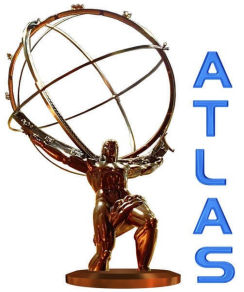


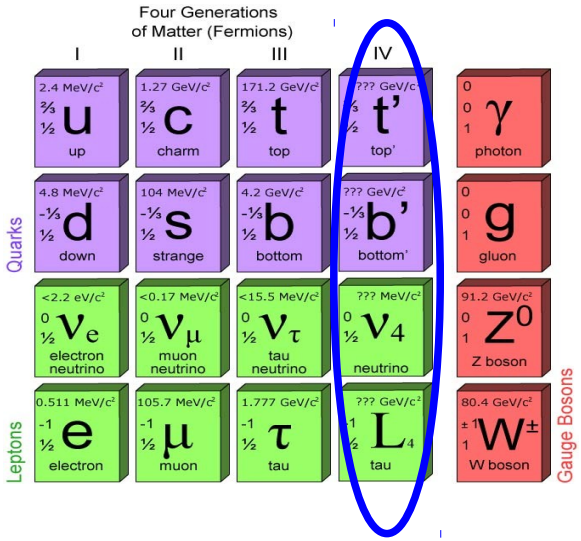
Fourth Generation Quark and Vector Like Quark with the ATLAS detector

Léa Gauthier (*CEA-Saclay / Montréal University)*
on behalf of the ATLAS collaboration

Quark Confinement and the Hadron Spectrum X

Fourth Generation Quark :

- new chiral generation : SU(2) doublet (t',b') with the corresponding right-handed singlets under SU(2)
- new CP violation to explain matter dominated Universe
- model disfavored by m_H ~126 GeV (arXiv:1207.0438)
- saved by extended 4th generation
- latest results presented here:
  - m(Q) > 350 GeV for up and down type Q
  - m(t') > 656 GeV m(b') > 670 GeV



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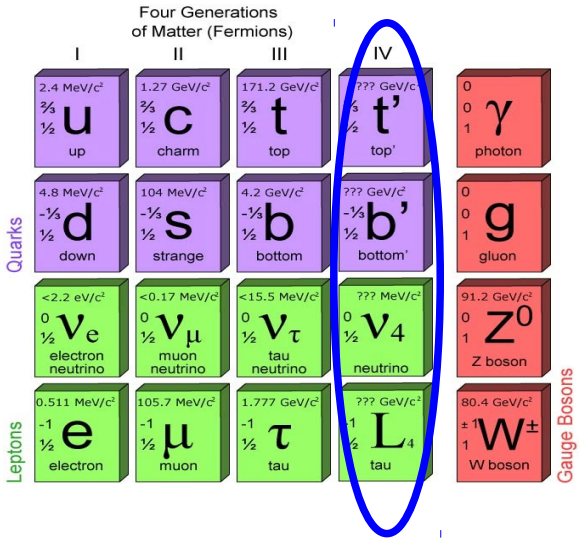

Vector Like Quark :

- both right and left handed components transform the same way under the EW gauge groups
- VLQs have been introduced in many different models : Composite Higgs, Extra Dimension, SUSY
- VLQs fix the hierarchy problem and explain the observed A_{FB} asymmetry of bottom quark
- VLQs mix with 3rd generation SM quarks (constraints from EWK precision and flavor observables)
- mixing to first generations is not excluded (in some models corrections to the quark mixings can cancel relaxing these constraints)

- Events were studied in l+jets and dilepton channel (e and μ) @ 7 TeV between 1.98 fb^{-1} and 4.7 fb^{-1}

- Events studied :
  - Fourth generation quarks : $Q\bar{Q} \rightarrow W^{+}qW^{-}\bar{q}$ for up and down type Q
    $t'\,\bar{t'} \rightarrow WbW\bar{b}$ and VLQ interpretation of $t' \rightarrow Wb$ $t' \rightarrow Zt$ $t' \rightarrow Ht$
    $b'\bar{b'} \rightarrow WtW\bar{t}$
  - Vector Like Quarks : VLQs with charge 5/3 for different coupling value $\lambda(T_{5/3}tW)$
    VLQ interpretation of $b'\bar{b'} \rightarrow Zb+X$ (vector like singlet model)
    single production of VLQ coupling to light generations

Searches

- Events were studied in l+jets and dilepton channel (e and μ) @ 7 TeV between 1.98 fb^{-1} and 4.7 fb^{-1}

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    single production of VLQ coupling to light generations

- Events are selected based on top quark selection :
  - Electrons :
    - $P_T > 25$ GeV
    - $|\eta| < 2.47$ and not $1.37 < |\eta| < 1.52$
    - isolated
  - Muons :
    - $P_T > 20$ GeV
    - $|\eta| < 2.50$
    - Isolated
    - cosmic rejection
  - Jets :
    - anti-k_T $\Delta R=0.4$
    - $P_T > 25$ GeV
    - $|\eta| < 2.50$
    - not inside an electron

- Limits are extracted using Cls (except Bayesian for single production of VLQ coupling to light generations)

Background

- For the dilepton final state :
  - dibosons : WW, WZ and ZZ (Herwig or Alpgen + Jimmy)
  - fake leptons (data-driven : matrix method)
  - for the opposite sign (OS) leptons :
    - $t\bar{t}$ and single top (MC@NLO+Herwig)
    - Z+jets (Alpgen + Jimmy or Sherpa)
    - Drell-Yann events (data-driven technique that extrapolates from a control region)
  - for the same sign (SS) leptons :
    - $t\bar{t}W$, $t\bar{t}Z$, $t\bar{t}WW$, WWjj (MadGraph + Pythia)
    - charge flip (data-driven)
- For the single lepton final state :
  - dibosons : WW, WZ and ZZ (Herwig)
  - $t\bar{t}$ (Alpgen+Herwig or MC@NLO+Herwig)
  - single top (MC@NLO+Herwig or AcerMC+Pythia)
  - W+jets, Z+jets (Alpgen + Herwig or Sherpa)
  - $t\bar{t}W$, $t\bar{t}Z$, $t\bar{t}WW$, WWjj (MadGraph + Pythia for b' analysis with W only)
  - multijets (data-driven)

Systematic uncertainties

- For the Monte Carlo :
  - object calibration, resolution and energy scale, missing energy
  - trigger and reconstruction efficiency
  - initial and final state radiations
  - luminosity
  - MC cross section
  - PDF
  - Modeling of b-tagging efficiency and fake rates
  - Modeling of the signal and background

- For the data-driven techniques :
  - fakes : estimated using variations on control region selection for the calculation of probability that a real or fake loose lepton passes the tight criteria
  - charge flip (for SS leptons) : estimated by differences between the 3 methods used (tag-and-probe, direct extraction, likelihood)

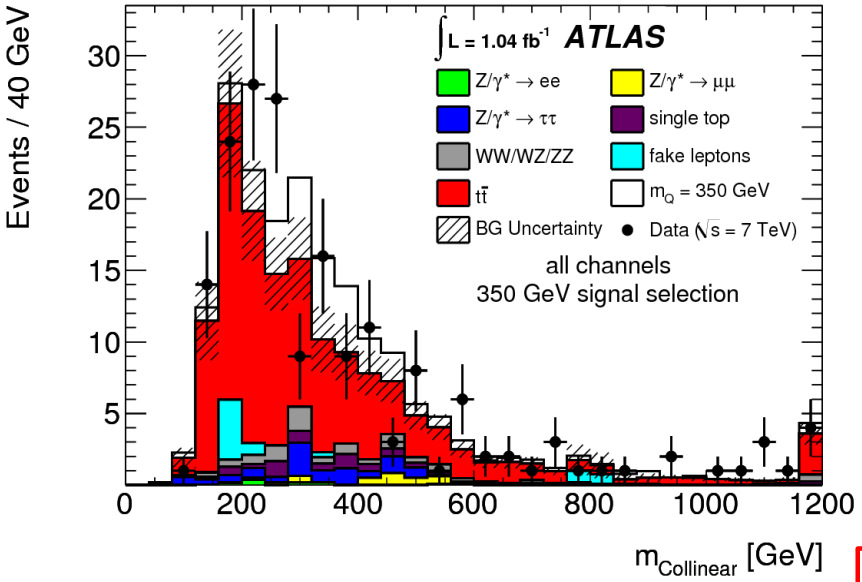
$Q\bar{Q} \rightarrow WqW\bar{q}$ in 2 leptons channel (e or μ)

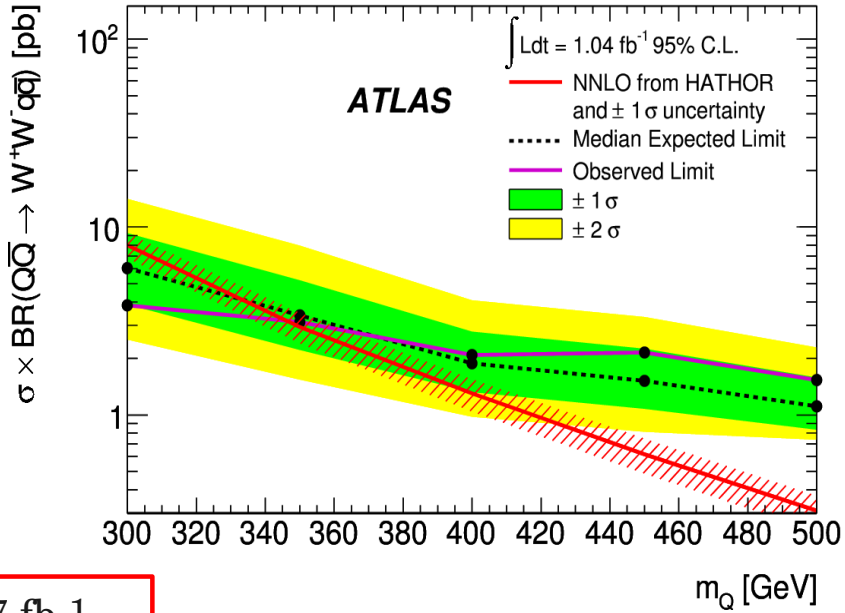
★ Events $Q\bar{Q} \rightarrow W^+qW^-\bar{q}$ q = d, s, b for up-type Q; q = u, c for down-type Q @ 1 fb^{-1} (arXiv : 1202.3389, Phys.Rev. D86 (2012) 012007)

★ Analysis :

- Mass reconstruction of heavy boosted Q quark candidates is performed ($m_{collinear}$)
- A cut $H_{T,}$ E_T^{miss} and $m_{collinear}$ dependent on the assumed signal mass is applied

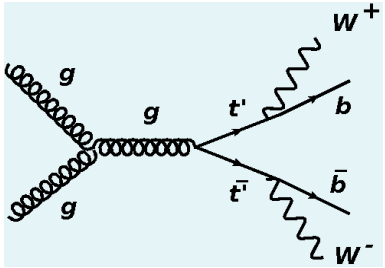
★ Results : a binned maximum-likelihood ratio technique is used to fit distributions of $m_{collinear}$ to the observed data





95% CL @ 4.7 fb-1
m(Q) > 335 GeV (exp)
m(Q) > 350 GeV (obs)

$t'\bar{t}' \rightarrow WbW\bar{b}$ in single lepton + jets channel (e or μ)



- Events $t'\bar{t}' \rightarrow WbW\bar{b}$ @ 4.7 fb^{-1} (soon on arXiv)

- Only the range m(t') < m(W) + m(b') is considered
  events with exactly 3 jets or with 4 or more jets are analyzed separately

- Signal generated with Pythia and normalized to the approximate NNLO theoretical cross sections

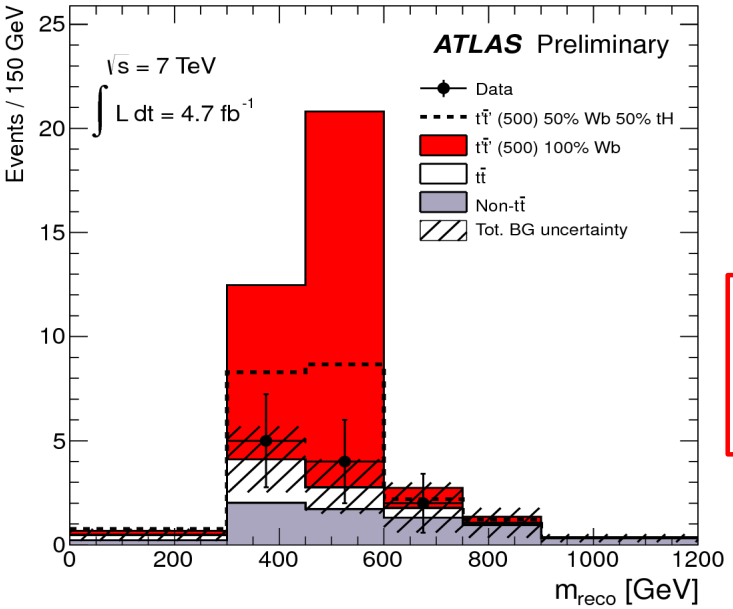
- Event selection :
  - exactly 1 lepton
  - 2 definitions of W_{had} : $W_{had}^{type\ I}$ (single jet with $p_T > 250$ GeV and mass in [60-110] GeV) and
    $W_{had}^{type\ II}$ (dijet with $p_T > 150$ GeV, $\Delta R(j, j) < 0.8$ and M_{jj} in [60-110] GeV)
  - ≥ 3 jets and ≥ 1 $W_{had}^{type\ I}$ candidates or ≥ 4 jets and ≥ 1 $W_{had}^{type\ II}$ candidates
  - H_T ($\sum$lep, E_T^{miss} , 4(3) jets) > 750 GeV
  - P_T (leading b-jet) > 160 GeV, P_T (subleading b-jet) > 60 GeV,
  - $\Delta R(l,\nu) < 1.4$, $\min(\Delta R(W_{had}, b_{1,2})) > 1.4$, $\min(\Delta R(l, b_{1,2})) > 1.4$

- t' mass reconstruction (built from W_{had}) :
  - m_{reco} built from W_{had} and one of the two b-jet candidates
  - reconstruction of W_{lep} → two solutions and two possible ways to pair the b-jet candidates
    - the solution yielding the smallest $|\Delta M(t', \bar{t}')|$ is chosen

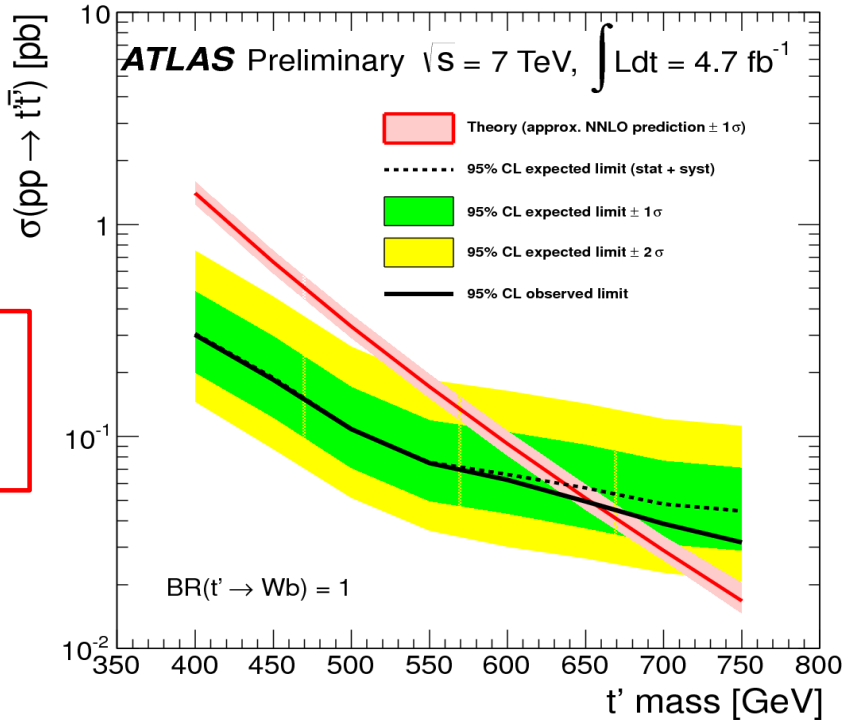
$t'\bar{t}' \rightarrow WbW\bar{b}$ in single lepton + jets channel (e or μ)

★ Results :

- m_{reco} is analyzed using a log-likelihood ratio as test-statistic
- 95% C.L. upper limits on the $t'\ \bar{t}'$ production cross section are derived using the CLs method
- the uncertainties are taken into account



95% CL @ 4.7 fb-1
m(t') > 638 GeV (exp)
m(t') > 656 GeV (obs)



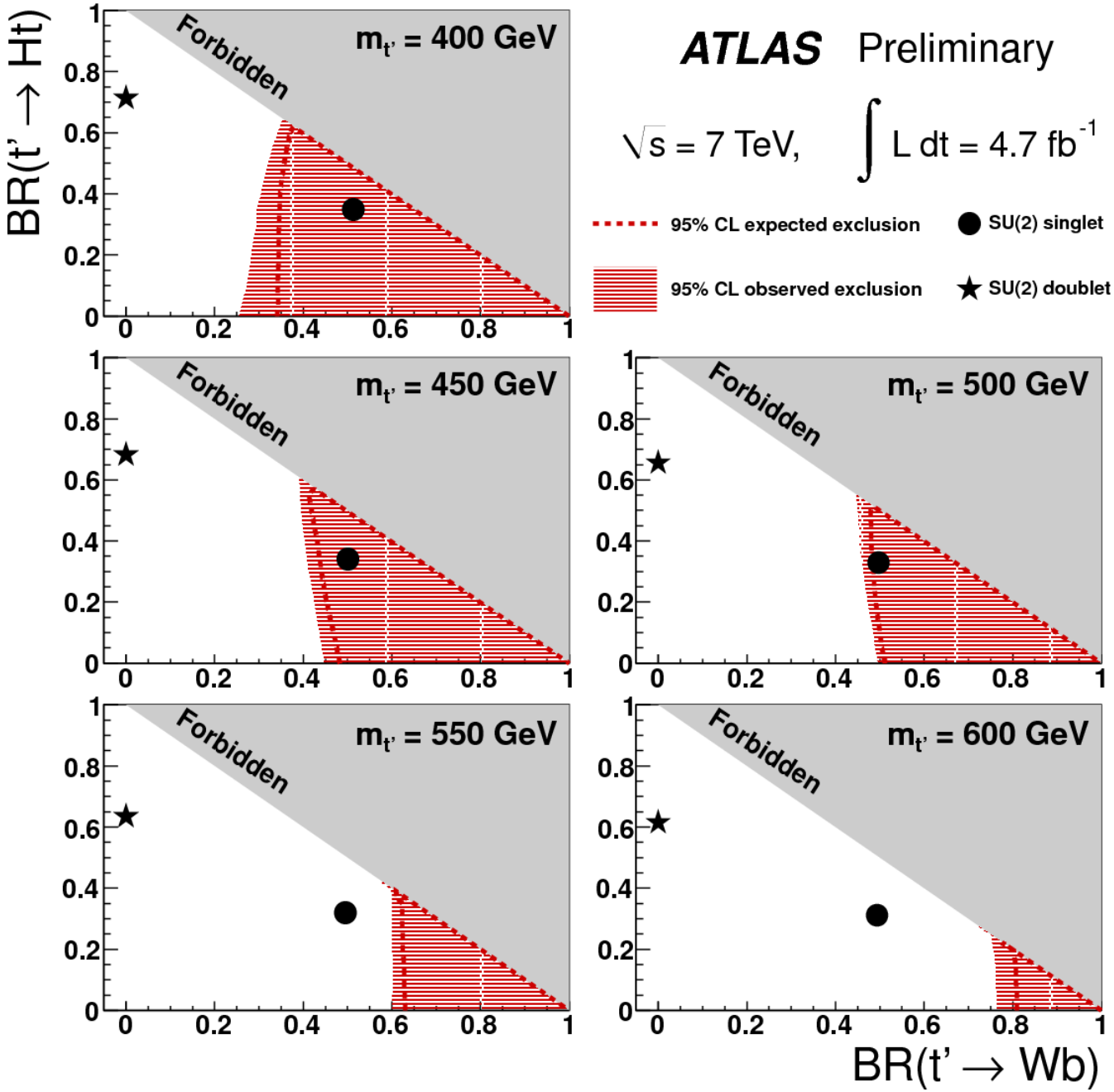
★ Previous limit @ 1 fb^{-1} : m(t') > 394 GeV (expected) *@ 1 fb^{-1}* *(arXiv : 1202.3076, Phys.Rev.Lett. 108 (2012) 261802)*
m(t') > 404 GeV (observed)

Vector Like Quark interpretation of $t'\bar{t}' \rightarrow WbW\bar{b}$

- VLQ interpretation of t' @ 4.7 fb-1
  → soon on arXiv

- the limit is interpreted in vector like quark model where t' → Wb
  t' → Zt
  t' → Ht

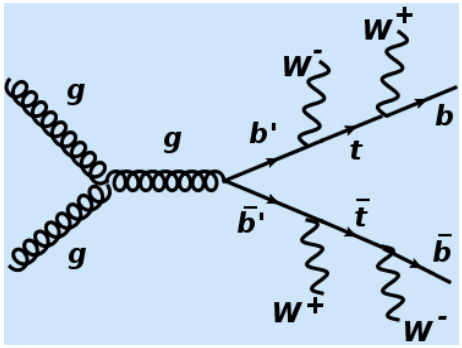
- the sum of the 3 BR is 1

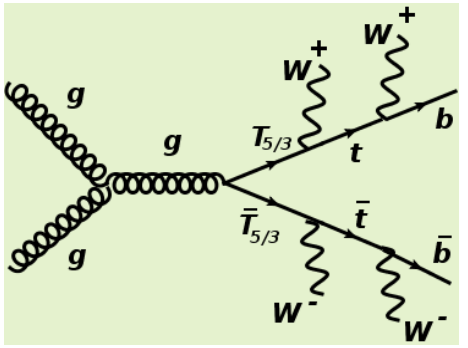


$b'\bar{b}'$ / $T_{5/3}\bar{T}_{5/3} \rightarrow WtW\bar{t}$ in same sign leptons channel (e or μ)

- Events $b'\bar{b}'$ / $T_{5/3}\bar{T}_{5/3} \rightarrow WtW\bar{t}$ @ 4.7 fb^{-1} for SS lepton channel (ATLAS-COM-CONF-2012-163)

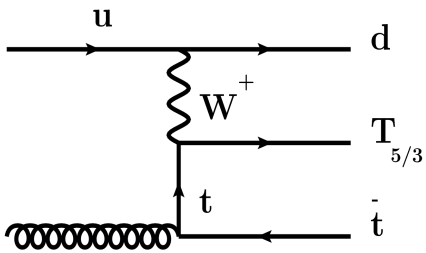
- Study :
  - b' : pair production only (limit on cross-section)
  - $T_{5/3}$: pair + single production (limit on cross-section depending on the coupling $T_{5/3}tW$)

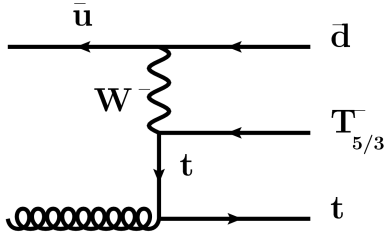




- Signal generated with Pythia and normalized to NNLO theoretical cross sections

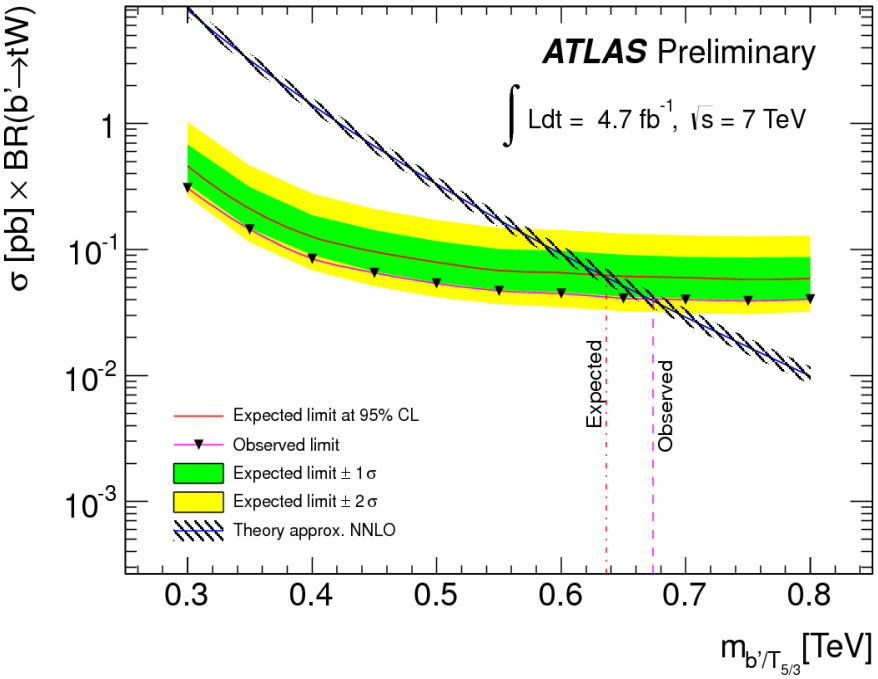
- Event selection :
  - >= 2 leptons (pair with highest P_T if multiple)
  - at least 2 jets and at least 1 b-tagged
  - $E_T^{miss} > 40$ GeV
  - $M_{ll} > 15$ GeV and $|M_{ll} - M_Z| > 10$ GeV (ee, μμ channels)
  - H_T (lep, jets) > 550 GeV

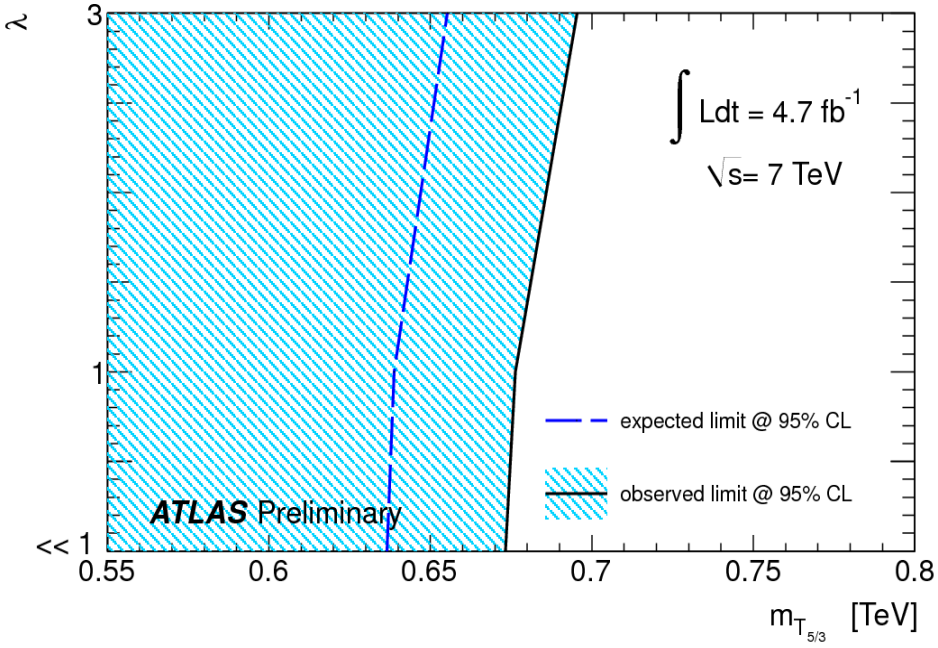




- Results :
  - A cut and count method is used
  - The CLs method is used to set 95% confidence level cross section upper limits for the pair production of fourth generation quarks

$b'\bar{b}'$ / $T_{5/3}\bar{T}_{5/3} \rightarrow WtW\bar{t}$ in same sign leptons channel (e or μ)





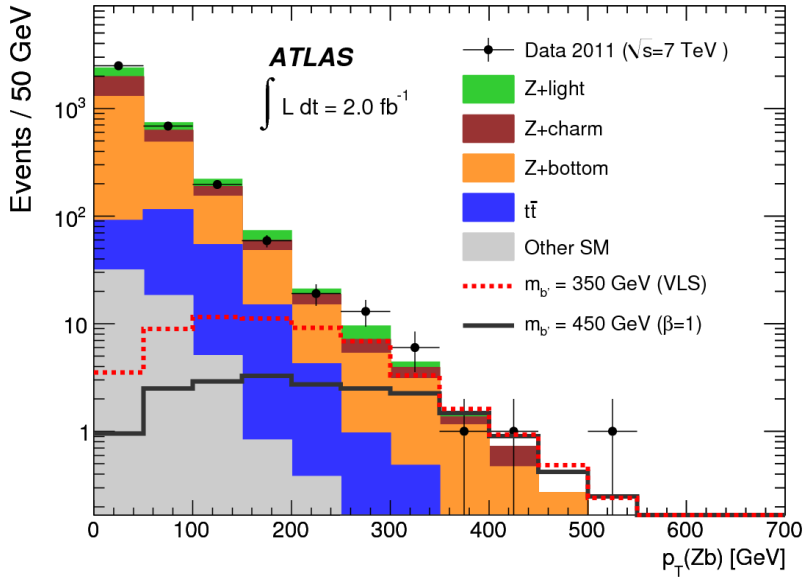
95% CL @ 4.7 fb-1		
pair production :	$m(b'/T_{5/3})$	> 670 GeV
pair+single coupling = 1	$m(T_{5/3})$	> 680 GeV
pair+single coupling = 3	$m(T_{5/3})$	> 700 GeV

★ Other results :

- study done @ 1 fb^{-1} for single lepton channel *(arXiv : 1202.6540, Phys.Rev.Lett. 109 (2012) 032001)*
- limit : m(b') > 480 GeV

$b'\bar{b}' \rightarrow Zb+X$ in single lepton and dilepton channel (e or μ)

- Events $b'\bar{b}' \rightarrow Zb+X$ @ 1.98 fb^{-1} where $Z \rightarrow ee$ (arXiv : 1204.1265, Phys.Rev.Lett. 109 (2012) 071801)
- Signal generated with MadGraph + Pythia and normalized to NNLO theoretical cross sections
- At least one b' decay to b' → Z + b
- The case of a vector-like singlet (VLS) mixing solely with the third SM generation is also considered (a SM Higgs of mass 125 GeV is assumed)

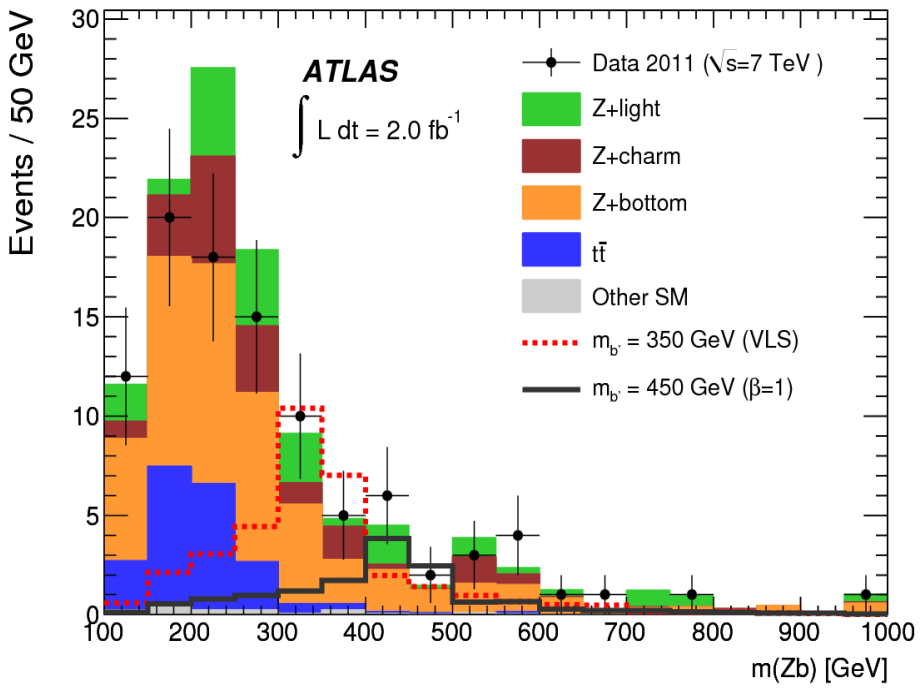


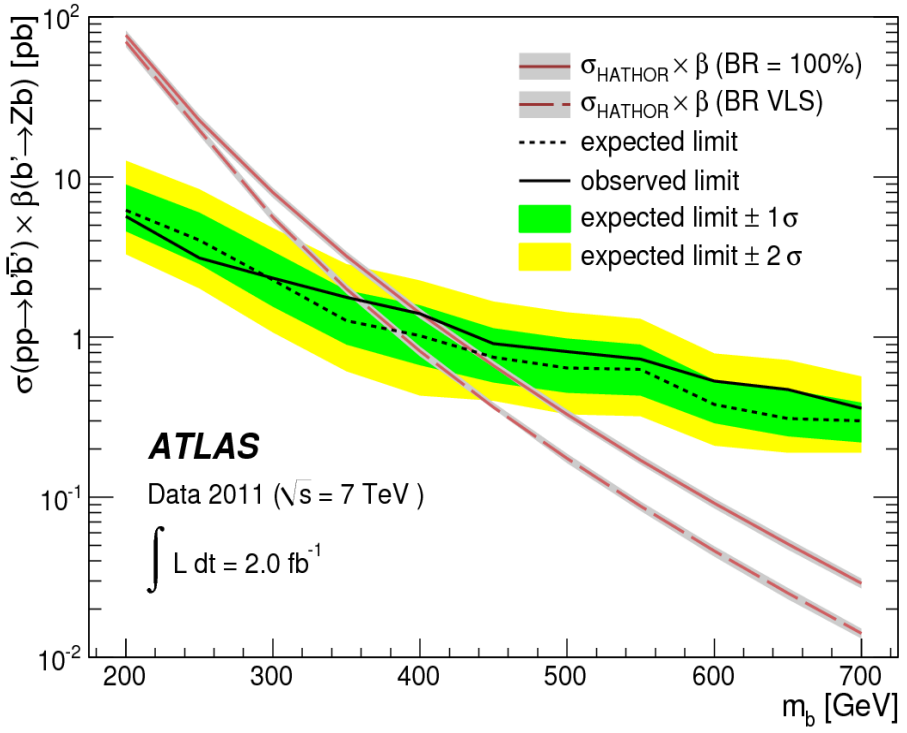
- Event selection :
  - at least 2 OS leptons
  - $|M_{ee} - M_Z| < 15$ GeV
  - at least 1 b-tagged jet
- Analysis :
  - the b′ candidate is formed from the $e^+ e^-$ pair and the highest p_T b-jet
  - the mass of the b′ candidate, m(Zb), is the discriminant variable
  - cut : p_T (Zb) > 150 GeV applied to increase the signal sensitivity

$b'\bar{b}' \rightarrow Zb+X$ in single lepton and dilepton channel (e or μ)

- The limit is computed using a binned Poisson likelihood ratio test of the m(Zb) distribution for different m(b′) hypothesis.

- The cross section limit is evaluated using the CLs modified frequentist approach



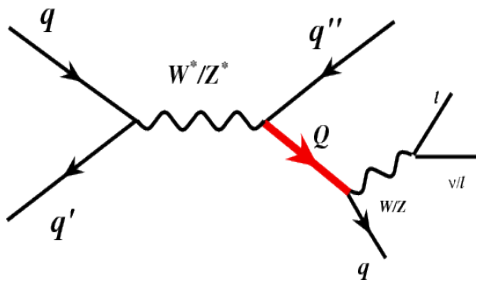


95% CL @ 4.7 fb-1

m(b') > 400 GeV

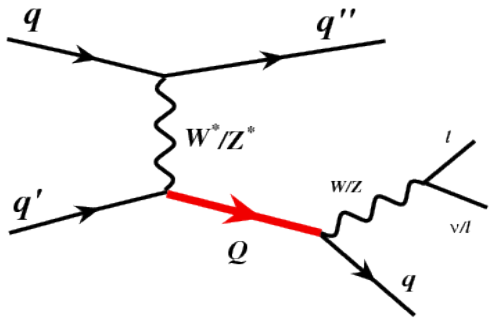
vector-like singlet b′ mixing solely with the third SM generation : m(b') for VLS > 358 GeV

- Events @ 4.64 fb^{-1} with a W → lν or Z → ll boson produced in association with at least 2 high P_T jets (ATLAS-CONF-2012-137)



- Signal generated with MadGraph + Pythia

charge	2/3	-1/3	5/3
σ(400 GeV).BR [pb]	0.849	5.47	7.78
σ(2 TeV).BR [pb]	0.305	1.32	3.64

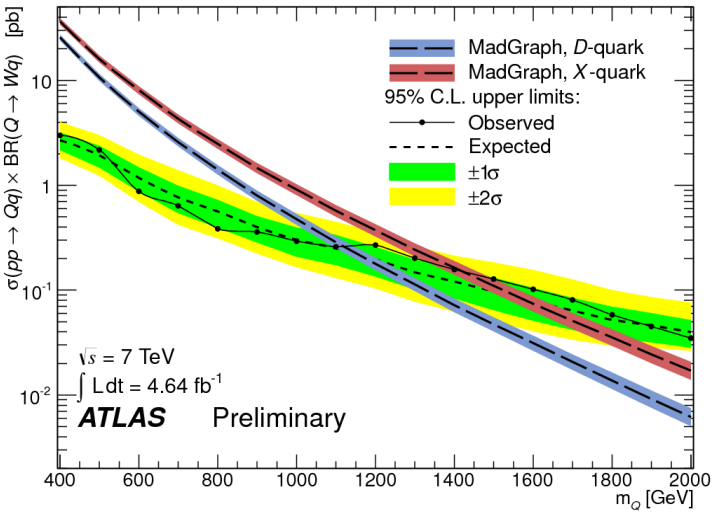


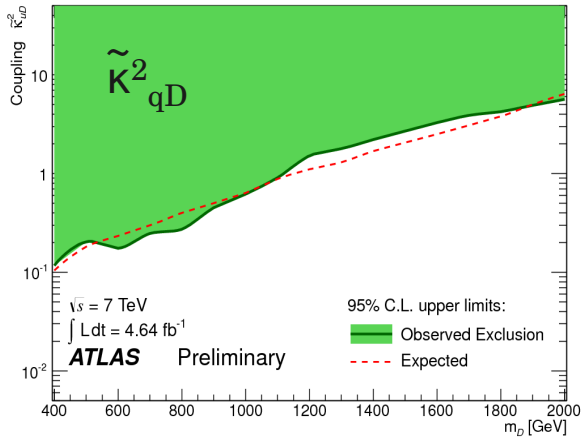
- <u>Event selection</u> :
  - analysis divided into 4 channels : CC and NC, each with either e or μ in the final state
  - the final event selection cuts are optimized independently for the CC and NC channels
  - CC channel : exactly 1 lepton and $E_T^{miss} > 50$ GeV → W reconstruction [$m_T(W) > 40$ GeV, $|\eta(W)| < 2.5$]
    $N_{jets} \geq 2$ and p_T(leading jet) > 60 GeV
    cut optimization on : $|\Delta\eta(W,jet)|$, $\Delta\eta(jet_{leading},jet_{associated})|$,
    $|\Delta\Phi(W,jet_{leading})|$, $|\Delta\Phi(l,E_T^{miss})|$
  - NC channel : 2 OS and same-flavour leptons (66 GeV < M_{ll} < 116 GeV)
    $N_{jets} \geq 2$
    cut optimization on : $|\Delta\eta(l,l)|$, $|\Delta\eta(Z,jet)|$, $|\Delta\eta(jet_{leading},jet_{associated})|$
    $|\Delta\Phi(l,l)|$, $|\Delta\Phi(Z,jet_{leading})|$,

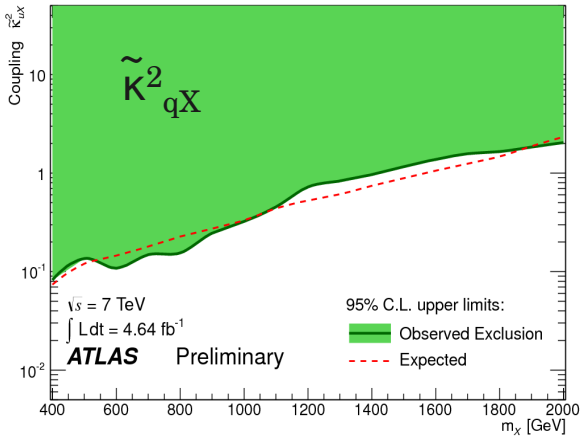
Single Production of VLQ Coupling to Light Generations

- Background :
  - estimated in data by fitting the reconstructed VLQ mass
  - as a cross-check, data are compared to the simulated background model

- Results are consistent with a background-only hypothesis :
  - limits are set on the production cross section and coupling (Bayesian limits)
  - stronger CC limits are obtained by requiring a negatively charged lepton in the final state (background (W^- + jets) = 1/3 * background (W^+ + jets))

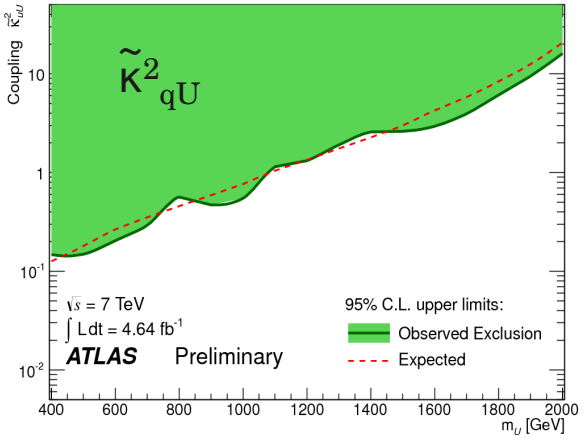






95% CL @ 4.64 fb^{-1} with $\tilde{\kappa}_{qQ} = 1$

- m(Q) > 1.12 TeV charge = 2/3
- m(Q) > 1.08 TeV charge = -1/3
- m(Q) > 1.42 TeV charge = 5/3



Conclusion and Outlook

- The fourth generation quark model has been studied and the following results were obtained @ 95% CL :
  - m(Q) > 350 GeV for up and down type Q
  - m(t') > 656 GeV for t' → W+b
  - m(b') > 670 GeV for b' → W+t

- This model is now disfavored by m_H ~126 GeV

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- The Vector Like Model has also been studied
  - a VLQ interpretation of t' @ 4.7 fb^{-1} has been shown
  - a vector-like singlet b′ (with b' → Z+b) mixing solely with the third SM generation has been studied
  - limits on VLQs with charge 5/3 has been shown for different coupling value $\lambda(T_{5/3}tW)$
  - the single production of VLQs coupling to light generations has been studied for VLQs with charges = -1/3, 2/3 and 5/3 and limits on the production cross section and coupling have been shown

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- This model survives m_H ~126 GeV

- We will continue to set limits on 4^{th} generation at 8 TeV
- The limits on the Vector Like Quark Model will be improved with data analysis at 8 TeV