Electroweak Corrections to Top-Squark Pair Production at the LHC

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DPG Frühjahrstagung 2007 in Heidelberg

March 8, 2007

Outline

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   supersymmetry and top-squark pair production

2. **SUSY-Electroweak Corrections**

   gg fusion at $\mathcal{O}(\alpha\alpha_s^2)$

   $q\bar{q}$ annihilation at $\mathcal{O}(\alpha\alpha_s^2)$

3. **Numerical Results**

   transverse momentum and invariant mass distribution

4. **Summary**

1. Introduction: Supersymmetry and Top-Squarks

- **Supersymmetry** (SUSY) is a possible and very attractive extension of the Standard Model (SM)
  - protective symmetry: Higgs mass below 1 TeV is possible
  - unification of the coupling constants
- **M**inimal **S**upersymmetric **S**tandard **M**odel:
  one new partner per SM-particle + second Higgs doublet
- **top-squarks** $\tilde{t}_{L/R}$
  - SUSY **partners of top-quarks**
  - have same quantum numbers as $t_{L/R}$
  - but are **scalar particles**
  - not yet observed $\rightarrow$ SUSY has to be broken, heavier SUSY masses

Why consider Top-Squark Production ?

- gauge eigenstates $\tilde{f}_{L/R}$ **mix to** mass eigenstates $\tilde{f}_{1/2}$,
  the mixing angle is proportional to mass of the SM partner

  $\longrightarrow$ mixing negligible except for $\tilde{b}_{1/2}, \tilde{t}_{1/2}, \tilde{\tau}_{1/2}$

  $\longrightarrow$ $\tilde{t}_1$ might be **lightest colored SUSY particle**

  $\longrightarrow$ very **high production rate** at hadron colliders!

- cross section depends mainly on top-squark mass $m_{\tilde{t}}$

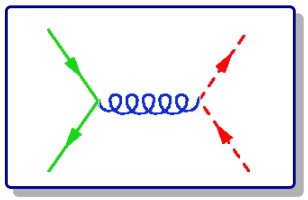
  $\longrightarrow$ bounds on cross section allow for lower bounds on $m_{\tilde{t}}$
  without specifying all other **SUSY parameters**!

  $\longrightarrow$ if stops are discovered $m_{\tilde{t}}$ can **directly** be **determined**!

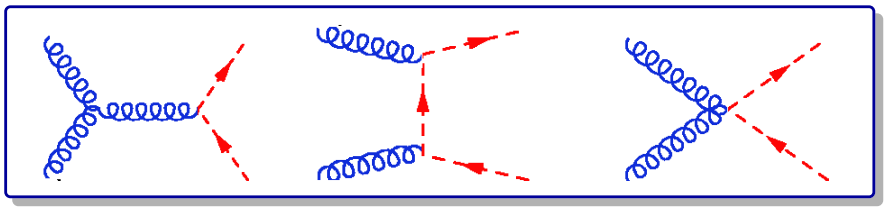
Top-Squark Production at Hadron Colliders

- at leading order (LO), **two main production channels**:

  $q\bar{q}$ annihilation

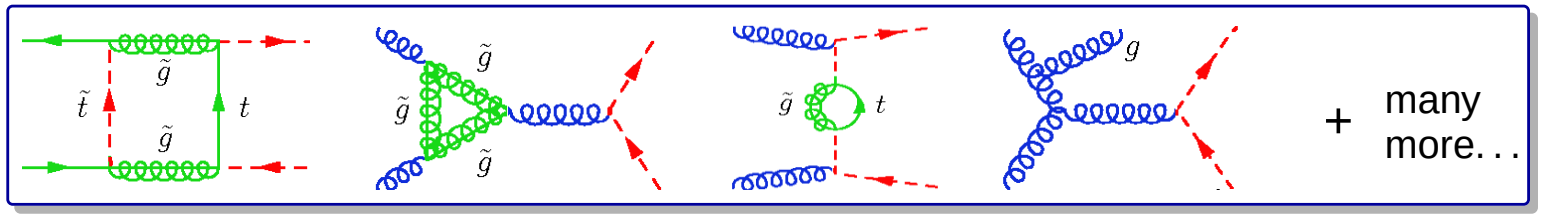


  gg fusion



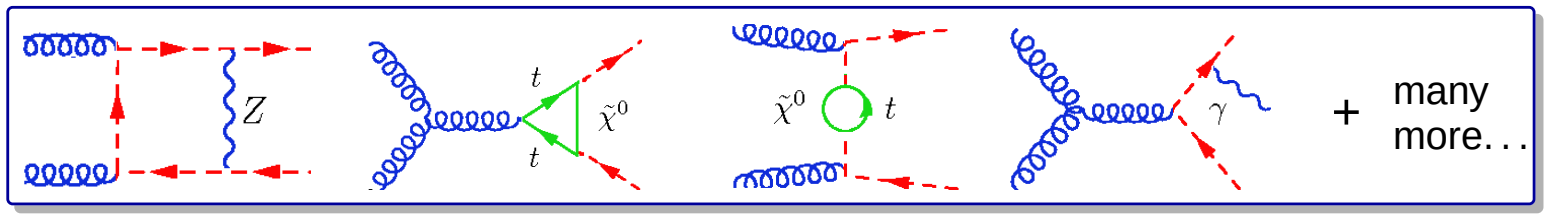
- important **higher order effects** due to

  - strong interactions (**SUSY-QCD effects**) [Beenakker et al. '97]



$\mathcal{O}(\alpha_s^3)$

  - electroweak interactions (**SUSY-EW effects**)



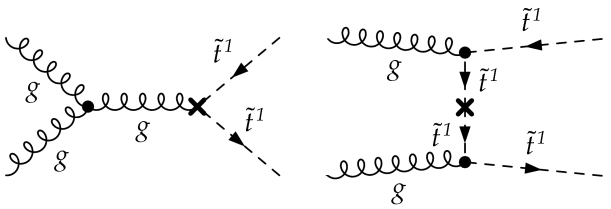
$\mathcal{O}(\alpha\alpha_s^2)$

(QED corrections not gauge invariant within MSSM)

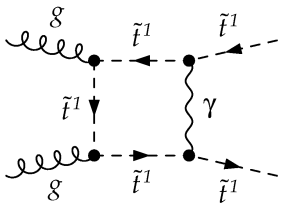
2. Electroweak Corrections to $gg \to \tilde{t}_1\tilde{t}_1^* / q\bar{q} \to \tilde{t}_1\tilde{t}_1^*$

Virtual Corrections:

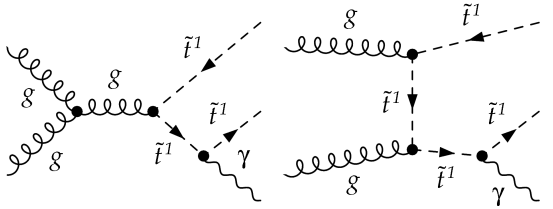
- no renormalization of gluon field and α_s, but need counterterms at $\mathcal{O}(g_s^2 e)$



- **soft singularities** arise where external particles exchange a photon



divergent for $m_\gamma = 0$

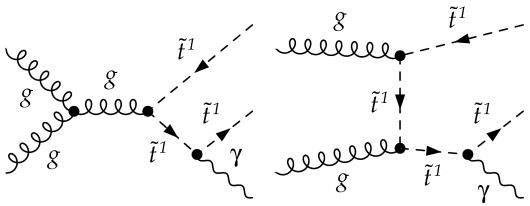


$(E_\gamma \leq \Delta E)$

$\to$ introduce small photon mass $\lambda \neq 0$, add **soft photon contributions** that lead to **same observable final state**

$\to$ **phase space slicing:** dependency on cut-off parameter ΔE cancels when hard photon bremsstrahlung is added

Real Corrections:

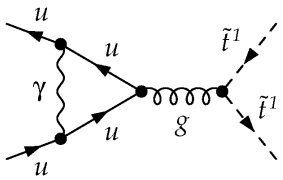


$(E_\gamma > \Delta E)$

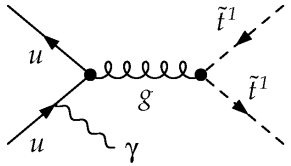
$$\sigma_{NLO}^{gg} = \sigma_{LO}^{gg}\,(1+\delta_{virt}(\lambda)+\delta_{soft}(\lambda,\Delta E)) + \sigma_{hard}^{2\to 3}(\lambda,\Delta E) \quad \text{independent of } \lambda, \Delta E$$

More about EW Corrections to $q\bar{q} \to \tilde{t}_1\tilde{t}_1^*$

- also **collinear singularities**



divergent
for $m_u = 0$



$(E_\gamma > \Delta E, \theta_{u\gamma} \leq \Delta\theta)$

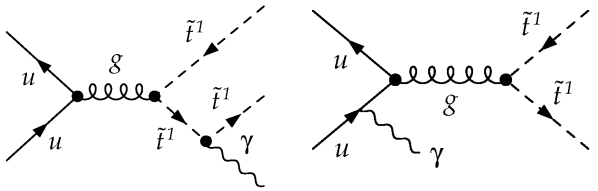
$\to$ keep small quark mass $m_q \neq 0$, add **collinear photon radiation** (ISR), introduce **second cut-off parameter** $\Delta\theta$

$\to$ **remaining log's** have to be absorbed into PDF's (**factorization**), result is independent of m_q, but depends on a factorization scale

$\to$ need PDF's that include NLO QED effects: **MRST 2004 QED** [Martin et al. '04]

Real corrections:

Hard, non-collinear
photon bremsstrahlung

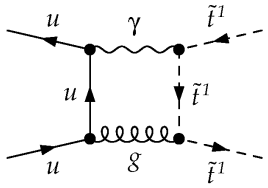


$(E_\gamma > \Delta E,$
$\theta > \Delta\theta)$

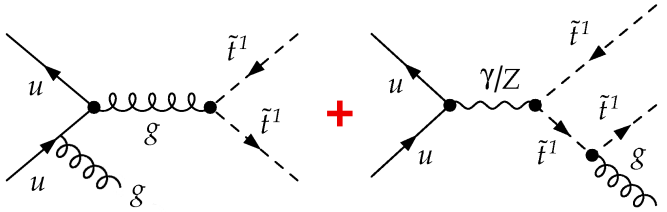
$$\sigma^{q\bar{q}}_{NLO} = \sigma^{q\bar{q}}_{LO}\,(1 + \delta_{virt} + \delta_{soft} + \delta_{coll}) + \sigma^{2\to3}_{hard,non-coll} \qquad \text{indep. of } \lambda, m_q, \Delta E, \Delta\theta$$

More Singularities for $q\bar{q} \to \tilde{t}_1\tilde{t}_1^*$

- **soft singularities** also for **gluon exchange** between external particles!



divergent
for $m_g = 0$ $\to$



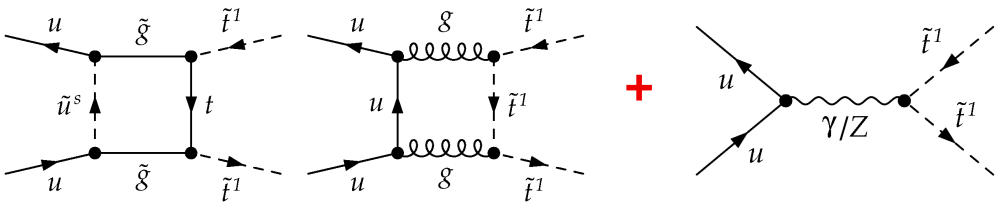
$(E_g \leq \Delta E)$

$\to$ need small gluon mass $\lambda \neq 0$ and **soft gluon bremsstrahlung** at $\mathcal{O}(\alpha\alpha_s^2)$

$\to$ **mixing of EW and QCD interactions** (vanishing at born level!)

$\to$ color flux: only **interference** of ISR and FSR contributes

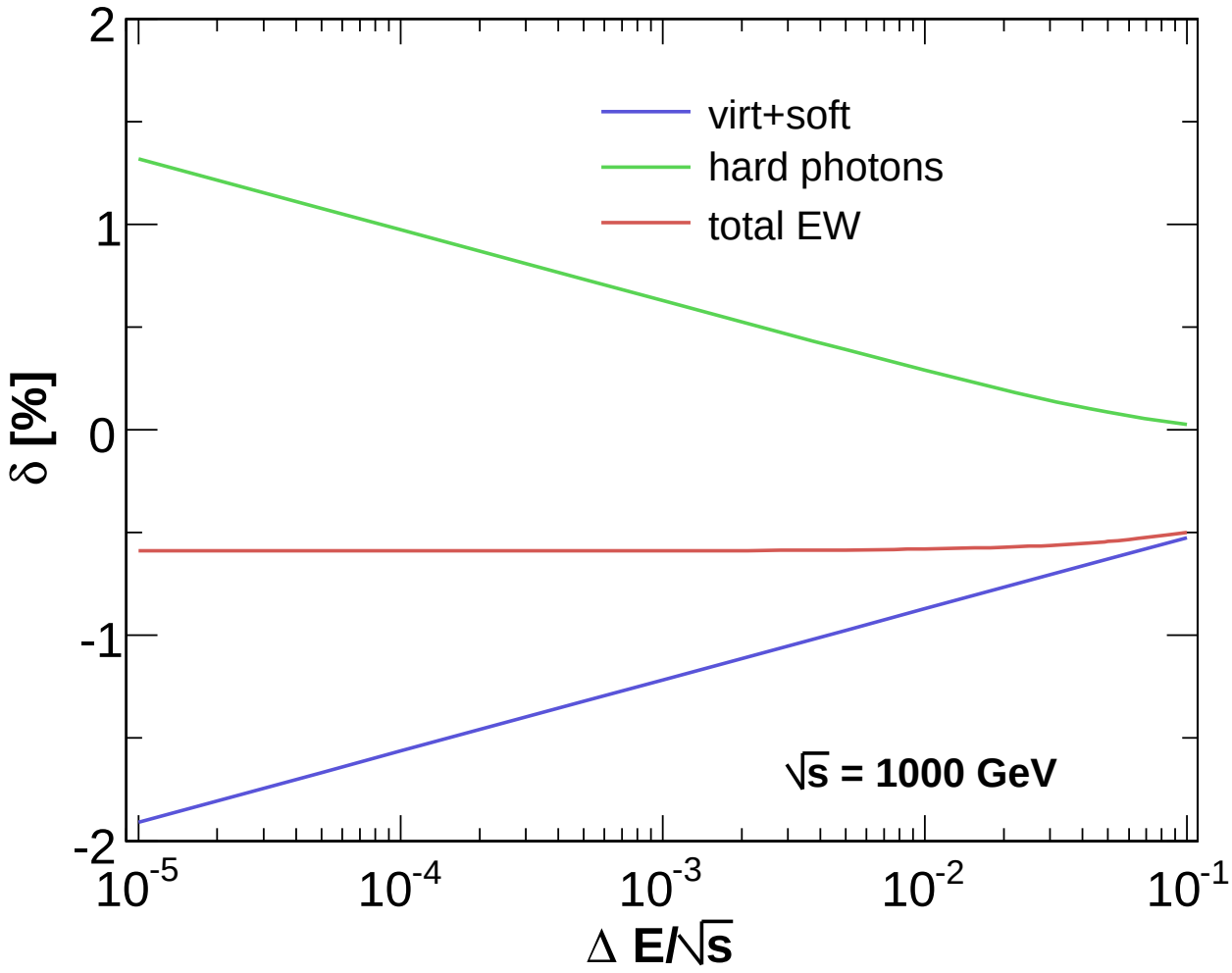
- also at $\mathcal{O}(\alpha\alpha_s^2)$: **QCD boxes** + **EW born**



3. Numerical Results

$gg \to \tilde{t}_1 \tilde{t}_1^*$
on parton level

relative EW corr's
$\sigma_{NLO} / \sigma_{LO}$
as function of cut-off parameter ΔE



Numerical Results II

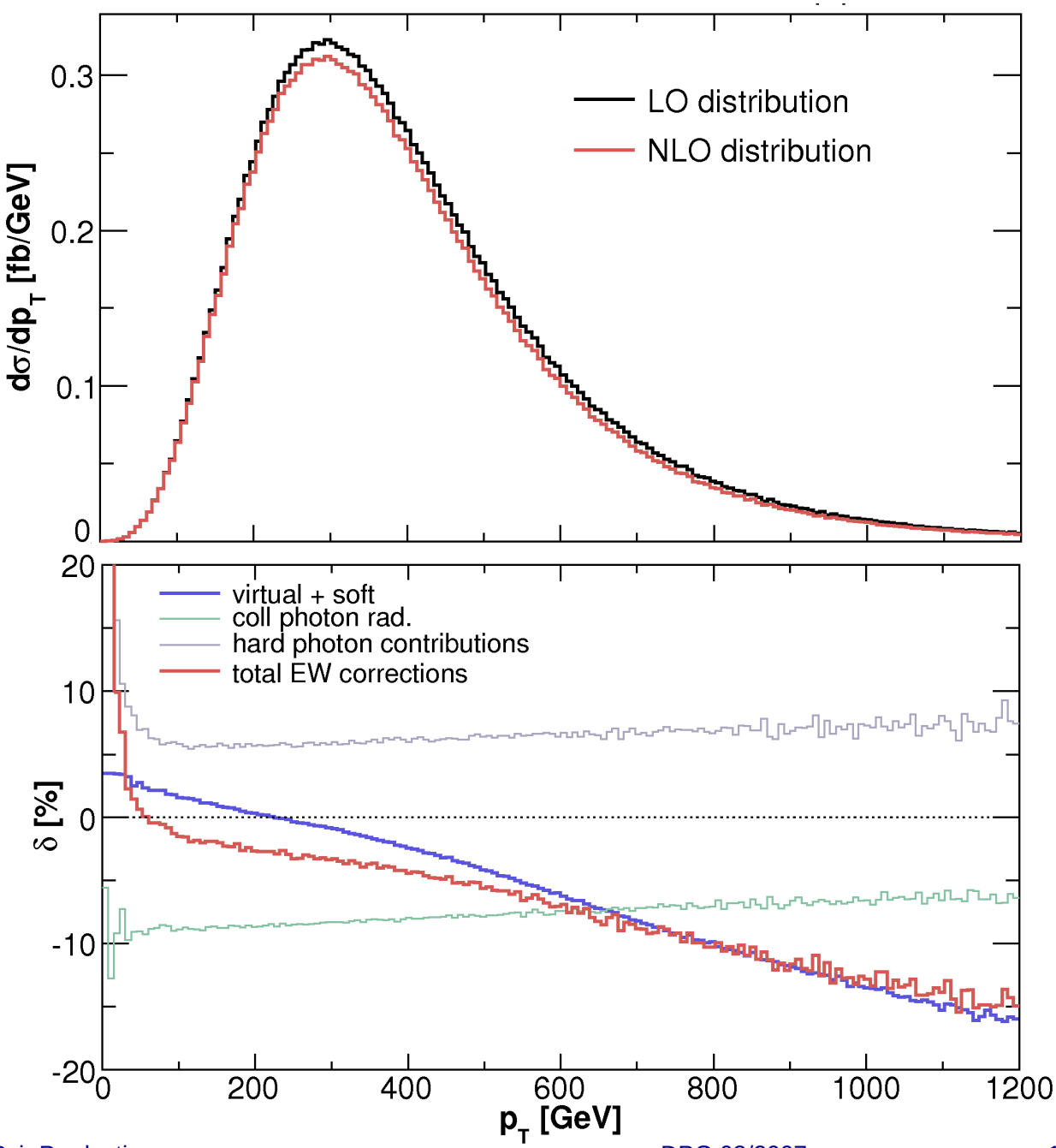
p_T distribution of $\tilde{t}_1$
$u\bar{u} \to \tilde{t}_1\tilde{t}_1^*$
(hadron level, LHC)

$\sigma_{LO}^{u\bar{u}}$ = 134.05 fb
$\sigma_{NLO}^{u\bar{u}}$ = 127.69 fb

with MRST 2004 QED,
$\mu_F = 2m_{\tilde{t}}$, $\sqrt{S} = 14$ TeV

SPS 1a

$\mathbf{m_{\tilde{t}_1} = 375.1\ GeV}$



Numerical Results III

invariant mass distribution $\frac{d\sigma_H}{dM_{inv}}$

$u\bar{u} \to \tilde{t}_1\tilde{t}_1^*$

(hadron level, LHC)

$\sigma_{LO}^{u\bar{u}}$ = 134.05 fb

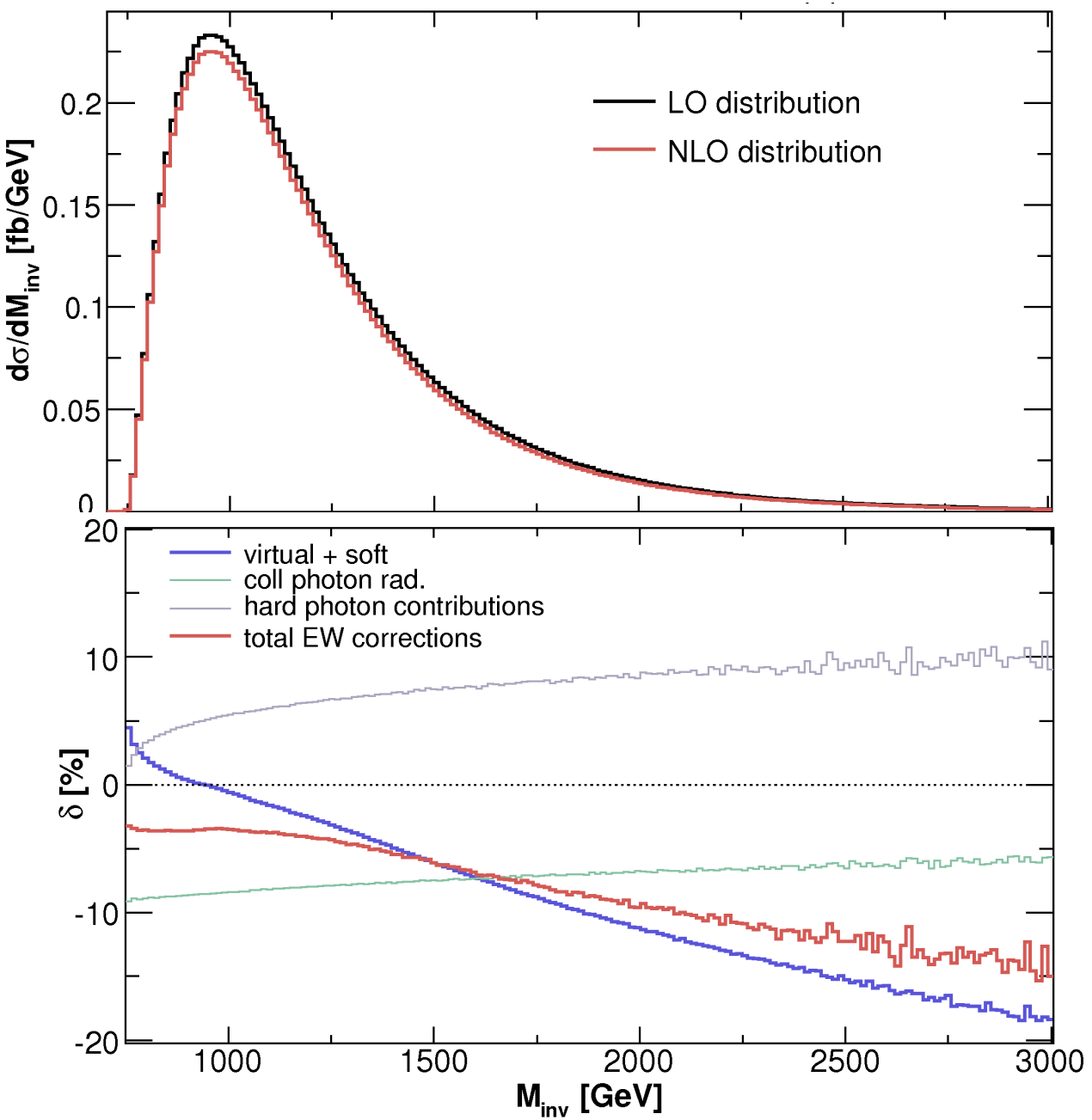
$\sigma_{NLO}^{u\bar{u}}$ = 127.69 fb (-4.7%)

with MRST2004QED,

$\mu_F = 2m_{\tilde{t}}$, $\sqrt{S} = 14$ TeV

SPS 1a

$m_{\tilde{t}_1} = 375.1$ GeV



4. Summary: Top-Squark Pair Production

- Exciting times ahead: SUSY will be probed at the LHC
  Top-Squarks will be produced at a **very high rate**
- SUSY-QCD corrections already well known,
  missing **SUSY-EW corrections** now (almost) **completed**
- Corrections $\mathcal{O}(\alpha_s^2\alpha)$ include also **interferences**
  of **EW and QCD** contributions
- **PDF's include QED and QCD** contributions at NLO

$\longrightarrow$ need to include QCD corrections for consistent picture
and reduced scale dependence

$\longrightarrow$ investigate also processes like