High $p_T$: EWK and QCD results from ATLAS
Outline

- ATLAS Detector
- Electroweak: W and Z
- Jet Physics
- Top Physics
- Direct Photon Production
- Summary
- Weight: 7000 tonnes
- ~100 million electronic channels
- ~3000 km of cables
- Muon System
  - ~1 million channels
  - Resolution ~80 microns
- Magnets
  - Toroid field: 4 T
  - Central Solenoid: 2 T
• Hadronic Calorimeter:
  • Scintillating tile/steel barrel; Liquid Argon endcaps and forward detectors
• EM Calorimeter:
  • Liquid Argon/lead barrel, endcaps, and forward detector

• High Granularity
• Full coverage up to $|\eta| < 4.9$
  • Cracks near $|\eta| \sim 1.0$, $|\eta| \sim 1.4$
ATLAS Inner Detector

- **Pixel:**
  - ~80 million pixels
  - Pixel size: 50x400 µm
  - Resolution: 10x115 µm

- **SCT**
  - Silicon microstrips
  - ~6 million channels
  - 17 x 580 µm

- **TRT**
  - Drift Tubes + Transition radiation
  - ~350000 channels
  - Electron ID
  - 130 µm

- **2T solenoid Field**
Inclusive production of $W^\pm$ and $Z$ bosons is a high cross section process:
- total $\sigma$ predicted with $\sim 4\%$ uncertainty (mainly PDF)
  - $\sigma_{\text{NNLO}}(W^+ \rightarrow \ell^+ \nu) = 6.16$ nb
  - $\sigma_{\text{NNLO}}(W^- \rightarrow \ell^- \bar{\nu}) = 4.30$ nb
  - $\sigma_{\text{NNLO}}(Z/\gamma^* \rightarrow \ell\ell) = 0.96$ nb
- $\sqrt{s} = 7$ TeV, calculated with FEWZ using MSTW 2008 NNLO PDFs
- MC Samples:
  - Pythia using MRSTLO* and fully simulated GEANT4, Scaled using WCD NNLO prediction by FEWZ
- $W/Z$ Measurements in the electron and muon channels are important:
  - Identification and calibration of the first sample of isolated high-$p_T$ leptons
  - Missing $E_T$ studies
  - Z mass precisely known:
    - Commissioning and calibration $Z/\gamma^* \rightarrow \ell\ell$
    - Calo/muon energy scale/uniformity
    - Determination of trigger efficiencies
  - Precise tests of QCD in unexplored regions
    - $\sim 100$ pb$^{-1}$, can start to constrain parton density functions in proton
Lepton Reconstruction

- **Electrons:**
  - Loose preselection:
    - EM calorimeter 2\(^{nd}\) layer sampling shapes and hadronic leakage.
      - 94\% eff
      - 20 GeV Rejection factor against jets: 1100
  - Medium (Z → ee):
    - Loose + calorimeter shape in 1st sampling, Silicon hits and impact parameter, track-cluster matching
      - 90\% eff.
      - 20 GeV Rejection factor against jets: 6800
  - Tight (W → ev):
    - Medium + b-layer hit and TRT high threshold hits, conversion rejection, E/p matching
      - 72\% eff.
      - 20 GeV Rejection factor against jets: 92000

- **Muons:**
  - Combined muon |\(\eta| < 2.4$: muon spectrometer (MS) + inner detector (ID) track
    - \(p_T > 10\) GeV, Eff 94\%
  - Decays in flight, cosmics and other background reduced by \(p_T\) and spatial matching cuts between MS and ID
**Electron channel (1.01 pb⁻¹):**
- **Preselection:**
  - L1 Calo Trigger
  - Primary vertex with 3 tracks:
    - $|\eta| < 1.37$, $1.52 < |\eta| < 2.47$
    - Electron $E_T > 20$ GeV
  - Loose ID
- **Final Selection:**
  - Tight ID
  - Missing $E_T > 25$ GeV
  - $m_T > 40$ GeV
- **BCK:**
  - $W \rightarrow \tau \nu$, QCD small
    - Data driven method for estimation

**Muon channel (991 nb⁻¹):**
- **Preselection:**
  - Primary vertex with 3 tracks
  - L1 Muon trigger (6 GeV)
  - $|\eta| < 2.4$
  - $p_T > 15$ GeV
- **Final Selection:**
  - $p_T > 20$ GeV
  - Track Isolation
  - Missing $E_T > 25$ GeV
  - $m_T > 40$ GeV
- **BCK:**
  - $Z \rightarrow \mu \mu$

$$m_T = \sqrt{2p_T^l p_T^\nu \left(1 - \cos(\phi^l - \phi^\nu)\right)}$$
\[ \sigma_W \times BR(W \rightarrow l \nu) = \frac{N^{obs}_W - N^{bck}_W}{A_W C_W L_{int}} \]

- **A_W**: Geometrical acceptance
  - $e^+$: 0.466 ± 0.03
  - $e^-$: 0.457 ± 0.03
  - $\mu^+$: 0.484 ± 0.03
  - $\mu^-$: 0.475 ± 0.03

- **C_W**: Correction factor.
  Ratio between number of signal events which pass the final selection requirements after reconstruction and the total number of events generated.
  - $e$: 0.66 ± 0.08
  - $\mu$: 0.81 ± 0.07

- **L_{int}**: Integrated luminosity

Integrated luminosity: 17 nb\(^{-1}\)

Analysis with updated luminosity ongoing

\[ \sigma_{tot}(W^+) [5.7 \pm 0.7 \text{(stat)} \pm 0.4 \text{(syst)} \pm 0.6 \text{(lumi)}] \text{ nb} \]

\[ \sigma_{tot}(W^-) [3.5 \pm 0.5 \text{(stat)} \pm 0.2 \text{(syst)} \pm 0.4 \text{(lumi)}] \text{ nb} \]

\[ \sigma_{tot}(W\rightarrow l\nu) [9.3 \pm 0.9 \text{(stat)} \pm 0.6 \text{(syst)} \pm 1.0 \text{(lumi)}] \text{ nb} \]

\[ \sigma_{NNLO}(W\rightarrow l\nu) = [10.46 \pm 0.42] \text{ nb} \]
**Lepton Charge asymmetry**

- $W^+$ and $W^-$ are produced at different rates.
- The measurement will provide important constraints on PDFs:
  - Constrains u/d quark ratio in proton, perform as function of $\eta_l$ (correlated to parton momentum fraction $x$).
  - Many uncertainties cancel fully (luminosity) or partially (lepton efficiency).
- The asymmetry is expected to be different from zero and increase with $\eta$.
- The uncertainties for the $W$ charge asymmetry at 16.9 nb$^{-1}$ are statistically dominated.

**Equation:**

$$A = \frac{\sigma^{l+} - \sigma^{l-}}{\sigma^{l+} + \sigma^{l-}}$$
**Electron channel (914 nb⁻¹):**
- L1 Calo Trigger
- 2 preselected electrons \( E_T > 20 \text{GeV}, |\eta| < 1.37, 1.52 < |\eta| < 2.47 \)
- Opposite charge
- Medium ID
- \( 66 < m_{ee} < 116 \text{ GeV} \)
  - 230 Z candidates
  - Peak position: \( 90.9 \pm 0.3 \text{ GeV} \)
  - Experimental resolution: \( 3.2 \pm 0.3 \text{ GeV} \)
- BCK: QCD, ZZ\( \rightarrow \tau \tau, W \rightarrow e \nu, t \bar{t}, b \bar{b} \)

**Muon channel (1.07 pb⁻¹):**
- L1 Muon Trigger
- 2 muons \( p_T > 20 \text{ GeV} \)
- Track isolation
- Opposite charge
- \( 66 < m_{\mu\mu} < 116 \text{ GeV} \)
  - 354 Z candidates
  - Peak position: \( 90.8 \pm 0.3 \text{ GeV} \)
  - Experimental Resolution: \( 3.3 \pm 0.3 \text{ GeV} \)
- BCK: ZZ\( \rightarrow \tau \tau, W \rightarrow \mu \nu, t \bar{t}, b \bar{b} \)
$\sigma_{Z/\gamma^*} \times BR(Z/\gamma^* \rightarrow ll) = \frac{N_Z^{obs} - N^{bck}}{A_Z C_Z L_{int}}$

$\sigma_{tot}(Z\rightarrow ee) [0.72 \pm 0.11 \text{(stat)} \pm 0.10 \text{(syst)} \pm 0.08 \text{(lumi)}] \text{ nb}$

$\sigma_{tot}(Z\rightarrow \mu\mu) [0.89 \pm 0.10 \text{(stat)} \pm 0.07 \text{(syst)} \pm 0.10 \text{(lumi)}] \text{ nb}$

$\sigma_{tot} = [0.83 \pm 0.07 \text{(stat)} \pm 0.06 \text{(syst)} \pm 0.09 \text{(lumi)}] \text{ nb}$

$\sigma_{NNLO} = [0.96 \pm 0.04] \text{ nb}$

- $A_Z$: Geometrical acceptance
  - ee: $0.446 \pm 0.013$
  - $\mu\mu$: $0.486 \pm 0.014$
- $C_Z$: Correction factor.
  Ratio between number of signal events which pass the final selection requirements after reconstruction and the total number of events generated.
  - ee: $0.645 \pm 0.090$
  - $\mu\mu$: $0.797 \pm 0.055$
- $L_{int}$: Integrated luminosity

Integrated luminosity: 225 nb$^{-1}$

Analysis with updated luminosity is ongoing
Jet Physics

- Dominant process with high $p_T$ final state
- Hard interaction of quarks and gluons leading to di-jet and multijet events
- Important tool to understand strong interaction and new physics search
- Jets measured/reconstructed in calorimeters
  - Critical to understand response-energy scale and resolution
- Interesting sensitivity already:
  - Di-jet resonance, see Haiping Peng talk
Jet reconstruction in ATLAS

- Jets:
  - Anti-$k_t$ algorithm, with radius 0.6(0.4)
  - Topoclusters used as input:
    - 3D objects with $E_{\text{cell}} > 4\sigma$ above noise.
      Neighbors cells with $E_{\text{cell}} > 2\sigma$ are added
  - Event selection:
    - “Good” data quality
    - Reconstructed primary vertex
    - Trigger:
      - MBTS
      - Calo Trigger: L1_J5
    - ~1 pb$^{-1}$
  - Jet Selection and calibration:
    - Rapidity: $|y| < 2.8$
    - $p_T > 60$ GeV
    - Momenta are calculated in the detector frame and then corrected according to the primary vertex
    - Calorimeter clean cuts
    - Jet Energy Scale (JES) used to convert EM calibration to calibrated hadronic scale.
      - $p_T$, jet and $y$ dependent

![Figure 8: Relative jet energy scale systematic uncertainty as a function of $p_T$ for jets in the pseudorapidity region $0.3 < |\eta| < 0.8$ in the calorimeter barrel. The total uncertainty is shown as the solid light blue area. The individual sources are also shown, with statistical errors if applicable.](image)

![Figure 9: Relative jet energy scale systematic uncertainty as a function of $p_T$ for jets in the pseudorapidity region $2.1 < |\eta| < 2.8$. The JES uncertainty for the endcap is extrapolated from the barrel uncertainty, with the contribution from the $\eta$ intercalibration between central and endcap jets in data and Monte Carlo added in quadrature. The total uncertainty is shown as the solid light blue area. The individual sources are also shown, with statistical errors if applicable.](image)
Jet reconstruction in ATLAS

- **Jets:**
  - Anti-\(k_t\) algorithm, with radius 0.6(0.4)
  - Topoclusters used as input:
    - 3D objects with \(E_{\text{cell}} > 4\sigma\) above noise.
    - Neighbors cells with \(E_{\text{cell}} > 2\sigma\) are added

- **Event selection:**
  - “Good” data quality
  - Reconstructed primary vertex
  - Trigger:
    - MBTS
    - Calo Trigger: L1_J5
  - \(\sim 1\) pb\(^{-1}\)

- **Jet Selection and calibration:**
  - Rapidity: \(|y|<2.8\)
  - \(p_T > 60\) GeV
  - Momenta are calculated in the detector frame and then corrected according to the primary vertex
  - Calorimeter clean cuts
  - Jet Energy Scale (JES) used to convert EM calibration to calibrated hadronic scale.
    - \(p_T\), jet and \(y\) dependent
- Data unfolded to particle/hadron level
- NLO + non-perturbative corrections QCD
- With available statistics, agreement between data and MC
$|y|_{\text{max}} = \max(|y_1|,|y_2|)$

- $m_{12}$ is invariant mass of first two leading jets with $p_T > 60$ GeV and $p_T > 30$ GeV
- Di-jet masses up to ~2 TeV
  - Overtaking Tevatron analysis in mass reach.
- Agreement between data and MC!!
• Early data, Top re-discovery:
  o Clear signal at 10 pb⁻¹
  o t→Wb, final state determined by W decay
  o Dilepton: tt→WbWb→lvblvb with l=e or μ (5%)
    ▷ e+μ dilepton. No reconstruction of m_{top}
  o Lepton+4-jets: tt→WbWb→lvbjjb with l=e or μ (30%)
    ▷ e/μ+jets, recon m_{jjj}=m_{top}, bck: W+jets b/g
  o Events with high-p_T lepton(s), E_T miss and (b)jets
  o Understand QCD and W/Z+jets bck

• Next:
  o 100pb⁻¹ cross section measurement at 10-20%
  o Precision measurements:
    ▷ Top Mass (~1000 tops) using Template Method, decay properties, polarization, spin correlations
  o Search beyond SM:
    ▷ Top-antitop resonances (>200pb⁻¹), anomalous couplings, non-SM resonances
  o Single top
    ▷ 200-1000 pb⁻¹: Etmiss + 2jets, multivariate techniques
- **Object selection:**
  - Electrons: Medium Selection, as seen in Z/W + isolation
  - Muons: As Z/W, $p_T > 20$ GeV, Isolation cut, minimum distance to jets
  - Jets: Anti-$k_t$ with $R=0.4$ from the EM scale topological clusters. Jets are calibrated to the hadronic energy scale, $p_T$ and $\eta$ dependent. Btagging: secondary vertex-based tagger SVO returns a value above the threshold that is defined by a 50% tagging efficiency
  - Missing $E_T$: Vector sum of all calorimeter cells.

- **Event selection:**
  - Lepton + jets ~46% -> ~14 expected events:
    - Primary vertex with 5 tracks
    - Exactly 1 lepton with $p_T > 20$ GeV
    - At least 4 jets with $p_T > 20$ GeV. One of them bttaged
    - Missing $E_T > 20$ GeV
  - Dileptons ~9% -> ~2 events expected:
    - 2 opposite charged leptons with $p_T > 20$ GeV
    - At least 2 jets with $p_T > 20$ GeV
    - $ee$: Missing $E_T > 40$ GeV, $m_{ee}$ far from Z mass.
    - $\mu\mu$: Missing $E_T > 30$ GeV, $m_{\mu\mu}$ far from Z mass
    - $e\mu$: Scalar sum of the transverse energies of the 2 leptons and all jets ($H_T > 150$GeV

- **Background QCD estimation:**
  - Matrix method, with loose lepton selection:
    - $e$: No B layer hit
    - $\mu$: No Isolation cut
Top Rediscovery: Status @ 280 nb\(^{-1}\)

- 9 top candidates.
- Compatible with NLO

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<th>ID</th>
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<th>Event number</th>
<th>Channel</th>
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<th>(E_T^{miss}) (GeV)</th>
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<th>(m_W) (GeV)</th>
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<th>(E_T^{miss}) (GeV)</th>
<th>(H_T) (GeV)</th>
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Direct Photon Production

- Test for perturbative QCD
  - $\sqrt{s} = 7$ TeV, $O(\mu b)$
- Constrain parton structure functions
- Photon ID is important for other physics signatures:
  - Higgs: $H \rightarrow \gamma\gamma$
  - Graviton decays $G \rightarrow \gamma\gamma$
  - Decays pairs of SuperSymmetric particles
  - Excited fermion decays
- “Prompt” photons, all photons not coming from hadron decays:
  - Hard-scattering processes
  - QED radiation off quarks
  - Non-perturbative fragmentation of $q/g$
- Main background:
  - Decays of light neutral mesons, $\pi_0$, $\eta$
- Data sample:
  - L1 Calorimeter trigger
  - Primary vertex with 3 tracks
- Photon ID:
  - EM clusters in second Layer 3x5
    - With inner detector track match: Converted $\gamma$
    - Without: Unconverted $\gamma$
Direct Photon Production

- **L1 Calo Trigger, >5GeV**
- **“Loose” photon selection:**
  - Shower shapes in calorimeters
    - Ratio of $E_T$ in hadronic calorimeter to $E_T$ in cluster < 1-2%
    - $R_\eta =$ Ratio of Energy depositions in $\eta$
    - $R_\phi =$ Ratio of Energy depositions in $\phi$
    - RMS width of energy distribution in $\eta$
  - “Tight” photon selection:
    - Shower shape in first EM cal layer
      - Total RMS of the energy distribution along $\eta$
      - Asymmetry $E_{\text{ratio}}$ between the second maxima and the first in the energy profile
      - Energy difference between second maximum and the minimum between the 2 maxima
      - The fraction of the energy $F_{\text{side}}$ in 7 cells centered around the first maximum which is not contained in the 3 core cells centered around the first maximum.
      - RMS of the energy distribution computed with the 3 core cells.
- **Isolation:**
  - $E(R < 0.4)$, EM and Hcal
  - Isolated if <3GeV

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• Background and signal extraction based on data driven method
  ○ Isolation variable and shower shape variables
  ○ Purity: Signal/Measurement
  ○ Clear signal of prompt Photons
    - $618 \pm 75$ Photons for $E_T > 20\text{GeV}$, 72% $\pm$ 7% purity
In this talk:
- EWK:
  - Z/W Cross section measured
- Jet Physics:
  - Single and Dijet Cross Sections measured
- Top Physics:
  - First candidates observed
- Single Photon Production:
  - Evidence of prompt photon production seen

Analysis are going to be updated with more luminosity soon

Full ATLAS community working hard:
- Looking into physics
- Understanding detector performance

Other related analysis done:
- Multiple jet production
- Dijet azimuthal angle correlation
- W/Z in jet channels
More details on ATLAS publications:

- **EWK**:
  - ATLAS-CONF-2010-044
  - ATLAS-CONF-2010-051
  - ATLAS-CONF-2010-076

- **Jets**
  - ATLAS-CONF-2010-050
  - ATLAS-CONF-2010-053
  - ATLAS-CONF-2010-056

- **Top**:
  - ATLAS-CONF-2010-063
  - ATLAS-CONF-2010-087
  - ATL-PHYS-PUB-2010-004
  - ATL-PHYS-PUB-2010-0012

- **Direct Photon**:
  - ATLAS-CONF-2010-077
Triggers in ATLAS

- **MBTS (Minimum Bias Trigger Scintillators)**
  - 2 sets of 16 scintillator counters installed on the inner face of the end-cap calorimeter cryostats
  - Located at |z| = 3560 mm,
  - Cover: 2.09 < |eta| < 3.84
  - Hit Coincidence between both sides
  - Hit Multiplicity

- **L1 muon trigger (Pt 6GeV)**
  - Looks for patterns of hits within |η| < 2.4 of high pt coming from the IP
  - W analysis, 2 stations time coincidence.
  - Z analysis, 2 stations time coincidence.

- **L1 Calo Trigger:**
  - Photons and electrons |η| < 2.5
  - W: Signal Cluster of trigger towers is above 5 trigger counts (each count ~1GeV)
  - Z: Signal Cluster of trigger towers is above 10 trigger counts (each count ~1GeV)

- **L1 Jet Trigger:**
  - Measurement of Jet Production: L1_J5: Requires a jet with Pt>5GeV
## W→ lv cross section

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<td>25.6</td>
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<tr>
<td>Correction $C_W$</td>
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<td>Total cross section (nb)</td>
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<td><strong>6.6</strong></td>
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Table 8: Results for the fiducial cross sections $\sigma_{fid}$ and total cross section $\sigma_{tot}$ for $W^+$, $W^-$, and $W^±$ in the electron and muon channels. Shown are the observed numbers of signal events after background subtraction for each channel, the average correction factors $C_W$, the fiducial cross sections, the geometrical acceptance correction factors, and the total cross sections with their statistical, systematic, and luminosity uncertainties quoted in that order.
• Measures the energy flow around the jet core
• Fraction of the jet momentum contained within a ring of thickness $\Delta r=0.1$ at a radius $r$ around the jet center divided by $\Delta r$
• Systematic uncertainty:
  • Dominated by JES

• Samples all scaled to the number of jets
  • Test of the shapes of the distributions

• Agreement is quite good across all $p_T$ and rapidity bins
  • Uncertainties not yet small enough to say whether Pythia or Herwig is better
• Test for pQCD at high energies
• Exotic process, where QCD is dominant BCK
• JES uncertainty dominated
Dijet production with jet veto

- Dijet search with a veto on additional radiation in the rapidity interval between the 2 jets
- Classically:
  - Search for evidence of color singlet exchange
- Also:
  - BFKL-like dynamics: Boundary jets as as those with the largest absolute rapidity
  - Wide-angle soft gluon radiation: Boundary jets are the leading jets
  - Higgs search, jet vetoes are used in searches via vector boson fusion
QCD predicts how the azimuthal angle between the 2 most energetic partons changes when additional radiation is produced.
Top Rediscovery
• Updated luminosity:

- Data 2010 (tight, isolated $\gamma$)

\[ E^\text{cluster} \text{ [GeV]} \]

\[ \text{Entries/5 GeV} \]

$\sqrt{s} = 7 \text{ TeV}, \int L dt = 1.84 \text{ pb}^{-1}$