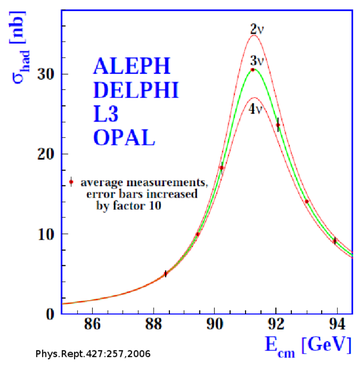
4th generation searches at ATLAS

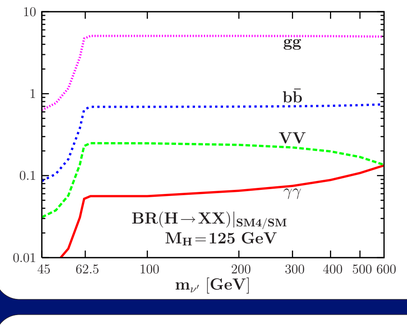
Introduction

· Presenting searches for 4th generation quarks as simple extension of the Standard Model (SM)
· Up-type quark: t', down-type quark: b'
· Until now 4th generation not excluded, neither by theoretical arguments nor by experimental constraints
· LEP: existence of 3 light ν generations $\rightarrow m_{\nu'} > m_Z/2$
· EW precision measurements favor: $m_{b'} > m_t + m_W$, $m_{t'} - m_{b'} < m_W$
· Possible role in electroweak symmetry breaking [1]
· Allow for a significantly higher Higgs-boson mass [2]
· Possible role in baryogenesis [3]
· Gauge coupling unification can be generated at a scale of order 10^{15} – 10^{16} GeV in the simplest non-supersymmetric Grand Unification model $SU(5)$ [4]



Implications from Higgs Searches

· **Within 4th generation (SM4):** would observe different Higgs decay branching fractions (BF) and higher (≈ factor 9) Higgs production cross section in comparison to 3 generation SM [5]



· If observed with SM expected BF hierarchy:
↪ SM4 as simple SM extension is ruled out!
↪ other models still possible: Higgs doublet, vector-like quarks

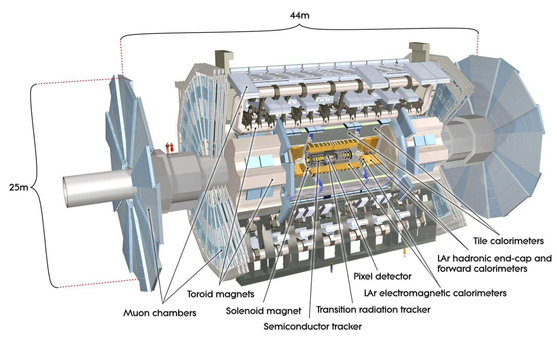
⇐ theor. Higgs decay branching ratios in SM4 normalised to their SM values as a function of the 4th gen. ν' mass [5]
⇐ assuming $m_H = 125\,\text{GeV}$, $m_{b'} = m_{t'} + 50\,\text{GeV} = 600\,\text{GeV}$ and $m_{\ell'} = m_{\nu'} + 50\,\text{GeV}$

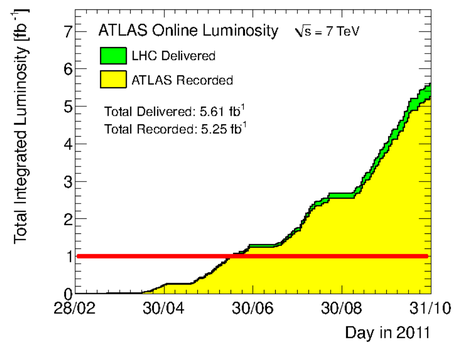
Signal model

· 4th generation quark pair production, decay and shower generated with *PYTHIA6* [6]
· Using approx. NNLO production cross-sections calculated with *HATHOR* [7]

The ATLAS Experiment

Inner detector: Inside solenoid magnet, consists of silicon pixels, silicon strips and transition radiation tracker, provides reconstruction of charged particle tracks and vertices
Calorimeters: Electromagnetic (liquid Argon) and hadronic (iron + scintillating plastic) calorimeters, reconstruction of particle showers
Muon spectrometer: In toroid magnet, mainly consists of gas chambers, reconstruction of muons
Luminosity: Presented analyses correspond to an integrated luminosity of $\mathcal{L} = 1.04\,\text{fb}^{-1}$





Physical object selection

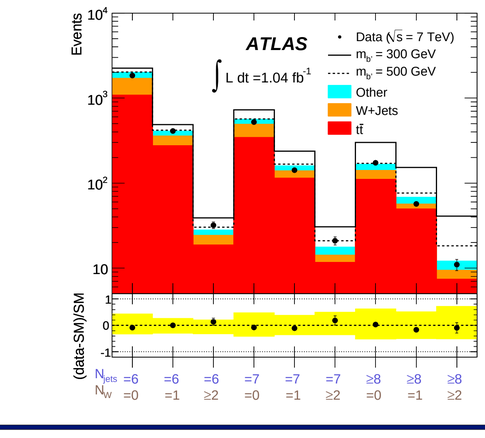
Trigger: single lepton (electron or muon) trigger chain
Electrons: $E_T > 25\,\text{GeV}$, $|\eta^{\text{Cluster}}| < 2.47$ (excl. $1.37 < |\eta^{\text{Cluster}}| < 1.52$), tight quality selection criteria, calorimeter isolation
Muons: $P_T > 20\,\text{GeV}$, $|\eta| < 2.5$, cosmics rejection, isolation, removing μ overlapping with jets
Jets: $P_T > 25\,\text{GeV}$, $|\eta| < 2.5$, anti-k_T algorithm ($R = 0.4$), topological calorimeter clusters, removing jets overlapping with e
$\mathbf{E_T^{Miss}}$: vector sum of calorimeter cluster deposits incl. contributions from muons
$\mathbf{H_T}$: scalar sum of jets and leptons P_T^ℓ ($\ell = e$ and μ)
$\mathbf{m_T}$: $m_T = \sqrt{2E_T^{Miss}P_T^\ell\left(1 - \cos\left(\Delta\Phi\left(E_T^{Miss}, P_T^\ell\right)\right)\right)}$
$\mathbf{m_{inv}^{\ell\ell}}$: invariant mass of dilepton system → Z-veto: $m_{inv}^{\ell\ell} \notin [81, 101]\text{GeV}$

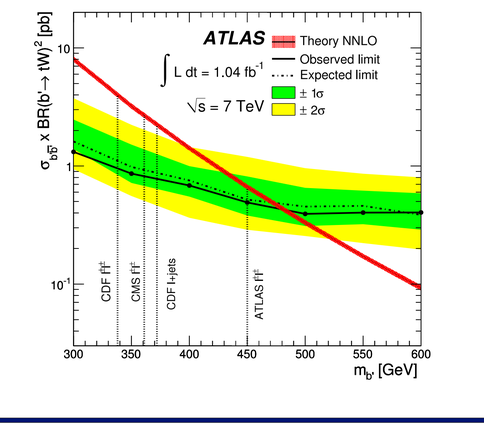
Search for b' in same-sign dilepton final states

(JHEP 1204 (2012) 069, arXiv:1202.5520)

Decay channel: $b'\bar{b'} \rightarrow \ell^\pm\ell^\pm$ + jets + E_T^{Miss}, assuming $b' \rightarrow tW$ (BR=100%, $m_{b'} > m_t + m_W$)
Event selection: ≥ 2 same-sign charged leptons (e or μ)
in $ee/\mu\mu$ events: $m_{inv}^{\ell\ell} > 15\,\text{GeV}$, Z-veto
≥ 2 jets, $E_T^{Miss} > 40\,\text{GeV}$, $H_T > 350\,\text{GeV}$
Backgrounds: MC(real): diboson (incl. $W^\pm W^\pm + 2$ jets), $t\bar{t} + W/Z$ + jets
fake leptons → matrix method on data
charge-misid → measuring charge-flip rate in opposite-sign Z events on data
Results: single-bin counting experiment
CL_S method for limit setting [8]

$\mathbf{m_{b'} > 450\,\text{GeV}}$ @ 95% CL





Search for b' in single lepton final states

(CERN-PH-EP-2011-230, arXiv:1202.6540)

Decay channel: $b'\bar{b'} \rightarrow \ell^\pm b\bar{b}$ + jets + E_T^{Miss}, assuming $b' \rightarrow tW$ (BR=100%, $m_{b'} > m_t + m_W$)
Event selection: 1 e or μ, ≥ 6 jets (assuming semi-boosted W bosons with decays: $W \rightarrow jj$)
in e events: $E_T^{Miss} > 35\,\text{GeV}$, $m_T > 25\,\text{GeV}$
in μ events: $E_T^{Miss} > 20\,\text{GeV}$, $E_T^{Miss} + m_T > 60\,\text{GeV}$
Backgrounds: MC: diboson, $t\bar{t}$ + jets, $t\bar{t} + W/Z$ + jets, Z + jets
W + jets → shape from MC and normalisation from data
Results: binned maximum-likelihood fit in 9 bins (N_W, N_{jets}) using profile likelihood ratio
→ $N_W = 0, 1, \geq 2$: # of reconstructed W (with $\Delta R(jj) < 1.0$, $m_{\text{inv}}^{jj} \in [70, 100]\text{GeV}$)
→ $N_{\text{jets}} = 6, 7, \geq 8$: # of reconstructed jets
CL_S method for limit setting [8]

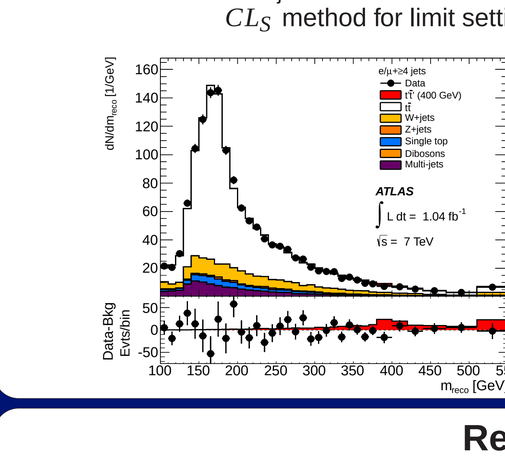
$\mathbf{m_{b'} > 480\,\text{GeV}}$ @ 95% CL

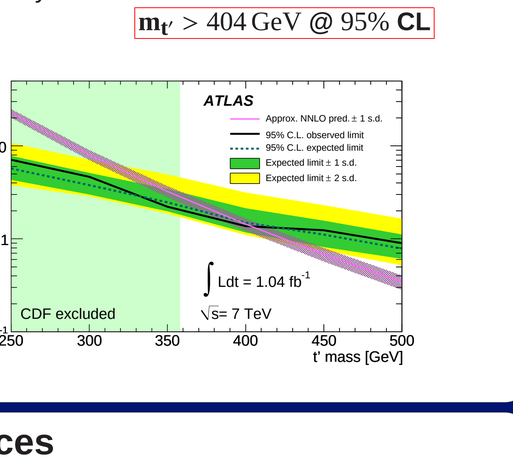
Search for heavy Q in opposite-sign dilepton final states

(CERN-PH-EP-2012-008, arXiv:1202.3389)

Decay channel: $Q\bar{Q} \rightarrow \ell^\pm\ell^\mp$ + jets + E_T^{Miss}, assuming heavy quark $Q \rightarrow qW$ ($q = u, d, c, s, b$)
Event selection: 2 opposite-sign charged leptons (e or μ), ≥ 2 jets
in $ee/\mu\mu$ events: $m_{inv}^{\ell\ell} > 15\,\text{GeV}$, Z-veto, $E_T^{Miss} > 60\,\text{GeV}$
in $e\mu$ events: $H_T > 130\,\text{GeV}$
m_{coll}: reconstructed heavy quark mass, assuming ν approx. collinear to leptons ($\Delta\eta$ and $\Delta\phi$ are fitted) → $H_T + E_T^{Miss} > m_Q - 0.4 \cdot m_{\text{coll}}$
Backgrounds: MC: diboson, $t\bar{t}$, Z + jets, single-top
Drell-Yan → estimation from Z-peak on data
fake leptons → matrix method on data
Results: binned maximum-likelihood ratio, fit of m_{coll}
CL_S method for limit setting [8]

$\mathbf{m_Q > 350\,\text{GeV}}$ @ 95% CL





Search for t' in single lepton final states

(CERN-PH-EP-2012-007, arXiv:1202.3076)

Decay channel: $t'\bar{t'} \rightarrow \ell^\pm b\bar{b}$ + jets + E_T^{Miss}, assuming $t' \rightarrow bW$ (BR=100%, $m_{t'} - m_{b'} < m_W$)
Event selection: 1 e or μ, ≥ 3 jets, leading jet $P_T > 60\,\text{GeV}$, ≥ 1 b-jet, $E_T^{Miss} + m_T > 60\,\text{GeV}$
in e events: $E_T^{Miss} > 35\,\text{GeV}$, in μ events: $E_T^{Miss} > 20\,\text{GeV}$
Backgrounds: MC: diboson, $t\bar{t}$, Z + jets, single-top
W + jets → shape from MC and normalisation from data
Multi jets → data-driven
Results: discr. variable: reconstructed t' mass m_{reco} (also used to constrain systematics)
→ $N_{\text{jets}} \geq 4$: kinematic likelihood fit (*KLfitter*) to decay hypothesis
→ $N_{\text{jets}} = 3$: invariant mass of 3-jet system
CL_S method for limit setting [8]

$\mathbf{m_{t'} > 404\,\text{GeV}}$ @ 95% CL

Considered systematics

· Object calibration, resolution and energy scale, E_T^{Miss}
· b-tagging algorithm
· Initial and final state QCD radiation
· Choice of parton distribution function
· Cross-section, luminosity and pile-up
· Trigger and reconstruction efficiencies
· Data-driven backgrounds

References

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