Top quark pair production cross section at LHC in ATLAS

ICNFP 2013
Κρήτη, Ελλάδα

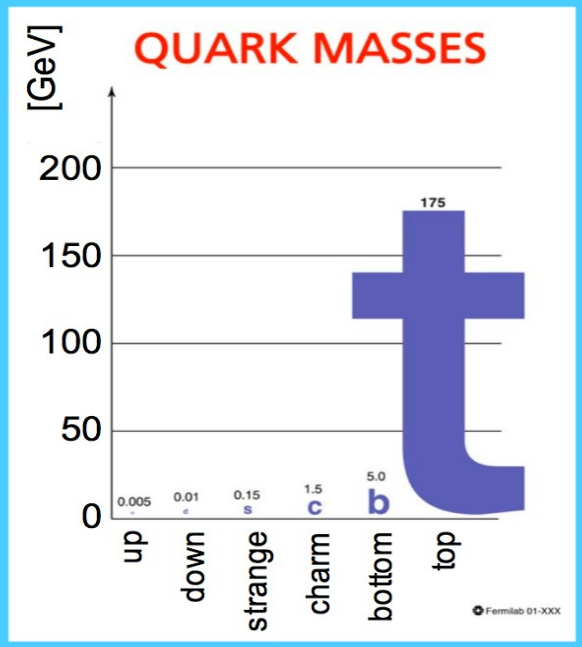
Sebastián Pedraza López (IFIC, CSIC-UV)
on behalf of the ATLAS collaboration

IFIC
INSTITUT DE FÍSICA CORPUSCULAR

VNIVERSITAT DE VALÈNCIA

CSIC
CONSEJO SUPERIOR DE INVESTIGACIONES CIENTÍFICAS

Introduction



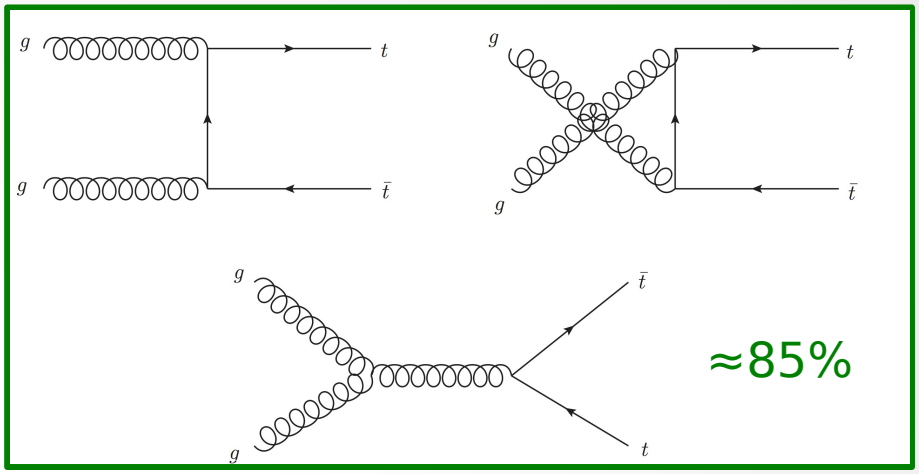
- Top quark is the heaviest particle in the SM
- It decays before hadronization

- The top quark pair production is a good probe to test...
  - Perturbative QCD
  - New physics in the production mechanism
  - The performance of the detector
  - MC simulations

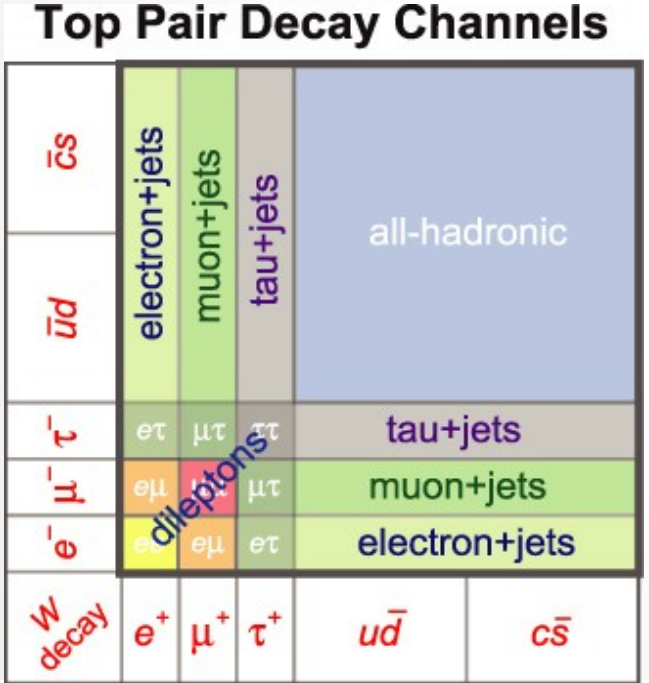
- This talk will show the results of the latest studies availables on the inclusive top quark pair cross section

Cross section

- Top quark pairs are produced through strong interaction (LHC → mainly via gluon fusion)
- Total inclusive cross section reaches full NNLO precision
  - Czakon, Fiedler, Mitov arXiv:1303.6254
  - Czakon, Mitov arXiv:1210.6832



$$\sigma_{t\bar{t}}\left(\sqrt{s}=7\,TeV\right)=177^{+10}_{-11}\,pb$$
$$\sigma_{t\bar{t}}\left(\sqrt{s}=8\,TeV\right)=253^{+13}_{-15}\,pb$$

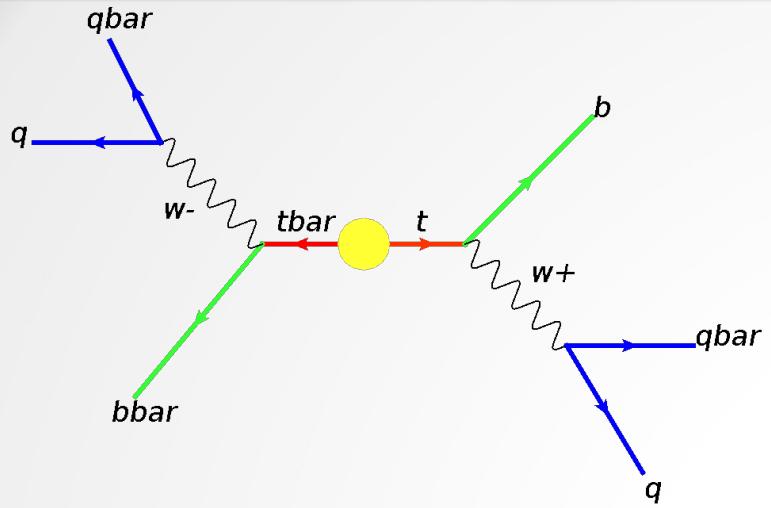


- Top decays by weak interaction to a W boson and a b quark ~100% of the times
  - W decay modes define the analysis channels

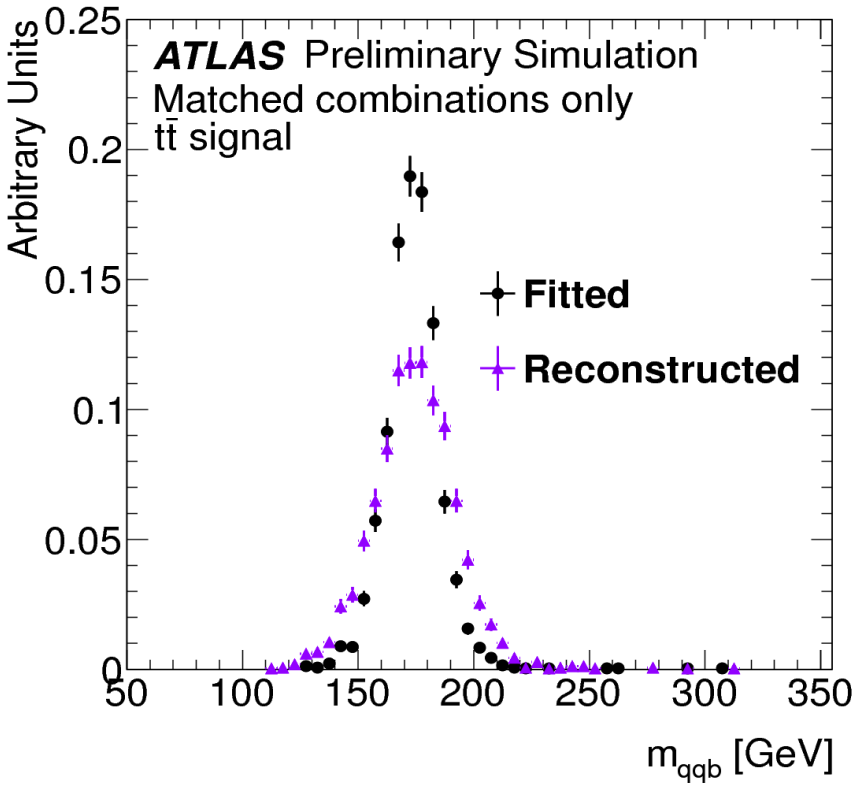
Available ATLAS results

	7 TeV	8 TeV
All hadronic, 46%	y	n
Lepton + jets, 34%	y	y
Tau + jets, 10%	y	n
Tau + lepton, 4%	y	n
Dilepton 6%	y	n

All hadronic, 7TeV 4.7 fb^{-1}, (ATLAS-CONF-2012-031)



- **Event selection:**
  - Requires ≥ 5 jets with p_t ≥ 55 GeV, 6th jet with p_T ≥ 30GeV within |η| < 2.5
  - At least 2 b-jets with p_T ≥ 55 GeV
  - ΔR(j,j') > 0.6, > 1.2 for the b-tagged jets
  - Veto leptons & missing energy

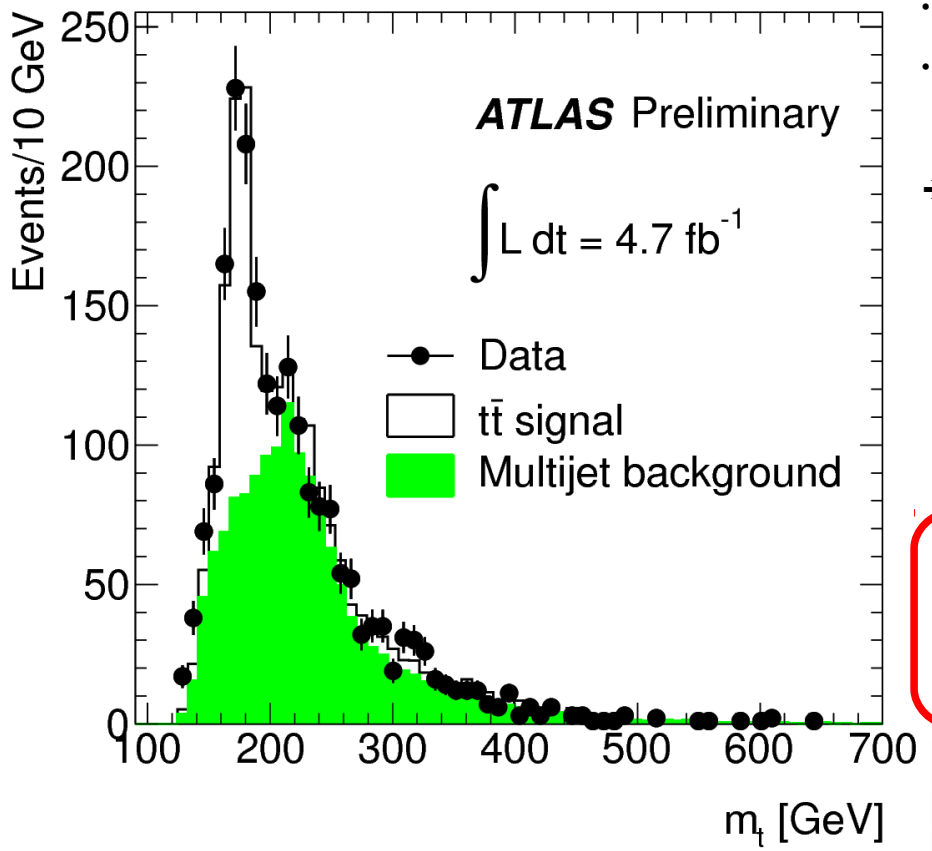


- **Strategy:**
  - Reconstruction of full event topology
  - Kinematic likelihood fit to assign jets to top quarks decays
  - Constraint on W mass and m(t) = m(t̄)
  - Allows to build m_{top} as discriminant improving resolution

- Background:
  - QCD multijet

All hadronic, 7TeV 4.7 fb^{-1}, (ATLAS-CONF-2012-031)

- Method
- Unbinned likelihood fit to extract cross section from m_{top}
- QCD multijet background template from data
- Correction factors to account for modeling & composition differences from MC

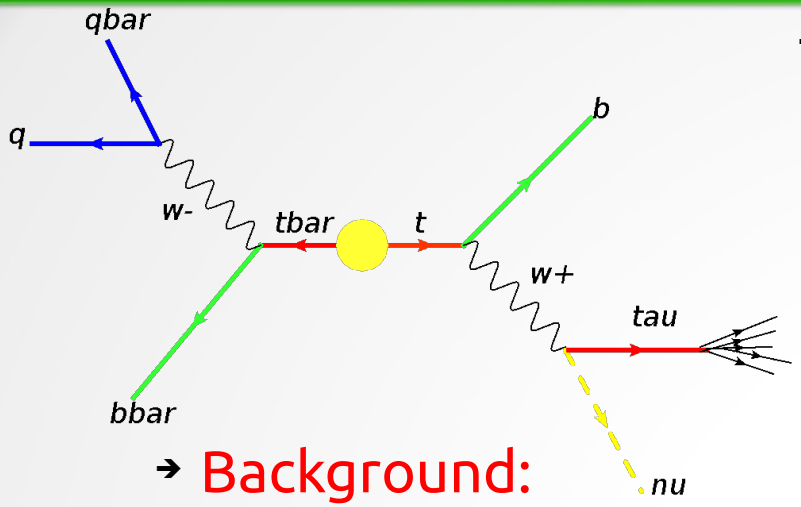


- Full 7 TeV dataset used
- Good agreement with SM

- Uncertainties:
  - Jet energy scale → 20%
  - b-tagging → 17%
  - ISR/FSR model → 17%
  - 36% total systematic uncertainty

$$\sigma_{t\bar{t}} = 168 \pm 12\,(stat.)^{+60}_{-57}\,(syst.) \pm 6\,(lumi)\ pb$$

τ+ jets, 7TeV 1.67 fb^{-1}, (Eur.Phys.J.C. 73 3 (2013) 2328)

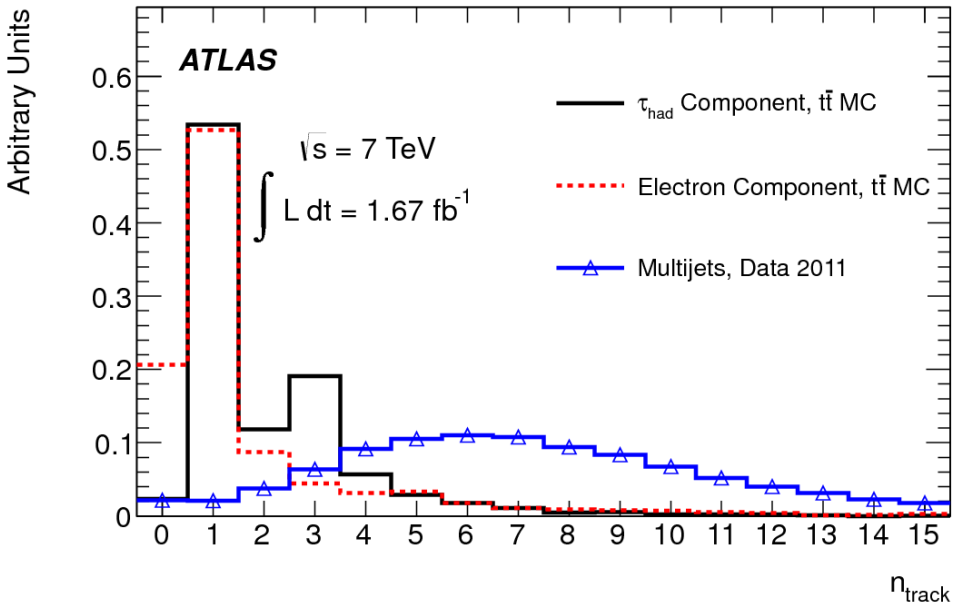


Background:

- QCD multijet
- $t\bar{t}$ → other channels
- W → e/μ
- Single top

Event selection:

- At least 5 jets with $p_T \geq 20$GeV & $|\eta| < 2.5$
- At least 2 b-jets
- Veto events with lepton $p_T \geq 15$ GeV
- $S(E_T^{miss}) = E_T^{miss}/(0.5\sqrt{\sum E_T}) > 8$
- Hadronic top decay reconstructed with the 3-jet combination of highest p_T sum, including one of the two b-jets
- Find τ_{had} with $p_T > 40$ GeV as highest p_T not b-tagged jet, not belonging to the hadronic top decay



Strategy:

- 1 or 3 prong decays of τ_{had} yield small number of tracks associated to τ_{had} candidate
- Count number of tracks with:
  - $p_T \geq 1$ GeV if $\Delta R < 0.2$
  - p_T dependent cut if $0.2 < \Delta R < 0.6$
- Real electrons from ttbar fail dedicated veto faking τ_{had} candidate: considered in the signal , estimated by simulation

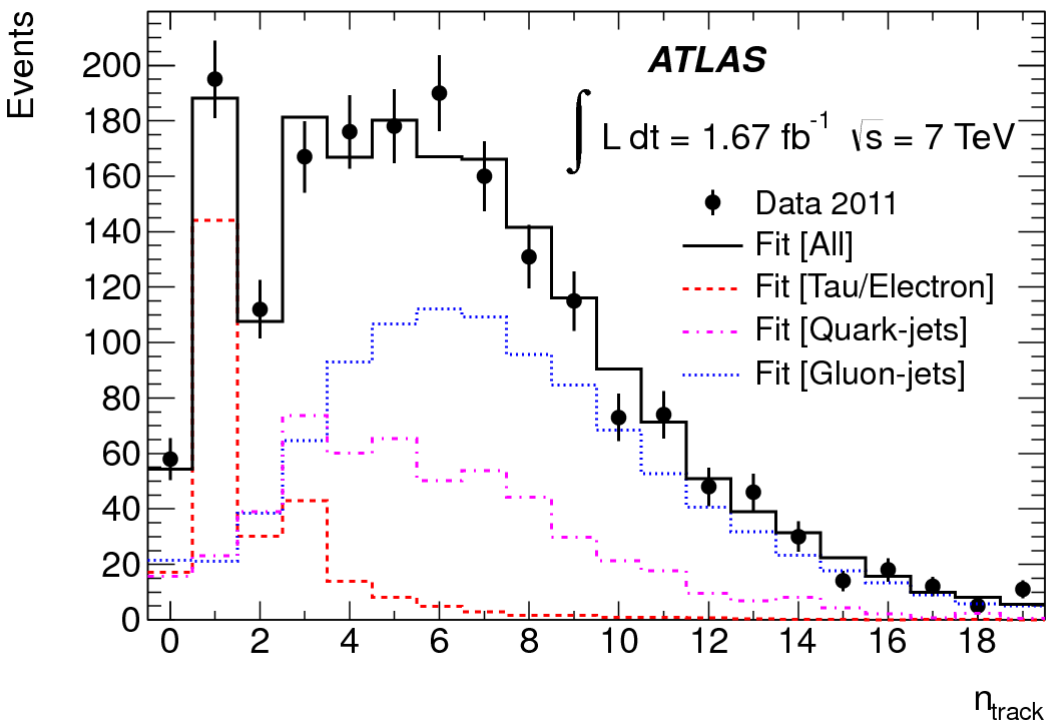
τ+ jets, 7TeV 1.67 fb^{-1}, (Eur.Phys.J.C. 73 3 (2013) 2328)

- ➔ **Method:**
- Likelihood fit to number of track distribution with:
  - Combined e/τ template (signal)
  - Gluon jet template (from multiijet-dominated sample)
  - Quark jet template (ttbar from mu+jets sample)

$$\sigma_{t\bar{t}} = \frac{N_\tau}{L \cdot \varepsilon}$$

- ➔ ε from MC
- ➔ N_τ from fit

$$\sigma_{t\bar{t}} = 194 \pm 18\,(stat.) \pm 46\,(syst.)\ pb$$

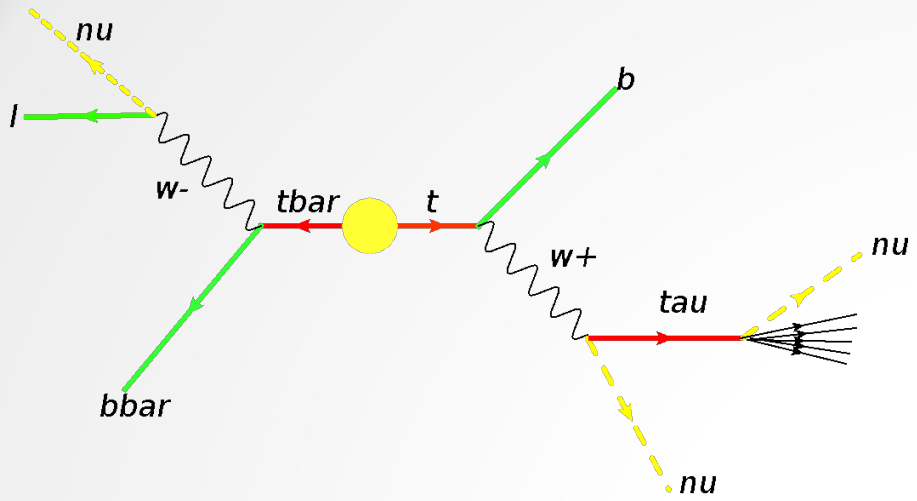


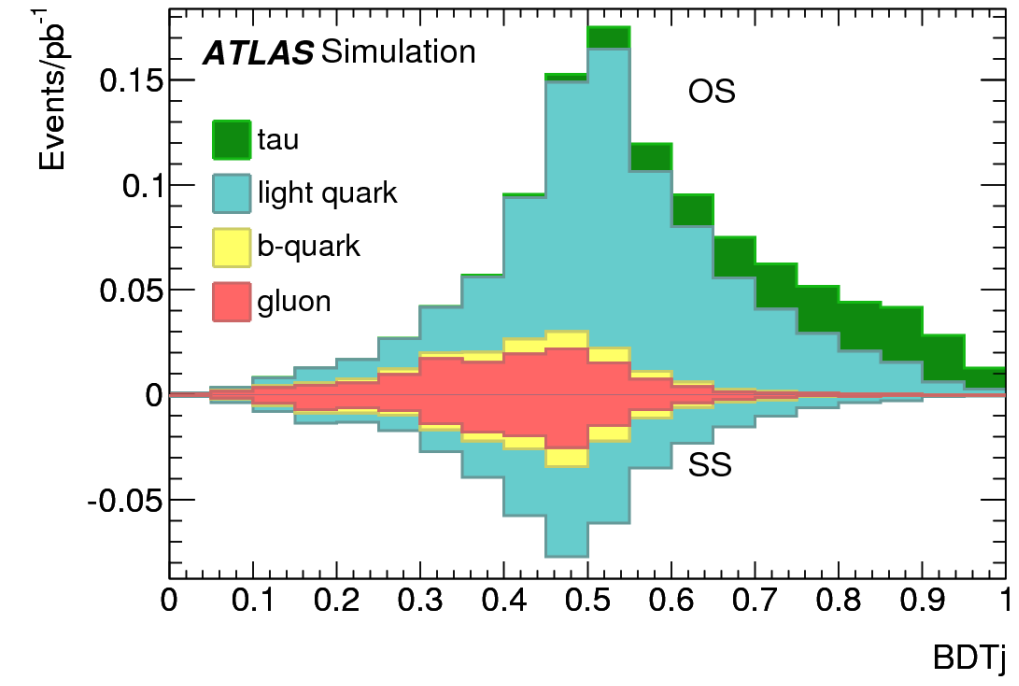
	Fit result
Tau/Electron	270 ±24 (stat) ±11(sys)
Quark-jets	520 ±97 (stat) ±78(sys)
Gluon-jets	960 ±77 (stat) ±74(sys)

- ➔ **Uncertainties:**
  - ISR/FSR modeling → 15%
  - Event generator → 11%
  - b-jet tagging efficiencies → 9%
  - 24% total systematic uncertainty

- First measurement in τ+ jets channel at LHC
- Good agreement with theoretical predictions

τ+ lepton, 7TeV 2.05 fb^{-1}, (Phys. Lett. B 717 (2012) 89-108)





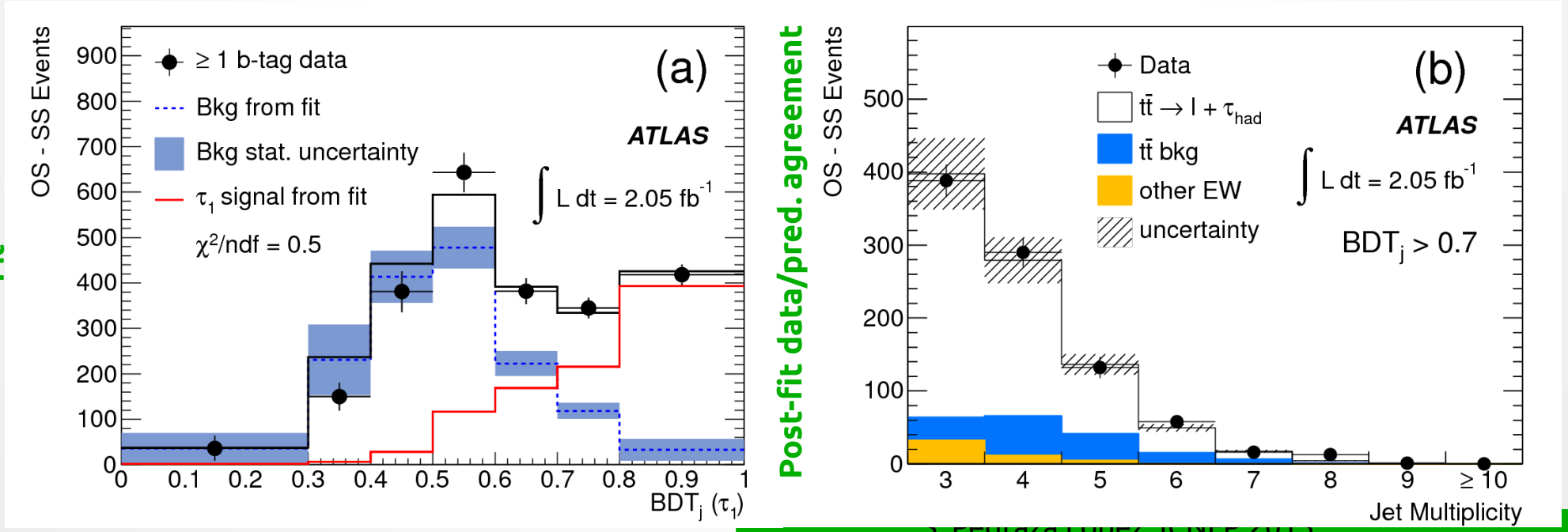
- **Event selection:**
  - 1 isolated μ (e) with $p_T \geq 20GeV$ ($p_T \geq 25GeV$)
  - 1 τ candidate
  - ≥2 jets with $p_T \geq 25GeV$ & $\Delta R(\tau,j) < 0.4$
  - Sample split into 0-bjet & ≥1-bjet events
  - $E_T^{miss} > 30$ GeV & $\sum E_T > 200GeV$
- Background:
  - Electrons faking τ: suppressed by dedicated Boosted Decision Tree (BDT_e)
  - OS (SS): events where tau and lepton have opposite (same) sign. The SS sample is bkg dominated while the OS contains real tau leptons
  - Gluon and light jets misidentified as τ jets
- **τ Identification:**
  - Starts by considering all jets as τ candidate
  - BDT_j from calorimeters & track-based variables
  - 1-3 associated tracks with pt ≥ 1GeV within $\Delta R < 0.4$
  - Sum of trk charges ≠ 0

τ+ lepton, 7TeV 2.05 fb^{-1}, (Phys. Lett. B 717 (2012) 89-108)

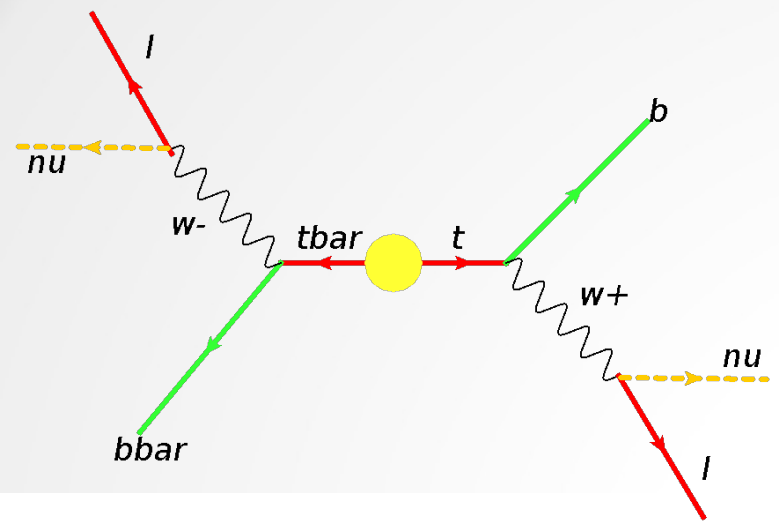
- **Method**
- X² template fits to Opposit Sign-Same Sign BDT$_j$ (τ vs jet) distribution for >=1 bjet
- Differentiated fits for τ_1,τ_3 and eτ,μτ channels
- Signal templates from MC, background from 0-b-jet events
- Final cross section as combination of τ_1,τ_3 and eτ,μτ

- **Uncertainties:**
  - b-jet tagging → +9% -7.7%
  - ISR/FSR models → ± 4.8%
  - τ-ID → ± 3%
  - 11% total systematics uncertainty

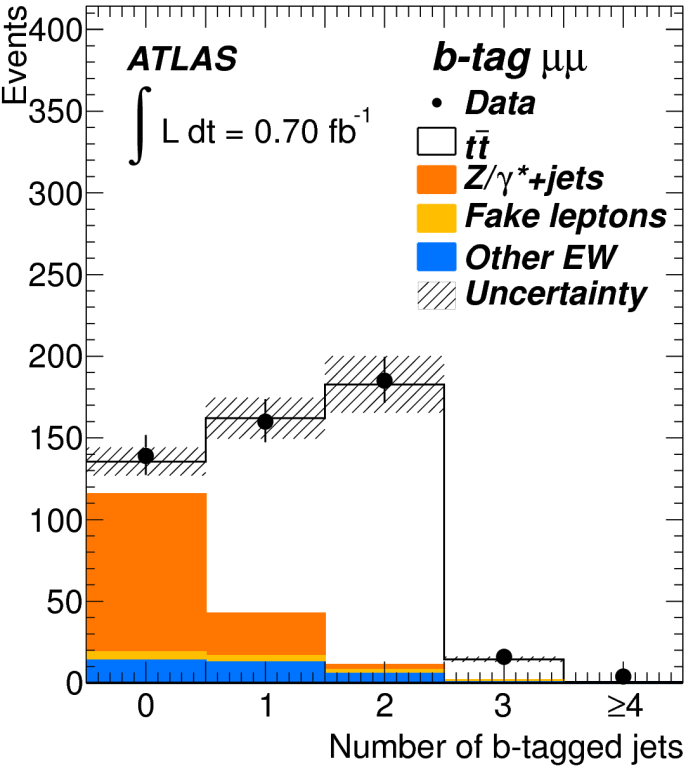
$$\sigma_{t\bar{t}} = 186 \pm 13\,(stat.) \pm 20\,(syst.) \pm 7\,(lumi)\ pb$$

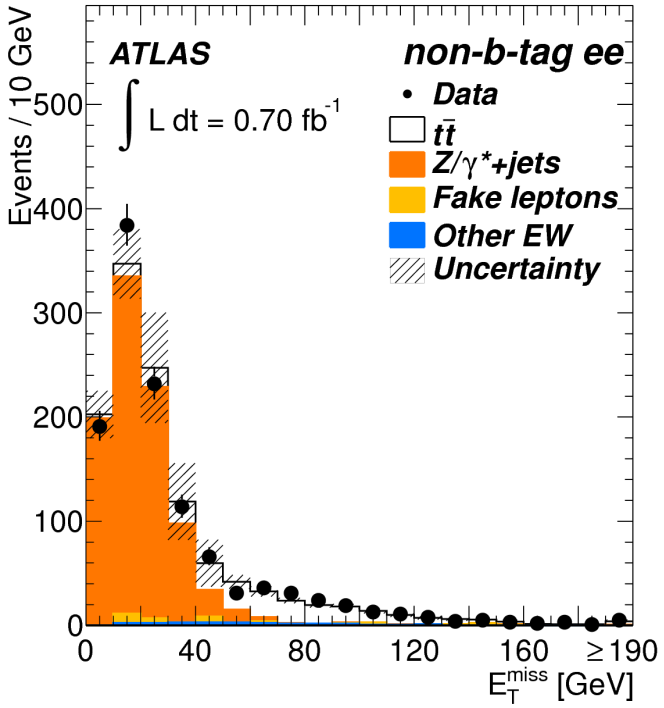


Dilepton, 7TeV 0.7 fb^{-1}, (JHEP 1205 (2012) 059)



- **Event selection:**
  - 2 oposite sign leptons with $p_T \geq$ 20-25 GeV
  - $\geq$ 2jets with $p_T \geq$ 25GeV
  - $m_{ll} > 15$ GeV & $|m_{ll} - m_z| > 10$ GeV & $E_T^{miss} > 60$ GeV for ee/μμ
  - $H_T > 130$GeV for eμ
  - Additional selection with $\geq$ 1 bjet → $E_T^{miss} > 40$GeV
- **Lepton + track**
  - Sensitivity enhaced selecting 1 isolated lepton+1 isolated track
  - ID track with $p_T \geq 25$ GeV
  - No additional b-tag
  - $E_T^{miss} > 45$ GeV & $H_T > 150$ GeV



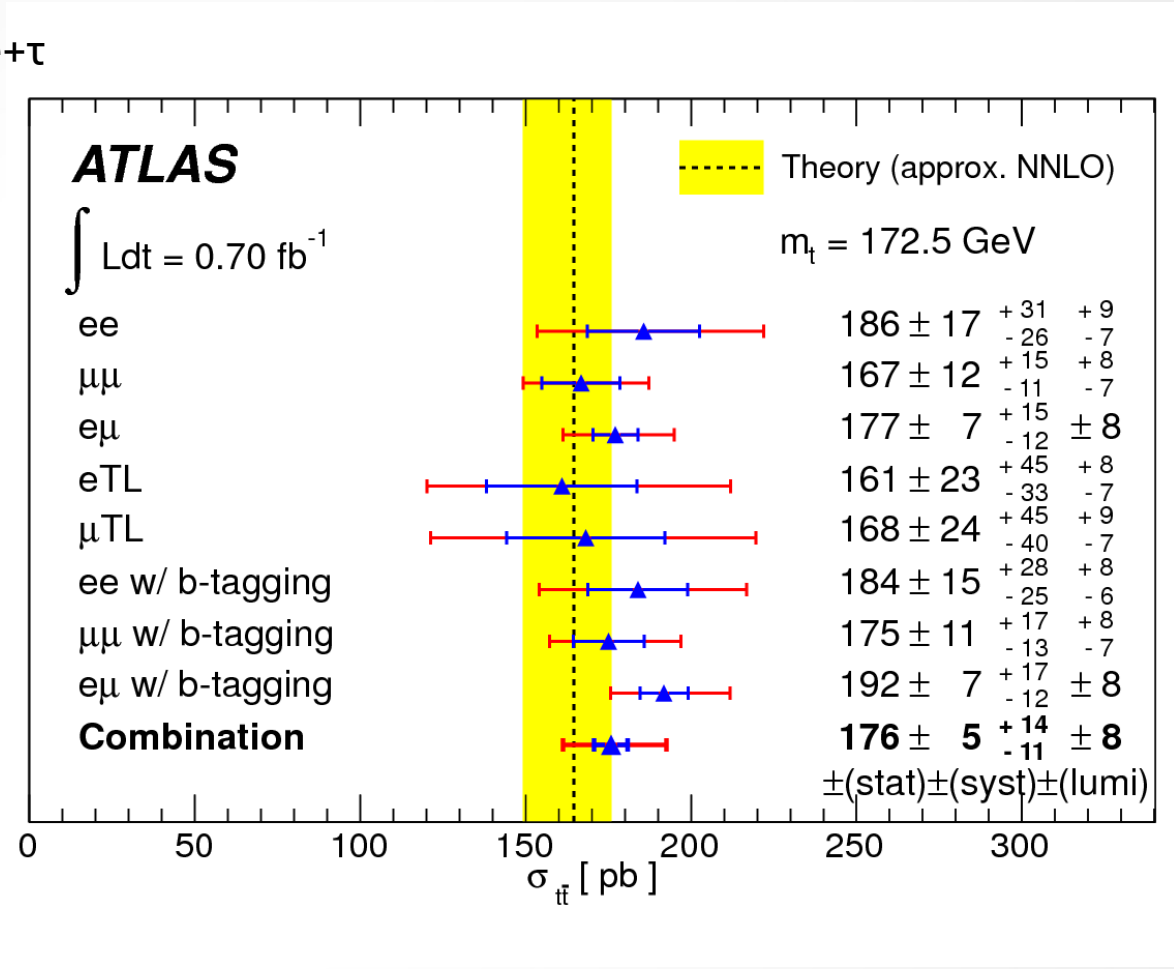


- **Background:**
  - Z/Y* +jets
  - W + jets,tt(l+j), single top → jets faking lepton

Dilepton, 7TeV 0.7 fb^{-1}, (JHEP 1205 (2012) 059)

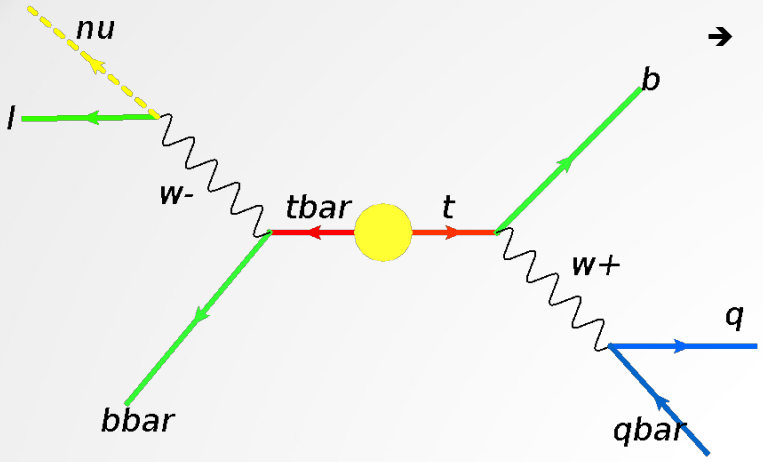
- **Method:**
  - Counting events in:
    - without b-tag → ee, μμ, eμ, μ+τ, e+τ
    - with b-tag → ee, μμ, eμ
  - Profile likelihood fit to all 8 bins simultaneously
  - $\sigma_{t\bar{t}}$ consistent between channels

- **Uncertainty:**
  - Modeling of signal process → 5%
  - Jet related uncertainties → 4%
  - Lepton related uncertainties → 3%
  - Systematic uncertainties dominate the measurement
  - 9.6% total uncertainty



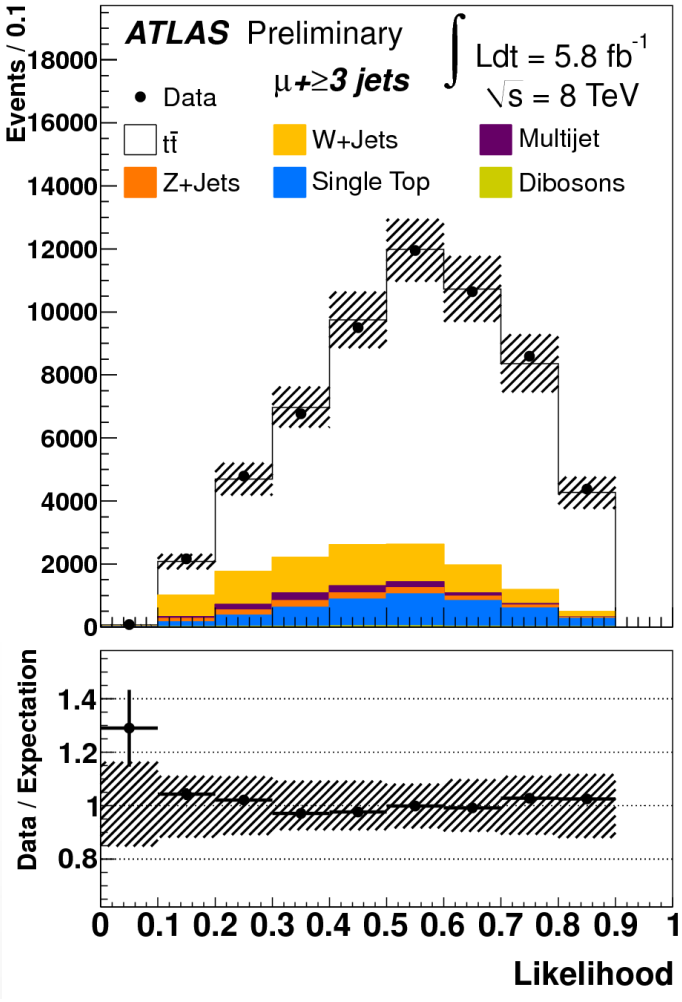
$$\sigma_{t\bar{t}} = 176 \pm 5\,(stat.)^{+14}_{-11}\,(syst.) \pm 8\,(lumi)\ pb$$

Lepton + Jets 7 & 8 TeV



Common event selection:

- 1 isolated lepton with $p_T \geq$ 20-25GeV
- ≥3 jets with $p_T \geq$ 25GeV
- E_T^{miss}> 30-35 (20-25) GeV in the e+jets (μ+jets) channel
- $m_T(W)$ > 20GeV or $m_T(W)+E_T^{miss}$> 60GeV → to suppress QCD multijets
- Can require ≥ 1b-jet



Background:

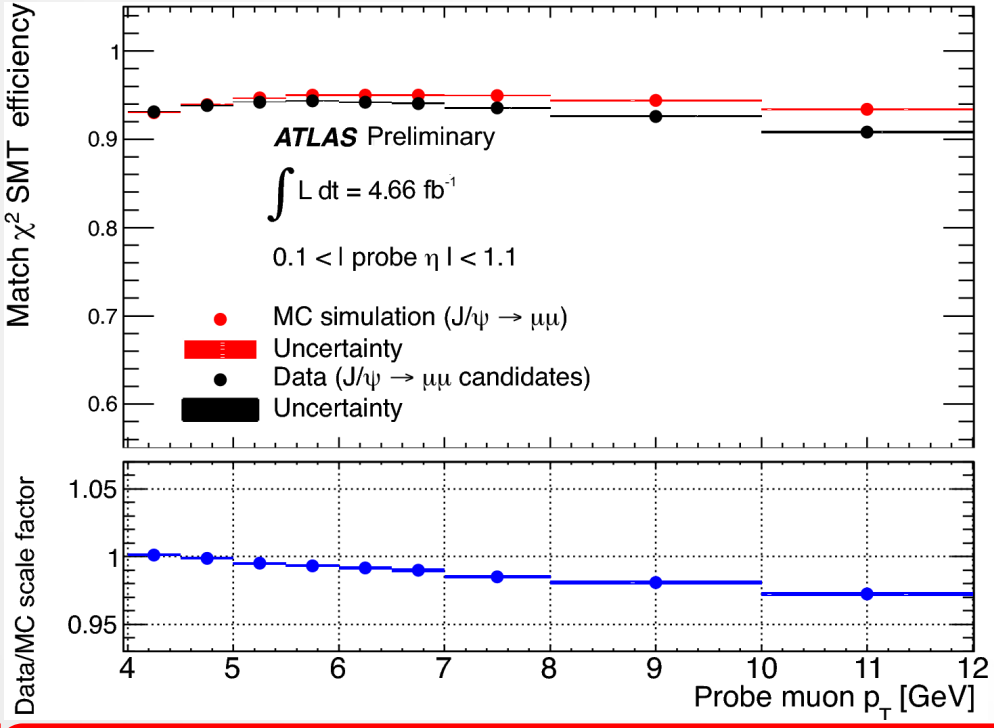
- W+jets
- QCD multijet, jets faking isolated leptons
- Single top production
- Z+jets
- Diboson production

Discriminators:

- b-tagging enhaces signal purity
- Use of several event shape variables, like aplanarity and energy ratios

Lepton + jets, 7TeV 4.66 fb^{-1}, (ATLAS-CONF-2012-131)

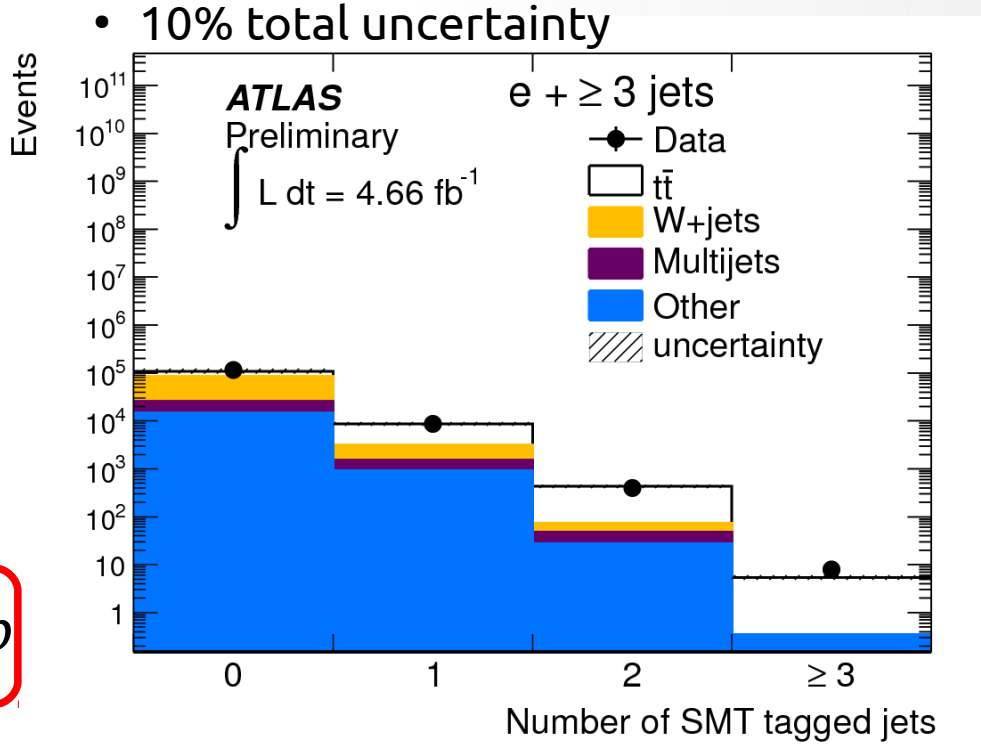
- **Soft muon tagging:**
  - Development of new technique
  - 36% signal events contain semimuonic b → μX decays
  - Uses quality of match between ID & MS tracks to discriminate b&c-jets from light & gluon jets



$$\sigma_{t\bar{t}} = 165 \pm 2(stat.) \pm 17(syst.) \pm 3(lumi)\ pb$$

- ≥ 3 jet selection, ≥ 1 SMT-bjet
- Remove Z/Y resonances in μ+jets events
- Dominant backgrounds estimated from data
- Cross section extraction via counting signal events after selection

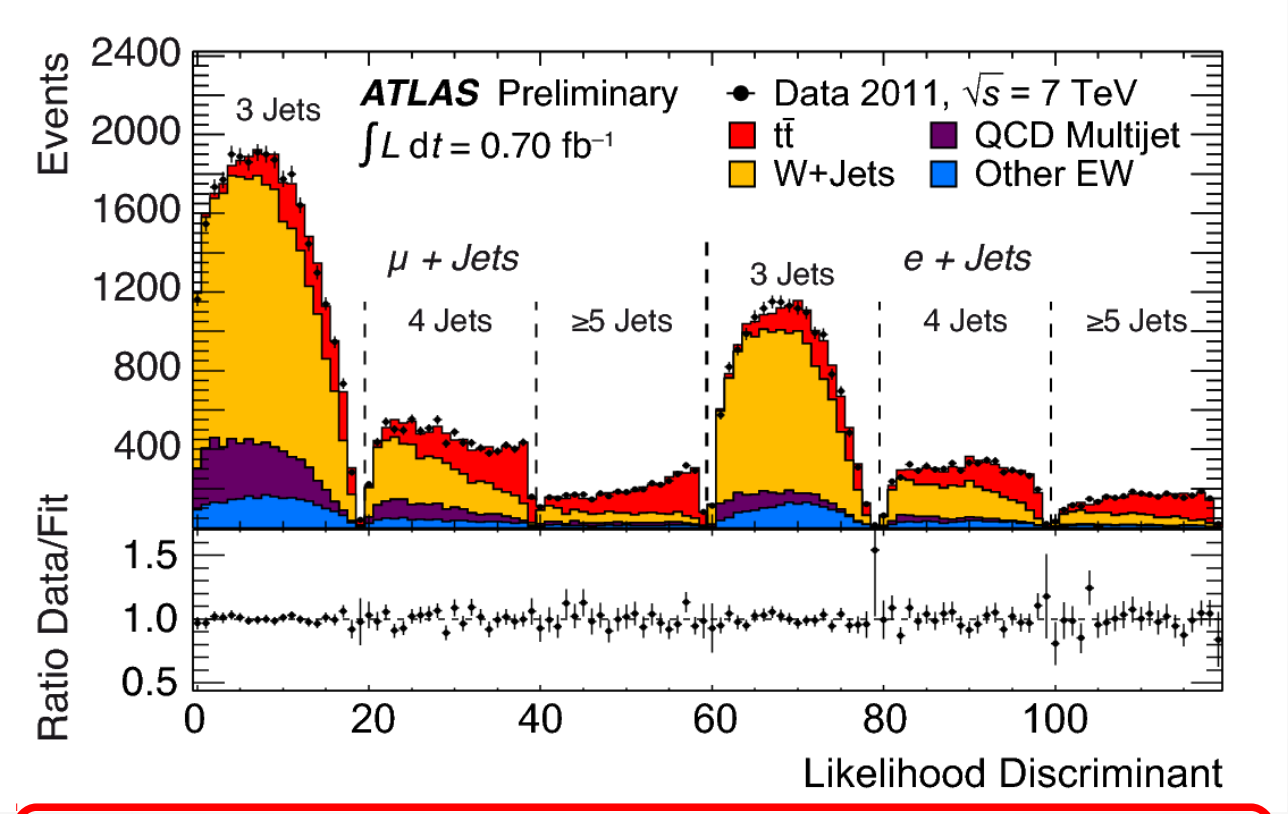
- **Uncertainties:**
  - Background normalization → 7%
  - Jet energy scale → 3.5%
  - Simulation of b → μX → 2.9%
  - 10% total uncertainty



Lepton + jets, 7TeV 0.7 fb^{-1}, (ATLAS-CONF-2011-121)

- Method
- Likelihood discriminant from η(e,μ), p_T(j), aplanarity
- b-tagging information is not required
- Simultaneous fit in e/μ + 3,4, ≥ 5 jet events
- Template likelihood fit including systematic uncertainties as nuisance parameters

- Uncertainties:
  - Signal modeling → 3%
  - Jet energy scale → 2%
  - MC statistics → 1.8%
  - 6.6% total uncertainty

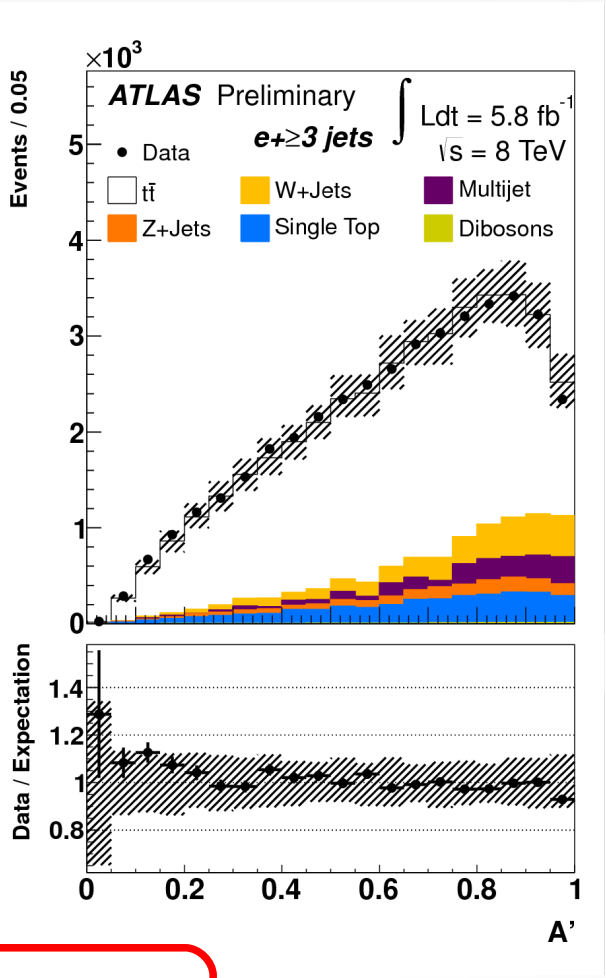


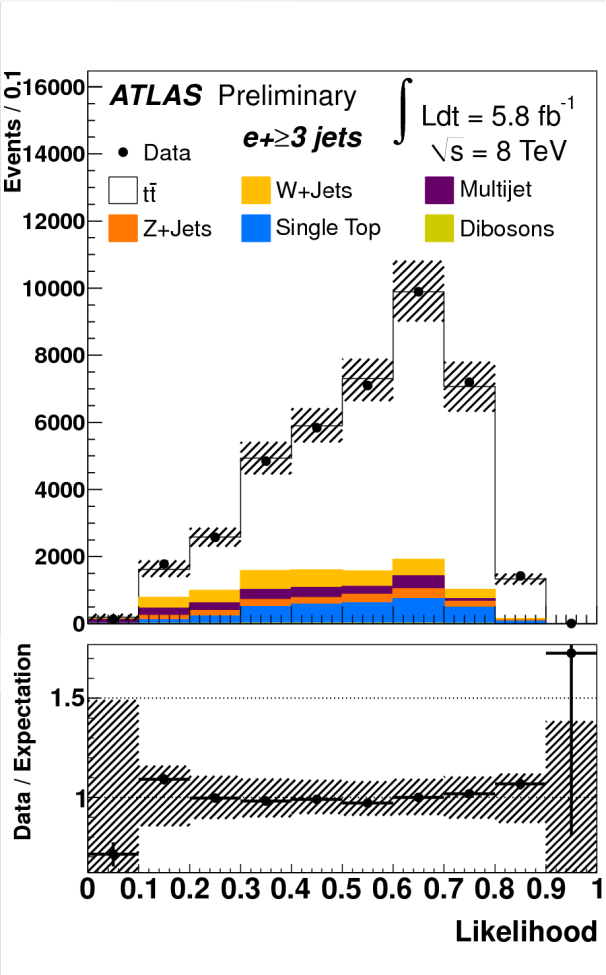
$$\sigma_{t\bar{t}} = 179 \pm 3.9(stat.) \pm 9(syst.) \pm 6.6(lumi)\, pb$$

Lepton + jets, 8TeV 5.8 fb^{-1}, (ATLAS-CONF-2012-149)

- Method
- Likelihood discriminant → η(e,μ), aplanarity
- Inclusive e/μ + ≥ 3 jet selection for high statistics
- ≥ 1 b-tagged jet to supress W+jets background
- Template likelihood fit to data to obtain cross section
- Consistent results betwen channels and with SM predictions

- Uncertainties:
  - Signal modeling → 11%
  - Jet calibrations → 6%
  - 13% systematic uncertainty





$$\sigma_{t\bar{t}} = 241 \pm 2(stat.) \pm 31(syst.) \pm 9(lumi)\ pb$$

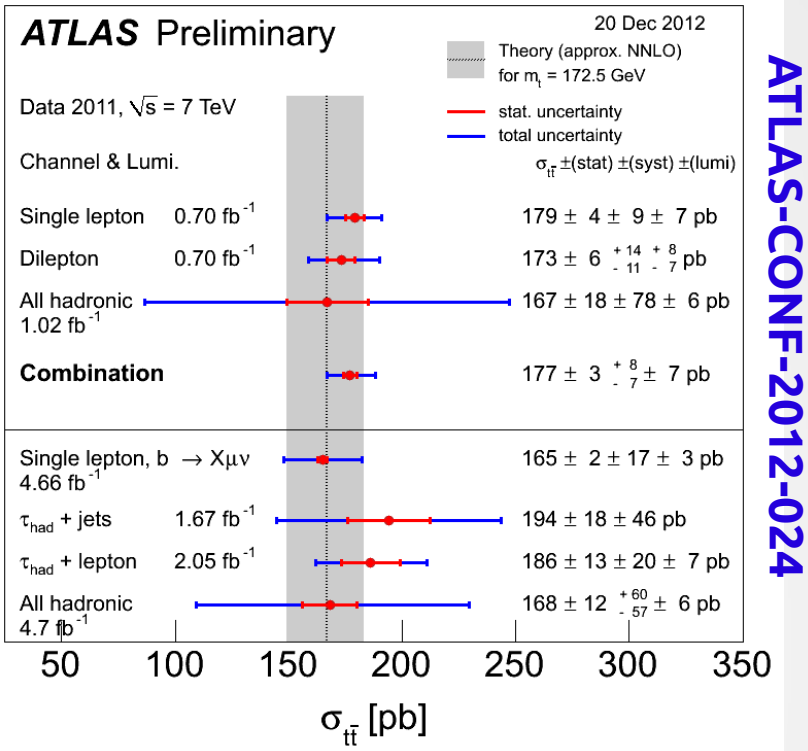
summary

ATLAS results presented for all channels

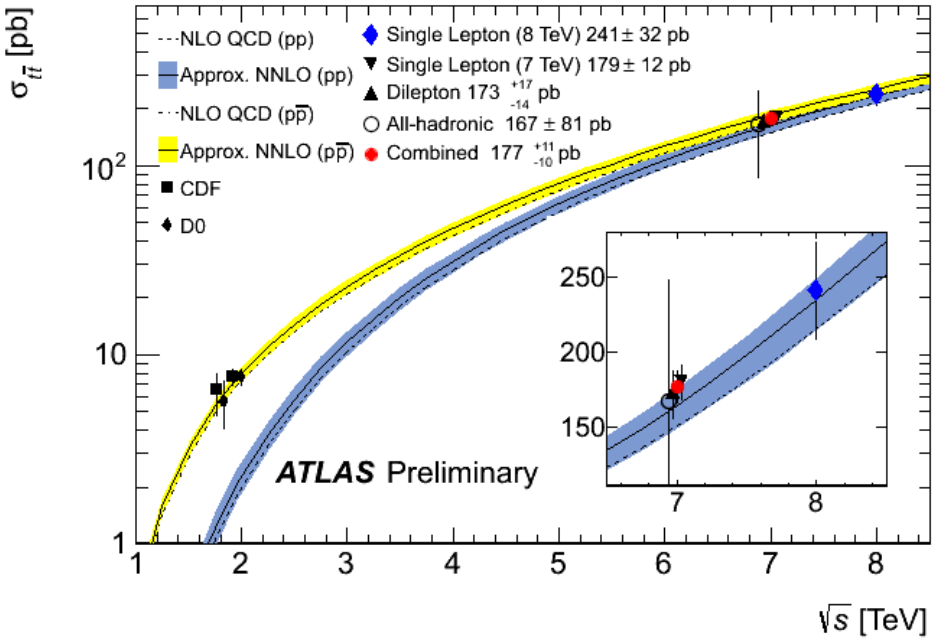
- 7 TeV:
  - All channels covered
  - New techniques development to improve the background determination
  - Good agreement with SM predictions:

Theo* → $\sigma_{t\bar{t}}\left(\sqrt{s}=7\,TeV\right)=177^{+10}_{-11}\,pb$

ATLAS comb. → $\sigma_{t\bar{t}}=177\pm3_{stat.}\ ^{+8}_{-7\,syst}\pm7_{lumi}\,pb$



ATLAS-CONF-2012-024



- 8 TeV:
  - Starting efforts to analyse the huge 8 TeV sample
  - First result in lepton+jets shown
  - Good agreement with SM:

Theo* → $\sigma_{t\bar{t}}\left(\sqrt{s}=8\,TeV\right)=253^{+13}_{-15}\,pb$

ATLAS 1st 8TeV result. → $\sigma_{t\bar{t}}=241\pm2_{stat.}\pm31_{syst.}\pm9_{lumi}\,pb$

* see slide 3 for references