Top cross section

L. Bellagamba, G. Bruni, R. Di Sipio, M. Corradi M. Romano(1)

G. Gagliardi, B. Osculati-Becchi(2)

A. Andreazza, **M. I. Besana**, A. Favareto, T. Lari, V. Lombardo*, F. Meloni, C. Troncon(3)

M. Cobal, B. Acharya, M. Pinamonti, K. Suruliz, R. Soualah, K. Shaw, U. De Sanctis(4)

(1) Bologna, (2) Genova, (3) Milano, (4) Udine e ICTP Trieste
* Moved to Annecy laboratory

Summary

- Introduction
  - analysis description
  - people involved and covered tasks
- Results obtained on 2010 data
  - results for Moriond conferences
- Conclusions and future plans

Publication list

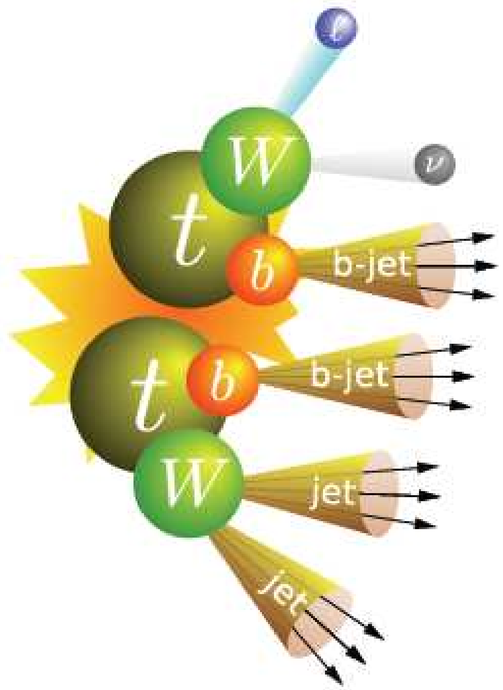
- Summer conference notes 2010:
  - *Search for top pair candidate events in ATLAS at √ s=7 TeV* (ATLAS-CONF-2010-063).
  - *Expected event distributions for early top pair candidates in ATLAS at √s=7 TeV* (ATLAS-PHYS-PUB-2010-012).
  - *Background studies for top pair production in lepton plus jets final states in sqrt(s)=7 TeV ATLAS data* (ATLAS-CONF-2010-087).
- Top paper: EPJC 71 (2011) 1577,
  - *Estimation of the W+Jets Background for Top Quark Re-Discovery in the Single Lepton+Jets Channel* (ATL-COM-PHYS-2010-834),
  - *Mis-identified lepton backgrounds to top quark pair production: Supporting note 5* (ATL-COM-PHYS-2010-849).
  - *Observation of top quark pair production in the semileptonic decay channel at sqrt(s) = 7 TeV with the ATLAS detector* (ATL-COM-PHYS-2010-855)
- Moriond 2011 conference:
  - *Top Quark Pair Production Cross-section Measurement in ATLAS in the Single Lepton+Jets Channel without b-tagging* (ATLAS-CONF-2011-023)
  - *Measurement of the top quark pair cross-section with ATLAS in pp collisions at √s = 7 TeV in the single-lepton channel using b-tagging* (ATLAS-CONF-2011-035)
  - *A combined measurement of the top quark pair production cross-section using dilepton and single-lepton final states* (ATLAS-CONF-2011-040)
  - *Cut-and-count measurement of the top quark pair production in the semileptonic decay channel at sqrt(s)=7 TeV with the ATLAS detector* (ATL-COM-PHYS-2011-122)

Introduction

The analysis I

- The aim of the Italian group analysis is the measurement of top quark pair production cross section.

- The analysis is performed in the single lepton channel, events are characterized by:
  - 1 electron or 1 muon,
  - missing transverse energy,
  - at least 4 jets, 2 of them are b-jets



The analysis II

- Simple cut count method used:

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

  - N_{obs} = number of observed events in data
  - N_{back} = expected number of background events
  - L = integrated luminosity
  - ε = signal selection efficiency, including BR, acceptance, trigger and cuts

- Most powerful analysis technique with low statistics
  - it enjoys lower statistical error with respect to fit methods
  - limited number of systematics affecting the measurement

Analysis needs

- Selection of signal candidates in data:
  - general task within top group
- Systematics coming from the selection:
  - input from Top Reconstruction group, contribution from **GENOVA** for b-tagging (see F. Parodi's talk)
- Background estimation, data-driven methods for the most important backgrounds:
  - W+ jets: Berends scaling method **MILANO** and **BONN**
  - W+ jets: W to Z ratio **MILANO** and **BONN**
  - W+ jets: Charge asymmetry **UDINE**
  - QCD: some work done in Udine and Milano, final estimation from **DESY** (e-channel) **IFAE** and **GOTTINGEN** (μ-channel)
- Signal acceptance: **UDINE**
- Single channel cross section measurement: **UDINE**
- Combination of electron and muon channel: **BOLOGNA**

Work organization

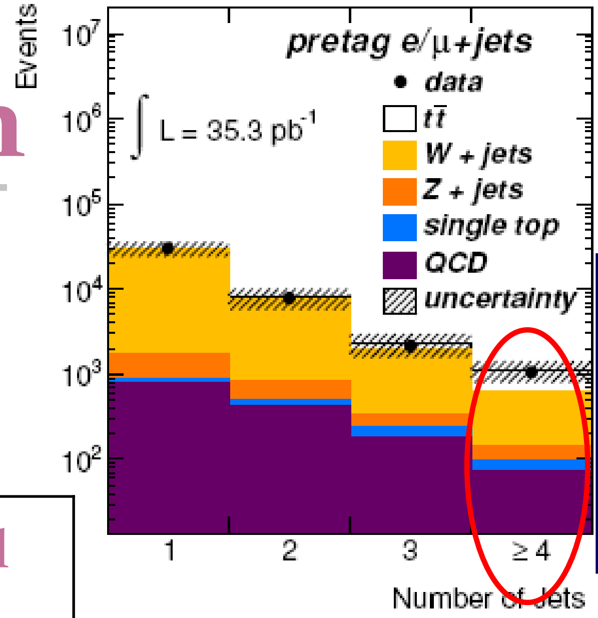
- Good collaboration between Italian groups:
  - all tasks (except QCD) covered by Italian groups
  - weekly meetings
- Bi-weekly ATLAS meeting dedicated to this analysis chaired by Tommaso Lari (Milano) and Kerim Suruliz (Udine).

Results obtained with 2010 data: integrated luminosity of 35.3 pb^{-1}

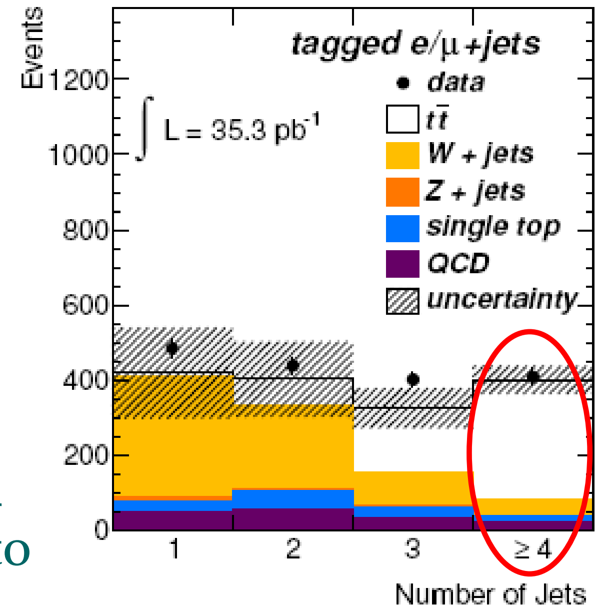
Event selection

- The analysis has been done selecting events **with** and without b-tagging request

Electron channel:	Muon channel
1 isolated e with p_T > 20 GeV	1 isolated μ with p_T > 20 GeV
E_T^{miss} > 35 GeV	E_T^{miss} > 20 GeV and
$m_T(W)$>25 GeV	$m_T(W) + E_T^{miss}$ >60 GeV
≥4 jets with p_T>25 GeV	≥4 jets with p_T>25 GeV
+ 1 tagged as a b-jet	**+ 1 tagged as a b-jet**



- tT, single top (MC@NLO)
- W (Alpgen),
- QCD (data) see later



The use of b-tagging increase S/B ratio from ~1 to ~4 in e-channel and from 0.6 to ~3 in μ-channel. Price to pay: systematic uncertainty on b-tagging.

W+jets estimate I

3 methods for the estimate WITHOUT b-tagging request:

- **W to Z ratio method:**
  - basic observation: uncertainty on W to Z ratio is significantly lower with respect to W+ ≥ 4jets MC uncertainty,
  - best performance for Moriond analysis

$$N_{W+\geq 4\,jets} = C_{MC} \cdot \frac{N_{Z+\geq 4\,jets}}{N_{Z+1\,jet}} \cdot N_{W+1\,jet}$$

- **Berends scaling method:**
  - based on the observation that ratio of W+(n+1)jets to W+njets is expected to be constant as a function of n (Berends scaling),
  - it has been used for W+jets estimation in the analysis with 2.9 pb^{-1}: lower statistical error (~5%), but higher systematic uncertainty: ~20%.

$$N_{W+\geq 4\,jets} = \sum_{i\geq 2}\left(\left(\frac{N_{W+2\,jets}}{N_{W+1\,jet}}\right)^{i} \cdot N_{W+2\,jet}\right)$$

- **Charge asymmetry method:**
  - based on the observation that W production at the LHC is charge asymmetric and that $r = W^+/W^-$ is better predicted by Monte Carlo simulation than the total W contribution,
  - very powerful with higher luminosity: low systematic error (<10%), but high statistical uncertainty: ~28%,

$$N_{W+\geq 4\,jets} = \left(\frac{r+1}{r-1}\right)_{MC} \cdot (N^{+} - N^{-})$$

W+jets estimate II

- W to Z ratio method: best performance and used as default. The other methods have been used as cross-checks

$$N_{W+\geq 4\,jets} = C_{MC} \cdot \frac{N_{Z+\geq 4\,jets}}{N_{Z+1\,jet}} \cdot N_{W+1\,jet}$$

$$C_{MC} = \left(\frac{N_{Z+1\,jet}}{N_{Z+\geq 4\,jets}} \cdot \frac{N_{W+\geq 4\,jets}}{N_{W+1\,jet}} \right)_{MC}$$

Channel	**Electron**	**Muon**
Estimated $W \to l\nu$	150.7	290.6
Estimated $W \to \tau\nu$	6	19
Statistical uncertainty	21%	17%
Purity of control samples	3%	2%
Theoretical uncertainties	12%	9.4%
Jet energy scale	3%	3%
PDFs	3.2%	3.2%
Total W+jets background	156.7 ± 38.1	309.6 ± 61.1

W+jets estimate III

- Estimate **with b-tagging** request: $N^{tagged}_{W+\geq 4\ jets} = f_{b-tagged} \cdot N^{pre-tag}_{W+\geq 4\ jets}$

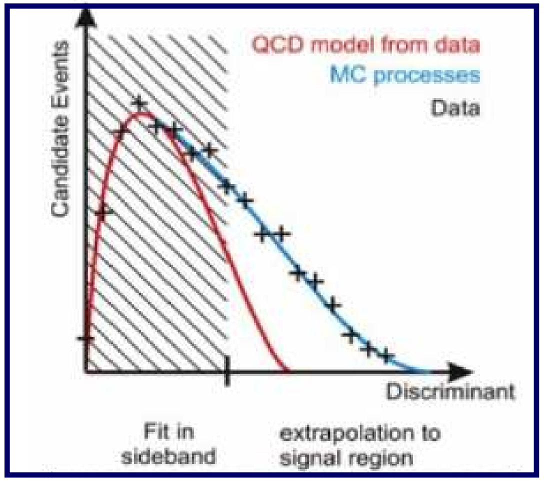
$f_{b\text{-tagged}}$ is the fraction of W events that passes b-tagging request, obtained by:

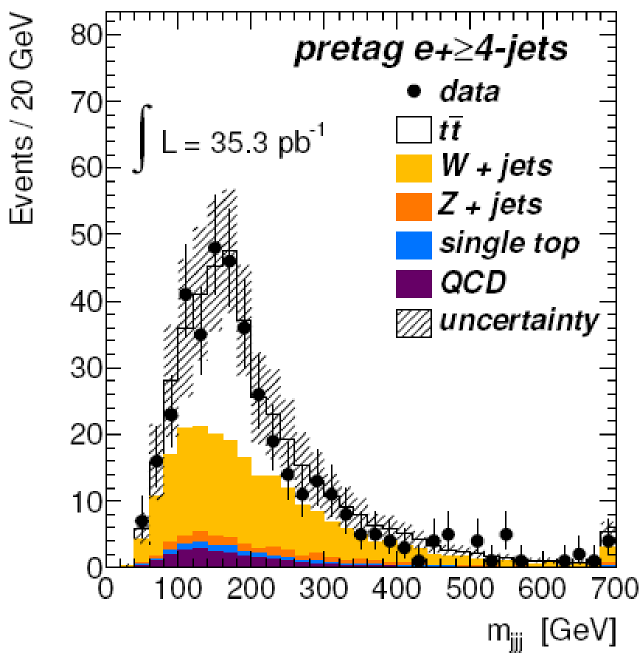
- measuring the tag fraction in 2 jets sample (no significant tT contamination):
  - 0.028 ± 0.005 (stat) ± 0.004 (syst) e channel
  - 0.040 ± 0.004 (stat) ± 0.003 (syst) μ channel
- use Monte Carlo for extrapolation from 2 jets bin to 4 jets bin
  - 2.8 ± 0.8 (syst) e channel
  - 3.2 ± 0.9 (syst) μ channel

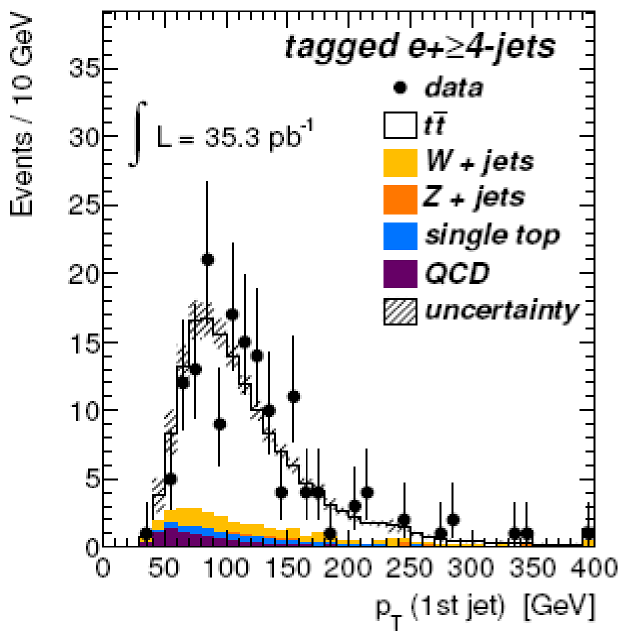
- Final result:
  - **W^{bTag} = 12.2 ± 4.0 (stat) ± 3.6 (syst) e channel**
  - **W^{bTag} = 39.5 ± 8.4 (stat) ± 11.7 (syst) μ channel**

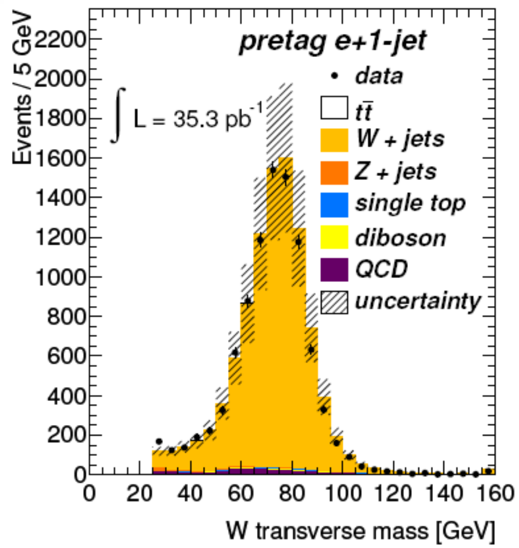
QCD estimate: e-channel

- <u>Fit method</u>
  - select a QCD-enriched sample by inverting some electron identification cuts,
  - template for E_T^{miss} distribution,
  - fit at low E_T^{miss} (E_T^{miss} <20 GeV)





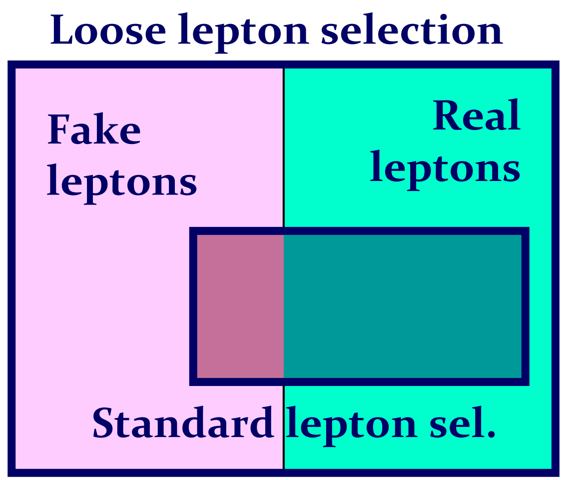




QCD estimate: μ-channel I

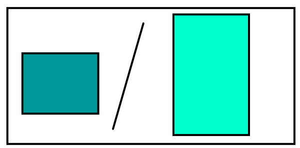
- matrix method
  - assumption: E_T^{miss} shape is independent from lepton ID cuts
  - define a control sample with looser selection cuts on the lepton (remove the isolation),
  - QCD is estimated by solving this 2x2 syst

$$
\begin{aligned}
N^{\mathrm{loose}} &= N^{\mathrm{loose}}_{\mathrm{real}} + N^{\mathrm{loose}}_{\mathrm{fake}}, \\
N^{\mathrm{tight}} &= \varepsilon_{\mathrm{real}} N^{\mathrm{loose}}_{\mathrm{real}} + \varepsilon_{\mathrm{fake}} N^{\mathrm{loose}}_{\mathrm{fake}},
\end{aligned}
$$

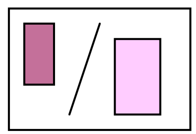


- N^{tight} = number of events with one muon passing all top selection cuts
- N^{loose} = number of events with one muon passing looser selection cuts

- ε_{real} measured with Z sample as a function of η

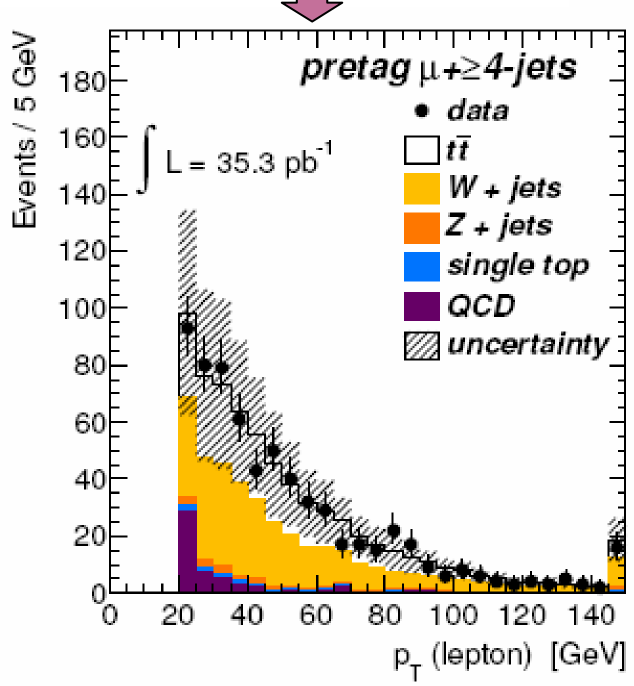


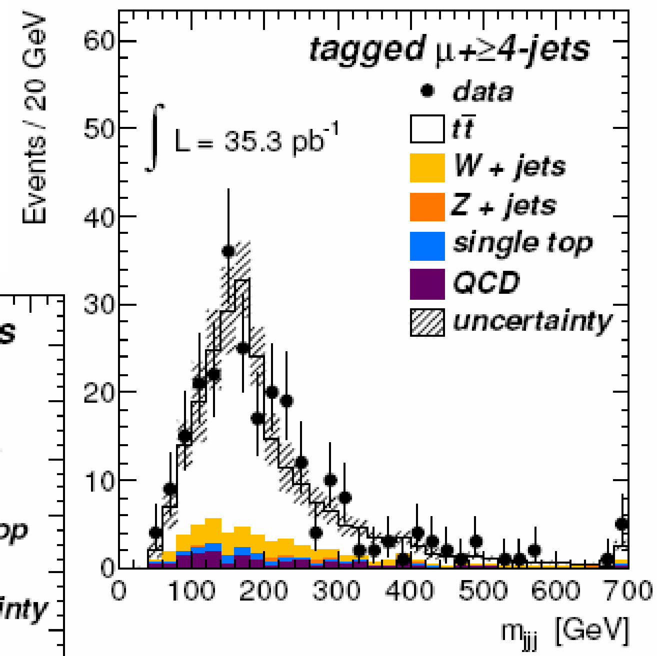
- ε_{fake} measured for E_T^{miss} < 10 GeV as a function of η



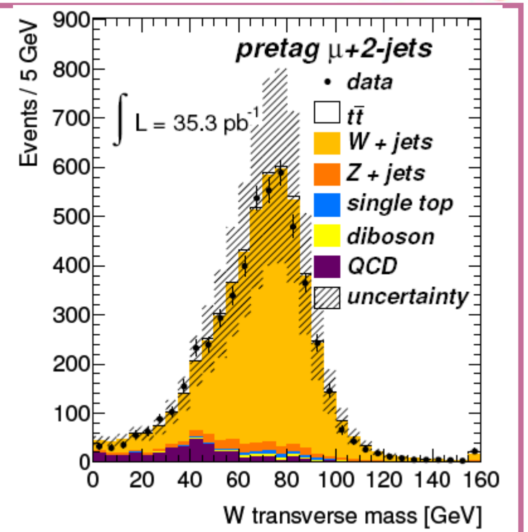
QCD estimate: μ-channel I

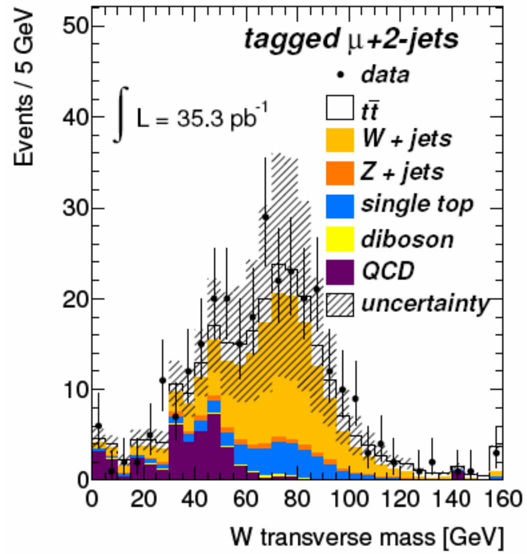
Control plots
signal region





Control plots
2 jet sample





Cross section measurement

Channel	Cross section (pb)
e+jets pre-tag	$159 \pm 17\,^{+50}_{-44} \pm 5$
μ+jets pre-tag	$148 \pm 16\,^{+47}_{-47} \pm 5$
e+jets tag	$153 \pm 16\,^{+41}_{-27} \pm 6$
μ+jets tag	$159 \pm 14\,^{+35}_{-27} \pm 6$

- Main sources of systematics:
  - ISR/FSR,
  - Jet energy scale
  - W+jets normalization (pre-tag measurement) and b-tagging (tag measurement)

Channels combination

- To combine e and μ channels (reducing the statistical uncertainty), the correlation between systematic uncertainties has to be taken into account

- Bayesian approach has been used
  - the result is an a posteriori probability distribution
  - the most probable value is taken as measured value

- Final result:

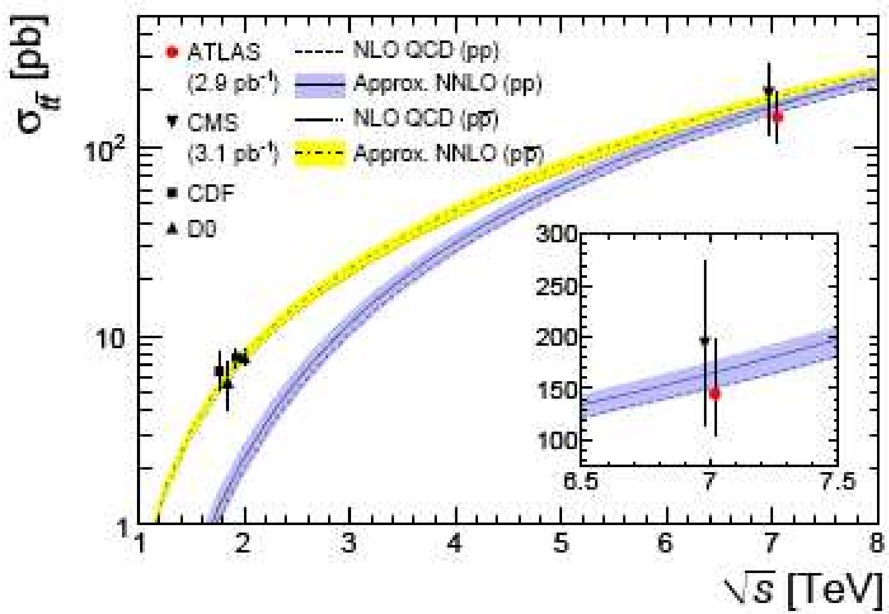
Channel	Cross section
pre-tag	$\sigma_{t\bar{t}} = 154\ ^{+52}_{-47}$ pb
tag	$\sigma_{t\bar{t}} = 156\ ^{+37}_{-29}$ pb

How our analysis in included in ATLAS?

First publication 2.9 pb^{-1}

- ATLAS top group first publication:
  Measurement of the top quark pair production cross-section with ATLAS in pp collisions at sqrt(s) = 7 TeV [**EPJC 71 (2011) 1577**],
  - it reports the first measurement of the production cross-section for top quark pairs(tT) in pp collisions at sqrt(s)=7 TeV
  - analysis performed using 2.9 pb^{-1} of data

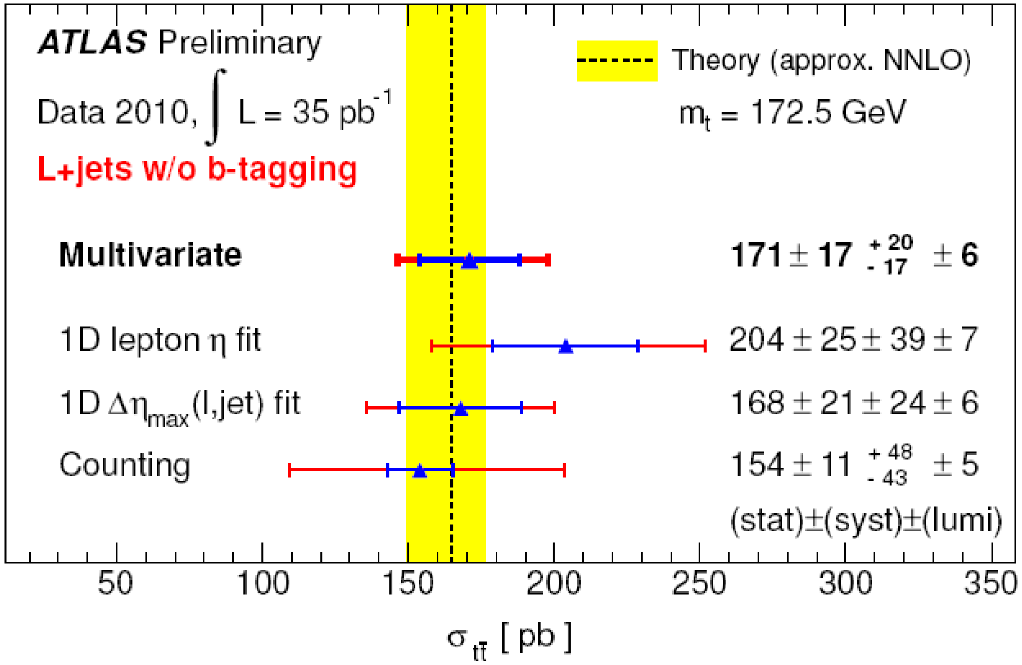
- Crucial contribution from Italian groups: **our analysis was the default one**



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

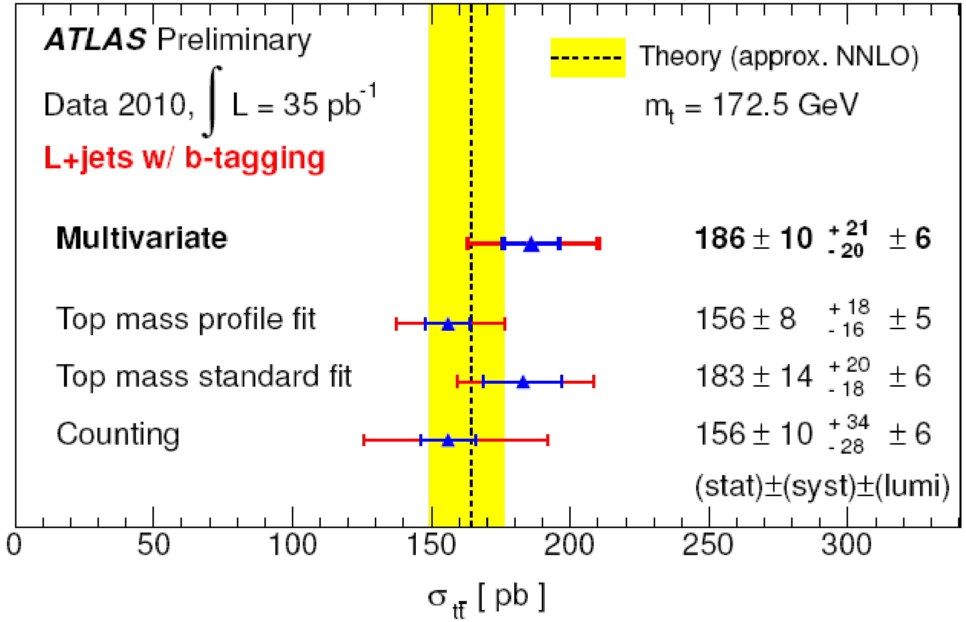
Moriond analysis I

- Multivariate techniques have become more powerful
- Default analysis WITHOUT b-tagging = multivariate technique which uses:
  - lepton pseudorapidity (leptons from tT more central)
  - lepton charge (W production in pp collisions is charge-asymmetric)
  - exponential of the event aplanarity (tT events more isotropic)



Moriond analysis II

- Default analysis WITH b-tagging = multivariate technique which uses:
  - lepton pseudorapidity
  - event aplanarity
  - transverse energy of jets involved in the event
  - b-tagging weight of jets



- BUT important role within Top Working group:
  - Tommaso Lari (Milano) and Kerim Suruliz (Udine/ICTP) editors of INT note on cut-count analysis,
  - Bobby Acharya (Udine/ICTP) editor of one of Moriond conf notes (ATLAS-CONF-2011-023) and editor of the paper on full 2010 data which is in preparation.

Conclusions and outlooks

Conclusions

- What have we done since last year?
  - important contribution to top notes for summer conferences:
    - *Search for top pair candidate events in ATLAS at √ s=7 TeV* (ATLAS-CONF-2010-063).
    - *Expected event distributions for early top pair candidates in ATLAS at √s=7 TeV* (ATLAS-PHYS-PUB-2010-012).
    - *Background studies for top pair production in lepton plus jets final states in sqrt(s)=7 TeV ATLAS data* (ATLAS-CONF-2010-087).
  - our analysis has been the default one reported in top paper:
    - EPJC 71 (2011) 1577,
  - our analysis repeated we full 2010 statistics has been an important cross check for Moriond:
    - *Top Quark Pair Production Cross-section Measurement in ATLAS in the Single Lepton+Jets Channel without b-tagging* (ATLAS-CONF-2011-023)
    - *Measurement of the top quark pair cross-section with ATLAS in pp collisions at √s = 7 TeV in the single-lepton channel using b-tagging* (ATLAS-CONF-2011-035)
    - *Cut-and-count measurement of the top quark pair production in the semileptonic decay channel at sqrt(s)=7 TeV with the ATLAS detector* (ATL-COM-PHYS-2011-122)

Conclusions

- Present situation:
  - multivariate techniques more competitive than cut and count:
    - on 2011 data statistical error would be negligible
    - systematic error of the order of 12% for Moriond: expect an improvement coming from lower uncertainty from (ex.) on b-tagging and JES
  - the cut & count method still provides a common ground for other more specific top-related analysis, such as top-antitop resonance or charge asymmetry.

Outlooks

- Future plans: groups have already moved to other analysis
  - Susy-dilepton (see M. Bianco's talk): Milano and Udine
  - Top charge asymmetry measurement (see U. De Sanctis's talk): Milano, Udine and Bologna
    - tT selection and reconstruction (MI-UD-BO)
    - study of observables (MI-UD-BO)
    - background estimation (common within top group, these estimations can be used for other analysis):
      - W+jets: (MI-UD)
      - QCD (UD)
    - unfolding (BO)
  - Top quark pair cross section in all hadronic channel: Genova

Back-up

W+jets estimate III

- **Berends scaling:** 179.6 ± 47.2 (e-ch.), 320.7 ± 68.1 (μ-ch)
  - statistical error is negligible ~5%.
  - high systematic uncertainty on the method
    - 22% e-ch,
    - 19% μ-ch
- **Charge asymmetry:** 242 ± 83 (e-ch.), 379 ± 106 (μ-ch)
  - lower systematics: <10% (main contribution from PDF uncertainty)
  - high statistical error:
    - 33% e-ch,
    - 27% μ-ch

Signal acceptance

rel.uncertainty(%)	e+jets pre-tag	μ+jets pre-tag	e+jets tagged	μ+jets tagged
b/c-tagging efficiency	0	0	+9.1/-10.4	+9.2/-10.5
light jets tagging efficiency	0	0	±0.2	±0.2
lepton trigger, reconstruction and selection	±3.6	±0.9	±3.6	±0.9
jet energy scale	+9.0/-9.1	+7.8/-8.7	+8.9/-9.0	+7.6/-8.5
jet energy resolution	±0.2	±0.2	±0.4	±0.4
jet reconstruction efficiency	±2	±2	±3	±3
electron energy scale	+0.2/-0.6	0	+0.2/-0.6	0
electron energy resolution	±0.2	0	±0.2	0
muon momentum scale	0	±0.3	0	±0.3
muon momentum resolution	0	±0.1	0	±0.1
ISR/FSR	+7.0/-9.6	+4.8/-9.3	+7.2/-8.2	+6.3/-7.7
NLO generator (MC@NLO *v.s.* POWHEG)	±6.6	±5.0	±6.5	±2.7
Parton Shower generator (HERWIG *v.s.* PYTHIA)	±4.6	±3.8	±4.6	±3.8
PDFs	±1.7	±1.4	±1.9	±1.6
Pile up	-1.2	-1.2	-0.6	-0.8
TOT	+19.2 -15.3	+15.0 -15.3	+14.4 -19.9	+16.1 -15.5

Cross section

Source	$\Delta\sigma(e)/\sigma[\%]$ pre-tag	$\Delta\sigma(\mu)/\sigma[\%]$ pre-tag	$\Delta\sigma(e)/\sigma[\%]$ tagged	$\Delta\sigma(\mu)/\sigma[\%]$ tagged
Statistical error	10.4	10.2	9.9	8.6
Object selection				
Lepton Reco,ID,Trigger	+3.8/-3.5	+1.0/-0.9	+3.8/-3.5	+1.0/-0.9
Jet energy Reco	+14.1/-11.8	+14.5/-12.3	+11.4/-9.6	+9.9/-8.5
b-tagging	-	-	+11.7/-8.4	+11.7/-8.4
Background rate				
QCD norm	4.4	6.1	6.2	0.7
W+jets norm	19.5	23.4	4.1	7.7
Other bkg norm	5.7	6.1	0.7	0.7
Signal simulation				
ISR/FSR	+10.6/-6.5	+10.3/-4.6	+8.9/-6.7	+8.3/-5.9
PDF	1.7	1.4	1.9	1.6
Parton Shower	+4.8/-4.4	+4.0/-3.7	+4.8/-4.4	+4.0/-3.7
NLO generator	+7.1/-6.2	+5.3/-4.8	+7.0/-6.1	+2.8/-2.6
Pile-up	1.2	1.2	0.6	0.8
Sum systematics	+28.9/-26.2	+31.4/-28.9	+22.2/-18.4	+19.8/-16.2
Integrated Luminosity	+3.8/-3.6	+3.8/-3.6	+3.5/-3.3	+3.5/-3.3