

Detecting Higgs Bosons with Muons in Supergravity Unified Models

Chung Kao
University of Oklahoma
Norman Oklahoma USA

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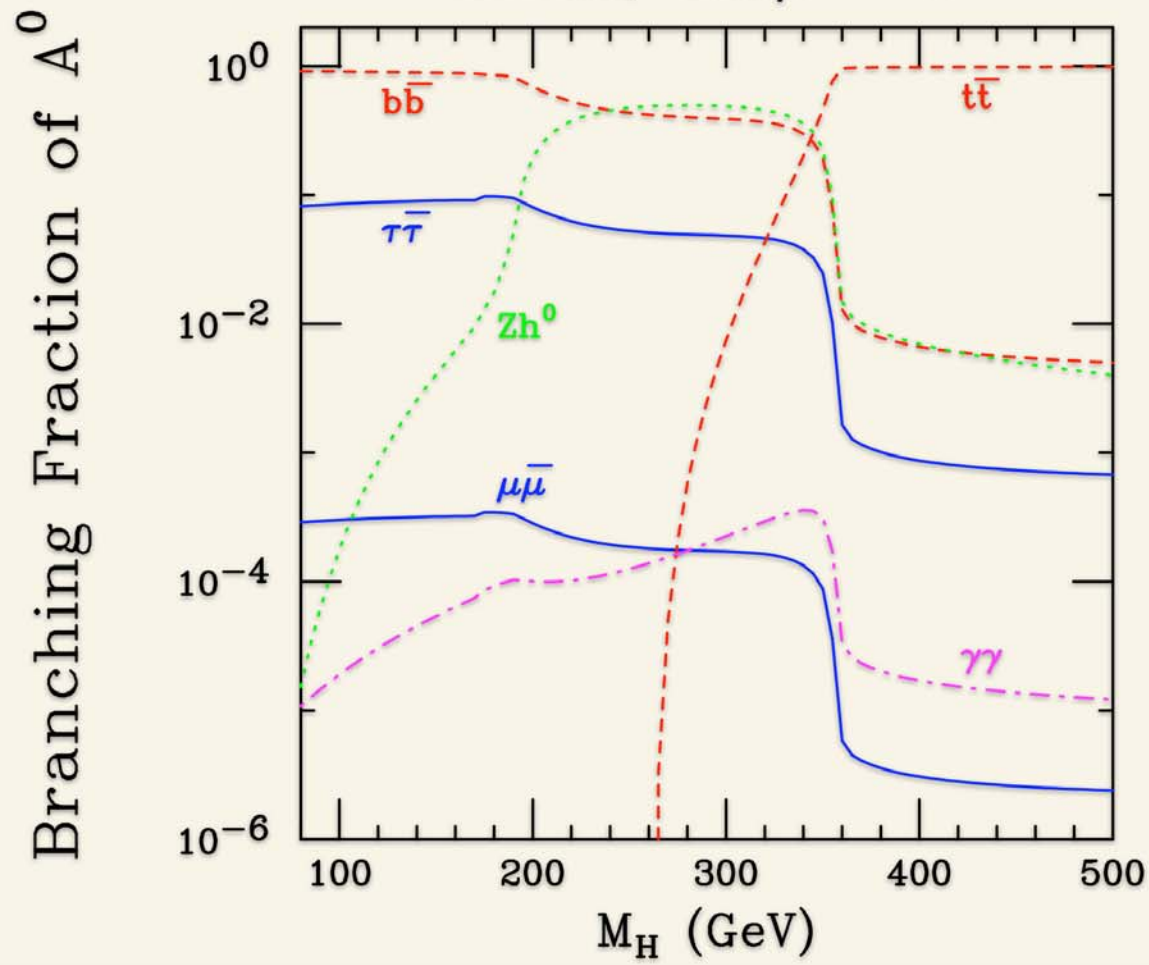
- ~ Based on a recent paper by C. Kao and Y. Wang, Phys. Lett. B **635** (2006) 30.
- ~ Direct search for Higgs bosons at the LHC
 $pp \rightarrow b\phi^0 \rightarrow b\mu^+\mu^- + X, \phi^0 = H^0, h^0, A^0$
- ~ Indirect search for Higgs bosons in
 $B_s \rightarrow \mu^+\mu^-$

The Minimal Supersymmetric Model

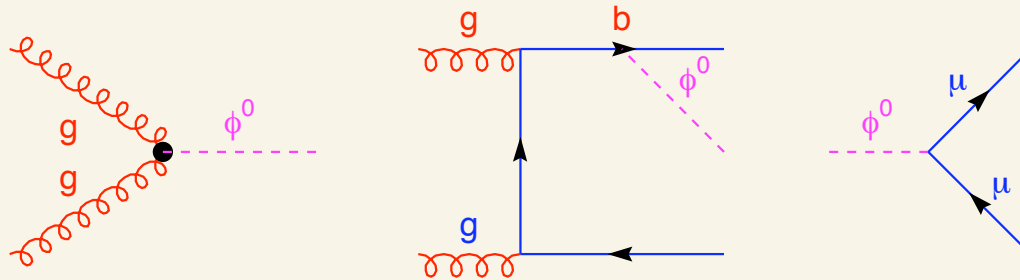
- ~ In the minimal supersymmetric standard model (MSSM), there are two Higgs doublets with vacuum expectation value (VEVs) v_1 and v_2 , and five Higgs bosons: two scalars H^0 and h^0 , one pseudoscalar A^0 , and a pair of singly charged Higgs bosons H^\pm .
- ~ At the tree level, $m_h \leq M_Z \approx 91 \text{ GeV} < m_H$, with radiative corrections, m_h can be in the range $125 \text{ GeV} \leq m_h \leq 135 \text{ GeV}$.
- ~ There are only two free parameters in the Higgs sector, often chosen to be m_A and $\tan \beta \equiv v_2/v_1$.

The Higgs Pseudoscalar (A^0)

MSSM, $\tan\beta = 2$



Discovering the Higgs Bosons with Muons



- The A^0 and the H^0 might be observable in a large region of parameter space with $\tan\beta \geq 10$.
- This discovery channel of $\mu^+\mu^-$ will allow precise reconstruction for the Higgs boson masses.
- Kao and Stepanov (1995);
Barger and Kao (1998);
Dawson, Dicus and Kao, Phys. Lett. **B545**, 132 (2002).

Cross Section in the MSSM

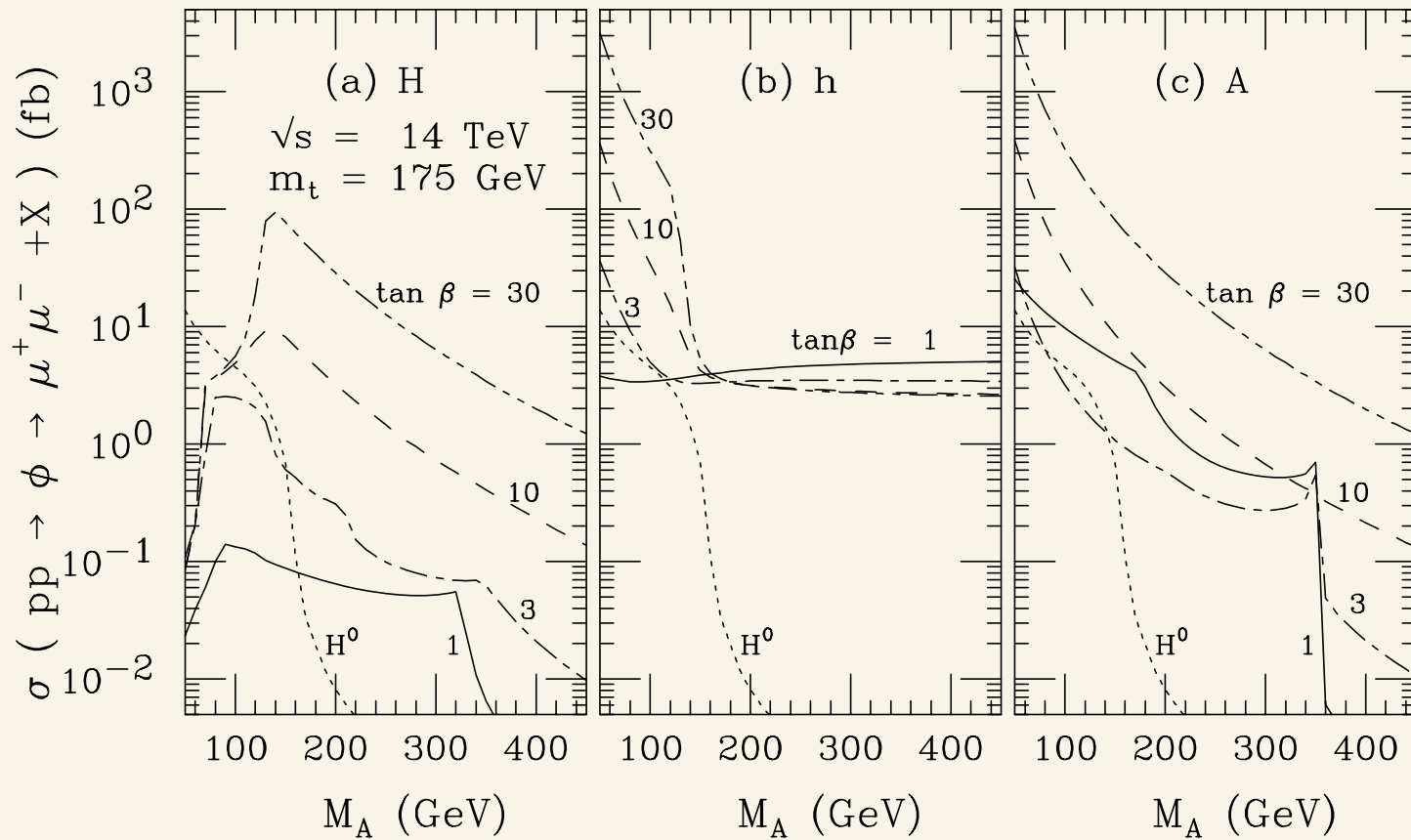
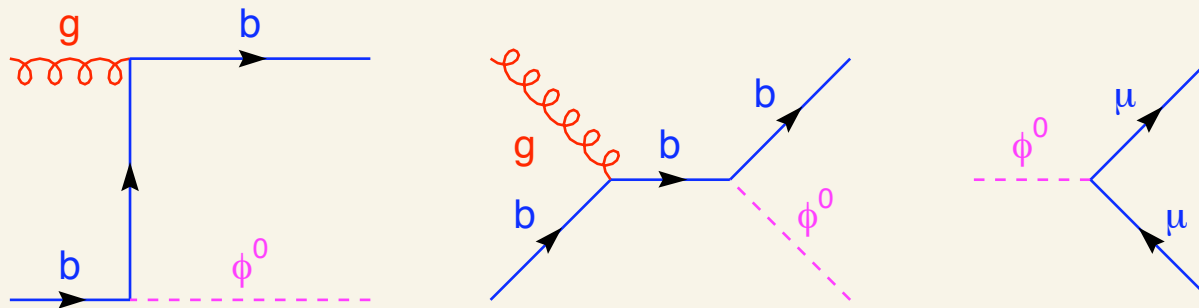


FIG 1/Kao and Stepanov

Discovering Higgs Bosons with Muons and a Bottom Quark



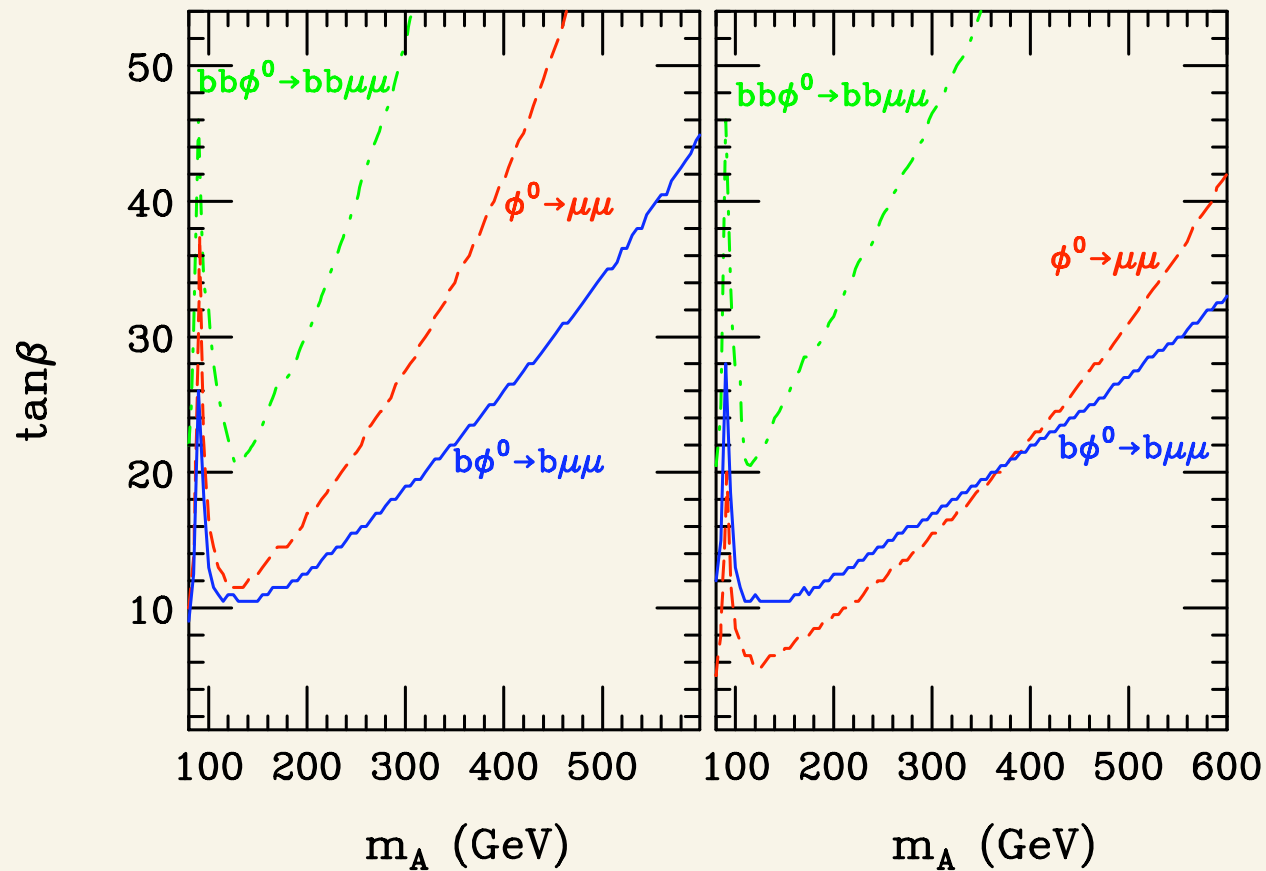
S. Dawson, D. Dicus, C. Kao and R. Malhotra, Phys. Rev. Lett. 92, 241801 (2004). S. Dawson, D. Dicus, and C. Kao, Phys. Lett. B **545**, 132 (2002); V. Barger and C. Kao, Phys. Lett. B **424**, 69 (1998); C. Kao and N. Stepanov, Phys. Rev. D **52**, 5025 (1995).

Discovery Potential at the LHC

MSSM, $M_{\text{SUSY}} = 1 \text{ TeV}$

(a) $L = 30 \text{ fb}^{-1}$

(b) $L = 300 \text{ fb}^{-1}$



Summary for Higgs Decay into Muons

- The discovery channel of $b\phi^0 \rightarrow b\mu^+\mu^-$ offers great promise to discover the A^0 and the H^0 at the LHC for $\tan\beta > 10$, $m_A < 650$ GeV with $L = 30$ fb $^{-1}$.
- A higher luminosity of 300 fb $^{-1}$ can improve the discovery reach in m_A up to $m_A = 800$ GeV.
- The $b\phi^0$ channel greatly improves the discovery potential beyond the reach of the inclusive channel $pp \rightarrow \phi^0 \rightarrow \mu^+\mu^- + X$.
- This discovery channel might provide good opportunities to measure important parameters such as the Higgs masses, $\tan\beta$, and Higgs couplings with bottom quarks and leptons.

The Minimal Supergravity Model

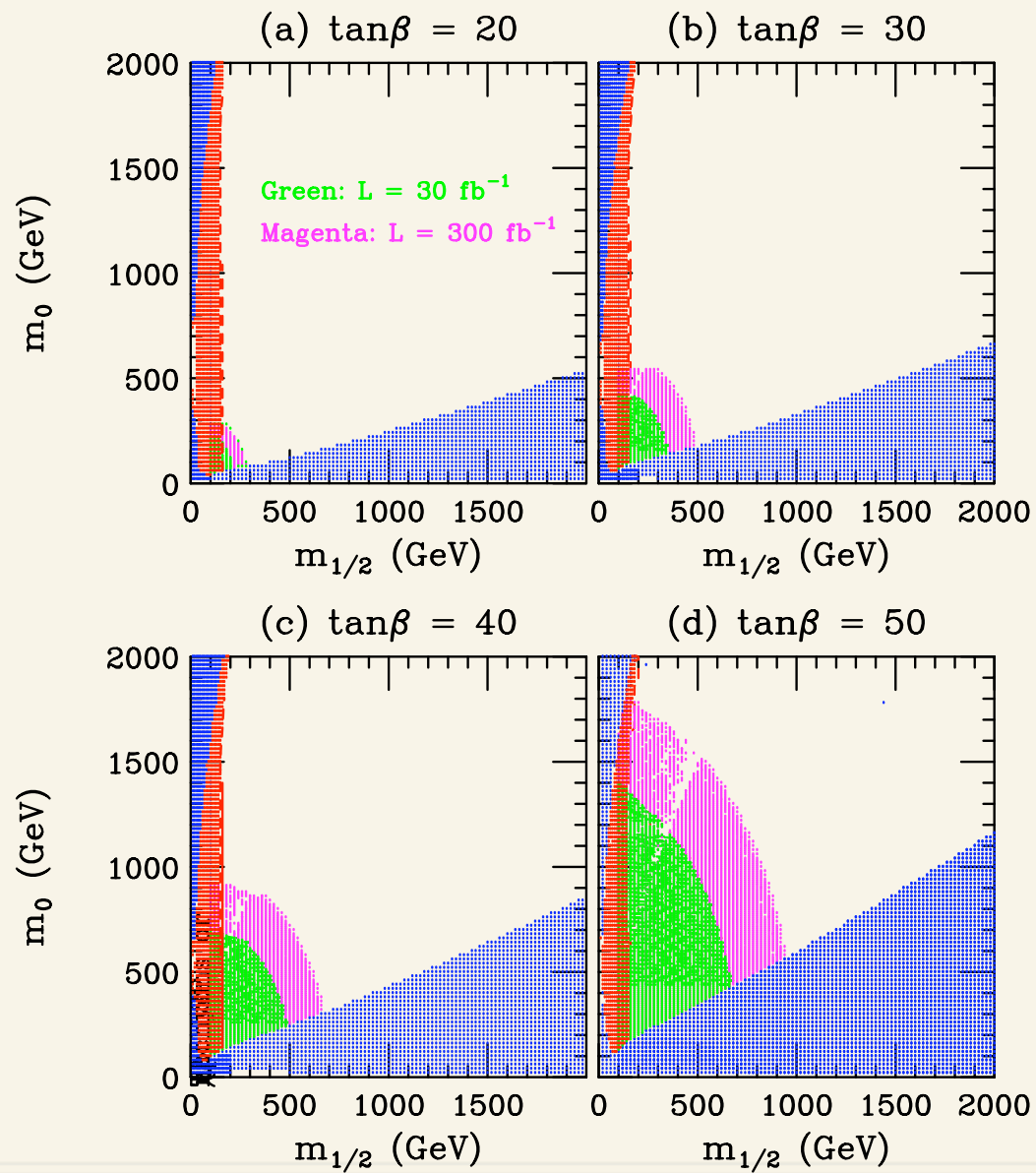
- ~ In the minimal supergravity unified model (mSUGRA), it is assumed that SUSY is broken in a hidden sector with SUSY breaking communicated to the observable sector through gravitational interactions, leading to a common scalar mass (m_0), a common gaugino mass ($m_{1/2}$), a common trilinear coupling (A_0), and a bilinear coupling (B_0) at the grand unified scale (M_{GUT}).
- ~ We often choose $m_0, m_{1/2}, A_0, \tan \beta,$ and $\text{sign}(\mu)$ as the 5 free parameters.
- ~ The masses and couplings of SUSY particles are evaluated with renormalization group equations.

Higgs bosons of minimal supergravity

In addition to m_0 and $m_{1/2}$, $\tan\beta$ is a very important parameter:

- an increase in $\tan\beta$ leads to a larger m_h but a reduction in m_A and m_H ;
- for $\tan\beta \sim 2$, m_A is usually large and the cross section of a Higgs signal for H^0 or A^0 is often much smaller than that of the background;
- for $\tan\beta \geq 35$, the cross section of the Higgs signal is greatly enhanced and can become slightly larger than the background.

Minimal Supergravity Model



$$B_s \rightarrow \mu^+ \mu^-$$

- ~ This rare decay has a small branching fraction in the Standard Model

$$B(B_s \rightarrow \mu^+ \mu^-) = (5.1 \pm 1.1) \times 10^{-9}$$

- ~ The current experimental upper limit from CDF and D0 is

$$B(B_s \rightarrow \mu^+ \mu^-) < 1.5 \times 10^{-7}$$

$B_s \rightarrow \mu^+ \mu^-$ in the MSSM

We consider SUSY contributions
from loop diagrams involving

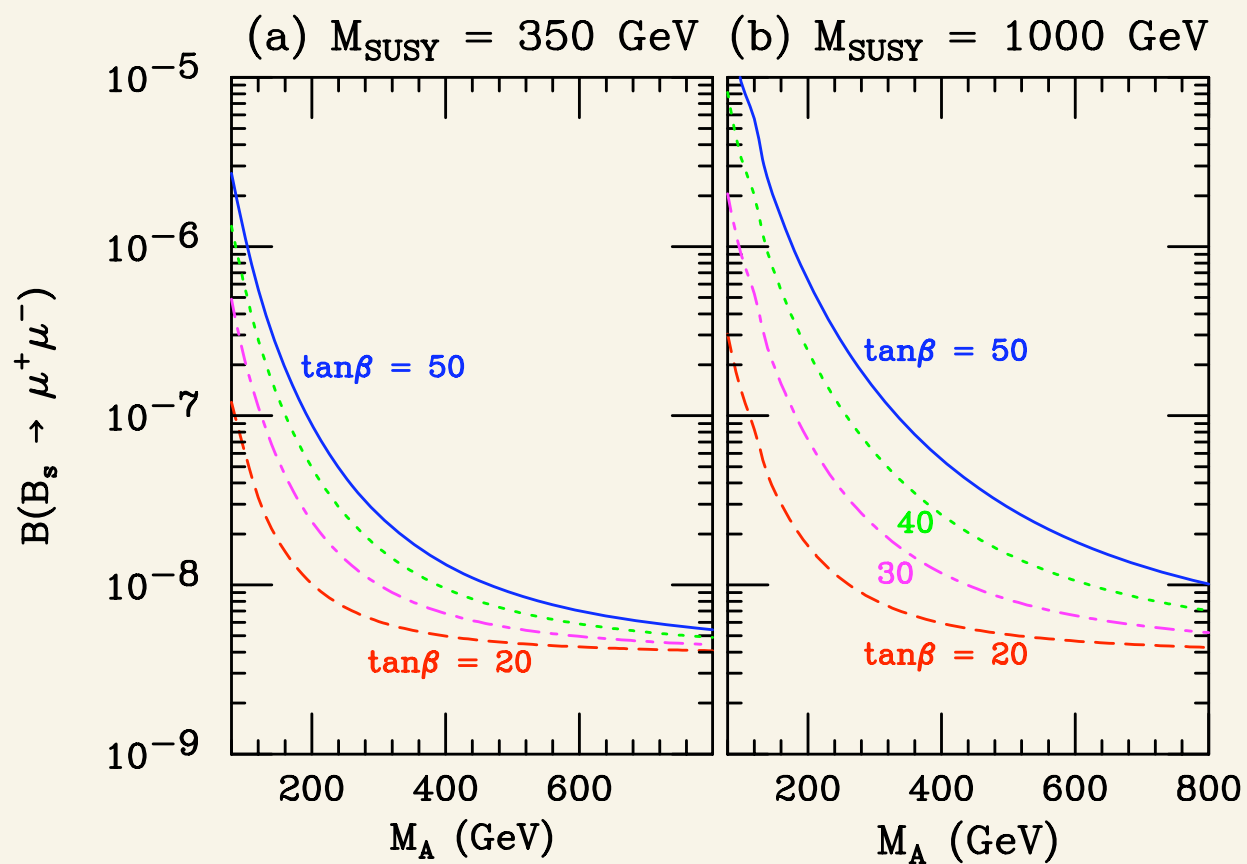
- ~ the charged Higgs boson,
- ~ the charginos,
- ~ the neutrinos, and
- ~ the gluino.

References for Recent Studies

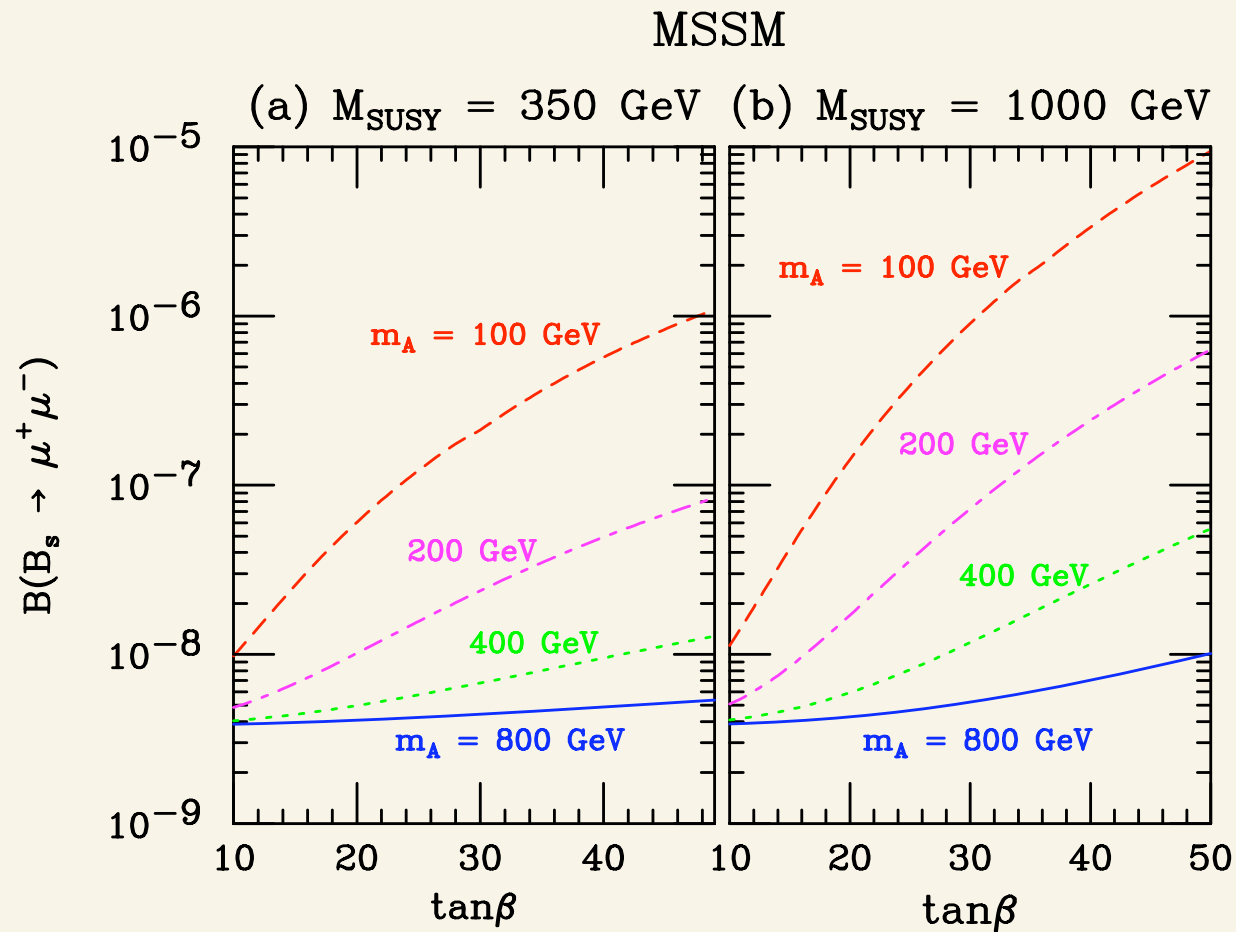
- ~ Mizukoshi, Tata and Wang (2002)
- ~ Babu and Kolda (2000)
- ~ Arnowitt, Dutta, Kamon and Tanaka (2002);
Bobeth, Ewerth, Kruger and Urban (2002);
Buras, Chankowski, Rosiek and Slawianowska
(2002); Kane, Kolda and Lennon (2003)
- ~ Dedes and Pilaftsis (2002); Dedes (2003);
Dedes and Huffma (2004)
- ~ Ellis, Olive and Spanos (2005)

Branching Fraction versus m_A

MSSM

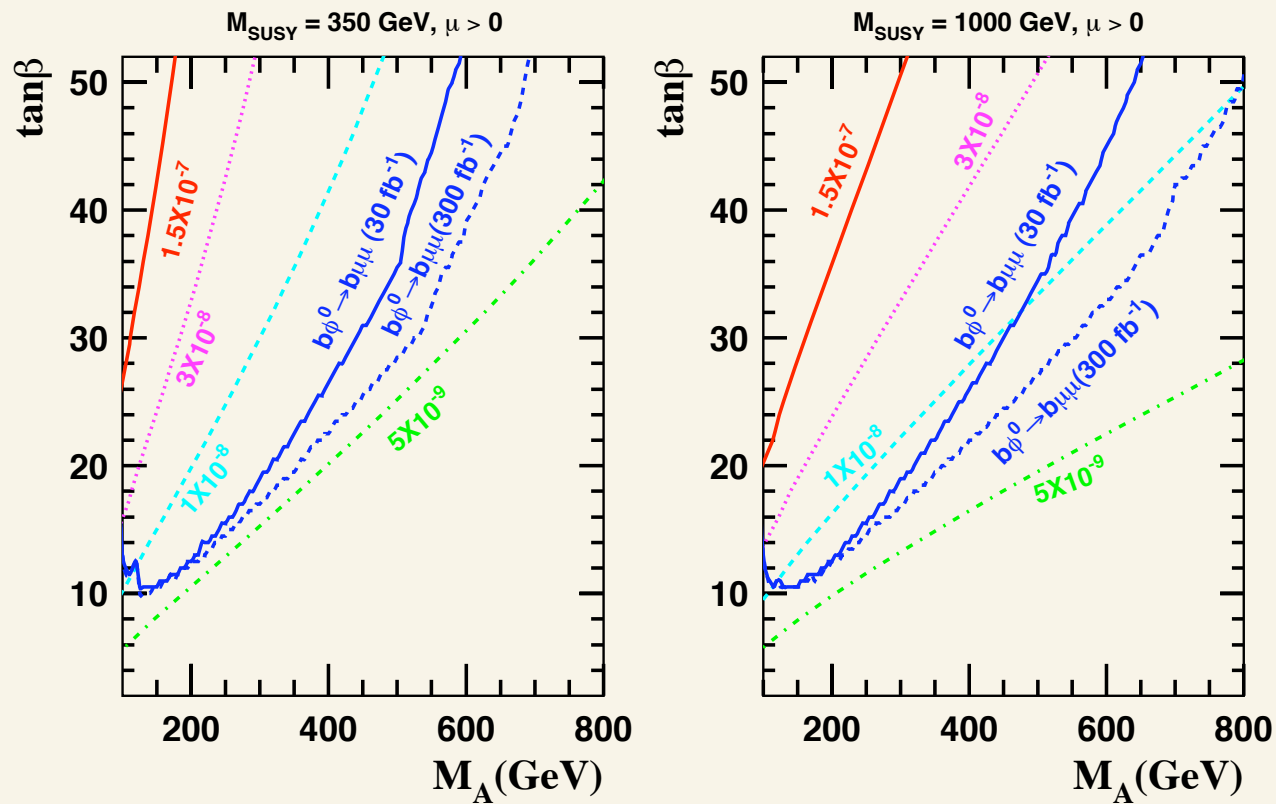


Branching Fraction versus $\tan(\beta)$



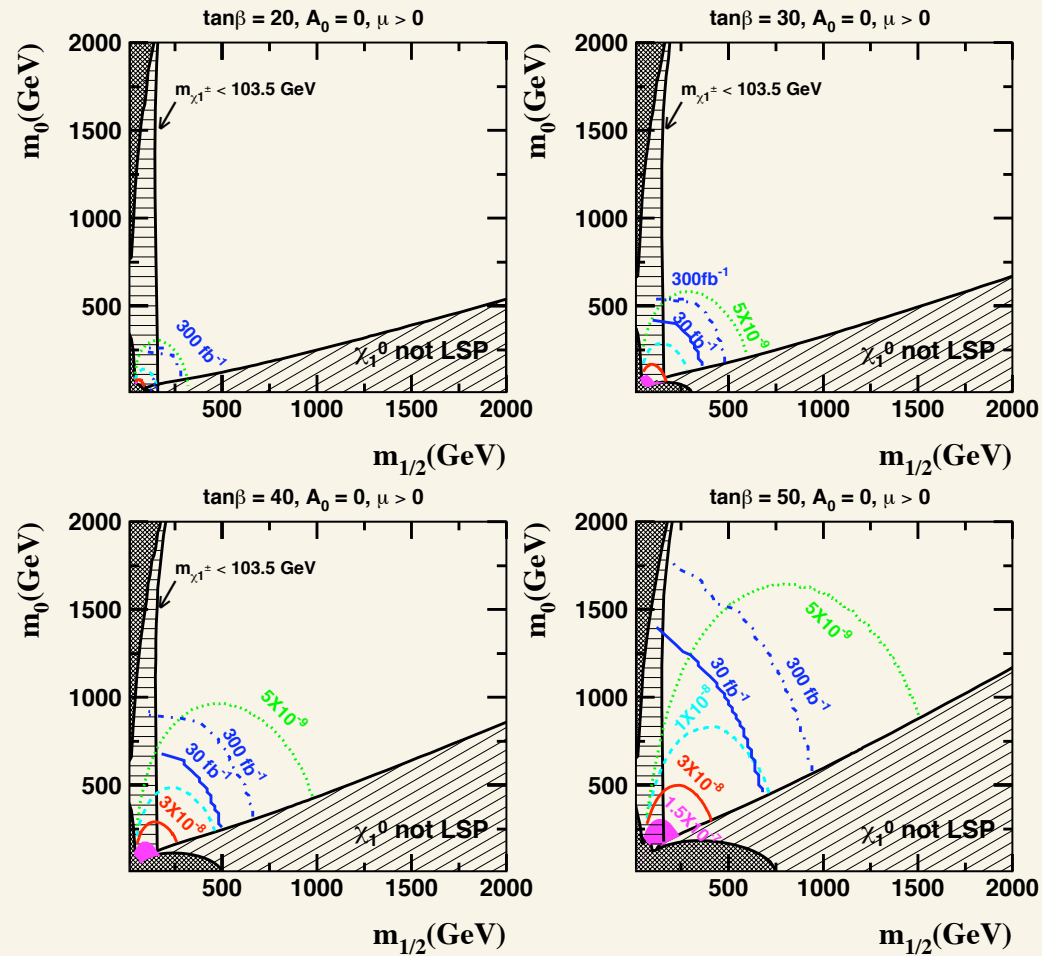
Minimal Supersymmetric Model

MSSM



Minimal Supergravity Model

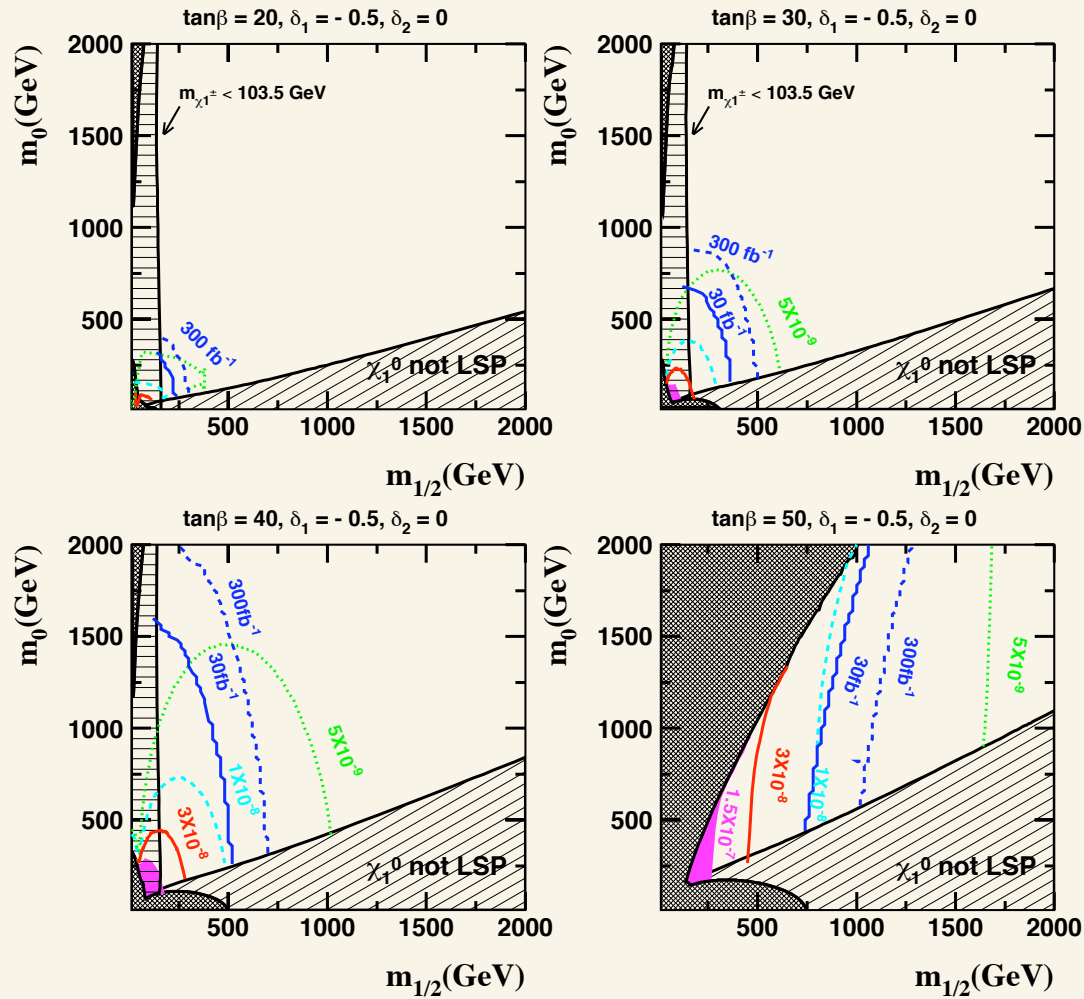
mSUGRA



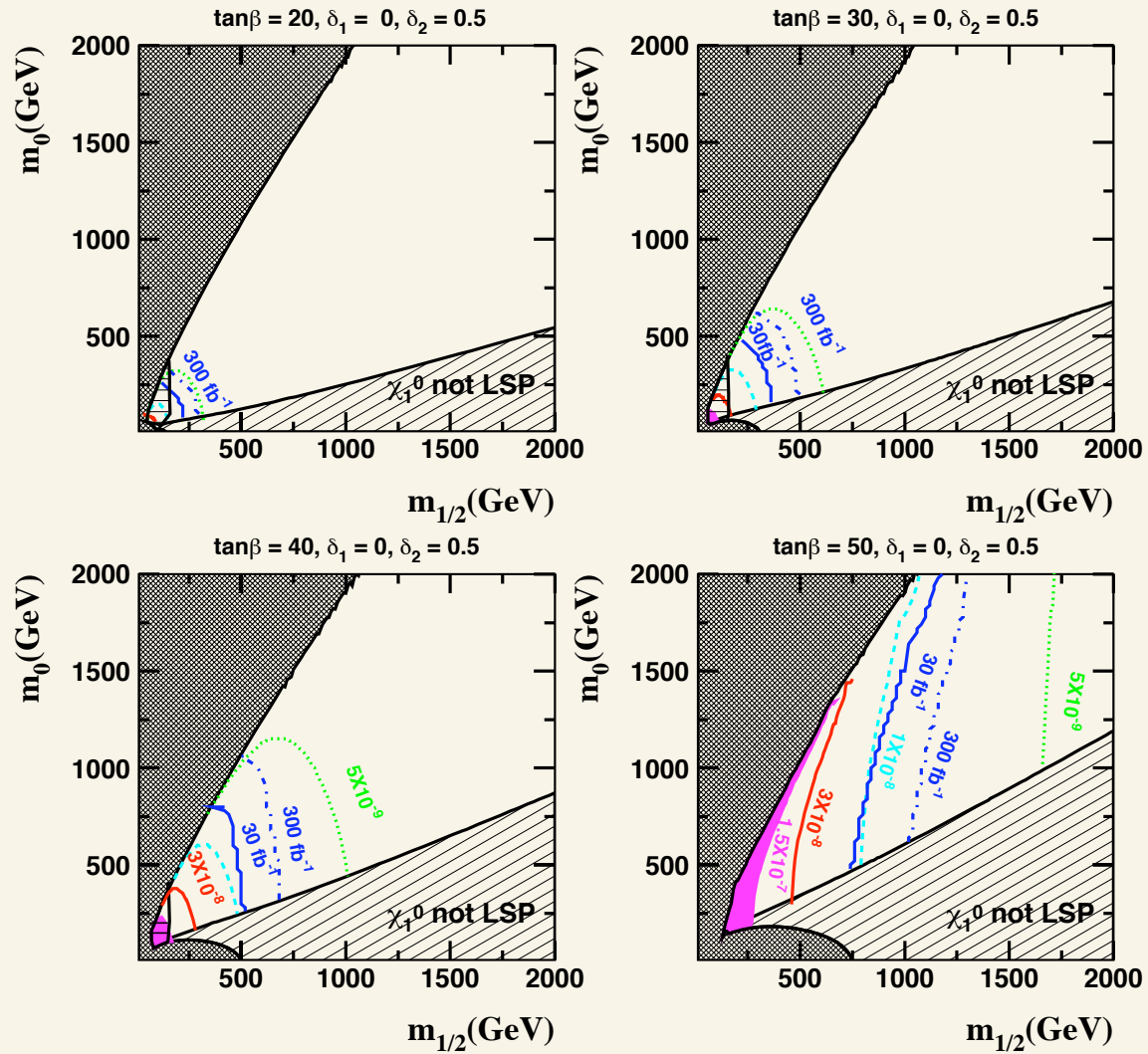
Non-universal Supergravity Models

- ~ Supergravity models with non-universal Higgs boson masses (NUHM SUGRA) give more interesting rates.
- ~ The Higgs masses at M_{GUT} are chosen to be $m_{H_i}^2(\text{GUT}) = (1 + \delta_i)m_0^2, i = 1, 2.$
- ~ In our NUHM SUGRA cases, m_A and m_H are smaller than those in the mSUGRA model for the same values of m_0 and $m_{1/2}$.
- ~ Consequently, both $b\phi^0 \rightarrow b\mu^+\mu^-$ and $B_s \rightarrow \mu^+\mu^-$ will be able to cover regions of the parameter space with larger values of m_0 and $m_{1/2}$.

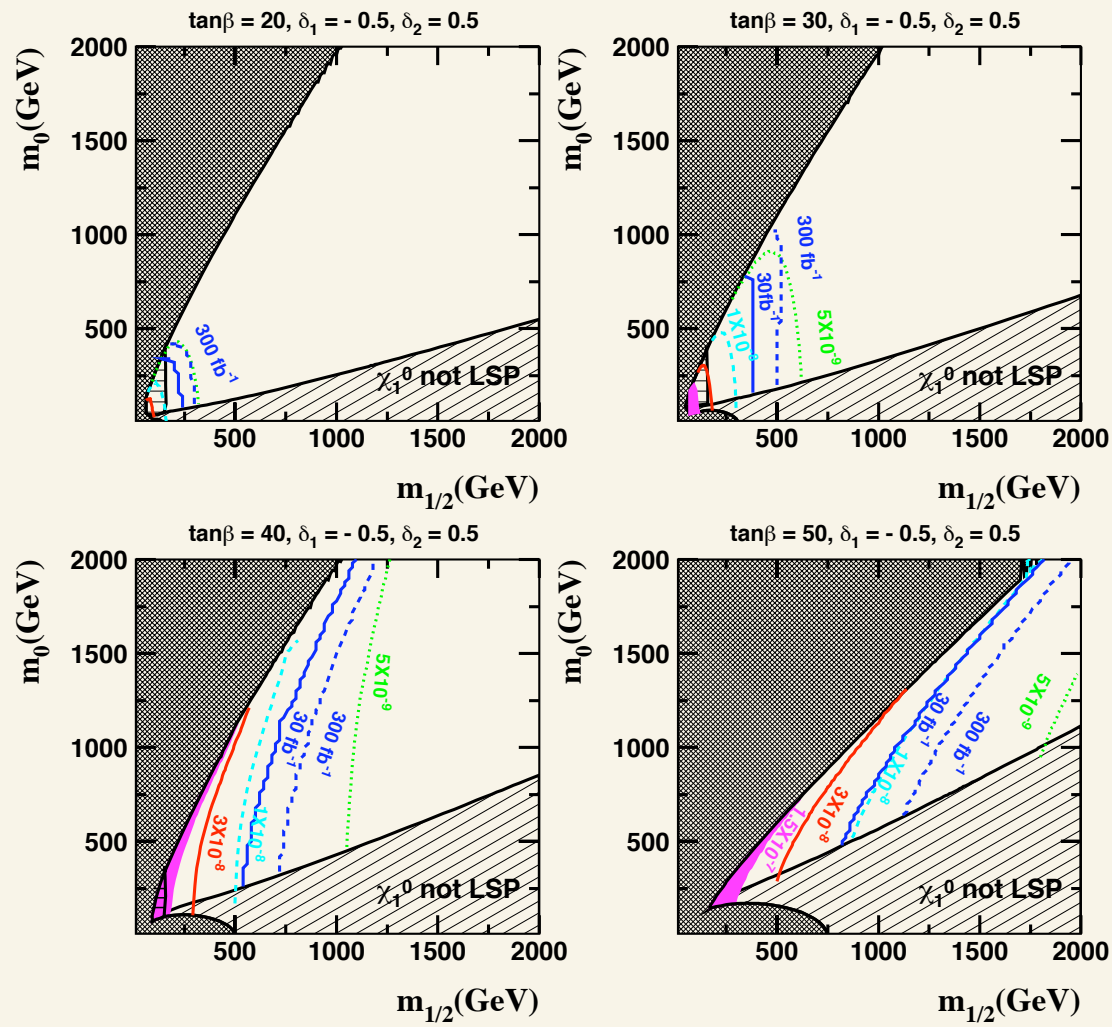
NUHM SUGRA Case I



NUHM SUGRA Case II



NUHM SUGRA Case III



Summary

(a) The contours for $B(B_s \rightarrow \mu^+ \mu^-) = 1 \times 10^{-8}$ in the parameter space are very close to the 5σ contours for $pp \rightarrow b\phi^0 \rightarrow b\mu^+ \mu^- + X$, at the LHC with $L = 30 \text{ fb}^{-1}$.

(b) The regions covered by $B(B_s \rightarrow \mu^+ \mu^-) \geq 5 \times 10^{-9}$ and the discovery region for $b\phi^0 \rightarrow b\mu^+ \mu^-$ with 300 fb^{-1} are complementary in the mSUGRA parameter space.

(c) in SUGRA models with nonuniversal Higgs masses, a discovery for $B(B_s \rightarrow \mu^+ \mu^-) \simeq 5 \times 10^{-9}$ at the LHC will cover regions of the parameter space beyond the direct search for $pp \rightarrow b\phi^0 \rightarrow b\mu^+ \mu^- + X$, with $L = 300 \text{ fb}^{-1}$.