Physics at LHC – Perugia, June 6-11th 2011

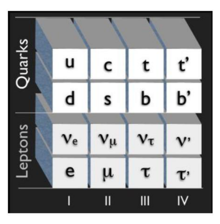
ATLAS New Heavy Quark Searches

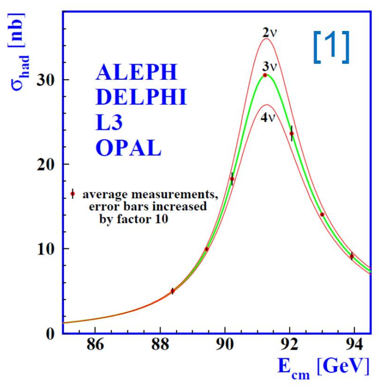
Why searching for extra generations of fermions ?

• Because the number of generation is not fixed by the SM

Since the discovery of neutrino oscillations, very massive neutrinos could exist !

- $N_\nu = 3$ with $m_\nu < m_Z/2$ (LEP) $\Rightarrow m_{\nu_4} > m_Z/2$





• Because it is not excluded by the EW precision data…

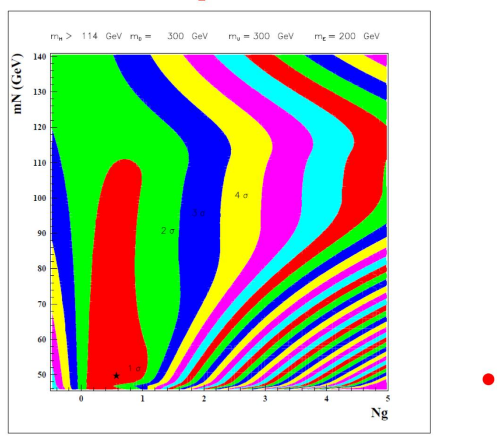


Figure 4: Exclusion plot on the plane N_g, m_N for fixed values $m_U = m_D = 300$ GeV, $m_E = 200$ GeV, χ^2 minimum is shown by the star. The condition $m_H > 114$ GeV is imposed.

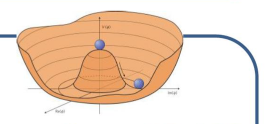
… even if only 1 extra generation is allowed [2]

A 4th generation (E,N,U4,D4) could have major implications…

… in understanding the fermion mass hierarchy:

- observed **masses of fermions** in the first 3 families **could arise from small perturbations to** a flavor-blind 4x4 mass matrix (**Democratic Mass Matrix**) [4]
- could be the **reason for only 4 families and small ν masses**

… in understanding EW symmetry breaking:

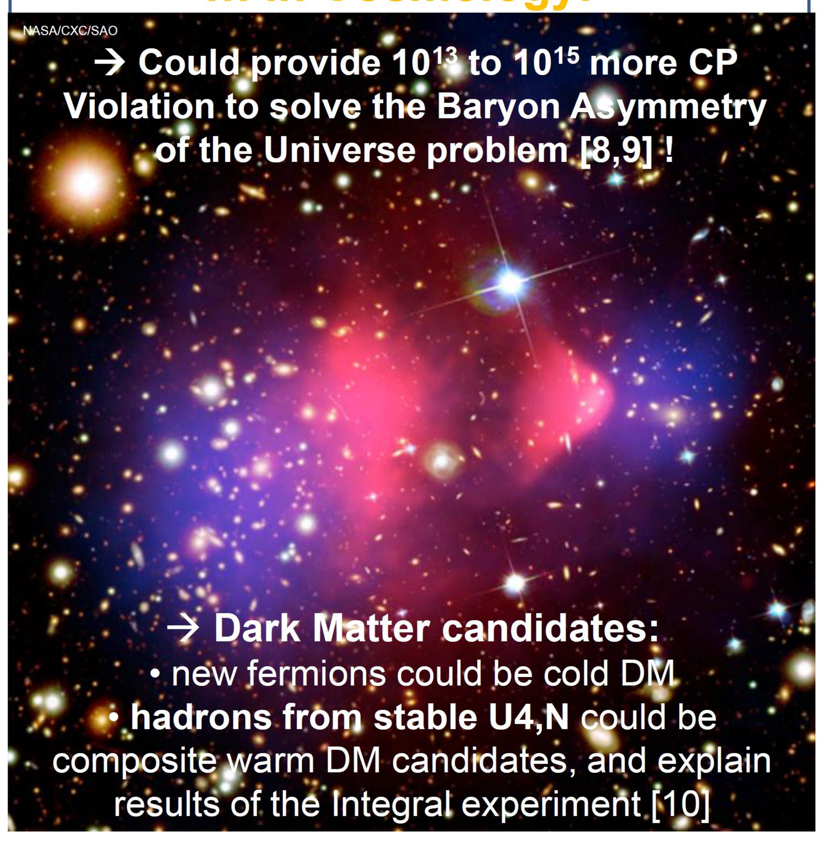


- **4G fermion condensate** can play the **role of the Higgs via some strong interactions** [5,10]
- If fermions propagate in **5D AdS space**, **K-K excitations of gauge bosons interacting with 4G fermions give rise** to **Yukawa couplings** and to the **mass hierarchy** [6]

… in the way to grand unification:

- 4G might help in **bringing the SU(3)xSU(2)xU(1) couplings close to a unification point** at scale ~10^{16} GeV in the **simplest non-SUSY grand unification model SU(5)** [7]

… in Cosmology:



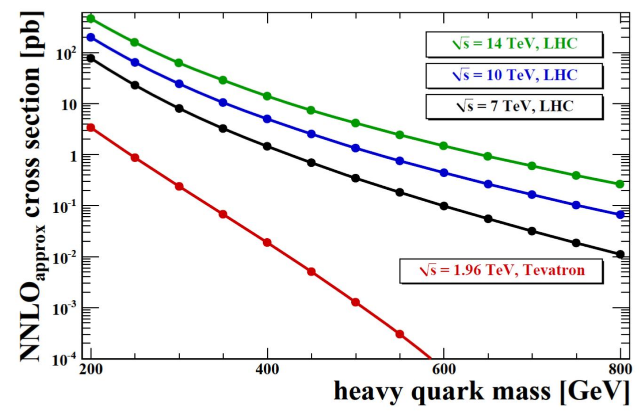
→ Could provide 10^{13} to 10^{15} more CP Violation to solve the Baryon Asymmetry of the Universe problem [8,9] !

→ Dark Matter candidates:
- new fermions could be cold DM
- hadrons from stable U4,N could be composite warm DM candidates, and explain results of the Integral experiment [10]

• Because it can allow a heavy Higgs:
Current EW fit [3] in disagreement with LEP lower limit of 114 GeV: $m_H = 80^{+30}_{-23}$ GeV

→ 4th generation is the simplest extension of the SM and its existence would modify profoundly our understanding of the Universe

How to detect new heavy quarks with ATLAS ?



Q4Q4 production rate is much higher than @Tevatron [11]

This will depend on: **Quark masses** | **Mixing with lighter generations**

Assuming unitarity of a 4x4 CKM matrix, **quark mixing of 4G to the other 3** is **constrained to be small from fit to flavor-physics data** [12]:

$$|\tilde{V}_{ub'}| < 0.06, |\tilde{V}_{cb'}| < 0.027, \text{ and } |\tilde{V}_{tb'}| < 0.31 \text{ at } 3\sigma$$

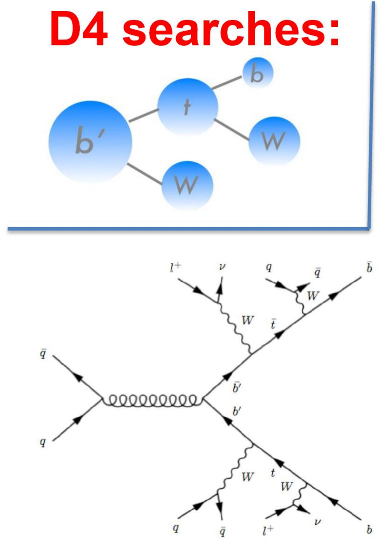
It has been recently pointed out [13,9] that **if mixing angles are tiny** (~10^{-13}< $\Theta_{bt'}$ < ~10^{-8}) and m_{U4}~m_{D4}, **heavy quarks could have a proper lifetime of 10^{-10}s < t_Q < 1s !**

→Their decay length could range from:

1- few millimeters → Potential displaced vertices close to the interaction point

2- to many meters ! → Could even decay outside ATLAS (so-called '*stable*' particles)

D4 searches:

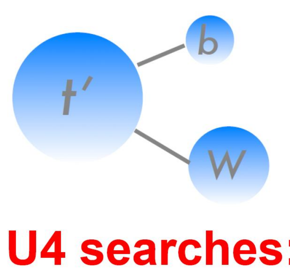


… or top-like + 2 W !

Assuming B.R. *D4→t+W* = 100%

Signal: Top-like+2W: WWb WWb
- Dilepton: lνqqb lνqqb (half-time same-charge!)
- Lepton+jets: lνqqb qqqqb
- All-hadronic: qqqqb qqqqb

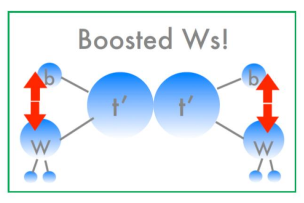
Backgrounds:
- Top-like l+jets
- Top-like dilepton
- true same sign lepton

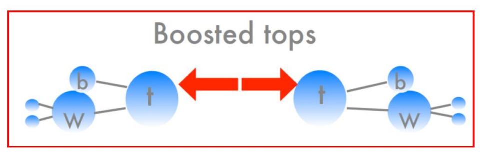


1- By looking at top-like decays …

General strategy:

Signal: Large p of W daughters → ~collinear decay products





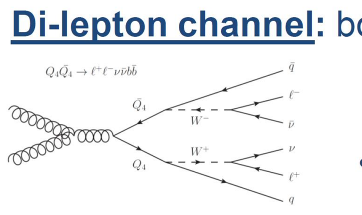
Main background is ttbar production

The idea is to apply cinematic cuts and use variables reflecting the higher pt spectra of decay products

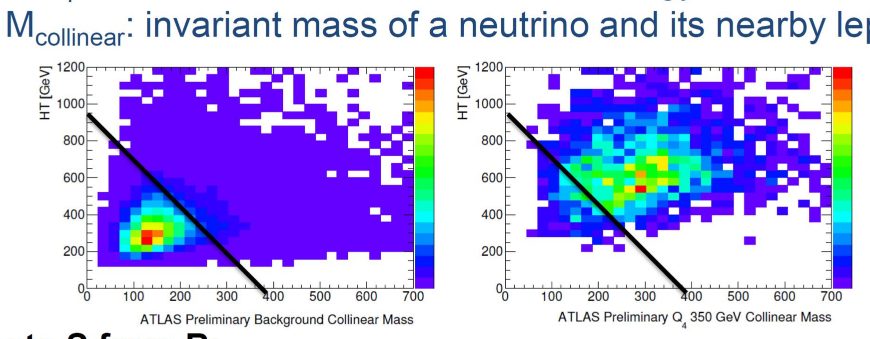
Signal samples	
m_{Q_4} [GeV]	σ^{NNLO}_{approx} [pb]
250	23
300	8.0
350	3.2
400	1.4

Background samples			
Process	σ[pb]	Process	σ[pb]
$t\bar{t}$	80.2	$Z \to \mu\mu$	846
single top t-chan $\to l\nu$	21.5	$Z \to \tau\tau$	845
single top s-chan $\to l\nu$	1.4	WW	11.5
single top Wt	14.6	WZ	3.5
$Z \to ee$	850	ZZ	1.0

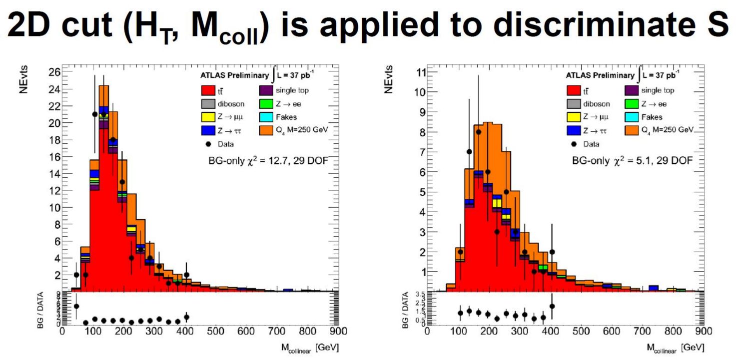
Di-lepton channel: both *Ws→ l+v*, assuming B.R. *U4→q=u,d,c,s,b + W* = 100%



Most discriminating variables are:
- H_T: ~ scalar sum of all transverse energy in the event
- $M_{collinear}$: invariant mass of a neutrino and its nearby lepton



A 2D cut (H_T, M_{coll}) is applied to discriminate S from B:



$M_{Collinear}$ before and after the triangle cut for the 250 GeV mass

Q_4 Mass [GeV]	250	300	350	400
Total BG	$40.4 \pm 0.7 \pm 3.9$	$16.8 \pm 0.5 \pm 1.7$	$10.1 \pm 0.4 \pm 0.1$	$6.3 \pm 0.4 \pm 0.8$
Signal	$20.7 \pm 0.5 \pm 1.9$	$7.1 \pm 0.2 \pm 0.3$	$3.0 \pm 0.1 \pm 0.2$	$1.4 \pm 0.1 \pm 0.1$
Observed	40	11	8	5

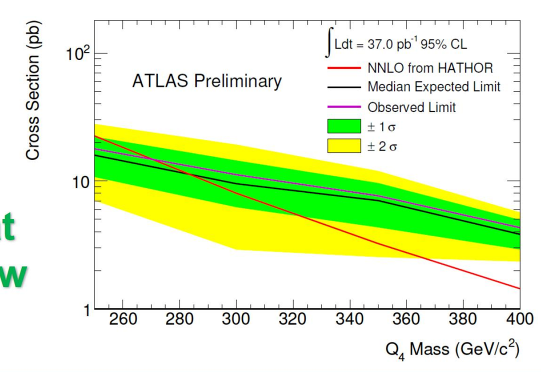
→ With 37pb-1, ATLAS already excluded at 95% C.L. a heavy quark with mass below 270 GeV in this channel [14]

Lepton+jets channel:

WWqq → lνq qqq

- **has more statistics**
- **allows to reconstruct the mass of the hypothetic quarks!**

Assuming BR Q4→b+W = 100% b-jets identification allows to kill almost all QCD background

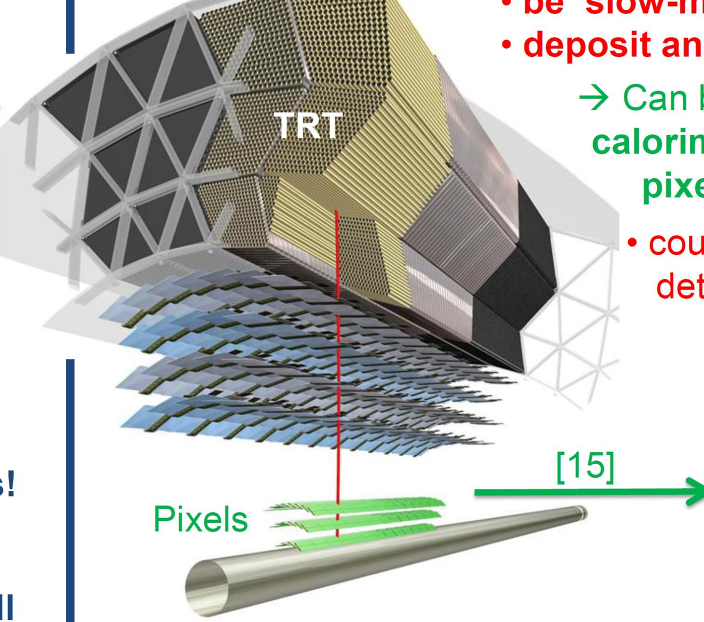


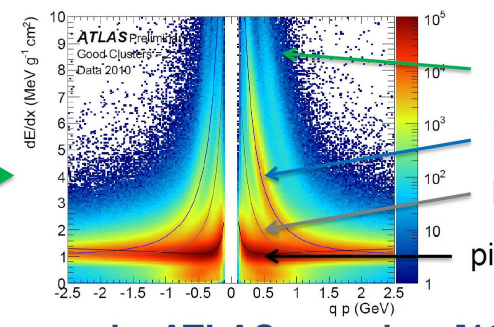
2- With unique experimental signatures !

Very massive long-lived particles could:
- **be 'slow-moving' (~0.3<β<1) (a)**
- **deposit anomalous large ionization energy (b)**

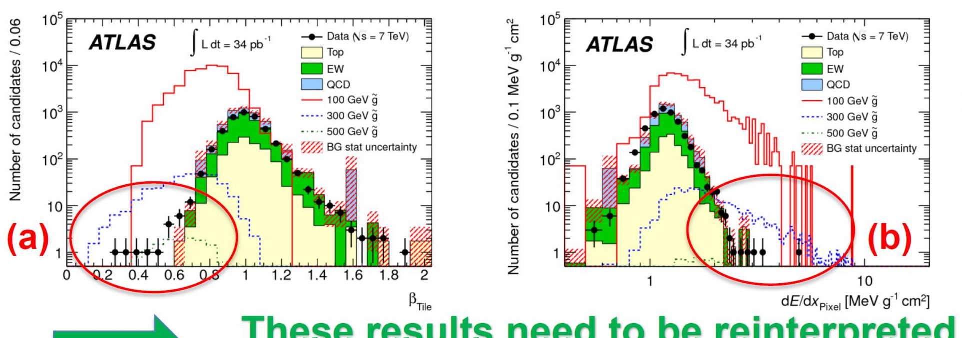
→ Can be seen by *time-of-flight* from the **tile calorimeter**, and *charge deposits* from the **pixel** (ToT) and **TRT detectors** (HT)

- could even look like **'dashed lines'** in the detector! (charged → neutral → charged…)





Similar to stable hadronizing squarks ATLAS searches [16]:



→ Mass reconstructed from p and βγ measurements: $m = p/\beta\gamma$

→ These results need to be reinterpreted in the framework of 4th generation

What are the best mass limits ?

• **Experimental limits on short lived particles:**

CDF excluded at 95% C.L.:
- **a D4 quark below 372 GeV with 4.8 fb-1 from D4→ tW [17]**
- **a U4 quark below 335 GeV with 4.6 fb-1 from U4→qW [18]**

Assuming an optimistic 100% B.R. in their channel (otherwise limits are less stringent)

→ ATLAS will be competitive with Tevatron with 2011 data

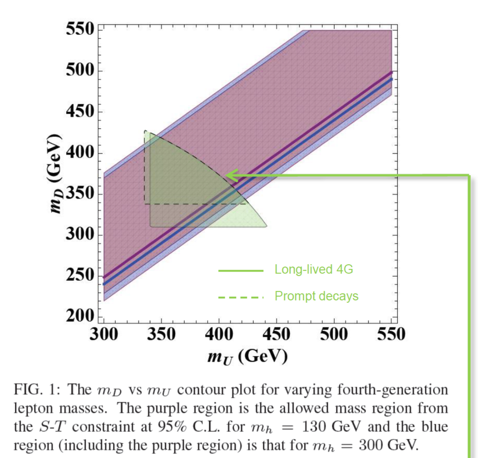
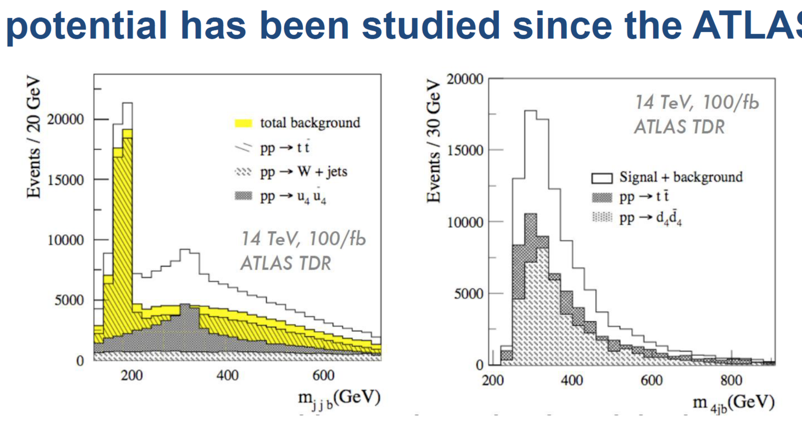


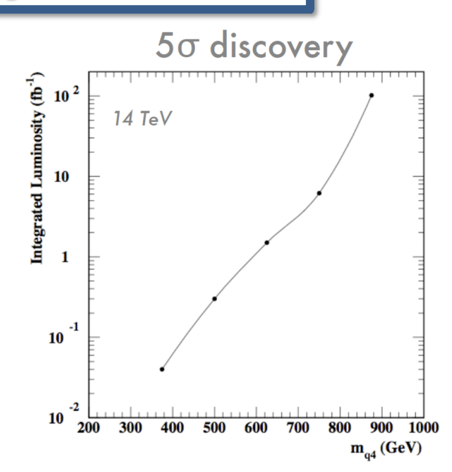
FIG. 1: The m_D vs m_U contour plot for varying fourth-generation lepton masses. The purple region is the allowed mass region from the S-T constraint at 95% C.L. for m_{l_4} = 130 GeV and the blue region (including the purple region) is that for m_{l_4} = 300 GeV.

• **Theoretical upper limits come mostly from tree level unitarity [9]**

What are the discovery prospects ?

Discovery potential has been studied since the ATLAS TDR [19]:





Given: - its high production rate, even at 7TeV - the upper limits on heavy quark masses

→ ATLAS has the potential to discover or fully exclude 4th generation !

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ATLAS EXPERIMENT