Observation of Z→ττ Decays with the ATLAS detector

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On behalf of the ATLAS collaboration

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Motivation

Why Z →ττ?

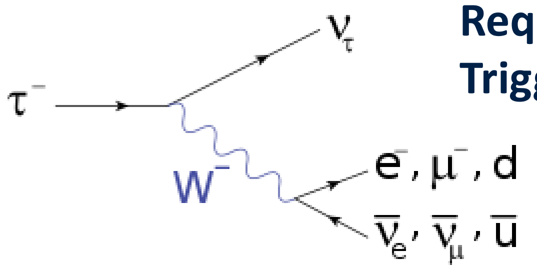
- Re-observe Standard Model processes such as Z →ττ to demonstrate understanding of detector
- Measure this important background to many new physics searches such as:
  - Higgs bosons – in particular H →ττ
  - Supersymmetry
  - Exotic Scenarios
- Allows us to do performance tau lepton studies by triggering on electron and muon tau decay products

First Step:

- This observation of $Z \rightarrow \tau_l \tau_h$ Decays with the ATLAS Detector has been performed at $\sqrt{s}$ = 7 TeV with 8.3 pb^{-1} and 8.5 pb^{-1} in the electron channel and muon channels respectively

https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/CONFNOTES/ATLAS-CONF-2011-010/

Event Signature

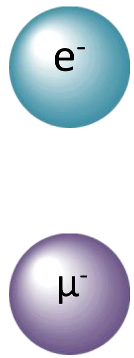


Require one leptonic tau decay
Require one hadronic tau decay
Trigger on single lepton

Main Backgrounds:

- W+jets
- Multijets
- Z → ee, Z → μμ

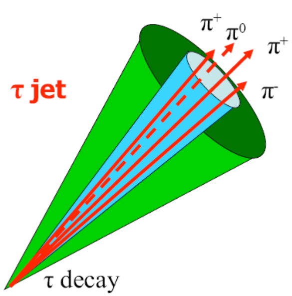
Leptonic Tau Decay:



Require one isolated lepton passing tight identification requirements with transverse momentum > 15 GeV

Hadronic Tau Decay:

Require energy deposit in calorimeter
Matching to 1 or 3 tracks
Passes tight hadronic tau identification
Has transverse energy > 15 GeV

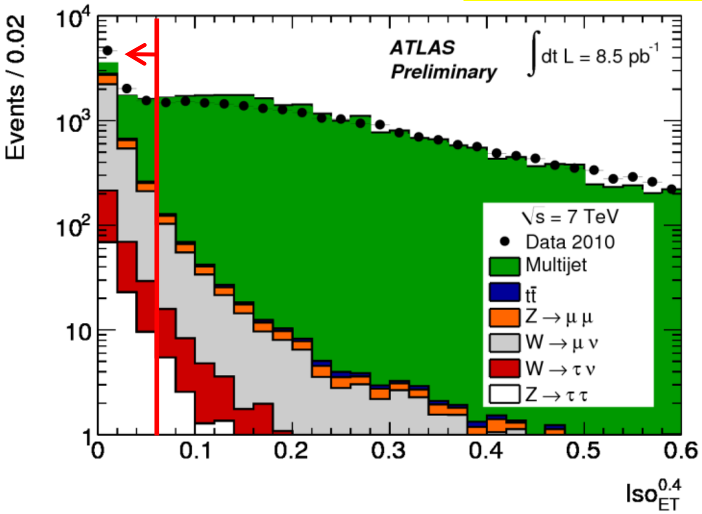


More information on particle identification:
Electron: arXiv:1010.2130
Muon: ATLAS-CONF-2010-036
Tau: ATLAS-CONF-2010-086

Lepton Isolation

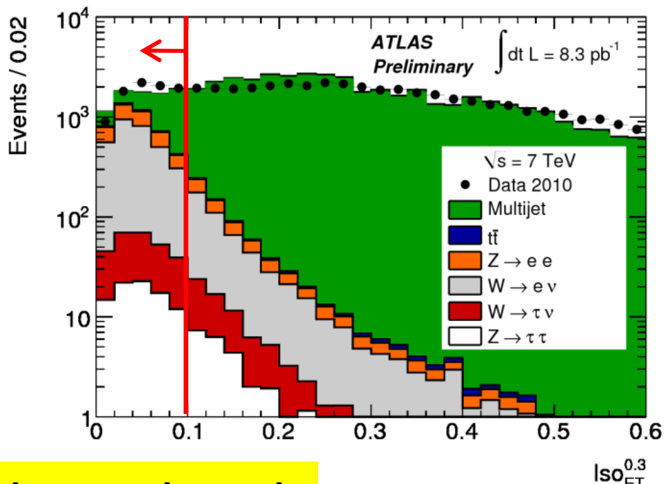
Two Isolation Variables:

Muon channel



$Iso^{0.4}_{PT}$ Sum of transverse momentum of associated **tracks** to charged particles in a cone of ΔR = 0.4

$Iso^{\Delta R}_{ET}$ Sum of transverse energy of particles in **calorimeter** in a cone of ΔR = 0.4 around muon or ΔR = 0.3 around electron



Electron channel

Best discriminator against multijet background

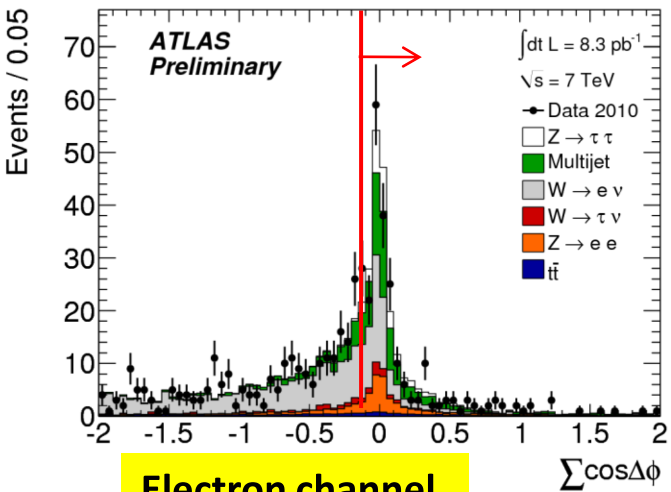
ϕ is measured around the beam axis and the polar angle θ is the angle from the beam axis

$\eta = -\ln\tan(\theta/2)$ and $\Delta R = \sqrt{(\Delta\eta)^2 + (\Delta\phi)^2}$

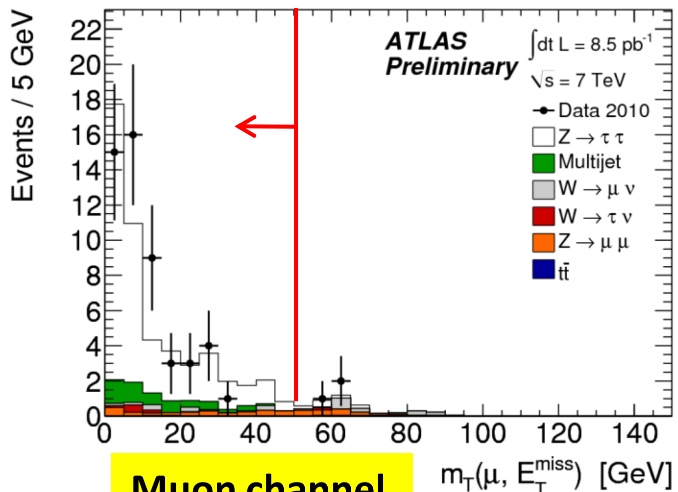
W+jets Background

Variable 1: $\sum \cos\Delta\phi = \cos\left(\phi(\ell) - \phi(E_T^{miss})\right) + \cos\left(\phi(\tau_h) - \phi(E_T^{miss})\right)$

Variable 2: $m_T(\ell, E_T^{miss}) = \sqrt{2\, p_T(\ell) \cdot E_T^{miss} \cdot \left(1 - \cos\Delta\phi(\ell, E_T^{miss})\right)}$



Electron channel



Muon channel

W Boson Control Region :

Obtained by reversing cuts on variables 1 and 2

Normalisation factor for Monte Carlo Simulation

k_W measured from data

Further event cuts:

Opposite charge tau and lepton

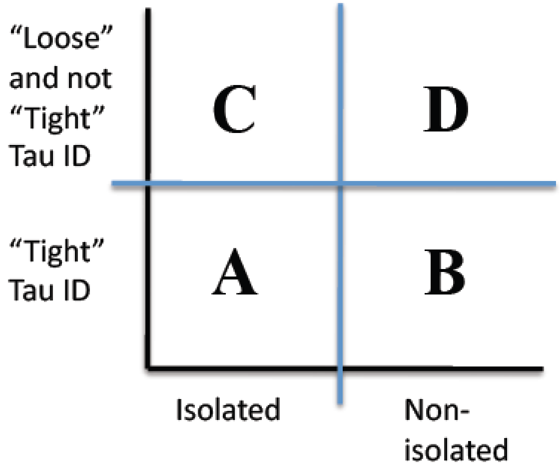
Visible Mass window cut on invariant

tau and lepton mass

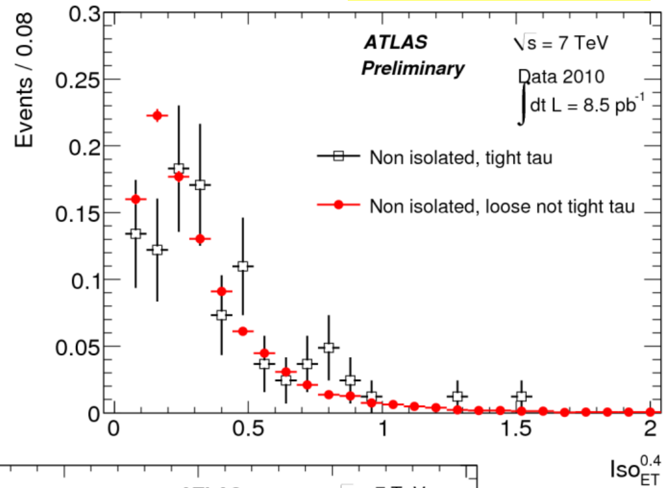
Multijet Background Estimation
- Data driven method

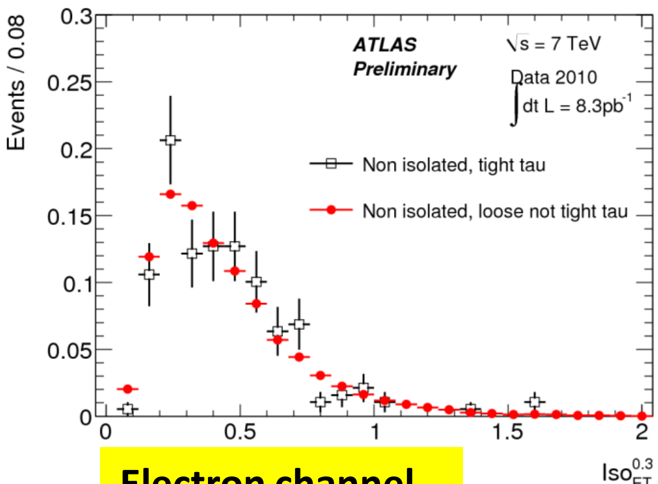
$$N^A = N^B\left(\frac{N^C}{N^D}\right) = N^B R_{\mathrm{iso}}$$

$$N^A_{\mathrm{QCD}} = \begin{cases} 5.2 \pm 0.7\ (\mathrm{stat.}) \pm 0.7\ (\mathrm{syst.}) & \text{muon channel} \\ 6.8 \pm 0.6\ (\mathrm{stat.}) \pm 0.7\ (\mathrm{syst.}) & \text{electron channel} \end{cases}$$



Muon channel



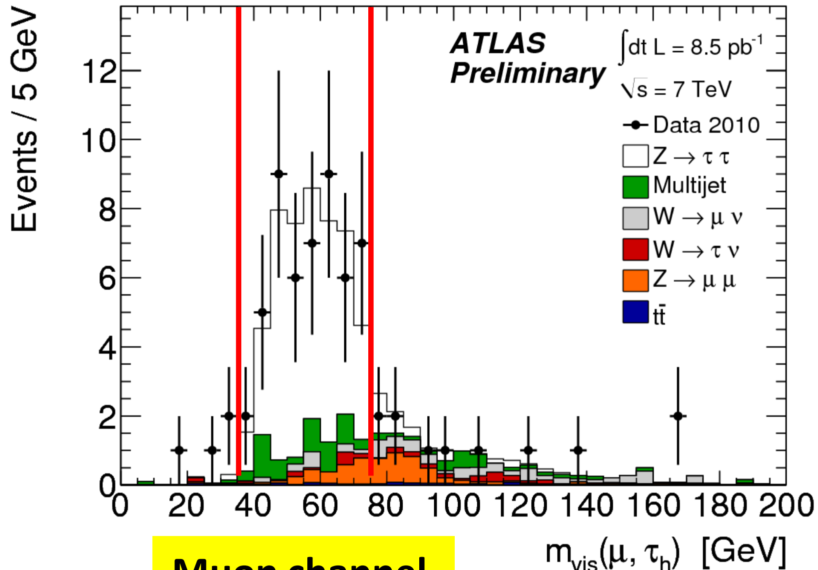


Electron channel

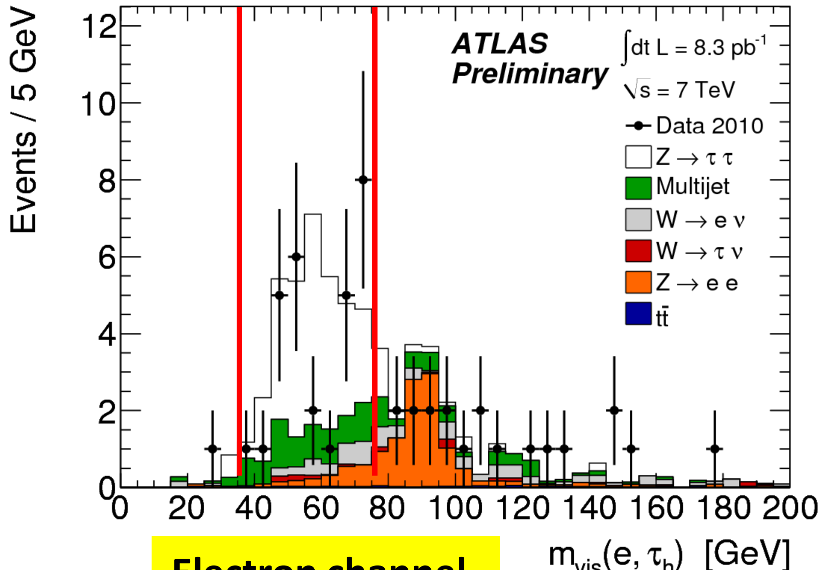
Other backgrounds:
- $Z \rightarrow ee$, $Z \rightarrow \mu\mu$ and tt taken from simulation
- W+jets normalised to data

Observation

	Muon Channel (8.5 pb^{-1})	Electron Channel (8.3 pb^{-1})
Data (after all selections)	51	29
Total Estimated Background	9.9 ± 2.1	11.8 ± 1.7
Estimated Multijet Background	*5.2 ± 0.7(stat.) ± 0.7 (syst.)*	*6.8 ± 0.6(stat.) ± 0.7 (syst.)*
Estimated W, Z, $t\bar{t}$ Background	*4.7 ± 0.5(stat.) ± 1.5(syst.)*	*5.0 ± 0.6 (stat.) ± 1.4(syst.)*
Data (after background subtraction)	41.1 ± 7.1(stat.) ± 2.1(bkg. est.)	17.2 ± 5.4(stat.) ± 1.7(bkg. est.)
SM Signal Expectation	39.9 ± 1.8(stat.) ± 6.7(syst.)	24.5 ± 1.4(stat.) ± 7.9(syst.)

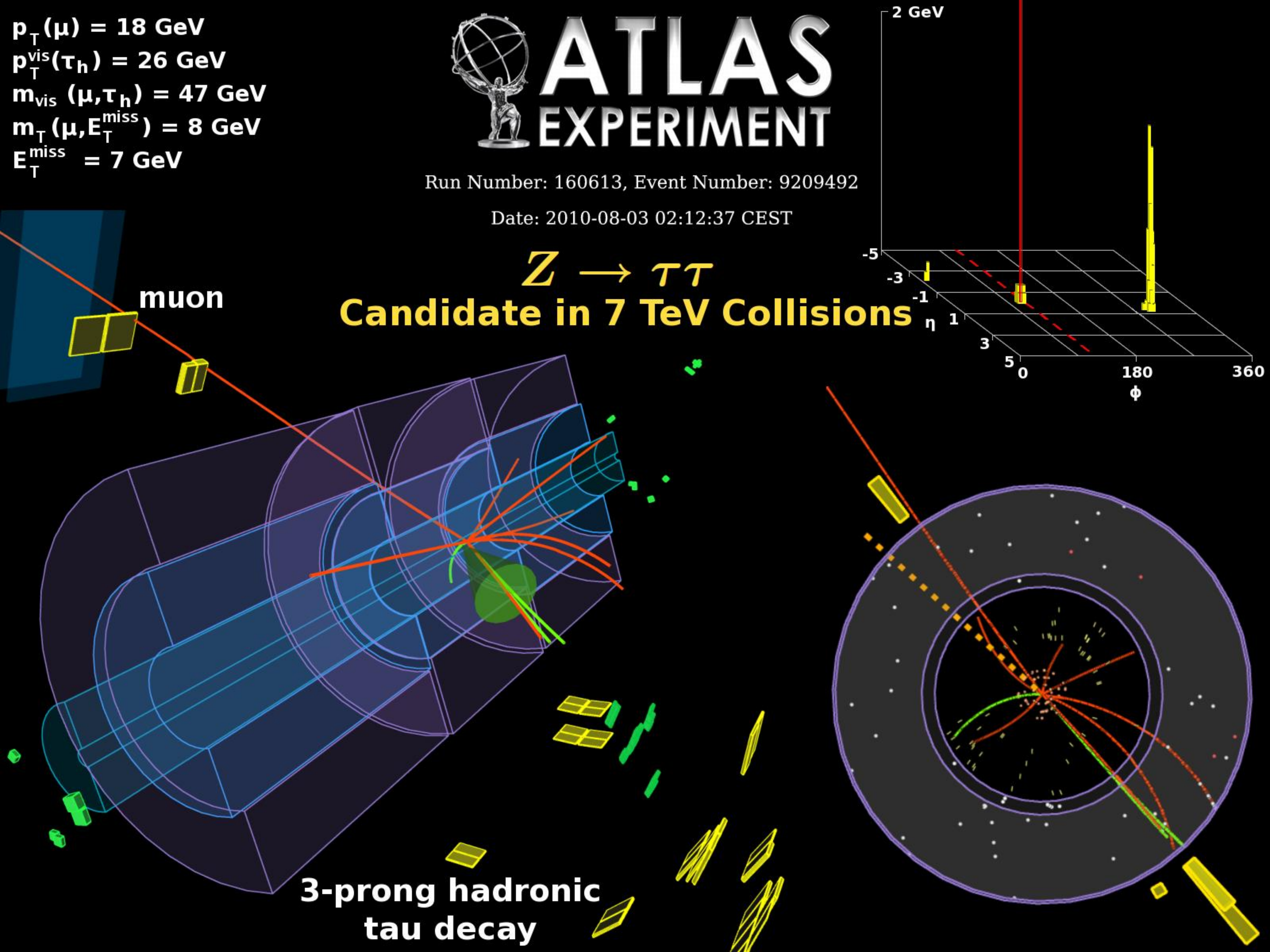


Muon channel



Electron channel

https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/CONFNOTES/ATLAS-CONF-2011-010/

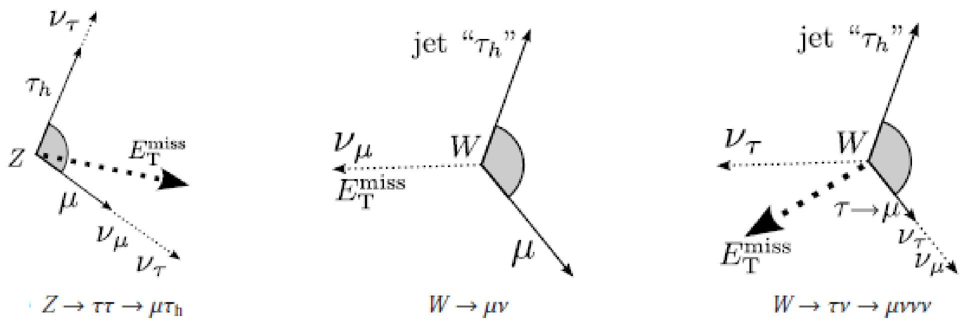


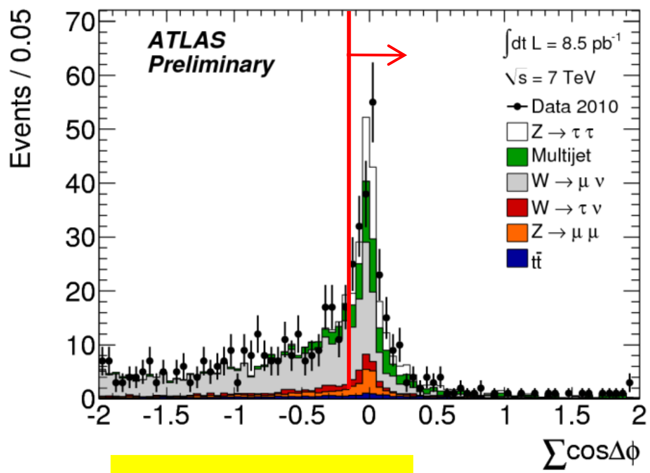
$p_T(\mu)$ = 18 GeV
$p_T^{vis}(\tau_h)$ = 26 GeV
m_{vis} (μ, τ_h) = 47 GeV
m_T (μ, E_T^{miss}) = 8 GeV
E_T^{miss} = 7 GeV
ATLAS EXPERIMENT
Run Number: 160613, Event Number: 9209492
Date: 2010-08-03 02:12:37 CEST
$Z \rightarrow \tau\tau$
Candidate in 7 TeV Collisions
muon
3-prong hadronic tau decay
2 GeV
-5
-3
-1
1
3
5
η
0
180
360
ϕ

Backup Slides

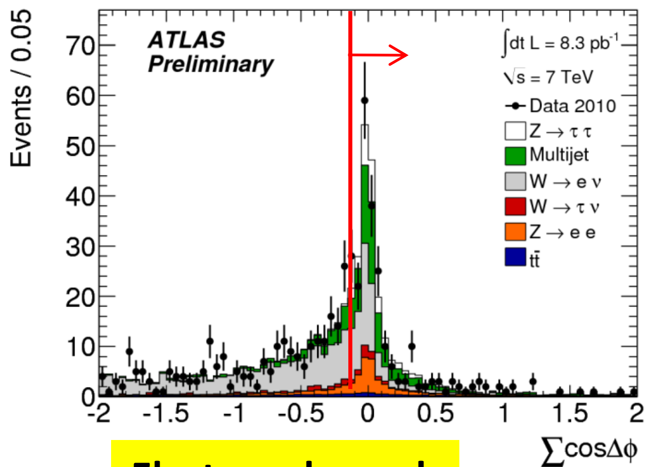
W+jets Background
- Angular variable

Variable 1: $\sum \cos\Delta\phi = \cos\left(\phi(\ell) - \phi(E_{\mathrm{T}}^{\mathrm{miss}})\right) + \cos\left(\phi(\tau_{\mathrm{h}}) - \phi(E_{\mathrm{T}}^{\mathrm{miss}})\right)$





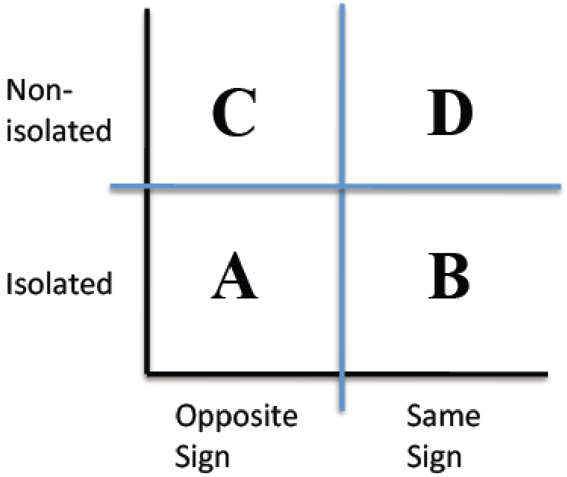
Muon channel



Electron channel

Multijet Background Estimation
- Cross-check method

$$N^A = N^B \left(\frac{N^C}{N^D} \right) = N^B\, R_{\mathrm{OSSS}}$$



$$R_{\mathrm{OSSS}} = \begin{cases} 1.10 \pm 0.22\ (\mathrm{stat.}) \pm 0.07\ (\mathrm{syst.}) & \text{muon channel} \\ 1.15 \pm 0.16\ (\mathrm{stat.}) \pm 0.17\ (\mathrm{syst.}) & \text{electron channel} \end{cases}$$

$$N^A_{\mathrm{QCD}} = \begin{cases} 2.14 \pm 2.35(\mathrm{stat.})\ \pm 0.42(\mathrm{syst.}) & \text{muon channel} \\ 2.73 \pm 2.36(\mathrm{stat.})\ \pm 0.71(\mathrm{syst.}) & \text{electron channel} \end{cases}$$

- Stability of R_{OSSS} was tested against isolation variables and systematic uncertainty assigned
- This method was **statistically limited**

Estimations for both methods are in statistical agreement

Cut Flow

- Muon channel

	data	$Z \to \tau\tau$	Multijets	$W \to \mu\nu$	$W \to \tau\nu$	$Z \to \mu\mu$	$t\bar{t}$
object selection	574	59(2)	78(3)	268(4)	25(1)	83.8(9)	25.9(3)
dilepton veto	522	58(2)	78(3)	267(4)	25(1)	33.7(6)	20.7(3)
W suppression cuts	173	52(2)	58(2)	33(1)	11.2(8)	12.7(3)	5.2(1)
$m_{\mathrm{vis}} = 35 - 75$ GeV	91	46(2)	32(2)	6.3(6)	3.1(4)	4.2(2)	0.89(6)
$N_{\mathrm{trk}}(\tau_{\mathrm{h}}) = 1$ or 3, $\lvert Q(\tau_{\mathrm{h}})\rvert = 1$	55	40(2)	10(1)	2.1(4)	0.9(2)	2.7(2)	0.37(4)
opposite sign	51	40(2)	5.2(7)	1.2(3)	0.8(2)	2.4(2)	0.28(3)

Numbers of events passing the cumulative event selections for the muon channel. Only statistical errors are given in parentheses. The predictions for signal, $Z \to \mu\mu$ and tt are taken from Monte Carlo normalized to 8.5 pb^{-1}

Cut Flow
- Electron channel

	data	$Z \to \tau\tau$	Multijet	$W \to e\nu$	$W \to \tau\nu$	$Z \to ee$	$t\bar{t}$
object selection	524	38(2)	109(3)	243(4)	18(1)	82.9(9)	21.6(3)
dilepton veto	485	37(2)	108(3)	243(4)	18(1)	48.9(7)	17.4(3)
W suppression cuts	163	33(2)	77(2)	34(2)	7.9(7)	26.5(5)	4.2(1)
$m_{\rm vis} = 35 - 75$ GeV	76	28(2)	40(2)	7.3(7)	1.7(3)	5.4(2)	0.72(5)
$N_{\rm trk}(\tau_{\rm h}) = 1$ or 3, $\lvert Q(\tau_{\rm h})\rvert = 1$	33	25(2)	12.8(9)	2.9(5)	0.5(2)	2.6(2)	0.25(3)
opposite sign	29	25(2)	6.8(6)	2.3(4)	0.5(2)	1.9(1)	0.20(3)

Numbers of events passing the cumulative event selections for the electron channel. Only statistical errors are given in parentheses. The predictions for signal, $Z \to ee$ and tt are taken from Monte Carlo normalized to 8.3 pb^{-1}

Systematics
– Muon channel

Systematic	Uncertainty	Multijets	W+jets	Z & $t\bar{t}$	$Z \to \tau\tau$
μ efficiency	2.7%	±0.03*	-	±0.07	±1.1
μ trigger efficiency	2.0%	±0.01*	-	±0.05	±0.8
μ isolation	1.6%	±0.01*	-	±0.04	±0.7
Jet τ fake rate	50%	±0.17*	-	±1.34	-
Energy scale	13% ($W \to \mu\nu$) / 16% ($W \to \tau\nu$)	±0.26*	±0.28	±0.40	±2.4
	6% (signal) / 13% (Z) / 21% ($t\bar{t}$)				
Pile-up re-weighting	0.5% (signal) / 0.58% ($t\bar{t}$)	±0.01*	-	±0.10	±0.2
	3.9% (Z)				
MC underlying event model	7%	±0.04*	-	-	±2.8
MC showering model	6%	±0.04*	-	-	±2.4
Luminosity	11%	±0.07*	-	±0.30	±4.4
Theoretical cross section	5% (Z)	±0.03*	-	±0.12	±2.0
	6% ($t\bar{t}$)	±0.01*	-	±0.02	-
W rescaling factor	8.8% in A, B	±0.04*	±0.17	-	-
	2.1% in C, D	-	-	-	-
Multijet est. (bkg subtraction)	-	±0.34	-	-	-
Multijet est. (method systematics)	-	±0.56	-	-	-
Total systematics	-	±0.66	±0.33	±1.44	±6.7

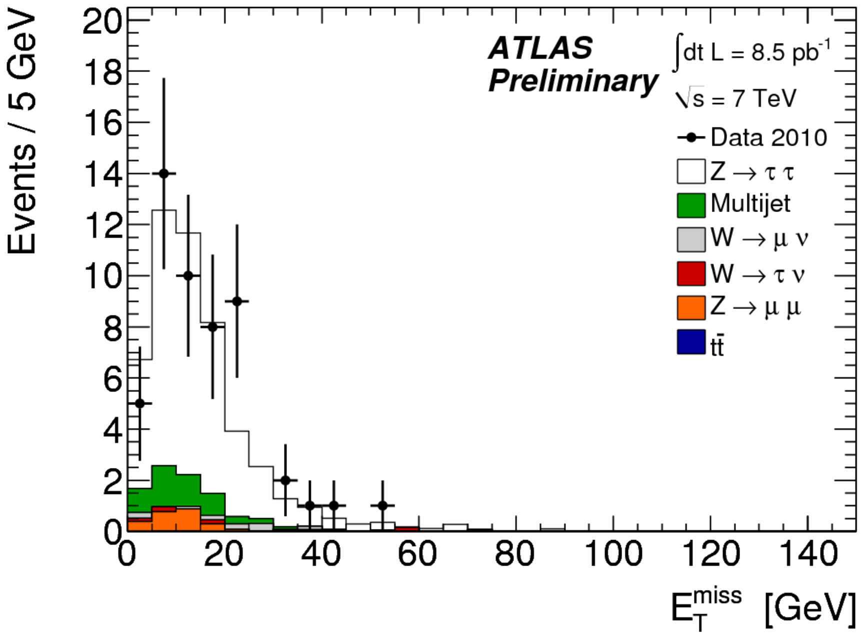
Summary of the sources of systematic uncertainty considered, the uncertainty used, and their effect on the background event estimates as well as on the expected signal (last column), for the muon channel. Most effects only enter indirectly in the multijet estimate, through the background subtraction in the control regions – these entries are labelled with an asterisk.

Systematics – Electron channel

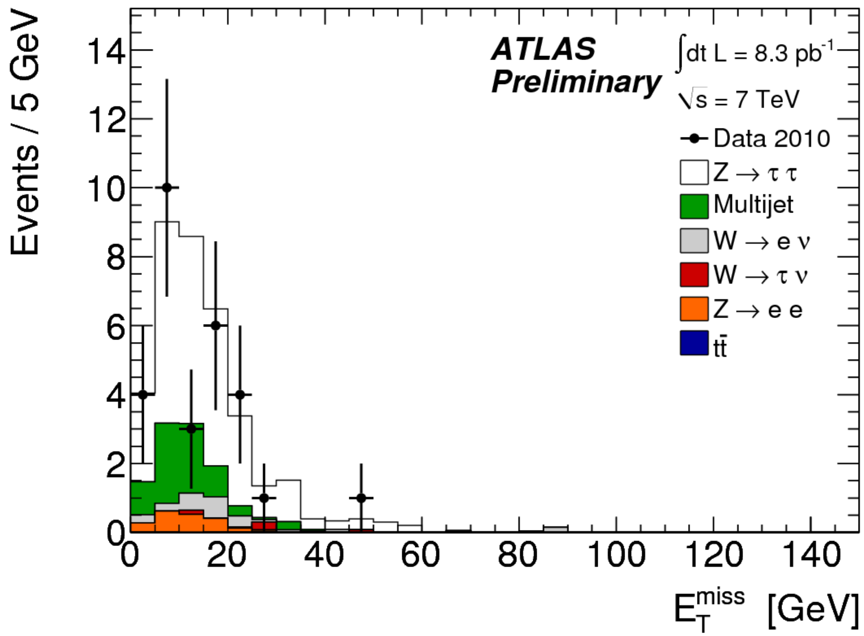
Systematic	Uncertainty	Multijets	W+jets	Z & $t\bar{t}$	$Z \to \tau\tau$
e efficiency	η, p_T dependent	±0.1*	-	±0.25	±4.7
e trigger efficiency	1%	±0.01*	-	±0.02	±0.2
e isolation	p_T dependent	±0.15*	-	±0.17	±3.7
e τ fake rate	33.5%	±0.19*	-	±0.65	-
Jet τ fake rate	50%	±0.29*	-	±1.07	-
Energy scale	13% ($W \to e\nu$) / 12% ($W \to \tau\nu$)	±0.28*	±0.36	±0.28	±1.7
	7% (signal) / 13% (Z) /15% (tt)				
Pile-up re-weighting	0.5% (signal) / 0.58% (tt)	±0.01*	-	±0.03	±0.1
	1.3% (Z)	-	-	-	-
MC underlying event model	8%	±0.03*	-	-	±2.0
MC showering model	13%	±0.05*	-	-	±3.2
Luminosity	11%	±0.07*	-	±0.24	±2.7
Theoretical cross section	5% (Z)	±0.03*	-	±0.10	±1.2
	6% ($t\bar{t}$)	±0.01*	-	±0.01	-
W rescaling factor	8.7% in A, B	±0.04*	±0.24	-	-
	3.1% in C, D	-	-	-	-
Multijet est. (bkg subtraction)	-	±0.47	-	-	-
Multijet est. (method systematics)	-	±0.44	-	-	-
Total systematics	-	±0.65	±0.43	±1.35	±7.9

Summary of the sources of systematic uncertainty considered, the uncertainty used, and their effect on the background event estimates as well as on the expected signal (last column), for the electron channel. Most effects only enter indirectly in the multijet estimate, through the background subtraction in the control regions – these entries are labelled with an asterisk.

Missing Transverse Energy



Muon channel



Electron channel