Supersymmetry and the LHC

A Bayesian Approach

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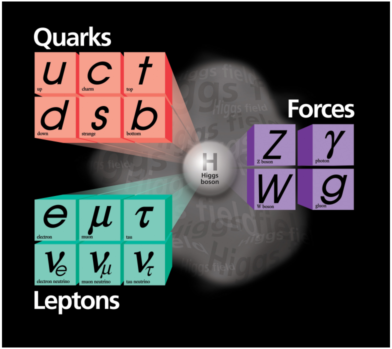
Departmental Research Day

Table of Contents

The Standard Model of Particle Physics

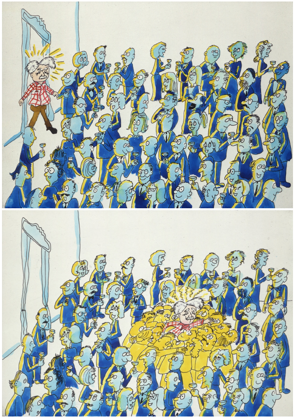


The Standard Model, from Fermi Lab

- Agrees with (almost) all experiments
- Three forces: strong, weak, and electromagnetic
- Each force is a gauge symmetry, and is mediated by a gauge boson
- Higgs boson gives particles their masses, but has not been observed (yet?)

Electroweak Symmetry Breaking

- Electroweak gauge symmetry forbids particle masses
- So it must be broken
- In the Standard Model, it is broken by the Higgs boson
- The Higgs boson gives particles their masses



Cartoon of Higgs mechanism, from *cdsweb.cern.ch*

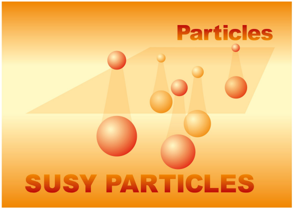
The Fine-tuning problem

- Particle masses receive “quantum corrections”
- For most particles, the corrections are small, because they are forbidden by (chiral and gauge) symmetries
- Without a symmetry to protect its mass, however, the Higgs boson receives massive quantum corrections
- For an acceptable Higgs boson mass, the Standard Model must be extraordinarily “fine-tuned”

$$\begin{aligned} m_{\text{Higgs}} &= m_{\text{Bare mass}} + \Delta m_{\text{Corrections}} \approx 150\ \text{GeV} \\ &\overset{?}{=} (-10^{19}\ \text{GeV} + 150\ \text{GeV}) + (10^{19}\ \text{GeV}) \end{aligned}$$

- This is considered “unnatural.” “Naturalness” now motivates many new theories

Supersymmetry



Cartoon of supersymmetry, from SUSY DESY

Supersymmetry

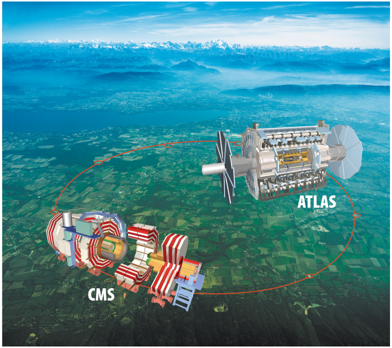
- A symmetry between fermions and bosons
- Postulates the existence of a “mirror image” of the Standard Model
- The superparticles have not been seen, so must be massive
- and supersymmetry must be spontaneously broken!
- Protects the mass of the Higgs boson, and solves the “fine-tuning” problem

The CMSSM

The Constrained Minimal Supersymmetric Standard Model

- Supersymmetry *breaking* introduces ≈100 free parameters
- That's too many to work with!
- We make as many simplifications as possible
- Resulting model, the CMSSM, has only four free parameters:
- CMSSM: m_0, $m_{1/2}$, A_0 and $\tan\beta$
- We must search for supersymmetry at the LHC…

The LHC

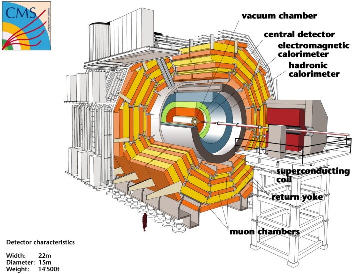


Aerial view of the LHC, from *cdsweb.cern.ch*

Large Hadron Collider

- $10 billion experiment on French/Swiss border
- Protons and anti-protons are collided in a subterranean ring
- The collisions are high energy
- They produce exotic forms of matter, not otherwise present today

The CMS detector



Exploded view of the CMS detector, from *cdsweb.cern.ch*

Compact Muon Solenoid

- Observe the results of the collisions with a detector
- CMS is a "general purpose" detector
- Sensitive to all particles and decay signatures
- Discriminate between "interesting" and background events with off-line cuts

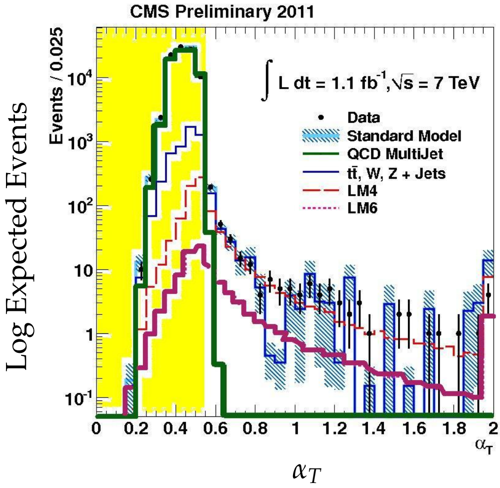
The CMS α_T search for supersymmetry

- CMS looked for supersymmetry in its 2011 data, by looking for "jets" and missing transverse energy
- Discriminator against background was its $\alpha_T > 0.55$ cut
- No significant excess over the Standard Model background

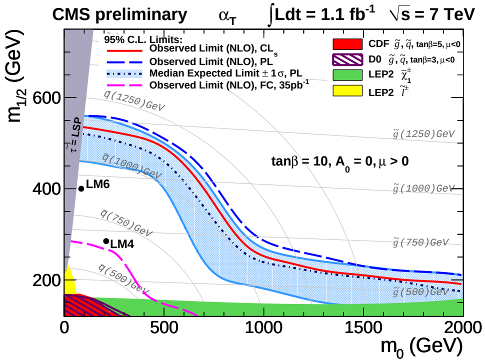
The CMS α_T search for supersymmetry

From CMS Public Web

- — = Expected SM QCD background
- — = Expected SUSY signal
- ■ = Excluded by $\alpha_T > 0.55$ — mostly QCD background
- ■= The observed data — close to total expected SM background



Exclusion in CMSSM from the CMS α_T



Exclusion, from CMS Public Web

- Supersymmetry particles were not seen
- So low-mass region of the CMSSM below the blue dotted line (– – –) is excluded at 95%

Simulating α_T likelihood

- Wanted to know the likelihood at each point on the (m_0, $m_{1/2}$) plane, not just the 95% exclusion contour
- Likelihood of observing o events, given that we expected s supersymmetry events and b Standard Model background events is given by a Poisson

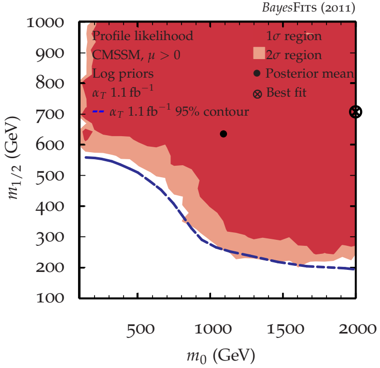
$$\mathcal{L} = \frac{e^{-s+b}\,(s+b)^o}{o!}$$

- Simulated the expected number of supersymmetry events, by first simulating the detector and selection efficiency

$$s = \epsilon \times \sigma \times L$$

Simulating α_T likelihood

- Simulating the efficiency was rather complicated; collaborated with NCNR, Warsaw
- We calculated our likelihood map on the $(m_0, m_{1/2})$ plane, and our 95% contour with $\Delta\chi^2 = 5.99$
- Excellent agreement between our 95% contour (■) and the official CMS 95% contour (– – –)



My result, from forthcoming publication

Comparing theory with experiments

- The CMSSM has four free parameters
- Does it agrees with all experiments, including the CMS α_T search?
- We use *SuperBayeS* computer program, to scan the CMSSM's parameter space and find regions that agree with experiments

We use the *iceberg* computer server

We use Bayesian statistics

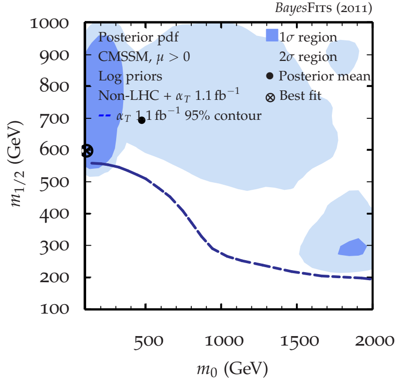
Frequentist *versus* Bayesian

- We use Bayesian statistics; we consider probability of theory given data
- A frequentist statistician, however, would consider probability of data given theory
- Frequentist *versus* Bayesian is a long-running argument…
- *"Bayesians address the question everyone is interested in by using assumptions noone believes, while frequentists use impeccable logic to deal with an issue of no interest to anyone"* — Louis Lyons

My Results — CMSSM global fit including CMS α_T

- Posterior probability map on the $(m_0, m_{1/2})$ plane of the CMSSM
- Consider all experiments, including the latest LHC results
- Two modes, but CMSSM is fast running out of viable parameter space
- 95% region = [light blue square], 68% region = [blue square]

My result, from forthcoming publication



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  Forthcoming