The $Z \to \tau\tau \to lh$ ($l = e, \mu$) analysis with ATLAS detector with early data

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Overview

- Introduction
- Tau Reconstruction and Identification with the ATLAS detector
- The $Z \rightarrow \tau\tau$ analysis with 10 TeV data
- Conclusion

Introduction

Introduction

Taus as tools in many areas:

Understanding of the Detector:

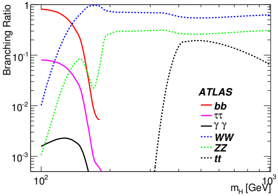
- measurement of the τ Energy Scale
- measurement of the τ E_T^{miss} Scale

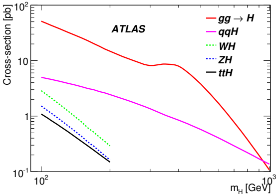
Standard Model (SM):

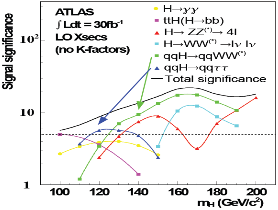
- Measurement of W/Z Production Cross Section
- Discovery of the Higgs Boson in $\tau\tau$ final state

Minimal Supersymmetric Standard Model (MSSM):

- $h/H/A \to \tau\tau$ excellent discovery potential
- Searches for Charged Higgs Bosons: $H^{\pm} \to \tau\nu$







Basic Tau Properties

TAU BRANCHING RATIOS

- Leptonic Decay Modes (35%):

$e\nu_e\nu_\tau$	18%
$\mu\nu_\mu\nu_\tau$	17%

- 1 Prong Hadronic Decay Modes (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%

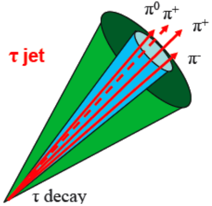
- 3 Prong Hadronic Decay Modes (15%):

$\pi^-\pi^+\pi^-\nu_\tau$	9%
$\pi^-\pi^+\pi^-\pi^0\nu_\tau$	4.5%
$K^-\pi^+\pi^-\nu_\tau$	0.4%

- Other Modes ($\approx$ 3%)

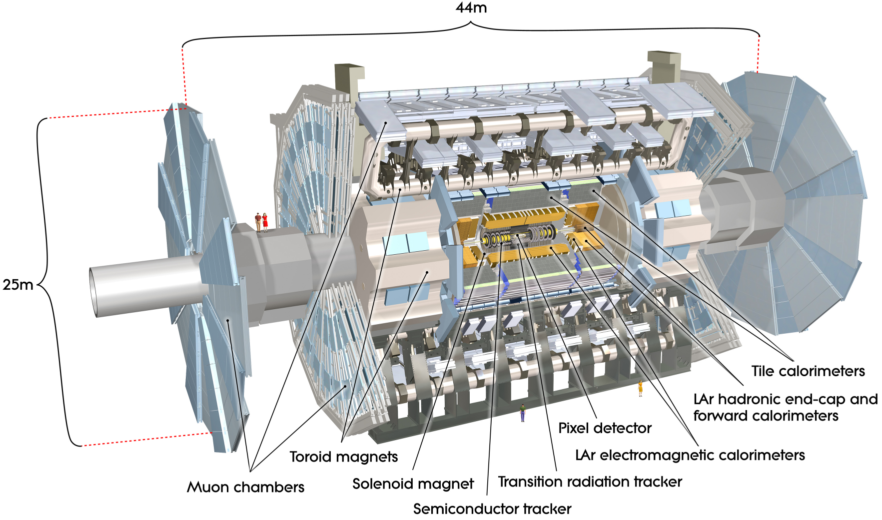
TAU CHARACTERISTICS

- $m_\tau \approx 1.7$ GeV
- $c\tau = 87\ \mu$m
- Hadronic Decays are well collimated collection of charged and neutral pions/kaons
- Most have 1 or 3 charged tracks
- Leading pions direction reproduces τ direction well



Tau Reconstruction and Identification with the ATLAS detector

The ATLAS detector at LHC



Tau Reconstruction in ATLAS

- ⇒ Because leptonic tau decays cannot really be separated from electrons and muons, we say tau reconstruction and ID to refer to hadronically decaying tau leptons.
- ⇒ We try to distinguish between 1-prong and 3-prong tau decays (neglect 5-prong).
- ⇒ The reconstruction of tau leptons is understood as a reconstruction of the hadronic τ-decay modes.

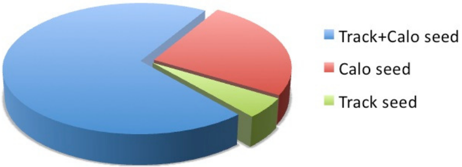
Track seed Algorithm

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

Calo seed Algorithm

1. *TopoJets* with $E_T > 10\ GeV$,
2. tracks associated if $\Delta R < 0.3$, passing minimal quality criteria,
3. energy calculation summing the weighted cells in $\Delta R < 0.4$

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



Tau Identification with early data

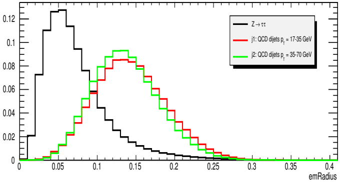
How can we distinguish τ-jets from QCD jets?
Optimizing the rejection/efficiency of-ID in Monte Carlo is interesting but data will be a much different story!

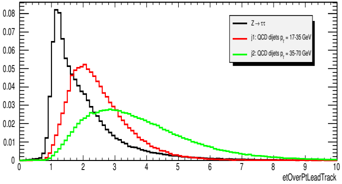
- proper MC modeling of variables is going to be inaccurate
- many variables require precision alignment/calibration before they are effective (secondary vertexing, track impact parameters, hadronic calibration)
- many variables will have different behaviour due to underlying event and pile-up (track and calorimeter isolation with wide cones)

For early data - can try to use only variables suspected to be under control with tens/hundreds of pb^{-1}. Try to avoid using multi-variate techniques, and use rectangular cuts instead. ATLAS looked at optimization of rectangular cuts on a set of "safe variables".

Tau Identification with early data: Safe Identification

- "Safe-variables" to identify τ's in the early data (Safe $\Rightarrow$ small sensitivity to systematic uncertainties).
- not used variables based on: precision tracking, π^0 reconstruction ...





Variables for "Safe ID Cut"

- electromagnetic radius R_{em}
- transverse energy width in the η strip layer
- isolation in the calorimeter
- Ratio of EM energy and total energy

→ Width of track momenta

→ Ratio E_T and p_T of the leading track

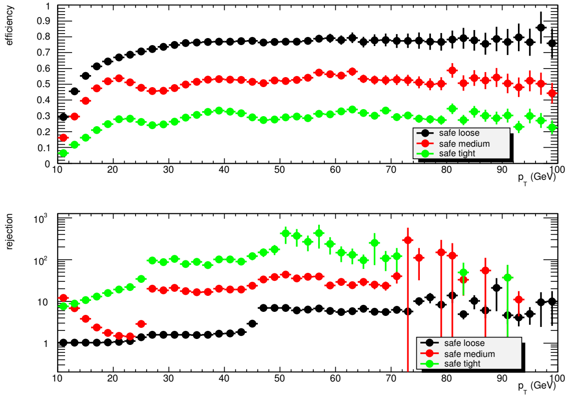
→ Ratio of EM energy and the total p_T of tracks

→ Ratio of hadronic energy and the total p_T of tracks

→ Ratio of total p_T of the tracks and the total energy (only for 3-p)

Taujet efficiency and QCD jet rejection

"Safe Cut" with Calo+Track seed



- *tight*, *medium*, *loose* cuts corresponding to 0.3, 0.5, 0.7 identification efficiency
- Identification performed 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.

The $Z \to \tau\tau$ Selection

$Z \rightarrow \tau\tau$ in early data

Motivation for $Z \rightarrow \tau\tau$ in early data:

Understanding of the Detector:

- $\tau\tau$ invariant mass sensitive to the τ E_T^{miss} Scale
- $\tau\tau$ visible invariant mass sensitive to the τ E_T Scale

Standard Model (SM) and Minimal Supersymmetric Standard Model (MSSM):

- Dominant background for Higgs Boson in $\tau\tau$ final state
- Background for MSSM $\tau\tau$ final states

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

	σ (nb)	ϵ_{filter}	Nr. events for 100 pb^{-1}
$Z \rightarrow \tau^+\tau^-$	1.128 (LO)	1	112800
$Z \rightarrow e^+e^-$	1.144 (LO)	0.96	109824
$Z \rightarrow \mu^+\mu^-$	1.144 (LO)	0.96	109824
$W \rightarrow e\nu_e$	11.765 (LO)	0.88	103532
$W \rightarrow \mu\nu_\mu$	11.765 (LO)	0.88	1035320
$W \rightarrow \tau_{lep}\nu_\mu$	4.148 (LO)	0.87	360876
$W \rightarrow \tau_{had}\nu_\mu$	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	$5.601 \cdot 10^4$	$5.11 \cdot 10^{-3}$	$28.6 \cdot 10^6$

Selection of the $Z \rightarrow \tau\tau \rightarrow lh$ signature

Medium Electrons

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

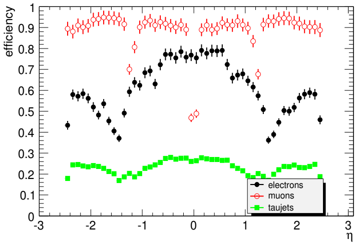
Combined muons

- $p_T > 15\ GeV$, $|\eta| < 2.5$ and $|Q| = 1$
- Identification: combined (Inner Tracker + Muon Spectrometer)
- Isolation: E_T (in cone 0.40) / $p_T < 0.10$ and no tracks in cone 0.40.

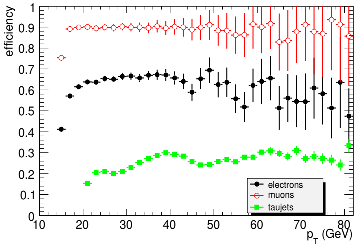
TauJets

- $E_T > 20\ GeV$, $|\eta| < 2.5$ and $|Q| = 1$
- Tau identification with safe variables tight.
- Remove Overlap between taujets and combined muons (and medium electron) in dR < 0.3
- Electron veto

- Efficiency after selection criteria on the left



- Efficiency after selection criteria on the left



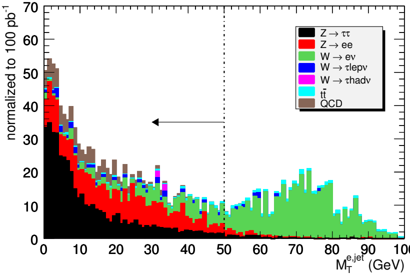
Signal Selection

- ⇒ Combining 1 taujet and 1 lepton (e,μ) with opposite charge (OS)
- ⇒ Cut on the transverse invariant mass $m_T^{lep,miss}$ (to reduce $W \to e(\mu)\nu$ background)
- ⇒ Cut on the collinearity between lepton and missing energy (to reduce $W \to e(\mu)\nu$ background)
- ⇒ Cut on the ΔR between lepton and taujet (to reduce $W \to e(\mu)\nu$ background)
- ⇒ Cut on the maximum p_T of the lepton (to reduce $Z \to ee$ background)
- ⇒ Background control with same-sign (τ, lepton) selection (SS).

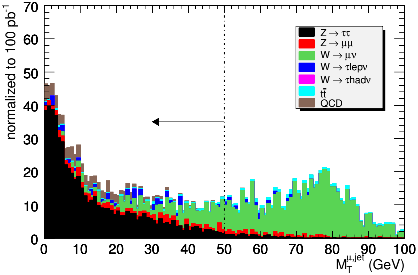
Transverse Invariant Mass

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

Electron+TauJet



Muon+TauJet

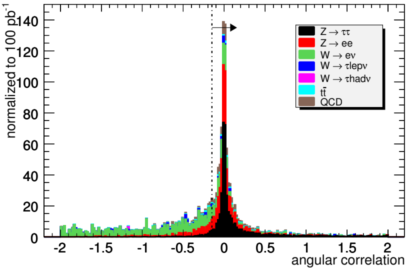


- $m_T^{lep,miss} < 50\ GeV$ for the analysis

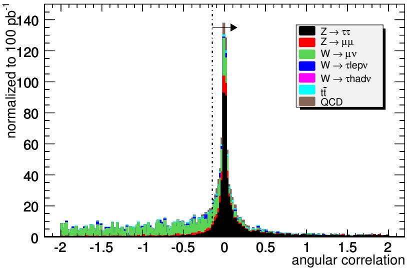
Angular Correlation

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

Electron+TauJet



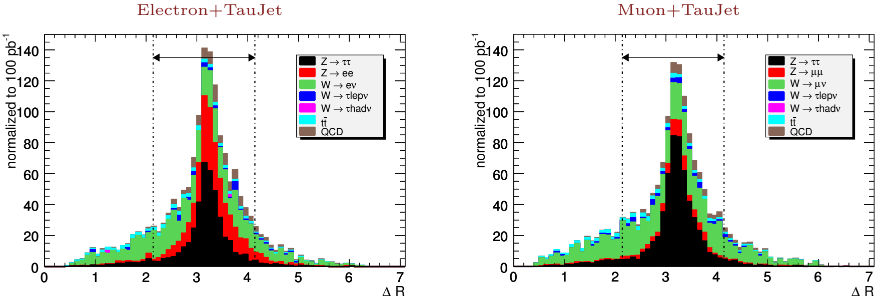
Muon+TauJet



- $\Delta\psi$ > -0.15

Distance between lepton-τ_{jet}

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



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

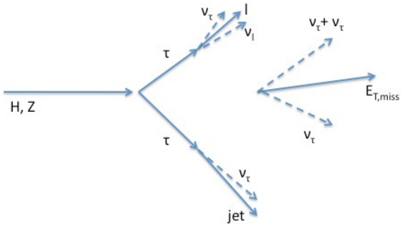
Reconstruction of the $\tau\tau$ invariant mass: the Collinear Approximation

- The Collinear Approximation assumes that the τ-decay products are collinear to the τ direction
- This approximation is a good approximation when the parent particle is heavily boosted.
- It breaks down when the decay daughters are back-to-back (as most of the signal events)

⇒ The presence of the $Z \to \tau\tau$ signal can be estimated through the visible invariant mass, *i.e.* the invariant mass of the electron (muon) and the taujet.

lepton momentum fraction $x_1 = \frac{p_1}{p_{\tau 1}}$

jet momentum fraction $x_2 = \frac{p_2}{p_{\tau 2}}$

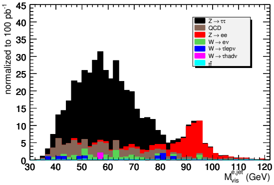


Visible Invariant Mass $M_{1,2} = \sqrt{2p_1 p_2(1 - \cos\alpha)}$ Total Invariant Mass $M_{\tau\tau} = \frac{M_{1,2}}{\sqrt{x_1 x_2}}$

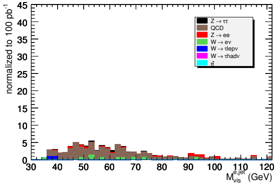
Results for the $Z \rightarrow \tau\tau \rightarrow e\tau_{jet}$ analysis

	$Z \rightarrow \tau^+\tau^-$	$Z \rightarrow e^+e^-$	$W \rightarrow e\nu$	$W \rightarrow \tau_l\nu$	$W \rightarrow \tau_h\nu$	$t\bar{t}$	QCD
Presel $1e+1\tau_{jet}$	450±7	416±11	772 ±22	52 ±7	6 ±3	91 ±2	235±46
OS							
$1e+1\tau_{jet}$	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
SS							
$1e+1\tau_{jet}$	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

Electron+TauJet Opposite Sign



Electron+TauJet Same Sign

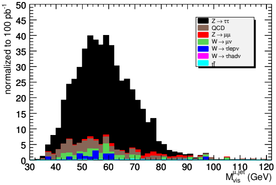


- QCD dijet is the dominant background
- Data-driven estimation of the QCD Opposite Sign background from the Same Sign selection

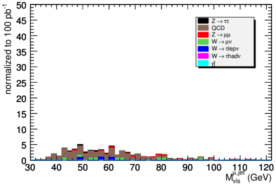
Results for the $Z \to \tau\tau \to \mu\tau_{jet}$ analysis

	$Z \to \tau^+\tau^-$	$Z \to \mu^+\mu^-$	$W \to \mu\nu$	$W \to \tau_l\nu$	$W \to \tau_h\nu$	$t\bar{t}$	QCD
Presel 1μ+$1\tau_{jet}$	600±8	143±6	906±24	62±8	<1.6	97±2	179±37
OS							
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
SS							
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

Muon+TauJet Opposite Sign



Muon+TauJet Same Sign



- QCD dijet is the dominant background
- Data-driven estimation of the QCD Opposite Sign background from the Same Sign selection

Conclusion

- LHC plans:
  a) from February 14^{th} 2010: collecting 1 fb^{-1} at 7 TeV
  b) end of 2011: shutdown for machine upgrade for 14 TeV collisions

- $Z \to \tau\tau$ analysis optimized for early data (100 pb^{-1}): good identification of the τ-jets over the QCD background

- Data driven estimation of the QCD background from the Same Sign selection

- Extend the analysis to the Z + jet final state (dominant background for SM Higgs searches in the $\tau\tau$ final state)