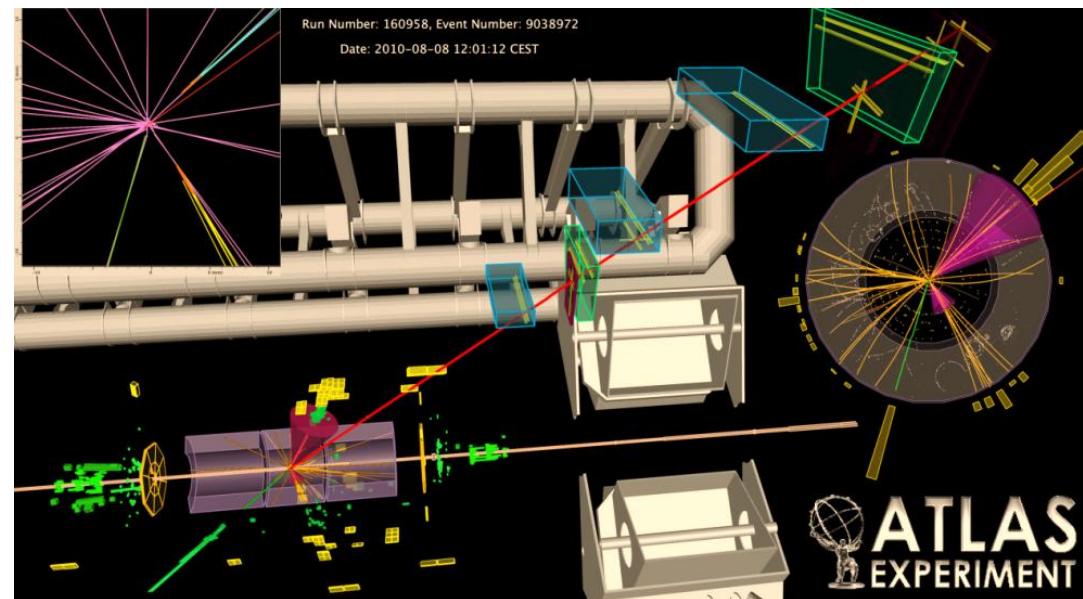
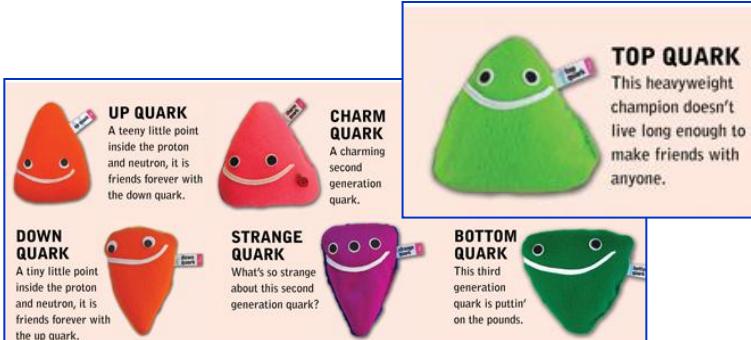


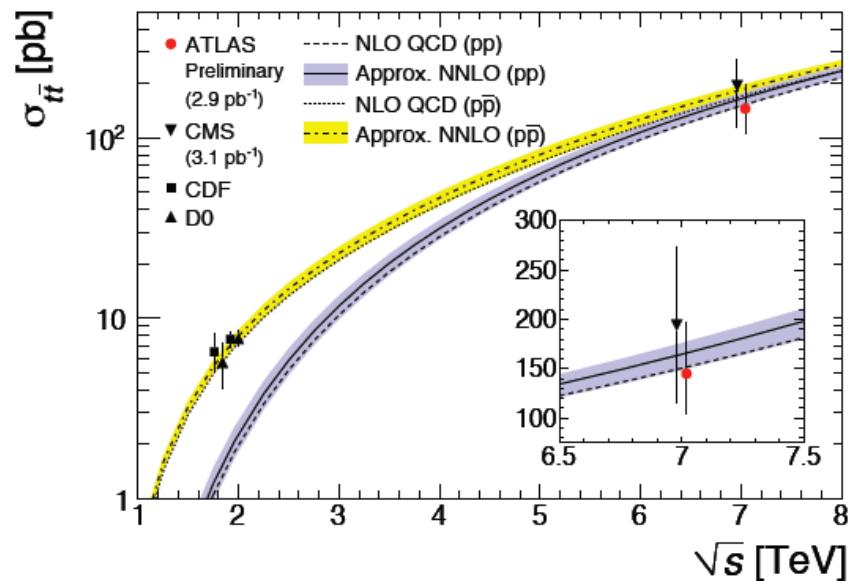
Experimental Overview: Cross-Section Measurements

Markus Cristinziani (Bonn)



Introduction

- ▶ **tt production: “new standard candle” for high-p_T physics**
 - baseline: precise inclusive cross-section measurement with good control of backgrounds and systematics
- ▶ **Initial ATLAS and CMS measurements had significant uncertainties**
- ▶ **Want to get more competitive compared to Tevatron (~9%, 7% from tt/Z ratio) and theoretical predictions (~9%)**
- ▶ **Analysis strategies with 2010 dataset geared towards best overall balance between statistical and systematic uncertainties**

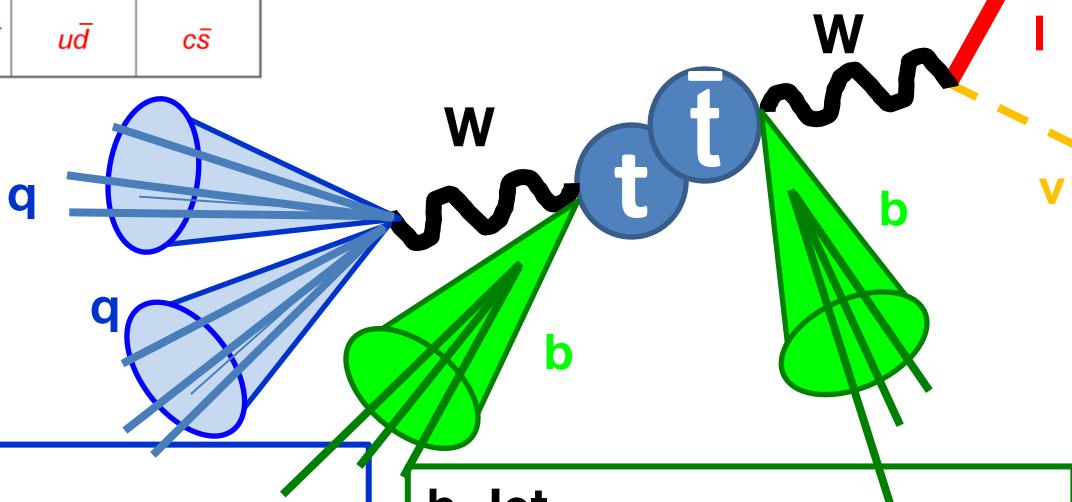


Theory Expectation
($m_t=172.5$ GeV, approx. NNLO, CTEQ66):

$$\sigma_{t\bar{t}}(\text{theory}) = 164.57^{+4.30}_{-9.27} (\text{scale})^{+7.15}_{-6.15} (\text{PDF}) \text{ pb.}$$

Selection of Top Quarks

$\bar{c}s$				all-hadronic	
$\bar{u}d$	electron+jets		muon+jets		tau+jets
$e^- \tau^+$	$e\tau$	$\mu\tau$	$\tau\tau$	tau+jets	
$\mu^- \tau^+$	$e\mu$	$\mu\tau$	$\mu\tau$	muon+jets	
$e^- e^+$	ee	$e\mu$	$e\tau$	electron+jets	
W decay	e^+	μ^+	τ^+	$u\bar{d}$	$c\bar{s}$



Jet

- Topological clusters
- Anti- k_T ($R=0.4$)
- MC-based calibration
- $p_T > 25$ (20) GeV
- $|\eta| < 2.5$

Electron

- Good isolated calo object
- Matched to track
- $E_T > 20$ GeV
- $|\eta| \in [0;1.37][1.52;2.47]$

Muon

- Segments in tracker and muon detector
- Isolated track
- $p_T > 20$ GeV
- $|\eta| < 2.5$

E_T^{miss}

- Vector sum of calo energy deposits
- Corrected for identified objects

b-Jet

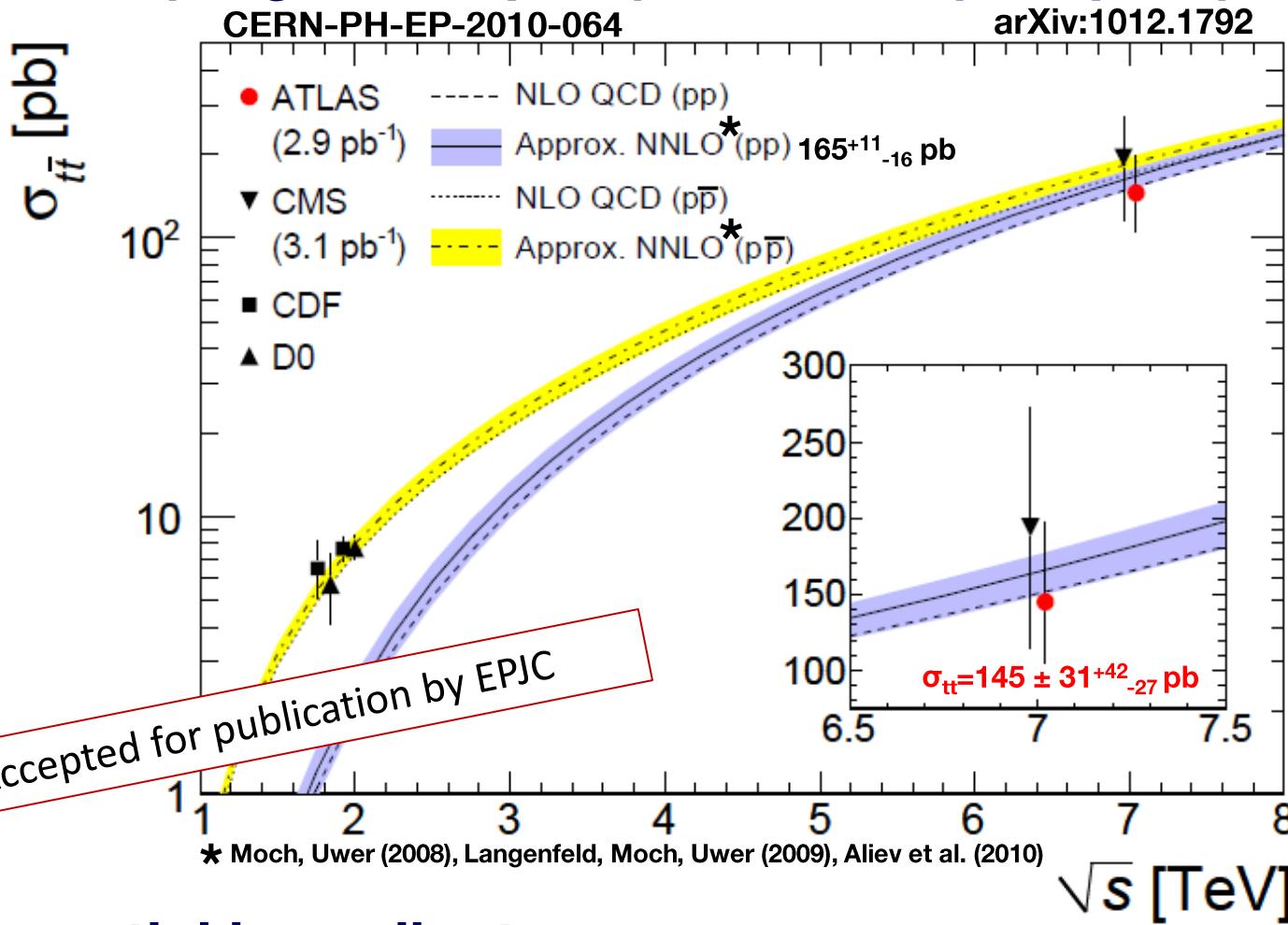
- Displaced tracks or secondary lepton
- SV0: reconstruct sec. vertex
- JetProb: track/jet compatibility with primary vertex

Event cleaning

- Good run conditions
- PV at least 5 tracks
- Bad jet veto
- Cosmic veto ($\mu\mu$)

First top quarks at LHC

► ATLAS (single, di-lepton) and CMS (di-lepton) measure σ_{tt}



► Essential ingredients:

- QCD multijet background; W,Z+jets; b-tagging calibration

QCD multi-jet background

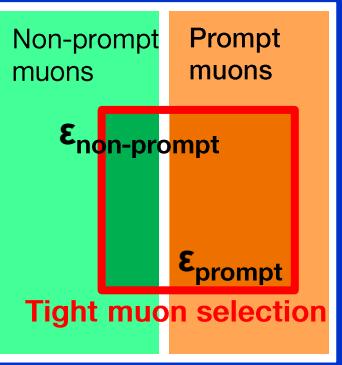
- ▶ Reject QCD multi-jet background by requiring
 - a lepton: $p_T > 20 \text{ GeV}$ a neutrino, $E_T^{\text{miss}} > 35(20) \text{ GeV}$ for $e(\mu)$
 - The combination to be consistent with a leptonic W decay
 - $m_T(W) > 25 \text{ GeV} (e)$ $m_T(W) + E_T^{\text{miss}} > 60 \text{ GeV} (\mu)$
- ▶ Remaining background with fake or non-prompt leptons
- ▶ Estimate this rate from data:

Matrix method

$$N^{\text{loose}} = N_{\text{prompt}}^{\text{loose}} + N_{\text{non-prompt}}^{\text{loose}},$$

$$N^{\text{tight}} = \epsilon_{\text{prompt}} N_{\text{prompt}}^{\text{loose}} + \epsilon_{\text{non-prompt}} N_{\text{non-prompt}}^{\text{loose}}$$

Loose muon selection



Use measurement of prompt and non-prompt lepton acceptance in control region

Invert matrix to obtain $N_{\text{non-prompt}}$ in tight selection

Uncertainty ~30%

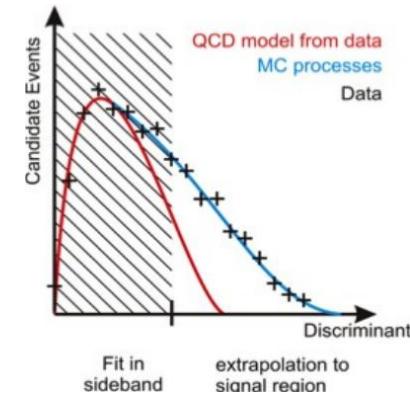
Fitting method

Extrapolate from low to high E_T^{miss}
QCD E_T^{miss} shape from control sample

Real or 'fake' electrons

QCD template built from electron sample with ID cut inversion

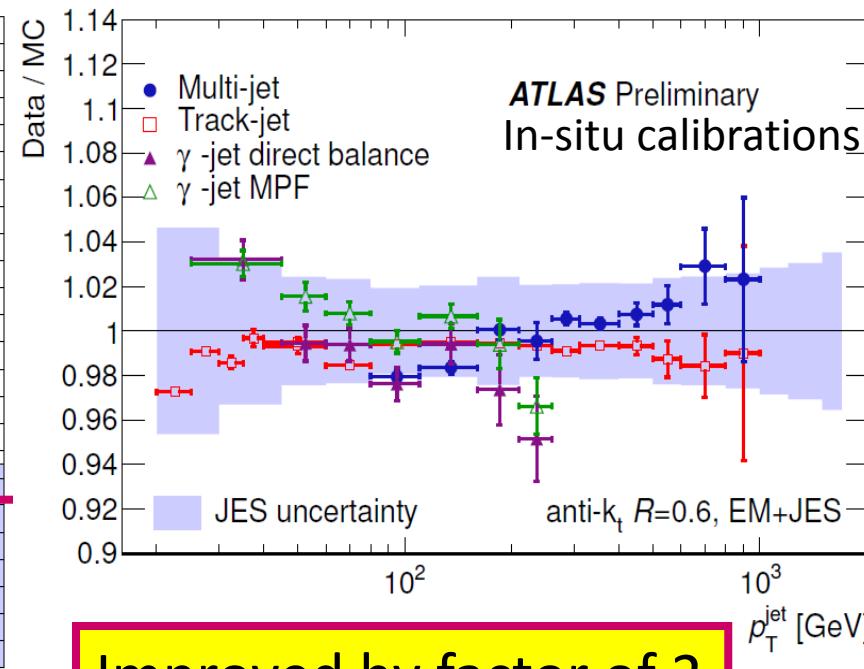
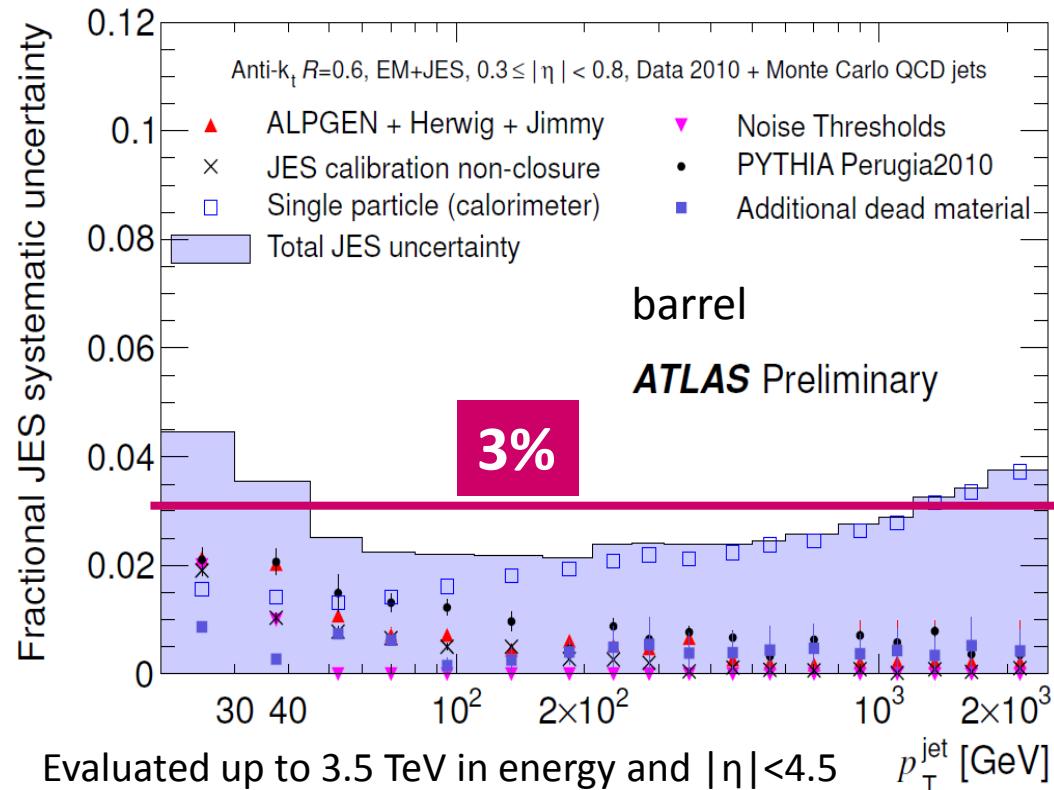
Uncertainty ~50%





Jet Energy Scale

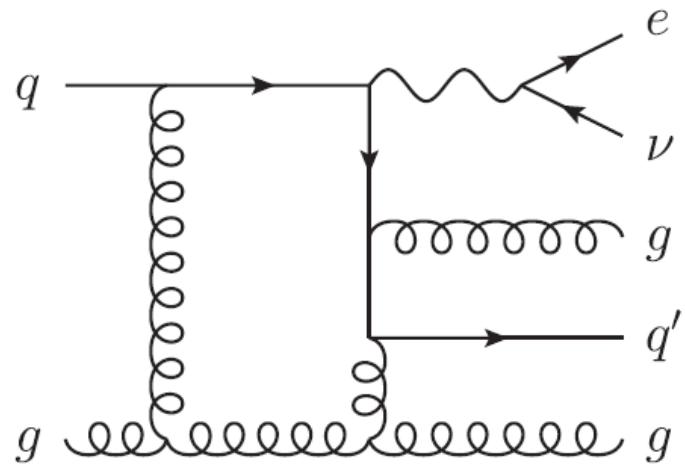
ATLAS-CONF-2011-032



η region	Maximal relative JES uncertainty		
	$P_T^{\text{jet}} = 20 \text{ GeV}$	$P_T^{\text{jet}} = 200 \text{ GeV}$	$P_T^{\text{jet}} = 1.5 \text{ TeV}$
$ \eta < 0.3$	4.6%	2.3%	3.1%
$2.1 < \eta < 2.8$	7.1%	2.5%	
$3.6 < \eta < 4.5$	12.6%	2.9%	

W/Z + jets

- ▶ **Diagrams: ordinary QCD+EWK**
- ▶ **Very challenging for NLO with many jets**
- ▶ **Recently available with up to 4(3) jets for W(Z)**
 - Phys. Rev. Lett. 106 (Mar 2011) 092001
 - Phys. Rev. D 82 (Oct 2010) 074002
- ▶ **Simulation: ME+PS with appropriate matching**
 - important to cross-check them with data
- ▶ **Berends-Giele and asymmetry methods**
- ▶ **W+b, W+bb large uncertainty**
 - see Tevatron measurements



Testing Berends-Giele scaling

Slide by Vitaliano Ciulli, Moriond QCD

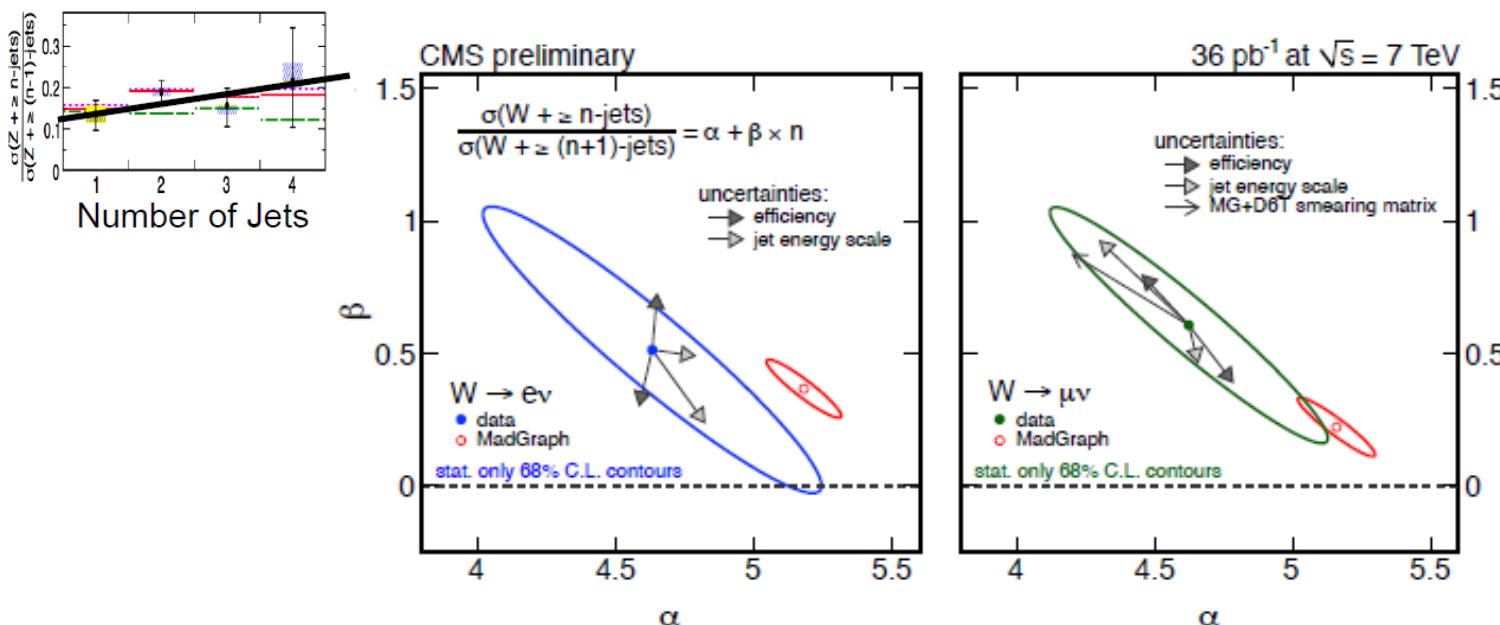
The ratio $C_n = \frac{\sigma_n}{\sigma_{n+1}}$ is approximately constant for $n \geq 1$

To test this scaling, we performed a fit to the signal yields with the constraint

$$C_n = \alpha + \beta n$$

α = LO, strong coupling
 β => LO+phase space

and taking into account in the fit the bin-to-bin migration due to detector resolution



Contours represent only statistical errors, while systematics are shown by arrows
 Within total uncertainty data agrees with MadGraph

Results agree with ME+PS for both W and Z

New measurements

- ▶ **ATLAS and CMS showed preliminary results with full 2010 dataset ($\sim 35\text{pb}^{-1}$) at Moriond (13 – 26 March)**
 - tt single lepton (with and without requiring a b-tagged jet)
 - tt dilepton (with and without requiring a b-tagged jet)
 - tt combination
 - t-channel single top
 - Wt channel single top
- ▶ **Similar analysis techniques across experiments**
 - data-driven background estimation
 - evaluation of systematic uncertainties
 - cut-and-count / multi-variate techniques / profile likelihood
 - more emphasis put on ATLAS measurements, as public documentation is available
- ▶ **Find all information at:**
 - <https://twiki.cern.ch/twiki/bin/view/AtlasPublic/TopPublicResults>
 - <https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsTOP>

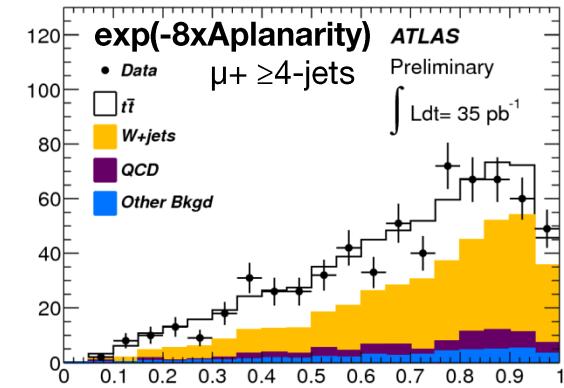
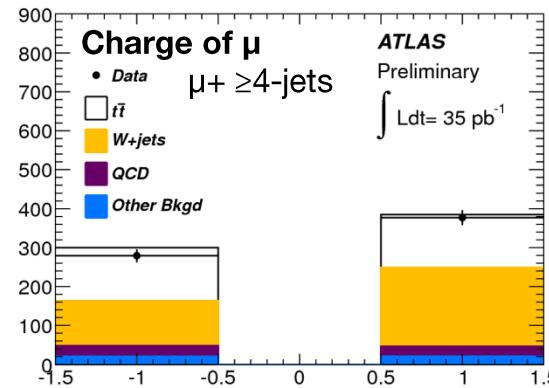
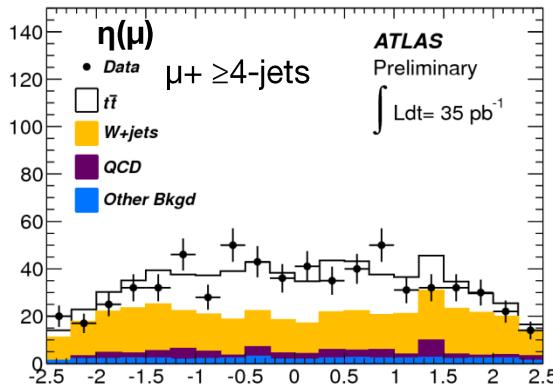


σ_{tt} single lepton (no b-tagging)

ATLAS-CONF-2011-023

► Analysis strategy

- Projective likelihood based on uncorrelated discriminating variables
- Three variables chosen:



- Binned maximum likelihood to 4 channels (3-jets, ≥ 4 -jets; e, μ)

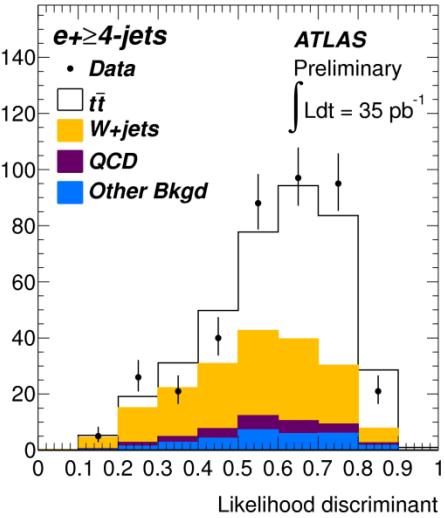
Syst. source	Rel. unc. %
Jet en. scale & Reconstruction	-6.1 / +5.7
ISR/FSR	-2.1 / +6.1
QCD norm.	3.9
QCD shape	3.4
Parton shower & hadronisation	3.3
Total syst.	-10.2 / +11.6

► Independent of b-tagging

- avoids related systematic uncertainty at the price of a worse S/B ratio
- Relative uncertainty $\sim 15\%$

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

- cross-checked by cut-and-count and 1d χ^2 and likelihood fits





Luminosity measurement

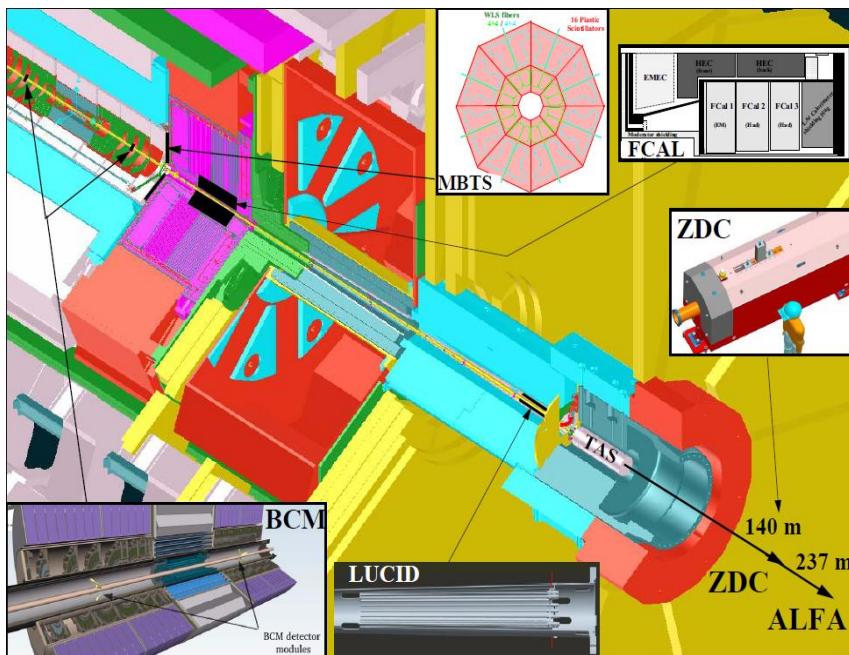
ATLAS-CONF-2011-011

► Improved determination

- LHC bunch currents: 10% → 2.9%

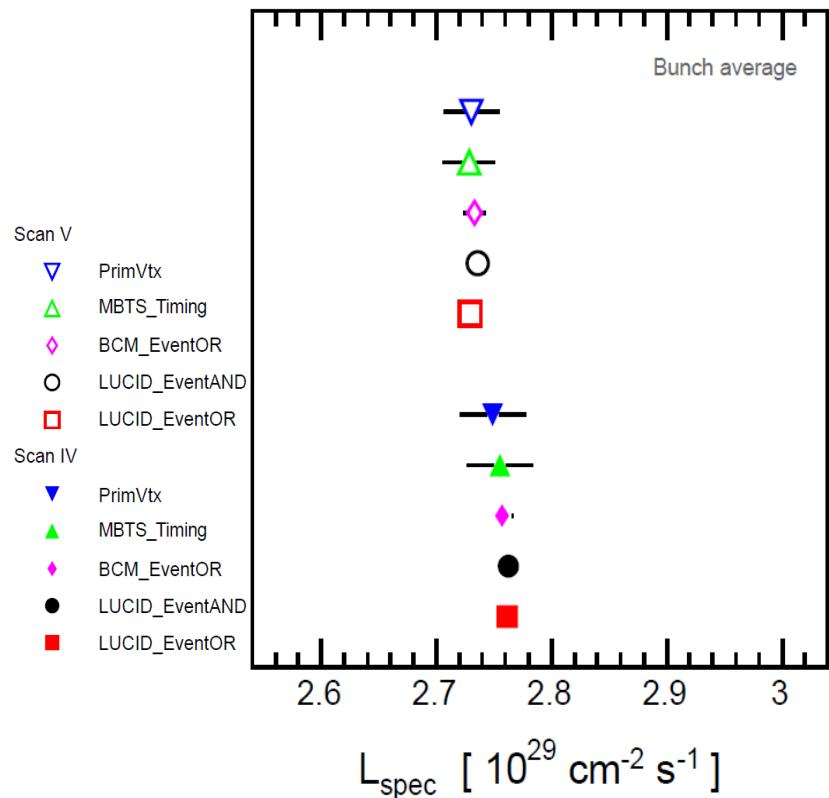
► ATLAS vdM scan analysis

- length scale: 2% → 0.3%
- emittance growth: 3% → 0.5%
- mu dependence: 2% → 0.5%
- fit model: 1% → 0.1%
- beam centering: 2% → 0.1%



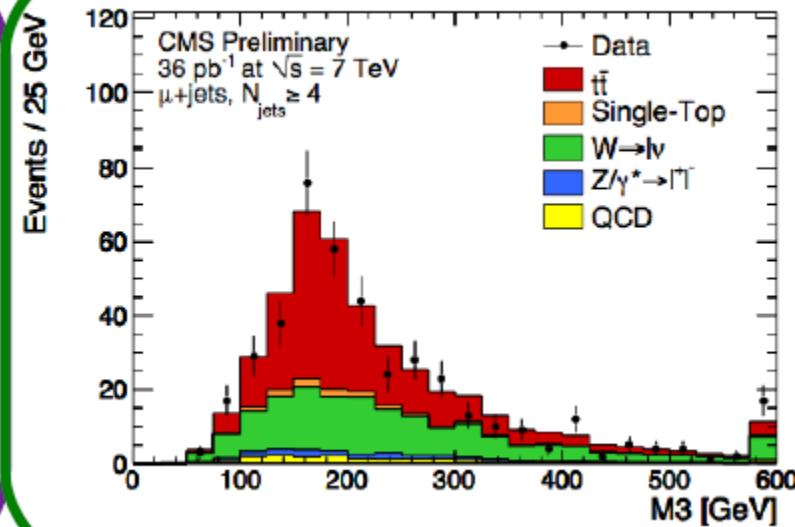
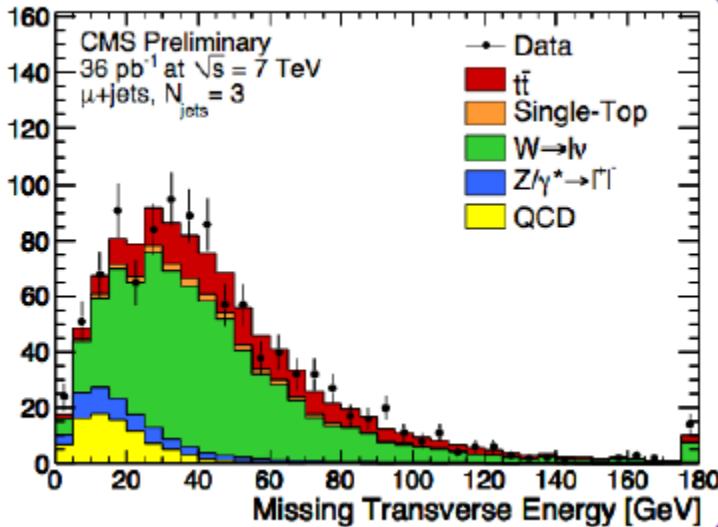
Van der Meer scans

5 lumi detectors and up to 5 algorithms

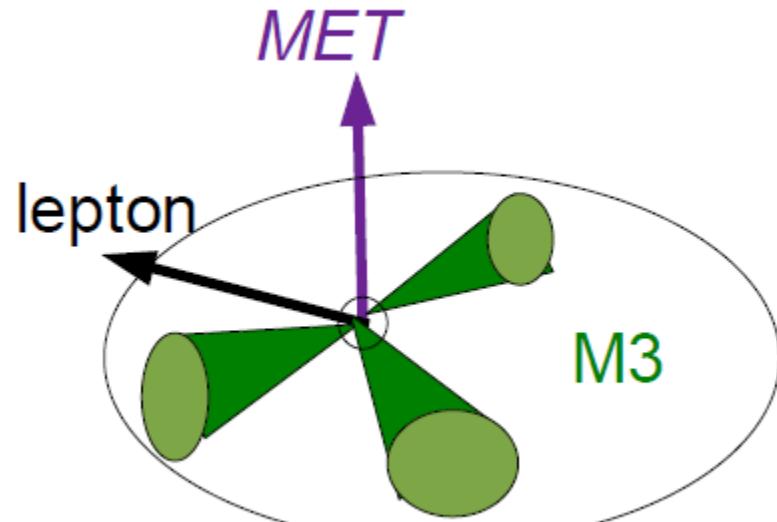


Uncertainty reduced 11% → 3.4%

σ_{tt} single lepton (no b-tagging)



- Lepton + 3 or more jets
- Simultaneous fit in
 - MET
 - M3 : Mass 3 jets w/ highest combined p_T
- **Results consistent w/b-tag measurement**



Slide by Philipp Harris, Moriond EWK



σ_{tt} single lepton with b-tags

ATLAS-CONF-2011-035

► Multivariate method

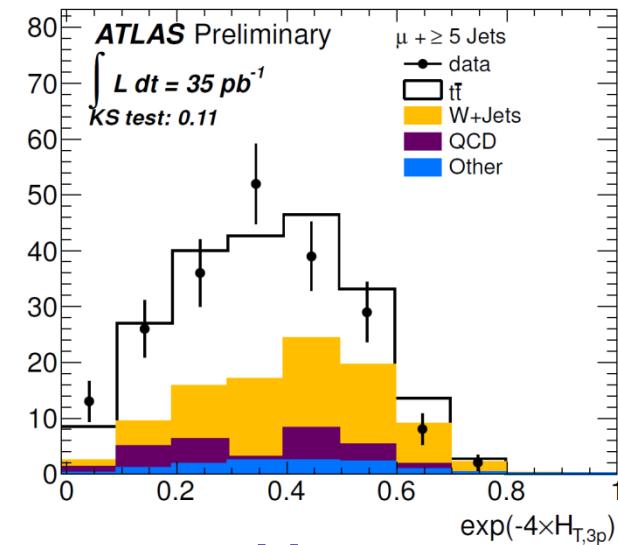
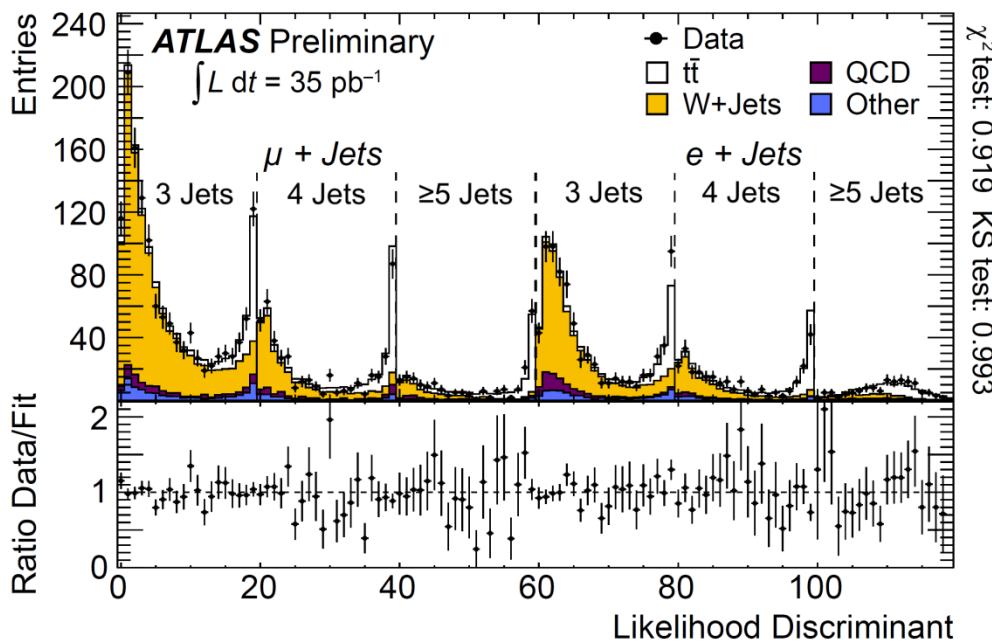
- split up in six channels ($3, 4, \geq 5$ jets, e/μ)

► Input variables

- lepton η , aplanarity, $H_{T,3p}$, b-tag weight

► Profile likelihood fit extracts

- 16 norm. parameters, including σ_{tt}



► Fit is set up with

- 17 nuisance parameters
- constrained from data

► Main systematics

- W+jets HF content (7%)
- Tagger calibration (7%)

uncert.
~13%

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

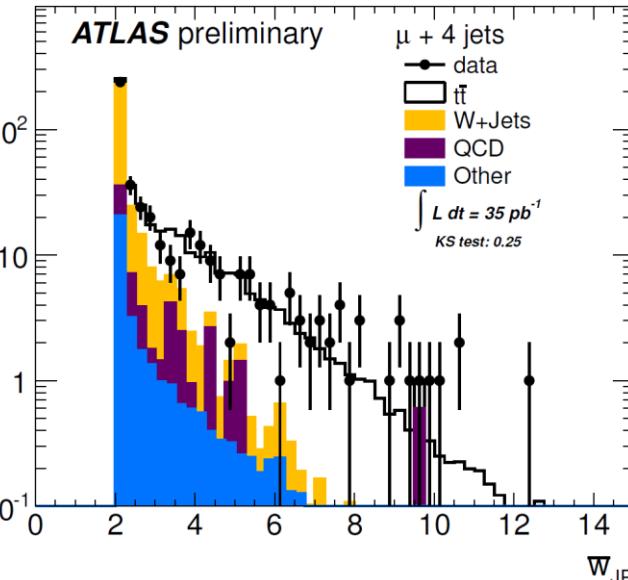
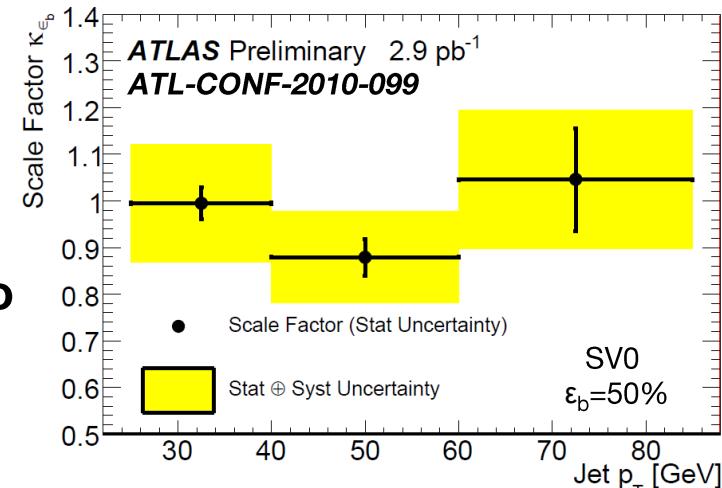
► Cross-check analysis

- Cut-and-count, fit to $m(jjj)$



b-tagging calibration

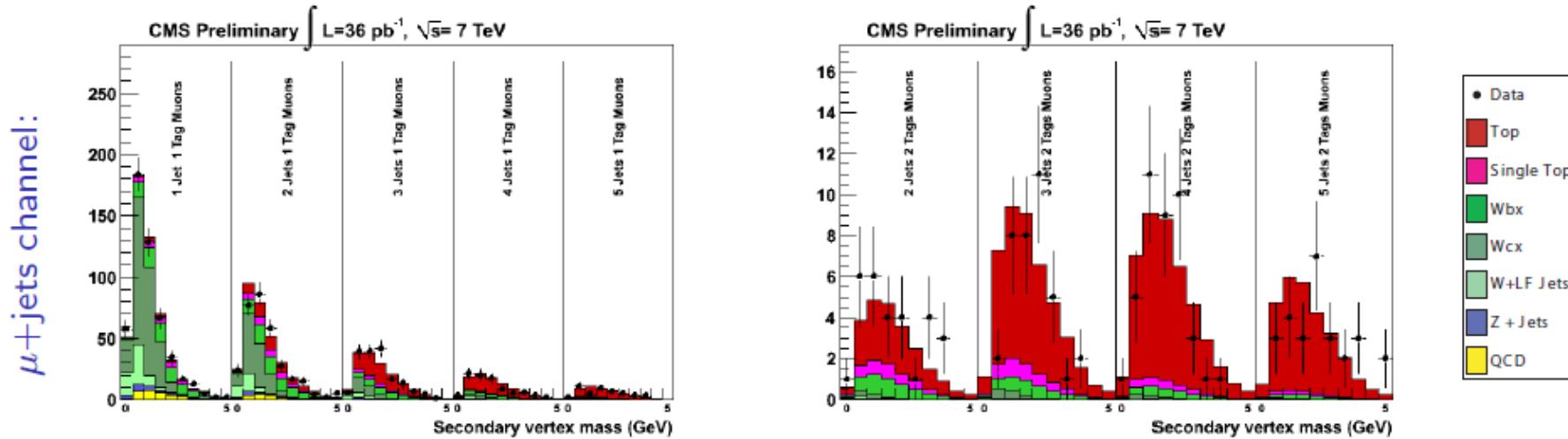
- ▶ Performance of b-tagging depends on details of detector performance
- ▶ Data-driven estimates of b-tag efficiency and mistag rate
 - ‘ p_T^{rel} ’ uses the p_T wrt jet axis of associated μ to extract the flavour composition in data
- ▶ Study repeated for full 2010 data sample
 - Efficiency data-to-MC scale factors κ_{ϵ_b} are unity within $\sim 10\%$
 - $D^*\mu$ and $t\bar{t}$ for cross-check
 - Mis-tag rate affects cross-section extraction less
- ▶ JetProb calibrated for $\epsilon_b = 50\%, 70\%$
 - Average JetProb weight of most b-like jets, w_{JP} used as continuous variable in the analysis



$\sigma_{t\bar{t}}$ single lepton with b-tags

CMS-TOP-10-003

Binned Likelihood Fit to the secondary vertex mass in the $e+jets$, $\mu+jets$ channel, and in the combination of both channels



Combined Measurement:

$$\sigma_{t\bar{t}} = 150 \pm 9 \text{ (stat.)} \pm 17 \text{ (syst.)} \pm 6 \text{ (lumi.) pb}$$

Profiling: most important systematics included as parameters, thus their impact reduced

μ -in-jet and neural net analyses as well as a counting experiment
($e+jets$ channel) can be found in the backup!

Slide by Jasmin Gruschke, Moriond QCD



σ_{tt} dilepton

ATLAS-CONF-2011-034

► Cut-based method

- require 2 OS hard leptons (e, μ), 20 GeV
- two energetic jets, 20 GeV
- **Z+jets is dominating background**
 - ee/ $\mu\mu$: $E_T^{\text{miss}} > 40$ GeV and $|m_{\parallel} - m_Z| > 10$ GeV
 - $e\mu$: $H_T > 130$ GeV

► MC-assisted data-driven estimation of remaining Z+jets background

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

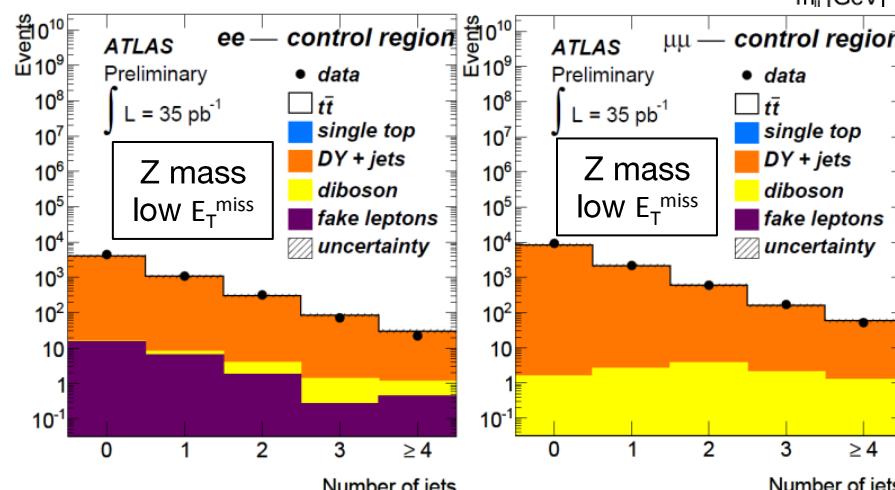
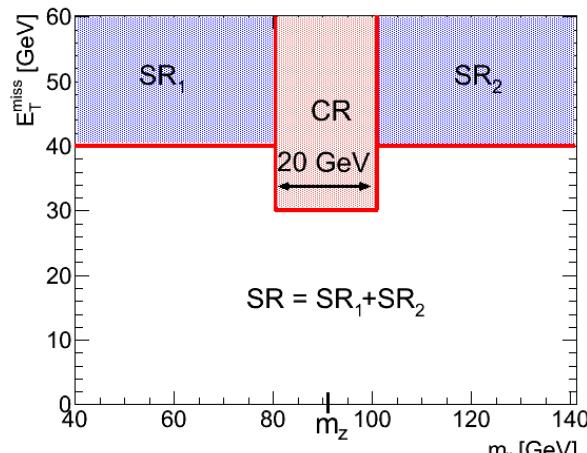
- Reduced uncertainty from $\sim 100\%$ to $< 50\%$

► Main systematics

- Jet energy scale (5%)
- Parton shower model (5%)
- Fakes (4%)

Can also simultaneously extract

- σ_Z , lumi uncertainty cancels in ratio
- σ_{tt} , σ_{WW} , $\sigma_{Z \rightarrow \text{TT}}$ from fit E_T^{miss} vs N_{jets}
- b-tagging efficiency





σ_{tt} dilepton

► Cross-section extraction

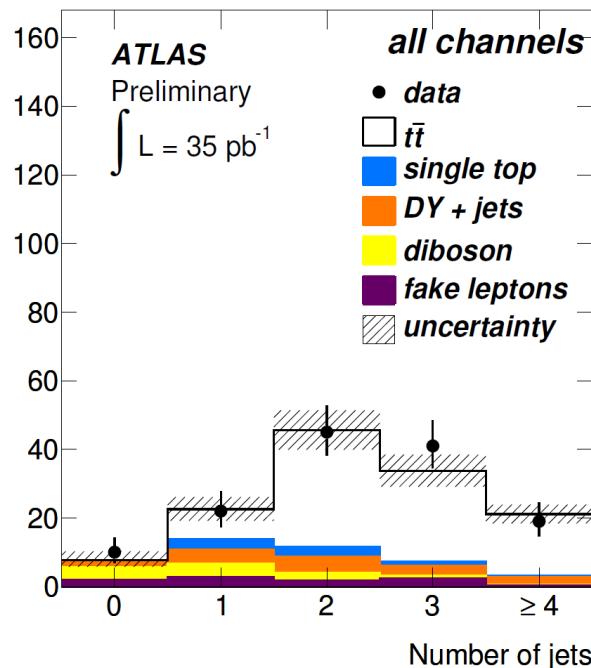
– Profile likelihood method to combine channels

$$L_{ll}(\sigma_{tt}, \mathcal{L}, \alpha_j) = \text{Gaus}(\mathcal{L}_0 | \mathcal{L}, \sigma_{\mathcal{L}}) \prod_{i \in \{ee, \mu\mu, e\mu\}} \text{Pois}(N_i^{obs} | N_{i,tot}^{exp}(\alpha_j)) \prod_{j \in syst} \text{Gaus}(0 | \alpha_j, 1)$$

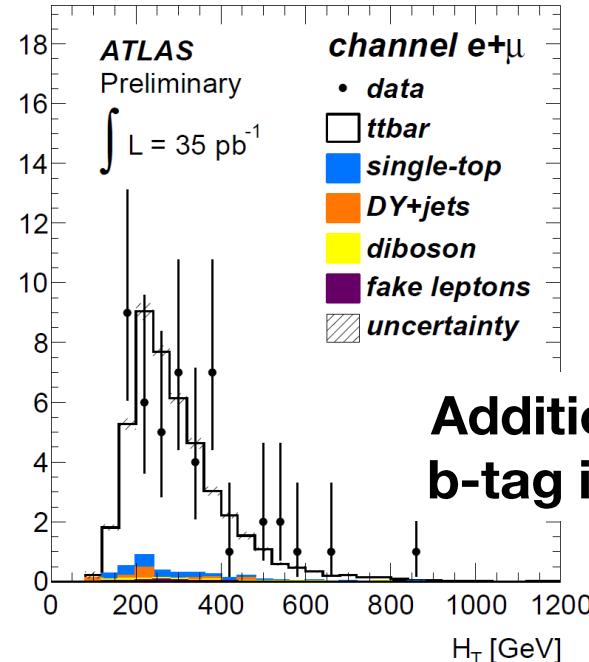
$\sigma_{tt} = 173 \pm 22(\text{stat})^{+18}_{-16} (\text{syst})^{+8}_{-7} (\text{lumi}) \text{ pb}$

– Events in SR are compatible with top quarks

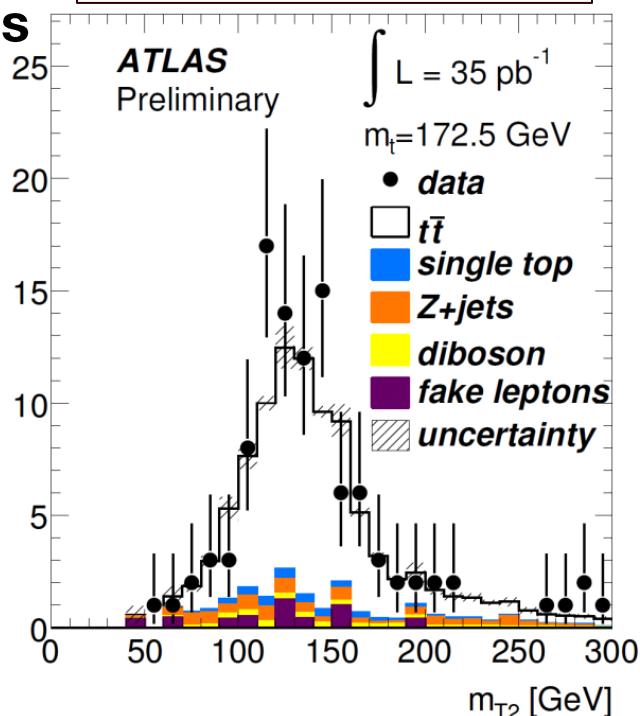
105 events selected, 101 ± 9 expected
Data well modeled by MC+DD methods



H_T : sum of lepton and jet momenta
Distribution after requiring 1 b-tag



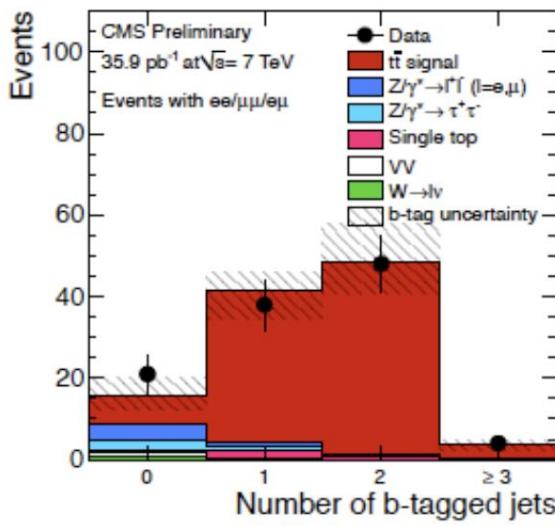
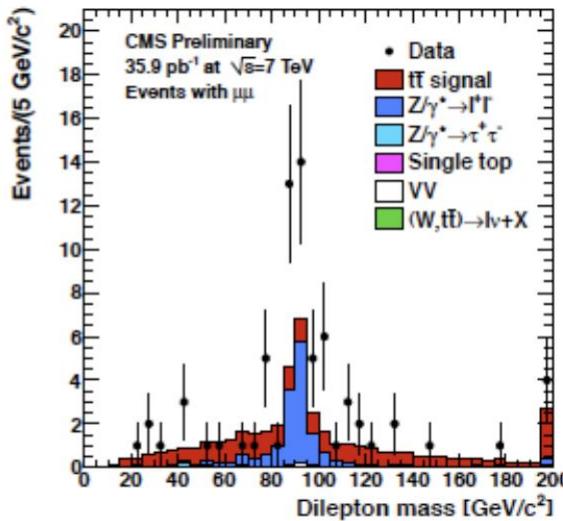
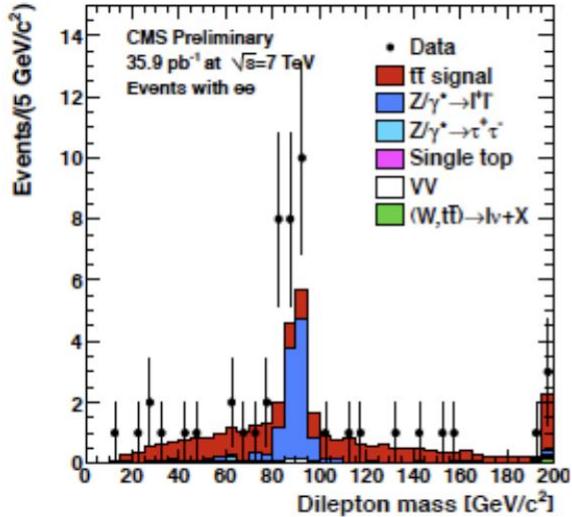
Stransverse mass: generalization of m_T concept with two neutrinos



Additionally requiring
b-tag improves S/B

σ_{tt} dileptons

CMS-PAS-TOP-10-005



Source	$N_{\text{jet}} = 1$		$N_{\text{jet}} \geq 2$	
	e ⁺ e ⁻ + $\mu^+\mu^-$	e [±] μ^\mp	e ⁺ e ⁻ + $\mu^+\mu^-$	e [±] μ^\mp
Lepton selection	1.91/1.30	1.11	1.91/1.30	1.11
Energy scale	-3.0	-5.5	3.8	2.8
Lepton selection model	4.0	4.0	4.0	4.0
Branching ratio	1.7	1.7	1.7	1.7
Decay model	2.0	2.0	2.0	2.0
Event Q^2 scale	8.2	10	-2.3	-1.7
Top-quark mass	-2.9	-1.0	2.6	1.5
Jet and \cancel{E}_T model	-3.0	-1.0	3.2	0.4
Shower model	1.0	3.3	-0.7	-0.7
Pileup	-2.0	-2.0	0.8	0.8
Subtotal (before tags)	11.2/11.1	13.1	8.0/7.9	6.2
b tagging (≥ 1 b tag)			5.0	5.0
Subtotal with tags			9.5/9.4	8.0
Luminosity	4	4	4	4

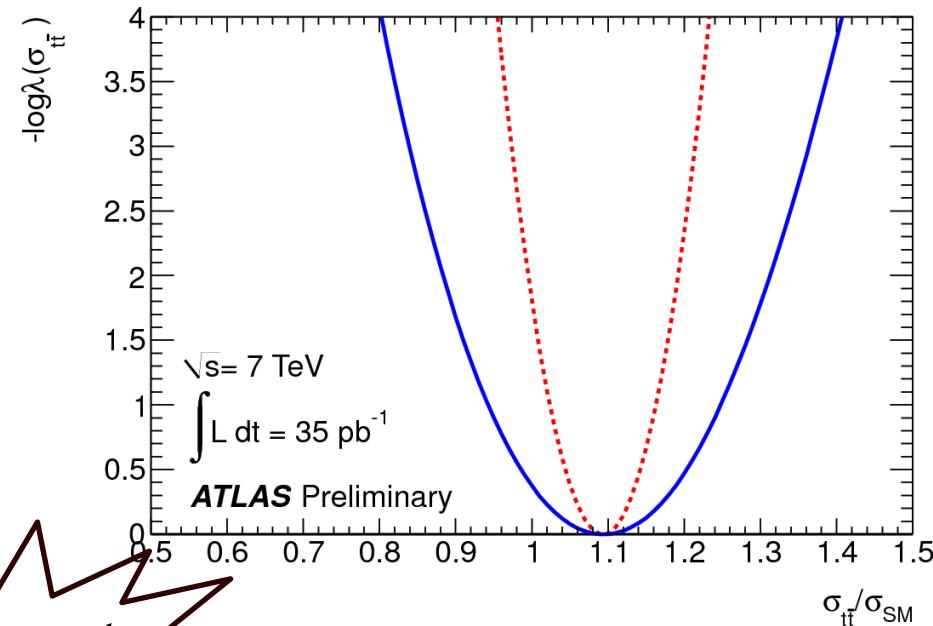
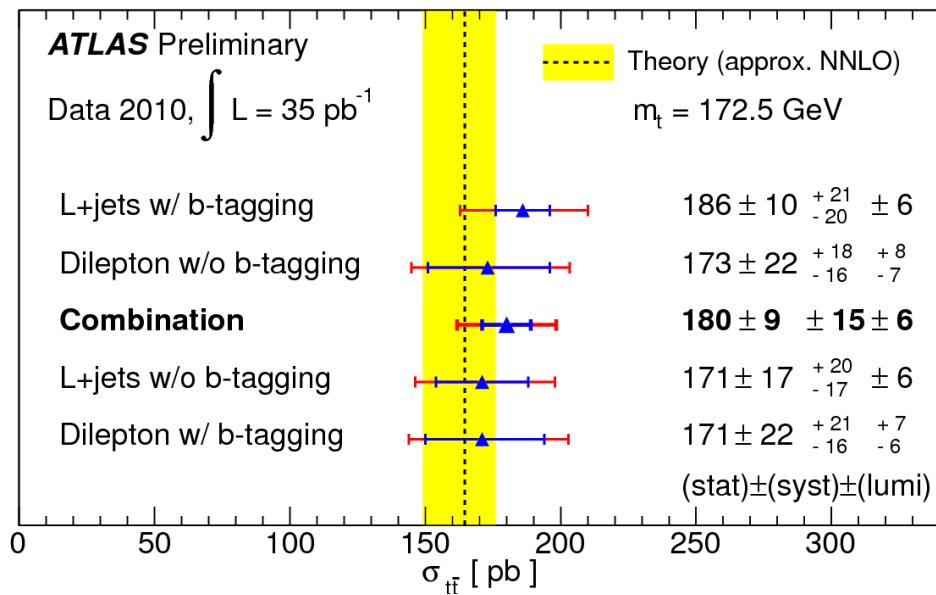
tt cross-section combination

► Combine dilepton and single lepton channels

- extend 3 channel to 5 channels

ATLAS-CONF-2011-040

- choose most precise: l+jets with b-tag, dilepton w/o b-tag



- Stat. uncertainty ~4%
 - Syst. uncertainty ~8%
 - Lumi. uncertainty ~3%
 - Agrees with QCD prediction
- $\delta\sigma = 10\%$

CMS-TOP-11-001

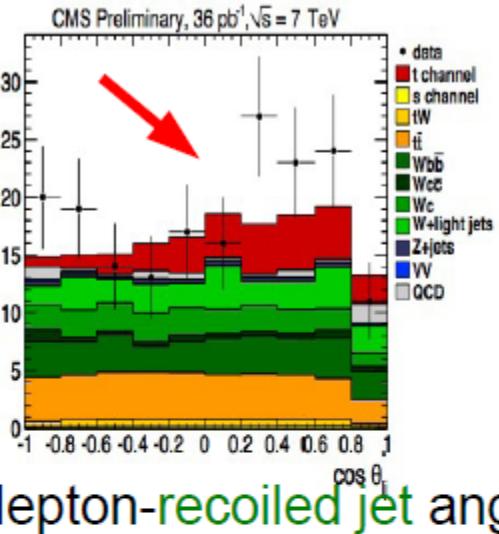
Measurement	Cross section [pb]	Weight
CMS l+jets+tag	$150 \pm 9(\text{stat}) \pm 17(\text{syst}) \pm 6(\text{lumi})$	58%
CMS dilepton	$168 \pm 18(\text{stat}) \pm 14(\text{syst}) \pm 7(\text{lumi})$	42%

Single top with MVA

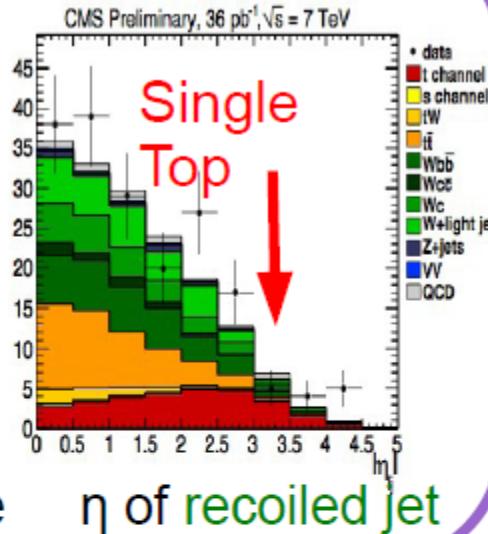
CMS-TOP-10-008

Slide by Philipp Harris, Moriond EWK

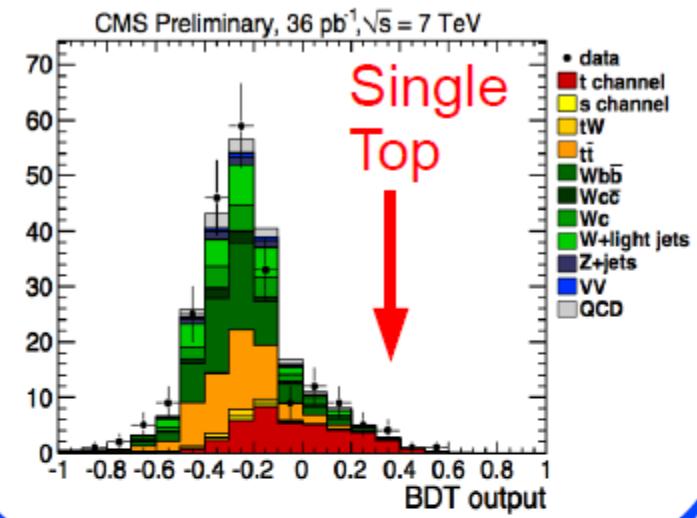
2 Dimensional fit



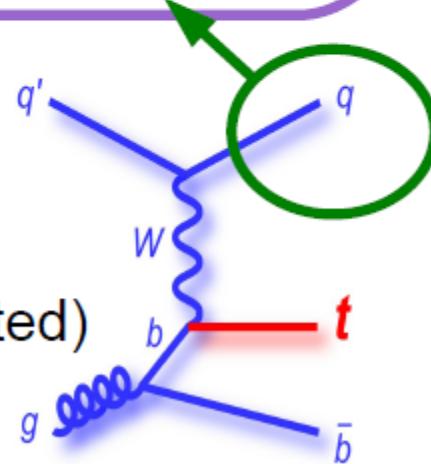
Events



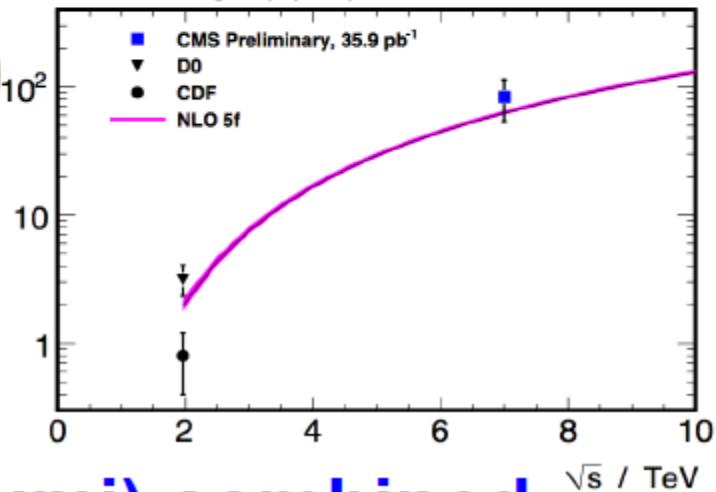
Fit to Boosted decision tree



- W+2 jet selection
 - Lepton + MET + 2 jets
 - Require 1 b-tag
- Significance meas(expected)
 - 2D: 3.7(2.1) sigma
 - BDT: 3.5(2.9) sigma



t-channel single top quark production



$83.6 \pm 29.8(\text{stat+sys}) \pm 3.3(\text{lumi}) \text{ combined}$

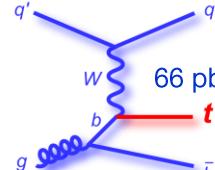


Single top: t- and Wt-channel

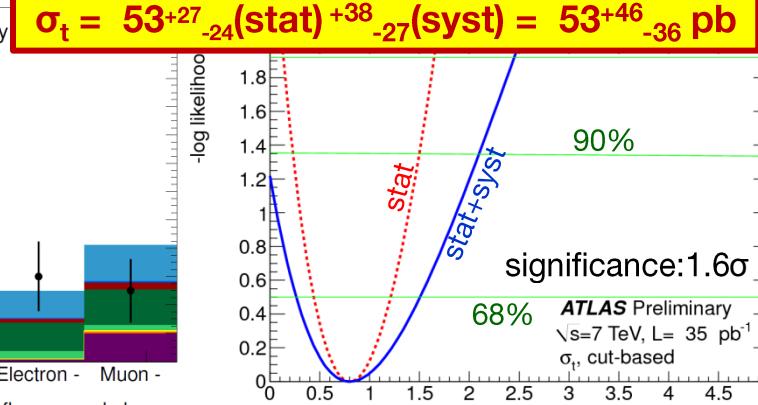
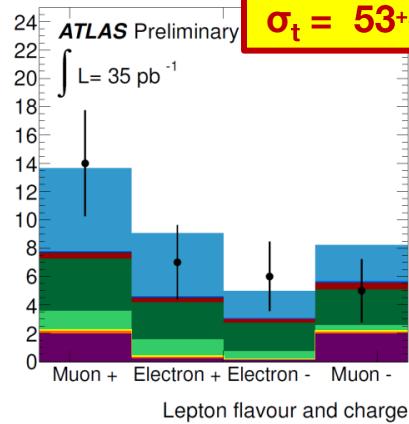
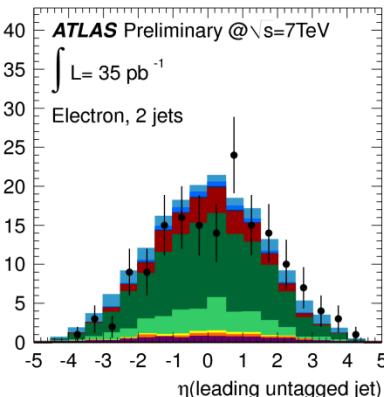
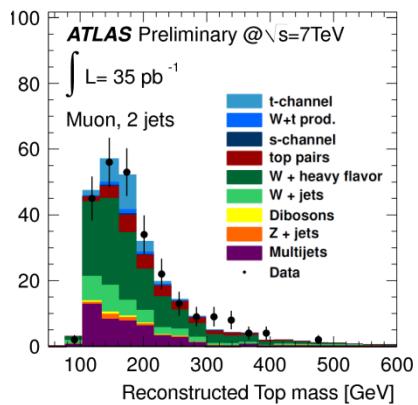
ATLAS-CONF-2011-027

► t-channel: cut-based (likelihood cross-check)

- 1 lepton, 1 b-jet, 1 light-jet, E_T^{miss}
- Bkg: QCD multi-jet, W+jets
- Final cut $m_{\text{top}} \in (130;210)\text{GeV}$; $|\eta_{\text{light-jet}}| > 2.5$
- Likelihood ratio adding $H_T(j)$, $\cos\Delta\phi(l, E_T^{\text{miss}})$, $\Delta R(b,l)$

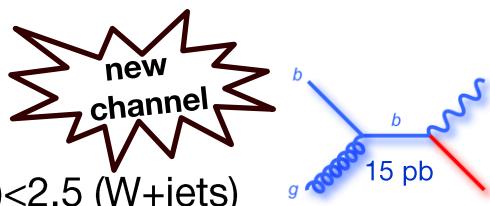


	Cut-based		Likelihood	
	Lepton +	Lepton -	Lepton +	Lepton -
t-channel	10.3 ± 1.8	4.4 ± 0.8	8.0 ± 1.8	3.4 ± 0.8
TOTAL Exp	22.7 ± 3.8	13.2 ± 2.8	15.4 ± 3.0	8.8 ± 2.0
S/B	0.83	0.50	1.08	0.62
DATA	21	11	16	11

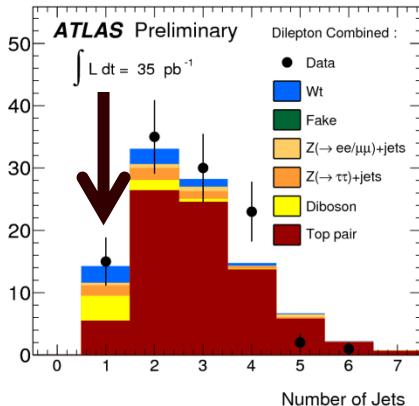


► Wt-channel: cut-based

- l+jets:
 - 2-4 jets, exactly 1b-jet (against tt), $\Delta R(j_1, j_2) < 2.5$ (W+jets)
- dilepton:
 - Data driven Z+jets, fakes, tt (from $N_{\text{jets}} > 1$)
- combine channels, expect $\sigma_{\text{Wt}} < 94 \text{ pb}$

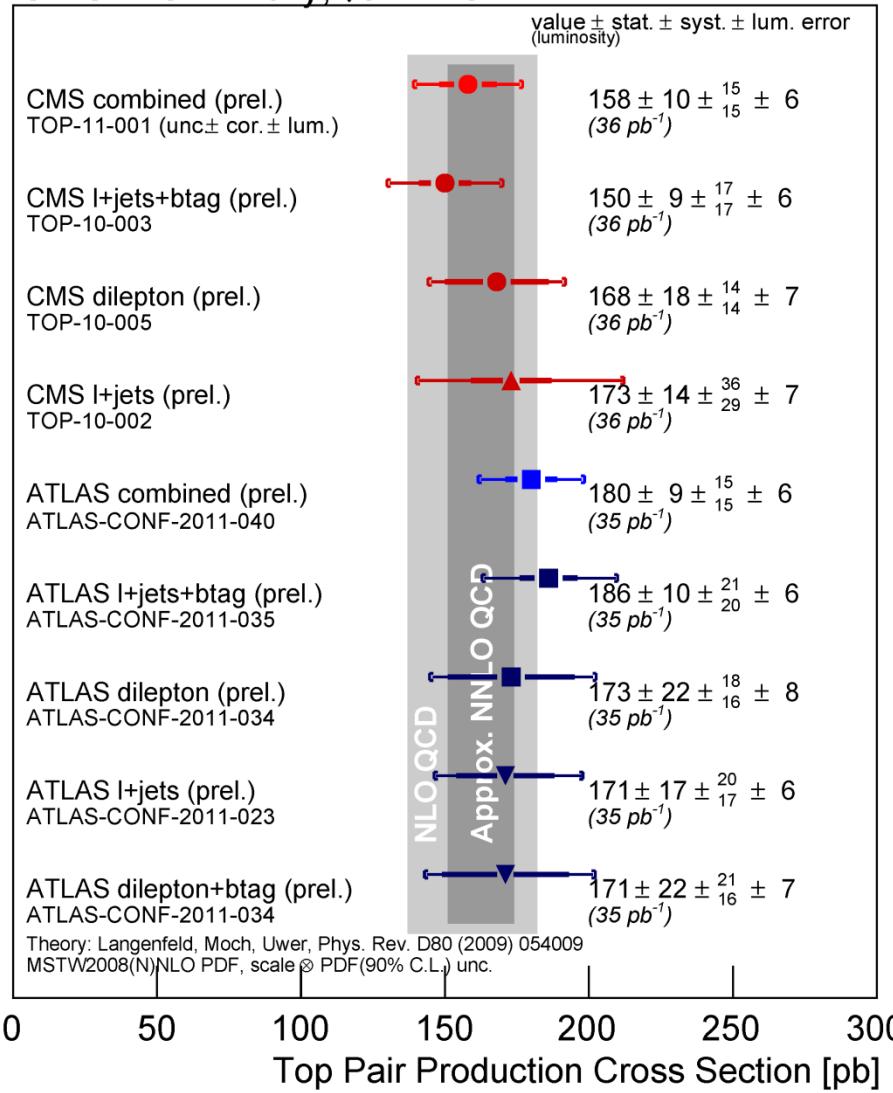


$\sigma_{\text{Wt}} < 158 \text{ pb at } 95\%$

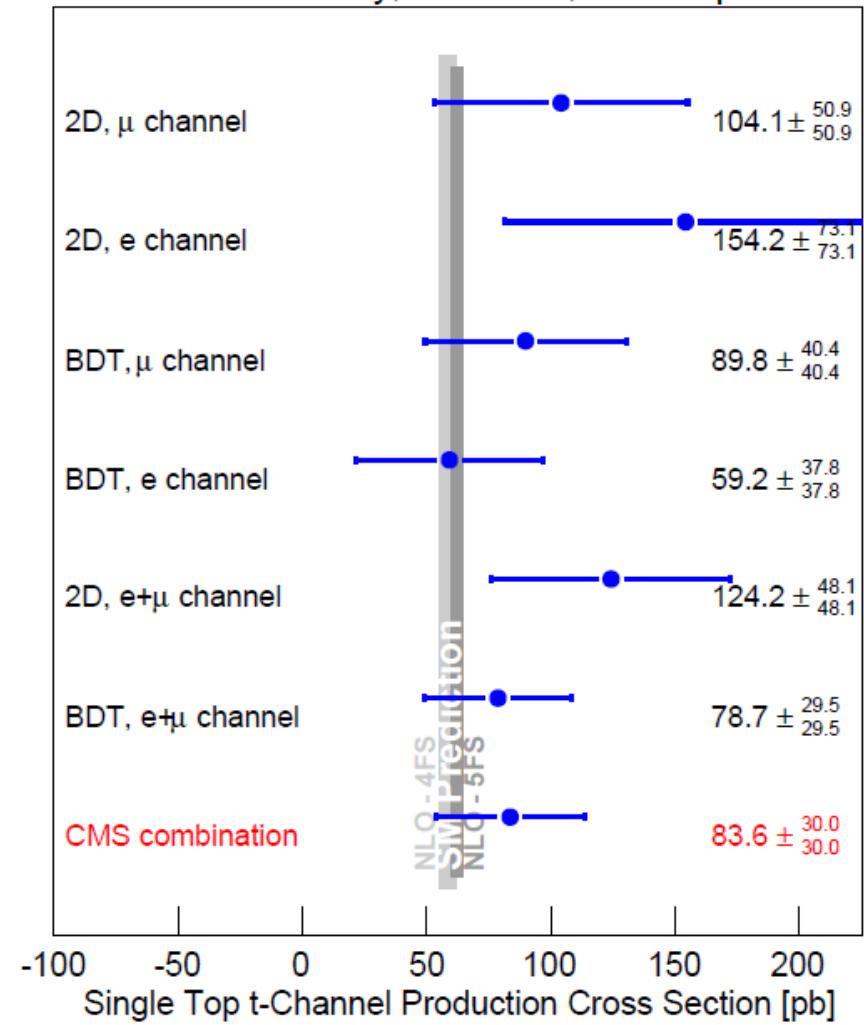


Summary of measurements

CMS Preliminary, $\sqrt{s}=7$ TeV



CMS Preliminary, $\sqrt{s}=7$ TeV, $L=35.9$ pb $^{-1}$



Systematics: Experimental

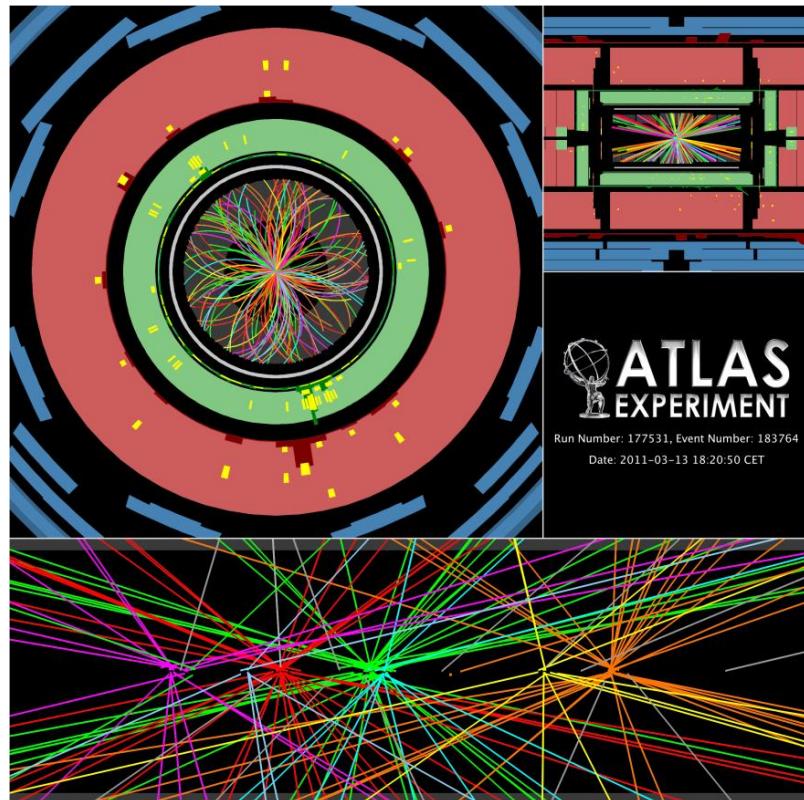
- ▶ Objects in Monte-Carlo simulation are ‘treated’ (efficiency, resolution) to match data in control regions
 - uncertainties due to limited statistics or disagreement of models
 - Determination of b-tagging efficiency and mis-tag rate
 - lepton trigger, reconstruction, and identification
 - lepton resolution, scale
 - jet reconstruction efficiency, jet energy scale
- ▶ Pile-up: well modeled in simulation
 - reweight distributions to match #primary vertices

Systematics: Modelling

- ▶ **Generator Model**
 - MC@NLO+Herwig vs Powheg+Herwig; Madgraph+Pythia vs ?
- ▶ **PDF**
 - Re-weighting procedure using LHAPDF and 22 Evs from CTEQ66
 - Follow PDF4LHC recommendation
- ▶ **ISR/FSR**
 - Variation in the amount of ISR/FSR-processes (dedicated samples)
- ▶ **Parton Shower**
 - Compare Powheg+Pythia with Powheg+Herwig
- ▶ **Scales**
 - Variation of renormalisation/factorisation scale (dedicated samples)
- ▶ **W+jets**
 - heavy flavour content

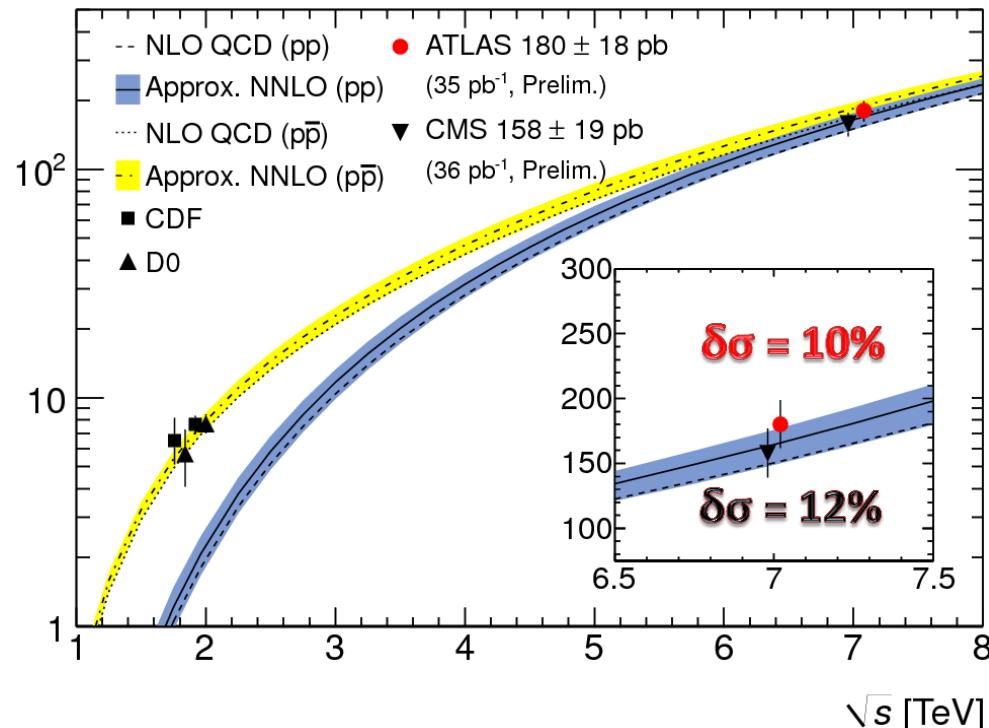
Perspectives in 2011

- ▶ Will increase dataset by O(20x) in Summer and O(100x) by the end of the year
 - New beam conditions (pileup)
 - Focus to understand systematics
- ▶ New measurements feasible
 - larger top sample than Tevatron
 - e.g. differential measurements
- ▶ Looking forward to discuss about what is interesting to test



Conclusion and Outlook

- ▶ The era of top physics at the LHC has just started
 - with only 35 pb^{-1} can already look into production cross-section, mass, single-top and several properties
 - competitive measurements are emerging: cross-section at 10%



- ▶ Statistics limited analysis will become attractive this year
 - anticipate $\sim 0.7 \text{ fb}^{-1}$ by Summer and $\sim 2 \text{ fb}^{-1}$ by the end of the year
- ▶ Focus to reduce systematics
 - improve detector understanding; use advanced analysis techniques
- ▶ 2011: the year of precision top measurements at the LHC

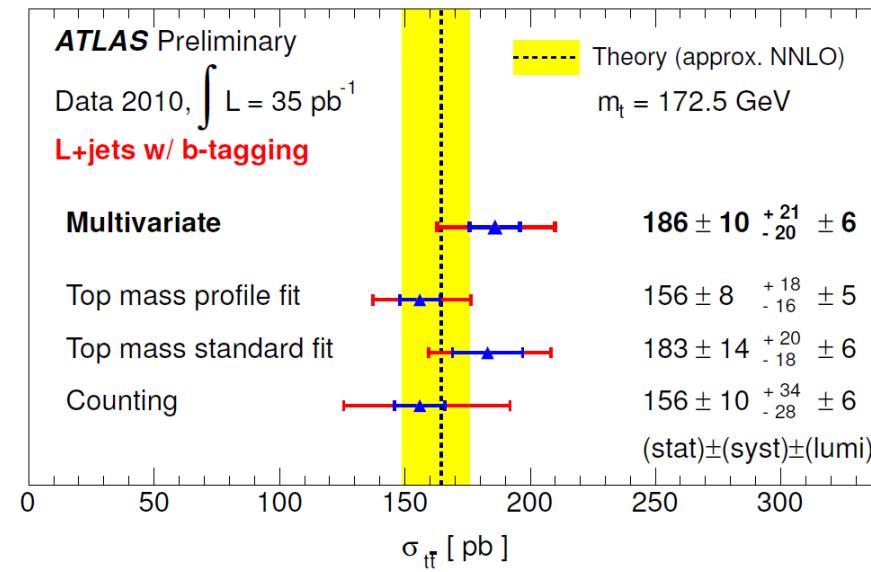
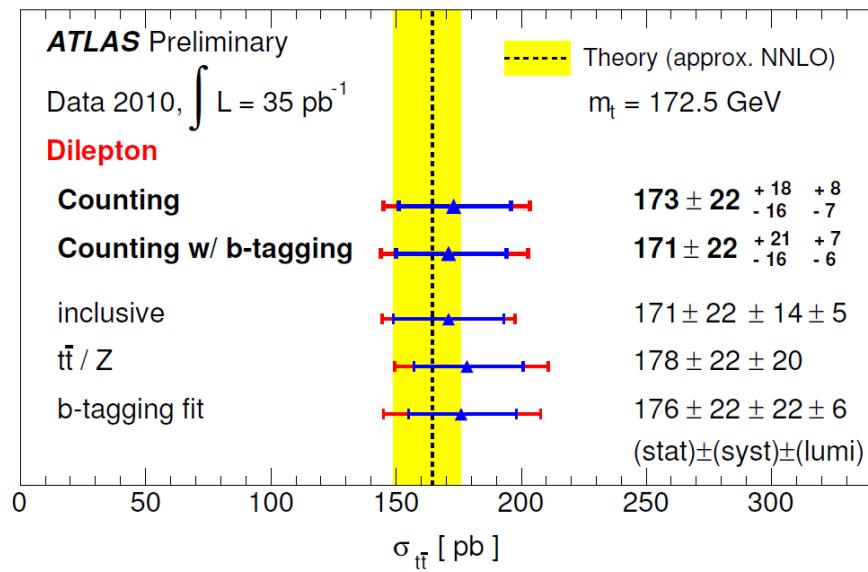
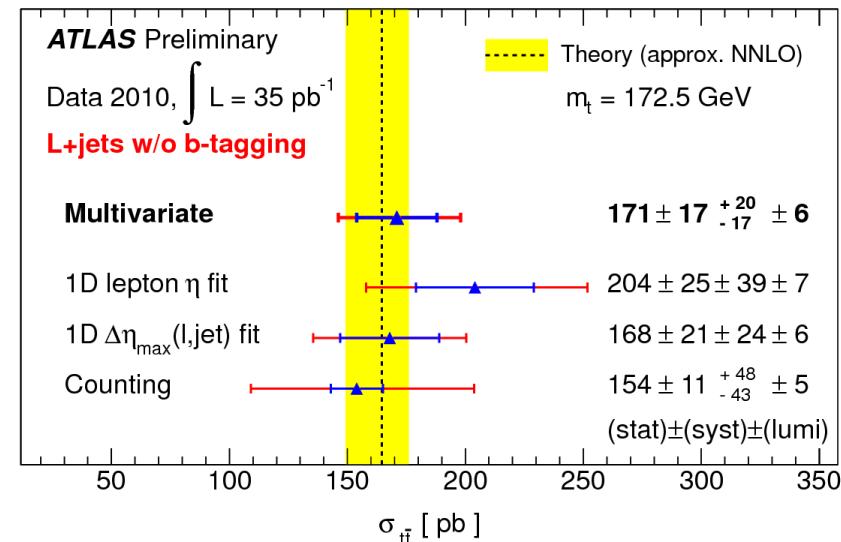
Backup slides

Lepton+jets systematics

Statistical Error (%)	+5.3	-5.2
Object selection (%)		
Jet energy scale	+3.8	-2.8
Jet reconstruction efficiency	+4.2	-4.2
Jet energy resolution	+0.8	-0.2
Electron scale factor	+1.2	-0.8
Muon scale factor	+0.5	-0.6
Electron smearing	+0.3	-0.2
Muon smearing	+0.6	-0.4
Background modeling (%)		
Wjets HF content	+7.2	-6.3
Wjets shape	+1.5	-1.5
QCD shape	+1.0	-1.0
$t\bar{t}$ signal modeling (%)		
ISR/FSR	+4.0	-4.0
NLO generator	+0.5	-0.7
Hadronisation	+0.0	-0.6
PDF	+1.7	-1.7
Others (%)		
b -tagging calibration	+7.5	-6.3
Simulation of pile-up	+1.5	-0.6
Templates statistics	+1.6	-1.5
Total Systematic (%)	+11.5	-10.5

All cross section results

Channel	$\sigma_{t\bar{t}}$ (pb) (stat., syst., lum.)
ee	$178^{+67+37+9}_{-57-27-5}$
$\mu\mu$	$194^{+57+20+12}_{-51-15-5}$
$e\mu$	$164 \pm 26 \pm 18^{+7}_{-6}$
combined	$173 \pm 22^{+18+8}_{-16-7}$



Dilepton analysis

► fake estimation

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

Non-Z lepton background estimates	N_{jets}	$e\mu$	ee	$\mu\mu$
Matrix method	0	$1.9 \pm 1.0 \pm 1.0$	$1.4 \pm 0.8 \pm 0.7$	$0.0^{+0.6}_{-0} \pm 0.3$
Matrix method	1	$3.9 \pm 1.5 \pm 2.0$	$1.9 \pm 0.9 \pm 1.0$	$0.0^{+0.6}_{-0} \pm 0.3$
Matrix method	≥ 2	$3.0 \pm 2.1 \pm 1.5$	$0.8 \pm 0.7 \pm 0.4$	$0.5 \pm 0.5 \pm 0.3$
Candidate weighting method	≥ 2	$1.1 \pm 0.6^{+0.3}_{-0.2}$	$0.6 \pm 0.3^{+0}_{-0.1}$	$2.2 \pm 1.1^{+0}_{-0.2}$

Definition of mT2

$$m_{T2}^2 = \min_{\not{p}_{(1)} + \not{p}_{(2)} = E_T^{\text{miss}}} \left[|E_T = \sqrt{m^2 + p_T^2}|, m_T^2(p_T^{lj(2)}, \not{p}_{(2)}) \right]$$

$$m_T^2(p_T^{lj(i)}, \not{p}_{(i)}) = m_{lj(i)}^2 + m_{\not{p}_{(i)}}^2 + 2[E_T^{lj(i)} E_T^{\not{p}_{(i)}} - \vec{p}_T^{lj(i)} \vec{p}_T^{\not{p}_{(i)}}]$$

with the transverse momentum of the composite object of one lepton and one jet $p_T^{lj(i)}$, of the trial neutrino $\not{p}_{(i)}$ and their transverse energy E_T and masses m . The minimization uses trial momenta for the neutrinos which only have to satisfy the measured E_T^{miss} . From the two possible combinations of leptons and highest- p_T jets the combination with the smallest m_{T2} is chosen.

C.G. Lester, D.J.Summers (1999)

Definition of input variables

Lepton pseudorapidity $\eta = -\ln(\tan(\theta/2))$, cluster η for electrons

Aplanarity A: 1.5 times smallest eigenvector of momentum tensor $M_{ij} = \frac{\sum_{k=1}^{N'_{\text{objects}}} p_{ik} p_{jk}}{\sum_{k=1}^{N'_{\text{objects}}} p_k^2}$
→ transformed to $\exp[-8 \times A]$

$H_{T,3p}$: transverse momentum of all but the leading two jets, divided by sum of absolute values of all longitudinal momenta in the event (neutrino p_z from solving event kinematics and taking solution with smallest p_z)

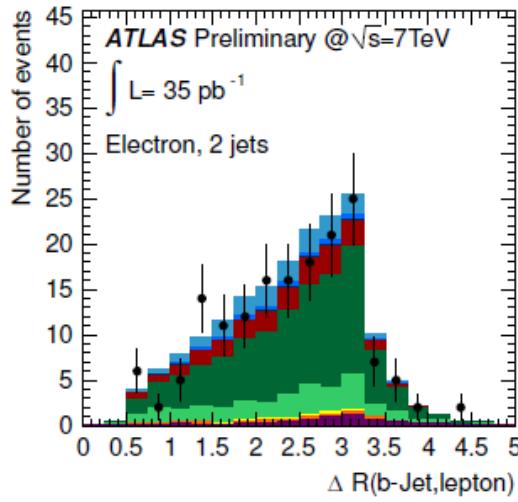
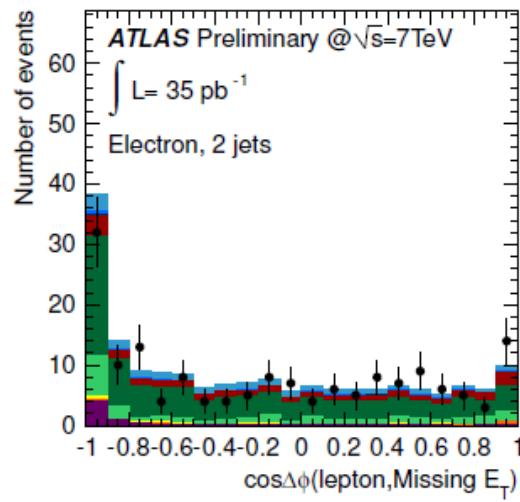
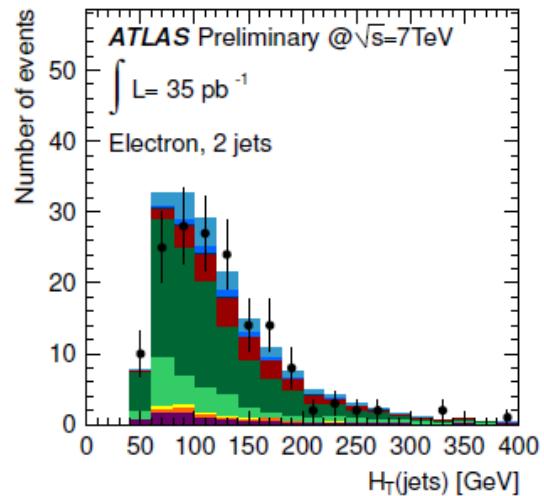
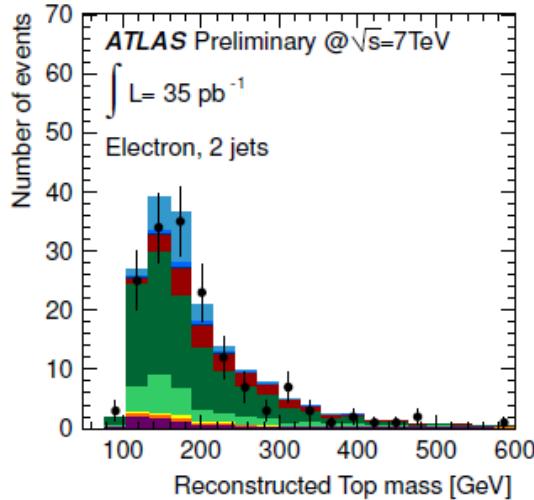
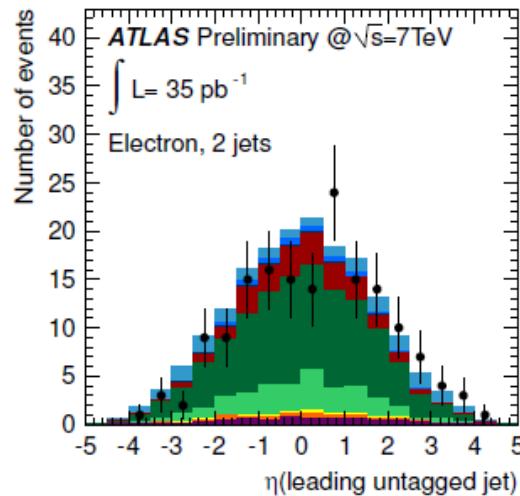
$$H_{T,3p} = \frac{\sum_{i=3}^{N_{\text{jets}}} |p_{T,i}^2|}{\sum_{j=1}^{N_{\text{objects}}} |p_{z,j}|}$$

→ transformed to $\exp[-4 \times H_{T,3p}]$

Continuous b-tagging weight w_{JP} from JetProb tagger → transformed to $-\log_{10}(w_{\text{JP}})$

Our choice: mean of two highest b-tagging weights (expect two b-jets in $t\bar{t}$ signal)

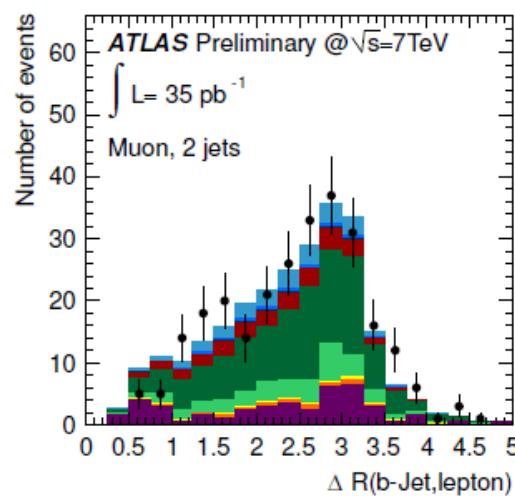
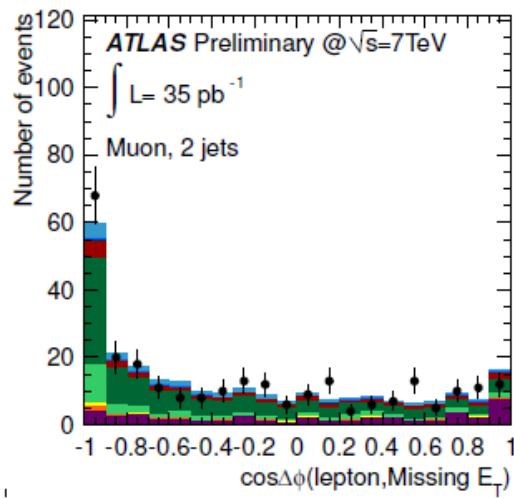
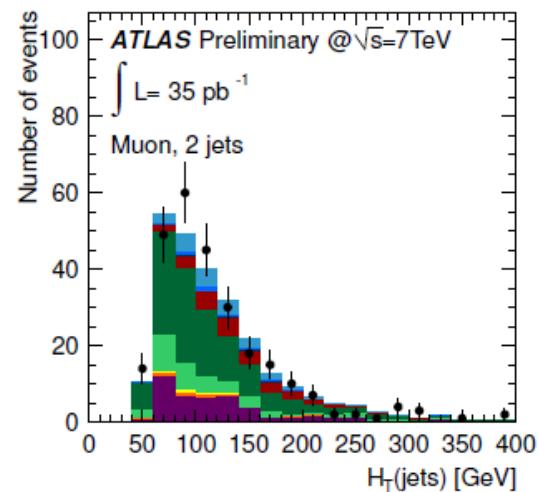
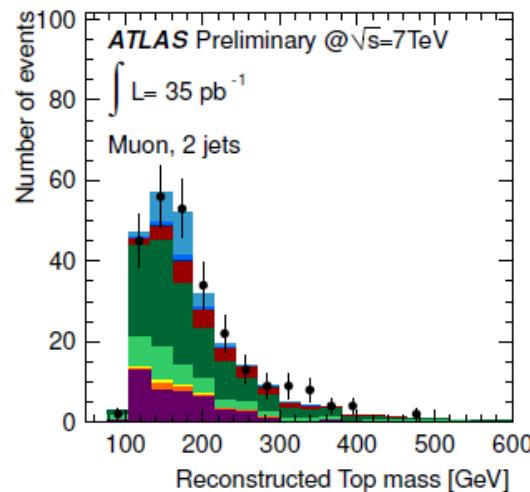
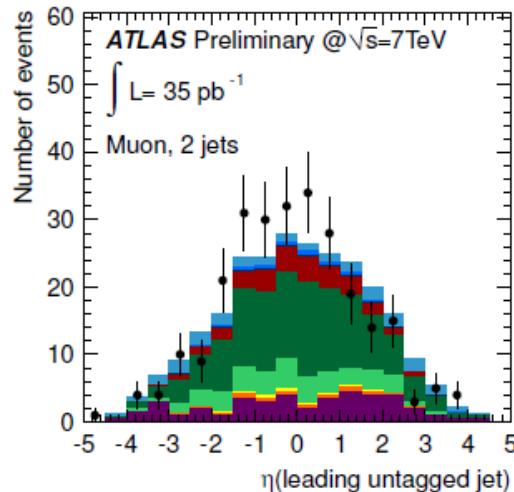
Single top – electron channel



- t-channel
- W+t prod.
- s-channel
- top pairs
- W + heavy flavor
- W + jets
- Dibosons
- Z + jets
- Multijets
- Data

Electron channel 2-jet tag sample

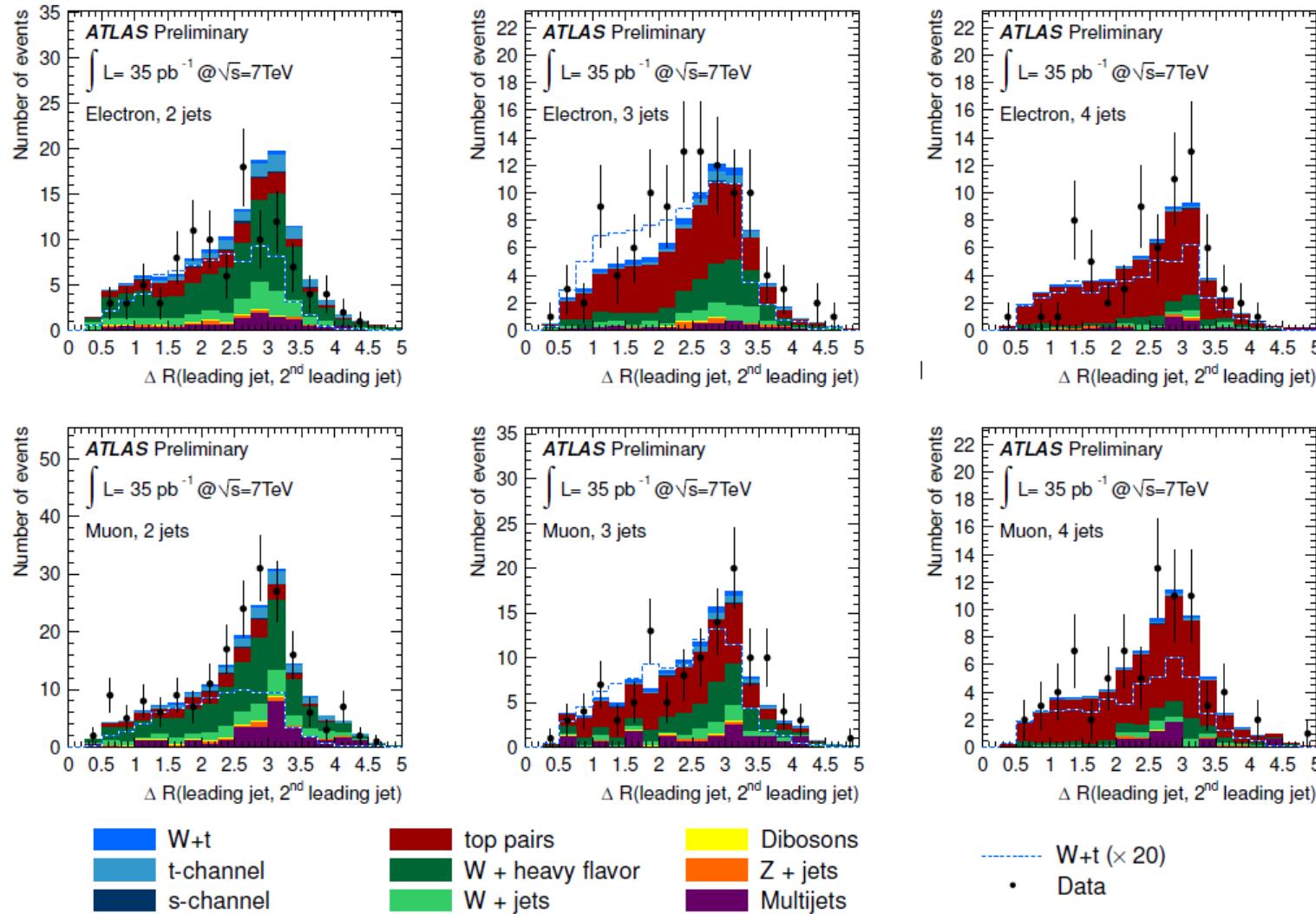
Single top - muon channel



- t-channel
- W+t prod.
- s-channel
- top pairs
- W + heavy flavor
- W + jets
- Dibosons
- Z + jets
- Multijets
- Data

Muon channel 2-jet tag sample

Single top - Wt channel



Luminosity uncertainty

Uncertainty Source	$\delta \mathcal{L}/\mathcal{L}$
Statistical	< 0.1%
Bunch charge product	3.1%
Beam centering	0.1%
Emittance growth and other non-reproducibility	0.4%
Beam position	
jitter	0.2%
Length scale calibration	0.3%
Absolute ID length scale	0.3%
Fit model	0.2%
Transverse correlations	0.9%
μ dependence	0.6%
Long-term consistency	0.5%
Total	3.4%