Discovering Higgs in SUSY GUTs with Tau Leptons at LHC

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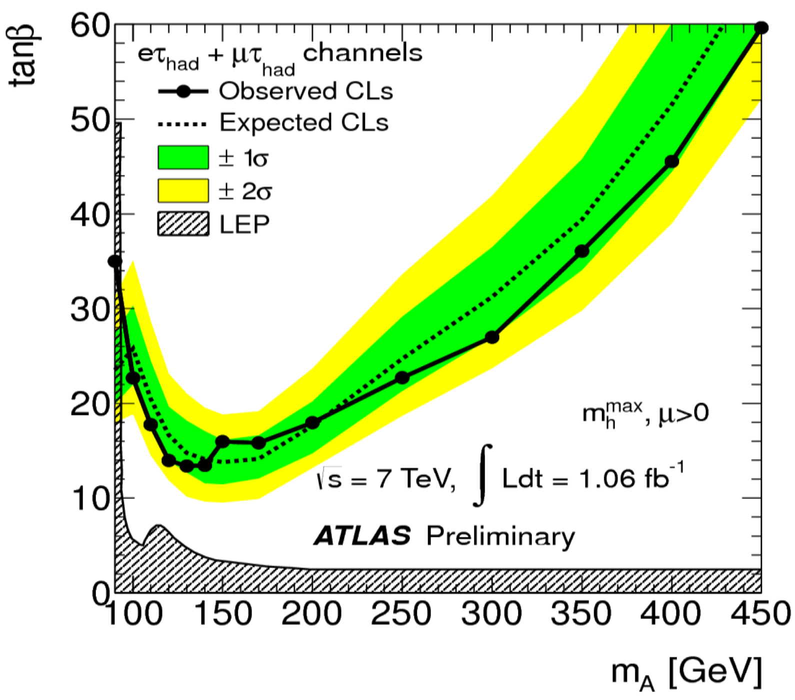
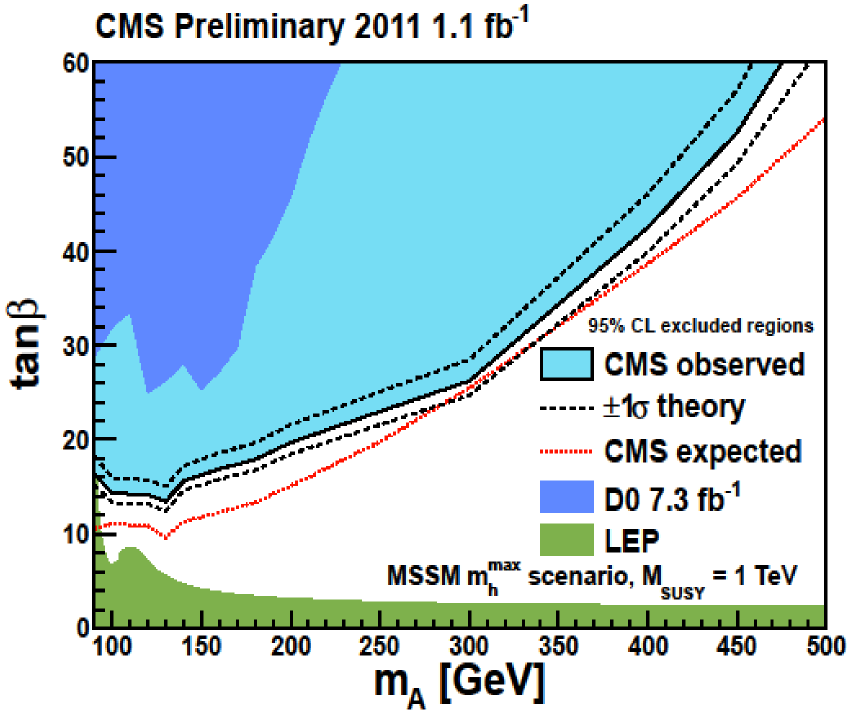
MSSM Higgs searches from ATLAS and CMS



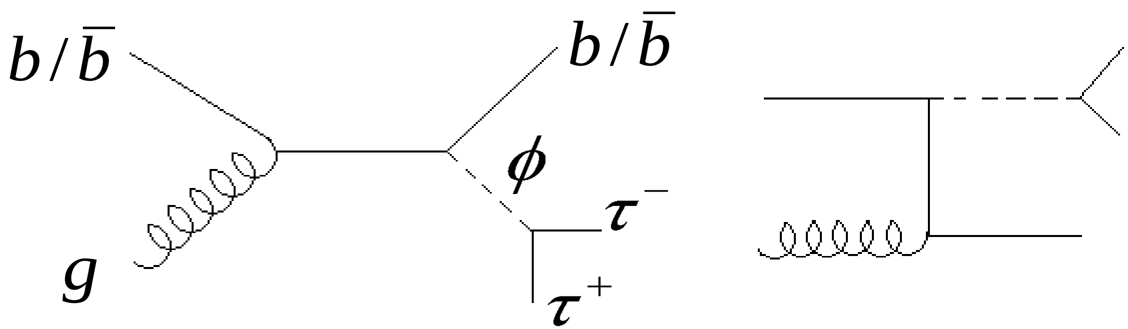
(ATLAS-CONF-2011-132)



(CMS-PAS-HIG-11-009)

Higgs Searches in the MSSM

- Higgs production associated with one b jet, and Higgs decay into $\tau^+\tau^-$ pairs.



  - One b jet in the final state is helpful to handle the fake jets by applying b tagging technique.
  - Neutral scalar ϕ could be h, H or A.
    - In low mass region, $m_h \sim m_A$. If $|m_h - m_A| < 10\% m_A$, we add the contribution from h together with that from pseudo scalar.
    - In high mass region, $m_H \sim m_A$, If $|m_H - m_A| < 10\% m_A$, we put the contribution from h together with that from pseudo scalar.
  - Scalars predominantly decay to $b\bar{b}(\sim 90\%)$, and $\tau^+\tau^-(\sim 10\%)$.

- The biggest decay mode of tau pairs is one into hadronic jet with the other into electron or muon.

$$BF(\tau \to \pi/\rho/a_1) = 54.77\%$$

$$BF(\tau \to e/\mu) = 35.20\%$$

(PDG)

- One final lepton helps to remove huge QCD background.

- Collinear Approximation of $\tau^{\pm}$ decay.

K. Hagiwara, A. D. Martin and D. Zeppenfeld(1990)

- Reconstruction of scalar mass.

  - $$(\frac{1}{x_l} - 1)P_T^l + (\frac{1}{x_h} - 1)P_T^h = P_T$$

    D. Rainwater, D. Zeppenfeld and K. Hagiwara(1998)

  - $$P_{\tau^1} = \frac{P_l}{x_l} \qquad P_{\tau^2} = \frac{P_h}{x_h}$$

    Chung Kao, Duane A. Dicus, Rahul Malhotra and Yili Wang(2008)

  - $$M_{\tau\tau} = \sqrt{(P_{\tau^1} + P_{\tau^2})^2}$$

- Total cross section of signal.

$$\sigma_{tot} = \int \left[f_b(x_1, \mu_F) f_g(x_2, \mu_F) + f_b(x_2, \mu_F) f_g(x_1, \mu_F) \right] \hat{\sigma}(bg \to b\phi \to b\tau^+\tau^-)$$
$$\times 2 \times 2 BF(\tau \to l) BF(\tau \to j_\tau)$$

  - Five flavor parton distribution function: CETQ6L1
  - Factorization scale: $\mu_F = \dfrac{M_\phi}{4}$
  - Renormalization scale: $\mu_R = \dfrac{M_\phi}{4}$

- Background processes.

  - Drell-Yan processes:

    $q/\bar{q}g \to q/\bar{q}Z^*/\gamma^* \to q/\bar{q}\tau^+\tau^- \qquad (q = u, d, s, c)$

    - To include the higher order correction, K factor is chosen to be *1.3*.

- $t\bar{t}$ production:

$$q\bar{q}(gg) \to t\bar{t} \to b\bar{b}W^+W^- \to b\bar{b}e^\pm(\mu^\pm)\tau^\mp + \not{E}$$

$$q\bar{q}(gg) \to t\bar{t} \to b\bar{b}W^+W^- \to b\bar{b}\,\tau^+\tau^- + \not{E}$$

$$q\bar{q}(gg) \to t\bar{t} \to b\bar{b}W^+W^- \to b\bar{b}e^\pm(\mu^\pm)\,j_1 j_2 + \not{E}$$

$$q\bar{q}(gg) \to t\bar{t} \to b\bar{b}W^+W^- \to b\bar{b}\,\tau^\pm j_1 j_2 + \not{E}$$

$$q\bar{q}(gg) \to t\bar{t} \to b\bar{b}W^+W^- \to b\bar{b}\,\tau^\pm j_1 j_2 + \not{E}$$

  - $j_1 j_2$ are quark and anti-quark pair form W decay.
  - $K = 2.0$

- tW production:

$$b(\bar{b})g \to t(\bar{t})W^\mp \to b(\bar{b})W^\pm W^\mp \to b(\bar{b})e^\mp(\mu^\mp)\tau^\pm + \not{E}$$

$$b(\bar{b})g \to t(\bar{t})W^\mp \to b(\bar{b})W^\pm W^\mp \to b(\bar{b})\tau^\mp\tau^\pm + \not{E}$$

$$b(\bar{b})g \to t(\bar{t})W^\mp \to b(\bar{b})W^\pm W^\mp \to b(\bar{b})e^\mp(\mu^\mp)\,j_1 j_2 + \not{E}$$

$$b(\bar{b})g \to t(\bar{t})W^\mp \to b(\bar{b})W^\pm W^\mp \to b(\bar{b})\tau^\mp j_1 j_2 + \not{E}$$

  - $K = 1.5$

- The production of $j_1 j_2 W$ and bjW are negligible.

➢ Acceptance cuts.

$\sqrt{s} = 14\,TeV$

$\int L dt = 30\, fb^{-1}$ $\int L dt = 300\, fb^{-1}$

$P_T(b) > 15 GeV$ $P_T(b) > 30 GeV$

$\not{E}_T > 20 GeV$ $\not{E}_T > 40 GeV$

$\left| M_{\tau\tau} - M_\phi \right| < 0.15 M_\phi$ $\left| M_{\tau\tau} - M_\phi \right| < 0.20 M_\phi$

$\sqrt{s} = 7\,TeV$

$\int L dt = 1\, fb^{-1}$ $\int L dt = 10\, fb^{-1}$

$P_T(b) > 15 GeV$

$E_T > 20 GeV$

$\left| M_{\tau\tau} - M_\phi \right| < 0.15 M_\phi$

$P_T(l) > 20 GeV$ $P_T(j_\tau) > 40 GeV$

$\eta(b) < 2.5$ $\eta(l) < 2.5$ $\eta(j_\tau) < 2.5$

$\Phi(l, j_\tau) < 170^\circ$ $\delta R(l, j_\tau) > 0.3$ $M(l, \not{E}_T) < 30 GeV$

- One more set of cuts is required by the physical meaning of energy fraction.

$0 < x_l < 1$ $0 < x_h < 1$

- Tagging efficiency and mistagging efficiency.

$\sqrt{s}=14TeV$

$\int Ldt=30\,fb^{-1}$ $\int Ldt=300\,fb^{-1}$

$\varepsilon_b=60\%$ $\varepsilon_b=50\%$

$\sqrt{s}=7TeV$

$\int Ldt=1\,fb^{-1}$ $\int Ldt=10\,fb^{-1}$

$\varepsilon_b=50\%$

$\varepsilon_{l_\tau}=26\%$

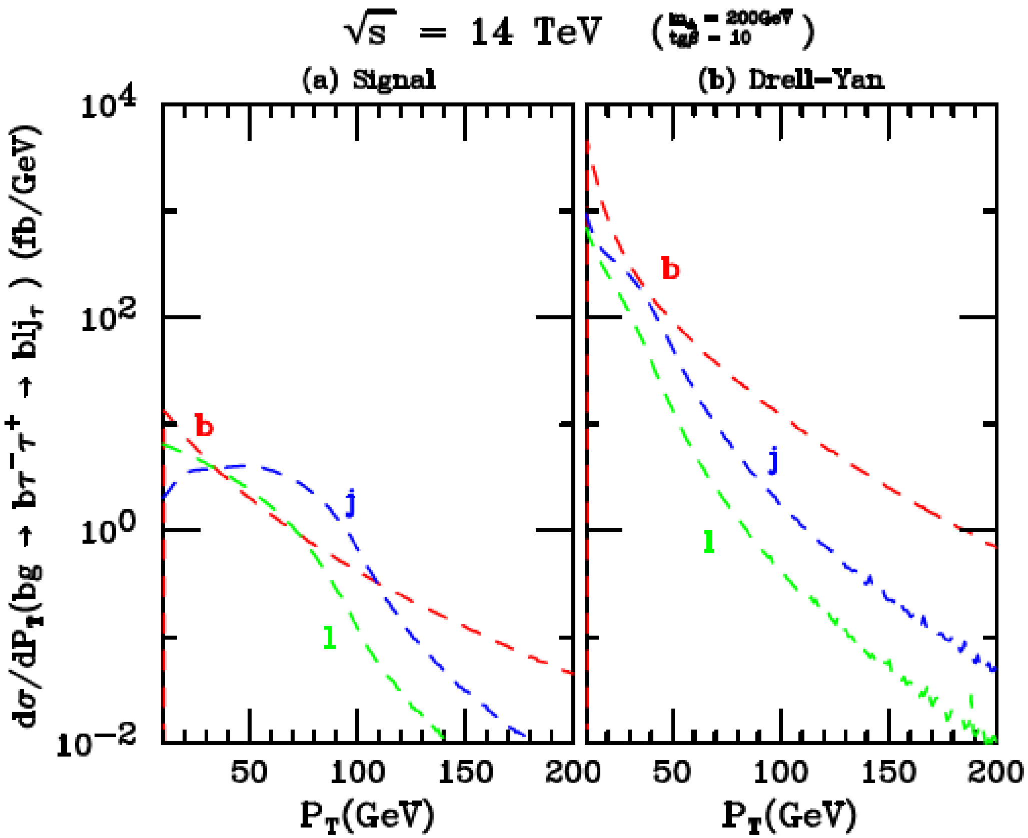
$P_{g,u,d,s\to b}=1\%$ $P_{c\to b}=10\%$ $P_{u,d,c,s\to j_\tau}=1/400$ $P_{b\to j_\tau}=1/600$

- Criterion for the observability of some signal .

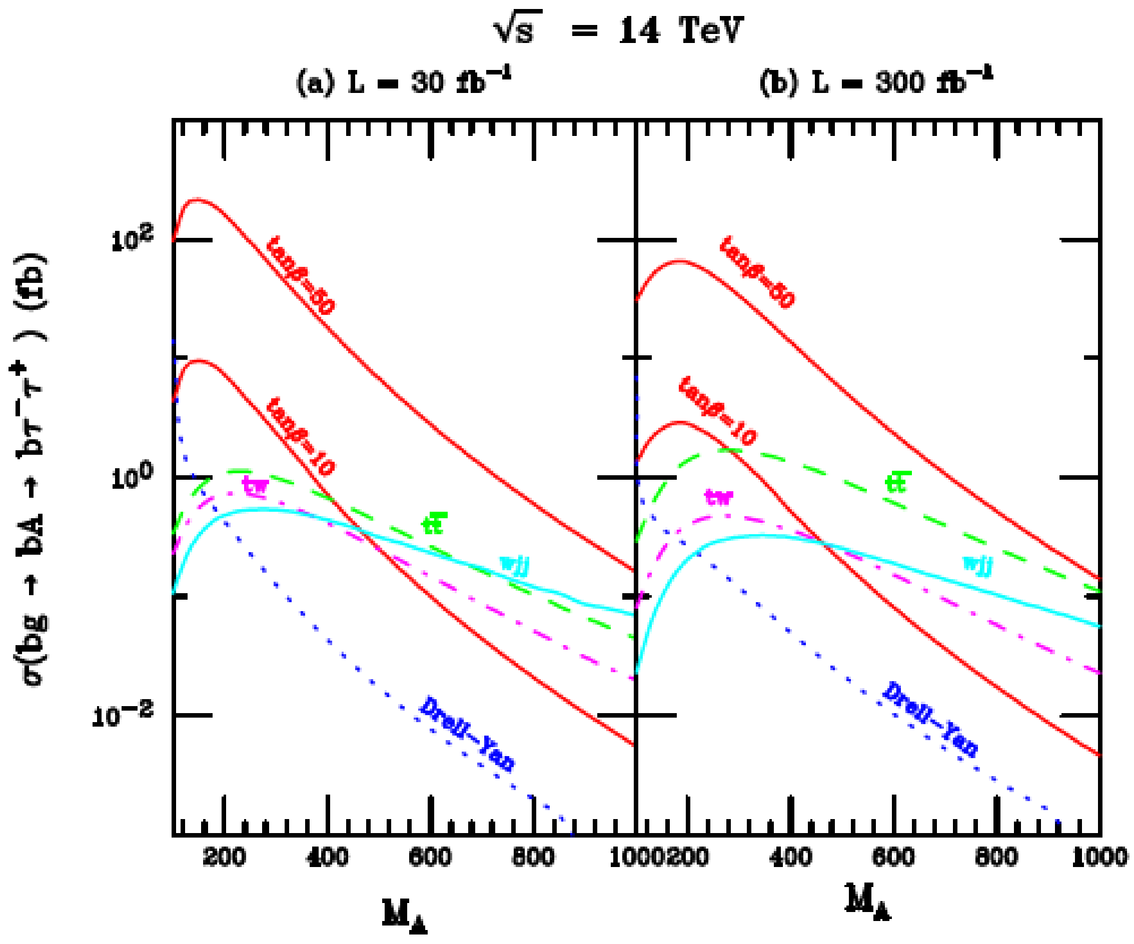
$$\sigma_s>\frac{N^2}{L}\left(1+2\sqrt{L\sigma_b}/N\right)$$

- $N=2.5$ corresponds to 5σ .

- P_T distribution without any cuts.



- $\sigma \sim m_A$



√s = 14 TeV
(a) L = 30 fb⁻¹
(b) L = 300 fb⁻¹
σ(bg → bA → bτ⁻τ⁺) (fb)
10²
10⁰
10⁻²
tanβ=50
tanβ=10
tt
tw
wjj
Drell-Yan
200
400
600
800
1000
M_A

- Signal significance.

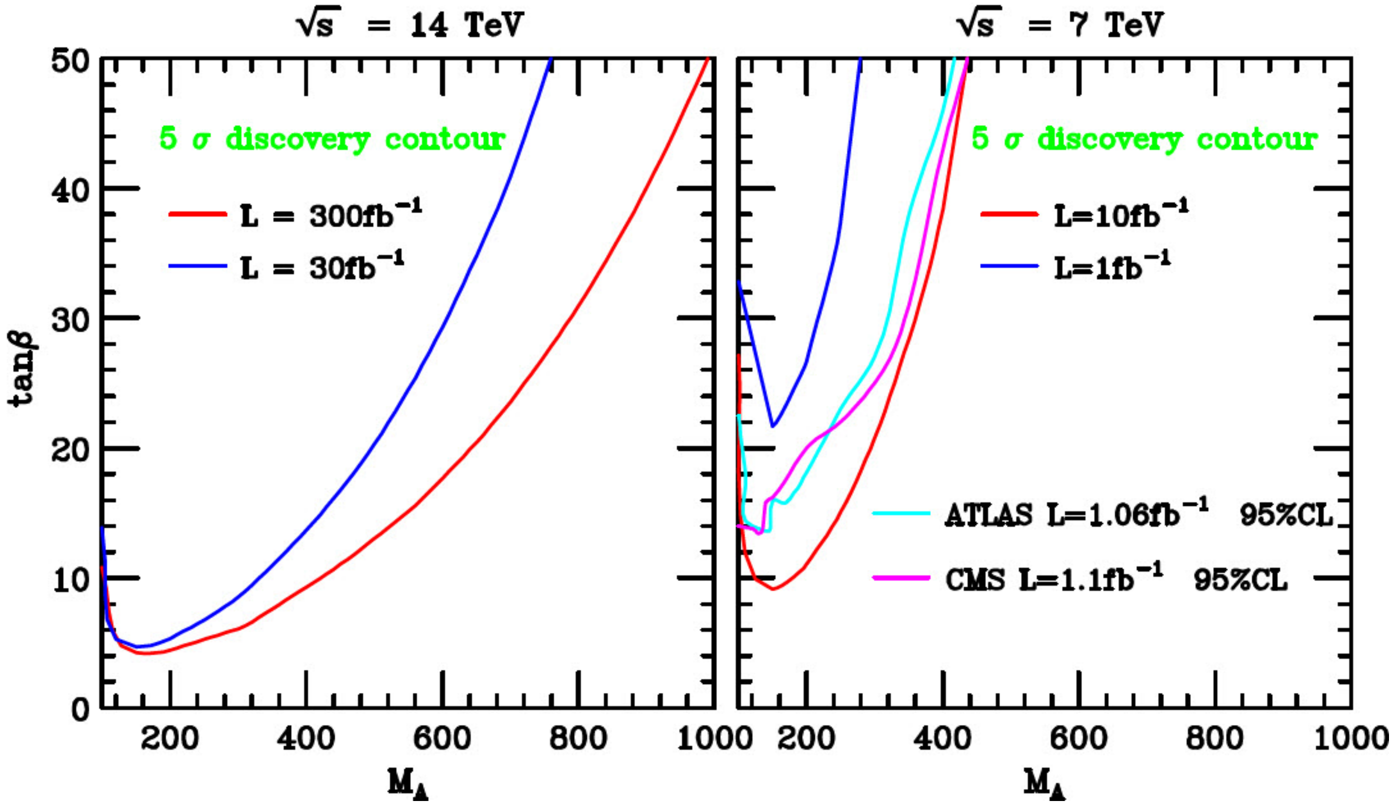
TABLE I: MSSM Higgs Production at $\sqrt{s} = 14TeV$ and $\mathcal{L} = 30 fb^{-1}$

$M_A(GeV)$	100	200	400	800
$\sigma_s(tan\beta = 10)$	4.38	7.28	7.14×10^{-1}	2.09×10^{-2}
$\sigma_s(tan\beta = 50)$	9.75×10^{1}	1.61×10^{2}	1.81×10^{1}	6.02×10^{-1}
σ_s(Drell-Yan)	1.41×10^{1}	4.27×10^{-1}	4.32×10^{-2}	1.99×10^{-3}
$\sigma_s(b\bar{b}W^+W^-)$	3.41×10^{-1}	1.10	6.75×10^{-1}	1.04×10^{-1}
$\sigma_s(bW^+W^-)$	2.30×10^{-1}	7.25×10^{-1}	4.13×10^{-1}	5.16×10^{-2}
$\sigma_s(Wjj)$	1.07×10^{-1}	4.83×10^{-1}	4.40×10^{-1}	1.21×10^{-1}
$N_{ss}(tan\beta = 10)$	6.24	24.1	3.12	0.217
$N_{ss}(tan\beta = 50)$	139	533	79.1	6.25

TABLE II: MSSM Higgs Production at $\sqrt{s} = 14TeV$ and $\mathcal{L} = 300 fb^{-1}$

$M_A(GeV)$	100	200	400	800
$\sigma_s(tan\beta = 10)$	1.34	2.83	5.21×10^{-1}	1.74×10^{-2}
$\sigma_s(tan\beta = 50)$	3.08×10^{1}	6.40×10^{1}	1.37×10^{1}	5.19×10^{-1}
σ_s(Drell-Yan)	6.97	2.64×10^{-1}	4.98×10^{-2}	2.84×10^{-3}
$\sigma_s(b\bar{b}W^+W^-)$	2.91×10^{-1}	1.39	1.35	2.55×10^{-1}
$\sigma_s(bW^+W^-)$	8.09×10^{-2}	4.00×10^{-1}	3.61×10^{-1}	5.78×10^{-2}
$\sigma_s(Wjj)$	2.31×10^{-2}	2.06×10^{-1}	3.13×10^{-1}	1.04×10^{-1}
$N_{ss}(tan\beta = 10)$	8.55	32.6	6.27	0.465
$N_{ss}(tan\beta = 50)$	197	737	165	13.9

- 5σ discovery contour.



Several Experimental Constrains

- $B_s^0 \to \mu^+ \mu^-$

$BF(B_s^0 \to \mu^+ \mu^-)^{\rm SM} = (3.2 \pm 0.2) \times 10^{-9}$ A. J. Buras arXiv:1012.1447v2

$BF(B_s^0 \to \mu^+ \mu^-)^{\rm EXP} < 1.08 \times 10^{-8}$ 95% C.L. LHCb-CONF-2011-047

- $b \to s\gamma$

$BF(b \to s\gamma)^{\rm SM} = (2.98 \pm 0.26) \times 10^{-4}$ Becher & Neubert (2007)

$= (3.15 \pm 0.23) \times 10^{-4}$ Misiak et al. (2007)

$BF(b \to X_s\gamma)^{\rm EXP} = (3.45 \pm 0.15 \pm 0.40) \times 10^{-4}$ Wenfeng Wang (2011)

- Δa_μ

$a_\mu^{\rm EXP} = 116592089(6.3) \times 10^{-10}$ PDG (2010)

$a_\mu^{\rm SM} = 116591830(5.1) \times 10^{-10}$ T. Teubner (2010)

$\Delta a_\mu \equiv a_\mu^{\rm EXP} - a_\mu^{\rm SM} = (25.9 \pm 8.1) \times 10^{-10}$ Gi-Chol Cho, Kaoru Hagiwara, Yu Matsumoto and Daisuke Nomura (2011)

mSUGRA Higgs Discovery Potential

- SUSY breaking happens in a hidden sector, and is mediated to visible sector by a messenger, gravity.
- mSUGRA/CMSSM assumes unified scalar mass m_0, fermionic mass $m_{1/2}$ and trilinear coupling A_0 at GUT scale. These are free inputs.
- In addition, two more parameters are defined at low-energy scale, $\tan\beta$ and $sign(\mu)$.
- RGEs evolve from GUT scale down to EW scale, and then generate particle spectrum at EW scale.

Isajet 7.81 (H. Baer, F.E. Paige, S.D. Protopopescu, X. Tata)

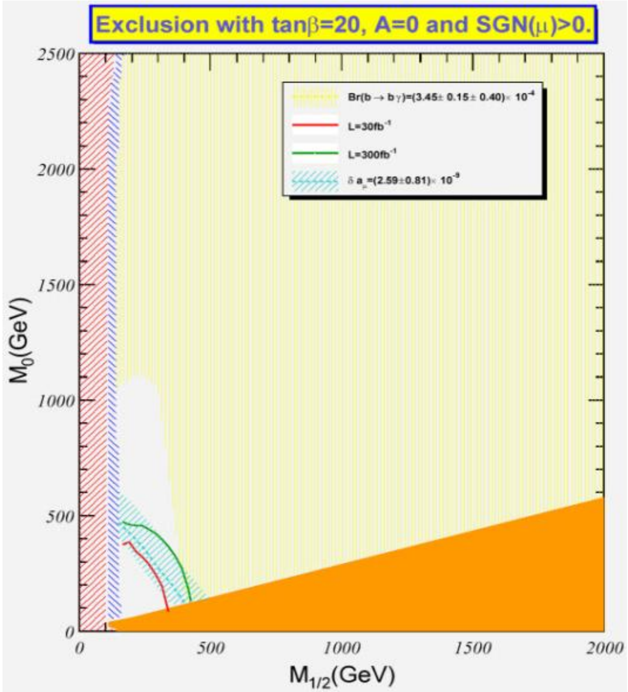
- The following parameter space will be scanned.

$$m_{1/2} \in [0,2000]\,GeV, \quad m_0 \in [0,25000]\,GeV, \quad \tan\beta \in [20,50]$$

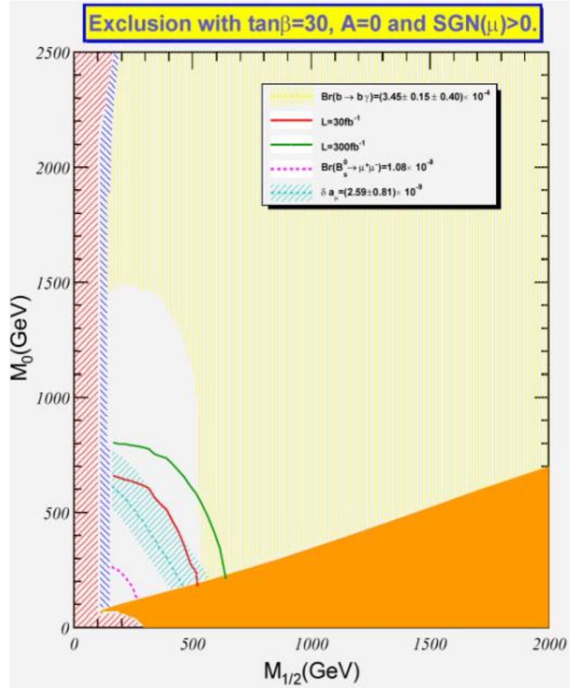
$$A_0 = 0\,GeV, \quad sign(\mu) = 1$$

$$m_{top} = 173.1\,GeV$$

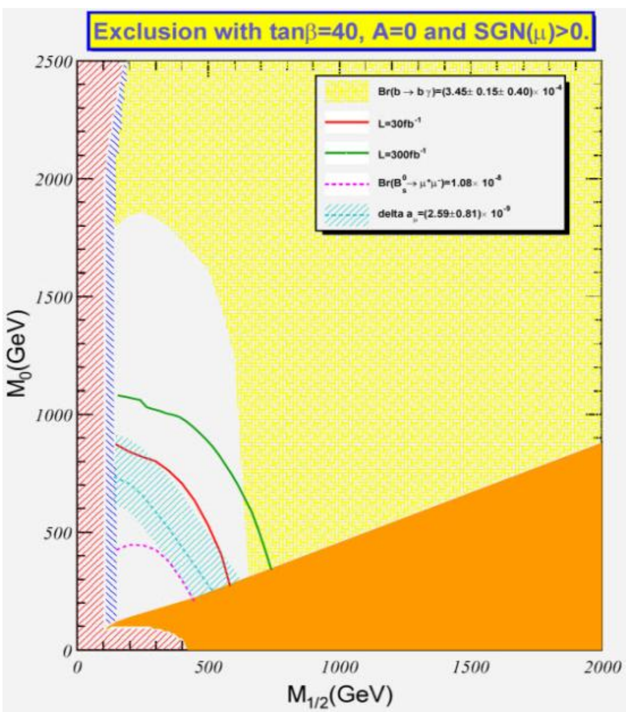
$14 TeV$



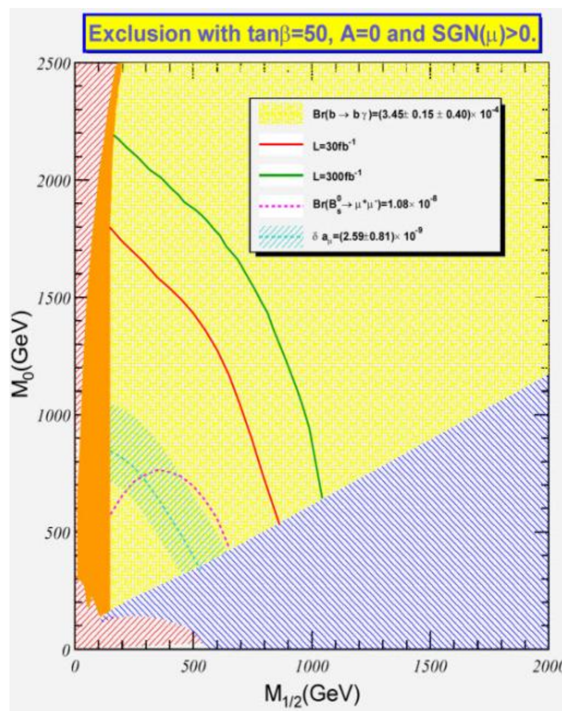
Exclusion with tanβ=20, A=0 and SGN(μ)>0.
Br(b → bγ)=(3.45± 0.15± 0.40)× 10⁻⁴
L=30fb⁻¹
L=300fb⁻¹
δ a_μ=(2.59±0.81)× 10⁻⁹
M_0(GeV)
M_1/2(GeV)
0
500
1000
1500
2000
2500



Exclusion with tanβ=30, A=0 and SGN(μ)>0.
Br(b → bγ)=(3.45± 0.15± 0.40)× 10⁻⁴
L=30fb⁻¹
L=300fb⁻¹
Br(B_s^0 → μ⁺μ⁻)=1.08× 10⁻⁸
δ a_μ=(2.59±0.81)× 10⁻⁹
M_0(GeV)
M_1/2(GeV)
0
500
1000
1500
2000
2500

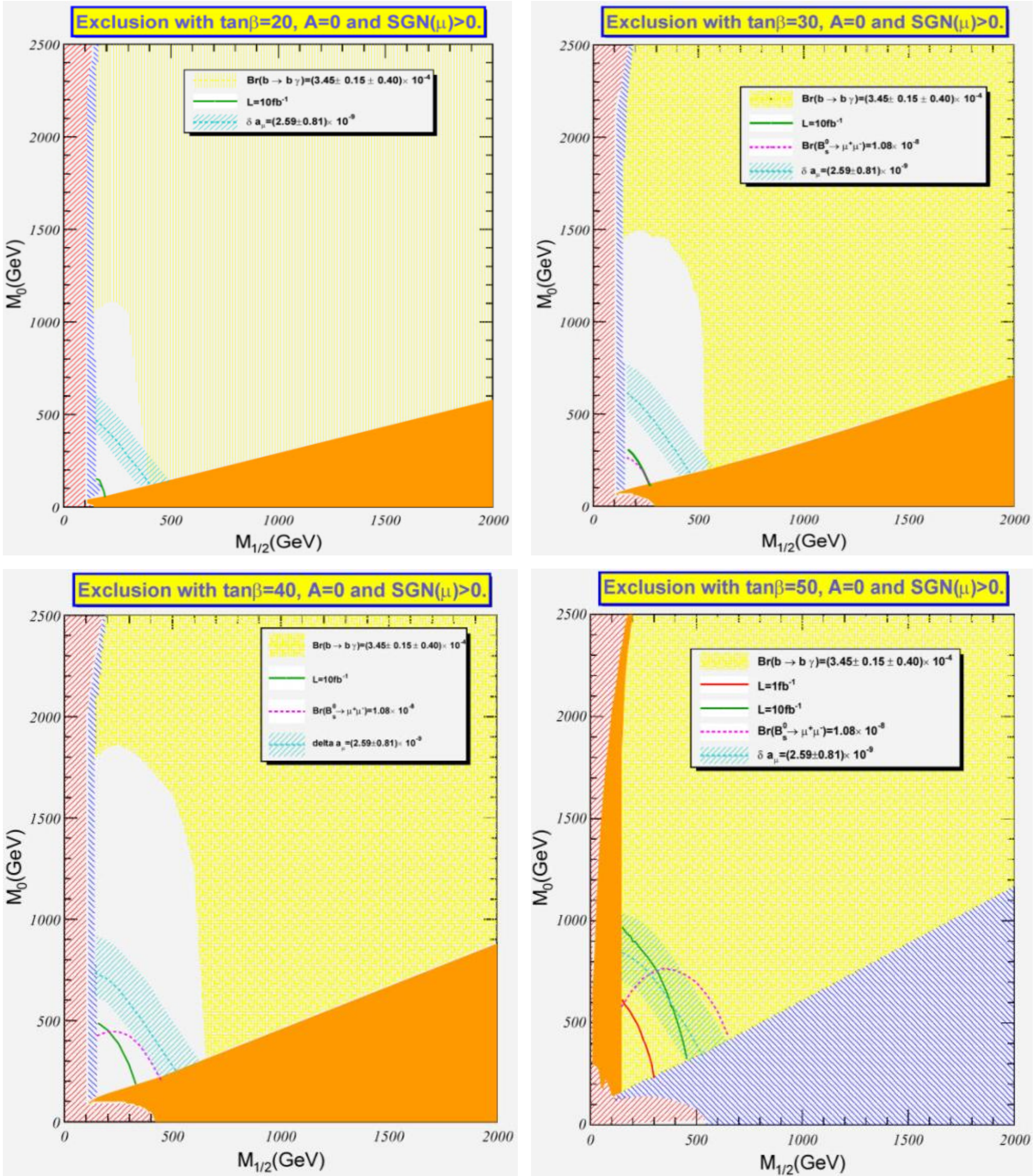


Exclusion with tanβ=40, A=0 and SGN(μ)>0.
Br(b → bγ)=(3.45± 0.15± 0.40)× 10⁻⁴
L=30fb⁻¹
L=300fb⁻¹
Br(B_s^0 → μ⁺μ⁻)=1.08× 10⁻⁸
delta a_μ=(2.59±0.81)× 10⁻⁹
M_0(GeV)
M_1/2(GeV)
0
500
1000
1500
2000
2500



Exclusion with tanβ=50, A=0 and SGN(μ)>0.
Br(b → bγ)=(3.45± 0.15 ± 0.40)× 10⁻⁴
L=30fb⁻¹
L=300fb⁻¹
Br(B_s^0 → μ⁺μ⁻)=1.08× 10⁻⁸
δ a_μ=(2.59±0.81)× 10⁻⁹
M_0(GeV)
M_1/2(GeV)
0
500
1000
1500
2000
2500

$7\,TeV$



Exclusion with tanβ=20, A=0 and SGN(μ)>0.
Br(b → b γ)=(3.45± 0.15 ± 0.40)× 10^-4
L=10fb^-1
δ a_μ=(2.59±0.81)× 10^-9
M_0(GeV)
M_1/2(GeV)
Exclusion with tanβ=30, A=0 and SGN(μ)>0.
Br(b → b γ)=(3.45± 0.15 ± 0.40)× 10^-4
L=10fb^-1
Br(B_s^0→ μ^+μ^-)=1.08× 10^-8
δ a_μ=(2.59±0.81)× 10^-9
M_0(GeV)
M_1/2(GeV)
Exclusion with tanβ=40, A=0 and SGN(μ)>0.
Br(b → b γ)=(3.45± 0.15± 0.40)× 10^-4
L=10fb^-1
Br(B_s^0→ μ^+μ^-)=1.08× 10^-8
delta a_μ=(2.59±0.81)× 10^-9
M_0(GeV)
M_1/2(GeV)
Exclusion with tanβ=50, A=0 and SGN(μ)>0.
Br(b → b γ)=(3.45± 0.15 ± 0.40)× 10^-4
L=1fb^-1
L=10fb^-1
Br(B_s^0→ μ^+μ^-)=1.08× 10^-8
δ a_μ=(2.59±0.81)× 10^-9
M_0(GeV)
M_1/2(GeV)

mAMSB Higgs Discovery Potential

- SUSY breaking happens in a separate brane, and is mediated to visible sector by super-Weyl anomaly.
- The parameter space is formed by four parameters.

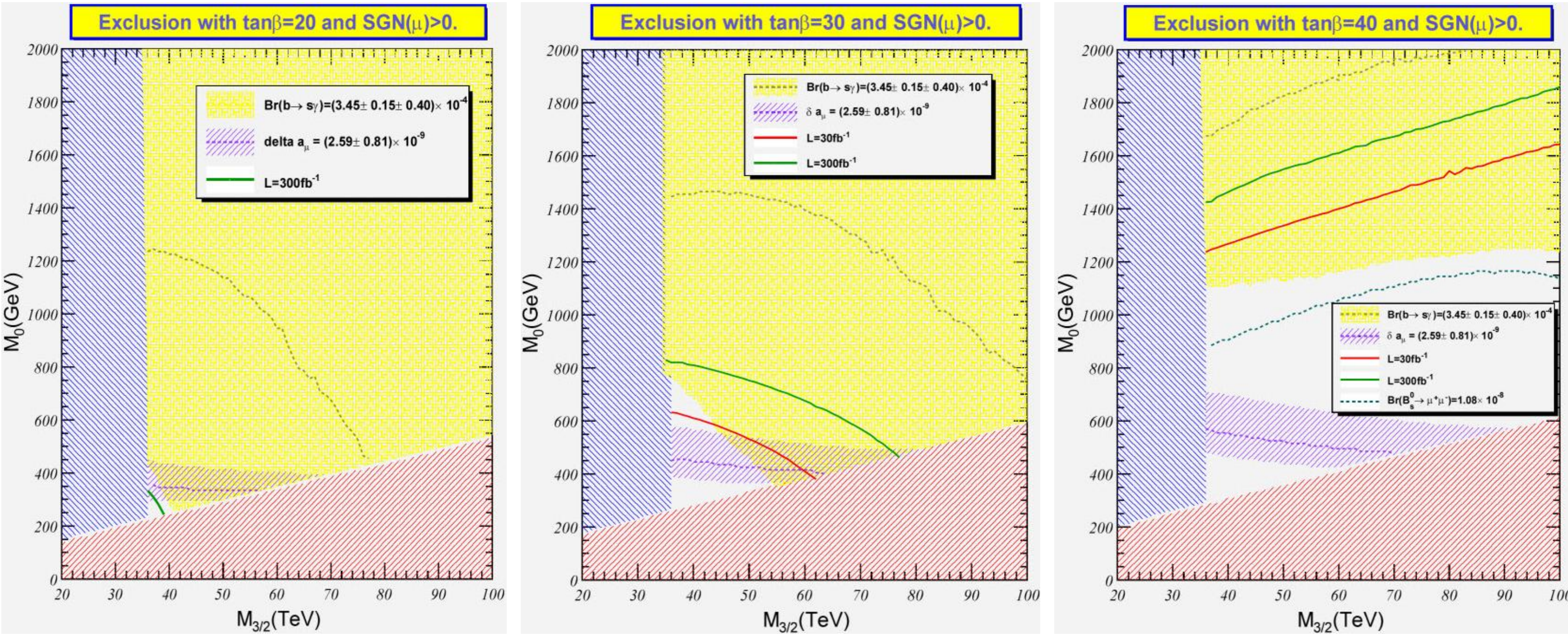
$$\{m_{3/2}, m_0, \tan\beta, sign(\mu)\}$$

- The scanned parameter space

$$m_{1/2} \in [20000,100000], \quad m \in [0,2000], \quad \tan\beta \in [20,50]$$

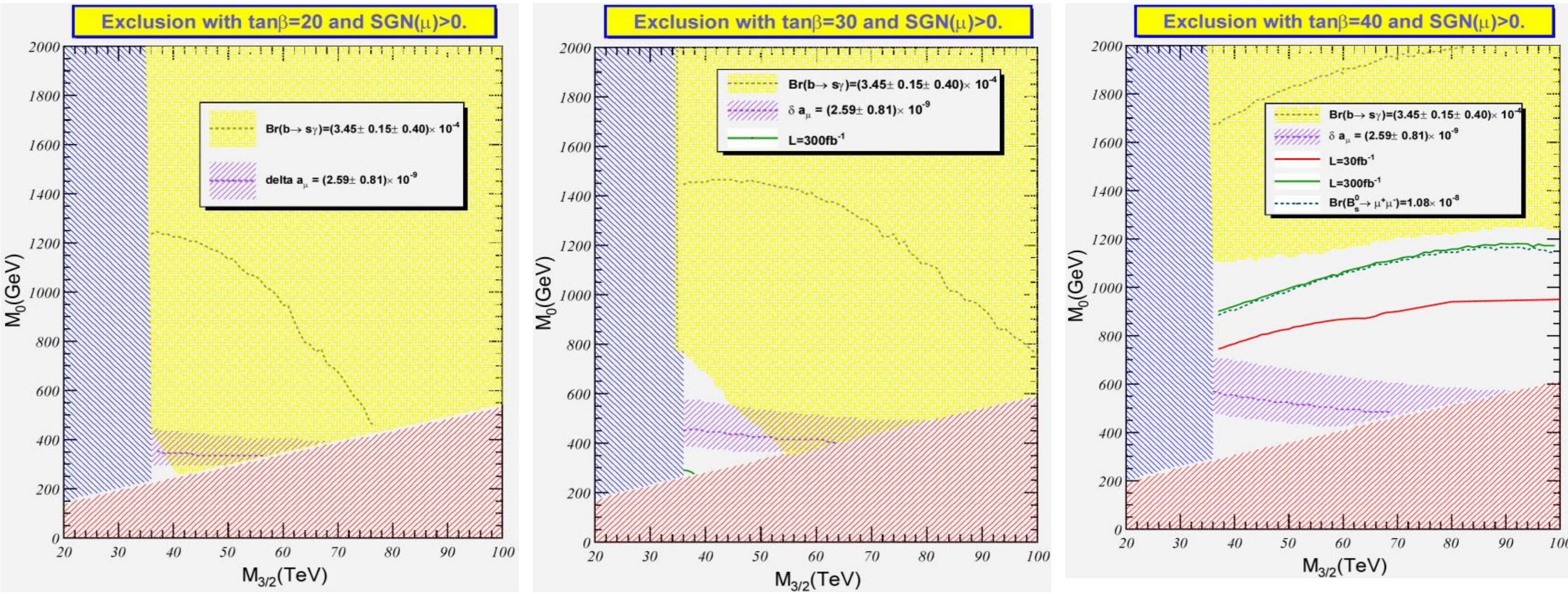
$$sign(\mu) = 1$$

$$m_{top} = 173.1 GeV$$



Exclusion with tanβ=20 and SGN(μ)>0.
Br(b→ sγ)=(3.45± 0.15± 0.40)× 10^-4
delta a_μ = (2.59± 0.81)× 10^-9
L=300fb^-1
Exclusion with tanβ=30 and SGN(μ)>0.
Br(b→ sγ)=(3.45± 0.15± 0.40)× 10^-4
δ a_μ = (2.59± 0.81)× 10^-9
L=30fb^-1
L=300fb^-1
Exclusion with tanβ=40 and SGN(μ)>0.
Br(b→ sγ)=(3.45± 0.15± 0.40)× 10^-4
δ a_μ = (2.59± 0.81)× 10^-9
L=30fb^-1
L=300fb^-1
Br(B_s^0→ μ^+μ^-)=1.08× 10^-8
M_0(GeV)
M_3/2(TeV)

$14TeV$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M_0(GeV)
M_3/2(TeV)
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δ a_μ = (2.59± 0.81)× 10^-9
L=30fb^-1
L=300fb^-1
Br(B_s^0→ μ^+μ^-)=1.08× 10^-8
M_0(GeV)
M_3/2(TeV)

7 TeV

Conclusion

- It's promising to discover Higgs by tau lepton pairs, even with Higgs mass up to 1 TeV at LHC.

- In mSUGRA, the model with high $\tan\beta$ favors the discovery of Higgs.

- In mAMSB, the model with intermediate $\tan\beta$ favors the discovery of Higgs.

- GMSB and related channels will be added.