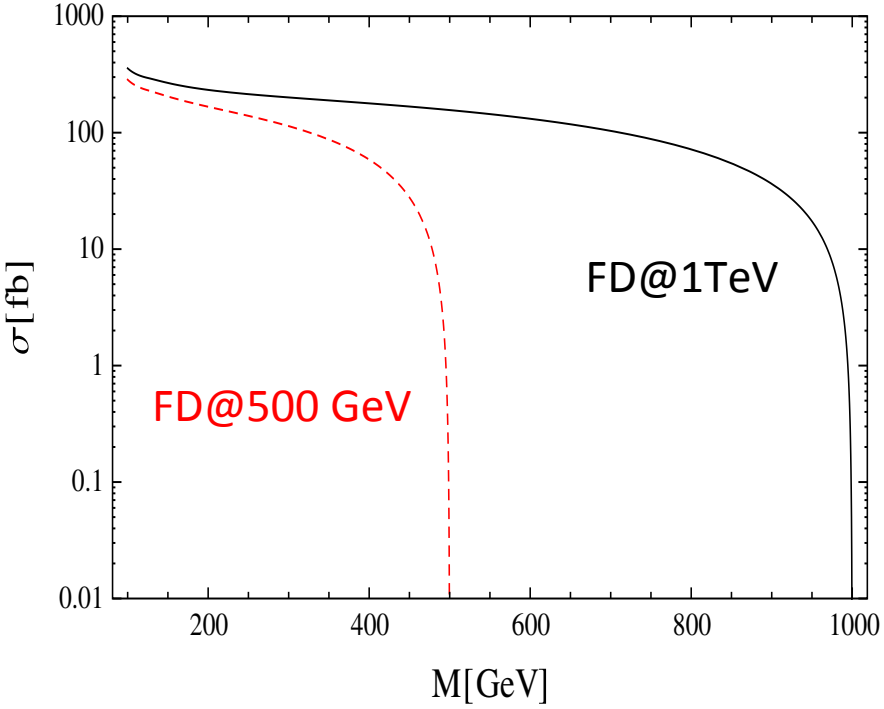
Heavy Neutrino Production at ILC



$l_\beta = e, \mu, \tau.$

- The heavy neutrino Mass is fixed at 150 GeV. Center of mass energy, $\sqrt{s} = 500\text{GeV}$ and $\sqrt{s} = 1\text{TeV}$





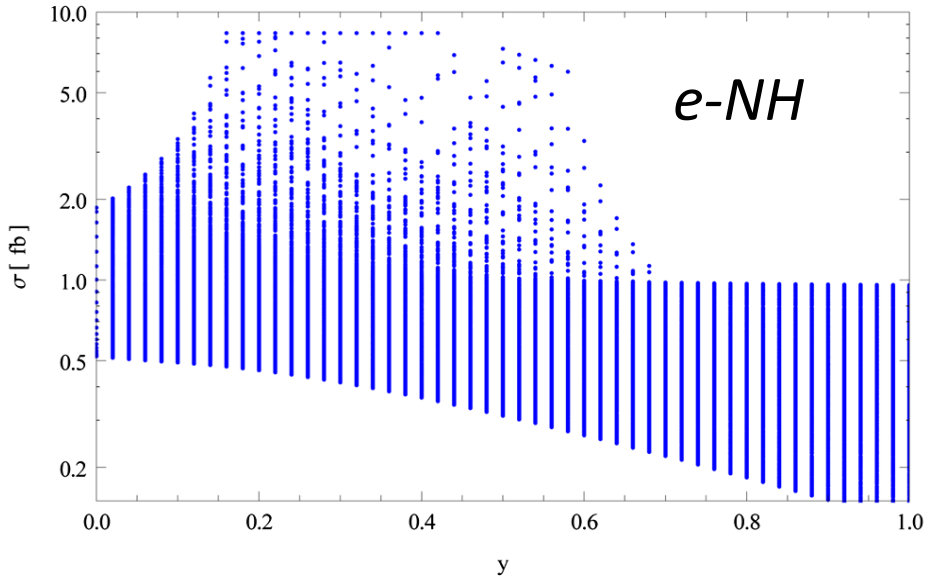
FD case is highly promising
FND is comparatively low

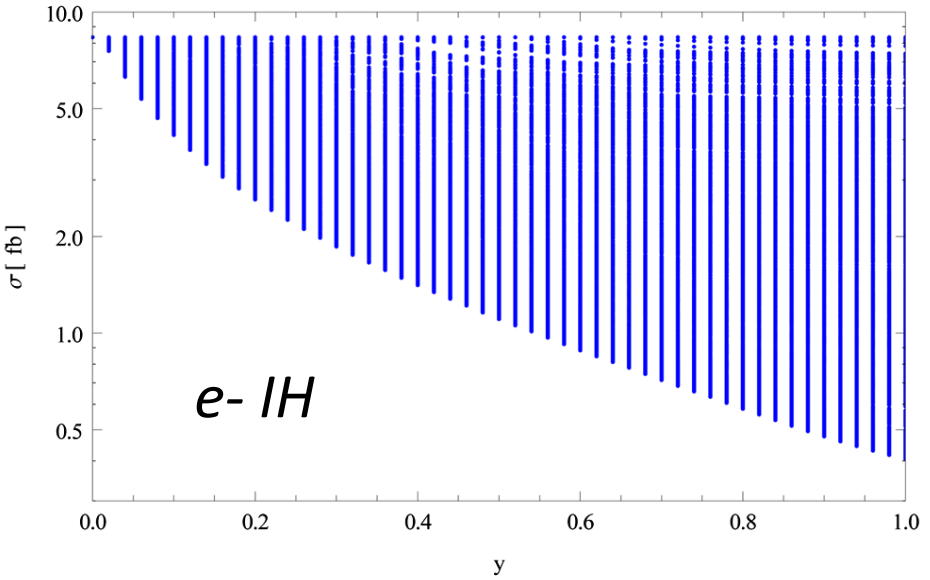
A General Scan ?????

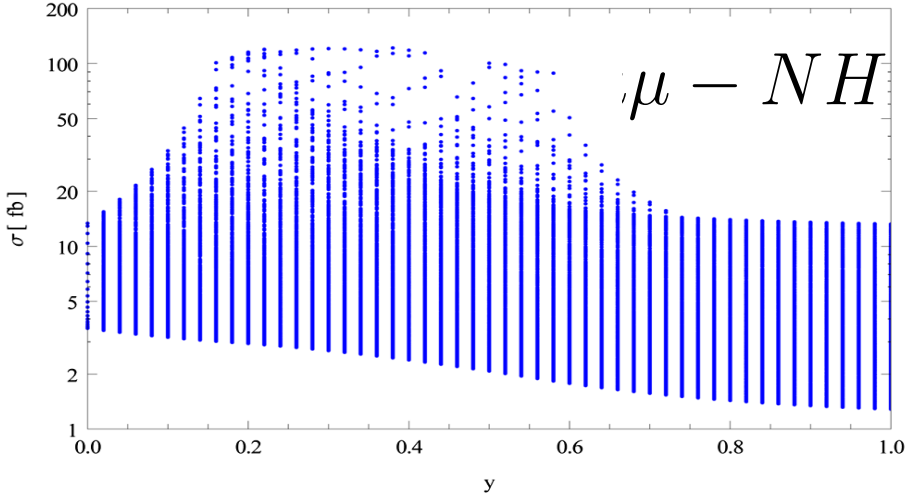
M= 150 GeV, Luminosity = 500 fb^{-1}

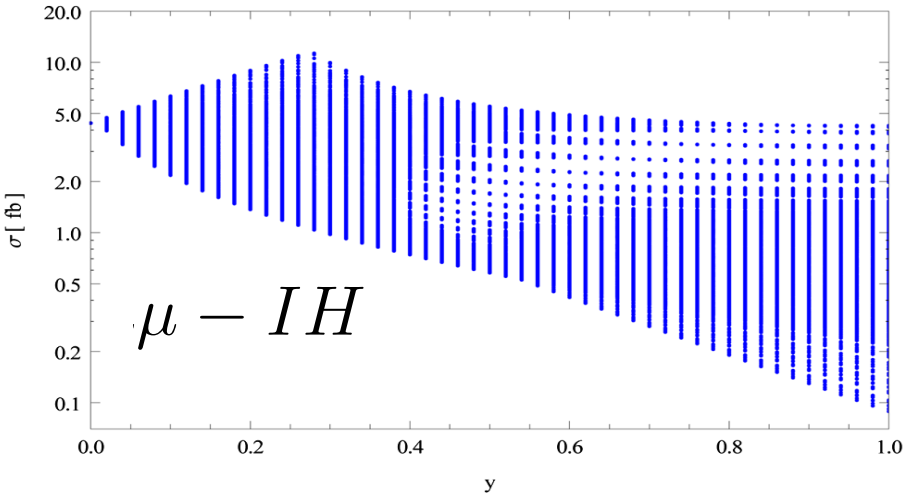
	Events before cuts	Events after cuts
FND (NH)	123.7	84.04
FND (IH)	2397	1363
FD	102210	69189.7
SM background	3210500	23346
FND (NH, $\ell = \mu$)	847.5	
FND (IH, $\ell = \mu$)	1261	

SM backgrounds PRD 82, 093004 (2010)









M= 150 GeV, Luminosity = 500 fb^{-1}

Significance is extremely high

	e	μ
NH	4500	65000
IH	4250	5500
SMBG	23346	

FND: Cross section is enhanced by the general parameterization

Direct bounds on the pseudo-Dirac Neutrinos from the 8TeV LHC data

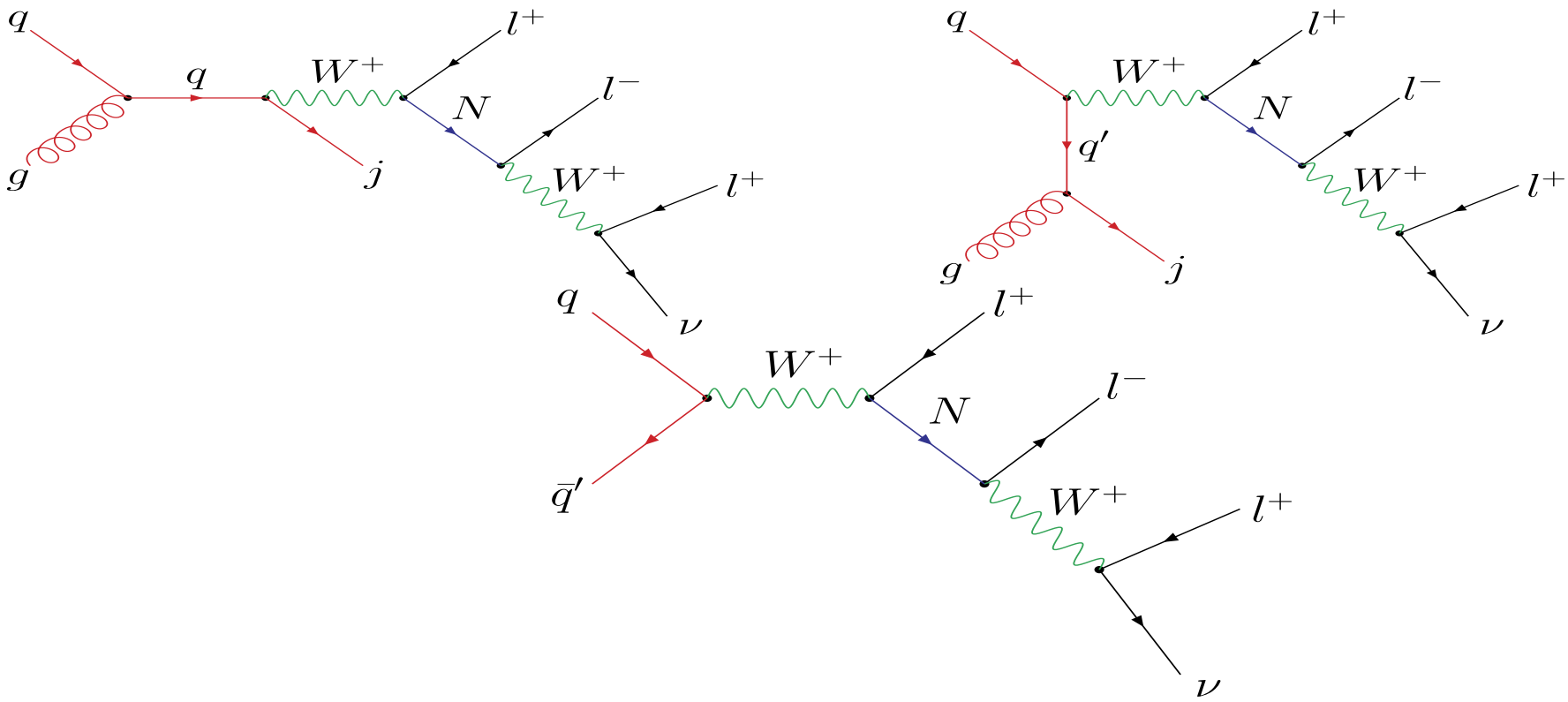
AD, P S Bhupal Dev, Nobuchika Okada, Physics Letters B 735(2014) 364-370

Production of the heavy neutrino

• We consider the two benchmark cases : a) Single Flavor (SF) and b) Flavor Diagonal (FD)

• SF: One heavy neutrino couples with one flavor.
Signal Example: $pp \to N\mu, N \to W\mu, W \to \ell_\alpha \nu_\alpha$

• FD: Two degenerate heavy neutrinos couple with two lepton flavors individually. The cross section is twice larger than that of the SF case.



CMS search for the tri-lepton+ MET (matches with our final state)

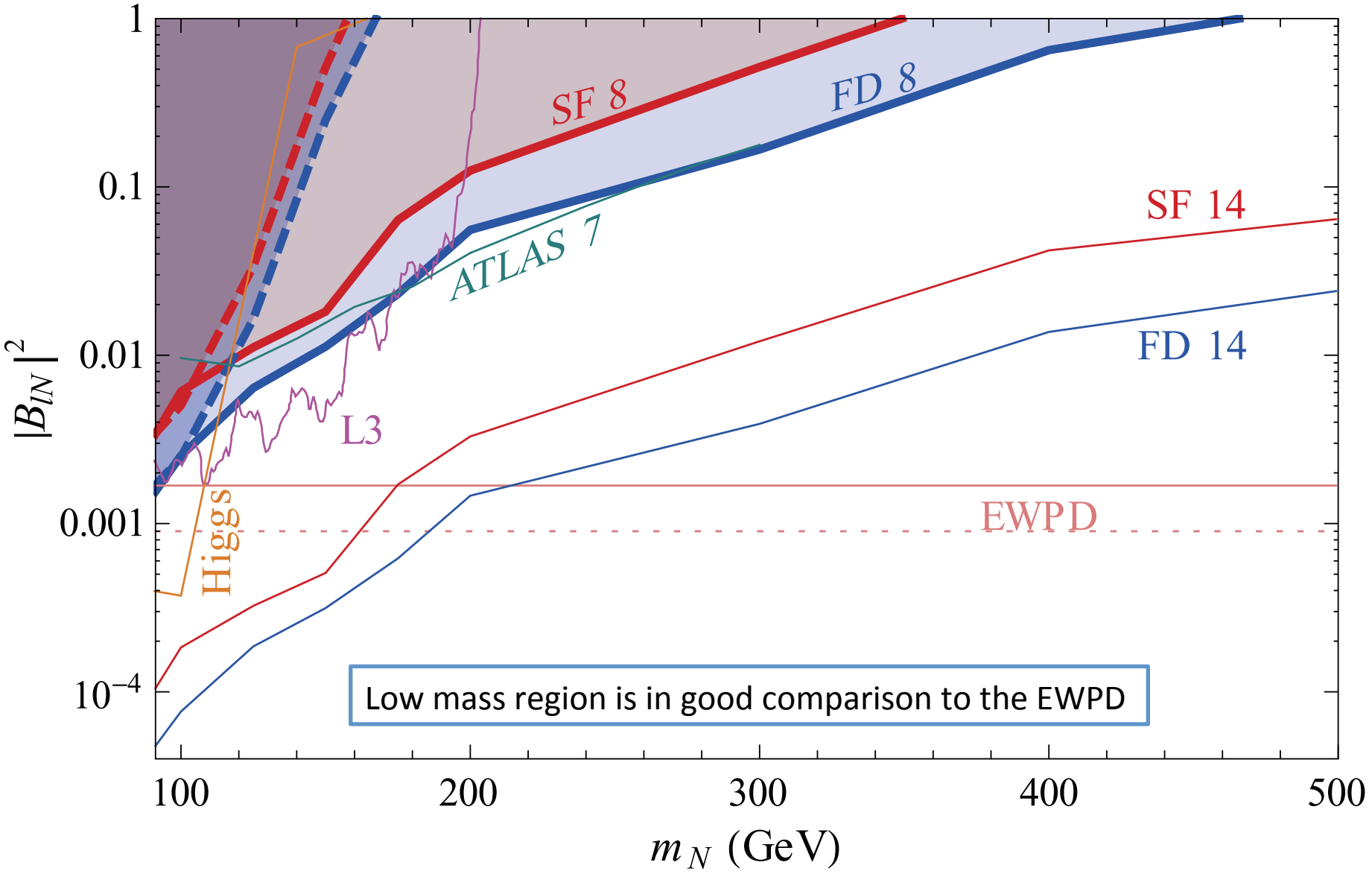
CMS Criteria

PHYSICAL REVIEW D **90,** 032006 (2014)

(i) The transverse momentum of each lepton: $p_T^{\ell} > 10$ GeV.
(ii) The transverse momentum of at least one lepton: $p_T^{\ell,\text{leading}} > 20$ GeV.
(iii) The jet transverse momentum: $p_T^{j} > 30$ GeV.
(iv) The pseudo-rapidity of leptons: $|\eta^{\ell}| < 2.4$ and of jets: $|\eta^{j}| < 2.5$.
(v) The lepton-lepton separation: $\Delta R_{\ell\ell} > 0.1$ and the lepton-jet separation: $\Delta R_{\ell j} > 0.3$.
(vi) The invariant mass of each OSSF lepton pair: a) $m_{\ell^+\ell^-} < 75$ GeV and b) $m_{\ell^+\ell^-} > 105$ GeV.
(vii) The scalar sum of the jet transverse momenta: $H_T < 200$ GeV.
(viii) The missing transverse energy: $\not{E}_T < 50$ GeV.

- Case I : $m_{\ell^+\ell^-} < 75$: CMS has observed 510 events with the SM background expectation 560 ± 87 events . Upper limit of $510 - (560 - 87) = 37$ events.
- Case II: $m_{\ell^+\ell^-} > 105$: CMS has observed 178 events with the SM background expectation 200 ± 35 events. Upper limit of $178 - (200 - 35) = 13$ events.
- These set a 95 % CL on the mixing parameter as a function of the heavy neutrino mass.
- The upper bound in FD case is twice stronger than that in the SF case as it was expected.

Upper bound on the Mixing angle from tri-lepton-lepton search from the pseudo-Dirac heavy neutrino (inverse seesaw)

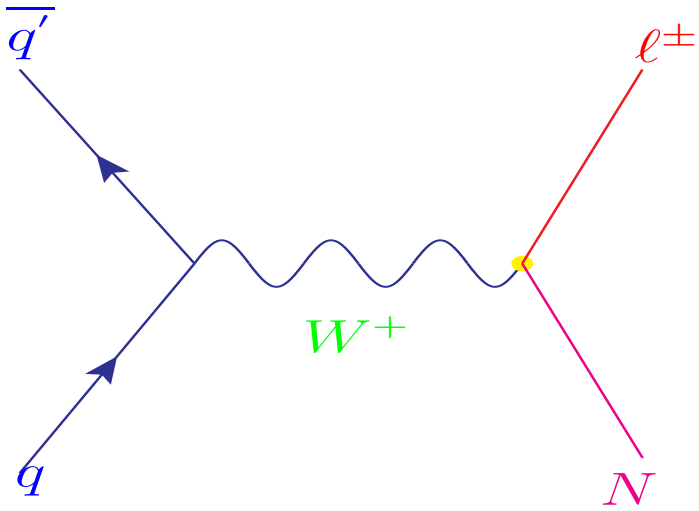


Improved bounds on the heavy neutrino production at the LHC

AD, Nobuchika Okada Physical Review D 93 (2016)033003

Various production channels of the heavy neutrino

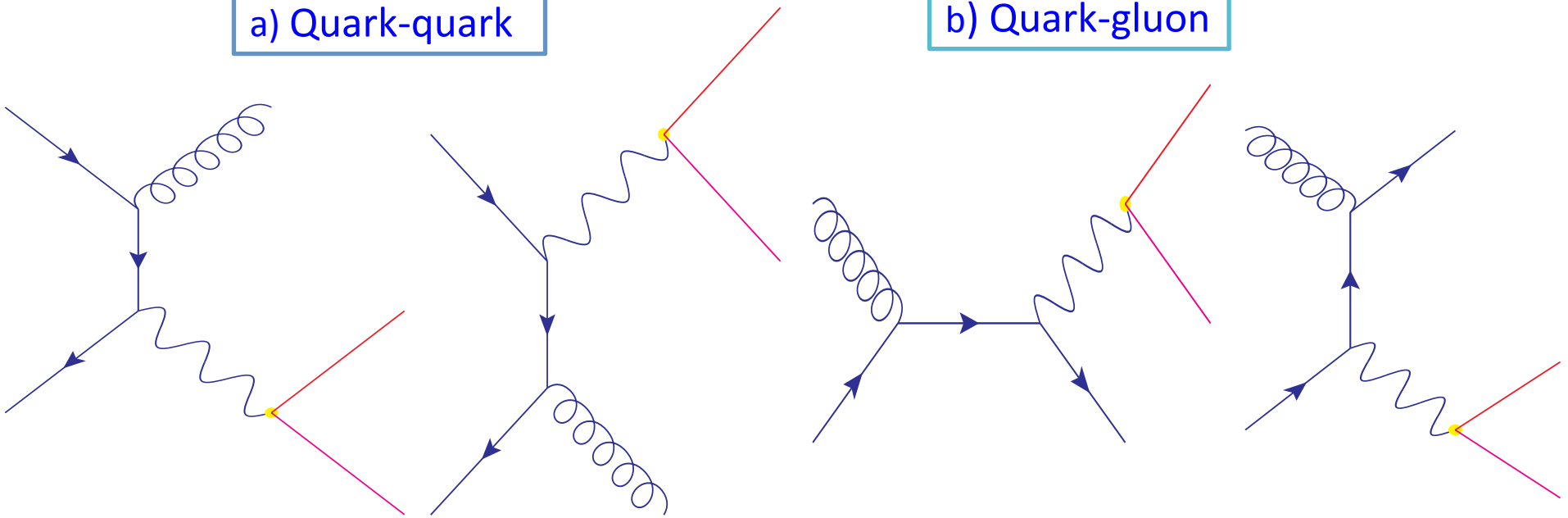
0-jet Process $pp \to N\ell^{\pm}$



1-jet processes $pp \to N\ell^{\pm}j$

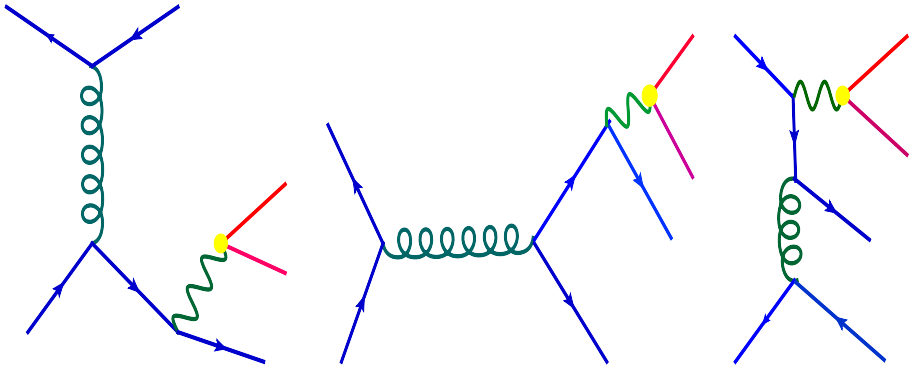
a) Quark-quark

b) Quark-gluon

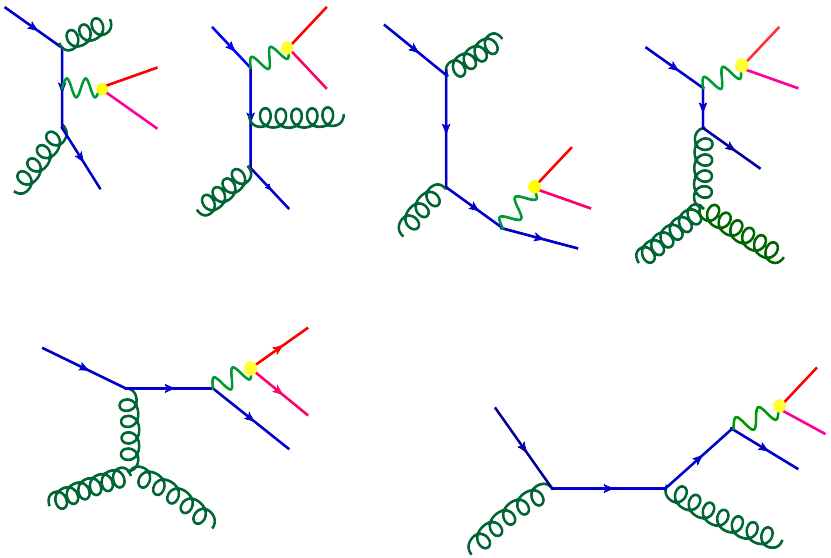


2 – jet processes $pp \to N\ell^{\pm} jj$

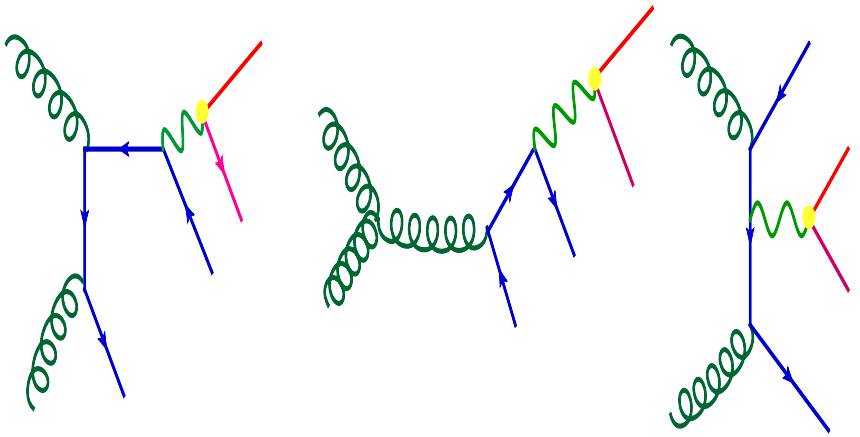
a) Quark-Quark



b) Quark-Gluon

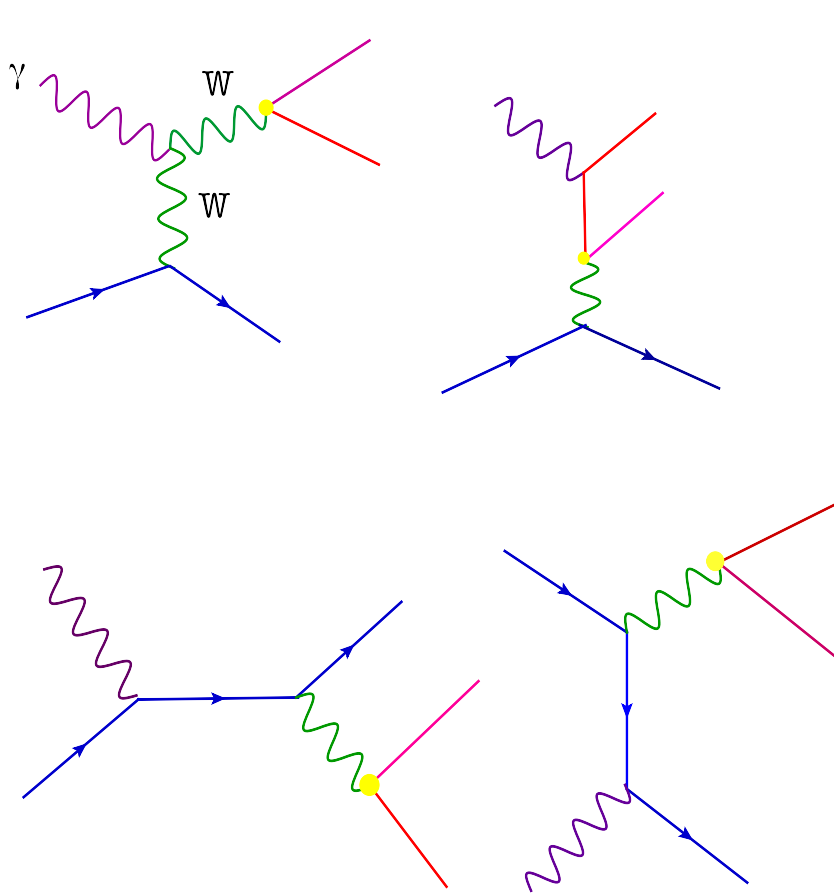


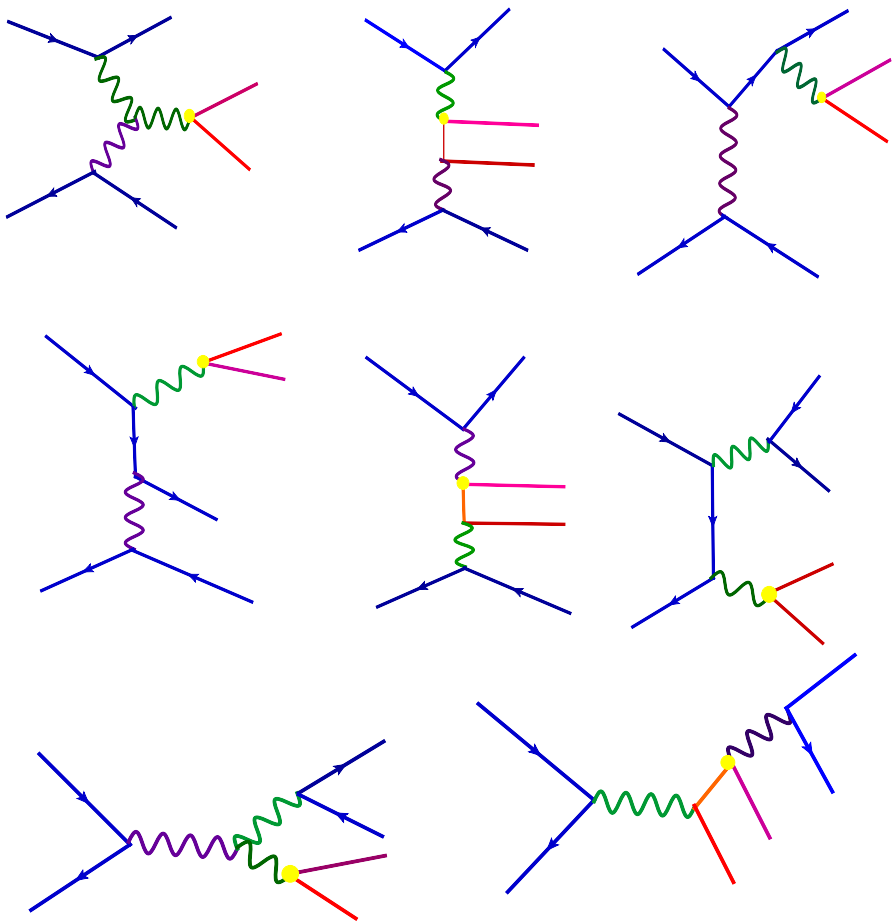
c) Gluon-Gluon

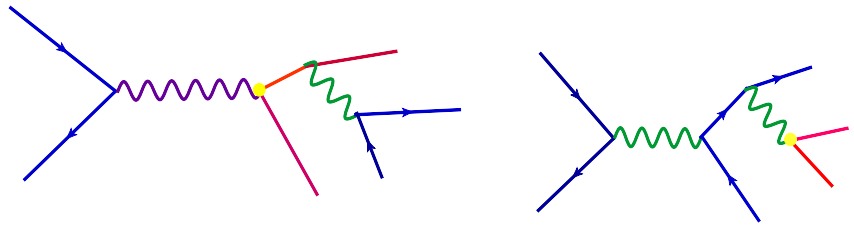


Proton-photon interaction $pa \to N\ell^{\pm} j$

Proton-proton QED Processes $pp \to N\ell^{\pm} jj$ (QED)



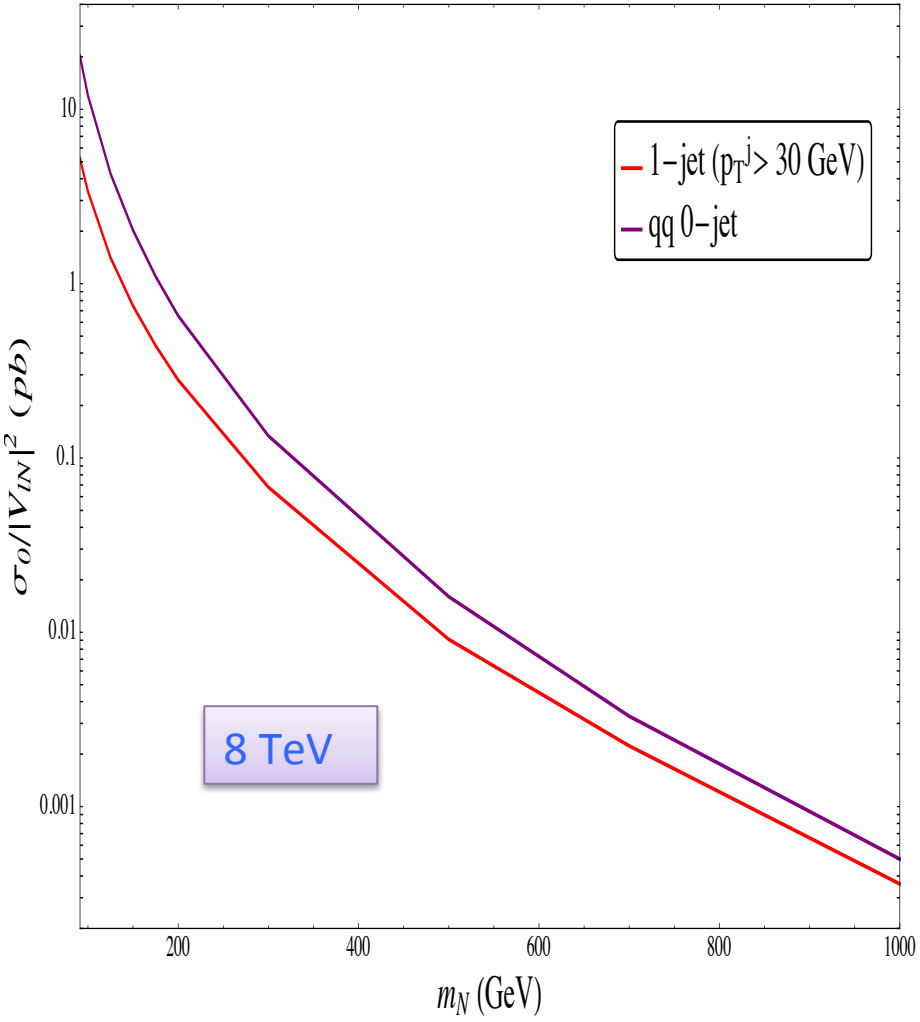




P S B Dev et. al. PRL 112 (2014)8, 081801

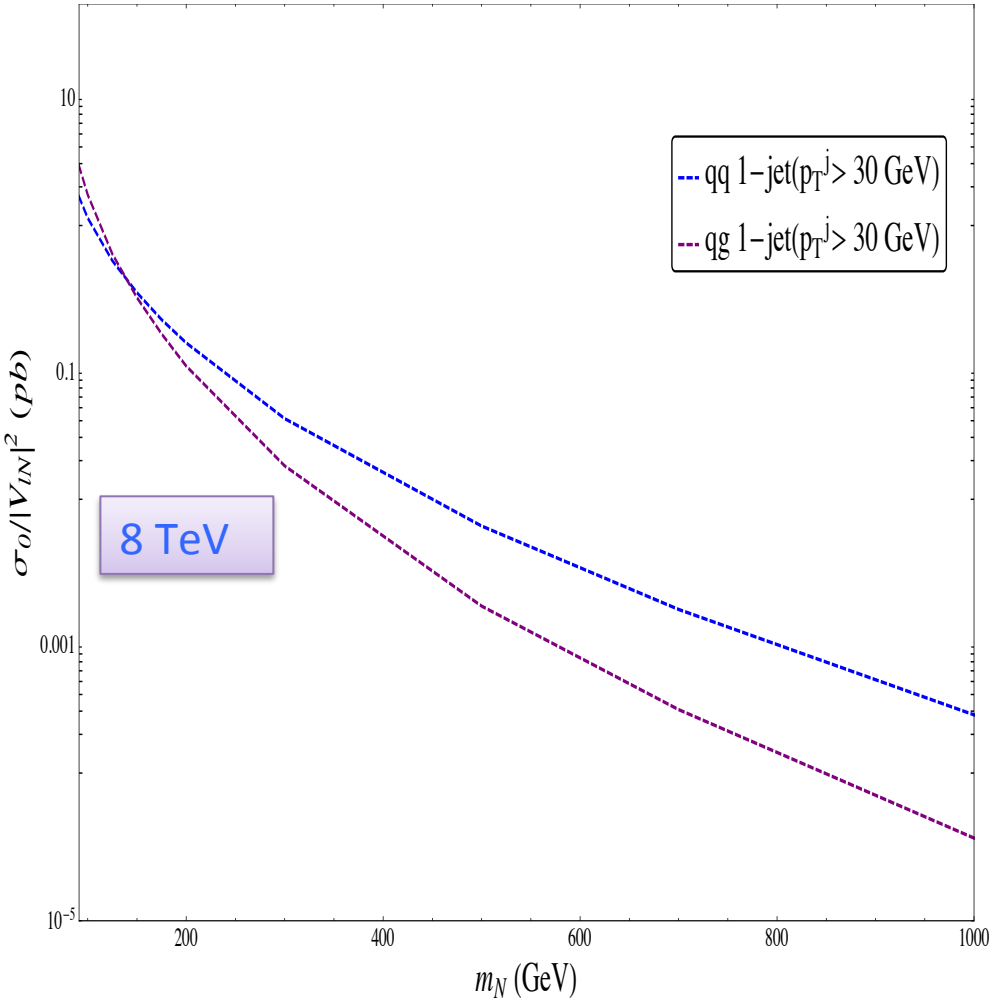
Daniel Alva et. al. JHEP 1502 (2015) 093006

Heavy neutrino production cross section for 1-jet Processes



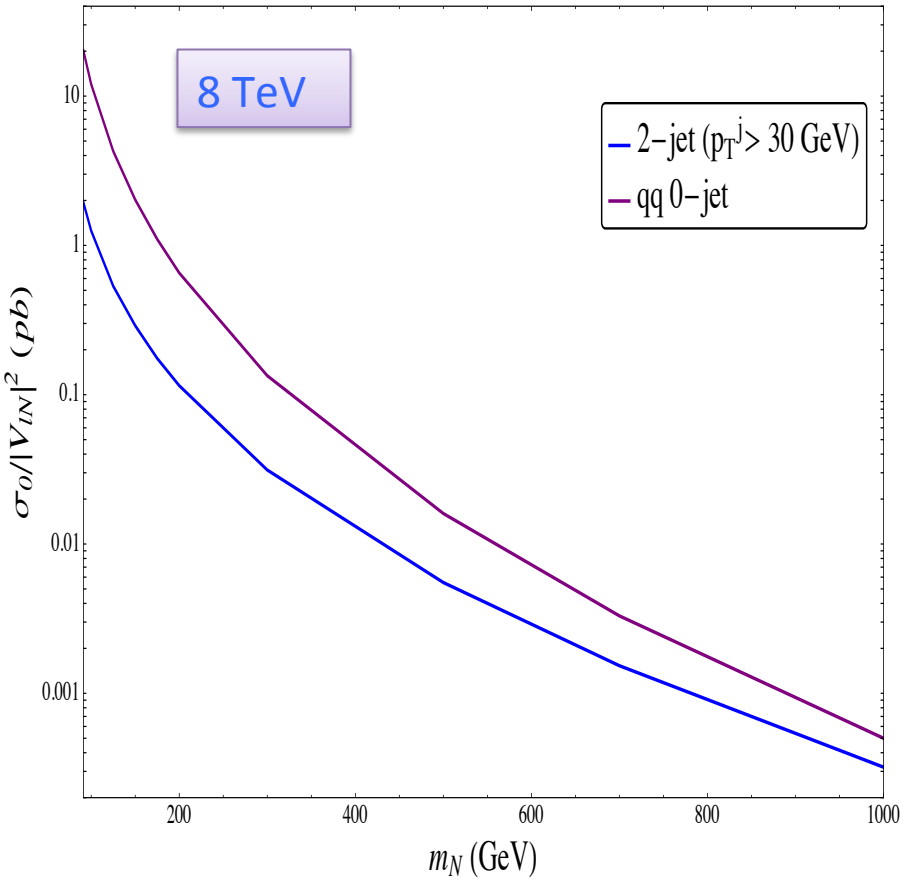
1-jet processes consist of quark-quark(qq) and quark-gluon(qg) initial states

Decomposition of the initial states from the 1-jet QCD processes



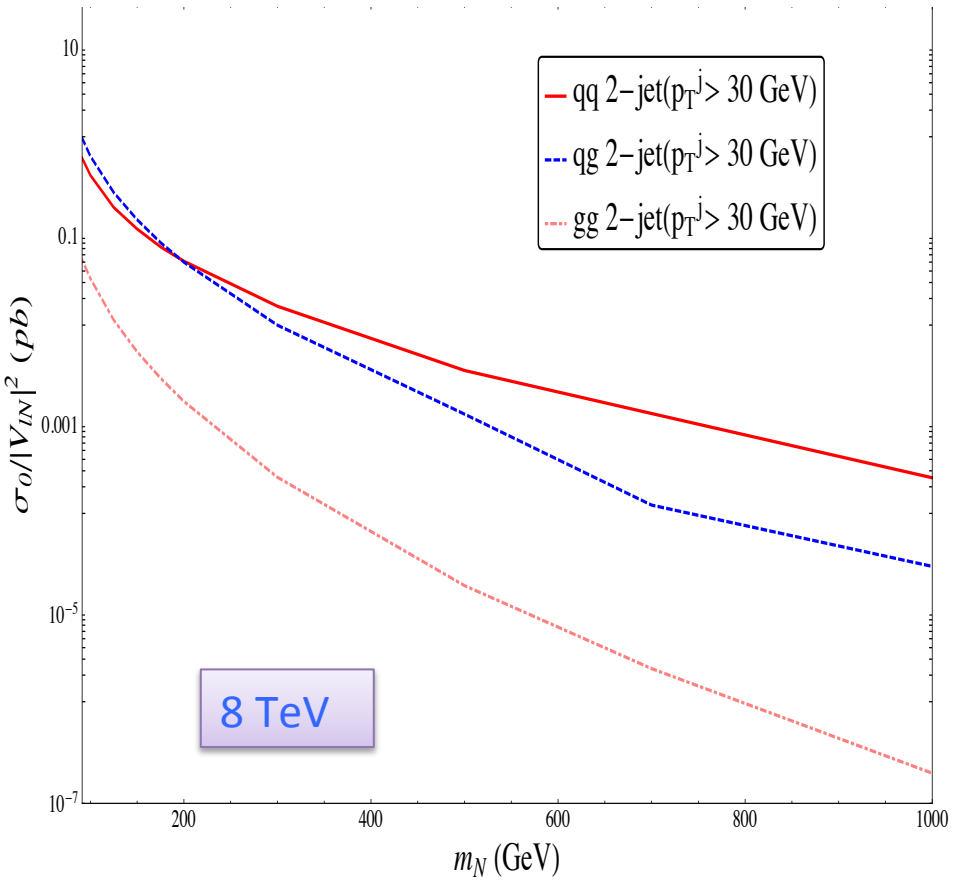
qq > qg , gluon PDF is larger than quark PDFs at the Low Bjorken scaling parameter

Heavy neutrino production cross section for 2-jet Processes



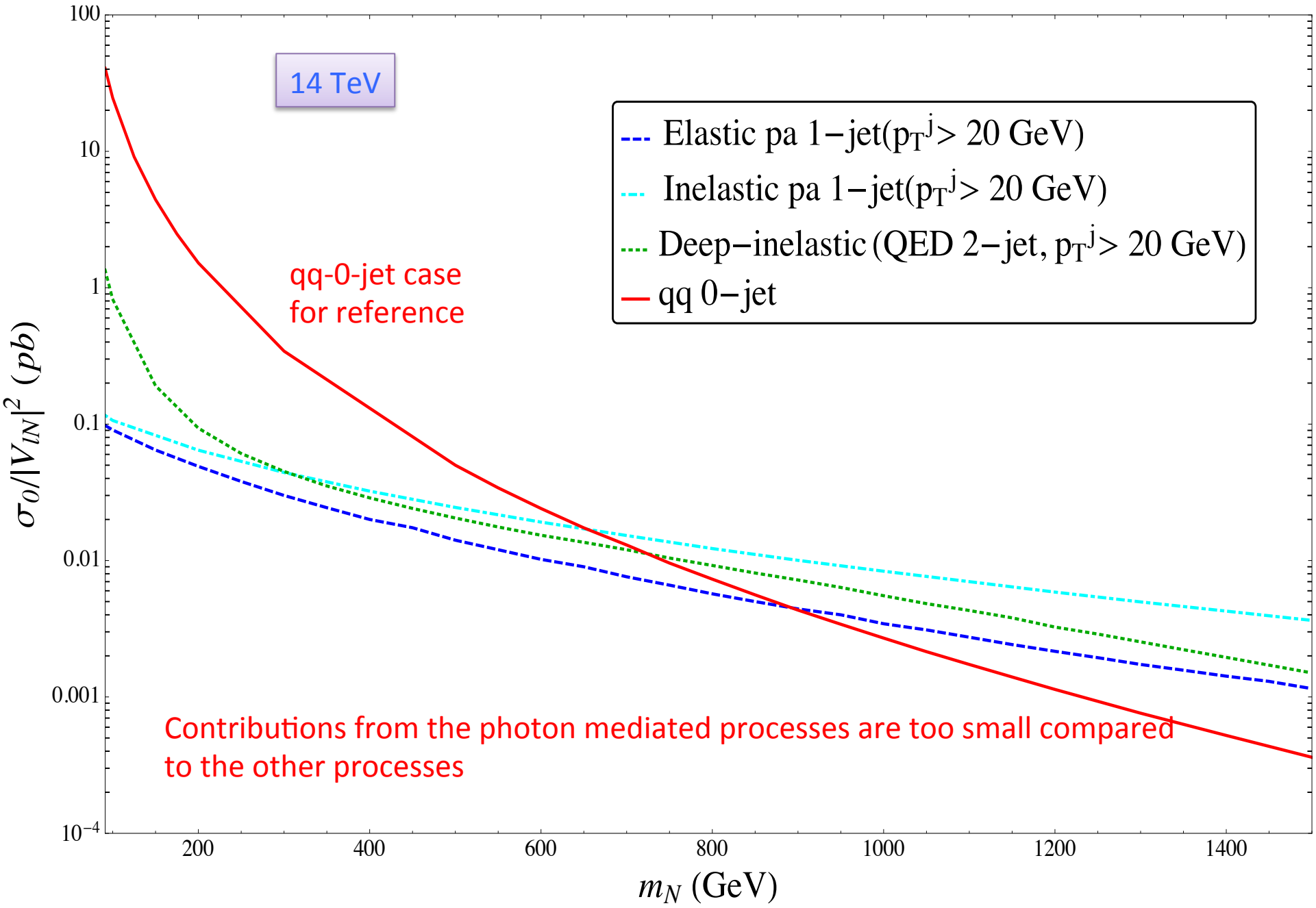
2-jet processes consist of quark-quark (qq), quark-gluon (qg) and gluon-gluon (gg) initial states

Decomposition of the initial states from the 2-jet QCD processes



gg always dominated by the qq, qg because two gluons can not have Bjorken scaling simultaneously small to produce N

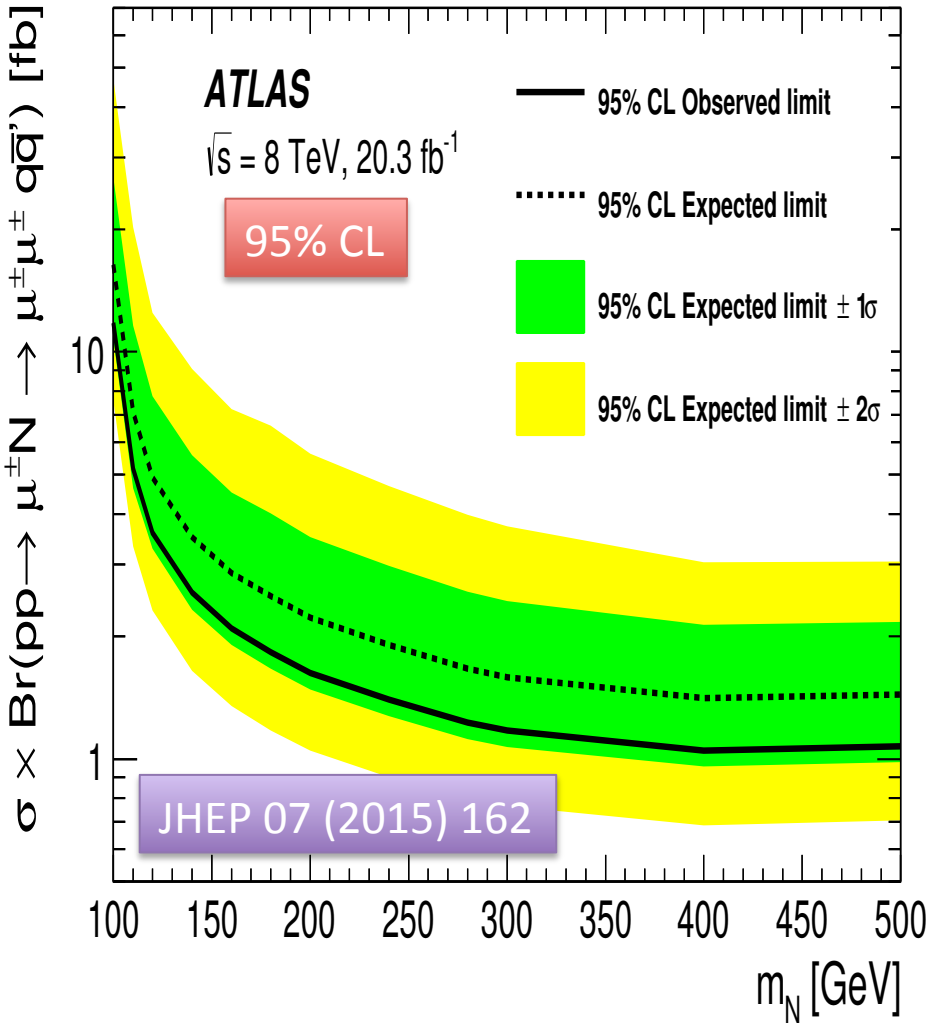
Production cross sections for the photon mediated processes

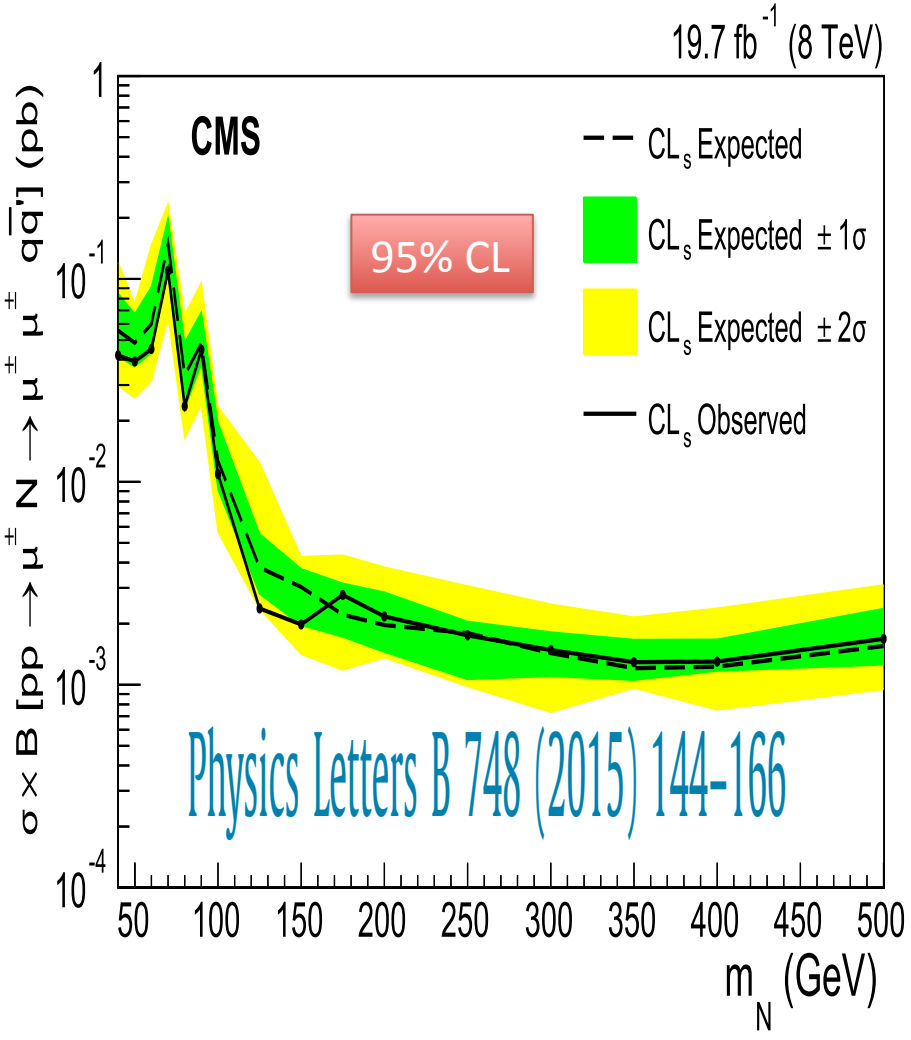


Signal Process at the 8 TeV LHC using same sign di-lepton plus di-jet (conventional seesaw case)

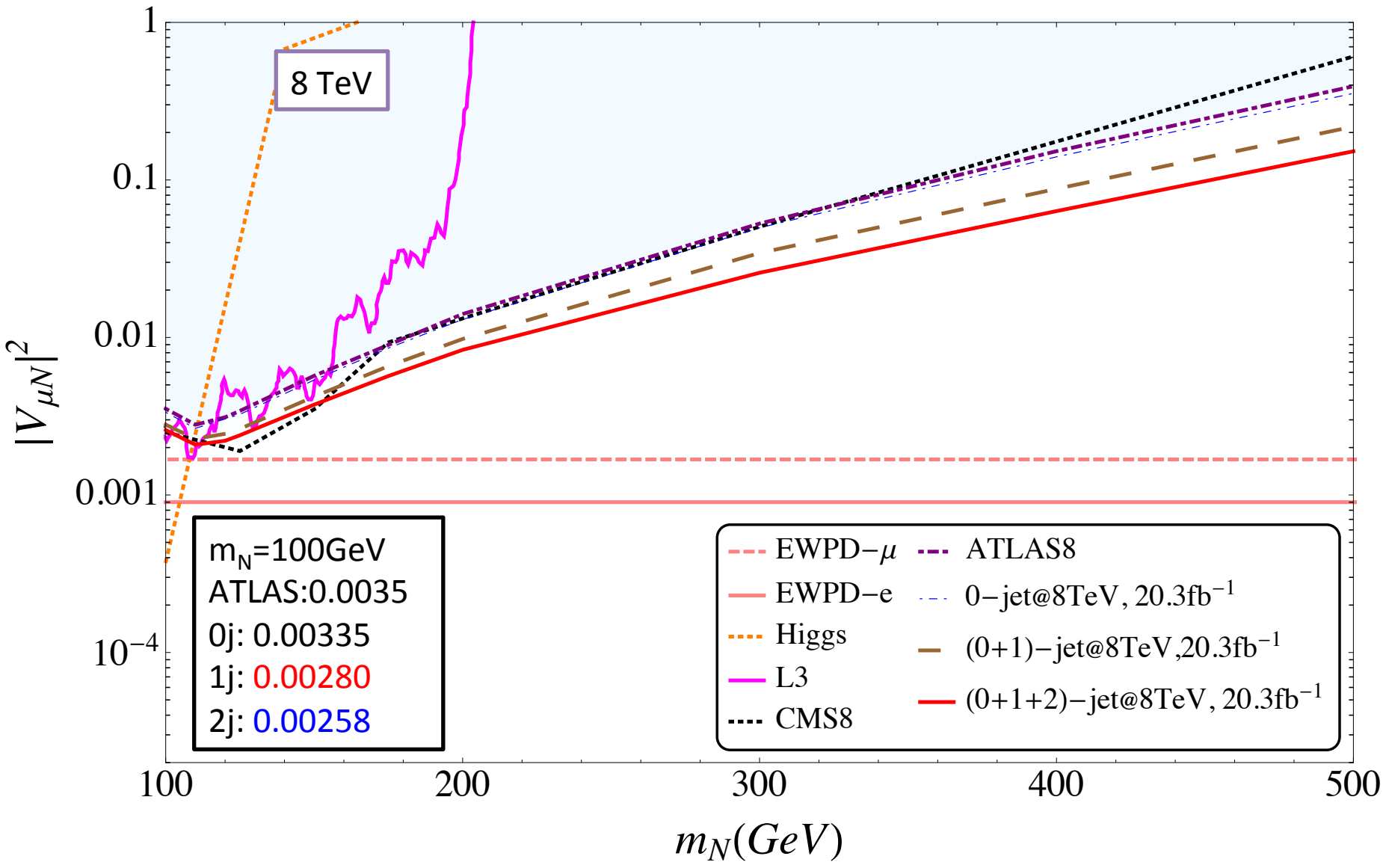
ATLAS Results, $p_T^j > 20$ GeV @
20.3 fb^{-1} 8 TeV , same-sign di-lepton

CMS Results, $p_T^j > 20$ GeV @
19.7 fb^{-1} 8 TeV same-sign di-lepton

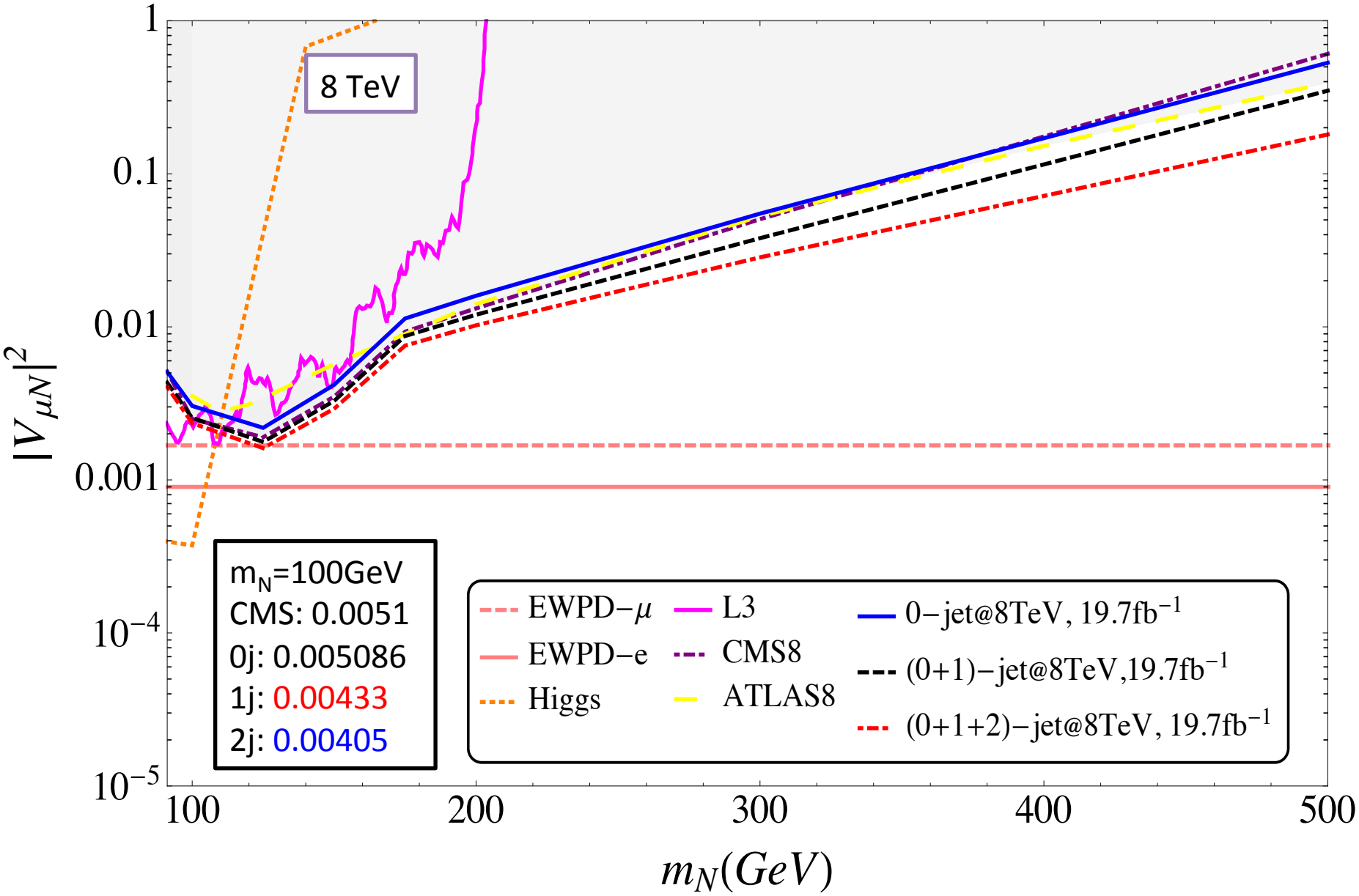




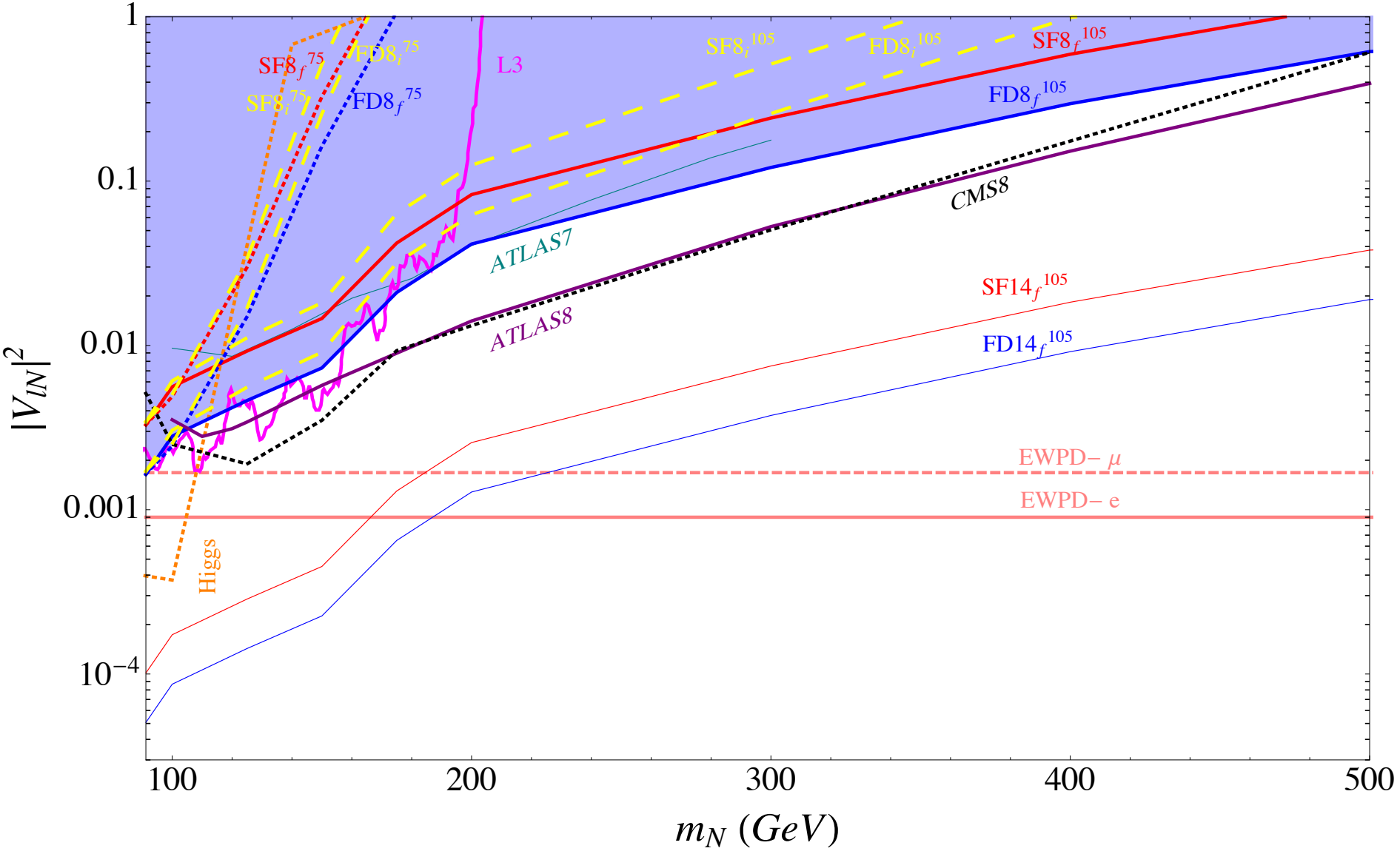
Upper bound on the Mixing angle from ATLAS same-sign di-lepton plus dijet (conventional seesaw case)



Upper bound on the Mixing angle from CMS same-sign di-lepton plus dijet (conventional seesaw case)



Improved upper bound on the Mixing angle from tri-lepton-lepton search (inverse seesaw case)

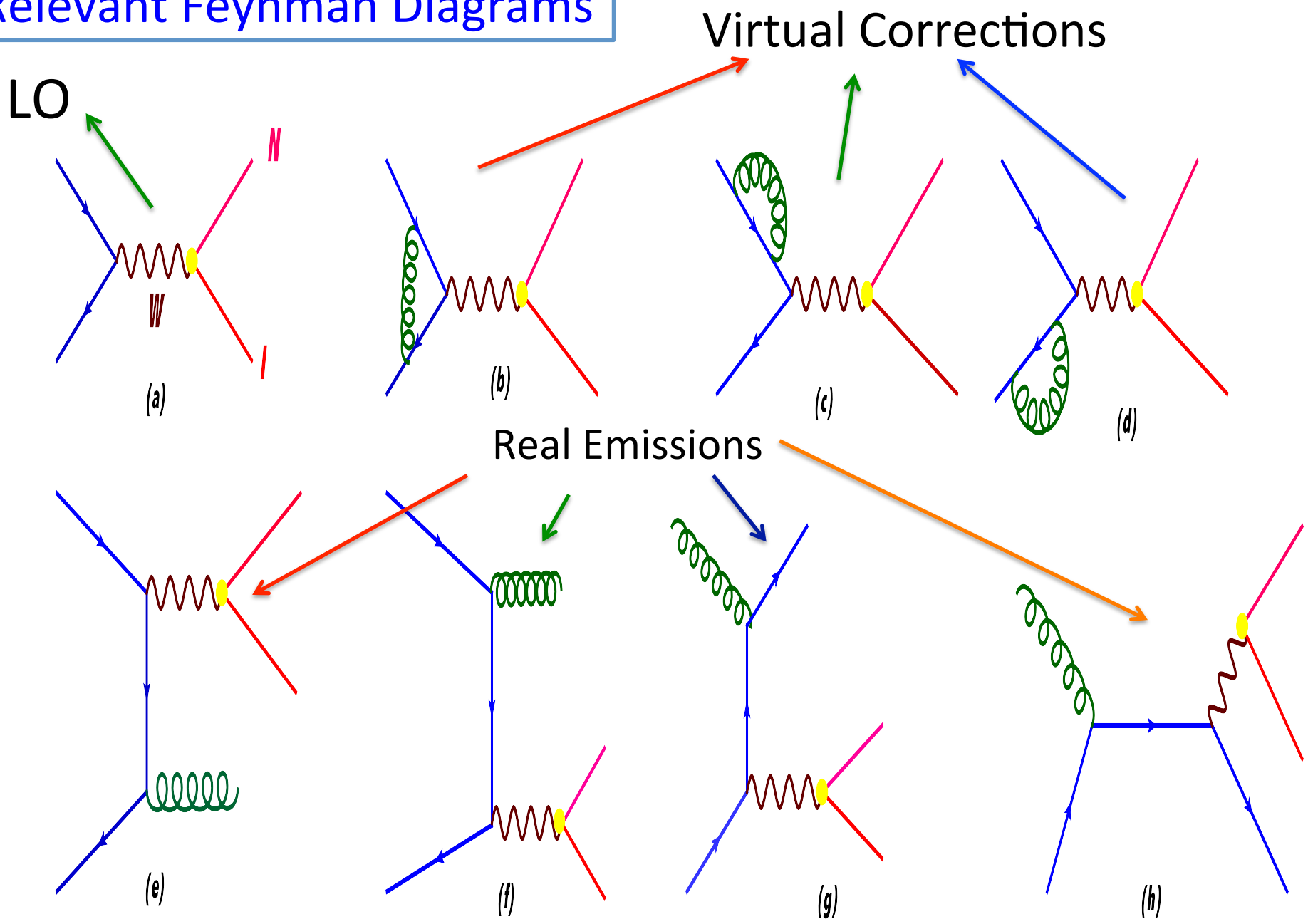


Production of heavy neutrino in next-to-leading order QCD at the LHC

AD, Partha Konar and Swapan Majhi, JHEP 06 (2016) 019.

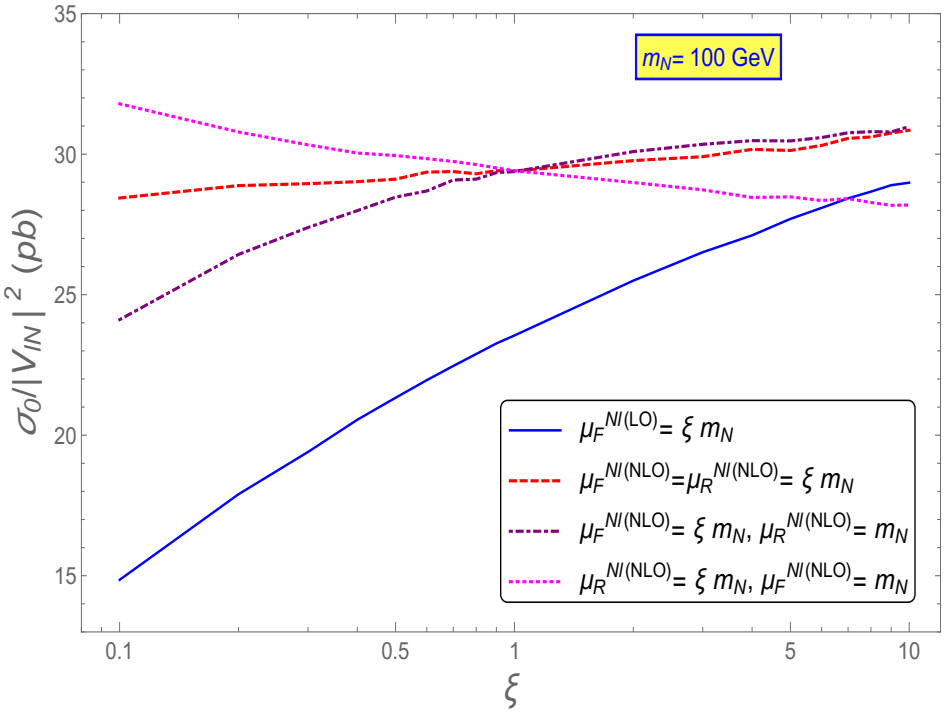
AD and P Konar, in progress, arxiv: XXXX.XXXXX

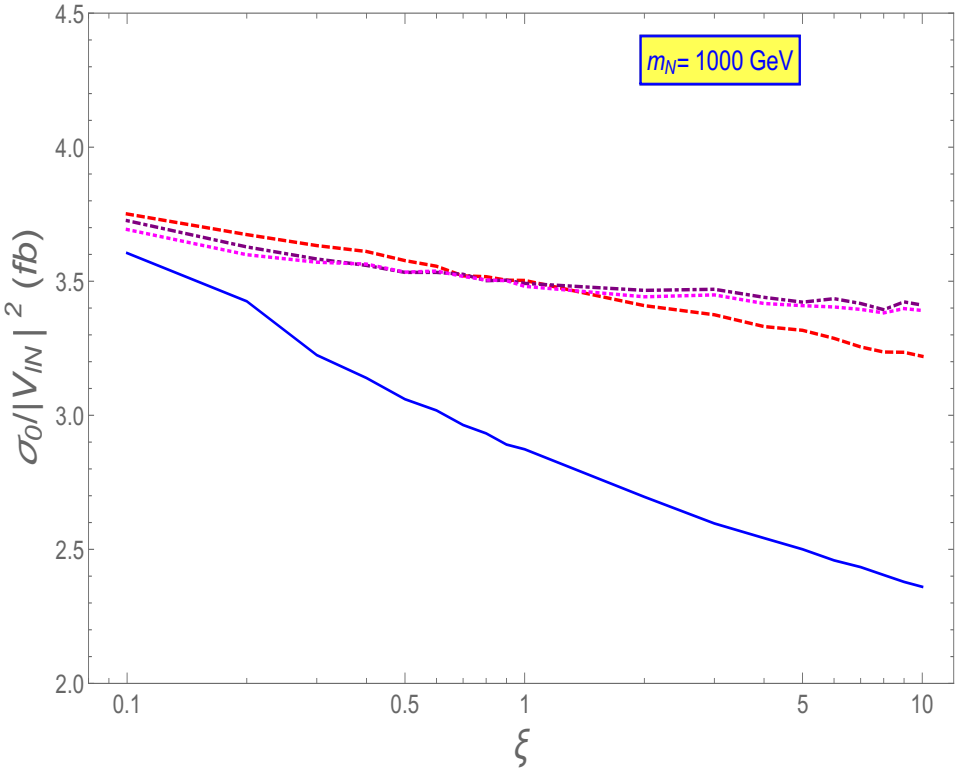
Relevant Feynman Diagrams



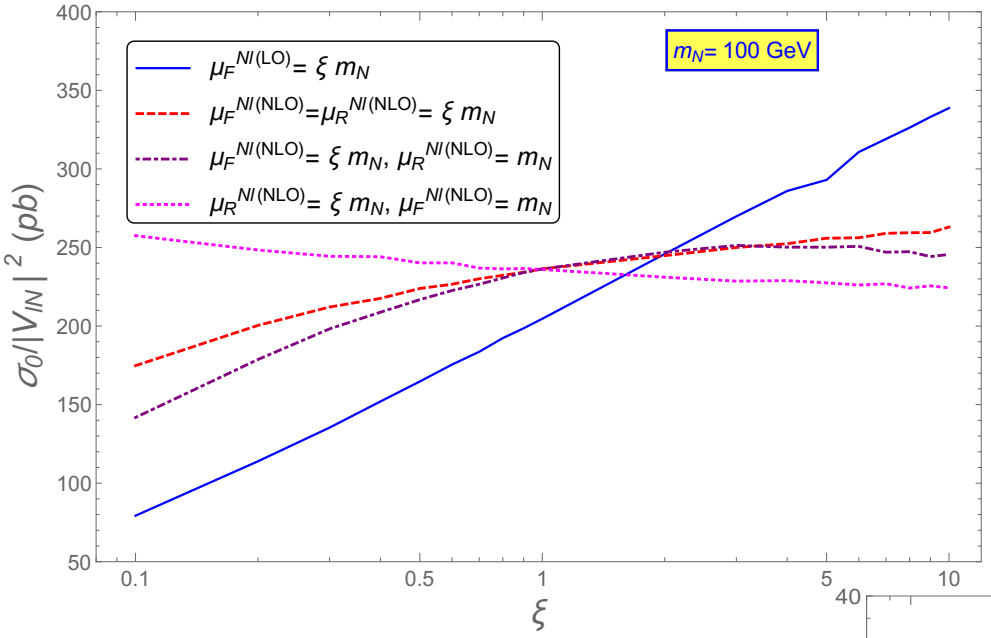
Scale dependent production of heavy neutrino ($pp \rightarrow \ell N$) at 14 TeV LHC

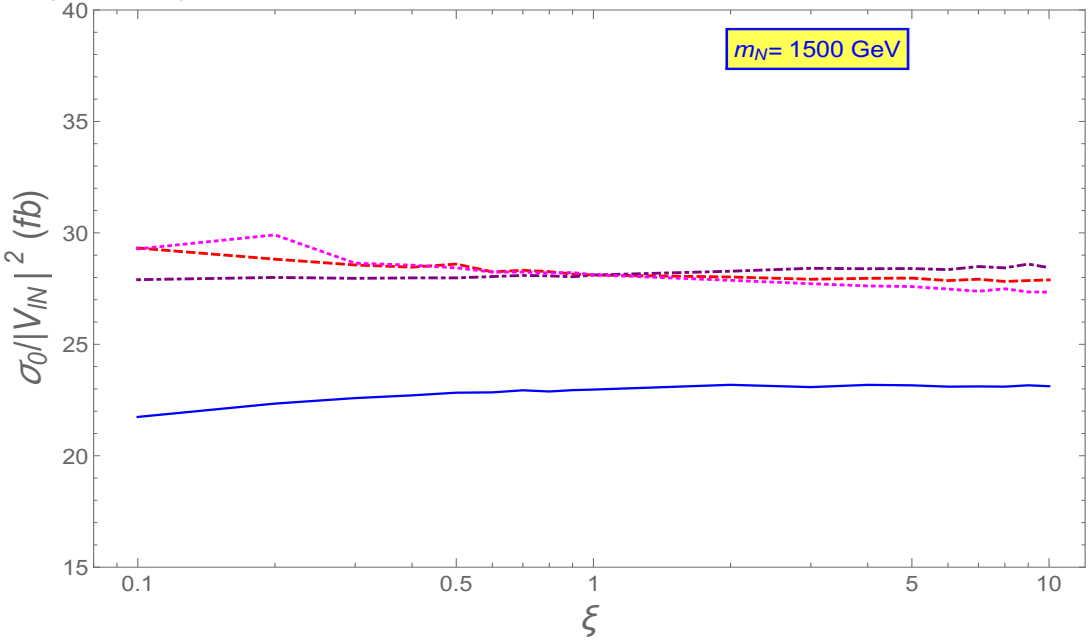
$$\mu_F = \xi m_N \qquad \mu_F = \mu_R = \xi m_N \quad \text{with} \quad 0.1 \leq \xi \leq 10$$



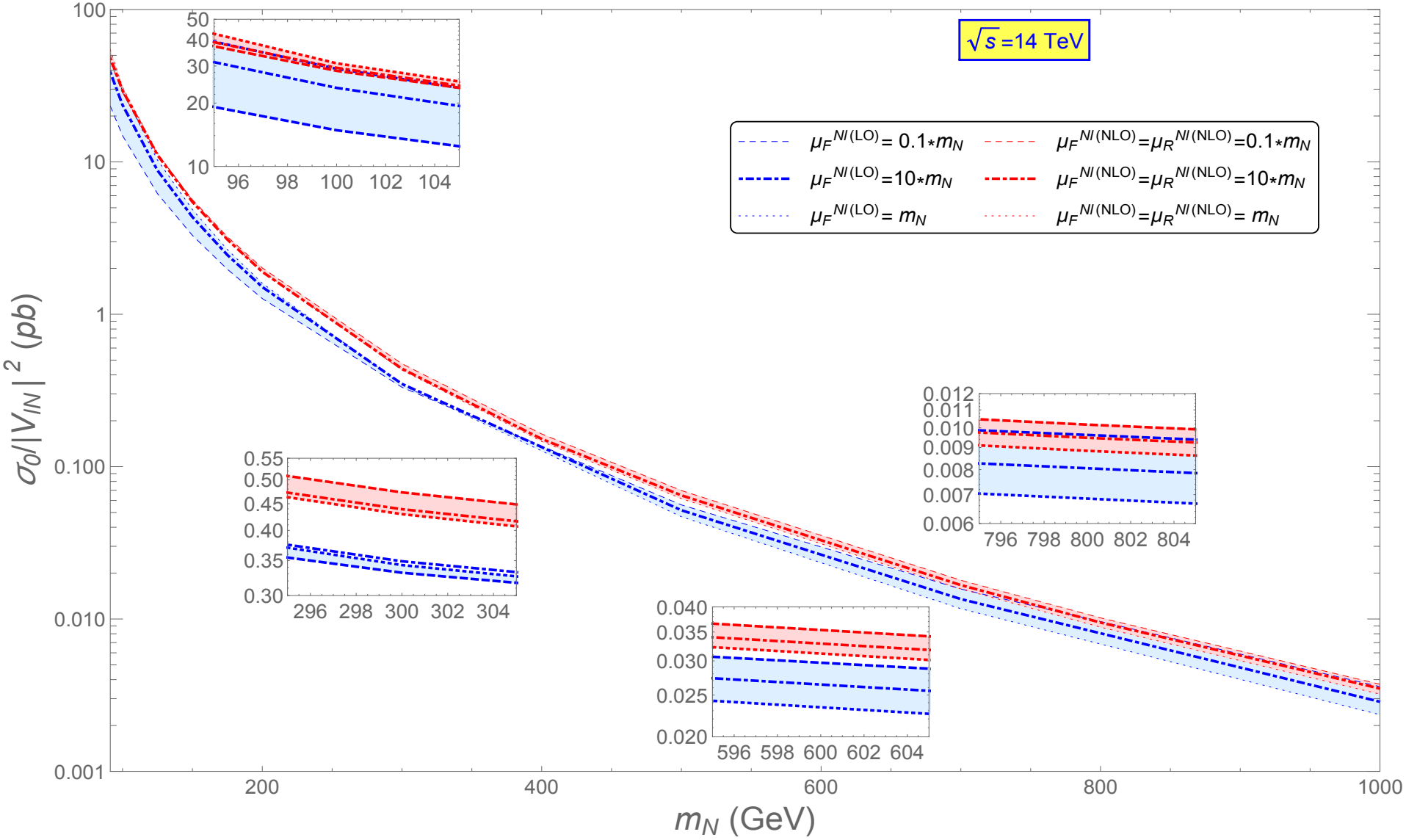


Scale dependent production of heavy neutrino ($pp \rightarrow \ell N$) at 100 TeV LHC

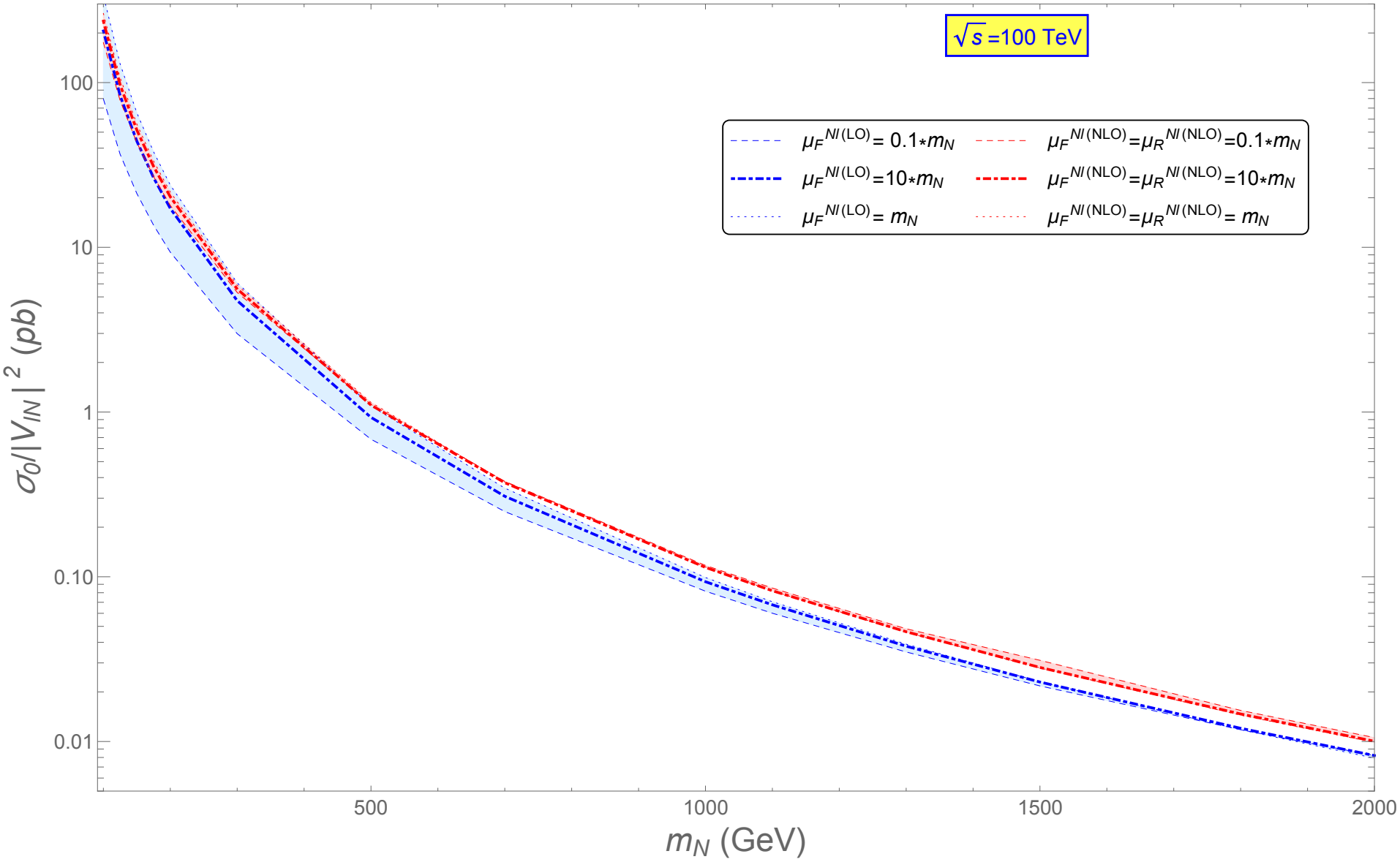




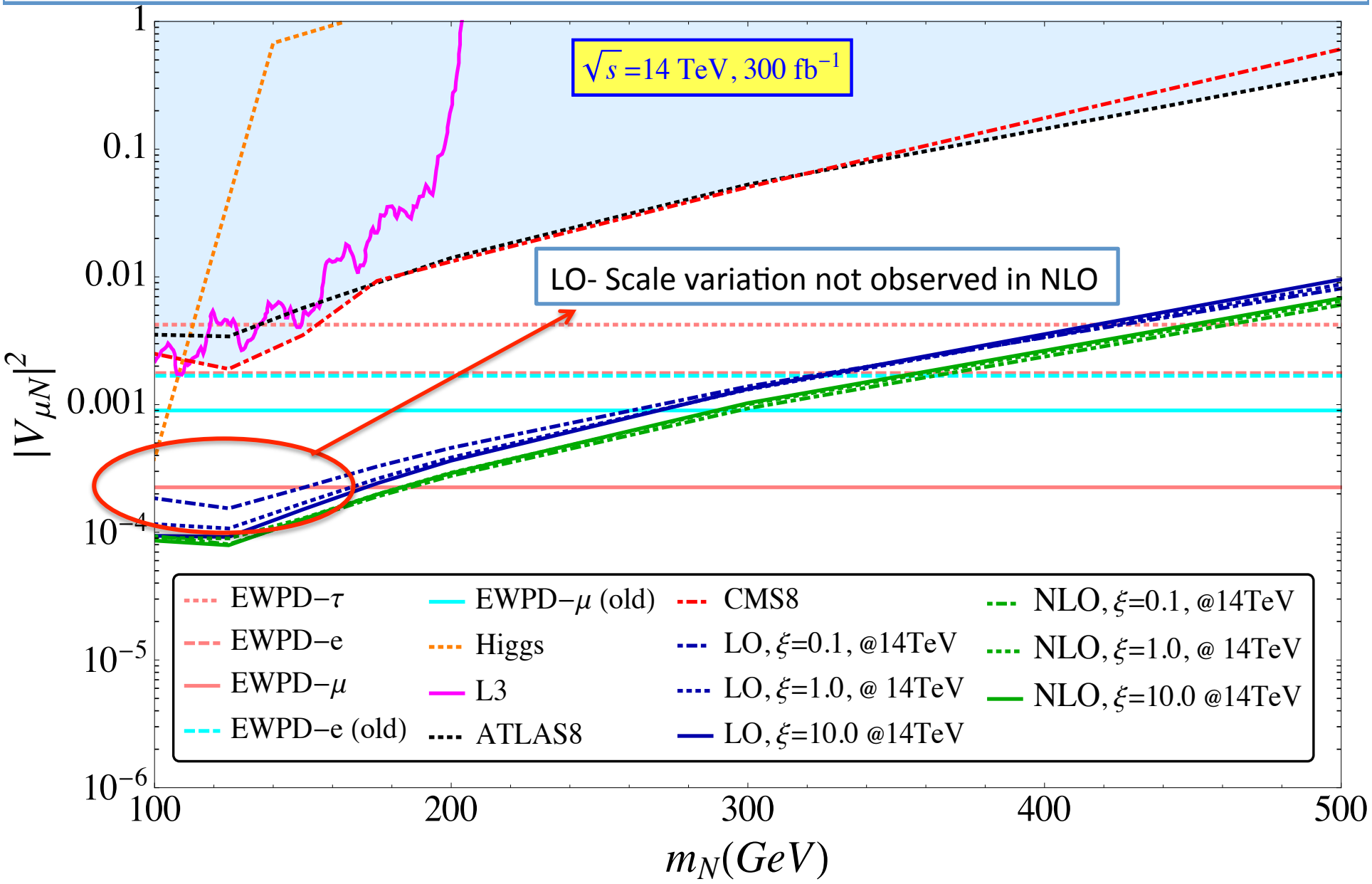
Production of heavy neutrino ($pp \rightarrow \ell N$) at 14 TeV LHC



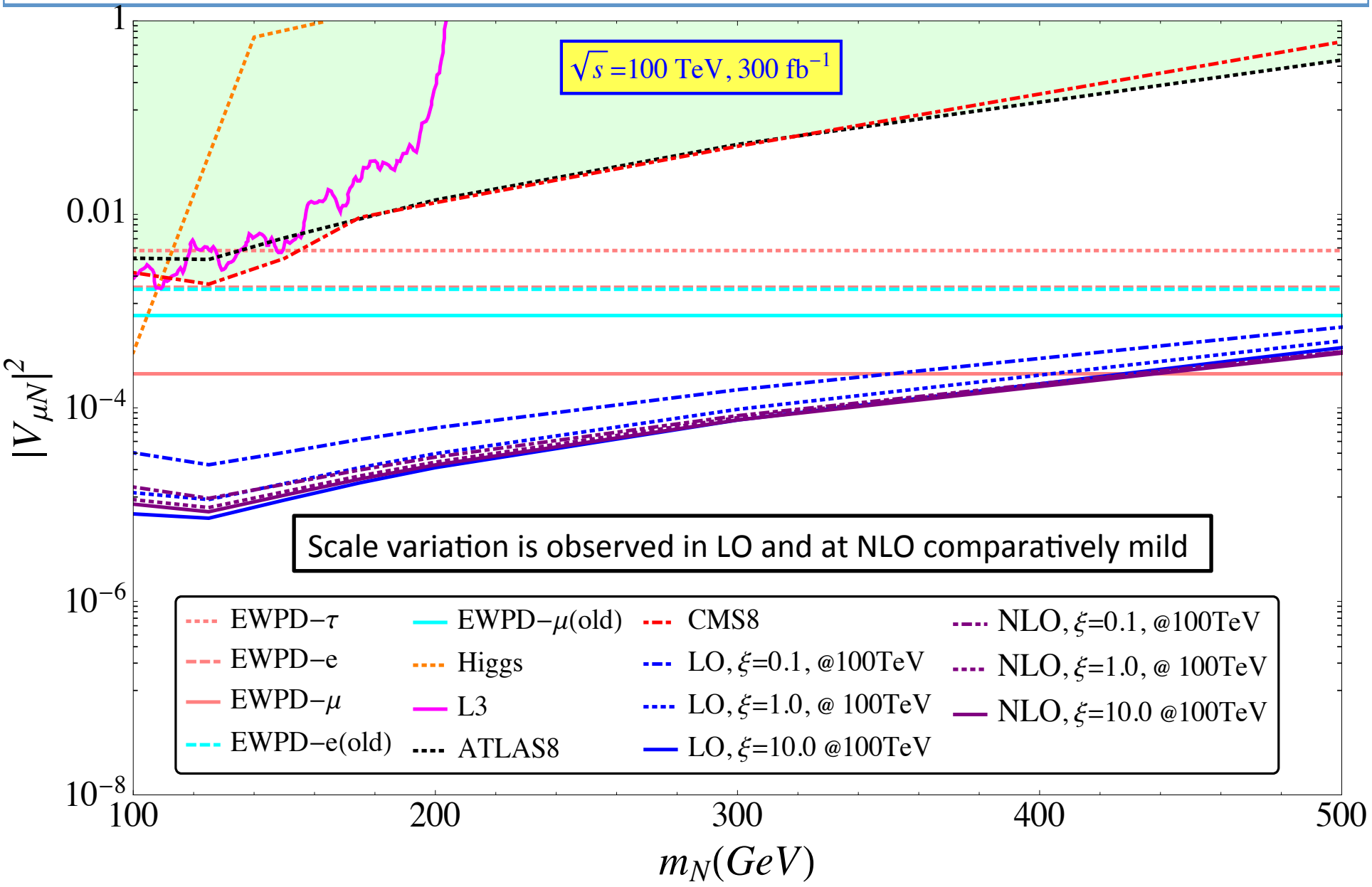
Production of heavy neutrino ($pp \rightarrow \ell N$) at 100 TeV LHC



Prospective mixing angle at 14 TeV with 300 fb^{-1} luminosity From same sign dilepton plus dijet (conventional seesaw)

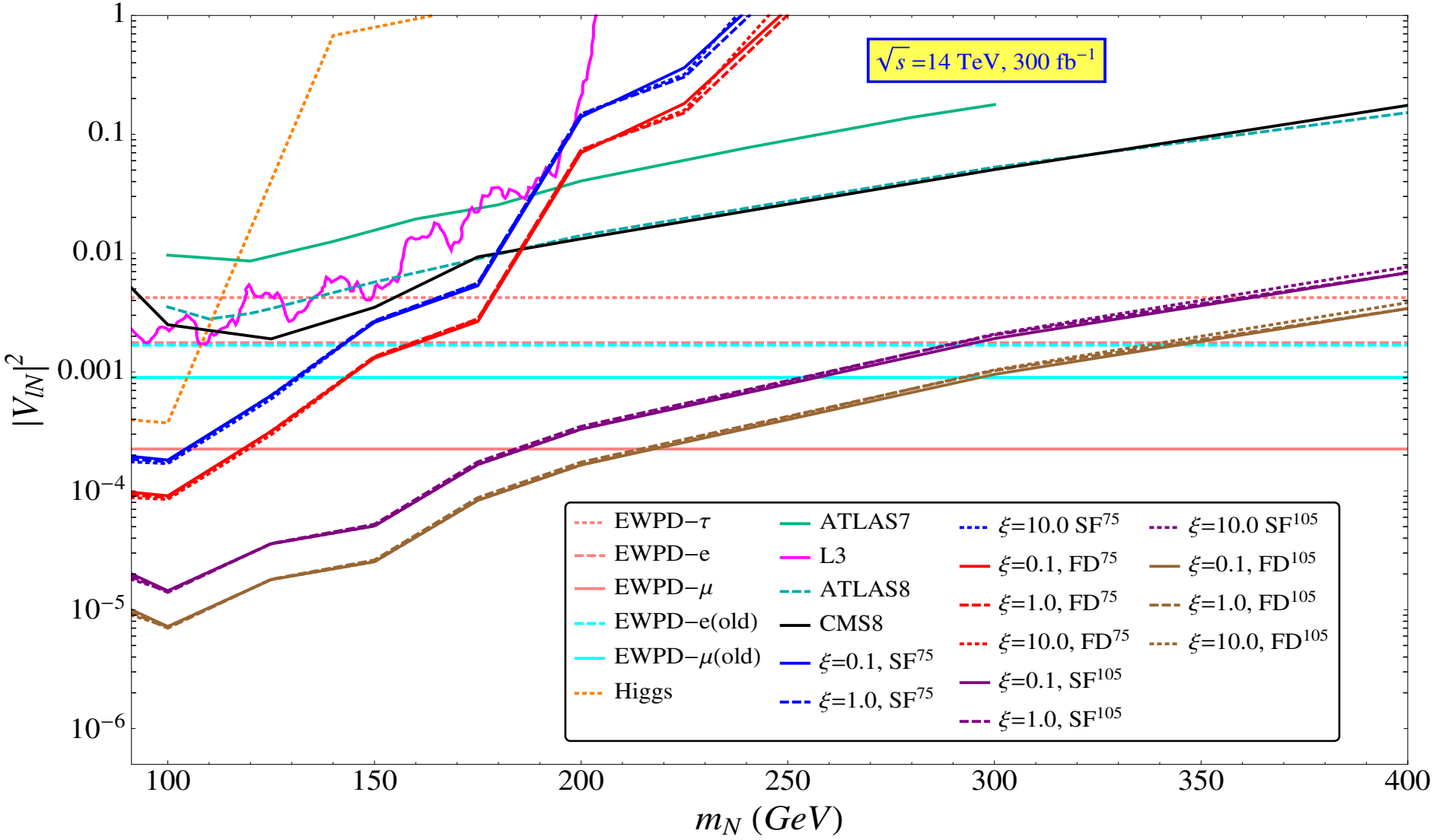


Prospective mixing angle at 100 TeV with 300 fb^{-1} luminosity From same sign dilepton plus dijet (conventional seesaw)



Prospective mixing angle at 14 TeV with 300 fb^{-1} luminosity From trilepton plus missing energy (Inverse seesaw)

$50\,\mathrm{GeV} < E_T^{\mathrm{miss}} < 100\,\mathrm{GeV} \qquad H_T > 200\,\mathrm{GeV}$



CONCLUSIONS

Topic-I

We have studied the general parameter scan for the Enhancement of the pseudo-Dirac heavy neutrino production cross section at the LHC.

We have also discussed the potential discovery mode of the pseudo-Dirac heavy neutrino at the ILC (CM energy 500 GeV) and enhancement of the cross section by general parameterization.

Topic -II

We calculated the direct upper bounds on $|V_{lN}|^2$ from the Pseudo-Dirac heavy neutrino using the tri-lepton + MET signal from the multi-lepton search from the 8 TeV CMS data using quark- gluon fusion.

Topic-III

We studied a variety of initial states such as quark-quark, quark-gluon and the gluon-gluon fusions.

From the same sign di-lepton signal for the Majorana type Heavy neutrino production in conventional seesaw mechanism we improve the upper bound on the mixing angles using the CMS and ATLAS results at 8 TeV.

We used the CMS results @ 8 TeV to improve the upper bound on $|V_{lN}|^2$ from the tri-lepton signal including all the QED and QCD processes from the pseudo-Dirac heavy neutrino in the Inverse Seesaw mechanism.

Topic -IV

We calculated the prospective upper bounds on $|V_{lN}|^2$ from the Majorana heavy neutrino using the same sign dilepton plus dijet from the 8 TeV ATLAS data using the scale dependent LO and NLO processes at the 14 TeV LHC at 300 fb^{-1}.

We did the same for the pseudo-Dirac heavy neutrino using the trilepton plus missing energy from the 8 TeV CMS data for the anomalous multilepton search using the scale dependent LO and NLO processes at the 14 TeV LHC at 300 fb^{-1}.

At LO in low mass there is a scale dependence and at NLO there is almost no scale dependence in conventional seesaw , however, in case of inverse seesaw there is almost no scale dependence.

THANK YOU

For your attention