

Fermiophobic Higgs boson scenario: probing the radiative fermionic sector at colliders

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talk based on PRD 83: 073009 (2011)

PRD 82: 113014 (2010)

Tartu-Tuorla annual meeting 2011

Tartu, 21-22 September 2011

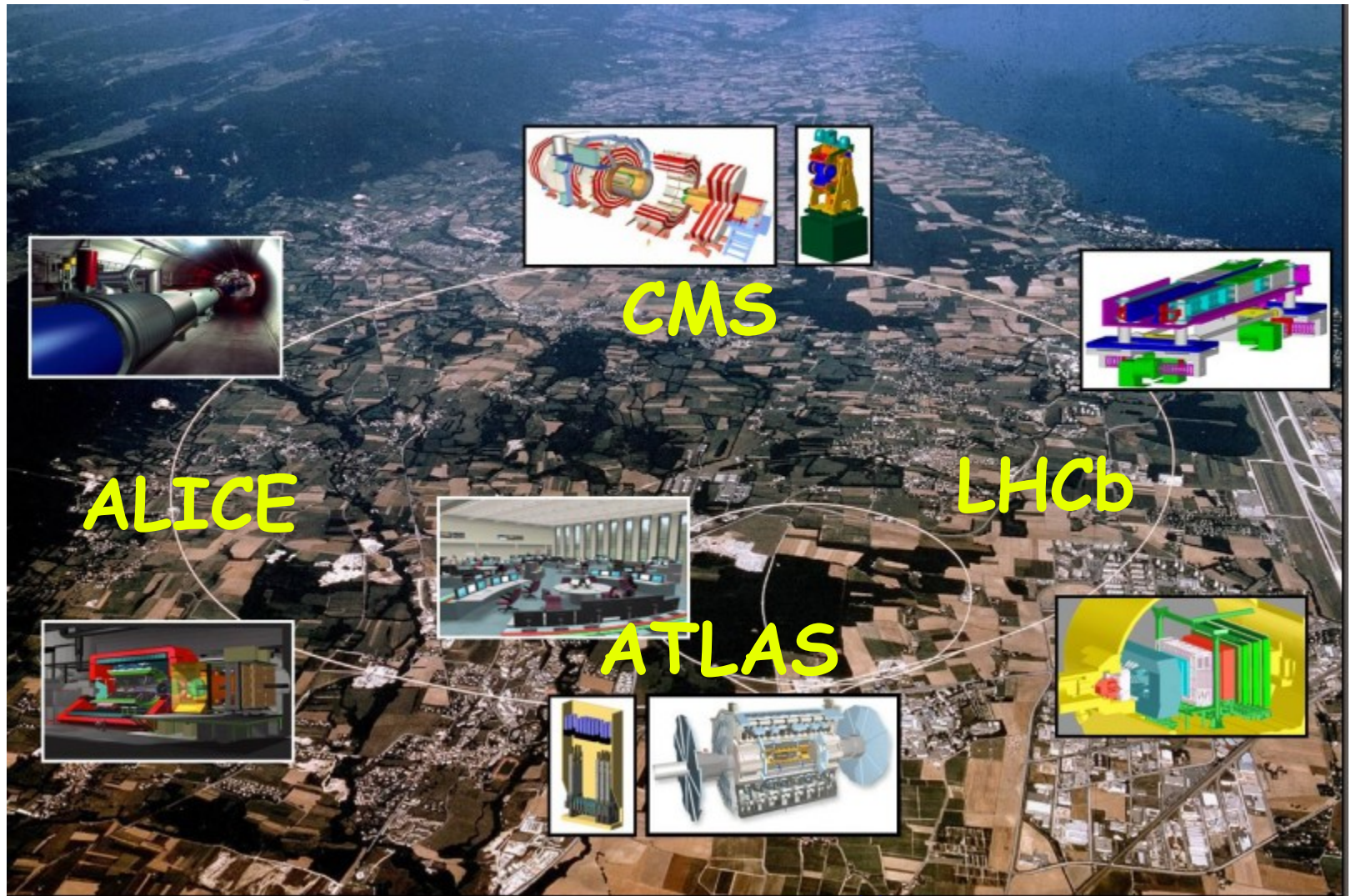
Outline

- present LHC results on SM Higgs
- a non-standard scenario: **F**ermio-**P**hobic (**FP**) Higgs



- radiative corrections $\rightarrow$ fermionic couplings regenerated
- expectations at the LHC and LC

Large Hadron Collider

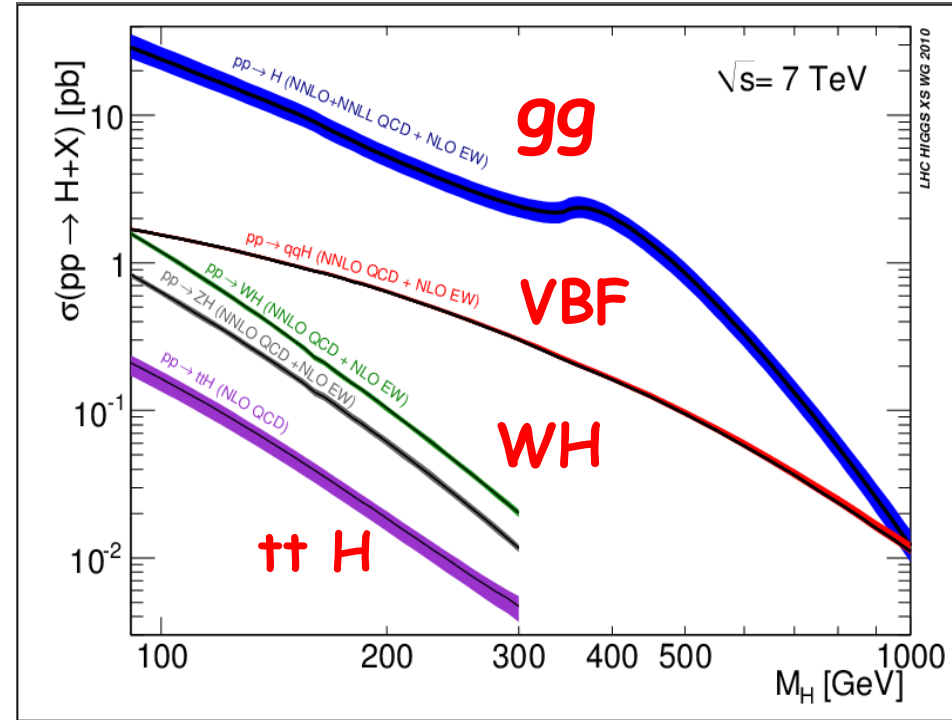
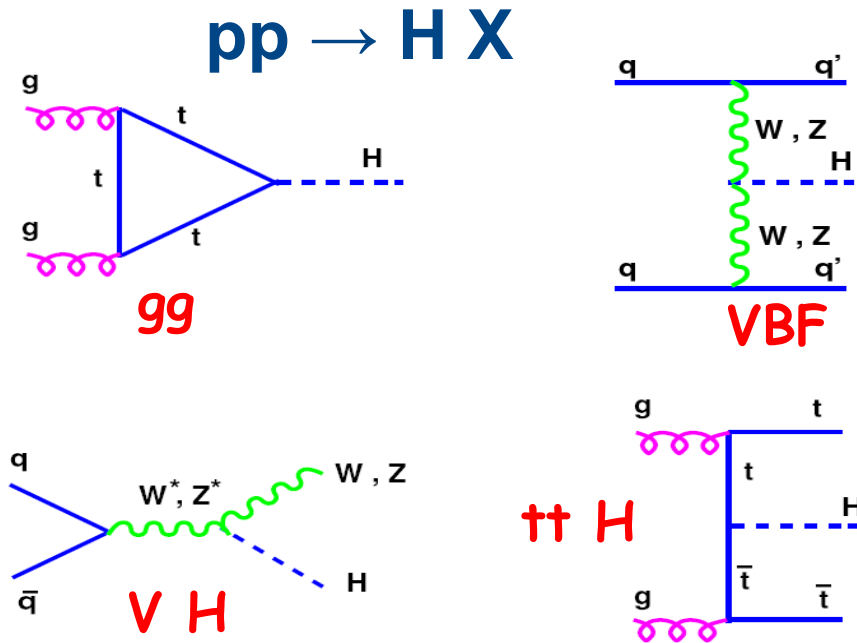


proton-proton collisions
at 7 TeV energy c.o.m. $\rightarrow$ 14 TeV

Higgs boson physics at the LHC

- Higgs boson search is one of main tasks of LHC
- range of Higgs boson mass not predicted in SM
 - $m_H > 114.5 \text{ GeV}$ (LEP2)
 - $m_H < 800 \text{ GeV}$ theoretical upper bound
- SM precision tests favor a light Higgs Boson, with mass below 150 GeV
- discovery channels of Higgs boson at LHC strongly depend on the actual Higgs mass
- light Higgs boson discovery → challenging at LHC due to the huge background (bckg) in bb

SM Higgs production mechanisms at LHC



inclusive x-sections (fb)

■ **gluon fusion**: main mechanism in the whole range

(gg cross-section $\sim O(10)$ pb for $m_H < 200 \text{ GeV}$)

■ **Vector-Boson-Fusion (VBF)** is also sizeable

■ **WH** and **ttH**: interesting at low Higgs masses

SM Higgs discovery channels at LHC

- $m_H = [115-130] \text{ GeV}$

$H \rightarrow \gamma \gamma$ golden channel

$H \rightarrow \tau \tau$

- $m_H = [130-150] \cup [180-800] \text{ GeV}$

$H \rightarrow Z Z \rightarrow 4l \quad (l=\mu, e)$ golden channel

$H \rightarrow W W \rightarrow 2l 2\nu \quad (l=\mu, e)$

- $m_H = [150-170] \text{ GeV}$

$H \rightarrow W W \rightarrow 2l 2\nu \quad (l=\mu, e)$ golden channel

hot LHC results on Higgs physics

- in a few months we should be able to complete the SM Higgs **search phase** → find out whether:

- there is a SM-Higgs-like signal !

- start testing its property

- there is **not** a SM-Higgs-like signal !!!

- what is there instead ? → it will take longer

- present bounds by **LHC** on **SM Higgs**

(CMS-PAS-HIG-11-02)
[156-216], [226-288] & [310-400] GeV @ 95%CL

(ATLAS-CONF-2011-135)
[146-232], [256-282] & [296-466] GeV @ 95%CL

Origins of Yukawa couplings

- Why the SM cannot be considered the ultimate theory → quantum instability of scalar potential, gauge-coupling unification, 19 free parameters...
- hierarchy of fermion masses is still a puzzle !
- in SM, problem just shifted to the Yukawa sector
$$\mathcal{L} = Y_f \bar{\psi}_f \psi_f H \longrightarrow m_f = Y_f \langle H \rangle$$
- difficult to explain all fermion spectrum and CKM mixing by means of few parameters
- many SM extensions proposed → but no one can be considered as conclusive

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

- fermion masses $m_f \longrightarrow$ ChSB
(Chiral Symmetry Breaking)
- in SM, ChSB and EWSB (M_W, M_Z) generated by the Higgs mechanism at same scale $\sim \langle H \rangle$
- not (yet) any experimental evidence supporting tree-level Yukawa couplings Y_f
- ChSB & EWSB can have different mechanisms $\rightarrow$ compositeness, extra-dimensions, technicolor...

- anyhow, there are indications that SM Higgs could be at the origin of M_W and M_Z
 - EW Precision Tests favour a light Higgs
 - EWPT not very sensitive to Y_f
 - $H \rightarrow WW \rightarrow WW$
- what if fermion masses put in by hand ?
 - switching off Yukawa couplings in the SM (keeping non-vanishing m_f) gives a non-renormalizable theory $\rightarrow$ UV divergencies do not cancel
 - SM $\rightarrow$ effective field theory (EFT) approach

Theoretical framework

- In the SM, **ChSB** (mf) and **EWSB** (mW, mZ) generated by Higgs mechanism at the same scale $\sim v = \langle H \rangle$
$$\mathcal{L} = Y_f H \bar{\Psi}_f \Psi_f \Rightarrow m_f = Y_f v$$
- assume instead **ChSB** and **EWSB** have different origin
- switch off Y_f 's $\rightarrow$ **Fermio-Phobic Higgs**
- **mf**'s generated by some new mechanism set at high-energy scale Λ ($\gg$ 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 ($m_H < 150$ GeV)

EFT approach connects two scales Λ and m_H

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

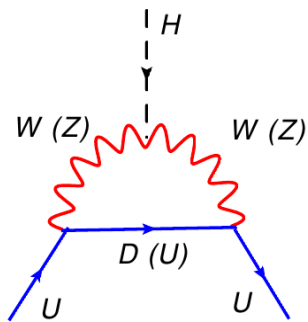
$$Y_f(\Lambda) = 0$$

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

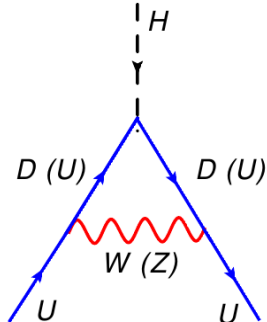
$$\begin{array}{ccc} Y_f(\Lambda) = 0 & \xrightarrow{\quad} & Y_f(m_H) \\ \text{(high energy)} & RGE & \text{(low energy)} \end{array}$$

- **note !** SM RGE (where Y_f 's and m_f are related) not suitable here $\rightarrow$ new RGE's derived by keeping Y_f 's and m_f 's as independent parameters!

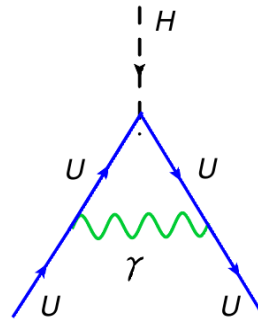
Diagrams contributing to the Y 's beta-functions



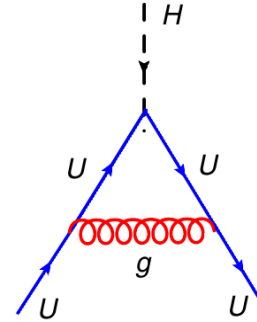
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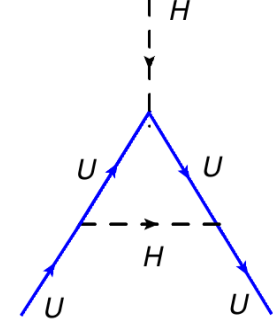
b)



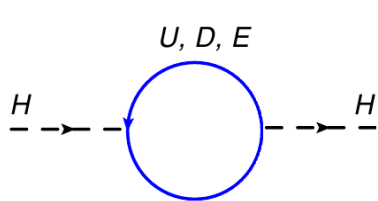
c)



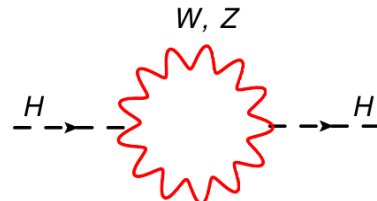
d)



e)

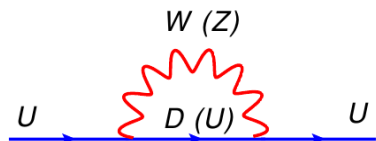


f)

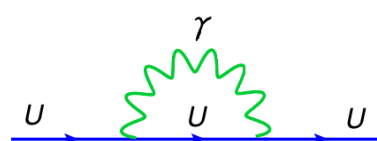


g)

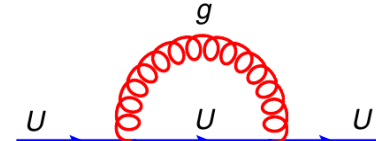
Up-type quark couplings



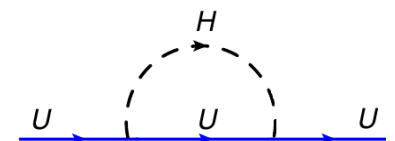
h)



i)



j)



k)

1-loop RGE's for Yukawa's

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

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

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

$$\xi_H \equiv \frac{g_2 m_H}{2M_W}$$

W_L polarization

$$\mathbf{Y}_f^{\text{SM}} \equiv \frac{g_2}{\sqrt{2}M_W} \text{diag}[m_{f_1}, m_{f_2}, m_{f_3}]$$

ChSB terms

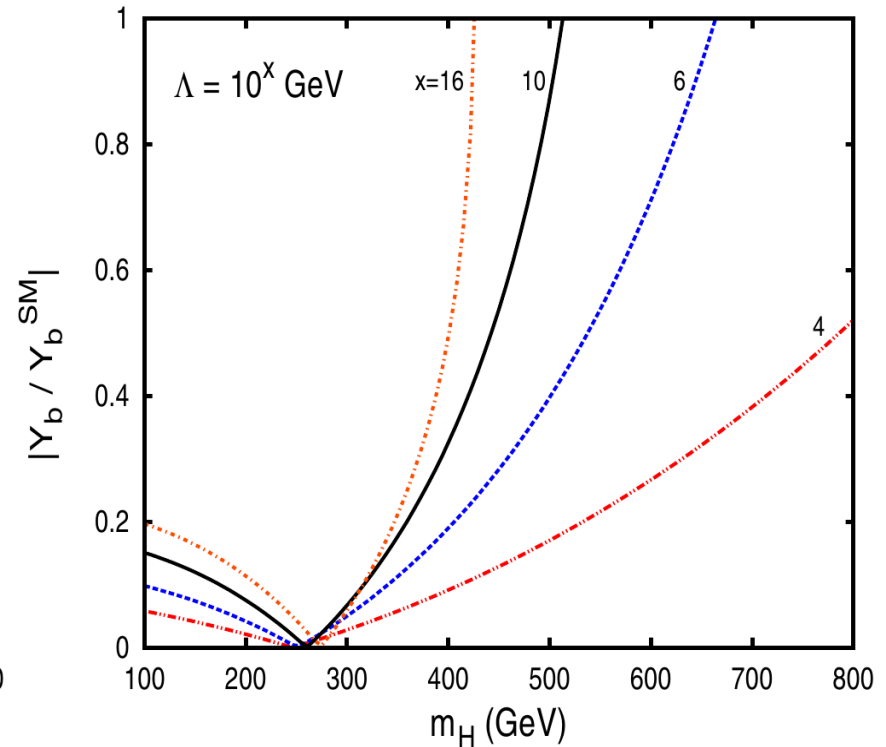
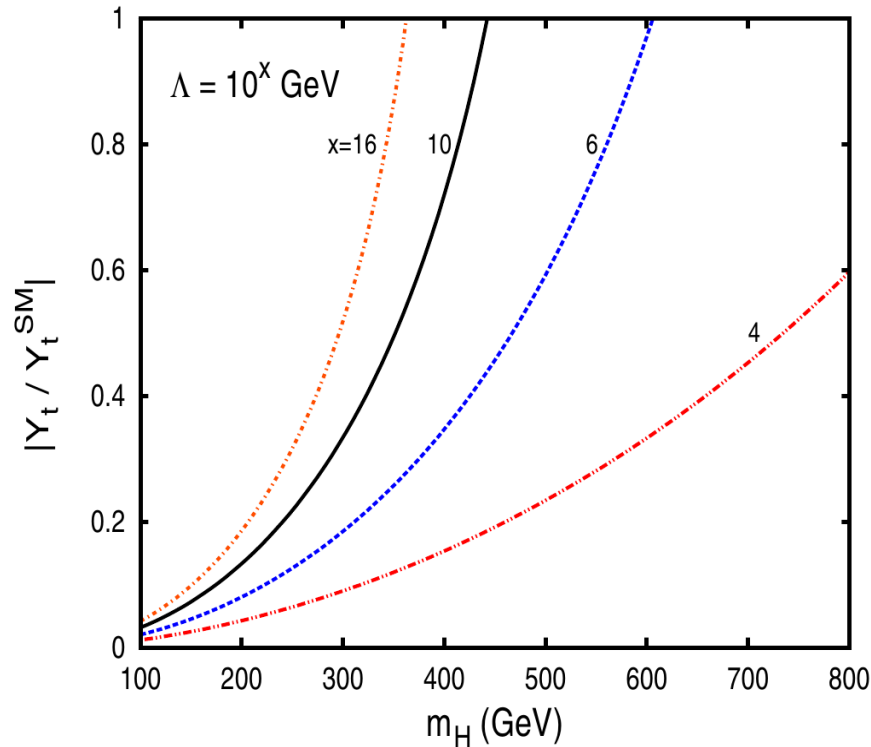
$$\mathbf{Y} \equiv N_c \mathbf{Y}_U \mathbf{Y}_U + N_c \mathbf{Y}_D \mathbf{Y}_D + \mathbf{Y}_E \mathbf{Y}_E$$

SM RGE's recovered for $\rightarrow \mathbf{Y}_f^{\text{SM}} \rightarrow \mathbf{Y}_f$

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

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PHYSICAL REVIEW D **82**, 113014 (2010)

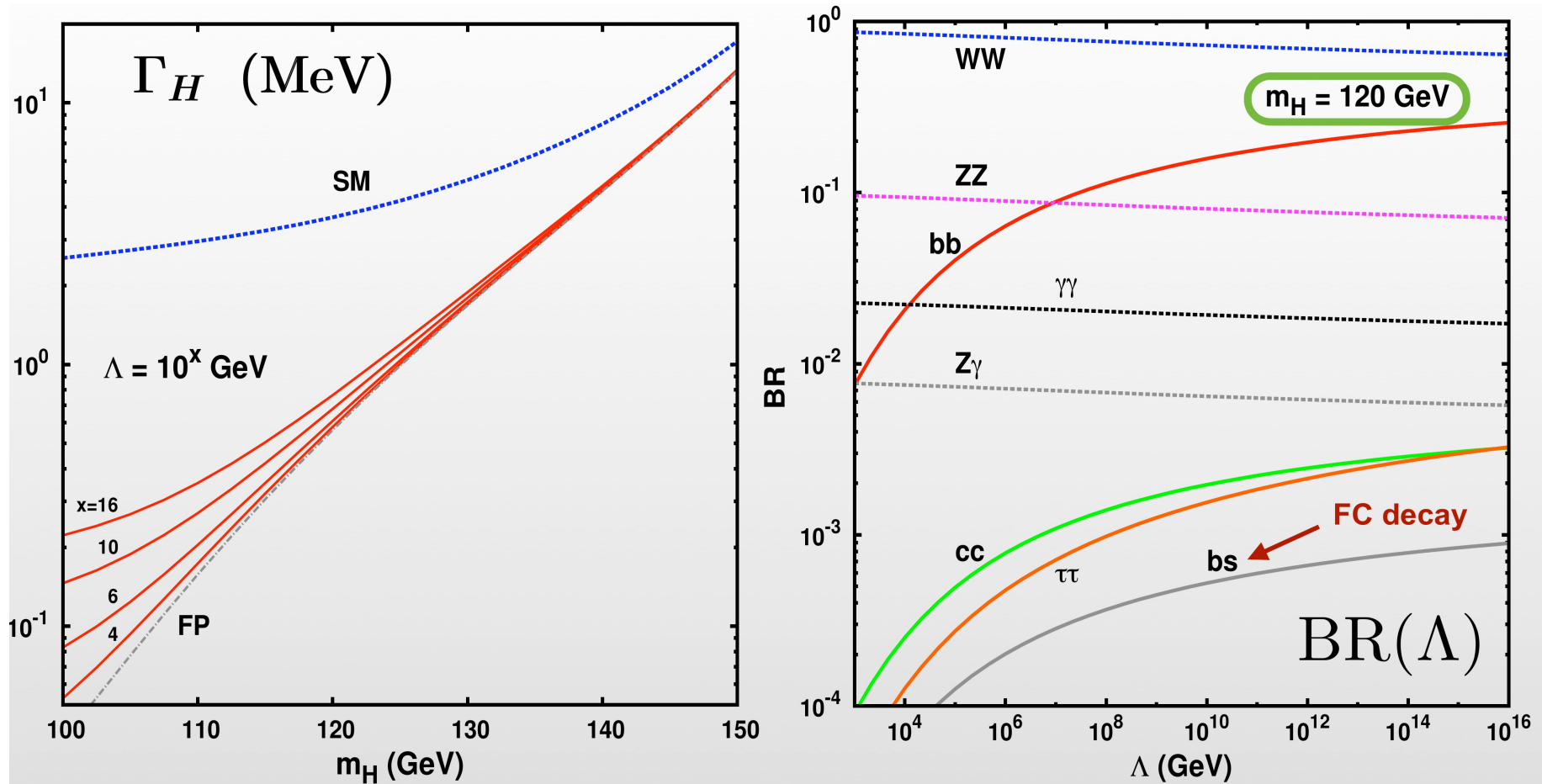


■ Λ varied between 10^4 and 10^{16} GeV

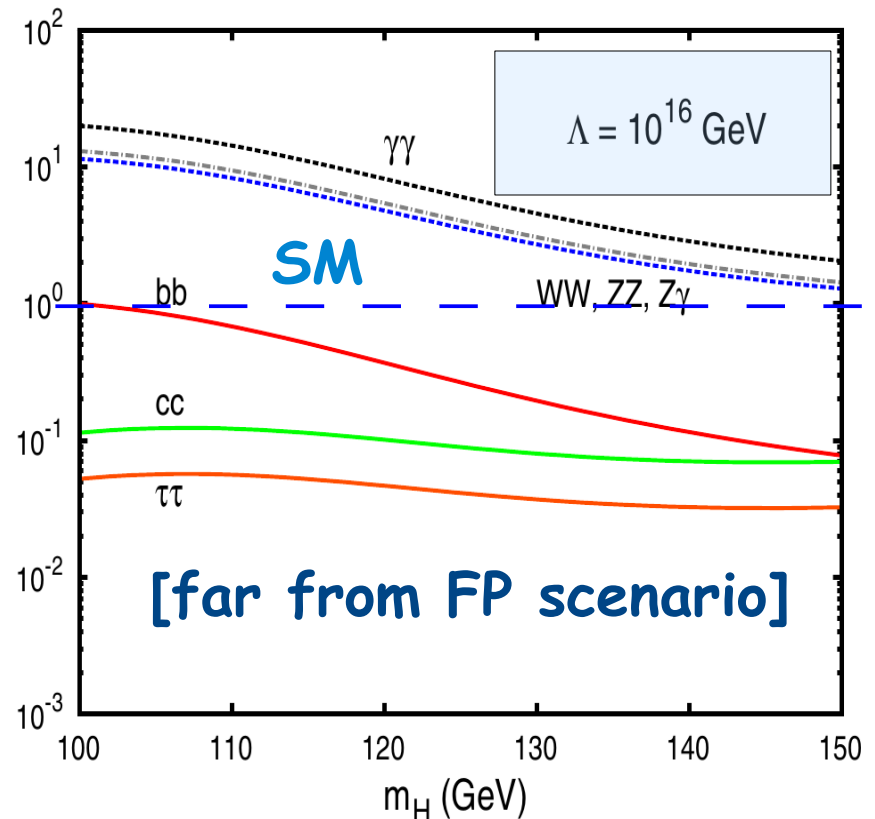
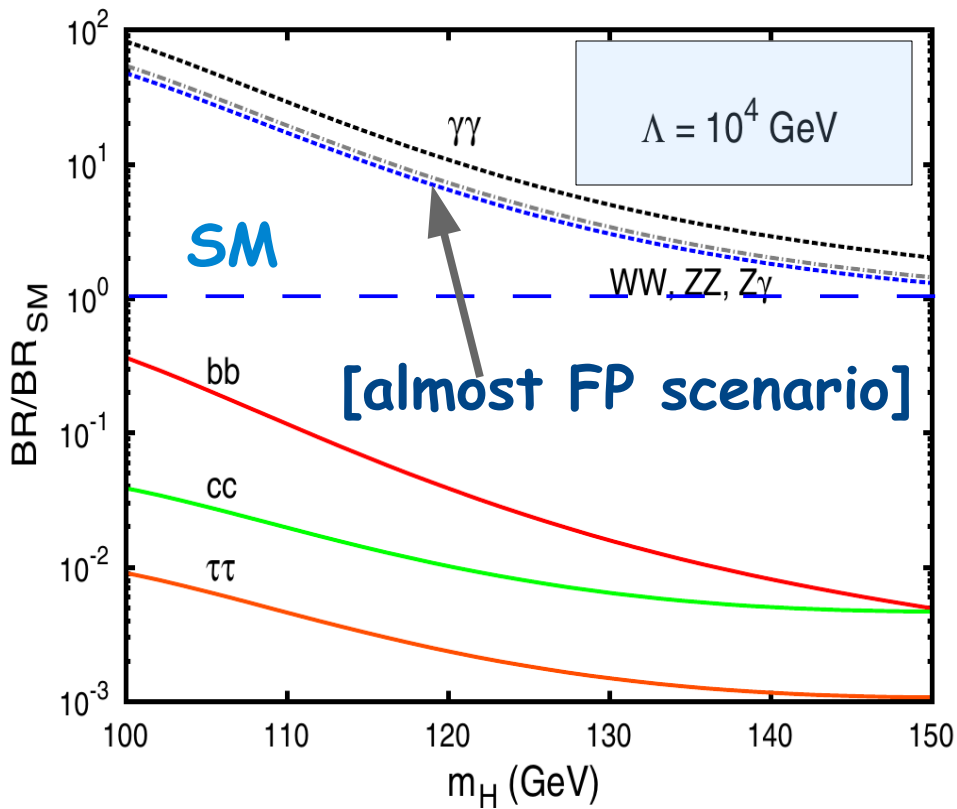
■ because of terms $\xi_H \equiv \frac{g_2 m_H}{2M_W}$ Y_f grows at large m_H

■ all Y_f 's perturbative for $m_H < \langle H \rangle \sim 246$ GeV

Results for Γ_H and BR's versus Λ

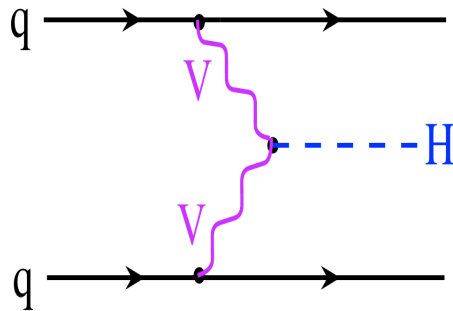


$BR / BR(SM): \Lambda \sim (10^4 \rightarrow 10^{16}) \text{ GeV}$

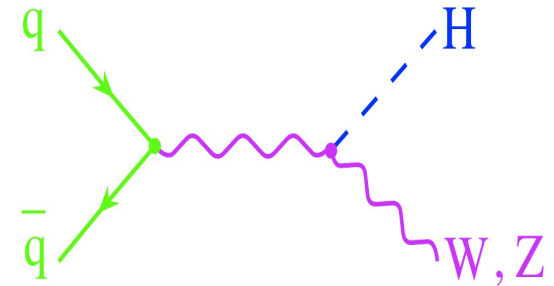


Higgs production at LHC changes

VBF

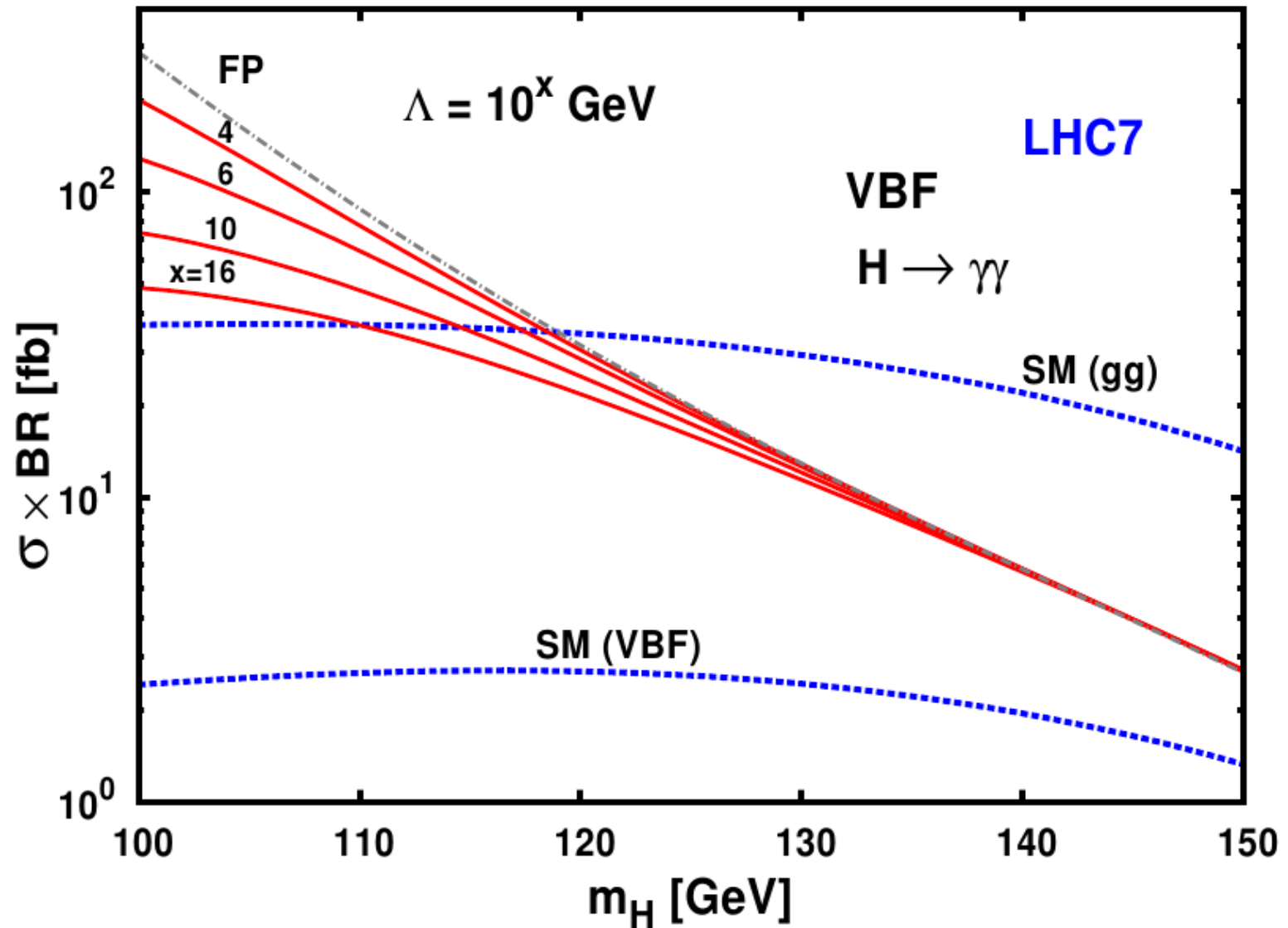


VH

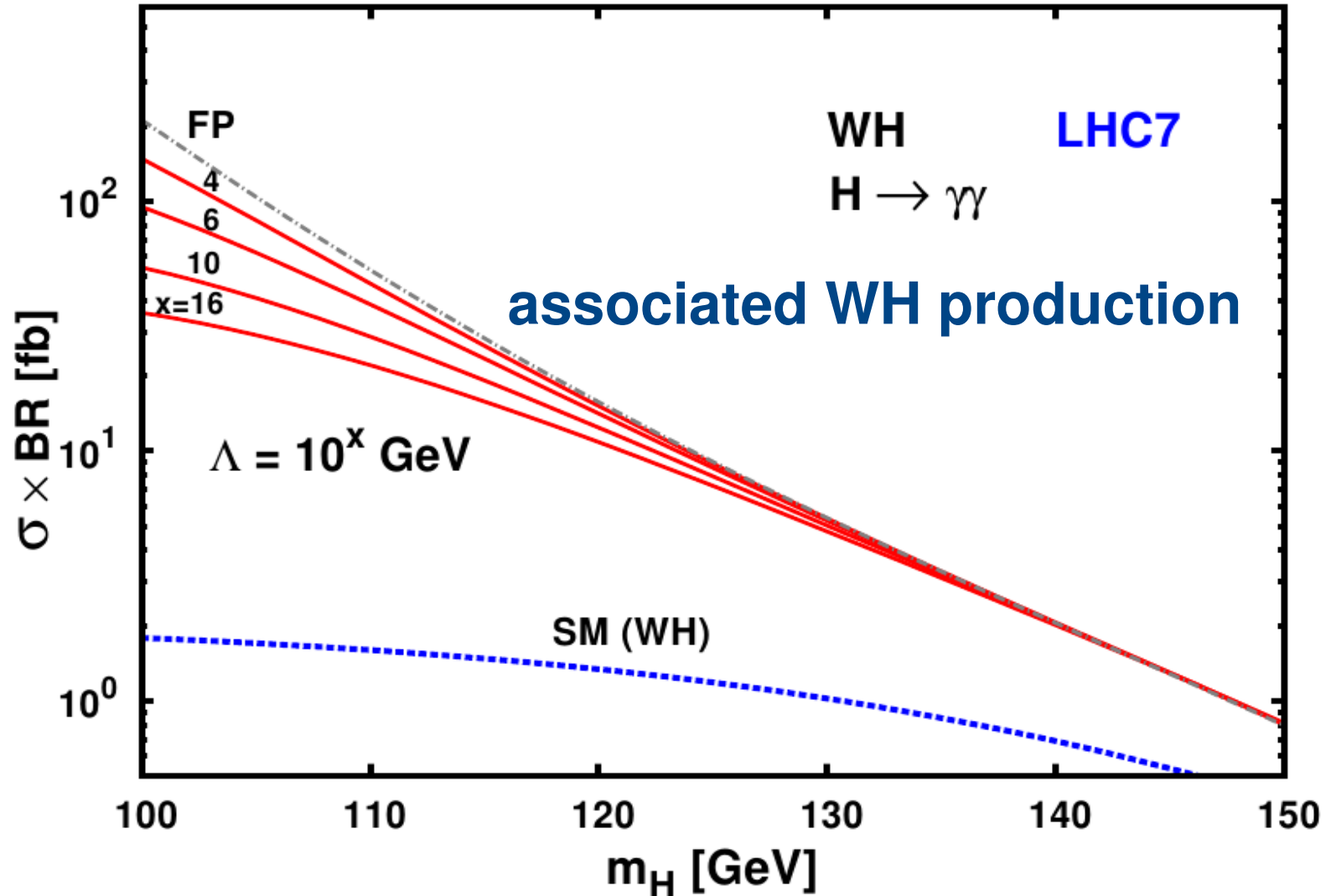


- **top-quark γt** radiatively induced (small)
- **gluon-gluon $\rightarrow$ [top-loop] $\rightarrow H$** suppressed
- **Vector Boson Fusion $\rightarrow H$** dominant production mechanism at LHC
- **harder $p_T(H) \rightarrow$ better S/B**

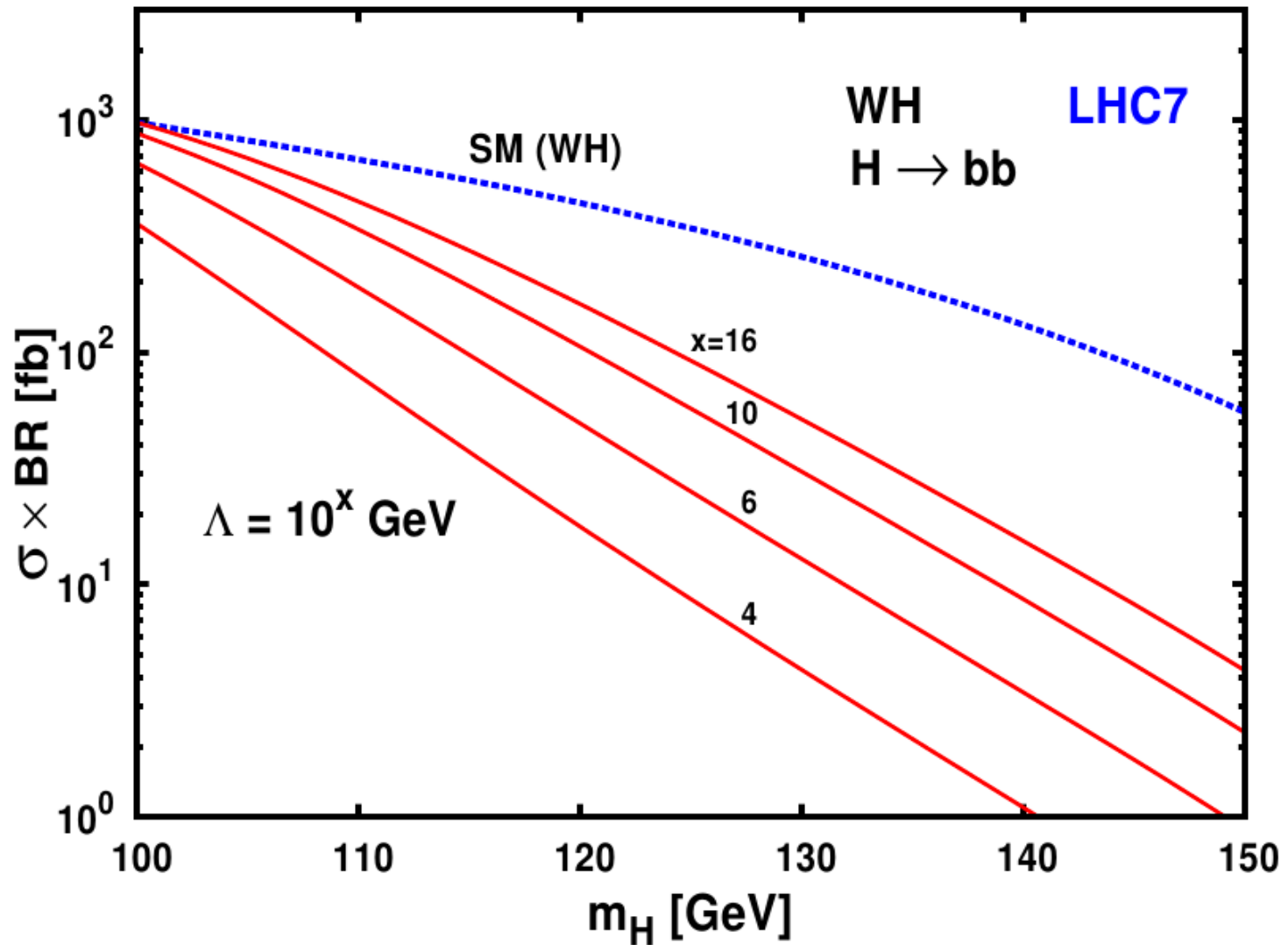
LHC (VBF) : $H \rightarrow \gamma\gamma$



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

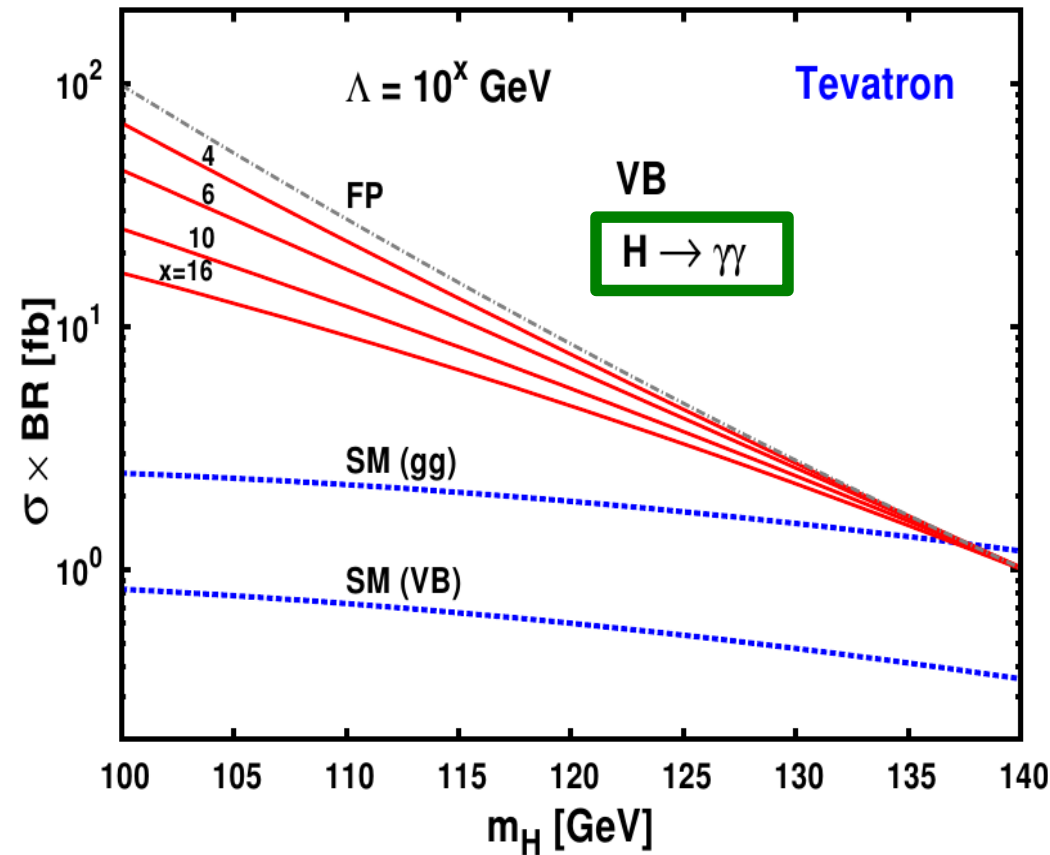


LHC (WH) : $H \rightarrow bb$

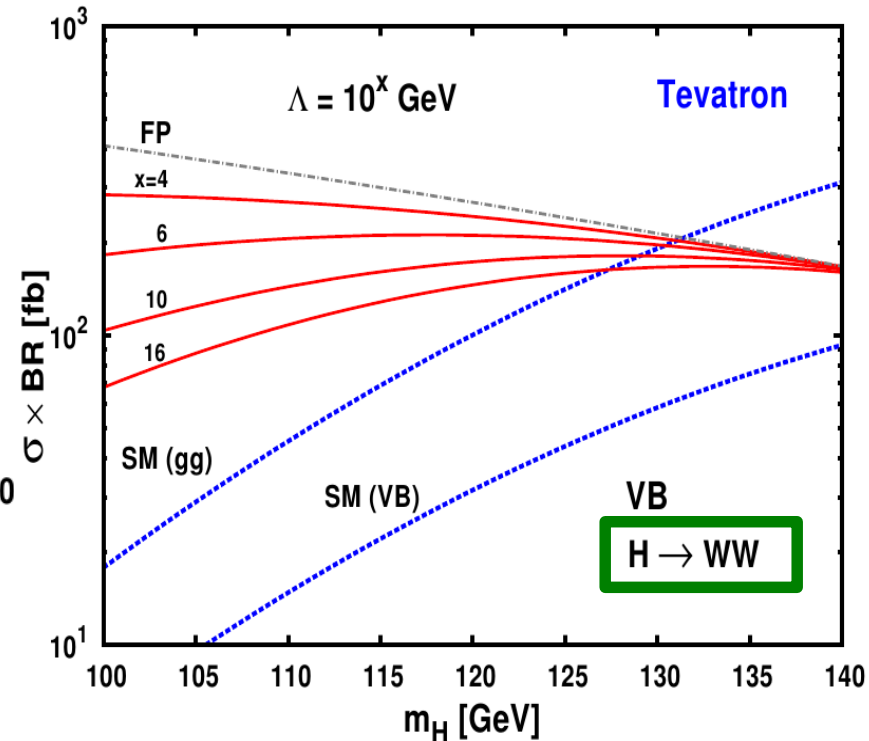
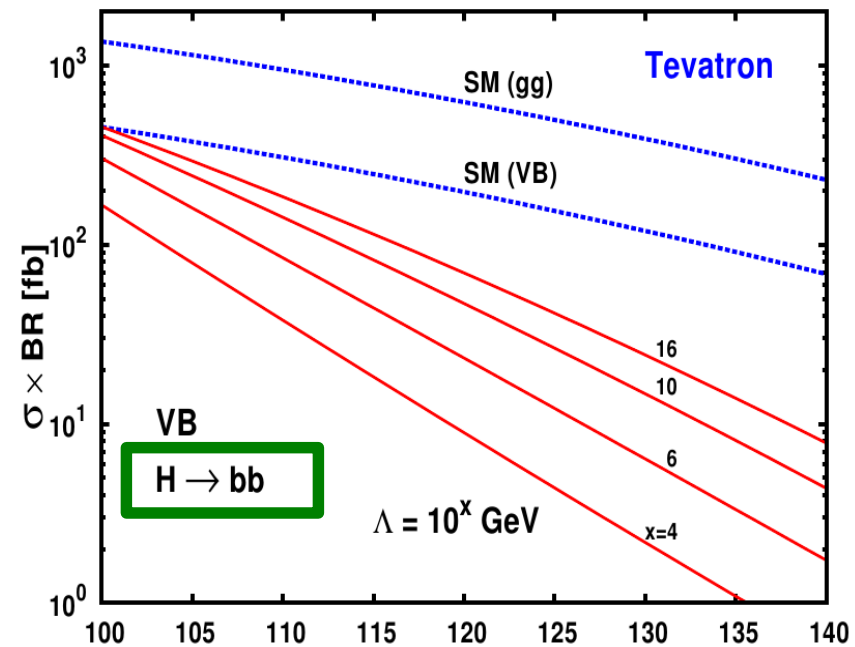


Tevatron ($p\bar{p} \rightarrow H X$)

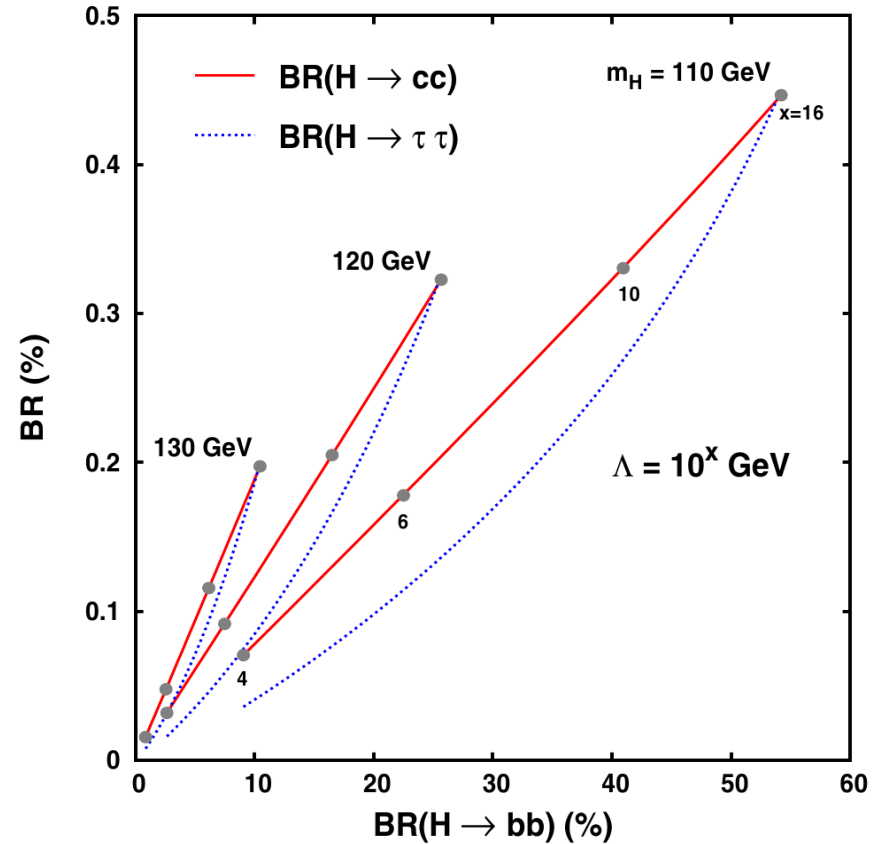
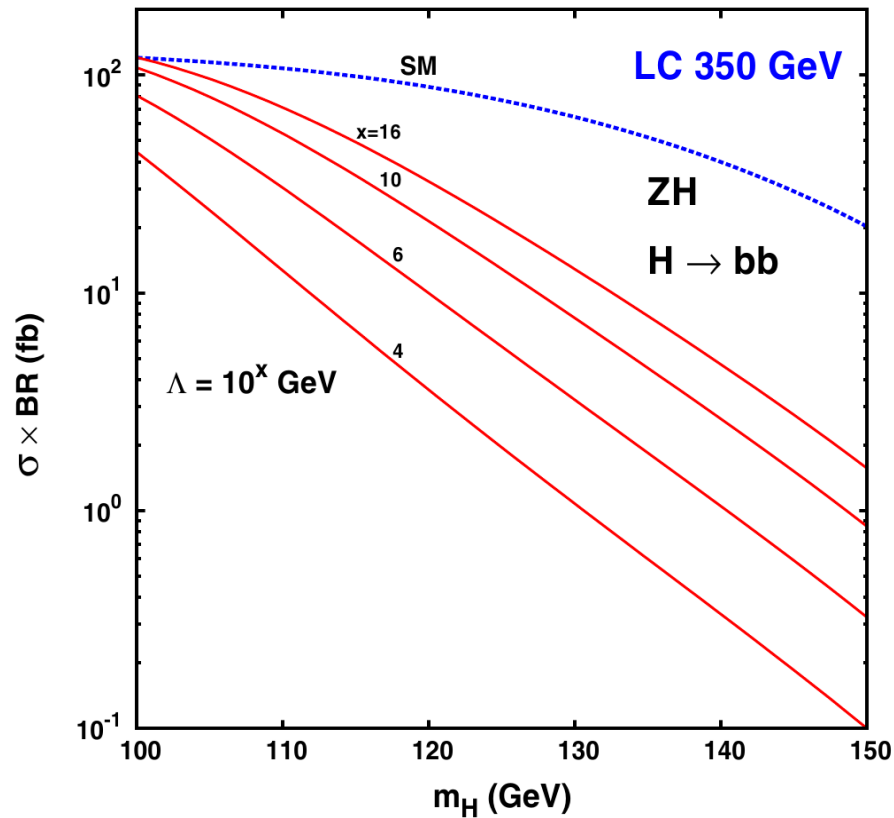
VB = (WH+ZH+VBF)



Tevatron can constrain the model !



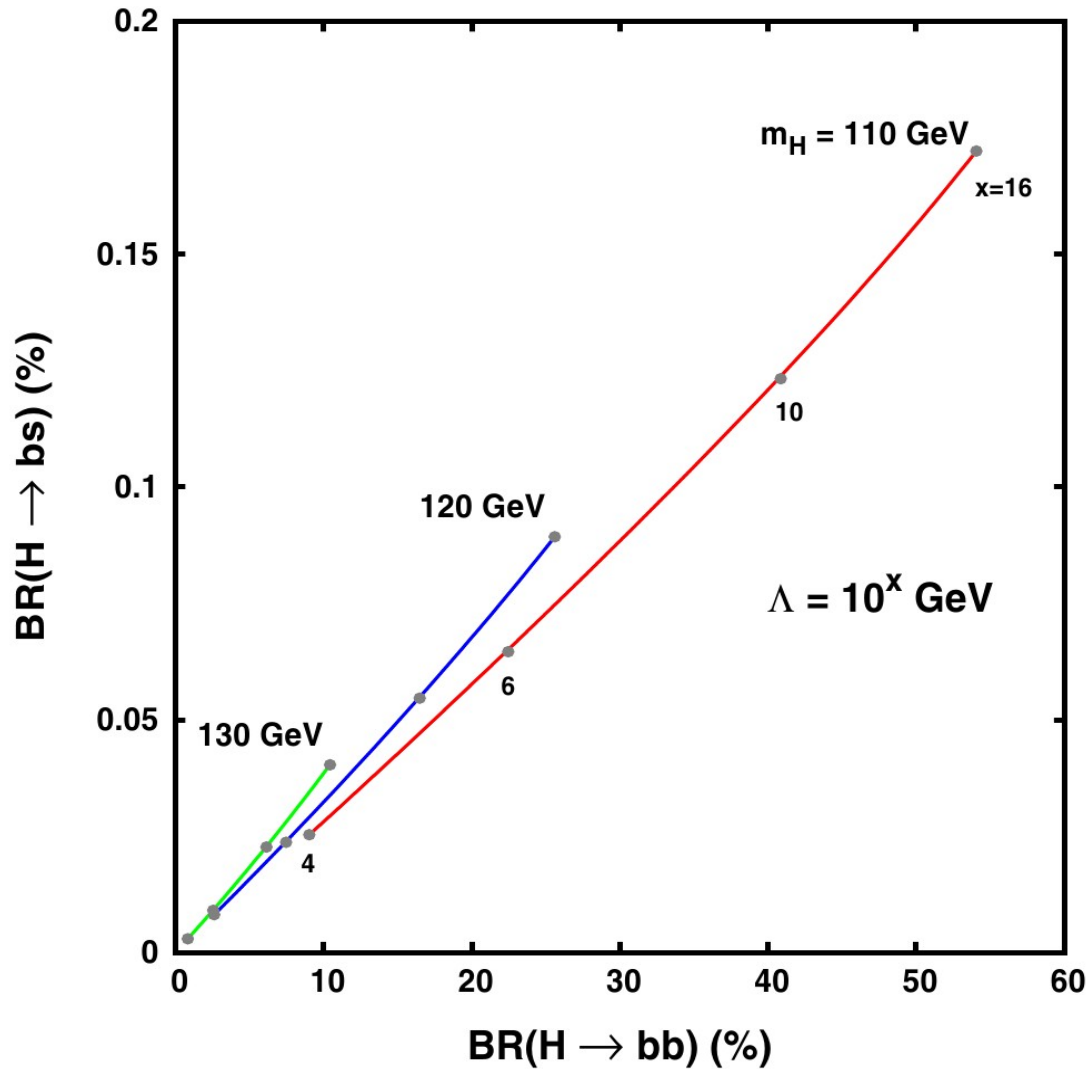
Linear Colliders case



EG, B.Mele, PHYSICAL REVIEW D 83, 073009 (2011)

■ testing BR's correlations crucial to prove
Effective Y_f 's scenario !

Correlations of FC $\text{BR}(H \rightarrow bs)/\text{BR}(H \rightarrow bb)$



EG, B.Mele, PHYSICAL REVIEW D **83**, 073009 (2011)

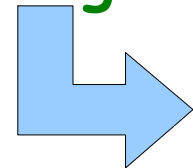
exp bounds on m_H (pure FP model)

■ Quite a number of studies on **pure FP** scenario

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

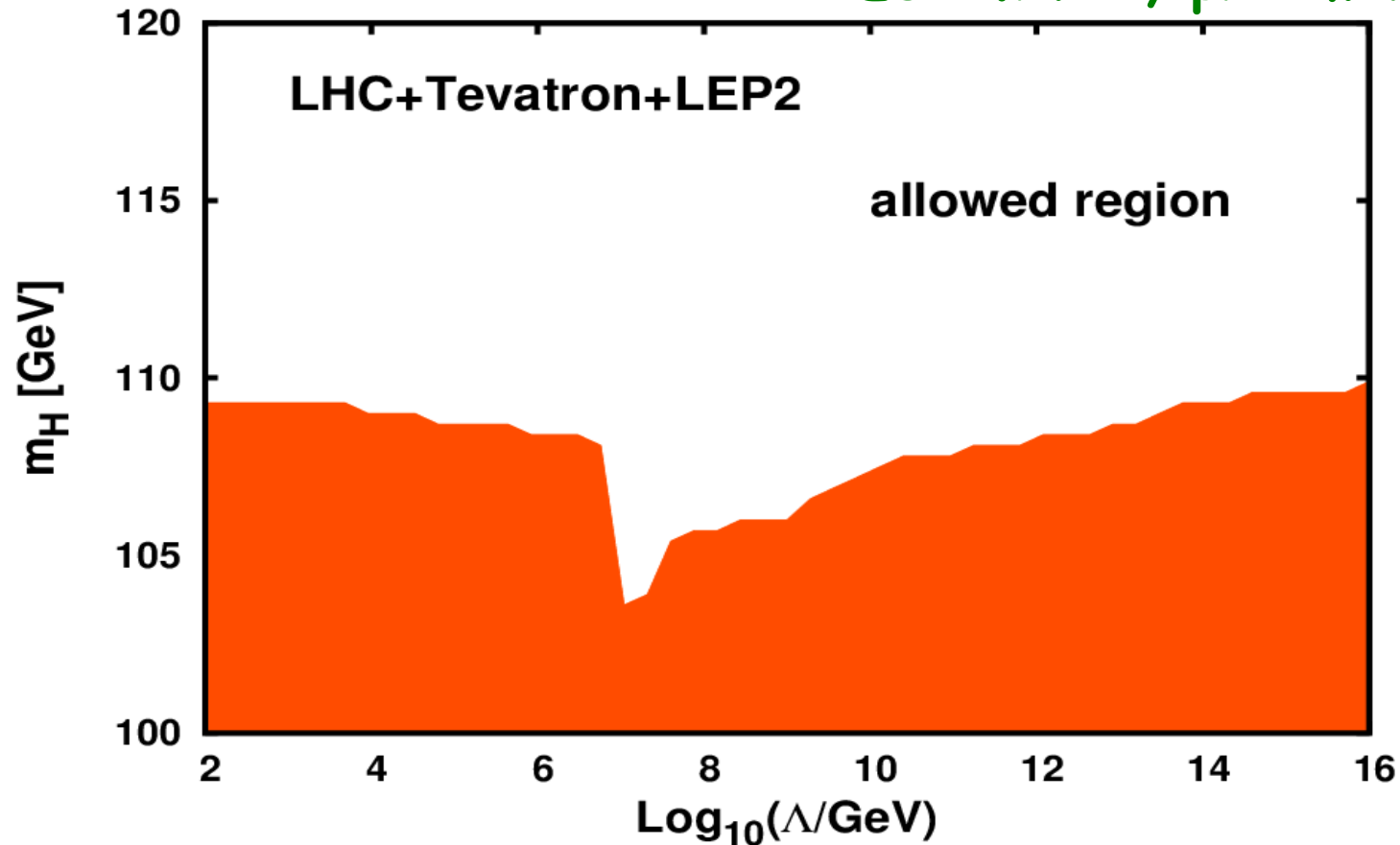
■ bounds in “Effective Y_f ” scenarios needs dedicated studies

- * in general weaker than in FP, and depending on Δ



bounds on m_H (effective Y_f 's model)

EG B.Mele, preliminary



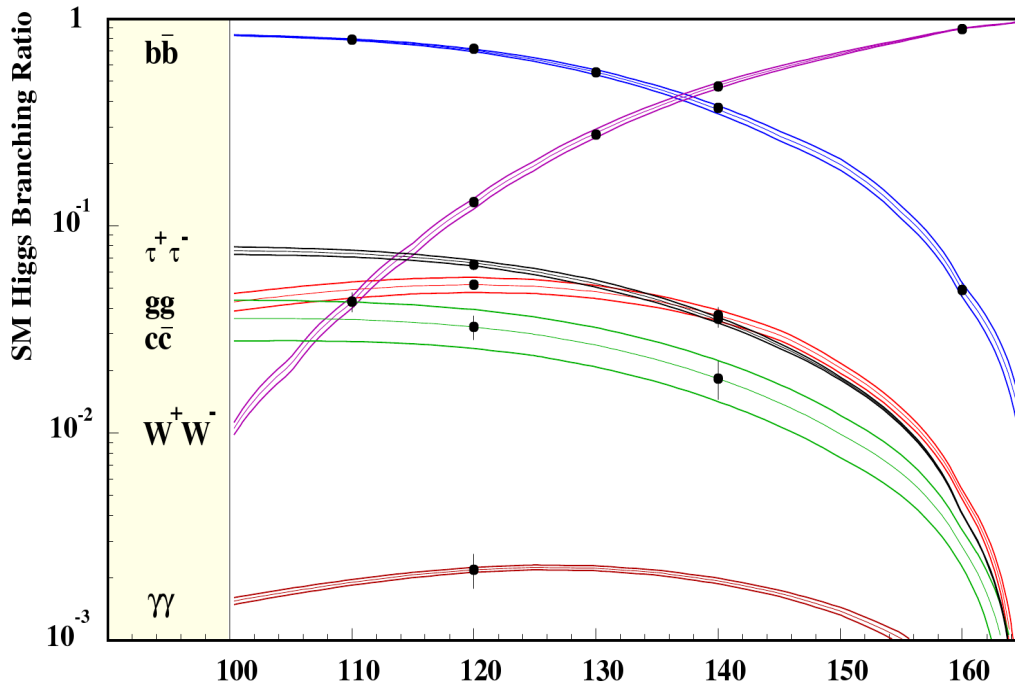
- bounds obtained with **Higgsbounds-3.4.0beta** (not updated with recent bounds on FP Higgs from LHC and CDF) **Comput.Phys.Comm.181:138 (2010)**

Outlook

- Fermio-Phobic Higgs scenario is unstable under radiative corrections → **ChSB regenerates Yukawa couplings**
- EFT approach to include radiative corrections → unified descriptions of a wide class of possibilities
- if the scale Λ of **ChSB** is very large **BR($H \rightarrow bb$)** can be comparable to SM one
- **LHC will test soon effective Y_f 's scenario** → intermediate between SM and naïve FP scenario, **but accurate study of $H \rightarrow bb, cc, \tau\tau$, requires LC**
- rates for **$e^+e^- \rightarrow ZH \rightarrow Zbb$** remarkably sensitive to the scale Λ !
- **new analysis of LC sensitivity to Higgs BRs in the new framework needed**

Backup

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%

New analysis needed
to establish $\Delta\text{BR}(H \rightarrow ff)$