Mitigation of the LHC Inverse Problem

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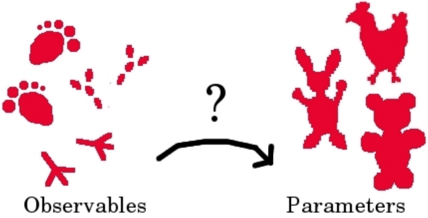
- The Large Hadron Collider (LHC) is working quite well. So far around $5\,\mathrm{fb}^{-1}$ of delivered data from proton-proton collisions. Maybe $20\,\mathrm{fb}^{-1}$ next year
- Soon we may see signs of new physics. This new physics could be some variety of Supersymmetry (SUSY)

→ What are the parameters of the underlying theory?!



- Simulation of 43026 models of a supersymmetric Standard Model with 15 free parameters $\rightarrow$ 283 degenerate model pairs which cannot be distinguished[a]

- 14 TeV center of mass energy and 10 fb^{-1} simulated data
- 1808 mainly kinematical observables are investigated

$\rightarrow$ Can we distinguish some of these model pairs focusing mainly on counting observables?!

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

- We simulate these models with Herwig++[a]
- Furthermore use SOFTSUSY[b], SUSY-HIT[c], and FastJet[d]
- The events have to pass certain cuts to reduce Standard Model background

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[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

- We look at 84 observables for the events after cuts
- Total cross section and 12 lepton classes with each 7 observables (minus one double information)

- Lepton classes: $0\ell \quad 1\ell^- \quad 1\ell^+ \quad 2\ell^- \quad 2\ell^+ \quad \ell_i^+\ell_i^- \quad \ell_i^+\ell_{j;\ j\neq i}^-$ $\ell_i^-\ell_j^-\ell_j^+ \quad \ell_i^+\ell_j^+\ell_j^- \quad \ell_i^-\ell_j^-\ell_{k;\ k\neq j,i \text{ for } +}^{\pm} \quad \ell_i^+\ell_j^+\ell_{k;\ k\neq j,i \text{ for } -}^{\pm} \quad 4\ell+$
- Observables: $n/N \quad n_{\tau^-}/n \quad n_{\tau^+}/n \quad n_b/n \quad \langle j\rangle \quad \langle j^2\rangle \quad \langle H_T\rangle$

$n =$ number of class events $\qquad N =$ total number of events

- Calculate χ^2 to compare the models:

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

$o_i^{A(B)}$ is the observable i of model $A(B)$ V_{ij}^{-1} is the inverse of the covariance matrix $V_{ij} = cov[o_i^A, o_j^A] + cov[o_i^B, o_j^B]$

- V^{-1} has non-diagonal entries because of correlations: $\sum_c n_c/N = 1$ over classes c $\langle j_c \rangle$ and $\langle {j_c}^2 \rangle$

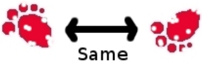
- The smaller χ^2_{AB} the more similar look the signatures of the two different models in an experiment
- Look at the p-value of the calculated χ^2_{AB}:

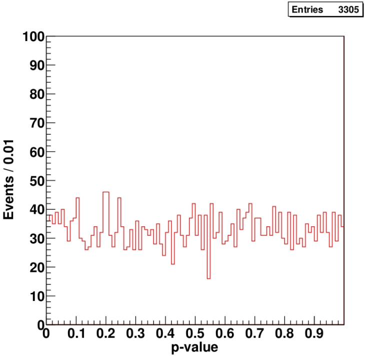
$$p = \int_{\chi^2_{AB}}^{\infty} f(z, n_d) dz$$

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

→ 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

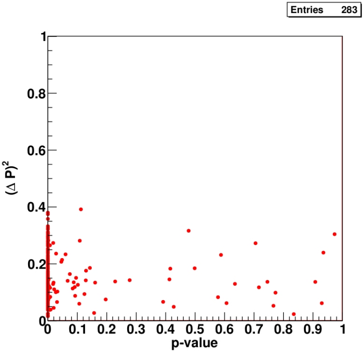
- Check the calculation of χ^2 by comparing models to themselves
- Simulate 3305 models with two different seeds in Herwig++
- Look at the p-value distribution:





- Arkani-Hamed *et. al.* take systematic errors into account (15 % for the total number of events and 1 % for all other observables), we do the same, but also look at the results without them
- They use a detector simulation, we use tagging efficiencies and appropriate cuts
- They do not include initial state radiation and multiple interactions, we do
- They do not consider Standard Model Background, we look at both cases

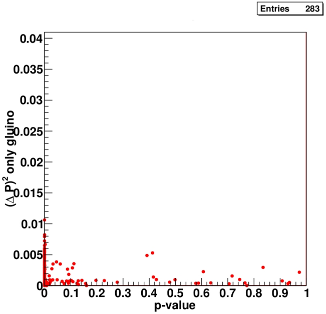
- Including systematic errors we can distinguish between 242 out of 283 degenerate pairs with a 95 % confidence level

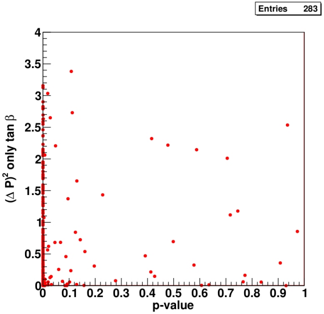


Parameter difference: $(\Delta P_{AB})^2 = \frac{1}{n_{para}} \sum_{i=1}^{n_{para}} \left(\frac{p_i^A - p_i^B}{\bar{p}_i^{AB}} \right)^2$ with $\bar{p}_i^{AB} = \frac{p_i^A + p_i^B}{2}$

p_i^A = i-th parameter of model A $\quad n_{para}$ = number of compared parameters

- The gluino mass and squark masses can be determined especially well, the other gaugino masses and μ still relatively nicely, but the slepton masses and tan β are much harder to distinguish





- Number of indistinguishable model pairs for a 95 % confidence level with and without Standard Model background (“Bg”) and systematic errors (“S.E.”)
- 283 degenerate pairs and bigger sample of the 4654 hardest distinguishable pairs for Arkani-Hamed *et. al.*

		Without Bg		With Bg	
Model Sample	# Pairs	S.E.	No S.E.	S.E.	No S.E.
Degenerate Pairs	283	41	1	71	12
Bigger Pair Sample	4654	204	6	689	129

- It seems to be possible to distinguish between all models after systematic error reduction
- Necessary to understand correlations between used observables
- Depending on the model counting or kinematical observables seem to be more helpful

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

Thank you for your attention!