MEASUREMENT OF THE TOP-QUARK PAIR PRODUCTION CROSS-SECTION IN ATLAS

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On behalf of the ATLAS Collaboration

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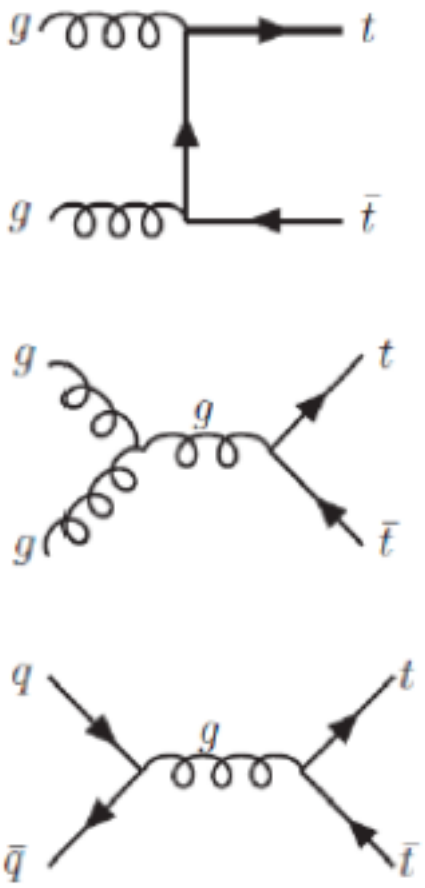
TOP QUARK PAIR PRODUCTION @ LHC

- The top pair production: QCD process, dominated at LHC by gg fusion.
- Theory NNLO (approx) for a m_{top} = 172.5 GeV:

$$\sigma_{t\bar{t}} = 164.6^{+11.4}_{-15.7}\ \text{pb}$$ @ √s=7 TeV

- More than 20 x Tevatron cross section



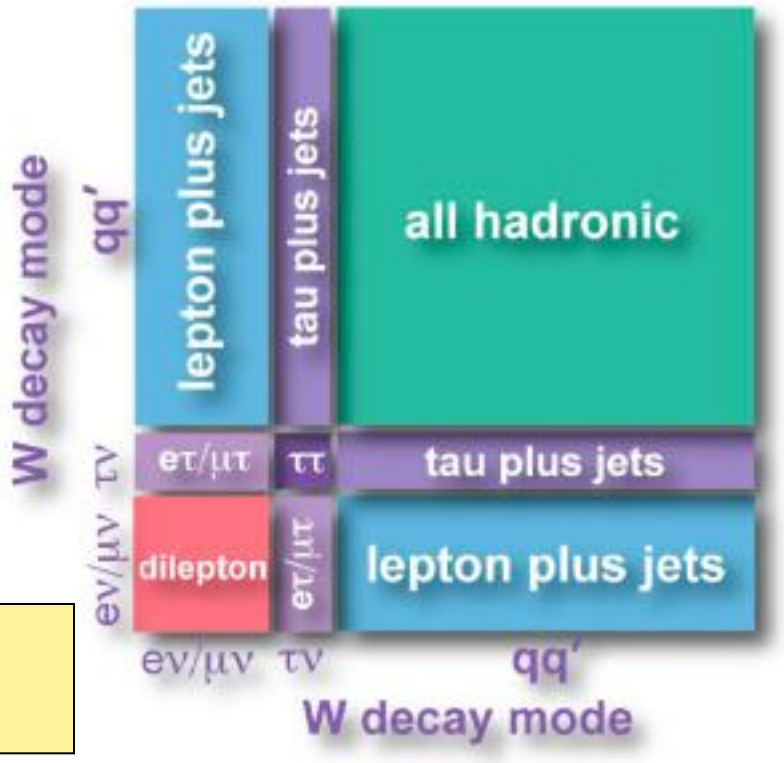
Why measure the top pair production cross section in the various decay channels?

- Test of perturbative QCD and of the 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

TOP PAIR EVENT TOPOLOGIES

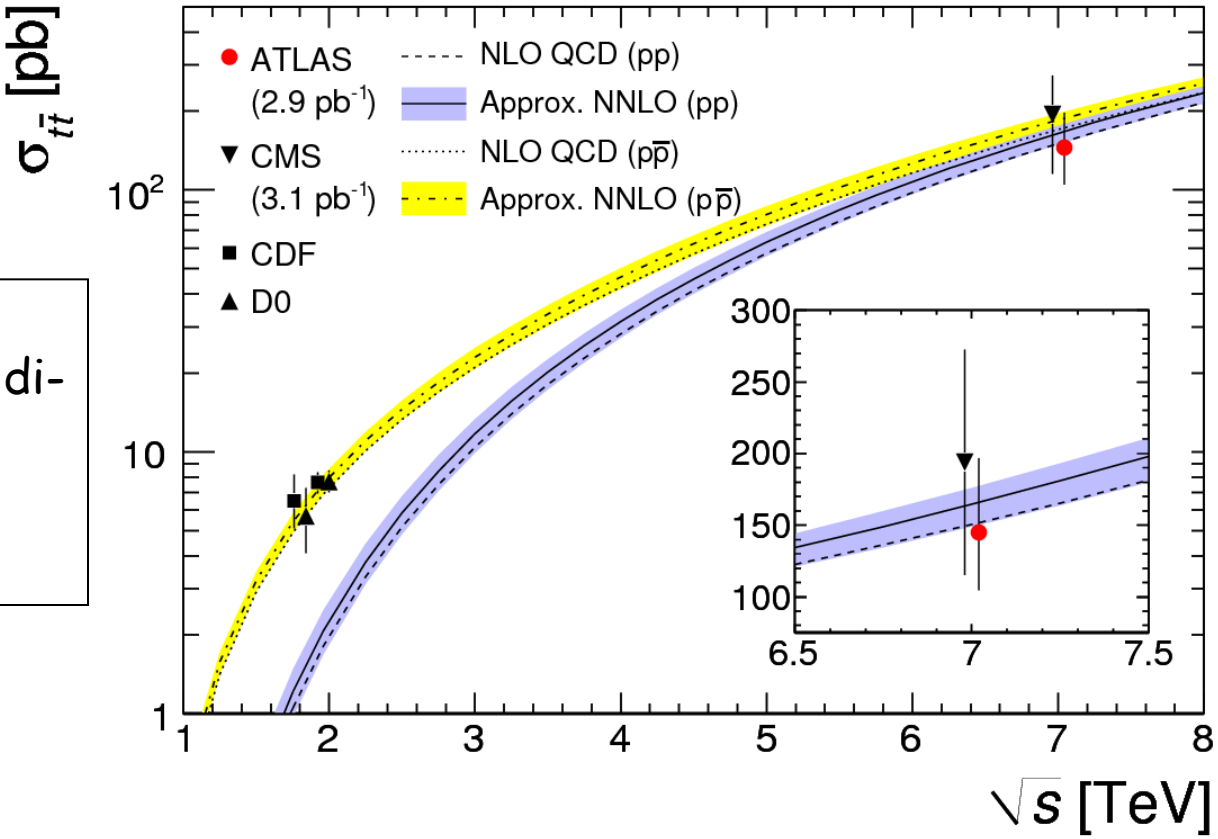
- SM: BR(t → W b) ~1
- Final states determined by W decays W → qqbar (2/3), W → ℓν(1/3):
  - All hadronic: 45% of all decays, large QCD background
  - Lepton (e,μ)+jets: 30% of all decays, moderate background
  - Dilepton (ee,μμ, eμ): 5% of all decays, very clean
- Main backgrounds for leptonic channels:
  - W/Z boson+jets (similar signature)
  - QCD jets (misidentified as leptons)

Challenging signature: multiple leptons and jets, missing E_T



FIRST TOP PAIR CROSS SECTION MEASUREMENT IN ATLAS WITH $3pb^{-1}$

- ATLAS: single and di-lepton
- CMS: di-lepton



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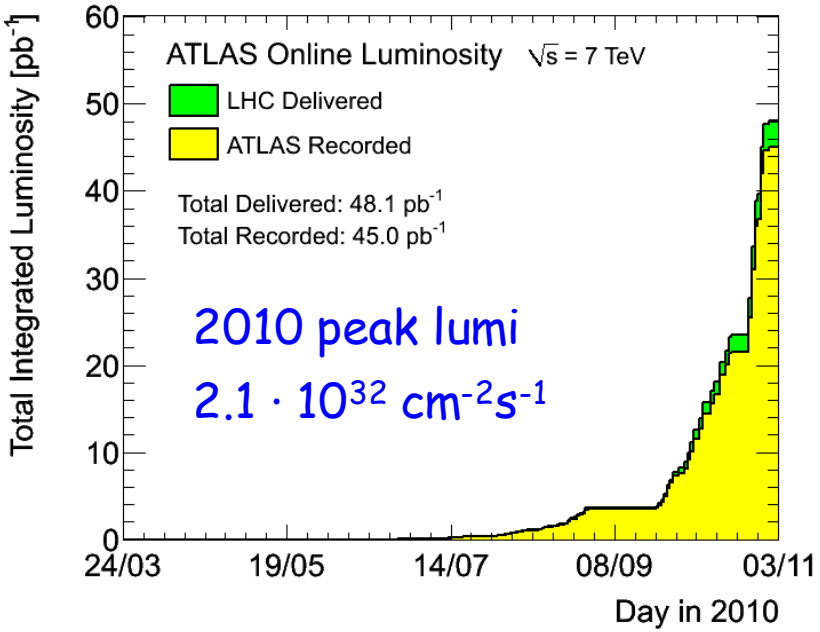
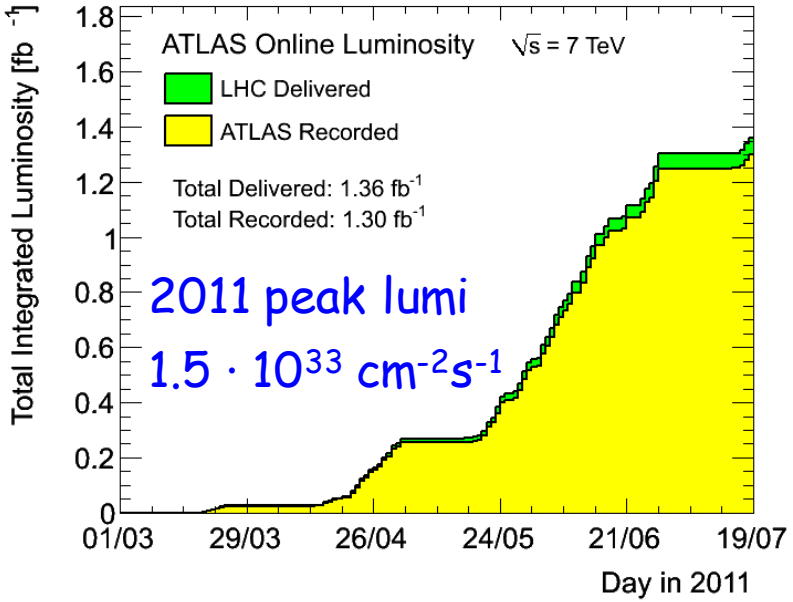
$$\sigma_{t\bar{t}} = 145 \pm 31 \,^{+42}_{-27}\ \text{pb}$$

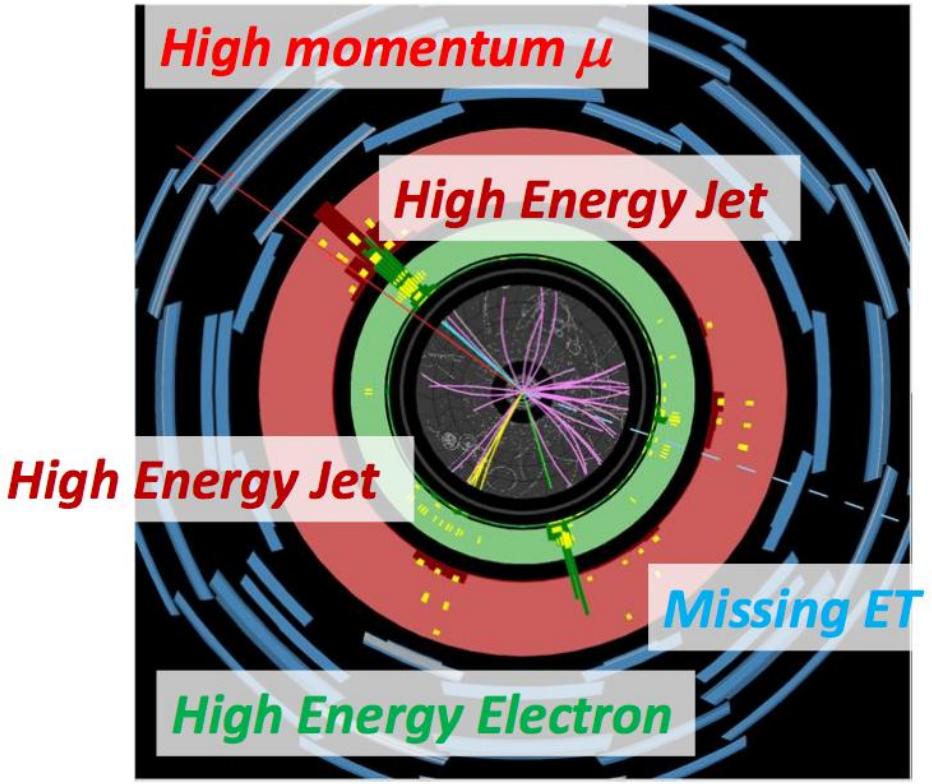
DATA SAMPLE

- Thanks to the excellent operation of the LHC and the high ATLAS data taking efficiency.
- Analyses performed:
  - 2010 data: 35 pb^{-1}
    - All Hadronic channel
    - Lepton (e,μ)+jets
    - Dilepton (ee, μμ, eμ)
  - 2011 partial data: 0.70 fb^{-1}
    - Dilepton (ee, μμ, eμ)
  - Combination:
    - Dilepton (0.70 fb^{-1}) and single-lepton (35 pb^{-1})





DILEPTON CHANNEL ANALYSES (BASED ON 0.70 fb^{-1} OF 2011 DATA)



DILEPTON EVENT SELECTION

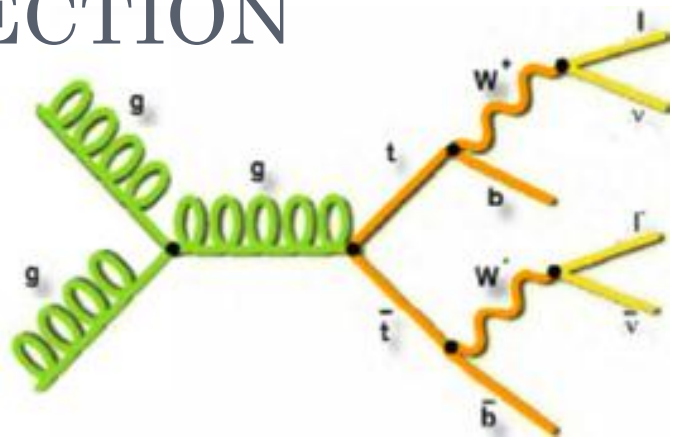
STRATEGY:

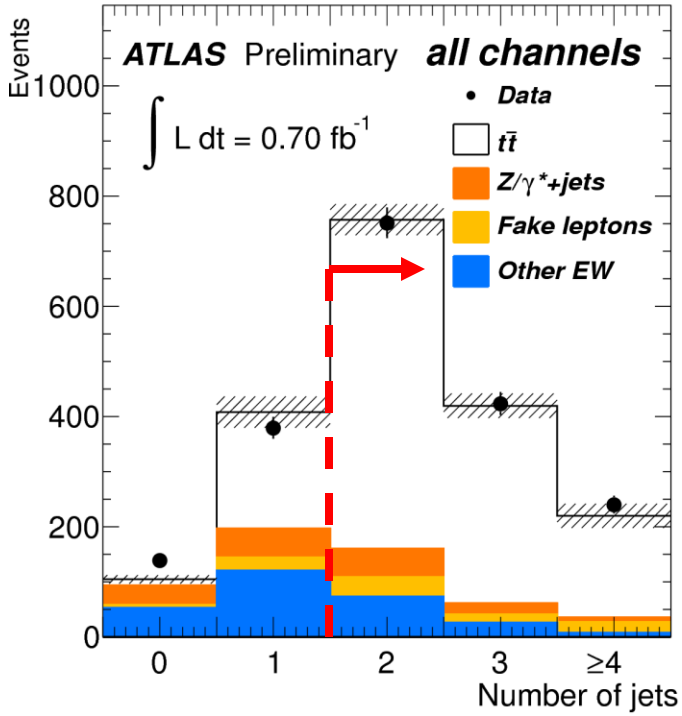
- Cross section estimated by counting number of signal events
- 2 complementary analyses: with and without b-tagging

EVENT SELECTION

Cuts were optimized for the 2 analyses: with and without b-tagging

- Single lepton (e or μ) trigger
- Exactly 2 oppositely charged leptons (ee. $\mu\mu$, eμ) with p_T > 20 GeV (μ), E_T>25 GeV (e) and at least one matched trigger
- Dilepton mass $m_{\ell\ell}$ > 15 GeV
- E_T^{miss} > 60 (40) GeV and $|m_{\ell\ell}-m_Z|$>10 GeV (ee, $\mu\mu$ channel)
- H_T(sum of jets and 2 leptons p_T) > 130 (140) GeV (eμ channel)
- ≥2 jets with p_T> 25 GeV and $|\eta|$<2.5
- ≥1 b-tagged jets with IP3DSV1 algorithm @ 80% efficiency.



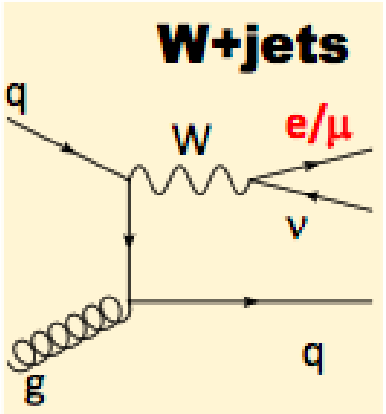


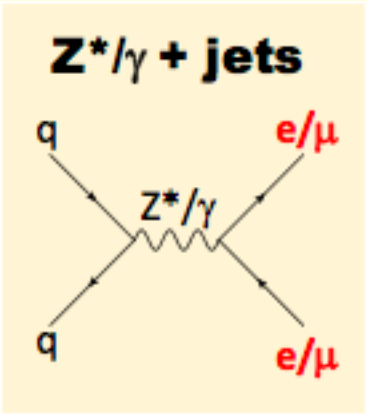
$$\sigma(t\bar{t}) = \frac{N_{sig}}{\int L\,dt \times \epsilon} = \frac{N_{obs} - N_{bkg}}{\int L\,dt \times \epsilon}$$

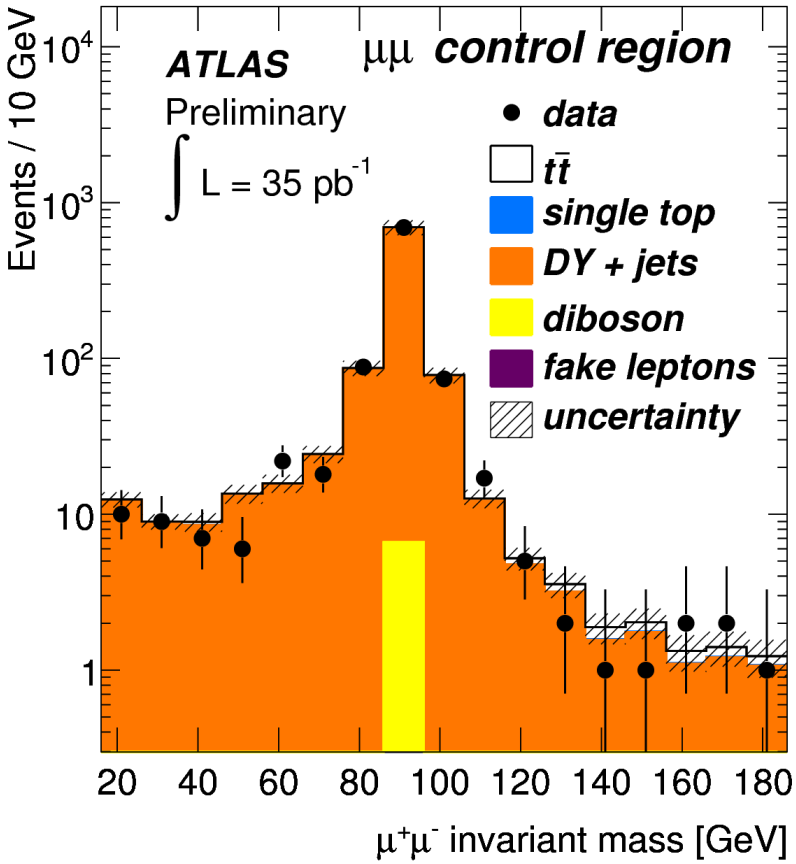
DILEPTON BACKGROUND ESTIMATION

BACKGROUND:

- $Z/\gamma^*(\rightarrow ee,\mu\mu)$+jets (data driven, assisted by MC)
- Events with fake leptons coming e.g. from W+jets, ttbar lepton+jets, single top and QCD (data driven)
- Other SM backgrounds: Single top, diboson, $Z/\gamma^*(\rightarrow\tau\tau)$+jets: from MC normalized using theoretical cross section







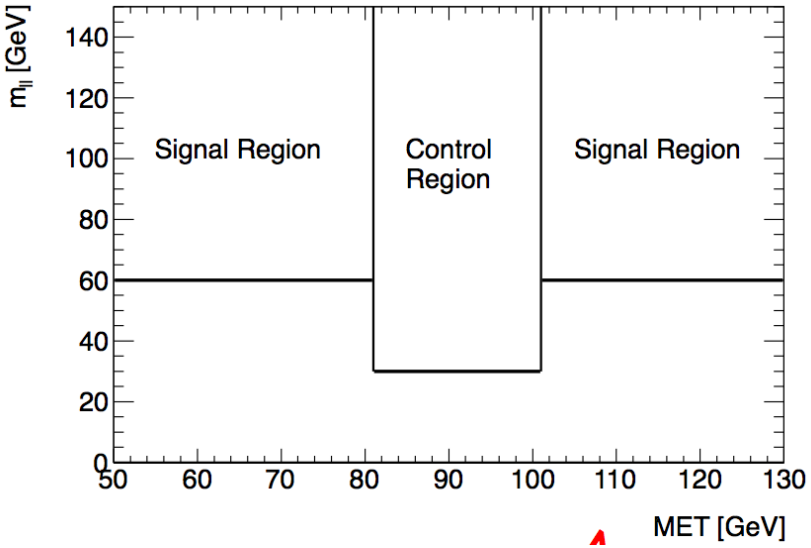
Z/γ*(→ee,μμ)+jets BACKGROUND DATA DRIVEN ESTIMATE

- Measure # Z/γ*+jets events in a sideband region where the fraction of Z/γ*+jets is ~90%.
- Extrapolate it to the signal region.

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

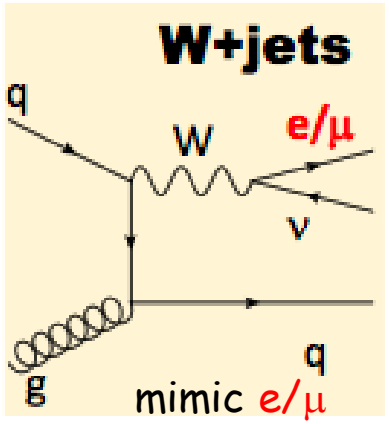
Control Region:

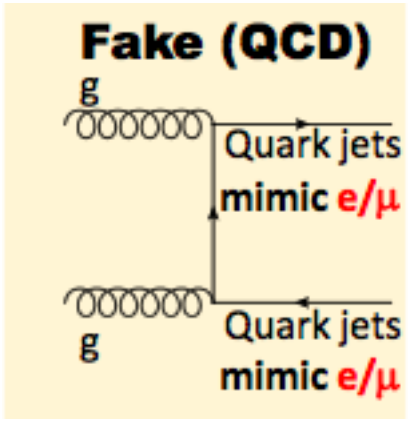
- same jet requirements as signal
- $|m_{\ell\ell}-m_Z| \leq 10$ GeV
- $E_T^{miss}>30$GeV



FAKE LEPTONS BACKGROUND DATA DRIVEN ESTIMATE

- Fake background comes e.g. from:
  - W+jets: 1 real, 1 fake lepton
  - QCD multi-jet: 2 fake leptons

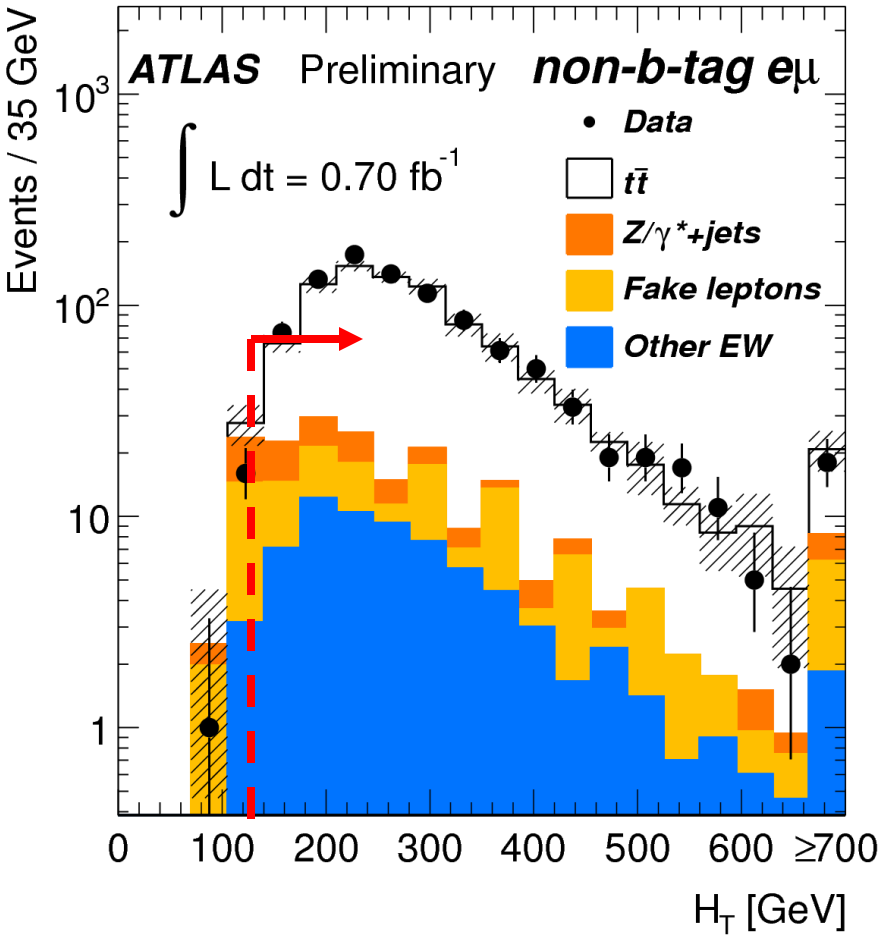


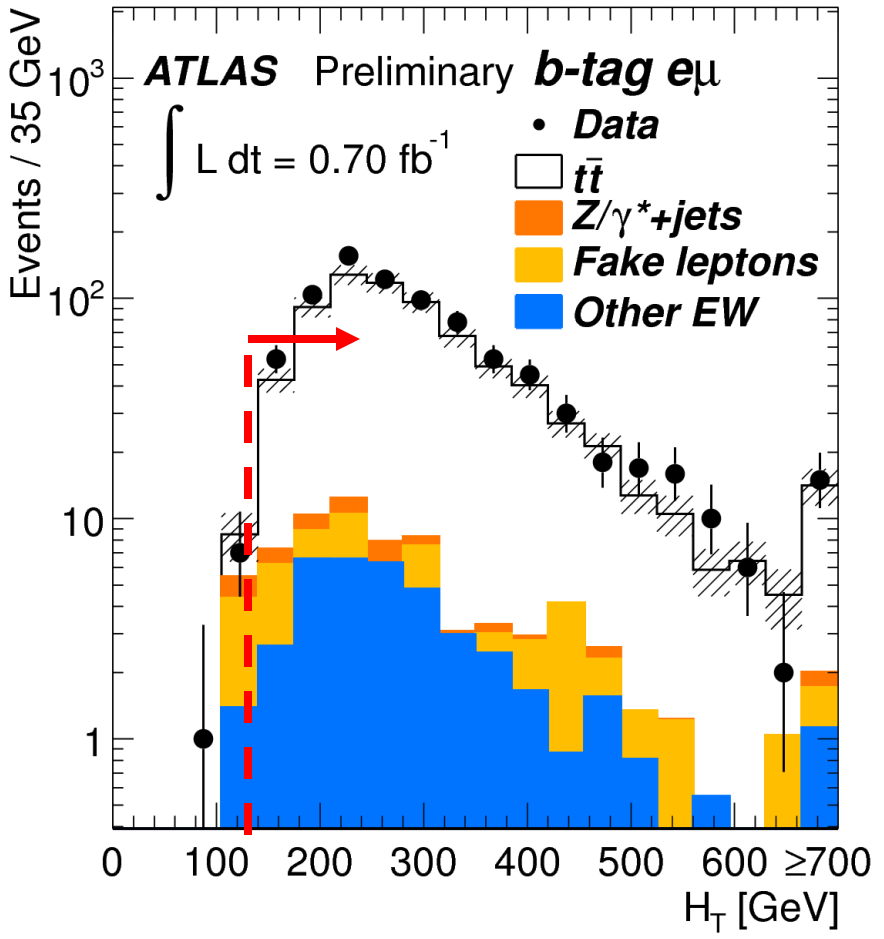


- Matrix method:
  - 2 lepton selection criteria: loose L and tight T
  - Count number of observed dilepton events with N_{TT}, N_{LL}, N_{TL}, N_{LT}
  - Efficiency for prompt (real r) and non-prompt (fake f) leptons are measured in in $Z \to \ell\ell$ and di-jet events.
  - Extract N_{RR}, N_{FF},N_{RF},N_{FR}.

$$\begin{bmatrix} N_{TT} \\ N_{TL} \\ N_{LT} \\ N_{LL} \end{bmatrix} = \begin{bmatrix} rr & rf & fr & ff \\ r(1-r) & r(1-f) & f(1-r) & f(1-f) \\ (1-r)r & (1-r)f & (1-f)r & (1-f)f \\ (1-r)(1-r) & (1-r)(1-f) & (1-f)(1-r) & (1-f)(1-f) \end{bmatrix} \begin{bmatrix} N_{RR} \\ N_{RF} \\ N_{FR} \\ N_{FF} \end{bmatrix}$$

H_T DISTRIBUTION IN THE SIGNAL REGION





DILEPTON CHANNEL SYSTEMATICS

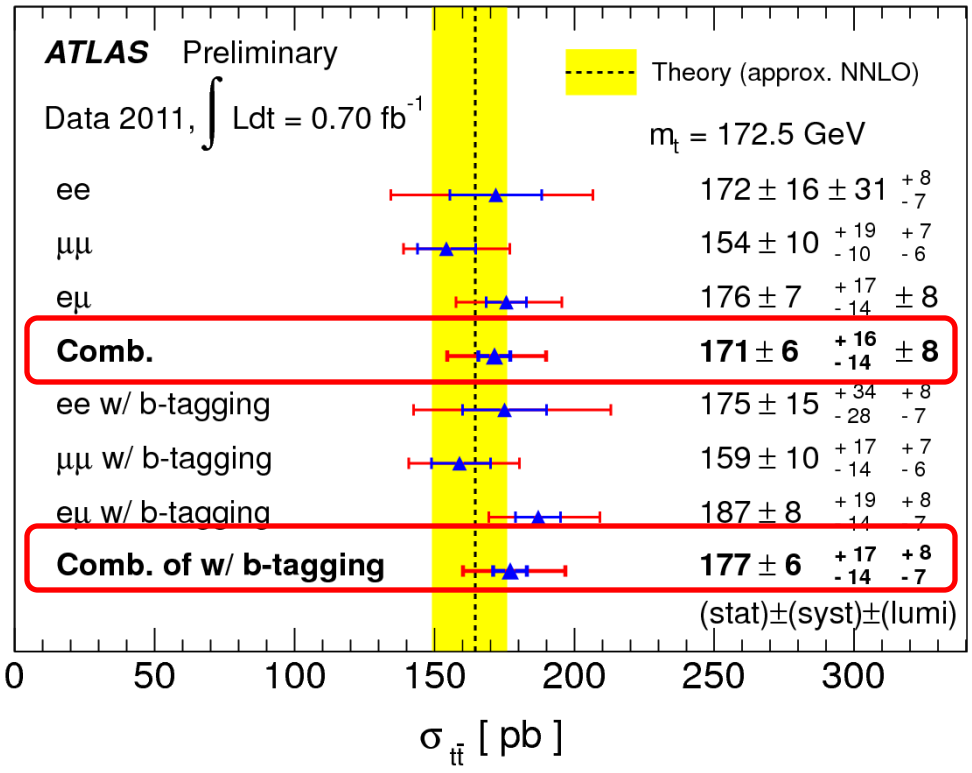
Analysis without b-tagging: systematics breakdown

	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 indent. 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
$E_{\mathrm{T}}^{\mathrm{miss}}$ 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

DILEPTON CHANNEL RESULTS

- The 2 complementary measurements are in agreement with each other.
- Dominated by systematics, dominant sources: luminosity, jet energy scale, for b-tagging analyses also b-tagging efficiency.
- The precision achieved (~11%) is significantly better than the previous measurement based on 2010 data (~17%)
- Consistent with state-of-the-art theory prediction and measurement in lepton+jets channel.

0.70 fb^{-1} 2011 data: ~ 11% precision



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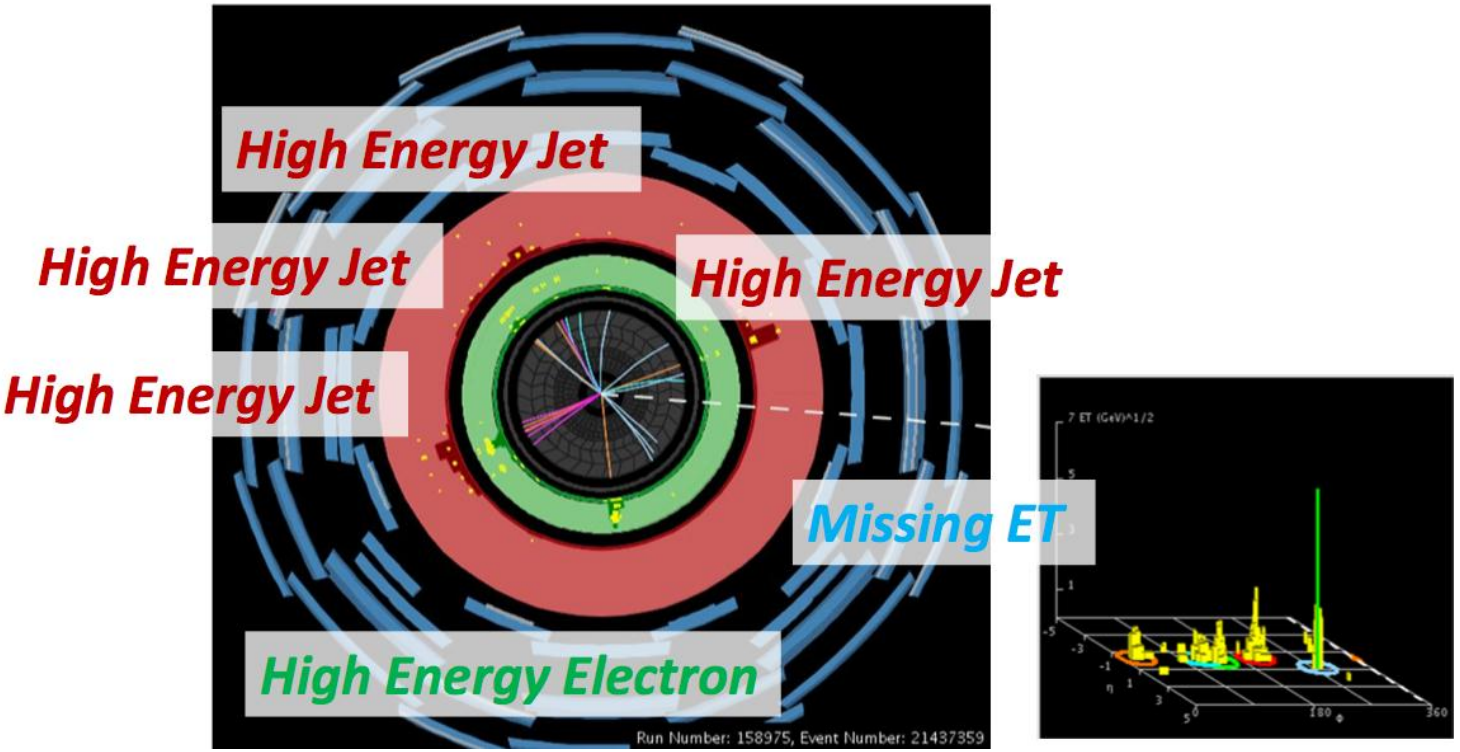
LEPTON+JETS CHANNEL ANALYSIS (BASED ON 35 pb^{-1} FULL 2010 DATA)

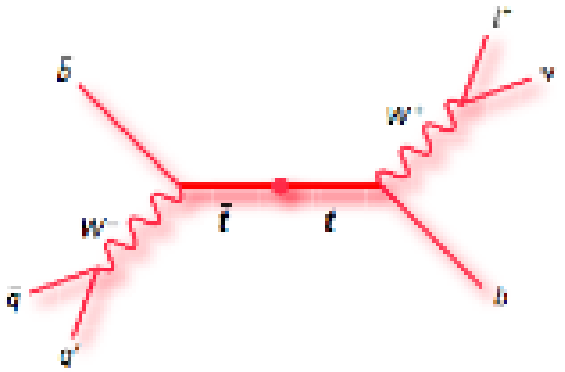


SELECTION AND BACKGROUND ESTIMATE

STRATEGY: Template fit to a LH discriminant

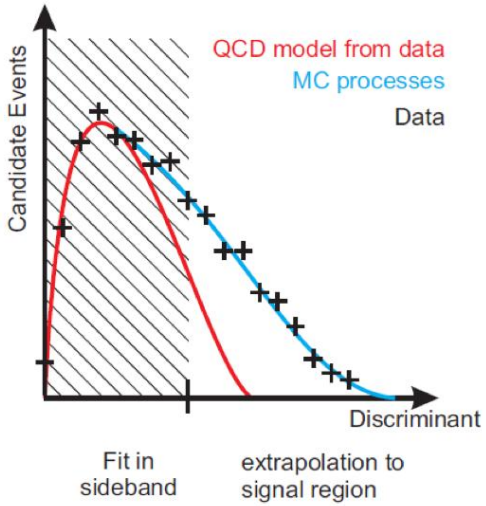
EVENT SELECTION

- Single lepton (e or μ) trigger
- Exactly 1 lepton (e or μ) with p_T > 20 GeV matched to trigger
- E_T^{miss} > 20 GeV, $E_T^{miss}+m_T(W)$ > 60 GeV (muon channel)
- E_T^{miss} > 35 GeV, $m_T(W)$ > 25 GeV (electron channel)
- ≥3 jets with p_T> 25 GeV and $|\eta|$<2.5



BACKGROUND ESTIMATION:

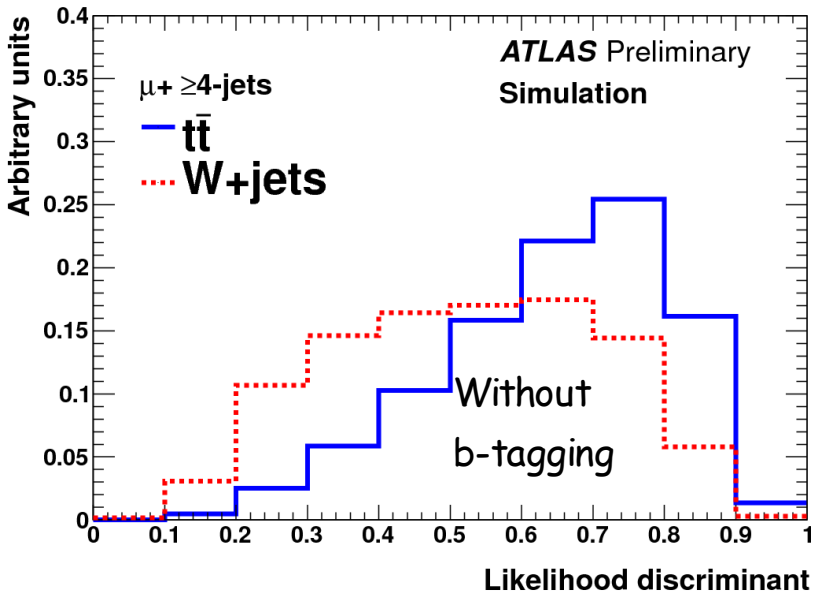
- W+jets: shape determined from MC, normalization from fit
- QCD multi-jet (due to non-prompt (fake) leptons): Estimated from data.
  - Muon channel: Matrix method
  - Electron channel: Likelihood template fit of E_T^{miss} distribution
- Small backgrounds (Z+jets, diboson, single top): shape from MC, normalization from theoretical calculation.



LEPTON+JETS ANALYSIS STRATEGY

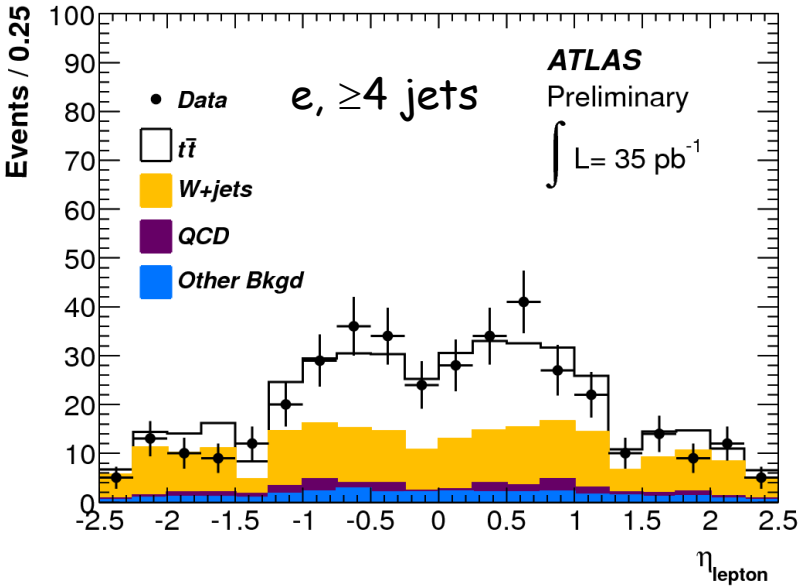
Baseline analyses: Multivariate measurement

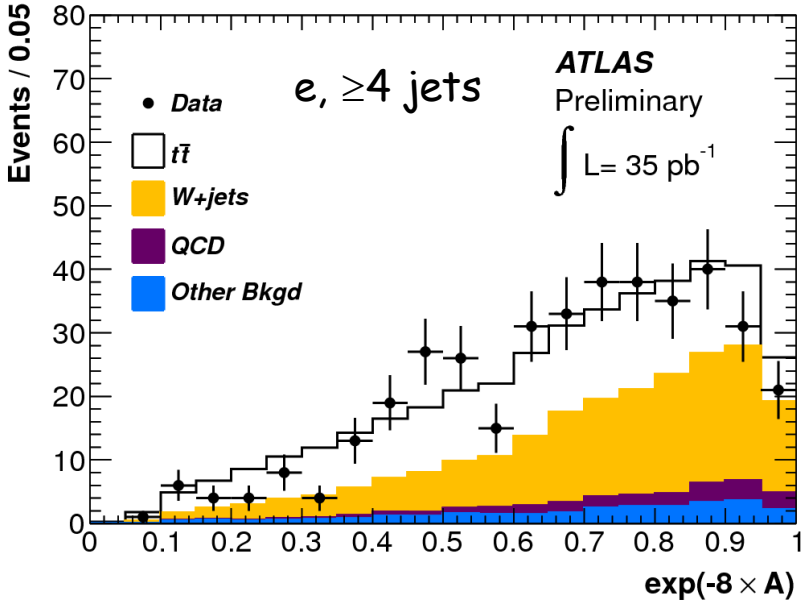
- Exploiting the difference between signal and W+jets dominant background
- A likelihood discriminant is built from well modeled event kinematic variables
- Cross section extracted from a binned likelihood fit of the discriminant to a weighted sum of signal and background templates
- 2 analyses: with and without b-tagging information

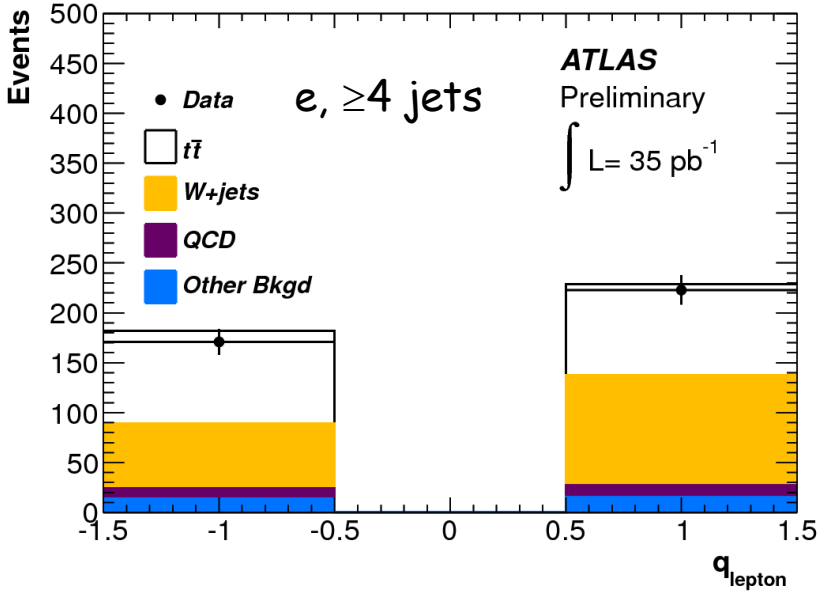


LEPTON+JETS WITHOUT B-TAGGING

- The following input variables were used:
  - Lepton η: ttbar more central
  - Lepton charge: ttbar symmetric, W+jets asymmetric
  - Aplanarity: ttbar more isotropic
- 4 channel fit: e, μ + 3 jets, ≥4 jets





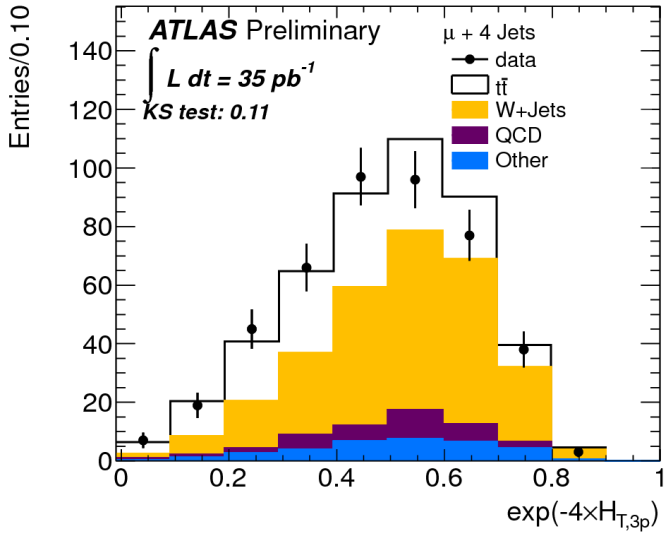


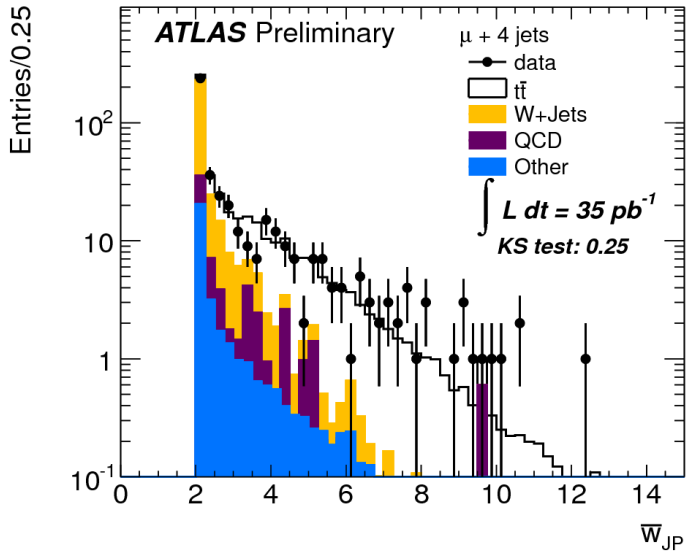
LEPTON+JETS WITH B-TAGGING

- The following input variables were used:
  - Lepton η: ttbar more central
  - Aplanarity: ttbar more isotropic
  - New variable: $H_{T,3p}$

$$H_{T,3p} = \sum_{i=3}^{N_{\text{njets}}} |p_{\text{T},i}^2| / \sum_{j=1}^{N_{\text{objects}}} |p_{z,j}|$$

  - New variable: Average b-tagging weight for the two most b-like jets
- 6 channel fit: e, μ + 3, 4, $\geq$5 jets using profile likelihood technique: systematic uncertainties included as nuisance parameters $\rightarrow$ constraint by data





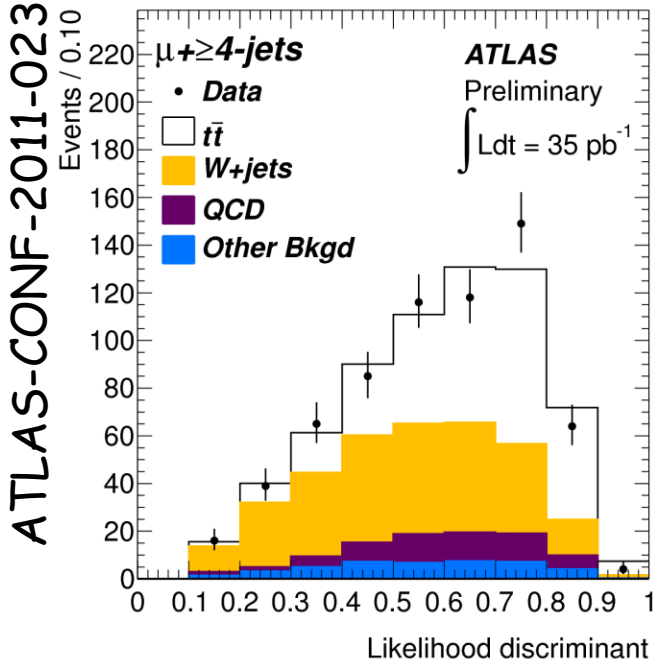
LEPTON+JETS ANALYSES RESULTS

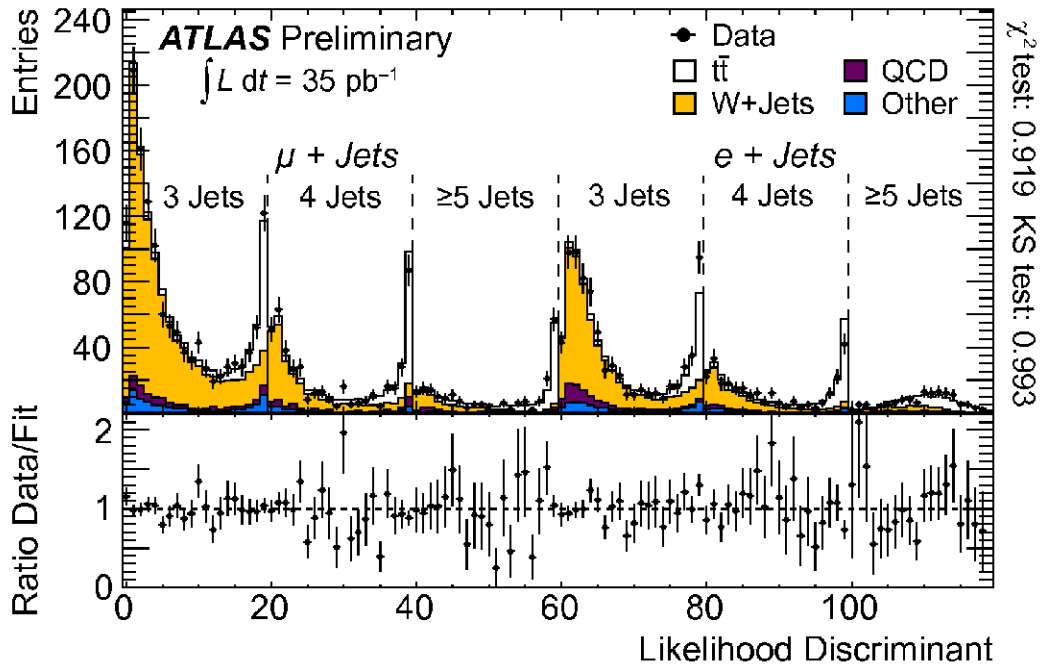
Without b-tagging: ~15% precision

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

With b-tagging: ~13% precision

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



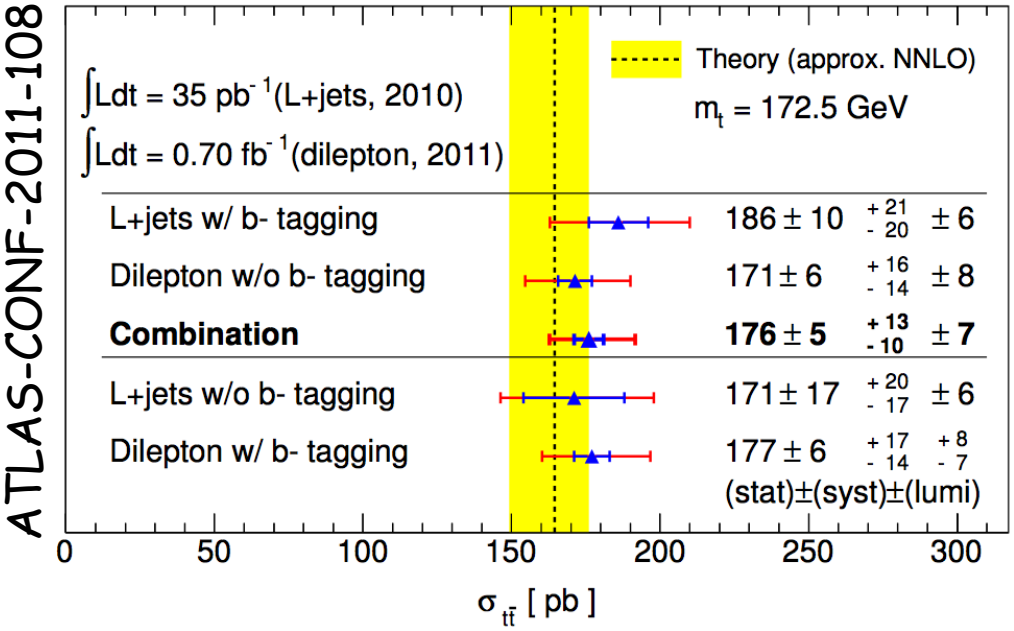


- Based on 2010 data and already dominated by systematics, dominant sources:
  - jet energy scale & resolution, ISR/FSR
  - for b-tagged analyses, also: b-tagging calibration, W+jets heavy flavour content
- Consistent with state-of-the-art theory prediction
- Consistent with various cross checks analyses (cut-and-count, 1-dim variable fit, hadronic top mass fits) performed and with the di-lepton channel.

COMBINATION
DILETON 0.70 fb^{-1} FROM 2011 DATA
□
LEPTON+JETS 35 pb^{-1} 2010 DATA

COMBINATION LEPTON+JETS & DILEPTON

- The most precise methods chosen for the combination:
  - Lepton+jets with b-tagging (e+jets,μ+jets) based on 35 pb^{-1}
  - Dilepton without b-tagging (ee, μμ, eμ) based on 0.70 fb^{-1}
- 5- channel combination done using a profile likelihood fit



Uncertainty source	Uncertainty (pb)
Heavy flavor	4.1
Jet energy scale	3.9
Fake lepton estimate	3.2
Initial and final state radiation	3.0
b-tagging	2.8
Event generator	2.3
Electron efficiency	2.0
Muon efficiency	1.5
W Shape	0.5
QCD Shape	0.4
All others	5.1

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

HADRONIC CHANNEL ANALYSES (BASED ON 35 pb^{-1} FULL 2010 DATA)

HADRONIC CHANNEL

- Measure cross section in all possible channels constitutes an important cross check
- Signature: ≥6 jets, 2 b-tagged
- Very challenging channel:
  - QCD overwhelming: S:B ~1:15
  - Main systematics: b-tagging, jet energy scale
- Construct mass χ^2 discriminant:

$$\chi^2 = \sum_{i=1}^{2} \left(\frac{m^i_{jjb} - m_t}{\sigma_t} \right)^2 + \left(\frac{m^i_{jj} - m_W}{\sigma_W} \right)^2$$

- Select the combination with lowest $\chi 2$

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

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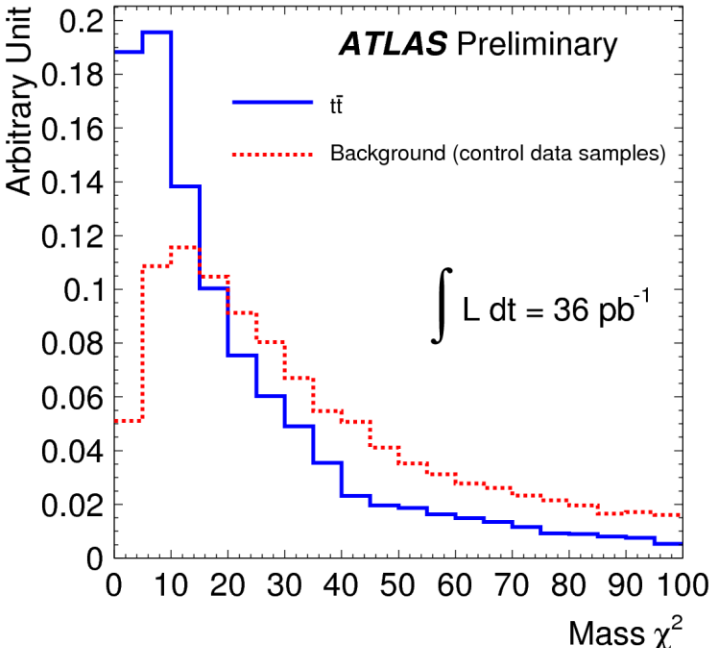
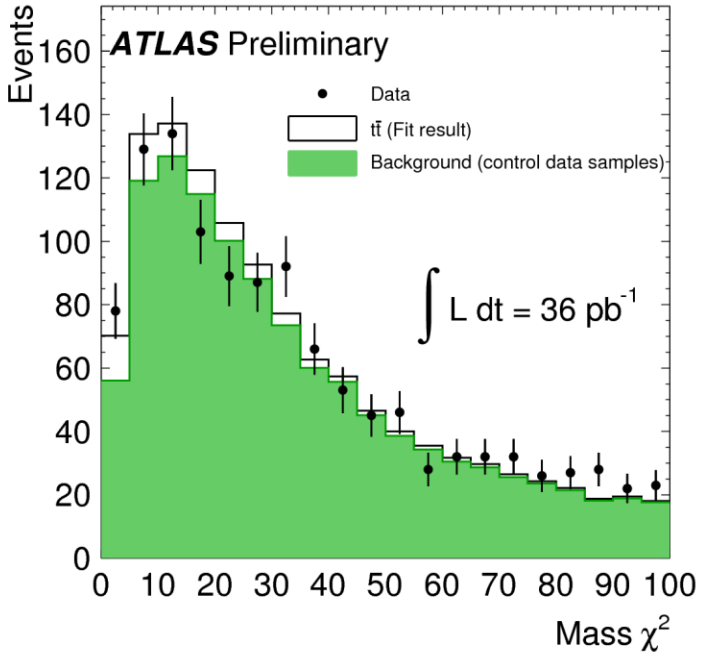
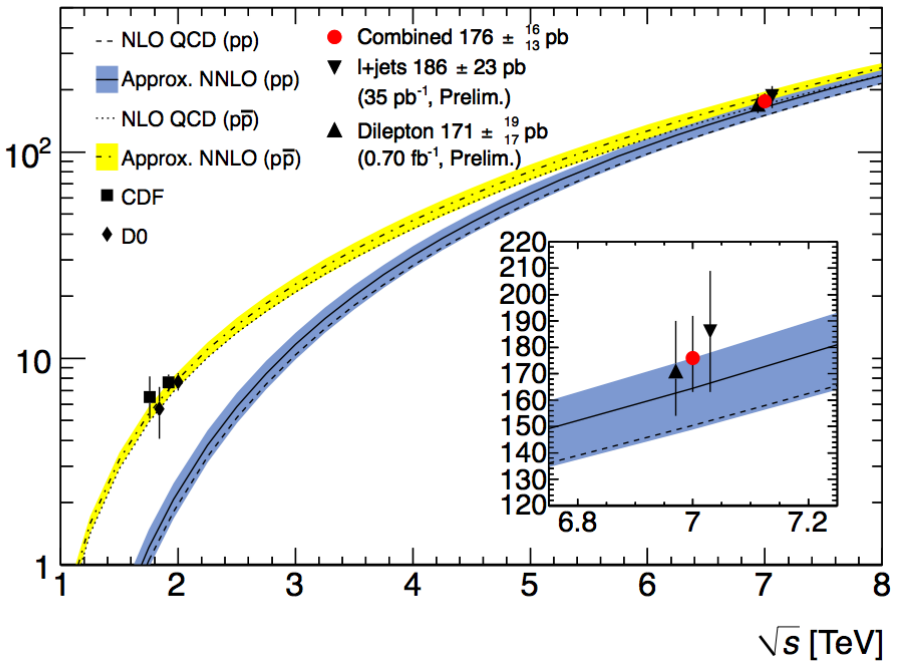




SUMMARY AND CONCLUSIONS

- 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^{-1} lepton+jets channel with 0.70 fb^{-1} dilepton channel.
- Results consistent with theoretical QCD predictions and with CMS results.
- Important to focus future work in improving systematic uncertainties



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

- A search of top pair production in the all hadronic channel has also been performed, observed upper limit in agreement with measurement.
- Other analyses coming along: hadronic tau channel, ttbar+jets and differential cross section measurements.