Fourth SM Family at the LHC: ATLAS prospects

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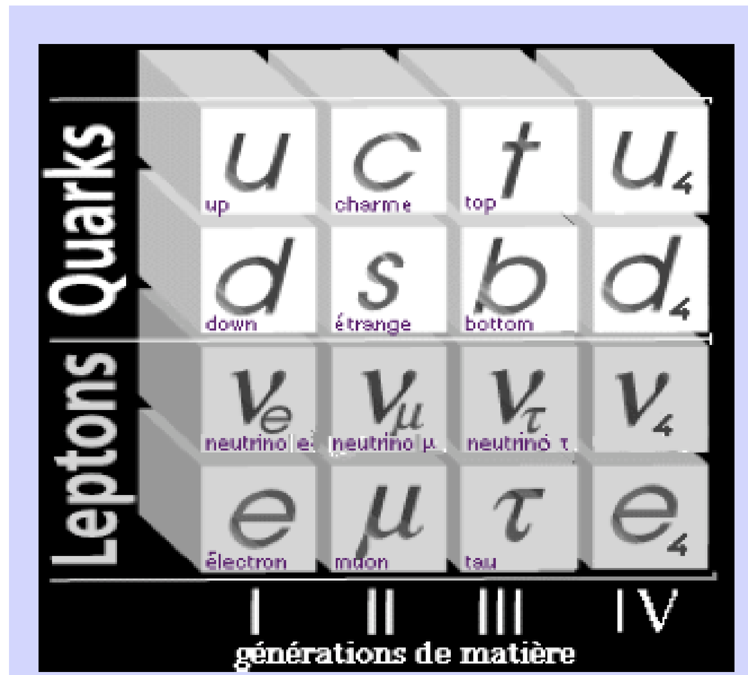
PDG 201?:



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1. Two kinds of New Physics

1. New Physics Beyond the SM (preons, SUSY and so on)

2. New Physics Within the SM structure #

Electroweak: massive neutrinos, fourth family

Strong: small x_g

Hypothesis: QCD – Confinement

GSW – Flavor Democracy

In debris of the MSSM, SUGRA and so on, we for forgot the SM itself. For example, MSSM-3 contains ~ 200 free parameters put by hand !!!

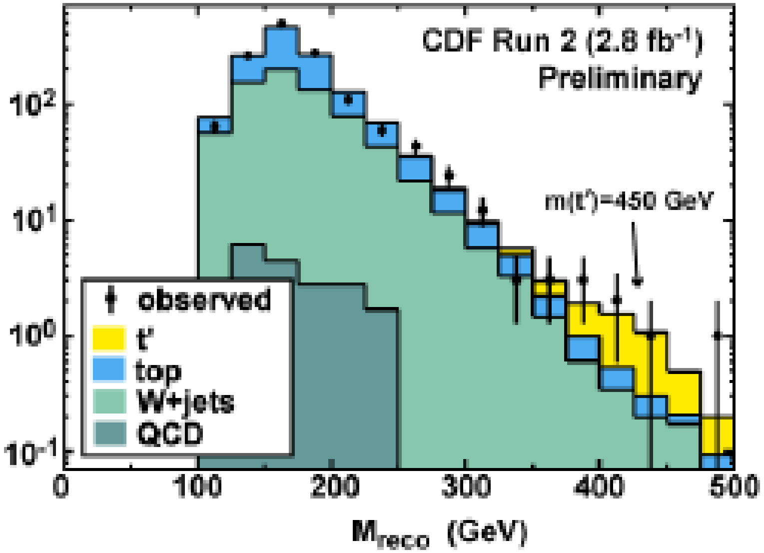
2. Why The Four SM Families

- SM does not determine the number of fermion families
  - LEP data (& Cosmology) $N \geq 3$ (N = 3 for "massless" v, $2m_v < m_Z$)
  - QCD Asymptotic Freedom: $N \leq 8$
- Precision EW data: SM-3 and SM-4 have the same status (SM-3: $m_H < 180$ GeV, SM-4: $m_H \sim 300$ GeV)
- **Flavor Democracy → Fourth SM Family**
- Precision EW data does not exclude Fourth Family, only prefers heavier Higgs boson (→ 300 GeV)
- There are some indications:

  B-decays, BAU (Hou's presentation)

  CDF bump (but cross-section!)

For interpretation of the CDF Excess see



arXiv:0808.0285v1 [hep-ph] 3 Aug 2008

Hints from Tevatron, a prelude to what?

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August 3, 2008

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Abstract

We comment on the recent results from the Tevatron experiments in the W+jets channel and consider some models as the possible underlying physical theories. We also list some channels for further studies.

1 Introduction

The Standard Model (SM) is expected to be the low energy limit of a more fundamental theory [1]. The known candidates for such a theory have more fundamental particles than what is experimentally known today. Therefore, searches for new particles hence for the new model of elementary particles and their interactions, continue in both the precision physics and collider experiments. In a recent public note, CDF experiment at Tevatron excluded a standard model fourth-generation t' quark with mass below 311 GeV at 95% CL using 2.8 fb^{-1} of data (see figure 1)[2]. The shown theoretical model shows the tree-level cross section of a new quark with q=2/3 charge.

The same note also reports an excess of about 5 events in the W+jets channel in the region between 375-500 GeV. Although this small number of excessive events can be explained by a detector over-efficiency or by some unknown SUSY process, in the following text we will consider some theoretical models where an additional heavy quark is predicted. Some of these models were also mentioned in the above mentioned note.

2 Recent CDF measurement on W+jet

The CDF result on the reconstructed invariant mass in the W+jet channel is presented in figure 2. The number of observed events in the range 375 - 500 GeV is 7 with an expected background of about 1.8 events. The Poisson probability of such a statistical deviation is 0.2%, which is rather low. Taking this excess at its face value, we calculate its significance, using the well known estimator [3] $S = \sqrt{2 \times [(s+b)\ln(1+\frac{s}{b}) - s]}$, to be about 2.9$\sigma$, perhaps a hint for a new quark decay. However the candidate underlying model has to be investigated in the

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).**

Twenty years later:

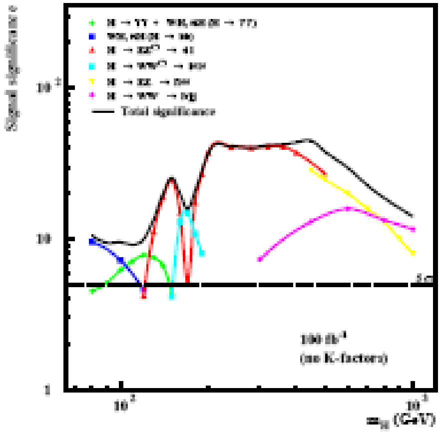
Workshop "Beyond the 3rd SM generation at the LHC era“
CERN, Sep 4-5, 2008
http://indico.cern.ch/conferenceDisplay.py?confId=33285

In between:

1999 – ATLAS TDR (thanks to P. Jenni & D. Froidevaux)
2004 – CLIC Yellow Report (thanks to A. de Roeck)

ATLAS

ATLAS DETECTOR AND PHYSICS PERFORMANCE



Technical Design Report

Issue:	1
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CERN-2004-005
10 June 2004
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hep-ph/0412251

ORGANISATION EUROPÉENNE POUR LA RECHERCHE NUCLÉAIRE
CERN EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

PHYSICS AT THE CLIC MULTI-TeV LINEAR COLLIDER

Report of the CLIC Physics Working Group

Editors: M. Battaglia, A. De Roeck, J. Ellis, D. Schulte

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

Mass and mixings pattern of the SM fermions is the most important problem of Particle Physics !!!

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.

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**:

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

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

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

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 CKM and lepton PMNS matrices in good agreement with experimental data.**

Alternative to Flavor Democracy – 4 Higgs doublets (1 per fermion type).

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 (SUSY)**
- **Allows relatively “light” isosinglet quarks (E6 predicted)**
- **Light composite particles (preonic models)**
- **…**

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

$$O^l_{\mathrm{CKM}} = \begin{bmatrix} 0.82 & 0.29 & 0.49 & -6.43 \times 10^{-6} \\ -0.55 & 0.60 & 0.58 & 1.28 \times 10^{-4} \\ 0.12 & 0.74 & -0.66 & 8.14 \times 10^{-4} \\ -2.34 \times 10^{-5} & 6.81 \times 10^{-4} & 4.64 \times 10^{-4} & 1.00 \end{bmatrix}.$$

These matrices should be compared with the experimental data

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

Good agreement both for CKM and PMNS !!

Input – masses, output – mixings.

3. The Fourth SM Family at the ATLAS LHC

3.1. Higgs Boson (yesterday)

3.2. u_4 & d_4 : pair production

3.3. u_4 & d_4 : single production

3.4. ν_4 & H

3.5. l_4

3.6. Fourth Family Quarkonia

3.1. Higgs Boson (yesterday, WG1) Conclusions

- **For more details see “Fourth SM Family Workshop”** http://indico.cern.ch/conferenceDisplay.py?confId=33285
- **Tevatron already exclude 130-180 GeV (scenario A)**
- At the LHC, **in the presence of the fourth SM family, even with 1 fb^{-1}**, the golden mode will cover almost **all of the Higgs mass region** at levels higher than 5 s, whereas the WW mode will be an important channel for the discovery of the Higgs boson in the region 150-200 GeV.
- **In the SM-4 case LHC with $\sqrt{s}$=10 TeV and L_{int}=200 pb^{-1} will cover 190-330 GeV at 3s level**
- A double discovery in the first year of the LHC start up is in the realm of the possible: the fourth family neutrino and a heavy Higgs boson
- Possibly the TEVATRON or most probably the LHC data will yield the final confirmation of the fourth SM family within few years

3.2. u_4 & d_4 : pair production

Pair u_4 production ($\sqrt{s}$ = 14 TeV), ATLAS Physics TDR, 1999

	320 GeV	640 GeV
100 fb^{-1}	74.5 σ	16.6 σ
10 fb^{-1}	23 σ	5.5 σ
5 σ	0.5 fb^{-1}	8 fb^{-1}
3 σ	0.3 fb^{-1}	4 fb^{-1}

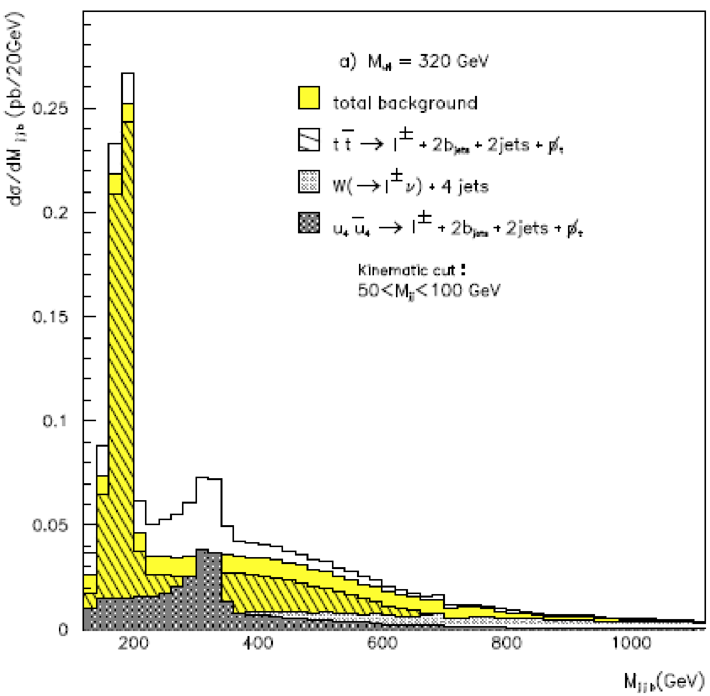
Pair production at the LHC, 100 fb^{-1}

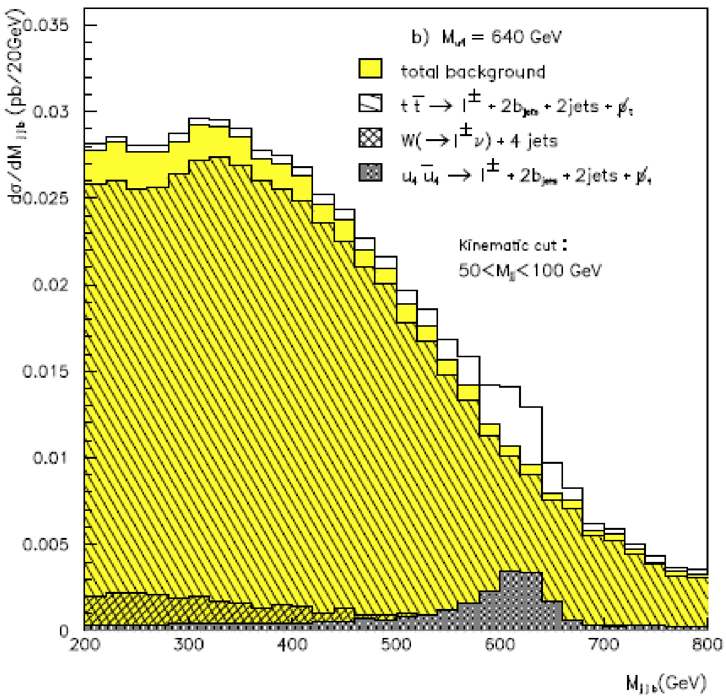
E. Arik et al., Phys. Rev. D 58 (1998) 117701

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

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

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





November 27, 2008

ATL-COM-PHYS-2008-239

Search for a fourth generation quark u_4 decaying to Wb

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Abstract

This note describes the search for a new fourth generation quark u_4 and the study of some of its properties in case of a discovery. Using a dedicated study, the u_4 quark can be discovered with 10 fb^{-1} of data.

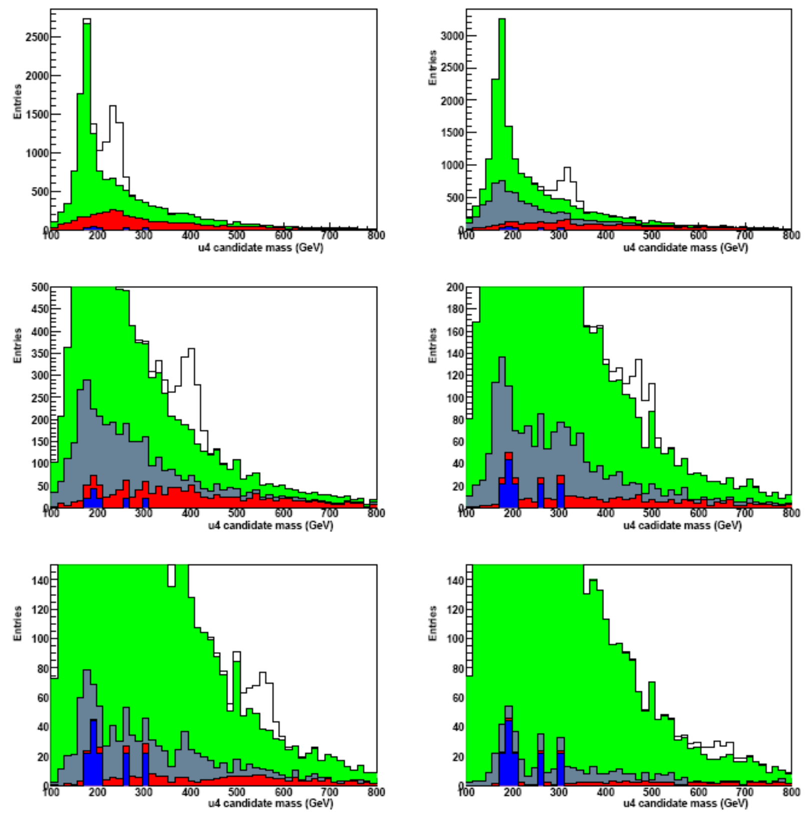


Figure 7: *Mass spectra of the u_4 candidates, including background, for, respectively, masses of 240, 320, 400, 480, 560 and 640 GeV/c^2, from left to right and top to bottom. The signal is in white, the top background in light grey, the d_4 combinatorial events in grey, the u_4 combinatorial events in dark grey and the $W + n$ partons background in black. All distributions have been normalized to an integrated luminosity of 10 fb^{-1}.*

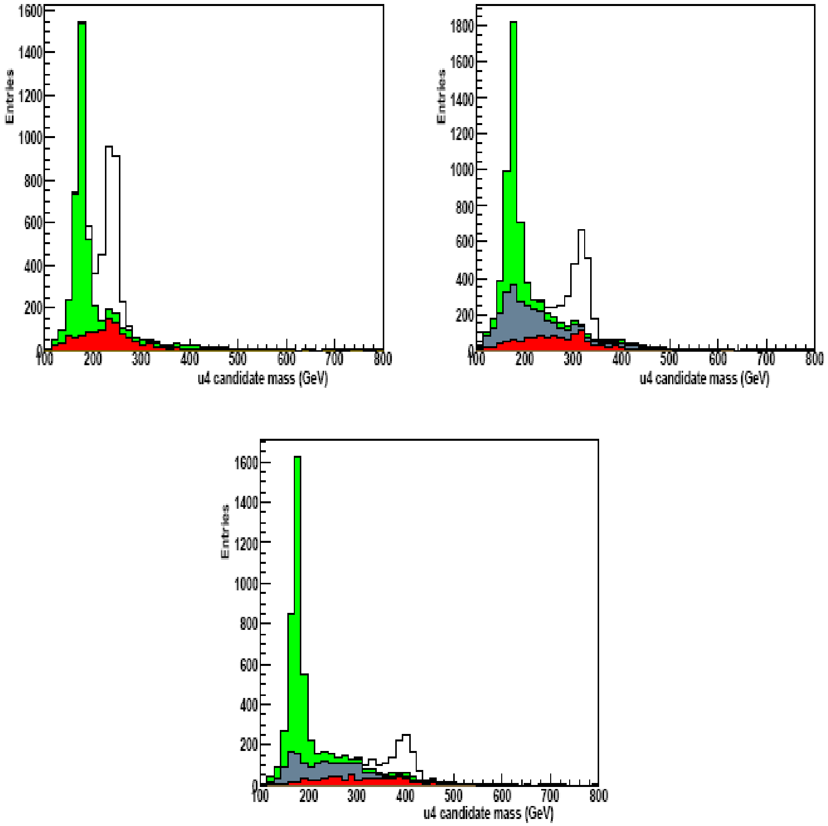


Figure 15: *Mass spectra of the* u_4 *candidates, including background, for, respectively, masses of 240, 320 and 400 GeV/*c^2*, from left to right and top to bottom. The signal is in white, the top background in light grey, the* d_4 *combinatorial events in grey and the* u_4 *combinatorial events in dark grey, for the low mass analysis (*$\mathcal{LM}$*). All distributions have been normalized to an integrated luminosity of 10 fb*$^{-1}$.

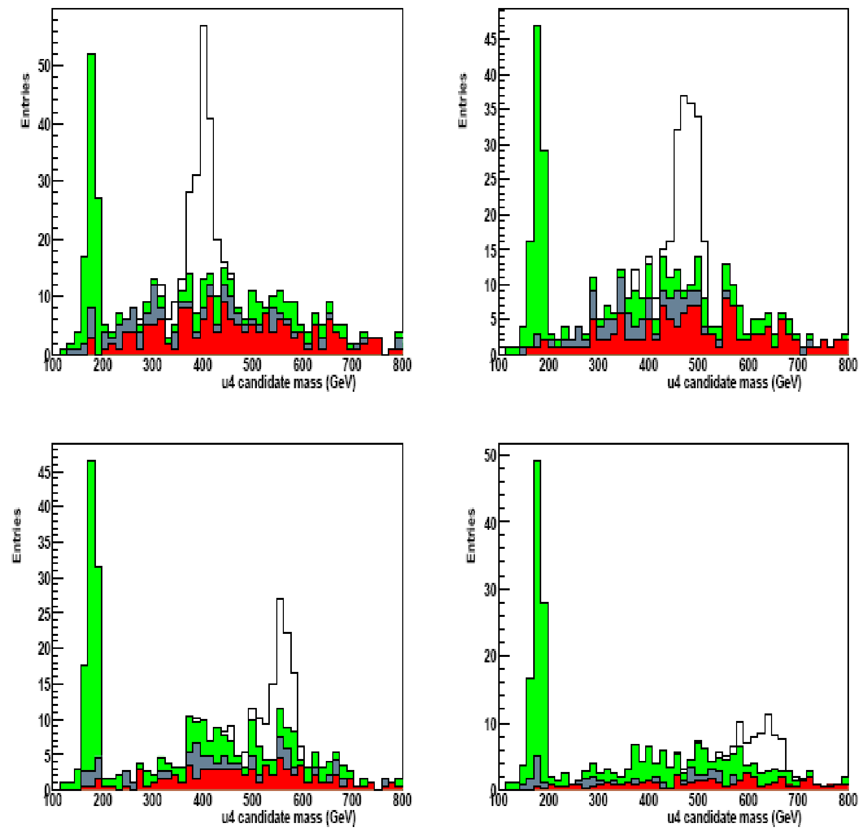


Figure 16: *Mass spectra of the* u_4 *candidates, including background, for, respectively, masses of 400, 480, 560 and 640 GeV/*c^2*, from left to right and top to bottom, for the high mass analysis (*$\mathcal{HM}$*). All distributions have been normalized to an integrated luminosity of 10 fb*$^{-1}$ *(colors are explained in figure 15).*

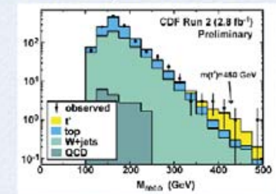
4TH FAMILY QUARKS AT ATLAS

V. Erkcan Ozcan
University College London

Beyond the 3SM generation at LHC era WS, CERN, Sept. 04, 2008

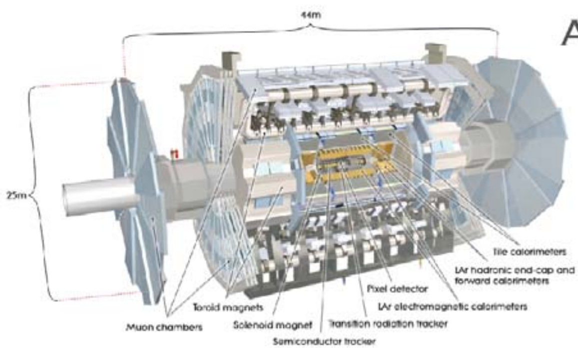
OUTLINE / MOTIVATION

- LHC scheduled to have first protons on Sept. 10, 2008.
- CM energy 7x larger than Tevatron, low x, gluon pdfs significant => pair production of heavy quarks…
- Recent exciting results from CDF => the first ~100pb^{-1} of data will be very interesting.
- u_4/d_4 discovery potential at ATLAS:
  - ATLAS TDR: q_4 mixing with t/b
  - Recent results: q_4 mixing with u/d/s/c
- Not in this talk - other heavy quark searches: isosinglets, FCNCs, …



2

ATLAS



Tracking	$\lvert\eta\rvert<2.5$
EM Cal.	$\lvert\eta\rvert<3.2$
Had. Cal.	$\lvert\eta\rvert<\sim4.9$

	Start-up of LHC	Ultimate goal
Electromagnetic energy uniformity	1–2%	0.5%
Electron energy scale	~2%	0.02%
Hadronic energy uniformity	2–3%	< 1%
Jet energy scale	< 10%	1%
Inner-detector alignment	50–100 μm	< 10 μm
Muon-spectrometer alignment	< 200 μm	30 μm
Muon momentum scale	~1%	0.02%

3

EVENT GENERATION

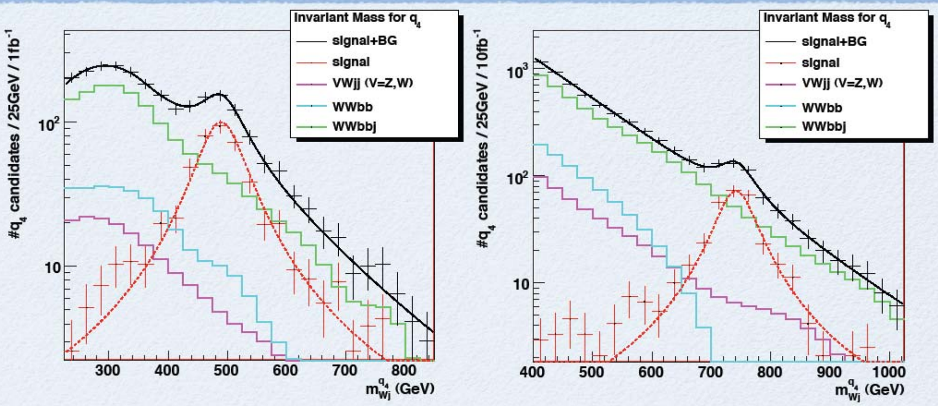
- Signal events with CompHep 4.4.3. 12k signal events each for two choices of mass.

m_{q4} (GeV)	500	750
Γ_{q4} (GeV)	8.2×10^{-3}	2.8×10^{-2}
$\sigma_{pp\to d4d4}$ (pb)	2.63	0.25

- Background events with MadGraph 3.95. A total of 280+k events at various QCD scales and jet P_T cuts.
- PDF=CTEQ6L1. Pythia 6.23 for parton showering, hadronization, etc.
- ATLFast fast simulation for detector effects.

8

Results



- From each event two q_4 candidates.
- Dominant background from *WbWbj*, other backgrounds an order of magnitude lower.

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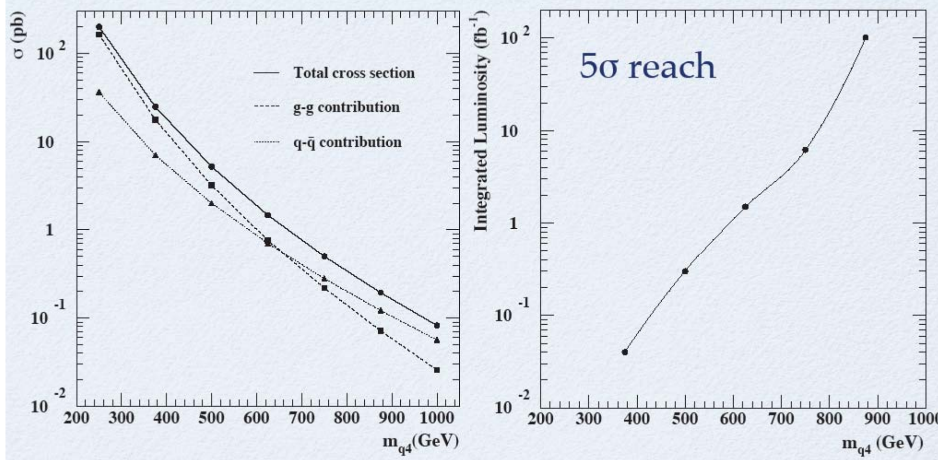
Discovery Range



- Reach plot obtained by: integrating BG fit function, extrapolating for signal efficiency and calculating the x-sec as function of mass.

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3.3. u_4 & d_4 : single production

PHYSICAL REVIEW D 78, 075018 (2008)

Anomalous single production of the fourth generation quarks at the CERN LHC

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(Received 27 July 2008; published 21 October 2008)

Possible anomalous single productions of the fourth standard model generation up and down type quarks at CERN Large Hadron Collider are studied. Namely, $pp \longrightarrow u_4(d_4)X$ with subsequent $u_4 \longrightarrow bW^+$ process followed by the leptonic decay of the W boson and $d_4 \longrightarrow b\gamma$ (and its H.c.) decay channel are considered. Signatures of these processes and corresponding standard model backgrounds are discussed in detail. Discovery limits for the quark mass and achievable values of the anomalous coupling strength are determined.

DOI: 10.1103/PhysRevD.78.075018 PACS numbers: 12.60.−i, 13.38.Be, 14.65.−q

Eur. Phys. J. C (2008) 56: 537–543
DOI 10.1140/epjc/s10052-008-0685-4

THE EUROPEAN PHYSICAL JOURNAL C

Regular Article - Theoretical Physics

Single production of fourth-family quarks at the LHC

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Abstract We study the single production of fourth-family quarks through the process $pp \to Q'jX$ at the Large Hadron Collider (LHC). We have calculated the decay

searches. The upcoming experiments at the Large Hadron Collider (LHC) are able to probe heavy quarks up to a heavier mass range, accessible to future experiments. Recently,

3.4. v4 & H

Fourth Family Neutrinos and Higgs Boson

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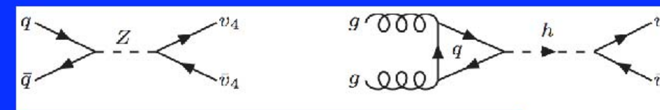
M.Karagoz Unel (University of Oxford)
V. E. Ozcan (University College London)
S. Sultansoy (TOBB University, Ankara & Institute of Physics, Baku)
G. Unel (CERN/UC Irvine)

Beyond the 3SM generation at the LHC era Workshop, CERN
September 4-5, 2008

1

Introduction

- Can the 4th family members be observed in LHC/ATLAS ?
- We have investigated the existence of ν_4 and the impact on the SM Higgs boson through ("silver mode") :
  $pp \to h \to \nu_4 \bar{\nu}_4$ (suggested by S. Sultansoy & G. Unel, Tr.J.Phys. 31 2007)
- ν_4 can still be produced via (in case Higgs does not exist)
  $pp \to Z \to \nu_4 \bar{\nu}_4$



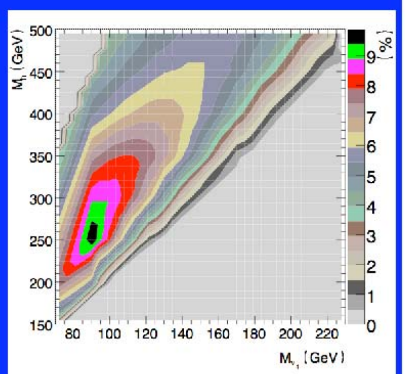
q = t, b, u_4, d_4

- Majorana or Dirac nature of ν_4 is studied
  - Particle =? Anti-Particle
- Preliminary results available in ArXiv:0806.4003v3 [hep-ph], Submitted to JHEP.

3

Higgs Decay Branching Fraction

- Branching fraction of Higgs decaying into heavy neutrino pairs computed via CompHEP
- Highest branching fraction $BR(h \to \nu_4 \bar{\nu}_4)$ ~10 % at $m_{\nu 4}$ = 90 GeV & m_h = 250 GeV
- Two points chosen for the test
  m_h = 300, Γ = 9 GeV
  m_h = 500, Γ =67 GeV



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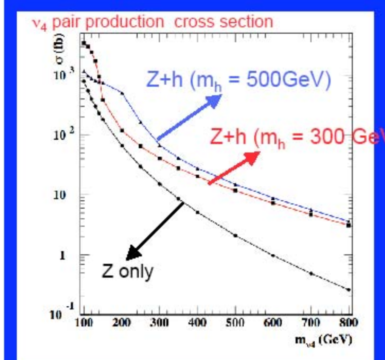
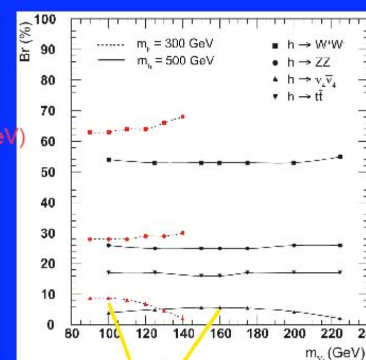
ν_4 Cross Section & Branching fraction





Two ν_4 mass values chosen as benchmark points

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Signal Events

- pp → h/Z → $\nu_4\bar{\nu}_4$
  - → l W (l = μ)
  - → l W (l = μ)
- BR (ν_4 → μW) ~ 68% (PRD 72 (2005) 053006)
- Considering only the hadronic decay of W
  Final State : 2μ + 4j

Summary of Benchmark points:

	$\sigma_{pp\to Z\to\nu_4\bar{\nu}_4}$ (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

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Background events

- Di-boson + di-muon
  - 2V+2μ , V = W / Z produced with MadGraph
  - Total cross section is negligible
    - less than 5 fb
  - Muon p_T > 15 GeV; $|n_\mu|$ < 2.5 and $m_{QCD} = m_Z$
- Di-muon + 4j (Z/γ + 4j)
  - Produced with MadGraph (compared with AlpGen)
  - Not negligible contribution, 57 pb
  - Muon and jet p_T > 15 GeV; $|n_\mu|$ < 2.5, $|n_j|$ < 5; δR_{jj} > 0.4 and $m_{QCD} = m_Z$
- $t\bar{t}$ background
  - Not negligible 755 pb

Process	cross section (fb)
$W^+W^-\mu^+\mu^-$	2.56 ± 0.02
$ZZ\mu^+\mu^-$	0.70 ± 0.06
$W^+Z\mu^+\mu^-$	0.97 ± 0.01
$W^-Z\mu^+\mu^-$	0.48 ± 0.06
Direct Total	4.71 ± 0.09

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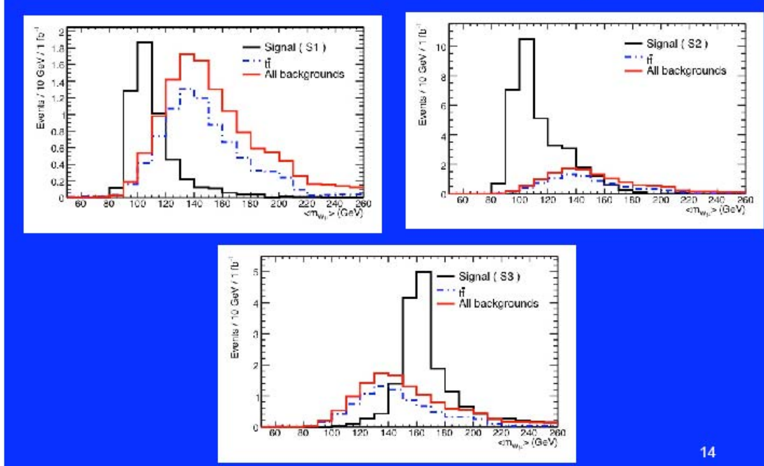
Results of Majorana ν_4



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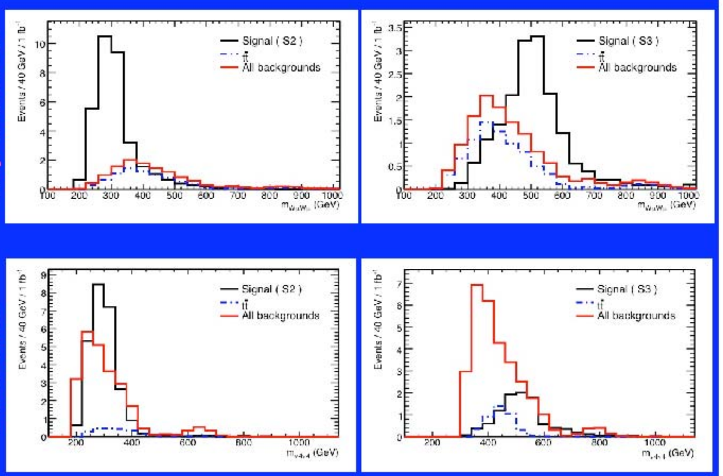
Reconstructed Higgs Mass

Majorana case

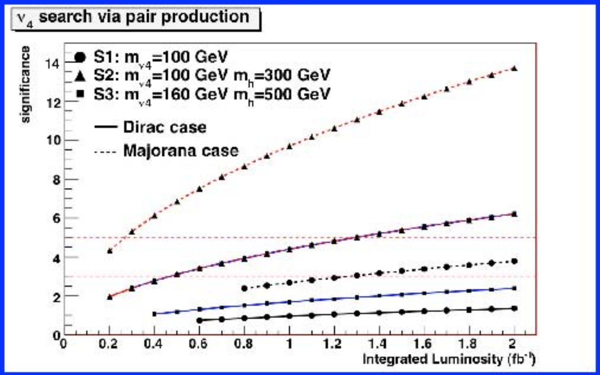
Dirac case



Significance

$$\sqrt{2 \times \left[(s+b)\ln\left(1+\frac{s}{b}\right)-s\right]}$$

- For each scenarios, significance computed from the 4 bins around signal peak
- Majorana ν_4 will be accessible for three benchmark points (i.e. with or without Higgs boson) around 1-2 fb^{-1}
- Dirac ν_4 can only be seen with Higgs



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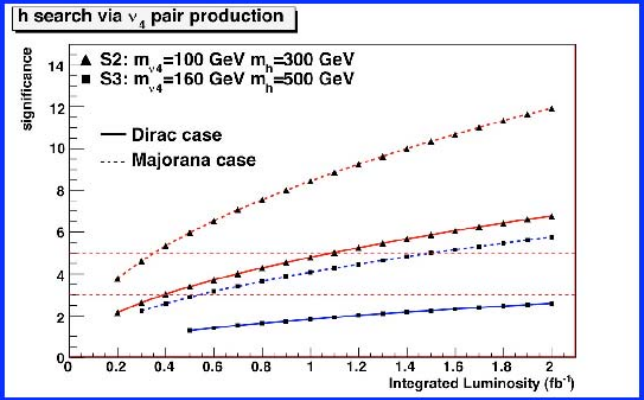
Significance (cont'd)

Majorana case: m_h = 300 GeV, 5σ with 0.3 fb^{-1} can be achieved

m_h = 500 GeV, 3σ with 1.5 fb^{-1} can be achieved

Dirac case: requires ~2x more luminosity to achieve the same significance



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Summary and Outlook

- We have made a feasibility study to determine whether
  SM higgs boson can be detected through its decay into ν_4-pair in ATLAS
  and/or
  ν_4 can be discovered
- Two masses of higgs boson are considered
- With 1-2 fb^{-1}, both ν_4 and Higgs boson can be discovered at the same time
  - Majorana case is promising

The analysis can be improved by :

- Cut optimization
  - Analysis based on the cut and count analysis
  - More statistics of background sample needed

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Fourth family neutrinos and the Higgs boson at the LHC

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JHEP10(2008)074

3.5. l_4

In Preparation

3.6. Fourth Family Quarkonia

PHYSICAL REVIEW D **66**, 116006 (2002)

Fourth generation pseudoscalar quarkonium production and observability at hadron colliders

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(Received 22 August 2002; published 18 December 2002)

The pseudoscalar quarkonium state η_4 $(^1S_0)$, formed by the standard model fourth generation quarks, is the best candidate among the fourth generation quarkonia to be produced at the CERN Large Hadron Collider and Very Large Hadron Collider. The production of this $J^{PC}=0^{-+}$ resonance is discussed and the background processes are studied to obtain the integrated luminosity limits for the discovery, depending on its mass.

TABLE V. The comparison of hadron and lepton colliders potentials in view of the fourth family quarkonia searches.

pp colliders	e^+e^- colliders
LHC 14, 100 fb^{-1}	JLC/NLC, TESLA, CLIC, stage 1
LHC 14, 1000 fb^{-1}	JLC/NLC, TESLA, CLIC, stage 2
LHC 28, 100 fb^{-1}	JLC/NLC, TESLA, CLIC, stage 2
LHC 28, 1000 fb^{-1}	CLIC, stage 3
VLHC 40, 100 fb^{-1}	JLC/NLC, CLIC, stage 2
RLHC 100, 100 fb^{-1}	CLIC, stage 3
VLHC 175, 200 fb^{-1}	CLIC, stage 3

needed to achieve 3σ and 5σ are presented. One can see that upgraded LHC with $\sqrt{s}=14$ TeV and $L_{int}=1000$ fb^{-1} cover the quarkonia mass up to 800 GeV. The same mass region could be covered by the energy upgraded LHC with $L_{int}=100$ fb^{-1}. With both the energy and luminosity upgrades LHC can reach $m_{\eta_4}=1200$ GeV. The same region will be covered by the VLHC stage 1. The whole predicted mass region for η_4 quarkonia will be covered by VLHC stage 2 and RLHC.

In our calculations we have used a rather strict cut on the invariant mass of two b-jets, namely, $|m_{bb}-m_h|<10$ GeV for $m_h=150$ GeV. With a more relaxed cut $|m_{bb}-m_h|$

4. Future Colliders

	u_4, d_4	l_4	ν_4	η_4	ψ_4
LHC	P, S, A(R)	$W \to l_4\nu_4$	$Z,H \to \nu_4\nu_4$	?	?
SLHC,..	P, S, A(R)	$W \to l_4\nu_4$	$Z,H \to \nu_4\nu_4$	R, R	S, S
QCD-E(ep)	A(R)	S	S	-	-
QCD-E(γp)	A(R)	-	-	-	-
e^+e^- if KA	P, A	P, A	P, A	-	R
γe if KA	-	A(R)	-	-	-
$\gamma\gamma$ if KA	P, A	P, A	-	R	-
$\mu^+\mu^-$	P, A	P, A	P, A	-	R

P – pair, S – single, A – anomalous single, R – resonant production

Black – good, Blue – very good, if KA – if kinematically allowed

Conclusions

- Fourth family quarks will clearly manifest themselves at the LHC.
- At the 14TeV LHC, **in the presence of the fourth SM family, even with 1 fb^{-1}**, the golden mode will cover almost **all of the Higgs mass region** at levels higher than 5σ, whereas the WW mode will be an important channel for the discovery of the Higgs boson in the region 150-200 GeV.
- A double discovery with **1 fb^{-1}** at the **14 TeV** LHC, is in the realm of the possible: the fourth family neutrino and a heavy Higgs boson
- Possibly the TEVATRON or most probably the LHC data will yield the final confirmation of the fourth SM family within few years