# Impact of the SM4 on the H@LHC

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&
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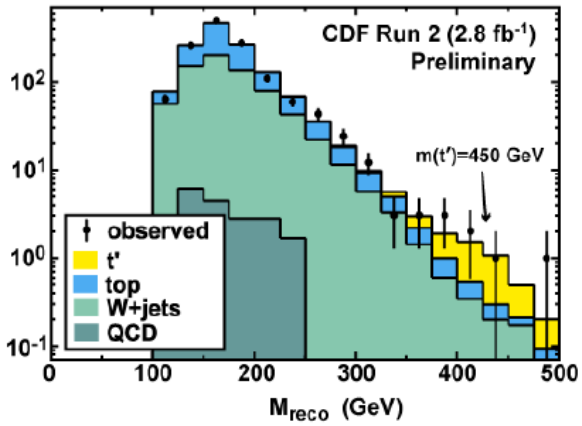
- **The Fourth SM Family**
- **gg → H enhancement**
- **Tevatron already exclude 130-180 GeV (scenario A)**
- **LHC: "Golden Mode"**
- **LHC: "Silver Mode"**

# The Fourth SM Family

- SM does not determine No of fermion families
- N ≥ 3 from LEP data, N ≤ 8 from asymptotic freedom
- Flavor Democracy → Fourth SM Family
- Precision EW data does not exclude Fourth Family, only prefers heavier Higgs boson (→ 300 GeV)
- There are some indications:

  CDF bump (but cross-section!)

  B-decays, BAU (Hou, tomorrow)




Essential enhancement of Higgs via gluon fusion (fourth family quarks in loop).

**1998: E. Arik & Co for the ATLAS**

**I. Ginzburg & Co for the Tevatron**

# Tevatron 2004

**DØ Higgs WG** (May 26, 2005)

## The Fourth SM Family at the Tevatron

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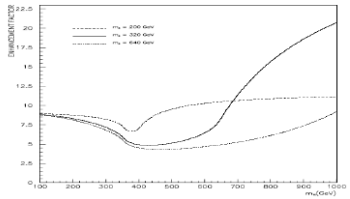
*Gazi University, Ankara, TURKEY & Institute of Physics, Baku, AZERBAIJAN*

1. ***Periodic Table of Elementary Particles***
2. ***Flavour Democracy ➔ the Fourth SM Family***
3. ***Extra generations and the Tevatron***

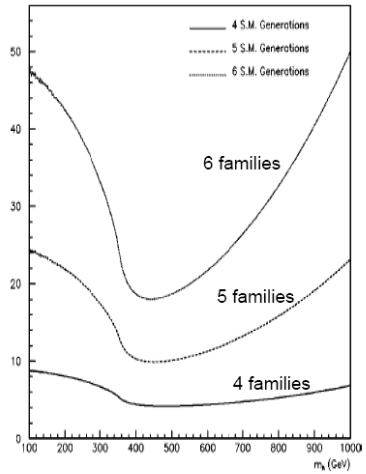
Enhancement factor as a function of Higgs mass:

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

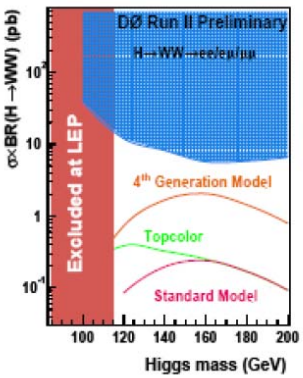
b) 4; 5 and 6 SM families with infinite masses (lower, mid and upper curves)



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




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

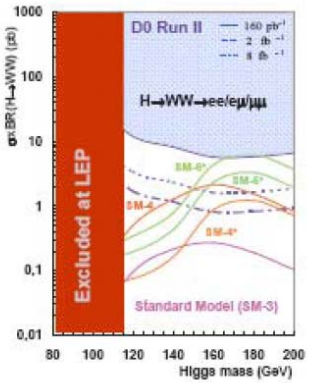



DØ presentations, for example,

A. Kharchilava, hep-ex/0407010

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

V. Buscher, hep-ex/0411063

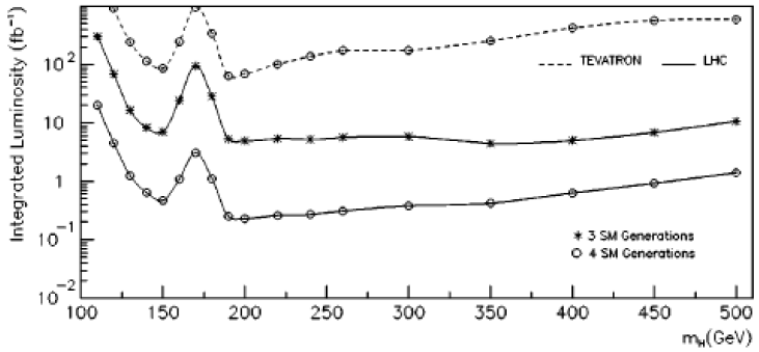



E. Arik et al., hep-ex/0411053

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

**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 0f operation.



# Tevatron 2005 -2006

PRL 96, 011801 (2006) PHYSICAL RE

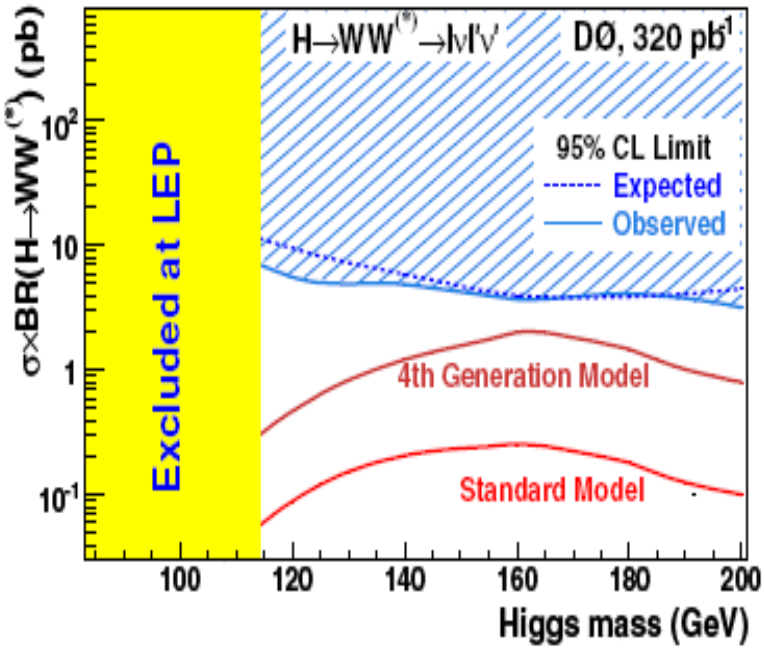
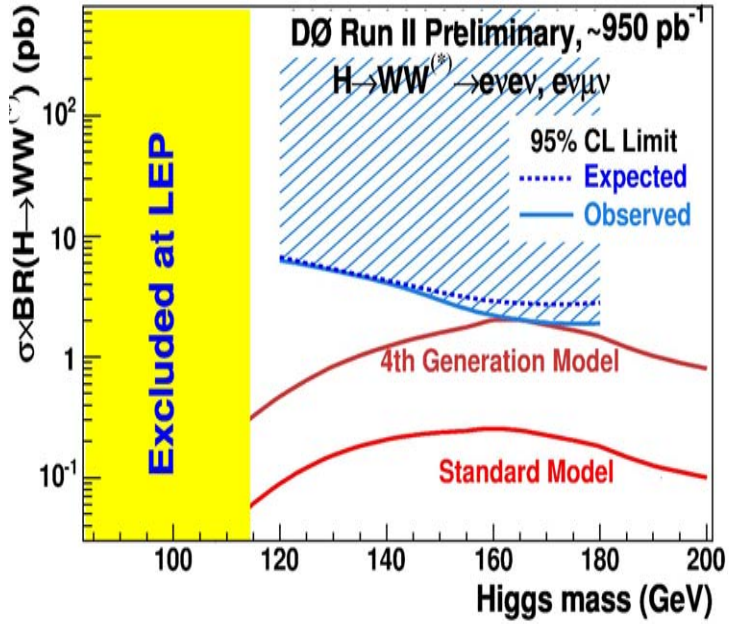
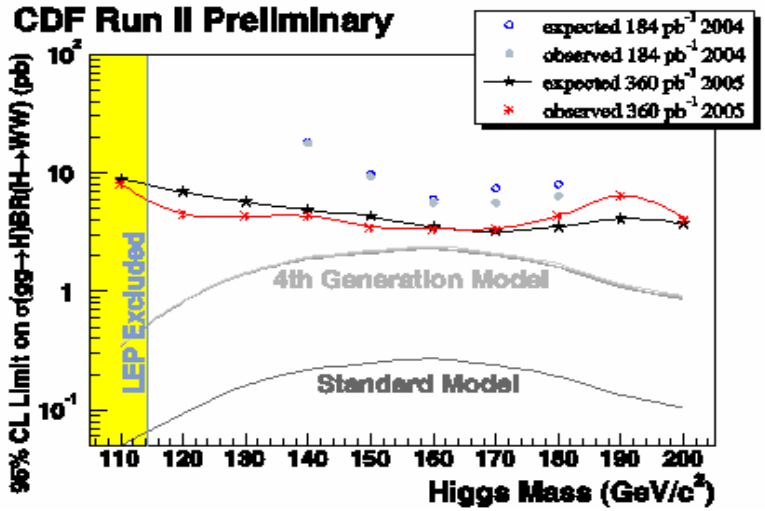


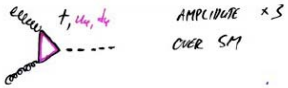

FIG. 2 (color online). Expected and observed upper limits on the cross section times branching ratio $\sigma \times \mathrm{BR}(H \rightarrow WW^{(*)})$ at the 95% C.L. together with expectations from standard model Higgs boson production and an alternative model. The LEP limit on the standard model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



# Tevatron 2008

## DØ Higgs Searches and a 4th Family



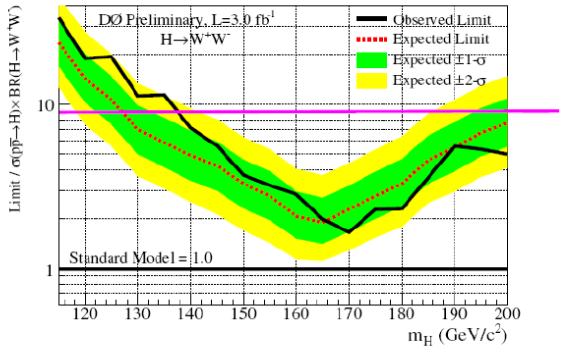

Andy Haas
Columbia University
*on behalf of the DØ experiment*

"Beyond 3 SM Families at the LHC"
CERN
Sept. 4-5, 2008

## H->WW-> lν lν

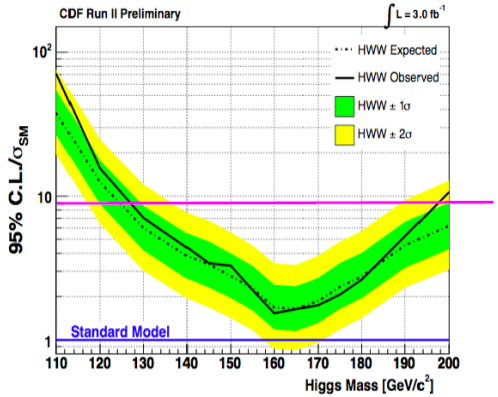
Need to learn exactly how to draw the purple line as a function of $m_h$
- gg->h enhancement
- BR(h->WW)

Only include gg->h signal
(This plot has VBF too, ~10% effect)




## H->WW-> lν lν

CDF has a similar result

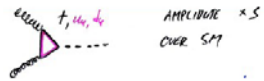







## Conclusions

4th family enhances gg->h cross-section dramatically!




!!

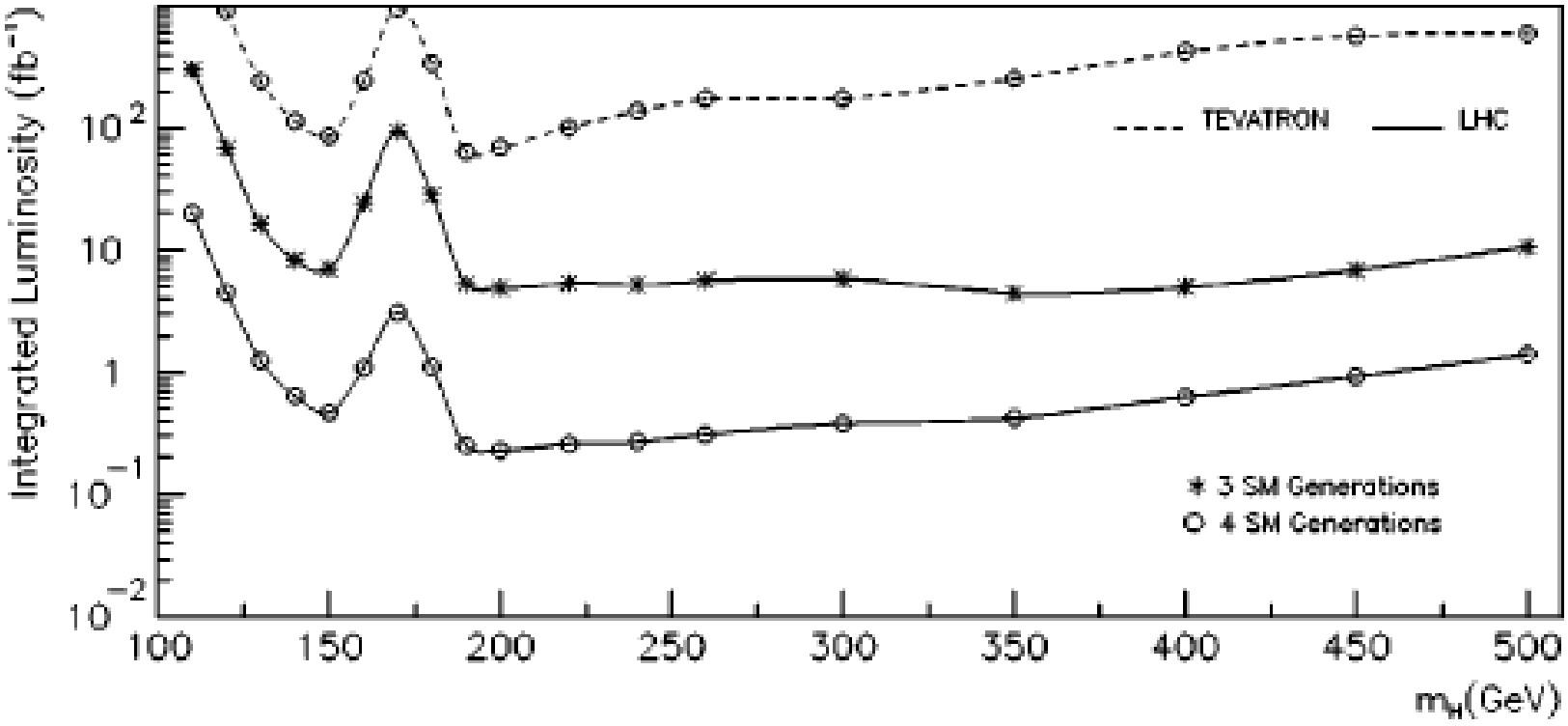
**DØ already has sensitivity to a ~130 – 200 GeV Higgs (in 4th family model)**
(~120 – 220 GeV if combined with CDF)

Precise interpretation in 4th family model and DØ / CDF combination underway...

***With full Tevatron data and analysis improvements, sensitive from LEP lower limit (110 GeV?) to ~240 GeV?***

**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



ATLAS Higgs Working Group Meeting
19.10.2007

# The impact of the fourth SM family on the Higgs observability at the LHC


Engin Arık [1]
Serkant Ali Çetin [2]
Saleh Sultansoy [3, 4]
Gökhan Ünel [5, 6]



e-Print's: **0708.0241**[hep-ph] & **arXiv:0707.3266**[hep-ph]

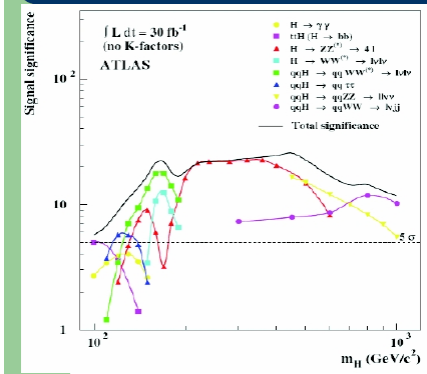


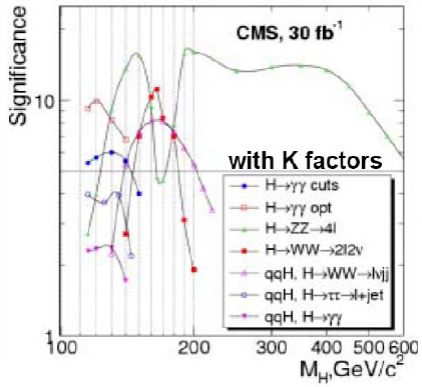
[1] Boğaziçi University, İstanbul
[2] Doğuş University, İstanbul
[3] TOBB ETU, Ankara
[4] Institute of Physics, Baku
[5] CERN
[6] University of California at Irvine



Saleh Sultansoy
TOBB University of Economics and Technology


**ATLAS (left) and CMS (right) sensitivities for the discovery of the SM Higgs boson in the 3 SM family case**




19.10.2007 / CERN ATLAS Higgs WG Meeting

arXiv:0708.0241 [hep-ph]


Saleh Sultansoy
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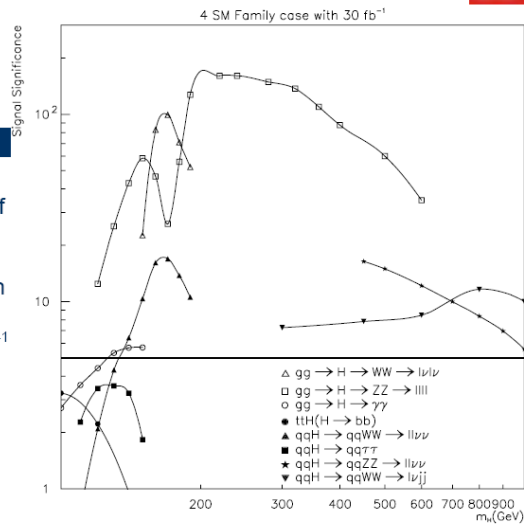
- ATLAS sensitivity for the discovery of the SM Higgs boson in the 4 SM family case with an integrated luminosity of 30 fb$^{-1}$

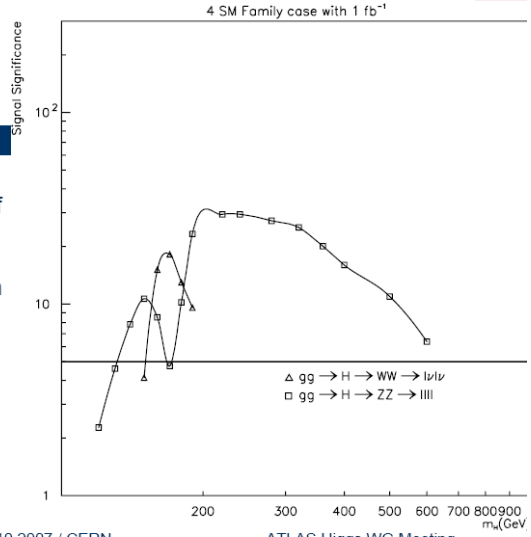



19.10.2007 / CERN ATLAS Higgs WG Meeting

arXiv:0708.0241 [hep-ph]


Saleh Sultansoy
TOBB University of Economics and Technology


- ATLAS sensitivity for the discovery of the SM Higgs boson in the 4 SM family case with an integrated luminosity of 1 fb$^{-1}$




19.10.2007 / CERN ATLAS Higgs WG Meeting

ATLAS Higgs Working Group Meeting
25.07.2008

# Golden Mode with the Fourth Family


Engin Arık [1] (1948-2007)
Neslihan Becerici [1]
Orhan Çakır [2]
Serkant Ali Çetin [1,3]
Saleh Sultansoy [2,4,5]

[1] Boğaziçi University, İstanbul
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## Enhancement of the Standard Model Higgs Boson Production Cross-section with the $4^{th}$ Standard Model Family


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ATL-PHYS-98-125 Quarks
26 Jan 1999


The first ATLAS document emphasizing $4^{th}$ family quark effects to Higgs production and decays

**2001:**
**"With four Standard Model families, the LHC could discover the Higgs boson with a few fb$^{-1}$"**
**SN-ATLAS-2001-006**; ATL-COM-PHYS-2001-019, Published in: **Eur. Phys. J. C 26 (2002) 9-11**

**2002:**
**"Consequences of the extra SM families on the Higgs boson production at Tevatron and LHC"**, e-Print: hep-ph/0203257, Published in **Phys.Rev.D66:033003,2002**.
**"The Fourth SM Family Enhancement to the Golden Mode at the Upgraded Tevatron"**,
e-print: hep-ph/0106312, Published in: **Phys. Rev. D 65 (2002) 013009**

**2005:**
**"Observability of the Higgs boson and extra SM families at the Tevatron"**
e-Print: hep-ph/0502050, Published in: **Acta Phys.Polon.B37:2839-2850,2006**.

**2007:**
**"The impact of the fourth SM family on the Higgs observability at the LHC"**,
e-Print: arXiv:0708.0241 [hep-ph], Published in **Balkan Physics Letters, 15(4) (2007)**

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## Golden mode in more detail*

*Work done by graduate student N. Becerici

| $m_H(GeV)$ | 120 | | 130 | | 140 | | 150 | | 160 | | 180 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | SM-3 | SM-4 | SM-3 | SM-4 | SM-3 | SM-4 | SM-3 | SM-4 | SM-3 | SM-4 | SM-3 | SM-4 |
| *Signal* | 0.281 | 1.474 | 0.816 | 4.436 | 1.511 | 8.877 | 1.94 | 12.94 | 1.03 | 8.121 | 1.32 | 10.69 |
| $ZZ^*/\gamma^*$ | 0.143 | | 0.150 | | 0.163 | | 0.151 | | 0.208 | | 0.938 | |
| $Zbb$ | 0.055 | | 0.047 | | 0.026 | | 0.021 | | 0.015 | | 0.013 | |
| $tt$ | <0.04 | | <0.04 | | <0.04 | | <0.04 | | <0.04 | | <0.04 | |
| sign. (1 fb$^{-1}$) | 0.5 | 2.0 | 1.3 | 4.5 | 2.1 | 7.2 | 2.6 | 9.3 | 1.5 | 6.6 | 1.1 | 6.0 |
| sign. (3 fb$^{-1}$) | 0.9 | 3.5 | 2.2 | 7.8 | 3.6 | 12.5 | 4.4 | 16.2 | 2.6 | 11.5 | 1.9 | 10.5 |
| sign. (10 fb$^{-1}$) | 1.6 | 6.4 | 4.1 | 14.2 | 6.6 | 22.8 | 8.1 | 29.6 | 4.7 | 21.0 | 3.6 | 19.2 |
| sign. (30 fb$^{-1}$) | 2.8 | 11.2 | 7.1 | 24.7 | 11.5 | 39.6 | 14.2 | 51.3 | 8.2 | 36.4 | 6.2 | 33.2 |

Table 2: Cross sections (in fb) for the signal and irreducible and reducible backgrounds. The expected significance is given for 1, 3, 10 and 30 fb$^{-1}$.

Background and SM3 signal cross sections taken from "Search for the Standard Model H -> ZZ*->4l with the ATLAS Detector" note.

Significances calculated using: $\sqrt{2}\sqrt{(s+b)\ln(1+s/b)-s}$

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## Golden mode in more detail*

*Work done by graduate student N. Becerici

| $m_H(GeV)$ | 200 | | 300 | | 400 | | 500 | |
|---|---|---|---|---|---|---|---|---|
| | SM-3 | SM-4 | SM-3 | SM-4 | SM-3 | SM-4 | SM-3 | SM-4 |
| *Signal* | 6.68 | 53.08 | 4.21 | 28.10 | 3.34 | 14.60 | 1.66 | 6.92 |
| $ZZ^*/\gamma^*$ | 3.09 | | 1.65 | | 1.21 | | 1.14 | |
| sign. (1 fb$^{-1}$) | 3.0 | 14.8 | 2.5 | 10.7 | 2.3 | 7.2 | 1.3 | 4.2 |
| sign. (3 fb$^{-1}$) | 5.2 | 25.6 | 4.4 | 18.6 | 4.0 | 12.5 | 2.2 | 7.2 |
| sign. (10 fb$^{-1}$) | 9.5 | 46.8 | 8.0 | 34.0 | 7.3 | 22.8 | 4.1 | 13.3 |
| sign. (30 fb$^{-1}$) | 16.5 | 81.1 | 13.8 | 58.9 | 12.7 | 39.5 | 7.1 | 22.6 |

Table 3: Cross sections (in fb) for the signal and reducible background. The expected significance is given for 1, 3, 10 and 30 fb$^{-1}$.

# Golden mode in more detail*

*Work done by graduate student N. Becerici

| $m_H(GeV)$ | 120 | | 130 | | 140 | | 150 | | 160 | | 180 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | SM-3 | SM-4 | SM-3 | SM-4 | SM-3 | SM-4 | SM-3 | SM-4 | SM-3 | SM-4 | SM-3 | SM-4 |
| $3\sigma$ | 31.6 | 1.37 | 5.34 | 0.44 | 2.02 | 0.17 | 1.34 | 0.10 | 3.97 | 0.20 | 6.85 | 0.24 |
| $5\sigma$ | 87.9 | 3.80 | 14.8 | 1.22 | 5.62 | 0.47 | 3.72 | 0.28 | 11.0 | 0.56 | 19.0 | 0.67 |

Table 4: Luminosity (in $fb^{-1}$) needed for $3\sigma$ and $5\sigma$

| $m_H(GeV)$ | 200 | | 300 | | 400 | | 500 | |
|---|---|---|---|---|---|---|---|---|
| | SM-3 | SM-4 | SM-3 | SM-4 | SM-3 | SM-4 | SM-3 | SM-4 |
| $3\sigma$ | 1.0 | 0.04 | 1.39 | 0.07 | 1.67 | 0.17 | 5.25 | 0.50 |
| $5\sigma$ | 2.73 | 0.11 | 3.88 | 0.21 | 4.65 | 0.48 | 14.6 | 1.41 |

Table 5: Luminosity (in $fb^{-1}$) needed for $3\sigma$ and $5\sigma$

!!

**In the SM-4 case LHC with $\sqrt{s}$=10 TeV and $L^{int}$=200 $pb^{-1}$ will cover 190-330 GeV at 3σ level**

# Fourth Family Neutrinos and Higgs Boson

T.Cuhadar Donszelman (University of Sheffield)
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

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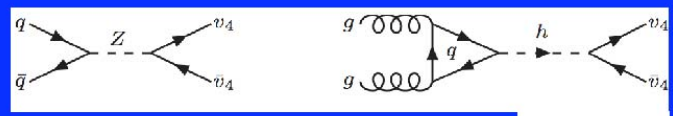
## Introduction

- Can the 4th family members be observed in LHC/ATLAS ?
- We have investigated the existence of $\nu_4$ and the impact on the SM Higgs boson through ("silver mode") :

  $pp \rightarrow h \rightarrow \nu_4 \bar{\nu}_4$ (suggested by S. Sultansoy & G. Unel, Tr.J.Phys. 31 2007)
- $\nu_4$ can still be produced via (in case Higgs does not exist )

  $pp \rightarrow Z \rightarrow \nu_4 \bar{\nu}_4$




q = t, b, $u_4$, $d_4$

- Majorana or Dirac nature of $\nu_4$ is studied
  - Particle =? Anti-Particle
- Preliminary results available in ArXiv:0806.4003v3 [hep-ph], Submitted to JHEP.

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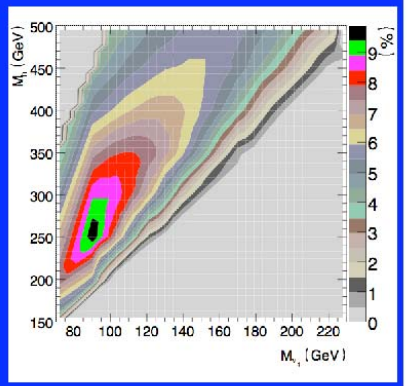
## Higgs Decay Branching Fraction

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

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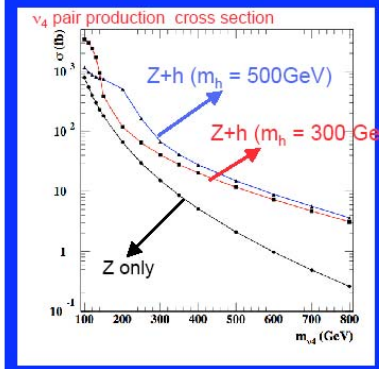
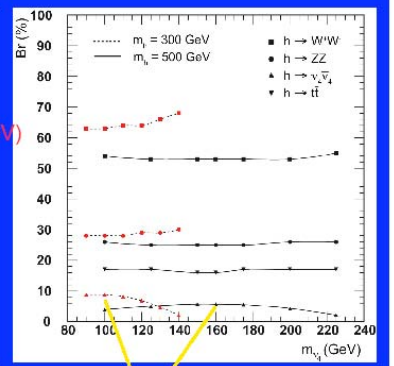
## $\nu_4$ Cross Section & Branching fraction




Two $\nu_4$ mass values chosen as benchmark points

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## Signal Events

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

Summary of Benchmark points:

| | $\sigma_{pp\rightarrow Z\rightarrow\nu_4\bar{\nu}_4}$ (fb) | $m_h$ (GeV) | $\sigma_{gg\rightarrow h}$ (pb) | $m_{\nu_4}$ (GeV) | BR($h\rightarrow\nu_4\bar{\nu}_4$) | $\sigma_{pp\rightarrow\nu_4\bar{\nu}_4\rightarrow WW\mu\mu}$ (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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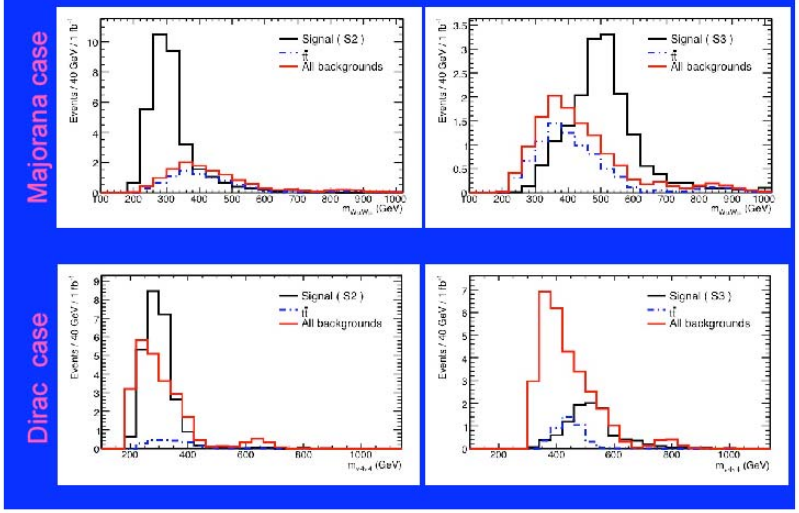
## Reconstructed Higgs Mass

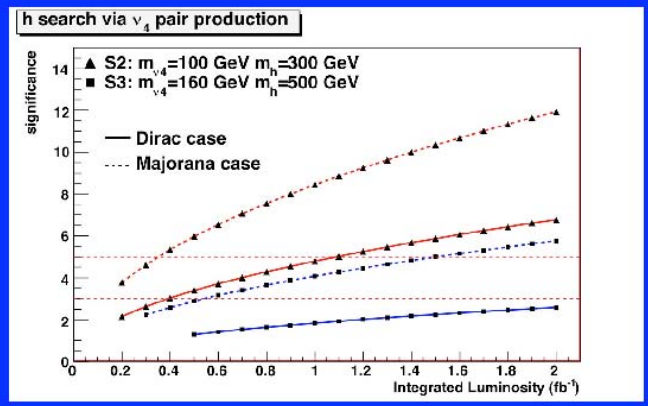



## Significance (cont'd)

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

$m_h$ = 500 GeV, 3$\sigma$ 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 $\nu_4$-pair in ATLAS
  and/or
  $\nu_4$ can be discovered
- Two masses of higgs boson are considered
- With 1-2 fb$^{-1}$, both $\nu_4$ 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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# 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 σ, 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 3σ 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