Theory Space, LHC and the Inverse Problem

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The Salam-Weinberg-Glashow Theory

- The Standard model works extremely well
- Tested precisely up to energy scales of order 100 GeV. No anomalies yet..
- In fact, the LEPII results test the modifications of the model by higher dimension operators indicate that there is no new physics even at the 5TeV scale

BUT: Why is M_W Small????????

- The Higgs Mass is quadratically divergent in the STANDARD MODEL.
- Therefore either nature is fine tuned or there must be new physics which cancels this divergence
- There are several proposals for physics which cancel this divergence and render the Higgs Mass finite and reasonable…..

Beyond The Standard Model

- Supersymmetry
- Large Extra Dimensions
- Warped Extra dimensions
- Higgsless models
- Technicolour
- Little Higgs Models
- String and M theory vacua

A Vast Theory Space

- There is clearly a large selection of proposals for BSM physics
- In each of these there are choices:
- In the EFT's couplings (eg 125 or so parameters of the MSSM alone)
- In string theory, a choice of where you are in the landscape eg which Calabi-Yau, flux etc

LHC Basics

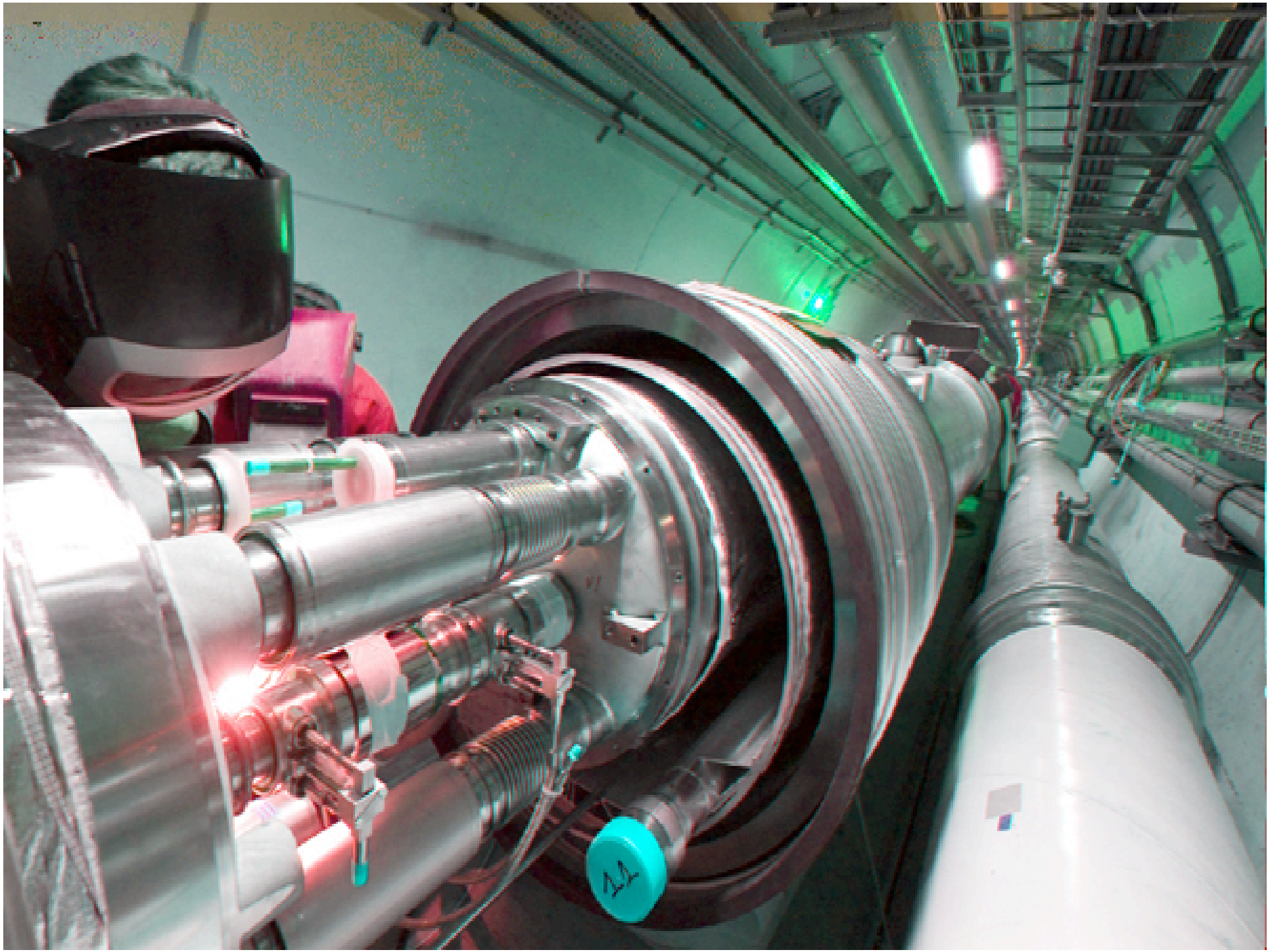
- LHC will test many of these theories
- Protons will collide with Protons at 14TeV
- The Luminosity of the machine will range from a few fb^{-1} to a few 100 fb^{-1}
- A large number of events per second (billions, but only hundreds recorded!)
- Will discover new physics if the scale of new physics is TeV or so.

LHC Data?

- HE particle physicists will focus on data recorded by two experiments at the collider: CMS and ATLAS
- The partons in the protons collide, produce other (new!) particles which then decay into QCD jets, leptons and photons
- The detectors record only the presence of charged leptons, QCD jets, photons, their momenta as well as the presence of missing energy (eg neutrinos or LSP)
- b- quarks can also be identified about 50% of the time and the lepton flavour (tau 50%)
- CUTS must be applied

Seeing New Physics at LHC

- The standard model predicts a signal at LHC in various channels
- eg at 10fb^{-1} it predicts very few events with only two leptons of the same charge with p_T > 20 GeV and four jets with p_T >100GeV
- If many such events are seen, there must be new physics.
- Hoorah!



Are We Ready For the LHC?

- LHC will switch on in 18 months or so :):):)
- Commissioned some time ago
- Theoretical Perspective has changed:
- Does supersymmetry naturally extend the standard model?
- Many new ideas: large extra dimensions, warped extra dimensions, little Higgs, Higgsless models……
- Theory space is vast
- The String Landscape vs. Naturalness

- **LHC is an incredible opportunity to learn about nature at short distances**

- **We should prepare ourselves for LHC as best as we possibly can**

- **Is the theory community ready?**

The LHC Olympics

- **Many theorists are NOT ready for the experiment which will dominate high energy physics for some years to come**

- **The LHC Olympics is a series of meetings which offers an opportunity to resolve this issue.**

The LHC Olympics Format

- http://wwwth.cern.ch/lhcOlympics/lhcolympicsII.html - online info and discussion

- Blackboxes - simulated data samples which participants can study as if real data

- Biannual meetings with talks and discussions.
- Hopefully this will help prepare us for the inverse problem…

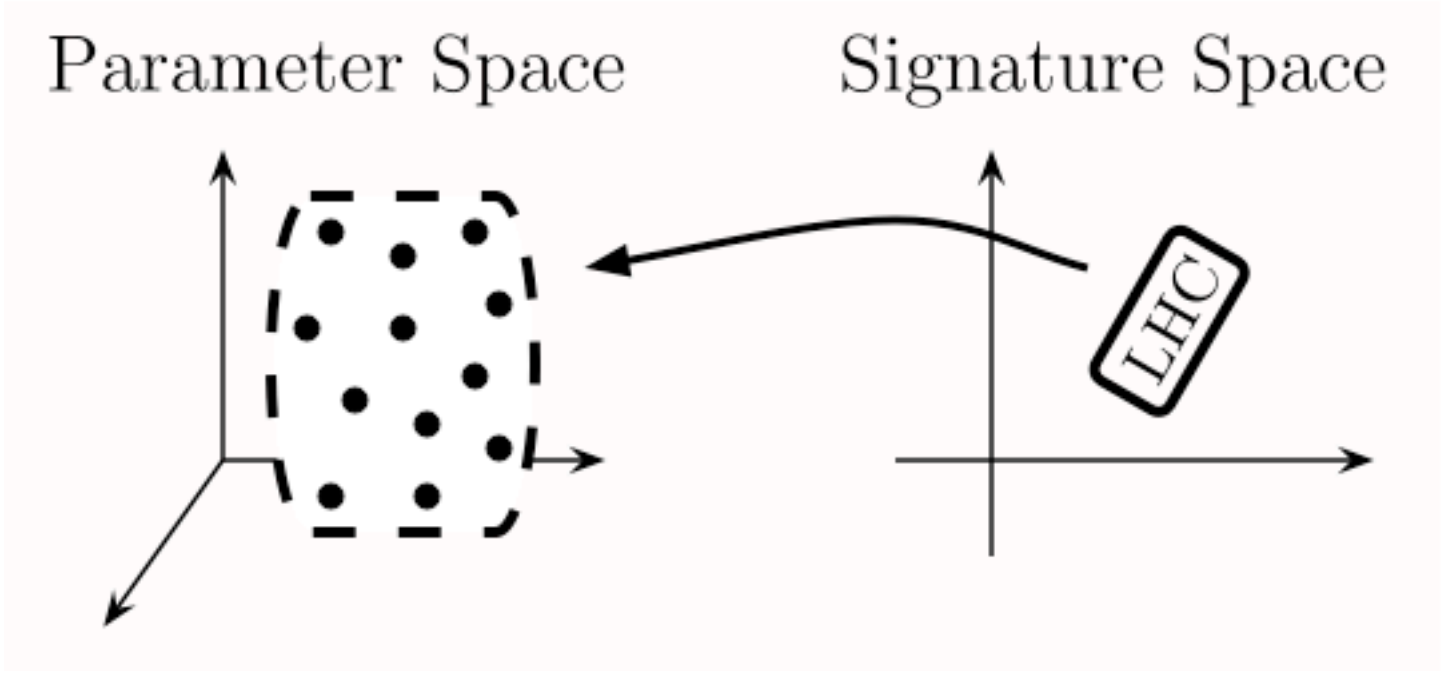
LHC Inverse Problem

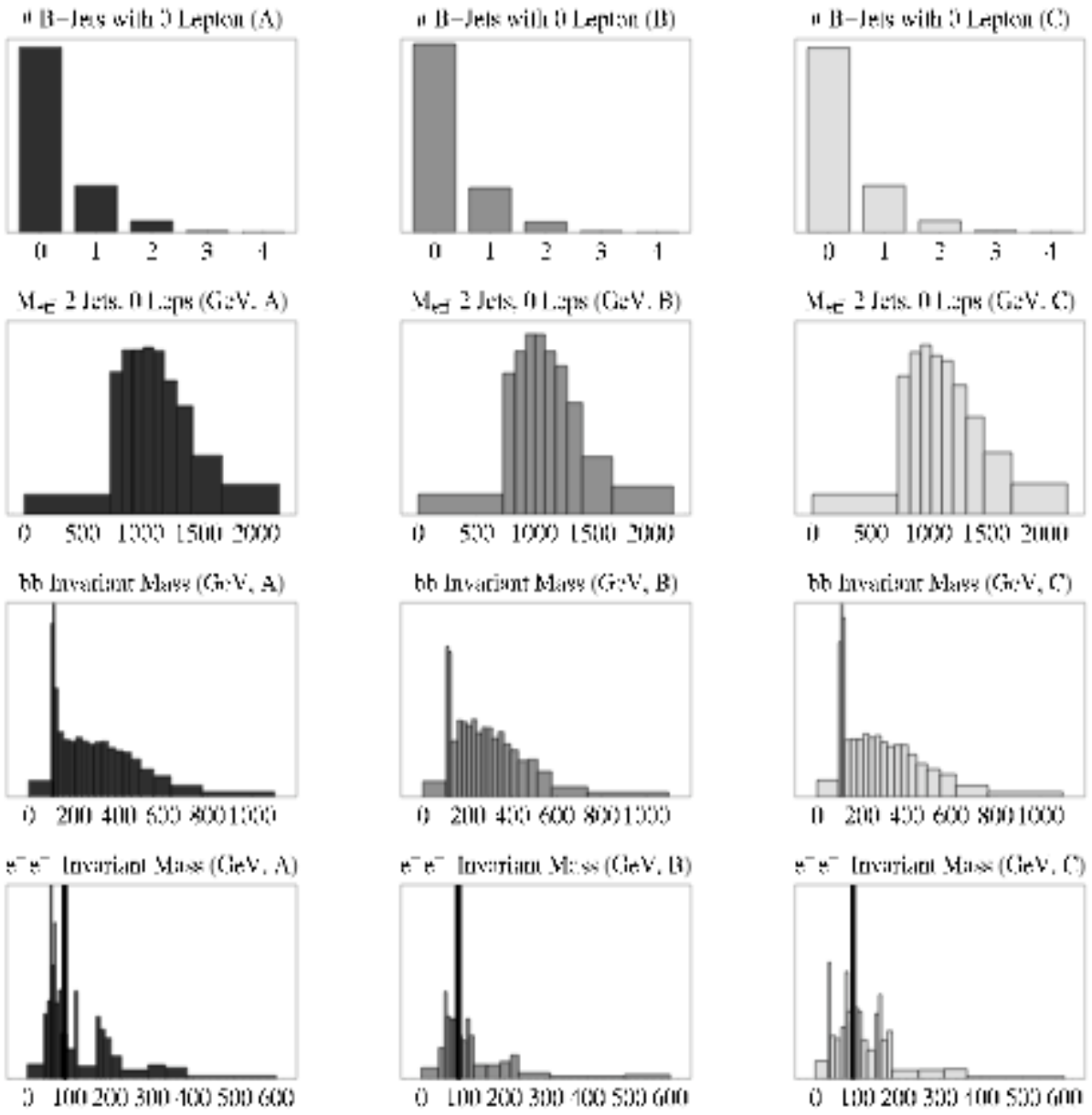
- If LHC produces a signal…….
- How can we use it to determine the TeV Lagrangian?
- What about the underlying theory?
- How will we identify the string/M theory vacuum?
- This is the LHC Inverse Problem
- A mini version of this problem is:

The SUSY LHC Inverse Problem

Arkani-Hamed, Kane, Thaler, Wang hep-ph/0512190

- **Simulated 43,026 MSSM's, 1808 observables**
- **Varied the 15 most LHC relevant parameters**
- **Found that 283 pairs of models were degenerate**
- **Determined the effective number of independent signature bins ~ 3 million ~ $(43\ 026)^2$ /283x2**
- **Found that each signal can come from from 5 - 100 different theories.**
- **Eg parameter vol/#sigs ~ 10^8 / 3 million ~ 30**


Parameter Space
Signature Space
LHC


B-Jets with 0 Lepton (A)
0 1 2 3 4
B-Jets with 0 Lepton (B)
0 1 2 3 4
B-Jets with 0 Lepton (C)
0 1 2 3 4
M_{eff} 2 Jets, 0 Leps (GeV, A)
0 500 1000 1500 2000
M_{eff} 2 Jets, 0 Leps (GeV, B)
0 500 1000 1500 2000
M_{eff} 2 Jets, 0 Leps (GeV, C)
0 500 1000 1500 2000
bb Invariant Mass (GeV, A)
0 200 400 600 800 1000
bb Invariant Mass (GeV, B)
0 200 400 600 800 1000
bb Invariant Mass (GeV, C)
0 200 400 600 800 1000
e^-e^- Invariant Mass (GeV, A)
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e^-e^- Invariant Mass (GeV, B)
0 100 200 300 400 500 600
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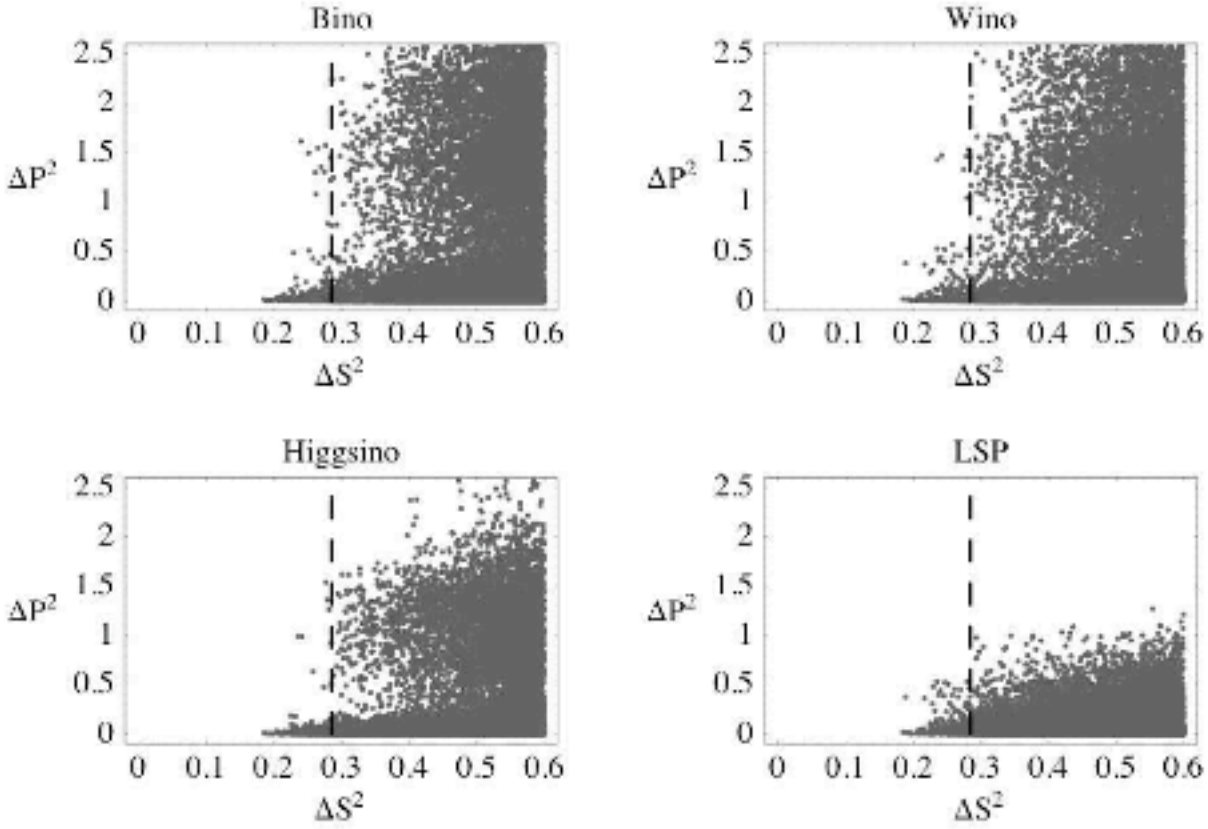
Bino
Wino
Higgsino
LSP
ΔP²
ΔS²
0
0.5
1
1.5
2
2.5
0.1
0.2
0.3
0.4
0.5
0.6

Explaining the Degeneracies

- **FLIPPER: swap a wino with a bino**

- **Then, to keep the total susy cross section fixed, change the superpartner masses**
- **Other degeneracies explained by sliding the spectrum around keeping various mass splittings fixed.**

How it was done.

- Event generation software by piping Pythia output into John Conways Pretty Good Simulator (PGS)
- Created a mathematica based data analysis package called Chameleon
- http://www.jthaler.net/olympics/software.html
- Extremely user friendly tools which are very useful for studying the hadron collider signals of any theory which can be simulated by Pythia. (eg a theorist with little experience with MC's can easily use these)
- To simulate so many models (each at 10fb^{-1}) used the Harvard Astro SAURON Cluster.

String theory and LHC

(BSA, G. Kane, P. Kumar…)

- We show that the LHC is capable of testing various ideas in string theory:
- eg the heterotic string on a Calabi-Yau or M theory on a G2 manifold, with assumptions about what the susy breaking mechanism is.

Method

- Have to first consider string/M theory vacua with moduli stabilised
- Compute the high scale lagrangian
- Run it down to TeV scale
- Simulate the LHC signal using Monte Carlo simulation and a detector simulation
- Compare the results between different theories

Conclusions

- We will have to face the LHC Inverse problem if LHC discovers any BSM physics
- This is a deep, important problem which theorists will be confronted with soon
- This is an exciting time for HE physics