The $Z \rightarrow \tau\tau \rightarrow (\tau_{jet}\nu_\tau)(l\nu_l\nu_\tau)$ analysis with ATLAS detector with early data

Daniele Capriotti

Max Planck Institut fuer Physik
Werner Heisenberg Institut
Muenchen, 80805, Germany
capriott@mppmu.mpg.de

Young Scientists Workshop @ Ringberg Casle

Overview

- Introduction
- Tau reconstruction and identification with the ATLAS detector
- The $Z \to \tau\tau$ analysis with early data
- Conclusion

Introduction

Why W/Z Boson physics?

- The study of the W and Z Boson production and their properties will be one of the most important measurements of ATLAS during the first phase of LHC.
- By measuring the inclusive production cross-section, we are able to test theoretical QCD predictions at an unknown energy regime.
- The measurement of the differential production cross-sections, e.g. vs. rapidity, transverse momentum and charge, will give new constraints on the structure functions of the proton.
- Knowing these to a high precision is absolutely necessary to conduct electroweak precision measurements, such as the W-mass measurement, at a later stage of the experiment.
- Understanding the W and Z boson production and their properties is a major ingredient for most of the searches for physics beyonds the Standard Model.

Why τ lepton final state?

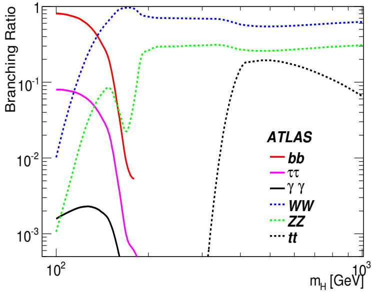
Tau reconstruction is an important (and challenging!) task:

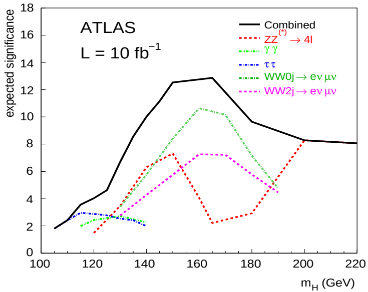
Understanding of the detector:

- Measurement of the τ energy scale
- Measurement of the E_T^{miss} scale

Physics motivations:

- Measurement of W/Z production cross section
- Discovery of the SM and MSSM Higgs boson in $\tau\tau$ final state





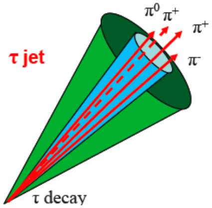
Basic Tau Properties

TAU BRANCHING RATIOS

Leptonic Modes	(35%)
$e\nu_e\nu_\tau$	18%
$\mu\nu_\mu\nu_\tau$	17%
Hadronic Modes: 1 Prong	(47%)
$\pi^-\nu_\tau$	11%
$\pi^-\pi^0\nu_\tau$	25%
$\pi^-\pi^0\pi^0\nu_\tau$	9%
$\pi^-\pi^0\pi^0\pi^0\nu_\tau$	1%
$K^- + Neutrals$	1.5%
Hadronic Modes: 3 Prong	(15%)
$\pi^-\pi^+\pi^-\nu_\tau$	9%
$\pi^-\pi^+\pi^-\pi^0\nu_\tau$	4.5%
$K^-\pi^+\pi^-\nu_\tau$	0.4%
Other Modes	($\approx$ 3%)

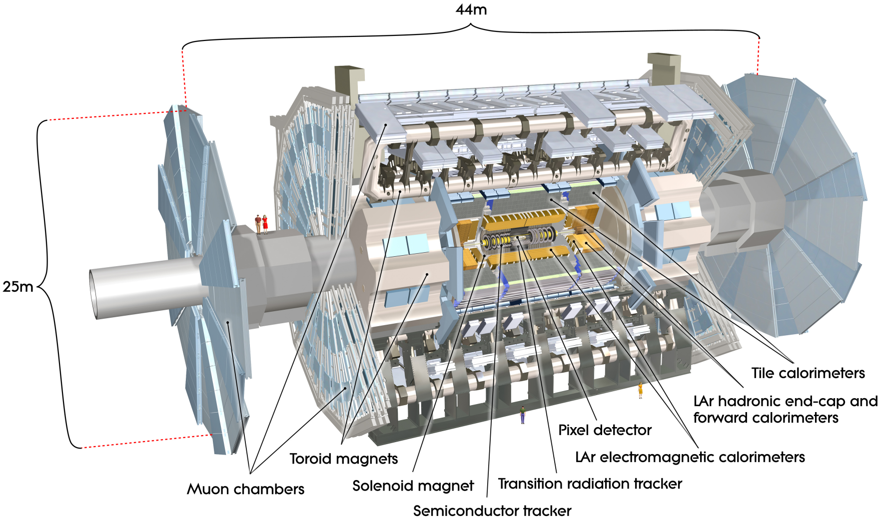
TAU CHARACTERISTICS

- $m_\tau \approx 1.8$ GeV
- $c\tau = 87\ \mu$m
- Hadronic decays are well collimated collection of charged and neutral pions/kaons: leading particle direction reproduces τ direction well
- 1 or 3 charged tracks in the τ-jet



Tau reconstruction and identification with the ATLAS detector

The ATLAS detector at LHC



Tau reconstruction in ATLAS

⇒ The τ reconstruction and ID refer to hadronically decaying τ leptons.

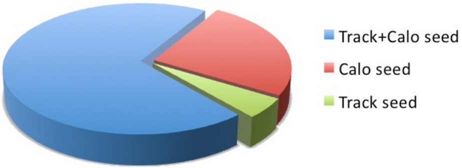
Track seed algorithm

1. Seed track with $p_T > 6\ GeV$ with good quality criteria.
2. Association with other tracks in $\Delta R < 0.2$ with quality criteria.
3. Total charge $|Q| = 1$.
4. Energy flow algorithm

Calorimeter seed algorithm

1. Jets with $E_T > 10\ GeV$.
2. Tracks associated if $\Delta R < 0.3$, passing minimal quality criteria.
3. Energy calculation summing the weighted calorimeter cells in $\Delta R < 0.4$

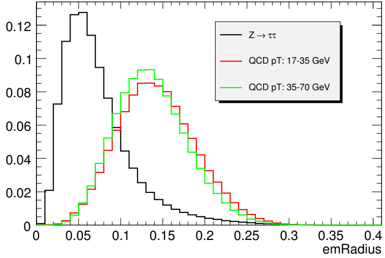
Calorimeter + Track seeds matched if $\Delta R < 0.2$



Tau Identification with early data: Safe Identification

- "Safe-variables": discriminating variables for the τ-ID in the early data ("Safe" $\Rightarrow$ small sensitivity to detector-related systematic uncertainties).
- Not used with early data: variables based on: precision tracking, π^0 reconstruction ...

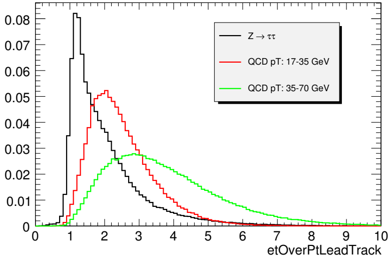
Electromagnetic Radius R_{em}



$$R_{em} = \frac{\sum_{i=1}^{\Delta R<0.4} E_{T,i}\sqrt{(\eta_i-\eta)^2+(\phi_i-\phi)^2}}{\sum_{i=1}^{\Delta R<0.4} E_{T,i}}$$

i calorimetric cell, E_T η_i ϕ_i measured in the EM calorimeter, η ϕ seeded tau coordinates.

Ratio E_T/p_T of the leading track

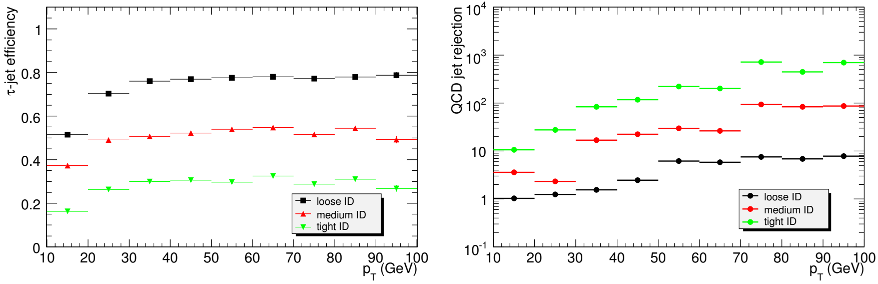


$$E_T^{total}/p_{T1} = \frac{\sum_{i=1} E_{T,i}^{EM} + \sum_{i=1} E_{T,i}^{Had}}{p_{T1}}$$

i calorimetric cell, p_{T1} momentum of the leading track

Taujet efficiency and QCD jet rejection

"Safe Cut" with Calorimeter+Track seed



- *Tight*, *medium*, *loose* cuts corresponding to 0.3, 0.5, 0.7 τ-jet efficiency
- Identification criteria optimized separetely for 5 p_T bins (10-25 GeV, 25-45 GeV, 45-70 GeV, 70-100 GeV, > 100 GeV) separately for 1-prong or 3-prong canditates.

Electron Reconstruction

Different reconstruction algorithms: Calo seed or Track seed

- Calo Seed: starts from clusters reconstructed in the calorimeters and then builds the identification variables based on info from the inner detector and EM calorimeters
- Track Seed: selects good-quality tracks matching a relatively isolated deposition of energy in the EM calorimeters. The identification variables are then calculated in the same way as for the Calo Seed algorithm

The standard identification of high-p_T electrons is based on many cuts which can all be applied indipendently. These cuts have been optimized in up to seven bins in η and six bins in p_T.
Definition of 3 different cuts:

- Loose simple electron identification based only on limited calorimetric info. Cuts applied on the hadronic leakage and on shower-shape variables, derived from the middle layer of the EM calo
- Medium same as loose but adding cuts on the strips in the first layer of EM calo and on the tracking variables
- Tight use of particle identification tool. Cutting on more variables than the Medium case.

Muon Recontruction

Different strategies, corresponding to different ways to combine data from more ATLAS subdetectors:

- standalone reconstruction algorithms: tracks from the Muon Spectrometer backtracked to the interaction point
- combined reconstruction algorithms: tracks from the Inner Detector combined with full Muon Spectrometer tracks
- segment tagging algorithms: tracks from the Inner Detector extrapolated to the Muon Spectrometer and combined with segments reconstructed in Muon Spectrometer stations
- calorimeter tagging algorithms: tracks from the Inner Detector with a MIP energy deposit in the Calorimeters.

The $Z \to \tau\tau$ selection

$Z \to \tau\tau$ in early data

Goal: reconstruct a clean sample of $Z \to \tau\tau$ events. This allows for:

- understanding of the τ-jet reconstruction
- understanding of the background in SM and MSSM Higgs search

Presented analysis performed in order to deal with early data (100 pb^{-1}) at 10 TeV.

	σ (nb)	ϵ_{filter}	Nr. events for 100 pb^{-1}
$Z \to \tau^+\tau^-$	1.128 (LO)	1	112800
$Z \to e^+e^-$	1.144 (LO)	0.96	109824
$Z \to \mu^+\mu^-$	1.144 (LO)	0.96	109824
$W \to e\nu_e$	11.765 (LO)	0.88	1035320
$W \to \mu\nu_\mu$	11.765 (LO)	0.88	1035320
$W \to \tau_{lep}\nu_\mu$	4.148 (LO)	0.87	360876
$W \to \tau_{had}\nu_\mu$	7.690 (LO)	1	769000
$t\bar{t}$	0.374 (NLO)	0.55	20570
QCD dijet (1e filter) p_T 17-35 GeV	$8.668 \cdot 10^5$	$1.09 \cdot 10^{-3}$	$94.5 \cdot 10^6$
QCD dijet (1e filter) p_T 35-70 GeV	$5.601 \cdot 10^4$	$5.45 \cdot 10^{-3}$	$30.5 \cdot 10^6$
QCD dijet (1μ filter) p_T 17-35 GeV	$8.668 \cdot 10^5$	$1.02 \cdot 10^{-3}$	$88.4 \cdot 10^6$
QCD dijet (1μ filter) p_T 35-70 GeV	$5.601 \cdot 10^4$	$5.11 \cdot 10^{-3}$	$28.6 \cdot 10^6$

- samples analysed with full detector simulation
- factorization of QCD background

Selection of the $Z \to \tau\tau \to (\tau_{jet}\nu_\tau)(l\nu_l\nu_\tau)$ signature

Medium Electrons

- $p_T > 15\ GeV$, $|\eta| < 2.5$ and $|Q| = 1$
- Identification flag: medium
- Isolation: E_T (in cone $\Delta R < 0.40$) / $p_T < 0.12$.

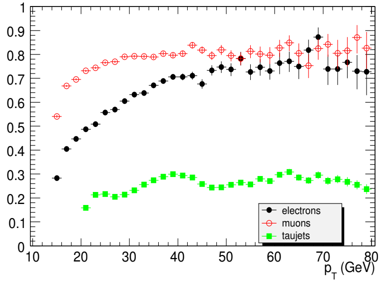
Combined muons

- $p_T > 15\ GeV$, $|\eta| < 2.5$ and $|Q| = 1$
- Identification: combined (inner tracker + muon spectrometer)
- Isolation: E_T (in cone $\Delta R < 0.40$) / $p_T < 0.10$ and no tracks in cone 0.40.

TauJets

- $E_T > 20\ GeV$, $|\eta| < 2.5$ and $|Q| = 1$
- Tau identification with tight safe variables
- Remove overlap between taujets and combined muons (and medium electron) in $\Delta R < 0.30$
- Electron veto

- Efficiency after selection criteria on the left



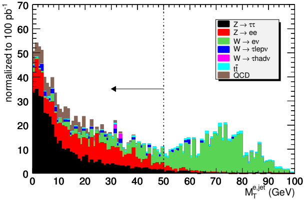
Signal Selection

⇒ Combining 1 taujet and 1 lepton (e,μ) with opposite charge ("OppositeSign")

⇒ Suppression of $W \to e(\mu)\nu$ background:

- cut on the transverse invariant mass $m_T^{lep,miss} = \sqrt{2p_T^{lep} E_T^{miss}(1 - \cos\phi_{lep,miss})}$
- cut on the collinearity between lepton and missing energy
- cut on the ΔR between lepton and τ-jet

Transverse invariant mass

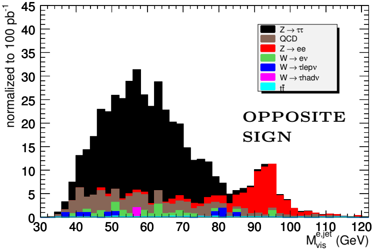


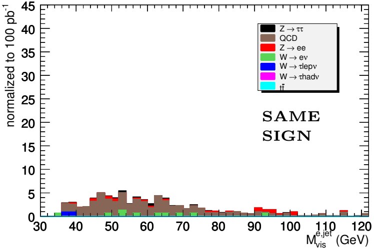
⇒ Counting events in the visible invariant mass windows (M_{vis}, invariant mass of lepton and τ-jet)

⇒ Background control with same-sign (τ, lepton) selection ("SameSign").

Results for the $Z \to \tau\tau \to (\tau_{jet}\nu_\tau)(e\nu_e\nu_\tau)$ analysis

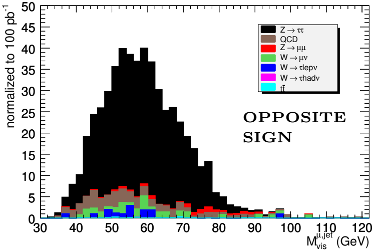
	$Z \to \tau^+\tau^-$	$Z \to e^+e^-$	$W \to e\nu$	$W \to \tau_l\nu$	$W \to \tau_h\nu$	$t\bar{t}$	QCD
Presel 1e+1τ_{jet}	450±7	416±11	772 ±22	52 ±7	6 ±3	91 ±2	235±46
Opposite Sign							
1e+1τ_{jet}	442±7	354±10	580±19	37±6	4±3	79±2	120±33
$m_T^{e,miss} < 50$ GeV	431±7	337±10	141±10	31±5	4±3	24±1	120±33
angular correl > -0.15	408±7	248±8	50±6	17±4	2±2	19±1	86±22
$2.1 < \Delta R < 4.1$	368±7	232±8	43±6	14±4	2±2	9±1	73±19
$p_T^{ele} < 35$ GeV	330±6	71±4	20±4	9±3	2±2	3.0±0.4	71±19
$p_T^{\tau jet} < 60$ GeV	326±6	65±4	18±3	8±3	2±2	2.7±0.3	69±19
$35 < M_{vis} < 80$ GeV	317±6	11±2	16±3	6±2	2±2	1.7±0.3	60±18
Same Sign							
1e+1τ_{jet}	7±1	62±4	192±11	15±4	2±2	12±1	115±32
$m_T^{e,miss} < 50$ GeV	7±1	57±4	35±5	8±3	2±2	4.0±0.4	114±32
angular correl > -0.15	5±1	41±3	18±3	3±2	<1.6	3.3±0.4	84±23
$2.1 < \Delta R < 4.1$	4±1	30±3	12±3	2±1	<1.6	1.7±0.4	66±17
$p_T^{ele} < 35$ GeV	3±1	8±1	7±2	2±1	<1.6	0.3±0.1	64±17
$p_T^{\tau jet} < 60$ GeV	3±1	8±1	7±2	2±1	<1.6	0.3±0.1	62±17
$35 < M_{vis} < 80$ GeV	2±1	4±1	5±2	2±1	<1.6	0.2±0.1	55±16

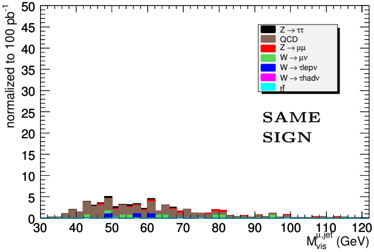




Results for the $Z \to \tau\tau \to (\tau_{jet}\nu_\tau)(\mu\nu_\mu\nu_\tau)$ analysis

	$Z \to \tau^+\tau^-$	$Z \to \mu^+\mu^-$	$W \to \mu\nu$	$W \to \tau_l\nu$	$W \to \tau_h\nu$	$t\bar{t}$	QCD
Presel 1μ+$1\tau_{jet}$	600±8	143±6	906±24	62±8	<1.6	97±2	179±37
OppositeSign							
1μ+$1\tau_{jet}$	590±8	102±5	689±21	47±7	<1.6	84±2	95±28
$m_T^{\mu,miss} < 50$ GeV	573±8	74±4	157±10	36±6	<1.6	24±1	95±28
angular correl > -0.15	537±8	49±3	55±6	18±4	<1.6	19±1	67±19
$2.1 < \Delta R < 4.1$	489±8	43±3	46±6	17±4	<1.6	9±1	55±16
$p_T^{ele} < 35$ GeV	444±7	14±2	26±4	15±4	<1.6	3.4±0.4	54±16
$p_T^{\tau jet} < 60$ GeV	440±7	13±2	25±4	13±3	<1.6	2.8±0.3	53±16
$35 < M_{vis} < 80$ GeV	430±7	10±1	22±4	12±3	<1.6	2.0±0.3	48±15
SameSign							
1μ+$1\tau_{jet}$	10±1	41±3	216±12	15±4	<1.6	12±1	84±24
$m_T^{\mu,miss} < 50$ GeV	10±1	27±2	49±6	9±3	<1.6	4.6±0.4	84±24
angular correl > -0.15	7±1	17±2	22±4	5±2	<1.6	3.4±0.4	59±17
$2.1 < \Delta R < 4.1$	6±1	13±2	18±4	3±2	<1.6	1.8±0.4	48±14
$p_T^{ele} < 35$ GeV	5±1	4±1	7±2	3±2	<1.6	0.4±0.1	48±14
$p_T^{\tau jet} < 60$ GeV	4±1	4±1	6±2	3±2	<1.6	0.3±0.1	47±13
$35 < M_{vis} < 80$ GeV	4±1	3±1	5±2	3±2	<1.6	0.3±0.1	42±13





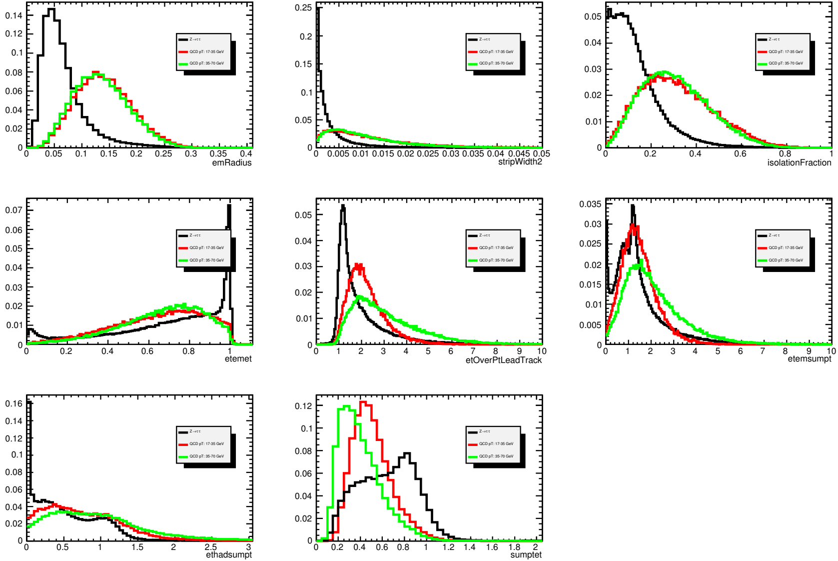
Conclusion

- Up to now less than 200 nb^{-1} of data $\Rightarrow$ no signal event passes the selection.
- $Z \rightarrow \tau\tau$ analysis optimized for early data (100 pb^{-1}): good identification of the τ-jets and separation from the QCD background.
- Data driven estimation of the QCD background from the Same Sign control data sample
- Extend the analysis to the Z + jet final state (dominant background for SM Higgs searches in the $\tau\tau$ final state)

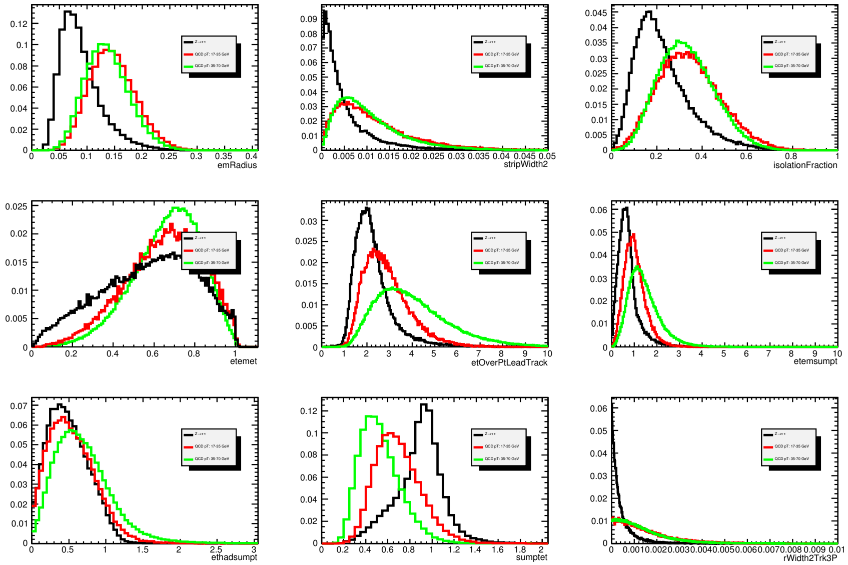
Backup Slides

- Safe variables for tau identification
- Factorization of the QCD background
- Transverse mass with missing energy and angular correlation
- Results with loose lepton isolation

Safe variables for 1 prong taujets



Safe variables for 3 prong taujets



Factorization of the QCD background

Due to low MC statistics for QCD background, its contribution has to be estimated from factorization procedure.

Procedure:

1. Performing the analysis with no safe ID cuts on τ-jets and avoiding lepton isolation (cut on E_T/p_T and number of tracks in cone)
2. Efficiencies of the lepton isolation and τ-jet identification are calculated separately: no correlation found with the other cuts applied in the analysis
3. QCD events weighted by the efficiency of the lepton isolation and τ-jet identification

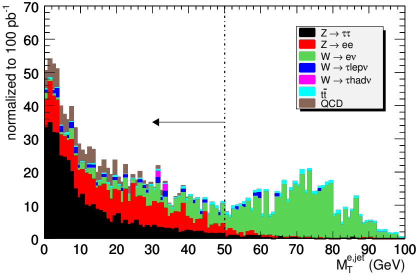
	QCD pT: 17-35 GeV, 1 electron filter	QCD pT: 35-70 GeV, 1 electron filter
lepton isolation efficiency	0.0359±0.0110	0.0224±0.0032
τ-jet identification efficiency	0.0229±0.0087	0.0149±0.0026

	QCD pT: 17-35 GeV, 1 muon filter	QCD pT: 35-70 GeV, 1 muon filter
lepton isolation efficiency	0.0158±0.0048	0.0024±0.0005
τ-jet identification efficiency	0.0274±0.0063	0.0140±0.0012

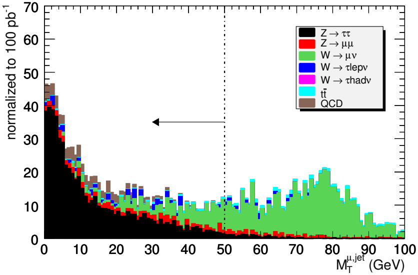
Transverse invariant mass

- Transverse invariant mass lepton + missing energy:
  $m_T = \sqrt{2p_T^{lep} E_T^{miss}(1 - \cos\phi_{lep,miss})}$

Electron+TauJet



Muon+TauJet

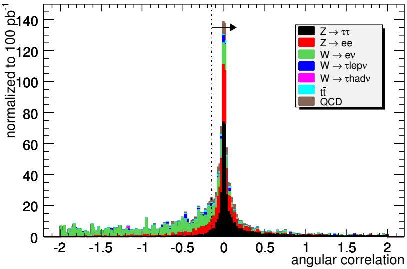


- $m_T^{lep,miss} < 50\ GeV$ for the analysis

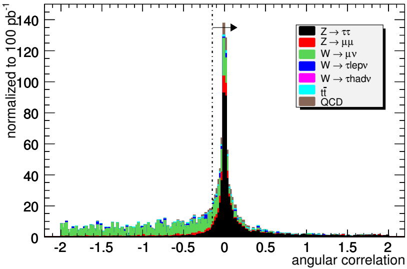
Angular Correlation

- Angular Correlation: $\Delta\psi = \cos(\phi_{lep} - \phi_{miss}) + \cos(\phi_{jet} - \phi_{miss})$

Electron+TauJet



Muon+TauJet

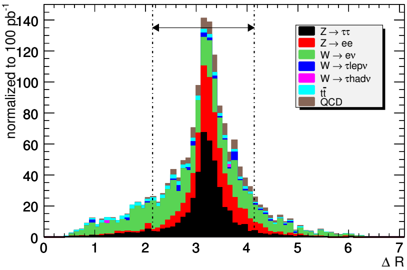


- $\Delta\psi$ > -0.15

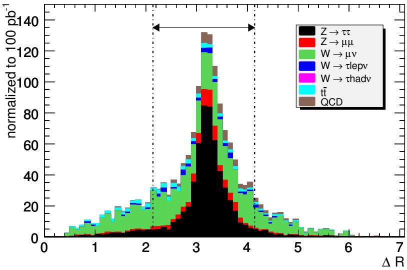
Distance between lepton-τ_{jet}

- Distance between the two visible particles: $\Delta R = \sqrt{\Delta\phi^2 + \Delta\theta^2}$

Electron+TauJet



Muon+TauJet



- $2.14 < \Delta R_{lep,\tau jet} < 4.14$ for the analysis

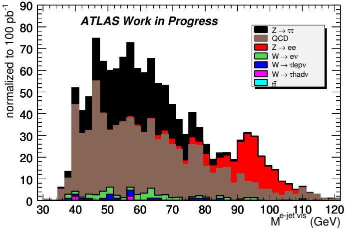
Old results for the $Z \to \tau\tau \to e\tau_{jet}$ analysis

Looser lepton isolation in order to compare SS and OS events with higher statistics

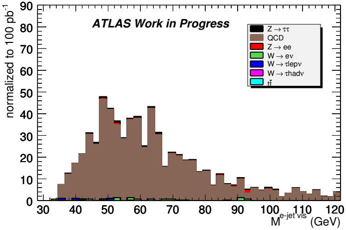
Number of events shown after trigger selection [trigger efficiency in brackets]

	$Z \to \tau^+\tau^-$	$Z \to e^+e^-$	$W \to e\nu$	$W \to \tau_l\nu$	$W \to \tau_h\nu$	$t\bar{t}$	QCD
Presel 1e+1τ_{jet}	508±8	746±14	764 ±22	60 ±7	6 ±3	80 ±2	1759 ± 256
Opposite Sign (OS)							
1e+1τ_{jet}	497±7	668±14	567±19	47±7	4±3	69±2	908 ± 134
$m_T^{e,miss} < 35$ GeV	457±7	511±12	78±7	31±5	4±3	14±1	885 ± 130
$2.1 < \Delta R < 4.1$	415±7	464±11	61±6	23±5	4±3	6.6±0.5	714 ± 105
$p_T^{ele} < 35$ GeV	385±7	182±7	49±6	19±4	4±3	2.9±0.3	700 ± 103
$p_T^{\tau jet} < 60$ GeV	380±6	161±7	45±5	17±4	4±3	2.4±0.3	667 ± 97
$35 < M_{vis} < 80$ GeV	369±6 [0.97]	24±3 [1]	38±5 [1]	15±4 [1]	4±3 [1]	1.5±0.3 [1]	550 ± 80 [0.99]
Same Sign (SS)							
1e+1τ_{jet}	10±1	78±5	197±11	13±3	2±2	11±1	850 ± 126
$m_T^{e,miss} < 35$ GeV	9±1	61±4 [	18±3	6±2	<1.6	2.8±0.3	831 ± 123
$2.1 < \Delta R < 4.1$	7±1	44±3	13±3	3±2	<1.6	1.3±0.2	654 ± 98
$p_T^{ele} < 35$ GeV	7±1	16±2	10±3	3±2	<1.6	0.4±0.1	639 ± 96
$p_T^{\tau jet} < 60$ GeV	6±1	15±2	10±3	3±2	<1.6	0.4±0.1	610 ± 91
$35 < M_{vis} < 80$ GeV	6±1 [1]	7±1 [1]	7±2 [1]	3±2 [1]	<1.6	0.3±0.1 [1]	505 ± 75 [0.99]

Electron+TauJet Opposite Sign



Electron+TauJet Same Sign



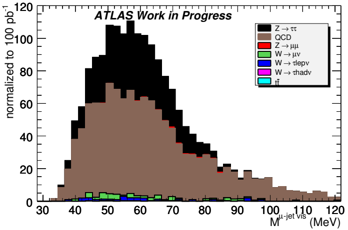
Old results for the $Z \to \tau\tau \to \mu\tau_{jet}$ analysis

Looser lepton isolation in order to compare SS and OS events with higher statistics

Number of events shown after trigger selection [trigger efficiency in brackets]

	$Z \to \tau^+\tau^-$	$Z \to \mu^+\mu^-$	$W \to \mu\nu$	$W \to \tau_l\nu$	$W \to \tau_h\nu$	$t\bar{t}$	QCD
Presel 1μ+$1\tau_{jet}$	613±8	134±5	901±24	57±7	<1.6	106±2	2685 ± 407
Opposite Sign (OS)							
1μ+$1\tau_{jet}$	602±8	96±5	674±21	44±6	<1.6	91±2	1373 ± 208
$m_T^{\mu,miss} < 35\ GeV$	540±8	52±3	66±7	29±5	<1.6	17±1	1317 ± 199
$2.1 < \Delta R < 4.1$	492±7	47±3	53±6	24±5	<1.6	9±1	1062 ± 162
$p_T^{ele} < 35$ GeV	457±7	18±2	40±5	21±4	<1.6	4.2±0.4	1049 ± 159
$p_T^{\tau jet} < 60$ GeV	452±7	17±2	37±5	20±4	<1.6	3.3±0.4	972 ± 146
$35 < M_{vis} < 80\ GeV$	440±7 [0.86]	13±2 [0.93]	30±4 [0.97]	18±4 [0.95]	<1.6	2.2±0.3 [1]	771 ± 114 [0.80]
Same Sign (SS)							
1μ+$1\tau_{jet}$	11±1	38±3	226±12	13±3	<1.6	14±1	1312 ± 201
$m_T^{\mu,miss} < 35\ GeV$	9±1	16±2	22±4	4±2	<1.6	2.6±0.3	1254 ± 191
$2.1 < \Delta R < 4.1$	7±1	10±1	17±3	2±1	<1.6	1.3±0.2	1014 ± 156
$p_T^{ele} < 35$ GeV	6±1	5±1	12±3	2±1	<1.6	0.5±0.1	1000 ± 153
$p_T^{\tau jet} < 60$ GeV	5±1	5±1	11±3	2±1	<1.6	0.4±0.1	921 ± 140
$35 < M_{vis} < 80\ GeV$	5±1	4±1 [1]	8±2 [1]	2±1 [0.67]	<1.6	0.3±0.1 [1]	745 ± 112 [0.80]

Muon+TauJet Opposite Sign



Muon+TauJet Same Sign