Standard Model Measurements at ATLAS

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On behalf of the ATLAS collaboration

Standard Model Flagship of the ATLAS Physics Program in 2010

Soft QCD
- Particle Multiplicities
- Underlying Event
- Total pp Cross Section

QCD
- Inclusive Jets
- Inclusive γ
- Jet Shapes
- W/Z + Jets
- Top pair production

Electro-weak
- W/Z cross section
- $Z \rightarrow \tau\tau$
- W Asymmetry
- Diboson:
  $W\gamma$ / $Z\gamma$ / WW
- Single Top

Standard Model as Standard Candles:

Use the Signals we expect to see to ...

- Understand Detector

- Refine Analysis techniques

Important for physics objects used everywhere:

Charged Leptons / Missing E_T / Jets / Photons

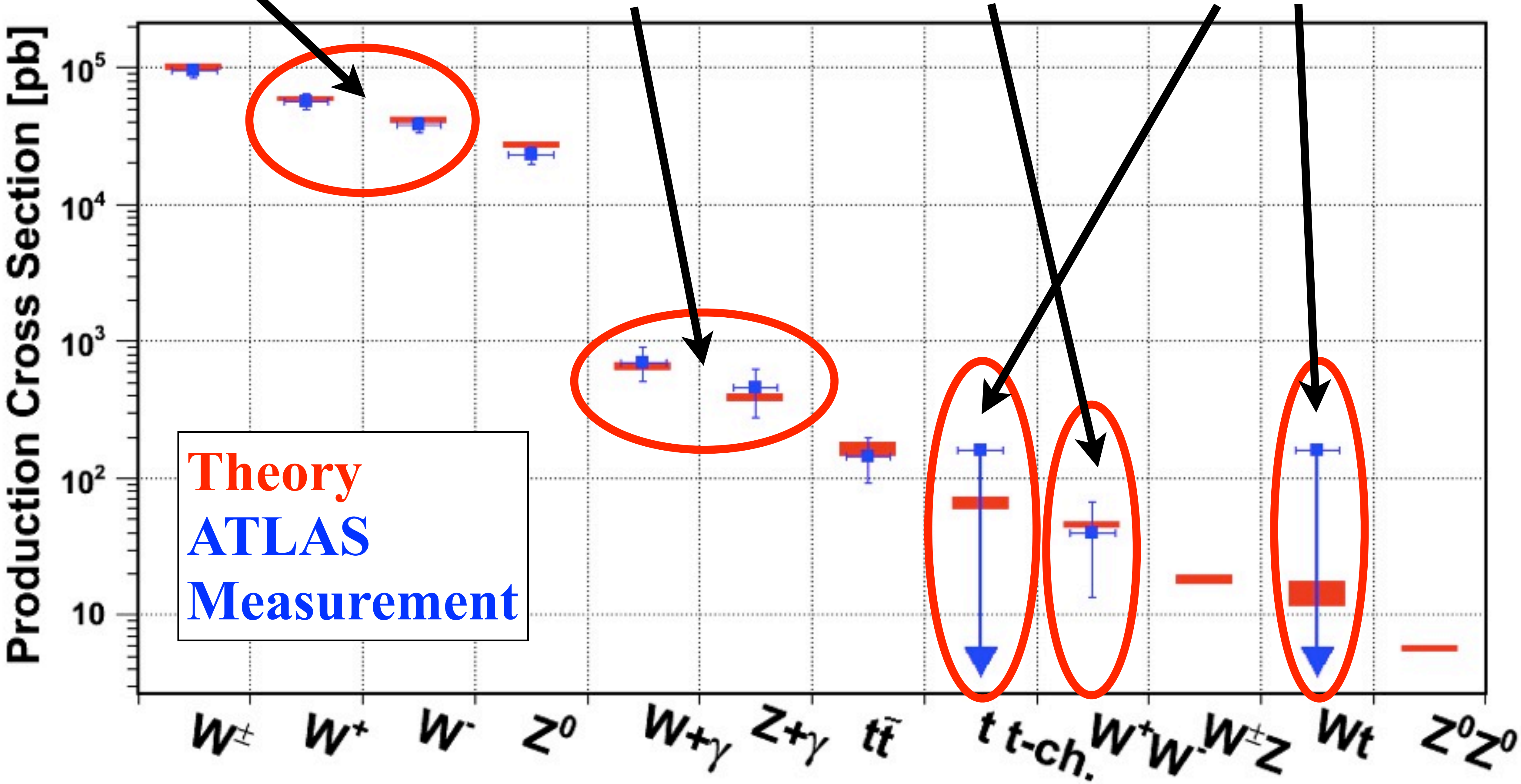
Outline

W→$\mu\nu$ Charge Asymmetry

Wγ/Zγ Cross Section

WW Cross Section

Single Top



Young Scientists Forum

- Jet production cross-section measurement
- Observation of Z→ττ decays.
- Top cross-section in lepton+jets channel
- Estimation of SM backgrounds to SUSY

W Charge Asymmetry

Sensitive to proton valence quark distribution.

- More W^+ than W^- produced at LHC (2u/1d - quark)
- Can be used to constrain PDFs. (Important for $10^{-3} \leq x \leq 10^{-1}$)

Measured in μ-channel vs μ pseudorapidity:

$$A_\mu = \frac{\frac{d\sigma_{W\mu^+}}{d\eta_\mu} - \frac{d\sigma_{W\mu^-}}{d\eta_\mu}}{\frac{d\sigma_{W\mu^+}}{d\eta_\mu} + \frac{d\sigma_{W\mu^-}}{d\eta_\mu}}$$

Many experimental uncertainties cancel in Asymmetry

Selection

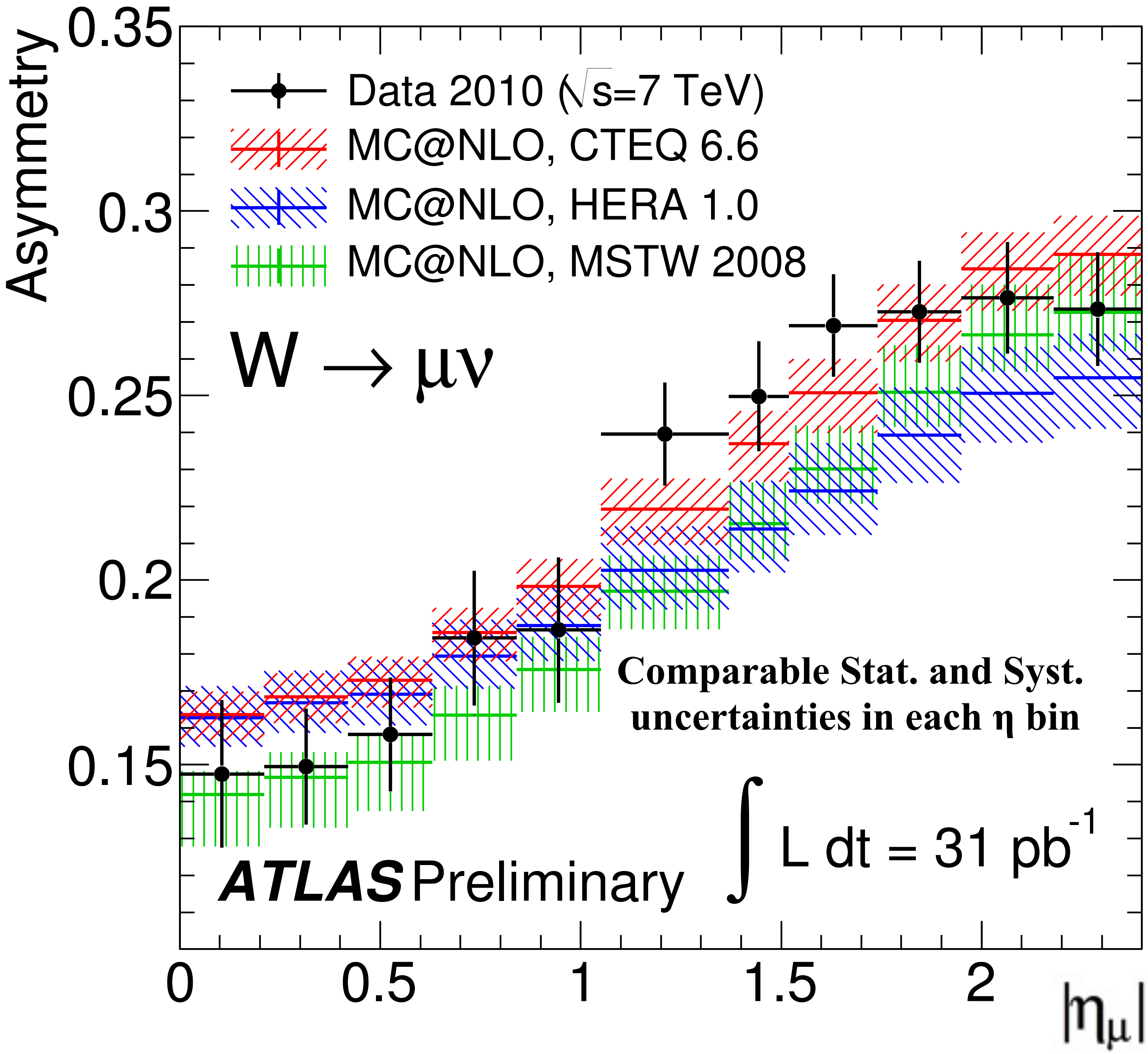
$$P_T^\mu > 20\ \mathrm{GeV},\ E_T^{miss} > 25\ \mathrm{GeV},\ m_T > 40\ \mathrm{GeV}$$

1.30×10^5 Candidates

Background Estimation

7% of candidate events: 6% leptonic (Z→μμ(ττ)/W→τυ/tt)
1% QCD jets (data-driven)

W Charge Asymmetry

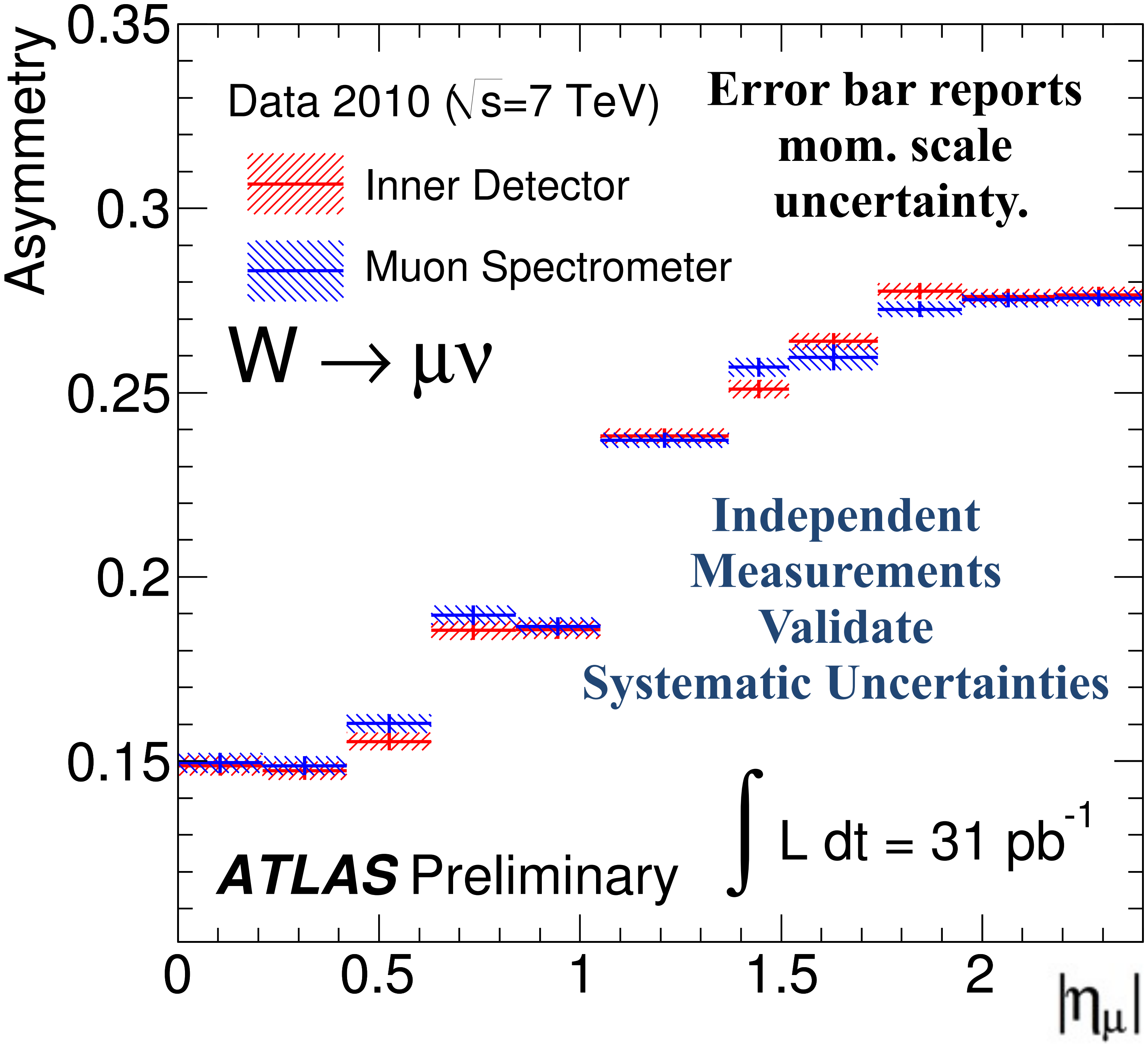


Source	Relative Uncertainty
Trigger	2-7%
μ- rec	1-7%
Mom. scale	1-2%
Background	1-2%

Systematics limited by Data Statistics in Control Samples

Current Experimental Uncertainties Already Comparable to those of Global Fits.

W Charge Asymmetry



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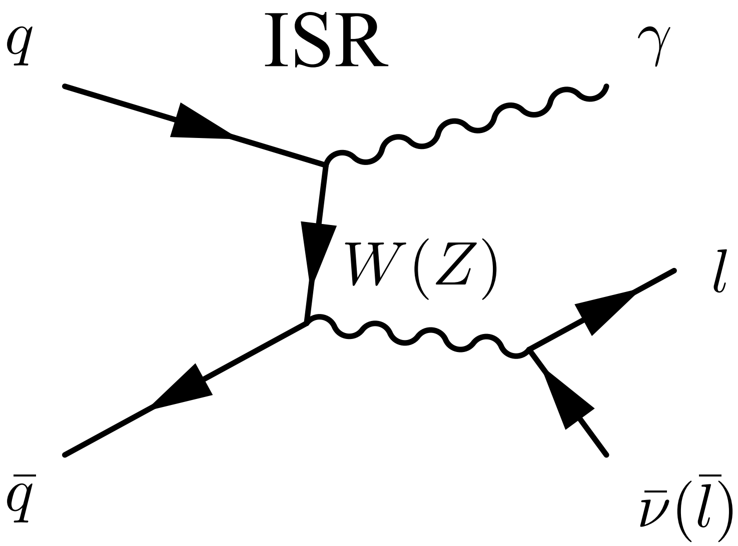
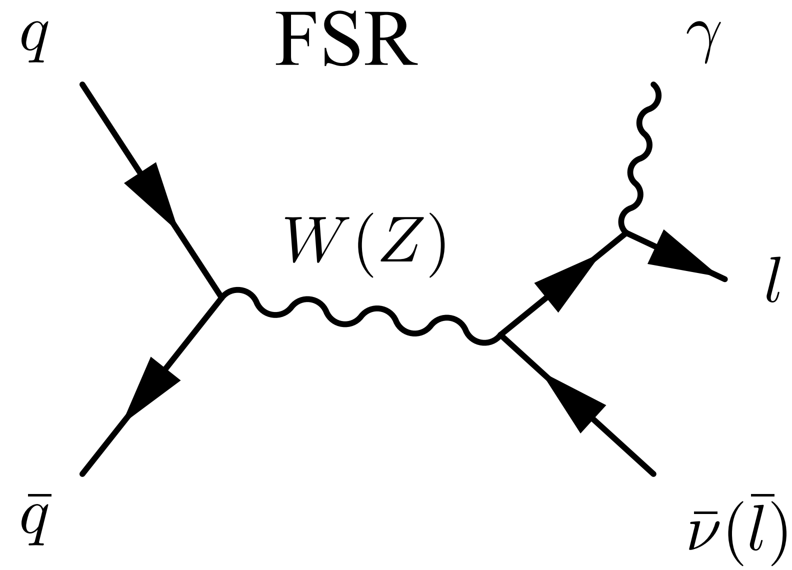
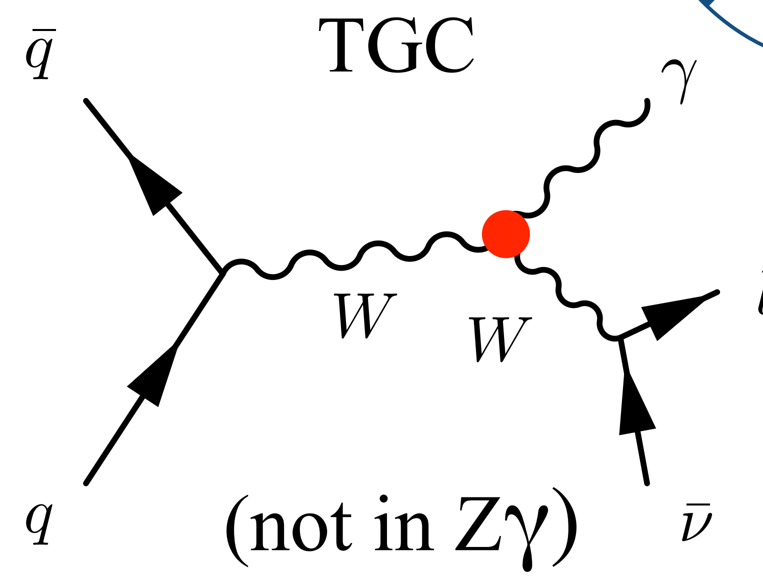
Wγ and Zγ cross sections







Motivation:

- **First Wγ, Zγ cross section measurements at 7 TeV**
- **Test EWK model, Sensitive to Triple Gauge Couplings**
- **Will Constrain New Physics in Anomalous TGCs**

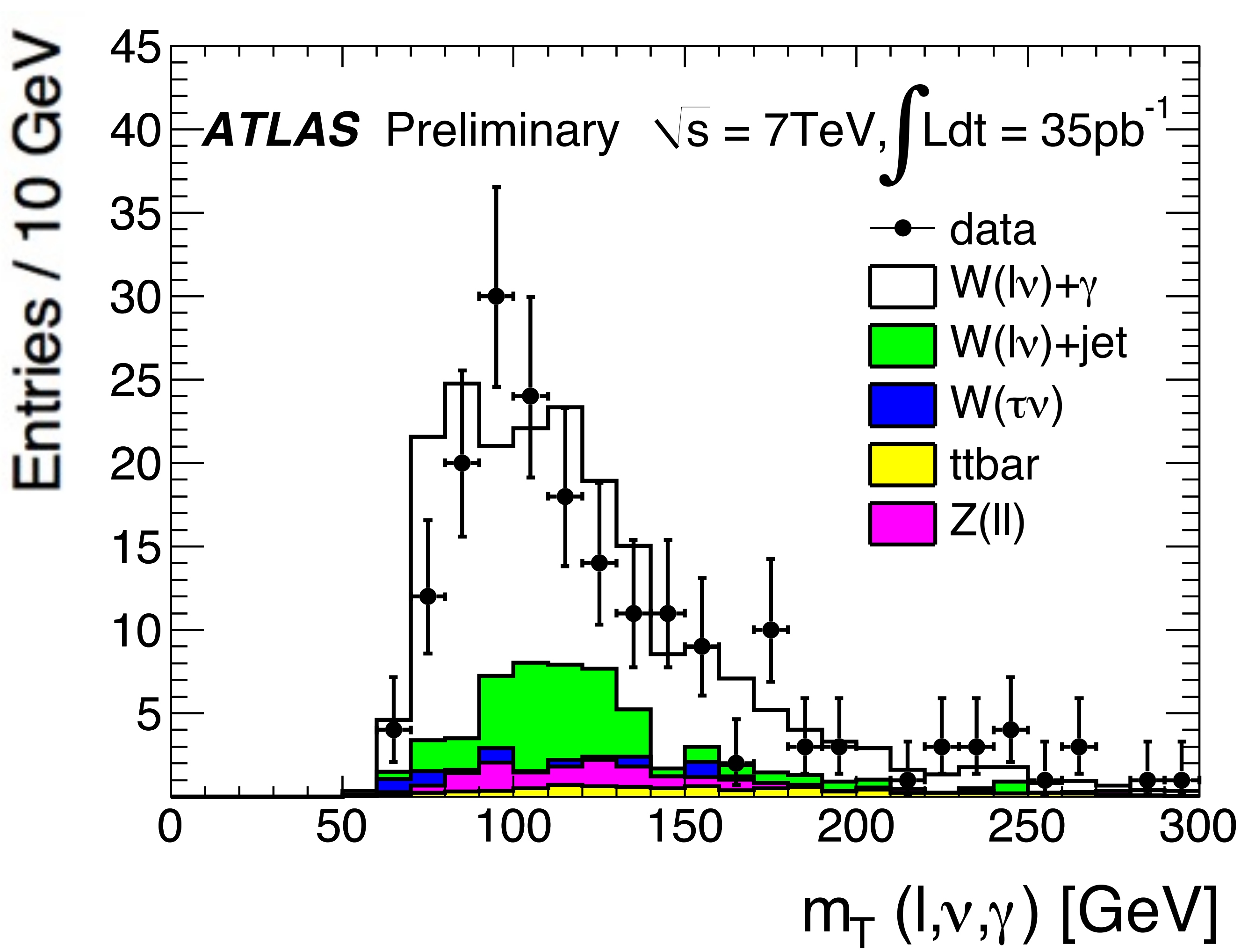
Signature:

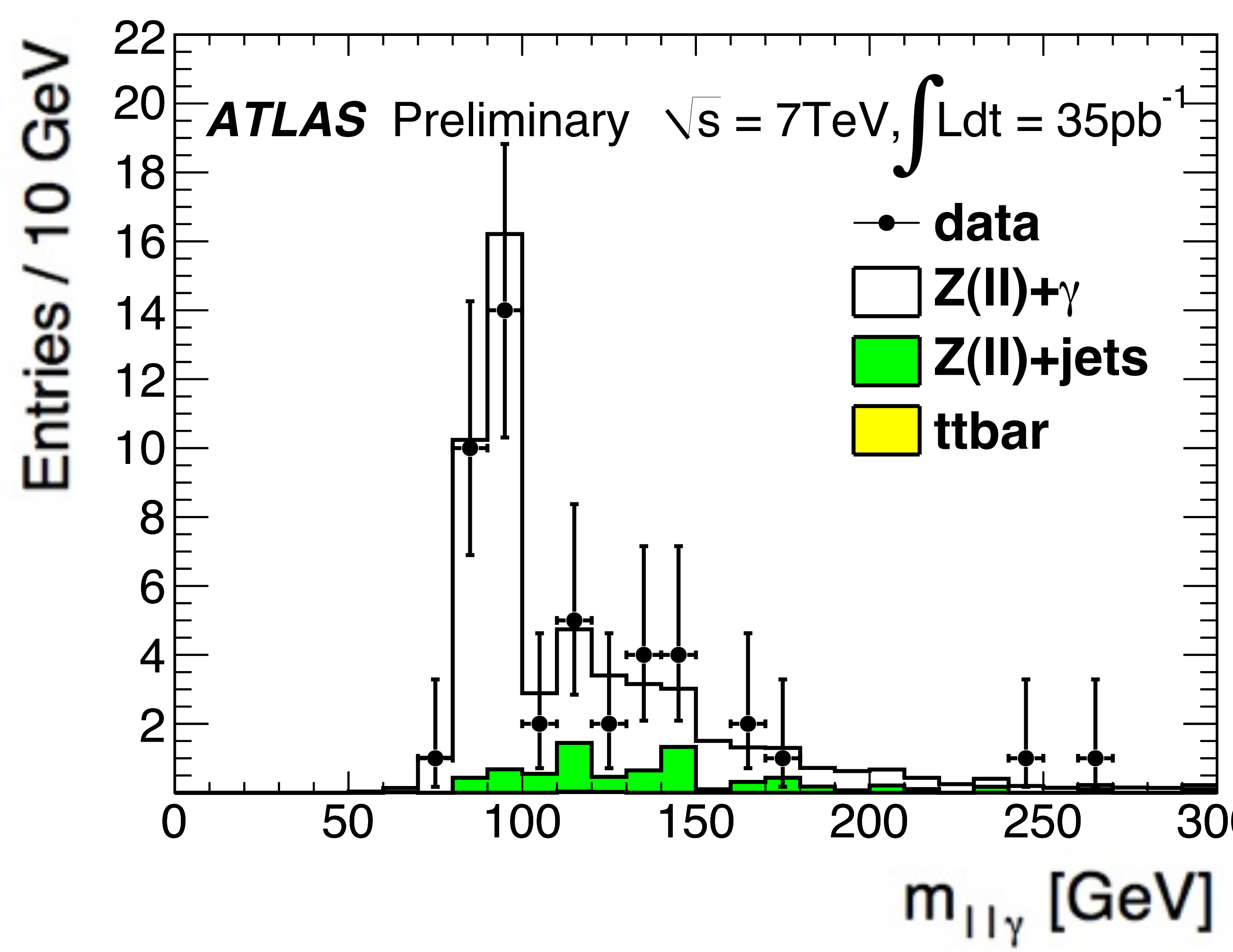
- Performed in Leptonic Decay Channels.
- W candidate - $E_T^l > 20$ GeV, $E_T^{miss} > 25$ GeV, $m_T^W > 40$ GeV
- Z candidate - $E_T^l > 20$ GeV, $m_{l^+l^-} > 40$ GeV
- Isolated γ - $E_T^\gamma > 15$ GeV, $E_T^{Iso(0.4)} < 5$ GeV, $\Delta R(l,\gamma) > 0.7$

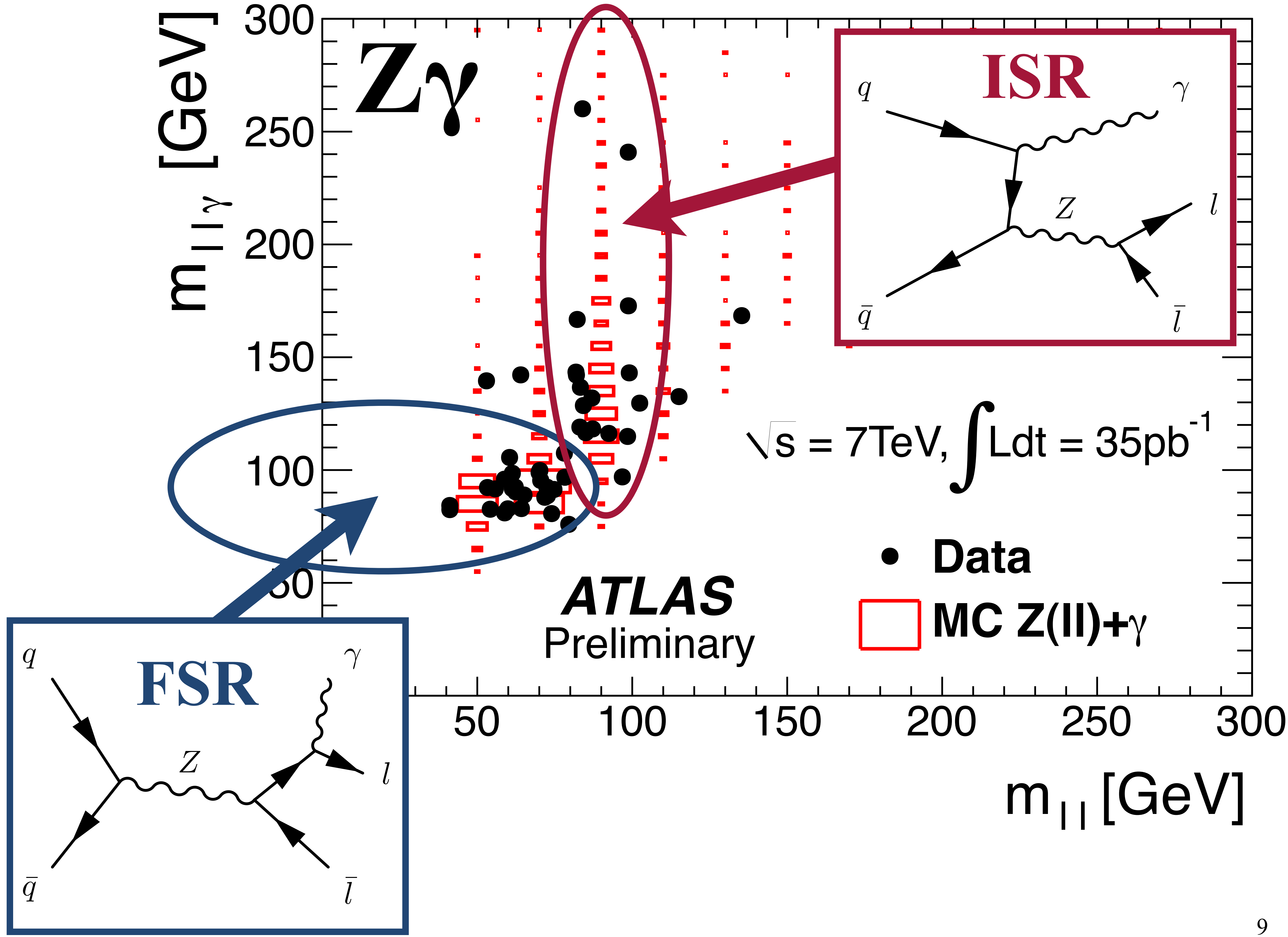
Yields / Background

Wγ	e-channel	μ-channel
Event Yield	95	97
W+Jets Bkg (Data)	16.9 ± 6.4 ± 7.3	16.8 ± 4.7 ± 7.3
EW Bkg (MC)	10.1 ± 0.8 ± 1.1	12.4 ± 0.9 ± 1.4

Zγ	e-channel	μ-channel
Event Yield	25	23
Background (MC)	3.8 ± 3.8	3.4 ± 3.4







Zγ
ISR
FSR
$\sqrt{s}$ = 7TeV, $\int$Ldt = 35pb^{-1}
Data
MC Z(ll)+γ
ATLAS
Preliminary
$m_{ll\gamma}$ [GeV]
m_{ll} [GeV]

Wγ and Zγ cross sections

W+γ+X	Measured cross section (pb)
e-channel	73.9 ± 10.5 (stat) ± 15.9 (sys) ± 8.1 (lumi)
μ-channel	58.6 ± 8.2 (stat) ± 11.7 (sys) ± 6.4 (lumi)

SM NLO Prediction: 69.0 ± 4.6 (sys)

Z+γ+X	Measured cross section (pb)
e-channel	16.4 ± 4.5 (stat) ± 4.3 (sys) ± 1.8 (lumi)
μ-channel	10.6 ± 2.6 (stat) ± 2.5 (sys) ± 1.2 (lumi)

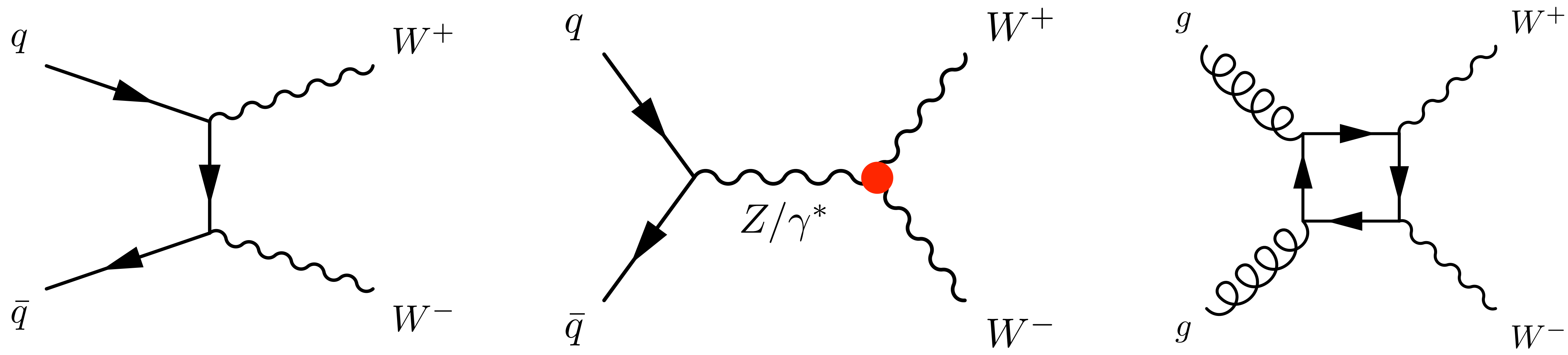
SM NLO Prediction: 13.8 ± 0.9 (sys)

Cross Section Reported for: $E_T^\gamma > 10$ GeV / $\Delta R(l, \gamma) > 0.5$ / $f_{iso}^\gamma < 0.5$

Systematics limited by: γ-Rec/ID, Background Estimation, Signal Acceptance.

First Wγ, Zγ cross section measurements at 7 TeV

WW Cross Section



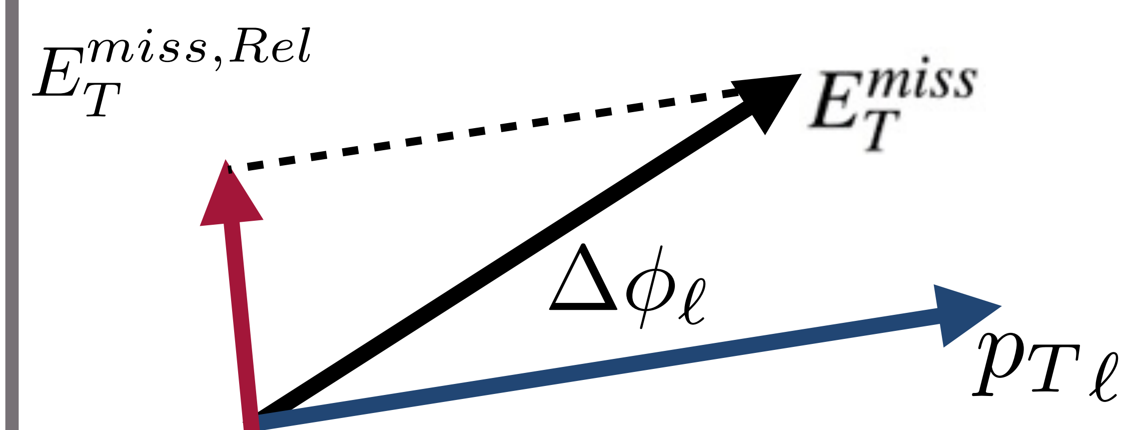
Motivation:

- Test EWK model, Sensitive to Triple Gauge Couplings
- Will Constrain New Physics in Anomalous TGCs
- Dominant Background to H→WW search

Signature:

- Performed Fully Leptonic Decays.
- 2 Opposite-Sign Leptons (e,μ)
- Large Missing Energy

Relative Missing Energy



WW Event Selection

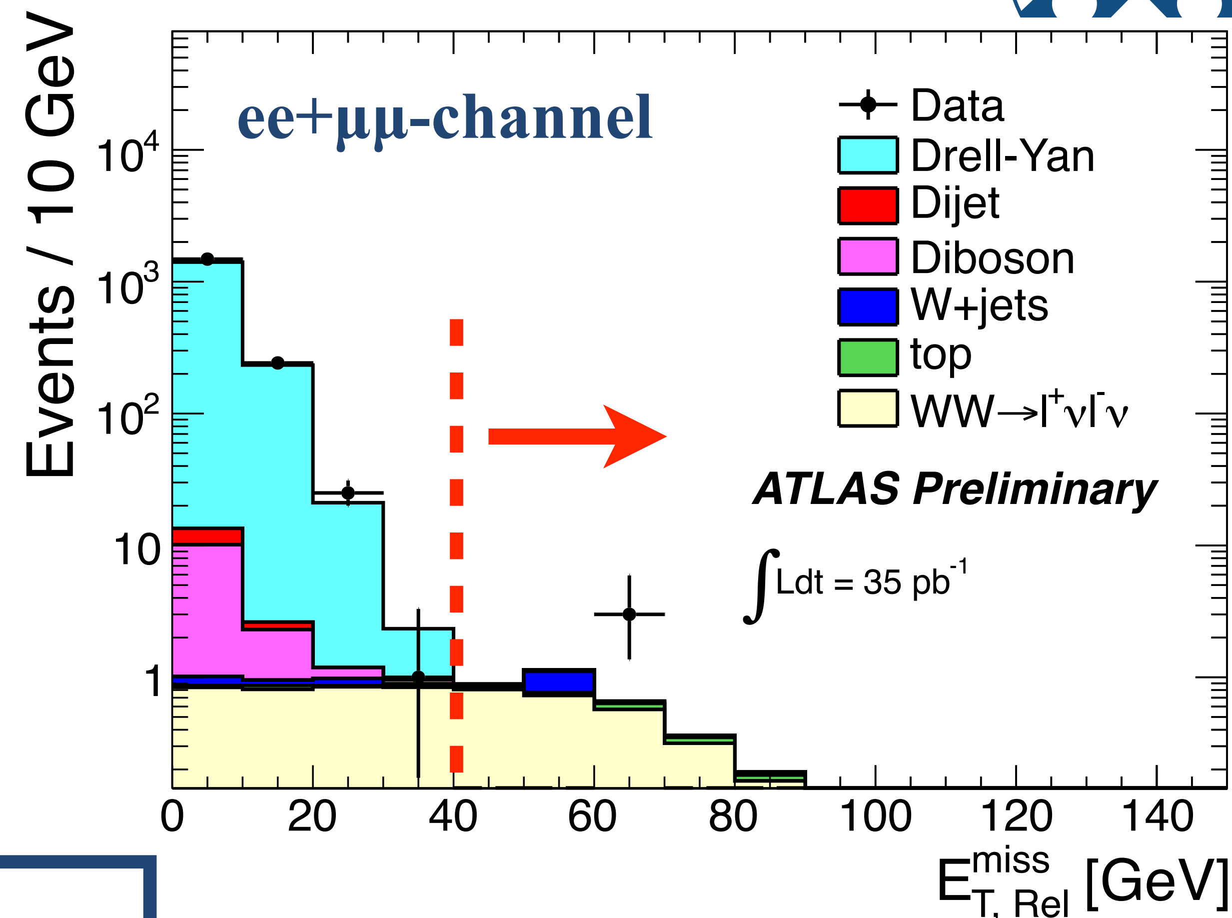
Backgrounds:

Drell-Yan: (lepton pair + 'fake' MeT)
- **Require Large Relative MeT**
- **Reject events consistent w/Z mass**

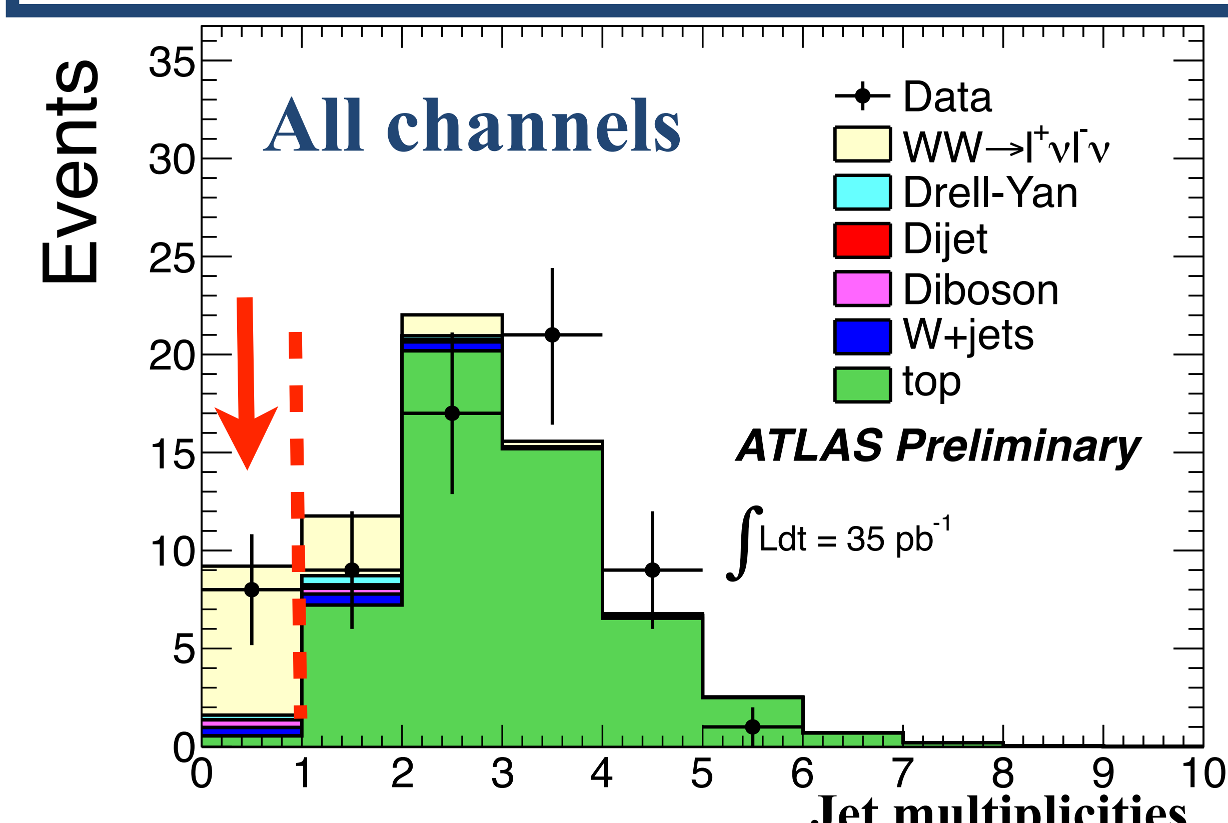
Other Diboson: (WZ, ZZ, Wγ)
- **remove events w/ > 2 leptons.**

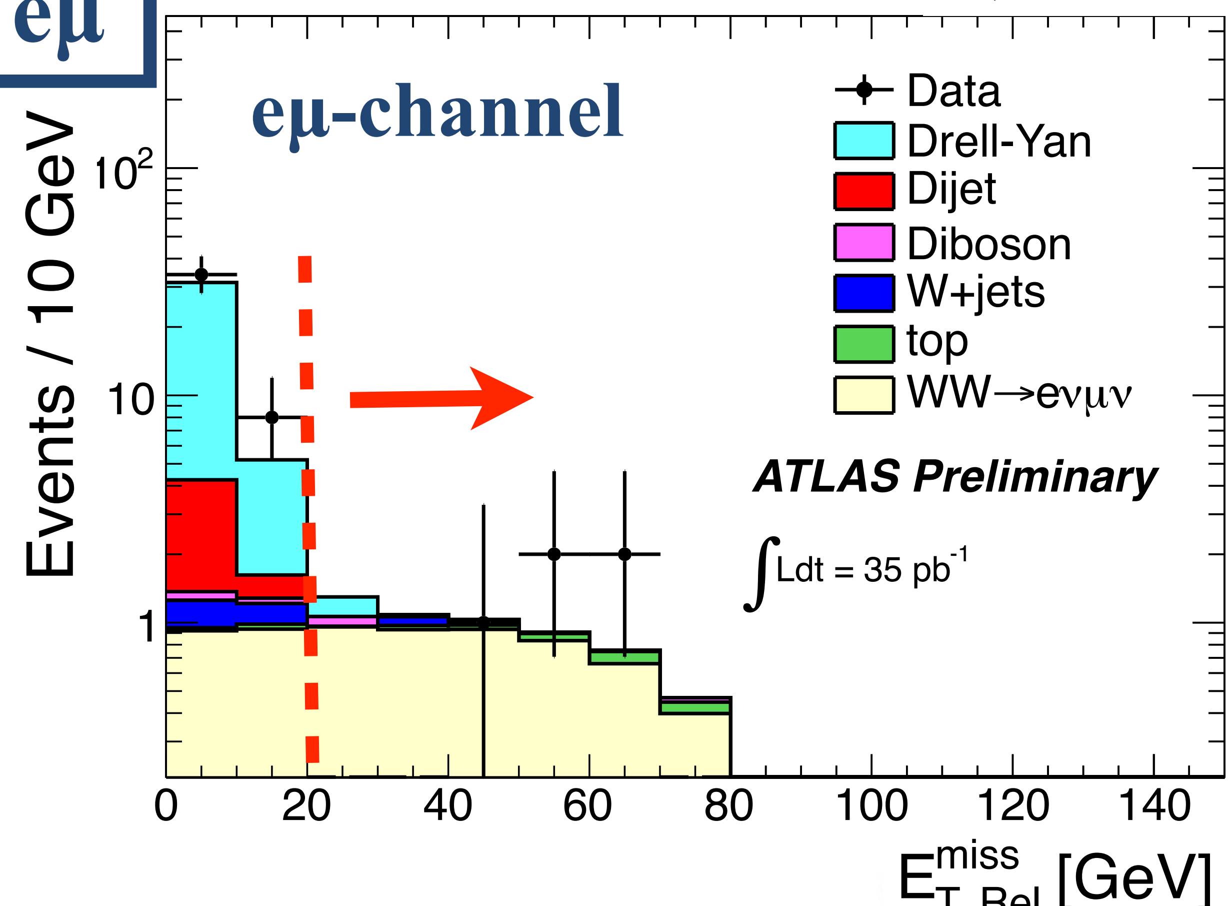
W+Jets: (lepton w/MeT + 'fake' lepton)
- **Isolation / lepton Identification**

Top: (WW produced w/2 b-jets)
- **Jet Veto**



8 Signal Candidates: 1 ee / 2 μμ / 5 eμ





WW Cross Section

Backgrounds	Events
Drell Yan (MC)	0.24 ± 0.15 ± 0.17
Top (MC)	0.55 ± 0.12 ± 0.30
W+Jets (Data)	0.54 ± 0.32 ± 0.21
Other Diboson (MC)	0.39 ± 0.04 ± 0.06
Total Background	**1.72 ± 0.37 ± 0.45**
Observed Events	**8**

Source	Uncertainty
Luminosity	11%
Background	9.6%
Acceptance	7.4%
Systematic	**16.4%**
Statistical	**44%**

$$\sigma_{WW} = 40^{+20}_{-16}(stat) \pm 7(syst)\ \mathrm{pb}.$$

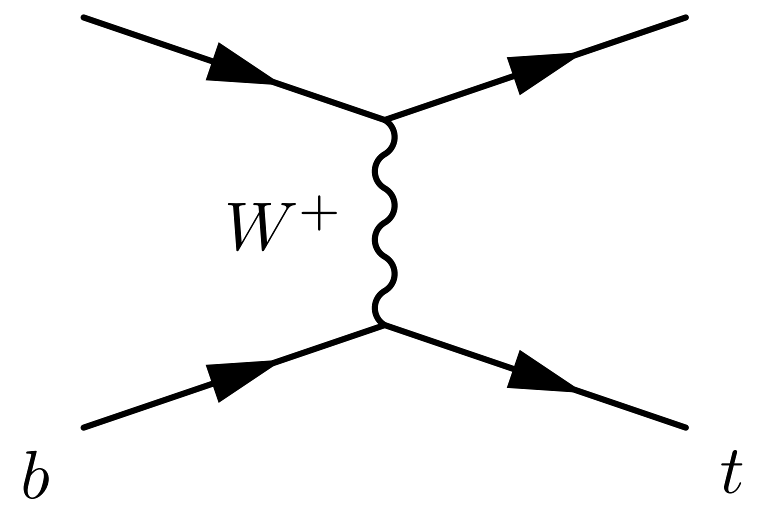
NLO Prediction: 46 ± 3 pb

(MCFM with MSTW2008 (including gg))

(Signal Significance 3.0 σ)

Single Top

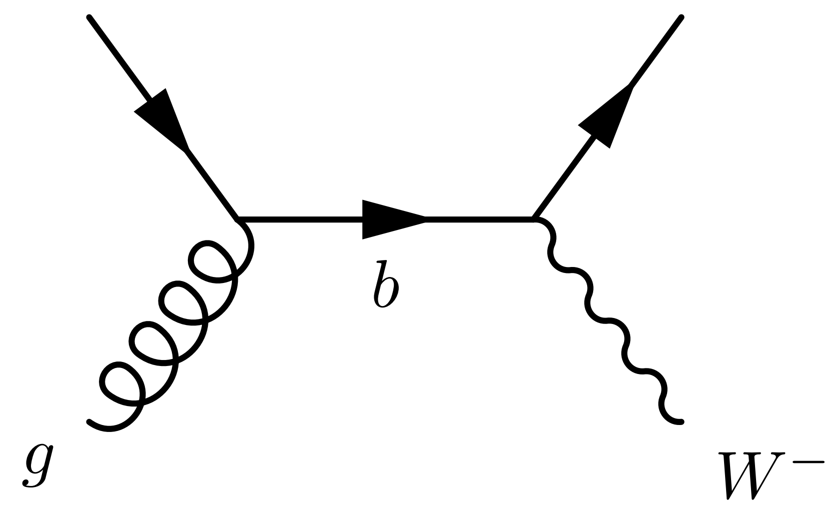
t-channel



$\sigma_{\text{t-ch.}} = 66 \text{ pb}$

$(\sigma^{\text{Tevatron}}_{\text{t-ch.}} = 2.4 \text{ pb})$

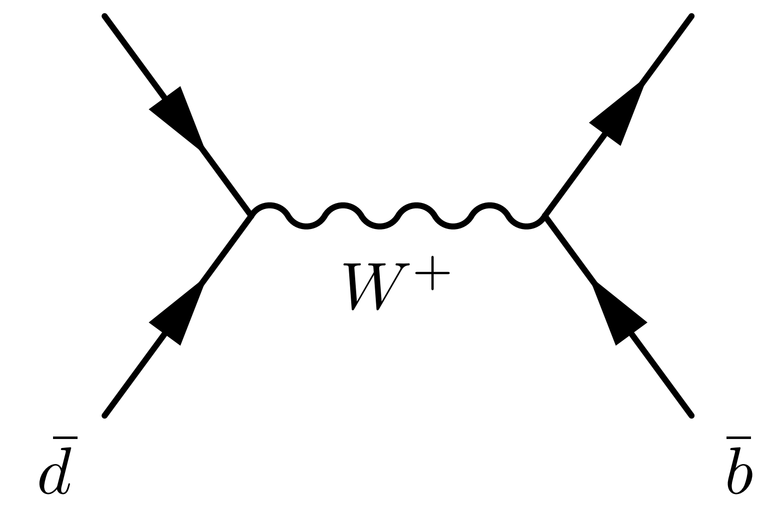
Wt



$\sigma_{\text{Wt}} = 15 \text{ pb}$

$(\sigma^{\text{Tevatron}}_{Wt} = 0.088 \text{ pb})$

s-channel



$\sigma_{\text{s-ch.}} = 4 \text{ pb}$

$(\sigma^{\text{Tevatron}}_{\text{s-ch.}} = 0.86 \text{ pb})$

Motivation:

- Single Top is a direct probe of CKM element V_{tb}
- 3 modes w/distinct signatures
- Sensitive to many models of new physics.

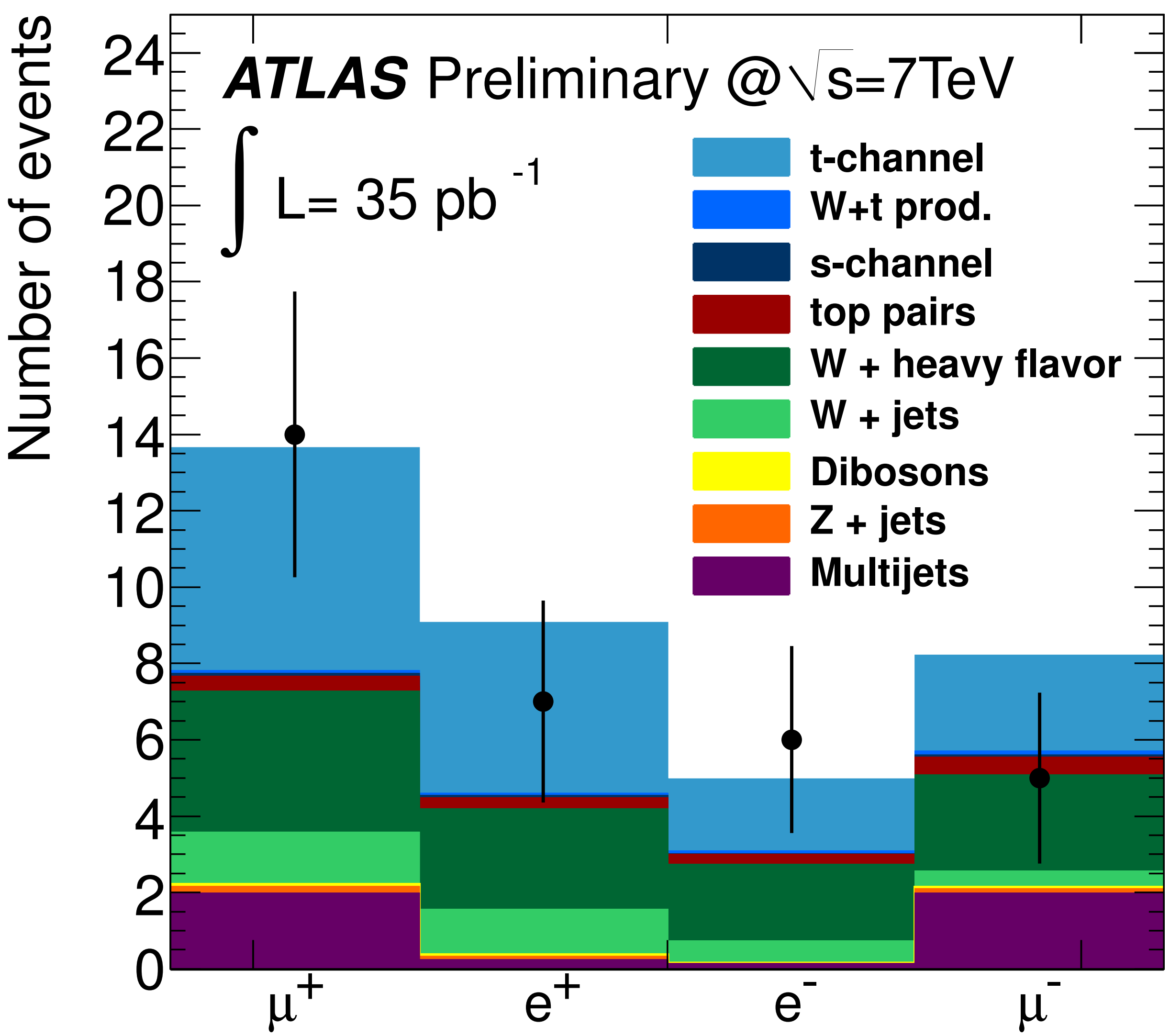
Present Searches in the t- and Wt channel

Single Top: t-channel

Signature

- One lepton (e/μ) $E_T^l > 20$ GeV
- $E_T^{miss} > 25$ GeV
- $m_T^W > 60 \text{ GeV} - E_T^{miss}$
- 2 - jets (one b-jet)
- 130 < m_{Top} < 210 GeV
- Light-jet eta $|\eta_{(\text{lf-jet})}| > 2.5$

	l^+ ch.	l^- ch.
t-channel expectation	10.3 ± 1.8	4.4 ± 0.8
Bkg (Data/MC)	12.4 ± 3.3	8.8 ± 1.8
Observed	**21**	**11**



Results

- Signal Significance of 1.6 σ
- Observed Limit: $\sigma_t < 162$ pb (95 % Confidence level)
- Expected Limit: $\sigma_t < 182$ pb

Limiting systematics: Jet Energy Scale, b-tagging efficiency, Background Modeling

Results

- crossed checked with likelihood method.
- observed excess consistent w/SM prediction

Single Top: Wt

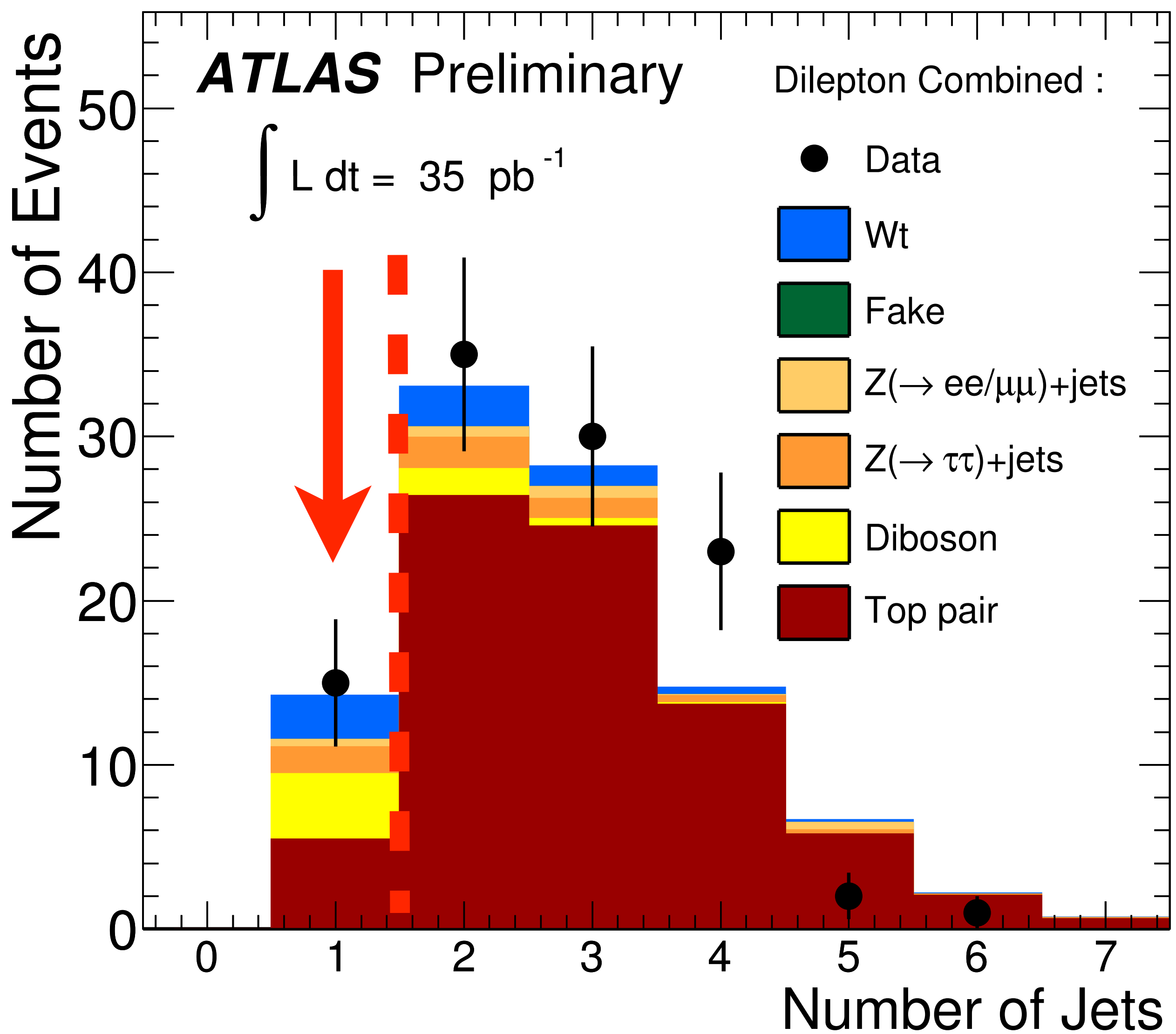
2 W Bosons in Final State

Single Lepton Channel

Similar to t-channel analysis (extra jet)
Allow 2-4 final state jets

DiLepton

- Dileptons (e/μ)
- 1 Jet
- Missing Et (ee/μμ-ch)
- Z veto
- $H_T = \sum_{l,jet,\not{E}_t} p_T > 160$ GeV



	Lepton Channel	Dilepton Channel
Wt	12.6 ± 0.9	7.1 ± 0.5
Background	262.0 ± 22.8	91.3 ± 5.4
Observed	294	107

Results

Analysis	Expected limit	Observed limit
Lepton+jets	123 pb	198 pb
Dilepton	112 pb	110 pb
Combined	94 pb	158 pb

Limiting systematics: Jet Energy Scale, b-tagging efficiency, Background Modeling

Results

- observed excess consistent w/SM prediction

Conclusions

W Asymmetry

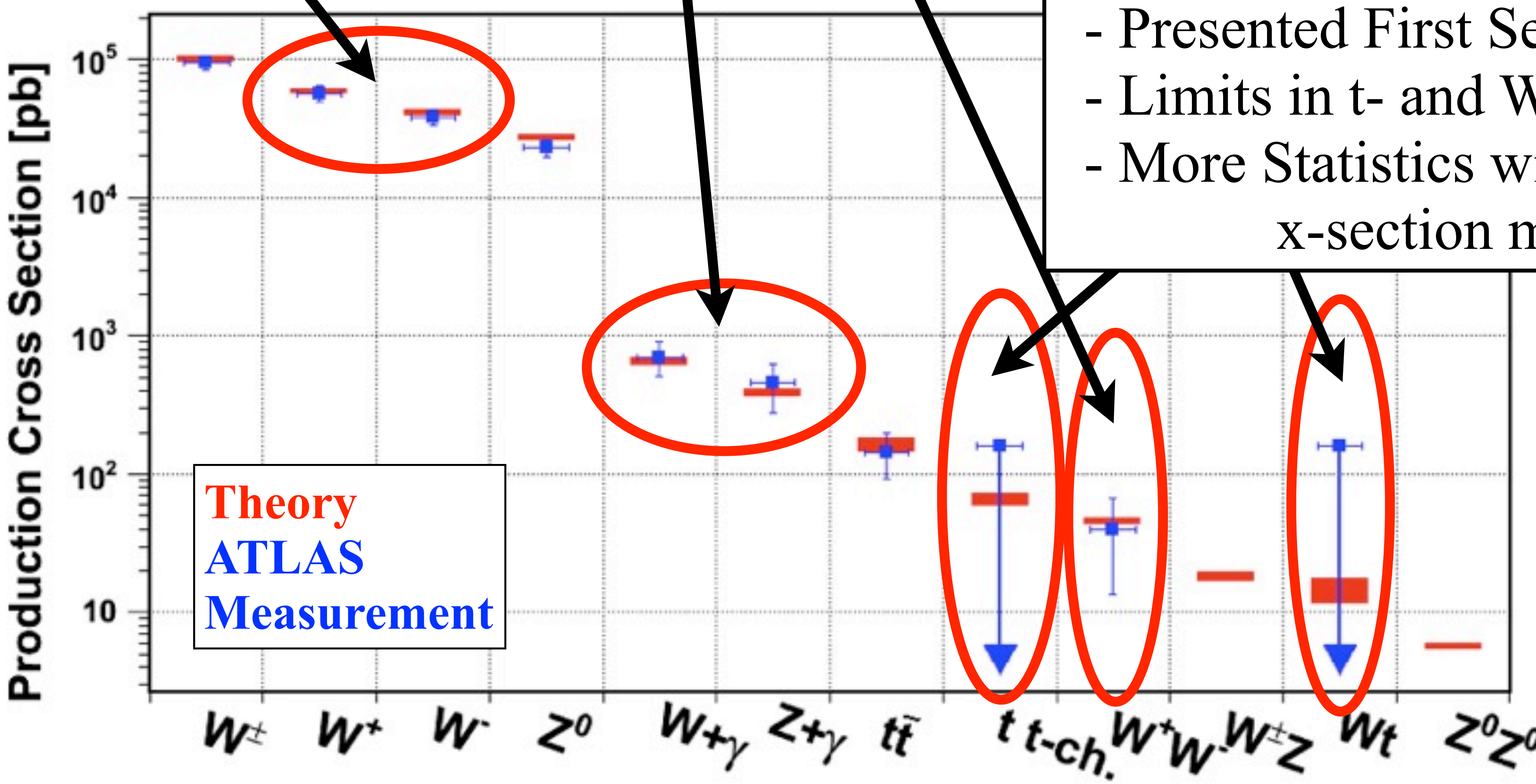
- Measured in μ-ch.
- Uncert. Comparable w/ current PDF fits.
- Future measurements Constrain PDFs

Dibosons

- First Wγ / Zγ x-section measurements at 7 TeV
- Measured WW cross section
- Future measurements constrain New Physics aTGCs

Single Top

- Presented First Searches.
- Limits in t- and Wt- channels
- More Statistics will allow x-section measurements



References

"Measurement of the Muon Charge Asymmetry from W Bosons Produced in pp Collisions at $\sqrt{s} = 7$ TeV with the ATLAS detector"
http://cdsweb.cern.ch/record/1334197

"Measurement of the production cross section of Wgamma and Zgamma at sqrt(s) = 7 TeV with the ATLAS Detector"
http://cdsweb.cern.ch/record/1334838

"Measurement of the WW production cross section in proton-proton collisions at $\sqrt{s} = 7$ TeV with the ATLAS detector"
http://cdsweb.cern.ch/record/1334877

"First Searches for Single Top-Quark Production with the ATLAS Detector in pp Collisions at sqrt(s) = 7TeV"
http://cdsweb.cern.ch/record/1329576

Back up

Leptons in ATLAS

Electrons

EM Cluster matched to track.
"Loose" RHad / shower 2nd layer
"Medium": shower strips/ track
"Tight": track matching / TR

Muons

2 Independent measurements
Matching reject decays in flight
Impact parameter reject cosmics

Isolation required to reduce QCD Background

Lepton Efficiencies measured in data from Ws and Zs

Neutrinos

Presence inferred through overall momentum imbalance.

Calculated using noise suppressed clusters in calorimeter + reco. muons

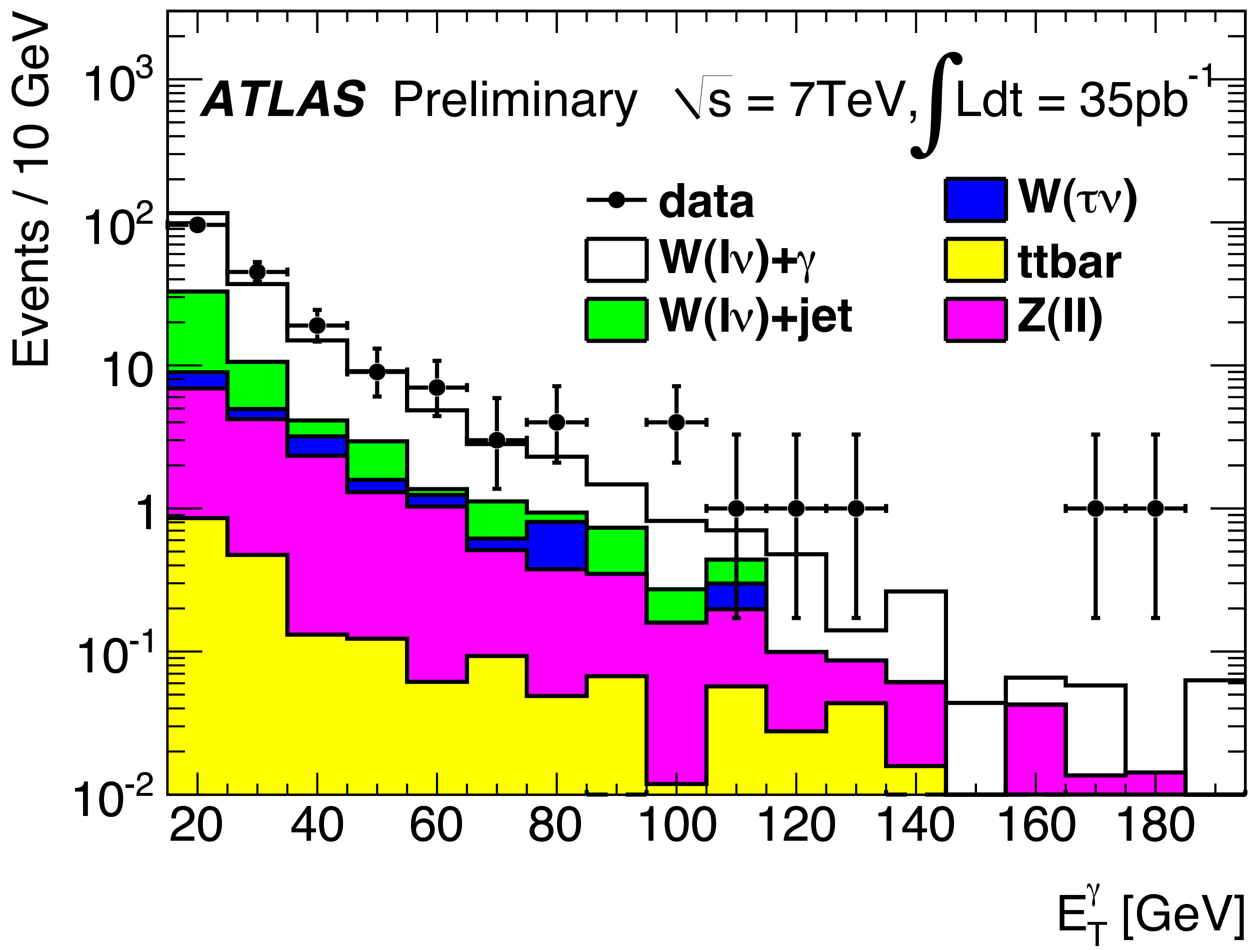
W-Candidates

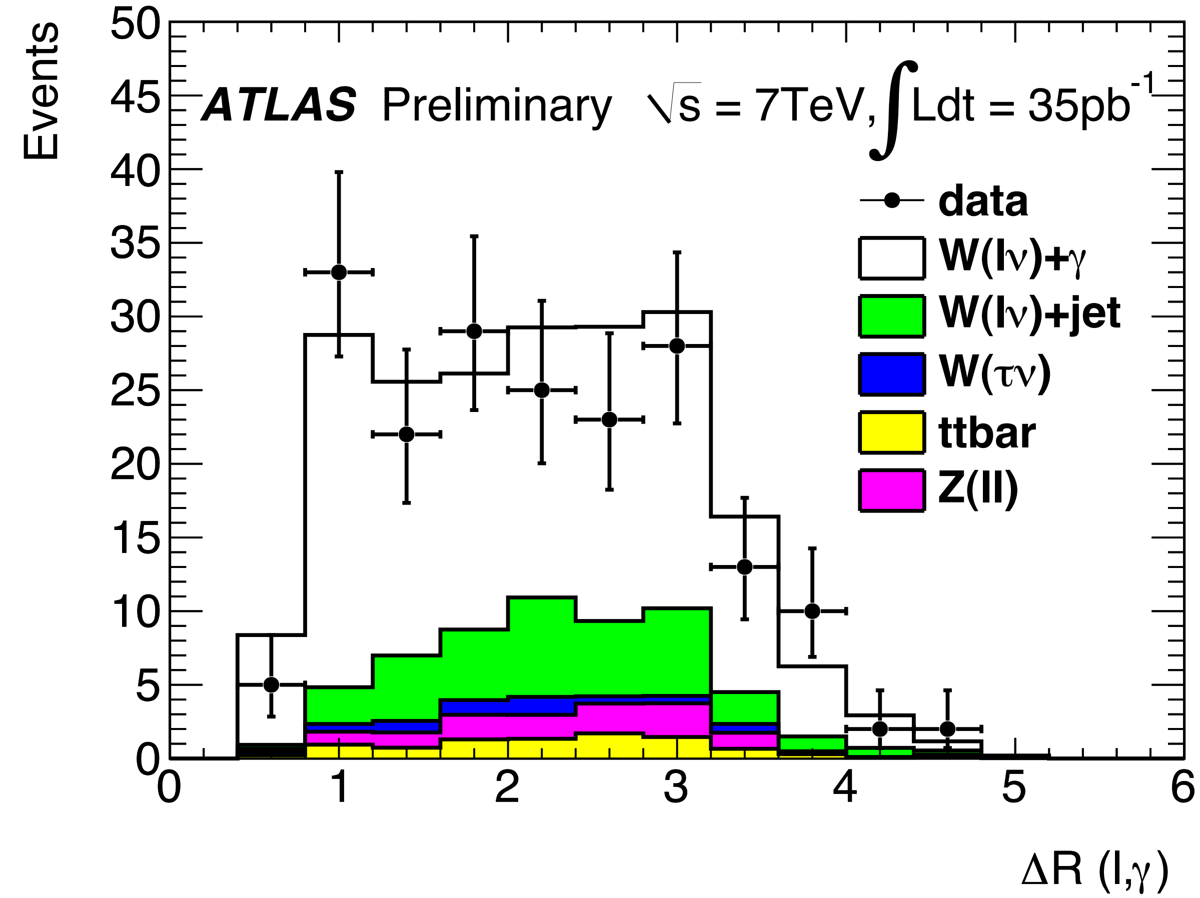
$$m_{\mathrm{T}} = \sqrt{2p_{\mathrm{T}}^{\ell}p_{\mathrm{T}}^{\nu}(1-\cos(\phi^{\ell}-\phi^{\nu}))},$$

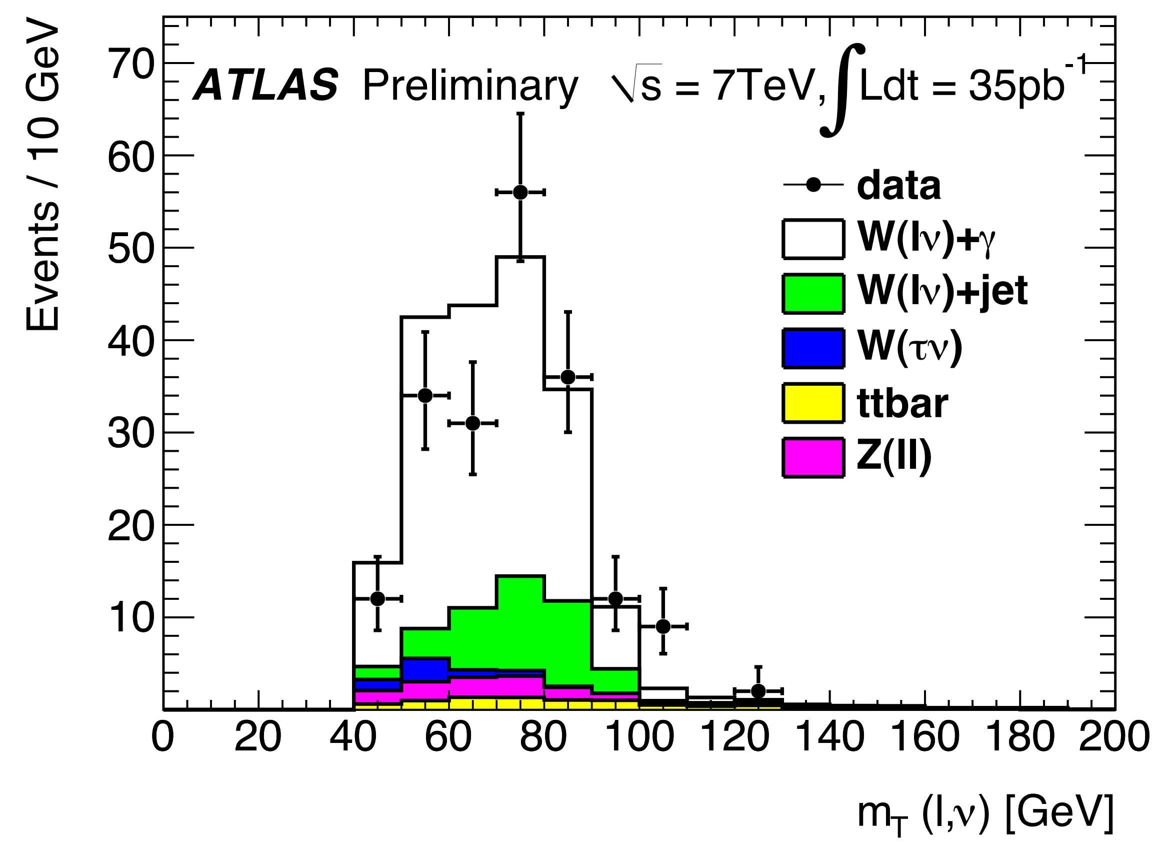
Muon Charge Asymmetry

	Trigger	Reconstruction	p_{T} Scale and Resolution	QCD Normalisation	Electro-weak and $t\bar{t}$ Normalisation	Theoretical Modelling
$0.00 < \|\eta_\mu\| < 0.21$	0.011	0.010	0.003	0.003	< 0.001	0.007
$0.21 < \|\eta_\mu\| < 0.42$	0.010	0.004	0.003	0.003	< 0.001	0.005
$0.42 < \|\eta_\mu\| < 0.63$	0.009	0.004	0.003	0.003	< 0.001	0.006
$0.63 < \|\eta_\mu\| < 0.84$	0.012	0.004	0.003	0.002	0.001	0.007
$0.84 < \|\eta_\mu\| < 1.05$	0.013	0.006	0.003	0.003	0.001	0.008
$1.05 < \|\eta_\mu\| < 1.37$	0.006	0.007	0.002	0.002	0.001	0.006
$1.37 < \|\eta_\mu\| < 1.52$	0.006	0.005	0.002	0.003	0.002	0.005
$1.52 < \|\eta_\mu\| < 1.74$	0.005	0.004	0.002	0.003	0.002	0.007
$1.74 < \|\eta_\mu\| < 1.95$	0.006	0.003	0.002	0.002	0.001	0.006
$1.95 < \|\eta_\mu\| < 2.18$	0.006	0.004	0.002	0.003	0.002	0.009
$2.18 < \|\eta_\mu\| < 2.40$	0.007	0.005	0.002	0.003	0.002	0.007

Wγ Kinematics



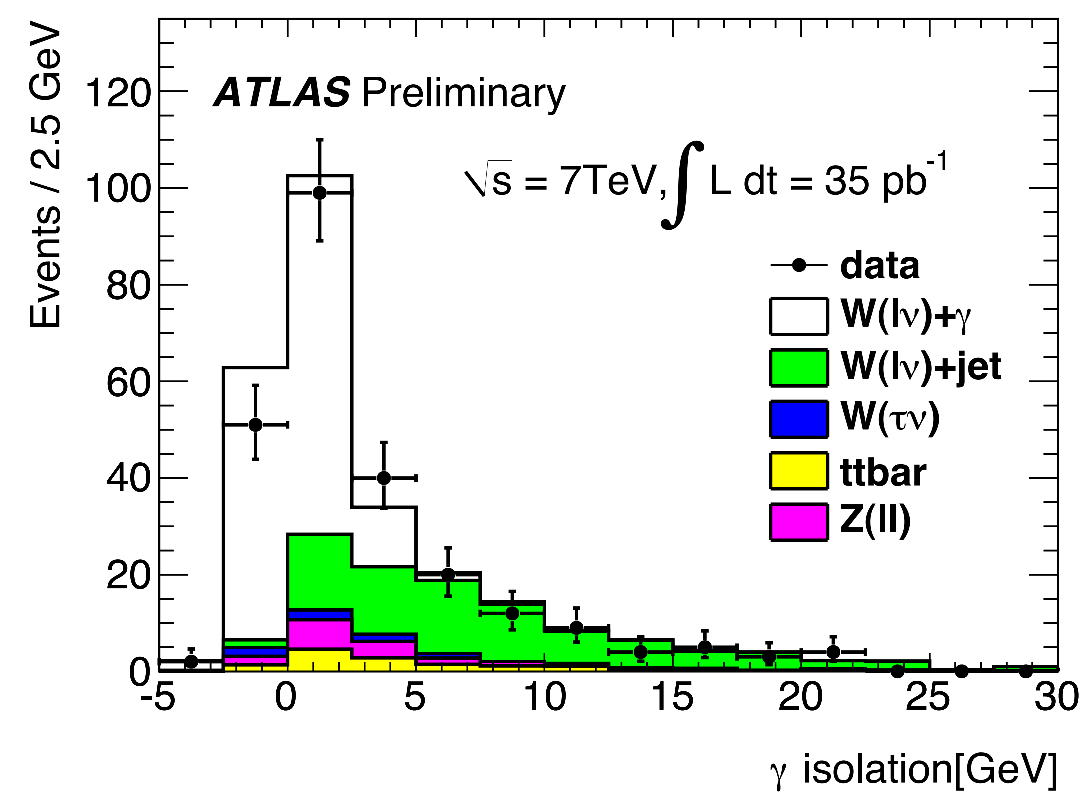




Wγ: W+jet Bkg

Isolated
E_T^{iso}<5 GeV

Non-Isolated
E_T^{iso}>6 GeV



Estimate 80 +/- 0.9 % purity

W/Z + γ Yield Systematics

Process	Observed events	non W+jets background	W+jet background	Extracted Signal
$pp \to e\nu\gamma$	95	$10.1\pm0.8\pm1.2$	$16.9\pm6.4\pm7.3$	$67.9\pm9.5\pm7.3$
$pp \to \mu\nu\gamma$	97	$12.4\pm0.9\pm1.4$	$16.8\pm4.7\pm7.3$	$67.8\pm9.3\pm7.4$
Process	Observed events	Total Background		Extracted Signal
$pp \to e^+e^-\gamma$	25	3.8 ± 3.8		$21.2\pm5.8\pm3.8$
$pp \to \mu^+\mu^-\gamma$	23	3.4 ± 3.4		$19.6\pm4.8\pm3.4$

Table 1: Numbers of the total observed candidate events, estimated number of background and estimated number of signal events for the $pp \to l\nu\gamma$ and $pp \to l^+l^-\gamma$ selected samples. The first uncertainty is statistical. The second uncertainty represents the systematics. The W+jets background contribution is estimated with a data-driven two-dimensional sideband method. Uncertainties on the luminosity determination and on the NLO theoretical cross section predictions are taken into account for the estimate of the non W+jets background. The uncertainty on the Monte Carlo based background estimate for the $pp \to l^+l^-\gamma$ process is 100%.

Zγ Systematics

Source	e-channel	μ-channel
γ Reco/ID	13.0%	13.0%
Background	10.8%	10.8%
Acceptance	8%	8%
lepton ID	5%	2.2%
EM Scale	4.5%	3%

Wγ Systematics

Source	e-channel	μ-channel
γ Reco/ID	13.0%	13.0%
Background	10.8%	10.8%
Acceptance	8%	8%
MeT scale/resolution	5%	5%
lepton ID	4.5%	1%
EM Scale	3%	4%

$W\gamma$ / $Z\gamma$ Cross Section

Definition

	$e\nu\gamma$	$\mu\nu\gamma$	$e^+e^-\gamma$	$\mu^+\mu^-\gamma$
Fiducial Cross Section				
Lepton $E_t(p_T)$ cut	$E_T^e > 20$ GeV $p_T^\nu > 25$ GeV	$p_T^\mu > 20$ GeV $p_T^\nu > 25$ GeV	$E_T^e > 20$ GeV	$p_T^\mu > 20$ GeV
Lepton η cut	$\lvert\eta_e\rvert < 2.47$ excluding $1.37 < \lvert\eta_e\rvert < 1.52$	$\lvert\eta_\mu\rvert < 2.4$	$\lvert\eta_e\rvert < 2.47$ excluding $1.37 < \lvert\eta_e\rvert < 1.52$	$\lvert\eta_\mu\rvert < 2.4$
Boson mass cut	$m_T > 40$ GeV	$m_T > 40$ GeV	$m_{ee} > 40$ GeV	$m_{\mu\mu} > 40$ GeV
Photon cut	$E_T^\gamma > 15$ GeV $\lvert\eta_\gamma\rvert < 2.47$ (excluding $1.37 < \lvert\eta_\gamma\rvert < 1.52$) $\Delta R(l,\gamma) > 0.7$ photon isolation fraction $\epsilon_h^p < 0.5$			
Total Cross Section				
Photon cut	$E_T^\gamma > 10$ GeV $\Delta R(l,\gamma) > 0.5$ photon isolation fraction $\epsilon_h^p < 0.5$			

Inputs

	value	stat.	syst.	lumi
	$pp \to e\nu\gamma$			
$N_{W\gamma}^{sig}$	67.9	9.5	7.3	-
$L_{W\gamma}[pb^{-1}]$	36.4	-	-	4
$C_{W\gamma}$	0.363	0.001	0.052	-
$A_{W\gamma}$	6.95×10^{-2}	0.1×10^{-2}	0.57×10^{-2}	-
	$pp \to e^+e^-\gamma$			
$N_{Z\gamma}^{sig}$	21.2	5.8	3.8	-
$L_{Z\gamma}[pb^{-1}]$	36.4	-	-	4
$C_{Z\gamma}$	0.289	0.01	0.042	-
$A_{Z\gamma}$	12.2×10^{-2}	0.2×10^{-2}	0.98×10^{-2}	-
	$pp \to \mu\nu\gamma$			
$N_{W\gamma}^{sig}$	67.8	9.3	7.4	-
$L_{W\gamma}[pb^{-1}]$	35.2	-	-	3.9
$C_{W\gamma}$	0.457	0.001	0.063	-
$A_{W\gamma}$	7.19×10^{-2}	0.1×10^{-2}	0.58×10^{-2}	-
	$pp \to \mu^+\mu^-\gamma$			
$N_{Z\gamma}^{sig}$	19.6	4.8	3.4	-
$L_{Z\gamma}[pb^{-1}]$	35.2	-	-	3.9
$C_{W\gamma}$	0.428	0.01	0.059	-
$A_{W\gamma}$	12.3×10^{-2}	0.15×10^{-2}	0.98×10^{-2}	-

Results

	experimental measurement	SM model prediction
	$\sigma^{fid}[pb]$(measured)	$\sigma^{fid}[pb]$(predicted)
$pp \to e\nu\gamma$	$5.1 \pm 0.7(stat) \pm 0.9(syst) \pm 0.6(lumi)$	4.6 ± 0.3(syst)
$pp \to \mu\nu\gamma$	$4.2 \pm 0.6(stat) \pm 0.7(syst) \pm 0.5(lumi)$	4.9 ± 0.3(syst)
$pp \to e^+e^-\gamma$	$2.0 \pm 0.6(stat) \pm 0.5(syst) \pm 0.2(lumi)$	1.7 ± 0.1(syst)
$pp \to \mu^+\mu^-\gamma$	$1.3 \pm 0.3(stat) \pm 0.3(syst) \pm 0.1(lumi)$	1.7 ± 0.1(syst)
	$\sigma^{total}[pb]$(measured)	$\sigma^{total}[pb]$(predicted)
$pp \to e\nu\gamma$	$73.9 \pm 10.5(stat) \pm 14.6(syst) \pm 8.1(lumi)$	69.0 ± 4.6(syst)
$pp \to \mu\nu\gamma$	$58.6 \pm 8.2(stat) \pm 11.3(syst) \pm 6.4(lumi)$	69.0 ± 4.6(syst)
$pp \to e^+e^-\gamma$	$16.4 \pm 4.5(stat) \pm 4.3(syst) \pm 1.8(lumi)$	13.8 ± 0.9(syst)
$pp \to \mu^+\mu^-\gamma$	$10.6 \pm 2.6(stat) \pm 2.5(syst) \pm 1.2(lumi)$	13.8 ± 0.9(syst)

WW Backgrounds

Final State	$e^+e^-E_T^{miss}$	$\mu^+\mu^-E_T^{miss}$	$e^\pm\mu^\mp E_T^{miss}$	combined
Observed Events	1	2	5	8
MC WW Signal	0.85±0.02±0.13	1.74±0.04±0.24	4.81±0.06±0.68	7.40±0.07±1.05
Backgrounds				
Top (MC)	0.04±0.02±0.03	0.15±0.06±0.08	0.36±0.10±0.19	0.55±0.12±0.30
W+jets (data)	0.08±0.05±0.03	0.00±0.29±0.10	0.46±0.12±0.17	0.54±0.32±0.21
DY (MC/data)	0.00±0.10±0.07	0.01±0.10±0.07	0.23±0.06±0.15	0.24±0.15±0.17
Other dibosons (MC)	0.05±0.01±0.01	0.10±0.01±0.01	0.24±0.05±0.03	0.39±0.04±0.06
Total Background	0.17±0.11±0.09	0.26±0.31±0.15	1.29±0.17±0.32	1.72±0.37±0.45
Signal / Background	5.0	6.7	3.7	4.3

Top

$$N_{top}^{zero-jet}(estimate) = N_{data}^{N-jet} \times (N_{MC\ top}^{zero-jet} / N_{MC\ top}^{N-jet})$$

W+Jets

$$f_l \equiv \frac{N_{\text{lepton ID}}}{N_{\text{Jet-Rich ID}}}$$ in di-jets

$$N_{W\text{+jet Bkg}} = f_l \times N_{\text{lepton ID + Jet-Rich ID}}$$

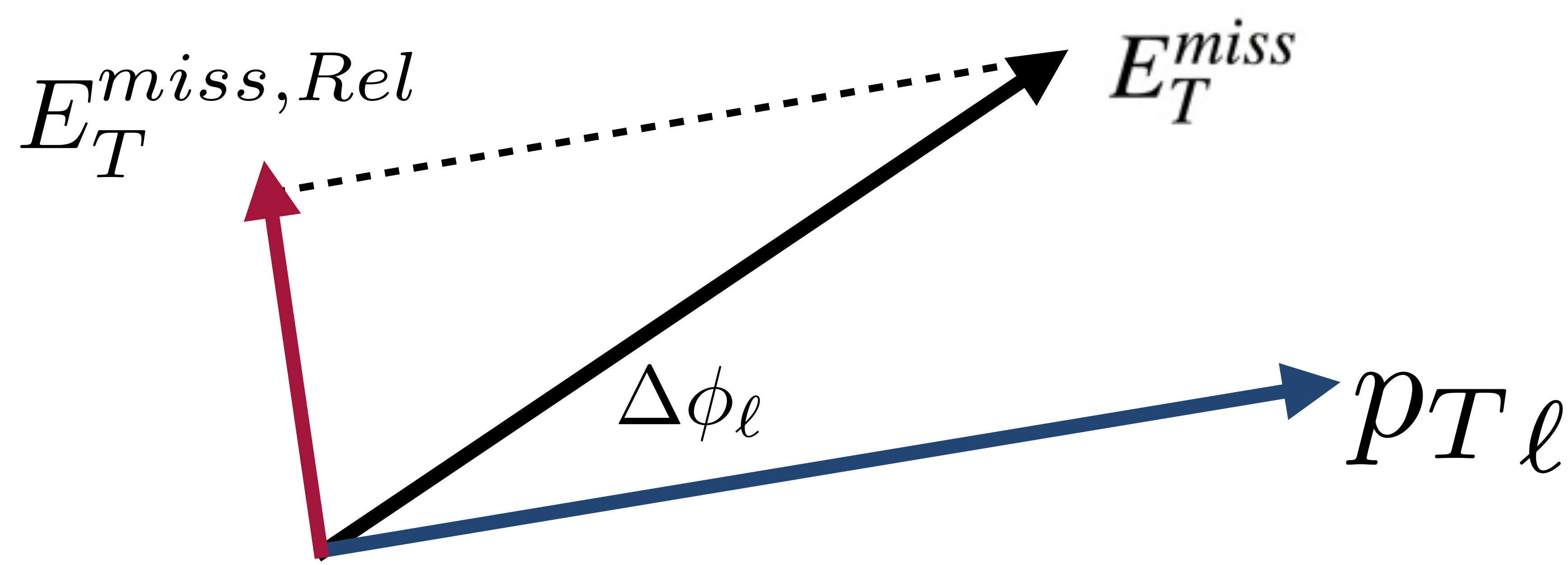
Drell Yan

$$S = \frac{N_{Data}(E_T^{miss,\,\mathrm{Rel}} > 30GeV) - N_{MC}(E_T^{miss,\,\mathrm{Rel}} > 30GeV)}{N_{DY}(E_T^{miss,\,\mathrm{Rel}} > 30GeV)}$$

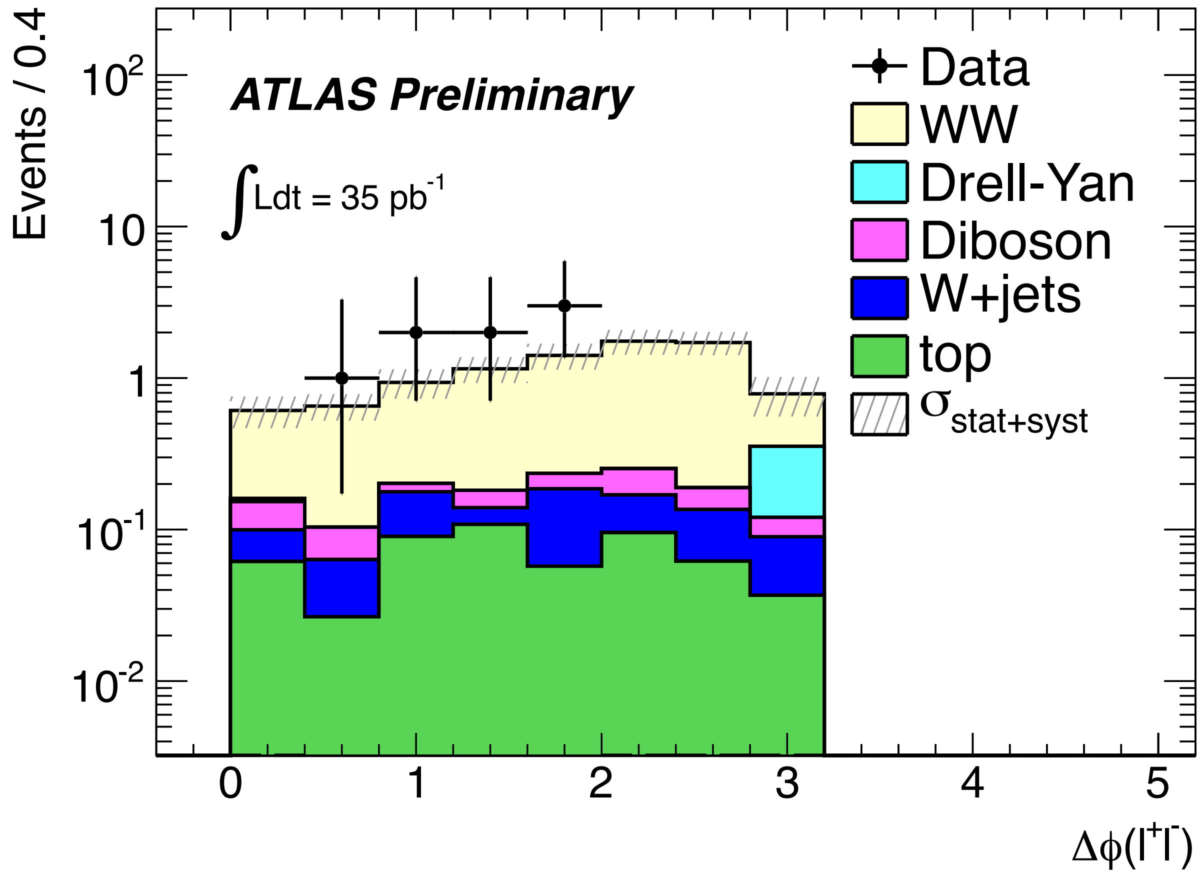
Relative Missing Energy

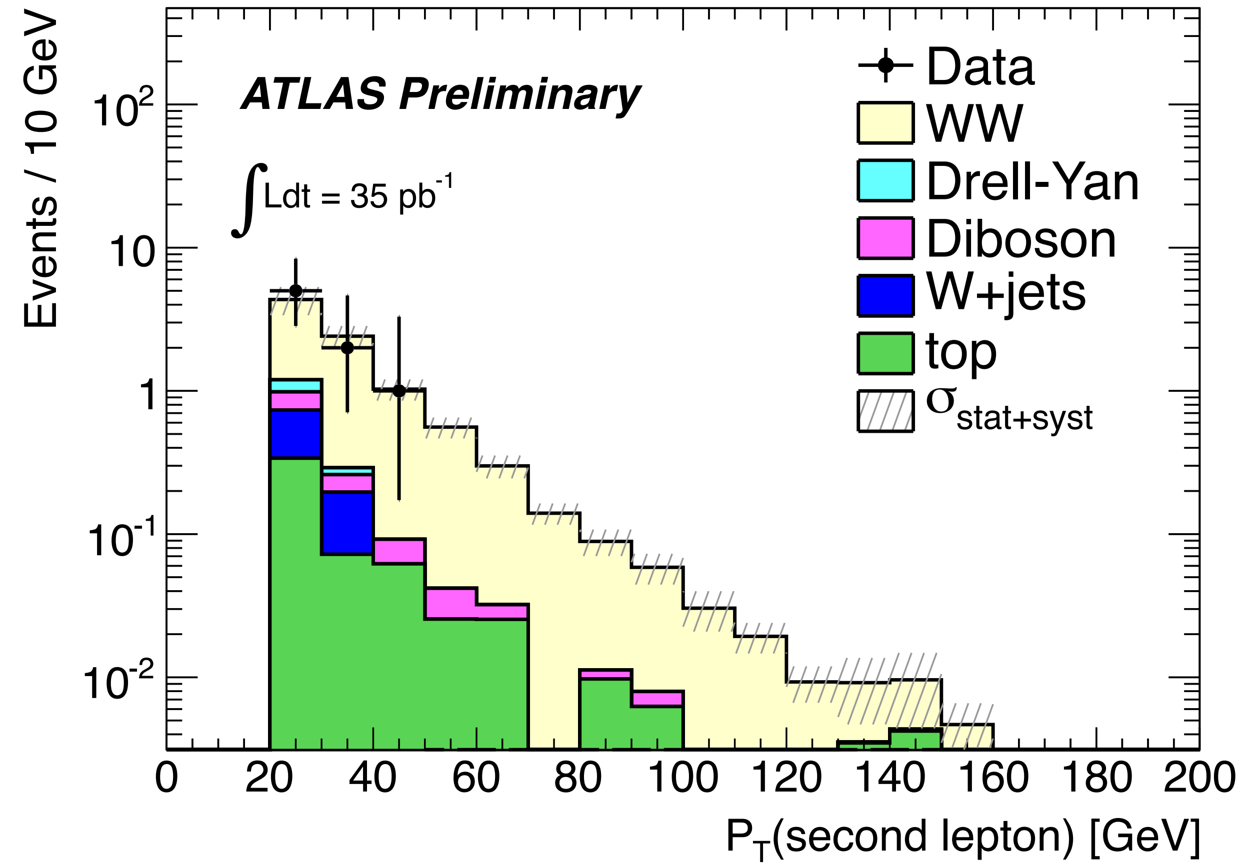
Relative Missing Energy

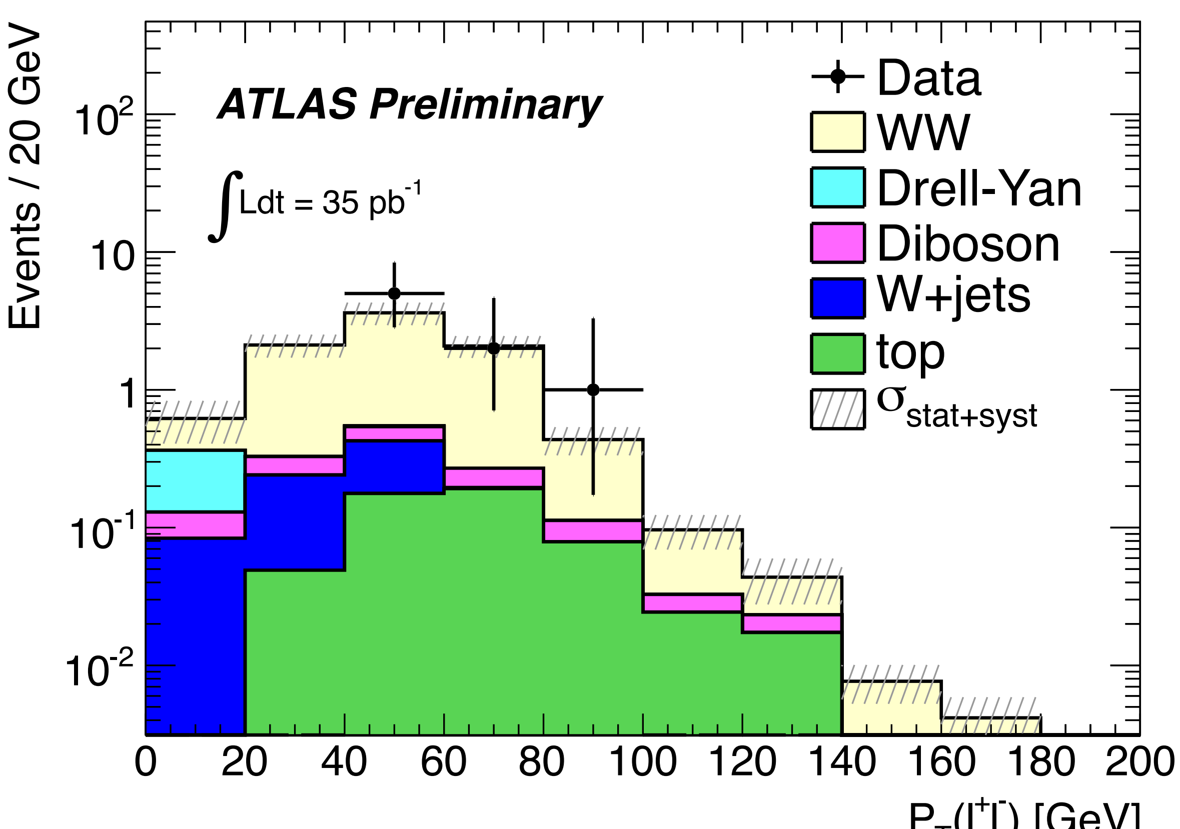
$$E_T^{miss,\,\mathrm{Rel}} = \begin{cases} E_T^{miss} \times \sin\left(\Delta\phi_\ell\right) & \text{if } \Delta\phi < \pi/2 \\ E_T^{miss} & \text{if } \Delta\phi \geq \pi/2. \end{cases}$$

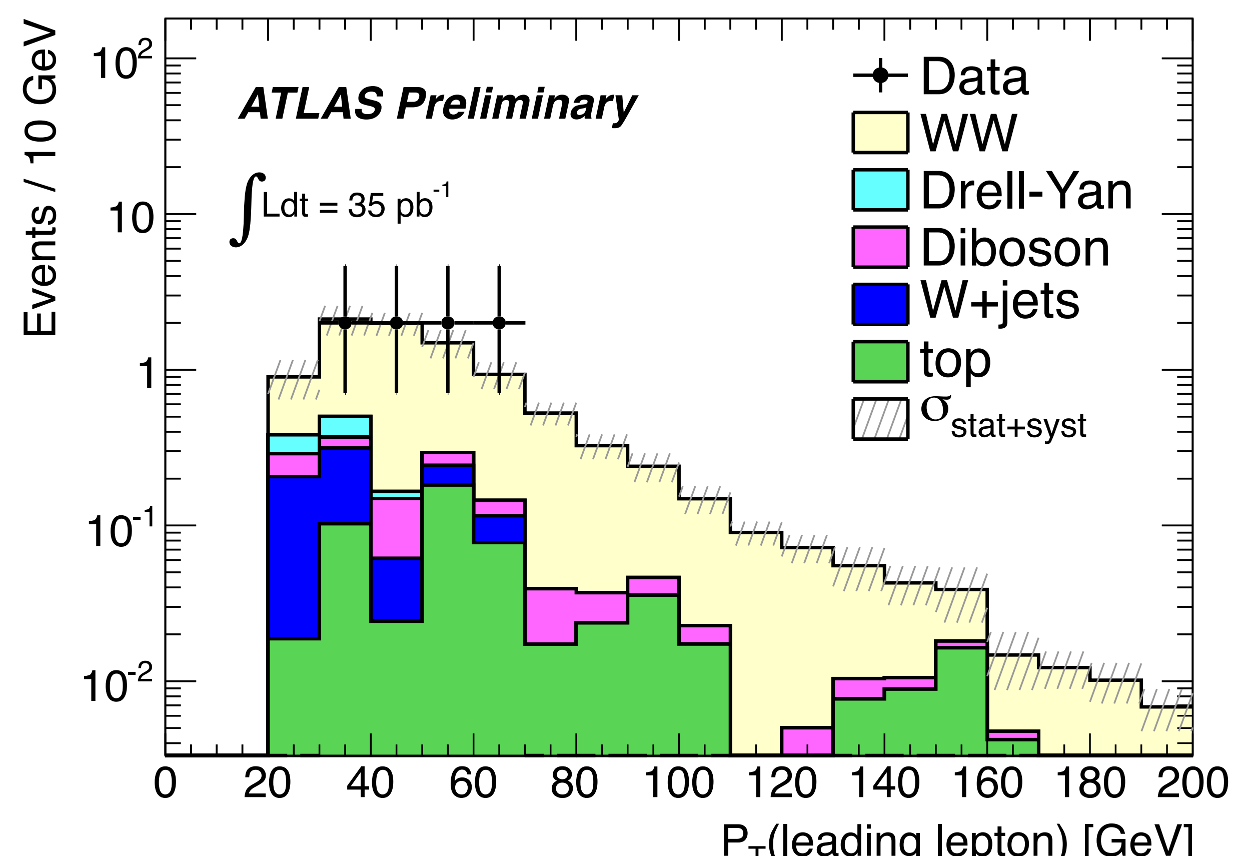


WW Kinematics









WW Cross Section

Acceptance

Cuts	eeE_T^{miss} Channel		$\mu\mu E_T^{miss}$ Channel		$e\mu E_T^{miss}$ Channel	
	$e\nu e\nu$	$\tau\tau/e\tau\nu\nu$	$\mu\nu\mu\nu$	$\tau\tau/\mu\tau\nu\nu$	$e\nu\mu\nu$	$\tau\tau/\mu\tau/e\tau\nu\nu$
Total Events	18.99	7.27	18.99	7.27	37.98	14.55
2 leptons (opposite charge)	3.46	0.41	7.70	0.85	10.36	1.16
$M_{\ell\ell} > 15$ GeV & Z veto	2.93	0.34	6.43	0.69	10.36	1.16
$E_{T, Rel}^{miss}$ cut	1.21	0.11	2.76	0.21	7.17	0.74
Jet veto	0.78	0.07	1.63	0.12	4.38	0.43
Overall acceptance	4.1%	0.9%	8.6%	1.6%	11.5%	2.9%

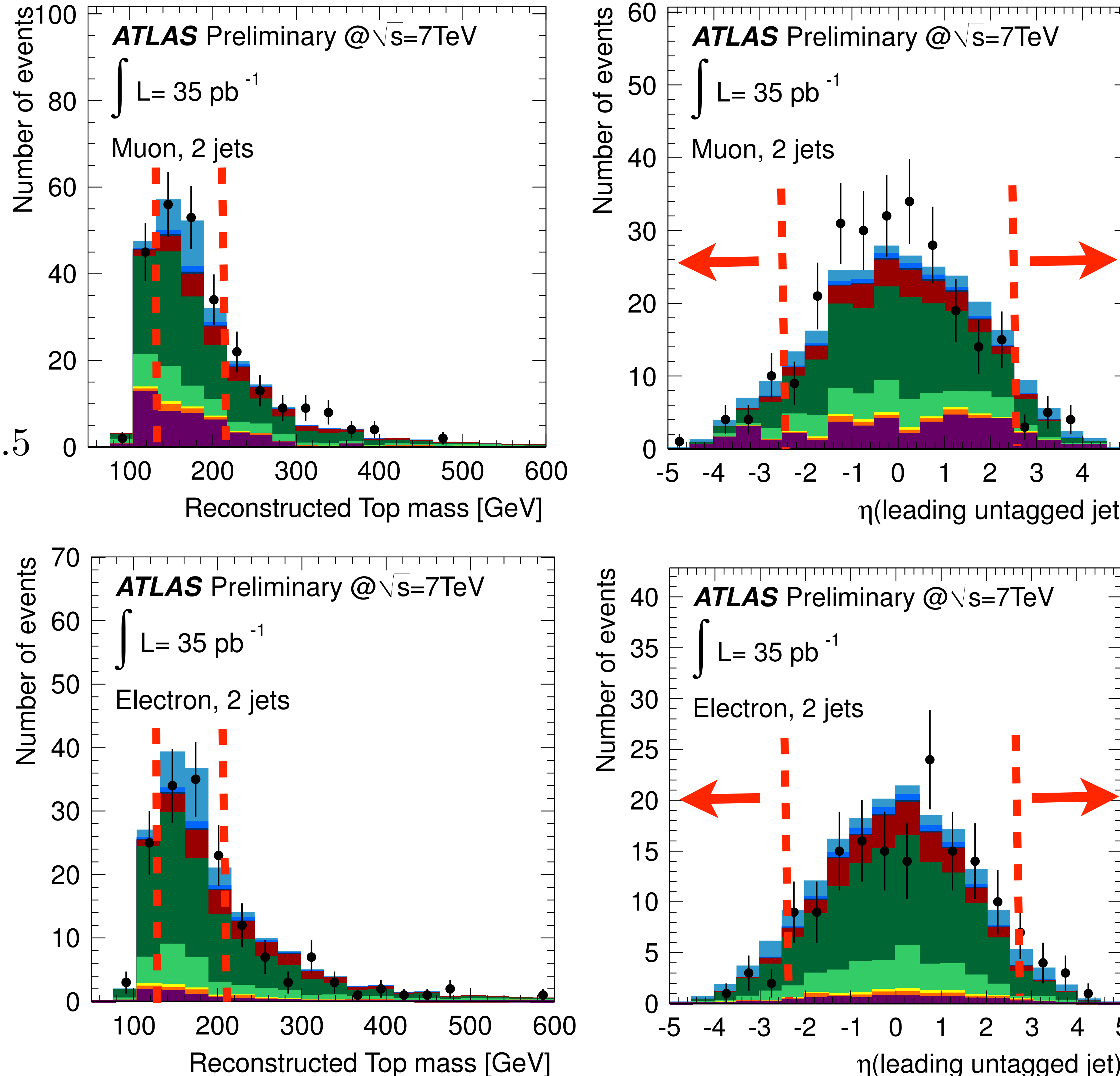
Cross Section

Channels	N_s(SM)	N_b	N_{obs}	σ_{WW} [pb]
$e^+e^-E_T^{miss}$	0.85	0.17	1	45^{+74}_{-38}
$\mu^+\mu^-E_T^{miss}$	1.74	0.26	2	46^{+47}_{-29}
$e^\pm\mu^\mp E_T^{miss}$	4.81	1.29	5	36^{+25}_{-19}
Total	7.40	1.72	8	40^{+20}_{-16}

Single Top: t-channel

Event Selection

- One lepton (e/μ)
  $E_T^l > 20\ \text{GeV}$
- $E_T^{miss} > 25\ \text{GeV}$
- $m_T^W > 60\ \text{GeV} - E_T^{miss}$
- 2 - jets (one b-jet)
- 130 < M_{Top} < 210 GeV
- Light-jet eta $|\eta_{(\text{lf-jet})}| > 2.5$



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

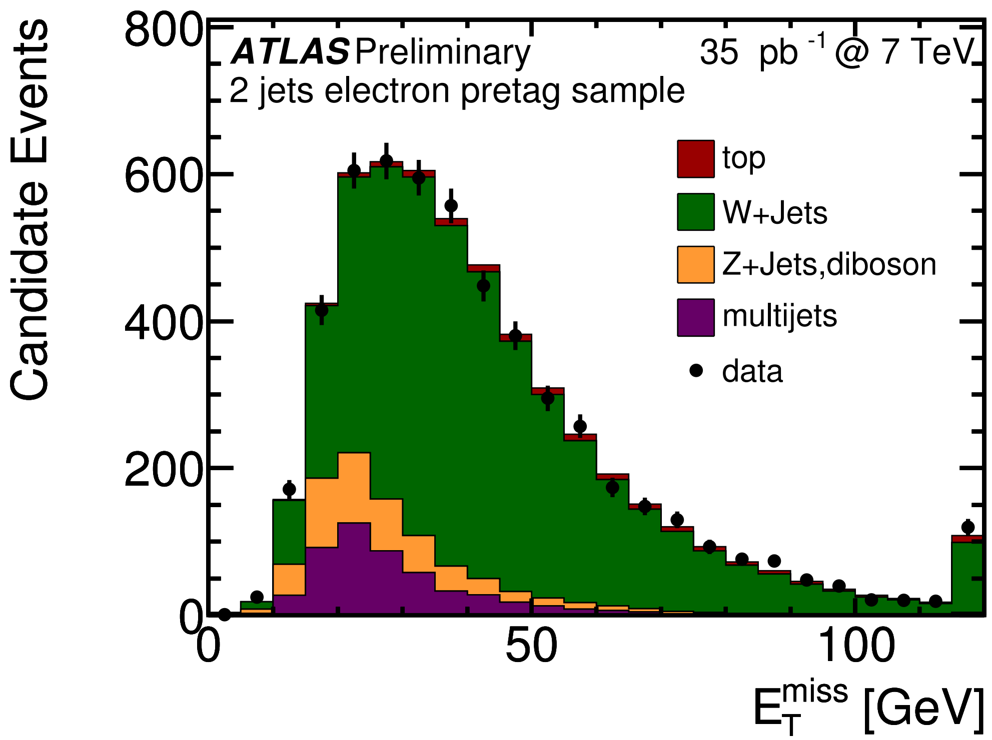
Single Top: lepton + Jets

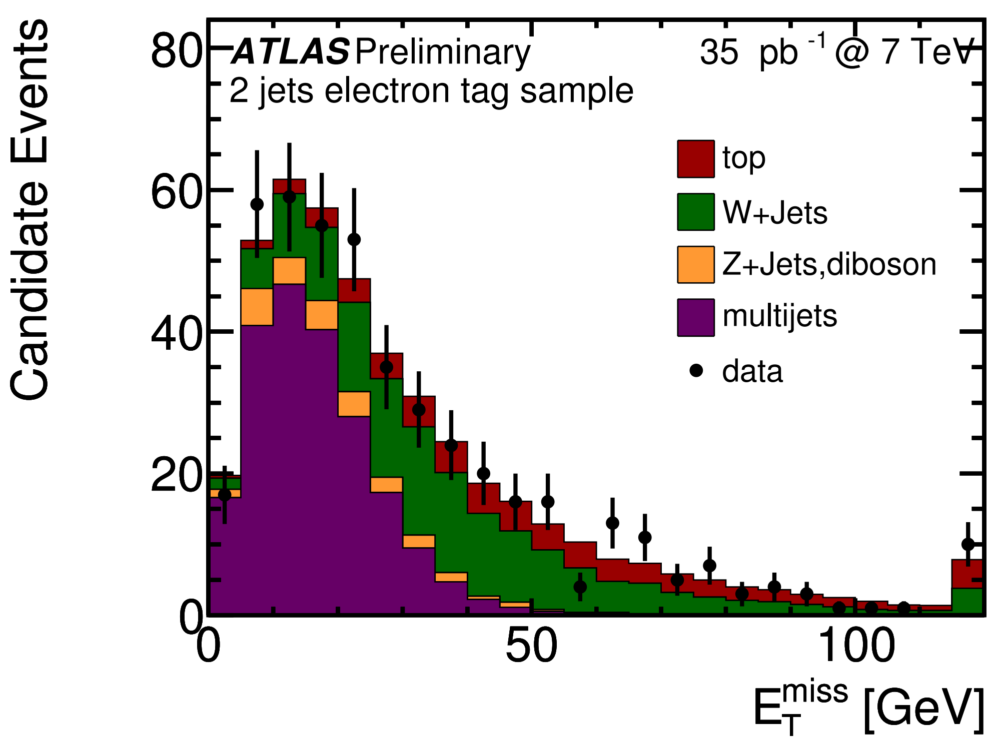
Background

QCD

“Matrix Method”

Fit MeT for Normalization (shapes from MC)





W+Jets

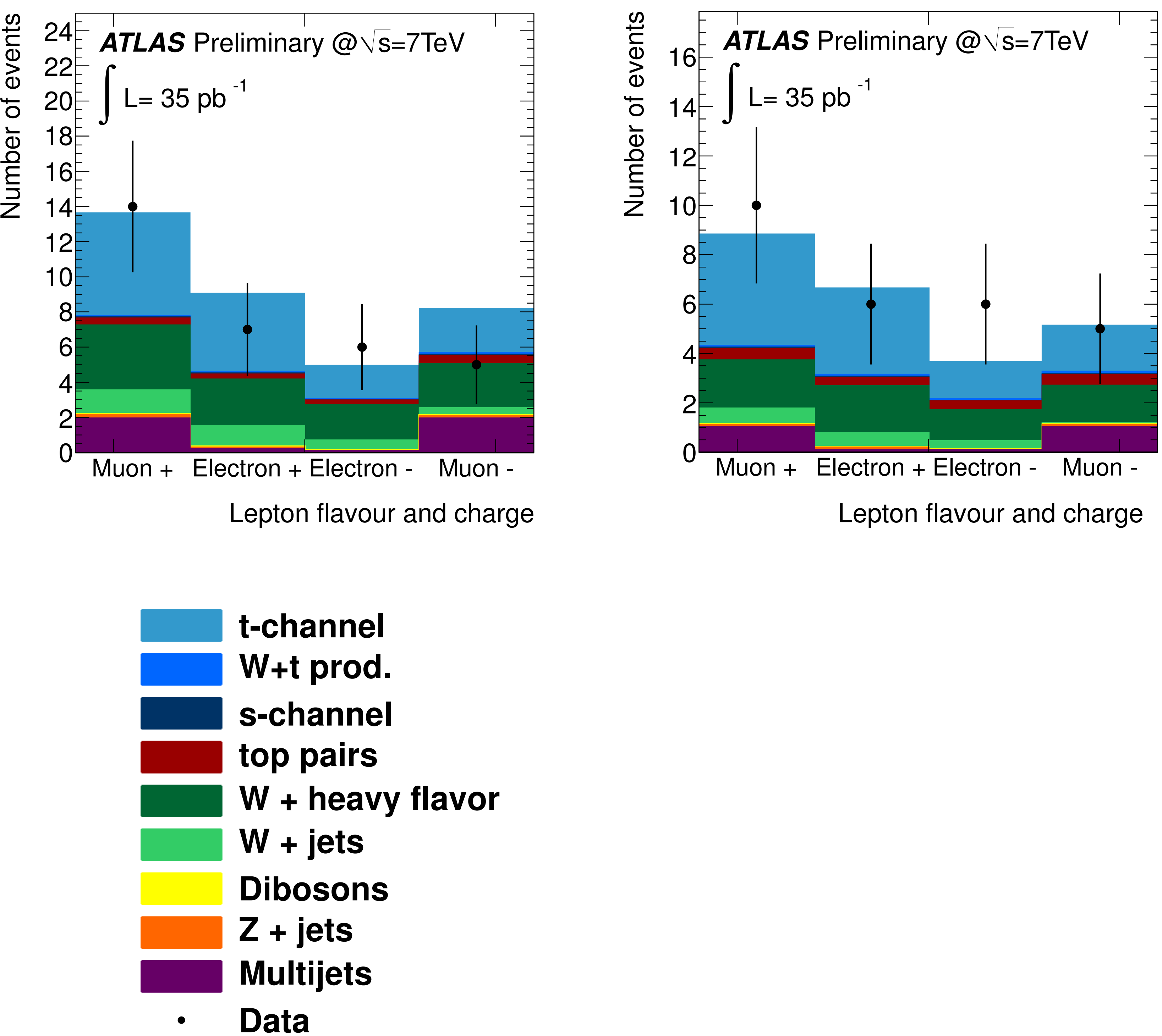
Normalize to Jet Multiplicity bins in Data.

Obtain correction factors for:

Wbb+jets / Wcc + jets / Wc + jets

Single Top: t-channel

Yields



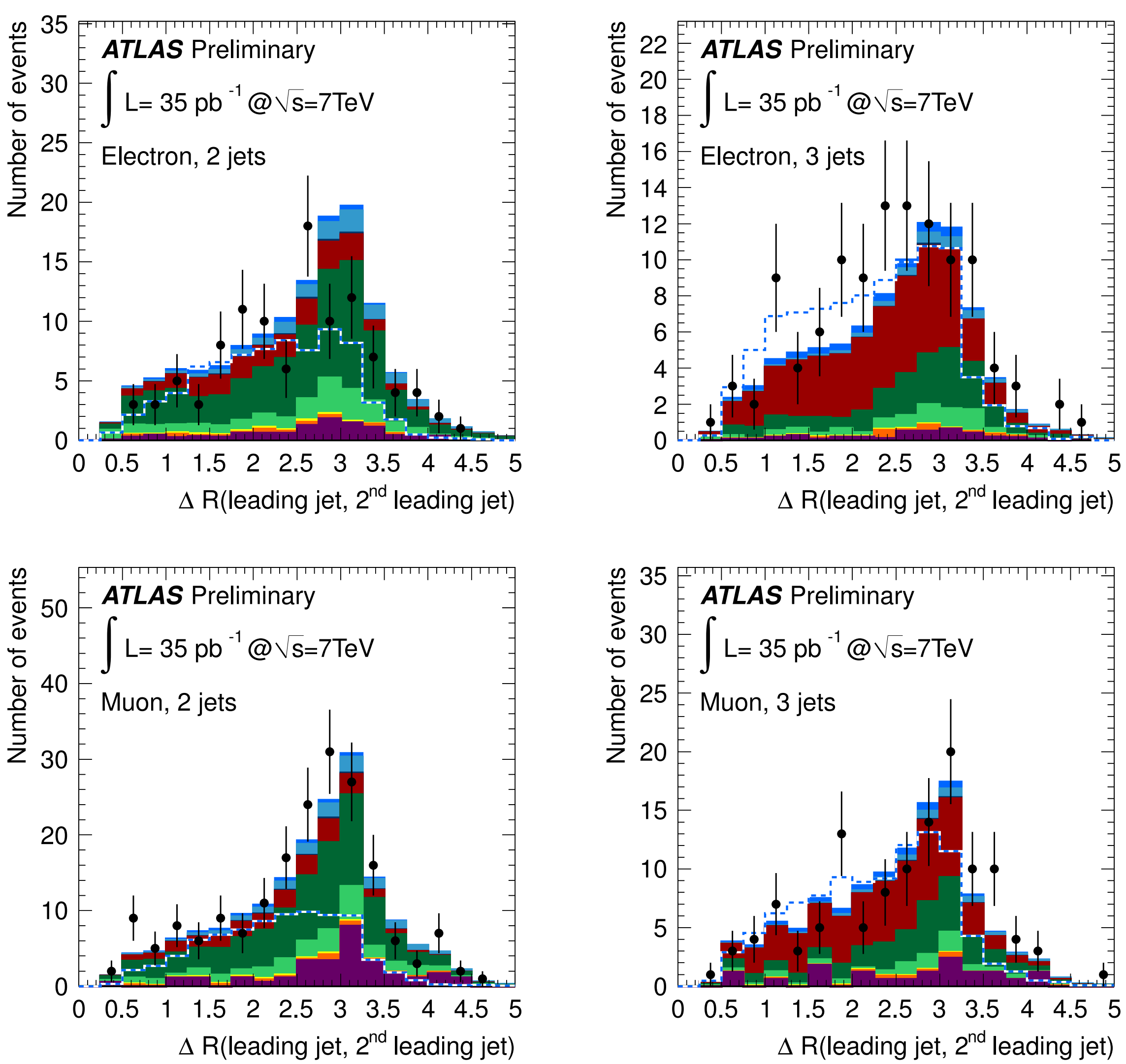
	Cut-based	
	Lepton +	Lepton −
t-channel	10.3 ± 1.8	4.4 ± 0.8
s-channel	0.1 ± 0.1	0.1 ± 0.1
Wt	0.1 ± 0.1	0.2 ± 0.1
$t\bar{t}$	0.7 ± 0.3	0.7 ± 0.4
W+jets	2.5 ± 1.1	1.0 ± 0.5
Wc+jets	4.5 ± 2.4	3.9 ± 2.1
$Wb\bar{b}$+jets	0.9 ± 0.9	0.2 ± 0.2
$Wc\bar{c}$+jets	0.9 ± 0.9	0.4 ± 0.4
Diboson	0.1 ± 0.1	0.1 ± 0.1
Z+jets	0.3 ± 0.3	0.1 ± 0.1
QCD	2.2 ± 1.6	2.1 ± 1.5
TOTAL Exp	22.7 ± 3.8	13.2 ± 2.8
S/B	0.83	0.50
DATA	21	11

Wt: Semi-Leptonic

Extra Light flavor jet in the final state.

Same Selection as t-channel with:

- 2-4 Jets (exactly 1 b-tag)
- $\Delta R(J_1, J_2) < 2.5$,



Yields

Table 5: Event yields after the Wt selections in the tag electron and muon samples. Uncertainties are from finite statistics in simulation samples and include all systematic effects.

	Electron			Muon		
	2 jets	3 jets	4 jets	2 jets	3 jets	4 jets
Wt	2.3 ± 0.5	2.7 ± 0.4	1.2 ± 0.2	2.4 ± 0.5	2.8 ± 0.4	1.2 ± 0.2
s,t-channel	3.7 ± 0.5	1.2 ± 0.2	0.3 ± 0.1	4.4 ± 0.6	1.3 ± 0.2	0.3 ± 0.1
$t\bar{t}$	11.4 ± 4.0	24.6 ± 5.3	23.2 ± 3.1	12.5 ± 4.1	27.5 ± 6.0	25.6 ± 3.8
W+jets	7.5 ± 3.8	2.4 ± 1.5	0.8 ± 0.7	8.6 ± 4.0	2.5 ± 1.6	1.0 ± 0.9
Wc+jets	19.7 ± 10.3	4.8 ± 2.6	1.5 ± 0.9	22.8 ± 11.8	6.4 ± 3.5	1.7 ± 1.1
$Wc\bar{c}$+jets	2.1 ± 2.0	0.9 ± 1.0	0.2 ± 0.3	2.7 ± 2.6	1.3 ± 1.4	0.4 ± 0.5
$Wb\bar{b}$+jets	3.8 ± 3.6	1.2 ± 1.3	0.6 ± 0.8	4.7 ± 4.4	2.1 ± 2.1	0.8 ± 1.0
Diboson	1.0 ± 0.2	0.4 ± 0.1	0.1 ± 0.0	1.2 ± 0.2	0.5 ± 0.1	0.1 ± 0.0
Z+jets	1.3 ± 1.3	0.5 ± 0.5	0.6 ± 0.6	1.2 ± 1.2	0.6 ± 0.6	0.2 ± 0.2
Multijet	3.5 ± 3.5	1.2 ± 1.3	0.5 ± 0.5	5.7 ± 3.4	5.5 ± 3.3	1.2 ± 1.0
TOTAL Exp	56.3 ± 12.9	40.0 ± 6.5	29.0 ± 3.5	66.2 ± 14.6	50.5 ± 8.2	32.6 ± 4.4
S/B	0.04	0.07	0.04	0.04	0.06	0.04
DATA	49	55	29	74	50	37

Wt: Dilepton

Backgrounds

Fake Lepton

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

Drell Yan

- MeT cut Efficiency from Z window
- Apply to Signal Region with reversed MeT

Top

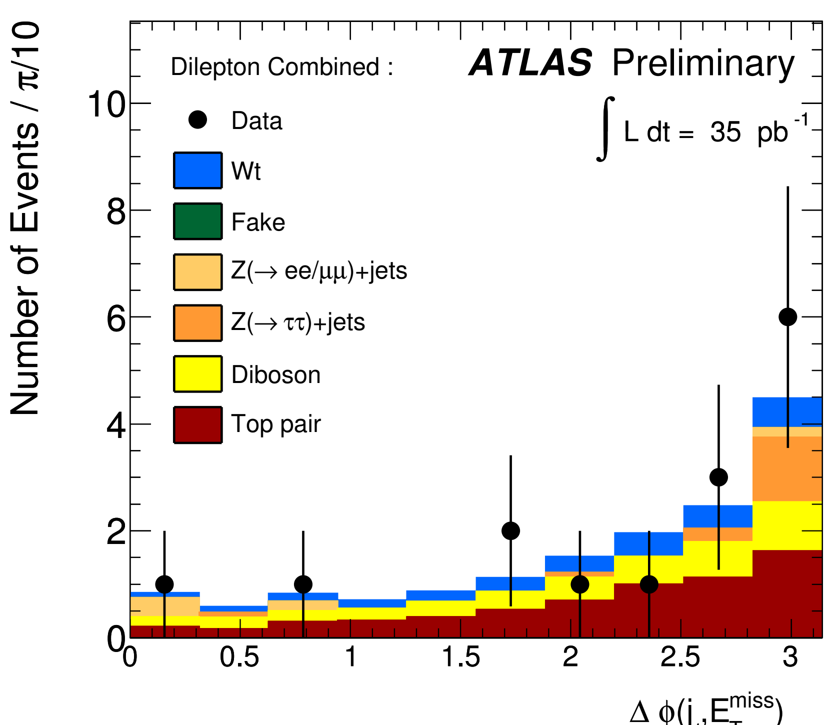
- Normalize to 2 Jet Bin

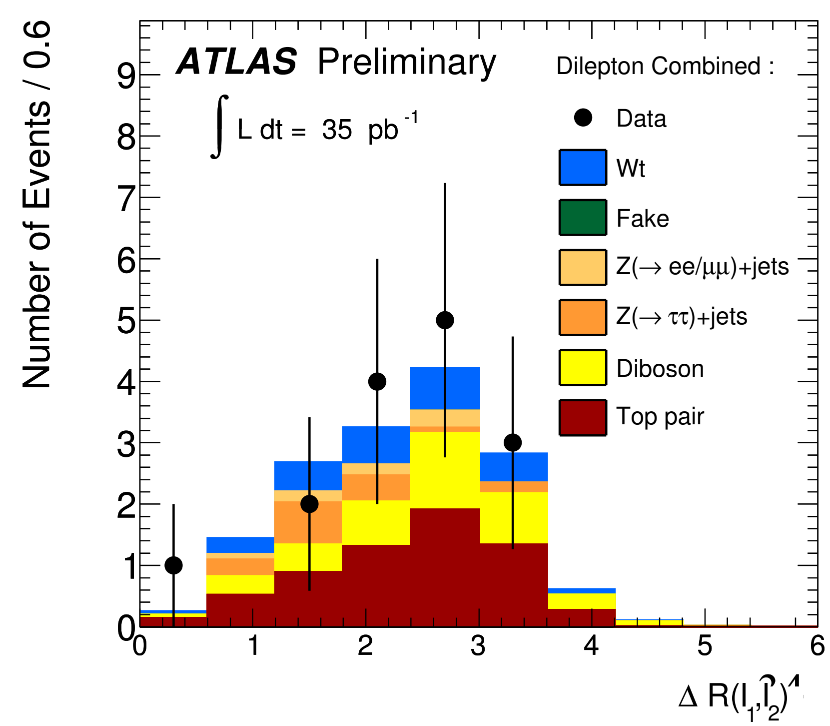
Other

- From MC

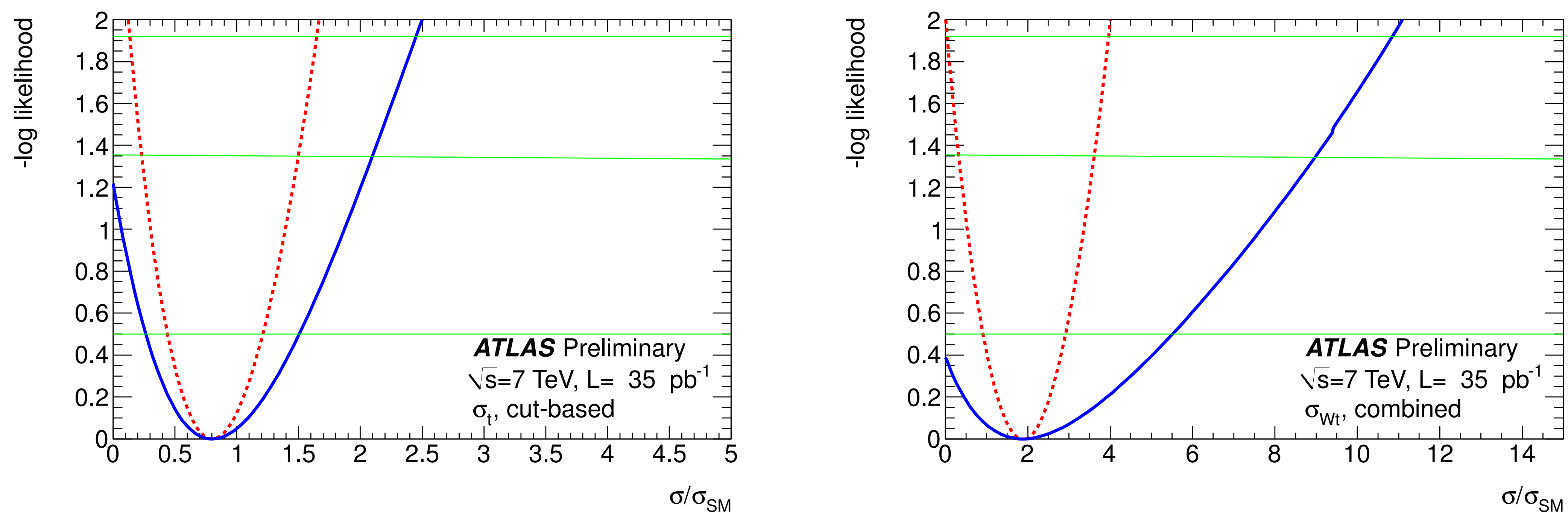
Yields

Process	$e\mu$	ee	$\mu\mu$
Wt	1.7 ± 0.5	0.3 ± 0.1	0.8 ± 0.2
$t\bar{t}$	$3.9^{+1.6}_{-1.5}$	0.9 ± 0.4	1.6 ± 0.6
$Z \to ee$	—	$0.0^{+0.3}_{-0.1}$	—
$Z \to \mu\mu$	—	—	$0.7^{+0.5}_{-0.4}$
$Z \to \tau\tau$	$1.1^{+0.5}_{-0.6}$	0.2 ± 0.1	0.4 ± 0.3
Diboson	2.5 ± 0.5	0.4 ± 0.1	1.0 ± 0.3
Fake leptons	0.0 ± 0.2	0.0 ± 0.1	0.0 ± 0.4
TOTAL Exp	$9.2^{+2.3}_{-2.5}$	$1.8^{+0.6}_{-0.5}$	4.5 ± 1.2
DATA	12	1	2





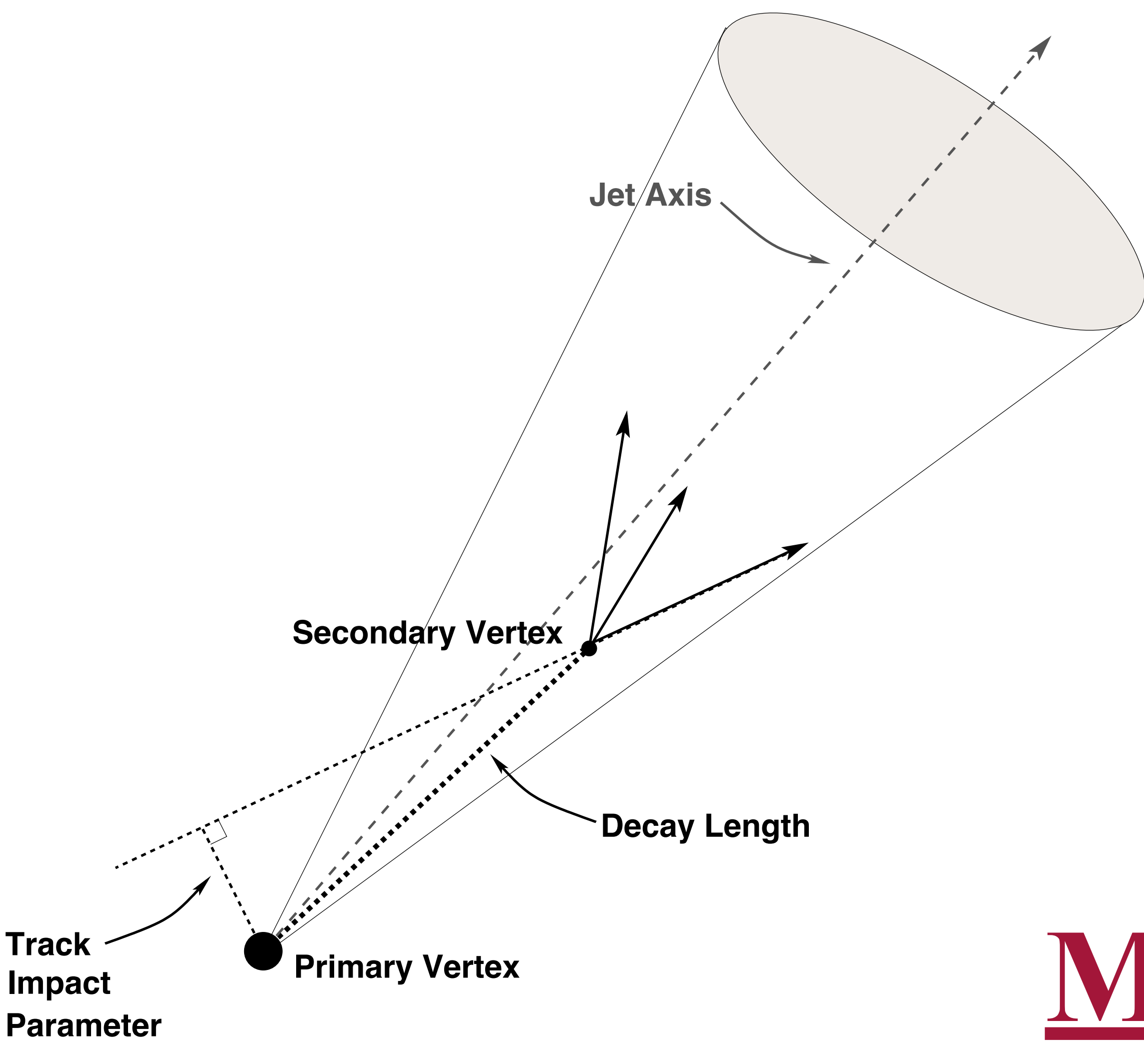
Single Top Cross Section



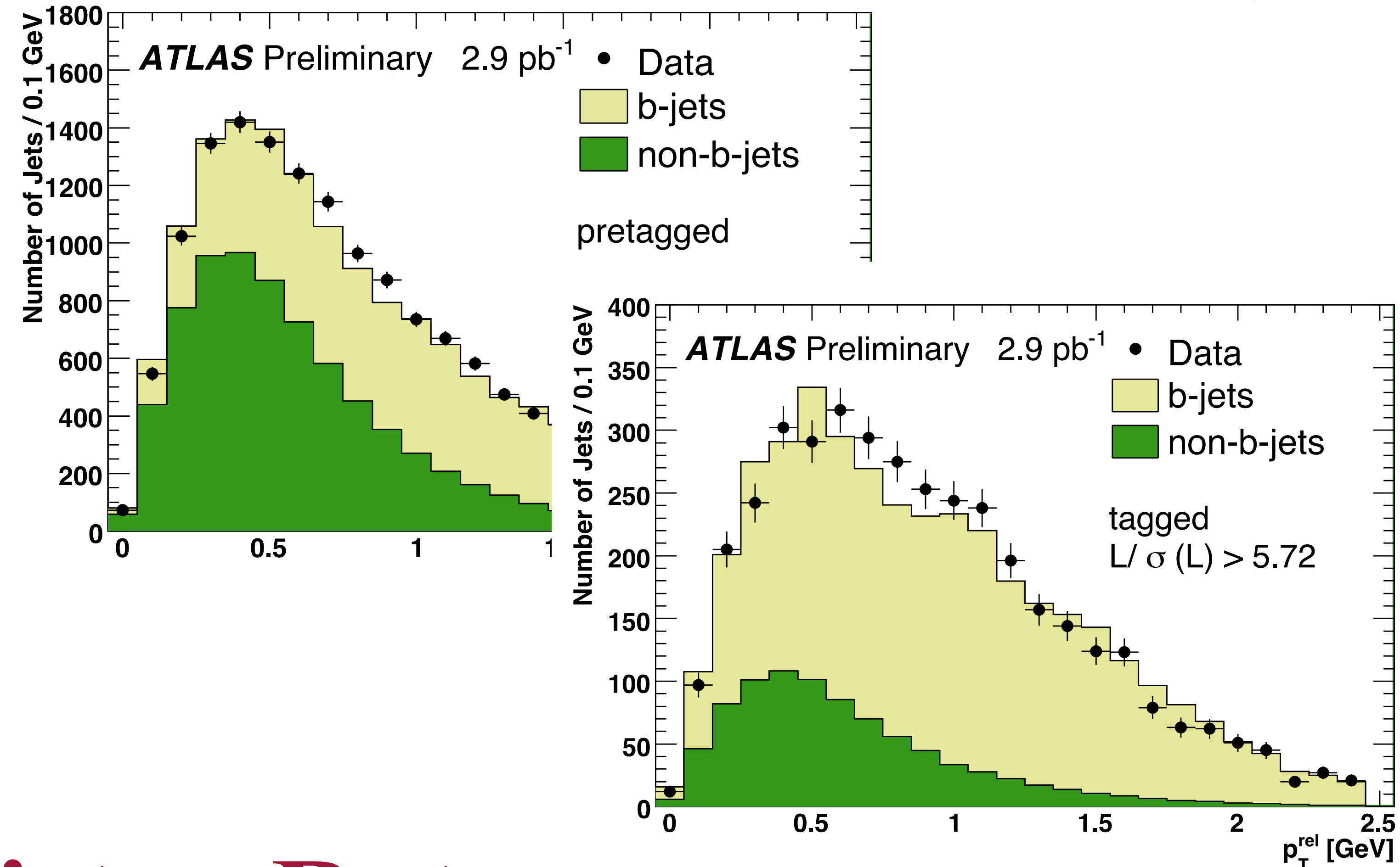
(a) (b)

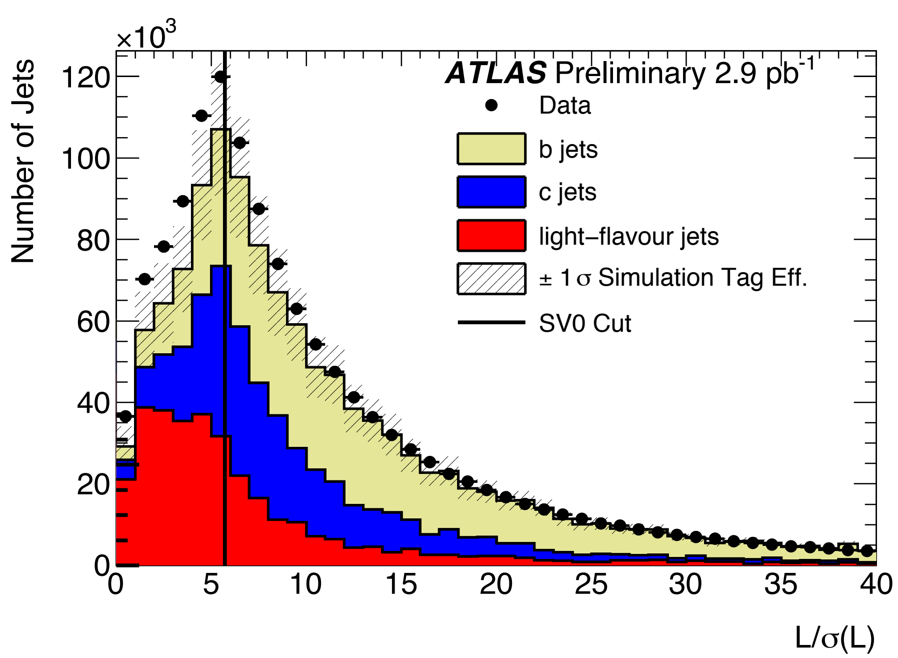
Figure 8: Observed likelihood ratio (red dashed) and profile likelihood ratio (blue solid) curves for (a) the t-channel cut-based analysis and (b) the combined Wt-channel analysis. The horizontal green lines represent, from the top, the 95%, 90%, and 68% confidence intervals on the extracted cross-section. The likelihood ratio shows the effect of statistical uncertainties while the profile likelihood ratio also includes the effect of all systematic uncertainties.

B-Tagging



Efficiency



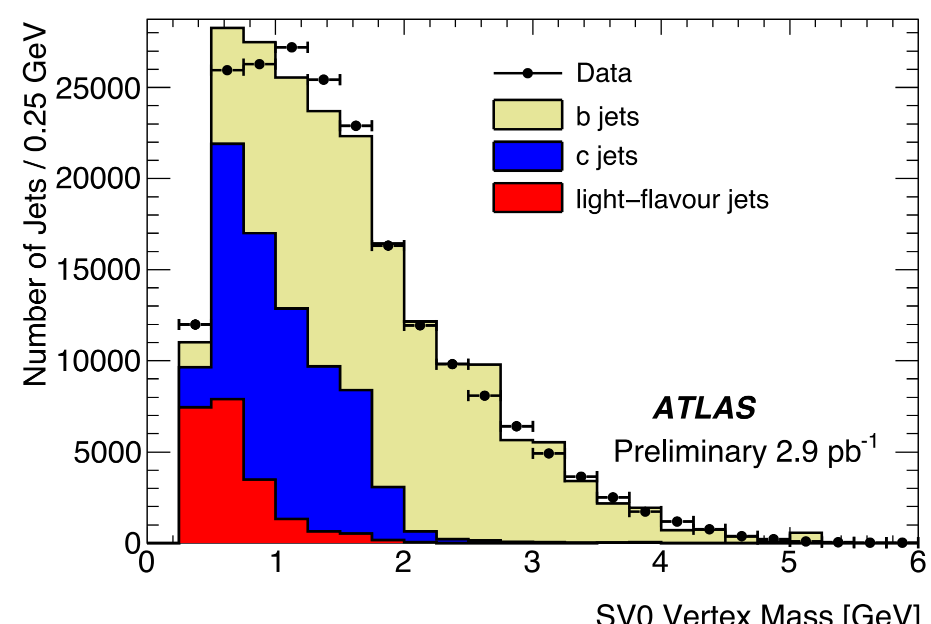


Mistag Rate

$$L/\sigma(L) > 5.72$$

$$\downarrow$$

$$L/\sigma(L) < -5.72$$



Other SM Results

Z→ττ Observation

τ's are an important part of the SM program

Unique Signal for many signals of new Physics

ττ
- 45% lep/had
- 43% had/had
- 11% lep/lep

Use semi-leptonic channel
study hadronic τ decays

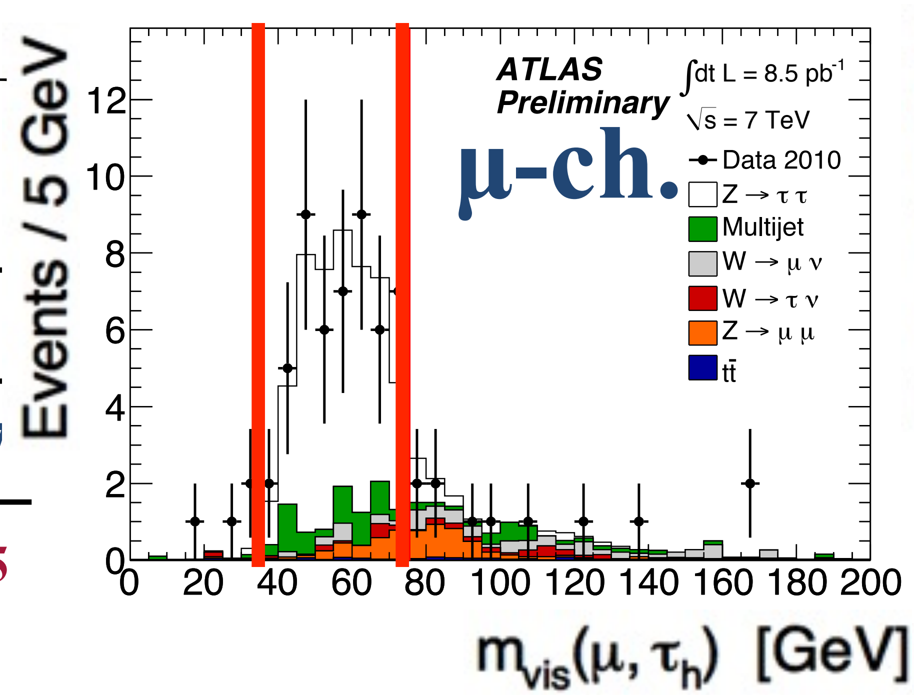
Signature
- High pT lepton (Trigger)
- Hadronic τ-candidate
  (1-prong/3-prong)

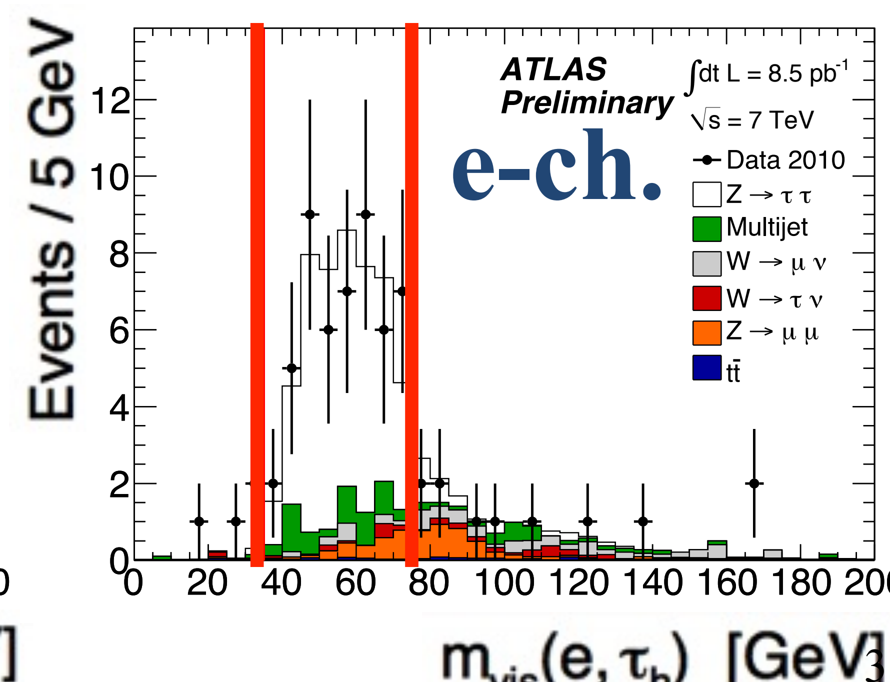
Event Selection
- W-Suppression: $\Delta\phi(\not{E}_T, l)|\Delta\phi(\not{E}_T, \tau_h)|m_T$
- Di-lepton veto
- Visible Mass Cut

Results $\int \mathscr{L} dt = 8.5 \text{ pb}^{-1}$

	e-channel	μ-channel
Event Yield	29	51
multi-jet	6.8±0.6±0.7	5.2±0.7±0.7
EW Bkg	5.0±0.6±1.4	4.7±0.5±1.5

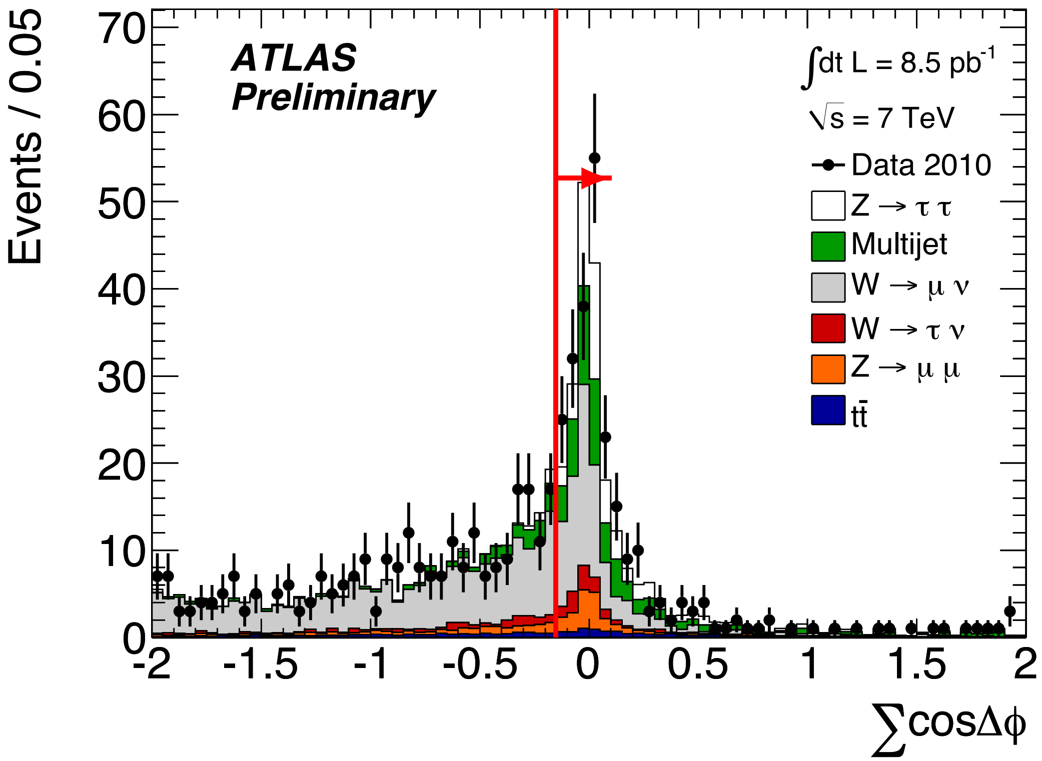
From: Data/MC





Z→ττ Observation

W+Jet Suppression

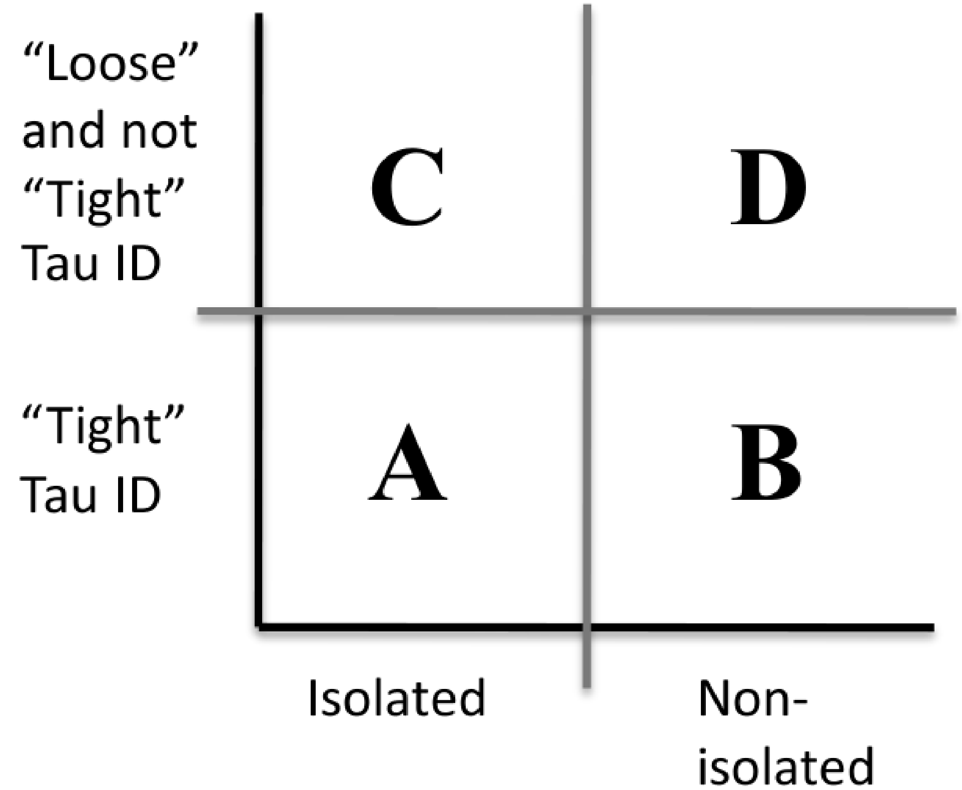


$$\sum \cos \Delta\phi = \cos\left(\phi(\ell) - \phi(E_{\mathrm{T}}^{\mathrm{miss}})\right) + \cos\left(\phi(\tau_{\mathrm{h}}) - \phi(E_{\mathrm{T}}^{\mathrm{miss}})\right),$$

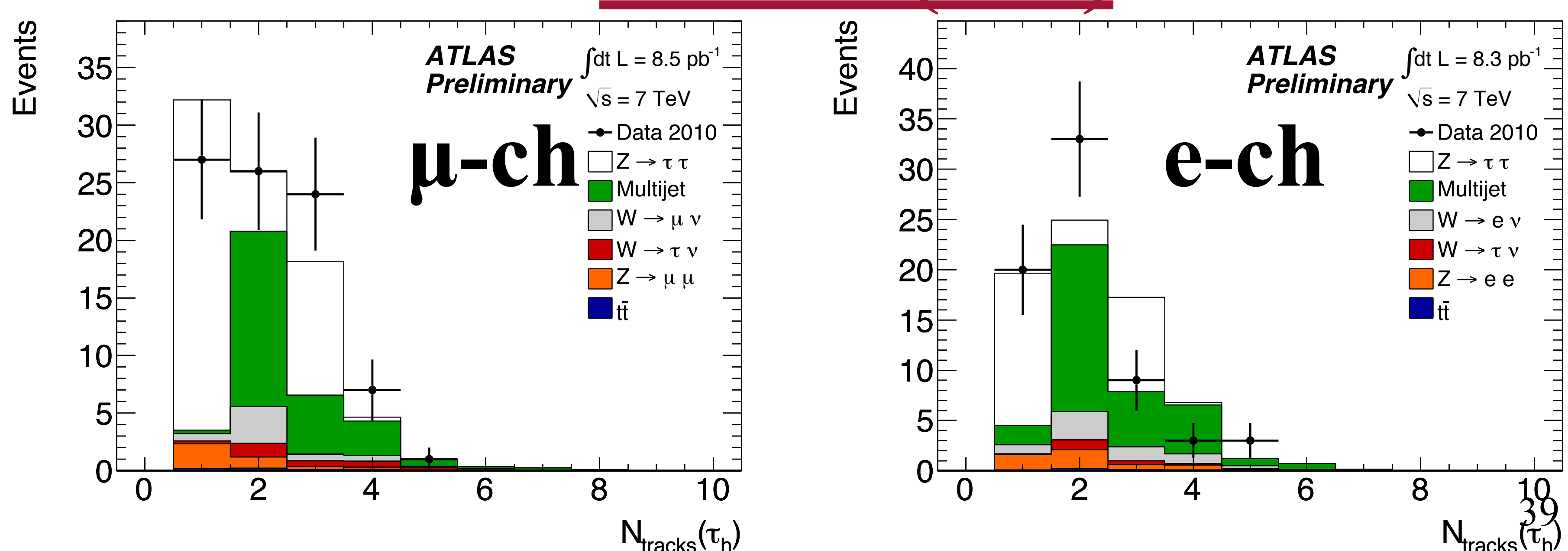
$m_{\mathrm{T}} < 50$ GeV

W+Jets MC Normalized to data in region defined by reversions W Suppression cuts

QCD background estimate



nTrack (N-1)



Top Cross Section

Semi-Leptonic Channel

Event Selection

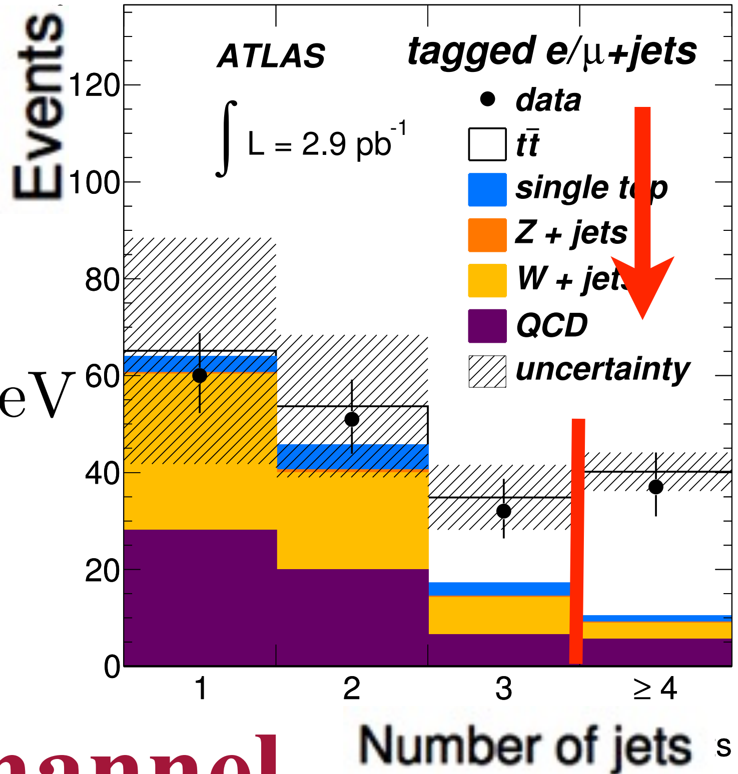
$E_T^l > 20$ GeV

$\not{E}_T > 25$ GeV

$\not{E}_T + m_T > 60$ GeV

≥ 1 b-jet

≥ 4 jets



Dilepton Channel

Event Selection

O.S. lepton pair

≥ 2 jets

ee/μμ-channel

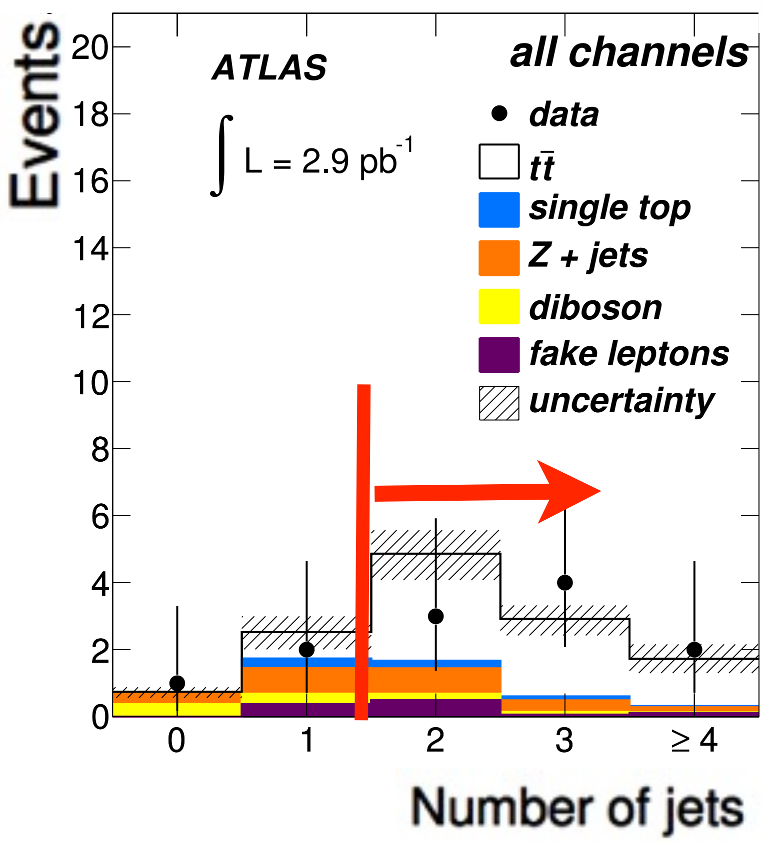
High $\not{E}_T$

Z-Veto

eμ-channel

$H_T > 150$ GeV

$$H_T = \sum_{l,jet} p_T$$

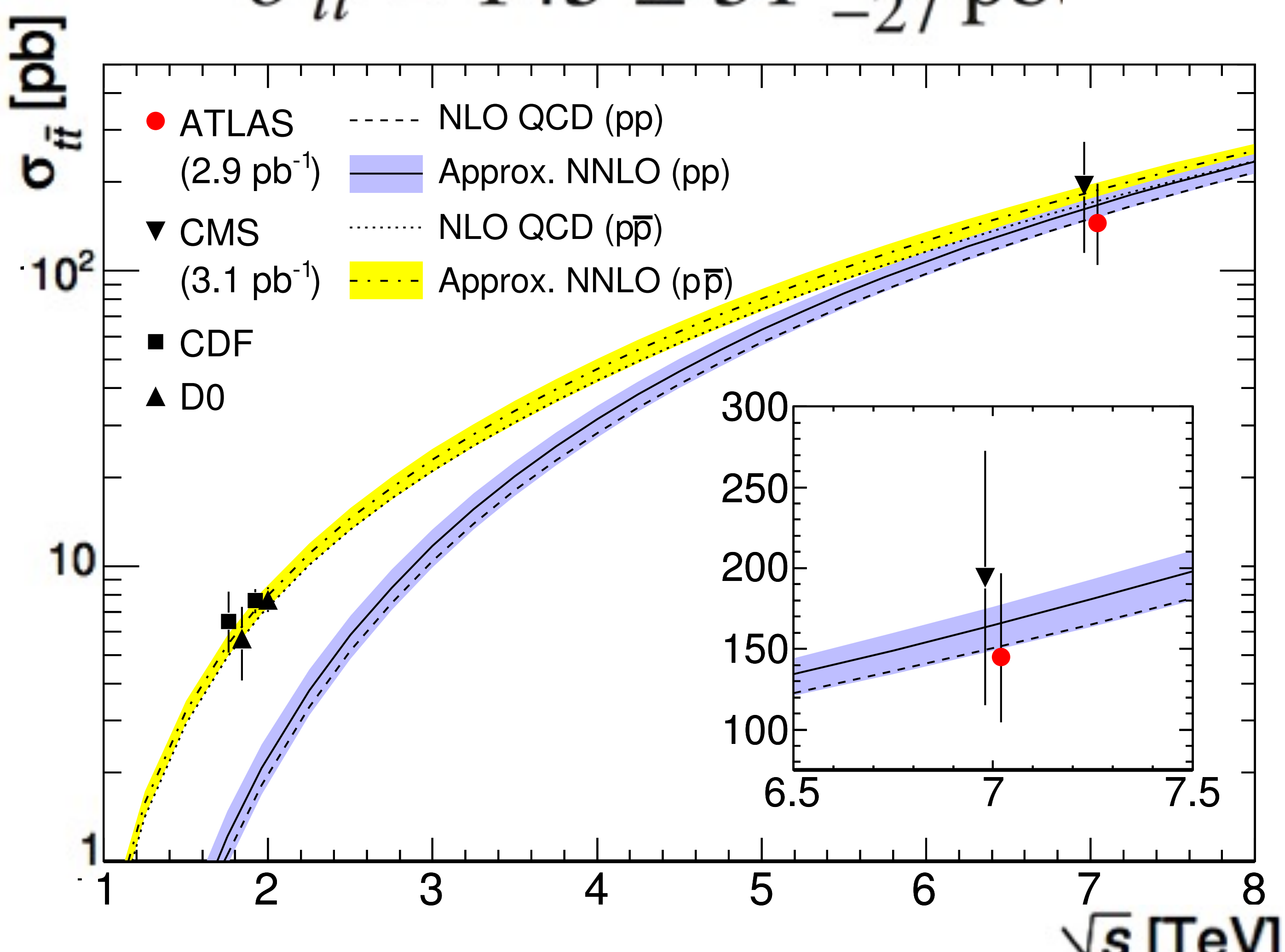


Results

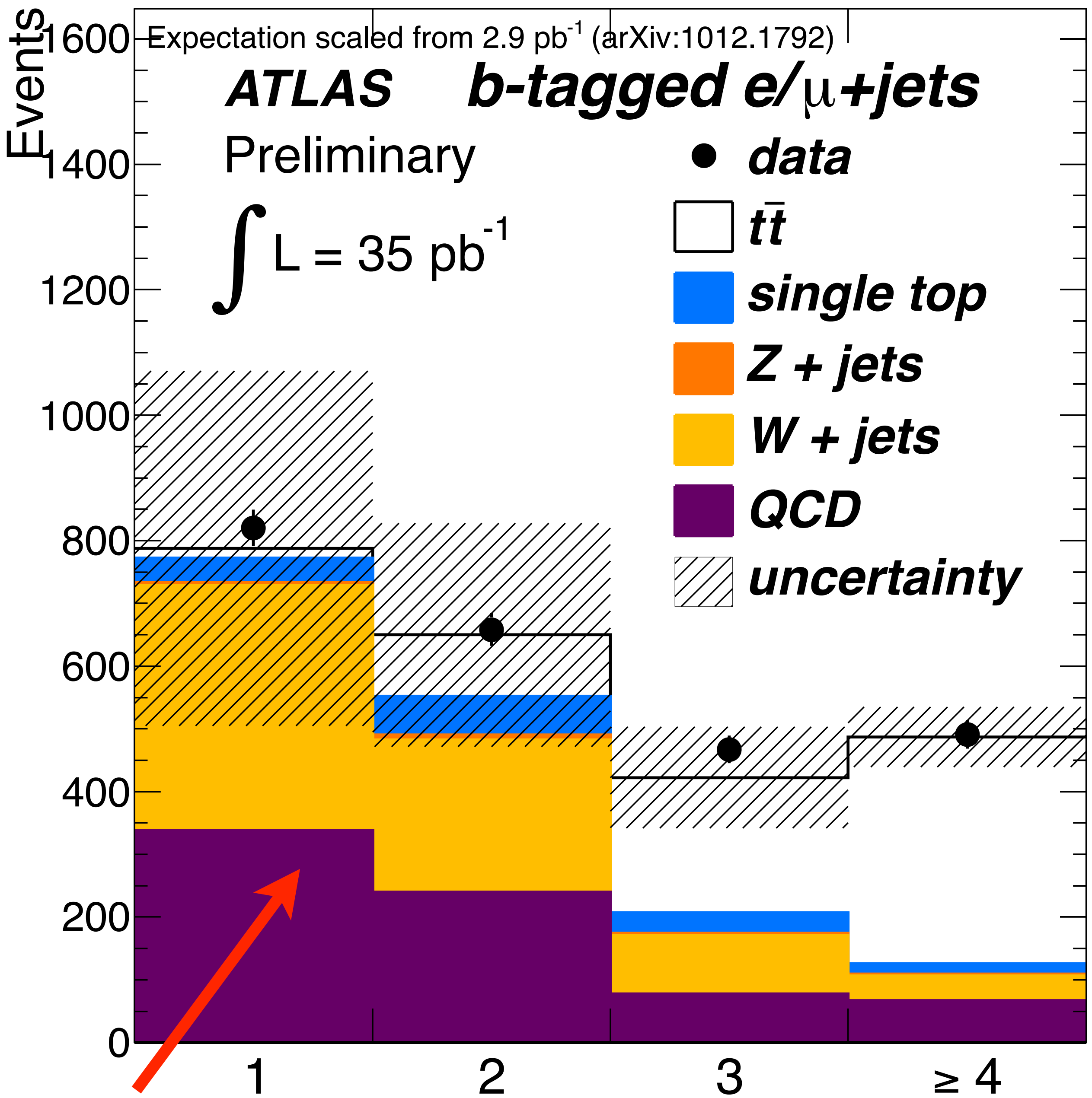
	Semi-Leptonic	Dilepton
Event Yield	37	9
Background	12.2 ± 5.1	2.5 ± 1.7

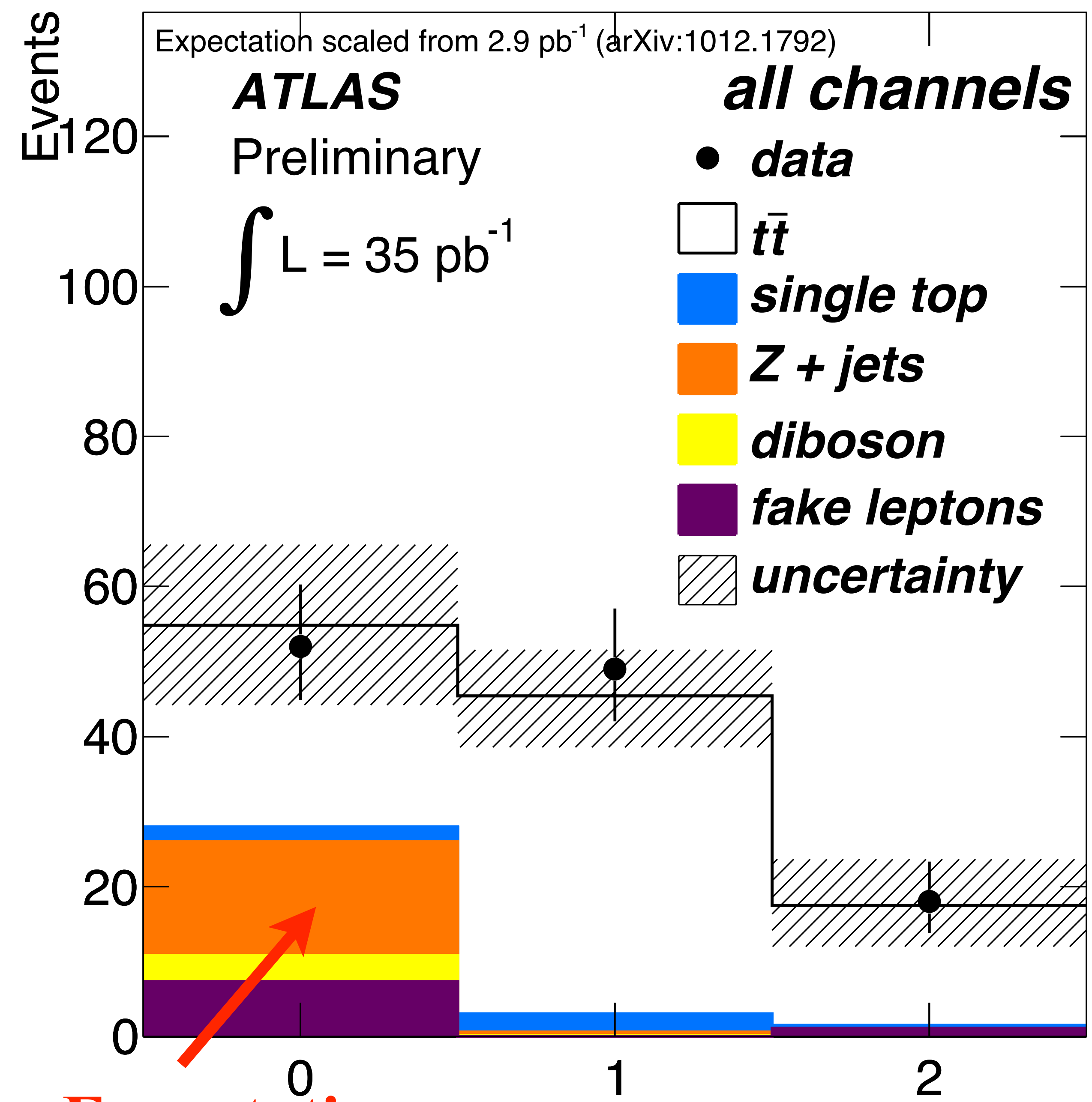
Combined Cross Section

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



Top w/ 35 pb^{-1}





Expectation Scaled from $3pb^{-1}$

Expectation Scaled from $3pb^{-1}$

Updated Cross Section Measurements Coming Soon!

Top Semi-Leptonic

Yields

e+jets channel						
	1-jet tagged	2-jet tagged	3-jet tagged	≥4-jet tagged	3-jet zero-tag	≥4-jet zero-tag
QCD (DD)	21.9 ± 3.4	16.4 ± 4.0	4.9 ± 2.7	4.8 ± 3.1	52.0 ± 19	23.0 ± 11
W+jets (MC)	14.5 ± 10	9.5 ± 6.6	3.4 ± 2.7	1.5 ± 1.4	55.1 ± 26	15.1 ± 10
W+jets (DD)	-	-	-	1.9 ± 1.1	-	9.3 ± 4.0
Z+jets (MC)	0.1 ± 0.1	0.3 ± 0.1	0.1 ± 0.1	0.2 ± 0.1	4.6 ± 2.2	1.7 ± 1.3
single-t (MC)	1.6 ± 0.3	2.6 ± 0.6	1.3 ± 0.3	0.7 ± 0.2	0.9 ± 0.2	0.4 ± 0.1
Total (non $t\bar{t}$)	38.1 ± 11	28.8 ± 7.7	9.7 ± 3.8	7.2 ± 3.4	112.6 ± 32	40.2 ± 15
$t\bar{t}$ (MC)	0.6 ± 0.2	4.0 ± 1.0	8.8 ± 1.8	14.9 ± 3.5	4.5 ± 0.8	5.4 ± 1.2
Total expected	39 ± 11	33 ± 8	19 ± 4	22 ± 5	117 ± 32	46 ± 15
Observed	30	21	14	17	106	39

μ+jets channel						
	1-jet tagged	2-jet tagged	3-jet tagged	≥4-jet tagged	3-jet zero-tag	≥4-jet zero-tag
QCD (DD)	6.1 ± 2.9	3.4 ± 1.8	1.5 ± 0.8	0.8 ± 0.5	4.9 ± 2.3	1.7 ± 1.1
W+jets (MC)	17.8 ± 12	10.5 ± 7.4	4.3 ± 3.3	1.7 ± 1.6	63.6 ± 28	17.6 ± 12
W+jets (DD)	-	-	-	3.2 ± 1.7	-	15.7 ± 4.5
Z+jets (MC)	0.3 ± 0.1	0.4 ± 0.2	0.1 ± 0.1	0.1 ± 0.1	3.3 ± 1.6	1.3 ± 0.8
single-t (MC)	1.7 ± 0.4	2.5 ± 0.5	1.5 ± 0.3	0.7 ± 0.2	1.1 ± 0.2	0.3 ± 0.1
Total (non $t\bar{t}$)	25.9 ± 13	16.8 ± 7.6	7.4 ± 3.4	3.3 ± 1.7	72.9 ± 29	20.9 ± 13
$t\bar{t}$(MC)	0.7 ± 0.2	4.1 ± 1.1	9.0 ± 1.8	15.0 ± 3.4	4.6 ± 0.7	5.5 ± 1.2
Total expected	27 ± 13	21 ± 8	16 ± 4	18 ±4	78 ± 29	26 ± 13
Observed	30	30	18	20	80	36

Systematics

	Relative cross-section uncertainty [%]	
Source	e + jets	μ + jets
Statistical uncertainty	±43	±29
Object selection		
Lepton reco,ID,Trigger	±3	±2
Jet energy reco	±13	±11
b-tagging	-10 ; +15	-10 ; +14
Background rates		
QCD norm	±30	±2
W+jets norm	±11	±11
Other bkg norm	±1	±1
Signal simulation		
ISR/FSR	-6 ; +13	±8
PDF	±2	±2
Parton shower & hadronisation	±1	±3
NLO generator	±4	±6
Sum systematics	-37 ; +41	-20 ; +24
Integrated luminosity	-11 ; +14	-10 ; +13

Top Semi-Leptonic

QCD Background

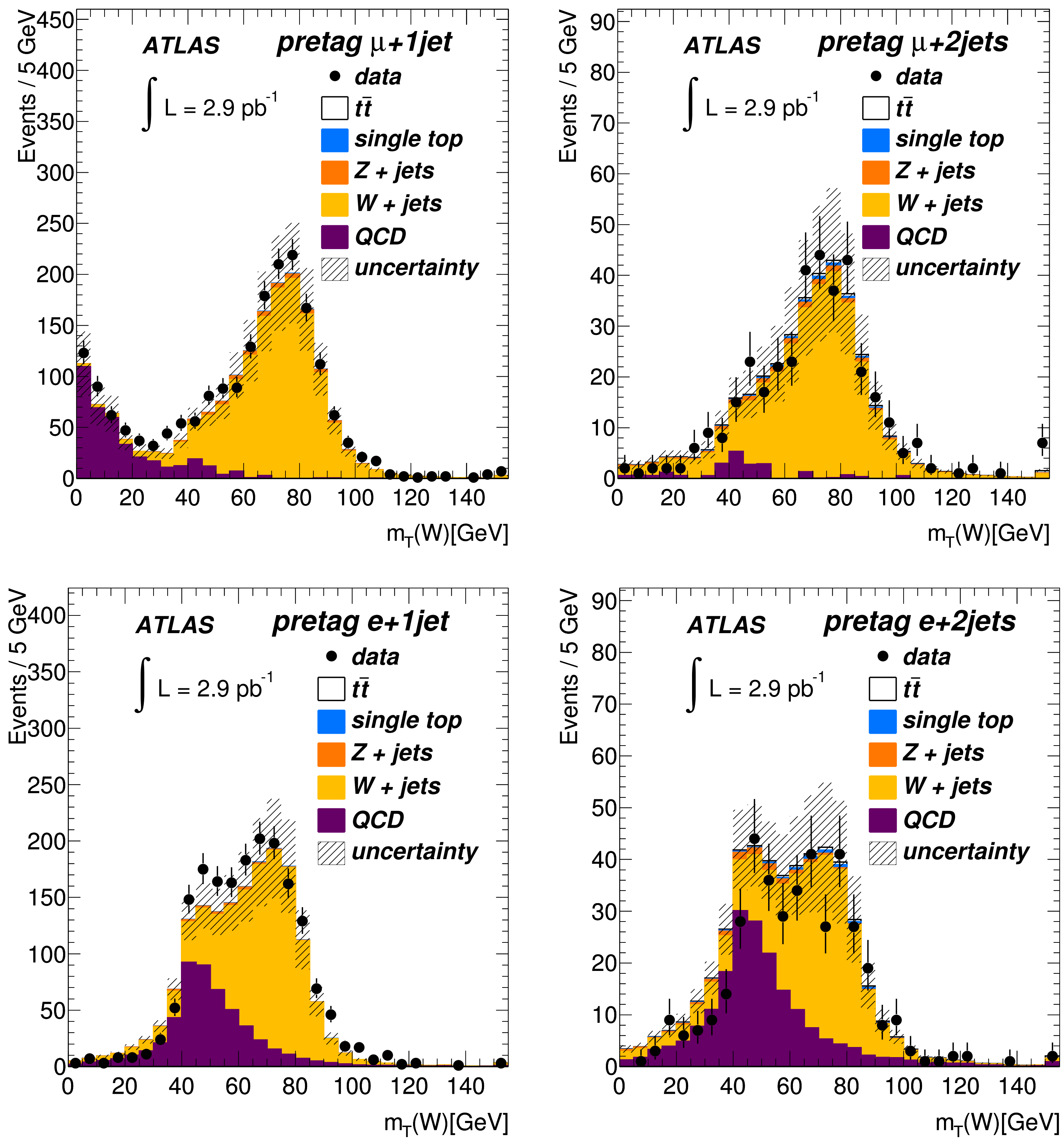
μ-channel

$$N^{\text{loose}} = N^{\text{loose}}_{\text{real}} + N^{\text{loose}}_{\text{fake}},$$
$$N^{\text{std}} = rN^{\text{loose}}_{\text{real}} + fN^{\text{loose}}_{\text{fake}},$$

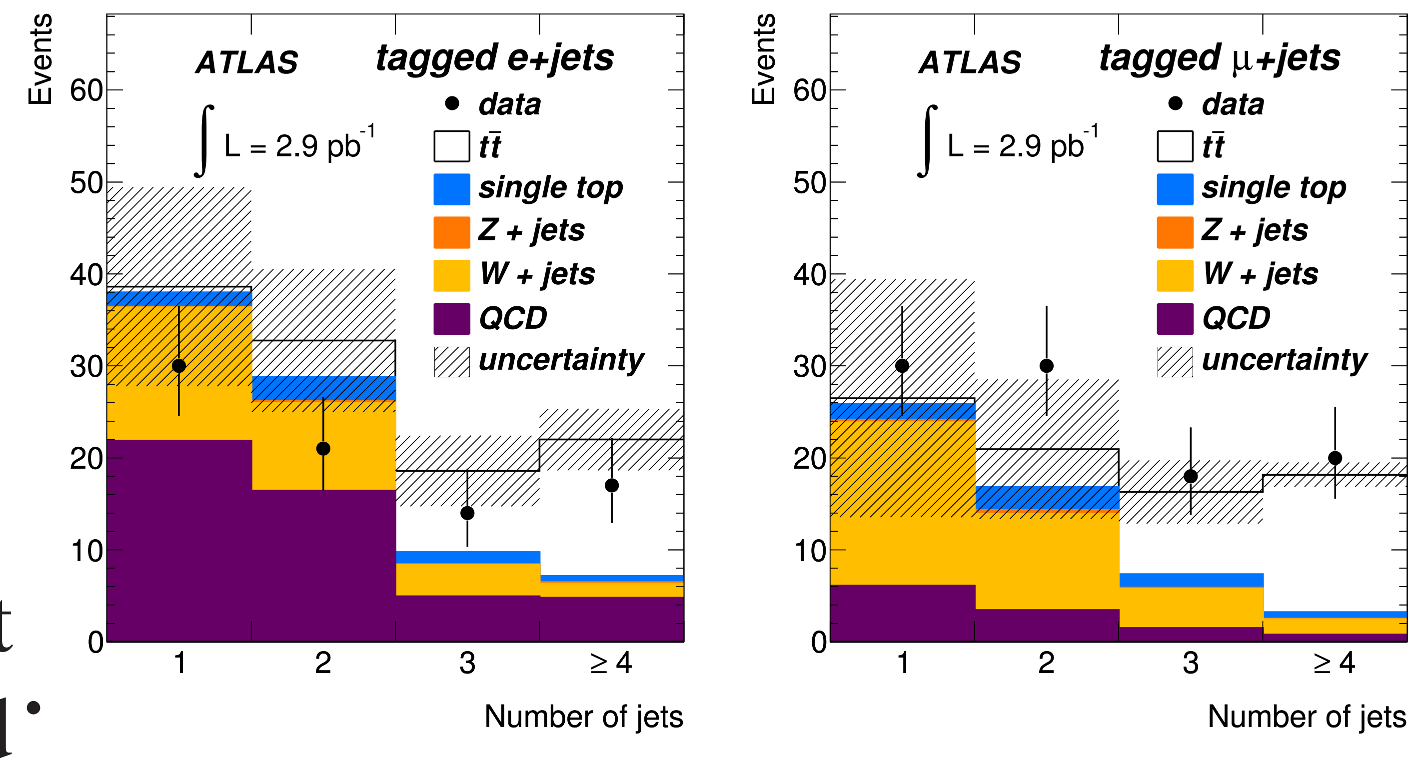
In pretag + extrapolation to tag

e-channel

Fit to MeT.
pretag and tag samples



Top Semi-Leptonic



W+Jets Background

$$W_{\text{tagged}}^{\geq 4\text{-jet}} = W_{\text{pre-tag}}^{\geq 4\text{-jet}} \cdot f_{\text{tagged}}^{\geq 4\text{-jet}}.$$

$$W_{\text{pre-tag}}^{\geq 4\text{-jet}} = W_{\text{pre-tag}}^{2\text{-jet}} \cdot \sum_{n=2}^{\infty} (W_{\text{pre-tag}}^{2\text{-jet}} / W_{\text{pre-tag}}^{1\text{-jet}})^n,$$

From μ-NJets after QCD Subtraction

$$f_{\text{tagged}}^{\geq 4\text{-jet}} = f_{\text{tagged}}^{2\text{-jet}} \cdot f_{2\to\geq 4}^{\text{corr}},$$

From μ-NJets after QCD Subtraction

From MC

$$f_{2\to 4}^{\text{corr}} = f_{\text{tagged}}^{\geq 4\text{-jet}} / f_{\text{tagged}}^{2\text{-jet}}.$$

Top Dilepton

Backgrounds

Process	ee	$\mu\mu$	$e\mu$
Z+jets (DD)	0.25 ± 0.18	0.67 ± 0.38	-
$Z(\to\tau\tau)$+jets (MC)	0.07 ± 0.04	0.14 ± 0.07	0.13 ± 0.06
Non-Z leptons (DD)	0.16 ± 0.18	-0.08 ± 0.07	0.47 ± 0.28
single top (MC)	0.08 ± 0.02	0.07 ± 0.03	0.22 ± 0.04
dibosons (MC)	0.04 ± 0.02	0.07 ± 0.03	0.15 ± 0.05
Total predicted (non $t\bar{t}$)	0.60 ± 0.27	0.88 ± 0.40	0.97 ± 0.30
$t\bar{t}$	1.19 ± 0.19	1.87 ± 0.26	3.85 ± 0.51
Total predicted	1.79 ± 0.38	2.75 ± 0.55	4.82 ± 0.65
Observed	2	3	4

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

Systematics

	Relative cross-section uncertainty [%]		
Source	ee	$\mu\mu$	$e\mu$
Statistical uncertainty	-79 ; +126	-67 ; +100	-56 ; +77
Object selection			
Lepton reco, ID, Trigger	-2 ; +11	-4 ; +3	-1 ; +3
JES	-7 ; +13	-14 ; +9	-3 ; +5
Background rates			
Fake leptons	-31 ; +24	-4 ; +1	-15 ; +8
Z+jets	-12 ; +4	-19 ; +5	-2 ; +1
MC stat.	-5 ; +3	-3 ; +4	± 2
Theoretical cross-section	± 3	-5 ; +4	± 3
Signal simulation			
ISR/FSR	-4 ; +5	-2 ; +3	-2 ; +3
PDF	-2 ; +1	-2 ; +3	-2 ; +3
Parton shower	-9 ; +14	-6 ; +9	± 3
NLO Generator	-8 ; +11	-11 ; +13	-3 ; +4
Luminosity	-11 ; +16	-11 ; +16	-12 ; +14
All syst.	-25 ; +44	-25 ; +30	-14 ; +25
Stat. + Syst.	-83 ; +134	-72 ; +104	-57 ; +81

Top Cross Section

Semi-Leptonic

Method	e + jets	μ + jets	e/μ +jets combined
Counting σ [pb]	$105 \pm 46\ ^{+45}_{-40}$	$168 \pm 49\ ^{+46}_{-38}$	$142 \pm 34\ ^{+50}_{-31}$

DiLepton

Channel	$\sigma_{t\bar{t}}$ (pb)
ee	$193\ ^{+243}_{-152}\ ^{+84}_{-48}$
$\mu\mu$	$185\ ^{+184}_{-124}\ ^{+56}_{-47}$
$e\mu$	$129\ ^{+100}_{-72}\ ^{+32}_{-18}$
Combined	$151\ ^{+78}_{-62}\ ^{+37}_{-24}$

Combination

Combination	Cross-section (pb)	Signal significance (σ)
Single lepton channels	$142 \pm 34\ ^{+50}_{-31}$	4.0
Dilepton channels	$151\ ^{+78}_{-62}\ ^{+37}_{-24}$	2.8
All channels	$145 \pm 31\ ^{+42}_{-27}$	4.8