Higgs-Boson Phenomenology in the NUHM

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based on collaborations with
J. Ellis, T. Hahn, K. Olive and *G. Weiglein*

1. Introduction: NUHM benchmark planes
2. Phenomenology of the NUHM benchmark planes
3. Implementation into FeynHiggs
4. The CDF $\tau^+\tau^-$ "excess" at ~ 160 GeV
5. Conclusions

1. Introduction: NUHM benchmark planes

Enlarged Higgs sector: Two Higgs doublets

$$H_1 = \begin{pmatrix} H_1^1 \\ H_1^2 \end{pmatrix} = \begin{pmatrix} v_1 + (\phi_1 + i\chi_1)/\sqrt{2} \\ \phi_1^- \end{pmatrix}$$

$$H_2 = \begin{pmatrix} H_2^1 \\ H_2^2 \end{pmatrix} = \begin{pmatrix} \phi_2^+ \\ v_2 + (\phi_2 + i\chi_2)/\sqrt{2} \end{pmatrix}$$

$$V = m_1^2 H_1 \bar{H}_1 + m_2^2 H_2 \bar{H}_2 - m_{12}^2 (\epsilon_{ab} H_1^a H_2^b + \text{h.c.})$$

$$+ \underbrace{\frac{g'^2 + g^2}{8}} (H_1 \bar{H}_1 - H_2 \bar{H}_2)^2 + \underbrace{\frac{g^2}{2}} |H_1 \bar{H}_2|^2$$

gauge couplings, in contrast to SM

physical states: $h^0, H^0, A^0, H^\pm$ Goldstone bosons: $G^0, G^\pm$

Input parameters: (to be determined experimentally)

$$\tan\beta = \frac{v_2}{v_1}, \qquad M_A^2 = -m_{12}^2 (\tan\beta + \cot\beta)$$

Search for the MSSM Higgs bosons:

$\to$ investigate benchmark scenarios:

> $\to$ Vary only M_A and $\tan\beta$
> $\to$ Keep all other SUSY parameters fixed

1. $m_h^{\rm max}$ scenario:
   $\to$ obtain conservative $\tan\beta$ exclusion bounds ($X_t = 2\,M_{\rm SUSY}$)
2. no-mixing scenario
   $\to$ no mixing in the scalar top sector ($X_t = 0$)
3. small $\alpha_{\rm eff}$ scenario
   $\to$ $hb\bar{b}$ coupling $\sim \sin\alpha_{\rm eff}/\cos\beta$ can be zero: $\alpha_{\rm eff} \to 0$:
   main decay mode vanishes, important search channel vanishes
4. gluophobic Higgs scenario
   $\to$ hgg coupling is small: main LHC production mode vanishes

[*M. Carena, S.H., C. Wagner, G. Weiglein '02*]

$\to$ included in FeynHiggs for a long time

Possible external constraints:

- cold dark matter (CDM)
- BR($b \to s\gamma$)
- anomalous magnetic moment of the μ
  (reason for change from $\mu = -200$ GeV $\to$ $\mu = +200$ GeV)

$\Rightarrow$ so far ignored (for (good) reasons)

Wanted: M_A–$\tan\beta$ planes in agreement with CDM

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Possible models:

1.) CMSSM (or mSUGRA):

$\Rightarrow$ Scenario characterized by

$$m_0,\ m_{1/2},\ A_0,\ \tan\beta,\ \text{sign}\,\mu$$

$\Rightarrow$ too restricted

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

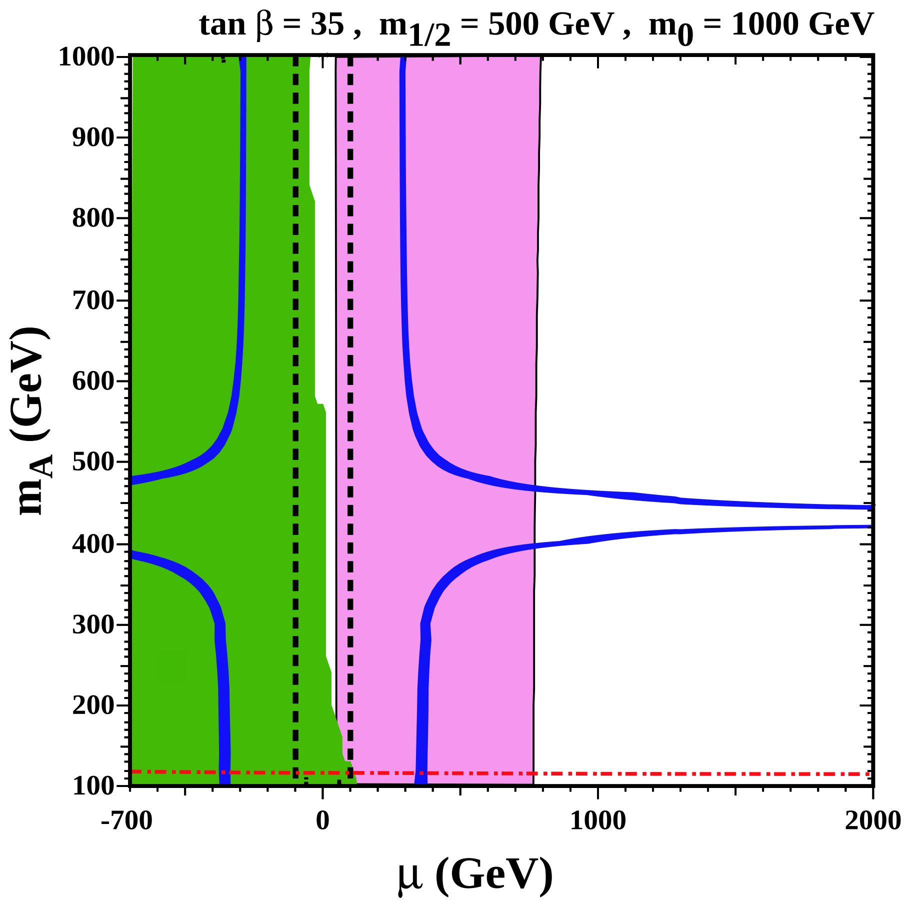
Assumption: no unification of scalar fermion and scalar Higgs parameters at the GUT scale

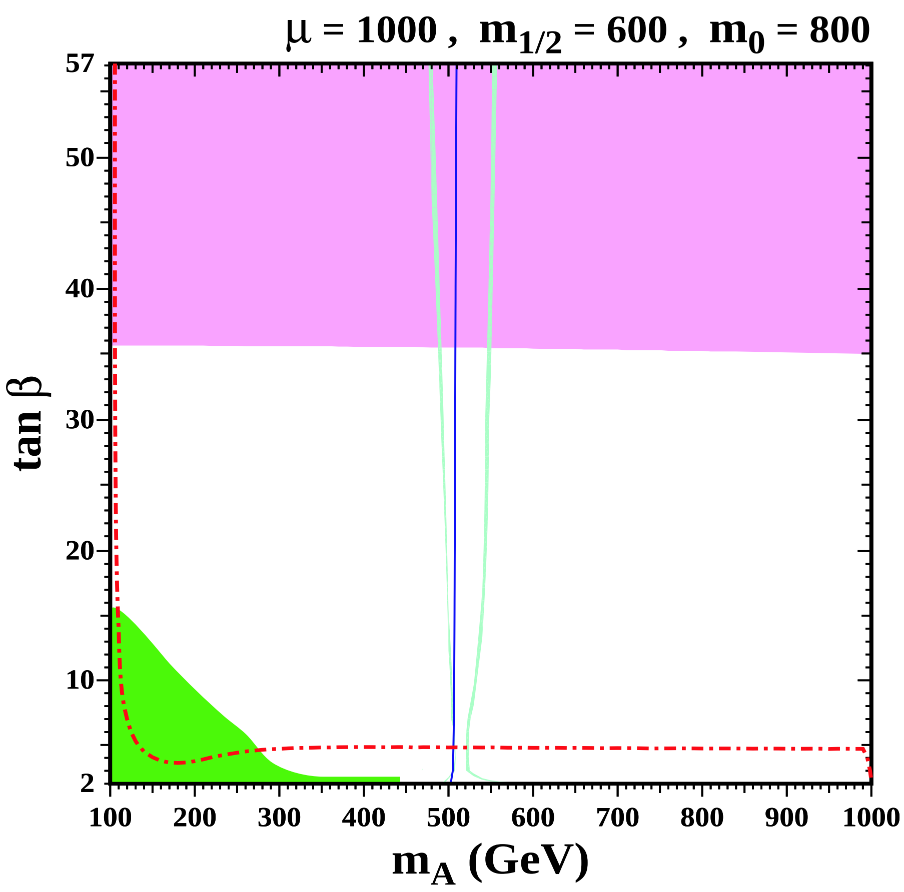
$\Rightarrow$ effectively M_A and μ free parameters at the EW scale

$\Rightarrow$ besides the CMSSM parameters

M_A and μ

Two different NUHM planes:





$\mu \gtrsim 1/2\, m_{1/2}$ $\qquad$ $m_{1/2} \approx M_A$

⇒ two "mechanisms"

⇒ adjust parameters accordingly

⇒ four planes

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⇒ four planes

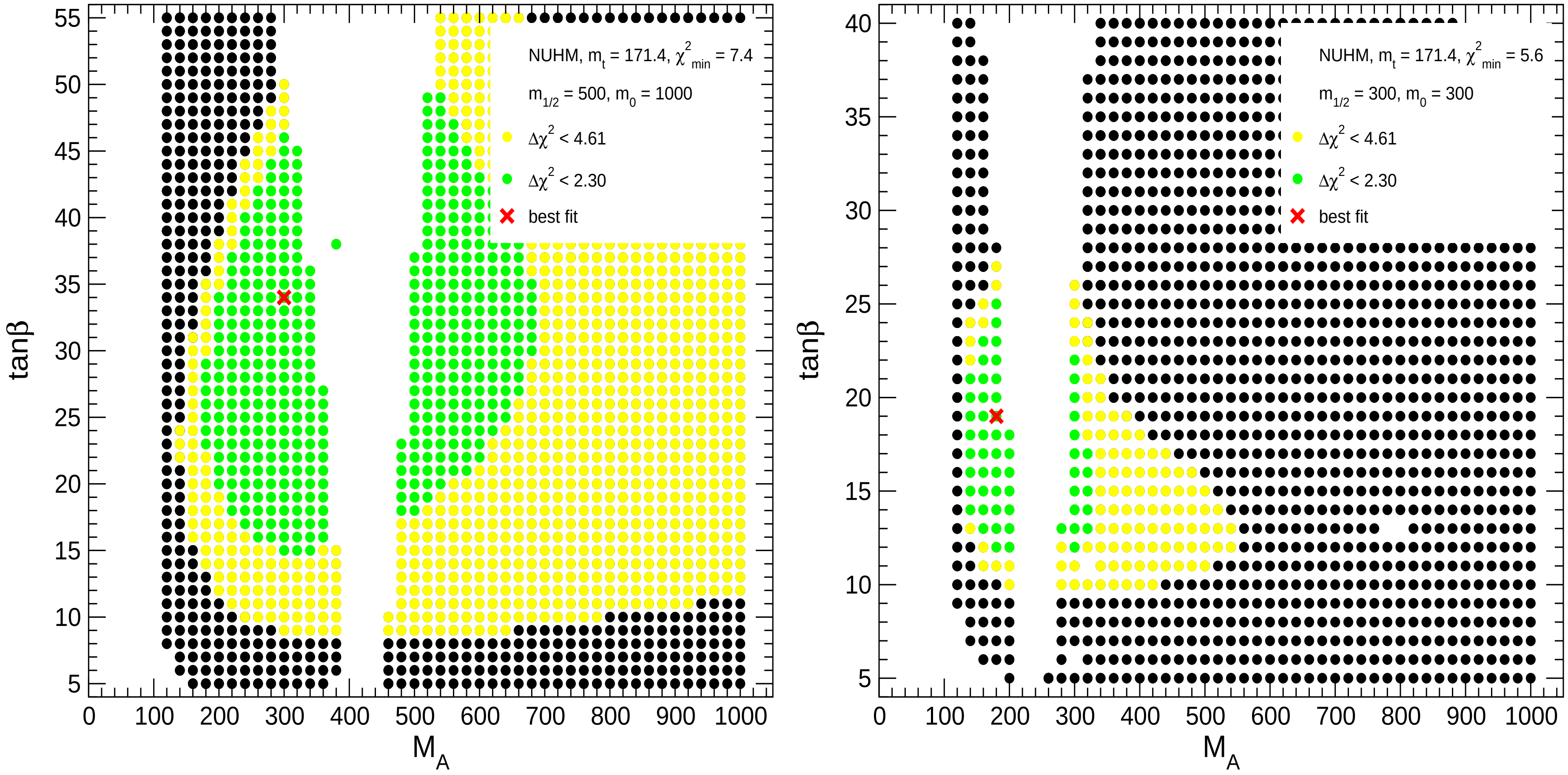
	$m_{1/2}$	m_0	A_0	μ	$\chi^2_{\rm min}$
Plane # 2	500	1000	0	200 ... 400	7.4
Plane # 4	300	300	0	200 ... 350	5.6
Plane # 3	$\sim \frac{9}{8} M_A$	800	0	1000	7.1
Plane # 5	$\sim 1.2 M_A$	300	0	800	3.5

larger variation in $m_{1/2}$, m_0 ⇒ variation in phenomenology

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

Results: NUHM: planes 2,4

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



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

$\Rightarrow$ larger regions o.k.

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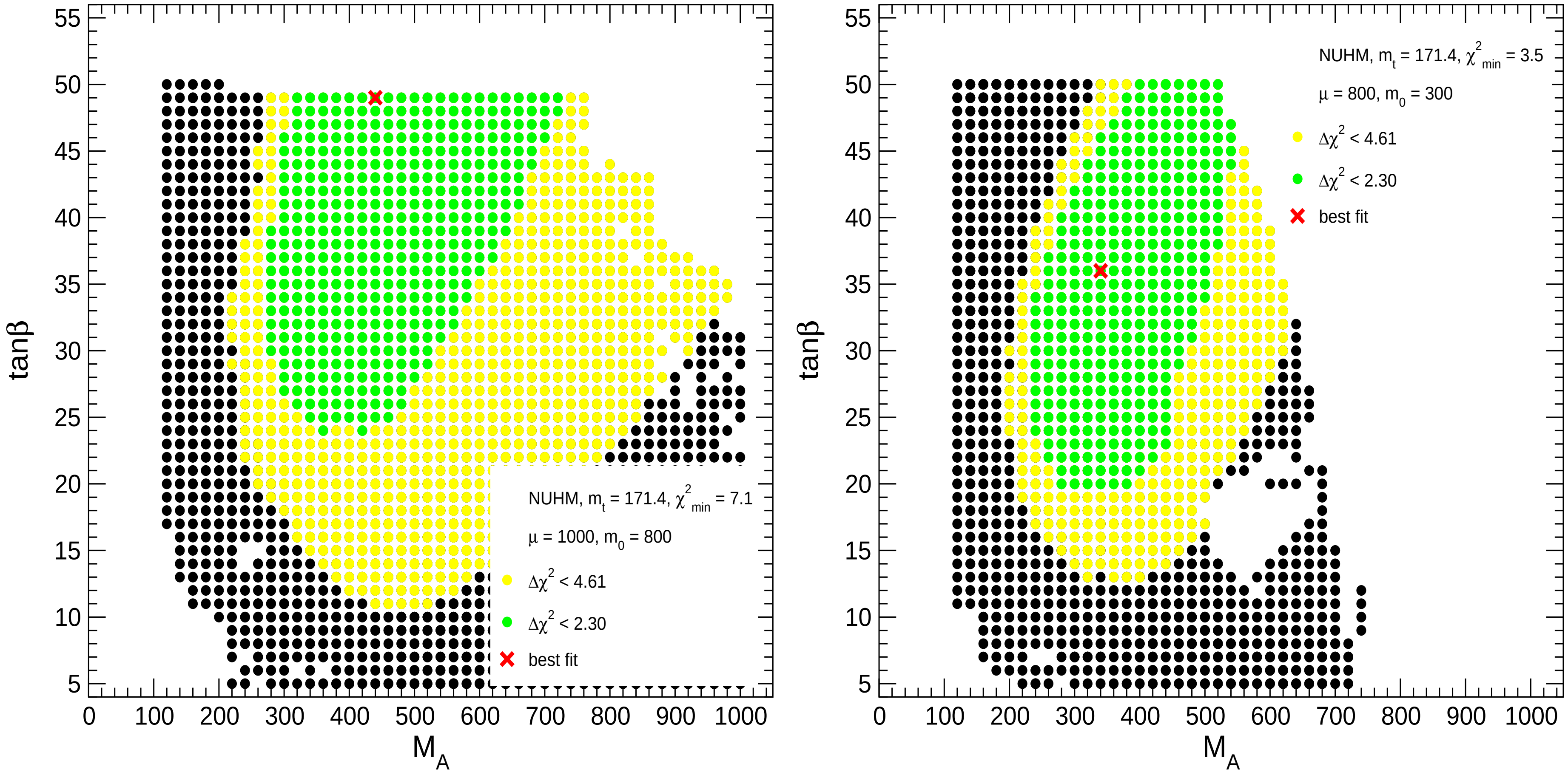

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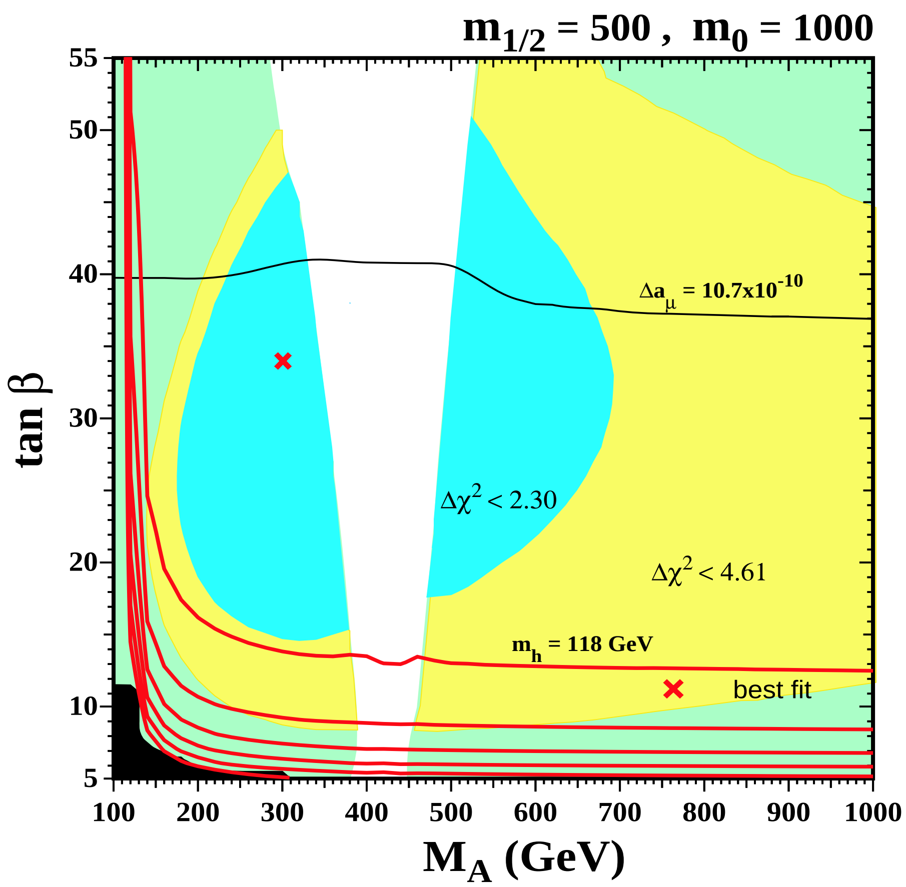
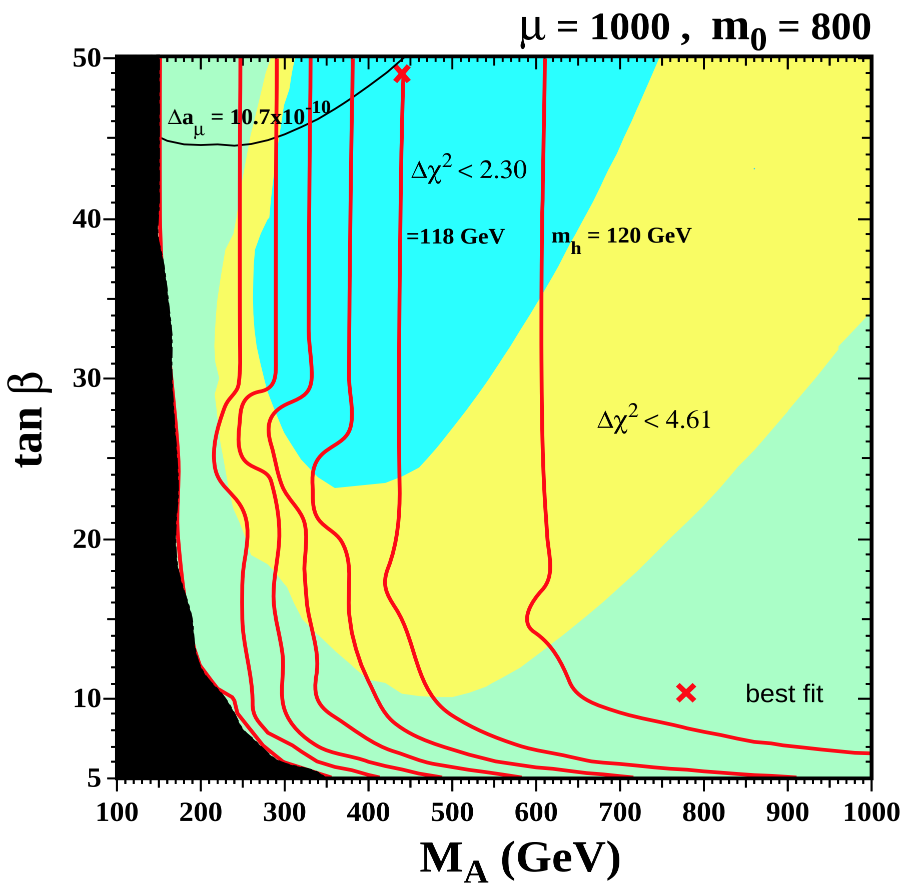
2. Phenomenology of the NUHM benchmark planes

1. Electroweak precision observables
2. B physics observables
3. Tevatron prospects
4. LHC: SM-like Higgs boson search
5. LHC: heavy MSSM Higgs boson searches
6. ILC: deviations in Higgs branching ratios
7. Direct detection of Cold Dark Matter

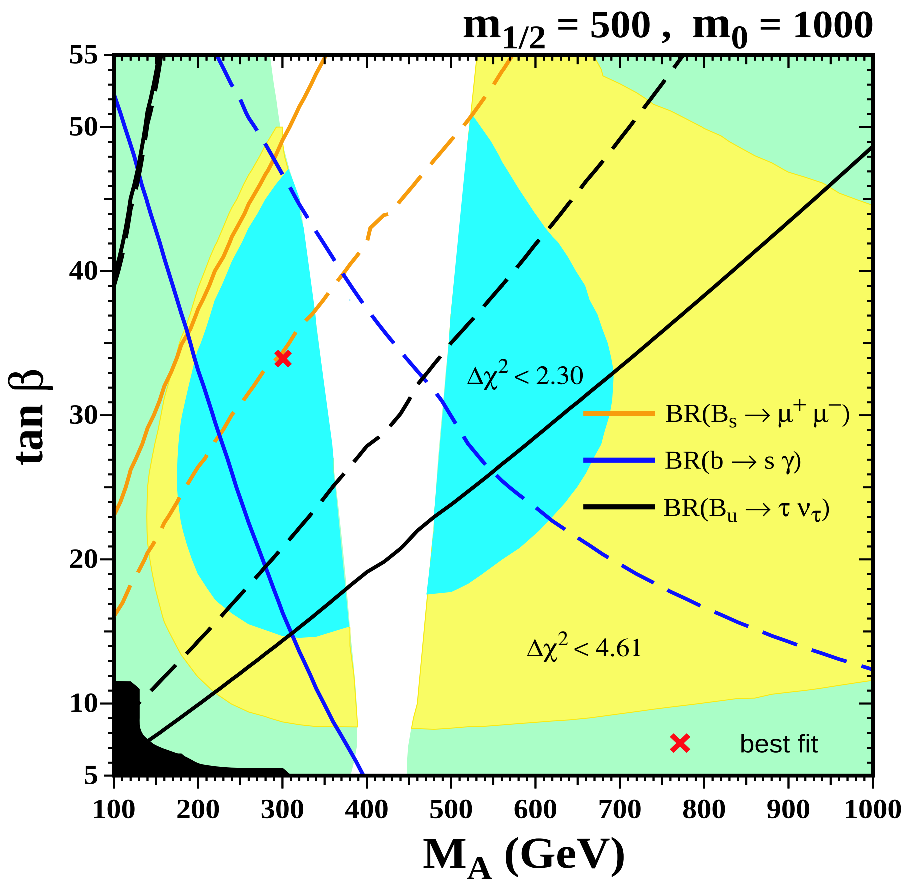
1. Electroweak precision observables

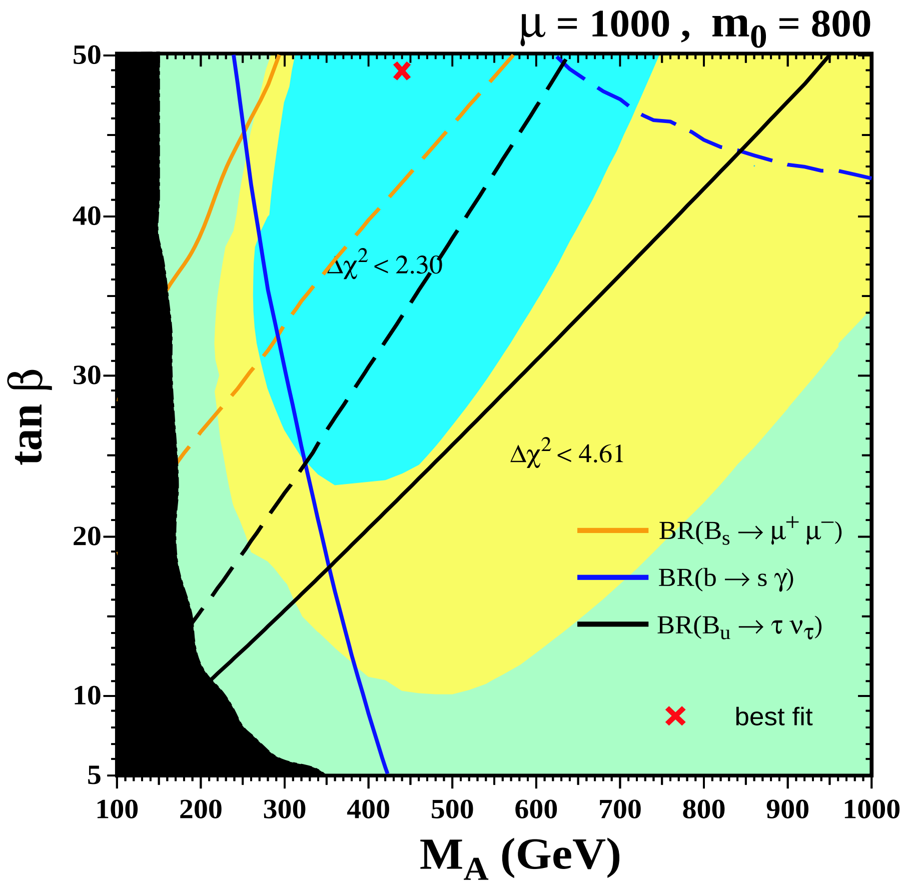




$\Rightarrow M_h$ and $(g-2)_\mu$ ok

2. B physics observables



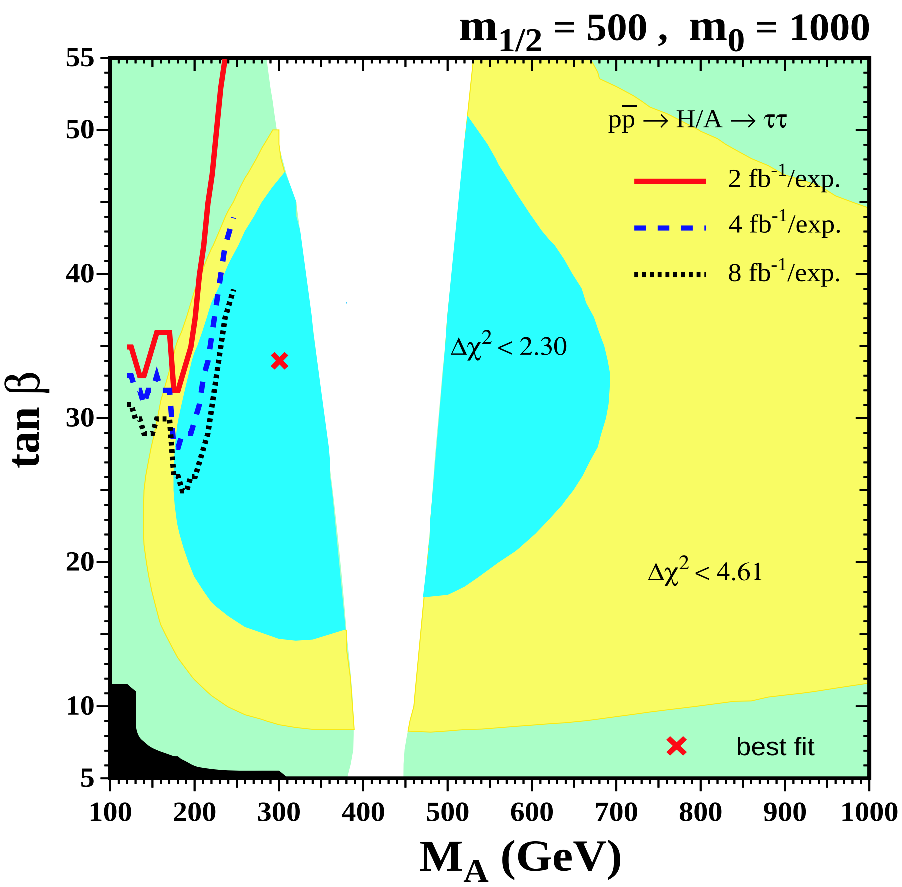


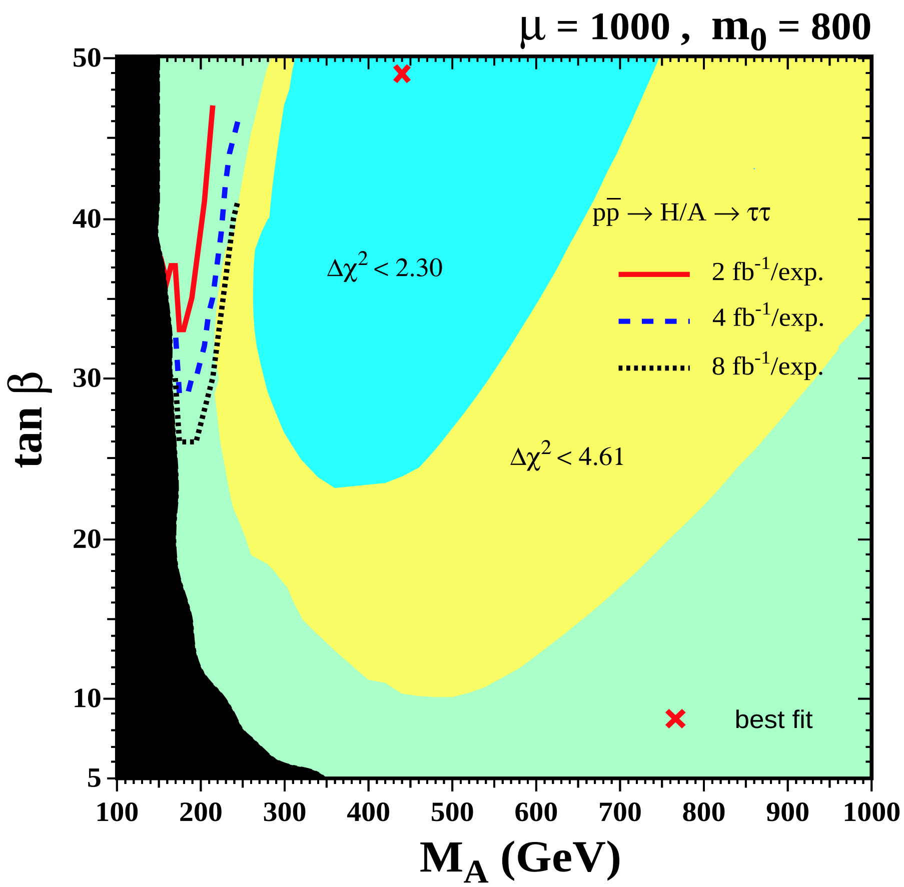
$\text{BR}(B_s \to \mu^+\mu^-) = 1.0(0.2) \times 10^{-7}$

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

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

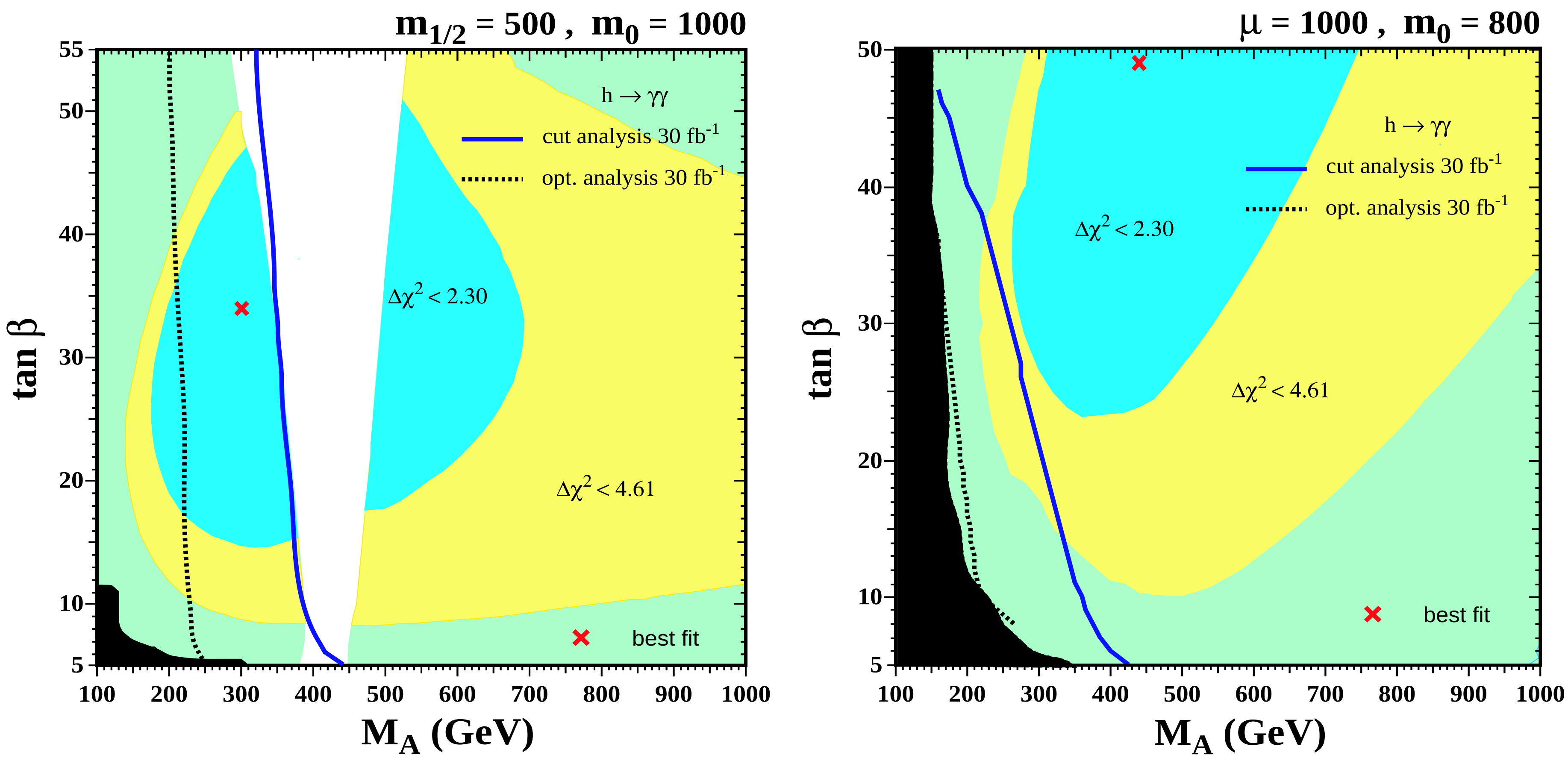
3. Tevatron prospects





⇒ Tevatron starts to probe the interesting regions

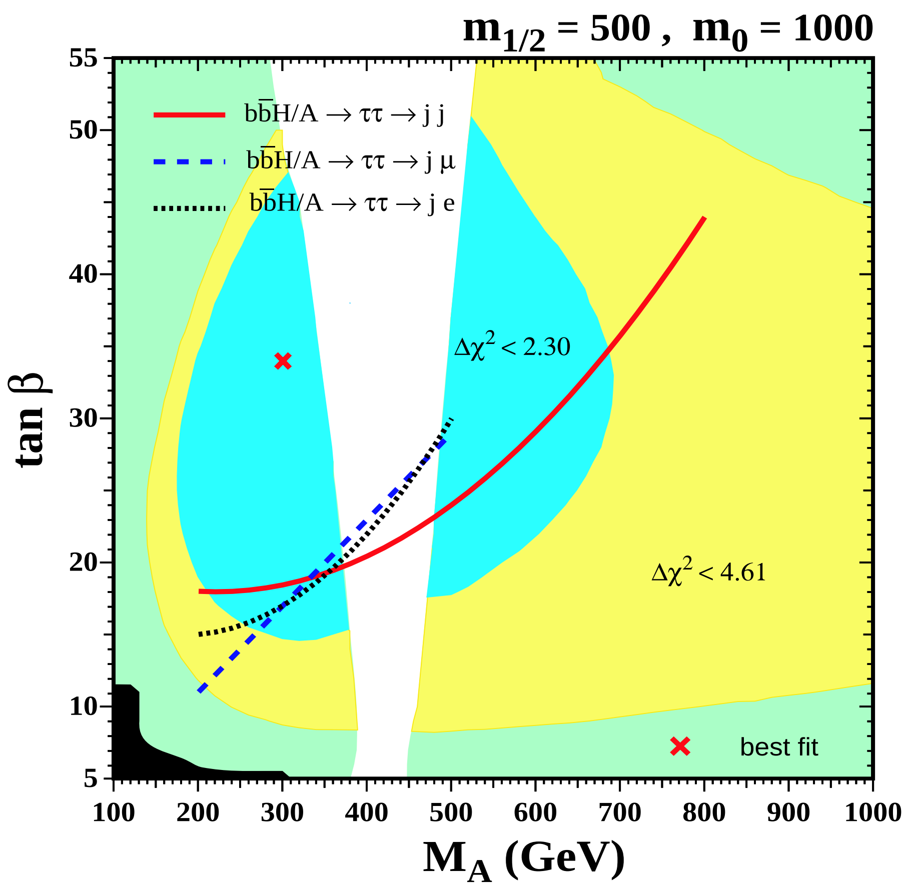
4. LHC: SM-like Higgs boson searches

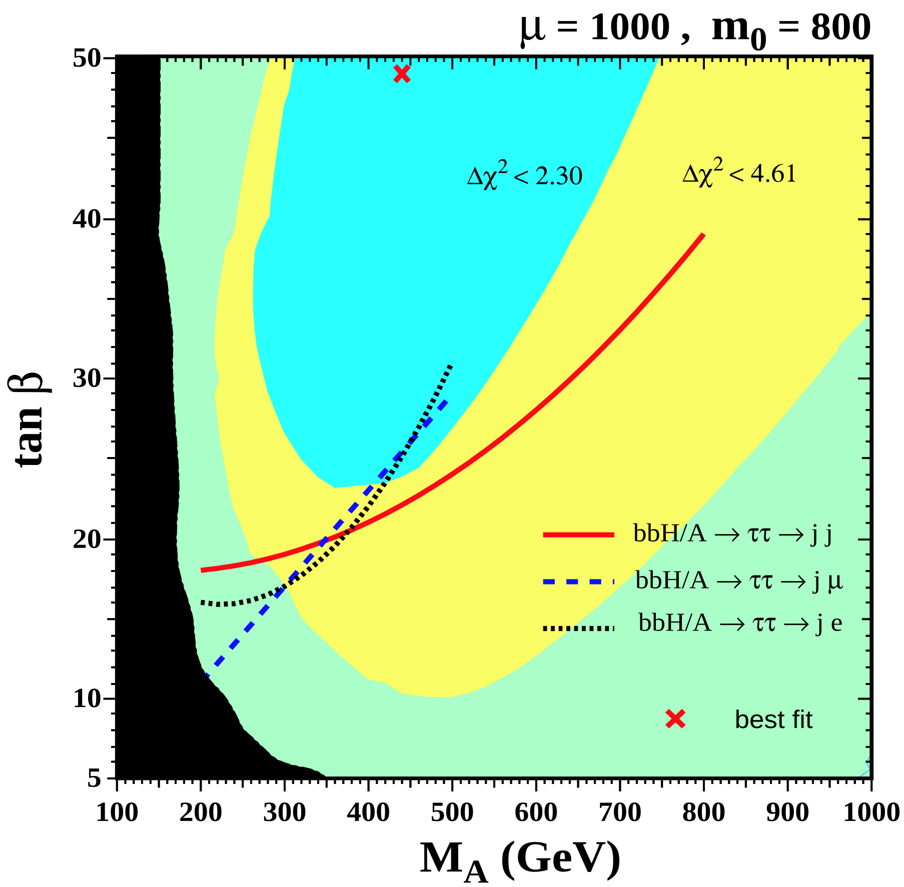


⇒ large parts allow $h \to \gamma\gamma$ detection

⇒ precise measurement of M_h possible

5. LHC: heavy MSSM Higgs boson searches

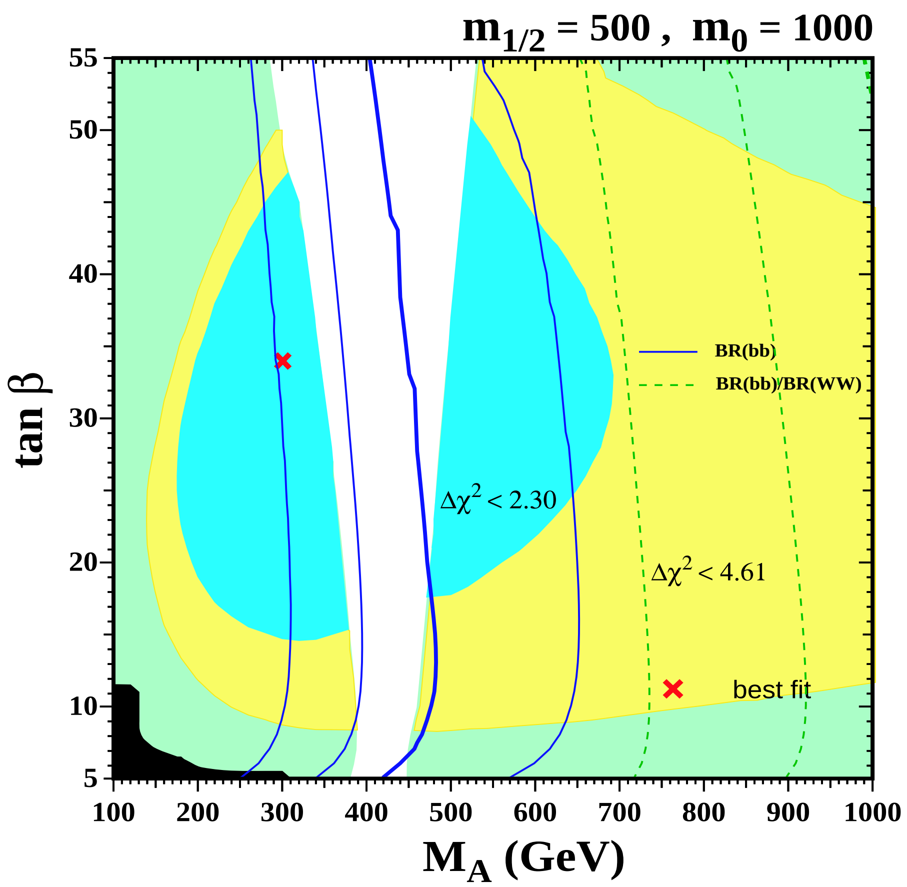


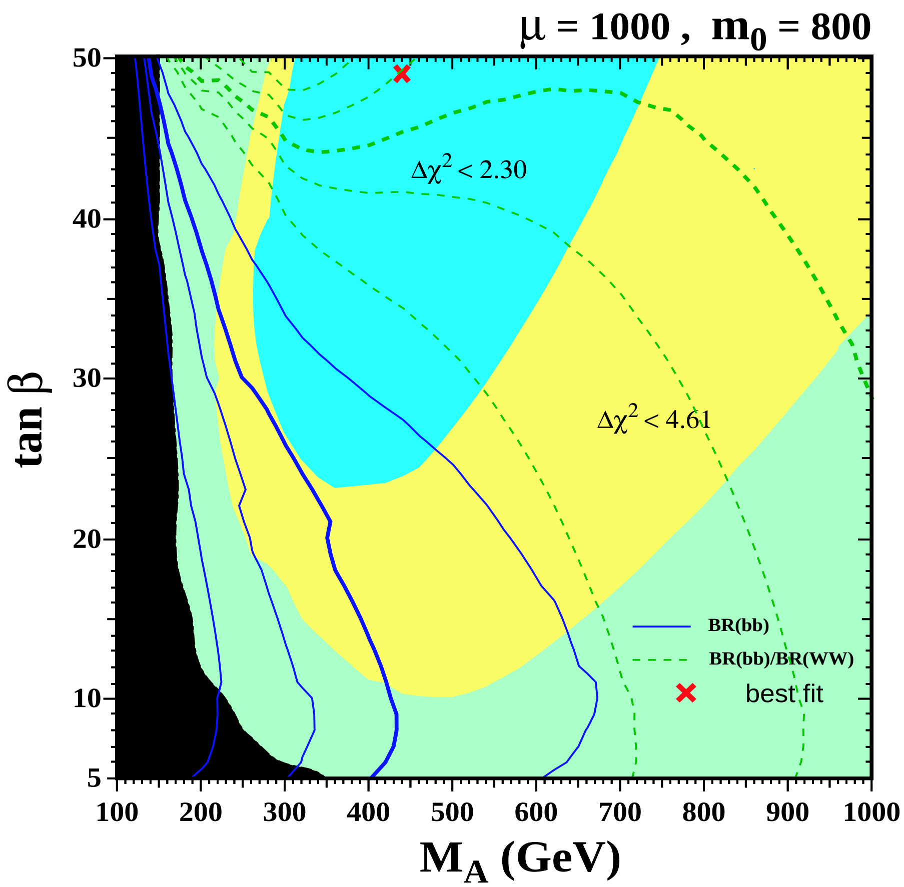


⇒ large parts are covered with H/A searches

⇒ precise measurement of $M_{H,A}$ possible

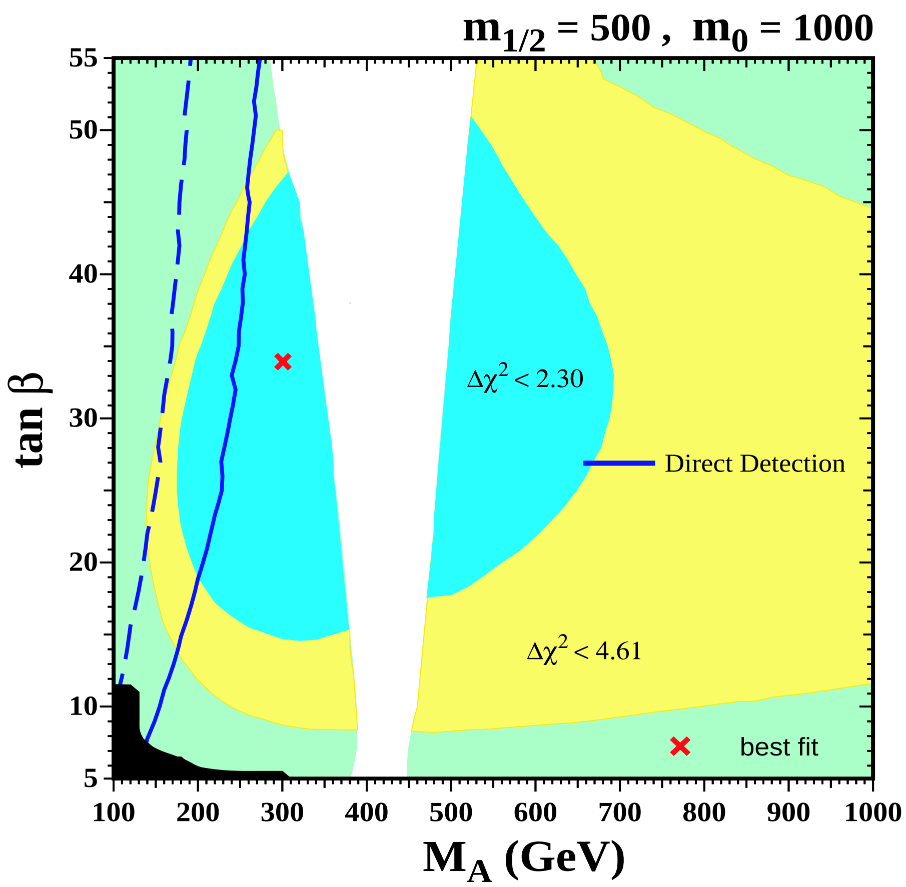
6. ILC: deviations in Higgs branching ratios

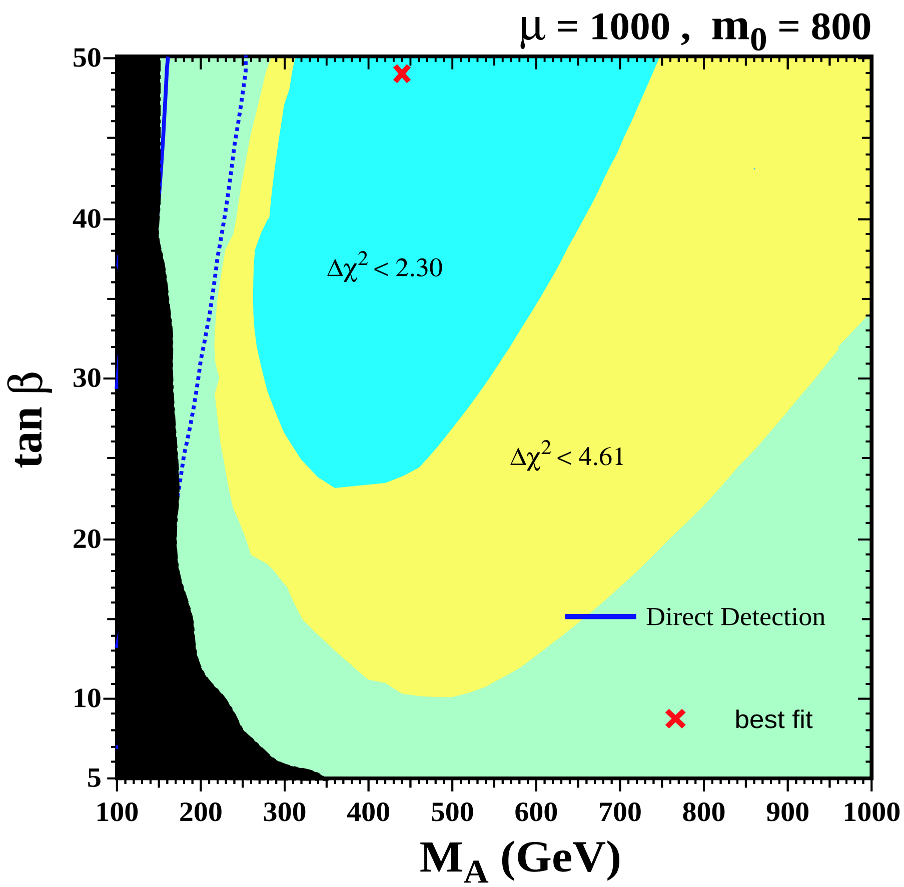




ILC can see BR deviations nearly everywhere

7. Direct detection of CDM





solid/dashed: XENON10 bounds ⇒ start to probe the planes

dotted: possible future sensitivity

3. Implementation into FeynHiggs

Q: Can YOU do phenomenology with these new benchmarks?

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A: YES!

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A: YES!

They are included in FeynHiggs 2.6.0beta

(released three days ago)

available at `www.feynhiggs.de`

You specify: → see talk by Thomas Hahn

– number of the plane

– M_A and $\tan\beta$

You get:

– all low energy parameters

– Higgs masses and mixings

– all Higgs branching ratios

– all Higgs production cross sections

– further precision observables

New M_A–$\tan\beta$ planes:

Data accessed within FeynHiggs in terms of tables
with a grid for M_A and $\tan\beta$

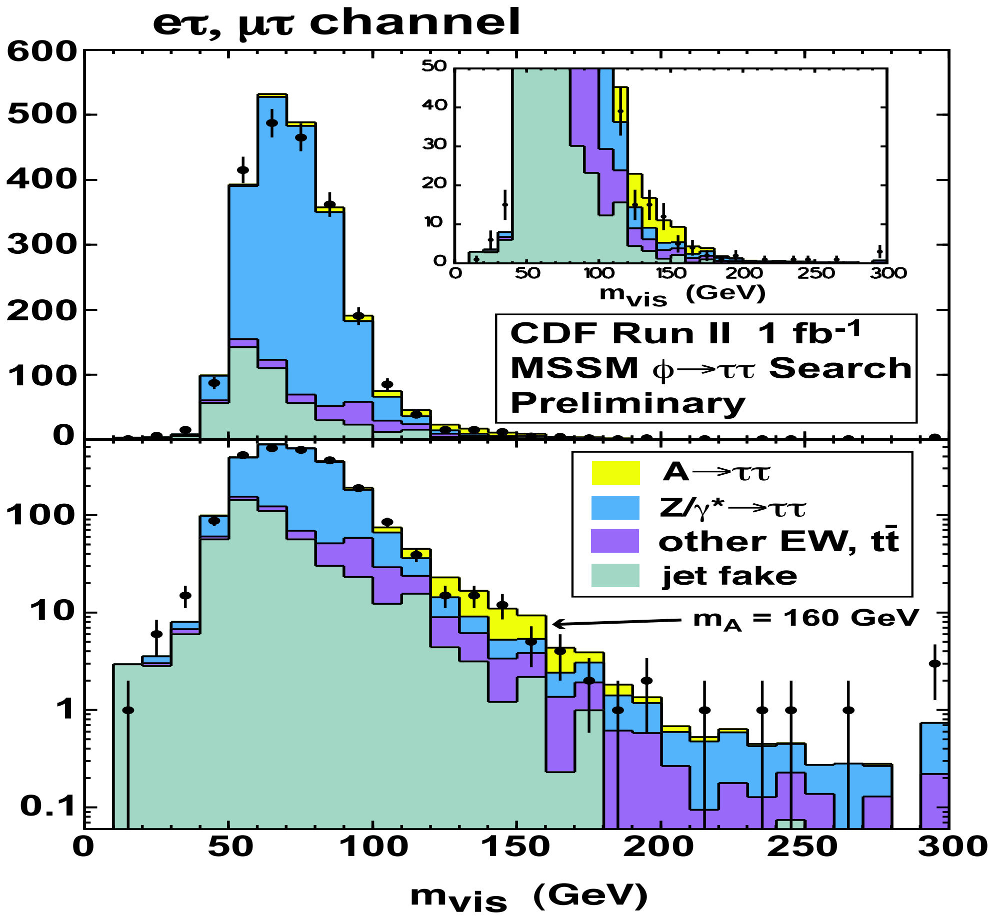
MT	MSUSY	MA0	TB	AT	MUE	...
171.4	500	200	5	1000	761	...
171.4	500	210	5	1000	753	...
⋮	⋮	⋮	⋮	⋮	⋮	⋮
171.4	500	200	6	1000	742	...
171.4	500	210	6	1000	735	...
⋮	⋮	⋮	⋮	⋮	⋮	⋮

FeynHiggs interpolates between the four NWSE points in M_A and $\tan\beta$
FeynHiggs gives an error if $\{M_A, \tan\beta\}$ combination is not allowed

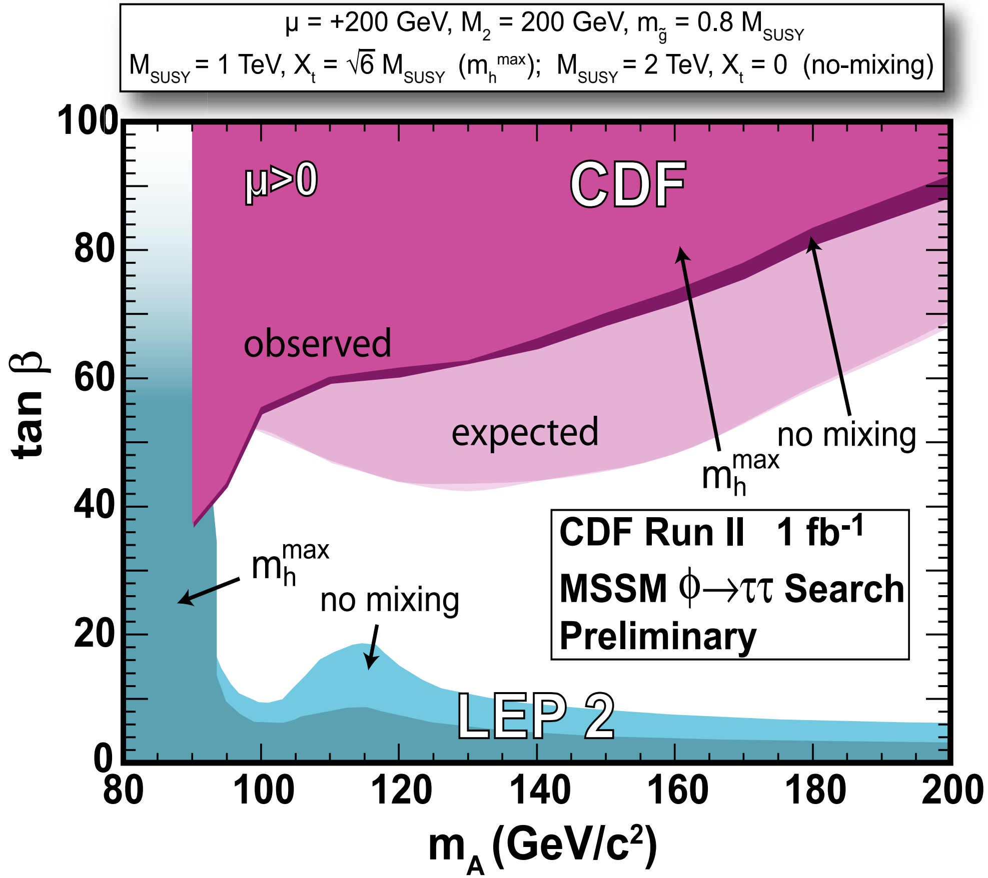
4 M_A–$\tan\beta$ planes can be downloaded from `www.feynhiggs.de`
Definition of new planes by the user is possible (respect table format)

4. The CDF $\tau^+\tau^-$ "excess" at ~ 160 GeV

NUHM compatible with $M_A \approx 160$ GeV, $\tan\beta \gtrsim 45$?



[CDF '07]



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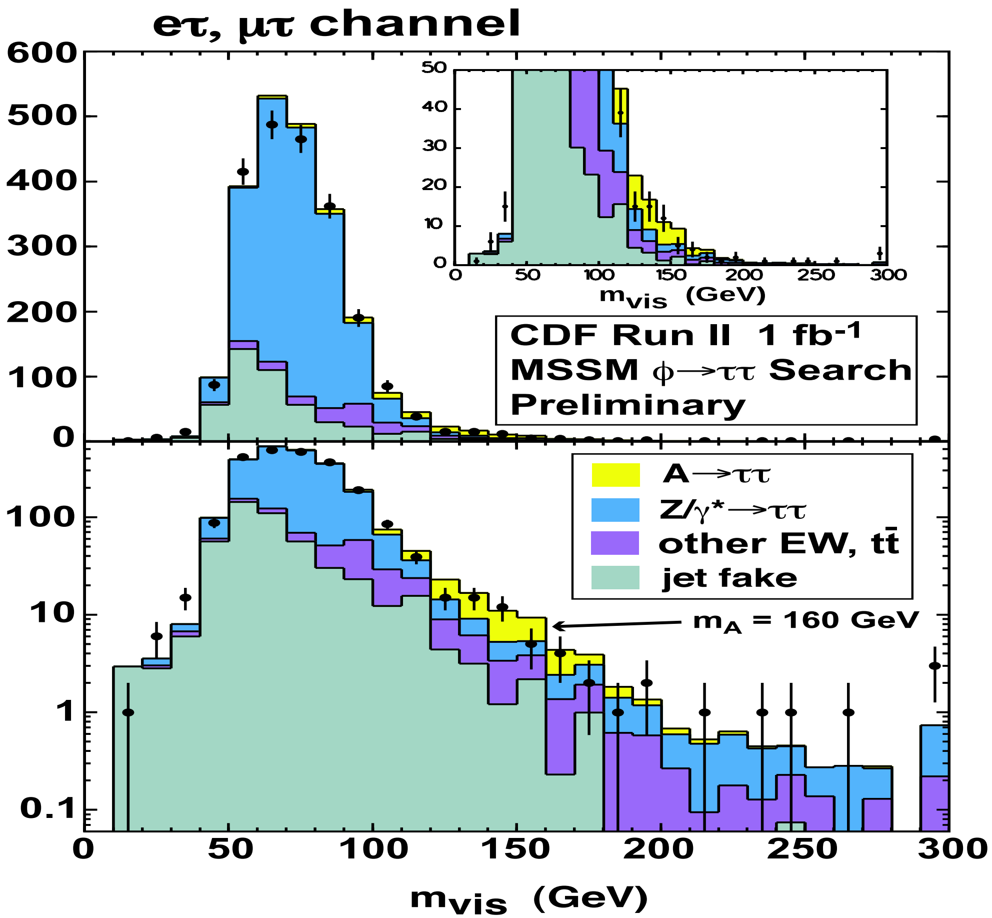
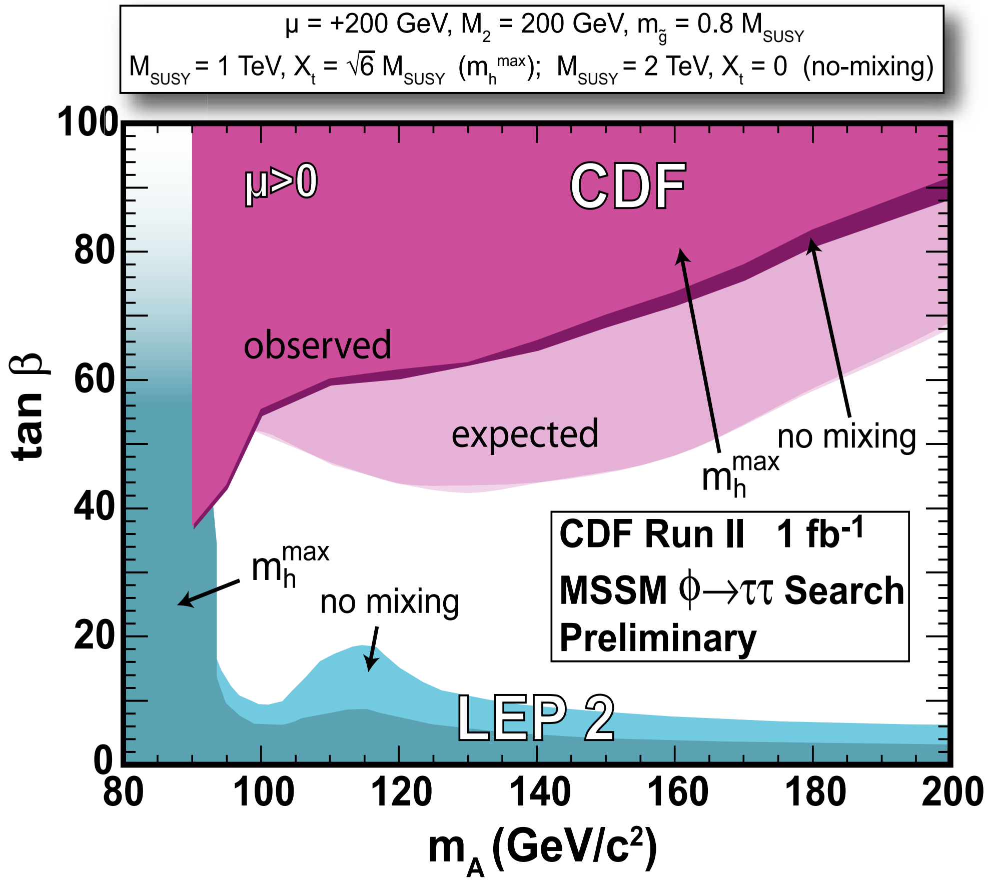


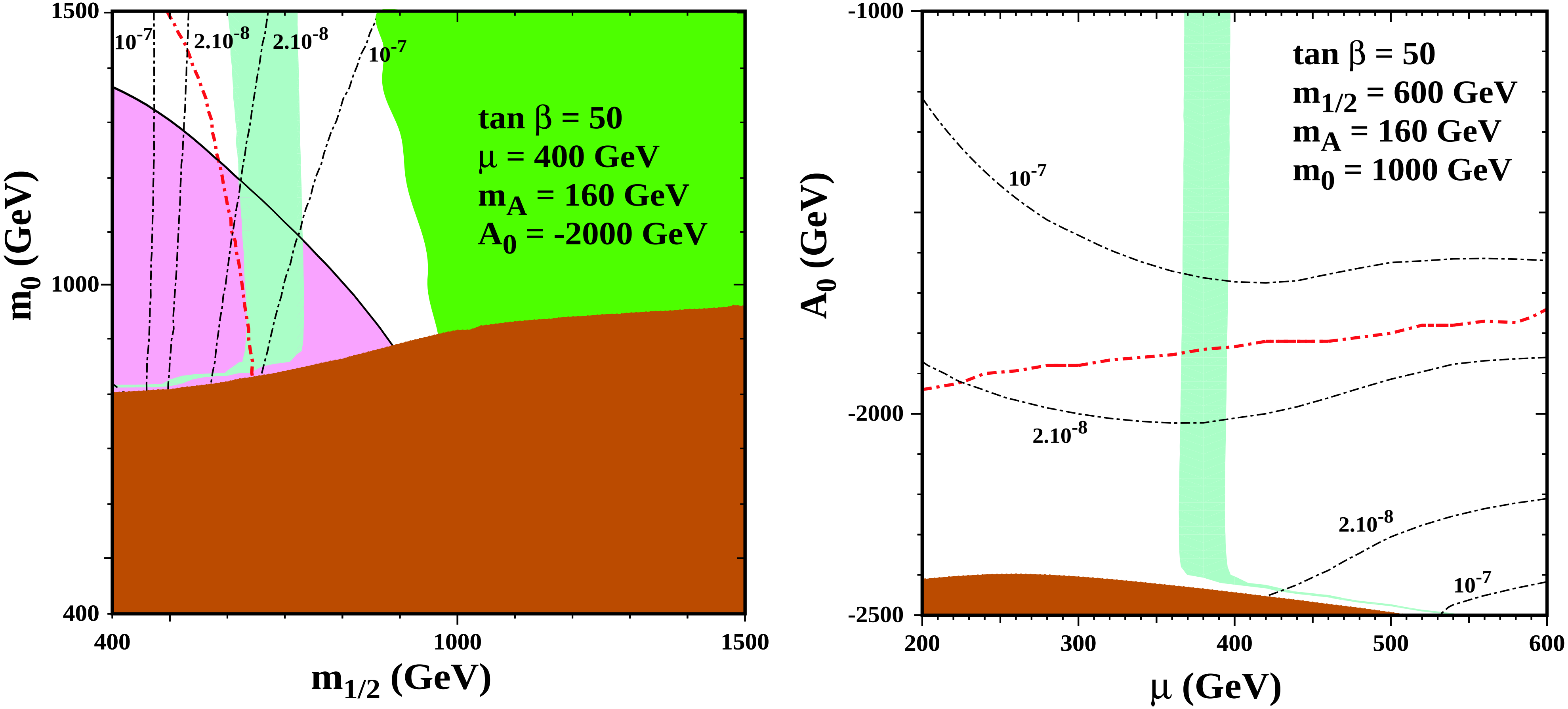


[CDF '07] *[CDF '07]*

YES! With important consequences!

NUHM parameters:

$M_A = 160$ GeV, $\tan\beta = 45$–55
$m_{1/2} \sim 600$ GeV, $m_0 \sim 1000$ GeV, $A_0 \sim -1800$ GeV, $\mu \sim 400$ GeV



[J. Ellis, S.H., K. Olive, G. Weiglein '07]

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YES! With important consequences!

1. lightest Higgs mass: $M_H \lesssim 115$ GeV
2. anomalous magnetic moment of the muon: $\Delta(\text{MSSM} - \text{SM}) \sim 1 - 2\,\sigma$
3. b decay $\text{BR}(b \to s\gamma) = 3.5 - 4.5 \times 10^{-4}$
4. b decay $\text{BR}(B_s \to \mu^+\mu^-) \gtrsim 2 \times 10^{-8}$
5. b decay $\text{BR}(B_u \to \tau\nu_\tau)$: MSSM/SM ≈ 0.33
6. direct detection of dark matter: CDMS or XENON10 should see a signal very soon

5. Conclusinos

- New: M_A–$\tan\beta$ planes in agreement with Cold Dark Matter
- Model: NUHM
  Free parameters: $m_{1/2}$, m_0, A_0, $\tan\beta$, M_A, μ
- Good agreement with:
  M_W, $\sin^2\theta_{\text{eff}}$, Γ_Z, M_h, $(g-2)_\mu$, BR($b \to s\gamma$) and other BPO
- Phenomenology of the NUHM benchmark planes:
  Tevatron: starts to probe interesting regions
  LHC: good coverage for SM-like and heavy Higgs bosons
  ILC: deviations in BR measurements
- YOU can do phenomenology with the benchmark planes:
  implemented into FeynHiggs
- CDF "excess", $M_A \approx 160$ GeV, $\tan\beta \gtrsim 45$:
  Can be realized in the NUHM
  Other (SUSY) signals should appear soon!