The Impact of B Physics Observables on SUSY Fits

Sven Heinemeyer, IFCA (Santander)

CERN, 12/2007

based on hep-ph/0706.0652, hep-ph/0707.3447, hep-ph/0709.0098
[Buchmüller, Cavanaugh, De Roeck, Ellis, Hahn, S.H., Isidori, Olive, Paradisi, Ronga, Weber, Weiglein]

1. Introduction
2. Impact of BPO on CMSSM fits
3. Impact of BPO on M_h fit in the CMSSM
4. Impact and prospects of BPO on NUHM fits
5. Conclusions

1. Introduction

Let's assume that low-energy SUSY is realized in Nature
(But you can play the same game with any NP model!)

What do we know about the SUSY mass scale?

1. Coupling constant unification $\Rightarrow M_{\text{SUSY}} \approx 1$ TeV
2. Solution for the Hierarchy problem $\Rightarrow M_{\text{SUSY}} \lesssim 1$ TeV
3. Indirect hints from existing data?

- Electroweak precision observables (EWPO) ?
- B physics observables (BPO) ?
- Cold dark matter (CDM) ?

$\Rightarrow$ combination of EWPO, BPO, CDM ?

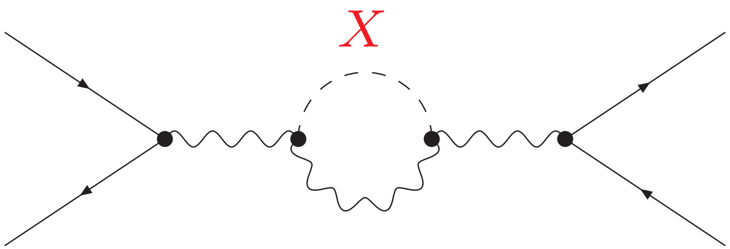
Precision Observables (POs):

Comparison of electro-weak precision observables with theory:

EW Precision data:		Theory:
$M_W, \sin^2\theta_{\text{eff}}, a_\mu$	$\leftrightarrow$	SM, MSSM , . . .

$$\Downarrow$$

Test of theory at quantum level: Sensitivity to loop corrections



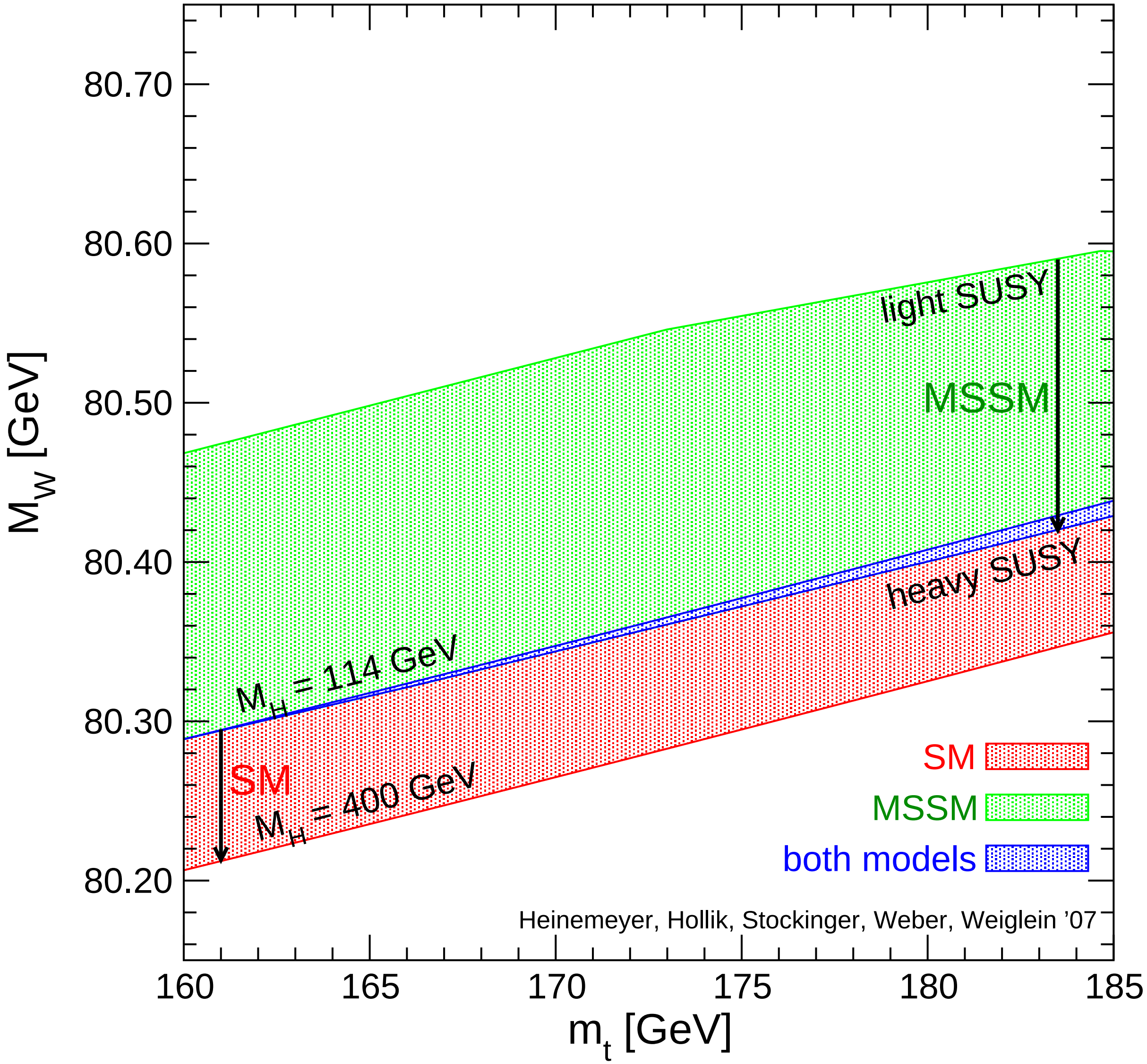
$$\Downarrow$$

Very high accuracy of measurements and theoretical predictions needed

- Which model fits better?
- Does the prediction of a model contradict the experimental data?

Example: Prediction for M_W in the SM and the MSSM :

[S.H., W. Hollik, D. Stockinger, A.M. Weber, G. Weiglein '07]



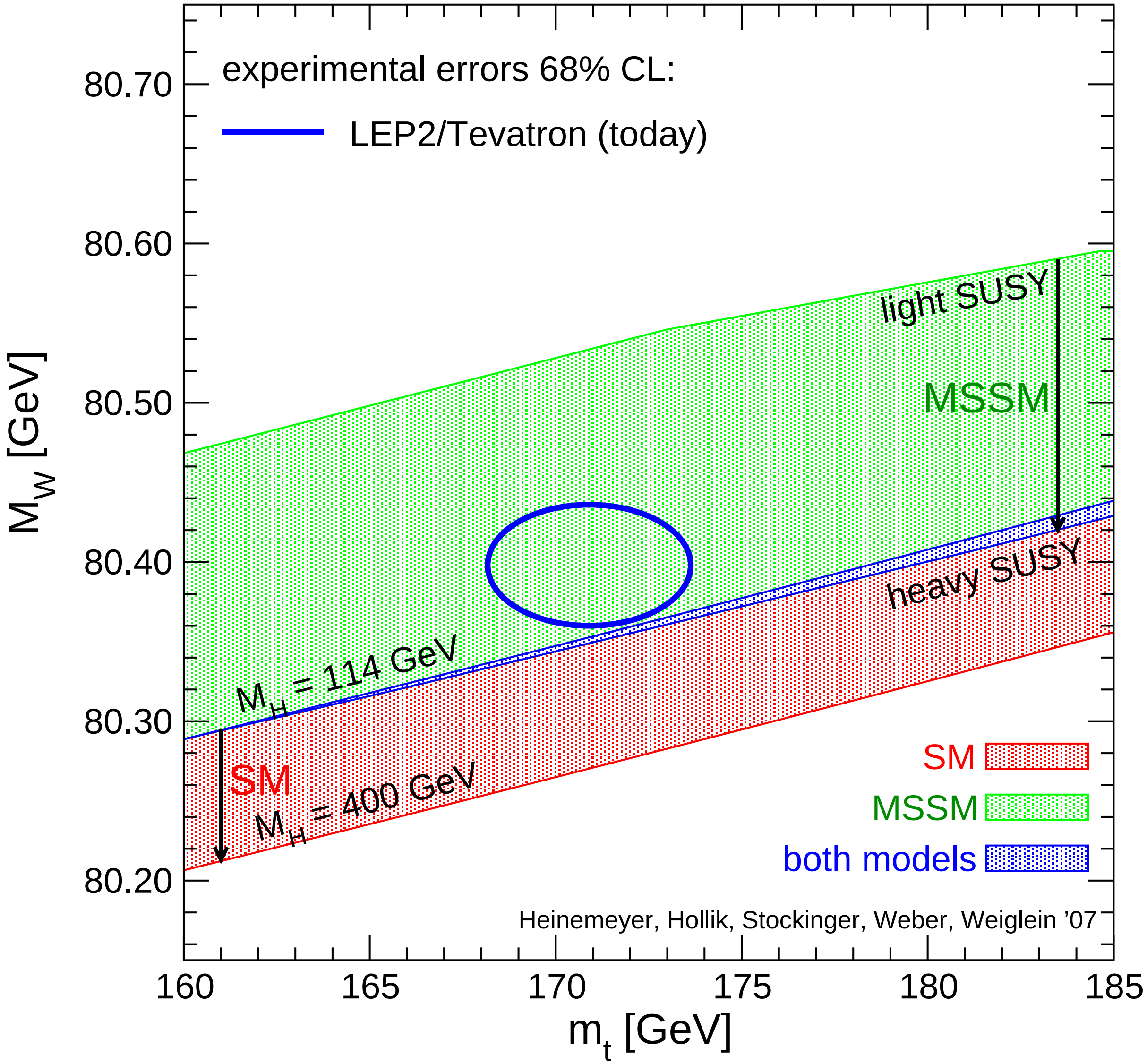
MSSM band:
scan over
SUSY masses

overlap:
SM is MSSM-like
MSSM is SM-like

SM band:
variation of M_H^{SM}

Example: Prediction for M_W in the SM and the MSSM :

[S.H., W. Hollik, D. Stockinger, A.M. Weber, G. Weiglein '07]



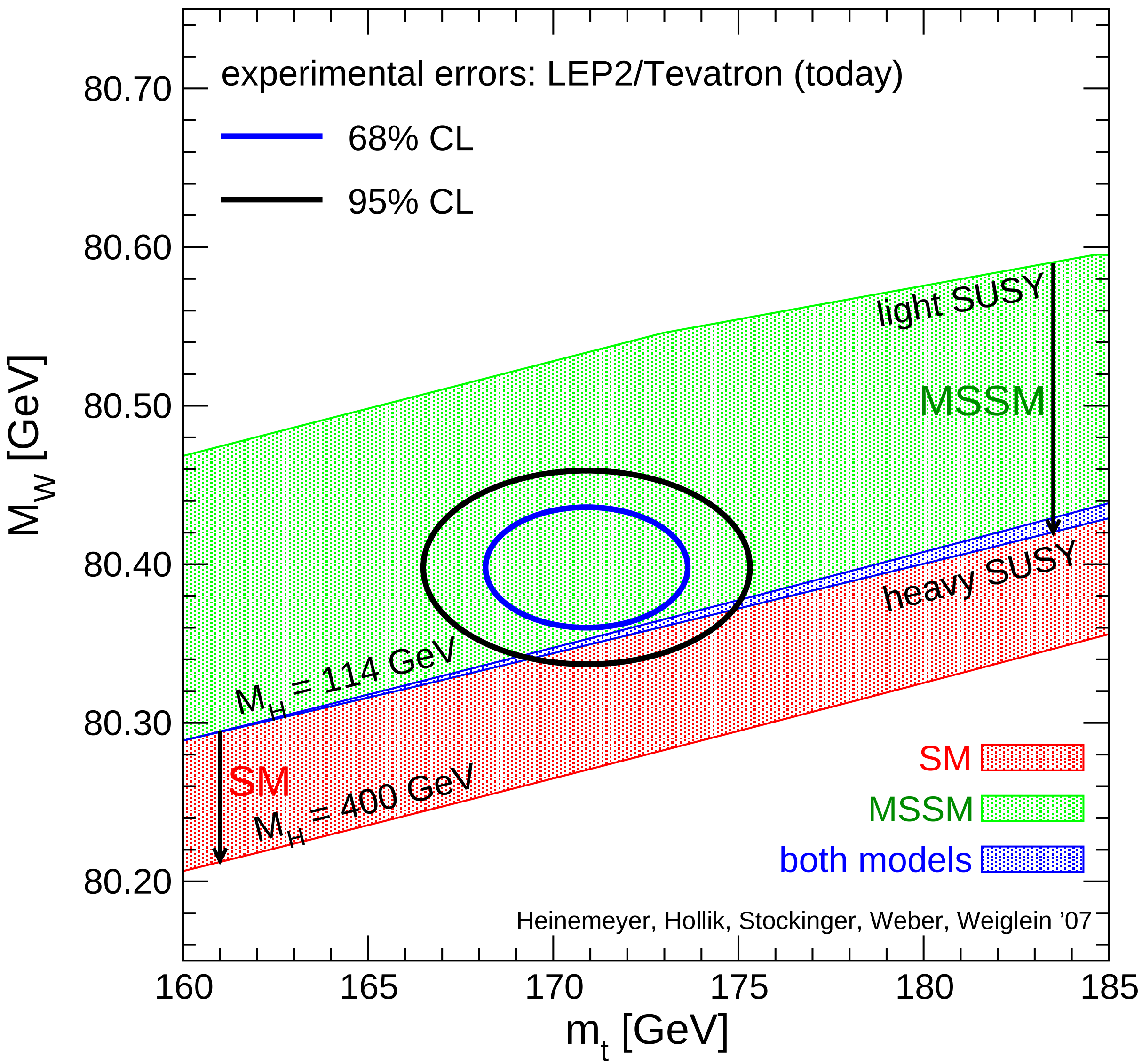
MSSM band:
scan over
SUSY masses

overlap:
SM is MSSM-like
MSSM is SM-like

SM band:
variation of M_H^{SM}

Example: Prediction for M_W in the SM and the MSSM :

[S.H., W. Hollik, D. Stockinger, A.M. Weber, G. Weiglein '07]



MSSM band:
scan over
SUSY masses

overlap:
SM is MSSM-like
MSSM is SM-like

SM band:
variation of M_H^{SM}

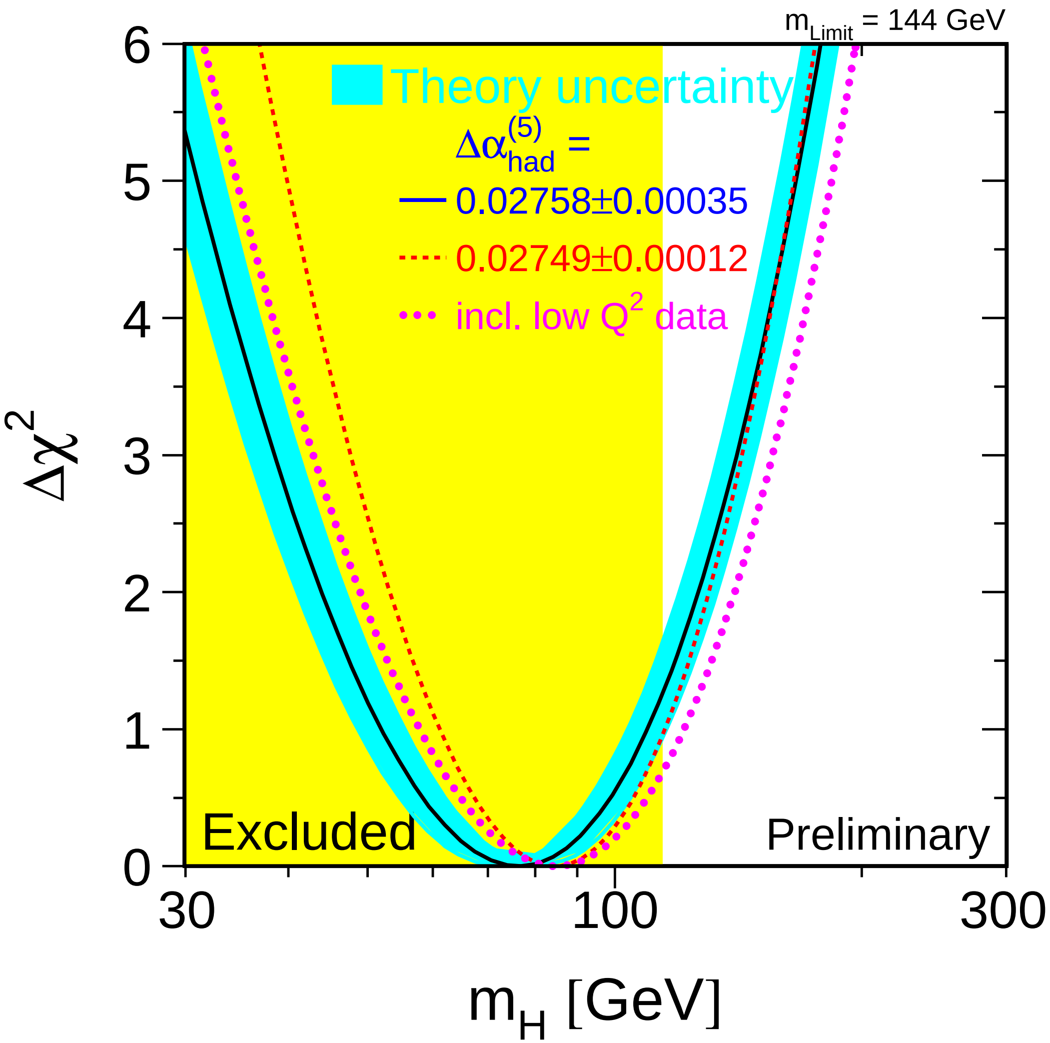
Within the SM: fit for the last unknown parameter: M_H^{SM}

Global fit to all SM data:

[*LEPEWWG '07*]

$\Rightarrow\ M_H = 76^{+33}_{-24}$ GeV

$M_H < 144$ GeV, 95% C.L.



Assumption for the fit:
SM incl. Higgs boson

$\Rightarrow$ no confirmation of Higgs mechanism

$\Rightarrow$ Higgs boson seems to be light, $M_H \lesssim 150$ GeV

Indirect hints on M_{SUSY} from existing data?

- Electroweak precision observables (EWPO) ?

- B physics observables (BPO) ?

- Cold dark matter (CDM) ?

$\Rightarrow$ combination of EWPO, BPO, CDM ?

Indirect hints on M_{SUSY} from existing data?

- Electroweak precision observables (EWPO) ?
- B physics observables (BPO) ?
- Cold dark matter (CDM) ?

$\Rightarrow$ combination of EWPO, BPO, CDM ?

EWPO M_W : information on $m_{\tilde{t}}$, $m_{\tilde{b}}$ or M_A, $\tan\beta$ or ...

EWPO $(g-2)_\mu$: information on $\tan\beta$ and/or $m_{\tilde{\chi}^0}$, $m_{\tilde{\chi}^\pm}$ and/or $m_{\tilde{\mu}}$, $m_{\tilde{\nu}_\mu}$

BPO $\text{BR}(b \to s\gamma)$: information on $\tan\beta$ and/or $M_{H^\pm}$ and/or $m_{\tilde{t}}$, $m_{\tilde{\chi}^\pm}$

CDM (LSP gives CDM) : information on $m_{\tilde{\chi}_1^0}$ and $m_{\tilde{\tau}}$ or M_A or ...

Indirect hints on M_{SUSY} from existing data?

- Electroweak precision observables (EWPO) ?
- B physics observables (BPO) ?
- Cold dark matter (CDM) ?

$\Rightarrow$ combination of EWPO, BPO, CDM ?

EWPO M_W : information on $m_{\tilde{t}}$, $m_{\tilde{b}}$ or M_A, $\tan\beta$ or . . .

EWPO $(g-2)_\mu$: information on $\tan\beta$ and/or $m_{\tilde{\chi}^0}$, $m_{\tilde{\chi}^\pm}$ and/or $m_{\tilde{\mu}}$, $m_{\tilde{\nu}_\mu}$

BPO BR$(b \to s\gamma)$: information on $\tan\beta$ and/or $M_{H^\pm}$ and/or $m_{\tilde{t}}$, $m_{\tilde{\chi}^\pm}$

CDM (LSP gives CDM) : information on $m_{\tilde{\chi}_1^0}$ and $m_{\tilde{\tau}}$ or M_A or . . .

$\Rightarrow$ combination makes only sense if all parameters are connected!
$\Rightarrow$ GUT based models, . . .

The models: 1.) CMSSM (or mSUGRA):

> ⇒ Scenario characterized by
>
> $$m_0,\ m_{1/2},\ A_0,\ \tan\beta,\ \text{sign}\,\mu$$

- m_0 : universal scalar mass parameter
- $m_{1/2}$: universal gaugino mass parameter
- A_0 : universal trilinear coupling

} at the GUT scale

- $\tan\beta$: ratio of Higgs vacuum expectation values
- $\text{sign}(\mu)$: sign of supersymmetric Higgs parameter

⇒ particle spectra from renormalization group running to weak scale

Lightest SUSY particle (LSP) is the lightest neutralino

The models: 1.) CMSSM (or mSUGRA):

⇒ Scenario charac

m_0 : universal scalar

$m_{1/2}$: universal gaug

A_0 : universal trilinea

$\tan\beta$: ratio of Higgs

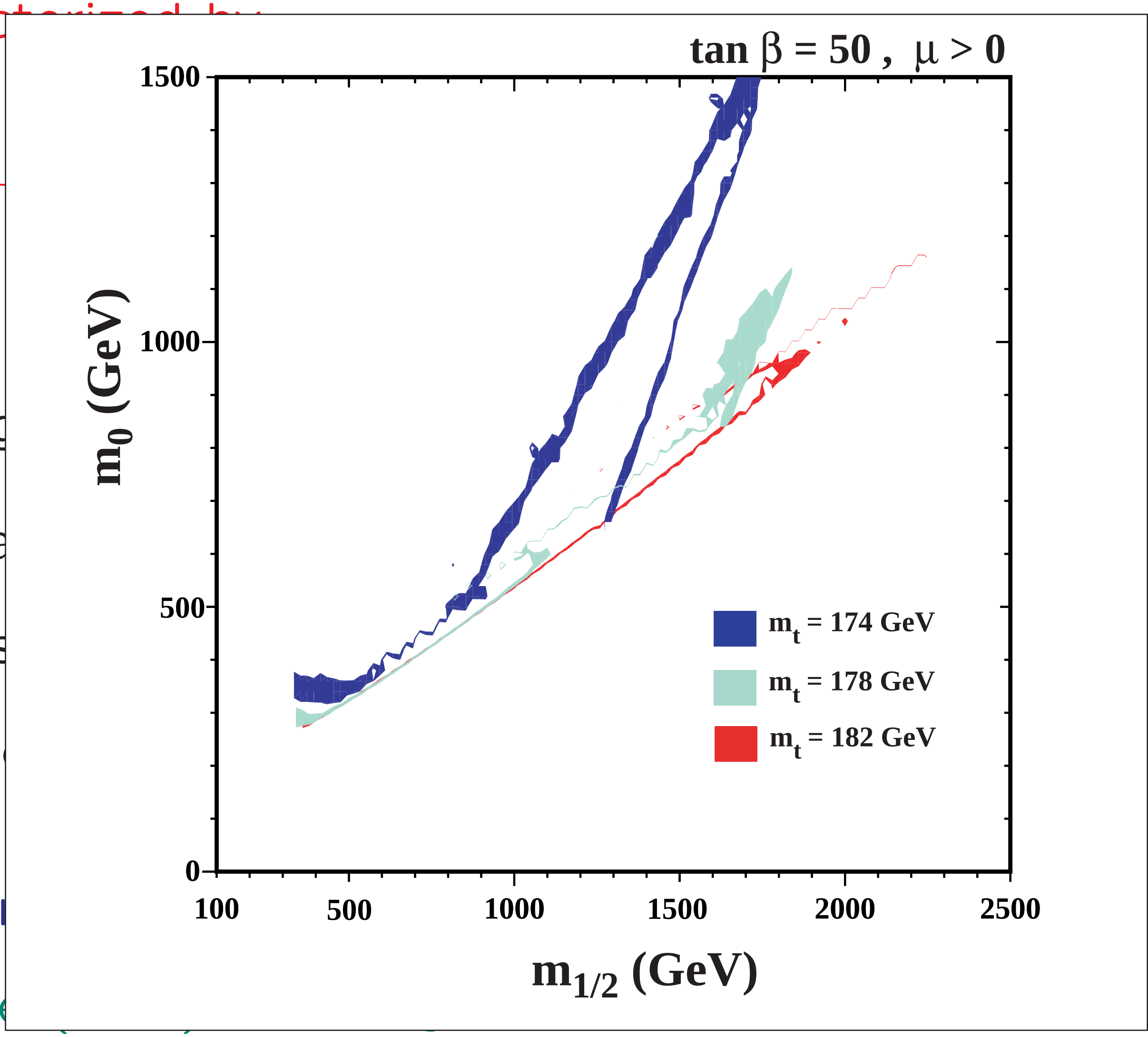
sign(μ) : sign of sup

ale

⇒ particle spectra fro

ale

Lightest SUSY particl



The models: 2.) NUHM: (Non-universal Higgs mass model)

⇒ besides the CMSSM parameters

M_A and μ

Assumption:

no unification of scalar fermion and scalar Higgs parameters at the GUT scale

⇒ effectively M_A and μ free parameters at the EW scale

⇒ particle spectra from renormalization group running to weak scale

Lightest SUSY particle (LSP) is the lightest neutralino

⇒ possible: M_A–$\tan\beta$ planes in agreement with CDM :-)

2. Impact of BPO on CMSSM fits

[*J. Ellis, S.H., K. Olive, A.M. Weber, G. Weiglein '07*]

What do we know about the SUSY mass scale?

1. Coupling constant unification $\Rightarrow M_{\text{SUSY}} \approx 1$ TeV
2. Solution for the Hierarchy problem $\Rightarrow M_{\text{SUSY}} \lesssim 1$ TeV
3. Indirect hints from existing data?
   - Focus on CMSSM

     small number of free parameters
   - hard constraint: LSP gives right amount of cold dark matter

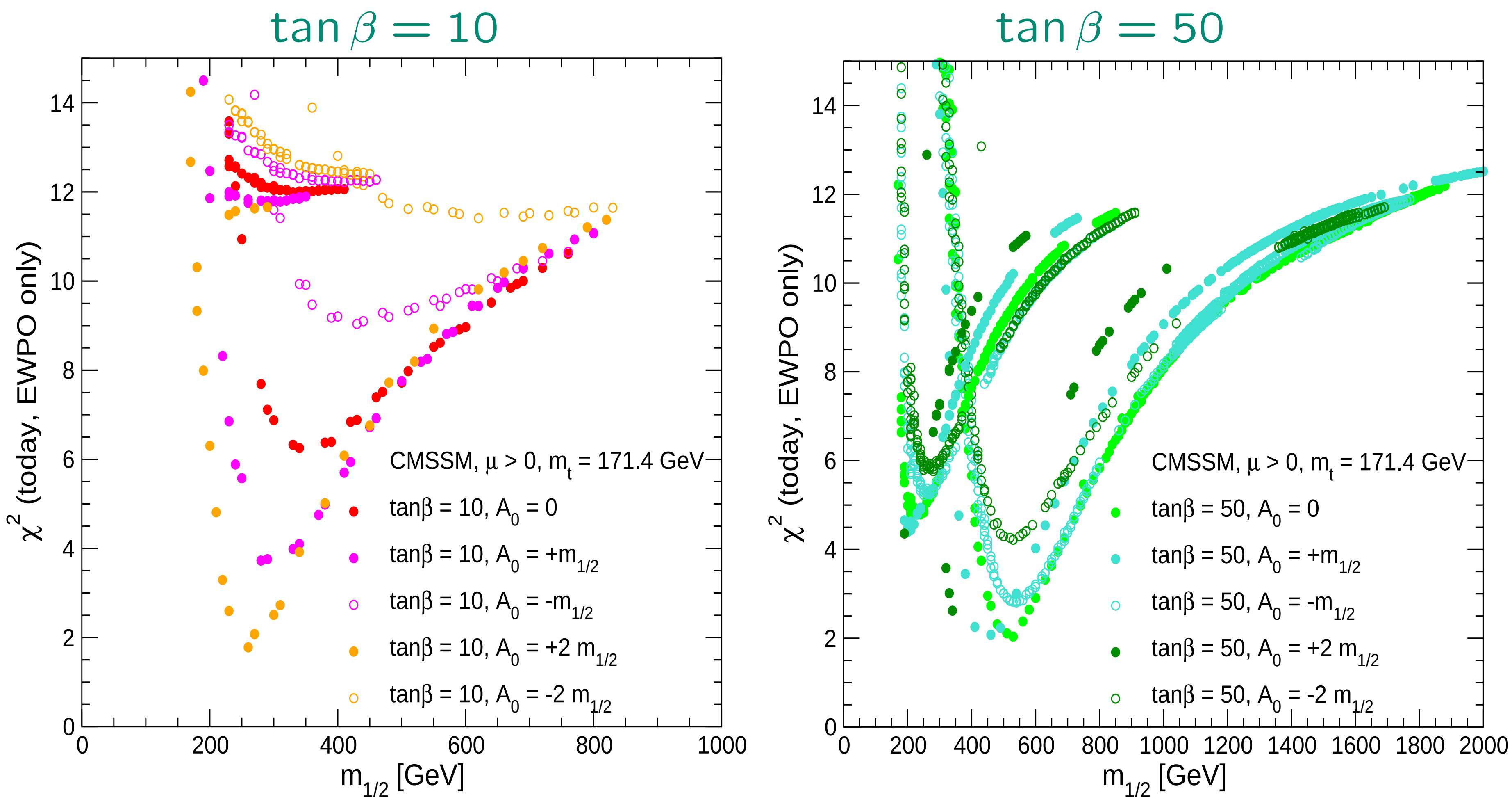
     CMSSM: only thin strips allowed in the $m_{1/2}$–m_0 plane
   - Use existing data of M_W, $\sin^2\theta_{\text{eff}}$, Γ_Z, $(g-2)_\mu$, M_h

     BR$(b \to s\gamma)$, BR$(B_s \to \mu^+\mu^-)$, BR$(B_u \to \tau\nu_\tau)$, ΔM_{B_s}

   $\Rightarrow \chi^2$ fit with these observables

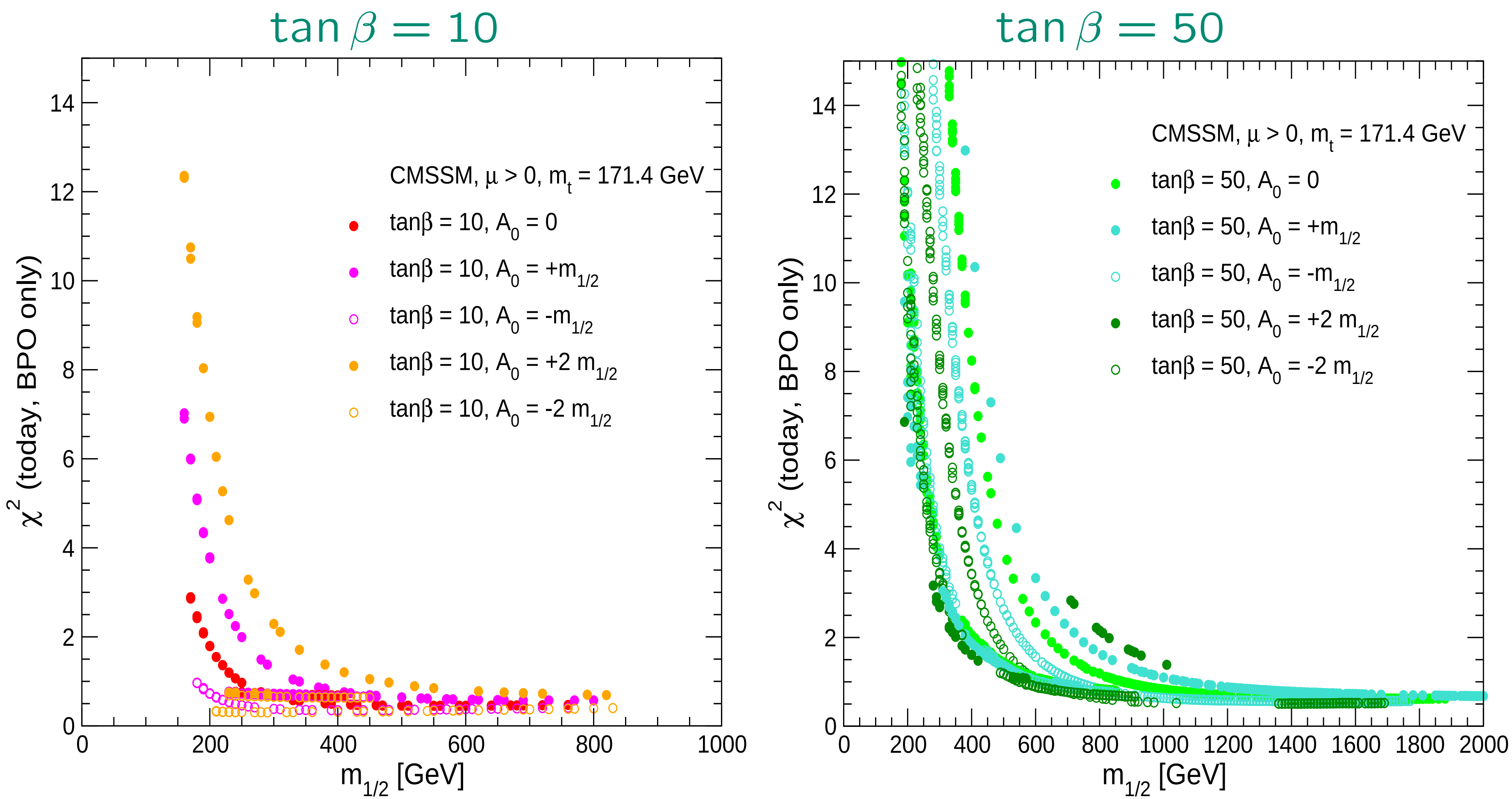
   $\Rightarrow$ best fit values for masses, couplings, . . .

Results: CMSSM: EWPO alone



$\Rightarrow$ preference for relatively small $m_{1/2}$

Results: CMSSM: BPO alone

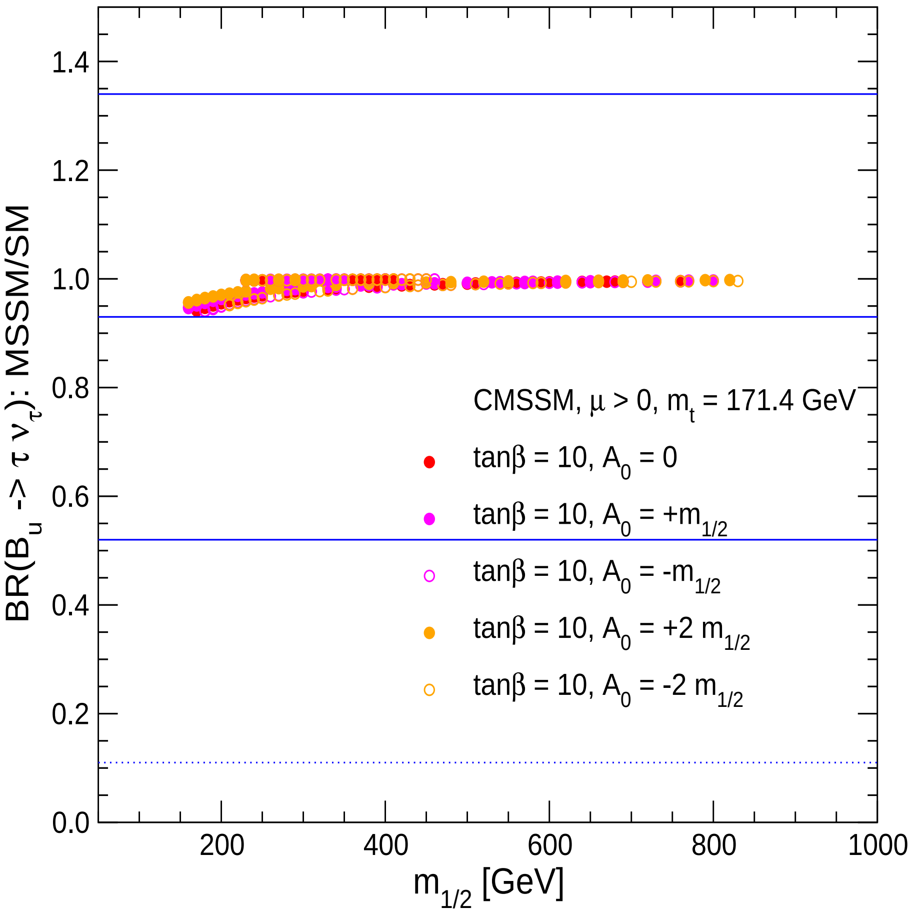


⇒ preference for relatively large $m_{1/2}$

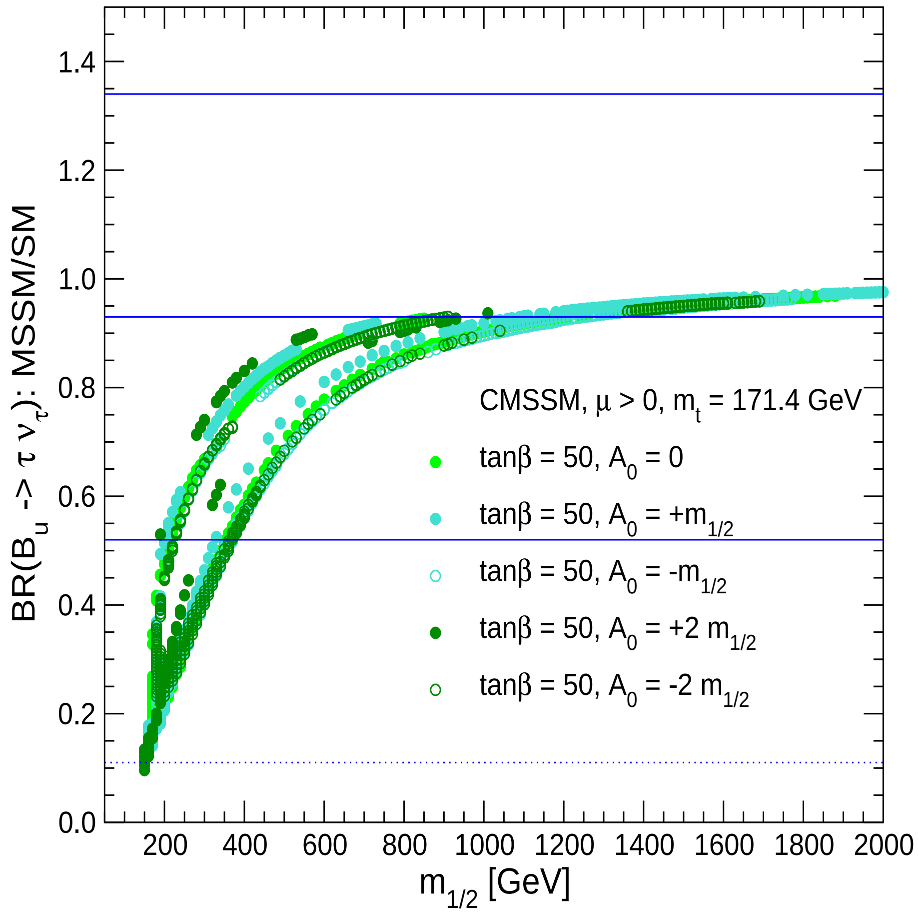
Problem of BPO: not precise enough yet

BR($B_u \to \tau\nu_\tau$): CMSSM/SM

$\tan\beta = 10$

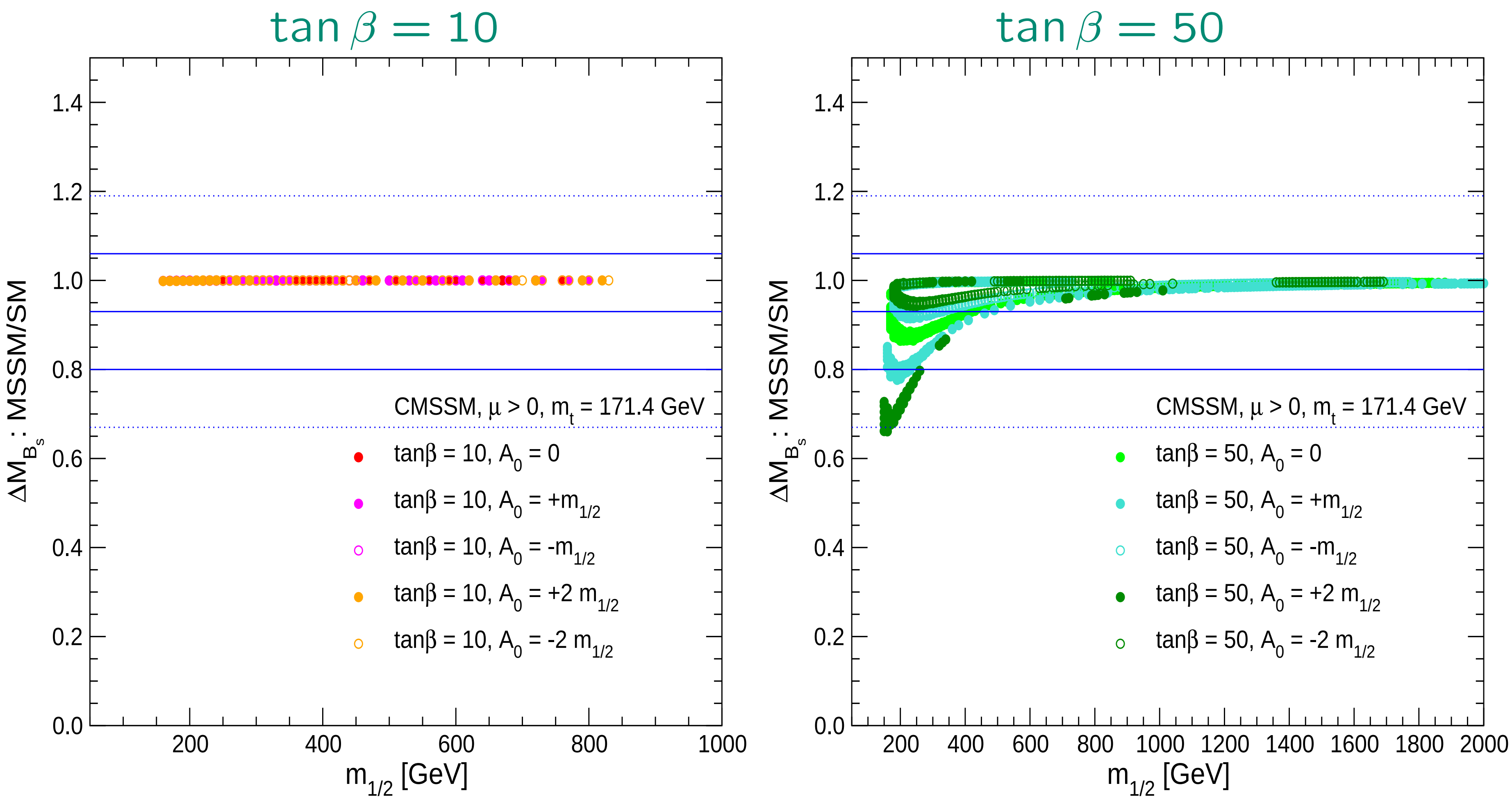


$\tan\beta = 50$



Problem of BPO: not precise enough yet

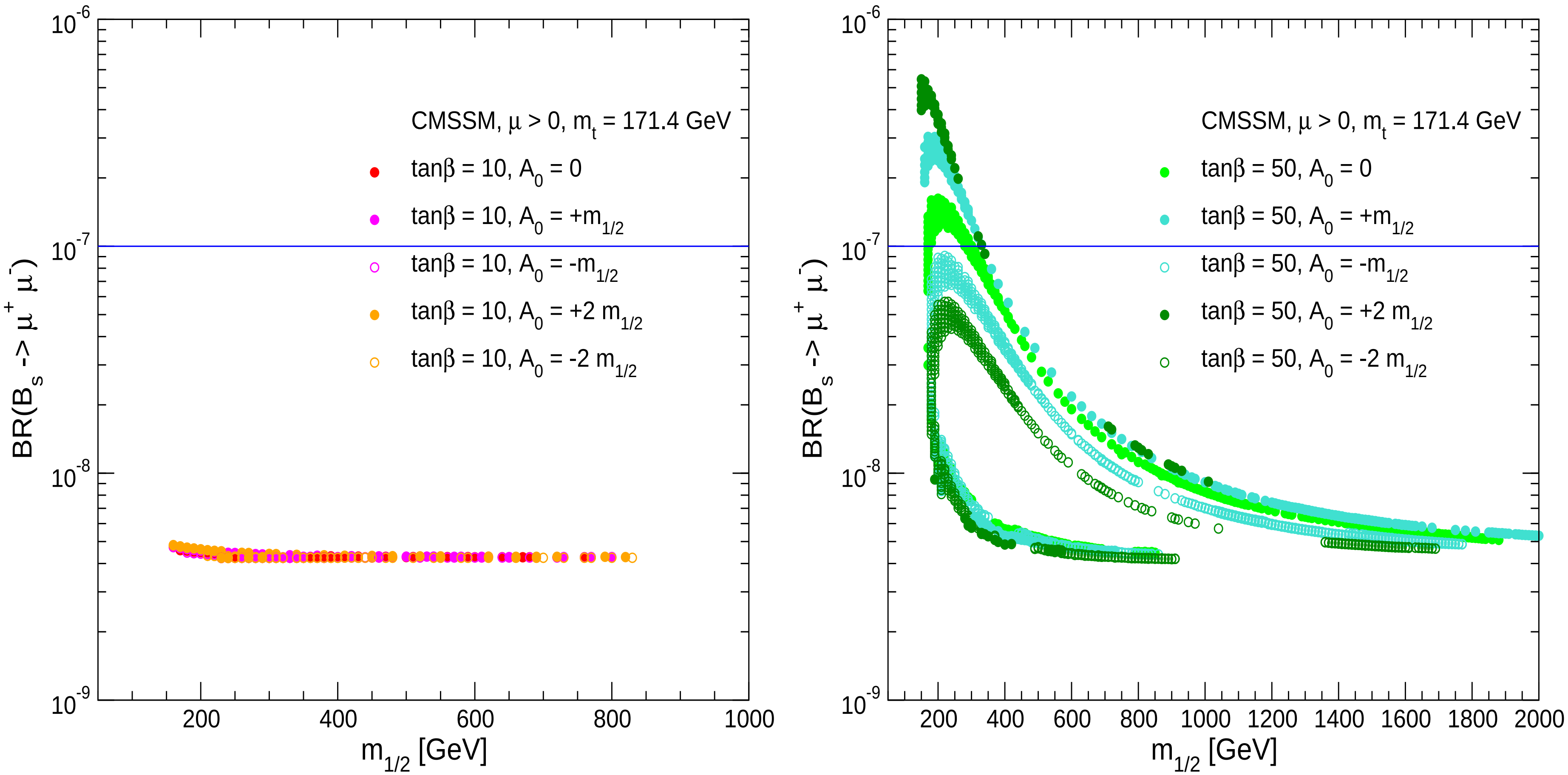
ΔM_{B_s}: CMSSM/SM



Problem of BPO: not precise enough yet (getting better)

$BR(B_s \to \mu^+\mu^-)$: CMSSM

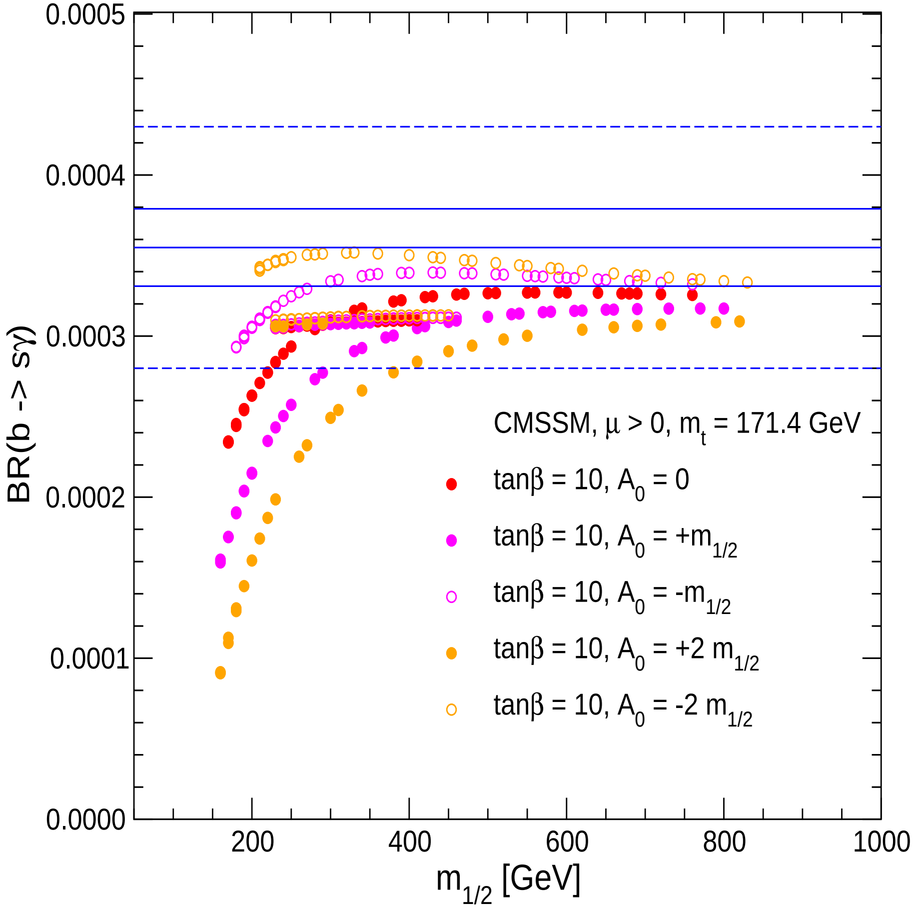
$\tan\beta = 10$ $\tan\beta = 50$



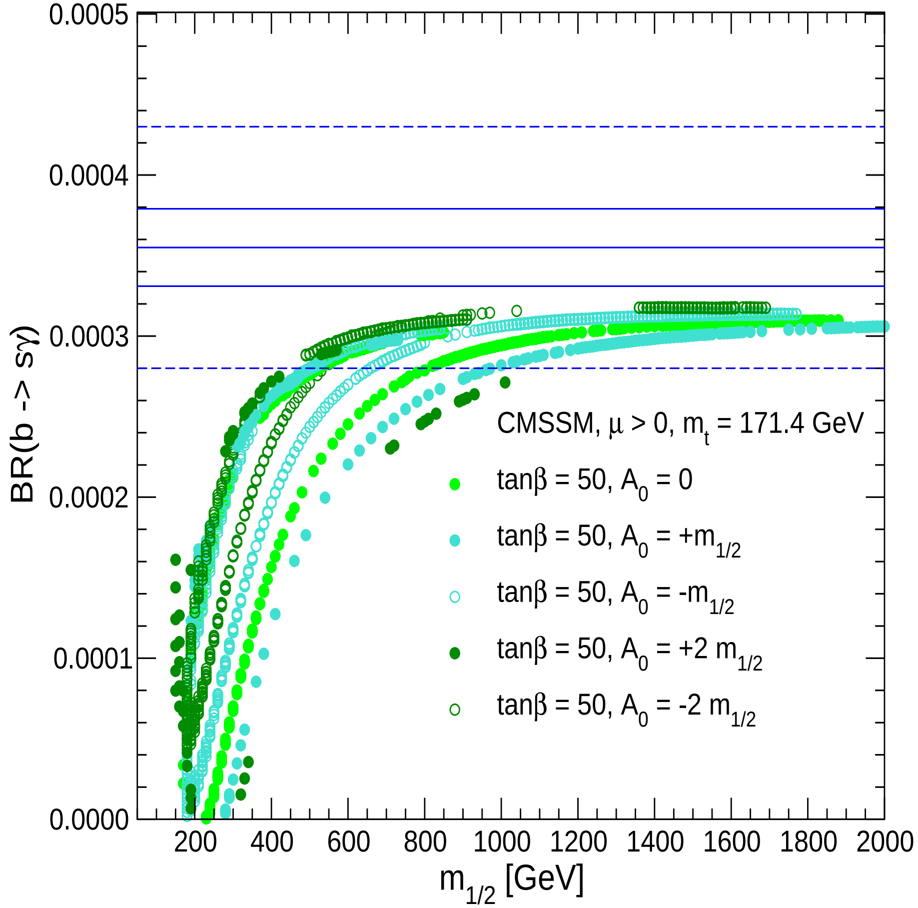
Problem of BPO: not precise enough yet (partial exception)

BR($b \to s\gamma$): CMSSM

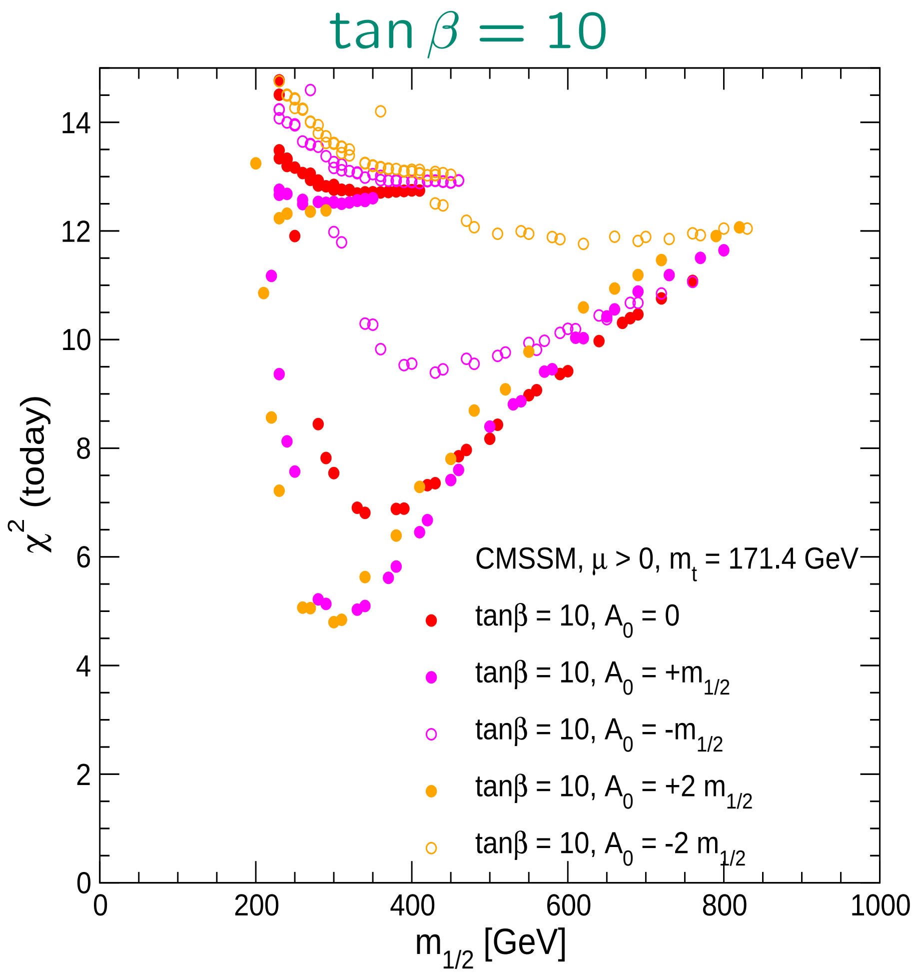
$\tan\beta = 10$

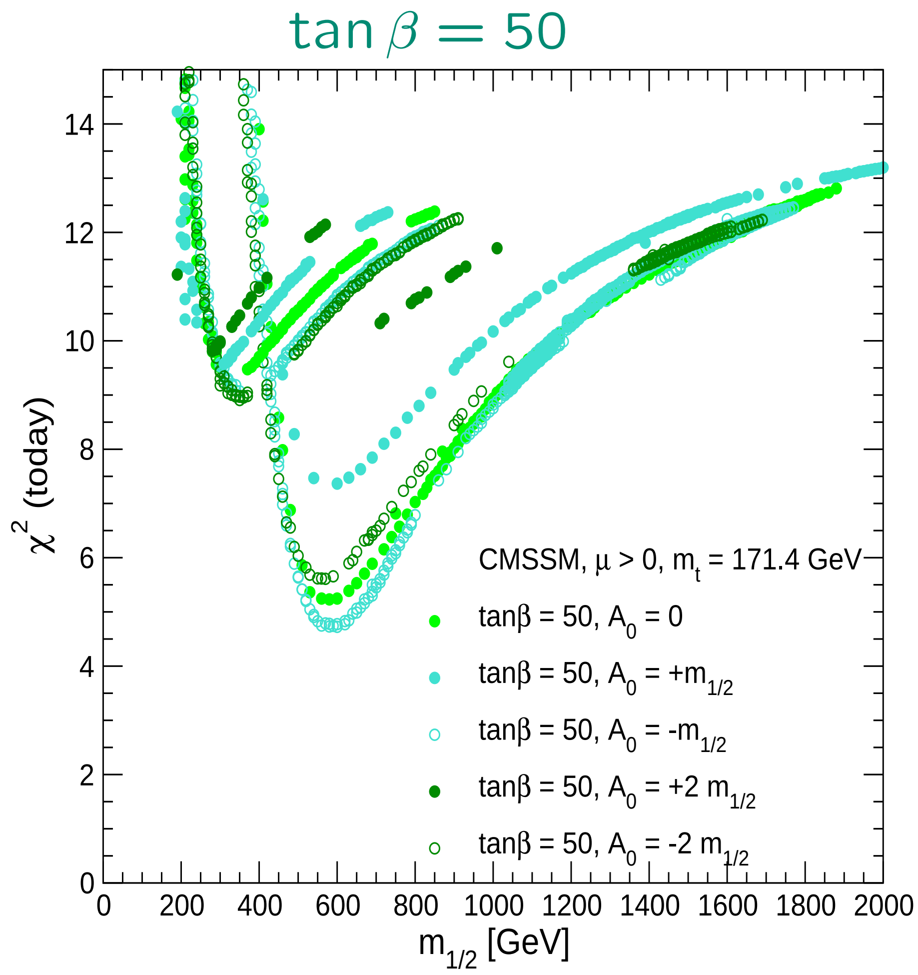


$\tan\beta = 50$



Results: CMSSM: everything combined

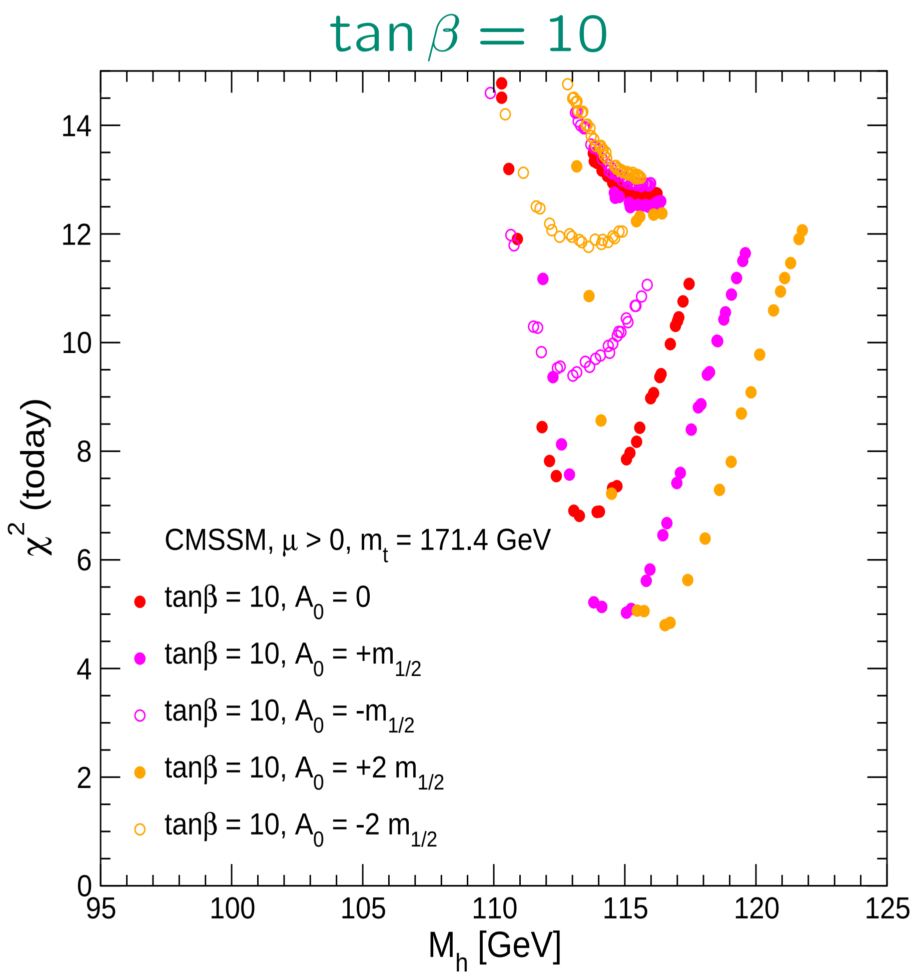


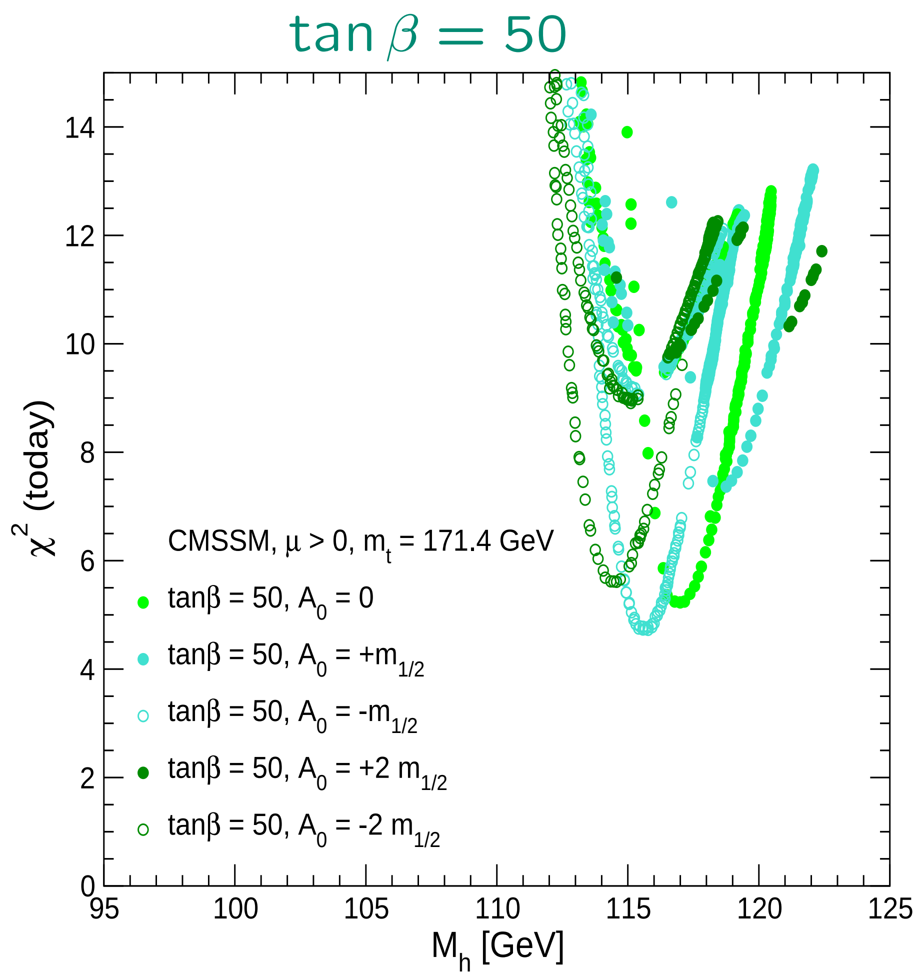


⇒ preference for somewhat smallish $m_{1/2}$ – but with a little tension

⇒ still a very good fit!

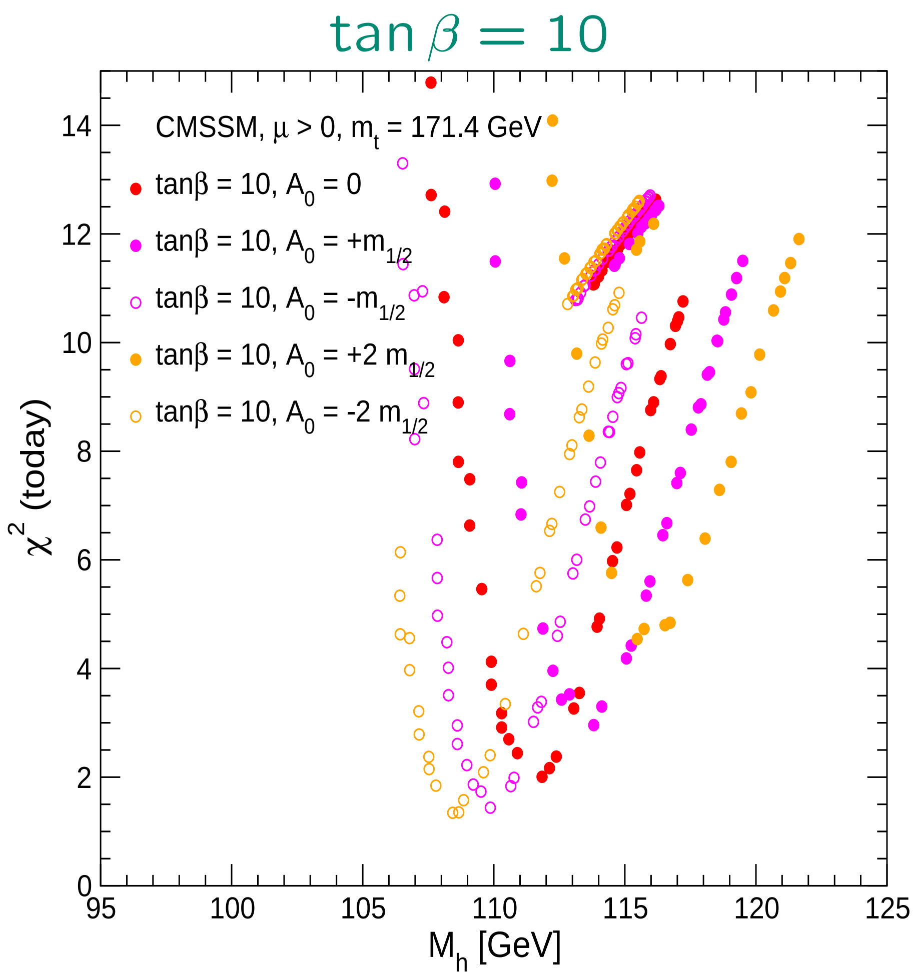
Results: CMSSM: prediction for M_h

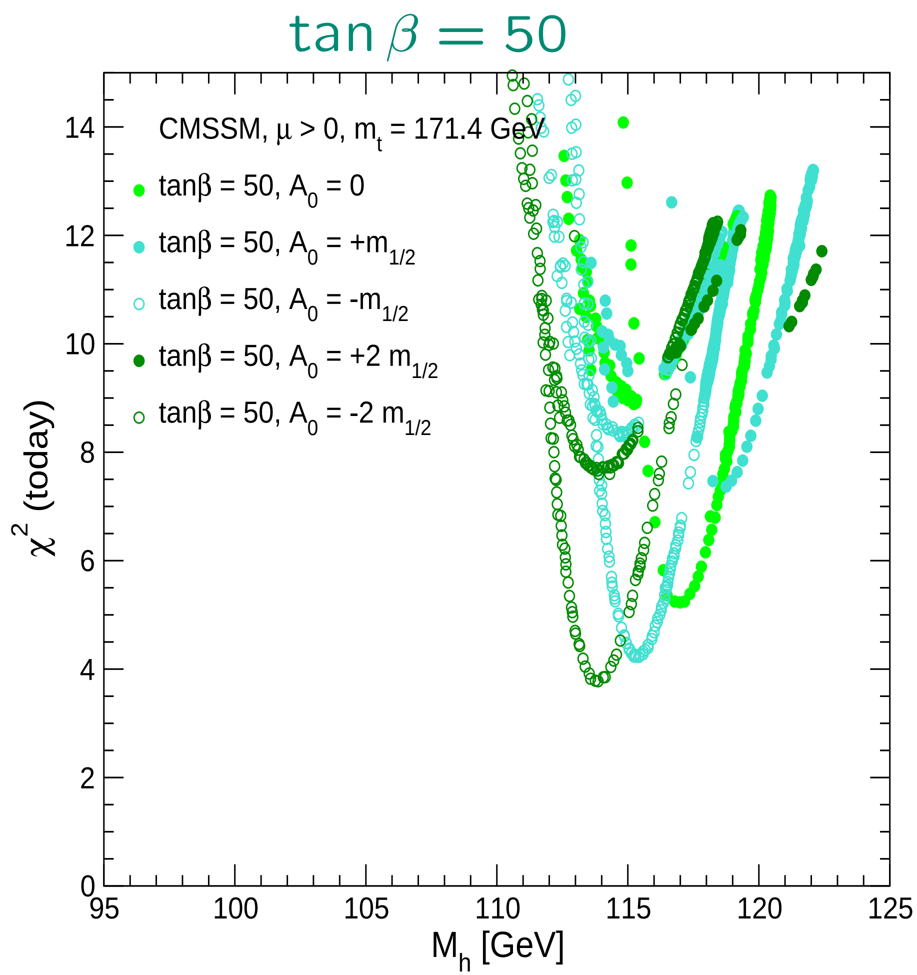




$\Rightarrow$ preference for $M_h \sim 115$ GeV (LEP . . .)

Results: CMSSM: "blue band" for M_h (without LEP results)





⇒ much "better" than in the SM

3. Impact of BPO on M_h in the CMSSM

[*Buchmüller, Cavanaugh, de Roeck, S.H., Isidori, Paradisi, Ronga, Weber, Weiglein '07*]

Main idea:

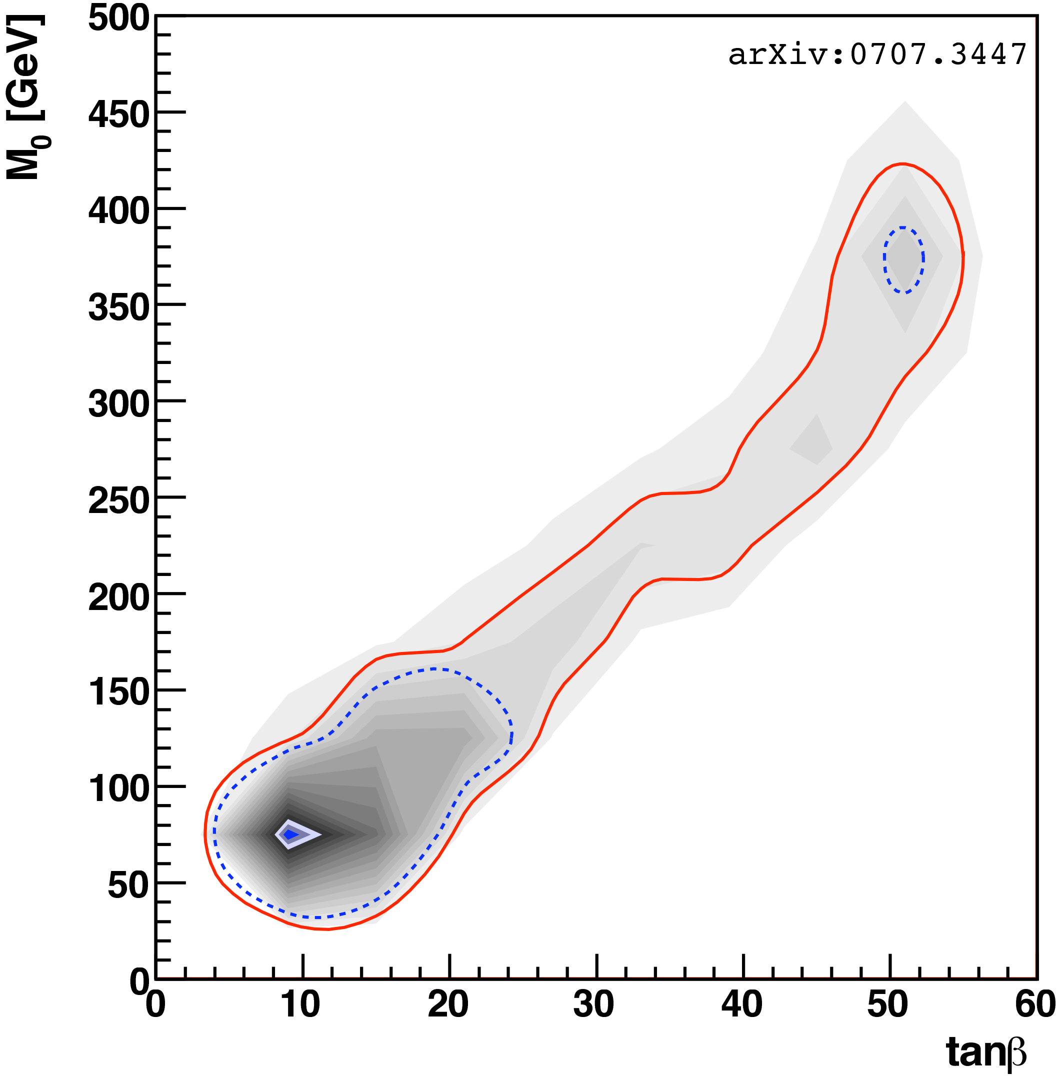
– combine all electroweak precision data as in the SM
– combine B physics observables
– include SM parameters with their errors: $m_t, \ldots$

– scan over the full CMSSM parameter space

⇒ preferred CMSSM parameters
⇒ preferred M_h values
⇒ LHC/ILC reach

Most important:
Produce better graphics! :-)

Preferred region in the m_0–$\tan\beta$ plane:



Pull distributions:

CMSSM

Variable	Measurement	Fit	$\lvert O^{meas}-O^{fit}\rvert/\sigma^{meas}$
$\Delta\alpha^{(5)}_{had}(m_Z)$	0.02758 ± 0.00035	0.02774	
m_Z [GeV]	91.1875 ± 0.0021	91.1873	
Γ_Z [GeV]	2.4952 ± 0.0023	2.4952	
σ^0_{had} [nb]	41.540 ± 0.037	41.486	
R_l	20.767 ± 0.025	20.744	
$A^{0,l}_{fb}$	0.01714 ± 0.00095	0.01641	
$A_l(P_\tau)$	0.1465 ± 0.0032	0.1479	
R_b	0.21629 ± 0.00066	0.21613	
R_c	0.1721 ± 0.0030	0.1722	
$A^{0,b}_{fb}$	0.0992 ± 0.0016	0.1037	
$A^{0,c}_{fb}$	0.0707 ± 0.0035	0.0741	
A_b	0.923 ± 0.020	0.935	
A_c	0.670 ± 0.027	0.668	
A_l(SLD)	0.1513 ± 0.0021	0.1479	
$\sin^2\theta^{lept}_{eff}(Q_{fb})$	0.2324 ± 0.0012	0.2314	
m_W [GeV]	80.398 ± 0.025	80.382	
m_t [GeV]	170.9 ± 1.8	170.8	
$R(b\to s\gamma)$	1.13 ± 0.12	1.12	
$B_s\to\mu\mu$ [$\times10^{-8}$]	< 8.00	0.33	N/A (upper limit)
Δa_μ [$\times10^{-9}$]	2.95 ± 0.87	2.95	
Ωh^2	0.113 ± 0.009	0.113	

SM

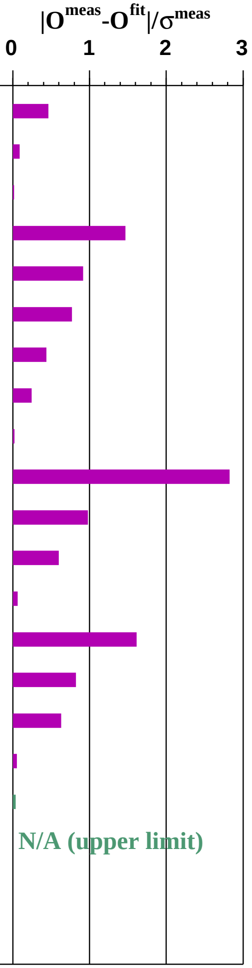
Variable	Measurement	Fit	$\lvert O^{meas}-O^{fit}\rvert/\sigma^{meas}$
$\Delta\alpha^{(5)}_{had}(m_Z)$	0.02758 ± 0.00035	0.02768	
m_Z [GeV]	91.1875 ± 0.0021	91.1875	
Γ_Z [GeV]	2.4952 ± 0.0023	2.4957	
σ^0_{had} [nb]	41.540 ± 0.037	41.477	
R_l	20.767 ± 0.025	20.744	
$A^{0,l}_{fb}$	0.01714 ± 0.00095	0.01645	
$A_l(P_\tau)$	0.1465 ± 0.0032	0.1481	
R_b	0.21629 ± 0.00066	0.21586	
R_c	0.1721 ± 0.0030	0.1722	
$A^{0,b}_{fb}$	0.0992 ± 0.0016	0.1038	
$A^{0,c}_{fb}$	0.0707 ± 0.0035	0.0742	
A_b	0.923 ± 0.020	0.935	
A_c	0.670 ± 0.027	0.668	
A_l(SLD)	0.1513 ± 0.0021	0.1481	
$\sin^2\theta^{lept}_{eff}(Q_{fb})$	0.2324 ± 0.0012	0.2314	
m_W [GeV]	80.398 ± 0.025	80.374	
m_t [GeV]	170.9 ± 1.8	171.3	
Γ_W [GeV]	2.140 ± 0.060	2.091	

$\Rightarrow$ note the new observables: BR($b \to s\gamma$), [BR($B_s \to \mu^+\mu^-$)], $(g-2)_\mu$, CDM

Pull distributions:

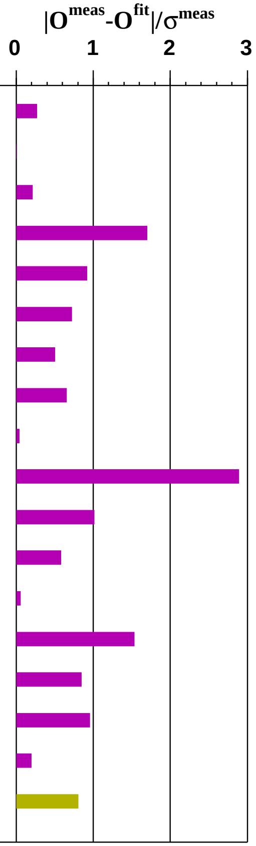
CMSSM

Variable	Measurement	Fit
$\Delta\alpha^{(5)}_{had}(m_Z)$	0.02758 ± 0.00035	0.02774
m_Z [GeV]	91.1875 ± 0.0021	91.1873
Γ_Z [GeV]	2.4952 ± 0.0023	2.4952
σ^0_{had} [nb]	41.540 ± 0.037	41.486
R_l	20.767 ± 0.025	20.744
$A^{0,l}_{fb}$	0.01714 ± 0.00095	0.01641
$A_l(P_\tau)$	0.1465 ± 0.0032	0.1479
R_b	0.21629 ± 0.00066	0.21613
R_c	0.1721 ± 0.0030	0.1722
$A^{0,b}_{fb}$	0.0992 ± 0.0016	0.1037
$A^{0,c}_{fb}$	0.0707 ± 0.0035	0.0741
A_b	0.923 ± 0.020	0.935
A_c	0.670 ± 0.027	0.668
A_l(SLD)	0.1513 ± 0.0021	0.1479
$\sin^2\theta^{lept}_{eff}(Q_{fb})$	0.2324 ± 0.0012	0.2314
m_W [GeV]	80.398 ± 0.025	80.382
m_t [GeV]	170.9 ± 1.8	170.8
$R(b \to s\gamma)$	1.13 ± 0.12	1.12
$B_s \to \mu\mu$ [$\times 10^{-8}$]	< 8.00	0.33
Δa_μ [$\times 10^{-9}$]	2.95 ± 0.87	2.95
Ωh^2	0.113 ± 0.009	0.113



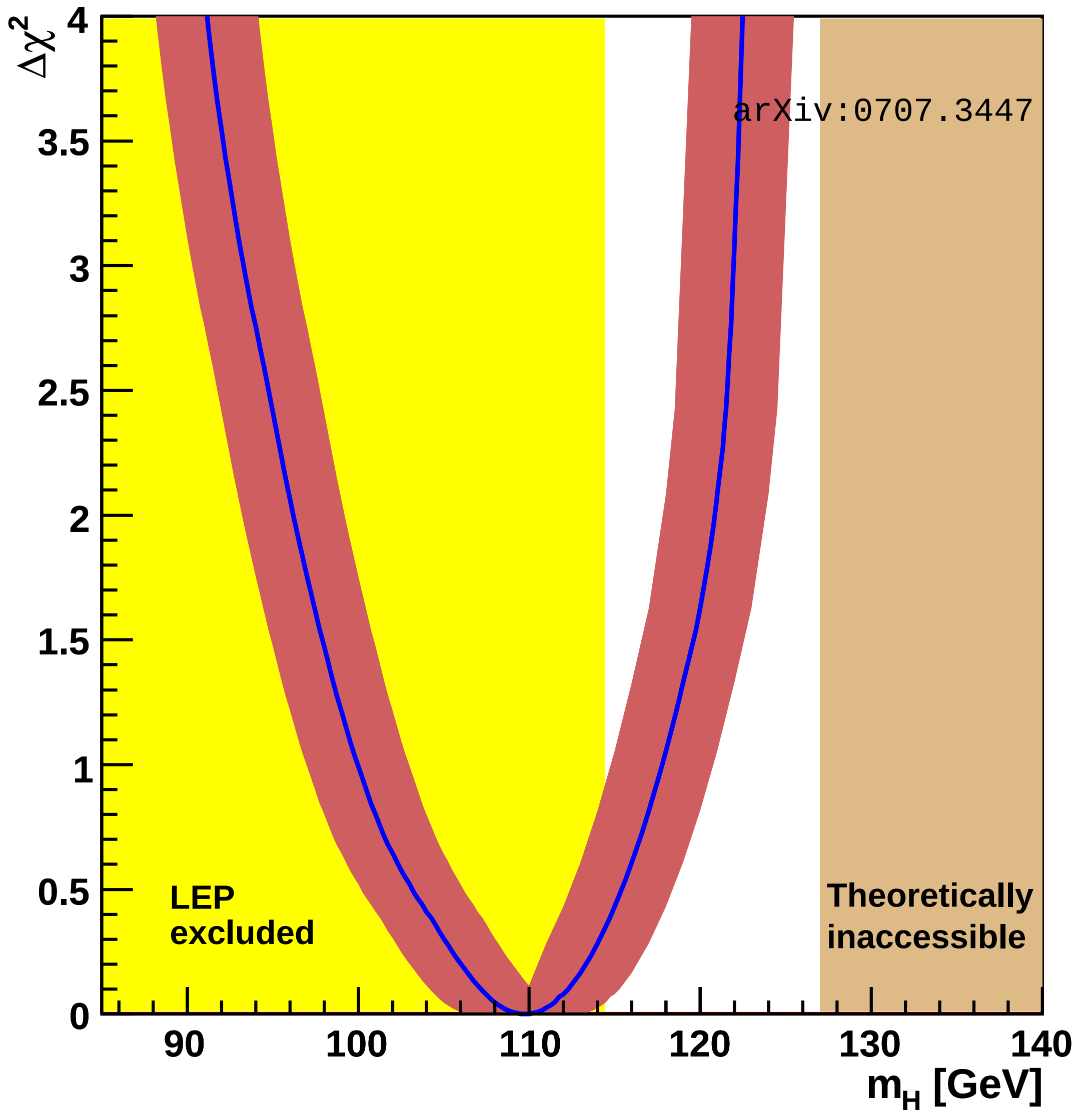
SM

Variable	Measurement	Fit
$\Delta\alpha^{(5)}_{had}(m_Z)$	0.02758 ± 0.00035	0.02768
m_Z [GeV]	91.1875 ± 0.0021	91.1875
Γ_Z [GeV]	2.4952 ± 0.0023	2.4957
σ^0_{had} [nb]	41.540 ± 0.037	41.477
R_l	20.767 ± 0.025	20.744
$A^{0,l}_{fb}$	0.01714 ± 0.00095	0.01645
$A_l(P_\tau)$	0.1465 ± 0.0032	0.1481
R_b	0.21629 ± 0.00066	0.21586
R_c	0.1721 ± 0.0030	0.1722
$A^{0,b}_{fb}$	0.0992 ± 0.0016	0.1038
$A^{0,c}_{fb}$	0.0707 ± 0.0035	0.0742
A_b	0.923 ± 0.020	0.935
A_c	0.670 ± 0.027	0.668
A_l(SLD)	0.1513 ± 0.0021	0.1481
$\sin^2\theta^{lept}_{eff}(Q_{fb})$	0.2324 ± 0.0012	0.2314
m_W [GeV]	80.398 ± 0.025	80.374
m_t [GeV]	170.9 ± 1.8	171.3
Γ_W [GeV]	2.140 ± 0.060	2.091



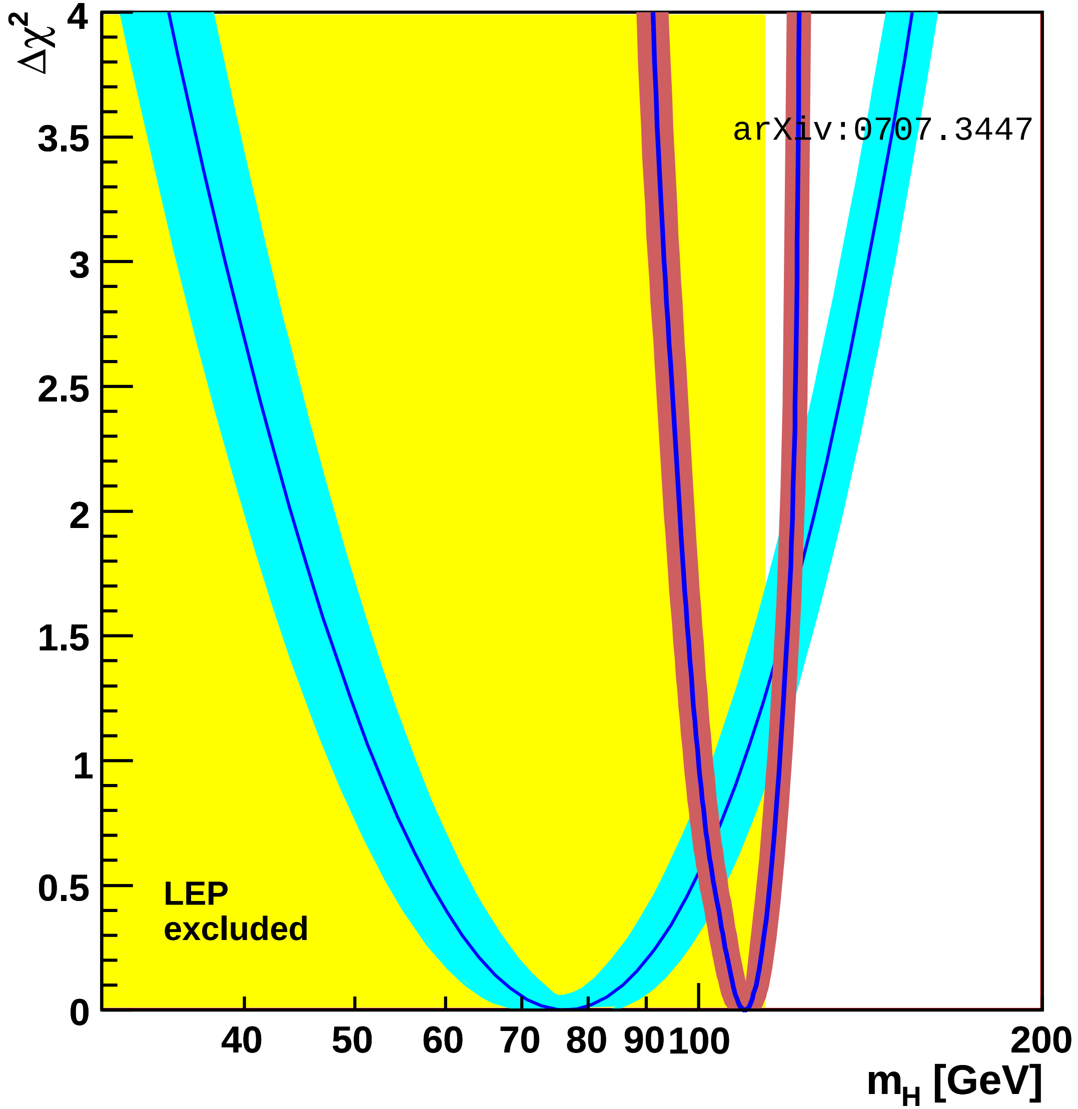
Probabilities: 24% / 20% 15% / 15% (incl. / excl. M_h)

Red band plot:



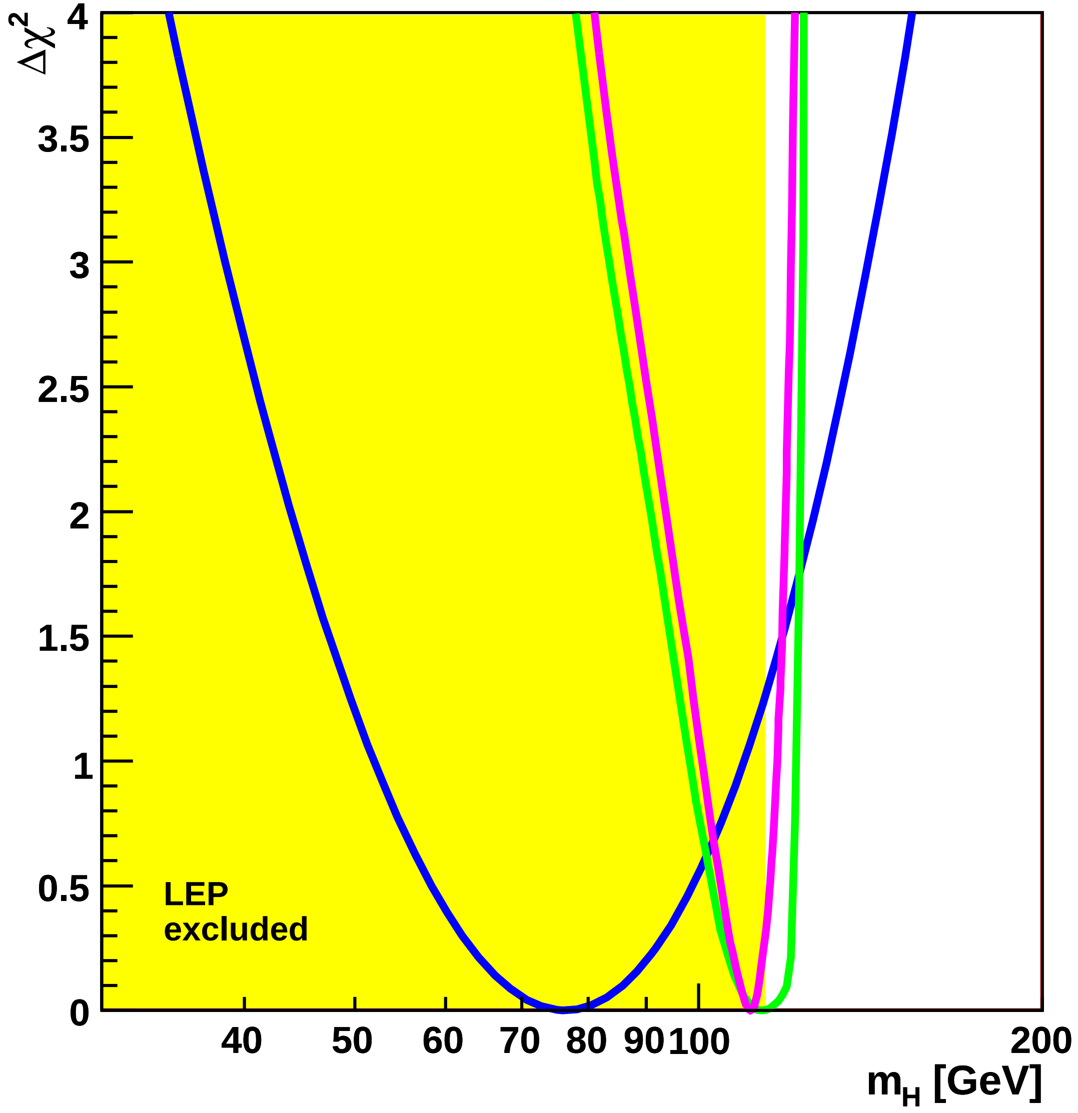
$$M_h = 110^{+8}_{-10}\,(\text{exp}) \pm 3(\text{theo})\ \text{GeV}$$

Blue/Red band plot:



CMSSM (despite its simplicity) is better than the SM

Impact of BR($b \to s\gamma$): $\Rightarrow$ green curve (preliminary!)

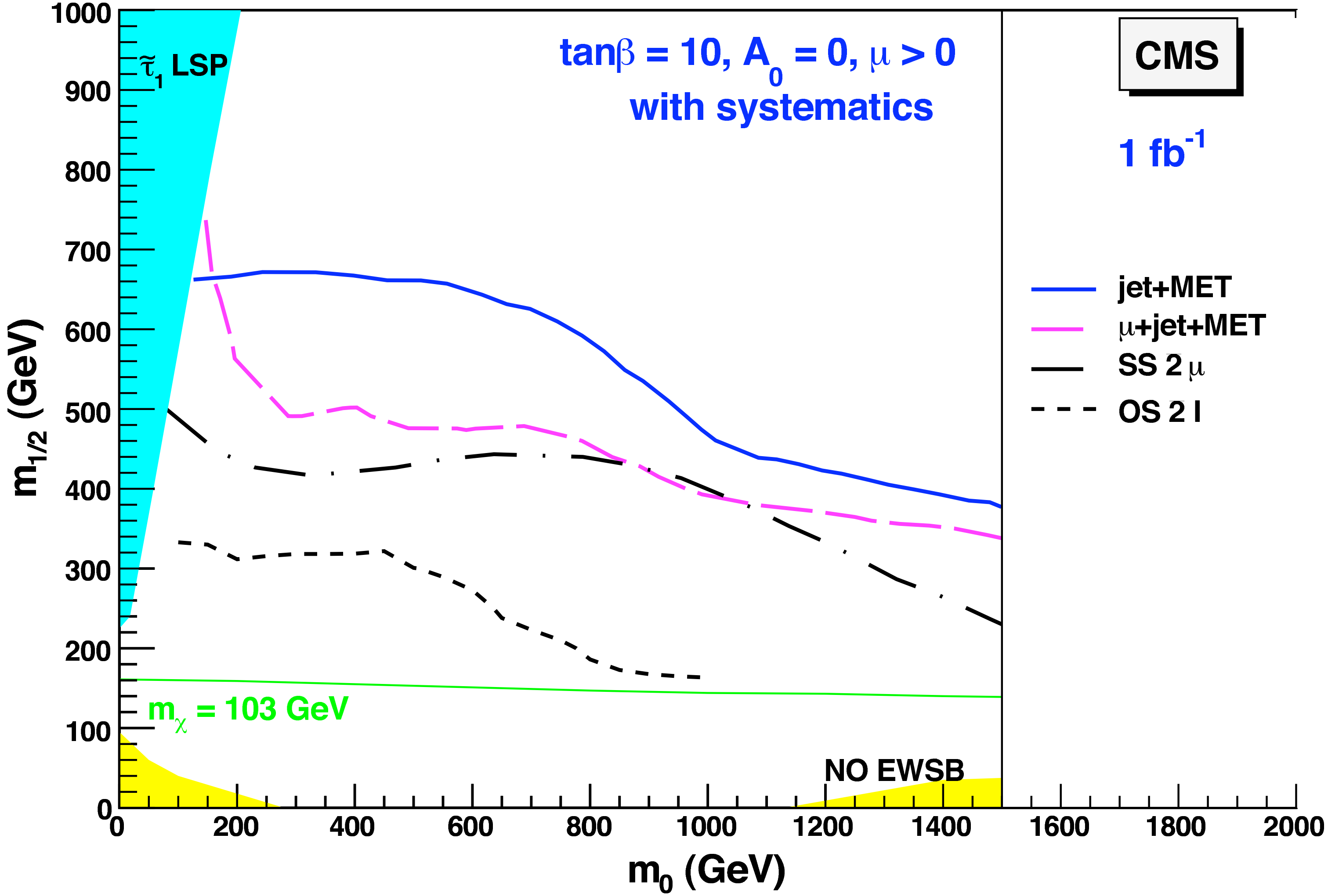


$\Rightarrow$ impact visible, but not decisive (location of minimum)

Connection to high P_T physics:

LHC (CMS) reach with 1 fb^{-1}:

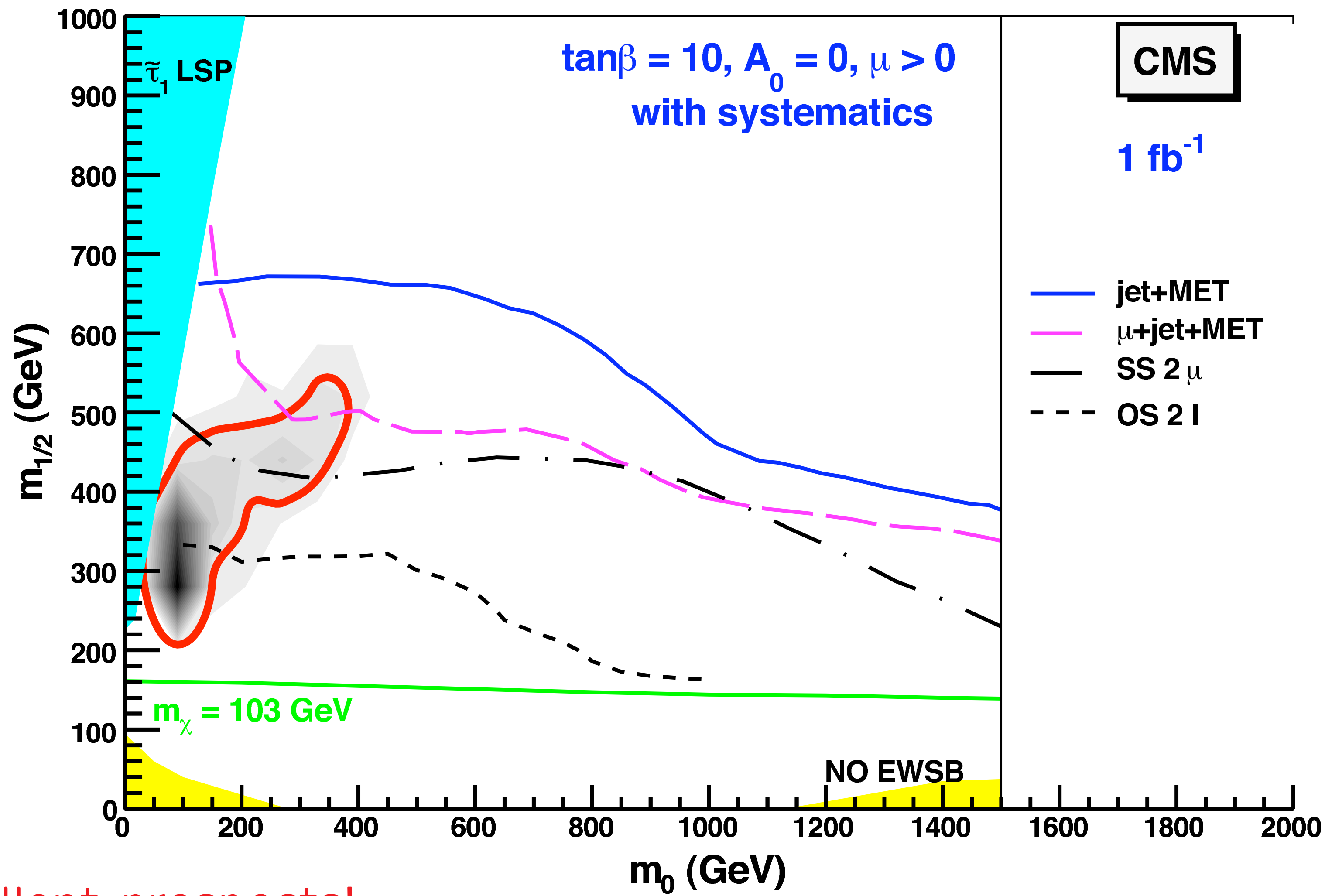
[*CMS '07*]



Connection to high P_T physics:

LHC (CMS) reach with 1 fb^{-1}:

[*CMS '07*]



$\Rightarrow$ excellent prospects!

4. Impact and prospects of BPO on NUHM fits

[J. Ellis, S.H., K. Olive, A.M. Weber, G. Weiglein '07][J. Ellis, T. Hahn, S.H., K. Olive, G. Weiglein '07]

NUHM: (Non-universal Higgs mass model)

⇒ besides the CMSSM parameters

M_A and μ

Assumption:

no unification of scalar fermion and scalar Higgs parameters
at the GUT scale

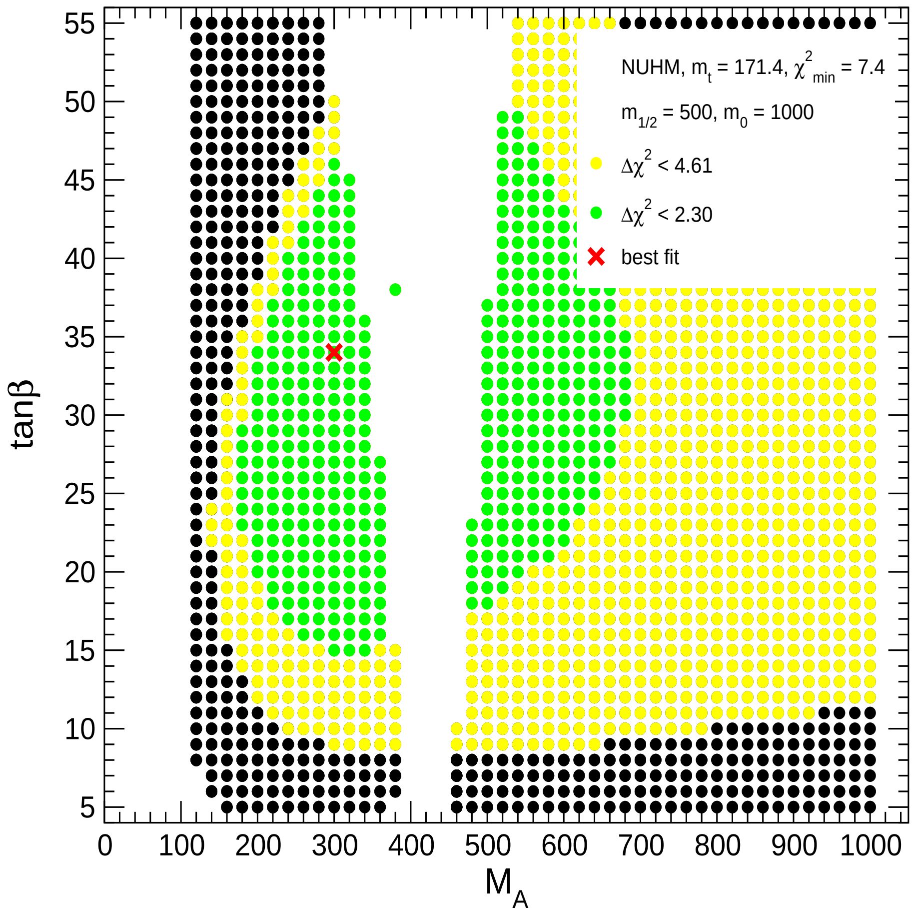
⇒ effectively M_A and μ free parameters at the EW scale

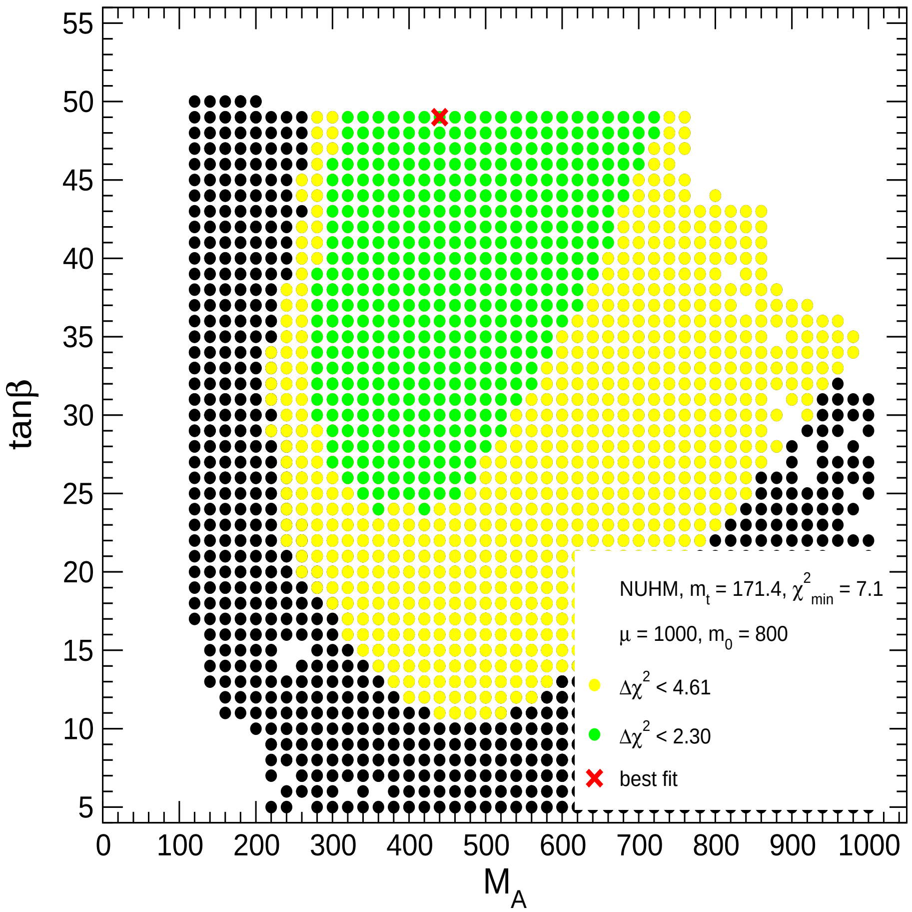
⇒ particle spectra from renormalization group running to weak scale

Lightest SUSY particle (LSP) is the lightest neutralino

⇒ possible: M_A–$\tan\beta$ planes in agreement with CDM :-)

Example: NUHM planes 2,3



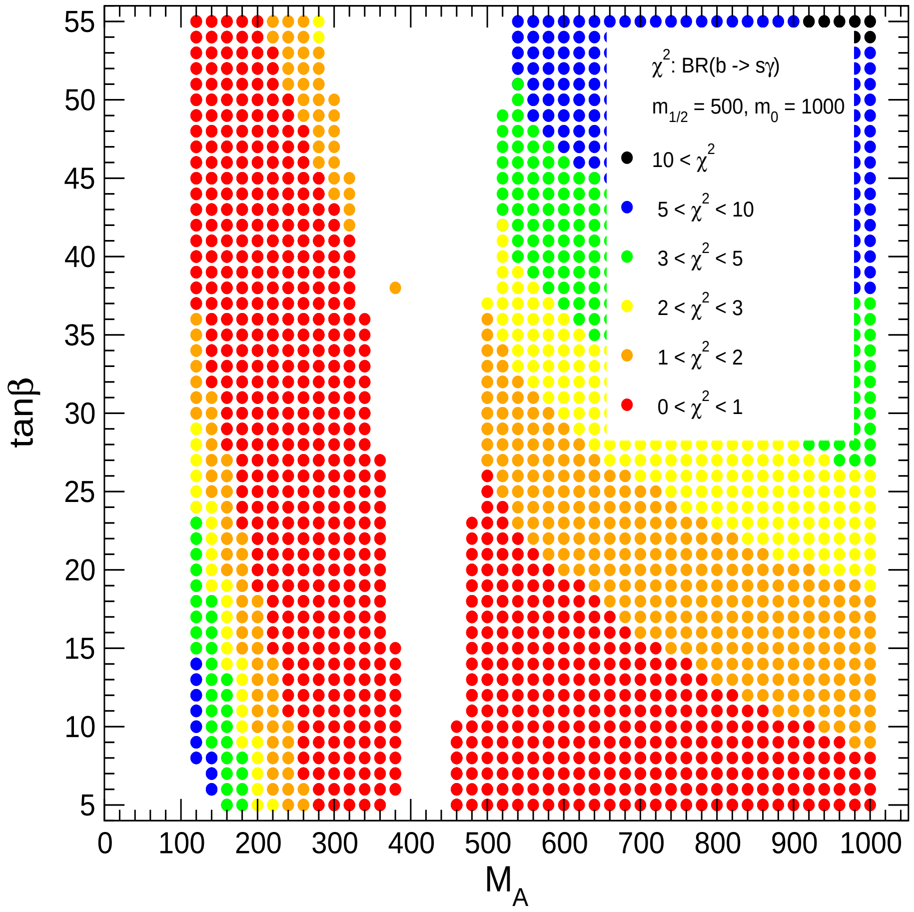


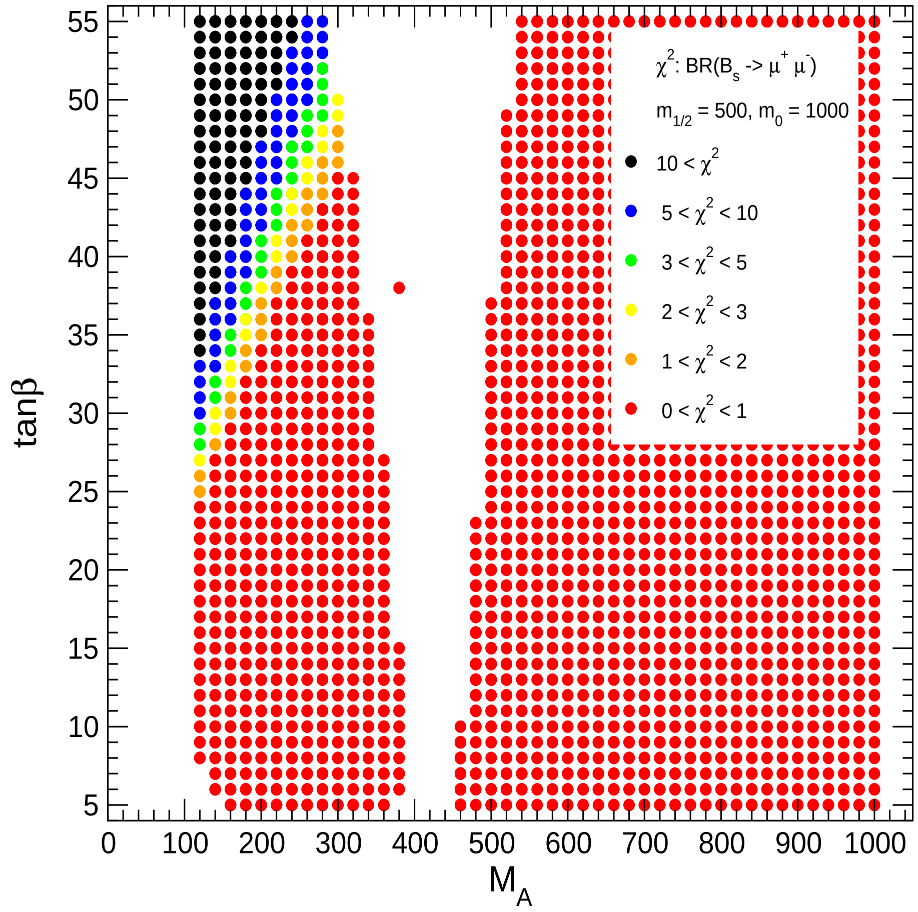
$\Rightarrow$ good χ^2 (M_W, $\sin^2\theta_{\text{eff}}$, Γ_Z, M_h, $(g-2)_\mu$, BR($b \to s\gamma$) and other BPO)

$\Rightarrow$ larger regions o.k.

Impact of BPO on plane 2:

$\mathrm{BR}(b \to s\gamma)$ $\mathrm{BR}(B_s \to \mu^+\mu^-)$

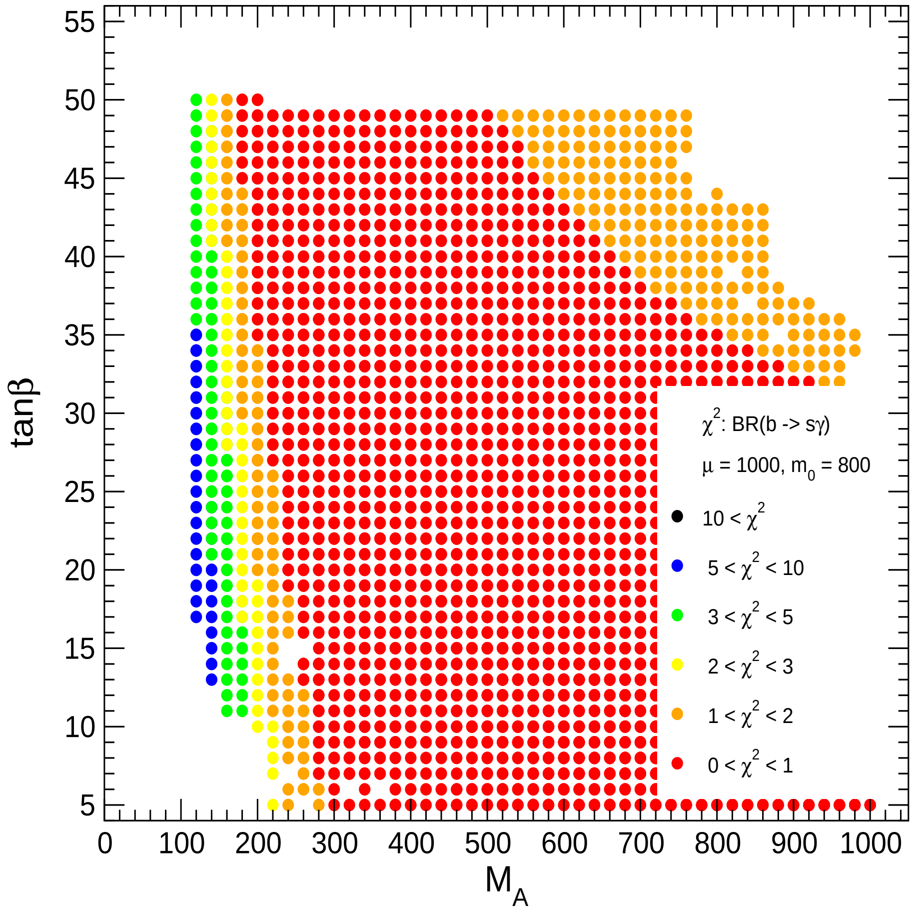




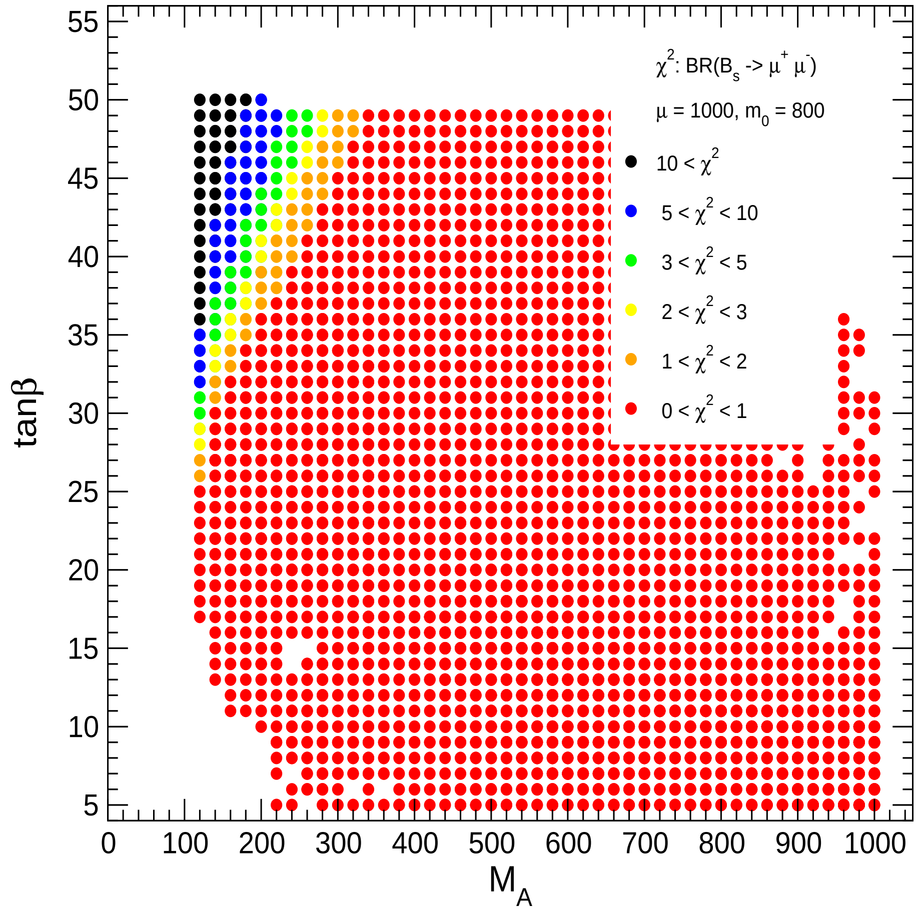
$\Rightarrow$ so far mostly "mild" impact

Impact of BPO on plane 3:

$\mathrm{BR}(b \to s\gamma)$

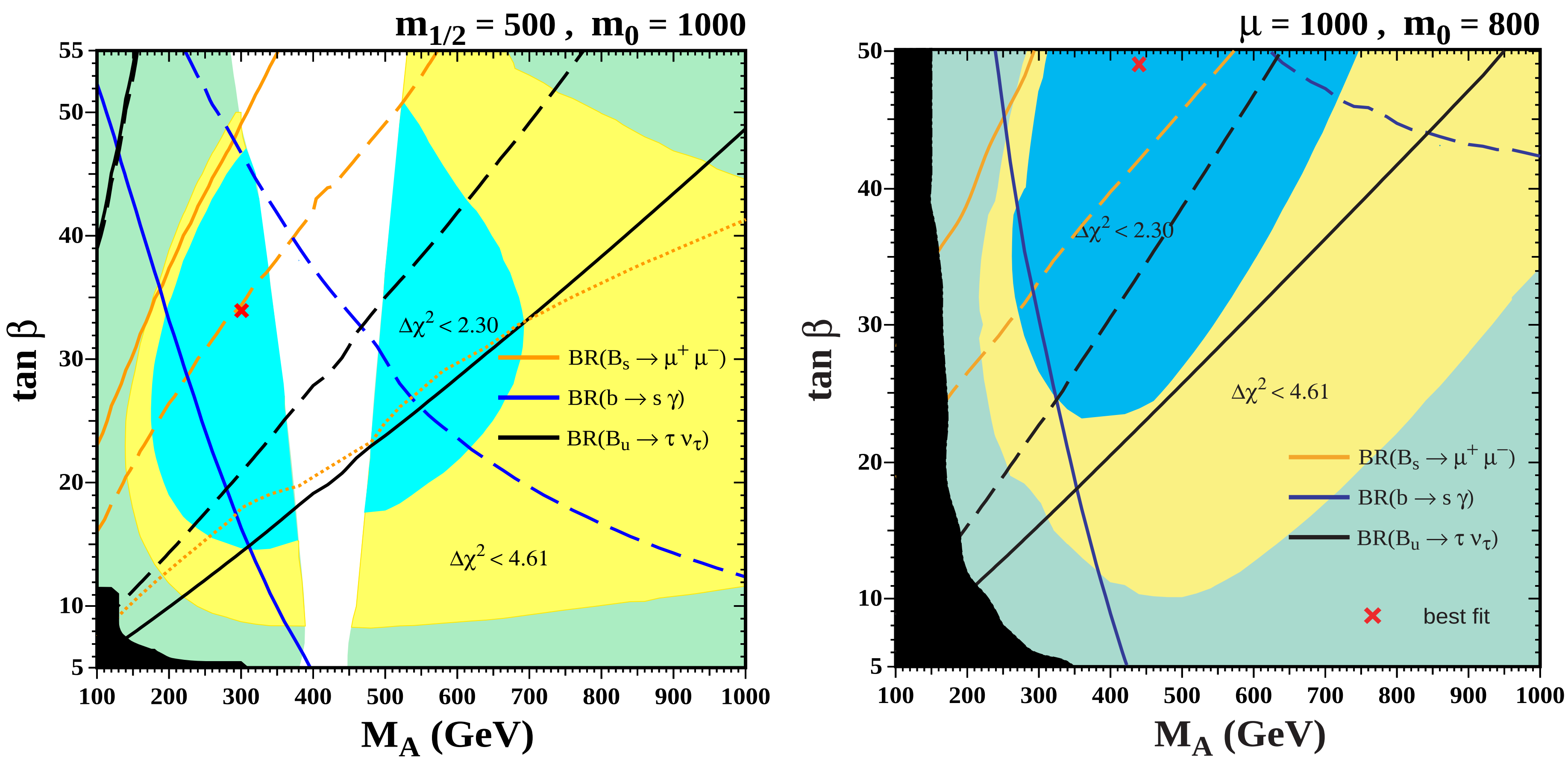


$\mathrm{BR}(B_s \to \mu^+\mu^-)$



$\Rightarrow$ so far mostly "mild" impact

Future prospects:

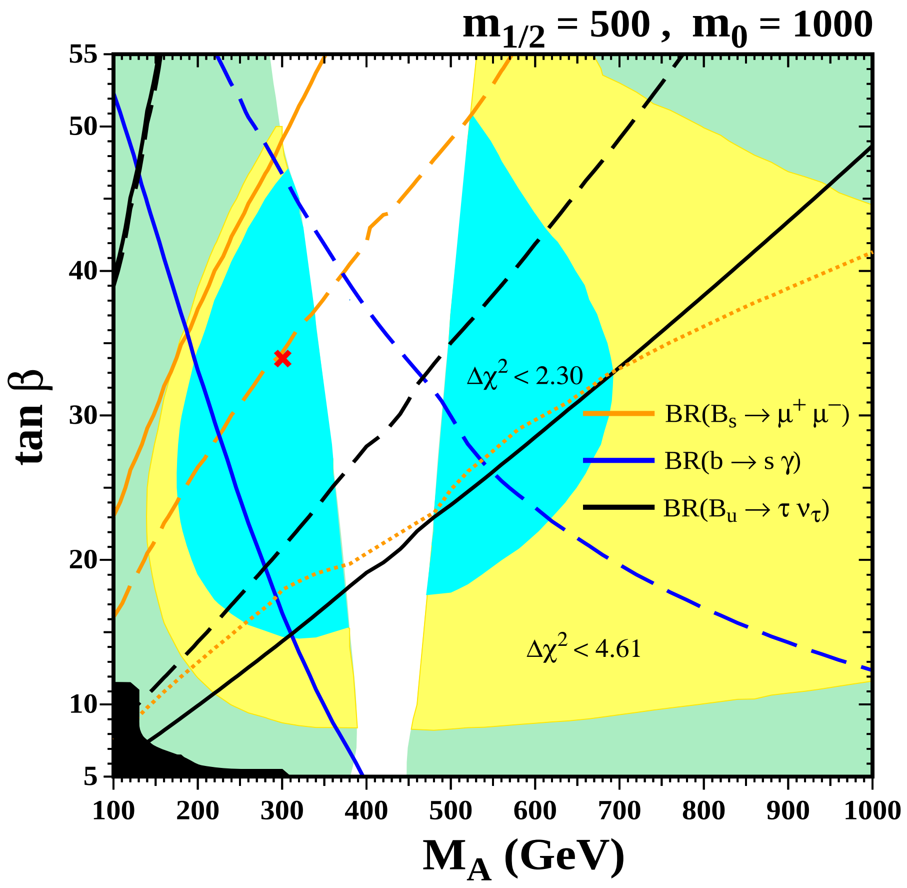


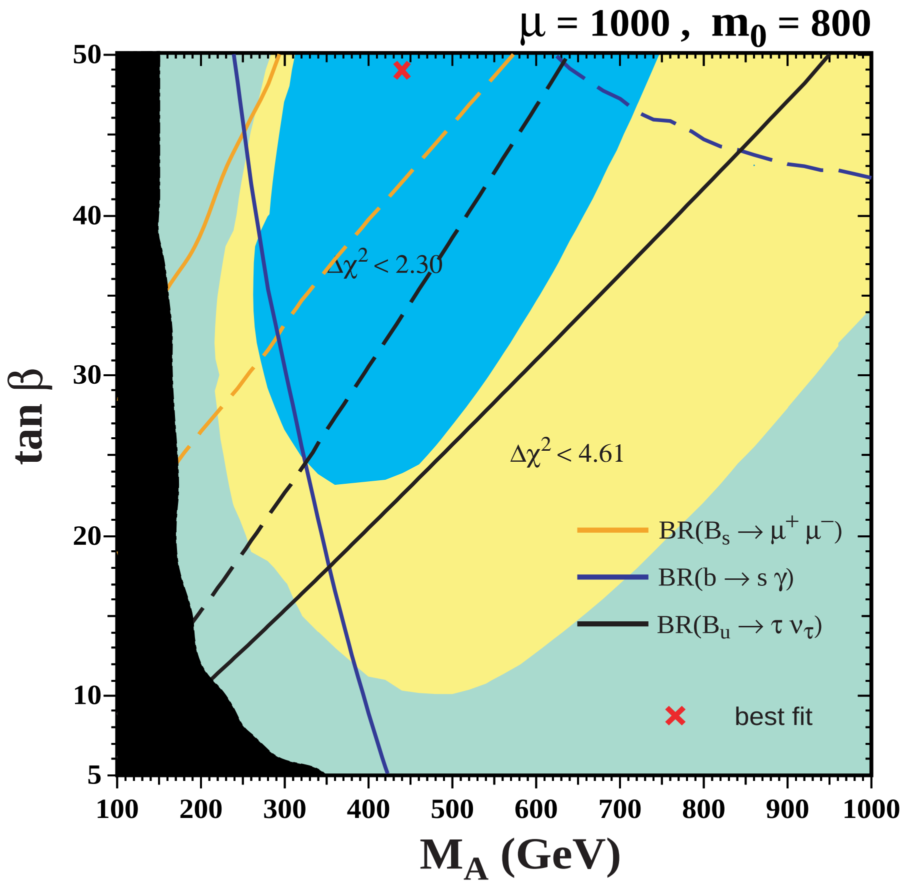
$\text{BR}(B_s \to \mu^+\mu^-) = 1.0(0.2) \times 10^{-7}$ [, LHCb]

$\text{BR}(b \to s\gamma) = 4.0(3.0) \times 10^{-4}$

$\text{BR}(B_u \to \tau\nu_\tau) = 0.9(0.7)$

Future prospects:





$\Rightarrow$ Improvement in precision for BPO is needed!
Improvement in precision for BPO will help a lot!

5. Conclusinos

- EWPO and BPO and CDM can give valuable information on the underlying Lagrangian

- Combination makes only sense in GUT based models

- CMSSM: (free parameters: $m_{1/2}$, m_0, A_0, $\tan\beta$)
  - slight tension between EWPO and BPO
    BPO not yet precise enough . . .
  - EWPO fit for M_h similar to "blue band" in the SM,
    but including BR($b \to s\gamma$) , $(g-2)_\mu$ and CDM:
    $\Rightarrow M_h = 110^{+8}_{-10} \pm 3$ GeV
    $\Rightarrow$ impact of BPO still small

- NUHM: (effectively M_A and μ as additional free parameters)
  - M_A–$\tan\beta$ planes in agreement with CDM possible
  - impact of BPO so far "mild"
  - good future prospects , especially for LHCb