Search for 4th Generation Quarks with the ATLAS-Detector

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30.09.2009

contents

motivation

present situation:

- the number of families is not fixed by the Standard Model
- three families of leptons and quarks experimentally verified
- Z-pole experiment: $N_\nu = 3$ with $m_\nu < m_Z/2$
- if ν_4 exists: $m_{\nu_4} \gtrsim m_Z/2$
- electroweak precision fit doesn't exclude 4th gen. model

  in contrast to PDG's statement

with a fourth generation:

- possible way to explain baryogenesis

  (Fok & Kribs, Phys.Rev.D78:075023,2008;

  Hou, Chin. J. Phys.47:134, 2009)
- higher Higgs mass (up to 600GeV) possible

  (Kribs, Plehn, Spannowsky & Tait, Phys.Rev.D76:075016,2007)

direct limits

current limits on short living particles:

- $m_{l_4} > 100.8$ GeV (LEP2)
- Dirac: $m_{\nu_4} > 90.3$GeV, Majorana: $m_{\nu_4} > 80.5$GeV (LEP2)
- $m_{t'} > 311$ GeV @ 95% CL (CDF 2008, 2.8 fb^{-1})
  $Q\bar{Q} \rightarrow q\bar{q} + 2W$ in single lepton events with jets
- $m_{b'} > 325$ GeV @ 95% CL (CDF 2009, 2.7 fb^{-1})
  $Q\bar{Q} \rightarrow t\bar{t} + 2W$ in same-charge dilepton events with jets

consequence:

- looking for 4th gen. quarks with m $\geq$ 300GeV

tiny mixing angles (particles could have long lifetime):

- relaxed mass limits
  (Hung & Sher, Phys.Rev.D77:037302,2008)

mc samples

final states of t' and b' decay with sizable branching fraction:

(assumption: m(b')-m(t) $>$ m(W), V$_{tb'}$ sufficiently large)

m(t') $>$ m(b')	m(t')-m(b') $>$ m(W)	$b'\bar{b'} \to t\bar{t} + 2W \to b\bar{b}2W^+2W^-$
		$t'\bar{t'} \to b'\bar{b'} + 2W \to b\bar{b}3W^+3W^-$
	m(t')-m(b') $<$ m(W)	$b'\bar{b'} \to tW^-\bar{t}W^+ \to b\bar{b}2W^+2W^-$
		$t'\bar{t'} \to bW^+\bar{b}W^-$
m(b') $>$ m(t')	m(b')-m(t') $>$ m(W)	$b'\bar{b'} \to t'W^-\bar{t'}W^+ \to b\bar{b}2W^+2W^-$
		$b'\bar{b'} \to tW^-\bar{t}W^+ \to b\bar{b}2W^+2W^-$
		$t'\bar{t'} \to bW^+\bar{b}W^-$
	m(b')-m(t') $<$ m(W)	$b'\bar{b'} \to tW^-\bar{t}W^+ \to b\bar{b}2W^+2W^-$
		$t'\bar{t'} \to bW^+\bar{b}W^-$

mc samples

decay channels:

- $b'\bar{b'} \rightarrow t\bar{t} + W^+W^- \rightarrow b\bar{b} + 2W^+2W^-$
- $t'\bar{t'} \rightarrow b'\bar{b'} + W^+W^- \rightarrow t\bar{t} + 2W^+2W^- \rightarrow b\bar{b} + 3W^+3W^-$

$\Rightarrow$ b' final states:

- $l^\pm l^\pm$ + 4 jets: BR = 0,0597 ($l^\pm l^\mp$ + 4 jets: BR = 0,1195)
- 3l + 2 jets: BR = 0,0465

$\Rightarrow$ t' final states:

- $l^\pm l^\pm$ + jets,
- 3l + jets,
- $l^\pm l^\pm l^\pm$ + jets

mc samples

signal production:

- mc generator: pythia6.4.19
- detector simulation: atlfast2
  - geant 4 full simuation of inner detector
  - calorimeter: parametrized simulation of particle energy reponse and energy distribution with fastcalo sim algorithm
  - geant 4 full simulation of the muon system
- geant4
  - toolkit for the simulation of the passage of particles through matter
  - problem: 15min/event for $Z^0 \rightarrow e^+e^-$
  - 80% of the full simulation time is spent for tracking particles through the calorimeters
- analysis tool: A^{++}

mc samples

analysis tool: A^{++}:

- main author: Oliver Maria Kind (HU Berlin)
- object-oriented analysis framework
- written in C++
- heavily based on the ROOT libraries
- convert different atlas data formats (ESD/AOD/D^{1}PD/D^{2}PD) in root event files directly
- user friendly (help function,...)
- tool used for different analyses

produced b' samples (10TeV):

m [GeV]	NLO cross section [pb] *
300	20.319
350	8.895
400	4.116
450	2.166
500	1.230

* NLO: LO with k-factor
from $t\bar{t}$ @ 14TeV
assuming same k @ 10TeV

produced t' samples (10TeV):

m [GeV]	NLO cross section [pb] *
400 ($m_{b'}$ = 300)	3.959
450 ($m_{b'}$ = 350)	2.207
500 ($m_{b'}$ = 400)	1.970
550 ($m_{b'}$ = 450)	0.642
600 ($m_{b'}$ = 500)	0.380

background (under consideration):

sample	cross section (10 TeV)
$t\bar{t} + jets$	12.66pb - 121.21pb
single top	2pb - 15pb
$W(\rightarrow l^{\pm}\nu) + jets$	10184.70pb - 16.60pb
$Z(\rightarrow l^{+}l^{-}) + jets$	898.20pb - 1.70pb
$WW(\rightarrow l^{\pm}\nu) + jets$	5.388pb - 1.128pb
$WZ(\rightarrow l^{\pm}\nu, l^{+}l^{-}) + jets$	1.840pb - 0.648pb
$ZZ(\rightarrow l^{+}l^{-}) + jets$	1.351pb - 0.190pb
ZWW, ZWZ, ZZZ and WWW	6 fb - 52fb
$W(\rightarrow l^{\pm}\nu) + bb + jets$	5.13pb - 1.61pb
$ttbar + W^{\pm} + jets$, $ttbar + 2W^{\pm} + jets$	
$ttbar + Z + jets$, $ttbar + 2Z + jets$	
$ttbar + H(m_H > 200 GeV) + jets$	
$W + \gamma + jets$	
QCD jets (J1, ..., J7)	$1.17 \cdot 10^{10}$ pb - 1.075pb

particle selection

electron:

- standard electron algorithm
  - cluster based algorithm
  - reconstruction of high p_T isolated electrons
- tight selection
  - electron candidates has to pass all cuts based on the shower shape properties in different compartments of the calorimeter as well as variables combining ID and Calo informations
- $p_T^{all} > 20\text{GeV}$ and $p_T^{leading} > 35\text{GeV}$
- isolation criterion: $E_t^{cone20} < 8\text{GeV}$
  - calculated by subtracting the lepton energy deposited in the calorimeter system from the overall deposited energy within a cone of radius $\text{R} = \sqrt{\Delta\eta - \Delta\phi} = 0.2$

particle selection

muon:

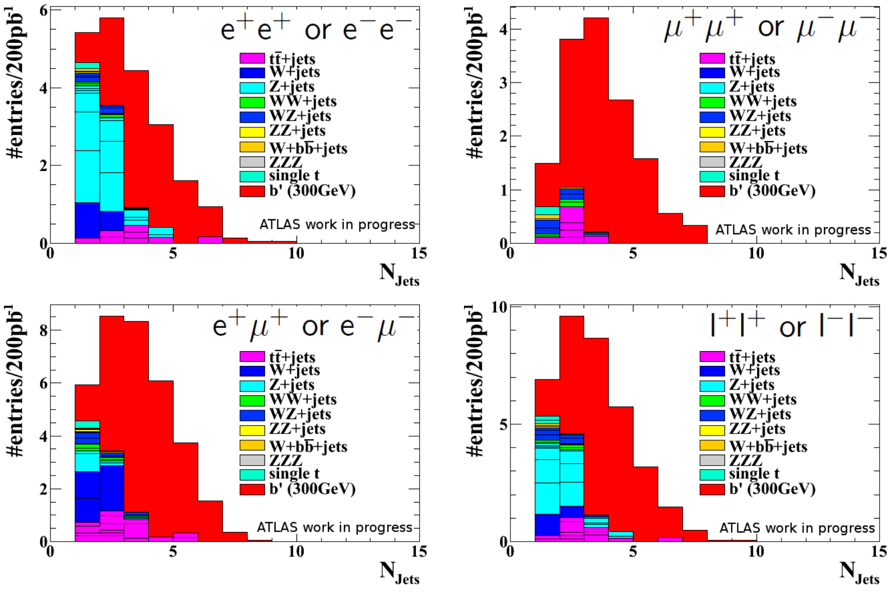
- staco algorithm
  - merge the two independent measurements derived from the inner detector track with the muon spectrometer track
- $\chi^2/NDoF < 5$
  - χ^2 define the difference between both tracks
- $p_T^{all} > 20\text{GeV}$ and $p_T^{leading} > 35\text{GeV}$
- isolation criterion in the calorimeter: $E_t^{cone20} < 10\text{GeV}$

particle selection

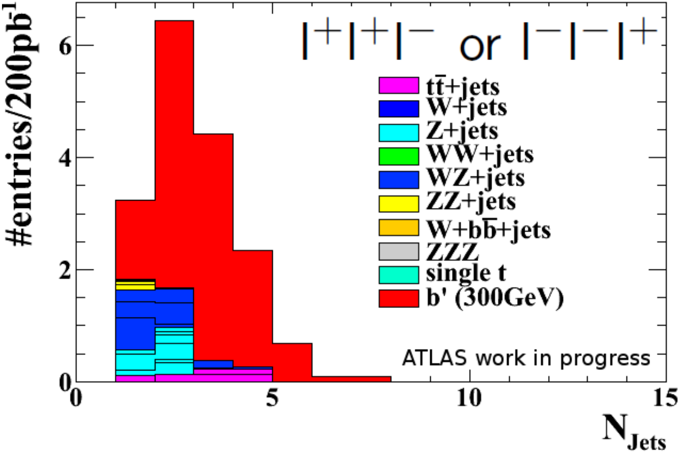
jets:

- Cone4H1TowerJets
  - standard ATLAS seeded cone algorithm in a radius of $R = \sqrt{\Delta\eta - \Delta\phi} < 0.4$
  - use calorimeter towers which have $\mathrm{E_T} > 1\mathrm{GeV}$
  - problem: every particle in the calorimeter will be reconstructed as a jet
- overlap removal ($\Delta R < 0.2$ and $|\eta| < 2.5$) with $e^{\pm}$, $\mu^{\pm}$, γ and $\tau^{\pm}$
- $\mathrm{E}_T^{all} > 25\mathrm{GeV}$ in order to supress jets from underlying event and $E_T^{leading} > 85\mathrm{GeV}$

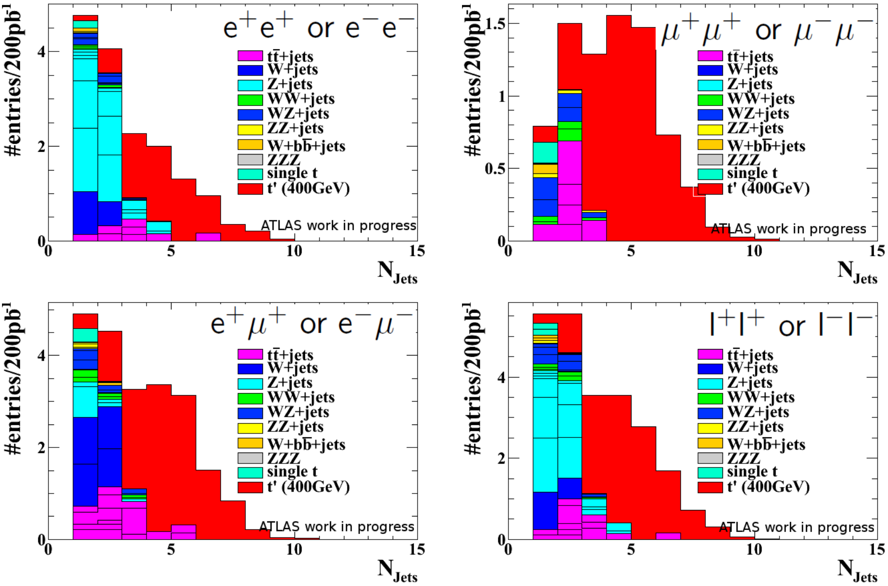
n_{jets} in same sign dilepton events with b'($m_{b'} = 300$GeV)



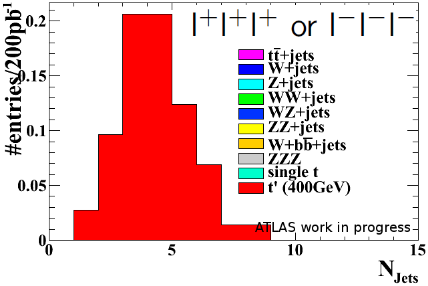
n_{jets} in trilepton events with b'($m_{b'} = 300$GeV)

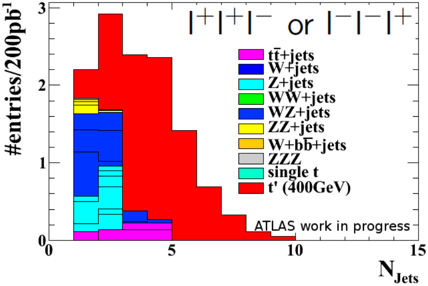


n_{jets} in same sign dilepton events with t'($m_{t'} = 400$GeV)



n_{jets} in trilepton events with t'($m_{t'} = 400$GeV)





outlook

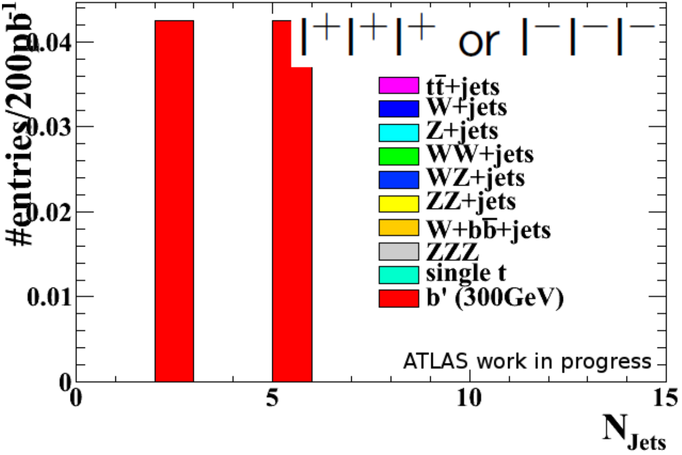
- work performed in collaboration with Michael Wilson (SLAC), M. Hickman (Irvine), A. Taffard (Irvine), D. Whiteson (Irvine), D. Berge (CERN) and S. Schaetzel (CERN)

  $\Rightarrow$ pubnote in preparation
- complete study of all background samples
- data driven background and signal extraction:

  likelihood fit in n_{jets} for dilepton and trilepton classes
- sensitivity study
- systematic studies
- analysis on first year data

backup slides

n_{jets} in trilepton events with b'($m_{b'}$ = 300GeV)



systematic studies

- lepton fakes
- background extraction method
- jet merging and jet algorithm
- underlying event
- PDF
- Pile-ups

branching fractions for $2W^+2W^-$ final state

$2W^+2W^-$	l=$e^\pm$	l=$\mu^\pm$	l=e/μ	l=$\tau(\mu, e)$	l=$e/\mu/\tau(\mu, e)$
1l + 6p	0,1317	0,1317	0,2634	0,0439	0,3073
2l(ss) + 4p	0,0110	0,0110	0,0439	0,0012	0,0597
2l(os) + 4p	0,0219	0,0219	0,0878	0,0024	0,1195
3l + 2p	0,0037	0,0037	0,0293	$1{,}4 \cdot 10^{-4}$	0,0465
4l + 0p	$1{,}5 \cdot 10^{-4}$	$1{,}5 \cdot 10^{-4}$	0,0024	$1{,}9 \cdot 10^{-6}$	0,0045

nlo cross calculation

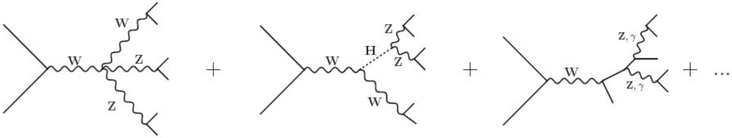
- pythia6 only a LO mc generator
- actually no NLO mc generator with 4th generation model
- $\sigma^{[NLO]} = k \cdot \sigma^{[LO]}$

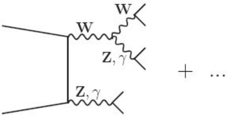
k-factor calculation via top cross section at 14TeV

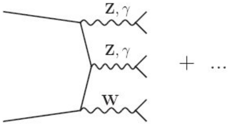
(ATL-COM-PHYS-2009-334) :

- $\sigma^{[LO]} = 583pb$
- $\sigma^{[NLO]} = 875pb$
- $k = \frac{\sigma^{[NLO]}}{\sigma^{[LO]}} = 1.5$
- use k-factor of 14TeV for 10 TeV

triple vector boson production

a) 

b) 

c) 

ckm matrix

$$V_{CKM}^{4\times 4} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} & V_{ud_4} \\ V_{cd} & V_{cs} & V_{cb} & V_{cd_4} \\ V_{td} & V_{ts} & V_{tb} & V_{td_4} \\ V_{u_4 d} & V_{u_4 s} & U_{u_4 t} & V_{u_4 d_4} \end{pmatrix} = \begin{pmatrix} 0.9738 & 0.225 & 0.0039 & 0.06 \\ 0.22 & 0.96 & 0.041 & 0.22 \\ 0.1 & 0.2 & 0.78 & 0.65 \\ 0.1 & 0.22 & 0.65 & 0.78 \end{pmatrix}$$