2nd International Conference on Particle Physics
in Memoriam Engin Arık and Her Colleagues

Status of the 4th SM Family

TOBB
EKONOMİ VE TEKNOLOJİ
ÜNİVERSİTESİ

AMEA
Fizika İnstitutu

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1. Why the Four SM Familiies

2. The Fourth SM Family at TeV Scale Colliders

3. The Fourth Family and the Higgs Boson

Prof. Dr. Engin ARIK street

Batıkent, Ankara

Engin ARIK: papers on the fourth SM family

Search for the fourth family up quarks at CERN LHC. E. Arik et al., **Phys.Rev.D58:117701,1998**.

With four standard model families, the LHC could discover the Higgs boson with a few fb-1.**
E. Arik et al., **Eur.Phys.J.C26:9-11,2002**. e-Print: **hep-ph/0109037**

Consequences of the extra SM families on the Higgs boson production at Tevatron and CERN LHC.
E. Arik, O. Cakir, S.A. Cetin, S. Sultansoy, **Phys.Rev.D66:033003,2002**. e-Print: **hep-ph/0203257**

Anomalous single production of the fourth SM family quarks at Tevatron.
E. Arik, O. Cakir, S. Sultansoy, **Phys.Rev.D67:035002,2003**. e-Print: **hep-ph/0208033**

Has the anomalous single production of the fourth SM family quarks decaying into light Higgs boson been observed by CDF? E. Arik, O. Cakir, S. Sultansoy, e-Print: **hep-ph/0208099**

Fourth generation pseudoscalar quarkonium production and observability at hadron colliders. E. Arik, O. Cakir, S.A. Cetin, S. Sultansoy, **Phys.Rev.D66:116006,2002**. e-Print: **hep-ph/0208169**

Turkish comments on 'Future perspectives in HEP'. Engin Arik, Saleh Sultansoy, BOUN-HEP-2003-01, GU-HEP-2003-01, Jan 2003. 11pp. e-Print: **hep-ph/0302012**

A Search for the fourth SM family quarks at the Tevatron. E. Arik, O. Cakir, S. Sultansoy, **Eur.Phys.J.C39:499-501,2005**. e-Print: **hep-ph/0308170**

Search for anomalous single production of the fourth SM family quark decaying into a light scalar. E. Arik, O. Cakir, S. Sultansoy, **Europhys.Lett.62:332-335,2003**. e-Print: **hep-ph/0309041**

Observability of the Higgs boson and extra SM families at the Tevatron. E. Arik, O. Cakir, S.A. Cetin, S. Sultansoy, **Acta Phys.Polon.B37:2839-2850,2006**. e-Print: **hep-ph/0502050**

Comments on the possible discovery of the Higgs boson with mass ~ 160-GeV at the Tevatron. E. Arik, S. Sultansoy, e-Print: **hep-ph/0508089**

Quark mixing with four standard model families. E. Arik et al, **Balk.Phys.Lett.15N1:9-12,2007**.

The impact of the fourth SM family on the Higgs observability at the LHC. E. Arik, S.A. Cetin, S. Sultansoy, **Balk.Phys.Lett.15N4:1-5,2007**. e-Print: **arXiv:0708.0241** [hep-ph]

ATLAS Scientific Notes

With four Standard Model families, the LHC could discover the Higgs boson with a few fb-1 / Arik, E et al., SN-ATLAS-2001-006; ATL-COM-PHYS-2001-019.- Geneva : CERN, 2002 - 7 p. - Published in : *Eur. Phys. J. C* 26 (2002) 9-11

ATLAS Notes

PRODUCTION AND DECAY PROPERTIES OF THE PSEUDOSCALAR QUARKONIUM / Arik, E et alATL-PHYS-2000-002. - 1999. - 17 p.

Observability of Standard Model Fourth Family Quarks at CERN-LHC / Arik, E et al., ATL-PHYS-99-005. - 1999. - 21 p.

Enhancement of the Standard Model Higgs Boson Production Cross-section with the Fourth Standard Model Family Quarks. / Arik, E et al., ATL-PHYS-98-125. - 1998. - 18 p.

ATLAS Theses

ATLAS Transition Radiation Tracker and Higgs Physics Related to Extra Standard Model Families / Cetin, S A (Supervisor E. Arik) CERN-THESIS-2004-020 - Istanbul : Bogazici Univ., 2002. - 130 p.

+ a numerous presentations

Preface: A little bit history

→1930's

e, p, n + γ + ν (Pauli) + π (Yukawa)

EM interactions mediated by γ

Strong int-ns mediated by $\pi^{\pm}$ and π^{0}

Weak int-ns - Fermi (four-fermion contact)

Leptons: e and ν; Mesons: $\pi^{\pm}$ and π^{0}; Barions: p and n.

Whole (visible) Universe is formed from a few particles:

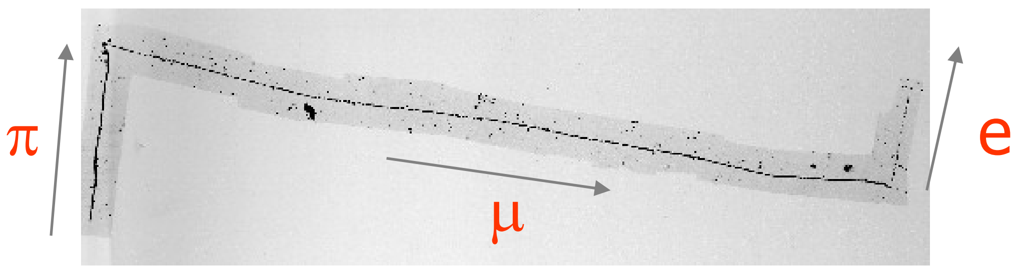
Nuclei are bound states of p's and n's, Atoms are bound states of nuclei and e's etc. Chemistry became the Science…

Whole technology of 20th century is based on this picture.

This nice picture was destroyed in 1937 by the discovery of μ !

We were looked for π –mesons but found something different. This new particle seems to be produced by strong interactions, but interacts with matter by EM interactions.

Real π –mesons were discovered 10 years later in emulsion experiments:



μ – e puzzle:

why the Nature needs the second “heavy” electron …

→ 1960’s: hadron (meson and barion) inflation ⇒ Quarks

→1970's

GİM ⇒ c-quark [1)] ⇒ 2 families

Experiment: charmed hadrons + τ-lepton + beauty

CKM ⇒ 3 families (CP phase, BAU [2)])

→1990's

Experiment: t-quark, $m_H > 114$ GeV

Fourth family revisited (Flavor Democracy or DMM approach)

[1)] Also from *q-l* symmetry (counterpart of ν_μ)
[2)] today, is not sufficient (fourth family? Hou & Co)

Periodic Table of the Elementary* Particles

family	ν (direct)	*l*	*u*	*d*
1	< 2 eV	510.998910(13) keV	1.7 to 3.1 MeV	4,1 to 5.7 MeV
2	< 190 keV	105.658367(4) MeV	1.18 to 1.34 GeV	80 to 130 MeV
3	< 18.2 MeV	1.77682(16) GeV	171.9(1.5) GeV	4.1 to 4.4 GeV
4	> 39.5 GeV	> 100 GeV	> 256 GeV	> 128 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.*

(Particle Data Group), JP G **37**, 075021 (2010) and 2011 partia

$$\sin^2(2\theta_{12}) = 0.861^{+0.026}_{-0.022}$$
$$\Delta m^2_{21} = (7.59+-0.21) \times 10^{-5}\ \text{eV}^2$$
$$\sin^2(2\theta_{23}) > 0.92$$ [i]
$$\Delta m^2_{32} = (2.43 \pm 0.13) \times 10^{-3}\ \text{eV}^2$$ [j]
$$\sin^2(2\theta_{13}) < 0.15,\ \text{CL} = 90\%$$

Stable Neutral Heavy Lepton Mass Limits

Mass $m >$ 45.0 GeV, CL = 95% (Dirac)
Mass $m >$ 39.5 GeV, CL = 95% (Majorana)

Neutral Heavy Lepton Mass Limits

Mass $m >$ 90.3 GeV, CL = 95%
(Dirac ν_L coupling to e, μ, τ; conservative case(τ))
Mass $m >$ 80.5 GeV, CL = 95%
(Majorana ν_L coupling to e, μ, τ; conservative case(τ))

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)

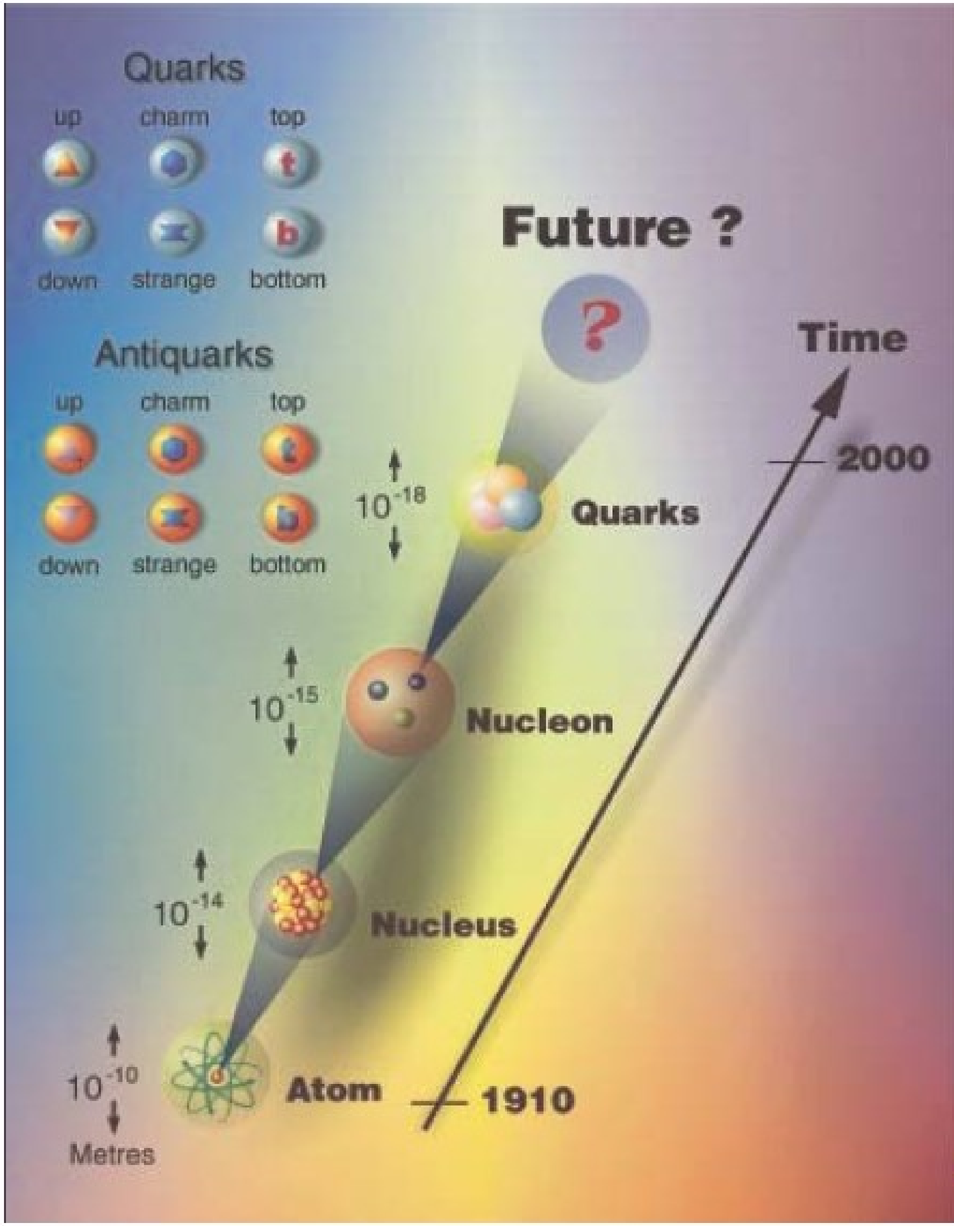
t' (4^{th} Generation) Quark, Searches for

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

Recent **CDF** exclusions

372 GeV with **4.8 fb^{-1}**
(d4 → tW)

358 GeV with **4.6 fb^{-1}**
(u4 → qW)



Physics:

Fourth SM family ?

Exotic leptons and quarks ?

New bosons (IVB and Higgs) ?

SUSY ?

Preons ?

Extra dimensions ?

.... Black holes, Un-particles ??
Un-physics ???

Tools:

Hadron, Lepton and Lepton-Hadron Colliders

Inflation	Systematic	Confirmed Predictions	Clarifying experiments	Fundamentals
Chemical Elements	Mendeleyev Periodic Table	New elements	Rutherford	p, n, e
Hadrons	Eight-fold Way	New hadrons	SLAC DIS	quarks
SM fermions	Flavor Democracy	Fourth family ?	LHC ?	Preons ?

Table I: Historical analogy

In my opinion, mass and mixing patterns of the SM fermions are the most important puzzles of particle physics.

Resolution of these puzzles should be the highest priority of the HEP community.

1st Int. Symp. on the Fourth Family of Quarks and Leptons,
Santa Monica, CA, Feb 26-28, 1987.
Published in **Annals N.Y. Acad. Sci. 518 (1987).**

Second International Symposium on The 4th Family of Quarks and Leptons,
Santa Monica, California, 23-25 Feb 1989.
Published in **Annals N.Y. Acad. Sci. 578 (1989).**

Since 1990 almost blocked by two (incorrect/wrong) objections:

1. LEP-1 data on invisible Z-decays
   - only "active" neutrinos (in SM LH ν) are in game
   - historical "paralogism" (V-A → massless $\nu \equiv \nu_L$)
   - but according the SM (q-l symmetry) RH ν is the partner of RH up-quark

2. Precision EW data (more important, see slides below)

Milestone

Workshop **"Beyond the 3rd SM generation at the LHC era",** CERN, Sep 4-5, 2008 http://indico.cern.ch/conferenceDisplay.py?confId=33285

Summary of the Workshop: **Four Statements about the Fourth Generation.**
B. Holdom, W.S. Hou, T. Hurth, M.L. Mangano, S. Sultansoy, G. Unel.
PMC Phys. A3: 4, 2009. e-Print: **arXiv:0904.4698** [hep-ph]

These statements are:

1. The fourth generation is not excluded by EW precision data.
2. SM4 address some of the currently open questions.
3. SM4 can accommodate emerging possible hints of new physics.
4. LHC has the potential to discover or fully exclude SM4.

1. Why The Four SM Families
(two approaches)

Flavour in the era of the LHC, CERN May 15-17 2006

The Fourth SM Family: Present Status

Saleh SULTANSOY

Gazi University, Ankara, TURKEY & Institute of Physics, Baku, AZERBAIJAN

1. Periodic Table of Elementary Particles

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

i) LEP data

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

ii) Precision EW data

2000: the 4^{th} 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

....

May 16, 2006 S. Sultansoy 4

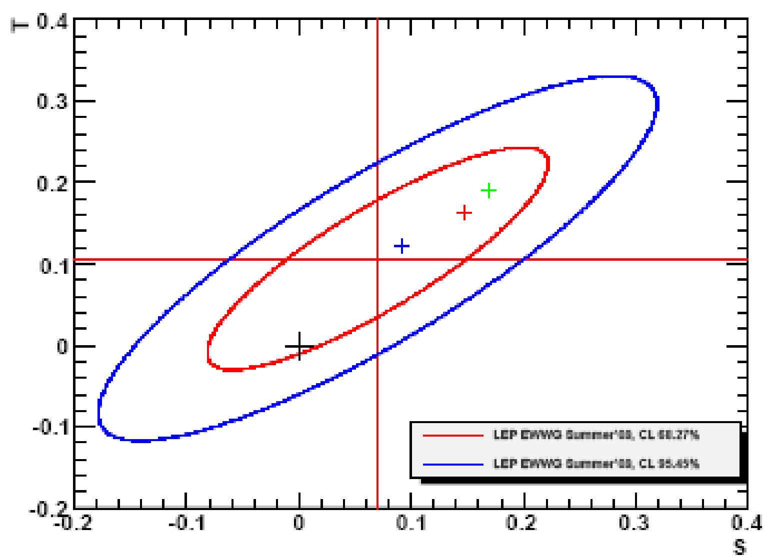
An extra generation of SM fermions is excluded at the 6 σ level on the basis of the S parameter alone, corresponding to $N_F = 2.85 \pm 0.20$ for the number of families. This result assumes that there are no new contributions to T or U and therefore that any new families are degenerate, and is in agreement with a fit to the number of light neutrinos, $N_\nu = 2.991 \pm 0.007$. However, the S parameter fits are valid even for a very heavy fourth family neutrino. This restriction can be relaxed by allowing T to vary as well, since $T > 0$ is expected from a non-degenerate extra family. Fixing $S = 2/3\pi$, the global fit favors a fourth family contribution to T of 0.22 ± 0.04. However, the quality of the fit deteriorates ($\Delta\chi^2 = 3.2$ relative to the SM fit with M_H forced not to drop below its LEP 2 bound of 114.4 GeV) so that this tuned T scenario is also disfavored but only at about the 90%

This statement from PDG 2010 is wrong !!

Red ellips 1σ CL 68.27%;
Blue ellips 2σ CL 95.45%;

Black cross – SM3;
Green, red and blue crosses – SM4 points 1, 2 and 3.

projects.hepforge.org/opucem/



SM4 points	1	2	3	SM3
m_{u_4}, GeV	410	440	440	-
m_{d_4}, GeV	390	390	390	-
m_{l_4}, GeV	450	390	390	-
m_{ν_4}(L),GeV	105	91	95	-
m_{ν_4}(H), GeV	2300	2900	2900	-
m_H, GeV	290	250	115	115
s_{34}	0.01	0.02	0.02	-
R	0.97	0.56	0.036	1.7
S	0.17	0.15	0.09	0
T	0.19	0.16	0.12	0

… more about OPUCEM

Oblique Parameters Using C with Error-checking Machinery

OPUCEM: A Library with Error Checking Mechanism for Computing Oblique Parameters.
Ozgur Cobanoglu, (CERN) , Erkcan Ozcan, (University Coll. London) , Saleh Sultansoy, (TOBB ETU, Ankara) , Gokhan Unel, (UC, Irvine) . May 2010. 10pp.
Published in **Comput.Phys.Commun.182:1732-1743,2011**.
e-Print: **arXiv:1005.2784** [hep-ex]

http://projects.hepforge.org/opucem/

Up today, OPUCEM is the sole library on the subject which includes Majorana neutrinos.

Majorana neutrinos drastically change the situation: for example, degenerate fourth family quarks are allowed. Also, allowed parameters space is essentially enlarged.

Below:
Several slides from Gökhan's presentation at METU seminar (11.05.2011)

oblique parameters
&
BSM physics

Computer Physics Communications
10.1016/j.cpc.2011.04.018

11 May 2011 - METU Physics Dept. Seminar

Gökhan Ünel / UCI

in collaboration with
Erkcan Özcan / UCL → Now at Boğaziçi Univ.
Saleh Sultansoy / TOBB ETU
Özgür Çobanoğlu / CERN → Now at Doğuş Univ.

software implementation: OPUCEM*

Oblique Parameters Using C with Error-checking Machinery

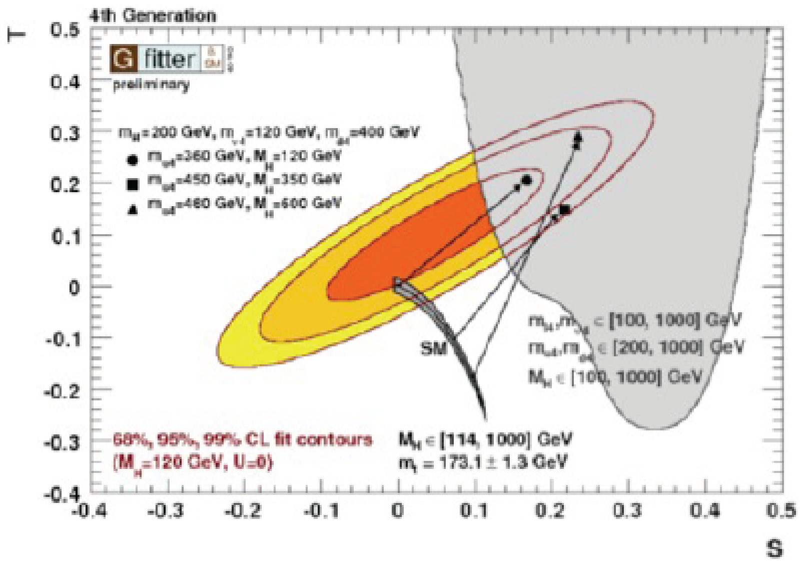
- A free and open-source C++ library for calculating STU parameters.
  - ➡ c++ version tested on Linux & OSX with g++ (>v4) windows branch exists
- The aim is to provide minimum-dependence code to facilitate the sharing of formulas, such that:
  - ➡ Article authors can provide typo-free versions of their formulas that match their published numerical results.
  - ➡ Cross-checks are done to compare formulas in different papers directly.
  - ➡ Reviews by any interested party is possible.
  - ➡ Further studies can refer to a certain version of the code and future errata can easily be done.
- Hosted on CEDAR Hepforge: https://projects.hepforge.org/opucem/
  - ➡ contains source code, documentation, examples, screenshots, "how to" files

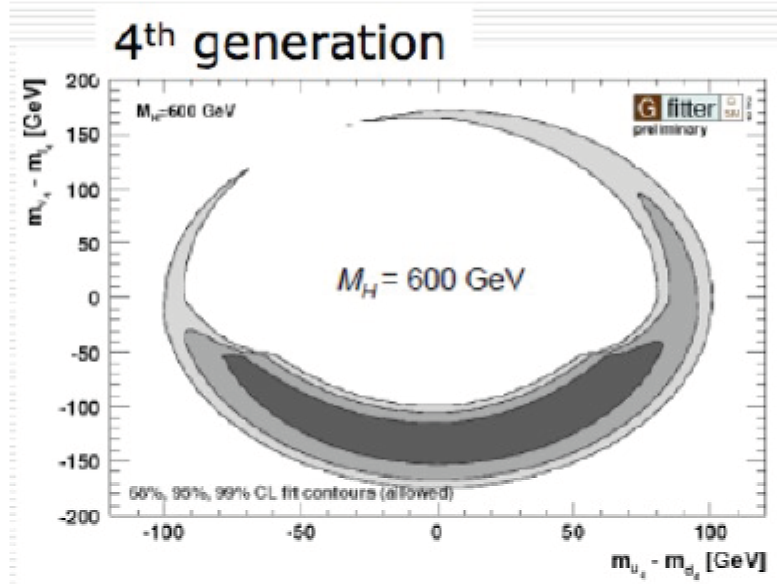
*A typical Turkish drunk trying to show his (otherwise suppressed) affection to his friends says this word. It literally means "I'll kiss you!"

Opucem provides

- Calculations
  - ➡Implementation of exact 1-loop and approximate formulas, each reviewed across multiple papers and validated to reproduce published numerical results.
- Error checking machinery
  - ➡Safe functions that cross check reported results automatically.
  - ➡Approx. formulas vs. exact formulas.
  - ➡Limiting cases: Majorana vs. Dirac, 2HDM vs. SM Higgs.
  - ➡Proper handling of real degeneracies (NaN's avoided).
- Examples & Accessibility
  - ➡GUI for SM & SM4 (fourth family) cases
  - ➡Auxiliary tools to draw ST error ellipses.
  - ➡Driver code for quick computations

meanwhile...

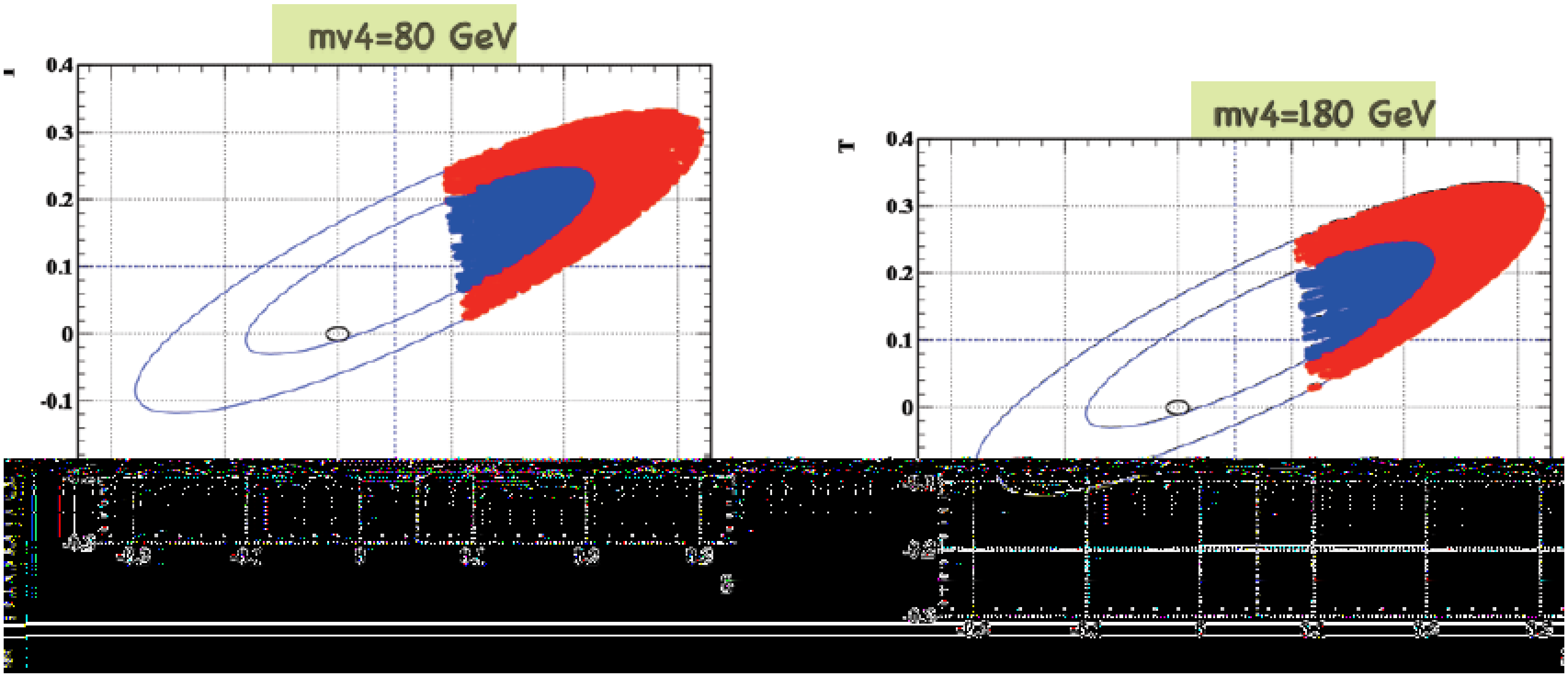




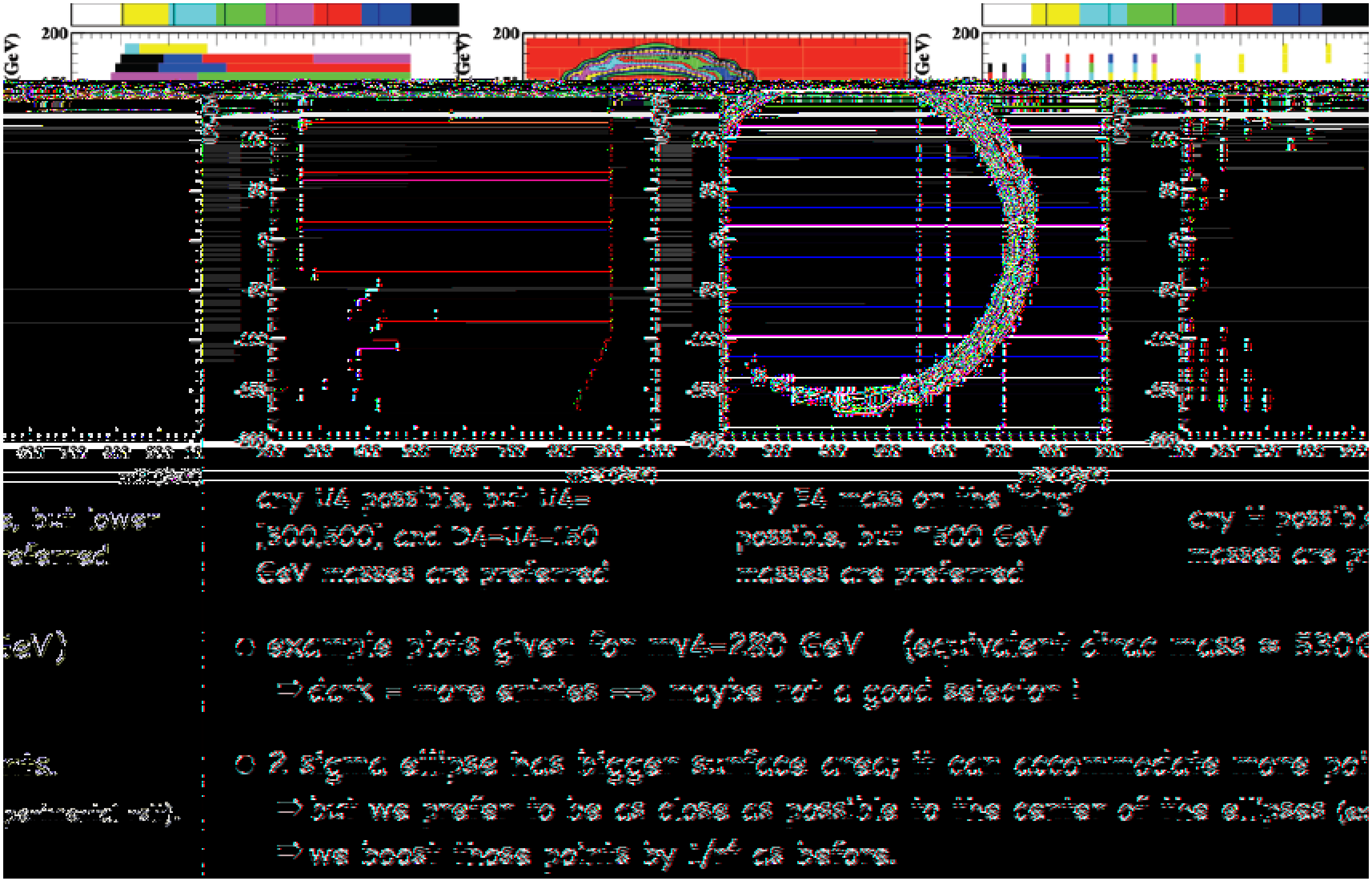
- With 4th generation getting more popular, many groups are now implementing it into various tools/fits.
  - ➡ The implementation of the Dirac case is rather straightforward, thanks to Dirac SM4 being the "simplest extension" of SM3.
  - ➡ Most recently, we saw results from the Gfitter group, confirming ours (and those of others).
    - note that 3-4 family mixing & majorana neutrinos are not in Gfitter implementation.
- OPUCEM also implements Majorana-type neutrinos.
  - ➡ Not implemented in any other tools, fitters yet.
  - ➡ Is considered more "natural" by some theorists.
  - ➡ Is more relevant to heavy Higgs scenarios, as you will see in the next slides.

Majorana neutrinos

- assume Mv4= 80 GeV, lowest allowed by PDG; other mass values = free parameters:
  - ➡ set the heavier neutrinos partner to 1 TeV, equivalent dirac mass = sqrt(m×M) where m, M are heavy and heavier Majorana neutrino masses
  - ➡ scan other fermions from 200GeV up to 1 TeV (Partial Wave Unitarity limit)
  - ➡ scan some Higgs values: 115 150 200 250 300 350 400 450 500 600 700 800 900 GeV.
- Is this plausible from an EW point of view? YES! See contours below.



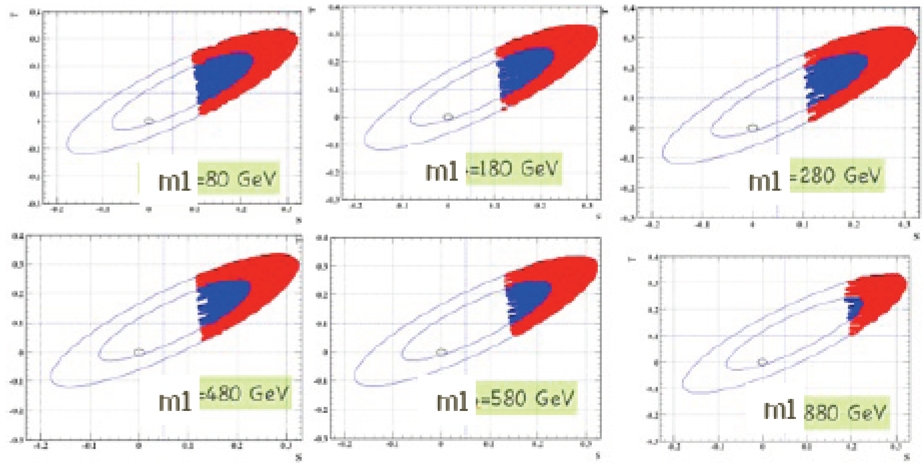
more correlations

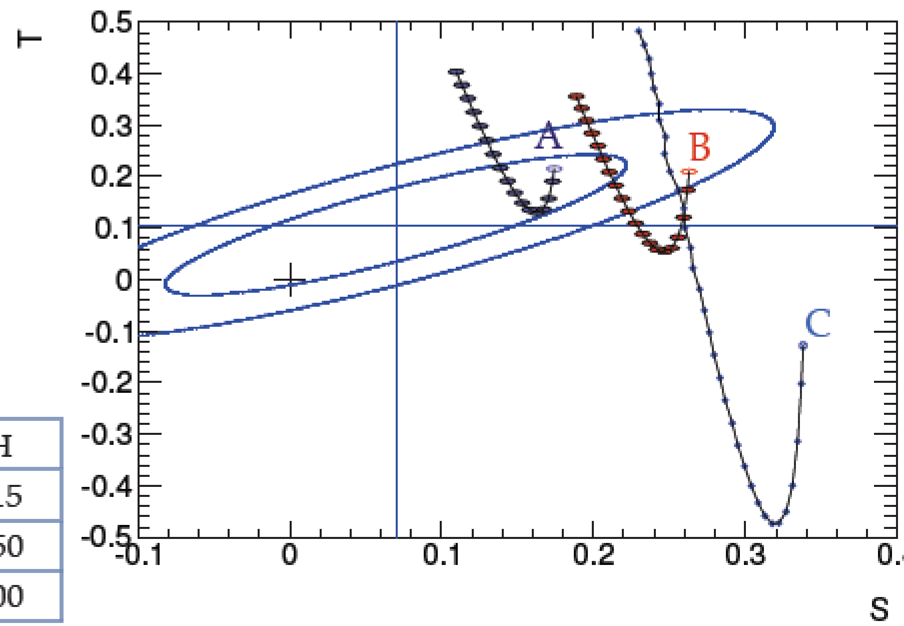


some results in Majorana case

For Majorana type neutrinos

- SM4 w/ Majorana vs have considerable parameter space within 2σ errors
  - ➡ see the RHS results, w/ m2=1TeV
- S-T contribution is same for a Dirac neutrino & Majorana neutrinos of equal mass (m1=m2).
- Keeping m1·m2 constant, increase m2/m1 from 1 to n in steps of 0.5.
  - ➡ n is the value of the ratio at which m1<=80GeV.
- Large neutrino mass differences make a <u>heavy Higgs</u> compatible w/ EW precision data



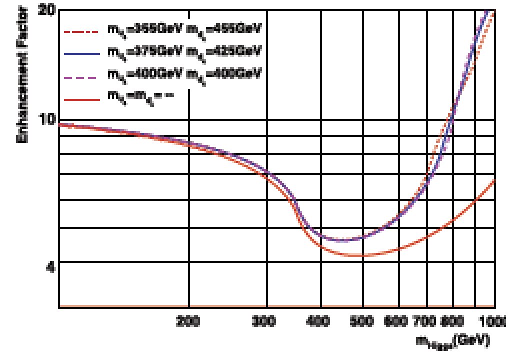


masses(GeV)	u_4	d_4	ν_4	e_4	H
A	300	300	245	355	115
B	335	265	265	335	450
C	435	455	365	435	900

Outlook

- conclusions & suggestions
  - ➡ Our tool, opucem, is debugged and freely available to download
  - ➡ Using the EW precision data, we see that a fourth generation is more plausible than some people are used to think.
    - The Majorana type 4th family neutrino is only available in opucem.
  - ➡ Using the opucem GUI, you can check your favorite mass values rather easily
    - Majorana type neutrinos allow higher Higgs masses
  - ➡ Existence of these additional fermions is very interesting from an experimental point of view.
    - Direct searches of the additional fermions (see presentations in exotics meetings)
    - Enhancement of the Higgs production (see presentation in Higgs (HWW) meetings)
    - exciting possibilities for early discoveries...

- opucem TO DO list
  - ➡ Using the existing work
    - find the available parameter space of the already implemented models, compatible with EW data
    - implement GUI for other already implemented models.
  - ➡ Improvements to the existing work
    - implement other models
    - import infinite precision library from gnu



conclusions

- ✓ There is now a free and mostly debugged library to calculate the EW oblique parameters for various models.
  - Your contributions on your favorite model are most welcome.
- ✓ Using this library we calculated likelihood of various fourth SM family (SM4) scenarios.
  - In some regions of the parameter space SM4 is more compatible with the EW data than SM3.
  - Some fermion masses, within are low enough to raise our hopes for the initial LHC data.
  - DMM predicts mv4 ≲ mE4 ~ mU4 ~ mD4 .
    - SM4 with Dirac or Majorana neutrinos mass up to ~200 GeV favors small difference between quark masses, complying to DMM.
    - SM4 with higher neutrino masses favors large difference between quark masses but also doesn't exclude a small difference (i.e. DMM).
  - The masses compatible with EW precision data define a donut (ring) in the (mU4-mD4 , E4) plane.

Second Approach:

Flavor Democracy favors the Fourth SM Family

in other words:

Existence of the fourth family follows from the basics of the Standard Model and the actual mass spectrum of the third family fermions.

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 still may be observed 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

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

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 $n\text{-}1$ 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

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

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

Fourth Family at TeV scale colliders

Colliders	Tevatron	LHC	ILC/CLIC			Linac-LHC QCD Explorer		Linac-LHC Energy Frontier		muon collider
Beams	$p\overline{p}$	pp	ee	γe	$\gamma\gamma$	ep	γp	ep	γp	$\mu\mu$
u_4 (P), SM decays	[60, 70]	[30, 44, 58, 59, 64, 65, 67]	[48, 55]		[48, 55					[46]
u_4(P), Anom decays										
d_4(P), SM decays	[70]	[30, 59, 64, 65, 67, 78]	[48, 55]		[48, 55					[46]
d_4 (P), Anom decays	[14, 45, 60]									
q_4(AP)										
q_4(S)		[66]				[74, 76]				
q_4(S, A), SM decays	[51, 53]	[69, 75]	[52]							
q_4(S, A), Anom decays	[50, 51, 53, 54]	[62, 63, 69]	[52, 62, 63]			[62, 63, 72]				
l_4(P)			[48, 55]		[48, 55					[46]
ν_4(P)	[77]	[39, 40, 77]	[48, 55, 56]							[46]
$l_4\nu_4$(AP)		[73]								
l_4(S, A)		[68]		[71]		[57]		[57]		
ν_4(S, A)						[61]		[61]		
Scalar Quarkonia		[30, 49]			[48, 55					
Vector Quarkonia			[47, 48, 55]							[46], [47]
Hadrons			[47]							[47]

Phys.Rev.D83:054022,2011; **arXiv:1009.5405** [hep-ph]

The Fourth SM Family at hadron colliders

a) Significant enhancement (~9 times) of the Higgs boson production cross section via gluon fusion. May provide first evidence!

b) Pair production of the fourth family quarks (at the Tevatron if m_{d4} and/or m_{u4} < 400 GeV)

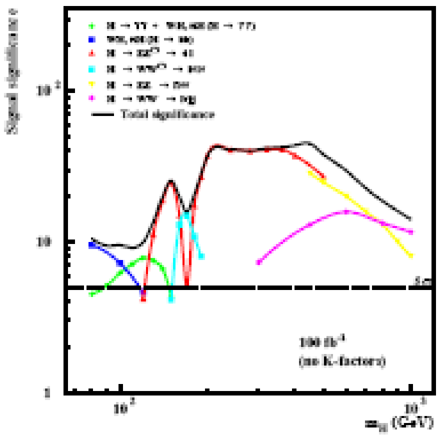
c) Single resonant production of fourth family quarks via the process

$qg \rightarrow q_4$ *(if anomalous coupling has sufficient strength)*

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

…

ATLAS DETECTOR AND PHYSICS PERFORMANCE



Technical Design Report

Volume II

Issue:	1
Revision:	0
Reference:	ATLAS TDR 15, CERN/LHCC 99-15
Created:	25 May 1999
Last modified:	25 May 1999
Prepared By:	ATLAS Collaboration

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 ρ parameter [18-29] constrains the mass splitting between the doublet members of possible heavy generations of quarks: $\Sigma_i (c_i/3)\Delta m_i^2 < (49\ \mathrm{GeV})^2, (83\ \mathrm{GeV})^2$, 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 $\sigma = 10$ 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 $50\ \mathrm{GeV} < m_{jj} < 100$ 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.

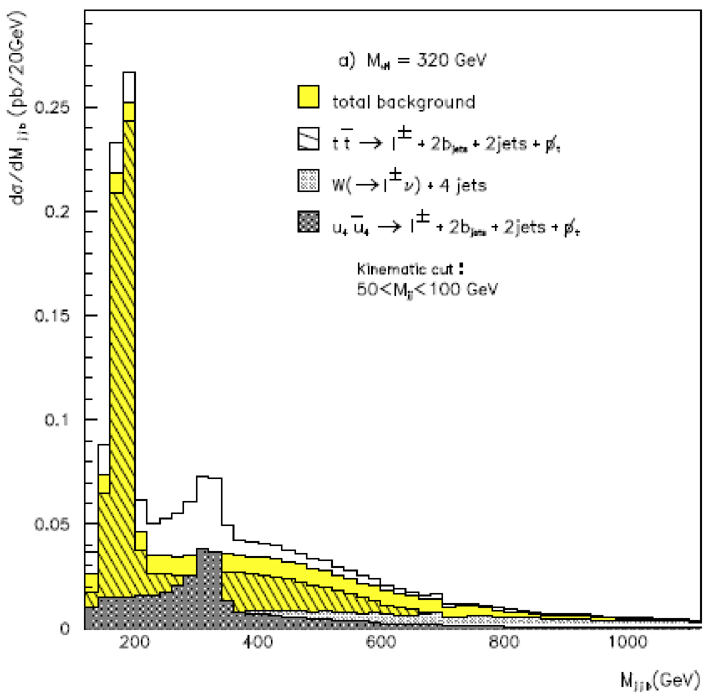
Pair production at the LHC, 100 fb^{-1}

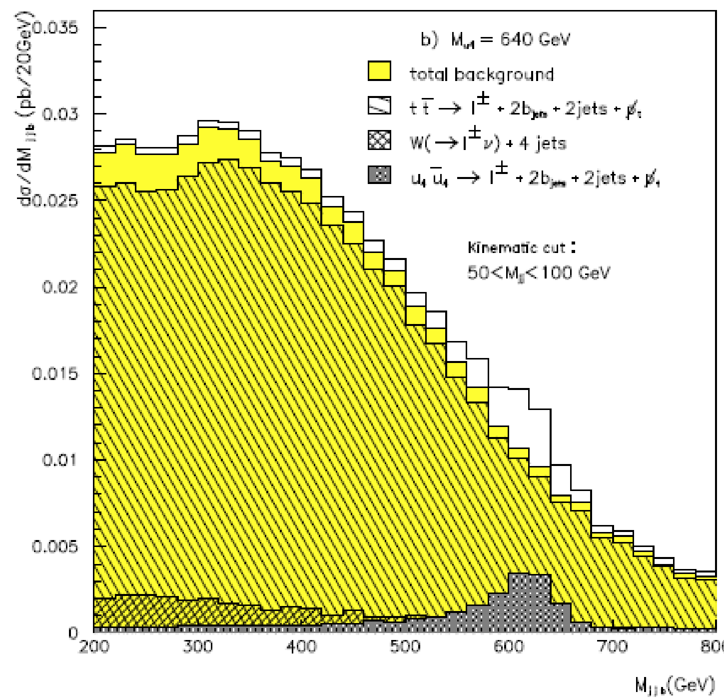
E. Arik et al., Phys. Rev. D 58 (1998) 117701

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

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

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





4th generation quarks : b'

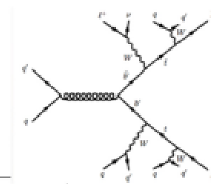
5.8 fb^{-1}

PRL 106, 141803 (2011)
arXiv : 1101.5728

Introduce a fourth generation of chiral fermions

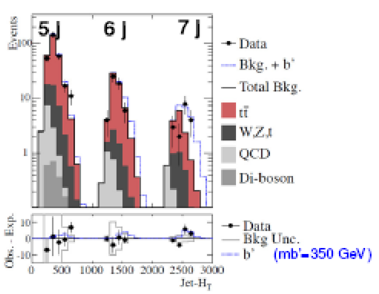
Direct searches $m_{b'}$ > 338 GeV $\Rightarrow$ b' -> t W

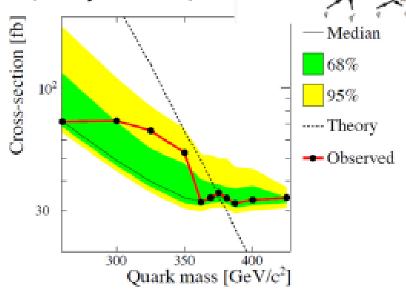
$q\bar{q} \rightarrow b'\bar{b}' \rightarrow t\,\bar{t}$ WW $\rightarrow b\bar{b}$WWWW



Signal : l + mET + ≥ 5 jets (≥ 1 b-jet)

2D-analysis performed : Njets and HT = Σ ET (on l, jets, mET)





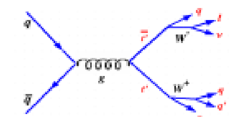
m(b') > 372 GeV

4th generation quarks : t'

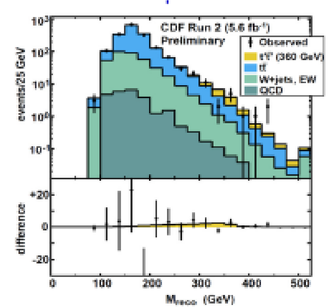
5.6 fb^{-1}

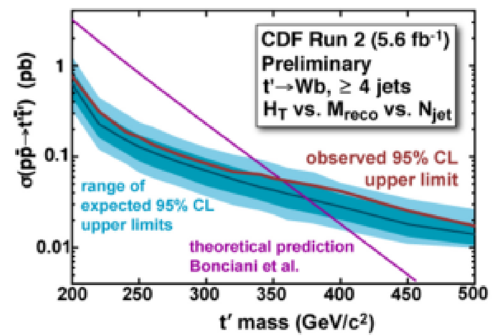
CDF note 10395

A small mass splitting is prefered between t' and b'
$\Rightarrow$ m(b') + m(W) > M(t') $\Rightarrow$ t' $\rightarrow$ Wb



Signal : l, mET, 4 jets (≥ 1b-jet)
l = e or μ

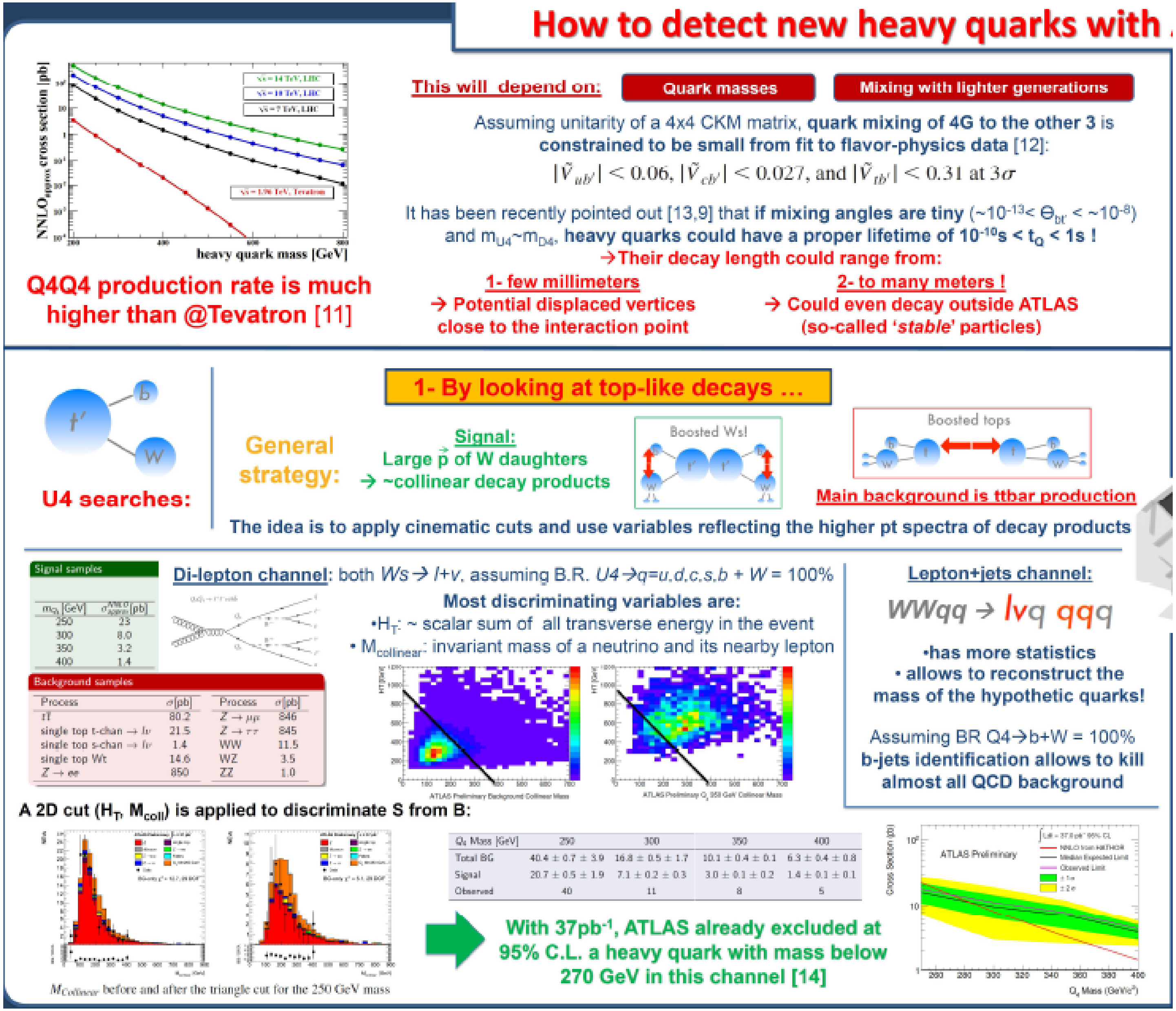




Wq analysis CDF note 10110 m(t') > 335 GeV

m(t') > 358 GeV

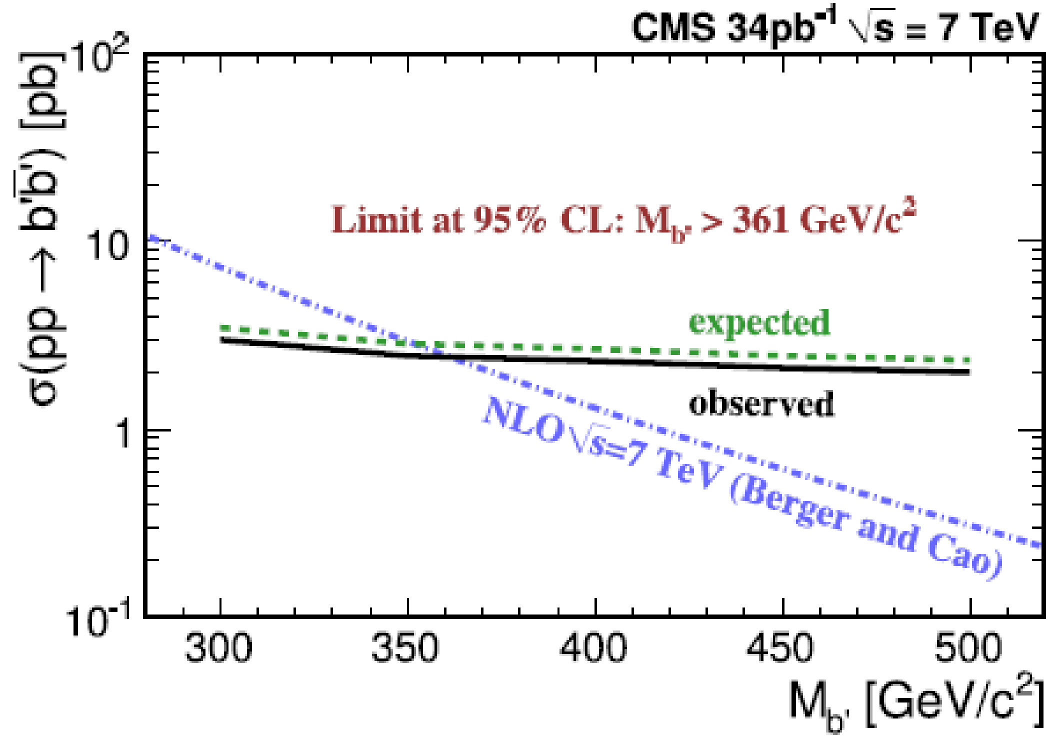
N. Bousson, PLHC2011, Perugia



Search for heavy bottom-like quark

Exclusion limits on production cross section

- Zero events selected. No excess over estimated SM background yield
- Bayesian 95% C.L. upper limit on σ as function of $M_{b'}$



RWTH AACHEN

The Fourth SM Family at the CLIC

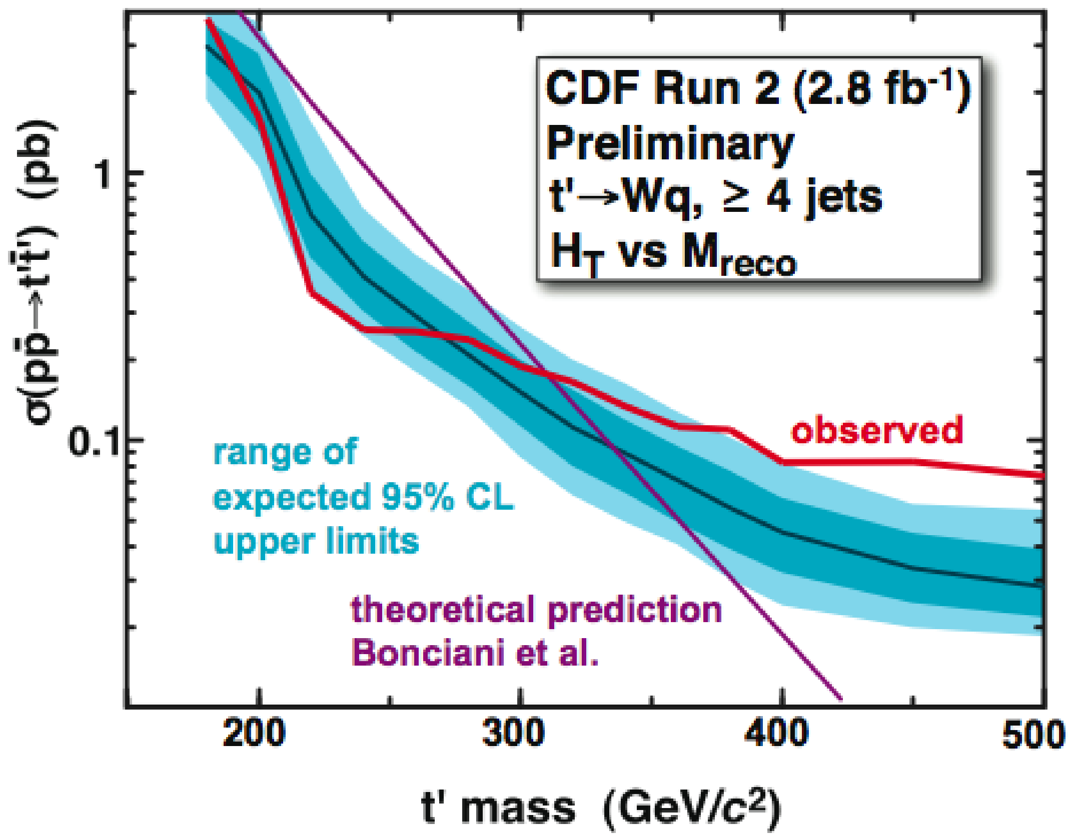
m_{u4} > 310 GeV at 95% CL

$m_{d4} > m_{u4}$

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

$m_{\nu 4}$ (D) $\approx m_{l4}$

$\sqrt{s}$ > 600 GeV is needed



CLIC Yellow Report: CERN-2004-005, hep-ph/0412251

Pair production

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, $L_{ee} = 2.7 \times 10^{34} \mathrm{cm}^{-2}\mathrm{s}^{-1}$ and $L_{\gamma\gamma} = 10^{34} \mathrm{cm}^{-2}\mathrm{s}^{-1}$)

		$u_4\overline{u_4}$	$d_4\overline{d_4}$	$l_4\overline{l_4}$	$\nu_4\overline{\nu_4}$
e^+e^- option	σ (fb)	130	60	86	15
	N_{ev}/year	35 000	16 000	23 000	4100
$\gamma\gamma$ option	σ (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, $L_{ee} = 1 \times 10^{35} \mathrm{cm}^{-2}\mathrm{s}^{-1}$ and $L_{\gamma\gamma} = 3 \times 10^{34} \mathrm{cm}^{-2}\mathrm{s}^{-1}$)

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

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Quarkonia

Table 6.14: The production event numbers per year for the fourth-SM-family ψ_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 ψ_4 for m_H = 150 GeV with $m_{\psi_4} \simeq 1$ TeV

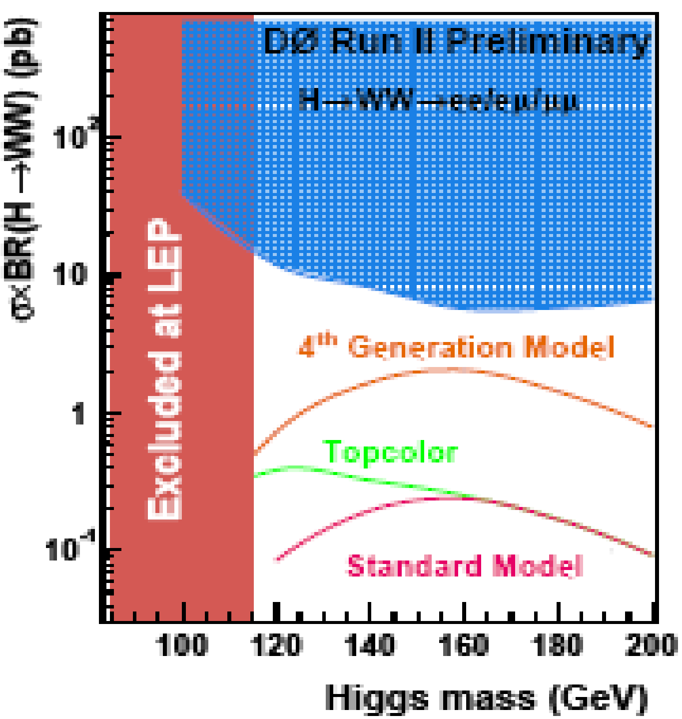
	$(u_4\overline{u_4})$	$(d_4\overline{d_4})$
$\Gamma(\psi_4 \to \ell^+\ell^-)$, 10^{-3} MeV	18.9	7.3
$\Gamma(\psi_4 \to u\bar{u})$, 10^{-2} MeV	3.2	1.9
$\Gamma(\psi_4 \to d\bar{d})$, 10^{-2} MeV	1.4	1.7
$\Gamma(\psi_4 \to Z\gamma)$, 10^{-1} MeV	15	3.7
$\Gamma(\psi_4 \to ZZ)$, 10^{-1} MeV	1.7	5.4
$\Gamma(\psi_4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

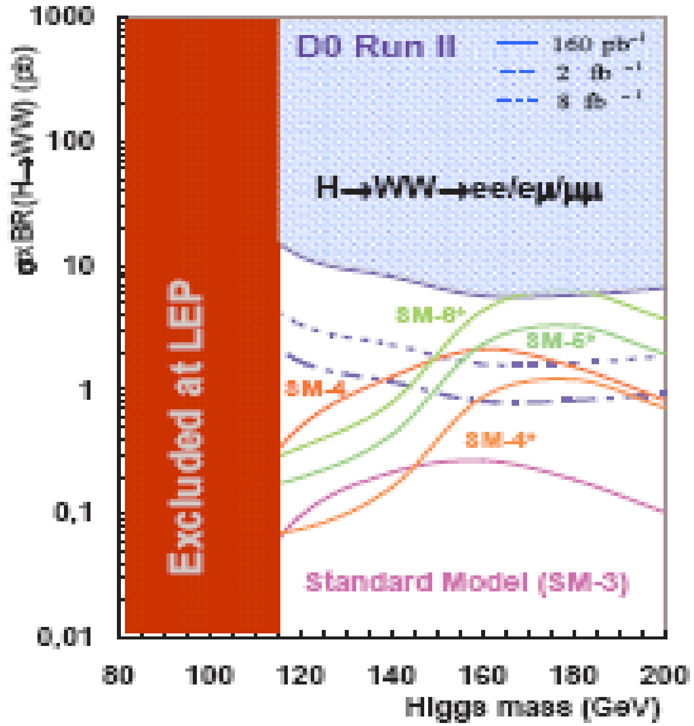
Future Studies for CLIC

- 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_4u_4H and d_4d_4H final states
- Identification: d_4 vs isosinglet D (E_6)
- Identification: u_4 vs isosinglet T (Little Higgs)
- ...

The Fourth Family and the Higgs Boson

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

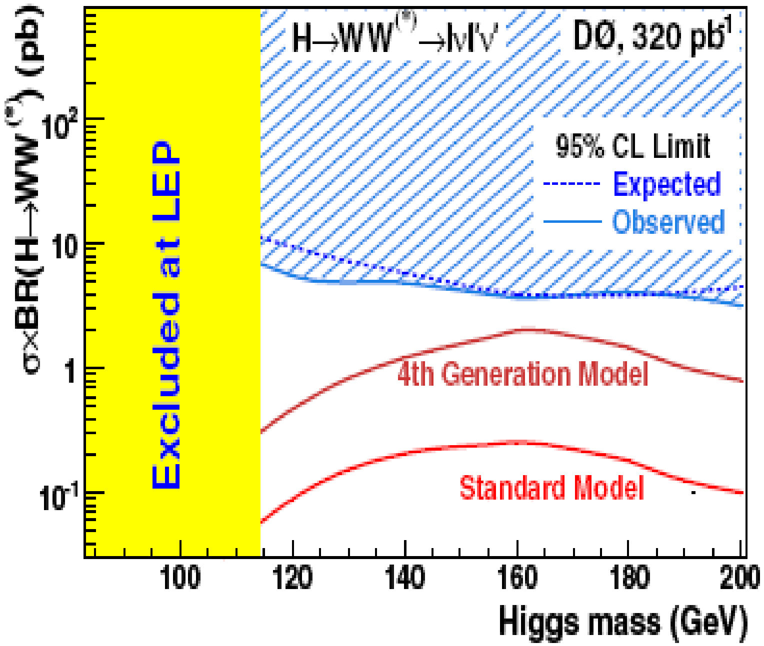
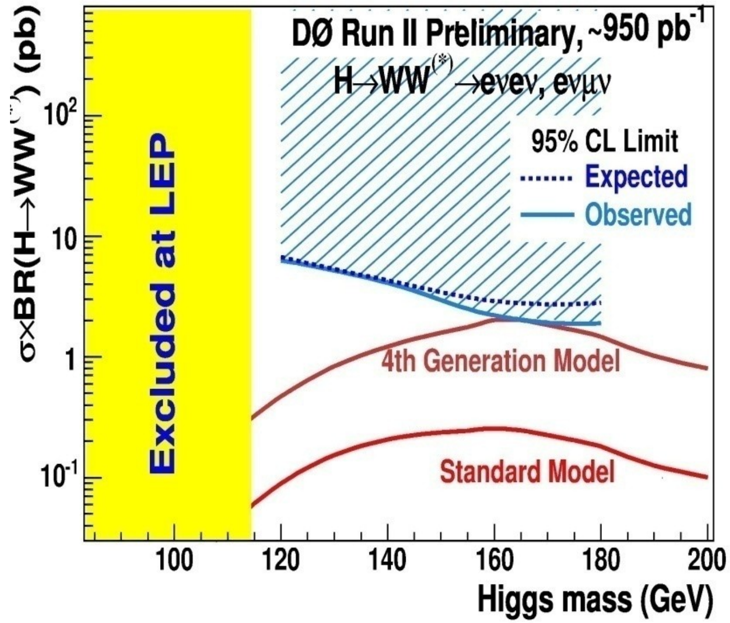
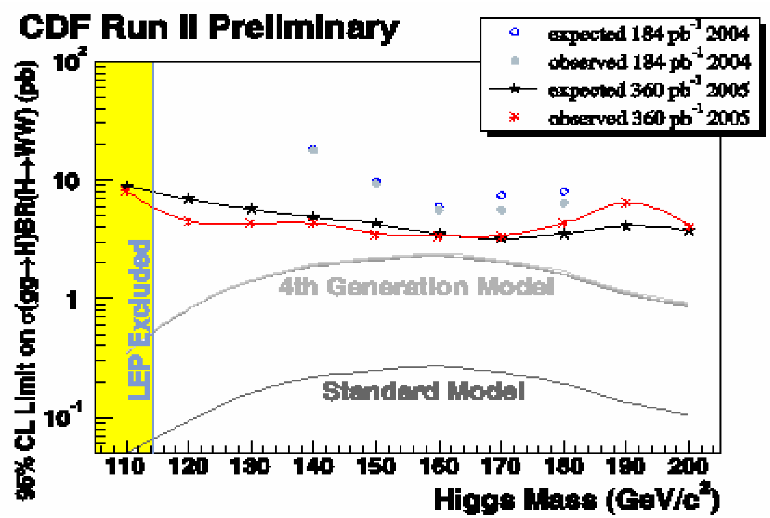


FIG. 2 (color online). Expected and observed upper limits on the cross section times branching ratio $\sigma \times \mathrm{BR}(H \rightarrow WW^{(*)})$ at the 95% C.L. together with expectations from standard model Higgs boson production and an alternative model. The LEP limit on the standard model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



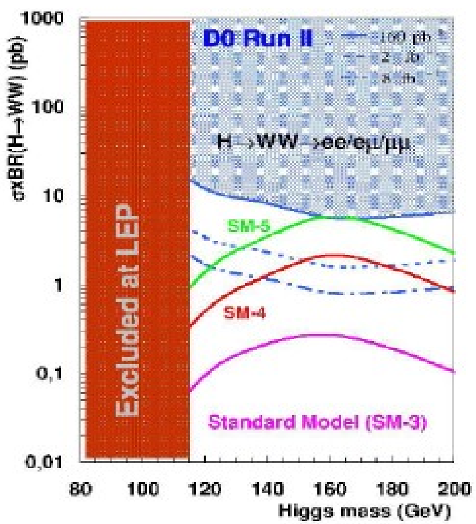


Accessible mass range of the Higgs boson at the Tevatron

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

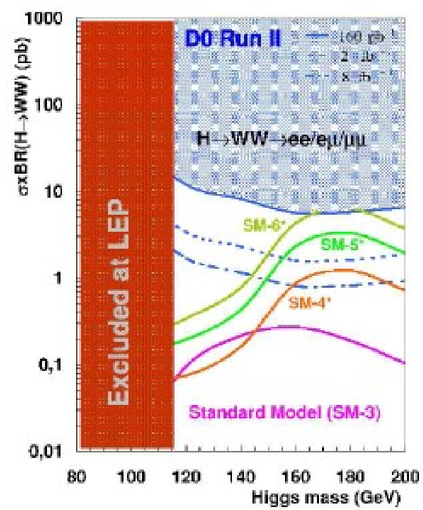
L_{int}	2 fb^{-1}	8 fb^{-1}
SM-4	150 GeV < m_H < 180 GeV	140 GeV < m_H < 200 GeV
SM-5	135 GeV < m_H	125 GeV < m_H
SM-4*	---	160 GeV < m_H < 195 GeV
SM-5*	155 GeV < m_H	150 GeV < m_H
SM-6*	150 GeV < m_H	145 GeV < m_H

Observability of the Higgs Boson in the Presence of ...



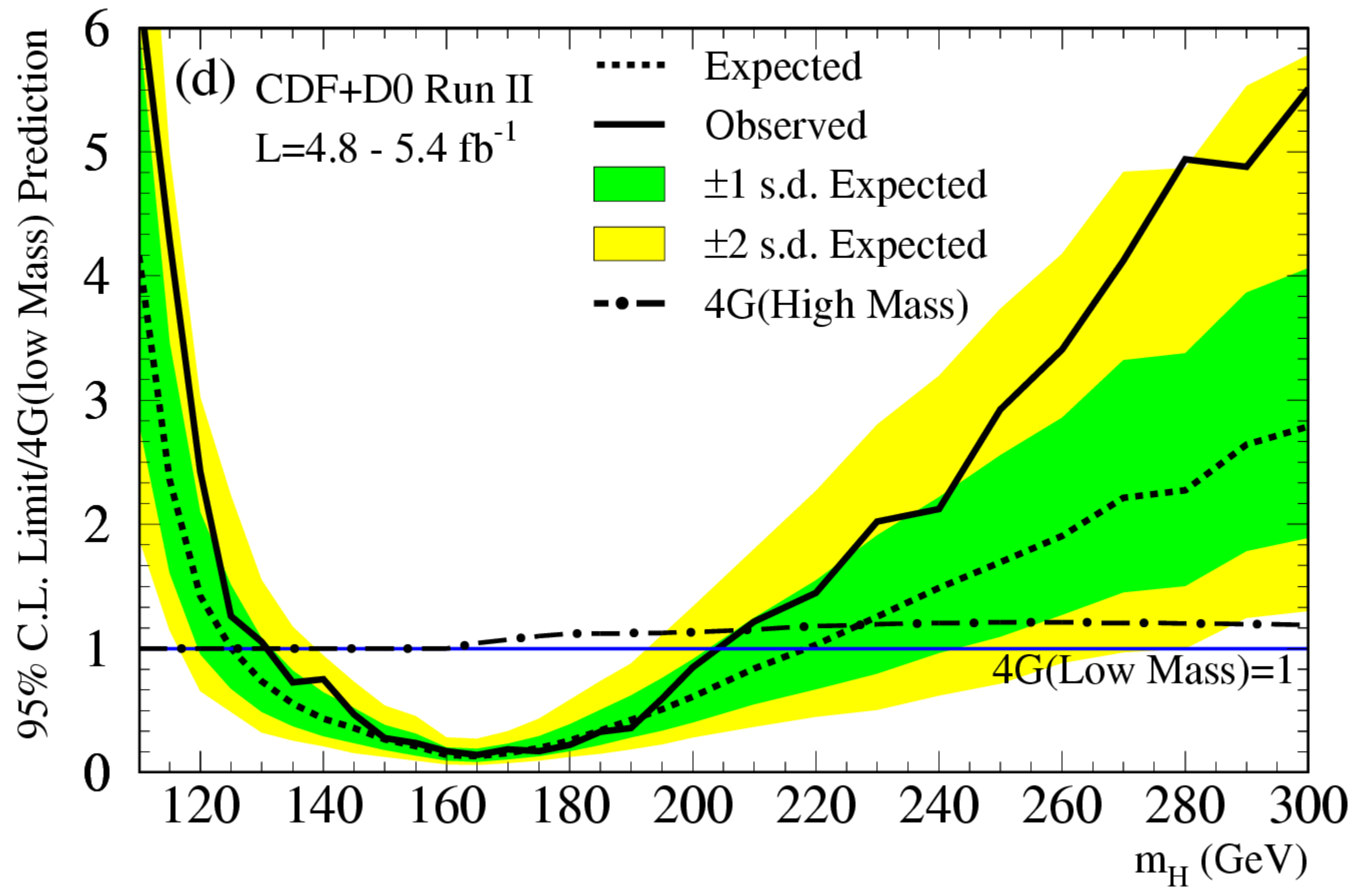
The excluded region of $\sigma\times$ BR$(H\to WW^{(*)})$ at 95 % C.L. t

E. ARIK ET AL.



. The excluded region of $\sigma\times$ BR$(H\to$ W W$^{(*)})$ at 95 % C.L. togeth

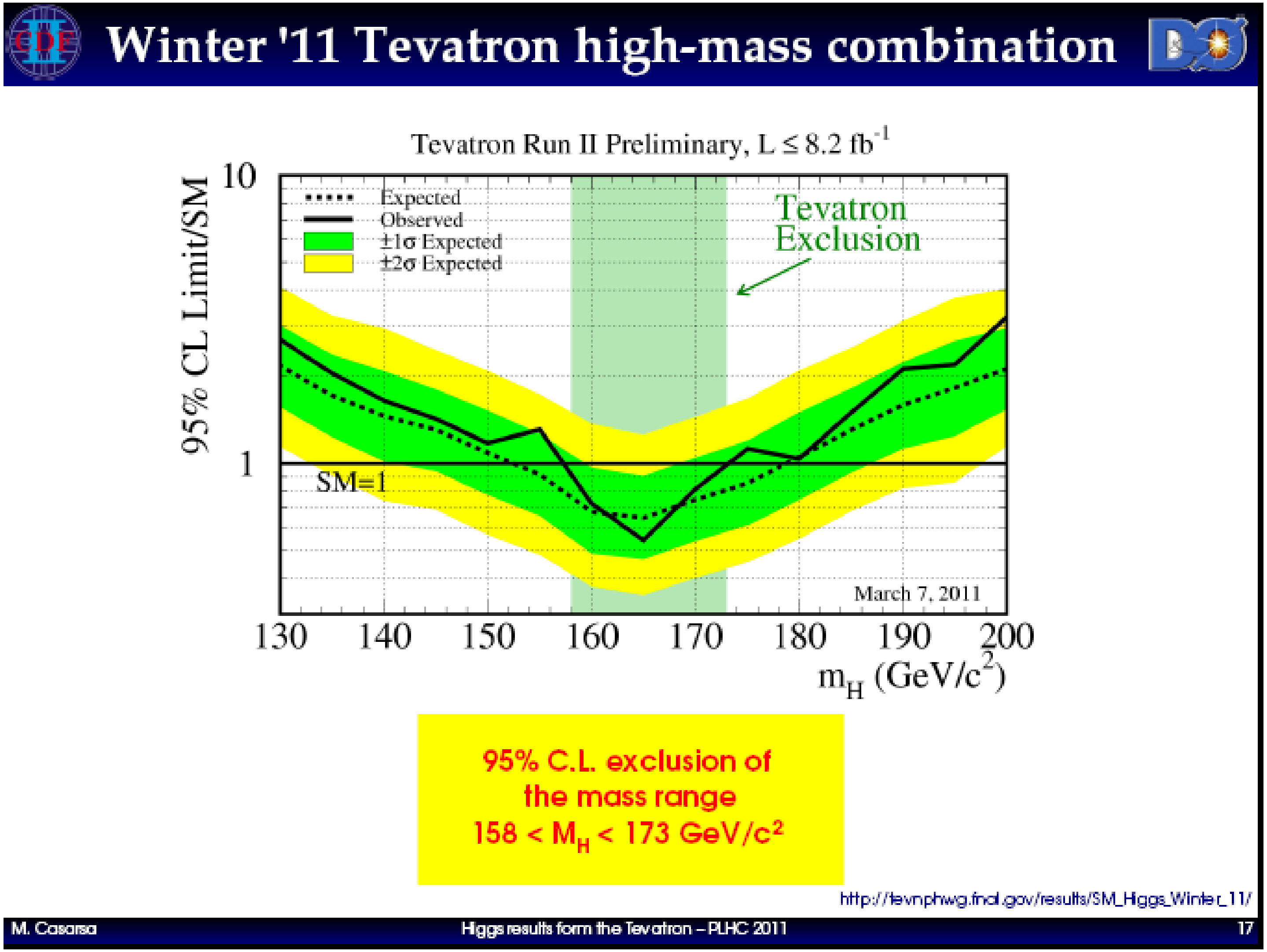
Phys. Rev. D 82, 011102(R) (2010) arXiv:1005.3216 [hep-ex]



Assuming the presence of a fourth sequential generation of fermions with large masses, we exclude at the 95% confidence level a standard-model-like Higgs boson with a **mass between 131 and 204 GeV**.

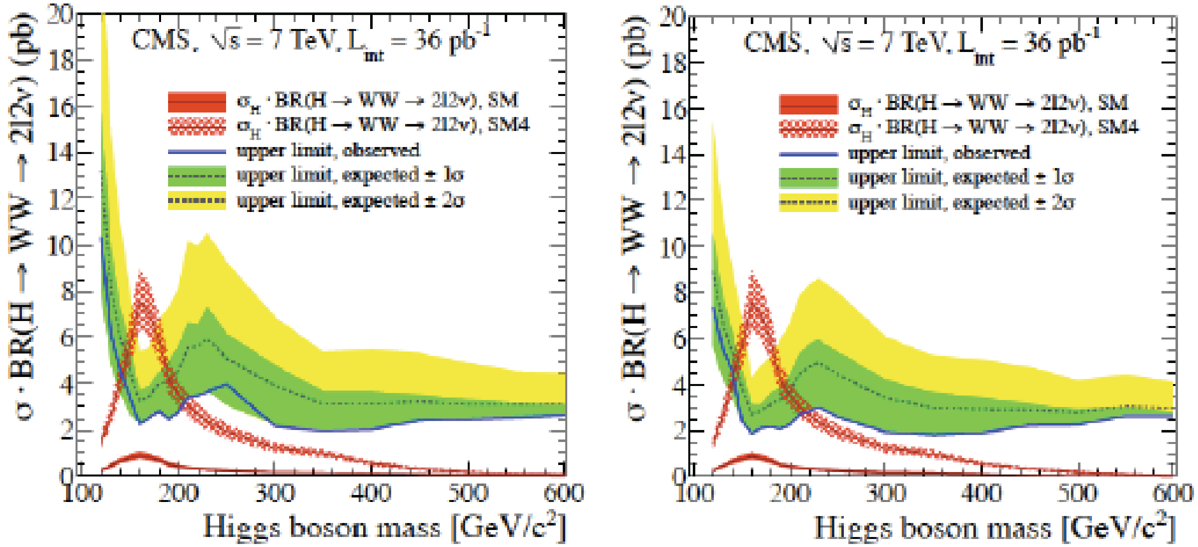
Compare with SM3

M. Casarsa, PLHC2011, Perugia



M. Mannelli, PLHC2011, Perugia

H -> WW -> 2l2ν
Results with 36pb^{-1}

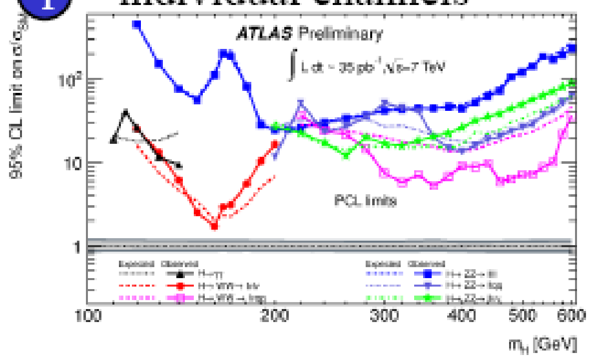


With 36pb^{-1} 95% CL limits on σ x BR (H -> WW) 2 ~ 4pb can be placed
In the region 150 GeV < M_H < 600 GeV, within a factor ~ 2 of SM for M_H ~ 160GeV

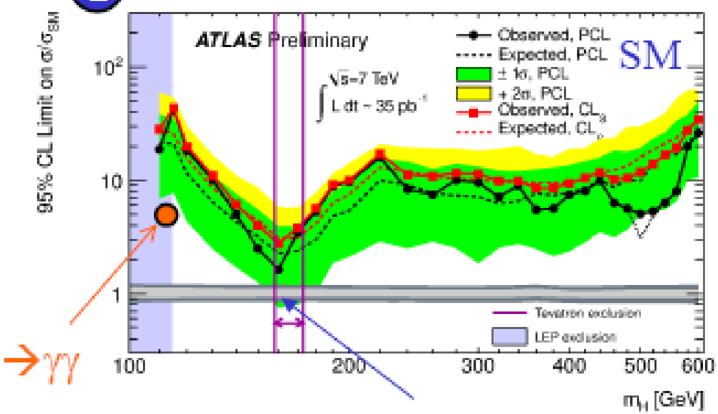
a Higgs Boson in the 4th Generation scenario can be excluded at 95% CL
In the mass range 144GeV < M_H < 207 GeV

Exclusion limits

1 individual channels



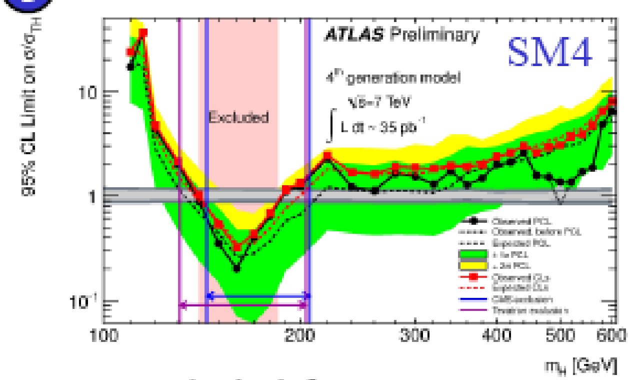
2 combination



current H→γγ

Atlas approaching SM (x1.6 SM)
Tevatron excl. limit

3



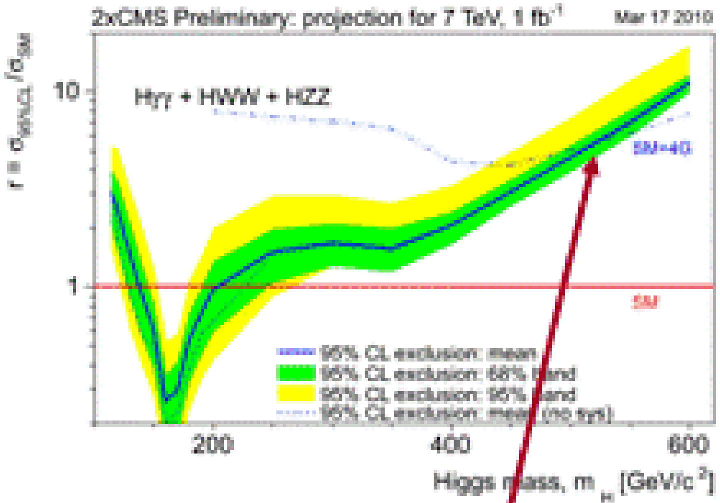
SM4 excluded for m_H : 140-185 GeV

Incorrect expression!
For correct one see previous (CMS) slide.

Combination of channels

By combining the results for the three channels shown before

& assuming twice amount of Data (~ ATLAS + CMS)



➔ Expected exclusion range for SM Higgs: 140 < mH < 200 GeV

➔ The Higgs boson with a mass m_H< 500 GeV would be excluded, should a fourth generation of heavy quarks exist

Conclusions

Higgs in SM4:

- Tevatron excludes via $H \rightarrow WW$ Higgs boson with a **mass between 131 and 204 GeV**. With 10 inverse fb per experiment D0+CDF could cover 120-250 GeV region via $H \rightarrow WW$, 200-300 GeV via "golden mode" and upto 350 GeV via $H \rightarrow ZZ \rightarrow ll\nu\nu/llqq$.

- At the LHC **with 1 fb^{-1}**, the golden mode will cover almost all of the Higgs mass region at levels higher than 5 σ, whereas the WW mode will be an important channel for the discovery of the Higgs boson in the region 150-200 GeV.

- Such a discovery will assure the existence of the 4th SM family

- A double discovery at the LHC is in the realm of the possible: the fourth family neutrino and a heavy Higgs boson

Conclusions (cont.)

Fourth family quarks:

- Depends on masses and mixings with first three families
- CDF excludes u4 with mass below 372 GeV and d4 with mass below 358 GeV. With 10 inverse fb per experiment D0+CDF could cover masses upto 400 GeV.
- LHC **with 1 fb^{-1}** is sensitive to masses upto 500 GeV.
- Fourth family quarks are most probable candidates for discovery (following the Higgs boson)

Back-up

Slides from Gökhan's presentation
at CERNTR meeting
(18.09.2008)

*Fourth Family Matters**

N. Gökhan Ünel
University of California, Irvine

CERNTR
18 September, 2008.

* (1) the present situation or state of affairs : *we can do nothing to change matters*
(2) be of importance; have significance : *to him, animals mattered more than human beings.*

recently renewed interest on 4th family

2

Beyond the 3SM generation Workshop September 2008

Theory, EW, flavour aspects, Current & future searches (including LC) were covered.

Fourth Family (FF)

5

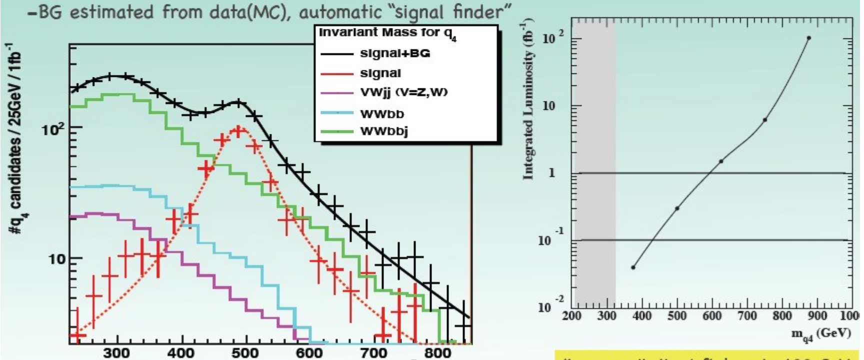
- FF is the simplest "modification" to SM as we know it today
  - SM does not give #families. not a true modification
  - predicts 4 new heavy fermions w/ m >100GeV
    - quarks are to be searched for,
- Why not approach (bottom-up)
  - FF is NOT excluded (details later)
- Predicted by DMM (top-down)
  - before SSB, same yukawa couplings
  - quasi-degenerate u_4, d_4 expected:
    $|m_{d4}-m_{u4}| < m_W/2$
- upper limit m< 1 TeV

	I	II	III	IV
Quarks	u	c	t	u_4
	d	s	b	d_4
Leptons	ν_e	ν_μ	ν_τ	ν_4
	e	μ	τ	e_4

Direct quark searches- ATLAS..

19

- Recent study scenario w/ dominant 1-2 family mixing
  - u4/d4 pair →WjWj , light jets
    - semi leptonic mode with both q4 reconstructed & compared
  - FAST simulation of detector response (recent comparison w/ GEANT: realistic enough)
  - BG from WWbb (+j) (80% ttbar) and (Z/W)W2j
    - MLM matching not done: pessimistic results
  - BG estimated from data(MC), automatic "signal finder"



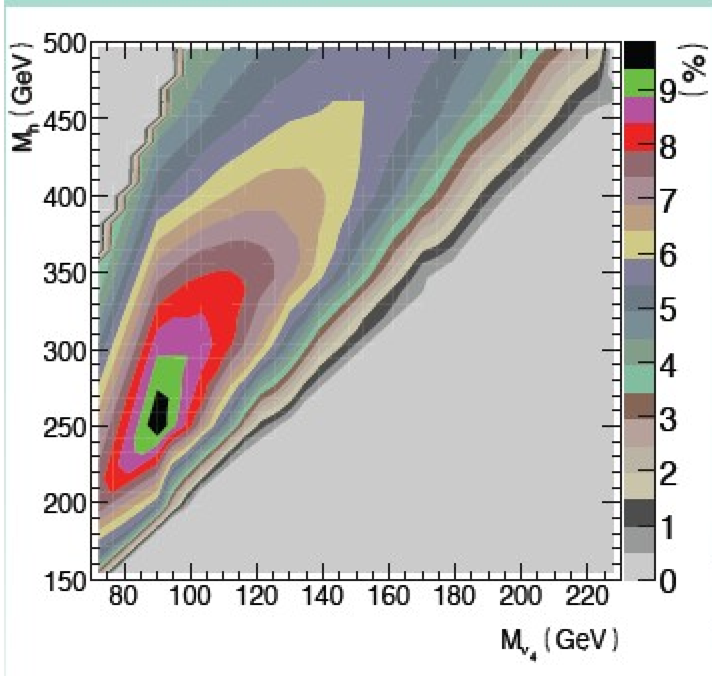
Ozcan, Sultansoy, Unel hep-ex/0802.2621,

discovery limits: 1 fb^{-1} up to 600 GeV

FF and Higgs ..

What about the Higgs decays to FF members ?

- In particular to ν_4



Sultansoy, Unel, hep-ph/0707.3266 & Turkish J. Phys. 31, (2007) 295-298

new search channel: h

"Silver & platinum modes" of Higgs search

Cuhadar-Donszelmann , Karagoz Unel, Ozcan, Sultansoy, Unel, arXiv:0806.4003 [hep-ph],

Define 3 benchmark points with different mass values all in the 2μ+4j final state BR ($\nu_4 \to \mu W$) = 68% (PRD72,2005, 053006)

	$\sigma_{pp\to Z\to\nu_4\bar{\nu}_4}$ (fb)	m_h (GeV)	$\sigma_{gg\to h}$ (pb)	m_{ν_4} (GeV)	BR($h\to\nu_4\bar{\nu}_4$)	$\sigma_{pp\to\nu_4\bar{\nu}_4\to WW\mu\mu}$ (fb)
S1	782	N/A	N/A	100	N/A	362
S2	782	300	30	100	0.088	1583
S3	144	500	10	160	0.055	321