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PROSPECTS FOR MSSM HIGGS SEARCHES AT THE TEVATRON

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Arxiv: 0905.4721, 0911.0034

In collaboration with Patrick Draper and Carlos Wagner

Outline

- Status of the SM Higgs Searches
- Prospects of the SM Higgs Searches at the Tevatron
- Prospects of the MSSM Higgs Searches at the Tevatron
- Combination of the SM-like Higgs Searches at the Tevatron and the Early LHC
- Conclusions

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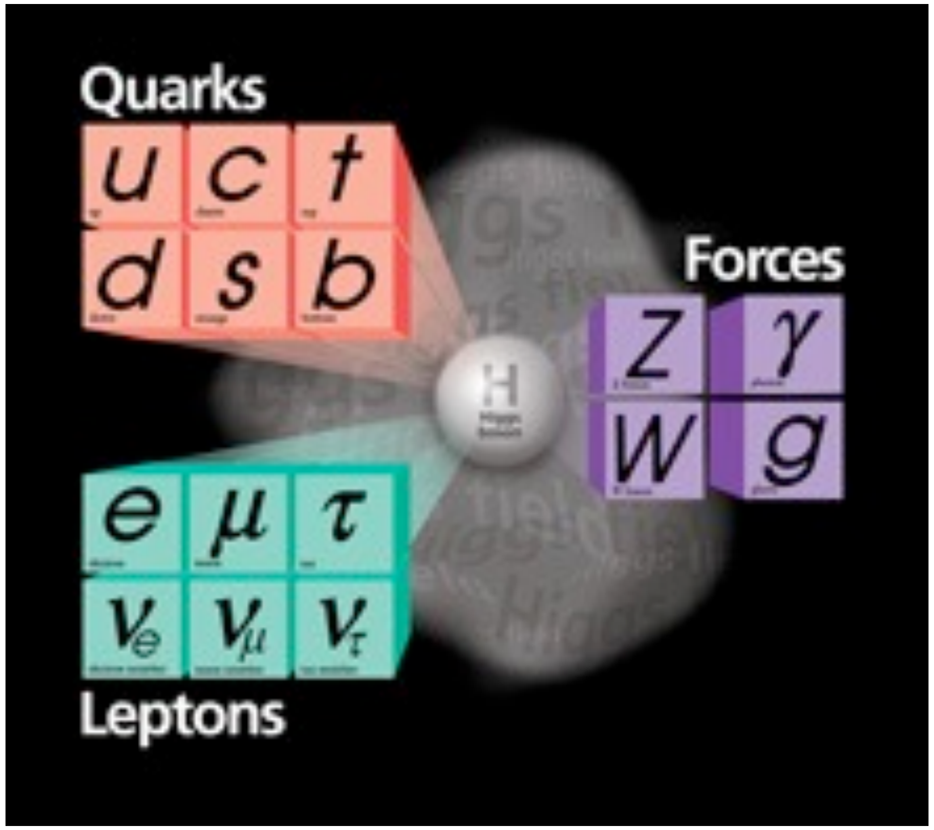
Higgs Mechanism

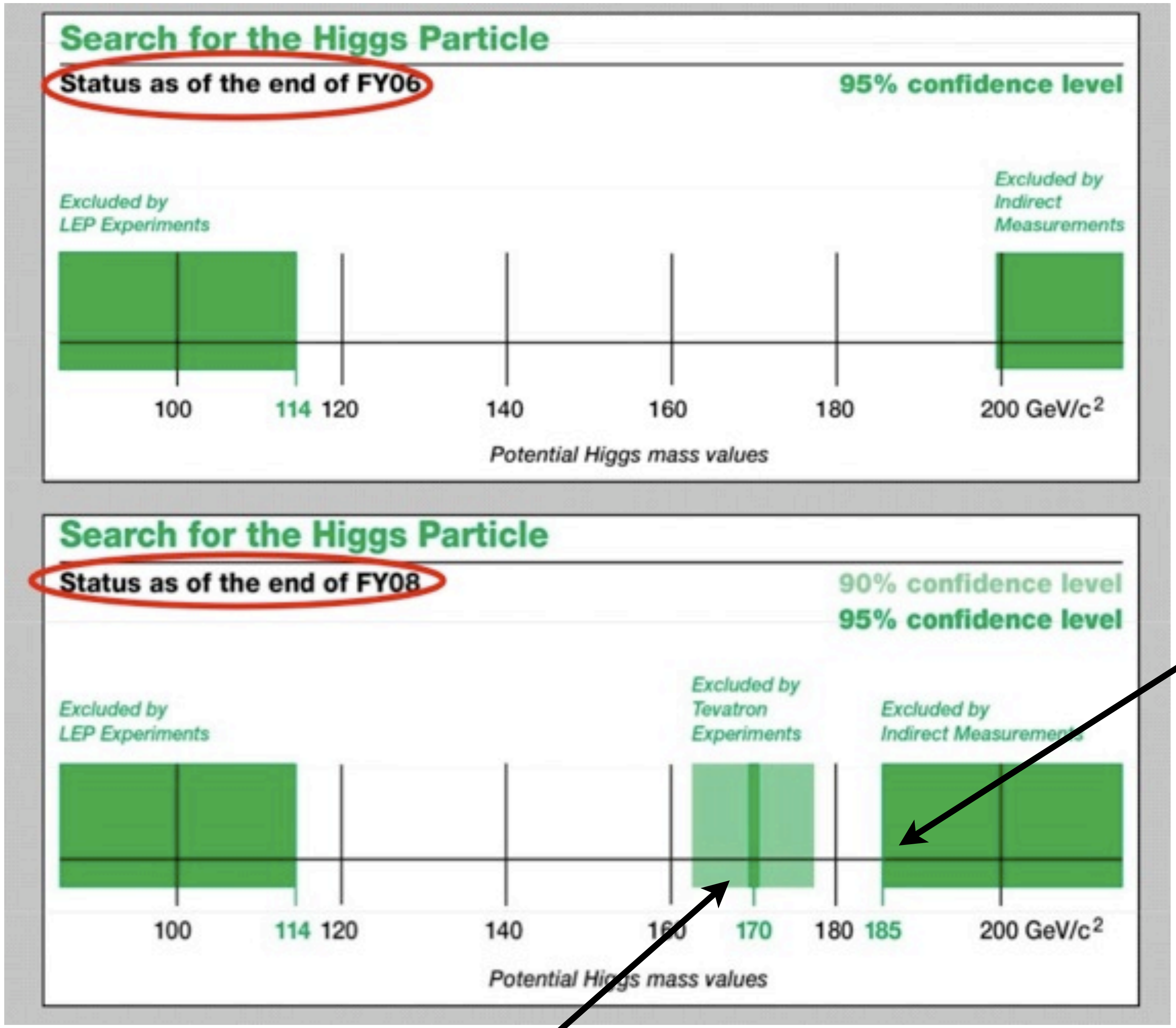
Two mysteries in the Electroweak theory :

- The cause of Electroweak symmetry breaking
- The origin of Quark and Lepton masses



They can be simultaneously explained by Higgs Mechanism ->
The existence of Higgs bosons with a mass of EW scale

The SM Higgs Searches at the Tevatron (Before 2009)

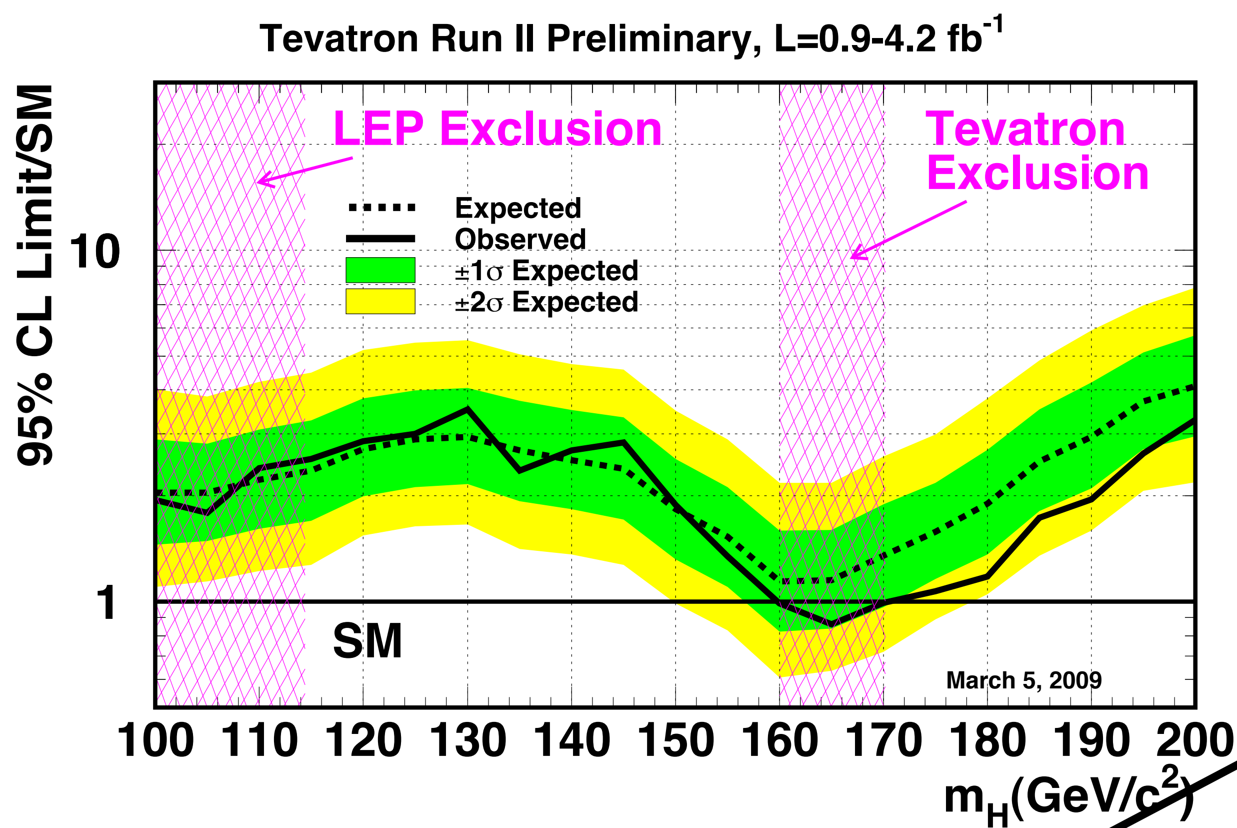


Indirect search: $m_H < 185$ GeV

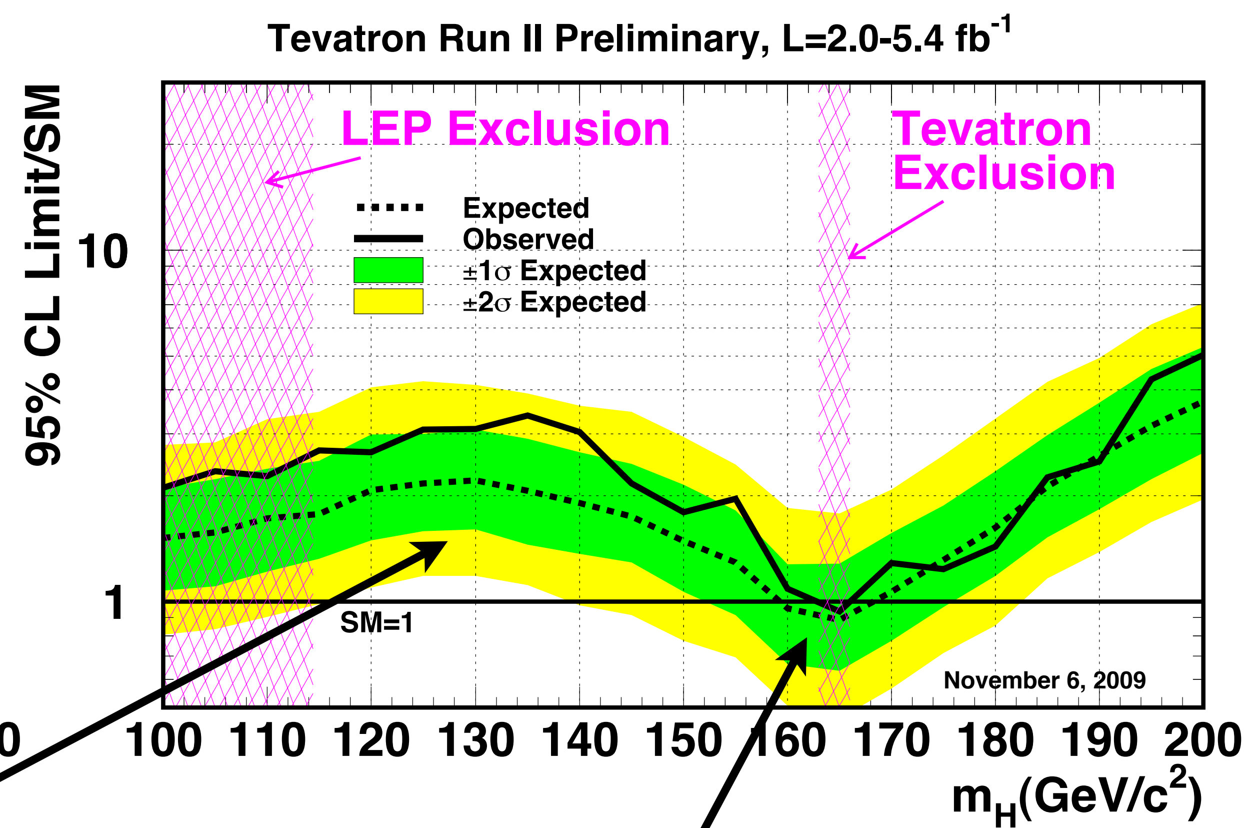
Direct search: exclude a Higgs with m_H =170 GeV at 95% C.L.

The Direct SM Higgs Searches at the Tevatron (2009)

arXiv: 09034001



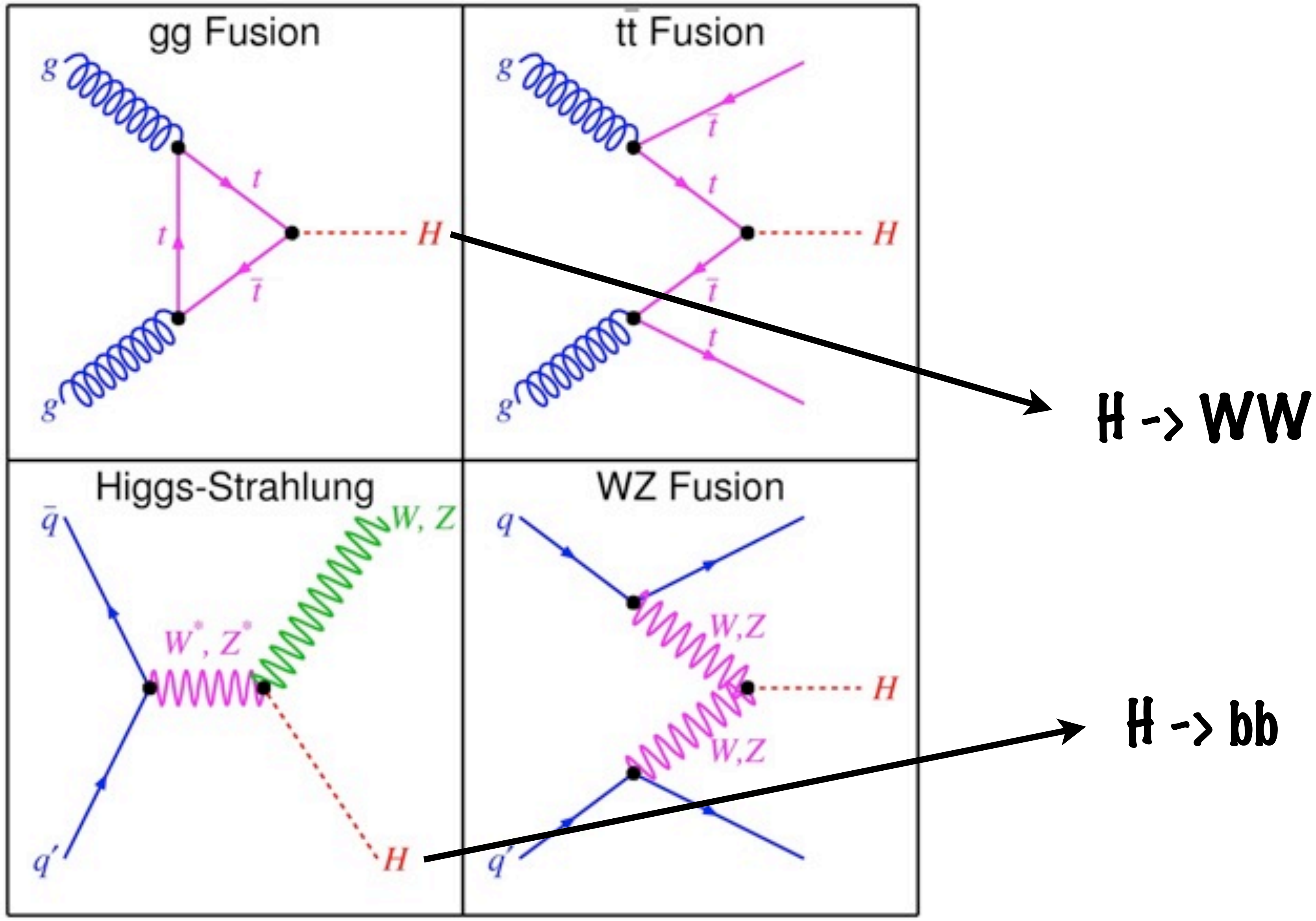
arXiv: 0911.3930



The bounds on $R_i = \frac{s_i}{s_i^{\mathrm{SM}}}$ (y-axis) in the lower mass range are improved

The mass range 163-166 GeV is excluded at 95% C.L.

Dominant Channels for the Direct Searches (Tevatron)



Question:

What luminosity and signal efficiency improvements are necessary for the Tevatron to constrain large regions of the MSSM Higgs parameter space, before the LHC starts to generate useful information for the Higgs search?

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Two Steps

- Step I: Calculate the expected limits on $R_{SM,i}$ in the ith channel. For large statistics and at 95% C.L., the formula is (ϵ_i^0 and L_i^0 are signal efficiency and integrated luminosity used in current experimental analyses)

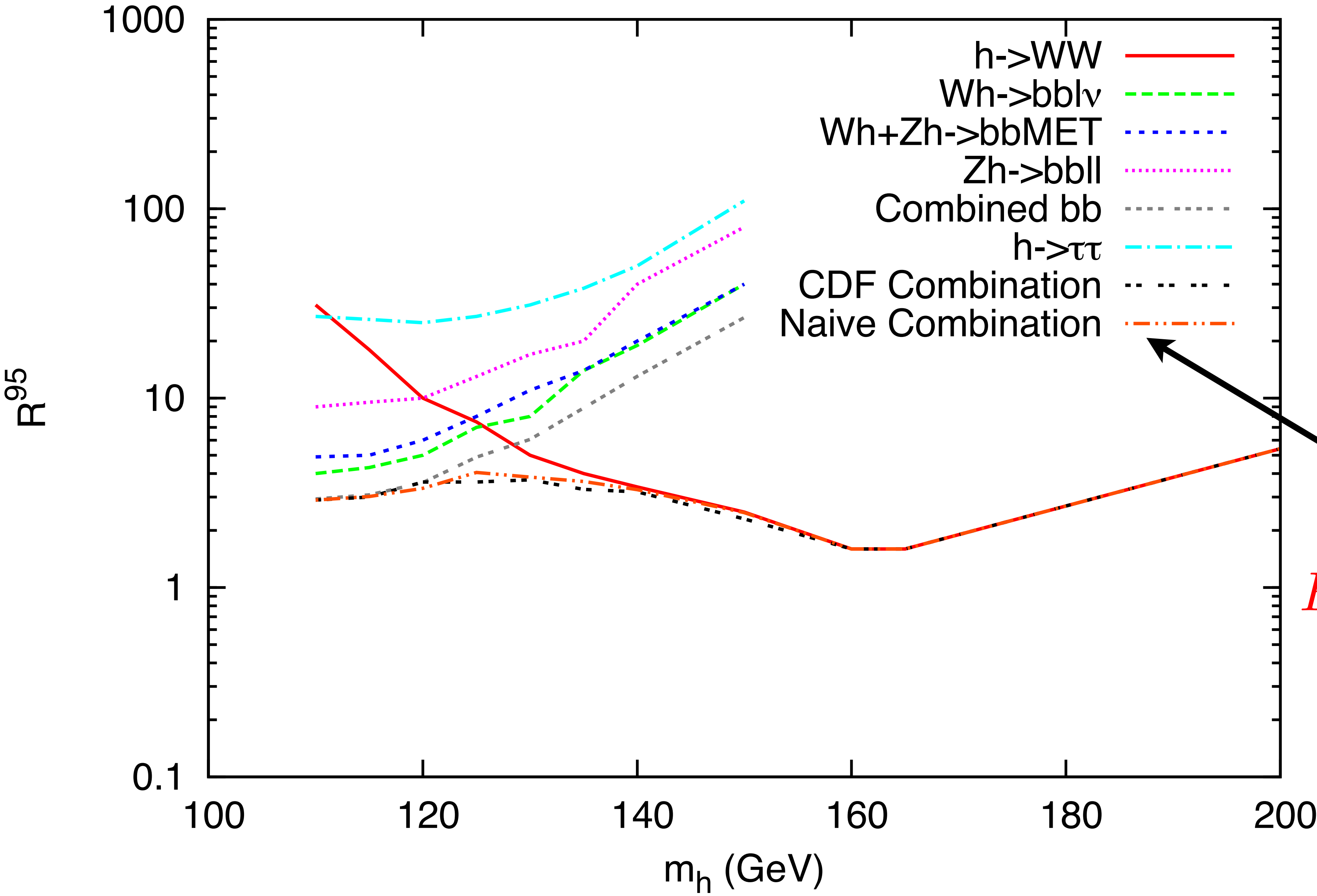
$$R_{SM,i}^{95} = 1.96 \times \frac{\sqrt{b_i}}{s_{SM,i}} \times \frac{1}{(\epsilon_i/\epsilon_i^0)\sqrt{L/L_i^0}}$$

- Step II: Make a combined analysis to get a net constraint on the SM. We introduce the formula (P. Draper, T.L., C. Wagner, arXiv: 0905.4721):

$$R_{SM,comb} = \frac{1}{\sqrt{\sum_i \frac{1}{(R_{SM,i})^2}}}$$

Consistency Check of the Combination Formula

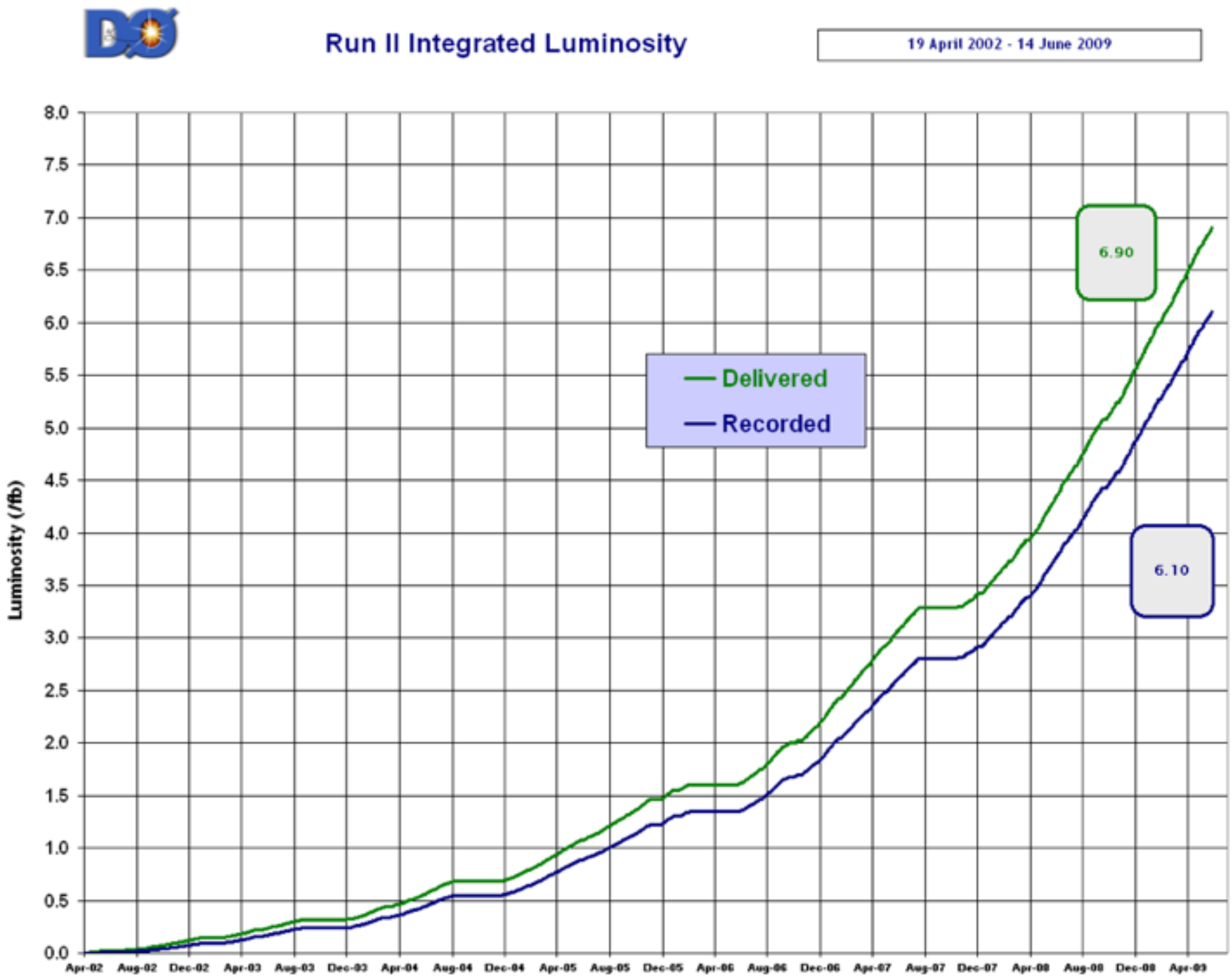
P. Draper, T.L., C. Wagner, arXiv: 09054721



$$R_{SM,comb} = \frac{1}{\sqrt{\sum_i \frac{1}{(R_{SM,i})^2}}}$$

The CDF combination and ours match with each other very well !

Expected Integrated Luminocity

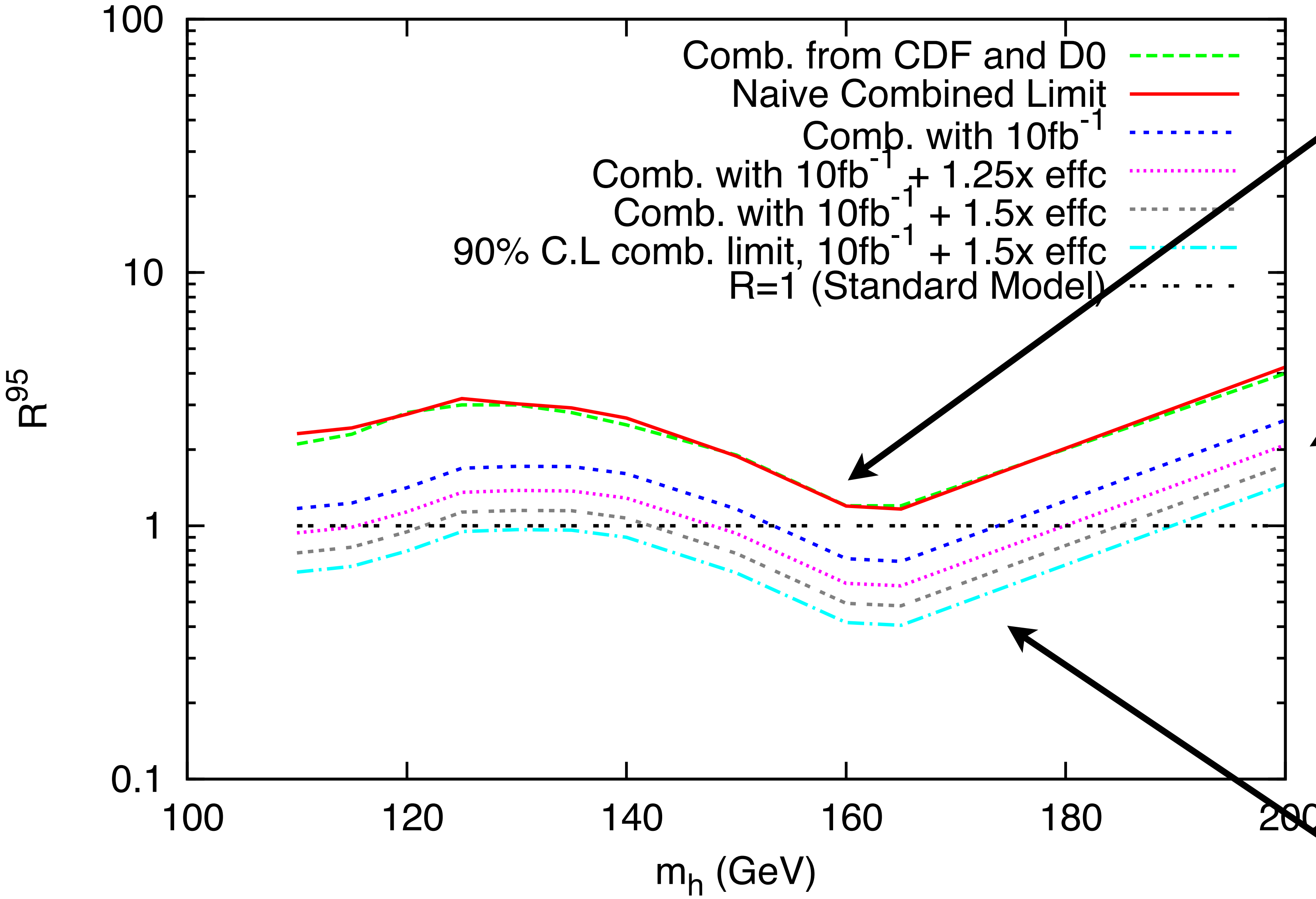


Obtain about 2/fb per year.

--> Assume a running until at least the end of 2010 -> 10/fb "good" data.

Prospects of the SM Higgs Searches at the Tevatron

P. Draper, T.L., C. Wagner, arXiv: 09054721



A combination of current D0 and CDF results

Each curve can have multiple interpretations in terms of the improvements in the integrated luminosity and signal efficiency

The Tevatron can search for the SM Higgs in the whole mass range preferred by the EW precision data at 90% C.L. (10/fb + 1.5*effc)

In the future, any new progresses in the SM Higgs searches can be understood as a step toward the aims set in this figure.

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Higgs Sector of the MSSM (No CP Violation)

- Two Higgs Doublets H_d and H_u coupling to down-type and up-type fermions, respectively
- Two CP-even masseigenstates h, H and one CP-odd masseigenstate A

$$\begin{pmatrix} h \\ H \end{pmatrix} = \begin{pmatrix} -\sin\alpha & \cos\alpha \\ \cos\alpha & \sin\alpha \end{pmatrix} \begin{pmatrix} H_d^0 \\ H_u^0 \end{pmatrix}$$

- At tree level, m_A and $\tan\beta = \frac{\langle H_u^0 \rangle}{\langle H_d^0 \rangle}$ completely determine the Higgs mass spectrum and their couplings to the SM particles.

(Continued)

- Relative to the SM, the tree-level couplings to fermions rescaled by

$$g_{hdd} = -\frac{m_d}{v}\frac{\sin\alpha}{\cos\beta}, \qquad g_{huu} = \frac{m_u}{v}\frac{\cos\alpha}{\sin\beta}$$
$$g_{Hdd} = \frac{m_d}{v}\frac{\cos\alpha}{\cos\beta}, \qquad g_{Huu} = \frac{m_u}{v}\frac{\sin\alpha}{\sin\beta}$$
$$g_{Add} = \frac{m_d}{v}\gamma_5\tan\beta, \quad g_{Auu} = \frac{m_u}{v}\gamma_5\cot\beta$$

- The tree-level couplings to VV rescaled by $\sin(\beta-\alpha)$, $\cos(\beta-\alpha)$ for h and H, respectively, while A doesn't couple to VV

- Usually there is one Higgs boson whose couplings to gauge bosons are similar to those of the SM Higgs boson
  - In the large m_A region ($|\sin(\beta-\alpha)| \to 1$), h is SM-like
  - in the small m_A and moderate to large tan_beta region ($|\cos(\beta-\alpha)| \to 1$), H becomes SM-like

- At loop level, more parameters are involved: $A_t, \mu, M_S \ldots$

Strategies of Our Analyses

- Choose benchmark values for $A_t, \mu, M_S \ldots$, which represent different effects of the radiative corrections
- Study the exclusion limits on the m_A - tan_beta plane in each scenario
- Four benchmark scenarios (M. Carena et. al.'02):

a. Maximal mixing scenario -- the radiative correction to m_h is maximized

b. Minimal mixing scenario -- the radiative correction to m_h is minimized

c. Gluophobic scenario -- gluon fusion production is strongly suppressed

d. Small α scenario -- bb search channel is strongly suppressed in some regions of the m_A - tan_beta plane

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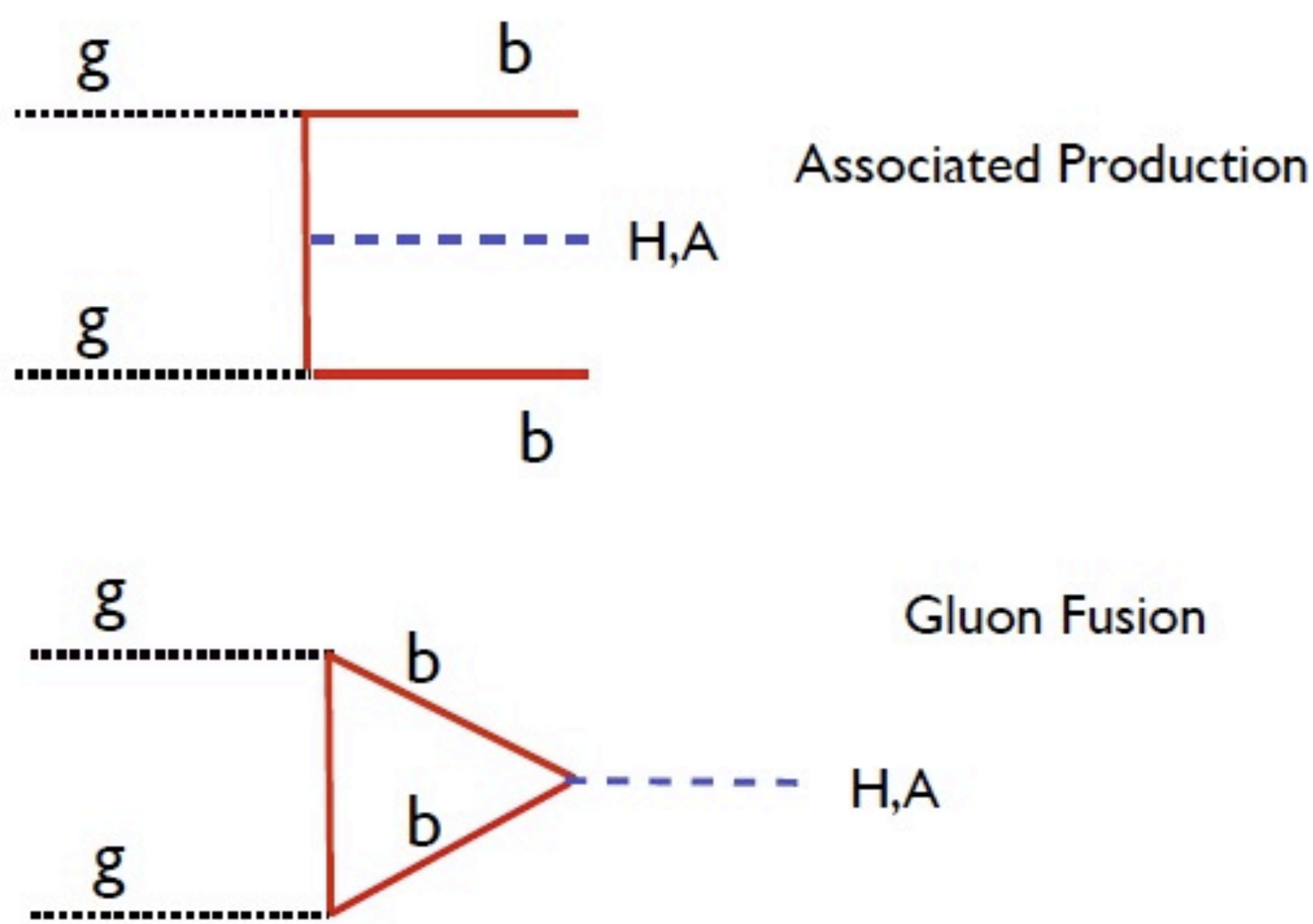
(Continued)

- SM-like Higgs (dominated) searches: H_i -> bb, WW
- Nonstandard Higgs (dominated) searches: H_i -> tau tau



(Continued)

- Step I: Calculate the expected limits on $R_{MSSM,i}$ from individual channels

$$R_{MSSM,i} = \frac{\sigma_i Br_i}{\sigma_{MSSM,i} Br_{MSSM,i}} = R_{SM,i} \times \frac{\sigma_{SM,i} Br_{SM,i}}{\sigma_{MSSM,i} Br_{MSSM,i}}$$

The values of $R_{SM,i}$ are given by the the analyses of the SM Higgs searches, while the rescaling factor is calculated by CPsuperH.

- Step II: Combine the expected limits of $R_{MSSM,i}$, and then find the excluded parameter regions (i.e., the regions with $R_{MSSM} < 1$).

(Continued)

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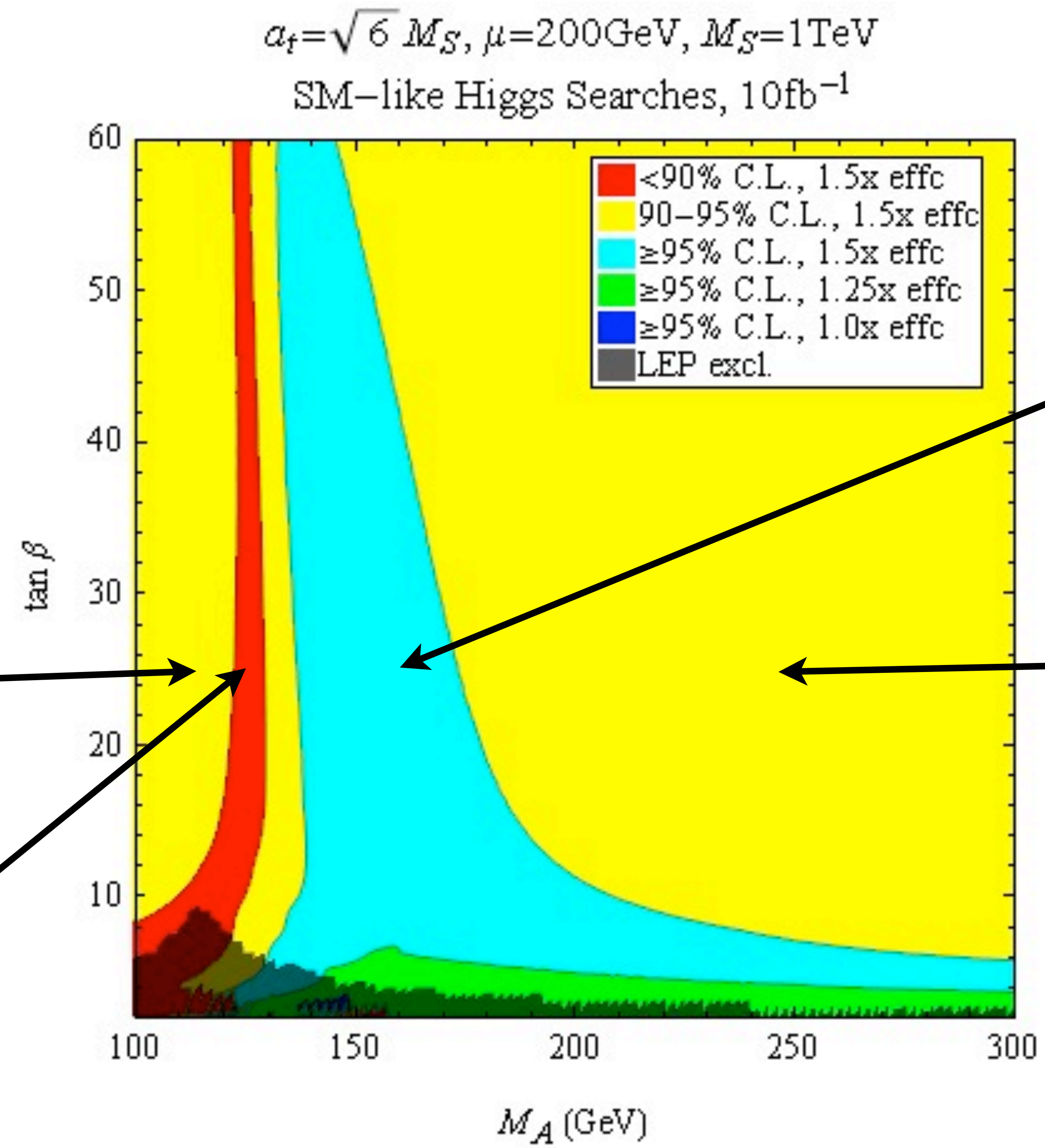
- Step II: Combine the expected limits of $R_{MSSM,i}$, and then find the excluded parameter regions (i.e., the regions with $R_{MSSM} < 1$).

Two crucial differences from the known discussions

- Combined analysis: bb + WW + tau tau
- The footstone of our analyses is the current experimental data, not the MC simulations.

Maximal Mixing Scenario (SM-like Higgs Searches)



H becomes SM-like

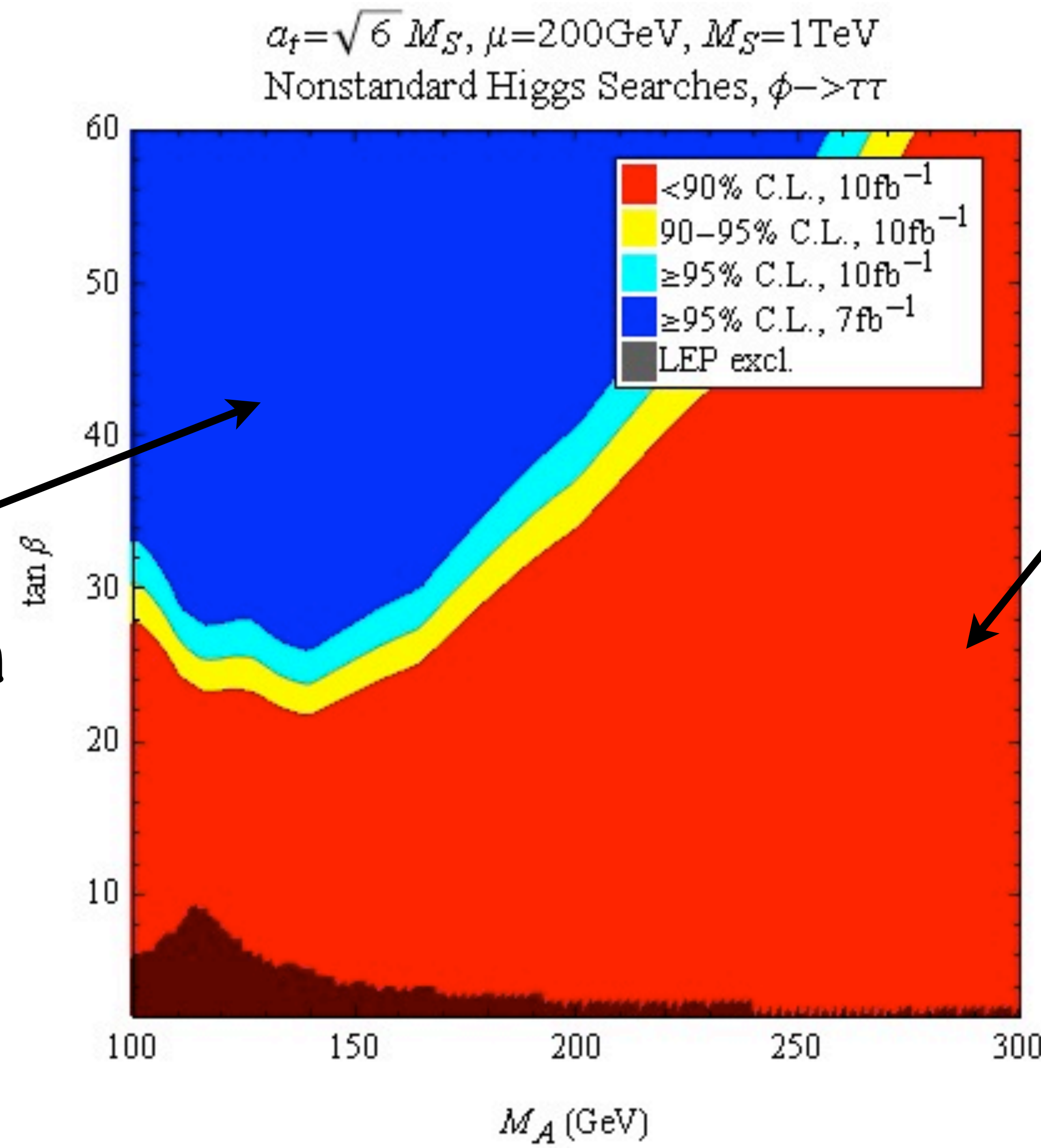
All of h and H, A are not SM-like

h is SM-like, with a larger down-type component

h is SM-like, with small down-type component

Maximal Scenario (Nonstandard Higgs Searches)

For large tan_beta, both the b mediated gluon fusion production and the tau tau decay are enhanced

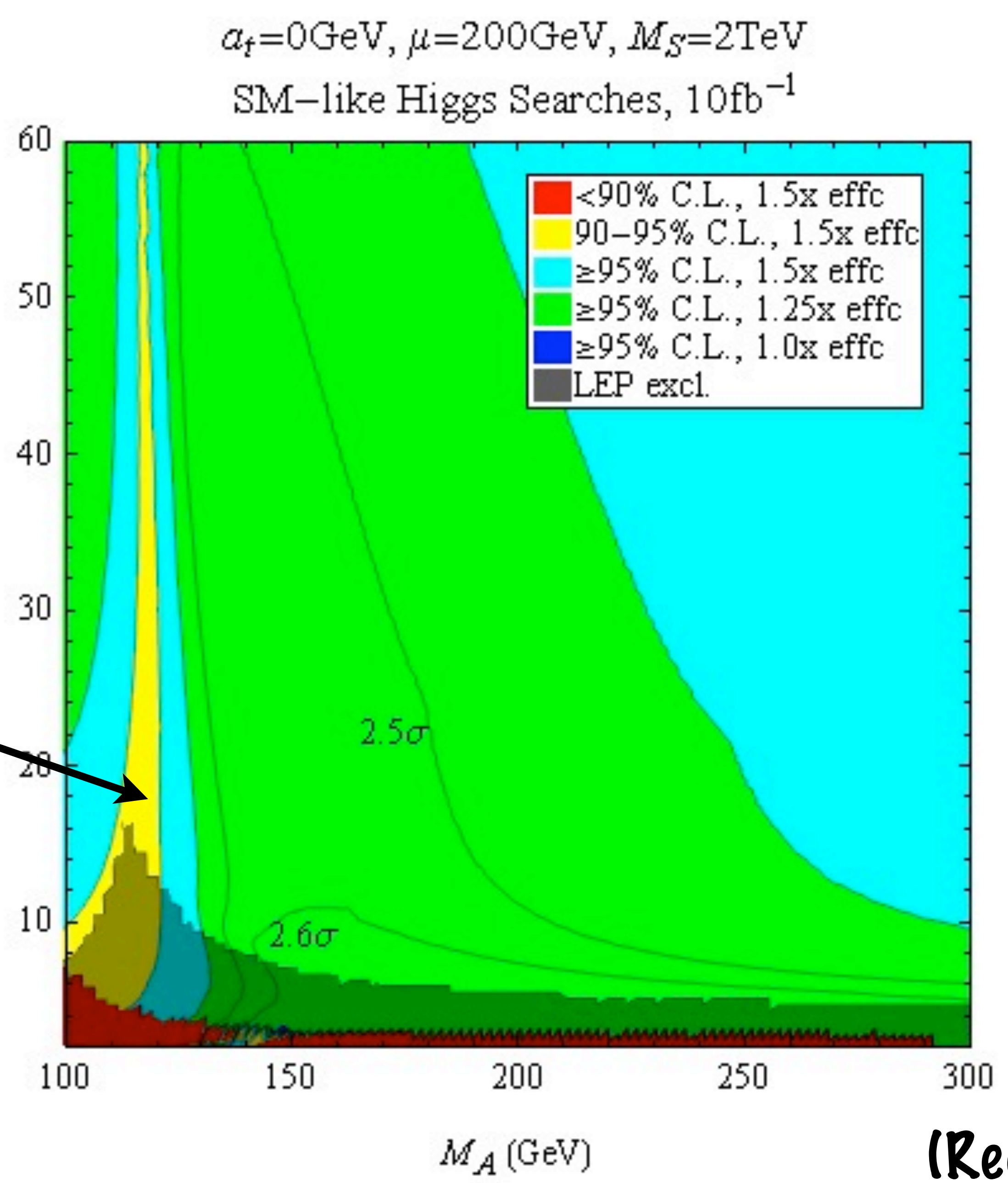


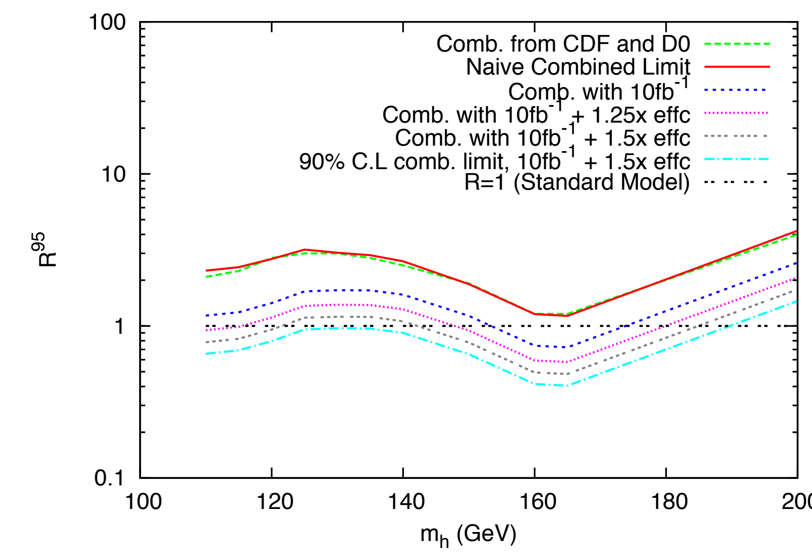
For large m_A, the production of the nonstandard higgs bosons (H, A) is suppressed due to their large masses

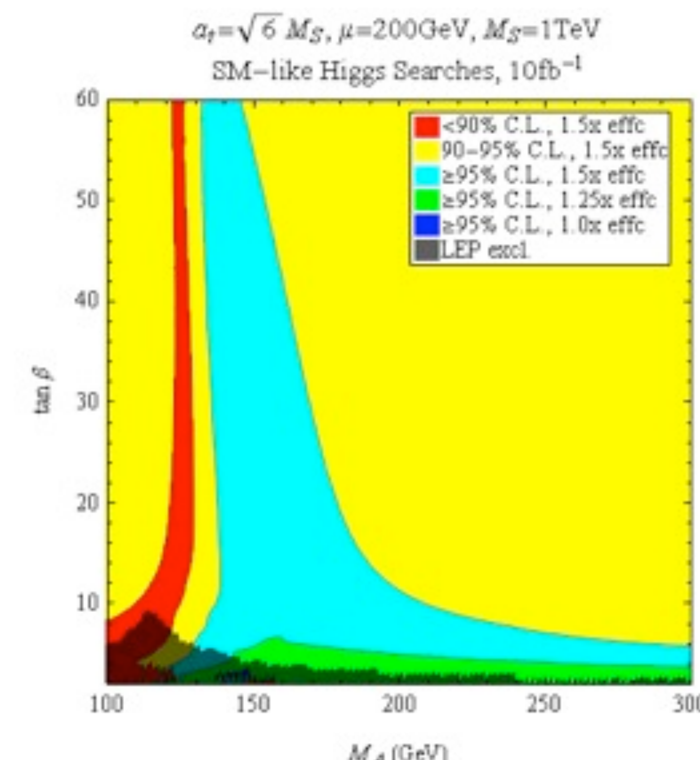
Compared to the SM, tautau channel is much more efficient for the higgs searches in the MSSM.

Minimal Mixing Scenario (SM-like Higgs Searches)

No allowed region: relatively small SM-like Higgs mass -> stronger SM-like constraints (vs. Maximal Mixing)





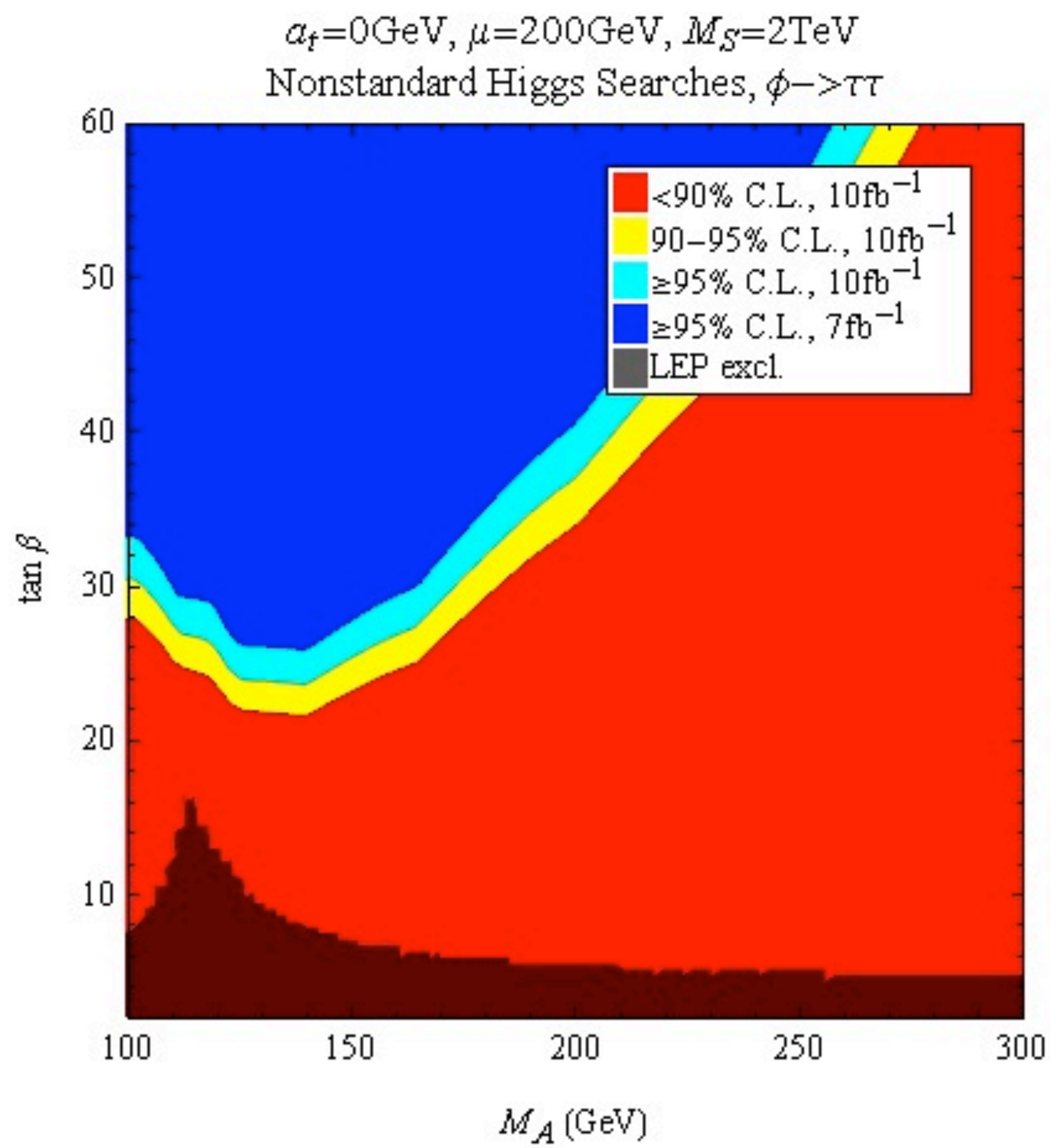


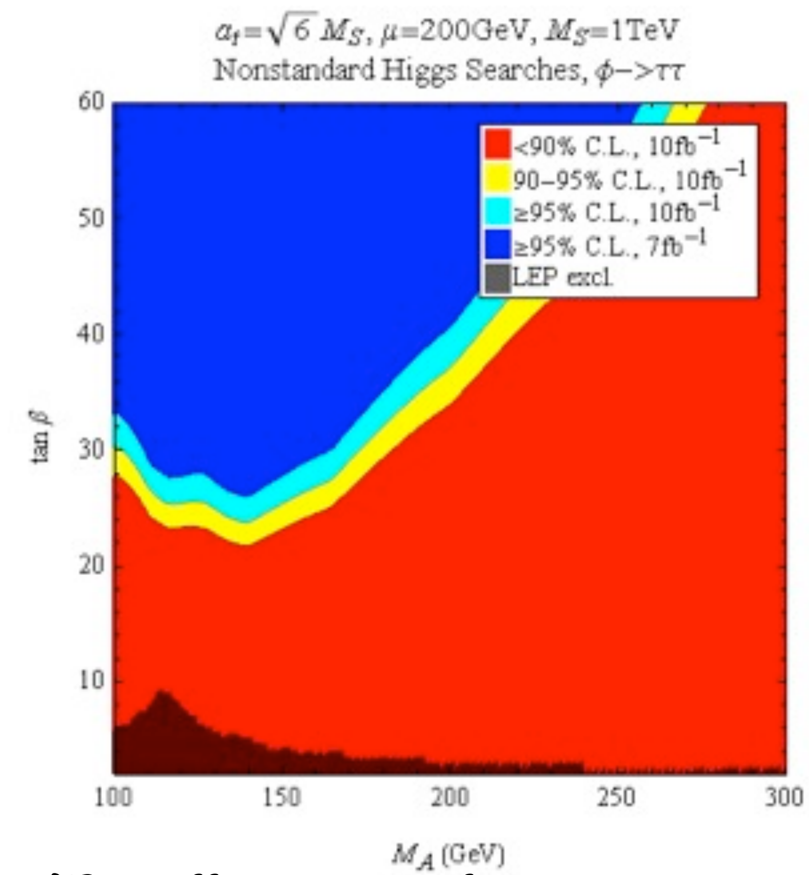
(Recall: SM, maximal mixing scenario)

Minimal mixing scenario: $m_h \sim 113 - 118\mathrm{GeV}$

(vs. Maximal mixing scenario: $m_h \sim 125 - 130\mathrm{GeV}$)

Minimal Mixing Scenario (Nonstandard Higgs Searches)





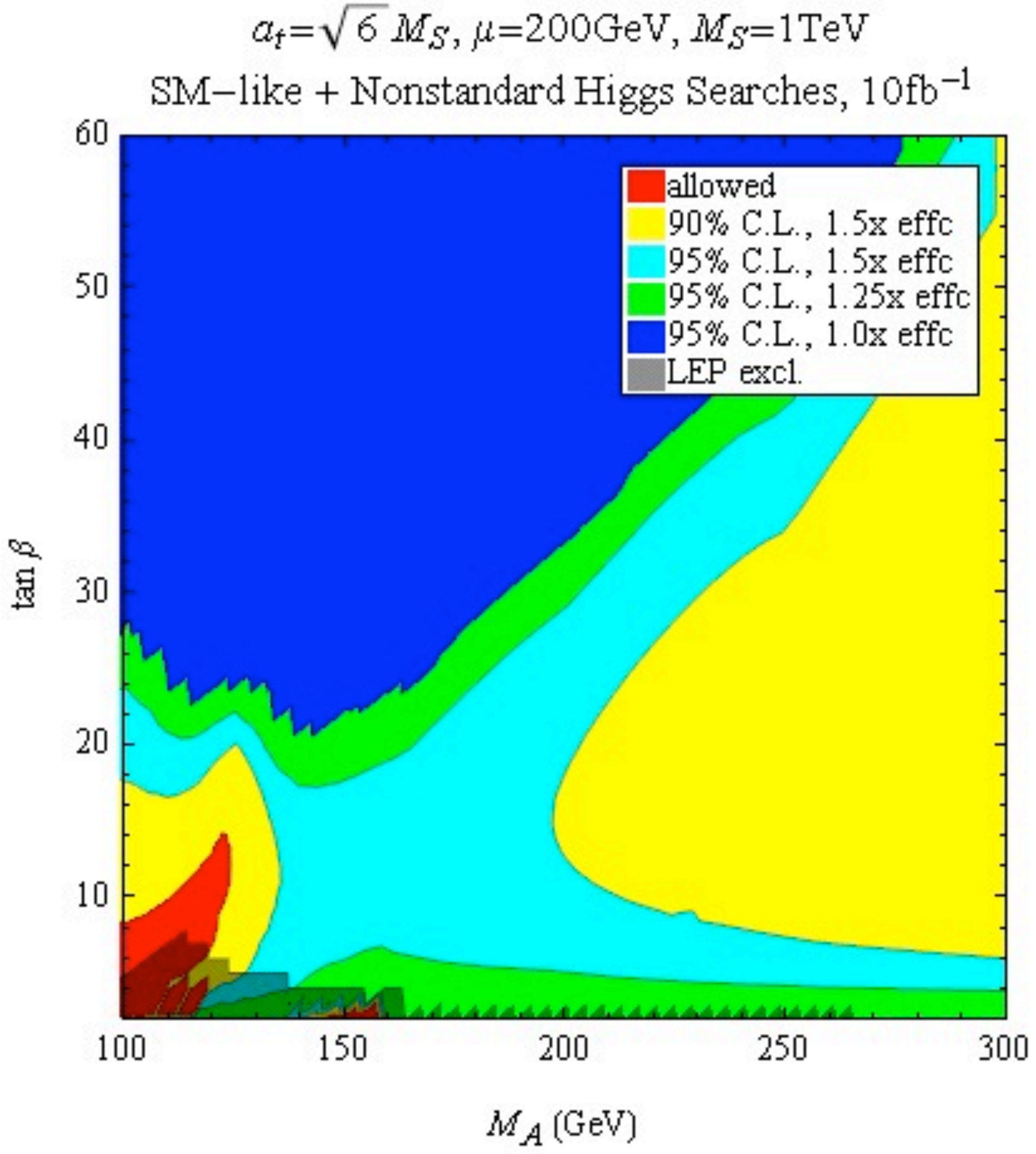
(Recall: maximal mixing scenario)

The exclusion limits based on the nonstandard Higgs searches are similar in the maximal and minimal mixing scenarios

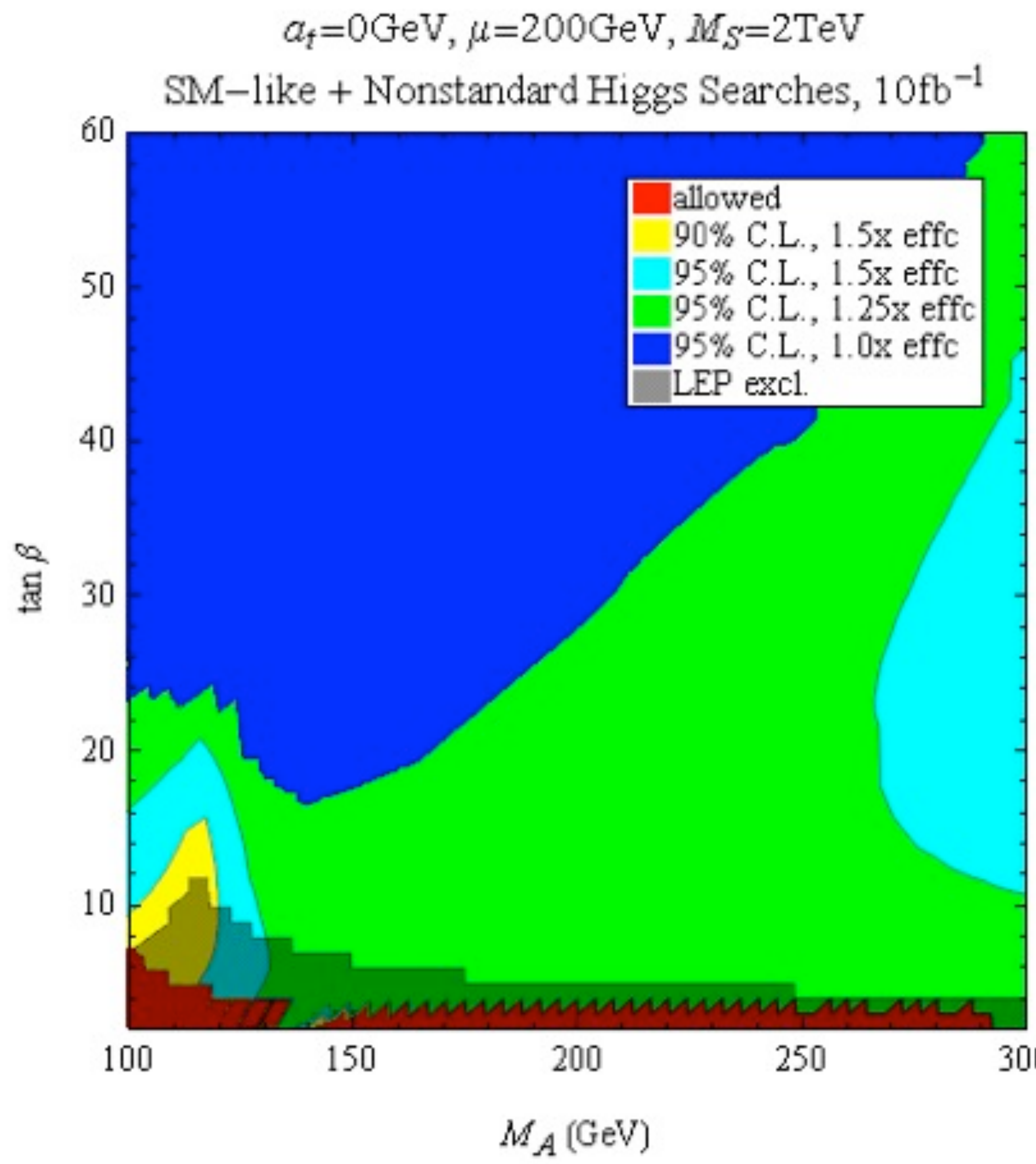
SM-like + Nonstandard Higgs Searches

P. Draper, T.L., C. Wagner, arXiv: 09054721

Maximal mixing scenario



Minimal mixing scenario



Most region can be covered at 90% C.L.

Most region can be covered at 95% C.L.

CP Violation in the MSSM

- CP phases enter the Higgs sector in the MSSM only at loop level
- They have two main effects for the Higgs physics :

  a. cause Higgs mass eigenstates to be mixture of CP-even and CP-odd components (define them as h1, h2 and h3 with $m_{h1} < m_{h2} < m_{h3}$)

  b. may significantly modify the Yukawa couplings of the SM-like Higgs bosons at loop level

CPX Scenario

- CPX scenario (M. S. Carena et. al '00):

$$
\begin{aligned}
M_S &= 500\ \mathrm{GeV}, & |A_t| &= 1\ \mathrm{TeV}, \\
\mu &= 2\ \mathrm{TeV}, & M_{1,2} &= 200\ \mathrm{GeV}, \\
A_{b,\tau} &= A_t, & |M_3| &= 1\ \mathrm{TeV}.
\end{aligned}
$$

a. CP-violation effects are maximized for given CP phase values

b. The bottom couplings of the SM-like Higgs are significantly suppressed in some regions of m_{H+} - tan_beta plane

c. There are two independent CP phases

- Three representative cases (M_3 - soft mass of gluino):

a. $\mathrm{Arg} M_3 = 0^\circ, \quad \mathrm{Arg} A_{t,b,\tau} = 0^\circ$

b. $\mathrm{Arg} M_3 = 90^\circ, \quad \mathrm{Arg} A_{t,b,\tau} = 90^\circ$

c. $\mathrm{Arg} M_3 = 140^\circ, \quad \mathrm{Arg} A_{t,b,\tau} = 140^\circ$

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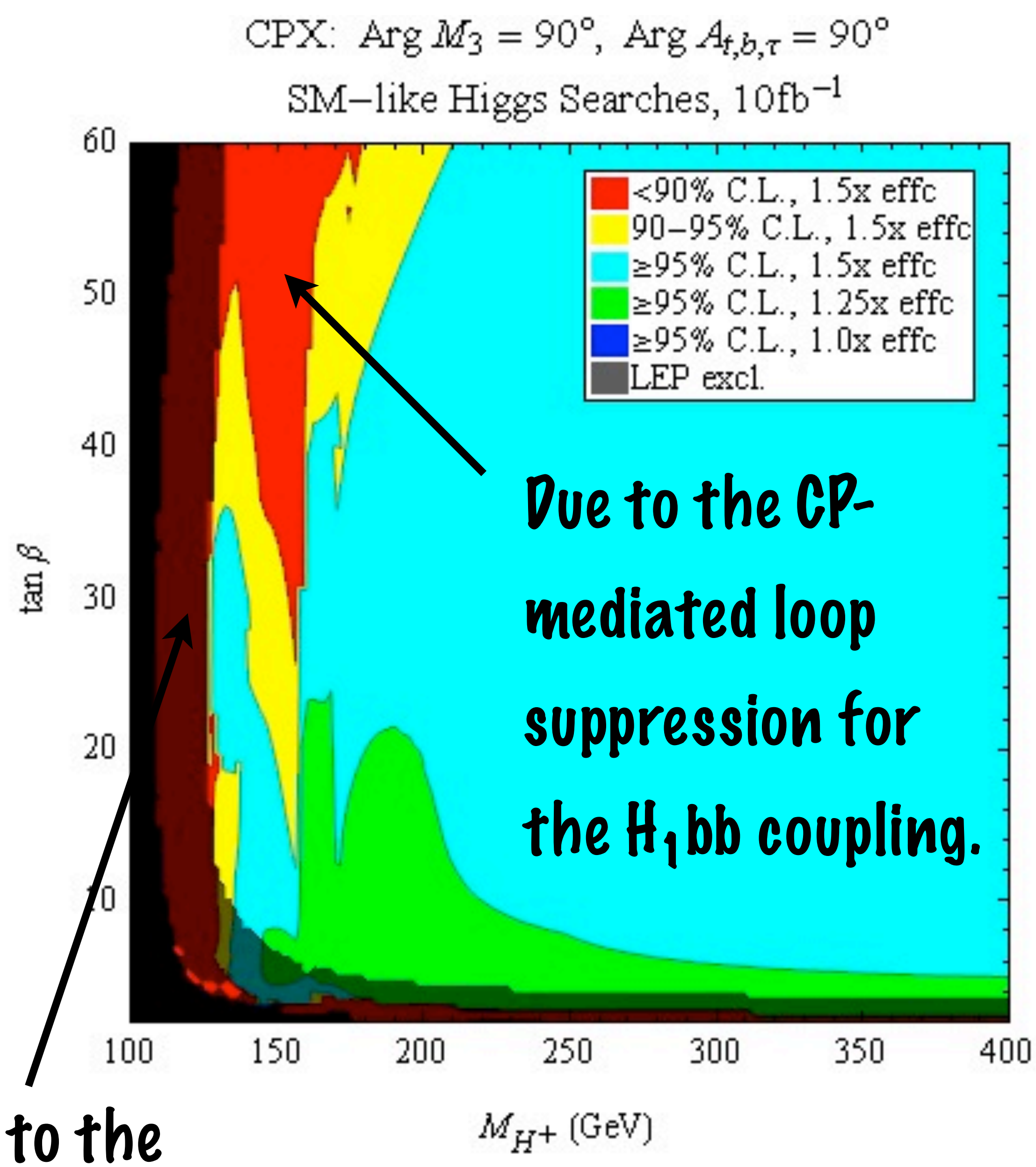
CPX Scenario: SM-like, Nonstandard Higgs Searches

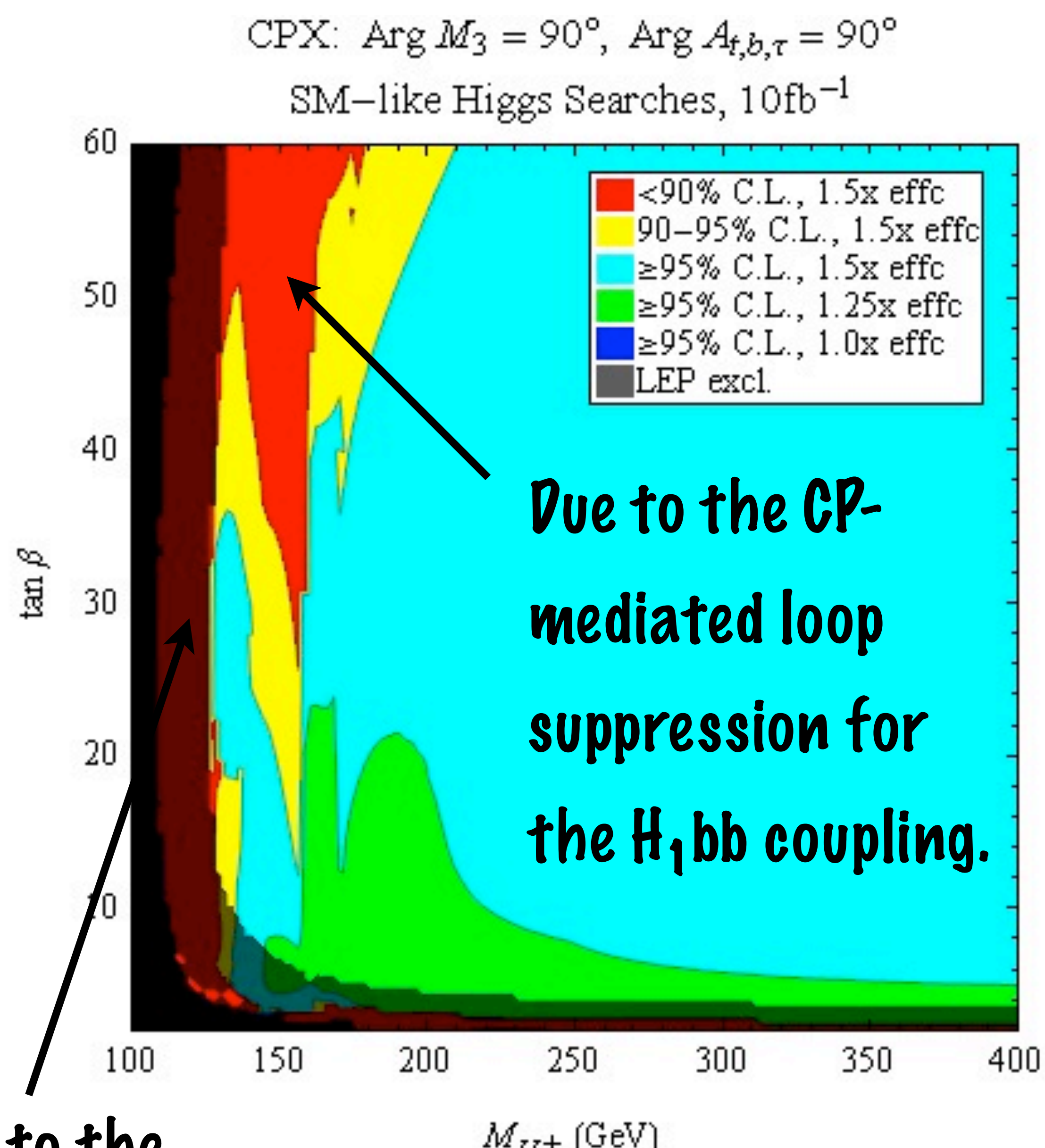


Due to the CP-mediated loop suppression for the H_1bb coupling.

Due to the opening of H_3-> $H_1H_{1,2}$ channels.

SM-like searches

CPX Scenario: SM-like, Nonstandard Higgs Searches



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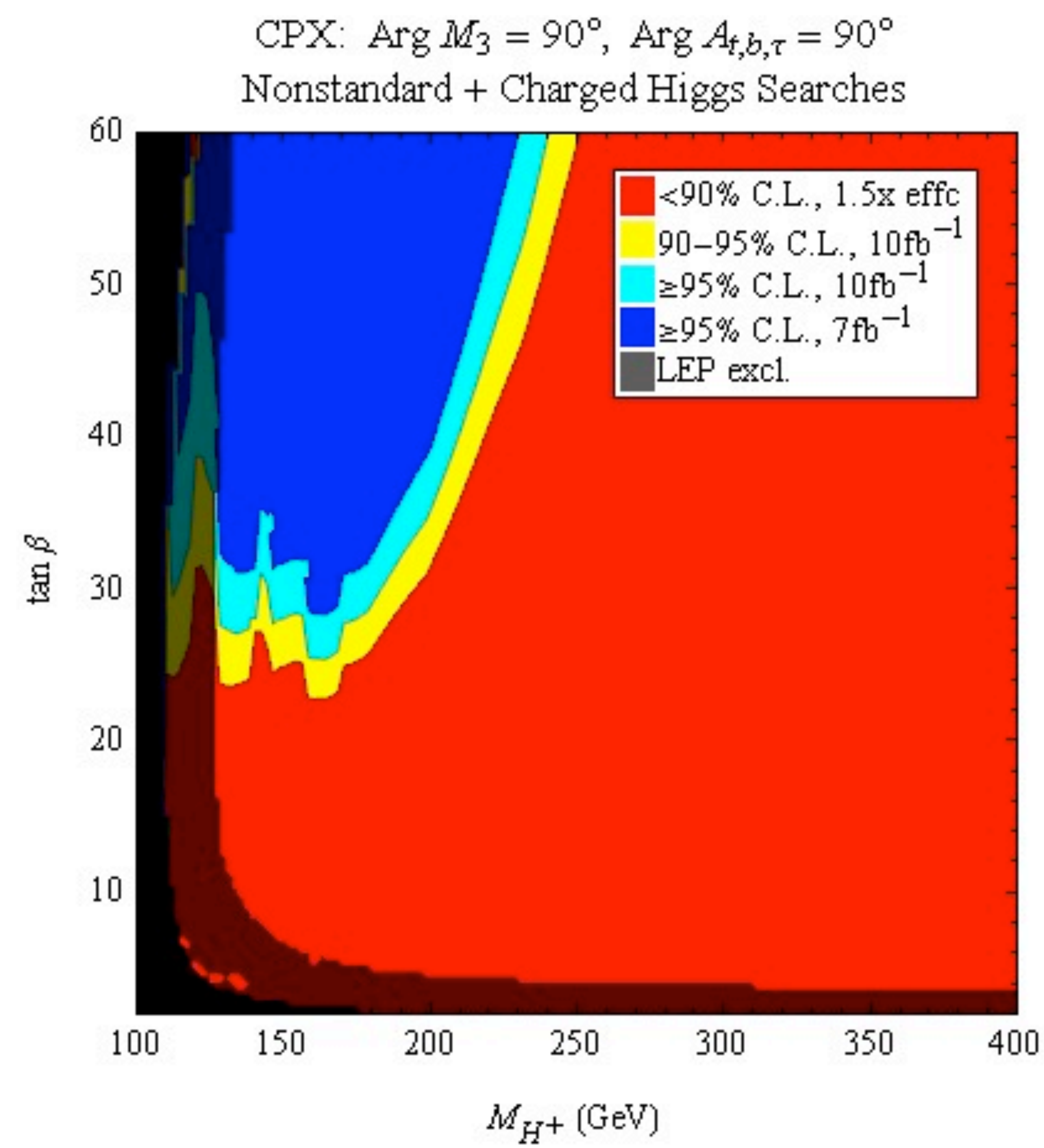


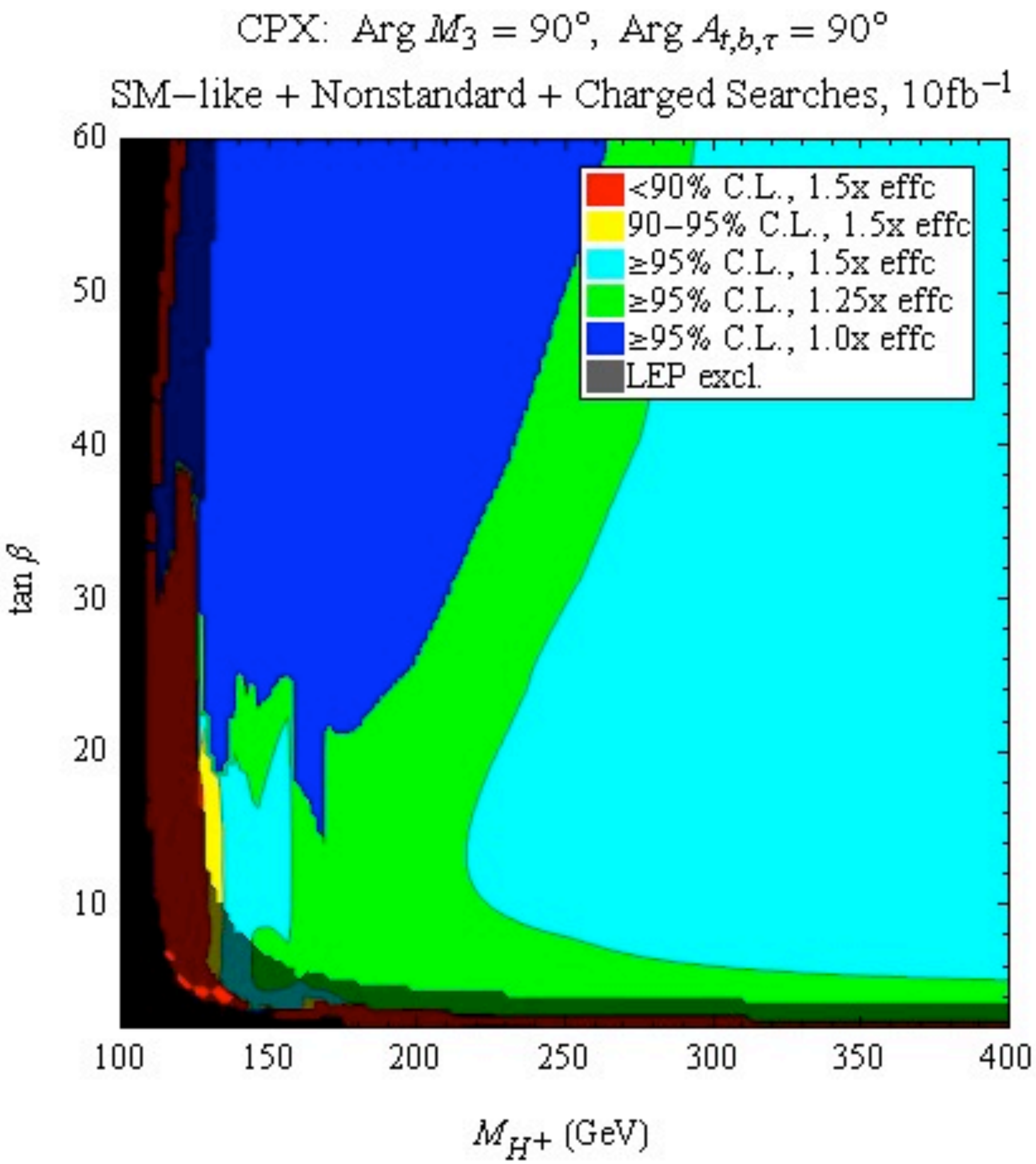
Due to the opening of H_3-> $H_1H_{1,2}$ channels.

SM-like searches

Nonstandard searches

CPX Scenario: SM-like + Nonstandard Higgs Searches

P. Draper, T.L., C. Wagner, arXiv: 0911.0034



Most region can be covered at 95% C.L.

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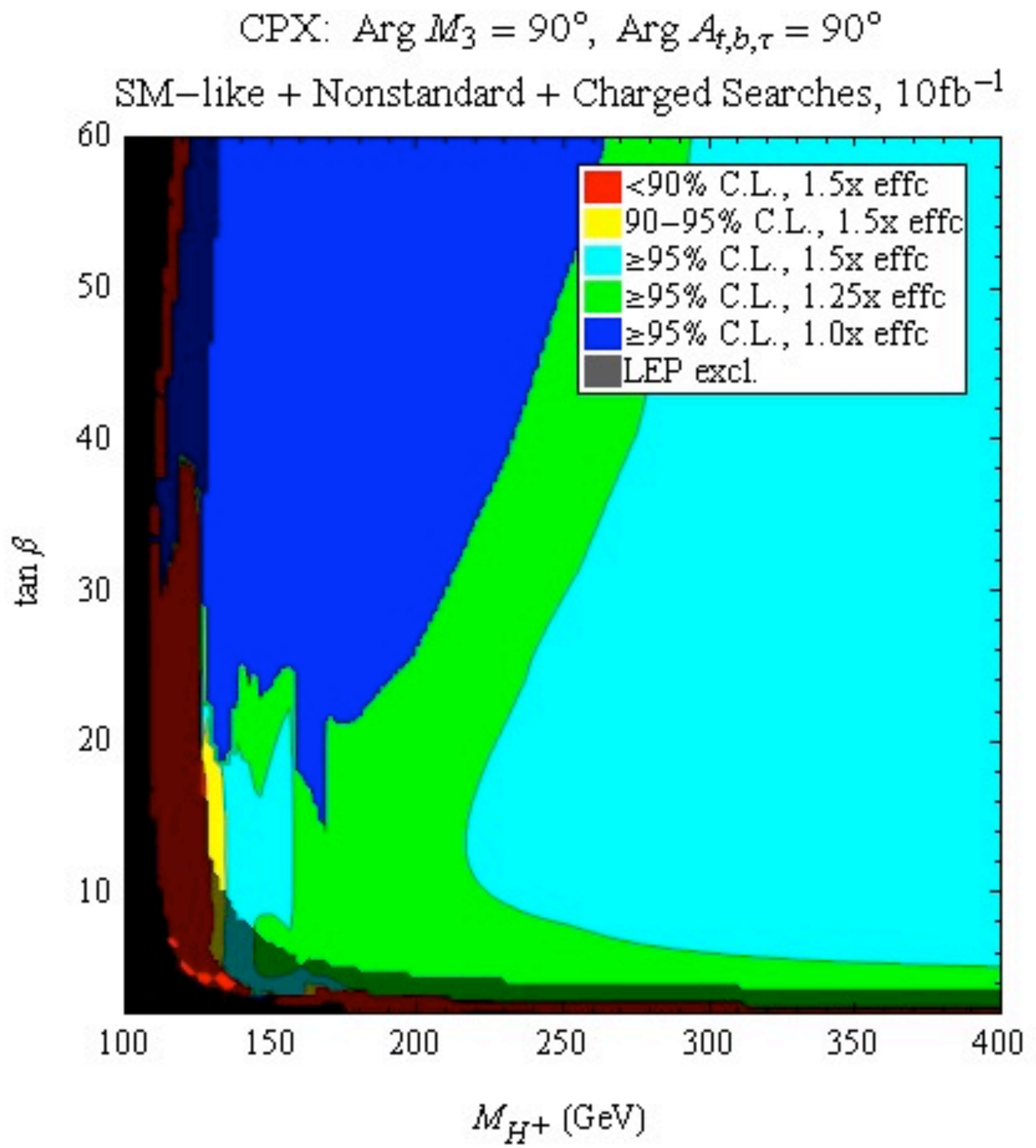

Most region can be covered at 95% C.L.

Concluding this section:

Almost the whole parameter space of the known benchmark scenarios can be covered at 95% C.L. for 50% improvement in signal efficiency and 10/fb integrated luminosity (except the large m_A region of the maximal mixing scenario).

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Motivation

- At the Tevatron, the SM-like Higgs searches (MSSM) -> bb channel (VBA)
- At the LHC (14 TeV), the SM-like Higgs searches (MSSM) -> the photon photon search (inclusive) + tau tau channel (VBF)

Motivation

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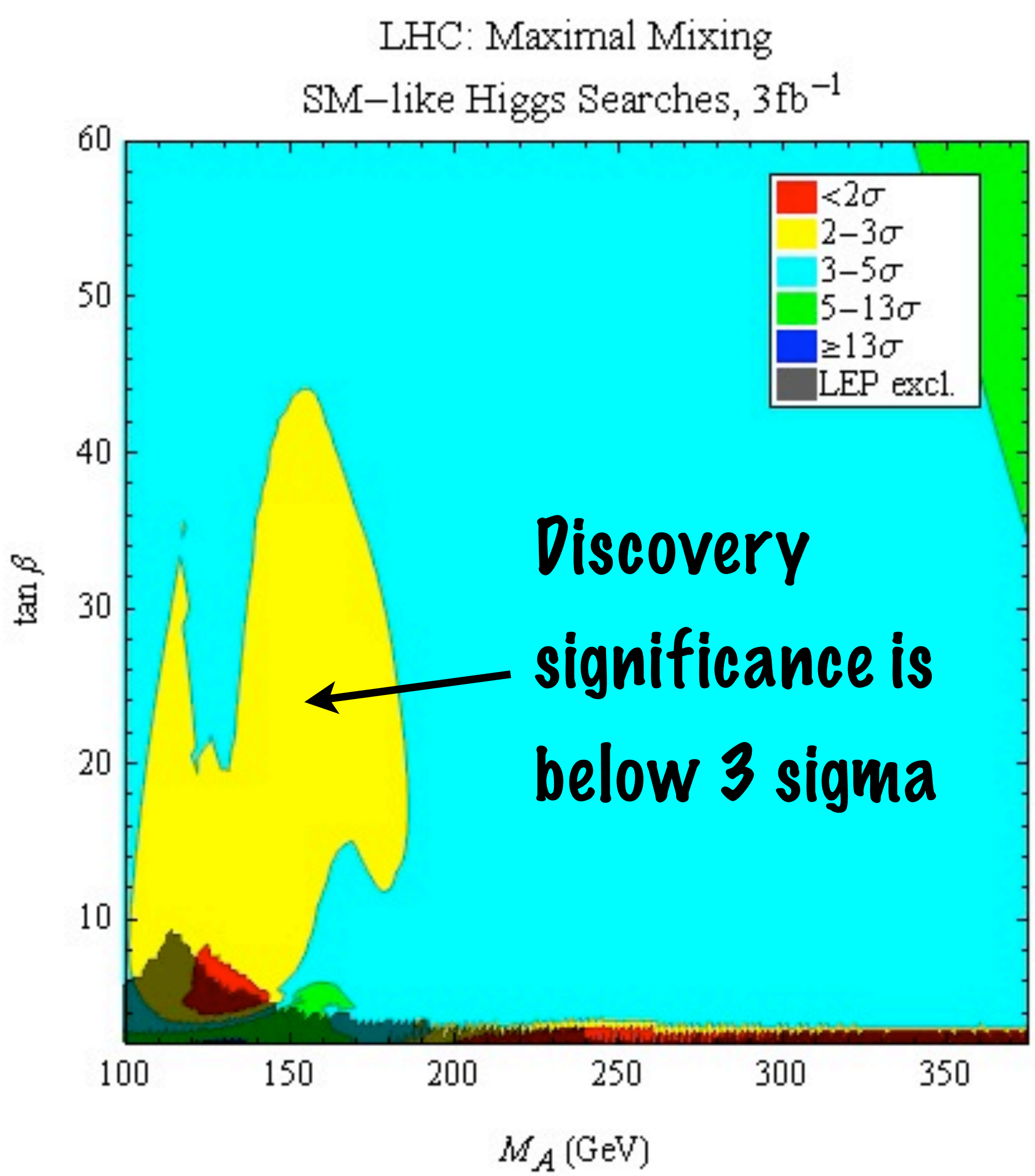
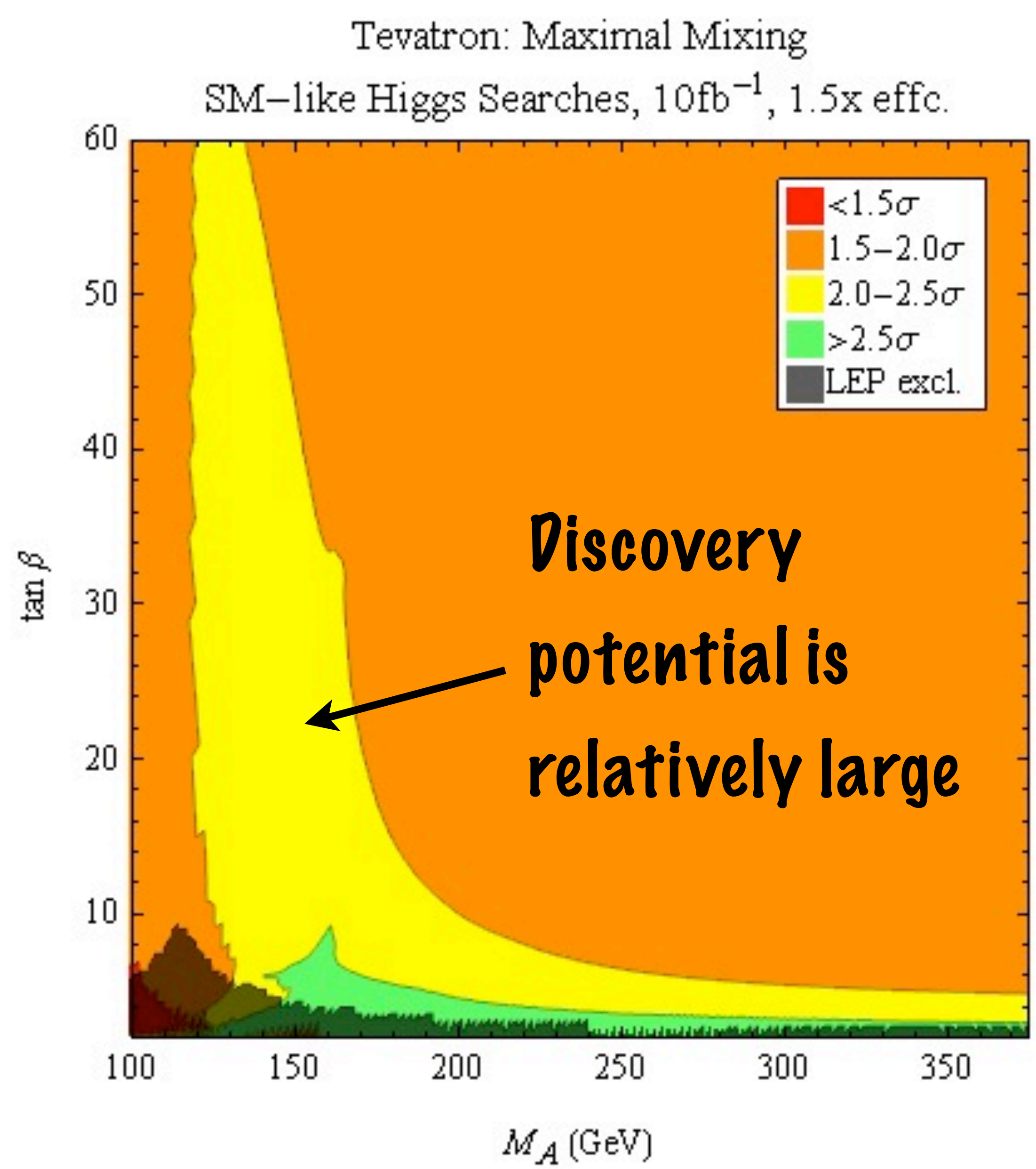
(Recall the mass range of the SM-like Higgs in the MSSM: 114 - 130 GeV)

-> Does there exist a complementarity between the SM-like Higgs searches (MSSM) at the Tevatron and the early LHC ?

Maximal Mixing Scenario



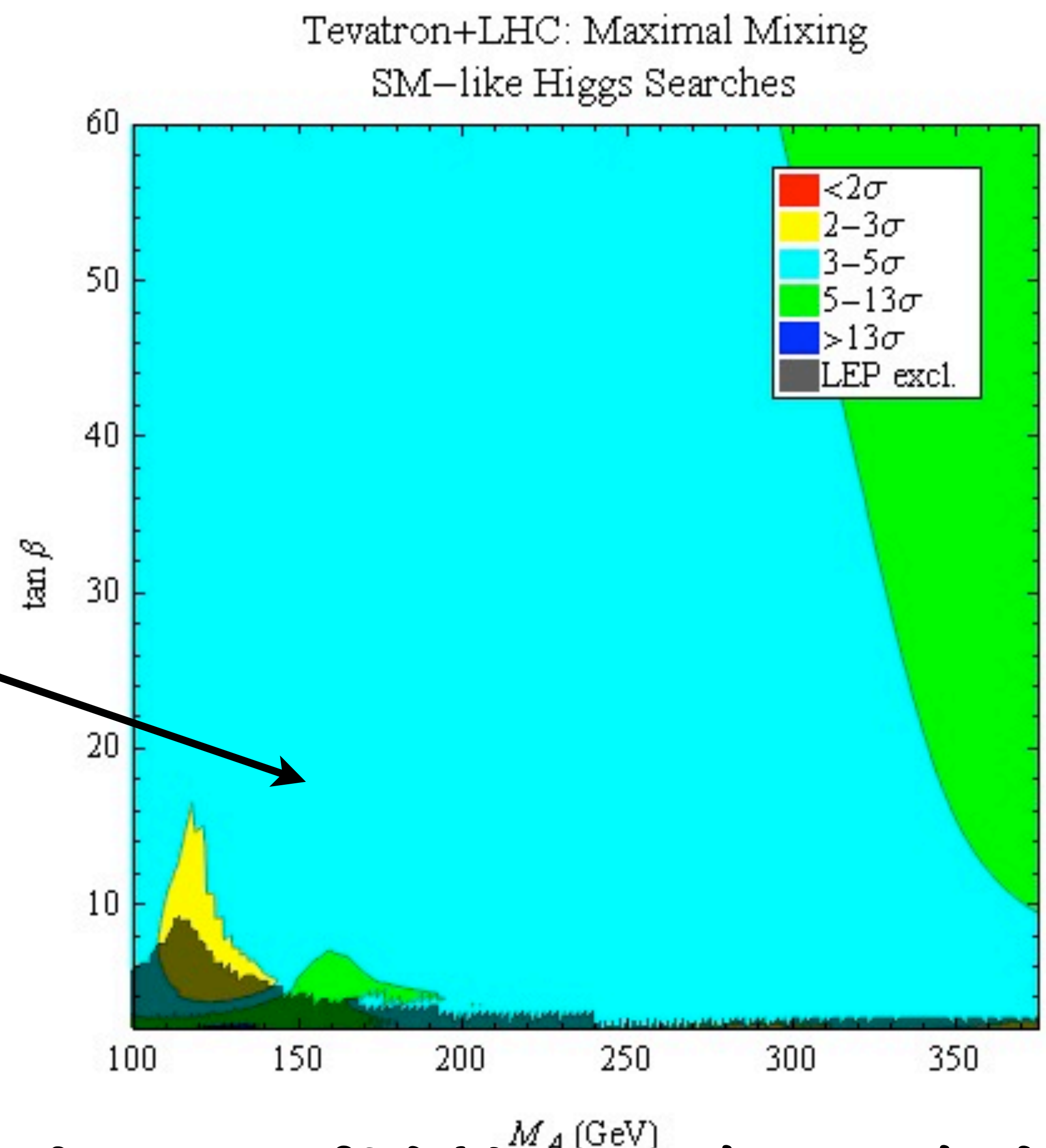


SM-like searches (gamma gamma + tau tau) at the LHC (3/fb)

SM-like searches (bb + WW) at the Tevatron (10/fb+ 1.5 * effc)

Maximal Mixing Scenario

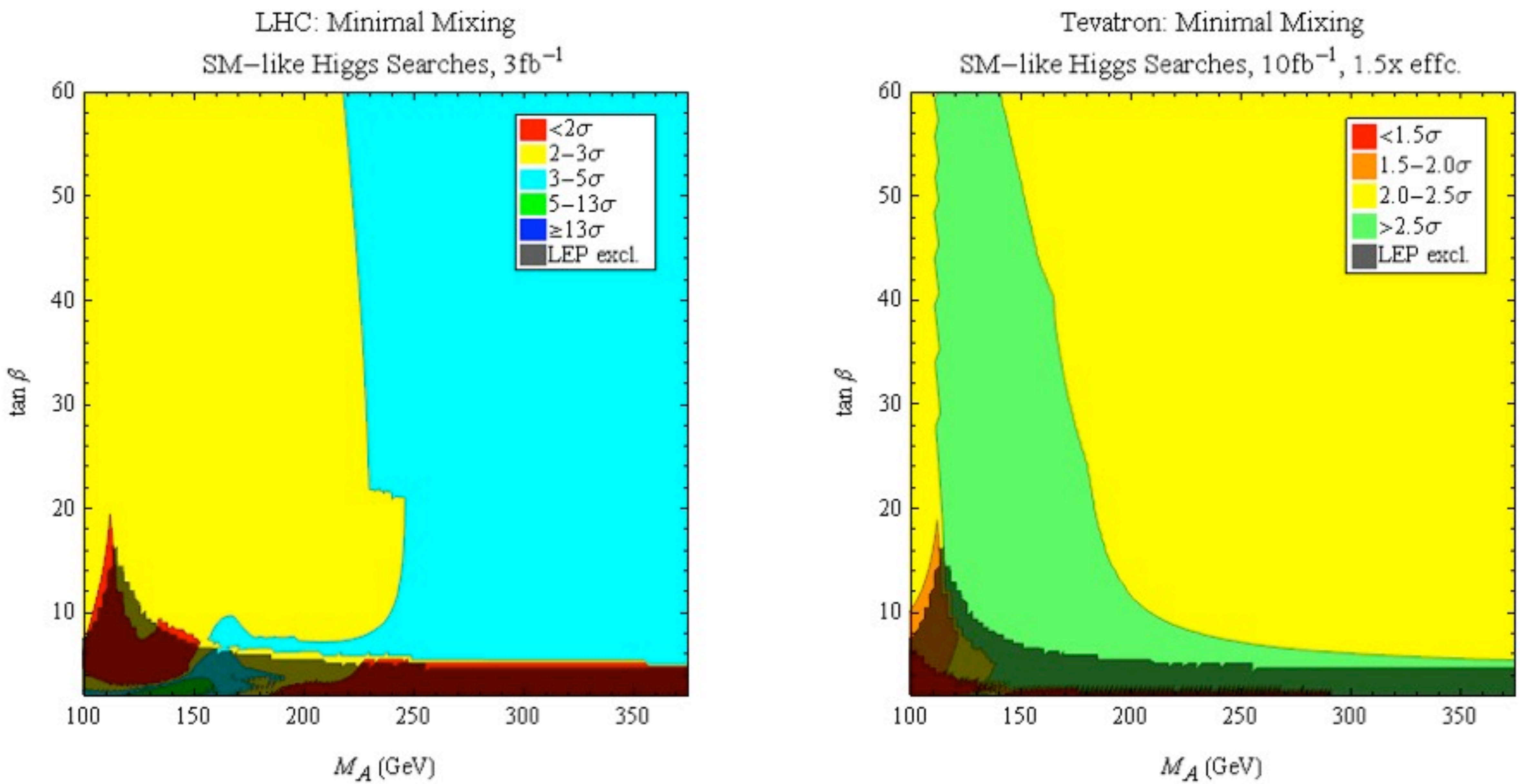
P. Draper, T.L., C. Wagner, arXiv: 0911.0034



The discovery potential is lifted to above 3 sigma

Combined SM-like searches at the LHC (3/fb) and Tevatron (10/fb+ 1.5 * effc)

Minimal Mixing Scenario



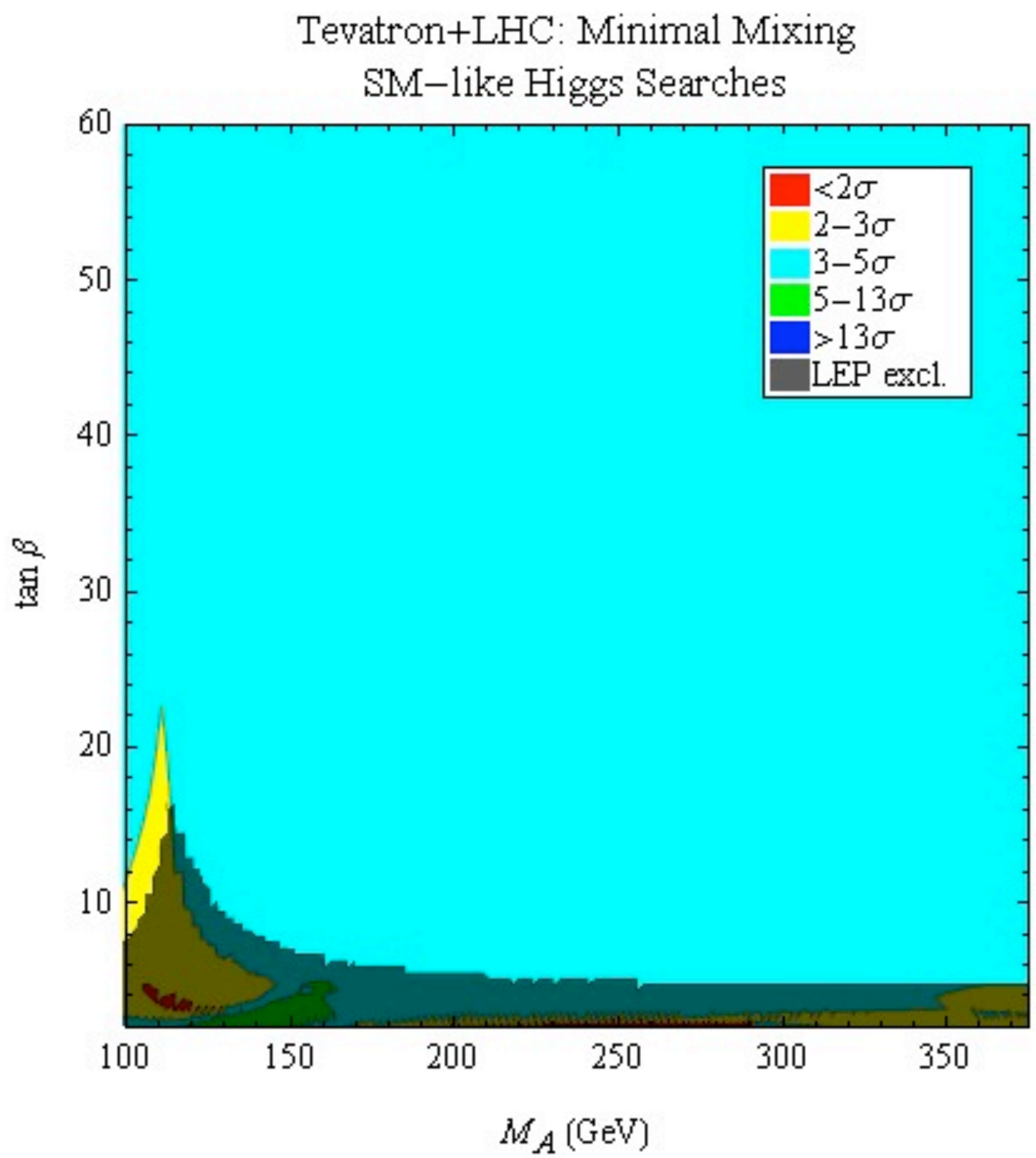
SM-like searches at the LHC (3/fb) SM-like searches at the Tevatron (10/fb+ 1.5 * effc)

Relatively light mass of the SM-like Higgs -> larger bb branching ratio

-> stronger complementarity provided by the Tevatron

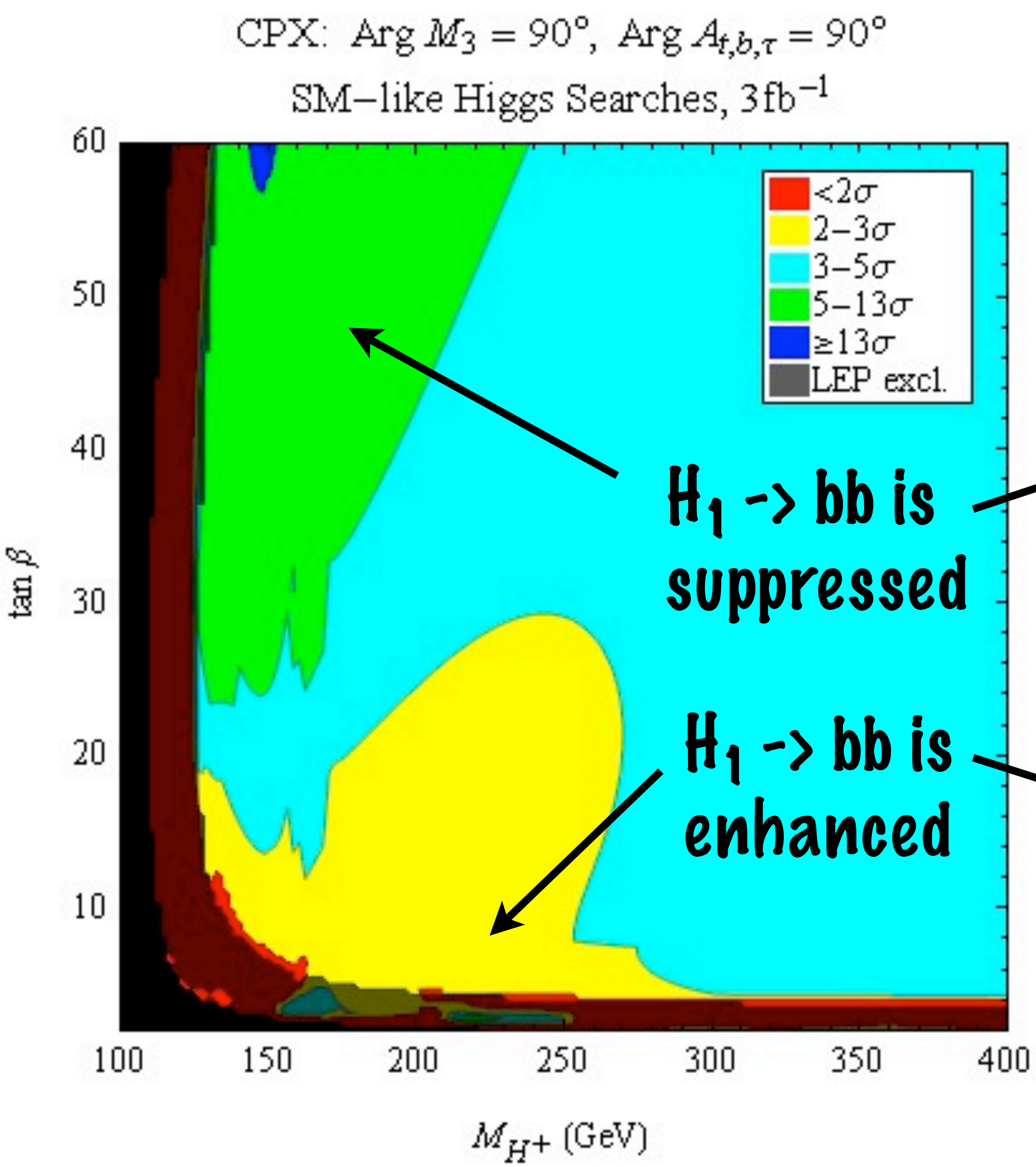
Minimal Mixing Scenario

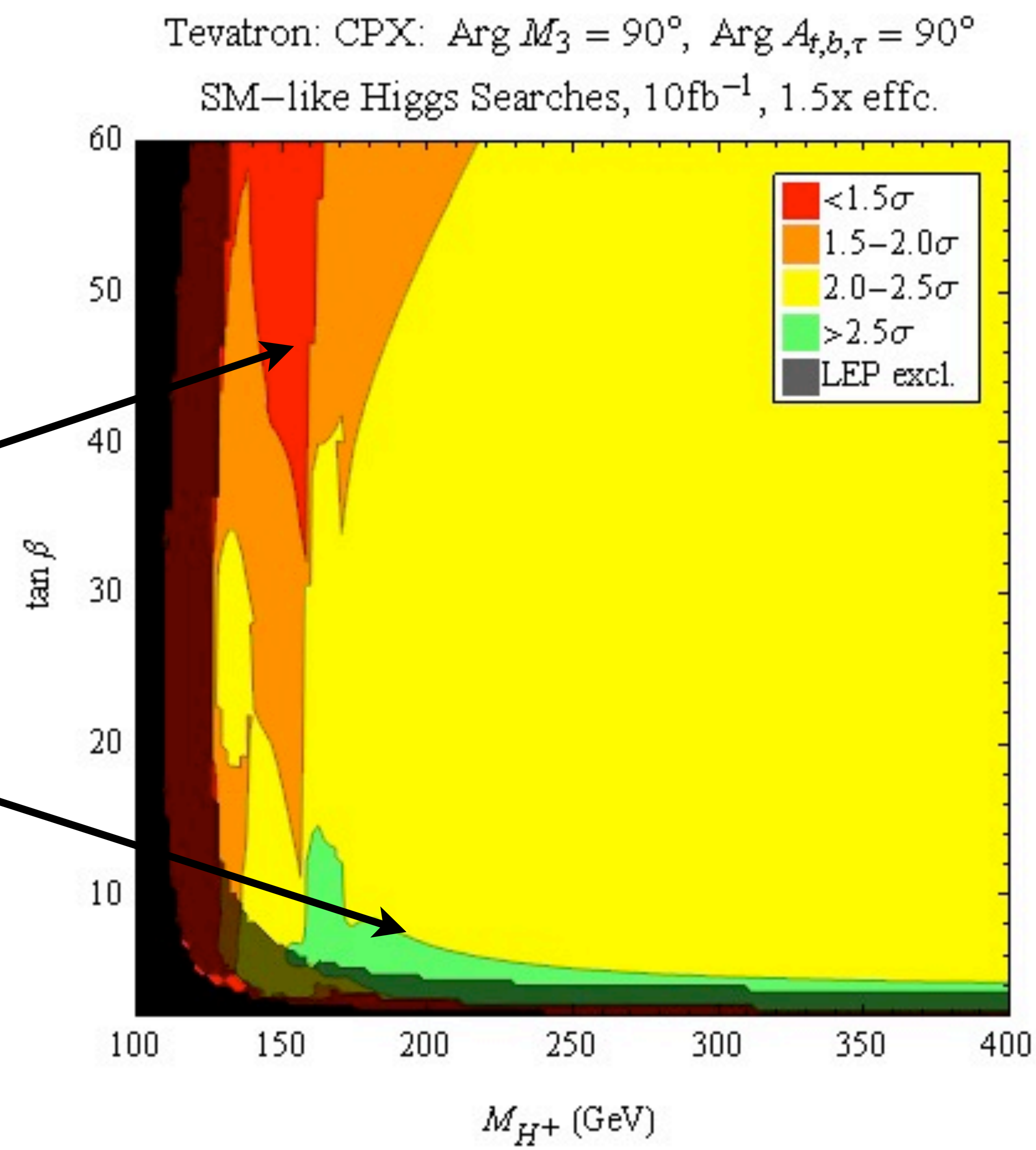
P. Draper, T.L., C. Wagner, arXiv: 0911.0034



Combined SM-like searches at the LHC (3/fb) and Tevatron (10/fb+ 1.5 * effc)

CPX Scenario





H_1 -> bb is suppressed

H_1 -> bb is enhanced

SM-like searches (gamma gamma + tau tau) at the LHC (3/fb)

SM-like searches (bb + WW) at the Tevatron (10/fb+ 1.5 * effc)

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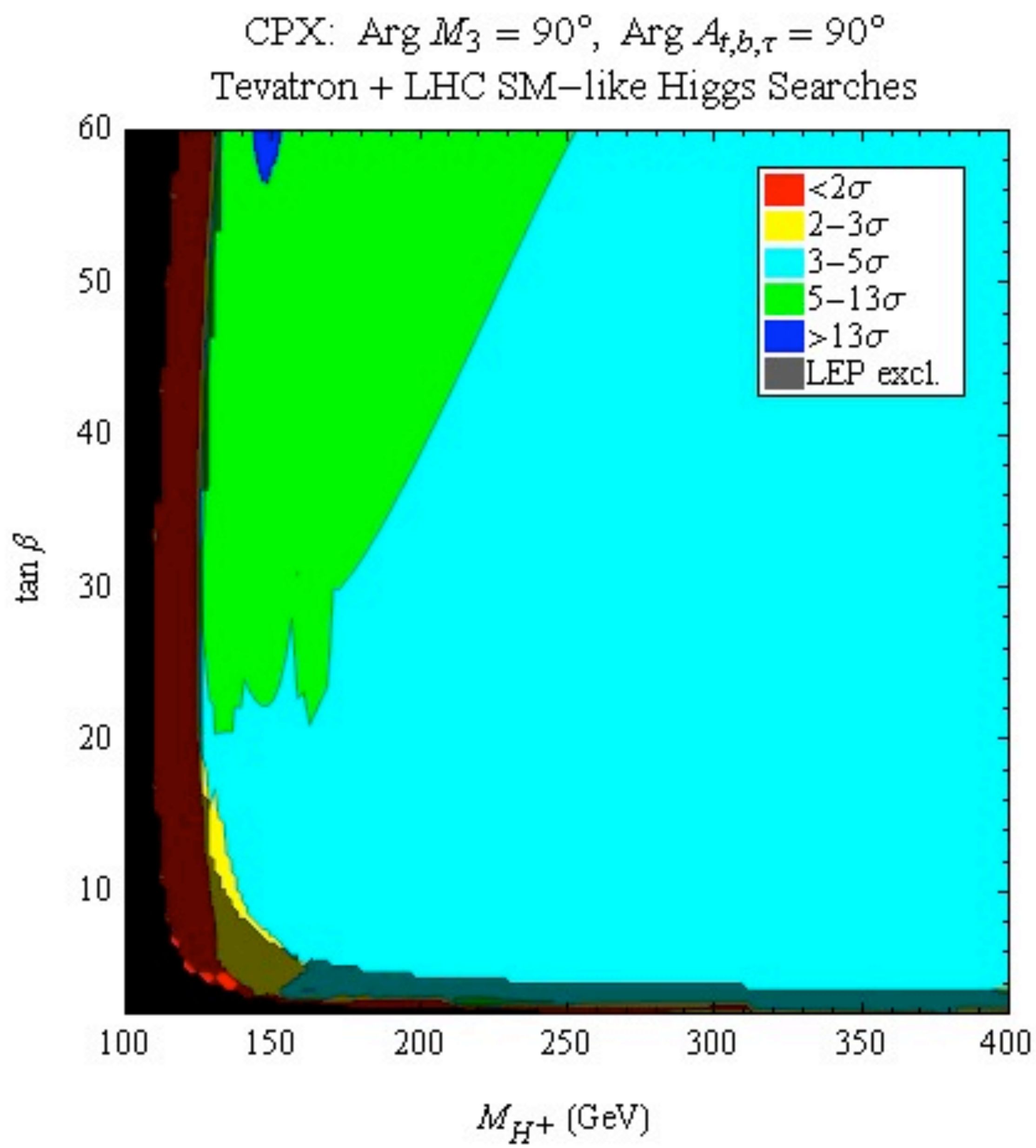

Combined SM-like searches at the LHC (3/fb) and Tevatron (10/fb+ 1.5 * effc)

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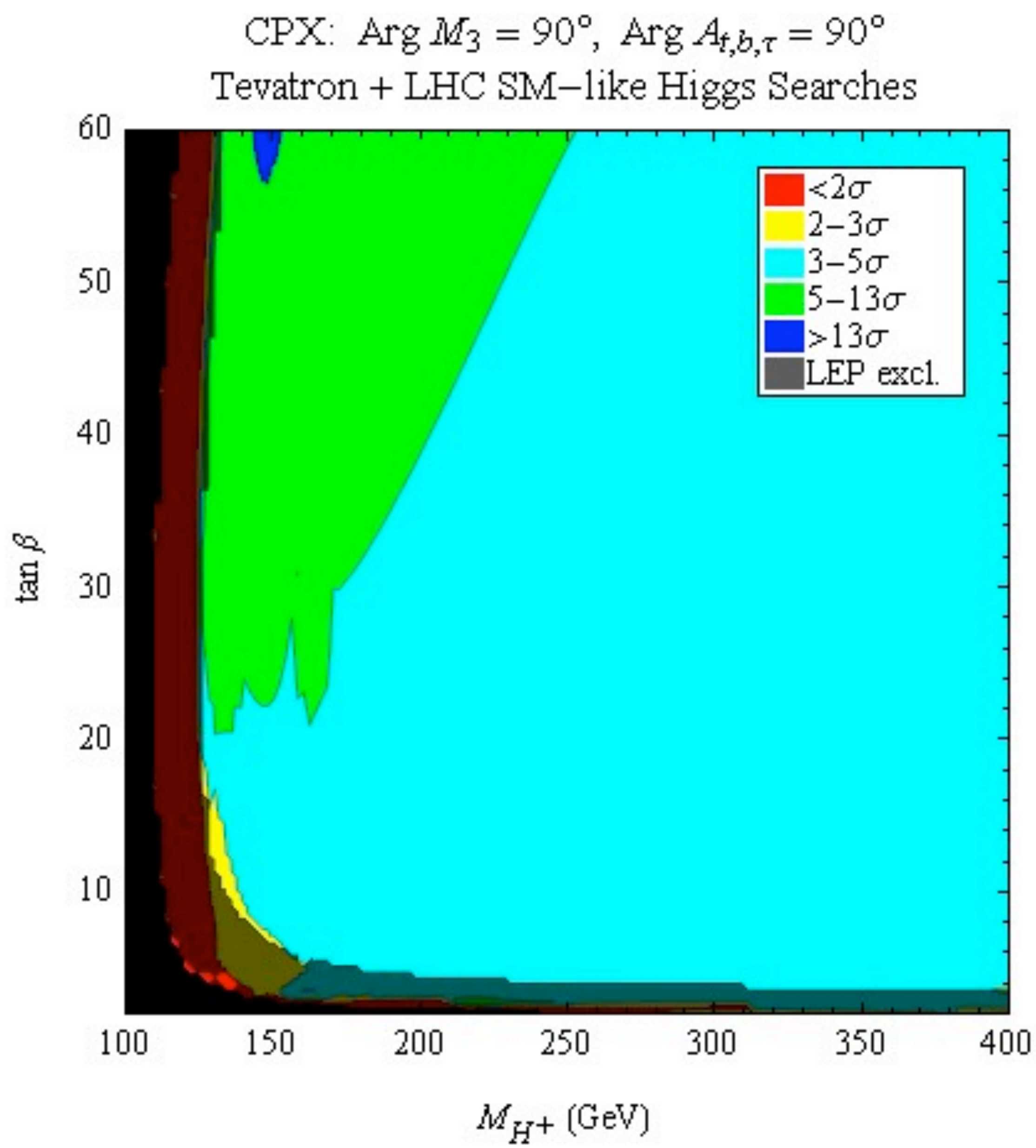

Combined SM-like searches at the LHC (3/fb) and Tevatron (10/fb+ 1.5 * effc)

Concluding this section:

There exists a good complementarity between the SM-like Higgs searches at the Tevatron and the early LHC.

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With a combination of SM-like and nonstandard Higgs searches, the Tevatron has the potential to probe almost the whole parameter space of all known MSSM Higgs benchmark scenarios, yielding 95% exclusions everywhere except in some large m_A region of the maximal mixing scenario

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With an increase in luminosity to 10/fb and 25-50% improvements in signal efficiencies, the Tevatron can cover the whole parameter space of the SM which is consistent with the EW precision data at 90% C.L.

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http://home.uchicago.edu/~pdraper/MSSMHiggs/MSSMHiggs.html

http://home.uchicago.edu/~pdraper/MSSMHiggsCPV/MSSMHiggsCPV.html