# Testing effective Yukawa couplings in Higgs studies at Linear Colliders

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**talk based on arxiv:1005.2498**

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# What if Higgs boson is only responsible of $M_W$ , $M_Z$ but not of fermion masses ?

- fermion masses $m_f$ → ChSB

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

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

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

- maybe ChSB & EWSB have different mechanisms → 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 a Higgs
  - not very sensitive to $Y_f$
  - H ⇒ perturbative unitarity in WW → WW
- What if fermion masses put in by hand ?
  - no tree-level $Y_f$ ⇒ NO spontaneous ChSB
    ⇓
  - SM becomes non-renormalizable, but can be considered as an effective field theory

# Proposed Scenario

- $m_f$ generated by some new mechanism set at a high-energy scale $\Lambda$ >> EW scale
- NO tree-level Yukawa couplings
- ChSB mechanism assumed to give a small contribution to EWSB
- H providing the main contribution to $M_W$ and $M_Z$
- only SM degrees of freedom propagating below $\Lambda$, with a light H

- $\Lambda$ → scale where $Y_f$ are vanishing

(i.e. scale of fermion mass generation)

- $Y_f$ not protected against radiative corrections due ChSB → radiatively generated

- large logs $g_i^{2n} \log^n (\Lambda / m_H)$ can be summed up

by solving Renormalization Group Equations

- SM RGE are not suitable due to tree-level Yukawas

↓

RGE derived by keeping $Y_f$ and $m_f$ as independent parameters

# 1-loop RGE for Yukawa couplings

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

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

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

**W(L) polarizations**

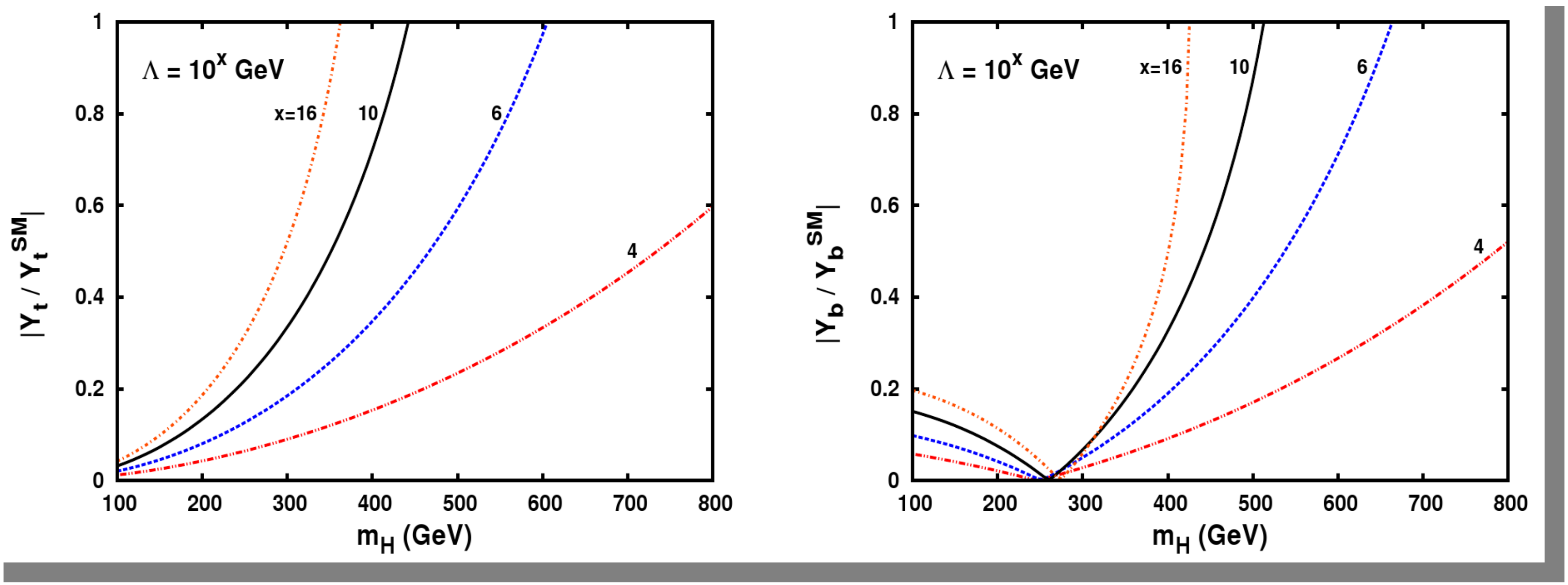
$$\xi_H \equiv \frac{g_2 m_H}{2M_W}, \qquad \mathbf{Y_f^{SM}} \equiv \frac{g_2}{\sqrt{2}M_W}\mathrm{diag}[\mathbf{m_f}]$$

**ChSB terms**

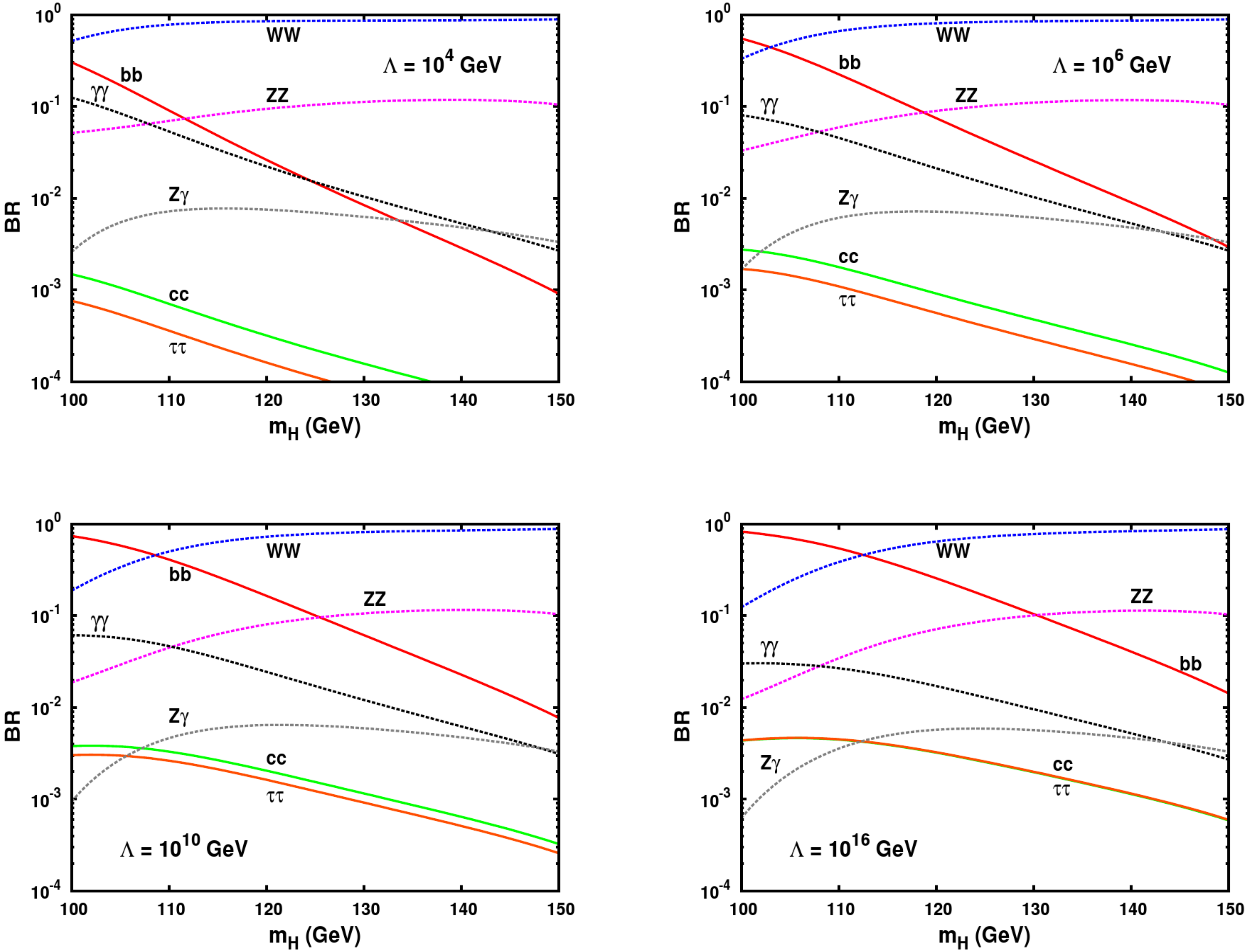
**SM RGE recovered for** $\mathbf{Y_f^{SM}} \to \mathbf{Y_f}$

# Theoretical Framework

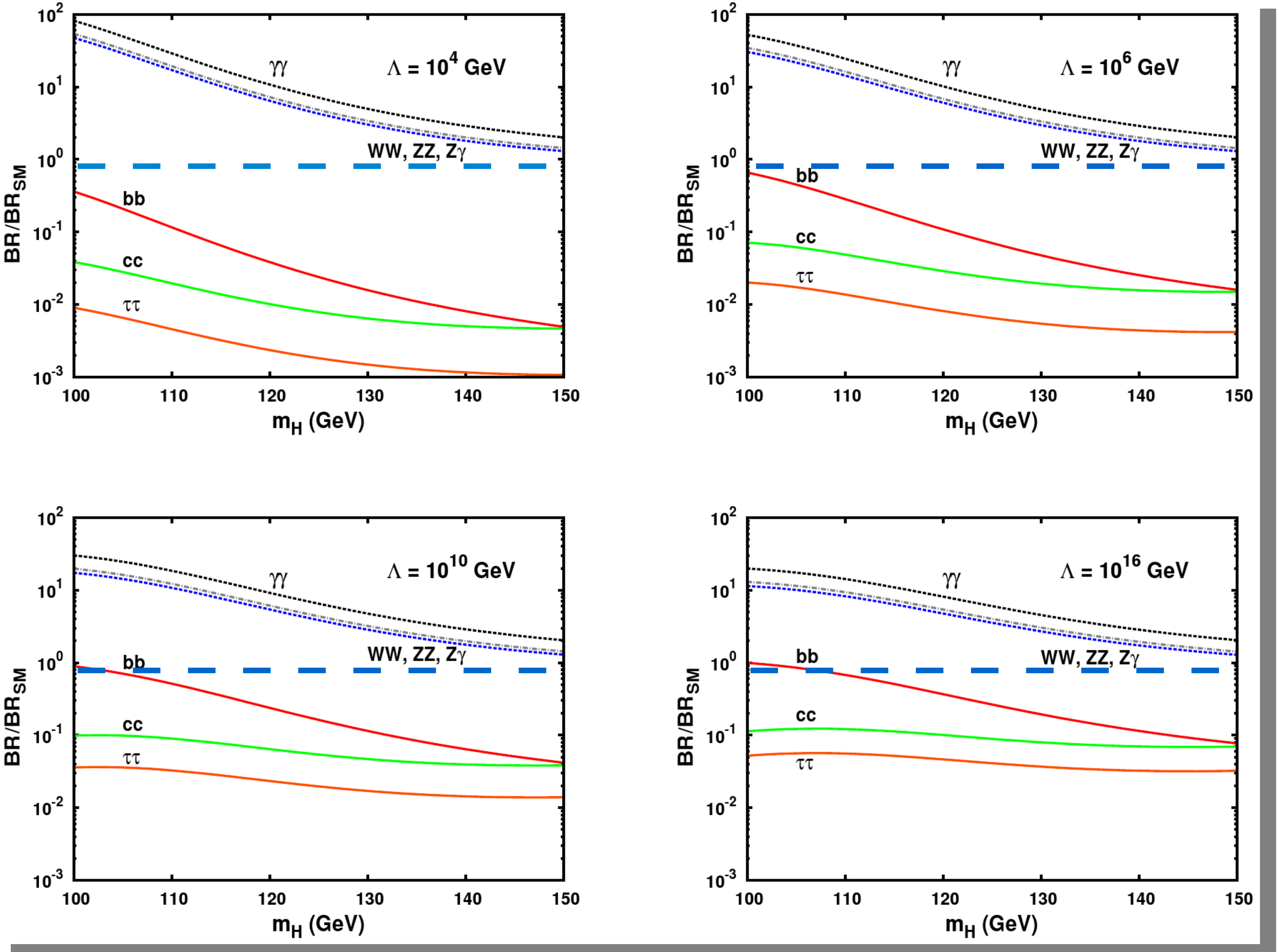
- $Y_f(\Lambda) = 0$ (high-energy) → RGE → $Y_f(M_H)$ (low-energy)
- only SM degrees of freedoms assumed below Λ
- $Y_f(M_H)$ perturbative for mH < $\langle H \rangle$ ~ 246 GeV



# Higgs BRs dramatically affected



# Higgs BRs normalized to SM ones



# Higgs decay modes dramatically affected

- differs from naïve fermiophobic scenarios where Yukawa couplings are set to zero at EW scale
- main H decays modes → WW, bb, $\gamma\gamma$, ZZ
- BR(H→ bb) comparable or larger then enhanced $\gamma\gamma$

# H production at LHC changes

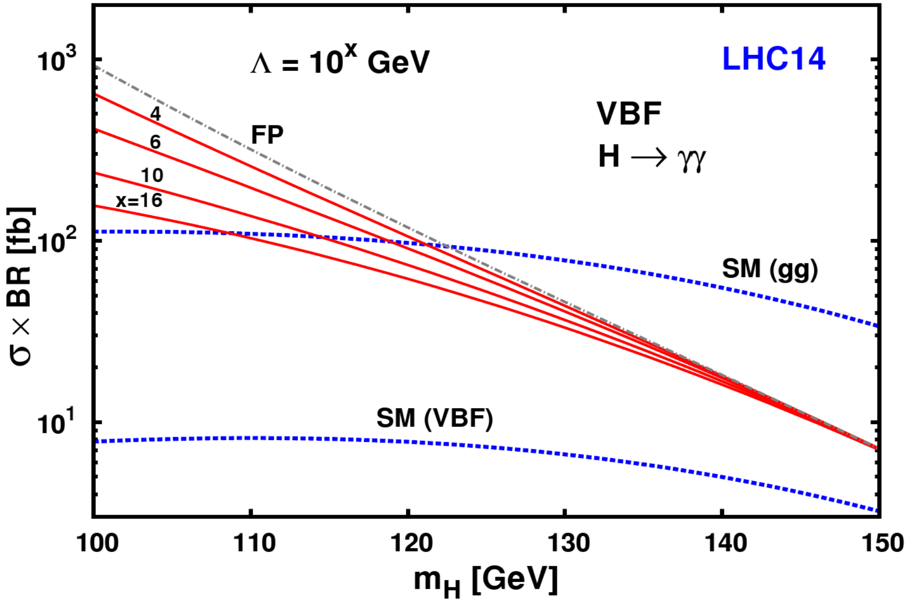
- $Y_t$ coupling radiatively induced (small)
- gluon-gluon fusion suppressed
- Vector boson fusion (VBF) becomes the dominant production mechanism at LHC

# LHC14 cross sections X BR [fb]

**VBF**

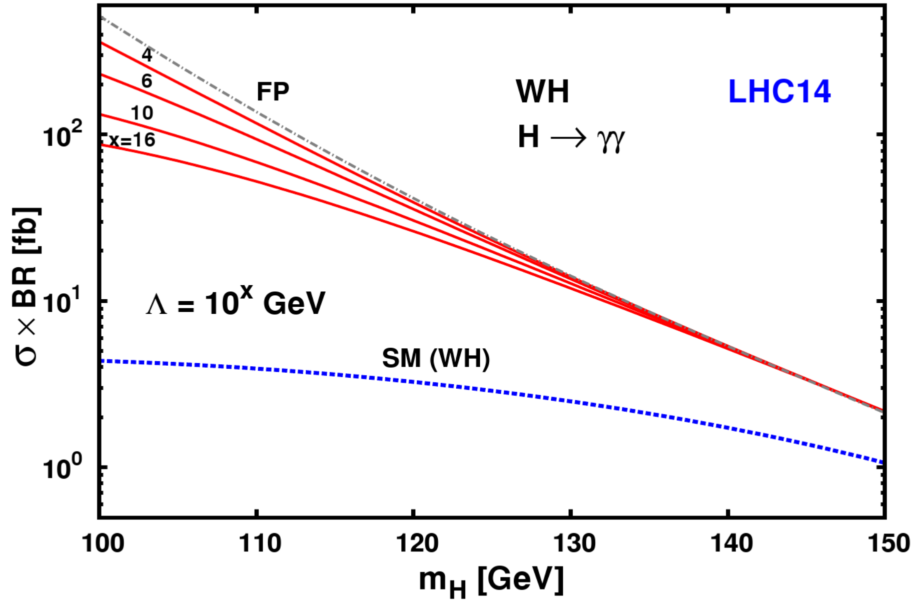
$\Lambda = 10^X$ GeV

**Fermiophobic scenario → FP**

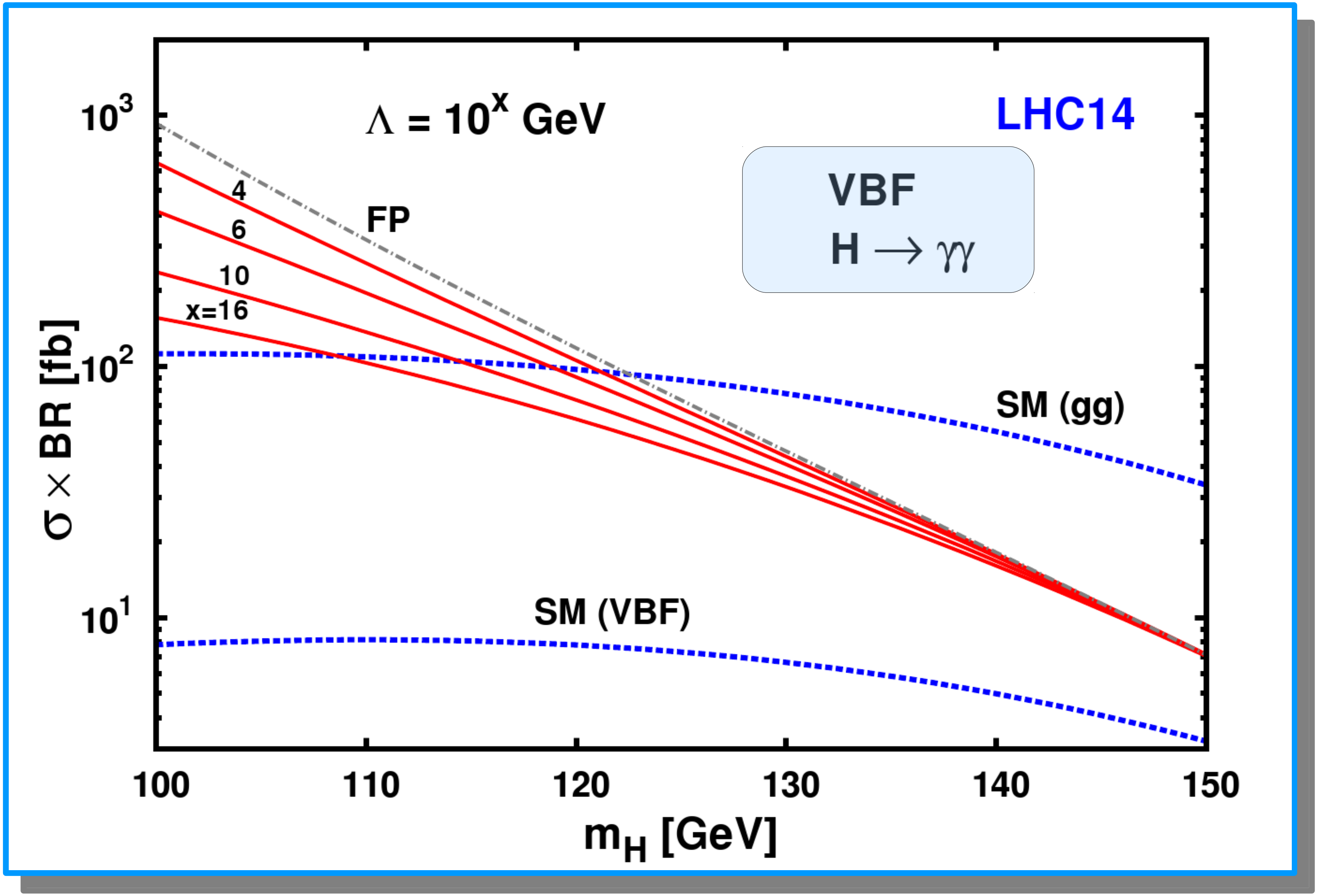



**H → γγ**

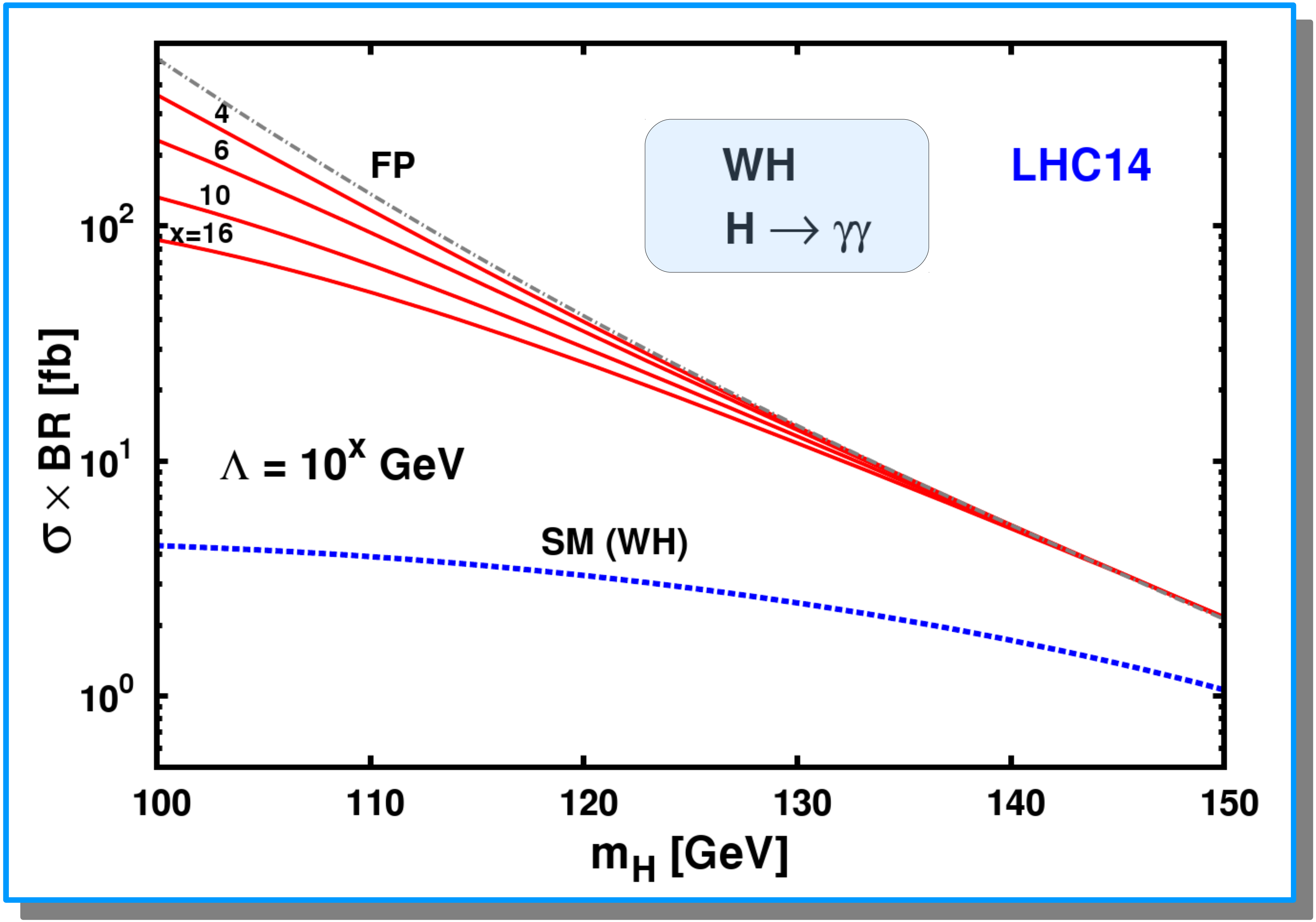
**WH**




**H → γγ**




- Comparable rate to the SM (gg) but VBF/BCKG much cleaner



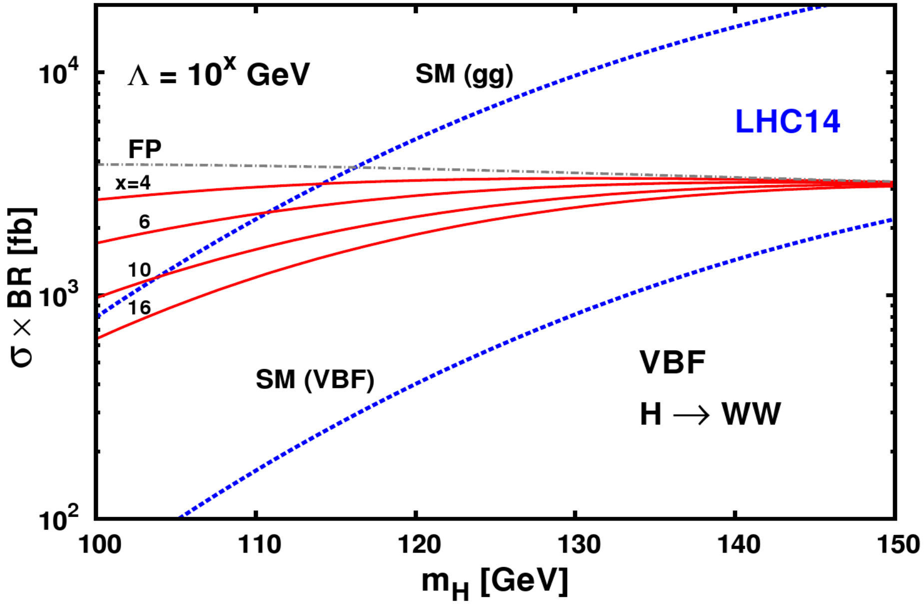
WH
$H \to \gamma\gamma$
LHC14
FP
4
6
10
x=16
$\Lambda = 10^x$ GeV
SM (WH)
$\sigma \times BR$ [fb]
$10^2$
$10^1$
$10^0$
100
110
120
130
140
150
$m_H$ [GeV]

# LHC14 cross sections X BR [fb]

VBF

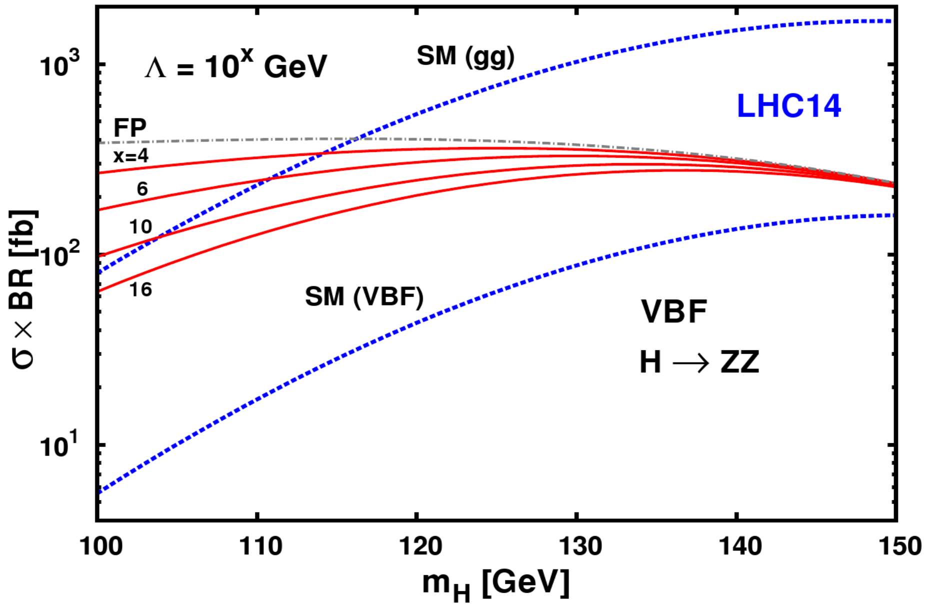
$\Lambda = 10^X$ GeV

**Fermiophobic scenario → FP**




## H → WW

VBF




## H → ZZ

## Tevatron: present bounds

- **CDF & D0** analyzed various fermiophobic scenarios with enhanced $H \to \gamma\gamma$
- **mH < 110 GeV excluded for pure FP**
- a dedicated analysis is necessary here due to non-trivial depletion of $BR(H \to bb)$
- **it could probe at best mH < 110 GeV**

## Future searches: LHC

- **Excellent probe of this scenario**
- $\sigma$xBR much larger than SM ($\gamma\gamma$,WW, ZZ,Z$\gamma$)
- better S/B ratio compared to SM (VBF,VH)
- better theoretical accuracy (VBF, VH)

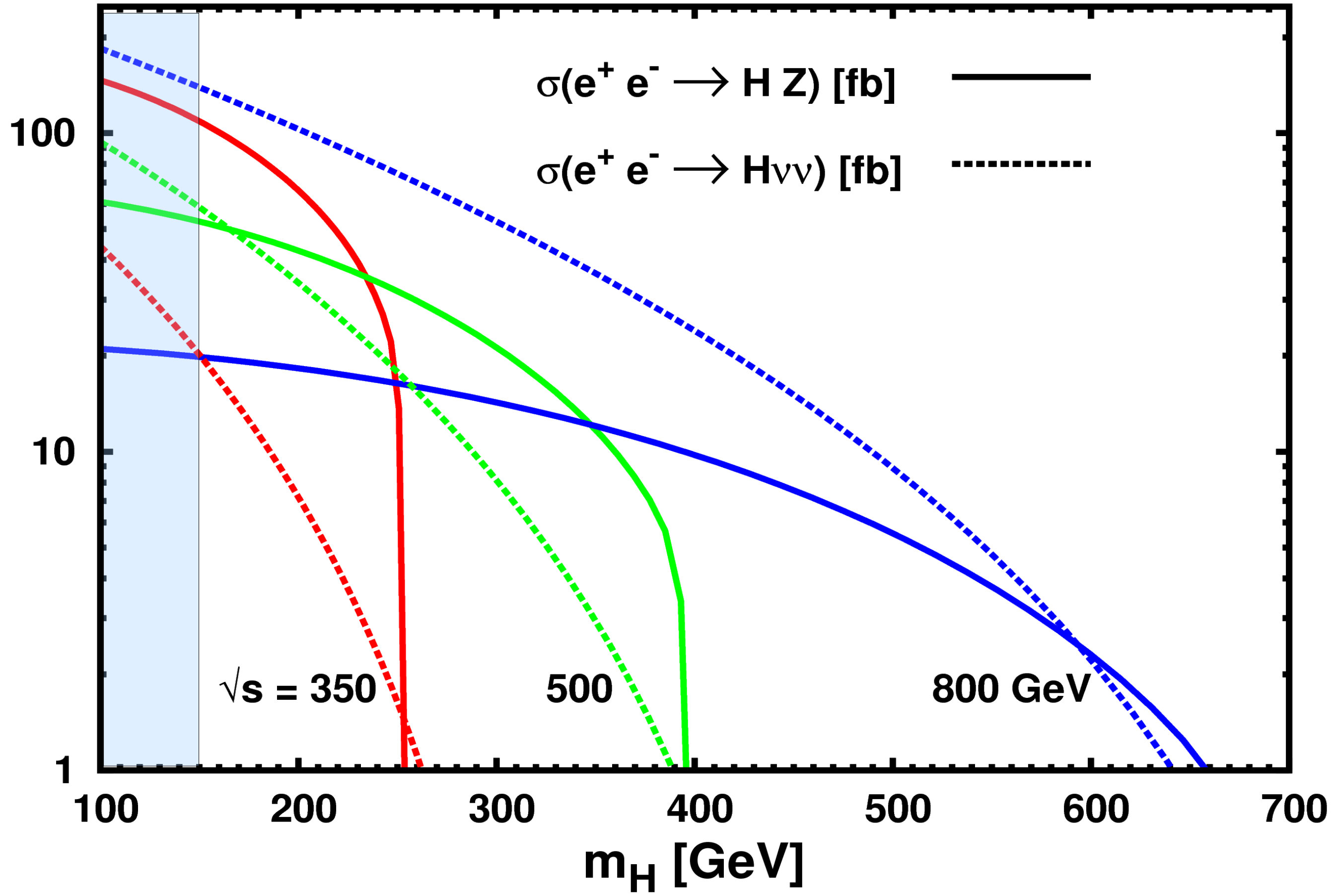
# Effective $Y_f$ at Linear Colliders

- no new degrees of freedom below TeV except an almost fermiophobic light Higgs
- **very good option →** $\sqrt{S} = 350\,\mathrm{GeV}$

**advantages**

- optimized Higgs production rate via ZH
- **$\sigma$(ZH) > $\sigma$(H$\nu\nu$) almost monochromatic H**
- **good potential to measure radiative Yukawa couplings**
- **could constrain the scale $\Lambda$ of ChSB**

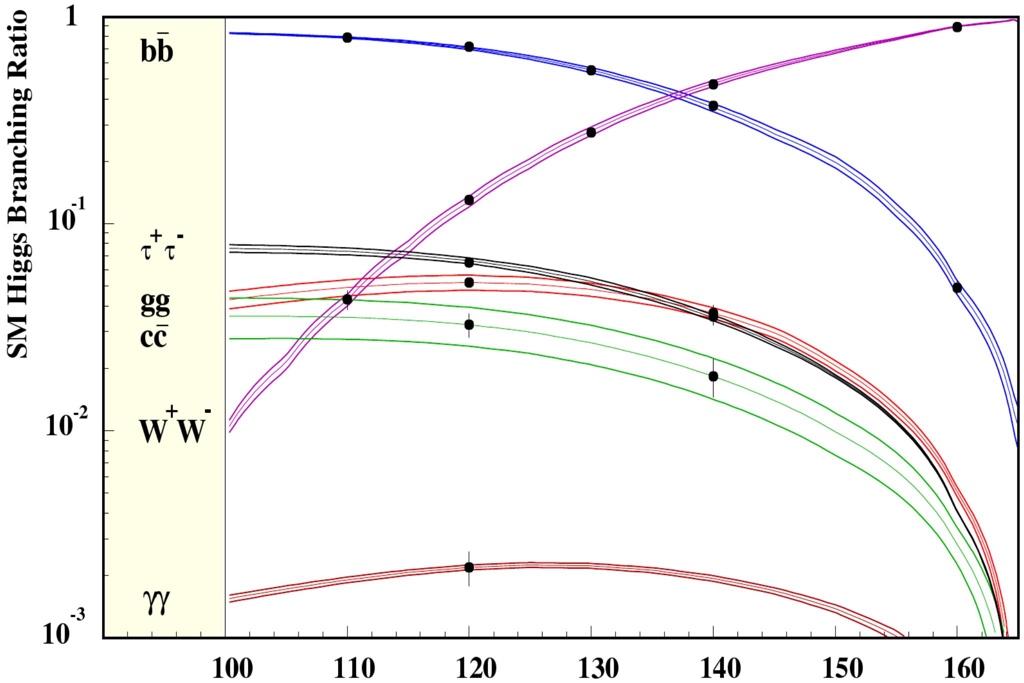
# Higgs production cross sections




- **we will show only σ(ZH) x BR at 350 GeV →** for interesting channels

- **note that:**
  σ(Hνν) + σ(HZ) @500GeV ~ σ(HZ) @350GeV for $M_H$<150 GeV

# Accuracy on BRS for SM Higgs boson




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

Expected experimental uncertainties

- error bars →exp. sensitivities

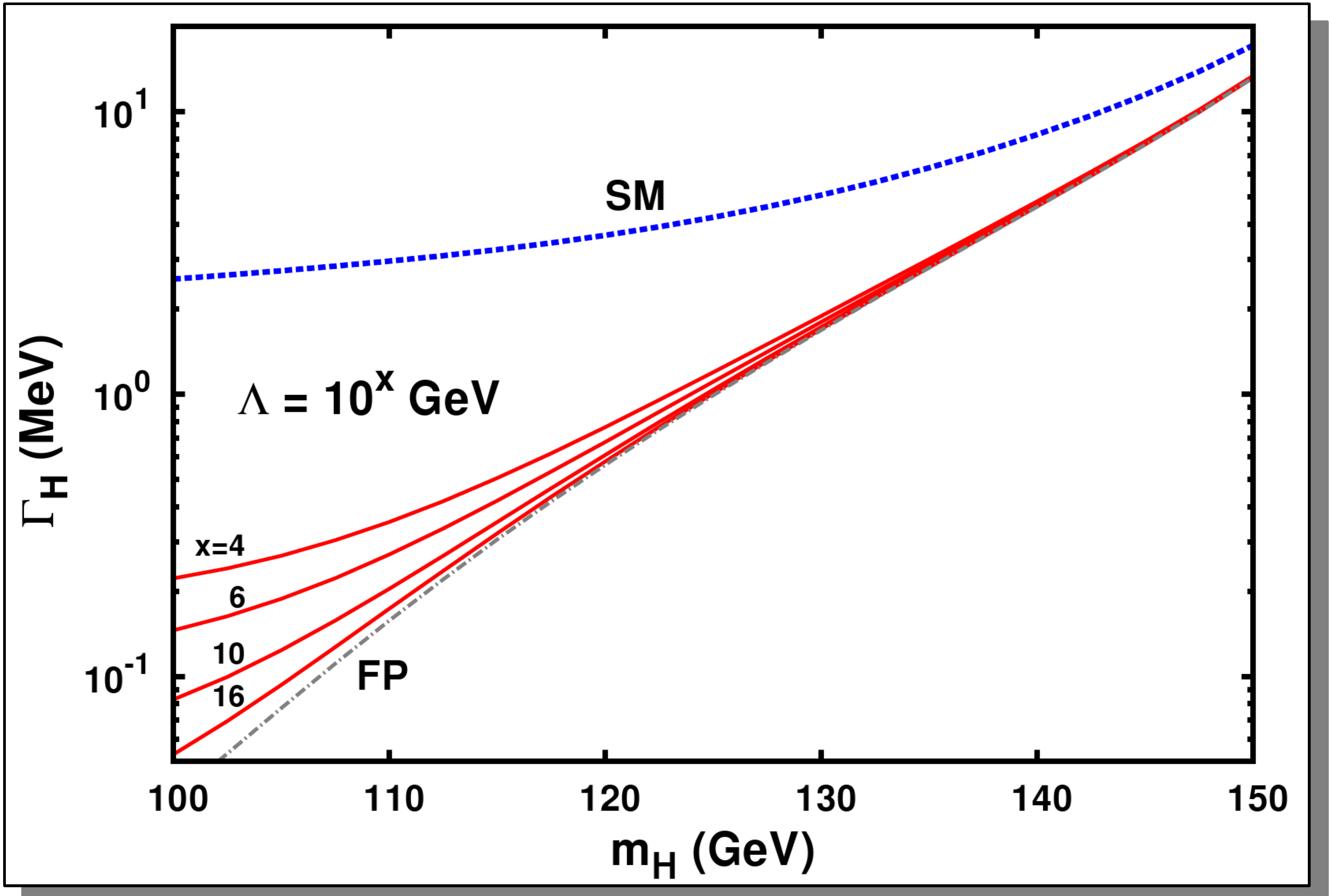
"Phase 1": 500 $fb^{-1}$ at 350 GeV, no bea

| 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

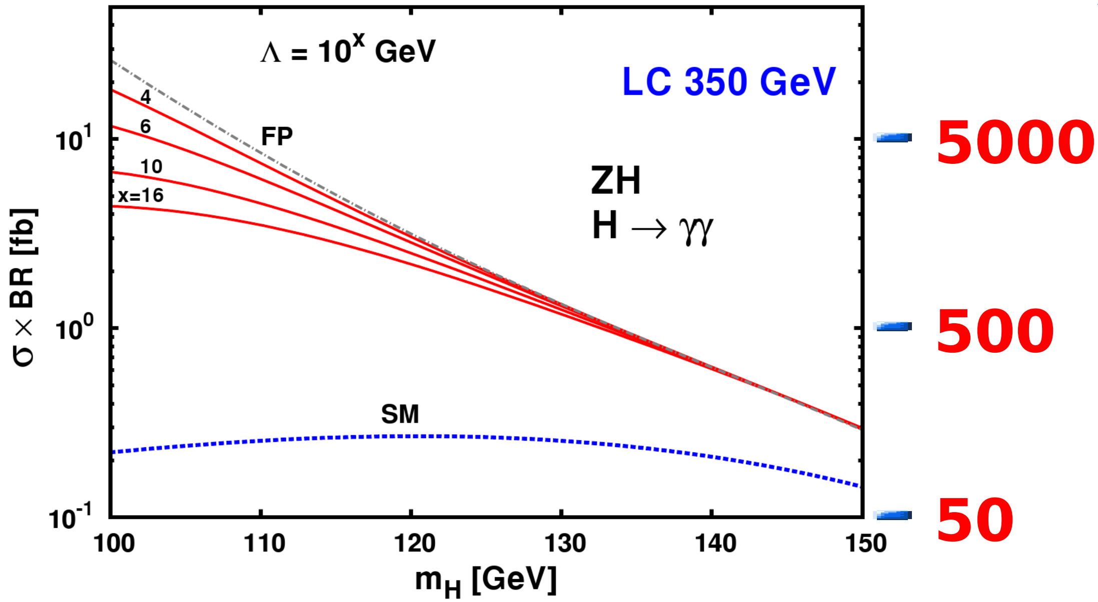
**New analysis needed to establish ΔBR(H → ff)**

# Total Higgs decay width



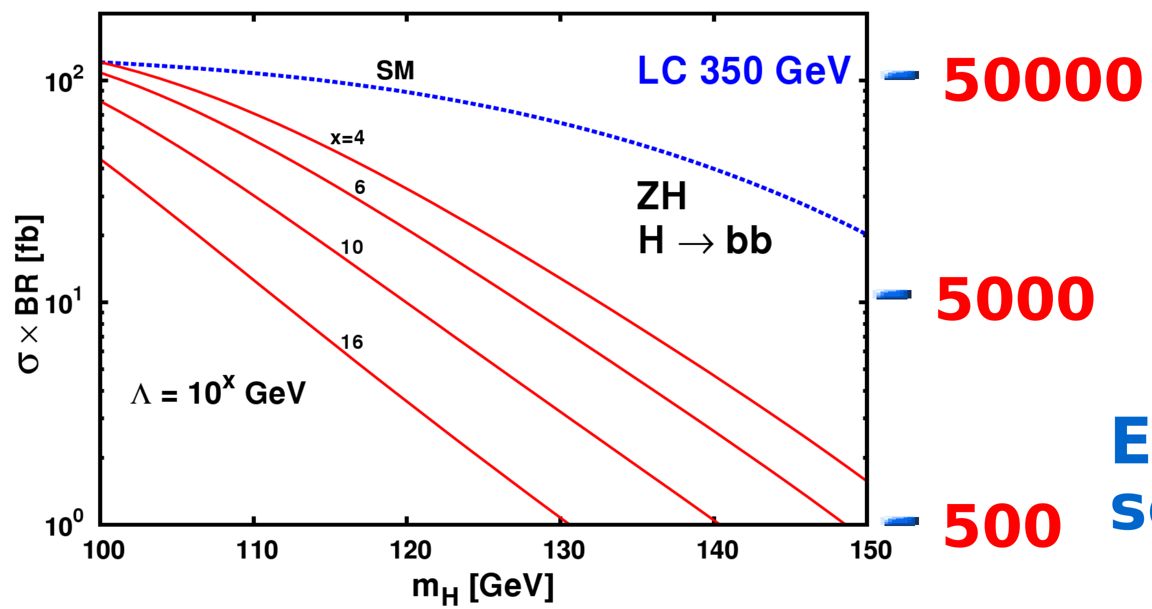
# σ x BR [fb]

**Nev/500 fb-1**




**LC 350**

**H → γγ**

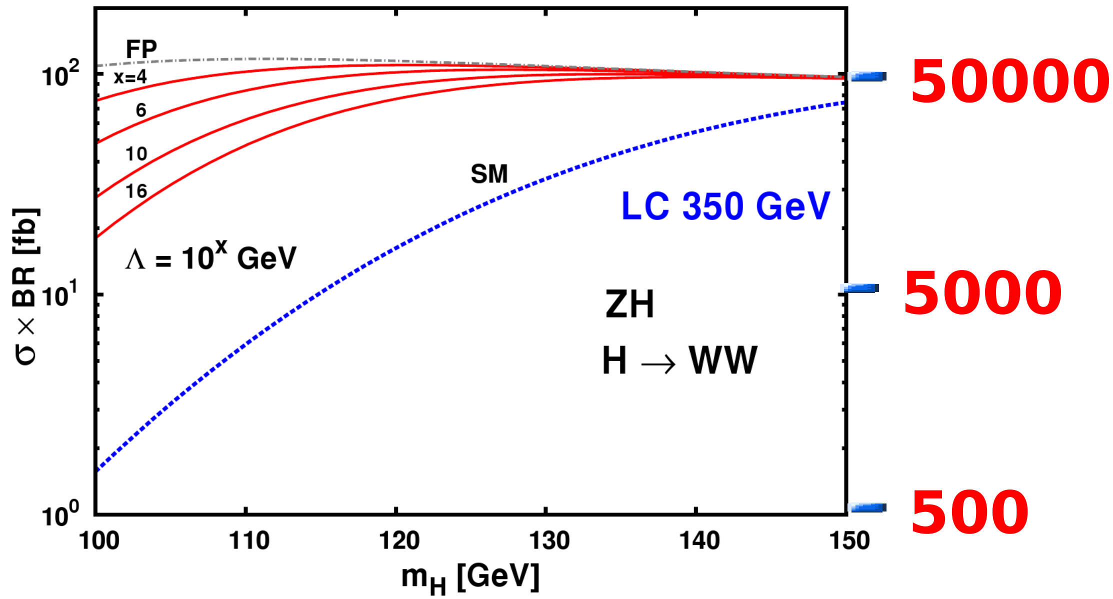



**LC 350**

**H → bb**

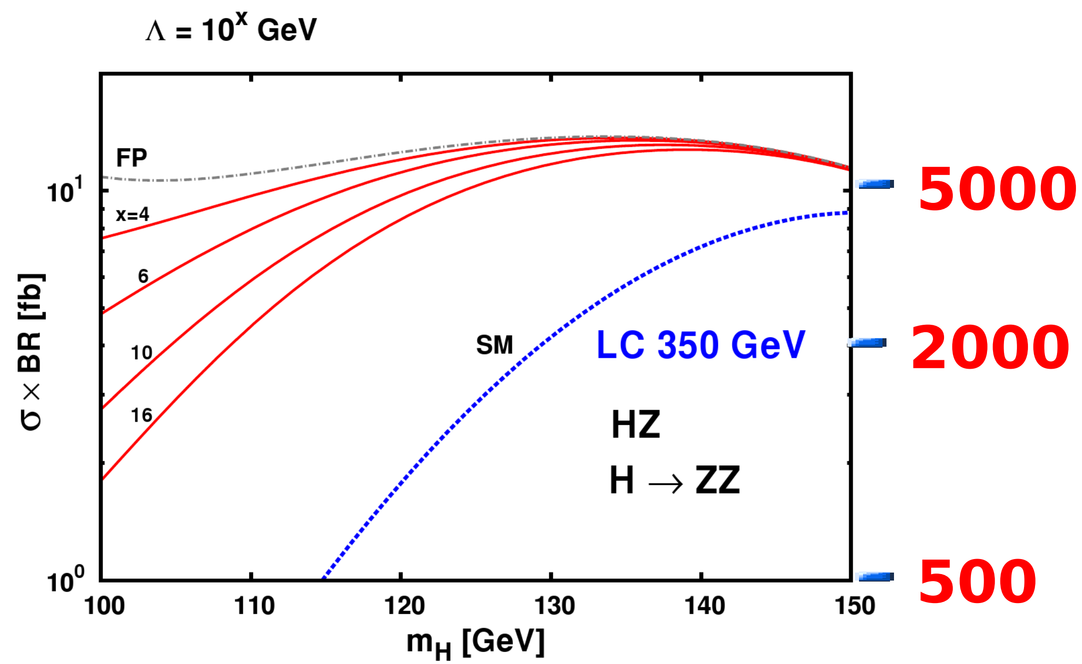
**Excellent sensitivity to Λ**

σ x BR [fb] **Nev/500 fb-1**




LC 350

H → WW

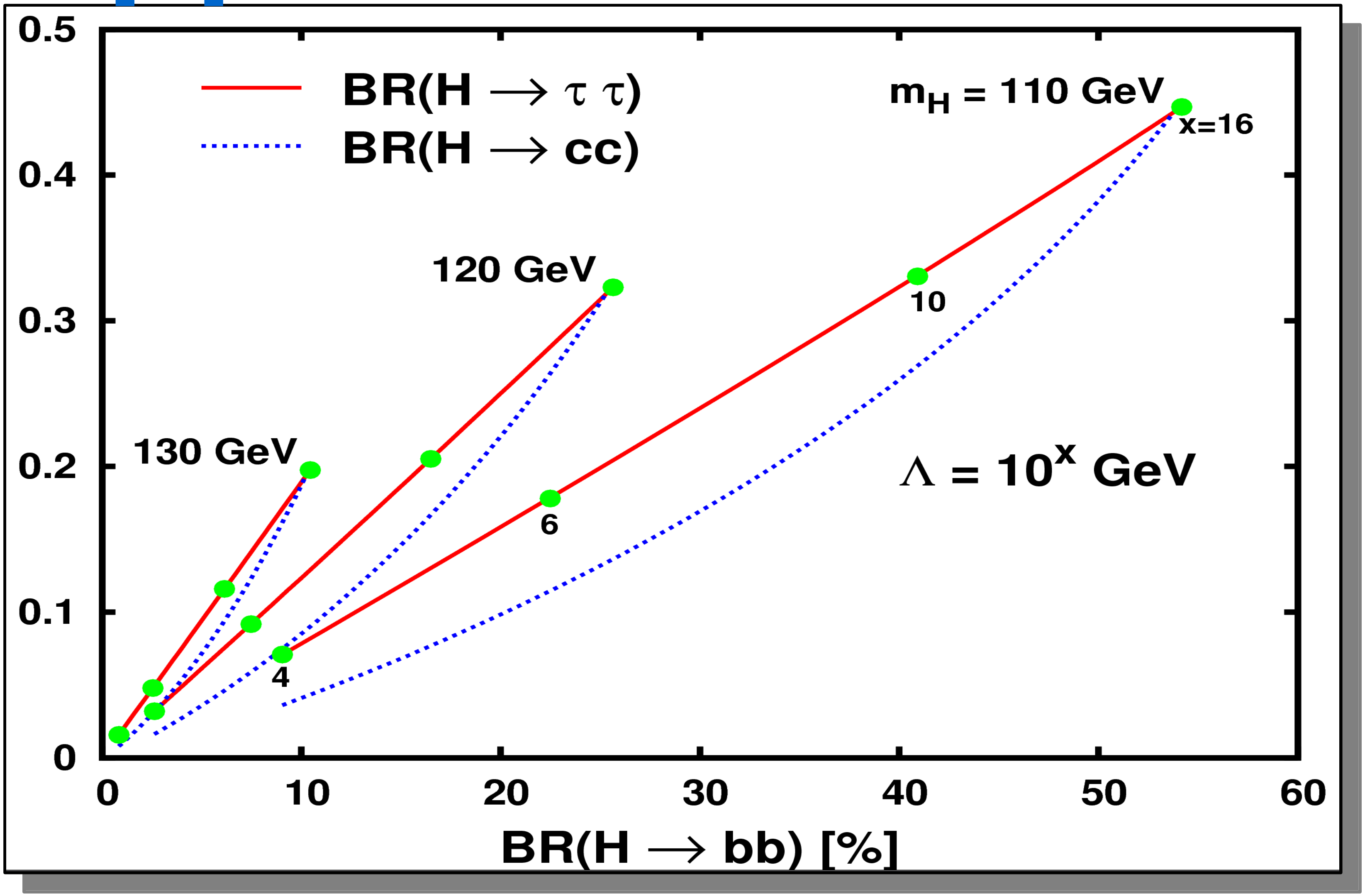



LC 350

H → ZZ

# Correlations of BR(H → ff)

BR[%]




**BR[ττ] ~ 1-2% BR[bb]**

# Outlook

- New predictive scenario where **mf's** arise at large scale $\Lambda$ and induce **Yf** radiatively → **only 1 free param.**
- **big impact on Higgs phenomenology →** "improved" FP scenario: effective **Yf** and Higgs production via W/Z radiation (no gg → H at LHC!)
- **Enhanced BR(γγ, WW, ZZ, γZ) for MH < 140 GeV** and possibly large radiative BR(H → bb)
- **Excellent LHC potential for testing this scenario,** but accurate study of **H → bb,cc, ττ,** requires LC
- Rates for **e+e- → ZH → Zbb** remarkably sensitive to the scale $\Lambda$ !
- **New analysis of LC sensitivity to Higgs BR in the new framework needed**

# Backup

# Tevatron cross sections X BR (fb)