Top-anti-top cross section measurements in the dilepton channel from LHC

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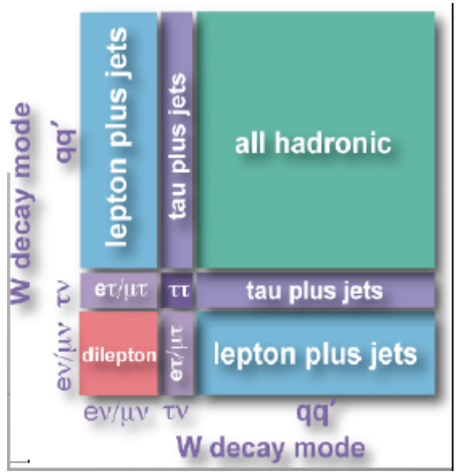
26th September 2011
TOP 2011 – Session VI

Overview

- Measurement of top-anti-top production cross section
  - Useful in its own right (QCD & EWK physics)
  - Sensitivity to new physics
  - Crucial background for BSM searches



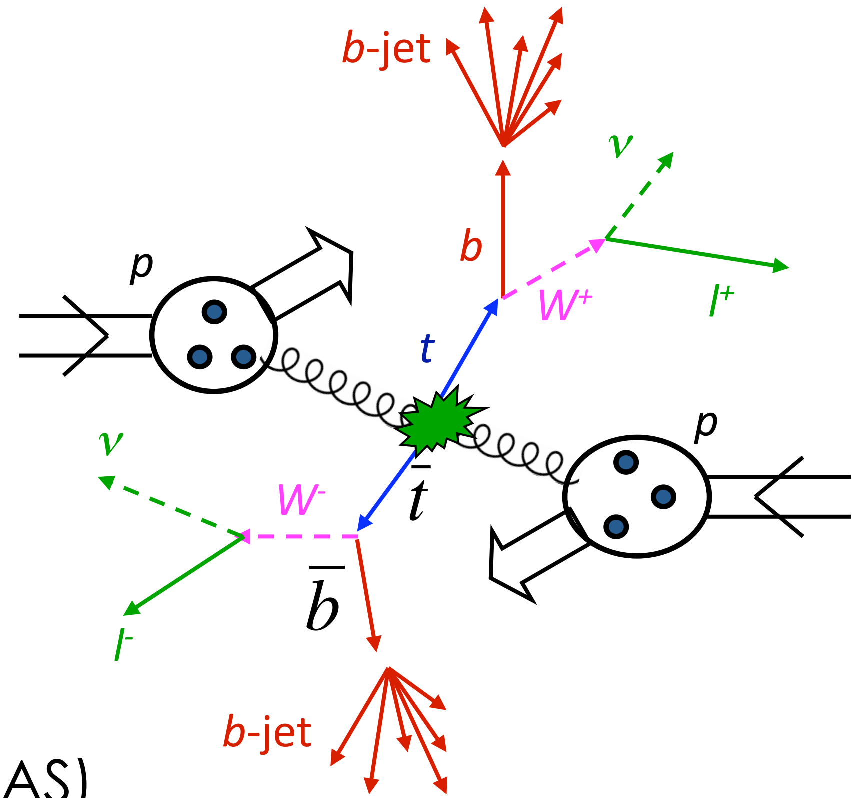
- Inclusive production cross section measurement for the ee/μμ/eμ decay channels
  - CMS PAS TOP-11-005
  - ATLAS-CONF-2011-100

- Inclusive production cross section measurement for the **μτ** decay channel
  - CMS PAS TOP-11-006
  - ATLAS-CONF-2011-119

- **New for 2011**: High pile-up (~6 per event); increased statistics

Dilepton cross sections

- Measured by both experiments
  - CMS: $\mathcal{L} = 1.1\ fb^{-1}$
  - ATLAS: $\mathcal{L} = 0.7\ fb^{-1}$
- ee, eμ, μμ
  - Branching ratio: 6.45 ± 0.11%
- Experimental signature
  - Two high-p_T leptons
  - 2 jets
    - Without b-tagging (ATLAS)
    - With b-tagging (CMS & ATLAS)
  - Missing E_T



Monte Carlo & Cross sections

m_{top} = 172.5 GeV/c^2

- ATLAS:
  - MC@NLO using CTEQ6.6 PDF set
  - Normalized to HATHOR prediction (approx. NNLO)

$$\sigma_{t\bar{t}} = 165^{+11}_{-16}\,\mathbf{pb}$$

- CMS:
  - MADGRAPH (v4.4.12) + PYTHIA (v6.422)
  - TAUOLA used for τ decays
  - Normalized to MCFM prediction (NLO)

$$\sigma_{t\bar{t}} = 158^{+23}_{-24}\,\mathbf{pb}$$

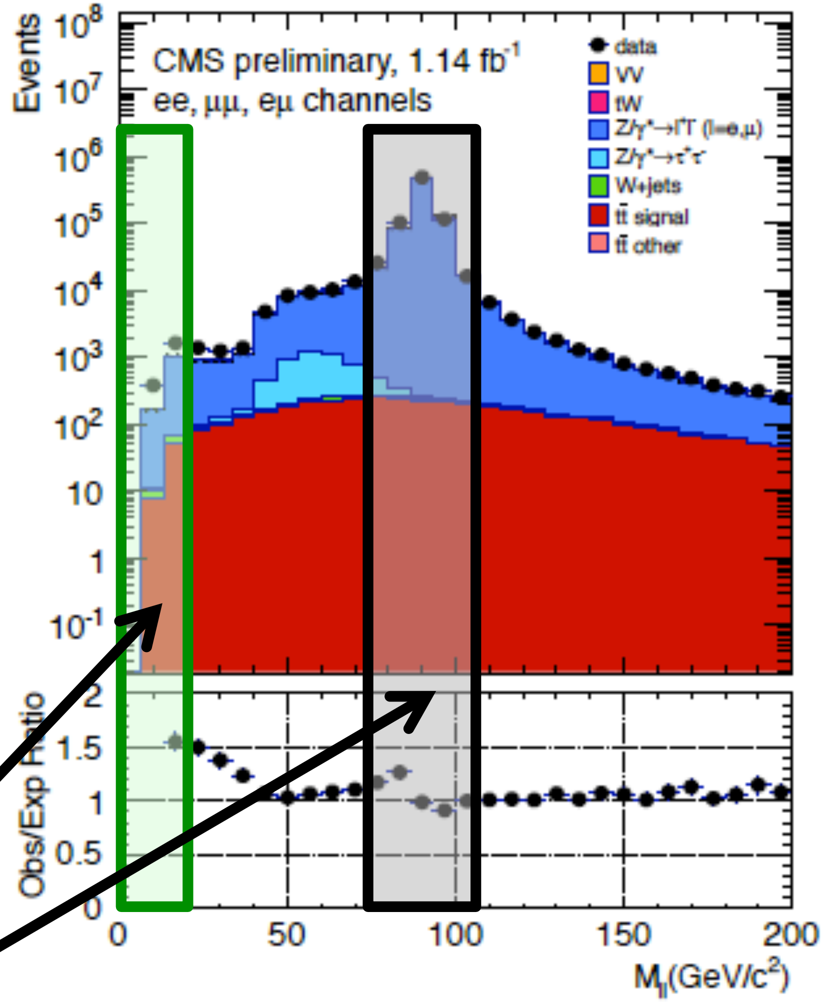
Lepton Identification

- CMS: dilepton trigger
  - Isolated lepton $p_T > 20$ GeV/c
  - $|\eta| < 2.5(e^{\pm}), 2.4(\mu^{\pm})$
- ATLAS: Single lepton trigger
  - Isolated electron $p_T > 25$ GeV/c, $|\eta| < 2.47$
  - Isolated muon $p_T > 20$ GeV/c, $|\eta| < 2.5$

Require oppositely-charged lepton pair

Rejection of Vector meson, b-quark production & low mass Drell-Yan

Z^0 veto ➔ Suppression of Z+jets background



$M_{ll} > 15(12)$ GeV/c^2
Veto ±10(15) around M_Z

Jet finding & b-tagging

Anti-k_T algorithm

ATLAS

R = 0.4
Calorimeter energy deposit input

≥ 2 jets
p_T > 25 GeV/c
$|\eta|$ < 2.5

Likelihood ratio based on a number of discriminating variables

~80% efficiency

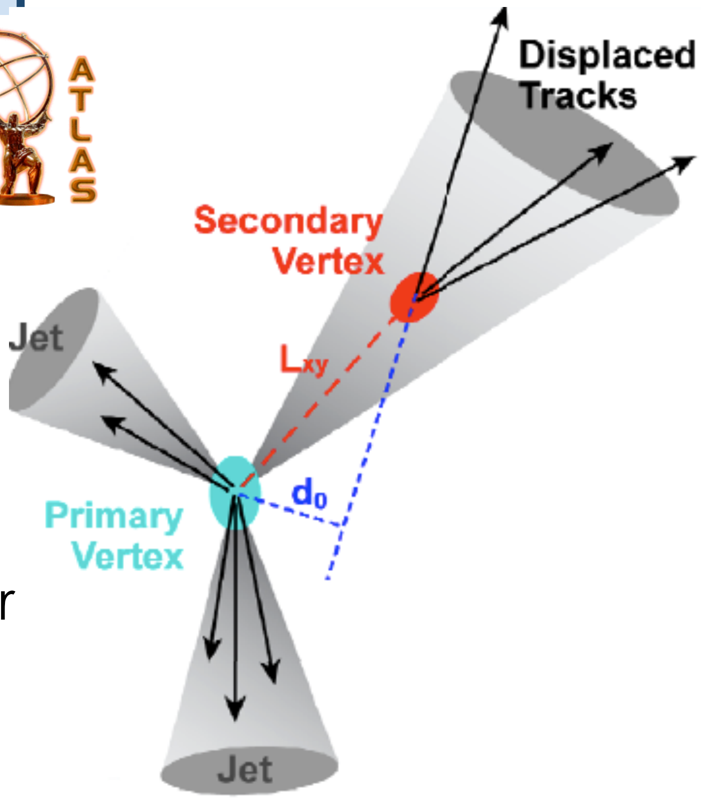
CMS

R = 0.5
Particle flow object input

≥ 2 jets
p_T > 30 GeV/c
$|\eta|$ < 2.5

3D impact parameter significance of 2nd track associated to jet

~80% efficiency

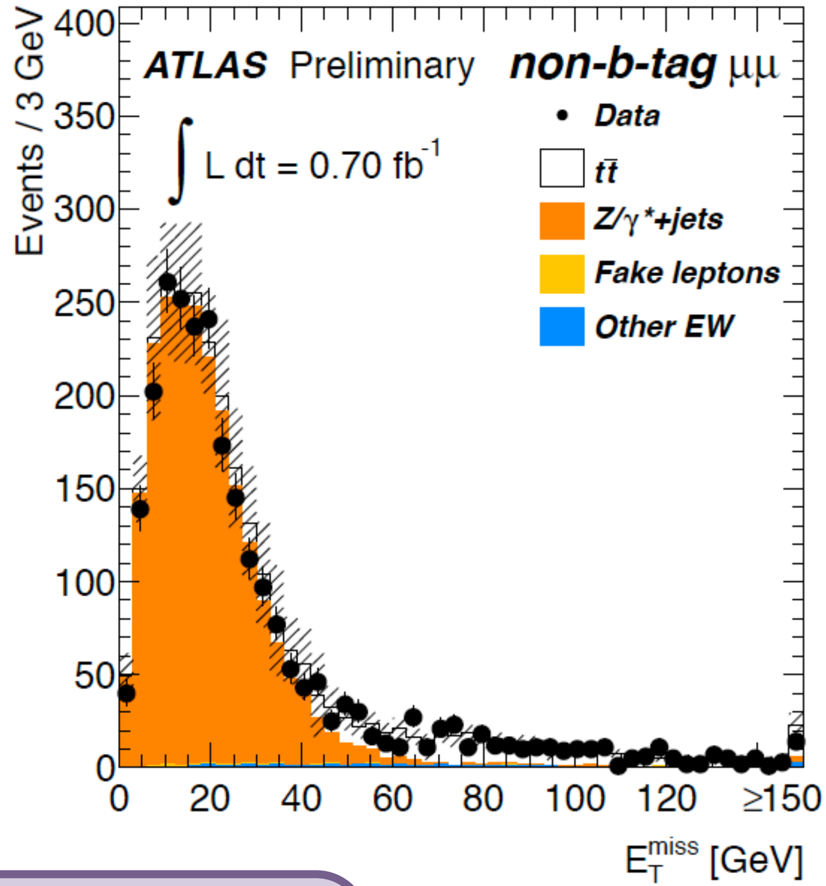


≥ 1 b-tagged jet

Missing Transverse Energy

- Reconstruction
  - ATLAS: Using jets, plus electrons, muons and any additional cal clusters
  - CMS: Using Pflow objects

- Selection only applied for ee & μμ
  - Suppress multijet and Drell-Yan backgrounds



$$\not{E}_T > (40)60\mathbf{GeV} \quad \text{(ATLAS)}$$

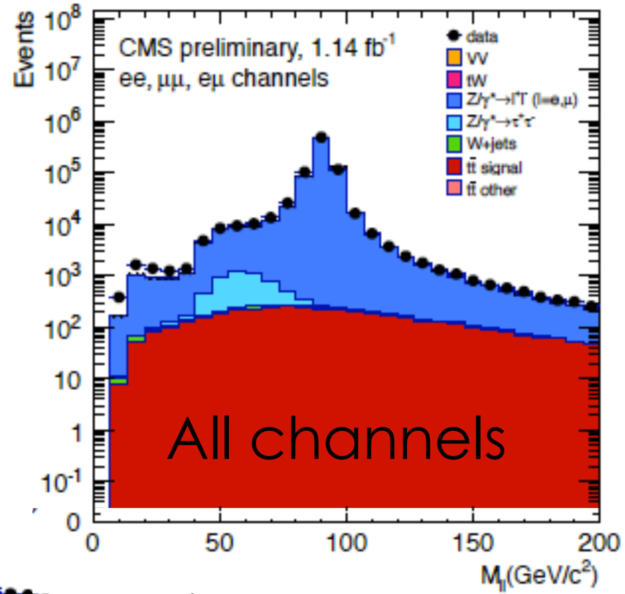
$$\not{E}_T > 30\mathbf{GeV} \quad \text{(CMS)}$$

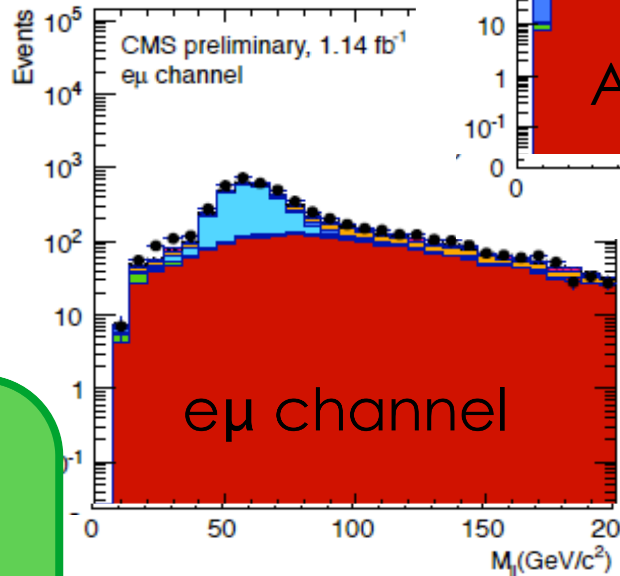
Backgrounds: $Z^0/\gamma^\star$ + Jets

- Z+jets: Ratio of events inside to outside Z veto region using MC

$$N^{Data}_{out} = N^{Data}_{in} \cdot \frac{N^{MC}_{out}}{N^{MC}_{in}}$$

- Use eμ channel to correct for other background contamination





CMS Monte Carlo:

- $M_{ll} > 50$ GeV/c^2 MADGRAPH normalized to FEWZ prediction
- $10 < M_{ll} < 20$ GeV/c^2 PYTHIA
- $20 < M_{ll} < 50$ GeV/c^2 POWHEG

ATLAS Monte Carlo:

ALPGEN normalized to NNLO prediction

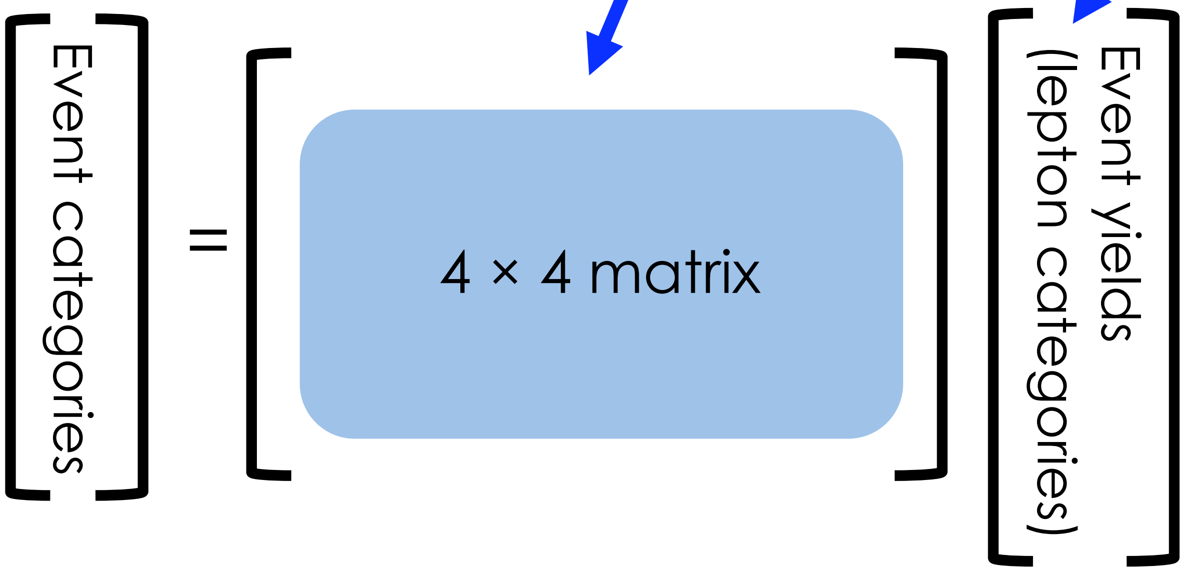
Backgrounds: W+jets

Estimated using the Matrix method (data-driven estimate)

Event categories based on isolation (standard/loose) SS, SL, LS, LL

Probabilities for real(fake) lepton passing L iso to pass S iso

Lepton categories:
Real (prompt)
Fake (non-prompt, π^0, conversions)



Real lepton: Z+jets enriched data sample

Fake lepton: QCD multi-jet enriched data sample (low missing E_T)

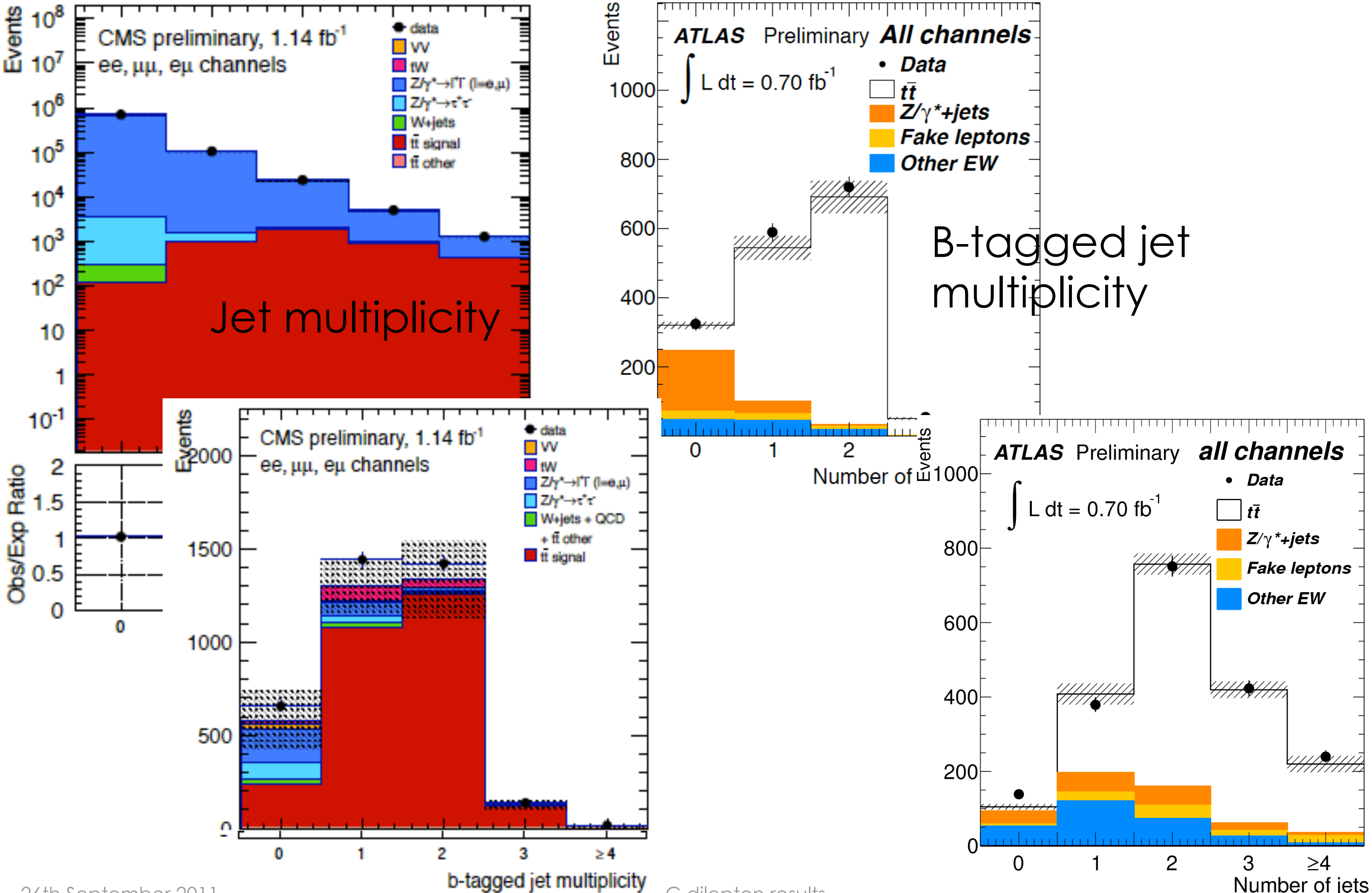
Single Top & Diboson Production

- These background sources estimated purely from MC

- CMS:
  - Single-top: Generated using POWHEG. Normalized to NLO+NNLL cross section prediction. tW channel generated using the diagram-removal scheme
  - Diboson: Generated using PYTHIA. Normalized to NLO MCFM predictions

- ATLAS:
  - Single-top: Generated using MC@NLO. tW channel generated using the diagram-removal scheme
  - Diboson: Generated using ALPGEN. Normalized to NLO MCFM predictions

Data-MC Comparisons



Systematic uncertainties

[9] CMS Collaboration, JHEP 1107 (2011) 049, arXiv:1105.5661

CMS

Source	ee	$\mu\mu$	eμ
Lepton efficiencies	3.0	1.6	2.3
Lepton selection model	4.0	4.0	4.0
Jet and $\not{E}_T$ energy scale	1.9	1.7	1.9
B-tagging	5.0	5.0	5.0
Pileup	4.0	4.0	4.0
Branching ratio	1.7	1.7	1.7
Decay model (from [9])	2.0	2.0	2.0
Event Q^2 scale (from [9])	2.3	2.3	1.7
Top quark mass (from [9])	2.6	2.6	1.5
Jet and $\not{E}_T$ model (from [9])	3.2	3.2	0.4
Shower model (from [9])	0.7	0.7	0.7
Total Systematic	10.0	9.6	8.8
Luminosity	4.5	4.5	4.5

✧Z+jets background estimate uncertainty 50%
✧W+jets background estimate uncertainty 50% difference between data and MC
✧Single top, VV and Z -> ττ 30%

ATLAS

	ee	$\mu\mu$	$e\mu$	Combined
Uncertainty Source	$\Delta\sigma/\sigma[\%]$	$\Delta\sigma/\sigma[\%]$	$\Delta\sigma/\sigma[\%]$	$\Delta\sigma/\sigma[\%]$
Data statistics	-9.3 / 9.8	-6.6 / 6.8	-4.1 / 4.2	-3.3 / 3.3
Luminosity	-4.0 / 4.7	-3.7 / 4.3	-4.3 / 4.7	-4.2 / 4.6
MC statistics	-4.2 / 4.9	-2.8 / 3.2	-1.9 / 2.1	-1.5 / 1.6
Lepton energy scale	0.0 / 0.9	0.0 / 0.5	-0.3 / 0.3	-0.4 / 0.0
Lepton energy resolution	0.0 / 0.6	-0.5 / 0.8	0.0 / 0.5	-0.4 / 0.3
Lepton indent. scale factor	-5.5 / 6.6	-1.2 / 2.7	-3.1 / 3.4	-2.6 / 2.7
Jet energy scale	-10.0 / 10.6	-3.8 / 7.6	-3.7 / 4.5	-5.9 / 5.3
Jet energy resolution	-0.6 / 0.8	-3.1 / 3.6	-0.6 / 0.7	-0.4 / 0.3
Jet reconstr. efficiency	0.0 / 0.0	0.0 / 0.0	0.0 / 0.0	0.0 / 0.0
Drell-Yan prediction	0.0 / 0.0	-0.4 / 0.4	0.0 / 0.0	0.0 / 0.0
Fake leptons	-1.6 / 1.6	-0.4 / 0.4	-3.2 / 3.2	-2.0 / 1.9
MC generator	-4.3 / 5.3	0.0 / 0.0	-2.9 / 3.2	-2.1 / 2.3
Parton shower	-4.7 / 5.8	-0.4 / 0.5	-2.9 / 3.2	-2.3 / 2.4
ISR	-7.1 / 0.6	-0.8 / 3.6	-0.5 / 2.4	-2.4 / 2.5
FSR	-13.6 / 0.6	-0.7 / 4.3	-2.4 / 0.5	-1.3 / 1.4
PDF	-2.4 / 2.8	-1.7 / 2.2	-2.4 / 2.7	-2.3 / 2.5
E_T^{miss} reconstruction	-1.0 / 1.1	-0.8 / 1.7	0.0 / 0.0	-0.5 / 0.6
Pile-up	-0.6 / 1.3	-0.5 / 1.5	0.0 / 0.0	-0.5 / 0.5
Detector modeling	-0.6 / 1.1	-0.7 / 1.5	-0.7 / 1.2	-1.0 / 1.3
Theoretical cross-sections	-1.4 / 1.3	-1.7 / 1.8	-2.1 / 2.1	-1.9 / 1.9
All systematics	-20 / 18	-7.3 / 13	-9.2 / 11	-9.3 / 10
Stat + Syst	-22 / 20	-9.9 / 15	-10 / 12	-9.8 / 11

Total systematic: 9.5 – 11.3%   Total systematic: 7.3 – 20%

Cross Section determination

- ATLAS
  - Likelihood fit of number of observed events in each channel, luminosity and systematics
  - σ_{top} free parameter of fit – extracted from profile likelihood ratio
  - Fit yields cross sections for individual channels and combined value

- CMS
  - Cross section extracted using: $\sigma_{t\bar{t}} = \sigma_{theory} \cdot \frac{N_{signal}}{SF \cdot N_{exp}}$
  - σ_{theory} = 157.5 pb; N_{exp} = number of expected events
  - N_{signal} = number of observed signal events
  - SF = scale factor (accounts for differences between data & MC)
  - Combined cross section determined using BLUE method★

★Lyons, Gibaut, Clifford NIM A270 (1988) 110

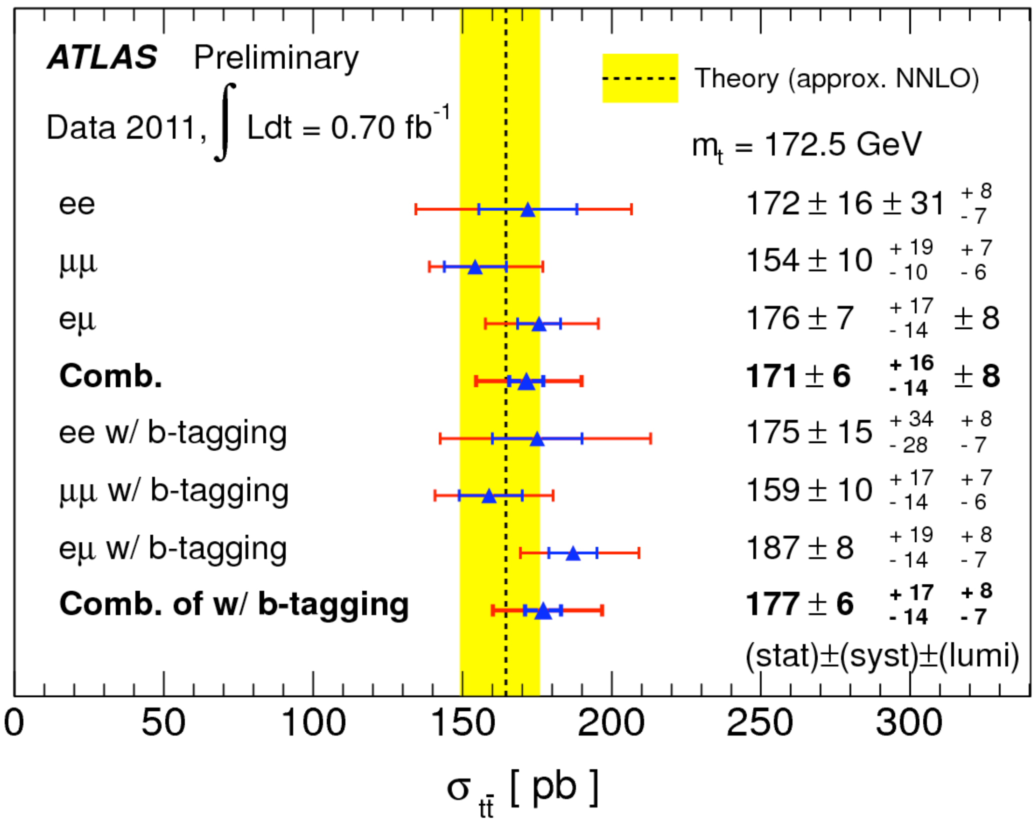
Results

CMS Preliminary:

ee channel
189.9 ± 8.9 ± 21.4 ± 8.5 pb

μμ channel
165.8 ± 7.4 ± 18.5 ± 7.5 pb

eμ channel
169.9 ± 4.4 ± 16.2 ± 7.6 pb

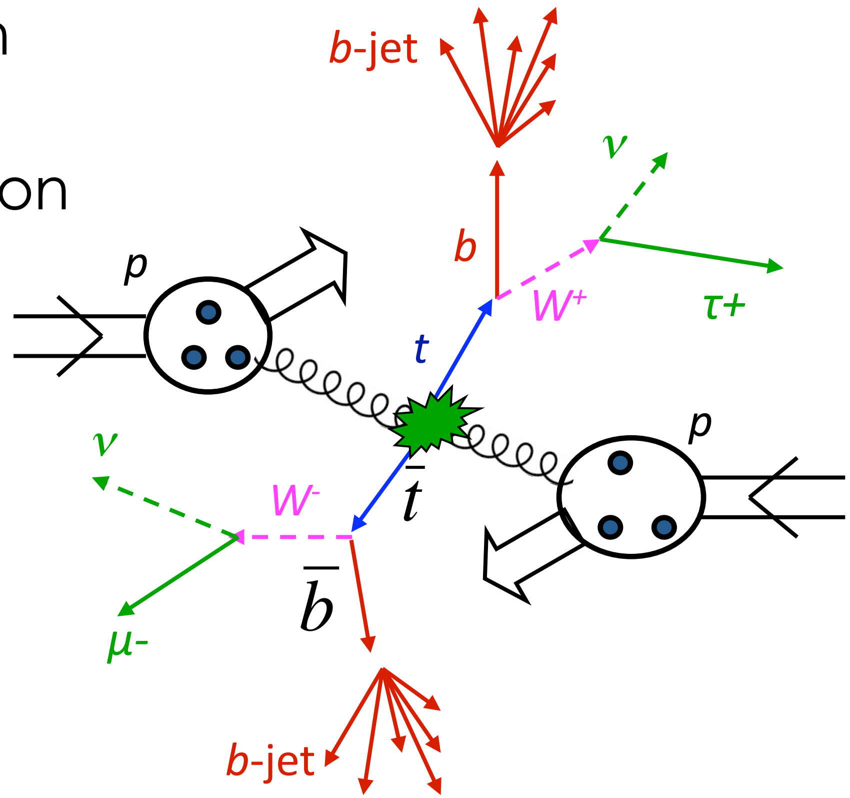


CMS: $\sigma_{t\bar{t}} = 169.9 \pm 3.9(stat) \pm 16.3(syst) \pm 7.6(lumi)\,pb$

ATLAS: $\sigma_{t\bar{t}} = 177 \pm 6(stat)^{+17}_{-14}(syst)^{+8}_{-7}(lumi)\,pb$

τμ cross section

- First measurement of top-anti-top cross section with τ in the final state
- New physics: Charged Higgs with $m_H < m_{top}$
  - Possible anomalous τ production
- $\mathcal{L} \approx 1.1\ \text{fb}^{-1}$
- Branching ratio ~2.4%
- Experimental signature:
  - Isolated high p_T muon
  - 2 or more jets (b-tagging)
  - Hadronically-decaying τ
  - Missing E_T



Identification of τ leptons

- Tau decays:
  - One or three charged mesons (mainly $\pi^{\pm}$)
  - Up to two π^0

- CMS: "Hadron plus strips" algorithm
  - Analyze jet constituents (jet cone $\Delta R = 2.8/p_T$)

Combine Pflow EM objects in "strips" → Make neutral objects → Combine with charged hadrons

Look for π^0 to $\gamma\gamma$ decays

Reconstruct τ decay products

- If results indicate more than one possible decay channel
  - Take the one with lowest E_T sum of jet constituents not associated with τ decay

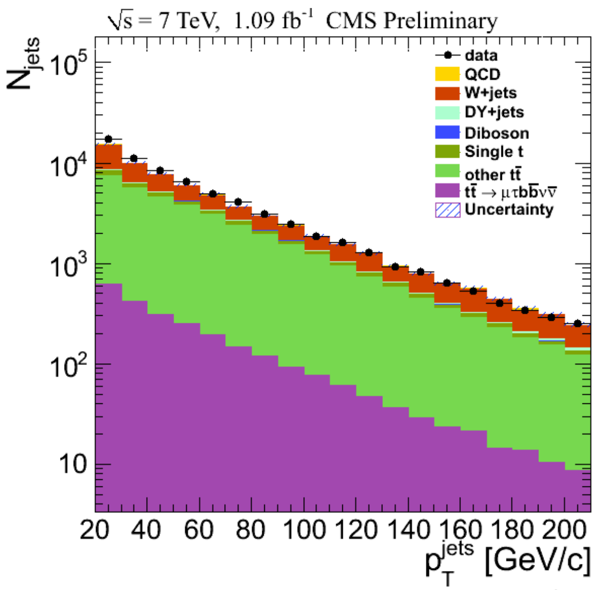
Identification of τ leptons (II)

- ATLAS: Two-stage process
  - Select jets with 1, 2 or 3 tracks associated ($p_T > 1$ GeV/c, leading track $p_T > 4$ GeV/c)
  - Use BDT to separate $e^{\pm}$ and $\tau^{\pm}$
- Remaining sample = mainly fakes
  - Use second BDT to identify τ with 1 (τ_1) or 3 (τ_3) tracks
  - Fit two BDT distributions separately with templates

Backgrounds

- Two sources of background:
  - τ-fakes: Data-driven estimate
  - Non-τ-fakes: Estimated from MC
    - Drell-Yan (ττ, ee, μμ), single top, dibosons & top-anti-top background

- τ-fake background = μ + missing E_T + ≥ 3 jets
    - 1 jet mis-identified as a τ-jet
  - Dominated by W+jets and tt → μ + jets

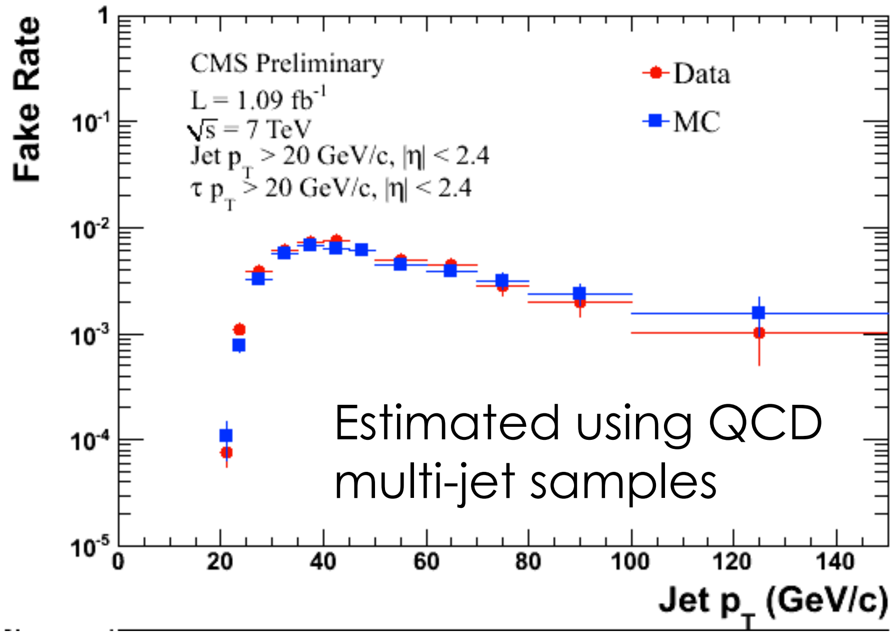


- Two different approaches

Backgrounds (CMS)

- ✧ Determine probability for a jet to be mis-identified as a τ-jet using:

- ✧ Two data samples:
  - ✧ QCD multijet (mainly gluon jets)
  - ✧ W + ≥ 1 jet (mainly quark jets)



- ✧ Signal sample is mixture of quark + gluon jets
  - ✧ Quark jets higher probability of faking τ-jets
  - ✧ Take average as correction - apply to all jets
  - ✧ Use difference as systematic uncertainty

Backgrounds (ATLAS)

- Expect τ and μ to have opposite sign (OS)
  - Exploit same-sign (SS) sample in background estimation
- Before missing E_T cut QCD multi-jet background dominant
  - Approx. equal in OS & SS samples
  - Subtract SS from OS to remove it

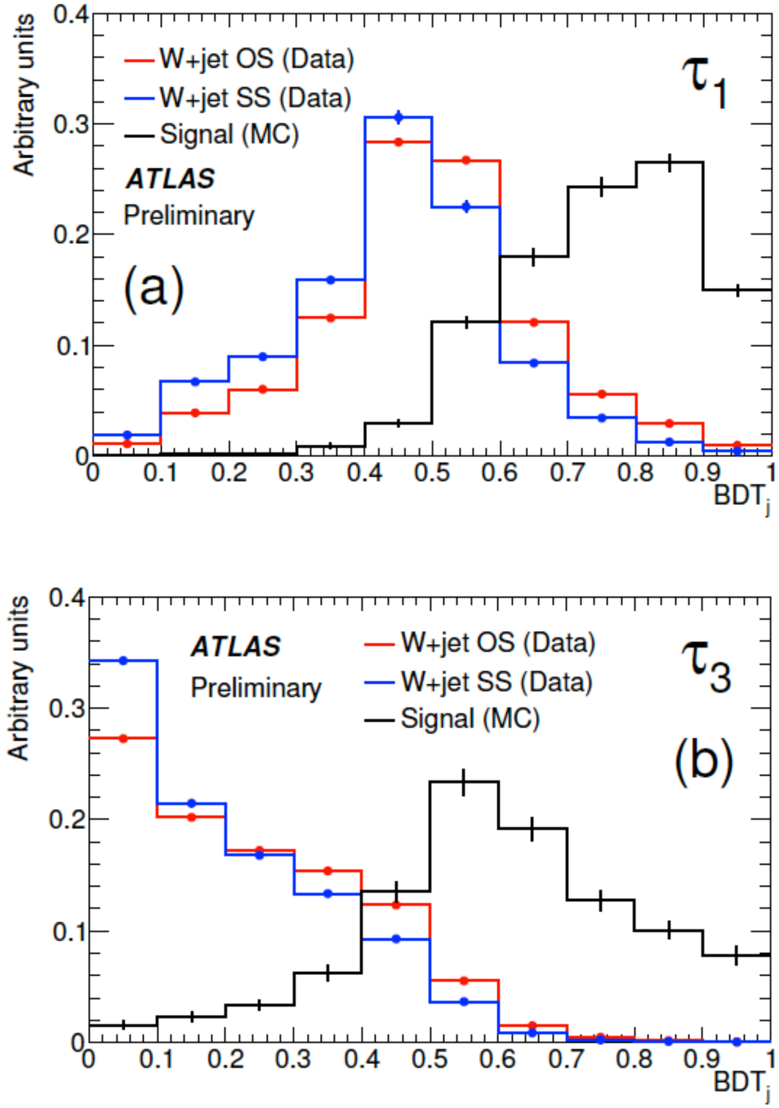
- Use W + ≥ 1 jet sample to estimate background
  - OS sample = mainly light-quark jets (some gluon jets & b-jets)
  - SS sample = significantly higher fraction of gluon jets

- Gluon component of τ fakes = charge symmetric ➠ same shape
  - Subtract SS from OS will remove it (and b/anti-b contribution)

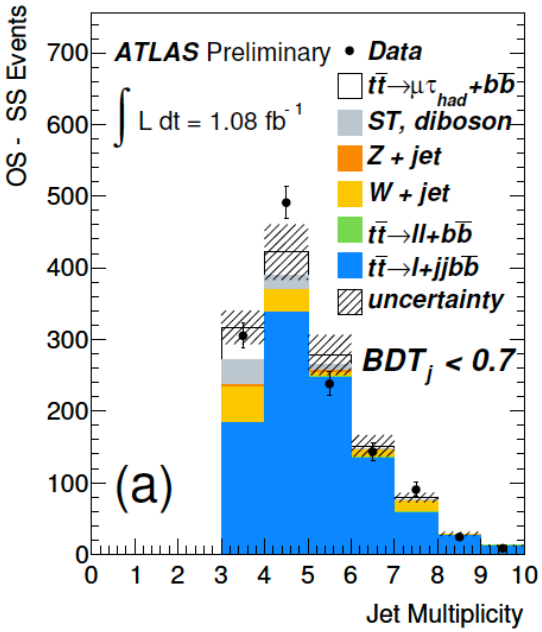
- Remaining background handled by BDT

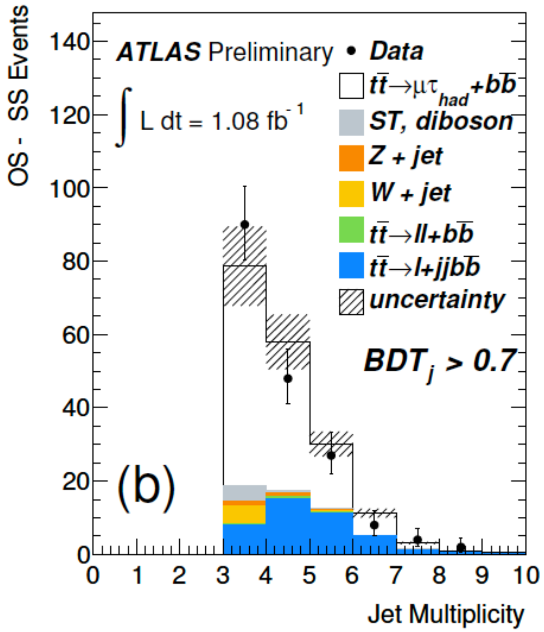
Backgrounds (ATLAS) (II)

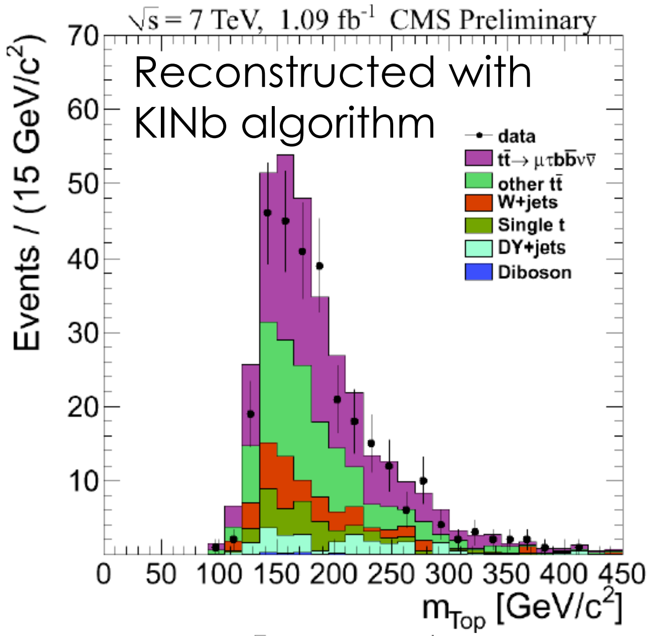
- τ identification only way to suppress remaining background
  - Apply BDT
- Build background template based on OS+SS W+jets data sample
- Signal template from tt → τ+jets and Z → $\tau^+\tau^-$ MC
- Remaining tt → μe + jets estimated using MC – added to signal template
- χ^2 fit made to determine normalisations

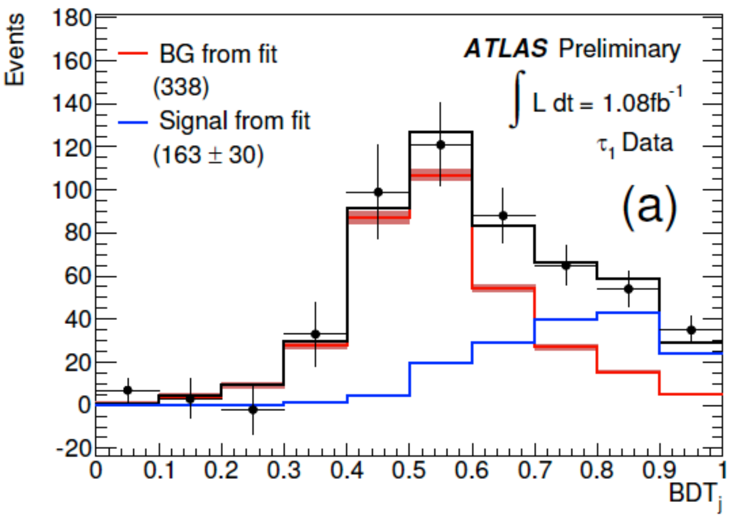


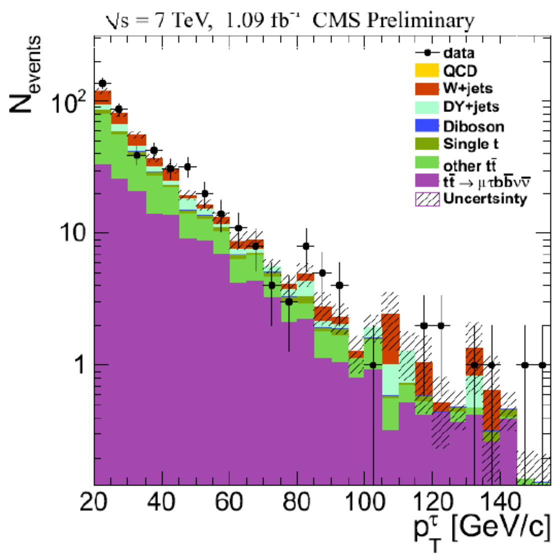
Data-MC Comparisons

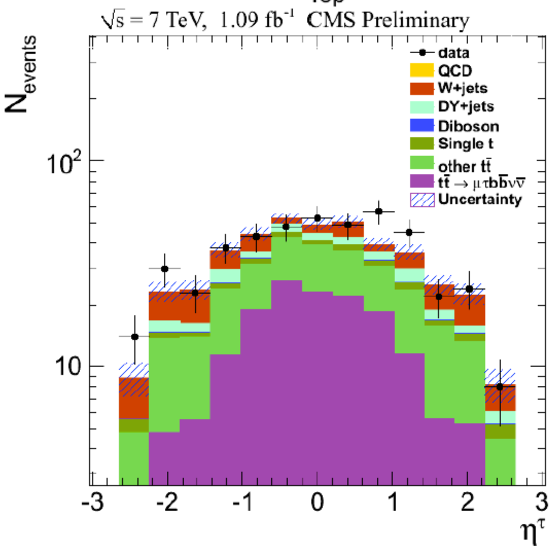












Results

- Systematic uncertainties similar to those already presented
- Uncertainty related to τ identification
  - CMS: τ fake background – 13%; τ identification – 7.3%
  - ATLAS: τ uncertainty 5.8 – 9.5%

τ_1 $136 \pm 23(stat)^{+19}_{-15}(syst) \pm 5(lumi)\,pb$

τ_3 $163 \pm 53(stat)^{+23}_{-20}(syst) \pm 6(lumi)\,pb$

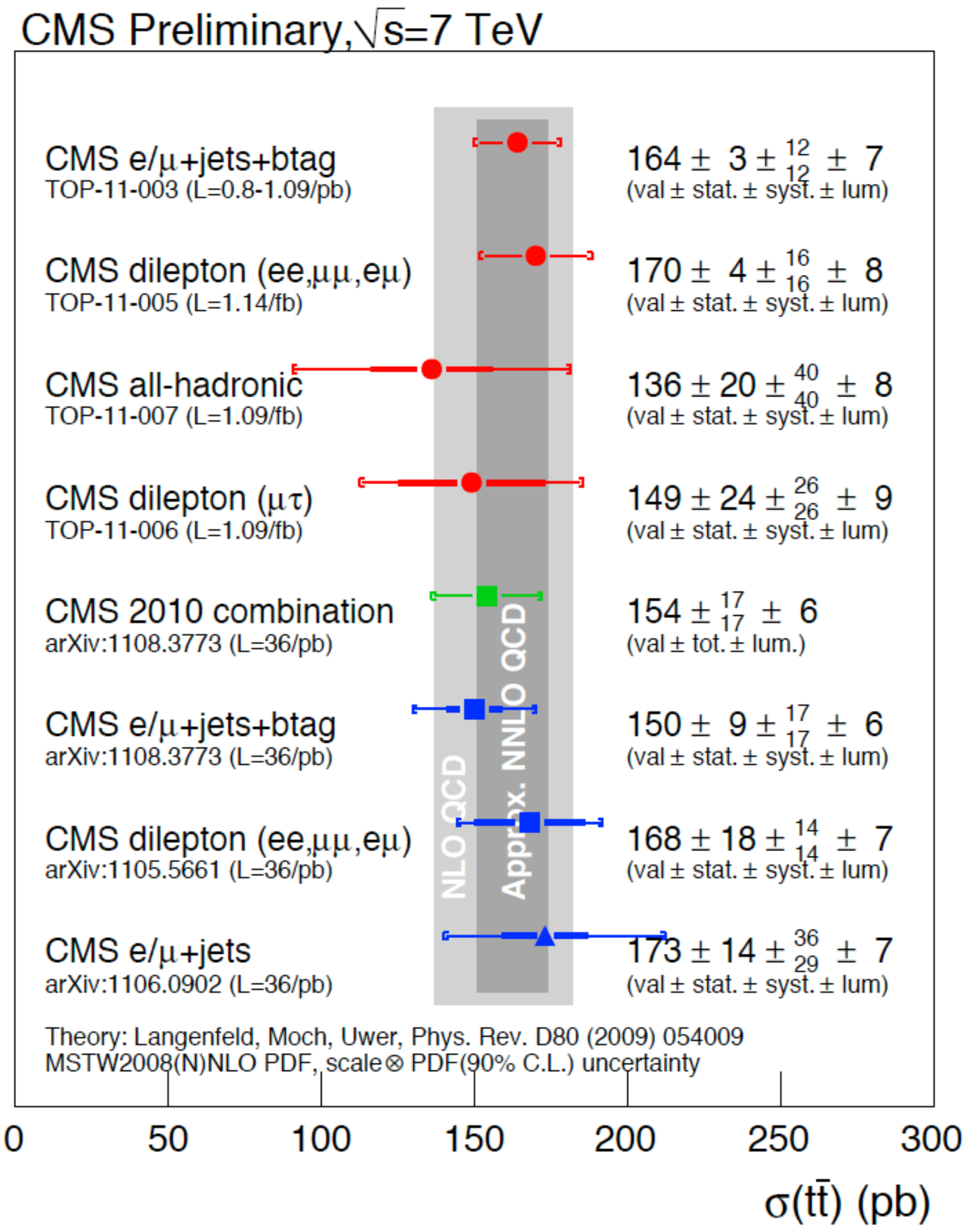
ATLAS Combined $\sigma_{t\bar{t}} = 142 \pm 21(stat)^{+20}_{-16}(syst) \pm 5(lumi)\,pb$

CMS $\sigma_{t\bar{t}} = 148.7 \pm 23.6(stat) \pm 26.0(syst) \pm 8.9(lumi)\,pb$

HATHOR $\sigma_{t\bar{t}} = 164^{+11}_{-16}\,pb$

Kidonakis $\sigma_{t\bar{t}} = 163^{+7}_{-5}(scale) \pm 9(PDF)\,pb$

Cross Section Summary (CMS)



Conclusions & outlook

- Updated measurement of top-anti-top cross section in the dilepton decay channel presented (ee/μμ/eμ)
  - Good agreement between CMS & ATLAS and with theory
  - High pile-up under good control
  - Slight increase in systematics

- First measurement of top-anti-top cross section in **μτ** decay channel presented
  - Experimentally challenging
  - Good agreement between expts & theory

- Measurements now limited by systematics
  - Look to reduce these by improved understanding of pile-up and b-tagging

BACK-UP SLIDES

Event Yields

CMS

Source	ee	$\mu\mu$	$e\mu$
Dilepton $t\bar{t}$	$427.5 \pm 19.7 \pm 44.5$	$559.3 \pm 22.9 \pm 56.3$	$1487.2 \pm 37.3 \pm 139.2$
VV	$2.6 \pm 1.6 \pm 0.8$	$3.4 \pm 1.9 \pm 1.1$	$6.9 \pm 2.6 \pm 2.2$
Single top - tW	$22.9 \pm 4.8 \pm 7.3$	$28.9 \pm 5.4 \pm 9.2$	$73.4 \pm 8.6 \pm 23.3$
Drell-Yan $\tau\tau$	$6.9 \pm 2.6 \pm 2.2$	$8.8 \pm 3.0 \pm 2.9$	$27.3 \pm 5.2 \pm 8.8$
Drell-Yan ee, $\mu\mu$	$38.2 \pm 4.3 \pm 19.1$	$50.5 \pm 5.1 \pm 25.2$	-
QCD/W+jets	2.9 ± 4.3(tot.)	7.6 ± 4.7(tot.)	30.0 ± 12.0(tot.)
Total background	73.6 ± 22.2(tot.)	99.1 ± 28.6(tot.)	137.6 ± 29.6(tot.)
Data	589	688	1742

ATLAS

	ee	$\mu\mu$	$e\mu$	b-tag ee	b-tag $\mu\mu$	b-tag $e\mu$
$Z/\gamma^*(\rightarrow ee/\mu\mu)$+jets	$3.8^{+2.5}_{-1.2}$	14.8 ± 4.7	-	$9.3^{+3.7}_{-1.9}$	$19.1^{+2.4}_{-1.6}$	-
$Z/\gamma^*(\rightarrow \tau\tau)$+jets	5.2 ± 2.6	11.2 ± 4.8	43 ± 16	$1.6^{+1.1}_{-0.9}$	$7.0^{+2.8}_{-3.2}$	$9.1^{+3.6}_{-3.7}$
Fake leptons	3.1 ± 2.2	$0.3^{+0.6}_{-0.3}$	44 ± 24	4.9 ± 3.1	1.0 ± 0.8	19 ± 12
Single top quarks	6.6 ± 1.2	16.2 ± 2.0	40.9 ± 5.6	$6.8^{+1.3}_{-1.2}$	$15.4^{+2.5}_{-2.4}$	$30.8^{+4.9}_{-4.5}$
Diboson	5.6 ± 1.0	8.2 ± 1.2	30.9 ± 4.6	2.1 ± 0.8	$2.7^{+0.9}_{-0.6}$	$8.7^{+1.5}_{-1.3}$
Total bkg.	$24.3^{+5.4}_{-4.7}$	50.8 ± 8.4	158 ± 34	$24.7^{+5.2}_{-4.0}$	$45.2^{+4.6}_{-4.4}$	68 ± 14
Predicted $t\bar{t}$	135 ± 17	252^{+23}_{-28}	753 ± 61	167^{+21}_{-22}	314^{+30}_{-38}	666^{+62}_{-77}
Total	159 ± 18	303^{+24}_{-29}	912 ± 70	192 ± 22	359^{+31}_{-38}	734^{+63}_{-78}
Observed	165	287	962	202	349	823

Event Yields

ATLAS

Before E_T^{miss} cut (data)	W + jet (OS)	W + jet (SS)	Signal	MC expectation
τ_1	3180 ± 610	1150 ± 580	672 ± 70	806 ± 20
τ_3	12100 ± 1200	6710 ± 1200	193 ± 50	261 ± 10
Before b–tag (data)	W + jet (OS)	W + jet (SS)	Signal	MC expectation
τ_1	1840 ± 400	740 ± 380	427 ± 50	477 ± 10
τ_3	7700 ± 810	4610 ± 810	106 ± 30	160 ± 10
After b–tag (data)	W + jet (OS)	W + jet (SS)	Signal	MC expectation
τ_1	700 ± 190	360 ± 170	163 ± 30	198 ± 3
τ_3	1930 ± 380	1010 ± 380	62 ± 20	66 ± 2

CMS

Source	Events (± stat. ± syst.)
$t\bar{t} \rightarrow WbWb \rightarrow \mu\nu b\ \tau\nu b$	152.7 ± 2.8 ± 16.6
τ fakes	163.0 ± 9.7 ± 17.3
other $t\bar{t}$	12.7 ± 0.8 ± 2.6
$Z/\gamma^* \rightarrow ee, \mu\mu$	0.7 ± 0.5 ± 0.5
$Z/\gamma^* \rightarrow \tau\tau$	30.9 ± 3.6 ± 5.8
Single top	13.8 ± 0.7 ± 2.0
VV	2.4 ± 0.2 ± 0.3
Total expected	376.4 ± 10.8 ± 29.7
Data	361

Cross Section Determination

$$\mathcal{L}(\sigma_{sig},L,\alpha) = \prod_{i\in\{channel\}} P(N_i^{obs} \mid N_{i,tot}^{\exp}(\vec{\alpha})) \times G(L_0 \mid L,\sigma_L) \times \prod_{j\in syst} G_j(0 \mid \alpha_j,1)$$

- Cross section = free parameter of the fit
- Vector of α values = systematic uncertainties
  - Each αj = "nuisance parameter" = ± 1std dev
- P = Poisson distribution expected number of signal & background events
- G = Gaussian distribution modeling of Luminosity
- Cross section determined from profile Likelihood ratio:

$$\lambda(\sigma_{sig}) = L(\sigma_{sig},\hat{\hat{L}},\hat{\hat{\vec{\alpha}}}) / L(\hat{\sigma}_{sig},\hat{L},\hat{\vec{\alpha}})$$

Single circumflex represents maximum likelihood estimate of parameter
Double circumflex represents conditional MLE for a given σ_{sig}