# Why the Four SM Families - 2008

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1. ***Why the Four SM Familiies***

3. ***The Fourth SM Family at hadron colliders***

4. ***The Fourth SM Family at the CLIC***

# 1. Why The Four SM Families
## (two approaches)

**First approach – Why not ?**

**N ≥ 3 from LEP data**

**N < 9 from asymptotic freedom**

"A 4th generation of ordinary fermions is excluded to 99.999% CL on the basis of S parameter alone"

PDG 2006

**This conclusion is wrong.**

**Graham Kribs, CERN Aug 2007**

***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* mN ≈ 50 GeV**

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

***2007: with 4 SM families Higgs masses between 115-750 GeV are allowed***

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
….
G.D. Kribs, T. Plehn, M. Spannowsky, T.M.P. Tait, Phys. Rev. D 76 (2007) 075016

**S. Sultansoy, CERN May 16, 2006**

## Second Approach –

## Flavor Democracy favors the Fourth SM Family

# Periodic Table of the Elementary* Particles

| family | $\nu$ | $l$ | $u$ | $d$ |
|---|---|---|---|---|
| 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 | 171.2(521) GeV | 4.1 to 4.4 GeV |
| 4 | > 45 GeV | > 100 GeV | > 310 GeV | > 130 GeV |

Also, $m_\gamma = 0$ ($10^{-18}$ eV) $m_g = 0$ (< few MeV)

$m_W = 80.396(25)$ 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.*

# PDG 2008

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## Quark Summary Table

### $b'$ ($4^{th}$ Generation) Quark, Searches for

Mass $m >$ 190 GeV, CL = 95% ($p\overline{p}$, quasi-stable $b'$)
Mass $m >$ 199 GeV, CL = 95% ($p\overline{p}$, neutral-current decays)
Mass $m >$ 128 GeV, CL = 95% ($p\overline{p}$, charged-current decays)
Mass $m >$ 46.0 GeV, CL = 95% ($e^+ e^-$, all decays)

### $t'$ ($4^{th}$ Generation) Quark, Searches for

Mass $m >$ 256 GeV, CL = 95% ($p\overline{p}$, $t'\overline{t}'$ prod., $t' \rightarrow Wq$)

### Free Quark Searches

All searches since 1977 have had negative results.

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

# Why the four SM families

(S. Sultansoy, DESY seminar, December 13, 2000; 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 ≥ 3 from LEP, N ≤ 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**

H. Fritzsch, Phys. Lett. B 289 (1992).

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

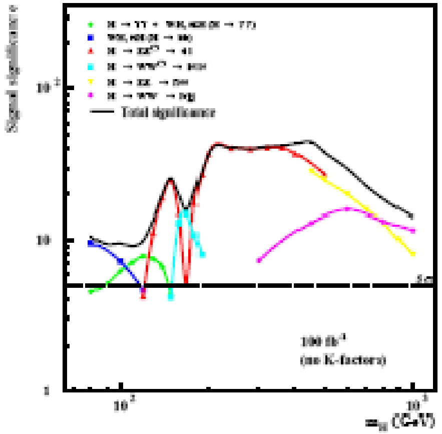
The fourth family quarks, if exist, will be copiously produced at the LHC.

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 at the Tevatron.

# ATLAS DETECTOR AND PHYSICS PERFORMANCE




# Technical Design Report

## Volume II


| | |
|---|---|
| Issue: | 1 |
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These large data sets will allow very sensitive studies of the properties of the top quark. The mass of the top quark will be measured with a precision of less than 2 GeV, dominated entirely by systematic errors. The top quark Yukawa coupling can be measured with a precision of less than 10% for a Higgs mass of 100 GeV. The $t\bar{t}$ spin correlations predicted in the SM can be observed, and used to probe for anomalous couplings or CP violation. Heavy resonances decaying to $t\bar{t}$ could be detected with masses up to 3 TeV for $\sigma \times$ BR greater than about 10 fb. Rare decays of the top quark can be probed down to branching ratios as low as of order a few times $10^{-5}$. Finally, the detailed study of three different mechanisms of electroweak single top production will yield a wealth of information including precision measurements of $V_{tb}$, measurement of the $W$ and $t$ polarisations, and searches for anomalous couplings.

## 18.2 Fourth generation quarks

Data from LEP and SLC imply the existence of only three SM families with light neutrinos. However, extra generations with heavy neutrinos are not excluded, and models which include them have been proposed. The current experimental limits on fourth family quarks and leptons are $m_l > 80$ GeV and $m_Q > 128$ GeV [18-29]. The measurement of the $\rho$ parameter [18-29] constrains the mass splitting between the doublet members of possible heavy generations of quarks: $\Sigma_i(c_i/3)\Delta m_i^2 < (49\ \text{GeV})^2, (83\ \text{GeV})^2$, where $c_i$ is the colour factor, and where the first (second) limit corresponds to a Higgs mass of about 90 GeV (300 GeV). Considering only fourth family quarks, an analysis gives $\Delta m = |m(d_4) - m(u_4)| < 43$ GeV (72 GeV).

To take a specific model as an example, the democratic mass matrix (DMM) approach, developed as one possibility for solving the problem of the masses and mixings of the fundamental particles is considered. In the DMM approach, the SM is extended to include a fourth generation of fundamental fermions, with masses typically in the range from 300 to 700 GeV [18-55]. In order to avoid violation of partial wave unitarity, the quark masses should be smaller than about 1 TeV [18-56]. A few efforts have been made to parametrise the CKM matrix to take into account a possible fourth family [18-57][18-58]. These models predict that the fourth generation quark masses are close to each other, and that two-body decays of fourth family quarks are dominant over three-body decays. Guided by these models, two sets of mass values: $m(u_4) = m(d_4) = 320$ GeV and $m(u_4) = m(d_4) = 640$ GeV, together with the CKM values in references [18-59] and [18-57] are studied.

A fourth generation of fermions would contribute to the loop-mediated processes in Higgs production ($gg \to H$) and decay ($H \to \gamma\gamma$, $H \to gg$) [18-61].





This effect would both enhance the Higgs production cross-section, and modify the branching ratios for Higgs decay. Table 18-18 summarises a few examples of the predicted enhancement, relative to the three-generation SM, a fourth generation would give in the values of $\sigma \times$ BR for the channels $H \to \gamma\gamma$ and $H \to ZZ$. The enhancement is typically a factor of approximately 7-10 for the $H \to ZZ$ (and also $H \to WW$) channels, and up to 2 for $H \to \gamma\gamma$. The enhancements are almost independent of the assumed mass of the fourth family quarks or any other parameters.

Table 18-18 The enhancement, compared to the prediction of the three generation SM, in Higgs production and decay due to a fourth generation of fermions of mass 320 GeV or 640 GeV.

| SM | Enhancement in $\sigma \times$ BR | | | |
|---|---|---|---|---|
| Higgs | $\sigma \times$ BR($H \to \gamma\gamma$) | | $\sigma \times$ BR($H \to ZZ^*$) | |
| Mass (GeV) | $m_4$=320 GeV | $m_4$=640 GeV | $m_4$=320 GeV | $m_4$=640 GeV |
| 120 | 1.16 | 1.18 | 9.79 | 7.79 |
| 130 | 1.33 | 1.35 | 9.46 | 9.40 |
| 150 | 2.19 | 2.22 | 7.36 | 7.28 |
| 170 | | | 11.4 | 11.2 |
| 180 | | | 8.39 | 8.23 |

Of course, as discussed below, more clear evidence for the existence of a fourth generation of quarks could be obtained by searching for them directly. Fourth family quarks would be produced in pairs at the LHC. The expected production cross-section as a function of heavy quark mass was plotted in Figure 18-1, and shows that $\sigma \approx 10$ pb for a quark mass of 400 GeV, decreasing to ≈0.25 pb for a mass of 800 GeV.

### 18.2.1 Fourth family up quarks

The fourth generation up-type quark ($u_4$) would predominantly decay via $u_4 \to Wb$. The expected event topologies are thus the same as for $t\bar{t}$ production, except for the different mass of the $u_4$ quark. The best channel for observing $u_4\bar{u}_4$ production would be the 'single lepton plus jets' mode where one $W$ decays leptonically ($W \to l\nu$) and the other hadronically ($W \to jj$) [18-60].

Events of the topology $u_4\bar{u}_4 \to WWb\bar{b} \to (l\nu)(jj)b\bar{b}$ were generated with PYTHIA and simulated with ATLFAST. Events were selected by requiring $E_T^{miss} > 20$ GeV and the presence of an isolated electron or muon with $p_T > 50$ GeV and $|\eta| < 2.5$. The lepton isolation criteria required the separation in pseudorapidity/azimuthal angle space between the lepton and any jet to exceed 0.4, and that the total transverse energy deposition in cells within a cone $\Delta R < 0.2$ around the lepton not exceed 10 GeV. Two very hard ($p_T > 250$ GeV) jets were required to be tagged as $b$-jets. An additional pair of jets, not tagged as $b$-jets, was required to satisfy $50\ \text{GeV} < m_{jj} < 100$ GeV in order to be loosely consistent with $m_W$. Accepted $W$ candidates were then combined with the $b$-tagged jets to search for evidence of $u_4 \to Wb \to jjb$. The mass resolution and efficiency were 21 GeV and 1.1%, respectively, for $m(u_4) = 320$ GeV. For $m(u_4) = 640$ GeV, the corresponding values were 40 GeV and 0.6%.

The background is dominated by $t\bar{t}$ production with subsequent decay $t\bar{t} \to (l\nu)(jj)b\bar{b}$. This background process has the same final state as the signal, as well as a large cross-section. In addition, there are smaller backgrounds from $W$ + 4 jets, $WW$ + 2 jets, and $ZZ$ + 2 jets. The hard kinematic cuts are effective at reducing the backgrounds. The $W$ and $WW$ backgrounds are further suppressed by the requirement of two $b$-tagged jets. The background from $ZZ$ + 2 jet production, with one $Z$ decaying leptonically and the other to $b\bar{b}$, is very small after cuts.

# 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

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

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

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

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**:

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

**For 3SM case this means:**

$$m_{\nu_\tau} = m_\tau = m_b = m_t = 3a\eta / sqrt(2)$$

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

$$M^0 = a\eta/v2 \begin{pmatrix} 1 & 1 & 1 & 1 \\ 1 & 1 & 1 & 1 \\ 1 & 1 & 1 & 1 \\ 1 & 1 & 1 & 1 \end{pmatrix} \Rightarrow M^m = 4a\eta/v2 \begin{pmatrix} 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix}$$

Therefore, the fourth family fermions are almost degenerate, in good agreement with experimental value $\rho = 0.9998 \pm 0.0008$.

If $a = 1$ the predicted mass value is coincide with 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**

If $a \approx g_w$ flavor democracy predicts $m_4 \approx 450$ 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.

## Concerning the BSM Physics, Flavor Democracy:

- **Favors the RS-LSP scenario**
- **Allows relatively “light” isosinglet quarks (E6 predicted)**
- **…**

For details see

S.Sultansoy **“Flavor Democracy in Particle Physics”**

e-Print: **hep-ph/0610279; AIP Conf. Proc. 899, 49-52 (2007)**

and references therein

# Masses and Mixings (breaking of democracy)

A.K. Ciftci, R. Ciftci and S. Sultansoy, Phys. Rev. D 72 (2005) 053006

$$M_{(M)} = a\eta \begin{bmatrix} 1 & 1+\gamma & 1+\beta & 1-\beta \\ 1+\gamma & 1+2\gamma & 1+\beta & 1-\beta \\ 1+\beta & 1+\beta & 1+\alpha & 1-\alpha \\ 1-\beta & 1-\beta & 1-\alpha & 1+\alpha+2\beta \end{bmatrix}.$$

Eighenvalues of the matrix give us masses of corresponding fermions which are used to fix the values of parameters α, β and γ.

The quark CKM matrix is given as $O_{\mathrm{CKM}} = O_u O_d^T$, where $O_u$ and $O_d$ are (real) rotations which diagonalize up- and down-quark mass matrices. (We assume that 3 phase parameters in the quarks' CKM matrix are small enough to be neglected.) With the parameters given in Table III, one obtains

$$O_{\mathrm{CKM}} = \begin{bmatrix} 0.9747 & -0.2235 & -0.0028 & -0.0001 \\ 0.2232 & -0.9738 & -0.0439 & -0.0006 \\ -0.0125 & 0.0422 & -0.9990 & -0.0008 \\ -0.0002 & 0.0005 & 0.0008 & -1.0000 \end{bmatrix}.$$

These matrices should be compared with the experimental one

$$\begin{bmatrix} 0.9730\text{–}0.9746 & 0.2174\text{–}0.2241 & 0.0030\text{–}0.0044 & * \\ 0.213\text{–}0.226 & 0.968\text{–}0.975 & 0.039\text{–}0.044 & * \\ 0\text{–}0.08 & 0\text{–}0.11 & 0.07\text{–}0.9993 & * \\ * & * & * & * \end{bmatrix}$$

# Similarly for leptons

$$O^l_{\mathrm{CKM}} = \begin{bmatrix} 0.82 & 0.29 & 0.49 & -6.43\times10^{-6} \\ -0.55 & 0.60 & 0.58 & 1.28\times10^{-4} \\ 0.12 & 0.74 & -0.66 & 8.14\times10^{-4} \\ -2.34\times10^{-5} & 6.81\times10^{-4} & 4.64\times10^{-4} & 1.00 \end{bmatrix}.$$

These matrices should be compared with the experimental data

$$\begin{bmatrix} 0.70\text{–}0.87 & 0.20\text{–}0.61 & 0.21\text{–}0.63 \\ 0.50\text{–}0.69 & 0.34\text{–}0.73 & 0.36\text{–}0.74 \\ 0.00\text{–}0.16 & 0.60\text{–}0.80 & 0.58\text{–}0.80 \end{bmatrix}, \qquad (25)$$

# *2. The Fourth SM Family at hadron colliders*

2.1. The fourth SM family manifestations at the upgraded Tevatron:

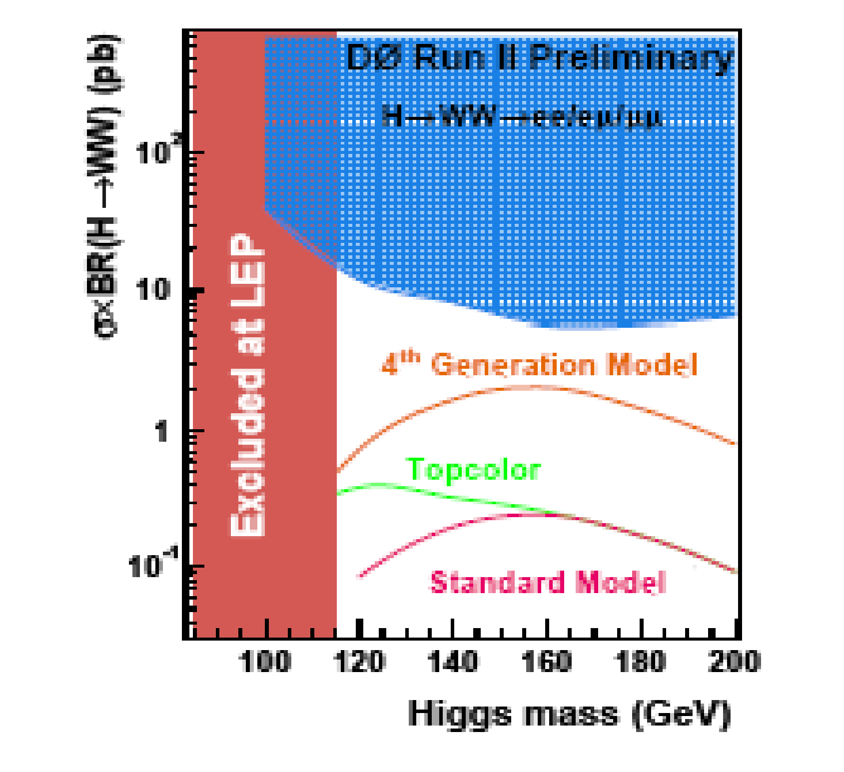
a) Significant enhancement (~8 times) of the Higgs boson production cross section via gluon fusion

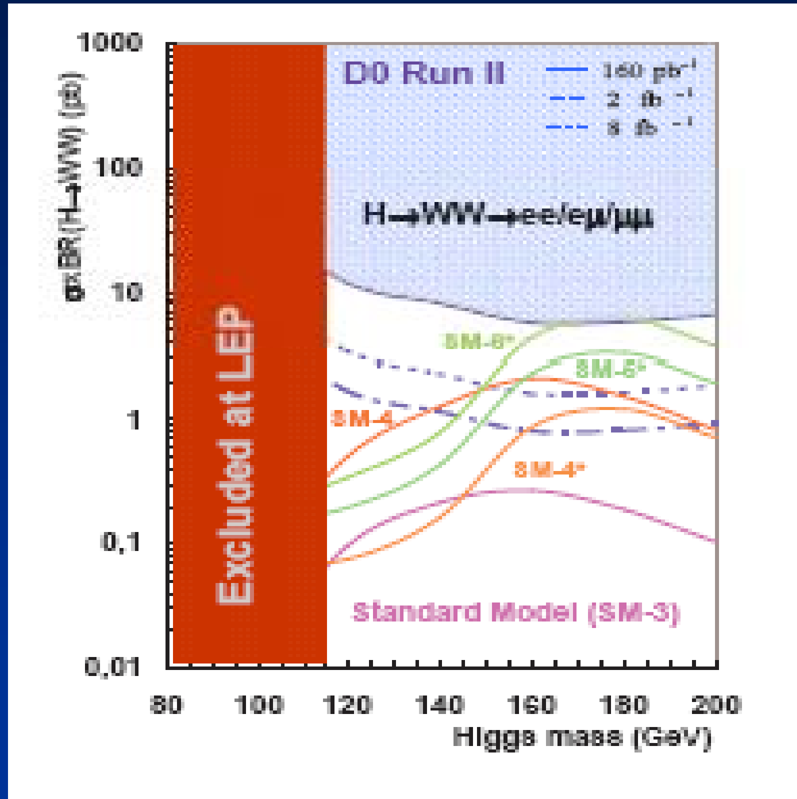
b) Pair production of the fourth family quarks (if $m_{d4}$ and/or $m_{u4}$ < 350 GeV)

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

d) Pair production of the fourth family neutrinos (via Z and/or H)

# 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

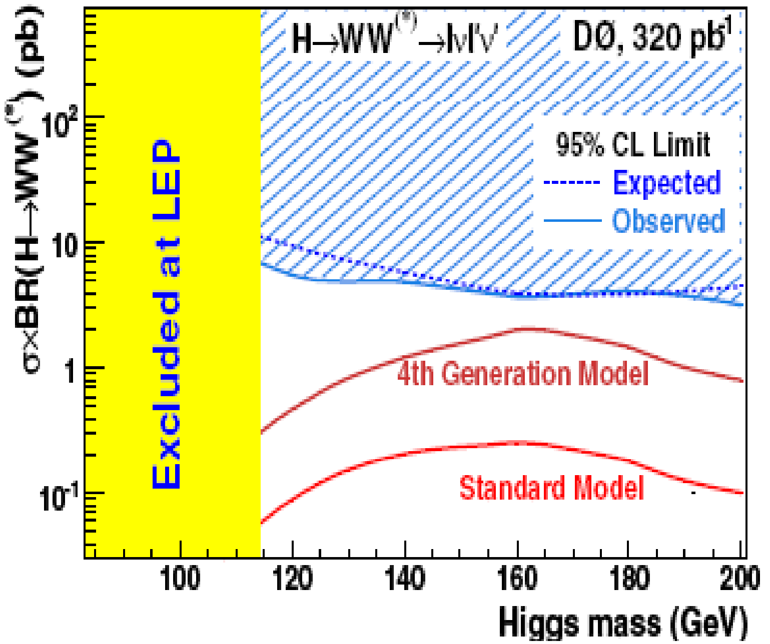
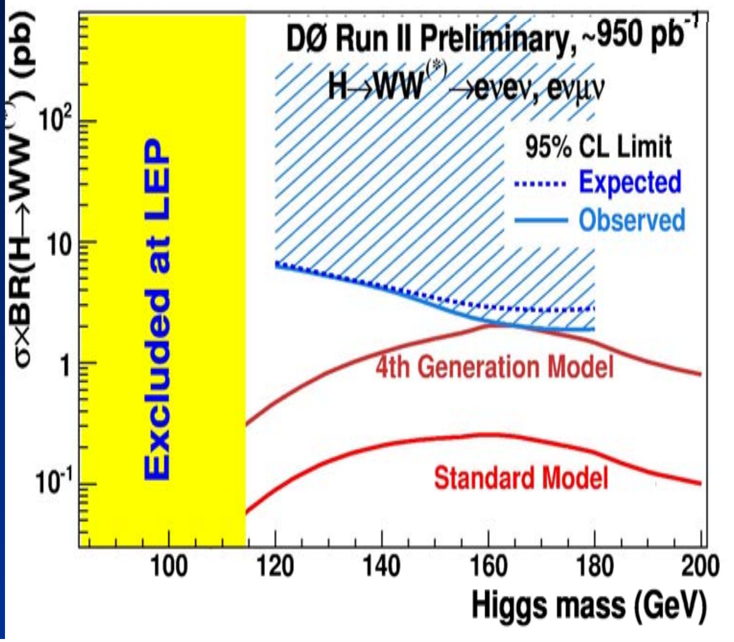
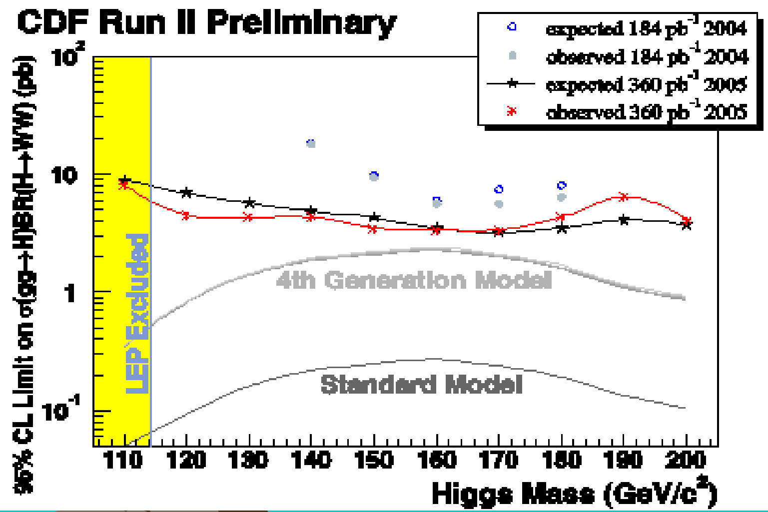



FIG. 2 (color online). Expected and observed upper limits on the cross section times branching ratio $\sigma \times \mathrm{BR}(H \to WW^{(*)})$ at the 95% C.L. together with expectations from standard model Higgs boson production and an alternative model. The LEP limit on the standard model Higgs boson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

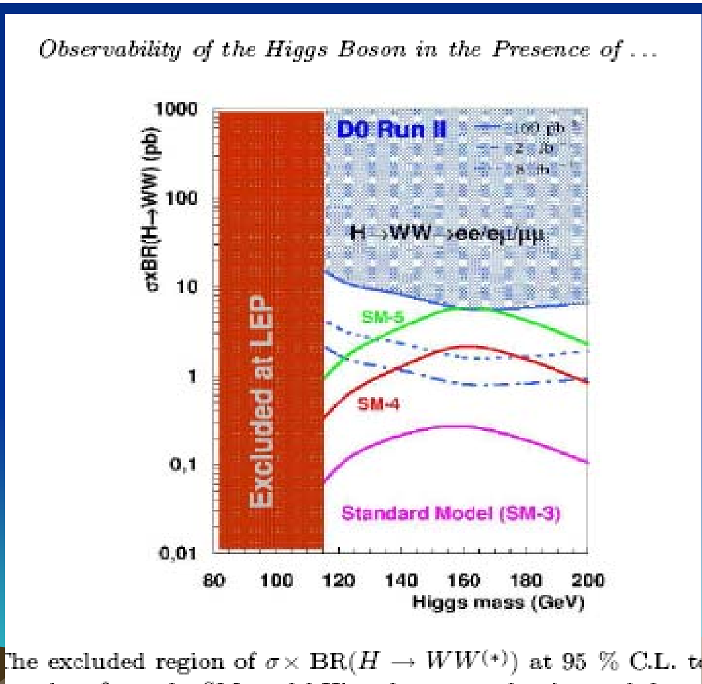


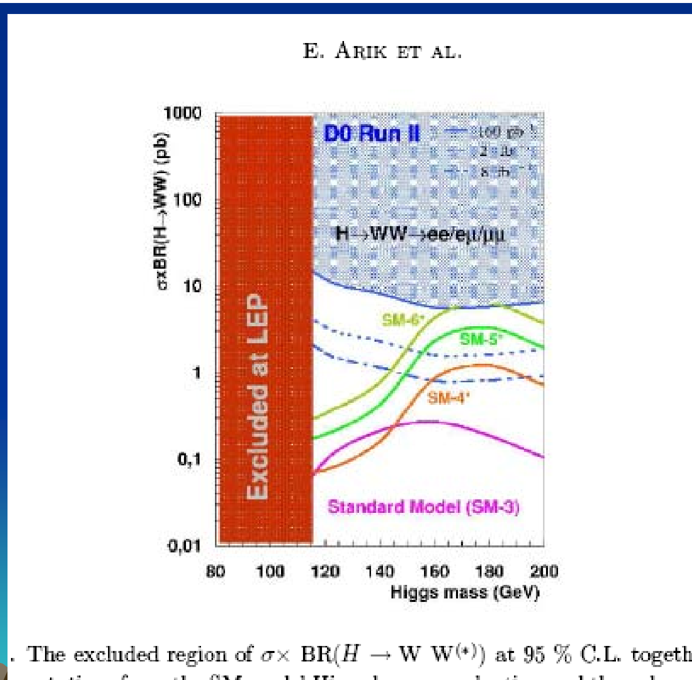



# Accessible mass range of the Higgs boson at the Tevatron

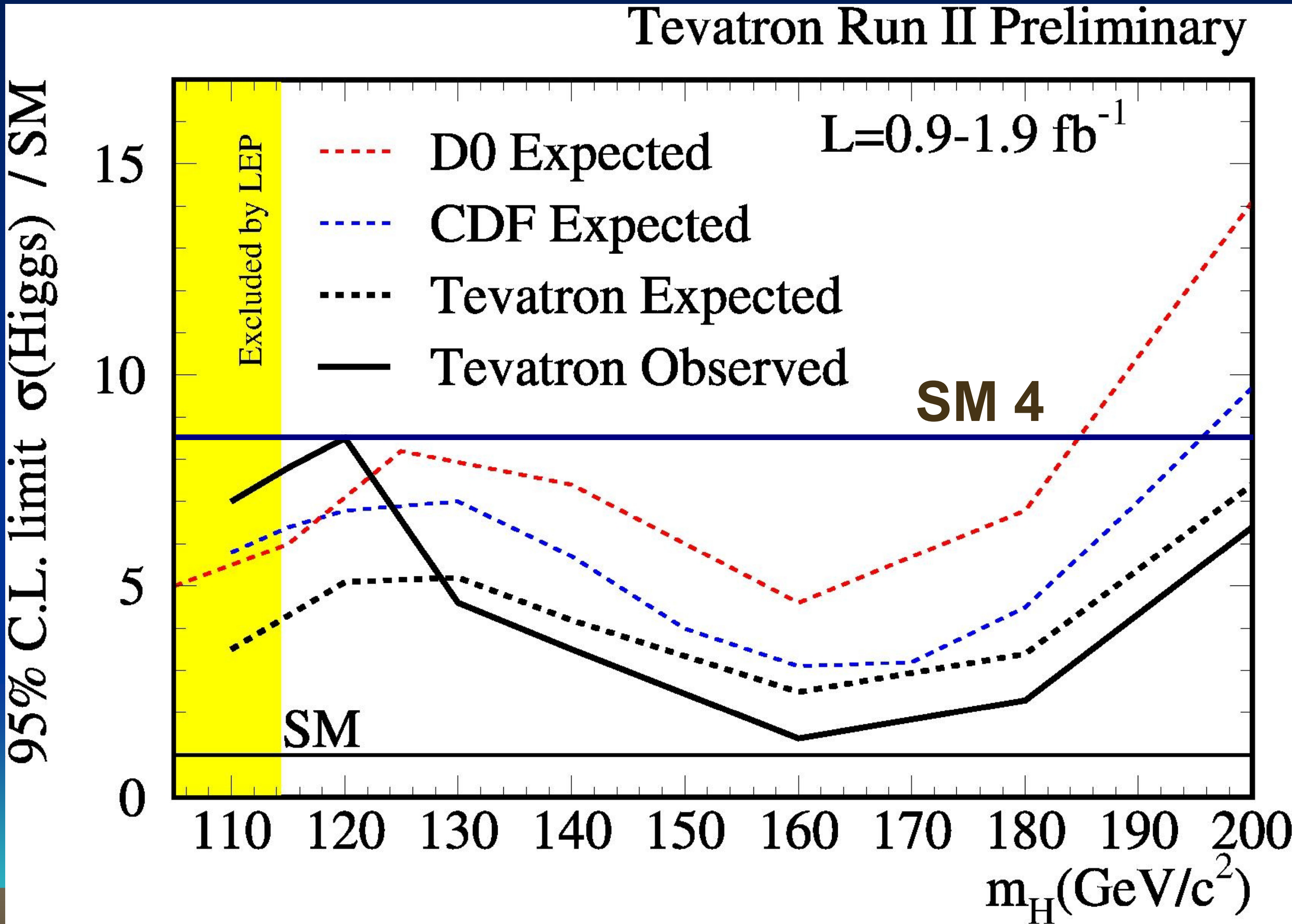
E. Arik et al., Acta Phys. Pol. B 37 (2006) 2839

| $L_{int}$ | 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 < $m_H$ |



# Wrong approach (all channels)



# Correct approach (WW channel)

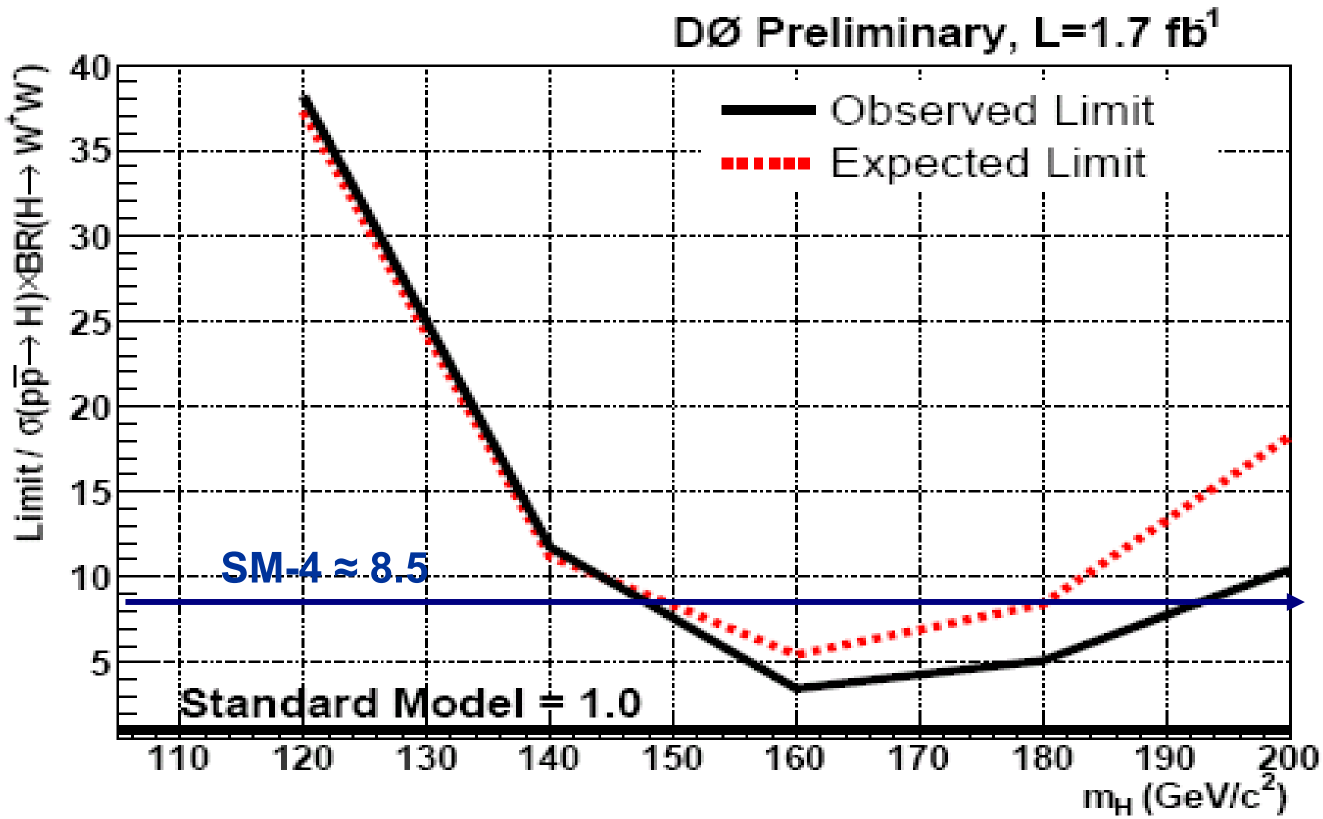



FIG. 4: Expected and observed 95% CL cross section ratio of the combined Run IIa and Run IIb analyses for $H \to WW^*$.

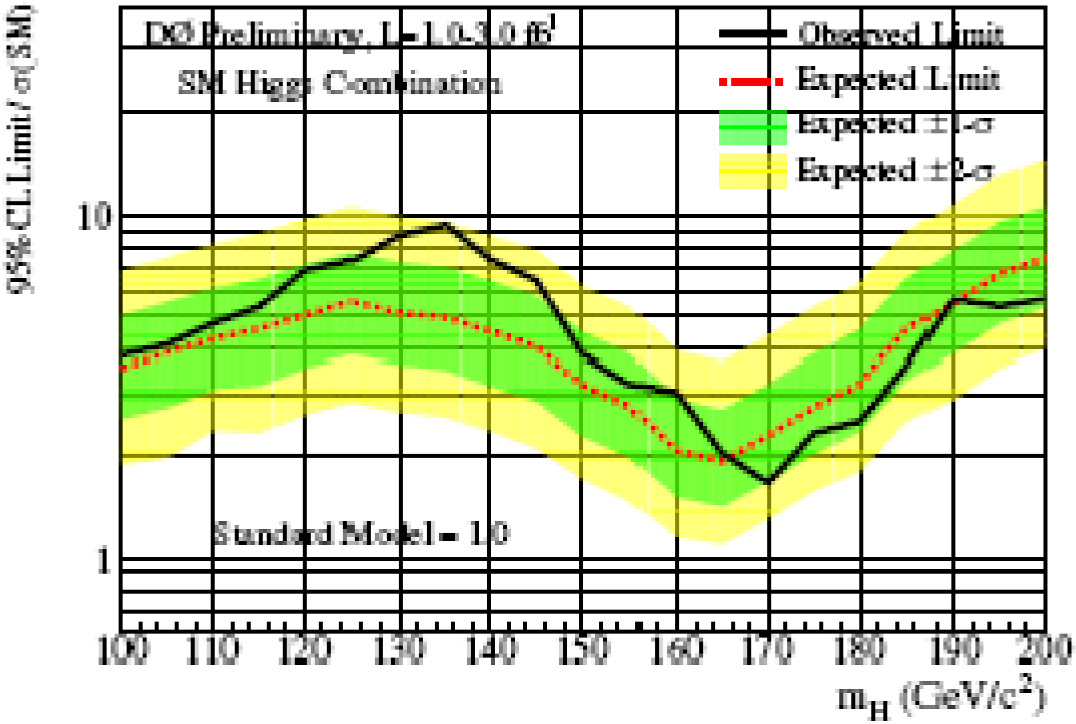



FIG. 5: Expected (median) and observed 95% C.L. cross section upper limit ratios for the combined $WH/ZH/H, H \to b\bar{b}/W^+W^-/\gamma\gamma$ analyses over the $100 \le m_H \le 200$ GeV/$c^2$ mass range.

In 4SM case 140 GeV < $m_H$ < ?? GeV is exluded at 95% CL

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

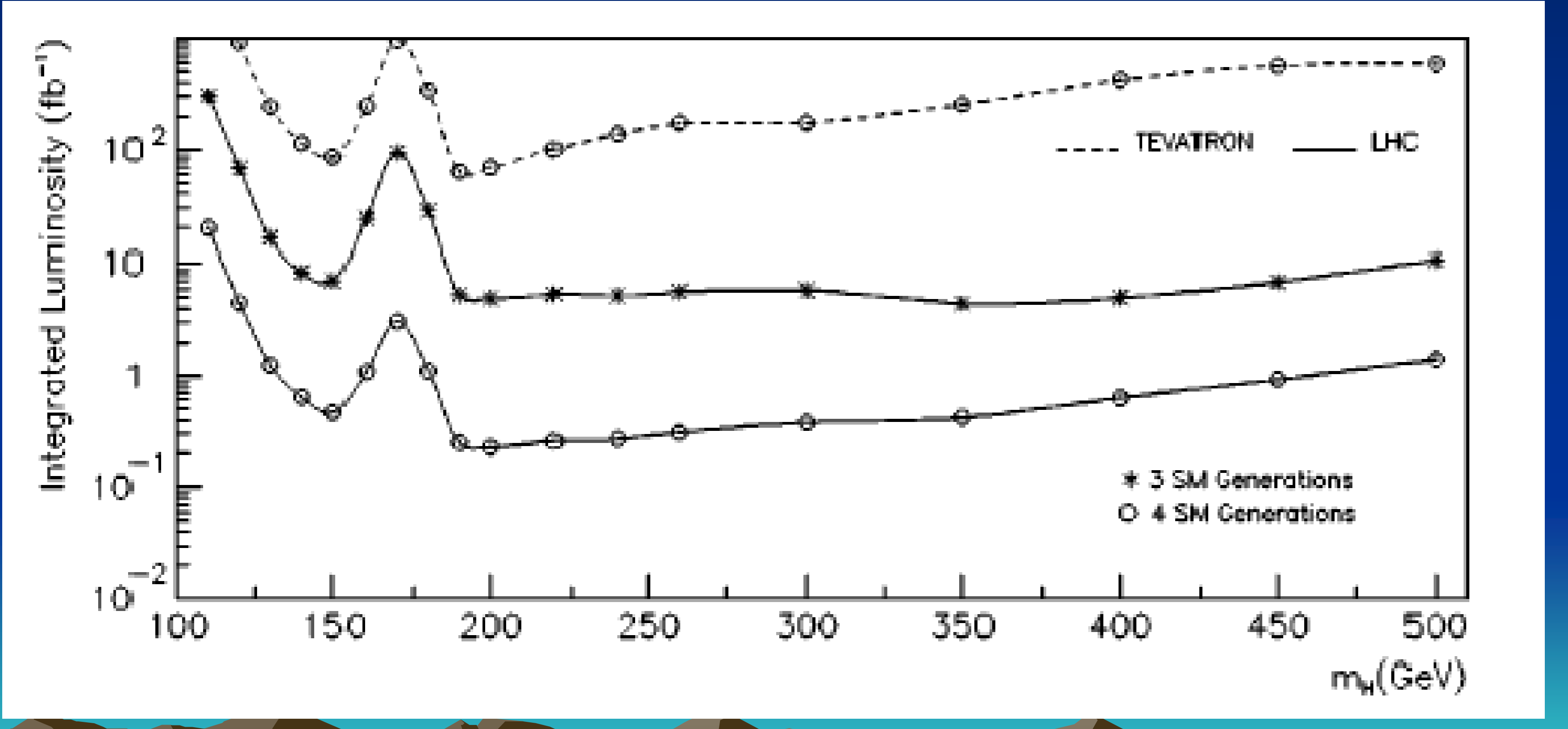
Eur Phys J C 39 (2005) 499

# 2.2. The Fourth SM Family at the LHC

- Higgs – “golden mode” (S.A. Çetin, today)
- Higgs – “silver mode” (T. Çuhadar Donszelmann, today)
- Pair production – fourth family quarks (V.E. Özcan, today)
- Single production – fourth family quarks (O. Çakır, tomorrow)
- Pair production – fourth family neutrinos (via Z and H)

**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



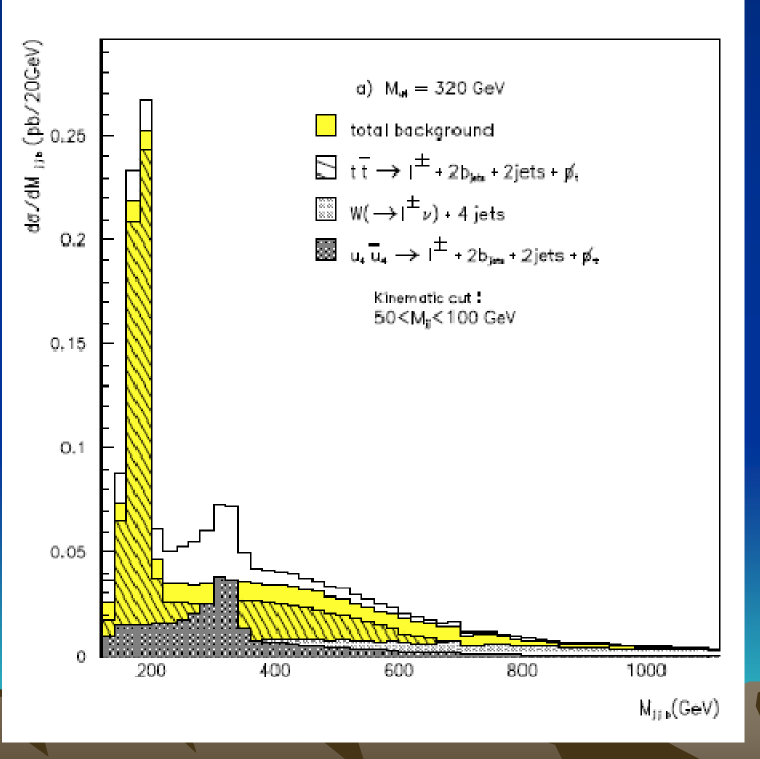
## Pair production LHC, 100 fb-1

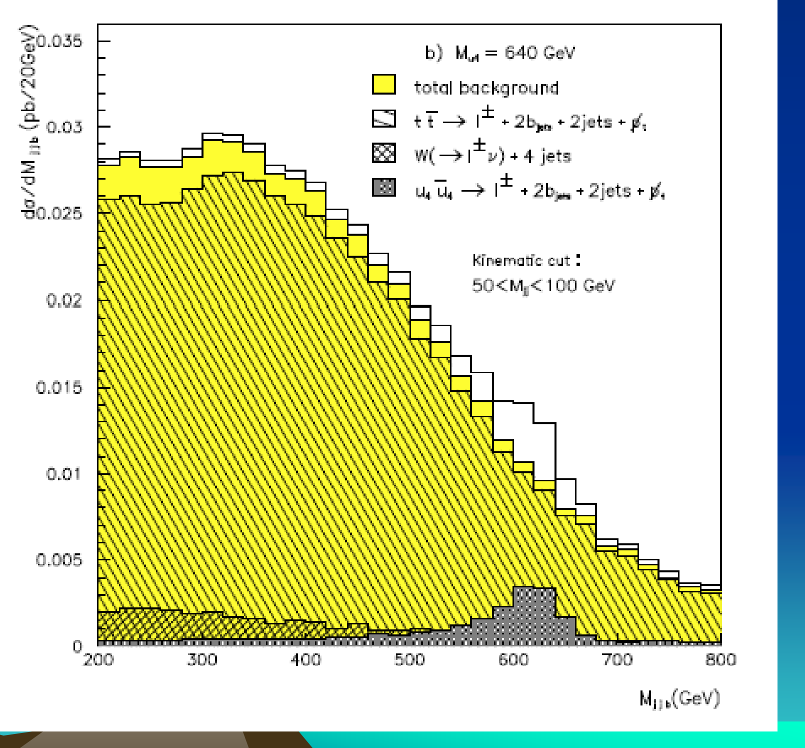
E. Arik et al., Phys. Rev. D 58 (1998) 117701

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

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

| $M_{u_4}$ | 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 |



# 3. The Fourth SM Family at the CLIC

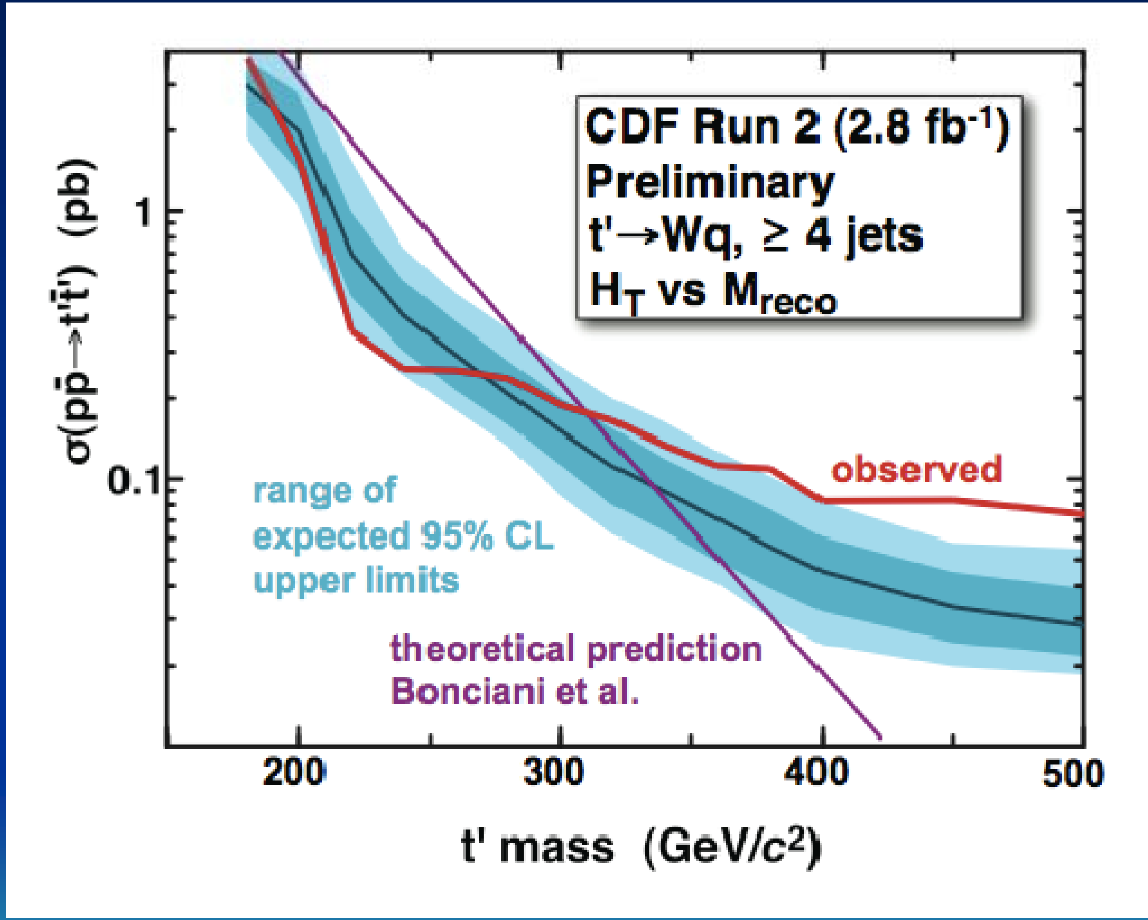
$m_{u4}$ > 310 GeV at 95% CL

$m_{d4} > m_{u4}$

$m_{l4} \approx m_{d4}$

$m_{\nu4}$ (D) $\approx m_{l4}$

√s > 600 GeV is needed



# Yellow Report CERN-2004-005, hep-ph/0412251

Table 6.11: Cross sections and event numbers per year for pair production of the fourth-SM-family fermions with mass 320 GeV at CLIC ($\sqrt{s_{ee}}$ = 1 TeV, $L_{ee} = 2.7 \times 10^{34}$cm$^{-2}$s$^{-1}$ and $L_{\gamma\gamma} = 10^{34}$cm$^{-2}$s$^{-1}$)

| | | $u_4\overline{u_4}$ | $d_4\overline{d_4}$ | $l_4\overline{l_4}$ | $\nu_4\overline{\nu_4}$ |
|---|---|---|---|---|---|
| $e^+e^-$ option | $\sigma$ (fb) | 130 | 60 | 86 | 15 |
| | $N_{ev}$/year | 35 000 | 16 000 | 23 000 | 4100 |
| $\gamma\gamma$ option | $\sigma$ (fb) | 34 | 2 | 58 | – |
| | $N_{ev}$/year | 3400 | 200 | 5700 | – |

Table 6.12: Cross sections and event numbers per year for pair production of the fourth-SM-family fermions with mass 640 GeV at CLIC ($\sqrt{s_{ee}}$ = 3 TeV, $L_{ee} = 1 \times 10^{35}$cm$^{-2}$s$^{-1}$ and $L_{\gamma\gamma} = 3 \times 10^{34}$cm$^{-2}$s$^{-1}$)

| | | $u_4\overline{u_4}$ | $d_4\overline{d_4}$ | $l_4\overline{l_4}$ | $\nu_4\overline{\nu_4}$ |
|---|---|---|---|---|---|
| $e^+e^-$ option | $\sigma$ (fb) | 16 | 8 | 10 | 2 |
| | $N_{ev}$/year | 16 000 | 8000 | 10 000 | 2000 |
| $\gamma\gamma$ option | $\sigma$ (fb) | 27 | 2 | 46 | – |
| | $N_{ev}$/year | 8100 | 600 | 14 000 | – |

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Table 6.14: The production event numbers per year for the fourth-SM-family $\psi_4$ quarkonia at a CLIC 1 TeV option with $m_{\psi_4} \simeq 1$ TeV

| | $(u_4\overline{u_4})$ | $(d_4\overline{d_4})$ |
|---|---|---|
| $e^+e^- \to \psi_4$ | 26 600 | 10 400 |
| $e^+e^- \to \psi_4 \to \gamma H$ | 510 | 50 |
| $e^+e^- \to \psi_4 \to ZH$ | 60 | 80 |

Table 6.13: Decay widths for main decay modes of $\psi_4$ for $m_H$ = 150 GeV with $m_{\psi_4} \simeq 1$ TeV

| | $(u_4\overline{u_4})$ | $(d_4\overline{d_4})$ |
|---|---|---|
| $\Gamma(\psi_4 \to \ell^+\ell^-)$, $10^{-3}$ MeV | 18.9 | 7.3 |
| $\Gamma(\psi_4 \to u\overline{u})$, $10^{-2}$ MeV | 3.2 | 1.9 |
| $\Gamma(\psi_4 \to d\overline{d})$, $10^{-2}$ MeV | 1.4 | 1.7 |
| $\Gamma(\psi_4 \to Z\gamma)$, $10^{-1}$ MeV | 15 | 3.7 |
| $\Gamma(\psi_4 \to ZZ)$, $10^{-1}$ MeV | 1.7 | 5.4 |
| $\Gamma(\psi_4 \to ZH)$, $10^{-1}$ MeV | 1.7 | 5.5 |
| $\Gamma(\psi_4 \to \gamma H)$, $10^{-1}$ MeV | 14.4 | 3.6 |
| $\Gamma(\psi_4 \to W^+W^-)$, MeV | 70.8 | 71.2 |

# Future Studies

- Detailed study of pair production of the 4-th family leptons
- Impact of beam dynamics on the 4-th family quarkonia
- Anomalous production and decays of the 4-th family quarks and leptons
- $u_4 u_4 H$ and $d_4 d_4 H$ final states
- Identification: $d_4$ vs isosinglet D ($E_6$)
- Identification: $u_4$ vs isosinglet T (Little Higgs)
- ...