Determination of SUSY Parameters at the LHC

Nicki Bornhauser
In Collaboration with Manuel Drees

University of Bonn

April 1st, 2011
DPG-Frühjahrstagung Karlsruhe 2011

- Until the end of 2010 the Large Hadron Collider (LHC) delivered around $48\,\mathrm{pb}^{-1}$ of data from proton-proton collisions
- Around $1\,\mathrm{fb}^{-1}$ of data are estimated at the end of 2011 $\rightarrow$ The LHC is taking data!

- Soon we may see signs of new physics. This new physics could be some variety of Supersymmetry (SUSY)

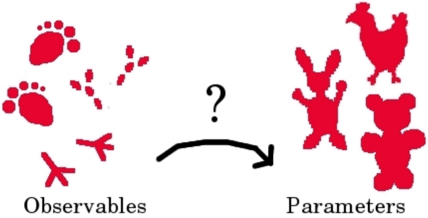
$\rightarrow$ What are the parameters of the underlying theory?!

- There are programs like Fittino[a] or SFitter[b] to determine SUSY parameters
- These methods use mainly kinematical information about the measurement like masses, widths or edges in mass spectra (cross sections, branching fractions are also used)

→ Our method relies mainly on dynamical instead of kinematical information of the measurement

[a] P. Bechtle *et. al.*, Comput. Phys. Commun. **174**, 47 (2006), arXiv:hep-ph/0412012

[b] R. Lafaye *et. al.*, Eur. Phys. J. C **54**, 617 (2008), arXiv:hep-ph/0709.3985



- We look at 85 mostly dynamical observables to differentiate between different models → Count numbers!
- 12 lepton classes with each 7 observables and the total cross section

12 classes depending on the number of leptons (electrons, muons and corresponding antiparticles):

- $0l$: Events with no leptons
- $1l^-$ ($1l^+$): Events with one negative (positive) charged lepton
- $2l^-$ ($2l^+$): Events with two negative (positive) charged leptons
- $l_i^+ l_i^-$ ($l_i^+ l_{j;\ j \neq i}^-$): Events with two opposite-sign charged leptons with same (different) flavor, i.e. for example $e^- e^+$ ($e^- \mu^+$)

- $l_i^- l_j^- l_j^+$ ($l_i^+ l_j^+ l_j^-$): Events with three leptons and overall negative (positive) charge, i.e. there are at least two negative (positive) charged leptons. There is an opposite-sign charged lepton pair with same flavor. For example $e^- \mu^- \mu^+$ ($e^+ \mu^- \mu^+$)
- $l_i^- l_j^- l^{\pm}_{k;\ k \neq j,i\ for\ +}$ ($l_i^+ l_j^+ l^{\pm}_{k;\ k \neq j,i\ for\ -}$): Events with three leptons and overall negative (positive) charge, i.e. there are at least two negative (positive) charged leptons. There is **NO** opposite-sign charged lepton pair with same flavor. For example $e^- e^- \mu^+$ ($e^+ e^+ \mu^-$)
- $4l$: Events with four or more leptons

For each class 7 observables are looked at:

- $\langle n \rangle$: "Average" number of events within a class, i.e. the number of class events divided by the total number of events
- $\langle n_{\tau^-} \rangle$ ($\langle n_{\tau^+} \rangle$): Average number of tagged τ^- (τ^+) within a class event
- $\langle n_b \rangle$: Average number of tagged b-hadrons (b-jets) within a class event
- $\langle n_j \rangle$: Average number of (non-b-) jets within a class event
- $\langle n_j^2 \rangle$: Average squared number of jets within a class event
- $\langle H_T \rangle$: Average value of H_T within a class event (H_T is the sum over the p_T values of all "hard" objects)

- 283 degenerate pairs of models which cannot be distinguished at the LHC using conventional methods[a]
- SUSY model with 15 free parameters
- 1808 observables are investigated (dynamical as well as kinematical information)

→ Can we distinguish some of these model pairs with our observables?!

[a] N. Arkani-Hamed *et. al.*, JHEP **0608**, 070 (2006), arXiv:hep-ph/0512190

- Simulate the models with Herwig++[a] for a center of mass energy $\sqrt{s} = 14\,\mathrm{TeV}$ and an integrated luminosity of $10\,\mathrm{fb}^{-1}$
- Furthermore use SOFTSUSY[b], SUSY-HIT[c], and FastJet[d]
- The events have to pass certain cuts to reduce Standard Model background

---

[a] M. Bähr *et. al.*, Eur. Phys. J. C **58**, 639 (2008), arXiv:hep-ph/0803.0883
[b] B.C. Allanach, Comput. Phys. Commun. **143**, 305 (2002), arXiv:hep-ph/0104145
[c] A. Djouadi *et. al.*, Acta Phys. Polon. B **38**, 635 (2007), arXiv:hep-ph/0609292
[d] M. Cacciari, G.P. Salam, Phys. Lett. B **641**, 57 (2006), arXiv:hep-ph/0512210

- Calculate χ^2 to compare the models:

$$\chi^2_{AB} = \sum_{i,j} (s_i^A - s_i^B) V_{ij}^{-1} (s_j^A - s_j^B)$$

$s_i^{A(B)}$ is the signature i of the model $A(B)$
V^{-1} is the inverse of the covariance matrix $V_{ij} = cov[s_i, s_j]$

- V^{-1} is mostly a diagonal matrix with entries

$$\frac{1}{\sigma^2(s_i^A) + \sigma^2(s_i^B)},$$

because only $\langle n_j \rangle$ and $\langle n_j^2 \rangle$ are correlated. $\sigma^2(s_i^A)$ is the variance of the observable s_i^A

- The smaller χ^2_{AB} the more similar look the signatures of the two different models in an experiment
- Look at the p-value of the calculated χ^2_{AB}:

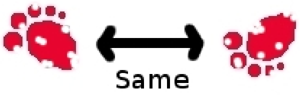
$$p = \int_{\chi^2_{AB}}^{\infty} f(z, n_d) dz$$

$f(z, n_d)$ is the χ^2 probability density function and n_d is the number of degrees of freedom, i.e. the number of summed signatures

→ The p-value gives the probability that an observed χ^2 is bigger than χ^2_{AB}, if both signatures originate from the same model

Compare 70 **SAME** models with different seeds in Herwig++:

- Calculate the average p-value of the pairs
- Change the minimal number of class events required for comparison
- $\langle p \rangle \approx 0.68$ can be reached with $p_{min} \approx 0.04$



Compare the degenerated pairs:

- Say model pair can be differentiated if $p < 0.01$
- 70 models lead to 42 degenerated pairs
- 8 out of 42 pairs have values $p \geq 0.01$ and still would be degenerated

- It seems to be possible to distinguish between most of the models for the degenerated pairs
- Our mostly dynamical observables seem to be useful for parameter determination
- Using more observables does not automatically improve the parameter determination

- Use the observables to determine parameters, e.g. using a Neural Network

Thank you for your attention!