PHYS 5326 – Lecture #21

Monday, Apr. 30, 2007
Dr. Jae Yu

- Requirement on Experiments for Higgs Searches
- SUSY and EW Symmetry Breaking
- Squark & Slepton Masses
- Chargino and Neutralino Sectors
- Coupling Constants
- SUSY GUT (SUGRA)
- SUSY Higgs production and decay

Announcement

- Homeworks
  - Please be sure to submit all yet-to-be-submitted homework by Monday, May 7
- Semester project presentation
  - 1:00 – 2:30pm, Wednesday, May 2 in CPB347
  - 25 minutes each + 5 minute questions
  - Send me slides by noon, Wednesday, May 2
  - Order of presentations: JS, AP, CM
- Project reports (in MS words) due to me via e-mail by noon, Monday, May 7

What do we need to search for the Higgs?

- Smaller x-sec → Need higher rate
- Increase CMS energy of the accelerator
  - Increased x-sec
  - Increased kinematic reach for higher M_H
- Increased instantaneous Luminosity
  - Increased Number of protons and anti-protons, especially anti-protons
  - Increased duty factor/efficiency
  - Shorter fill time of anti-protons

Run II TeVatron Benchmarks

Parameters	Run I	RunIIa/b
$\mathcal{L}_{inst}$ (cm^{-2} sec^{-1})	$\sim 10^{31}$	$2x10^{32}$ $\sim 10^{33}$
Bunch Spacing	3.5 μsec	396 / 132 nsec
E_{CMS}(TeV)	1.8	1.98
$\mathcal{L}_{int}$	$\sim 110pb^{-1}$	$2fb^{-1}$ / $>4fb^{-1}$

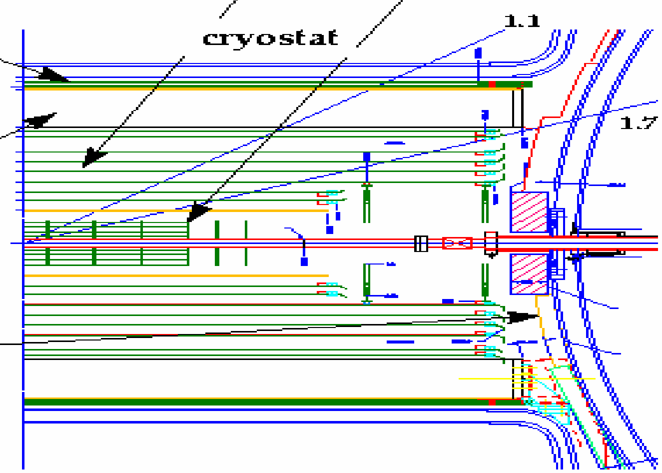
- σ(tt) ~ 40% higher at 2 TeV
- δM_H ~ 40% per experiment
- Increase in rates
- Decrease in bunch spacing

- Detectors need to be able to:
  - Tag the b-quark jets
    - Capable of measuring vertex that are ~100μm away from the primary vertex ➔ Precision vertex detector
    - Tag and associate leptons with a jet
  - Good Track momentum measurement, charge, and P-ID
  - Good jet mass resolution
  - Faster and more efficient and targeted trigger
    - Track trigger
  - Higher data recording bandwidth

Upgraded DØ Tracking System

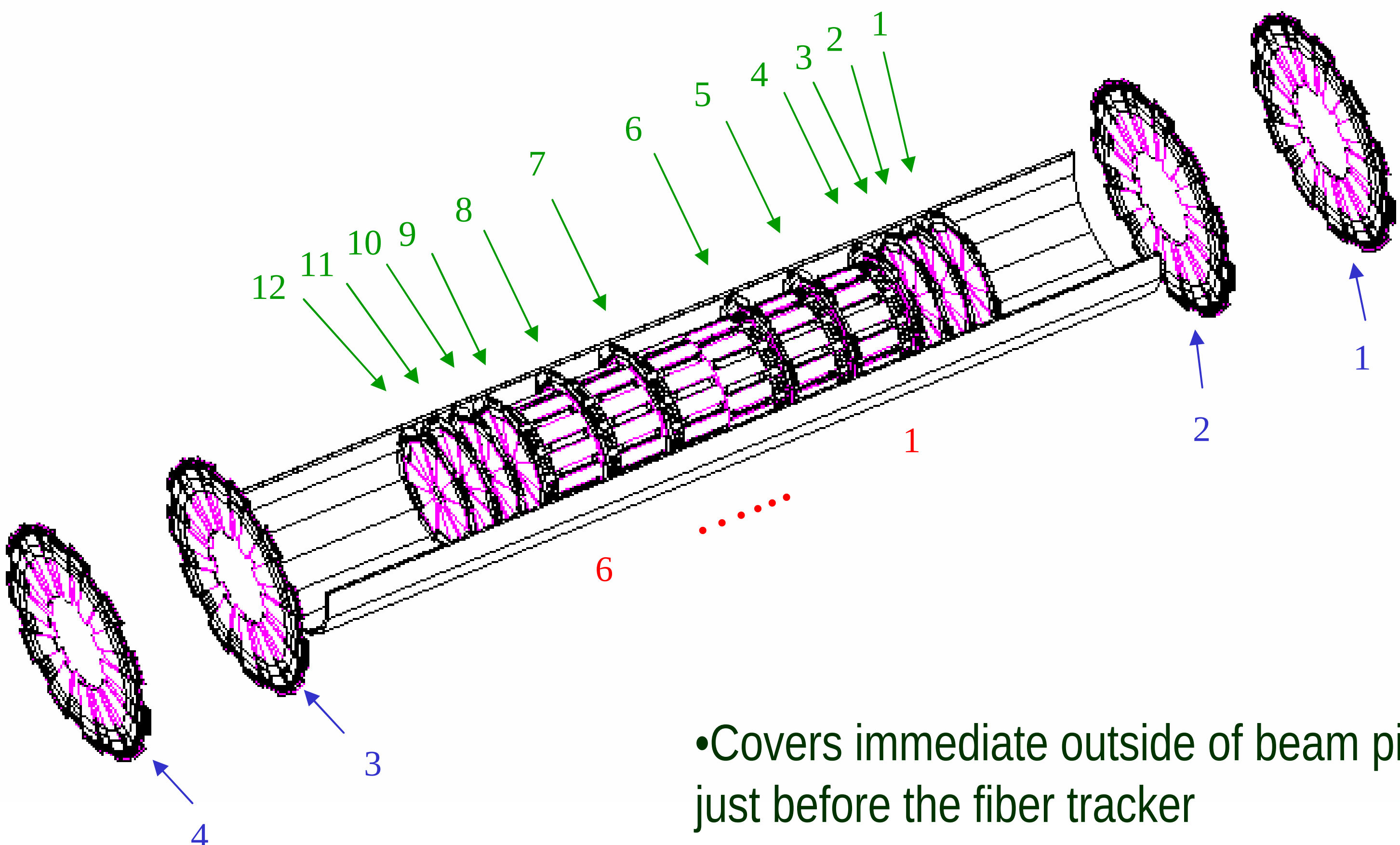
- Ability to trigger on tracks for quick decision
- Measure momentum and identify charges
- Upgrade tracking & Trigger systems

- **Silicon Tracker**
  - Four layer barrels (double/single sided)
  - Interspersed double sided disks
  - 840,00 channels
- **Fiber Tracker**
  - Eight layers sci-fi ribbon doublets (z-u-v, or z)
  - 74,000 830um fibers w/ VLPC readout
- **Central Preshower**
  - Scintillator strips, WLS fiber readout
  - 6,000 channels
- **Solenoid**
  - 2T superconducting
- **Forward Preshower**
  - Scintillator strips, stereo, WLS readout
  - 16,000 channels



Charged Particle Momentum Resolution
$\Delta p_T/p_T \sim 5\%$ @ $p_T = 10$ GeV/c

DØ Silicon Microstrip Detector

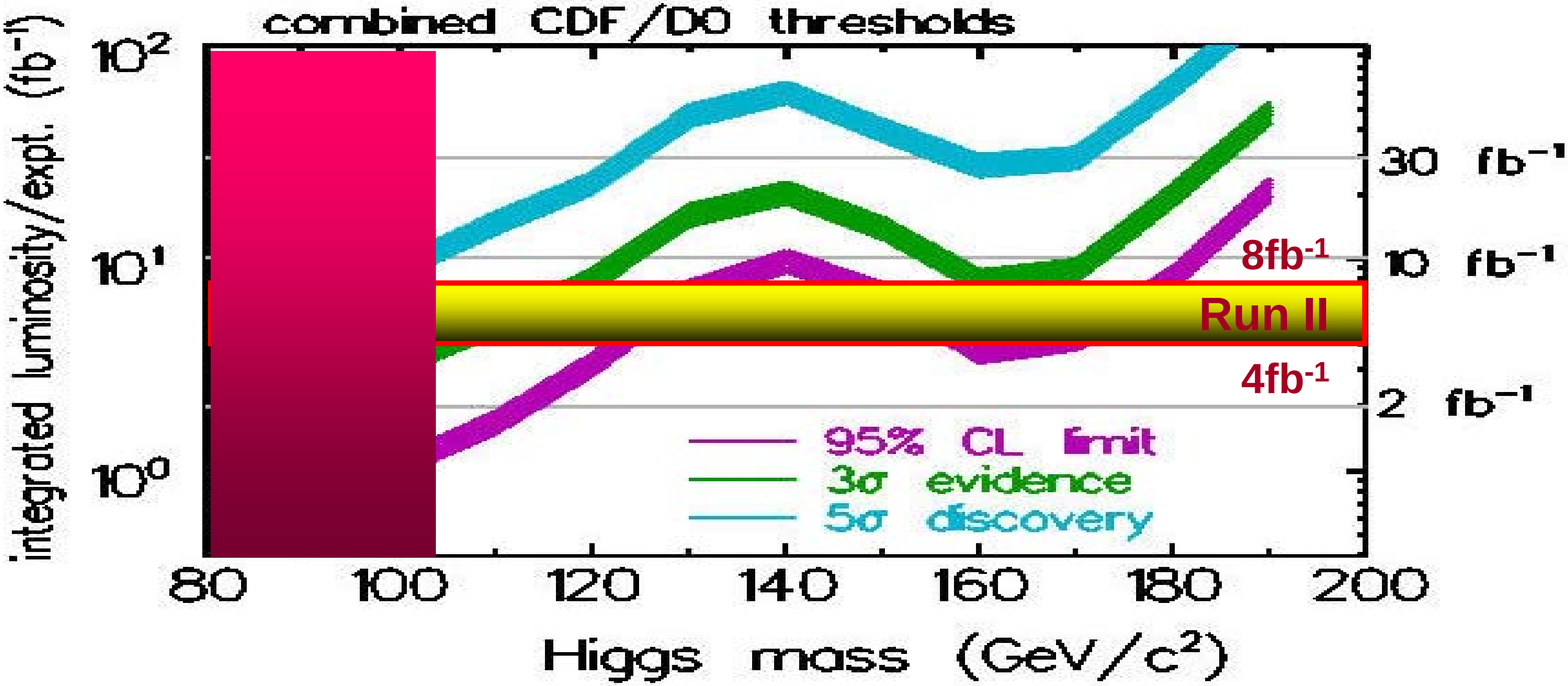


	Barrels	F-Disks	H-Disks
Channels	387072	258048	147456
Modules	432	144	96
Inner R	2.7 cm	2.6 cm	9.5 cm
Outer R	9.4 cm	10.5 cm	26 cm

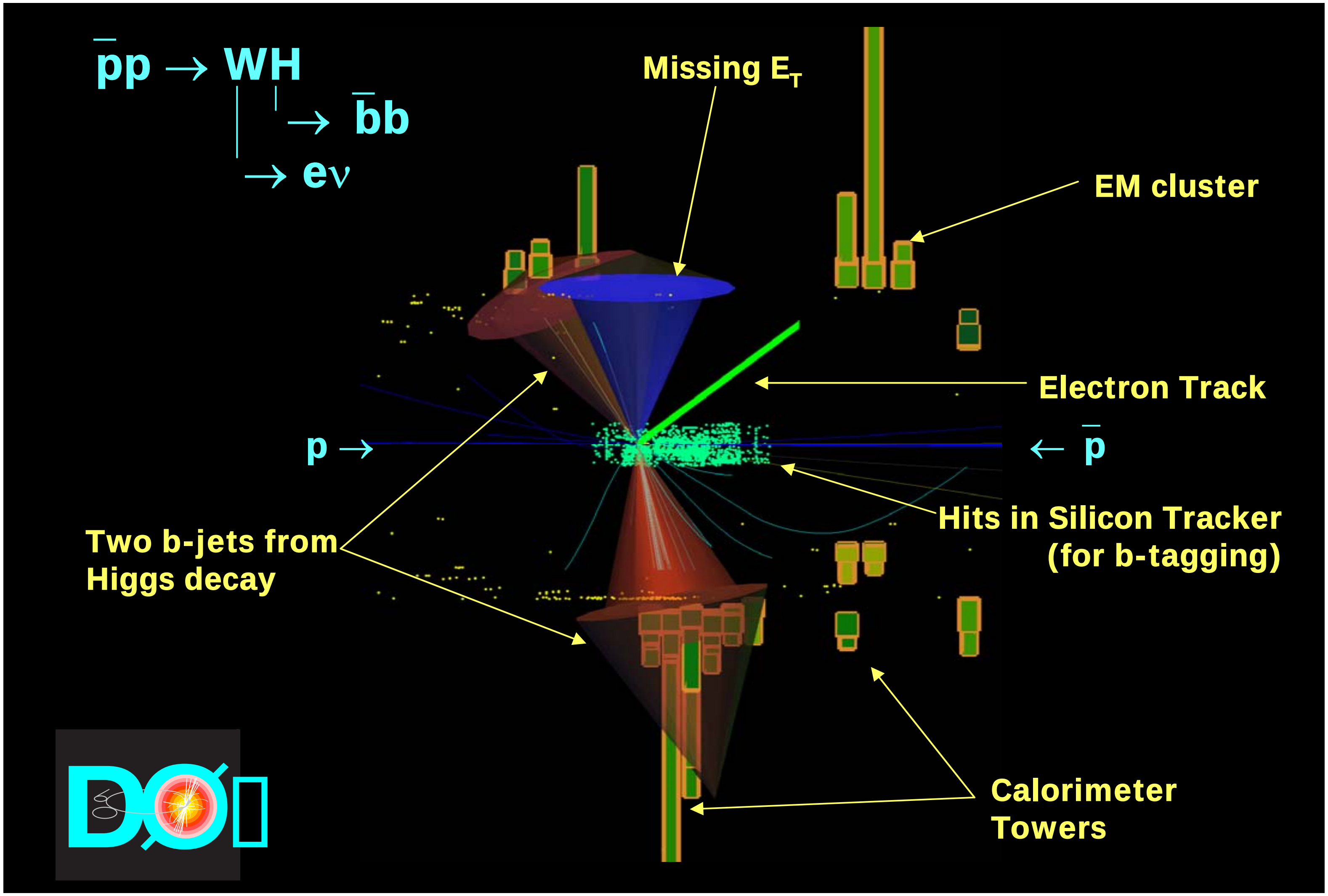
- Covers immediate outside of beam pipe to just before the fiber tracker
- Consists of Barrels and Disks
- Total number of readout channels are 800k
- Expected Position resolution 10~20μm

Run II Expectation

- LEP limit M_H>114.4 GeV
- Can have 4-8 fb^{-1}/exp by FY 2008
  - Possible discovery (~3 σ) up to 118 GeV or so
  - Good to reach 95% CL limit up to M_H ~ 180GeV



Lepton+MET+Jets SM Higgs Signal Event



SUSY Symmetry Breaking

- General assumption is that SUSY breaking occurs at very high scale, such as Planck Scale
- The usual approach is the assumption that MSSM is an effective low energy theory
- The SUSY breaking is implemented by by including explicit "soft" mass terms for
  - scalar member of chiral multiplets
  - gaugino member of the vector super-multiplets
- The dimension of soft operators in $\mathcal{L}$ must be 3 or less:
  - Mass terms, bi-linear mixing terms (B terms), tri-linear scalar mixing terms (A terms)
- The origins of these SUSY breaking terms are left unspecified…

SUSY Breaking Lagrangian

- The complete set of soft SUSY breaking terms that respects R-parity and $SU(3)xSU(2)_LxU(1)_Y$ for the first generation is given by the $\mathcal{L}$

$$-\mathcal{L}_{soft}=m_1^2\left|H_1\right|^2+m_2^2\left|H_2\right|^2-B\mu\varepsilon_{ij}\left(H_1^iH_2^j+h.c.\right)+\tilde{M}_Q^2\left(\tilde{u}_L^*\tilde{u}_L+\tilde{d}_L^*\tilde{d}_L\right)$$

$$+\tilde{M}_u^2\tilde{u}_R^*\tilde{u}_R+\tilde{M}_d^2\tilde{d}_R^*\tilde{d}_R+\tilde{M}_L^2\left(\tilde{e}_L^*\tilde{e}_L+\tilde{\nu}_L^*\tilde{\nu}_L\right)+\tilde{M}_e^2\tilde{e}_R^*\tilde{e}_R$$

$$+\frac{1}{2}\left[M_3\bar{\tilde{g}}\tilde{g}+M_2\bar{\tilde{w}}_i\tilde{w}_i+M_1\bar{\tilde{b}}\tilde{b}\right]+\frac{g}{\sqrt{2}M_W}\varepsilon_{ij}\left[\frac{M_d}{\cos\beta}A_dH_1^i\tilde{Q}^j\tilde{d}_R^*\right.$$

$$\left.+\frac{M_u}{\sin\beta}A_dH_1^j\tilde{Q}^i\tilde{u}_R^*+\frac{M_e}{\cos\beta}A_eH_1^i\tilde{L}^j\tilde{e}_R^*+h.c.\right]$$

bi-linear terms

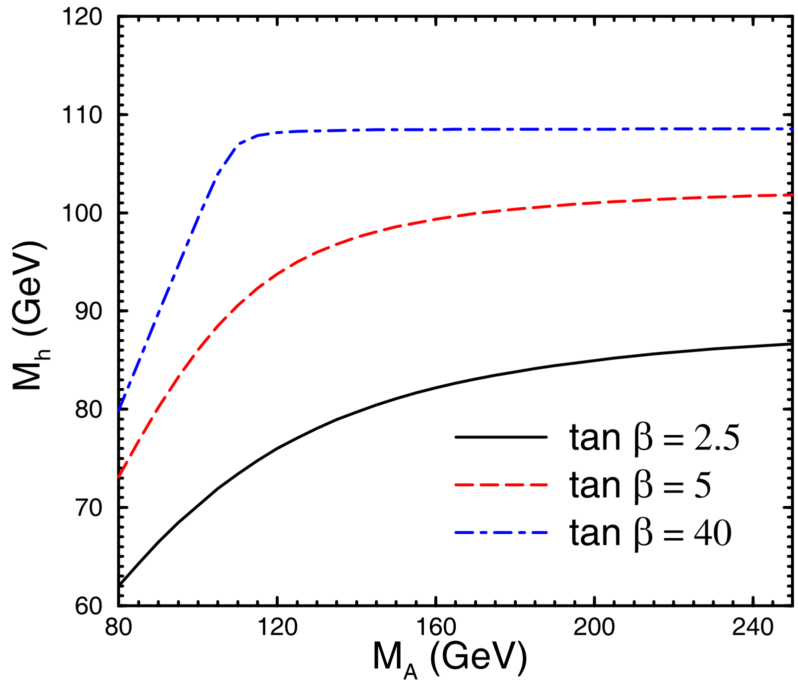
tri-linear terms

- This $\mathcal{L}$ has arbitrary masses for scalars (m_1, m_2, $\sim M_Q$, $\sim M_u$, $\sim M_d$, $\sim M_L$) and gauginos (M_1, M_2, M_3)

SUSY Breaking Lagrangian Properties

- The mass terms in $\mathcal{L}$ breaks the mass degeneracy between particle and their super partners
- The tri-linear A-terms defined with explicit factor of mass that affects particles of the third generation
- When A terms are non-zero the scalar partners of the left and right-handed fermions can mix when the Higgs bosons get VEV
- The B-term (bi-linear) mixes scalar components of 2 Higgs doublets
- Adding all of the mass and mixing terms to $\mathcal{L}$ is allowed by gauge symmetries
- $\mathcal{L}_{soft}$ breaks SUSY but at the expense of more than <u>50 additional parameters</u>
- Since the gauge interactions in SUSY are fixed, SUSY can still preserve its predictive power

Mass of CP-even h^0 vs M_A and tanβ

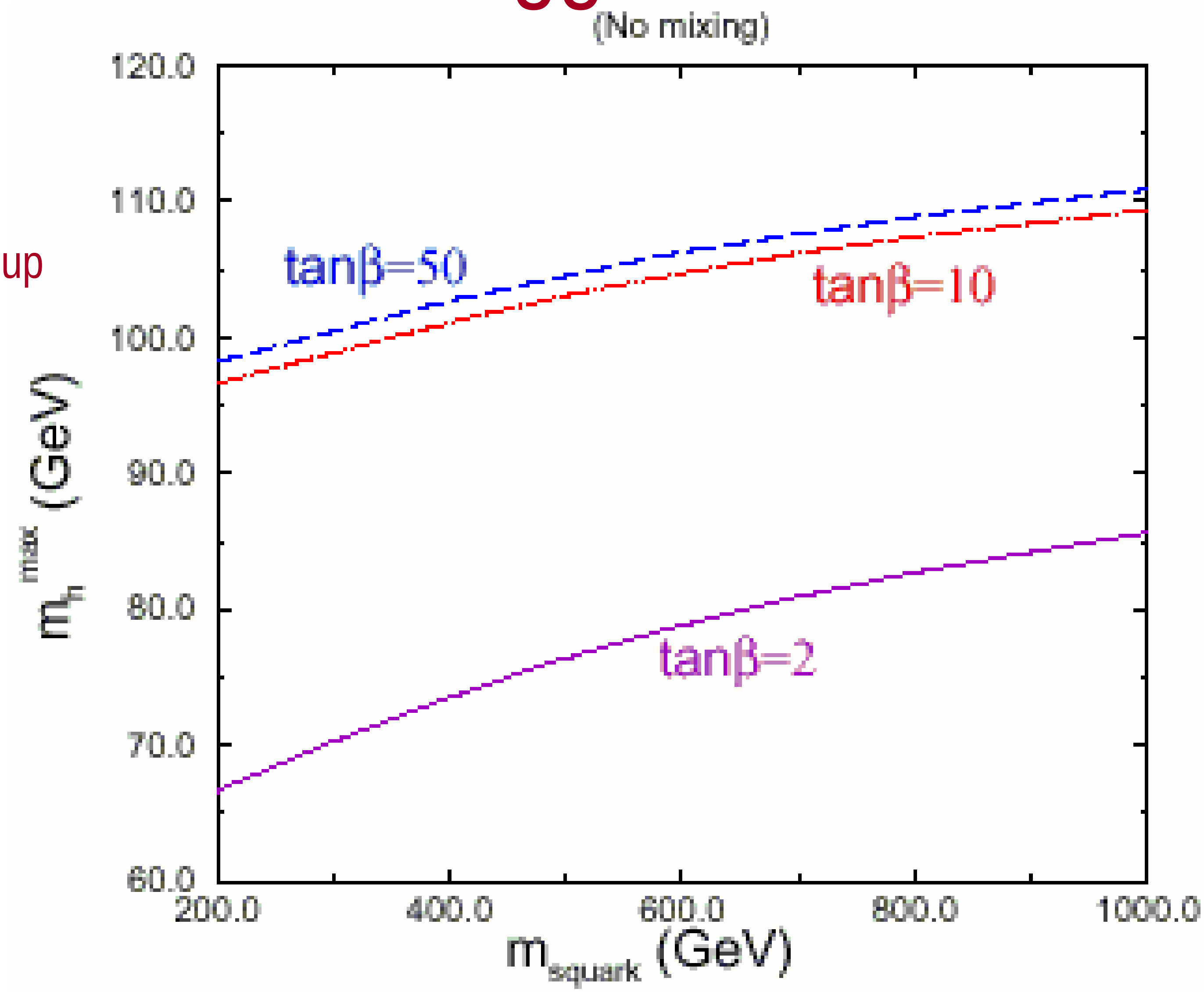


M_h plateaus with M_A>300GeV/c^2

For given values of tanβ and the squark masses, there is an upper bound on the lightest higgs mass at around 110GeV for a small mixing and 130 GeV for large mixing.

Maximum Higgs Mass

For large values of $\tan\beta$, $M_h \sim 110GeV$
Different approach can bring this value up to ~130GeV



Maximum Higgs Mass

Minimal SUSY Standard (MSSM) model predicts a neutral Higgs with the mass less than 130GeV

- More complicated SUSY models bring different picture on the mass.
- However, the requirement that Higgs self-coupling remains perturbative gives the upper bound on the lightest SUSY Higgs mass at around 150~175 GeV in all models

What is the physical implication of not observing higgs at this mass range?

There must be a new physics between the weak (~1TeV) and the Planck scale (~10^{16}TeV) which causes the Higgs couplings non-perturbative!!

SUSY Higgs Boson Couplings to Fermions

- The Higgs coupling to fermions is dictated by the gauge invariance of the super-potential. At lowest order, it is completely specified by M_A and $\tan\beta$.
- Requiring fermions to have their observed masses fixes the couplings in the super-potential:

$$\lambda_D = \frac{gM_d}{\sqrt{2}M_W \cos\beta} \qquad \lambda_U = \frac{gM_u}{\sqrt{2}M_W \sin\beta} \qquad \lambda_L = \frac{gM_l}{\sqrt{2}M_W \cos\beta}$$

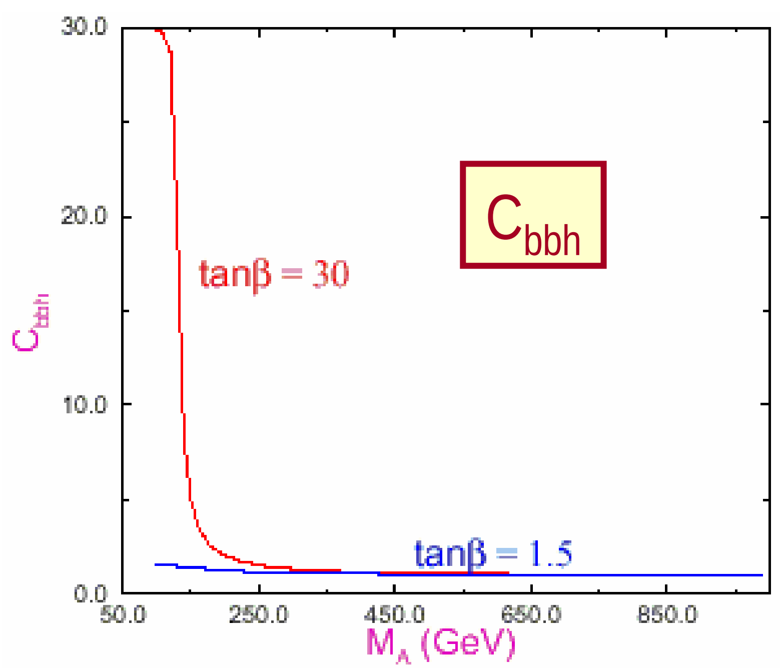
Where g is the $SU(2)_L$ gauge coupling, $g^2 = 4\sqrt{2}G_F M_W^2$

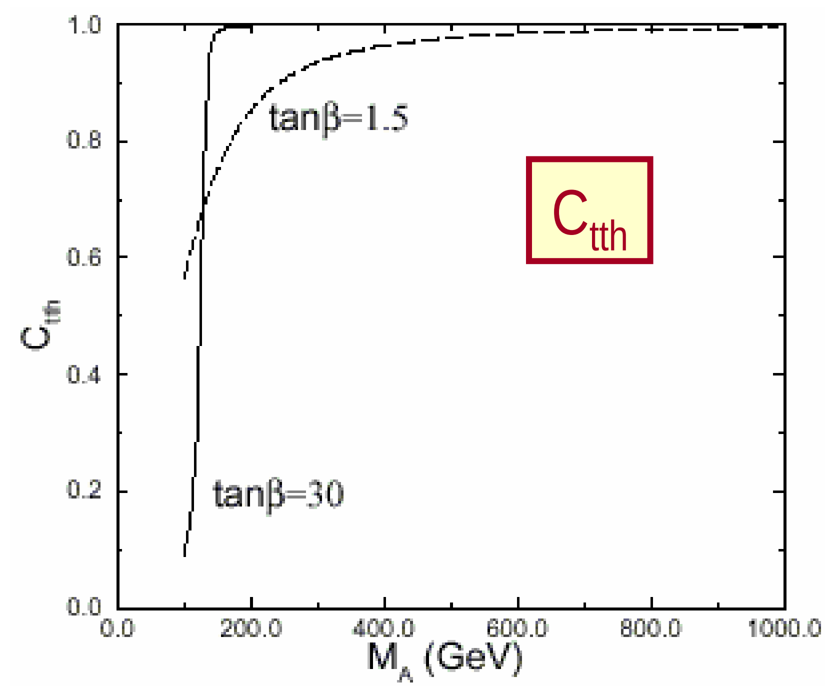
$\mathcal{L}$ that contains couplings can be written, in terms of SM couplings, C_{ffx}:

$$\mathcal{L} = -\frac{gm_i}{2M_W}\left[C_{ffh}\overline{f}_i f_i h + C_{ffH}\overline{f}_i f_i H + C_{ffA}\overline{f}_i f_i A\right]$$

SUSY Higgs Boson Couplings to Fermions

f	C_{ffh}	C_{ffH}	C_{ffA}
u	$\frac{\cos\alpha}{\sin\beta}$	$\frac{\sin\alpha}{\sin\beta}$	$\cot\beta$
d	$-\frac{\sin\alpha}{\cos\beta}$	$\frac{\cos\alpha}{\cos\beta}$	$\tan\beta$





For SM C_{ffh}=1

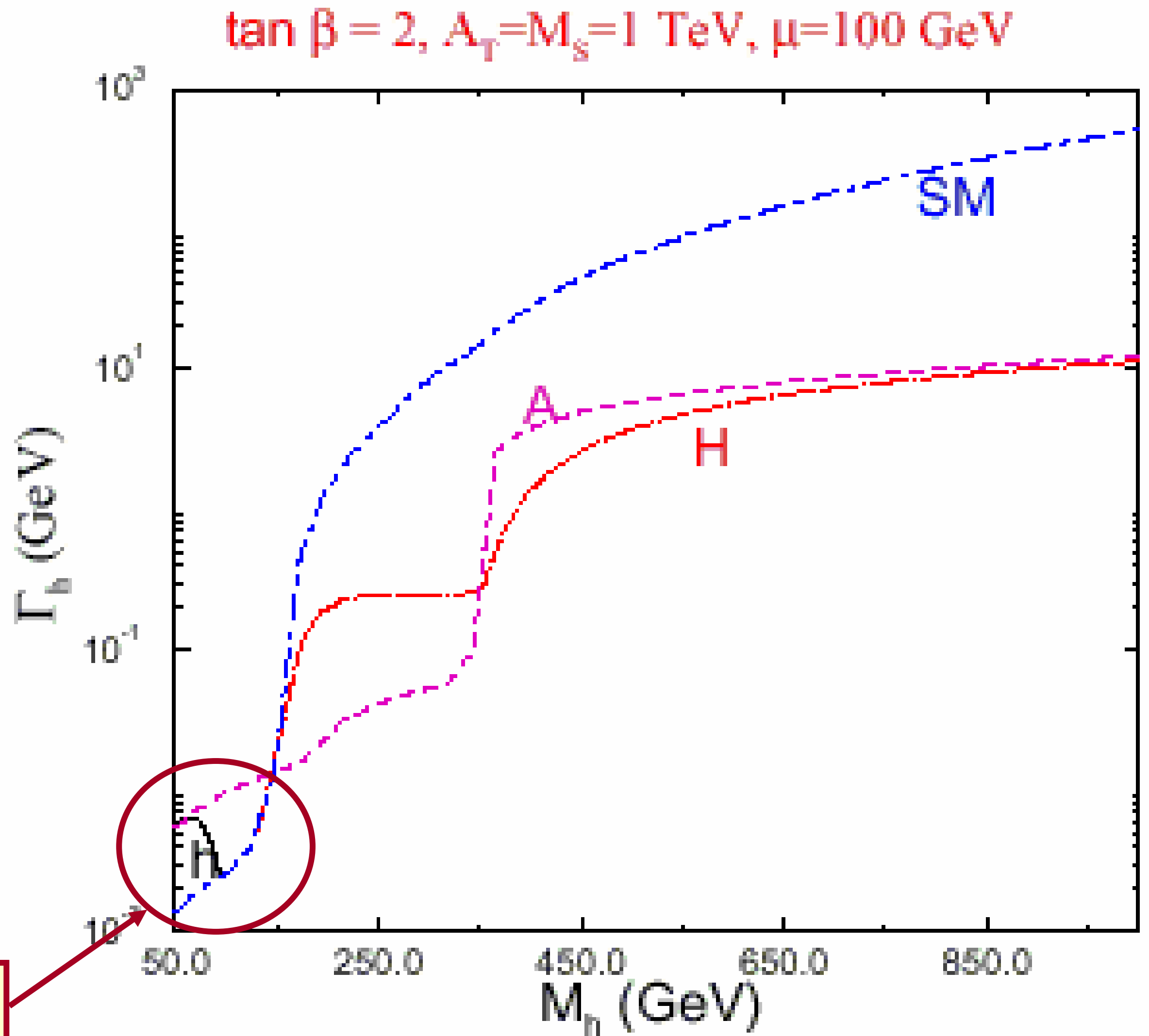
MSSM approaches to SM at large M_A

MSSM Higgs Couplings

- As M_A becomes large
- $M_{H+/-}$ and M_{H0} get large too
- Only lightest higgs stays within the spectrum
- The couplings of the lighter Higgs boson to fermions and gauge bosons take on their SM values
- Thus, at large M_A limit (M_A >300GeV), it is difficult to distinguish MSSM from SM

MSSM Higgs Width

- Higgs width depends on the value of tanβ.
- $M_h \sim 110GeV$
- Lightest higgs width is 10-100MeV while the heavier ones range .1-1 GeV.
- Considerably smaller than SM width (a few GeV)

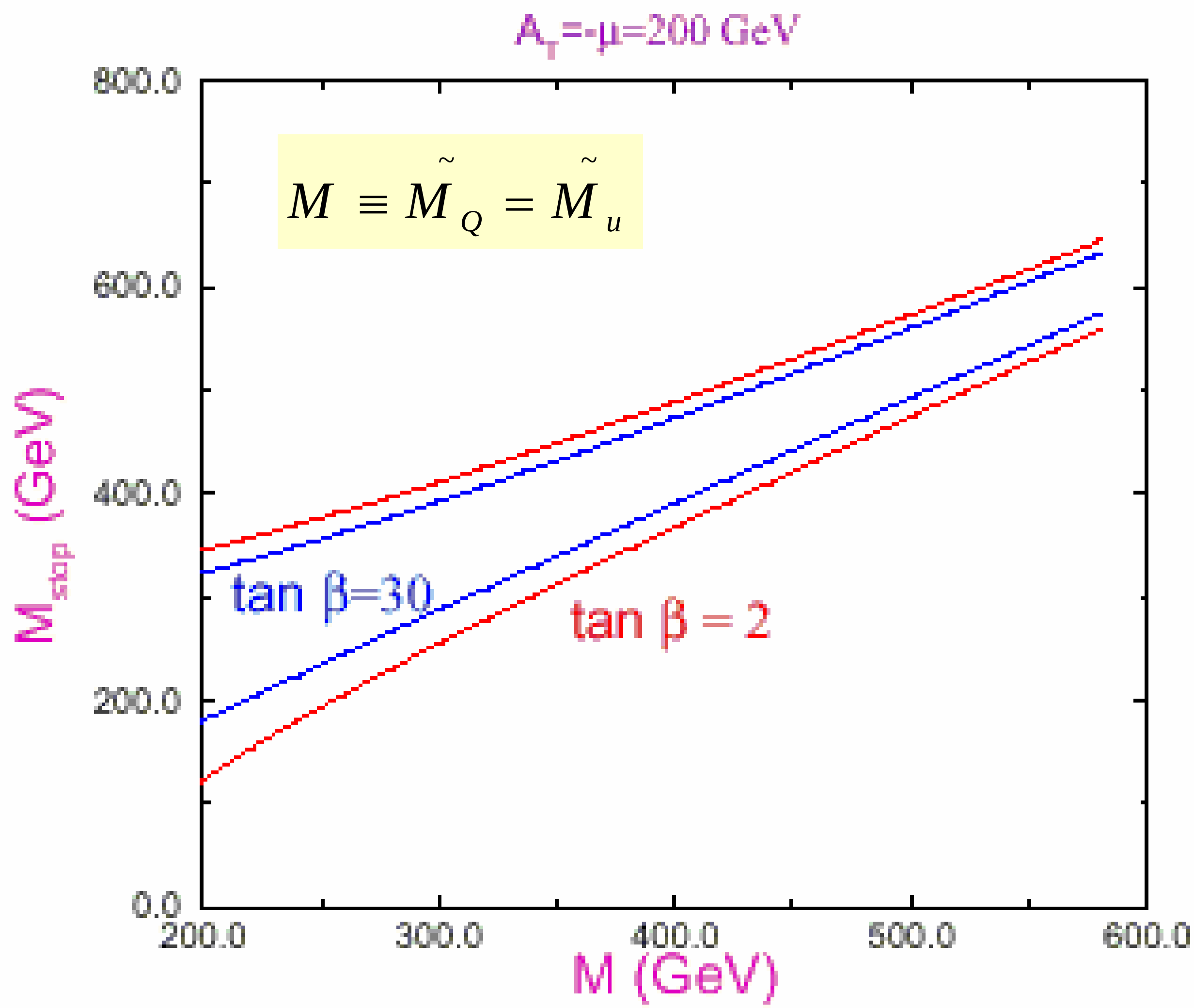


Confined to this region..

Squark and Slepton Masses

If soft SUSY breaking occurs at the scale much larger than Mz, M_T, or A_T, all soft masses are approximately equal and there will be 12 degenerate squarks.

If the scale is at EWSB, mixing effects become important. For large mixing, one of the stop squarks become lightest in this sector.



Chargino ($\chi^{\pm}$) Sector

- There are two charge 1, spin-1/2 Majorana fermions, winos, and higgsinos
- The physical mass states, charginos, are linear combinations formed by diagonalizing the mass matrix
- The chargino mass matrix is:

$$M_{\tilde{\chi}^{\pm}} = \begin{pmatrix} M_2 & \sqrt{2} M_W \sin\beta \\ \sqrt{2} M_W \cos\beta & -\mu \end{pmatrix}$$

Mass eigenstates are:

$$M_{\tilde{\chi}^{\pm}_{1,2}} = \frac{1}{2}\left\{ M_2^2 + 2M_W^2 + \mu^2 \mp \begin{bmatrix} \left(M_2^2 - \mu^2\right) + 4M_W^4 \cos^2 2\beta \\ +4M_W^4 \left(M_2^2 + \mu^2 - 2M_2 \mu \sin^2\beta\right) \end{bmatrix}^{1/2} \right\}$$

By convention χ_1 are the lightest charginos

Neutralino (χ^0) Sector

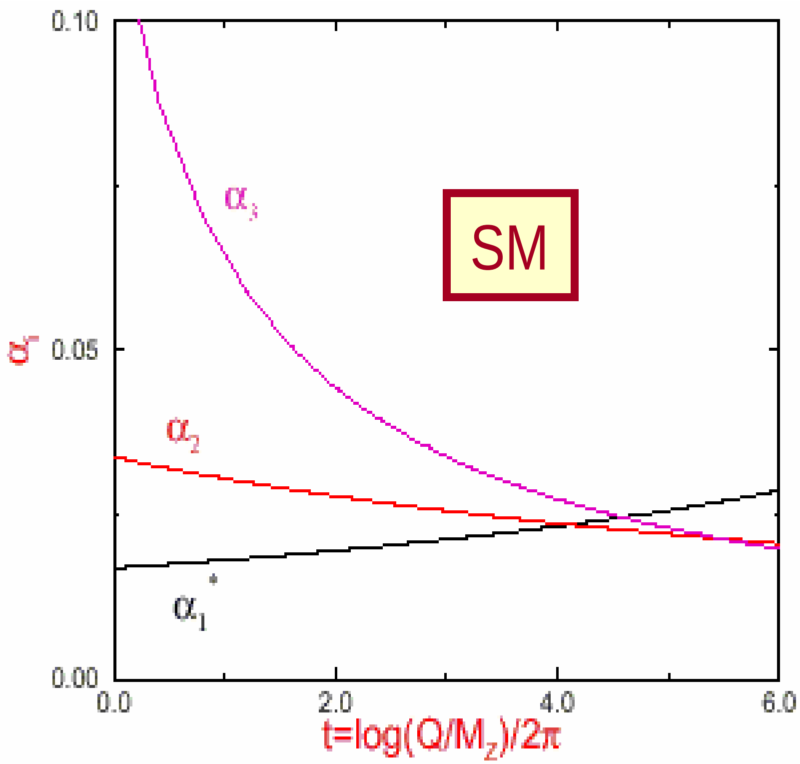
- In neutral fermion sector, binos and winos can mix with higgsinos.
- The physical mass states, neutralinos, are linear combinations formed by diagonalizing the mass matrix
- The neutralino mass matrix is:

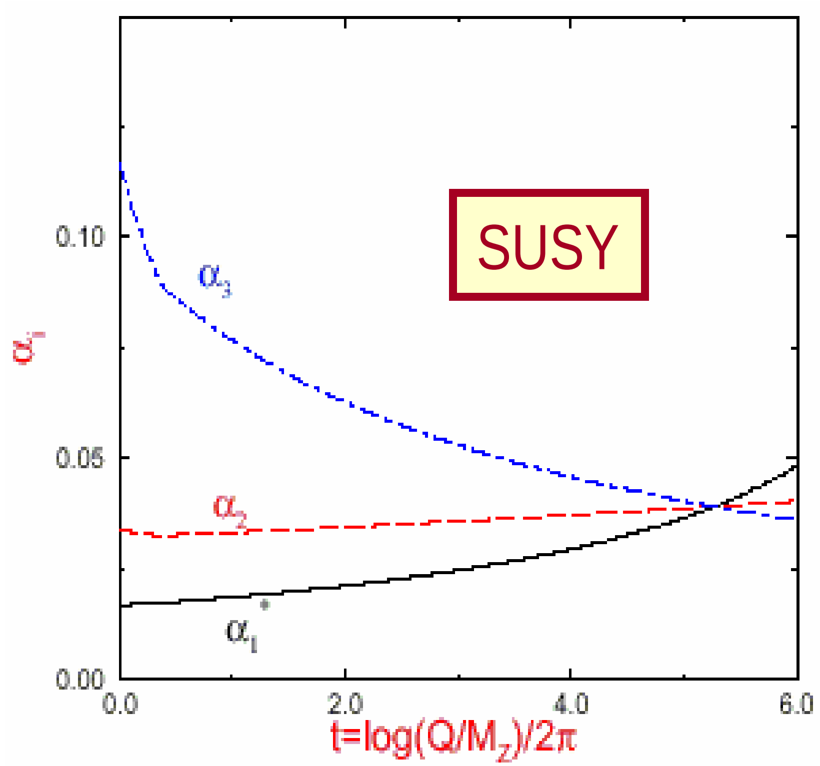
$$M_{\tilde{\chi}_i^0} = \begin{pmatrix} M_1 & 0 & -M_Z\cos\beta\sin\theta_W & M_Z\sin\beta\sin\theta_W \\ 0 & M_2 & M_Z\cos\beta\cos\theta_W & -M_Z\sin\beta\cos\theta_W \\ -M_Z\cos\beta\sin\theta_W & M_Z\cos\beta\sin\theta_W & 0 & \mu \\ M_Z\sin\beta\sin\theta_W & -M_Z\sin\beta\cos\theta_W & \mu & 0 \end{pmatrix}$$

θ_W is the Weinberg EW mixing angle. The index i runs 1-4. The lightest neutralino is usually assumed to be LSP.

Coupling Constants

In both SM and SUSY, coupling strength varies as a function of the energy scale. In SM, however, the three couplings never merge while SUSY it does at around 10^{16} GeV.





Thus, SUSY theories can naturally be incorporated into GUT.

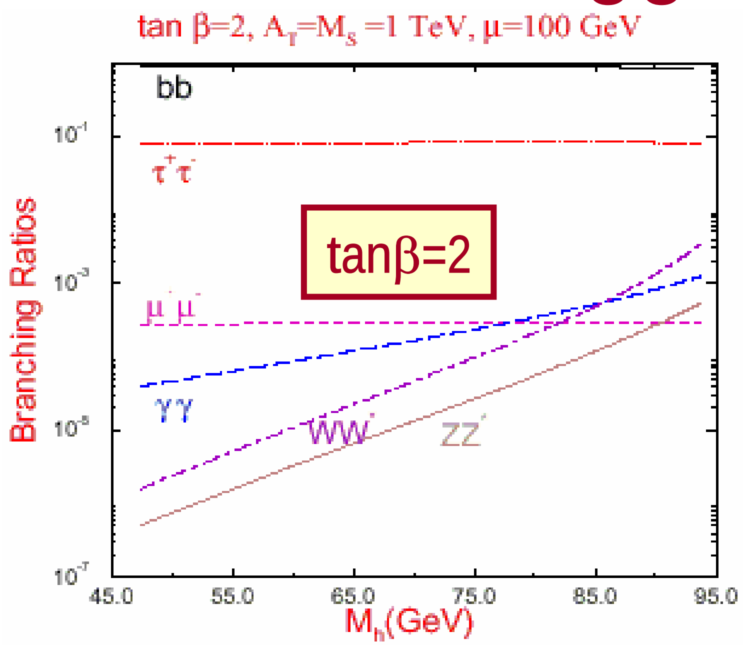
SUSY GUT

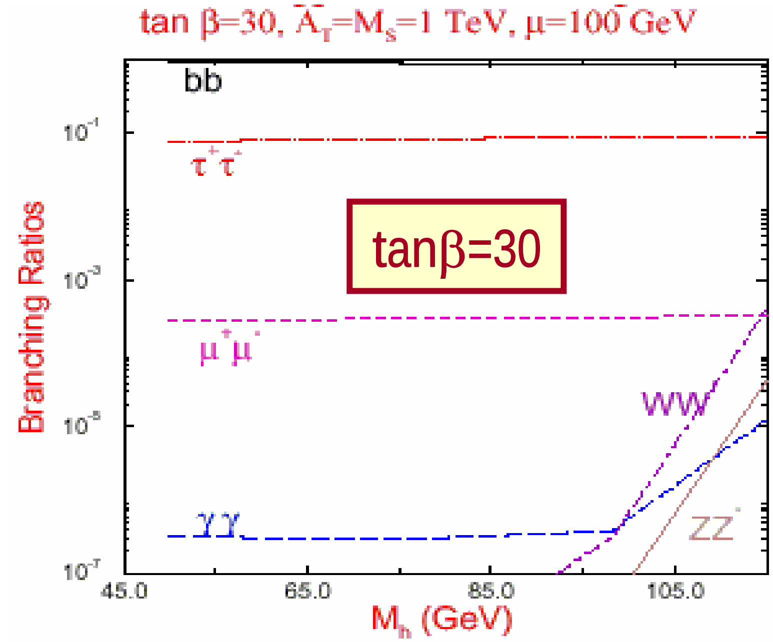
- Since the coupling constants in SUSY theories unifies at a higher energy scale, the SUSY GUT model is widely accepted.
- In SUSY GUT model, the entire SUSY sectors are described by 5 parameters:

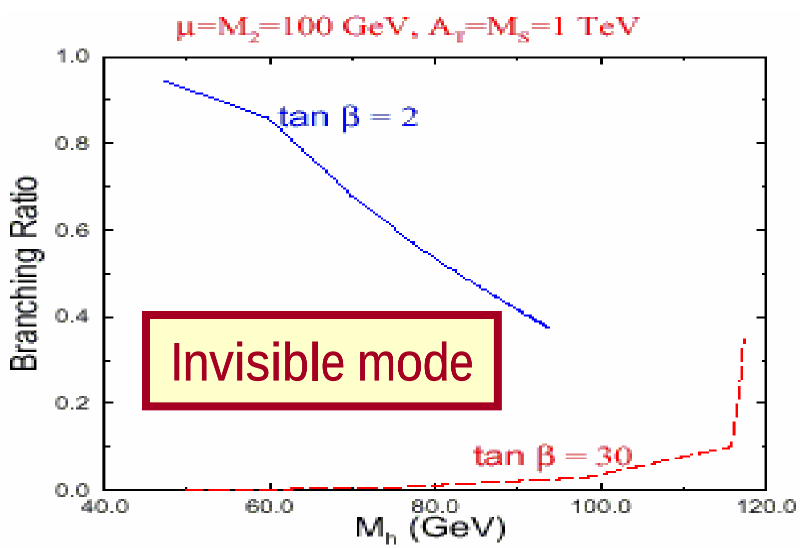
1. A common scalar mass, m_0.
2. A common gaugino mass, $m_{1/2}$.
3. A common tri-linear coupling, A_0.
4. A Higgs mass parameter, μ.
5. A Higgs mixing parameter, B.

This set of assumptions is often called “Superstring inspired SUSY GUT” or SUGRA

SUSY Higgs Branching Ratios

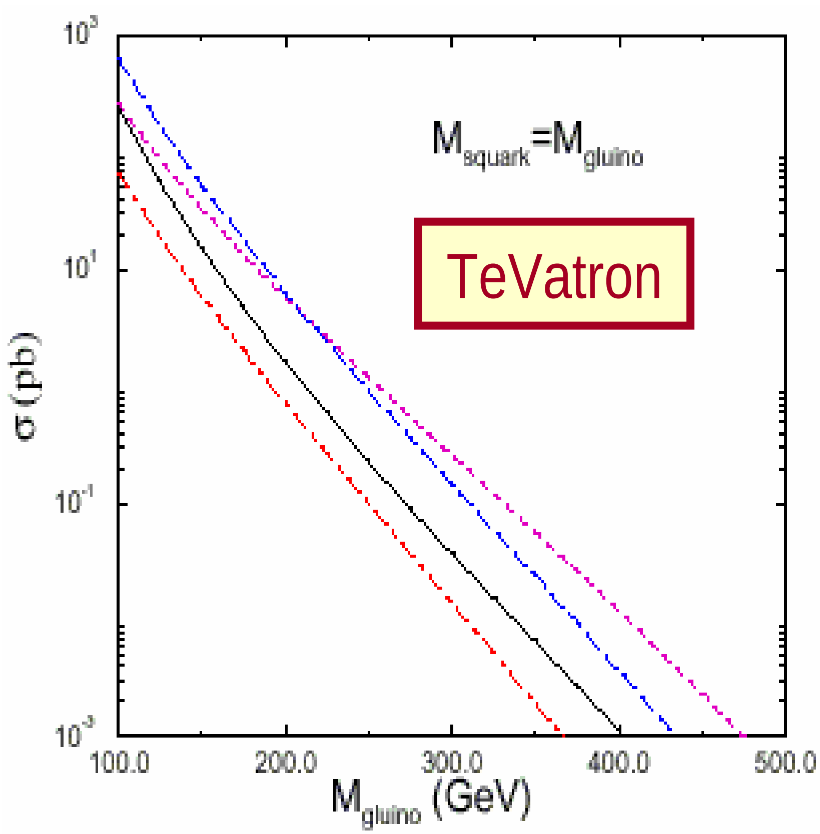


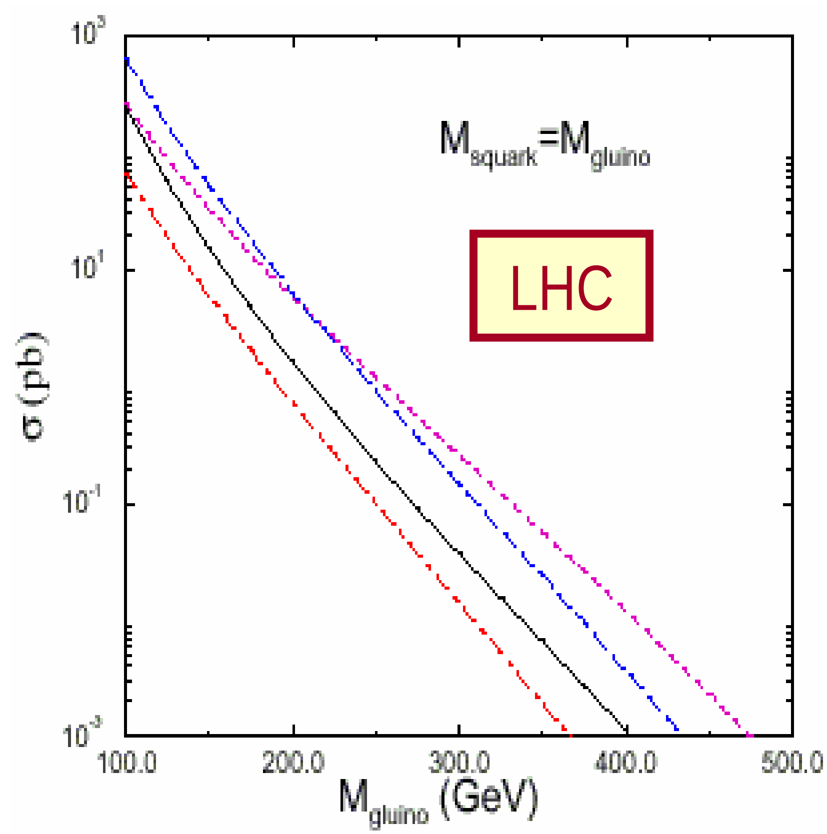




The branching ratio is very sensitive to tanβ.

Squark and gluino production





Solid line is $p\bar{p}$ to gluino pairs, dot-dashed is squark pairs, dotted is squark and excited squark, and dashed is squark and gluino.