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Measurement of the $Z\to\tau\tau$ and $W\to\tau\nu$ Cross Sections with the ATLAS detector

The measurement of the W and Z boson production cross-sections with tau leptons in the final state is important in demonstrating the capabilities of the ATLAS detector in probing for new physics. The study of W and Z bosons with taus in the final state allows the measurement of the tau trigger, reconstruction, and identification efficiencies in data. Reconstruction and identification of tau leptons is important for Standard Model Higgs ($H\to\tau\tau$) searches as well as in Supersymmetry models involving charged Higgs.

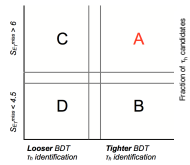
Tau leptons decay hadronically 65% of the time and leptonically (e/μ) 35% of the time. The W boson production cross-section is measured when the tau decays hadronically ($W\to\tau_h\nu_\tau$), while the Z boson production cross-section is measured in 4 final states where the final visible decay products are: an electron and a hadronic tau ($\tau_e\tau_h$), a muon and a hadronic tau ($\tau_\mu\tau_h$), an electron and a muon ($\tau_e\tau_\mu$), and two muons ($\tau_\mu\tau_\mu$). The total cross-section is measured in all 5 final states by: $\sigma = \frac{N - Bkgrd}{BACL}$. Where B is the branching ratio, A accounts for the theoretical acceptance, C is the detector efficiency, and L is the integrated luminosity (36 pb^{-1}).

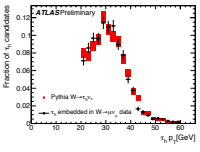
$W\to\tau_h\nu_\tau$:

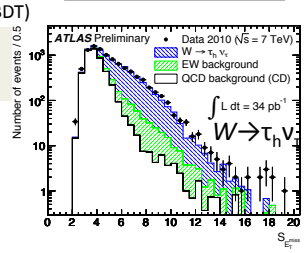
- Trigger on hadronic tau and missing energy (E_T^{miss})
- Use Tight τ identification (Boosted Decision Tree (BDT))
- **QCD Suppression:**
  - $S_{E_T^{miss}} > 6.0$
  - $E_T^{miss} > 30$ GeV
- **Z→ll/W→lν Suppression:**
  - Veto event with identified e/μ
- **Background Estimation (ABCD):**

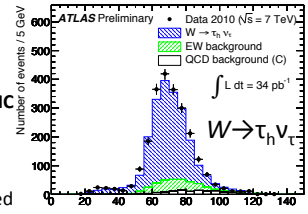
$$S_{E_T^{miss}} = \frac{E_T^{miss}[\text{GeV}]}{0.5\sqrt{\text{GeV}}\sqrt{E_T[\text{GeV}]}}$$

ABCD method:
$N_{A,QCD} = N_B N_C / N_D$

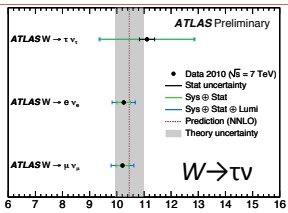








- **Electroweak (EW) backgrounds estimated from MC**
  - W→τν shape verified with embedding
    - Replace μ in data with simulated τ rerun full reconstruction
    - Underlying event and pileup correctly modeled
- **Multijet: Tight τ vs. Loose-not-Tight τ** and $S_{E_T^{miss}} > 6.0$ vs. $S_{E_T^{miss}} < 4.5$
  - Must show that the $S_{E_T^{miss}}$ is independent of the τ_h identification and that regions CBD have negligible signal and EW contamination.



Final Results

σ(Z→ττ)[nb]:

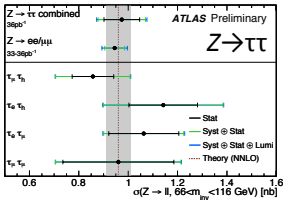
$0.97 \pm 0.07_{stat} \pm 0.06_{sys} \pm 0.03_{lumi}$

σ(W→τν)[nb]:

$11.1 \pm 0.3_{stat} \pm 1.7_{sys} \pm 0.4_{lumi}$

$W\to\tau_h\nu$ systematics

	$\frac{\delta C_W}{C_W}$	$\frac{\delta N_{EW}}{N_{EW}}$	$\frac{\delta N_{QCD}}{N_{QCD}}$	$\frac{\delta\sigma^{fid}_{W\to\tau_h\nu_\tau}}{\sigma^{fid}_{W\to\tau_h\nu_\tau}}$
Trigger efficiency	6.1%	6.1%	-	7.0%
Energy scale	6.7%	8.7%	-	8.0%
τ_h ID efficiency	9.6%	4.1%	-	10.3%
Jet τ_h misidentification	-	7.2%	-	1.1%
Electron τ_h misidentification	-	4.5%	-	0.7%
Pile-up reweighting	1.4%	1.2%	-	1.6%
Electron reconstruction/identification	-	1.2%	-	0.2%
Muon reconstruction	-	0.3%	-	0.04%
Underlying event modelling	1.3%	1.1%	-	1.5%
Cross section	-	4.5%	-	0.7%
QCD estimation: Stability/correlation	-	-	2.7%	0.2%
QCD estimation: Sig./EW contamination	-	-	2.1%	0.1%
Monte Carlo statistics	1.4%	2.4%	6.0%	1.5%
Total systematic uncertainty	13.4%	15.2%	6.9%	15.1%



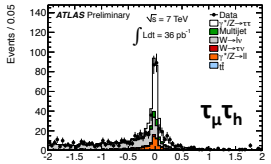
$Z\to\tau\tau$ systematics

Systematic uncertainty	$\tau_\mu\tau_h$	$\tau_e\tau_h$	$\tau_e\tau_\mu$	$\tau_\mu\tau_\mu$	Correlation
Muon efficiency	3.8%	–	2.2%	8.6%	✓
Muon d_0 (shape and scale)	–	–	–	6.2%	X
Muon resolution & energy scale	0.2%	–	0.1%	1.0%	✓
Electron efficiency, resolution &					
Charge misidentification	–	9.6%	5.9%	–	✓
τ_h identification efficiency	8.6%	8.6%	–	–	✓
τ_h misidentification	1.1%	0.7%	–	–	✓
Energy scale (e/τ/jets/E_T^{miss})	10%	11%	1.7%	0.1%	✓
Multijet estimate method	0.8%	2%	1.0%	1.7%	(✓)
W normalization factor	0.1%	0.2%	–	–	X
Object quality cuts	1.9%	1.9%	0.4%	0.4%	✓
Pileup description in simulation	0.4%	0.4%	0.5%	0.1%	✓
Theoret. cross-section	0.2%	0.1%	0.3%	4.3%	✓
A_Z systematics	3%	3%	3%	4%	✓
Total Systematic uncertainty	15%	17%	7.3%	14%	
Statistical uncertainty	9.8%	12%	13%	23%	X
Luminosity	3.4%	3.4%	3.4%	3.4%	✓

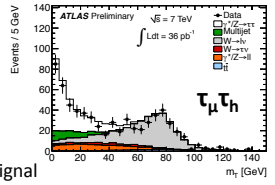
$Z\to\tau\tau$:

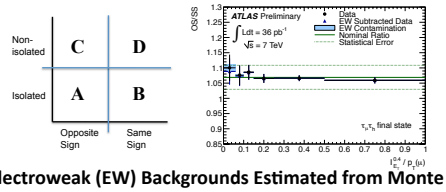
$$\sum \cos\Delta\phi = \cos(\phi(l) - \phi(E_T^{miss})) + \cos(\phi(\tau) - \phi(E_T^{miss}))$$

- **$\tau_e\tau_h$, $\tau_\mu\tau_h$:**
  - Trigger on lepton (e/μ)
  - Require Tight τ (cut based)
  - **Z→ll Suppression:**
    - Require exactly one lepton
- **$\tau_e\tau_\mu$:**
  - Trigger on electron
  - $t\bar{t}$ Suppression:
    - $\sum E_T + E_T^{miss} = E_T(e) + p_T(\mu) + \sum_{jets} p_T + E_T^{miss} < 150$ GeV
- **$\tau_e\tau_h$, $\tau_\mu\tau_h$, and $\tau_e\tau_\mu$:**
  - **W + Jets Suppression:**
    - ΣcosΔϕ > -0.15
    - $m_T < 50$ GeV
- **$\tau_\mu\tau_\mu$:**
  - Trigger on muon
  - Require two oppositely charged muons.
  - Z→ll:
    - Use BDT to separate from signal
- **Background Estimation (ABCD):**



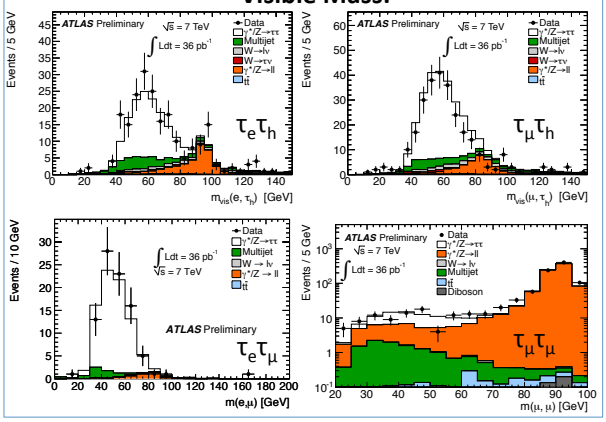
$$m_T = \sqrt{2 p_T(l) \cdot E_T^{miss} \cdot (1 - \cos\Delta\phi(l, E_T^{miss}))}$$





- **Electroweak (EW) Backgrounds Estimated from Monte Carlo (MC)**
  - W+jets MC normalized to data
- **Multijet: OS vs. SS and isolated vs. non-isolated (Z→ττ)**
  - Must show ratio of Opposite to Same Sign Events is independent of isolation and that regions CBD have negligible signal and EW contamination.

Visible Mass:



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