

# Charged and neutral Higgs bosons in final states with 6 bottom quarks

with E. Lunghi, N. McGinnis and S. Shin

arXiv:2005.07222 [hep-ph]

arXiv:1901.03701 [hep-ph]

arXiv:1812.05240 [hep-ph]

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Radovan Dermisek

Indiana University, Bloomington

# Simple Extensions of the Standard Model

## Standard Model

$$3 \times \{q, \bar{u}, \bar{d}, l, \bar{e}\}, g, \gamma, Z, W^\pm, h$$

more Higgses? 2HDM?

$$H, A, H^\pm$$

more matter?

$$\begin{aligned} & Q, \bar{U}, \bar{D}, L, \bar{E} \\ & + \\ & \bar{Q}, U, D, \bar{L}, E \end{aligned}$$

Appear in many models: SUSY, composite Higgs, phenomenologically motivated extensions...

**My personal motivation:** exactly this particle content + SUSY provide an understanding of the values of all large couplings in the SM from the IR fixed point behavior from random large boundary conditions

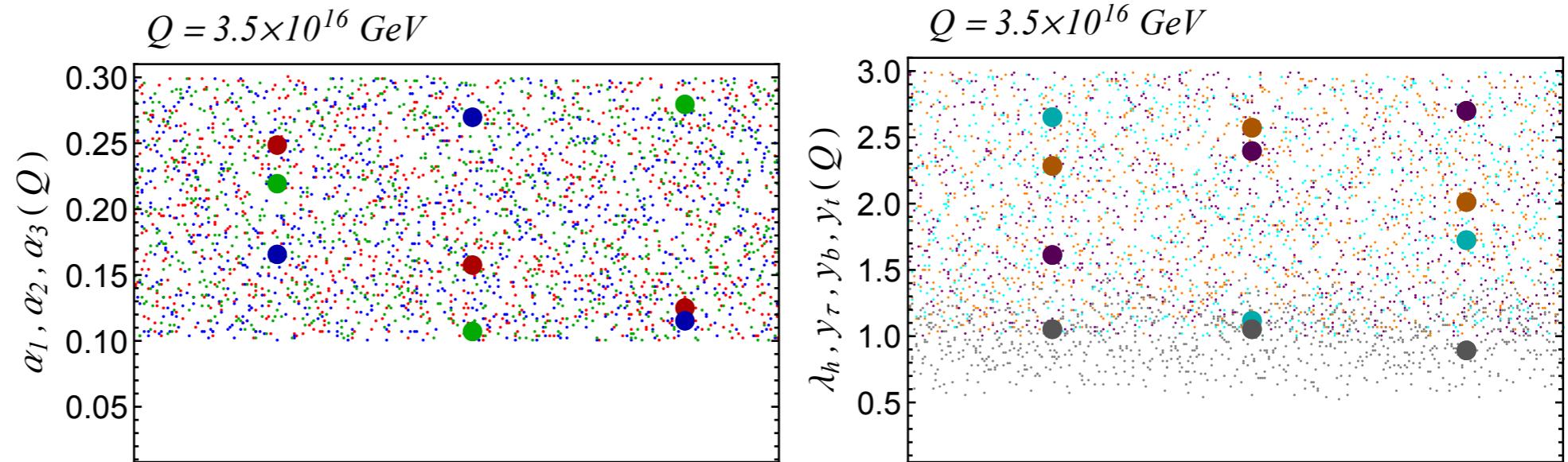
R.D. and N. McGinnis, arXiv:1812.05240 [hep-ph]

# 7 largest SM couplings from random b.c.

GUT scale

$\sim 3 \times 10^{16}$  GeV

MSSM+1VF



Random unrelated boundary conditions:

$$\alpha_1(M_G), \alpha_2(M_G), \alpha_3(M_G) \in [0.1, 0.3]$$

$$y_t(M_G), y_b(M_G), y_\tau(M_G), Y_V(M_G) \in [1, 3]$$

(larger values of couplings do not affect results significantly)

Higgs quartic given by gauge couplings at any scale:

$$\lambda_h(Q) \equiv \frac{g_2^2(Q) + (3/5)g_1^2(Q)}{4} \cos^2 2\beta$$

the plots assume:  $\tan \beta = 40$

# 7 largest SM couplings from random b.c.

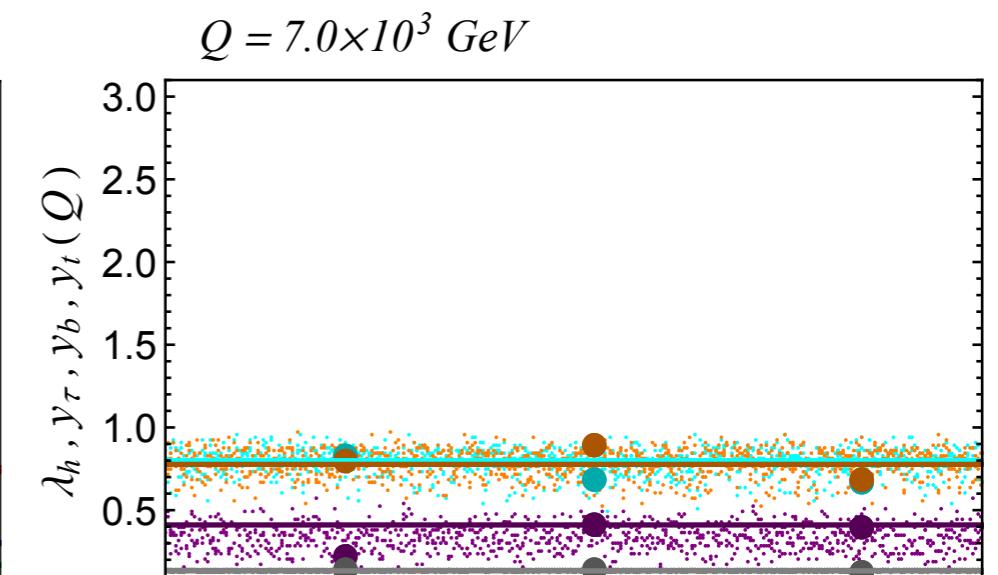
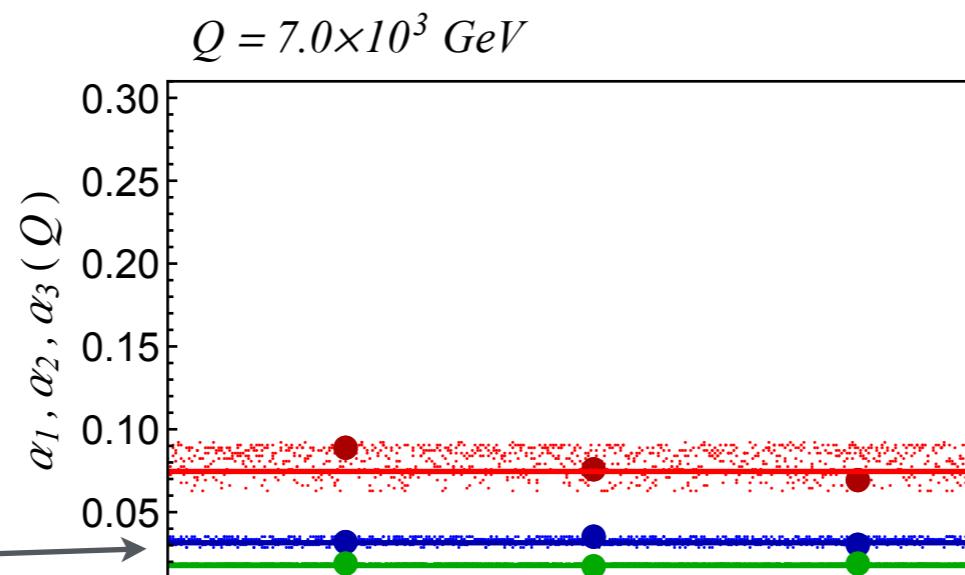
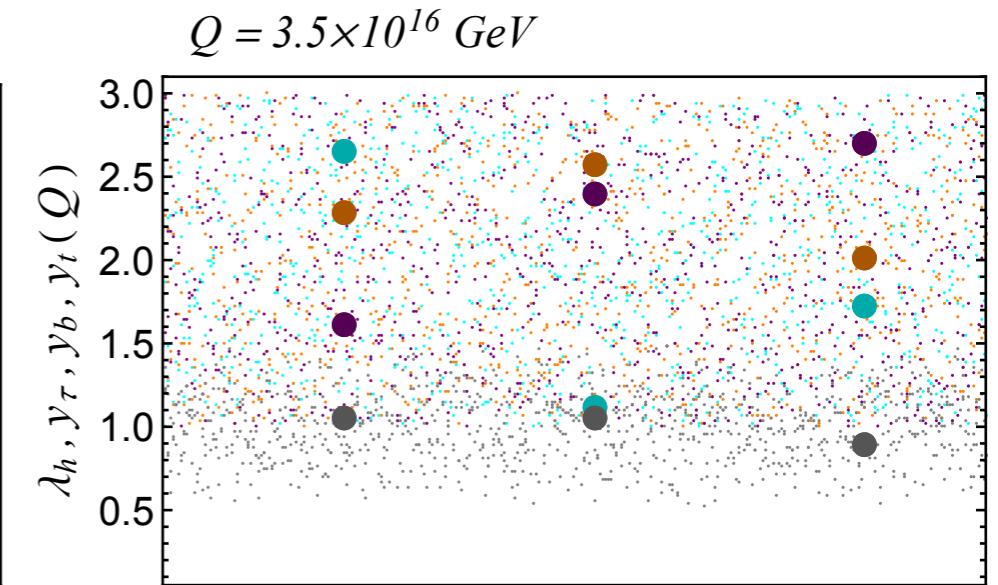
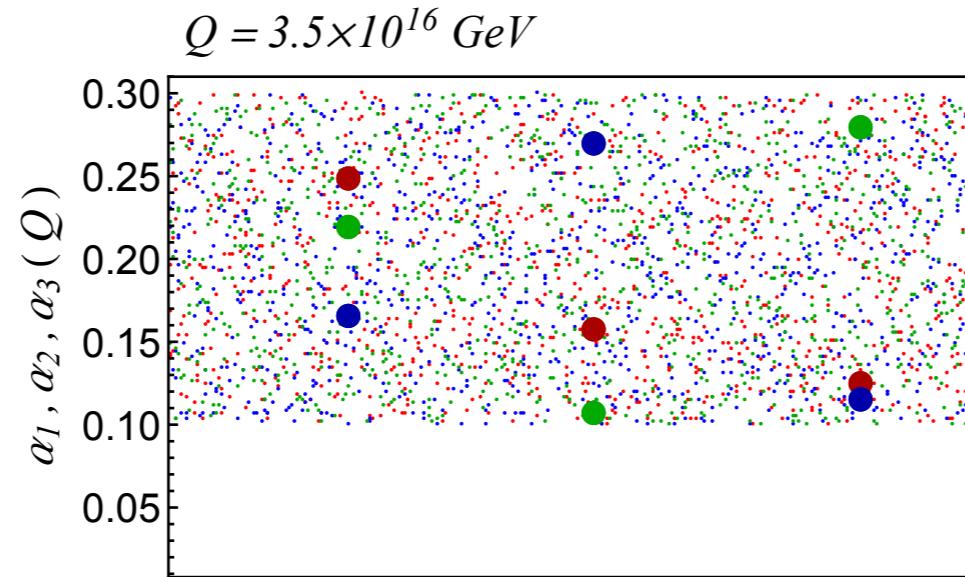
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MSSM+1VF

M = few TeV

solid line are SM measured values evolved to a given scale, they include SUSY threshold corrections assuming  $\tan \beta = 40$



**Distinctive pattern of couplings emerges**

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GUT scale

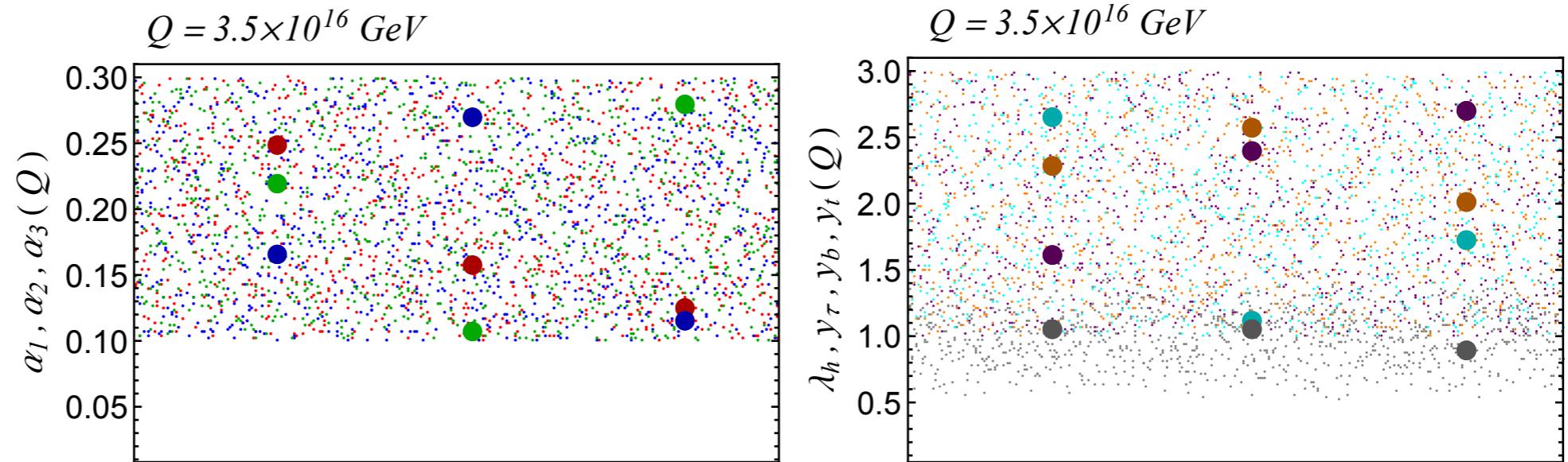
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SM

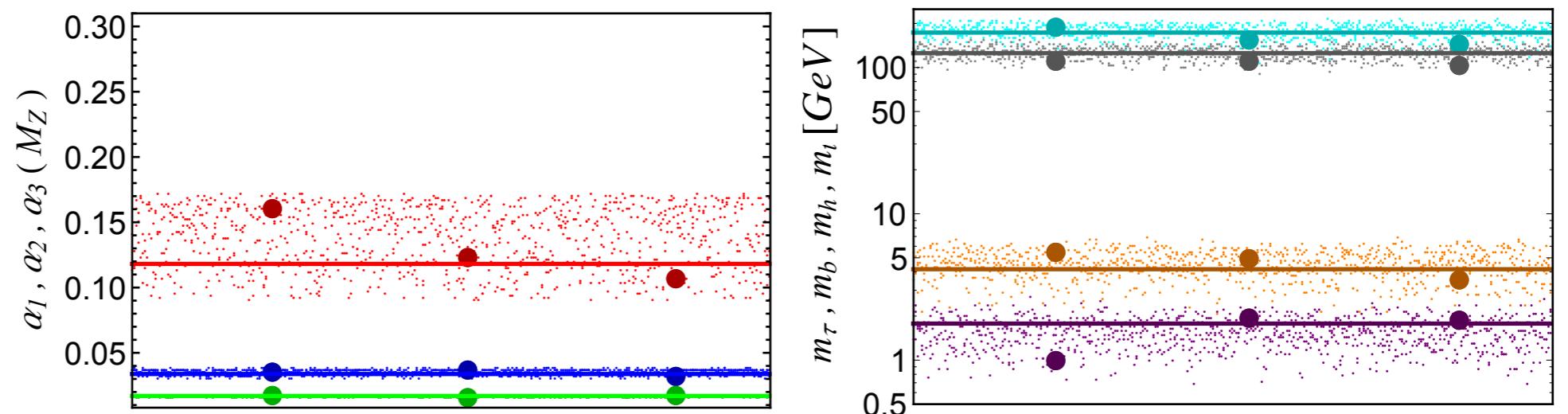
EW scale



GUT: Random boundary conditions



EW: familiar pattern of couplings and masses



# Optimizing parameters related to scales

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For random unrelated (or unified) parameters:

$$\alpha_1(M_G), \alpha_2(M_G), \alpha_3(M_G) \in [0.1, 0.3]$$

$$y_t(M_G), y_b(M_G), y_\tau(M_G), Y_V(M_G) \in [1, 3]$$

three parameters,

$$M_G, M, \tan \beta,$$

can be optimized so that none of the seven observables is more than 25% (or 15%) from the measured values.

Further optimizing  $Y_V$  to obtain the required overall scale of Yukawa couplings, all 7 observables are within 11% (or 7.5%) from their measured values.

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more matter?

$$\begin{aligned} Q, \bar{U}, \bar{D}, L, \bar{E} \\ + \\ \bar{Q}, U, D, \bar{L}, E \end{aligned}$$

Many searches for individual new particle; but **searching for their combined signatures can be more advantageous than separate searches!**

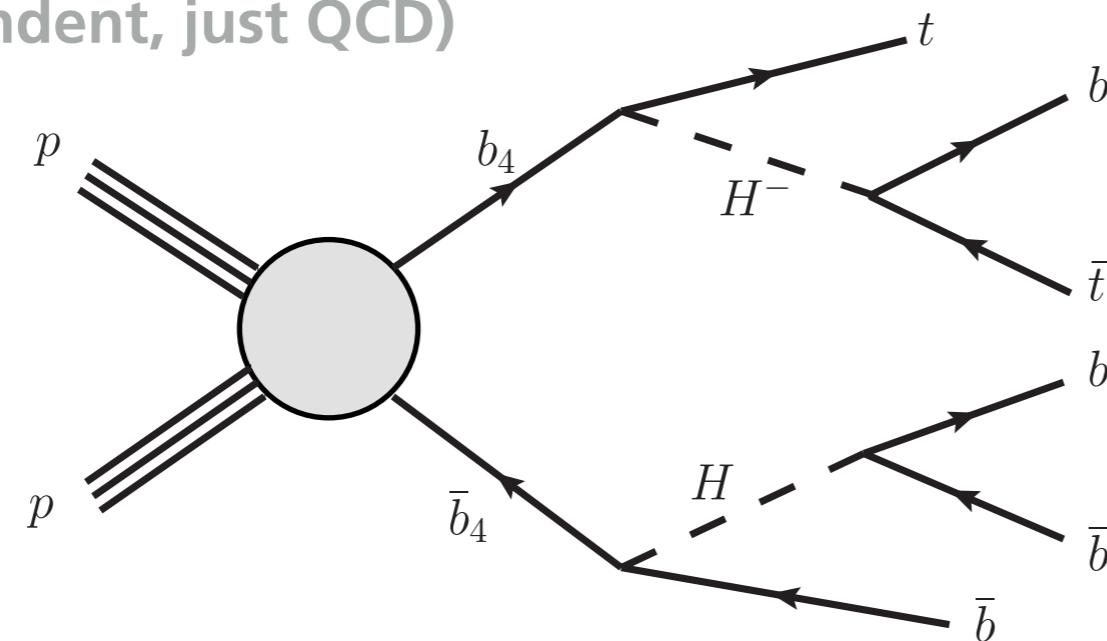
# Heavy Higgses in vectorlike quark decays

**Large production cross sections at the LHC:**

$$\sigma(m_Q = 1 \text{ TeV}) \simeq 50 \text{ fb}$$

$$\sigma(m_Q = 2 \text{ TeV}) \simeq 0.2 \text{ fb}$$

(model independent, just QCD)



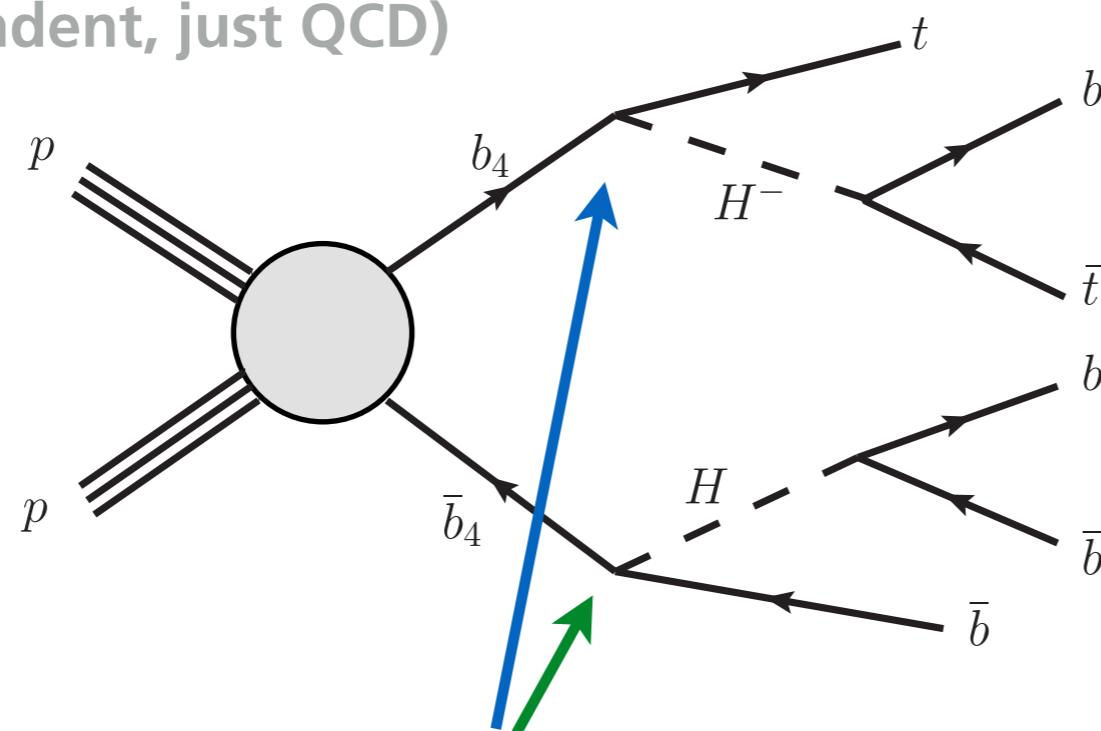
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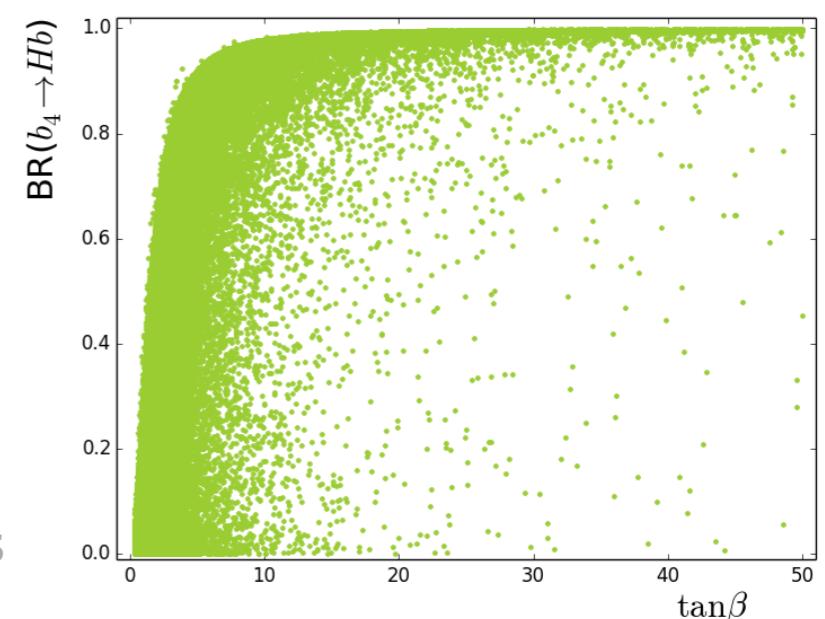
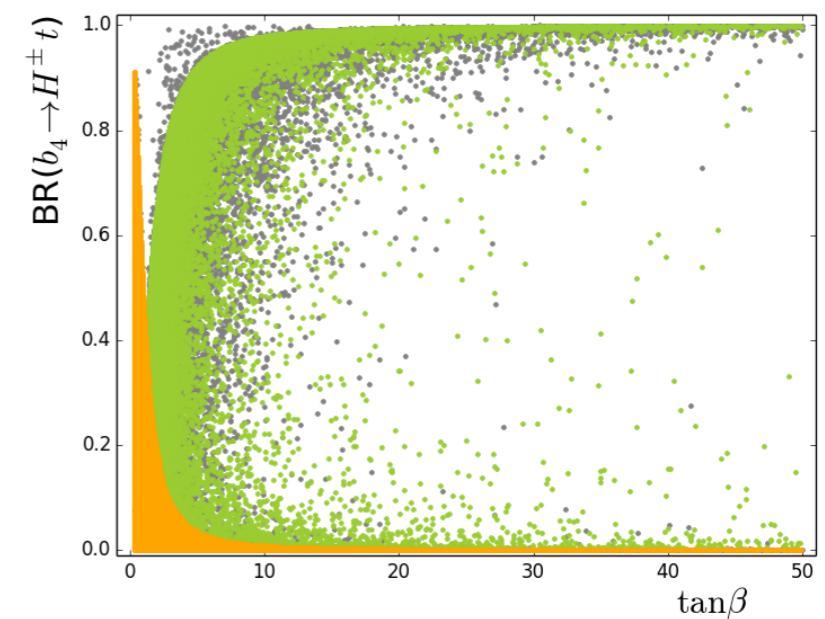
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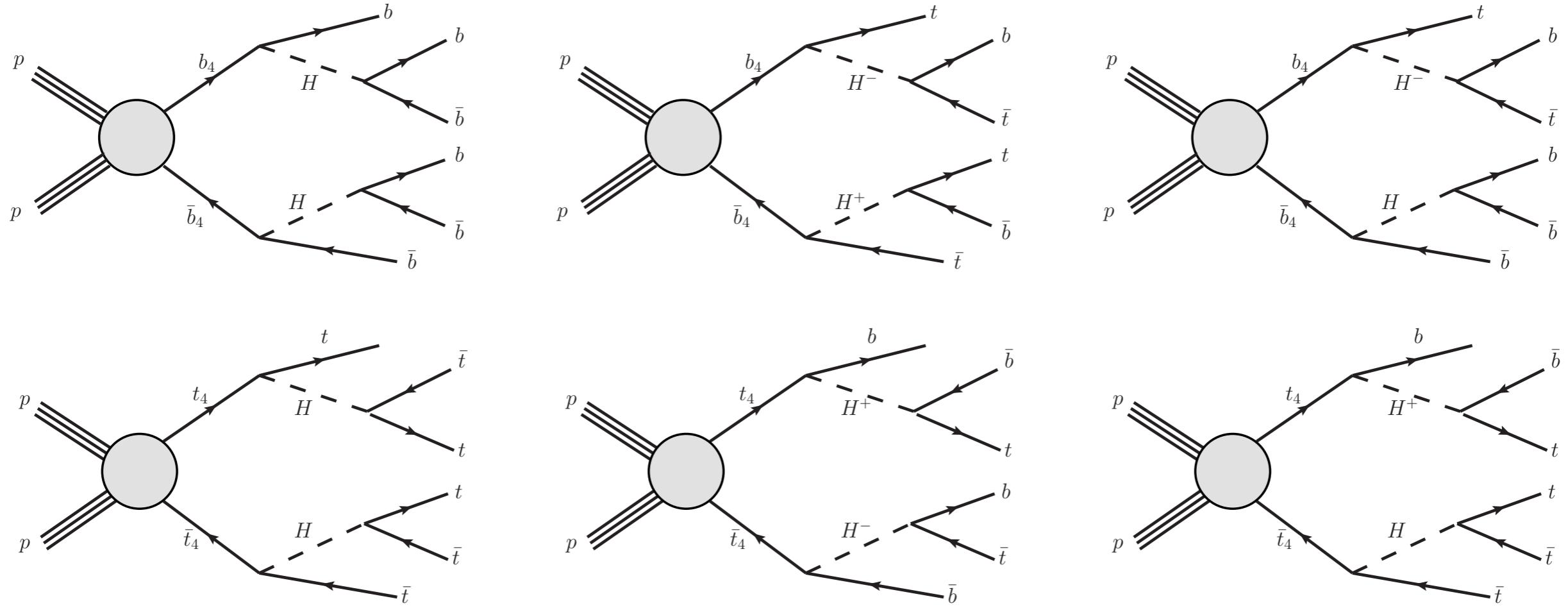
**BRs easily close to 100%  
in 2HDM type-II**

even tiny couplings that mix VQ with SM quarks  
make them decay, and decays through heavy Higgses  
easily dominate especially at medium to large  $\tan \beta$

R.D., E. Lunghi and S. Shin, arXiv:1901.03701



# Heavy Higgses in vectorlike quark decays



**heavy Higgses are effectively pair-produced with QCD size cross sections**

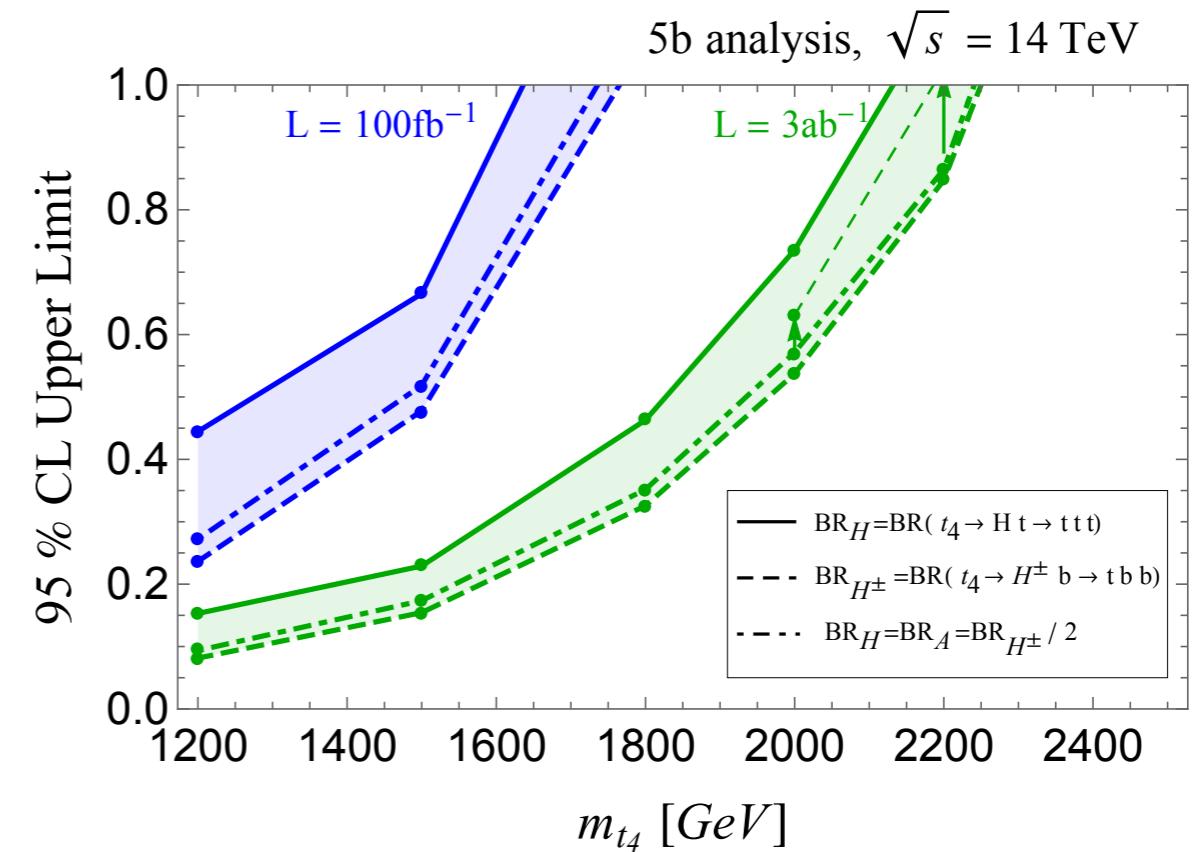
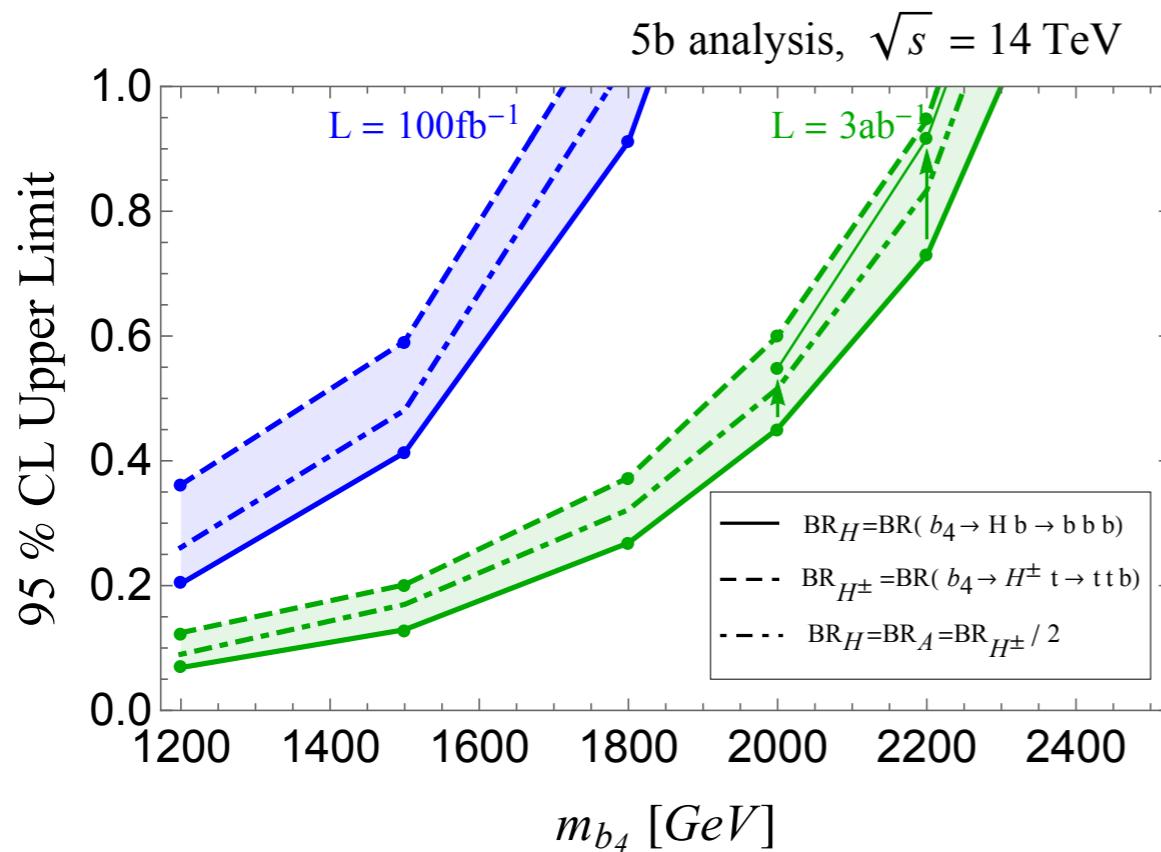
**6t, 4t2b, 2t4b, 6b final states have tiny irreducible SM background**

**Many possible ways to search, 6b in final states is common to all!**

# Heavy Higgses in 6b final states

Reach of a search strategy requiring at least 5 bottom quarks:

details in R.D., E. Lunghi, N. McGinnis and S. Shin, arXiv:2005.07222 [hep-ph]



LHC with  $139 \text{ fb}^{-1}$  sensitive to heavy Higgses up to  $\sim 1.6 \text{ TeV}$

HL-LHC sensitive to heavy Higgses up to  $\sim 2 \text{ TeV}$

# Conclusions

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Models with more Higgses and vectorlike matter are among the simplest extensions of the standard model,  
and can provide understanding of values of 7 largest couplings in the SM.

Interesting combined signatures of heavy Higgses and VQs:

$$gg \rightarrow t_4 t_4 \\ t_4 \rightarrow Ht, H^\pm b$$

$$gg \rightarrow b_4 b_4 \\ b_4 \rightarrow Hb, H^\pm t$$

or combinations with the usual decay modes through Z, W and h;

some signatures the same as in other models: various top partners, composite Higgs, Z', W' (reach of suggested searches can be easily interpreted in such models).

- LHC with  $139 \text{ fb}^{-1}$  sensitive to heavy Higgses up to  $\sim 1.6 \text{ TeV}$
- HL-LHC sensitive to heavy Higgses up to  $\sim 2 \text{ TeV}$