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Top Quark Mass Measurements at ATLAS

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Motivation: why should we study top quarks?

Top quark mass

- relation to W boson mass for discrimination between SM and MSSM Higgs
- determination of the Higgs quartic coupling and the vacuum stability





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 - polarisation, charge asymmetry, cross-section etc. as handle for physics beyond the SM (FCNC, MSSM etc.)



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- determination of the Higgs quartic coupling and the vacuum stability
- Top quark properties
 - polarisation, charge asymmetry, cross-section etc. as handle for physics beyond the SM (FCNC, MSSM etc.)
- Side effects
 - driver for developments in detector calibration and reconstruction performance
 - improvements in MC modelling
 - and much more



Top quarks pairs at LHC

- The LHC serves as a top quark factory
 - production cross-section: $\sigma_{t\bar{t}}(7TeV) = 177 \stackrel{+10}{_{-11}} pb$
 - 2011 ATLAS dataset: ~0.8 M top pair events (4.7 fb⁻¹)



- Decay channels for $t\bar{t} \rightarrow W^+ b W^- \bar{b}$
 - "all jets" $WW \rightarrow qqqq$ 46 %
 - "lepton + jets" $WW \rightarrow l\nu qq$ 45 %
 - "dilepton" $WW \rightarrow l\nu l\nu$ 9 %

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The dileptonic event hypothesis





The dilepton measurement

Selection cuts:

- **2** oppositely charged isolated leptons with high p_{τ}
- igh missing transverse momentum E_T^{miss} caused by the two ν_s
- 2 jets identified as originating from a b quark
- additional cuts to reduce background
 - e.g. Z-boson mass exclusion for same flavour lepton channels

The numbers of events after the final selection are shown here:

Yield	Unc.
2913	
2400	400
-4	7
73	15
3.1	1.3
0.75	0.29
2500	400
	Yield 2913 2400 -4 73 3.1 0.75 2500



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μ-

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Available information:

	2 x 4	(charged leptons)
	2 x 4	(b-quarks from b-jets)
	2	(E_T^{miss})
+	2	(neutrino masses)
+	2	(W masses)
+	1	(equality of t-quark masses)
=	23	Parameters

Required information for full reconstruction:

- 6 final four-vectors $(E, \vec{p}) \rightarrow$ 24 parameters
- problem: underconstrained kinematics



Simple solution: the m_{lb} estimator

Defined as the mean of invariant masses of lepton-b-jet systems

$$m_{\ell b}^{t} = \sqrt{E_{\ell b}^{2} - p_{\ell b}^{2}}, \quad m_{\ell b}^{\bar{t}} = \sqrt{E_{\ell b}^{2} - p_{\ell b}^{2}} \quad \rightarrow \quad m_{lb} = \frac{m_{\ell b}^{t} + m_{\ell b}^{t}}{2}$$





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b-jet to parton assignment: take pairing with minimum m_{in}

Correct choice in about 77% of the cases





Extracting the mass information

Evaluation of Monte Carlo simulation samples for different m_{top} hypotheses
 A clear sensitivity is observed and can be used for a measurement





Extracting the mass information

- Evaluation of Monte Carlo simulation samples for different m_{top} hypotheses
- A clear sensitivity is observed and can be used for a measurement
- Construction of "template fit functions" varying with m_{top} as the only parameter
- An unbinned likelihood fit of this function to data yields the most probable m_{ton}





Central value in 2011 ATLAS data

ATLAS-CONF-2013-077, last Friday

The template fit to data with the likelihood profile as inset





Evaluation of systematic uncertainties

- analyse distributions varied by systematic effect difference in m_{top}^{out} with respect to the standard sample as estimate of the 2 impact on the measurement

A selection including the most important contributions is shown here

Uncertainty source	Uncertainty [GeV]
Data statistics	0.64
Modelling uncertainties:	
Signal MC generator	0.20
Hadronisation	0.44
ISR and FSR	0.37
Detector uncertainties:	
Jet energy scale	0.89
b-jet energy scale	0.71
b-tagging efficiency and mistag rate	0.46
Total systematic uncertainty	1.50
Total uncertainty	1.63



Difference in m_{top}^{out} using different MC generators

- MC@NLO vs. POWHEG both using HERWIG fragmentation
- renormalisation and factorisation scale variation

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Difference in m_{top}^{out} using two different hadronisation programs

Pythia P2011C (Lund-string model) vs. HERWIG (cluster fragmentation model) both using POWHEG event generator

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Difference in m_{top}^{out} using different amount of QCD initial and final state radiation

AcerMC with varied parton shower parameter using Pythia P2011C by 1σ





Difference in m_{top}^{out} using different jet energy scales

 $\,$ $\,$ $\,$ Variation of the scale up and down by 1 σ





Difference in m_{top}^{out} using different b-jet energy scales

 $\,$ $\,$ $\,$ Variation of the bJES up and down by 1 σ





Difference in m_{top}^{out} using different b-tagging scale factors

 $\,$ $\,$ $\,$ Variation the scale factors up and down by 1 σ





Current ATLAS results

ATLAS-CONF-2013-077, last Friday

ATLAS m _{top} summary - July 2013, L _{int} = 35 pb ⁻¹ - 4.7 fb ⁻¹ (*Preliminary)								
ATLAS CONF-20	5 2010, I+jets* 11-033, L _{Int} = 35 pb ⁻¹	· ·	÷		169.3	± 4.0		± 4.9
ATLAS Eur. Phys	5 2011, I+jets J. C72 (2012) 2046,	$L_{int} = 1.04 \text{ fb}^{-1}$	•		174.53	3 ± 0.61± 0.4	43	± 2.27
ATLAS CONF-20	5 2011, all jets* 12-030, L _{int} = 2.05 fb ⁻	1			174.9	± 2.1		± 3.8
ATLAS CONF-20	5 2011, dilepto 12-082, L _{int} = 4.7 fb ⁻¹	n, m_{T2}*	-		175.2	± 1.6		± 3.1 2.8
ATLAS CONF-20	2011, I+jets* 13-046, L _{int} = 4.7 fb ⁻¹				172.3	$1 \pm 0.23 \pm 0.23$	27 ± 0.67	± 1.35
ATLAS CONF-20	5 2011, dilepto 13-077, L _{int} = 4.7 fb ⁻¹	n, m _{lb} *	-	⊨∄-II I	173.09	9 ± 0.64	hice	± 1.50
CMS Average September 2012 $173.36 \pm 0.38_{stat} \pm 0.91_{JSF \oplus syst.}$ stat. \oplus JSF \oplus bJSF \oplus total uncertainty total uncertaintyTevatron Average May 2013 $173.20 \pm 0.51_{stat} \pm 0.71_{USF \oplus syst.}$ \blacksquare <td>ty DJSF uncerta ty eliminar</td> <td>inty</td>						ty DJSF uncerta ty eliminar	inty	
	5.62.	55/ @335.	I	I	1			J
155	160	165	170	175	180	185	190	195 m _{top} [GeV]



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173.20±0.	.51 _{stat.} ± 0.7	1 _{JSF⊕syst.}	-		A	ATLAS Pre	eliminar	·у
155	160	165	170	175	180	185	190	195
100		100	170	170	100	100	100	m _{top} [GeV]

^{\sim} Previous measurement with same statistics, but based on $\mu\mu$ channel only (67% of data)

Main improvements: choice of estimator, JES and bJES calibrations, template method



Current ATLAS results

	ATLAS	S m _{top} summ	ary - July 20	013, L _{int} = 3	5 pb ⁻¹ - 4.7 ft	o ⁻¹ (*Prelimina	ary)	
ATLA CONF-2	S 2010, I+jets* 011-033, L _{Int} = 35 pb ⁻¹	, 	÷		169.3	± 4.0		± 4.9
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- The analyses from other channels
- Lets take a quick look at them to conclude the overview



The all jets measurement

ATLAS-CONF-2012-030, March 2012

Large statistics, large background Assignment of jets via minimal χ^2 based reconstruction: $\chi^{2} = \frac{(m_{j_{1},j_{2}} - m_{W})^{2}}{\sigma_{W}^{2}} + \frac{(m_{j_{1},j_{2},b_{1}} - m_{t})^{2}}{\sigma_{t}^{2}} + \frac{(m_{j_{3},j_{4}} - m_{W})^{2}}{\sigma_{W}^{2}} + \frac{(m_{j_{3},j_{4},b_{2}} - m_{t})^{2}}{\sigma_{t}^{2}}$ data driven QCD multijet background Entries / 7.5 GeV ATLAS Preliminary √s = 7 TeV 2011 Data 250 tīt m_{top}=172.5 GeV $Ldt = 2.04 \text{ fb}^{-1}$ h Background 200 h 150 100 50 \overline{q} 140 160 180 200 220 240 260 120 280 300 m_{iib} [GeV] $m_{j,j,b}$ is then used to measure the mass with the template method:

 $m_{top} = 174.9 \pm 2.1_{stat} \pm 3.8_{syst} GeV$

The lepton + jets measurement

ATLAS-CONF-2013-046, May 2013

- Large statistics, moderate background (golden channel)
- Assignment of jets via maximal likelihood in Kinematical Likelihood Fitter relating jets to partons.
- Simultaneous fit of m_{top}, the jet scale factor (JSF) and the b-jet scale factor (bJSF) using a
- 3 dimensional template method.
- Leads to reduced systematic uncertainties at the cost of additional statistical components

$$m_{top}^{reco}, m_W^{reco}, R_{lb}^{reco} = \frac{\sum p_T^{b-tagjet}}{\sum p_T^{lightjet}}$$
 used as estimators for the measurement



 $m_{top} = 172.31 \pm 0.23_{stat} \pm 0.27_{JSF} \pm 0.67_{bJSF} \pm 1.35_{syst} GeV$



Conclusion

- MPP and LMU provide significant contributions to the ATLAS m_{top} measurements
- A combination of channels is under investigation
- Full 2013 dataset awaits beeing analysed
- Stay tuned for the next developments





Backup

Andreas Alexander Maier

Multipurpose detector covering almost the full solid angle
 Analyzing pp collisions at LHC: 4.7 fb⁻¹ in 2011





Multipurpose detector covering almost the full solid angle
 Analyzing pp collisions at LHC: 4.7 fb⁻¹ in 2011



Inner detector

Calorimeters

electron energy and

direction

jet energy and direction



Multipurpose detector covering almost the full solid angle
 Analyzing pp collisions at LHC: 4.7 fb⁻¹ in 2011





Multipurpose detector covering almost the full solid angle
 Analyzing pp collisions at LHC: 4.7 fb⁻¹ in 2011



Inner detector
Calorimeters
Muon
spectrometer
Magnet system

Measure for forward direction: pseudorapidity (a transformation of the polar angle)

