Search for 4th Generation Quarks with the ATLAS-Detector

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contents

motivation

present situation:

- the number of families 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 @ 95% CL (LEP2)
- Dirac: $m_{\nu_4} > 90.3$GeV @ 95% CL,
  Majorana: $m_{\nu_4} > 80.5$GeV @ 95% CL (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 for us:

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

tiny mixing angles between different families (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:

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

$\Rightarrow$ b' final states:

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

$\Rightarrow$ t' final states:

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

- signature also used in "Search for A Fourth Generation b' Quark in tW Final State at CMS in pp Collisions at $\sqrt{s} = 10$ TeV" (CMS PAS EXO-09-012)

mc samples

signal production:

- mc generator: pythia6.4.19
- detector simulation: atlfast2
  - geant4 full simulation of inner detector
  - calorimeter: parametrized simulation of particle energy response and energy distribution with fastcalo sim algorithm
  - geant4 full simulation of the muon system
- analysis tool: A^{++}

mc samples

analysis tool: $\mathbf{A}^{++}$:

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

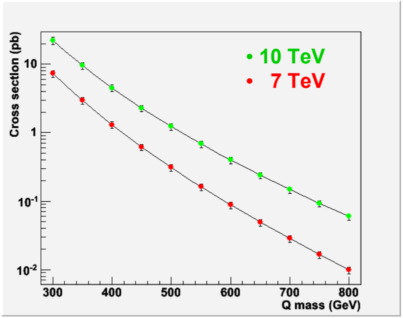
Tool for cross sections calculation (by M. Aliev HU Berlin*)

$$\sigma^{q\bar{q}}(\sqrt{s}, m_q) = \sum_{i,j=q,\bar{q},g} \int dx_1 dx_2 f_i^A(x_1,\mu) f_j^B(x_2,\mu) \times \sigma^{ij\to q\bar{q}}(\rho, m_q^2, x_1, x_2, \alpha_s, \mu)$$

1. $\sigma^{ij\to q\bar{q}}$ are taken from *P.Nason,S.Dawson&R.K.Ellis,Nucl.Phys.B303(1998)607-633*
2. PDFs are included using *the Les Houches Accord PDF (LHAPDF) Interface,* version 5.7.1
3. Integration is done by MC Integration tool *VEGAS* (part of GNU Scientific Library)

CME,TeV	m_q,GeV	σ(NLO,cteq66),pb	k-factor
10	300	$22.3^{+2.3}_{-2.7}$	1.461
10	400	$4.5^{+0.4}_{-0.5}$	1.456
10	500	$1.23^{+0.11}_{-0.14}$	1.439
7	300	$7.3^{+0.8}_{-0.9}$	1.468
7	400	$1.31^{+0.13}_{-0.16}$	1.442
7	500	$(3.1^{+0.3}_{-0.4})\times10^{-1}$	1.408

k-factor=σ(NLO,cteq66)/σ(LO,cteq6ll)



**Thanks to P.Uwer and U.Langenfeld (HU Berlin), S.Moch (DESY, Zeuthen) for the help in the development of the tool.*
The tool will soon be available for public use.

background (under consideration):

sample	cross section (10 TeV)
$t\bar{t} + jets$	12.66pb - 121.21pb
$W(\rightarrow l^{\pm}\nu) + jets$	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
single top	2pb - 15pb
$ttbar + W^{\pm} + jets,\ ttbar + 2W^{\pm} + jets$	
$ttbar + Z + jets,\ ttbar + 2Z + jets$	
$ttbar + H(m_H > 200 GeV) + jets$	
$W + \gamma + jets$	
QCD jets (J1, ..., J7)	$1.17 \cdot 10^{10}$ pb - 1.075pb

particle selection

electron:

- standard electron algorithm
  - electromagnetic calorimeter cluster based algorithm
  - reconstruction of high p_T isolated electrons
- tight selection
  - electron candidates has to pass all cuts which are based on the shower shape properties in the calorimeter and track properties in the inner detector
- $p_T^{all} > 20\text{GeV}$ 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 $\mathrm{R} = \sqrt{\Delta\eta^2 + \Delta\phi^2} = 0.2$

particle selection

muon:

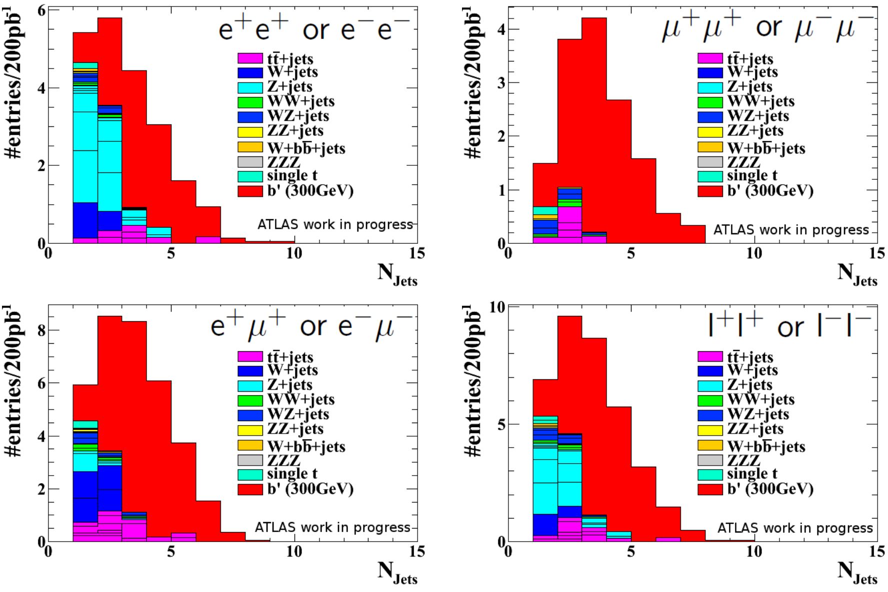
- staco algorithm
  - merge the two independent measurements derived from the inner detector track with the muon spectrometer track
- $\chi^2/NDoF < 5$ for matching χ^2 between both tracks
- $p_T^{all} > 20\text{GeV}$ and $p_T^{leading} > 35\text{GeV}$
- isolation criterion in the calorimeter: $E_t^{cone20}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

particle selection

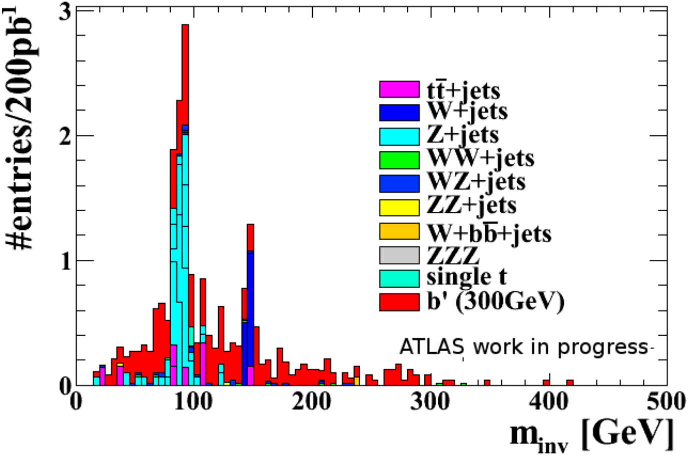
jets:

- Cone4H1TowerJets
  - standard ATLAS seeded cone algorithm in a radius of $R = \sqrt{\Delta\eta^2 + \Delta\phi^2} < 0.4$
  - use (em and hadronic) calorimeter towers which have $E_T > 1\text{GeV}$
  - problem: every particle in the calorimeter possibly reconstructed as a jet
- overlap removal ($\Delta R < 0.2$ and $|\eta| < 2.5$) with $e^{\pm}$, $\mu^{\pm}$, γ and $\tau^{\pm}$
- $E_T^{all} > 25\text{GeV}$ in order to suppress jets from underlying event and $E_T^{leading} > 85\text{GeV}$

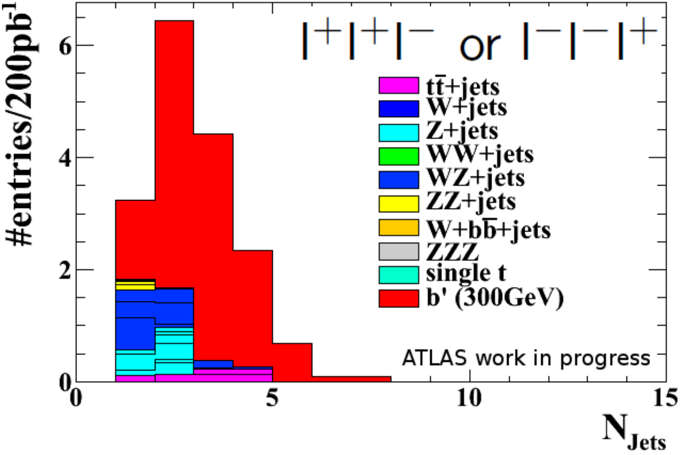
same sign dilepton events ($\sqrt{s} = 10\text{TeV}$, Lumi $= 200\text{pb}^{-1}$)



m_{inv} for e^+e^+ or e^-e^-



trilepton events ($\sqrt{s} = 10\text{TeV}$, Lumi = 200pb^{-1})



outlook

- work performed in collaboration with Michael Wilson (SLAC),

  M. Hickman (Irvine), A. Taffard (Irvine), D. Whiteson (Irvine),

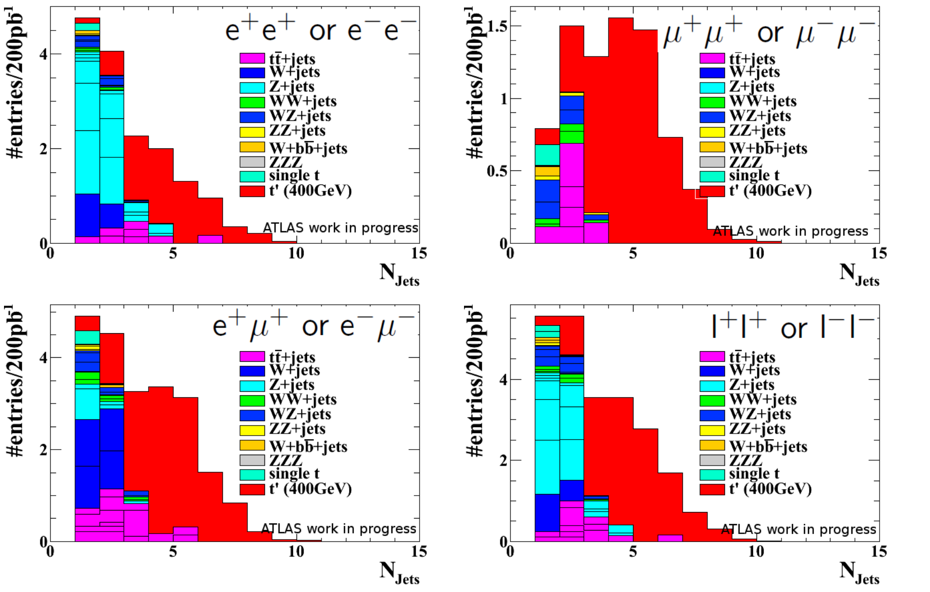
  D. Berge (CERN) and S. Schaetzel (CERN)

  $\Rightarrow$ pubnote in preparation

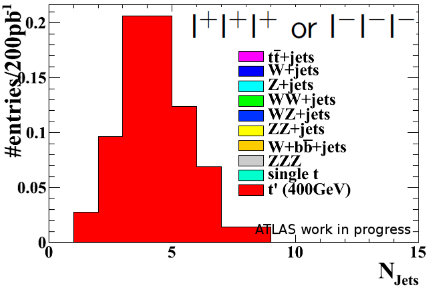
- complete study of all background samples
- data driven background and signal extraction:
  - cut based counting analysis
  - likelihoodfit in n_{jets} for dilepton and trilepton classes with different background contributions ($t\bar{t} + jets$, $W + jets$, $Z + jets$, etc)

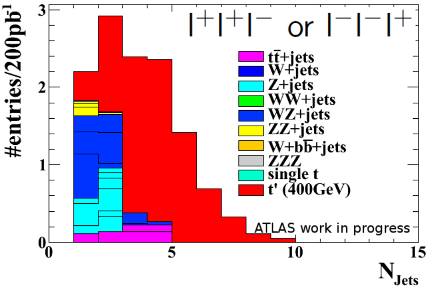
backup slides

same sign dilepton events ($\sqrt{s} = 10\text{TeV}$, Lumi $= 200\text{pb}^{-1}$)

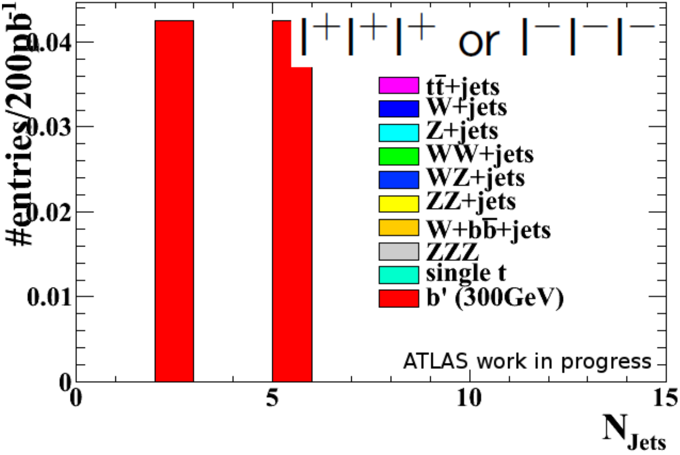


trilepton events ($\sqrt{s} = 10\text{TeV}$, Lumi $= 200\text{pb}^{-1}$)





trilepton events ($\sqrt{s} = 10\text{TeV}$, Lumi $= 200\text{pb}^{-1}$)



likelihood fit

- method already used for b' analysis in CDF (CDF 2009)
- use R.Barlow and C.Beeston method

  (Comp.Phys.Comm.77(1993) 219-228)
- PDFs extracted from signal/background MC histograms
- calculate a combined fit to data, that uses the relative weights as parameters common to all categories

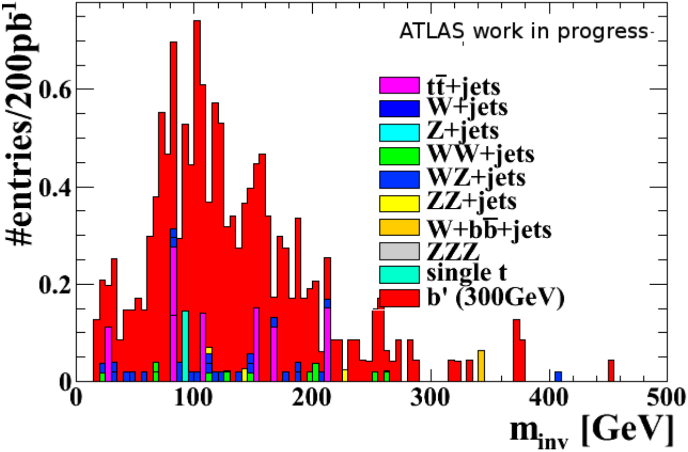
likelihood fit

- use SImPdfBuilder, light and extendible fit package developed for BaBar by M. Wilson and C. Flacco
  - it is build on ROOT and use MINUIT as fitter
  - allow implementation of complex propability density functions (e.g. having non-trivial multidimensional correlations or introducing parameters that are not calculated by MINUIT)
  - under review to be included as an official ATLAS package

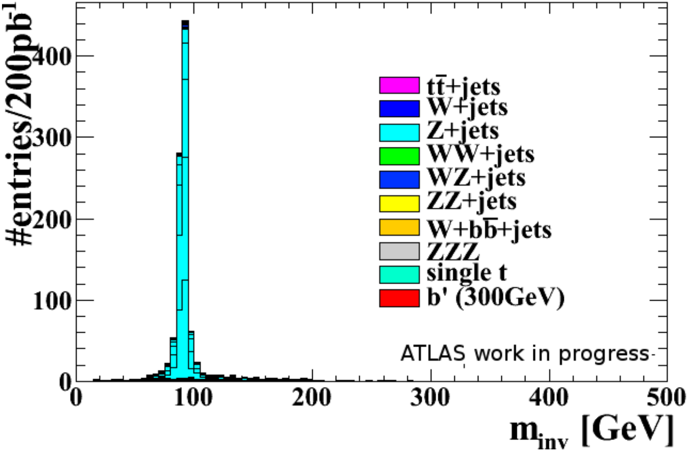
next steps

- sensitivity studies
  - lepton fakes
  - background extraction method
  - jet merging and jet algorithm
  - underlying event
  - PDF
  - Pile-ups
- systematic studies
- analysis on first year data

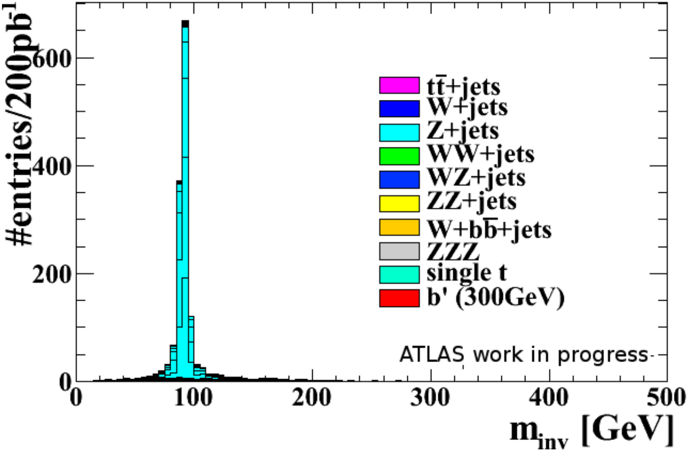
m_{inv} for $\mu^+\mu^+$ or $\mu^-\mu^-$



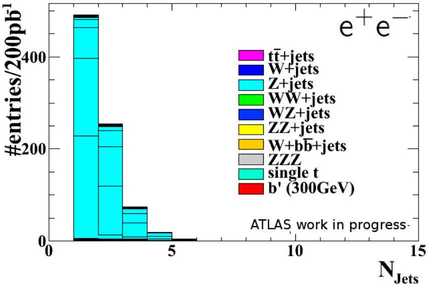
m_{inv} for e^+e^-

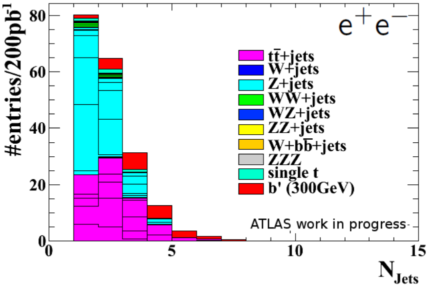

#entries/200pb⁻¹
0
100
200
300
400
0
100
200
300
400
500
m_inv [GeV]
tt̄+jets
W+jets
Z+jets
WW+jets
WZ+jets
ZZ+jets
W+bb̄+jets
ZZZ
single t
b' (300GeV)
ATLAS work in progress

m_{inv} of leading lepton for $\mu^+\mu^-$



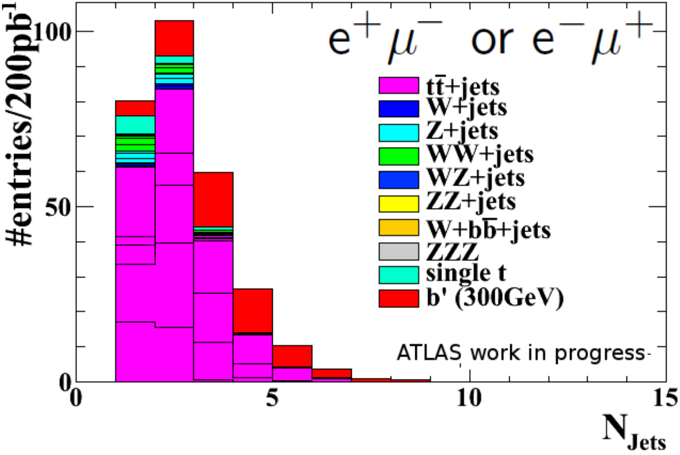
Z+jets background control





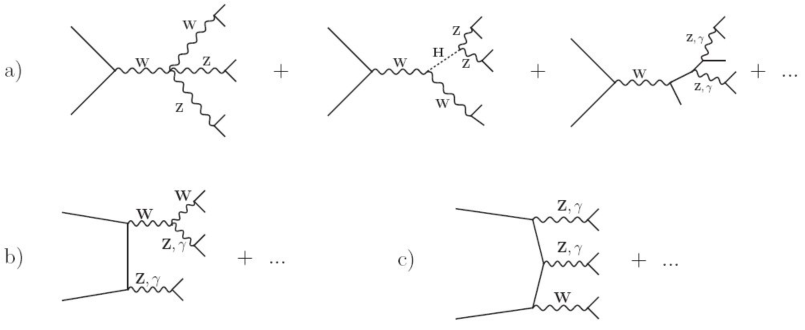
- $81 < m_{inv}^{e^+e^-} < 101$
- $m_{inv}^{e^+e^-} > 101$ or $m_{inv}^{e^+e^-} < 81$

$t\bar{t}$+jets background control



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



- Phys.Rev.D78:094012,2008

ckm matrix

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

mc samples

produced b' samples (10TeV):

m [GeV]	NLO cross section [pb] *
300	22.3
350	9.6
400	4.5
450	2.3
500	1.23

* NLO: Tool for cross sections calculation (by HU Berlin)

produced t' samples (10TeV):

m [GeV]	NLO cross section [pb] *
400 ($m_{b'}$ = 300)	4.5
450 ($m_{b'}$ = 350)	2.3
500 ($m_{b'}$ = 400)	1.23
550 ($m_{b'}$ = 450)	0.2
600 ($m_{b'}$ = 500)	0.4