

Charged and Neutral Higgs Bosons in Models with Vectorlike Quarks or Leptons

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

arXiv:2005.07222 [hep-ph]

arXiv:1901.03701 [hep-ph]

arXiv:1812.05240 [hep-ph]

arXiv:1608.00662 [hep-ph]

arXiv:1512.07837 [hep-ph]

and related studies:

arXiv:1907.07188 [hep-ph]

arXiv:[1509.04292](https://arxiv.org/abs/1509.04292) [hep-ph]

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Snowmass-EF02, 2HDM meeting, June 12, 2020

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 matter?

$$Q, \bar{U}, \bar{D}, L, \bar{E}$$

+

$$\bar{Q}, U, D, \bar{L}, E$$

more Higgses? 2HDM?

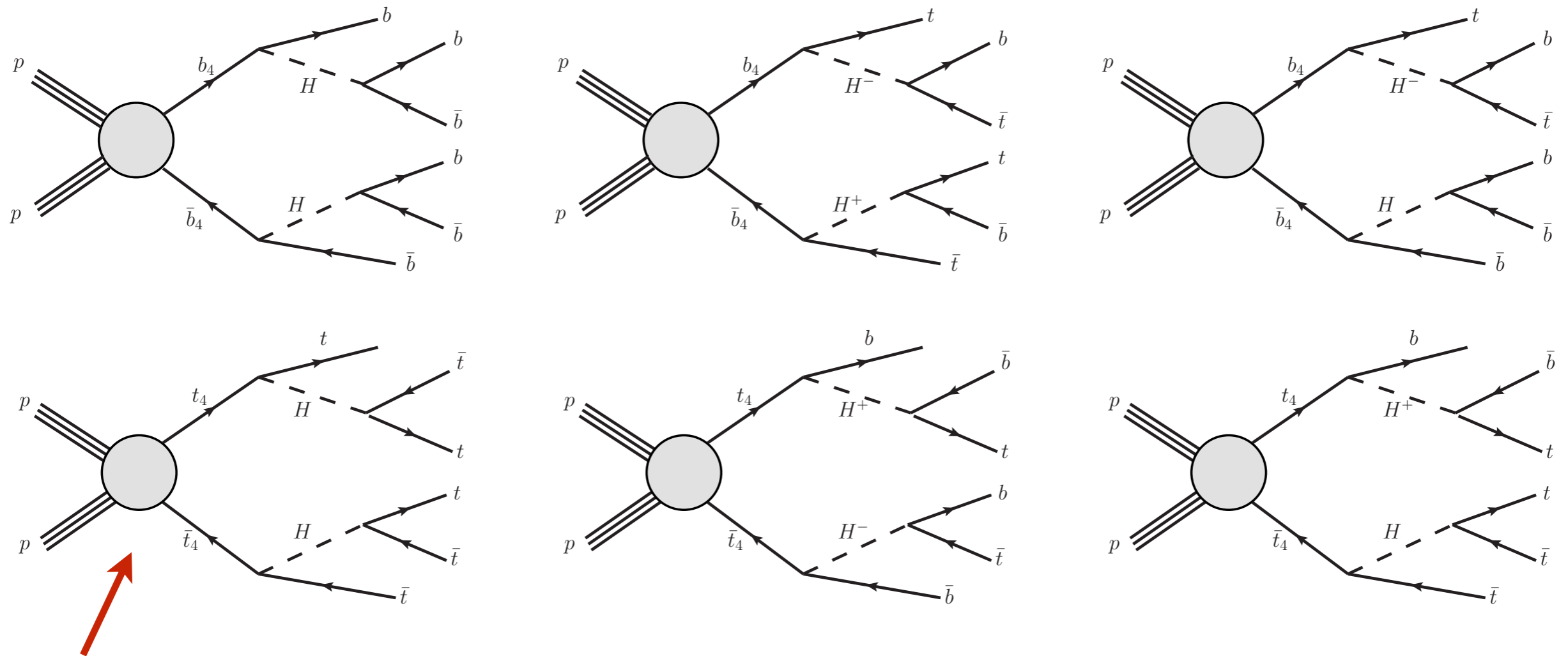
$$H, A, H^{\pm}$$

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]

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:

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

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

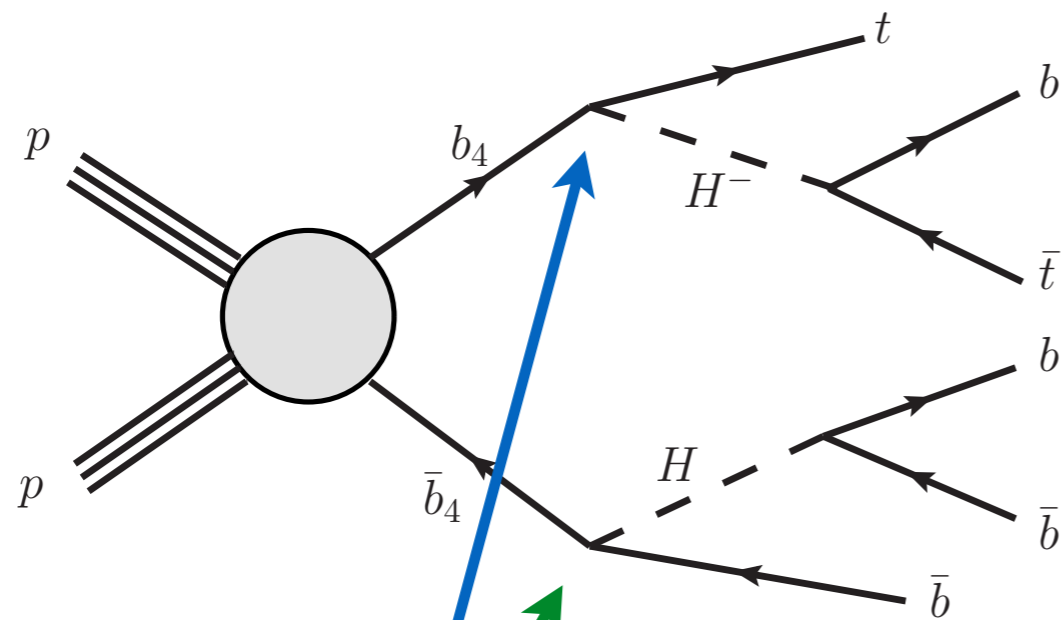
(model independent, just QCD)

Some of these signatures also appear in composite Higgs models or models with Z' , W'

we study them in 2HDM type-2
(rates and constraints are different)

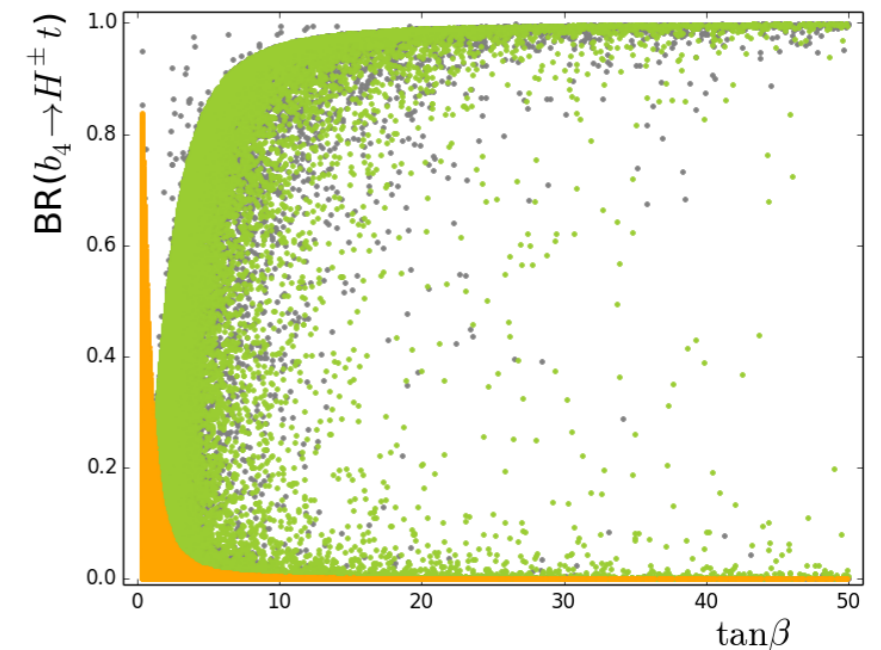
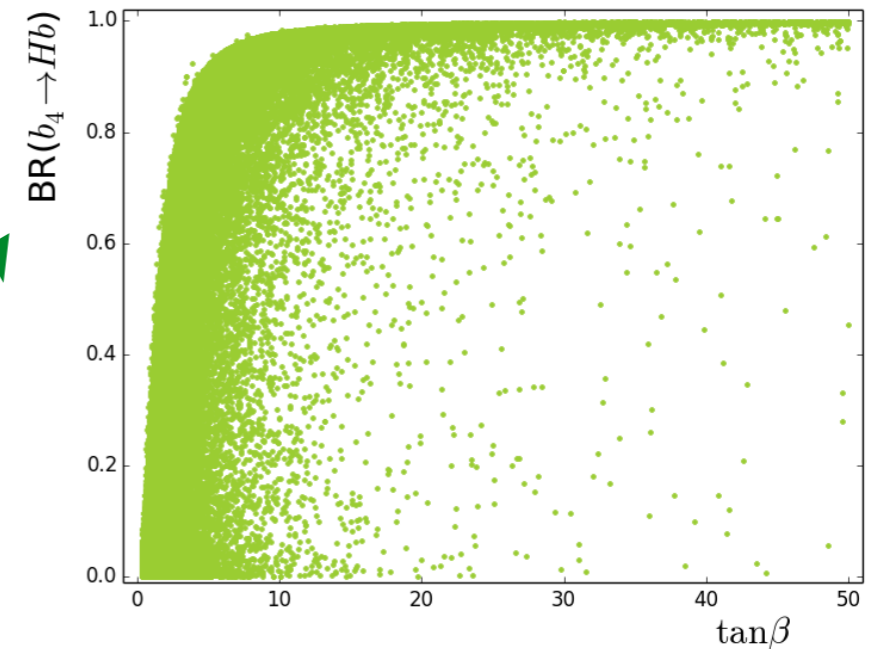
BRs in 2HDM type-2

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

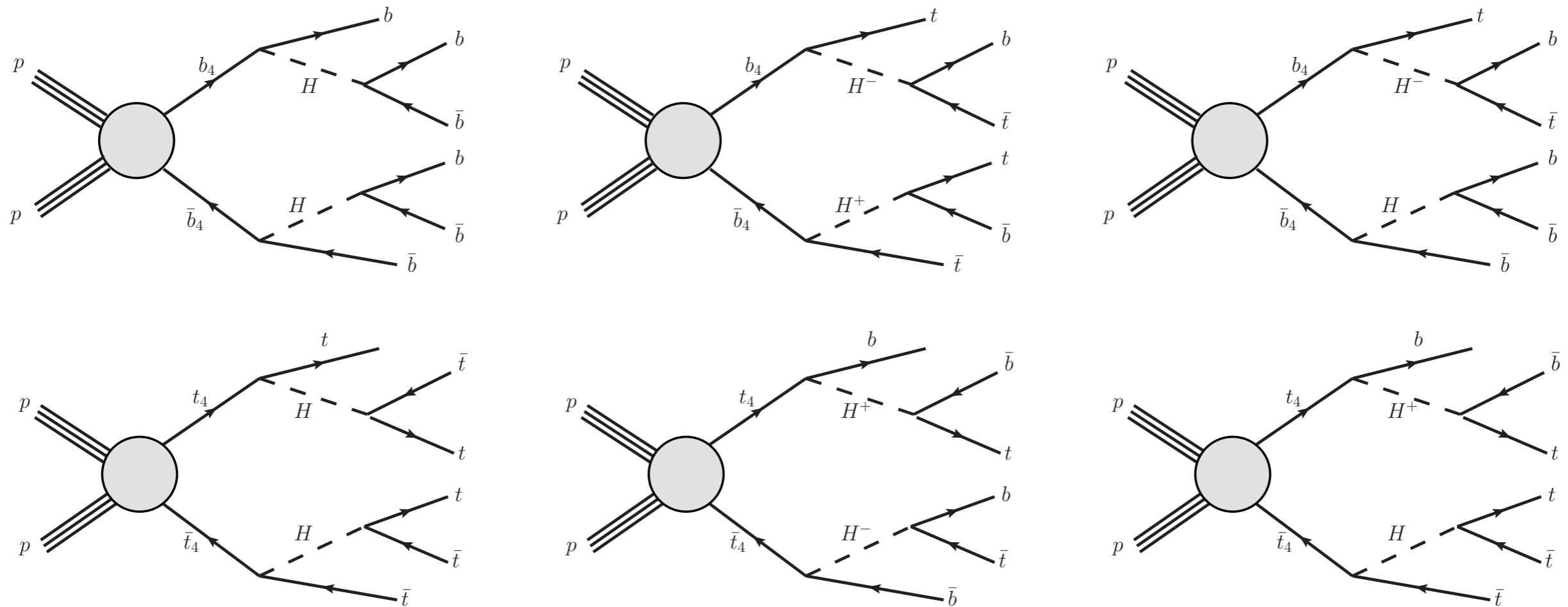


BRs easily close to 100%

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



Heavy Higgses in vectorlike quark decays



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

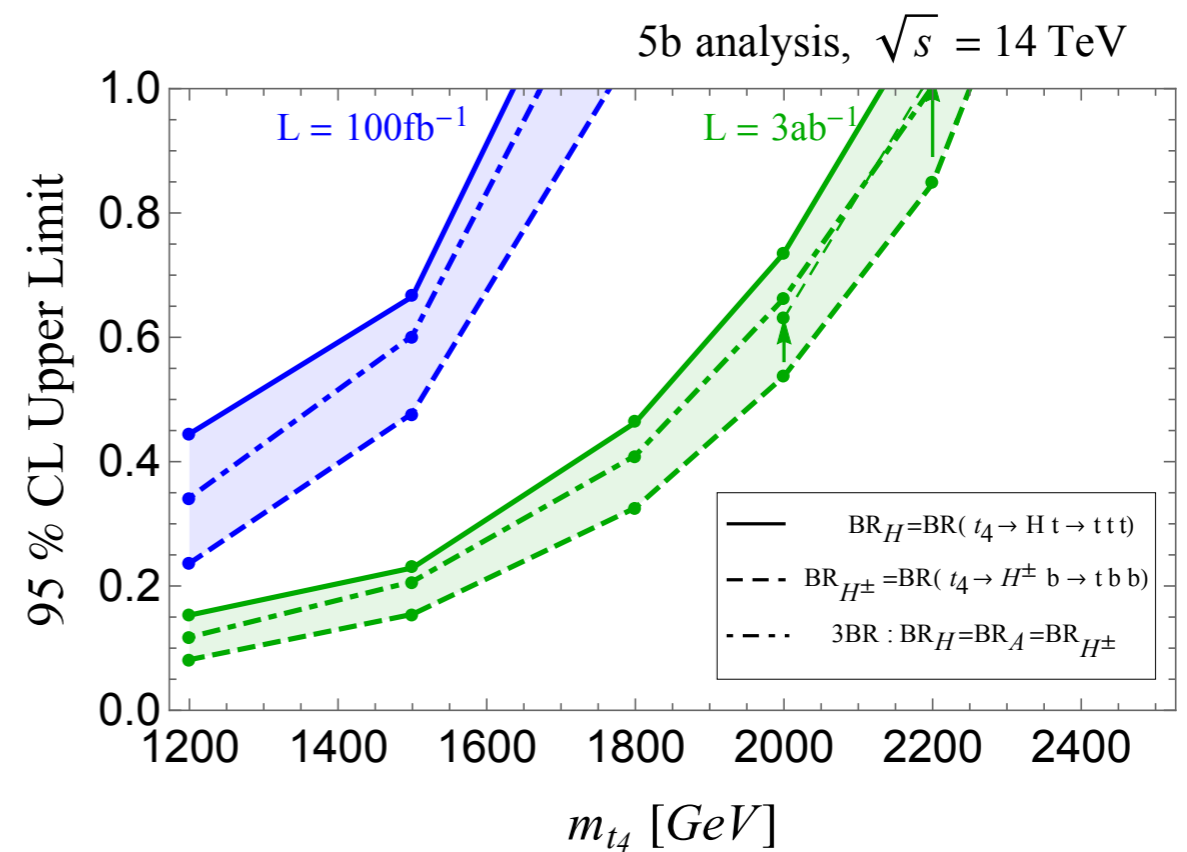
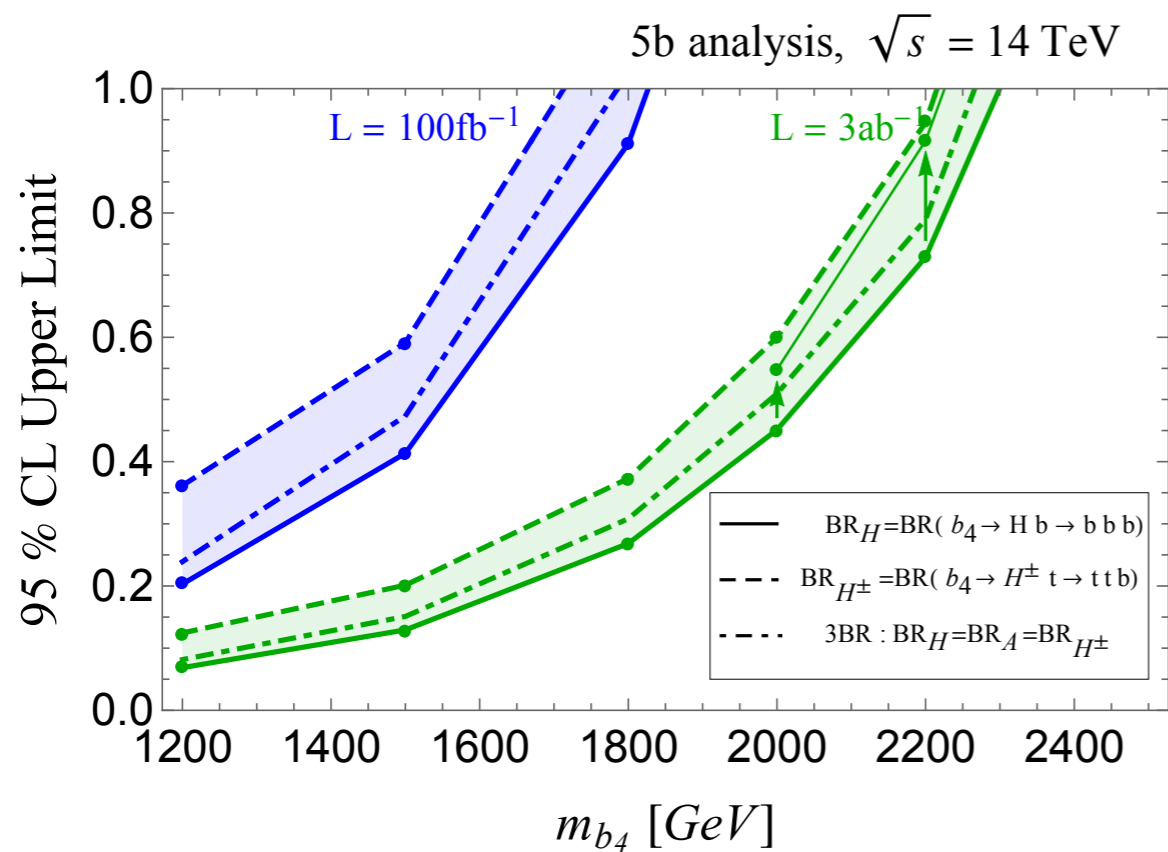
6t, 4t2b, 2t4b, 6b final states have tiny irreducible SM background

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 139fb^{-1} sensitive to heavy Higgses up to ~ 1.6 TeV

HL-LHC sensitive to heavy Higgses up to ~ 2 TeV

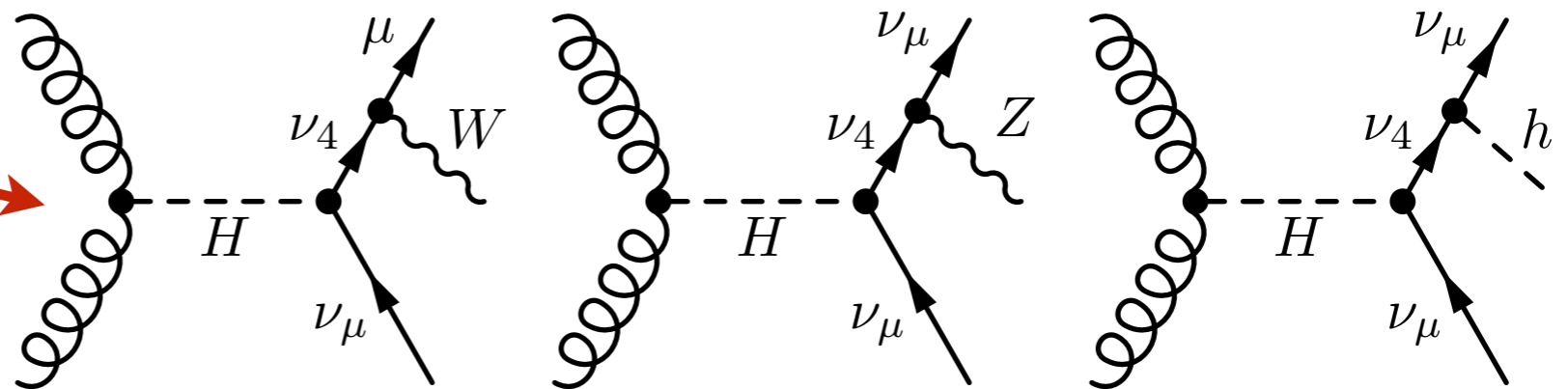
Vectorlike leptons in Higgs decays

The flavor changing couplings (originating from mixing of VL with SM leptons) lead to new decay modes of heavy Higgses:

Large cross section:

$$\sigma(m_H = 3 \text{ TeV}) \simeq 0.2 \text{ fb}$$

at large $\tan \beta$



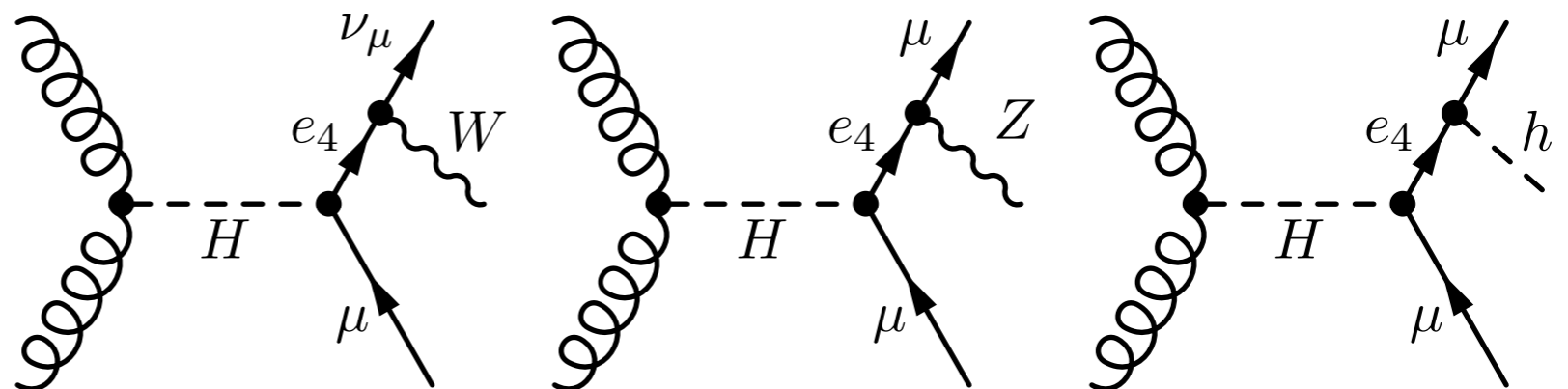
compared to

VL pair production:

$$\sigma(m_L = 1 \text{ TeV}) \simeq 0.07 \text{ fb}$$

$$\sigma(m_L = 2 \text{ TeV}) \simeq 0.4 \text{ ab}$$

(for charged SU(2) doublet)



can be repeated with e or tau or quarks

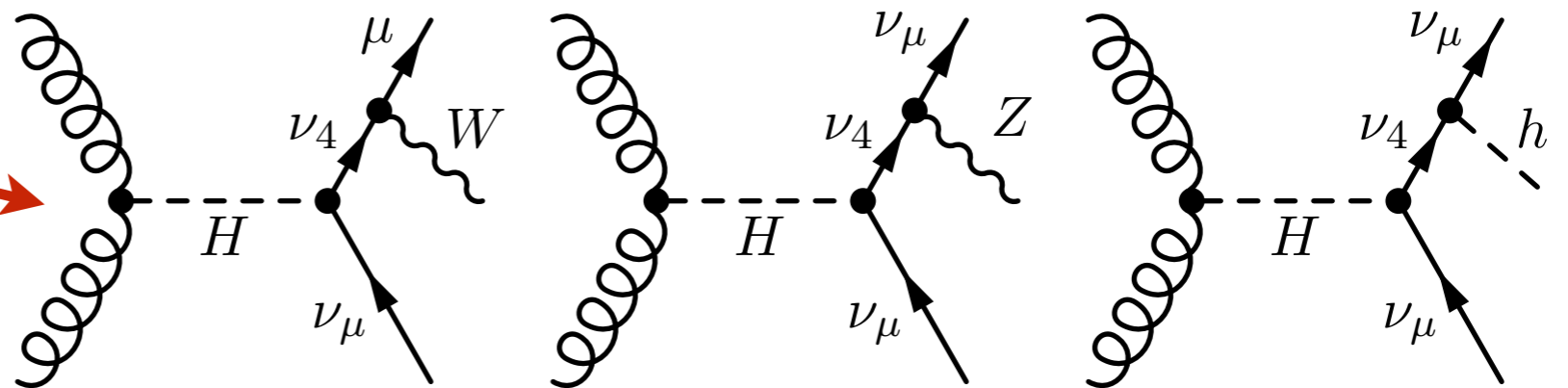
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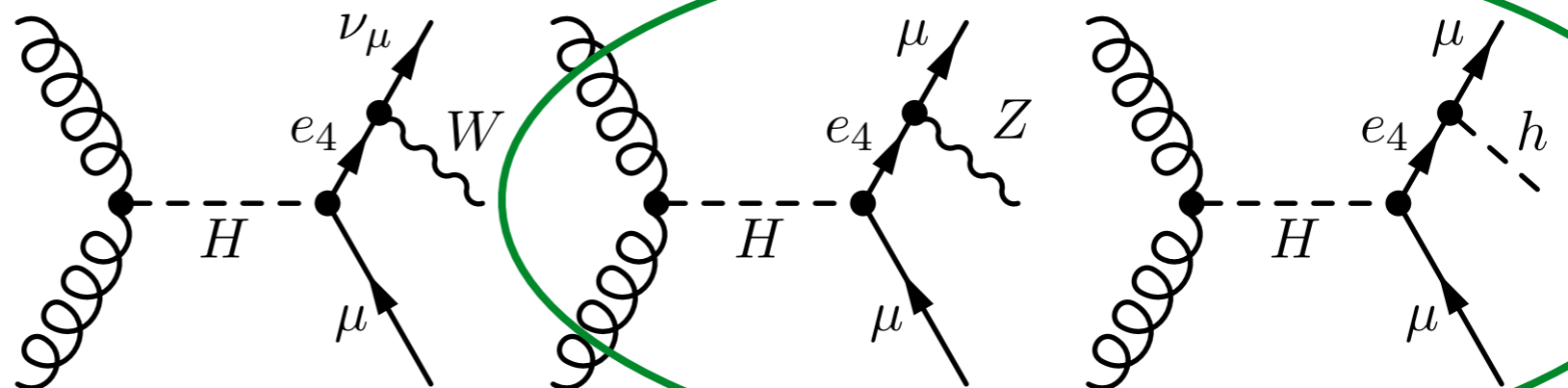
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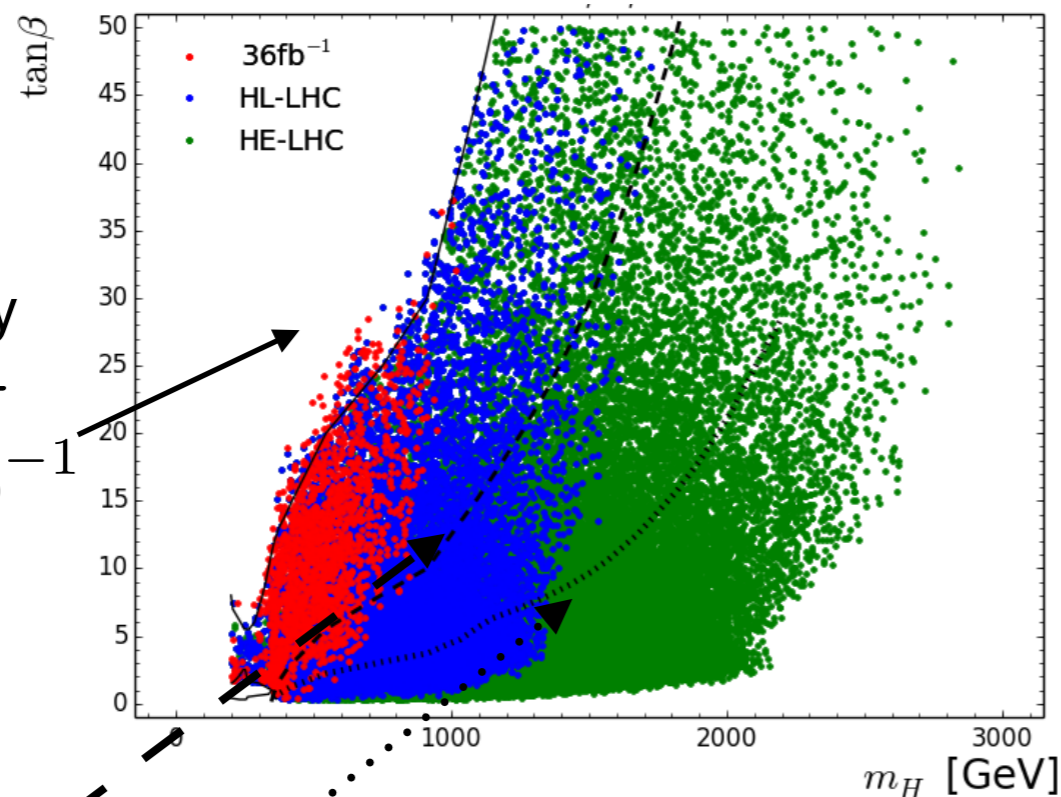


some have negligible SM background!

Sensitivity to $H \rightarrow h\mu\mu, Z\mu\mu$ at HL/HE-LHC

Scenarios satisfying all the limits that can be seen at 95% C.L.:

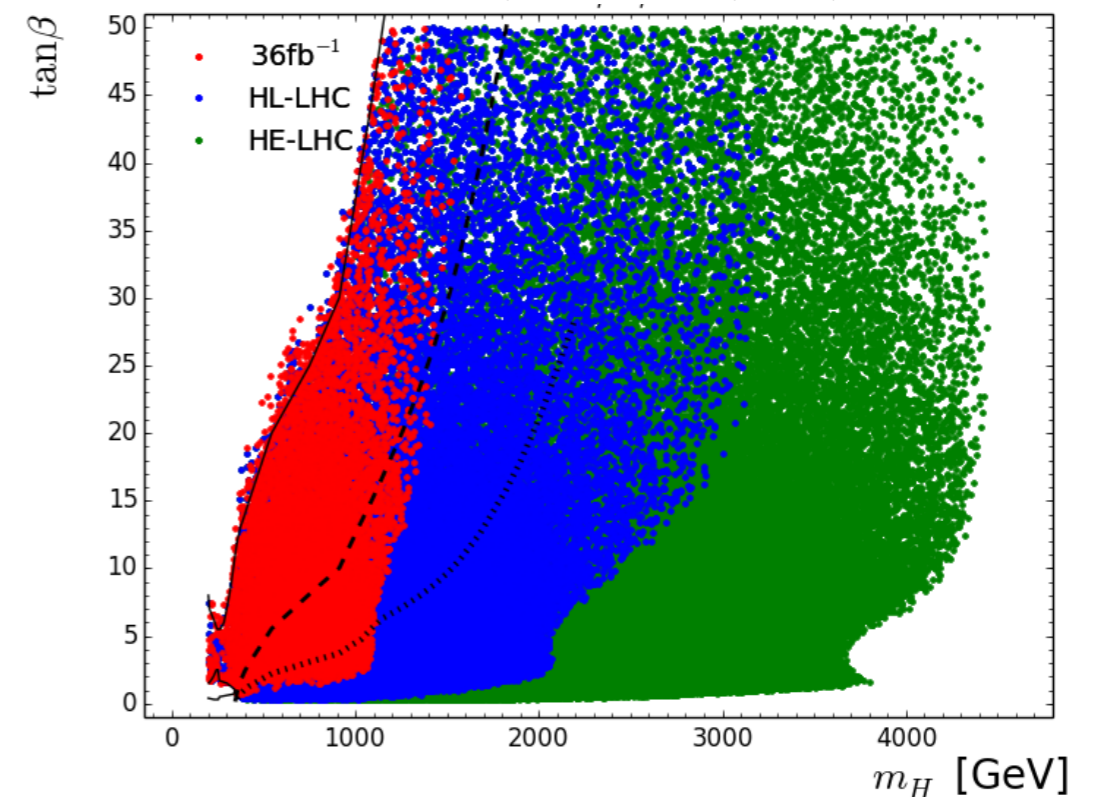
$$H \rightarrow e_4\mu \rightarrow h\mu^+\mu^-$$



excluded by
 $H \rightarrow \tau\tau$
with 36 fb⁻¹

projected
 $H \rightarrow \tau\tau$
at HL-LHC and at HE-LHC

$$H \rightarrow e_4\mu \rightarrow Z\mu^+\mu^-$$



HL(HE)-LHC sensitive to heavy Higgses up to ~3(4.5) TeV

Conclusions

models with more Higgses and vectorlike matter are among the simplest extensions of the standard model

many interesting combined signatures, e.g.

$$\begin{array}{ll} gg \rightarrow t_4 t_4 & gg \rightarrow b_4 b_4 \\ t_4 \rightarrow Ht, H^\pm b & b_4 \rightarrow Hb, H^\pm t \end{array}$$

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, if somebody is interested)
- any suggestions or collaborations are welcome