PLANCK 2013
Bonn, May 21, 2013

Top and bottom partner production at the LHC

José Santiago (CAFPE and U. Granada)

Based on: A. Carmona, M. Chala, J.S. 1205.2378 [JHEP]
M. Chala, J.S. 1305.1940

Take-Home Message

SUSY should go back to EXOTICS!

Take-Home Message

SUSY should go back to EXOTICS!

Current searches motivated by SM or SUSY can be easily turned into powerful probes of many other models

$Ht\bar{t}$, $Hb\bar{b}$ as probes of composite Higgs models

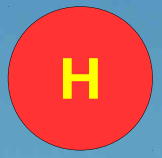
Outline

- Composite Higgs Models
- Partial Compositeness
- Resonances in Composite Higgs Models
  - Top/bottom partners
  - Heavy gluons
- Top/Bottom partner production at the LHC
- New Higgs channels through top/bottom partners
  - $Ht\bar{t}$ in Composite Higgs models
  - $Hb\bar{b}$ in Composite Higgs models
- Conclusions

Composite Higgs Models

- The Higgs boson is a composite state of a new strongly coupled interaction

Georgi, Kaplan et al. 84-85



Higgs mass protected by its finite size
Extra protection if Higgs is a pseudo Goldstone boson

Must contain (at least) $SO(4)$ custodial symmetry

$$G \to H$$
$$f \sim \mathrm{TeV}$$

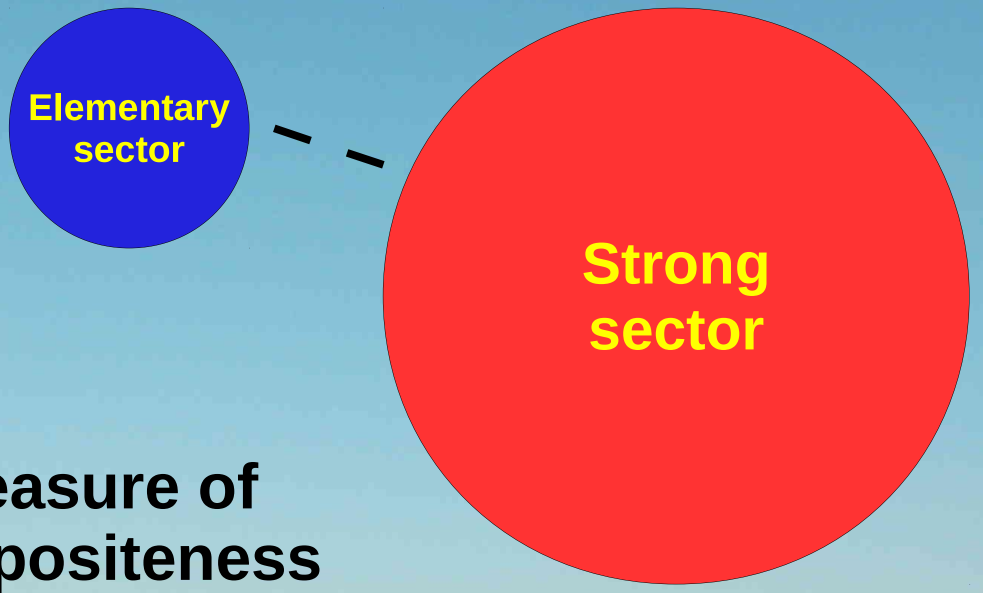
E

v **EWSB**

$$\mathrm{SM} \subset H$$

$$\xi \equiv \frac{v^2}{f^2}$$

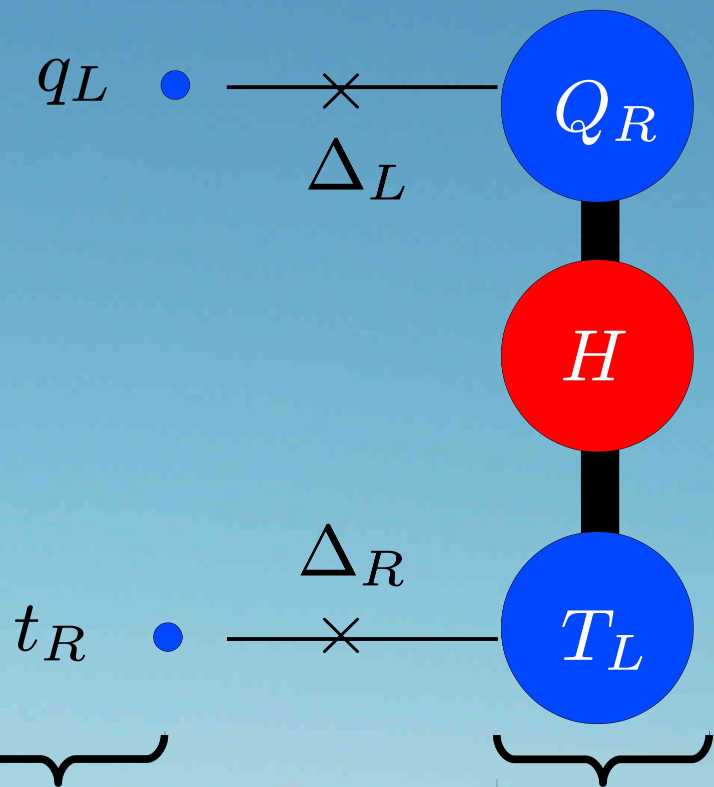
Measure of compositeness



Partial Compositeness

- SM particles acquire their mass through linear coupling to the composite sector

Kaplan 91



Elementary Sector

Composite Sector

$$\tan\theta_L = \frac{\Delta_L}{M_Q}$$

$$\tan\theta_R = \frac{\Delta_R}{M_T}$$

Degree of compositeness

$$\boxed{m_t \sim Y s_L s_R \frac{v}{\sqrt{2}}}$$

Heavier SM particles are more composite

New Resonances in CHM

- Top/bottom partners:
  - The composite (vector-like) quarks t and b mix with to acquire their masses plus their partners under the global symmetries of the composite sector

New Resonances in CHM

- Top/bottom partners:
  - The composite (vector-like) quarks t and b mix with to acquire their masses plus their partners under the global symmetries of the composite sector

MCHM5 example:
SO(5)/SO(4)

Agashe, Contino, Da Rold, Pomarol '06
Contino, Da Rold, Pomarol '06

$$\begin{pmatrix} t_L \\ b_L \end{pmatrix} - \begin{bmatrix} T & X_{5/3} \\ B & T_{2/3} \end{bmatrix} \qquad \begin{bmatrix} B_{-1/3} & T \\ Y_{-4/3} & B \end{bmatrix}$$

$$\begin{bmatrix} \phi_0^\dagger & \phi^+ \\ -\phi^- & \phi_0 \end{bmatrix}$$

$$t_R - T \qquad B - b_R$$

New Resonances in CHM

- Top/bottom partners:
  - The composite (vector-like) quarks t and b mix with to acquire their masses plus their partners under the global symmetries of the composite sector
  - Naturalness and EWPT predict light top partners

Matsedonskyi, Panico, Wulzer '12; Redi, Tesi '12; Marzocca, Serone, Shu '12; Pomarol, Riva '12; Panico, Redi, Tesi, Wulzer '12

Carena, Pontón, J.S., Wagner '06-07; Anastasiou, Furlan, J.S. '09

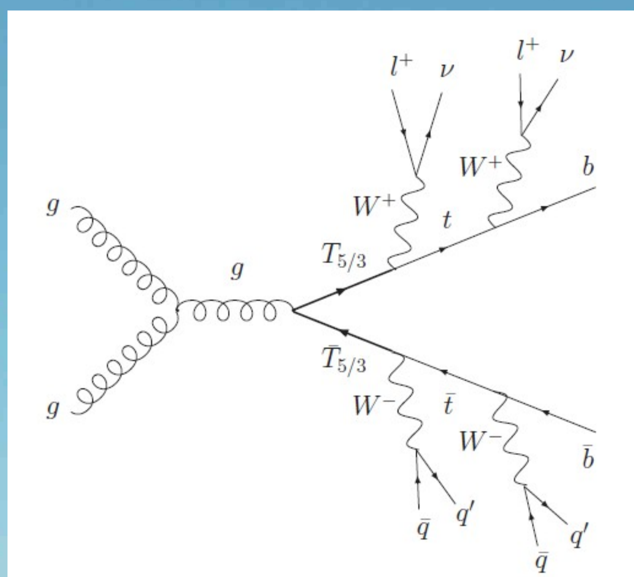
New Resonances in CHM

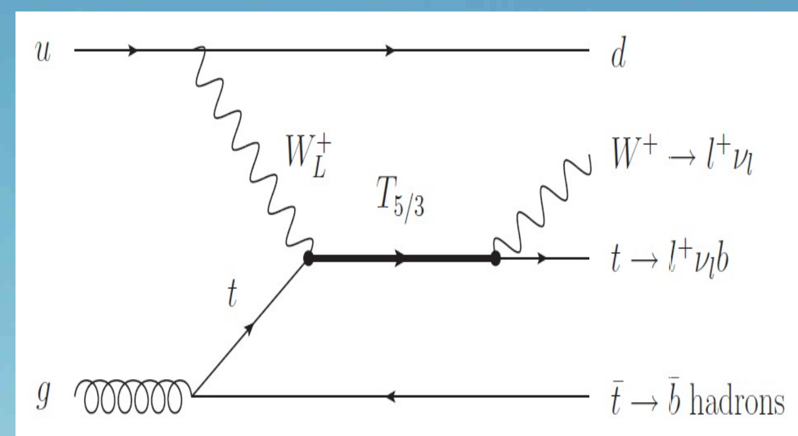
- Top/bottom partners:
  - The composite (vector-like) quarks t and b mix with to acquire their masses plus their partners under the global symmetries of the composite sector
  - Naturalness and EWPT predict light top partners
- Heavy gluons:
  - Partial top/bottom compositeness implies SU(3) is among the unbroken global symmetries
  - It is natural to expect QCD weakly gauged through linear mixing between elementary gluon and composite gluons

Top/Bottom partner production

- Traditional channels
  - Pair production (QCD)
  - (EW) single production

Contino, Servant '08; Aguilar-Saavedra '09; Mrazek, Wulzer '09; Dissertori, Furlan, Moorgat, Nef '10; De Simone, Matsedonskyi, Rattazzi, Wulzer '12; Cacciapaglia, De Andrea, Panizzi, Perries, Sordini '12; Pappadopulo, Thamm, Torre '13



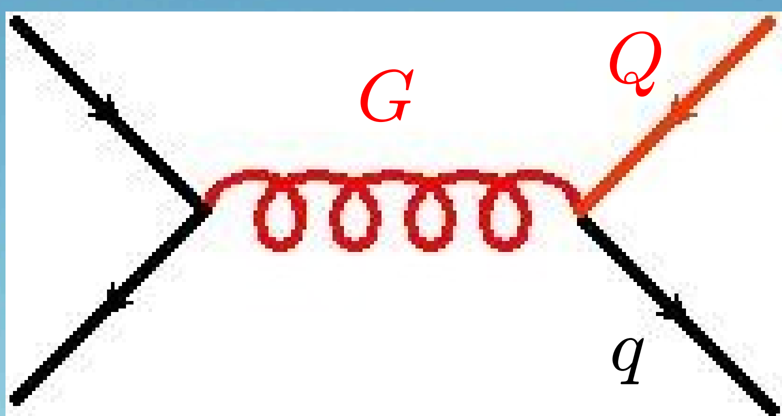


- Excellent reach if light, can be tested up to $M \sim 1.5\ \mathrm{TeV}$

Top/Bottom partner production

- New channels
  - Single (or pair) production through heavy gluons

Barcelo, Carmona, Chala, Masip, J.S. '11; Bini, Contino, Vignaroli '11; Carmona, Chala, J.S. '12; Chala, J.S. '13



$Q = T, B$

$q = t, b$

$W^+ b\bar{t}$ $\quad W^- t\bar{b}$

$Zt\bar{t}$ $\quad Zb\bar{b}$

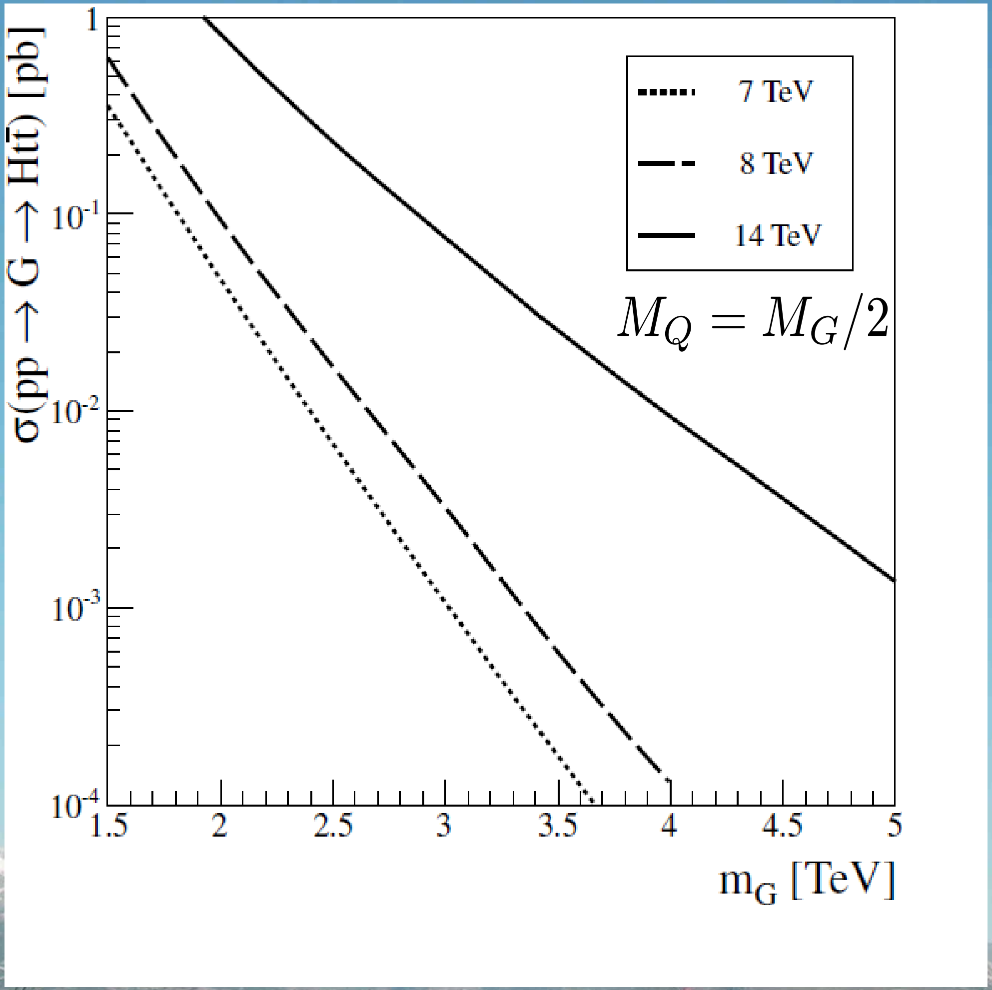
$Ht\bar{t}$ $\quad Hb\bar{b}$

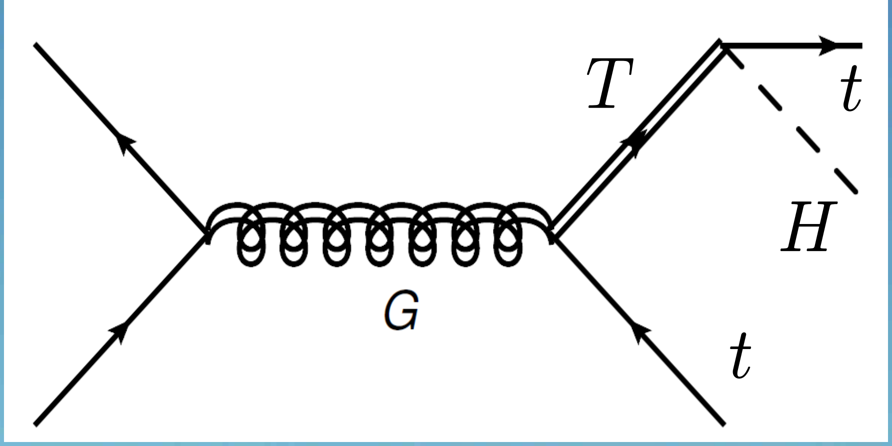
- Sizeable cross sections and distinctive kinematics
- Complementary to traditional channels
- Impressive reach!

$Ht\bar{t}$ in composite Higgs Models

- $pp \to G \to Tt \to Htt$: sizeable cross section and distinctive kinematics

Carmona, Chala, J.S. '12





- Very hard (and quite boosted) particles in the final state

$Ht\bar{t}$ in composite Higgs Models

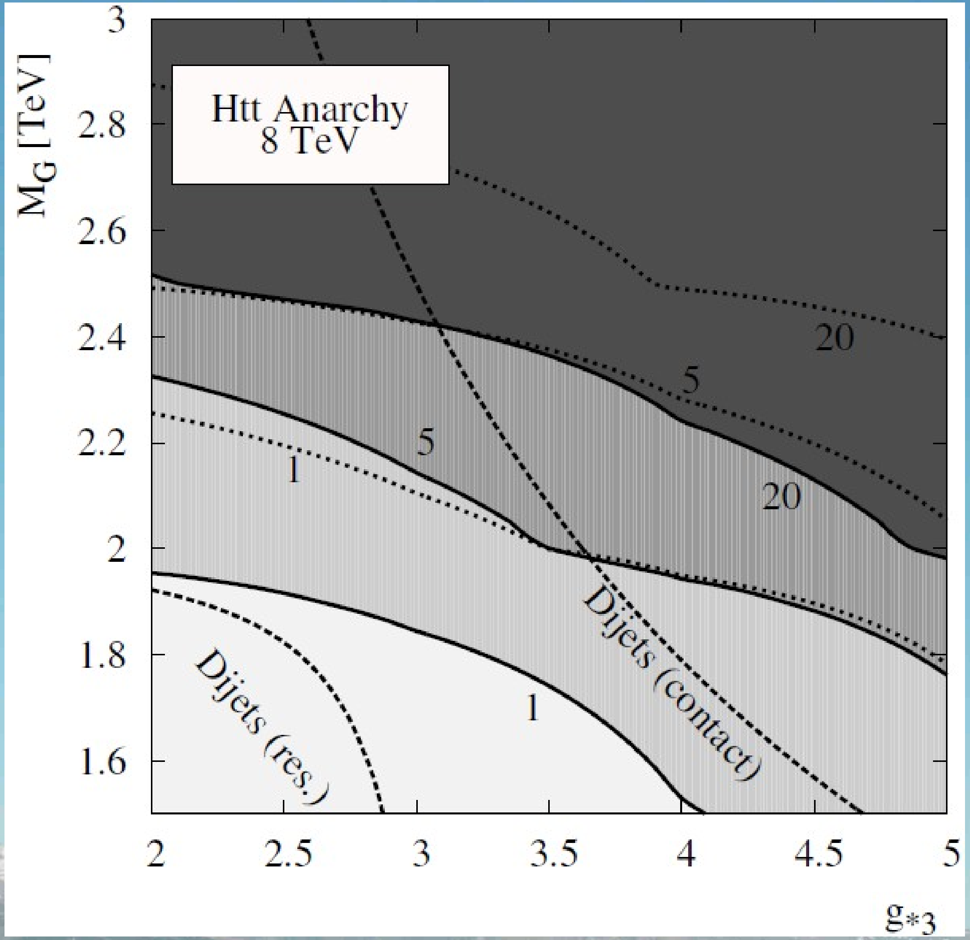
- Results

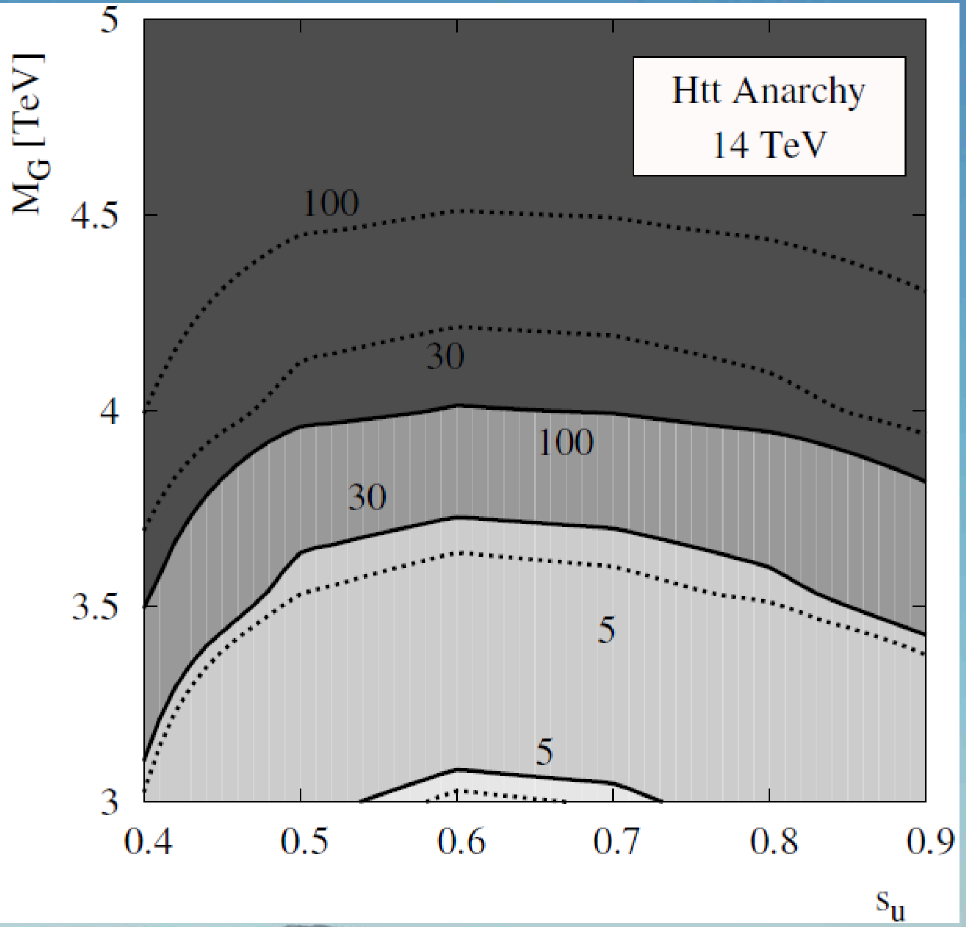
$$M_G \lesssim 2.8 \text{ TeV (LHC8)}$$

$$M_G \lesssim 4.5 - 4.8 \text{ TeV (LHC14)}$$

$$M_Q = \frac{M_G}{2}$$

Carmona, Chala, J.S. '12

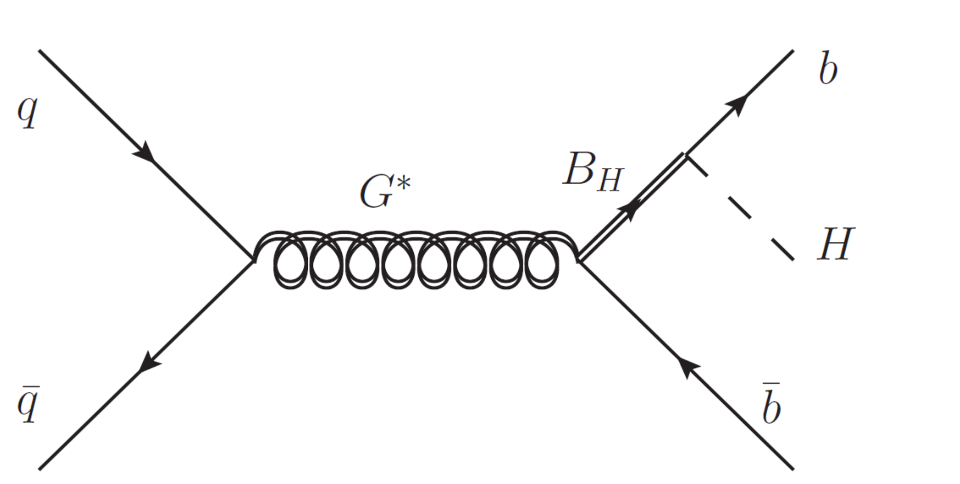




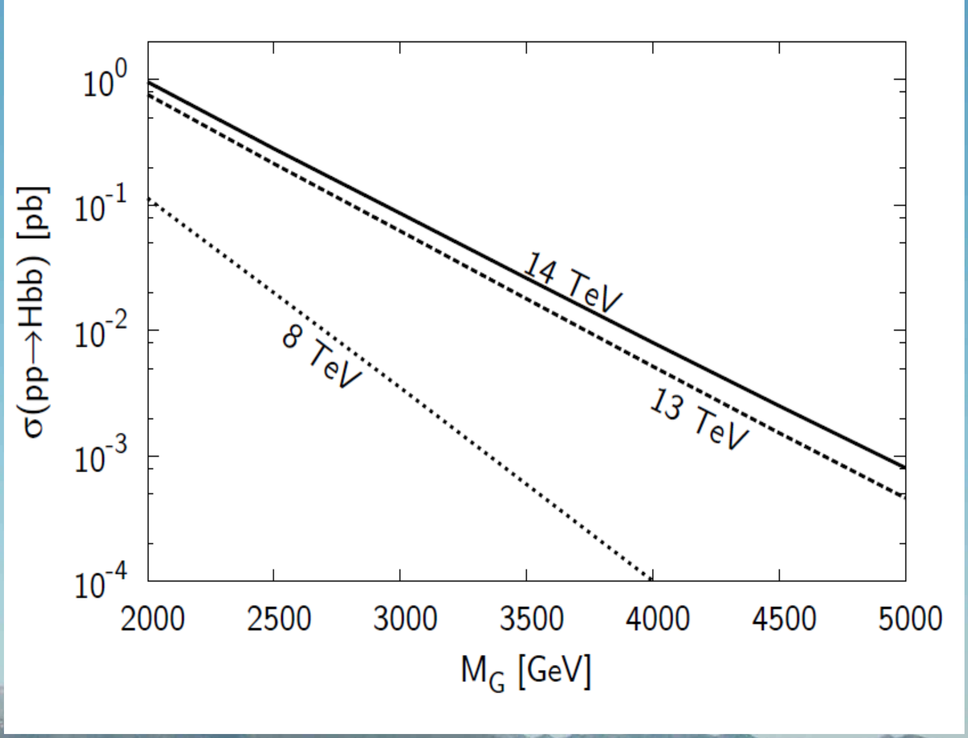
$Hb\bar{b}$ in composite Higgs Models

Chala, J.S. '13

- $Hb\bar{b}$ can be copiously produced in CHMs



- Sizeable cross-section



- Distinctive kinematics:
  - Heavy G and B: very hard decay products
  - Can use H->bb channel

$Hb\bar{b}$ in composite Higgs Models

Chala, J.S. '13

- Why the large cross-section?
  - Lightest B quark decays into H b with BR=1
  - Non- (or rather slow-)decoupling effect
  - EWSB effects very important in bottom partners
    - B has a small coupling to b but large couplings to the rest of top and bottom partners
    - Interesting possibility: B the only accessible new quark at LHC with highly non-singlet behavior (see backup)
    - What about Equivalence Theorem? Fulfilled by heavier modes

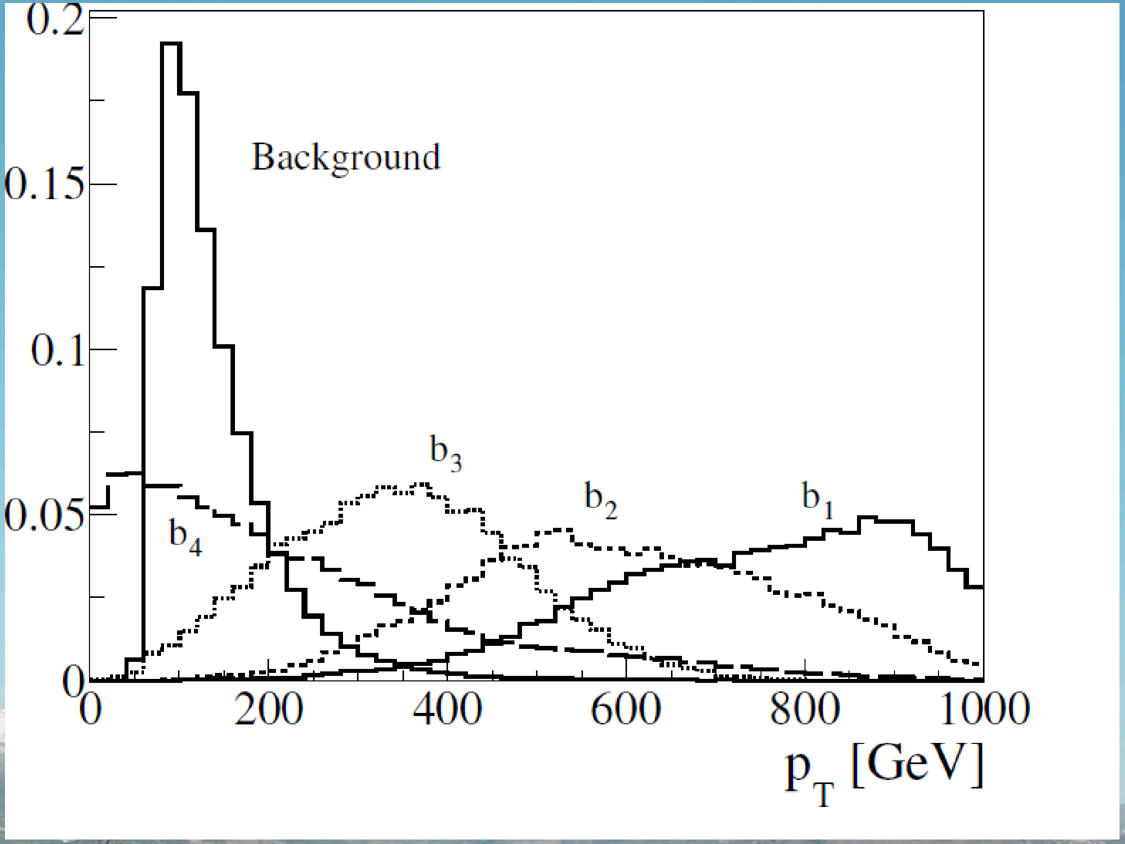
Check out back-up slides (and ask me!)

$Hb\bar{b}$ in composite Higgs Models

Chala, J.S. '13

- $Hb\bar{b}$ can be copiously produced in CHMs

$$pp \to G \to bB \to Hbb \to 4b$$



- Very hard spectrum:
  - Efficient trigger
  - 4 hard b's: background killer

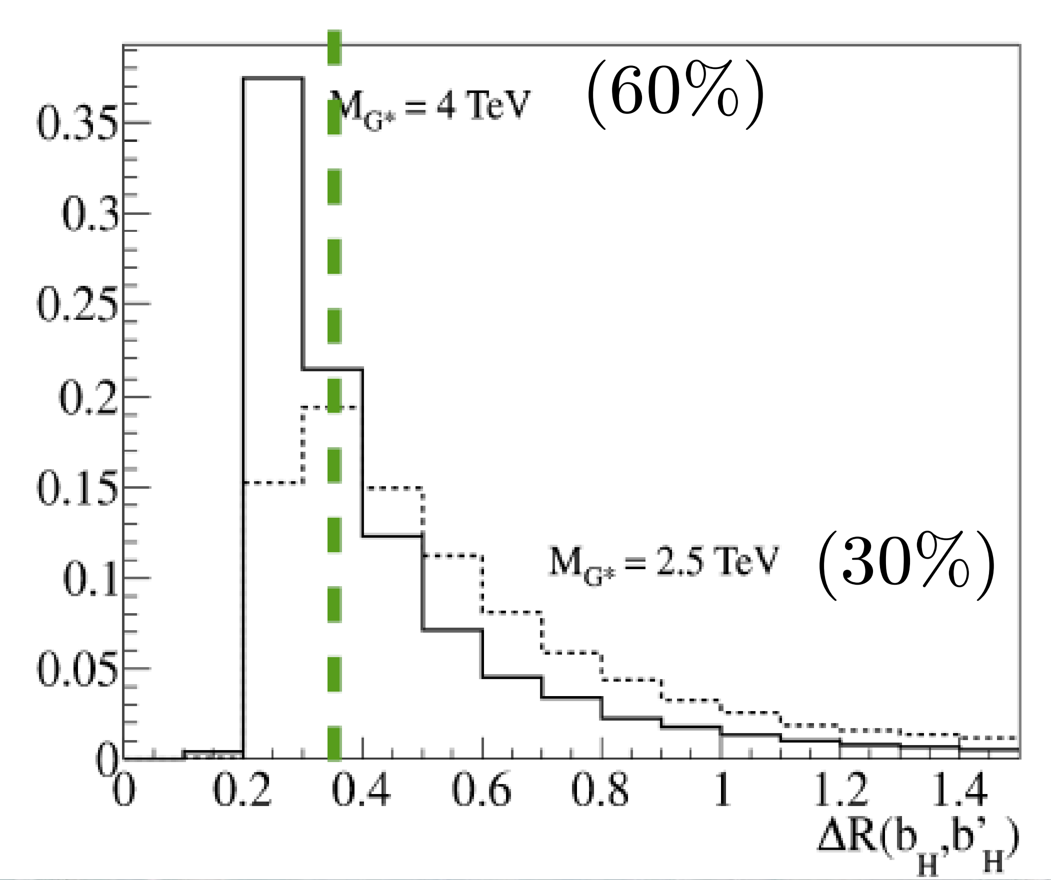
Irreducible QCD 4b is the only relevant background

$Hb\bar{b}$ in composite Higgs Models

Chala, J.S. '13

- $Hb\bar{b}$ can be copiously produced in CHMs

$$pp \to G \to bB \to Hbb \to 4b$$



- Boosted H:
  - 2 b's merged for large MG
  - Boosted techniques useful but background estimation harder

We stick to non-boosted techniques

$Hb\bar{b}$ in composite Higgs Models

Chala, J.S. '13

- Analysis
  - We use MG/ME and ALPGEN + PYTHIA + DELPHES for simulations
    - Only relevant background is the irreducible QCD 4b
  - Basic cuts:

$$N_b \geq 4, \quad N_l = 0, \quad p_T(b) \geq \begin{cases} 50 \text{ GeV (LHC8)}, \\ 60 \text{ GeV (LHC14)}, \end{cases}$$

$$p_T(b_1) \geq \begin{cases} 200 \text{ GeV (LHC8)}, \\ 300 \text{ GeV (LHC14)}, \end{cases} \qquad p_T(b_2) \geq \begin{cases} 100 \text{ GeV (LHC8)}, \\ 200 \text{ GeV (LHC14)}, \end{cases}$$

$$|m_{b_H b'_H} - m_H| \leq 30 GeV$$

$Hb\bar{b}$ in composite Higgs Models

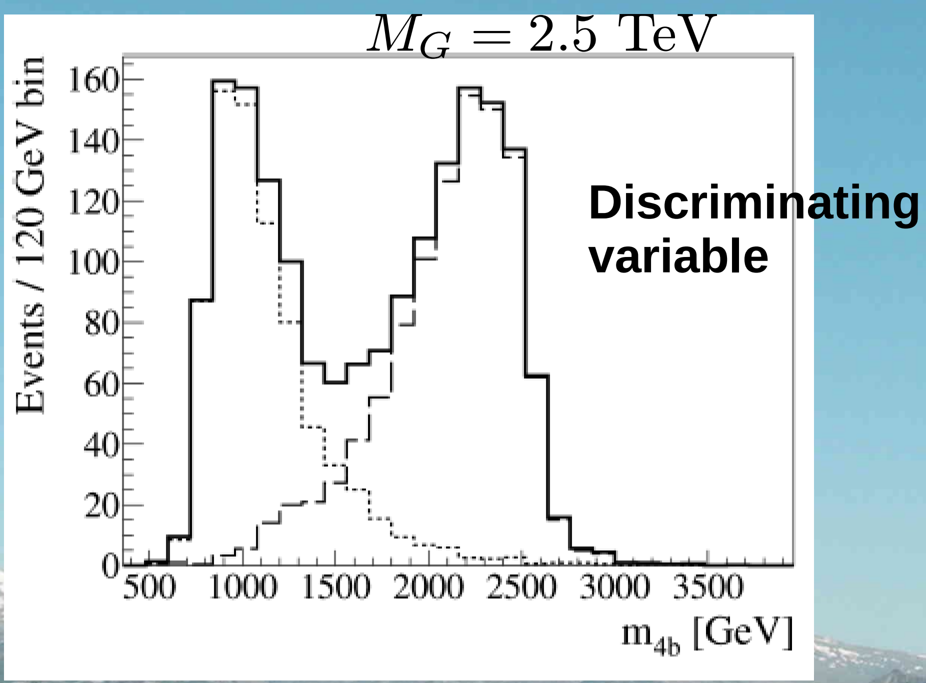
Chala, J.S. '13

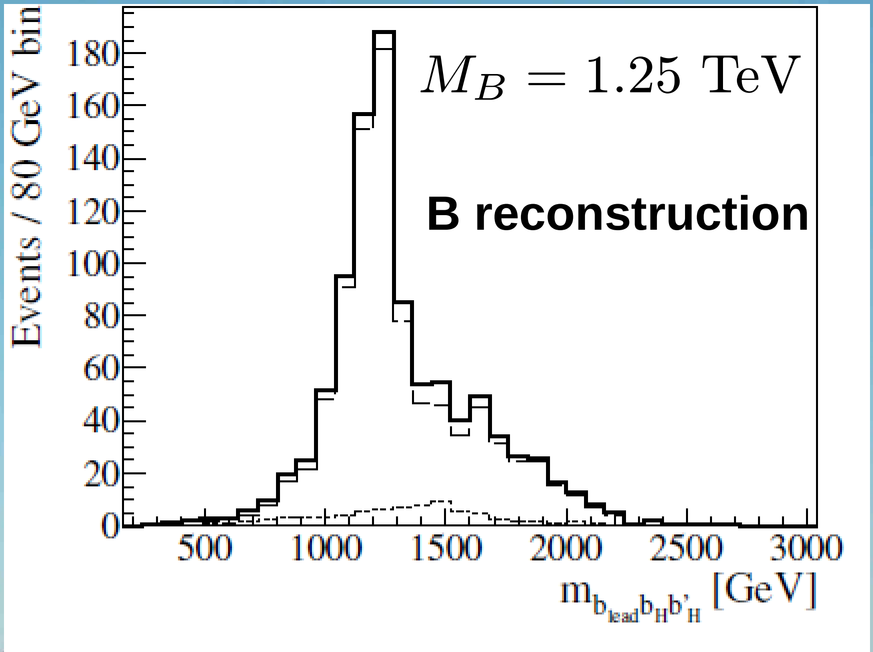
- Analysis

$$N_b \geq 4, \quad N_l = 0, \quad p_T(b) \geq \begin{cases} 50 \text{ GeV (LHC8)}, \\ 60 \text{ GeV (LHC14)}, \end{cases}$$

$$p_T(b_1) \geq \begin{cases} 200 \text{ GeV (LHC8)}, \\ 300 \text{ GeV (LHC14)}, \end{cases} \qquad p_T(b_2) \geq \begin{cases} 100 \text{ GeV (LHC8)}, \\ 200 \text{ GeV (LHC14)}, \end{cases}$$

$$|m_{b_H b'_H} - m_H| \leq 30GeV$$



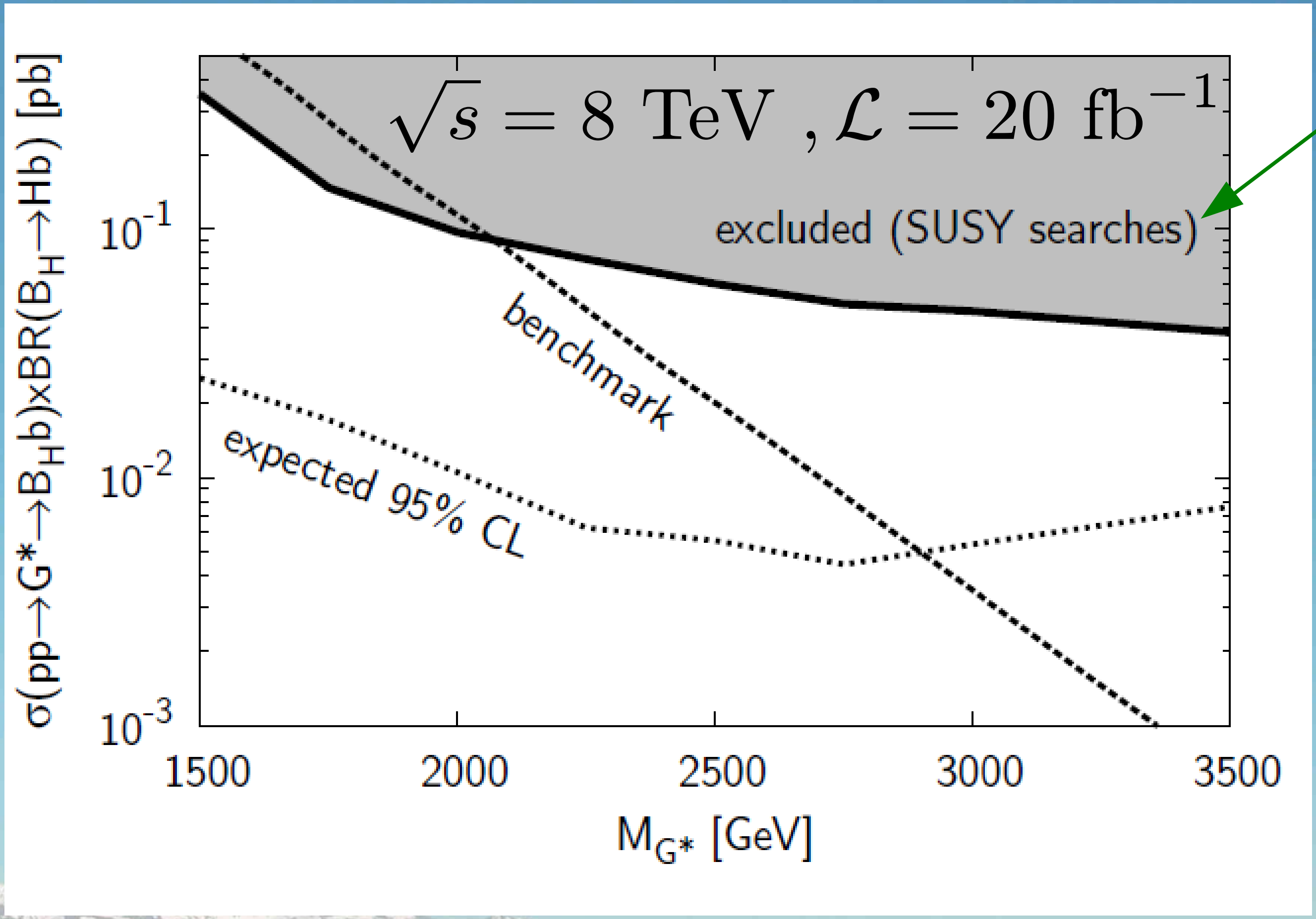


$Hb\bar{b}$ in composite Higgs Models

Chala, J.S. '13

- Results: exclusion @ 8 TeV

CMS-PAS-SUS-12-24



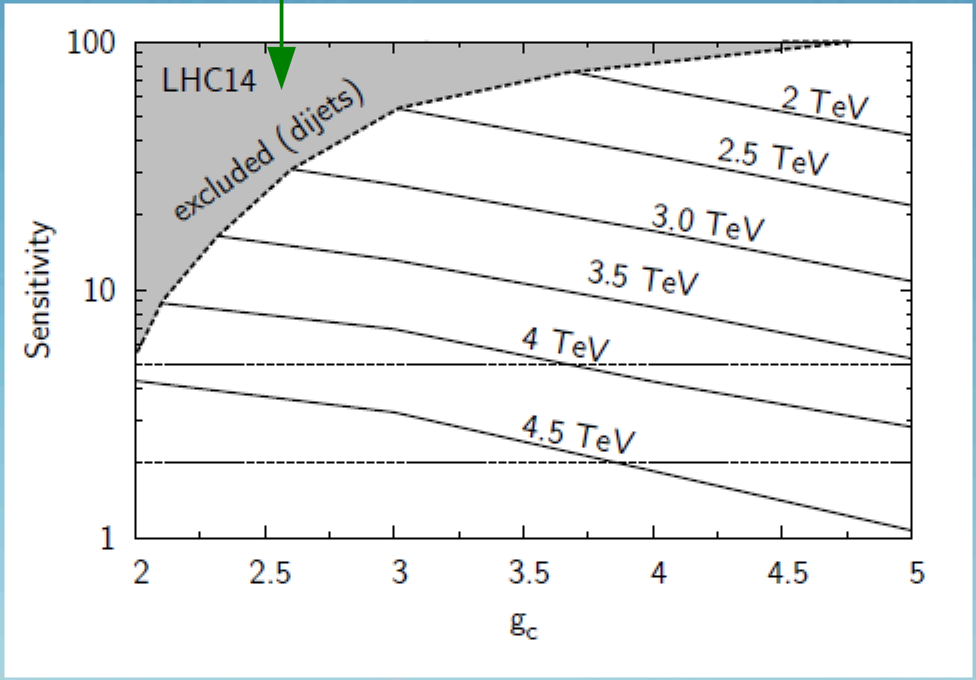
$Hb\bar{b}$ in composite Higgs Models

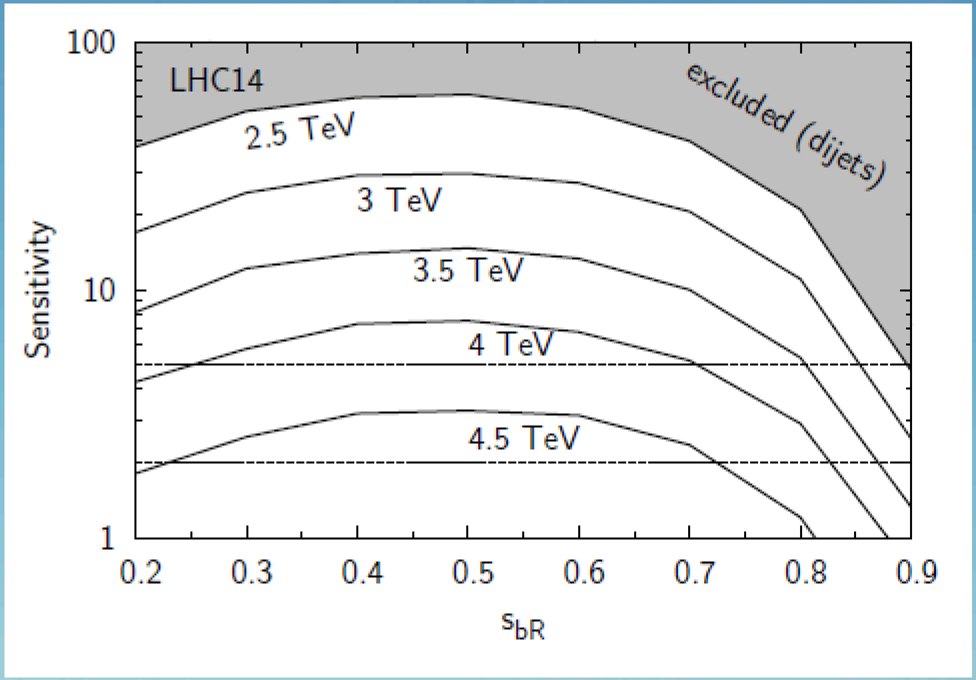
Chala, J.S. '13

- Results: sensitivity @ 14 TeV (SigCalc [Cowan])

Domenech, Pomarol, Serra '12

$$\sqrt{s} = 14\ \mathrm{TeV}\ , \mathcal{L} = 100\ \mathrm{fb}^{-1}$$





Conclusions

- Top/bottom partners can be produced via heavy gluons in composite Higgs models
- Large cross-sections and particular kinematics provide excellent reach
- Processes that are already present in the SM (or SUSY models) with completely different origin:
  - Simple modifications of current analyses become powerful probes of the strong sector
  - Complementary tests of composite Higgs models

$M_B \sim 1.5$ TeV at LHC8

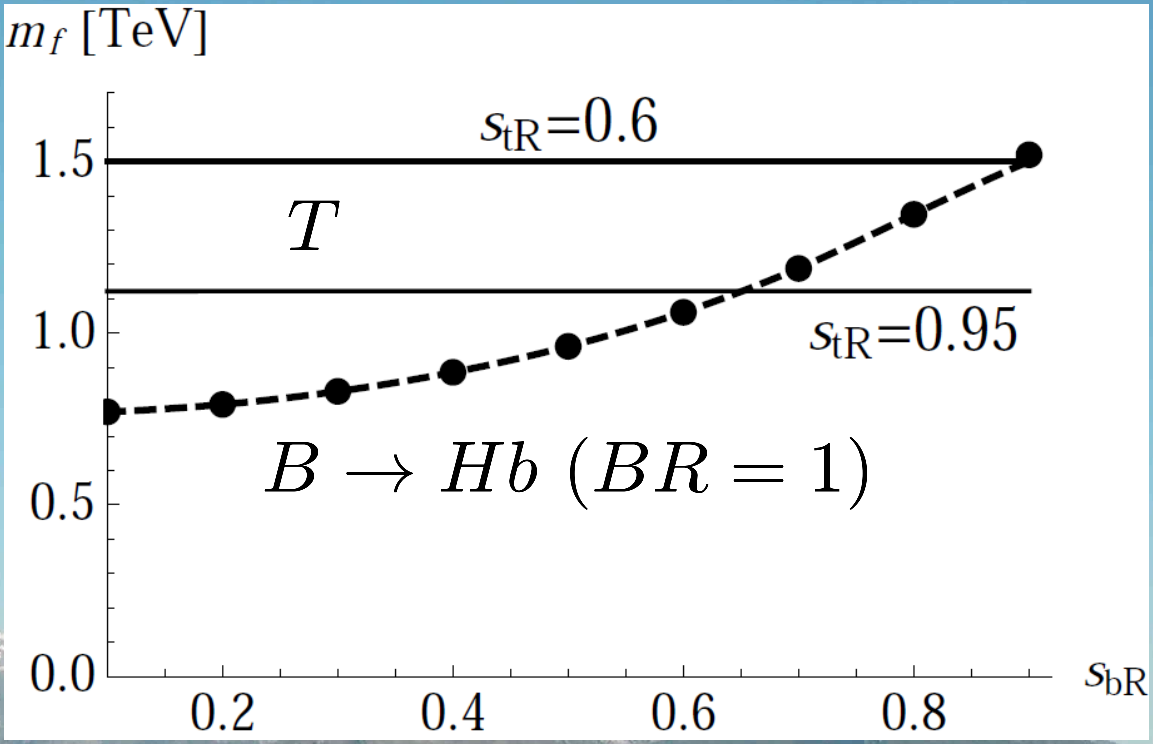
$M_B \sim 2.5$ TeV at LHC14

Room for improvement
In boosted regime

Back-up slides

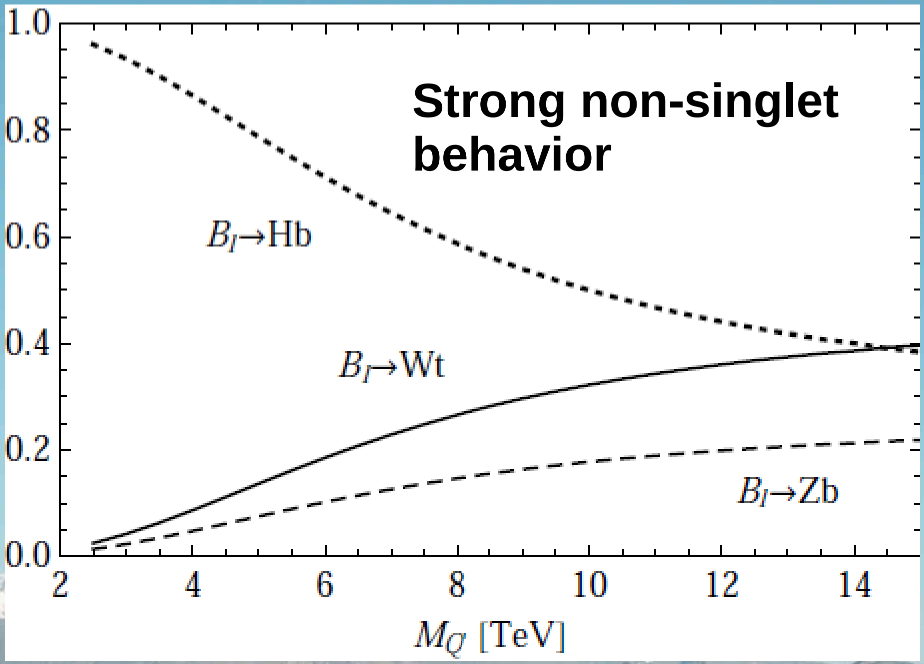
$Hb\bar{b}$ in composite Higgs Models

- $Hb\bar{b}$ can be copiously produced in CHMs
  - Assumptions:
    - All fermionic resonances of similar masses before mixing
    - b_R has a non-negligible degree of compositeness



$Hb\bar{b}$ in composite Higgs Models

- $Hb\bar{b}$ can be copiously produced in CHMs
  - Assumptions:
    - All fermionic resonances of similar masses before mixing
    - b_R has a non-negligible degree of compositeness



$Hb\bar{b}$ in composite Higgs Models

- $Hb\bar{b}$: details of the analysis

$$N_b \geq 4, \quad N_l = 0, \quad p_T(b) \geq \begin{cases} 50 \text{ GeV (LHC8)}, \\ 60 \text{ GeV (LHC14)}, \end{cases}$$

$$p_T(b_1) \geq \begin{cases} 200 \text{ GeV (LHC8)}, \\ 300 \text{ GeV (LHC14)}, \end{cases} \qquad p_T(b_2) \geq \begin{cases} 100 \text{ GeV (LHC8)}, \\ 200 \text{ GeV (LHC14)}, \end{cases}$$

$$|m_{b_H b'_H} - m_H| \leq 30GeV$$

8 TeV	N_b	N_l	p_T^b	$p_T^{b_1}$	$p_T^{b_2}$	$\lvert m_{bb} - m_H \rvert$	$m(4b)$
Signal	16	99	68	99	99	56	89
Background	17	99	10	13	89	46	0.7
14 TeV							
Signal	16	99	59	98	98	59	92
Background	20	99	12	7.6	63	36	11