NLO corrections to resonant sneutrino/slepton production at hadron collider

Swapan Majhi

Collaboration with :

V. Ravindran
Debajyoti Choudhury

pascos 2003

TIFR, India

January 3 - 8

- Introduction
- NLO corrections
- Results and Discussion
- Summary

Introduction

- Supersymmetry is a new symmetry that relate fermions and bosons

$$Q|bosons\rangle = |fermions\rangle$$

$$Q|fermions\rangle = |bosons\rangle$$

- One of the main features of supersymmetry is

$$n_B = n_F$$

- Every SM particle has a superpartner

Particle content in MSSM

Names		spin 0	spin 1/2	$SU(3)_C, SU(2)_L, U(1)_Y$
squarks, quarks	Q	$(\widetilde{u}_L \;\; \widetilde{d}_L)$	$(u_L \;\; d_L)$	$(\,\mathbf{3},\ \mathbf{2}\,,\ \frac{1}{6})$
(×3 families)	$\overline{u}$	$\widetilde{u}^*_R$	$u^\dagger_R$	$(\,\overline{\mathbf{3}},\ \mathbf{1},\ -\frac{2}{3})$
	$\overline{d}$	$\widetilde{d}^*_R$	$d^\dagger_R$	$(\,\overline{\mathbf{3}},\ \mathbf{1},\ \frac{1}{3})$
sleptons, leptons	L	$(\widetilde{\nu} \;\; \widetilde{e}_L)$	$(\nu \;\; e_L)$	$(\,\mathbf{1},\ \mathbf{2}\,,\ -\frac{1}{2})$
(×3 families)	$\overline{e}$	$\widetilde{e}^*_R$	$e^\dagger_R$	$(\,\mathbf{1},\ \mathbf{1},\ 1)$
Higgs, higgsinos	H_u	$(H^+_u \;\; H^0_u)$	$(\widetilde{H}^+_u \;\; \widetilde{H}^0_u)$	$(\,\mathbf{1},\ \mathbf{2}\,,\ +\frac{1}{2})$
	H_d	$(H^0_d \;\; H^-_d)$	$(\widetilde{H}^0_d \;\; \widetilde{H}^-_d)$	$(\,\mathbf{1},\ \mathbf{2},\ -\frac{1}{2})$

Chiral superfields in the MSSM

Names	spin 1/2	spin 1	$SU(3)_C, SU(2)_L, U(1)_Y$
gluino, gluon	$\widetilde{g}$	g	$(\,\mathbf{8},\ \mathbf{1}\,,\ 0)$
winos, W bosons	$\widetilde{W}^\pm \;\; \widetilde{W}^0$	$W^\pm \;\; W^0$	$(\,\mathbf{1},\ \mathbf{3}\,,\ 0)$
bino, B boson	$\widetilde{B}^0$	B^0	$(\,\mathbf{1},\ \mathbf{1}\,,\ 0)$

Gauge superfields in the MSSM

Introduction

- In supersymmetry, the most general gauge invariant renormalizable superpotential is

$$W = W_{MSSM} + W_{\not R_p}$$

$$W_{MSSM} = h^e_{ij} L_i H_1 E^c_j + h^d_{ij} Q_i H_1 D^c_j + h^u_{ij} Q_i H_2 U^c_j + \mu H_1 H_2$$

$$W_{\not R_p} = \frac{1}{2}\lambda_{ijk} L^a_i L^b_j E^c_k + \underline{\lambda'_{ijk} L^a_i Q^b_j D^c_k} + \frac{1}{2}\lambda''_{ijk} U^c_i D^c_j D^c_k + k_i L_i H_2$$

$$L_{\triangle L=1} = \lambda'_{ijk}[\underline{\tilde{\nu}^i_L \bar{d}^k_R d^j_L} + \nu^i_L \bar{d}^k_R \tilde{d}^j_L + \bar{\nu^c}^i_L (\tilde{d}^k_R)^\star d^j_L \underline{-\tilde{e}^i_L \bar{d}^k_R d^j_L} - e^i_L \bar{d}^k_R \tilde{d}^j_L - \bar{e^c}^i_L (\tilde{d}^k_R)^\star d^j_L] + h.c.$$

- $\not{R}_p$ violating interaction term can produce resonant sneutrino, slepton and squark (from $q\bar{q}$) at hadron collider.

- H.Dreiner, P. Richardson and M.H.Seymour have done their calculation for the resonant sneutrino, slepton production cross-section at the tree level.

- So may be QCD correction is relevant for these type of processes.

Motivation

- Problem in calculating the LO cross-section at the high energy.

- QCD corrections - quark, antiquark and gluon interact among themselves.

- Higher order corrections enhanced the LO cross-section.

NLO corrections

- The processes are

$$q\bar{q} \;\to\; \tilde{\nu} \qquad (Treelevel)$$

$$q\bar{q} \;\to\; \tilde{\nu} \qquad (oneloop\ \mathcal{O}(\alpha_s))$$

$$q\bar{q} \;\to\; \tilde{\nu} g \qquad (bremsstrahlung\ \mathcal{O}(\alpha_s))$$

$$qg \;\to\; \tilde{\nu} q \qquad (compton\ \mathcal{O}(\alpha_s))$$

- Divergences present in any higher order corrections:

(i) UV-divergence $(k -> \infty)$

(ii) IR -divergence $(k -> 0)$

IR-divergence

soft | collinear

($\lambda \to 0, \lambda$ is the mass of the gauge field) ....

(Both$\lambda, m \to 0, m$ is the mass of the of the matter field)

- Procedure to remove the divergences:

$\boxed{\text{UV + IR (soft + collinear)-divergences}}$

Renormalisation

$\boxed{\text{IR (soft + collinear)-divergences}}$

Virtual + real

$\boxed{\text{IR (collinear)-divergence}}$

KLN-theorem or Mass Factorisation

$\boxed{\text{Finite}}$

- We have done the calculation in $n-$dimension and $\overline{MS}$ scheme.

$$\hat{\sigma}^q = \frac{1}{3}\,\frac{\pi}{2\hat{s}}\lambda_R^2\delta(1-\hat{\tau}) + \frac{1}{3}\,\frac{\alpha_s}{4\hat{s}}C_F\lambda_R^2\Big[\Big(-3\ \ln\left(\frac{q^2}{\mu^2}\right)$$

$$-2 + \frac{2\pi^2}{3}\Big)\delta(1-\hat{\tau}) + 3\ \delta(1-\hat{\tau})\ln\left(\frac{q^2}{M^2}\right)$$

$$+2(1-\hat{\tau}) + 4(1+\hat{\tau}^2)\left(\frac{\ln(1-\hat{\tau})}{(1-\hat{\tau})}\right)_+$$

$$+2\frac{1+\hat{\tau}^2}{(1-\hat{\tau})_+}\ln\left(\frac{q^2}{M^2\,\hat{\tau}}\right)\Big]$$

$$\hat{\sigma}^g = \frac{\alpha_s}{4\hat{s}}\,\frac{1}{3}\,\lambda_R^2\Big[\frac{1}{2}\,(\hat{\tau}^2 + (1-\hat{\tau})^2)\ln\left(\frac{q^2}{M^2}\right)$$

$$+\frac{1}{2}\,(\hat{\tau}^2 + (1-\hat{\tau})^2)\ln\left(\frac{(1-\hat{\tau})^2}{\hat{\tau}}\right)$$

$$+\frac{1}{4}\,(1-\hat{\tau})(7\hat{\tau}-3)\ \Big]$$

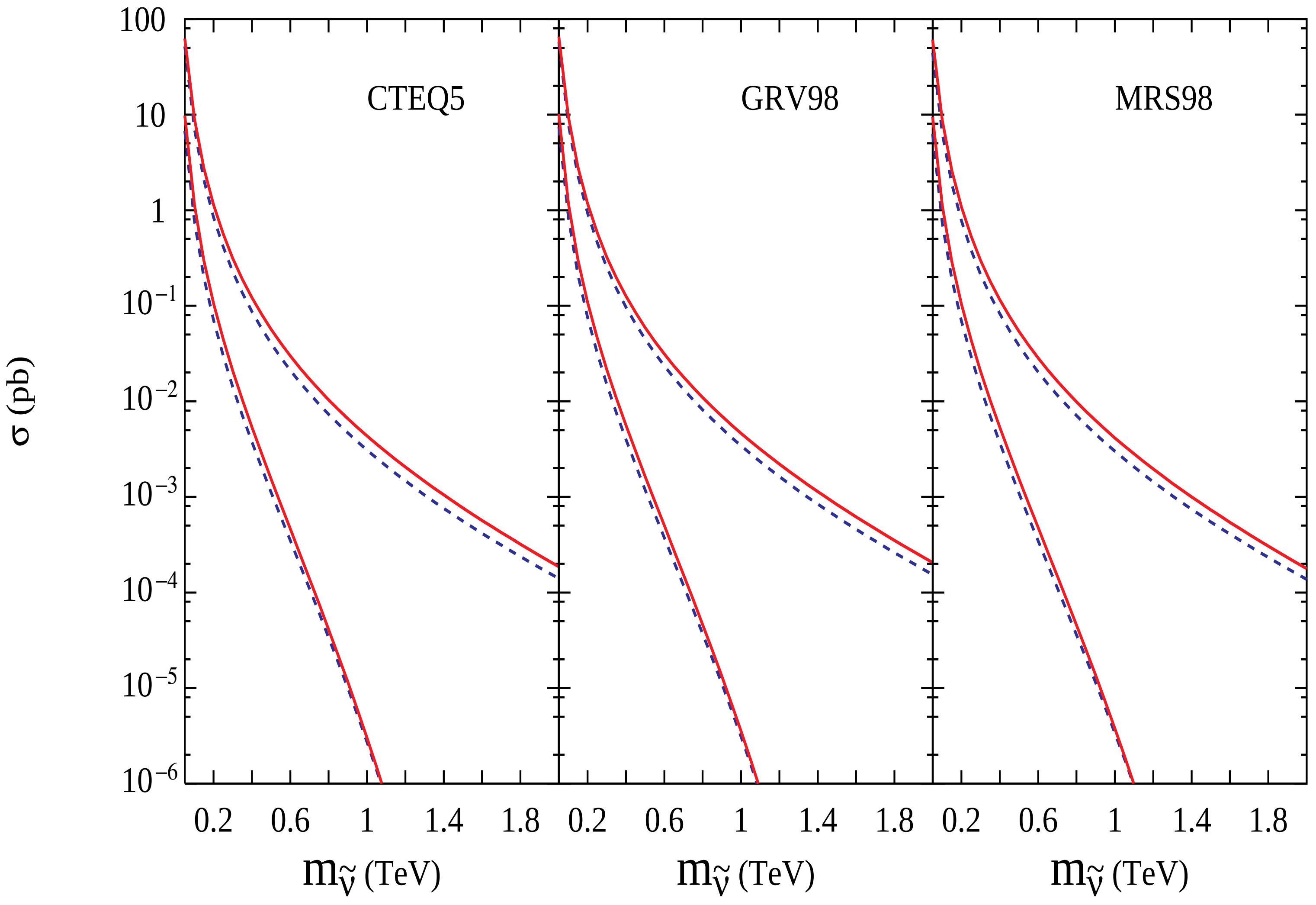
Where $\hat{\tau} = q^2/\hat{s}$.

Results and Discussion

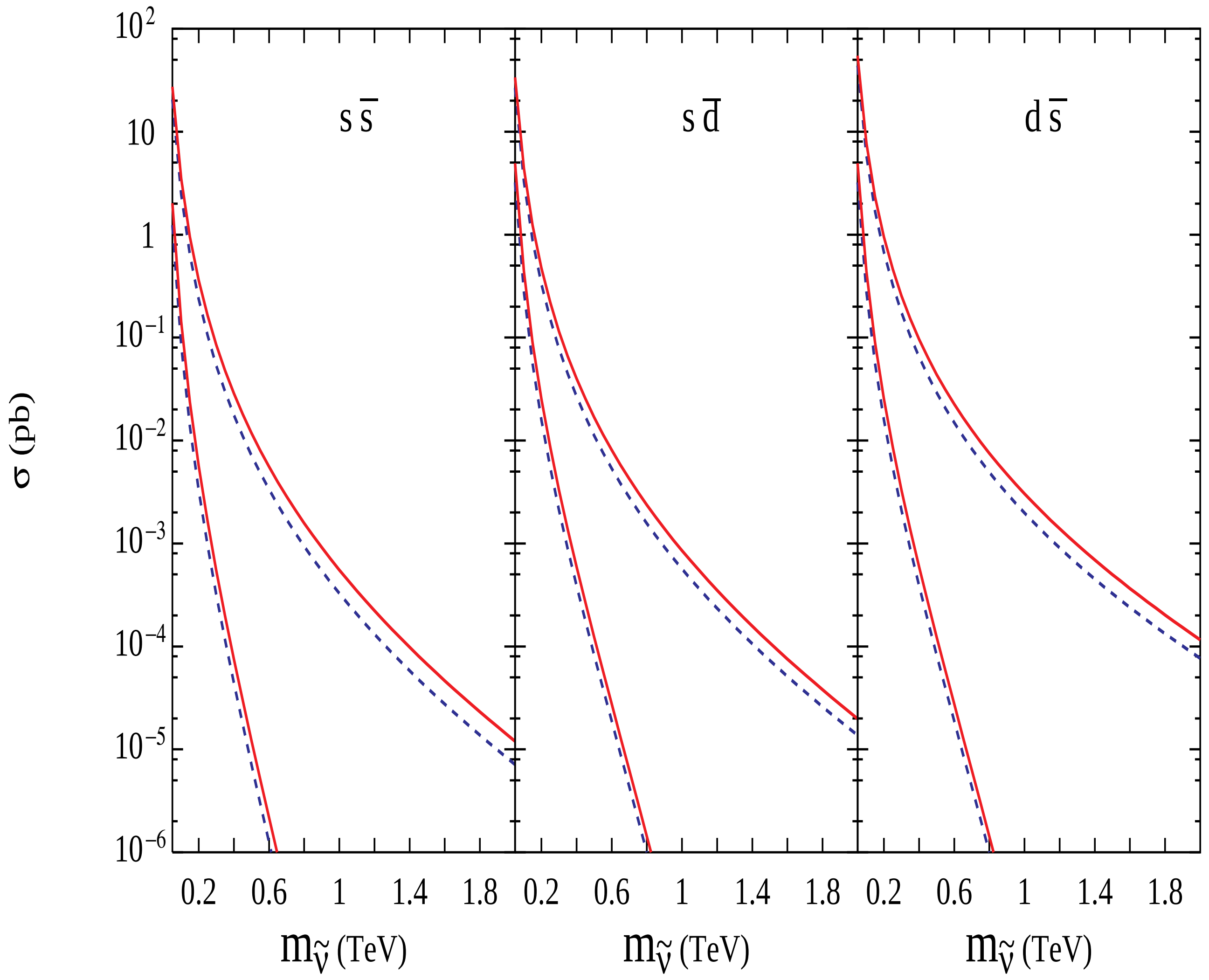
- We have performed our calculation with light quarks and massive sneutrino/slepton.

- The numerical values of various constants:

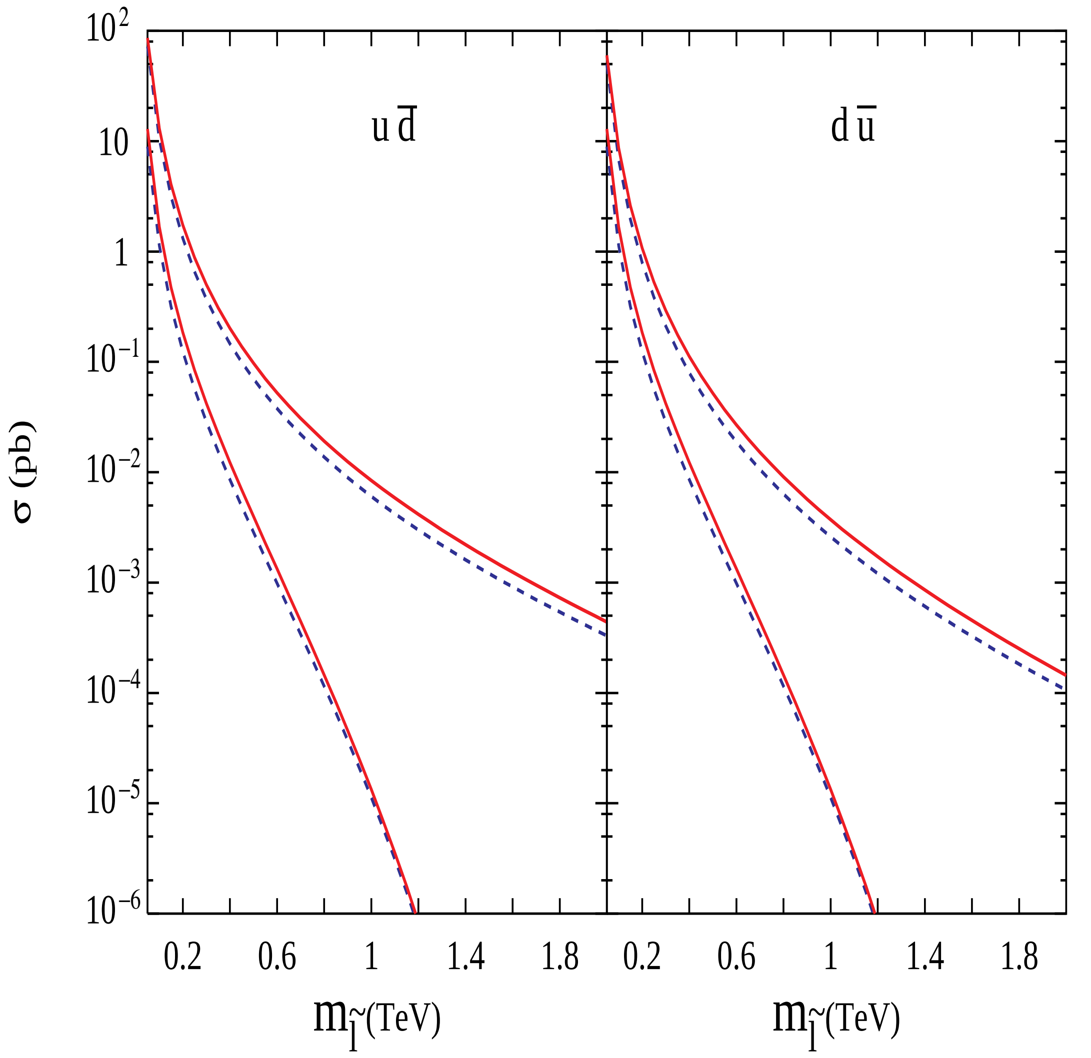
C.M. energy $\sqrt{s}$	14 TeV at LHC 2 TeV at Tevatron
R_p coupling λ'	0.01
scale (For simplicity)	$\mu^2 = M^2 = q^2 \quad (ms^2)$
Strong coupling α_s (Running coupling)	$\alpha_s(Q^2) = \alpha_s(M_Z^2) \times \ln(\frac{M_Z^2}{\Lambda^2}) / \ln(\frac{Q^2}{\Lambda^2})$ $\alpha_s(M_Z^2) = 0.118$ (typically)



- The solid (dashed) lines represent the NLO (LO) cross-sections. The R_P violating coupling has been set to $\lambda_{i11} = 0.01$.



σ (pb)
10^2
10
1
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
$s\bar{s}$
$s\bar{d}$
$d\bar{s}$
0.2
0.6
1
1.4
1.8
$m_{\tilde{\nu}}$ (TeV)

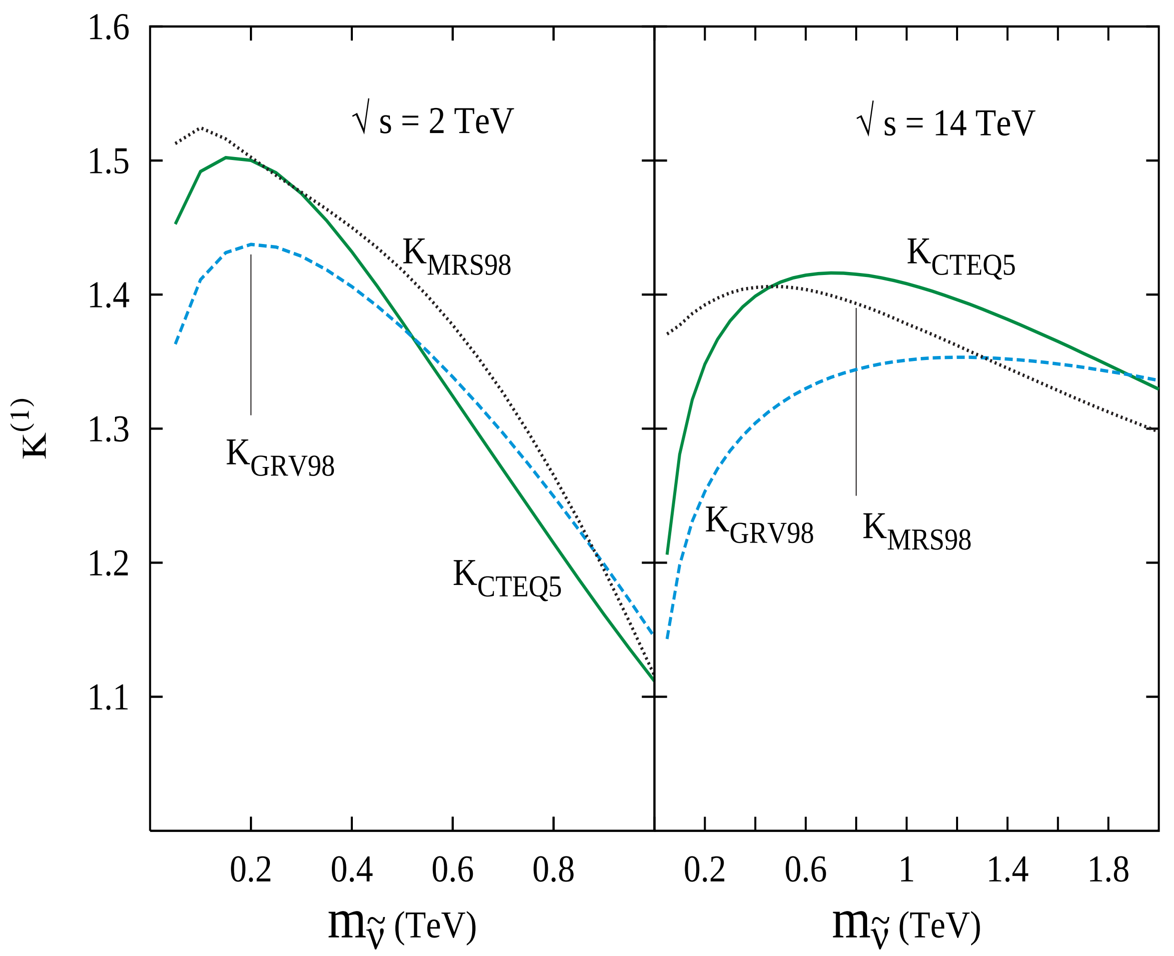


σ (pb)
10^2
10
1
10^-1
10^-2
10^-3
10^-4
10^-5
10^-6
u d̄
d ū
0.2
0.6
1
1.4
1.8
m_l̃ (TeV)

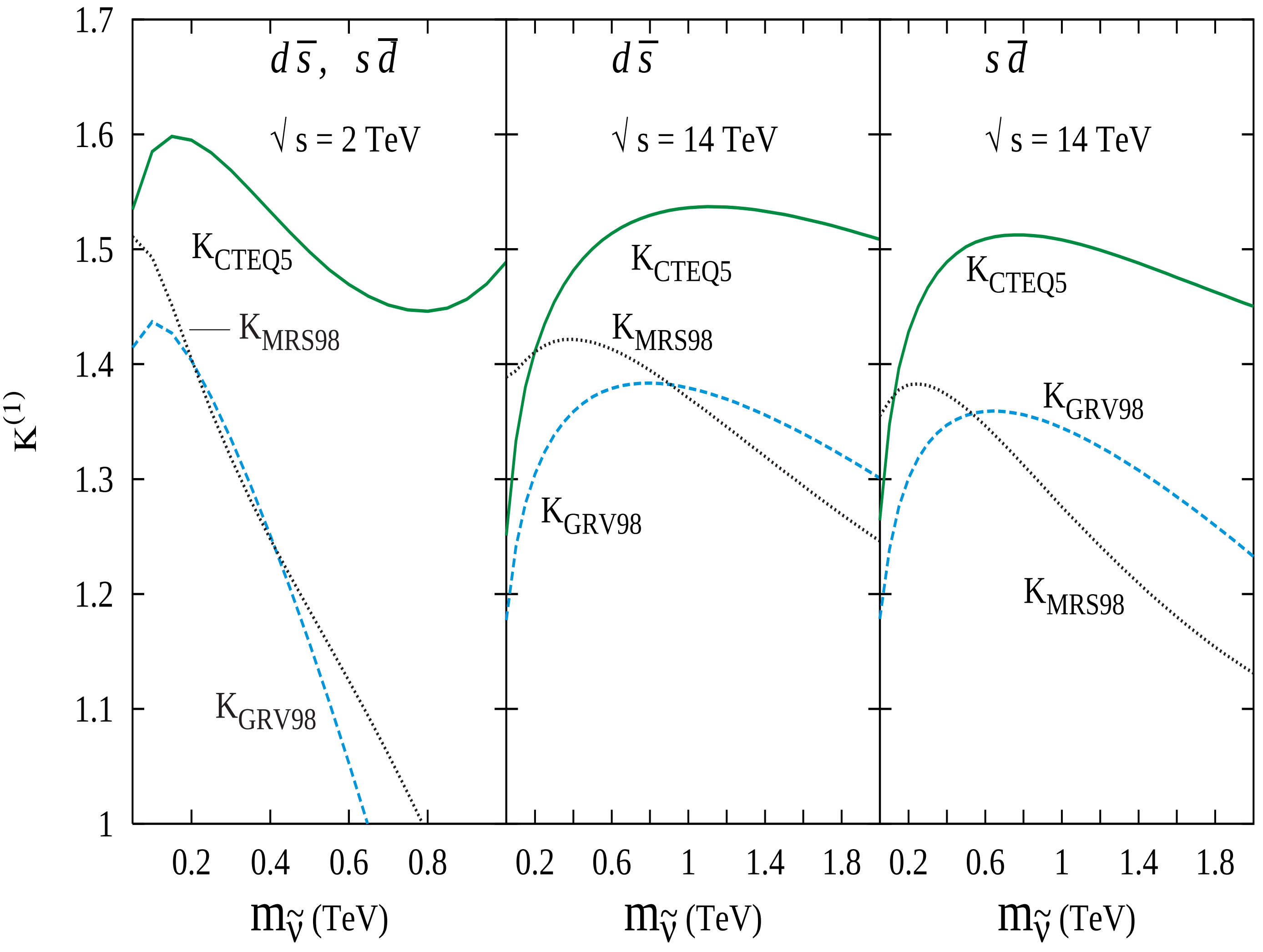
- QCD corrections increase the LO cross-section about 20% - 40% for both the machine Tevatron and LHC

- The K-factor is defined as

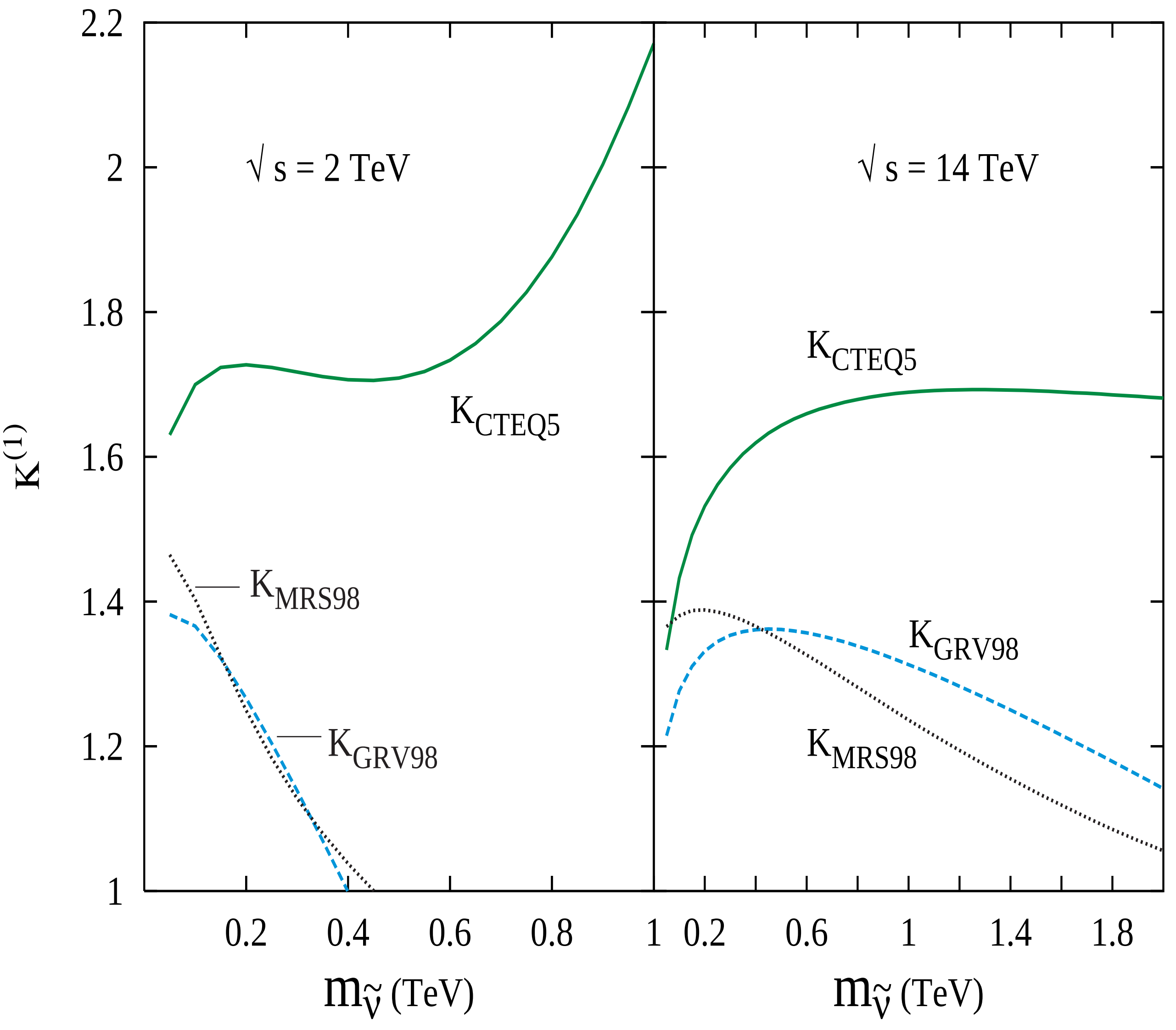
$$K = \frac{\sigma_{\mathrm{NLO}}}{\sigma_{\mathrm{LO}}}$$



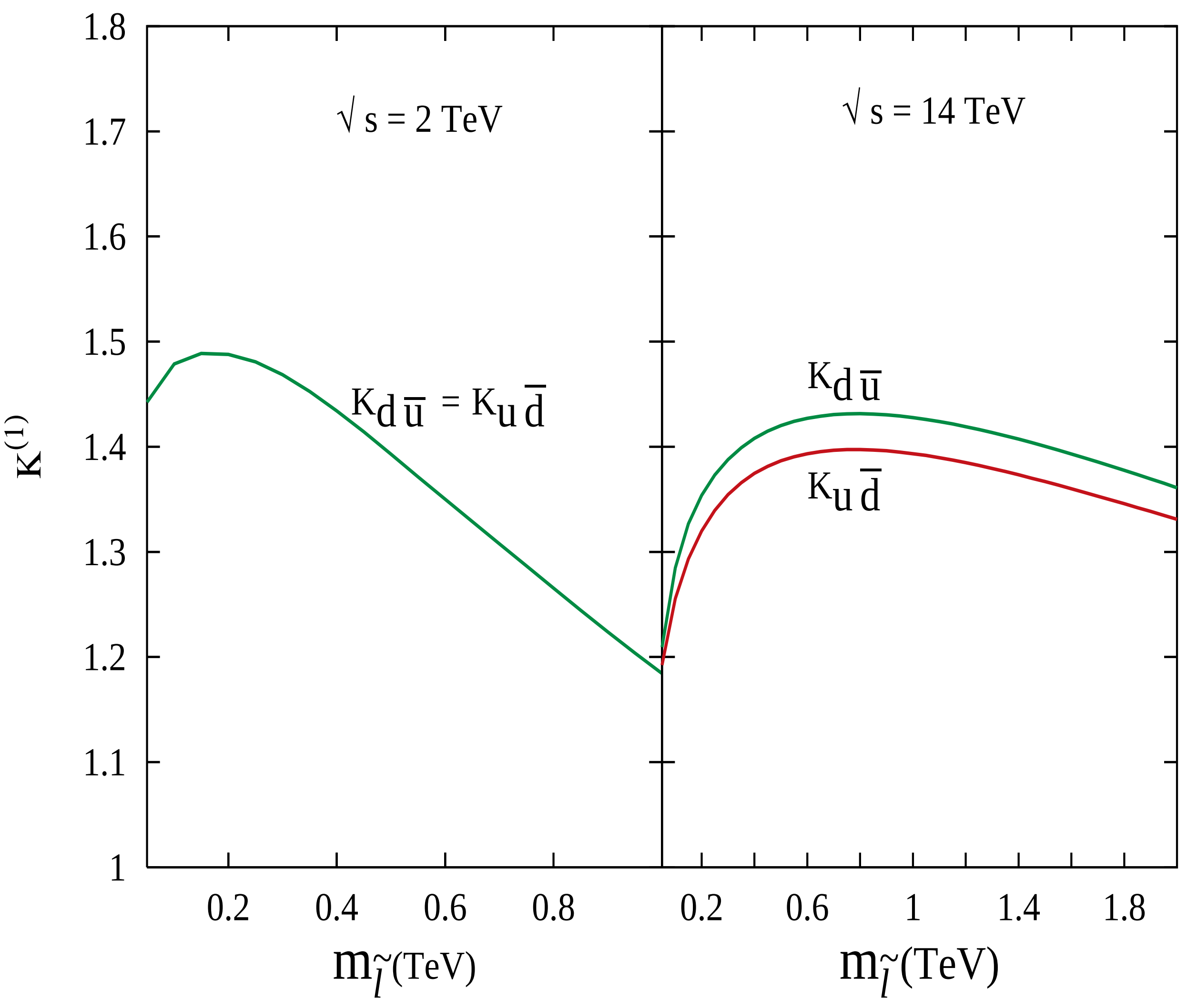
- K-factor for the processes involving coupling λ'_{i11} as a function of smeutrino mass.



- K-factor for the processes involving coupling λ'_{i21} *or* λ'_{i12} as a function of smeutrino mass.



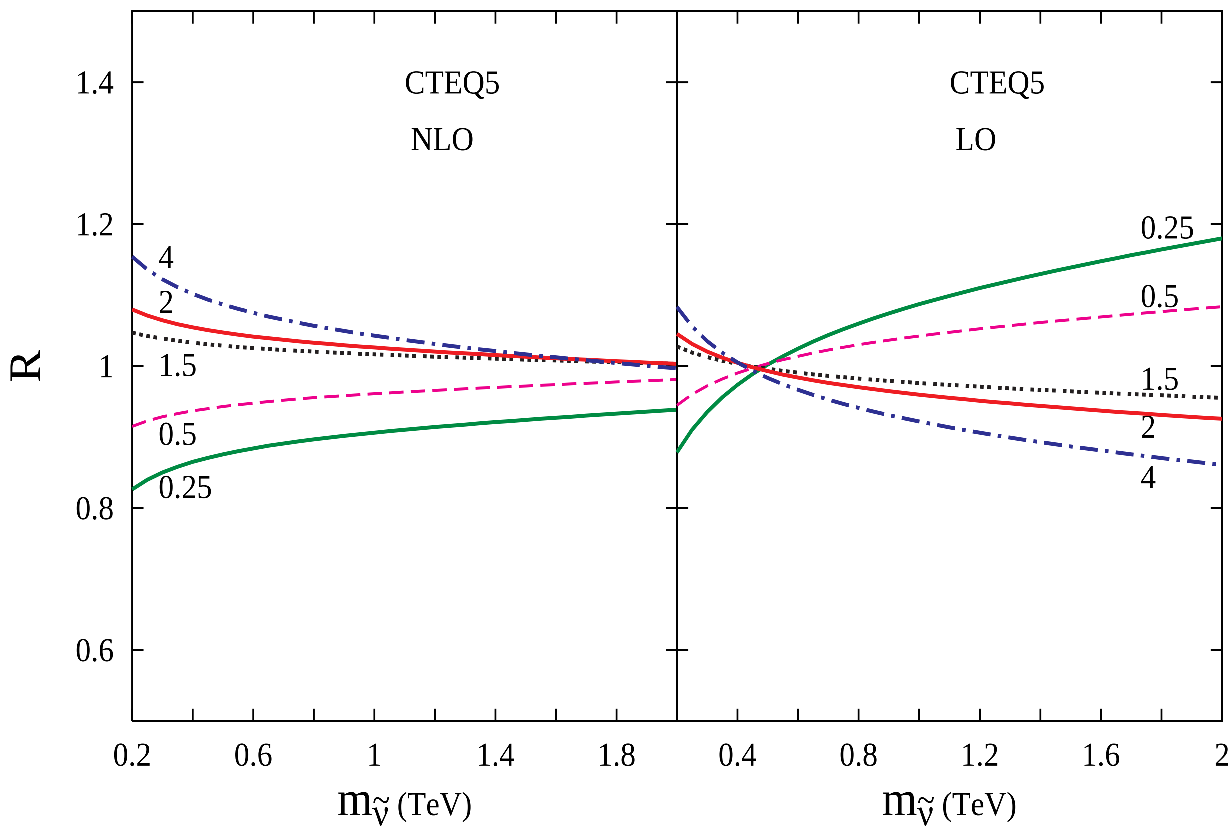
• K-factor for the processes involving coupling λ'_{i22} as a function of smeutrino mass.



- K-factor for the processes involving coupling λ'_{i11} as a function of smeutrino mass.

• The renormalisation scale dependence of the cross-section. Define a quantity R as:

$$R_{\mathrm{NLO}}(\mu_F; m_{\tilde{\nu}}) \equiv \frac{\sigma_{\mathrm{NLO}}(\mu_F)}{\sigma_{\mathrm{NLO}}(\mu_F = m_{\tilde{\nu}})}$$



summary and conclusion

- We have calculated the NLO correction to resonant sneutrino/slepton production cross-section for both LHC and Tevatron.

- Production cross-section is larger in LHC than Tevatron

- K -factor is larger in Tevatron than LHC

- Since production cross-sections are large enough to be interesting, an $NNLO$ calculation seems to be called for future study.

- This calculation can be applied to any color-singlet scalar (pseudoscalar) coupling to quark-antiquark pair.

$d\bar{d} \to \tilde{\nu}_i$ $\lambda'_{i11} = 0.01$

Slepton mass (GeV)	Central Gluon (Pb)		Higher Gluon (Pb)	
	LO	NLO	LO	NLO
50	6.49	8.62	6.42	8.53
100	0.73	0.99	0.73	0.98
150	0.18	0.25	0.18	0.25
200	6.28×10^{-2}	8.74×10^{-2}	6.30×10^{-2}	8.74×10^{-2}
250	2.53×10^{-2}	3.56×10^{-2}	2.55×10^{-2}	3.58×10^{-2}
300	1.12×10^{-2}	1.60×10^{-2}	1.13×10^{-2}	1.61×10^{-2}
350	5.31×10^{-3}	7.63×10^{-3}	5.38×10^{-3}	7.72×10^{-3}
400	2.60×10^{-3}	3.78×10^{-3}	2.64×10^{-3}	3.83×10^{-3}
450	1.31×10^{-3}	1.92×10^{-3}	1.33×10^{-3}	1.95×10^{-3}
500	6.71×10^{-4}	9.98×10^{-4}	6.81×10^{-4}	1.01×10^{-3}