A Chiral Fourth Generation

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work in progress with:

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Pheno 2007
5/8/2007

Outline

- Introduction: A chiral fourth family
- Vacuum stability & Triviality
- Electroweak Precision Constraints
- Higgs Physics
- Outlook

Introduction / Motivation

For a nice review: Frampton, Hung, Sher
Phys Rep 330, 263 (2000)

- A fourth generation is a natural extension of the Standard Model, containing the minimal chiral unit that cancels anomalies.
- We have no real understanding why there should be three generations, so why not more?
- Perturbativity bounds the Yukawa interactions - the LHC will answer this question definitively!
- A model such as "top" condensation would have worked better with a heavier top quark. Perhaps a fourth generation could work without embellishments such as the seesaw or technicolor.

B. Holdom, JHEP 0608:076,2006

Parameters

- A fourth generation contains states Q_4, u_4, d_4, L_4, e_4, (and perhaps a right-handed neutrino ν_4).

- Masses come from electroweak symmetry breaking. Higgs couplings at tree level are m / v.

- Because all of the new states have the same representations as the SM matter, no flavor-changing neutral currents are induced. Flavor-violation is per the charged currents, described by a 4x4 unitary "CKM" matrix:

$$\begin{aligned} |V_{u4}|^2 &= 0.0008 \pm 0.0011 \\ |V_{c4}|^2 &= -0.003 \pm 0.027 \\ |V_{4d}|^2 &= -0.001 \pm 0.005 \end{aligned}$$

PDG

$|V_{tb}| \gtrsim 0.68$ from single top at D0 still allows sizeable 3-4 mixing.

D0, PRL98, 181802 (2007)

- The Neutrino mass(es) could come either from a dimension 5 operator, a Dirac mass, or a "seesaw"-like structure:

$$\mathcal{L} \supset y^{\nu}_{4A} \tilde{\Phi} \bar{L}_4 \nu_{4R} + M \, \bar{\nu}^c_{4R} \nu_{4R}$$

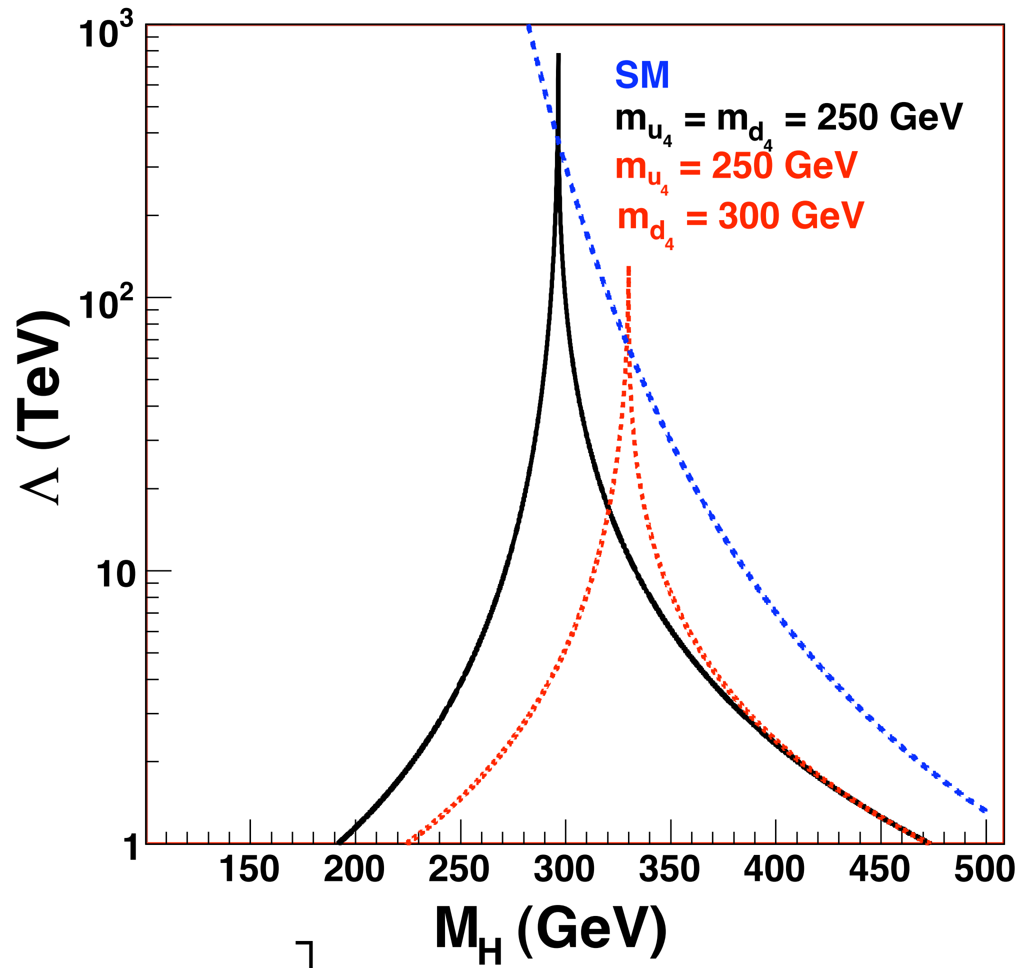
Vacuum Stability & Triviality

Sher, Phys Rep 179, 273 (1989)

- We can bound the range of Higgs masses based on the requirement of vacuum stability or triviality.

$$m_H^2 = \lambda v^2$$

- We evolve the quartic, Yukawas, and gauge couplings including the fourth generation.
- As in the SM, for large m_H the quartic becomes large at relatively low scales.
- Vacuum (meta)-stability is derived by requiring the probability of transition to the "true" vacuum be at most of order one.



$$\frac{d\lambda}{dt} = \frac{1}{16\pi^2}\left[12\lambda^2 + 4\sum_f N_C^f\left(\lambda y_f^2 - y_f^4\right) + \ldots\right]$$

Direct Search Limits

- Limits on the leptons from LEP-II are expected to be of order 100 GeV, close to the kinematic limit.
- Limits on leptons from the Tevatron are a little more subtle... existing neutralino or chargino limits are difficult to interpret.

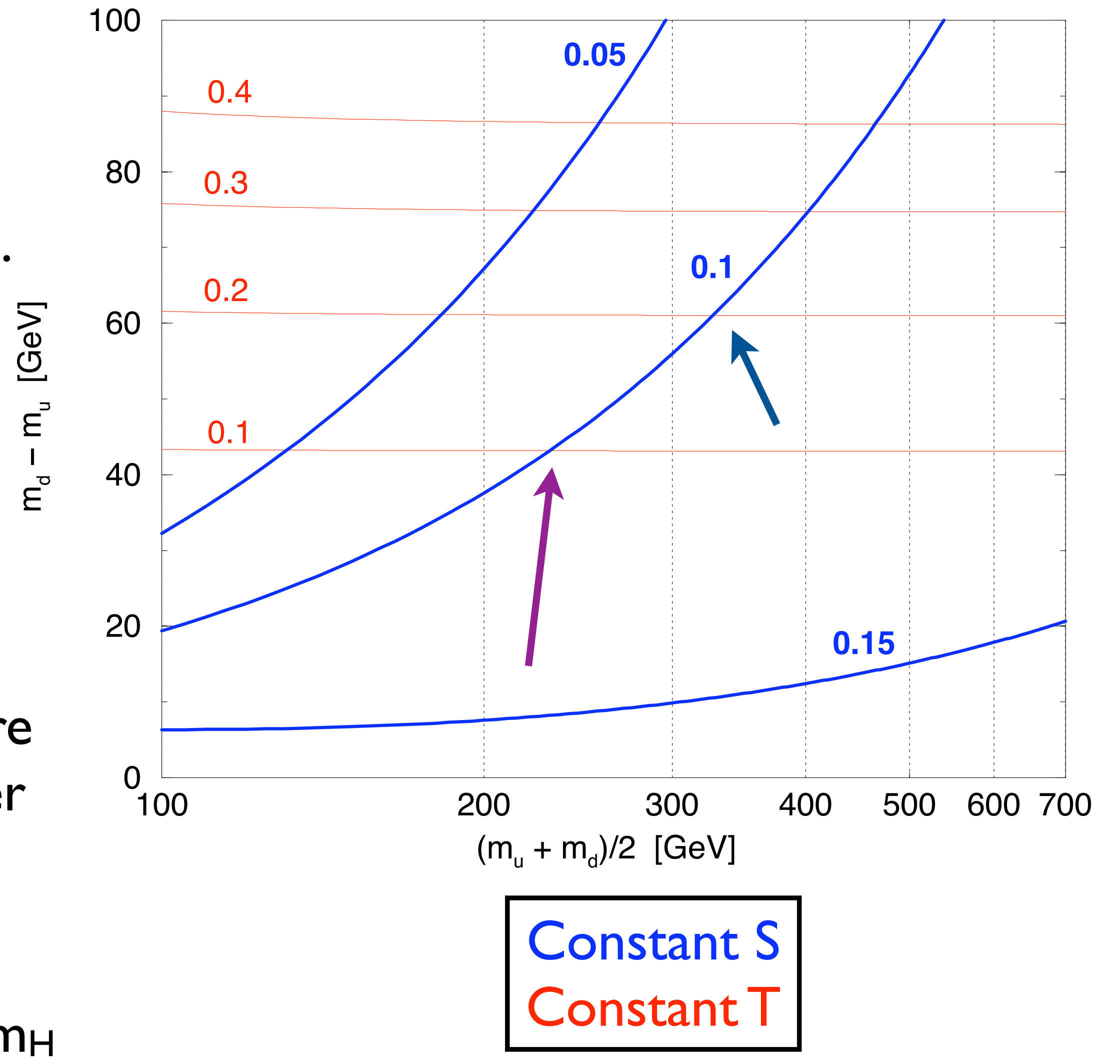
http://www-cdf.fnal.gov/physics/new/top/top.html

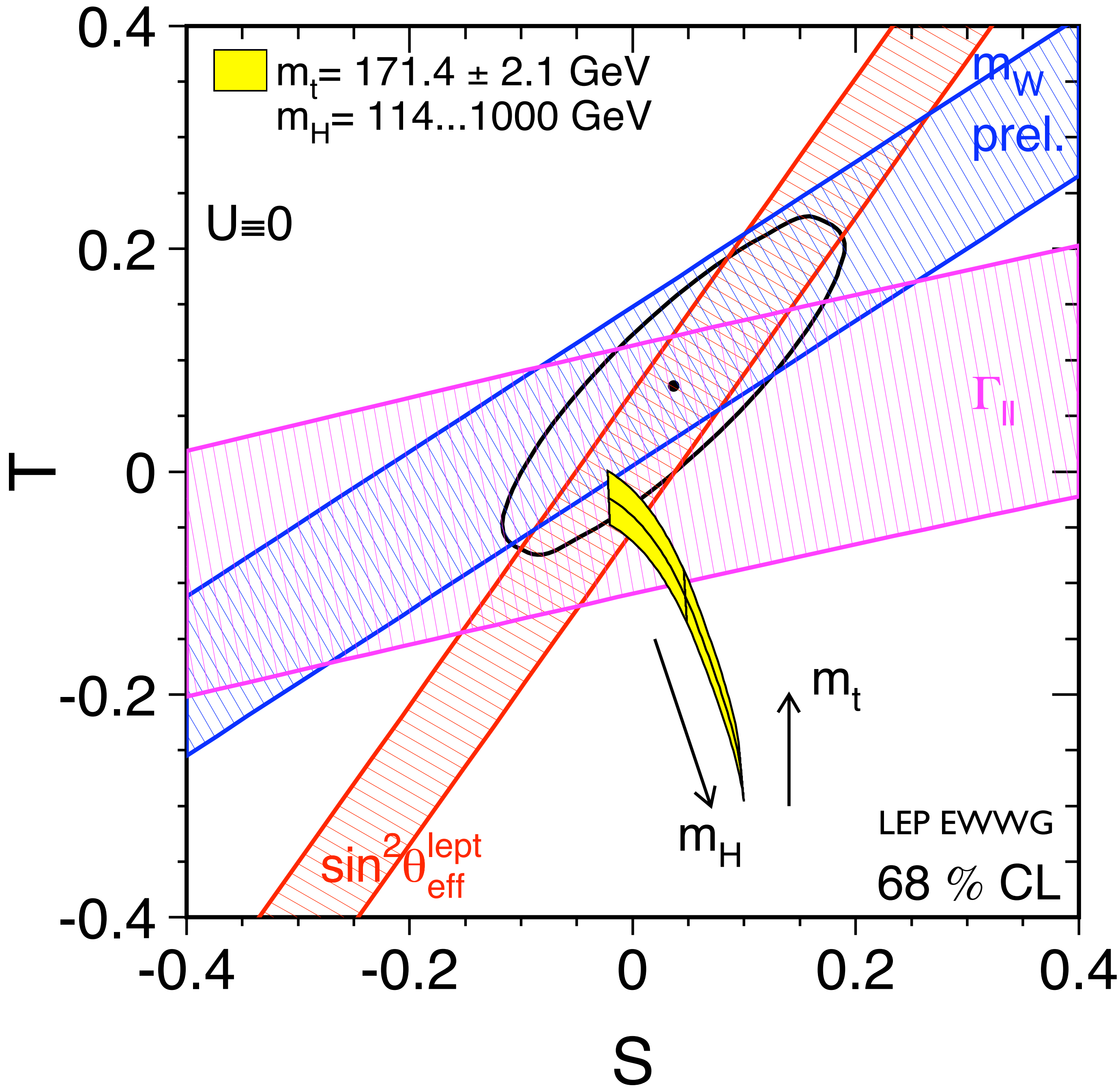
- Limits on a t' (-> Wb) are 265 GeV with about 1 fb^{-1}.
- Limits on a b' are around 300 GeV, though no dedicated search for b' -> Wj or b'->Wt with 100% branching ratio seems to be available.
- (However, bounds on a specific model with vector-like d-quarks are around 300 GeV).

http://www-cdf.fnal.gov/physics/exotic/exotic.html

Precision Electroweak

- We take all of the mixings to be small, so the dominant constraints from precision measurements is from the oblique parameters S, T, and U.
- As in the SM, a chiral fourth generation contributes negligibly to the U parameter, so we compare with the LEP EWWG fit to S, T with U=0.
- Assuming the quark masses are the largest, they dominate over the leptons.
- Finite mass effects, and a correlation between S, T and m_H allow a fourth generation!





Origin defined by reference values:

m_t = 175 GeV
m_H = 150 GeV

For low m_H:
$\Delta S \sim 0.2$
provided $\Delta T \sim \Delta S$
is allowed.

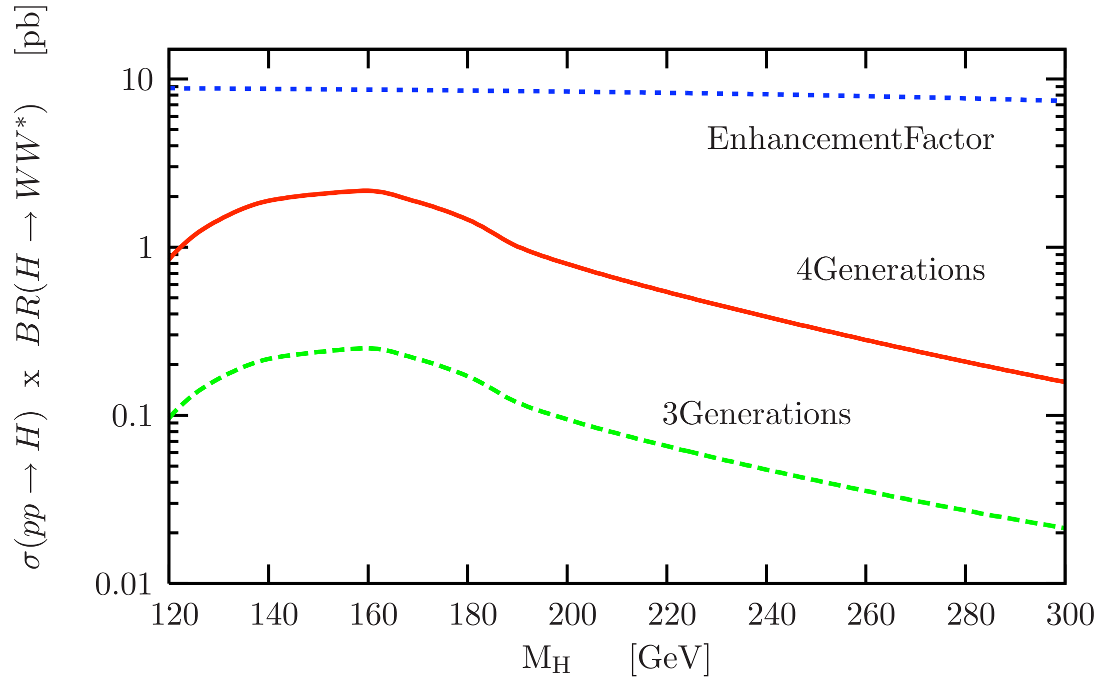
For large m_H:
$\Delta S \sim 0.1$
provided
$\Delta T \sim 0.2 + \Delta S$
is allowed.

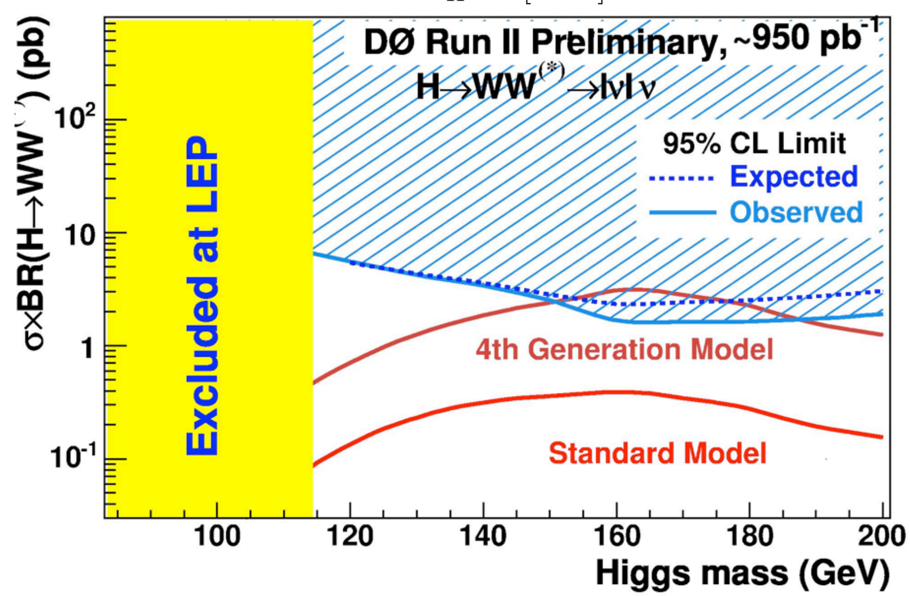
Higgs Production

- The H-g-g operator receives new contributions from u_4 and d_4.
- In the asymptotic limit of large quark masses compared to m_H, this provides an enhancement of about a factor of nine.

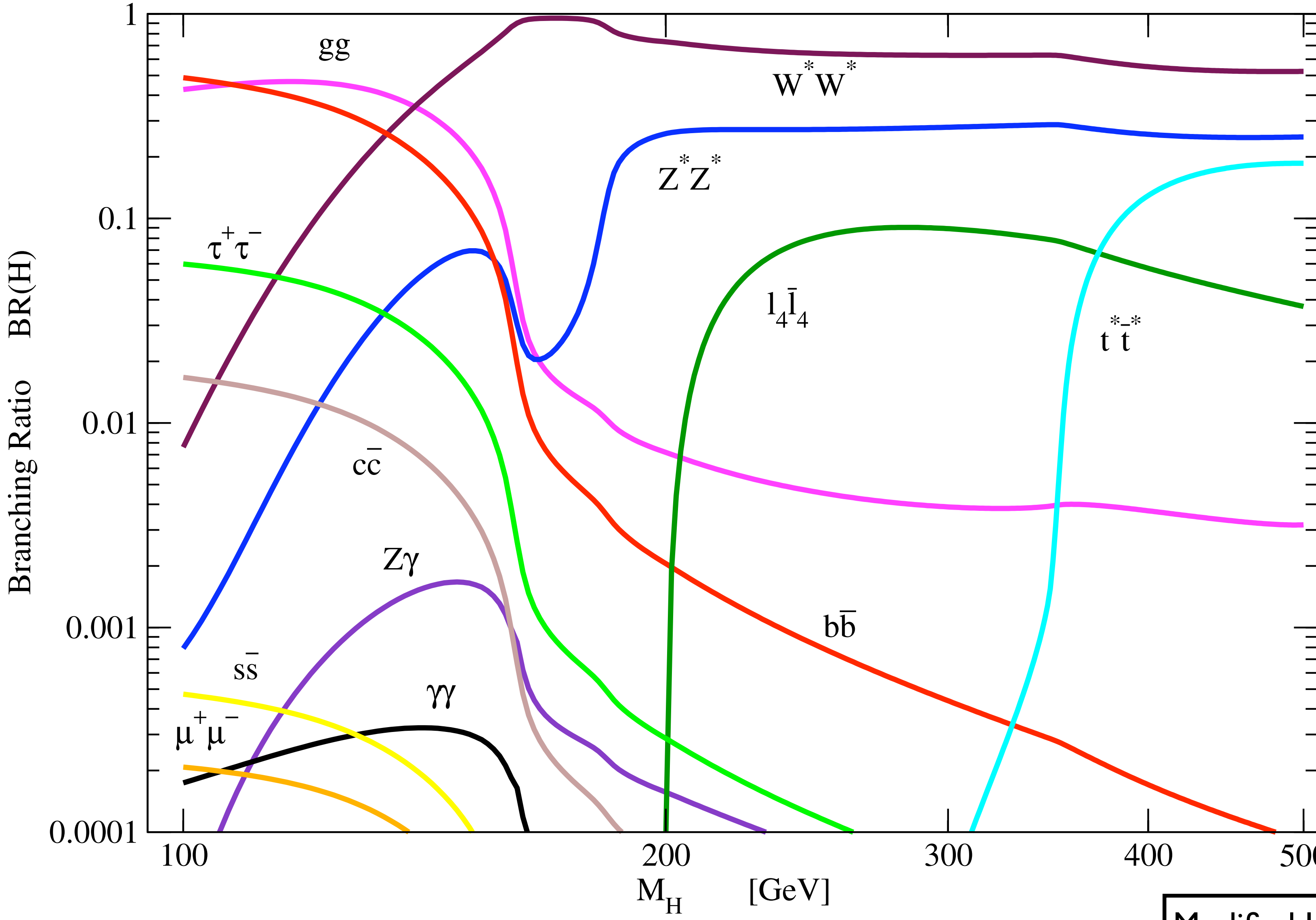
Gunion, McKay, Pois
PRD53, 1616 (1996)

- The H-γ-γ operator, instead, is reduced because the new fermions interfere with the dominant W loop contribution.



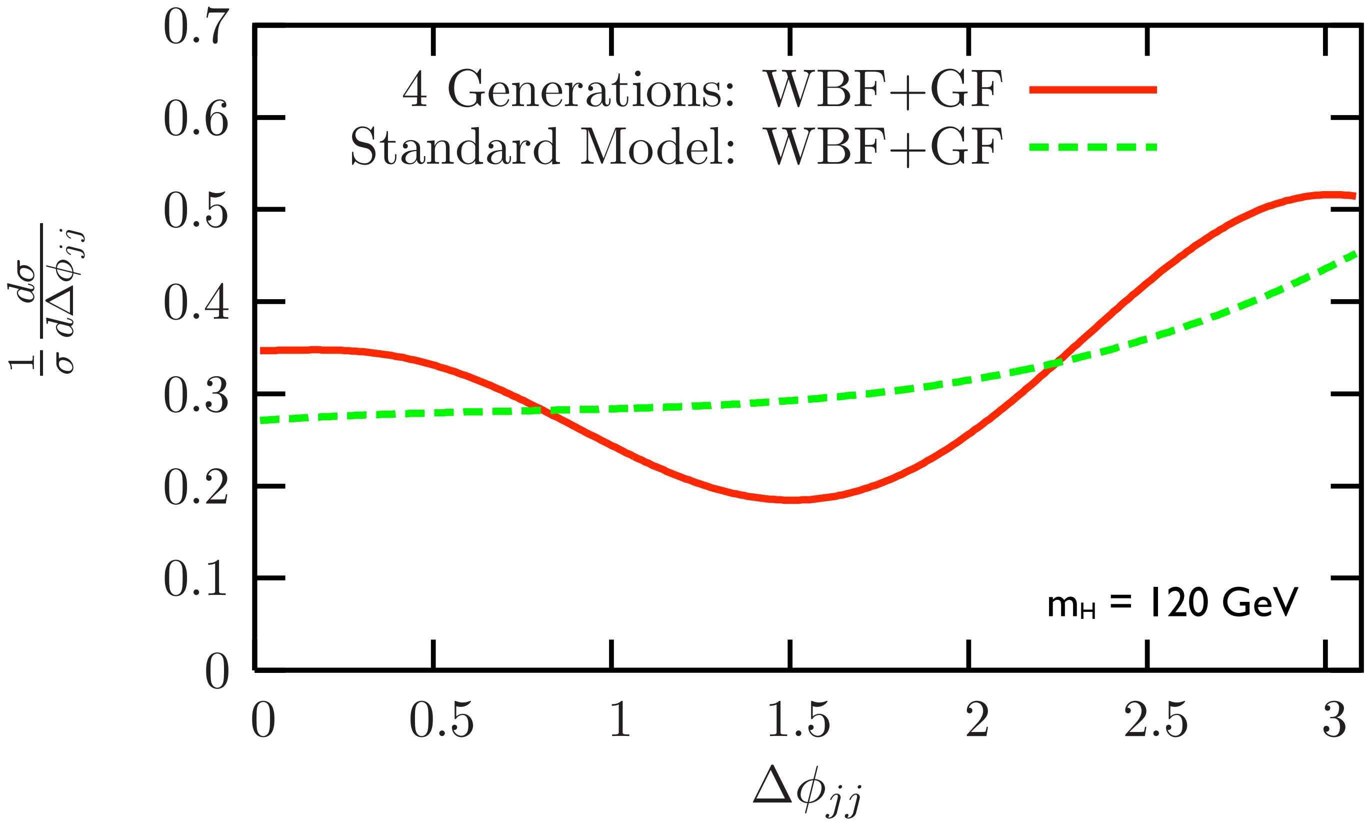


Higgs Decays



Modified HDecay

WBF versus GF



- The enhancement of the H-g-g operator also increases the “pollution” of Weak Boson Fusion from higher order corrections to Gluon Fusion.
- The difference reflects itself in the angular distributions of the associated jets, which take on more of a GF character.

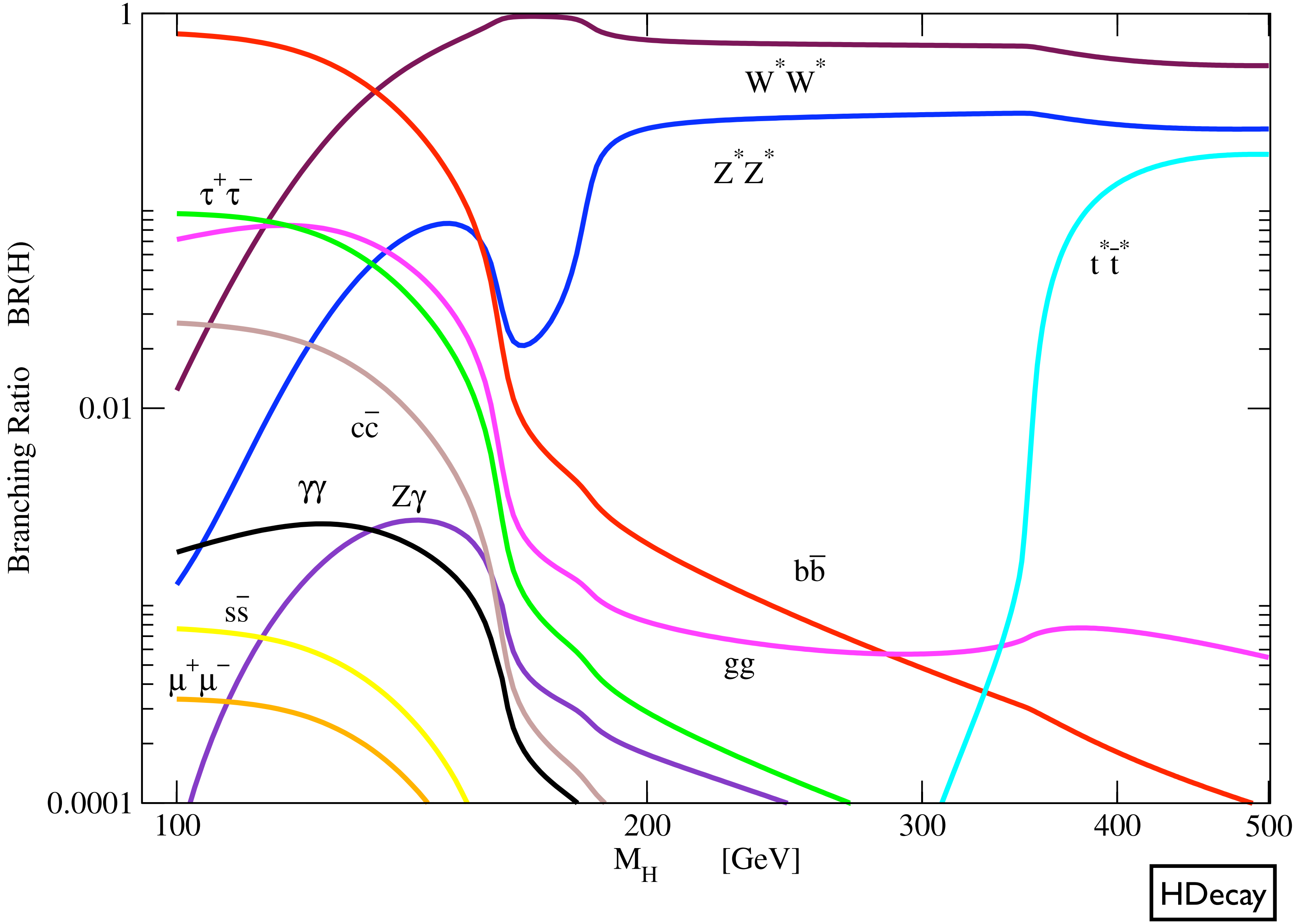
Outlook

- A chiral fourth generation is an obvious extension of the SM, and has deep implications for Higgs physics.
- Regions most compatible with EW precision data, stability, and triviality favor a moderately heavy Higgs, and quarks in the ~300 GeV range.
- Large 4i mixing could have an effect on flavor physics, and is probably constrained.
- The new fermions could be helpful in generating a first order EW phase transition.

  Carena, Megevand, Quiros, Wagner
  NPB716, 319 (2005)
- With some Majorana splitting, the new neutrino might even play the role of dark matter!

Supplementary

SM Higgs BRs



1
0.01
0.0001
Branching Ratio BR(H)
W*W*
Z*Z*
t*t̄*
τ+τ−
cc̄
γγ
Zγ
bb̄
ss̄
μ+μ−
gg
100
200
300
400
500
M_H [GeV]
HDecay