Results from Top Physics at ATLAS

Saleem, M (University of Oklahoma)
On behalf of the ATLAS Collaboration

23rd Rencontres de Blois
(May 29 – June 3, 2011)

Top Quark Pair Production @ LHC

- **Top quark pair production cross section prediction:**

  Theory approx. NNLO p-QCD calculation with $\sqrt{s}$ of pp = 7 TeV , m_t = 172.5 GeV

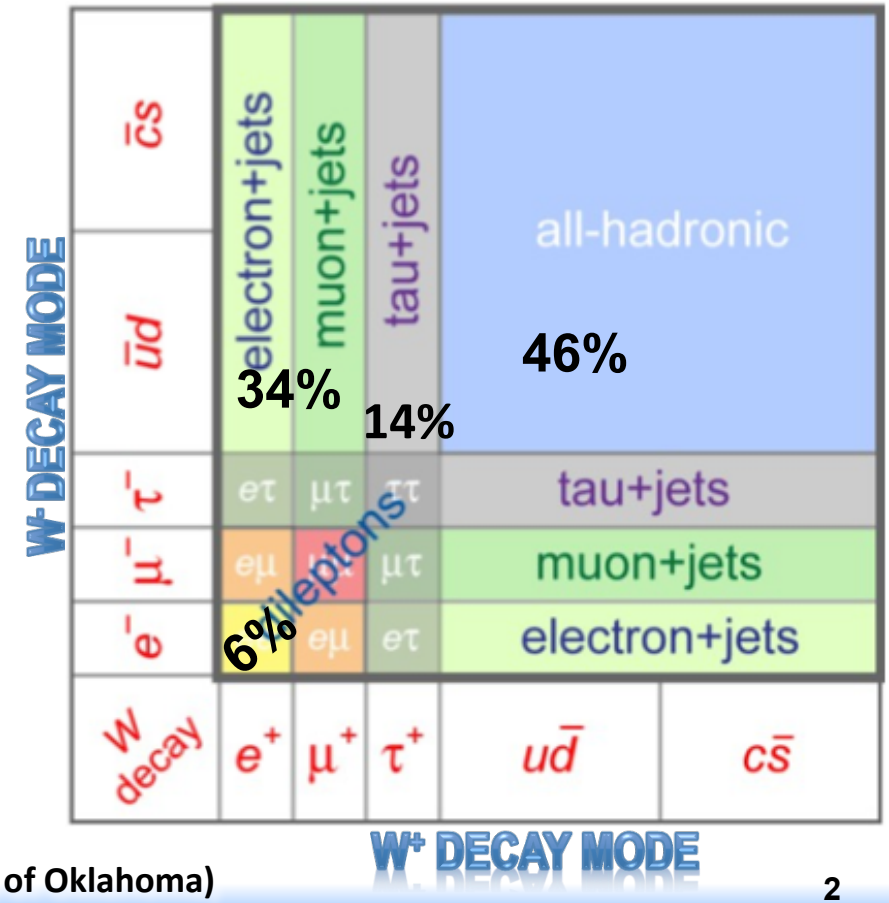
  ① Theoretical cross section : $165\ ^{+11}_{-16}$ pb **9.6 %** **arXiv:0907.2527**

- At LHC:
  - gg fusion (90%)
  - qq annihilation (10%)
- Top quark pair decay topology:

  ① Br(t ⟶ bW) ~ 100% in SM

  ② Final state is categorized by the decay of 2 W bosons:

  (W ⟶ eν, μν, τν ; W ⟶ qq')

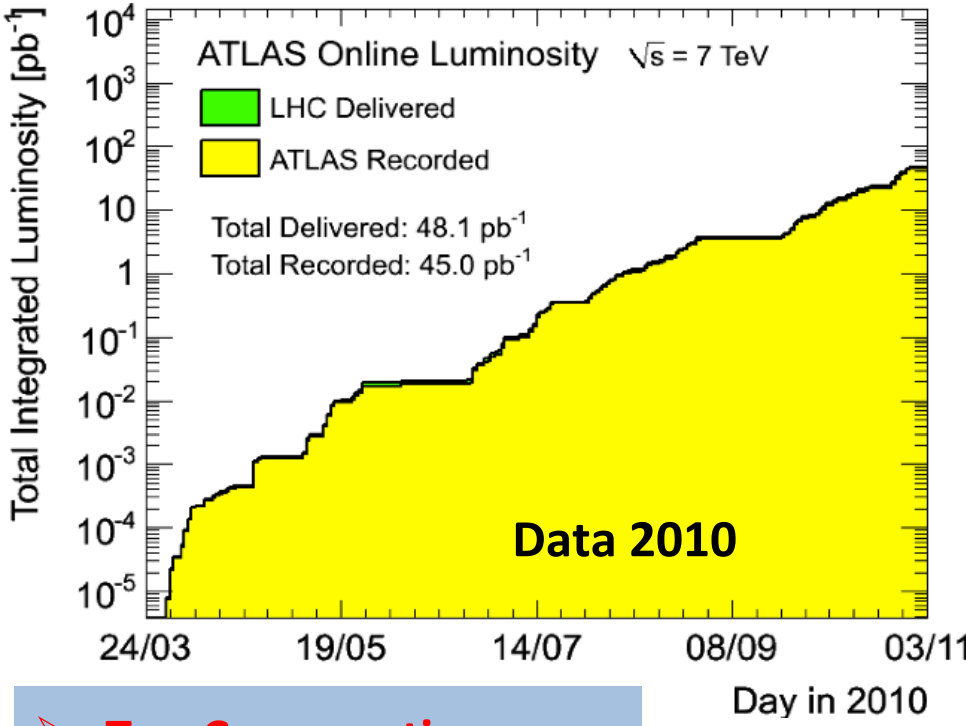


2010 Data samples

- **Data collected in 2010 at PP collision @ √s = 7TeV.**
- ✓ Data collected in 2010 : 45 pb^{-1}
- ✓ Used Data : 35 pb^{-1}
  (Single lepton trigger , Data Quality)
- ✓ Peak lumi 2.1 x 10^{32} cm^{-2} s^{-1}
- ✓ Lumi. uncertainty down to 3.4%
- ✓ 10 times more statistics w.r.t the first Atlas measurement on cross section
  ($\sigma_{t\bar{t}} = 145 \pm 31\ ^{+42}/_{-27}$ with $2.9 pb^{-1}$)

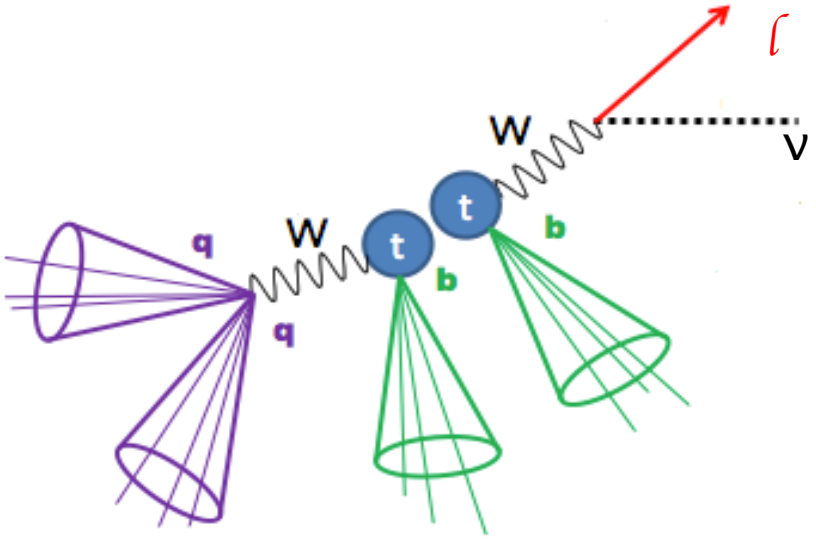
$$\delta\sigma_{t\bar{t}} / \sigma_{t\bar{t}} = {}^{+36}_{-28}\ \%$$

arXiv:1012.1792, accepted by EPJC



- **Top Cross section**
  - ✓ **Lepton+jets**
  - ✓ **dilepton**
  - ✓ **All Hadronic**
- **Top properties**
  - ✓ **Top mass**
  - ✓ **W-helicity**

Cross section Measurements



Top Quark Event Selection

- ✓ **Electron** : Good Isolated calo EM object; match to track ; $E_T > 20$ GeV ; $|\eta| \in [0,2.47]$; Remove:[1.37,1.52]
- ✓ **Muons** : Isolated muon track (Tracker & muon chamber) ; $p_T > 20$ GeV ; $|\eta| < 2.5$
- ✓ **Jets** : Topological cluster ; Anti-K_T ($R = 0.4$) ; $|\eta| < 2.5$
- ✓ **Trigger** : single lepton trigger (electron : 15 GeV ; muon : 13 GeV)
- ✓ **Missing E_T :** Vector Sum of Calo Energy deposits ; Corrected for Identified objects
- ✓ **Event Cleaning** : pile up rejection > 4 tracks from PV ; Good run condition ; Bad jet veto
- ✓ **B-tagging :** Combine IP significance of all the tracks associated to jets or Secondary Vertex

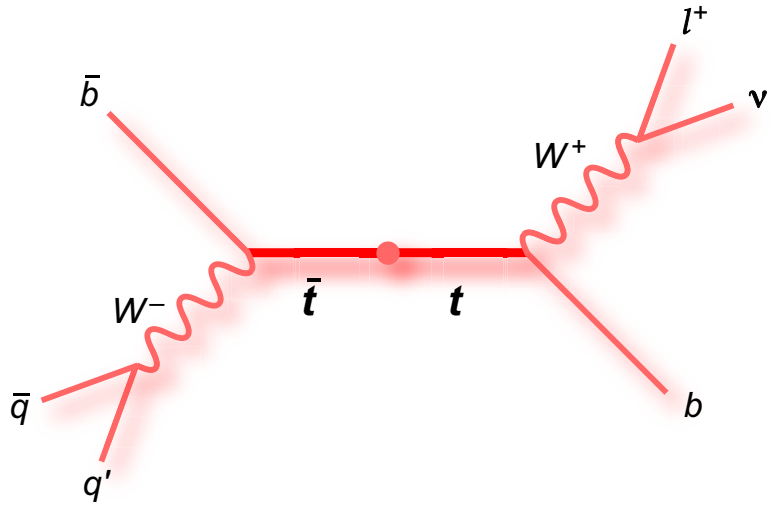
1-lepton channel

- ✓ 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
- ✓ ≥ 1jet b-tagged (Jet Prob with 70% eff.)

2-lepton channel

- ✓ 2 oppositely charged leptons (ee, μμ, eμ) with at least one matched to trigger
- ✓ 2 or more jets with p_T >20 GeV
- ✓ ee/μμ: MET > 40 GeV ; $|M_{ll} - M_Z| > 10$ GeV
- ✓ eμ: $H_T > 130$ GeV
- ✓ Cosmic muon rejection

Cross section Measurements (1 Lepton + jets)



Single Lepton Analysis Strategy

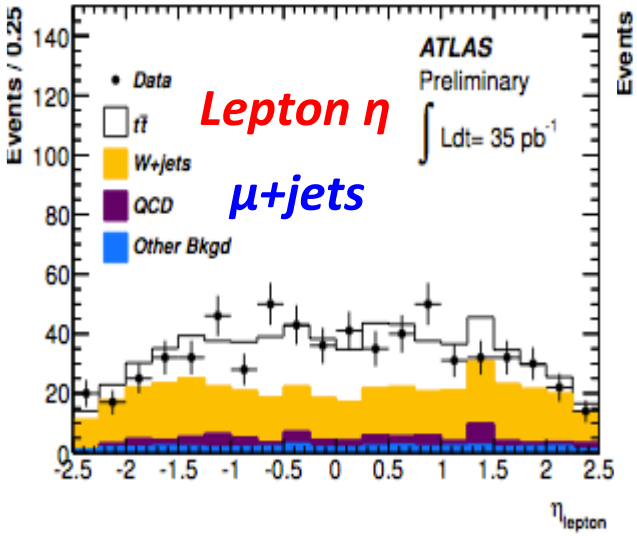
- Extract cross section by a fit of multivariate LH:
  - This exploits the difference in kinematic distributions of signal and background events
- **Backgrounds:**
  - **W+jets backgrounds**
    - Shape is determined by MC
    - Normalization from fit
  - **Small Bkgd** (Z+jets , diboson , single top)
    - 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 μ channel

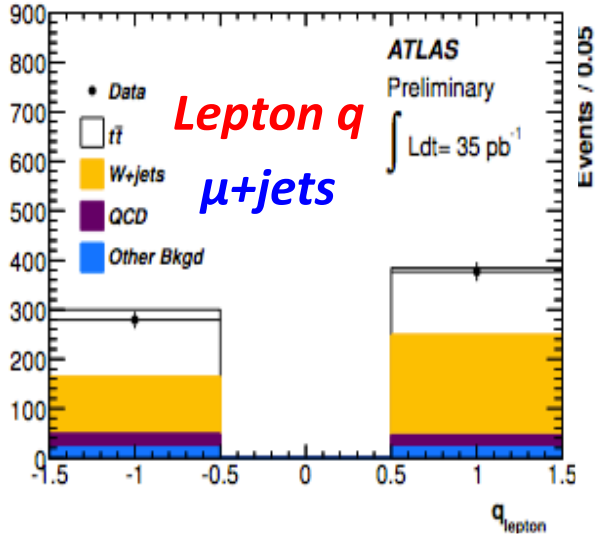
$$N_{loose} = N_{fake,\mu} + N_{real,\mu}$$

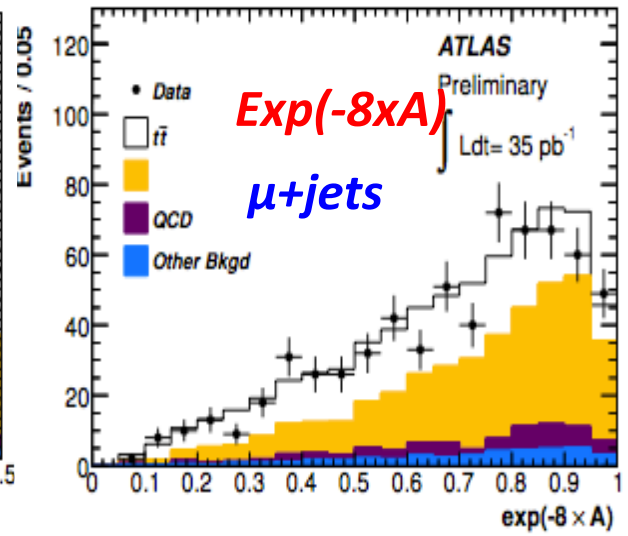
$$N_{tight} = \varepsilon_{tight}^{fake} N_{fake,\mu} + \varepsilon_{tight}^{real} N_{real,\mu}$$

$\sigma_{t\bar{t}}$ For Single Lepton with no b-tag

- Cross section is extracted from a fit of projective likelihood (split into 4 channels : 3 jet ; ≥ 4jet ; e , μ) calculated using the discriminating variables







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

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

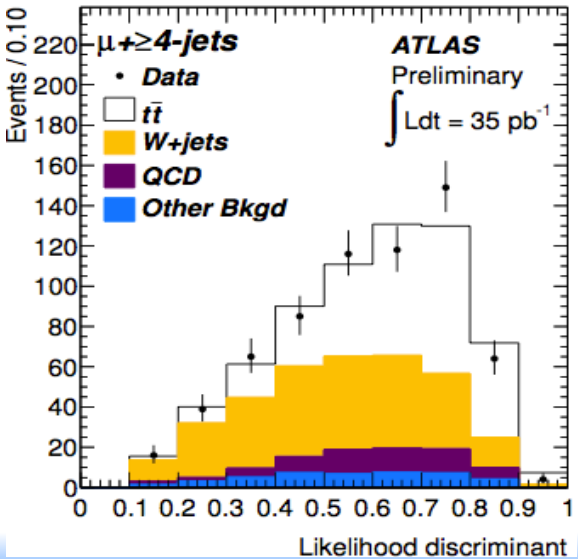
(Relative uncertainty)

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

Cross-checked by

- ✓ cut-and-count
- ✓ 1D χ^2 LH fit.

Multivariate discriminant



$\sigma_{t\bar{t}}$ For Single Lepton with b-tag

- Cross section is extracted from a fit of projective likelihood (split in 6 channels : 3 , 4 , ≥ 5jet e , μ)
- Lepton **η** , exp(**-8xA**) , exp(**-4x$H_{T,3p}$**) ; mean of b-tag weight of 2 jets with highest b-tag weight.
- Profile LH fit extracts:
  - ✓ 16 normalization parameters including $\sigma_{t\bar{t}}$
- Fit is Setup
  - ✓ With 17 nuisance parameters constrained from data (profiling)
- Systematic uncertainties : 11%

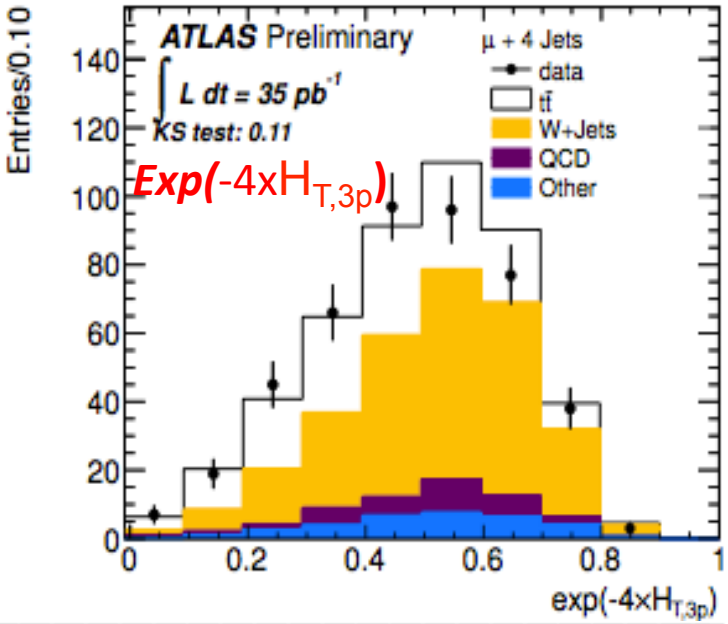
  HF fraction in W+jets (7%)

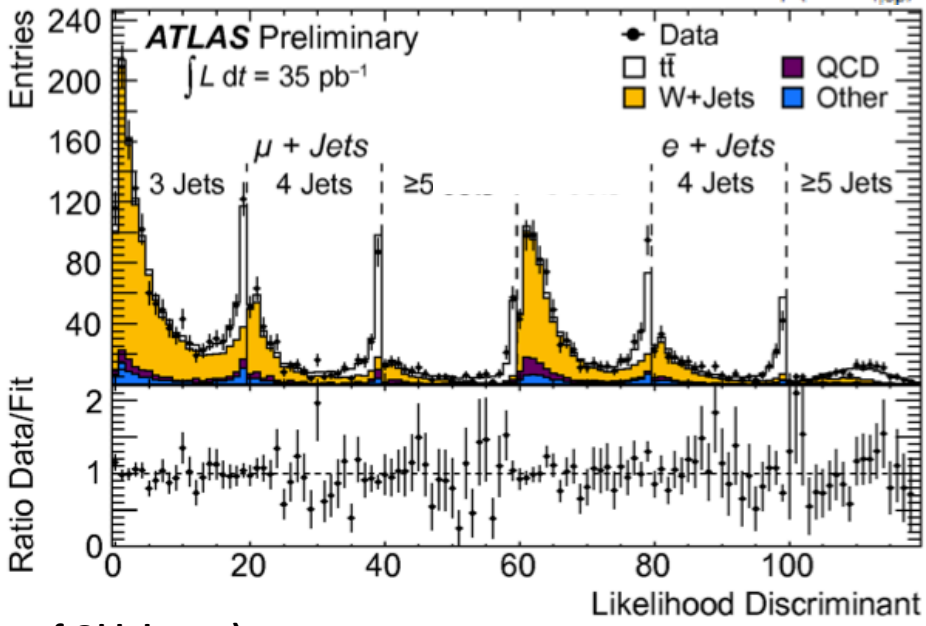
  B-tagging Calibration (7%)

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

- Cross-check analysis
  - ✓ Cut-and-count
  - ✓ Fit to m(jjj)

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



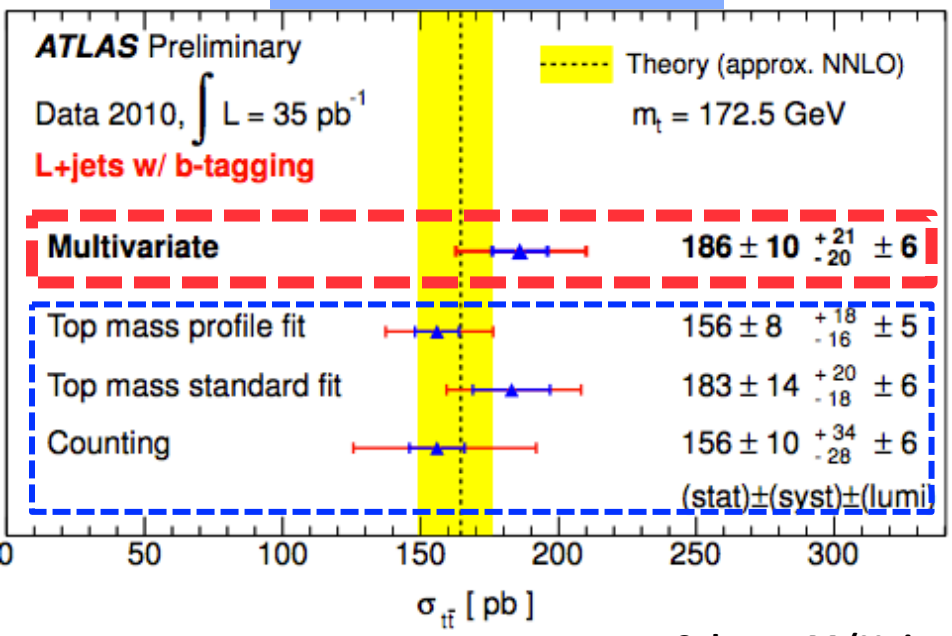


1-lepton Analysis Summary

- 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 ($165\ ^{+11}_{-16}$ pb)

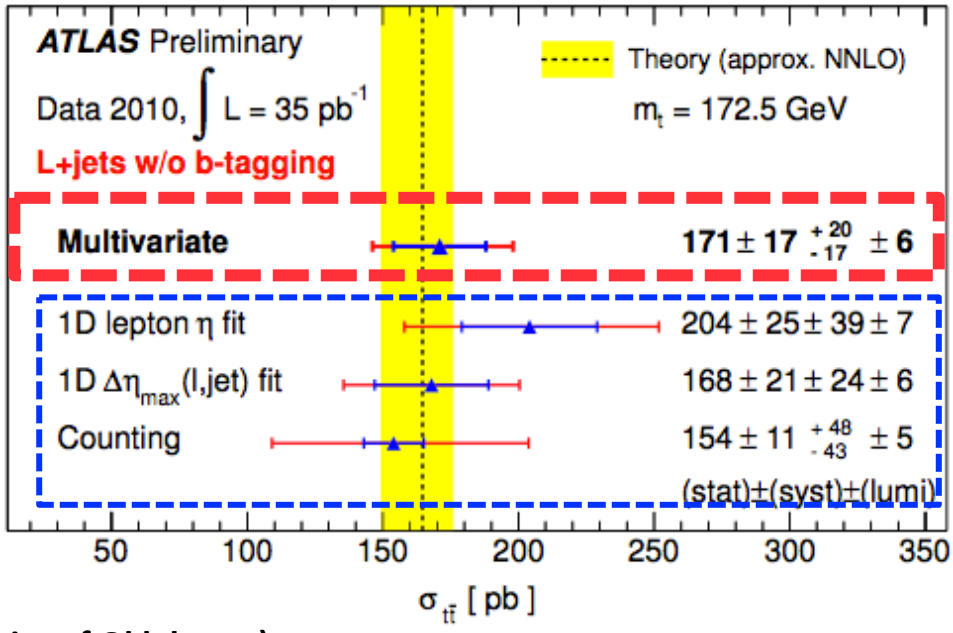
ATLAS-CONF-2011-035

1-lepton with btag



ATLAS-CONF-2011-023

1-lepton no btag



Cross section Measurements (2 Leptons)

2 lepton Analysis Strategy

- Cross section estimated by counting No. of signal events
- **Backgrounds:**

① **Z*/γ (➔ee/*μμ*) + jets backgrounds**

✓ Estimated w/data & assisted with MC

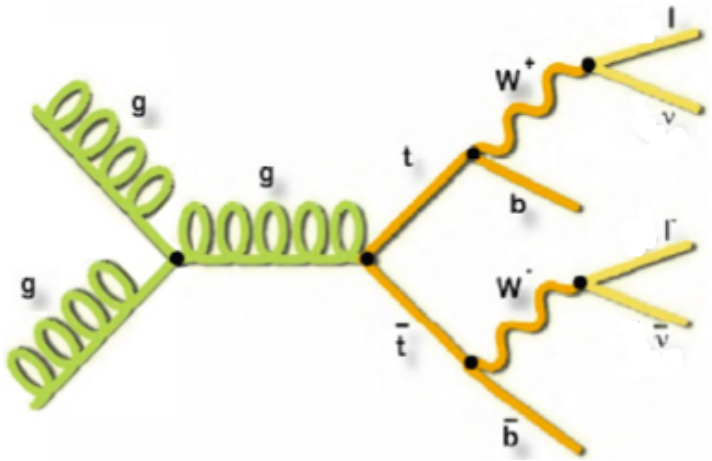
② **Fake from QCD, W+jets (using Data driven methods)**

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

③ **Other SM backgrounds**

✓ Single top, 2-boson, Z*/γ (➔ $\tau\ \tau$) + jets backgrounds

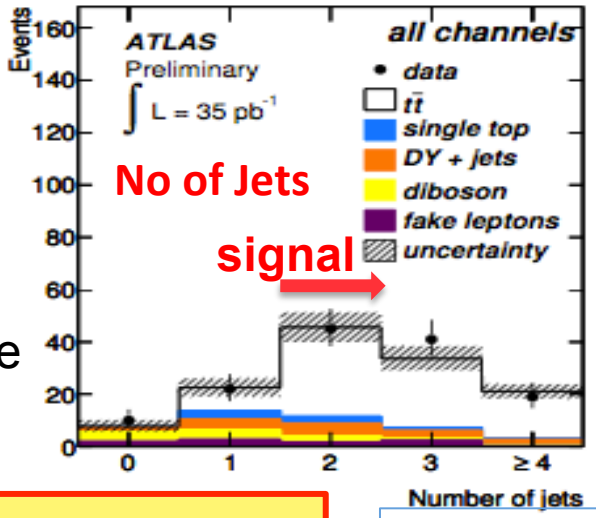
(normalized using the theoretical cross section)

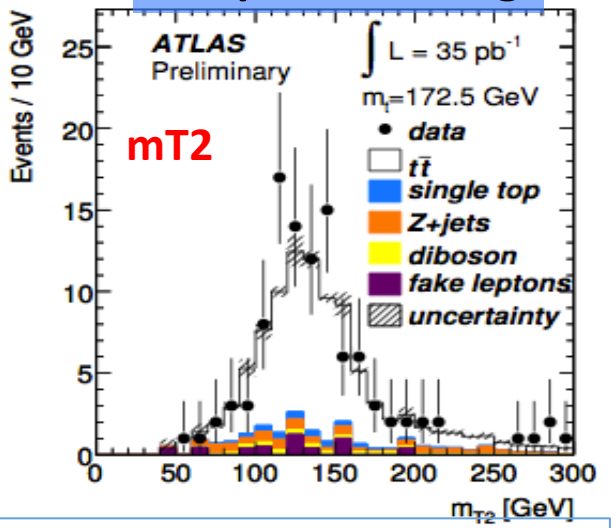


$\sigma_{t\bar{t}}$ Measurement in 2-Lepton

- Cross section is extracted simply by counting experiment

2-lepton no btag



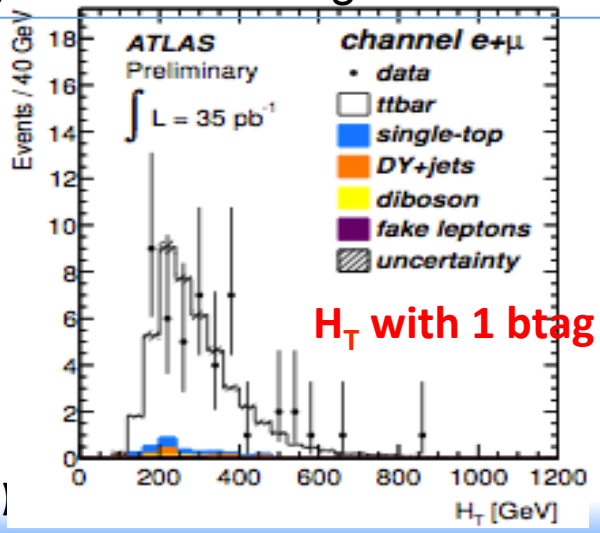


- ✓ Data well modeled by MC
  105 events selected ;
  101 ± 9 expected
- ✓ Profile LH method to combine channels.

$$\sigma_{t\bar{t}} = 173 \pm 22(\text{stat.})^{+18}_{-16}(\text{syst.})^{+8}_{-7}(\text{lumi.})\ \text{pb}$$

$$\delta\sigma_{t\bar{t}} / \sigma_{t\bar{t}} = 17\%$$

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



Systematic Uncertainty: Total=10%

- ✓ **Jet reconstruction: :5%**
- ✓ **QCD :4%**
- ✓ **Parton shower modeling :5%**

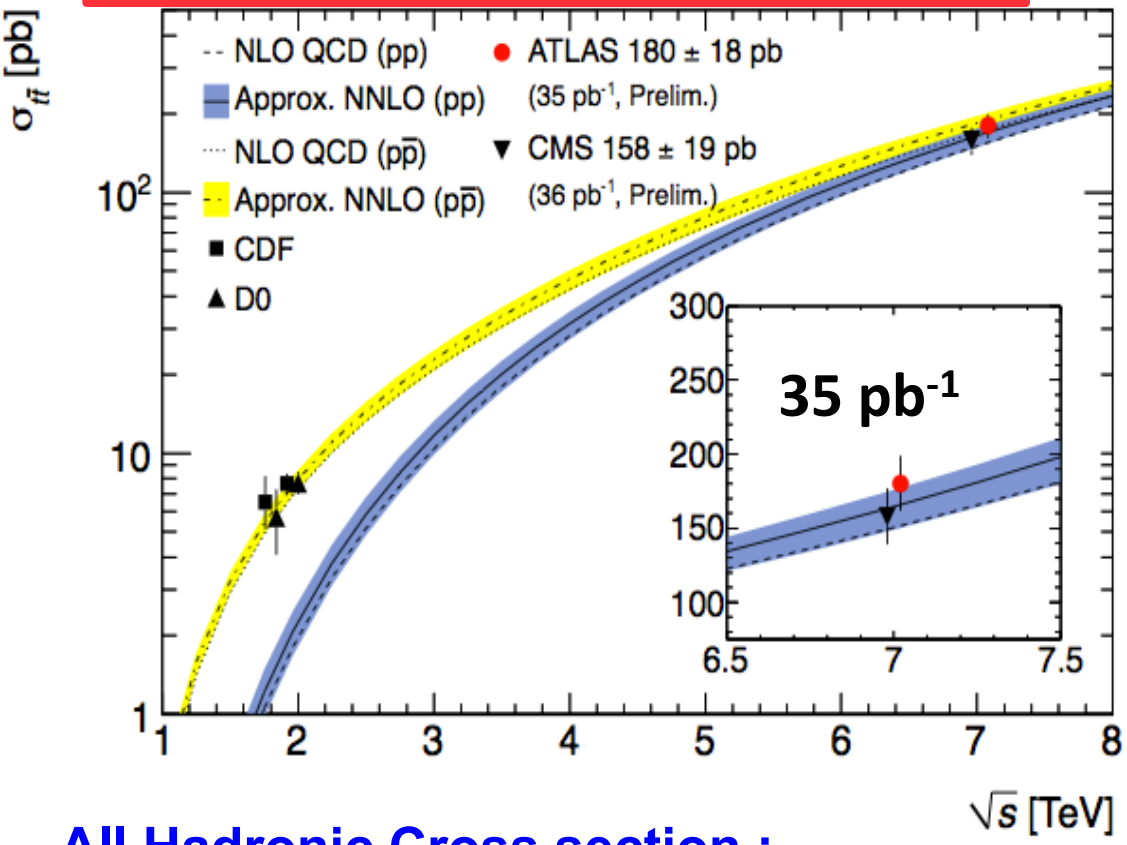
$\sigma_{t\bar{t}}$ Combination (l+jets + dilepton)

- **Combine single lepton and di-lepton channels**

ATLAS-CONF-2011-040

$\sigma_{t\bar{t}} = 180 \pm 9(\text{stat.}) \pm 15(\text{syst.}) \pm 6(\text{lumi.})$ pb

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



- ✓ Stat. uncertainty (4 %)
- ✓ Systematic uncertainty (8 %)
- ✓ Luminosity uncertainty (3.4%)

Good agreement with SM prediction

$165\ ^{+11}_{-16}$ pb

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

All Hadronic Cross section :

The measured uncertainty on fitted XS is found to be too large to claim observation

$\sigma_{t\bar{t}} < 261$ pb @ 95% CL

ATLAS-CONF-2011-066

Top quark mass
W helicity

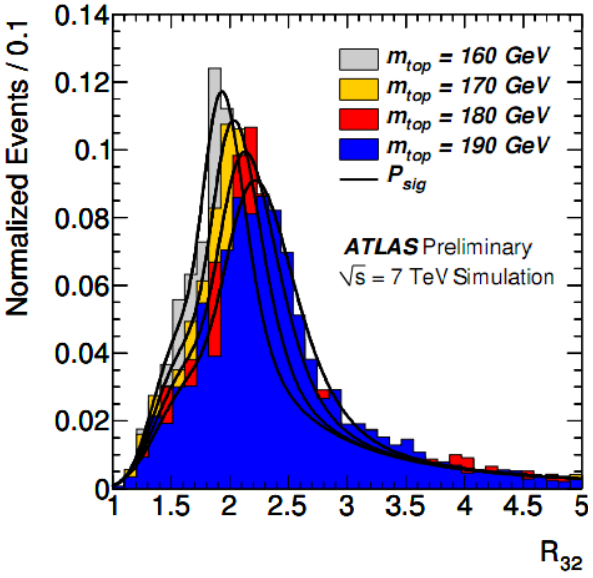
Top Quark Mass (Template Method)

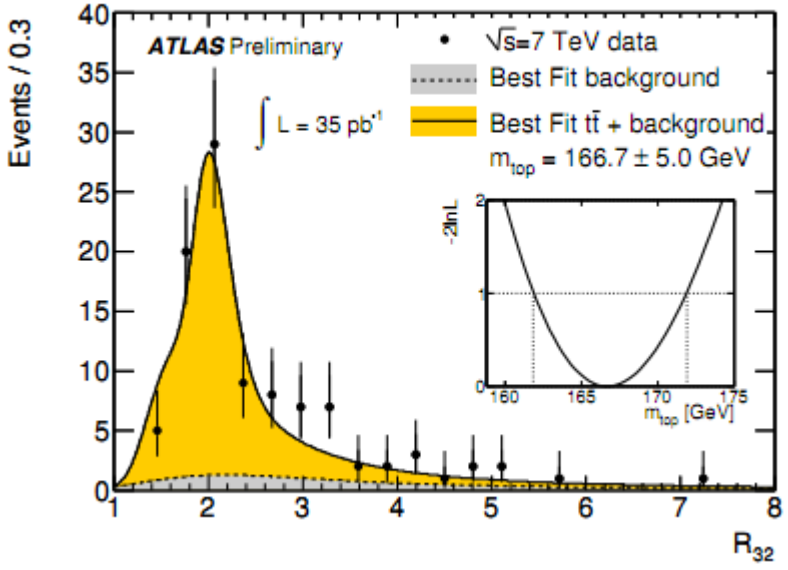
- First Atlas measurement on Top mass in e/μ + jets channel
- Measure the mass of Hadronic top (t → W (qq')b)
  - ✓ JES is major issue
- Use ratio reconstructed top and W mass
  - ✓ Less sensitive to JES – crucial for this measurement.
  - ✓ JES , ISR/FSR are biggest systematics

ATLAS-CONF-2011-033

$$M_{top} = 169.3 \pm 4.0(\text{stat.}) \pm 4.9(\text{syst.})\ \text{GeV}$$

World average: 173.3 ± 1.1 GeV





- Cross-checked:
- ✓ kinematics fit template
- ✓ 2D template with Jet scale factor

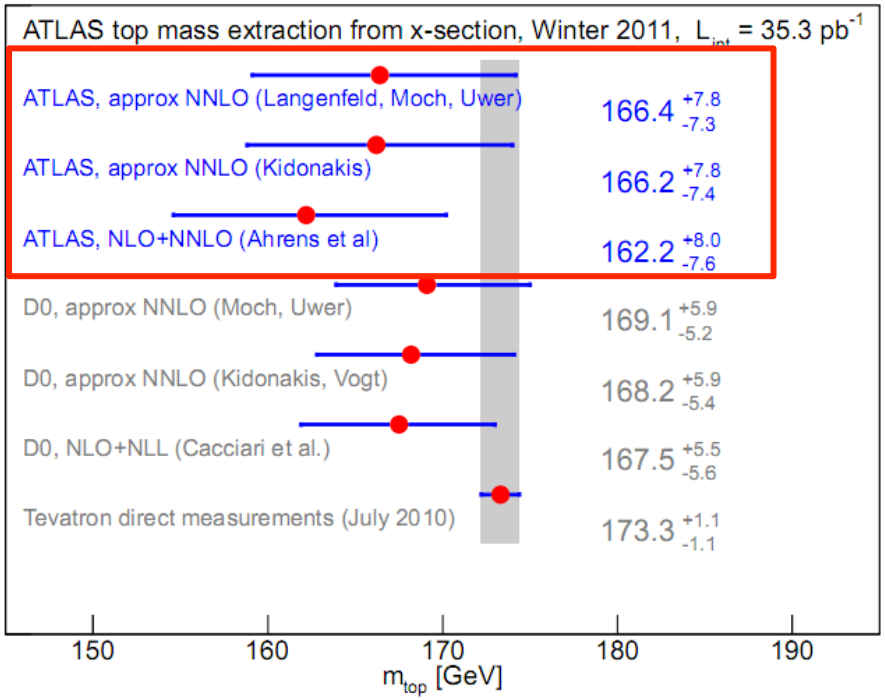
Top Quark Mass (ttbar Xsec)

- **New Atlas measurement**
- Use lepton + jets tagged cross section as in put
- Th. predictions for cross section using various approaches and top pole mass
- Top mass is extracted from a combination of uncorrelated theoretical and experiment LH

$$f(m_{top}) \propto \int f_{theory}(\sigma \mid m_{top}) \cdot \int f_{exp}(\sigma \mid m_{top})\, d\sigma$$

- Max. of this LH determines the extracted m_{top} :
  - ✓ Fit performed for 3 theoretical calculations
  - ✓ Default analysis based NNLO-Langenfeld Phys. Rev. D80 (2009) 054009)

ATLAS-CONF-2011-054



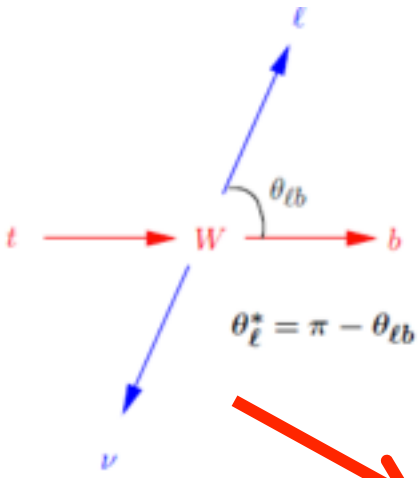
$$M_{top} = 166.4\ ^{+7.8}_{-7.3}\ \text{GeV}$$

W helicity in Top Decays

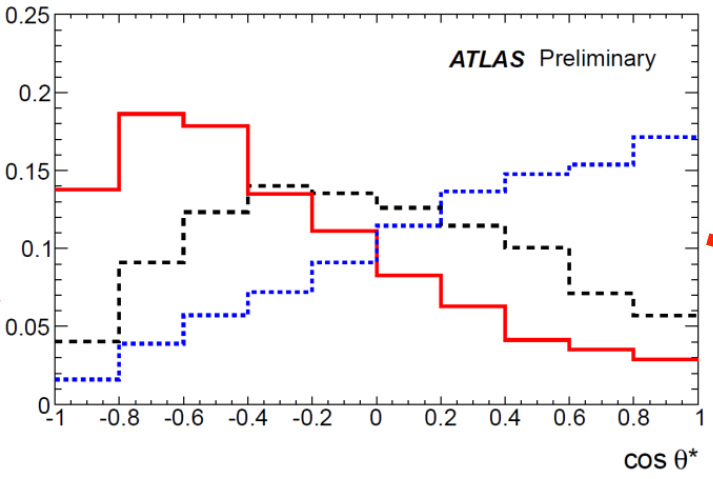
- **The standard Model predicts helecity fraction of W from top**
  - ✓ F_L = 0.301 , F_0 = 0.698 , F_R = 4.1×10^{-4}
  - ✓ This verification probes Wtb structure; set a limit on new physics window
  - ✓ Can be extracted directly from cos θ^* or by unfolding and calculating the asymmetry.
  - ✓ *l* (e or μ) + jets channels used for this study.

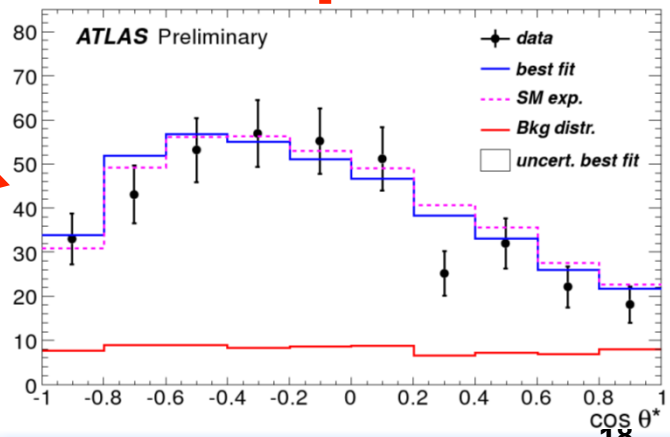
	Template method	Asymmetry method
F_L	0.41 ± 0.12	0.36 ± 0.10
F_0	0.59 ± 0.12	0.65 ± 0.15
F_R	Fixed 0	-0.01 ± 0.07

ATLAS-CONF-2011-037



Combined e/μ +jets





Summary and Outlook

- The era of top physics at the LHC has just started
  - ✓ With only 35 pb^{-1} of data
  - ✓ Competitive measurements are emerging
    - ◆ Cross section 180pb with 10% precision by combining 1,2-lepton results – uncertainty now compatible with theory error: 165 +11/-16 pb
- Anticipate ~0.6 fb^{-1} by summer and ~2 fb^{-1} by the end of year
- Soon more top quark events on tape than Tevatron
- Large number of top events enable many interesting new analysis - performing precision tests of the SM or probing for new physics.
- Atlas has already ~539 pb^{-1} of collected data (as of yesterday)

2011: the year of top measurements at LHC and may be discoveries !!

More Results are available at the top public result page

Backup

Single Lepton Analysis

1Lepton+Jets

- This analysis exploits the difference in kinematic distributions of signal and background events.
- Projective Likelihood (LH) is used:
  - ✓ by baseline analysis with and without b-tag
  - ✓ Discriminant constructed from multiple variables
  - ✓ MC signal and background models are used to select variables for building LH discriminant
  - ✓ Used as variable for binned LH fit to extract $\sigma_{t\bar{t}}$

$$D_i = \frac{\mathcal{L}_s^i}{\mathcal{L}_s^i + \mathcal{L}_b^i}$$

$$\mathcal{L}_{s(b)}^i = \prod_{k=1}^{N_{\text{var}}} p_{s(b)}(x_k^i)$$

x_k : kinematic variable

For each event i we calculat the D_i

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

Main Idea of the MV analysis and choice of input variables:

- This analysis exploits the difference in kinematic distributions of signal and background events.
- To separate signal from background, use projective likelihood method from TMVA package

① **For each event i, we calculate the likelihood discriminant D_i:**

$$D_i = \frac{L_{i,S}}{L_{i,S} + L_{i,B}}, \text{ where } L_{i,S(B)} = \prod_{j=1}^{k} p_{i,S(B)}(x_j)$$

② **Assume that the variables are uncorrelated**

- **Used only 3 variables to have a well-understood and robust analysis on the basis of:**

① Optimization of the combined expected statistical and JES errors

② 3 variables (for example, in case of pre-tag analysis):

lepton η, lepton charge and exp(-8*A) (A is aplanarity) are selected because of negligible correlations between them (up to 2 % in the worst case)

③ Use b-tagging probability as one discriminating variable(with b-tag analysis)

b-tagging Algorithms

Analyses with b-tag

- Btagging at ATLAS:
  - **2 b-tagging algorithms:**
    - ① Combines transverse impact parameters significance of tracks inside jets – JetProb (gives probability track originates from PV)
    - ② Displacement of vertex reconstructed with tracks inside jets and PV – SV0 (Used in cross-check analyses)
  - Performance and Separation
    - ① JetProb
      - Mistag rate is 5% for 70% b-tagging efficiency
    - ② SV0
      - Mistag rate is 0.4% for 50% b-tagging efficiency

Single Lepton Yield

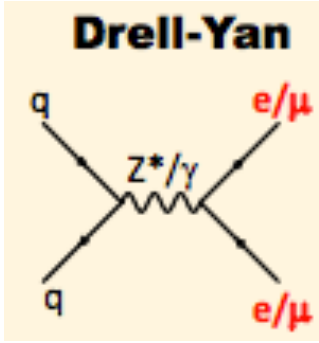
Electron Channel	1 jet	2 jets	3 jets	4 jets	≥ 5 jets
$t\bar{t}$	14.3 ± 2.9	61 ± 9	116 ± 13	111 ± 16	82 ± 12
W+jets	9000 ± 1900	2300 ± 700	580 ± 250	140 ± 90	41 ± 26
QCD multijets	290 ± 140	123 ± 62	62 ± 31	13 ± 7	8 ± 4
Single Top	36 ± 4	42 ± 5	22 ± 4	7.8 ± 1.8	3.1± 0.7
Z+jets	65 ± 14	62 ± 20	32 ± 14	12 ± 8	6 ± 4
Diboson	35.3 ± 2.8	30.1 ± 2.4	9.3 ± 1.5	2.2 ± 0.5	0.4± 1
Total Predicted	9400 ± 1900	2700 ± 800	830 ± 250	290 ± 90	141 ± 29
Data Observed	9481	2552	781	273	127

Muon Channel	1 jet	2 jets	3 jets	4 jets	≥ 5 jets
$t\bar{t}$	19 ± 4	81 ± 12	161 ± 18	158 ± 22	115 ± 16
W+jets	19000 ± 4000	4600 ± 1500	1100 ± 500	250 ± 150	70 ± 40
QCD multijets	520 ± 160	287 ± 86	121 ± 36	30 ± 10	20 ± 6
Single Top	57 ± 7	64 ± 8	32 ± 6	11.1± 2.5	4.0± 0.9
Z+jets	770 ± 160	250 ± 80	69 ± 30	19 ± 12	6 ± 4
Diboson	63 ± 5	55 ± 4	16.1 ± 2.6	3.4± 0.7	0.6± 0.1
Total Predicted	20000 ± 4000	5300 ± 1500	1500 ± 500	470 ± 160	210 ± 50
Data Observed	20583	5228	1356	448	205

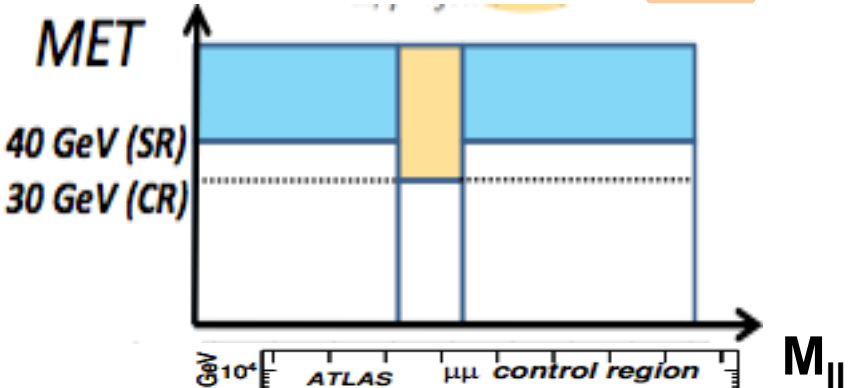
$Z^*/\gamma(\rightarrow ee/\mu\mu)$ + jet background

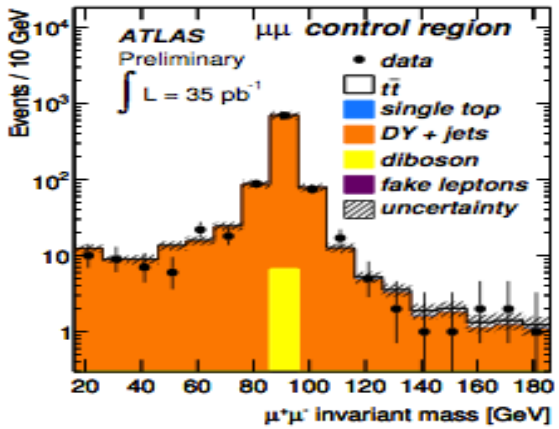
2 lepton

- 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 GeV $< |M_{ll}| <$ 101 GeV
High MET region; MET > 30 GeV
High jet multiplicity events >= 2jets

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