Looking for a Fermiophobic Higgs at LHC

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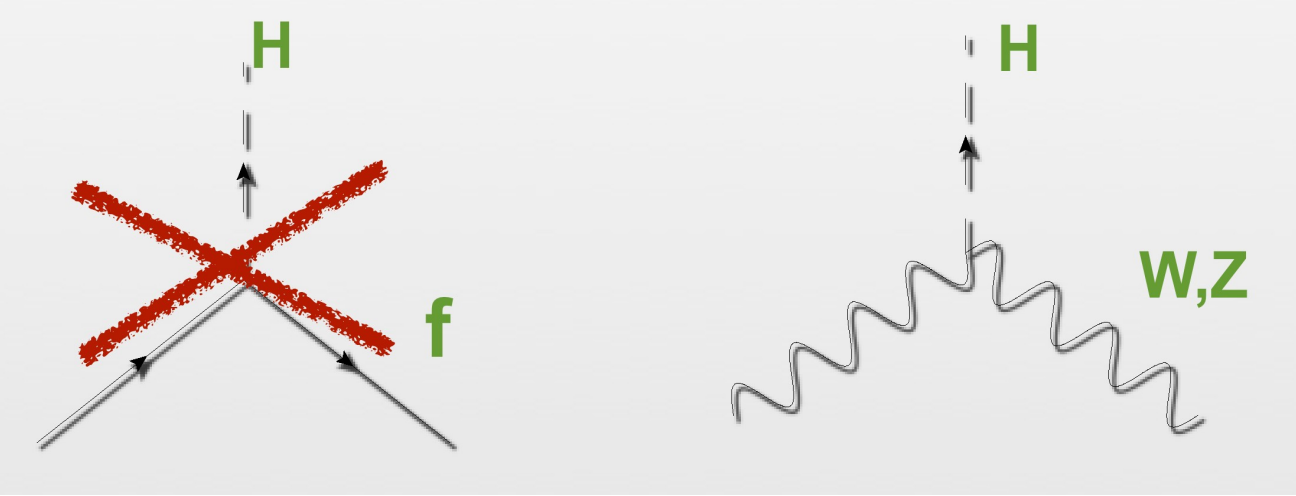
talk based on 1202.1796 [hep-ph], PRD 83: 073009 (2011),
PRD 82: 113014 (2010)

Implications of LHC results for Tev-scale physics, CERN, 26-30 March 2012

Motivations

- fermion masses → Chiral Symmetry Breaking
- W and Z masses → EW gauge Symmetry Breaking
- ChSB → EWSB (i.e. QCD), while EWSB does not necessarily imply ChSB
- ChSB and EWSB could have different origins
- in SM, ChSB and EWSB generated by the Higgs mechanism at same scale ~ <H> → Yukawa couplings
- SM does not explain the fermion mass hierarchies !
- not (yet) any experimental evidence supporting tree-level Yukawa couplings
- EWPT not sensitive to Yukawa couplings: at 1-loop rad. corr. depend on quark masses not on Yukawas.

Fermio-Phobic (FP) Higgs



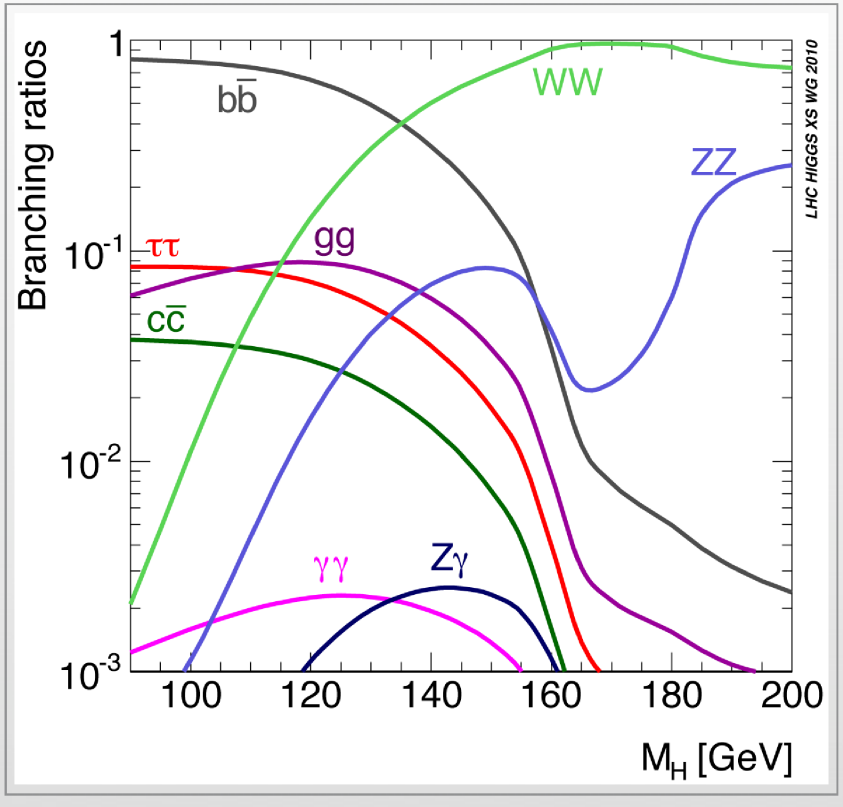
- Higgs mechanism gives rise to EWSB and Mw,Mz but is NOT responsible for ChSB →fermion masses
- Perturbative unitarity in WW scattering cured !
- NO Yukawa couplings at tree-level

Higgs decays : FP vs SM

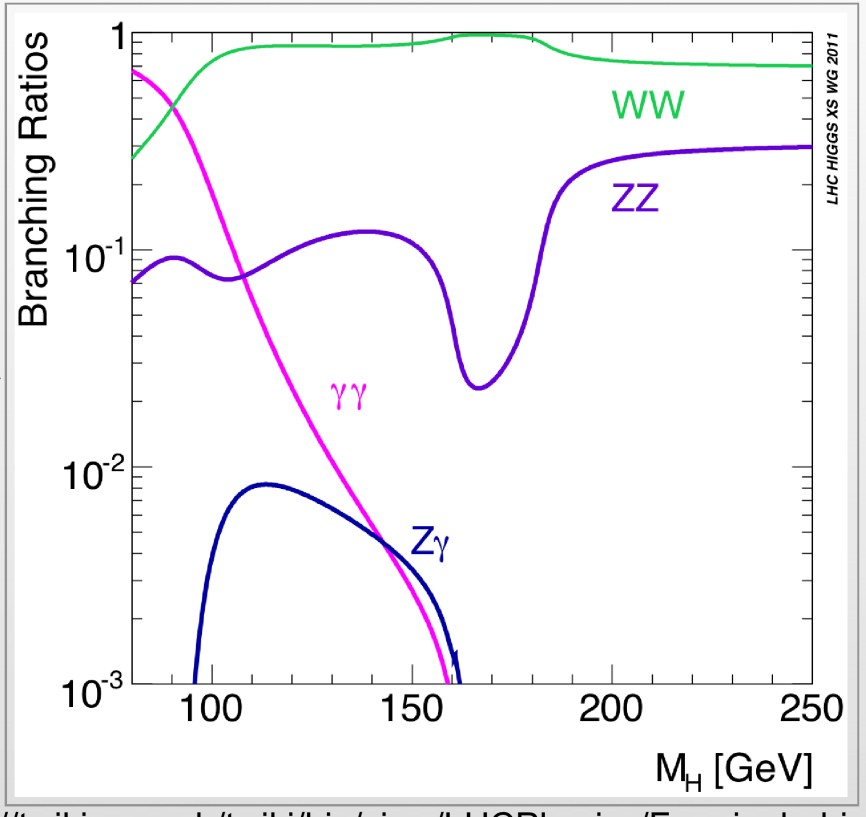
[through W loops (no-top loops)]

- H → WW, ZZ, γγ, Zγ

SM Higgs



FP Higgs

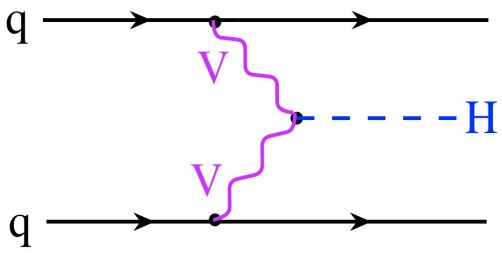


https://twiki.cern.ch/twiki/bin/view/LHCPhysics/Fermiophobic

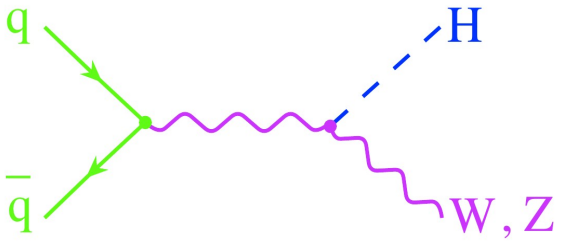
for m_H ~[100,110,120] GeV : $BR(\gamma\gamma)_{FP}$ ~[110, 30, 10] x$BR(\gamma\gamma)_{SM}$

Fermio-Phobic Higgs production mechanisms at LHC

VBF



VH



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

FP model is unstable under radiative corrections
Yukawa couplings radiatively generated

E. Gabrielli and B. Mele, PRD 84 054017 (2011), PRD 83 073009 (2011)

- Fermion mass put by hand → SM is not renormalizable
- SM → effective field theory valid up to some Λ scale
- FP model → Yukawas Yf vanish at the scale Λ
- due to explicit ChSB, the Yukawas are not protected under radiative corrections → Yf radiatively generated at low energy → large $\mathrm{Log}(\Lambda/m_H)$ need to be summed up
- Effective Field Theory approach allows to calculate the leading universal contributions $[\, g^2 \mathrm{Log}(\Lambda/M_H)]^n$
  universal → independent of UV completion of SM above Λ

EFT approach connects two scales Λ and mH

- assume Yf's vanishing at the scale $\Lambda \gg m_H$

  (related to fermion-mass generation scale)

$$Y_f(\Lambda) = 0$$

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

  Renormalization Group Equation (RGE) technique

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

(high energy) *(low energy)*

- note ! SM RGE (where Yf's and mf are related) not suitable here → new RGE's derived by keeping Yf's and mf's as independent parameters! Higgs field is assumed on-shell

1-loop RGE's for Yukawa's

(Higgs on-shell)

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

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

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

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

W_L polarization

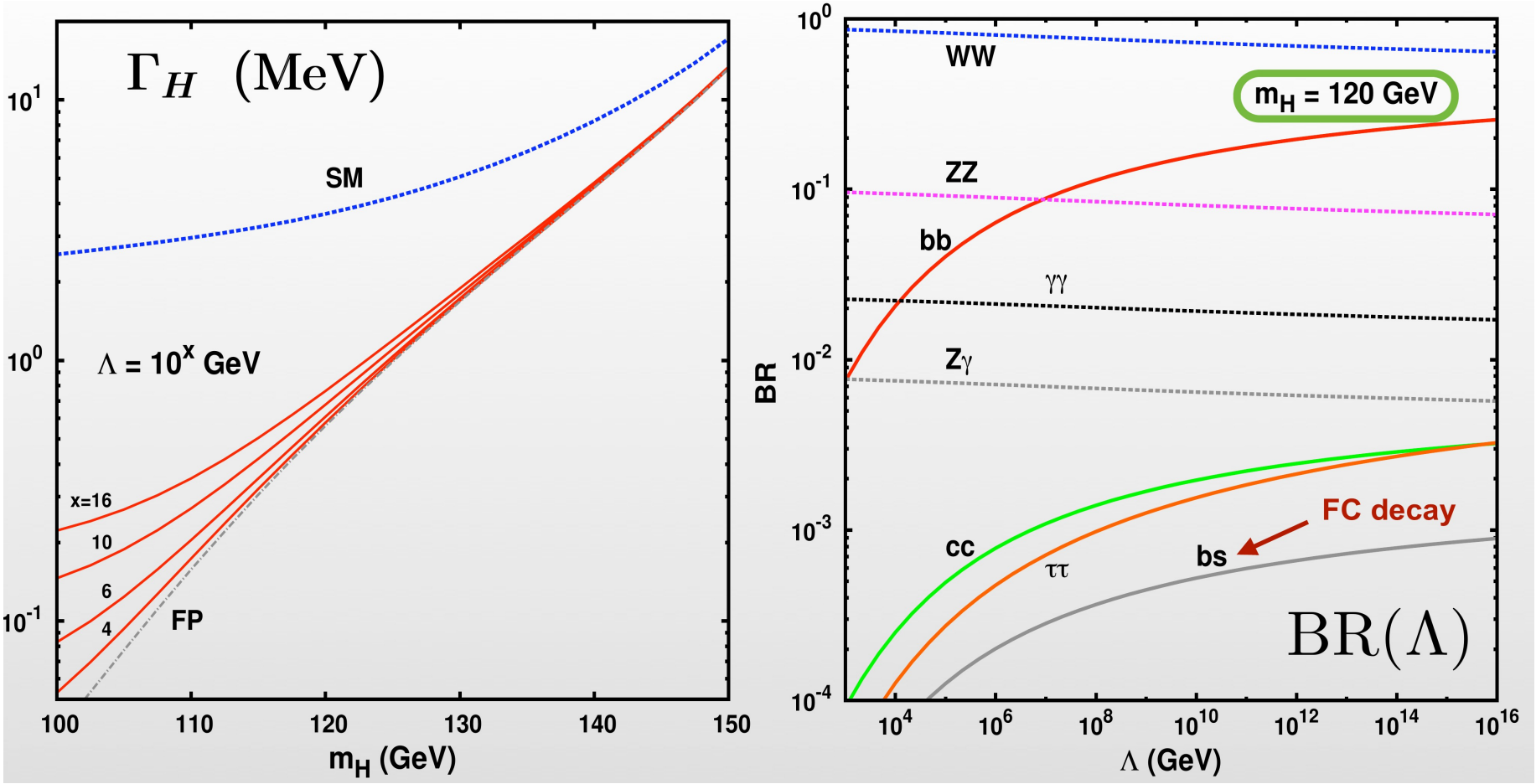
$$\mathbf{Y_f^{SM}} \equiv \frac{g_2}{\sqrt{2}M_W}\mathrm{diag}[m_{f_1}, m_{f_2}, m_{f_3}]$$

ChSB terms

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

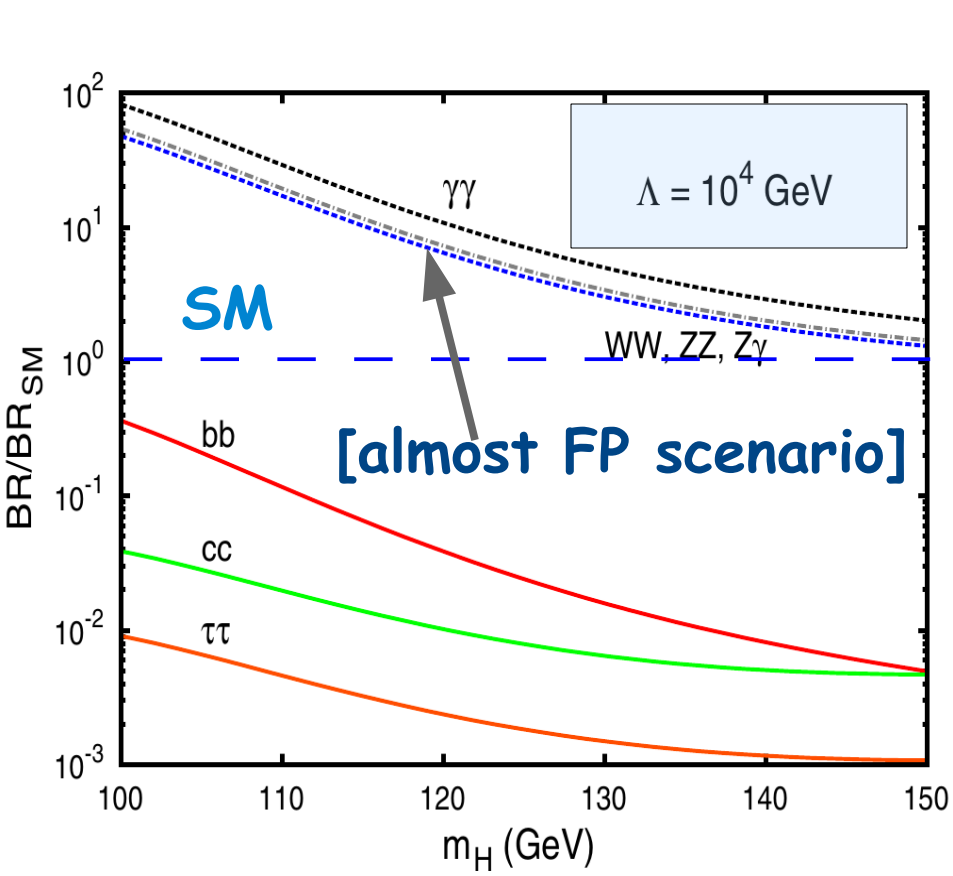
SM RGE's recovered for → $\mathbf{Y_f^{SM}} \to \mathbf{Y_f}$

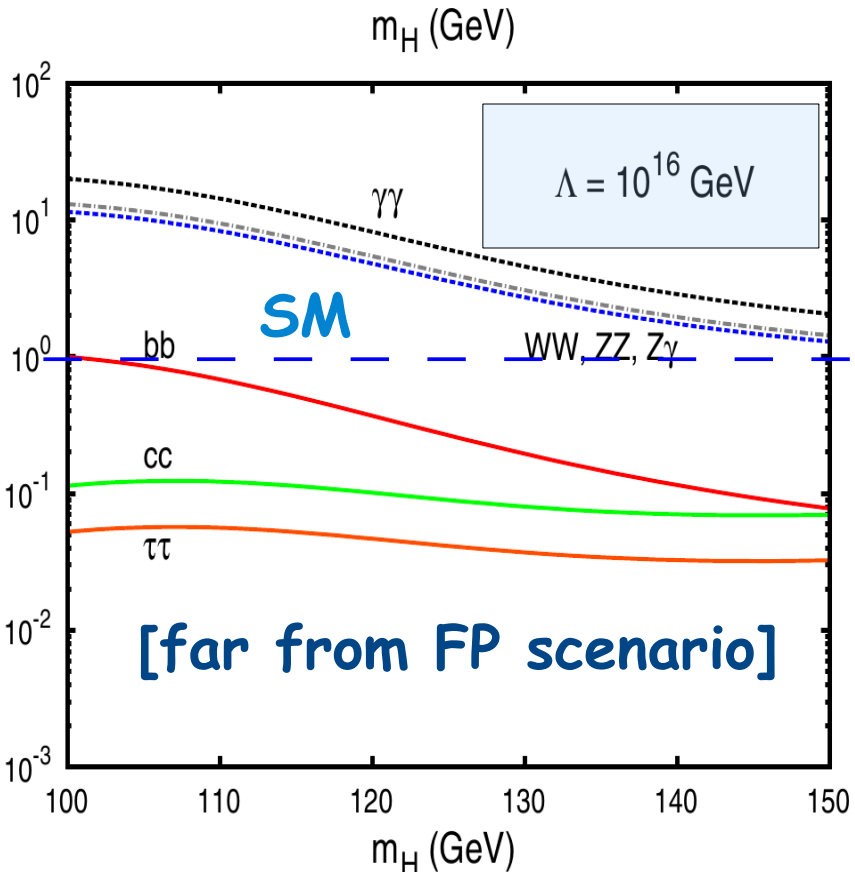
Results for Γ_H and BR's versus Λ



BR's enhanced by small total width

BR / BR(SM): Λ ~ ($10^4 \rightarrow 10^{16}$) GeV





Higgs BR's in fermionic channels quite sensitive to the new physics scale Λ

Status of LHC Higgs searches

ATLAS before Moriond 2012: data: [1.04 - 4.9] fb-1

- Higgs mass ranges [112.9-115.5] GeV ,[131-238] GeV and [251-466] GeV excluded at 95% CL

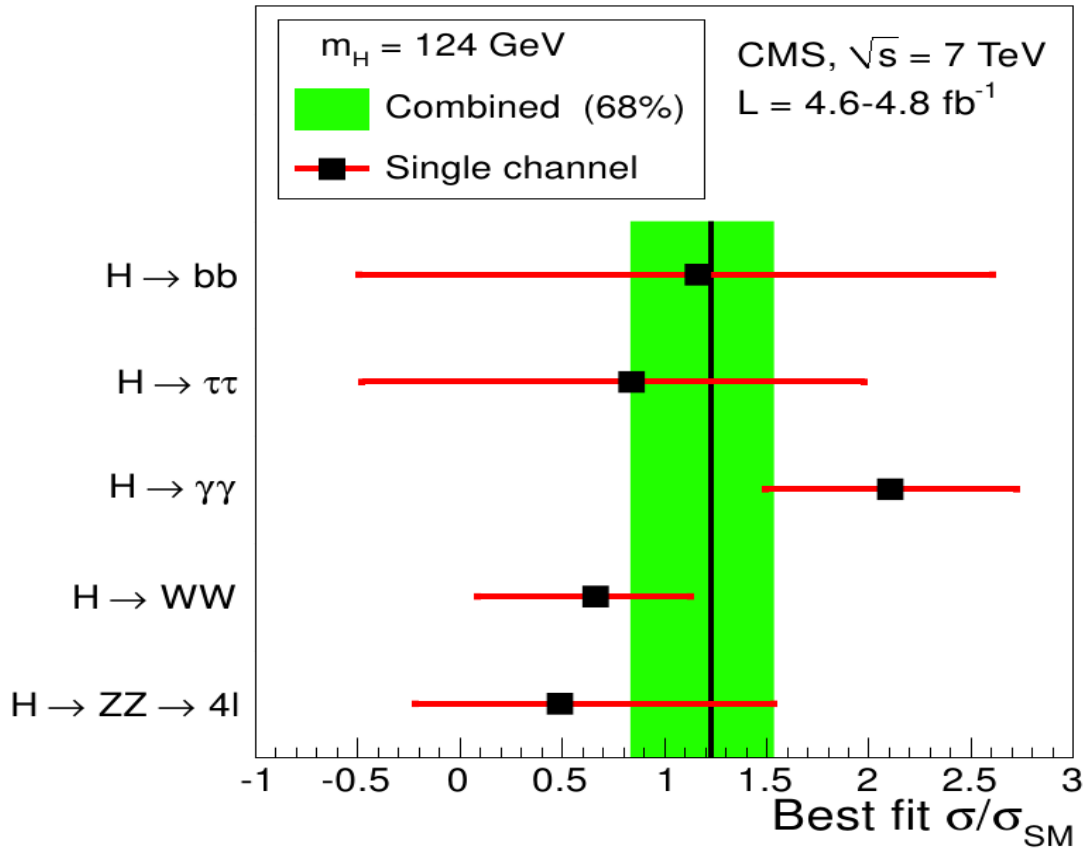
- Excess of events observed at mH =126 GeV with local significance of 3.5 σ

  - $H \to \gamma\gamma$ 2.8 σ
  - $H \to WW^* \to 2l2\nu$ 1.4 σ
  - $H \to ZZ^* \to 4l$ 2.1 σ

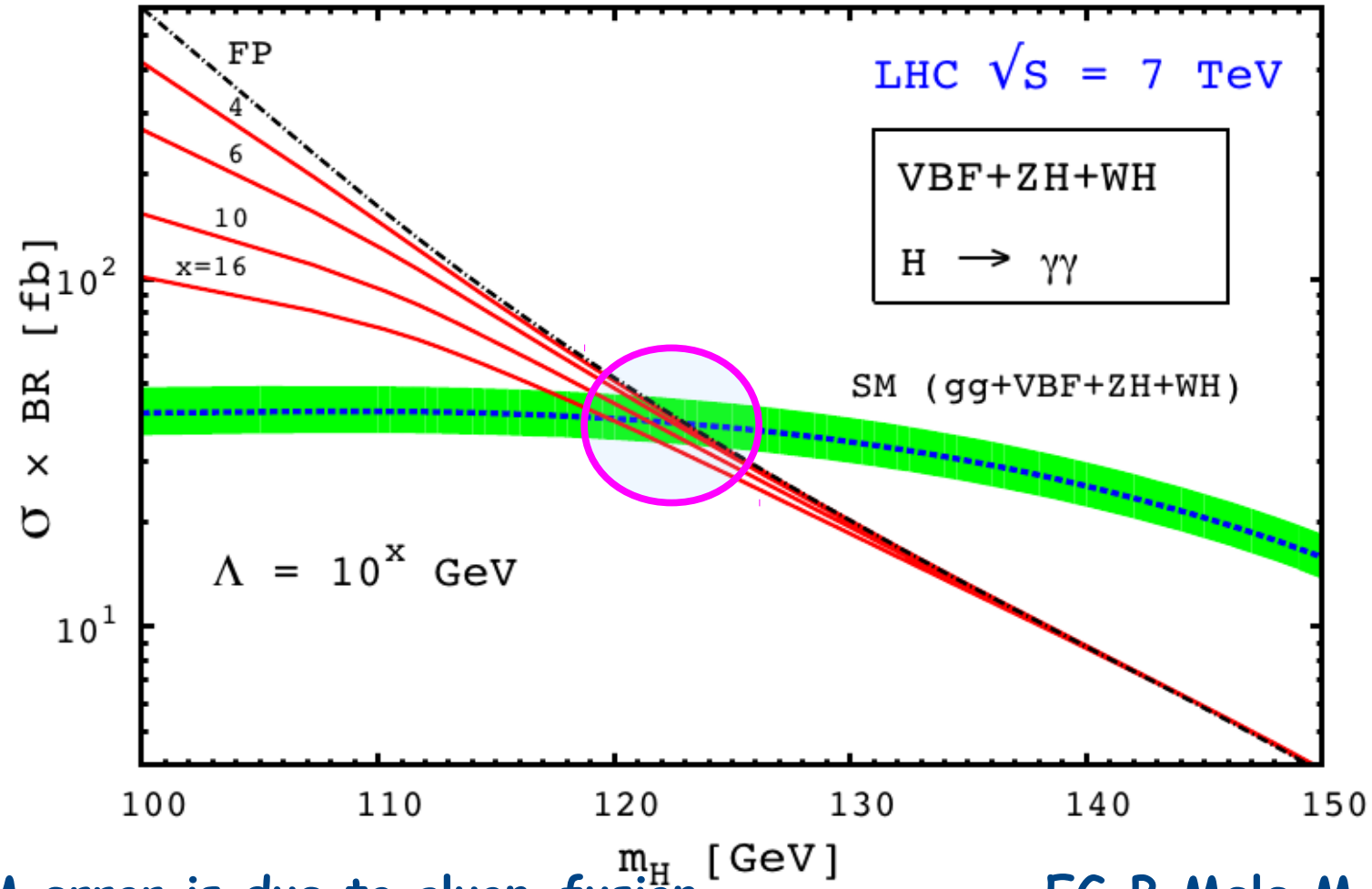
- probability that the excess is a statistical fluctuation of bckg in [110-660] GeV is 1.4% → 2.2 σ

CMS before Moriond 2012: data set: 4.6 - 4.8 fb-1

- Higgs mass [127 - 600] GeV excluded @ 95% CL
  [129 - 525] GeV excluded @ 99% CL
- Excess of events observed at mH=124 GeV with local significance of 3.1 σ, largest excess in H → γγ



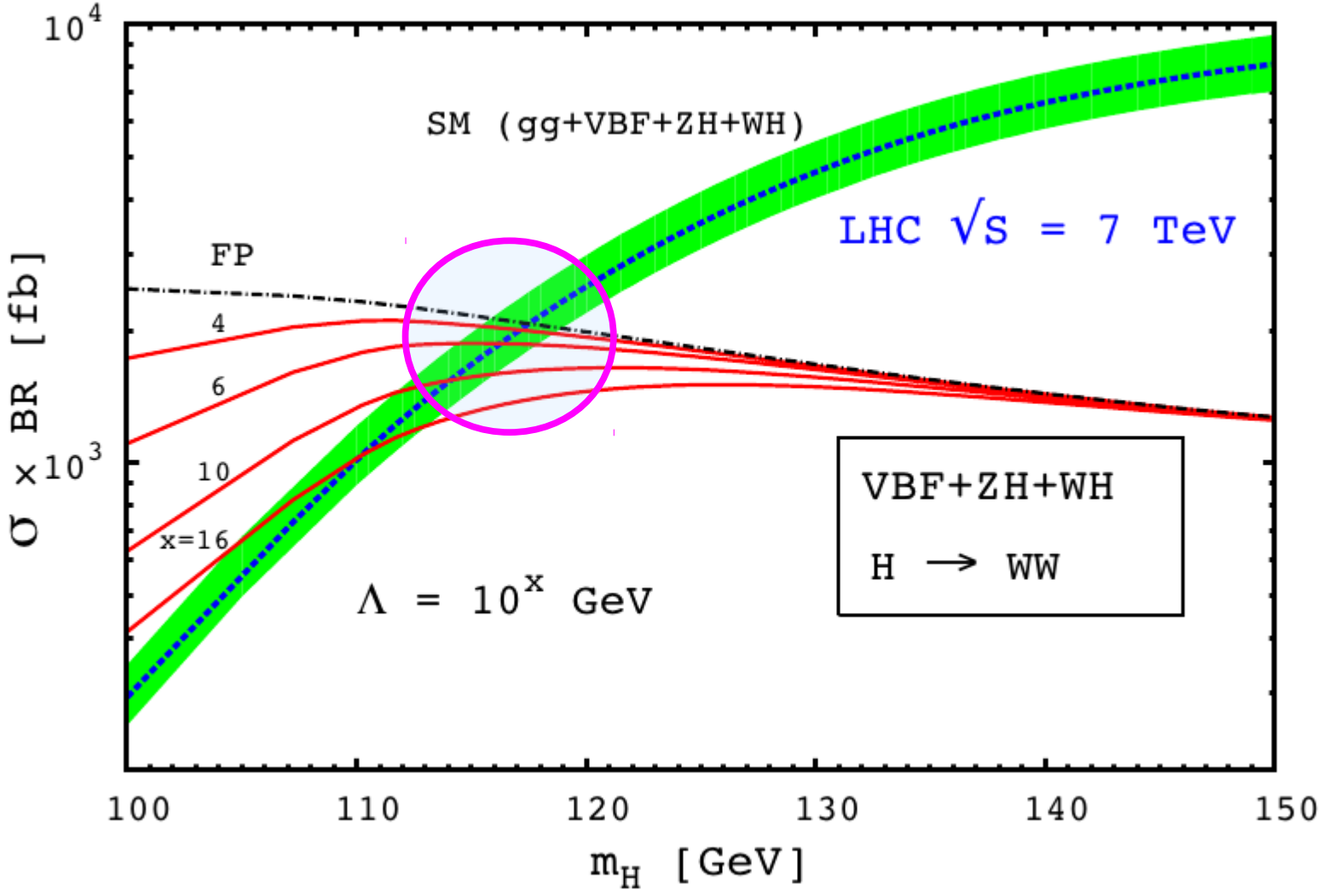
For mH=124-126 GeV, SM and FP Higgs predict ~ same inclusive production rate for H → γγ



SM error is due to gluon-fusion cross-section

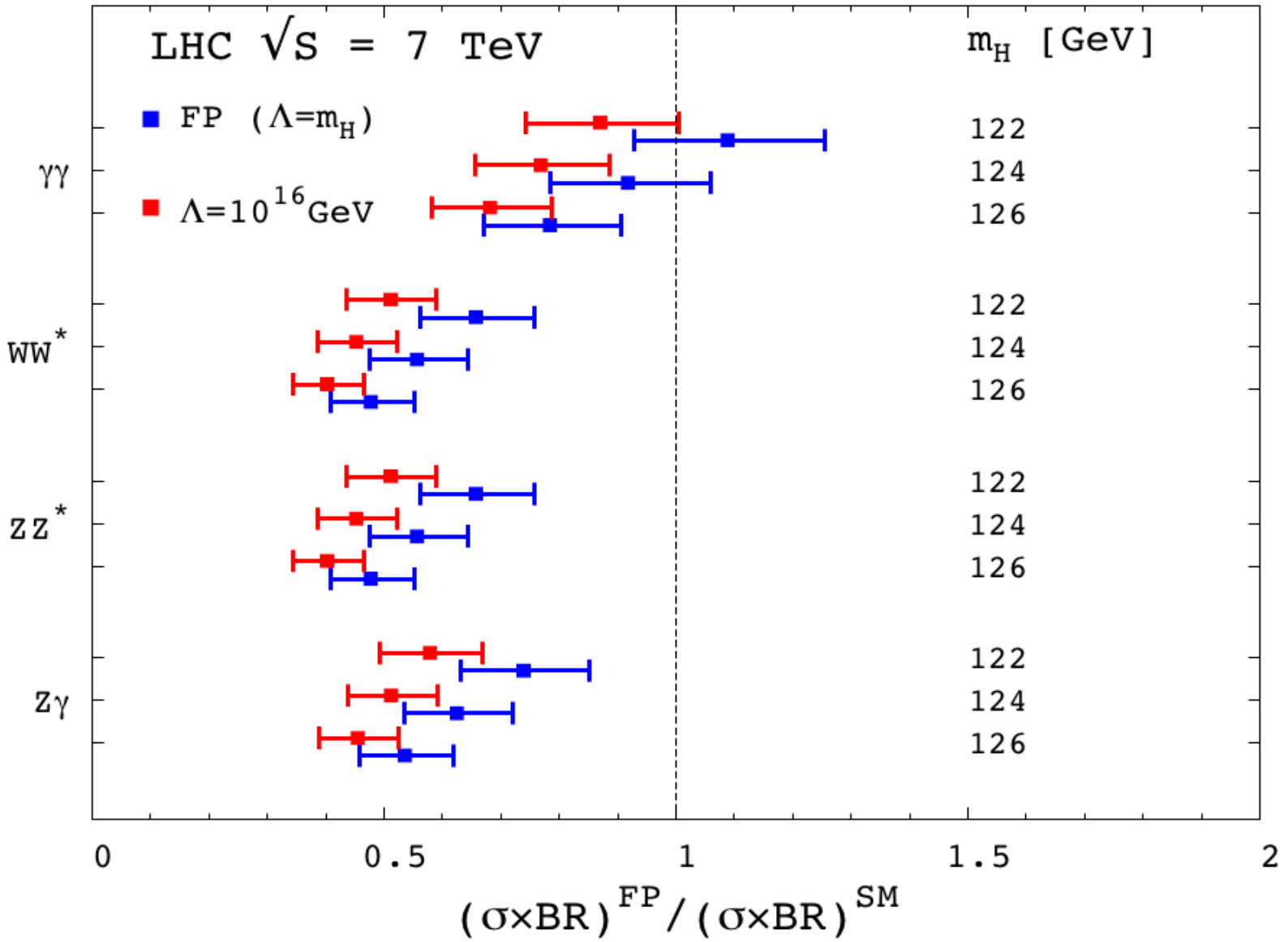
EG,B.Mele,M.Raidal
1202.1792 [hep-ph]

FP(VBF+VH) : H → WW*



For mH=124-126 GeV, FP Higgs has a smaller inclusive WW* production rate with respect to SM!

FP H → γγ compatible with SM @ 125 GeV

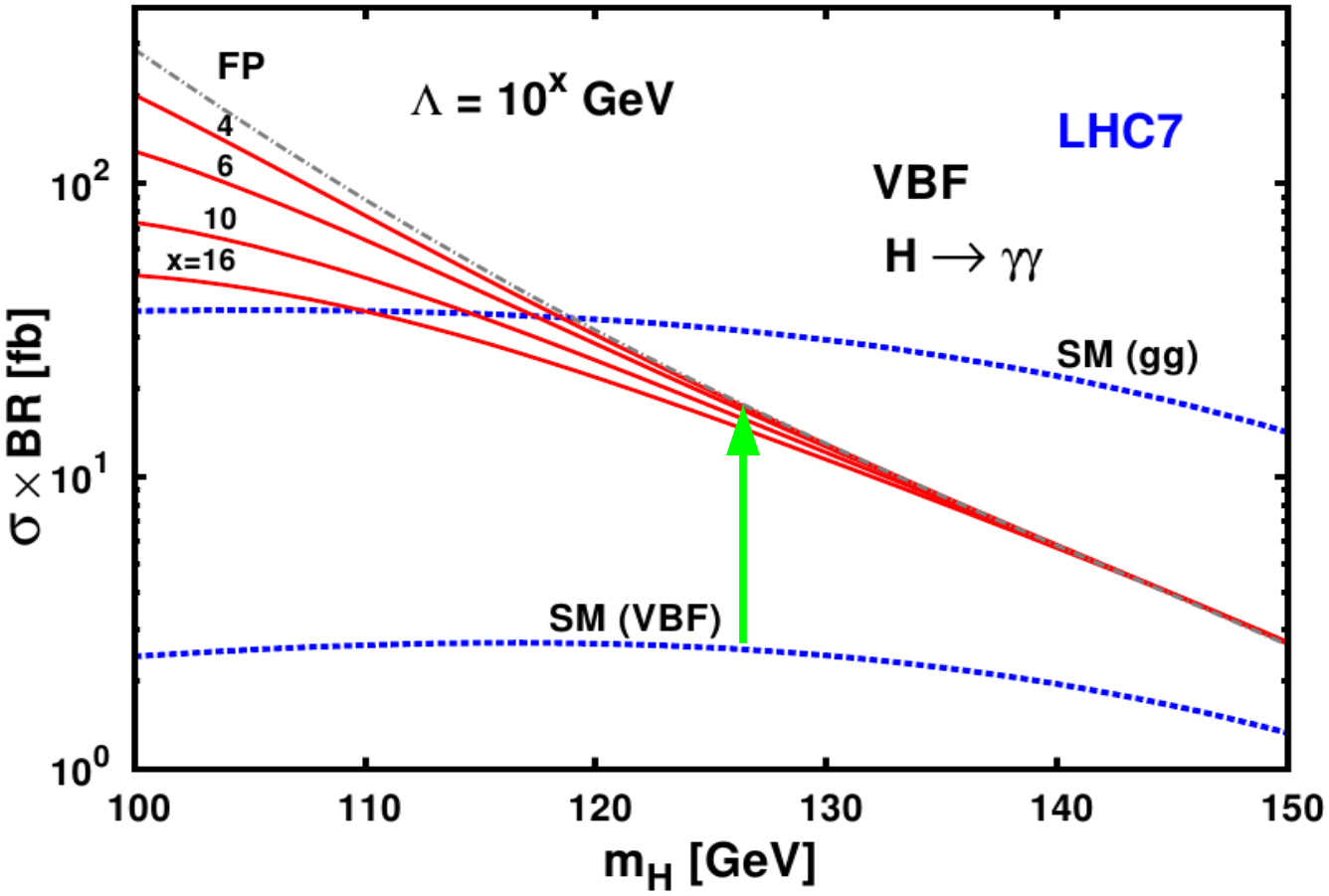


- But, SM Higgs and FP Higgs have different production mechanisms

- To disentangle the two scenarios it is necessary to look at the exclusive production channels via VBF and HW, HZ → jj-tagging and V-tagging

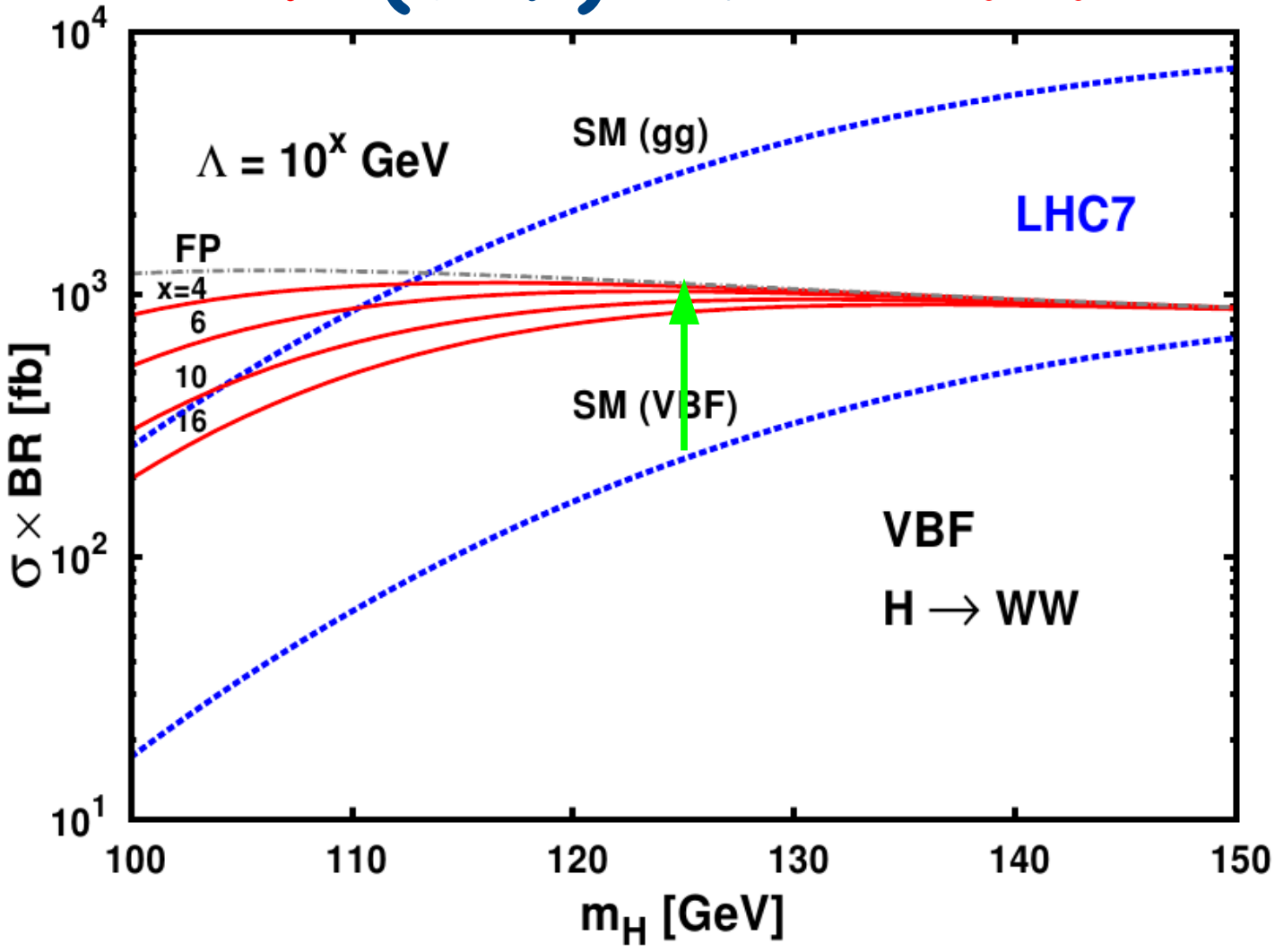
- In VBF and VH the signal is strongly enhanced with respect to the SM Higgs due to the enhanced Higgs BRs

LHC (VBF) : H → γγ



- In VBF, FP Higgs predicts a larger rate for γγ jj production with respect to SM (VBF)
- At mH=125 GeV for H → γ γ jj rate[FP] ~ 7 x Rate[SM(VBF)]

FP(VBF) : H → WW*



For H → WW*jj at mH=125 GeV

Rate[FP] ~ 5 x Rate[SM(VBF)]

Moriond 2012:

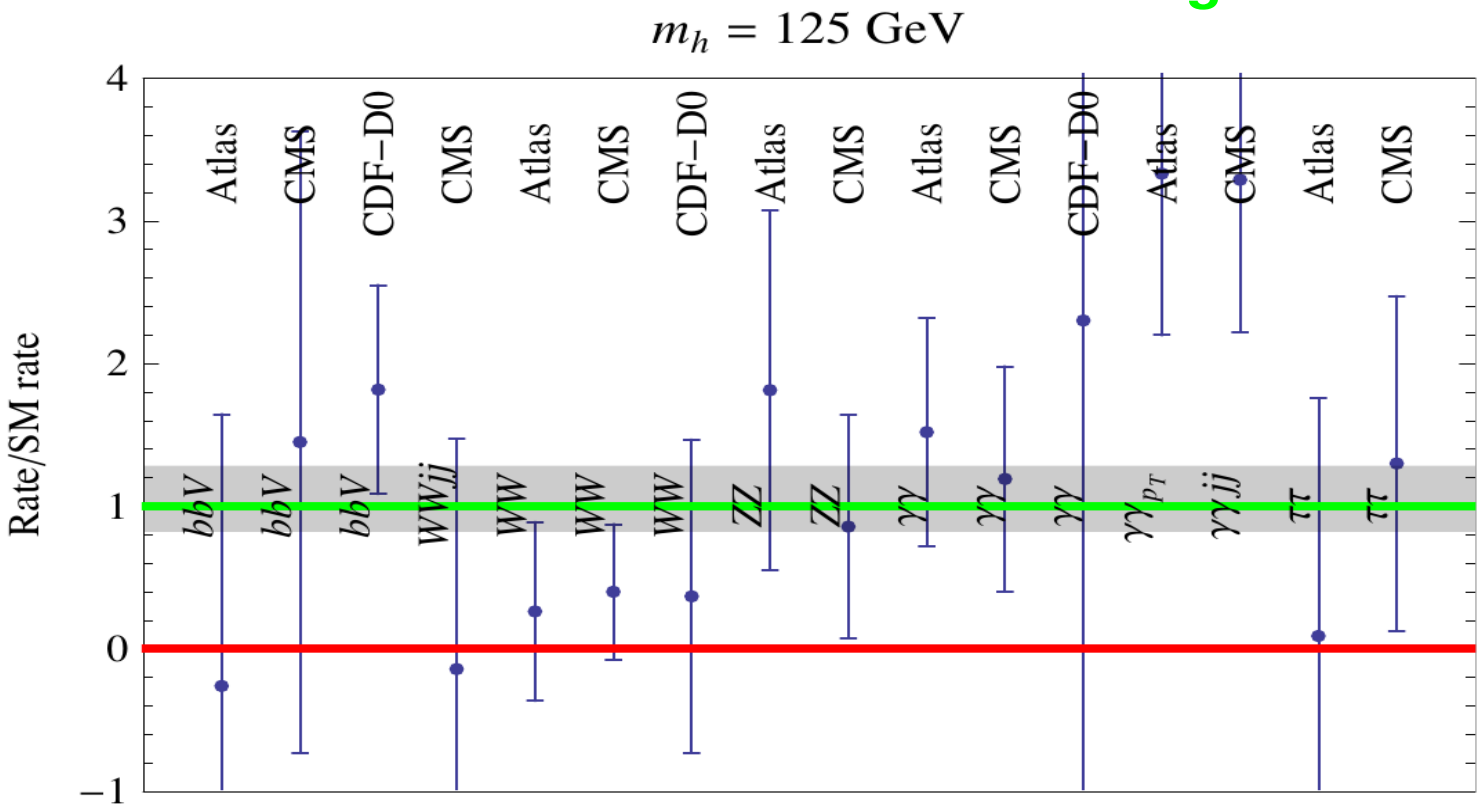
- New ATLAS and CMS searches for FP Higgs → γγ
  - -ATLAS → 9 categories : both low and high pT(γγ),
  - -CMS → jj-tagged (VBF), lepton-tagged (VH), 4 inclusive

Surprise: in γγ events the VBF component (high pT(H)) is much larger than SM predictions → local significance for FP signal: 2.8σ (CMS) at 126 GeV, 3σ (ATLAS) at 125.5 GeV

- A hint of FP Higgs ? To confirm that, test H → VV*
- A deficit in WW*jj channel is observed in both experiments with respect to FP Higgs expectations.
- Exclusion mass ranges for FP Higgs in γγ @ 95% CL
  - -CMS → [110-124] , [128-136] GeV
  - -ATLAS → [110-118] , [119.5-121] GeV
- CMS combined results in all channels exclude FP Higgs 110-192 GeV @ 95% CL (hint at mH=126 GeV)

- **After Moriond 2012, new fits disfavor the SM and motivate for New Physics**

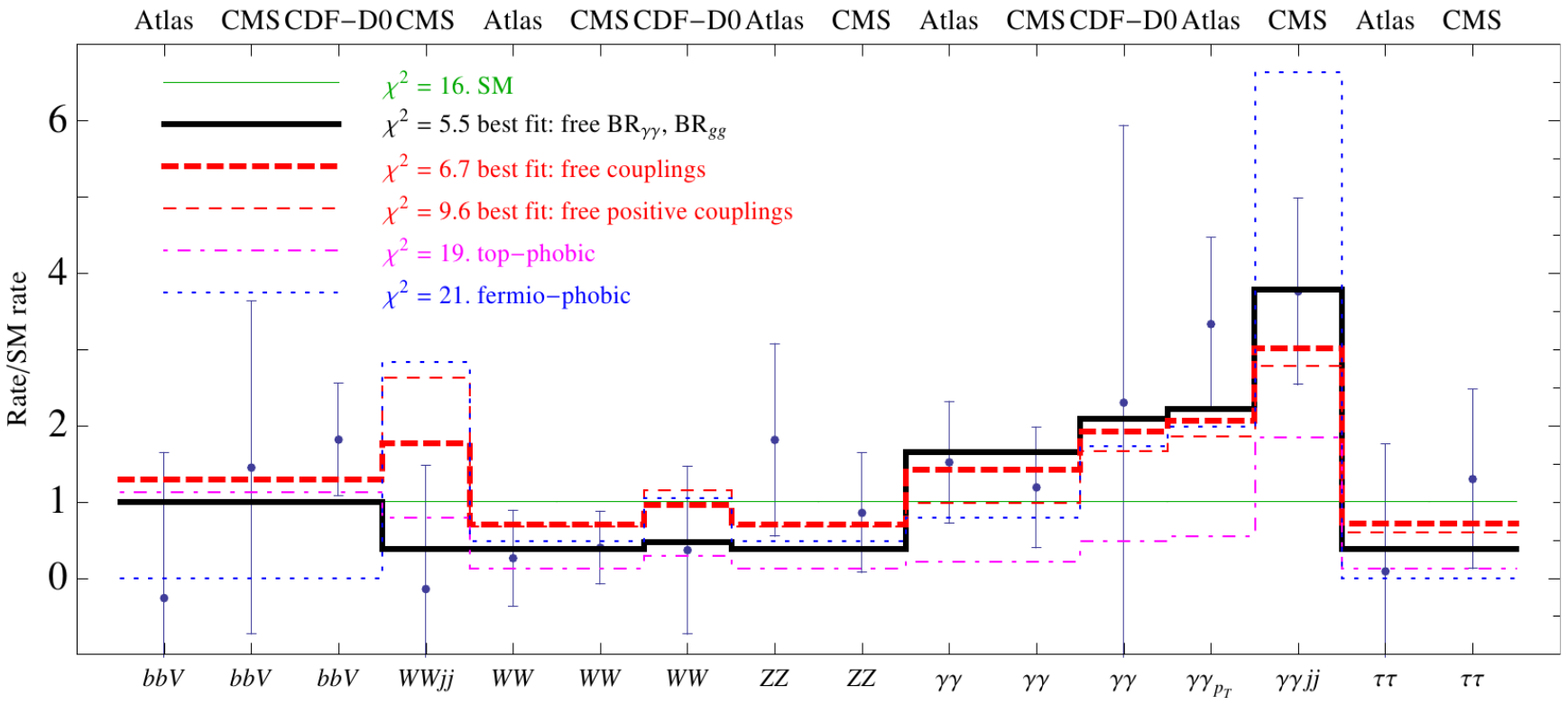
red = no Higgs boson
green = SM



P. Giardino, K. Kannike, M. Raidal, A. Strumia, 1203.4254

- a SM Higgs is not as favored as a FP Higgs

- pure FP model (vanishing Yukawa) gives a good fit, but
- best fit suggests partially FP model (small Yukawas)
- radiative corrections to FP model go in the right direction!



P. Giardino, K. Kannike, M. Raidal, A. Strumia, 1203.4254

Conclusions

- 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

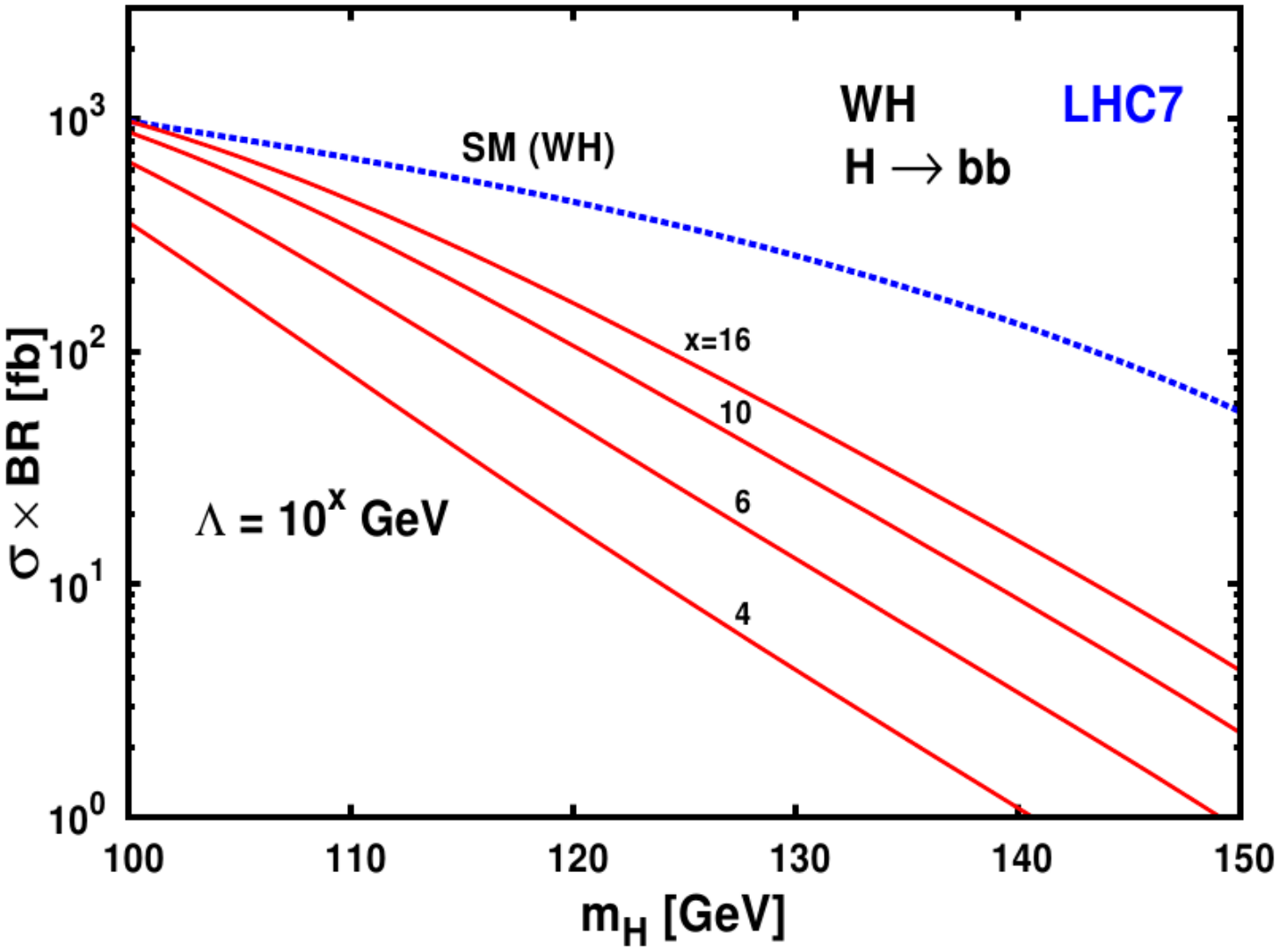
- if the scale Λ of ChSB is very large → BR(H →bb) at mH=125 GeV can be as large as a few 10%

- ATLAS and CMS excesses of events at mH= 125 GeV is compatible with a FP Higgs, although they suggest also a depletion of H → WW* with resp. to pure FP scenario

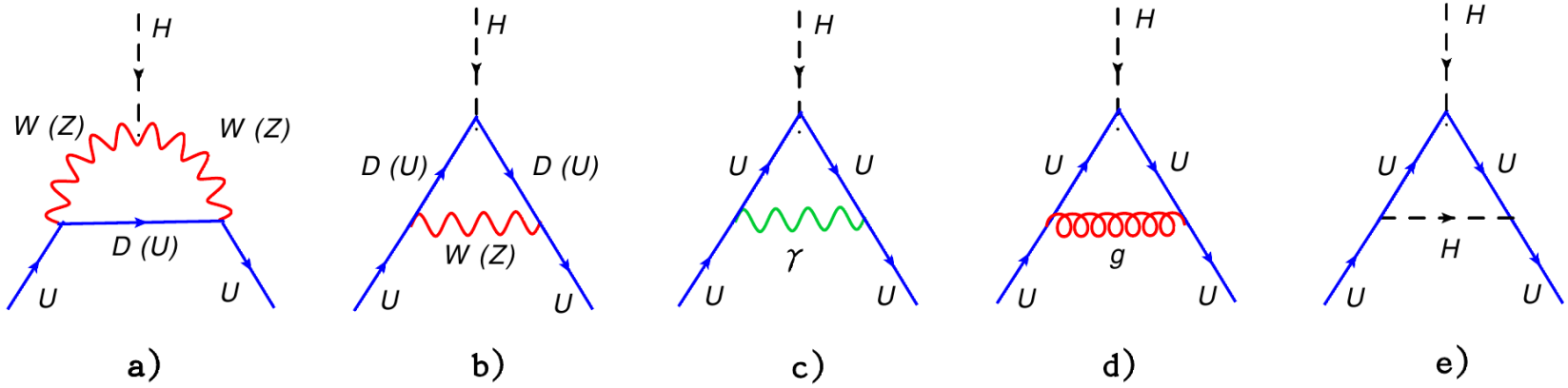
- Best fit points toward a partially FP Higgs, suggesting effective Yukawa couplings induced by large values of Λ

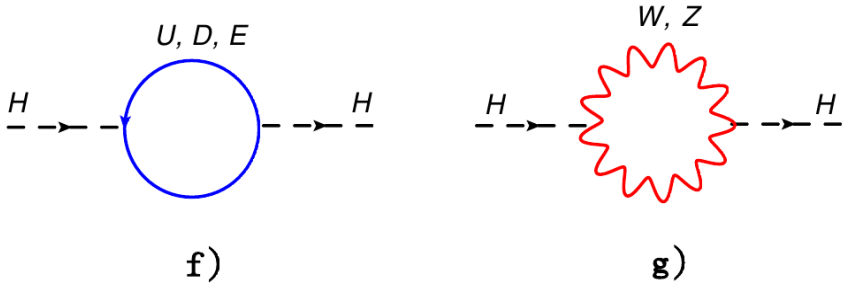
Backup slides

LHC (WH) : H → bb

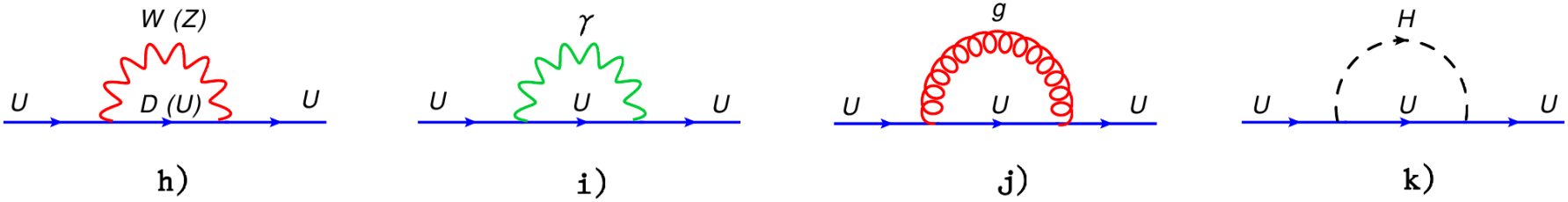

WH
LHC7
H → bb
SM (WH)
x=16
10
6
4
Λ = 10^x GeV
σ × BR [fb]
10^3
10^2
10^1
10^0
100
110
120
130
140
150
m_H [GeV]

Diagrams contributing to the Y's beta-functions

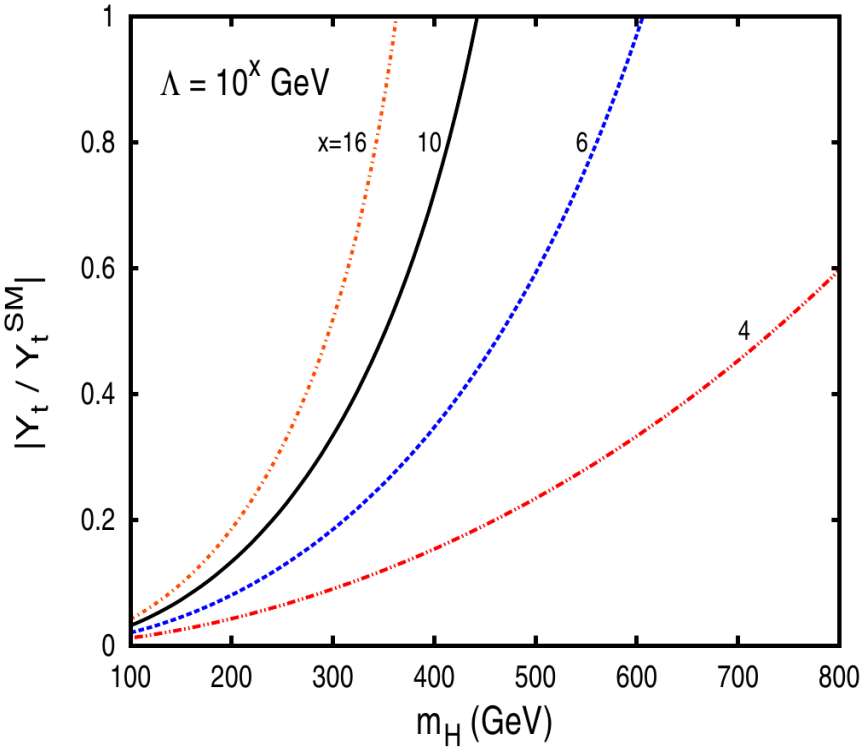


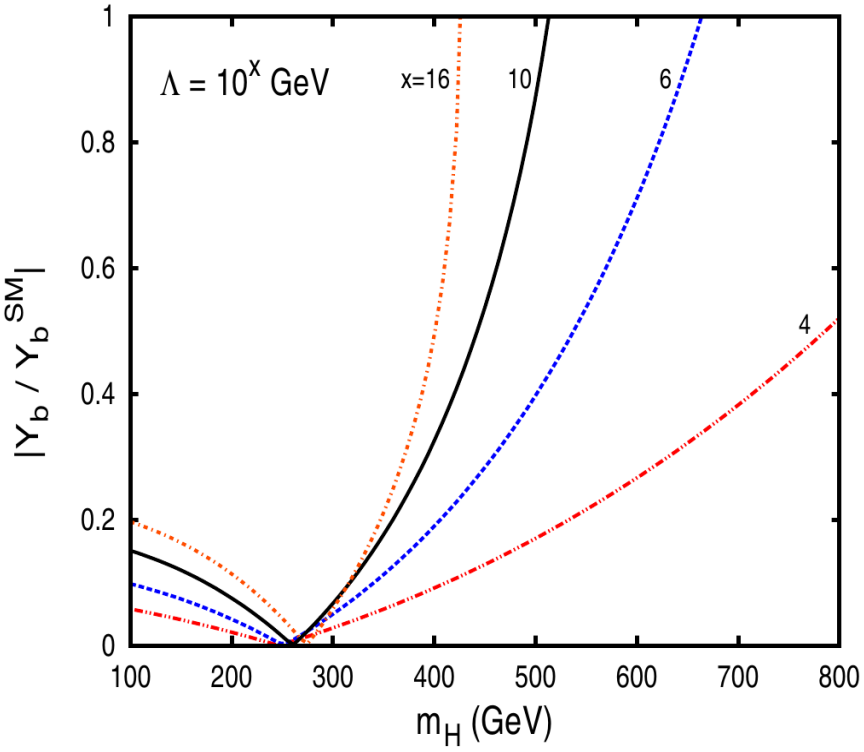


Up-type quark couplings



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





- Λ varied between 10^4 and 10^{16} GeV
- because of terms $\xi_H \equiv \frac{g_2 m_H}{2M_W}$ Yf grows at large mH
- all Yf's perturbative for mH < <H> ~246 GeV