Reconstructing supersymmetric particle masses from collider experiments

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Faggruppemøte for subatomær fysikk og astrofysikk,
Norsk fysisk selskap, 30.04.2014
Outline

- Supersymmetry (again)
- Dark matter (again)
- SUSY at the LHC, chain decays
- A method for inferring SUSY particle masses
- My project & outlook
What is Supersymmetry?

An extension of the Poincaré algebra of spacetime by Majorana spinor charges...
What is Supersymmetry?

- ...or simply: Many new particles!
- Everybody gets (at least) one heavy friend – differ by spin and mass
- Please supply particle names with s'es and -ino's to own liking
  - Squarks, sleptons, gauginos, (gravitino)
R-parity

• Usually assumed: SUSY particles cannot decay to only SM particles – number of SUSY particles conserved

• This implies the existence of a stable \textit{Lightest SUSY Particle} (LSP)
Dark matter (1)

• We know it exists, but what is it?
• Popular candidate: Weakly Interacting Massive Particle (WIMP)
• SUSY can provide us with a WIMP particle: the Neutralino
  – A spin-1/2 fermion with zero electric charge, SUSY-partner of Z-boson/photon/Higgs.
  – Couples to weak force and gravitation only
  – Cannot decay because of R-parity (it's the LSP)
Dark matter (2)

- SUSY as dark matter – as good a reason as any to look for SUSY!
- Use the Large Hadron Collider at CERN to look.
- It is invisible – i.e. looks a lot like neutrinos
SUSY production (and decays) at LHC

• The LHC collides protons, so the force is strong (with this one)
• Squarks are strong SUSY particles, so we expect production of squark-antisquark pairs
• A squark will typically decay in a chain down to the LSP (neutralino 1)
My favourite decay chain

- $X \rightarrow 1 + Y$, $Y \rightarrow 2 + Z$, $Z \rightarrow 3 + N$
- E.g. (i.e.)
  - squark $\rightarrow$ quark + lepton + antilepton + neutralino$^1$

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1. squark
2. quark
3. lepton
4. antilepton
5. neutralino
What can be measured?

- The LHC detectors measure energy and momentum of produced particles
- But some particles are invisible (neutrino, neutralino)
- Infer these from energy conservation
The method

- Imagine that my chain has been identified in some LHC event
  - (in practice difficult: Two hadron jets, four leptons and two missing energies, plus background)
- Would really like to know the mass of the SUSY particles!
My favourite article

Mass determination in sequential particle decay chains

Bryan Webber

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ABSTRACT: A simple method is proposed for determining the masses of new particles in collider events containing a pair of decay chains (not necessarily identical) of the form $Z \rightarrow Y + 1$, $Y \rightarrow X + 2$, $X \rightarrow N + 3$, where 1,2 and 3 are visible but $N$ is not. Initial study of a possible supersymmetric case suggests that the method can determine the four unknown masses in effectively identical chains with good accuracy from samples of a few tens of events.

KEYWORDS: Hadronic Colliders, Supersymmetry Phenomenology, Beyond Standard Model.

arXiv:0907.5307v2
\[ \tilde{q} \rightarrow \tilde{\chi}_2^0 + q, \quad \tilde{\chi}_2^0 \rightarrow \tilde{\ell}^\pm + \ell^\mp, \quad \tilde{\ell}^\pm \rightarrow \tilde{\chi}_1^0 + \ell^\pm, \]  \quad (1.1)
Kinematical constraints (1)

- "Small width approximation"
  => everything is on-shell

\[
\begin{align*}
(p_1 + p_2 + p_3 + p_4)^2 &= M_Z^2 \\
(p_2 + p_3 + p_4)^2 &= M_Y^2 \\
(p_3 + p_4)^2 &= M_X^2 \\
p_4^2 &= M_N^2
\end{align*}
\]
Kinematical constraints (2)

Leaving aside the last equation, the others give three linear constraints on the invisible 4-momentum $p_4$:

\[-2p_1 \cdot p_4 = M_1^2 - M_2^2 + 2p_1 \cdot p_2 + 2p_1 \cdot p_3 + m_1^2 \equiv S_1\]
\[-2p_2 \cdot p_4 = M_2^2 - M_3^2 + 2p_2 \cdot p_3 + m_2^2 \equiv S_2\]
\[-2p_3 \cdot p_4 = M_3^2 - M_4^2 + m_3^2 \equiv S_3\]

(2.2)

Similarly for the lower chain:

\[-2p_5 \cdot p_8 = M_5^2 - M_6^2 + 2p_5 \cdot p_6 + 2p_5 \cdot p_7 + m_5^2 \equiv S_5\]
\[-2p_6 \cdot p_8 = M_6^2 - M_7^2 + 2p_6 \cdot p_7 + m_6^2 \equiv S_6\]
\[-2p_7 \cdot p_8 = M_7^2 - M_8^2 + m_7^2 \equiv S_7\]

(2.3)

We also have the missing transverse momentum constraints:

\[p_T^4 + p_T^8 = p_T^\text{miss} \equiv S_4\]
\[p_T^5 + p_T^8 = p_T^\text{miss} \equiv S_5\]

(2.4)

Let us make an 8-vector of the invisible 4-momenta,

\[\mathbf{P} = (p_T^4, p_T^5, p_T^6, E_4, p_T^6, p_T^7, p_T^8, E_8)\]

(2.5)
Kinematical constraints (3)

\[
\begin{pmatrix}
 p_1^x & p_1^y & p_1^z & -E_1 & 0 & 0 & 0 & 0 \\
 p_2^x & p_2^y & p_2^z & -E_2 & 0 & 0 & 0 & 0 \\
 p_3^x & p_3^y & p_3^z & -E_3 & 0 & 0 & 0 & 0 \\
 1/2 & 0 & 0 & 0 & 1/2 & 0 & 0 & 0 \\
 0 & 0 & 0 & 0 & p_5^x & p_5^y & p_5^z & -E_5 \\
 0 & 0 & 0 & 0 & p_6^x & p_6^y & p_6^z & -E_6 \\
 0 & 0 & 0 & 0 & p_7^x & p_7^y & p_7^z & -E_7 \\
 0 & 1/2 & 0 & 0 & 0 & 1/2 & 0 & 0 \\
\end{pmatrix}
\]

\[
(p_4^2)_n = (P_4^2 - P_1^2 - P_2^2 - P_3^2)_n = M_N^2
\]

\[
(p_8^2)_n = (P_8^2 - P_5^2 - P_6^2 - P_7^2)_n = M_N^2
\]

(2.13)
Mass fitting

- Make a guess for the four/eight unknown SUSY masses
- Minimize the on-shell requirement

\[
\xi^2(M) = \sum_n [(p^2_4)_n - M^2_N]^2 + \sum_n [(p^2_8)_n - M^2_{N'}]^2
\]

- Should be zero for the correct mass hypothesis
Promising:
Promising

- Expect few SUSY events at LHC based on current data
- This method can give good fits based on few tens of events
My project

• Get more familiar with this...
• Look into the technical aspects: Matrix inversion with stochastic variables, optimizing the fitting function, …
• Play with Monte Carlo
Summary

- Really, really want to find SUSY at LHC
- Have a novel method to infer the new masses
  - Works with few events
- Lots of linear algebra and Monte Carlo ahead! :-)

30.04.2014
On a side note...

Norwegians, please note: The deadline for submitting tax returns is today!
Thank you

Questions?
Comments?