LPCC SUSY/BSM cross-section working group

Michael Krämer (RWTH Aachen)

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Aim of the WG: provide state-of-the-art cross section and branching ratio predictions for SUSY and other new physics models at the LHC.

[cf. the LHC Higgs cross section working group]

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Specific tasks:

▶ collect SUSY/BSM cross section and branching ratio predictions, including the most advanced theory calculations (NLO, NLL resummation, electroweak corrections,...), up-to-date SM inputs like pdfs *and a proper error estimate*;

▶ compare dedicated theory calculations, including higher-order corrections, with Monte Carlo predictions;

▶ compile a list of existing SUSY/BSM LHC tools with contact persons and test these tools for a wide region of parameter space;

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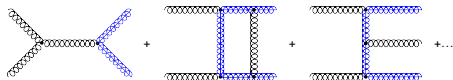
Coordination: Michelangelo Mangano & Michael Krämer
with Atlas and CMS SUSY & exotics conveners as experimental contacts

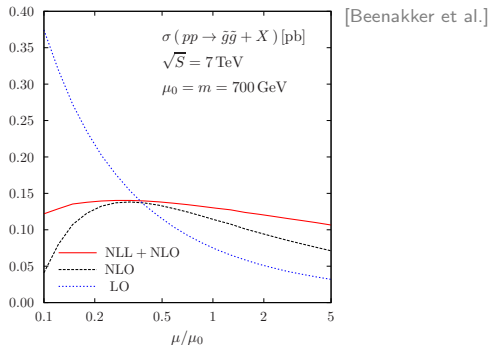http://web.physik.rwth-aachen.de/service/wiki/bin/view/Main/BSMCrossSectionWorkingGroup

SUSY cross section calculations

- squark and gluino pair production: $pp \rightarrow \tilde{q}\tilde{q}^*, \tilde{q}\tilde{q}, \tilde{q}\tilde{g}, \tilde{g}\tilde{g}$

  - NLO+NLL SUSY-QCD for all processes (Beenakker et al., Kulesza et al.)
    (assuming mass degenerate $\tilde{q}_{L/R}$, $\tilde{t}_i/\tilde{b}_i$ treated separately)

  - NNLL/approximate NNLO/Coloumb resummation for $\tilde{q}\tilde{q}^*$
    (Beenakker et al., Langenfeld et al., Beneke et al.)

  - NLO SUSY-EWK for all processes (Hollik et al.)

  - bound state effects (Hagiwara et al., Kauth et al.)

- slepton and electroweak gaugino pair production: $pp \rightarrow \tilde{l}\tilde{l}^*, \tilde{\nu}\tilde{\nu}^*, \tilde{\chi}\tilde{\chi}$
  - NLO+NLL SUSY-QCD for all processes (Beenakker et al., Debove et al.)

- associated production of squarks/gluinos with $\tilde{\chi}$s: $pp \rightarrow \tilde{q}\tilde{\chi}, \tilde{g}\tilde{\chi}$
  - NLO SUSY-QCD (Beenakker et al., Binoth et al.)

Example: squark and gluino production at NLO+NLL

Take gluino-pair production as an example

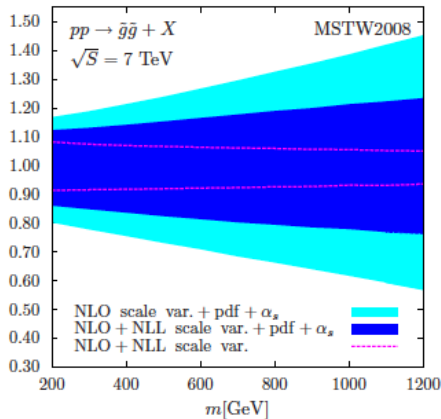## Scale dependence

[Beenakker et al.]

$\sigma\,(\,pp \to \tilde{g}\tilde{g} + X\,)\,[\mathrm{pb}]$
$\sqrt{S} = 7\,\mathrm{TeV}$
$\mu_0 = m = 700\,\mathrm{GeV}$

NLL + NLO
NLO
LO

$\to \Delta\sigma(\mathrm{scale}) \lesssim \pm 10\%$ at NLO+NLL

Example: squark and gluino production at NLO+NLL

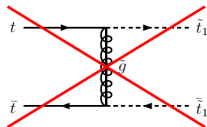Theory error: $\Delta\sigma = \Delta\mu \pm \sqrt{\Delta(\mathrm{pdf})^2 + \Delta(\alpha_{\mathrm{s}})^2}$

[Beenakker et al.]

$\to \Delta\sigma \lesssim \pm 20\%$ at NLO+NLL

Stop (and sbottom) pair production

- mixing: $\tilde{t}_1 = \tilde{t}_L \cos\theta_{\tilde{t}} + \tilde{t}_R \sin\theta_{\tilde{t}}$ and $\tilde{t}_2 = -\tilde{t}_L \sin\theta_{\tilde{t}} + \tilde{t}_R \cos\theta_{\tilde{t}}$

- no top initial state
  - $\rightarrow$ no gluino t-channel contribution
  - $\rightarrow$ LO cross section only depends on $m_{\tilde{t}}$
  - $\rightarrow$ $q\bar{q}$ cross section suppressed (P-wave)

- Dependence on $\theta_{\tilde{t}}, m_{\tilde{q}}, m_{\tilde{g}}$ enters at NLO; numerically small $\lesssim 2\%$

- mixed pair production $pp \rightarrow \tilde{t}_1\tilde{t}_2^* + \tilde{t}_2\tilde{t}_1^*$ is suppressed by $\mathcal{O}(\alpha_s^2)$

- theoretical uncertainty (e.g. $m_{\tilde{t}} = 400$ GeV, LHC@7 TeV):

$\sigma(pp \rightarrow \tilde{t}_1\tilde{t}_1^*) = 0.22\,\text{pb} \pm 10\%\,(\text{scale}) \pm 6\text{–}10\%\,(\text{pdf}) \pm 3\%\,(\alpha_s)$

EWK effects include $\mathcal{O}(\alpha)$ loop corrections and QCD/EWK interference
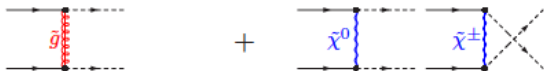
$p_t(\tilde{q})$ distribution:
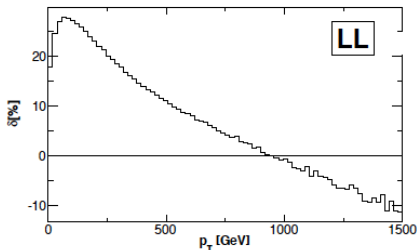
[Germer et al.]

$\rightarrow$ potentially significant effects, depending in detail on the process and the SUSY scenario

Example: squark pair production with EWK corrections

First results for benchmark #1: tanbeta=40; m0=700 GeV; m1/2=600 GeV; A0=-500 GeV; mu>0

#proc	BornQCD[fb]	BornEW[fb]	NloEW[fb]	dBornEW[%]	dNloEW[%]	dAllEW[%]
LL	0.0055	-0.0003713	-0.0004853	-6.75	-8.82	-15.57
RR	0.0080	-0.0002912	-0.0002600	-3.64	-3.25	-6.89
SUM	0.0135	-0.0006625	-0.0007453	-4.90	-5.52	-10.42

#DETAILS

#proc	BornQCD[fb]	BornEW[fb]	NloEW[fb]	dBornEW[%]	dNloEW[%]	dAllEW[%]
u1u1	0.0023	-0.0003358	-0.0003363	-14.44	-14.46	-28.91
u2u2	0.0032	-0.0002828	-0.0001775	-8.59	-5.39	-13.98
d1d1	0.0012	-0.0000449	-0.0002348	-3.75	-19.62	-23.37
d2d2	0.0018	-0.0000115	-0.0000376	-0.62	-2.03	-2.65
c1c1	0.0010	0.0000102	0.0000500	0.98	4.78	5.76
c2c2	0.0015	0.0000033	-0.0000141	0.21	-0.92	-0.71
s1s1	0.0010	-0.0000008	0.0000358	-0.49	3.49	3.40
s2s2	0.0015	-0.0000002	-0.0000308	-0.01	-1.94	-1.96

Squark and gluino pair production: public codes

Prospino:
- ► NLO SUSY-QCD;
- ► reads SLHA input;
- ► LO for generic scenarios;
- ► NLO K-factor assumes mass degenerate $\tilde{q}_{L/R}, \tilde{q} \in \{\tilde{u}, \tilde{d}, \tilde{c}, \tilde{s}, \tilde{b}\}$

NLL-fast:
- ► NLO+NLL SUSY-QCD;
- ► assumes mass degenerate $\tilde{q}_{L/R}, \tilde{q} \in \{\tilde{u}, \tilde{d}, \tilde{c}, \tilde{s}, \tilde{b}\}$

Sample output

```
# LHC @ 7 TeV, MSTW 2008 NLO
# process: tot
# ms[GeV]  mg[GeV]  LO[pb]     NLO[pb]     NLL+NLO[pb]  d_mu+[pb]   d_mu-[pb]   d_pdf+[%]  d_pdf-[%]  d_as+[%]  d_as-[%]  K_NLO  K_NLL
```

ms[GeV]	mg[GeV]	LO[pb]	NLO[pb]	NLL+NLO[pb]	d_mu+[pb]	d_mu-[pb]	d_pdf+[%]	d_pdf-[%]	d_as+[%]	d_as-[%]	K_NLO	K_NLL
500.	500.	0.102E+02	0.127E+02	0.132E+02	0.101E+01	-0.124E+01	3.2	-3.0	1.9	-2.3	1.25	1.04
600.	600.	0.310E+01	0.386E+01	0.403E+01	0.314E+00	-0.388E+00	3.7	-3.2	1.9	-2.2	1.25	1.04
700.	700.	0.106E+01	0.132E+01	0.138E+01	0.110E+00	-0.135E+00	4.1	-3.3	1.8	-2.0	1.25	1.05
800.	800.	0.389E+00	0.485E+00	0.511E+00	0.423E-01	-0.510E-01	4.4	-3.6	1.8	-1.9	1.25	1.05
900.	900.	0.151E+00	0.189E+00	0.200E+00	0.170E-01	-0.205E-01	4.5	-3.8	1.7	-1.8	1.25	1.06
1000.	1000.	0.612E-01	0.761E-01	0.810E-01	0.717E-02	-0.848E-02	4.9	-3.8	1.6	-1.6	1.24	1.06
1100.	1100.	0.254E-01	0.315E-01	0.338E-01	0.306E-02	-0.362E-02	5.0	-4.1	1.5	-1.5	1.24	1.07
1200.	1200.	0.107E-01	0.133E-01	0.144E-01	0.135E-02	-0.156E-02	5.2	-4.0	1.4	-1.3	1.24	1.08
1300.	1300.	0.457E-02	0.563E-02	0.612E-02	0.594E-03	-0.679E-03	5.4	-4.2	1.4	-1.2	1.23	1.09
1400.	1400.	0.195E-02	0.239E-02	0.262E-02	0.261E-03	-0.296E-03	5.5	-4.2	1.2	-1.0	1.23	1.10
1500.	1500.	0.829E-03	0.101E-02	0.112E-02	0.115E-03	-0.129E-03	5.7	-4.3	1.2	-0.8	1.22	1.11
1600.	1600.	0.349E-03	0.424E-03	0.474E-03	0.500E-04	-0.552E-04	5.9	-4.4	1.0	-0.6	1.21	1.12
1700.	1700.	0.145E-03	0.175E-03	0.198E-03	0.212E-04	-0.237E-04	5.9	-4.7	0.9	-0.4	1.21	1.13
1800.	1800.	0.588E-04	0.705E-04	0.807E-04	0.896E-05	-0.970E-05	6.0	-4.8	0.7	-0.2	1.20	1.14
1900.	1900.	0.232E-04	0.277E-04	0.322E-04	0.362E-05	-0.397E-05	6.2	-5.0	0.6	-0.1	1.19	1.16
2000.	2000.	0.889E-05	0.105E-04	0.124E-04	0.143E-05	-0.155E-05	6.3	-5.2	0.4	-0.0	1.18	1.18

Example: Gaugino pair production at NLO+NLL
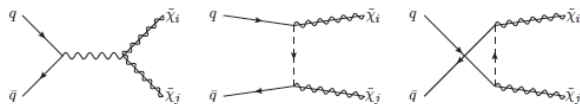
Invariant mass distribution [Debove, Fuks, Klasen]
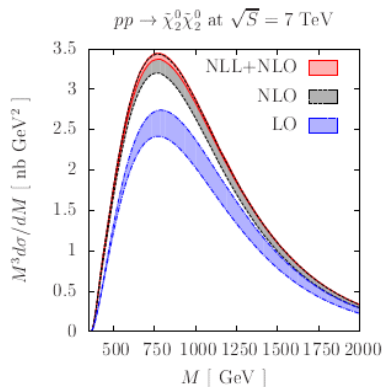
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Results

- Center of mass energy: 7 TeV
- PDF set: MSTW2008LO/NLO
- Scale variations: muF = muR = {mu/2, mu, 2 mu}; mu being the average final particle mass.

Benchmark #1: tanbeta=40; m0=700 GeV; m1/2=600 GeV; A0=-500 GeV; mu>0

Process	LO [pb]	NLO [pb]	NLO+NLL [pb]
chi^0_1 chi^0_1	6.64e-05 + 9.7 % - 8.3 %	8.23e-05 + 3.6 % - 3.6 %	8.06e-05 + 0.0 % - 0.6 %
chi^0_1 chi^0_2	6.33e-06 + 12.1 % - 10.1 %	7.66e-06 + 3.9 % - 4.2 %	7.62e-06 + 0.5 % - 0.0 %
chi^0_1 chi^0_3	1.54e-06 + 12.4 % - 10.4 %	1.77e-06 + 3.1 % - 3.7 %	1.76e-06 + 0.6 % - 1.3 %
chi^0_1 chi^0_4	3.08e-07 + 13.8 % - 11.4 %	3.56e-07 + 3.7 % - 4.4 %	3.53e-07 + 0.7 % - 1.5 %
chi^0_1 chi^-_1	4.52e-06 + 11.6 % - 9.8 %	5.59e-06 + 3.5 % - 3.8 %	5.46e-06 + 1.0 % - 0.0 %
chi^0_1 chi^-_2	8.66e-07 + 12.9 % - 10.7 %	1.04e-06 + 3.2 % - 3.8 %	1.02e-06 + 0.7 % - 1.5 %
chi^0_2 chi^0_2	4.14e-05 + 13.4 % - 11.1 %	4.91e-05 + 4.1 % - 4.5 %	4.95e-05 + 0.0 % - 0.4 %
chi^0_2 chi^0_3	4.29e-06 + 14.1 % - 11.6 %	4.81e-06 + 3.4 % - 4.2 %	4.76e-06 + 1.2 % - 1.8 %
chi^0_2 chi^0_4	5.43e-07 + 16.0 % - 12.9 %	6.14e-07 + 4.7 % - 5.4 %	6.11e-07 + 1.2 % - 2.5 %
chi^0_2 chi^-_1	1.02e-03 + 11.3 % - 9.6 %	1.18e-03 + 2.2 % - 2.8 %	1.17e-03 + 0.8 % - 1.4 %
chi^0_2 chi^-_2	7.94e-08 + 13.6 % - 11.2 %	6.25e-08 + 2.7 % - 6.2 %	5.88e-08 + 5.0 % - 5.6 %

SUSY decay rate calculations

with Sven Heinemeyer & Margarete Mühlleitner

- ▶ SUSY QCD and EWK corrections available for all two-body decay processes within the real MSSM

- ▶ `SDECAY` and `SPHENO`: two-, three- and four-body decay modes, some loop-induced decays, SUSY-QCD corrections for two-body modes, leading EWK corrections.

- ▶ extension to the complex MSSM is underway

- ▶ provide SLHA files for benchmark planes defined in arXiv:1109.3859

  1. CMSSM plane I: $\tan \beta = 10, A_0 = 0 \, \text{GeV}, \text{sign}(\mu) = +1, m_0 = 0...2000, \text{GeV}, m_{1/2} = 100...1000 \, \text{GeV}$

  2. CMSSM plane II: $\tan \beta = 40, A_0 = -500 \, \text{GeV}, \text{sign}(\mu) = +1, m_0 = 0...2000 \, \text{GeV}, m_{1/2} = 100...1000 \, \text{GeV}$

Further BSM models

with JoAnne Hewett & Tom Rizzo

- ▶ Leptoquarks (very similar to squark production. . .)
  $\rightarrow$ public NLO code available

- ▶ Extra Dimensions
  $\rightarrow$ public NLO code for ADD graviton $+$ jet production available

- ▶ W', Z'

- ▶ 4th generation quarks

- ▶ Little Higgs models

- ▶ Excited Fermions

- ▶ Technicolor

- ▶ . . .

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We are properly starting now,

please join in and/or provide feedback