



# Measurement of the top-pair production cross-section at ATLAS

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On behalf of the ATLAS Collaboration**

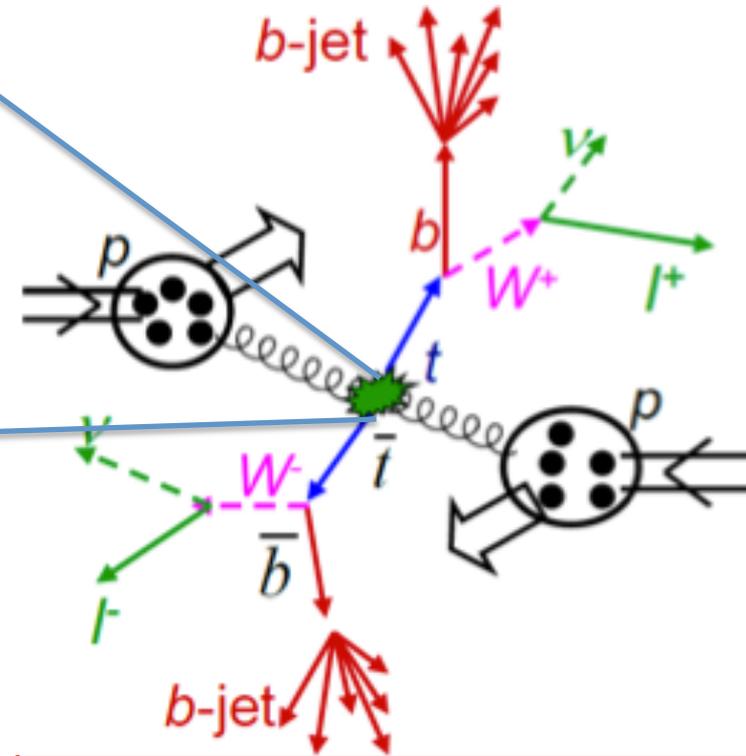
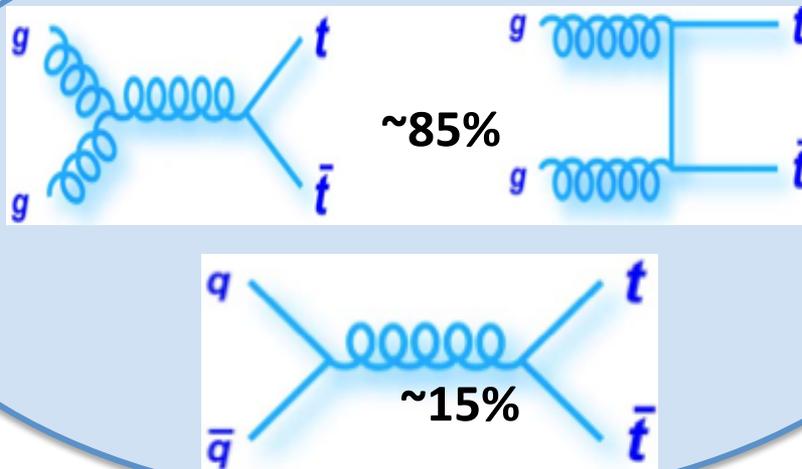
**DPF 2011**

**(Aug 08 – Aug 13, 2011)**



# Top quark pair production

**Production:**  $\sigma_{tt}(\text{LHC}) \sim 160 \text{ pb}$   
 cross section LHC = 20 x Tevatron



Why measure the top pair production cross section in the various decay channels :

- ✓ Test of perturbative QCD and of SM description of the top quark decay.
- ✓ Important background in searches for Higgs and BSM physics
- ✓ Might reveal new physics that modifies the production and/or decay of top quarks.

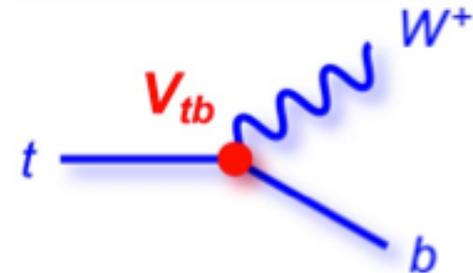
Total Cross section @ 7TeV **9.6 %**

approx. NNLO :  $164.6^{+11.4}_{-15.7} \text{ pb}$   
 ( $m_t : 172.5 \text{ GeV}$ )

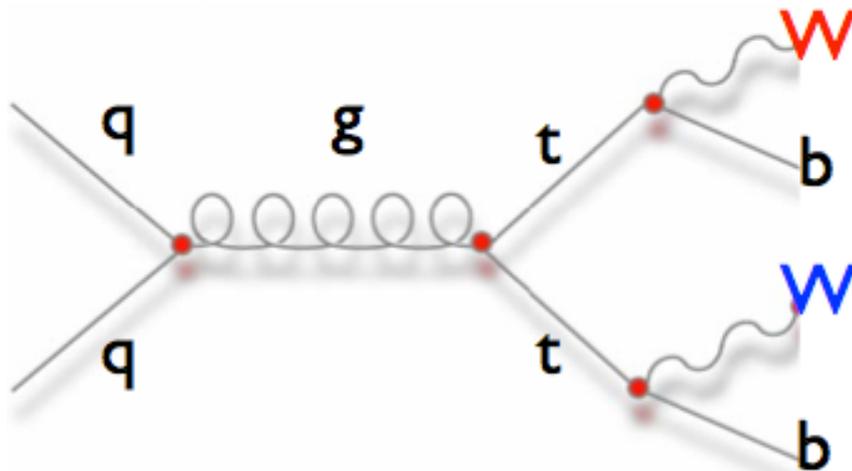
[arXiv:0907.2527](https://arxiv.org/abs/0907.2527)

# Top decay and event classification

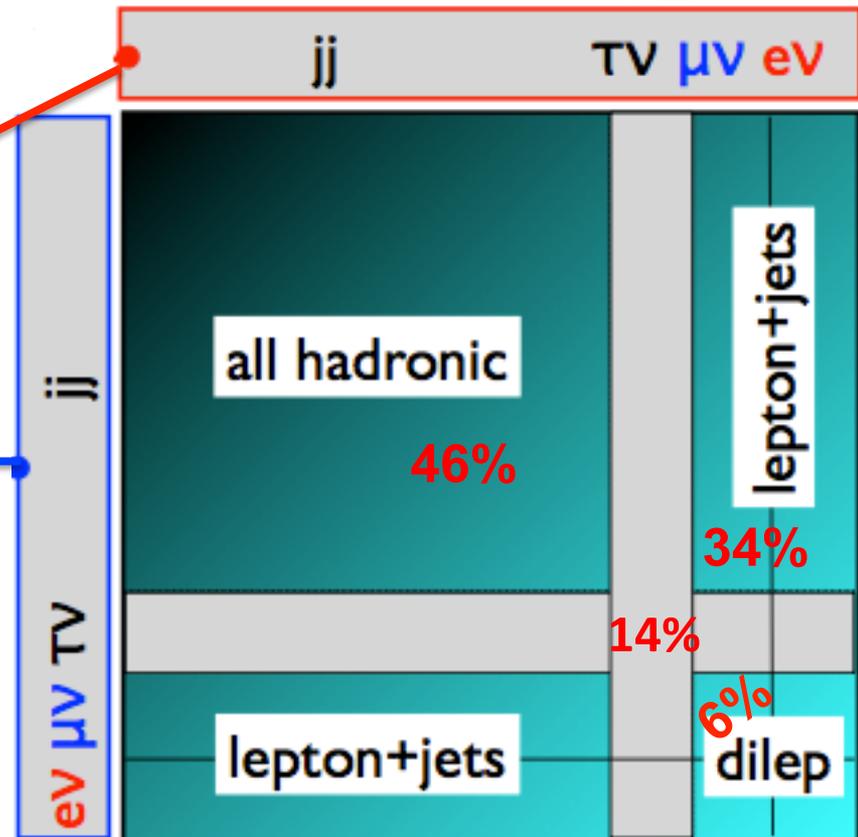
- Top decays even before it can hadronize
  - ✓ almost exclusively to ( $t \rightarrow bW$ )



Event classification follows the  $W$  decay channels:



$\text{Br}(W \rightarrow \text{lepton}) = 1/3$   
 $\text{Br}(W \rightarrow \text{quarks}) = 2/3$

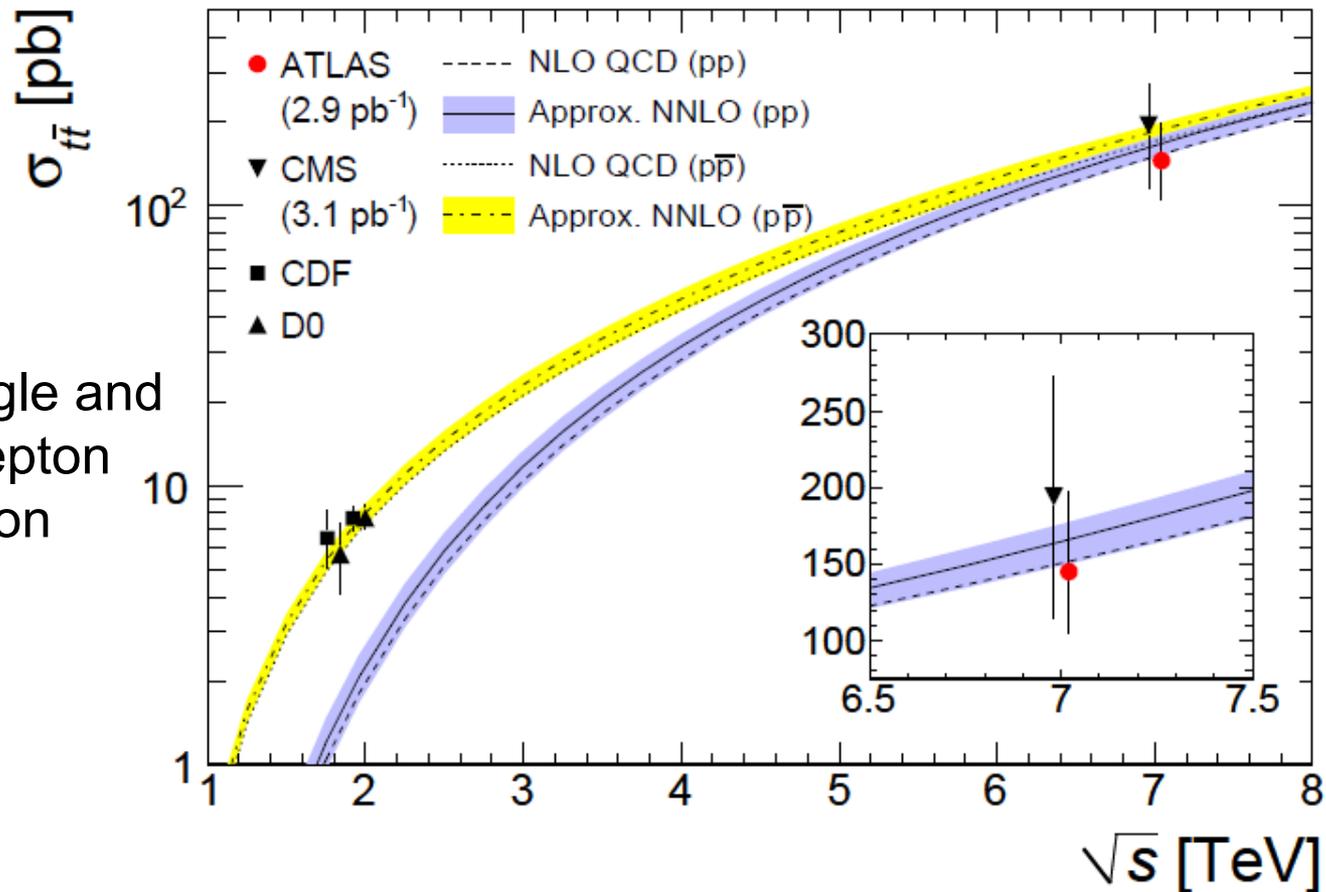


# Measurement in Atlas with 3pb<sup>-1</sup>

- ✓ Measurement of top quark pair production cross section
  - Single lepton and dilepton channel, 3 pb<sup>-1</sup>
  - Observe 46 candidates

$$\sigma_{t\bar{t}} = 145 \pm 31(\text{stat.})^{+42}_{-27}(\text{syst.}) \text{ pb}$$

$$\frac{\delta\sigma_{t\bar{t}}}{\sigma_{t\bar{t}}} = \begin{matrix} +36\% \\ -28\% \end{matrix}$$

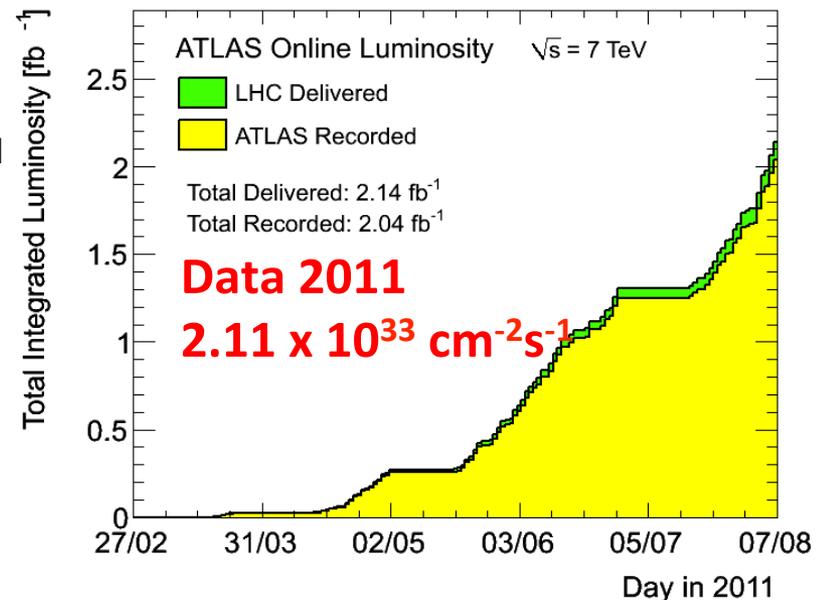
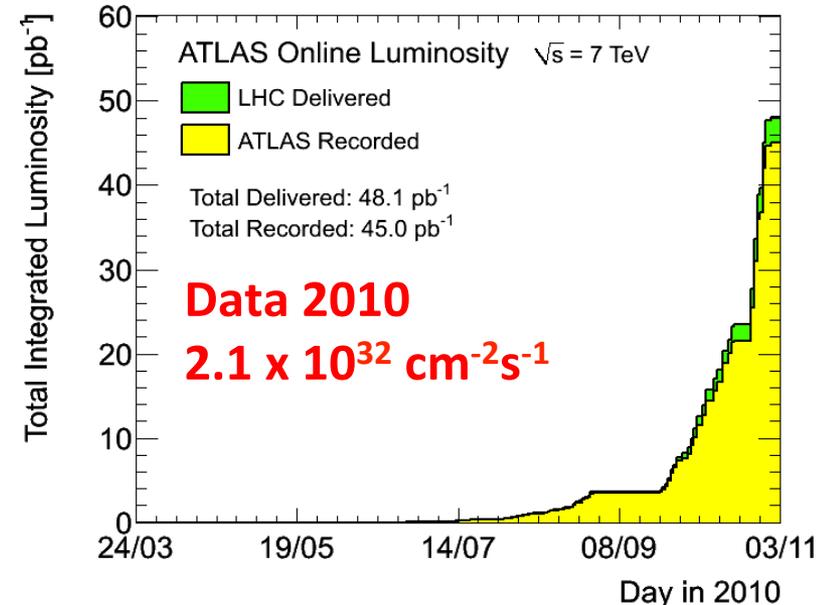


● **ATLAS**: single and dilepton  
 ▼ **CMS**: dilepton

EPJC71(2011) 1577

# Data samples (Today's Talk)

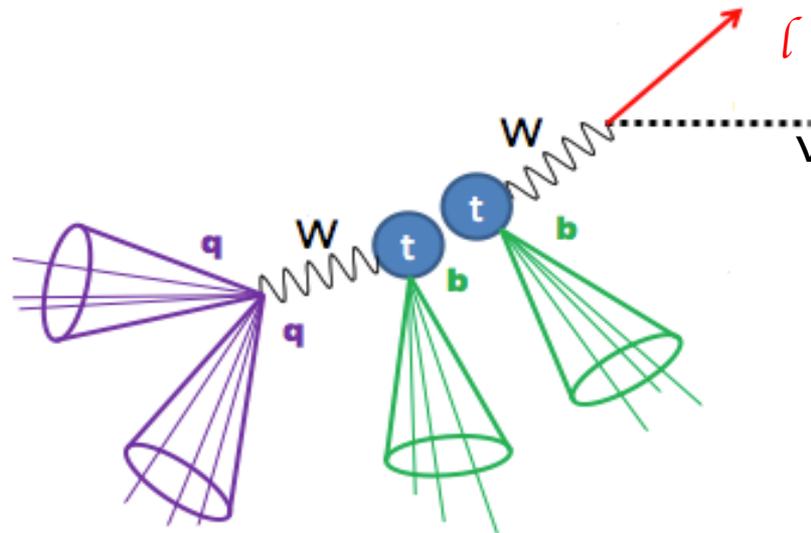
- ❑ Data collected in 2010, 2011 at PP collision @  $\sqrt{s} = 7\text{TeV}$ .
- ❑ Analysis performed (today's talk):
  - Data collected in 2010 :  $45\text{ pb}^{-1}$ 
    - ✓ Lepton ( $e, \mu$ ) + jets
    - ✓ Used Data :  $35\text{ pb}^{-1}$
  - Data collected in 2011 :  $2.04\text{ fb}^{-1}$ 
    - ✓ Dilepton ( $ee, \mu\mu, e\mu$ )
    - ✓ Used Data (partial data) :  $0.70\text{ fb}^{-1}$
  - Combination :
    - ✓ Dilepton ( $0.70\text{ fb}^{-1}$ )
    - ✓ Single lepton ( $35\text{ pb}^{-1}$ )



# Cross section Measurements

1 lepton + jets channel ( $35 \text{ pb}^{-1}$ )

Dilpton channel ( $0.70 \text{ fb}^{-1}$ )



# Object definition and Event Selection

**Muon:**  
 $P_T > 20$  GeV  
 $|\eta| < 2.5$   
 Isolated muon track  
 Tracker & muon chamber

**Electron:**  
 Isolated EM calo object  
 Matching to track  
 $E_T > 20(25)$  GeV,  $0 < |\eta| < 2.47$   
 Remove:  $1.37 < |\eta| < 1.52$

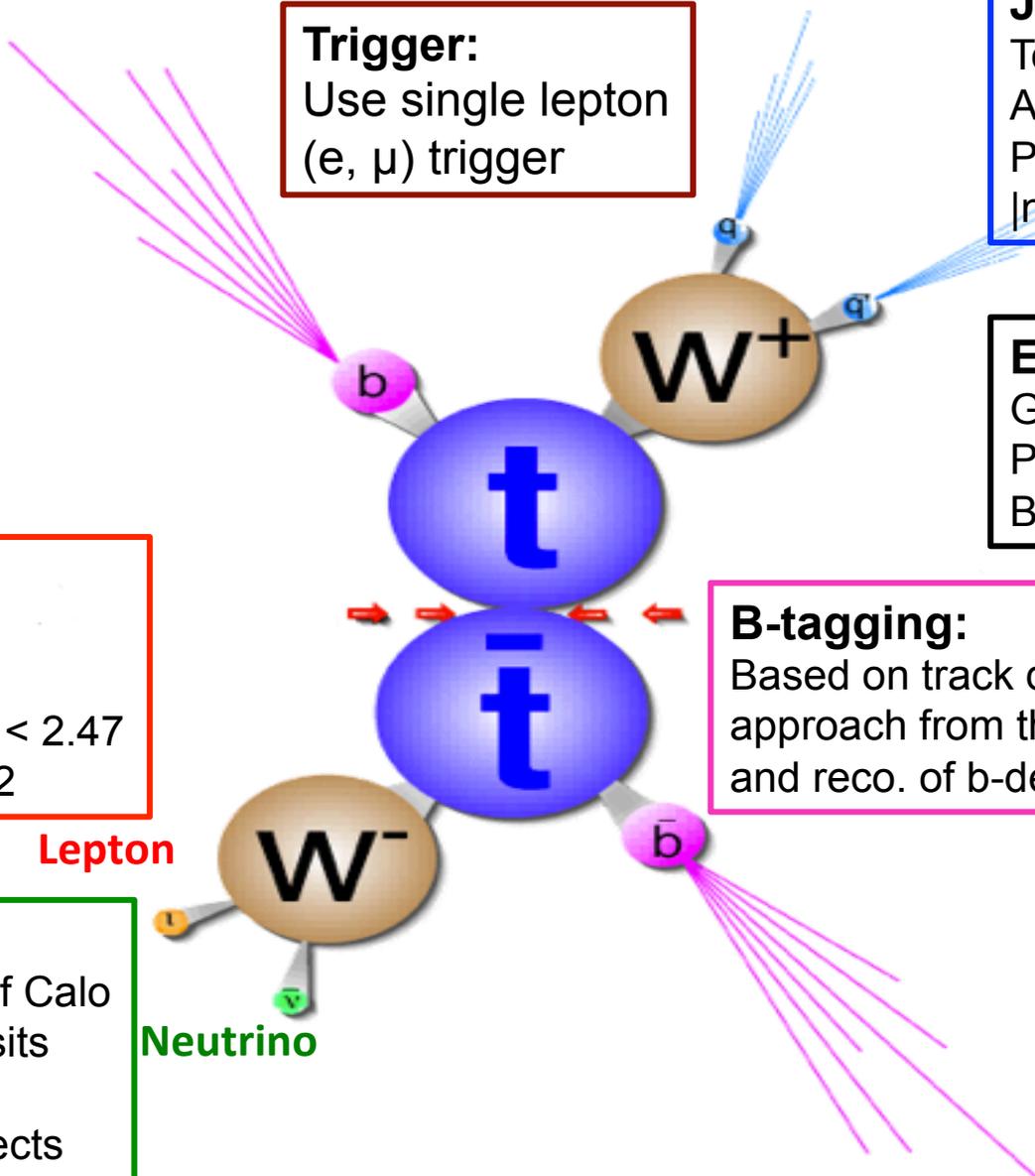
**Missing  $E_T$ :**  
 Vector Sum of Calo  
 Energy deposits  
 Corrected for  
 Identified objects

**Trigger:**  
 Use single lepton  
 (e,  $\mu$ ) trigger

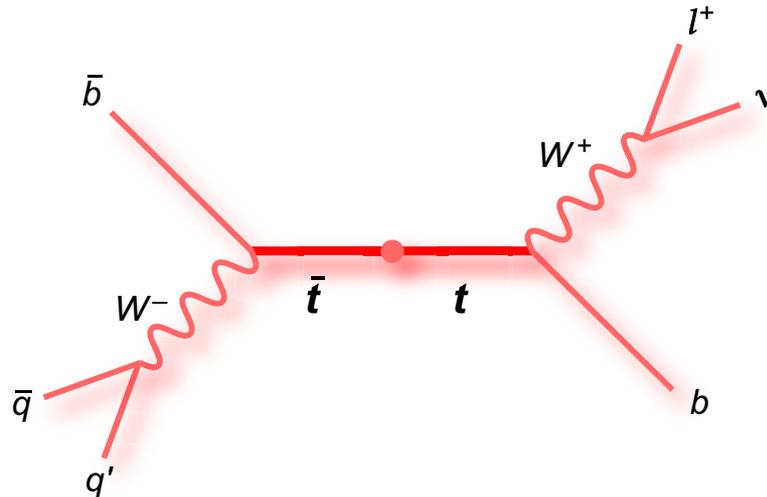
**Jet:**  
 Topological cluster  
 Anti- $K_T$  ( $R = 0.4$ )  
 $P_T > 25(20)$  GeV  
 $|\eta| < 2.5$

**Event cleaning:**  
 Good Run condition  
 $PV > 4$  tracks  
 Bad jet veto

**B-tagging:**  
 Based on track distance of closest  
 approach from the collision point,  
 and reco. of b-decay Vtx inside jet



# Cross section Measurements (1 Lepton + jets) Using $35\text{pb}^{-1}$



# Lepton + Jets: Analysis Strategy

- **Measurement strategy (multivariate)** :
  - ✓ exploits the difference in kinematic distributions of signal and background events.
- Projective Likelihood (LH) is used: to separate signal from bkg (both analysis with and without b-tag)
- Discriminant constructed from multiple variables
- MC signal and background models these variables for building LH discriminant
- Fit the likelihood discriminant distribution in data by sum of two “templates”, signal and bkg, and get the  $N_{sig}$

$$D_i = \frac{L_s^i}{L_s^i + L_b^i}$$

$$L_{s(b)}^i = \prod_{k=1}^{N_{var}} p_{s(b)}(X_k^i)$$

For each event  $i$  we calculate the  $D_i$

Assume that the variable  $(X_k^i)$  are uncorrelated

$$\sigma_{t\bar{t}} = \frac{N_{sig}}{\int L dt \times \epsilon_{sig}}$$

# Lepton + Jets: Background Estimate

## ➤ Backgrounds:

### ➤ W+jets backgrounds

- Shape is determined by MC
- Normalization from fit

### ➤ Small Bkgd (Z+jets , diboson , single top)

- Shape from MC
- Normalization from NLO calculation

### ➤ QCD multijet (Fake lepton)

- Due to mis-ID of lepton, not well modeled in simulation
- Used (for example) matrix method for  $\mu$  channel

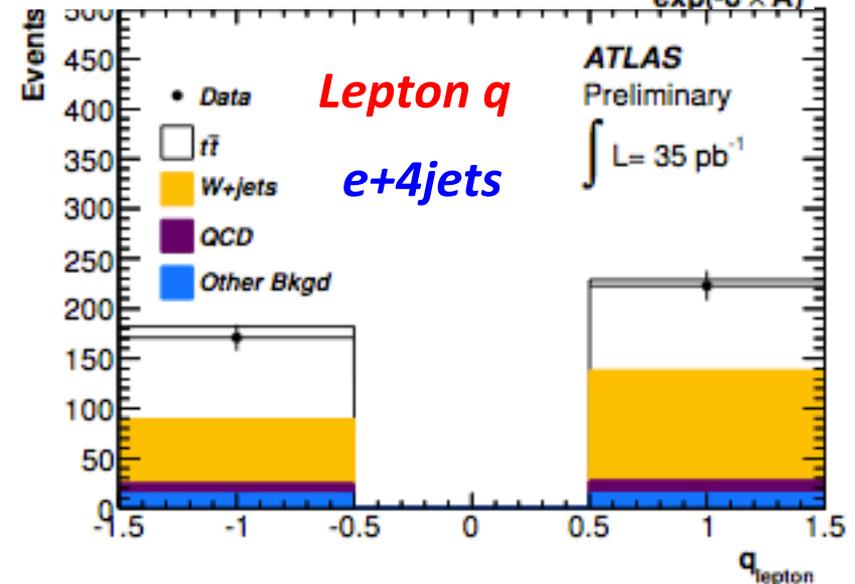
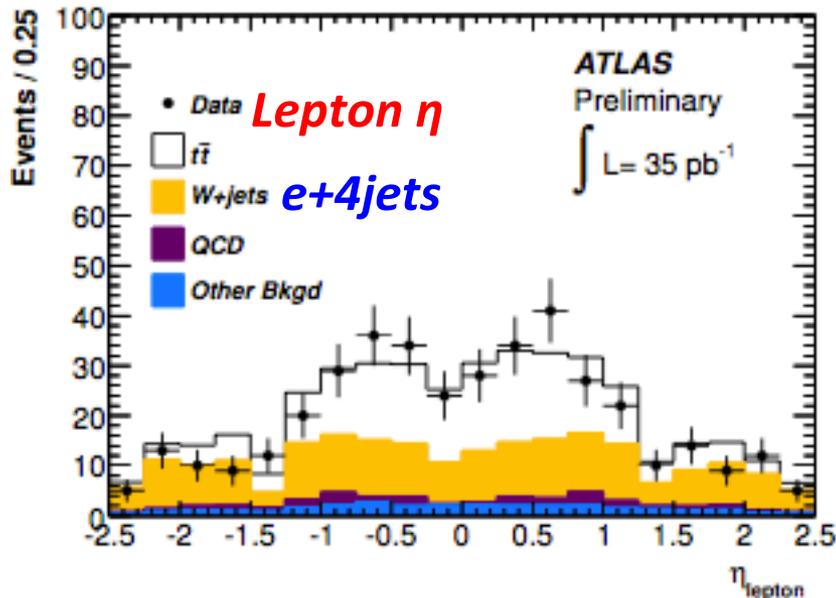
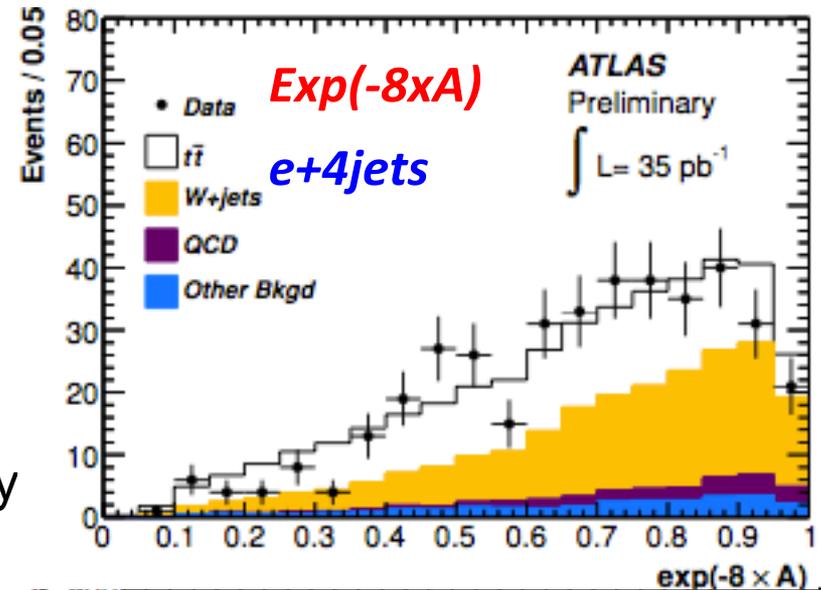


$$N_{\text{loose}} = N_{\text{fake}, \mu} + N_{\text{real}, \mu}$$

$$N_{\text{tight}} = \epsilon_{\text{tight}}^{\text{fake}} N_{\text{fake}, \mu} + \epsilon_{\text{tight}}^{\text{real}} N_{\text{real}, \mu}$$

# Lepton + Jets: Analysis (No Btag)

- Variables chosen (based on the optimization w.r.t. stat+JES error):
  - ✓ **lepton  $\eta$** :  $t\bar{t}$  more central
  - ✓ **lepton  $q$** :  $t\bar{t}$  symmetric, W+jets asymmetric
  - ✓ **aplanarity**:  $t\bar{t}$  more isotropic transformed to  $e^{-8 \times A}$  for uniformity



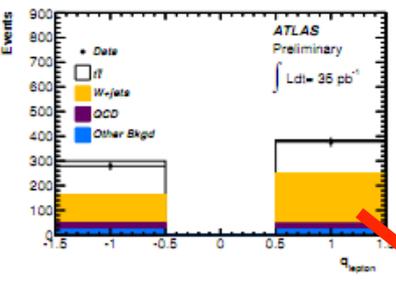
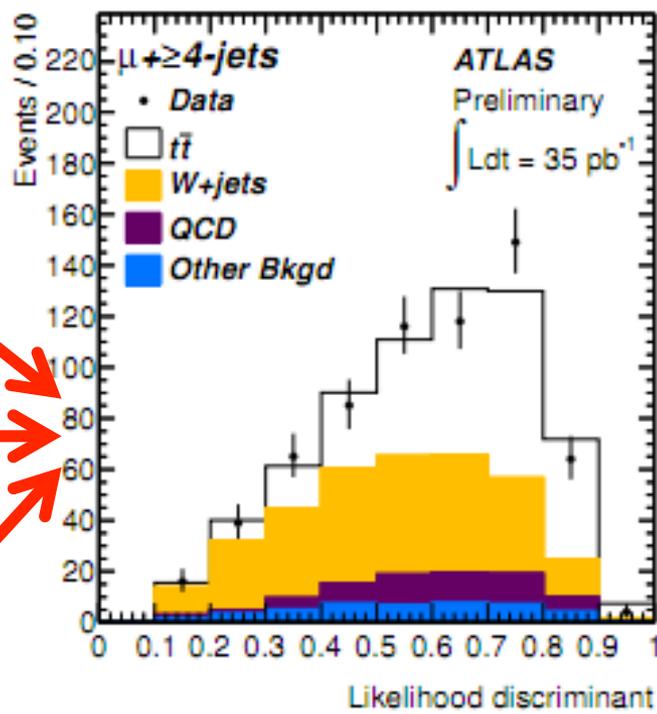
# Fit To The Data (**No** BTag)

➤ Cross-section is extracted from a fit of projective likelihood discriminant reconstructed with the chosen set variables :

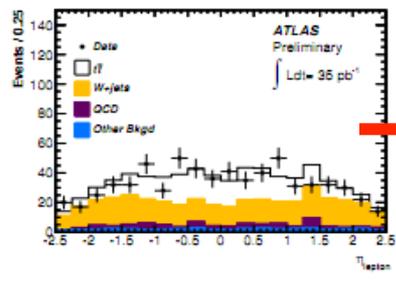
✓ Combined cross-section: 3-jet(exclusive), 4-jet(inclusive):

Independent of b-tagging ,  
avoids the related  
systematics uncertainty at  
price of higher s/b

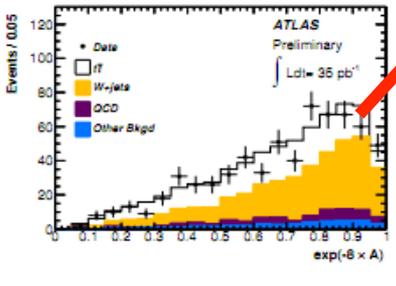
- ✓ **Stat. uncertainty** (3 %)
- ✓ **Syst uncertainty** (11 %)
  - ✓ **JES (6.0%)**
- ✓ **Lumi uncertainty** (3.4%)



(b)  $\geq 4$ -jets



(d)  $\geq 4$ -jet



(f)  $\geq 4$ -jet

$$\sigma_{t\bar{t}} = 171 \pm 17(\text{stat.})^{+20}_{-17}(\text{syst.}) \pm 6(\text{lumi.}) \text{ pb}$$

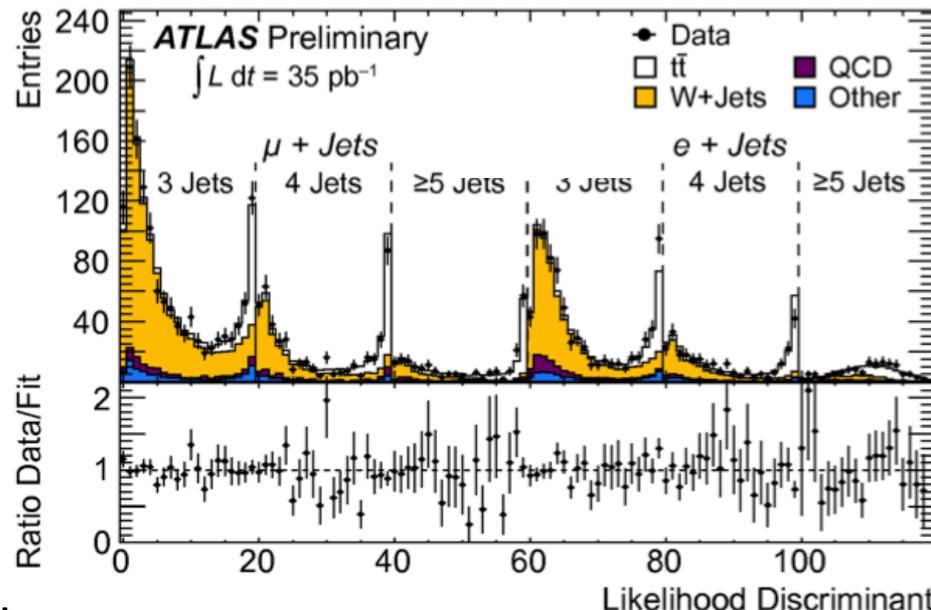
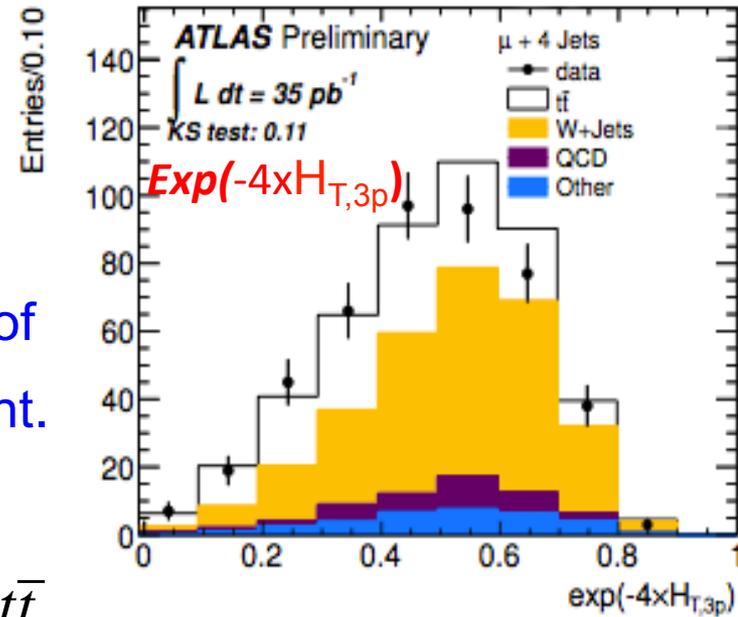
$$\frac{\delta\sigma_{t\bar{t}}}{\sigma_{t\bar{t}}} = 15\%$$

# Lepton + Jets: Analysis (With Btag)

- Cross section is extracted from a fit of projective likelihood  
(split in 6 channels : 3 , 4 ,  $\geq 5$ jet e ,  $\mu$ )
- **Lepton  $\eta$**  ,  $\exp(-8xA)$  ,  $\exp(-4xH_{T,3p})$  ; mean of b-tag weight of 2 jets with highest b-tag weight.
- Profile LH fit extracts:
  - ✓ 16 normalization parameters including  $\sigma_{t\bar{t}}$
- Systematic uncertainties : 11%  
HF fraction in W+jets (7%)  
B-tagging Calibration (7%)

$$\sigma_{t\bar{t}} = 186 \pm 10(\text{stat.})^{+21}_{-20}(\text{syst.}) \pm 6(\text{lumi.}) \text{ pb}$$

$$\frac{\delta\sigma_{t\bar{t}}}{\sigma_{t\bar{t}}} = 13\%$$

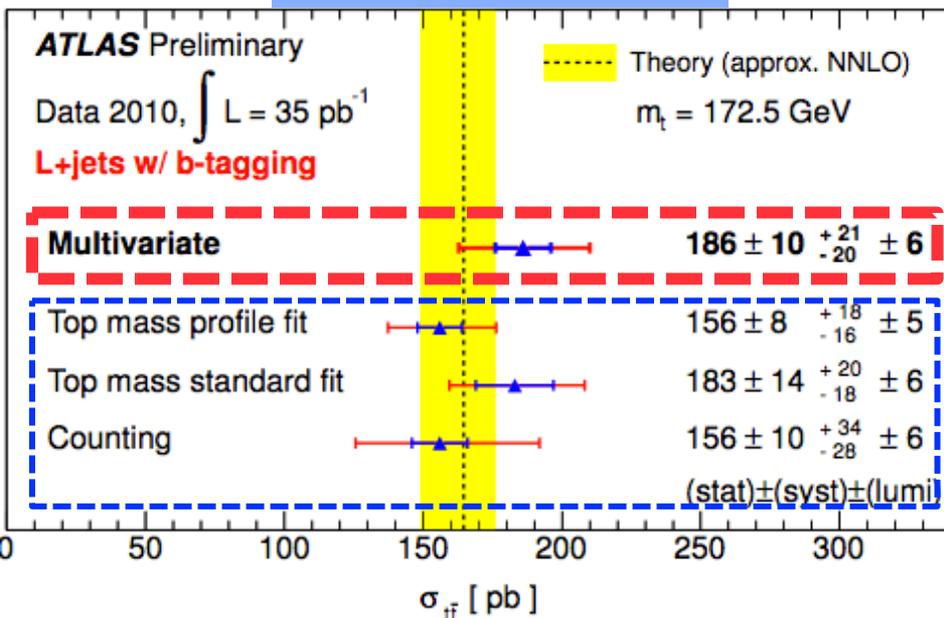


# 1-lepton Analysis Summary

- Complementary and consistent results are obtained from similar analysis with and w/o b-tag information
  - ✓ Baseline and complementary cross section measurements are in agreement within uncertainties
  - ✓ Also consistent with theoretical prediction ( $164.6^{+11.4}_{-15.7}$  pb)

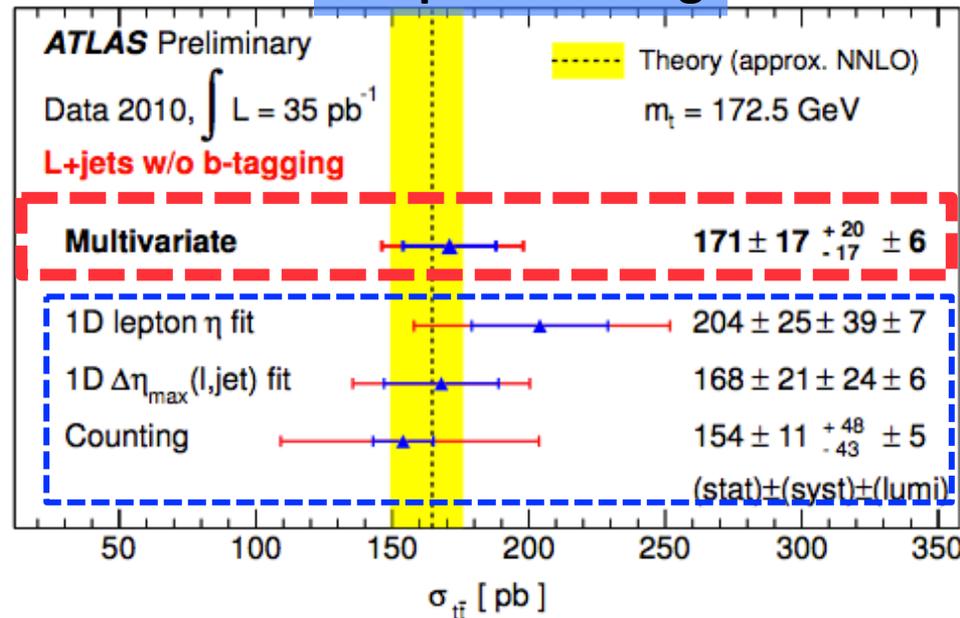
**ATLAS-CONF-2011-035**

**1-lepton with btag**



**ATLAS-CONF-2011-023**

**1-lepton no btag**



**Cross section Measurements**  
**(2 Leptons)**  
**Using  $0.70 \text{ fb}^{-1}$**

# 2 lepton Analysis Strategy

➤ Cross section estimated by counting No. of signal events

## ➤ Backgrounds:

### ① $Z^*/\gamma (\rightarrow ee/\mu\mu) + \text{jets}$ backgrounds

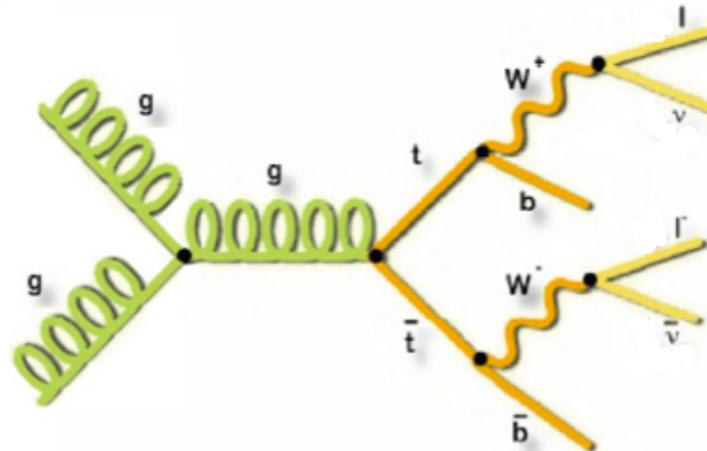
✓ Estimated w/data & assisted with MC

### ② Fake from QCD, W+jets (using Data driven methods)

✓ For QCD: Matrix method – same as in case of 1-lepton analysis.

### ③ Other SM backgrounds

✓ Single top, 2-boson,  $Z^*/\gamma (\rightarrow \tau \tau) + \text{jets}$  backgrounds  
(normalized using the theoretical cross section)



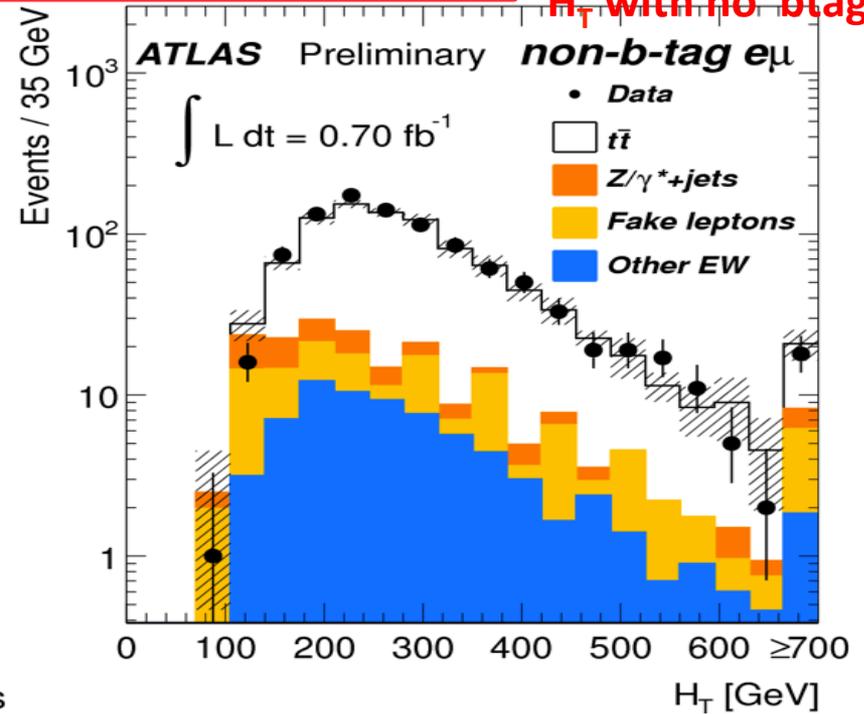
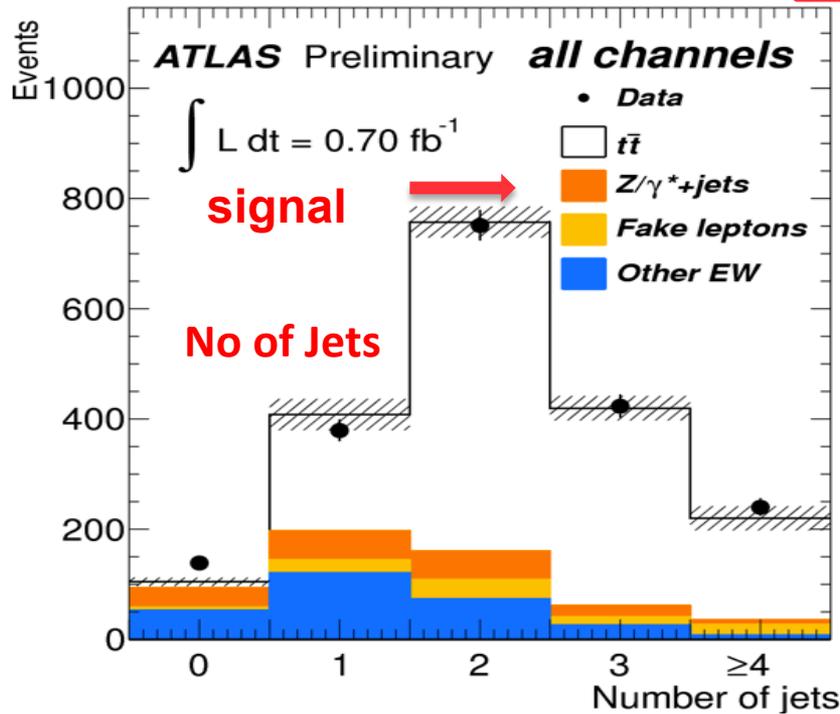
# $\sigma_{t\bar{t}}$ Measurement in 2-Lepton

- Cross section is extracted simply by counting experiment
- ✓ Data well modeled by MC
- ✓ Profile LH method to combine channels.

2-lepton **no btag**

**ATLAS-CONF-2011-100**

$H_T$  with no btag



$$\sigma_{t\bar{t}} = 171 \pm 6(\text{stat.})^{+16}_{-14} (\text{syst.}) \pm 8(\text{lumi.}) \text{ pb}$$

$$\frac{\delta\sigma_{t\bar{t}}}{\sigma_{t\bar{t}}} = 10\%$$

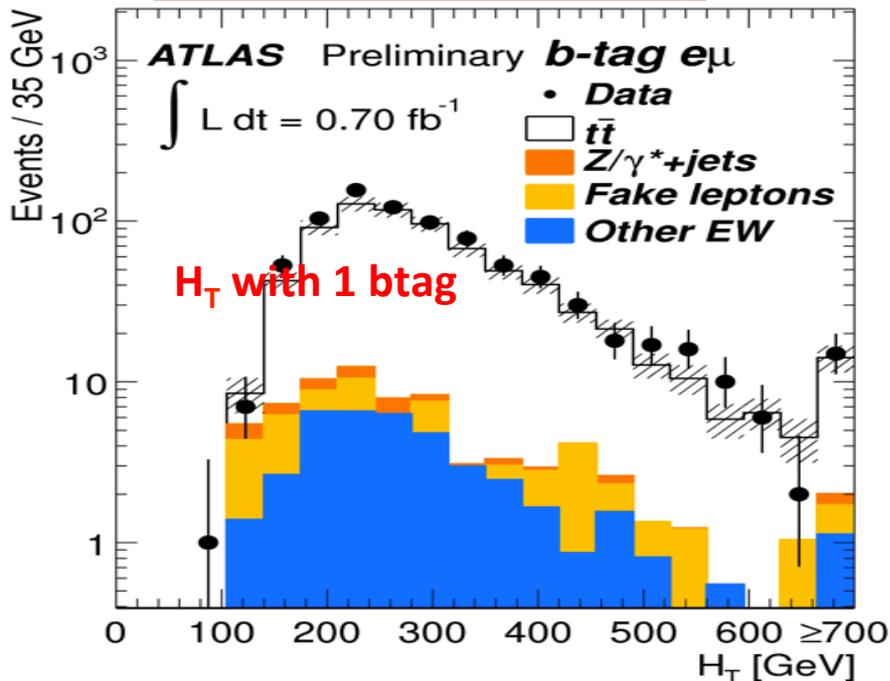
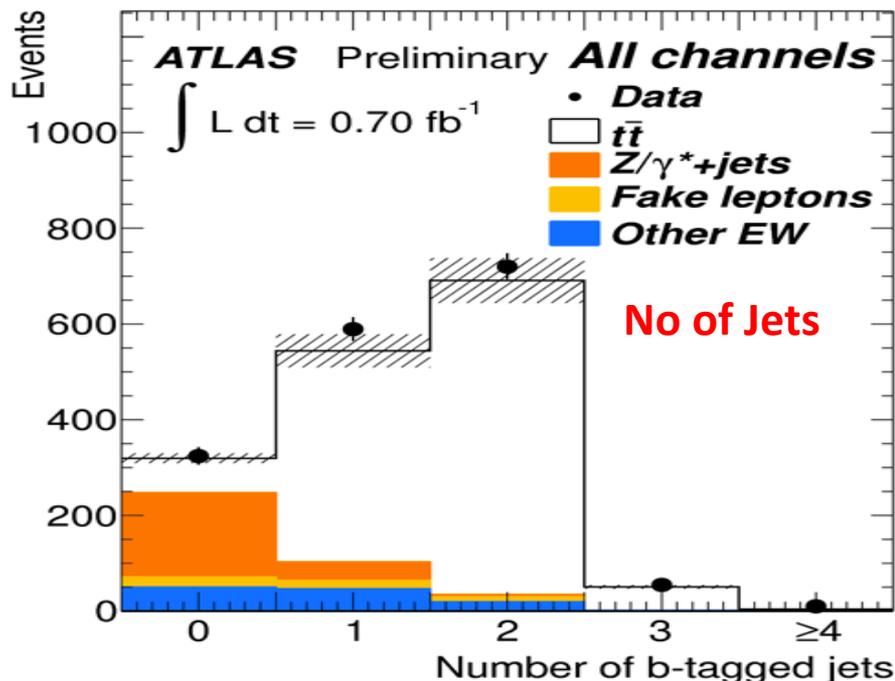
# $\sigma_{t\bar{t}}$ Measurement in 2-Lepton

- Cross section is extracted simply by counting experiment

**Additional b-tagging:** improves S/B but systematics is large.

2-lepton **With** btag

**ATLAS-CONF-2011-100**



**Systematic Uncertainty : 10%**  
**✓ b-tag Calibration : 5%**

$$\sigma_{t\bar{t}} = 177 \pm 6(\text{stat.})^{+17}_{-14} (\text{syst.})^{+8}_{-7} (\text{lumi.}) \text{ pb}$$

$$\frac{\delta\sigma_{t\bar{t}}}{\sigma_{t\bar{t}}} = 10.1\%$$

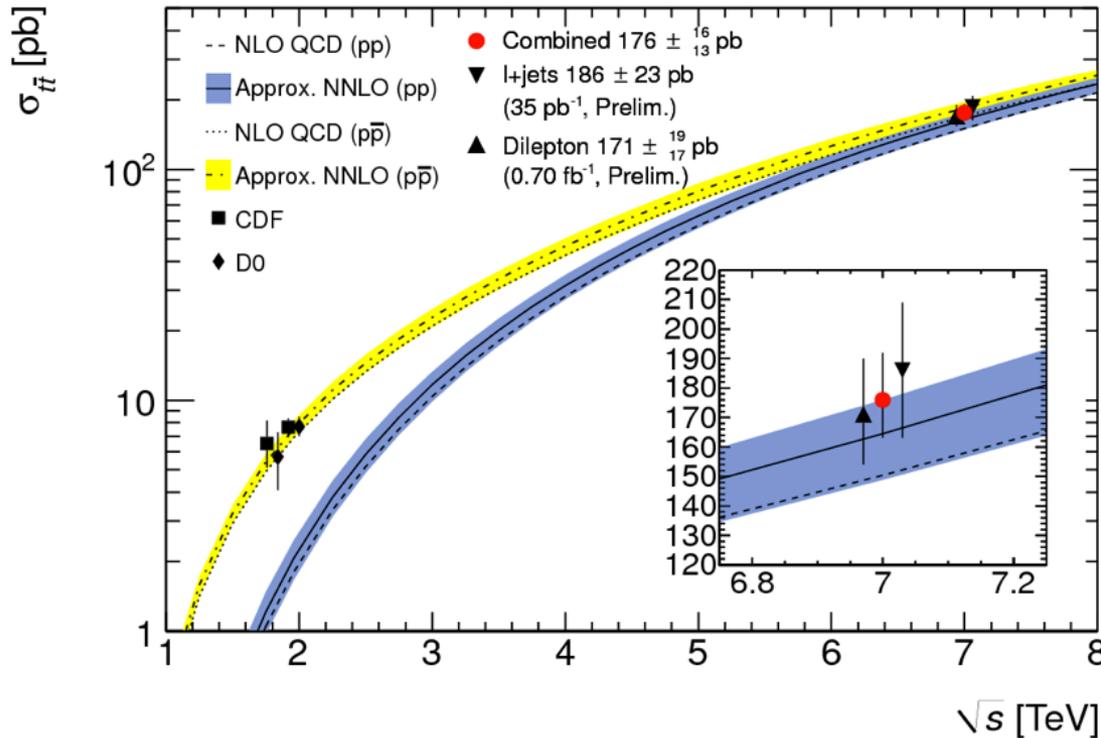
# $\sigma_{t\bar{t}}$ Combination (l+jets + dilepton)

➤ Combine single lepton and di-lepton channels

ATLAS-CONF-2011-108

$$\sigma_{t\bar{t}} = 176 \pm 5(\text{stat.})^{+13}_{-10} (\text{syst.}) \pm 7(\text{lumi.}) \text{ pb}$$

$$\frac{\delta\sigma_{t\bar{t}}}{\sigma_{t\bar{t}}} = 8.3\%$$



- ✓ Stat. uncertainty (3 %)
- ✓ Systematic uncertainty (7.4 %)
- ✓ Luminosity uncertainty (4%)

Good agreement with SM prediction

$$164.6^{+11.4}_{-15.7} \text{ pb}$$

$$\frac{\delta\sigma_{t\bar{t}}}{\sigma_{t\bar{t}}} = 9.6\%$$

# Summary and Outlook

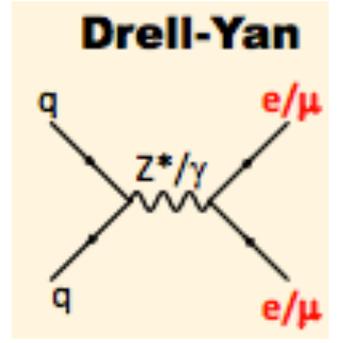
- **The era of top physics at the LHC has just started**
  - ✓ Cross section measured in ATLAS within 8.2% uncertainty with LHC pp collisions at  $\sqrt{s} = 7$  TeV by combining results:
    - ✓ obtained with 35 pb<sup>-1</sup> lepton + jets channel
    - ✓ With 0.70 fb<sup>-1</sup> dilepton channel
  - ✓ Competitive measurements are emerging (176pb with 8.2% precision)
    - ◆ compatible with theory error: 164.6 +11.4/-15.7 pb
  - ✓ Focus future work in improving systematic uncertainties
- **Top pair production cross section (lepton + jets) with 0.7 fb<sup>-1</sup> (in approval process)**
- **Anticipate ~3 fb<sup>-1</sup> by the end of year (2.04 fb<sup>-1</sup> already on tape)**  
**2011: the year of top measurements at LHC and may be discoveries !!**  
[More Results are available at the top public result page](#)

# Thank You

# Z\*/γ(→ ee/μμ) + jet background

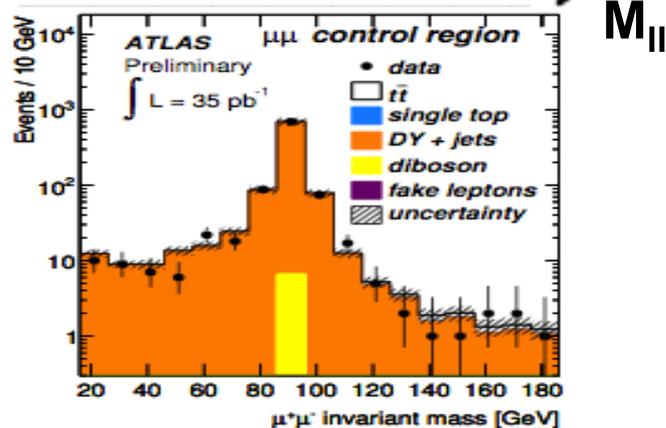
2 lepton

- Count the Z\*/γ contribution in sideband region  
Where fraction of Z\*/γ is about 90%
- Extrapolate it to signal region



$$N_{Z/\gamma^*+jets} = \frac{MC_{Z/\gamma^*+jets}(SR)}{MC_{Z/\gamma^*+jets}(CR)} \times (Data(CR) - MC_{other}(CR))$$

Definition of control region (CR):  
 Inside Z mass window  $81 \text{ GeV} < |M_{ll}| < 101 \text{ GeV}$   
 High MET region; MET > 30 GeV  
 High jet multiplicity events  $\geq 2$  jets



Channel	Estimation
ee	$1.2^{+0.5}_{-0.6}$
μμ	$3.4^{+1.9}_{-1.4}$

# Object definition and Event Selection

## Muon:

$P_T > 20$  GeV  
 $|\eta| < 2.5$   
 Isolated muon track  
 Tracker & muon chamber

## Electron:

Isolated EM calo object  
 Matching to track  
 $E_T > 20(25)$  GeV,  $0 < |\eta| < 2.47$   
 Remove:  $1.37 < |\eta| < 1.52$

## 1-lepton channel

- ✓ Exactly 1 isolated lepton with (matched to single lepton trigger)
- ✓ electron: MET > 35 GeV ;  
 $m_T(W) > 25$  GeV
- ✓ muon: MET > 20 GeV ;  
 MET +  $m_T(W) > 25$  GeV
- ✓ At least 3 jets with  $p_T > 25$  GeV
- ✓  $\geq 1$  jet b-tagged (Jet Prob: 70% eff)

## Jet:

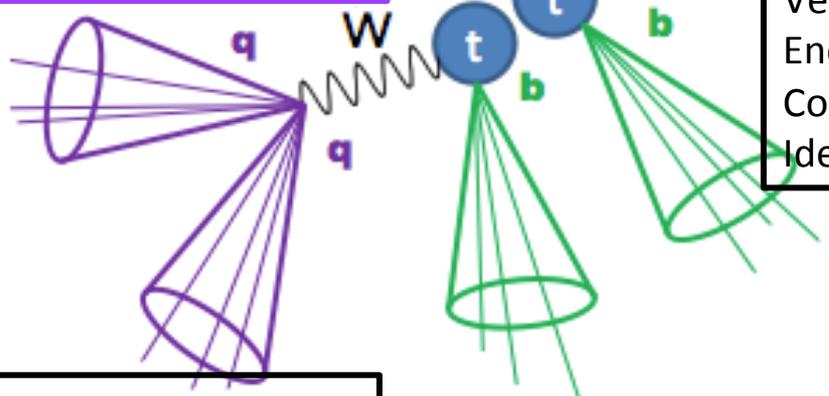
Topological cluster  
 Anti- $K_T$  (R = 0.4)  
 $P_T > 25(20)$  GeV  
 $|\eta| < 2.5$

## Lepton

## Neutrino

## Missing $E_T$ :

Vector Sum of Calo Energy deposits  
 Corrected for Identified objects



## Event cleaning:

Good Run condition  
 PV > 4 tracks  
 Bad jet veto

## B-tagging:

Displaced tracks or secondary leptons  
 (Track/jet compatibility with primary vertex or Secondary Vertex)

## 2-lepton channel (W/O b-tag)

- ✓ 2 oppositely charged (ee,  $\mu\mu$ , e $\mu$ )  
 at least one matched to trigger
- ✓ 2 or more jets with  $p_T > 20$  GeV
- ✓ MET > 60(40) GeV ;  
 $|M_{11} - M_{22}| > 10$  GeV
- ✓ e $\mu$ :  $H_T > 130(140)$  GeV
- ✓ Cosmic muon rejection
- ✓  $\geq 1$  b-tagged (IP3DSV1: 80% eff.)

# SYSTEMATICS (lepton+jets - NO BTAG)

Source	Relative cross-section uncertainty [%]
<i>Object selection</i>	
Lepton reconstruction, identification, trigger	-1.9 / +2.6
Jet energy scale and reconstruction	-6.1 / +5.7
<i>Background rates and shape</i>	
QCD normalisation	±3.9
QCD shape	±3.4
W+jets shape	±1.2
Other backgrounds normalisation	±0.5
<i>Simulation</i>	
Initial/final state radiation	-2.1 / +6.1
Parton distribution functions	-3.0 / +2.8
Parton shower and hadronisation	±3.3
Next-to-leading-order generator	±2.1
MC statistics	±1.8
Pile-up	±1.2
Total systematic uncertainty	-10.2 / +11.6

Luminosity uncertainty 3.4%

$$\sigma_{t\bar{t}} = 171 \pm 17 (\text{stat.})^{+20}_{-17} (\text{syst.}) \pm 6 (\text{lumi.}) \text{ pb}$$

$$\delta\sigma_{t\bar{t}} / \sigma_{t\bar{t}} = 15\%$$

$$\sigma_{t\bar{t}} = \frac{N_{sig} - N_{bka}}{\int L dt} \times \epsilon_{sig}$$

Background uncertainties

Object reconstruction, signal modeling

# SYSTEMATICS (dilepton **NO** BTAG)

	$ee$	$\mu\mu$	$e\mu$	Combined
Uncertainty Source	$\Delta\sigma/\sigma[\%]$	$\Delta\sigma/\sigma[\%]$	$\Delta\sigma/\sigma[\%]$	$\Delta\sigma/\sigma[\%]$
Data statistics	-9.3 / 9.8	-6.6 / 6.8	-4.1 / 4.2	-3.3 / 3.3
Luminosity	-4.0 / 4.7	-3.7 / 4.3	-4.3 / 4.7	-4.2 / 4.6
MC statistics	-4.2 / 4.9	-2.8 / 3.2	-1.9 / 2.1	-1.5 / 1.6
Lepton energy scale	0.0 / 0.9	0.0 / 0.5	-0.3 / 0.3	-0.4 / 0.0
Lepton energy resolution	0.0 / 0.6	-0.5 / 0.8	0.0 / 0.5	-0.4 / 0.3
Lepton ident. scale factor	-5.5 / 6.6	-1.2 / 2.7	-3.1 / 3.4	-2.6 / 2.7
Jet energy scale	-10.0 / 10.6	-3.8 / 7.6	-3.7 / 4.5	-5.9 / 5.3
Jet energy resolution	-0.6 / 0.8	-3.1 / 3.6	-0.6 / 0.7	-0.4 / 0.3
Jet reconstr. efficiency	0.0 / 0.0	0.0 / 0.0	0.0 / 0.0	0.0 / 0.0
Drell-Yan prediction	0.0 / 0.0	-0.4 / 0.4	0.0 / 0.0	0.0 / 0.0
Fake leptons	-1.6 / 1.6	-0.4 / 0.4	-3.2 / 3.2	-2.0 / 1.9
MC generator	-4.3 / 5.3	0.0 / 0.0	-2.9 / 3.2	-2.1 / 2.3
Parton shower	-4.7 / 5.8	-0.4 / 0.5	-2.9 / 3.2	-2.3 / 2.4
ISR	-7.1 / 0.6	-0.8 / 3.6	-0.5 / 2.4	-2.4 / 2.5
FSR	-13.6 / 0.6	-0.7 / 4.3	-2.4 / 0.5	-1.3 / 1.4
PDF	-2.4 / 2.8	-1.7 / 2.2	-2.4 / 2.7	-2.3 / 2.5
$E_T^{\text{miss}}$ reconstruction	-1.0 / 1.1	-0.8 / 1.7	0.0 / 0.0	-0.5 / 0.6
Pile-up	-0.6 / 1.3	-0.5 / 1.5	0.0 / 0.0	-0.5 / 0.5
Detector modeling	-0.6 / 1.1	-0.7 / 1.5	-0.7 / 1.2	-1.0 / 1.3
Theoretical cross-sections	-1.4 / 1.3	-1.7 / 1.8	-2.1 / 2.1	-1.9 / 1.9
All systematics	-20 / 18	-7.3 / 13	-9.2 / 11	-9.3 / 10
Stat + Syst	-22 / 20	-9.9 / 15	-10 / 12	-9.8 / 11

$$\sigma_{t\bar{t}} = \frac{N_{\text{sig}} - N_{\text{bkg}}}{\int L dt \times \epsilon_{\text{sig}}}$$

$$\sigma_{t\bar{t}} = 171 \pm 6(\text{stat.})^{+16}_{-14}(\text{syst.}) \pm 8(\text{lumi.}) \text{ pb}$$

$$\delta\sigma_{t\bar{t}} / \sigma_{t\bar{t}} = 10\%$$