

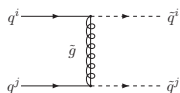
Squark pair production at NLO

in collaboration with R. Gavin, C. Hangst, M. Krämer, M. Mühlleitner, M. Pellen and M. Spira
Eva Popena | 06.05.2013

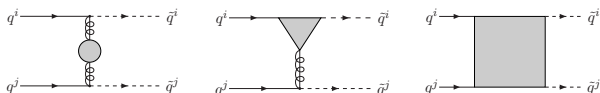


- **Major task at the LHC:** Direct Search for supersymmetric particles and determination of their properties
- **Main production channels:** Coloured sparticles $\tilde{q}\tilde{q}$, $\tilde{q}\tilde{q}^*$, $\tilde{q}\tilde{g}$ and $\tilde{g}\tilde{g}$
- **In the currently tested mass region:** $\tilde{q}\tilde{q}$ production dominant channel
[Falgari, Schwinn & Wever, '12]
- **Status:** QCD NLO predictions for cross sections of pair produced sparticles by PROSPINO
[Beenakker, Hopker, Spira & Zerwas, '96]
 - Squark masses assumed to be degenerate
 - Various subchannels not treated individually
 - (Differential) K -factors assumed to be flat
- **Here: Squark pair production at NLO**
 - Without any assumptions on mass spectrum
 - Embedded fully differentially in partonic Monte Carlo program
- **Recently:** Completely independent calculation
[Hollik, Lindert & Pagani, '12]

Tree level



Virtual corrections



UV divergent

[FeynArts, FormCalc, LoopTools]

Dimensional regularization: $D = 4 - 2\epsilon$

Mismatch between fermionic and bosonic degrees of freedom \rightarrow Breaks SUSY
SUSY restoring counterterm:

$$\hat{g}_s = g_s(1 + \alpha_s/3\pi)$$

Renormalization:

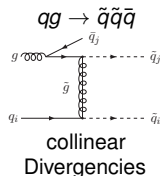
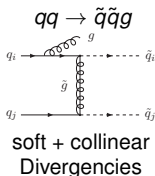
- Mass and field renormalization in on-shell scheme

- Strong coupling constant in \overline{MS} scheme: $\tilde{g}_s^{(0)} = g_s + \delta g_s$

Decouple heavy particles from running of α_s to match experimental value

$$\delta g_s = \frac{\alpha_s}{8\pi} \left[\beta_0 \left(-\Delta + \log \frac{Q^2}{\mu^2} \right) - 2 \log \frac{m_g^2}{Q^2} - \frac{2}{3} \log \frac{m_t^2}{Q^2} - \sum_{i=1,12} \frac{1}{6} \log \frac{m_{q_i}^2}{Q^2} \right]$$

Real corrections



[Madgraph]

Catani-Seymour subtraction formalism

$$\sigma_{NLO} = \int d\Phi_3 d\sigma^R + \int d\Phi_2 d\sigma^V$$

→ Monte Carlo implementation technically difficult:

Cancellation between integrated phase spaces of different multiplicities

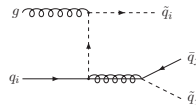
$$\sigma^{NLO} = \int d\Phi_3 [d\sigma^R - d\sigma^A] + \int d\Phi_2 [d\sigma^V + \int d\Phi_1 d\sigma^A]$$

- $d\sigma^A$ same singular behaviour as $d\sigma^R$
- Integration over one-parton subspace analytically
- Cancel divergencies, carry out remaining integration numerically

[Catani, Seymour '97]
[Catani, Dittmaier, Seymour, Trocsanyi '02]

For $m_{\tilde{q}_j} < m_{\tilde{g}}$:

Resonant $\tilde{q}\tilde{g}$ production with subsequent decay



$$|M_{qg}|^2 = |M_{nr}|^2 + 2 \cdot \text{Re}(M_r M_{nr}^*) + |M_r|^2$$

On-shell subtraction methods

- Diagram removal - type I (DR): $|M_{qg}|^2 \approx |M_{nr}|^2$
- Diagram removal - type II (DR-II): $|M_{qg}|^2 \approx |M_{nr}|^2 + 2 \cdot \text{Re}(M_r M_{nr}^*)$
- Diagram subtraction (DS):

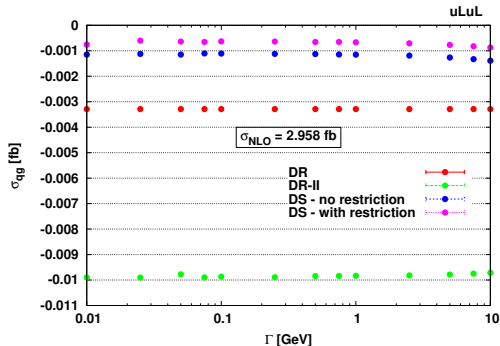
Remove resonant contribution for $(p_{\tilde{q}_j} + p_{\tilde{q}_j})^2 \rightarrow m_{\tilde{g}}^2$ by a local counterterm $d\sigma_{\text{sub}}$

→ Gauge invariant in the limit $\Gamma_{\tilde{g}} \rightarrow 0$

→ Ideal for MC event generators

$$d\sigma_{\text{sub}} = \Theta(\sqrt{\hat{s}} - m_{\tilde{g}} - m_{\tilde{q}_j}) \cdot \Theta(m_{\tilde{g}} - m_{\tilde{q}_j}) \cdot |M_r(\tilde{\Phi}_3)|^2 \cdot \frac{m_{\tilde{g}}^2 \Gamma_{\tilde{g}}^2}{(m_{\tilde{q}_j \tilde{q}_j}^2 - m_{\tilde{g}}^2)^2 + m_{\tilde{g}}^2 \Gamma_{\tilde{g}}^2} \cdot d\tilde{\Phi}_3$$

Comparison of different on-shell subtraction methods



- Magnitude of terms neglected in Diagram Removal (DR) schemes can be sizable
- Influence of jacobian in DS scheme not negligible
- Impact on specific channels (e.g. $\tilde{u}_L \tilde{c}_L$) can be as large as $\mathcal{O}(20\%)$
- Impact on total NLO cross section is a sub percent effect

K-factors in individual subchannels

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

PROSPINO: NLO cross sections of individual subchannels obtained by scaling LO cross sections with global *K*-factor of the total cross section

→ Is the *K*-factor constant in the various subchannels?

$$m_{\tilde{q}} = 1800 \text{ GeV} \quad m_{\tilde{g}} = 1600 \text{ GeV} \quad \sqrt{s} = 8 \text{ TeV}$$

Channel	$\tilde{u}_L \tilde{u}_L$	$\tilde{u}_L \tilde{u}_R$	$\tilde{u}_L \tilde{d}_L$	$\tilde{u}_L \tilde{d}_R$	$\tilde{d}_L \tilde{d}_L$	$\tilde{d}_L \tilde{d}_R$	Sum
<i>K</i> -Factor	1,10	1,17	1,21	1,22	1,19	1,30	1,16

- *K*-factors vary in a range of 20 %
- Independent treatment reasonable: different channels have different kinematic distributions

Differential K -factors on Production Level

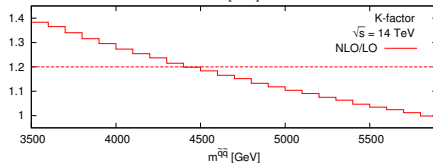
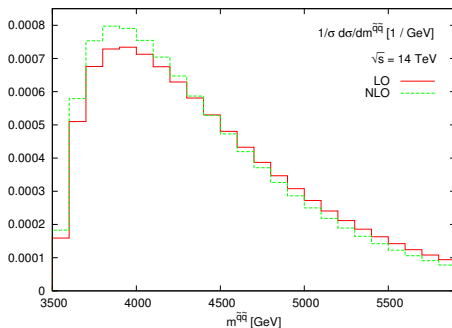
So far:

- NLO corrections have no impact on shape of distributions
- NLO distributions obtained by scaling LO distributions with the global K -factor

$$m_{\tilde{q}} \approx 1800 \text{ GeV} \quad m_{\tilde{g}} = 1602 \text{ GeV}$$

$$\sqrt{s} = 14 \text{ TeV}$$

- Differential K -factor varies in a range of 40%
- NLO corrections can change shape of distributions
- Full NLO distributions should be taken into account



Differential K -factors with Decays

- Shortest decay chain: $\tilde{q} \rightarrow q + \tilde{\chi}_1^0$

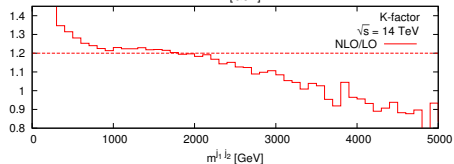
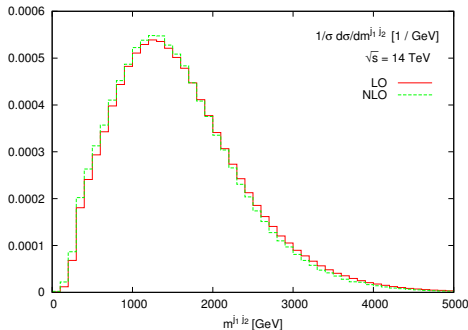
$\text{BR}(\tilde{u}_L \rightarrow u\tilde{\chi}_1^0)$	$\text{BR}(\tilde{u}_R \rightarrow u\tilde{\chi}_1^0)$
0.0098	0.566

- Partons clustered with anti- k_T algorithm with $R = 0.4$ [FastJet 3.0.3]
- Jets required to fulfil

$$p_T^j > 20 \text{ GeV}, \quad |\eta^j| < 2.8$$

- Distribution inherits strong phase space dependence observed at production level

[Hollik, Lindert & Pagani, '12]



Summary

- Squark pair production at NLO completed
- Calculation passed various checks and comparisons
 - Cancellation of IR singularities
 - Comparison to implementation in POWHEG BOX
 - Comparison to PROSPINO, independent calculation
- Treating different subchannels independently reasonable
- Important to take full NLO distribution into account

→ talk by R. Gavin

Outlook

- Combine with decay $\tilde{q} \rightarrow q\tilde{\chi}_1^0$ at NLO
- Study phenomenological effects with full NLO accuracy
- Calculate and implement other processes: Keep track of spin information