Top physics in ATLAS

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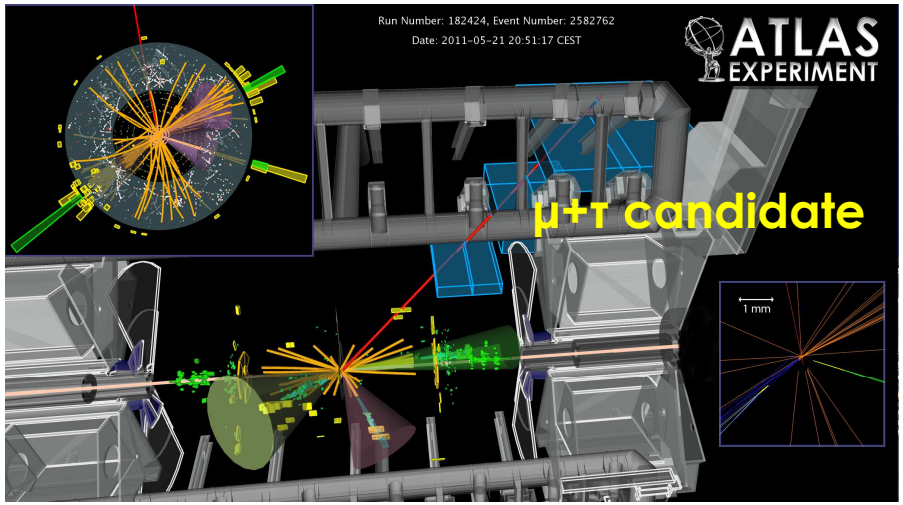
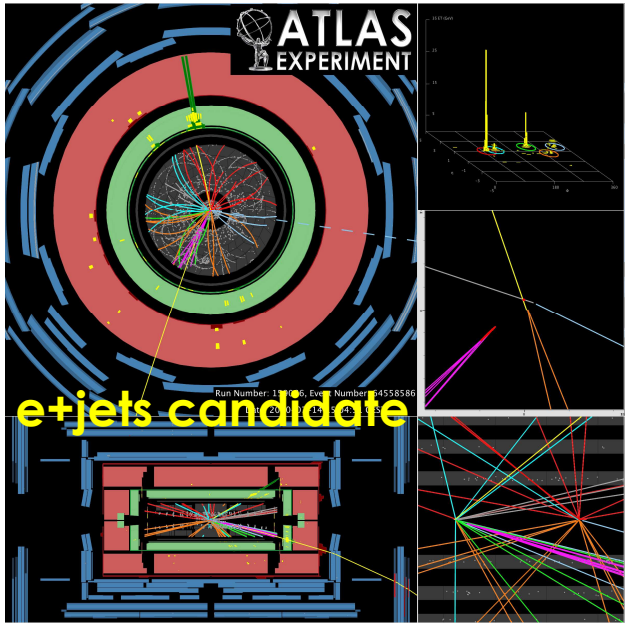
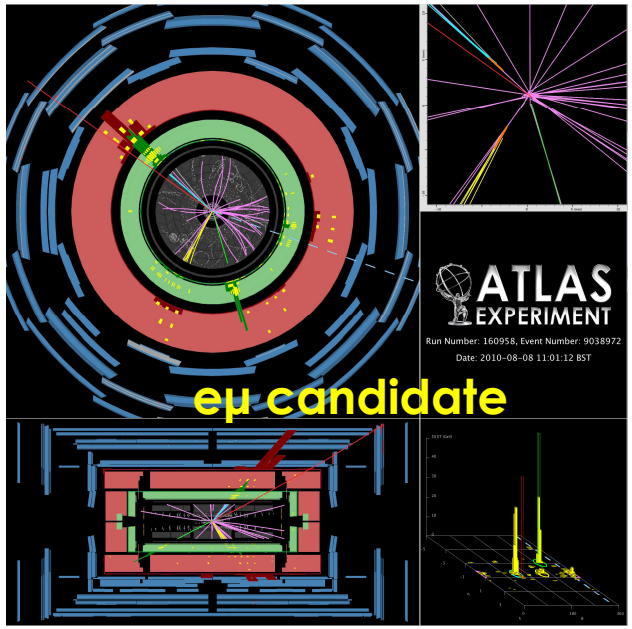
on behalf of
the ATLAS Collaboration





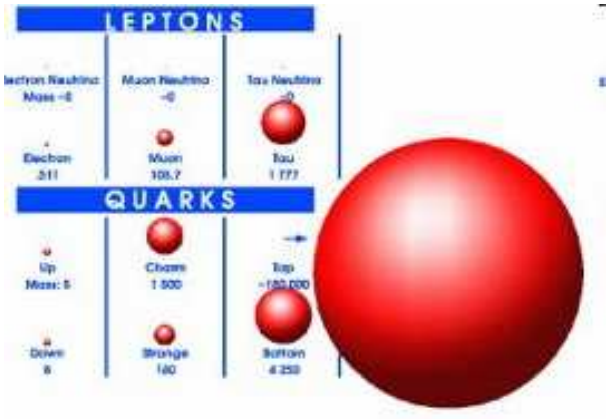


Outline

- Introduction
- Review of ATLAS measurements on top physics:
  - top quark pair cross section
  - single top cross section
  - main properties:
    - mass
    - charge asymmetry
    - Wtb vertex
    - spin correlations
    - charge
    - flavour changing neutral currents (FCNC)
  - searches for resonances in top-antitop events
- Conclusions

Why top quark physics

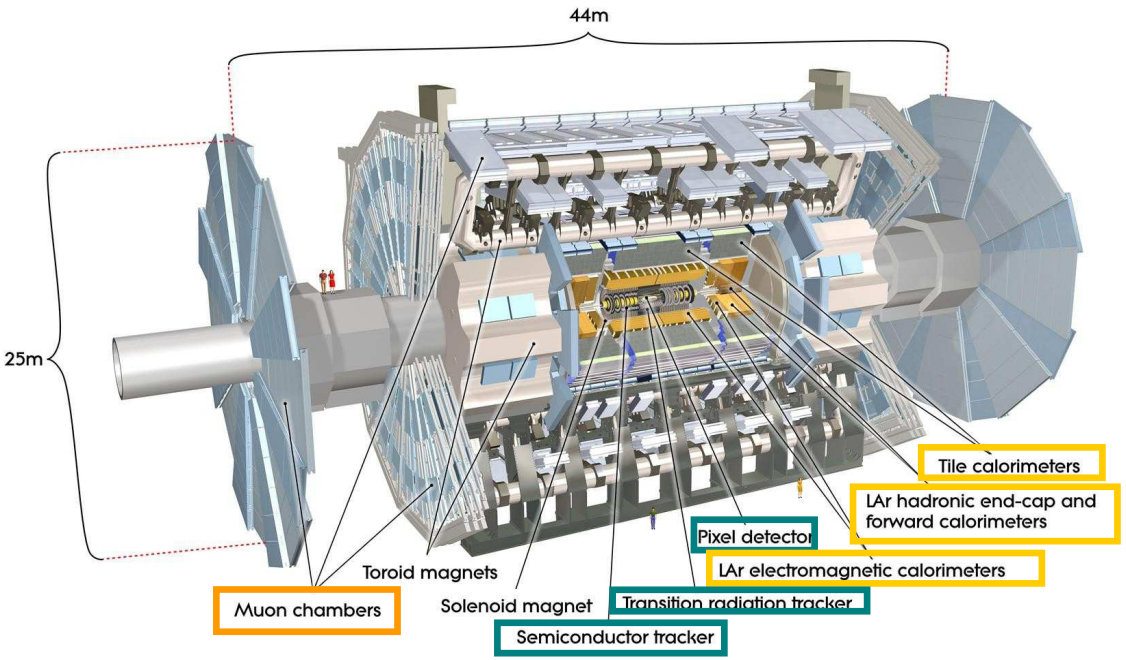
- Top quark is very different from the other 5 quarks
  - short lifetime: **it decays before hadronizing**
    - possibility to study **the properties of a BARE QUARK**
  - **high mass**



- Main goals of top physics:
  - **test of Standard Model predictions**:
    - precision measurements on cross section, mass, couplings
    - searches for deviations as hint of new physics
  - **search for new physics:**
    - new non-Standard Model particles, decaying into top quark pairs (resonances)
  - **detector calibration:**
    - top quark decay involves all possible products: electrons, muons, jets, b-jets and neutrinos

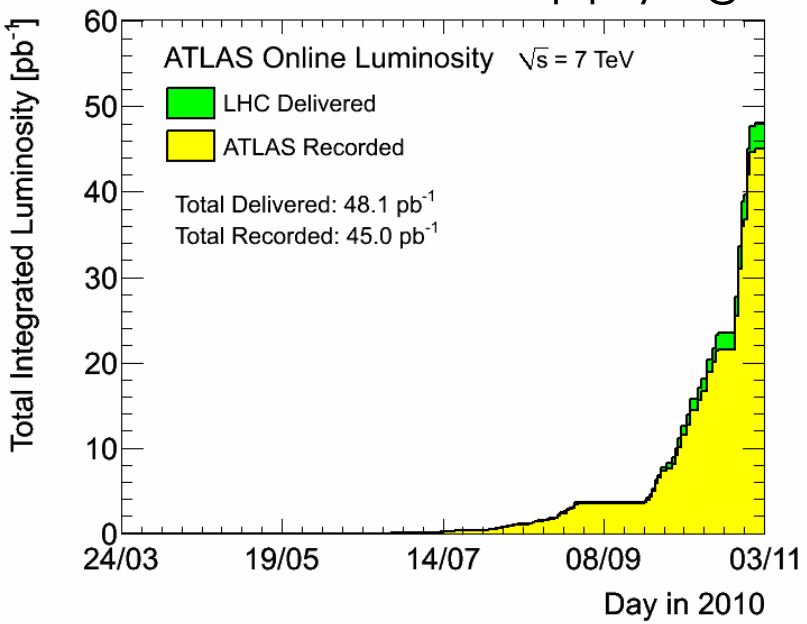
The ATLAS detector

- **Inner detector:**
  tracking for charged particles, primary and secondary vertex reconstruction
- **Calorimeter system:**
  measurement of electron and jet energy, fundamental for E_T^{miss} reconstruction
- **Muon chambers:**
  muon identification and reconstruction

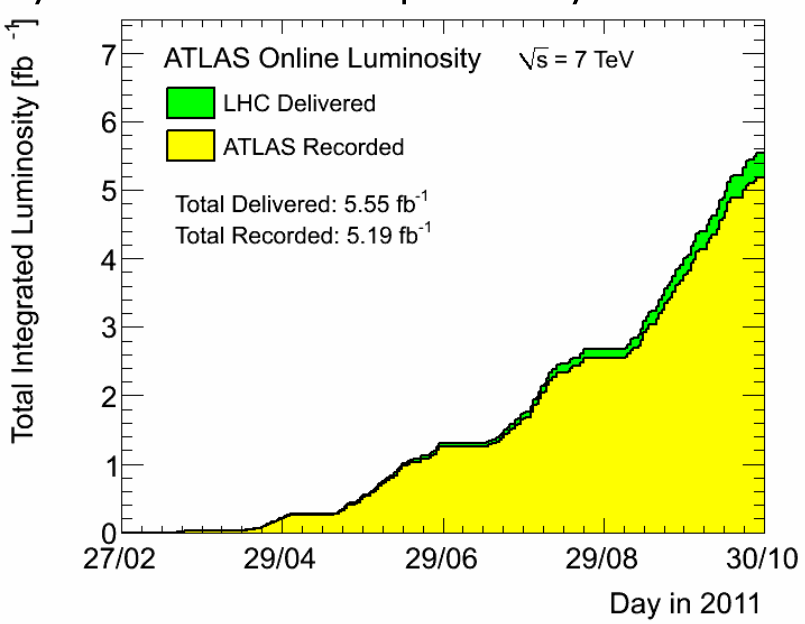


2010 and 2011 data

- Analyses based on data collected by the ATLAS detector in **2010** and **2011** after applying all quality criteria for top analysis



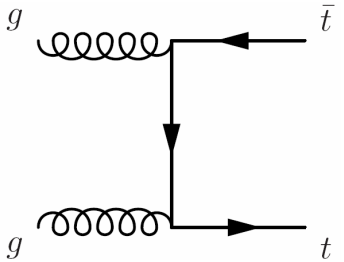
- **35 pb^{-1}**: all data collected in 2010

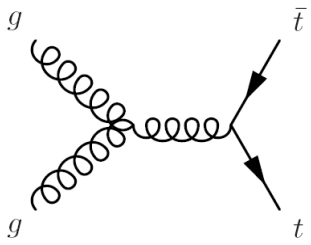


- **0.70 fb^{-1}**: data collected until the end of June
- **1 fb^{-1}**: data collected until July

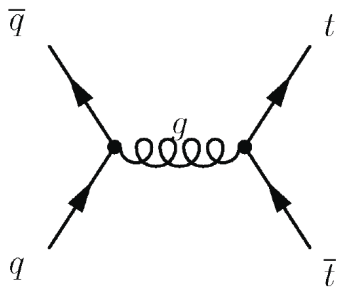
Top quark production

- Top quark pair: 
  - $\sigma = (164.6^{+11.4}_{-15.7})$pb
  - **gluon-gluon fusion :** ~85% at 7 TeV, in p-p collisions

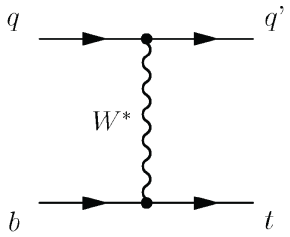


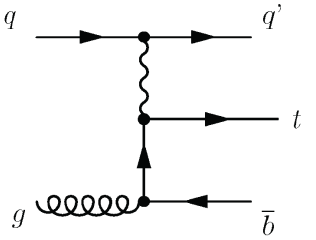


  - **Quark-antiquark annihilation:** ~15% at 7 TeV, in p-p collisions

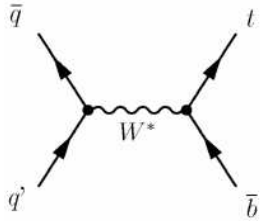


- Single top:  or 
  - **t-channel:** $(64.6^{+3.3}_{-2.6})$pb

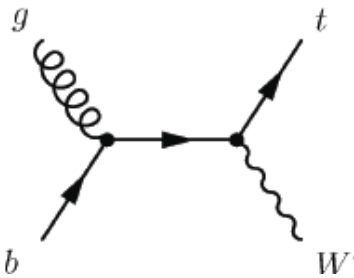


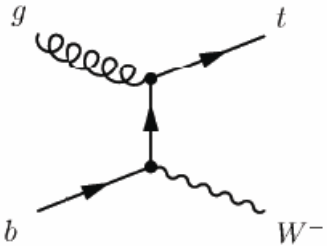


  - **s-channel:** (4.6±0.3) pb



  - **Wt-channel:** (15.7±1.4) pb

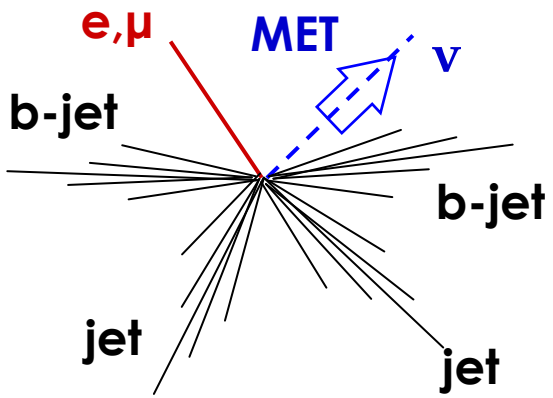




Top quark signatures

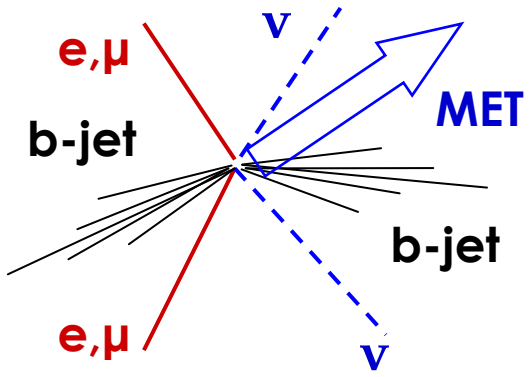
- Top quarks decay almost 100% of the times in **W-boson** and **b-quark**
- The W boson decays:
  - into lepton+ neutrino (33%)
  - into di-jets (67%)
- Top quark pair decay modes:

l+jets channel:



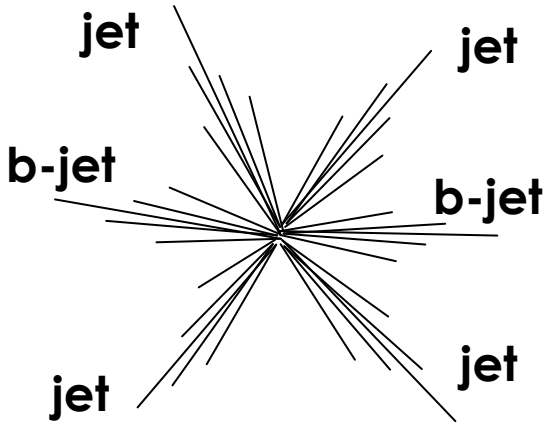
- 1 high p_T and isolated e or μ
- E_T^{miss} from the neutrino,
- at least 4 energetic jets, 2 of them are b-jets

dilepton channel:



- 2 high p_T, isolated and opposite charge leptons,
- E_T^{miss} from the neutrinos,
- at least 2 b-jets

all-hadronic channel:



- at least 6 jets, 2 of them coming from a b-quark

Top quark event selections

Object definition (unless otherwise noted)

- Electrons: $|\eta|<2.5$ (excluding calorimeter transition region), $p_T > 25$ GeV (20 GeV in 2010), isolated
- Muons: combined (ID+MS) muons, $p_T > 20$ GeV, $|\eta|<2.5$, isolated
- Jets: reconstructed with antiKT $\Delta R=0.4$, $|\eta| < 2.5$, p_T (hadronic scale)> 25 GeV
- b-jets: 2 algorithms used with 50% (70%) b-eff and 270 (100) light jet rejection
- E_T^{miss}: reconstructed objects included at the appropriate scale

More details in performance talks: A. Favareto, E. Dawe and V. Gallo

Event selection

- Non-collision background rejection
  - at least one primary vertex, no energy deposits in the calorimeter not associated to collisions
- Lepton+jets
  - presence of only one lepton, cuts on E_T^{miss} and M_T(lepton, E_T^{miss}) variables, ask at least 4 jets **+** request a tagged jet (tag analysis)
- Dilepton
  - presence of two opposite charge leptons and at least 2 jets, veto on the Z mass window and cuts on E_T^{miss} for ee and μμ ch. and cut on H_T variable for eμ ch. **+** request a tagged jet (tag analysis)

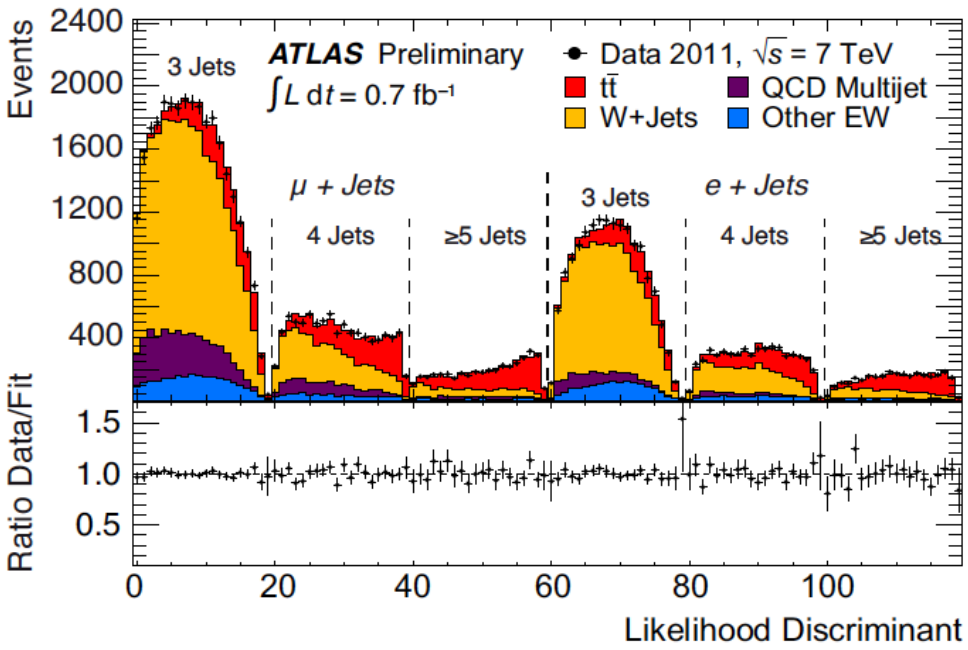
Top quark pair production cross section measurements

In the following:

- **Inclusive cross section** in different channels:
  - l+jets channel with/without using b-tagging
  - dilepton
  - $\mu + \tau$
  - all hadronic
- **Jet multiplicity** in $t\bar{t}$+ jets events
- **$t\bar{t}$+photon**

Inclusive cross section: l+jets pre-tag

- Analysis with **0.70 fb^{-1}**.
- **No b-tagging** request applied
- Make use of kinematical differences between $t\bar{t}$ and W+jets:
  - **likelihood discriminant** based on 4 variables
    - lepton η, leading jet p_T, event aplanarity and transverse momentum of all jets but the two leading ones
- **Fit in 6 channels**: 3, 4 and >= 5jets in e and μ ch.
- Main systematics:
  - signal modelling (choice of signal MC generator, ISR/FSR) and jet energy scale (JES)



$$\sigma_{t\bar{t}} = 179.0 \pm 3.9\,(\text{stat}) \pm 9.0\,(\text{syst}) \pm 6.6\,(\text{lumi})\ \text{pb}$$

7% uncertainty!

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Inclusive cross section: l+jets tag

- Analysis based on **35 pb^{-1}**:
- **Multivariate technique** to separate signal from background
  - **likelihood discriminant** based on 4 variables
    - lepton η, event aplanarity, transverse momentum of all jets but the two leading ones, average **b-tagging probability** (considering the two jets with the lowest light jet probability)
- **Fit in 6 channels**: 3, 4 and ≥5 jets in e and μ channel
- Main systematics:
  - W+jets heavy flavour fraction
  - b-tagging calibration

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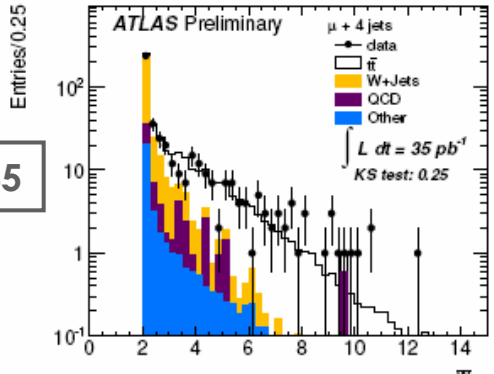
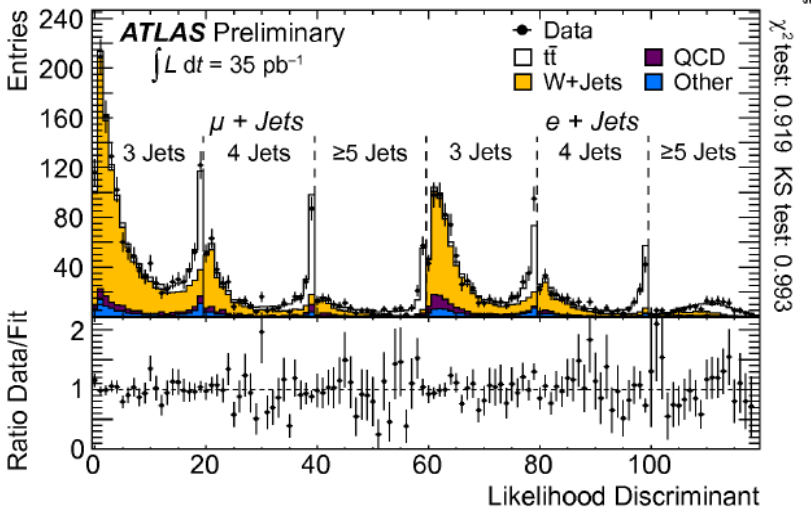


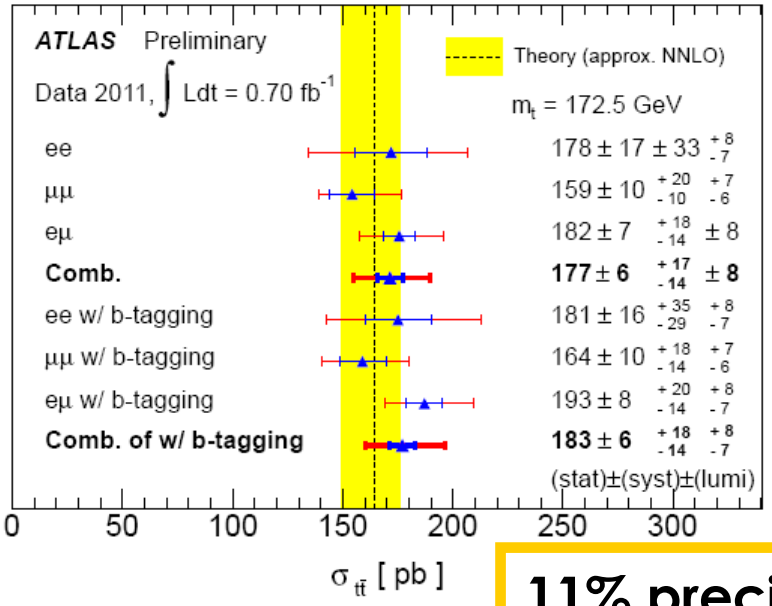


$$\sigma_{t\bar{t}} = 186 \pm 10\,(\text{stat.})^{+21}_{-20}\,(\text{syst.}) \pm 6\,(\text{lumi.})\,\text{pb}$$

13% uncertainty

Inclusive cross section: dilepton

- Data corresponding to **0.70 fb^{-1}**
- Two counting analysis **with/without** the request of a b-tagged jet
- Main backgrounds estimated from data:
  - QCD
  - Z+jets



11% precision

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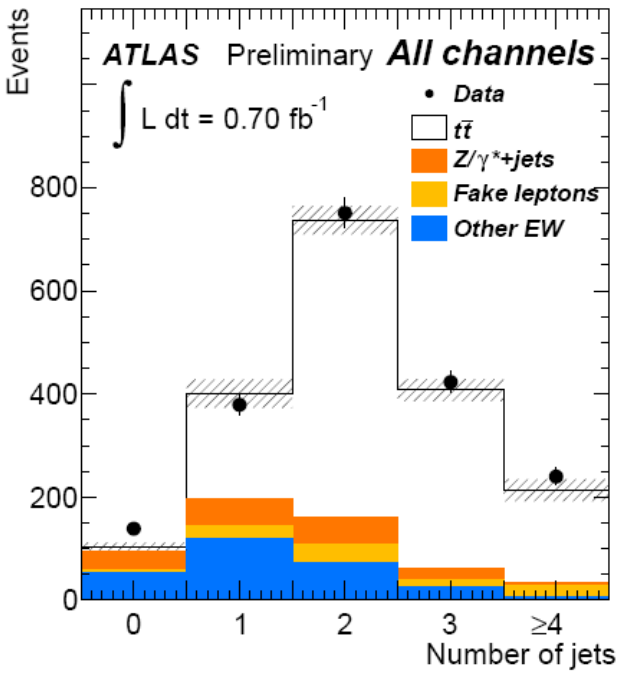
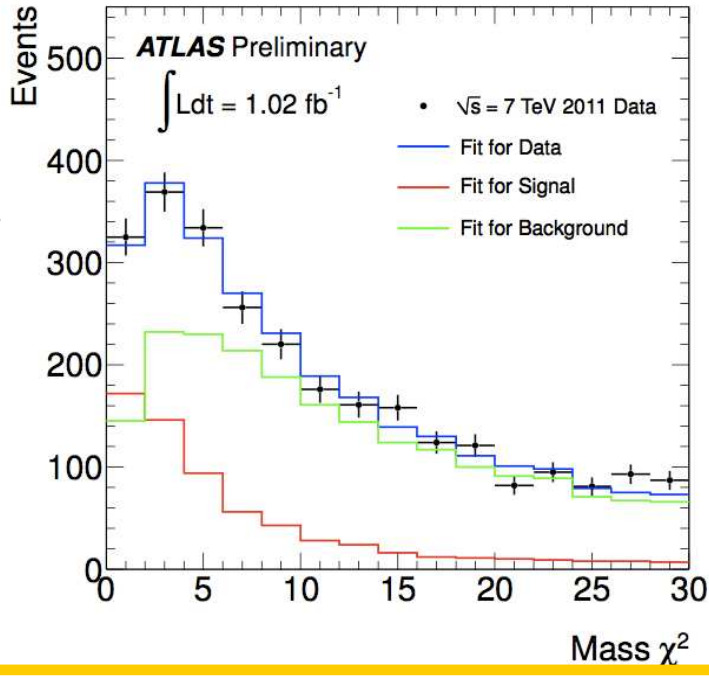


- Main systematics:
  - JES
  - luminosity
  - b-tagging efficiency (tag analysis)

Inclusive cross section: all hadronic

- Analysis based on **1.02 fb^{-1}**
- Event selection
  - multi-jet trigger
  - at least 6 jets, 2 b-tagged
  - upper cut on **E_T^{miss} significance**: $E_T^{miss}/\sqrt{H_T}$
    - H_T = scalar sum of the transverse momentum of all jets in the event
  - minimal **ΔR separation between the two b-jets**: $\Delta R(b,\bar{b}) > 1.2$
- The signal fraction is extracted from a fit on χ^2 mass distribution using signal+background templates
  - signal: from MC
  - QCD: from data using control samples with exactly 4 or 5 jets
- Main systematics:
  - ISR/FSR modelling
  - JES
  - b-tagging efficiency



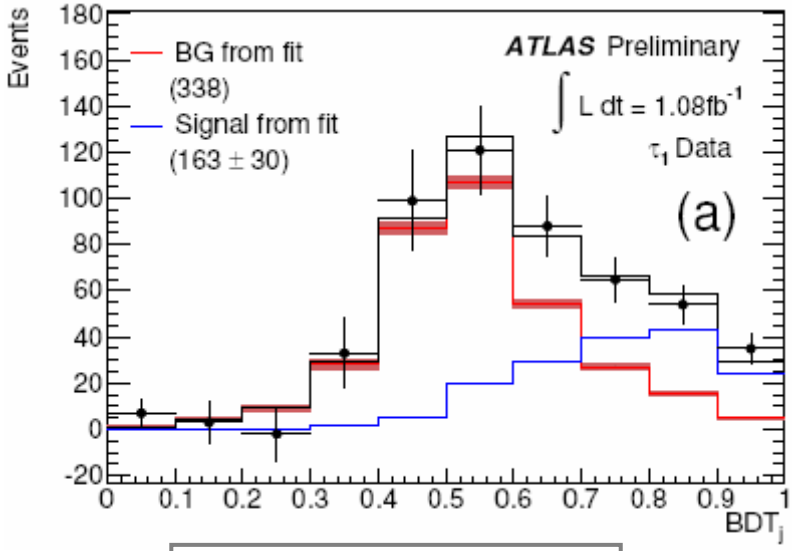
ATLAS-CONF-2011-140

$$\sigma(pp \to t\bar{t}) = 167 \pm 18\ (\text{stat.}) \pm 78\ (\text{syst.}) \pm 6\ (\text{lum.})\ \text{pb}$$

48% precision

Inclusive cross section: μ+τ

- Motivation: decays like **$t \to bH^+$** can enhance BR of final states involving τ-leptons
- Analysis on **1.1 fb^{-1}**, with **one μ and one hadronically decaying τ**
  - event selection: 1 μ, 1 τ-jet (with one track τ_1 and with three tracks τ_3) and two other jets, one of them passing b-tagging
- **Boosted decision trees (BDT) used to identify τ's** and reject electrons and jets
- **Signal fractions from a fit on BDT$_j$**
  - **backgrounds** templates using control samples in data
- Main systematics:
  - τ-identification,
  - ISR/FSR modelling
  - b-tagging



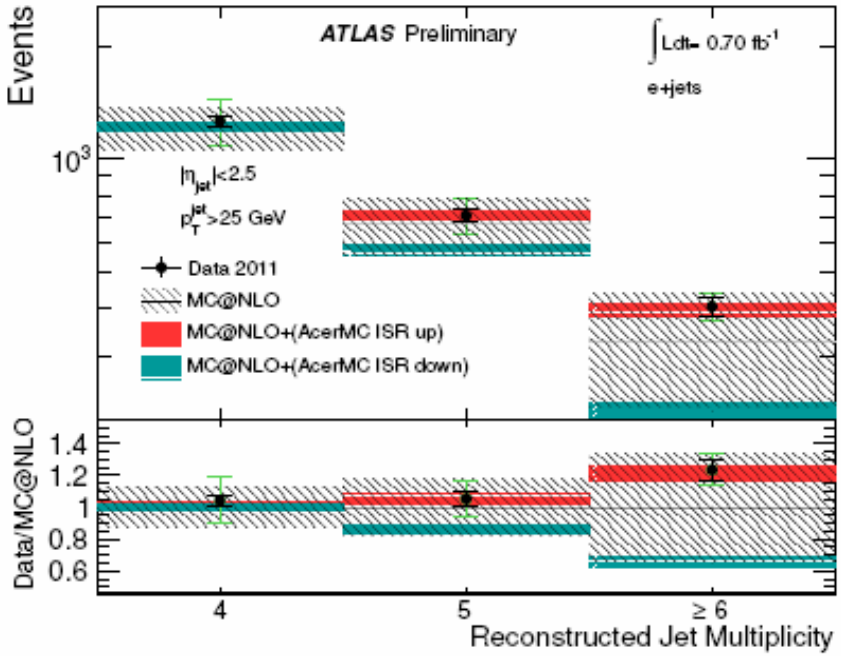
ATLAS-CONF-2010-119

$$\sigma_{t\bar{t}} = 142 \pm 21\ (\text{stat.}) \pm^{20}_{16}\ (\text{syst.}) \pm 5\ (\text{lumi.})\ \text{pb}$$

~20% precision

Jet multiplicity in $t\bar{t}$ events

- Motivation: jet multiplicity measurement gives the **possibility to constrain ISR at m_{top} energy**
- Analysis based on **0.70 fb^{-1}** in **l+jets** channel
- QCD and W+jets backgrounds estimated from data
- Jet multiplicity distribution after background subtraction compared to different MC predictions:
  - **ISR varied within the uncertainty**
- Main uncertainties:
  - at low jet multiplicity (4 jets): QCD and W+jets backgrounds
  - at high jet multiplicity: JES



ATLAS-CONF-2011-142

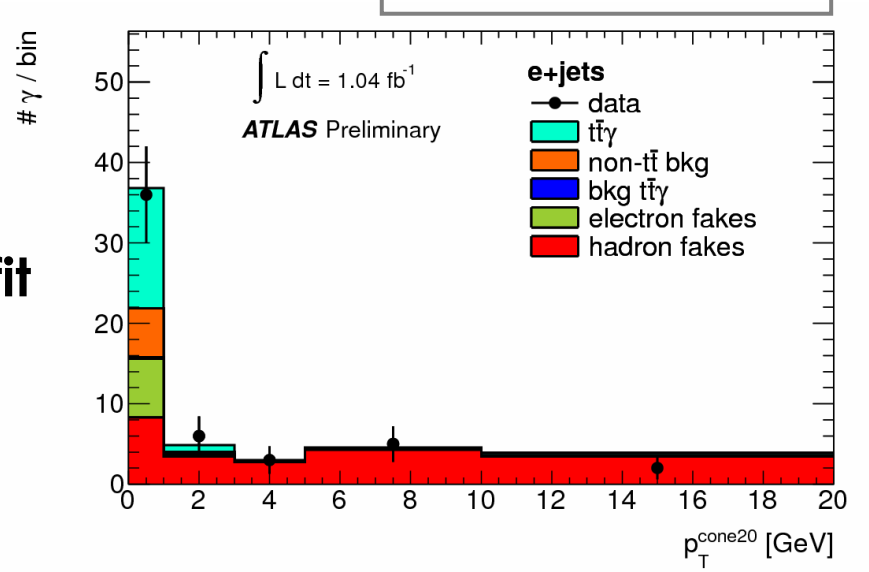
Present uncertainty:
no discrimination is possible

$t\bar{t}$+photon

NEW !!

- Motivation: knowledge about the tγ vertex
- Analysis performed using **1.04 fb^{-1}** of data in **l+jets** channel
- Standard single lepton selection, **+** presence of **one identified photon,** $p_T > 15$ GeV and $|\eta| < 2.5$, not close to a jet:
  - removed the jets within $\Delta R=0.5$ from the photon
- Backgrounds:
  - from control regions in data: $t\bar{t}$ with fakes, W+jets + γ, QCD + γ
  - from MC: diboson, single top, Z+jets + γ/electron fake
- **Signal fraction extracted from a fit on photon tracking isolation:**
  - templates for signal and backgrounds from data
- Main systematics: γ ID, γ purity, JES, b-tagging, ISR/FSR
  - higher statistics will help in reducing γ contribution

ATLAS-CONF-2011-153



$$\sigma_{t\bar{t}\gamma} = 2.0 \pm 0.5\,(\text{stat.}) \pm 0.7\,(\text{syst.}) \pm 0.08\,(\text{lumi.})\,\text{pb}$$

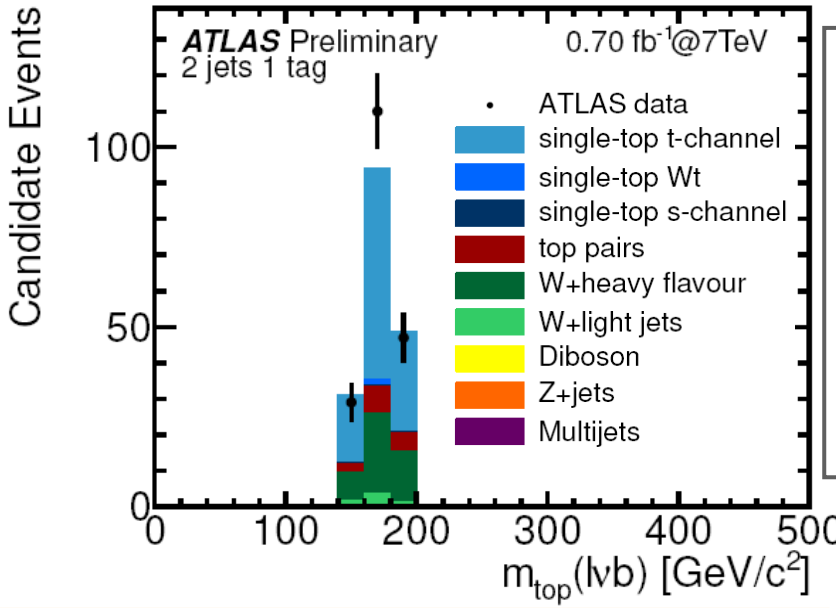
Single top production cross section measurements

In the following different channels:

- t-channel
- Wt-channel
- s-channel

t-channel

- Analysis performed with **0.70 fb^{-1}**, considering only events with W boson decaying into electron/muon
- Signature: 1 energetic lepton, E_T^{miss}, ≥2 jets, 1b-jet
- **Cut based analysis** in 2-jet and 3-jet bin separately, asking 1 tagged jet and additional cuts on:
  - M_T(l, E_T^{miss}), leading light jet η, event H_T, m(b-jet, l, ν), ΔR(b-jet, light-jet)
- Main backgrounds
  - W+jets: shape from Monte Carlo, normalization from data
  - QCD: data driven both shapes and normalization
  - $t\bar{t}$: from Monte Carlo
- Main systematics from ISR/FSR modelling and b-tagging



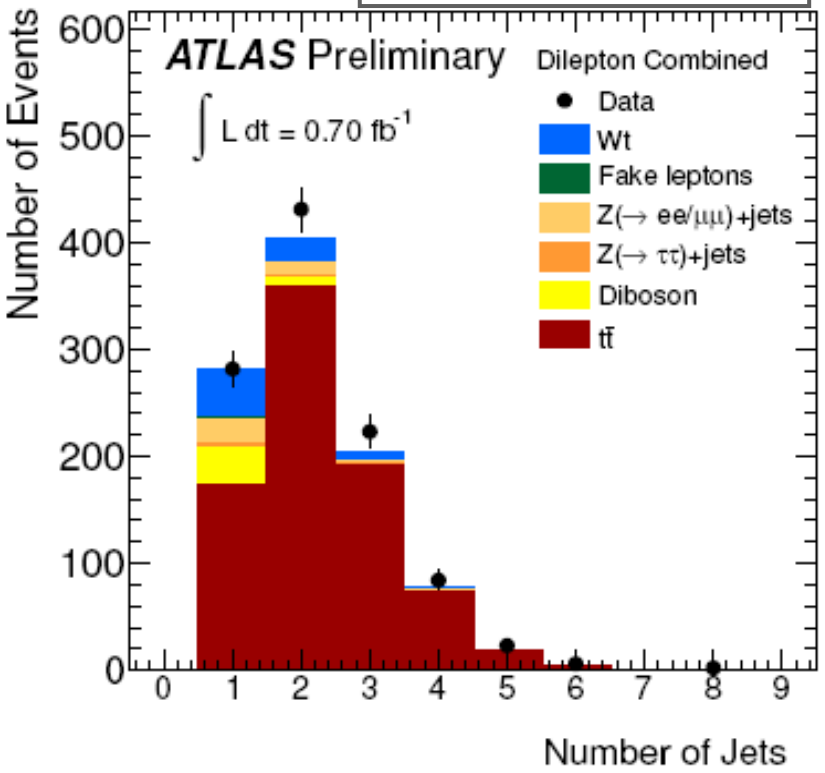
ATLAS-CONF-2011-101

$$\sigma_t = 90^{+9}_{-9}(\text{stat})\,^{+31}_{-20}(\text{syst})\,\text{pb}$$

Wt-channel

- Analysis performed with **0.70 fb^{-1}**
- Selected events with **both Ws decaying leptonically**
- Event selection
  - two opposite charge leptons
  - veto on Z boson mass region
  - cut on $\Delta\Phi$(lepton,E_T^{miss})
  - presence of exactly one jet
- Main **backgrounds** estimated using **control samples in data**:
  - fake leptons, Z(ee, μμ, ττ)+jets, $t\bar{t}$
- Main uncertainties from:
  - available statistics
  - jet energy scale, jet energy resolution (JER) and jet reconstruction efficiency (JRE)
  - $t\bar{t}$ contamination

ATLAS-CONF-2011-104



$$\sigma(pp \to Wt + X) = 14.4^{+5.3}_{-5.1}(\text{stat})^{+9.7}_{-9.4}(\text{syst})\ \text{pb}$$

s-channel

- Analysis performed with **0.70 fb^{-1}**
- Challenging measurement:
  $\sigma_t / \sigma_{t\bar{t}} \approx 0.03$ and $\sigma_t / \sigma_{W+2\,jets} \approx 10^{-3}$
- Main **backgrounds**:
  - QCD: from fitting method
  - W+jets: MC predictions rescaled to match measurements in control samples
- To enhance signal contribution, additional cuts on:
  - number of tagged jets
  - ΔR between the two leading jets and ΔR(leading jet-lepton)
  - W boson transverse mass M_T
  - m(b-jet, lepton, neutrino)
  - p_T of the two leading jets

- Main uncertainties:
  - statistical uncertainty, signal modelling, JES, JER and JRE

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	Final Selection
s-channel	16 ± 6
t-channel	33 ± 13
Wt	5 ± 3
$t\bar{t}$	111 ± 47
W+jets	4 ± 5
Wc+jets	10 ± 8
$Wc\bar{c}$+jets	14 ± 12
$Wb\bar{b}$+jets	70 ± 51
Z+jets	1 ± 1
Diboson	4 ± 1
Multijets	17 ± 10
TOTAL Exp	285 ± 17
$S/\sqrt{B}$	0.98
DATA	296

σ_t (s-channel) < 26.5 pb

Top quark properties

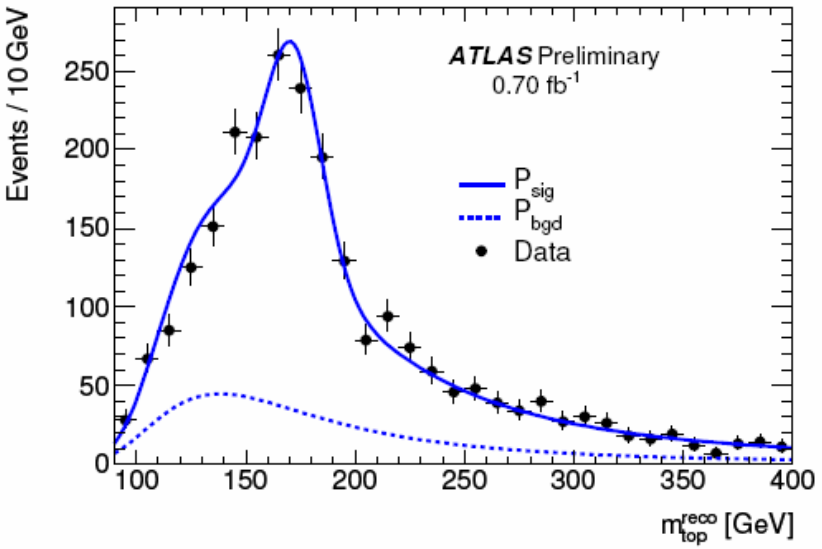
In the following:

- Top quark mass
- Charge asymmetry
- Wtb vertex
- Spin correlations
- Top quark charge
- FCNC

Top quark mass

- Motivation: large contribution to electroweak radiative corrections from m_{top}
  - **constrain Higgs boson mass from precision measurements**
- Analysis performed with **0.70 fb^{-1}** in **l+jets** channel,
  - asking the presence of one b-jet
- 3-jet from hadronic top: combination with higher total p_T
- Technique: **m_{top} and JES determined simultaneously**
  - W mass and width used as constraints
- m_{top}^{reco} in data have been compared to signal + backgrounds templates with ≠ JES and m_{top}
  - **m_{top} and JES from a likelihood fit**

- Main systematics:
  - signal modelling
  - JES for light jets and b-jets



$$m_{\text{top}} = \left(175.9 \pm 0.9_{\text{stat}} \pm 2.7_{\text{syst}}\right) \text{ GeV}$$

Limited by systematics

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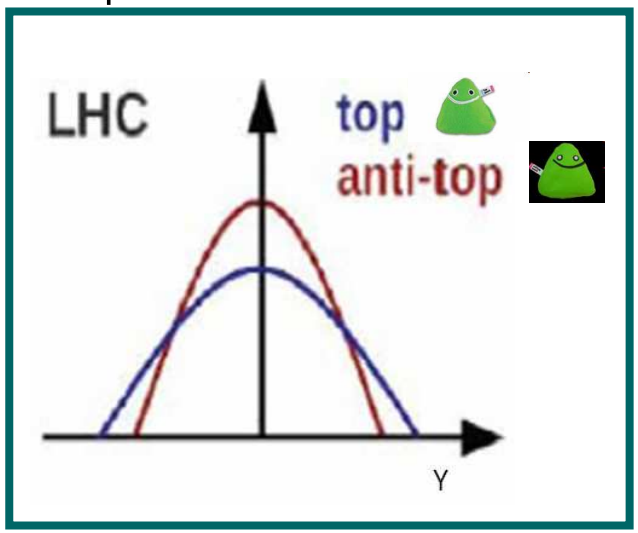
Charge asymmetry I

- Charge asymmetry only in asymmetric initial states
  - **main contribution: quark-antiquark annihilation**

- Valence quarks more boosted than sea antiquarks
  - top more boosted than antitops
  - broader rapidity



- Sensible observables to the asymmetry:

$$A_c = \frac{N(\Delta|Y|>0) - N(\Delta|Y|<0)}{N(\Delta|Y|>0) + N(\Delta|Y|<0)}$$

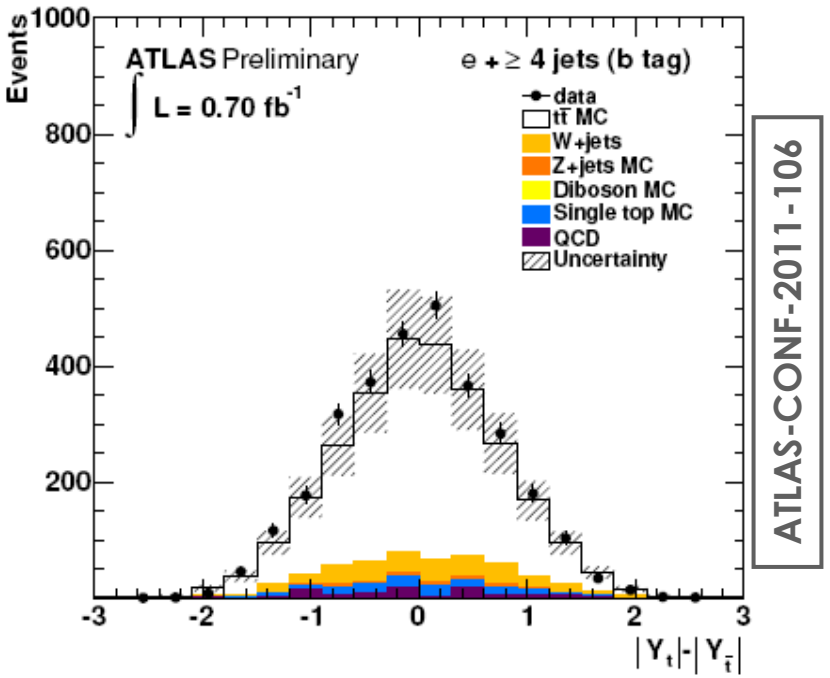
where $\Delta|Y| = |Y_t| - |Y_{\bar{t}}|$

- In SM asymmetry only at NLO: **A~1%**

Charge asymmetry II

- Analysis performed with **0.70 fb^{-1}** in **l+jets** channel
- Standard l+jets selection, using b-tagging
- W+jets and QCD backgrounds from data, other backgrounds from MC
- **Event kinematics** reconstructed with a kinematic likelihood fitter
  - input: p_T, η, Φ of decay products
  - constraints from m_t, m_W, Γ_t and Γ_W
  - b-tagging info taken into account
- **Bayesian unfolding** used to correct for acceptance and detector effects

- Main systematics:
  - signal modelling and JER



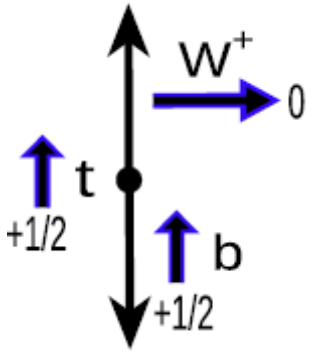
$$A_C = -0.024 \pm 0.016\,(\text{stat.}) \pm 0.023\,(\text{syst.})$$

in agreement with SM predictions

Wtb vertex I

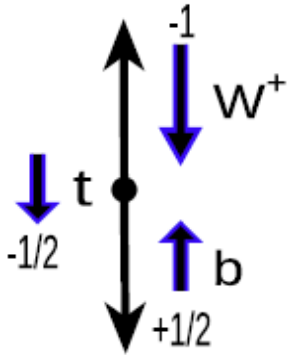
- Motivation: check V-A structure of Wtb vertex
- SM prediction:

Longitudinal W



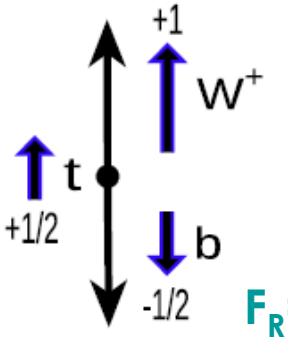
F_0=0.678

Left-handed W



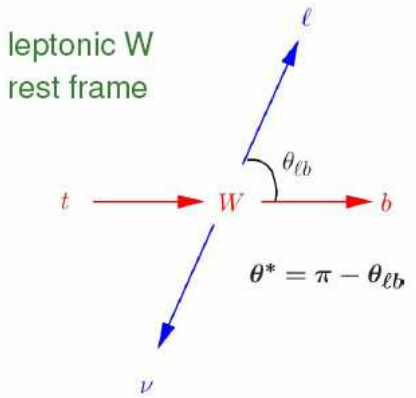
F_L=0.311

Right-handed W



F_R=0.0017

- Analysis performed with **0.70 fb^{-1}**, both in l+jets and dilepton channel
- W polarization affects the angular distribution of decay products
  - **observable: cosθ***, angle between the lepton and the inverse of momentum direction of the b-quark in W boson rest frame



Wtb vertex II

- The differential decay rate is fitted with signal+backgrounds templates:
  - QCD from data, signal and other backgrounds from MC
- **Helicity fractions extracted from the fit**
- Main systematics: signal modelling and b-jet identification

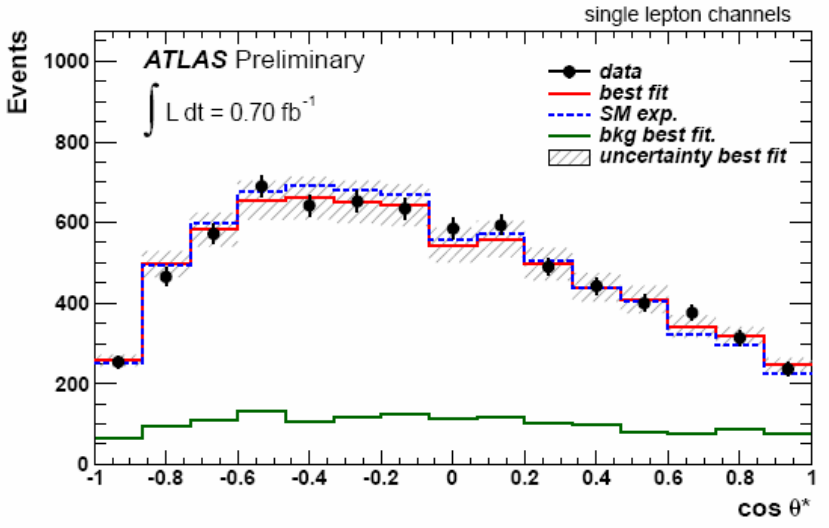
Single lepton

$$F_0 = 0.57 \pm 0.07\,(\text{stat.}) \pm 0.09\,(\text{syst.})$$
$$F_L = 0.35 \pm 0.04\,(\text{stat.}) \pm 0.04\,(\text{syst.})$$
$$F_R = 0.09 \pm 0.04\,(\text{stat.}) \pm 0.08\,(\text{syst.})$$

Dilepton and single lepton combined (F_R =0)

$$F_0 = 0.75 \pm 0.08\,(\text{stat.+syst.})$$

Agreement with SM!

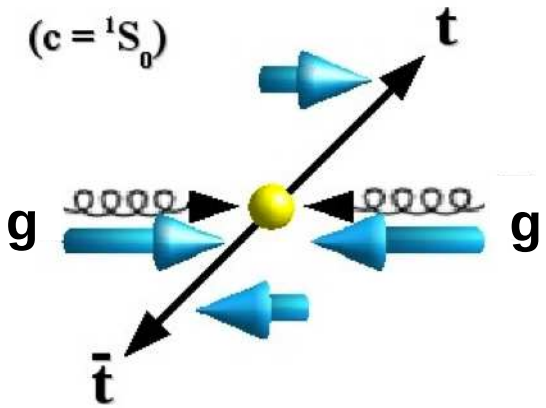


ATLAS-CONF-2011-122

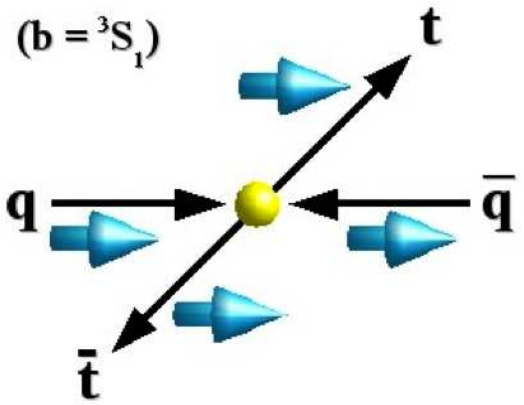
Spin correlations I

- Motivation: test of SM predictions, BSM scenario predicts different correlations
  - complementary to Tevatron measurements: ≠ energy and ≠ dominant production mechanism
- Top and antitop decay before hadronizing:
  - polarization is not lost
  - **spin correlation from angular distributions of decay products**
- **SM prediction compared with non correlation hypothesis**

Dominant at LHC



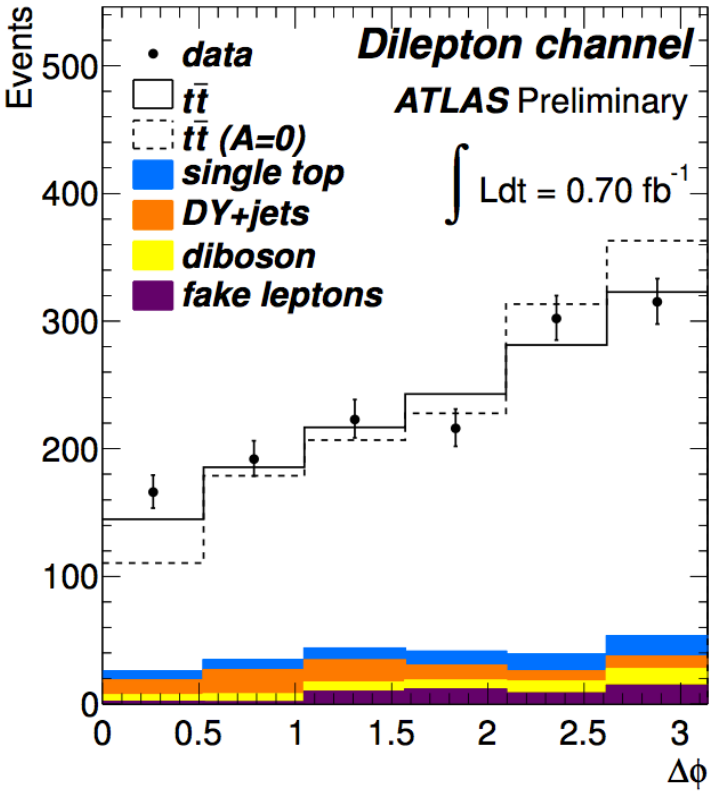
Dominant at Tevatron



Spin correlations II

- Analysis in **dilepton** ch. using **0.70 fb^{-1}**
- Observable: **$\Delta\Phi(l^+,l^-)$ in the lab frame**
  - **no need to reconstruct event kinematics**
- Dilepton selection (sl. 8), no b-tagging
- Main backgrounds (DY+jets and fake leptons) using DD methods
- $\Delta\Phi(l^+,l^-)$ distribution in data is fitted with SM and no-correlation predictions
- **SM contribution: $f^{SM} = 1.06 \pm 0.21$**
  - combining all channels

- Main systematics:
  - MC available statistics
  - signal modelling (MC generator and ISR/FSR)

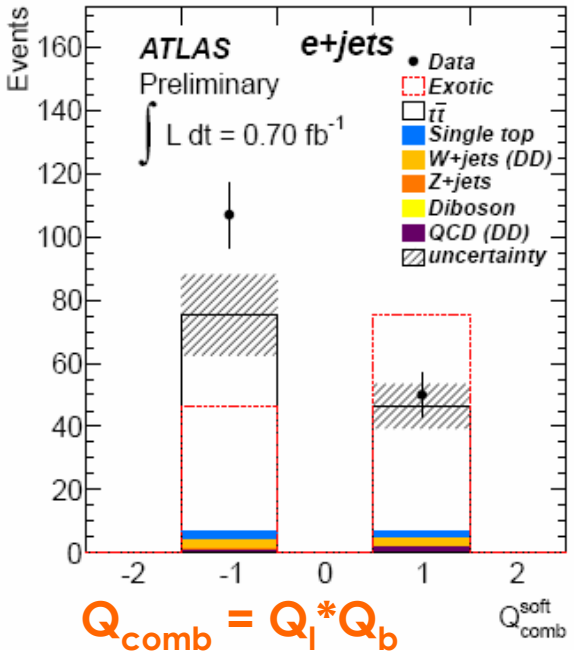


ATLAS-CONF-2011-117

Top quark charge

- Motivation: **exclude an exotic top quark** with a charge -4/3
- Analysis with **0.70 fb^{-1}**, l+jets ch.
- Crucial points for the analysis:
  - **pair W-boson and b-jet** in the correct way
  - **measure W boson and b-jet charge**
    - W boson charge from the lepton
- Two techniques:
  - W-b pairing from m(lepton,b-jets), **b-jet charge = sum of associated tracks charges**
  - W-b pairing using a kinematic fitter, select events with a soft μ inside the b-jet of the leptonic leg: **$Q_b = Q_\mu$**

- Main systematics: ISR/FSR modelling



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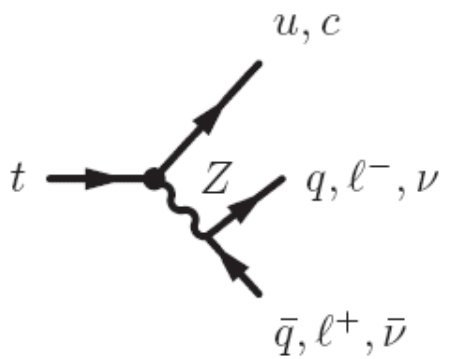
Agreement with SM: **exotic top excluded with >5σ** with both techniques combining electron and muon channels

FCNC I

- Motivation:
  - in SM top quark FCNC are **absent at tree-level** and are **highly suppressed** by the GIM mechanism; present only through loop corrections
  - several BSM physics models predict **higher branching ratios** for FCNC top quark decays
- Possible channels for top quark FCNC are:
  - $t \to Z\,q$
  - $t \to g\,q$
  - $t \to \gamma q$
- ATLAS searches:
  - $t \to qZ$ decay (see next slide)
  - $qg \to t$ production:
    - analysis performed selecting single top events, with 2010 data
    - **σ_{gq} x BR($t \to bW$) < 17.3 pb**

$t \to qZ$ decay

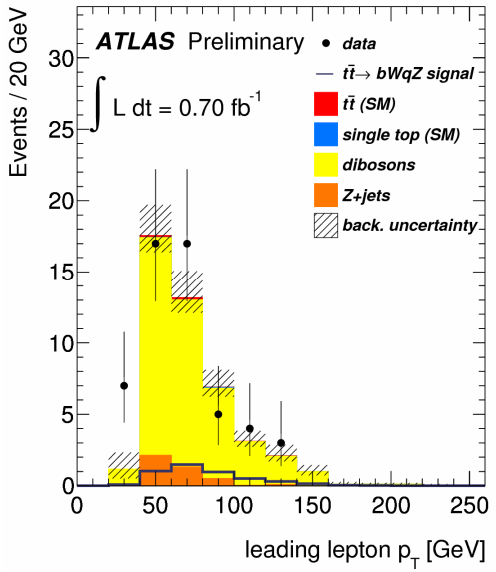


FCNC II

NEW !!

- Analysis performed with **0.70 fb^{-1}**
- $t\bar{t}$ events, with one top decaying according to SM and the other through FCNC: **$t\bar{t} \rightarrow WbZq$**
- Considered only events with: W(lν) and Z(l^+l^-)
  - SIGNATURE: **3 isolated leptons,** two of them with same flavour and opposite charge and invariant mass equal to M_Z, **2 jets and E_T^{miss}**
- Main backgrounds:
  - WW, ZW with 3 real isolated leptons: from MC
  - Z+jets, $t\bar{t}$ (l+jets, dilepton), single top, W+jets and QCD with 1, 2 or 3 fake leptons: DD techniques
- Main systematics: WW, ZW modelling

No signal evidence: BR(t→qZ) < 1.1%



ATLAS-CONF-2011-154

Search for new physics in $t\bar{t}$ events

In the following:

- Resonances in $t\bar{t}$ events
  - lepton+jets and dilepton channels
- Search for new particles in top events

Resonances

- Motivation: the existence of new resonances that decay predominantly in top quark pair predicted by some BSM models
- Analysis performed in **dilepton** ch. with **1.04 fb^{-1}** of data
- Goal: **search for excess in the H_T+E_T^{miss} spectrum**
- Signal: KK-gluon in Randall-Sundrum model
- Event selection: no b-tagging request
- Backgrounds:
  - DY+jets and fakes from data
  - SM $t\bar{t}$, t, dibosons from MC
- **Data are compatible with SM background only hypothesis:**

m_{KK} > 0.84 TeV at 95% CL

- Main systamatics:
  - JES and $t\bar{t}$ modelling

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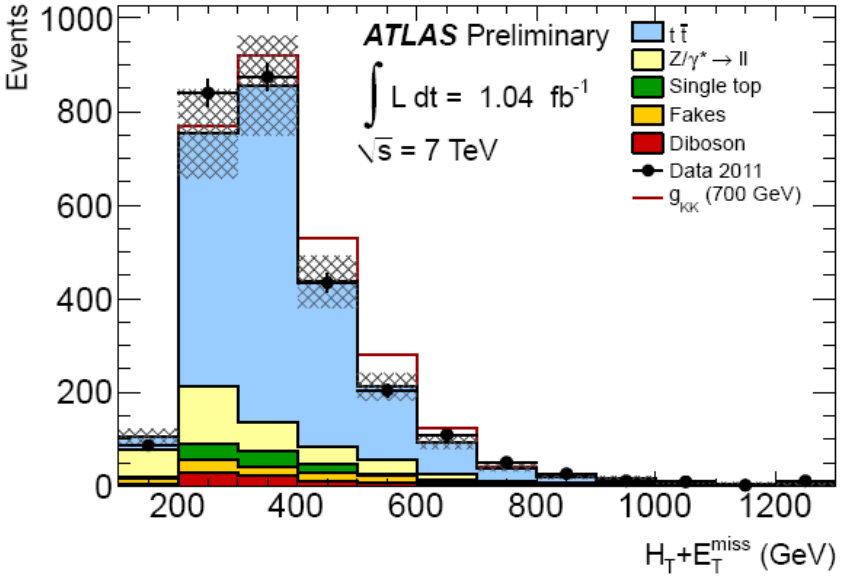

Other new physics searches

- Search for resonances in m(top-antitop) spectrum performed in l+jets ch. with 200 pb^{-1}: **limits for a Z' boson:**
  - 95% C.L. limits on $\sigma \times BR(Z' \to t\bar{t})$: 38 at $m_{Z'}$=500 GeV and 3.2 at $m_{Z'}$=1300 GeV
- Other new physics searches involving top quark reported in Nenad Vranjes talk:
  - $t\bar{t}$ + E_T^{miss} searches:
    - data are found to be consistent with SM expectations. Limits at 95% CL put on new particles masses and cross sections
  - same sign top search:
    - no observation of same sign tops, upper limits on flavour-changing Z' boson cross-section
  - …

Conclusions

Conclusions

- All results are consistent with SM expectation
- Very competitive measurements:
  - top quark pair cross section measured in different channels, using 2011 data
    - **up to 7% precision reached**
  - measurement of jet multiplicity to constrain ISR
    - VERY RECENT RESULT, presented at TOP2011 conference
  - **NEW result: top-antitop + photon cross section**
  - single top cross section measured for different production mechanisms
  - measurements of the main top properties:
    - **NEW result: UPDATE on FCNC measurement**
  - searches for new physics in top events: constraints on the mass of new particles
- Most of them already limited by systematics
  - work ongoing to decrease the various contributions
- Still a lot of 2011 data to be analyzed