Measurement of W^+W^- production in Proton-Proton Collisions at $\sqrt{s} = 7$ TeV with the ATLAS Detector at LHC

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Jan 3^{rd}, 2013

Outline

1. Introduction
    - The Standard Model Electroweak interactions and diboson productions
    - The Large Hadron Collider and the ATLAS Detector

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   - WW group efforts and mile-stones in ATLAS
   - Personal Statement

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Standard Model diboson productions

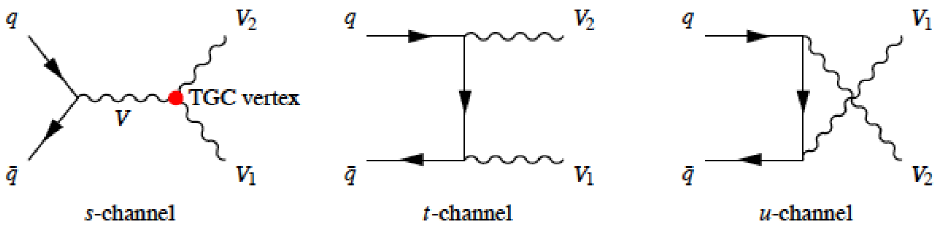


Figure: Generic SM tree-level Feynman diagrams for diboson production with triple-gauge boson couplings(aTGC) (left). V1,V2 = W,Z,γ.

- Specific couplings between gauge bosons which obey a non-Abelian gauge group $SU(2)_L \times U(1)_Y$
- **Physics Motivations:**
  - Stringent test of high energy behavior of the SM electroweak interactions ($W/Z+\gamma$, WW, WZ, ZZ), particularly through the fully leptonic decay final states
  - Probe anomalous triple-gauge boson vertices for model-independent new physics searches
  - Irreducible backgrounds of Higgs to diboson decays (e.g. $H \to ZZ/WW$)

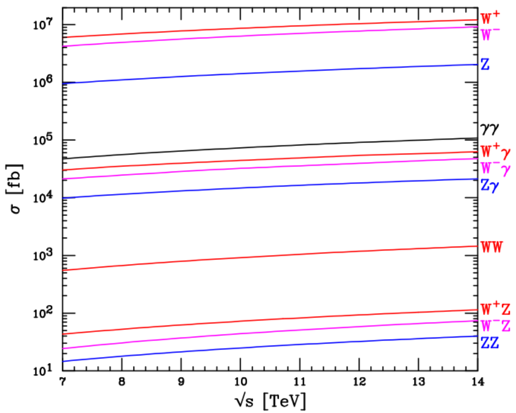
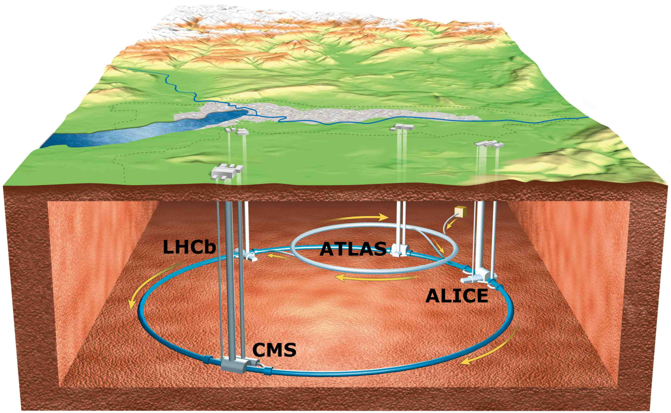


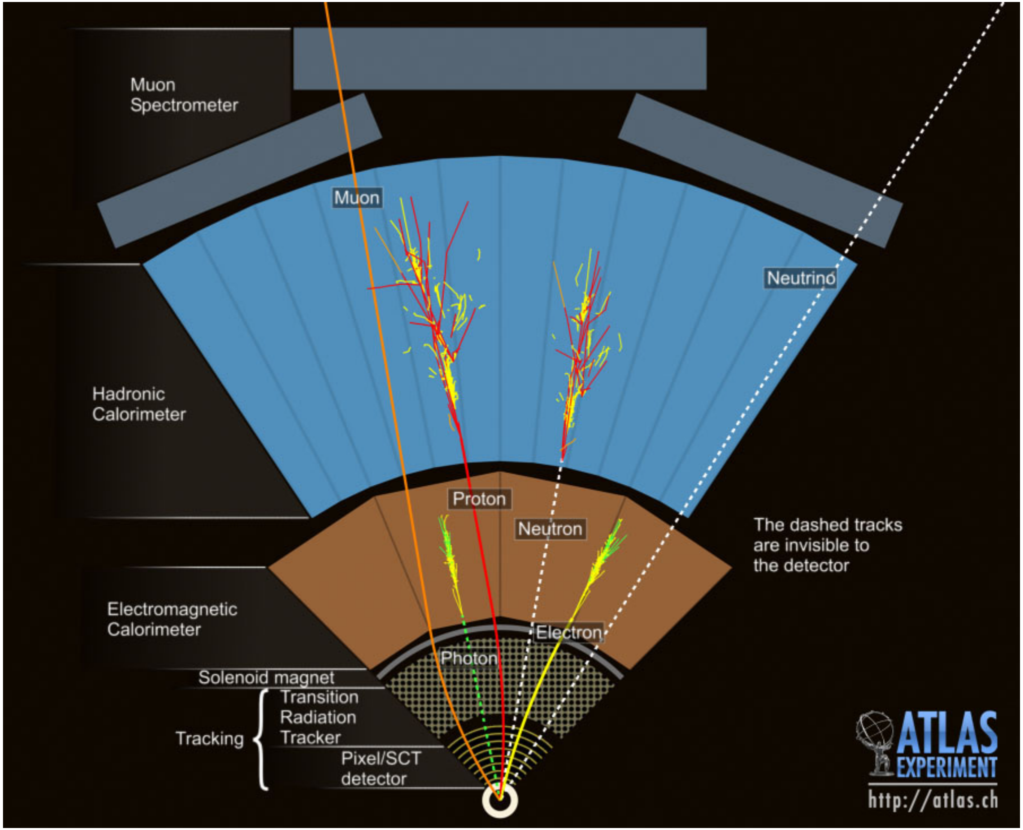
Figure: NLO boson production cross section in pp-collisions with leptonic decays.

The Large Hadron Collider (LHC)

- Worlds largest particle accelerator with the highest center of mass energy at CERN near Geneva, ~27 km tunnel spanning the border of France and Switzerland
- General purpose: New physics and phenomenon searches, particularly Higgs boson (higher production rate at higher center-of-mass energy)
- $\sqrt{s} = 7/8$ TeV (designed energy: 14 TeV) for proton-proton collision and 2.76 TeV for Pb-Pb nuclei collision
- Six major detectors located at four collision points: ALICE, **ATLAS**, CMS, LHCb, LHCf, TOTEM
- Luminosity of ATLAS/CMS: $10^{33} \sim 10^{34}$ cm^{-2}s^{-1} (achieved $> 7 \times 10^{33}$ cm^{-2}s^{-1} in 2012) ALICE: $10^{27} cm^{-2} s^{-1}$ LHCb: $10^{32} cm^{-2} s^{-1}$

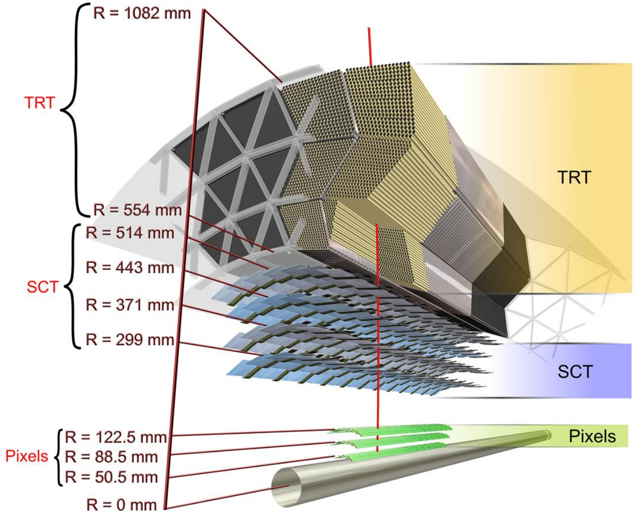


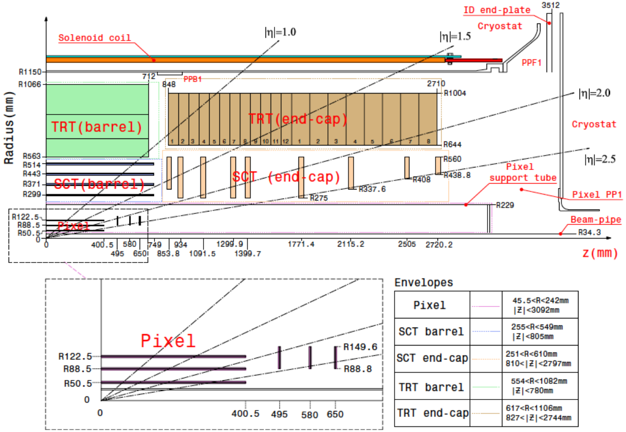
Particle Identification at ATLAS



The Inner Detectors (ID)

- Extemely large inner track density (~1000 particles per 25/50 ns)
- High granularity for the measurement of the track momenta, impact parameters and primary/secondary vertices of charged particles
- $|\eta| < 2.5$ geometry coverage within 2 T solenoid magnet field
- Three compartments:
  Pixel Detector
  Silicon Microstrip Tracker (SCT)
  Transition Radiation Tracker (TRT)
- $\sim 4\%$ momemtum resolution at 40 GeV





The Calorimeters

- Outside the ID and solenoid magnet
- Measure particle energies using the energy deposit via the cascaded electromagnetic (EM) processes (e and γ) and hadronic processes (gluons and quarks reconstructed as "jets")
- Two sampling calorimeters:
  The lead-**LAr** calorimeter
  Tile hadronic barrel calorimeter
- Good pseudorapidity coverage: $|\eta| < 4.9$
  - Good reconstruction of missing transverse energy (E_T^{miss}) (important new physics signature)
- EM depth: $\sim$22(24) X_0 (radiation length) in the barrel (endcaps). Overall 11 λ (interaction length) of active calorimeter, 1.3 λ for outer services (sufficient to suppress the punch-through into the MS)
- Major subdetector where L1 and High Level Trigger originate for electrons, photons, jets and E_T^{miss}

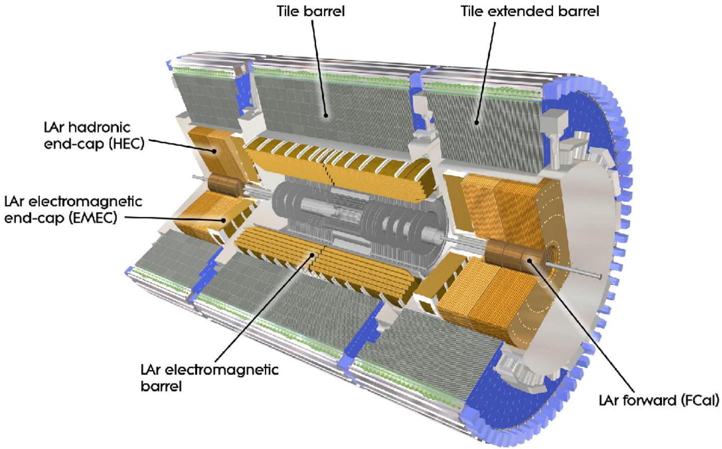
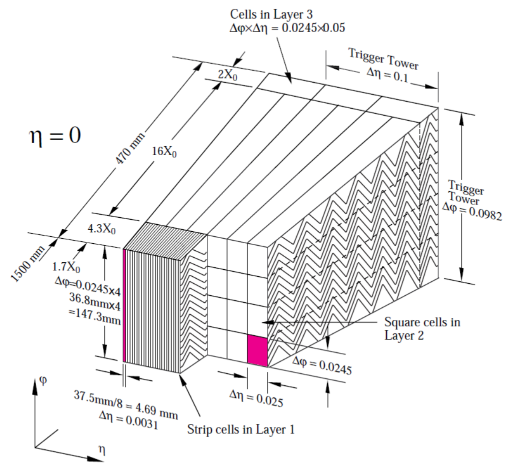
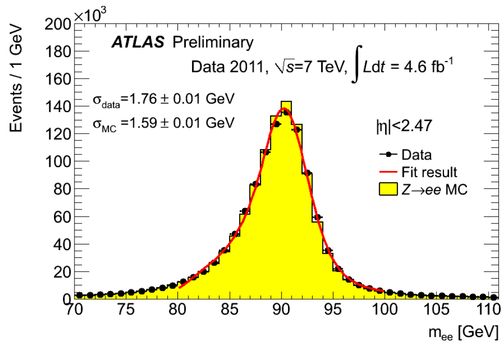


Figure: The ATLAS Calorimeters.

Lead-LAr Calorimeter

- Accordion-shaped kapton electrodes + full-coverage lead absorber plates
- One barrel ($|\eta| < 1.475$) + two end-cap ($1.375 < |\eta| < 3.2$)
- 1-layer presampler ($0 < |\eta| < 1.8$) to compensate energy loss before the EM calo
- Absorber: lead and stainless steel, good containment of EM energy depositions
- Precision measurement region: $0 < |\eta| < 2.5$
- 1^{st} and 2^{nd} layers: the finest segmentation along η, 3^{rd} layer: less segmented to take the residual of the EM showers deposition
- Nominal resolution: $\frac{\sigma_E}{E} = \frac{10\%}{\sqrt{E(GeV)}} \oplus 0.7\%$ over the full coverage, constant term achieved 1.2%∼1.8% (indication of non-uniformity)
- **Electron**/photon trigger





Hadronic Calorimeters

- 3 complementary compartments:
  Tile calorimeter, LAr hadronic end-cap calorimeter (**HEC**) and LAr forward calorimeter (**FCal**)

- **Nominal resolution**:
  $\frac{\sigma_E}{E} = \frac{50\%}{\sqrt{E(GeV)}} \oplus 3\%$ (**Tile** and **HEC**)
  $\frac{\sigma_E}{E} = \frac{100\%}{\sqrt{E(GeV)}} \oplus 10\%$ (**FCal**)

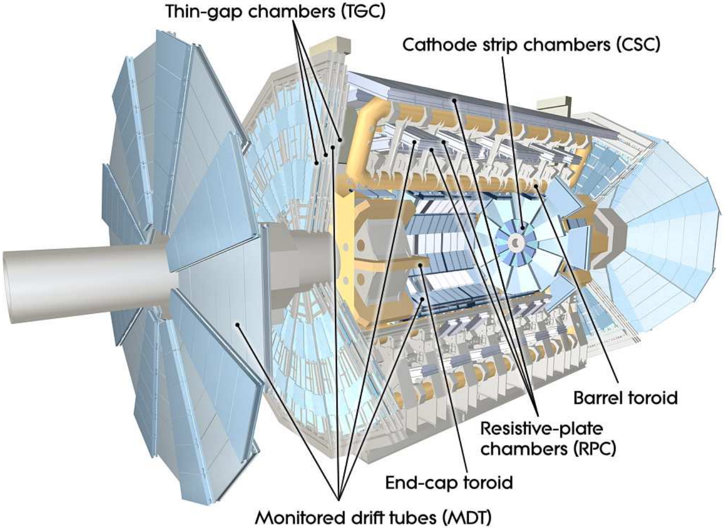
- **Tile calorimeter**
  Absorber: steel; sampling medium: scintillating tiles
  3 layers in the central barrel and the extended barrel

- **HEC**
  Behind EM calo on each side and extend geometry coverage of **Tile** to $|\eta| < 3.2$
  4 layers for each side of the HEC

- **LAr forward calorimeter (FCal)**
  Geometry coverage extension: $3.1 < |\eta| < 4.9$
  guarantee the hermeticity of the detector coverage and suppress background into MS
  depth: $\sim$10 λ

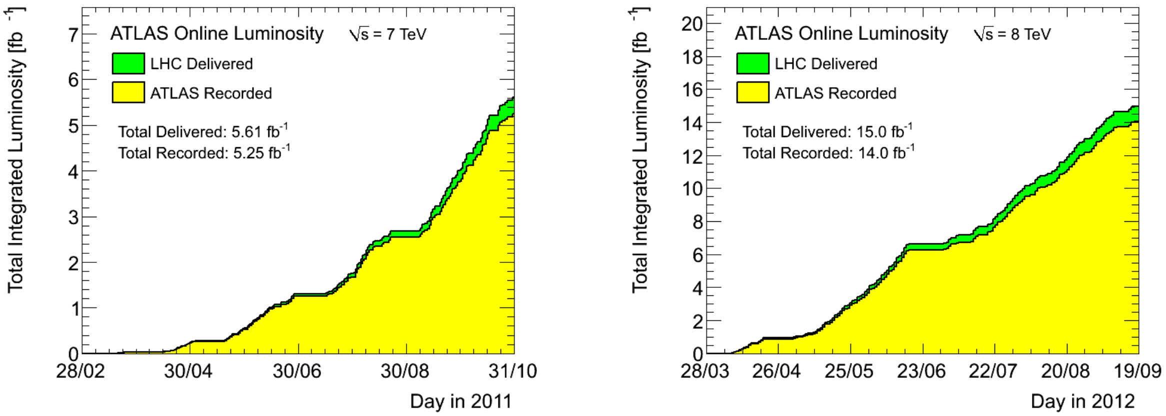
Muon Spectrometer

- Toroid magnet: 1 in the barrel and 2 in the end-caps, η-dependent bending power
- 4 types of chambers:
  Precise Tracking chambers ($|\eta| < 2.7$)
  monitored drift tube (MDT)
  cathode strip chambers (CSC)
  Trigger chambers ($|\eta| < 2.4$)
  resistive plate chambers (RPC)
  thin gap chambers (TGC)
- Reconstruction of the muon trajectories, measure the muon momenta with tracks deflected in the magnetic field
- $\sim 4\%(15\%)$ momentum resolution at 40 GeV (1 TeV)



LHC and ATLAS run summary of 2011/2012

- **2011:** pp collisions at $\sqrt{s} = 7$ TeV, 5.25 fb^{-1} **integrated luminosity** recorded by ATLAS detector, 4.6 fb^{-1} after general data quality constraints, stable beam **peak instaneous luminosity**: $10^{32} \sim 10^{33} cm^{-2}s^{-1}$
- **2012:** $\sqrt{s} = 8$ TeV pp collisions, stable beam **peak instaneous luminosity**: $\sim 7 \times 10^{33} cm^{-2}s^{-1}$

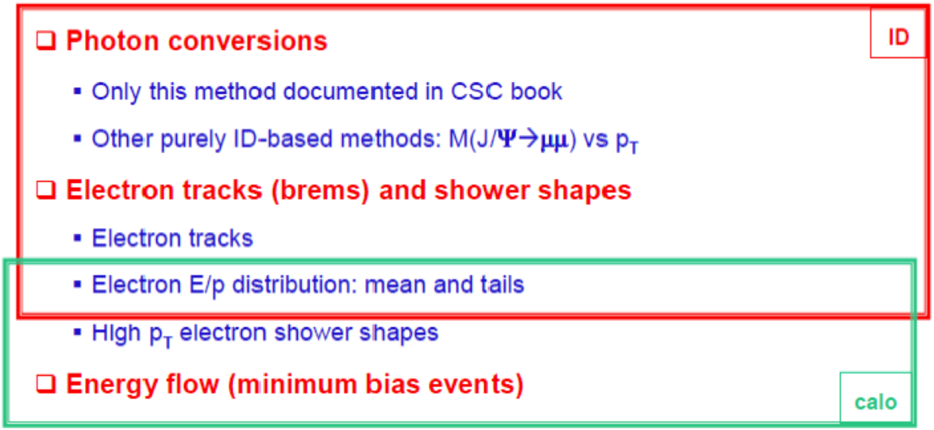


Data quality (DQ)

- ATLAS **data quality** challenged by the performance of each subdetector
- Impact on physics analysis, particularly in new physics searches
- Essential guideline for detector monitoring and warranty of safe and physical analysis results
- Data qualified to have good condition in each subdetector are included in `Good Run List` (**GRL**)
- **LAr defects are crucial in the overall DQ evalution:**
  Data integrity error, Noise Burst, High Voltage Trips, Beam Halo, etc.

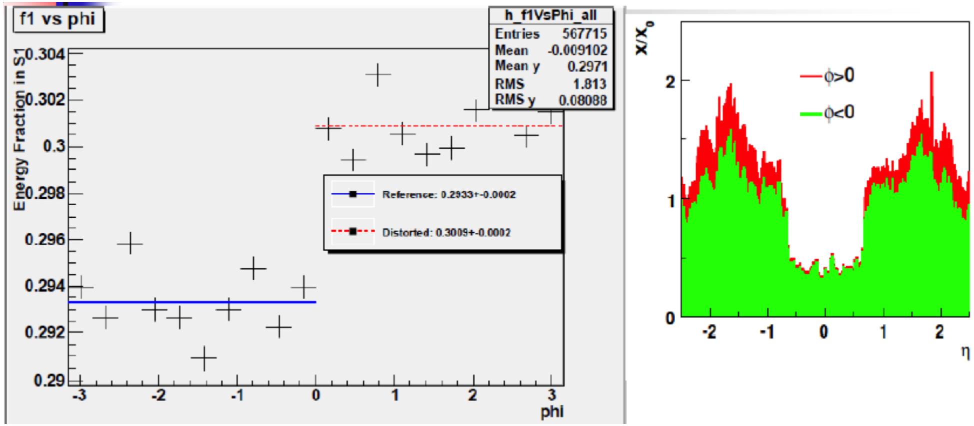
Subdetector	Number of Channels	Approximate Operational Fraction
Pixels	80 M	95.0%
SCT Silicon Strips	6.3 M	99.3%
TRT Transition Radiation Tracker	350 k	97.5%
LAr EM Calorimeter	170 k	99.9%
Tile calorimeter	9800	98.3%
Hadronic endcap LAr calorimeter	5600	99.6%
Forward LAr calorimeter	3500	99.8%
LVL1 Calo trigger	7160	100%
LVL1 Muon RPC trigger	370 k	100%
LVL1 Muon TGC trigger	320 k	100%
MDT Muon Drift Tubes	350 k	99.7%
CSC Cathode Strip Chambers	31 k	96.0%
RPC Barrel Muon Chambers	370 k	97.1%
TGC Endcap Muon Chambers	320 k	98.2%

LAr Material Mapping using electron showershapes I: methodology



- Good e/γ reconstruction performance guaranteed by the correct modeling of the material quantity in front of the EM Calo
- Shower shape based material mapping: a powerful way to study the material both in the tracker and beyond the tracker. Aim for: 1% radiation length precision for the material mapping of Before PS study and 5%∼10% just in front of the EM Calo

LAr Material Mapping using electron showershapes II: introduction



- MC simulated Distorted geometry (ϕ-asymmetric)
- f1 (fraction of energy deposit in 1^{st} layer) as the discriminant
- E = Distorted D / Reference R, significance of E deviating from 1 is taken as the **Estimator**
- Comparison between the usages of $W \to e\nu$ and $b \to e$ using TMVA optimized selectron criteria

LAr Material Mapping using electron showershapes III: $f1$-profile

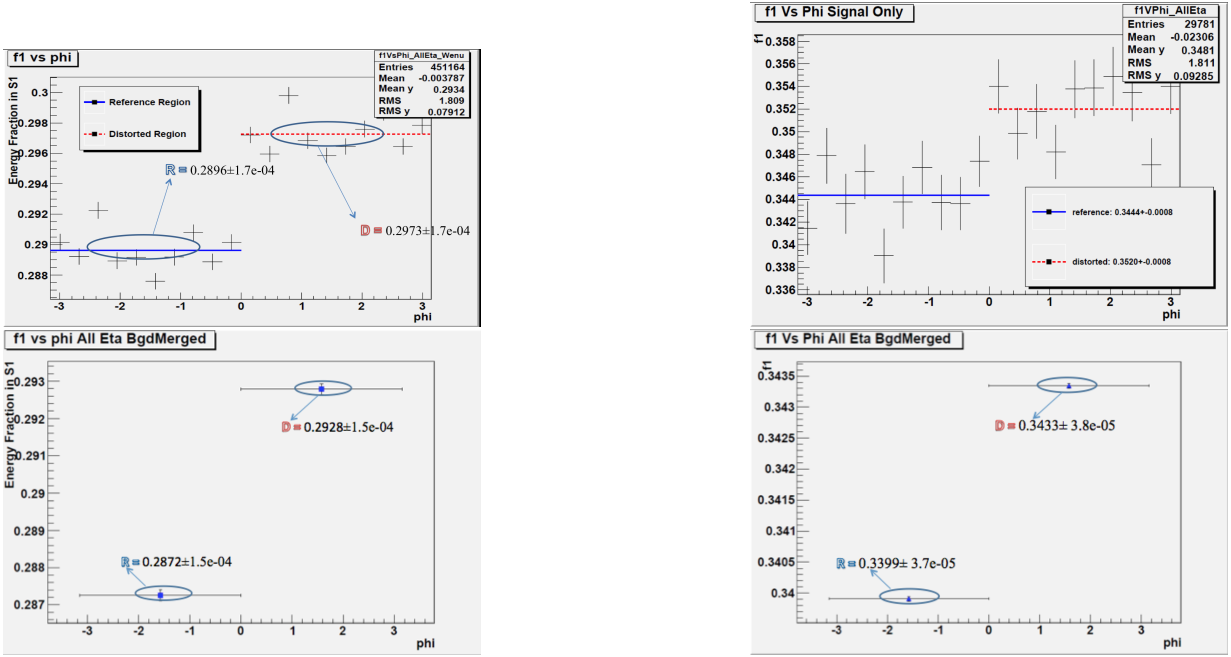


Figure: $f1$ profile of $W \rightarrow e\nu$ (left) and $b \rightarrow e$ (right) w/ background merged (upper) and w/o (bottom).

LAr Material Mapping using electrion showershapes IV: results

Sample	Estimator
$W \to e\nu$(signal ONLY)	38.9
$W \to e\nu$(w/ background)	25.3
$b \to e$ (signal ONLY)	58.5
$b \to e$ (w/ background)	52.1

- TMVA cut-based tuning of both $b \to e$ and $W \to e\nu$ selection variables (showershapes) for optimal working points
- **$W \to e\nu$ gives ~50% lower significance of geometry distortion compared with $b \to e$ but 5 times higher purity**

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Introduction to Standard Model W^+W^- measurement

- **Characteristics:**
  - Isolated high p_T di-leptonic decay channels: ee, $e\mu$ and $\mu\mu$
  - $W \to \tau + X \to e/\mu + X$ included
  - $qq \to WW$: $\sigma_{NLO} = (43.4 \pm 2.25)$ pb (**DOMINANT**); $gg \to WW$: ~3%: 1.3 pb
- **Major backgrounds:**
  - jet/photon→lepton misidentification: W+jets, QCD Multi-jet, $W+\gamma$
  - fake $E_{\mathrm{T}}^{\mathrm{miss}}$: Z+jets
  - W^+W^- + multi-jets: $t\bar{t}$ and single top
  - Other diboson: $WZ \to \ell\ell\ell\nu$, $ZZ \to \ell\ell\nu\nu$

Cross section measurement: methodology

- Cross section calculation:

$$\sigma_{WW} = \frac{N_{obs} - N_{bkg}}{\epsilon\mathcal{A}\mathcal{L}\ Br} \quad (1)$$

N_{obs}: number of observed events; N_{bkg}: estimated backgrounds;
$\epsilon\mathcal{A}$: Overall efficiency including fiducial acceptance and cut efficiency;
Br: dilepton decay branching ratio; $\mathcal{L}$: integrated luminosity.

$$A_{WW} = \frac{N(generator-level\ fiducial\ cuts)}{N(generated\ events)}, \quad (2)$$

$$\epsilon\mathcal{A} = A_{WW}\cdot C_{WW} = \frac{N(reco-level\ analysis\ cuts)}{N(generated\ events)}, \quad (3)$$

$$C_{WW} = \frac{\epsilon\mathcal{A}}{A_{WW}} = \frac{N(reco-level\ analysis\ cuts)}{N(generator-level\ fiducial\ cuts)}, \quad (4)$$

- W^+W^- total cross sections determined in the three dilepton channels by maximising log-likelihood functions:

$$L(\sigma_{WW}^{total}) = \ln\prod_{i=1}^{3}\frac{e^{-(N_s^i+N_b^i)}\times(N_s^i+N_b^i)^{N_{obs}^i}}{N_{obs}^i!}, \qquad N_s^i = \sigma_{WW}^{total}\times Br\times\mathcal{L}\times\epsilon_{WW}^i \quad (5)$$

Object Definition I: Leptons/Jets

Electron Identification (ID + Calo):

- Criteria optimized to provide good separation between electrons and fakes (γ or jets)
- Electron id based on shower shapes and tracking information, we use the best identified electrons - efficiency 70-80%
- $|\eta| < 2.47$, $E_T > 25/20 GeV$
- Cut on Calorimeter/Track Isolation, Transverse/Longitudinal Impact Parameter (IP)

Muon Identification (ID + MS)

- Reconstructed with good ID/MS combination and track quality
- $|\eta| < 2.4$, $p_T > 25/20$ **GeV**
- Calorimeter/Track Isolation, Longitudinal/Transverse IP

Leading lepton $p_T > 25$ GeV to stay on the trigger plateau

Jet Definition:

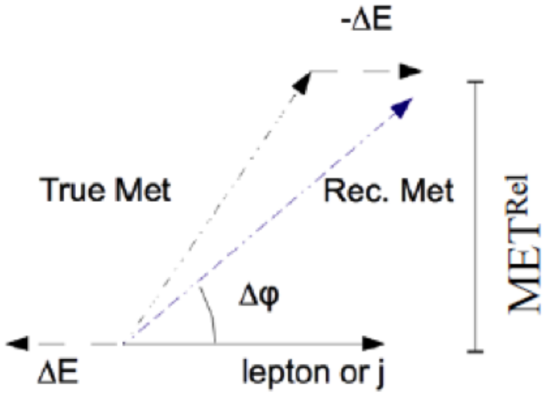
- $p_{\mathrm{T}} > 25$ **GeV**, $|\eta| < 4.5$, calibrated to the hadronic energy scale

Object Definition II: $E_{\mathrm{T}}^{\mathrm{miss}}$

$E_{\mathrm{T}}^{\mathrm{miss}}$ definition:

- Sum of the transverse energy of calibrated topological clusters in the calorimeter
- Redefine the $E_{\mathrm{T}}^{\mathrm{miss}}$ as $E_{\mathrm{T,\ Rel}}^{\mathrm{miss}}$ to reduce the sensitivity to mis-measured leptons or jets

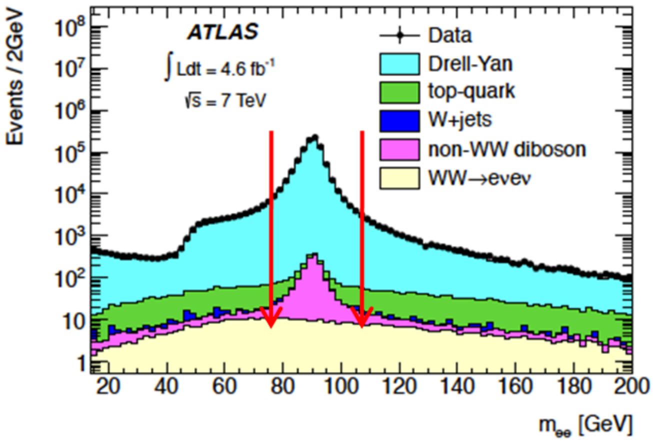
$$E_{\mathrm{T,\ Rel}}^{\mathrm{miss}} = \begin{cases} E_{\mathrm{T}}^{\mathrm{miss}} \times \sin(\Delta\phi_{\ell,j}) & \text{if } \Delta\phi_{\ell,j} < \pi/2 \\ E_{\mathrm{T}}^{\mathrm{miss}} & \text{if } \Delta\phi_{\ell,j} \geq \pi/2 \end{cases} \quad (6)$$



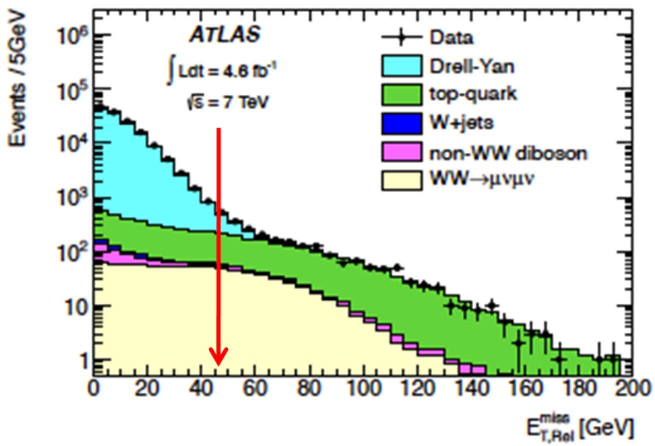
, where $\Delta\phi_{\ell,j}$ is the difference in azimuthal angle between the $E_{\mathrm{T}}^{\mathrm{miss}}$ and nearest good lepton or jet

Event Selection II: channel specific selections (Drell-Yan treatment)

- $m_{ll} > 15$ GeV for ee and $\mu\mu$ and 10 GeV for $e\mu$
- $|m_{ll} - m_Z| > 15$ GeV for ee and $\mu\mu$ (Use MC only)

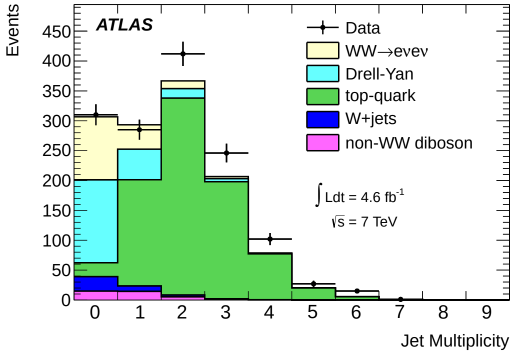


- $E^{miss}_{T,\ Rel} > 45/45/25$ GeV for $\mu\mu/ee/e\mu$ (Use MC only)

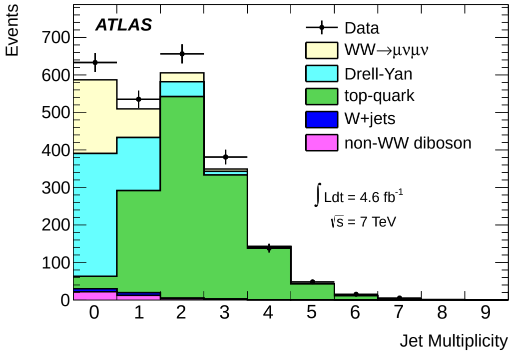


Event Selection III: Jet Multiplicity (Top treatment)

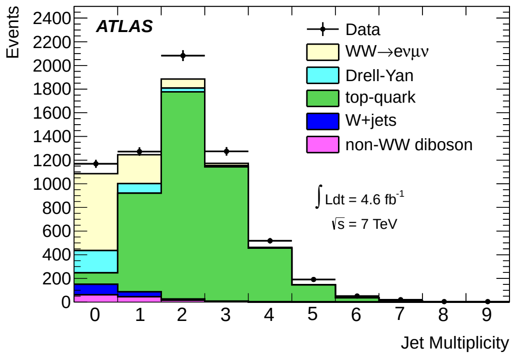
- 0-jet in the W^+W^- signal region



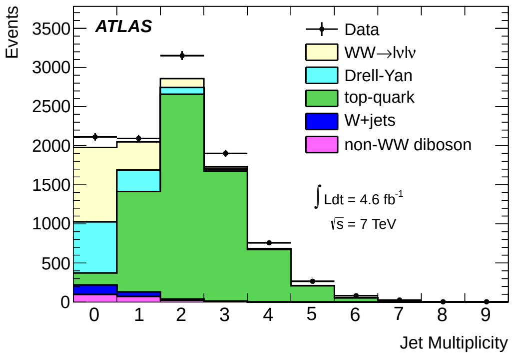
(a)



(b)



(c)



(d)

Background Estimation I: W+jet

- W+jets contamination: one jet misidentified as a good lepton
- Jet misidentification rate not correctly modeled in MC
- Use W+jet enriched control region and fake factors measured from data:
    - Fake factor: ratio of identified leptons over "jet-rich" ones
    - W+jet **C**ontrol **R**egion: 1 "jet-rich" lepton + 1 good lepton
    - Systematics: **trigger bias**, away-side jet p_T dependence, **sample dependence(W+jet Vs dijet)**, etc.
- Final estimation:

$$N_{\text{one id + one fake}} = f_l \times N_{\text{one id + one jet-rich}}. \quad (7)$$

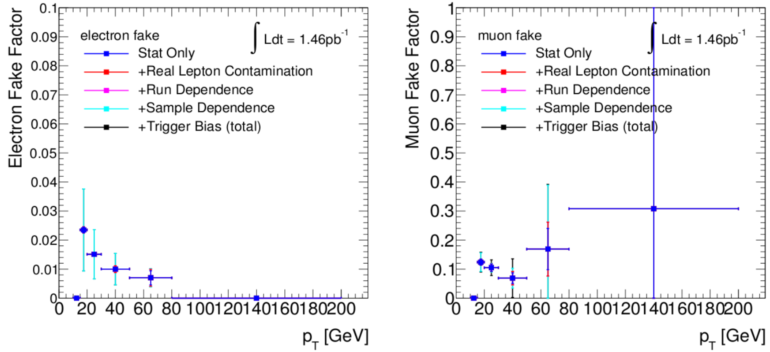


Figure: W+jets fake factor with stat./syst. uncertainties

	ee-ch	eμ-ch	$\mu\mu$-ch	Total
W+jet background (e-fakes)	$21.38 \pm 0.53 \pm 11.34$	$56.25 \pm 0.90 \pm 30.19$	-	$77.6 \pm 1.0 \pm 41.5$
W+jet background (μ-fakes)	-	$13.8 \pm 1.4 \pm 8.1$	$6.56 \pm 0.96 \pm 2.77$	$20.4 \pm 1.7 \pm 10.9$
Total W+jet background	$21.38 \pm 0.53 \pm 11.34$	$70.0 \pm 1.7 \pm 31.3$	$6.56 \pm 0.96 \pm 2.77$	$98.0 \pm 2.0 \pm 42.9$
W+jet MC (comparison)	16.2 ± 4.5	60.1 ± 8.4	5.5 ± 2.1	81.8 ± 9.8

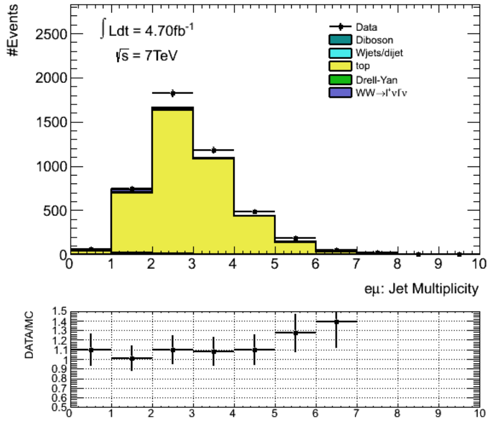
Background Estimation II: Top (Template fit method)

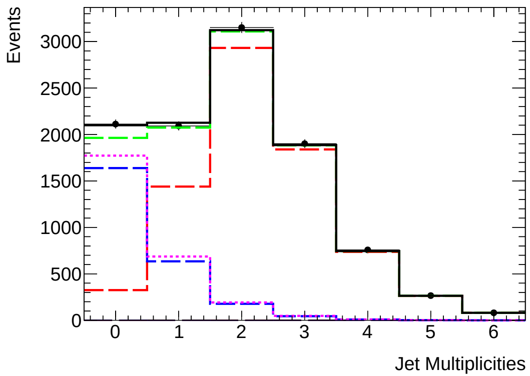
- Top background estimation **using a jet multiplicity template fit method**
  - SR1: after $E_{\mathrm{T,\ Rel}}^{\mathrm{miss}}$
  - CR: SR1 with at least 1 b-jet with $p_T > 20$ GeV
  - SR2: after all the cuts

$$\text{Data-Driven Top}^{\text{SR1}} = \frac{\text{MC Top}^{\text{SR1}}}{\text{MC Top}^{\text{CR}}} \cdot \left(\text{Data}^{\text{CR}} - f \cdot \text{MC Non-Top}^{\text{CR}}\right) \quad (8)$$

$$\text{Data}^{\text{SR1}} = \text{Data-Driven Top}^{\text{SR1}}(f) + f \cdot \text{MC Non-Top}^{\text{SR1}} \quad (9)$$

$$\text{Top Estimate}^{\text{SR2}}\ (\text{bin } 0) = \text{Data-Driven Top}^{\text{SR1}}(\text{bin } 0) \cdot \frac{\text{MC Top}^{\text{SR2}}(\text{bin } 0)}{\text{MC Top}^{\text{SR1}}(\text{bin } 0)} \quad (10)$$





Channel	ee	$\mu\mu$	$e\mu$	Combined
N_{top}	$22.4 \pm 11.8 \pm 3.4$	$32.3 \pm 14.2 \pm 4.9$	$86.5 \pm 23.3 \pm 13.1$	$141.2 \pm 29.7 \pm 21.5$

Background Estimation II: Top (Jet Veto SF method)

- Top data-driven estimation using a b-tagging CR:
  - P1: b-tagging CR jet veto survival probability
  - P2: full jet veto survival probability

$$
\begin{aligned}
N_{\rm top}^{\rm Est.}(\ell\ell + E_T^{\rm miss}, 0j) &\simeq N_{\rm top}^{\rm Data}(\ell\ell + E_T^{\rm miss}) \times \underbrace{\boxed{P_2^{\rm MC} \times \left(\frac{P_1^{\rm Btag,data}}{P_1^{\rm Btag,MC}}\right)^2}}_{P_2^{\rm Exp}} \\
&= (N_{\rm all}^{\rm Data} - N^{\rm non-top}) \times (P_1^{\rm Btag,data})^2 \times \frac{P_2^{\rm MC}}{(P_1^{\rm Btag,MC})^2}
\end{aligned}
$$

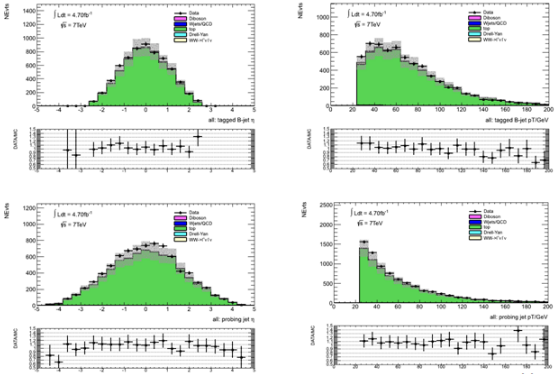
$$P_1^{\rm Btag} = N_{0j}^{\rm Btag} / N_{\rm all\text{-}jets}^{\rm Btag}$$

$$P_2^{\rm MC} = N_{0j}^{\rm MC} / N_{\rm all\text{-}jets}^{\rm MC}$$

- Insensitive to the normalization, b-tagging eff., lumi and theo. σ, JES/JER, ISR/FSR, etc.
- Agree well with MC prediction
- $\sim$16.2% overall syst. dominated by theo. uncertainty $\sim$15%
- An MC closure test using top samples with a different generator (MC@NLO Vs PowHeg) was performed well ($\sim$2% deviation)

channel	Top MC	Top DD
ee	23.3 ± 1.1(stat)	19.0 ± 3.2(stat) ± 3.1(syst)
$e\mu$	89.8 ± 2.3(stat)	88.5 ± 7.1(stat) ± 14.3(syst)
$\mu\mu$	33.7 ± 1.4(stat)	$42.6 \pm 7.3 \pm 6.9$
combined	146.8 ± 2.9(stat)	$150.1 \pm 10.7 \pm 22.3$

Table: Final DY background estimates for all three channels.

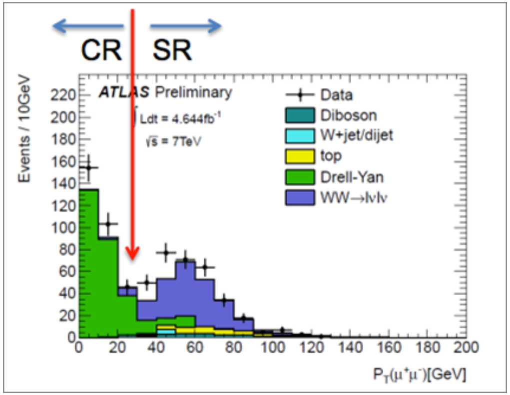


Background Estimation III: Drell-Yan and diboson backgrounds

Drell-Yan (DY) background

- Correct DY yields using a Scale Factor derived from a control region by inverting $p_T(\ell\ell) > 30$ cut

$$\text{SF} = \frac{N^{\text{data}}_{Z,\text{CR}}}{N^{\text{MC}}_{Z,\text{CR}}} = \frac{N^{\text{data}}_{\text{CR}} - N^{\text{MC}}_{non-Z,\text{CR}}}{N^{\text{MC}}_{Z,\text{CR}}}$$



(Other) diboson backgrounds

- Less contribution compared to other backgrounds, estimated using MC prediction

Final State	$e^+e^-E_{\text{T}}^{\text{miss}}$	$\mu^+\mu^-E_{\text{T}}^{\text{miss}}$	$e^{\pm}\mu^{\mp}E_{\text{T}}^{\text{miss}}$	Combined
diboson Background				
WZ	3.18±0.31	10.82±0.56	17.42±0.72	31.41±0.96
ZZ	3.43±0.32	6.93±0.48	1.17±0.26	11.53±0.63
Wγ	3.84±0.75	0±0	15.14±1.46	18.98±1.64
W$\gamma*$	2.26±0.48	3.29±0.44	10.40±0.93	15.95±1.13
Total Background	12.70±0.99	21.04±0.86	44.12±1.89	77.87±2.30

Final WW candidate plots

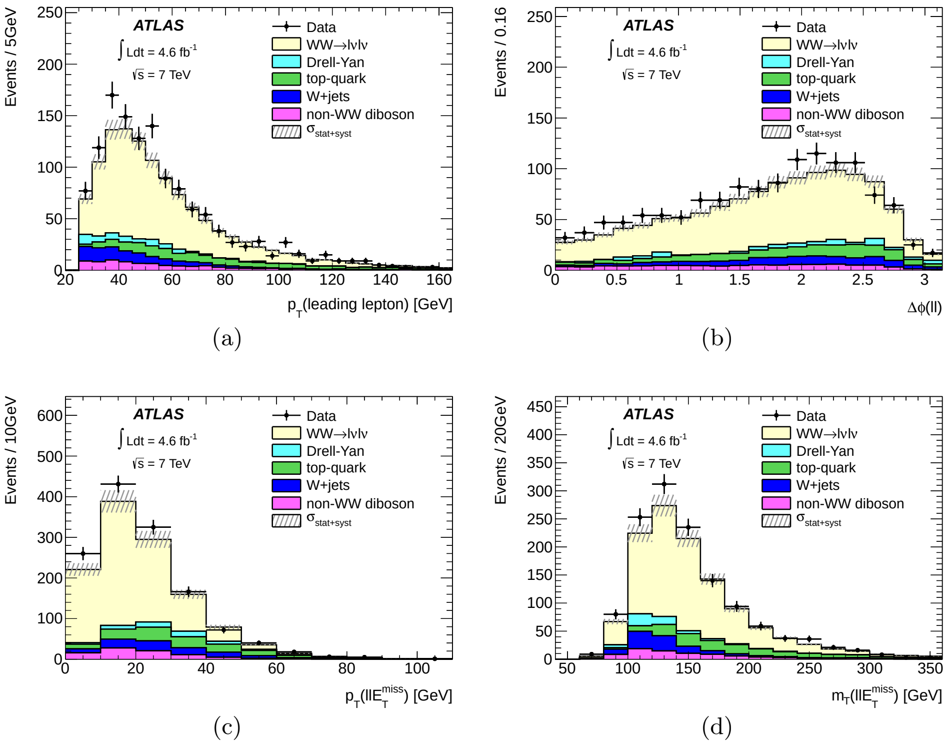


Figure: Final distributions for W^+W^- candidates in all channels: (a) leading lepton p_{T} (b) opening angle between the two leptons ($\Delta\phi(\ell\ell')$), (c) p_{T} and (d) m_{T} of the $\ell\ell' + E_{\mathrm{T}}^{\mathrm{miss}}$ system.

Cross section measurement: results

Channels	expected σ^{fid} (fb)	measured σ^{fid} (fb)	$\Delta\sigma_{stat}$ (fb)	$\Delta\sigma_{syst}$ (fb)	$\Delta\sigma_{lumi}$ (fb)
$e\nu e\nu$	54.6±4.1	56.4	± 6.8	± 9.8	± 1.0
$\mu\nu\mu\nu$	58.9±4.5	73.9	± 5.9	± 6.9	± 1.3
$e\nu\mu\nu$	231.4±19.9	262.3	± 12.3	± 20.7	± 4.7

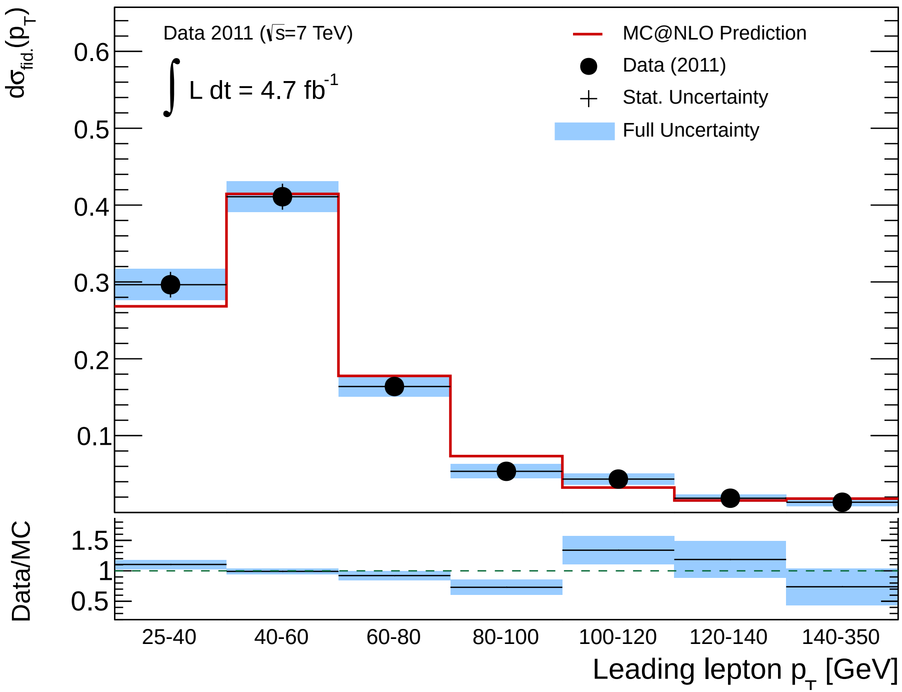
Table: The predicted and measured fiducial W^+W^- production cross sections.

Channels	Total cross-section (pb)	$\Delta\sigma_{stat}$(pb)	$\Delta\sigma_{syst}$(pb)	$\Delta\sigma_{lumi}$(pb)
$e\nu e\nu$	46.85	± 5.65	± 8.21	± 0.84
$\mu\nu\mu\nu$	56.65	± 4.52	± 5.46	± 1.02
$e\nu\mu\nu$	51.13	± 2.41	± 4.24	± 0.92
Combined	51.91	± 2.0	± 3.92	± 0.93

Table: Measured total W^+W^- production cross sections, consistent with SM NLO prediction of $44.7^{+2.1}_{-1.9}$ pb.

Differential distribution measurement

- **Motivation:**
  - Get rid of detector effects and flexible for the comparisons between various experiments
  - Essentially important for testing existing and future theory models and MC tuning
- Use Bayesian iterative treatment to unfold the leading lepton (e/μ) transverse momentum spectrum used in aTGC limit setting (same binning)



Anomalous Triple-Gauge coupling (aTGC) I

- aTGC will enhance the W^+W^- production rate particularly at the high transverse momentum and high transverse mass regions

- Effective Lagrangian conserving C and P symmetries separately:

$$L/g_{WWV} = ig_1^V(W^*_{\mu\nu}W^{\mu}V^{\nu} - W_{\mu\nu}W^{*\mu}V^{\nu}) + ik_V W^*_{\mu}W_{\nu}V^{\mu\nu} + \frac{\lambda_V}{M_W^2}W^*_{\rho\mu}W^{\mu}_{\nu}V^{\nu\rho} \quad (11)$$

, where V can be either γ or Z, $X_{\mu\nu} = \partial_\mu X_\nu - \partial_\nu X_\mu$, W^μ refers to the W^- field

- aTGC (WWZ and $WW\gamma$) limits extracted by fitting the expected leading lepton p_T distribution (as a function of aTGC parameters g_1^V, k_V and λ_V) to the observed one

$$\Delta g_1^Z \equiv g_1^Z - 1, \Delta k_\gamma \equiv k_\gamma - 1, \Delta k_Z \equiv k_Z - 1, \lambda_Z, \lambda_\gamma. \quad (12)$$

- Cutoff form factor Λ is introduced to avoid tree-level unitarity violation at high energy

$$\Delta k(\hat{s}) = \frac{\Delta k}{(1 + \hat{s}/\Lambda^2)^2}, \quad (13)$$

, where $\hat{s}$ is the invariant mass of W^+W^-

Anomalous Triple-Gauge coupling (aTGC) II

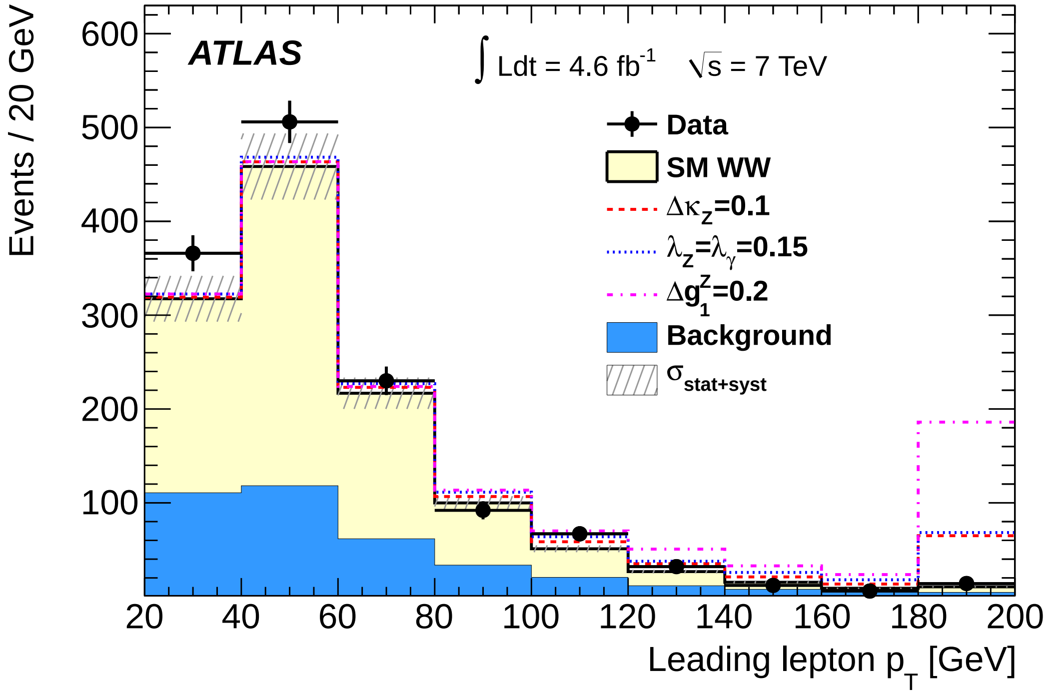


Figure: The reconstructed leading lepton p_T spectrum for the SM prediction and for three different anomalous TGC predictions. The rightmost bin shows the sum of all events with leading lepton p_T above 180 GeV.

Anomalous Triple-Gauge coupling (aTGC) III

- Limits of four scenarios of aTGC constraint are extracted: LEP, HISZ, Equal and no-constraint
  - The LEP scenario (three free parameters)
    $\Delta k_\gamma = (\cos^2\theta_W/\sin^2\theta_W)(\Delta g_1^Z - \Delta k_Z), \quad \lambda_Z = \lambda_\gamma$
  - The HISZ scenario (two free parameters)
    $\Delta g_1^Z = \Delta k_Z/(\cos^2\theta_W - \sin^2\theta_W), \quad \Delta k_\gamma = 2\Delta k_Z \ \cos^2\theta_W/(\cos^2\theta_W - \sin^2\theta_W), \quad \lambda_Z = \lambda_\gamma$
  - The equal couplings scenario (two free parameters)
    $\Delta k_Z = \Delta k_\gamma, \quad \lambda_Z = \lambda_\gamma, \quad \Delta g_1^Z = \Delta g_1^\gamma = 0$
- aTGC events are generated with BHO generator at NLO
- The full parameter space is accessed with a reweighting technique based on truth kinematics of two leptons

Anomalous Triple-Gauge coupling (aTGC) IV

- Final results of the aTGC limits for different scenarios with $\Lambda = 6$ TeV and ∞.

Scenario	Parameter	Expected ($\Lambda = 6$ TeV)	Observed ($\Lambda = 6$ TeV)	Expected ($\Lambda = \infty$)	Observed ($\Lambda = \infty$)
LEP	Δk_Z	[−0.043, 0.040]	[−0.045, 0.044]	[−0.039, 0.039]	[−0.043, 0.043]
	$\lambda_Z = \lambda_\gamma$	[−0.060, 0.062]	[−0.062, 0.065]	[−0.060, 0.056]	[−0.062, 0.059]
	Δg_1^Z	[−0.034, 0.062]	[−0.036, 0.066]	[−0.038, 0.047]	[−0.039, 0.052]
HISZ	Δk_Z	[−0.040, 0.054]	[−0.039, 0.057]	[−0.037, 0.054]	[−0.036, 0.057]
	$\lambda_Z = \lambda_\gamma$	[−0.064, 0.062]	[−0.066, 0.065]	[−0.061, 0.060]	[−0.063, 0.063]
Equal Couplings	Δk_Z	[−0.058, 0.089]	[−0.061, 0.093]	[−0.057, 0.080]	[−0.061, 0.083]
	$\lambda_Z = \lambda_\gamma$	[−0.060, 0.062]	[−0.062, 0.065]	[−0.060, 0.056]	[−0.062, 0.059]

Table: The 95% C.L. expected and observed limits on anomalous TGCs in the LEP, HISZ and Equal Couplings scenarios.

Parameter	Expected ($\Lambda = \infty$)	Observed ($\Lambda = \infty$)
Δk_Z	[−0.077, 0.086]	[−0.078, 0.092]
λ_Z	[−0.071, 0.069]	[−0.074, 0.073]
λ_γ	[−0.144, 0.135]	[−0.152, 0.146]
Δg_1^Z	[−0.449, 0.546]	[−0.373, 0.562]
Δk_γ	[−0.128, 0.176]	[−0.135, 0.190]

Table: The 95% C.L. expected and observed limits on anomalous TGCs assuming no relationships between these five coupling parameters for $\Lambda = \infty$.

aTGC limit comparison between different HEP experiments

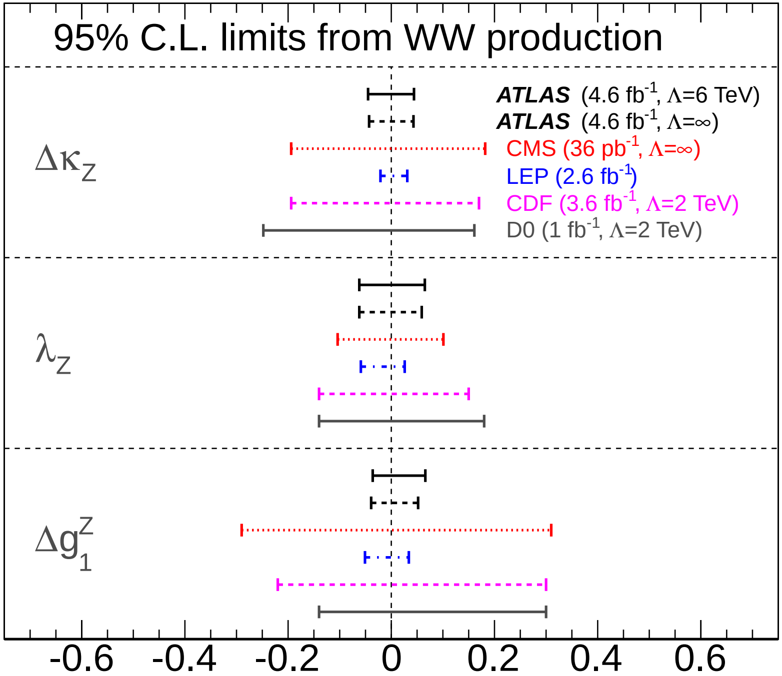


Figure: **The latest aTGC limits with 4.6 fb^{-1} 2011 data are getting more restrictive than Tevatron and competitive with LEP.**

Outline

1. Introduction
   - The Standard Model Electroweak interactions and diboson productions
   - The Large Hadron Collider and the ATLAS Detector

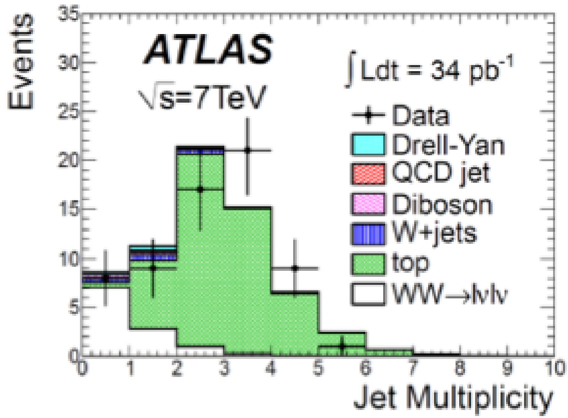
2. Measurement of W^+W^- Production
   - Measurement of the total cross section of the Standard Model W^+W^- production
   - Measurement of the differential cross section of the Standard Model W^+W^- production
   - Limits on the anomalous triple gauge boson couplings

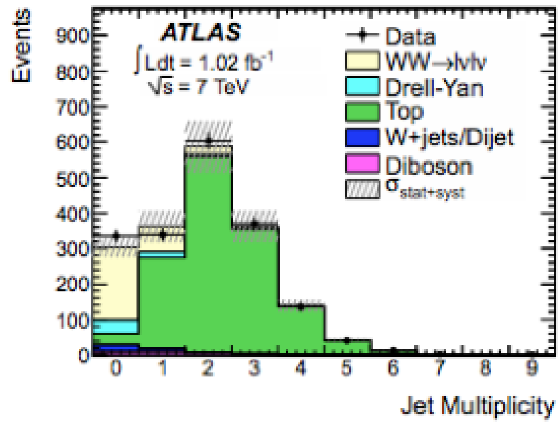
3. Conclusions
   - Summary
   - WW group efforts and mile-stones in ATLAS
   - Personal Statement

Summary

- Standard Model WW cross section measured from all three purely leptonic decay channels with pp collision data recorded by ATLAS at $\sqrt{s} = 7$ TeV of 4.6 fb^{-1} integrated luminosity (full dataset in 2011)
- Measured cross section 51.9±2.0(stat.)±3.9(syst.)±0.93(lumi.) is **consistent with the Standard Model theoretical prediciton $44.7^{+2.1}_{-1.9}$ pb**. Fiducial cross sections for all channels are also measured.
- `Extension of SM` W^+W^- `cross section measurement:`
  - First differential distribution is extracted for leading lepton transverse momentum
  - aTGC limits are set with the same amount of data and is **getting more restrictive than Tevatron and more competitive with LEP results.**
- Prospective future:
  - More exciting results can be expected with 25 fb^{-1} data by the end of the year of 2012 (Fighting with systematics)
  - aTGC combination of all diboson channels is in preparation

WW group efforts and mile-stones in ATLAS





Njets = 0: 8 candidate evts

WW signal ~ 6.9

Background ~ 1.7

S/B ~ 4

- $\sigma_{W^+W^-} = 41^{+20}_{-16}(stat.) \pm 5(syst.) \pm 1(lumi.)pb$
- ATLAS-CONF-2011-015 (Moriond-EWK 2011) and Phys.Rev.Lett.107 (2011) 041802

Njets = 0: 414 candidate evts

WW signal ~ 233 (207 scaled from 2010)

Background ~ 147 (51 scaled from 2010)

Background increase due to

- $\sigma_{W^+W^-} = 54.4 \pm 4.0(stat.) \pm 3.8(syst.) \pm 2.0(lumi.)pb$
- ATLAS-COM-CONF-2011-125 (EPSHEP 2011) and Phys.Lett. B712 (2012) 289-308

- 4.6 fb^{-1} results: ATLAS-COM-CONF-2012-024 (Moriond-EWK 2012), Phys.Rev.D publication expected in Jan. 2013

Personal contributions

- **W^+W^- Analysis contributions:**
  - Event selection optimization
  - Lepton, jet and $E_{\mathrm{T}}^{\mathrm{miss}}$ performance and systematics
  - W+jet and top background estimation
  - Signal and other diboson systematics
  - Collaborative work on differential measurement
- **Performance work:**
  - Electron shower-shape based material maping in front of the electromagnetic calorimeter
  - LAr data quality and investigation
- **Hardware work:**
  - LAr Detector Monitoring
  - Design of a cosmic muon lifetime measurement scintillator detector (Data acquisition programming)

Personal Statement

- Discussed with Dr.David Christian for a postdoc position at FNAL
- Aim to introduce myself to your group so that you may have a brief overview of my previous activities and past involvements, particularly in ATLAS
- **Brief overview:**
  - Bachelor degree in 2008: University of Science and Technology of China (USTC)
  - Start of co-Ph.D of Physics for USTC in 2008 and Centre de Physique des Particules de Marseille (CPPM) in 2009
  - Topic: Measurement of Standard Model WW production cross sections with ATLAS detector
  - Supervised by: Prof.Zhengguo ZHAO(USTC), Prof.Yanwen LIU (USTC) and Dr. Emmanuel MONNIER(CPPM)
- **Major activities:**
  - 2008-2009: Design of a cosmic muon lifetime measurement scintillator detector cooperated with Prof. Jingbo YE at SMU and Yusheng WU at USTC
  - 2009-2010: (ATLAS E/gamma Service) Material Mapping using electron showershapes from W-¿e and b-¿e
  - 2010: (LAr service task) LAr offline data quality shifter and investigation team member
  - 2010-2012: thesis work
  - Ph.D thesis defended successfully on Nov.2^{nd} 2012

List of publications and conference notes/talks/proceedings

- Measurement of the W+W Production Cross Section in Proton-Proton Collisions at $\sqrt{s} = 7$ TeV with the ATLAS Detector
  ATLAS-COM-CONF-2012-024
- A publication is expected in Jan. 2013
  my contributions: MC validation, event selection optimization, cutflow, data-driven top background estimation, final plots and numbers, systematic uncertainty cross check
- Measurement of the W+W production cross section in proton-proton collisions at $\sqrt{s} = 7$ TeV with the ATLAS detector
  ATLAS-COM-CONF-2011-125
- Measurement of theWWcross section in $\sqrt{s} = 7$ TeV pp collisions with the ATLAS detector and limits on anomalous gauge couplings, Phys. Lett. B712 (2012) 289-308
  my contributions: MC validation, event selection optimization and final numbers, cutflow, data-driven W+jet background estimation cross check
- Measurement of the WW production cross section in proton-proton collisions at $\sqrt{s} = 7$ TeV with the ATLAS detector
  ATLAS-CONF-2011-015
- Measurement of theWWcross section in $\sqrt{s} = 7$ TeV pp collisions with ATLAS, Phys.Rev.Lett.107 (2011) 041802
  my contributions: cutflow, data-driven W+jet background estimation cross check
- ATLAS DiBoson Measurement(15+5) ATL-PHYS-SLIDE-2012-507
  parallel talk at PLHC2012@UBC, Vancouver, Canada
- Diboson cross section measurement at ATLAS and limits on anomalous gauge couplings ATL-PHYS-PROC-2012-151
  proceeding for PLHC2012@UBC, Vancouver, Canada

Backup Slides

- Electromagnetism and the weak interaction can be unified as one electroweak force above the unification energy 100 GeV achieved by achieved by means of $SU(2)_L \times U(1)_Y$ gauge symmetry.
- By introducing the spontaneous breaking of electroweak symmetry, the original $SU(2)_L$ ($W^{\pm}$ and W^0) and $U(1)_Y$ B^0 bosons are transformed into new gauge bosons Z^0 and γ.

$$\begin{pmatrix} \gamma \\ Z^0 \end{pmatrix} = \begin{pmatrix} cos\theta_W & sin\theta_W \\ -sin\theta_W & cos\theta_W \end{pmatrix} \begin{pmatrix} B^0 \\ W^0 \end{pmatrix} \tag{14}$$

, where θ_W stands for the weak mixing angle while γ and Z^0 refer to photon and neutral weak field, respectively. In Higgs mechanism, $U(1)_{em}$ does not interact with the Higgs boson which is the eigenstate of both Y and I_3. Therefore $U(1)_{em}$ is not broken and eventually leads to the distinction between electromagnetic and weak interactions.

- The charged and neutral current interactions occurs when $W^{\pm}$ and Z^0 bosons are absorbed or emitted by quarks or leptons and coherently the up-down type quarks conversion or the rapid decay of the gauge bosons.
- In SM, only charged current interactions allow the flavors of quarks and leptons to be changed.

Standard Model WW production

- Share the same motivation as all the other diboson measurements
- Special attention due to the background role in Higgs searches via $H \rightarrow WW$ channel
- Mainly produced from quark-antiquark annihilation and another non-negligible 3% contribution from gluon-gluon fusion
- Overall cross section predicted by Standard Model: $44.7^{+2.1}_{-1.9}$ pb (calculated with MCFM and CT10 PDFs)

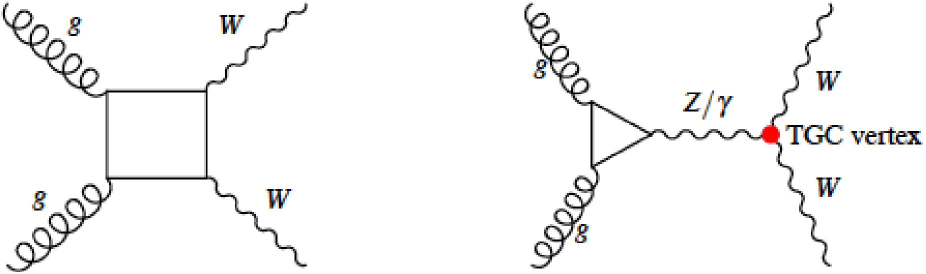
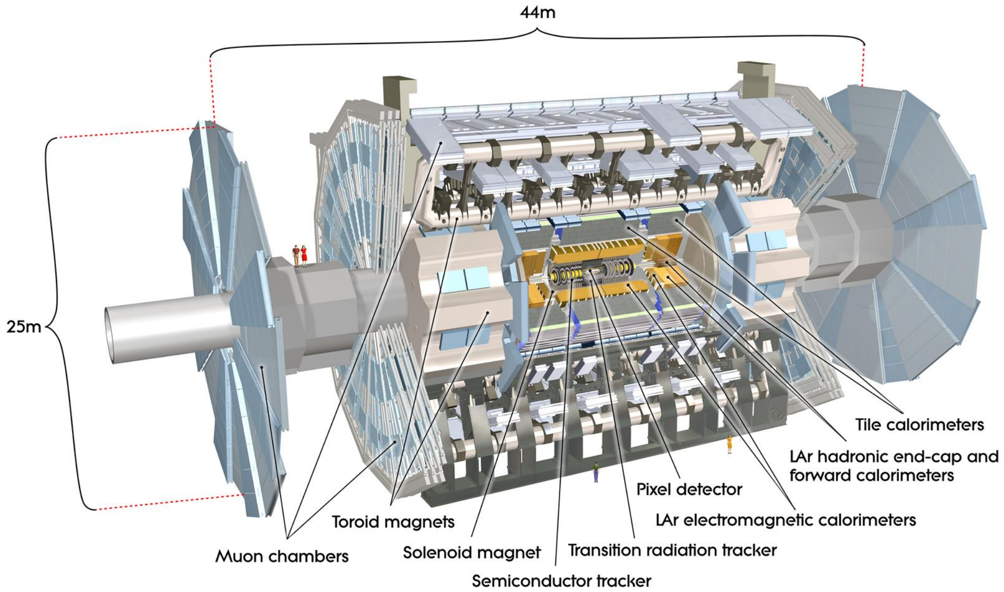


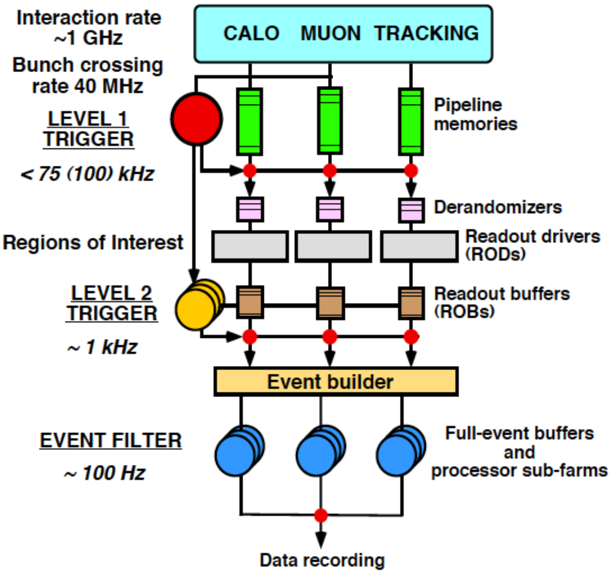
Figure: The SM Feynman diagrams for W^+W production through gluon-gluon fusion in hadron colliders. Please note that the Z-exchange triangle diagrams cancel when summed over massless up- and down-type contributions.

Introduction to ATLAS

- One of the two general-purpose detectors at LHC
- **Requirements:** radiation-hard, high granularity, good resolution, particle identification, good hadronic coverage, optimal trigger rate, etc.
- **Three major subdetector systems:** Inner Tracking Detectors (ID), Calorimeters (LAr and Tile), Muon Spectrometers (MS)
- *pp* collisions at $\sqrt(s) = 7(8)$ TeV in 2011(2012), instantaneous luminosity peaking at $10^{32} \sim 10^{34}$ cm^{-2}s^{-1}



The ATLAS Trigger System



- High collision rate challenge (1.5 MB desired per event at a high rate of 40 MHz)
- **Three levels of trigger system**:
  L1 triggers hardware level ($\leq$75 kHz and upgradable to 100 kHz)
  L2 triggers seeded by RoIs after L1 ($\leq$3.5 kHz)
  Event Filters judge fully-constructed events passing L2 for offline analysis (400$\sim$800 Hz)
- EF level electron and muon triggers to be considered in this analysis

The lead-LAr Calorimeter III: LAr DQ defects

Table: Summary of LAr DQ defects which may have impacts on physics analysis results. <PART> refers to different LAr calorimeter partitions.

Defect	Description	Recoverable	Tolerable
LAR_DATACORRUPT	Data integrity problem	NO	NO
LAR_UNCHECKED	Shifter did not look at ES	YES	NO
LAR_BULK_UNCHECKED	Shifter did not look at bulk	YES	YES
LAR_LOWSTAT	Not enough stat for assessment	NO	YES
LAR_<PART>_DISABLED	Partition not included in the run	NO	NO
LAR_<PART>_HVTRIP	LB with HV ramping or off on both sides	NO	NO
LAR_<PART>_HVNONNOMINAL	LB with stable non-nominal HV (Noise not corrected)	YES	NO
LAR_<PART>_HVNONNOM_CORRECTED	LB with stable non-nominal HV (Noise corrected, impact on trigger)	NO	YES
LAR_<PART>_NOISEBURST	LB with minor noise burst	NO	YES
LAR_<PART>_SEVNOISEBURST	LB with severe noise bursts	NO	NO
LAR_<PART>_NOISYCHANNEL	Noisy cell, but harmless	YES	YES
LAR_<PART>_SEVNOISYCHANNEL	Very noisy cell, inducing many clusters	YES	NO
LAR_<PART>_MINORUNKNOWN	Data affected by minor (yet) unknown pathology	MAYBE	YES
LAR_<PART>_SEVUNKNOWN	Data unusable for (yet) unknown reason	MAYBE	NO

Data and MC Samples of singal and backgrounds

- 2011 $\sqrt{s} = 7$ TeV pp collision data of ($4.6\ fb^{-1}$ in GRL) recorded by ATLAS
- WW **Signal:**
  - $q\bar{q} \rightarrow W^+W^- \rightarrow \ell^+\nu_\ell\ell^-\bar{\nu}_\ell$: MC@NLO generator, HERWIG/Jimmy parton shower and CT10 PDF
  - $gg \rightarrow W^+W^- \rightarrow \ell^+\nu_\ell\ell^-\bar{\nu}_\ell$: `gg2ww` generator and CT10 PDF
- **Background samples:**
  - $t\bar{t}$: MC@NLO
  - Single Top: AcerMC
  - V+jets: Alpgen
  - WZ, ZZ: Herwig
  - $W + \gamma$: ALPGEN
  - $W + \gamma^*$: MADGRAPH
- ATLAS full simulation is used for all required MC samples

Distributions of discriminants at preselection level

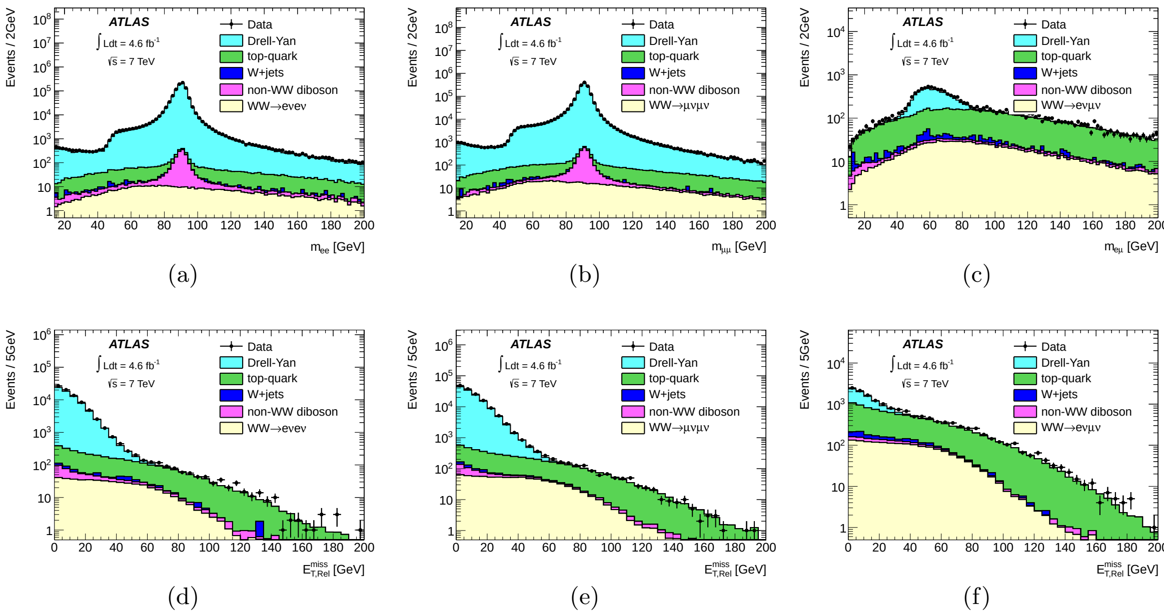
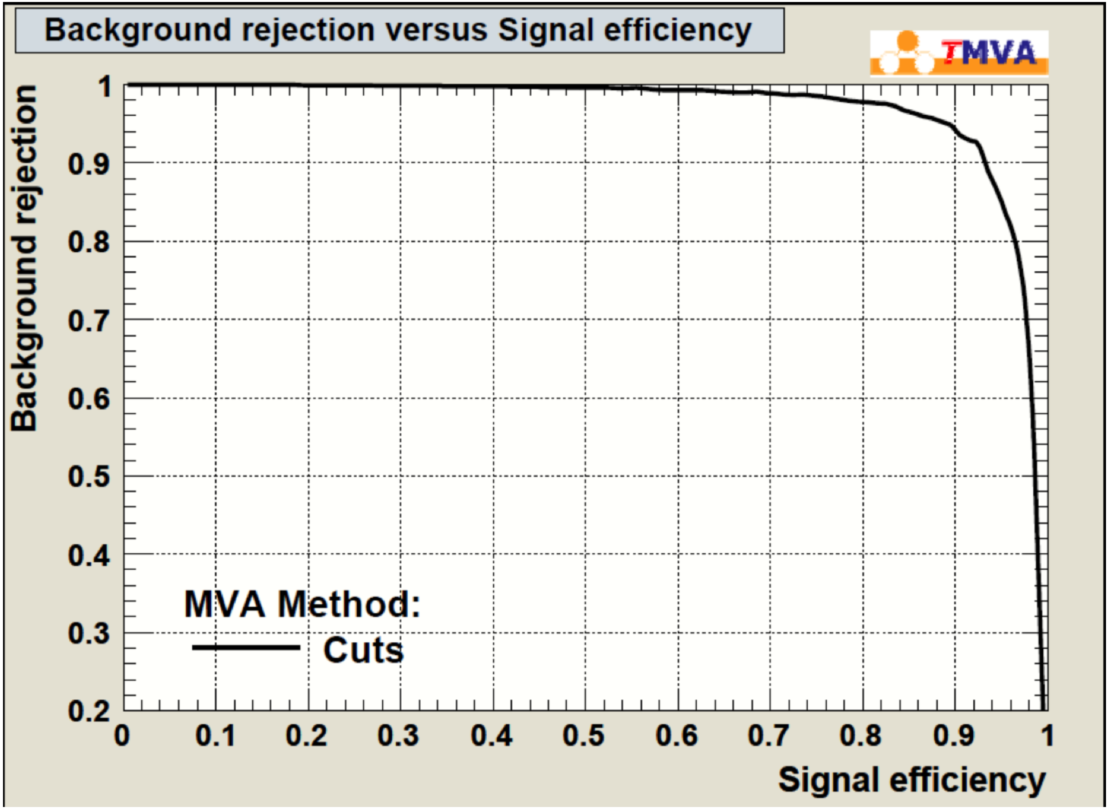
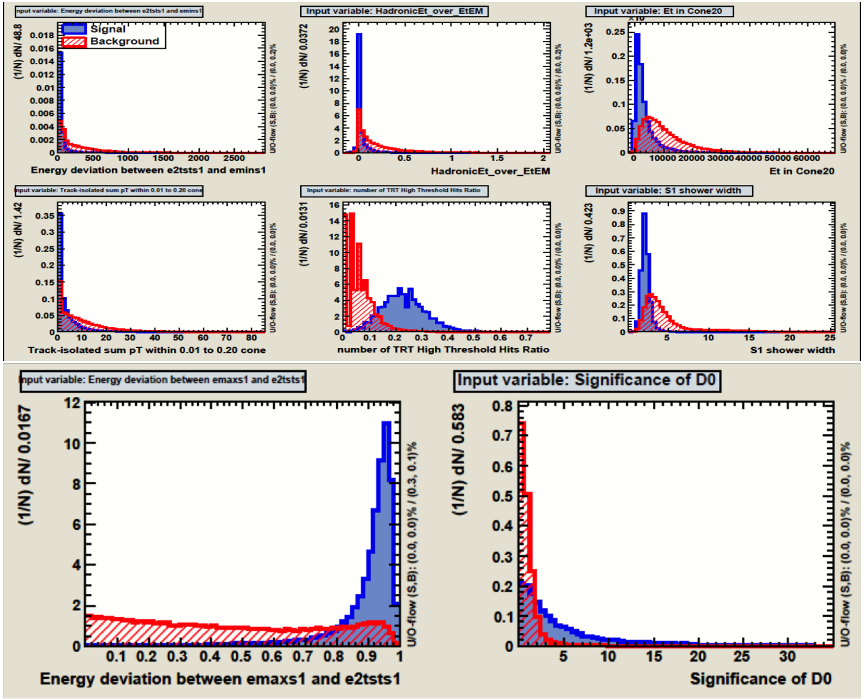


Figure: Comparison between data and simulation for the m(ll) (top) and $E_{\mathrm{T,\ Rel}}^{\mathrm{miss}}$ (bottom) distribution before the m(ll) or $E_{\mathrm{T,\ Rel}}^{\mathrm{miss}}$ cut for the (a/d) ee, (b/e) $\mu\mu$ and (c/f) $e\mu$ channels, respectively.

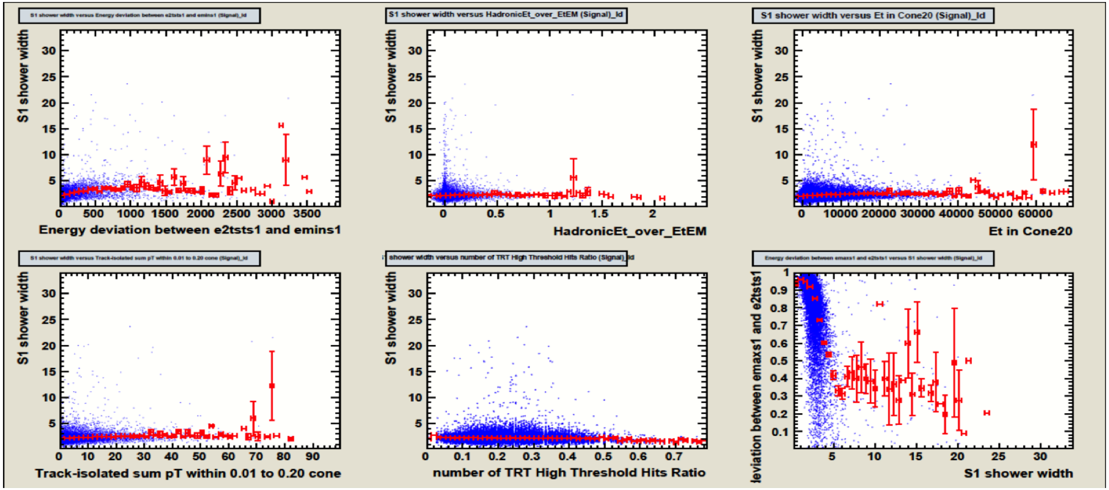
$b \to e$ TMVA tuning: efficiency Vs rejection curve

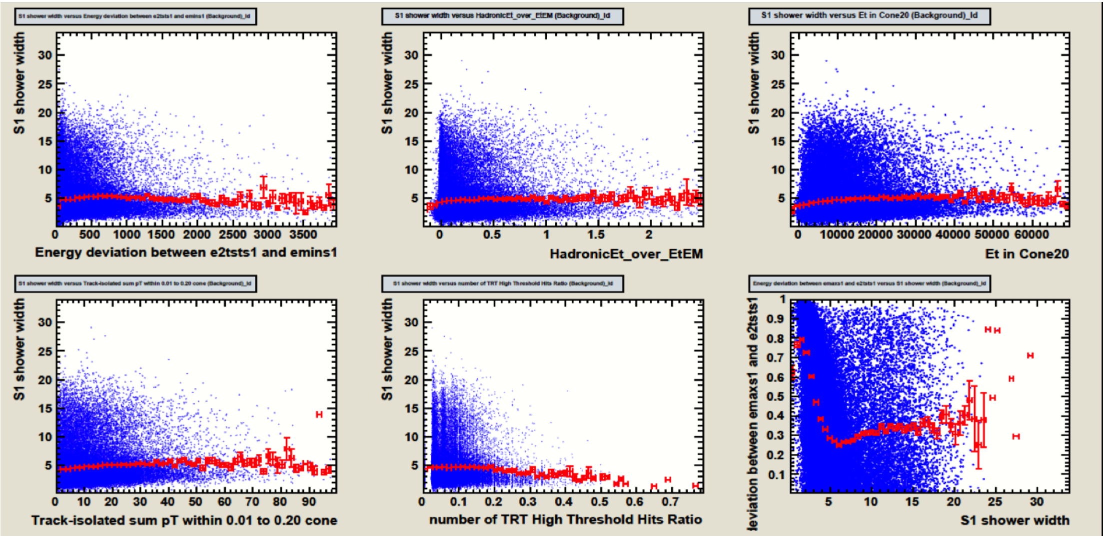


$b \to e$ TMVA tuning: TMVA input variables



$b \to e$ TMVA tuning: variable correlations (signal)




S1 shower width
Energy deviation between e2tsts1 and emins1
S1 shower width versus HadronicEt_over_EtEM (Background)_Id
S1 shower width
HadronicEt_over_EtEM
S1 shower width versus Et in Cone20 (Background)_Id
S1 shower width
Et in Cone20
S1 shower width
Track-isolated sum pT within 0.01 to 0.20 cone
S1 shower width
number of TRT High Threshold Hits Ratio
deviation between emaxs1 and e2tsts1
S1 shower width

Cutflow summary for data

Cuts	$ee + E_{\mathrm{T}}^{\mathrm{miss}}$	$\mu\mu + E_{\mathrm{T}}^{\mathrm{miss}}$	$e\mu + E_{\mathrm{T}}^{\mathrm{miss}}$
>= 2 leptons (SS+OS)	995273	1706679	16453
2 leptons (OS)	989740	1706493	16453
ℓ $p_{\mathrm{T}} > 25$GeV	979364	1678578	15157
trigger matching	978920	1678539	15063
$M_{\ell\ell(')}$ >15/10 GeV	977327	1674123	15052
Z mass veto	80140	148841	15052
$E_{\mathrm{T,\ Rel}}^{\mathrm{miss}}$ cut	1398	2411	6586
Njet(0,1,2,3,>=4)	(310,285,412,246,145)	(633,535,656,381,206)	(1169,1272,2083,1274,788)
Jet veto	310	633	1169
$p_T(\ell\ell) > 30$ GeV	174	330	821

MC prediction summary

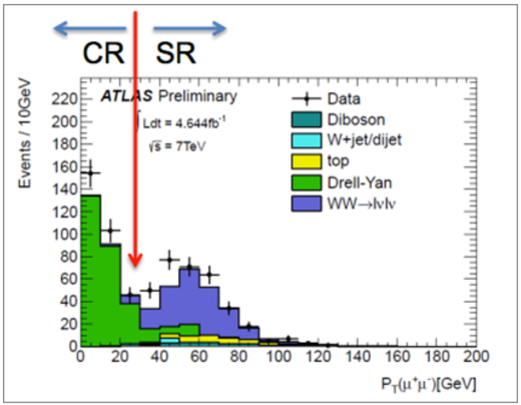
Final State	ee Channel	$\mu\mu$ Channel	$e\mu$ Channel	combined
Observed Events	174	330	821	1325
total MC prediction(S+B)	163.5	278.0	740.0	1181.6
MC WW signal	100.3	185.5	537.8	823.6
Top	23.3	33.7	90.1	147.1
W+jets+QCD	14.6	5.58	63.1	83.3
Drell-Yan	12.6	32.2	4.87	49.7
Diboson	12.70	21.0	44.1	77.9
Total Background	63.2	92.5	202.2	358.0

Table: Summary of observed data events and MC expected signal and background contributions in the three channels and their combined results.

- The Drell-Yan (DY) contamination: fake $E_{\mathrm{T}}^{\mathrm{miss}}$/jet energies not well modeled in DY MC
- Pseudo-data-driven method for DY estimation:
  - DY CR by inverting $p_T(\ell\ell) < 30$ GeV cut
  - Scale Factor (SF) derived from DY CR:

$$\mathrm{SF} = \frac{N_{Z,\mathrm{CR}}^{\mathrm{data}}}{N_{Z,\mathrm{CR}}^{\mathrm{MC}}} = \frac{N_{\mathrm{CR}}^{\mathrm{data}} - N_{non-Z,\mathrm{CR}}^{\mathrm{MC}}}{N_{Z,\mathrm{CR}}^{\mathrm{MC}}} \qquad (15)$$

  - MC predictions in the Signal Region are renormalized using SFs for all three channels



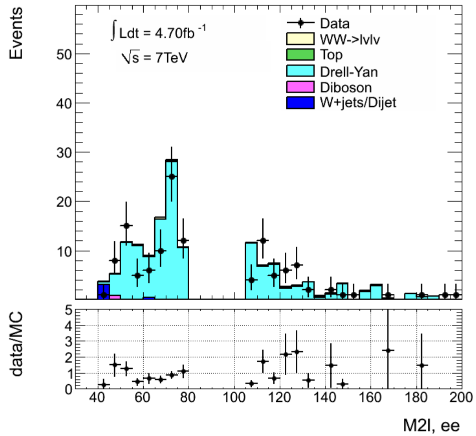


Figure: DY CR definition(left) and ee invariant mass distribution in CR (right).

	ee	$\mu\mu$	$e\mu$	combined
data-driven estimation	11.9 ± 3.0(stat) ± 2.5(syst)	34.4 ± 5.8(stat) ± 9.8(syst)	5.2 ± 1.6(stat) ± 1.1(syst)	51.4 ± 6.8(stat) ± 11.5(syst)
MC prediction	12.7 ± 2.9(stat)	32.9 ± 5.0(stat)	4.6 ± 1.3(stat)	50.3 ± 5.9(stat)

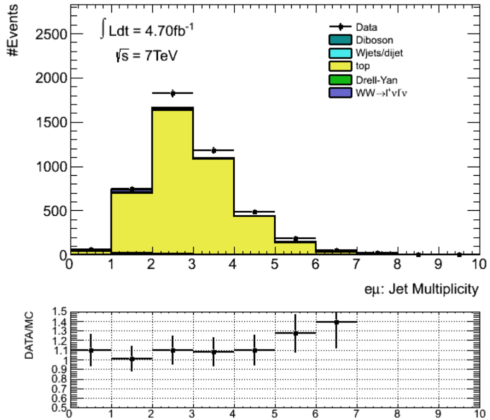
Background Estimation III: Top (Template fit method)

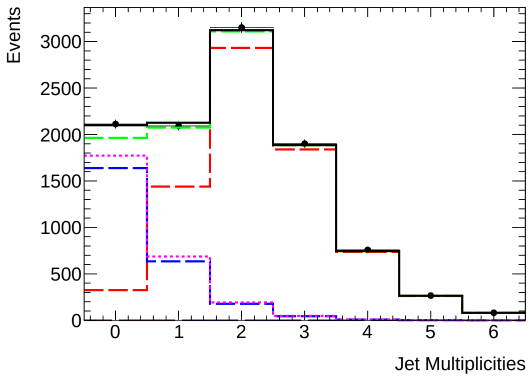
- Top background estimation **using a jet multiplicity template fit method**
  - SR1: after $E_{\mathrm{T,\ Rel}}^{\mathrm{miss}}$
  - CR: SR1 with at least 1 b-jet with $p_T > 20$ GeV
  - SR2: after all the cuts

$$\text{Data-Driven Top}^{\text{SR1}} = \frac{\text{MC Top}^{\text{SR1}}}{\text{MC Top}^{\text{CR}}} \cdot \left(\text{Data}^{\text{CR}} - f \cdot \text{MC Non-Top}^{\text{CR}}\right) \quad (16)$$

$$\text{Data}^{\text{SR1}} = \text{Data-Driven Top}^{\text{SR1}}(f) + f \cdot \text{MC Non-Top}^{\text{SR1}} \quad (17)$$

$$\text{Top Estimate}^{\text{SR2}}\ (\text{bin } 0) = \text{Data-Driven Top}^{\text{SR1}}(\text{bin } 0) \cdot \frac{\text{MC Top}^{\text{SR2}}(\text{bin } 0)}{\text{MC Top}^{\text{SR1}}(\text{bin } 0)} \quad (18)$$





Channel	ee	$\mu\mu$	$e\mu$	Combined
N_{top}	$22.4 \pm 11.8 \pm 3.4$	$32.3 \pm 14.2 \pm 4.9$	$86.5 \pm 23.3 \pm 13.1$	$141.2 \pm 29.7 \pm 21.5$

Background Estimation III: Top (Jet Veto SF method)

- Top data-driven estimation using a b-tagging CR:
  - P1: b-tagging CR jet veto survival probability
  - P2: full jet veto survival probability

$$P_2^{\mathrm{Exp}}$$

$$N_{\mathrm{top}}^{\mathrm{Est.}}(\ell\ell + E_T^{\mathrm{miss}}, 0j) \simeq N_{\mathrm{top}}^{\mathrm{Data}}(\ell\ell + E_T^{\mathrm{miss}}) \times P_2^{\mathrm{MC}} \times \left(\frac{P_1^{\mathrm{Btag,data}}}{P_1^{\mathrm{Btag,MC}}}\right)^2$$

$$= (N_{\mathrm{all}}^{\mathrm{Data}} - N^{\mathrm{non-top}}) \times (P_1^{\mathrm{Btag,data}})^2 \times \frac{P_2^{\mathrm{MC}}}{(P_1^{\mathrm{Btag,MC}})^2}$$

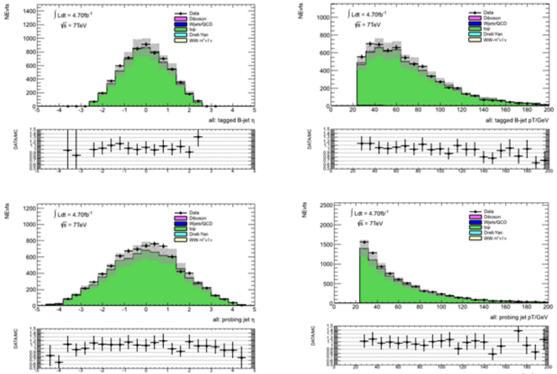
$$P_1^{\mathrm{Btag}} = N_{0j}^{\mathrm{Btag}} / N_{\mathrm{all\text{-}jets}}^{\mathrm{Btag}}$$

$$P_2^{\mathrm{MC}} = N_{0j}^{\mathrm{MC}} / N_{\mathrm{all\text{-}jets}}^{\mathrm{MC}}$$

- Insensitive to the normalization, b-tagging eff., lumi and theo. σ, JES/JER, ISR/FSR, etc.
- Agree well with MC prediction
- $\sim$16.2% overall syst. dominated by theo. uncertainty $\sim$15%
- An MC closure test using top samples with a different generator (MC@NLO Vs PowHeg) was performed well ($\sim$2% deviation)

channel	Top MC	Top DD
ee	23.3 ± 1.1(stat)	19.0 ± 3.2(stat) ± 3.1(syst)
$e\mu$	89.8 ± 2.3(stat)	88.5 ± 7.1(stat) ± 14.3(syst)
$\mu\mu$	33.7 ± 1.4(stat)	$42.6 \pm 7.3 \pm 6.9$
combined	146.8 ± 2.9(stat)	$150.1 \pm 10.7 \pm 22.3$

Table: Final DY background estimates for all three channels.



- Estimated by MC prediction (Use di-lepton invariant mass as the lower mass boundary of $W\gamma^*$)
- $W\gamma^*$ partially overlap with WZ. Scaled down using the ratio passing WZ gauge boson high mass cut.
- Off-shell Z contributions accounted in WZ and ZZ cross sections

Final State	$e^+e^- E_T^{miss}$	$\mu^+\mu^- E_T^{miss}$	$e^\pm\mu^\mp E_T^{miss}$	Combined
diboson Background				
WZ	3.18±0.31	10.82±0.56	17.42±0.72	31.41±0.96
ZZ	3.43±0.32	6.93±0.48	1.17±0.26	11.53±0.63
Wγ	3.84±0.75	0±0	15.14±1.46	18.98±1.64
W$\gamma*$	2.26±0.48	3.29±0.44	10.40±0.93	15.95±1.13
Total Background	12.70±0.99	21.04±0.86	44.12±1.89	77.87±2.30

Table: Other diboson background yields and associated stat. uncertainties

Background Estimation III: Top (Jet Veto SF method)

- Top data-driven estimation using a b-tagging CR:
  - P1: b-tagging CR jet veto survival probability
  - P2: full jet veto survival probability

$$P_2^{\text{Exp}}$$

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$$= (N_{\text{all}}^{\text{Data}} - N^{\text{non-top}}) \times (P_1^{\text{Btag,data}})^2 \times \frac{P_2^{\text{MC}}}{(P_1^{\text{Btag,MC}})^2}$$

$$P_1^{\text{Btag}} = N_{0j}^{\text{Btag}} / N_{\text{all-jets}}^{\text{Btag}}$$

$$P_2^{\text{MC}} = N_{0j}^{\text{MC}} / N_{\text{all-jets}}^{\text{MC}}$$

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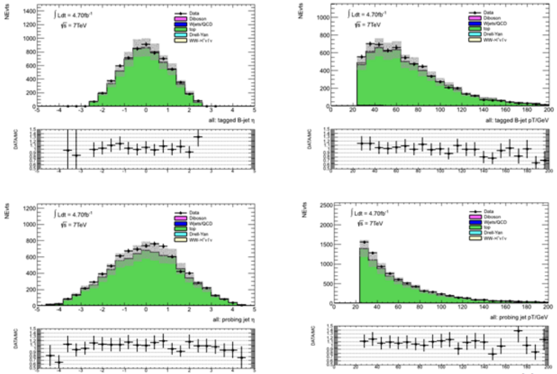
Table: Final DY background estimates for all three channels.



Data-driven Jet veto acceptance systematic estimation

- WW jet veto acceptance uncertainty is challenged by the large Jet Energy Scale and Resolution uncertainties
- Use a Z control sample from data and MC to access to the systematics data-drivenly
- MC@NLO generator used for both Z and WW samples
- Theoretical uncertainties accounted: Scales, PDFs, Parton shower modeling...
- A_{WW}: fiducial acceptance, C_{WW}: final acceptance within fiducial phase space

Uncertainties

- Consider the uncertainties on this method:

$$C_{WW} = \frac{N^{WW}_{0\ jet}(\text{MC,reco})}{N^{WW}_{0\ jet}(\text{MC,truth})} \times \frac{\epsilon^{Z}(\text{measured})}{\epsilon^{Z}(\text{MC,reco})}$$

$$A_{WW} = \epsilon^{WW}(\text{MC, truth})$$

- (MC, truth) contains theoretical uncertainties
- (MC, reco) contains both JES/JER and theoretical uncertainties

	JES/JER unc.	Theoretical unc.
C_{WW}	WW/Z	$WW/(WW \times Z)$
A_{WW}		WW
$C_{WW}A_{WW}$	WW/Z	WW/Z

- Correlations between WW and Z MC mean we get cancellations in both JES/JER and theoretical uncertainties

WW signal (MC) acceptance and cutflow

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 (4.6 fb^{-1})	2421.1	922.4	2421.1	922.4	4842.2	1844.9
2 leptons (SS+OS)	562.89	69.58	964.07	108.44	1493.68	173.51
2 leptons (OS)	558.23	69.19	964.07	108.44	1493.68	173.51
ℓ $p_{\mathrm{T}} >$ 25GeV	554.78	68.32	954.58	106.45	1475.24	169.36
trigger matching	551.17	67.71	944.83	105.30	1461.02	167.10
$M_{\ell\ell^{(\prime)}}$ >15/10 GeV	548.81	67.59	938.84	104.98	1460.10	167.00
Z mass veto	424.96	49.98	724.75	78.52	1460.10	167.00
$E_{\mathrm{T,\ Rel}}^{\mathrm{miss}}$ cut	154.42	12.91	286.98	24.21	921.08	94.69
Jet veto	97.60	7.03	180.07	14.56	586.40	57.33
$p_T(\ell\ell) > 30$ GeV	93.57	6.68	171.89	13.66	490.71	47.10
W^+W^- **Acceptance**	3.86%	0.72%	7.10%	1.48%	10.13%	2.55%

W^+W^- Signal Uncertainty

- The systematic uncertainties of lepton/jet energy scale/resolution (JES/JER) are quoted by varying independently the corresponding systematic term up and down by one σ
- The $E_{\mathrm{T}}^{\mathrm{miss}}$ systematic uncertainties have 100% correlation with the lepton and jet energy related uncertainties, which have their systematic variation propagated simultaneously to the $E_{\mathrm{T}}^{\mathrm{miss}}$
- PDF uncertainty quoted from:
  the CT10 error matrices
  central value differences between CTEQ and MSTW
  renormalisation (μ_R) and factorisation (μ_F) scale factor variation
- Dominant systematic uncertainties: total cross-section uncertainties (6.2%), **JES/JER (5.6%)**, additonal luminosity (1.8%)
- Overall systematic uncertainty: 7.6%

Signal Uncertainty Summary

- The systematic uncertainties of lepton/jet energy scale/resolution are quoted by varying independently the corresponding systematic term up and down by one σ.
- The $E_{\mathrm{T}}^{\mathrm{miss}}$ systematic uncertainties have 100% correlation with the lepton and jet energy related uncertainties, which have their systematic variation propagated simultaneously to the $E_{\mathrm{T}}^{\mathrm{miss}}$.
- PDF uncertainty quoted from: the CT10 error matrices central value differences between CTEQ and MSTW renormalisation (μ_R) and factorisation (μ_F) scale factor variation

Sources	$e^+e^- E_{\mathrm{T}}^{\mathrm{miss}}$	$\mu^+\mu^- E_{\mathrm{T}}^{\mathrm{miss}}$	$e^\pm\mu^\mp E_{\mathrm{T}}^{\mathrm{miss}}$	Combined
Luminosity	1.8%	1.8%	1.8%	1.8%
A_{WW} uncertainties				
PDF	0.85%	0.93%	0.88%	0.88%
Scale (μ_R, μ_F)	0.48%	0.48%	0.63%	0.41%
Jet veto	5.60%	5.60%	5.60%	5.60%
$\Delta A_{WW}/A_{WW}$	5.68%	5.69%	5.70%	5.69%
C_{WW} uncertainties				
Trigger	0.1%	0.6%	0.3%	0.4%
Electron Scale	0.8%	≤0.1%	0.4%	0.3%
Electron Resolution	0.2%	≤0.1%	≤0.1%	≤0.1%
Muon Scale	≤0.1%	0.5%	0.2%	0.2%
ID Muon Resolution	≤0.1%	0.1%	≤0.1%	≤0.1%
MS Muon Resolution	≤0.1%	0.1%	≤0.1%	≤0.1%
Electron recon. SF	1.6%	≤0.1%	0.8%	0.7%
Electron ID SF	2.3%	≤0.1%	1.1%	1.0%
Muon ID SF	≤0.1%	0.5%	0.3%	0.3%
Electron IsoIP	0.7%	≤0.1%	0.3%	0.3%
Muon IsoIP	≤0.1%	0.4%	0.2%	0.2%
Scale Soft Terms	0.4%	0.2%	0.4%	0.2%
Reso Soft Terms	0.3%	0.1%	≤0.1%	≤0.1%
JES & JER	0.6%	0.5%	0.5%	0.5%
Jet veto scale factor	2.8%	2.8%	2.7%	2.8%
PDF and Scale	0.7%	0.7%	0.3%	0.3%
$\Delta C_{WW}/C_{WW}$	4.2%	3.1%	3.2%	3.2%
$A_{WW}C_{WW}$ uncertainties				
Jet veto scale factor	3.7%	3.6%	3.6%	3.6%
$\Delta C_{WW}A_{WW}/C_{WW}A_{WW}$	4.9%	4.0%	4.1%	4.0%
$\sigma(W^+W^-)$ theoretic uncertainty	6.2%	6.2%	6.2%	6.2%
Full W^+W^- signal estimation uncertainty	8.1%	7.6%	7.6%	7.6%

Table: Uncertainty sources and associated relative uncertainties for W^+W^- signal acceptance estimations for ee, $e\mu$ and $\mu\mu$ channels. The overall W^+W^- signal estimation uncertainties include additonal luminosity (1.8%) and total cross-section (6.2%) uncertainties.

Diboson background uncertainties

			Uncertainties				$\pm\Delta$N
	Lumi.	Cross-section*	Jets	Leptons	MET	Trigger	
ee	1.8%	8.6%	12.0%	3.5%	0.1%	0.1%	1.92
$\mu\mu$	1.8%	8.0%	7.8%	1.2%	0.4%	0.6%	2.34
$e\mu$	1.8%	9.8%	9.6%	2.3%	0.6%	0.4%	6.09
total	1.9%	9.1%	9.4%	1.9%	0.4%	0.4%	10.20

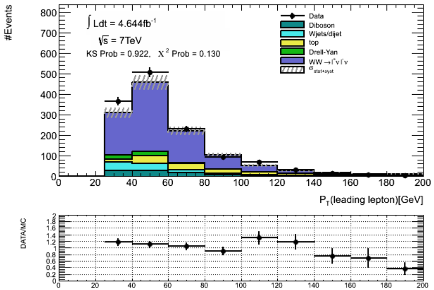
Table: Systematic uncertainty summary for other diboson backgrounds.

Signal and background summary

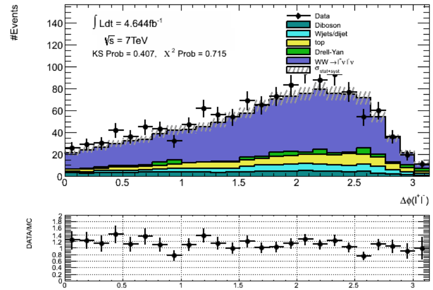
Final State	$e^+e^- E_T^{miss}$	$\mu^+\mu^- E_T^{miss}$	$e^\pm\mu^\mp E_T^{miss}$	Combined
Observed Events	174	330	821	1325
Total expected events (S+B)	168.7±12.3±15.0	279.8±15.5±19.5	743.6±23.7±53.6	1192.1±30.9±82.2
MC WW Signal	100.3±1.5±8.1	185.5±2.0±14.1	537.8±3.4±40.9	823.6±4.2±63.1
Background estimations				
Top(data-driven)	22.4±11.8±3.4	32.3±14.2±4.9	86.5±23.3±13.1	141.2±29.7±21.5
W+jets(data-driven)	21.38±0.53±11.34	6.56±0.96±2.77	70.0±1.7±31.3	98.0±2.0±42.9
Z+jets (data-driven)	11.9±3.0±2.5	34.4±5.8±9.8	5.2±1.6±1.1	51.4±6.8±11.5
Other dibosons (MC)	12.70±0.99±1.92	21.04±0.86±2.33	44.14±1.89±6.09	77.88±2.30±10.20
Total Background	68.4±12.2±12.6	94.3±15.4±13.4	205.8±23.5±34.7	368.5±30.6±52.7
Significance (S / $\sqrt{B}$)	12.1	19.1	37.5	42.9

- **The overall systematic uncertainties of W^+W^- signal are estimated using MC simulation**

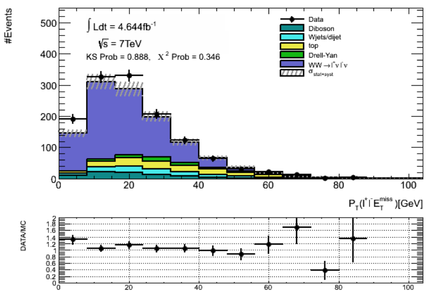
Final WW candidate plots with statistical tests



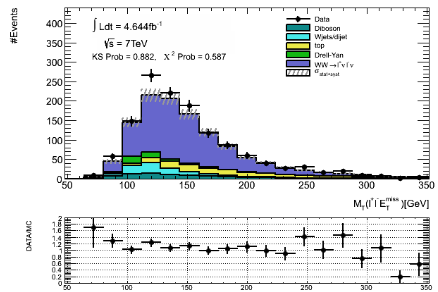
(a)



(b)

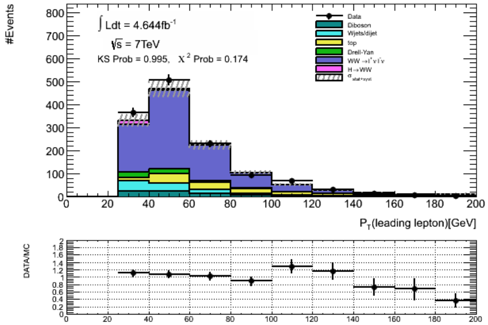


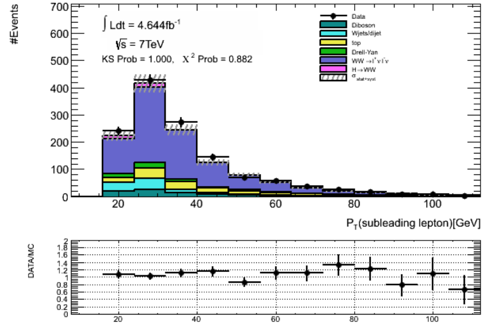
(c)

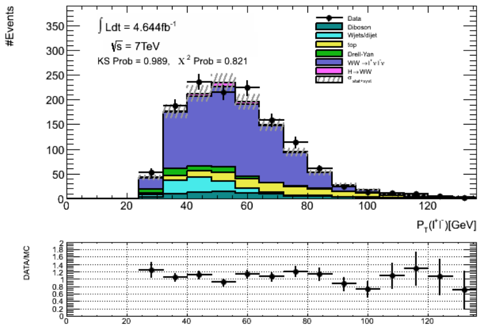


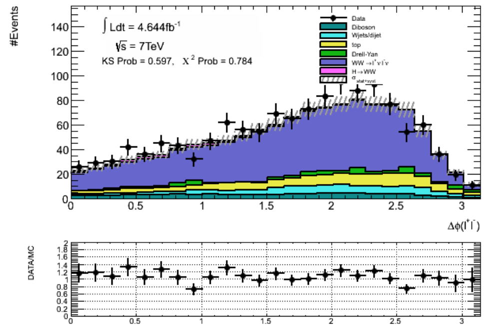
(d)

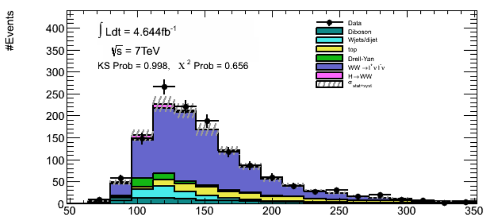
Figure: Final distributions for W^+W^- candidates in all channels: (a) leading lepton p_{T} (b) opening angle between the two leptons ($\Delta\phi(\ell\ell')$), (c) p_{T} and (d) m_{T} of the $\ell\ell' + E_{\mathrm{T}}^{\mathrm{miss}}$ system.

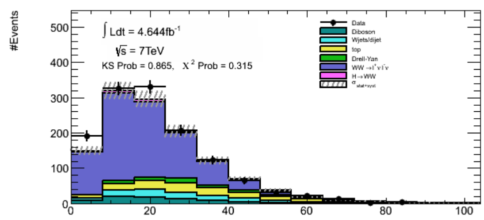

∫ Ldt = 4.644fb⁻¹
√s = 7TeV
KS Prob = 0.995, χ² Prob = 0.174
Data
Diboson
Wjets/dijet
top
Drell-Yan
WW → l⁺νl⁻ν
H → WW
σ stat+syst
#Events
P_T(leading lepton)[GeV]
DATA/MC

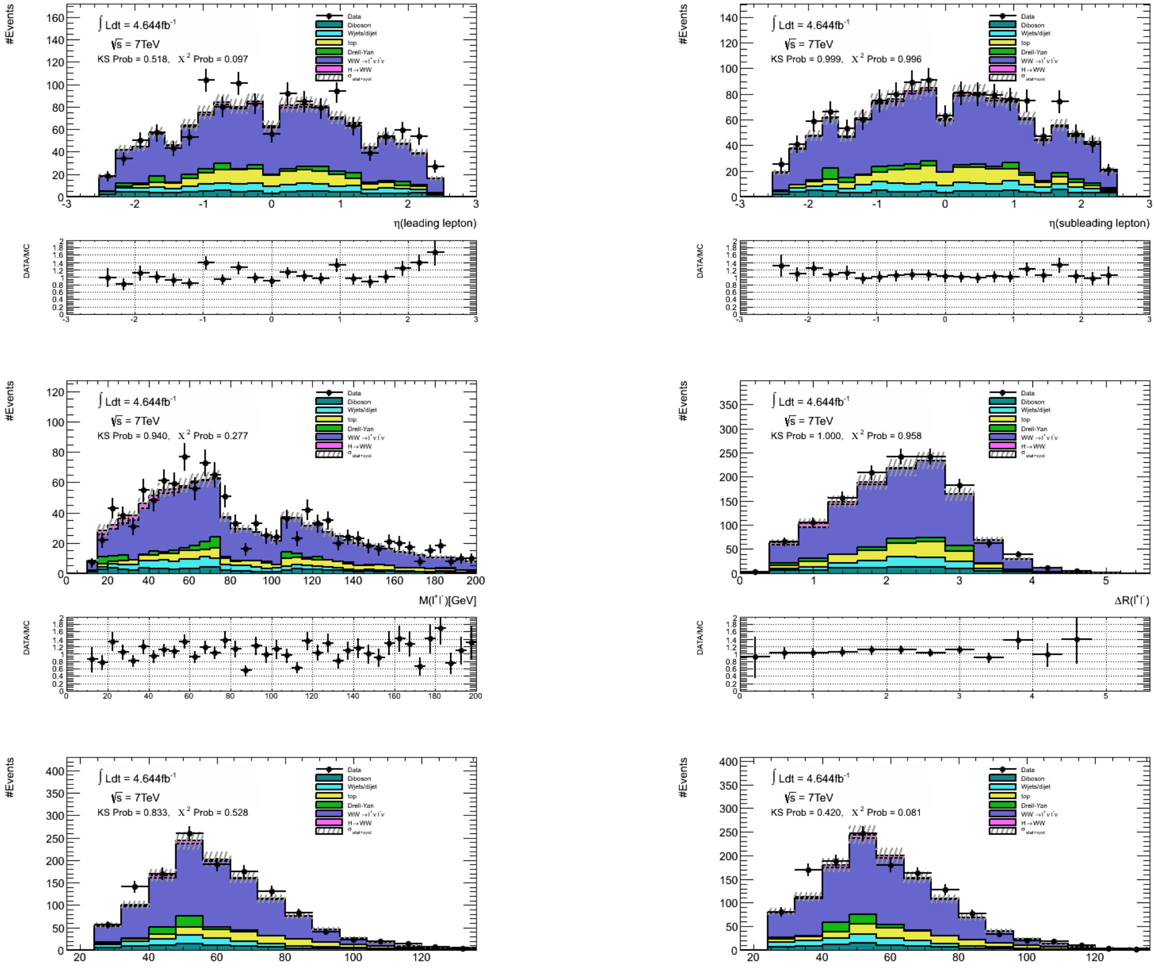

∫ Ldt = 4.644fb⁻¹
√s = 7TeV
KS Prob = 1.000, χ² Prob = 0.882
Data
Diboson
Wjets/dijet
top
Drell-Yan
WW → l⁺νl⁻ν
H → WW
σ stat+syst
#Events
P_T(subleading lepton)[GeV]
DATA/MC


∫ Ldt = 4.644fb⁻¹
√s = 7TeV
KS Prob = 0.989, χ² Prob = 0.821
Data
Diboson
Wjets/dijet
top
Drell-Yan
WW → l⁺νl⁻ν
H → WW
σ stat+syst
#Events
P_T(l⁺l⁻)[GeV]
DATA/MC


∫ Ldt = 4.644fb⁻¹
√s = 7TeV
KS Prob = 0.597, χ² Prob = 0.784
Data
Diboson
Wjets/dijet
top
Drell-Yan
WW → l⁺νl⁻ν
H → WW
σ stat+syst
#Events
Δφ(l⁺l⁻)
DATA/MC


∫ Ldt = 4.644fb⁻¹
√s = 7TeV
KS Prob = 0.998, χ² Prob = 0.656
Data
Diboson
Wjets/dijet
top
Drell-Yan
WW → l⁺νl⁻ν
H → WW
σ stat+syst
#Events


∫ Ldt = 4.644fb⁻¹
√s = 7TeV
KS Prob = 0.865, χ² Prob = 0.315
Data
Diboson
Wjets/dijet
top
Drell-Yan
WW → l⁺νl⁻ν
H → WW
σ stat+syst
#Events


∫ Ldt = 4.644fb-1
√s = 7TeV
KS Prob = 0.518, X2 Prob = 0.097
Data
Diboson
Wjets/dijet
top
Drell-Yan
WW → l+νl-ν
H → WW
σstat+syst
#Events
η(leading lepton)
DATA/MC
∫ Ldt = 4.644fb-1
√s = 7TeV
KS Prob = 0.999, X2 Prob = 0.996
η(subleading lepton)
∫ Ldt = 4.644fb-1
√s = 7TeV
KS Prob = 0.940, X2 Prob = 0.277
M(l+l-)[GeV]
∫ Ldt = 4.644fb-1
√s = 7TeV
KS Prob = 1.000, X2 Prob = 0.958
ΔR(l+l-)
∫ Ldt = 4.644fb-1
√s = 7TeV
KS Prob = 0.833, X2 Prob = 0.528
∫ Ldt = 4.644fb-1
√s = 7TeV
KS Prob = 0.420, X2 Prob = 0.081

Differential distribution measurement I

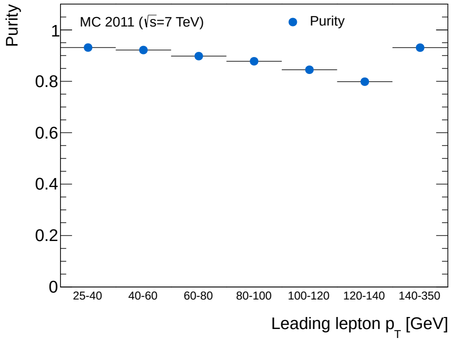
- Motivation:
  - Get rid of detector effects and flexible for the comparisons between various experiments
  - Essentially important for testing existing and future theory models and MC tuning
- Choose to unfold the leading lepton (e/μ) transverse momentum spectrum which is also used for aTGC limit setting (same binning)
- The relation of the actual observable x distributed as $f(x)$ and the $g(y)$-distributed experimental variable y is presented by:

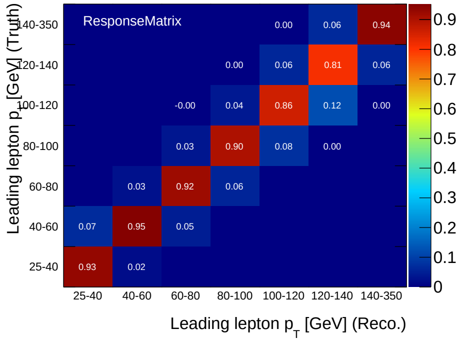
$$\int A(y,x)f(x)\mathrm{d}x = g(y) \tag{19}$$

using a kernel $A(y,x)$ in the Fredholm integration , which can be further interpreted experimentally as the response matrix form:

$$\mathbf{Ax} = \mathbf{y}. \tag{20}$$

- Bayesian unfolding treat iteratively the response matrix as the probability of measuring a given true distribution as a reconstructed observable
- High purity is verified to avoid the high bin-migration effects



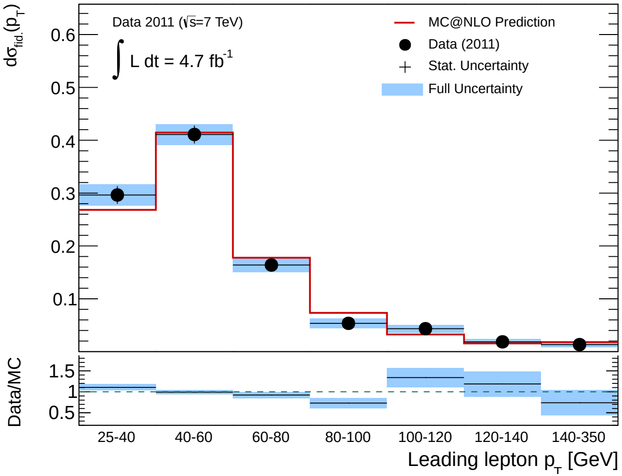


Differential distribution measurement II

- Statistical uncertainty: determined using toy MC
- Systematic uncertainty:
  - For each systematic source, create individual ntuples w.r.t. to upward and downward variations and full unfolding process is repeated for each
  - The difference $\delta_i^{sys} = x_i - x_i^{sys}$ is then taken as the systematic uncertainty in each bin. The corresponding covariance matrix for bins i and j is defined by

$$\text{Cov}_{i,j} = \delta_i^{sys} \times \delta_j^{sys}.$$

  - Covariance matrix of each systematic uncertainty is linearly added up
  - Stability test: 2 (nominal) Vs 3 iterations with the same unfolding algorithm
  - Robustness test: The nominal SIGNAL NTUPLE is not only used to define the unfolding procedure but also chosen as the input signal distribution. The agreement is well demonstrated.
- All channels are eventually combined using a common response matrix



List of presentations in ATLAS collaboration I

Parallel conference talk at PLHC2012, UBC@Vancouver, BC Canada
2012-06-07 "ATLAS diboson measurements"
https://indico.cern.ch/conferenceOtherViews.py?view=standard&confId=164272
5th France China Particle Physics Laboratory (FCPPL) Workshop:
2012-03-21 "Standard Model WW-¿lnulnu cross section measurement"
https://indico.in2p3.fr/conferenceOtherViews.py?view=standard&confId=6153
Workshop Physique Atlas France 2011:
2011-10-04 "Section efficace WW"
https://indico.cern.ch/conferenceOtherViews.py?view=cdsagenda&confId=147821
seminaire des doctorants de 1ere annee @CPPM:
2010-06-14 "(Di-)Boson WW Production Research in ATLAS Experiment"
https://indico.in2p3.fr/conferenceDisplay.py?confId=3875
PLHC2012 Session 2 rehearsal:
2012-05-30 "ATLAS diboson measurements (15'+5')"
http://indico.cern.ch/conferenceDisplay.py?confId=191464
CERN Workshop on QCD background to W:
2010-06-14 "MET Vs TRT HT Probability"
http://indico.cern.ch/conferenceDisplay.py?confId=96553
ATLAS Physics Plenary approval
2012-02-28 "Measurement of SM WW Cross-section"
http://indico.cern.ch/conferenceDisplay.py?confId=179829

List of presentations in ATLAS collaboration II

Standard Model Plenary talks of anlaysis status report and paper/conf note approval:
2012-06-28 "WW cross section (FULL STATUS REPORT) - 25+10 min"
http://indico.cern.ch/conferenceDisplay.py?confId=153427
2012-02-09 "WW-¿lnulnu (STATUS REPORT FOR MORIOND CONF)"
http://indico.cern.ch/conferenceDisplay.py?confId=153407
2012-01-12 "WW status report (20+10)"
http://indico.cern.ch/conferenceDisplay.py?confId=153403
2011-07-19 "Overview of SM WW Cross-section Analysis (15+10 mins)"
http://indico.cern.ch/conferenceDisplay.py?confId=147822
2011-05-19 "Status Report on WW Measurements for 2011 (15+5 mins)"
http://indico.cern.ch/conferenceDisplay.py?confId=137517
2011-04-21 "First look at 2011 data in the WW analysis"
http://indico.cern.ch/conferenceDisplay.py?confId=128324
Joint sub-group plenary for W/Z common topics:
2012-11-14 "MET studies"
https://indico.cern.ch/conferenceDisplay.py?confId=162435

List of presentations in ATLAS collaboration III

Standard Model electroweak subgroup plenary talks:
2012-08-03 "WW lnulnu"
http://indico.cern.ch/conferenceDisplay.py?confId=202639
2012-06-01 "WW-¿lnln"
http://indico.cern.ch/conferenceDisplay.py?confId=193978
2012-05-04 "WW status report and JetETMiss uncertainty evaluation in 5fb-1 7TeV analysis"
http://indico.cern.ch/conferenceDisplay.py?confId=189580
2012-03-30 "WW preselection update"
http://indico.cern.ch/conferenceDisplay.py?confId=184438
2012-03-02 "Track MET study for WW post-Moriond"
http://indico.cern.ch/conferenceDisplay.py?confId=180515
2012-01-20 "WW update"
http://indico.cern.ch/conferenceDisplay.py?confId=172817
2012-01-06 "mc11c performance and WW Met optimization"
http://indico.cern.ch/conferenceDisplay.py?confId=169362
2011-12-09 "Met Performance Study"
http://indico.cern.ch/conferenceDisplay.py?confId=165799
2011-12-02 "Met optimization for WW in Rel17"
http://indico.cern.ch/conferenceDisplay.py?confId=164856
2011-11-25 "Update on the Etmiss performance study in r17"
http://indico.cern.ch/conferenceDisplay.py?confId=164012
2011-11-18 "MET performance study for R17"
http://indico.cern.ch/conferenceDisplay.py?confId=163077
2011-11-04 "A first look at WW-¿lnulnu analysis in R17"
http://indico.cern.ch/conferenceDisplay.py?confId=160671
2011-08-05 "Wjets update with lower jet pT"

List of presentations in ATLAS collaboration IV

Egamma combined performance meeting:
2010-03-31 "Material mapping with Electron shower shape from b-¿e"
http://indico.cern.ch/conferenceDisplay.py?confId=82382
2010-01-14 "Material mapping with showers shape for b-¿e"
http://indico.cern.ch/conferenceDisplay.py?confId=77965
WWlnulnu analysis meeting:
2012-06-18 "Baseline Top-Bg Method"
http://indico.cern.ch/conferenceDisplay.py?confId=196390
2012-06-13 "Unfolding"
http://indico.cern.ch/conferenceDisplay.py?confId=195656
2012-05-30 "Status of Event Selection and Plots"
http://indico.cern.ch/conferenceDisplay.py?confId=193507
2012-05-23 "Event Selection and JES"
http://indico.cern.ch/conferenceDisplay.py?confId=192385
2012-05-15 "Cut-Flow, Tables, Plots and Top"
http://indico.cern.ch/conferenceDisplay.py?confId=191273
2012-05-09 "event selection and top background"
http://indico.cern.ch/conferenceDisplay.py?confId=190361
2012-04-25 "Event Selection and Uncertainties"
http://indico.cern.ch/conferenceDisplay.py?confId=187962
2012-04-18 "EventSelection, MCCorrections and Top"
http://indico.cern.ch/conferenceDisplay.py?confId=187126
2012-04-11 "DD Top Estimate and new Selection"
http://indico.cern.ch/conferenceDisplay.py?confId=185358
2012-04-05 "Preselection status"
http://indico.cern.ch/conferenceDisplay.py?confId=185531

List of presentations in ATLAS collaboration V

HSG3 track/calo MET meeting - Higgs WG subgroup informal:
2012-04-23 "contributions from everyone"
http://indico.cern.ch/conferenceDisplay.py?confId=187653
2012-04-16 "contributions from everyone"
http://indico.cern.ch/conferenceDisplay.py?confId=186770
2012-04-12 "contributions from everyone"
http://indico.cern.ch/conferenceDisplay.py?confId=186238
2012-04-02 "contributions from everyone"
http://indico.cern.ch/conferenceDisplay.py?confId=184902
2012-03-14 "Wg/Wg* MC Samples"
http://indico.cern.ch/conferenceDisplay.py?confId=180010
Data Preparation and Data Quality meeting:
2010-09-29 "LAr (EMB, EMEC, HEC and FCAL)"
https://indico.cern.ch/conferenceDisplay.py?confId=102556
2010-08-25 "LAr (EMB, EMEC, HEC and FCAL)"
https://indico.cern.ch/conferenceDisplay.py?confId=102551
2010-08-11 "LAr (EMB, EMEC, HEC and FCAL)"
https://indico.cern.ch/conferenceDisplay.py?confId=102549
LAr Weekly meeting:
2010-09-27 "Report from DQ offline"
http://indico.cern.ch/conferenceDisplay.py?confId=72631
2010-09-13 "DQ offline report"
http://indico.cern.ch/conferenceDisplay.py?confId=72630
2010-09-06 "DQ report"
http://indico.cern.ch/conferenceDisplay.py?confId=72629
2010-08-30 "DQ report"