Status and Prospects for observation of top quark pair production in ATLAS

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The LHC Operation in 2010/2011

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- High energy proton collisions at 7 TeV are ongoing.
- Target $L_{\text{int}} \sim 1 \text{ fb}^{-1}$ by end of 2011.

LHC program for 2010-11 focusses on:

- ▶ Detector commissioning.
- ▶ Standard Model Physics.
- ▶ Physics beyond TeV scale:
 - Possible surprises (Susy, Higgs, Exotics..)

ATLAS Performance so far

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- Expect a few pb^{-1} by the end of summer 2010

Cumulative integrated luminosity versus day delivered to (green), and recorded by ATLAS (yellow) during stable beams and for 7 TeV centre-of-mass energy. Given is the luminosity as determined online using counting rates measured by the luminosity detectors, and by assuming a total inelastic cross section of 71.5 mb.

Roadmap to Top quark Re-discovery

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- We are heavily involved in understanding our detector and basic reconstruction objects:
 - leptons, jets, b-tagging, Missing transverse energy (MET)
- understanding QCD processes
- First steps towards Z and W + jets observation.
- Need to understand the above items when proceeding to top quark re-discovery.

Top Quark Physics @ ATLAS

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- Top physics @ ATLAS:
 - First:
 - Top re-discovery:
top-antitop production
 - Detector calibrations
Jet energy scale (JES)
b-tagging efficiency
 - Next:
 - Precision tests of SM
 - Search beyond SM:
top-antitop resonances
anomalous couplings
non-SM top production

QCD: top-antitop production:

1 fb⁻¹ @ 7 TeV: 160k tt pairs produced
top re-discovery process

$\sigma_{tt} = 160 \text{ pb @ 7 TeV} \sim 20 \times \text{Tevatron}$

EW: single top production:

Sensitive to beyond SM physics

Single top (t-channel)

$\sigma_t \sim 1/3 \sigma_{tt}$

Top Pair Decay Channels

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- **Top-antitop decay modes:**

- **Di-leptonic channel:**

- low statistics (9%)
- clean signature S/B 4.5-6.5

- **Semi-leptonic channel (e/μ):**

- 45% of total
- $S/B \sim 1$ (without b-tag)
- Visible top and/or W invariant mass peaks helps

- **Fully hadronic channel:**

- 46% of total:
- high QCD backgrounds.
- Not easy to trigger on (no leptons, need b-tag trigger?)
- Not for early data!

First top Measurements

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The first top measurement to be done with early data is the $t\bar{t}$ x-section determination

- **Dilepton channel**

- ▶ 2 opp. charged leptons
- ▶ 2 jets or more
- ▶ Missing E_T

$$t\bar{t} \rightarrow \ell^+ \nu \ell^- \nu b \bar{b}$$

$\ell = e, \mu$

- **Backgrounds:**

- ▶ 2 real leptons
 - Drell-Yan
 - Dibosons
 - Single-top (Wt)
- ▶ fake leptons
 - W +jets, QCD multijet [$\gg 1000 \times \sigma_{t\bar{t}}$]

- **Strategy:**

- ▶ Veto Z window and require MET

- **Lepton+jets channel**

- ▶ 1 lepton
- ▶ 4 jets or more
- ▶ Missing E_T

$$t\bar{t} \rightarrow \ell \nu q q b \bar{b}$$

$\ell = e, \mu$

- **Backgrounds:**

- ▶ combinatorial
- ▶ W +jets [$\sim 40 \times \sigma_{t\bar{t}}$]
- ▶ single-top
- ▶ fake leptons from QCD multijet [$\gg 1000 \times \sigma_{t\bar{t}}$]

- **Strategy:**

- ▶ reconstruct hadronic top
- ▶ cut or fit methods

Re-discovery Methods

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- **Simple methods first:**
 - ▶ "Cut and count" (C&C): $\sigma_{\text{signal}} = (N_{\text{data}} - N_{\text{Background}}) / (\text{eff.} \times \text{acc.} \times L)$
 - ▶ Template fit to a discriminating variable $\rightarrow \sigma_{\text{signal}}$
- **Cautious with event selection:**
 - ▶ Very simple/safe definition of measured objects.
 - ▶ Missing E_T poorly known at startup.
 - ▶ Consider b-tag but use cautiously: Commissioning of b-tagging algorithms will take some time..
- **Data-driven background measurements:**
 - ▶ Do not rely (too much) on simulation:
 - Theoretical uncertainties (QCD-multijet, W+jets about 80-100% ...)
 - Acceptance uncertainties (lepton fake rate, b-tagging efficiency ...)
 - ▶ Preferable to measure (main) backgrounds using data itself.

A note on b-tagging

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- b-tagging commissioning is ongoing:
 - not envisaged in the first top re-discovery analyses presented here.
 - as soon as the commissioning is completed it can be included: strongly suppresses the W +jets, QCD and Drell-Yan backgrounds.

ATLAS Lepton+jets @10 TeV

- **Basic event selection:**

- high p_T isolated lepton
- 4 high p_T jets, 3 of them > 40 GeV

- **In addition:**

- Missing $E_T > 20$ GeV
- Combine 3 jets to form hadronic Top (selection that maximizes p_T top)
- 2 jets satisfy W mass constraint ($m_W \pm 10$ GeV) $\epsilon=10\%$.

200 pb-1 @ 10 TeV	Signal: el. channel	backgrounds	S/B
After selection	1286	598	2.1

Atlas W+jets Data Driven Estimate

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- **Event selection:**

- ▶ require 2 leptons $80 < m_{ll} < 100$ GeV for Z+jets and 1 lepton +MET for W+jets

- **Use extrapolation:**

- ▶ low jet multiplicity region as control region (CR) for Z +jets (W+jets) events:
 - ▶ Extrapolate ratio in the top signal region (SR) : 4 jets or more
 - ▶ Use ratio W / Z to extrapolate W into signal region:

$$(W^{SR}/W^{CR})_{\text{data}} = (Z^{SR}/Z^{CR})_{\text{data}} \cdot C_{MC} \quad C_{MC} = \frac{(W^{SR}/W^{CR})_{MC}}{(Z^{SR}/Z^{CR})_{MC}}$$

ATL-PHYS-PUB-2009-087

- **Overall uncertainty:**

- ▶ 20 % @ 10 TeV with 200 pb⁻¹
 - ▶ 50 % @ 7 TeV with 10 pb⁻¹
 - ▶ 20 % @ 7 TeV with 100 pb⁻¹

- **Largest contributions:**

- ▶ 50 % uncertainty on QCD
 - ▶ C_{MC} : ~ 12 % Pythia - Alpgen discrepancy

Two Main Methods to Extract cross-section

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ATL-PHYS-PUB-2009-087

- **Cut and count method (C&C):**
 - **Advantage:** simple method
 - **Disadvantage:** Depends on background subtraction. Evaluate backgrounds from data!
- **The fit or template fit to hadronic top mass:**
 - **Advantage:** much less sensitive to the Jet energy scale and background normalisation
 - **Disadvantage:** relies on shape of distributions

200 pb⁻¹ @ 10 TeV, electron channel

Method	$\Delta\sigma/\sigma$	Dominant systematics
C&C	$3.4(\text{stat})^{+18.2}_{-21.1}(\text{syst}) \pm 29.3(\text{lumi})\%$	JES, ISR/FSR, W+jets
Fit	$14(\text{stat})^{+6}_{-15}(\text{syst}) \pm 20(\text{lumi})\%$	JES, ISR/FSR
No MET	$3.4(\text{stat})^{+23}_{-25}(\text{syst}) \pm 34(\text{lumi})\%$	JES, ISR/FSR, W+jets

Top Re-discovery at 7 TeV - lepton + jets

- With $\sim 10 \text{ pb}^{-1}$ notable signal:

- ATLAS will have ~ 60 signal events with an expected background of ~ 40 events per lepton flavor.
- Results before and after the additional M_W cut are shown:
2 jets satisfying W mass constraint ($m_W \pm 10 \text{ GeV}$)
- Note that in addition b-tagging might be used:

S/B enhanced up to ~ 5 times!

Cross-section scaling:

$$\sigma(t\bar{t})_7 \cong 40\% \sigma(t\bar{t})_{10}$$

$$\sigma(W + \text{jets})_7 \cong 45\% \sigma(W + \text{jets})_{10}$$

Expected sensitivity for 10 pb^{-1} @7 TeV

Scaled down from ATL-PHYS-PUB-2009-087 results

Channel	el. analysis	μ analysis
$t\bar{t}$	53	64
$W + \text{jets}$	29	40
single top	5	25
Other	6	6

Additional M_W cut: M_{jj} in $M_W \pm 10 \text{ GeV}$

Channel	el. analysis	μ analysis
$t\bar{t}$	26	32
$W + \text{jets}$	10	14
single top	2	2
Other	2	2

ATLAS di-lepton Analysis

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200 pb⁻¹ @10 TeV

- Basic event selection:
 - 2 high p_T (>20 GeV) isolated leptons
 - ≥2 jets p_T >20 GeV
 - MET >20 (eμ)/35 (ee/μμ) GeV
 - veto Z mass window

Cross-section estimation:

- Simple cut and count method
- Profile likelihood ratio
- Final sensitivity (eμ, ee, μμ combined):

$$\Delta\sigma/\sigma = 3.1(\text{stat})_{-8.7}^{+9.6}(\text{syst})_{-17.4}^{+26.2}(\text{lumi})\%$$

Main syst: signal model, fake rate,
Luminosity not included.

Drell-Yan and Fake Leptons

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- **Drell-Yan estimate from data:** Drell-Yan mainly in **G,H,I** regions - **top-antitop** in **A,C**
 - ▶ Use Z Monte-Carlo and data (same for C_{Est})

$$A_{Est} = G_{Data} \left(\frac{A_{MC}}{G_{MC}} \right) \left(\frac{B_{Data}}{H_{Data}} \right) \left(\frac{H_{MC}}{B_{MC}} \right)$$

- **Systematic uncertainty (stat. dependent!):**
 - ▶ Shift boundaries of the grid:
~15% for both channels @ 10 TeV and 200 pb⁻¹

- **Fake leptons in QCD jets:** from W+jets (1 fake lepton) and QCD (2 fake leptons):

- ▶ **muons:**

- Decays in flight of π or K mesons in light jets
- Punch through muons
- Semileptonic decay in a heavy flavor (b/c) jet

- ▶ **electrons:**

- Jets with high EM fraction
- Photon mis-associated with a track, conversions
- Semileptonic decay in a heavy flavor (b/c) jet

Tracking Iso: $\sum p_T^{track}$ in $\eta - \phi$
Calorimeter Iso: $\sum E_T^{tower}$ in $\eta - \phi$

Fake leptons in detail

- **Fake leptons from QCD jets:** from W+jets (1 fake lepton) and QCD (2 fake leptons)
- Define a "tight(T)" and a "loose(L)" lepton, the latter enriched with fake leptons.
- Efficiencies to select a "tight(T)" lepton for real (R) ϵ and fake(F) f leptons from data:
 - ▶ $\epsilon_{1|2} = N_{T,R}/(N_{T,R}+N_{L,R})$: Tag-and-probe on two leptons in Z mass window, low MET required.
 - ▶ $f_{1|2} = N_{T,F}/(N_{T,F}+N_{L,F})$: one (tight or loose) lepton and low MET required.
 - ▶ $\epsilon_{1|2}$ and $f_{1|2}$ for first|second lepton can exhibit p_T or η dependence.
- Neglecting the possibility of two fake leptons being reconstructed as tight leptons:

$$\begin{bmatrix} N_{TT} \\ N_{TL} \\ N_{LT} \end{bmatrix} = \begin{bmatrix} \epsilon_1 \epsilon_2 & \epsilon_1 f_2 & f_1 \epsilon_2 \\ \epsilon_1 (1 - \epsilon_2) & \epsilon_1 (1 - f_2) & f_1 (1 - \epsilon_2) \\ (1 - \epsilon_1) \epsilon_2 & (1 - \epsilon_1) f_2 & (1 - f_1) \epsilon_2 \end{bmatrix} \begin{bmatrix} N_{RR} \\ N_{RF} \\ N_{FR} \end{bmatrix}$$
- Inverting and defining as fake all events with two tight leptons not coming from 2 real ones:

$$N_{\text{Fake}} = \left[\frac{f_2(\epsilon_2 - 1)}{\epsilon_2 - f_2} + \frac{f_1(\epsilon_1 - 1)}{\epsilon_1 - f_1} \right] N_{TT} + \frac{f_2 \epsilon_2}{\epsilon_2 - f_2} N_{TL} + \frac{f_1 \epsilon_1}{\epsilon_1 - f_1} N_{LT}$$
- Rate uncertainty on MC 50-100% (need data for estimation).

Top Re-discovery at 7 TeV - dilepton

- With $\sim 10 \text{ pb}^{-1}$ **convincing signal**

- ▶ ATLAS will have ~ 30 events with an expected background of 5 or 6.
- ▶ Even with 5 pb^{-1} , signal already plausible..
- ▶ At 1 pb^{-1} , interesting event displays will start to appear at conferences
- ▶ Note that in addition b-tagging might be used.

Expected sensitivity for 10 pb^{-1} @7 TeV

Scaled down from ATL-PHYS-PUB-2009-086 results

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

Cross-section scaling:

$$\sigma(t\bar{t})_7 \cong 40\% \sigma(t\bar{t})_{10} \quad \sigma(W + \text{jets})_7 \cong 45\% \sigma(W + \text{jets})_{10}$$

Conclusions

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- Signatures of top pair signal will come fast
 - Significant signal for “rediscovery” will require $O(10\text{pb}^{-1})$
- By the end of 2010 LHC might have statistics comparable to TeVatron.
- By the end of 2011 the samples will be significantly larger.
 - Precision Standard Model physics: top quark properties.
 - Hints of new Physics?
- Still a lot of work ahead:
 - Trigger and lepton ID
 - b-tagging
 - Light jet and b jet energy scale
 - Missing E_T
 - Estimate backgrounds from data: QCD, W/Z + jets..