

# Macroscopic Supersymmetry

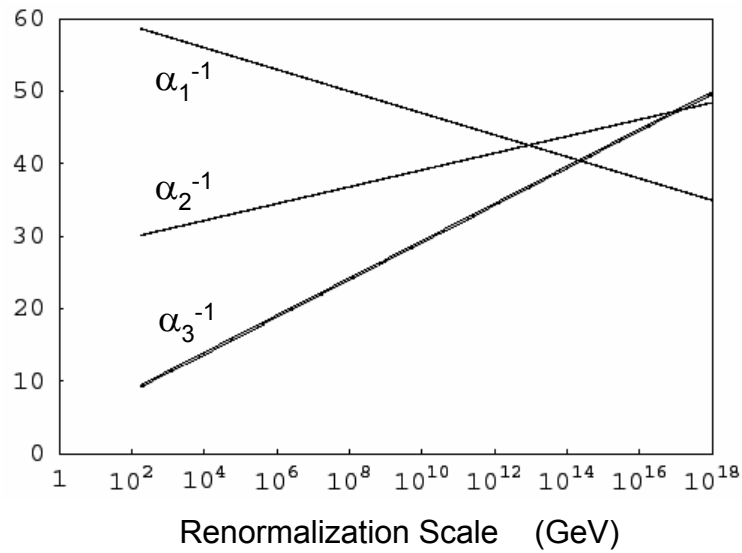
Scott Thomas

## Lecture 2

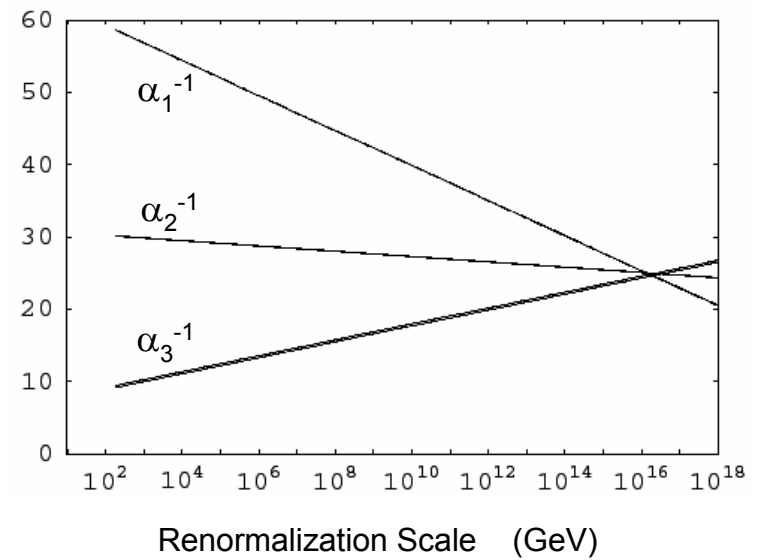
(Supplementary Material)

# (One-Loop) Gauge Coupling Unification in the SM and MSSM

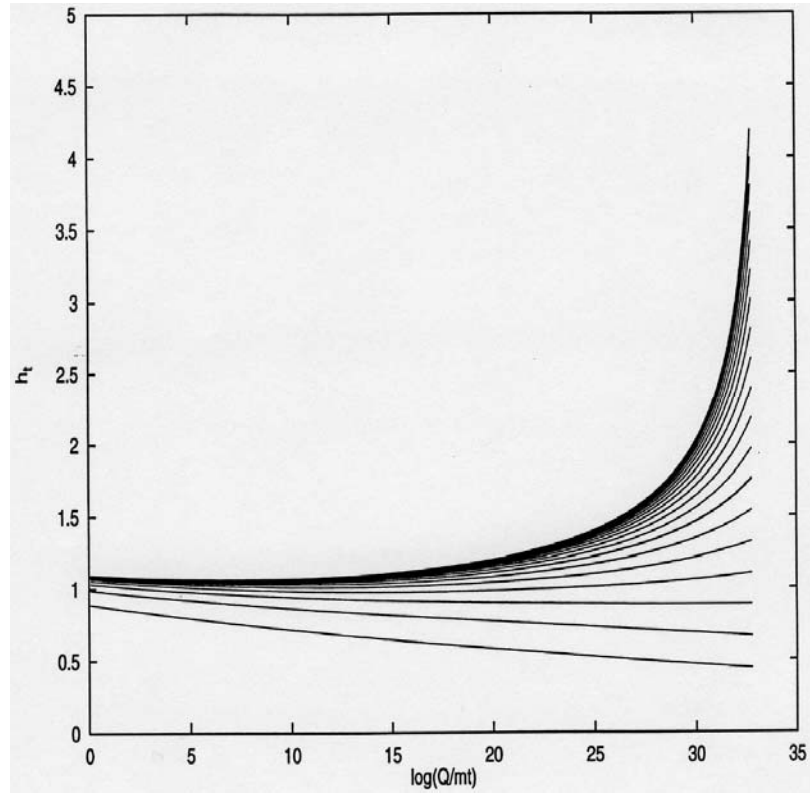
## Standard Model



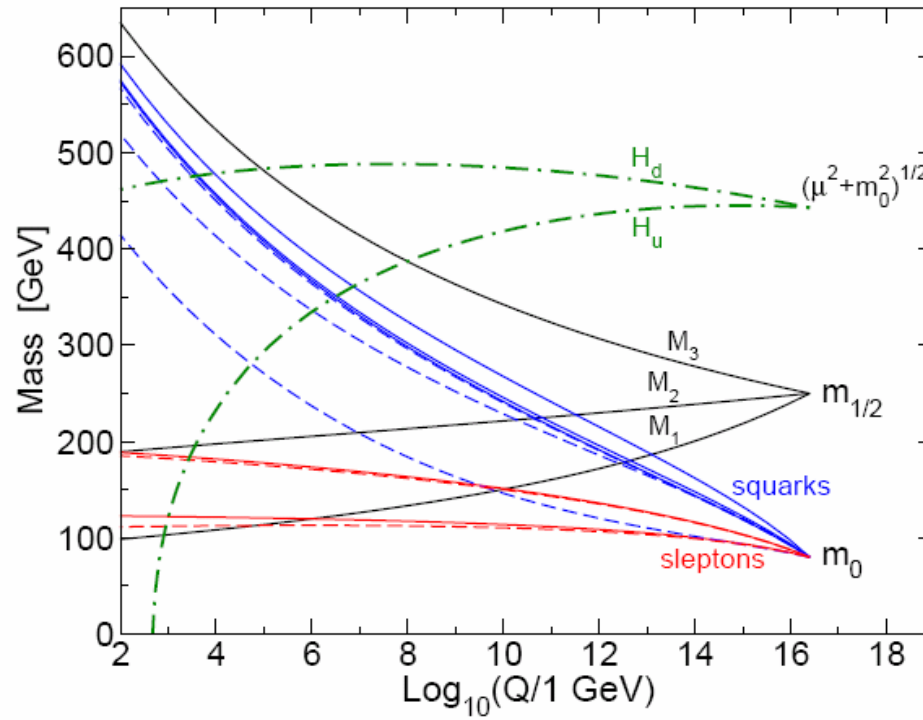
## Supersymmetric Standard Model



# MSSM Top Quark Yukawa Renormalization Group Evolution



# MSSM Soft SUSY Breaking Masses Renormalization Group Evolution



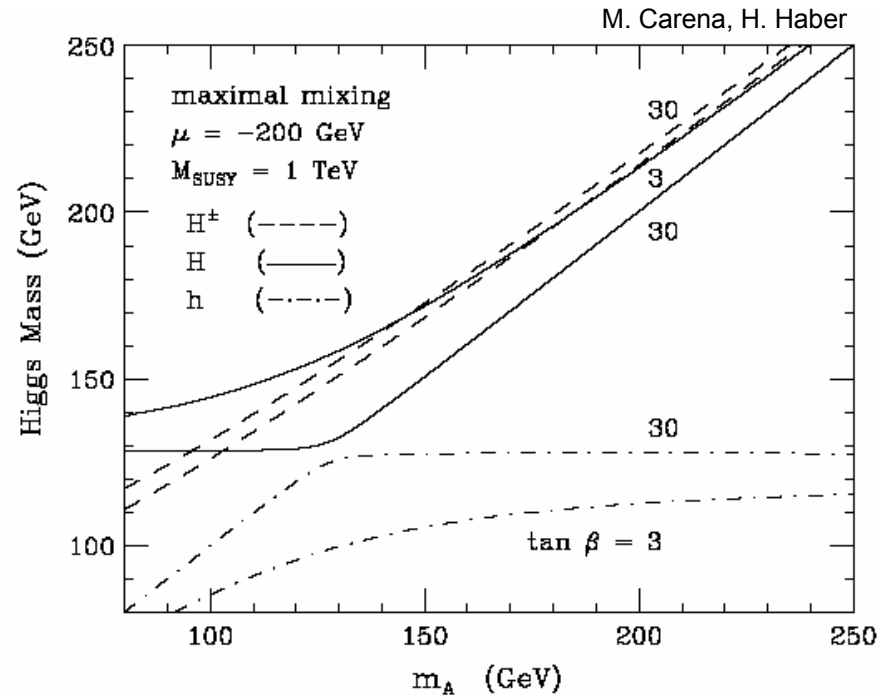
# MSSM Higgs Potential

$$V = \widetilde{m}_{H_u}^2 H_u^\dagger H_u + \widetilde{m}_{H_d}^2 H_d^\dagger H_d - (m_{ud}^2 H_u H_d + \text{h.c.})$$

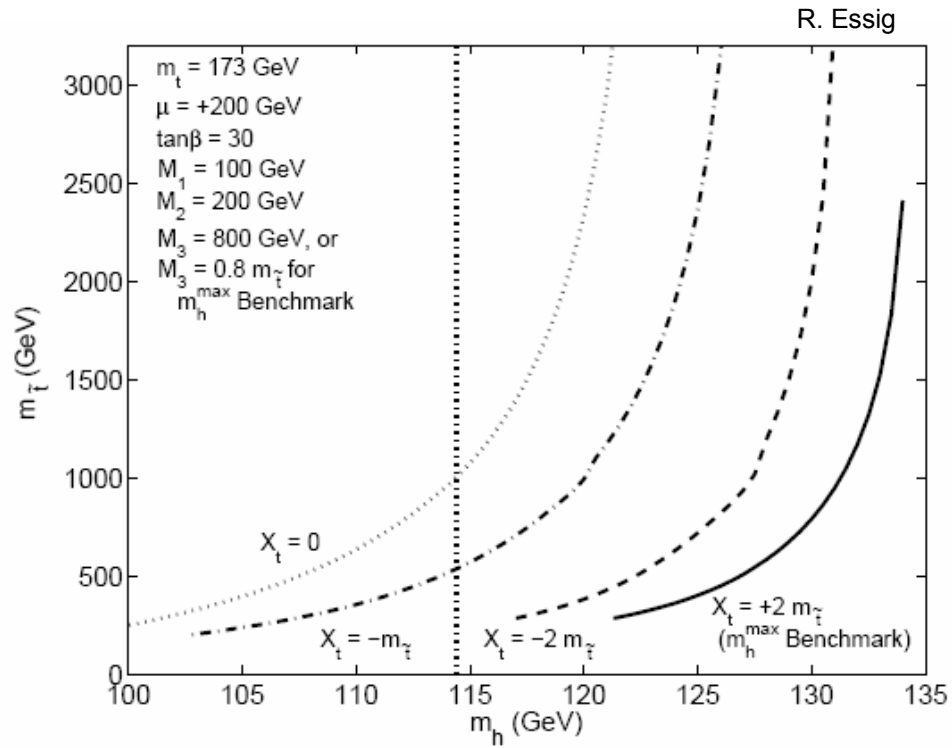
$$+ \frac{g^2}{8} [(H_u^\dagger H_u + H_d^\dagger H_d)^2 - 4(H_u H_d)^\dagger (H_u H_d)] + \frac{g'^2}{8} (H_u^\dagger H_u - H_d^\dagger H_d)^2$$

$$\widetilde{m}_{H_u}^2 = |\mu|^2 + m_{H_u}^2$$

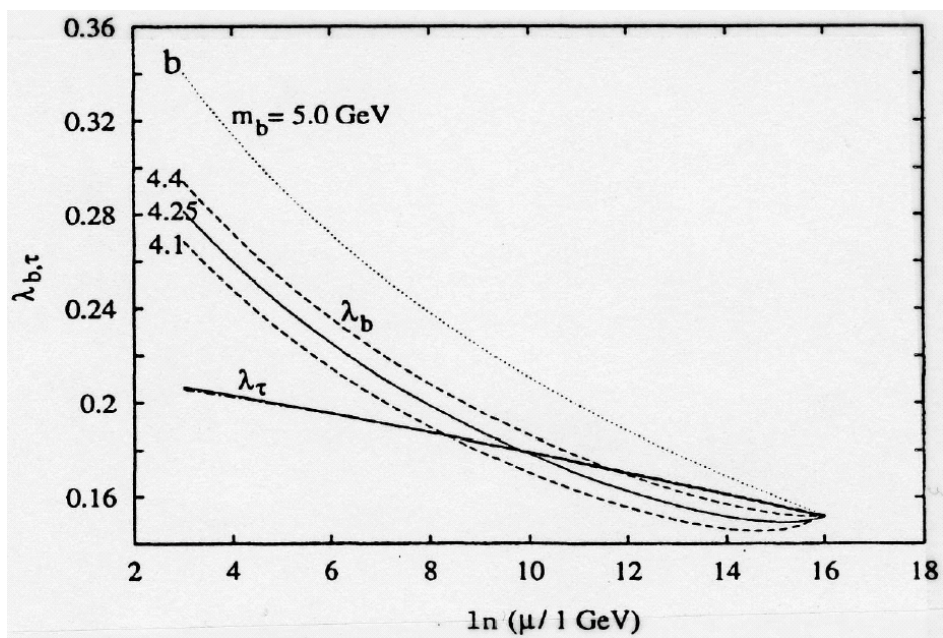
$$\widetilde{m}_{H_d}^2 = |\mu|^2 + m_{H_d}^2$$



# MSSM Stop Mass Required for a given Higgs Mass



# MSSM $b$ - $\tau$ Unification



## Exercises: Lecture 2

1. Show that the renormalizable MSSM with  $Z_2$  baryon parity and general soft supersymmetry breaking gives rise to neutrino Majorana masses. Estimate the magnitude of the neutrino masses in terms of the parameters of the theory.
2. Show at one-loop that the MSSM with an extra generation of quark and lepton chiral multiplets has gauge coupling unification. An anti-generation is defined to be chiral matter which transforms in the conjugate representation of  $SU(3)_C \times SU(2)_L \times U(1)_Y$  as compared with a generation. Find a vector representation within a subset of a generation plus anti-generation which when added to the MSSM also has gauge coupling unification. Show that the gauge couplings unify in this extended MSSM for any value of the supersymmetric mass of the vector representation. Discuss the significance of this result.
3. Calculate the tree-level light Higgs mass squared in the MSSM in the Higgs decoupling and large  $\tan\beta$  limits. Calculate in the leading one-loop log approximation and for  $g^2 \ll \lambda_t^2$  the quantum corrections to the mass squared from integrating out the top squarks in the limit of vanishing stop squark left-right mixing. Useful information: The Standard Model  $\beta$ -function for the Higgs self coupling normalized as

$$V(H) \supset \lambda_H (H^* H)^2$$

including only one-loop corrections from Higgs and top quark loops is

$$16\pi^2 \beta_{\lambda_H} = \lambda_H (24\lambda_H + 12\lambda_t^2) - 6\lambda_t^4$$

where  $\lambda_t$  is the Standard Model top quark Yukawa coupling.