Testing effective Yukawa couplings in Higgs searches at Tevatron & LHC

Emidio Gabrielli
CERN PH-TH

in collaboration with B. Mele
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Yukawa couplings

- Hierarchy of fermion masses is still a puzzle
- in SM, problem just shifted to the Yukawa sector
- difficult to explain all fermion spectrum and CKM mixing by means of few parameters
- many SM extensions proposed → no one can be considered as conclusive
- maybe ChSB and EWSB have not the same origin → different symmetry-breaking mechanisms
- examples: compositeness, extradimensions, technicolor, unknown mechanism of ChSB ?

- However, there are indications that SM Higgs mechanism is behind the EWSB

- EW precision tests favour a light SM Higgs boson

- perturbative unitarity in WW $\rightarrow$ WW satisfied

what if the SM Higgs boson is only responsible of EWSB $\rightarrow$ W and Z masses ?

- fermion masses put in by hand, no tree-level Yukawa couplings $\rightarrow$ explicit ChSB

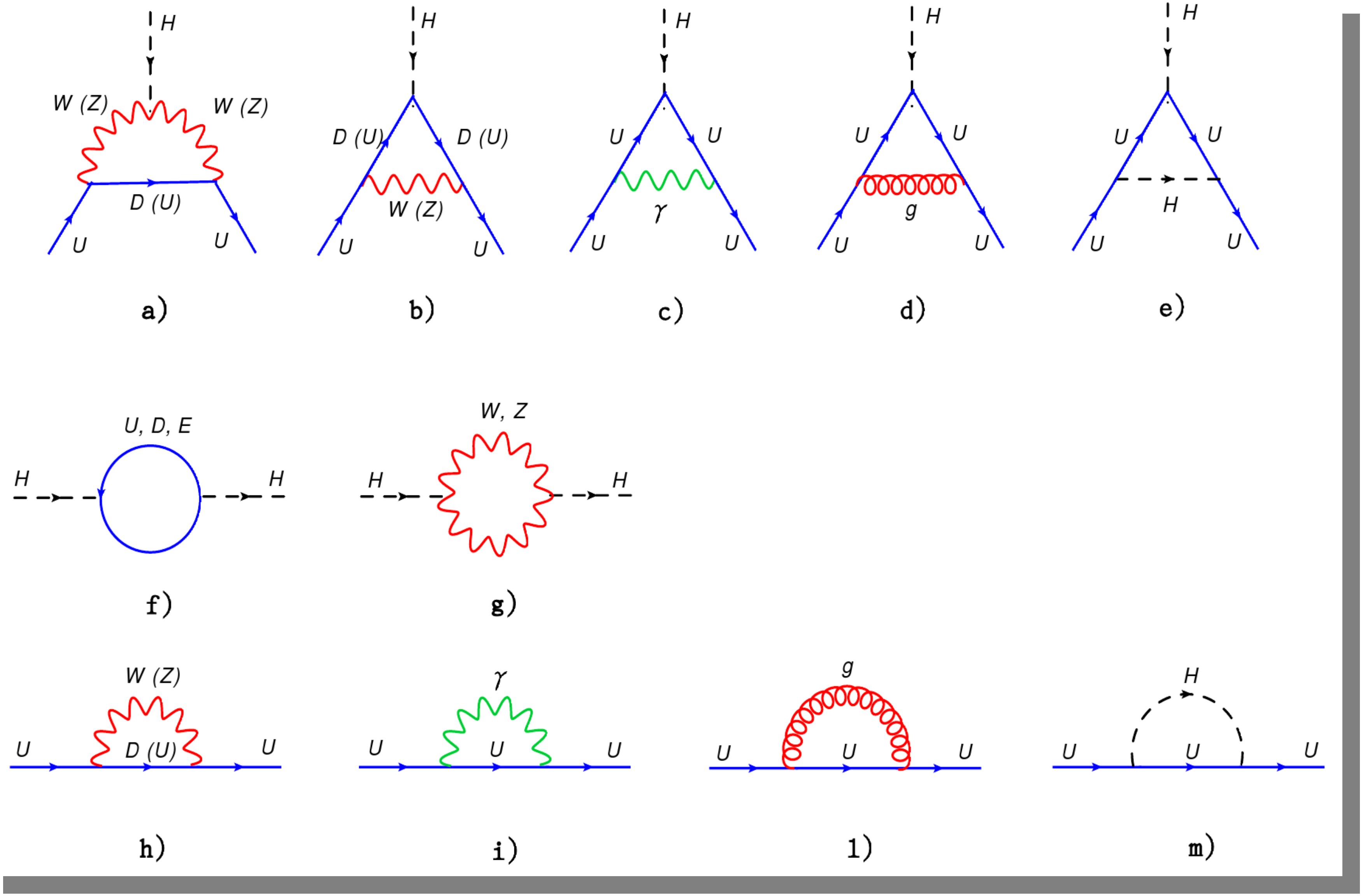
- SM becomes non-renormalizable, but still it can be considered as an effective field theory suppose Λ is the scale where Yukawas are vanishing (i.e. scale of fermion mass generation)

- Yukawa couplings not protected against radiative corrections due ChSB → radiatively generated
- we need to re-sum large logs $g_i^{2n} \log^n (\Lambda/m_H)$
- efficient tool → Renormalization Group Equations
- SM RGE are not valid (tree-level Yukawa couplings)

⇓

RGE must be derived by keeping Yukawa couplings and fermion masses separate

Relevant Feynman diagrams for the Up Yukawa's beta-functions. Unitary gauge



RGE for Yukawa couplings of U , D quarks

SM RGE recovered for $\mathbf{Y_f^{SM}} \to \mathbf{Y_f}$

$$\frac{d\mathbf{Y_U}}{dt} = \frac{1}{16\pi^2}\Big\{3\,\xi_H^2\left(\mathbf{Y_U}-\mathbf{Y_U^{SM}}\right)-3\mathbf{Y_U^{SM}}\mathbf{Y_D^{SM}}\left(\mathbf{Y_D}-\mathbf{Y_D^{SM}}\right)+\frac{3}{2}\mathbf{Y_U}\left(\mathbf{Y_U}\mathbf{Y_U}-\mathbf{Y_D^{SM}}\mathbf{Y_D^{SM}}\right)$$
$$-\ \mathbf{Y_U}\left(\frac{17}{20}g_1^2+\frac{9}{4}g_2^2+8g_3^2-\mathbf{Tr}(\mathbf{Y})\right)\Big\}\,,$$

$$\frac{d\mathbf{Y_D}}{dt} = \frac{1}{16\pi^2}\Big\{3\,\xi_H^2\left(\mathbf{Y_D}-\mathbf{Y_D^{SM}}\right)-3\mathbf{Y_D^{SM}}\mathbf{Y_U^{SM}}\left(\mathbf{Y_U}-\mathbf{Y_U^{SM}}\right)+\frac{3}{2}\mathbf{Y_D}\left(\mathbf{Y_D}\mathbf{Y_D}-\mathbf{Y_U^{SM}}\mathbf{Y_U^{SM}}\right)$$
$$-\ \mathbf{Y_D}\left(\frac{1}{4}g_1^2+\frac{9}{4}g_2^2+8g_3^2-\mathbf{Tr}(\mathbf{Y})\right)\Big\}\,,$$

$$\mathbf{Y} \equiv N_c\mathbf{Y_U}\mathbf{Y_U}+N_c\mathbf{Y_D}\mathbf{Y_D}+\mathbf{Y_E}\mathbf{Y_E}$$

W(L) polarizations

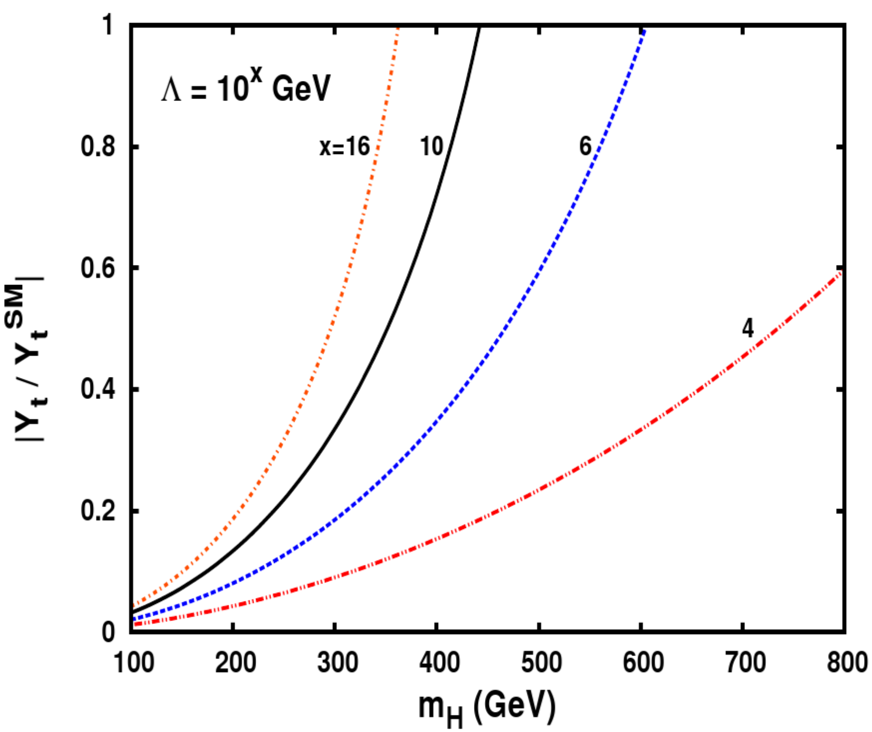
$$\xi_H \equiv \frac{g_2 m_H}{2M_W}, \qquad \mathbf{Y_f^{SM}} \equiv \frac{g_2}{\sqrt{2}M_W}\mathrm{diag}[\mathbf{m}_\mathrm{f}]$$

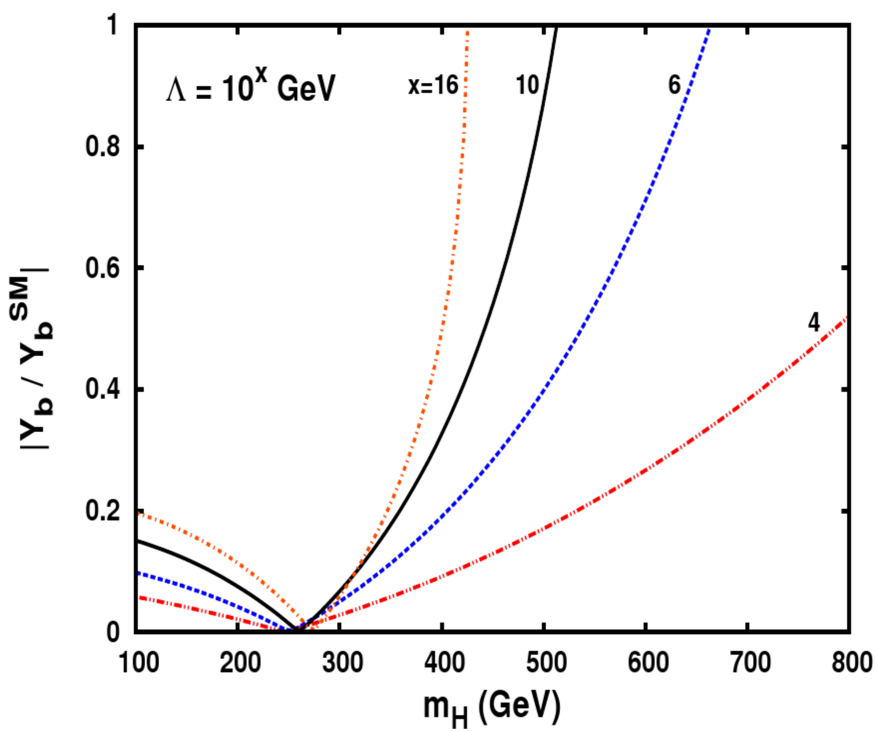
ChSB terms

Theoretical Framework

- Yukawa couplings set to zero at scale Λ and connected to mH scale by solving the RGE
- only SM degrees of freedoms below Λ assumed
- |Y(mH)| < 1 ⇨ satisfied for light Higgs masses

top-Yukawa (mH) **b-Yukawa (mH)**





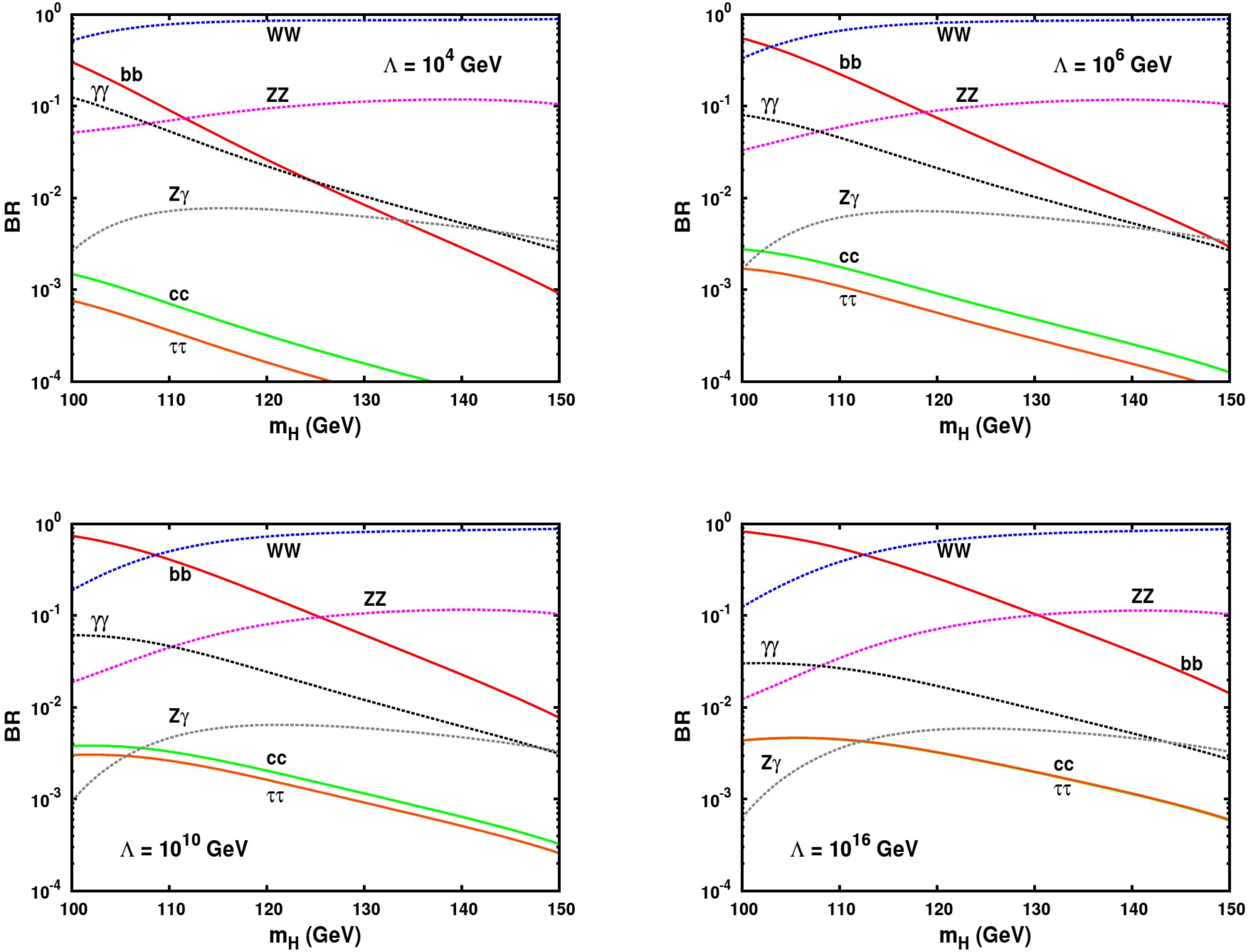
Higgs decay modes dramatically affected

- main Higgs decays into $\gamma\gamma$, WW, ZZ, γZ
- BR($H \rightarrow bb$) can be comparable to enhanced $\gamma\gamma$
- differs from naïve fermiophobic scenarios where Yukawa couplings are set to zero at EW scale

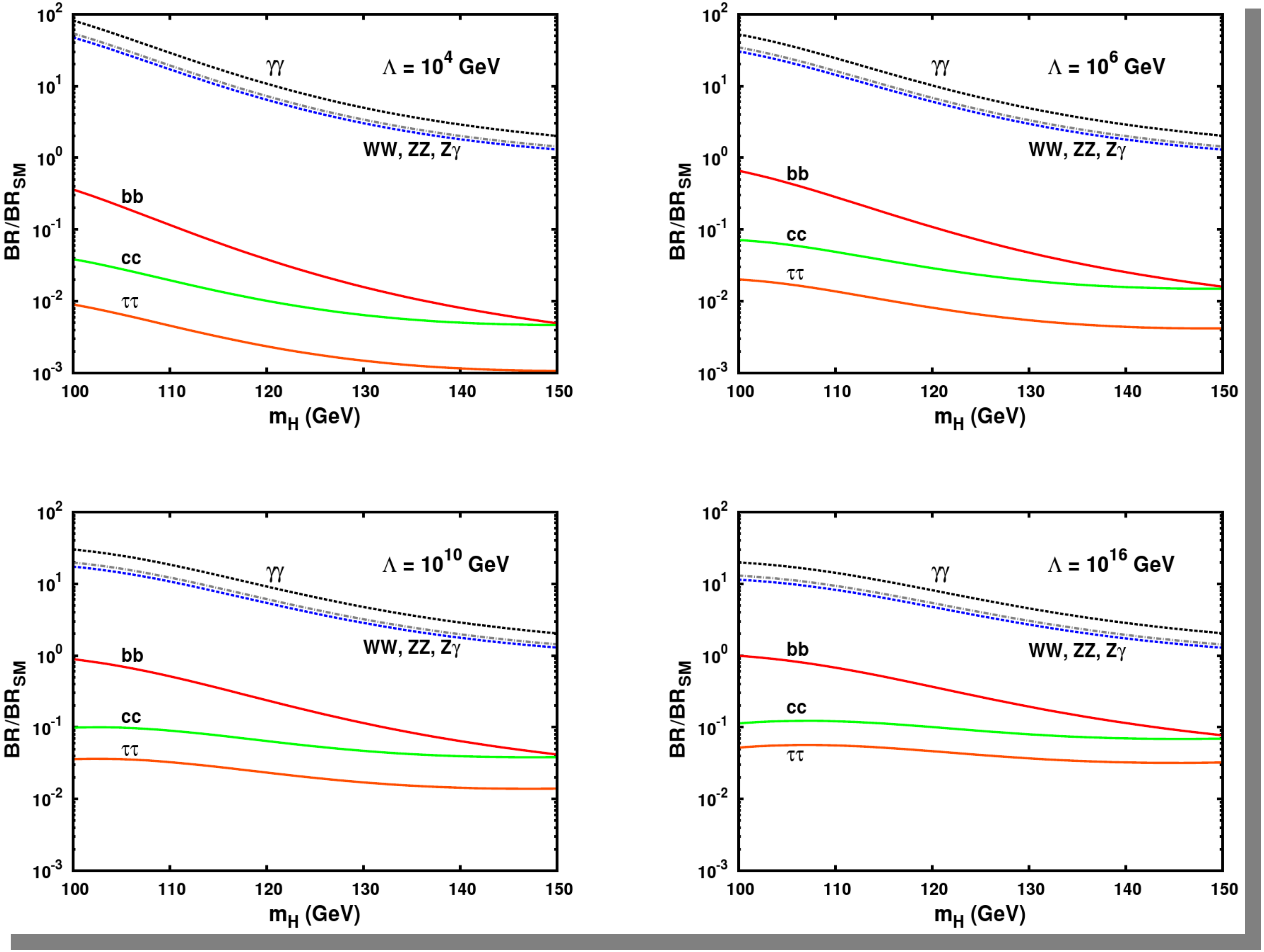
Higgs production mechanisms change

- top-Yukawa coupling radiatively induced (small)
- gluon-gluon fusion suppressed
- Vector boson fusion (VBF) becomes the dominant production mechanism

Higgs branching ratios



SM normalized branching ratios



Higgs production at hadron colliders

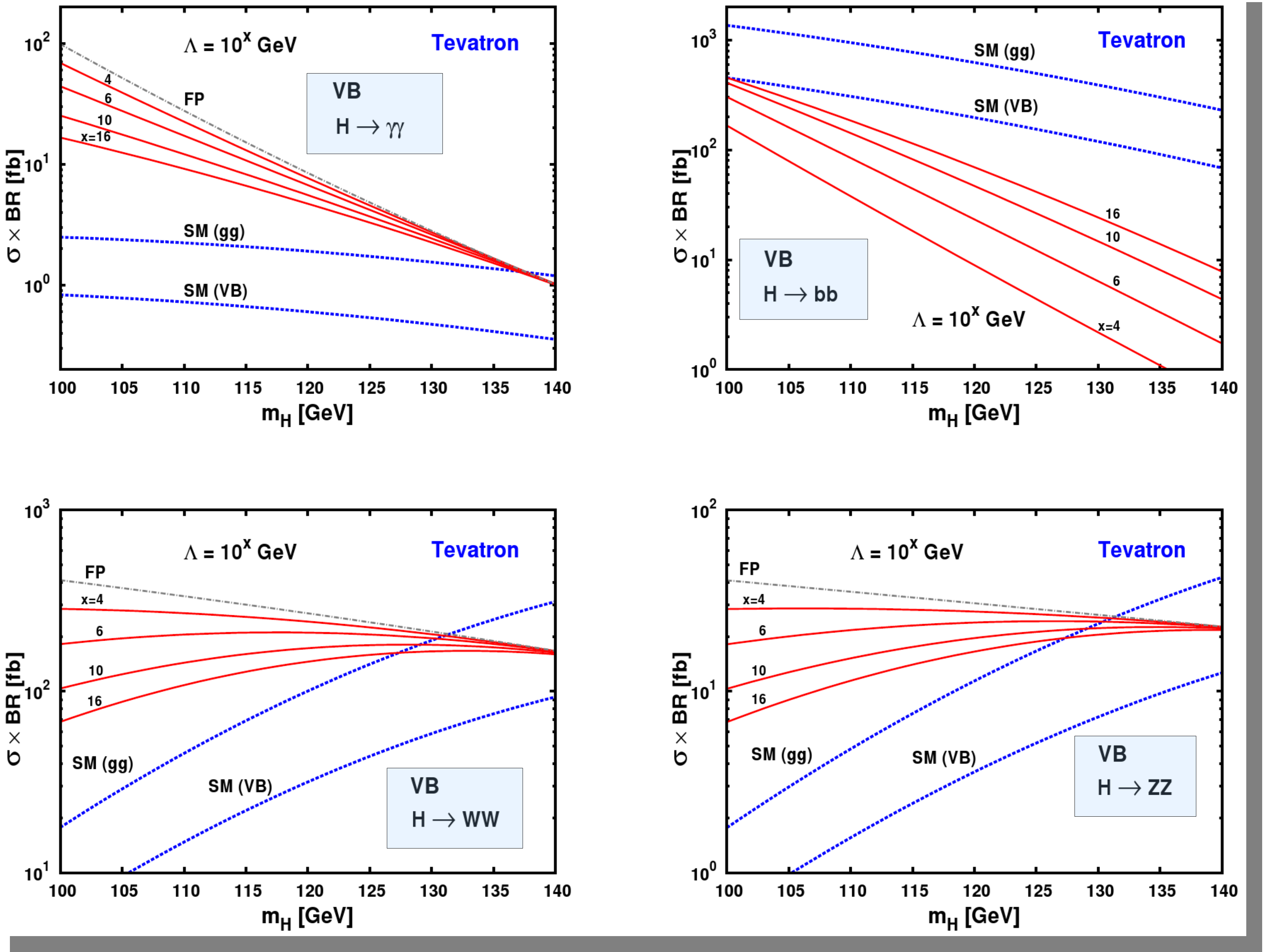
Tevatron $\sqrt{S} = 1.96\ \mathrm{TeV}$

- Inclusive cross sections used **VB=ZH+WH+VBF**
- gg fusion contribution neglected (suppressed by more than **SM/100**)
- computed at NLO, central values presented

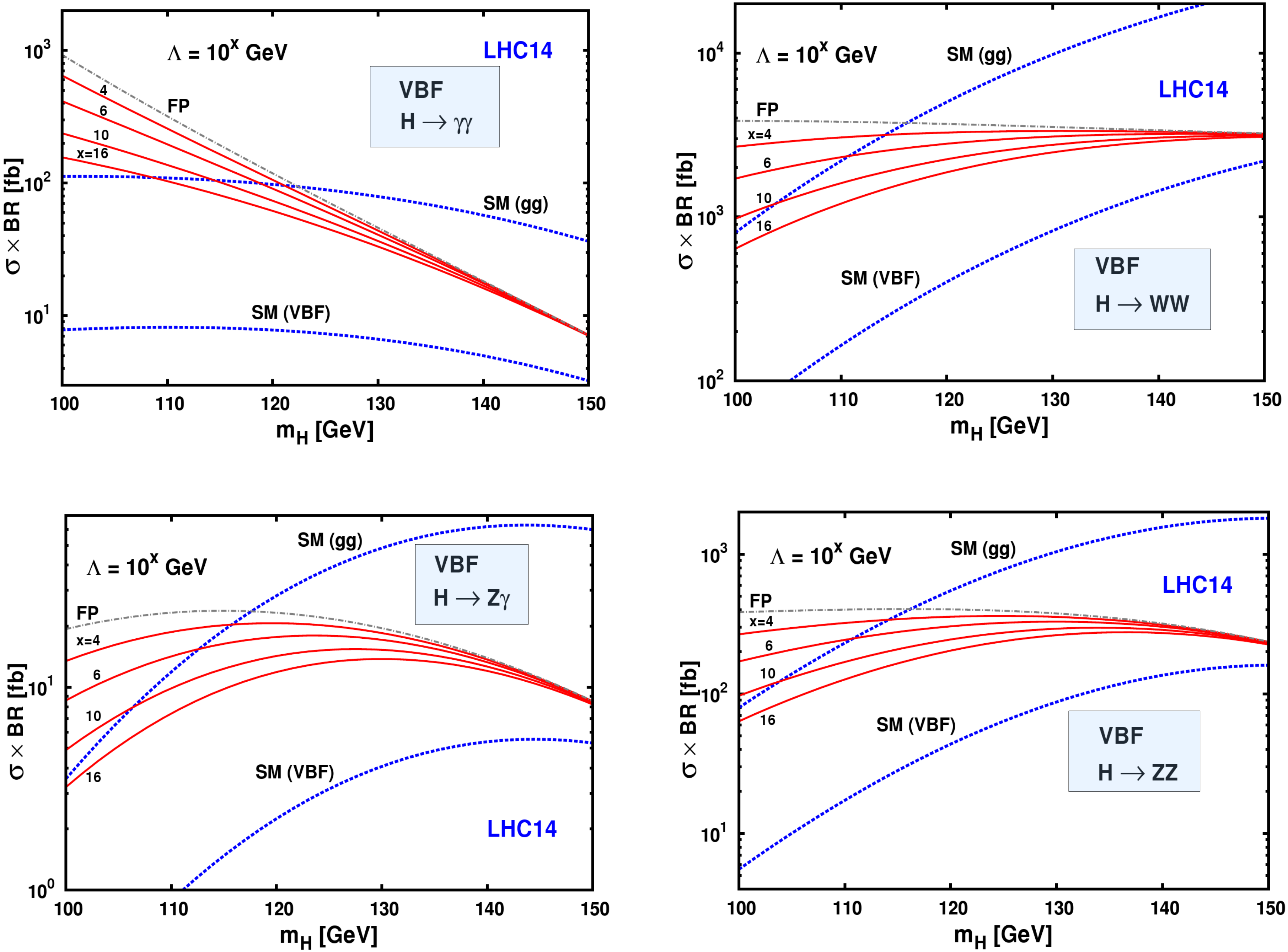
LHC $\sqrt{S} = 14\ \mathrm{TeV}$

- cross section used $\rightarrow$ **VBF** at NLO
- gg fusion neglected (a few percent of VBF)
- central values presented

Tevatron cross sections X BR (fb)



LHC14 cross sections X BR (fb)



Conclusions

- Scenario: Yukawa vanishing at a scale Λ
- radiatively generated at EW scale
- enhanced $H \to \gamma\gamma, WW, ZZ, Z\gamma$
- non-trivial depletion of bb decay
- Tevatron: could probe mH < 110 GeV
- LHC 14 TeV
  - excellent probe of this scenario
  - VBF signature larger than SM
  - better S/B ratio compared to SM
  - better theoretical accuracy (VBF)
- LC e+e- best probe: allow to directly test radiatively induced Yukawa couplings