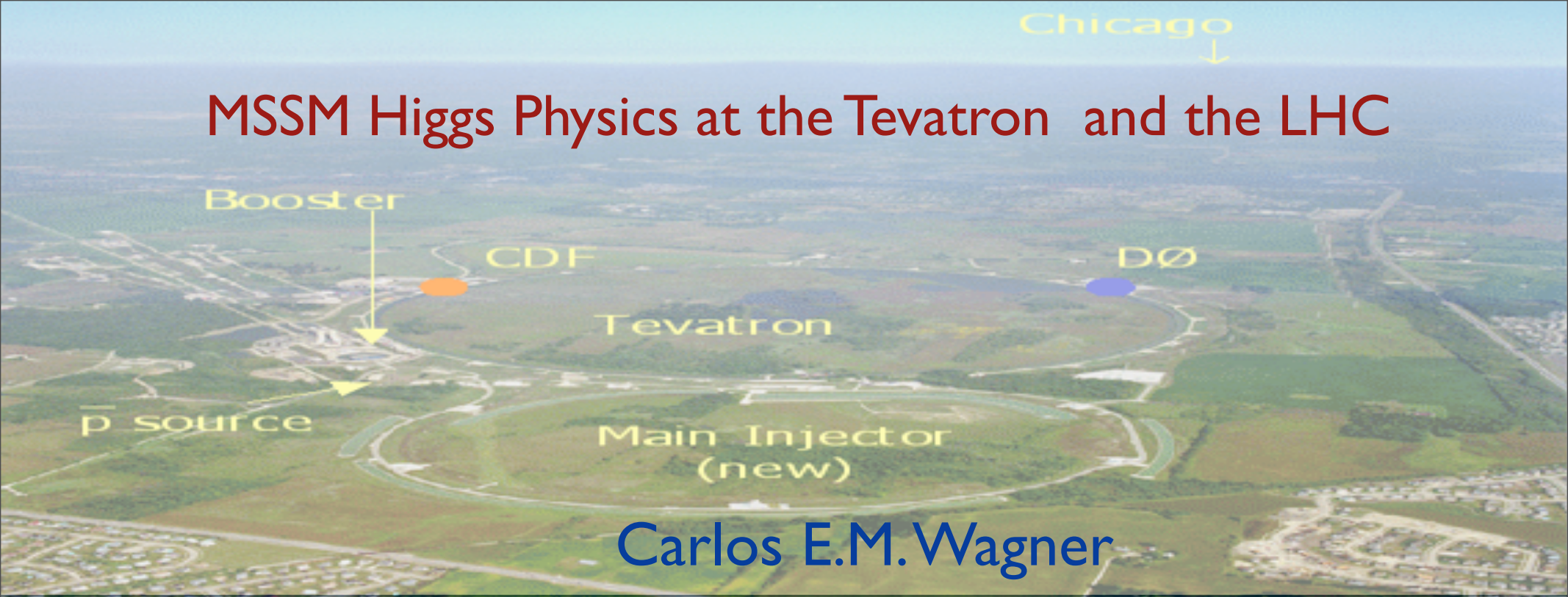
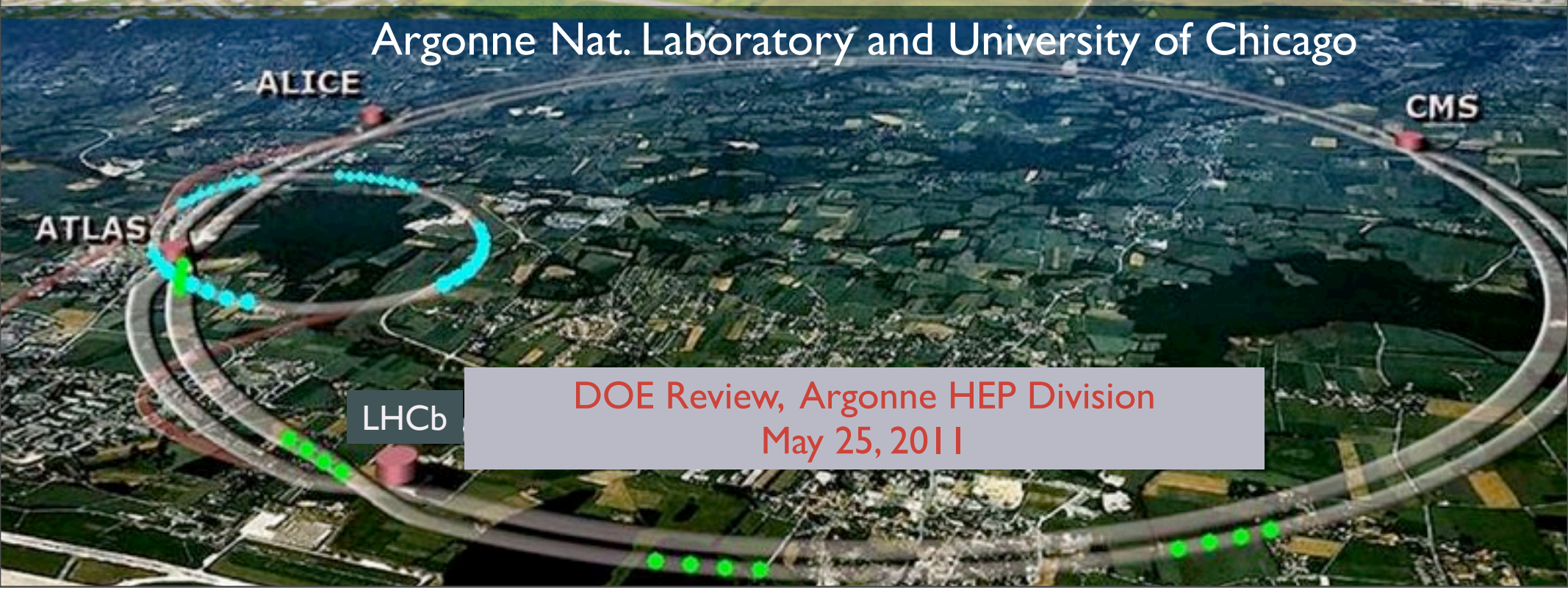
MSSM Higgs Physics at the Tevatron and the LHC



Carlos E.M. Wagner

Argonne Nat. Laboratory and University of Chicago



DOE Review, Argonne HEP Division
May 25, 2011

Carlos Wagner 2010-2011 Research Activities

Tevatron ttbar asymmetry : Analyzed different new physics scenarios.
Phys.Rev.D81:114004,2010 **(Cao, Mc Keen, Rosner, Shaughnessy)**

Direct DM Detection Anomalies : Near PQ Symmetry limit of NMSSM,
Phys.Rev.Lett.106:121805,2011 **(Cao, Draper, Liu, Wang,Zhang)**

RG Invariants in the MSSM :
Phys.Rev.D82:075005,2010; D83:035014,2011 **(Carena, Draper, Shah)**

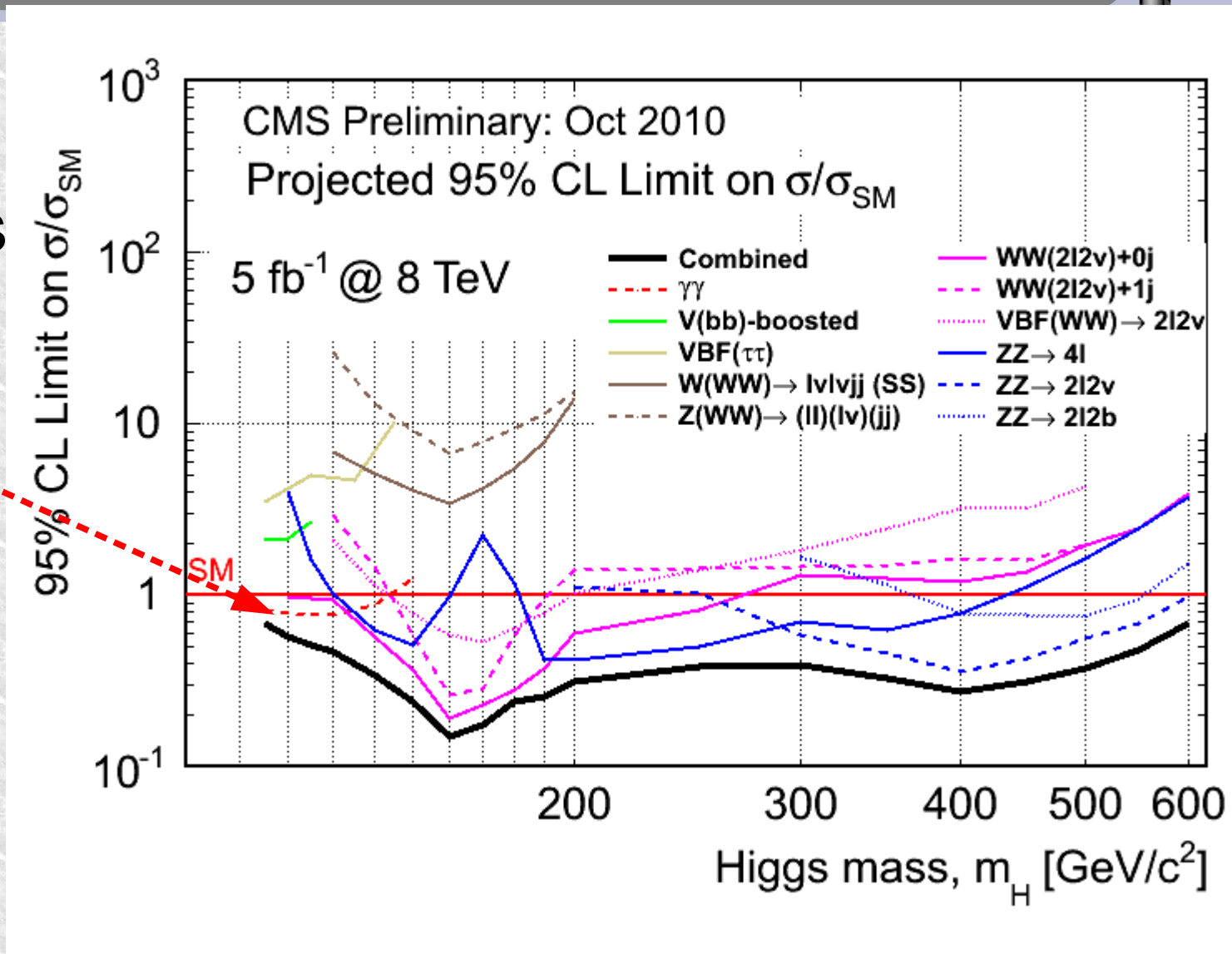
MSSM Higgs searches at hadron colliders :
Phys.Rev.D81:015014,2010; D83:055007,2011 **(Carena, Draper,Liu)**

Higgs from SUSY cascade decays :
arXiv:1103.4138 **(Gori, Schwaller)**

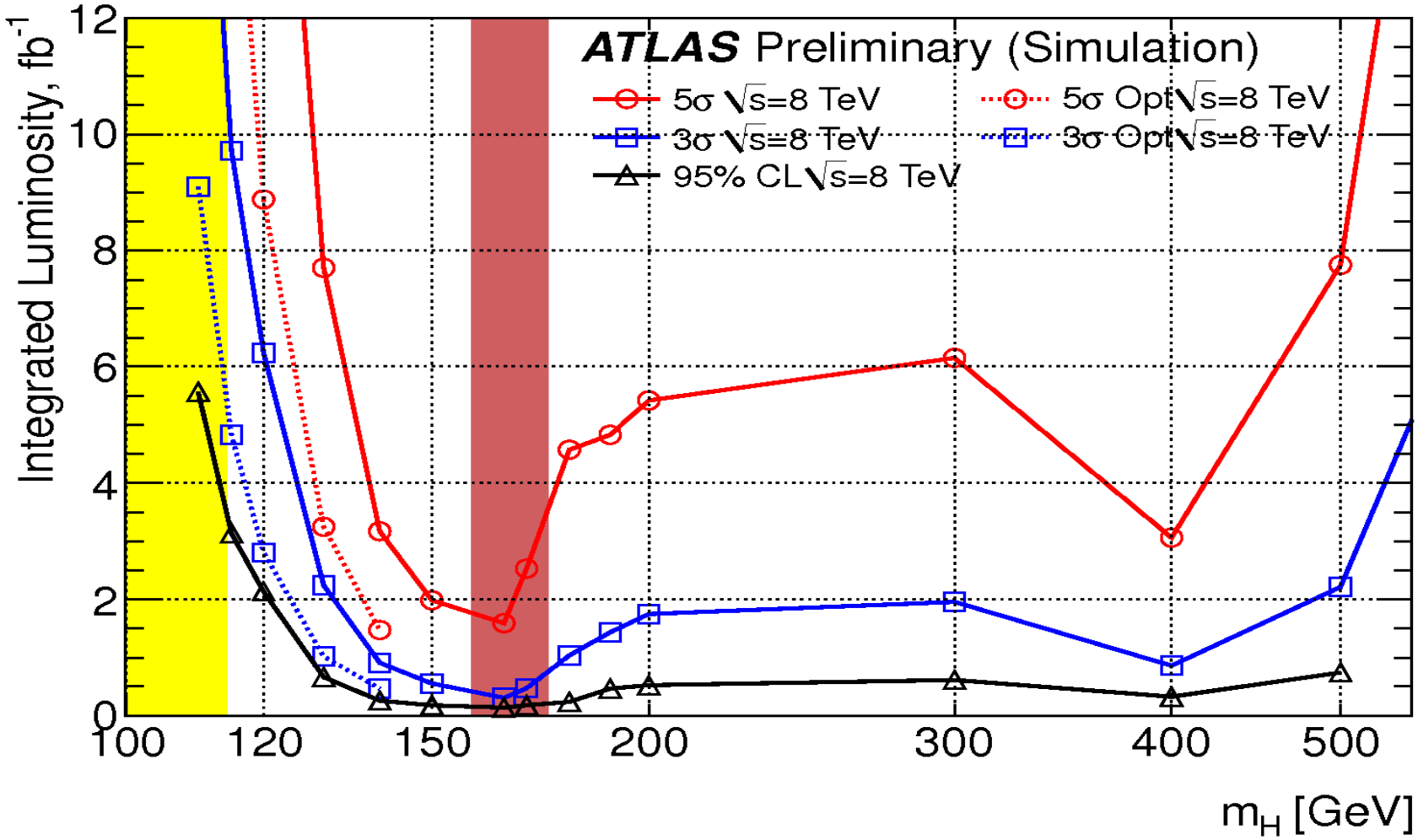
Higgs Doublet Explanation of Tevatron W+2j
arXiv:1104.4776 **(Cao, Gori, Carena, Menon, Schwaller, and Wang)**

Contributions by channel

- Hardest point is lowest mass
- 5 channels at 120GeV
- H→γγ best



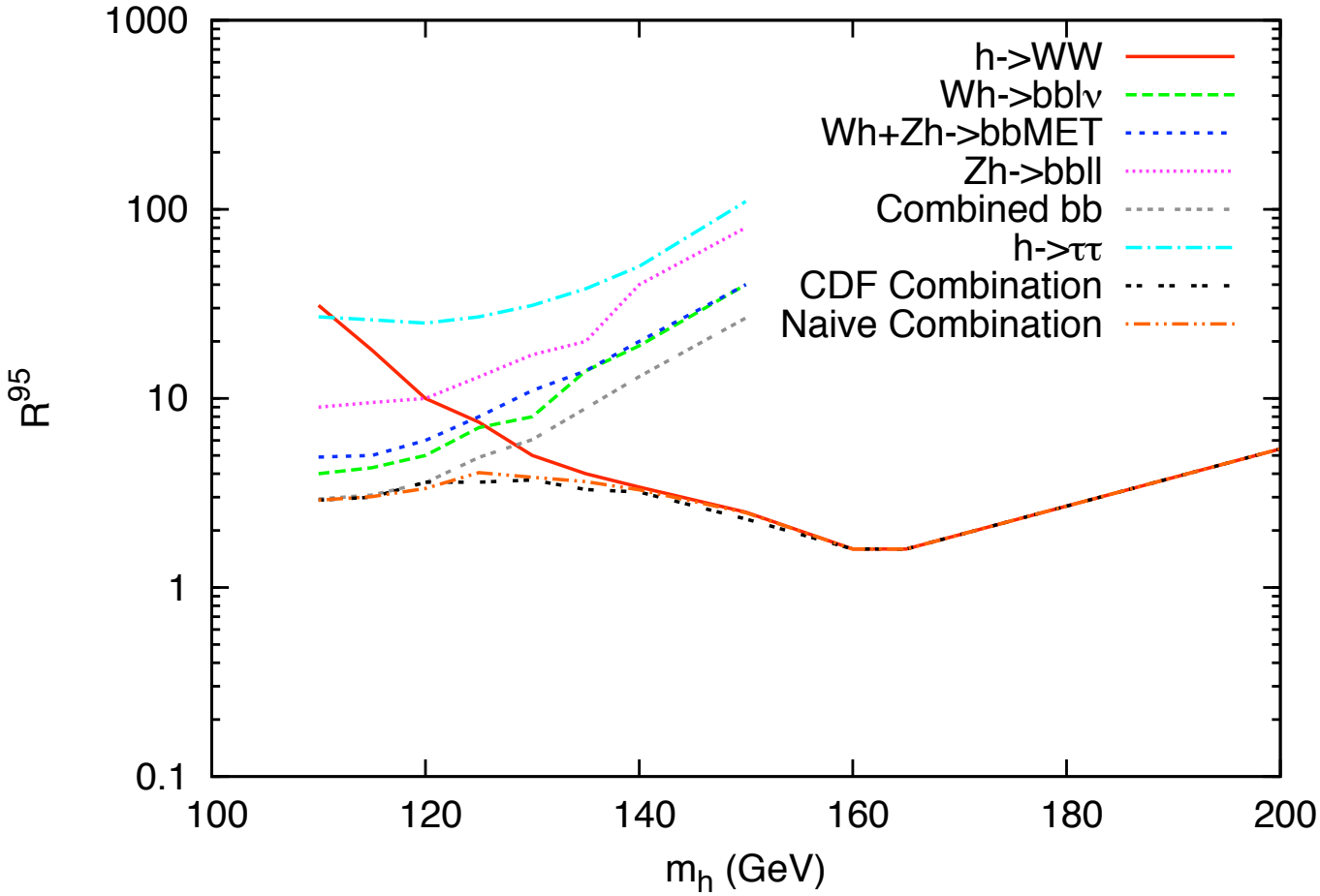
Sensitivity of Higgs search



5fb^{-1} at 8TeV gives 3σ for 114 to >500GeV

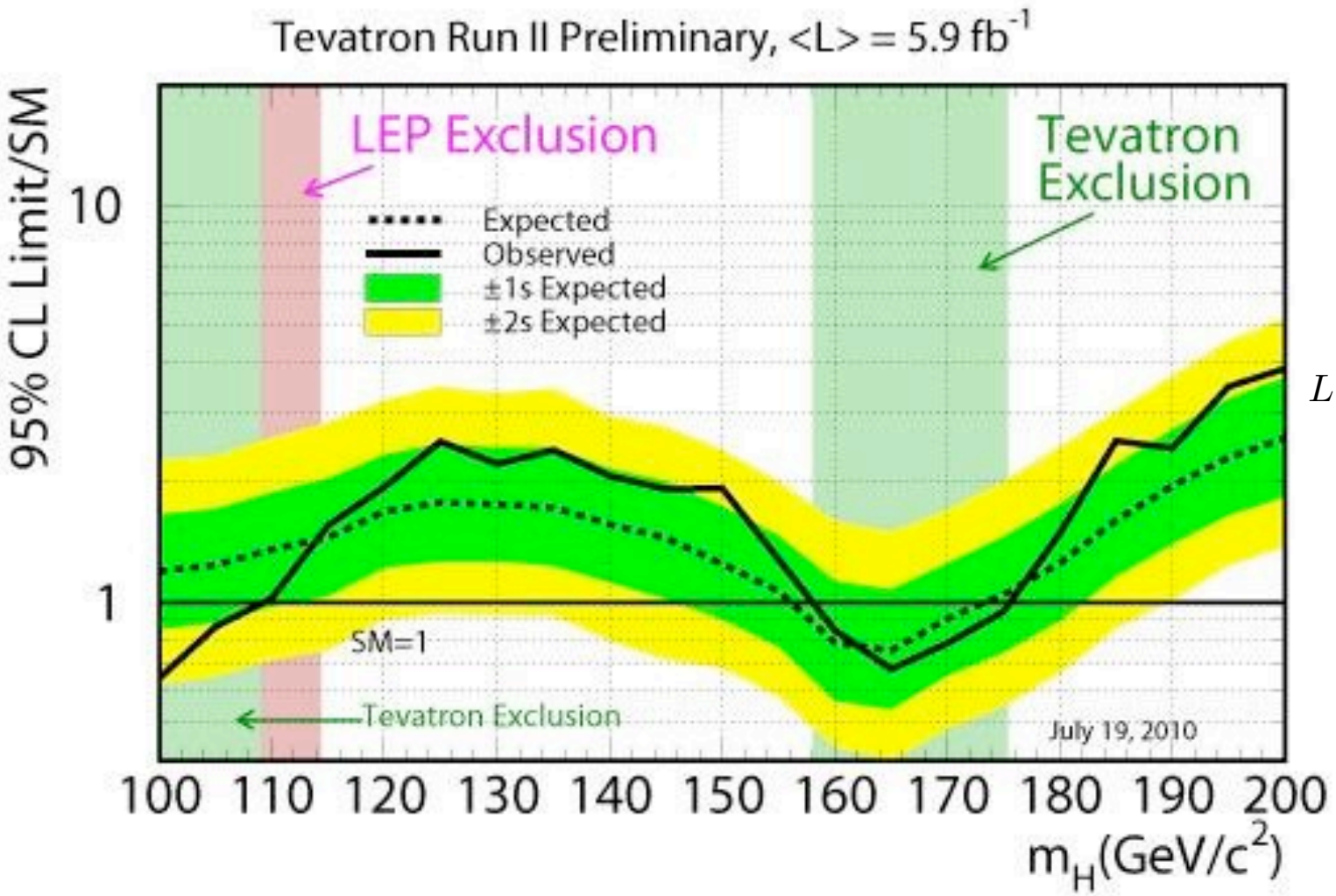
Comparison of Simple Combination of Channels with CDF Results. Ratio R for exclusion

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



Applicable to new model in which all channels rescale in the same way.
In the MSSM, channels should be considered separately and recombined.

The Tevatron is already providing bounds on the Higgs mass

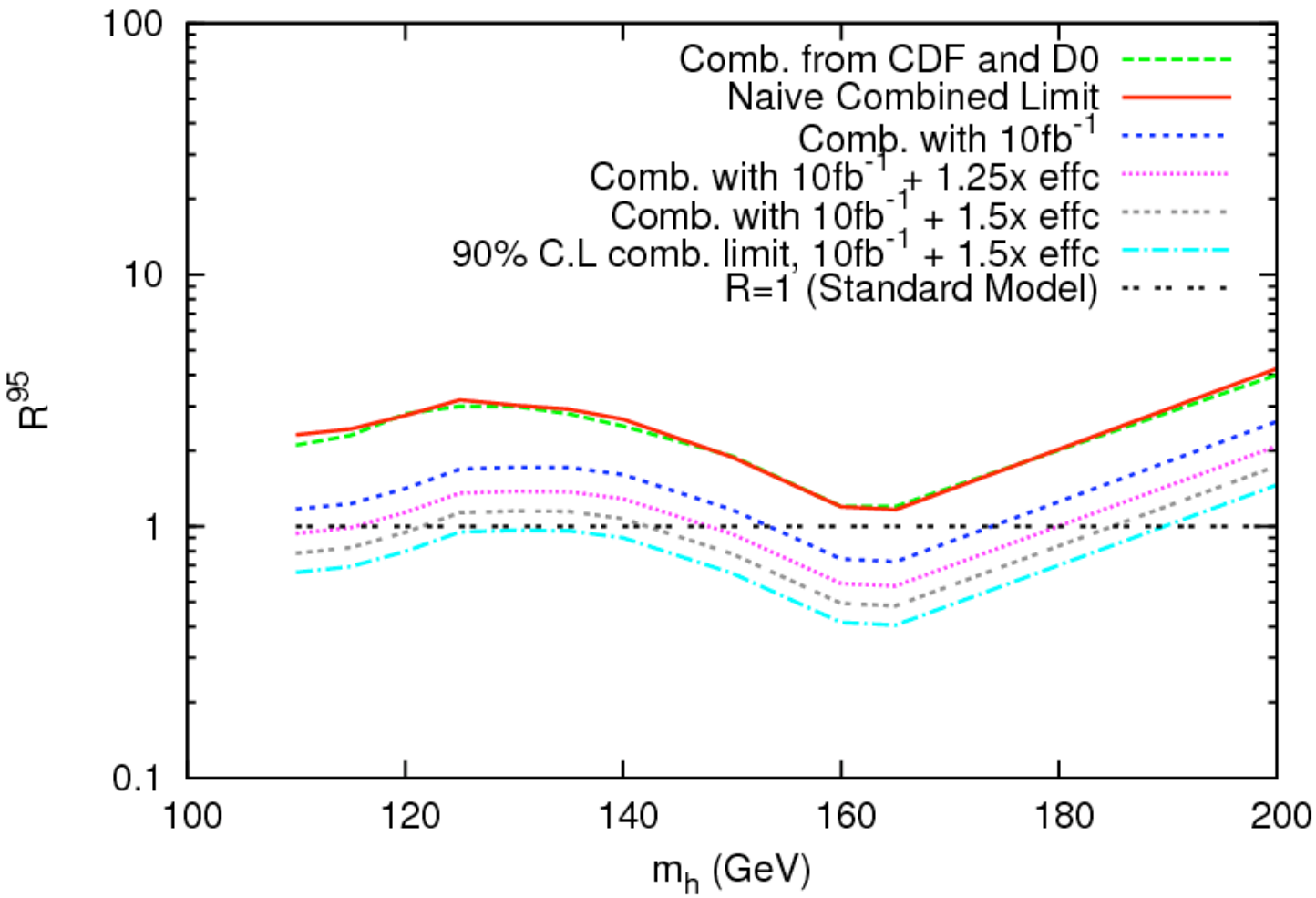


$$1 \text{ barn} : 10^{-24} \text{ cm}^2$$
$$1 \text{ pb} = 10^{-12} \text{ barn}$$
$$1 \text{ fb} = 10^{-15} \text{ barn}$$
$$L \times \sigma = \text{Number of events}$$

Interesting enough, if a Higgs were there, one would expect, in average $R_{\rm obs} = R_{\rm exp} + 1$.
The excess statistical significance is, however, $2/R_{\rm exp}$

Prospects for Higgs Searches at the Tevatron

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



Improvements with respect to Winter'09 10 percent already achieved

Tevatron shutdown expected this fall, with about $10\ \mathrm{fb}^{-1}$ of luminosity

With the current run, and expected improvements, the Tevatron should probe the Higgs mass region up to 190 GeV

Physics Beyond the SM : 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,

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

- 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

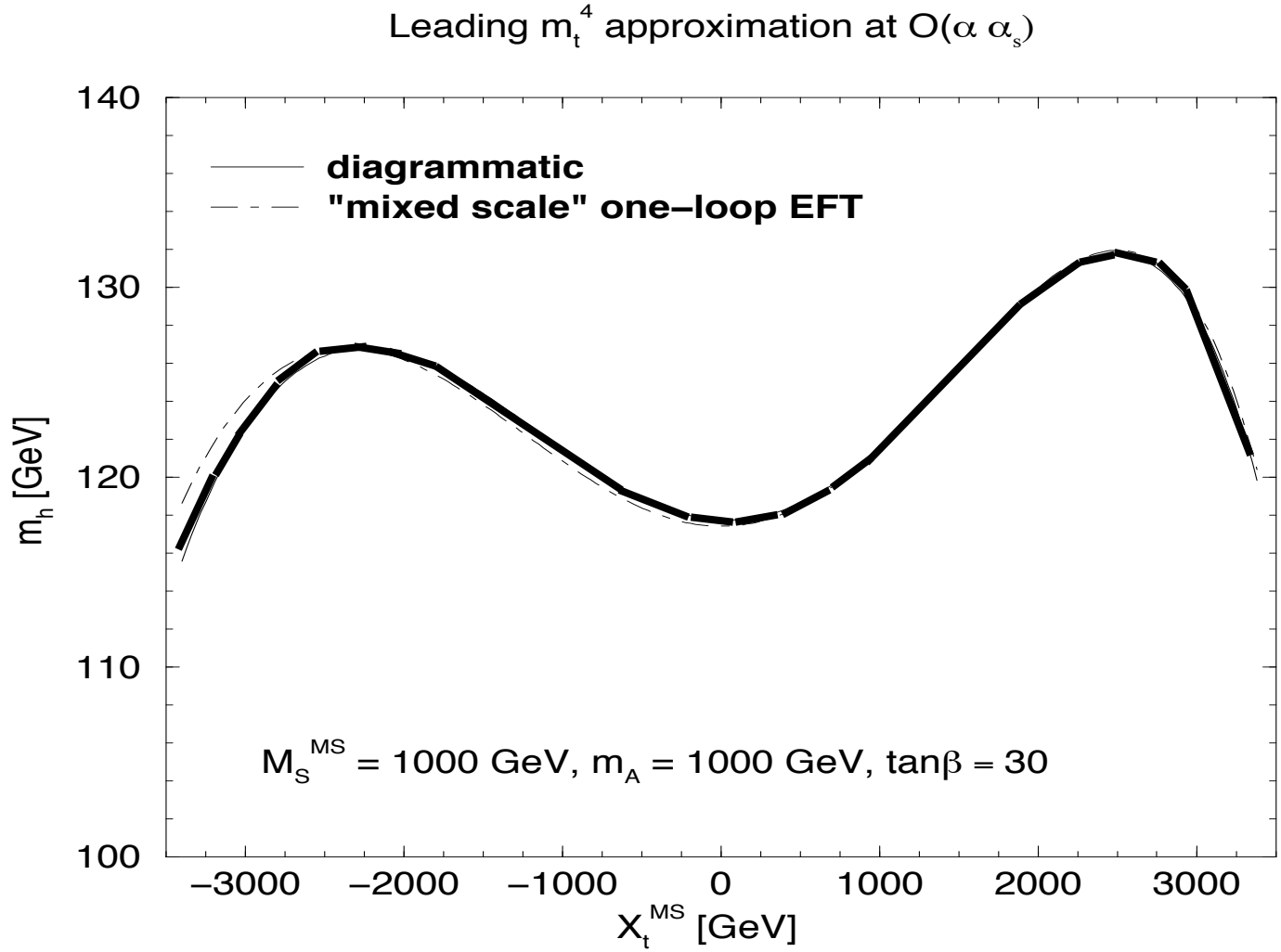
$M_S = 1 \to 2$ TeV $\Longrightarrow \Delta m_h \simeq 2 - 5$ GeV

$\Delta m_t = 1$ 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



$m_t = 180$ GeV.
For $m_t = 173$ GeV, the maximum m_h shifts to 127 GeV.

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

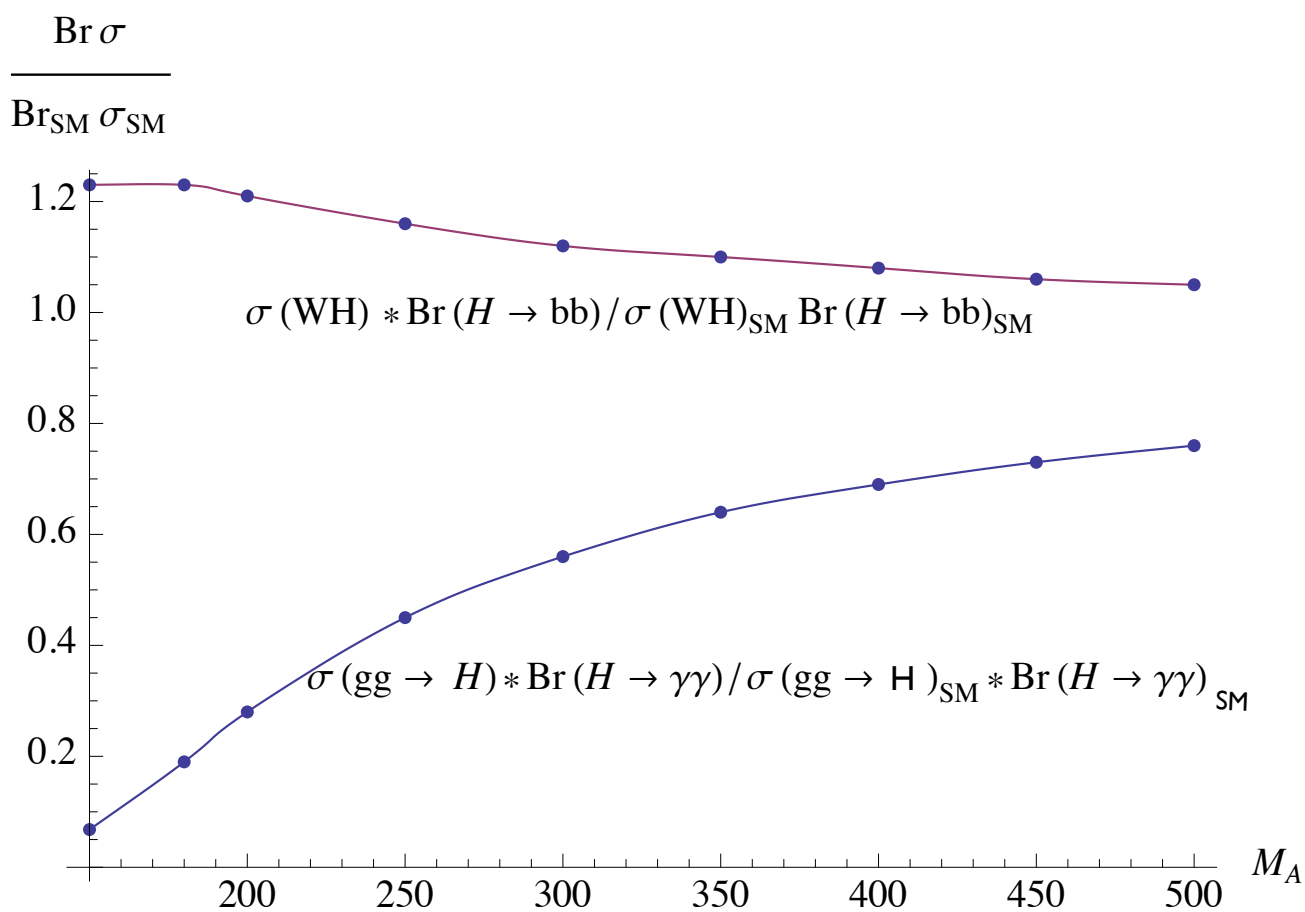
MSSM SM Higgs Searches at the LHC

- In the MSSM, one of the Higgs bosons has standard model like couplings to the top and gauge bosons

- The main SM-like channels of production and/or decay are induced by loops, which are affected by new physics (mainly stops)

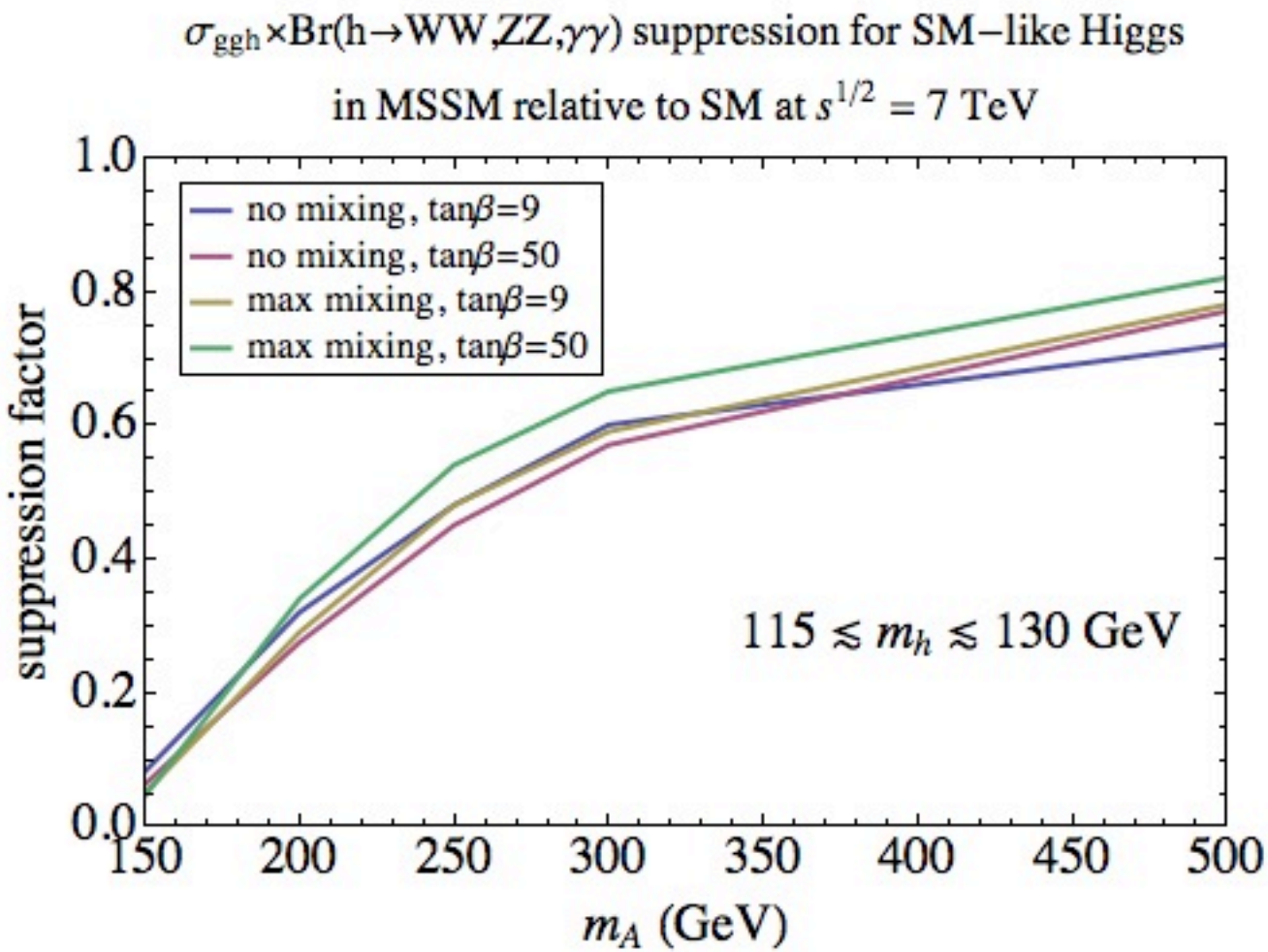
- Moreover, the dominant width of Higgs decay into bottom quarks may be enhanced due to mixing with non-standard Higgs bosons. Top Yukawa tend to be somewhat reduced by same effect.

Suppression factor in the LHC channels at the 2012--2013 run

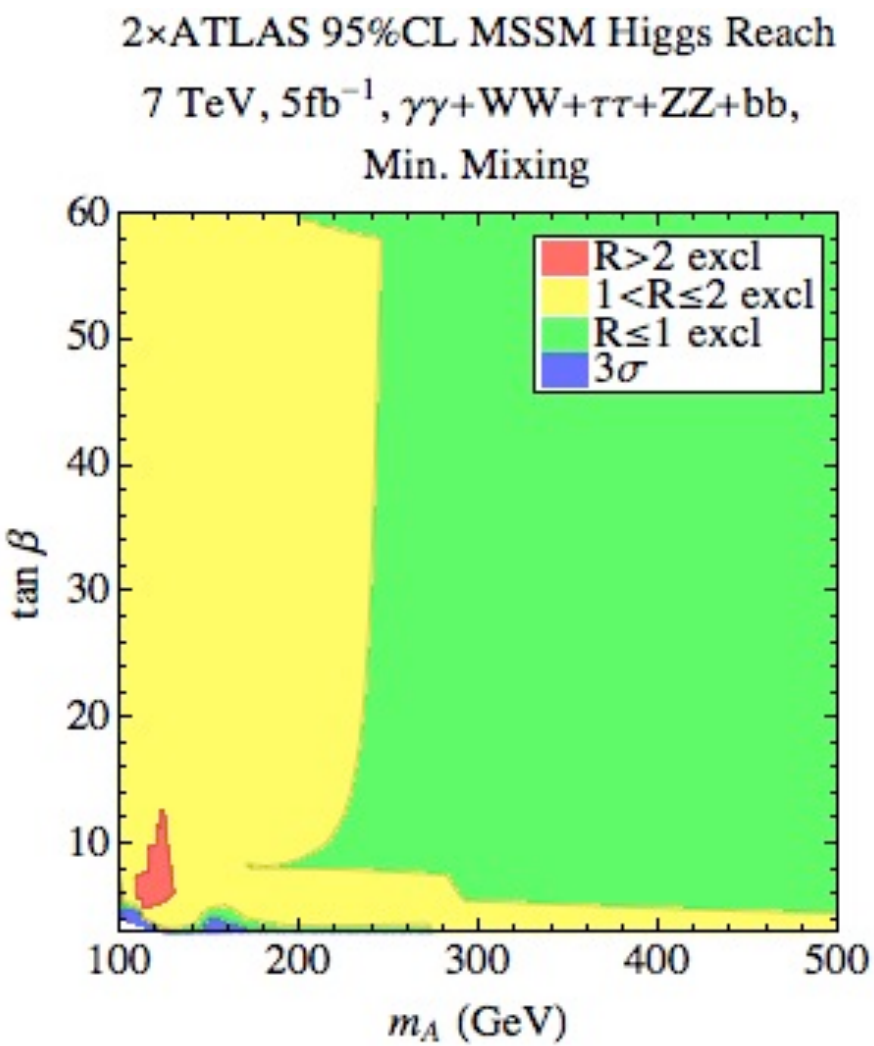


Even for a CP-odd Higgs mass of 500 GeV, suppression is quite relevant.

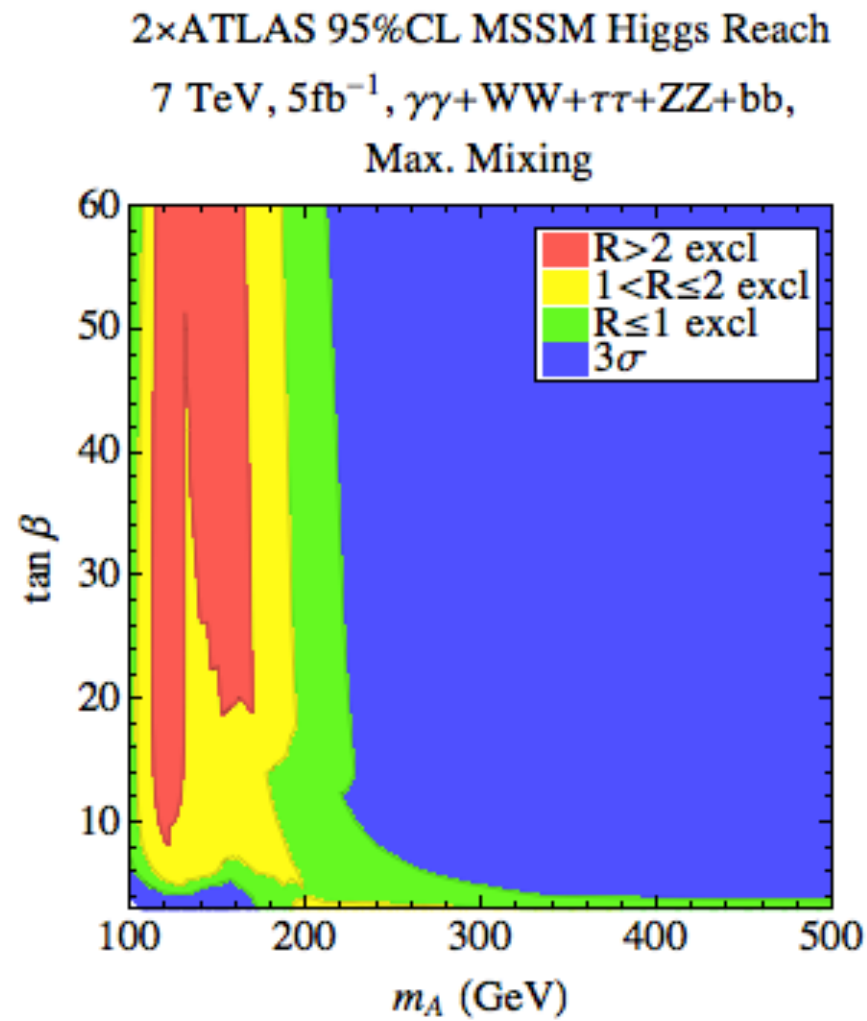
Suppression factor in the LHC channels at the 2012--2013 run



The SM-like Higgs reach is worse than the one at small luminosity at the 14 TeV LHC (P. Draper, T. Liu, C.W. '10)



$m_h \simeq 115\text{GeV}$



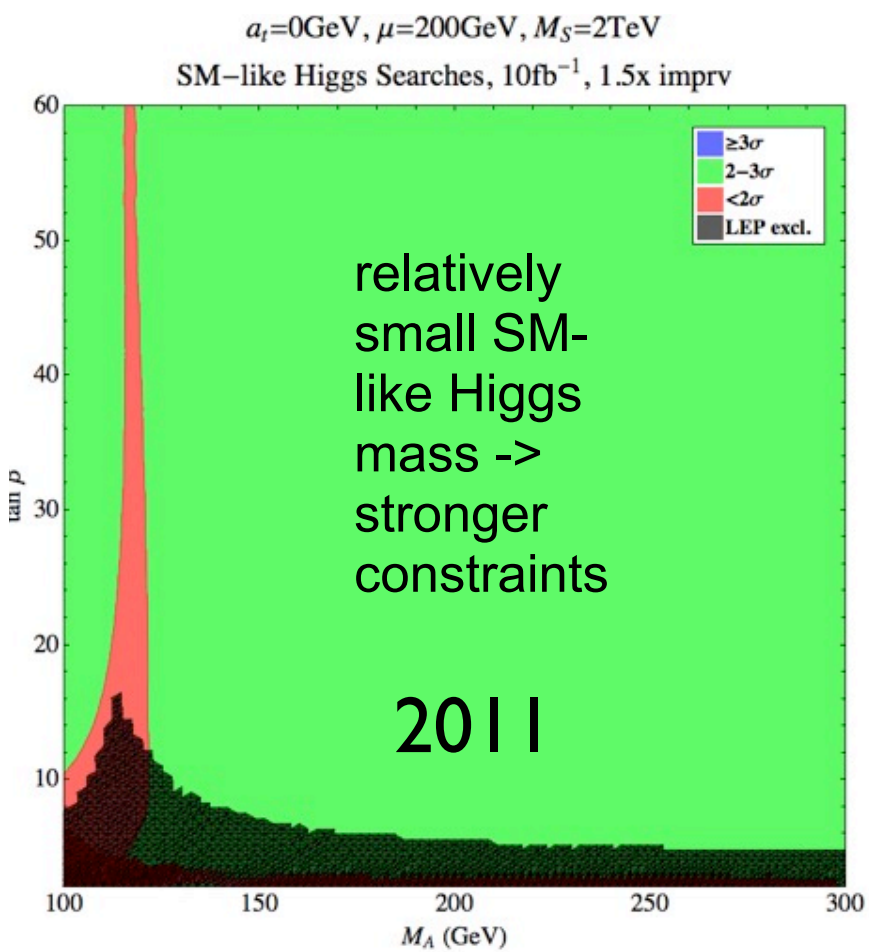
$m_h \simeq 130$ GeV

M. Carena, P. Draper, T. Liu, C.W.'11, to appear

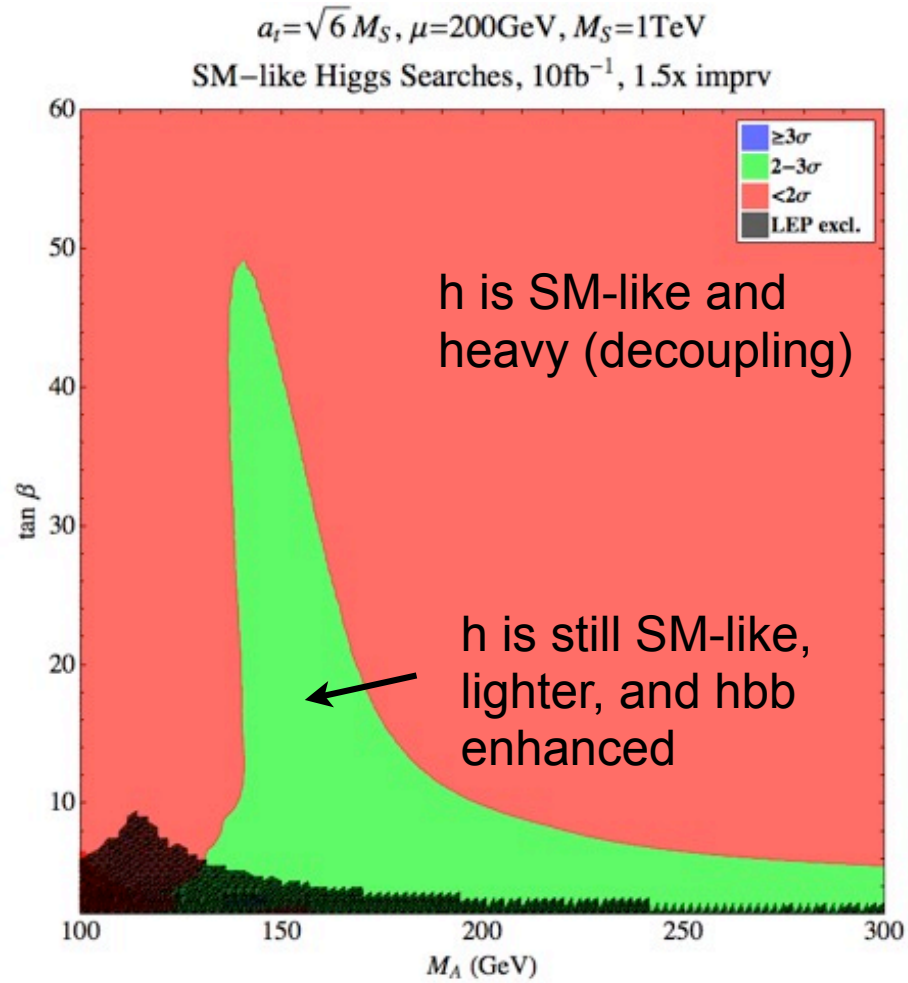
P. Draper, T. Liu and C.W. '10

Standard Higgs search channels at the Tevatron.

$m_h \simeq 115\text{GeV}$

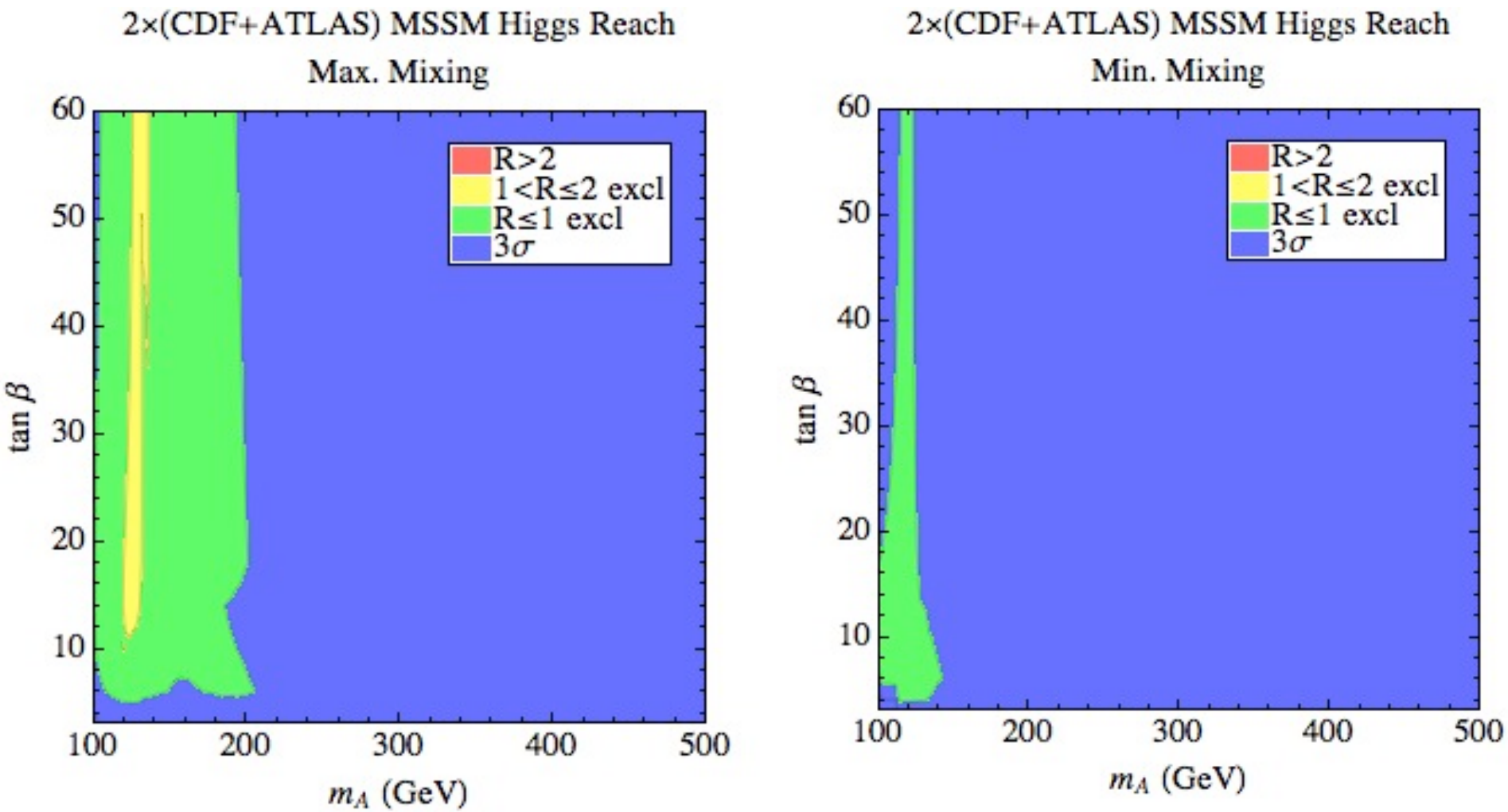


$m_h \simeq 130\ \text{GeV}$



At the end of the Tevatron run, more than 2 sigma sensitivity is achieved in most parameter space in minimal mixing, while weaker reach in maximal mixing scenario.

Since sensitivity is somewhat complementary to that of the Tevatron, combination of data from all experiments at the end of 2012 may be useful



Evidence of SM-like Higgs presence in almost all parameter space

M. Carena, P. Draper, T. Liu, C.W.'11, to appear (non-standard Higgs searches included)

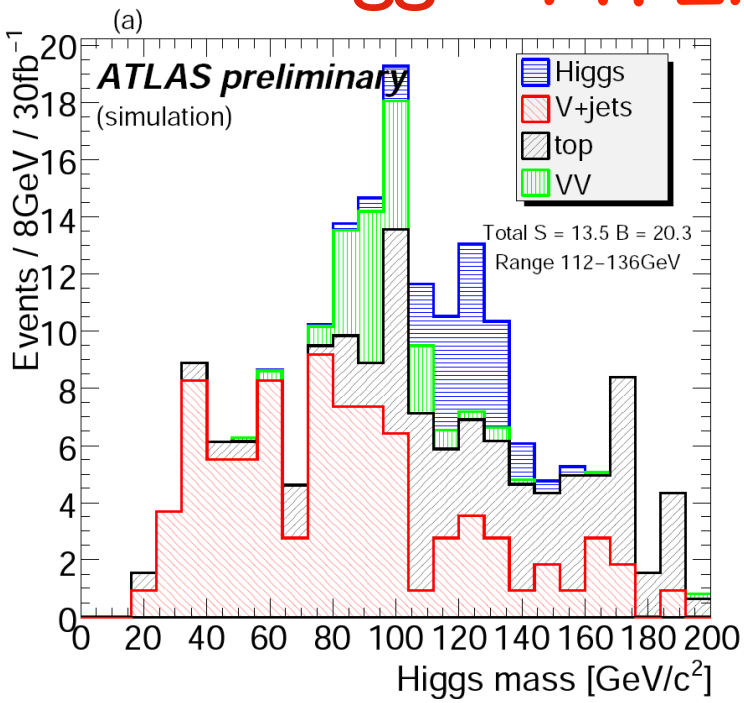
Higgs Bosons Decaying to Bottom pairs at the LHC

- In the past the decay of Higgs into bottom quarks have been ignored due to overwhelming backgrounds
- However, the study of jet substructure has revealed new possibilities
- In particular, boosted Higgs bosons decaying to bottom pairs might be easily separated from the QCD background by the use of these techniques
- This is true in the SM model, for a light Higgs produced in association with W bosons, where the proportion of boosted Higgs is small

  Butterworth, Davison, Rubin, Salam'08
  Plehn, Salam, Spannowsky'09 (ttbar+H)
- In the MSSM, there are new possibilities for boosted Higgs

  Kribs, Martin, Roy, Sapnnowsky'10

SM Higgs : ATLAS Simulation



The WH (W→lν,H→bb) analysis: cut flow (main signal and backgrounds samples)

Loose jet veto and loose b-tagging (to be used as input to likelihood fit):

L=30 fb^{-1}

	WH(120)	WZ	$t\bar{t}(p_T^{min})$	Wt	W+jets
After filter cuts	1252.8 ± 7.8	9331	1609356	169519	2433885
1 Higgs candidate	569.7 ± 3.0	3509.7 ± 8.0	806175	69375	562030
filtered p_T > 200 GeV	512.7 ± 3.2	3108 ± 10	709271	60241	413406
Missing E_T > 30 GeV	362.4 ± 3.2	2183 ± 13	552284	46779	318400
p_T(W) > 200 GeV	171.0 ± 2.6	1216 ± 12	137946	18524	206331
p_T(e/μ)>30 GeV	145.6 ± 2.4	996 ± 11	115053	15724	178004
p_T(additional μ)<10 GeV	144.6 ± 2.4	942 ± 11	106836	14992	177542
p_T(additional e)<10 GeV	142.9 ± 2.4	885 ± 11	97305	13881	174941
$\Delta\phi$(W,H)> $\frac{2}{3}\pi$	142.2 ± 2.4	841 ± 11	84773	12999	167704
no additional b-jets p_T >15 GeV	130.6 ± 2.3	790 ± 10	30605	7805	160608
add. jets on W side p_T <60 GeV	115.7 ± 2.2	637.2 ± 9.5	19422	5870	121437
add. jets on H side p_T <60 GeV	102.7 ± 2.1	525.6 ± 8.8	13841	4370	94055
one subjet b-tagged	91.4 ± 2.0	126.1 ± 4.5	8638	2421	6964
both subjets b-tagged	45.6 ± 1.4	43.7 ± 2.7	576	161.4 ± 7.0	266
loose fit cuts	45.4 ± 1.4	43.0 ± 2.7	565	156.3 ± 6.9	257

Tight jet veto and tight b-tagging at ε_b~63 % and c(l)=0.2 (for counting based analysis)

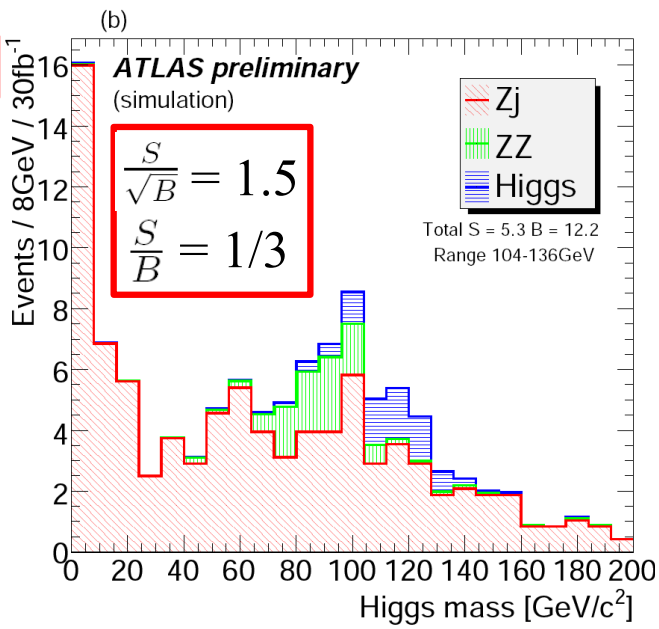
	WH(120)	WZ	$t\bar{t}(p_T^{min})$	Wt	W+jets
add. jets on W side p_T <20 GeV	83.2 ± 1.9	461.3 ± 8.3	7227	3343	86087
add. jets on H side p_T <20 GeV	55.8 ± 1.6	275.6 ± 6.6	1895	1142	48229
one subjet b-tagged	46.4 ± 1.5	49.8 ± 2.9	986	498 ± 12	1825
both subjets b-tagged	19.51 ± 0.96	16.5 ± 1.7	38.9 ± 4.9	18.2 ± 2.4	87.3 ± 9.0
112 GeV < mass(H) < 136 GeV	13.25 ± 0.79	1.18 ± 0.45	5.6 ± 1.9	4.2 ± 1.1	8.3 ± 2.8

Signal events (m_H~120 GeV): ~13.5
Background events: ~20.3

$$\frac{S}{\sqrt{B}} = 3.0 \pm 0.3$$

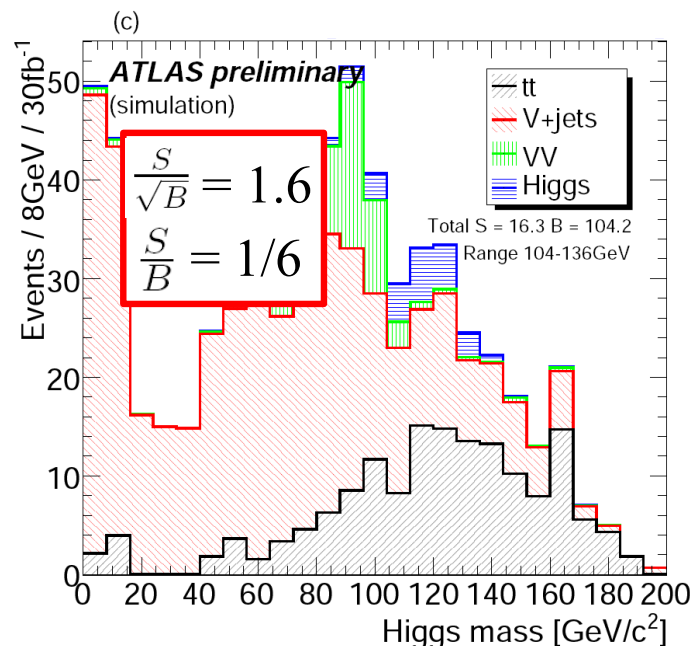
Giacinto Piacquadio

llbb



ATL-PHYS-PUB-2009-088 (Aug 2009)

ννbb



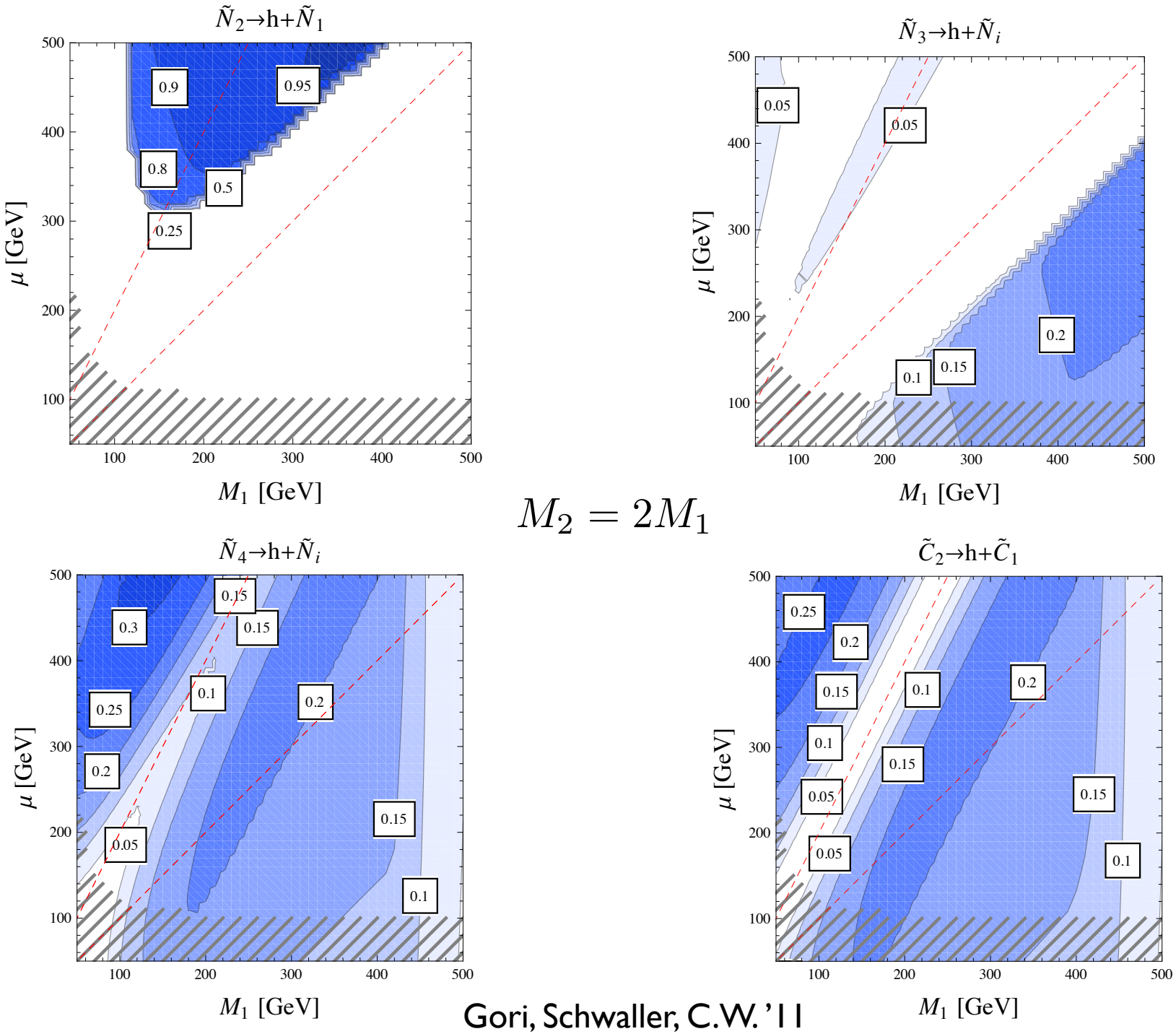
MSSM with Higgsino LSP

	SHSP 1a / SHSP 1b	SHSP 2a / SHSP 2b	SHSP 3	SHSP 4	SHSP 5	SHSP 6
$\tan\beta$	10	10	10	5	6.5	10
M_1	300 GeV	150 GeV	163 GeV	200 GeV	200 GeV	300 GeV
M_2	600 GeV	300 GeV	400 GeV	400 GeV	400 GeV	600 GeV
M_3	2.1 TeV	1.05 TeV	1.0 TeV	1.4 TeV	1.4 TeV	2.1 TeV
μ	150 GeV	150 GeV	200 GeV	200 GeV	−150 GeV	150 GeV
m_A	1 TeV	1 TeV	1 TeV	150 GeV	150 GeV	200 GeV
a_t	900 GeV	−900 GeV	900 GeV	2.04 TeV[a]	1.4 TeV	900 GeV
$m_{\tilde{q}}$	1 TeV	1 TeV/750 GeV	1 TeV	1 TeV	1 TeV	1 TeV
$m_{\tilde{l}}$	1 TeV/350 GeV	1 TeV/350 GeV	350 GeV	1 TeV	1 TeV	1 TeV
m_h	116 GeV	117 GeV	116 GeV	114 GeV	115 GeV	115 GeV
m_H	1 TeV	1 TeV	1 TeV	161 GeV	157 GeV	202 GeV
m_A	1 TeV	1 TeV	1 TeV	150 GeV	150 GeV	200 GeV
$m_{H^\pm}$	1 TeV	1 TeV	1 TeV	169 GeV	170 GeV	216 GeV
χ_1	138 GeV	110 GeV	140 GeV	157 GeV	136 GeV	138 GeV
χ_2	−158 GeV	−161 GeV	209 GeV	−207 GeV	−163 GeV	−158 GeV
χ_3	206 GeV	174 GeV	−209 GeV	227 GeV	210 GeV	306 GeV
χ_4	625 GeV	338 GeV	429 GeV	433 GeV	426 GeV	623 GeV
χ_1^+	148 GeV	137 GeV	191 GeV	187 GeV	152 GeV	148 GeV
χ_2^+	625 GeV	337 GeV	429 GeV	433 GeV	426 GeV	623 GeV
$\sigma_{\rm tot}$	3.9 pb	5.8 pb / 8.07 pb	2.76 pb	2.4 pb	4.1 pb	4.0 pb
% Higgs	4.5%/3.4%	4.2%/6.8%	6.6%	12.8%	8.6%	7.0%
$\sigma_{h/H/A}$	0.18 pb/0.13 pb	0.24 pb/0.55 pb	0.18 pb	0.31 pb	0.35 pb	0.28 pb

Discovery of Higgs boson with 10 inverse fb at a 14 TeV LHC possible

- Kribs et al concentrated on the region of light Higgsinos, where the proportion of boosted Higgs bosons tends to be large.
- The appearence of hard jets, b-tagging and large missing energy already provide interesting ways of suppressing the background
- Highly boosted Higgs provide an additional tool
- Light Higgsinos tend to be inconsistent with the standard neutralino relic density
- It is therefore interesting to study what happens when one departs from these regions.

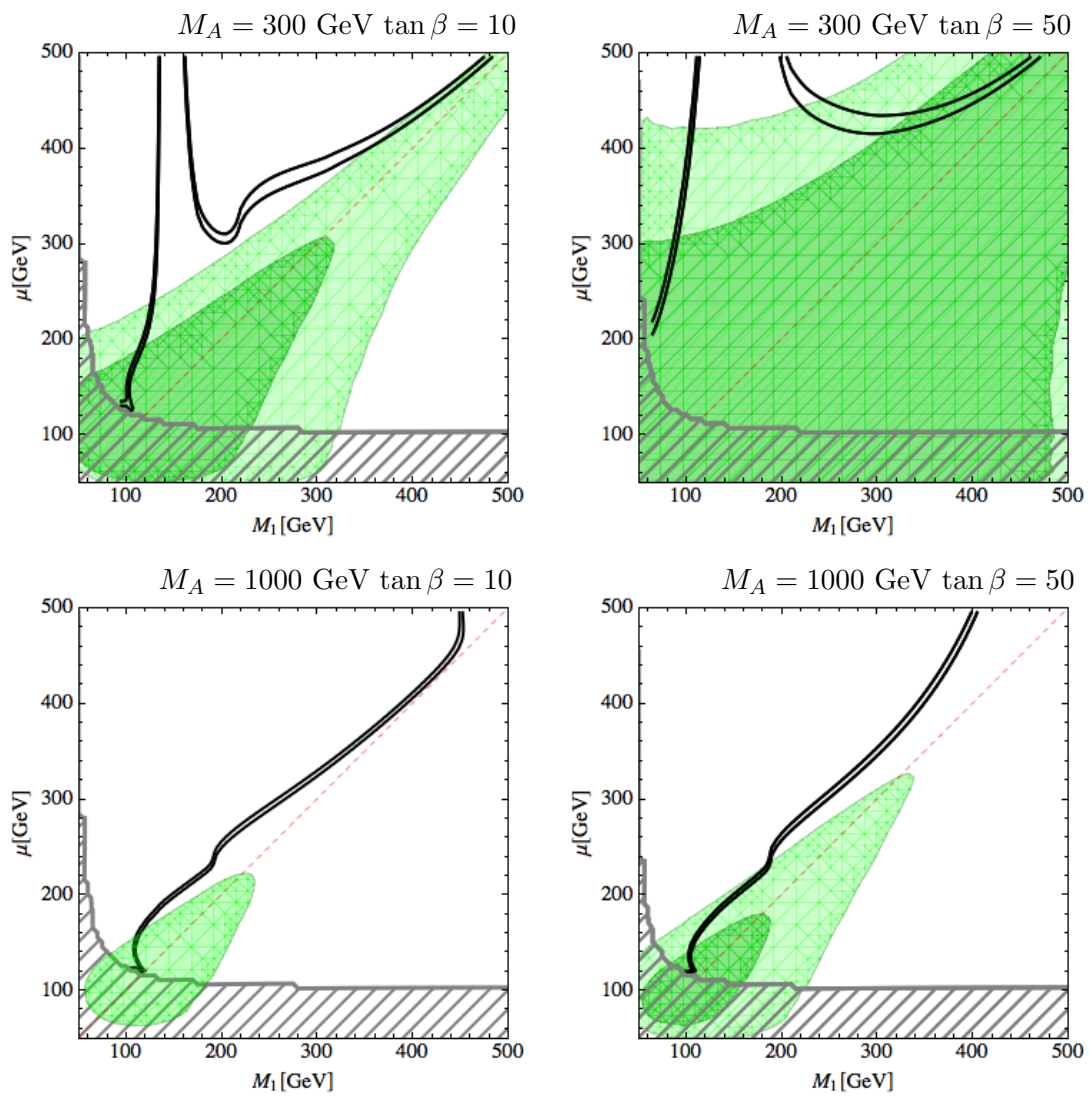
Chargino and Neutralino Decays into Higgs



$$M_2 = 2M_1$$

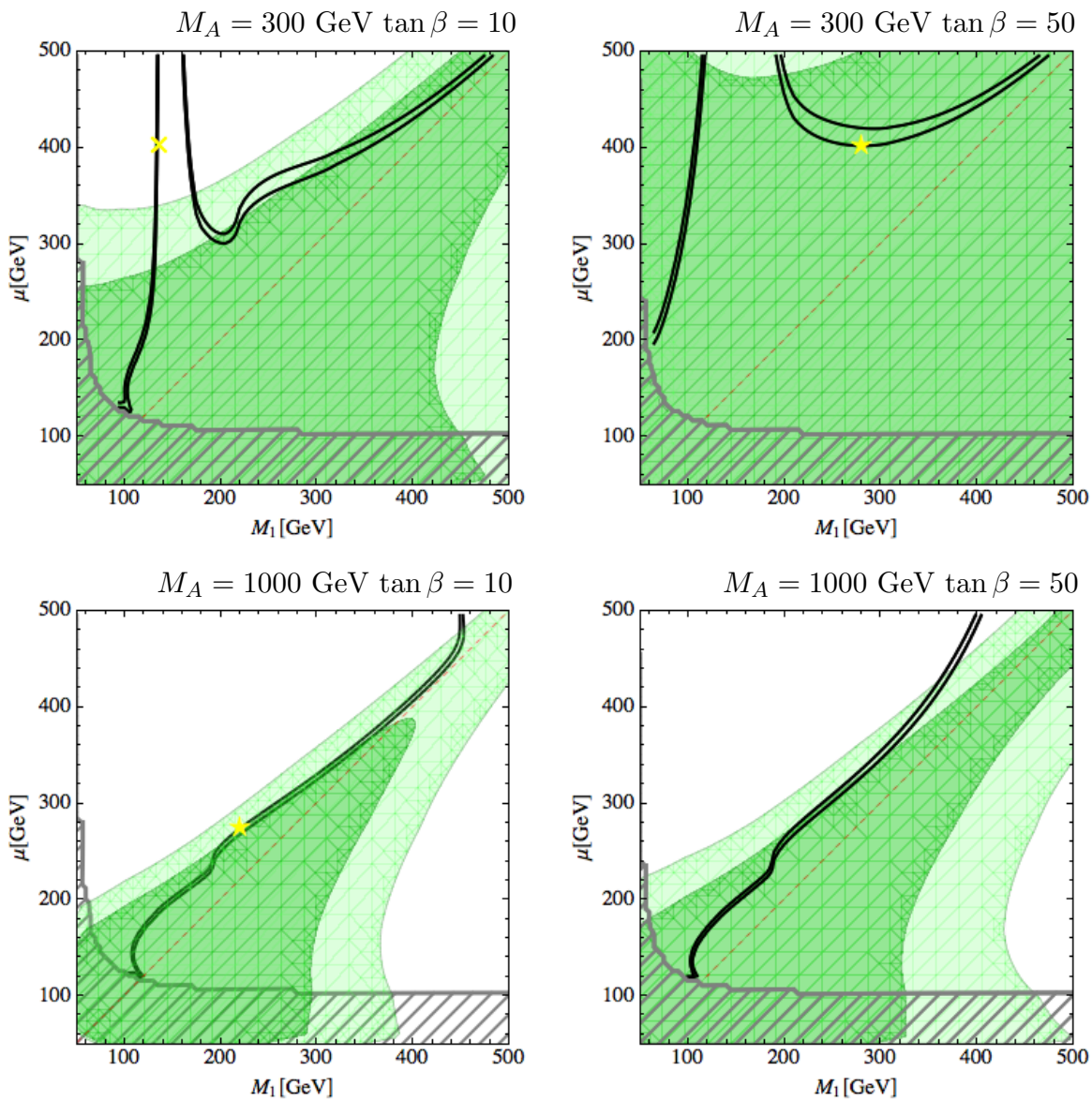
Gori, Schwaller, C.W. '11

Direct Dark Matter Cross Section Constraints (pre Xenon)



Gori, Schwaller, C.W. '11

Direct Dark Matter Cross Section Constraints (post Xenon)



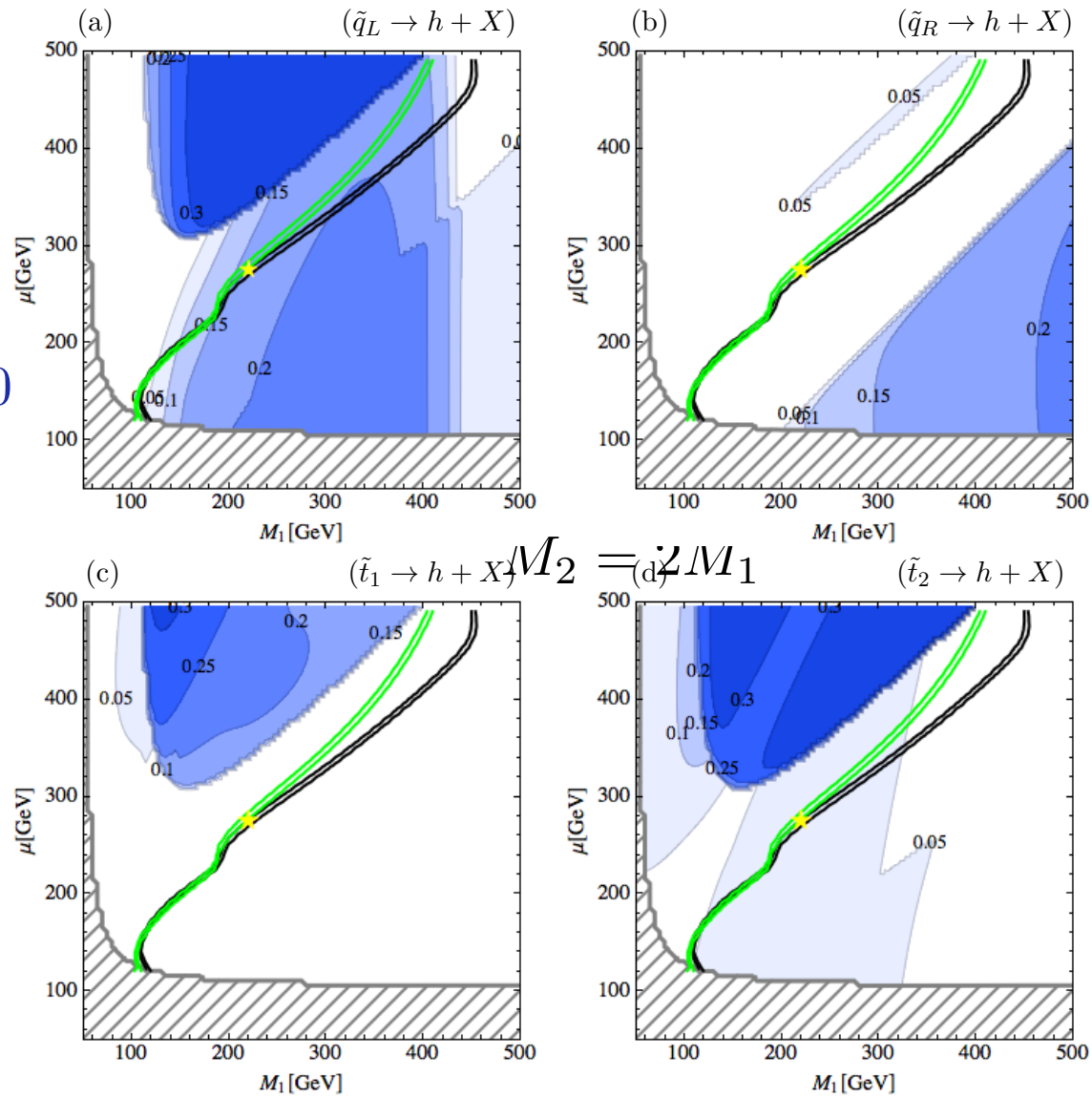
Gori, Schwaller, C.W. '11

Regions of parameter space consistent with Neutralino relic density: Heavy CP-odd boson and heavy Sleptons

$\text{Green}: \tan\beta = 50$
$\text{Black}: \tan\beta = 10$

$m_A = 1TeV$

$m_{\tilde{q}} \simeq 1 \text{ TeV}$
$M_{\tilde{g}} \simeq 6M_1$



$M_2 = 2M_1$

Gori, Schwaller, C.W. '11

Regions of parameter space consistent with Neutralino relic density: Heavy Sleptons and Light CP-odd boson

Countours of proper relic density

Green : $\tan\beta = 50$

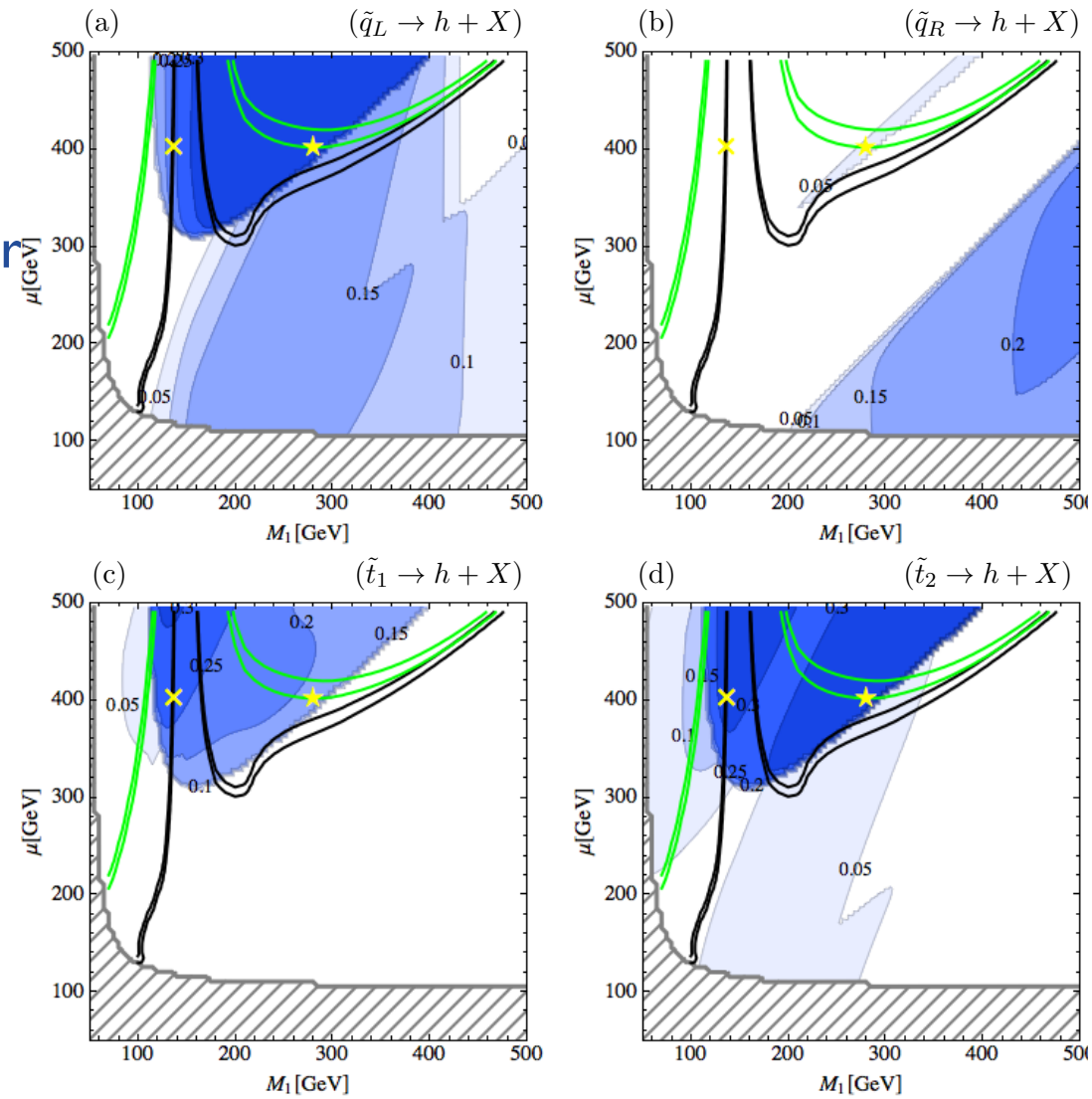
Black : $\tan\beta = 10$

$m_A = 300$ GeV

$m_{\tilde{q}} \simeq 1$ TeV

$M_{\tilde{g}} \simeq 6M_1$

$M_2 = 2M_1$



Blue regions :

Appreciable Branching Decay Fraction.

Darker means larger branching decay fraction.

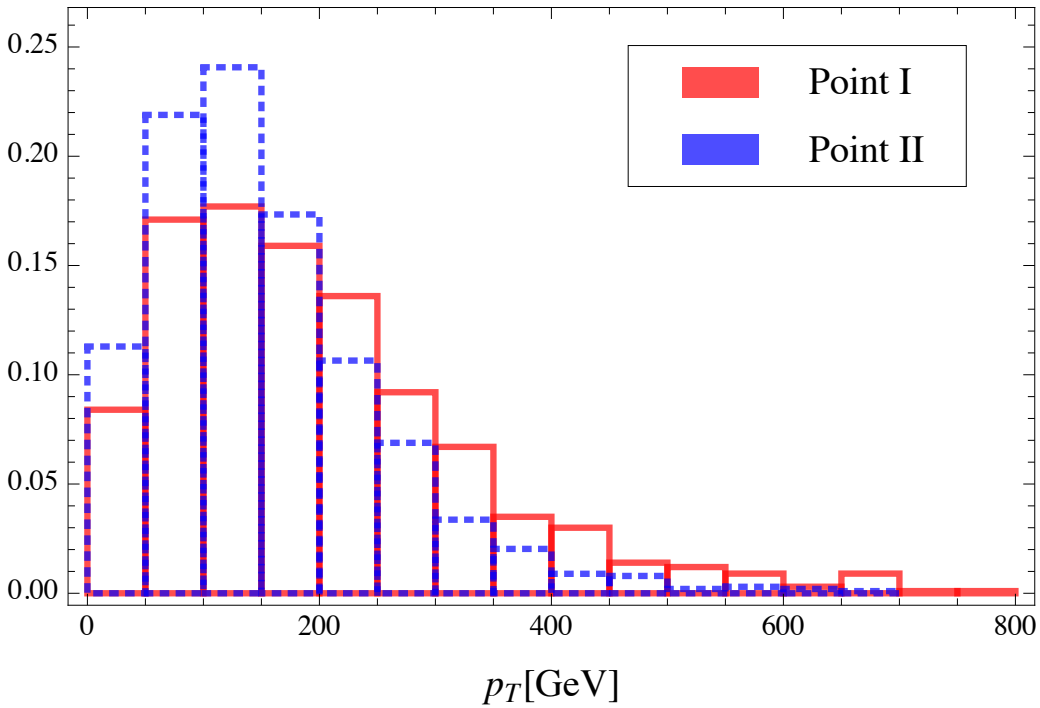
X : energetic quarks, leptons and missing energy

Good prospects of observing Higgs in the 14 TeV run and, perhaps, even in the 7 TeV run.

Gori, Schwaller, C.W., arXiv:1103.4138

Heavy sleptons : The presence of (boosted) Higgs bosons is quite generic in the high p_T sample (14 TeV analysis)

(I)	$M_A = 1000$ GeV	$M_1 = 220$ GeV	$\mu = 280$ GeV	$\tan\beta = 10$,
(II)	$M_A = 300$ GeV	$M_1 = 280$ GeV	$\mu = 400$ GeV	$\tan\beta = 50$,
(III)	$M_A = 300$ GeV	$M_1 = 135$ GeV	$\mu = 400$ GeV	$\tan\beta = 10$.
(IV)	$M_A = 300$ GeV	$M_1 = 49$ GeV	$M_2 = 400$ GeV	$\mu = 300$ GeV	$\tan\beta = 10$



- $\not{E}_T > 200$ GeV,
- at least two jets, with $p_{T1} > 300$ GeV and $p_{T2} > 200$ GeV,
- no isolated leptons.

Boosted Higgs : $p_T > 200$ GeV

	σ[pb]	$\sigma_{\rm cut}$[pb]	σ_h[fb]	$\sigma_{\rm boosted}$[fb]
(I)	1.11	0.52	78	31
(II)	0.73	0.34	116	31
(III)	2.59	0.90	360	135
(IV)	1.60	0.83	231	101

Good prospects of observing Higgs in the 14 TeV run and, perhaps, even in the 7 TeV run.

Gori, Schwaller, C.W., arXiv:1103.4138

Boosted Higgs at the 7 TeV Run

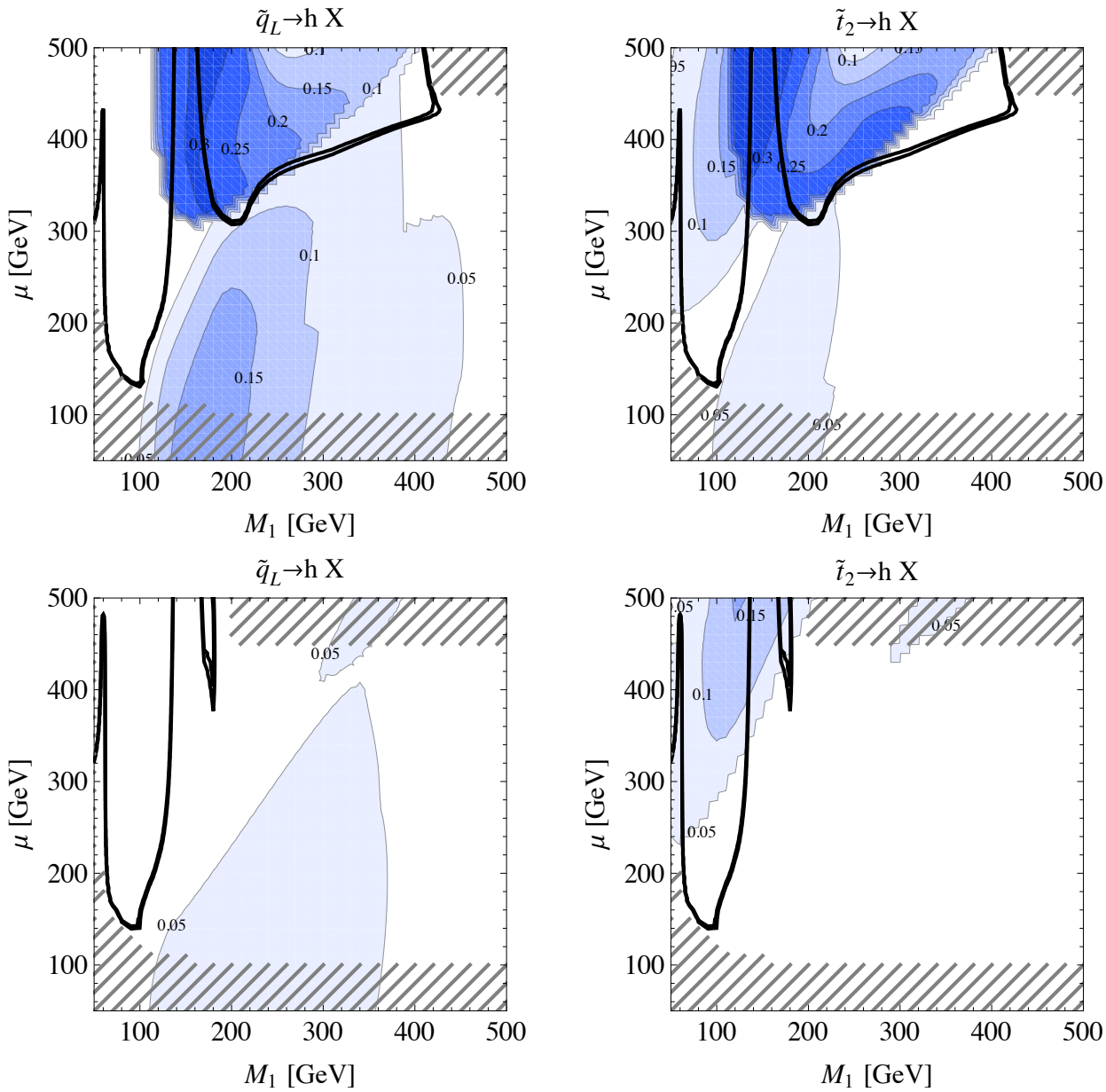
	σ[pb]	$\sigma_{\rm cut}$[pb]	σ_h[fb]	$\sigma_{\rm boosted}$[fb]
(I)	0.092	0.019	2.7	1.1
(II)	0.042	0.015	5.1	1.1
(III)	0.113	0.030	10	3.6
(IV)	0.106	0.029	8.2	3.3

Squark Masses 1 TeV

	σ[pb]	$\sigma_{\rm cut}$[pb]	σ_h[fb]	$\sigma_{\rm boosted}$[fb]
(I)	0.23	0.086	11	3.0
(II)	0.18	0.063	17	2.0
(III)	0.31	0.142	36	11
(IV)	0.36	0.169	45	14

Squark Masses 800 GeV

Regions of parameter space consistent with Neutralino relic density: Light CP-odd boson and light Sleptons



$$M_2 = 2M_1$$
$$m_{\tilde{q}} \simeq 1\ \text{TeV}$$
$$M_{\tilde{g}} \simeq 6M_1$$

Upper Row : $m_{\tilde{l}} = 400$ GeV
Lower Row : $m_{\tilde{l}} = 200$ GeV

Clear degradation of Higgs signal for light sleptons

Gori, Schwaller, C.W.'11

Renormalization Group allows the obtention of couplings and masses at high energies. RG Invariants allow a direct connection between low and high energy quantities. Interestingly enough, there are 14 RGIs in the MSSM

Invariant	Symmetry	Dependence on Soft Masses
$D_{B_{13}}$	$B_1 - B_3$	$2(m^2_{\tilde{Q}_1} - m^2_{\tilde{Q}_3}) - m^2_{\tilde{u}_1} + m^2_{\tilde{u}_3} - m^2_{\tilde{d}_1} + m^2_{\tilde{d}_3}$
$D_{L_{13}}$	$L_1 - L_3$	$2(m^2_{\tilde{L}_1} - m^2_{\tilde{L}_3}) - m^2_{\tilde{e}_1} + m^2_{\tilde{e}_3}$
D_{χ_1}	χ_1	$3(3m^2_{\tilde{d}_1} - 2(m^2_{\tilde{Q}_1} - m^2_{\tilde{L}_1}) - m^2_{\tilde{u}_1}) - m^2_{\tilde{e}_1}$
$D_{Y_{13H}}$	$Y_1 - \frac{10}{13} Y_{3H}$	$m^2_{\tilde{Q}_1} - 2m^2_{\tilde{u}_1} + m^2_{\tilde{d}_1} - m^2_{\tilde{L}_1} + m^2_{\tilde{e}_1} - \frac{10}{13}$ (1<->3+H)
D_Z	Z	$3(m^2_{\tilde{d}_3} - m^2_{\tilde{d}_1}) + 2(m^2_{\tilde{L}_3} - m^2_{H_d})$
$I_{Y\alpha}$	Y	$(m^2_{H_u} - m^2_{H_d} + \sum_{gen}(m^2_{\tilde{Q}} - 2m^2_{\tilde{u}} + m^2_{\tilde{d}} - m^2_{\tilde{L}} + m^2_{\tilde{e}}))/g_1^2$
I_{B_r}		M_r/g_r^2
I_{M_1}		$M_1^2 - \frac{33}{8}(m^2_{\tilde{d}_1} - m^2_{\tilde{u}_1} - m^2_{\tilde{e}_1})$
I_{M_2}		$M_2^2 + \frac{1}{24}(9(m^2_{\tilde{d}_1} - m^2_{\tilde{u}_1}) + 16m^2_{\tilde{L}_1} - m^2_{\tilde{e}_1})$
I_{M_3}		$M_3^2 - \frac{3}{16}(5m^2_{\tilde{d}_1} + m^2_{\tilde{u}_1} - m^2_{\tilde{e}_1})$
I_{g_2}		$1/g_1^2 - 33/(5g_2^2)$
I_{g_3}		$1/g_1^2 + 33/(15g_3^2)$

M. Carena, PD, N. Shah, C. Wagner 2010

Applications of RGI's

- For Most general flavor independent models, establish two some rules and a one to one relationship between RGIs and parameters of the model, apart from the messenger scale

- For General Gauge Mediation, additional sum rules are established, plus a possibility of determining the messenger scale.

- For minimal models, several rum rules are established, that allow to establish spectrum predictions from a limited number of observables.

- Two loop effects, which break the rules, can be taken into account in a simple way. Efficiency of method strongly dependent on experimental uncertainties.

M. Carena, P. Draper, N. Shah, '10 & '11

Conclusions

- Search for Higgs bosons in the low mass region will be very challenging, both at the Tevatron as well as the LHC
- If expected efficiency improvements are implemented, Tevatron can probe the whole region consistent with SM precision electroweak measurements by data at the end of this year.
- Intermediate mass region around 130 GeV remains, however, challenging, and this translates to other well motivated models like the MSSM
- At an early LHC, and moderate values of the CP-odd Higgs mass, reach in relevant channels is affected by increase in bottom width. Discovery potential increased in large CP-odd Higgs mass region.
- Complementarity between searches at colliders calls for eventual combination of Tevatron-LHC results at the end of 2012.
- Large proportion of Higgs events is there if sleptons are above neutralino N_2
- RGI Invariant very efficient in establishing an infrared-ultraviolet connection in the MSSM

Backup Slides

Efficiency Improvements in the low Mass Region

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.

Higgs Couplings to fermions

- At tree level, only one of the Higgs doublets couples to down-quarks and leptons, and the other couples to up quarks

$$\mathcal{L} = \bar{\Psi}_L^i \left(h_{d,ij} H_1 d_R + h_{u,ij} H_2 u_R \right) + h.c.$$

- Since the up and down quark sectors are diagonalized independently, the interactions remain flavor diagonal.

$$\bar{d}_L \frac{\hat{m}_d}{v} \left(h + \tan\beta \left(H + iA \right) \right) d_R + h.c.$$

- h is SM-like, while H and A have enhanced couplings to down quarks

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.

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

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

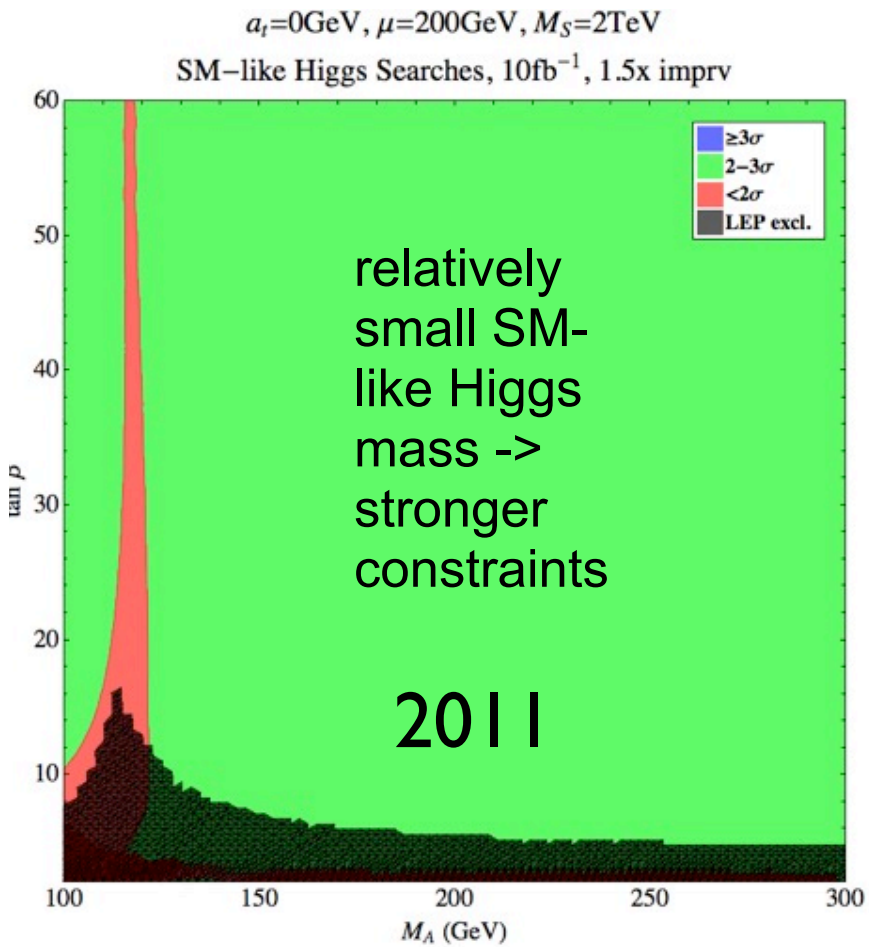
- There may be a strong dependence on the parameters in the bb search channel, which is strongly reduced in the tau tau mode.

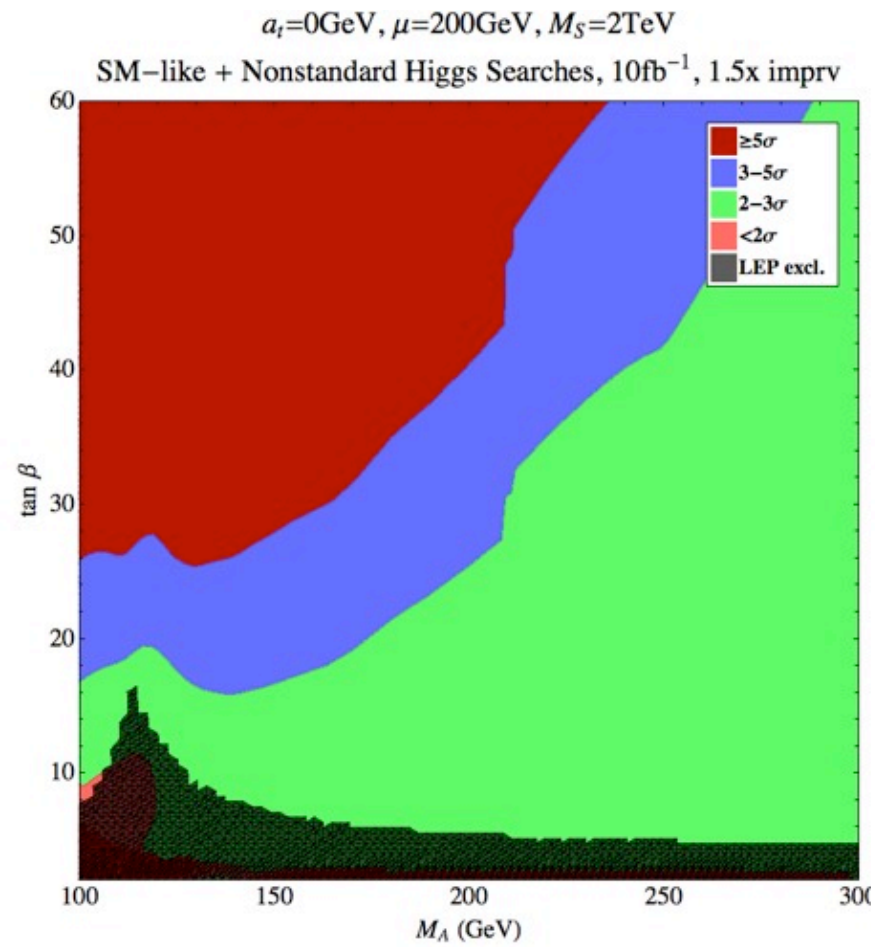
Validity of this approximation confirmed by NLO computation by
D. North and M. Spira, arXiv:0808.0087
Further work by Mhulleitner, Rzehak and Spira, 0812.3815

Minimal Mixing Scenario : Standard and non-standard Higgs search channels.

$m_h \simeq 115\text{GeV}$

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

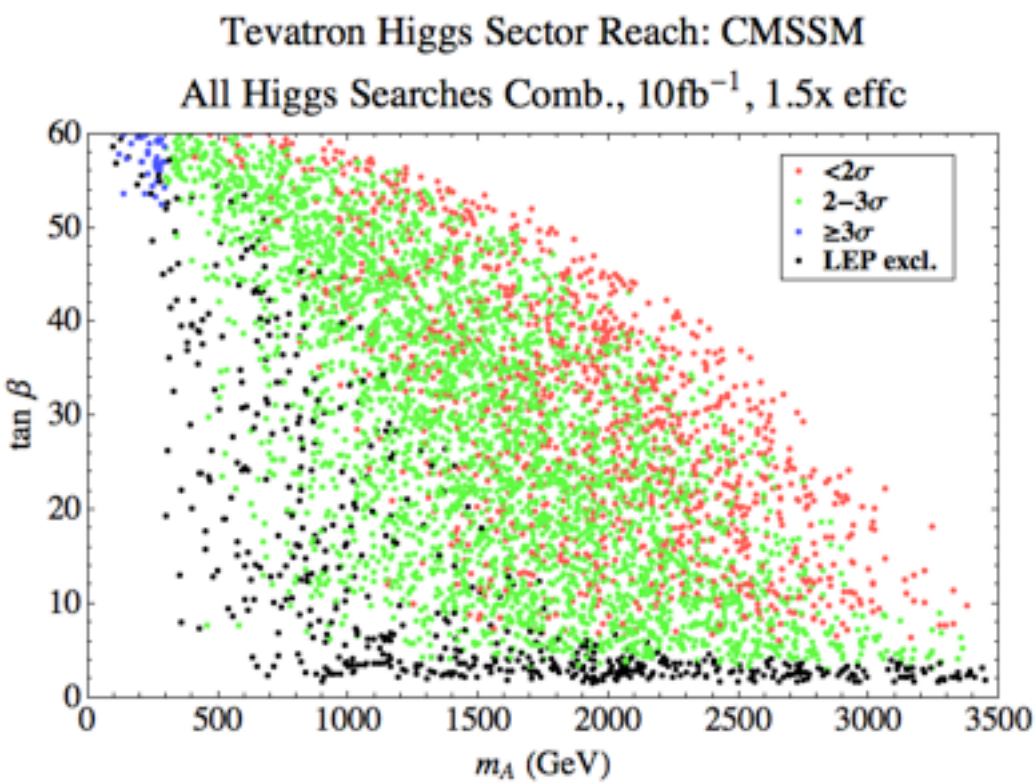


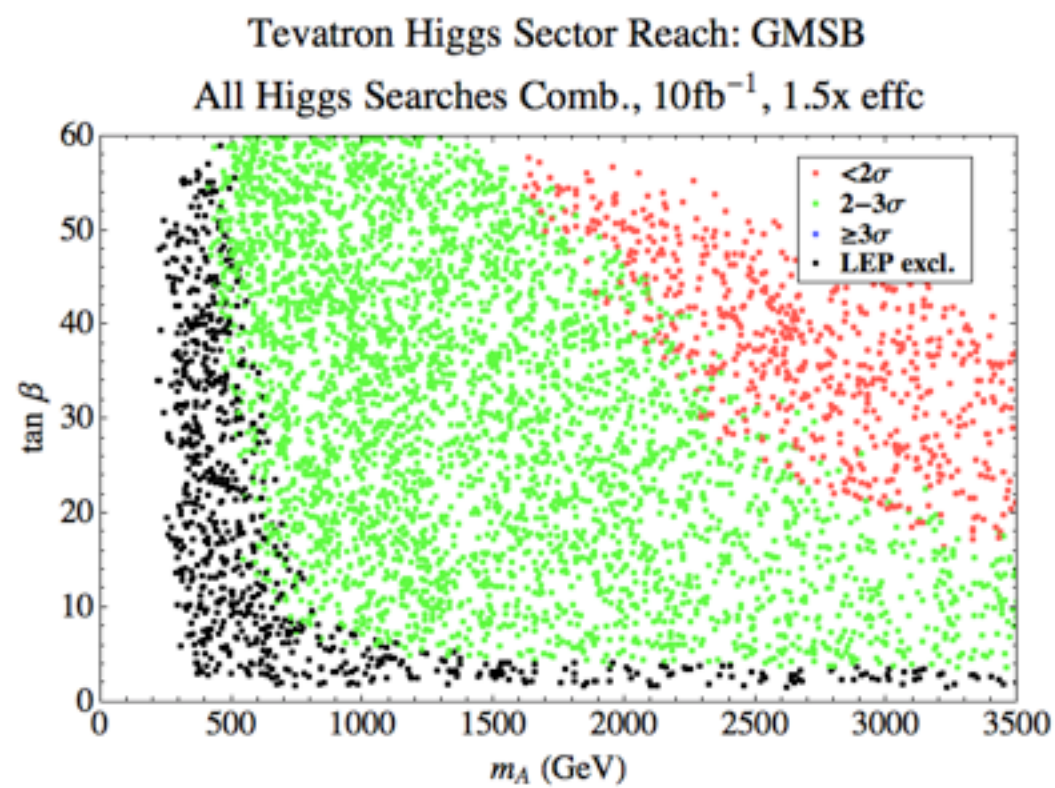


Even with only SM channels and 2011 run, more than 2 sigma sensitivity is achieved in most parameter space. Combination with non standard channels enhances sensitivity considerably.

CMSSM and MGM at the Tevatron

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





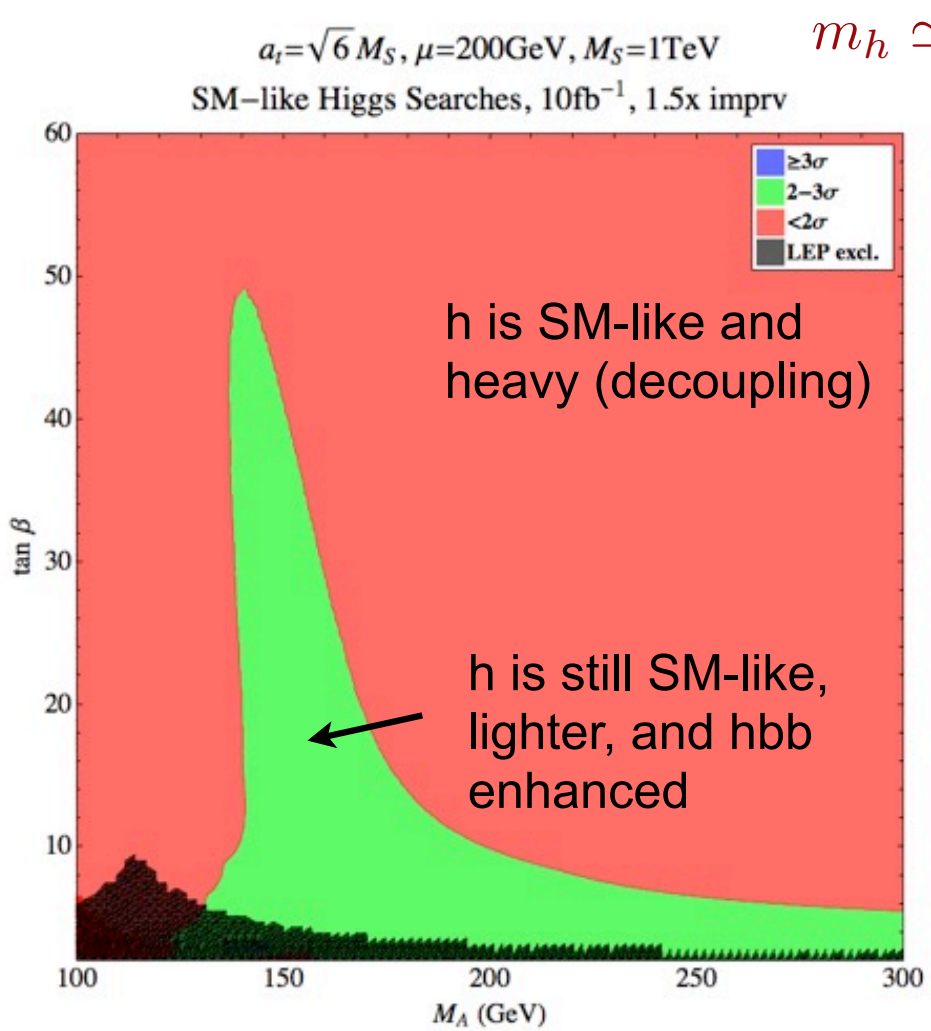
In both cases, the Tevatron could probe most of the models with squarks at the LHC reach and values of the CP-odd mass below 1 TeV.

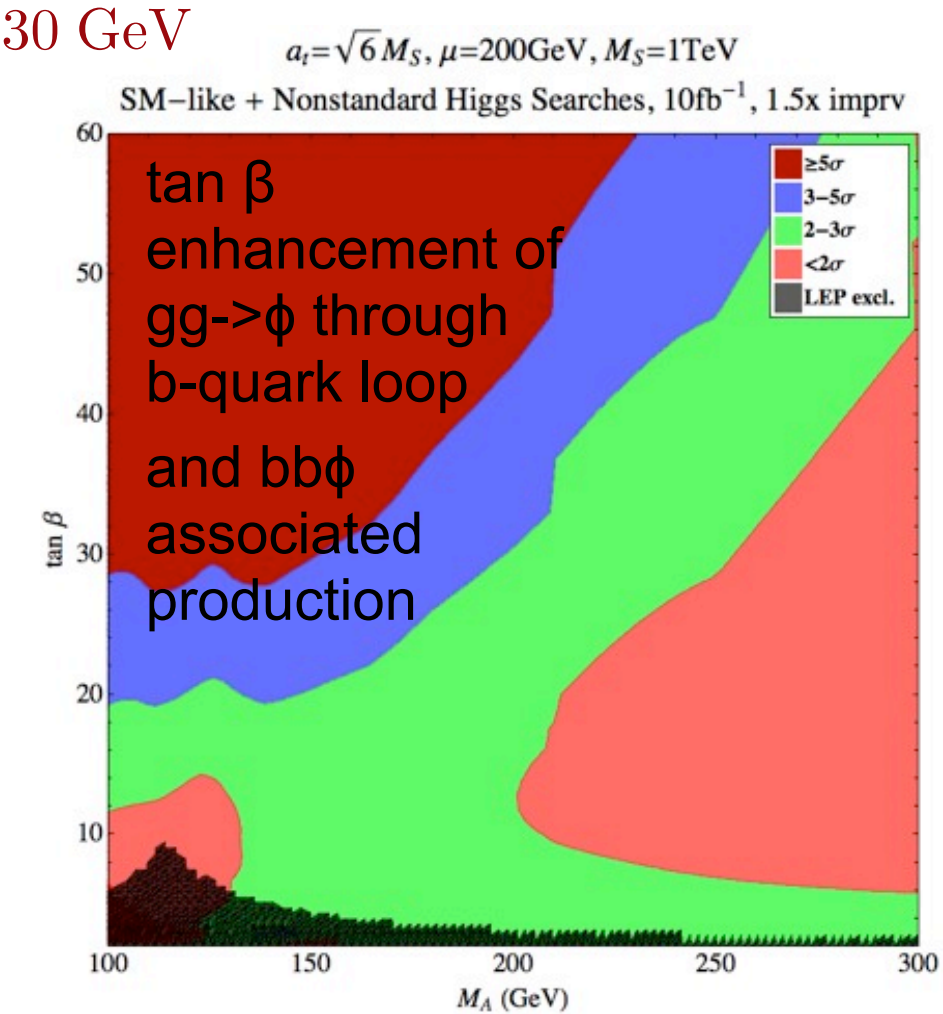
$$\mu^2 \simeq -M_Z^2/2 - m_{H_u}^2$$
$$m_A^2 \simeq -M_Z^2 + (m_{H_d}^2 - m_{H_u}^2)$$

$$m_Q^2 \simeq m_0^2\left(1 - y_t^2/2\right) + 5.5 M_{1/2}^2$$
$$m_U^2 \simeq m_0^2\left(1 - y_t^2\right) + 5 M_{1/2}^2$$

Combination with Non-Standard Higgs channels

$m_h \simeq 130$ GeV

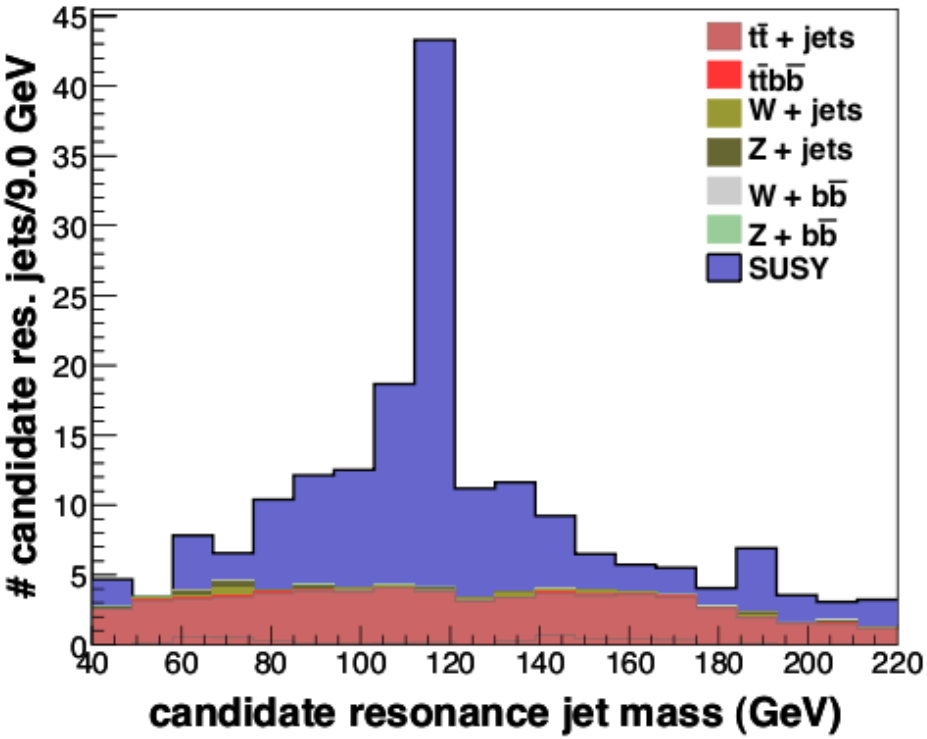




End of 2011

Maximal Mixing Scenario : Red region is barely below 2 sigma. Combination of non-SM channels become significant to probe large regions of parameter space.

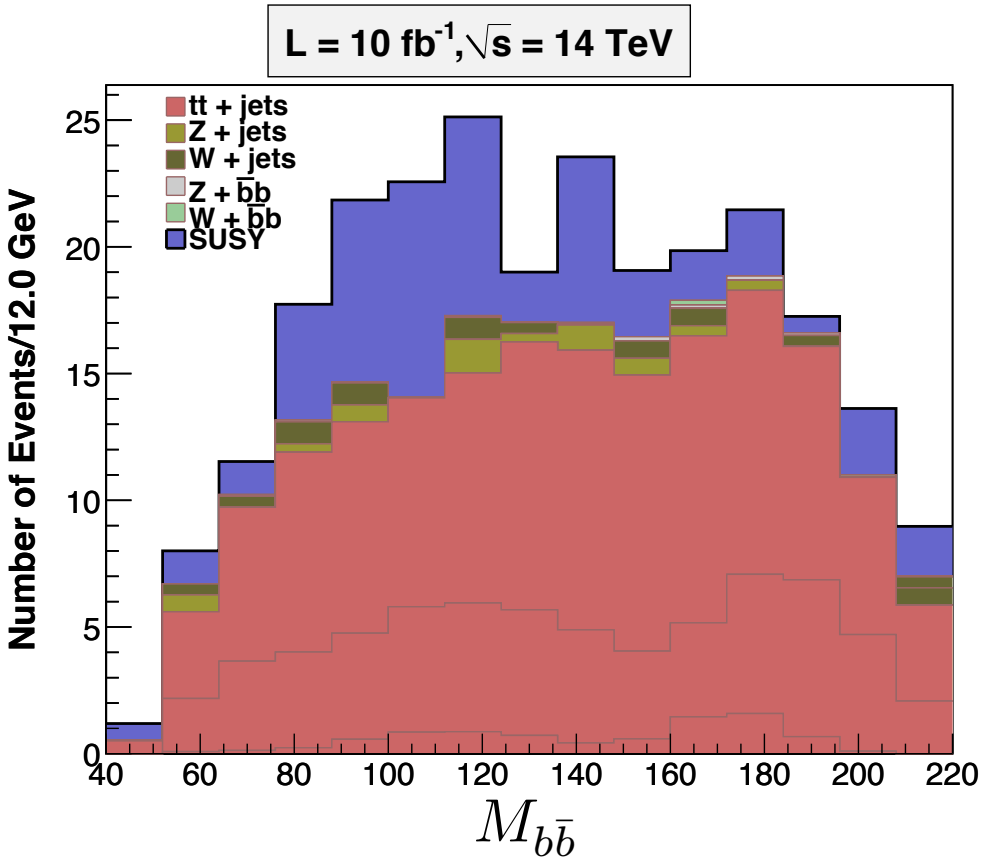
Comparison*: with substructure analysis vs. with PGS



$H_T > 1$ TeV, $\not{E}_T > 300$ GeV

3^+ high-p_T jets, no leptons

1 candidate Higgs



$H_T > 1$ TeV, $\not{E}_T > 300$ GeV

4^+ high $- p_T$ jets, no leptons

2^+ b-tags

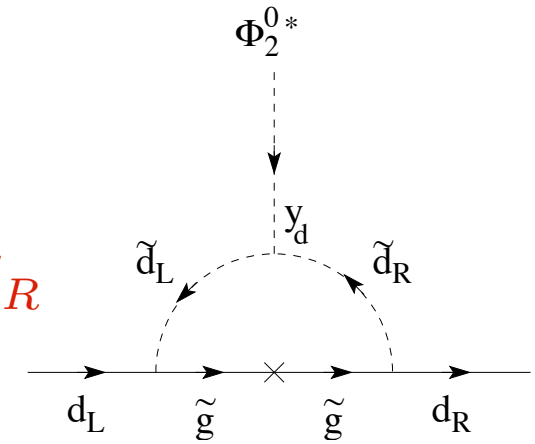
(Stolen from A. Martin slides)

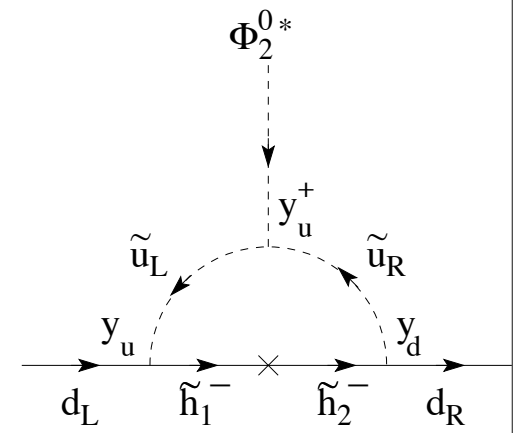
*not totally fair

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

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

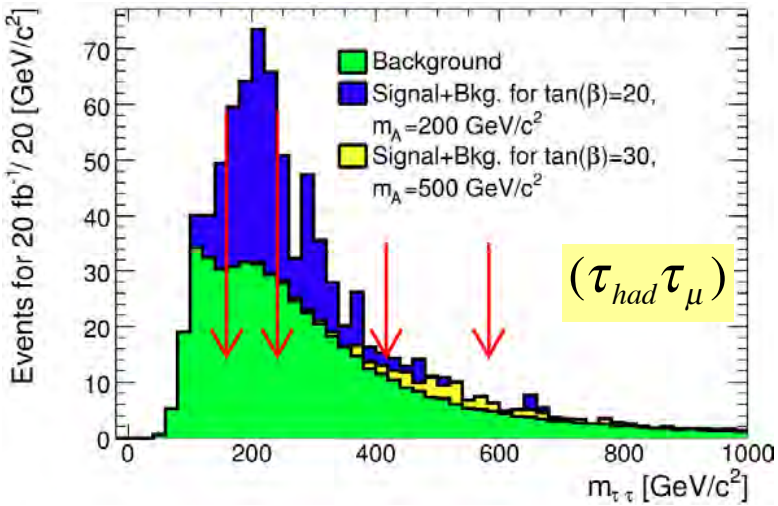
$$\boxed{\tan\beta = \frac{v_2}{v_1}}$$

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

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

Non-Standard LHC Channels may also help

MSSM Higgs In $pp \to bb\Phi$; $\Phi \to \tau^+ \tau^-$



– – Isolated pairs of $(\tau_{had}\tau_\mu),(\tau_{had}\tau_e),(\tau_\mu\tau_e)$

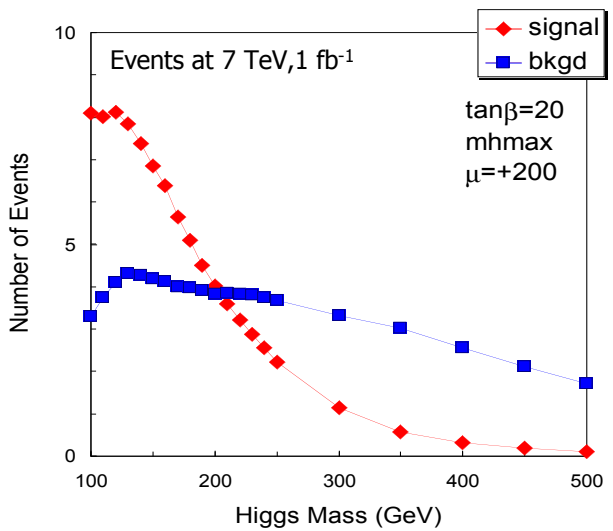
– – With MET, 1 tagged bjet, veto extra jets

– – Build $\tau\tau$-mass using collinear approx

– – Count events in sliding $\tau\tau$-mass window

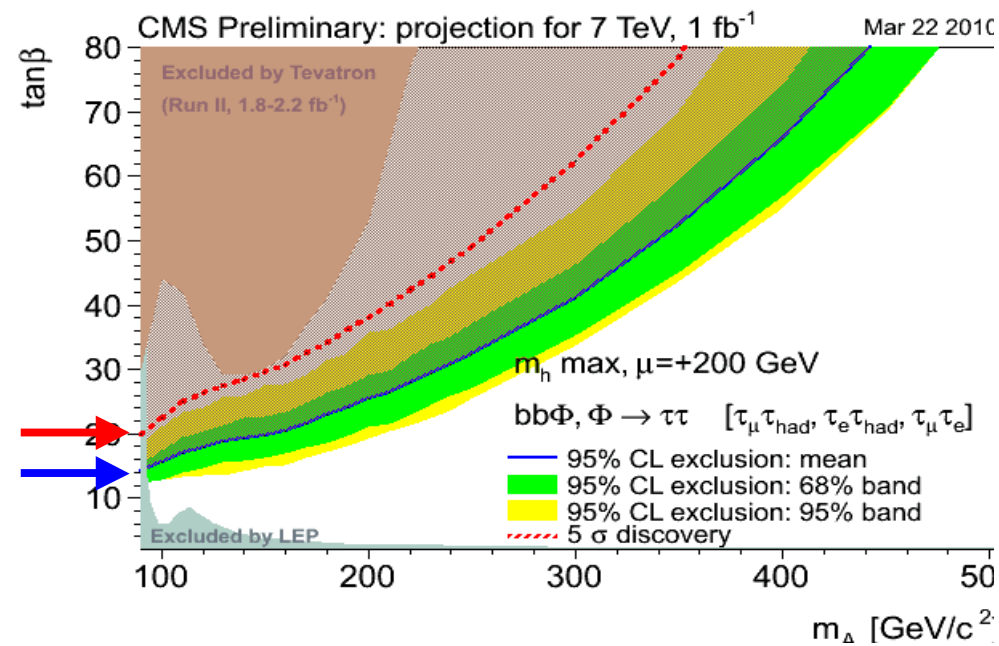
– – Dominant backgrounds: $t\bar{t}$, $Z+b\bar{b}$ & $Z+c\bar{c}$

-- assessed from data



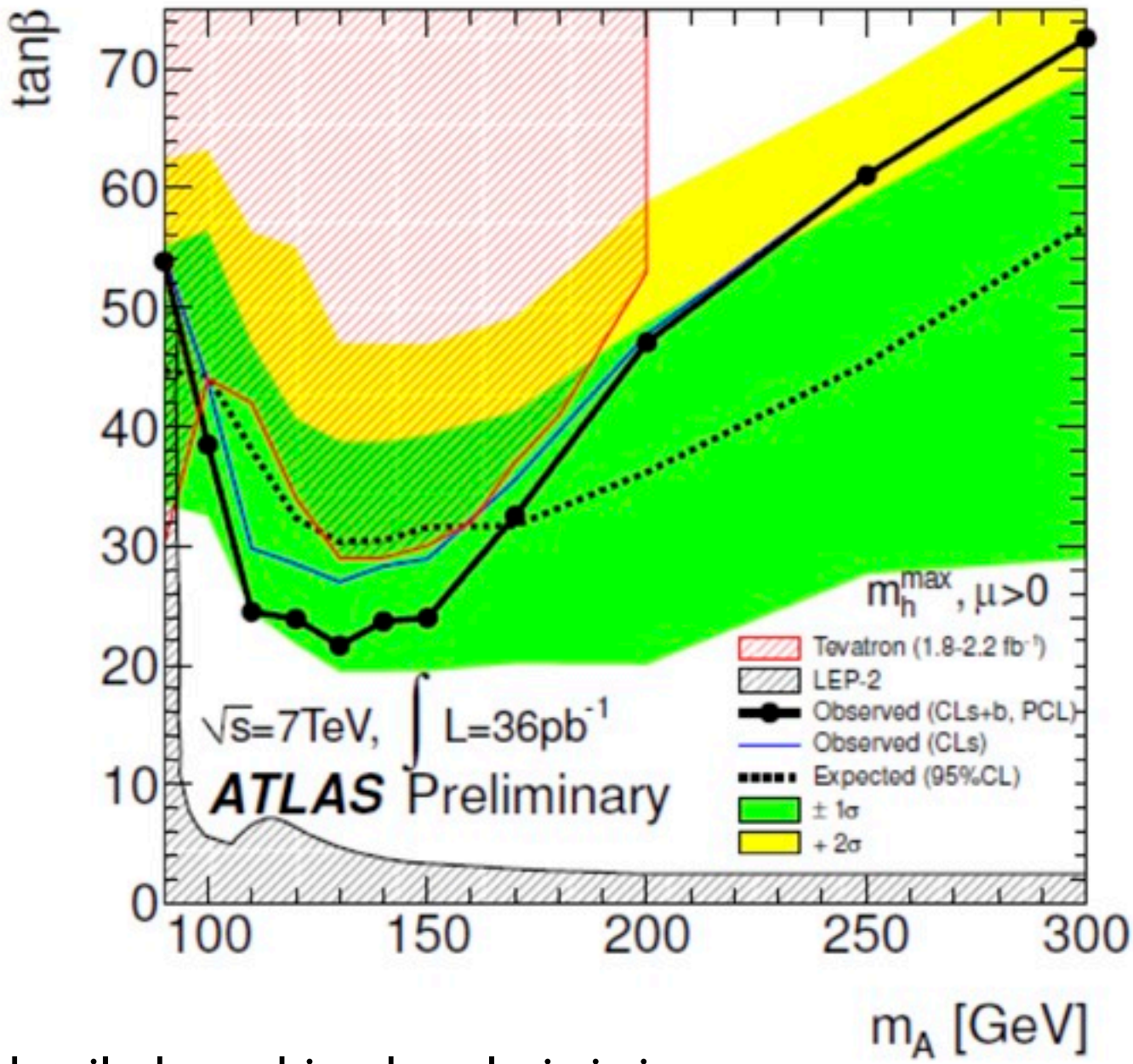
discover

exclude



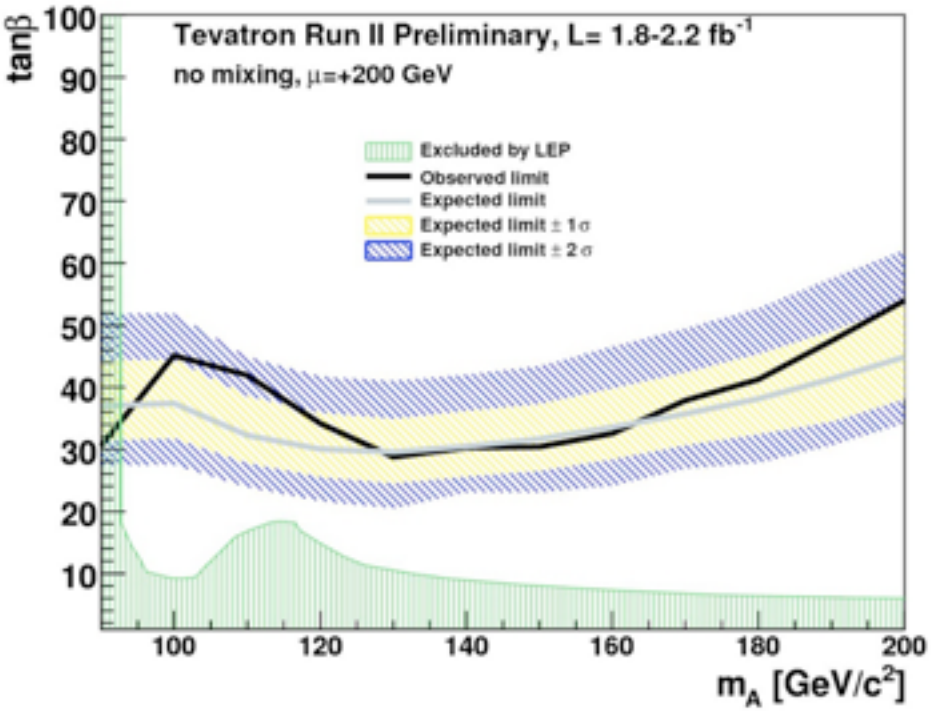
V. Sharma '10

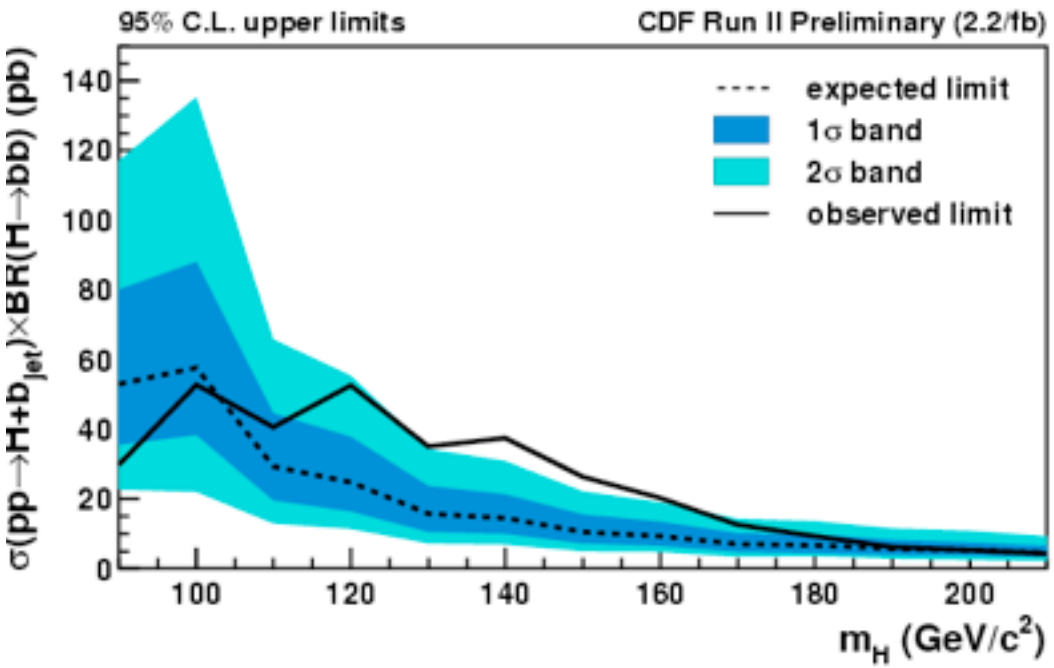
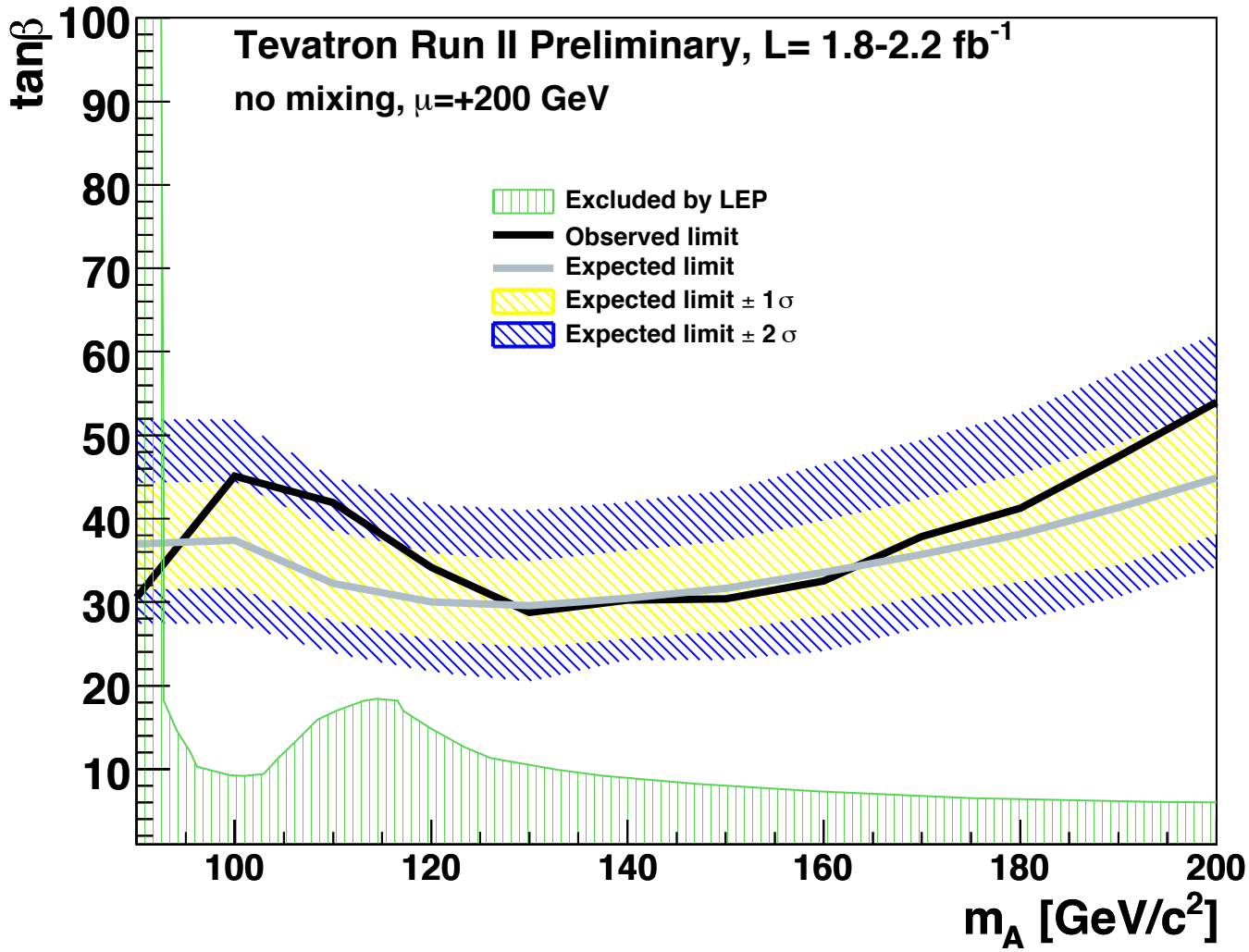
And they are already providing meaningful limits



A detailed combined analysis is in progress

Searches for non-standard Higgs bosons at the Tevatron





Combination of CDF and D0 Non-Standard Higgs Searches