

TOP PHYSICS AT ATLAS

Kerim Suruliz (INFN & Udine/ICTP)
on behalf of the ATLAS collaboration

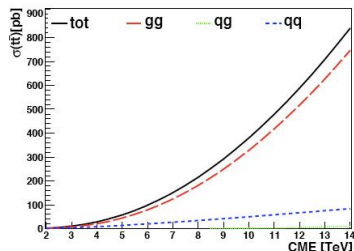
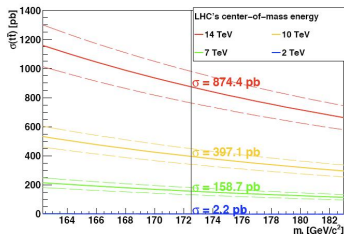
BEACH2010, Perugia, June 2010



OUTLINE

- Theoretical preliminaries
- Top physics program at ATLAS - timeline for measurements
- Top cross section
- Top mass
- Single top: t -channel cross-section
- Conclusions

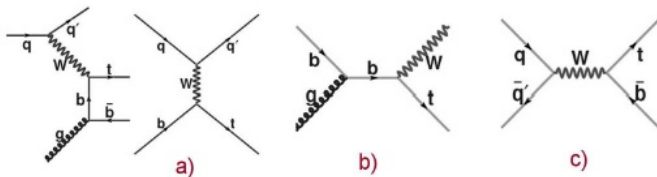
TOP PAIR PRODUCTION



NNLO $t\bar{t}$ cross section in pp collisions - uncertainty about 6%
(scale + PDF - see Langenfeld et al, arXiv:0906.5273):

CME (TeV)	σ_{tot} (pb)	σ_{gg}/σ_{tot}	σ_{qq}/σ_{tot}
14	886	89%	10%
10	403	86%	13%
7	161	70%	18%

SINGLE TOP PRODUCTION



3 channels for single top production.

Cross-sections significantly smaller than for $t\bar{t}$ production. Can hope to measure t -channel production cross-section with early data.

	7TeV	14TeV
t -channel (a)	58.7pb	246.6 pb
s -channel (c)	3.9pb	10.7pb
Wt -channel (b)	13.1pb	66pb

TOP DECAYS

Tops almost always decay to a W and a b .

Branching ratio of W to leptons - $BR(W \rightarrow l\nu) \approx 0.11$.

- **single lepton** $t\bar{t} \rightarrow b\bar{b}q\bar{q}l\nu$ - 44% . Lepton can be triggered on, missing energy due to neutrino escaping the detector, hadronic top can be reconstructed.
- **dilepton** $t\bar{t} \rightarrow b\bar{b}ll'\nu_1\nu_2$ - 10% - limited statistics, but clean events, small background, easy to trigger on; hard to reconstruct top due to two neutrinos.
- **all-hadronic** $t\bar{t} \rightarrow b\bar{b}qqqq$ - 46% - lots of jet activity, very busy events, difficult to trigger on (requires b-tagging in trigger), hard to reconstruct tops due to combinatorics.

TOP MEASUREMENTS

Measurements involving top quarks (x-sec, mass) generically involve **leptons**, **jets** (light and **heavy flavour**) and missing energy, and therefore require understanding of most detector components and their performance.

Timeline:

- 1 event displays with $\sim 1\text{pb}^{-1}$ of data
- 2 clear signal with a few pb^{-1}
- 3 subsequently cross section measurement, in the **single lepton** and **dilepton** channels.
- 4 with $\mathcal{O}(100)\text{pb}^{-1}$: rich top physics programme, including top mass measurement, single top, rare decays and more!

All the results in this talk are for 10 or 14TeV, with scaled expectations for 7TeV where explicitly stated.

CROSS-SECTION MEASUREMENT: EVENT SELECTION

Top pair events are selected by applying cuts, which are different for the two decay channels:

Single lepton channel

- lepton trigger fired
- 1 isolated electron or muon, $P_T > 20\text{GeV}$
- $\cancel{E}_T > 20\text{GeV}$
- 3 jets with $P_T > 40\text{GeV}$ and one with $P_T > 20\text{GeV}$.
- At least one b-tagged jet, for the b-tagging variant of the analysis

Dilepton channel

- lepton trigger fired
- 2 isolated leptons (e or μ), $P_T > 20\text{GeV}$
- $\cancel{E}_T > 20\text{GeV}$ ($e\mu$),
 $\cancel{E}_T > 35\text{GeV}$ ($ee/\mu\mu$)
- 2 jet with $P_T > 20\text{GeV}$
- veto Z mass window

CROSS-SECTION MEASUREMENT: METHODS

Two main methods are used in ATLAS for measuring the cross-section:

Cut and count

- Based on the simple formula

$$\sigma_{t\bar{t}} = \frac{\mathcal{D} - N_B}{\epsilon \times A \times \mathcal{L}} \quad (1)$$

Here \mathcal{D} is the number of events in the data passing the cuts, N_B the expected number of background events, ϵ the efficiency, A - acceptance, \mathcal{L} - integrated luminosity.

- Backgrounds are estimated using a combination of data-driven methods and MC.

CROSS-SECTION MEASUREMENT: METHODS II

Fit/template methods

- Sensitive to shapes rather than knowledge of overall background normalisations.
- Less sensitive to jet energy scale than cut and count.

The main **backgrounds** to $t\bar{t}$ signal:

SINGLE LEPTON

- W +jets (dominant)
- single top
- Z +jets
- QCD with fake leptons, or non-isolated leptons from heavy quark decays

DILEPTON

- Z +jets
- diboson
- Wt -channel single top
- W +jets with fake leptons/leptons from heavy quark decays

MEASUREMENT STRATEGY

Rely on a **simple selection**. Can optionally use b-tagging. Also have analyses without \cancel{E}_T .

Use **data-driven methods** for measuring the backgrounds for which there is a large theoretical uncertainty (W +jets and QCD). These can also be used to derive background **shapes** for the fit methods.

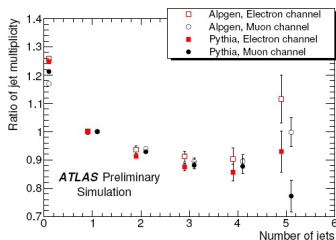
Apply data-driven methods for measuring trigger and reconstruction efficiencies by tag and probe in Z events.

The Drell-Yan background in the dilepton channel can also be evaluated from data.

DATA-DRIVEN METHODS

An illustration of the data-driven methods used in the x-sec measurement: determination of the W +jets background in the single lepton channel.

Relies on the simple observation that the ratio $\sigma(W + k \text{ jets})/\sigma(Z + k \text{ jets})$ is approximately independent of k . Thus measuring the ratio for in control region (1-jet) and the number of Z +4 jet events gives the number of W +4 jet events.



Can determine the W +jets background to 20% uncertainty with 200pb^{-1} at 10TeV.
Dominant sources of uncertainty: MC correction factor, purity of control sample, statistics of Z +jets in CR.

SINGLE LEPTON CHANNEL: EVENT YIELDS

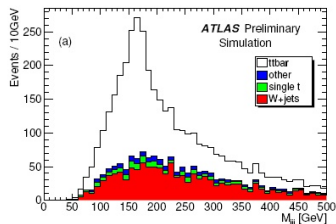
In single lep channel can reconstruct the hadronic top: take highest P_T combination of three jets.

Additional cut: two jets satisfy W mass constraint

$|m_{jj} - m_W| < 10\text{GeV}$. This removes some of the combinatorial background.

Expected events for 200pb^{-1}
@ 10TeV:

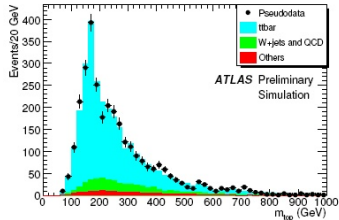
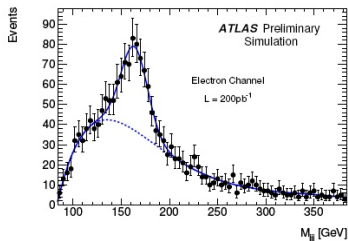
Signal	Background	S/B
1286	598	2.1



Requiring a b-tagged jet can further improve S/B by a factor of 3-4!

SINGLE LEPTON CHANNEL - RESULTS

Method	$\Delta\sigma/\sigma$	dominant systematics
cut and count	$3.4(\text{stat})^{+18.2}_{-21.1}(\text{syst}) \pm 29.3(\text{lumi})$	JES, ISR/FSR, W +jets
fit	$14(\text{stat})^{+6}_{-15}(\text{syst}) \pm 20(\text{lumi})$	JES, ISR/FSR
No MET fit	$3.4(\text{stat})^{+23}_{-25}(\text{syst}) \pm 34(\text{lumi})$	JES, ISR/FSR

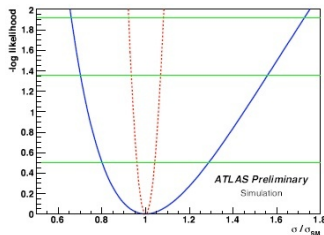
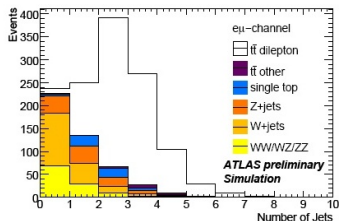


Left: fit method, e channel, 200pb^{-1} ; right: template fit, no MET analysis.

DILEPTON CHANNEL: RESULTS

Here the statistical uncertainty dominates. The JES uncertainty is significantly reduced wrt single lepton analysis.

Combine the channels ($ee, e\mu, \mu\mu$) using a profile likelihood taking into account correlations between systematics: $\Delta\sigma/\sigma =$
 $3.1(\text{stat})^{+9.6}_{-8.7}(\text{syst})^{+26.2}_{-17.4}(\text{lumi})$



EXPECTATIONS FOR EARLY DATA @ 7TeV

Expected events in 10pb^{-1} in dilepton channel:

Channel	N(Signal)	N(background)
$e\mu$	14	2.5
ee	4.3	1.1
$\mu\mu$	6.6	1.9
Total	25	5.5

Used 10TeV numbers from ATL-PHYS-PUB-2009-086 and applied x-sec scalings:

$$\begin{aligned}\sigma(t\bar{t})_{7TeV} &\approx 40\% \sigma(t\bar{t})_{10TeV} \\ \sigma(W + \text{jets})_{7TeV} &\approx 45\% \sigma(W + \text{jets})_{10TeV}\end{aligned}$$

TOP MASS

Measurement performed with likelihood method (1D or 2D) with $\sim 100\text{pb}^{-1}$ of data.

1D likelihood method

exactly one lepton (e or μ), 4 jets with P_T s 75/40/40/20GeV. Top reconstructed as highest P_T combination of three jets. **No b-tagging requirement is used.**

To minimise the impact of the JES use the **stabilised top mass** rather than the reconstructed m_{top} .

$$m_{top}^{stab} = \frac{m_{top}^{reco}}{m_W^{reco}} \cdot m_W$$

TOP MASS: 2D METHOD

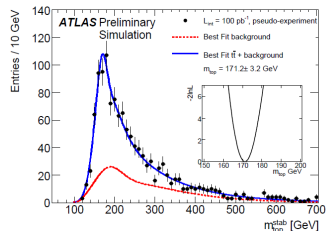
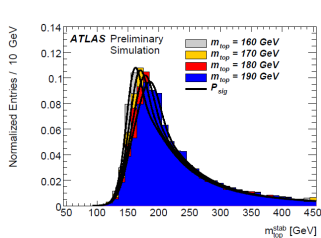
2D LIKELIHOOD METHOD

Use b-tagging and a kinematic fit; m_{top} and JES simultaneously determined from reconstructed top and W masses. Better understanding of detector performance is required.

The likelihood templates are derived from MC with m_t in the range $[160, 190]$ GeV, and a likelihood is defined:

$$\begin{aligned}\mathcal{L}(m_{top}^{est}|m_{top}, JES) &= \mathcal{L}_{shape}(m_{top}^{est}|m_{top}, JES) \\ &\times \mathcal{L}_{shape}(m_W^{reco}|JES) \times \mathcal{L}_{n_S+n_B} \times \mathcal{L}_{bkg}\end{aligned}$$

TOP MASS: 1D LIKELIHOOD METHOD

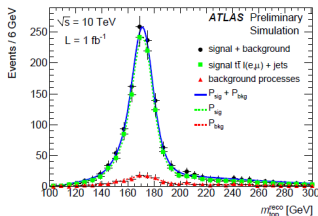


Left: signal template and corresponding fit. Right: 1D likelihood fit in μ channel for 100pb^{-1} at 10TeV.

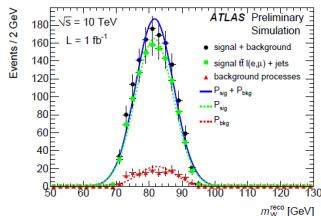
Statistical uncertainty [GeV] @ 10TeV			
	10 pb^{-1}	30pb^{-1}	100pb^{-1}
Electron channel	10.8	7.0	2.7
Muon channel	9.9	5.8	2.8

At 7TeV, the statistical uncertainty is roughly a factor of 2 larger.

TOP MASS: EXPECTED UNCERTAINTIES



(a) The m_{top}^{reco} distribution



(b) The m_W^{reco} distribution

Above: m_{top}^{reco} (left) and m_W^{reco} (right) distributions for $\mathcal{L} = 1\text{fb}^{-1}$.
Results with combined e and μ channels @ 10TeV:

1D, 100pb^{-1} @ 10TeV	$2(\text{stat}) \pm 3.8(\text{syst})$
2D, 1fb^{-1} @ 10TeV	$0.6(\text{stat}) \pm 2.0(\text{syst})$

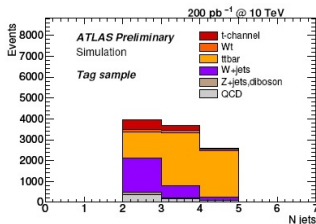
Systematics that dominate are the b-jet energy scale (1.6GeV), ISR/FSR and choice of signal MC generator.

SINGLE TOP X-SEC MEASUREMENT

Basic event selection: 1 lepton $P_T > 15\text{GeV}$, $E_T > 20\text{GeV}$, 2-4 jets with $P_T > 30\text{GeV}$ (one b-tagged), $M_W^T > 30\text{GeV}$ (for suppressing QCD).

With 200pb^{-1} at 10TeV, 2 jets:

t -chan	470
Wt -chan	125
$t\bar{t}$	1250
W +jets	1650
other	485
S/B	0.13



Small $S/B \rightarrow$ the background must be constrained accurately by data-driven techniques. Use a neural network to extract $t\bar{t}$ and W +jets rates in a control (pretag, 3 jets) sample - total uncertainty is 6.9% in the $t\bar{t}$ background and 14.1% in W +jets.

SINGLE TOP X-SEC: METHODS

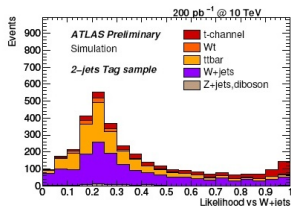
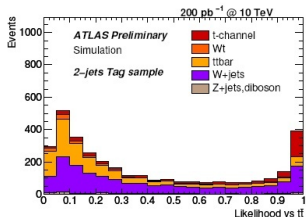
Two methods to extract t -channel single top x-sec: cut and count with sequential cuts or likelihood. For straight cuts, require b-tagged jet $P_T > 50\text{GeV}$ - kills 40% of W +jets. Event yields @10TeV, 200pb $^{-1}$:

	sequential cuts	likelihood
S	118	112
B	303	127
S/B	0.64	0.89

In the likelihood approach, two discriminants are constructed to reject $t\bar{t}$ and W +jets; 6 kinematic variables are used for this.

S/B significantly higher in likelihood analysis compared to sequential cuts analysis.

SINGLE TOP: RESULTS



Likelihood discriminants: for $t\bar{t}$ (left) and W +jets (right) rejection.

Uncertainties of the result:

Method	$\Delta\sigma/\sigma$
cut and count	$15(\text{stat}) \pm 34.7(\text{syst}) \pm 11(\text{lumi})$
likelihood	$14(\text{stat}) \pm 32.1(\text{syst}) \pm 11(\text{lumi})$

The dominant systematics are b-tagging, MC generator and background normalisation, including Wbb +jets - **challenging at 7TeV!**

CONCLUSIONS

- Exciting times for top physics at ATLAS are just round the corner!
- top rediscovery (few pb^{-1}), cross-section ($< 100\text{pb}^{-1}$), top mass and single top (hundreds of pb^{-1})
- All this will also greatly help with commissioning of the detector - trigger, leptons, b-tagging, light & b-jet energy scales, missing energy...
- Then move to searches for new physics effects in top physics: $t\bar{t}$ resonances, 4th generation, rare top decays/FCNC, Wtb coupling, and more...

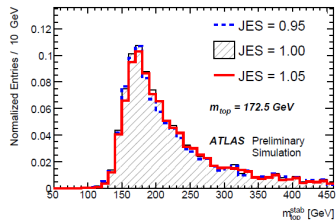
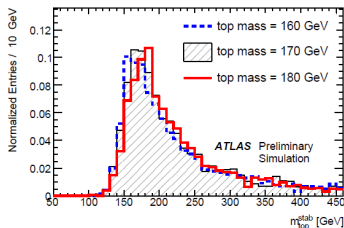
BACKUP: SYSTEMATICS FOR X-SEC MEASUREMENT

Source		
Lepton id	1	1
Lepton trigger	1	1
20% W +jets	7.0	3.3
JES($\pm 5\%$)	+8.6-9.3	-3.7
PDF	1.9	1.9
ISR/FSR	7.6-8.2	-12.9
Signal MC	4.4	4.5
Bkg uncertainty	0.4	-

Source	$e\mu$ channel
Stat only	-4.0/4.1
Luminosity	-17.4/26.2
Electron Efficiency	-2.2/2.4
Muon Efficiency	-2.1/2.2
Lepton Energy Scale	-0.5/0.5
Jet Energy Scale	-2.5/2.5
PDF	-1.6/1.8
ISR/FSR	-3.5/3.5
Signal Generator	-4.7/5.3
Cross-Sections	-0.3/0.3
Drell Yan	-0.5/0.5
Fake Rate	-6.2/6.2

Pileup uncertainty was evaluated for a $10^{32}\text{cm}^{-2}\text{s}^{-1}$ instantaneous luminosity (~ 4 $p-p$ interactions per bunch crossing). This was 2-8%.

BACKUP: STABILISED TOP MASS



JES variations much smaller when using m_{stab} than when using m_{reco} . Both mass distributions exhibit similar changes when m_{top} is changed from 160 GeV to 180 GeV.

BACKUP: TOP MASS MEASUREMENT UNCERTAINTIES

Statistical and systematic uncertainties [GeV]			
	1-d per channel		2-d combined
	Electron	Muon	
Statistics 100 (1000) pb ¹	2.7	2.8	1.8 (0.6)
Method calibration	0.8	0.6	0.4
Signal MC generator (AcerMC vs. MC@NLO)	0.8	1.3	0.5
ISR and FSR (signal only)	2.5	1.1	1.0
Proton PDF uncertainty	1.1	0.8	0.1
Fast vs. full sim (signal only)	0.6	0.7	0.2
Assumed background fraction (50%, $^{+100}_{-50}$ %)	0.8	0.9	0.1
W/Z+jets background SHERPA vs. ALPGEN	0.5	0.5	na
Alternative QCD shape	0.6	0.5	na
Single-top shape	0.8	0.3	na
Jet energy scale (5%)	1.4	2.2	na
Relative b-jet to light jet energy scale (2.5%)	1.6	2.1	1.6
b-tagging performance	na	na	0
\cancel{E}_T (5%)	na	na	0.2
Jet energy resolution (20%)	na	na	0.1
Total systematic	3.8	3.9	2.0

BACKUP: SINGLE TOP t -CHANNEL X-SEC - SYSTEMATICS BREAKDOWN

Source of uncertainty	$\Delta\sigma/\sigma$	
	Sequential cuts	Likelihood
Data statistics	15%	14%
Monte Carlo statistics	6%	6%
JES	8%	3%
b-tagging	26%	22%
Background normalization	12%	10%
ISR/FSR	10%	10%
PDF	7%	6%
Generator	11%	16%
Lep. ID, trigger	4%	3%
Luminosity	11%	11%
Total	45%	40%