Prospects for MSSM Higgs Searches at the Tevatron Collider

C.E.M. Wagner

EFI and KICP, University of Chicago
Argonne National Laboratory

in collaboration with

M. Carena, S. Heinemeyer and G. Weiglein, Eur. Phys. J. C45:497, 2006.
P. Draper, T. Liu, PRD80:015001 (2009) and PRD81:015014 (2010)
M. Carena, P. Draper, T. Liu, S. Heinmeyer, G. Weiglein, to appear

MCTP Higgs Symposium, University of Michgan, Ann Arbor, May 15, 2010

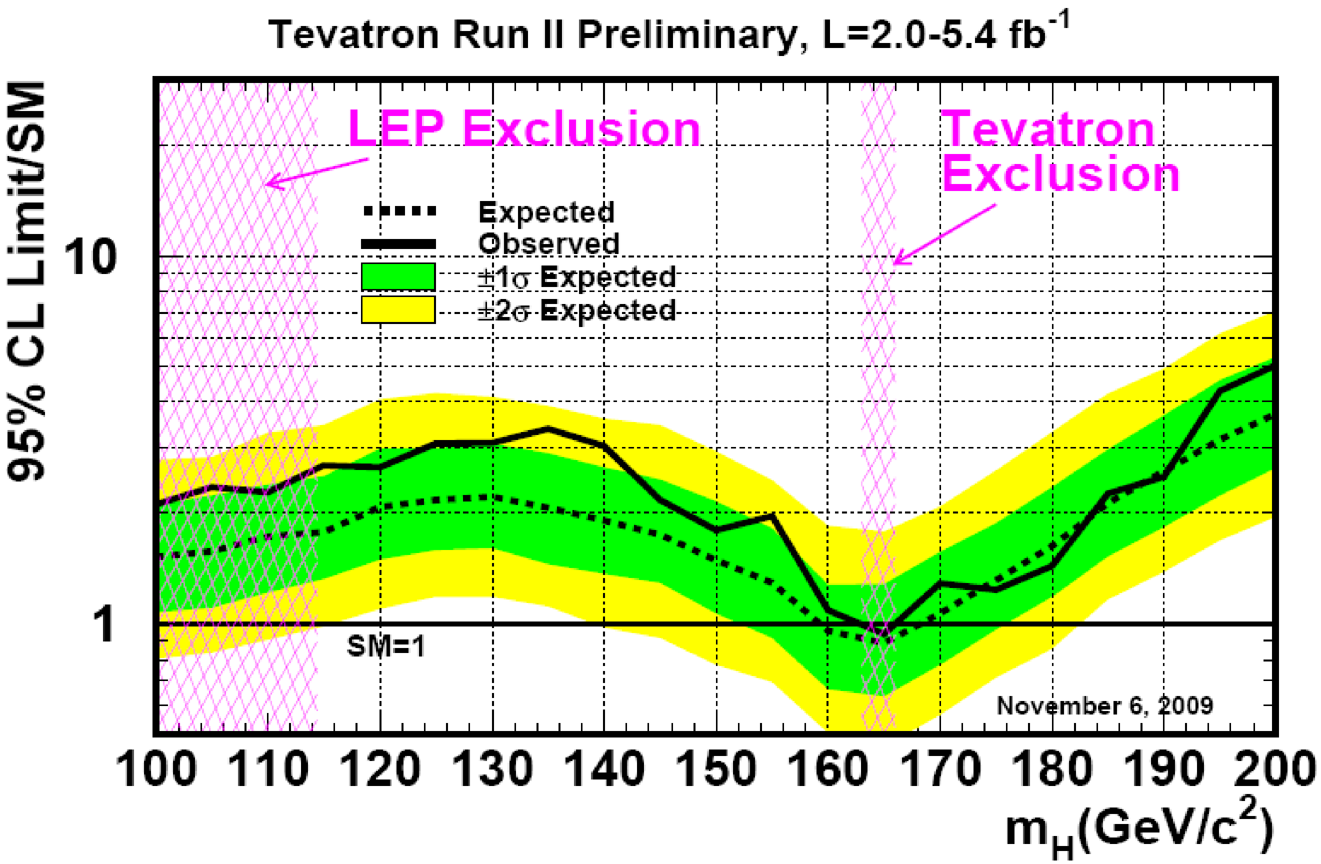
Higgs Searches at the Tevatron

- Higgs searches at the Tevatron collider are reaching maturity, both in the high mass as well as in the low mass region.
- By the end of next year, the luminosity will be high enough to probe the existence of the Standard Model Higgs boson on a large range of masses.
- The question is what is that range and what kind of sensitivity improvement will that demand
- Moreover, what would that imply for well motivated models like the MSSM ?
- The LHC will eventually surpass the Tevatron capabilities, but in the meantime, we should be able to make use of the available data and profit from the information we can extract from it.
- Also, the Tevatron is searching for the Higgs in bottom quark decays, something that the LHC may be only able to do applying sophisticated methods.

  T. Plehn's talk
- This also raises the question : Is it worth to continue running the Tevatron after its planned shutdown at the end of 2011 ?

Current Tevatron Experimental Status

Tevatron already probing high mass region



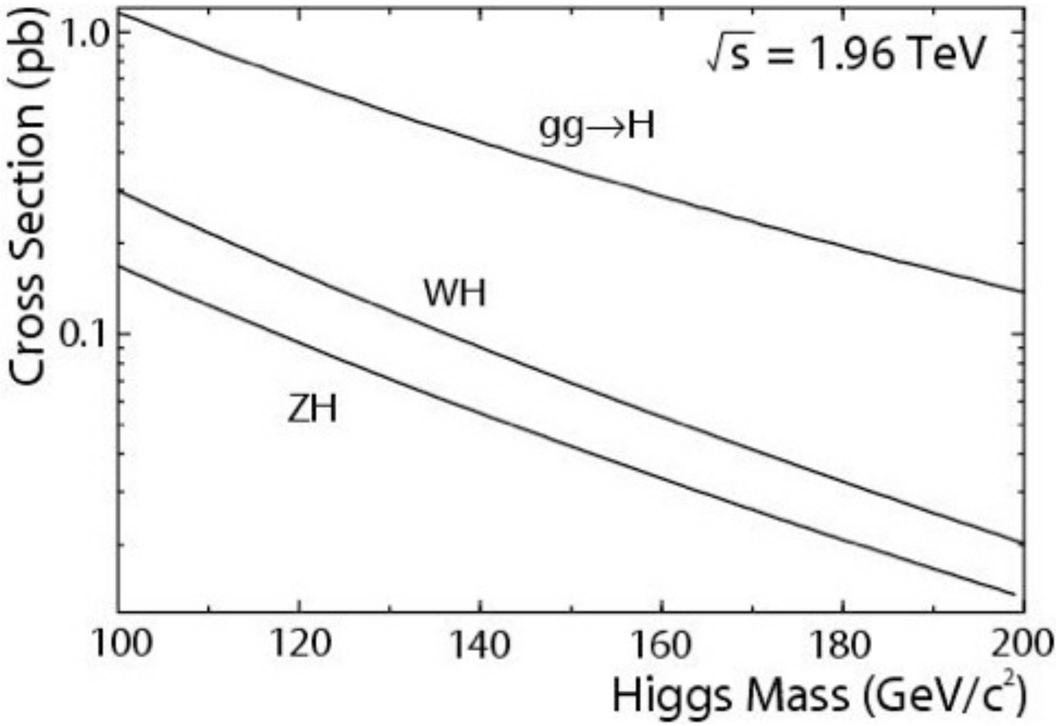
At m_H=165GeV:
Exp 0.89xSM, Obs 0.94xSM

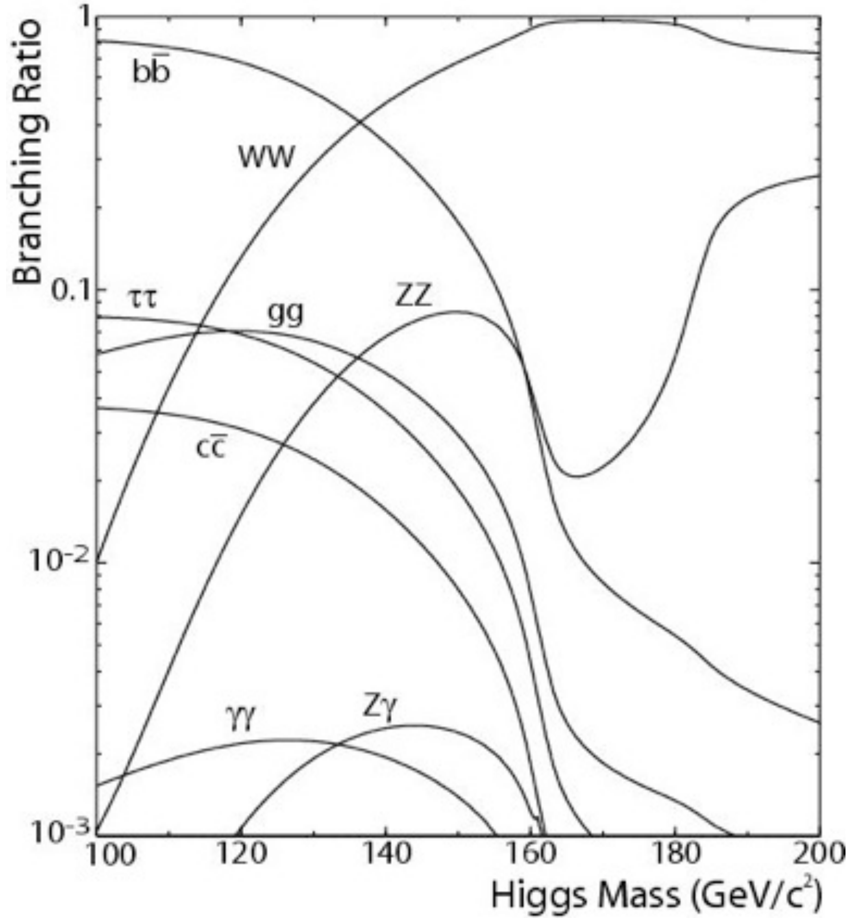
At m_H =115GeV:
Exp 1.8xSM, Obs 2.7xSM

Interesting enough, if a Higgs were there, one would expect, in average $R_{\rm obs} = R_{\rm exp} + 1$. However, observed distribution is very broad and the statistical significance is $2/R_{\rm exp}$

Higgs Search Channels at the Tevatron

http://www-cdf.fnal.gov/physics/exotic/r2a/20040722.lmetbj_wh_tc/



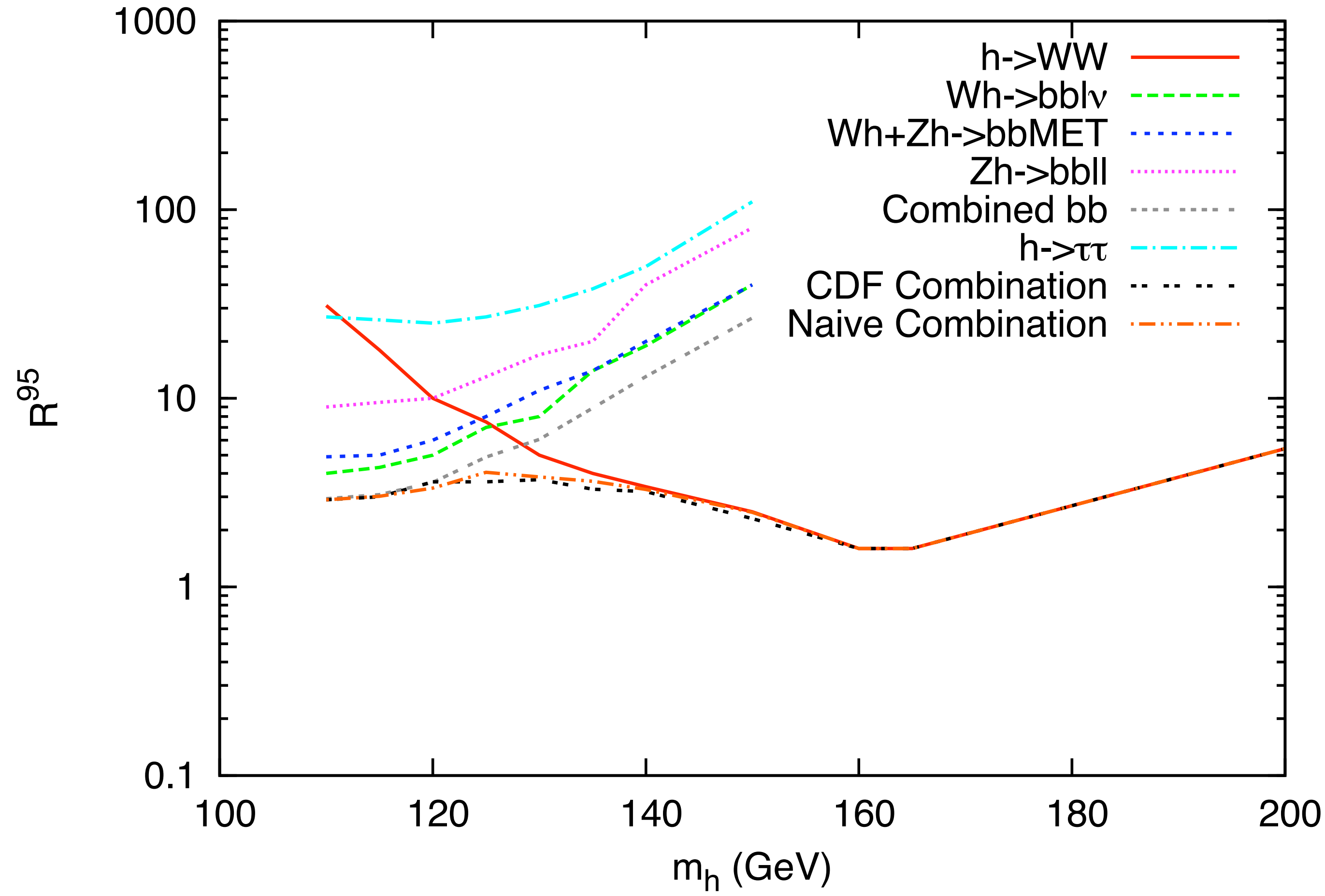


Multiple channels from CDF and DZero can be put together to give a combined sensitivity S in units of Gaussian standard deviations. Approximately add in quadrature.

$$\sum \left(\frac{\epsilon_i}{\epsilon_i^0} \sqrt{\frac{L_i}{L_i^0}} \times \frac{s_i}{\sqrt{b_i}} \right)^2 = S^2$$

Comparison of Simple Combination of Channels with CDF Results. Ratio R for exclusion

P. Draper, T. Liu and C. Wagner'09



Applicable to new model in which all channels rescale in the same way.

Efficiency Improvements in the low Mass Region

Wade Fisher — Tevatron Low Mass Higgs Searches — 21

Higgs Sensitivity Projections

Moriond EW
March 7th 2010

A few active areas of analysis improvements (not a full list!):

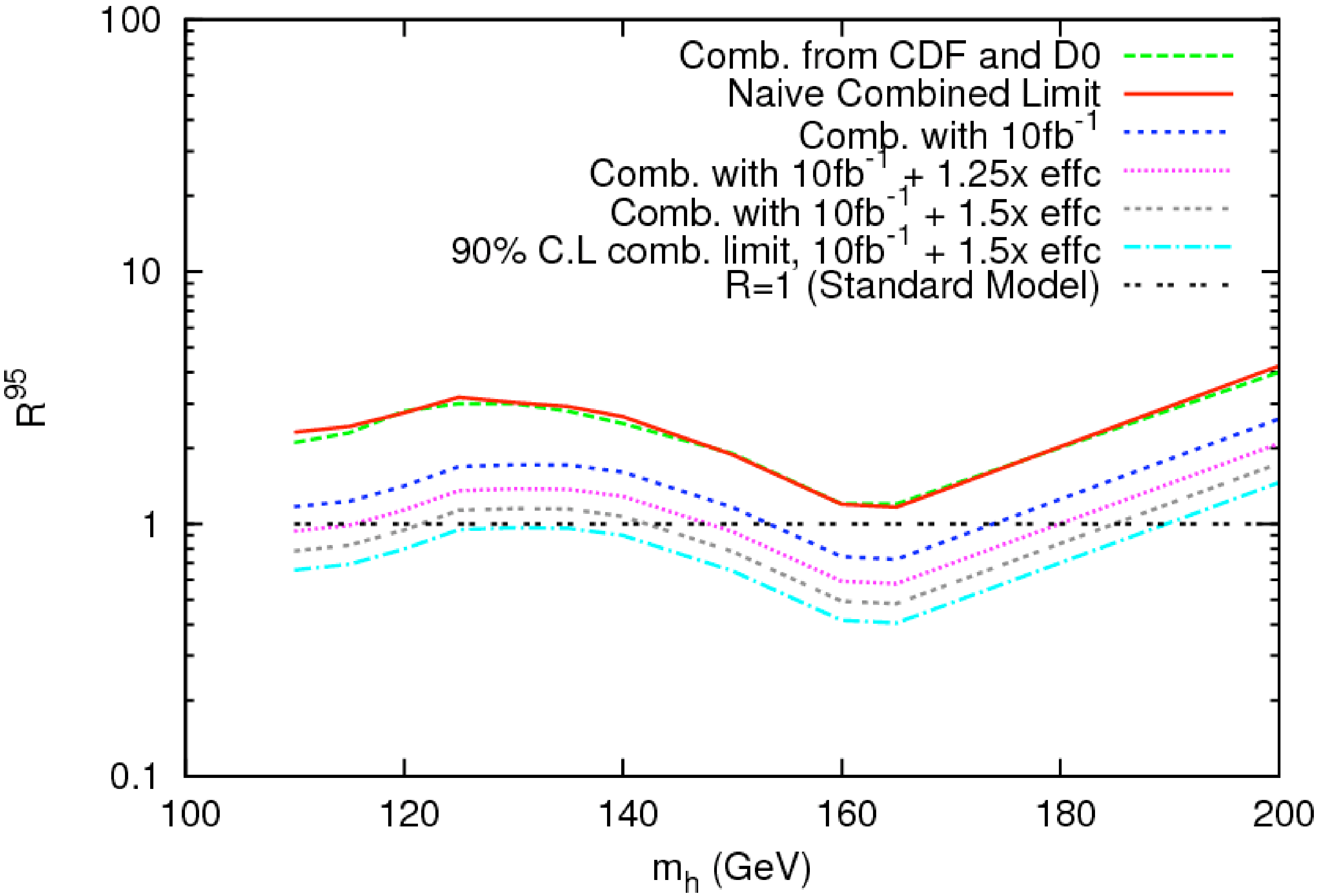
Demonstrated charm quark discrimination ability:	~30% equiv lumi gain
Improved usage of b-Tagging information:	~20% equiv lumi gain
Reduced dijet mass resolution:	~15% equiv lumi gain
for every 1% absolute gain in σ_{Mbb} for up to ~50-60% possible	
Addition of lower yield final states ($H \to \tau\tau/\gamma\gamma/ZZ/l\nu jj$, etc):	~5-10% equiv lumi gain
Improved lepton ID eff & reduced inst. lumi dependence:	~5-10% equiv lumi gain

These factors alone can buy us ~1.4× in the limit (~2× in effective luminosity)

Additional improvements ongoing, eg. $\tau\tau$ channels -> projections typically done with **50%** improvements.
CDF and D0 each have about 7 fb^{-1} of analyzable data at present, and are gaining data at >2fb^{-1}/yr. Expect to have about **10 fb^{-1} apiece** by the end of 2011.

Prospects for Higgs Searches at the Tevatron

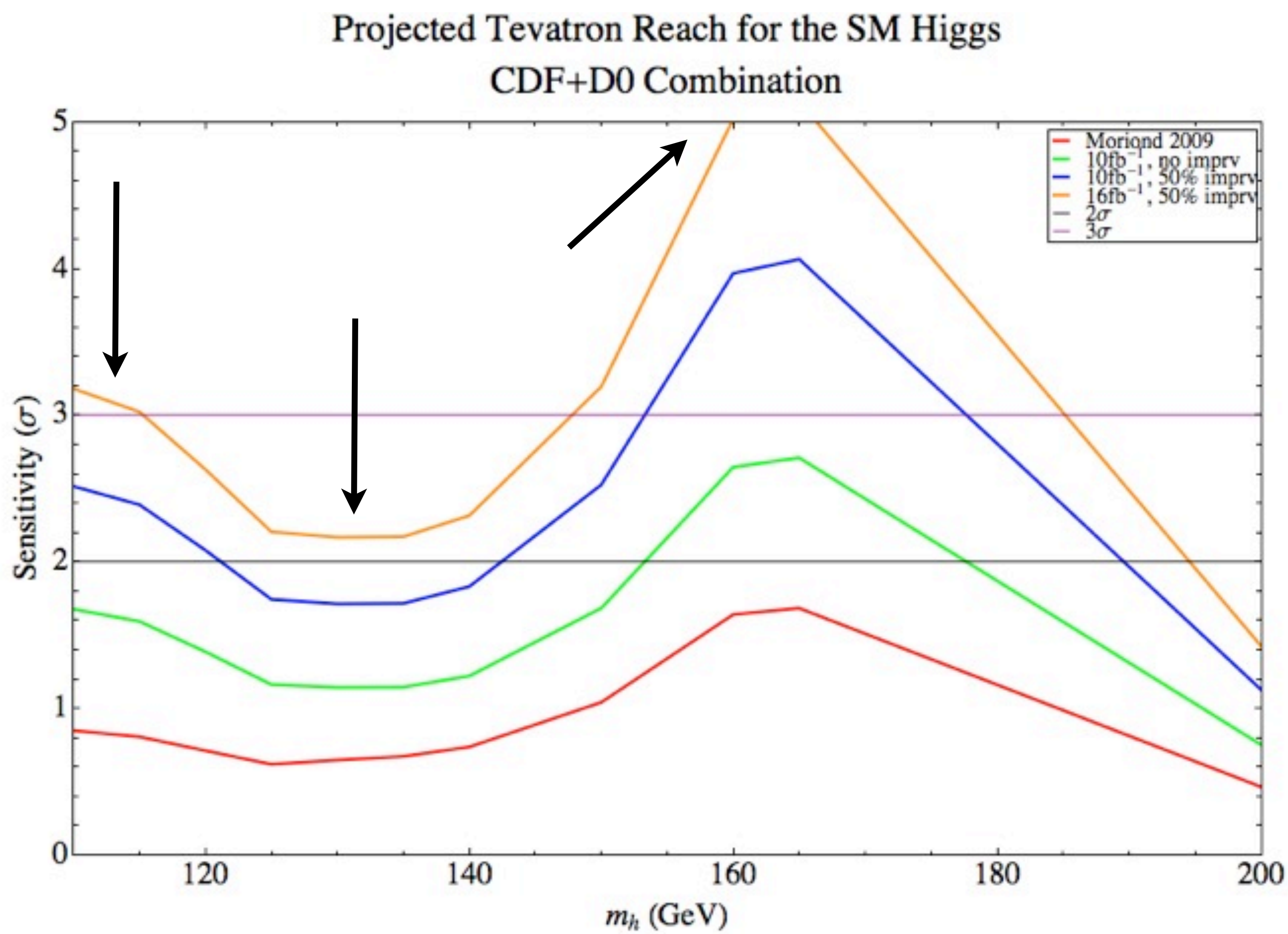
P. Draper, T. Liu and C. Wagner'09



Running for two years more, the Tevatron should collect more than 10 fb^{-1}

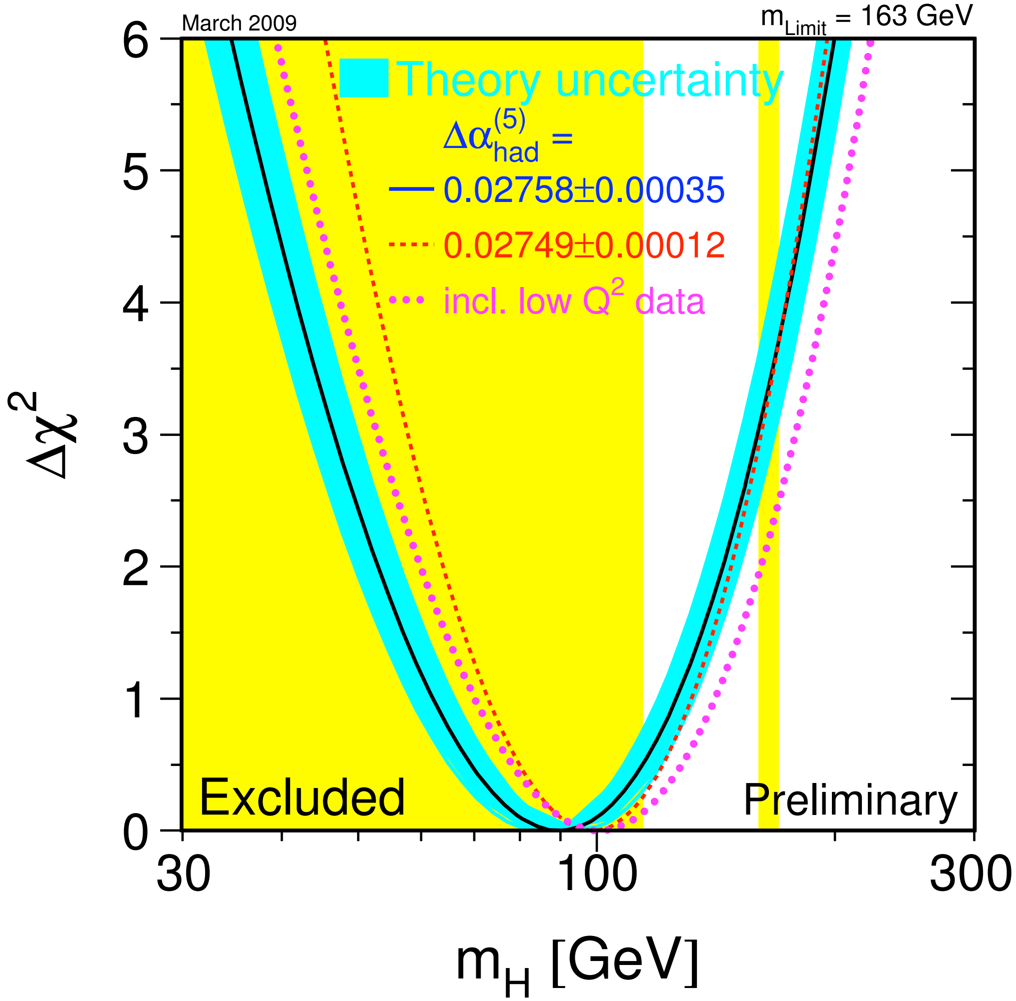
With expected detector/analysis performance, $m_H < 185$ GeV may be probed.

Prospects for SM Higgs Searches at the Tevatron

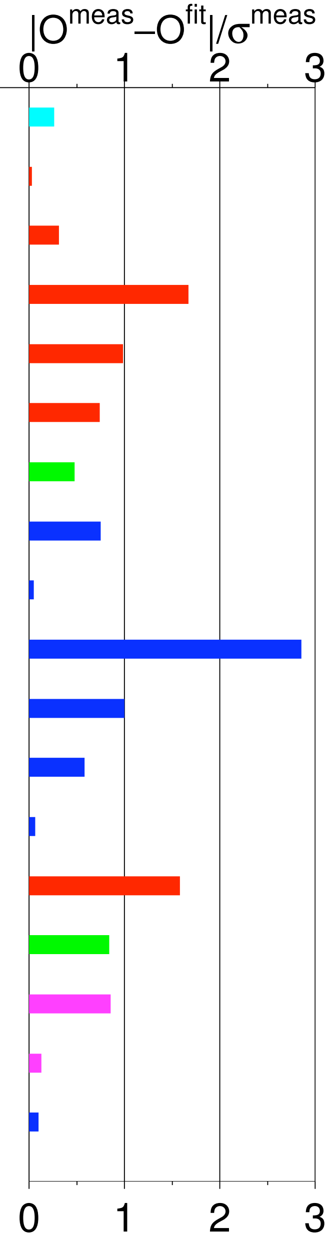


CDF+D0 multi-channel combination. WH->bb dominates at 115 GeV, gg->H->WW dominates at 160 GeV. Both contribute in intermediate range.

Tevatron testing the region preferred by SM Precision Electroweak Data

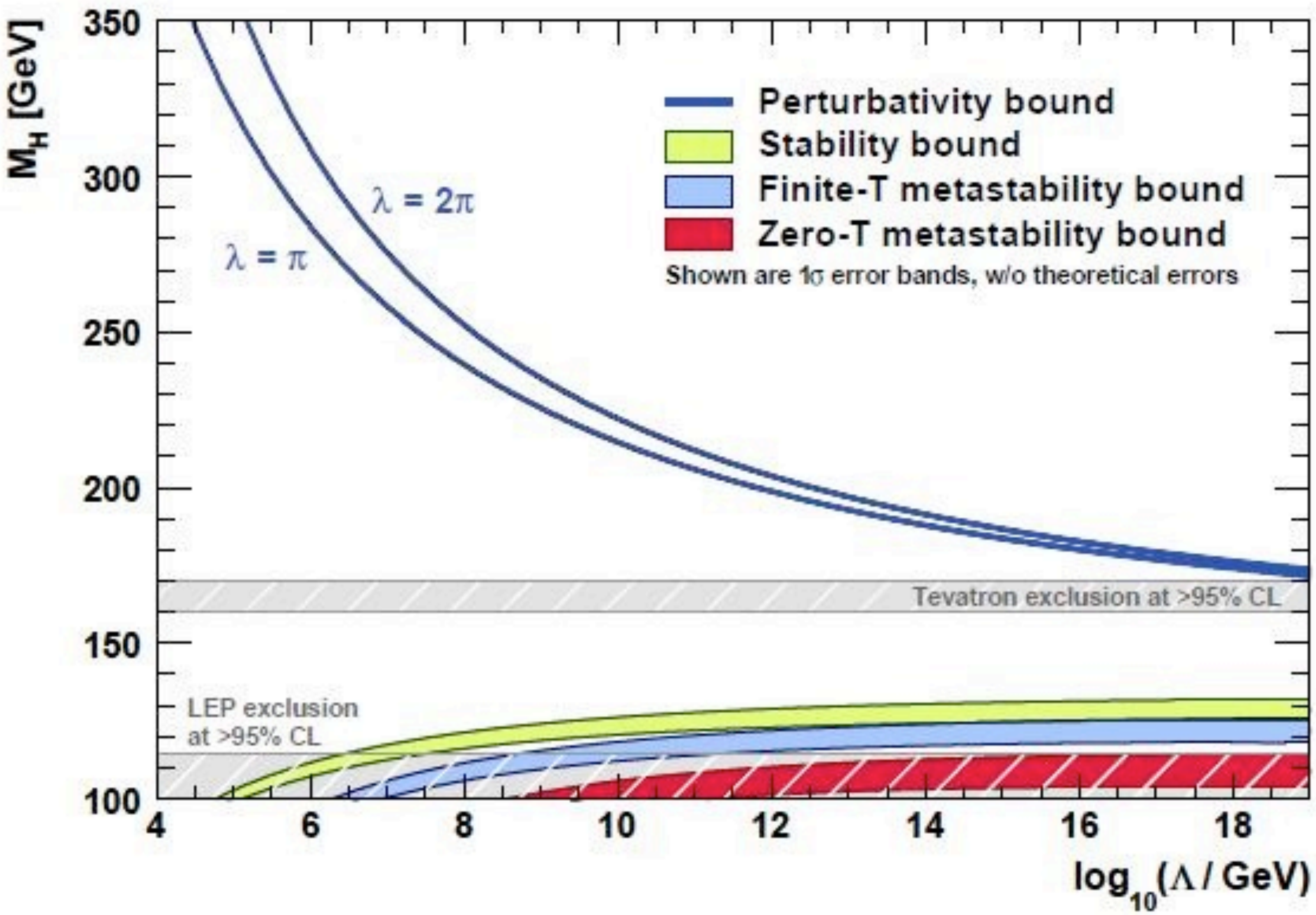


	Measurement	Fit
$\Delta\alpha^{(5)}_{had}(m_Z)$	0.02758 ± 0.00035	0.02767
m_Z [GeV]	91.1875 ± 0.0021	91.1874
Γ_Z [GeV]	2.4952 ± 0.0023	2.4959
σ^0_{had} [nb]	41.540 ± 0.037	41.478
R_l	20.767 ± 0.025	20.742
$A^{0,l}_{fb}$	0.01714 ± 0.00095	0.01643
$A_l(P_\tau)$	0.1465 ± 0.0032	0.1480
R_b	0.21629 ± 0.00066	0.21579
R_c	0.1721 ± 0.0030	0.1723
$A^{0,b}_{fb}$	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	0.1480
$\sin^2\theta^{lept}_{eff}(Q_{fb})$	0.2324 ± 0.0012	0.2314
m_W [GeV]	80.399 ± 0.025	80.378
Γ_W [GeV]	2.098 ± 0.048	2.092
m_t [GeV]	173.1 ± 1.3	173.2



March 2009

Tevatron also testing region of Higgs Masses consistent with SM extrapolation until high scales



Supersymmetry

Mass of the SM-like Higgs h

- Most important corrections come from the stop sector,

$$M^2_{\tilde{t}} = \begin{pmatrix} m_Q^2 + m_t^2 + D_L & m_t X_t \\ m_t X_t & m_U^2 + m_t^2 + D_R \end{pmatrix}$$

where the off-diagonal term depends on the stop-Higgs trilinear couplings, $X_t = A_t - \mu^* / \tan\beta$

- For large CP-odd Higgs boson masses, and with $M_S = m_Q = m_U$ dominant one-loop corrections are given by,

$$m_h^2 \approx M_Z^2 \cos^2 2\beta + \frac{3 m_t^4}{4\pi^2 v^2} \left(\log\left(\frac{M_S^2}{m_t^2} \right) + \frac{X_t^2}{M_S^2} \left(1 - \frac{X_t^2}{12 M_S^2} \right) \right)$$

- After two-loop corrections:

M.Carena, J.R. Espinosa, M. Quiros, C.W. '95
M. Carena, M. Quiros, C.W.'95

• upper limit on Higgs mass:

$m_h \lesssim 135$ GeV

$M_S = 1 \rightarrow 2$ TeV $\Longrightarrow \Delta m_h \simeq 2 - 5$ GeV

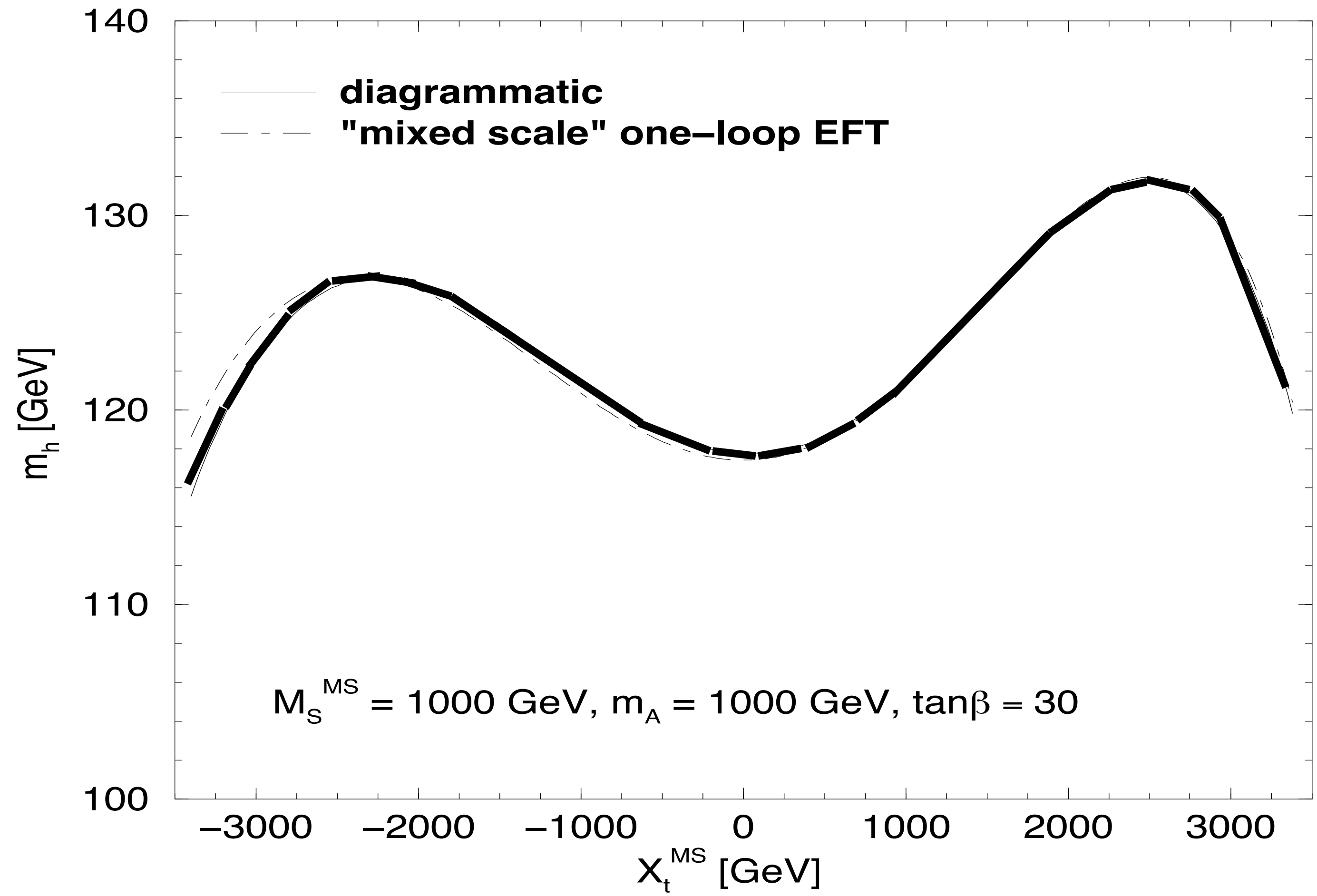
$\Delta m_t = 1$ GeV $\Longrightarrow \Delta m_h \sim 1$ GeV

Standard Model-like Higgs Mass

Long list of two-loop computations: Carena, Degrassi, Ellis, Espinosa, Haber, Harlander, Heinemeyer, Hempfling, Hoang, Hollik, Hahn, Martin, Pilaftsis, Quiros, Ridolfi, Rzehak, Slavich, C.W., Weiglein, Zhang, Zwirner

Carena, Haber, Heinemeyer, Hollik, Weiglein, C.W.'00

Leading m_t^4 approximation at $O(\alpha\, \alpha_s)$

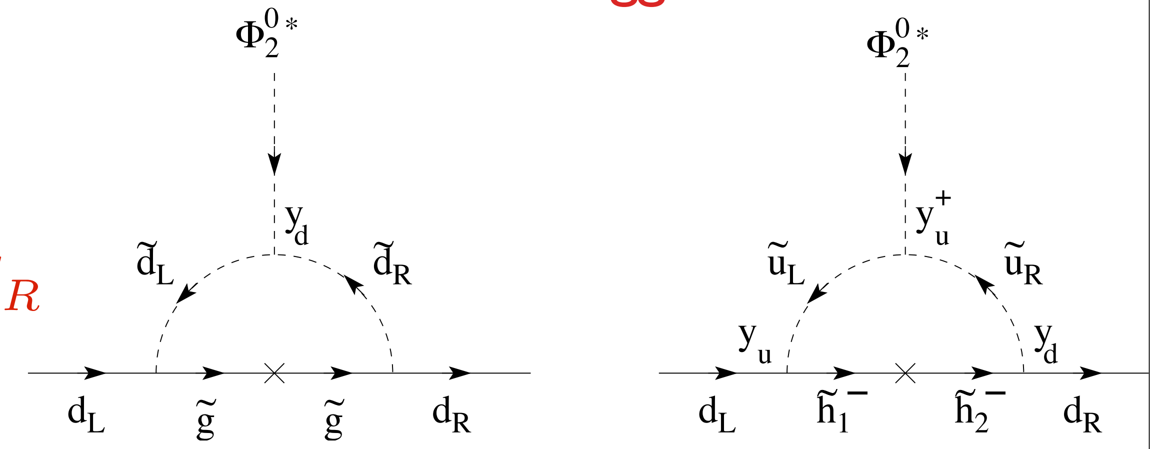


$$X_t = A_t - \mu/\tan\beta, \qquad X_t = 0 : \text{ No mixing;} \qquad X_t = \sqrt{6} M_S : \text{ Max. Mixing}$$

Radiative Corrections to Flavor Conserving Higgs Couplings

- Couplings of down and up quark fermions to both Higgs fields arise after radiative corrections.

$$\mathcal{L} = \bar{d}_L (h_d H_1^0 + \Delta h_d H_2^0) d_R$$



- The radiatively induced coupling depends on ratios of supersymmetry breaking parameters

$$m_b = h_b v_1 \left(1 + \frac{\Delta h_b}{h_b} \tan\beta \right)$$

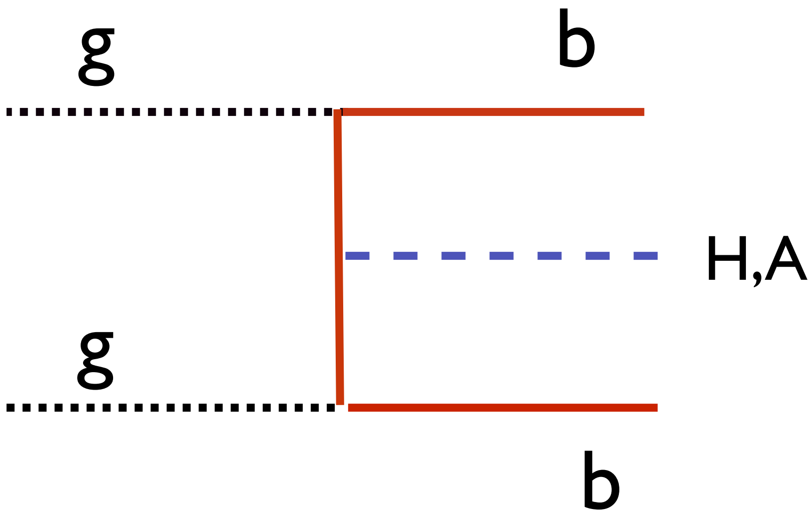
$$\tan\beta = \frac{v_2}{v_1}$$

$$\frac{\Delta_b}{\tan\beta} = \frac{\Delta h_b}{h_b} \simeq \frac{2\alpha_s}{3\pi} \frac{\mu M_{\tilde{g}}}{\max(m_{\tilde{b}_i}^2, M_{\tilde{g}}^2)} + \frac{h_t^2}{16\pi^2} \frac{\mu A_t}{\max(m_{\tilde{t}_i}^2, \mu^2)}$$

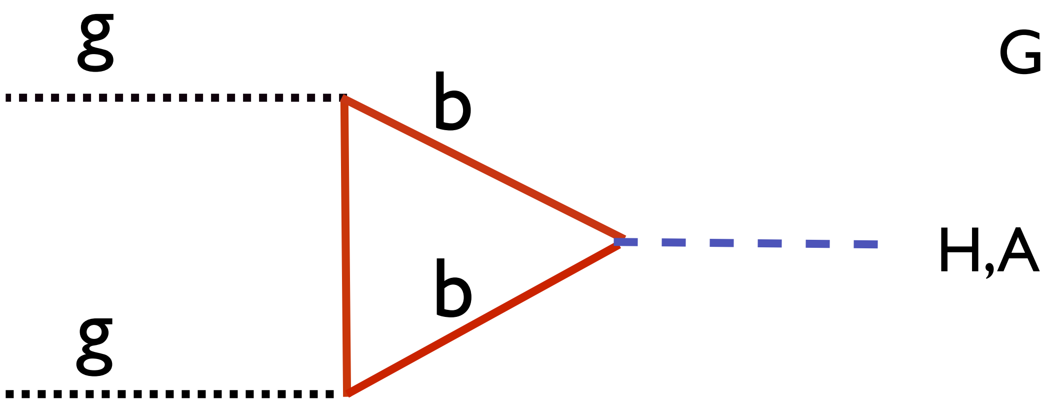
$$X_t = A_t - \mu/\tan\beta \simeq A_t \qquad \Delta_b = (E_g + E_t h_t^2) \tan\beta$$

Non-Standard Higgs Production

QCD: S. Dawson, C.B. Jackson, L. Reina, D.Wackeroth, hep-ph/0603112



Associated Production



Gluon Fusion

$$g_{Abb} \simeq g_{Hbb} \simeq \frac{m_b \tan\beta}{(1+\Delta_b)v}, \qquad g_{A\tau\tau} \simeq g_{H\tau\tau} \simeq \frac{m_\tau \tan\beta}{v}$$

Searches for non-standard Higgs bosons

M. Carena, S. Heinemeyer, G.Weiglein,C.W, EJPC'06

- Searches at the Tevatron and the LHC are induced by production channels associated with the large bottom Yukawa coupling.

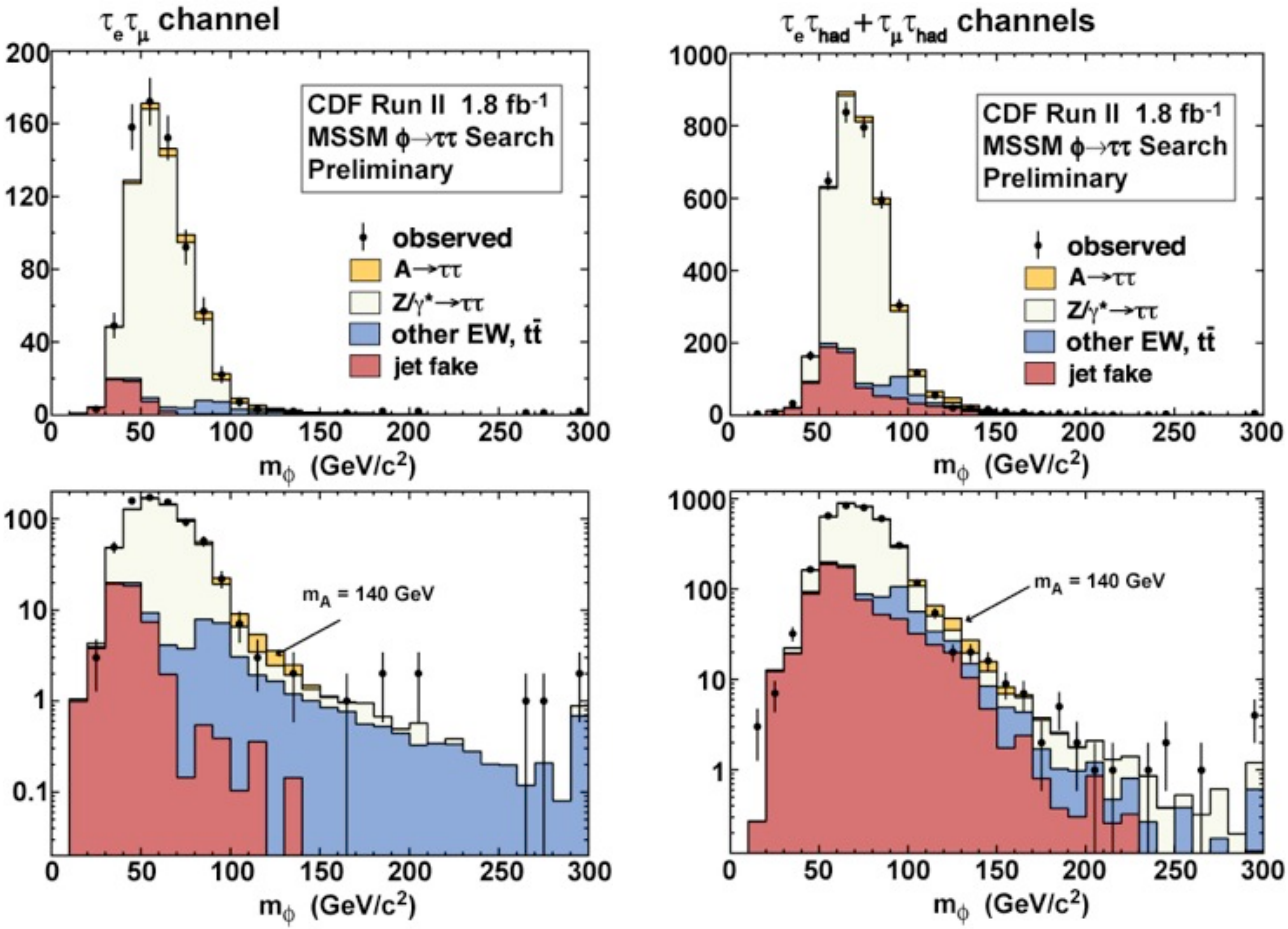
$$\sigma(b\bar{b}A) \times BR(A \to b\bar{b}) \simeq \sigma(b\bar{b}A)_{\rm SM} \frac{\tan^2\beta}{(1+\Delta_b)^2} \times \frac{9}{(1+\Delta_b)^2 + 9}$$

$$\sigma(b\bar{b}, gg \to A) \times BR(A \to \tau\tau) \simeq \sigma(b\bar{b}, gg \to A)_{\rm SM} \frac{\tan^2\beta}{(1+\Delta_b)^2 + 9}$$

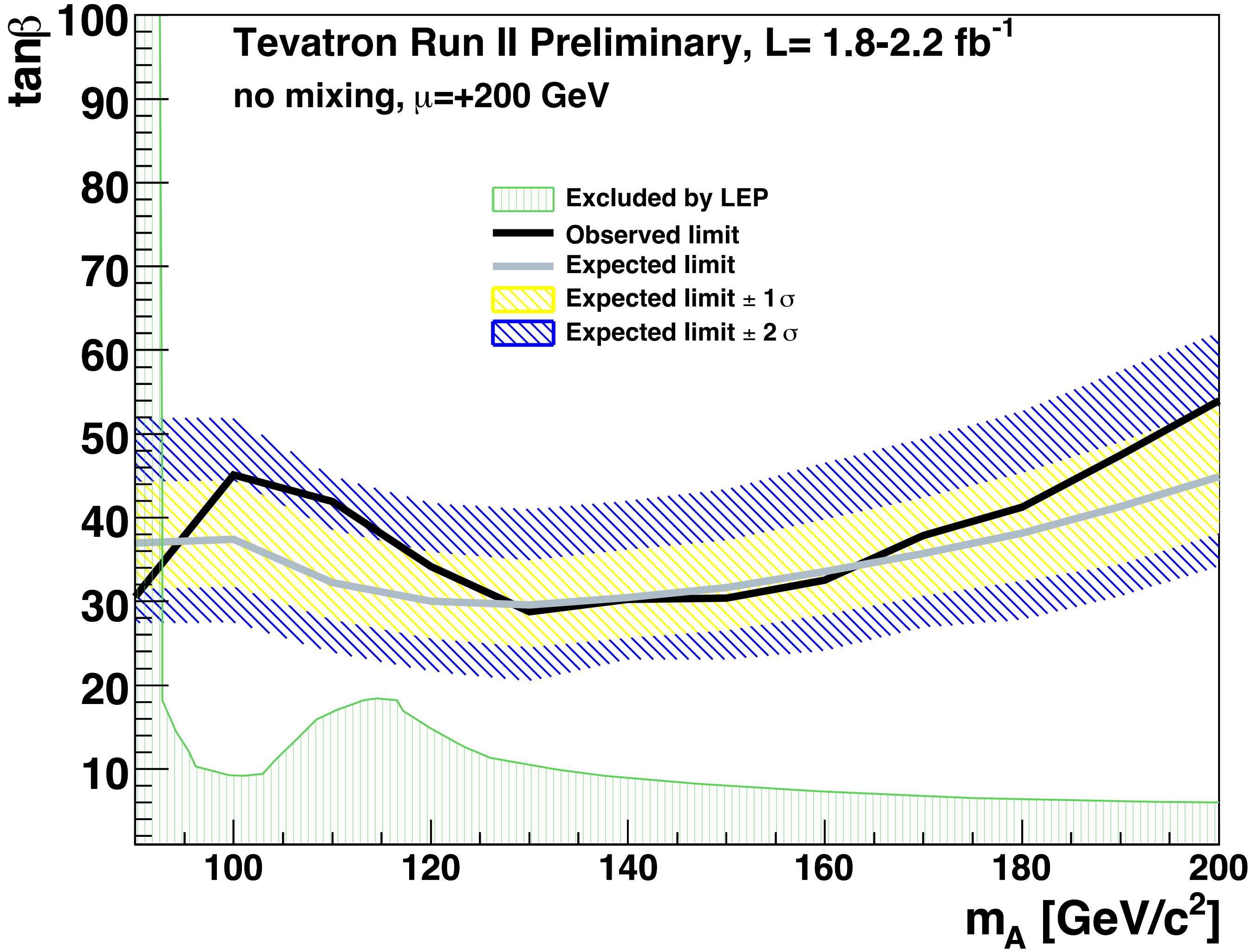
- There may be a strong dependence on the parameters in the bb search channel, which is strongly reduced in the tau tau mode.

Validity of this approximation confirmed by NLO computation by
D. North and M. Spira, arXiv:0808.0087
Further work by Mhulleitner, Rzehak and Spira, 0812.3815

CDF Higgs Search Results



Combination of CDF and D0 Non-Standard Higgs Searches

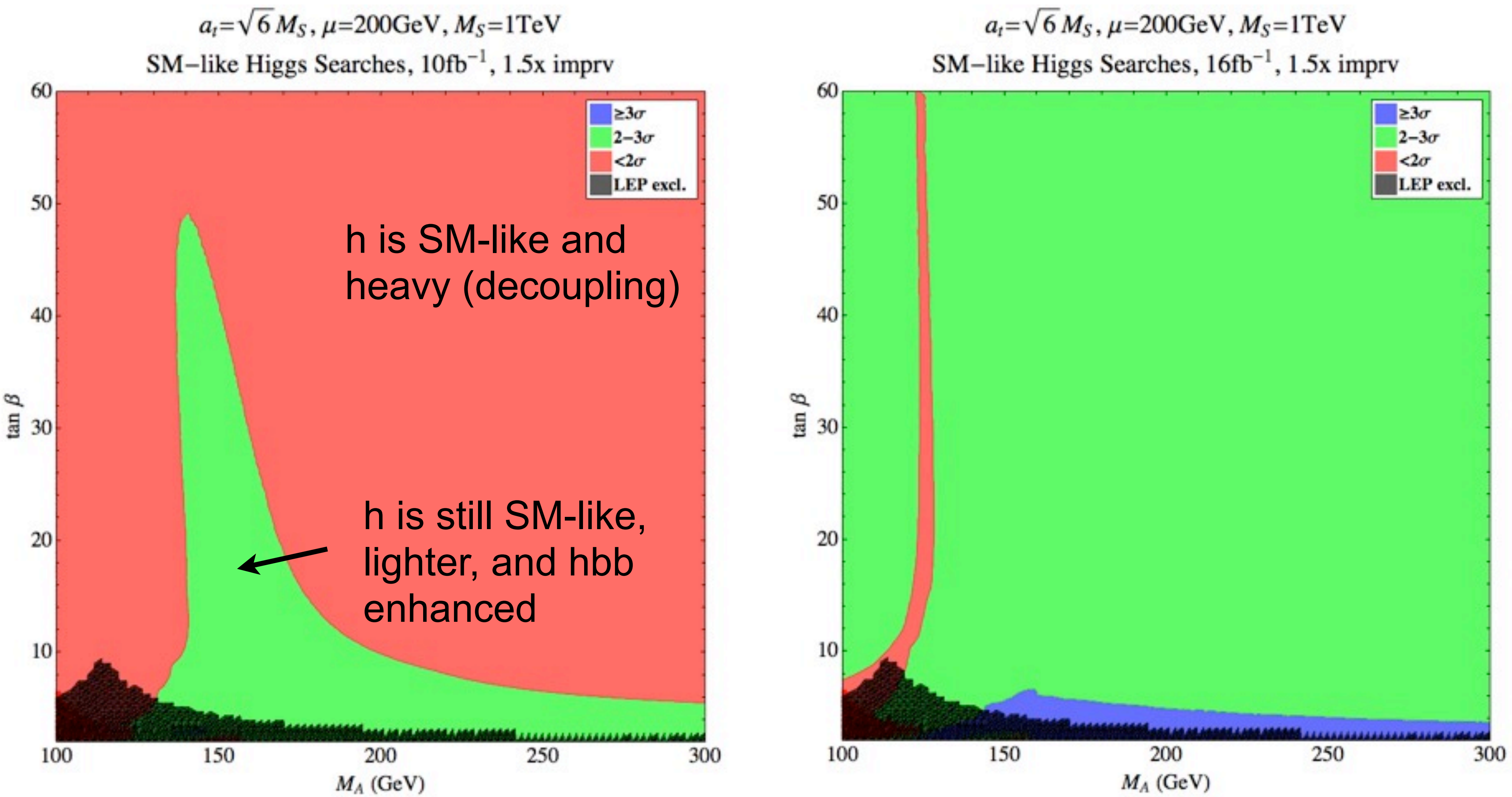


Relevance of Combination of Channels

- As we have seen, the Tevatron has the potential to probe the Standard Model in all the allowed region of the lightest MSSM CP-even Higgs mass.
- There are regions of parameter space, however, where this Higgs boson present significant departures from the SM behavior
- In particular either the production cross section or the branching ratio into bottom quarks can be suppressed
- When this happens, there tend to be other light Higgs bosons which can give significant signatures, or alternatively, additional decay channels of the same Higgs boson, like the $\tau\tau$ or W^+W^- modes
- In this talk, I will combine in quadrature the significance of different channels for the SM-like Higgs. At some point, we will combine it also with non-standard sources, even when coming from different Higgs boson sources. I show the relevance of these combinations.

Expected Sensitivity Maximal Mixing Scenario

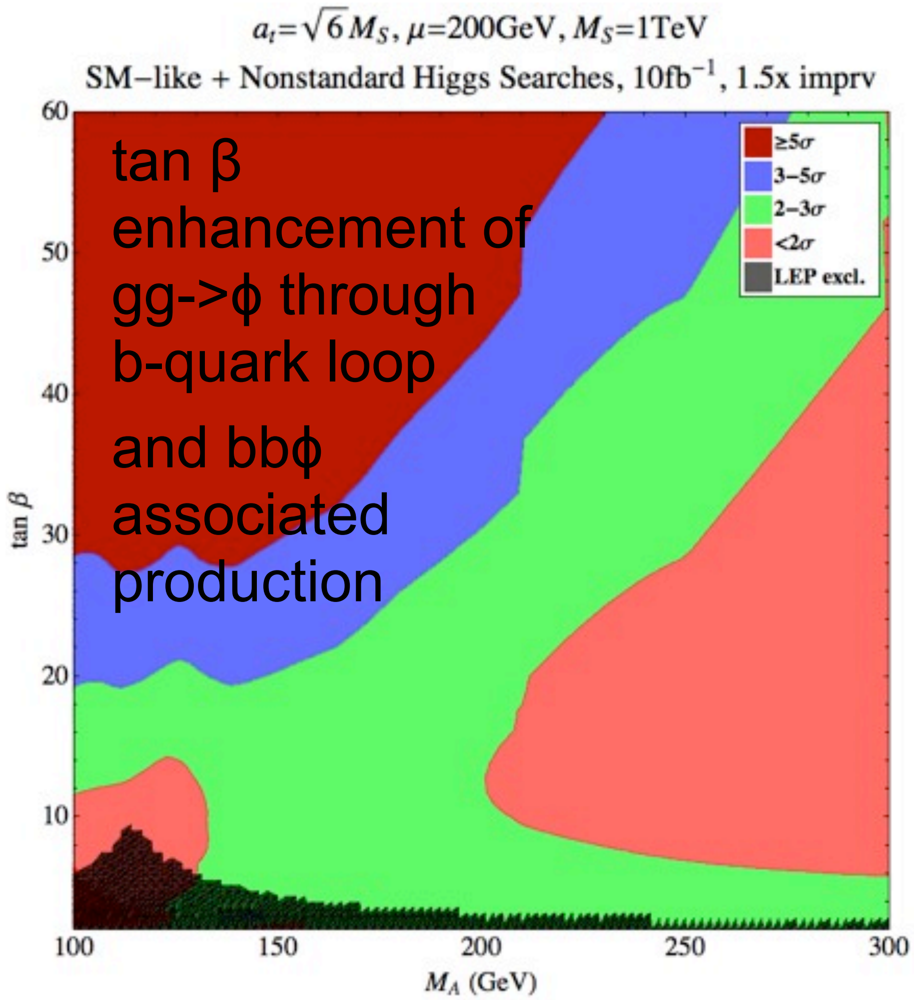
P. Draper, T. Liu and C.W. '09 + M. Carena'10



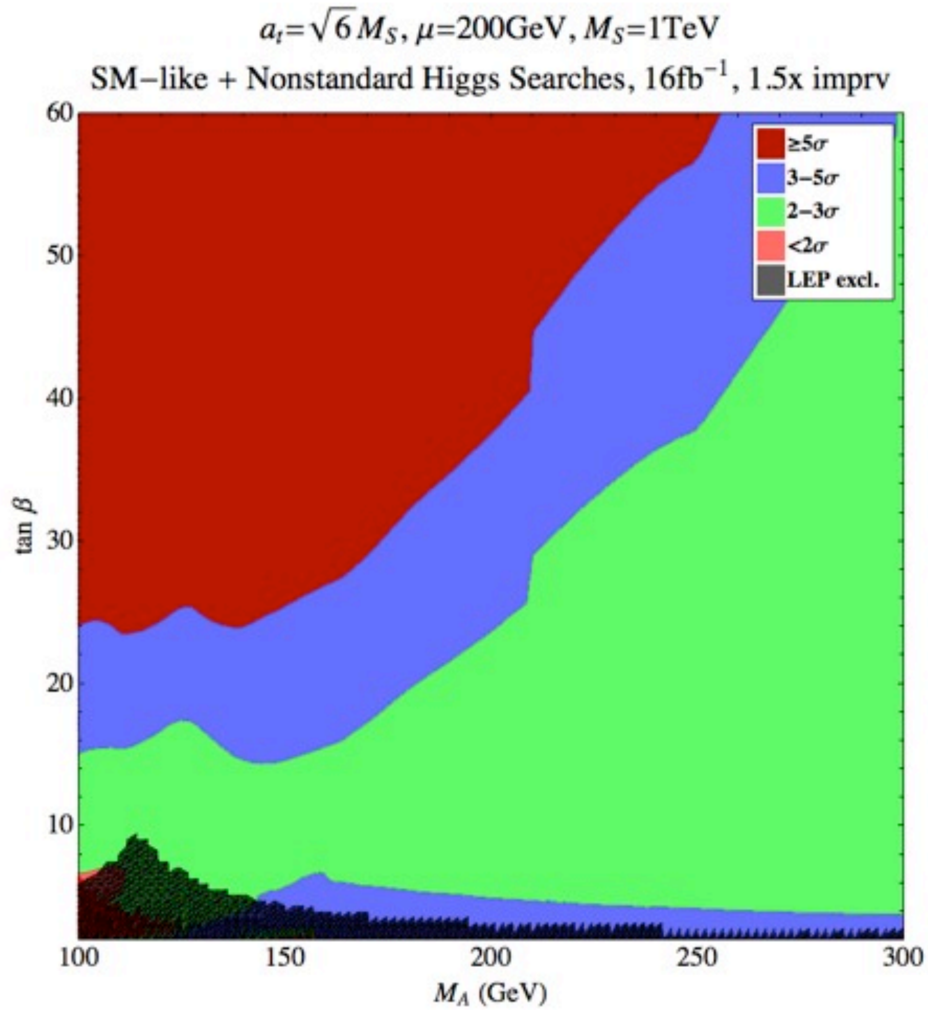
End of 2011

End of 2014

Combination with Non-Standard Higgs channels



End of 2011

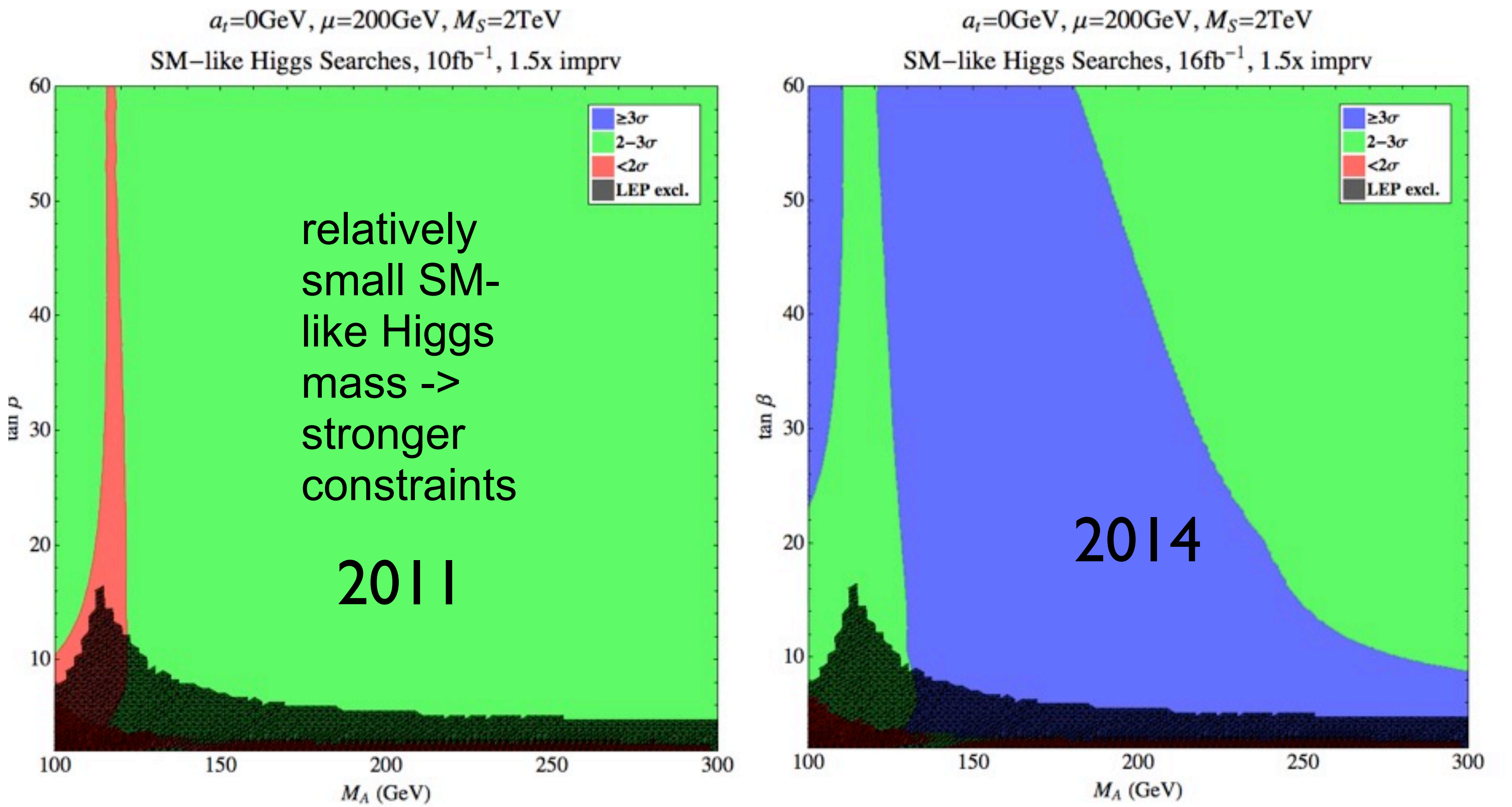


End of 2014

Maximal Mixing Scenario : More than two sigma sensitivity in all parameter space if running continues. Three sigma obtain in large regions of parameters

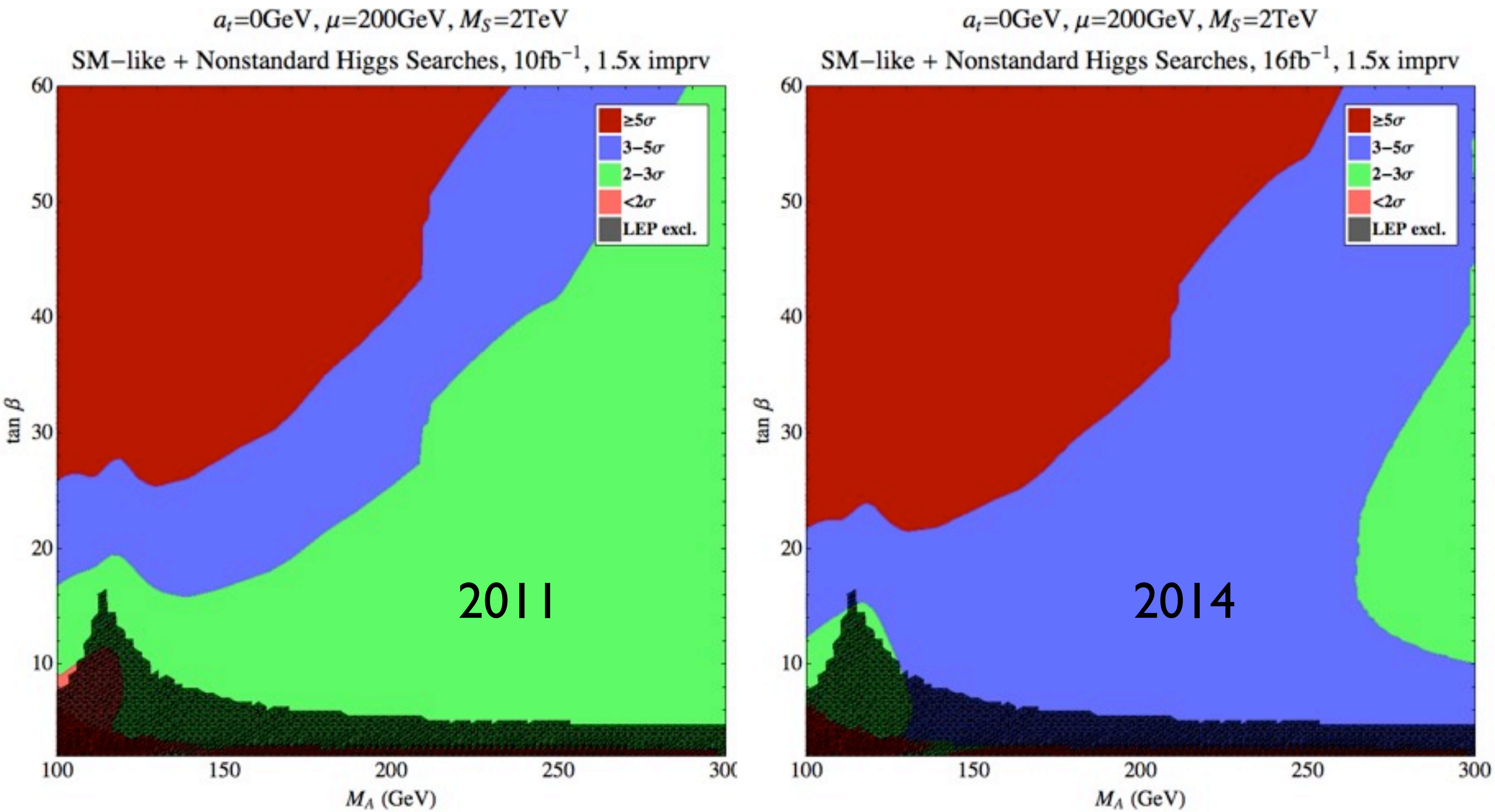
Minimal Mixing Scenario

P. Draper, T. Liu and C.W. '09 + M. Carena'10



Even with only SM channels and 2011 run, 2 sigma sensitivity is achieved in most parameter space. Evidence may be achieved with further running.

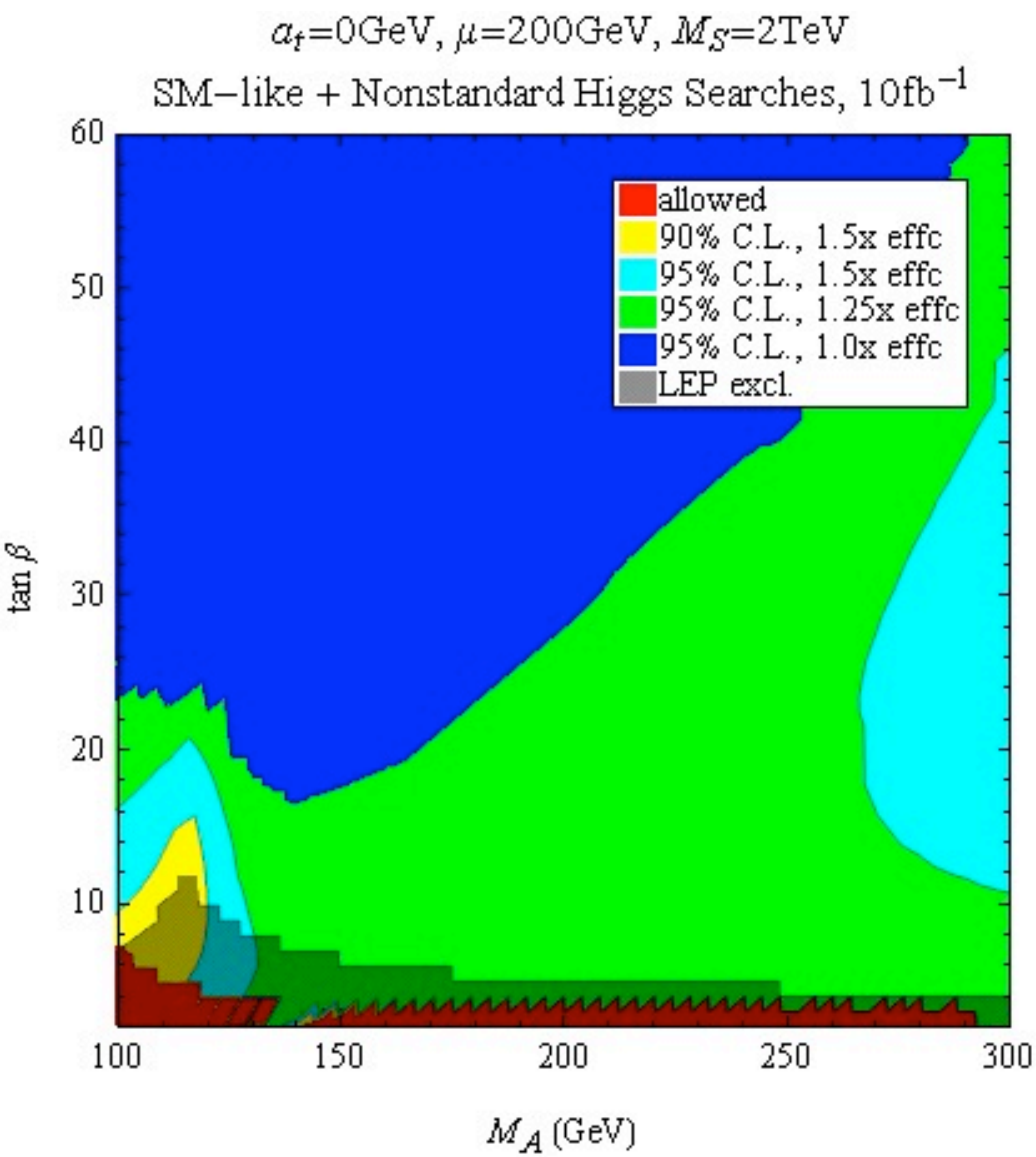
Combination with Non-Standard Higgs channels



Combination enlarges the region where evidence may be achieved in a considerable way

Minimal Mixing Scenario

P. Draper, T. Liu and C.W. '09



Interesting coverage in minimal mixing scenario, even for a reasonable 25 percent increase in efficiencies in the low Higgs mass region.

Somewhat weaker results in maximal mixing scenario. Fifty percent increase necessary for interesting coverage.

Interesting contribution from WW when bb coupling suppressed.

P. Draper, T. Liu, C.W.'10

CPX Scenario

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

$$M_S = 500\ \text{GeV}, \qquad |A_t| = 1\ \text{TeV},$$
$$\mu = 2\ \text{TeV}, \qquad M_{1,2} = 200\ \text{GeV},$$
$$A_{b,\tau} = A_t, \qquad |M_3| = 1\ \text{TeV}.$$

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

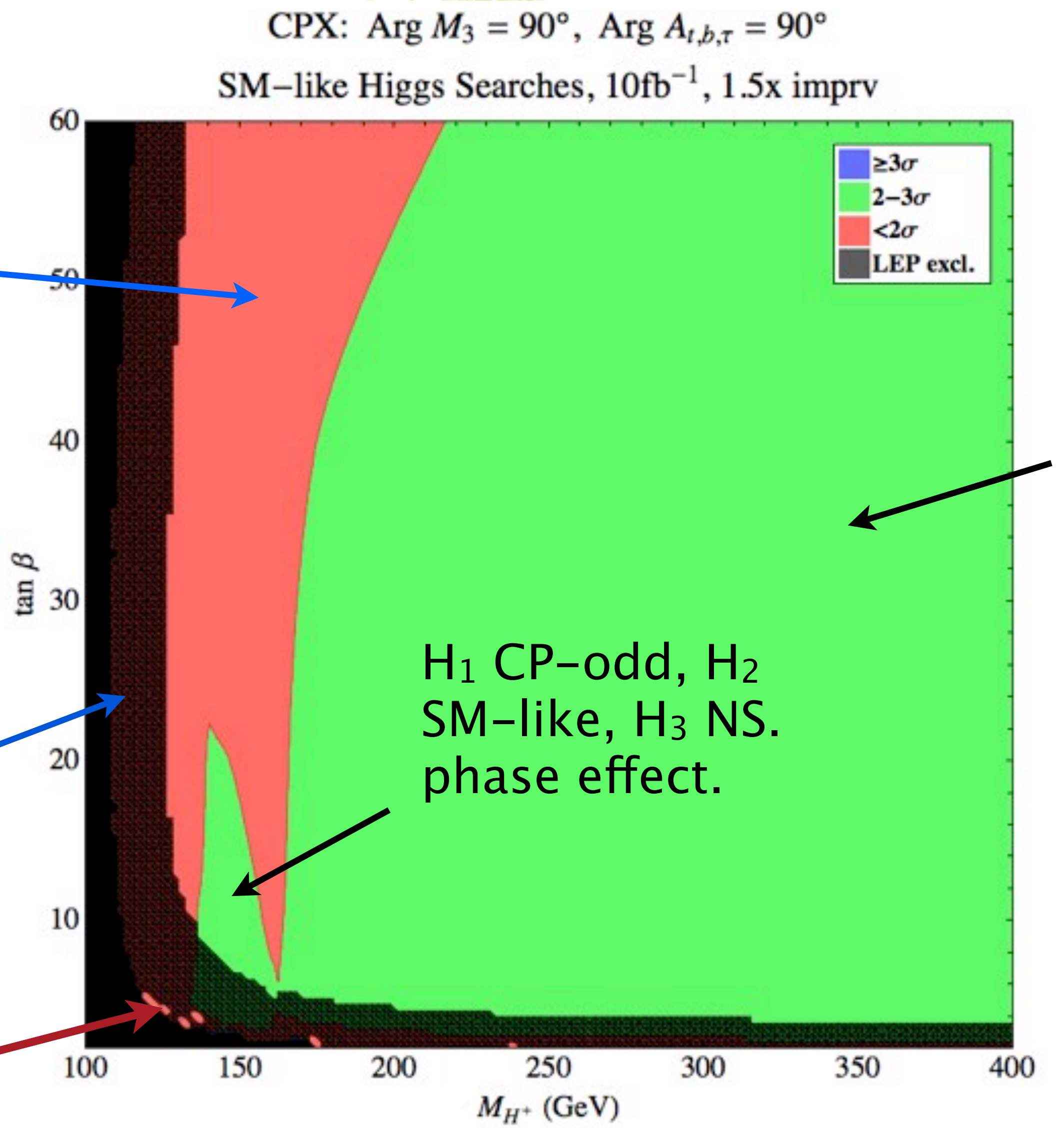
a. $\text{Arg}M_3 = 0^\circ, \quad \text{Arg}A_{t,b,\tau} = 0^\circ$

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

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

CPX Scenario SM channels

P. Draper, T. Liu, C.W. '10
arXiv: 0911.0034



Weak due to the large tan β loop suppression of the H_2bb coupling. Large μ effect.

H_1 SM-like, H_2 mostly CP-odd, H_3 mostly NS CP-even

H_1 CP-odd, H_2 SM-like, H_3 NS. phase effect.

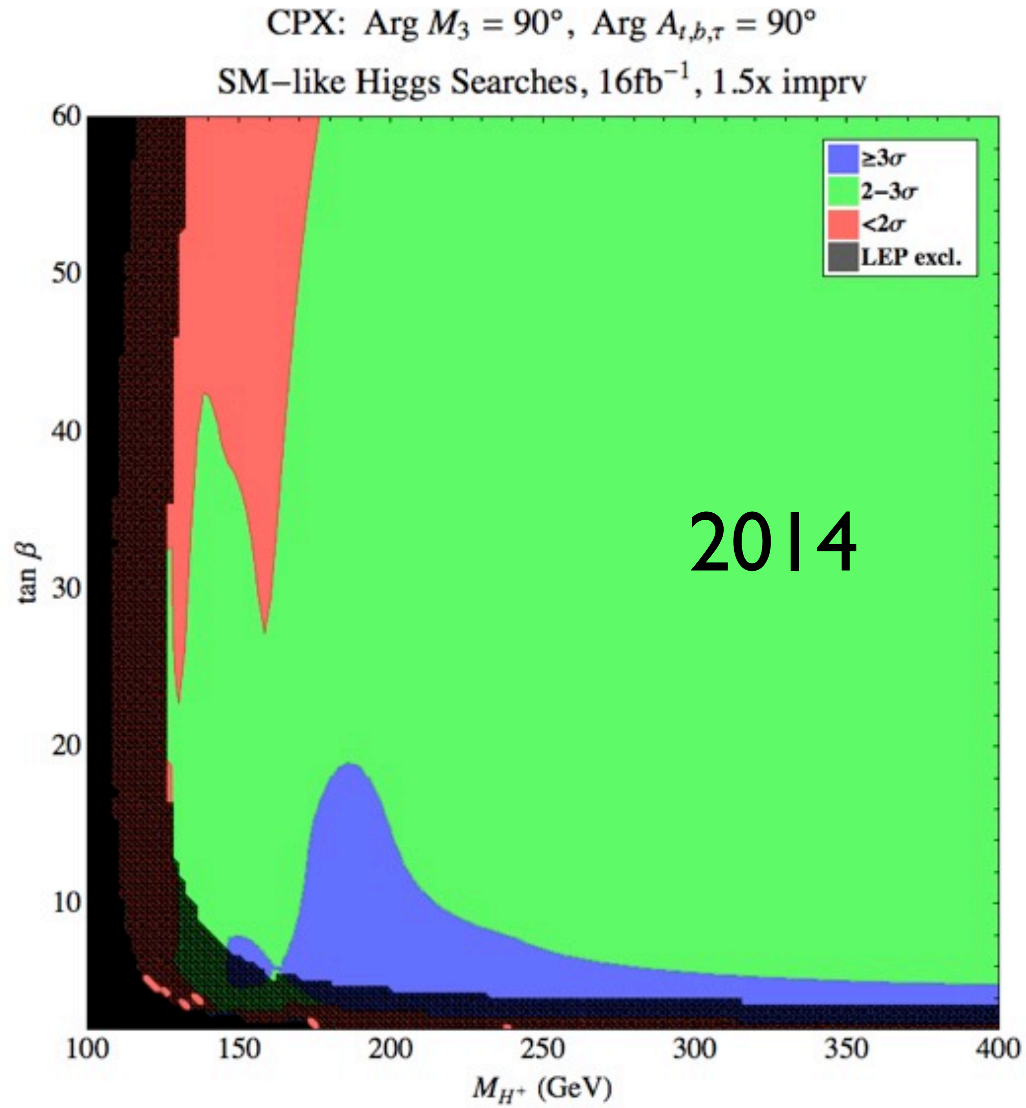
H_1 NS, H_2 CP-odd, H_3 SM-like. Weak due to the opening of

H_3-> H_1H_1

Similar to situations described in J. Gunion and R. Dermisek talks

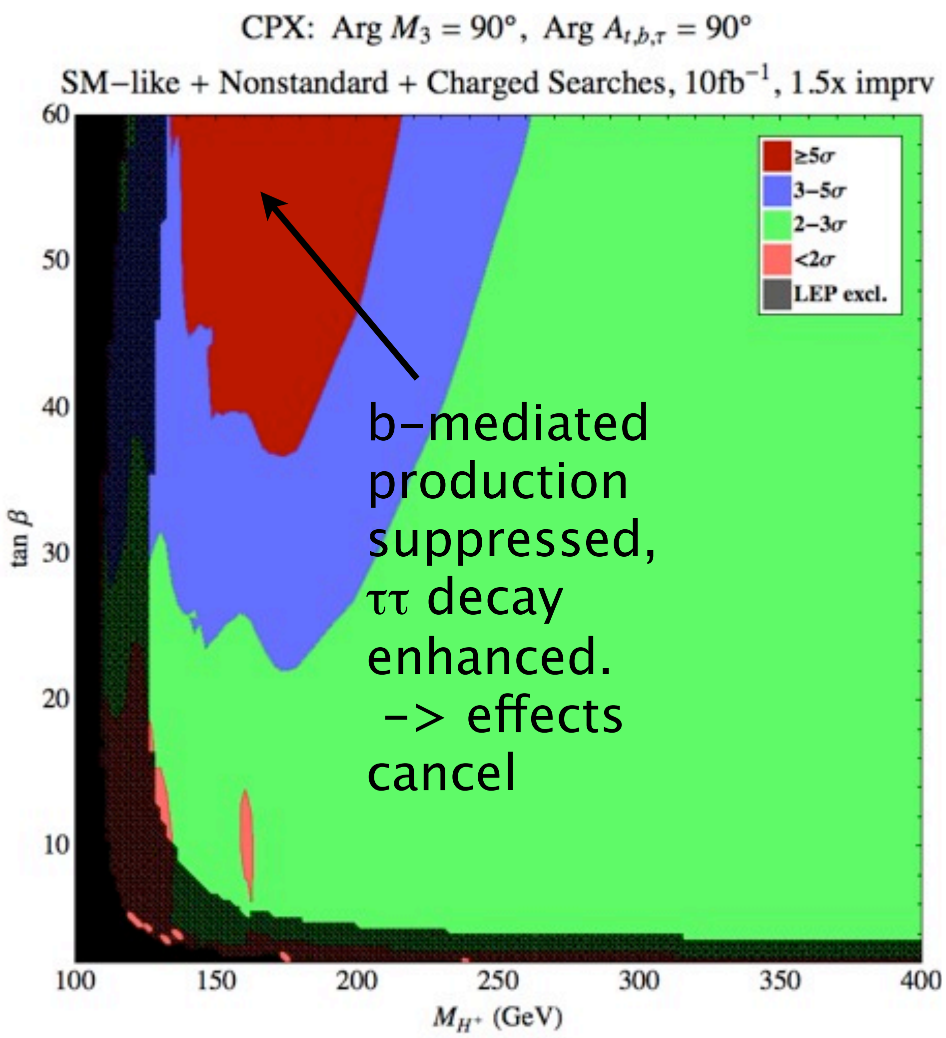
CPX Scenario SM channels

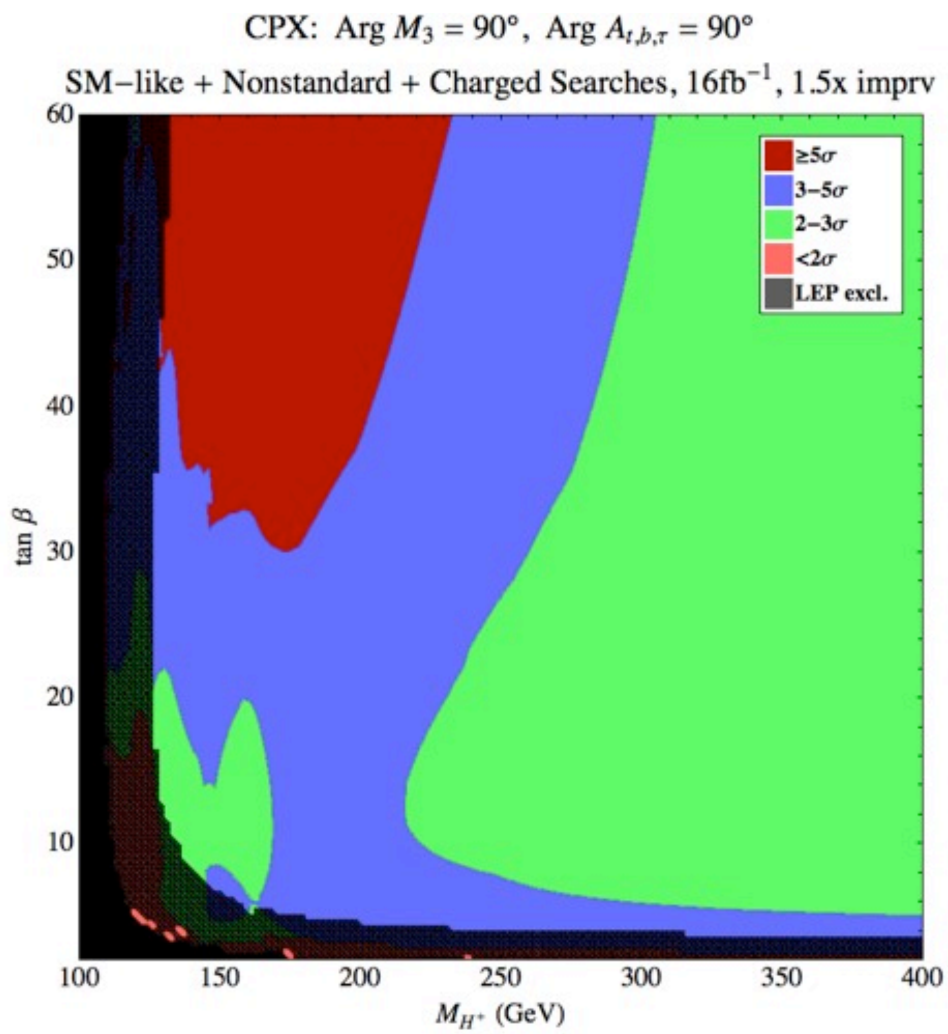
P. Draper, T. Liu, C.W. '10
arXiv: 0911.0034



CPX Scenario. Combination of Channels

P. Draper, T. Liu, C.W. '10





Constraints on SUSY Breaking Models

M. Carena, P. Draper, T. Liu, C. Wagner and G. Weiglein, in preparation

- Behavior in specific models are governed, by the scale of squark masses, the relative values of A_t and μ, as well as by the value of $\tan\beta$
- In the CMSSM, for instance

Carena, Pokorski, Olechowsi, C.W. '93

$$\begin{aligned} A_t &\simeq A_0\left(1-y_t^2\right)-2M_{1/2} \\ m_Q^2 &\simeq m_0^2\left(1-y_t^2/2\right)+5.5M_{1/2}^2 \\ m_U^2 &\simeq m_0^2\left(1-y_t^2\right)+5M_{1/2}^2 \\ m_{H_u}^2 &\simeq m_0^2\left(1-3y_t^2/2\right)-3M_{1/2}^2 \end{aligned}$$

- Closer to minimal than to maximal mixing unless A_0 is large.

- Here the top Yukawa factor refers to the ratio with respect to its IR fixed point, of order 2/3. Additional bottom Yukawa factors appear at large $\tan\beta$. In addition, μ is not small and m_A diminish for large values of $\tan\beta$

$$\begin{aligned} \mu^2 &\simeq -M_Z^2/2-m_{H_u}^2 \\ m_A^2 &\simeq -M_Z^2+(m_{H_d}^2-m_{H_u}^2) \end{aligned}$$

Scans in High-Scale Models: CMSSM & GMSB

Constrained MSSM: Scan over GUT-scale values for common soft scalar mass m_0, gaugino mass $m_{1/2}$, trilinear coupling A_0, and tan beta.

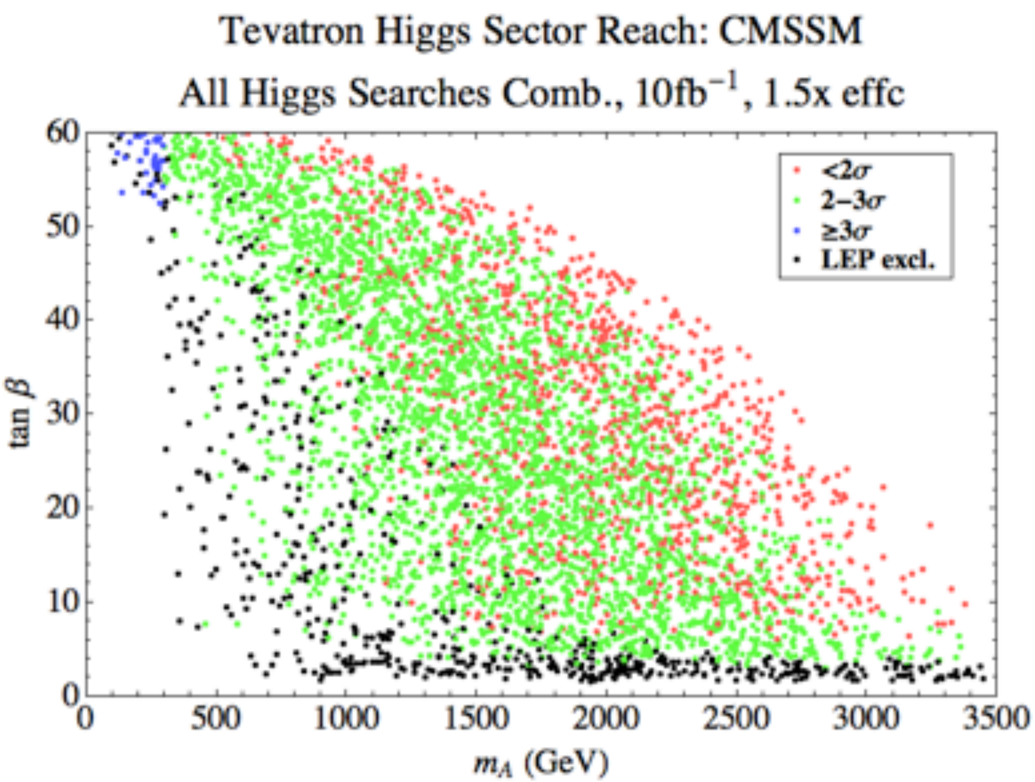
$$50 \text{ GeV} < m_0 < 2 \text{ TeV}$$
$$50 \text{ GeV} < m_{1/2} < 2 \text{ TeV}$$
$$-3 \text{ TeV} < A_0 < 3 \text{ TeV}$$
$$1.5 < \tan\beta < 60$$

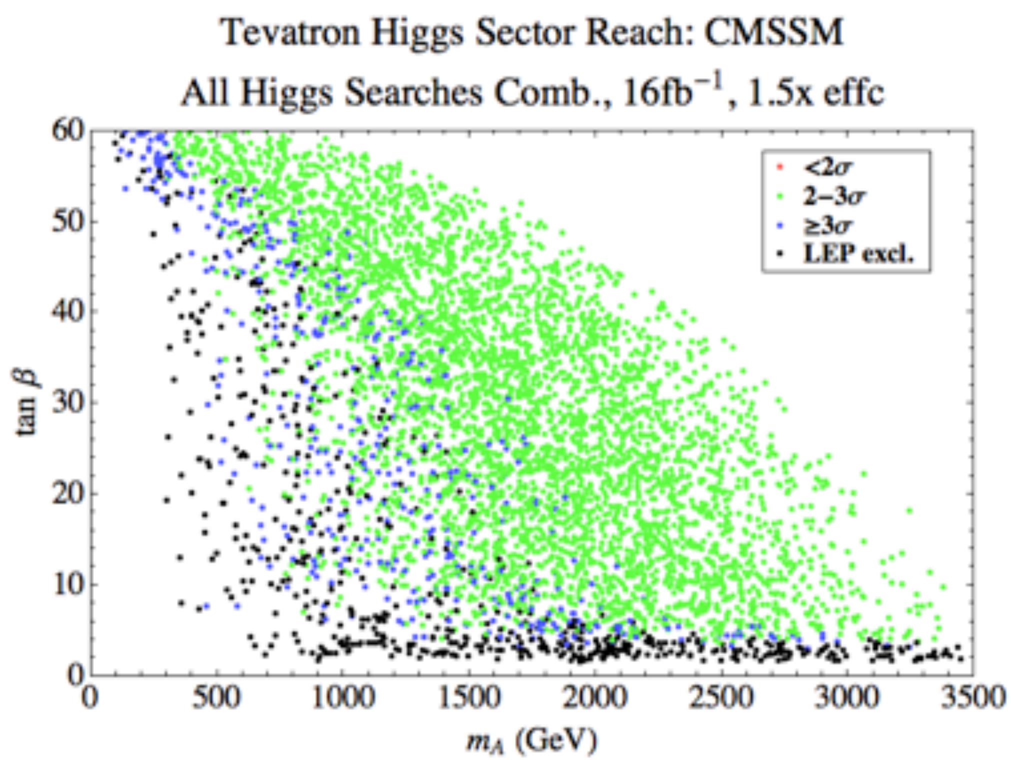
Minimal Gauge Mediation: Scan over...
-messenger scale M_{mess} where SUSY-breaking is communicated to the MSSM
-SUSY-breaking vev scale $\Lambda \sim \langle F \rangle / \langle S \rangle$ (soft masses ~ $\alpha\Lambda/4\pi$)
-number of messengers N_{mess} in complete SU(5) $5+\bar{5}$ reps
-tan beta

$$10^4 \text{ GeV} < \Lambda < 2 \times 10^5 \text{ GeV}$$
$$\Lambda < M_{mess} < 10^4 \times \Lambda$$
$$1 \leq N_{mess} \leq 8$$
$$1.5 < \tan\beta < 60$$

CMSSM

M. Carena, P. Draper, S. Heinemeyer, T. Liu, G. Weiglein, C.W. '10

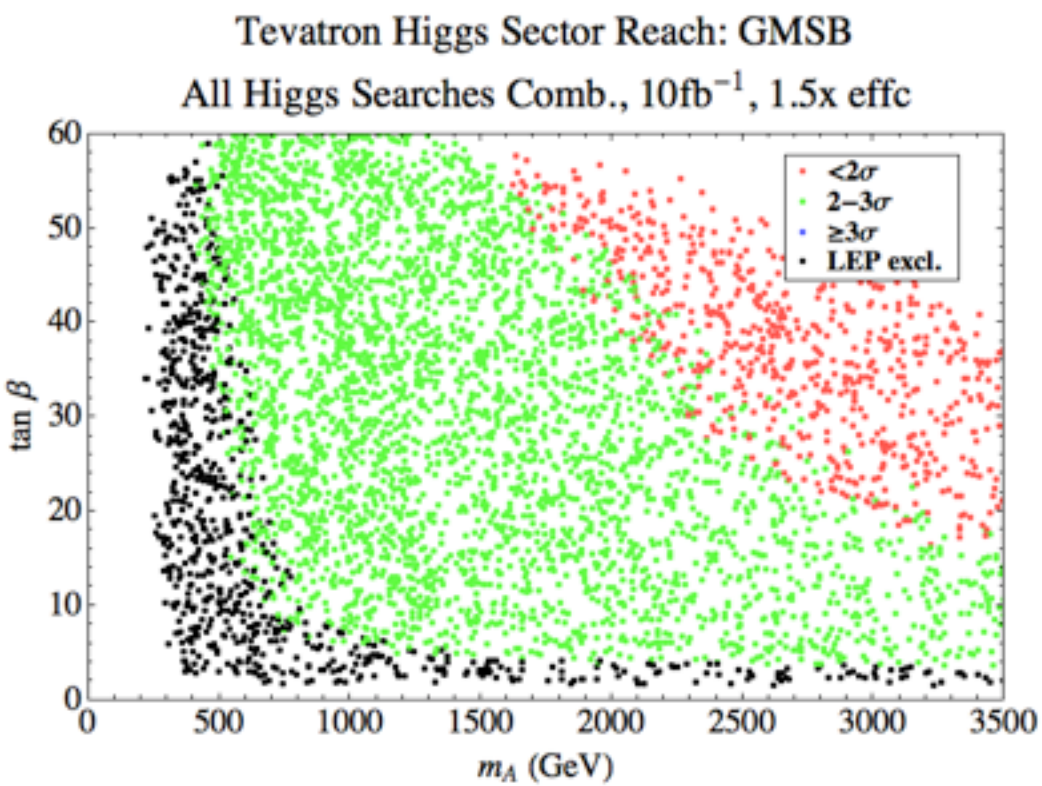


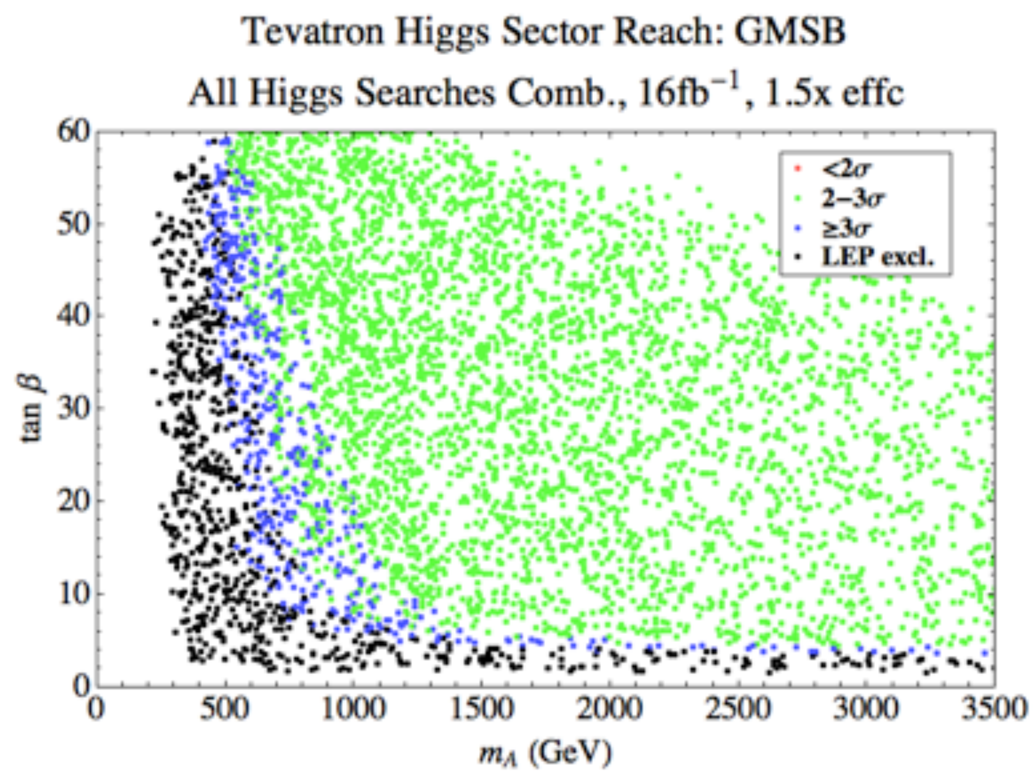


Even for very large values of the squark masses, combining all Higgs search channels, the CMSSM may be probed if Tevatron continues running. Evidence found in large regions of parameters

Minimal Gauge Mediation

M. Carena, P. Draper, S. Heinemeyer, T. Liu, G. Weiglein, C.W. '10





Results in Minimal Gauge Mediation similar to the case of the MSSM. Complete coverage at the 2 sigma level for the case of continuous Tevatron running.

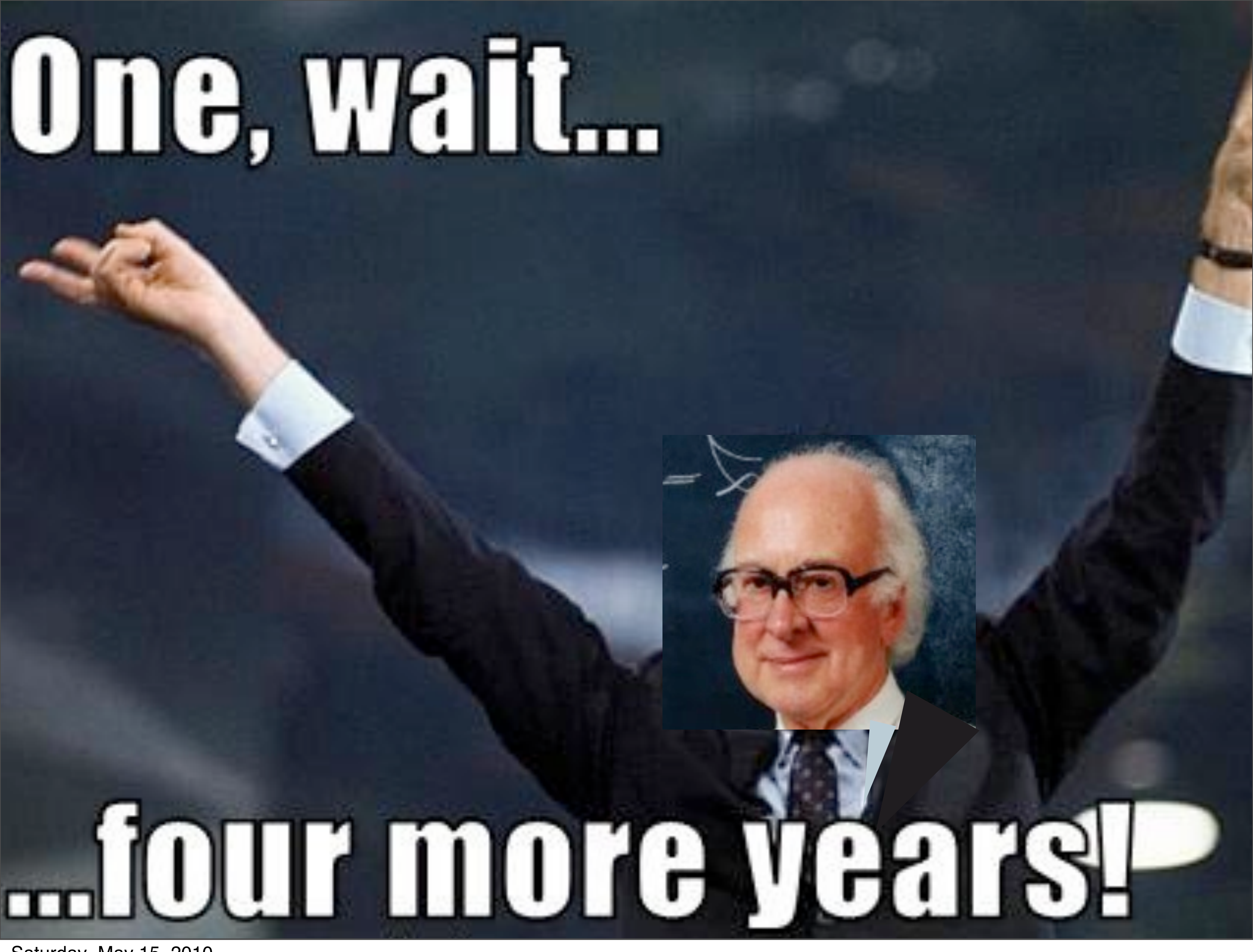
I think this shows that the Tevatron can still add very interesting information on Higgs searches, both in SM as well as in non-standard channels.

There is a clear complementarity with early LHC searches in both the high mass region as in non-standard Higgs boson searches.

P. Draper, T. Liu, C.W. '10

An extended run will further strengthen this capabilities, leading to possibilities of discoveries before the LHC developes its full potential.

I will therefore request in the same way as Higgs, in his recent visit to Fermilab demanded, supported in mass by the large audience, crowding the Fermilab auditorium


One, wait...
...four more years!

Conclusions

- Search for Higgs bosons in the low mass region will be very challenging, both at the Tevatron as well as the LHC
- At the Tevatron, additional luminosity as well as efficiency improvements are necessary to fully probe the region of masses below 140 GeV
- If expected efficiency improvements are implemented, Tevatron can probe the whole region consistent with SM precision electroweak measurements
- Intermediate mass region around 130 GeV remains, however, challenging, and this translates to other well motivated models like the MSSM
- An extended run will allow to test the whole mass range with relative comfort, as well as to ensure the necessary manpower to implement the necessary improvement in the analyses
- These improvements will not only serve to probe this well motivated region, but could allow us to find evidence of the existence of a Higgs decaying into bottom quarks. Prospects for discovery, although still weak, are also enhanced.

There is also the fact that you remain sensitive to many other search channels, beyond the Higgs

As John Lennon once stated

Life is what happens to you when you are busy making other plans