Four Statements about the Fourth Generation

Gökhan Ünel / *U.C Irvine*

2nd Workshop on “Beyond 3-Generation SM”
New Fermions at the Crossroads of Tevatron and LHC

14-16 January 2010 - NTU/ Taiwan

...previously

- Once popular, an additional 4th generation was no longer "a la mode". Last workshop around late 1980s
  - ➡misinformation disseminated by PDG contributed to this omission.

- S. Sultansoy (Turkey) had the idea of organizing a topical workshop, to gather the 4 family SM enthusiasts
  - ➡Recent "flavour at the LHC era" workshop had put us in contact with some of the key players (Hou, Hurt, Mangano,...)

- The first topical workshop since long time in September 2008: "Beyond the 3SM generation at the LHC era"
  - ➡A 2 day event at CERN with 32 talks
  - ➡details @ http://indico.cern.ch/conferenceDisplay.py?confId=33285

Beyond the 3SM generation at the LHC era Workshop

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4-5 September 2008 CERN

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"Beyond the 3SM generation at the LHC era" workshop aims to review the status of the models with additional fermion families. Theory, precision data from b/c factories, astroparticle/cosmology and collider aspects will be reviewed in this 2 day workshop.

Dates: from 04 September 2008 09:00 to 05 September 2008 19:45

Location: *CERN*
Room: **40-S2-D01**

Chairs: Holdom, Robert
Hou, George
Sultansoy, Saleh
Unel, Gokhan
Mangano, Michelangelo
Hurth, Tobias

Material: **agenda**

Additional info: Organizing Committee:

R. Holdom (University of Toronto, Canada)
G. Hou (National Taiwan University, Taiwan)
M. Mangano (CERN, Switzerland)
L. Mapelli (CERN, Switzerland)
S. Sultansoy (TOBB Economics and Technology University, Turkey)
G. Unel (University of California at Irvine, USA & CERN, Switzerland)

T. Hurth (CERN, Switzerland, as link to WG on Interplay Between Collider & Flavour Physics)

Many thanks to L. Mapelli (CERN) to pick up the phone and convince some of the colleagues to help us.

goals of the 1st workshop

- Renew the interest in 4th generation phenomenology
  - ➡Review Theory, astroparticle/cosmology, B factories and hadron collider aspects
  - ➡motivate the experiments (experimenters) for searches involving the 4th family
  - ➡Bring together experimentalists & theorists
    - Establish a "user" basis : get the know each other.

- More goals appeared after the workshop
  - ➡find common notation (difficult task!)
  - ➡write up a summary of the workshop
    - which was subsequently published as the "4 Statements"

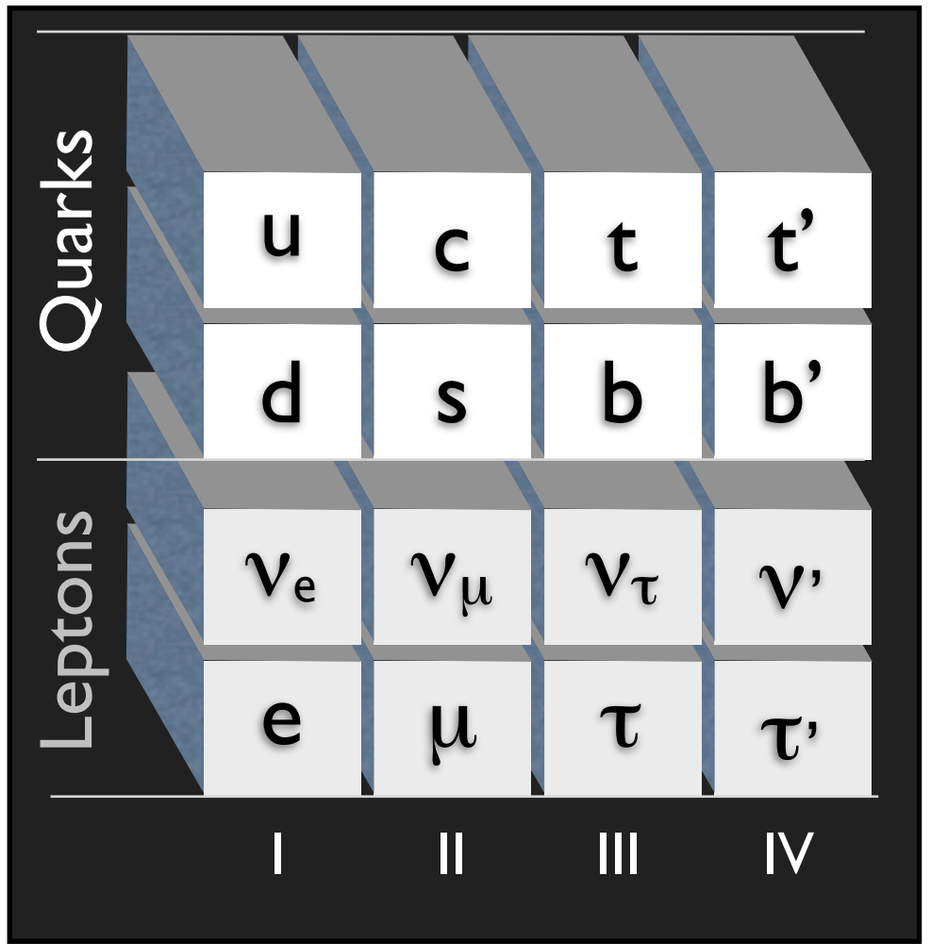
1)The fourth generation (SM4) is not excluded by EW precision data.
2)The SM4 addresses some of the currently open questions.
3)The SM4 can accommodate emerging possible hints of new physics.
4)LHC has the potential to discover or fully exclude the SM4.

arXiv:0904.4698 PMC Phys.A3:4,2009

What is it?

- 4th generation is the simplest "modification" to SM
  - ➡SM does not give #families => not a true modification
  - ➡upper bound from QCD (asymptotic freedom): #families < 9
  - ➡predicts 4 new heavy fermions with 1TeV > m >100GeV

$m_{t'} > 256\,\text{GeV}$; $m_{b'} > 128\,\text{GeV}$ (CC decay; 199 GeV for 100% NC decay);
$m_{\tau'} > 100.8\,\text{GeV}$; $m_{\nu'_\tau} > 90.3\,\text{GeV}$ (Dirac coupling; 80.5 GeV for Majorana coupling)



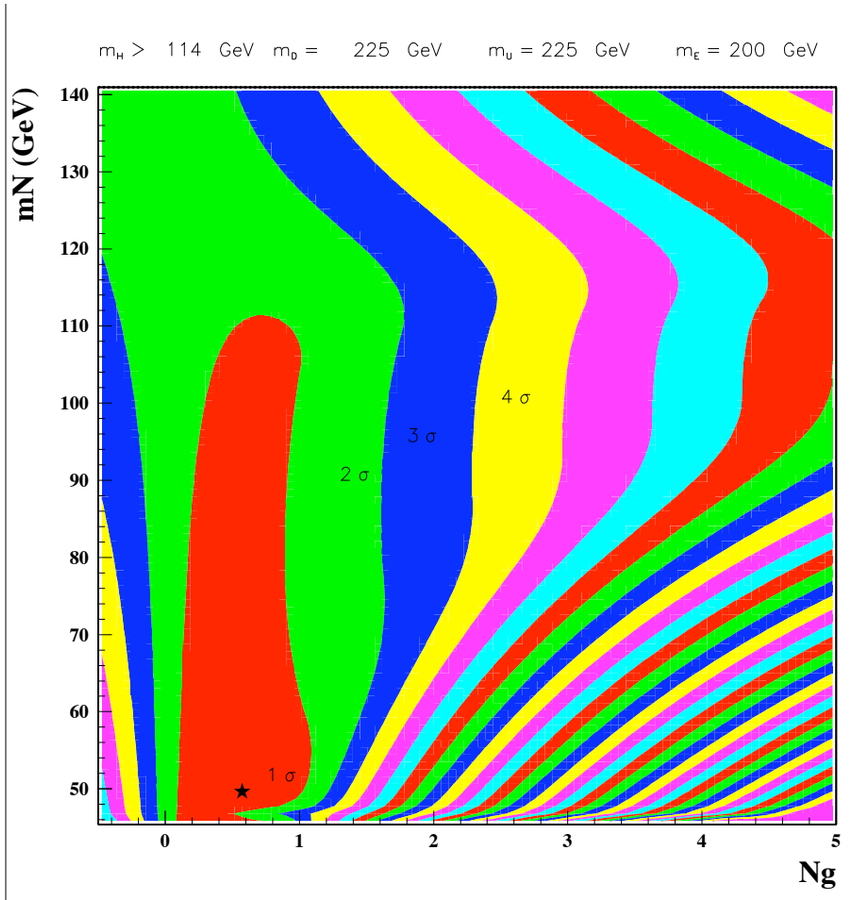
S1: viability

- What about the 6σ evidence reported by PDG against 4th generation from the "S parameter alone"?
  - ➡Valid only if total mass degeneracy, e.g.

$$\delta S = \frac{2}{3\pi} - \frac{1}{3\pi}\left[\log\frac{m_{t'}}{m_{b'}} - \log\frac{m_{\nu'_\tau}}{m_{\tau'}}\right]$$

  - ➡adjusting the mass split cures the problem

- What about EW fits?
  - ➡SM3 & SM4 have same χ^2 from fits, for certain mass values
  - ➡SM4 can accommodate heavier Higgs better than SM3.
  - ➡Majorana neutrinos contribute negatively to T, better suiting to EW precision data



S1: viability (cont.)

- What about CKM & PMNS?
  - ➡There is enough uncertainty to extend the known 3x3 fermion matrices to their 4x4 counterparts.
  - ➡for the most precise measured row 1:

$$|V_{ud}|^2 + |V_{us}|^2 + |V_{ub}|^2 = 0.9999 \pm 0.0011 = 1 - |V_{ub'}|^2$$

$$|V_{ub'}| < 0.04$$

  - ➡an analysis of W & τ decays combining hadronic and leptonic modes including the correlation study would improve the constraints.

S2: desirability

- CPV source for BAU problem
  - ➡3x3 CKM is 10^{10} too short to match WMAP data
  - ➡new quarks of (300) 600 GeV would give (10^{13}) 10^{15} more CPV
- Alternative EW symmetry breaking (composite Higgs)
  - ➡4th generation fermion condensate can play the role of the Higgs via some strong interaction. Such a model could also explain the lightness of neutrino masses.
  - ➡if fermions propagate in 5D AdS, Kaluza-Klein excitations of gauge bosons interacting with 4th generation fermions give rise to Yukawa couplings & give rise to the mass hierarchy
- Fermion mass hierarchy (Democratic Mass Matrix)
  - ➡Observed masses of fermions in the first 3 families arise from small perturbations to a flavour-blind 4x4 mass matrix.
  - ➡Could be the reason for only 4 families and small ν masses.

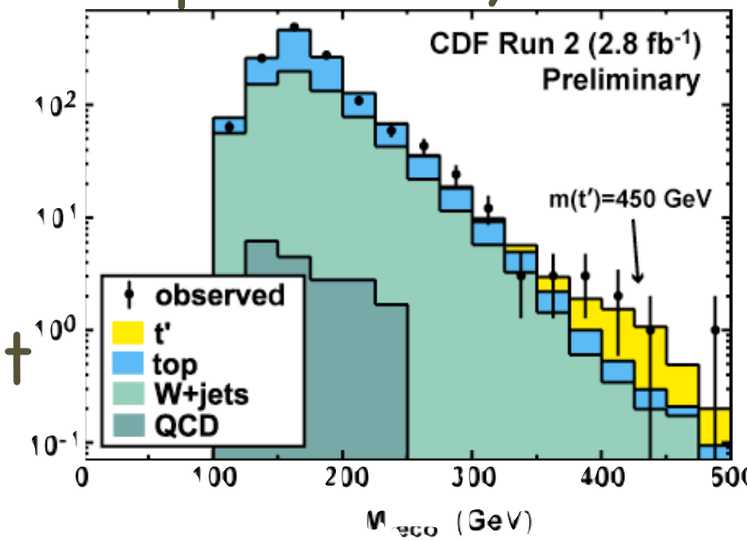
S2: desirability (cont.)

- Dark Matter candidates
  - ➡new fermions (singlets, sterile neutrinos, mirror fermions) can be cold DM candidates
  - ➡additional families from spin-charge unification models as DM candidates
  - ➡hadrons from stable t′, ν′ could be composite (warm) DM candidates, explaining the results of DAMA & Integral experiments

S3: accountability

- Caution:
  - ➡experiments tacitly assume unstable quarks, usual mixing angles, 100% branching fractions. These assumptions are to be kept in mind.

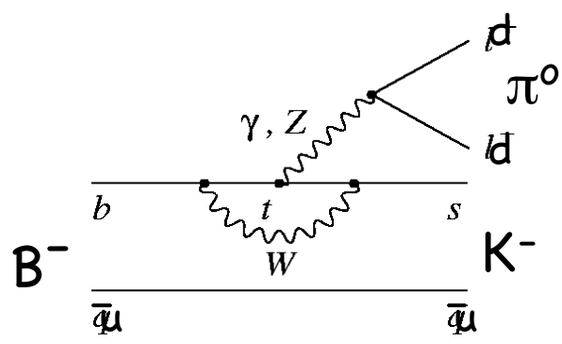
- Tevatron Hints
  - ➡excess in direct t' search via Wj channel could be explained by SM4 (but x-section too small)



  - ➡2.8σ deviation from SM of the mixing-dependent CPV in $B_s \to J/\Psi\,\Phi$ could be explained by SM4

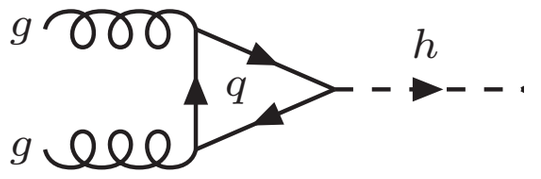
- Indirectly from B-factories
  - ➡Direct CPV difference in $B^+ \to K^+\pi^0$ & $B^0 \to K^+\pi^-$ established above 5σ could also be explained by SM4

$$\Delta A_{K\pi} = A_{cp}(K^+\pi^-) - A_{cp}(K^+\pi^0) = -0.147 \pm 0.028 \;@\; 5.3\sigma$$



S4: discoverability

- Tevatron prospects:
  - ➡direct searches still ongoing...
  - ➡indirect searches via Higgs production is possible



    - quarks can be indirectly discovered since the gluon fusion loop would be enhanced by the additional quarks by about x8

- ATLAS/CMS prospects @ 14 TeV (somewhat weaker @ 10TeV)
  - ➡Can discover or exclude the 4th generation models
  - ➡Quark pair production is the main target (analysis & results depend on masses & mixing w/ light vs heavy families) for early data
    - ATLAS (TDR, post-TDR) 0.4fb^{-1} Lumi reaches 500GeV at 5σ
    - CMS (post TDR) : 0.1fb^{-1} Lumi reaches 300GeV at 7σ
  - ➡Neutral leptons can be searched as well via Z/H mediated channels which would probe Dirac vs Majorana nature of the neutrinos.
  - ➡indirect searches via Higgs production is possible, increasing the "golden mode" range maximally with 1fb^{-1} data.

S4: discoverability (cont.)

- more on LHC searches
  - ➡Single and/or anomalous production => a possibility that would help to measure 4x4 CKM entries. (suppressed @ SM3 masses)
  - ➡Boosted W's invariant mass can be reconstructed as a "single jet"

- LHCb prospects
  - ➡$B_s \to J/\Psi\ \Phi$ anomaly can be fully exploited at the LHC using early data ($0.5\ fb^{-1}$)
  - ➡$B_d \to K^*\ \mu^+\ \mu-$ hint could be compared to the SM using $1 fb^{-1}$.

- Prospects for future colliders
  - ➡Charged leptons could be pair produced at the Linear Colliders.
  - ➡If not enough energy is available, single production could be considered provided there is enough mixing or additional NP such as 2HDM.

conclusions

- The reports of the death of the 4th generation have been greatly exaggerated.
  - ➡The field is, in fact, active and thriving
  - ➡viable !
  - ➡desirable !!
  - ➡discoverable !!!

outlook

- Our interest in 4th SM generation is obvious
  - ➡Dedicated day at CERN TH Institute in August 2009.
  - ➡This workshop to review the progress since September 2008.

- But there is more...
  - ➡"...workshop will focus on work that has come out since the first workshop, while covering some topics that may have been left out previously. The aim is to bring together theorists and experimentalists with active interests in the 4th generation, or any kind of new fermions beyond the existing ones..."

  - ➡Expect talks/discussions about BSM fermions from LH, ED, E6, TC,...