Measurement of WW Cross Section at 7 TeV with the ATLAS Detector at LHC

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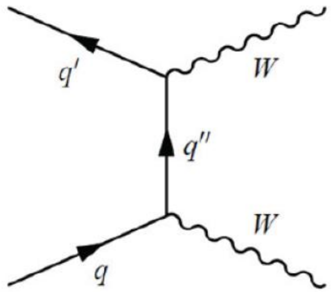
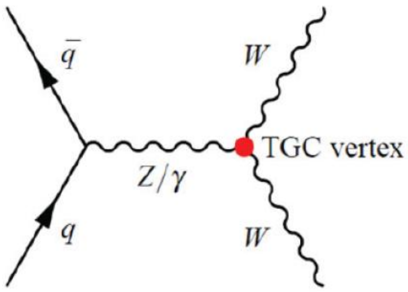
Outline

- WW Production at LHC
- WW Event Selection
- Background Estimations
- Sources of Systematic Uncertainties
- WW Fiducial and Total Cross Sections
- Summary

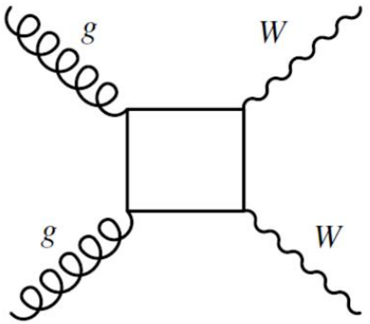
WW Production at LHC

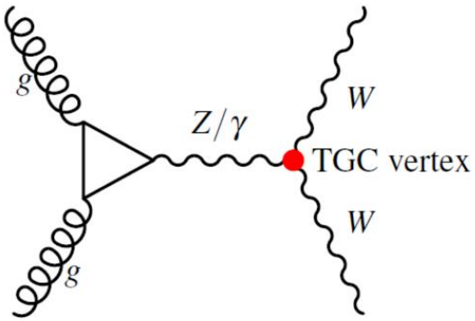
qq’ → WW production σ_{NLO} = (44.92 ± 2.25) pb at 7 TeV





gg → WW contributes additional ~3% of WW event rate : 1.3 pb

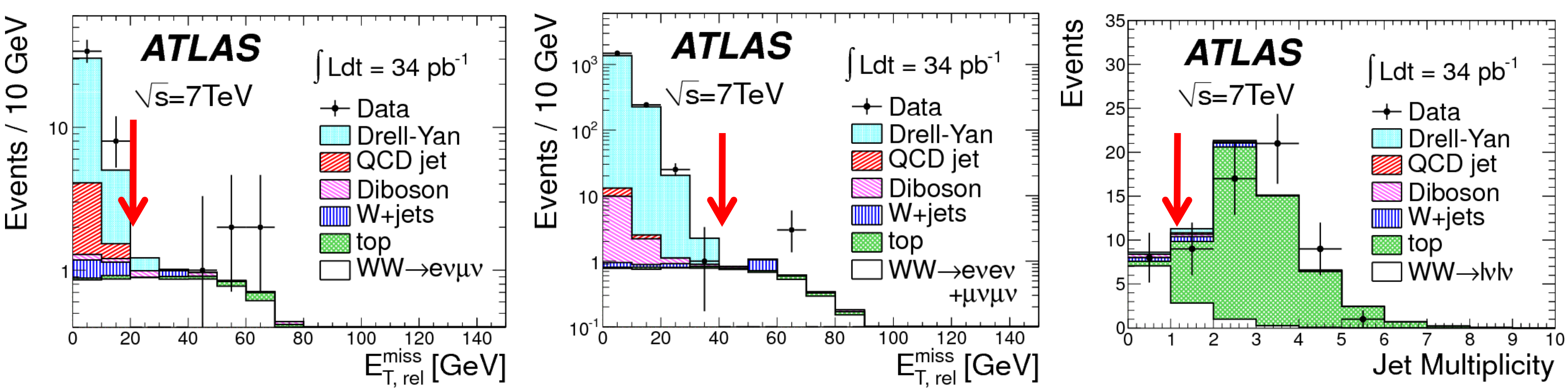




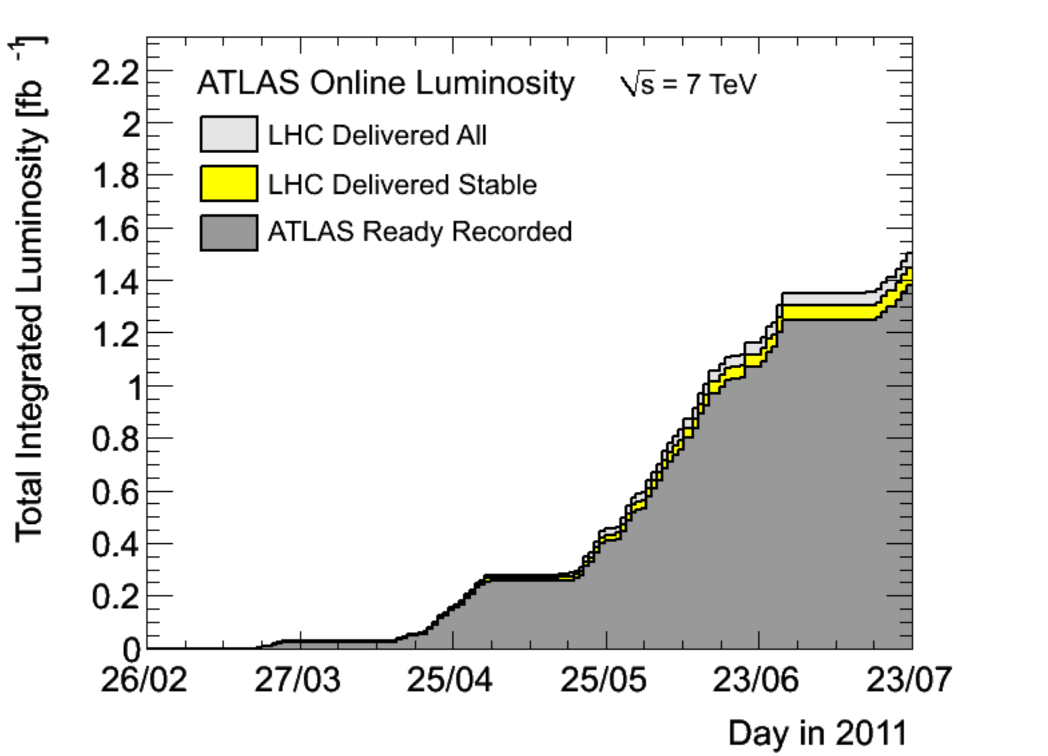
- Major background to SM Higgs → WW search
- Sensitive to new physics through anomalous TGC
- Experimental signature: two isolated leptons with large MET
- Major backgrounds: W/Z + jets, ttbar, single top

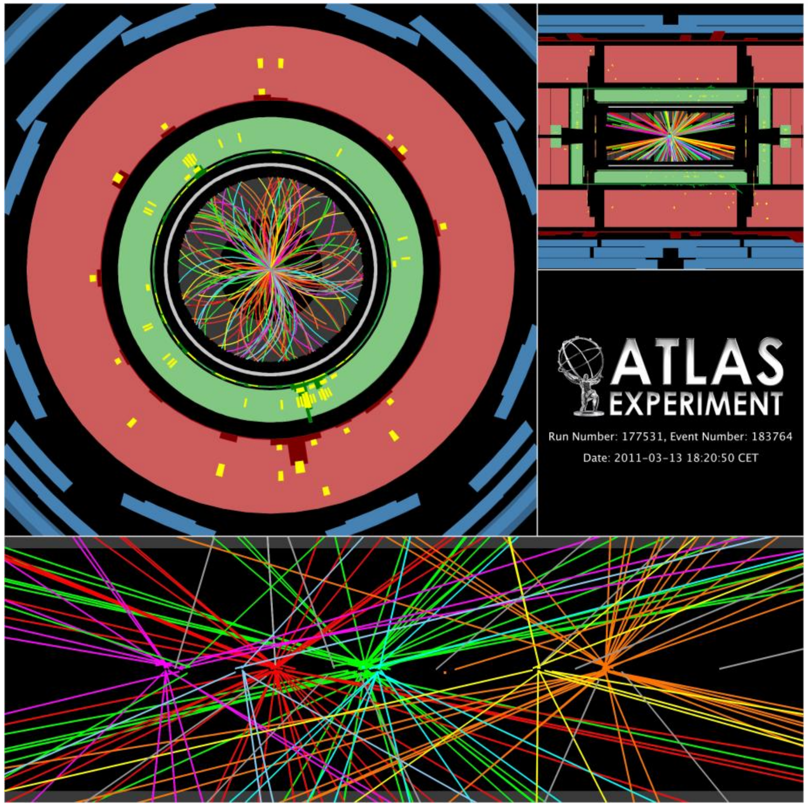
WW Analysis using 2010 Data

- Based on 34 pb^{-1} integrated luminosity at 7 TeV
  - Observed 8 WW candidates (1 ee, 2 μμ, 5 eμ)
  - Expected signal: $6.85 \pm 0.07 \pm 0.66$
  - Expected background: $1.68 \pm 0.37 \pm 0.42$
  - WW : $\sigma_{W^+W^-} = 41^{+20}_{-16}(stat.) \pm 5(syst.) \pm 1(lumi.)\,pb$
  - **Published: Phys. Rev. Lett. 107, 041802 (2011)**



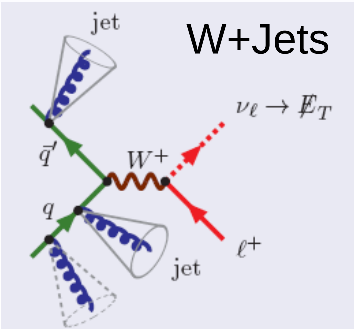
Major Challenges in 2011 Data

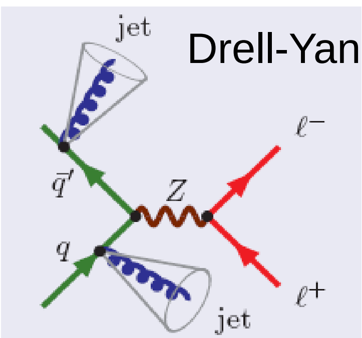


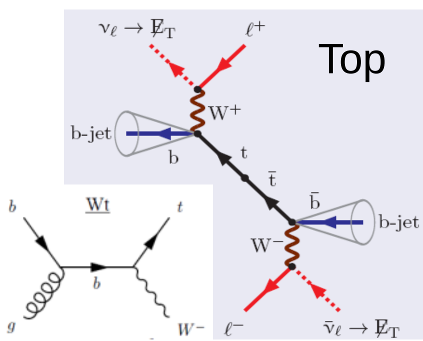


- **Higher luminosity** **(~1.75×10^{33}cm^{-2}s^{-1})**
  - higher pileup, more backgrounds from Drell-Yan, Top etc.
  - Corrections on JES, MET, lepton isolation
  - Needs better understanding of systematic uncertainties

Major $\ell^+\ell^-$ + E_T^{miss} Backgrounds





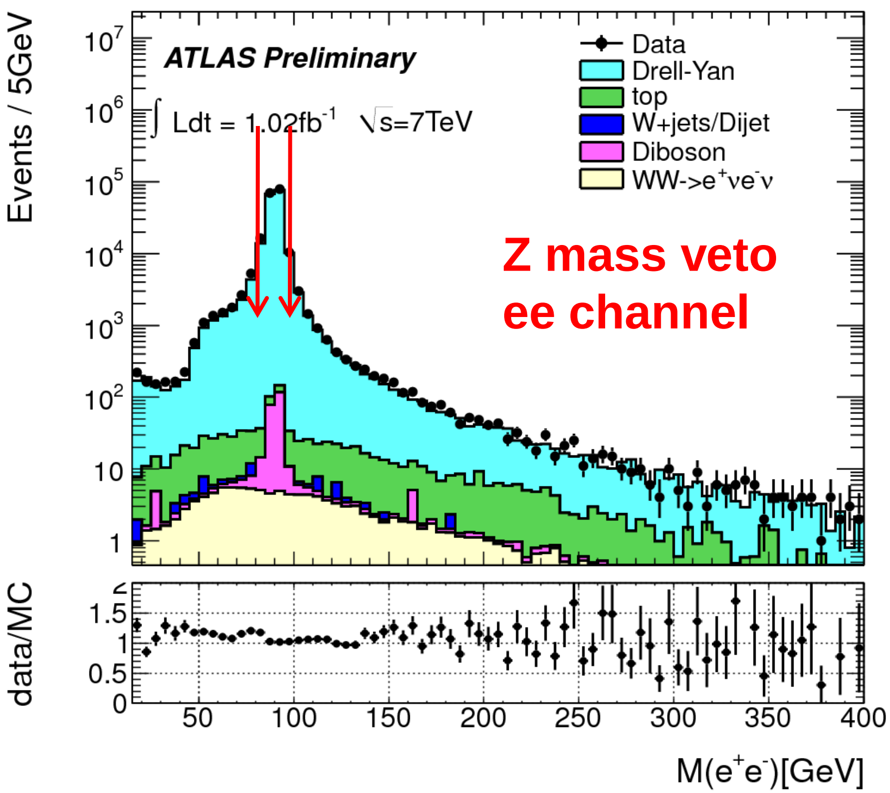


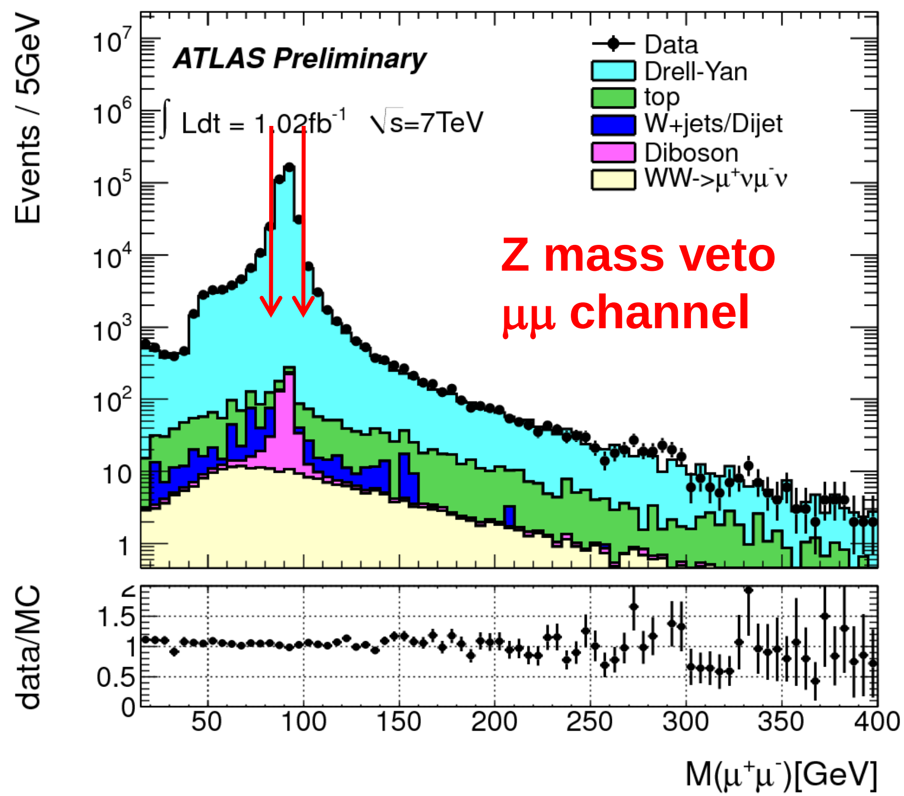
- **W+jets**
  - W leptonic decay produces a charged lepton and large missing E_T.
  - Associated jets can fake a second charged lepton.
  - ➢ **Suppressed by lepton identification.**
- **Drell-Yan**
  - high P_T charged lepton pairs produced from leptonic decays of Drell-Yan bosons.
  - Missing E_T either from mis-measurement of leptons or of associated jets, or from $Z \to \tau\tau$.
  - ➢ **Reduced by *Z* mass veto and missing E_T cut.**
- **Top**
  - *WW* pairs produced in *tt* or single top processes.
  - ➢ **Rejected by vetoing on high-P_T jets.**
- **Di-boson (*WZ,ZZ,W/Z+*γ)**
  - Leptons from boson decays or faked by photons.
  - Missing E_T from neutrino production or e/μ escape.
  - ➢ **Suppressed by the criteria mentioned above plus the requirement of exactly two high P_T charged leptons.**

WW Event Selection

❖ **Remove Drell-Yan Background:**

- Exact two leptons with opposite sign charge, p^{ℓ}_{T} > 20 GeV
- $|M_{ll} - M_Z|$ > 15GeV for ee and μμ channels
- M_{ll} >15GeV for ee and μμ, and M_{ll} > 10 GeV for eμ channel



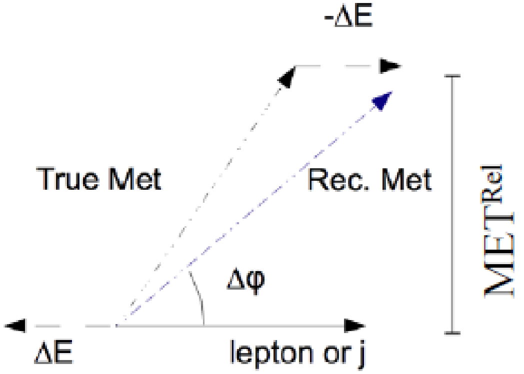


WW Event Selection

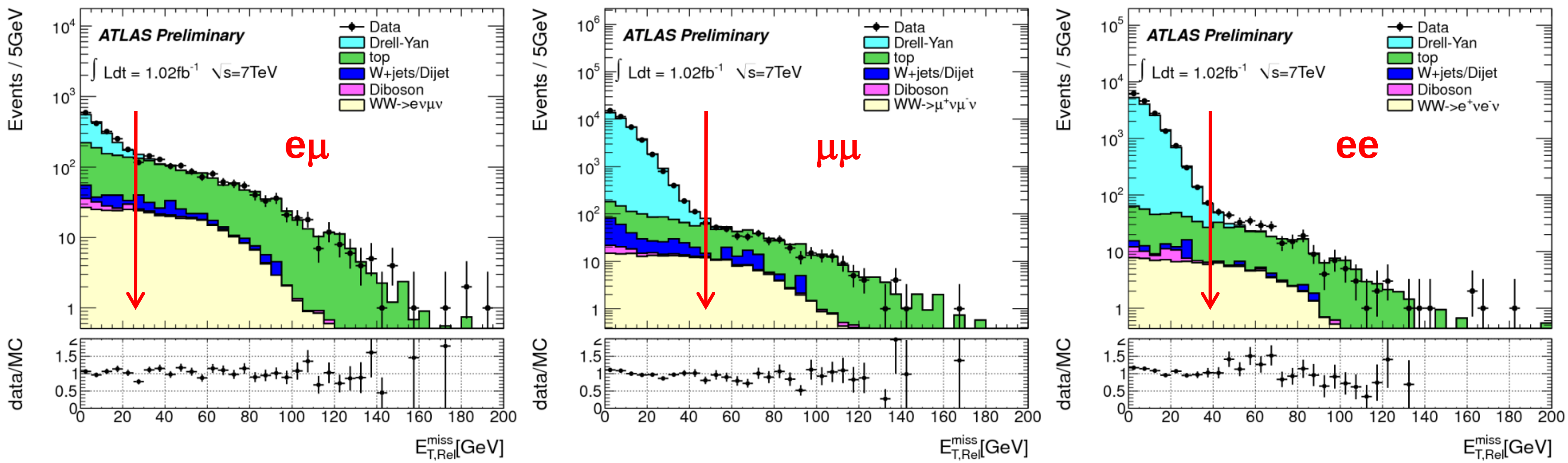
❖ **Further remove Drell-Yan and Wjets/QCD:**

- MET^{Rel} > 25 GeV (for eμ)
- MET^{Rel} > 45 GeV (for μμ)
- MET^{Rel} > 40 GeV (for ee)

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

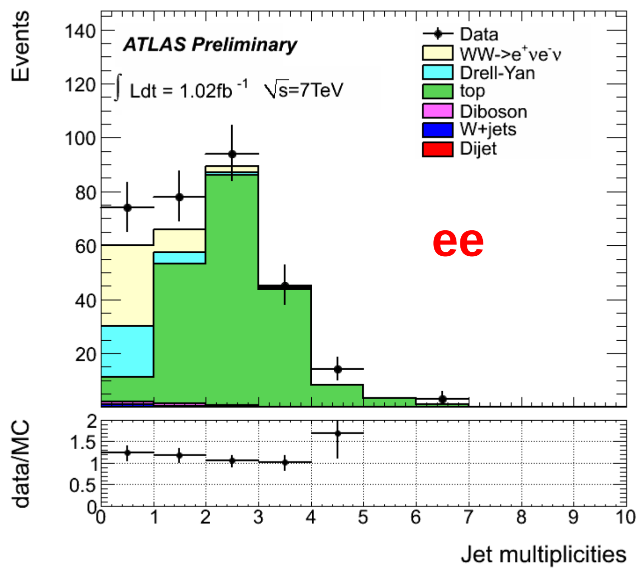


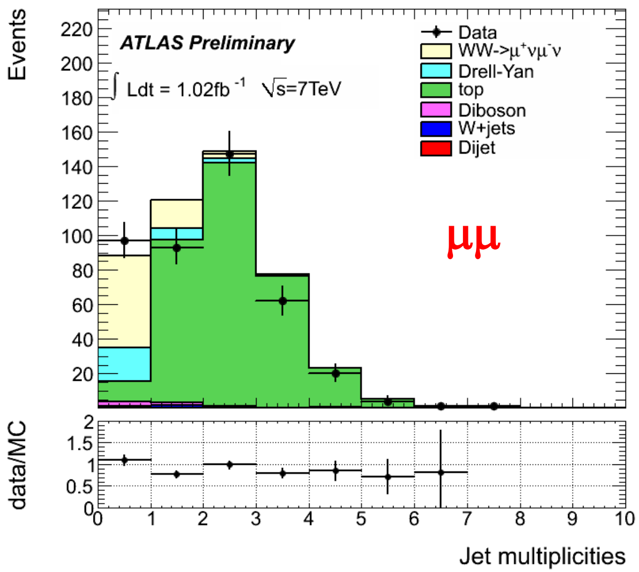
MET^{Rel} distributions after Z mass veto cut

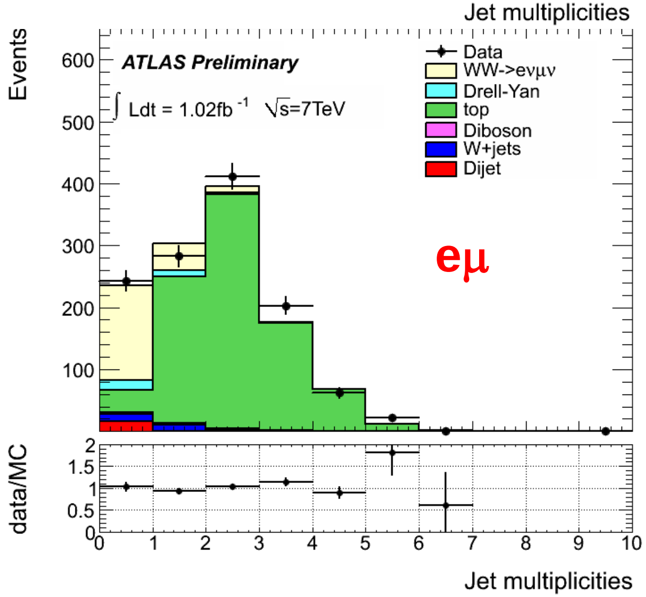


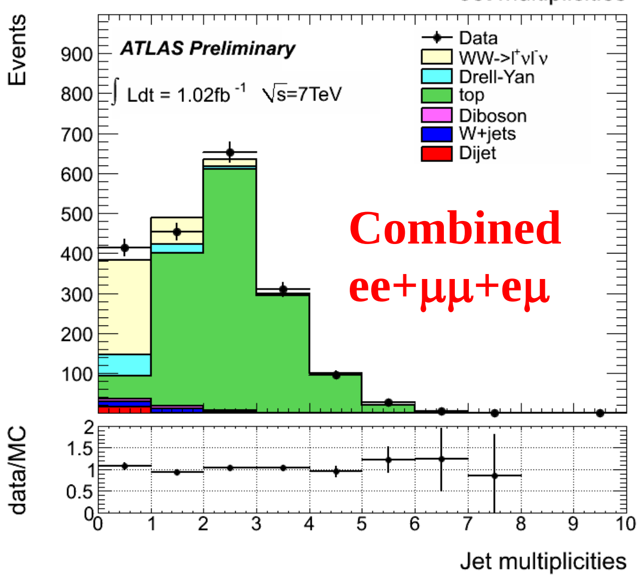
Jet Veto to Remove Top Background

no jet with E_T > 30 GeV and |η| < 4.5





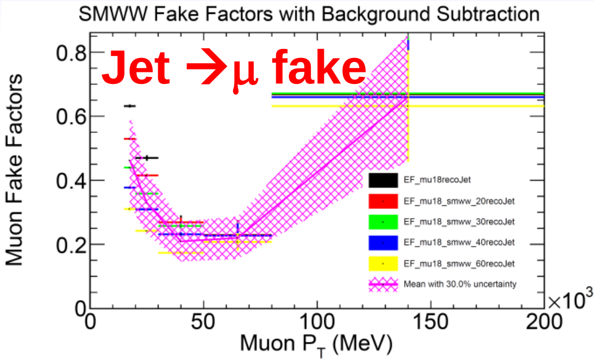




W+Jets Background Estimation

- **Data driven method to estimate W + Jets**
  - Define a fake factor f :

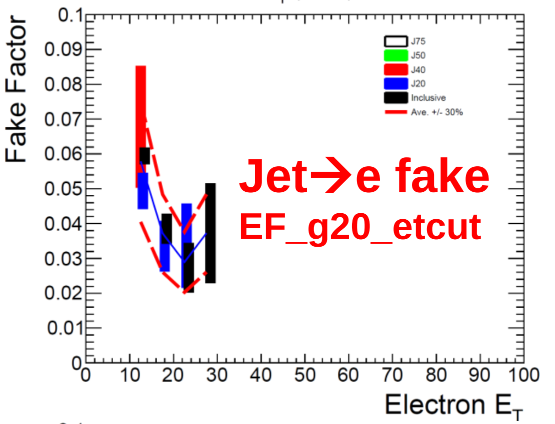
$$f_l \equiv \frac{N_{\text{lepton ID}}}{N_{\text{Jet-Rich ID}}} \longrightarrow \text{using di-jet samples in data}$$



  - W+jet background contributes to WW selection:

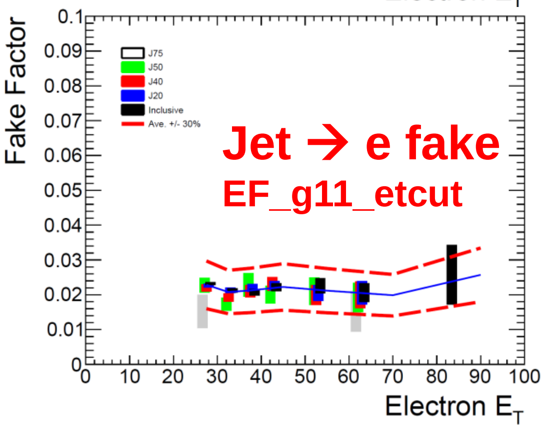
$$N_{W\text{+jet Bkg}} = f_l \times N_{\text{lepton ID + Jet-Rich ID}}$$

$$N^{e\mu\text{-ch}}_{W\text{+jet Bkg}} = f_e \times N_{\mu \text{ ID + Jet-Rich e}} + f_\mu \times N_{\text{elec. ID + Jet-Rich } \mu}$$



- Checked with an independent data driven matrix method

Channel	Estimated W+jets background from Data
ee-channel	5.3±0.4(stat)±1.7(syst)
$e\mu$-channel (e fake)	8.1±0.5(stat)±2.9(syst)
Sum of e fake background	13.4±0.6(stat)±4.6(syst)
$\mu\mu$-channel	12.4±2.9(stat)±5.2(syst)
$e\ \mu$-channel (μ fake)	24.7±3.8(stat)±8.7(syst)
Sum of μ fake background	37.1±4.8(stat)±14.0(syst)
Sum of $e\mu$-channel	32.9±3.8(stat)±9.2(syst)
$ee+\mu\mu+e\mu$-channel	50.5±4.8(stat)±14.7(syst)



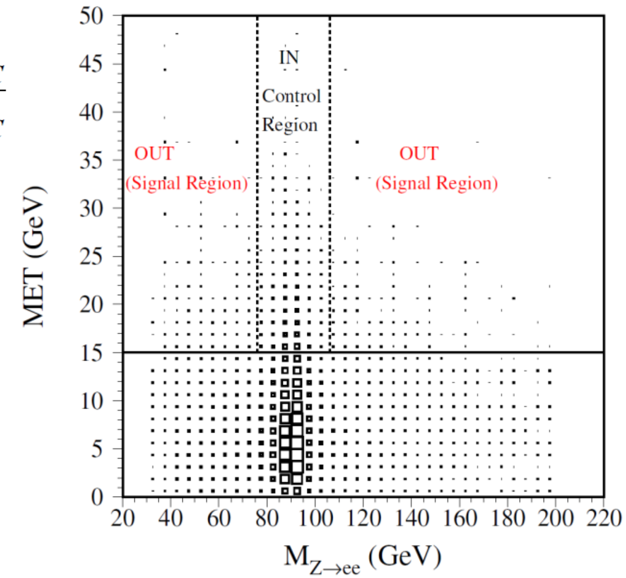
Drell-Yan Background Estimation

- **Data-Driven Method (DDM):**

$$N_{DY}^{out}(estimated) = N_{DY\,DATA}^{in} \times R_{out/in}; \quad here \quad R_{out/in} = \frac{N_{DY\,MC}^{out}}{N_{DY\,MC}^{in}}$$

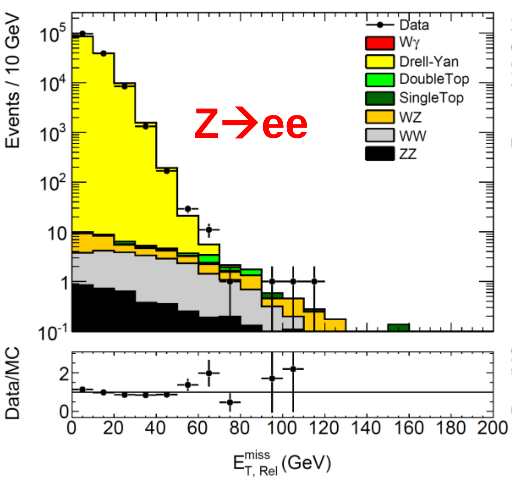
- **MC closure test:** good agreement between input and estimated DY background has been observed

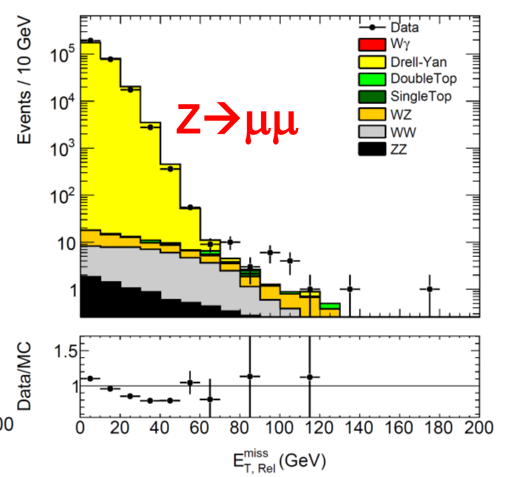
	ee	μμ	eμ
MC	18.7±1.9±1.9	19.2±1.7±2.1	16.0±2.8±1.7
DDM	18.2±3.4	20.1 ± 3.6	-



- Drell-Yan is estimated from Alpgen MC prediction. Systematic uncertainty (~10.4%) is determined by comparing MET^{rel} distributions from Data and MC using Z control sample

$$S(E_{T,\,Rel}^{miss}cut) = \frac{N_{MC}(E_{T,\,Rel}^{miss}cut) - N_{data}(E_{T,\,Rel}^{miss}cut)}{N_{DY}(E_{T,\,Rel}^{miss}cut)}$$

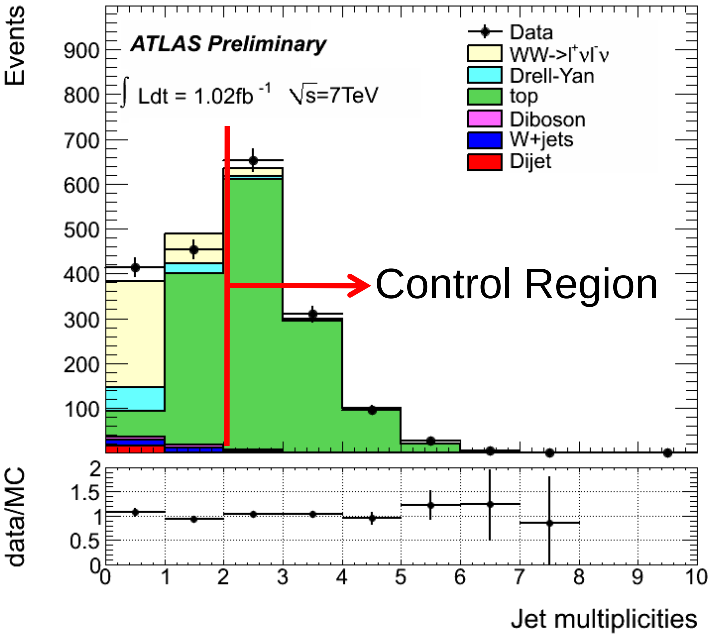




Top Background Estimation

- Top background is estimated using a ***semi-data-driven method***:
  - $N_{jet} \geq 2$: Control region is dominated by Top background
  - Assuming fraction of Top events with $N_{jet} = 0$ and $N_{jet} \geq 2$ are similar in MC and data
  - Advantage: uncertainties on luminosity and the top cross sections are cancelled out in the MC ratio

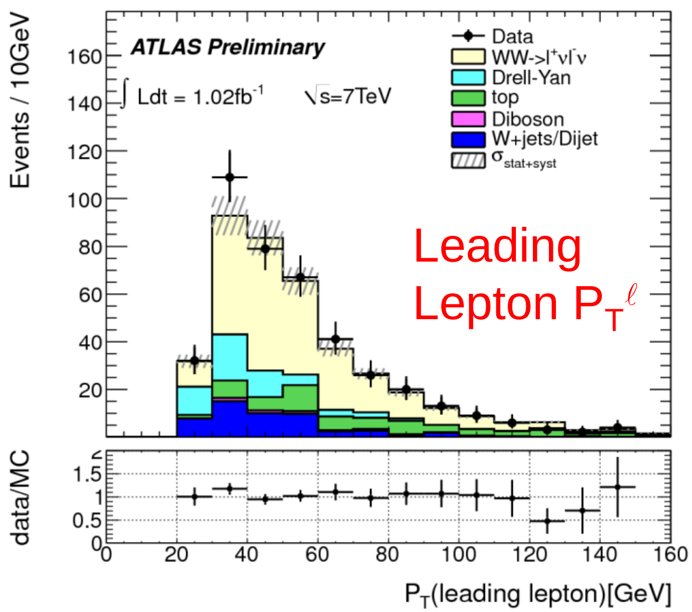
$$N_{\text{Top}}^{\text{Estimated}}(N_{\text{jet}} = 0) = N_{\text{Top}}^{\text{MC}}(N_{\text{jet}} = 0) \times \frac{N_{\text{data}}(\text{control region})}{N_{\text{Top}}^{\text{MC}}(\text{control region})}$$

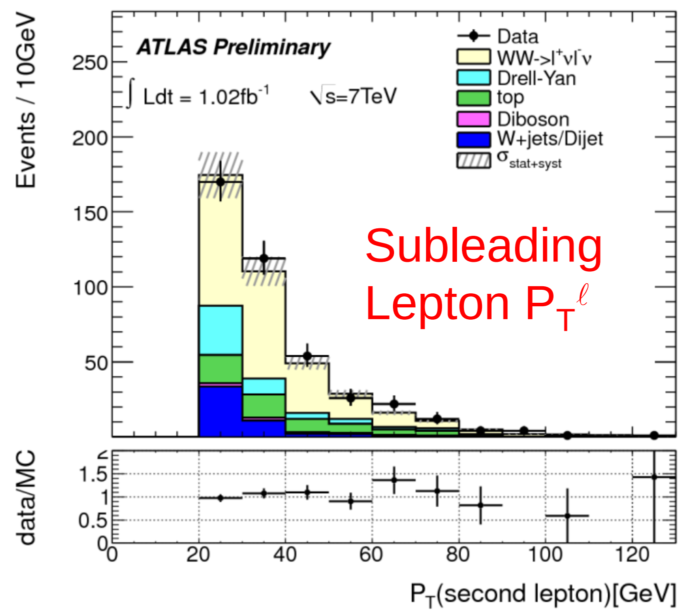


- Estimated Top in signal region (N_{jet}=0)
  - 58.6±2.1 (stat)±22.3 (syst, from JES)
  - Cross-checked with b-tagged Top control sample to estimate Top background
- MC Expectation: 56.7

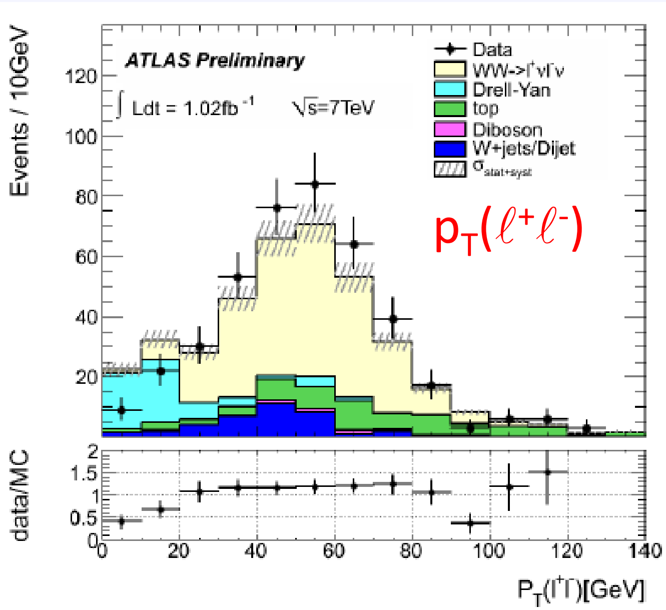
WW Selected Events (1.02 fb^{-1})

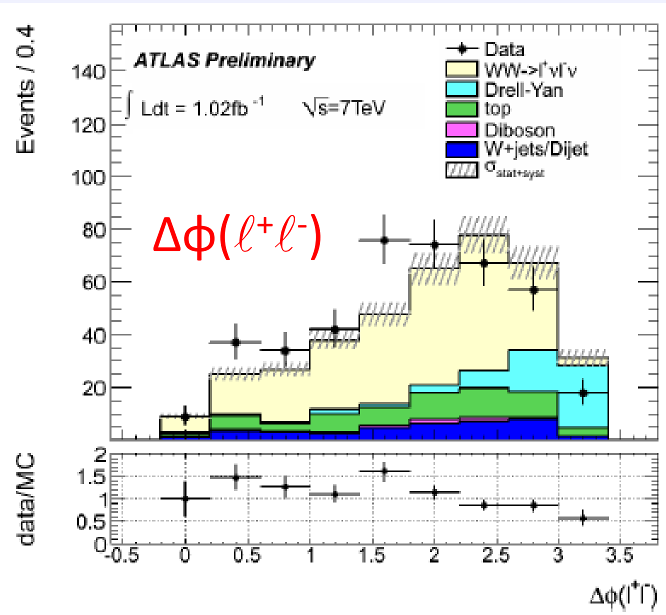
Final State	$e^+e^-E_T^{miss}$	$\mu^+\mu^-E_T^{miss}$	$e^\pm\mu^\mp E_T^{miss}$	Combined
Observed Events	74	97	243	414
Background estimations				
Top(data-driven)	9.5±0.3±3.6	12.3 ±0.4±4.7	36.8±1.3±14.0	58.6±2.1±22.3
W+jets (data-driven)	5.3±0.4±1.7	12.4±2.9±5.2	32.9±3.8±9.2	50.5±4.8±14.7
Drell-Yan (MC/data-driven)	18.7±1.9±1.9	19.2±1.7±2.1	16.0±2.8±1.7	54.0±3.7± 4.5
Other dibosons (MC)	0.9±0.1±0.1	2.4±0.2±0.3	3.4±0.3±0.4	6.8±0.4±0.8
Total Background	34.4±2.0±4.4	46.3±3.4±7.3	89.1±4.9±16.8	169.8±6.4±27.1
Expected *WW* Signal	29.5±0.3±3.0	52.5±0.4±4.9	150.5±0.7±13.4	232.4±0.9±21.5
Significance ($S/\sqrt{B}$)	5.0	7.7	15.9	17.8

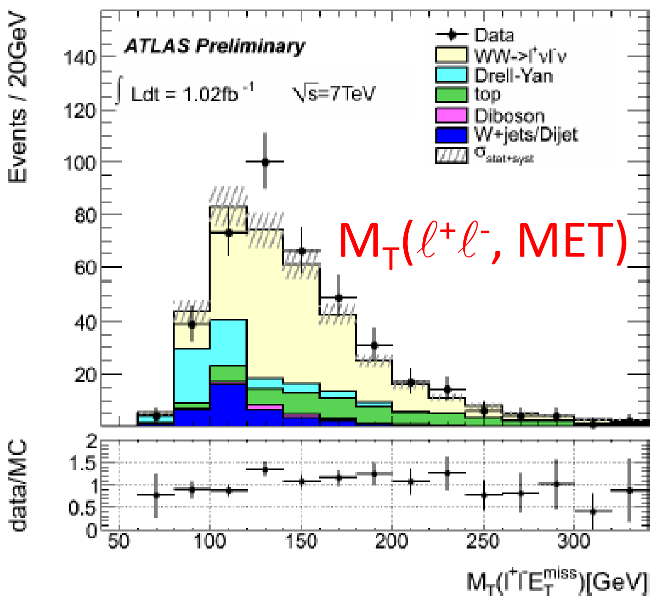


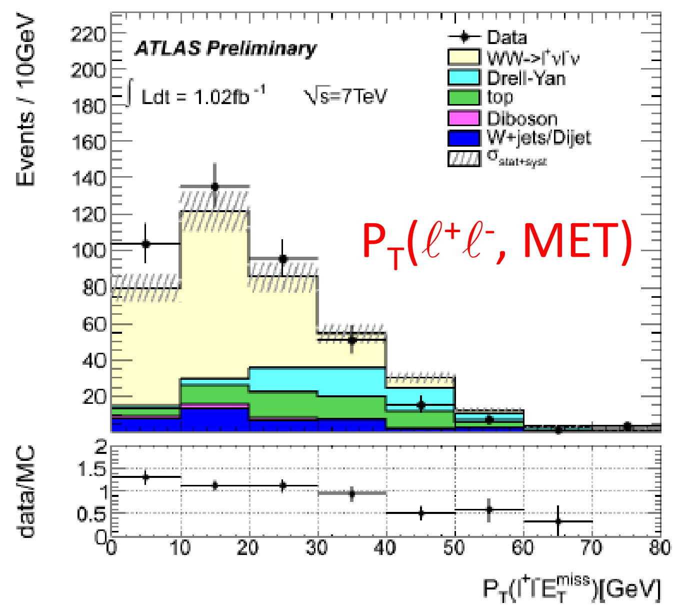


Kinematic Distributions of WW Candidates









Sources of Systematic Uncertainties

Sources	$e^+e^- E_T^{miss}$	$\mu^+\mu^- E_T^{miss}$	$e^\pm\mu^\mp E_T^{miss}$
Luminosity	3.7%	3.7%	3.7%
Cross-section (theory)	5%	5%	5%
PDF	1.2%	1.4%	1.4%
Trigger	1.0%	1.0%	1.0%
Lepton p_T smearing	0.2%	0.1%	0.1%
Reco eff. scale factors	1.4%	0.0%	0.7%
E_T/p_T scale correction	0.9%	0.0%	0.4%
Particle ID eff. scale factors	3.3%	1.4%	1.6%
Isolation	4.0%	2.0%	3.0%
E_T^{miss} in-time contribution	3.5%	3.9%	1.4%
E_T^{miss} out-of-time contribution	0.5%	0.5%	0.3%
Jet-veto	4.8%	4.8%	4.8%
Total experimental uncertainty	8.1%	6.7%	6.2%
Overall uncertainty for WW signal estimation	10.3%	9.2%	8.9%

Lepton recon. Eff E/P scale / smearing (Lepton p_T smearing, Reco eff. scale factors, E_T/p_T scale correction)

Lepton ID and Isolation Eff. (Particle ID eff. scale factors, Isolation)

Missing Transverse Energy uncertainty (E_T^{miss} in-time and out-of-time contributions)

Dominant Syst. Uncertainties

WW Fiducial Phase Space

- Measure "fiducial" cross section to minimize the dependence on theoretical prediction. The WW fiducial phase space requirements:

- muon cuts: $p_T > 20$ GeV, $|\eta| < 2.4$
- electron cuts: $p_T > 20$ GeV, $|\eta| < 1.37$ or $1.52 < |\eta| < 2.47$
  - leading electron in ee channel and electron in $e\mu$ channel: $p_T > 25$ GeV
- jet cuts: $p_T > 30$ GeV, $|y| < 4.5$, $\Delta R(e,\text{jet}) > 0.3$
- event cuts:
  - $\mu\mu$ channel: $p_{T,\text{Rel}}^{\nu+\bar{\nu}} > 45$ GeV, $m_{\mu\mu} > 15$ GeV and $|m_{\mu\mu} - m_Z| > 15$ GeV
  - ee channel: $p_{T,\text{Rel}}^{\nu+\bar{\nu}} > 40$ GeV, $m_{ee} > 15$ GeV and $|m_{ee} - m_Z| > 15$ GeV
  - $e\mu$ channel: $p_{T,\text{Rel}}^{\nu+\bar{\nu}} > 25$ GeV, $m_{e\mu} > 10$ GeV

$$A_{WW} = \frac{N_{MC}^{fiducial}}{N_{MC}^{total}}$$

$$C_{WW} = \frac{N_{MC}^{selected}}{N_{MC}^{fiducial}}$$

$$\varepsilon_{WW} = A_{WW} \times C_{WW}$$

Channels	$A_{WW} \times C_{WW}$	A_{WW}	C_{WW}
$e\nu e\nu$	$0.039 \pm 0.001 \pm 0.004$	$0.090 \pm 0.001 \pm 0.007$	$0.432 \pm 0.006 \pm 0.035$
$\mu\nu\mu\nu$	$0.069 \pm 0.001 \pm 0.006$	$0.086 \pm 0.001 \pm 0.005$	$0.802 \pm 0.006 \pm 0.066$
$e\nu\mu\nu$	$0.100 \pm 0.001 \pm 0.008$	$0.167 \pm 0.001 \pm 0.011$	$0.596 \pm 0.005 \pm 0.040$

Stat. error

Syst. error

WW Fiducial Cross Section

- The WW fiducial phase space acceptance A_{WW} and correction factor C_{WW}
  - Systematic uncertainties of A_{WW} include
    - PDF uncertainty (~1.2% - 1.4%)
    - Renormalization and factorization scales uncertainty (~1.5% – 5.3%)
    - Parton shower/fragmentation modeling uncertainty (~4.8%)
  - Systematic uncertainties of C_{WW} include (slide p17)
    - Uncertainty associated with jet veto cut is replaced by JES uncertainty (~4.5%)
    - Renormalization and factorization scales uncertainty (~2.0%)

- The measured WW fiducial cross sections in three dilepton channels.

$$L(\sigma_{WW}^{i,fid}) = \ln \frac{e^{-(N_s^i+N_b^i)} \times (N_s^i + N_b^i)^{N_{obs}^i}}{N_{obs}^i!}, \; N_s^i = \sigma_{WW\to\ell\nu\ell\nu}^i \times \mathscr{L} \times C_{WW}^i$$

Channels	expected σ^{fid} (fb)	measured σ^{fid}(fb)	$\Delta\sigma_{stat}$(fb)	$\Delta\sigma_{syst}$(fb)	$\Delta\sigma_{lumi}$(fb)
$e\nu e\nu$	66.8	90.1	$\pm$ 18.9	$\pm$ 11.3	$\pm$ 3.3
$\mu\nu\mu\nu$	63.8	62.0	$\pm$ 12.1	$\pm$ 10.7	$\pm$ 2.3
$e\nu\mu\nu$	245.1	252.0	$\pm$ 24.6	$\pm$ 29.4	$\pm$ 9.3

WW Production Cross Section

- The total WW production cross section is determined from three dilepton channels (e^+e^-, $\mu^+\mu^-$, $e\mu$ + E_T^{miss}) by maximizing the log-likelihood function using 1.02 fb^{-1} data.

$$L(\sigma_{WW}^{tot}) = \ln \prod_{i=1}^{3} \frac{e^{-(N_s^i+N_b^i)} \times (N_s^i + N_b^i)^{N_{obs}^i}}{N_{obs}^i!}, \quad N_s^i = \sigma_{WW}^{tot} \times Br^i \times \mathcal{L} \times \varepsilon_{WW}^i$$

Channels	Total cross-section (pb)	$\Delta\sigma_{stat}$(pb)	$\Delta\sigma_{syst}$(pb)	$\Delta\sigma_{lumi}$(pb)
$e\nu e\nu$	62.1	$\pm$ 13.5	$\pm$ 9.1	$\pm$ 2.3
$\mu\nu\mu\nu$	44.7	$\pm$ 8.7	$\pm$ 7.7	$\pm$ 1.7
$e\nu\mu\nu$	47.3	$\pm$ 4.8	$\pm$ 6.2	$\pm$ 1.8
Combined	48.2	$\pm$ 4.0	$\pm$ 6.4	$\pm$ 1.8

- **Fitted σ_{WW} = 48.2 $\pm$ 4.0 (stat) $\pm$ 6.4 (syst) $\pm$ 1.8 (lumi) pb**
  - Dominated by systematic uncertainties, mainly come from uncertainties of data driven background estimations
- **NLO SM prediction: σ_{WW} (SM) = 46 $\pm$3 (theory) pb**

https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/CONFNOTES/ATLAS-CONF-2011-110/

Summary

- The WW production cross section and fiducial cross section are measured using three dilepton channels (e^+e^-, $\mu^+\mu^-$, $e\mu$ + E_T^{miss}).
- Total integrated luminosity of 1.02 fb^{-1} data collected by the ATLAS detector in 2011 are used for this analysis. 414 WW candidates are observed, 232 WW signal and 170 backgrounds events are expected.
- The measured WW cross section is consistent with NLO SM prediction (46 ± 3 pb):

σ_{WW} = 48.2 ± 4.0 (stat) ± 6.4 (syst) ± 1.8 (lumi) pb

- We expect to extract limits on anomalous TGC (WWγ, WWZ) based on 1.02 fb^{-1} data soon.

Backup Slides

WW → $\ell\nu\ell\nu$ Signal Acceptance

Cuts	ee Channel		$\mu\mu$ Channel		$e\mu$ Channel	
	$e\nu e\nu$	$\tau\nu\ell\nu$	$\mu\nu\mu\nu$	$\tau\nu\ell\nu$	$e\nu\mu\nu$	$\tau\nu\ell\nu$
Total Events	552.3	211.4	552.3	211.4	1104.5	423.1
2 leptons (SS+OS)	116.6	11.8	229.0	25.5	332.7	35.5
2 leptons (OS)	115.7	11.6	229.0	25.5	331.3	35.3
leading electron Pt > 25GeV	114.4	11.4	-	-	305.5	30.2
trigger matching	114.2	11.4	231.9	25.8	305.3	30.2
$M_{\ell\ell} > 15$ GeV, $M_{e\mu} > 10$ GeV	113.5	11.3	229.7	25.6	304.5	30.1
Z mass veto	88.2	8.4	176.6	19.0	-	-
$E_{\mathrm{T,\ Rel}}^{\mathrm{miss}}$ cut	38.6	2.9	69.7	5.2	193.2	16.1
Jet veto (Num of Jet=0)	27.8	1.7	49.4	3.1	139.6	10.9
W^+W^- Acceptance	5.0%	0.8%	8.9%	1.5%	12.6%	2.6%

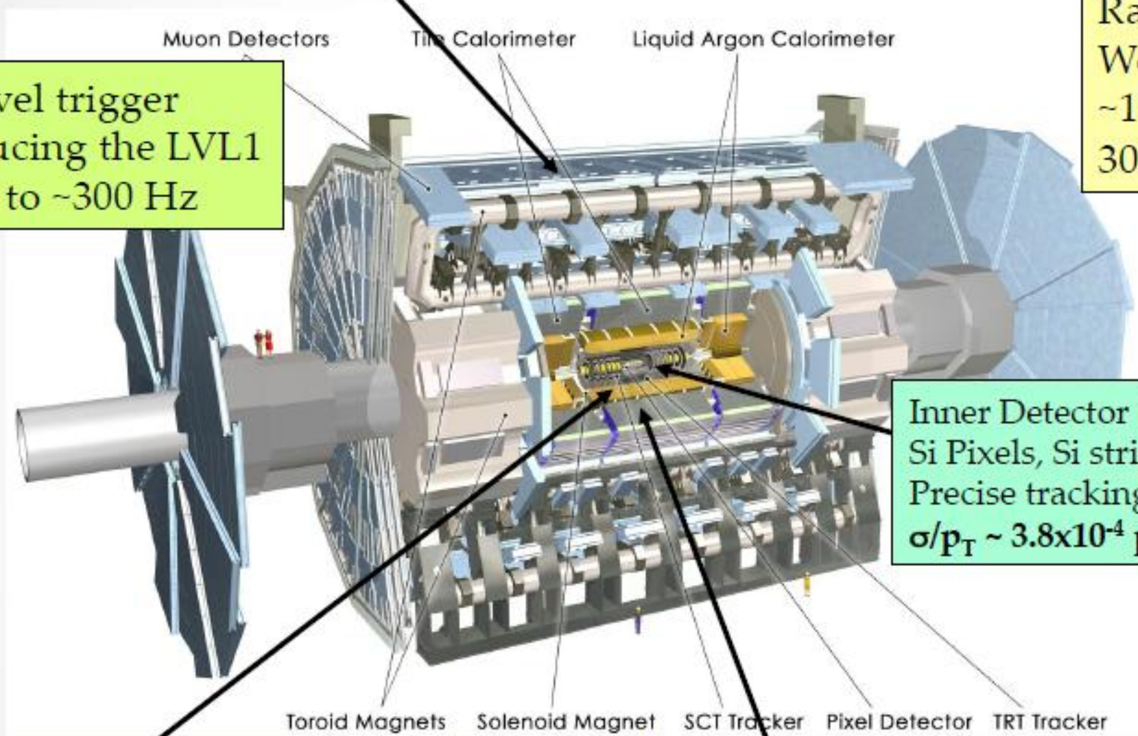
- The numbers are normalized to the data integrated luminosity of 1.02 fb^{-1} using the SM W^+W^- cross sections.
- MC efficiency correction factors ($\varepsilon_{data}/\varepsilon_{MC}$) have been applied.

ATLAS Detector

Muon Spectrometer ($|\eta|<2.7$) : air-core toroids with gas-based muon chambers
Muon trigger and measurement with momentum resolution **< 10% up to E_μ ~ 1 TeV**

Length : ~ 46 m
Radius : ~ 12 m
Weight : ~ 7000 tons
~10^8 electronic channels
3000 km of cables

3-level trigger reducing the LVL1 rate to ~300 Hz

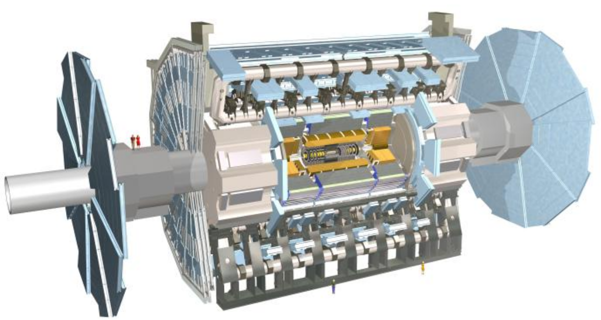


Inner Detector ($|\eta|<2.5$, B=2T):
Si Pixels, Si strips, TRT
Precise tracking and vertexing,
σ/p_T ~ 3.8×10^{-4} p_T (GeV) $\oplus$ 0.015

EM calorimeter: Pb-LAr Accordion
e/γ trigger, identification and measurement
E-resolution: σ/E ~ $10\%/\sqrt{E} \oplus 0.007$
High granularity

Hadron calorimetry ($|\eta|<4.9$)
Fe/scintillator Tiles (central), Cu-LAr (endcap)
E-resolution: **σ/E ~ $50\%/\sqrt{E} \oplus 0.03$**
FWD calorimetry:Cu/W-LAr **σ/E ~ $90\%/\sqrt{E} \oplus 0.07$**

Data, Trigger, Physics Objects



GRL (35.2 pb^{-1})

Trigger:

Single e with E_T > 15 GeV
Single m with p_T > 13 GeV
Efficiency plateau $E_T(p_T)$ > 20 GeV
Dilepton ε(data)/ε(MC) = 1.0 (σ_{syst} < 0.1%)

Primary vertex:

Vertex with max. sum track p_T^2
N_{track} > = 3 (with p_T > 150 MeV)
Two leptons from primary vertex
MC pile-up reweighted to reproduce data

'RobusterTight' electron

E_T > 20 GeV; $|\eta|$ < 2.5, (remove [1.37--1.52])
Isolation: Sum $E_T^i{}_{Cone=0.3}$ < 6 GeV
d0/σd0 < 10; |z0| < 10 mm
ε(data)/ε(MC) = 0.97 (with σ_{syst} ~ 5.3%)

'Combined' Muon:

p_T > 20 GeV; $|\eta|$ < 2.4
p_T^{MS} > 10 GeV; | (p_T^{MS} – p_T^{ID})/ p_T^{ID} | < 0.5
Isolation: (Sum $p_T^i{}_{Cone=0.2}$)/ p_T^{μ}< 0.1
d0/σd0 < 10; |z0| < 10 mm
ε(data)/ε(MC) = 0.98 (with σ_{syst} ~ 1.0%)

Jet:

Anti-Kt, R = 0.4; $|\eta|$ < 3.0; p_T > 20 GeV
Discarded if ΔR (jet, electron) < 0.2
Jet veto SF = 0.97 (with σ_{syst} ~ 6.0%)

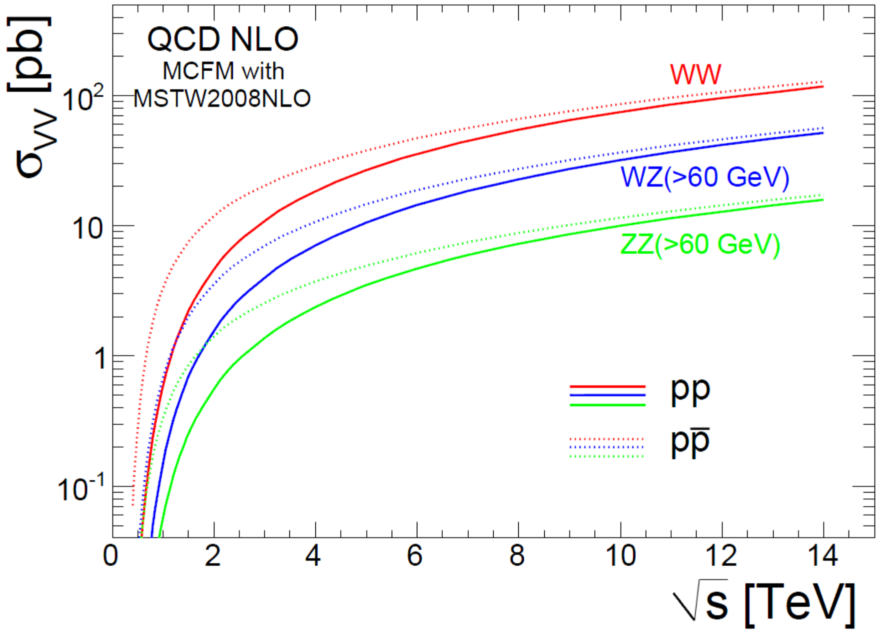
E_T^{miss}:

MET_LocHadTopo ($|\eta|$<4.5), account for μ's

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

Diboson Production Cross Sections

SM cross section	Tevatron (ppbar,1.96 TeV, pb)	LHC (pp,7TeV, pb)	LHC (pp,14 TeV, pb)
WW	12.4	44.9	111.6
WZ	3.7	18.5	47.8
ZZ	1.4	6.0	14.8
Wγ	19.3*	69.0#	120.1#
Zγ	4.7*	13.8#	28.8#



(*) $E_T^\gamma > 7$ GeV and $\Delta R(\ell,\gamma) > 0.7$, for W/Z e/μ decay channels only

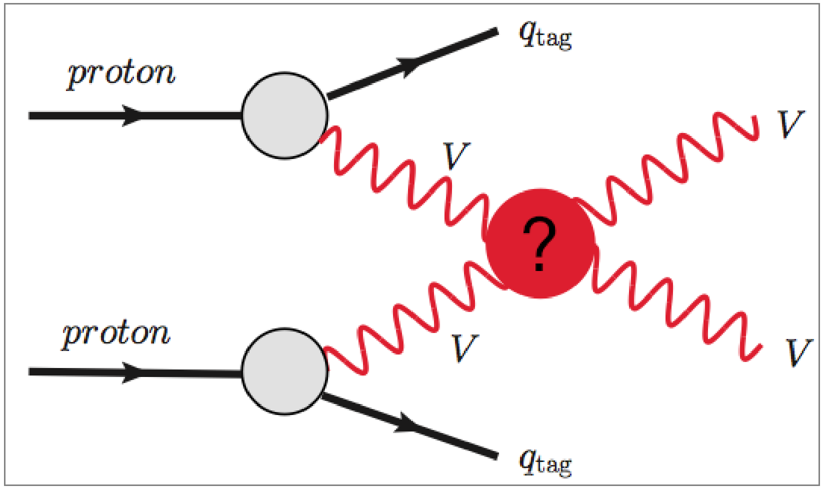
(#) $E_T^\gamma > 10$ GeV and $\Delta R(\ell,\gamma) > 0.7$, for W/Z e/μ decay channels only

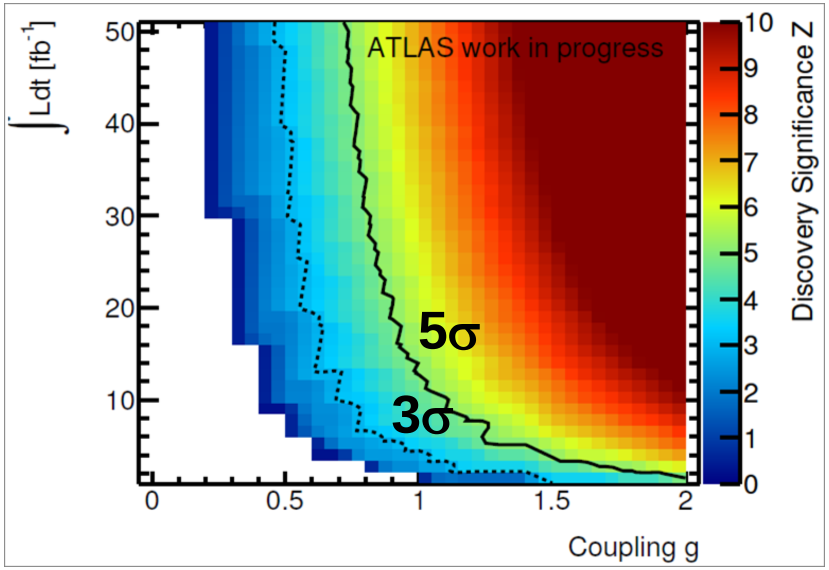
➔ Diboson production rates at LHC (7 TeV) are ~3-5 times of Tevatron

➔ $\sqrt{s}$ at LHC is higher than Tevatron (3.5x-7x) which greatly enhances the detection sensitivity to anomalous triple-gauge-boson couplings

Generic Search for New Particles with Diboson through VBF Process

- Vector-Boson Fusion (VBF) Process: $qq \rightarrow q_{tag} q_{tag} V V$ (V = W, Z)
  - Two vector bosons with two tagged jets in F/B regions
  - Production rate ~ 2.5% of $qq \rightarrow WW$ (WHIZARD, PDF MRST2004)
- An example of ATLAS sensitivity to a 850 GeV spin-zero resonance produced in VBF process (at 14 TeV).





Search for new physics through Anomalous TGCs with Diboson Events

- Effective Lagrangian with charged/neutral triple-gauge-boson interactions

$$L/g_{WWV} = ig_1^V(W_{\mu\nu}^* W^\mu V^\nu - W_{\mu\nu} W^{*\mu} V^\nu) + ik^V W_\mu^* W_\nu V^{\mu\nu} + \frac{i\lambda^V}{M_W^2} W_{\rho\mu}^* W_\nu^\mu V^{\nu\rho}$$

$$L = -\frac{e}{M_Z^2}[f_4^V(\partial_\mu V^{\mu\beta})Z_\alpha(\partial^\alpha Z_\beta) + f_5^V(\partial^\sigma V_{\sigma\mu})\tilde{Z}^{\mu\beta} Z_\beta]$$

- The anomalous parameters: Δg_1^Z, $\Delta\kappa_Z$, λ_Z, $\Delta\kappa_\gamma$, λ_γ , f_4^Z, f_5^Z, f_4^γ, f_5^γ , h_3^Z, h_4^Z, h_3^γ, h_4^γ

- Complementary studies through different Diboson channels ($\hat{s} = M^2_{VV}$)

Production	$\Delta\kappa_Z$, $\Delta\kappa_\gamma$ term	Δg_1^Z term	λ_Z, λ_γ term
WW	**grow as $\hat{s}$**	**grow as $\hat{s}^{1/2}$**	**grow as $\hat{s}$**
WZ	grow as $\hat{s}^{1/2}$	grow as $\hat{s}$	grow as $\hat{s}$
Wγ	grow as $\hat{s}^{1/2}$	---	grow as $\hat{s}$

Limits on Anomalous Couplings

	λ_Z	$\Delta\kappa_Z$	Δg_1^Z	$\Delta\kappa_\gamma$	λ_γ
WW (D0, $1.1fb^{-1}$)	$\lambda_Z = \lambda_\gamma$	$\Delta\kappa_Z = \Delta\kappa_\gamma$	[-0.14, 0.30]	[-0.54, 0.83]	[-0.14, 0.18]
WW (LEP)	$\lambda_Z = \lambda_\gamma$	$\Delta\kappa_Z = \Delta g_1^Z - \Delta\kappa_\gamma \tan^2\theta_W$	[-0.051,0.034]	[-0.105,0.069]	[-0.059,0.026]
WZ (D0, $4.1fb^{-1}$)	[-0.075,0.093]	[-0.376,0.686]	[-0.053,0.156]		
WZ (CDF, $1.9fb^{-1}$)	[-0.14,0.15]	[-0.81,1.29]	[-0.14,0.25]		
$W\gamma$ (D0, 0.7 fb^{-1})				[-0.51,0.51]	[-0.12,0.13]

Λ = 1.2 TeV	f_4^Z	f_5^Z	f_4^γ	f_5^γ
ZZ (CDF, $1.9fb^{-1}$)	[-0.12,0.12]	[-0.13,0.12]	[-0.10,0.10]	[-0.11,0.11]
ZZ (D0, $1.1fb^{-1}$)	[-0.28,0.28]	[-0.31,0.29]	[-0.26,0.26]	[-0.30,0.28]
ZZ (LEP combined)	[-0.30,0.30]	[-0.34,0.38]	[-0.17,0.19]	[-0.32,0.36]

Λ = 1.5 TeV	h_3^Z	h_4^Z	h_3^γ	h_4^γ
$Z\gamma$ (CDF, $5.0fb^{-1}$)	[-0.017,0.0167]	[-0.0006,0.0005]	[-0.017,0.016]	[-0.0006,0.0006]
$Z\gamma$ (D0, $3.6fb^{-1}$)	[-0.033,0.033]	[-0.0017,0.0017]	[-0.033,0.033]	[-0.0017,0.0017]
$Z\gamma$ (LEP combined)	[-0.30,0.30]	[-0.34,0.38]	[-0.17,0.19]	[-0.32,0.36]