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

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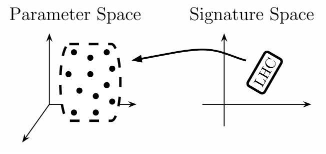
Outline

Motivation for supersymmetric parameter determination

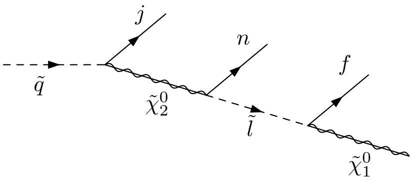
- Well, *assuming* a significant deviation from SM predictions is found at the LHC...the quest just begins.
  - What is the nature of the new theory? SUSY, Extra Dimensions, Little Higgs, or something else?
  - What are the Lagrangian parameters of the new theory?

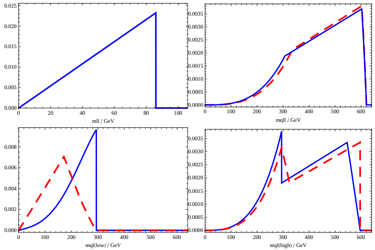
  Without any guidance these are very tough questions!
- *Assuming* Nature is supersymmetric at LHC-accessible scales...still many questions remain.
  - Mechanism of SUSY-Breaking?
  - Hints of physics to GUT or Planck scale?
  - underlying Lagrangian parameters need to be determined accurately to start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



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

Cascade decays

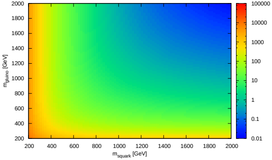




- Most effort for determining SUSY parameters so far has gone into cascade decay kinematics
- Expected that colored sparticles produced copiously, then decay in stages emitting observable SM particle each time (assuming R-parity conservation)
- Unknown center of momentum + $\tilde{\chi}_1^0$ escaping detector → 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 observables → better determination of parameters! (in general)
- 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 100%).



- Cascade decay endpoint mimic points exist – cross-sections can provide discrimination
- Cascade decay endpoints can be underconstraining for certain parameter regions and for certain hierarchies (Three-Body decays, Split-SUSY etc.)
- Non-supersymmetric models can have very similar spectra but with differing spins and thus potentially very different cross sections.

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).

$\Rightarrow$ 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

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

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; calculated using `Prospino 2.1`, http://www.thphys.uni-heidelberg.de/ plehn/prospino/)
- 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`: a program by Philip Bechtle, Klaus Desch and Peter Wienemann (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

Some details

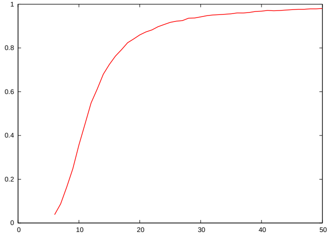
Currently two signals are implemented:

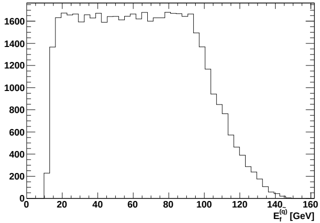
- $R_{jj\not{E}_T}$: more than two jets with $p_j^T > 50\text{GeV}, |\eta_j| < 2.5$, missing $E_T > 100\text{GeV}$
- $R_{\ell\ell jj\not{E}_T}$: additionally exactly two OS-SF leptons with $p_l^T > 10\text{GeV}, |\eta_l| < 2.5$

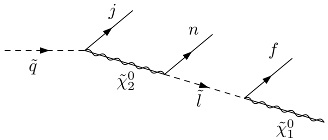
Cross-sections and acceptancies are parameterized by $m_{\tilde{g}}, m_{\tilde{q}}$, for each point we provide as grids:

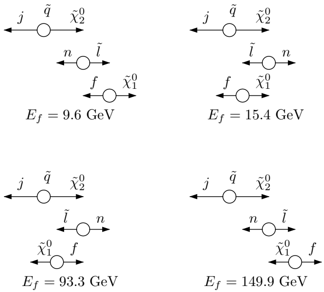
- NLO cross-sections for $\tilde{g}\tilde{g}, \tilde{q}\tilde{g}, \tilde{q}\tilde{q}$ chirality combinations and $\tilde{t}\tilde{t}$
- numbers parameterizing cut acceptances for massless particles (e, μ, j assumed so) for given energies in $\tilde{q}$ rest frame
- numbers parameterizing $\not{E}_T$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

Lepton acceptance example

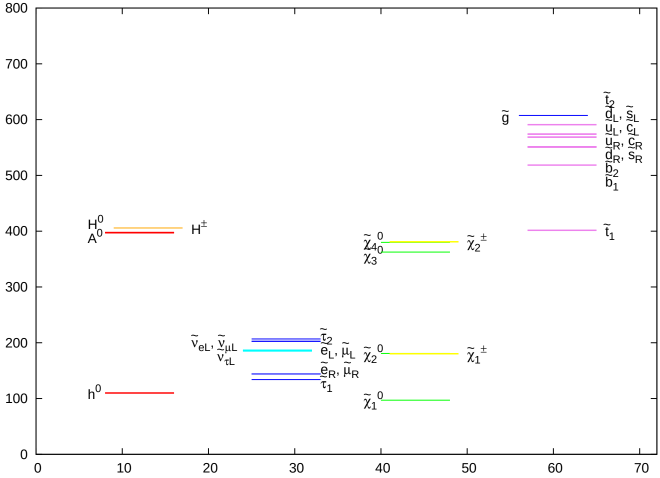








Fitting universal mSUGRA SPS1a @ 14 TeV, 10 fb^{-1} and @ 7 TeV, 1 fb^{-1}



SPS1a

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

SPS1a inputs

group I:

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

group II:

- $m_{q\ell\ell}^{\mathrm{thr.}}$, the jet-dilepton threshold invariant mass edge,
- $m_{T2}^{\tilde{q}}$, the squark stransverse mass,
- $m_{\tau\tau}^{\max}$, the di-tau invariant mass edge,
- m_{tb}^{w}, the weighted top-bottom invariant mass edge, and
- $r_{\tilde{\ell}\tilde{\tau}\mathrm{BR}}$, the ratio of selectron- to stau-mediated $\tilde{\chi}_2^0$ decays.

group III:

- $\Delta m_{\tilde{g}\tilde{\chi}_1^0}$, the mass difference between the gluino and the LSP,
- $m_{(\tilde{\chi}_4^0)\ell\ell}^{\max}$, the dilepton invariant mass edge from the decay of a $\tilde{\chi}_4^0$,
- $m_{b\ell\ell}^{\mathrm{thr.}}$, the b-tagged jet-dilepton threshold invariant mass edge, and
- m_h, the mass of the lightest neutral scalar Higgs boson.

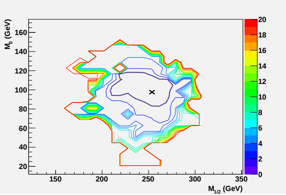
new observables:

- $R_{jj\not{E}_T}$, the inclusive event rate for at least two hard jets with missing transverse energy, and
- $R_{\ell\ell jj\not{E}_T}$, the exclusive event rate for at least two hard jets with missing transverse energy plus a pair of opposite-sign same-flavour light leptons.

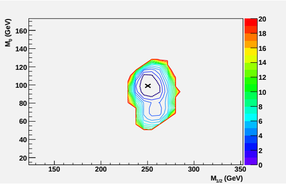
Results

7 TeV 1 fb^{-1}

I, ~~rates~~

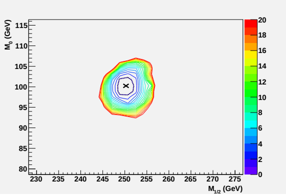


I + rates

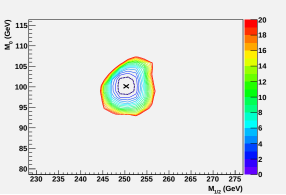


14 TeV 10 fb^{-1}

I + II + III, ~~rates~~



I + II + III + rates



Summary and Outlook

Summary:

- Cross-sections can be calculated within 20% quickly
- 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:

- Verification of cut acceptances with full detector simulation needed.
- Further signals to be added (*e.g.* multilepton signals without OSSF-OSDF subtraction)
- Further flexibility to be added (different mass hierarchies)

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	$100.1^{+1.6}_{-1.5}$	$250.3^{+1.1}_{-1.4}$	$10.3^{+0.7}_{-1.0}$	$-90.3^{+52.1}_{-57.7}$