

Impact of new PDF sets on searches at the LHC

C.-P. Yuan

Michigan State University

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Impact of new CTEQ6.5 (M,S,C) PDFs to

- SM processes: W , Z , top, Higgs
- hH^+ and AH^+ productions in MSSM (Light Higgs Scenario)
- s-channel H^+ production in TopColor and MSSM

Impact of new CTEQ6.5 (M,S,C) PDFs on Collider Phenomenology

(from better treatment of heavy quark mass effects)

- New minimal global analysis:
CTEQ6.5M + uncertainties (hep-ph/0611254)
- 1st focused study of *strange* distributions:
CTEQ6.5S (hep-ph/0702268)
- 1st study of *charm* distributions (intrinsic charm?):
CTEQ6.5C (hep-ph/0701220)

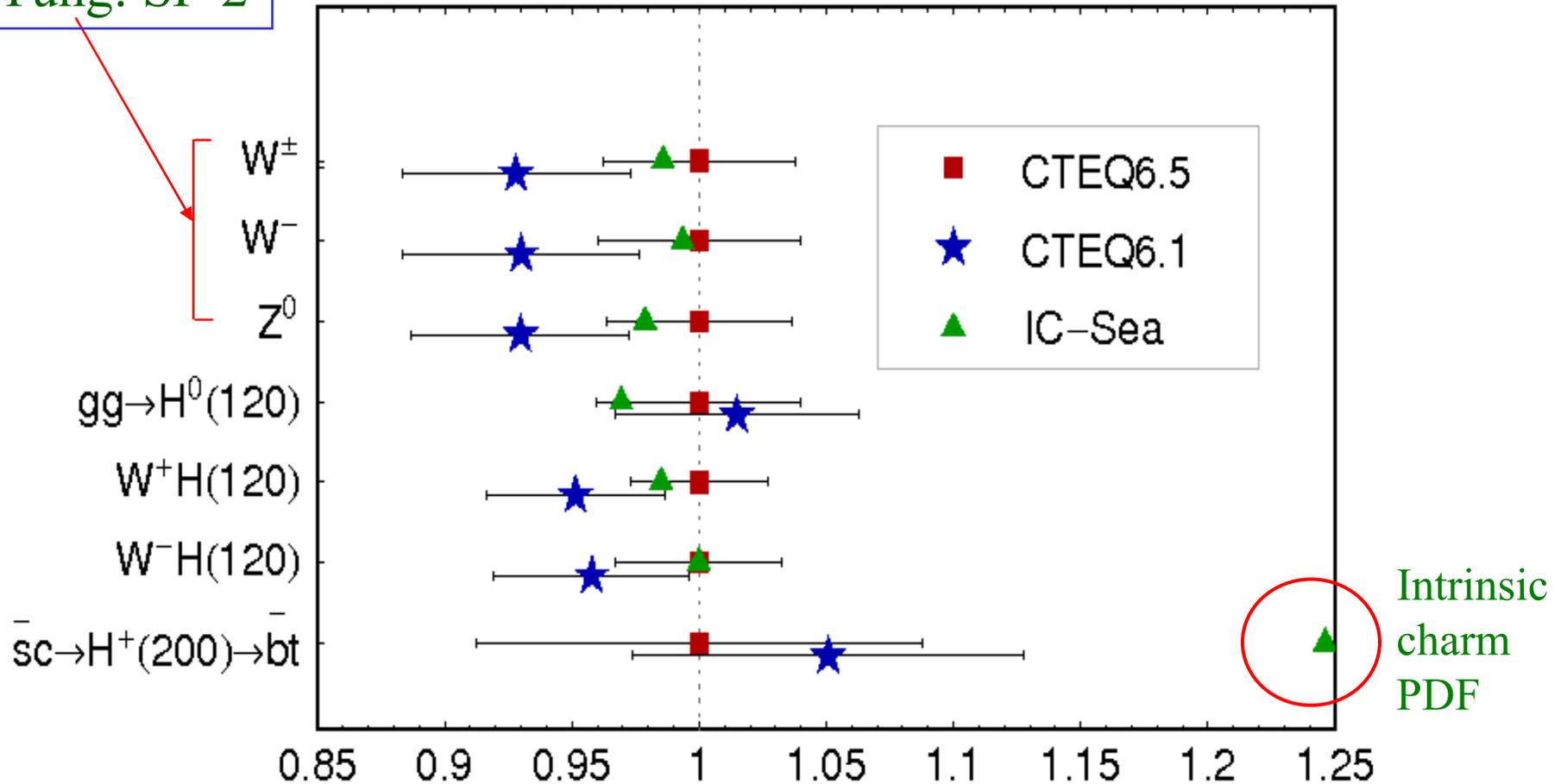
In collaboration with

Tung, Lai, Nadolsky, Cao, Huston, Pumplin, Stump
(Argonne, UC Riverside, Michigan State, U Washington)

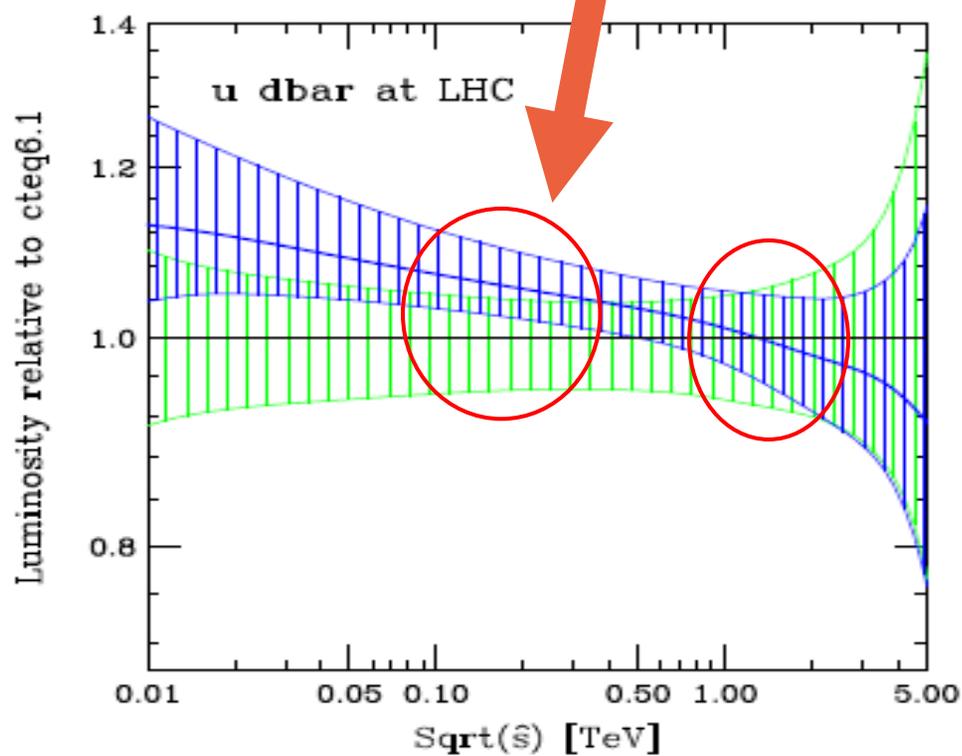
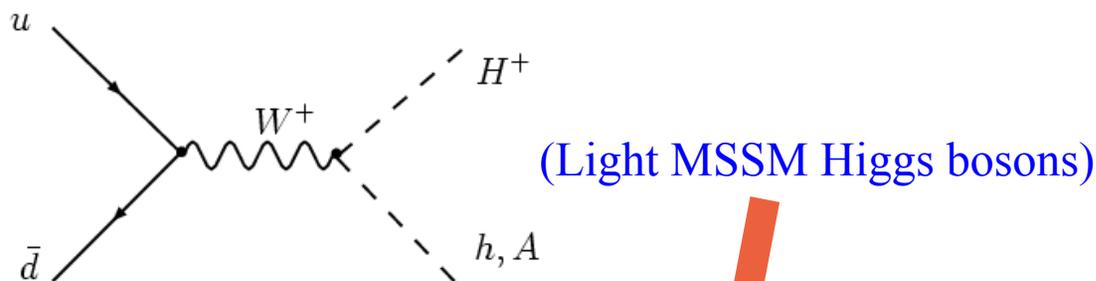
Impact of CTEQ6.5M,S,C PDF's on σ_{tot} 's at LHC

Tung: SF-2

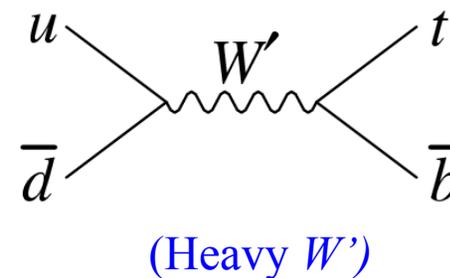
$\sigma \pm \delta\sigma_{\text{PDF}}$ in units of $\sigma(\text{CTEQ65M})$
LHC, NLO, PRELIMINARY



Impact of new CTEQ6.5M PDFs on LHC Phenomenology



Parton Luminosities:
 Blue: Cteq6.5 err. band
 Green: Cteq6.1 err. band



hH^+ and AH^+ productions in **MSSM**
(Light Higgs Scenario)

Light Higgs boson with mass $M_h < M_Z$
is still allowed by LEP data

→ How can LHC/Tevatron test it?

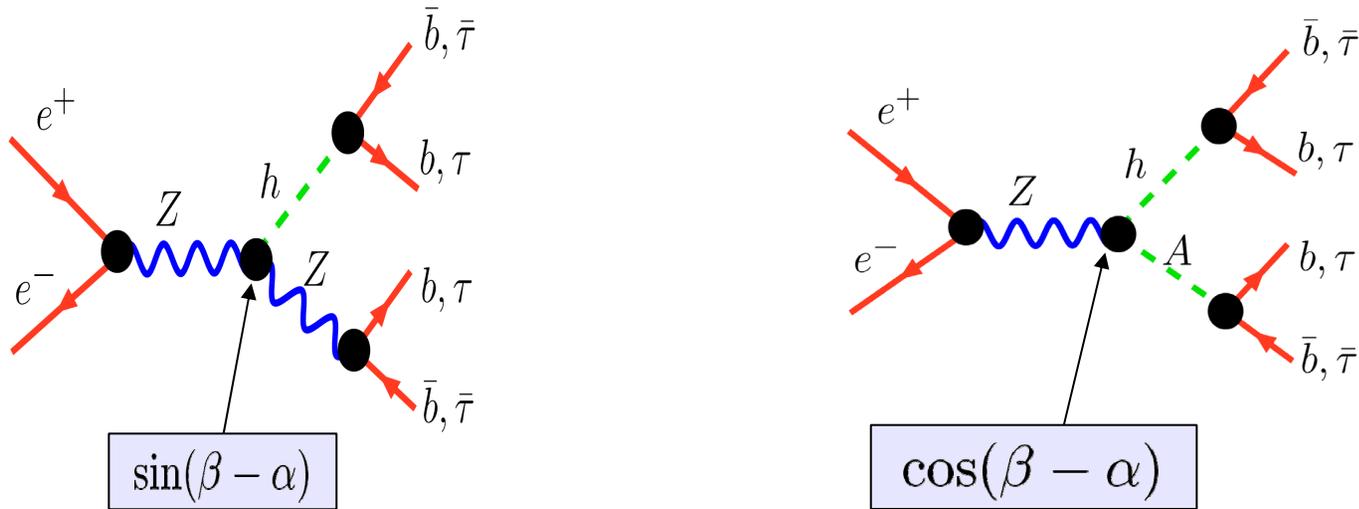
hep-ph/0311083

hep-ph/0609079

In collaboration with

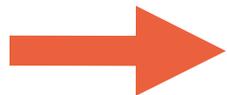
Cao, Kanemura, Belyaev, Nomura, Tobe
(Michigan State)

Relax LEP constraints on MSSM Higgs bosons



$$g_{ZZh}^2 + g_{ZA h}^2 = 1$$

Zh and *Ah* channels are complementary.



Reduce $\sin(\beta - \alpha)$ and $Br(h, A \rightarrow b\bar{b})$

hH^+ and AH^+ productions in MSSM
(constrained by LEP, $\Delta\rho$, ...)

- $M_h < M_Z$ is still allowed by LEP data

➤ Decoupling limit: M_A large (> 120 GeV)

$$\sin(\beta - \alpha) \rightarrow 1 \quad \Rightarrow \quad M_h > M_Z$$

(large radiative corrections from top and stop loops)

➤ Non-decoupling limit: M_A small (< 120 GeV)

$$\sin(\beta - \alpha) \ll 1 \quad \Rightarrow \quad M_h < M_Z$$

(large radiative corrections from top and stop loops)

⇒ Light Higgs Boson

Light Higgs Boson in MSSM

Non-decoupling limit \oplus Non-universal radiative corrections

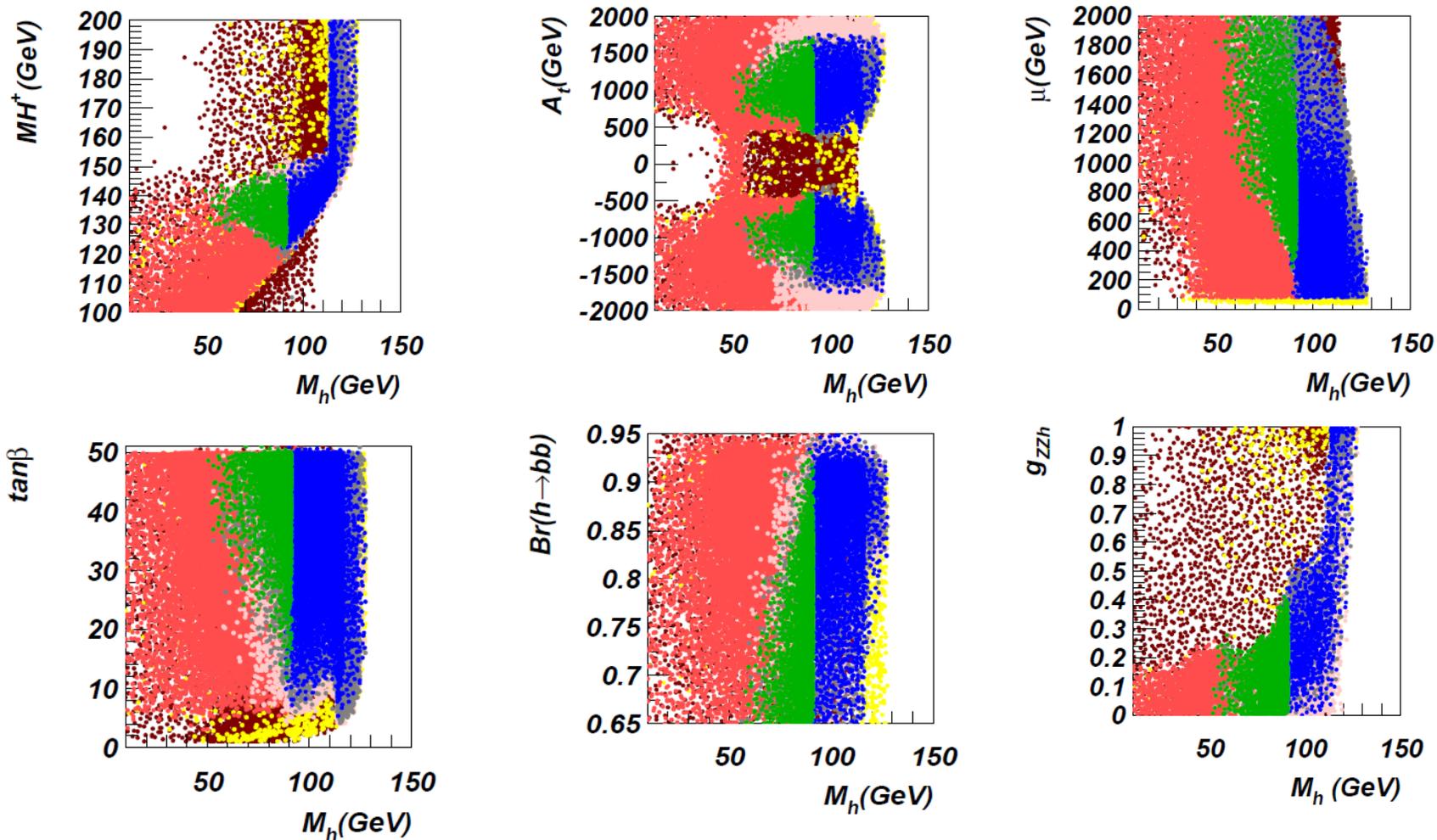
$$\Rightarrow \begin{array}{ll} Br(h \rightarrow b\bar{b}) & \text{reduced} \\ Br(h \rightarrow \tau\bar{\tau}) & \text{enhanced} \end{array}$$

- scanned with **CPsuperH** (Lee,Pilaftsis,Carena,Choi,Drees,Ellis,Wagner)

hep-ph/0307377

parameter	lower limit	upper limit	
$\tan \beta$	1.1	50	LEP II $Z\mathcal{H}$ and $A\mathcal{H}$ constraint $\mathcal{H} = (h, H)$
M_{H^\pm}	100	200	$g_{ZZ\mathcal{H}}^2 \times Br(\mathcal{H} \rightarrow b\bar{b}) < F_{Z\mathcal{H}}(M_{\mathcal{H}})$
μ	-2000	2000	$g_{ZZh}^2 \times Br(A \rightarrow b\bar{b}) \times Br(H \rightarrow b\bar{b}) < F_{Ah}$
M_1	50	500	$g_{ZZH}^2 \times Br(A \rightarrow b\bar{b}) \times Br(h \rightarrow b\bar{b}) < F_{AH}$
M_2	50	500	$M_{\chi_1^\pm} > 100, M_{\tilde{t}_1} > 100, M_3 > 270 \text{ GeV}$
M_3	50	1000	Color breaking constraints
A_t	-2000	2000	$A_t^2 < 3(M_{Q3}^2 + M_{U3}^2 + \mu^2 + M_{H_2}^2)$
M_{Q3}	300	700	$\Delta\rho_{SUSY} < 2 \times 10^{-3}$
			$b \rightarrow s\gamma$ SUSY constraint:
			$ \Delta Br(b \rightarrow s\gamma) < 1 \times 10^{-4}$

Scan Results (Green: M_h is below M_Z)



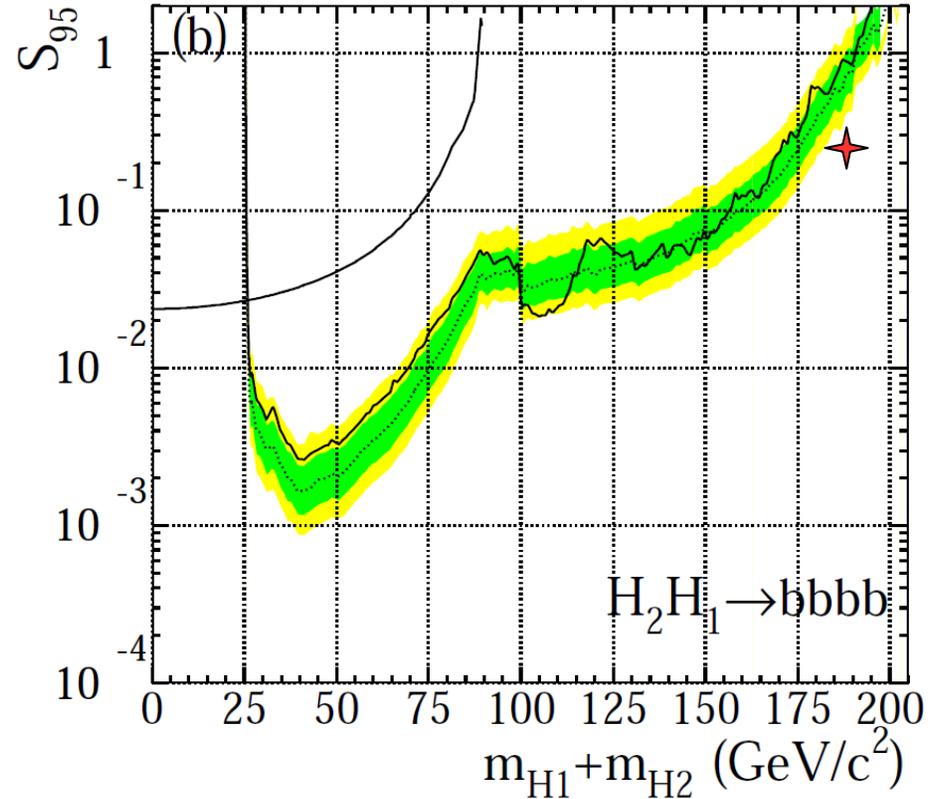
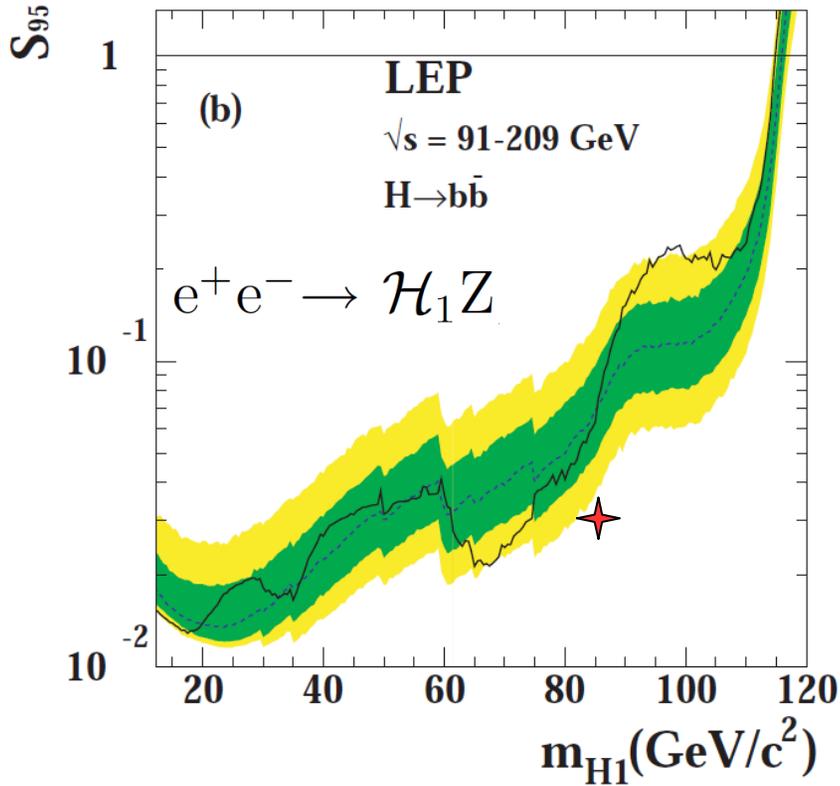
excluded by: ■ LEP2 Zh search ■ LEP2 Ah search ■ LEP2/TEV SUSY search

■ the color breaking constraint

allowed: ■ $M_h < M_Z$ ■ $M_h > M_Z$

(CP conserving case)

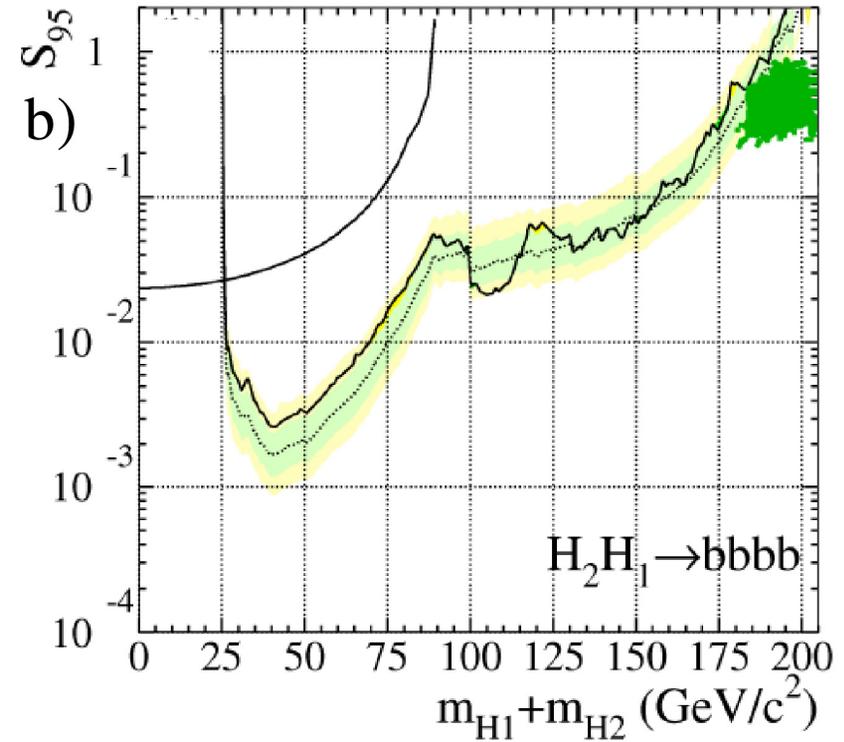
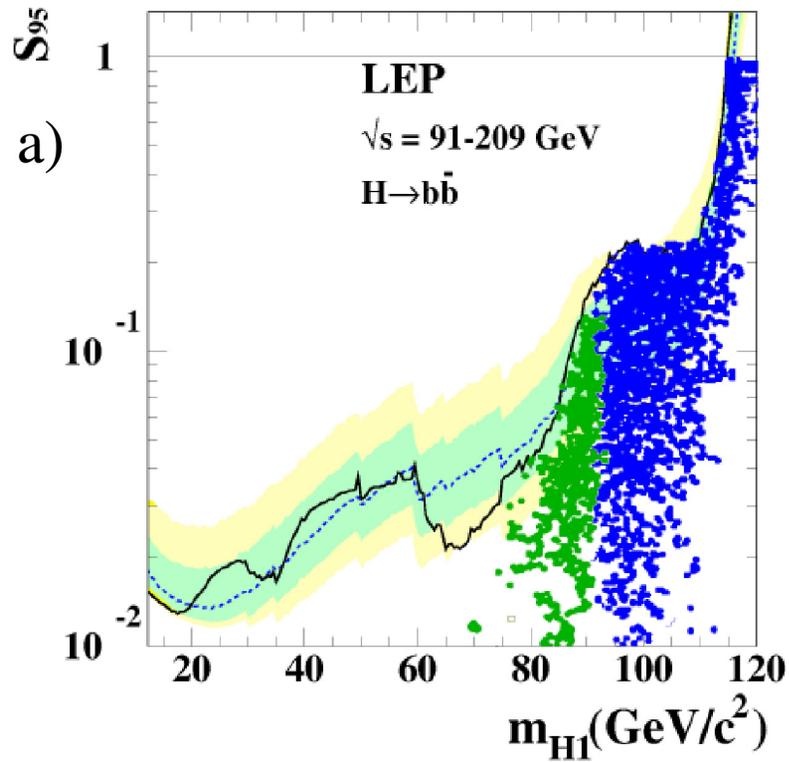
The LHS Sample Point (CP conserving case)



$\tan \beta$	M_H^+	μ	A_t	M_1/M_2	M_3	M_Q
40	130	600	600	100/200	300	300

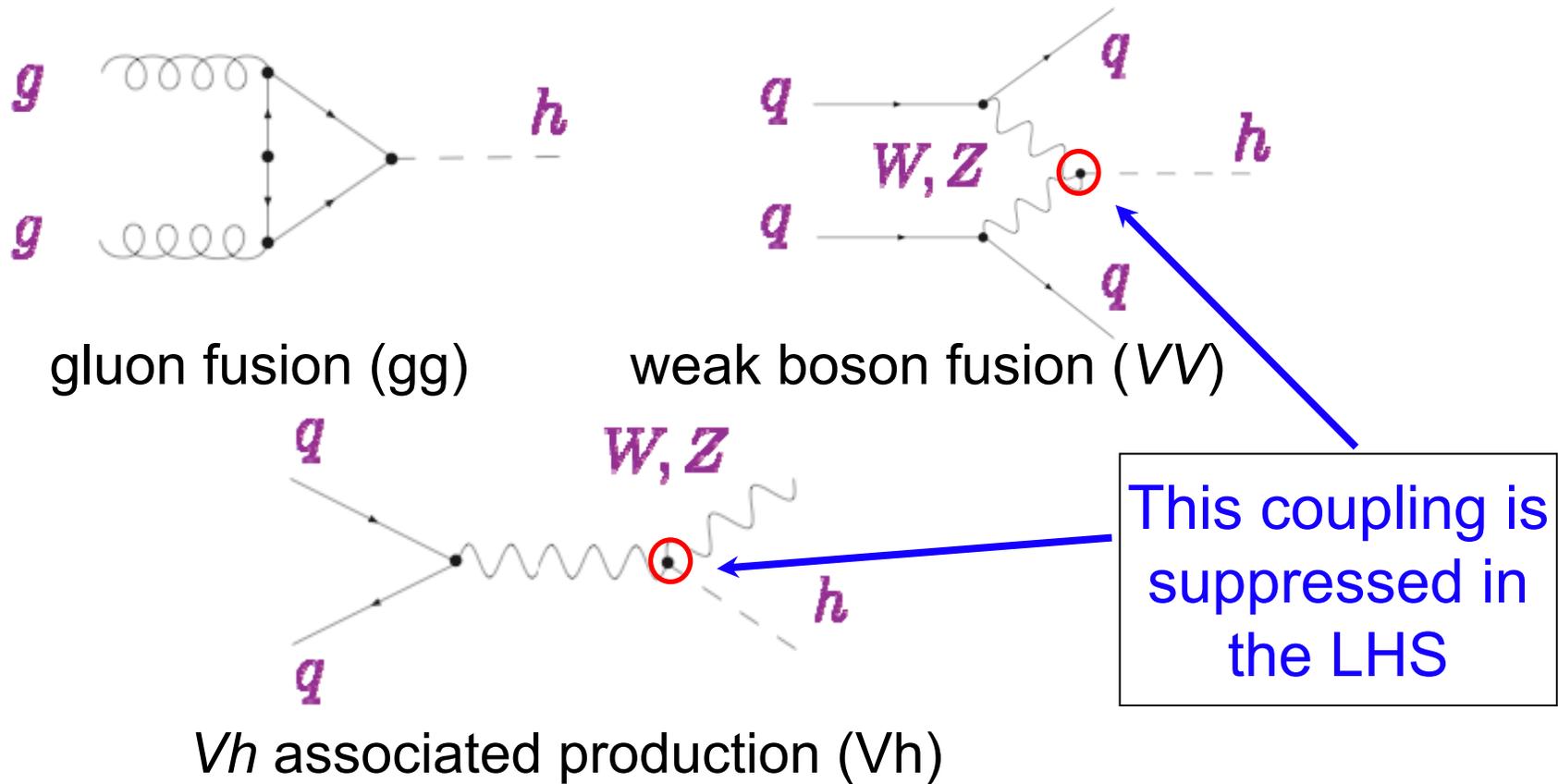
$M_h/M_A/M_H = 84/101/120 \text{ GeV}$
 $Br(h/A/H \rightarrow b\bar{b}) = 0.71/0.70/0.62$
 $g_{ZZh}^2 = 0.05, g_{ZZH}^2 = 0.94, M_{\chi_1^+} = 196 \text{ GeV}, M_{\tilde{t}_1} = 138 \text{ GeV}$
 $\Delta\rho = 0.9 \times 10^{-3}, Br(b \rightarrow s\gamma) = 2.9 \times 10^{-4}$
 $\sigma_{Zh}/\sigma_{Zh}^{exp} = 0.04, \sigma_{Ah}/\sigma_{Ah}^{exp} = 0.4$

LHS parameter space versus LEP2 constraints



Green: M_h is below M_Z

Higgs Production in LHS

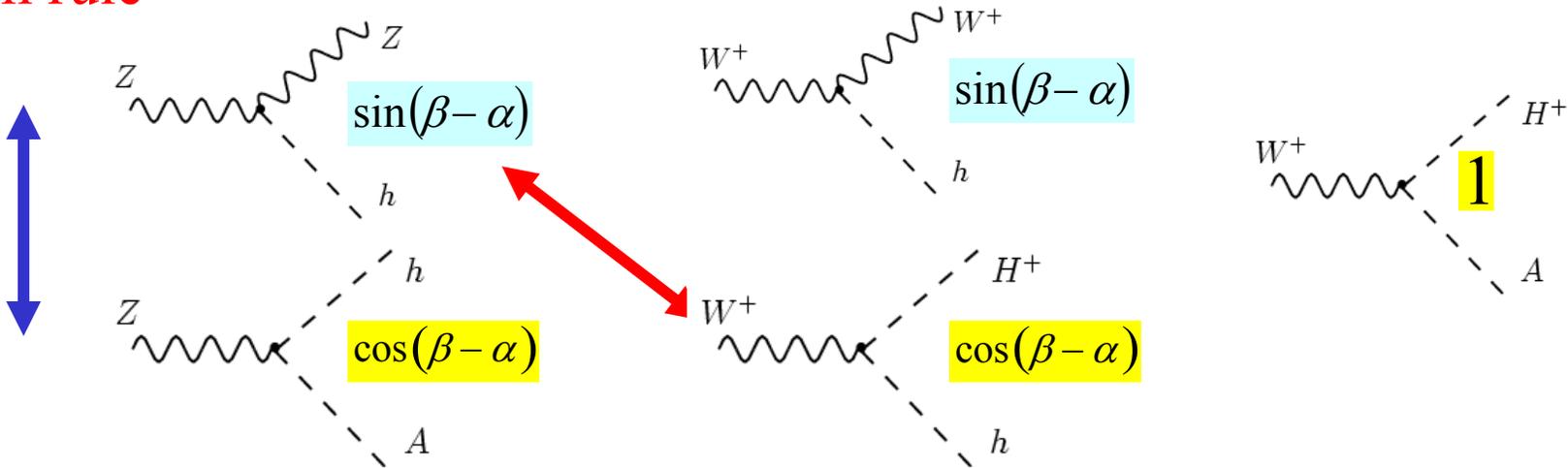


$Br(h \rightarrow \gamma \gamma)$ is suppressed by orders of magnitude.

➔ How to test the LHS scenario at the LHC?

LHC (and Tevatron) can test the LHS scenario

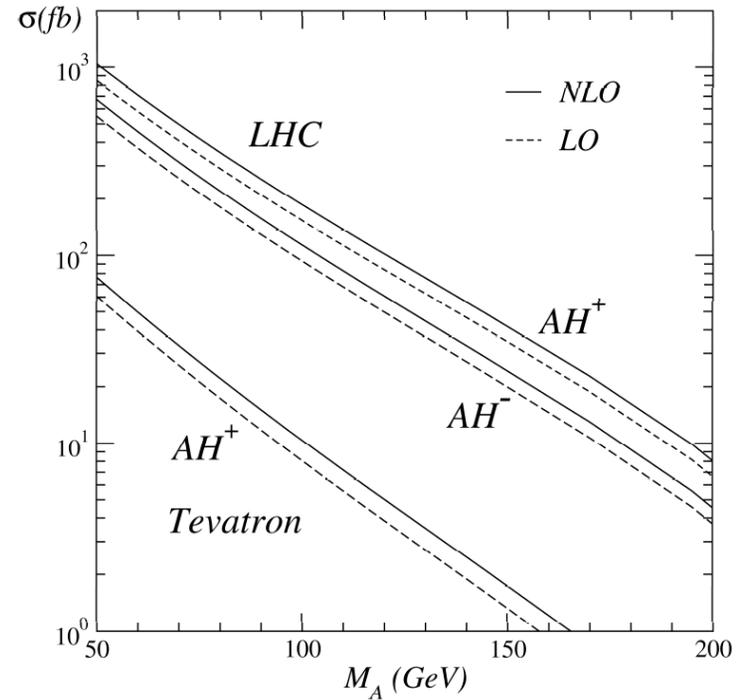
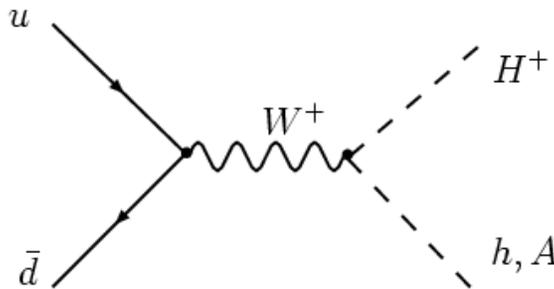
Sum rule



- small $\sin(\beta - \alpha)$

→ large $\cos(\beta - \alpha)$

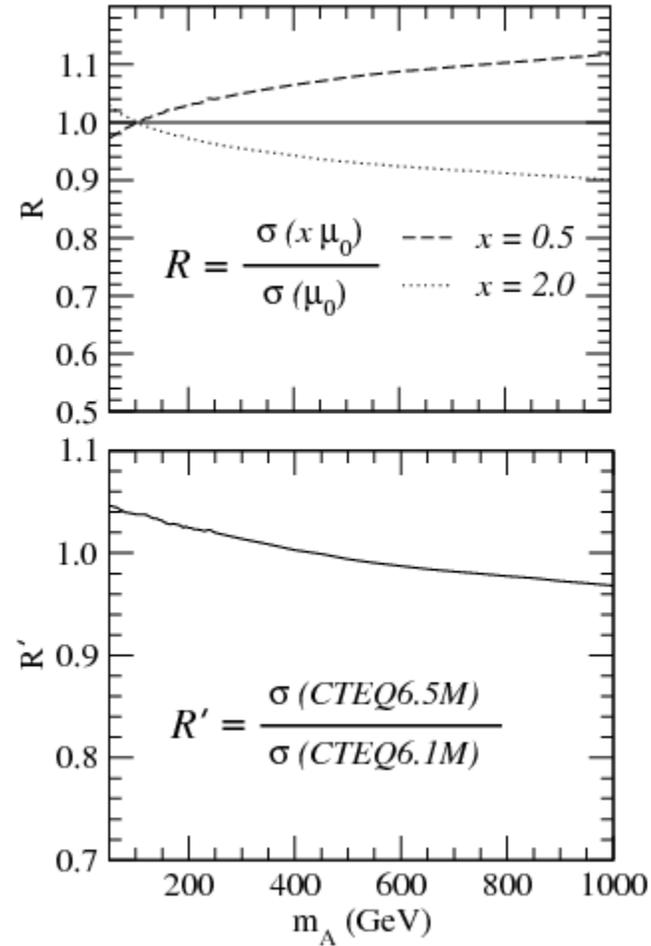
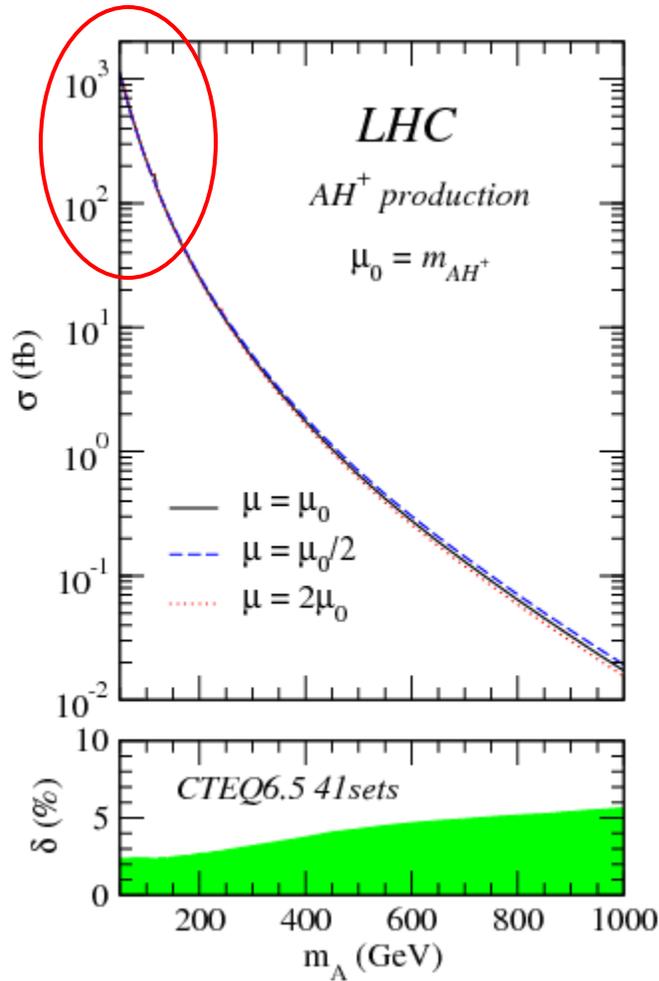
- large



Impact of new CTEQ6.5M PDFs

AH^+ production in MSSM

LHS

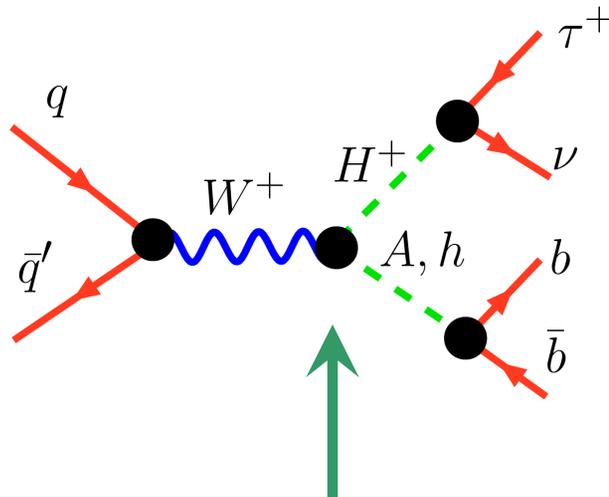


NLO QCD correction is about 20%.

hep-ph/0311083

Associated production of H^+h or/and H^+A as a test of the light Higgs scenario

- small ZZh coupling and large WH^+h coupling scenario makes H^+h or/and H^+A associate production very special:
complementary to LEP II



hep-ph/0112165

hep-ph/0311083

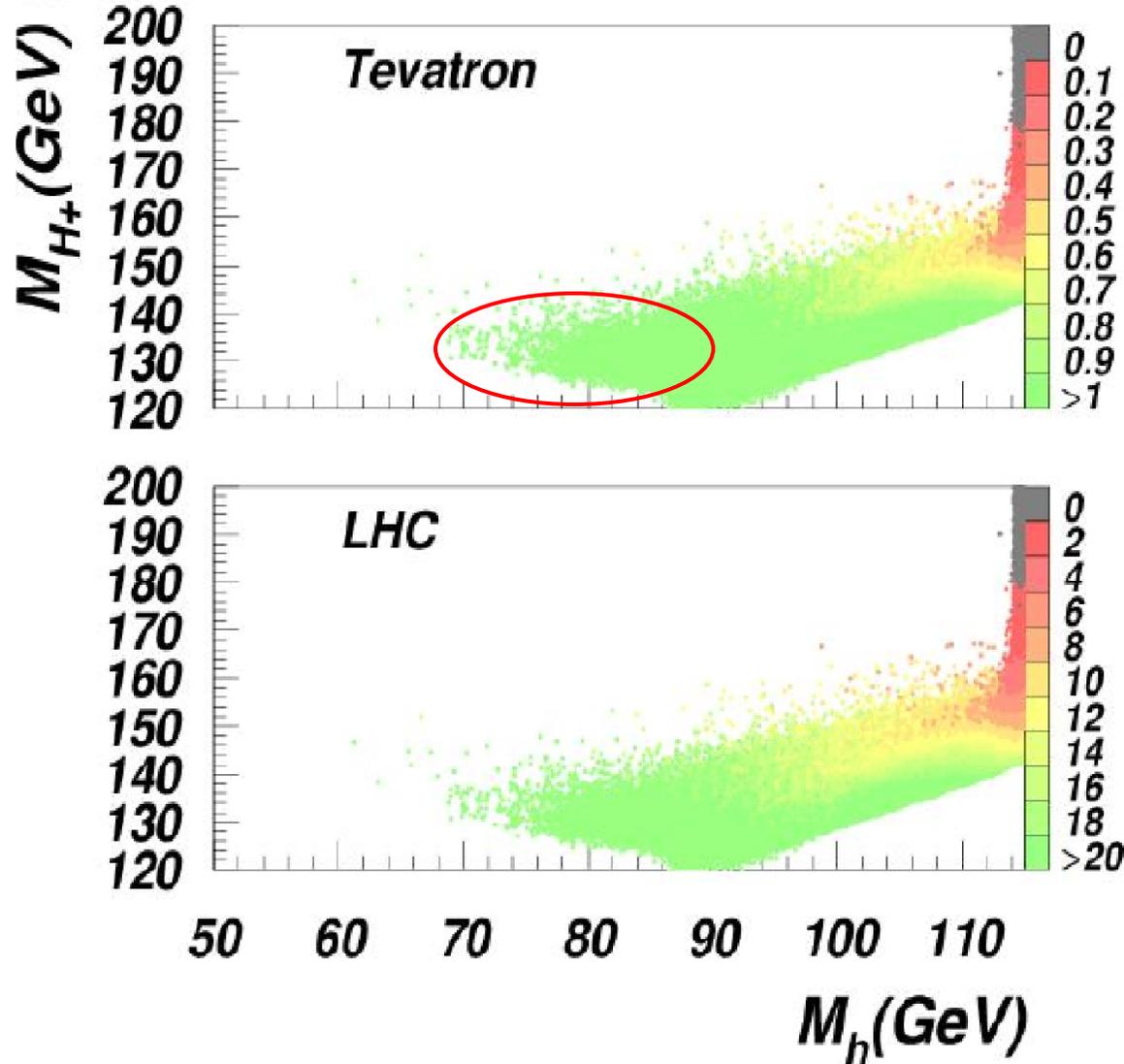
(S. Kanemura, Q-H Cao, CPY)

1 for A , $\cos(\beta - \alpha)$ for h

- $g_{AH^+W^-} = 1$
does not depend on SUSY parameters at tree-level.
(independent of $\tan \beta$)

Tevatron/LHC H^+A production rates

$pp(pp) \rightarrow H^+ h(A) \rightarrow \tau^+ \nu \bar{b} b \rightarrow \pi^+ \bar{\nu} \nu \bar{b} b$ rates in fb

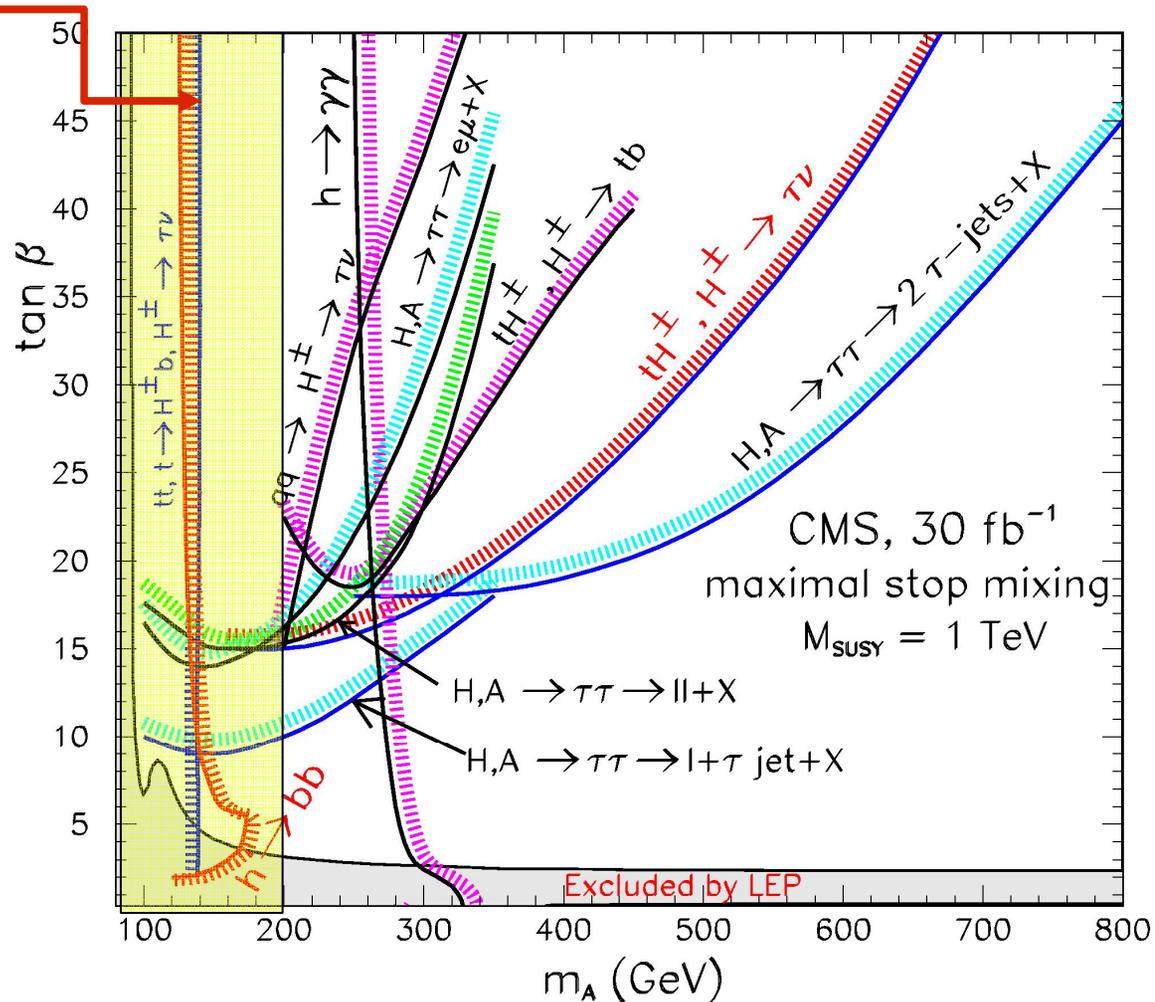


Tevatron can probe some parameter space of LHS with lighter h .

LHC is sensitive to the entire parameter space of LHS via studying this production channel

What can we gain from studying AH^+ production?

H^+A



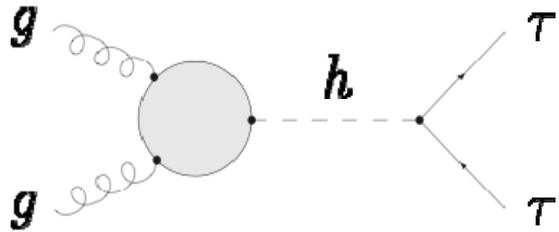
LHC is sensitive to the entire parameter space of LHS.
(independent of $\tan \beta$)

Other interesting processes at the Tevatron and the LHC

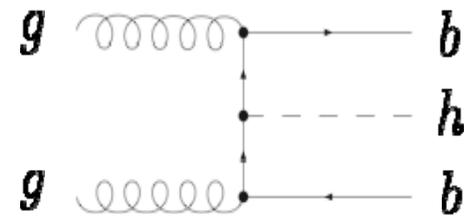
“ $\tan \beta$ enhanced processes”

$$\frac{g_{ddh}}{g_{ddh}^{\text{SM}}} = -\frac{\sin \alpha}{\cos \beta} = \sin(\beta - \alpha) - \tan \beta \cos(\beta - \alpha)$$

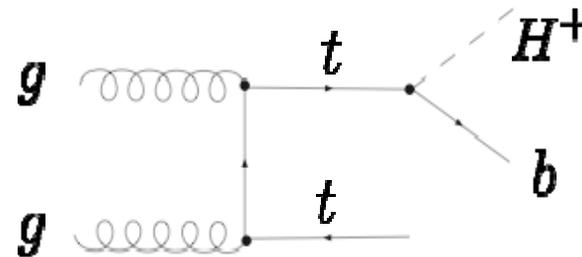
$p\bar{p} \rightarrow h/A \rightarrow \tau^+ \tau^-$



$p\bar{p} \rightarrow h b \bar{b}, A b \bar{b}$



$p\bar{p} \rightarrow t \bar{t} (t \rightarrow b H^+)$



At Tevatron, these processes may probe the LHS in large $\tan \beta$ region.

Impact of new CTEQ6.5(M,S,C) PDFs on

s-channel H^+ production in
TopColor and MSSM

- Top-pion resonances in TopColor model

hep-ph/9812263

In collaboration with

C. Balazs, H.-J. He (Michigan State)

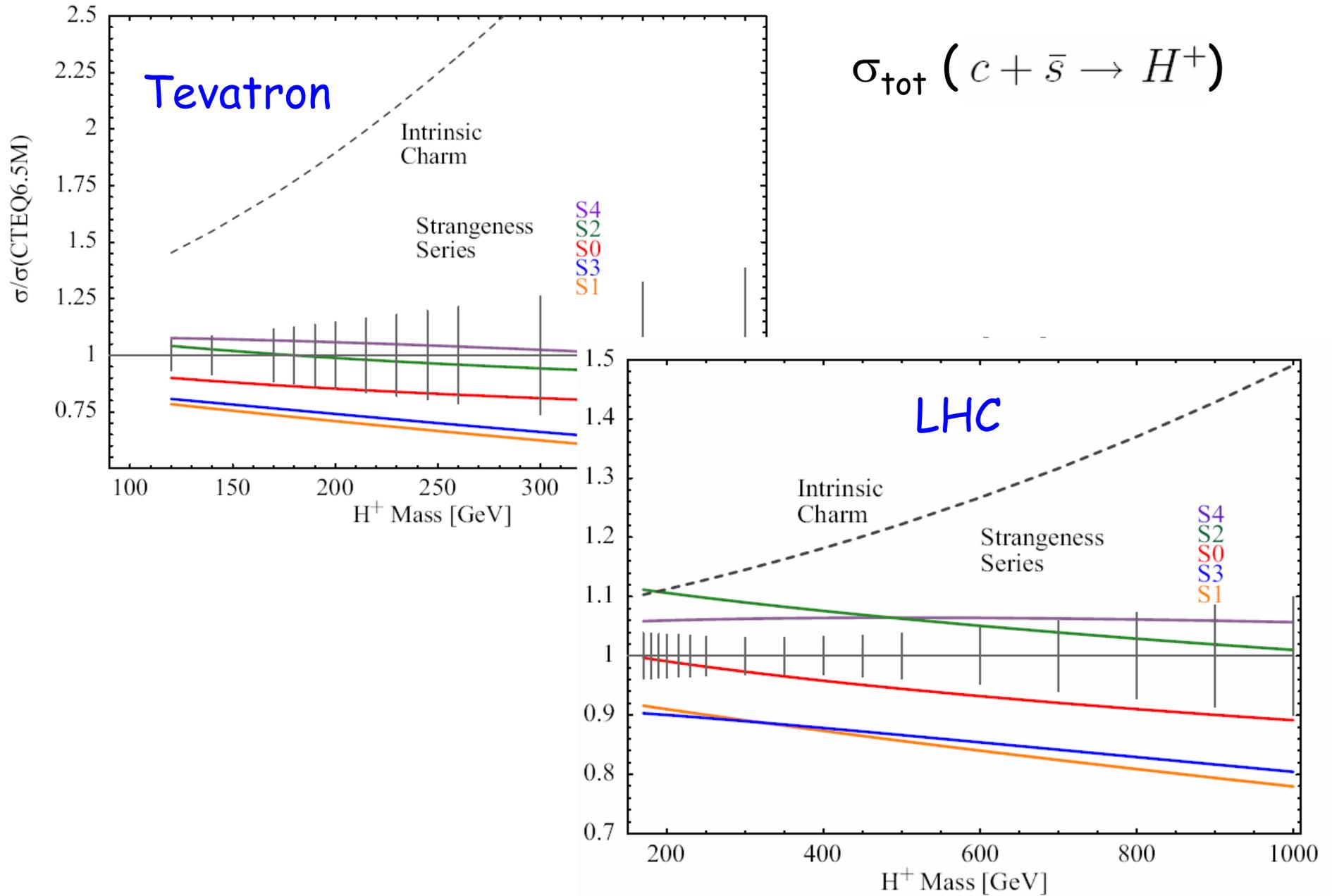
- Charged Higgs in MSSM with large $\tilde{t} - \tilde{c}$ mixing.

hep-ph/0103178

In collaboration with

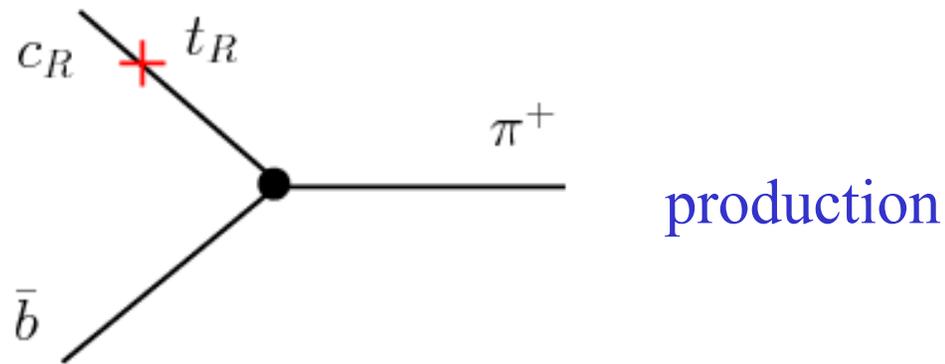
L. Diaz-Cruz, H.-J. He

Impact of new CTEQ6.5(M,S,C) PDFs

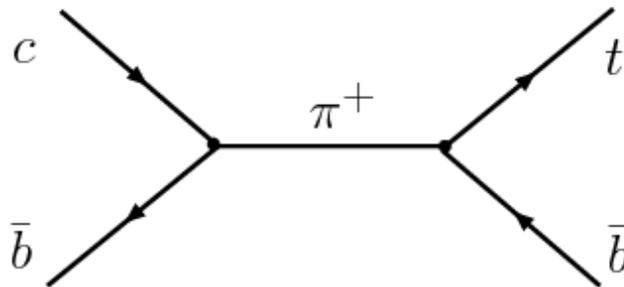


s-channel Charged Resonances in TopColor

- In TopColor model, large t_R - c_R mixing enhances



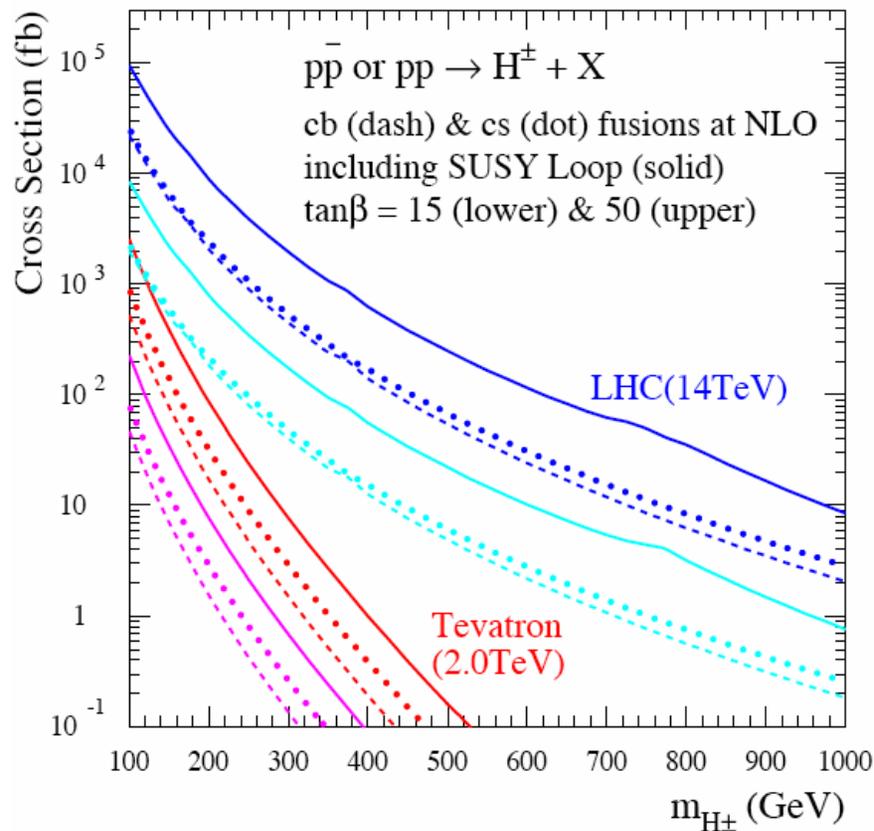
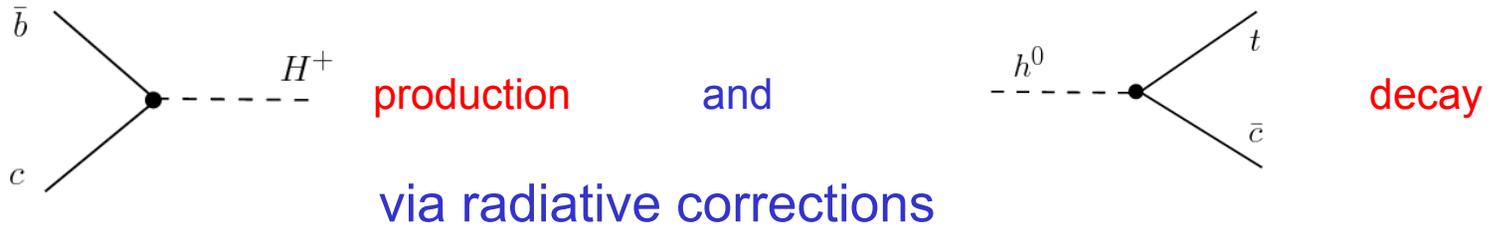
→ $pp \xrightarrow{(-)} \pi^+ \rightarrow t\bar{b}$



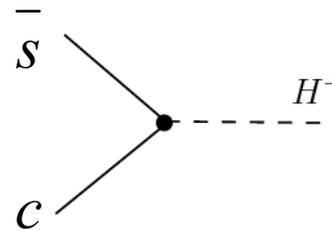
hep-ph/9812263
(Balazs, He, CPY)

Soft SUSY Breaking and $\tilde{t} - \tilde{c}$ Mixings

- Large $\tilde{t} - \tilde{c}$ mixing can enhance



$\text{Br}(t \rightarrow ch^0)$ can range from 10^{-5} to 10^{-3} , and is sensitive to \tilde{t}_1 mass and squark mixing



hep-ph/0103178

Diaz-Cruz, He, CPY

Summary

- New CTEQ6.5 (M,S,C) PDFs impact collider Phenomenology at the LHC/Tevatron
- hH^+ and AH^+ associated productions should be measured at the LHC / Tevatron

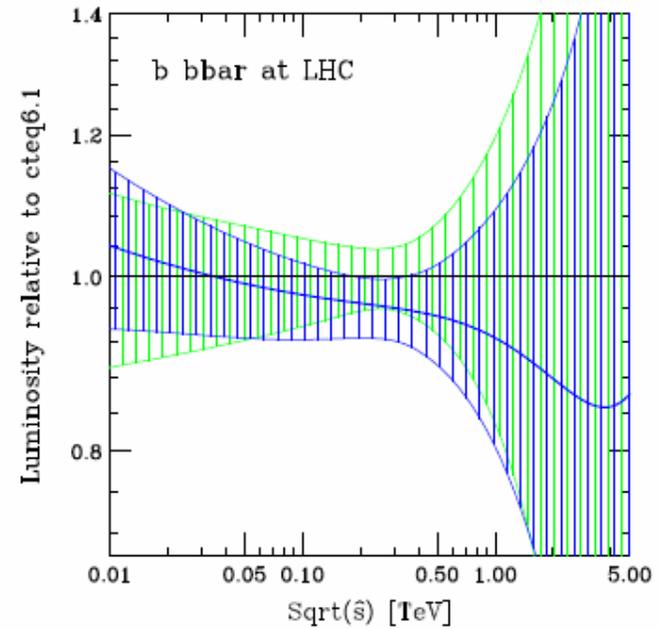
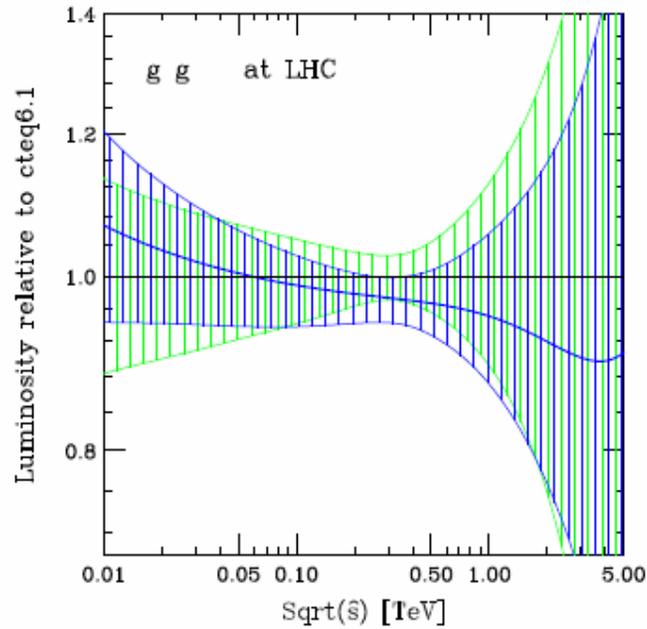
➔ To test Light MSSM Higgs boson scenario (LHS)

- s-channel Charged Resonances in TopColor and MSSM

➔ Can modify single-top production rates and decay distributions

Backup Slides

Impact of new CTEQ6.5M PDFs on LHC Phenomenology



Affect $g g \rightarrow h$
 $g g \rightarrow t \bar{t}$

Affect $b \bar{b} \rightarrow h$

How to get small $g_{ZZh} \propto \sin(\beta - \alpha)$?

(Including radiative corrections)

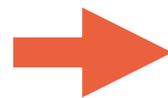
$$M_h^2 = \begin{pmatrix} M_{11}^2 & M_{12}^2 \\ M_{12}^2 & M_{22}^2 \end{pmatrix} = \begin{pmatrix} M_{11}^2 - M_{22}^2 & M_{12}^2 \\ M_{12}^2 & 0 \end{pmatrix} + M_{22}^2 \mathbf{1}$$

$$\begin{pmatrix} H \\ h \end{pmatrix} = \begin{pmatrix} \cos \alpha & \sin \alpha \\ -\sin \alpha & \cos \alpha \end{pmatrix} \begin{pmatrix} \eta_1 \\ \eta_2 \end{pmatrix}$$

The mixing α depends on $M_{11}^2 - M_{22}^2$ and M_{12}^2

When $\tan \beta > 1$,
 need $M_{11}^2 - M_{22}^2 < 0, M_{12}^2 \sim 0$
 to get small $\sin(\beta - \alpha)$

(Small $m_A < 120$ GeV)



For example, when $\tan \beta \gg 1$

$$M_h^2 \simeq \begin{pmatrix} m_A^2 & \sim 0 \\ \sim 0 & m_Z^2 \end{pmatrix}$$

$h \simeq \eta_1, H \simeq \eta_2$

m_A m_Z Δm_h^2

$H_1 (\eta_1)$ $H_2 (\eta_2)$

radiative correction

LHS ample point as an example

$\tan \beta$	M_{H^+}	μ	A_t	M_1/M_2	M_3	M_Q
40	130	600	600	100/200	300	300

• *tree level:*

$$\mathcal{M}_0^2 = \begin{bmatrix} (101)^2 & -(22)^2 \\ -(22)^2 & (91)^2 \end{bmatrix}$$

$$\sin(\beta - \alpha) \simeq 0.98$$



• *loop corrected:*

$$\mathcal{M}^2 = \begin{bmatrix} (86)^2 & -(38)^2 \\ -(38)^2 & (119)^2 \end{bmatrix}$$

$$\sin(\beta - \alpha) \simeq 0.22$$

$$s_\beta \gg c_\beta, |\mathcal{M}_{11}^2 - \mathcal{M}_{22}^2| \gg |\mathcal{M}_{12}^2|, \mathcal{M}_{22}^2 > \mathcal{M}_{11}^2$$

$$\Rightarrow s_{\beta\alpha} \sim 0$$

TopColor Model

hep-ph/9411426
C. Hill

$$SU(3)_1 \otimes SU(3)_2 \otimes U(1)_1 \otimes U(1)_2 \otimes SU(2)_W$$

$$\Lambda_{\text{TopC}} \sim O(1 - 10) \text{ TeV} \quad \Leftarrow \text{TopC Breaking}$$

$$SU(3)_C \otimes U(1)_Y \otimes SU(2)_W$$

$$v \simeq 246 \text{ GeV} \quad \Leftarrow \text{EW Breaking}$$

$$SU(3)_C \otimes U(1)_{\text{em}}$$

- Large flavor mixings among right-handed up-type quarks are possible.

- Predicted $\bar{q} - q' - \pi_t^\pm$ Couplings:

$$c_L^{tb} \simeq 0 \quad c_L^{cb} \simeq 0$$

$$c_R^{tb} \simeq \sqrt{2} m_t / v_t \simeq O(3)$$

$$c_R^{bc} \simeq c_R^{tb} \times (0.11 - 0.33)$$

In the strongly interacting scenario, the Yukawa couplings

$$Y_t(\Lambda) \simeq Y_b(\Lambda) > 1$$

at the scale Λ where new dynamics sets in. Because Y_t and Y_b satisfy similar Renormalization group equations,

$$Y_t(\mu) \simeq Y_b(\mu) \quad \text{for any } \mu, \Lambda .$$

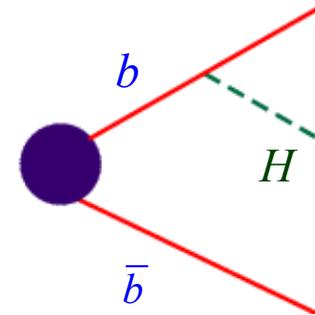
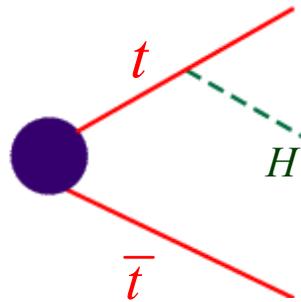
Also, due to the infrared quasi-fixed point structure,

$$Y_t(m_t) \simeq Y_b(m_t) \simeq 1 .$$

hep-ph/9810367
He, CPY

Discriminating Models of Electroweak Symmetry Breaking

Testing the interaction of Top, Bottom and Higgs Boson



SM: $y_t^{\text{SM}} = \frac{m_t}{\sqrt{2}v} = 1$

$y_b^{\text{SM}} = \frac{m_b}{\sqrt{2}v} = \frac{1}{40}$

MSSM:
($\tan \beta = 40$) $y_t = y_t^{\text{SM}} \cdot \cot \beta = \frac{1}{40}$

$y_b = y_b^{\text{SM}} \cdot \tan \beta = 1$

TopColor:
 $H \equiv \langle t \bar{t} \rangle$ $y_t = 1$

$y_b = 1$

Soft SUSY Breaking and $\tilde{t} - \tilde{c}$ Mixings

- MSSM Squark Mass-terms and Trilinear A-terms:

hep-ph/0103178

$$\tilde{M}_{\tilde{u}}^2 = \begin{pmatrix} M_{LL}^2 & M_{LR}^2 \\ M_{LR}^{2\dagger} & M_{RR}^2 \end{pmatrix}$$

$$M_{LR}^2 = A_u \frac{v \sin \beta}{\sqrt{2}} - M_u \mu \cot \beta$$

Where $A'_u = A \begin{pmatrix} 0 & 0 & 0 \\ 0 & 0 & x \\ 0 & y & 1 \end{pmatrix}$

in 3 - \tilde{q} families

If $x = 0$, then \tilde{c}_L decouples
 y = 0, then \tilde{c}_R decouples

If $(x,y) \sim O(1)$, then
 large flavor mixing in $\tilde{t} - \tilde{c}$ sector

- For $(\tilde{c}_L, \tilde{c}_R, \tilde{t}_L, \tilde{t}_R)$

$$M_{\tilde{u}} = \begin{pmatrix} \tilde{m}_0^2 & 0 & 0 & A_x \\ 0 & \tilde{m}_0^2 & A_y & 0 \\ 0 & A_y & \tilde{m}_0^2 & -X_t \\ A_x & 0 & -X_t & \tilde{m}_0^2 \end{pmatrix}$$

$$A_x = x \frac{A v \sin \beta}{\sqrt{2}}$$

$$A_y = y \frac{A v \sin \beta}{\sqrt{2}}$$

$$X_t = -\frac{A v \sin \beta}{\sqrt{2}} + \mu m_t \cot \beta$$

with $m_{\tilde{t}_1} < m_{\tilde{c}_1} < m_{\tilde{c}_2} < m_{\tilde{t}_2}$