PROCEEDINGS OF SCIENCE

Supersymmetry Working group report, “From Strings to LHC” Workshop, Goa, (January, 2007)

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Activities in the SUSY working group included phenomenology (mainly SUSY and Higgs) at LHC, Higgs mass bounds in a general class of SUSY models, gauge extensions of the MSSM, M-theory, moduli stabilisation and string inflationary models. We briefly report here on all these activities.

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Activities in this working group covered a wide variety of topics. They ranged from LHC phenomenology (sparticle signals, spectra of mixed modulus AMSB models, light charged Higgs with CP violating couplings, top polarization as a discriminator between SUSY and little Higgs) to Higgs mass bounds in general SUSY models, gauge extensions of the MSSM as well as to issues in M-theory, moduli stabilization and string inflationary models. We summarize below the highlighted contents of the individual presentations.

G.Polesello discussed classic sparticle production and decay signatures in the MSSM: the two undetected LSPs in the final state as end products of two chains of cascade decays. Then, generically, one has a multijet +multilepton + missing transverse energy signal. One can define an effective mass:

$$M_{eff} = \sum_i |P_{T(i)}| + \not{E}_T$$

and plot $d\sigma/dM_{eff}$ vs. M_{eff}(Fig.1)

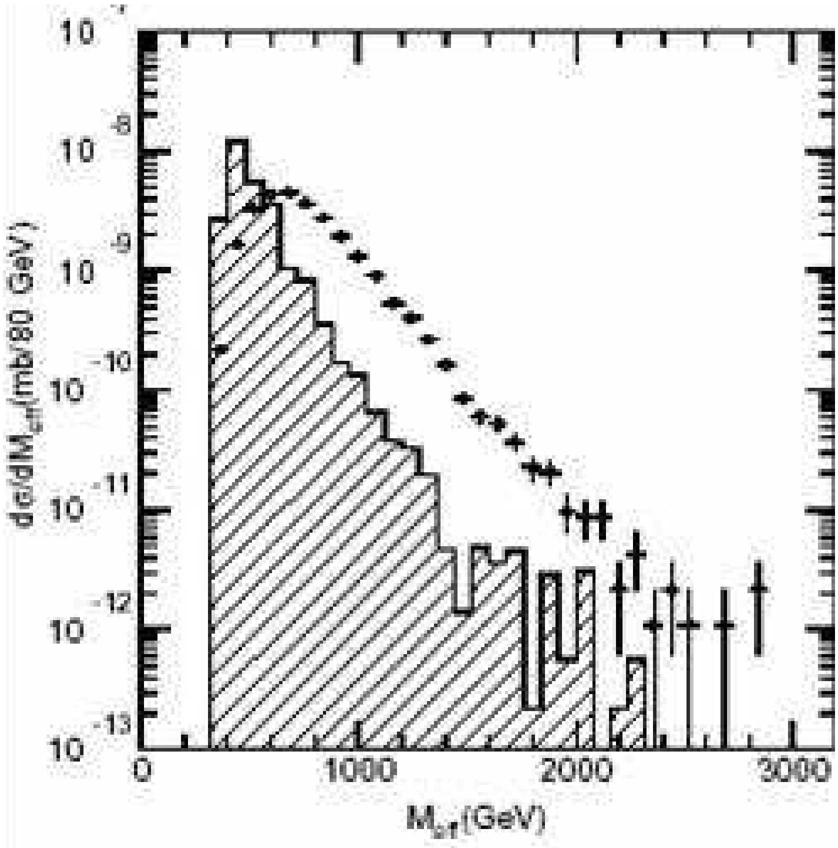

Figure 1: Effective mass (M_{eff}) distribution for the signal and total standard model background (hatched region). For the signal, squark and gluino masses are about ∼1 TeV.

Typical numbers are σ_{susy} ∼50 pb (1 pb) for $m_{\tilde{q},\tilde{g}} \sim$ 500 GeV (1 TeV). An mSUGRA contour plot of the discovery regions in the $M_{1/2} - M_0$ plane appears in Fig.2 for various integrated luminosities. The effective mass reach is ∼1.3 TeV, 1.8 TeV and 3.2 TeV for $\int \mathscr{L} dt$=100/pb, 1/fb and 10/fb respectively. But one needs care in handling background and detector responses which will control the time required for an actual discovery.

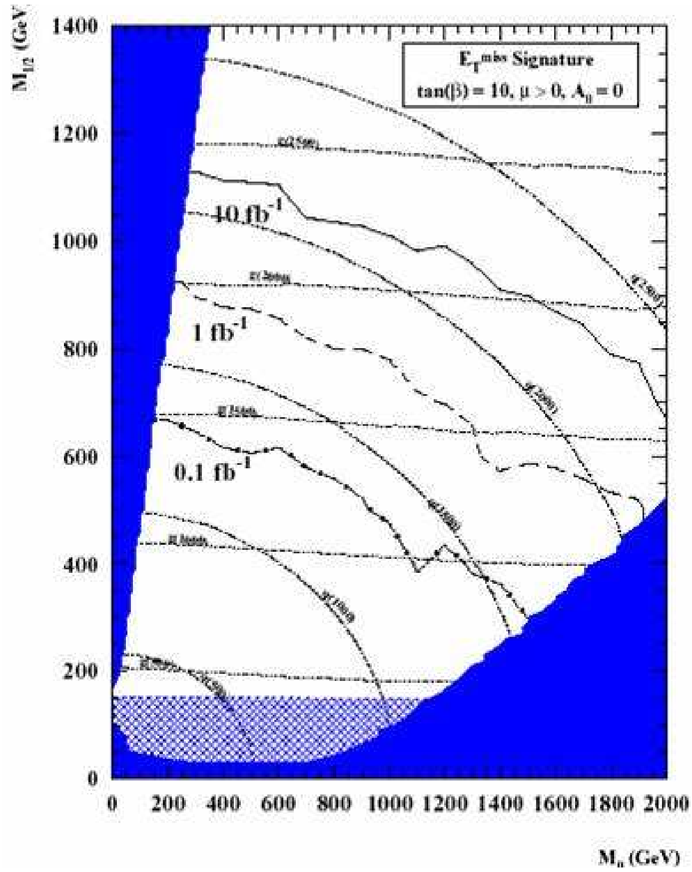

Figure 2: Contour plots for various luminosities, squark and gluino masses in the $M_0 - M_{1/2}$ plane.

Polesello also focused on mass and spin measurements with respect to specific benchmark points. If a chain of at least three two-body decays in a cascade can be isolated (Fig.3), then the concerned sparticle masses can be measured in a model independent way. The SM background for such events is virtually negligible, while SUSY backgrounds come mostly from uncorrelated $\tilde{\chi}^{\pm}$

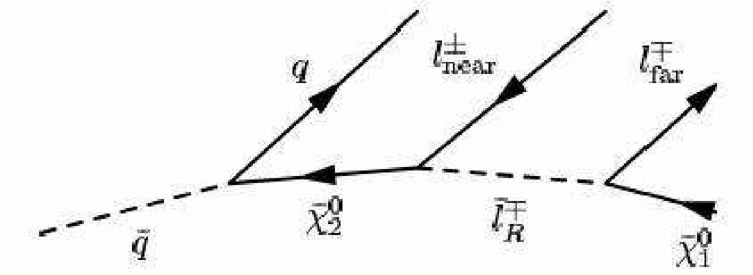

Figure 3: Squark decay chain

decays. Both SM and SUSY backgrounds can be subtracted by measuring flavour-correlated combinations such as $N(e^+e^-) + N(\mu^+\mu^-) - N(e^{\pm}\mu^{\mp})$. In an event sample from a $\int \mathscr{L} dt$ of 100/pb, the error is dominated by the 0.1% uncertainty in the lepton energy scale. A typical simu-

PoS(stringsLHC)033

lation result is shown for opposite sign minus same sign fermions (OS-SS) in Fig.4.

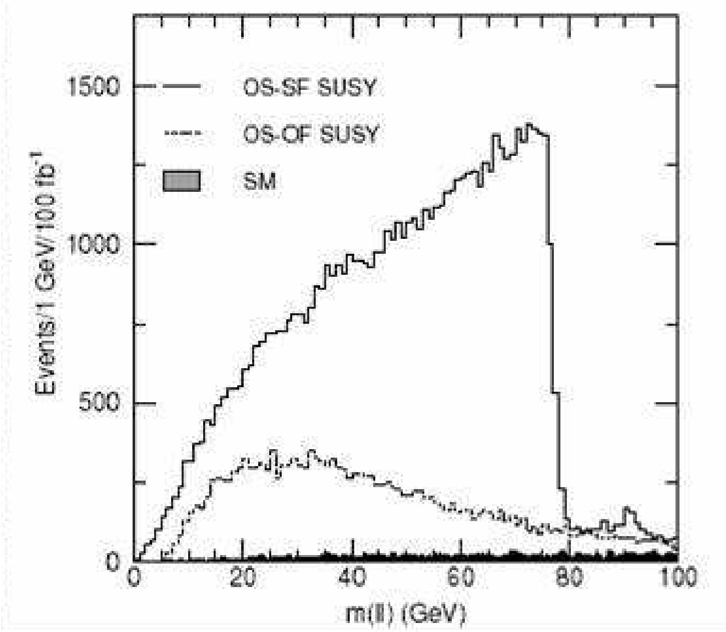

Figure 4: Dilepton invariant mass distribution.

K.Choi and X. Tata gave talks on the phenomenology of mixed modulus anomaly mediated (MMAMSB) models of supersymmetry breaking. Modulus (gravity) mediation, together with mSUGRA assumptions, implies universal scalar masses and a binolike neutralino or a gravitino LSP. In contrast, anomaly mediation makes the scalar mass m_i proportional to the corresponding β_i and prefers a winolike neutralino LSP. Though more complicated, the mixed model is completely specified by five parameters ($m_{3/2}, \alpha, \tan\beta, n_i, \ell_a$) with a two fold sign-$\mu$ ambiguity. The parameters n_i are rational fractions between 0 and 1, while $\ell_\alpha = 0$ or 1. Here $|\mu|$ gets determined by the condition of radiative breakdown of EW symmetry.

Gaugino masses, A-parameters and scalar masses are given in terms of the overall SUSY scale M_s by

$$M_a = M_s(\ell_a\alpha + b_a g_a^2), \quad (1)$$
$$A_{ijk} = M_s(-a_{ijk}\alpha + \gamma_i + \gamma_j), \quad (2)$$
$$m_i^2 = M_s^2[(1-n)\alpha^2 + 4\alpha\xi_i - \gamma_i] \quad (3)$$

respectively. Here γ_i is the anomalous mass dimension of the i-th matter superfield with

$$\gamma_i = 8\pi^2 \frac{\partial\gamma_i}{\partial(ln\mu)}, \quad (4)$$
$$a_{ijk} = 3 - n_i - n_j - n_k, \quad (5)$$
$$\xi_i = \frac{1}{4}\sum_{ijk} a_{ijk} y_{jk}^2 - \sum_a \ell_a g_a^2 C_2^a(f_i), \quad (6)$$

y_{ijk} being Yukawa coupling strengths. Moreover, α is the relative strength between the AMSB ($\alpha = 0$) and modulus mediated (MM, large $|\alpha|$) contributions. A characteristics feature is the "mirage unification" of running gaugino masses M_a at the energy scale $\sim 10^9 - 10^{10}$ GeV.

R.Godbole reported on the possibility of a light Higgs h with a mass 10 $GeV < m_h <$ 50 GeV which may have been missed at LEP on account of its CP-violating couplings. It could be observed in the decay of a charged Higgs $H^{\pm}(H^{\pm} \to Wh, h \to b\bar{b})$ lighter than the top. But is such an $H^{\pm}$ allowed by loop constraints from $b \to s\gamma$ decay? A calculation scheme has been set up for this problem by Borzumati, Misiak and Godbole and the results are expected shortly.

Another issue addressed by Godbole was the possibility of experimentally distinguishing between the SUSY and little Higgs scenarios in top production at the LHC. In pp collision, one can have a TTX ($\tilde{t}_1\bar{\tilde{t}}_1$X) final state in the little Higgs (SUSY) case. The T dcays by gauge interaction through the process $T \to t_A H$ with equal numbers of the t_L and t_R produced. In contrast, the $\tilde{t}_1$ decays by a combination of gauge and Yukawa interactions, with $\sigma(t_L) \neq \sigma(t_R)$, resulting in a polarized top. Therefore, a measurement of the top polarization should enable a discrimination between the two scenarios. Experimental issues raised were (i) the identification of a top coming specifically from t or T, (ii) top charge measurement, (iii) background from new physics, (iv) gluino production and decay into a stop as a spoiler mode and (v) event selection criteria.

K.S. Babu discussed Higgs mass bounds in general SUSY models. Specifically, he considered loop effects of additional heavy vectorlike SU(5) multiplets such as $5 \oplus \bar{5}$ or $10 \oplus \overline{10}$. For instance, the upper bound on the lightest Higgs mass m_h, as a function of $\tan\beta$, in the MSSM gets enhanced if a $10 \oplus \overline{10}$ is inserted (Fig.5). He also considered the effects on this of a lateral gauge symmetry whereby an extra lateral gauge group factor like $SU(N)_{lat}$ is put in after N copies of $5 \oplus \bar{5}$ and singlets $S \oplus \bar{S}$, under the regular SU(5), have been added. This can lead to a substantial enhancement in m_h, e.g. it can exceed 300 GeV.

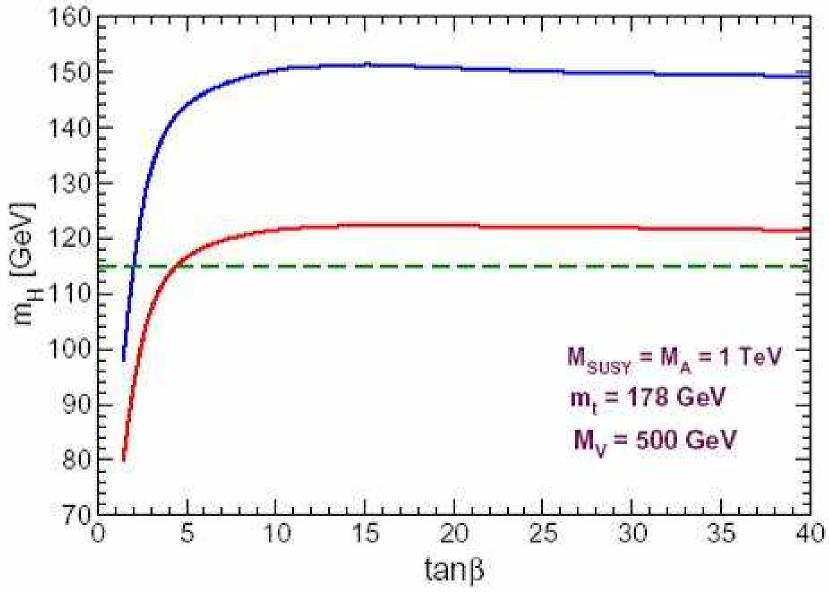

Figure 5: Upper bound on the lightest higgs mass against $\tan\beta$

P. Batra considered gauge extensions of the MSSM. His focus was on the little hierarchy problem (fine tunning of m_h) in SUSY. He tried to solve this by combining SUSY with dynamical symmetry breaking. He considered the following scheme(Fig.6), and specifically made use of non-decoupling D-terms. He found large values of m_{higgs}, depending on the cut-off Λ (Fig.7). He showed that it is possible to simultaneously have (i) gauge coupling unification, (ii) precision parameters under control, (iii) non-universal 3rd generation couplings. He always had a light charged Higgs.

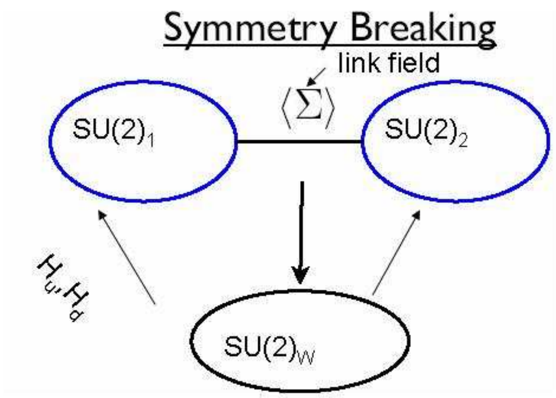

Figure 6: Schematics of symmetry breaking

E Dudas dealt with aspects of moduli stabilization. In general, vevs of residual moduli fields, {d}, predicted from string theory, tend to run away the Planck scale values leading to uninteresting configurations. They need to be stabilized, especially considering that the string coupling strength is $g_s = e^{<d>}$. Dudas discussed the KKLT approach which stabilizes volume moduli, adds non-perturbative terms and uplifts the vacuum energy to a positive value by explicit SUSY breaking. This uplifting could be done in different ways by using D-terms or F-terms. In a simple example he had $V_{uplift} \sim 3m_{3/2}^2 M_P^2$ with $m_{3/2} \sim$1 TeV. Phenomenological features depended on whether the SM couplings to the hidden sector mesons were weak (causing suppressed FCNC, universal scalar masses, light gauginos, hierarchical A-terms) or strong (leading to non-universal scalar masses comparable to gaugino masses and non hierarchical A-terms)

B. Acharya discussed predictions from well-defined "continents" in the landscape, e.g type

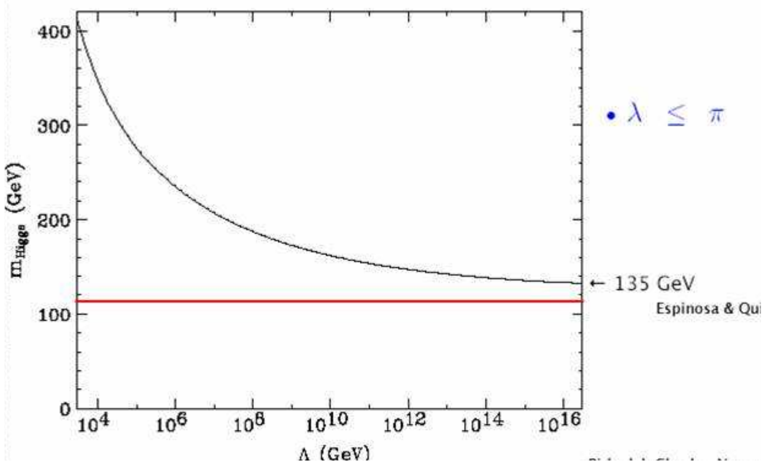

Figure 7: Lightest Higgs mass against the cut-off scale.

IIA and IIB, string heterotic string or M-theory. He argued that the LHC would most likely lead to the determination of the continent. He specifically considered M-theory with compactification on a $(G2)_{d=7}$ manifold which predicts

$$\Lambda \simeq M_{pl} e^{-\frac{2\pi}{\alpha b_0}} \tag{7}$$

and more specifically

$$\Lambda \simeq M_{pl} e^{-2\pi M_{pl} R_0} \tag{8}$$

for warped compactification. Starting with a high scale Lagrangian, he had the following phenomenological predictions:

$$m_{3/2} = M_{pl} e^{k/2} |W| \simeq 2.1\ TeV, \tag{9}$$

$$M_{11} = \frac{M_{pl}}{V_{x^{1/2}}} \simeq 1.1 \times 10^{18} GeV)\ (11\ \ dim\ \ Planck\ \ scale) \tag{10}$$

$$\Lambda_g \sim 10^{15} - 10^{16}\ \ (gaugino\ \ condensation\ \ scale). \tag{11}$$

Generally, he had light gauginos and scalars with significant AMSB contributions and an LSP which is mostly a bino. He made the point that stringy towers of states with increasing spins in warped string models are spaced differently from standard KK towers.

S. Trivedi discussed the emission of gravity waves through tensor perturbations in string inflationary models. The location of a 3-brane within a bigger, say 6D, manifold (Fig.8) can be thought of as a scalar field in a 4D effective field theory. This field will go through a slow roll and then reheat in an inflationary potential (Fig.8).

One can then have brane inflation - either small field inflation ($\Delta < M_{pl}$) or large field inflation ($\Delta > M_{pl}$), leading to

$$\Delta\phi = T_3^{1/2} \Delta R \tag{12}$$

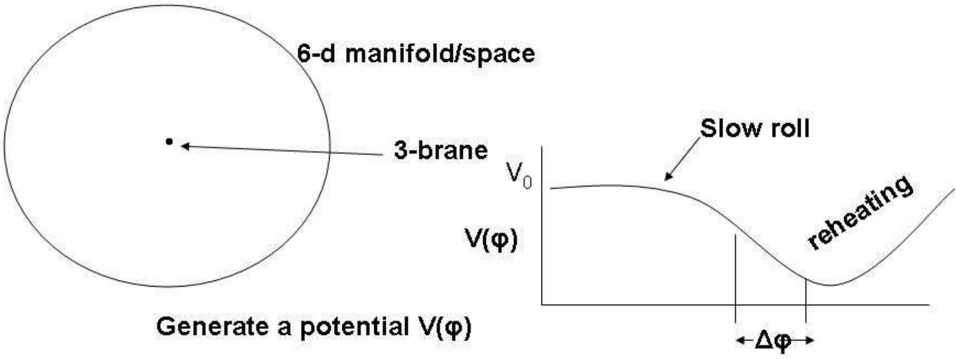

Figure 8: From a 3-brane inside a 6D manifold to slow roll and reheating

and

$$\Delta R < L(\frac{L}{\ell_s})\frac{1}{g_s}. \tag{13}$$

Consequently,

$$r = \frac{P_{gravity}}{P_{scalar}} \sim \frac{\Delta\phi}{M_{pl}N_c} < 0.1 \tag{14}$$

for $\Delta\phi < M_{pl}$, Thus the Planck satellite, which will be sensitive only down to r =0.1, should not see gravity waves as effects of tensor perturbations. If it does, this class of models will be ruled out.

Acknowledgments

We thank all the speakers for making this working group activity a success