SUSY parameter determination at the LHC using cross section and kinematic edges

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arXiv:1003.2648

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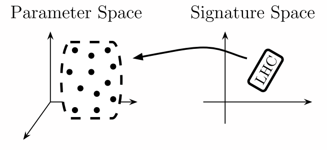
PHENO11, Madison, May 09, 2010

Motivation for supersymmetric parameter determination

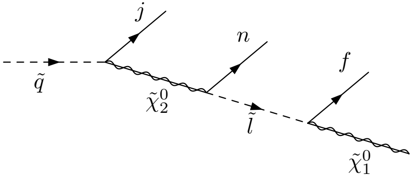
- Well, *assuming* a significant deviation from SM predictions is found at the LHC eventually...the quest just begins.
  - What is the nature of the new theory? SUSY, Extra Dimensions, Little Higgs, or something else?
  - What are the Lagrangian parameters of the new theory?

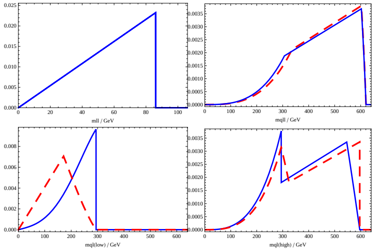
  Without any guidance these are very tough questions!
- *Assuming* Nature is supersymmetric at LHC-accessible scales...still many questions remain.
  - Mechanism of SUSY-Breaking?
  - Hints of physics to GUT or Planck scale?
  - underlying Lagrangian parameters need to be determined accurately to start answering these questions.



[Arkani-Hamed et. al., 2005, hep-ph/0512190]

Cascade decays

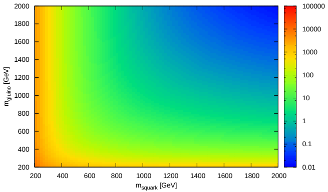




- Most effort for determining SUSY parameters so far has gone into cascade decay kinematics.
- Expected that colored sparticles produced copiously, then decay in stages emitting observable SM particle each time (assuming R-parity conservation).
- Unknown center of momentum + $\tilde{\chi}_1^0$ escaping detector $\rightarrow$ event reconstruction difficult.
- Various kinematic quantities have distributions with well-defined **endpoints** (however inverting these relations might be ambigous).

Motivation for utilizing cross-sections

- More independent observables → better determination of parameters!
- LHC cross-sections very sensitive to colored sparticle masses.
- Lot of effort has gone into supersymmetric QCD LO/NLO/NLL processes [*e.g.* Beenakker, Höpker, Spira, Zerwas, hep-ph/9610490]. (NLO needed since cross-sections can vary by up to 100%).



- Cascade decay endpoint mimic points exist – cross-sections can provide discrimination.
- Endpoints relations can be underconstraining for certain parameter regions and for certain hierarchies (in general three-Body decays).

Obstacles and Idea

- NLO SUSY-QCD calculations are not fast.
- Monte Carlo computation of rate signatures including experimental cuts is too time consuming to be efficiently used in fit algorithms (or not feasible due to statistical fluctuations in MC calculation). Compare: Lester et. al. [hep-ph/0508143].

$\Rightarrow$ Efficient parameterization needed!

Using the approach we developed a **fast** and **reliable** estimate of

$$\frac{N}{L} = \sigma_{theo} \times BR \times \text{Acceptance}$$

with

$$\Delta N = \sqrt{(\Delta\sigma_{theo.})^2 + (\Delta\sigma_{acc.})^2 + (\Delta\sigma_{exp.})^2} \lesssim 20\%$$

Error estimated to be 15% on cross-section (typical NLO error including PDF uncertainty *etc.*), 5% on cut acceptances (from comparison with full parton-level MC simulation with `Herwig++`). Experimental error includes statistical and systematical errors - yet not well explored.

Some details

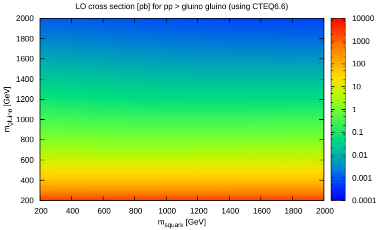
Currently two signals are implemented:

- $R_{jj\not{E}_T}$: more than two jets with $p_j^T > 50\text{GeV}, |\eta_j| < 2.5$, missing $E_T > 100\text{GeV}$
- $R_{\ell\ell jj\not{E}_T}$: additionally exactly two OS-SF leptons with $p_l^T > 10\text{GeV}, |\eta_l| < 2.5$

Cross-sections and acceptancies are parameterized by $m_{\tilde{g}}, m_{\tilde{q}}$, for each point we provide as grids:

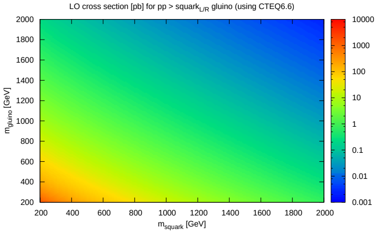
- NLO cross-sections (K-factors calculated using `Prospino 2.1`) for $\tilde{g}\tilde{g}, \tilde{q}\tilde{g}, \tilde{q}\tilde{q}$ chirality combinations and $\tilde{t}\tilde{t}$,
- numbers parameterizing cut acceptances for massless particles (e, μ, j assumed so) for given energies in $\tilde{q}$ rest frame
- numbers parameterizing $\not{E}_T$ cut acceptances for given $m_{\tilde{\chi}^0}$.

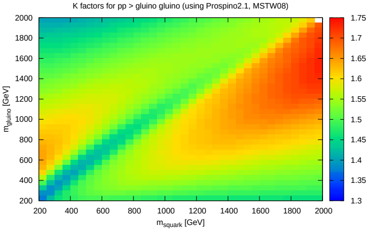
Cross Section



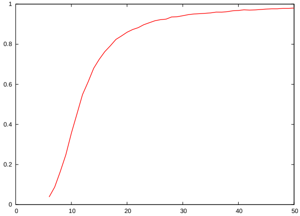
LO and NLO K-Factors:

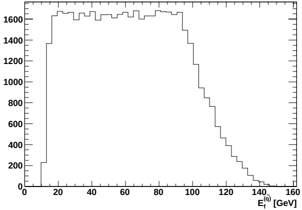
- Very smooth.
- Parameterizable by two paramters: $m_{\tilde{g}}$ and $m_{\tilde{q}}$.
- Easy to access via a grid (like PDFs).
- Channels: $\tilde{g}\tilde{g}$, $\tilde{g}\tilde{q}$, $2 \times \tilde{q}\tilde{q}$, $\tilde{t}\tilde{t}$.



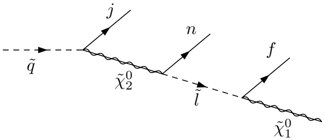


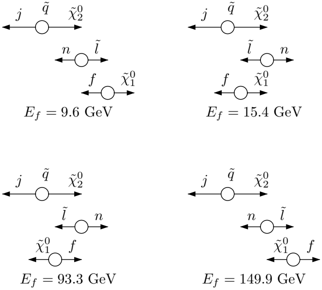
Lepton acceptance example





Analytic expressions dependent on all masses in the chain.





Technical overview of our implementation

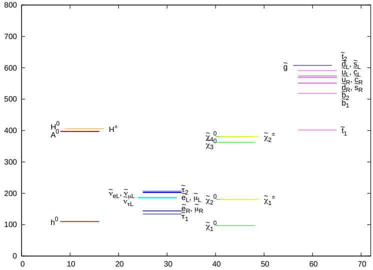
We provide a self-contained code which

- takes LHC-scale SUSY spectrum (*e.g.* from SLHA-format file)
- looks up table of cross-sections for colored sparticle production (LO + NLO K-Factors stored in grids)
- works out relevant cascade decays and multiplies with relevant branching ratios (BRs taken from SLHA file, such as produced by `SPheno` or `SUSY-HIT`)
- applies approximations for cut acceptances depending on sparticle masses
- returns event rates for particular signals

This is incorporated into `Fittino` (http://www.-flc.desy.de/fittino/) which

- explores SUSY parameter space (simulated annealing or Markov chain)
- determines LHC-scale or GUT-scale (uses `SPheno` to run from one scale to the other) Lagrangian parameters with errors

Fitting mSUGRA/CMSSM SPS1a @ 7 TeV, 1 fb^{-1}



M_0	100
$M_{1/2}$	250
$\tan\beta$	10
A_0	-100
sgn(μ)	$+$

Observables

group I:

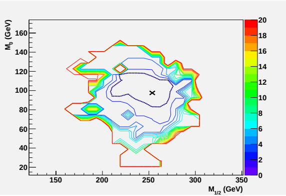
- $m_{\ell\ell}^{\max}$, the dilepton invariant mass edge,
- $m_{q\ell\ell}^{\max}$, the jet-dilepton invariant mass edge,
- $m_{q\ell}^{\text{low}}$, the jet-lepton low invariant mass edge, and
- $m_{q\ell}^{\text{high}}$, the jet-lepton high invariant mass edge

with experimental errors of $\approx 5\%$.

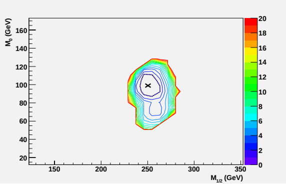
Results: mSUGRA/CMSSM SPS1a

7 TeV 1 fb^{-1}
universal $m_{1/2}$

I, ~~rates~~

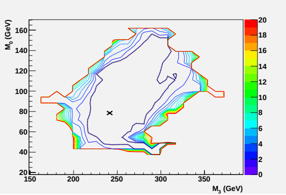


I + rates

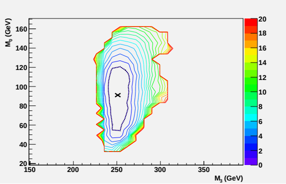


7 TeV 1 fb^{-1}
non-u M_1, M_2, M_3

I, ~~rates~~



I + rates



Summary and Outlook

Summary:

- Cross-sections can be calculated within 20% quickly ("Sure, it's only an estimate, but it's fast - and fairly accurate!").
- Rates can make a big difference to reducing errors on $M_{1/2}$ and $\tan\beta$ in parameter fits.
- Especially important with early data.

Outlook:

- Further signals to be added (*e.g.* general multilepton signals without OSSF-OSDF subtraction, multi-jet ($\geq 2, \geq 3, \geq 4$ jets) signals, combinations, ...).
- Further flexibility to be added (different mass hierarchies).
- Getting ready for first signals.
- All being persuaded actively in the framework of **LHC-FASER** (LHC - Fast Approximation of Supersymmetric Event Rates).

Thank You!

Numerical Results

	M_0 [GeV]	$M_{1/2}$ [GeV]	$\tan\beta$	A_0 [GeV]
SPS1a	100	250	10	-100
7 TeV and 1 fb^{-1}				
I + rates	$99.0\,^{+9.9}_{-9.1}$	$250.0\,^{+8.7}_{-6.5}$	$10.7\,^{+4.0}_{-8.8}$	$55.2\,^{+1048}_{-254}$
14 TeV and 1 fb^{-1}				
I + rates	$99.7\,^{+4.3}_{-5.7}$	$251.1\,^{+7.5}_{-5.8}$	$11.2\,^{+3.5}_{-5.1}$	$-50.9\,^{+1233}_{-350}$
I + II, ~~rates~~	$99.8\,^{+3.3}_{-4.4}$	$249.7\,^{+6.6}_{-5.2}$	$10.1\,^{+3.8}_{-3.2}$	$-94.1\,^{+1610}_{-216}$
I + II + rates	$99.8\,^{+3.9}_{-4.2}$	$251.3\,^{+5.0}_{-5.0}$	$10.7\,^{+3.1}_{-3.1}$	$-55.7\,^{+263}_{-233}$
14 TeV and 10 fb^{-1}				
I + rates	$100.0\,^{+2.9}_{-3.2}$	$250.7\,^{+2.9}_{-3.0}$	$11.0\,^{+2.5}_{-3.1}$	$-63.3\,^{+165}_{-192}$
I + II, ~~rates~~	$100.1\,^{+1.7}_{-1.9}$	$250.4\,^{+1.2}_{-1.7}$	$10.1\,^{+1.1}_{-1.0}$	$-89.8\,^{+70.4}_{-80.3}$
I + II + rates	$100.3\,^{+1.6}_{-1.9}$	$250.4\,^{+1.4}_{-1.6}$	$10.2\,^{+1.2}_{-1.0}$	$-96.5\,^{+86.3}_{-68.5}$
I + II + III, ~~rates~~	$100.2\,^{+1.4}_{-1.6}$	$250.3\,^{+1.1}_{-1.4}$	$10.1\,^{+0.8}_{-0.8}$	$-94.6\,^{+48.2}_{-55.0}$
I + II + III + rates	$100.1\,^{+1.6}_{-1.5}$	$250.3\,^{+1.1}_{-1.4}$	$10.3\,^{+0.7}_{-1.0}$	$-90.3\,^{+52.1}_{-57.7}$

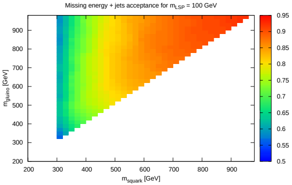
First new observable: Inclusive R^j

Defined by:

- more than 2 jets with $p_j^T > 50\text{GeV}, |\eta_j| < 2.5$.
- Missing $E_T > 100\text{GeV}$.

This can be paramterized by three paramters: $m_{\tilde{g}}$, $m_{\tilde{q}}$, $m_{\tilde{\chi}_1^0}$, obeying:

$$200\ GeV < m_{\tilde{q}} < m_{\tilde{g}} < 2\ TeV \qquad 0 < m_{\tilde{\chi}_1^0} < m_{\tilde{q}} - 200\ GeV$$



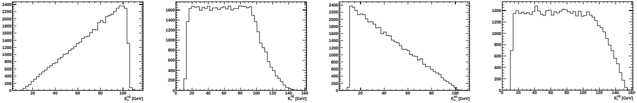
Dicrepancy from proper Monte Carlo $\lesssim 5\%$ (random scan)

Second new observable: Leptonic R^l

Defined by:

- same as R^j
- exactly two OS-SF leptons with $p_l^T > 10\text{GeV}, |\eta_l| < 2.5$.

In the limit of infinite statistics only decay chains with an on-shell $\tilde{\chi}_2^0$ (and Z/h) contribute $\rightarrow$ use OS-DF subtraction.
Energy distributions in the the squark rest-frame for different chirality combinations can be calculated analytical:



- These depend on all masses in the decay chain.
- During the fit we convolute with energy distributions in squark rest frame paramterized still by just two paramters: $m_{\tilde{g}}$ and $m_{\tilde{q}}$.

Dicrepancy from proper Monte Carlo $\lesssim$ 5% (random scan).