The Fourth SM Family: Present Status

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Periodic Table of the Elementary* Particles

family	ν	*l*	*u*	*d*
1	< 3 eV	510.99892(4) keV	1.5 to 4 MeV	4 to 8 MeV
2	< 190 keV	105.658369(9) MeV	1.15 to 1.35 GeV	80 to 130 MeV
3	< 18.2 MeV	1.77699(+29-26) GeV	174.3(5.1) GeV	4.1 to 4.4 GeV
4	> 45 GeV	> 100 GeV	> 200 GeV	> 130 GeV

Also,

$m_\gamma = 0$ (< $6 \cdot 10^{-17}$ eV) **$m_g = 0$ (< few MeV)**

$m_W = 80.425(38)$ GeV **$m_Z = 91.1876(21)$ GeV**

$m_H > 114.4$ GeV

Scale: **$\eta \approx 247$ GeV**

* *Elementary in the SM framework. At least one more level (preons) should exist.*

Yukawa couplings

In standard approach: $m_f = g_f \eta$ ($\eta \approx 245$ GeV) $g_t / g_e = 0 (m_t / m_e) \approx 340000$

Moreover, $g_t / g_{\nu e} \approx 1.75 \cdot 10^{11}$ (if $m_{\nu e} = 1$ eV) compare with $m_{GUT}/m_W \sim 10^{13}$

However, see-saw mechanism …

For same type fermions: $g_t / g_u \approx 35000 \div 175000$, $g_b / g_d \approx 300 \div 1500$,

$g_\tau / g_e \approx 3500$

Within third family: $g_t / g_b \approx 40$, $g_t / g_\tau \approx 100$, $g_t / g_{\nu\tau} > 10000$

et cetera **Therefore, 3 family case is unnatural**

Hierarchy: $m_u \ll m_c \ll m_t$ $m_d \ll m_s \ll m_b$ $m_e \ll m_\mu \ll m_\tau$

i) LEP data

Three SM families with $m_{\nu(L)} < m_Z / 2$

ii) Precision EW data

2000: the 4th family excluded at 99% CL

2002: 3 and 4 families have the same status

5 and even 6 families are allowed if $m_N \approx 50$ GeV

2004: 6`th SM family is excluded at 3σ ...

2006: ???

H.J. Su, N. Polonsky and S. Su, Phys. Rev. D 64 (2001) 117701

V.A. Novikov, L.B. Okun, A.N. Rosanov and M.I. Vysotsky, Phys. Lett. B 529 (2002) 111

....

Why the four SM families (S. Sultansoy, hep-ph/0004271)

Today, the mass and mixing patterns of the fundamental fermions are the most mysterious aspects of the particle physics. Even the number of fermion generations is not fixed by the Standard Model **(N $\geq$ 3 from LEP, N $\leq$ 8 from Asymptotic Freedom)**.

The statement of the Flavor Democracy (or, in other words, the Democratic Mass Matrix approach)

H. Harari, H. Haut and J. Weyers, Phys. Lett. B 78 (1978) 459;

H. Fritzch, Nucl. Phys. B 155 (1979) 189; B 184 (1987) 391;

P. Kaus and S. Meshkov, Mod. Phys. Lett. A 3 (1988) 1251;

H. Fritzch and J. Plankl, Phys. Lett. B 237 (1990) 451.

which is quite natural in the SM framework, may be considered as the interesting step in true direction.

It is intriguing, that **Flavor Democracy favors the existence of the fourth SM family**

A. Datta, Pramana 40 (1993) L503.

A. Celikel, A.K. Ciftci and S. Sultansoy, Phys. Lett. B 342 (1995) 257.

Moreover, Democratic Mass Matrix approach provide, in principle the possibility to obtain the small masses for the first three neutrino species without see-saw mechanism

J. L. Silva-Marcos, Phys Rev D 59 (1999) 091301

The fourth family quarks, if exist, will be copiously produced at the LHC.

ATLAS Detector and Physics Performance TDR, CERN/LHCC/99-15 (1999), p. 663-

Then, the fourth family leads to an essential increase of the Higgs boson production cross section via gluon fusion at hadron colliders and this effect may be observed soon at the Tevatron.

Flavor Democracy and the Standard Model

It is useful to consider three different bases:

- Standard Model basis $\{f^0\}$,
- Mass basis $\{f^m\}$ and
- Weak basis $\{f^w\}$.

According to the three family SM, before the spontaneous symmetry breaking quarks are grouped into the following SU(2)×U(1) multiplets:

$$\begin{pmatrix} u_L^0 \\ d_L^0 \end{pmatrix}, u_R^0, d_R^0; \quad \begin{pmatrix} c_L^0 \\ s_L^0 \end{pmatrix}, c_R^0, d_R^0; \quad \begin{pmatrix} t_L^0 \\ b_{Ll}^0 \end{pmatrix}, t_R^0, b_R^0.$$

In **one family** case all bases are equal and, for example, d-quark mass is obtained due to Yukawa interaction

$$L_Y^{(d)} = a_d \begin{pmatrix} \bar{u}_L & \bar{d}_L \end{pmatrix} \begin{pmatrix} \varphi^+ \\ \varphi^0 \end{pmatrix} d_R + h.c. \;\Rightarrow\; L_m^{(d)} = m_d \bar{d} d$$

where $m_d = a_d \eta/\sqrt{2}$, $\eta = \langle \varphi^0 \rangle \cong 247$ GeV. In the same manner $m_u = a_u \eta/\sqrt{2}$, $m_e = a_e \eta/\sqrt{2}$ and $m_{\nu e} = a_{\nu e} \eta/\sqrt{2}$ (if neutrino is Dirac particle).

In ***n* family** case

$$L_Y^{(d)} = \sum_{i,j=1}^{n} a_{ij}^{d} \begin{pmatrix} \bar{u}_{Li}^{0} & \bar{d}_{Li}^{0} \end{pmatrix} \begin{pmatrix} \varphi^+ \\ \varphi^0 \end{pmatrix} d_{Rj}^{0} + h.c. = \sum_{i,j=1}^{n} m_{ij}^{d} \bar{d}_i^{0} d_j^{0}, \quad m_{ij}^{d} = a_{ij}^{d} \eta/\sqrt{2}$$

where d_1^0 denotes d^0, d_2^0 denotes s^0 etc.

Flavor Democracy assumptions

Before the spontaneous symmetry breaking all quarks are massless and there are no differences between d^0, s^0 and b^0. In other words fermions with the same quantum numbers are indistinguishable. This leads us to the ***first assumption***, namely, **Yukawa couplings are equal within each type of fermions**:

$$a_{ij}^{d} \cong a^{d}, \quad a_{ij}^{u} \cong a^{u}, \quad a_{ij}^{l} \cong a^{l}, \quad a_{ij}^{\nu} \cong a^{\nu}.$$

The first assumption result in *n-1* massless particles and one massive particle with $m = n \cdot a^F \cdot \eta / \sqrt{2}$ (F = u, d, l, ν) *for each type of the SM fermions.*

Because there is only one Higgs doublet which gives Dirac masses to all four types of fermions (up quarks, down quarks, charged leptons and neutrinos), it seems natural to make the ***second assumption***, namely, **Yukawa constants for different types of fermions should be nearly equal**:

$$a^d \approx a^u \approx a^l \approx a^\nu \approx a$$

.

Taking into account the mass values for the third generation

$$m_{\nu_\tau} << m_\tau < m_b << m_t$$

the second assumption leads to the statement that ***according to the flavor democracy the fourth SM family should exist.***

Above arguments, in terms of the mass matrix, mean

$$M^0 = a\eta/\text{v}2 \begin{pmatrix} 1 & 1 & 1 & 1 \\ 1 & 1 & 1 & 1 \\ 1 & 1 & 1 & 1 \\ 1 & 1 & 1 & 1 \end{pmatrix} \Rightarrow M^m = 4a\eta/\text{v}2 \begin{pmatrix} 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix}$$

Now, let us make the ***third assumption***, namely, ***a/√2* is between $e = g_w \sin\theta_W$ and $g_z = g_w/\cos\theta_W$**. Therefore, the fourth family fermions are almost degenerate, in good agreement with experimental value $\rho = 0.9998 \pm 0.0008$, and their common mass lies between **320 GeV and 730 GeV**. The last value is close to the upper limit on heavy quark masses, $m_Q \leq 700$ GeV, which follows from partial-wave unitarity at high energies

M.S. Chanowitz, M.A. Furlan and I. Hinchliffe, Nucl. Phys. B 153 (1979) 402

It is interesting that with value of $a/\sqrt{2} \approx g_w$ flavor democracy predicts

$$m_4 \approx 8m_W \approx 640 \text{ GeV}.$$

The masses of the first three family fermions, as well as an observable interfamily mixings, are generated due to the small deviations from the full flavor democracy

A. Datta and S. Rayachaudhiri, Phys. Rev. D 49 (1994) 4762.
S. Atag et al., Phys. Rev. D 54 (1996) 5745.
A.K. Ciftci, R. Ciftci and S. Sultansoy, Phys. Rev. D 72 (2005) 053006.

Last parameterization, which gives correct values for fundamental fermion masses, at the same time, **predicts quark and lepton CKM matrices in good agreement with experimental data.**

Arguments against the Fifth SM Family

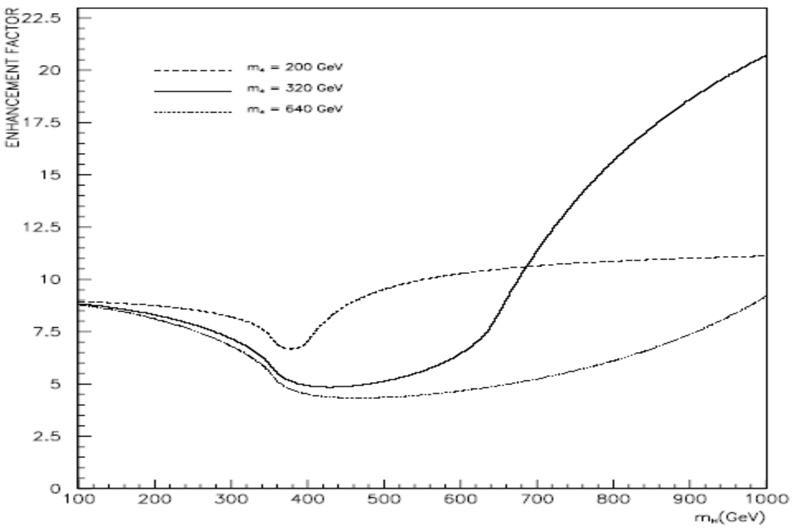
The **first argument** disfavoring the fifth SM family is the large value of $m_t \approx$ 175 GeV. Indeed, partial-wave unitarity leads to $m_Q \leq$ 700 GeV $\approx 4\, m_t$ and in general we expect that $m_t << m_4 << m_5$.

Second argument: neutrino counting at LEP results in fact that there are only three "light" ($2m_\nu < m_Z$) non-sterile neutrinos, whereas in the case of five SM families four "light" neutrinos are expected.

The Fourth SM Family and the Higgs Boson

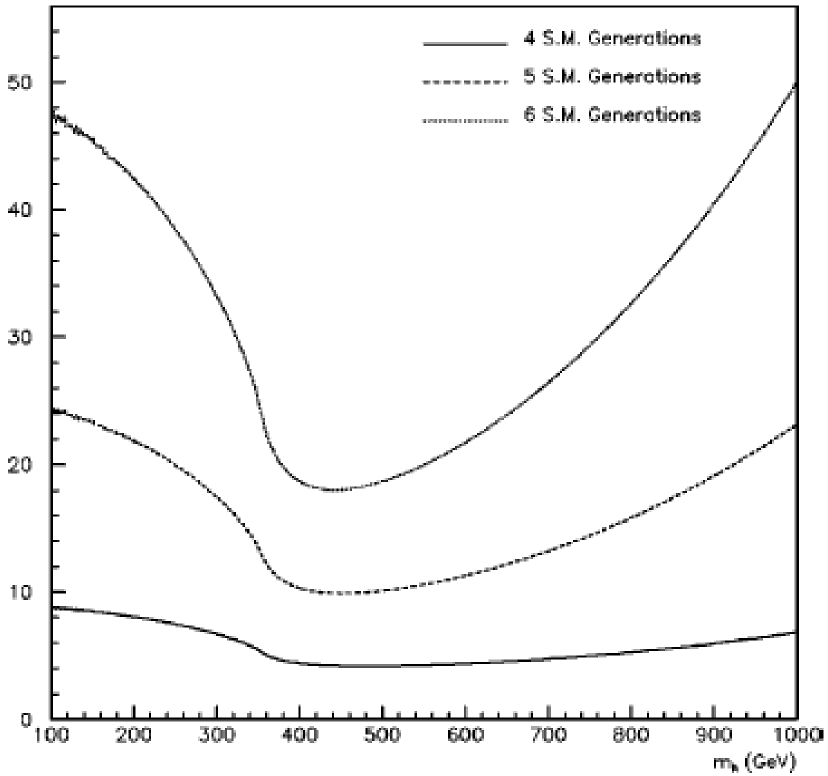
gg → H enhancement factor as a function of Higgs mass:

four SM family case with m_4 = 200; 320 and 640 GeV (upper, mid and lower curves, respectively)



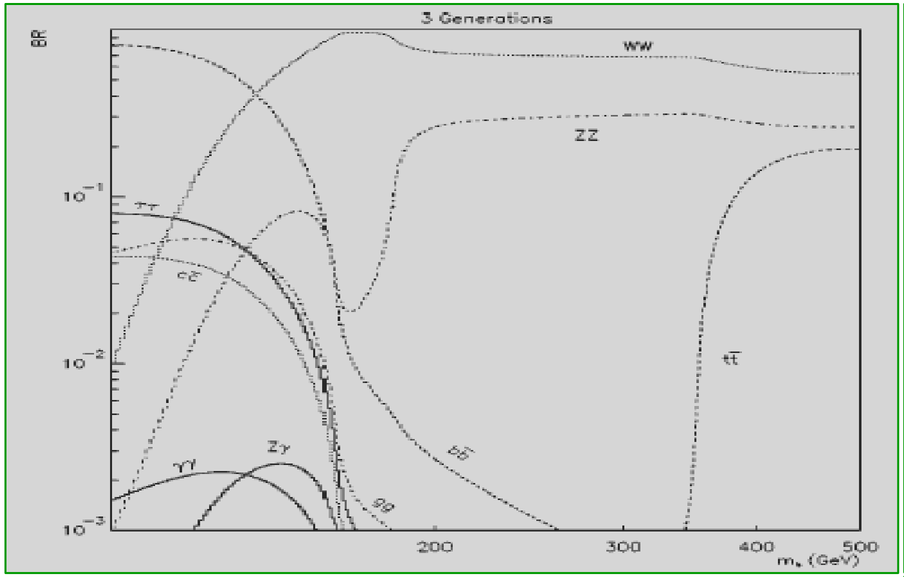
E. Arik et al., Eur Phys J C 26 (2002) 9

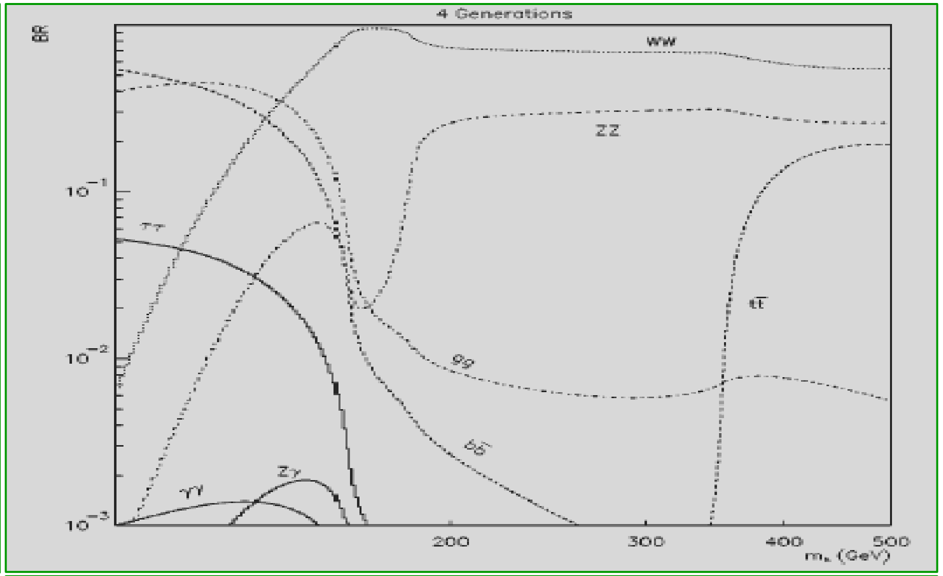
4; 5 and 6 SM families with infinite masses (lower, mid and upper curves)

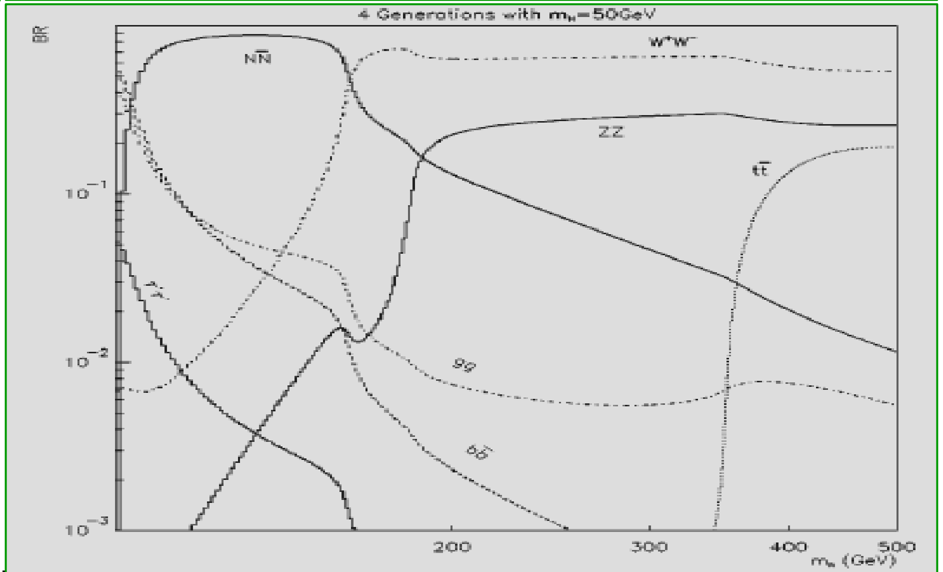


E. Arik et al., Phys Rev D 66 (2002) 033003

Higgs decay branching ratios







E. Arık, O. Çakır, S. A. Çetin, S. Sultansoy, Phys. Rev. D 66, 033003 (2002).

The Fourth SM Family at the Tevatron

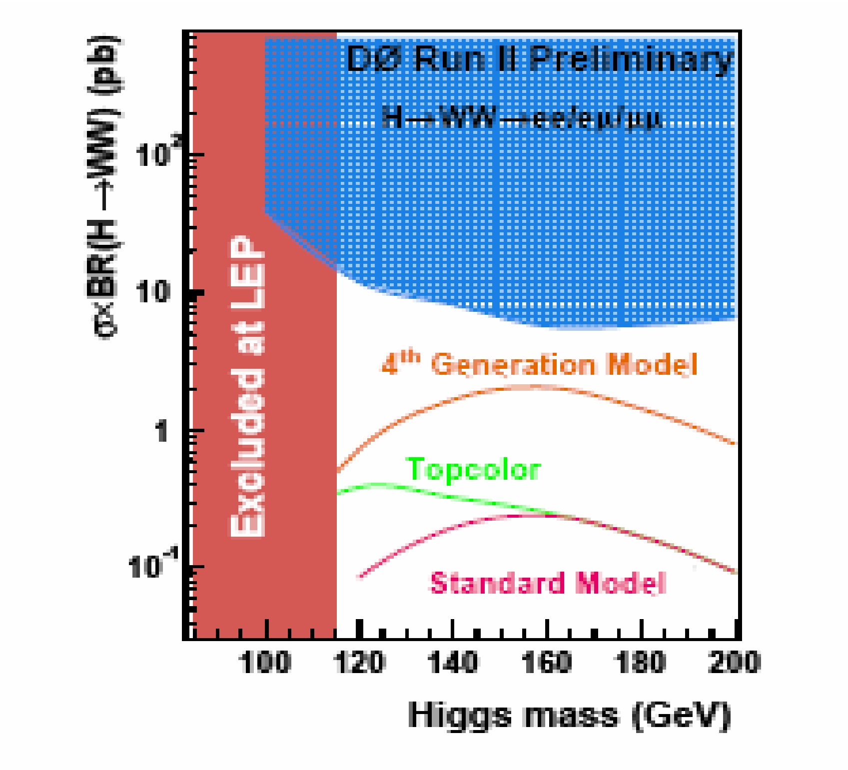
The fourth SM family (quarks) manifestations at the upgraded Tevatron:

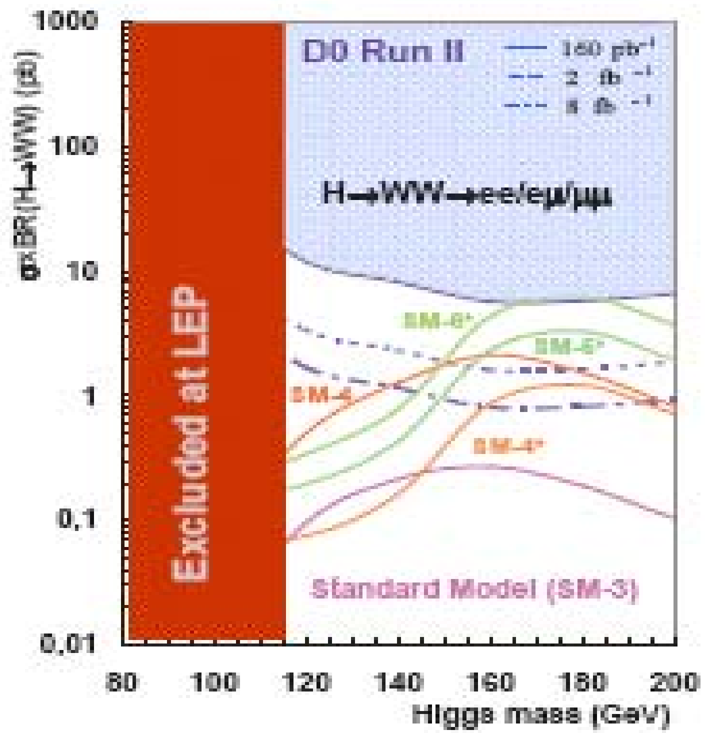
a) Significant enhancement (~8 times) of the Higgs boson production cross section via gluon fusion

b) Pair production of the fourth family quarks (if m_{d4} and/or m_{u4} < 300 GeV)

c) Single resonant production of fourth family quarks via the process $qg \rightarrow q_4$ *(if anomalous coupling has sufficient strength)*

Tevatron 2004





DØ presentations, for example,

A. Kharchilava, hep-ex/0407010

W.-M. Yao, hep-ex/0411053

V. Buscher, hep-ex/0411063

E. Arik et al., hep-ex/0411053

* means extra SM families with $m_N \approx 50$ GeV

Tevatron 2005 -2006

PRL 96, 011801 (2006) PHYSICAL RE

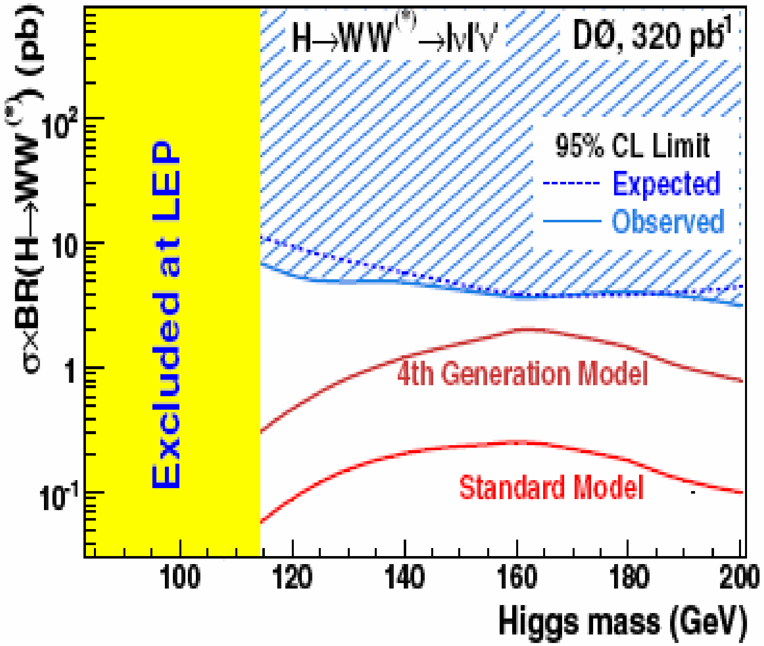
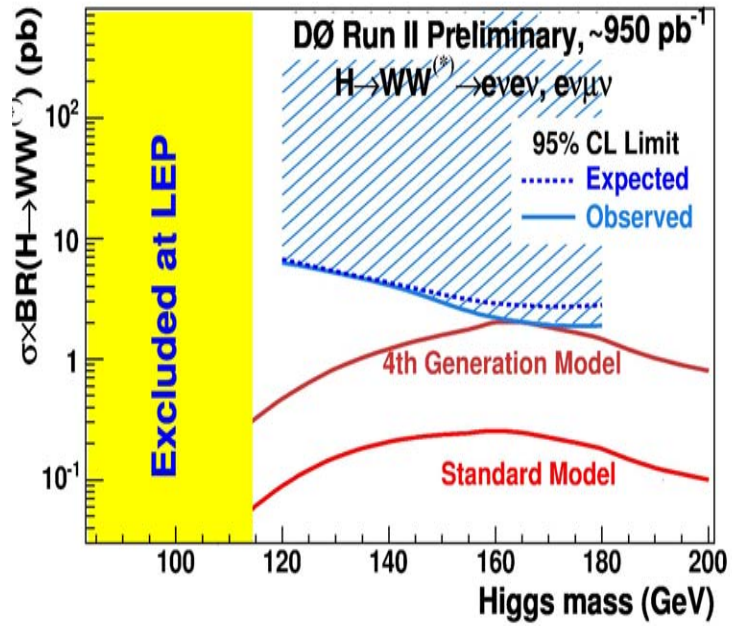
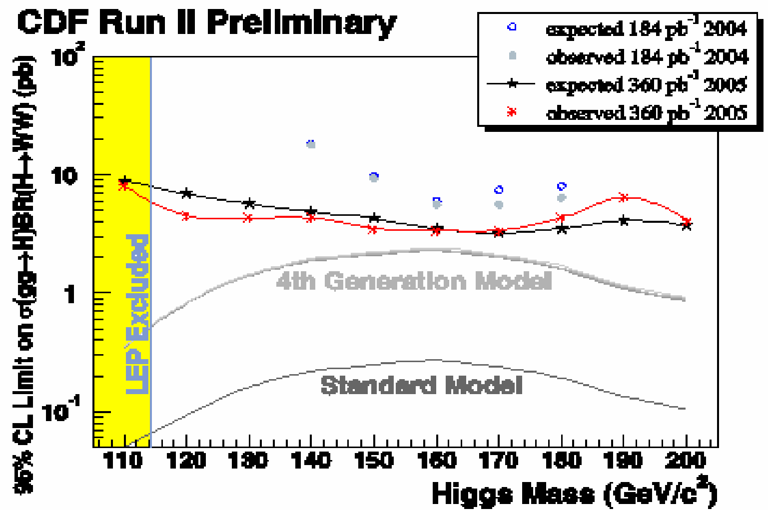


FIG. 2 (color online). Expected and observed upper limits on the cross section times branching ratio $\sigma \times \mathrm{BR}(H \to WW^{(*)})$ at the 95% C.L. together with expectations from standard model Higgs boson production and an alternative model. The LEP limit on the standard model Higgs boson production is taken from [1] and the 4th generation model prediction is described in [6].





Accessible mass range of the Higgs boson at the Tevatron

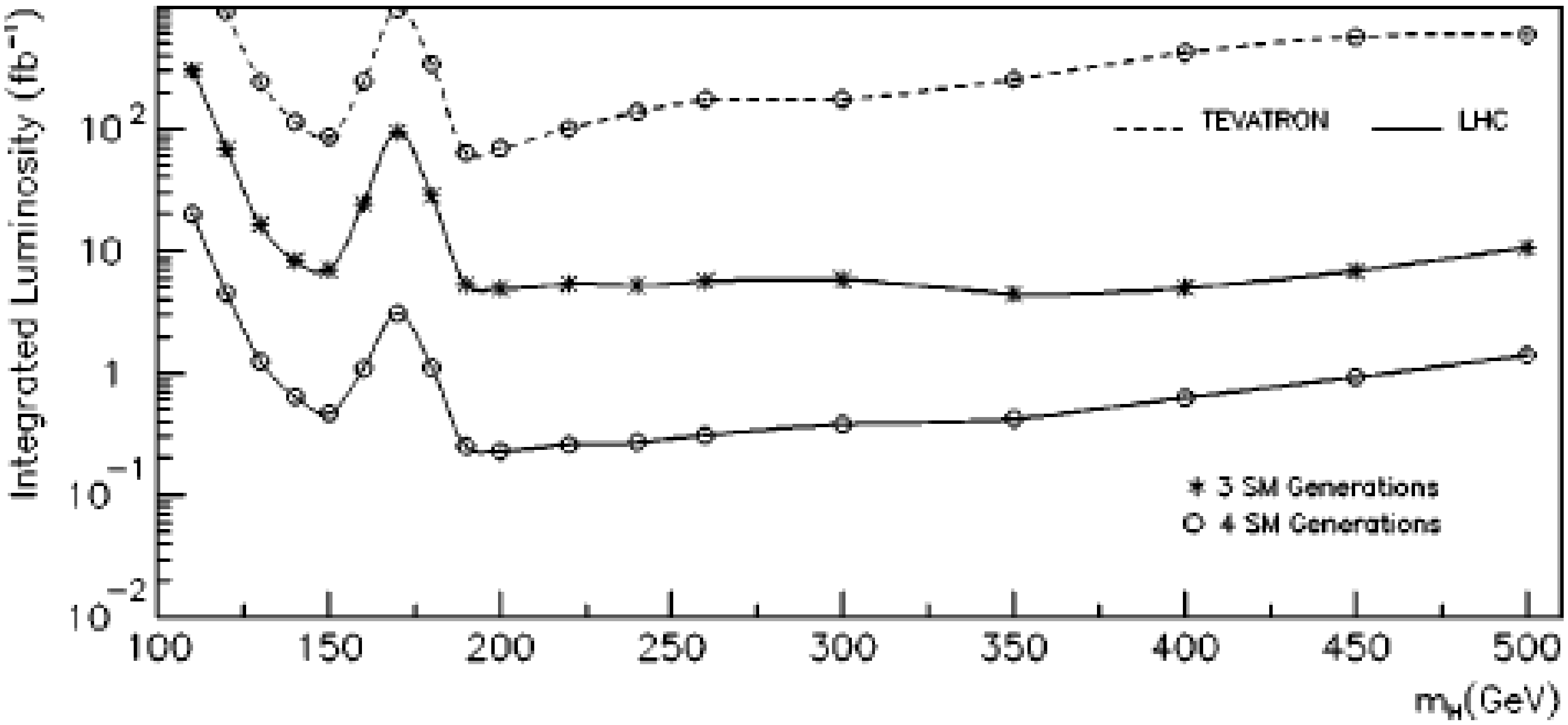
L_{int}	2 fb^{-1}	8 fb^{-1}
SM-4	150 GeV < m_H < 180 GeV	140 GeV < m_H < 200 GeV
SM-5	135 GeV < m_H	125 GeV < m_H
SM-4*	---	160 GeV < m_H < 195 GeV
SM-5*	155 GeV < m_H	150 GeV < m_H
SM-6*	150 GeV < m_H	145 GeV < m_H

Another opportunity to observe the fourth SM family quarks at the Tevatron is their anomalous production via qg-fusion if anomalous coupling has sufficient strength

E. Arik. O. Cakir and S. Sultansoy, Phys Rev D 67 (2003) 035002
Eur Phys Lett 62 (2003) 332
Eur Phys J C 39 (2005) 499

Existence of the fourth SM family can give opportunity for Tevatron to observe the intermediate mass Higgs boson before the LHC.

However, LHC will cover whole region via golden mode during the first year of operation. E. Arik et al., Phys. Rev. D 66 (2002) 033003



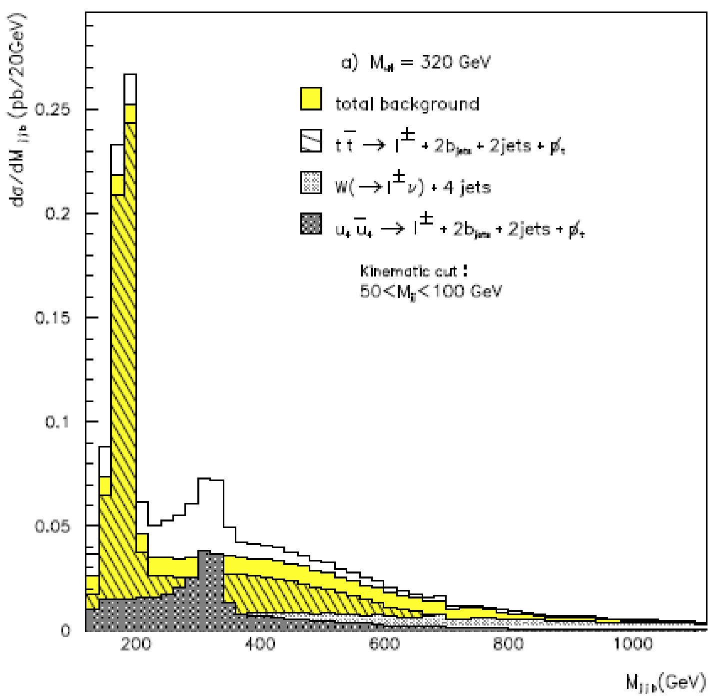
Pair production LHC, 100 fb-1

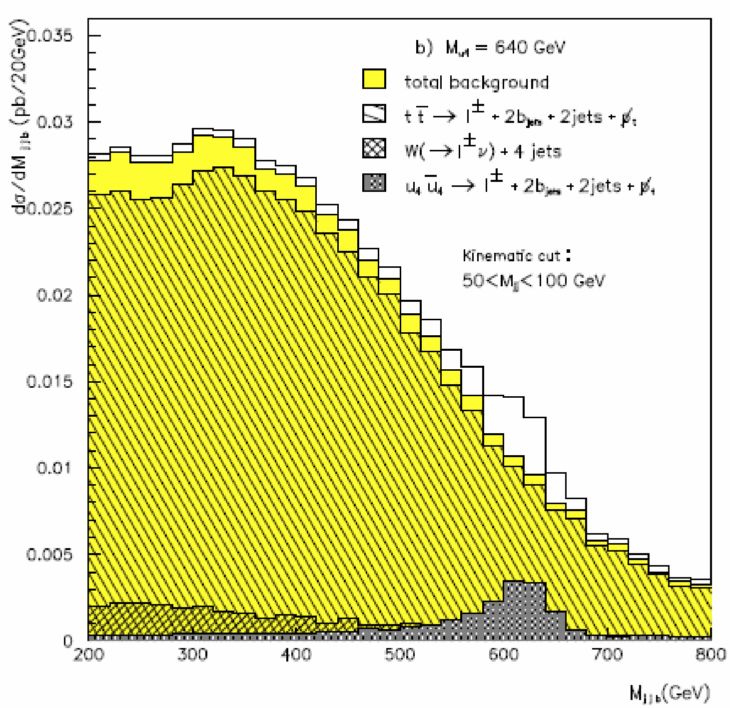
E. Arik et al., Phys. Rev. D 58 (1998) 117701

$$pp \to u_4\bar{u}_4 \to b\bar{b}\; W^+W^-$$

$$u_4\bar{u}_4 \to l^\pm + 2j + 2b_{jet} + \not{p}_t,$$

M_{u_4}	320 GeV	640 GeV
$t\bar{t}$	19320	8930
$W+4j$	760	327
$WW+2j$	113	48
$ZZ+2j$	17	6
Background	20210	9311
Signal	10600	1591
$\frac{S}{\sqrt{B}}$	74.5	16.6





The Fourth SM Family and Particle Factories

Outline

- Intro: 12
  - On Boxes and Z Penguins — charm, top, CPV … **nondecoupling**
  - 4^{th} generation? — The jury is out …
  - EM/Strong/EW $b \to s$ penguins; Two recent CPV $b \to s$ discrepancies
- $\mathcal{A}_{K^+\pi^-} - \mathcal{A}_{K^+\pi^0}$ and 4^{th} generation 16
  - LO PQCD Solution, w/ B_s mixing and $b \to s \ell \ell$ Constraints
  - Predictions: Δm_{B_s} and $\sin 2\Phi_{B_s} < 0$; $A_{CP}(b \to s\gamma)$;
  - $\mathcal{S}_{\pi K_S}, \mathcal{S}_{\phi K_S}$ correct trend and robust!
- Large $V^*_{t's} V_{t'b}$ and kaons: enhanced $K_L \to \pi^0 \nu \bar{\nu}$ 8
  - $b \to d$ "triangle" (degenerate quad); D^0 mixing
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- b', t' (and t) FCNC at LHC 5
  - $t \to cX$; $b' \to bX$; $t' \to tX$; CPV in $b' \to sX$
- Conclusion

w/ A. Arhrib, M. Nagashima, G. Raz and A. Soddu
references given at appropriate places

4th generation George W.S. Hou (NTU) Flavour/LHC 2/06 2

Future Studies

- Reconsider pair production of 4-th family quarks (previous study in 1998)
- Impact of 4-th family on the Higgs boson searches in all channels
- Anomalous production and decays of 4-th family quarks
- Identification: u_4 vs Little Higgs t’
- Identification: d_4 vs isosinglet D
- 4-th family leptons ?
- ...

Thanks: to organizers for invitation

to Turkish State Planning Organization for support