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

Shu LI$^{1,2}$

Supervisors:
Zhengguo ZHAO$^1$
Yanwen LIU$^1$
Emmanuel MONNIER$^2$

$^1$University of Science and Technology of China
$^2$Centre de Physique des Particules de Marseille, France

Nov 2$^{nd}$, 2012
1 Introduction
   • The Standard Model Framework and the Electroweak interactions
   • The Large Hadron Collider and the ATLAS Detector
Outline

1 Introduction
   - The Standard Model Framework and the Electroweak interactions
   - 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
Outline

1 Introduction
   • The Standard Model Framework and the Electroweak interactions
   • 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
Outline

1 Introduction
   - The Standard Model Framework and the Electroweak interactions
   - 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
Introduction to the Standard Model

- Matured framework of quantized field theory for modern elementary particles and interactions
- **Elementary particles and three fundamental interactions:** strong, weak and electromagnetic (EM)
- **Shortcomings:**
  - Many free parameters and unsolved topics: hierarchy problem, neutrino mass, dark matter candidate, etc.
### Standard Model Particles and Interactions

#### Generations

<table>
<thead>
<tr>
<th>Quarks</th>
<th>Charge $[e]$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1st generation</td>
<td>2nd generation</td>
</tr>
<tr>
<td>$u$(Up)</td>
<td>$c$(Charm)</td>
</tr>
<tr>
<td>$d$(Down)</td>
<td>$s$(Strange)</td>
</tr>
<tr>
<td>$m_u = 1.7 - 3.3$ MeV</td>
<td>$m_c = 1.27$ GeV</td>
</tr>
<tr>
<td>$m_d = 4.1 - 5.8$ MeV</td>
<td>$m_s = 101$ MeV</td>
</tr>
</tbody>
</table>
| $
u_e < 2 \times 10^{-6}$ MeV | $\nu_\mu < 0.19$ MeV | $\nu_\tau < 18.2$ MeV |
| $e = 0.511$ MeV | $\mu = 105.7$ MeV | $\tau = 1.777$ GeV |

#### Leptons

<table>
<thead>
<tr>
<th>Charge $[e]$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$m_{\nu_e} = 2.17$ MeV</td>
</tr>
<tr>
<td>$m_{\nu_\mu} = 0.19$ MeV</td>
</tr>
<tr>
<td>$m_{\nu_\tau} = 18.2$ MeV</td>
</tr>
<tr>
<td>$m_e = 0.511$ MeV</td>
</tr>
<tr>
<td>$m_\mu = 105.7$ MeV</td>
</tr>
<tr>
<td>$m_\tau = 1.777$ GeV</td>
</tr>
</tbody>
</table>

#### Gauge Bosons

<table>
<thead>
<tr>
<th>Mass [GeV]</th>
<th>Charge $[e]$</th>
</tr>
</thead>
<tbody>
<tr>
<td>gluon($g_i$, $i=1,...,8$)</td>
<td>0</td>
</tr>
<tr>
<td>Photon($\gamma$)</td>
<td>0</td>
</tr>
<tr>
<td>$W^+$ (weak boson)</td>
<td>80.4</td>
</tr>
<tr>
<td>$W^-$ (weak boson)</td>
<td>-1</td>
</tr>
<tr>
<td>$Z^0$ (weak boson)</td>
<td>91.2</td>
</tr>
</tbody>
</table>

#### Graviton (hypothetical)

Standard Model diboson productions

Figure: Generic SM tree-level Feynman diagrams for diboson production with triple-gauge boson couplings (aTGC) (left). $V_1, V_2 = W, Z, \gamma$.

- 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. $H \rightarrow ZZ/WW$)

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)

- \( \sqrt{s} = 7/8 \text{ TeV} \) (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: \( 10^{33} \sim 10^{34} \text{ cm}^{-2}\text{s}^{-1} \)
    (achieved \( > 7 \times 10^{33} \text{ cm}^{-2}\text{s}^{-1} \) in 2012)
  - ALICE: \( 10^{27} \text{ cm}^{-2}\text{s}^{-1} \)
  - LHCb: \( 10^{32} \text{ cm}^{-2}\text{s}^{-1} \)
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$^{-1}$
Particle Identification at ATLAS
The Inner Detectors (ID)

- Extremely 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)
- ∼ 4% momentum 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: |η| < 4.9
  - Good reconstruction of missing transverse energy ($E_{T}^{\text{miss}}$) (important new physics signature)

- EM depth: $\sim 22(24) \, X_0$ (radiation length) in the barrel (endcaps). Overall 11 $\lambda$ (interaction length) of active calorimeter, 1.3 $\lambda$ 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 $E_{T}^{\text{miss}}$

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: $0 < |\eta| < 2.5$
- 1ˢᵗ and 2ⁿᵈ layers: the finest segmentation along $\eta$, 3ʳᵈ layer: less segmented to take the residual of the EM showers deposition
- Nominal resolution: $\sigma_E / E = \frac{10%}{\sqrt{E(\text{GeV})}} \oplus 0.7%$
  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**:
  \[
  \frac{\sigma_E}{E} = \frac{50\%}{\sqrt{E(\text{GeV})}} \oplus 3\% \text{ (Tile and HEC)}
  \]
  \[
  \frac{\sigma_E}{E} = \frac{100\%}{\sqrt{E(\text{GeV})}} \oplus 10\% \text{ (FCal)}
  \]

- **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: \(\sim 10 \lambda\)
Muon Spectrometer

- Toroid magnet: 1 in the barrel and 2 in the end-caps, $\eta$-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)
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 (400~800 Hz)
- **EF level** electron and muon triggers to be considered in this analysis
**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 instantaneous luminosity: \( 10^{32} \sim 10^{33} cm^{-2}s^{-1} \)

**2012:** \( \sqrt{s} = 8 \) TeV \( pp \) collisions, stable beam peak instantaneous 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 evaluation:** Data integrity error, Noise Burst, High Voltage Trips, Beam Halo, etc.

<table>
<thead>
<tr>
<th>Subdetector</th>
<th>Number of Channels</th>
<th>Approximate Operational Fraction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pixels</td>
<td>80 M</td>
<td>95.0%</td>
</tr>
<tr>
<td>SCT Silicon Strips</td>
<td>6.3 M</td>
<td>99.3%</td>
</tr>
<tr>
<td>TRT Transition Radiation Tracker</td>
<td>350 k</td>
<td>97.5%</td>
</tr>
<tr>
<td>LAr EM Calorimeter</td>
<td>170 k</td>
<td>99.9%</td>
</tr>
<tr>
<td>Tile calorimeter</td>
<td>9800</td>
<td>98.3%</td>
</tr>
<tr>
<td>Hadronic endcap LAr calorimeter</td>
<td>5600</td>
<td>99.8%</td>
</tr>
<tr>
<td>Forward LAr calorimeter</td>
<td>3500</td>
<td>99.8%</td>
</tr>
<tr>
<td>LVL1 Calo trigger</td>
<td>7160</td>
<td>100%</td>
</tr>
<tr>
<td>LVL1 Muon RPC trigger</td>
<td>370 k</td>
<td>100%</td>
</tr>
<tr>
<td>LVL1 Muon TGC trigger</td>
<td>320 k</td>
<td>100%</td>
</tr>
<tr>
<td>MDT Muon Drift Tubes</td>
<td>350 k</td>
<td>99.7%</td>
</tr>
<tr>
<td>CSC Cathode Strip Chambers</td>
<td>31 k</td>
<td>96.0%</td>
</tr>
<tr>
<td>RPC Barrel Muon Chambers</td>
<td>370 k</td>
<td>97.1%</td>
</tr>
<tr>
<td>TGC Endcap Muon Chambers</td>
<td>320 k</td>
<td>98.2%</td>
</tr>
</tbody>
</table>
Data and MC for ATLAS analysis

- Raw collision data reconstruction and offline data preparation challenged by the high collision rates and complex interaction at LHC
- Data processing chain:
  - Raw data
  - ESD: Event Summary Data
  - AOD: Analysis Object Data
  - DPD: Derived Physics Data (D1PD, D2PD and D3PD)
- MC production:
  - Full detector simulation / ATLAS Fast simulation
  - Offline object momentum/energy rescaling/smearing to account for the difference between MC and data
- Analysis based on D3PD of data and MC with full simulation
Outline

1 Introduction
   - The Standard Model Framework and the Electroweak interactions
   - 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
Introduction to Standard Model $W^+W^-$ measurement

- **Characteristics:**
  - Isolated high $p_T$ di-leptonic decay channels: $ee$, $e\mu$ and $\mu\mu$
  - $W \rightarrow \tau + X \rightarrow e/\mu + X$ included
  - $qq \rightarrow WW$: $\sigma_{NLO} = (43.4 \pm 2.25) \text{ pb (DOMINANT)}$; $gg \rightarrow WW$: $\sim 3\%$: 1.3 pb

- **Major backgrounds:**
  - jet/photon→lepton misidentification: $W$+jets, QCD Multi-jet, $W+\gamma$
  - fake $E_T^\text{miss}$: $Z$+jets
  - $W^+W^-$ + multi-jets: $t\bar{t}$ and single top
  - Other diboson: $WZ \rightarrow lll\nu$, $ZZ \rightarrow lll\nu$
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:**
- $tt$: 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
Object Definition I: Leptons

**Electron Identification (ID + Calo):**
- Criteria optimized to provide good separation between electrons and fakes (γ or jets)
- Three reference cut sets: *loose++*, *medium++* and *tight++* with increasing background rejection
- Baseline definition in $W^+W^-$ analysis:
  - Reconstructed Electron Candidate with DQ constraints
  - $|\eta| < 2.47$ (excluding transition region $1.37 \leq |\eta| \leq 1.52$), $E_T > 25/20\text{GeV}$
  - Identification Criteria: *tight++* (75~80% efficiency)
  - Calorimeter/Track Isolation
  - Transverse/Longitudinal Impact Parameter Requirements

**Muon Identification (ID + MS)**
- Reconstructed muon with good ID/MS combination and track quality
- $p_T > 25/20 \text{GeV}$, $|\eta| < 2.4$
- Longitudinal/Transverse Impact parameter requirements
- Calorimeter/Track Isolation

**Leading lepton $p_T > 25$ GeV to stay on the trigger plateau**
Object Definition II: Jet and $E_{T}^{\text{miss}}$

Jet Definition:
- $p_{T} > 25$ GeV, $|\eta| < 4.5$, calibrated to the hadronic energy scale
- $b$-tagged jets used in top background estimation (ATLAS MV1 algorithm)

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

\[
E_{T, \text{Rel}}^{\text{miss}} = \begin{cases} 
E_{T}^{\text{miss}} \times \sin(\Delta \phi_{\ell,j}) & \text{if } \Delta \phi_{\ell,j} < \pi/2 \\
\frac{E_{T}^{\text{miss}}}{E_{T}^{\text{miss}}} & \text{if } \Delta \phi_{\ell,j} \geq \pi/2
\end{cases} \quad (1)
\]

, where $\Delta \phi_{\ell,j}$ is the difference in azimuthal angle between the $E_{T}^{\text{miss}}$ and nearest good lepton or jet
Event Selection I: general selection

- Data Quality: within GRL

- Primary vertex with $nTracks > 2$

- Trigger: single $e$ and single $\mu$ trigger ("OR" for $e\mu$ channel) (trigger scale factors applied to account for MC mismodeling)

- Pileup reweighting, momentum smearing/scaling, etc.

- Dilepton selection: two and only two opposite sign good leptons
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)

- \( E_{T,\text{Rel}}^{\text{miss}} > 45/45/25 \) 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) 0-jet in the $W^+W^-$ signal region

(b) 0-jet in the $W^+W^-$ signal region

(c) 0-jet in the $W^+W^-$ signal region

(d) 0-jet in the $W^+W^-$ signal region
Background Estimation I: \(W+\text{jet}\)

- \(W+\text{jets}\) contamination: one jet misidentified as a good lepton
- Jet misidentification rate not correctly modeled in MC
- Use \(W+\text{jet}\) enriched control region and fake factors measured from data:
  - Fake factor: ratio of identified leptons over ”jet-rich” ones
  - \(W+\text{jet}\) Control Region: 1 ”jet-rich” lepton + 1 good lepton
  - Systematics: trigger bias, away-side jet \(p_T\) dependence, sample dependence(\(W+\text{jet}\) Vs dijet), etc.
- Final estimation:
  \[
  N_{\text{one id + one fake}} = f_t \times N_{\text{one id + one jet-rich}}. 
  \]
  (2)

<table>
<thead>
<tr>
<th></th>
<th>ee-ch</th>
<th>(e\mu)-ch</th>
<th>(\mu\mu)-ch</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>(W+\text{jet background (e-fakes)})</td>
<td>21.38 ± 0.53 ± 11.34</td>
<td>56.25 ± 0.90 ± 30.19</td>
<td>-</td>
<td>77.6 ± 1.0 ± 41.5</td>
</tr>
<tr>
<td>(W+\text{jet background ((\mu)-fakes)})</td>
<td>-</td>
<td>13.8 ± 1.4 ± 8.1</td>
<td>6.56 ± 0.96 ± 2.77</td>
<td>20.4 ± 1.7 ± 10.9</td>
</tr>
<tr>
<td>Total (W+\text{jet background})</td>
<td>21.38 ± 0.53 ± 11.34</td>
<td>70.0 ± 1.7 ± 31.3</td>
<td>6.56 ± 0.96 ± 2.77</td>
<td>98.0 ± 2.0 ± 42.9</td>
</tr>
<tr>
<td>(W+\text{jet MC (comparison)})</td>
<td>16.2 ± 4.5</td>
<td>60.1 ± 8.4</td>
<td>5.5 ± 2.1</td>
<td>81.8 ± 9.8</td>
</tr>
</tbody>
</table>

Figure: \(W+\text{jets}\) fake factor with stat./syst. uncertainties
Background Estimation II: Drell-Yan

- The Drell-Yan (DY) contamination: fake $E_T^{\text{miss}}$/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:
    \[
    SF = \frac{N_{data,Z,CR}}{N_{MC,Z,CR}} = \frac{N_{data} - N_{MC}^{non-Z,CR}}{N_{MC}^{Z,CR}}
    \] (3)
  - 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).

<table>
<thead>
<tr>
<th></th>
<th>$ee$</th>
<th>$\mu\mu$</th>
<th>$e\mu$</th>
<th>combined</th>
</tr>
</thead>
<tbody>
<tr>
<td>data-driven estimation</td>
<td>$11.9 \pm 3.0(\text{stat}) \pm 2.5(\text{syst})$</td>
<td>$34.4 \pm 5.8(\text{stat}) \pm 9.8(\text{syst})$</td>
<td>$5.2 \pm 1.6(\text{stat}) \pm 1.1(\text{syst})$</td>
<td>$51.4 \pm 6.8(\text{stat}) \pm 11.5(\text{syst})$</td>
</tr>
<tr>
<td>MC prediction</td>
<td>$12.7 \pm 2.9(\text{stat})$</td>
<td>$32.9 \pm 5.0(\text{stat})$</td>
<td>$4.6 \pm 1.3(\text{stat})$</td>
<td>$50.3 \pm 5.9(\text{stat})$</td>
</tr>
</tbody>
</table>
Background Estimation III: Top (Jet Veto SF method)

- Top data-driven estimation using a b-tagging CR to be propagated to the $W^+W^-$ signal region
- Insensitive to normalization, b-tagging, theo. $\sigma$, JES/JER, ISR/FSR, etc.
- An MC closure test using top samples with a different generator (MC@NLO Vs PowHeg) was performed well ($\sim$2% deviation)
- $\sim$16.2% overall syst. dominated by theo. uncertainty $\sim$15%

Figure: Jet $p_T$(left)/$\eta$(right) spectrum b-tagged CR comparison between data and MC.
Background Estimation III: Top (Template fit method)

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

$$\text{Data-Driven Top}^{\text{SR1}} = \frac{\text{MC Top}^{\text{SR1}}}{\text{MC Top}^{\text{CR}}} \cdot (\text{Data}^{\text{CR}} - f \cdot \text{MC Non-Top}^{\text{CR}})$$ (4)

$$\text{Data}^{\text{SR1}} = \text{Data-Driven Top}^{\text{SR1}}(f) + f \cdot \text{MC Non-Top}^{\text{SR1}}$$ (5)

$$\text{Top Estimate}^{\text{SR2}} \text{ (bin 0)} = \text{Data-Driven Top}^{\text{SR1}} \text{ (bin 0)} \cdot \frac{\text{MC Top}^{\text{SR2}} \text{ (bin 0)}}{\text{MC Top}^{\text{SR1}} \text{ (bin 0)}}$$ (6)

![Jet Multiplicities](image)

<table>
<thead>
<tr>
<th>Channel</th>
<th>$ee$</th>
<th>$\mu\mu$</th>
<th>$e\mu$</th>
<th>Combined</th>
</tr>
</thead>
<tbody>
<tr>
<td>$N_{top}$</td>
<td>$22.4 \pm 11.8 \pm 3.4$</td>
<td>$32.3 \pm 14.2 \pm 4.9$</td>
<td>$86.5 \pm 23.3 \pm 13.1$</td>
<td>$141.2 \pm 29.7 \pm 21.5$</td>
</tr>
</tbody>
</table>
Background Estimation IV: other diboson

- 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

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

Table: Other diboson background yields and associated stat. uncertainties
### WW signal (MC) acceptance and cutflow

<table>
<thead>
<tr>
<th>Cuts</th>
<th>$ee$ Channel</th>
<th>$\mu\mu$ Channel</th>
<th>$e\mu$ Channel</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$ee\nu\nu$</td>
<td>$\tau\nu\ell\nu$</td>
<td>$\mu\mu\nu$</td>
</tr>
<tr>
<td>Total Events (4.6 fb⁻¹)</td>
<td>2421.1</td>
<td>922.4</td>
<td>2421.1</td>
</tr>
<tr>
<td>2 leptons (SS+OS)</td>
<td>562.89</td>
<td>69.58</td>
<td>964.07</td>
</tr>
<tr>
<td>2 leptons (OS)</td>
<td>558.23</td>
<td>69.19</td>
<td>964.07</td>
</tr>
<tr>
<td>$\ell p_T &gt; 25$ GeV</td>
<td>554.78</td>
<td>68.32</td>
<td>954.58</td>
</tr>
<tr>
<td>trigger matching</td>
<td>551.17</td>
<td>67.71</td>
<td>944.83</td>
</tr>
<tr>
<td>$M_{\ell\ell(')} &gt; 15/10$ GeV</td>
<td>548.81</td>
<td>67.59</td>
<td>938.84</td>
</tr>
<tr>
<td>Z mass veto</td>
<td>424.96</td>
<td>49.98</td>
<td>724.75</td>
</tr>
<tr>
<td>$E_{T,\text{Rel}}^\text{miss}$</td>
<td>154.42</td>
<td>12.91</td>
<td>286.98</td>
</tr>
<tr>
<td>Jet veto</td>
<td>97.60</td>
<td>7.03</td>
<td>180.07</td>
</tr>
<tr>
<td>$p_T(\ell\ell) &gt; 30$ GeV</td>
<td>93.57</td>
<td>6.68</td>
<td>171.89</td>
</tr>
<tr>
<td><strong>$W^+W^-$ Acceptance</strong></td>
<td><strong>3.86%</strong></td>
<td><strong>0.72%</strong></td>
<td><strong>7.10%</strong></td>
</tr>
</tbody>
</table>
Systematics I: 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:

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

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

(MC, truth) contains theoretical uncertainties

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

<table>
<thead>
<tr>
<th></th>
<th>JES/JER unc.</th>
<th>Theoretical unc.</th>
</tr>
</thead>
<tbody>
<tr>
<td>$C_{WW}$</td>
<td>WW/Z</td>
<td>WW/(WW × Z)</td>
</tr>
<tr>
<td>$A_{WW}$</td>
<td>WW/Z</td>
<td>WW</td>
</tr>
<tr>
<td>$C_{WW}A_{WW}$</td>
<td>WW/Z</td>
<td>WW/Z</td>
</tr>
</tbody>
</table>

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

The $E_{T}^{\text{miss}}$ systematic uncertainties have 100% correlation with the lepton and jet energy related uncertainties, which have their systematic variation propagated simultaneously to the $E_{T}^{\text{miss}}$.

PDF uncertainty quoted from:
- the CT10 error matrices
- central value differences between CTEQ and MSTW
- renormalisation ($\mu_R$) and factorisation ($\mu_F$) scale factor variation

Dominant systematic uncertainties: total cross-section uncertainties (6.2%), JES/JER (5.6%), additional luminosity (1.8%)

Overall systematic uncertainty: 7.6%
Signal and background summary

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

- The overall systematic uncertainties of $W^+W^-$ signal are estimated using MC simulation
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 $\ell\ell' + E_T^{miss}$ system.
Cross section measurement: methodology

- Cross section calculation:
  \[
  \sigma_{WW} = \frac{N_{\text{obs}} - N_{\text{bkg}}}{\epsilon A L Br}
  \]  

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

  \[
  A_{WW} = \frac{N(\text{generator - level fiducial cuts})}{N(\text{generated events})},
  \]  

  \[
  \epsilon A = A_{WW} \cdot C_{WW} = \frac{N(\text{reco - level analysis cuts})}{N(\text{generated events})},
  \]  

  \[
  C_{WW} = \frac{\epsilon A}{A_{WW}} = \frac{N(\text{reco - level analysis cuts})}{N(\text{generator - level fiducial cuts})},
  \]

- Fiducial cross section allows for easier comparisons with other theoretical predictions, and constitutes a measurement which minimises theoretical uncertainties

  \[
  \sigma_{WW}^{\text{fiducial}} = \frac{N_{\text{obs}} - N_{\text{bkg}}}{C_{WW} L}
  \]  

- Fiducial definition mimic the nominal selection using truth information
- \( W^+W^- \) fiducial/total cross sections determined in the three dilepton channels by maximising log-likelihood functions:

  \[
  L(\sigma_{WW}^{\text{fid}}) = \ln \prod_{i=1}^{3} e^{-\left( N_{s}^{i} + N_{b}^{i} \right)} \times \left( N_{s}^{i} + N_{b}^{i} \right)^{N_{\text{obs}}^{i}}, \quad N_{s}^{i} = \sigma_{WW \rightarrow \ell\nu\ell\nu}^{i} \times L \times C_{WW}^{i}
  \]

  \[
  L(\sigma_{WW}^{\text{total}}) = \ln \prod_{i=1}^{3} e^{-\left( N_{s}^{i} + N_{b}^{i} \right)} \times \left( N_{s}^{i} + N_{b}^{i} \right)^{N_{\text{obs}}^{i}}, \quad N_{s}^{i} = \sigma_{WW}^{\text{total}} \times Br \times L \times \epsilon_{WW}^{i}
  \]
Cross section measurement: results

<table>
<thead>
<tr>
<th>Channels</th>
<th>expected $\sigma^{fid} (\text{fb})$</th>
<th>measured $\sigma^{fid} (\text{fb})$</th>
<th>$\Delta\sigma_{stat} (\text{fb})$</th>
<th>$\Delta\sigma_{syst} (\text{fb})$</th>
<th>$\Delta\sigma_{lumi} (\text{fb})$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$e\nu e\bar{\nu}$</td>
<td>54.6±4.1</td>
<td>56.4</td>
<td>± 6.8</td>
<td>± 9.8</td>
<td>± 1.0</td>
</tr>
<tr>
<td>$\mu\nu\mu\bar{\nu}$</td>
<td>58.9±4.5</td>
<td>73.9</td>
<td>± 5.9</td>
<td>± 6.9</td>
<td>± 1.3</td>
</tr>
<tr>
<td>$e\nu\mu\bar{\nu}$</td>
<td>231.4±19.9</td>
<td>262.3</td>
<td>± 12.3</td>
<td>± 20.7</td>
<td>± 4.7</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Channels</th>
<th>Total cross-section (pb)</th>
<th>$\Delta\sigma_{stat}(\text{pb})$</th>
<th>$\Delta\sigma_{syst}(\text{pb})$</th>
<th>$\Delta\sigma_{lumi}(\text{pb})$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$e\nu e\bar{\nu}$</td>
<td>46.85</td>
<td>± 5.65</td>
<td>± 8.21</td>
<td>± 0.84</td>
</tr>
<tr>
<td>$\mu\nu\mu\bar{\nu}$</td>
<td>56.65</td>
<td>± 4.52</td>
<td>± 5.46</td>
<td>± 1.02</td>
</tr>
<tr>
<td>$e\nu\mu\bar{\nu}$</td>
<td>51.13</td>
<td>± 2.41</td>
<td>± 4.24</td>
<td>± 0.92</td>
</tr>
<tr>
<td>Combined</td>
<td>51.91</td>
<td>± 2.0</td>
<td>± 3.92</td>
<td>± 0.93</td>
</tr>
</tbody>
</table>

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 ($e/\mu$) transverse momentum spectrum used in aTGC limit setting (same binning)

![Graph showing differential distribution measurement](image-url)
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:

$$L/g_{WWV} = ig_1^V (W^*_\mu W^\mu V^\nu - W_{\mu\nu} W^*_{\mu\nu} V^\nu) + ik_V W^*_\mu W_\nu V^{\mu\nu} + \frac{\lambda_V}{M_W^2} W^*_\rho W^\mu V^{\nu\rho}$$  \hspace{1cm} (14)

, where $V$ can be either $\gamma$ or $Z$, $X_{\mu\nu} = \partial_\mu X_\nu - \partial_\nu X_\mu$, $W^\mu$ 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 $\lambda_V$) to the observed one

$$\Delta g_1^Z \equiv g_1^Z - 1, \Delta k_\gamma \equiv k_\gamma - 1, \Delta k_Z \equiv k_Z - 1, \lambda_Z, \lambda_\gamma.$$  \hspace{1cm} (15)

- Cutoff form factor $\Lambda$ is introduced to avoid tree-level unitarity violation at high energy

$$\Delta k(\hat{s}) = \frac{\Delta k}{(1 + \hat{s}/\Lambda^2)^2},$$  \hspace{1cm} (16)

, where $\hat{s}$ is the invariant mass of $W^+W^-$. 
Anomalous Triple-Gauge coupling (aTGC) II

- 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) III

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

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Parameter</th>
<th>Expected $(\Lambda = 6$ TeV)</th>
<th>Observed $(\Lambda = 6$ TeV)</th>
<th>Expected $(\Lambda = \infty)$</th>
<th>Observed $(\Lambda = \infty)$</th>
</tr>
</thead>
<tbody>
<tr>
<td>LEP</td>
<td>$\Delta k_Z$</td>
<td>$[-0.043, 0.040]$</td>
<td>$[-0.045, 0.044]$</td>
<td>$[-0.039, 0.039]$</td>
<td>$[-0.043, 0.043]$</td>
</tr>
<tr>
<td></td>
<td>$\lambda_Z = \lambda_\gamma$</td>
<td>$[-0.060, 0.062]$</td>
<td>$[-0.062, 0.065]$</td>
<td>$[-0.060, 0.056]$</td>
<td>$[-0.062, 0.059]$</td>
</tr>
<tr>
<td></td>
<td>$\Delta g_1^Z$</td>
<td>$[-0.034, 0.062]$</td>
<td>$[-0.036, 0.066]$</td>
<td>$[-0.038, 0.047]$</td>
<td>$[-0.039, 0.052]$</td>
</tr>
<tr>
<td>HISZ</td>
<td>$\Delta k_Z$</td>
<td>$[-0.040, 0.054]$</td>
<td>$[-0.039, 0.057]$</td>
<td>$[-0.037, 0.054]$</td>
<td>$[-0.036, 0.057]$</td>
</tr>
<tr>
<td></td>
<td>$\lambda_Z = \lambda_\gamma$</td>
<td>$[-0.064, 0.062]$</td>
<td>$[-0.066, 0.065]$</td>
<td>$[-0.061, 0.060]$</td>
<td>$[-0.063, 0.063]$</td>
</tr>
<tr>
<td>Equal Couplings</td>
<td>$\Delta k_Z$</td>
<td>$[-0.058, 0.089]$</td>
<td>$[-0.061, 0.093]$</td>
<td>$[-0.057, 0.080]$</td>
<td>$[-0.061, 0.083]$</td>
</tr>
<tr>
<td></td>
<td>$\lambda_Z = \lambda_\gamma$</td>
<td>$[-0.060, 0.062]$</td>
<td>$[-0.062, 0.065]$</td>
<td>$[-0.060, 0.056]$</td>
<td>$[-0.062, 0.059]$</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Expected $(\Lambda = \infty)$</th>
<th>Observed $(\Lambda = \infty)$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\Delta k_Z$</td>
<td>$[-0.077, 0.086]$</td>
<td>$[-0.078, 0.092]$</td>
</tr>
<tr>
<td>$\lambda_Z$</td>
<td>$[-0.071, 0.069]$</td>
<td>$[-0.074, 0.073]$</td>
</tr>
<tr>
<td>$\lambda_\gamma$</td>
<td>$[-0.144, 0.135]$</td>
<td>$[-0.152, 0.146]$</td>
</tr>
<tr>
<td>$\Delta g_1^Z$</td>
<td>$[-0.449, 0.546]$</td>
<td>$[-0.373, 0.562]$</td>
</tr>
<tr>
<td>$\Delta k_\gamma$</td>
<td>$[-0.128, 0.176]$</td>
<td>$[-0.135, 0.190]$</td>
</tr>
</tbody>
</table>

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 Framework and the Electroweak interactions
   - 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
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 $51.9 \pm 2.0\ (\text{stat.}) \pm 3.9\ (\text{syst.}) \pm 0.93\ (\text{lumi.})$ is consistent with the Standard Model theoretical prediction $44.7^{+2.1}_{-1.9} \ pb$. Fiducial cross sections for all channels are also measured.

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
- aTGC combination of all diboson channels is in preparation
Backup Slides
Electroweak Interactions in Standard Model

- Electromagnetism and the weak interaction can be unified as one electroweak force above the unification energy 100 GeV 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 $\gamma$.

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

(17)

, where $\theta_W$ stands for the weak mixing angle while $\gamma$ 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.
### Table: Summary of LAr DQ defects which may have impacts on physics analysis results. <PART> refers to different LAr calorimeter partitions.

<table>
<thead>
<tr>
<th>Defect</th>
<th>Description</th>
<th>Recoverable</th>
<th>Tolerable</th>
</tr>
</thead>
<tbody>
<tr>
<td>LAR_DATACORRUPT</td>
<td>Data integrity problem</td>
<td>NO</td>
<td>NO</td>
</tr>
<tr>
<td>LAR_UNCHECKED</td>
<td>Shifter did not look at ES</td>
<td>YES</td>
<td>NO</td>
</tr>
<tr>
<td>LAR_BULK_UNCHECKED</td>
<td>Shifter did not look at bulk</td>
<td>YES</td>
<td>YES</td>
</tr>
<tr>
<td>LAR_LOWSTAT</td>
<td>Not enough stat for assessment</td>
<td>NO</td>
<td>YES</td>
</tr>
<tr>
<td>LAR.&lt;PART&gt;DISABLED</td>
<td>Partition not included in the run</td>
<td>NO</td>
<td>NO</td>
</tr>
<tr>
<td>LAR.&lt;PART&gt;.HVTRIP</td>
<td>LB with HV ramping or off on both sides</td>
<td>NO</td>
<td>NO</td>
</tr>
<tr>
<td>LAR.&lt;PART&gt;.HVNONNOMINAL</td>
<td>LB with stable non-nominal HV (Noise not corrected)</td>
<td>YES</td>
<td>NO</td>
</tr>
<tr>
<td>LAR.&lt;PART&gt;.HVNONNOM_CORRECTED</td>
<td>LB with stable non-nominal HV (Noise corrected, impact on trigger)</td>
<td>NO</td>
<td>YES</td>
</tr>
<tr>
<td>LAR.&lt;PART&gt;.NOISEBURST</td>
<td>LB with minor noise burst</td>
<td>NO</td>
<td>YES</td>
</tr>
<tr>
<td>LAR.&lt;PART&gt;.SEVNOISEBURST</td>
<td>LB with severe noise bursts</td>
<td>NO</td>
<td>NO</td>
</tr>
<tr>
<td>LAR.&lt;PART&gt;.NOISYCHANNEL</td>
<td>Noisy cell, but harmless</td>
<td>YES</td>
<td>YES</td>
</tr>
<tr>
<td>LAR.&lt;PART&gt;.SEVNOISYCHANNEL</td>
<td>Very noisy cell, inducing many clusters</td>
<td>YES</td>
<td>NO</td>
</tr>
<tr>
<td>LAR.&lt;PART&gt;.MINORUNKNOWN</td>
<td>Data affected by minor (yet) unknown pathology</td>
<td>MAYBE</td>
<td>YES</td>
</tr>
<tr>
<td>LAR.&lt;PART&gt;.SEVUNKNOWN</td>
<td>Data unusable for (yet) unknown reason</td>
<td>MAYBE</td>
<td>NO</td>
</tr>
</tbody>
</table>
Distributions of discriminants at preselection level

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

<table>
<thead>
<tr>
<th>Cuts</th>
<th>$ee + E_{T}^{miss}$</th>
<th>$\mu\mu + E_{T}^{miss}$</th>
<th>$e\mu + E_{T}^{miss}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\geq 2$ leptons (SS+OS)</td>
<td>995273</td>
<td>1706679</td>
<td>16453</td>
</tr>
<tr>
<td>2 leptons (OS)</td>
<td>989740</td>
<td>1706493</td>
<td>16453</td>
</tr>
<tr>
<td>$\ell p_{T} &gt; 25$ GeV</td>
<td>979364</td>
<td>1678578</td>
<td>15157</td>
</tr>
<tr>
<td>trigger matching</td>
<td>978920</td>
<td>1678539</td>
<td>15063</td>
</tr>
<tr>
<td>$M_{\ell\ell'} &gt; 15/10$ GeV</td>
<td>977327</td>
<td>1674123</td>
<td>15052</td>
</tr>
<tr>
<td>Z mass veto</td>
<td>80140</td>
<td>148841</td>
<td>15052</td>
</tr>
<tr>
<td>$E_{T}^{miss}$, Rel cut</td>
<td>1398</td>
<td>2411</td>
<td>6586</td>
</tr>
<tr>
<td>Njet(0,1,2,3,$\geq 4$)</td>
<td>(310,285,412,246,145)</td>
<td>(633,535,656,381,206)</td>
<td>(1169,1272,2083,1274,788)</td>
</tr>
<tr>
<td>Jet veto</td>
<td>310</td>
<td>633</td>
<td>1169</td>
</tr>
<tr>
<td>$p_{T}(\ell\ell) &gt; 30$ GeV</td>
<td>174</td>
<td>330</td>
<td>821</td>
</tr>
<tr>
<td>Final State</td>
<td>ee Channel</td>
<td>µµ Channel</td>
<td>eµ Channel</td>
</tr>
<tr>
<td>-----------------------------------</td>
<td>------------</td>
<td>------------</td>
<td>------------</td>
</tr>
<tr>
<td>Observed Events</td>
<td>174</td>
<td>330</td>
<td>821</td>
</tr>
<tr>
<td>total MC prediction(S+B)</td>
<td>163.5</td>
<td>278.0</td>
<td>740.0</td>
</tr>
<tr>
<td>MC WW signal</td>
<td>100.3</td>
<td>185.5</td>
<td>537.8</td>
</tr>
<tr>
<td>Top</td>
<td>23.3</td>
<td>33.7</td>
<td>90.1</td>
</tr>
<tr>
<td>W+jets+QCD</td>
<td>14.6</td>
<td>5.58</td>
<td>63.1</td>
</tr>
<tr>
<td>Drell-Yan</td>
<td>12.6</td>
<td>32.2</td>
<td>4.87</td>
</tr>
<tr>
<td>Diboson</td>
<td>12.70</td>
<td>21.0</td>
<td>44.1</td>
</tr>
<tr>
<td>Total Background</td>
<td>63.2</td>
<td>92.5</td>
<td>202.2</td>
</tr>
</tbody>
</table>

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

\[
N_{\text{top}}^{\text{Est}}(\ell\ell + E_T^{\text{miss}}, 0j) \approx N_{\text{top}}^{\text{Data}}(\ell\ell + E_T^{\text{miss}}) \times P_2^{\text{Exp}} = \left( \frac{P_1^{\text{Btag, data}}}{P_1^{\text{Btag, MC}}} \right) P_2^{\text{MC}} \times \left( \frac{P_1^{\text{Btag, data}}}{P_1^{\text{Btag, MC}}} \right)^2
\]

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

<table>
<thead>
<tr>
<th>channel</th>
<th>Top MC</th>
<th>Top DD</th>
</tr>
</thead>
<tbody>
<tr>
<td>ee</td>
<td>23.3 ± 1.1(stat)</td>
<td>19.0 ± 3.2(stat) ± 3.1(syst)</td>
</tr>
<tr>
<td>eμ</td>
<td>89.8 ± 2.3(stat)</td>
<td>88.5 ± 7.1(stat) ± 14.3(syst)</td>
</tr>
<tr>
<td>μμ</td>
<td>33.7 ± 1.4(stat)</td>
<td>42.6 ± 7.3 ± 6.9</td>
</tr>
<tr>
<td>combined</td>
<td>146.8 ± 2.9(stat)</td>
<td>150.1 ± 10.7 ± 22.3</td>
</tr>
</tbody>
</table>

**Table:** Final DY background estimates for all three channels.
The systematic uncertainties of lepton/jet energy scale/resolution are quoted by varying independently the corresponding systematic term up and down by one $\sigma$.

The $E_T^{\text{miss}}$ systematic uncertainties have 100% correlation with the lepton and jet energy related uncertainties, which have their systematic variation propagated simultaneously to the $E_T^{\text{miss}}$.

PDF uncertainty quoted from: the CT10 error matrices central value differences between CTEQ and MSTW renormalisation ($\mu_R$) and factorisation ($\mu_F$) scale factor variation.

<table>
<thead>
<tr>
<th>Sources</th>
<th>$e^+e^-E_T^{\text{miss}}$</th>
<th>$\mu^+\mu^-E_T^{\text{miss}}$</th>
<th>$e^+\mu^-E_T^{\text{miss}}$</th>
<th>Combined</th>
</tr>
</thead>
<tbody>
<tr>
<td>Luminosity</td>
<td>1.8%</td>
<td>1.8%</td>
<td>1.8%</td>
<td>1.8%</td>
</tr>
<tr>
<td>$A_{WW}$ uncertainties</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PDF</td>
<td>0.85%</td>
<td>0.93%</td>
<td>0.88%</td>
<td>0.88%</td>
</tr>
<tr>
<td>Scale ($\mu_R$, $\mu_F$)</td>
<td>0.48%</td>
<td>0.48%</td>
<td>0.63%</td>
<td>0.41%</td>
</tr>
<tr>
<td>Jet veto</td>
<td>5.60%</td>
<td>5.60%</td>
<td>5.60%</td>
<td>5.60%</td>
</tr>
<tr>
<td>$\Delta A_{WW}/A_{WW}$</td>
<td>5.68%</td>
<td>5.69%</td>
<td>5.70%</td>
<td>5.69%</td>
</tr>
<tr>
<td>$C_{WW}$ uncertainties</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Trigger</td>
<td>0.1%</td>
<td>0.6%</td>
<td>0.3%</td>
<td>0.4%</td>
</tr>
<tr>
<td>Electron Scale</td>
<td>0.8%</td>
<td>$\leq0.1$</td>
<td>0.4%</td>
<td>0.3%</td>
</tr>
<tr>
<td>Electron Resolution</td>
<td>0.2%</td>
<td>$\leq0.1$</td>
<td>$\leq0.1$</td>
<td>0.1%</td>
</tr>
<tr>
<td>Muon Scale</td>
<td>$\leq0.1$</td>
<td>0.5%</td>
<td>0.2%</td>
<td>0.2%</td>
</tr>
<tr>
<td>ID Muon Resolution</td>
<td>$\leq0.1$</td>
<td>0.1%</td>
<td>$\leq0.1$</td>
<td>$\leq0.1$</td>
</tr>
<tr>
<td>MS Muon Resolution</td>
<td>$\leq0.1$</td>
<td>0.1%</td>
<td>$\leq0.1$</td>
<td>$\leq0.1$</td>
</tr>
<tr>
<td>Electron recon. SF</td>
<td>1.6%</td>
<td>$\leq0.1$</td>
<td>0.8%</td>
<td>0.7%</td>
</tr>
<tr>
<td>Electron ID SF</td>
<td>2.3%</td>
<td>$\leq0.1$</td>
<td>1.1%</td>
<td>1.0%</td>
</tr>
<tr>
<td>Muon ID SF</td>
<td>$\leq0.1$</td>
<td>0.5%</td>
<td>0.3%</td>
<td>0.3%</td>
</tr>
<tr>
<td>Electron IsoIP</td>
<td>0.7%</td>
<td>$\leq0.1$</td>
<td>0.3%</td>
<td>0.3%</td>
</tr>
<tr>
<td>Muon IsoIP</td>
<td>$\leq0.1$</td>
<td>0.4%</td>
<td>0.2%</td>
<td>0.2%</td>
</tr>
<tr>
<td>Scale Soft Terms</td>
<td>0.4%</td>
<td>0.2%</td>
<td>0.2%</td>
<td>0.2%</td>
</tr>
<tr>
<td>Reso Soft Terms</td>
<td>0.3%</td>
<td>0.1%</td>
<td>$\leq0.1$</td>
<td>$\leq0.1$</td>
</tr>
<tr>
<td>JES &amp; JER</td>
<td>0.6%</td>
<td>0.5%</td>
<td>0.5%</td>
<td>0.5%</td>
</tr>
<tr>
<td>Jet veto scale factor</td>
<td>2.8%</td>
<td>2.8%</td>
<td>2.7%</td>
<td>2.8%</td>
</tr>
<tr>
<td>PDF and Scale</td>
<td>0.7%</td>
<td>0.7%</td>
<td>0.3%</td>
<td>0.3%</td>
</tr>
<tr>
<td>$\Delta C_{WW}/C_{WW}$</td>
<td>4.2%</td>
<td>3.1%</td>
<td>3.2%</td>
<td>3.2%</td>
</tr>
<tr>
<td>$A_{WW}$/$C_{WW}$</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Jet veto scale factor</td>
<td>3.7%</td>
<td>3.6%</td>
<td>3.6%</td>
<td>3.6%</td>
</tr>
<tr>
<td>$\Delta C_{WW}/A_{WW}$</td>
<td>4.9%</td>
<td>4.0%</td>
<td>4.1%</td>
<td>4.0%</td>
</tr>
<tr>
<td>$\sigma(W^+W^-)$ theoretic uncertainty</td>
<td>6.2%</td>
<td>6.2%</td>
<td>6.2%</td>
<td>6.2%</td>
</tr>
<tr>
<td>Full $W^+W^-$ signal estimation uncertainty</td>
<td>8.1%</td>
<td>7.6%</td>
<td>7.6%</td>
<td>7.6%</td>
</tr>
</tbody>
</table>

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 additional luminosity (1.8%) and total cross-section (6.2%) uncertainties.
Diboson background uncertainties

<table>
<thead>
<tr>
<th></th>
<th>Lumi.</th>
<th>Cross-section*</th>
<th>Uncertainties</th>
<th>±ΔN</th>
</tr>
</thead>
<tbody>
<tr>
<td>$ee$</td>
<td>1.8%</td>
<td>8.6%</td>
<td>12.0%</td>
<td>3.5%</td>
</tr>
<tr>
<td>$\mu\mu$</td>
<td>1.8%</td>
<td>8.0%</td>
<td>7.8%</td>
<td>1.2%</td>
</tr>
<tr>
<td>$e\mu$</td>
<td>1.8%</td>
<td>9.8%</td>
<td>9.6%</td>
<td>2.3%</td>
</tr>
<tr>
<td>total</td>
<td>1.9%</td>
<td>9.1%</td>
<td>9.4%</td>
<td>1.9%</td>
</tr>
</tbody>
</table>

**Table:** Systematic uncertainty summary for other diboson backgrounds.
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 $\ell\ell' + E_T^{\text{miss}}$ system.
Figure: Distributions for $W^+W^-$ candidates after the final event selection for all 3 channels: the first row is the $p_T$ of leading lepton (left) and the $p_T$ of trailing lepton (right); the second row is the $p_T$ (``$p_T$'') (left) and the angle difference between two leptons (right); the third row is the $M_{\text{di-lepton}+E_{\text{miss}}}$ system (left) and $p_T$ for di-lepton+$E_{\text{miss}}$ (right). The points represent data and stacked histograms are from MC predictions except $W$+jets/Dijet background, obtained from a data-driven method.
Figure: Distributions for \( W + W \) candidates after the final event selection for all 3 channels: the first row is the \( \eta \) of the leading lepton (left) and the \( \eta \) of the trailing lepton (right); the second row is the \( M(\eta) \) (left) and the \( R \) between the leptons (right); the third row is the \( E_{\text{miss}} \) (left) and \( E_{\text{miss}}^{\text{Rel}} \) (right).

The points represent data and stacked histograms are from MC predictions except \( W + \text{jets/\ell+\ell} \) background, obtained from a data-driven method. (\( H(125) \) included)
**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:

  \[ \int A(y, x)f(x)dx = g(y) \]  

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

  \[ Ax = y. \]  

- 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

**Figure:** Purity distribution (left) and response matrix (right) of the $p_T$ distribution.

Shu LI Ph.D thesis Defense 60/68
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 $\delta_{sys}^{i} = x_{i} - x_{i}^{sys}$ is then taken as the systematic uncertainty in each bin. The corresponding covariance matrix for bins $i$ and $j$ is defined by $\text{Cov}_{i,j} = \delta_{sys}^{i} \times \delta_{sys}^{j}$.
  - 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
Personal contributions

- **Analysis:**
  - Event selection optimization
  - Lepton, jet and $E_T^{\text{miss}}$ performance
  - $W+$jet and top background estimation
  - Signal and other diboson systematics
  - Collaborative work on differential measurement

- **Performance work:**
  - Electron shower-shape based material mapping in front of the electromagnetic calorimeter
  - LAr data quality and investigation
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 November 2012
  
  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

  
  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

  
  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
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
semainaire 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
Standard Model Plenary talks of analysis 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 "Update on the Etmiss performance study in r17”
http://indico.cern.ch/conferenceDisplay.py?confId=164012

2011-11-25 "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"