A 4th generation scenario

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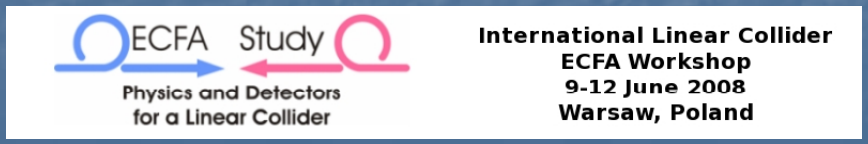
Beyond the 3SM generation at the LHC era



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Introduction

- In view of the LHC start, it seems worthwhile to envisage unexpected (but well motivated) scenarios which would strongly impact on ILC

  Examples:
- Discovery of a heavy Higgs
- Discovery of heavy fermions with or without SUSY
- This talk is presenting one of these scenarios

Outline

- Is a 4th generation allowed by LEP/SLC/TeVatron PM ?
- Is it useful and why ?
- What does it predict ?
- Are there some experimental indications ?
- Apologies: very incomplete discussion & referencing

$$\Delta T \sim \frac{\Delta m^2}{(150GeV)^2}$$

4th & PM

- Common wisdom (PDG): 4th chiral generation is excluded by S/T constraints.
- Excluded only for the mass degenerate case
- $\Delta T=0 \quad \Delta S=2/3\pi$

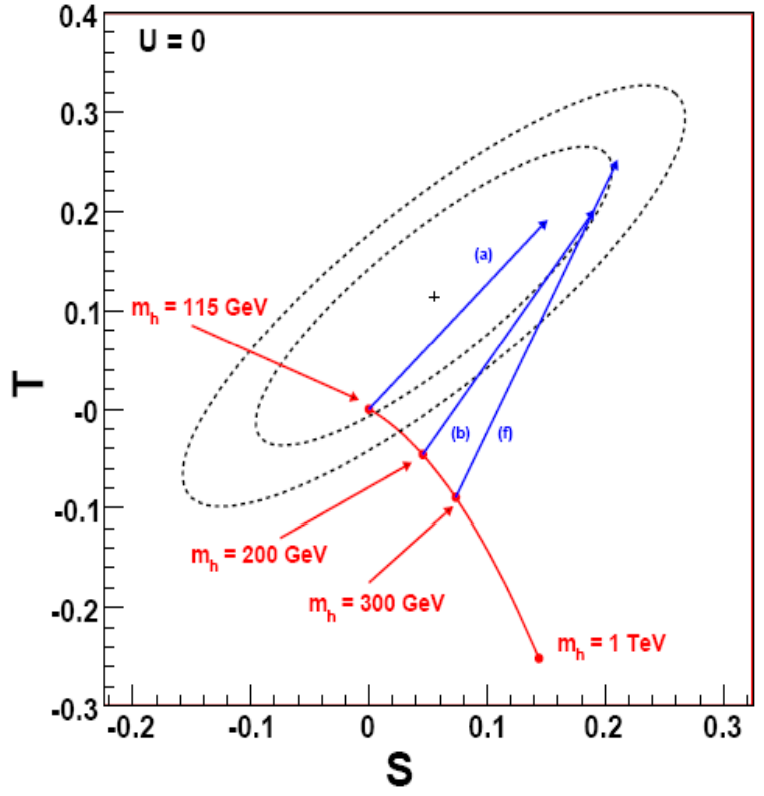
$$\Delta S = \frac{N_c}{6\pi}\left(1 - 2Y \ln \frac{m_u^2}{m_d^2}\right)$$

$$\Delta T \sim \frac{\Delta m^2}{(150GeV)^2}$$

- One can play with the >0 correlation between these variables and easily pass the constraints when fermions are partially degenerate in mass

An example

parameter set	m_{u_4}	m_{d_4}	m_H	$\Delta S_{\rm tot}$	$\Delta T_{\rm tot}$
(a)	310	260	115	0.15	0.19
(b)	320	260	200	0.19	0.20
(c)	330	260	300	0.21	0.22
(d)	400	350	115	0.15	0.19
(e)	400	340	200	0.19	0.20
(f)	400	325	300	0.21	0.25



- G. Kribs et al
  http://arxiv.org/abs/0706.3718v1
- Heavy Higgs allowed

Motivation for >3 generations

- Baryogenesis needs C+CP violation & strong EW 1st order transition

  SM alone
- Not enough CPV
- Insufficient EW transition

  MSSM alone
- New phases but severely constrained by EDM
- EW transition not strong enough unless very FT (light stop ?)
- -> extra particles needed, strongly coupled to the Higgs field, scalars or fermions

  (cf. M. Carena et al hep-ph 0410352)

4th generation

- CPV fine (2 extra phases in CKM; Jarlskog determinant >> SM)
- Large Yukawa couplings $y_{t'}$ to Higgs field (NB: $y_{t'}$ and quartic coupling λ become **strong** at scale Λ~TeV)
- However not enough to get the right EW transition
- Works including SUSY, hence 4MSSM
- R. Fok G. Kribs **arXiv:0803.4207**

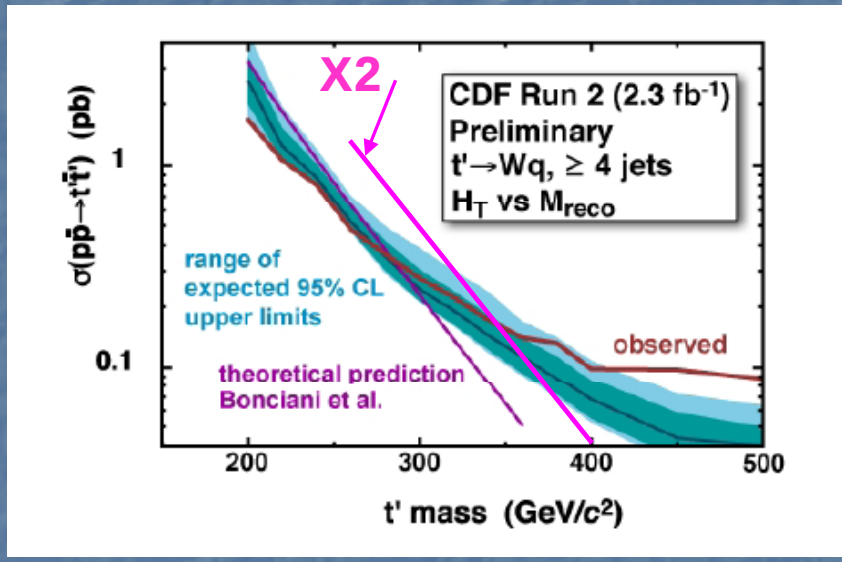
Predictions:

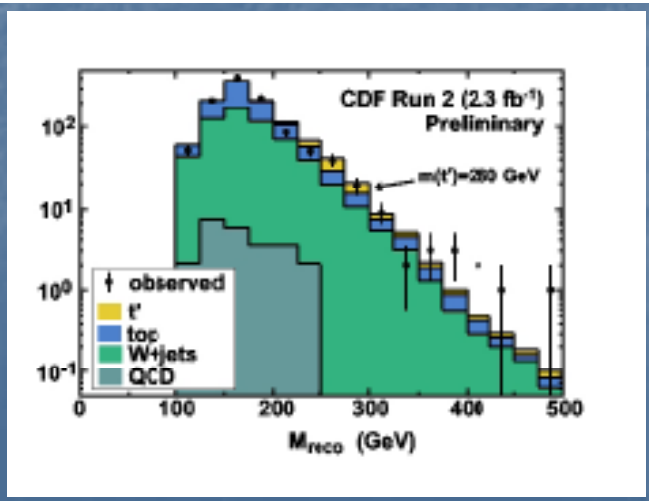
- 300<Mt',b'<450 GeV + lighter leptons
- squarks ~ mass degenerate with quarks
- Higgs could be heavy through RC
- Spectacular & early signals at LHC
- Accessible at a TeV LC (heavy leptons)
- Note that Tevatron already excludes mt'<260 GeV & 140<mH<180 GeV
- The latter is due to X9 cross section in gg->H

$$m_h^2 = \sum_{f=t,t',b'} \frac{3}{2\pi^2} \frac{m_f^4}{v^2} \ln \frac{m_f^2}{m_f^2} .$$

Search at TeVatron

- Recent CDF update 2.3fb-1
  http://www-cdf.fnal.gov /physics/new/top/2008/tprop/Tprime2.3/cdf9234_tprime_23_pub.pdf
- **Mt'>284 GeV**
- Slight excess above this limit
- Assumes t'->Wq with mt'-mb'<Mw
- Should therefore add the b' contribution and X2 ?
  -> mt',b'>330 GeV ?





The flavour sector

- **Bs** SM mixing goes like ~mtVtb without CPV
- mt'Vt'b could be of similar size

$$\frac{NP}{SM} = \frac{m_{t'}}{m_t}\frac{V_{t'b}V_{t's}}{V_{ts}} \leq 1$$

- Vt'b complex, then CPV present in Bs mixing
- More generally CPV present in b->s transitions while are almost absent in the SM
- Has it been seen ?

b->s with 4 generations

- Several indications b->s ‘penguin’ transitions but plagued by usual QCD uncertainties
- cf. e.g. Kπ puzzle G. Hou **arXiv:0710.5424**
- For the 1st time Tevatron is measuring the time dependence of the ‘gold plated’ mode J/ΨΦ with tagged events
- Could provide an unambiguous answer with sufficient statistics
- ☞ Watch carefully

UTfit

- Recent but unofficial (UTfit collaboration) combination of CDF (1.35 fb-1)+D0 gives ~3 σ effect on CPV for Bs with 2 solutions
- One of them has NP/SM<1
- The 2nd solution removed using $J/\Psi K^*$+SU(3)
- http://fr.arxiv.org/abs/0803.0659v1

$\phi_s^{\rm NP}[^\circ]$	-51 ± 11
	-79 ± 3
$A_s^{\rm NP}/A_s^{\rm SM}$	0.73 ± 0.35
	1.87 ± 0.06

$$C_{B_s} e^{2i\phi_{B_s}} = \frac{A_s^{\rm SM} e^{-2i\beta_s} + A_s^{\rm NP} e^{2i(\phi_s^{\rm NP} - \beta_s)}}{A_s^{\rm SM} e^{-2i\beta_s}}$$

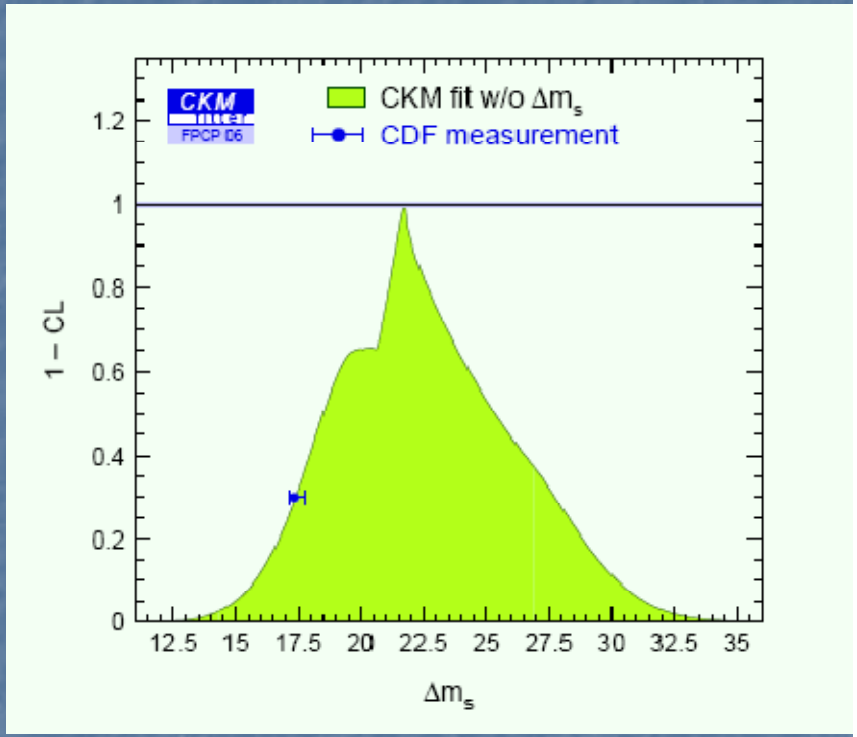
Δms

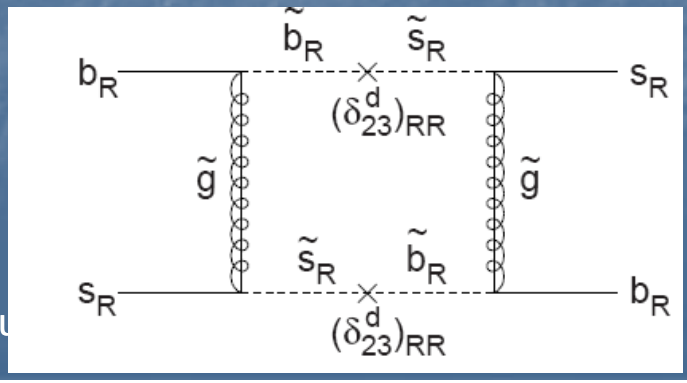
- The UTfit negative phase predicts a destructive interference SM-NP with reduction on Δms
- Indicated (with usual QCD caveats) by the CKM fit
- Other interpretations of b->s are obviously possible e.g. within SUSY-GUT where $\nu \sim b_R$ implies large $s_R \leftrightarrow b_R$ (see D. Chang et al.)

Phys.Rev.D67:075013,2003

- Less predictive, allows NP>>SM as in R. Harnik et al. **Phys.Rev.D69:094024,2004**

☞ Keep an eye on these developments





Possible scenario

- At LHC an early discovery of the new fermions + SUSY squarks
- A heavy Higgs very easily observed or a light Higgs as difficult as SM

  (same 2γ rate but H->2 g prominent)
- Rich and confusing
- ILC at 500 GeV very powerful in particular for leptons and for a light Higgs
- 1 TeV is needed to measure the heaviest quarks and the squarks

Final remarks

- For simplicity one assumes a 4th generation, simple replica of the first 3
- It seems that this is an unnecessary limitation
- What matters is the occurrence of extra heavy quarks which provide the extra degrees of freedom needed for baryogenesis and CPV in the b sector
- Models predicting KK extra fermions e.g. on the basis of ND>4 could also provide similar mechanisms
- This type of scenario needs to be investigated in more detail in specific cases

Conclusion

- A reasonably well motivated scenario
- Requires SUSY but cannot be extrapolated to GUT because of the large Yukawa constants
- Early signals expected at LHC (or even at Tevatron with full luminosity)
- Allows for a heavy Higgs within SUSY
- Rich physics for a TeV LC with access to squarks
- Watch for the Bs sector @ Tevatron
- -> Could serve as an illustration of LHC/LC complementarity

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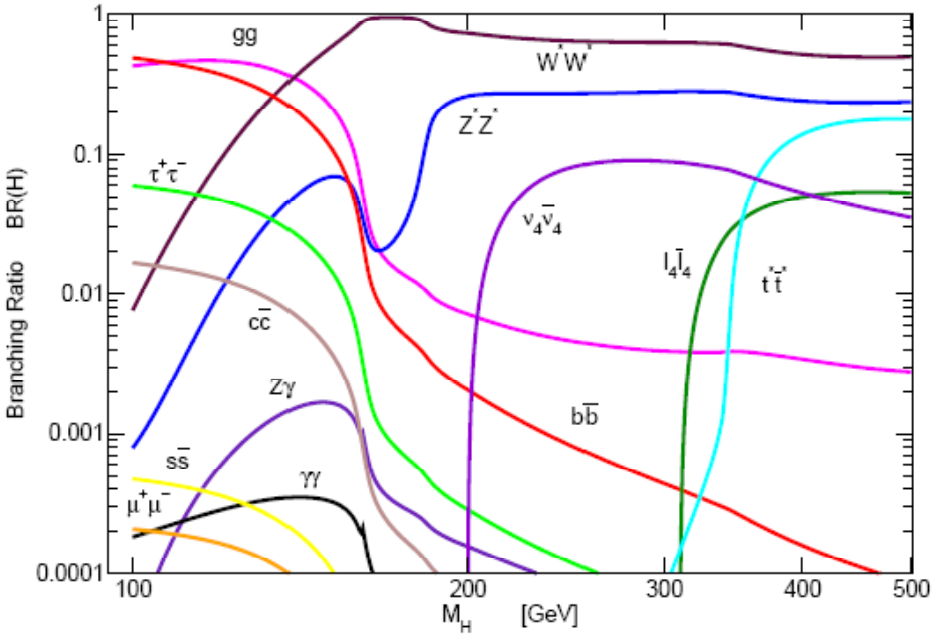
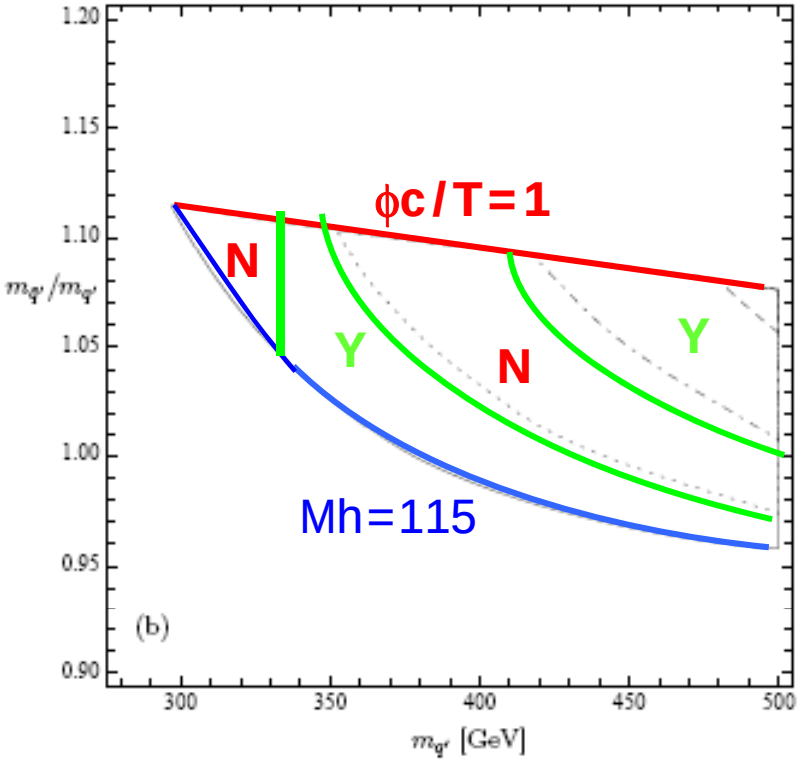
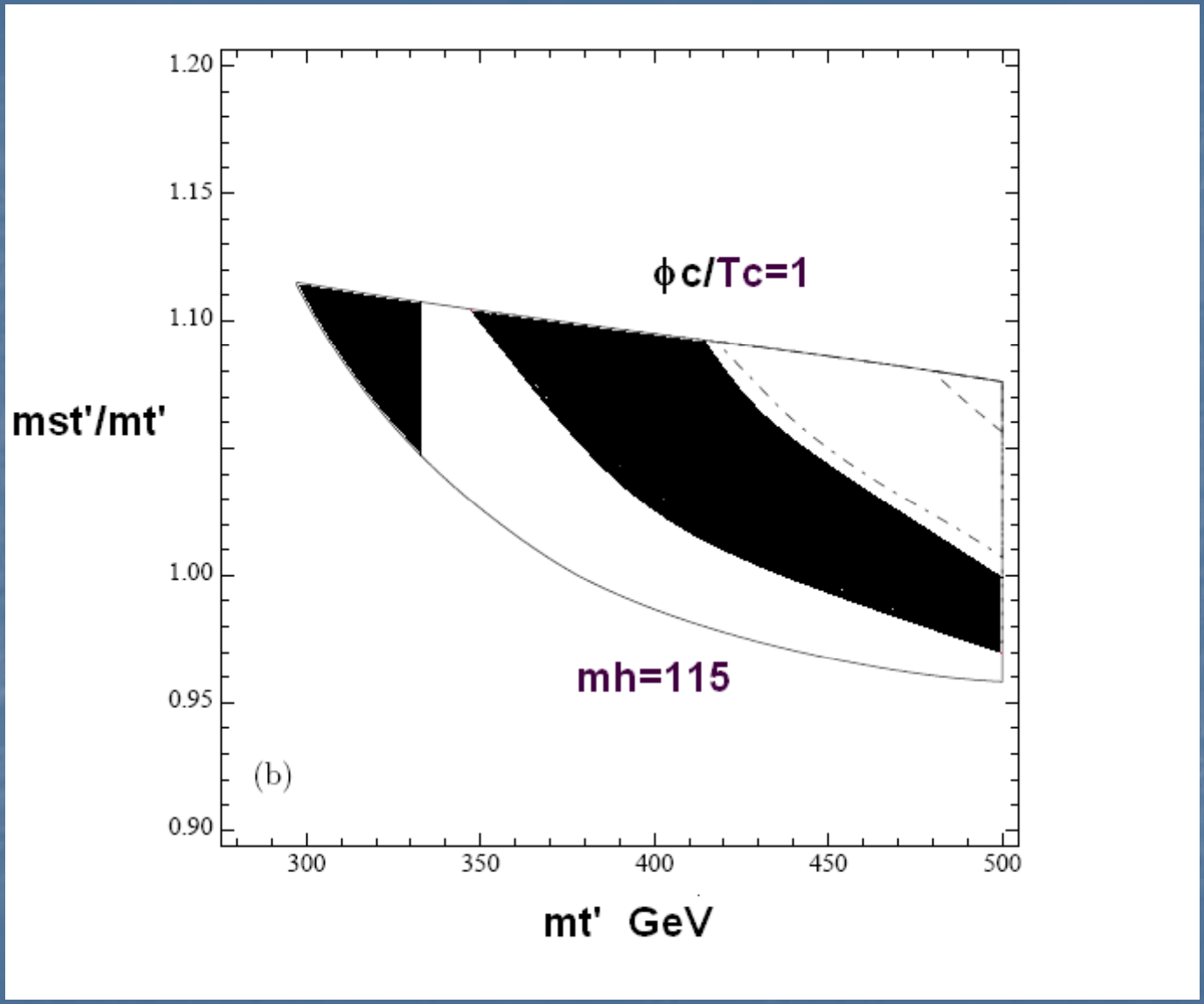
4-5 September 2008

http://indico.cern.ch/conferenceDisplay.py?confId=33285


gg
W*W*
Z*Z*
τ+τ−
νν
ll
tt
cc
Zγ
bb
ss
γγ
μ+μ−
Branching Ratio BR(H)
1
0.1
0.01
0.001
0.0001
100
200
300
400
500
M_H [GeV]


F. Richard ECFA Stu


φc/T=1
N
Y
N
Y
Mh=115
(b)
1.20
1.15
1.10
1.05
1.00
0.95
0.90
300
350
400
450
500
m_q' [GeV]


1.20
1.15
1.10
1.00
0.95
0.90
mst'/mt'
ϕc/Tc=1
mh=115
(b)
300
350
400
450
500
mt' GeV