Fermiophobic Higgs boson decays: probing the radiative fermionic sector at a linear collider

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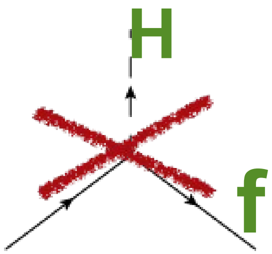
talk based on PRD 83: 073009 (2011)
PRD 82: 113014 (2010)

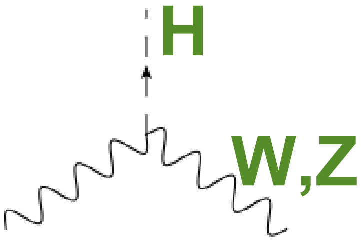
LCWS11, International Workshop on Future Linear Colliders

Granada, 26-30 September 2011

Outline

- a non-standard scenario: Fermio-Phobic (FP) Higgs





- radiative corrections → fermionic couplings regenerated
- expectations at the LHC and LC
- present experimental bounds

Origins of Yukawa couplings

- hierarchy of fermion masses is still a puzzle !
- in SM, problem just shifted to the Yukawa sector

$$\mathcal{L} = \mathbf{Y_f}\bar{\psi}_\mathbf{f}\psi_\mathbf{f}\,\mathbf{H} \Rightarrow \mathbf{m_f} = \mathbf{Y_f}\langle\mathbf{H}\rangle$$

- difficult to explain all fermion spectrum and CKM mixing by means of few parameters
- maybe the mechanism of fermion and W/Z masses is different
- but EW precision tests favor a light Higgs !

...what if Higgs boson is only responsible for M_W, M_Z but not of fermion masses ?

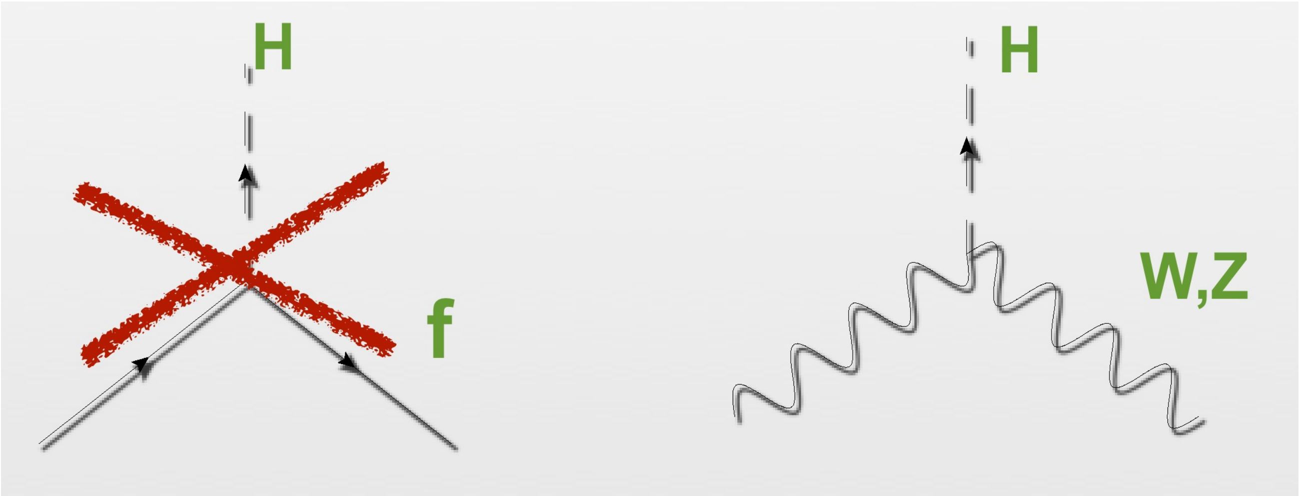
- fermion masses m_f → ChSB
  (Chiral Symmetry Breaking)

- in SM, ChSB and EWSB (M_W,M_Z) generated by the Higgs mechanism at same scale ~ $\langle H \rangle$

- not (yet) any experimental evidence supporting tree-level Yukawa couplings Y_f

- ChSB and EWSB can have different mechanisms
→ compositeness, extra-dimensions, technicolor...

a non-standard scenario:
a Fermio-Phobic (FP) Higgs



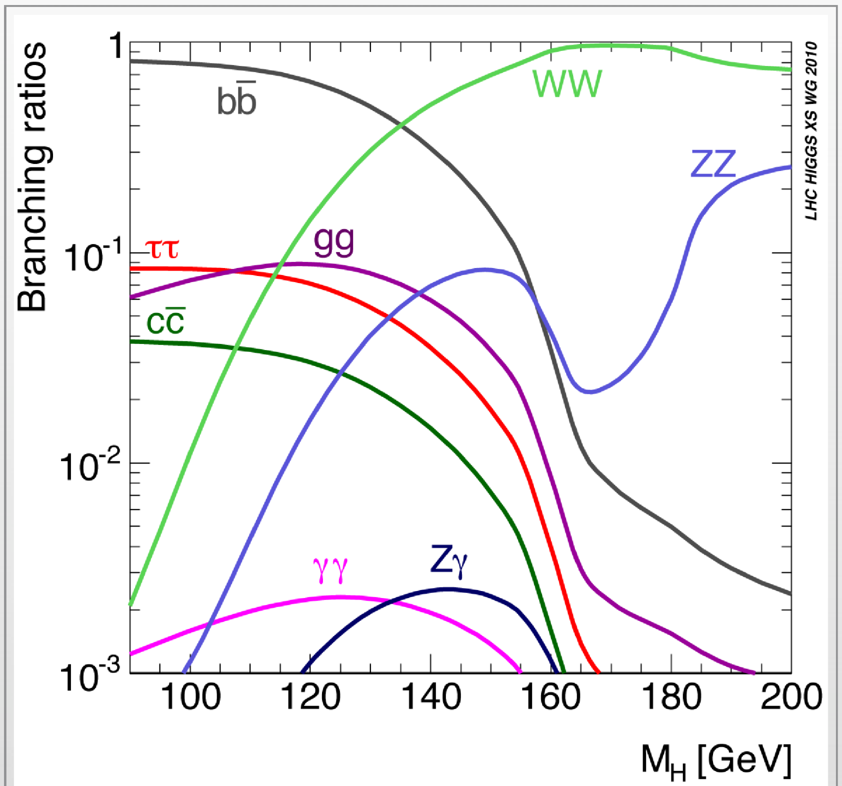
- NO Yukawa couplings at tree-level
- Higgs mechanism gives rise to EWSB and Mw,Mz but is not responsible for ChSB and fermion masses

Higgs decays : FP vs SM

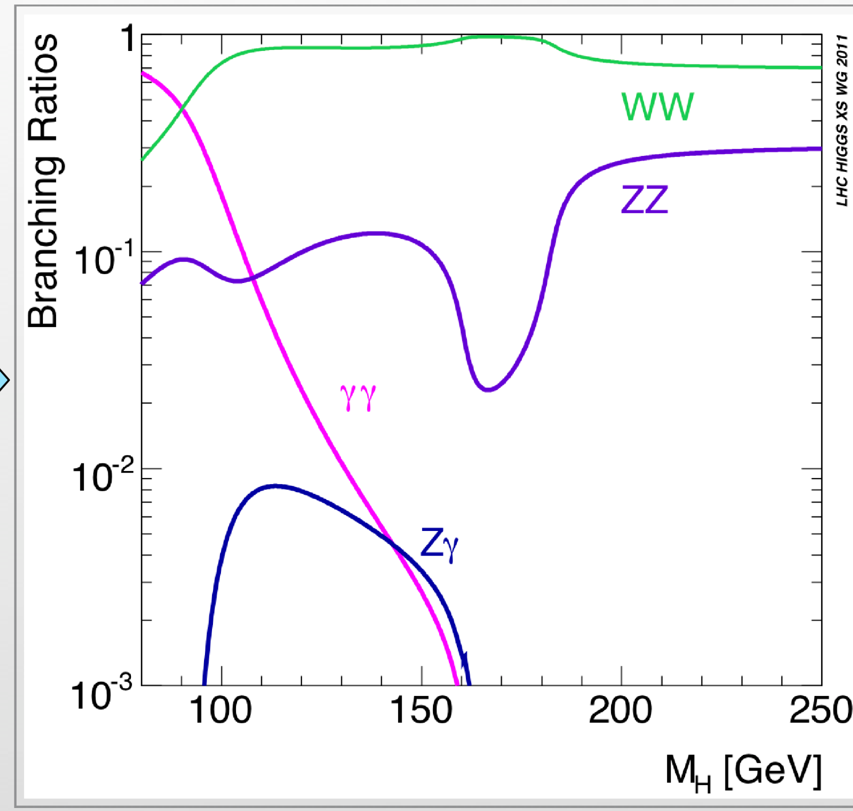
[through W loops (no-top loops)]

- H → WW, ZZ, γγ, Zγ

SM Higgs



FP Higgs

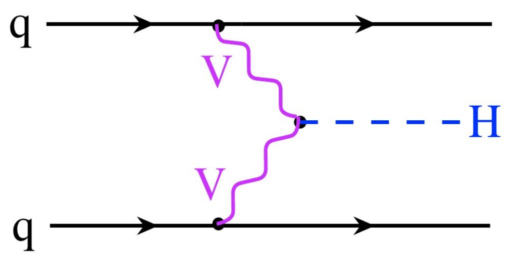


https://twiki.cern.ch/twiki/bin/view/LHCPhysics/Fermiophobic

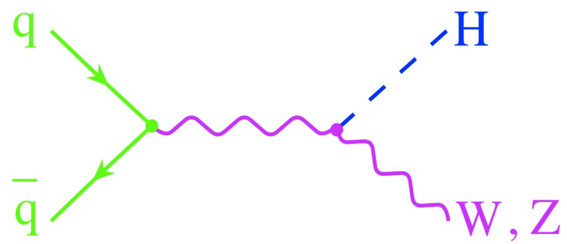
for m_H ~[100,110,120] GeV : $BR(\gamma\gamma)_{FP}$ ~[110, 30, 10] x$BR(\gamma\gamma)_{SM}$

Fermio-Phobic Higgs Production mechanisms

VBF



VH



- no gluon-gluon fusion
- VBF fusion dominant mechanism
- harder pT spectrum → better S/B !

How to include radiative corrections ?

- if m_f's are put by hand → SM becomes not renormalizable
- SM → effective field theory valid up to Λ scale
- radiative corrections depend by the UV completion of the theory, but less sensitive if $Y_f(\Lambda) \to 0$
- EFT approach allows to calculate the leading universal contributions ~$[g^2 \mathrm{Log}(\Lambda/M_H)]^n$ which are independent of the UV completion

Theoretical framework

- assume ChSB and EWSB have different origin
- switch off Yf's → **Fermio-Phobic Higgs**
- mf's generated by some new mechanism set at a high-energy scale Λ (>> EW scale)
- Higgs gives dominant contributions to Mw e Mz (contributions to EWSB arising from ChSB, small)
- only SM degrees of freedom propagating at scales below Λ
- a light Higgs in the spectrum (mH < 150 GeV)

EFT approach connects two scales Λ and mH

- assume Yf's vanishing at the scale $\Lambda \gg m_H$ (related to mf's generation)

$$Y_f(\Lambda) = 0$$

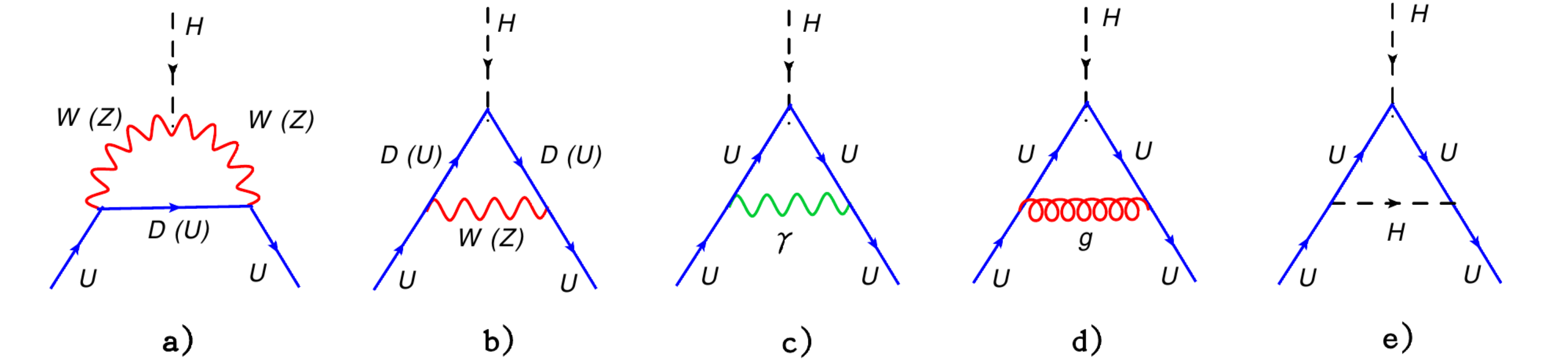
- due to ChSB, Yf's are not protected under radiative corrections → radiatively generated → large Log(Λ/mH)
- large logs $g_i^{2n} \log^n(\Lambda/m_H)$ can be summed up by Renormalization Group Equation (RGE) technique

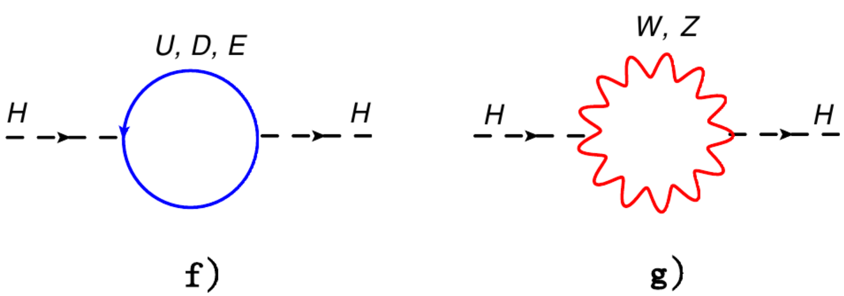
$$Y_f(\Lambda) = 0 \xrightarrow{RGE} Y_f(m_H)$$

(high energy) RGE (low energy)

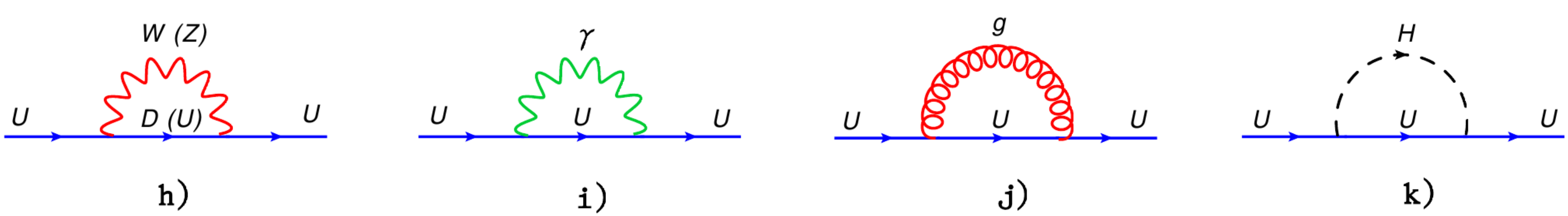
- note ! SM RGE (where Yf's and mf are related) not suitable here → new RGE's deerived by keeping Yf's and mf's as independent parameters!

Diagrams contributing to the Y's beta-functions





Up-type quark couplings



1-loop RGE's for Yukawa's

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

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

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

$$\xi_H \equiv \frac{g_2 m_H}{2M_W} \qquad \mathbf{Y_f^{SM}} \equiv \frac{g_2}{\sqrt{2}M_W}\mathrm{diag}[m_{\mathrm{f}_1}, m_{\mathrm{f}_2}, m_{\mathrm{f}_3}]$$

W_L polarization → ξ_H

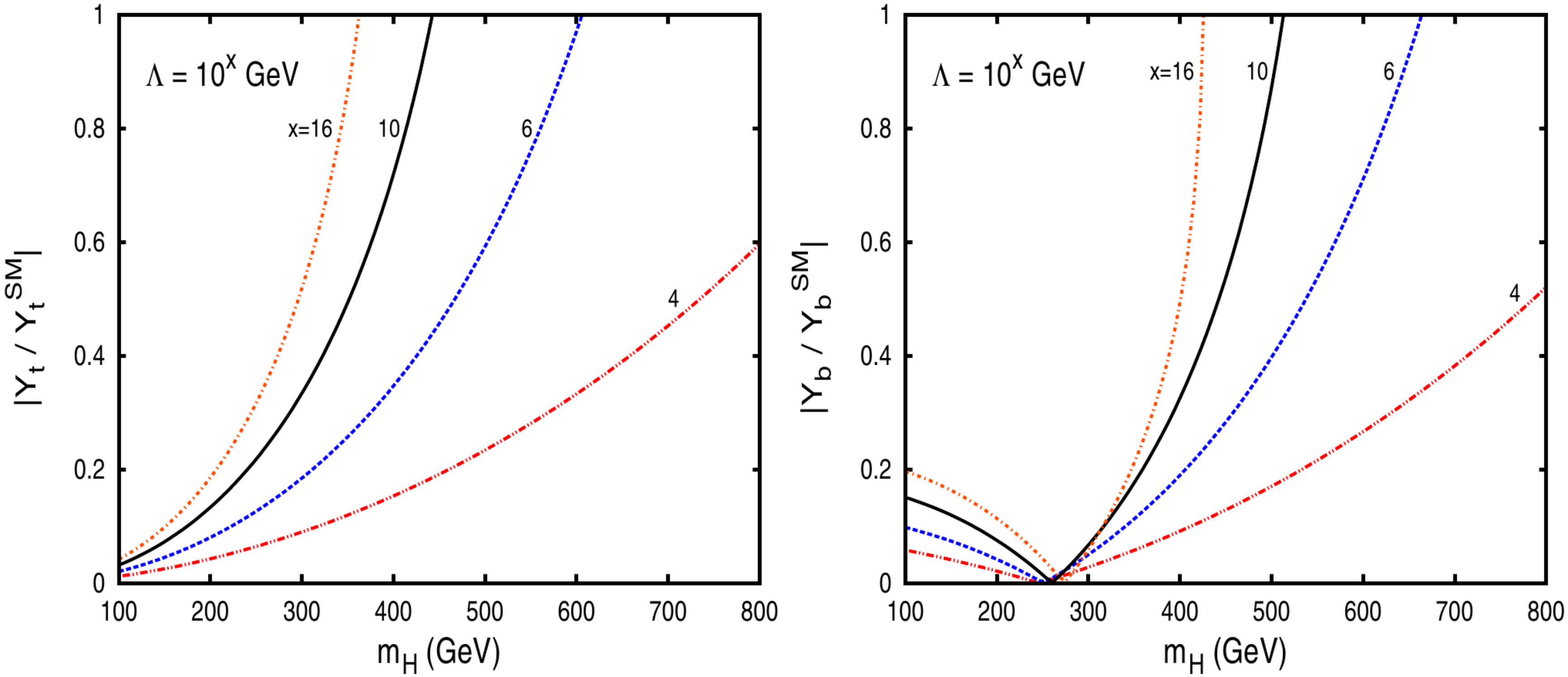
ChSB terms → $\mathbf{Y_f^{SM}}$

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

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

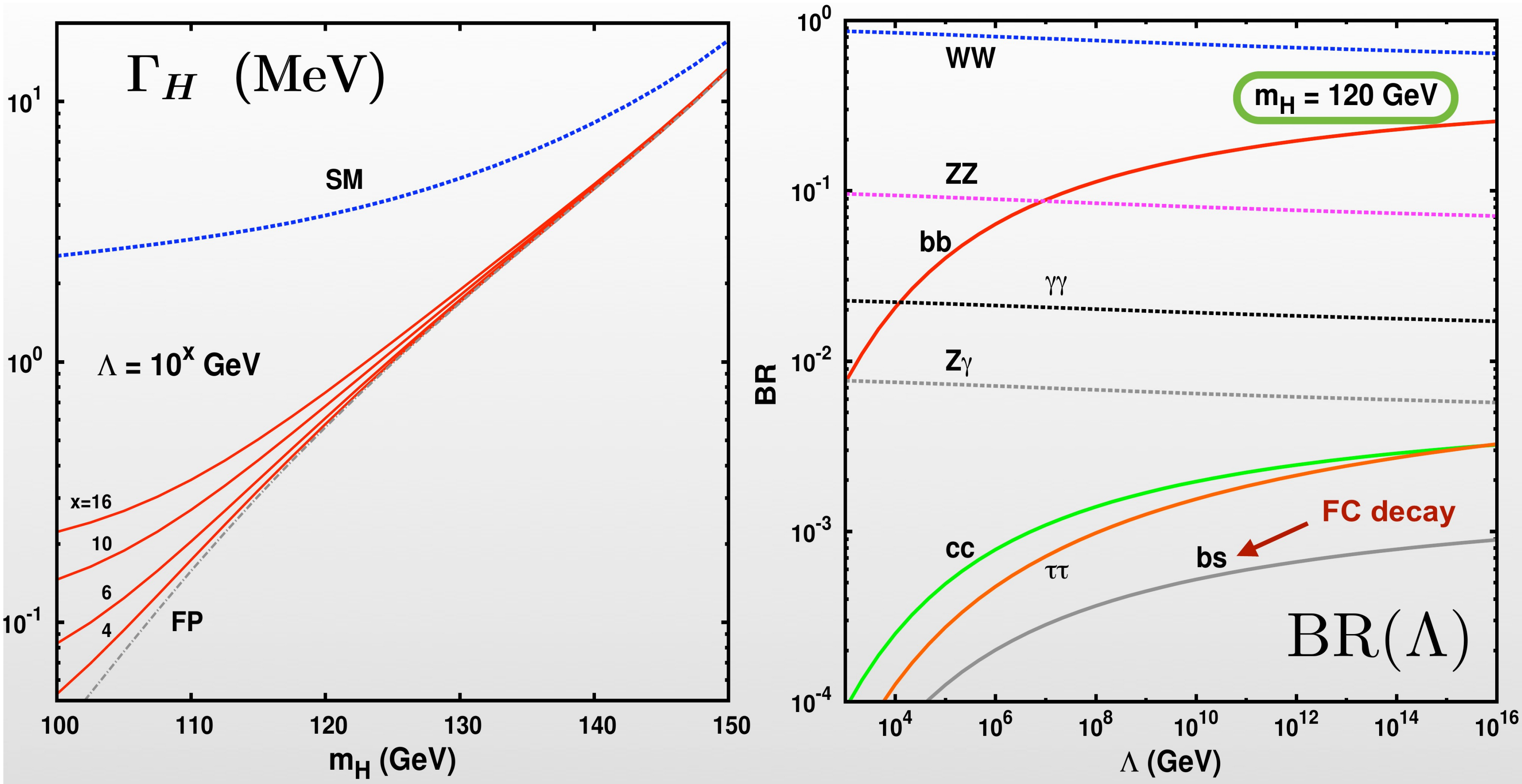
Results for $Y_t(mH)/Y_t^{SM}$ and $Y_b(mH)/Y_b^{SM}$

E. GABRIELLI AND B. MELE PHYSICAL REVIEW D **82,** 113014 (2010)



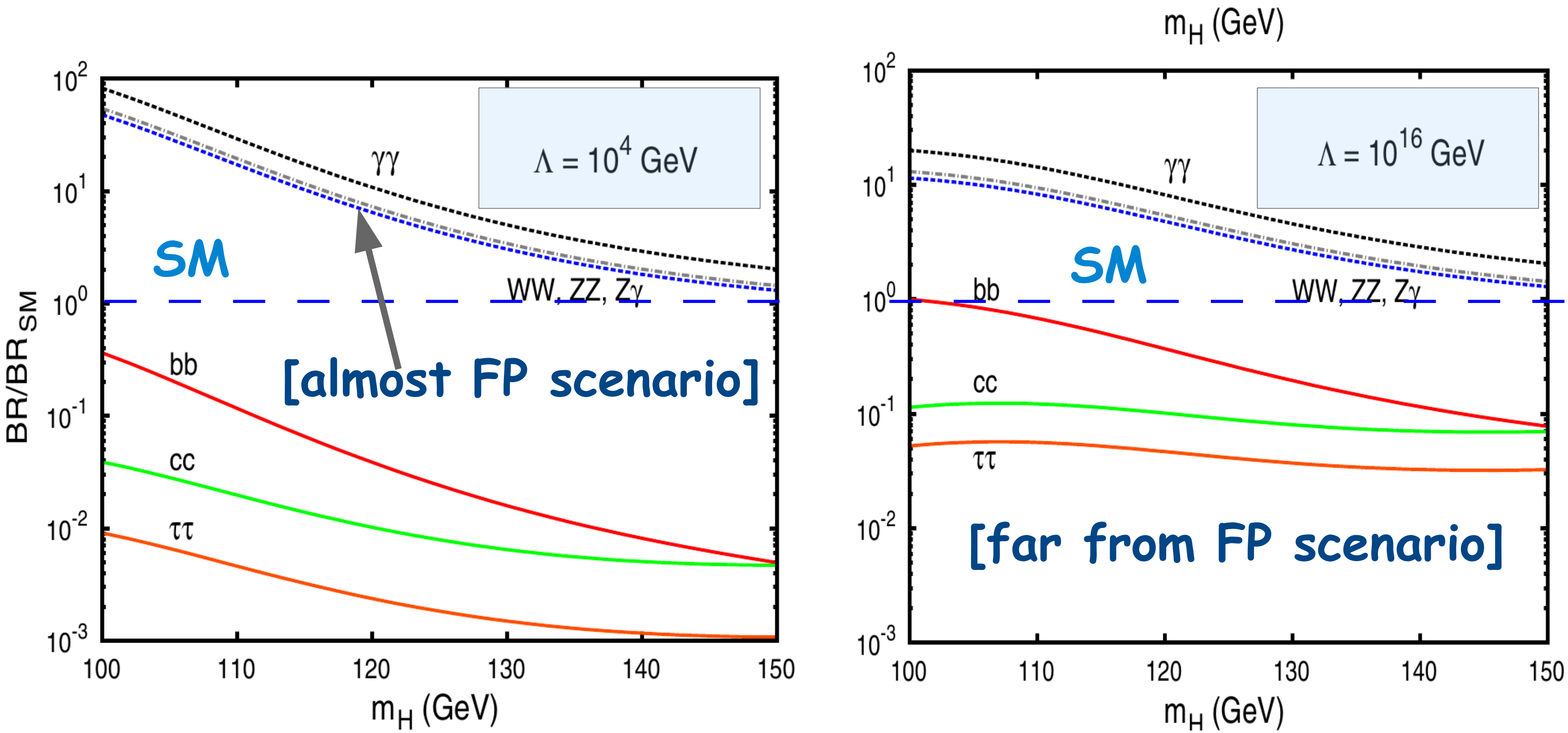
- Λ varied between 104 and 1016 GeV
- because of terms $\xi_H \equiv \dfrac{g_2 m_H}{2M_W}$ Yf grows at large mH
- all Yf's perturbative for mH < <H> ~246 GeV

Results for Γ_H and BR's versus Λ

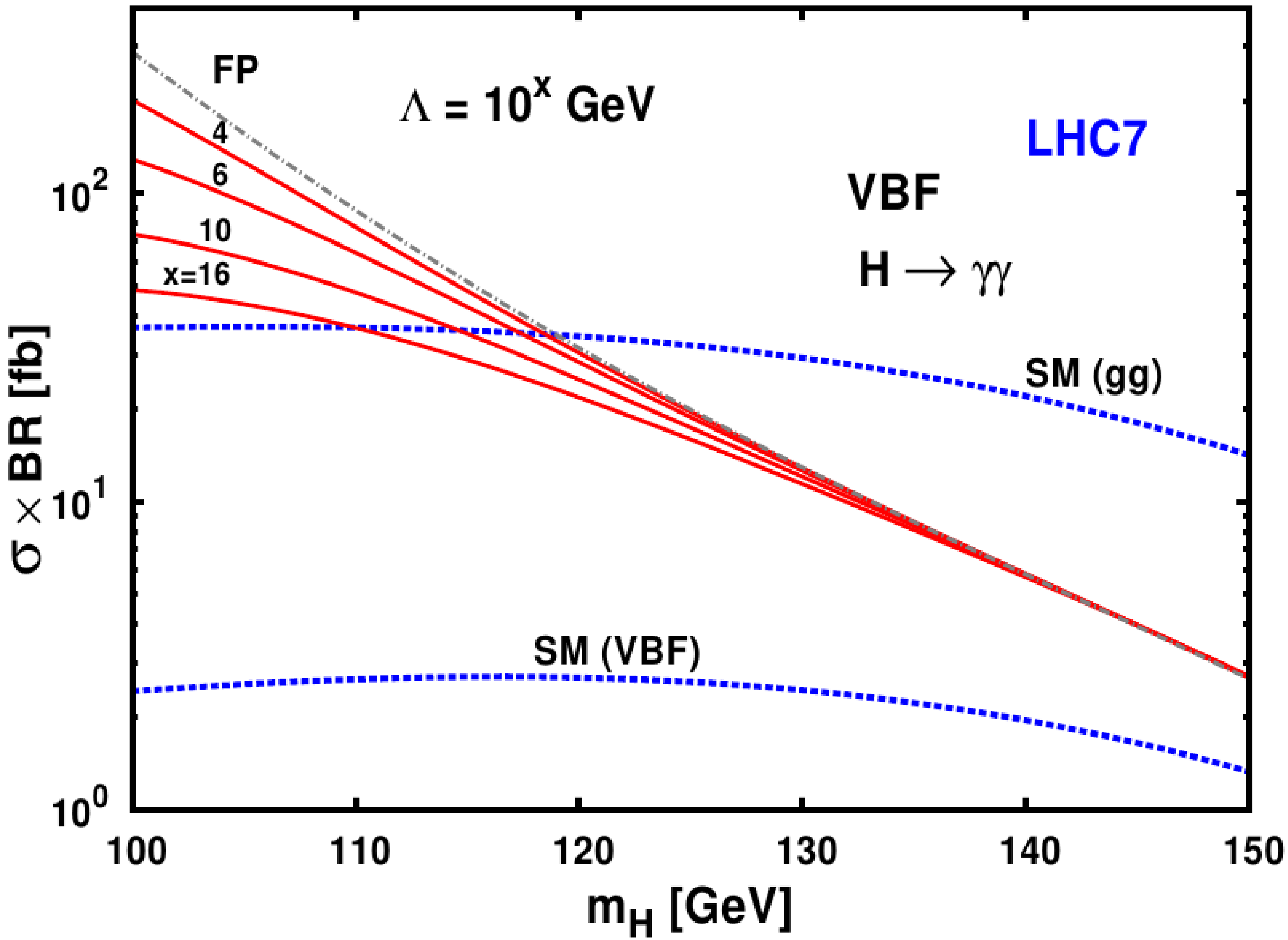


BR's enhanced by small total width

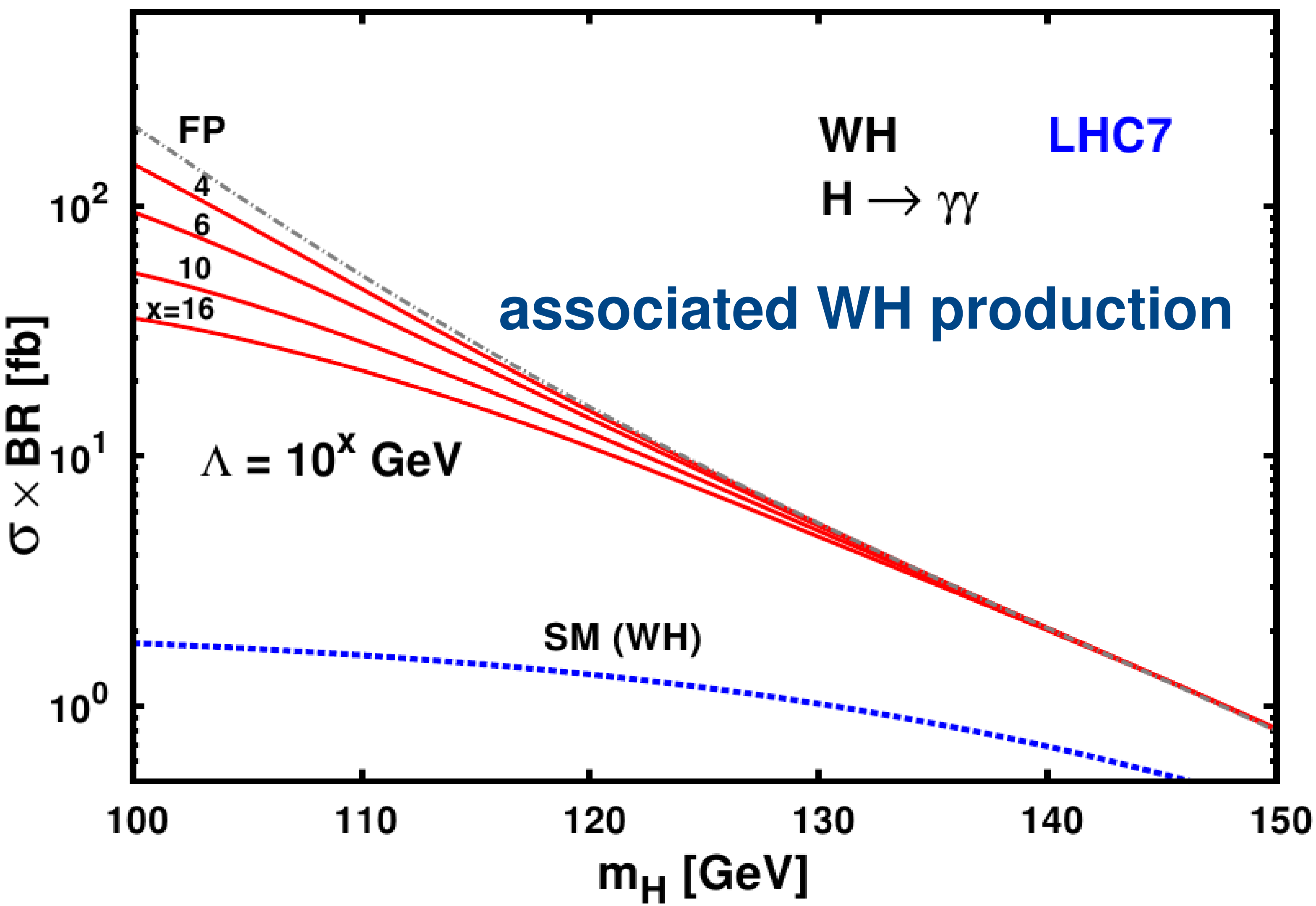
BR / BR(SM): Λ ~ (104 → 1016) GeV



LHC (VBF) : $H \rightarrow \gamma\gamma$



LHC (WH) : H → γγ



FP
4
6
10
x=16
WH
H ⟶ γγ
LHC7
associated WH production
Λ = 10^x GeV
SM (WH)
σ × BR [fb]
10^2
10^1
10^0
100
110
120
130
140
150
m_H [GeV]

exp bounds on mH (pure FP model)

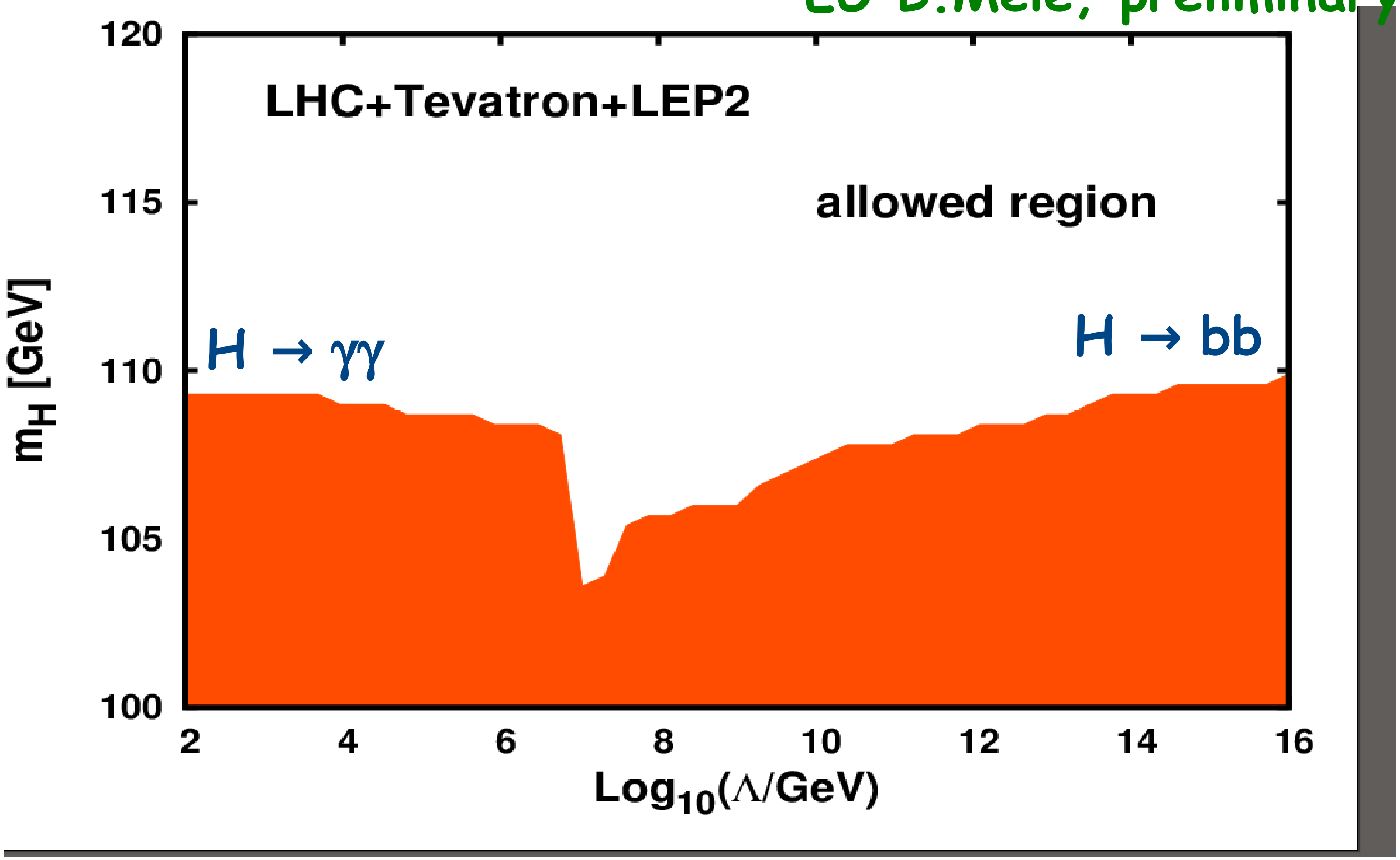
- Quite a number of studies on pure FP scenario

  * LEP → 109.7 GeV (comb. $\gamma\gamma$ data on 4 exps) ('02)
    (108.3 GeV, comb. $\gamma\gamma$+WW* in L3)
  * CDF → (100-) 114 GeV 7 fb^{-1} (May 2011)
  * D0 → (100-) 112.9 GeV 8.2 fb^{-1} (July 2011)
  * CMS → (110-) 112 GeV 1.7 fb^{-1} (LP2011)

- bounds in "Effective Yf" scenarios needs dedicated studies
  * in general weaker than in FP, and depending on Λ

bounds on mH (effective Yf's model)

EG B.Mele, preliminary



- bounds obtained with Higgsbounds-3.4.0beta (not updated with recent bounds on FP Higgs from LHC and CDF) Comput.Phys.Comm.181:138 (2010)

FP light Higgs at Linear Colliders

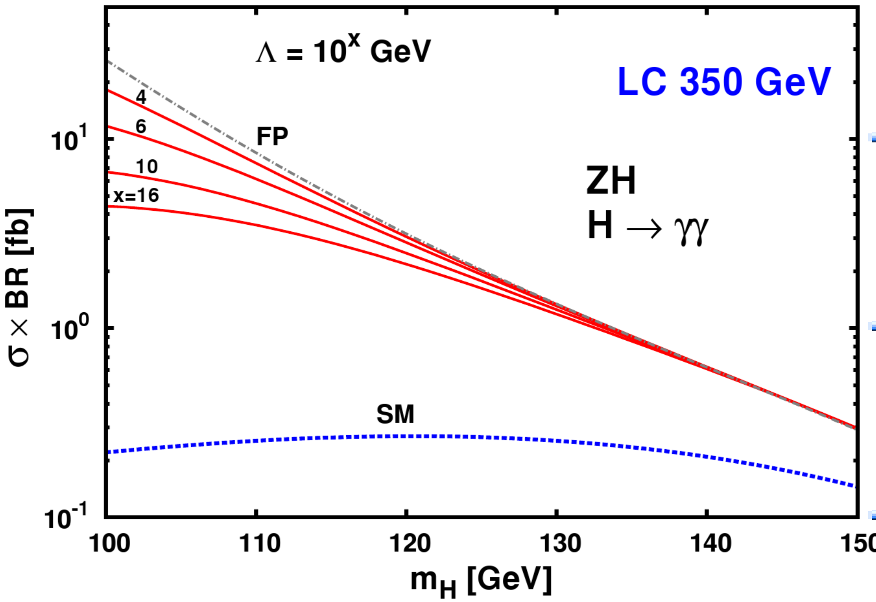
- very good option → $\sqrt{S} = 350\,\mathrm{GeV}$

advantages

- it allows an accurate study of a light Higgs boson's properties
- precise measurements of Yukawas
- LHC and Tevatron will constrain the scale Λ of ChSB
- LC could provide a measurement of Λ

$\sigma \times$ BR [fb]

N_{ev}/500 fb-1



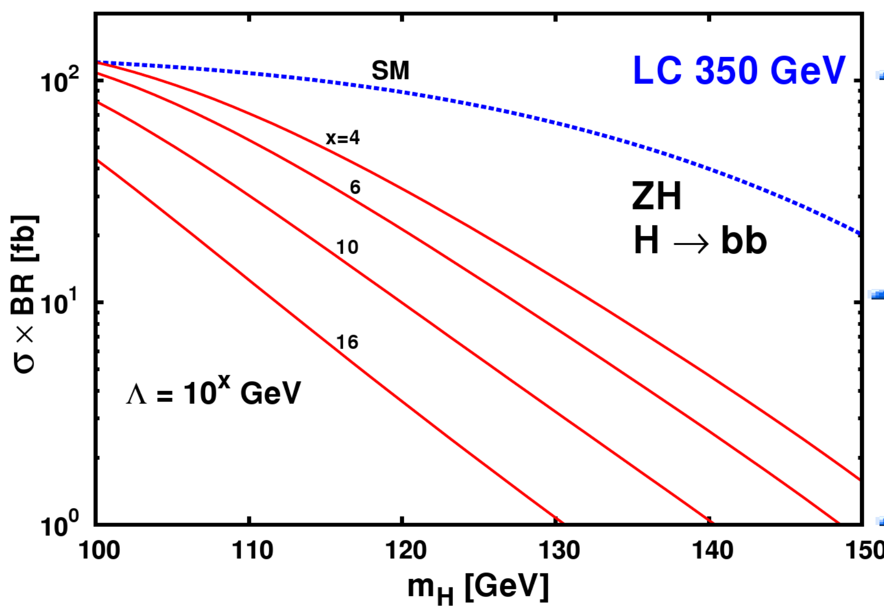
5000

500

50

LC 350

H → γγ



50000

5000

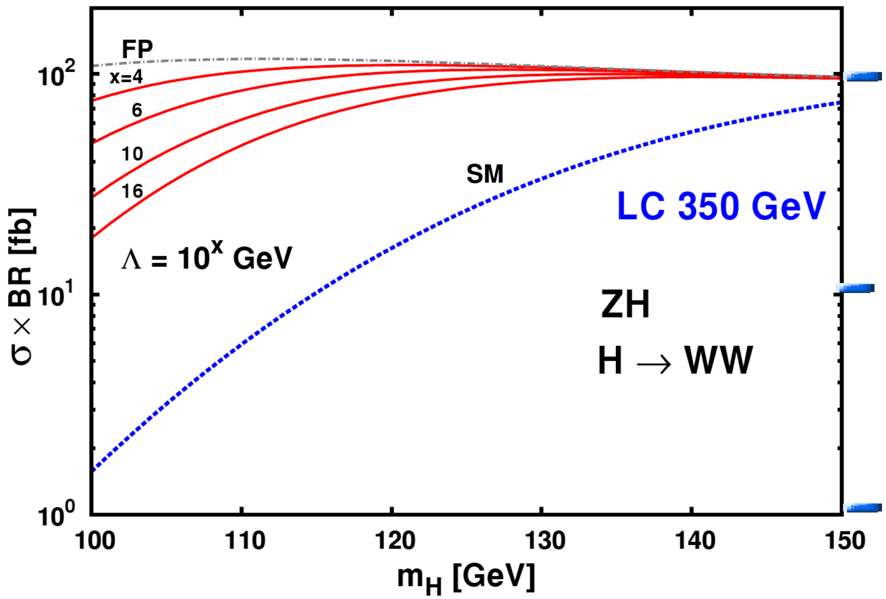
500

LC 350

H → bb

Excellent sensitivity to Λ

σ x BR [fb] N_{ev}/500 fb-1



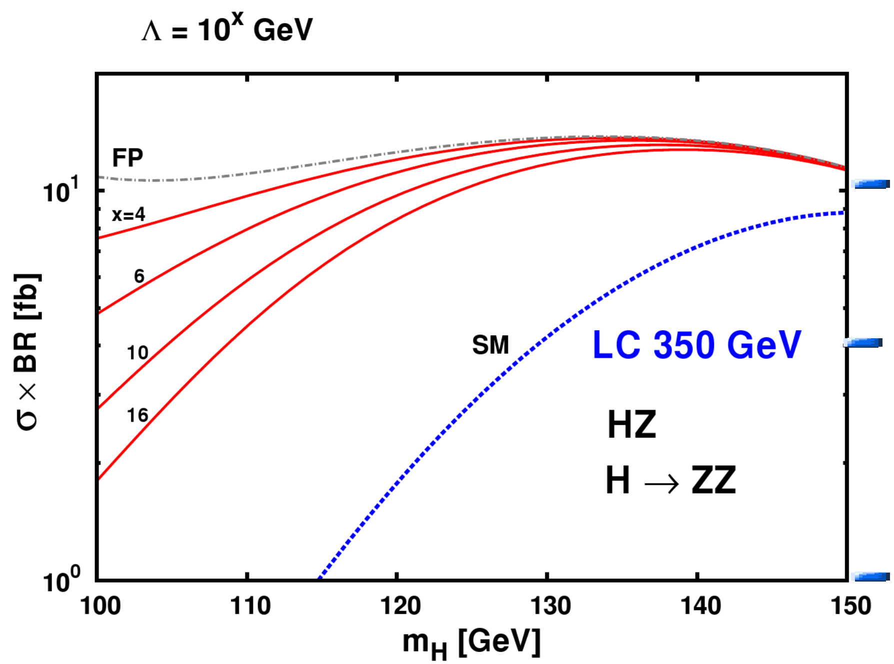
50000

5000

500

LC 350

H → WW



5000

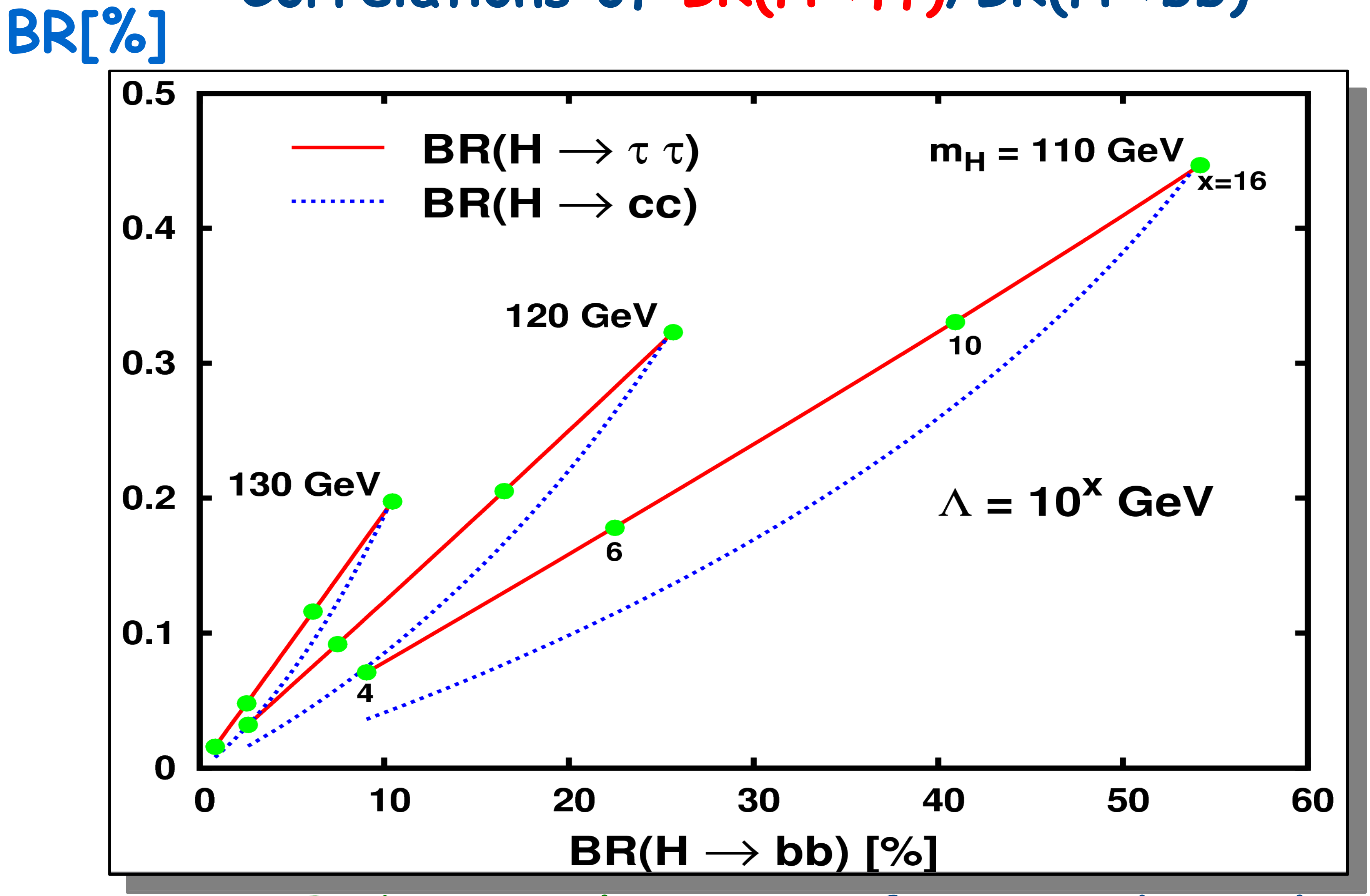
2000

500

LC 350

H → ZZ

Correlations of BR(H→ff)/BR(H→bb)



- testing BR's correlations in fermion channels is crucial to prove Effective Yf's scenario !

Flavor-Changing Higgs decay $H \to bs$

- SM $BR(H \to bs) < O(10^{-7})$ radiatively induced

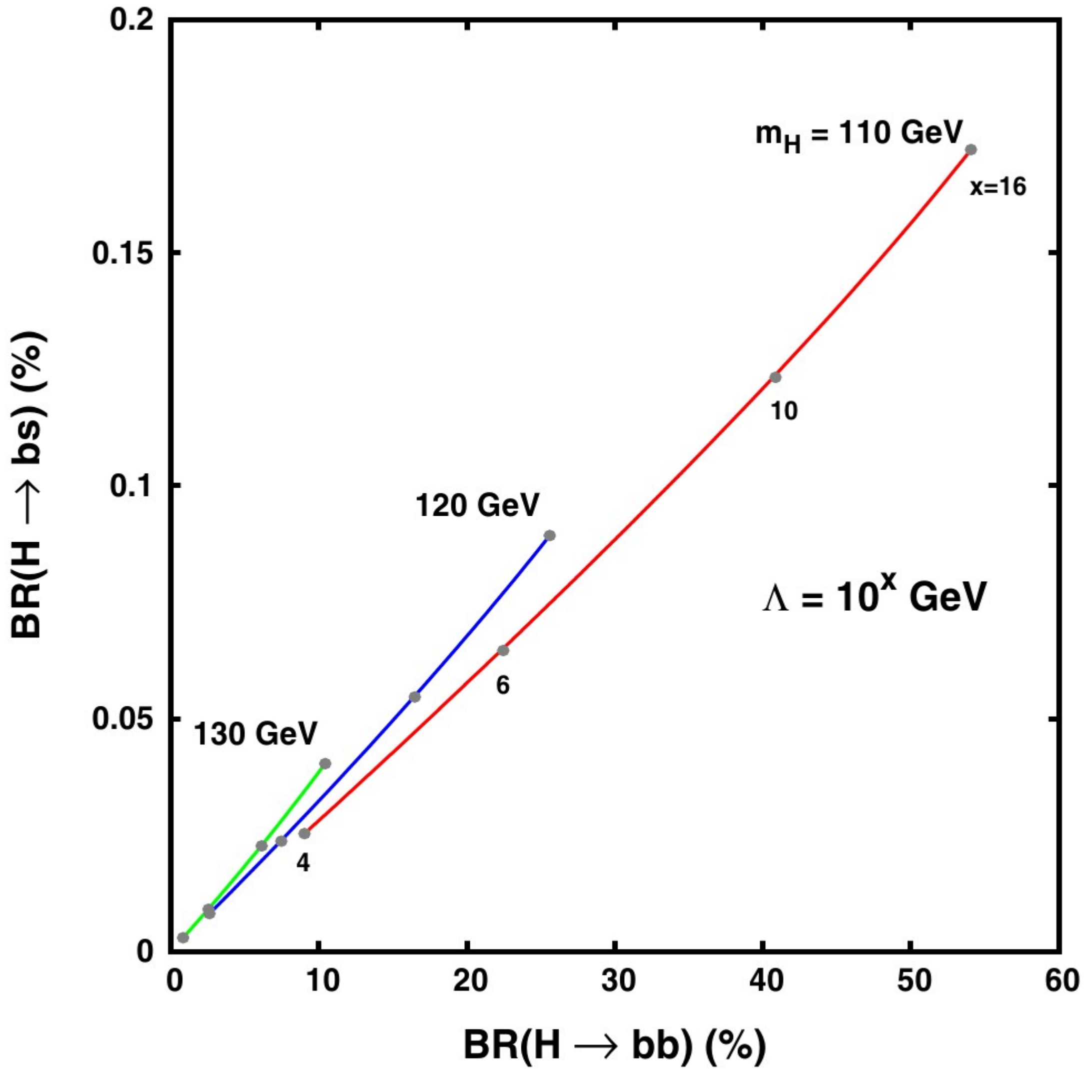
- in FP Higgs scenario $H \to bs$ also radiatively induced → but BR enhanced since Γ_H depressed

- CKM matrix responsible of FC decay $H \to bs$

- we computed RGE for the off-diagonal Yf's

- $BR(H \to bs)$ of order $O(10^{-4} \to 10^{-3})$ for $\Lambda \sim 10^4 \to 10^{16}$ GeV

Correlations of FC BR(H→bs)/BR(H→bb)



EG, B.Mele,

Less sensitive to MH
due to unitarity of CKM

Outlook

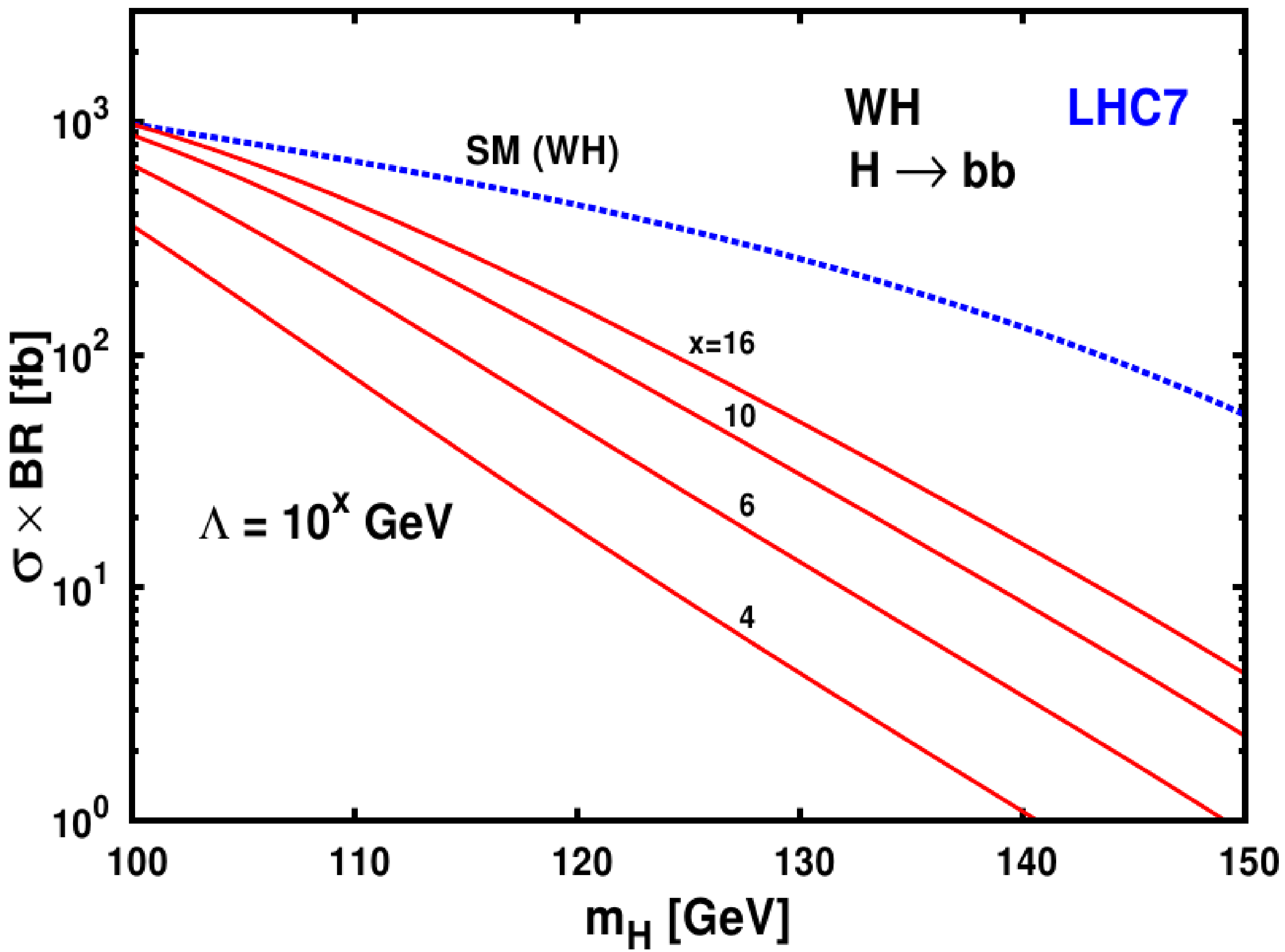
- Fermio-Phobic Higgs scenario is unstable under radiative corrections → ChSB regenerates Yukawa couplings
- EFT approach to calculate radiative corrections → unified descriptions of a wide class of possibilities
- if the scale Λ of ChSB is very large → BR(H →bb) can be comparable to SM one
- LHC will test soon effective Yf's scenario →

  but accurate study of H → bb, cc, $\tau\tau$, requires LC
- rates for e+e- → ZH → Zbb remarkably sensitive

  to the scale Λ !
- new analysis of LC sensitivity to Higgs BRs in the new framework needed

Backup

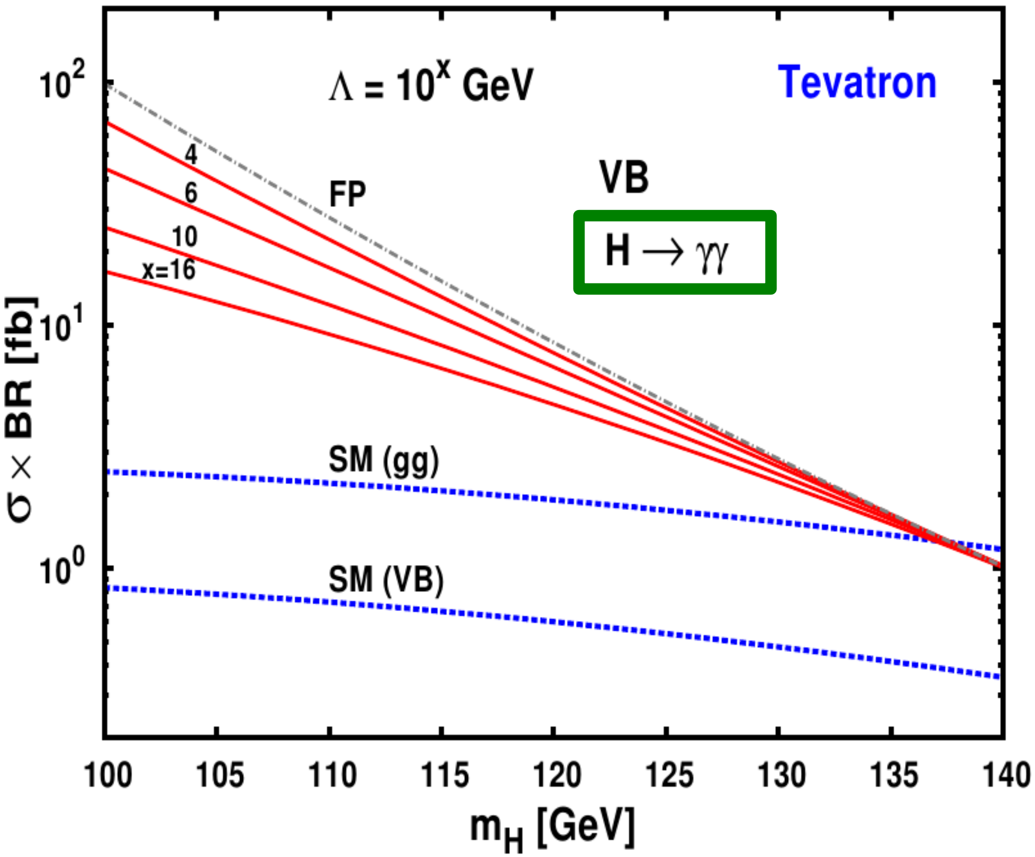
LHC (WH) : H → bb

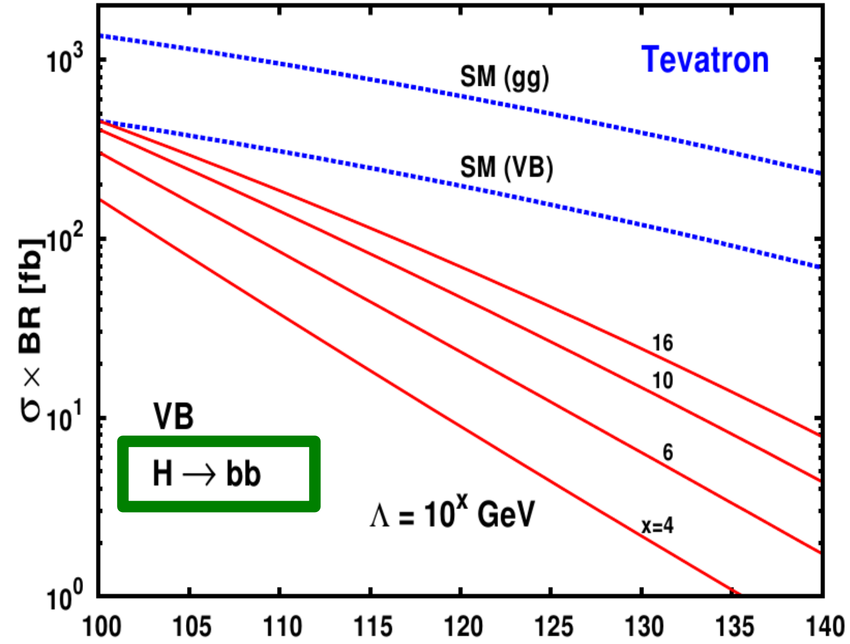


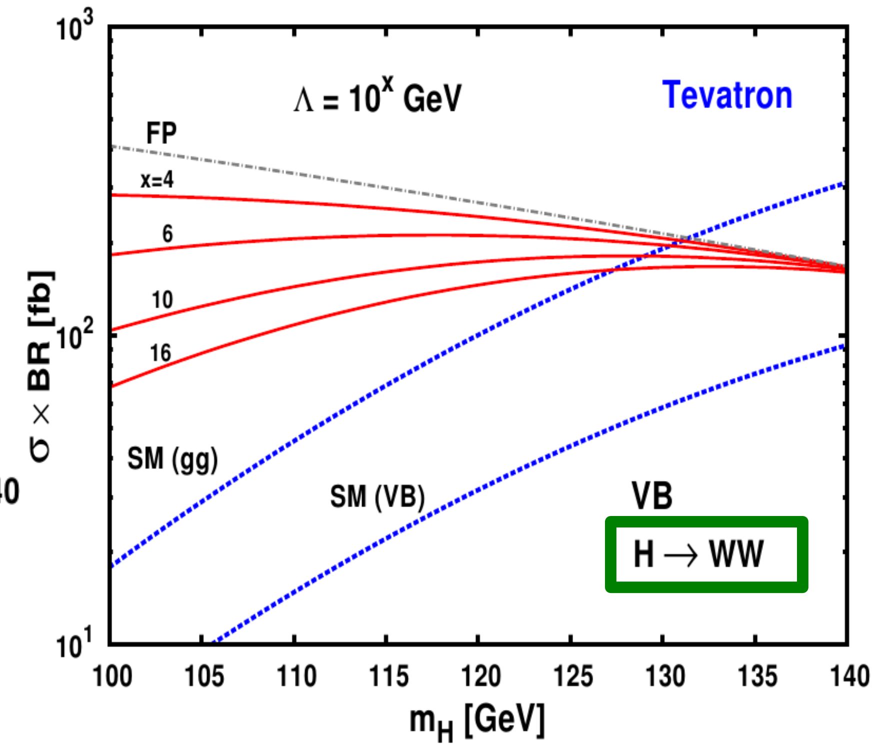
WH
H → bb
LHC7
SM (WH)
x=16
10
6
4
Λ = 10^x GeV
σ × BR [fb]
m_H [GeV]
10^3
10^2
10^1
10^0
100
110
120
130
140
150

Tevatron $(p\bar{p} \to H\ X)$

VB = (WH+ZH+VBF)

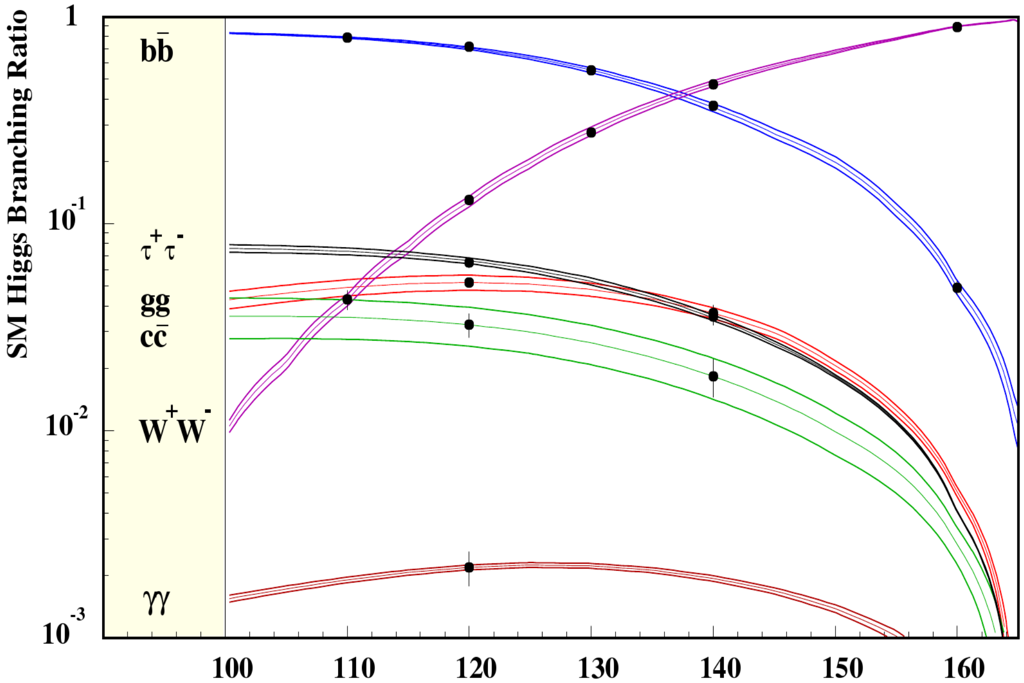






- Tevatron can constrain the model !

Accuracy on BRS for SM Higgs boson



[hep-ph/0106315]
Tesla, Technical Design Report (part III)

Expected experimental uncertainties

error bars →exp. sensitivities

"Phase 1": 500 fb^{-1} at 350 GeV, no beam

SM Higgs branching ratio uncertainties		
	m_H = 120 GeV	140 GeV
BR($b\bar{b}$)	2.4%	2.6%
BR($c\bar{c}$)	8.3%	19.0%
BR($\tau\tau$)	5.0%	8.0%
BR(WW)	5.1%	2.5%
BR(gg)	5.5%	14.0%

from K. Desch, hep-ph/0311092

New analysis needed to establish ΔBR(H → ff)