4th generation

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for the 4th generation WG of LAL-LPT-Orsay

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LABORATOIRE DE L'ACCÉLÉRATEUR LINÉAIRE

In2p3

Outline

- Intro: what’s so exciting about the 4th generation?
- Signal search at high energy colliders
- Flavour physics
- Conclusions

Introduction

What’s so exciting about the 4th generation?

Experimental aspects...

Heavy fermion production

4th generation ➠ a few hundreds GeV fermion ➠ early discovery at LHC!

Bs-Bs mixing

4th generation ➠ new CP phases ➠ Bs oscillation at LHCb!

Single top production

4th generation ➠ 4x4 CKM ➠ determination of Vtb at LHC!

What’s so exciting about the 4th generation?

Theoretical aspects...

Simplest extension of SM (few new parameters)

Very clear flavour-collider interplay (mass v.s. CKM)

Many new physics models “require” a heavy fermion!

- ✌ 4th gene. baryogenesis
  - *Fok and Kribs 0803.4207*
  - *Kikukawa et al 0901.1962*
  - *Hou 0803.1234*
- ✌ Composite Higgs
  - *Burdman et al 0812.0368*
- ✌ Extra-D (KK fermion)

Impact of the Tevatron mass bound

discussed more in details at "Beyond the 3SM gene. workshop"
see e.g. talk by Holdom, Da Rold ...

- The Tevatron bounds on the 4th generation masses imply a large Yukawa coupling:

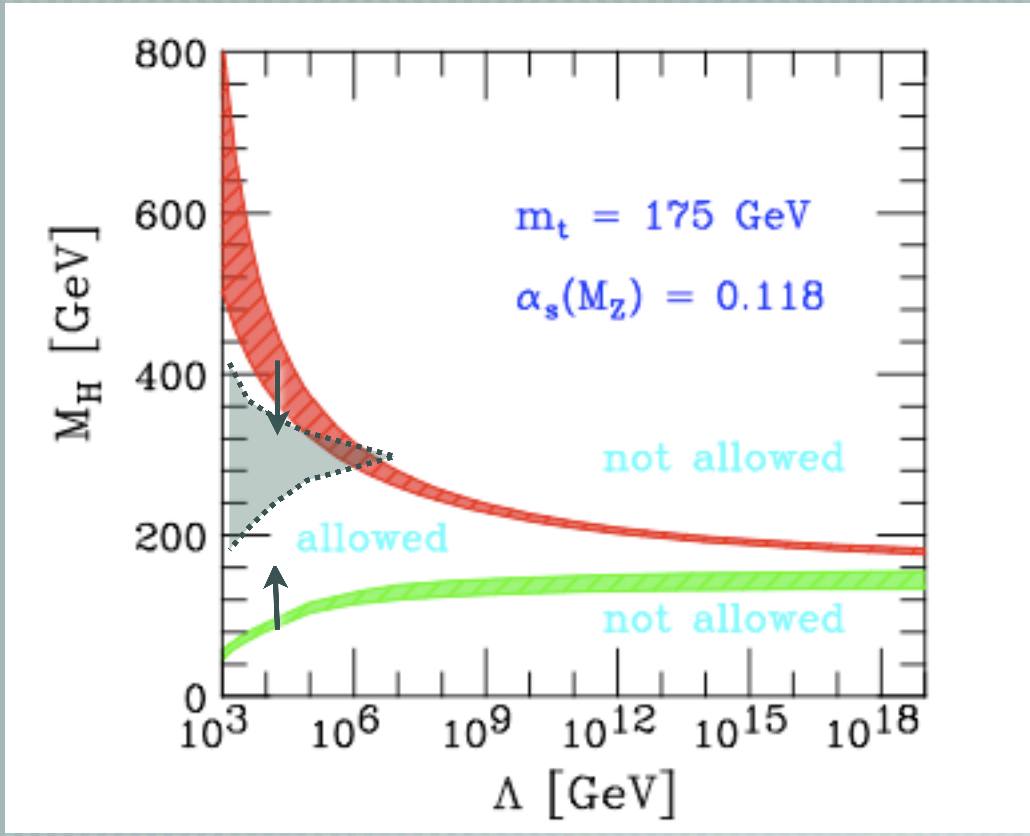
$m_{t'} > 311$ GeV $(t' \to bW)$ $m_{b'} > 199$ GeV $(b' \to bZ)$

- Such a large Yukawa coupling has a strong impact on the theoretical models, c.f. Higgs mass bounds:

$$M_H^2 > \frac{v^2}{8\pi^2}\left[-12\frac{m_t^4}{v^4} + \frac{3}{16}(2g_2^4 + (g_2^2 + g_1^2)^2)\right] \log \frac{Q^2}{v^2}$$

$$\Lambda_c = v\left(\frac{4\pi^2}{3\lambda}\right) = v \exp\left(\frac{4\pi^2 v^2}{M_H^2}\right)$$

4th generation and Higgs mass limits



Hambye et al 9610272
Djouadi 0503172
Kribs et al 0706.3718 (detailed study of Higgs physics for 4th generation)

✓ Due to **the large Yukawa**, the stability bound goes up and the triviality bound goes down.

✓ SM becomes non-valid at the M_{plank} scale for any Higgs mass!

✓ **A new theory must enter at some TeV scale to keep theory weakly coupled.**

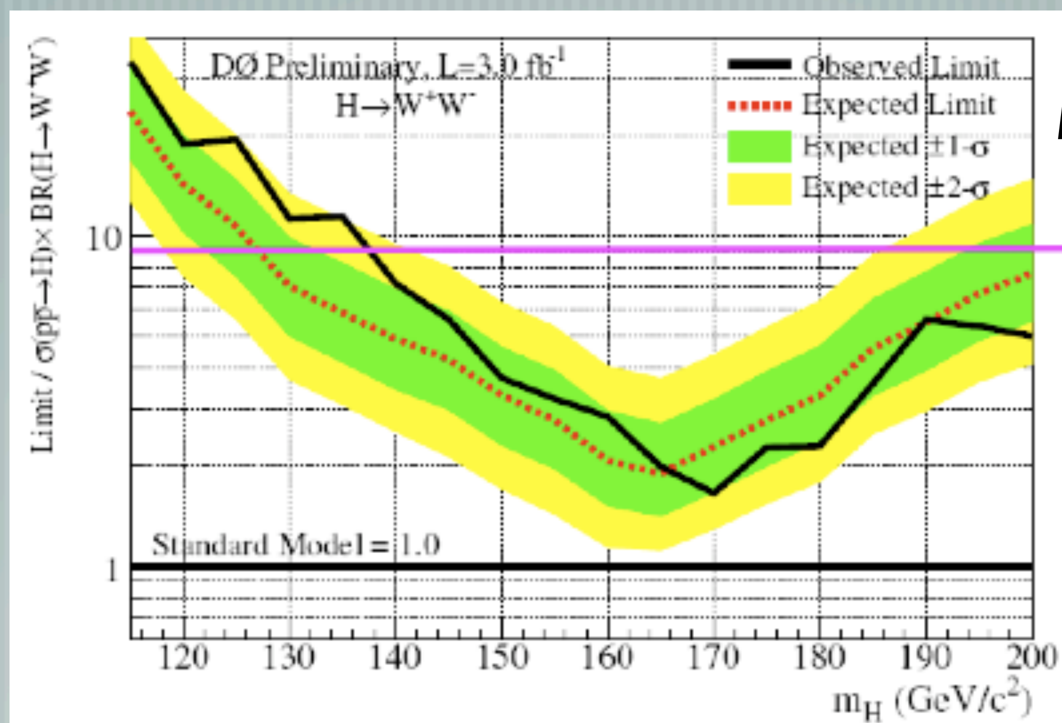
Murdock et al 0806.2064

Higgs search in 4th generation SM

discussed more in details at "Beyond the 3SM gene. workshop"

The gg→H cross section is about 9 times larger!

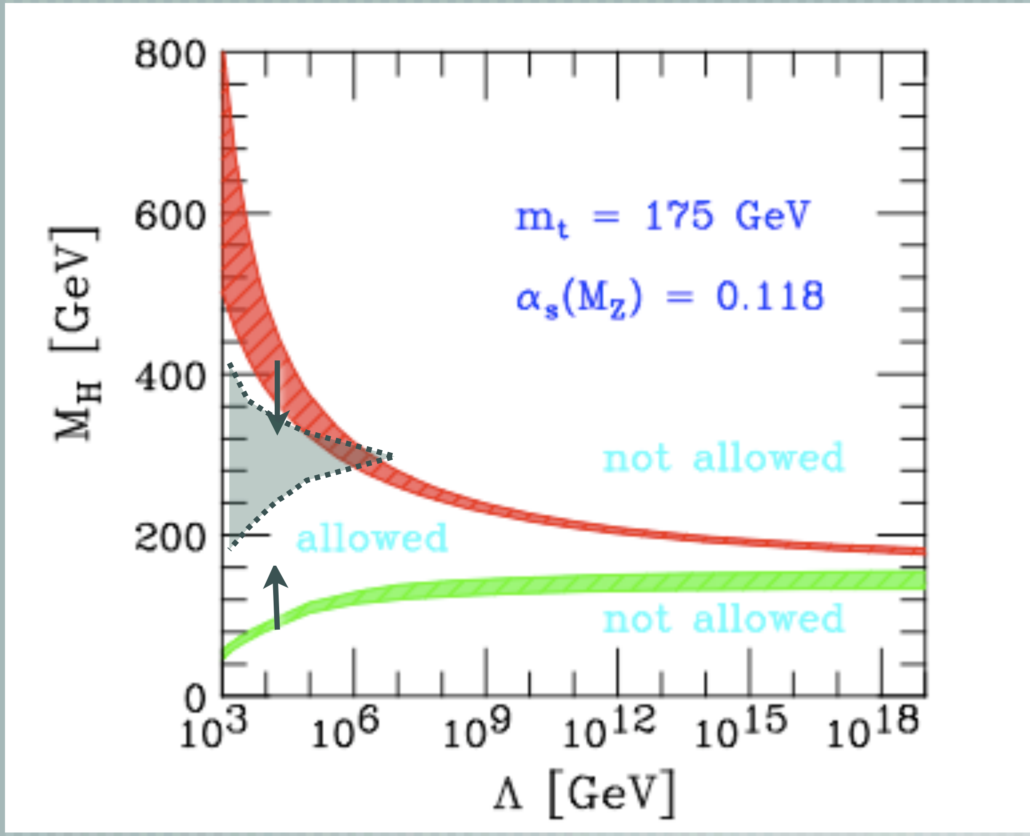
Kribs et al 0706.3718
(detailed study of Higgs physics for 4th generation)



Talk by Haas at beyond 3SM gene. workshop

➡ D0/CDF already have sensitivity to 120-240 GeV Higgs

4th generation and Higgs mass limits



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Murdock et al 0806.2064

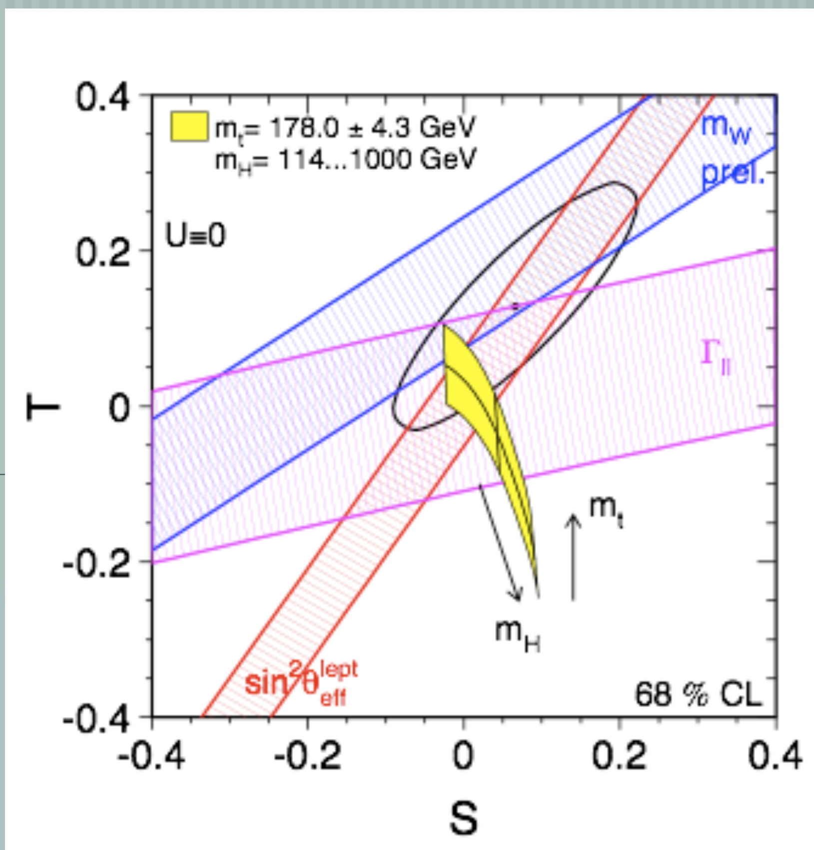
4th generation and dynamical EWSB

- ✓ The large Yukawa may favour the strongly coupled theory.
- ✓ For realizing the top-condensate mechanism, a heavy fermion ($m_{t'} \geq 500$ GeV e.g.) is required. *Burdman et al 0812.0368*
- ✓ Many new theoretical proposals with five-dimension: Higgsless, Composite etc etc...
- ✓ A possibility of KK fermion to be as light as a few 100 GeV.

Signal search at high energy colliders

but before...

Comment on the STU parameters



LEP EW Working Group
http://lepewwg.web.cern.ch/LEPEWWG/

✓ ~~Common wisdom: 4th chiral generation is excluded by S/T constraints: $\Delta T=0$, $\Delta S=2/3\pi\approx0.21$~~

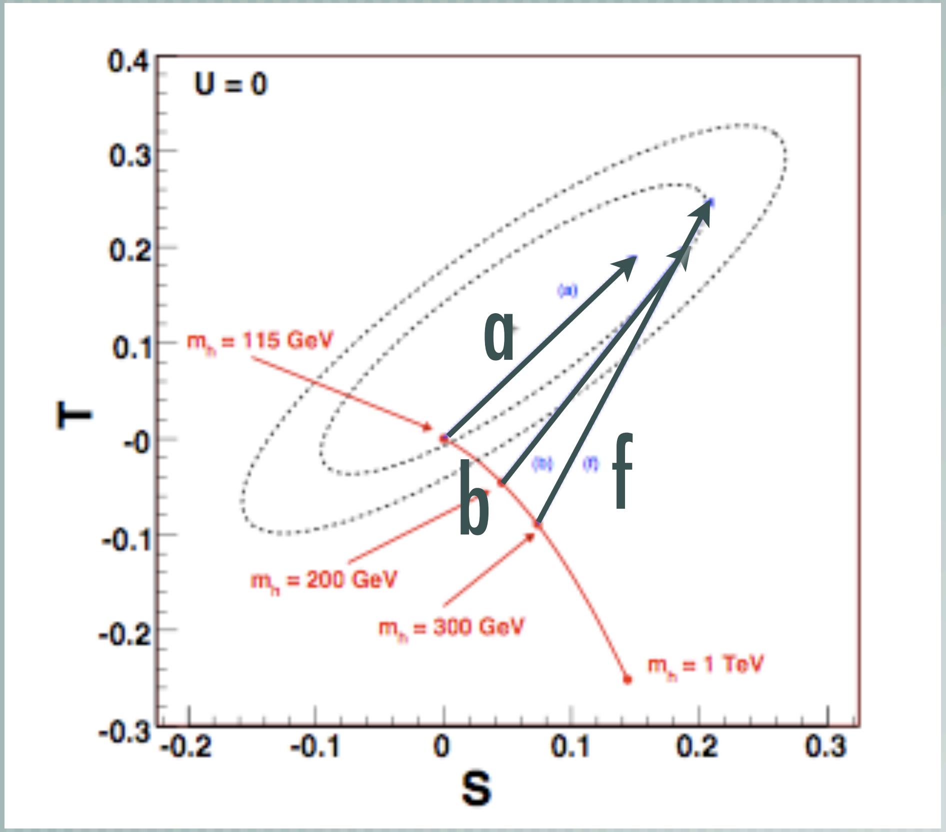
✓ For e.g. $m_{t'}-m_{b'}\approx50$ GeV, $\Delta T=0.2\sim0.3$ and $\Delta S= 0.13\sim0.15$.

4th generation can easily pass the constraint!

Holdom , 0606146
He et al, 0102144
Novikov et al 0203132

but before...

Comment on the STU parameters



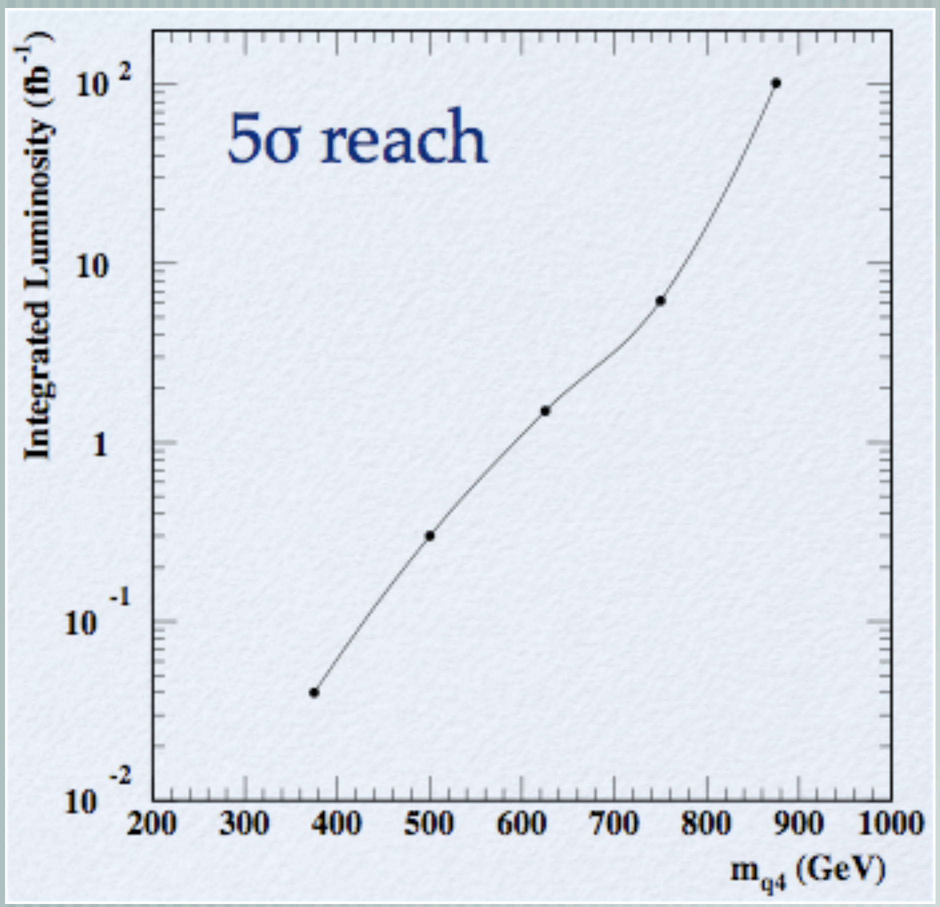
✓Not only the heavy fermions are allowed, but also a heavy Higgs becomes possible!

GeV	$M_{t'}$	$M_{b'}$	M_h
a	310	260	115
b	320	260	200
f	400	325	300

Kribs et al 0706.3718

t′ search at high energy colliders

discussed more in details at “Beyond the 3SM gene. workshop”



ATLAS

✓ Searching $t' \rightarrow Wb$ channel

✓ Spectacular early signal at LHC: possible discovery at $100pb^{-1}$ for 400-500 GeV

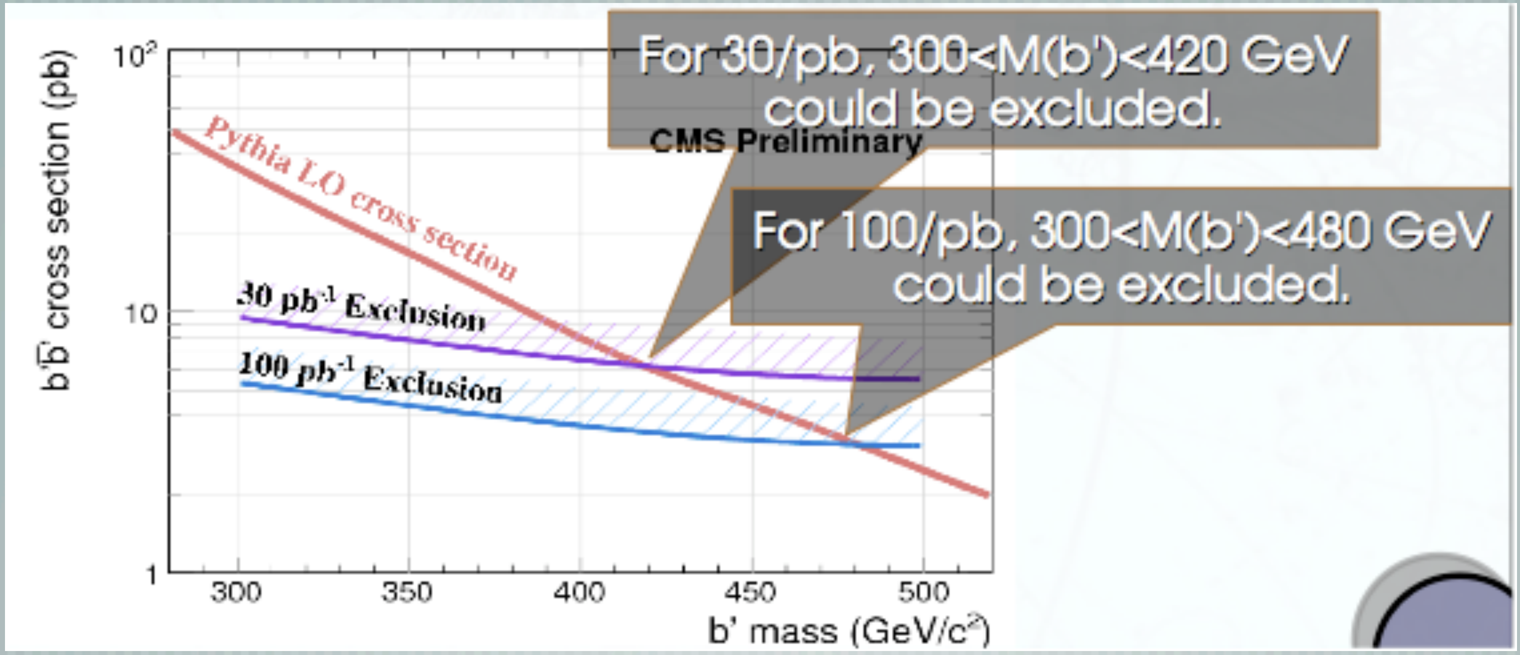
Talk by Ozcan at beyond 3SM gene. workshop

b′ search at high energy colliders

discussed more in details at “Beyond the 3SM gene. workshop”

✓Searching b′ → Wt channel

✓ The mass bound will be rapidly improved as LHC starts.

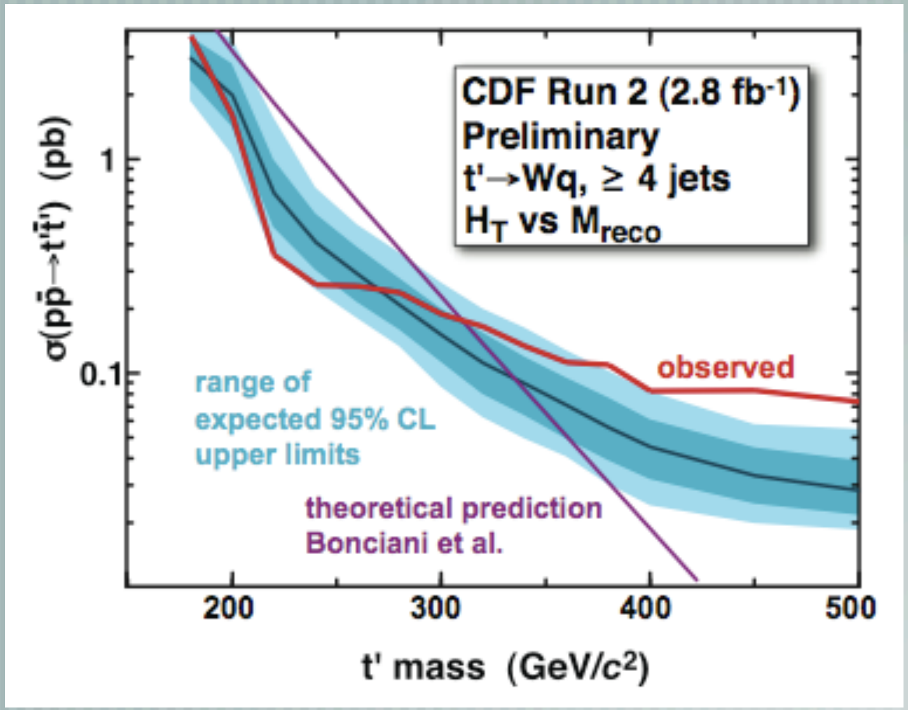


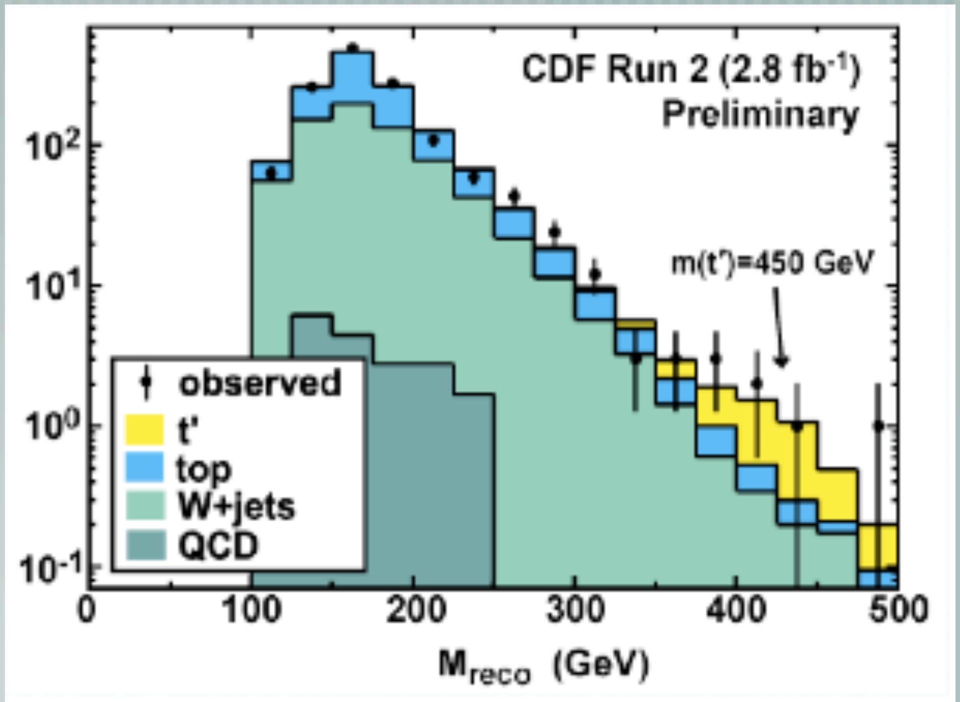
CMS

Talk by Chao
at beyond 3SM gene. workshop

t′ search at Tevatron CDF

CDF saw a slight excess at t′ mass around 400 GeV.





➡ Very encouraging!

Flavour physics

4x4 CKM matrix

- 4x4 CKM requires 3 more angles and 2 more phases

Hou et al Phys Lett.B192('87)

$$\boxed{V_{\rm CKM}^{4\times 4} = \tilde{V}_{\rm CKM}^{3\times 3}\omega(\theta_{34},0)\omega(\theta_{24},\delta_2)\omega(\theta_{14},\delta_3)}$$

$$V_{\rm CKM}^{3\times 3} = \omega(\theta_{23},0)\omega(\theta_{13},\delta_1)\omega(\theta_{12},0).$$

- Let us impose a "natural" hierarchy in the new angles

$$\boxed{\sin\theta_{14} \simeq \mathcal{O}(\lambda^3), \quad \sin\theta_{24} \simeq \mathcal{O}(\lambda^2), \quad \sin\theta_{34} \simeq \mathcal{O}(\lambda^3)}$$

- In this parameterization, the first two rows are almost untouched.
  - ☛ Almost no constraints on $\theta_{14}\,\theta_{24}\,\theta_{34}$ from the 4x4 unitarity.

Some CKM elements

$$
\begin{aligned}
V_{td} &= A(1 - e^{i\delta_1}\sqrt{\rho^2 + \eta^2})\lambda^3 \\
V_{ts} &= -A\lambda^2 - B_2 B_3 e^{i\delta_2}\lambda^3 \\
V_{tb} &= 1 - B_3^2/2\lambda^2 \\
V_{t'd} &= -B_1 e^{i\delta_3}\lambda^3 \\
V_{t's} &= -B_2 e^{i\delta_2}\lambda^2 \\
V_{t'b} &= -B_3\lambda
\end{aligned}
$$

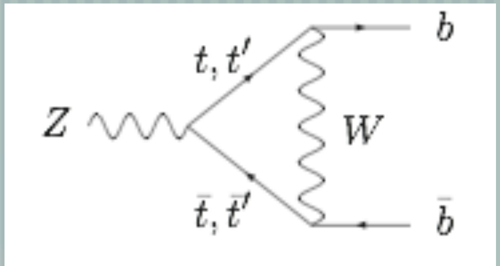
V_{tb}: Direct (tree level) test by the single top production: up to ≃5%

Alwall et al 0607115

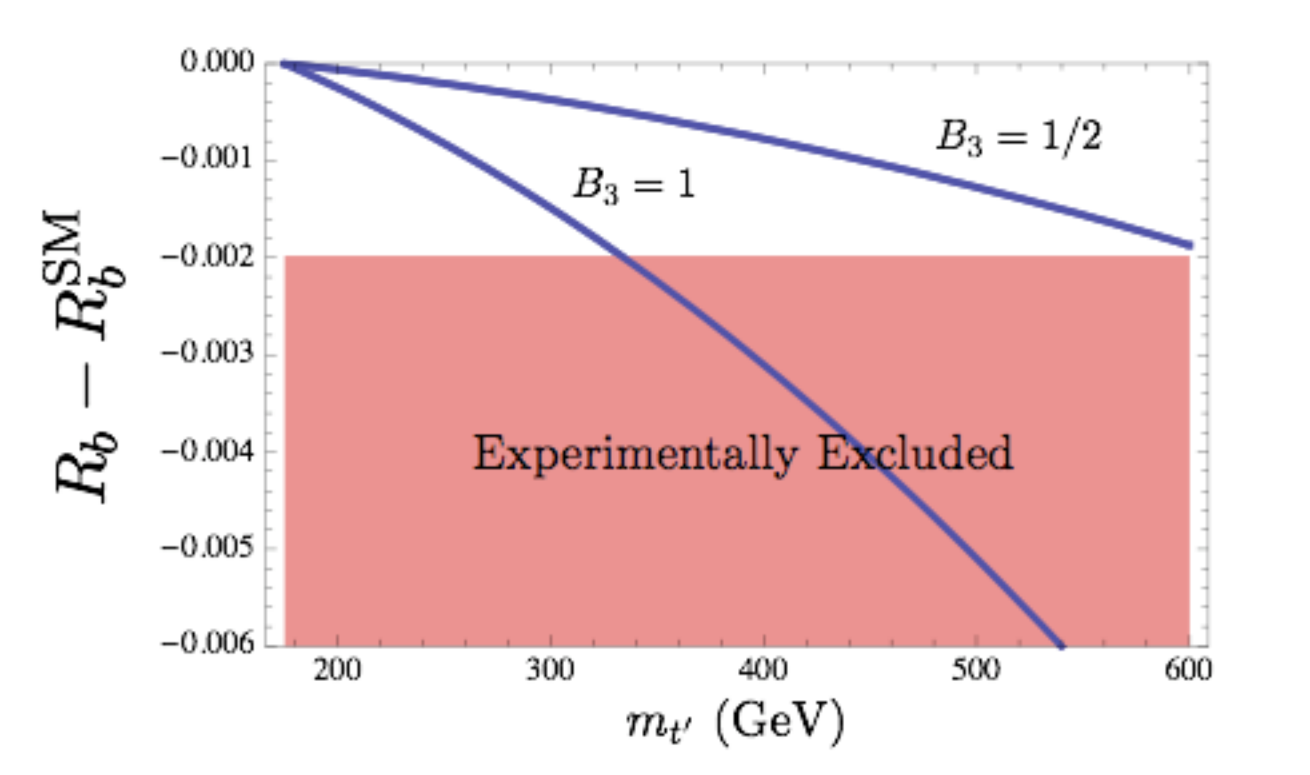
$V_{t'b}$: Important input for t′ search!

Constraints from R_b ratio on θ_{34}

✓ Rb ratio constrains on V_{tb} and $V_{t'b}$, i.e. B_3.



Bamert et al Phys Rev D54 '96



$B_3 \leq 1/2$ for $M_{t'} \leq 600$GeV

Alwall et al 0607115

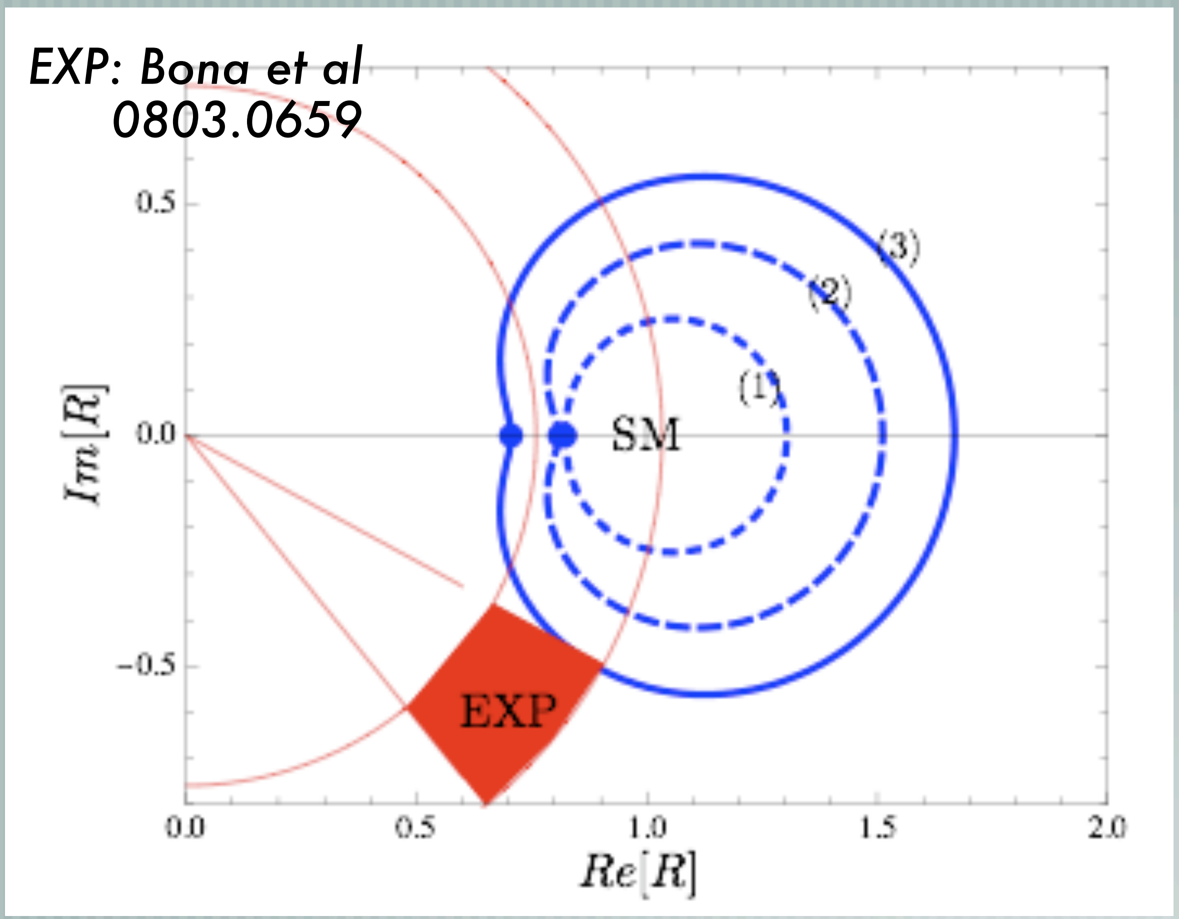
Hint of new physics in B_s-$\bar{B}_s$ mixing

- Tevatron reported 2-3σ deviation from SM in Bs-Bs oscillation phase.
  ☛LHCb will measure at a very high precision!

- Can the t′ contribution explain this excess within the constraint from R_b?
  ☛Recall the new CP violating phase e.g.:

$$\boxed{V_{t's} = -B_2 e^{i\delta_2} \lambda^2}$$

t′ contribution to Bs-$\overline{\text{Bs}}$ mixing



$$R \equiv \frac{M_{12}}{M_{12}^{\rm SM}}$$

	$m_{t'}$ (GeV)	B_2
①	450	1
②	700	1
③	450	2

$B_3=1/2$, $\delta_2=[0, 2\pi]$

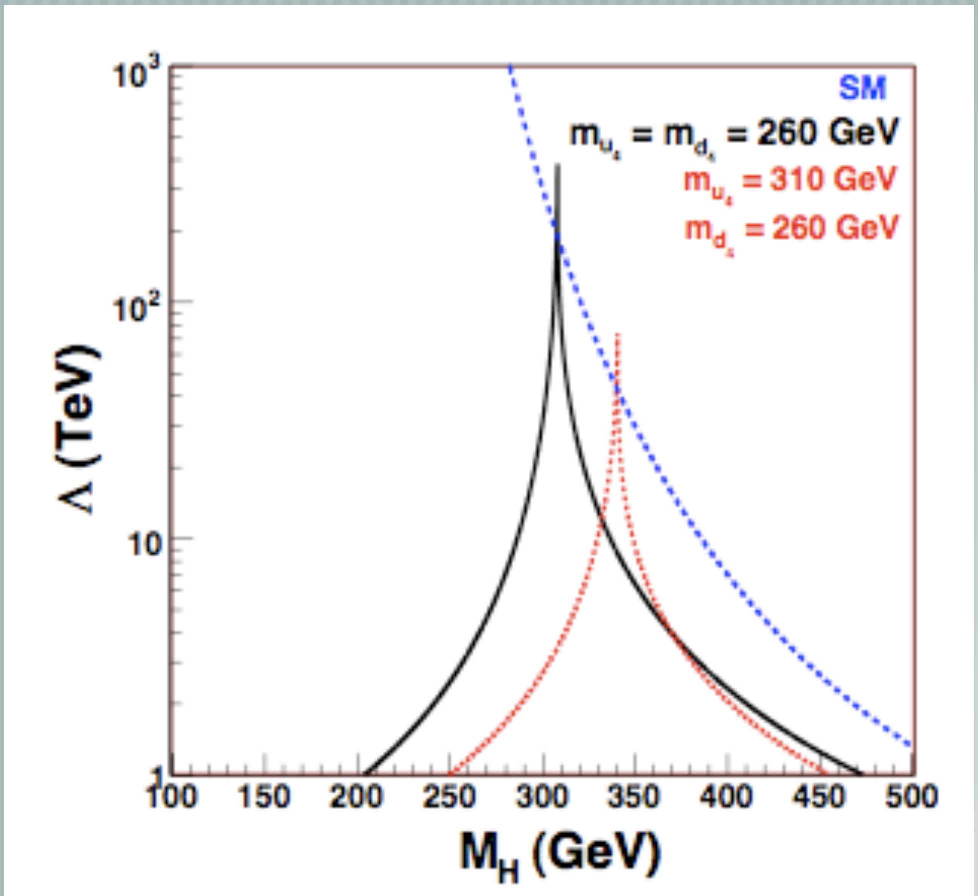
Hou et al e.g.0211267

☛More t′ contribution to B physics (e.g. Z penguins) are investigated.

Conclusions

- Tevatron bound for $m_{t'}$ passed the perturbative limit (strong impact on Higgs mass bounds).
- The LHC has a very high ability to search for the 4th family even in the very early time.
- Flavour observables are also very important.

Higgs mass limit with 4th SM



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Kribs et al 0706.3718 (detailed study of Higgs physics for 4th generation)

Many new physics models "require" a

- ☛ New particle at the TeV scale for weakly coupled theories
- ☛ Strongly coupled theory (dynamical symmetry breaking)