Model Fitting in Particle Physics

Matthew Dolan[1]

[1]DAMTP
University of Cambridge

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Outline

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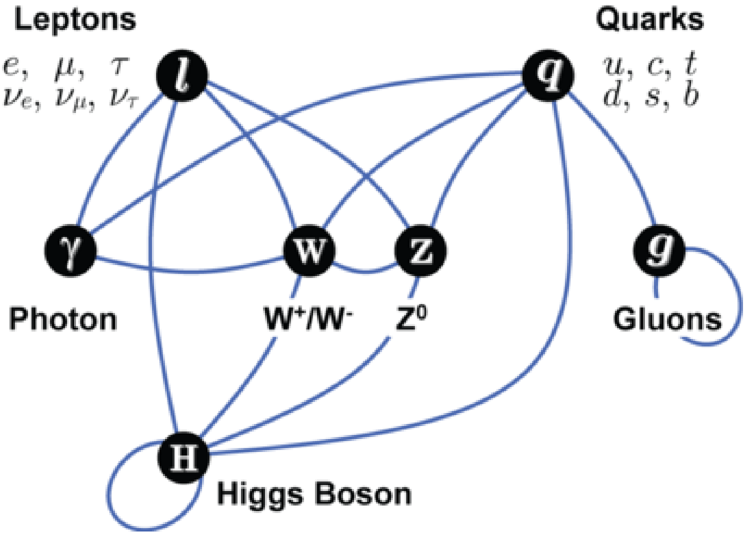
The Standard Model

- The Standard Model of particle physics describes three of the four known fundamental forces: electromagnetism, the weak force and the strong force.
- It contains all the particles we know and love: electrons, quarks, photons and the famous Higgs particle and describes their interactions.
- Almost all experimental tests of these forces agree with Standard Model predictions.

The Standard Model



But....

- It does not include the fourth force: gravity.
- No dark matter in the Standard Model.
- 20 or so free parameters: we'd like to predict these somehow.
- Along with other more technical problems.

Supersymmetry

- Supersymmetry (SUSY) is the particle theorist's favourite way to solve these.
- It extends the symmetries of the Standard Model and doubles the number of particles.
- The simplest way to implement this is known as the Minimally Supersymmetric Standard Model (MSSM).
- I'll be talking about the MSSM today.

Why is SUSY so great?

- Can solve the problems mentioned above.
- Downside: needs about 120 new parameters.
- Haven't seen any of the new particles (yet!)
- But by including some ideas from gravity we can whittle this down to four parameters and a sign!
- This approach to the MSSM is known as minimal supergravity (mSUGRA).

String Theory

- Unless we can motivate the inclusion of these gravity ideas, it's still rather *ad hoc*.
- A natural framework is string theory, the best candidate (so far) for a theory of everything.
- This postulates that elementary particles are stringy, rather than point like.
- The theory only exists in 10 dimensions.
- We compactify the unwanted dimensions on a (very small!) Calabi-Yau manifold: a complex 6 dimensional shape.
- Some choices of Calabi-Yau give minimal supergravity.

The Large Volume Scenario

- A subset of these are known collectively as the Large Volume Scenario
- The MSSM parameters are controlled by the geometry of the extra dimensions.
- The number of free parameters is further reduced to two: a mass M and an angle $\tan\beta$.
- We want to see how well this model fits current data by varying the 2 Large Volume and 4 Standard Model parameters.
- Do this by exploration of model parameter space.

Outline

Scanning Parameter Space.

- Naïve: scan through a grid
- Plus side:
  - Control of ranges, step size $\rightarrow$ know where we are probing.
- Down-side
  - Points required scales as k^N $\rightarrow$ highly inefficient for $N > 3$.
  - Can miss narrow features.
  - Sources of uncertainties, external info are hard to incorporate.

Bayes is Best

- Central quantity: likelihood $\mathcal{L} \equiv p(d|m)$.
- Bayes theorem:

$$p(m|d) = p(d|m)\frac{p(m)}{p(d)} \tag{1}$$

- $p(m)$: probability of the model (the *prior*)
- $p(d)$: probability of the data being reproduced, over all models.
- Impossible to estimate!
- However, can take ratios:

$$\frac{p(m_1|d)}{p(m_2|d)} = \frac{p(d|m_1)p(m_1)}{p(d|m_2)p(m_2)} \tag{2}$$

Priors

- $\frac{p(m_1|d)}{p(m_2|d)} = \frac{p(d|m_1)p(m_1)}{p(d|m_2)p(m_2)}$
- Need to specify priors.
- Equivalent to putting probability measure on parameter space.
- "'Principle of indifference"': Flat priors.
- Can also assume priors according to personal beliefs: naturalness[1]: same-order, fine-tuning.
- REWSB priors: $\tan\beta$ is derived parameter, not appearing in the MSSM Lagrangian.
- Better(?) to have priors flat in B, μ: these are REWSB priors.

[1] Allanach hep-ph/0601089, 0705.0487

Constructing the Likelihood.

- Given a point in param. space, use `Softsusy 2.0.17` to get MSSM spectrum (masses etc.)
- We fit to a set of 14 observables from cosmology, electroweak physics and B-physics.
- Given a prediction p_i of some SM quantity the log likelihood is
- $\ln \mathcal{L}_i = -\frac{(m_i - p_i)^2}{2s_i^2} - \frac{1}{2}\ln(2\pi) - \ln s_i$
- m_i: SM experimental value. s_i: standard deviation.

Outline

Markov chains, Monte Carlo and all that.[2]

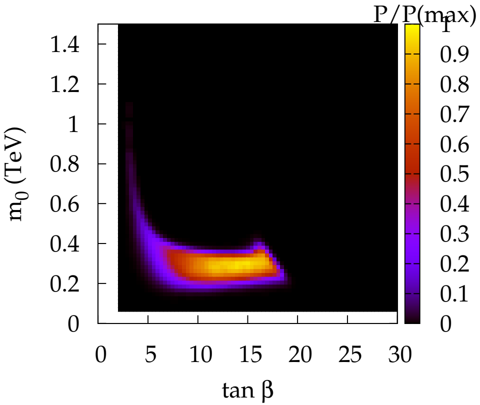
- Markov chain: A list of parameter points $\mathbf{x}^{(t)}$, and likelihoods $\mathcal{L}^{(t)}$.
- Metropolis-Hastings algorithm: pick some random potential point $\mathbf{x}^{(t+1)}$ using a proposal pdf Q.
- If $\mathcal{L}^{(t+1)} > \mathcal{L}^{(t)}$ append the new point to the chain.
- Else accept with probability $\mathcal{L}^{(t+1)}/\mathcal{L}^{(t)}$.
- If new point not accepted then $\mathbf{x}^{(t+1)} = \mathbf{x}^{(t)}$, and is copied to end of chain.
- If 'detailed balance' satisfied, then sampling density is proportional to target distribution (likelihood).

[2] Allanach & Lester hep-ph/0507283

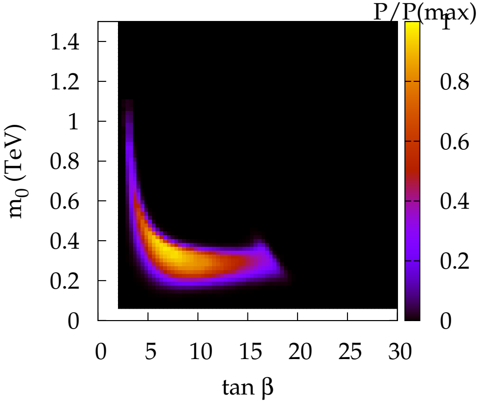
Method

- We run 10 independent chains of 10^5 steps for flat & REWSB priors, and for both signs of μ.
- Discard first 2000 points as " burn in".
- Use Gelman-Rubin $\hat{R}$ test for convergence$\rightarrow$ demand $r < 1.05$.
- Bin data into 75×75 bins for analysis.

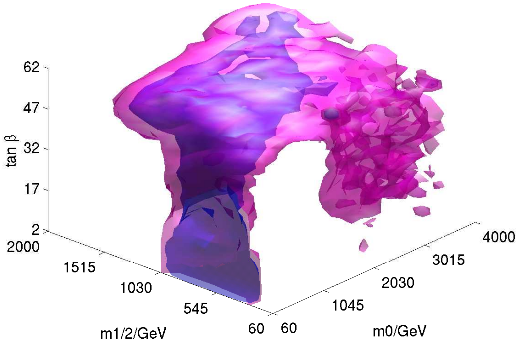
M_0 vs $\tan\beta$ (Flat priors)



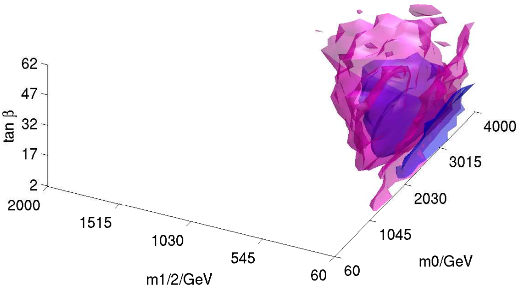
M_0 vs $\tan\beta$ (REWSB priors)



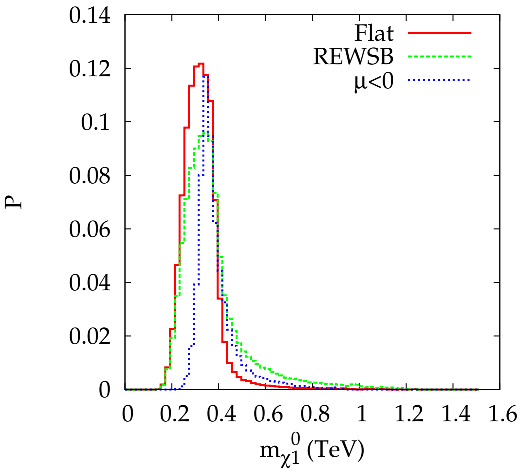
3D plot for standard mSUGRA (flat priors)



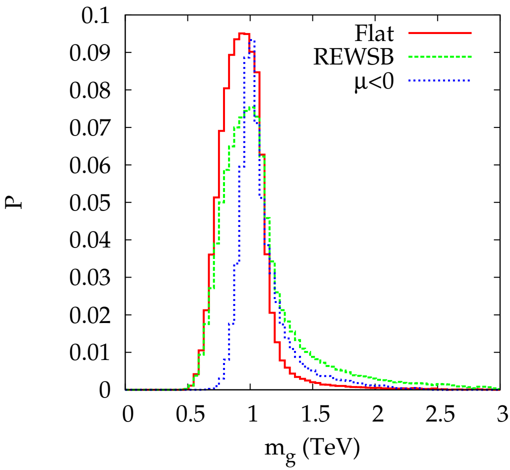
3D plot for standard mSUGRA (REWSB priors)



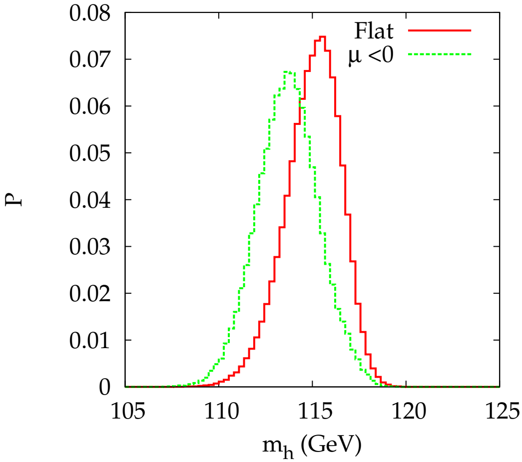
I'm Sparticle! (Neutralino)



No, I'm Sparticle! (Gluino)



Higgs mass


0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
P
105
110
115
120
125
m_h (GeV)
Flat
μ <0

Signals of the LVS

- Smoking gun(?):Ratio of gaugino masses $6 : 2 : 1.5 - 2$
- Minimal supergravity $6 : 2 : 1$.
- Other masses: 95% c.l. below 1.5TeV
- $m_h < 120$GeV
- Good for finding SUSY at LHC!
- Higgs particle: not seen for a few years.

Summary

- The Large Volume Scenario is a well motivated and predictive stringy model.
- Interesting & realistic phenomenology.
- MCMC is an efficient and simple technique for model fitting.
- Well suited to distributed computing.

Acknowledgements

- Collaborators: Ben and Arne.
- Mark Calleja and Camgrid.
- The Organisers of this conference.
- More details:
- *Global Fits to the Large Volume Scenario Using WMAP5 and Other Indirect Constraints Using Markov Chain Monte Carlo*
- arXiv:0806.1184