Measurement of the $Z \to \tau\tau$ Cross Section with the ATLAS Detector

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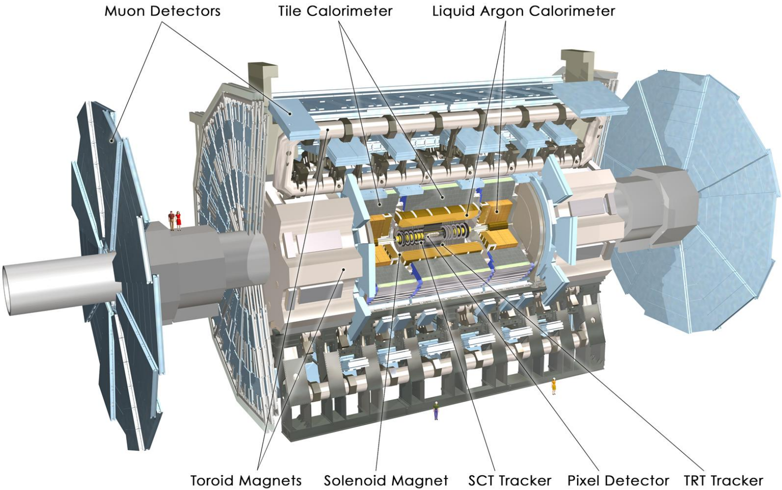
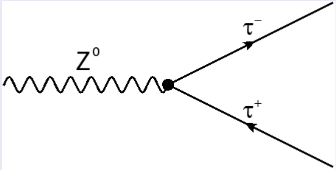


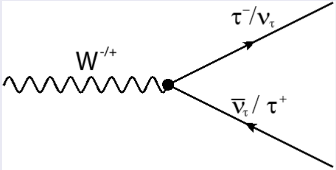
Decays of SM gauge bosons into $\tau^{\pm}$ leptons...

Z^0



- $Z^0 \to \tau^+\tau^-$
- $BR_{Z\to\tau^+\tau^-} = 3.367 \pm 0.008\,\%$ @ $p = 45.559\,\mathrm{GeV}$ [PDG2011]

$W^{\pm}$



- $W^{\pm} \to \tau^{\pm}\nu_\tau/\overline{\nu}_\tau$
- $BR_{W\to\tau^{\pm}\nu_\tau/\overline{\nu}_\tau} = 11.25 \pm 0.20\,\%$ @ $p = 40.180\,\mathrm{GeV}$ [PDG2011]

...are interesting in their own right...

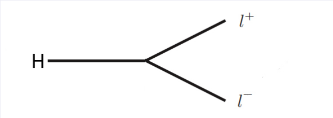
$Z^0 \to \tau^+\tau^-$

- Complements $Z^0 \to e^+e^-$ and $Z^0 \to \mu^+\mu^-$ measurements
- Has a well-known SM cross section
- ▷ Commissioning and validation of the $\tau^{\pm}$ identification technique

Motivation

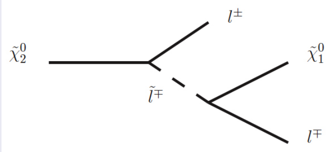
...apart from constituting an important BG for new physics where the $\tau^{\pm}$ plays a significant role.

Higgs decay:



- $H \to \tau^+\tau^-$
- Yukawa coupling $\propto m_l$:
  - ▷ $BR_{H\to\tau^+\tau^-} > BR_{H\to l^+l^-}$ with $l = \mu, e$

SUSY processes:



- $\tan\beta$: ratio of the VEV of 2 neutral Higgs fields
- If $\tan\beta$ large:
  - ▷ $BR_{\tilde{\chi}_2^0\to\tau^+\tau^-\tilde{\tau}_1} > BR_{\tilde{\chi}_2^0\to l^+l^-\tilde{l}_1}$ with $l = \mu, e$
- If $\tan\beta$ small:
  - ▷ $BR_{\tilde{\chi}_2^0\to\tau^+\tau^-\tilde{\tau}_1}$ still important to test the universality of the coupling.

Object Reconstruction

$Z \to \tau\tau$ is reconstructed via 4 final states

$\mu + \text{hadrons} + 3\nu$

$e + \text{hadrons} + 3\nu$

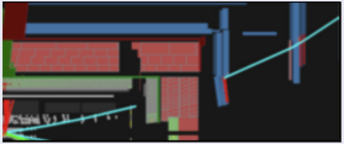
$e + \mu + 4\nu$

$\mu + \mu + 4\nu$

Muon

- association
- isolation requirements:

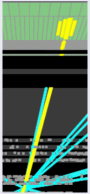
  Σp_T(from inner detector in cone around muon) / p_{T_μ}
  ΣE_T(from calorimeter in cone aroun muon) / p_{T_μ}



Electron

- association
- additional quality cuts (medium or tight) depend on quality of tracks and shower shapes
- isolation requirements:

  Σp_T(from inner detector in cone around electron) / E_{T_e}
  ΣE_T(from calorimeter in cone aroun electron) / E_{T_e}



Object Reconstruction

Missing Transverse Energy

calculated using energy deposits in calorimeter and reconstructed muon tracks

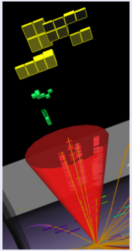
$$E_T^{miss} = E_T^{miss}(\mathrm{calo}) + \mathrm{E}_\mathrm{T}^\mathrm{miss}(\mathrm{muon}) - \mathrm{E}_\mathrm{T}^\mathrm{miss}(\mathrm{energyloss})$$ [vector sum]

Jet

- anti-kT algorithm
- energy calibration is based on simulation and validated using test beam and collision data

Hadronic τ

- seeded by calorimeter jet
- associated with exactly 1 or 3 tracks, where $|\Sigma q^{tracks}| = 1$
- required to pass additional identification criteria using:
  - energy-weighted transverse width
  - p_T-weighted track width
  - p_T of leading track in jet



Selection

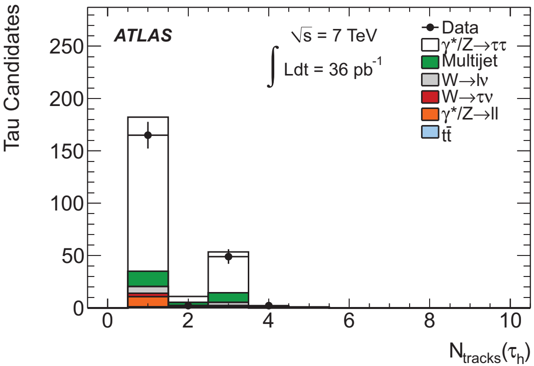
- Muon trigger ($p_T > 10 - 13\ GeV$)
- 1 isolated tight quality muon with $p_T > 15\ GeV$, $|\eta| < 2.4$
- 1 hadronic tau with $p_T > 20\ GeV$, $|\eta| < 2.47$ (removed crack region)
- hadronic tau candidate with 1 or 3 tracks, $q = \pm 1$
- $q_{had} q_\mu < 0$

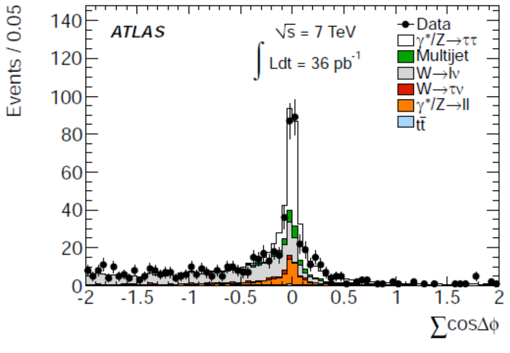
$\gamma^*/Z \to ll + jets$ rejection

- No additional (loose) muons in the event

$W + jets$ rejection

- $m_T < 50\ GeV$ where $m_T = \sqrt{2 p_T^\mu E_T^{miss}(1 - \cos(\phi(\mu) - \phi(E_T^{miss})))}$
- $\Sigma \cos(\Delta\phi) > -0.15$ where $\Sigma \cos(\Delta\phi) = \cos(\phi(\mu) - \phi(E_T^{miss})) + cos(\phi(\tau_h) - \phi(E_T^{miss}))$





Background Estimation

W→ $\ell\nu$ background estimation

A control region is defined:

- All selection cuts are applied; m_T and $\sum \cos \Delta\phi$ are inverted
- Contributions in the control region from $\gamma^*/Z \rightarrow \ell\ell$ and $t\bar{t}$ estimated on MC simulations

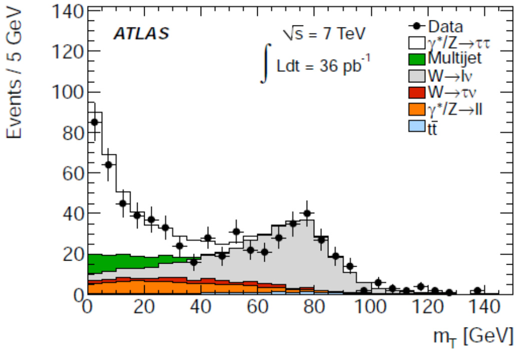
  normalisation factor can then be calculated: $0.73 \pm 0.06_{stat}$

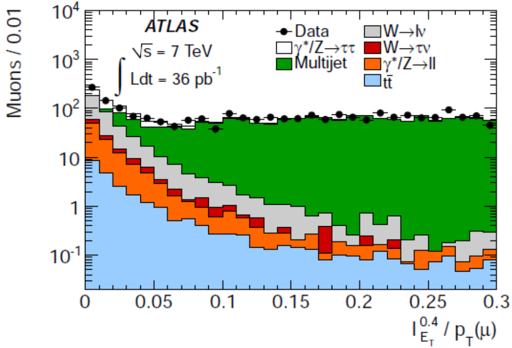
Multijet Control Region

A control region is also defined to estimate the multijet background:

- Both τ candidates must have the same sign
- The lepton isolation requirement is inverted and the ratio $R_{OS/SS}$ is measured

  The ratio is assumed to be consistent in events passing normal isolation cut
- After subtracting non-QCD backgrounds this is found to be: $1.07 \pm 0.04_{stat} \pm 0.04_{syst}$
- This ratio is used to estimate QCD contribution in the signal region



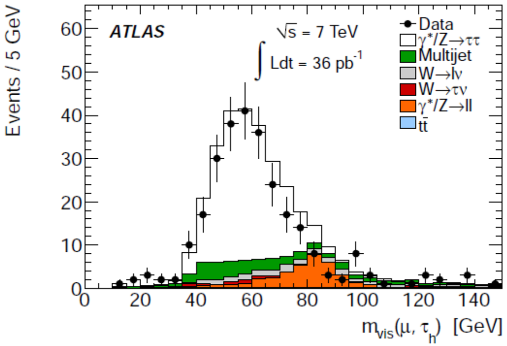


Remaining Backgrounds

All of the other backgrounds are estimated from MC simulations

	$\tau_\mu \tau_h$
$\gamma^*/Z \to \ell\ell$	11.1 ± 0.5
$W \to \ell\nu$	9.3 ± 0.7
$W \to \tau\nu$	3.6 ± 0.8
$t\bar{t}$	1.3 ± 0.1
Diboson	0.28 ± 0.02
Multijet	24 ± 6
$\gamma^*/Z \to \tau\tau$	186 ± 2
Total expected events	235 ± 6
N_{obs}	213

Expected number of events and number of events in data for $36\ pb^{-1}$ after full selection. Only statistical uncertainty shown.



Cross Section Calculation

Fiducial cross section

$\sigma^{fid}(Z \rightarrow \tau\tau) \times BR = \frac{N_{obs} - N_{bkg}}{C_Z L}$

C_Z definition

- Selection efficiency in the given phase space
- Takes into account many factors: triggering and reconstruction efficiency, resolutions...

C_Z calculation

- Evaluated on signal MC simulation
- The simulation is corrected to agree with data for:
  - Trigger efficiency
  - Reconstruction efficiency
  - Jet energy scale
  - ...
- Generator level $\rightarrow$ number of events in the phase space N_{gen}
- Reconstructed level $\rightarrow$ number of events passing full selection N_{reco}
- $C_Z = N_{reco}/N_{gen}$

Fiducial phase space for the $\tau_\mu \tau_h$ channel

Muon	$p_T > 15\ GeV$ $\lvert\eta\rvert < 2.4$
Tau	$p_T > 20\ GeV$ $\lvert\eta\rvert < 2.4$, excluded $1.37 < \lvert\eta\rvert < 1.52$
Event	$\Sigma \cos(\Delta\phi) > -0.15$ $m_T < 50\ GeV$ $35\ GeV < m_{vis} < 75\ GeV$

Final cross section

$\sigma(Z \rightarrow \tau\tau) = \sigma^{fid}/A_Z$

Defined for $66\ GeV < m_{\tau\tau} < 116\ GeV$ before FSR

Acceptance factor A_Z

- Allows for an extrapolation to the full space phase
- Evaluated using MC simulation

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%	✓
pile-up 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%	✓

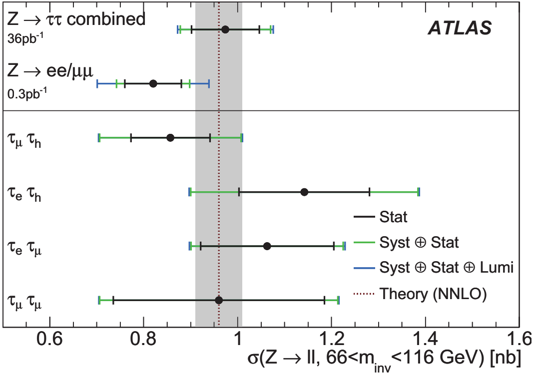
Correlation taken into account between different sources

Final result

$\sigma(Z \to \tau\tau) = 0.97 \pm 0.07_{stat} \pm 0.06_{sys} \pm 0.03_{lumi}$ nb

	N_{obs}	$N_{obs} - N_{bkg}$	stat	sys
$\tau_\mu\tau_h$	213	164	±16	±4
$\tau_e\tau_h$	151	114	±14	±3
$\tau_e\tau_\mu$	85	76	±10	±1
$\tau_\mu\tau_\mu$	90	43	±10	±3

	σ [nb]	stat	sys
$\tau_\mu\tau_h$	0.86	±0.08	±0.12
$\tau_e\tau_h$	1.14	±0.14	±0.2
$\tau_e\tau_\mu$	1.06	±0.14	±0.08
$\tau_\mu\tau_\mu$	0.96	±0.22	±0.12



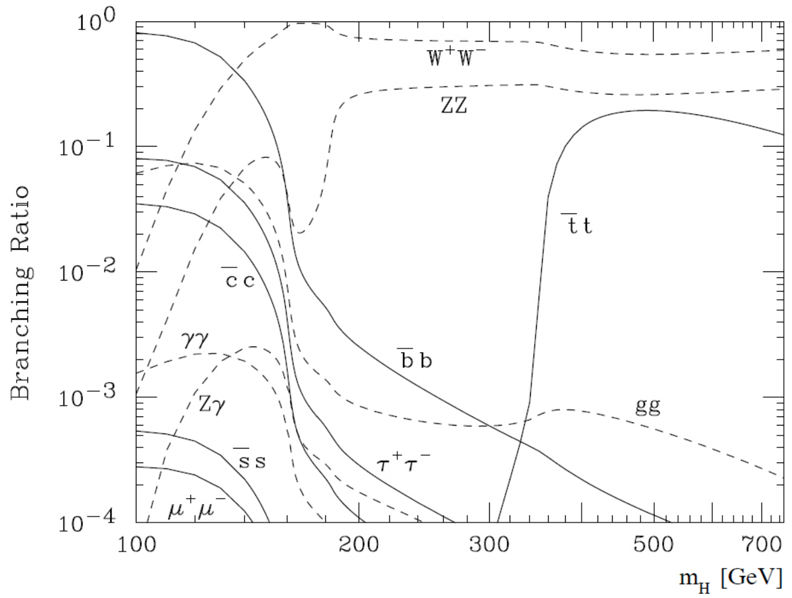
$\sigma(Z \to \tau\tau) = 1.00 \pm 0.05_{stat} \pm 0.08_{sys} \pm 0.04_{lumi}$ nb

@CMS ($m_{inv} \in [60, 120]$ GeV)

Conclusions

- Measured cross section is in agreement with SM
- Tau reconstruction in ATLAS performing well
- Now we sit and wait for new physics to show

Higgs decay modes branching ratios:



Backup Systematics Errors (1)

Muons

- Muon Efficiency + Impact parameter d_0 smearing

Electrons

- Charge identification

Hadronic τ_h

- Identification Efficiency (Jets)
- Energy scale smearing and description

Efficiency of lepton trigger, identification, and isolation

5-9% for e and 2-4% for muons

Efficiency of hadronic identification

(9-12%). Its calculated by varying the simulation conditions, such as the amount of detector material, calorimeter cell thresholds and so on.

Backup Systematics Errors (2)

Electron and jet misidentification as τ candidates

- The probability for an electron or a QCD jet to be misidentified as a hadronic τ is measured.
- The misidentification probability for electrons: τ search in $Z \to ee$ events.
- The misidentification probability for QCD jet: τ search in $Z \to ll + jet$ events.

Energy scale

The τ energy scale uncertainty is estimated by varying the detector geometry, hadronic showering model, underlying event model etc.

Other sources of systematic uncertainty

Uncertainty on the luminosity is 3.4%. Uncertainties due to a few problematic calorimetric regions, affecting electron reconstruction, are evaluated and found to a have a very small effect.

	$\tau_\mu \tau_h$	$\tau_e \tau_h$
N_{obs}	213	151
$N_{obs} - N_{bkg}$	$164 \pm 16 \pm 4$	$114 \pm 14 \pm 3$
A_z	0.117 ± 0.004	0.101 ± 0.003
C_z	0.20 ± 0.03	0.12 ± 0.02
B	0.2250 ± 0.0009	0.2313 ± 0.0009
L	$35.5 \pm 1.2\ \text{pb}^{-1}$	$35.7 \pm 1.2\ \text{pb}^{-1}$

	$\tau_e \tau_\mu$	$\tau_\mu \tau_\mu$
N_{obs}	85	90
$114 \pm 14 \pm 3$	$76 \pm 10 \pm 1$	$43 \pm 10 \pm 3$
A_z	0.114 ± 0.003	0.156 ± 0.006
C_z	0.29 ± 0.02	0.27 ± 0.02
B	0.0620 ± 0.0002	0.0301 ± 0.0001
L	$35.5 \pm 1.2\ \text{pb}^{-1}$	$35.5 \pm 1.2\ \text{pb}^{-1}$