Supersymmetric NLO QCD Corrections to Top Quark Pair Production at Hadron Colliders

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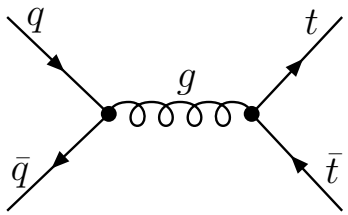
1. Introduction
2. MSSM parameters and limits
3. SQCD corrections for unpolarized top quark pair production
4. SQCD corrections for polarized top quark pairs
5. Conclusion

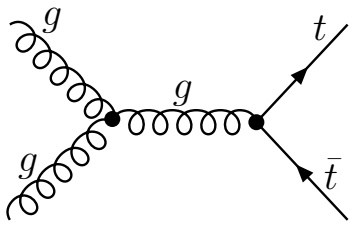
1. Introduction: Top quark pair production at Hadron Colliders

Partonic Tree level production modes:

$q\bar{q}$-annihilation:



gg-fusion:



$+\ t, u$ channels

LO: *Glück (1978), Combridge (1978), Babcock et al. (1978), Hagiwara et al. (1979), Jones et al. (1978), Georgi et al. (1978)*

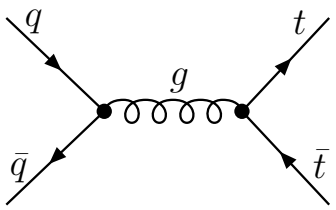
NLO-QCD: *Nason, Dawson, Ellis (1988), Beenakker, Kuijf, van Neerven, Smith (19989)*

NNLO-QCD: *see Kidonakis, Vogt, hep-ph/0410367 and references*

NLO-EW: *Beenakker et al. (1993)*

1. Introduction: NLO MSSM corrections

$q\bar{q}$-annihilation:



NLO supersymmetric EW corrections:

Hollik, Mösle, Wackeroth (1998) (unpolarized)

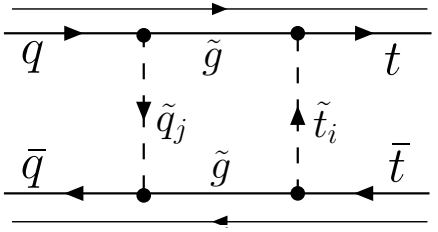
Kao, Wackeroth (1999) (polarized top quarks)

NLO supersymmetric QCD corrections (unpolarized):

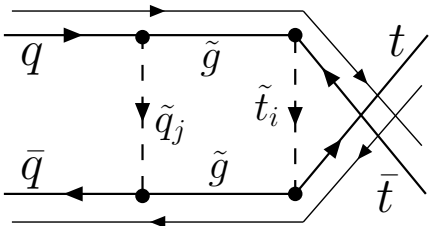
C. Li et al. (1995), S. Alam et al. (1996), Z. Sullivan (1996),

D. Wackeroth (1998), S. B. (1999)

Direct Box:



Crossed Box:

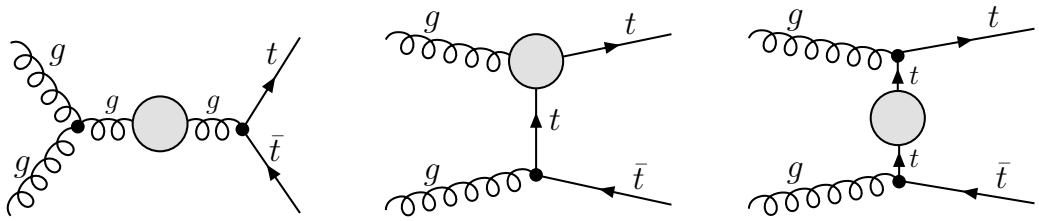


Denner, Eck, Hahn, Küblbeck (1992)

"Feynman rules for fermion-number-violating interactions"

1. Introduction: NLO MSSM corrections

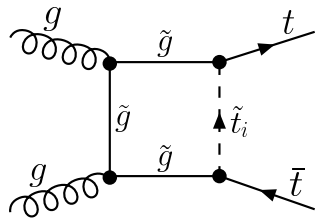
gg-fusion:



NLO supersymmetric EW corrections:

Hollik, Mösle, Wackeroth (1998) (unpolarized)

Kao, Wackeroth (1999) (polarized top quarks)



NLO supersymmetric QCD corrections:

Zhou, Li (1997) (unpolarized)

Zeng-Hui, Pietschmann, Wen-Gan, Liang, Yi (1999) (polarized gluons)

We examine the NLO SQCD corrections for the combined $q\bar{q}$ and gg channels at Tevatron and LHC for unpolarized and polarized top quark pairs.

2. MSSM Parameters and limits

- Lagrangian of the MSSM top squark sector:

$$\mathcal{L} = -(\tilde{t}_L^*, \tilde{t}_R^*)\,\mathcal{M}\begin{pmatrix}\tilde{t}_L \\ \tilde{t}_R\end{pmatrix} = -(\tilde{t}_1^*, \tilde{t}_2^*)\begin{pmatrix} m_{\tilde{t}_1}^2 & 0 \\ 0 & m_{\tilde{t}_2}^2\end{pmatrix}\begin{pmatrix}\tilde{t}_1 \\ \tilde{t}_2\end{pmatrix}$$

with

$$\begin{pmatrix}\tilde{t}_1 \\ \tilde{t}_2\end{pmatrix} = \begin{pmatrix} \cos\theta_{\tilde{t}} & \sin\theta_{\tilde{t}} \\ -\sin\theta_{\tilde{t}} & \cos\theta_{\tilde{t}}\end{pmatrix}\begin{pmatrix}\tilde{t}_L \\ \tilde{t}_R\end{pmatrix}$$

and

$$\mathcal{M} = \begin{pmatrix} m_{\tilde{t}_L}^2 & m_t X_t \\ m_t X_t & m_{\tilde{t}_R}^2\end{pmatrix}$$

2. MSSM Parameters and limits

- Mixing Matrix:

$$\mathcal{M} = \begin{pmatrix} m^2_{\tilde{t}_L} & m_t X_t \\ m_t X_t & m^2_{\tilde{t}_R} \end{pmatrix} = \begin{pmatrix} \cos^2\theta_{\tilde{t}}\, m^2_{\tilde{t}_1} + \sin^2\theta_{\tilde{t}}\, m^2_{\tilde{t}_2} & \sin\theta_{\tilde{t}}\cos\theta_{\tilde{t}}\,(m^2_{\tilde{t}_1} - m^2_{\tilde{t}_2}) \\ \sin\theta_{\tilde{t}}\cos\theta_{\tilde{t}}\,(m^2_{\tilde{t}_1} - m^2_{\tilde{t}_2}) & \sin^2\theta_{\tilde{t}}\, m^2_{\tilde{t}_1} + \cos^2\theta_{\tilde{t}}\, m^2_{\tilde{t}_2} \end{pmatrix}$$

- $\mathcal{M}$ is invariant under the transformation:

  1) $\theta_{\tilde{t}} \longrightarrow \theta_{\tilde{t}} + n \cdot \pi \quad (n \in \mathcal{I})$

  2) $m^2_{\tilde{t}_1} \leftrightarrow m^2_{\tilde{t}_2}$ and $\theta_{\tilde{t}} \longrightarrow \theta_{\tilde{t}} + \pi/2$

- $\longrightarrow$ Choosing $m_{\tilde{t}_2}$ as the lighter squark and varying $-\pi/2 \leq \theta_{\tilde{t}} \leq \pi/2$

2. MSSM Parameters and limits

- $q\bar{q}, gg \longrightarrow t\bar{t}$ depends on $(q = u, d, s, c)$:

  $m_{\tilde{g}}$, $m_{\tilde{t}_{1,2}}$, $\theta_{\tilde{t}}$, $m_{\tilde{q}}$

- $m_{\tilde{t}_2}$ is the lighter squark mass and we vary $-\pi/2 \leq \theta_{\tilde{t}} \leq \pi/2$

  $m_{\tilde{b}_L} = m_{\tilde{b}_R}$

  $m_{\tilde{q}}$ degenerated and $m_{\tilde{q}} = 2$ TeV

- Limits:

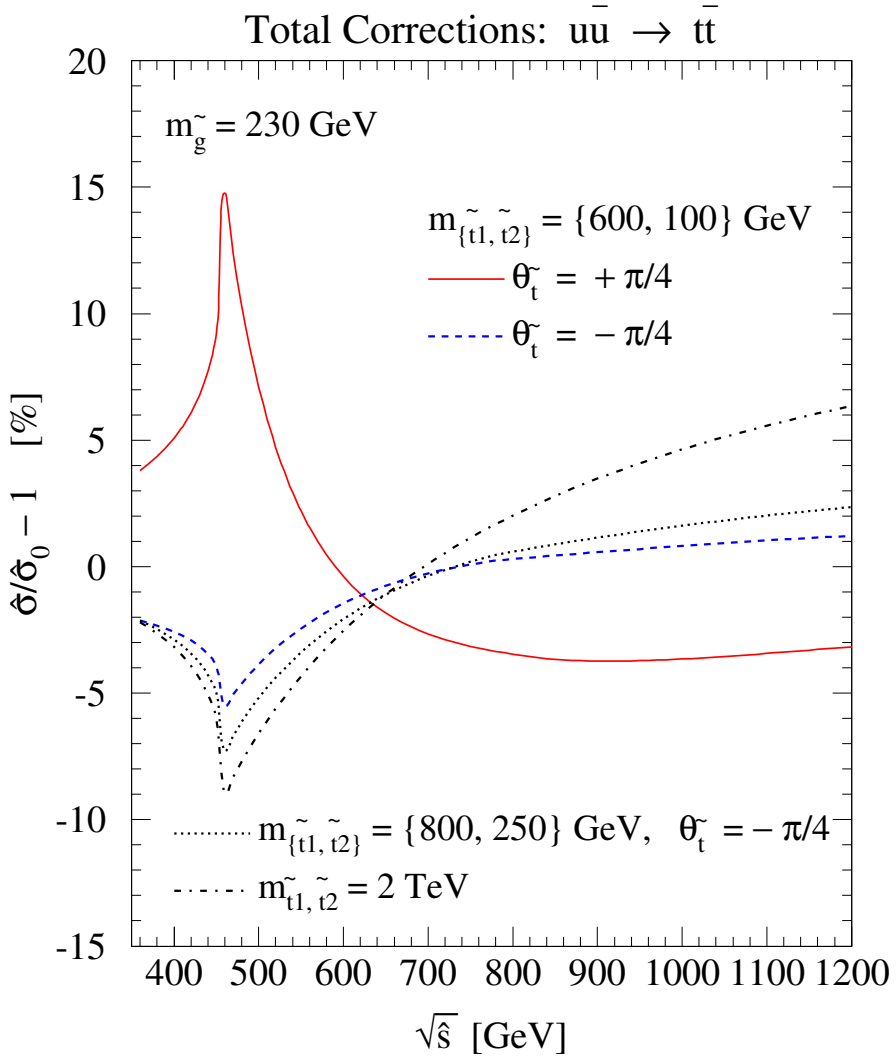
$$
\begin{aligned}
m_{\tilde{t}_2} &\geq 100 \text{ GeV} \\
m_{\tilde{b}} &\geq 100 \text{ GeV} \\
m_{\tilde{g}} &\geq 230 \text{ GeV} \qquad \textit{(Manca et al. hep-ex/0505056)} \\
\\
|\Delta\rho| &\leq 0.0035
\end{aligned}
$$

3. Unpolarized top quark pair production

$q\bar{q} \to t\bar{t}$ unpolarized partonic cross section:

- Threshold at $\sqrt{\hat{s}} = 2 \cdot m_{\tilde{g}}$
- No $\theta_{\tilde{t}}$ dependence for degenerated $m_{\tilde{t}_1}$, $m_{\tilde{t}_2}$
- Large $\theta_{\tilde{t}}$ dependence for large $m_{\tilde{t}_1}$, $m_{\tilde{t}_2}$ splitting
- Large positive for $\theta_{\tilde{t}} = +\pi/2$ negative for $\theta_{\tilde{t}} = -\pi/2$
- For $\sigma(S)$, large corrections must occur at $\sqrt{\hat{s}} = 350 - 550$ GeV

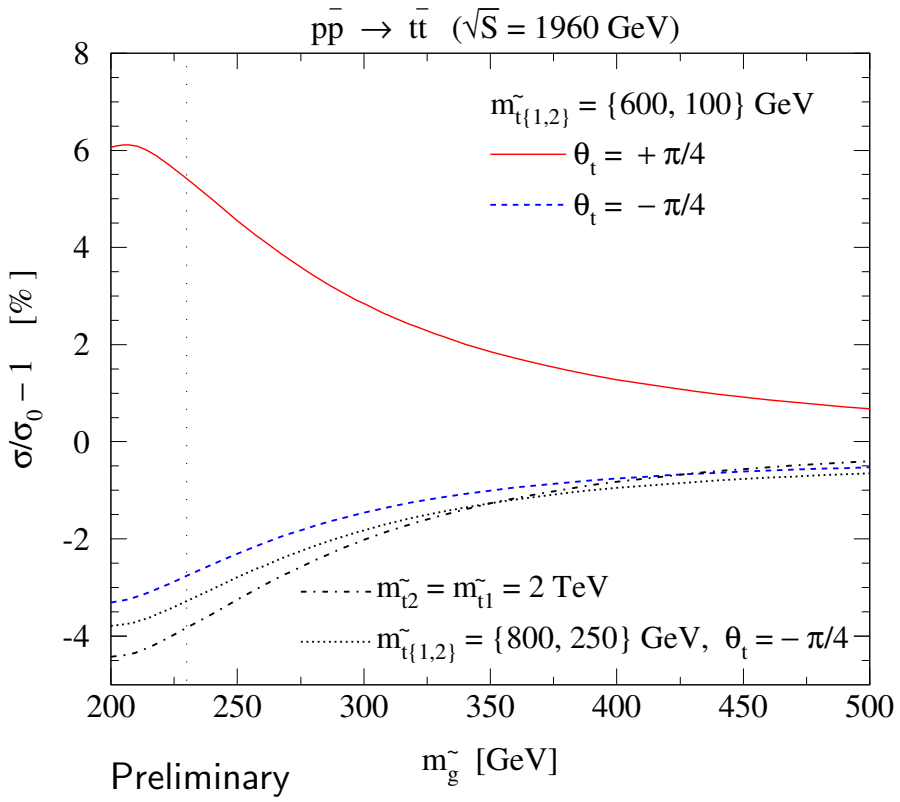
Similar behavior for gg fusion channel



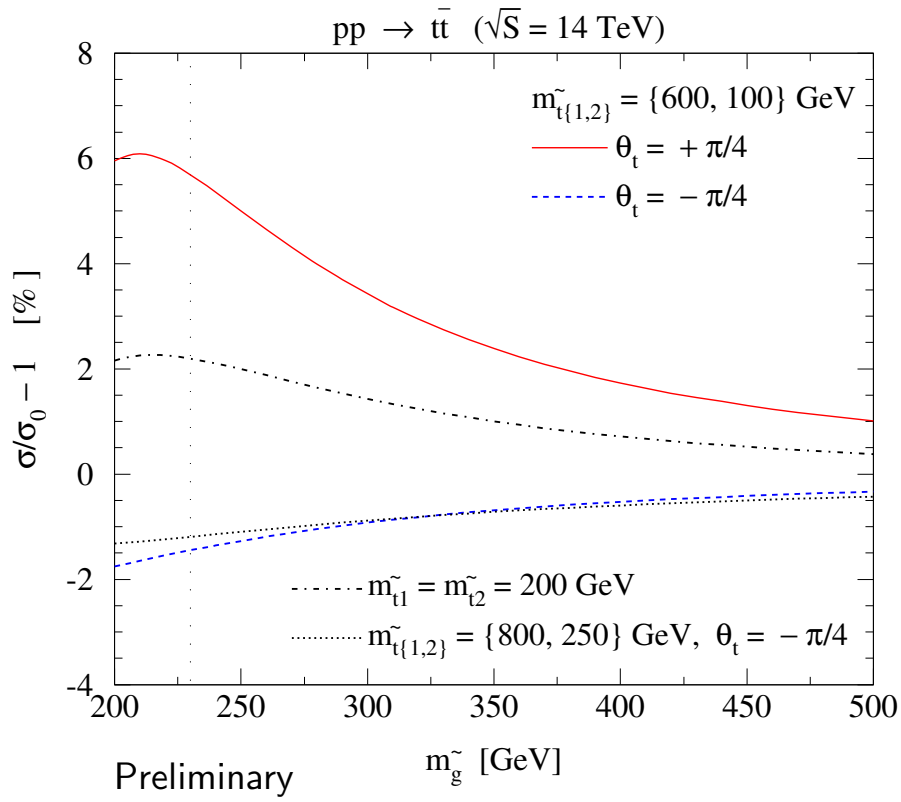
Preliminary

3. Unpolarized top quark pair production at Hadron Colliders

Tevatron



LHC



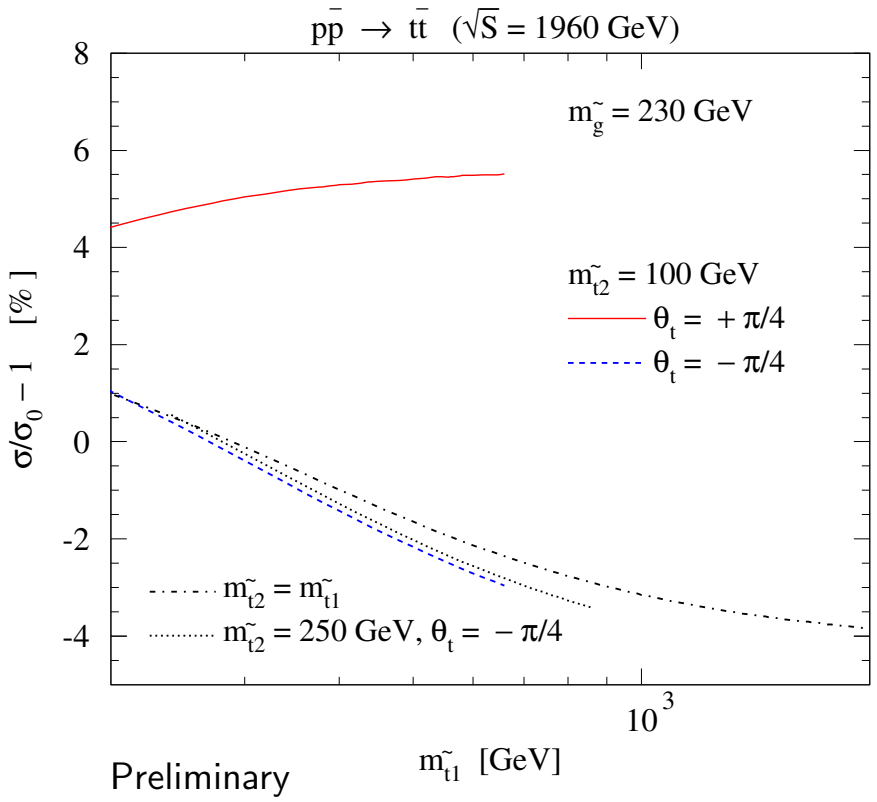
- QCD cross section ($m_t = 175$ GeV, Kidonakis, Vogt, 2003):

  Tevatron: $\sigma(S = 1960\ \mathrm{GeV}) = 6.77$ pb
  LHC: $\sigma(S = 14\ \mathrm{TeV}) = 873$ pb

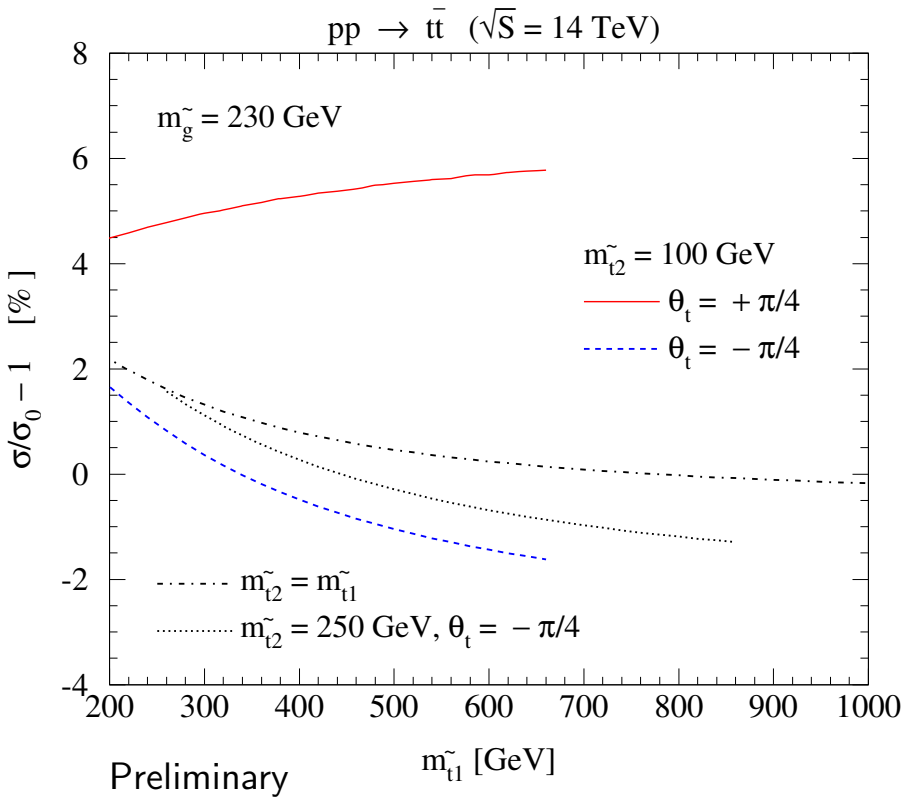
- NLO MSSM EW corrections: -7% to $+1\%$

3. Unpolarized top quark pair production at Hadron Colliders

Tevatron



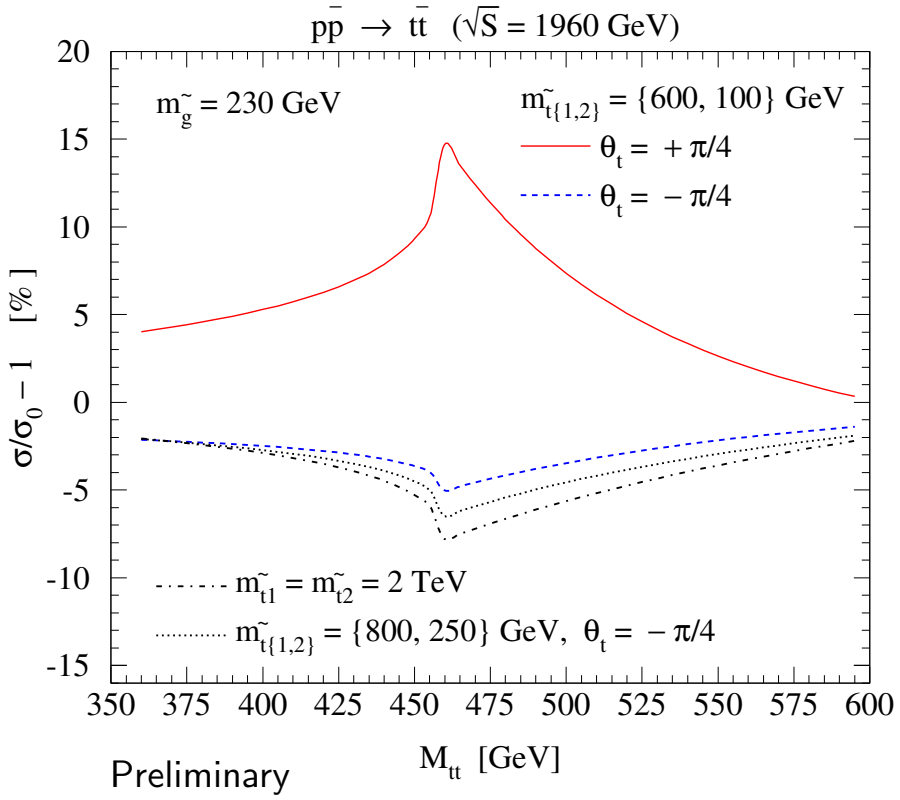
LHC



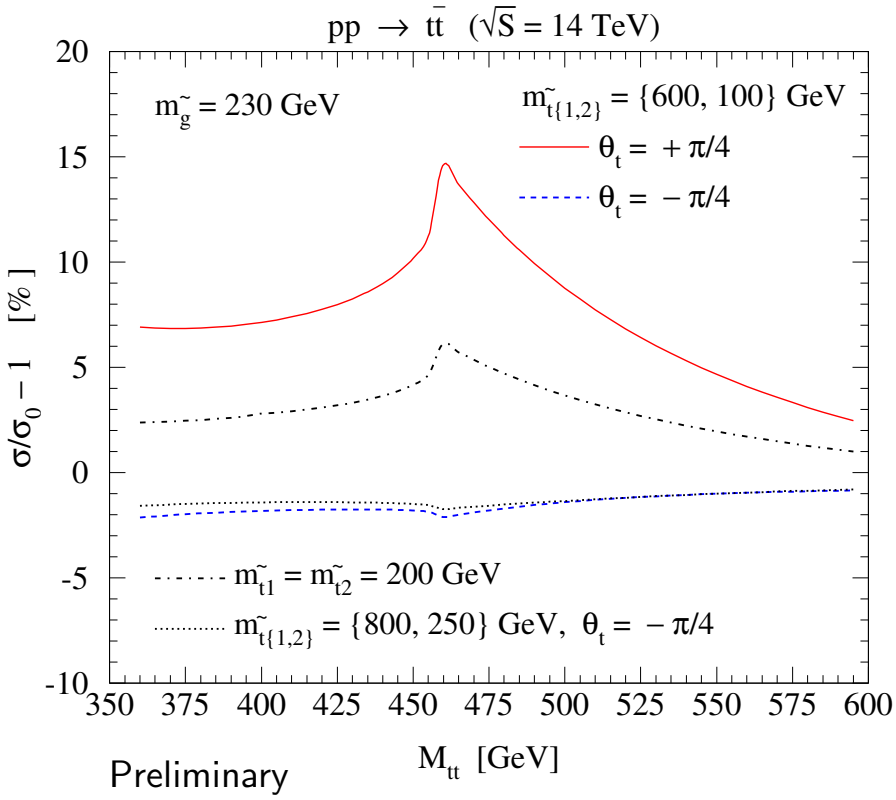
- Dependence of the heavier stop mass, $m_{\tilde{t}_1}$ ($\Delta = \frac{\sigma - \sigma_0}{\sigma_0}$)
- $m_{\tilde{g}} = 230$ GeV

3. Unpolarized top quark pair production at Hadron Colliders

Tevatron



LHC



- Change of the invariant mass distribution:

$$\Delta(M_{t\bar{t}}) = \frac{d\sigma_{NLO}/dM_{t\bar{t}} - d\sigma_{LO}/dM_{t\bar{t}}}{d\sigma_{LO}/dM_{t\bar{t}}}$$

- $m_{\tilde{g}} = 230$ GeV
- Tevatron: $\frac{d\sigma}{dM_{t\bar{t}}^{460}} \approx 25$ fb/GeV

  $\frac{d\sigma}{dM_{t\bar{t}}^{550}} \approx 9$ fb/GeV

4. Polarized top quark pair production

Polarized Top quarks:

- $q\bar{q} \to t(\lambda_1)\bar{t}(\lambda_2)$
- $gg \to t(\lambda_1)\bar{t}(\lambda_2)$

- Using helicity basis with $\lambda = \{L, R\}$

$$A_{LR}(M_{t\bar{t}}) = \frac{d\sigma_{RL}/dM_{t\bar{t}} - d\sigma_{LR}/M_{t\bar{t}}}{\sigma_{RL}/dM_{t\bar{t}} + d\sigma_{LR}/M_{t\bar{t}}}$$

$A_{LR} = 0$:

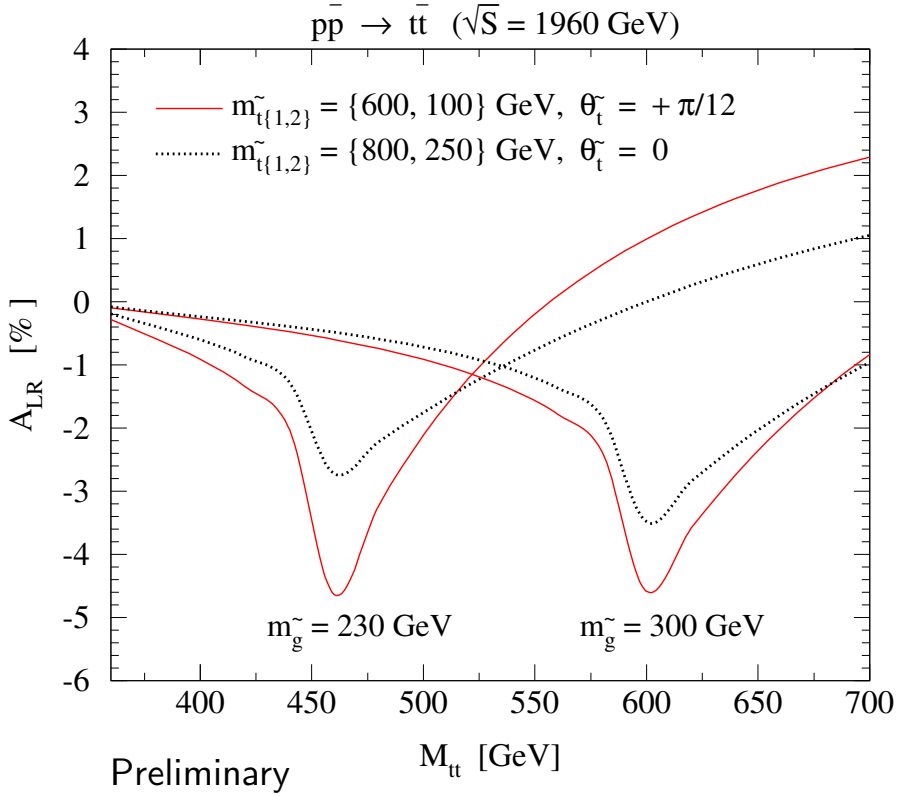
- Tree level, because QCD preserves parity
- $m_{\tilde{t}_1} = m_{\tilde{t}_2}$ because $\sim \pm \sin(2\theta_{\tilde{t}})\gamma_5$ dependence cancel
- $\theta_{\tilde{t}} = \pm\pi/4$: because

  $\tilde{g}t\bar{\tilde{t}}_1 = -iT^c\ (\gamma_5)$

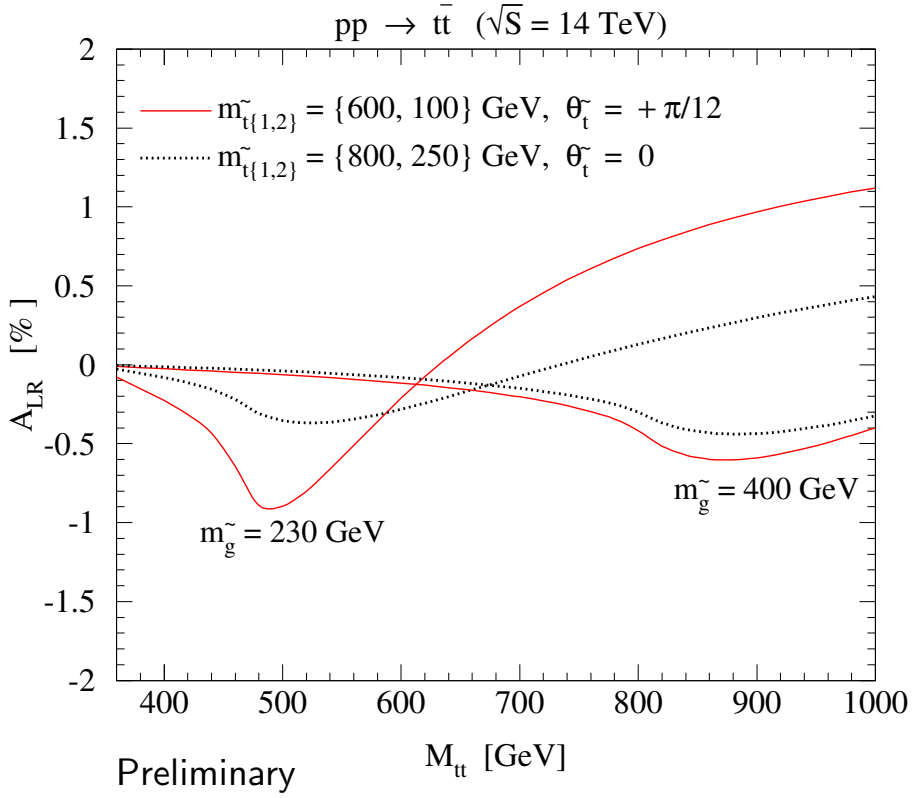
  $\tilde{g}t\bar{\tilde{t}}_2 = -iT^c\ (-1)$

4. Polarized top quark pair production

Tevatron



LHC



- Largest for vertex correction
- Tevatron: Vertex corrections dominant

  $\frac{d\sigma^{RL}}{dM^{460}_{t\bar{t}}} \approx 10$ fb/GeV

  $A^{total}_{LR} = 1\%$ for

  $m_{\tilde{g}} = 230$ GeV, $m_{\tilde{t}_{\{1,2\}}} = \{600, 100\}$ GeV

- LHC: Box correction dominant

  $A_{LR} \geq 0.1\%$ expected to be observable (hep-ph/9902202)

- MSSM-EW: $A^{\text{Tevatron}}_{LR} \leq 1.7\%$

  $A^{\text{LHC}}_{LR} \leq 3\%$

5. Conclusion

NLO supersymmetric QCD corrections changes the $t\bar{t}$ production cross section by:

- Total cross section: Corrections largest for small gluino masses (230 GeV)

  Tevatron: -4% to $+5.5\%$

  LHC: -1.5% to $+5.5\%$

- Invariant Mass distribution: largest for light gluinos (230 GeV)

  Tevatron: -8% to $+15\%$

  LHC: -2% to $+15\%$

- Left-Right asymmetry: largest for light $m_{\tilde{t}_2} = 100$ GeV and small $\theta_{\tilde{t}}$

  for invariant mass distribution:

  Tevatron: up to 4.5%

  LHC: up to 1%