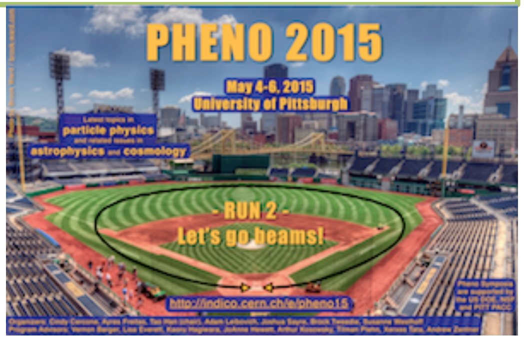
The Improved Bounds on the Heavy Neutrino Productions at the 8 TeV LHC



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Introduction

- Standard Model (SM) Neutrinos are massless
- Recent experiments on the neutrino oscillation disproves the massless-ness of the SM neutrinos.
- Extend the SM

Right Handed singlet Majorana neutrino (N_R)

- Seesaw mechanism

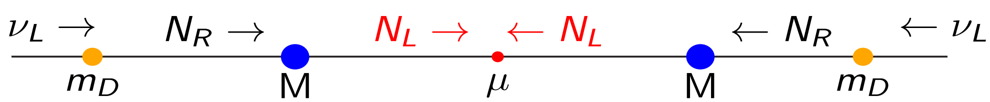
$\bullet \mathcal{L}_{Seesaw} \supset -m_D \bar{\nu}_L N_R - \frac{1}{2} M \bar{N}_R^C N_R + h.c : m_\nu = \begin{pmatrix} 0 & m_D \\ m_D & M \end{pmatrix}$ $\bullet\ m_\nu = m_D \boxed{\frac{m_D}{M}}$

- Inverse Seesaw Mechanism

Phys. Lett. B 672(2009) 235-239: Gogoladze, Okada, Shafi

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

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



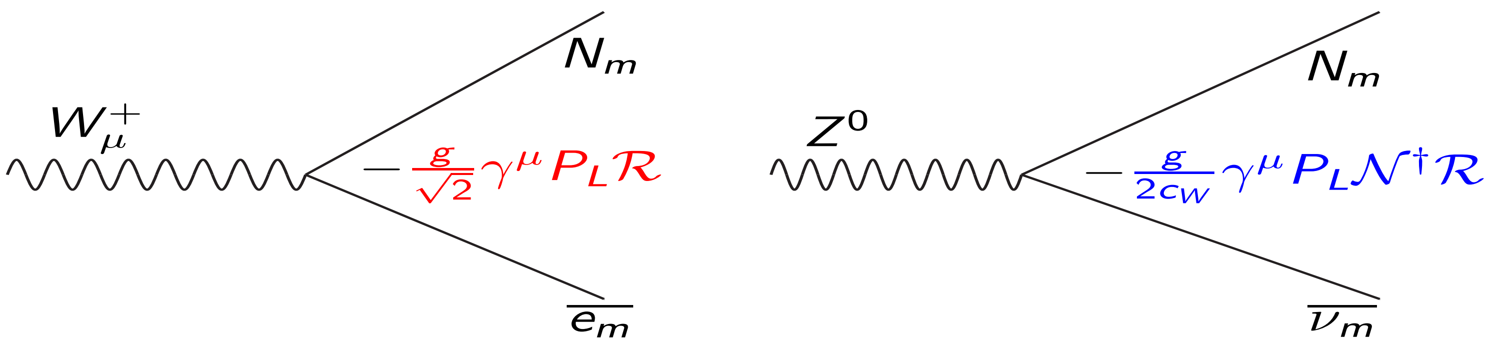
$m_D M^{-1} \ll 1,\ m_\nu = (m_D \mathbf{M}^{-1}) \mu (m_D \mathbf{M}^{-1})^T$

Heavy (Pseudo-Dirac) neutrino can be produced at high energy colliders

Charged and the neutral current interactions

The flavour eigenstate (ν) in terms of the mass eigenstates

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



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

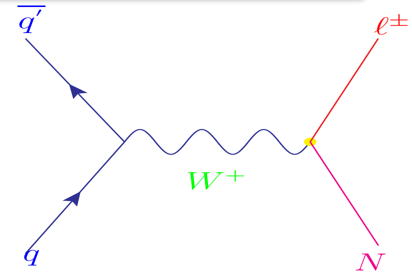
$$\begin{aligned}\mathcal{L}_{NC} &= -\frac{g}{2c_w} Z_\mu \left[\overline{\nu_m}\gamma^\mu P_L(\mathcal{N}^\dagger\mathcal{N})\nu_m + \overline{N_m}\gamma^\mu P_L(\mathcal{R}^\dagger\mathcal{R})N_m\right] \\ &- \frac{g}{2c_w} Z_\mu \left[\overline{\nu_m}\gamma^\mu P_L(\mathcal{N}^\dagger\mathcal{R})N_m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

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

(A. D. and N. Okada, PRD 88 (2013) 113001)

Various production processes

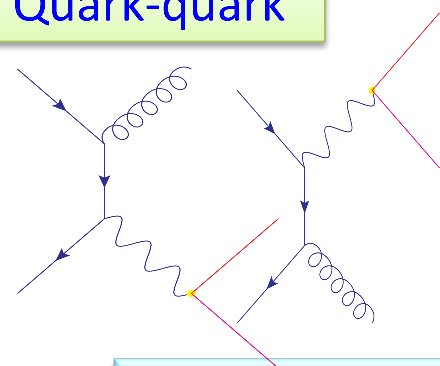
Drell-Yan(DY) Process $pp \to N\ell^{\pm}$



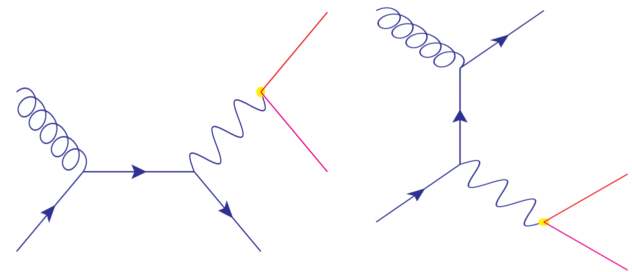
1-jet processes $pp \to N\ell^{\pm}j$

(Detail Phys. Lett. B 735 (2014) 364–370: AD, P. S. B. DeV, N. Okada)

a) Quark-quark

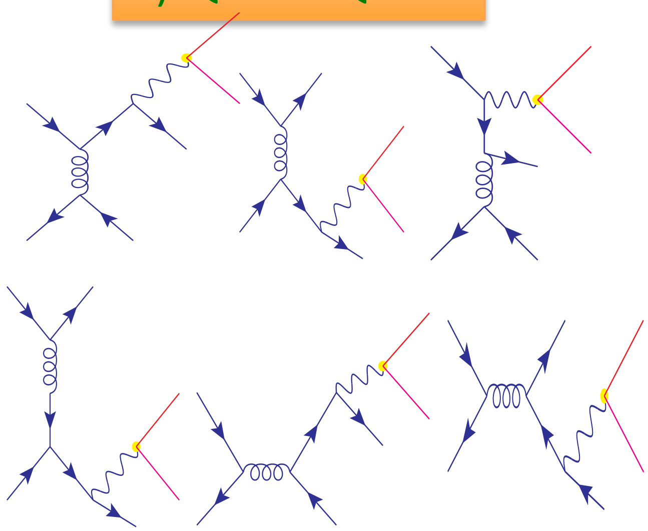


b) Quark-gluon

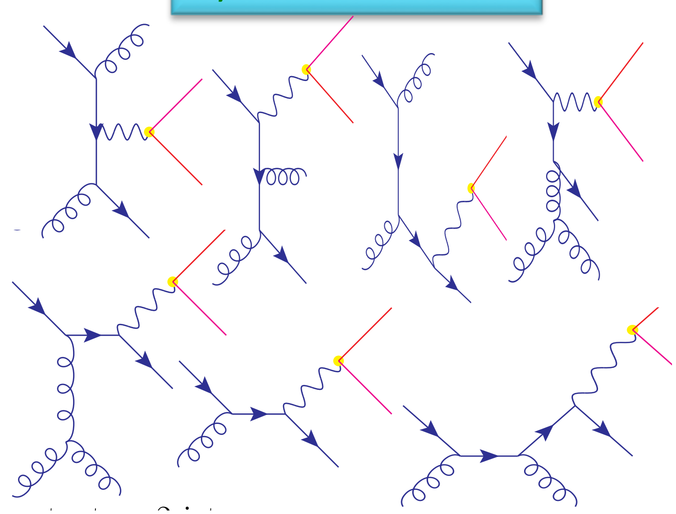


2 – jet processes $pp \to N\ell^{\pm}jj$

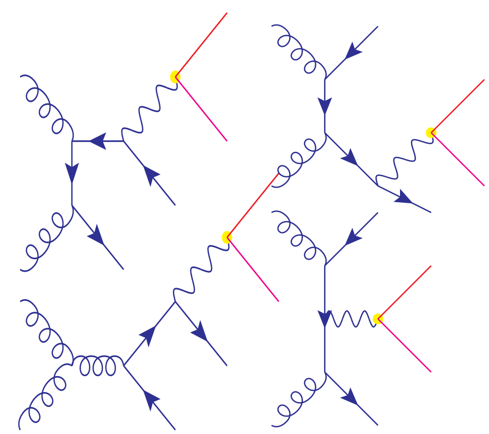
a) Quark-Quark



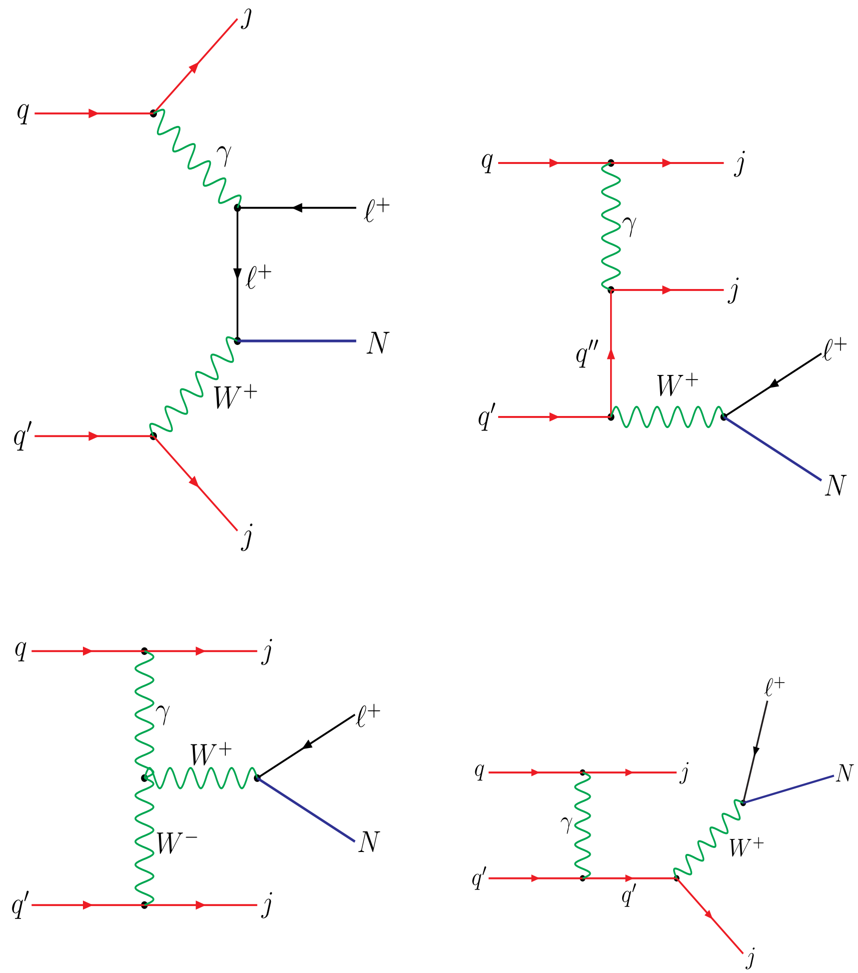
b) Quark-Gluon



c) Gluon-Gluon

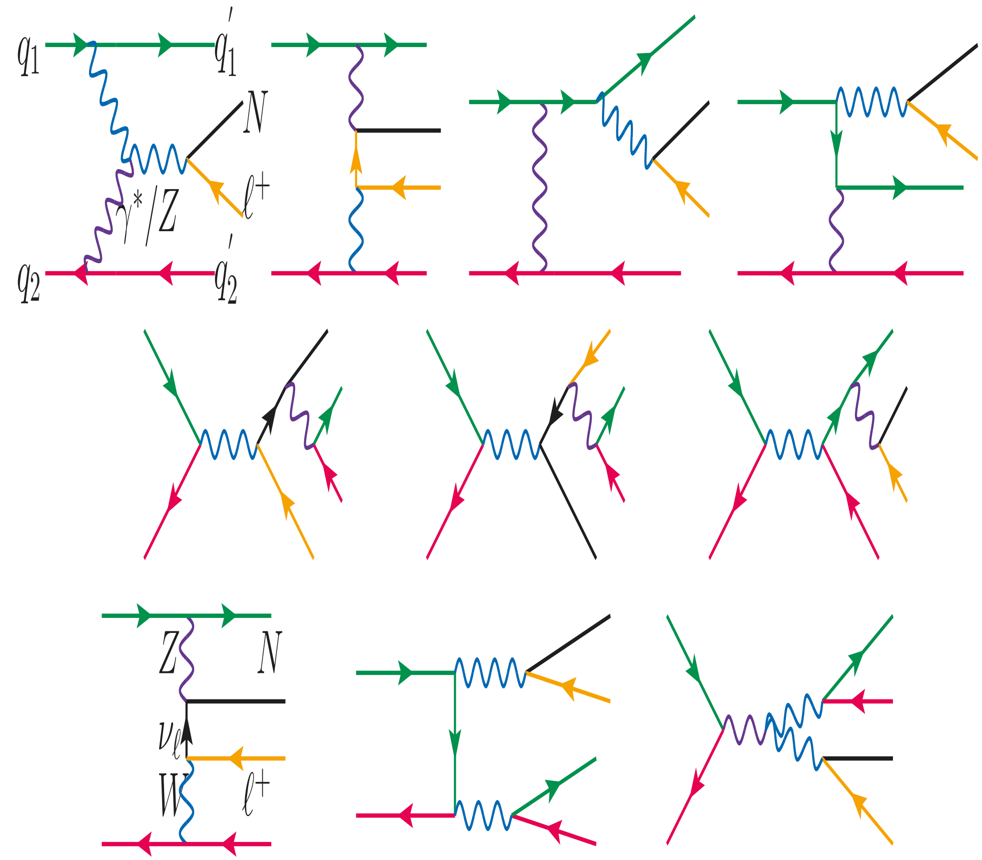


Proton-photon interaction $pa \to N\ell^{\pm}j$



Phys. Rev. Lett. 112, (2014) 8, 081801 :
P.S.B. Dev, A. Pilaftsis, U. K. Yang

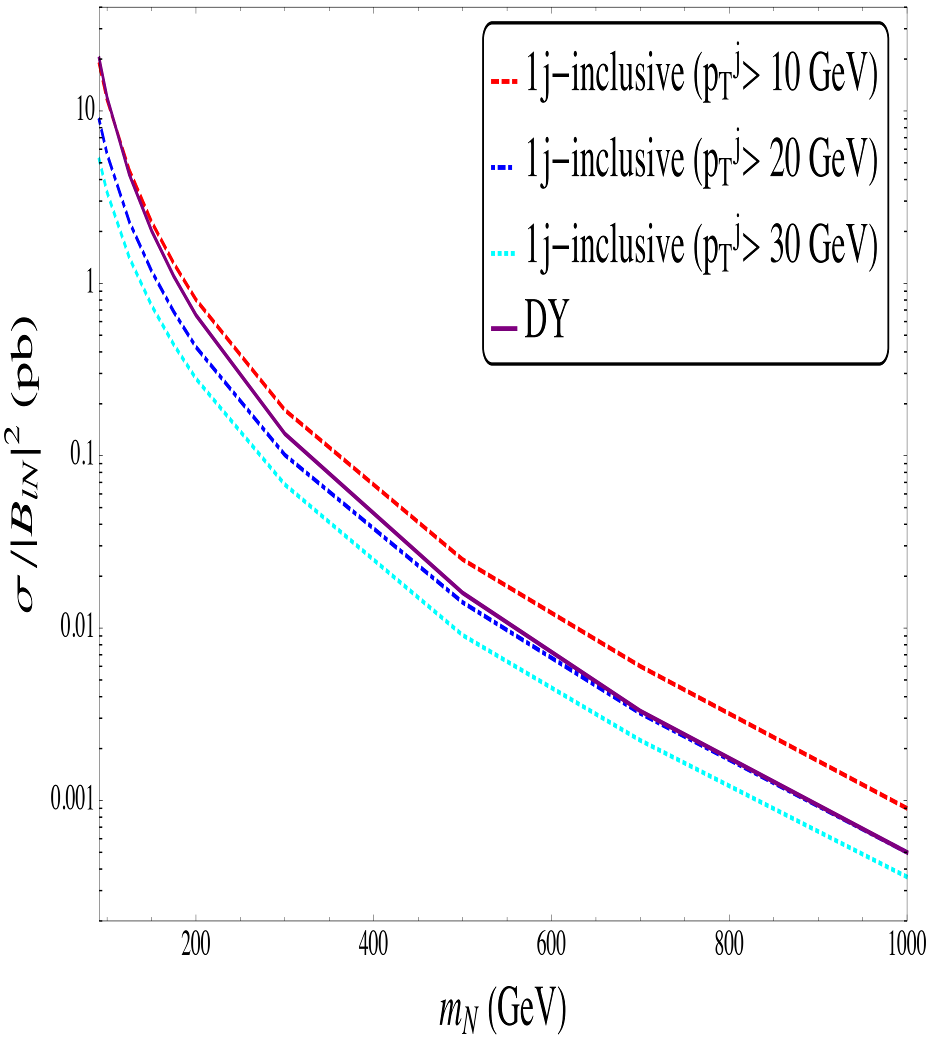
Proton-proton QED Processes $pp \to N\ell^{\pm}jj$ (QED)



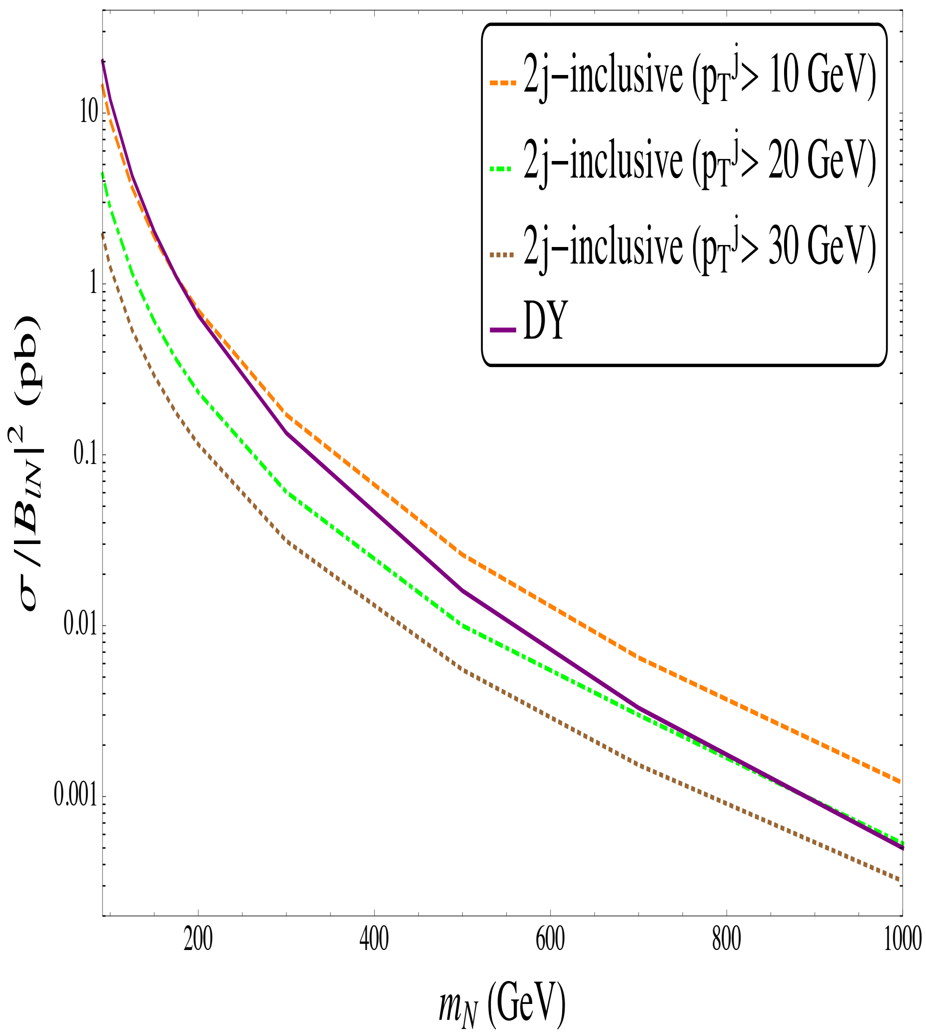
JHEP 1502 (2015) 072 : D. Alva, T. Han, R. Ruiz

Phys. Rev. D91 (2015) 075007 : G. Bambhaniya et. al

Inclusive production cross section normalized by the square of the mixing

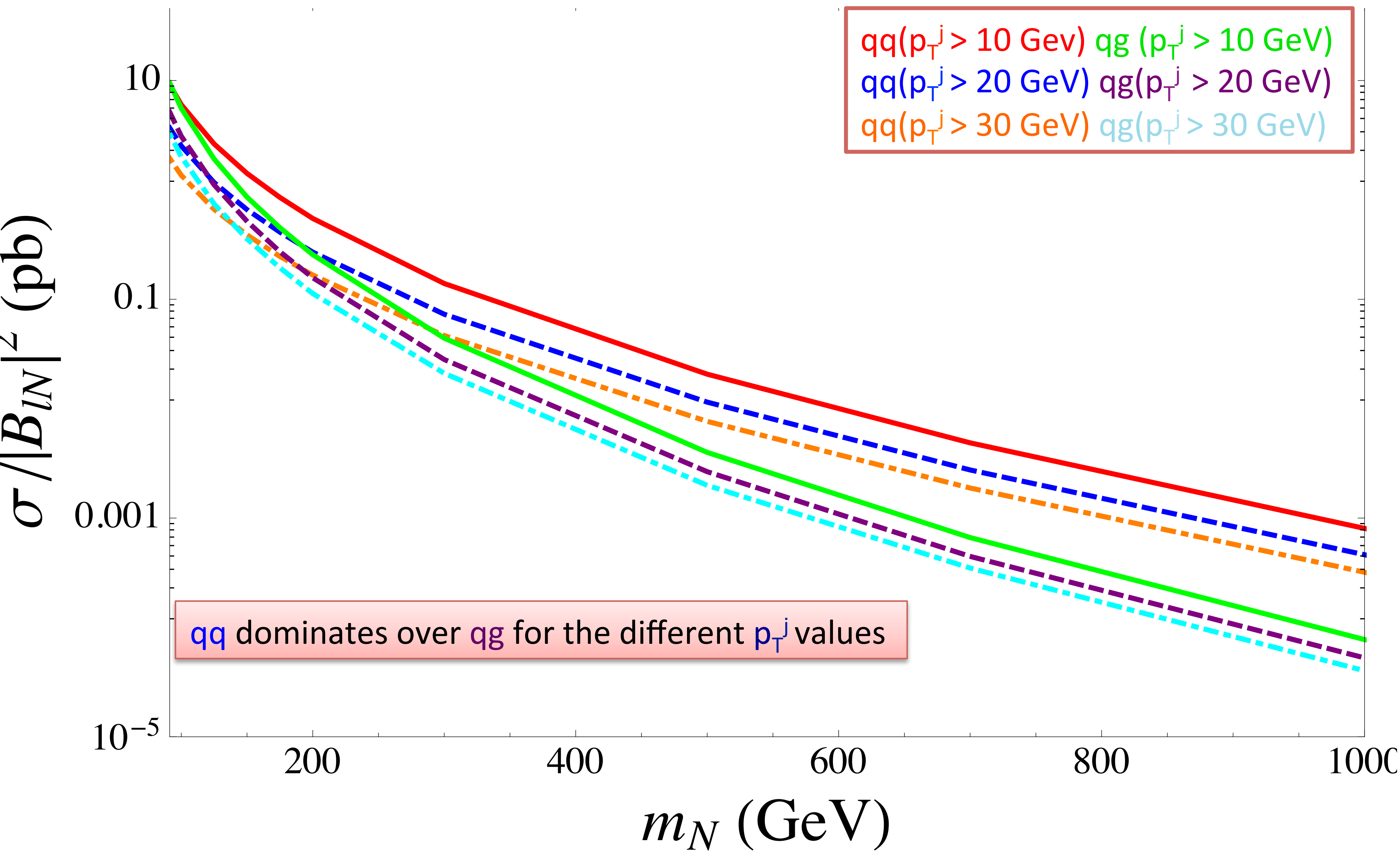


1-jet inclusive QCD

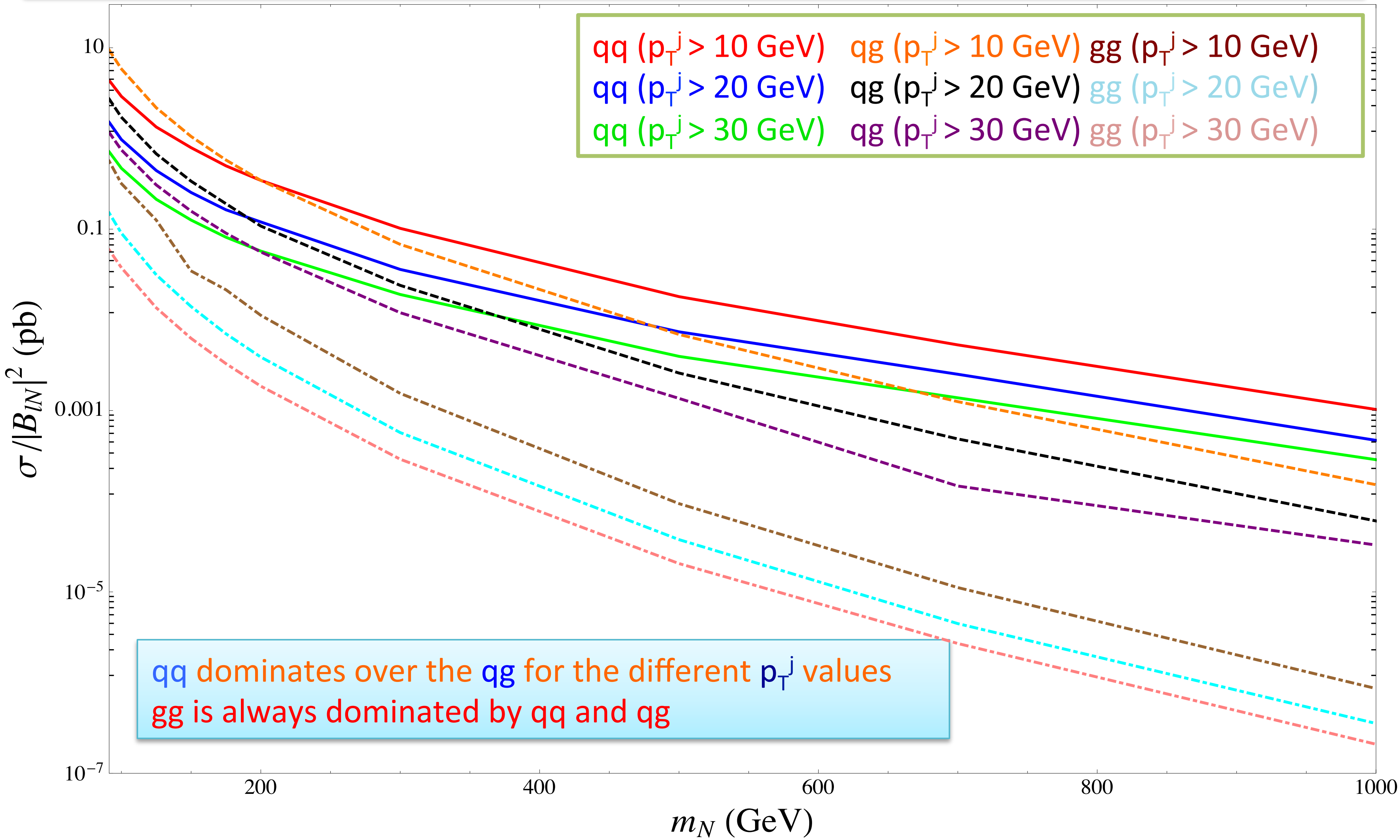


2-jet inclusive QCD

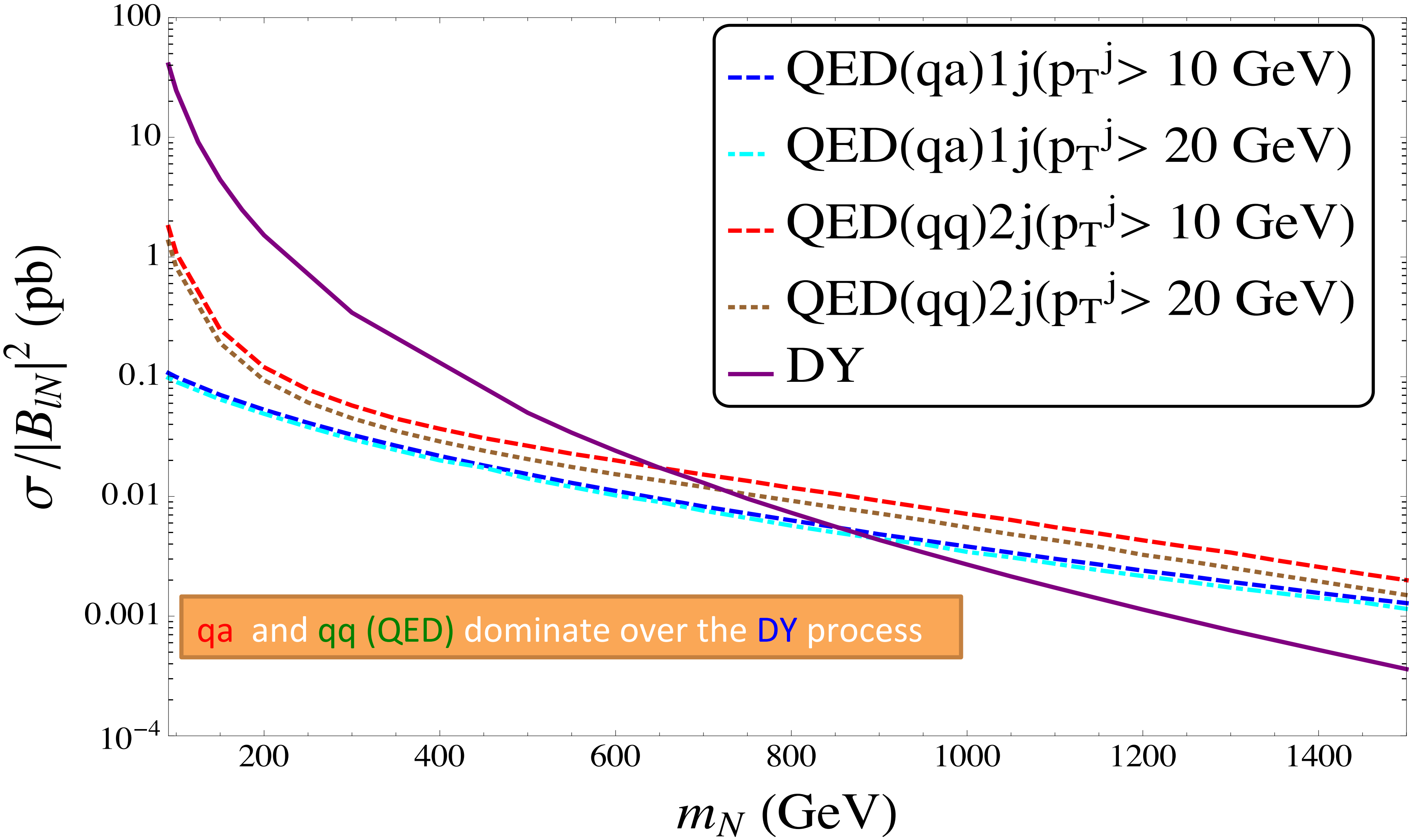
Contributions from the quark-quark and the quark-gluon interaction from the 1-jet inclusive processes normalized by the square of the mixing



Contributions from the quark-quark, quark-gluon and the gluon-gluon interactions from the 2-jet inclusive processes normalized by the square of the mixing

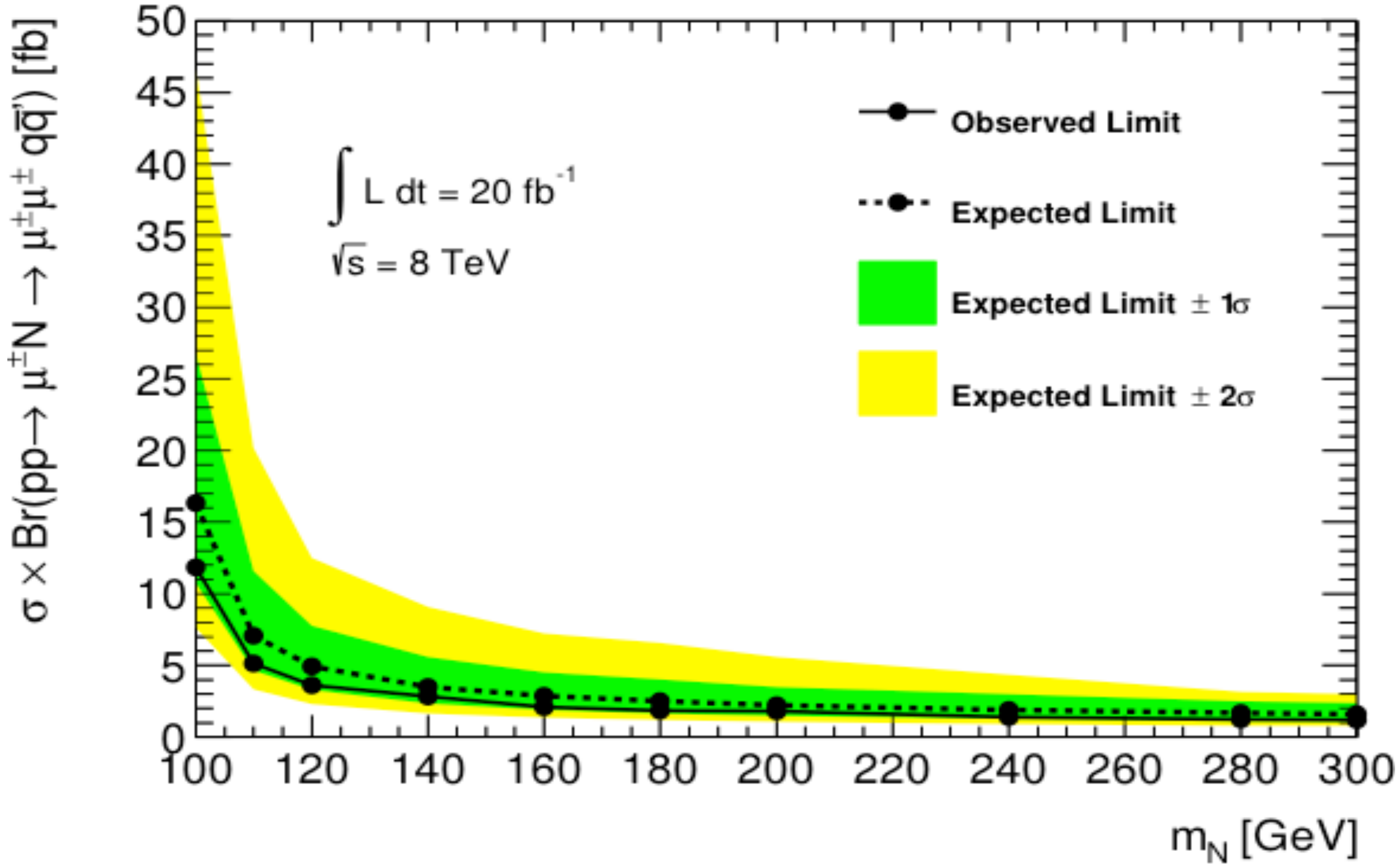


Cross sections of the 1-jet (proton- photon from proton) and 2-jet QED processes normalized by the square of the mixing



Signal Process at the LHC

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

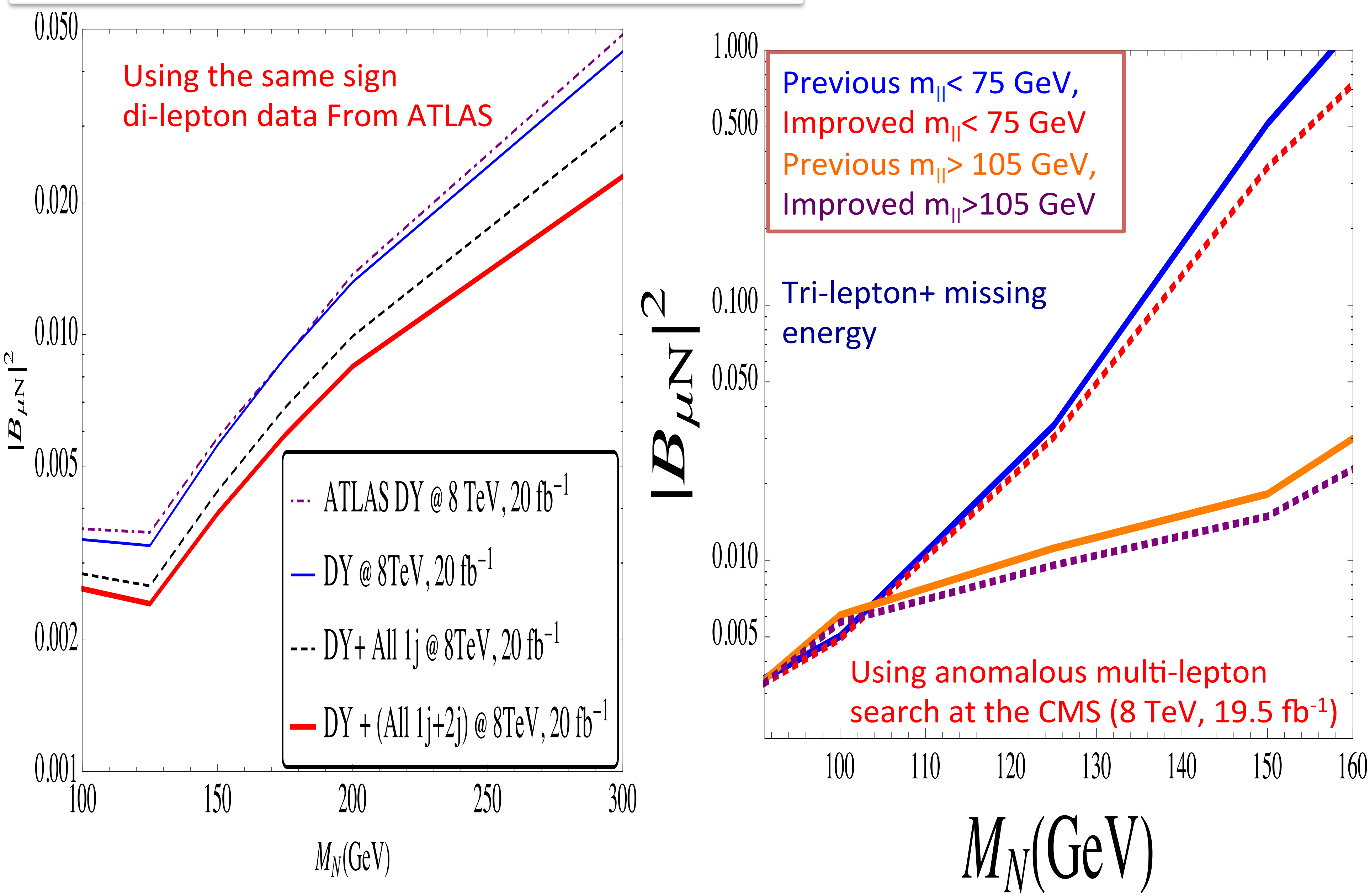


CMS Criteria for tri-lepton signal at 8 TeV LHC. [arXiv:1404.5801[hep-ex]], 19. 5 fb^{-1}

(i) The transverse momentum of each lepton: $p_T^\ell > 10$ GeV.
(ii) The transverse momentum of at least one lepton: $p_T^{\ell,\mathrm{leading}} > 20$ 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$\pm$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$\pm$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.

Upper bound on the Mixing Square



CONCLUSIONS

- We studied the seesaw and the inverse seesaw mechanisms for generation of the SM neutrino mass including the heavy right handed neutrinos.
- The production mechanisms of the Heavy Neutrino at the LHC.
- We studied the contributions from the quark-quark, quark-gluon and the gluon-gluon fusions to produce the heavy neutrinos.
- We used the same sign di-lepton signal for the heavy neutrino production.
- Using the recent ATLAS analysis of the same sign di-lepton data we improve the upper limit on the mixing angle including all the QED and QCD processes.
- We use the CMS results to improve the upper bound from the tri-lepton signal including all the QED and QCD processes.