

Looking for a Fermiophobic Higgs at LHC: an update

Emidio Gabrielli

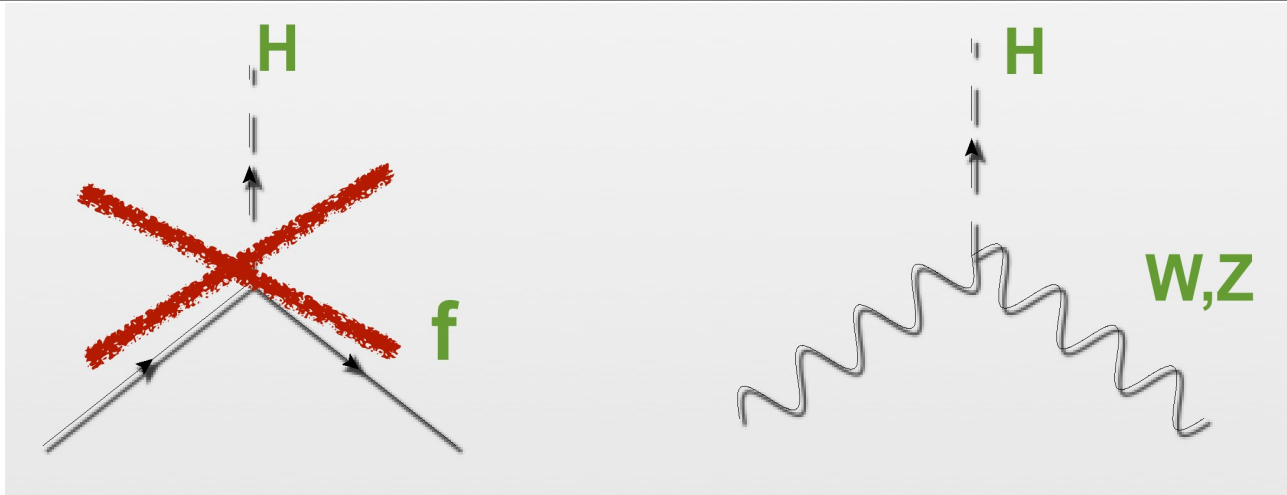
NICPB, Tallinn, Estonia

INFN, Trieste, Italy

in collaboration with **B. Mele** (INFN, Rome 1), **M. Raidal** (NICPB)
talk based on 1202.1796 [hep-ph], PRD 83: 073009 (2011),
PRD 82: 113014 (2010)

**Implications of LHC results for
Tev-scale physics, CERN, 13-17 July 2012**

Fermio-**P**hobic (**FP**) Higgs



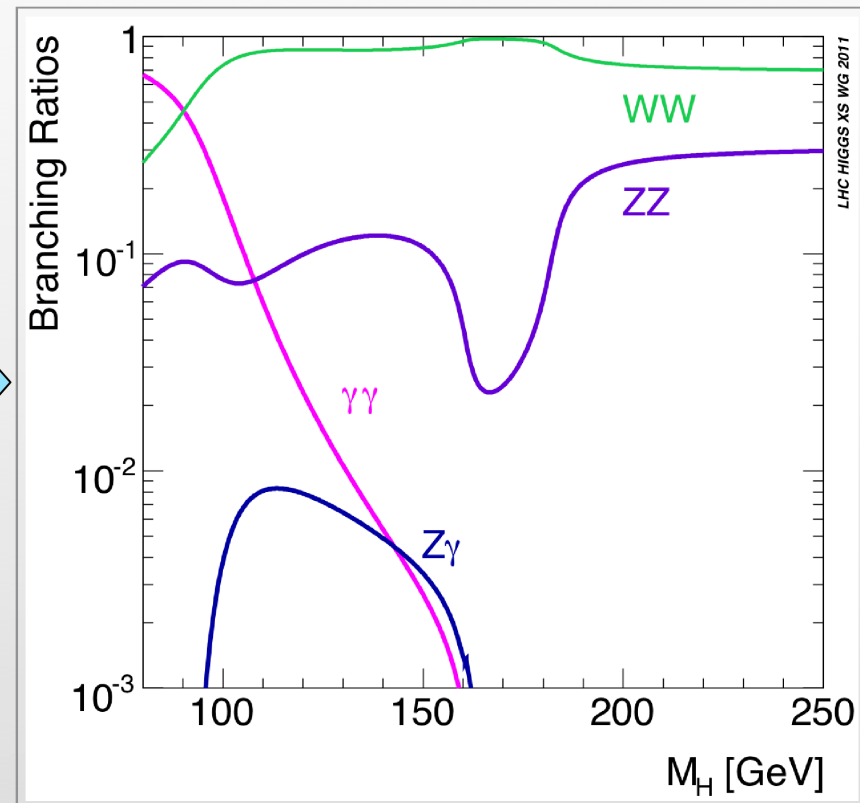
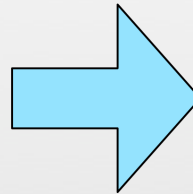
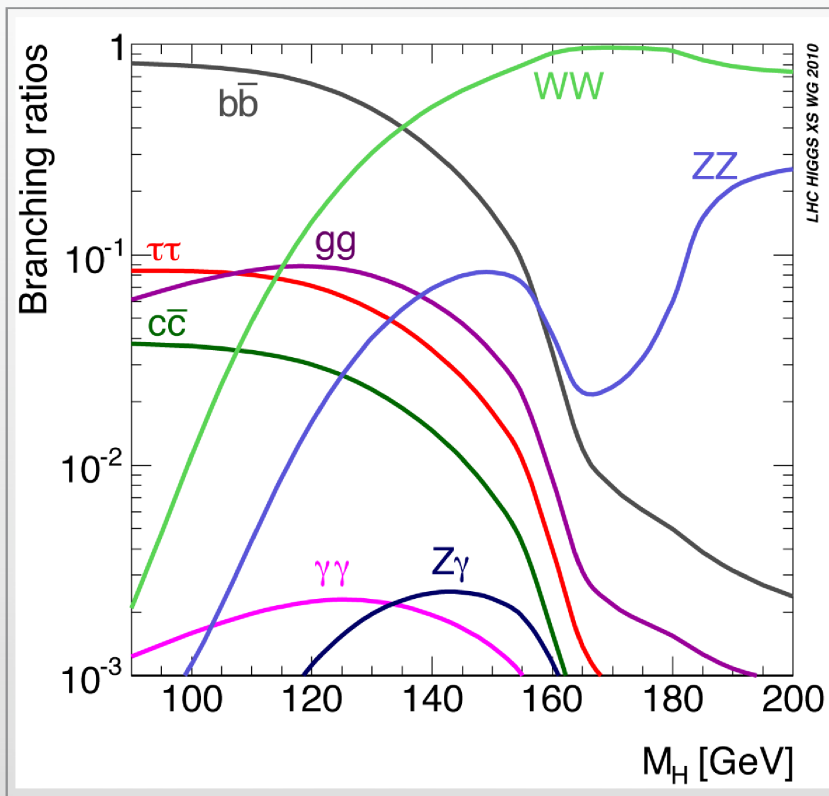
- Higgs mechanism gives rise to **EWSB** and M_W, M_Z but is **NOT** responsible for **ChSB** $\rightarrow$ **fermion masses**
- **Perturbative unitarity in WW scattering cured !**
- **NO** Yukawa couplings at tree-level

Higgs decays : FP vs SM

$H \rightarrow WW, ZZ, \gamma\gamma, Z\gamma$ [through W loops (no-top loops)]

SM Higgs

FP Higgs

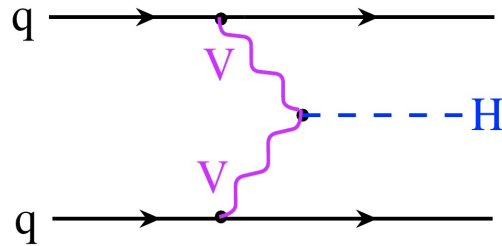


<https://twiki.cern.ch/twiki/bin/view/LHCPhysics/Fermiophobic>

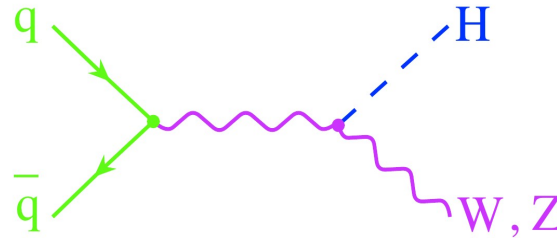
for $m_H \sim [100, 110, 120]$ GeV : $BR(\gamma\gamma)_{FP} \sim [110, 30, 10] \times BR(\gamma\gamma)_{SM}$

Fermio-**P**hobic Higgs production mechanisms at LHC

VBF



VH



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

FP Higgs not stable → Partial Fermiophobia Yukawa couplings always 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 Y_f vanish at the scale Λ
- due to explicit **ChSB**, the **Yukawas** are not protected under radiative corrections → Y_f **radiatively generated at low energy** → large $\text{Log}(\Lambda/m_H)$ need to be summed up
- **Effective Field Theory** approach allows to calculate the leading **universal** contributions $[g^2 \text{Log}(\Lambda/M_H)]^n$
universal → independent of UV completion of SM above Λ

EFT approach connects two scales Λ and m_H

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

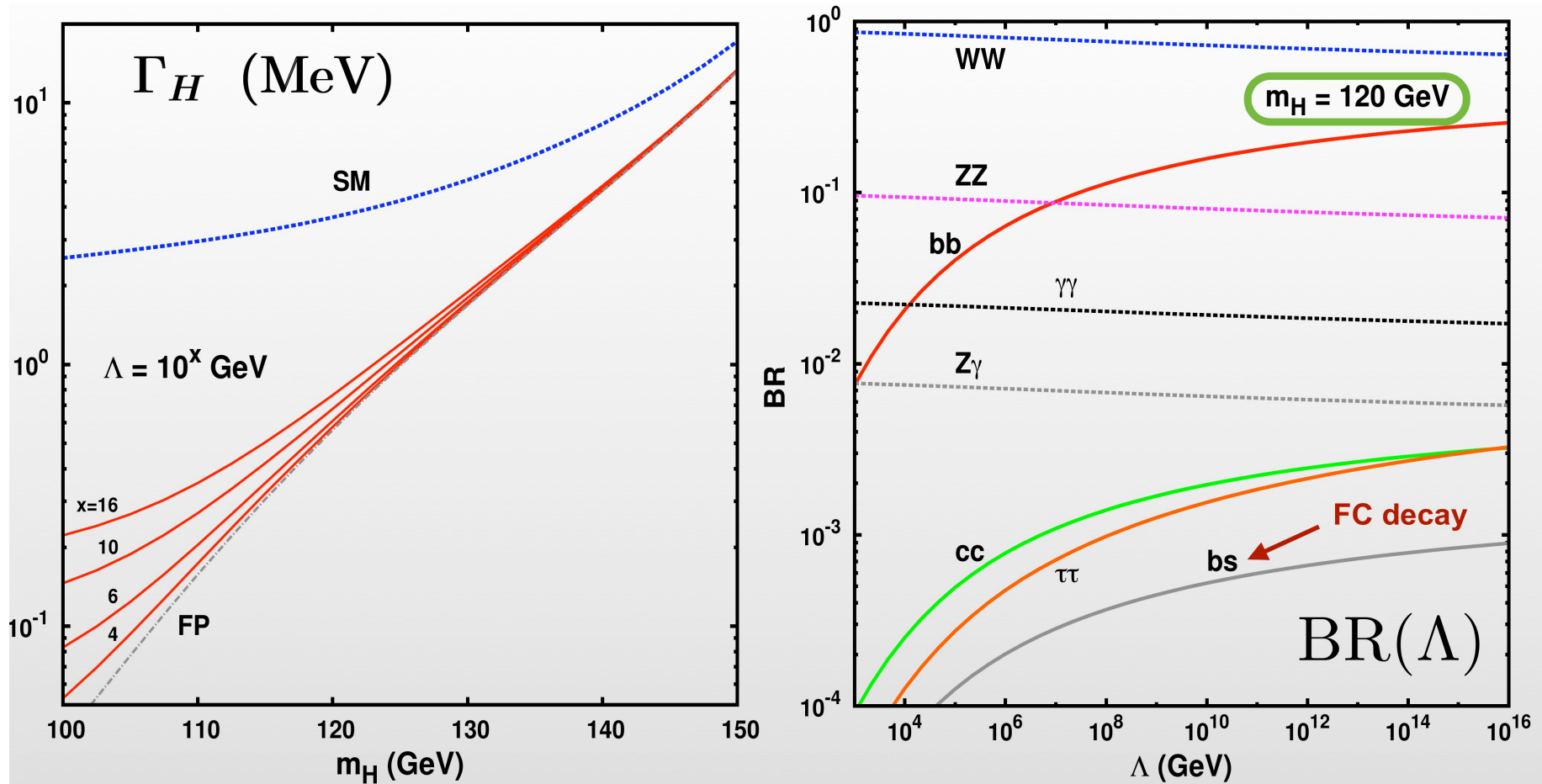
$$Y_f(\Lambda) = 0$$

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

$Y_f(\Lambda) = 0$	$\longrightarrow$	$Y_f(m_H)$
(high energy)	RGE	(low energy)

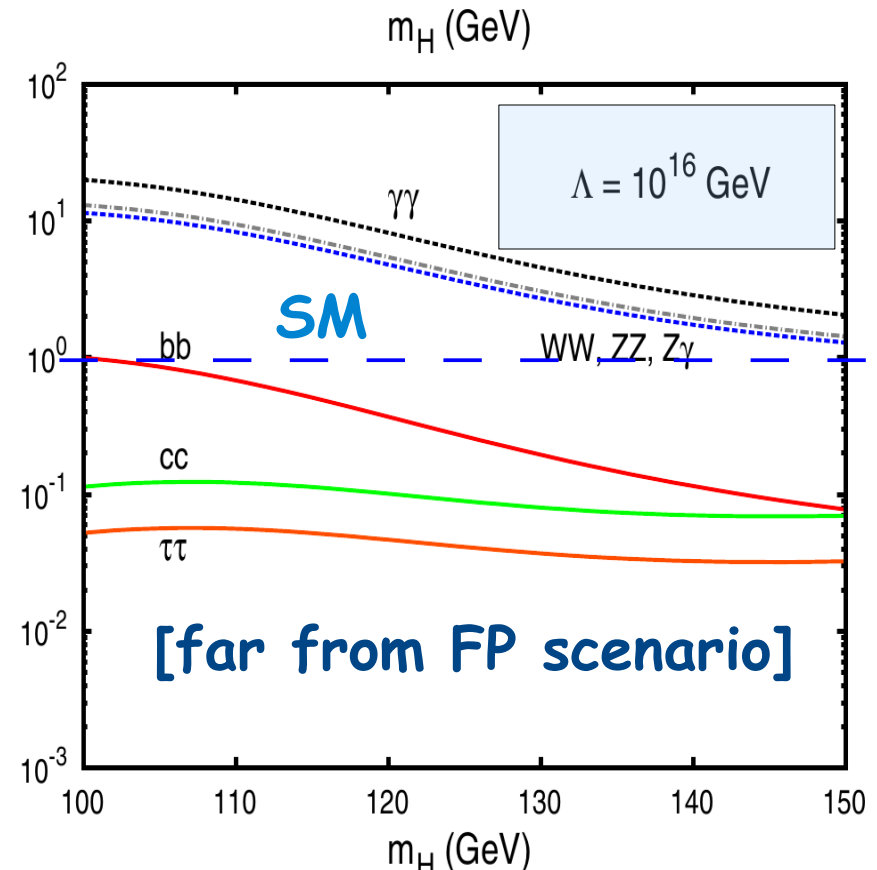
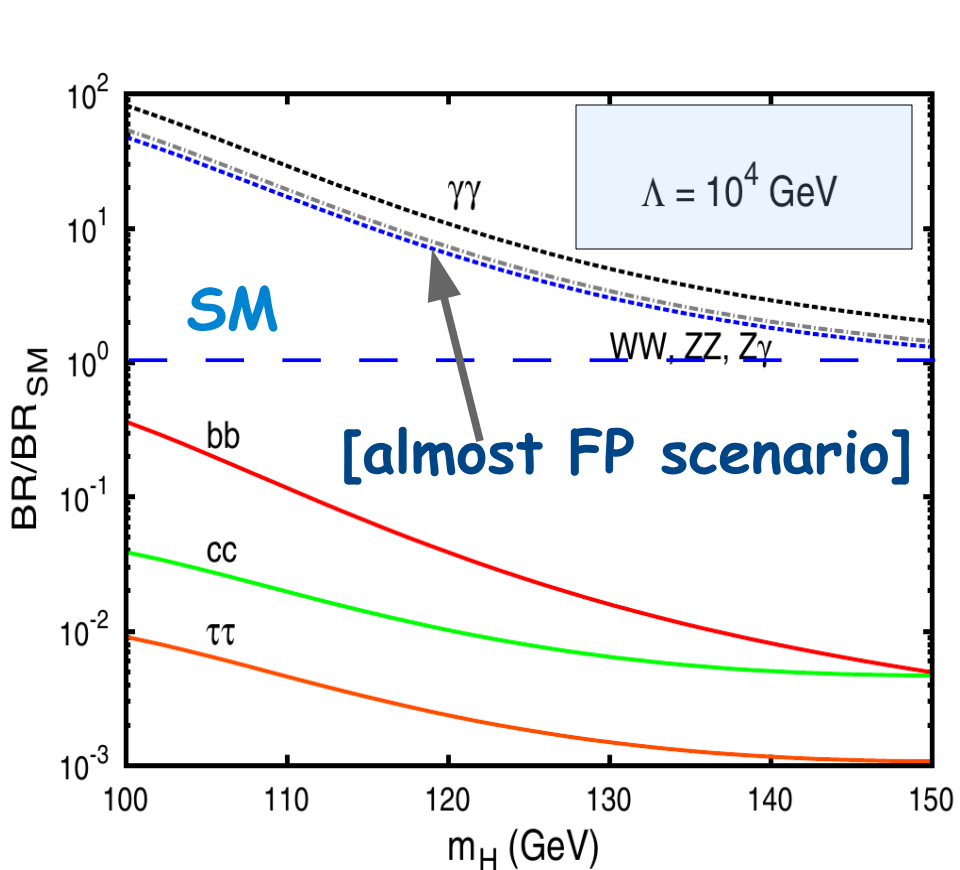
- **note ! SM RGE** (where Y_f 's and m_f are related) **not** suitable here $\rightarrow$ new RGE's derived by keeping **Y_f 's** and **m_f 's** as **independent** parameters! **Higgs field is assumed on-shell**

Results for Γ_H and BR's versus Λ



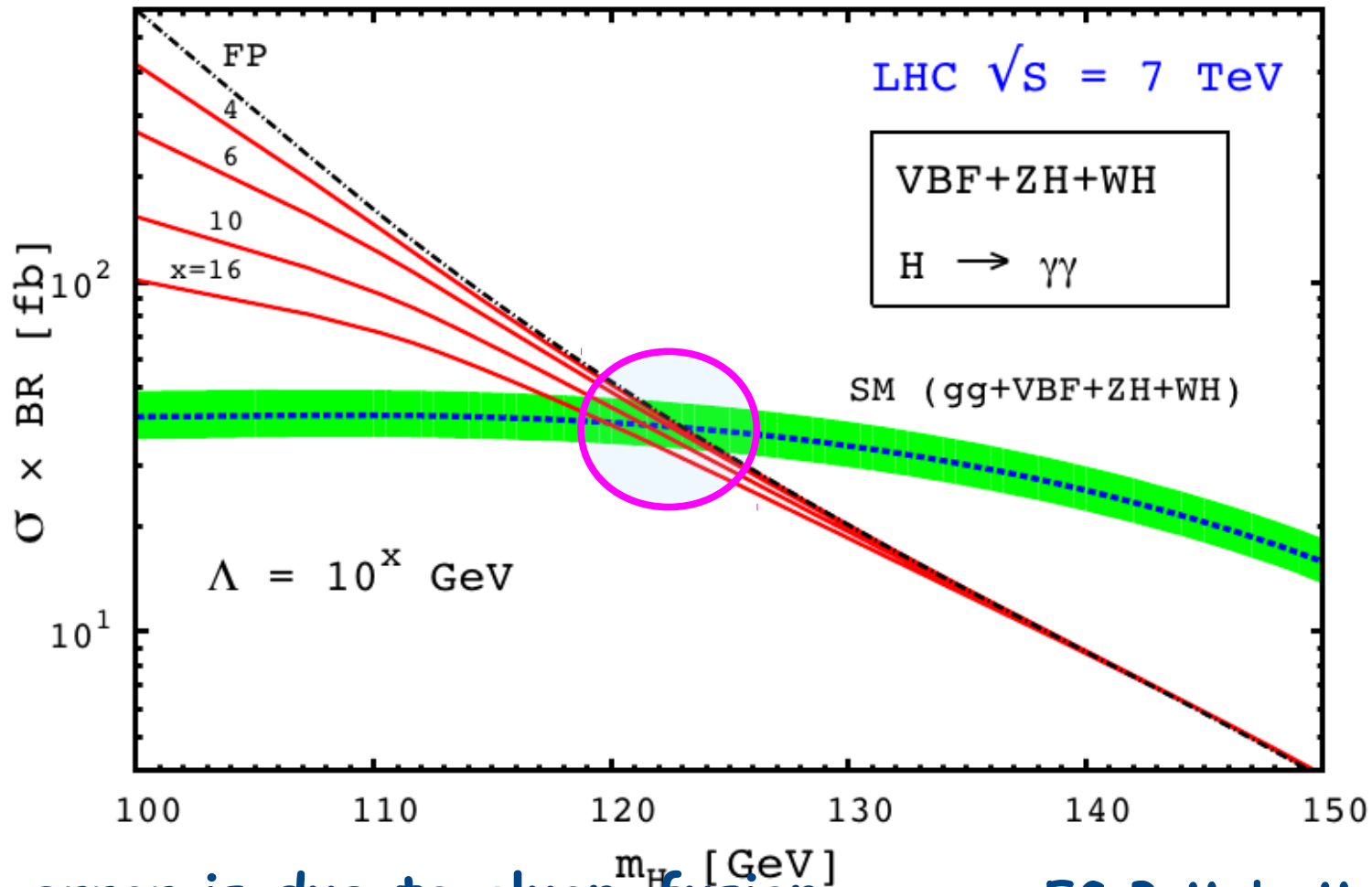
BR's enhanced by small total width

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



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

For $m_H=124-126$ GeV, SM and FP Higgs predict
 $\sim$ same inclusive production rate for $H \rightarrow \gamma\gamma$



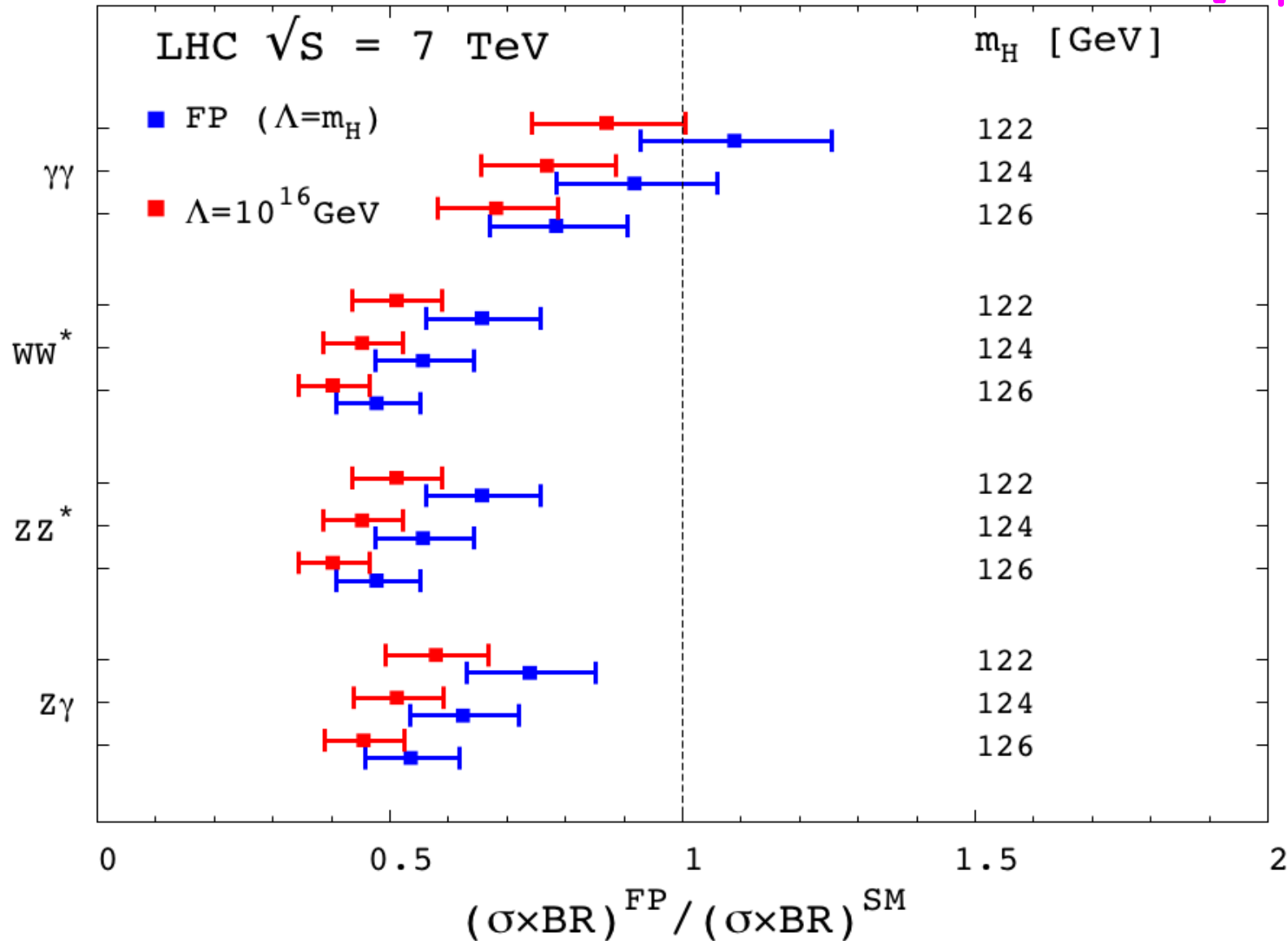
SM error is due to gluon-fusion
cross-section

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

FP $H \rightarrow \gamma\gamma$ compatible with SM @ 125 GeV within 1-2 σ

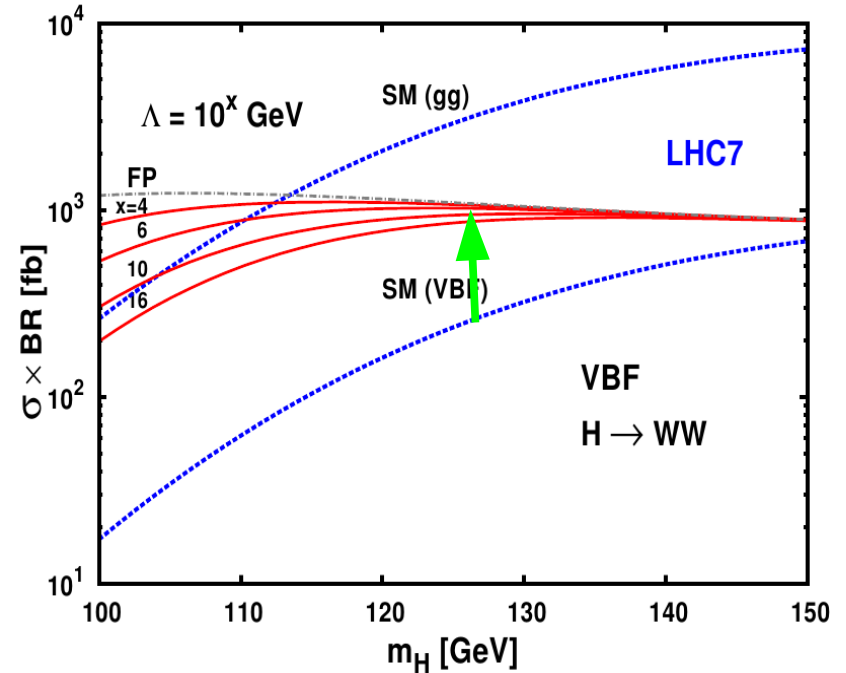
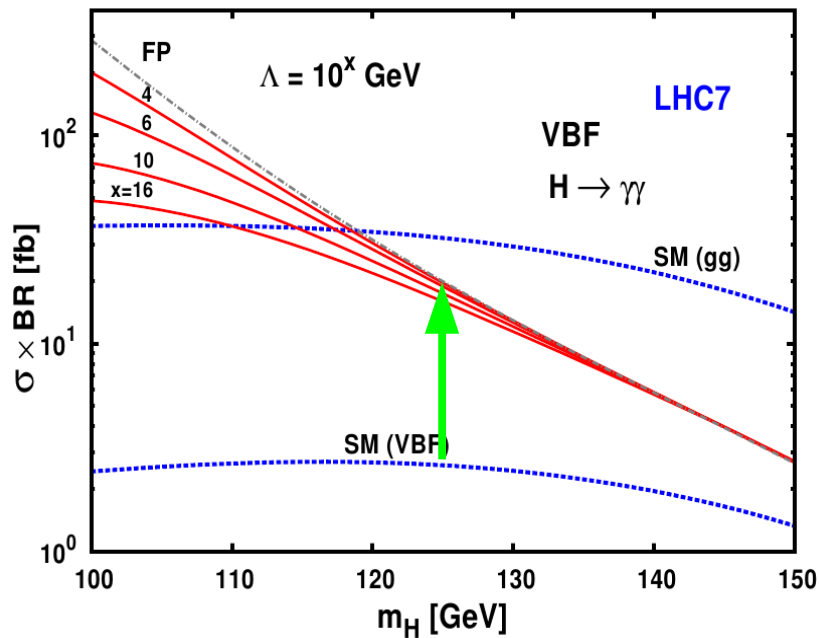
EG, B. Mele, M. Raidal

1202.1792 [hep-ph]



- ◆ 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) : $H \rightarrow \gamma\gamma, WW^*$



➡ FP/VFB[SM] at $m_H = 125$ GeV

➡ $H \rightarrow \gamma\gamma$

rate[FP] $\sim 7 \times$ rate[SM(VBF)]

➡ $H \rightarrow WW^*$

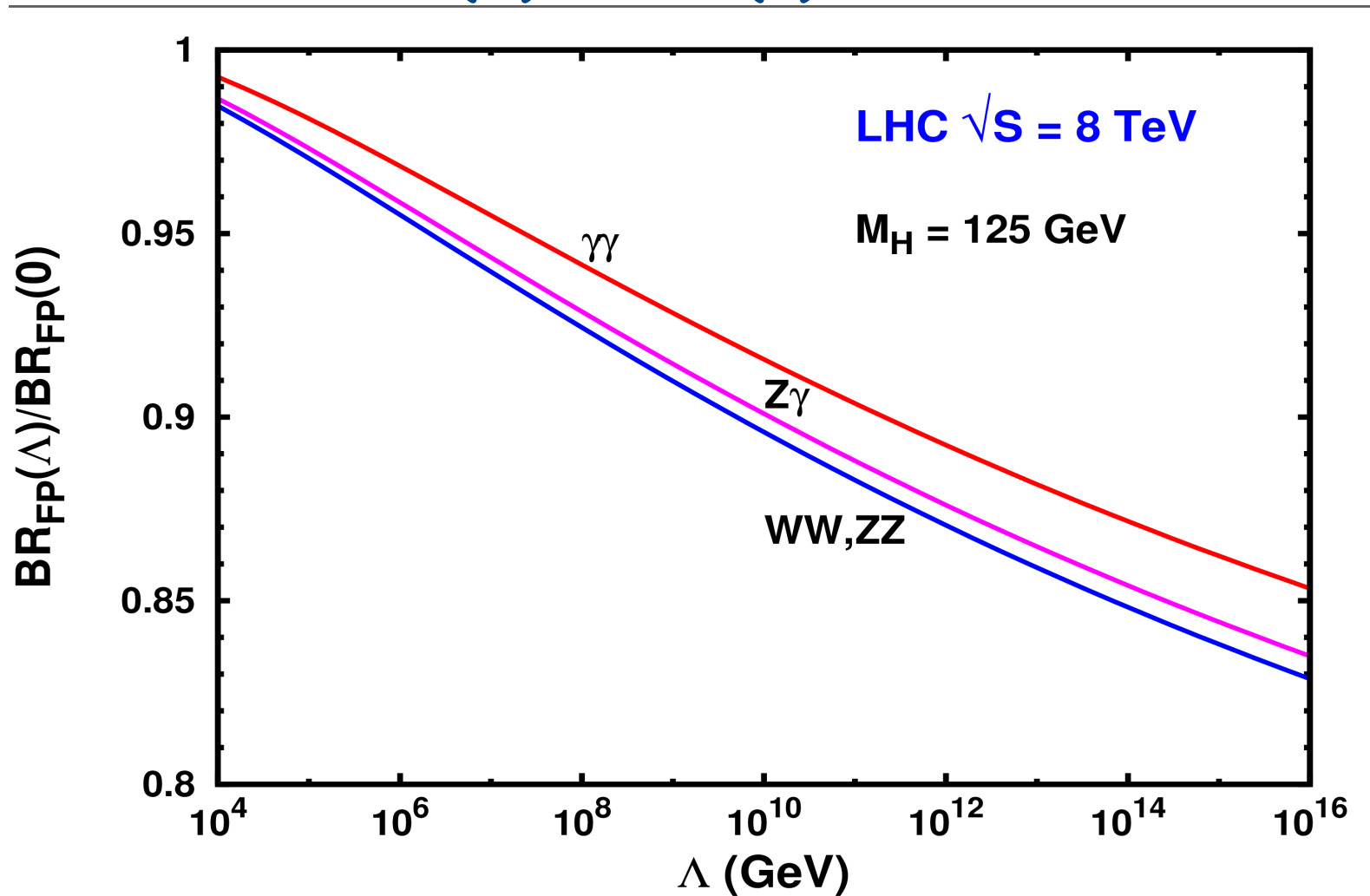
rate[FP] $\sim 5 \times$ rate[SM(VBF)]

➡ $H \rightarrow ZZ^*$

rate[FP] $\sim 5 \times$ rate[SM(VBF)]

Effects of radiative corrections on

$$\text{BR}_{\text{FP}}(\Lambda) / \text{BR}_{\text{FP}}(0): M_H = 125 \text{ GeV}$$



reduction < 10 - 20% for $\Lambda \sim 10^{10} - 10^{16} \text{ GeV}$

Anatomy of the new boson signal with Mass = 125-126 GeV

- July 4th ATLAS and CMS both confirmed the observation of a new boson with mass $M_H = 125-126 \text{ GeV}$ at significance level of 5σ (2011+2012 data) compatible with SM Higgs boson

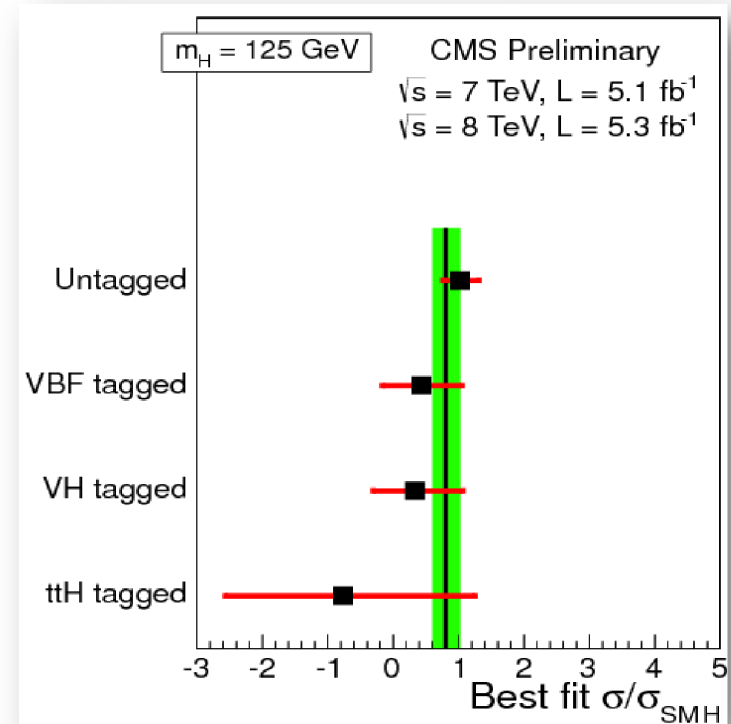
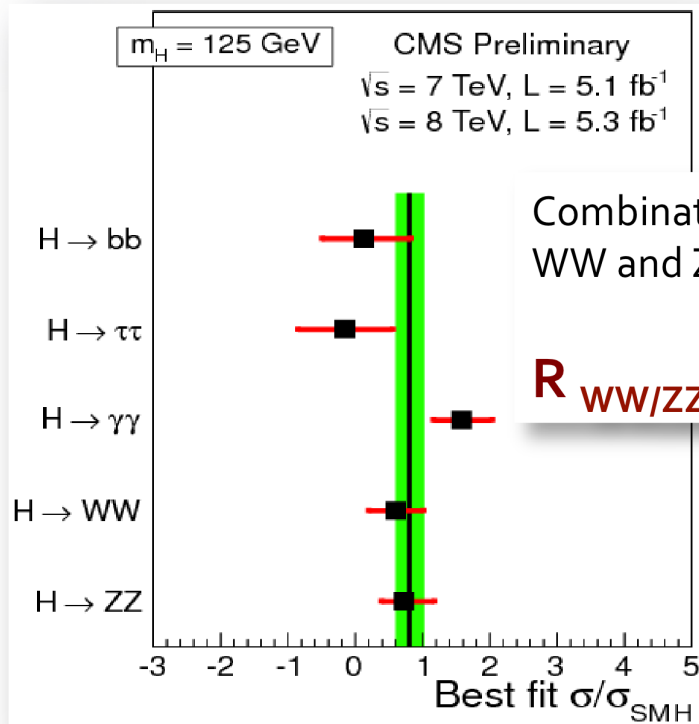
$M_H \sim 125.3 \text{ GeV}$ CMS

$M_H \sim 126.5 \text{ GeV}$ ATLAS

- large excess of events in $H \rightarrow \gamma\gamma$ and $H \rightarrow ZZ^*$
- rates of signal/SM(Higgs) in various channels suggest that might not be SM-like Higgs, although still compatible with SM-Higgs at 2σ

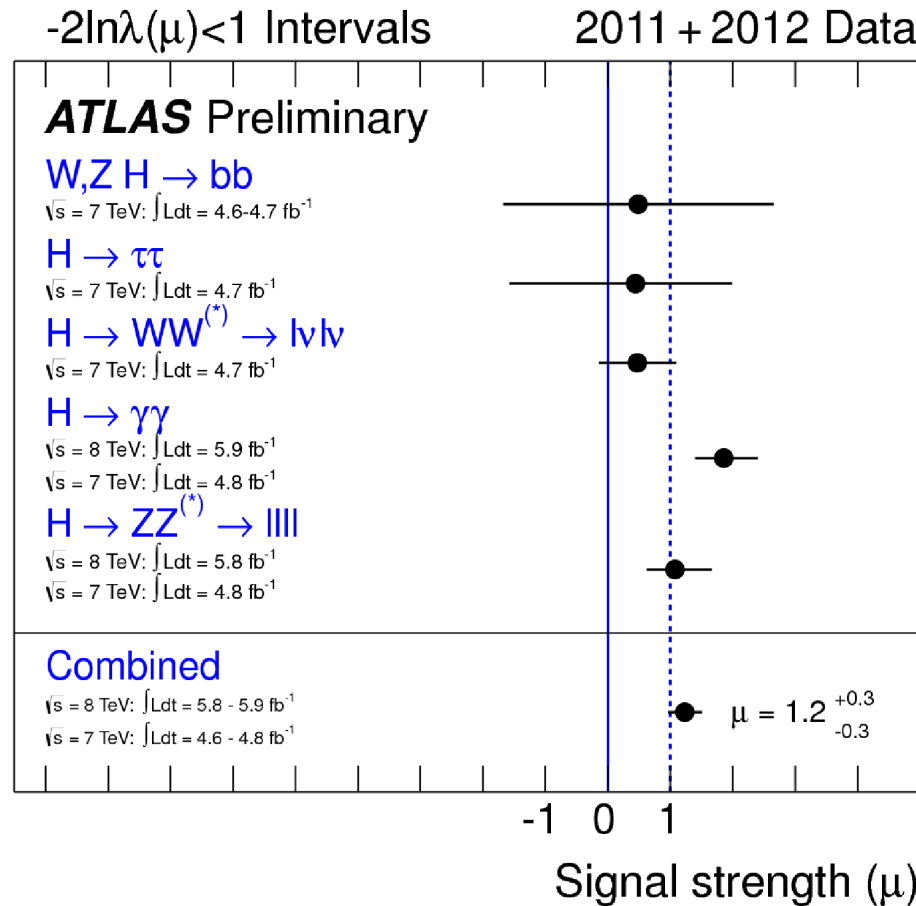


Compatibility with SM Higgs boson event yields in different modes



- Event yields in different decay modes are self-consistent
- Event yields in different production topologies are self-consistent

Contributions of the different channels



- Contributions of different channels at 126.5 GeV
 - Most important contributions from H→γγ, H→ZZ(*)→4l, H→WW(*)→lνlν



Group the Higgs couplings into Vectorial and Fermionic sets.

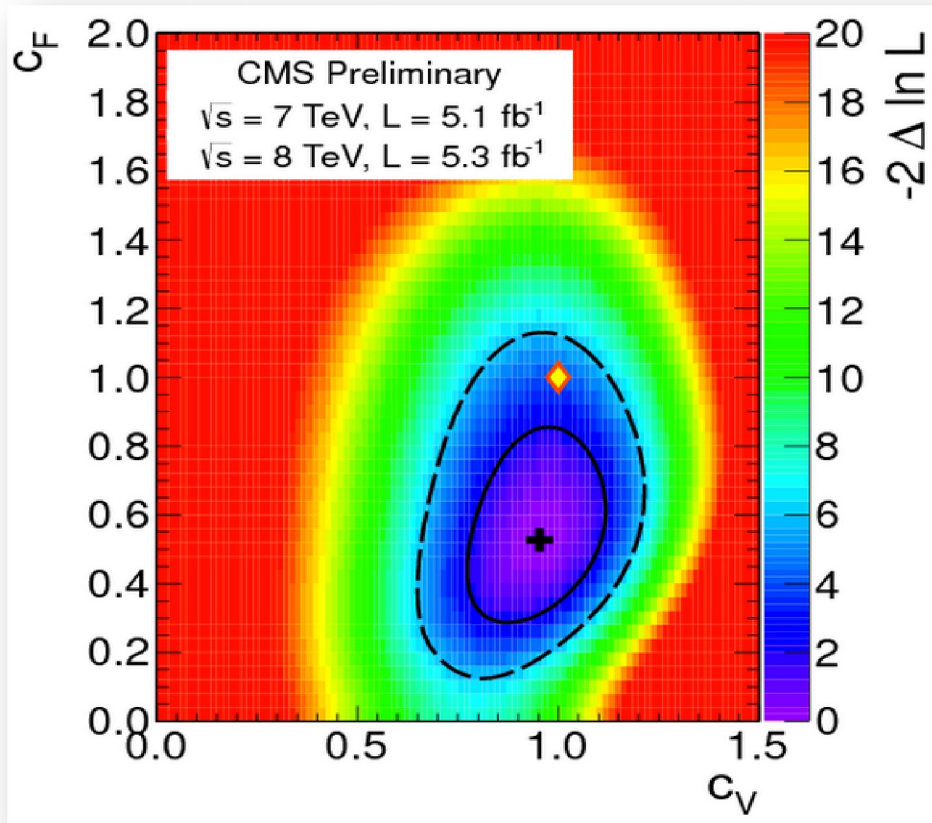
Attach a modifier to the SM prediction to each of those (C_V and C_F).

Use LO theoretical prediction for loop-induced $H \rightarrow \gamma\gamma$, $H \rightarrow gg$ couplings.

In agreement with the SM within the 95% confidence range

→ Need more data!

Fit to C_V and C_F



solid contour: 68% CL

dashed contour: 95% CL

■ Data → indication of a partial FP Higgs model ?

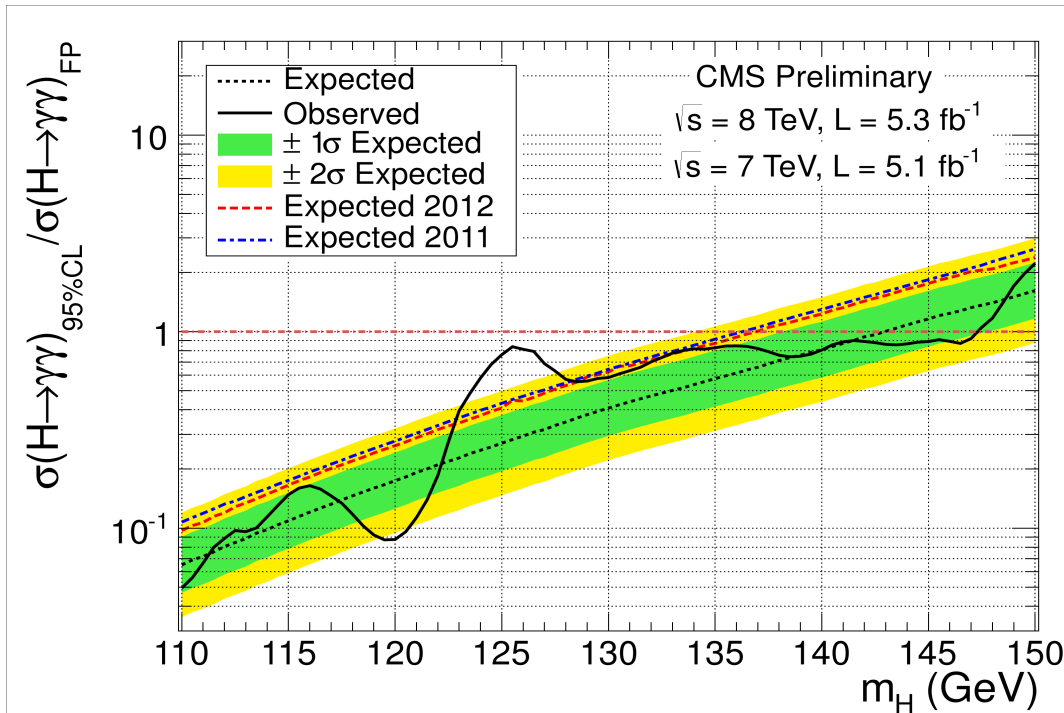
■ if so → not FP SM-like! New Physics needed

■ radiative corrections do not help :

→ reduce the VBF rate of $H \rightarrow \gamma\gamma$ max 17%

→ but also reduce $\text{BR}(H \rightarrow gg)$

■ CMS has excluded tree-level SM FP model
for $M_H = 110 - 134$ GeV at 99% CL !

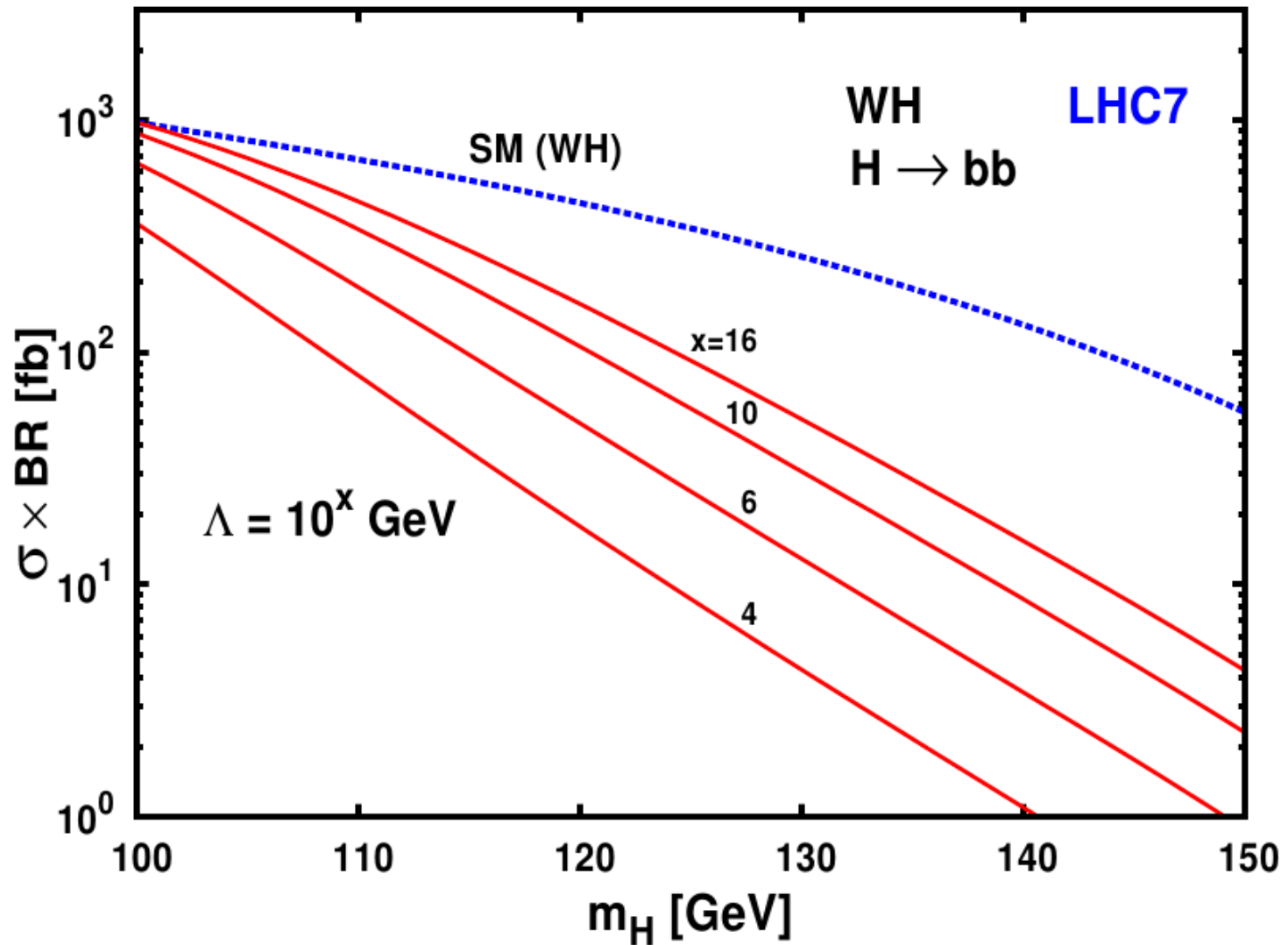


Conclusions

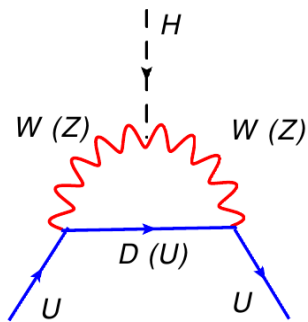
- Fermio-Phobic Higgs scenario is unstable under radiative corrections → **ChSB regenerates Yukawa couplings**
- EFT approach to calculate radiative corrections → **unified descriptions of a wide class of possibilities**
- if the scale Λ of **ChSB** is very large → **BR(H $\rightarrow$ bb)** at $m_H=125$ GeV can be as large as a few 10%
- ATLAS and CMS excesses of events at **$m_H=125$ GeV** is **compatible** with a **FP Higgs**, although they suggest also a depletion of $H \rightarrow WW^*$ 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

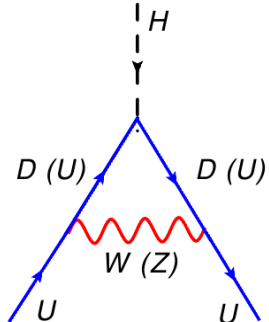
LHC (WH) : $H \rightarrow bb$



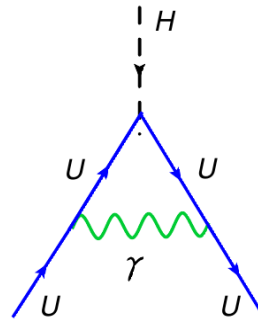
Diagrams contributing to the Y 's beta-functions



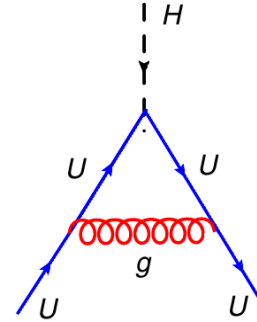
a)



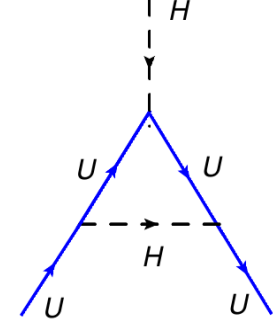
b)



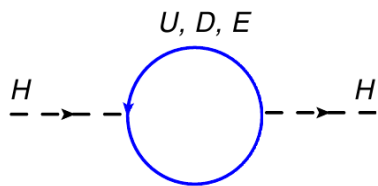
c)



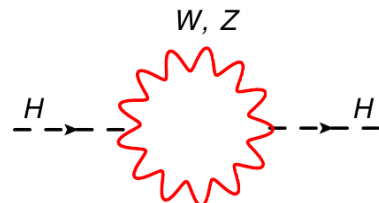
d)



e)



f)

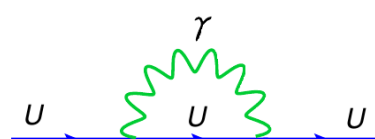


g)

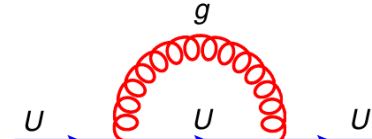
Up-type quark couplings



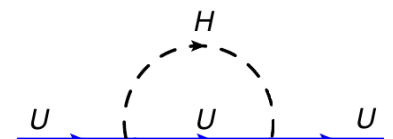
h)



i)



j)

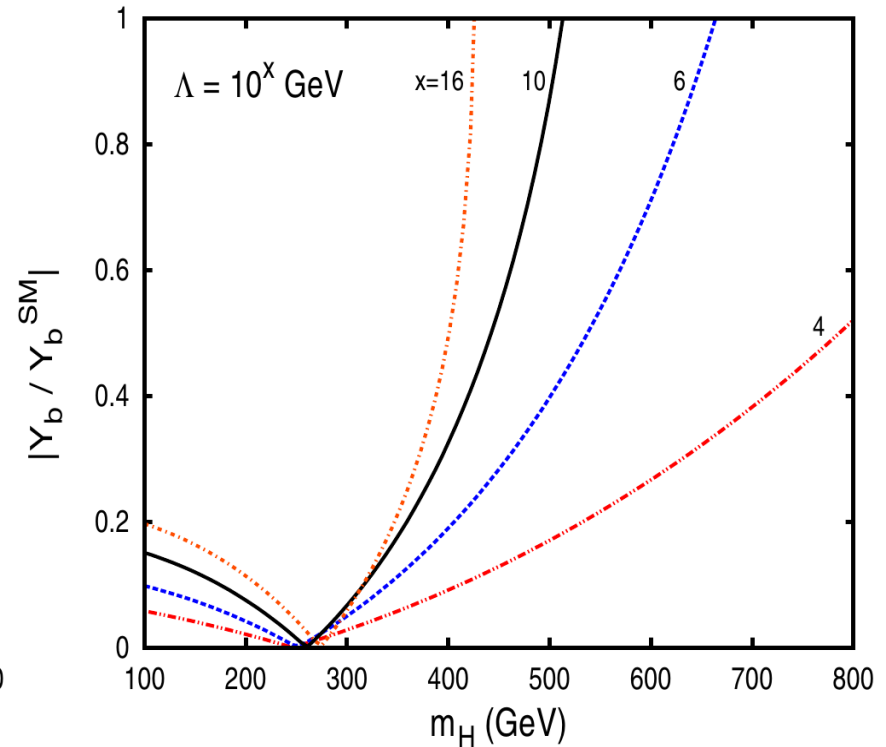
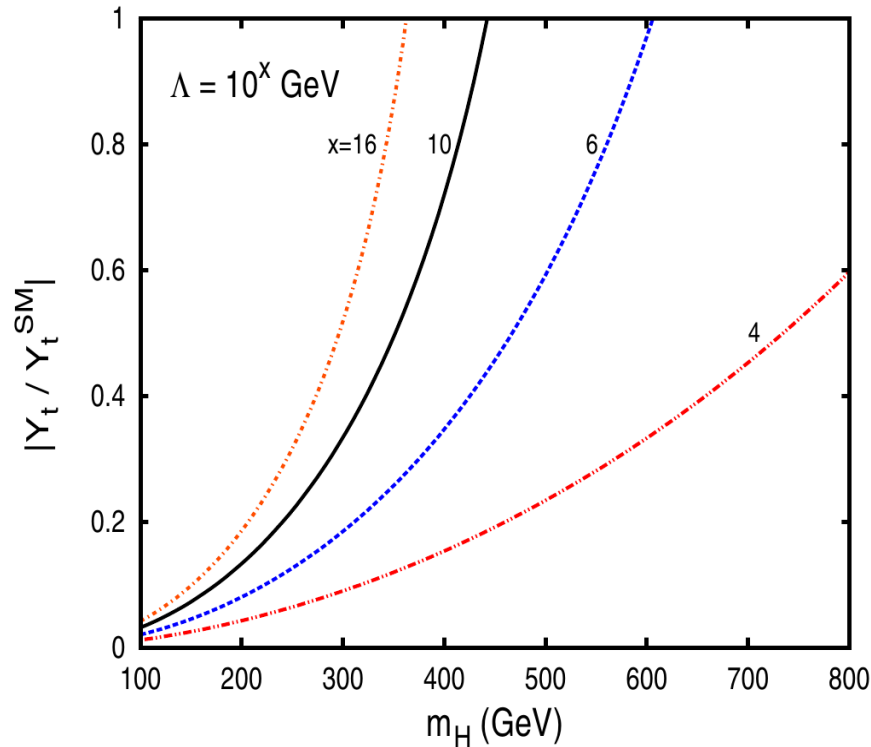


k)

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

E. GABRIELLI AND B. MELE

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

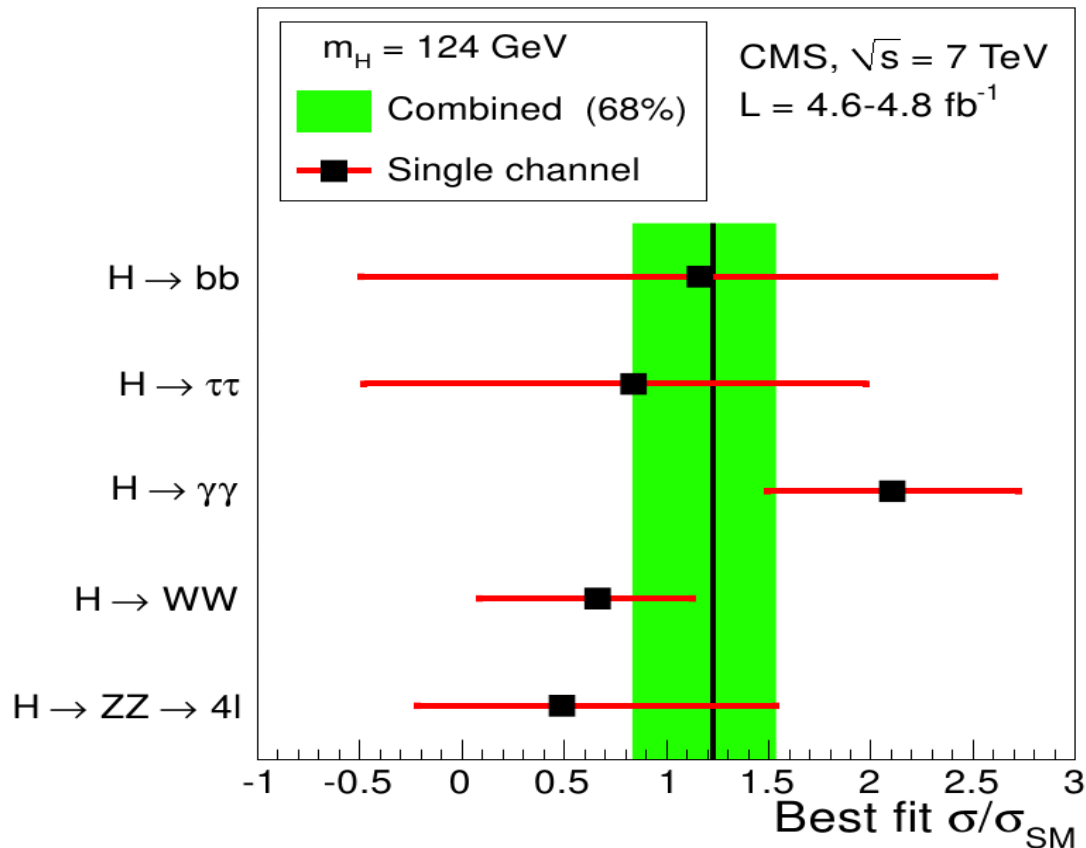
Status of LHC Higgs searches

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 $m_H = 126$ GeV with local significance of 3.5σ
 - $H \rightarrow \gamma \gamma$ 2.8σ
 - $H \rightarrow WW^* \rightarrow 2l2\nu$ 1.4σ
 - $H \rightarrow ZZ^* \rightarrow 4l$ 2.1σ
- probability that the excess is a statistical fluctuation of bckg in [110-660] GeV is 1.4% $\rightarrow 2.2 \sigma$

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 $m_H=124$ GeV with local significance of 3.1σ , largest excess in $H \rightarrow \gamma\gamma$



1-loop RGE's for Yukawa's

(Higgs on-shell)

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

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

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

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

W_L polarization

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

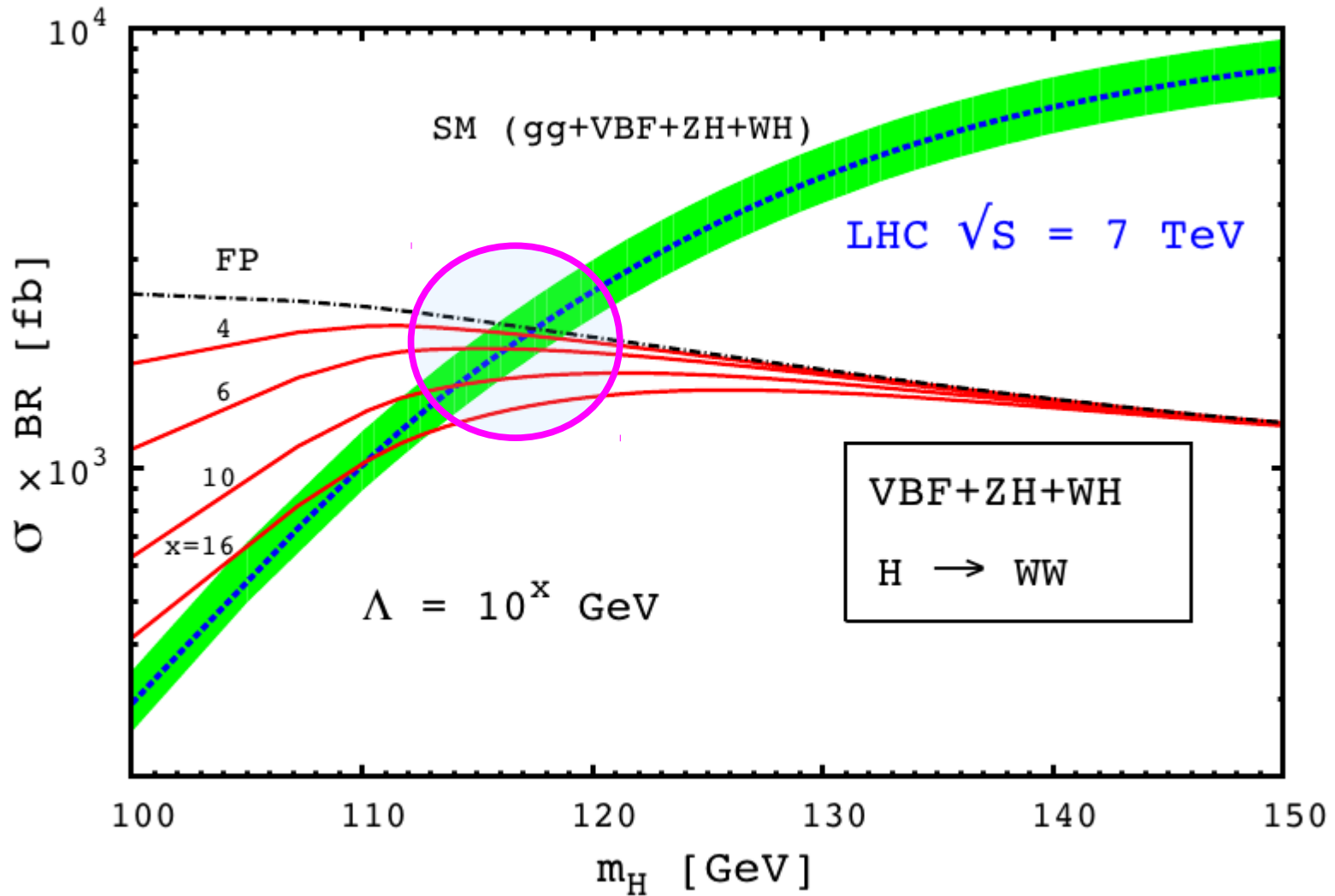
ChSB terms

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

SM RGE's recovered for

$$\mathbf{Y}_f^{\text{SM}} \rightarrow \mathbf{Y}_f$$

FP(VBF+VH) : $H \rightarrow WW^*$



For $m_H = 124-126 \text{ GeV}$, FP Higgs has a smaller inclusive WW^* production rate with respect to SM!

Moriond 2012:

- **New ATLAS and CMS searches for FP Higgs $\rightarrow \gamma\gamma$**
 - ATLAS $\rightarrow$ 9 categories : both low and high $p_T(\gamma\gamma)$,
 - CMS $\rightarrow$ jj-tagged (VBF), lepton-tagged (VH), 4 inclusive

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

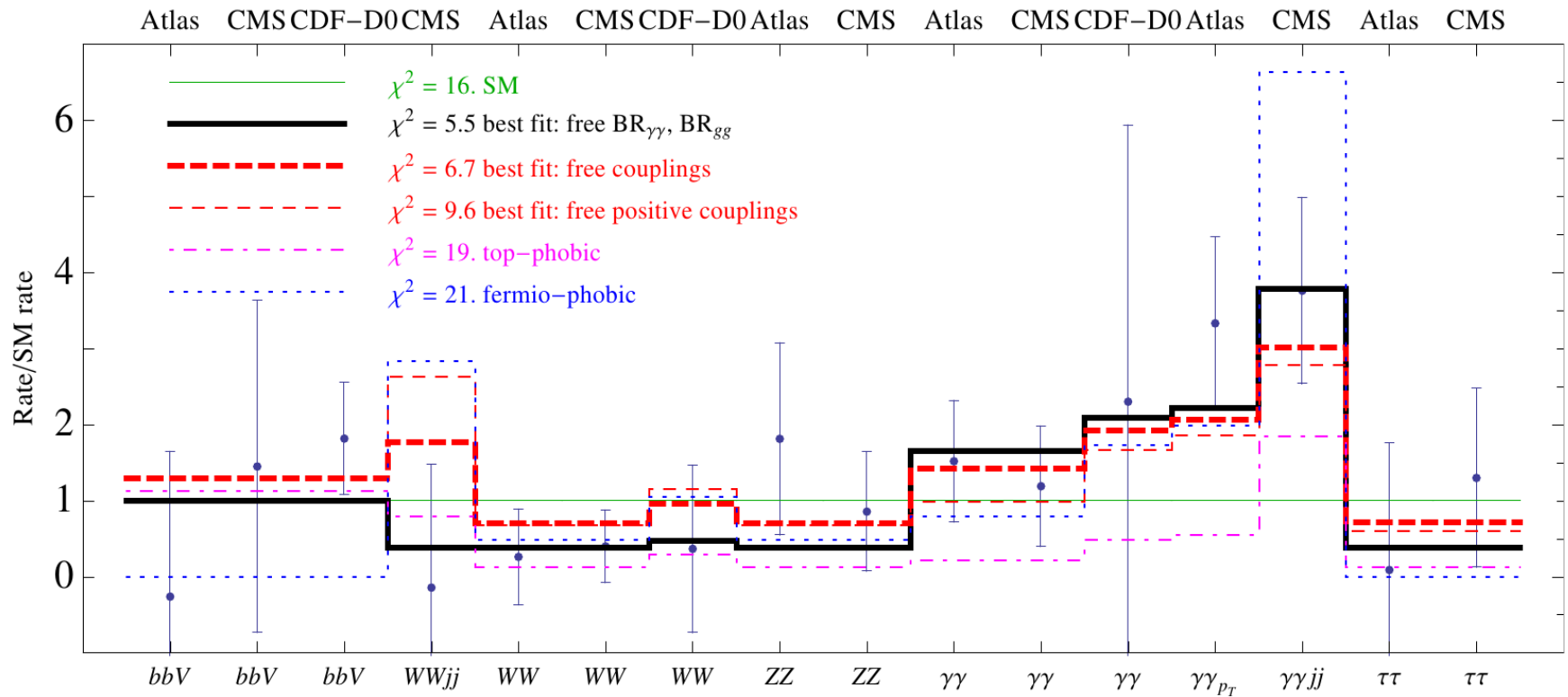
- **A hint of FP Higgs ? To confirm that, test $H \rightarrow VV^*$**
- **A deficit in WW^*jj channel is observed in both experiments with respect to FP Higgs expectations.**
- **Exclusion mass ranges for FP Higgs in $\gamma\gamma$ @ 95% CL**
 - CMS $\rightarrow$ [110-124] , [128-136] GeV
 - ATLAS $\rightarrow$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

■ 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

Fermiophobia:

Fermions acquire masses from a different mechanism than the Higgs mechanism responsible of W and Z masses

Theoretical motivations →

- SM does not explain the fermion mass hierarchy !
- problem shifted to the Yukawa couplings
- not yet any experimental evidence supporting tree-level Yukawa couplings
- EWPT not sensitive to Yukawa couplings at 1-loop
- 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
- in SM, ChSB and EWSB generated by the Higgs mechanism at same scale $\sim \langle H \rangle \rightarrow$ Yukawa couplings