Baryogenesis and Phenomenological Properties of Models with an extended Weak Gauge Symmetry

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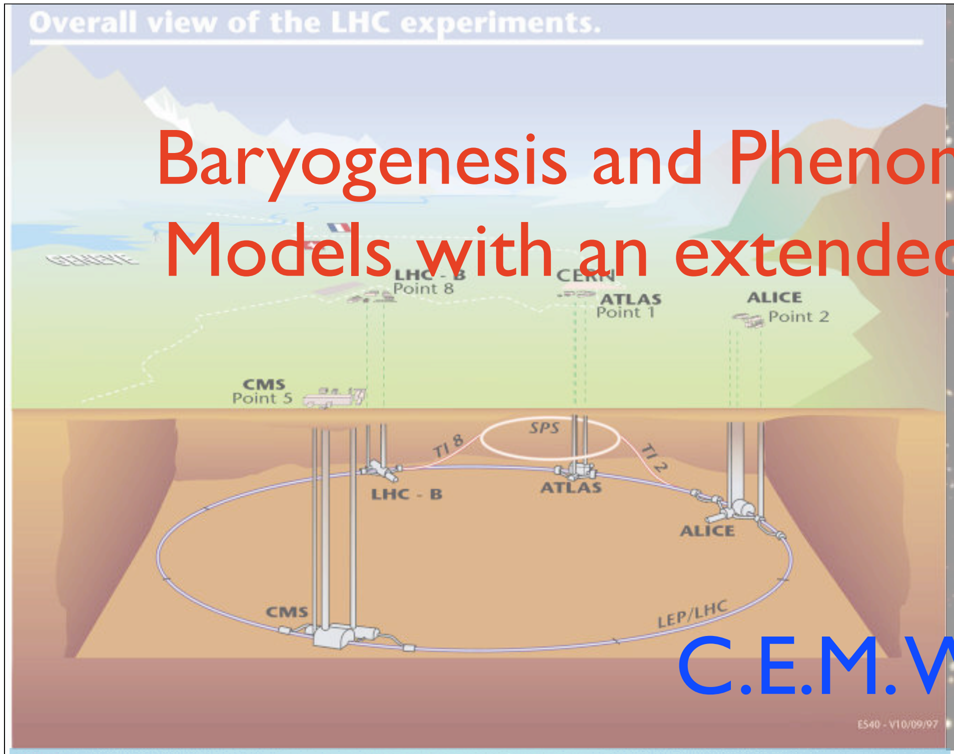
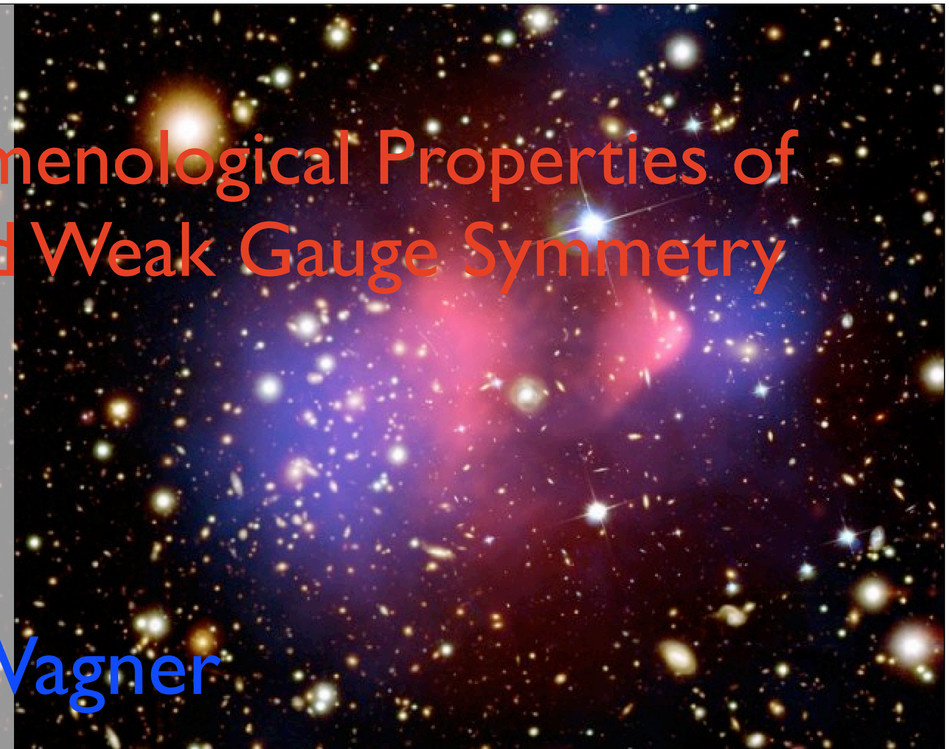
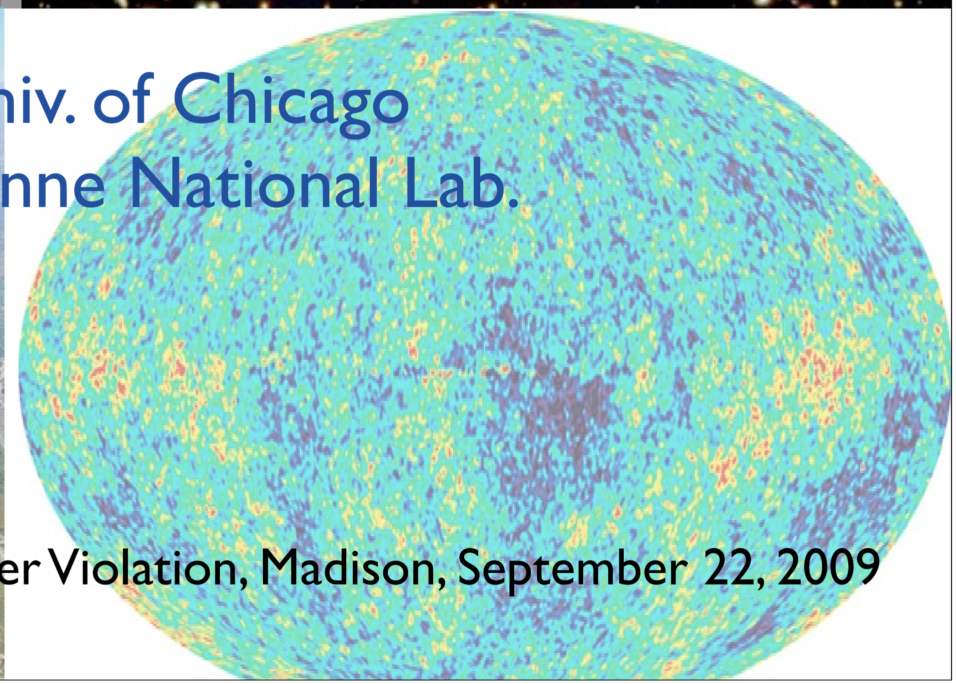






Baryon Asymmetry Preservation

If Baryon number generated at the electroweak phase

transition,

$$\frac{n_B}{s} = \frac{n_B(T_c)}{s} \exp\left(- \frac{10^{16}}{\mathrm{T_c(GeV)}} \exp\left(- \frac{\mathrm{E_{sph}}(\mathrm{T_c})}{\mathrm{T_c}} \right) \right)$$

Kuzmin, Rubakov and Shaposhnikov, '85—'87

Baryon number erased unless the baryon number violating

processes are out of equilibrium in the broken phase.

Therefore, to preserve the baryon asymmetry, a strongly first order

phase transition is necessary:

$$\mathbf{E_{sph}} \propto \frac{8\pi\,\mathbf{v}}{\mathbf{g}} \qquad\qquad \frac{\mathrm{v}(T_c)}{T_c} > 1$$

Finite Temperature Higgs Potential

$$V(T) \quad = \quad D(T^2 - T_0^2)\phi^2 - E_B T\phi^3 + \frac{\lambda(T)}{2}\phi^4$$

D receives contributions at one-loop proportional to the sum of the couplings of all bosons and fermions squared, and is responsible for the phenomenon of symmetry restoration

E receives contributions proportional to the sum of the cube of all light boson particle couplings

$$\frac{v(T_c)}{T_c} \approx \frac{E}{\lambda} \quad , \quad \text{with} \quad \lambda \propto \frac{m_H^2}{v^2}$$

Since in the SM the only bosons are the gauge bosons, and the quartic coupling is proportional to the square of the Higgs mass,

$$\frac{v(T_c)}{T_c} > 1 \quad \text{implies} \quad m_H \quad < 40 \text{ GeV.}$$

Electroweak Baryogenesis in the SM is ruled out

Preservation of the Baryon Asymmetry

- EW Baryogenesis requires new boson degrees of freedom with strong couplings to the Higgs.

- Supersymmetry provides a natural framework for this scenario. Huet, Nelson '91; Giudice '91, Espinosa, Quiros,Zwirner '93.

- Relevant SUSY particle: Superpartner of the top

- Each stop has six degrees of freedom (3 of color, two of charge) and coupling of order one to the Higgs

$$E_{SUSY} = \frac{g_w^3}{4\pi} + \frac{h_t^3}{2\pi} \approx 8\, E_{SM}$$

M. Carena, M. Quiros, C.W. '96, '98

$$\frac{v(T_c)}{T_c} \approx \frac{E}{\lambda} \quad , \quad \text{with} \quad \lambda \propto \frac{m_H^2}{v^2}$$

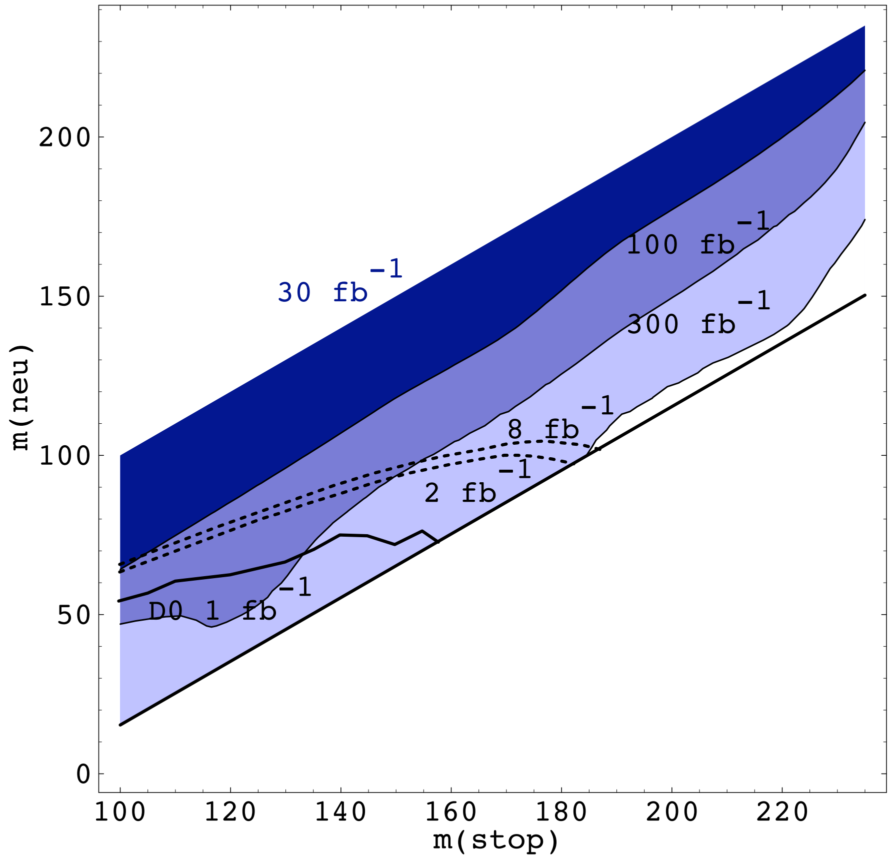
- Since

Higgs masses up to 120 GeV may be accomodated

Alternative Channel at the LHC

- When the stops and neutralino mass difference is small, the jets will be soft.
- One can look for the production of stops in association with jets or photons. Signature: Jets plus missing energy

M. Carena, A. Freitas, C.W. '08



Baryogenesis demands stops and Higgs bosons with masses smaller than 125 GeV

Carena, Nardini, Quiros, C.W. '08

Excellent reach until masses of the order of 220 GeV and larger.

Full region consistent with EWBG will be probed by combining the LHC with the Tevatron searches.

Light Higgs may be probed at the Tevatron.

P. Draper, T. Liu, C.W. '09

Baryogenesis in Gauge Extensions of the MSSM

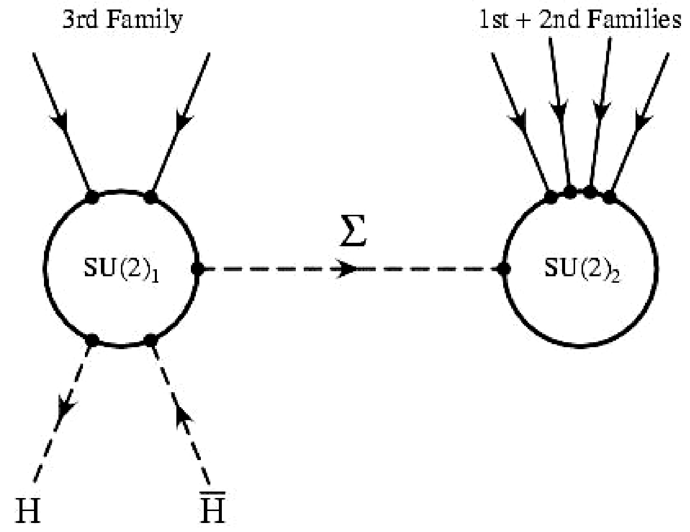
Solution to the SUSY Hierarchy Problem

An SU(2) Gauge Extension

P Batra, A. Delgado, D.E. Kaplan, T Tait, JHEP 0402,043 (2004)

- One solution to this problem is to increase the Higgs mass by having it participate in new strong gauge interactions.
- Consistent with data, m_H may increase as high as **350 GeV** – radically affecting MSSM Higgs phenomenology.
- We invoke a new SU(2) interaction under which the Higgses and third family are charged.

  $SU(2)_1 \times SU(2)_2 \times U(1)_Y$
- This model has been called "**Topflavor**":



How does this work in practice ?

If SUSY breaking scale is smaller than gauge symmetry breaking scale, decoupling occurs. Low energy D-terms are just the standard ones.

Therefore, supersymmetry breaking terms larger than the vev that breaks the gauge symmetry should be present. Calling $< \Sigma >= uI$, to this vev

$$V = m_\Sigma^2 \Sigma^\dagger \Sigma + \frac{\lambda_1^2}{4} |\Sigma\Sigma|^2 - \frac{B}{2} (\Sigma\Sigma + h.c.) + ... \qquad u^2 = (B - m_\Sigma^2)/\lambda_1^2.$$

$$\Delta V = \frac{g_1^2}{8} \left(\mathrm{Tr}[\Sigma^\dagger \tau^a \Sigma] + \mathrm{H}_u^\dagger \tau^a \mathrm{H}_u + \mathrm{H}_d^\dagger \tau^a \mathrm{H}_d + \mathrm{L}^\dagger \tau^a \mathrm{L} + \mathrm{Q}^\dagger \tau^a \mathrm{Q}\right)^2 + \frac{g_2^2}{8} \left(\mathrm{Tr}[\Sigma^\dagger \tau^a \Sigma] + ...\right)^2$$

Integrating out the sigma field, we obtain a modification of the low energy D-term

$$\Delta V_D = \frac{g^2}{2} \Delta \sum_a \left(H_u^\dagger \tau^a H_u + H_d^\dagger \tau^a H_d + L_3^\dagger \tau^a L_3 + Q_3^\dagger \tau^a Q_3\right)^2$$

$$\Delta = \frac{1 + \frac{2m_\Sigma^2}{g_2^2 u^2}}{1 + \frac{2m_\Sigma^2}{(g_2^2 + g_1^2) u^2}}.$$

As mentioned before, if the supersymmetry breaking scale is small, $\Delta \rightarrow 1$. Observe that for $g_1^2 \gg g_2^2$ and large values of m_Σ, $\Delta \gg 1$.

Tree-level Higgs Mass modification and Sparticle Spectrum

A. Medina, N. Shah, C.W.'09

The low energy D-terms control the tree-level Higgs mass

$$m_h^2 = \frac{1}{2}\left(g^2\Delta + g_Y^2\right) v^2 \cos^2 2\beta + \text{loop corrections}$$

So, large values of the Higgs mass may be obtained.

Same D-terms, however, modify the rest of the third generation spectrum:

$$\begin{aligned} m_{\tilde{\tau}_L}^2 - m_{\tilde{\nu}_\tau}^2 &= \Delta_D \\ m_{\tilde{b}_L}^2 - m_{\tilde{t}_L}^2 &= \Delta_D - m_t^2 \end{aligned}$$

$$\Delta_D = \frac{g^2 v^2}{2}\Delta|\cos 2\beta|$$

As well as the non-standard Higgs mass splittings

$$m_{H^\pm}^2 - m_A^2 = \frac{g^2\Delta}{2}v^2.$$

Large values of Δ can induce large values of the Higgs mass, up to 250 GeV, but also produce large modifications of the spectrum.

Modified spectrum and precision measurements

Large values of the Higgs mass tend to induce large corrections to the T and S parameters

$$\begin{aligned}\Delta T &= -\frac{3}{8\pi c_W^2}\ln\frac{m_h}{m_{h_{\rm ref}}}\\ \Delta S &= \frac{1}{6\pi}\ln\frac{m_h}{m_{h_{\rm ref}}},\end{aligned}$$

It is known, however, that if an extra positive contribution to the T parameter is present, agreement may be restored. The split sparticle spectrum provides such a contribution in a natural way. Calling Δm_{ud} the mass differrence between the upper and lower doublet component, each doublet contributes by

$$\begin{aligned}\Delta T &= \frac{N_c}{12\pi s_W^2 m_W^2}(\Delta m_{ud})^2\\ &= \frac{N_c}{12\pi s_W^2 m_W^2}\frac{(\Delta m_{ud}^2)^2}{(m_u+m_d)^2},\end{aligned}$$

Sparticle Spectrum Consistent with Precision Measurements

Assuming, for instance, that the sleptons are the lightest sfermions in the spectrum, we obtain

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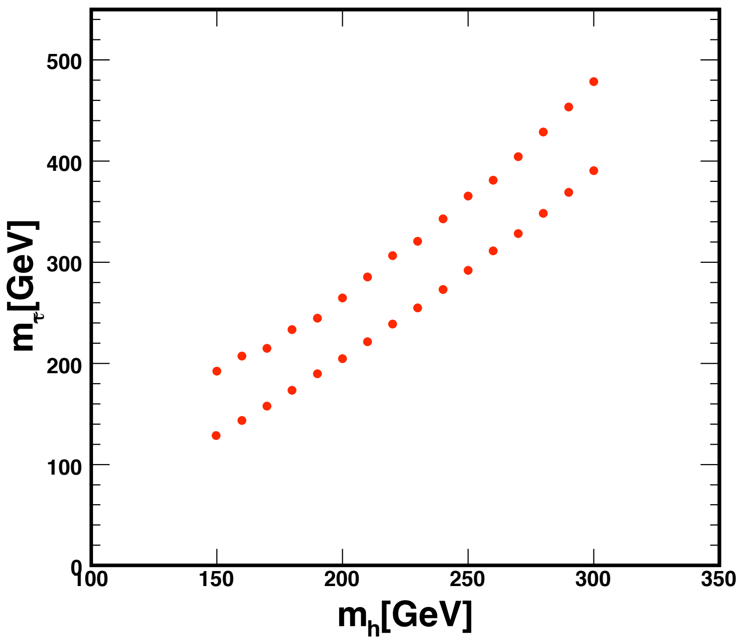

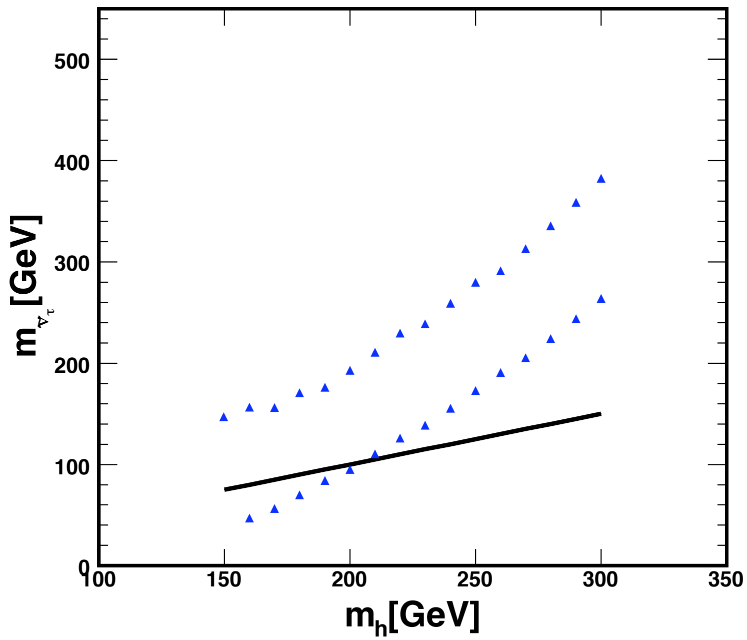

Sleptons acquire values that are of the order of the weak scale.
Particle physics phenomenology depends on characteristics of SUSY spectrum.
Different possibilities were studied in above reference.
Observe that when the Higgs is at the current reach of the Tevatron, sneutrinos may be light.

Light sneutrinos and Higgs searches

Presence of light sneutrinos may affect Higgs searches, in particular due to their enhanced couplings to Higgs bosons:

$$\Gamma(h \to \tilde{\nu}_\tau \tilde{\nu}_\tau) \simeq \frac{(g^2 \Delta + g_Y^2)^2 \; v^2}{128 \; \pi \; m_h} \left(1 - \frac{4 m_{\tilde{\nu}_\tau}^2}{m_h^2}\right)^{1/2}$$

This should be compared with the width into gauge bosons

$$\Gamma(h \to VV) \simeq \frac{G_F(|Q_V| + 1) \; m_h^3}{\sqrt{2} \; 16 \; \pi} \left(1 - \frac{4 m_V^2}{m_h^2} + \frac{12 m_V^4}{m_h^4}\right) \left(1 - \frac{4 m_V^2}{m_h^2}\right)^{1/2}$$

For instance, for a light sneutrino of order 70 GeV, and a Higgs mass of about 170 GeV, the gauge boson width is reduced by half.

The Tevatron bounds can be therefore avoided.

Baryogenesis

- At the phase transition at which SU(2) x SU(2) breaks to the weak group, a baryon and lepton number of the third generation is obtained

- For large gauge couplings, this amount can be large. However, it is diluted by low energy weak sphalerons, that tend to dilute the obtained baryon number. But they preserve an asymmetry in the three generation lepton numbers :

$$\Delta(B/3 - L_i) = 0$$

- Final baryon number is obtained by effects of this asymmetry during the second order electroweak phase transition. This was studied by Dreiner and Ross. They showed that the tau mass effects are enough to induce a final asymmetry in the baryon number. Assuming the sphalerons are in equilibrium during the phase transition,

$$B = \begin{cases} \frac{4}{13}(B-L) & B-L \neq 0 \\ -\frac{4}{13\pi^2}\sum_{i=1}^{N}\Delta_i \frac{m_{l_i}^2}{T^2} & B-L=0\ . \end{cases} \qquad \Delta_i \equiv L_i - \frac{1}{3}B$$

Baryogenesis from an early Phase Transition

- At the early phase transition, an asymmetry of order 10^{-4} may be obtained

- This early result is, however, diluted by standard sphaleron effects

- For a standard transition temperature of order of 100 GeV, the tau mass effects are approximately equal to 10^{-6}, leading to a final result for the baryon asymmetry

$$\frac{n_B}{n_S} \simeq 10^{-10}$$

T. Tait, J. Shu, C.W. '07

- Consistency with observatioins therefore may be obtained within this framework

Conclusions

- Electroweak Baryogenesis provides a very attractive framework for the obtention of the observed baryon asymmetry
- Supersymmetry provides a natural realization of this scenario, for either light stops or (not discussed) light singlets
- We explored the alternative possibility of generating the baryon number from an early phase transition, associated with strong interactions in the weak sector.
- This scenario is motivated by a solution to the hierarchy problem and/or to explain the large differences in quark masses of different generations. Splitting between sparticles can compensate the precision electroweak corrections associated with a heavy Higgs.
- Proton decay may be induced in this models, for sufficiently large values of the strong gauge couplings.
- Baryogenesis may occur, in spite of standard sphaleron dilutioin, and for values of the gauge couplings consistent with proton stability.