MSSM Higgs Bosons at the Tevatron

Patrick Draper
University of Chicago

P. D., Tao Liu, and Carlos E.M. Wagner, arXiv:0905.xxxx

May 18, 2009

Introduction

- The Tevatron reach for the Standard Model Higgs is getting stronger.
- Current exclusion at 95% C.L for
  $160 \text{ GeV} < m_h < 170 \text{ GeV}$
- Current data set is $\approx 6 \text{ fb}^{-1}/\text{experiment}$
- May run for two more years, gaining
  $\approx 2 \text{ fb}^{-1}/\text{experiment}/\text{year}$
- May be able to improve signal efficiencies in some channels.

Goal

What efficiency and luminosity improvements are necessary to constrain large regions of the MSSM Higgs parameter space?

Constraints on m_h in the SM

- Tevatron searches produce constraints on the signal relative to the signal predicted by the SM:

$$\frac{\sigma \times \mathrm{Br}}{\sigma_{SM} \times \mathrm{Br}_{SM}} \leq R^{95}_{SM}$$

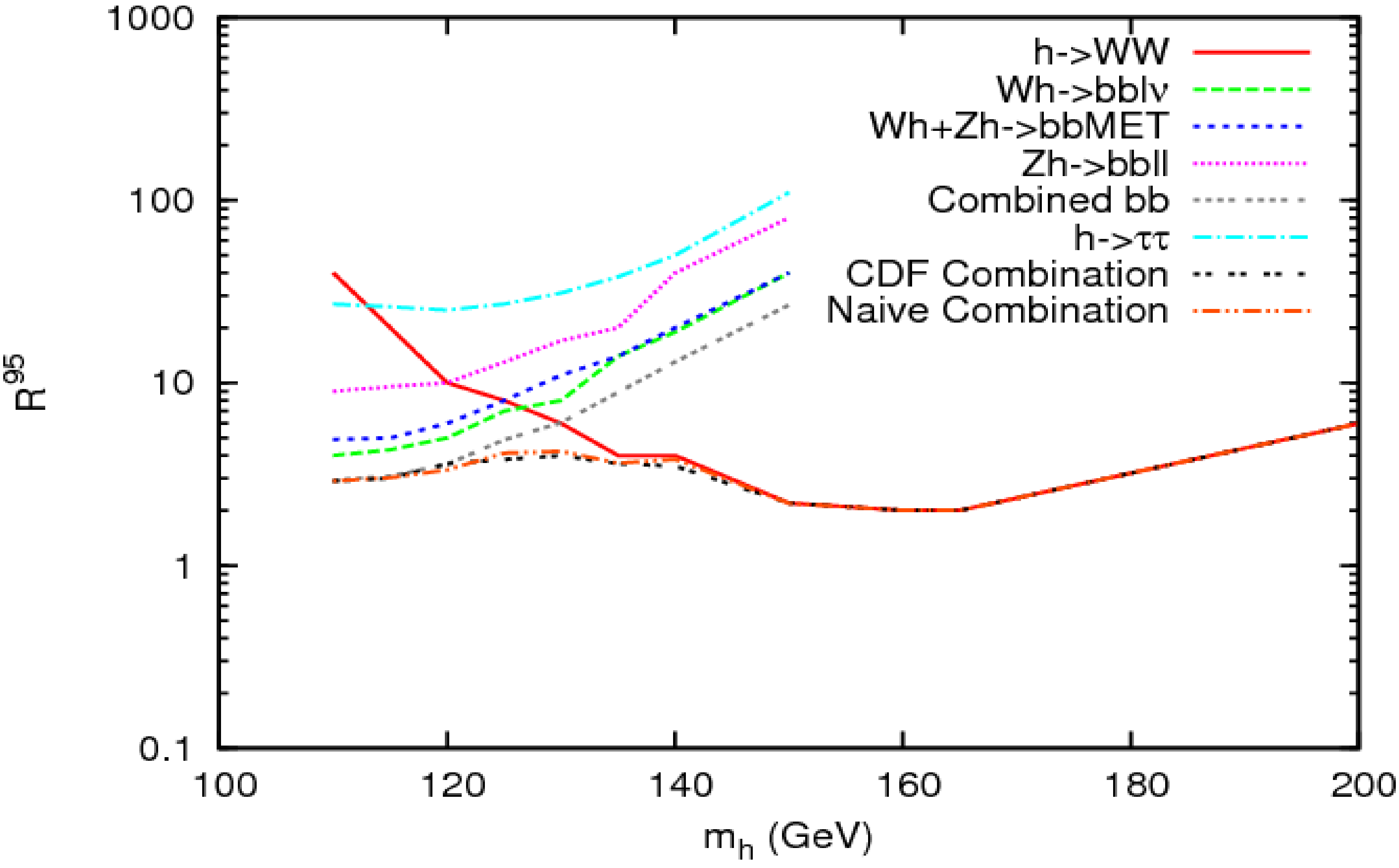
- Can compute naïve expected limits in each channel *i* at 95% C.L. (statistical errors + no signal):

$$R^{95}_{SM,i} = 2 \times \sqrt{b_i}/s_i$$

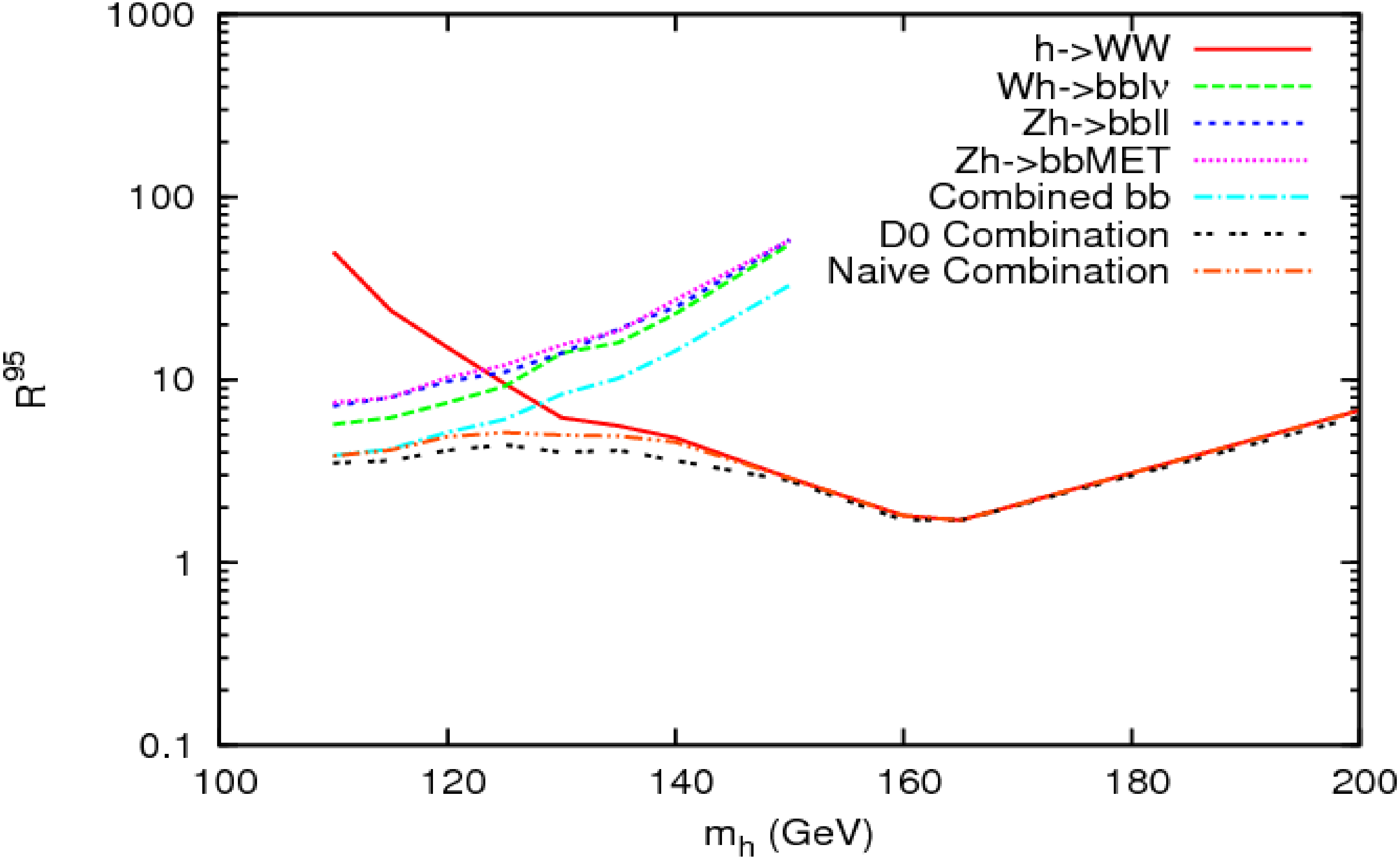
- → Combined expected limit:

$$\frac{1}{(R^{95}_{SM})^2} = \sum_i \frac{1}{(R^{95}_{SM,i})^2}$$

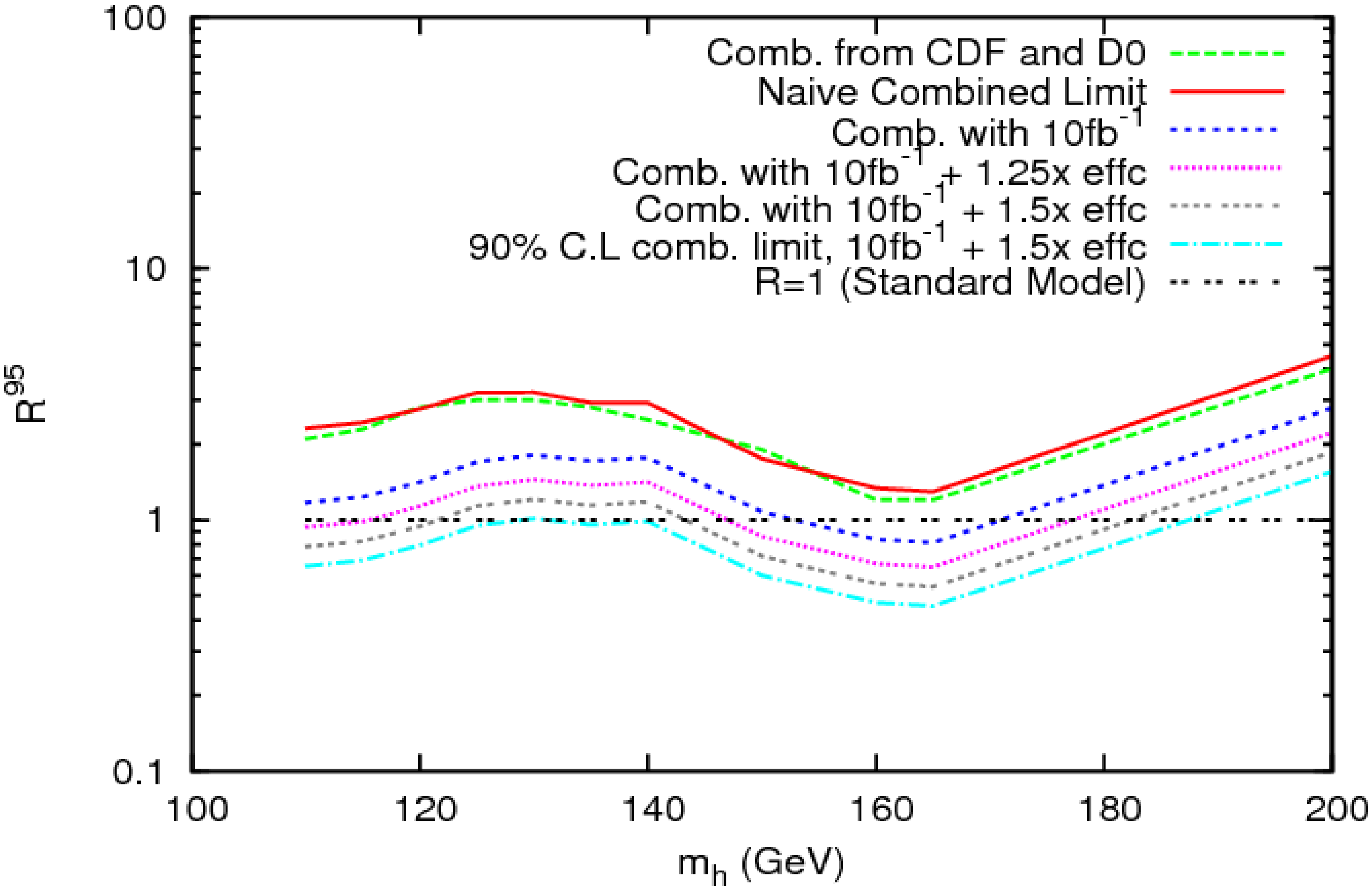
Naïve Combined Limit vs CDF



Naïve Combined Limit vs D0



Naïve Combined Limit vs Limit from CDF + D0



- R^{95}_{SM} scales with luminosity as $L^{-1/2}$ and signal efficiency as e^{-1}

Translating Limits into the MSSM

- Rescale limits from individual channels

$$R^{95}_{MSSM,i} = R^{95}_{SM,i} \times \frac{\sigma_{SM,i} \times \mathrm{Br}_{SM,i}}{\sigma_{MSSM,i} \times \mathrm{Br}_{MSSM,i}}$$

- Allow each channel to go through any MSSM Higgs state:

$$gg \to h \to WW, \; gg \to H \to WW$$

- Recombine. Limit is a function of MSSM parameters.
- Initially, keep separate combined limits from SM-like Higgs search channels and MSSM direct searches to see complementarity.

MSSM Higgs Sector

- Two Higgs Doublets H_1 and H_2 coupling to down-type and up-type fermions, respectively
- Neutral components get vevs

$$\sqrt{v_1^2 + v_2^2} = 174 \text{ GeV} \qquad v_2/v_1 \equiv \tan\beta$$

- 1 CP-odd mass eigenstate *A*, mass m_A
- 2 CP-even states: $\begin{pmatrix} h \\ H \end{pmatrix} = \begin{pmatrix} -\sin\alpha & \cos\alpha \\ \cos\alpha & \sin\alpha \end{pmatrix} \begin{pmatrix} H_1^0 \\ H_2^0 \end{pmatrix}$

$$\frac{m_A^2 + m_Z^2}{m_A^2 - m_Z^2} \cdot (\cot\alpha - \tan\alpha) = (\cot\beta - \tan\beta)$$

Properties of Lightest CP-even *h*

- Tree level: $m_h = \frac{1}{2}\left(m_A^2 + m_Z^2 - \sqrt{(m_A^2 + m_Z^2)^2 - 4m_A^2 m_Z^2 \cos^2 2\beta}\right)$
- → bounded: $m_h \leq m_Z$
- Large radiative corrections: $m_h \lesssim 130 \text{ GeV}$
- Couplings to fermions rescaled relative to the SM:

$$g_{hdd} = -(m_d/v)\frac{\sin\alpha}{\cos\beta} \qquad g_{huu} = (m_u/v)\frac{\cos\alpha}{\sin\beta}$$

- Couplings to gauge bosons rescaled by $\sin^2(\beta - \alpha)$
- Typically up-type, but can be down-type for small m_A
- SM-like gauge and fermion couplings for large m_A

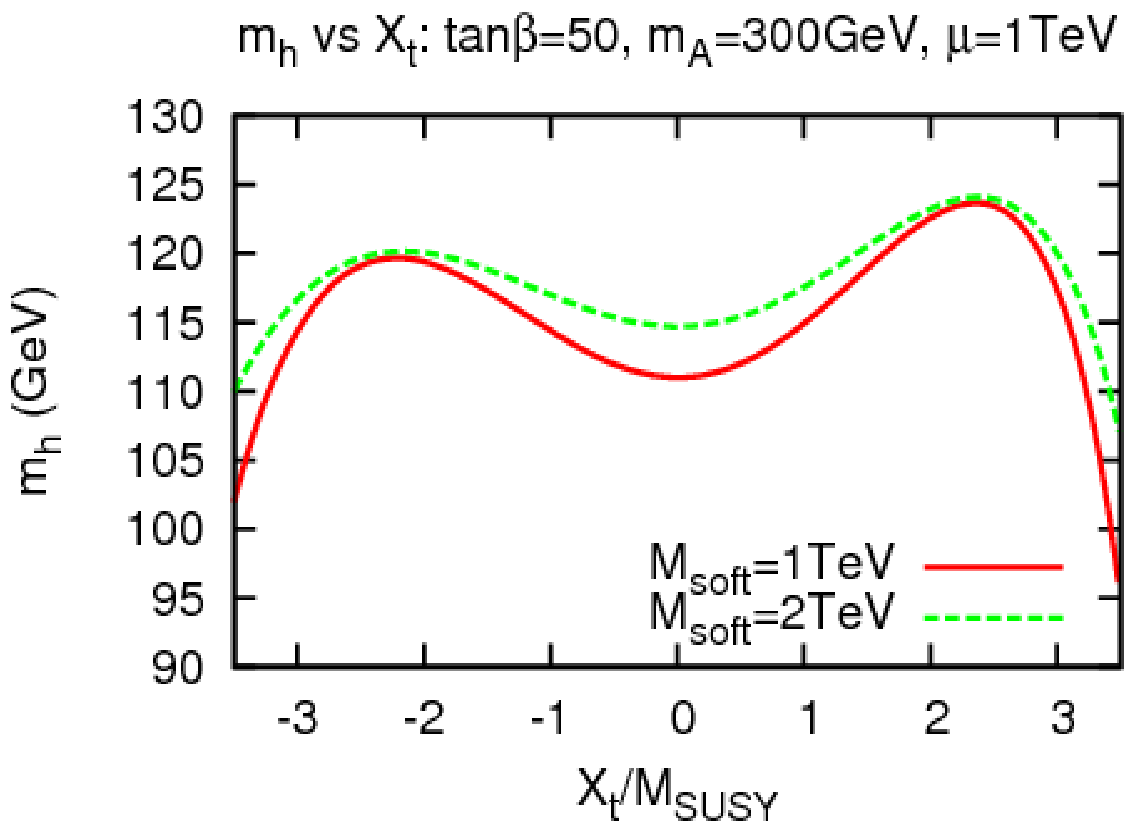
MSSM Benchmark Scenarios

- At tree level, m_A and $\tan\beta$ determine the Higgs spectrum and couplings to the SM.
- At loop level, more parameters enter $A_t,\ \mu,\ M_S$...
- Choose 4 sets of benchmark values representative of different effects of the radiative corrections
- Scan over $(m_A, \tan\beta)$ plane, compute combined R^{95}_{MSSM}
- Plot 95% C.L. exclusions for various increases in luminosity and signal efficiency

Scenario 1: Maximal Mixing

- Off-diagonal component $X_t \equiv A_t - \mu/\tan\beta$ of $\tilde{t}$ mass matrix chosen so that m_h maximized

$$M_S = 1 \text{ TeV}$$
$$\mu = 1 \text{ TeV}$$
$$X_t = \sqrt{6} M_S$$

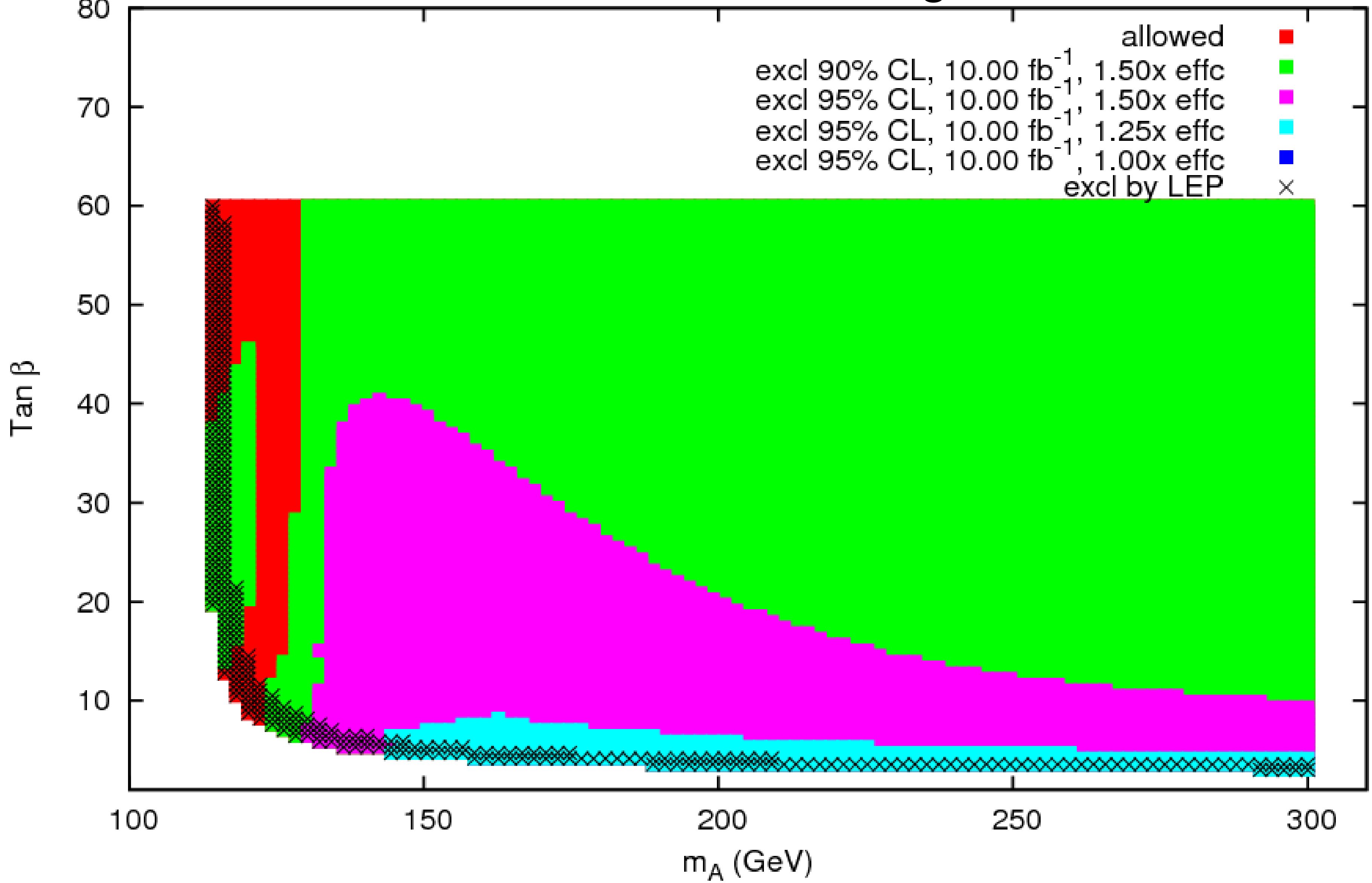


- Typically

$$120 \text{ GeV} \lesssim m_h \lesssim 125 \text{ GeV}$$

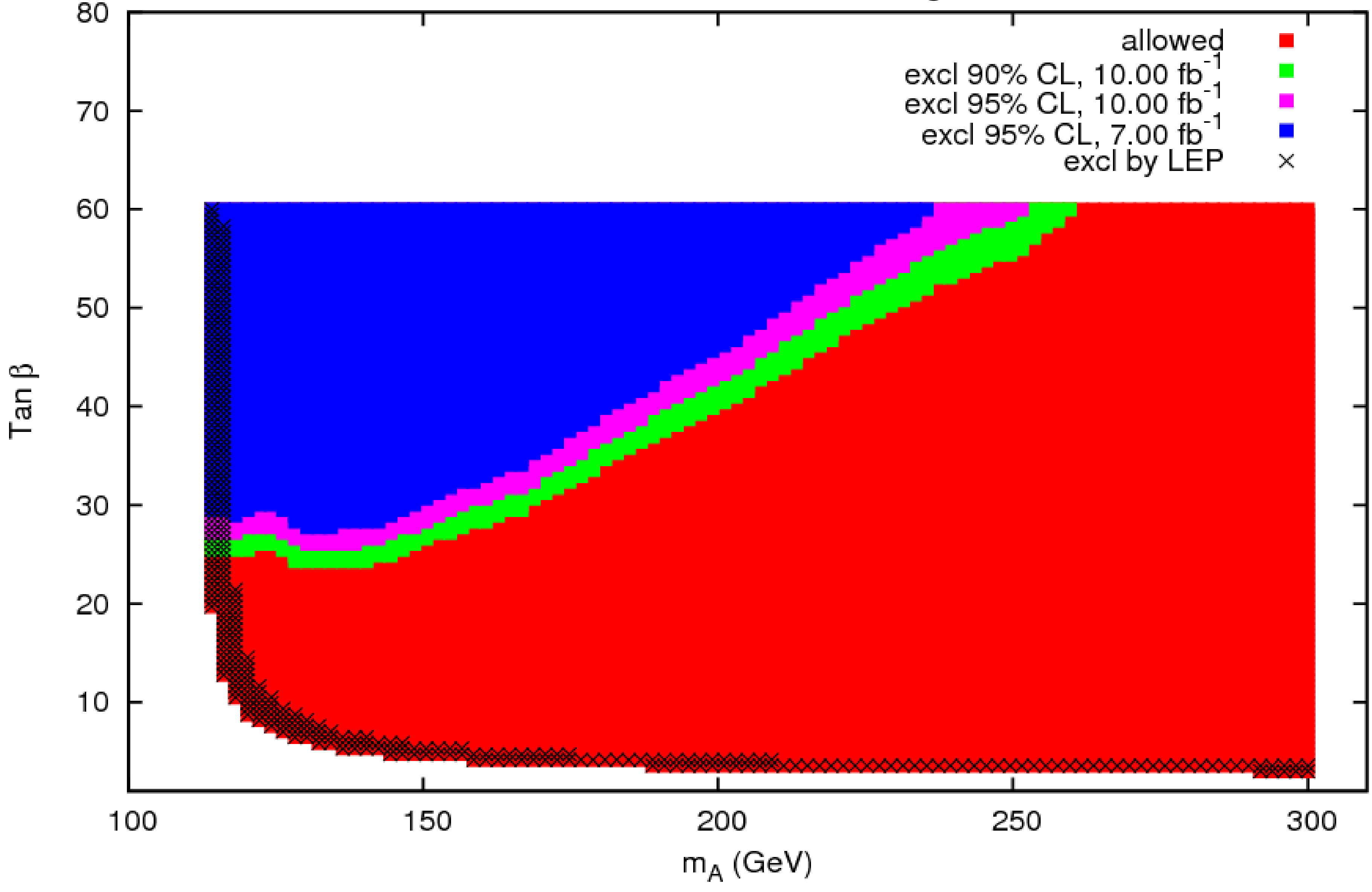
for $m_t = 172.6$ GeV

Constraints from SM-like Higgs Searches for Maximal Mixing

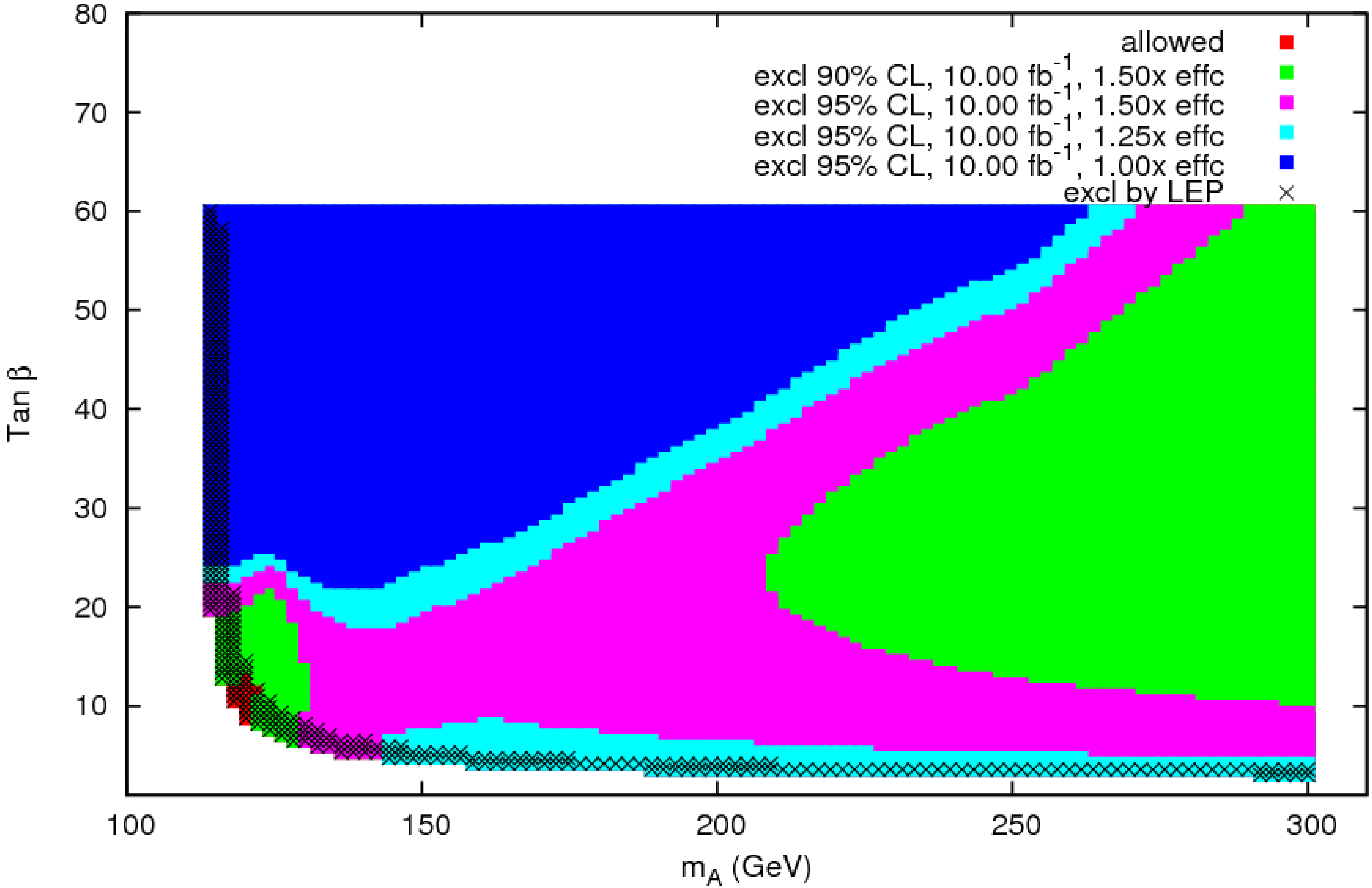


May 18, 2009

Constraints from Nonstandard Higgs Searches for Maximal Mixing



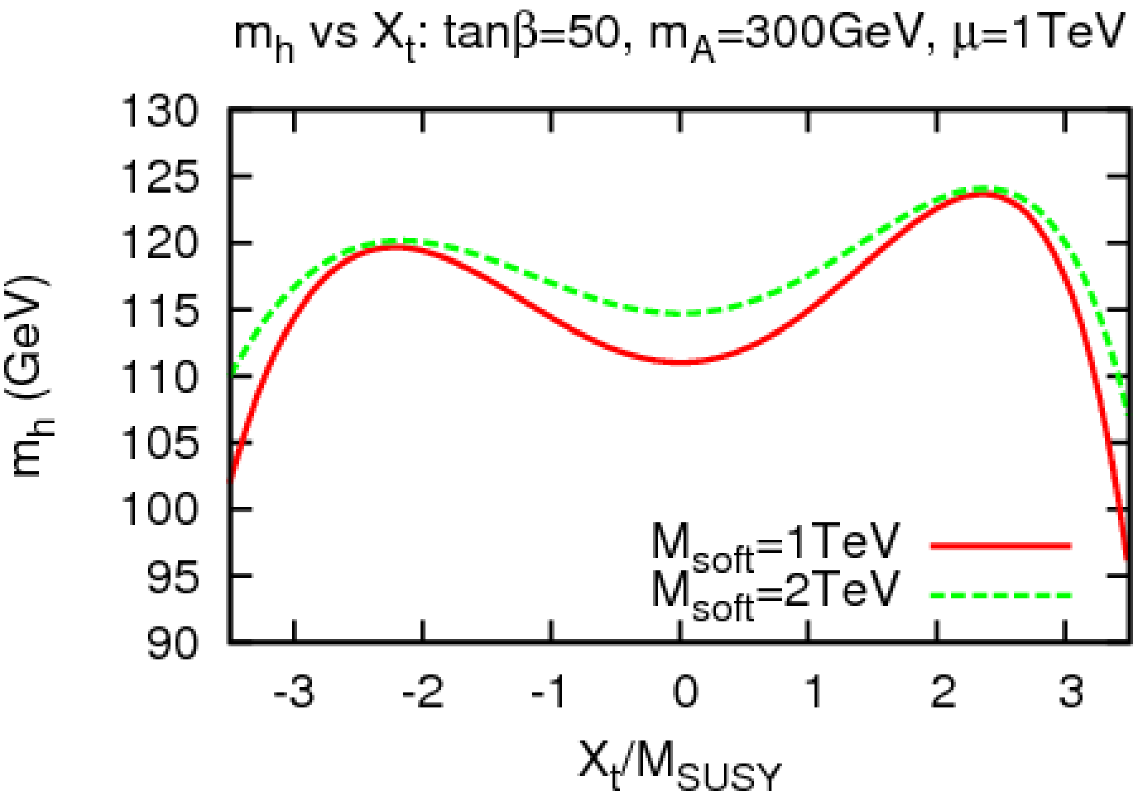
Combined Constraints for Maximal Mixing



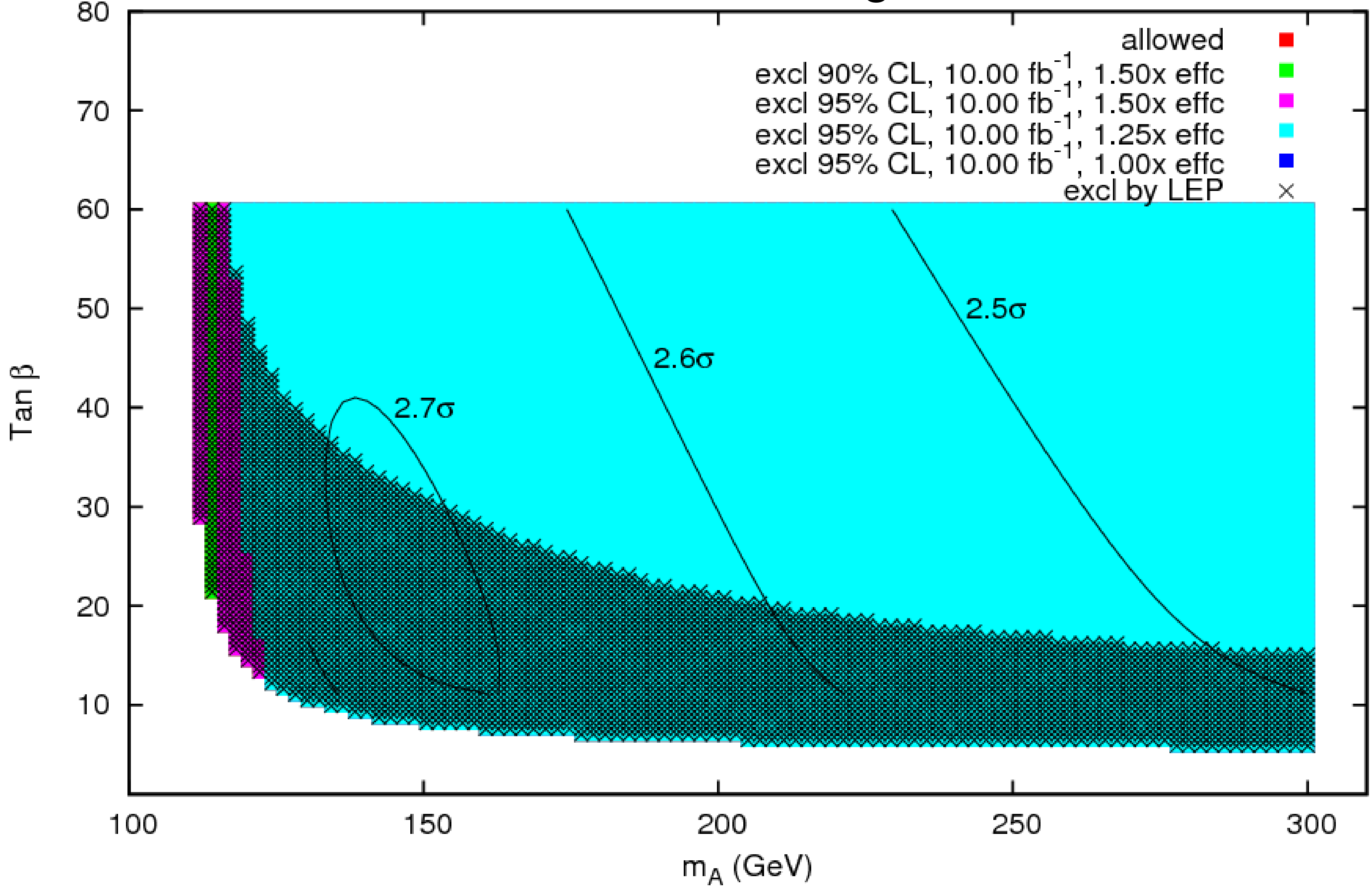
Scenario 2: No Mixing

- No mixing in the stop sector minimizes m_h, $m_h \sim 110 - 115 \text{ GeV}$
- Soft mass scale raised to (partially) avoid LEP bounds
- Lighter Higgs → constraints stronger vs. Maximal Mixing

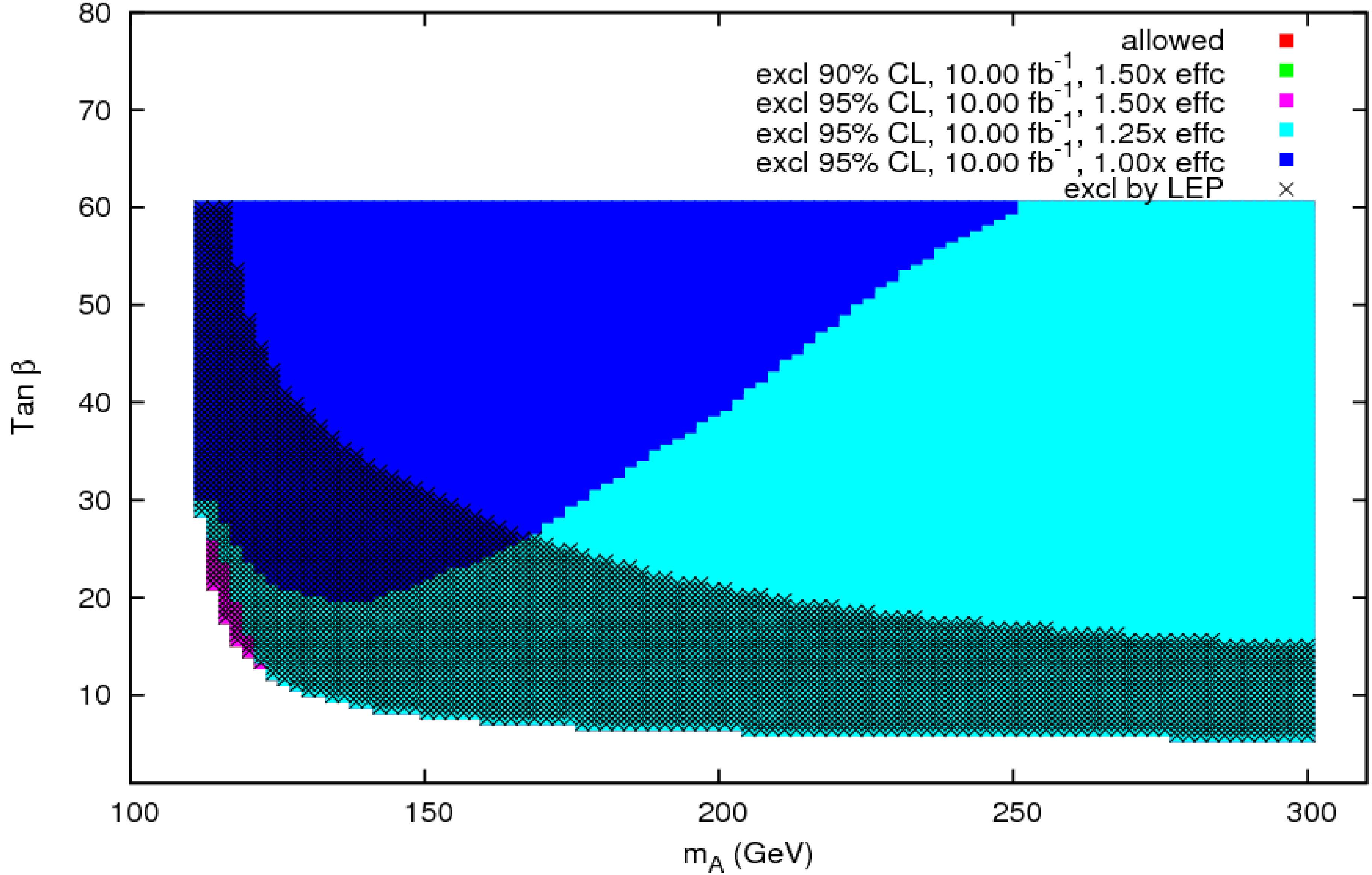
$$M_S = 2 \text{ TeV}$$
$$\mu = 1 \text{ TeV}$$
$$X_t \approx 0$$



Constraints from SM-like Higgs Searches for No-Mixing



Combined Constraints for No-Mixing

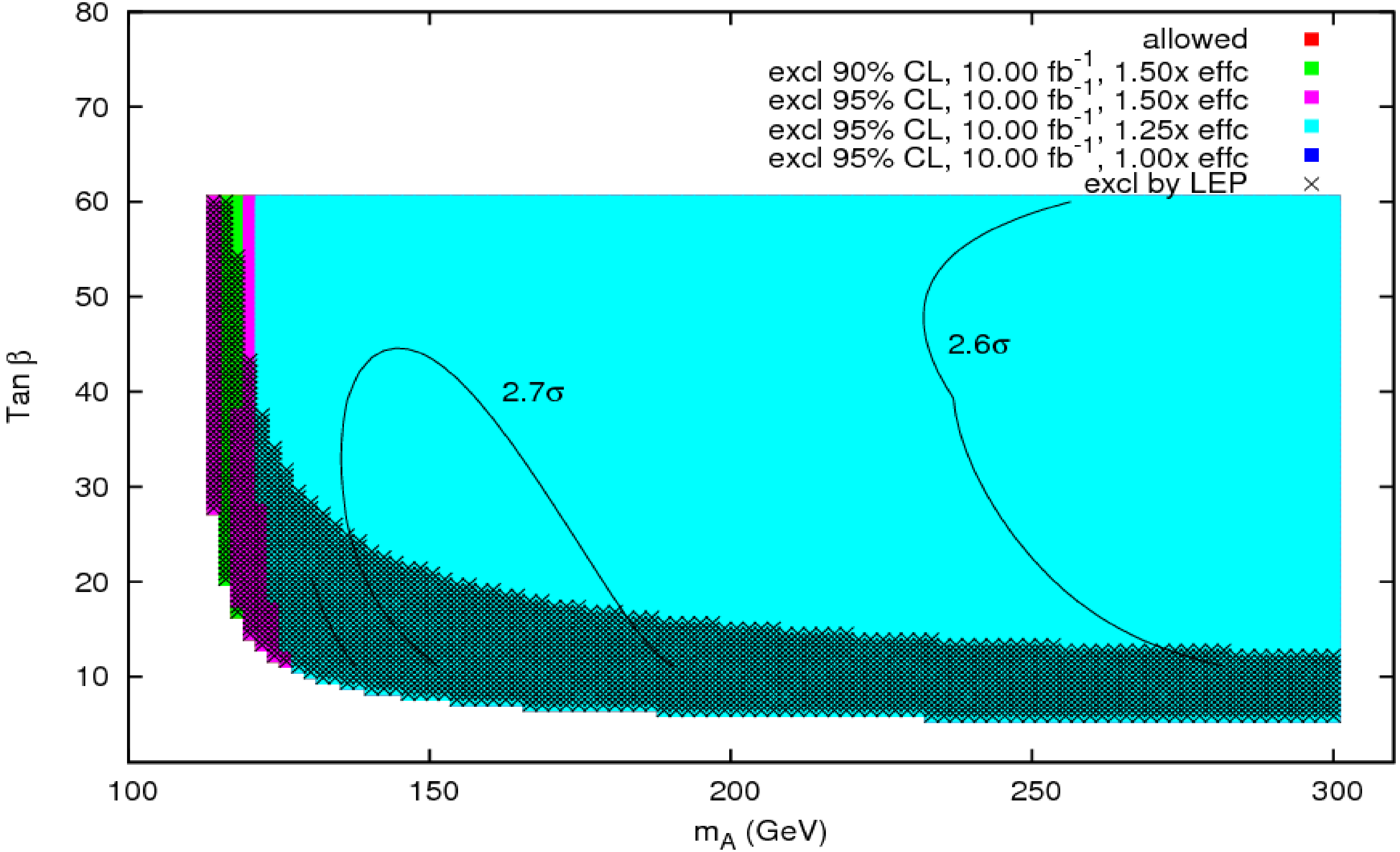


Scenario 3: Gluophobic

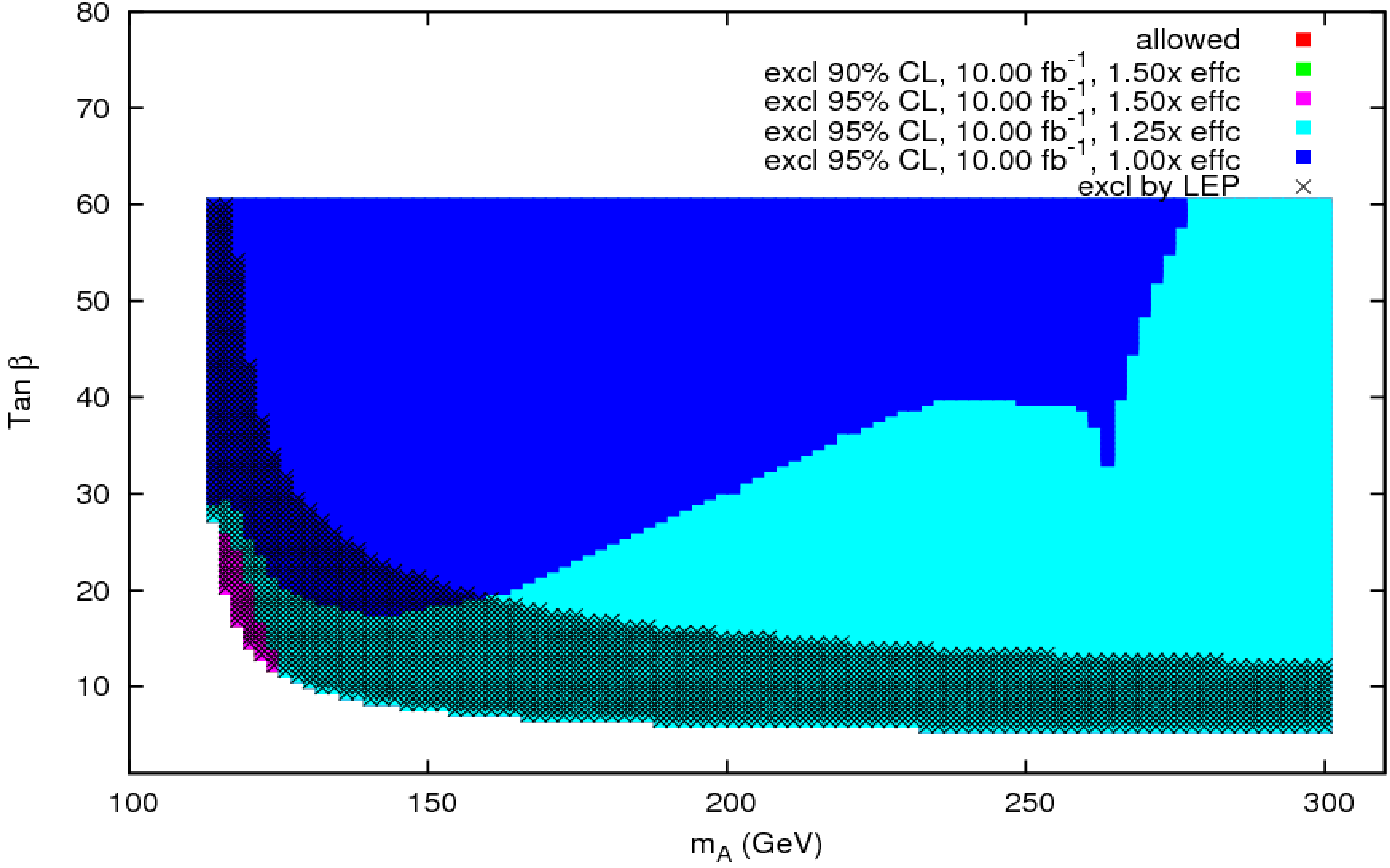
- Stop loop interferes destructively with top loop in gluon fusion production of SM-like Higgs
- Requires light top → soft mass scale lowered, A_t kept moderately large
- Lighter h, associated production in the bb channel → constraints similar to minimal mixing

$$M_S = 350 \text{ GeV}$$
$$\mu = 300 \text{ GeV}$$
$$A_t = -770 \text{ GeV}$$

Constraints from SM-like Higgs Searches for the Gluophobic Scenario



Combined Constraints for Gluophobic



Scenario 4: Small α_{eff}

- Higgs mixing angle → 0 in a region of the $(m_A, \tan\beta)$ plane because of cancellation between tree level and loop corrections to off-diagonal term in the mass matrix:

$$\mathcal{M}_{12} \simeq -(m_A^2 + m_Z^2)/\tan\beta + \frac{h_t^4 v^2}{16\pi^2}\bar{\mu}\bar{A}_t(\bar{A}_t{}^2 - 6)$$

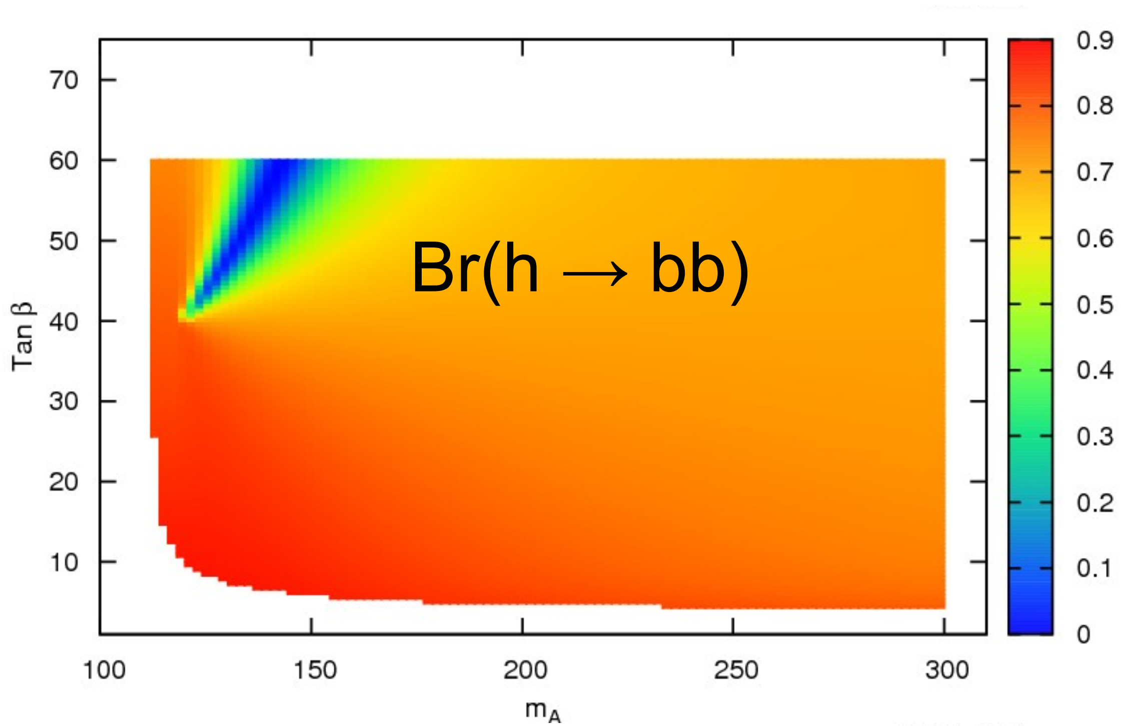
$$\bar{A}_t \equiv A_t/M_S,\ \bar{\mu} \equiv \mu/M_S$$

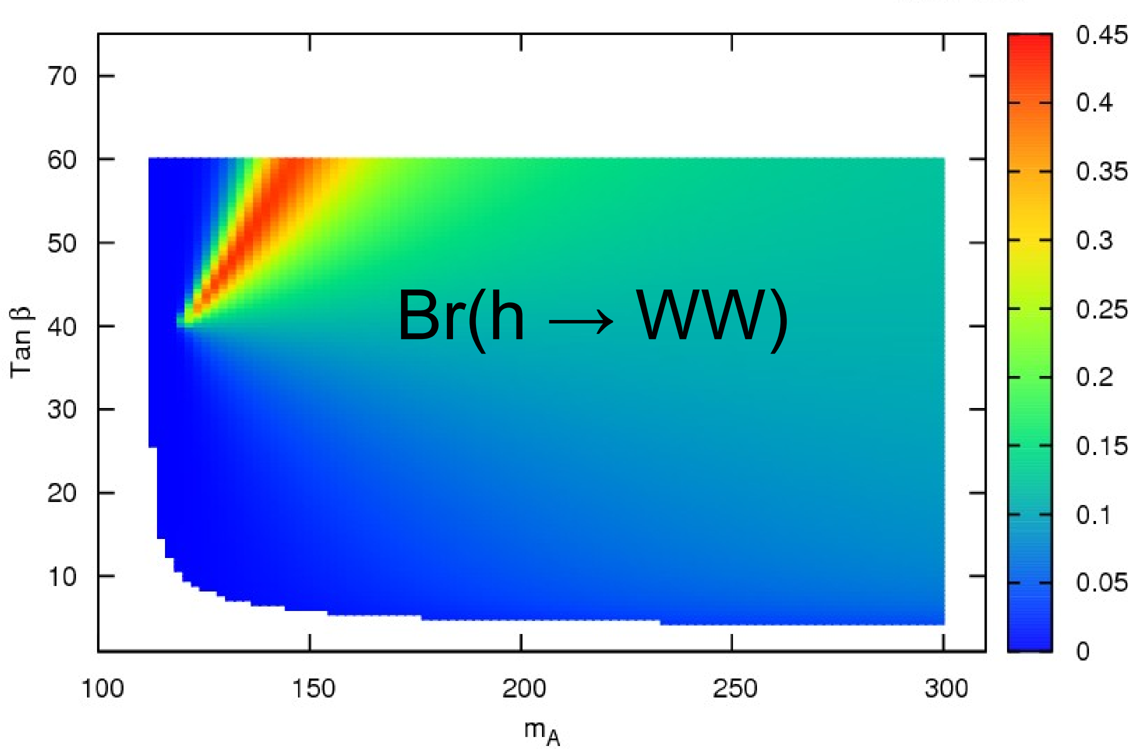
- → need moderate, opposite-signed $A_t,\ \mu$

Scenario 4: Small α_{eff}

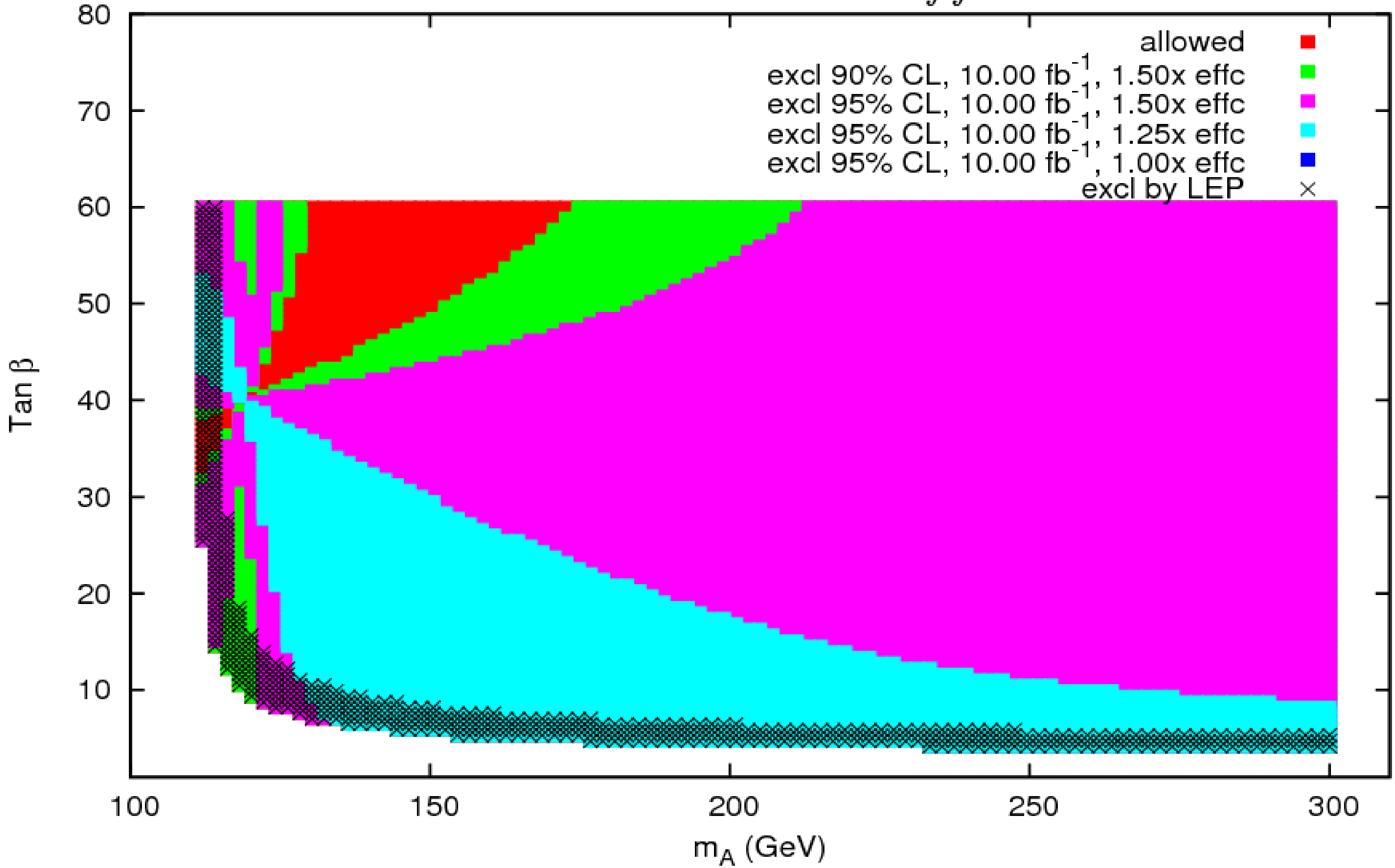
- Strongly suppresses $h \to b\bar{b}$ search channels, enhances $h \to WW$
- Demonstrates utility of WW in low-mass region

$$M_S = 1 \text{ TeV}$$
$$\mu = 1.5 \text{ TeV}$$
$$A_t = -1.5 \text{ TeV}$$

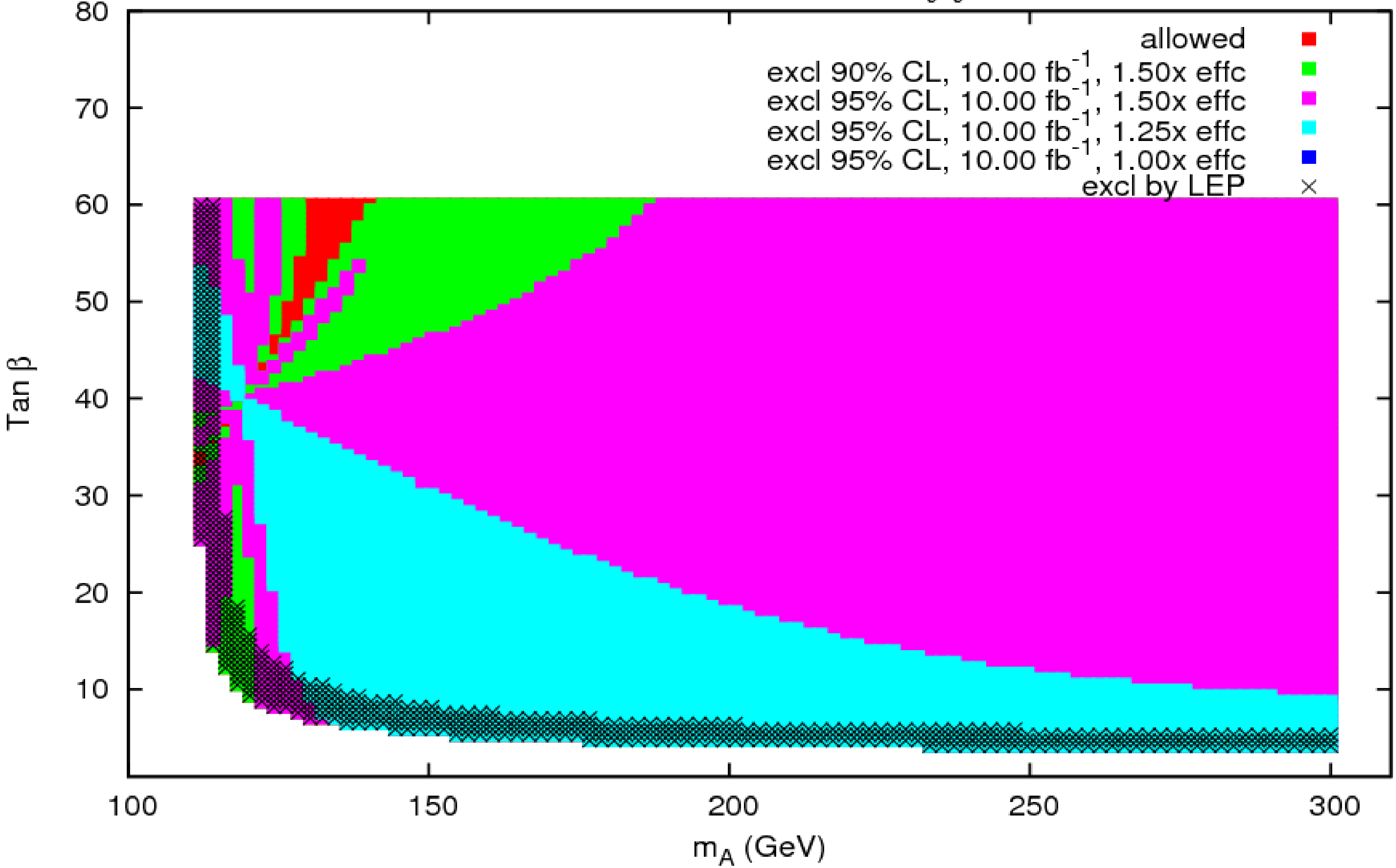

Br(h → bb)
Tan β
m_A
70
60
50
40
30
20
10
100
150
200
250
300
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0


Br(h → WW)
Tan β
m_A
70
60
50
40
30
20
10
100
150
200
250
300
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0

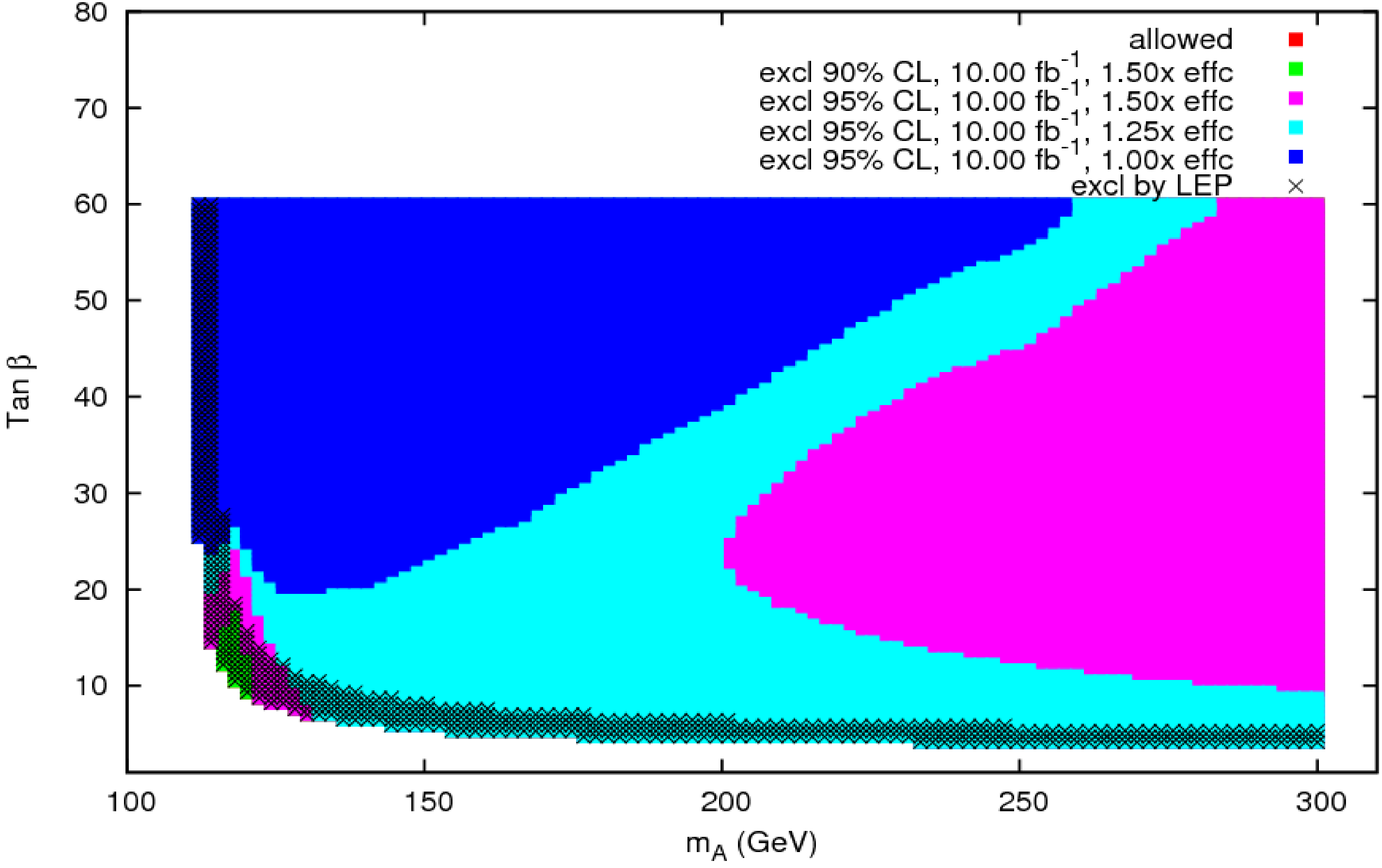
h→bb search for SM-like Higgs for small α_{eff}



$(h\to bb + h\to WW)$ search for SM-like Higgs for small α_{eff}



Combined search for small α_{eff}

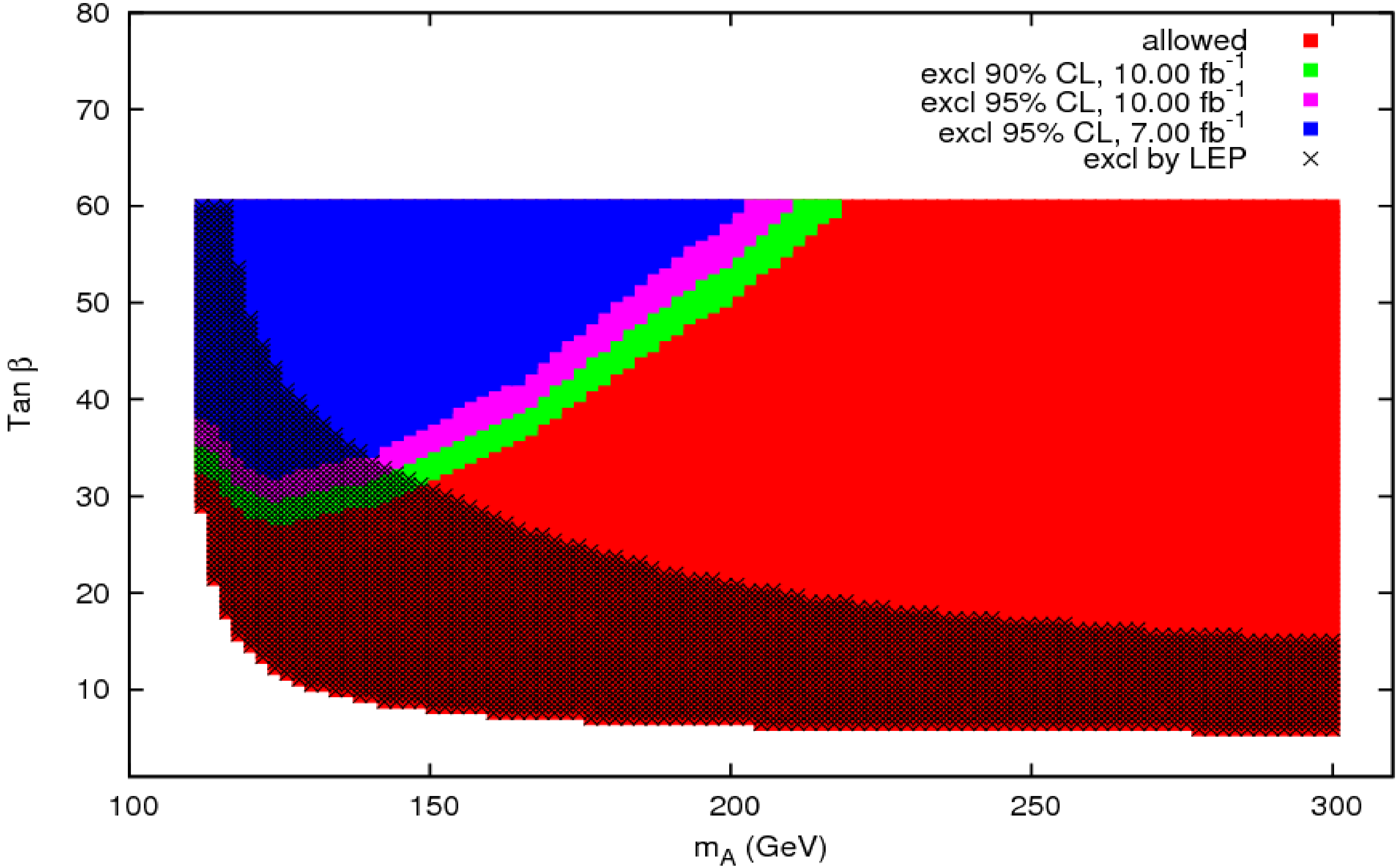


Conclusions

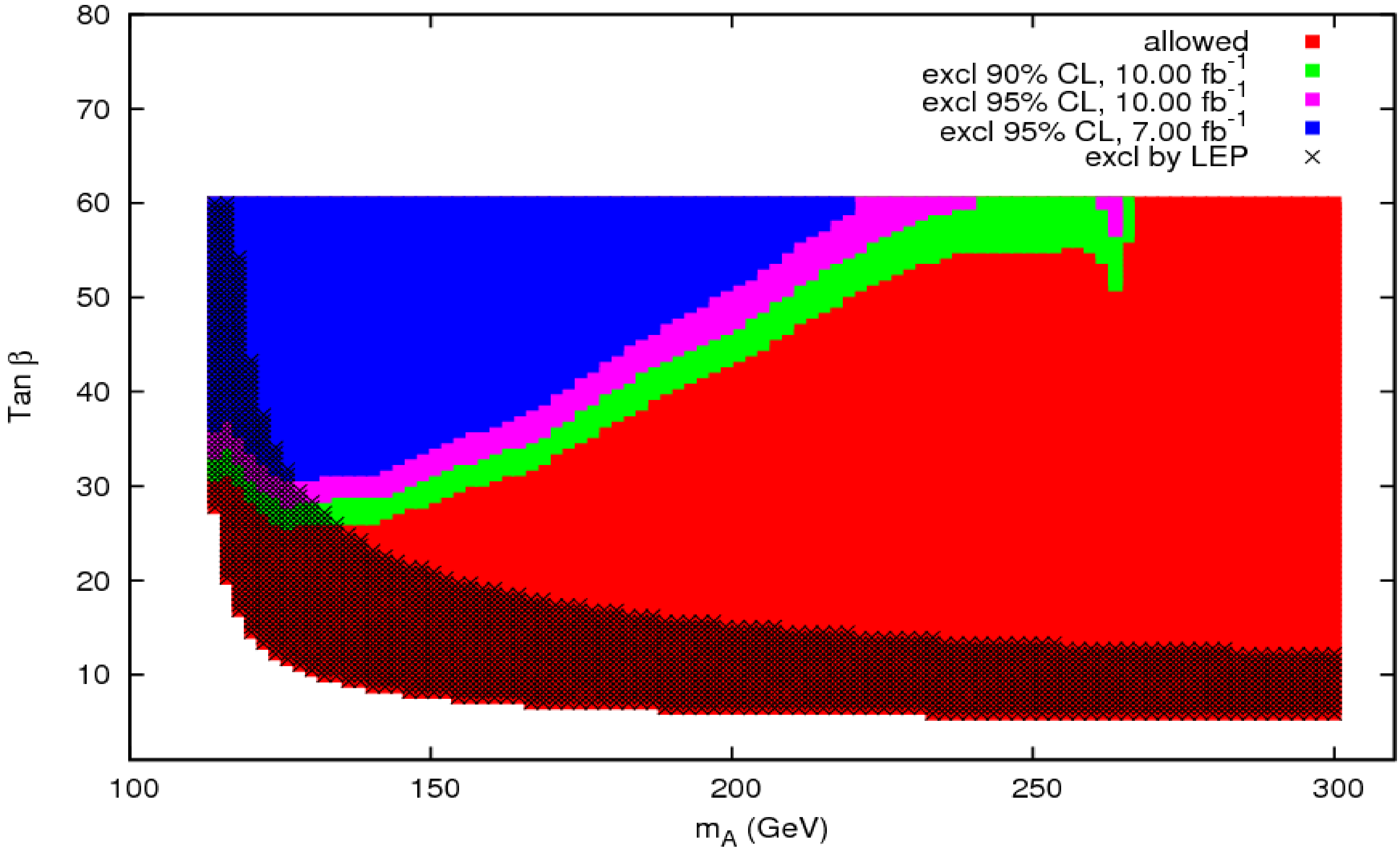
- Tevatron has the potential to exclude almost all of MSSM Higgs parameter space at 95% C.L.
- 10 fb^{-1} and 1.25x improvement in efficiency is necessary in all benchmark scenarios
- Wide coverage requires 1.5x efficiency improvement in the maximal mixing and small-α_{eff} scenarios
- Complementarity between bb and WW channels in SM-like Higgs searches can extend coverage when h is fermiophobic, even in the low-mass region
- Complementarity between SM-like and nonstandard Higgs searches can yield 95% exclusions everywhere except in the maximal-mixing decoupling limit
- 3σ evidence is not likely in any scenario

Backup Slides

Constraints from nonstandard Higgs Searches for No-Mixing



Constraints from nonstandard Higgs Searches for Gluophobic



Constraints from nonstandard Higgs Searches for small α_{eff}