Measurement of the $Z \rightarrow \tau\tau$ decay with the ATLAS detector at 10 TeV

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Introduction

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

$\longrightarrow$ unbiased source of τ-jets for calibration

$\longrightarrow$ cross section measurement of SM process

$\longrightarrow$ background for new particle searches (MSSM or SM Higgs)

- Several groups inside the ATLAS Collaboration have been working on this topic previously: Milano, Freiburg, Cracow and Pennsylvania.
- Analysis based on Atlas notes with 14 TeV data: presented analysis performed with 10 TeV in order to deal with early data (100 pb^{-1}).

... concerning the $Z \to \tau\tau$ analysis:

- cross section at 10 TeV: $\sigma(pp \to Z)\cdot \mathrm{BR}(Z \to \tau\tau) \simeq 1.1\ nb$ (LO)
- τ mass = $1.777\ GeV$, τ mean lifetime = $2.9 \cdot 10^{-13}\ s$
- τ leptonic decay: $\to l\nu_l\nu_\tau$ (35 %)
- τ hadronic decay: $\to had\ \nu_\tau$ (65 %)
- $Z \to \tau\tau$ decays:
  - leptonic decay: BR = $(0.35)^2 \simeq 12$ %
  - semileptonic decay: BR = $2\cdot(0.35)\cdot(0.65) \simeq 46$ %
  - hadronic decay: BR = $(0.65)^2 \simeq 42$ %

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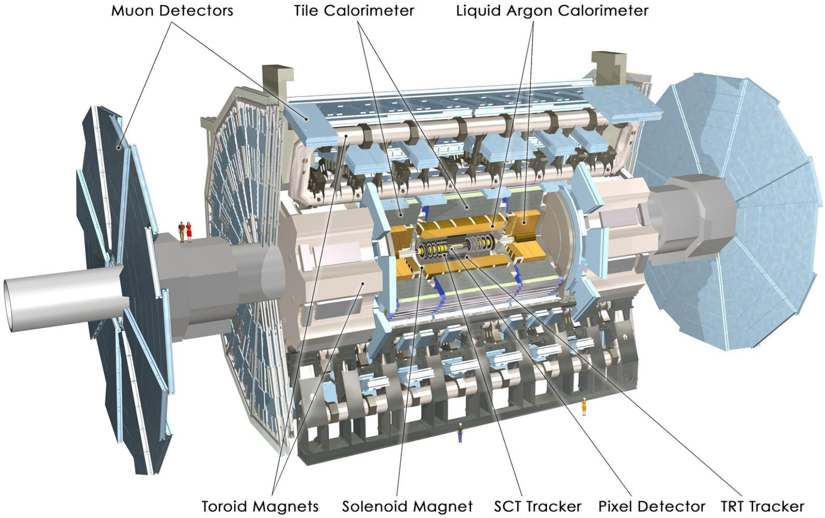
The ATLAS detector at LHC



TauJet Reconstruction in ATLAS

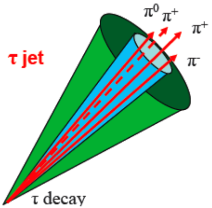
The reconstruction of tau leptons is understood as a reconstruction of the hadronic τ-decay modes.

Track seed Algorithm

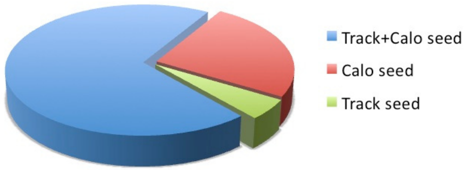
1. seed track with $p_T > 6\ GeV$ with quality criteria,
2. association with other tracks in $\Delta R < 0.2$ with quality criteria,
3. total charge $|Q| = 1$.
4. energy flow algorithm

Calo seed Algorithm

1. $TopoJet$ 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 $\Delta R < 0.4$

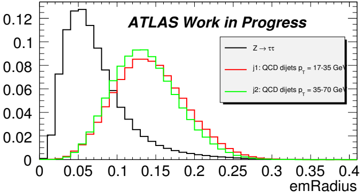


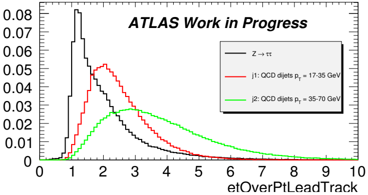
Calo + Track seeds matched if $\Delta R < 0.2$



Tau Identification: cut-based

- "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"

$\Rightarrow$ **at least Calo Seed**:

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

$\Rightarrow$ **only Calo+Track Seed**:

$\rightarrow$ Width of track momenta

$\rightarrow$ Ratio E_T and p_T of the leading track

$\rightarrow$ Ratio of EM energy and the total p_T of tracks

$\rightarrow$ Ratio of hadronic energy and the total p_T of tracks

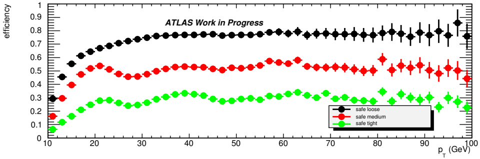
Safe cut efficiency and QCD dijet rejection

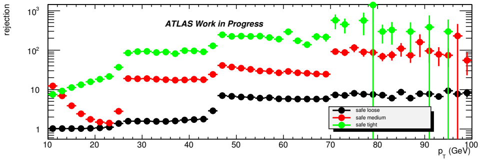
$$\epsilon_{signal} = \frac{\text{(true } \tau_{jet}\text{'s) matched with (reconstructed } \tau_{jet}\text{'s after ID cuts)}}{\text{true } \tau_{jet}\text{'s in same kinematic range}}$$

$$r_{jet} = \frac{\text{reconstructed } \tau_{jet}\text{'s (before ID cuts) matched to jets}}{\text{reconstructed } \tau_{jet}\text{'s (after ID cuts) matched to jets}}$$

- *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.

"Safe Cut" with (Calo+Track) seed





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

Signal and Background for the $Z \to \tau\tau$ Analysis at 10 TeV

	σ (nb)	ϵ_{filter}	Nr. events for 100 pb^{-1}	Nr. MC events	weight*
$Z \to \tau^+\tau^-$	1.128 (LO)	1	112800	998671	0.11
$Z \to e^+e^-$	1.144 (LO)	0.96	109824	399197	0.27
$Z \to \mu^+\mu^-$	1.144 (LO)	0.96	109824	498002	0.22
$W \to e\nu_e$	11.765 (LO)	0.88	103532	1572584	0.66
$W \to \mu\nu_\mu$	11.765 (LO)	0.88	1035320	1573696	0.66
$W \to \tau_{lep}\nu_\mu$	4.148 (LO)	0.87	360876	389053	0.93
$W \to \tau_{had}\nu_\mu$	7.690 (LO)	1	769000	399882	1.92
$t\bar{t}$	0.374 (NLO)	0.55	20570	478694	0.04
Full j1	$8.668 \cdot 10^5$	1	$86.7 \cdot 10^9$	997956	86857
Full j2	$5.601 \cdot 10^4$	1	$5.6 \cdot 10^9$	979316	5719
Full j1 (1e filter)	$8.668 \cdot 10^5$	$1.09 \cdot 10^{-3}$	$94.5 \cdot 10^6$	199776	473
Full j2 (1e filter)	$5.601 \cdot 10^4$	$5.45 \cdot 10^{-3}$	$30.5 \cdot 10^6$	199754	153
Full j1 (1μ filter)	$8.668 \cdot 10^5$	$1.02 \cdot 10^{-3}$	$88.4 \cdot 10^6$	199707	443
Full j2 (1μ filter)	$5.601 \cdot 10^4$	$5.11 \cdot 10^{-3}$	$28.6 \cdot 10^6$	196130	146

*weight = Nr. events for 100 pb^{-1} / Nr. MC events

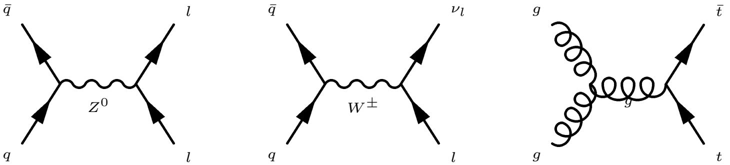


Figure: Feynman diagrams for: $Z \to \tau\tau$ LO (left), $W \to l\nu_l$ LO (center), $t\bar{t}$ LO (right)

Final selection criteria for analysis

⇒ Trigger: electron with $p_T > 10\ GeV$ or muon with $p_T > 10\ GeV$

⇒ Preselection:

→ **"Medium-ID" Electrons**: $p_T > 15\ GeV$, $|\eta| < 2.5$, E_T(in cone $\Delta R = 0.30) < 4.1\ GeV$

→ **"Combined" muons**: $p_T > 15\ GeV$, $|\eta| < 2.5$, E_T(in cone $\Delta R = 0.30) < 3.2\ GeV$, nb tracks(in cone $\Delta R = 0.40) < 2$

→ **TauJets**: $p_T > 20\ GeV$, $|\eta| < 2.5$, $|Q| = 1$, (Calo+Track) seed and "Safe cut"-Tight, remove overlap(taujet, e-medium/μ-combined, 0.30), $E_{T,had}/p_T > 0.1$

⇒ Selection:

- Combining 1 taujet and 1 lepton (e,μ) with opposite charge (OS)
- 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 ΔR between lepton and taujet
- Cut on the maximum p_T of the lepton
- No QCD background event survive after selection due to low statistics of the sample

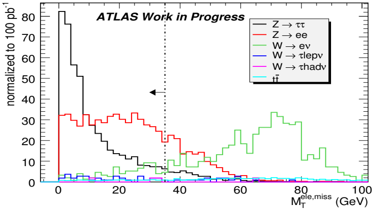
⇒ Factorization of the QCD backround

- Background control with same-sign (τ, lepton) selection (SS).

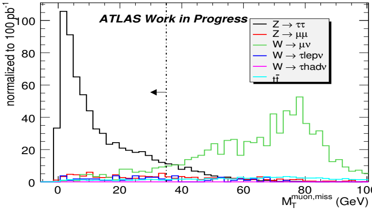
Transverse Invariant Mass and Distance between Visible Partcles

- Transverse Invariant Mass: $m_T < 35\ GeV$

Electron+TauJet

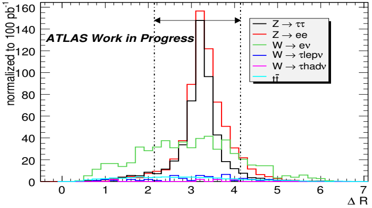


Muon+TauJet

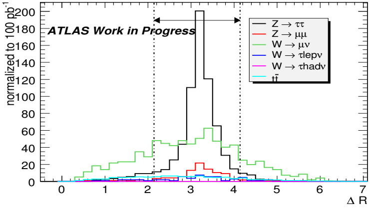


- Distance between the two visible particles: $2.14 < \Delta R_{lep,\tau jet} < 4.14$

Electron+TauJet



Muon+TauJet



Factorization of the QCD backround

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

Procedure:

1. Performing the previous analysis with no Safe ID cuts on τ-jets and avoiding lepton isolation
2. Use SS sample with this loosened selection and extrapolate to OS with standard analysis cuts, by multiplying with appropriate "Safe" τ-tight and lepton isolation efficiencies

$\Rightarrow$ the number of expected events rescaled by factorization efficiencies is compatible with number of events predicted by MC when loose τ-ID cuts are applied

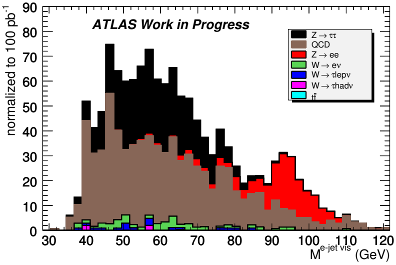
$\Rightarrow$ good agreement between the number of Opposite Sign events and Same Sign events, as expected for the dijet background.

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

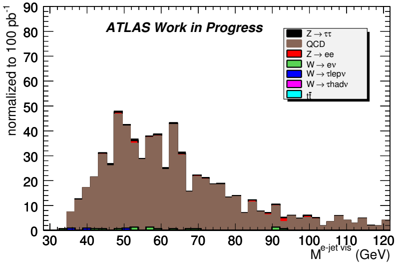
Number of events shown after trigger selection [trigger efficiency in brackets]

	$Z \to \tau^+\tau^-$	$Z \to e^+e^-$	$W \to e\nu$	$W \to \tau_l \nu$	$W \to \tau_h \nu$	$t\bar{t}$	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 < ΔR < 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 < ΔR < 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

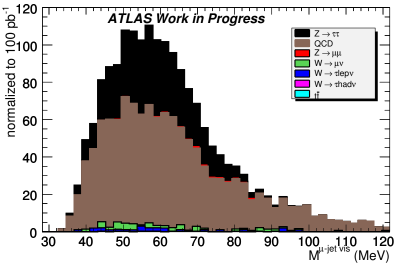


Results for the $Z \to \tau\tau \to \mu\tau_{jet}$ analysis

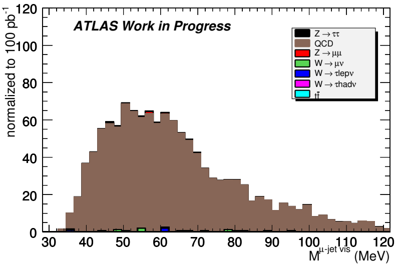
Number of events shown after trigger selection [trigger efficiency in brackets]

	$Z \to \tau^+\tau^-$	$Z \to \mu^+\mu^-$	$W \to \mu\nu$	$W \to \tau_l\nu$	$W \to \tau_h\nu$	$t\bar{t}$	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	1.33±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



Conclusion

- Trigger-aware $Z \rightarrow \tau\tau$ analysis performed with "Safe Cut"-Tight τ selection, optimized for early data (100 pb^{-1})
- QCD jet contribution taken into account by means of the cut factorization
- SS sample shown to be a reliable control data sample, which can be used for QCD background estimation from real data

... to do

- Optimization of the QCD factorization: event-wise factorization of the QCD background (to account for the p_T dependence of the lepton isolation efficiency and τ rejection)
- further optimization of analysis selection cuts
- systematic effects
- extension to $Z \rightarrow \tau\tau$ + jets

Reference

- ATL-PHYS-INT-2009-005: $Z \to \tau^+\tau^-$ in first ATLAS data (D. Cavalli, C. Pizio)
- ATL-PHYS-INT-2009-019: Prospects for physics measurements with the $Z \to \tau\tau(e, \tau_{had})$ process for 100 pb^{-1} with the ATLAS detector (Anna Kaczmarska, Elzbieta Richter-Was)
- ATL-PHYS-INT-2009-044: A Selection Strategy for $Z \to \tau\tau \to \mu\tau_h$ with the First 100 pb^{-1} from ATLAS (Ryan D. Reece, H. H. Williams)

Backup Slides

- Electron Reconstruction in ATLAS
- Muon Reconstruction in ATLAS
- Safe Cut Variables
- Overlap Removal
- Electron Veto
- Visible Invariant Mass and Collinear Approximation
- Factorization of the QCD Background

Electron Recontruction

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

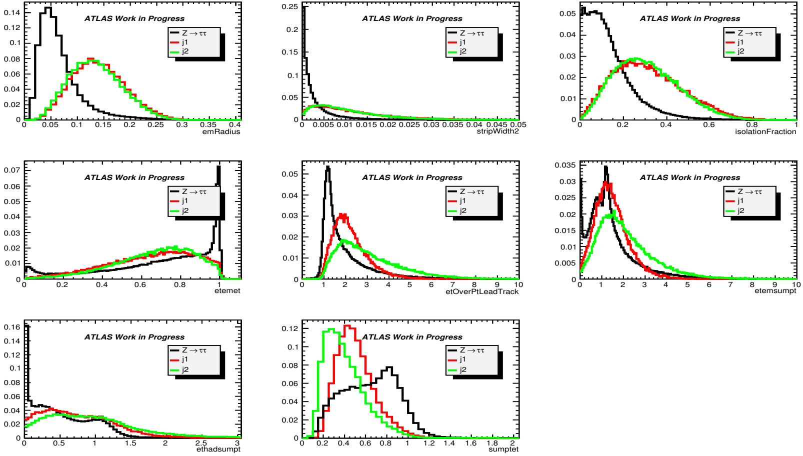
Different strategies, corresponding to different ways to combine data from more ATLAS subdetectors:

- 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 extrapolated through the Calorimeters and combined with energy deposits

Safe cut variables: signal and QCD background

Track+Calo based safe cuts (8 variables for 1 prong)

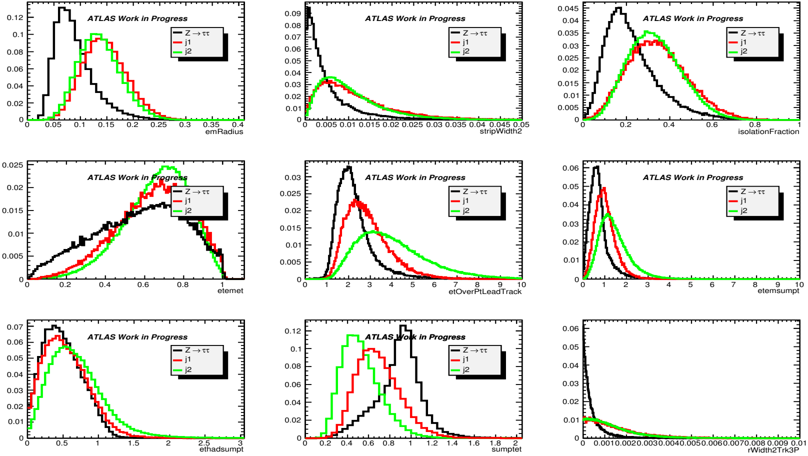
Reconstructed taujets matched with truth for 1-p taujets



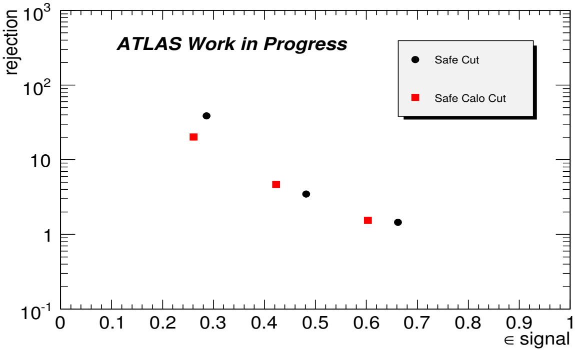
Safe cut variables: signal and QCD background

Track+Calo based safe cuts (9 variables for 3 prong)

Reconstructed taujets matched with truth for 3-p taujets



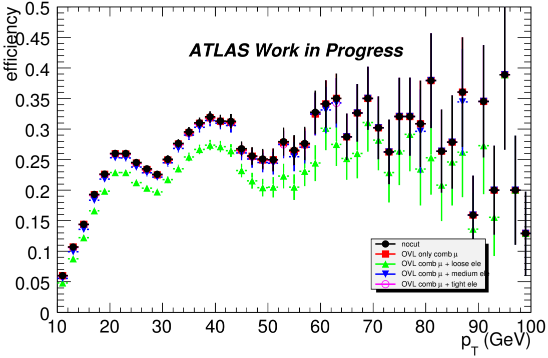
Safe cut efficiency VS. jet rejection



Efficiency VS. Rejection plot using τ-jet with $p_T > 20\ GeV$

Overlap Removal with leptons

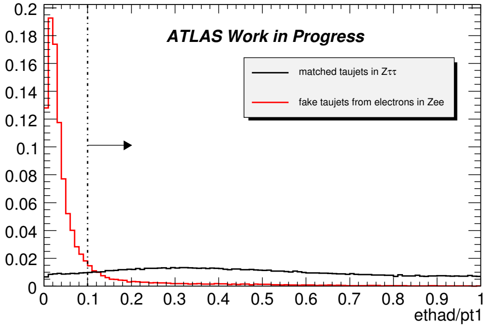
- *Remove Overlap* if $\Delta R < 0.3$ with *combined* muons and (*tight* or *medium* or *loose*) electrons.
- τ-efficiency reduced if overlap with loose electrons. No changing in efficiency if medium or tight electrons are used for overlap removal
- Using overlap with medium electrons for the analysis



*Plot with "safe cut"-tight τ-jets and no electron veto.

Fake τ-jets from electrons

- electrons can be reconstructed as 1-prong τ-jets
- electrons interact strongly in the e.m. calorimeter, so the ratio $E_{T,hadcalo}/p_{T,leadingtrack}$ should be low.



"Electro veto": ratio $E_{T,hadcalo}/p_{T,leadingtrack} > 0.1$ for the analysis.

Final selection criteria for analysis

Medium Electrons

- $p_T > 15\ GeV$
- $|\eta| < 2.5$
- $E_T(\Delta R = 0.30) < 4.1\ GeV$

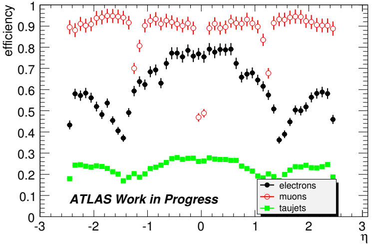
Combined muons

- $p_T > 15\ GeV$
- $|\eta| < 2.5$
- $E_T(\Delta R = 0.30) < 3.2\ GeV$
- nb tracks$(\Delta R = 0.40) < 2$

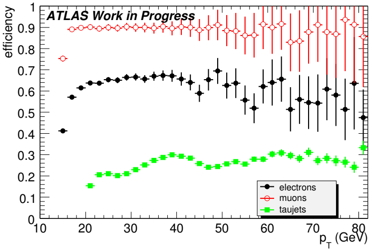
TauJets

- $p_T > 20\ GeV$
- $|\eta| < 2.5$, $|Q| = 1$
- (Calo+Track) seed and "Safe cut"-Tight
- remove overlap(taujet, e-medium/μcombined, 0.30)
- $E_{T,had}/p_T > 0.1$

- Efficiency after selection criteria on the left



- Efficiency after selection criteria on the left



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- $p_T > 15\ GeV$
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- $E_T(\Delta R = 0.30) < 4.1\ GeV$

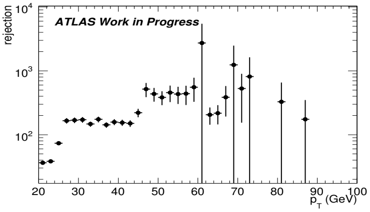
Combined muons

- $p_T > 15\ GeV$
- $|\eta| < 2.5$
- $E_T(\Delta R = 0.30) < 3.2\ GeV$
- nb tracks$(\Delta R = 0.40) < 2$

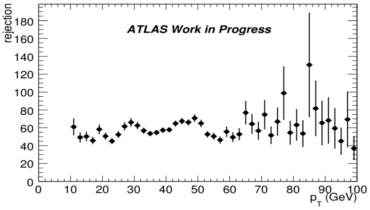
TauJets

- $p_T > 20\ GeV$
- $|\eta| < 2.5$, $|Q| = 1$
- (Calo+Track) seed and "Safe cut"-Tight
- remove overlap(taujet, e-medium/μcombined, 0.30)
- $E_{T,had}/p_T > 0.1$

- rejection against jet in J1+J2 sample, after τ-jet selection on the left



- rejection against electrons in $Z \to ee$, after τ-jet selection on the left



The lepton-τ_{jet} Visible Invariant Mass

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

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

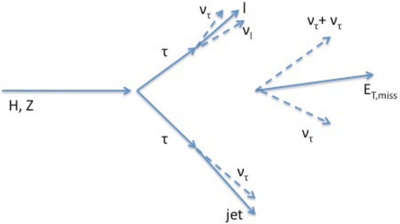
Reconstruction of the $\tau\tau$ invariant mass

lepton momentum fraction

$$x_1 = \frac{p_1}{p_{\tau 1}} = \frac{p_1^x}{p_{\tau_1}^x} = \frac{p_1^y}{p_{\tau_1}^y} \text{ jet}$$

momentum fraction

$$x_2 = \frac{p_2}{p_{\tau 2}} = \frac{p_2^x}{p_{\tau_2}^x} = \frac{p_2^y}{p_{\tau_2}^y}$$



$$p_{\tau 1}^x = p_1^x + p_{\nu 1}^x \qquad p_{\tau 1}^y = p_1^y + p_{\nu 1}^y \qquad p_{\tau 2}^x = p_2^x + p_{\nu 2}^x \qquad p_{\tau 2}^y = p_2^y + p_{\nu 2}^y$$

$$E_{miss}^x = p_{\nu 1}^x + p_{\nu 2}^x = p_1^x \frac{1-x_1}{x_1} + p_2^x \frac{1-x_2}{x_2} \qquad E_{miss}^y = p_{\nu 1}^y + p_{\nu 2}^y = p_1^x \frac{1-x_1}{x_1} + p_2^y \frac{1-x_2}{x_2}$$

$$x_l = \frac{p_l}{p_\tau} = \frac{p_{l,x}p_{jet,y} - p_{l,y}p_{jet,x}}{p_{l,x}p_{jet,y} + p_{miss,x}p_{l,y} - p_{l,y}p_{jet,x} - p_{miss,y}p_{l,x}}$$

$$x_{jet} = \frac{p_{jet}}{p_\tau} = \frac{p_{l,x}p_{jet,y} - p_{l,y}p_{jet,x}}{p_{l,x}p_{jet,y} - p_{miss,x}p_{l,y} - p_{l,y}p_{jet,x} + p_{miss,y}p_{l,x}}$$

Visible Invariant Mass $M_{1,2} = \sqrt{2p_1p_2(1-\cos\alpha)}$ Total Invariant Mass $M_{\tau\tau} = \frac{M_{1,2}}{\sqrt{x_1x_2}}$

QCD background for the $e - \tau_{jet}$ Selection

- Number of QCD events after all analysis cuts, scaled to 100 pb^{-1}
  - *"no ID cuts" $\longrightarrow$ "loose"*

	no ID cut	$\epsilon_{fact}^{(a)}$ loose	predicted	obtained from MC
J1F OS (a)	11825 ± 2365	0.66 ± 0.07	7804 ±1767	
J2F OS (a)	11934 ± 1351	0.66 ± 0.07	7876 ±1222	
J1F+J2F OS (a)			15681 ± 2148	15399 ± 2253
J1F SS (a)	10879 ± 2268	0.66 ± 0.07	7180 ±1679	
J2F SS (a)	10557 ± 1271	0.66 ± 0.07	6968 ±1118	
J1F+J2F SS (a)			14148 ± 2017	14453 ± 2152
		$\epsilon_{fact}^{(b)}$ loose		
J1F OS (b)	64328 ± 5516	0.082 ± 0.011	5275±840	
J2F OS (b)	128061 ± 4426	0.082 ± 0.011	10501±1455	
J1F+J2F OS (b)			15776 ± 1680	15399 ± 2253
J1F SS (b)	51557 ± 4938	0.082 ± 0.11	4228±697	
J2F SS (b)	125154 ± 4376	0.082 ± 0.11	10263±1423	
J1F+J2F SS (b)			14490 ± 1584	14453 ± 2152

(a) = selection of the complete analysis except tau ID
(b) = selection of the complete analysis except tau ID and lepton isolation
*J1F = J1 dijet sample with 1 electron filter
*J2F = J2 dijet sample with 1 electron filter

$\Rightarrow$ good agreement between prediction from factorization and MC observation

$\Rightarrow$ good agreement between OS and SS

QCD background for the $e - \tau_{jet}$ Selection

- Number of QCD events after all analysis cuts, scaled to 100 pb^{-1}
  - *"no ID cut" → "medium"*

	no ID cut	$\epsilon_{fact}^{(a)}$ medium	predicted	obtained from MC
J1F OS (a)	11825 ± 2365	0.24 ± 0.02	2838±615	
J2F OS (a)	11934 ± 1351	0.24 ± 0.02	2864±403	
J1F+J2F OS (a)			5702 ± 735	4994 ± 1350
J1F SS (a)	10879 ± 2268	0.24 ± 0.02	2611±586	
J2F SS (a)	10557 ± 1271	0.24 ± 0.02	2534±371	
J1F+J2F SS (a)			5145 ± 694	3561 ± 999
		$\epsilon_{fact}^{(b)}$ medium		
J1F OS (b)	64328 ± 5516	0.029 ± 0.004	1865±303	
J2F OS (b)	128061 ± 4426	0.029 ± 0.004	3714±528	
J1F+J2F OS (b)			5579 ± 609	4994 ± 1350
J1F SS (b)	51557 ± 4938	0.029 ± 0.004	1495 ±251	
J2F SS (b)	125154 ± 4376	0.029 ± 0.004	3629 ±516	
J1F+J2F SS (b)			5125 ± 574	3561 ± 999

(a) = selection of the complete analysis except tau ID
(b) = selection of the complete analysis except tau ID and lepton isolation
*J1F = J1 dijet sample with 1 electron filter
*J2F = J2 dijet sample with 1 electron filter

⇒ reasonable agreement (within the statistical error) between prediction from factorization and MC observation

⇒ good agreement between OS and SS

QCD background for the $e - \tau_{jet}$ Selection

- Number of QCD events after all analysis cuts, scaled to 100 pb^{-1}
  - *"no ID cut" → "tight"*

	no cut	$\epsilon^{(a)}_{fact}$ tight	predicted	obtained from MC
J1F OS (a)	11825 ± 2365	0.030 ± 0.005	355±92	
J2F OS (a)	11934 ± 1351	0.030 ± 0.005	358±72	
J1F+J2F OS (a)			713 ± 117	626 ± 497
J1F SS (a)	10879 ± 2268	0.030 ± 0.005	326±87	
J2F SS (a)	10557 ± 1271	0.030 ± 0.005	317±65	
J1F+J2F SS (a)			643 ± 109	153 ± 153
		$\epsilon^{(b)}_{fact}$ tight		
J1F OS (b)	64328 ± 5516	0.0037 ± 0.005	238.014 ± 38	
J2F OS (b)	128061 ± 4426	0.0037 ± 0.005	474±66	
J1F+J2F OS (b)			712 ± 76	626 ± 497
J1F SS (b)	51557 ± 4938	0.0037 ± 0.0007	191 ± 32	
J2F SS (b)	125154 ± 4376	0.0037 ± 0.0007	63 ±65	
J1F+J2F SS (b)			654 ± 72	153 ± 153

(a) = selection of the complete analysis except tau ID
(b) = selection of the complete analysis except tau ID and lepton isolation
*J1F = J1 dijet sample with 1 electron filter
*J2F = J2 dijet sample with 1 electron filter

⇒ difficult comparison due to low statistics, but one can assume a good agreement according to the factorization results for "loose" or "medium" on two previous pages

QCD background for the $\mu - \tau_{jet}$ Selection

- Number of QCD events after all analysis cuts, scaled to 100 pb^{-1}
  - *"no ID cut" → "loose"*

	no ID cut	$\epsilon^{(a)}_{fact}$ loose	predicted	obtained from MC
J1F OS (a)	25694 ± 3374	0.66 ± 0.07	16958±2862	
J2F OS (a)	17228 ± 1586	0.66 ± 0.07	11370±1597	
J1F+J2F OS (a)			28328 ± 3278	31464 ± 3222
J1F SS (a)	20821 ± 3037	0.66 ± 0.07	13742±2478	
J2F SS (a)	16644 ± 1559	0.66 ± 0.07	10985±1554	
J1F+J2F SS (a)			24727 ± 2925	26762 ± 2985
		$\epsilon^{(b)}_{fact}$ loose		
J1F OS (b)	123154 ± 7386	0.042 ± 0.006	5172 ± 801	
J2F OS (b)	516548 ± 8684	0.042 ± 0.006	21695 ± 3121	
J1F+J2F OS (b)			26867 ± 3222	31464 ± 3222
J1F SS (b)	116952 ± 7198	0.042 ± 0.006	4912 ± 764	
J2F SS (b)	493626 ± 8489	0.042 ± 0.006	20732 ± 2983	
J1F+J2F SS (b)			25644 ± 3079	26762 ± 2985

(a) = selection of the complete analysis except tau ID
(b) = selection of the complete analysis except tau ID and lepton isolation
*J1F = J1 dijet sample with 1 muon filter
*J2F = J2 dijet sample with 1 muon filter

⇒ reasonable agreement (within the statistical error) between prediction from factorization and MC observation

⇒ good agreement between OS and SS

QCD background for the $\mu - \tau_{jet}$ Selection

- Number of QCD events after all analysis cuts, scaled to 100 pb^{-1}
  - *"no ID cut" → "medium"*

	no ID cut	$\epsilon_{fact}^{(a)}$ medium	predicted	obtained from MC
J1F OS (a)	25694 ± 3374	0.24 ± 0.02	6167 ± 959	
J2F OS (a)	17228 ± 1586	0.24 ± 0.02	4135 ± 513	
J1F+J2F OS (a)			10301 ± 1088	9273 ± 1824
J1F SS (a)	20821 ± 3037	0.24 ± 0.02	4997 ± 839	
J2F SS (a)	16644 ± 1559	0.24 ± 0.02	3995 ± 501	
J1F+J2F SS (a)			8992 ± 977	9575 ± 1906
		$\epsilon_{fact}^{(b)}$ medium		
J1F OS (b)	123154 ± 7386	0.015 ± 0.002	1847 ± 270	
J2F OS (b)	516548 ± 8684	0.015 ± 0.002	7748 ± 1041	
J1F+J2F OS (b)			9595 ± 1076	9273 ± 1824
J1F SS (b)	116952 ± 7198	0.015 ± 0.002	1754 ± 258	
J2F SS (b)	493626 ± 8489	0.015 ± 0.002	7404 ± 995	
J1F+J2F SS (b)			9159 ± 1028	9575 ± 1906

(a) = selection of the complete analysis except tau ID
(b) = selection of the complete analysis except tau ID and lepton isolation
*J1F = J1 dijet sample with 1 muon filter
*J2F = J2 dijet sample with 1 muon filter

⇒ good agreement between prediction from factorization and MC observation

⇒ good agreement between OS and SS

QCD background for the $\mu - \tau_{jet}$ Selection

- Number of QCD events after all analysis cuts, scaled to 100 pb^{-1}
  - *"no ID cut" → "tight"*

	no cut	$\epsilon_{fact}^{(a)}$ tight	predicted	obtained from MC
J1F OS (a)	25694 ± 3374	0.030 ± 0.005	771 ± 163	
J2F OS (a)	17228 ± 1586	0.030 ± 0.005	517 ± 98	
J1F+J2F OS (a)			1288 ± 191	886 ± 626
J1F SS (a)	20821 ± 3037	0.030 ± 0.005	625 ± 138	
J2F SS (a)	16644 ± 1559	0.030 ± 0.005	499 ± 95	
J1F+J2F SS (a)			1124 ± 168	1178 ± 659
		$\epsilon_{fact}^{(b)}$ tight		
J1F OS (b)	123154 ± 7386	0.0019 ± 0.0006	234 ± 44	
J2F OS (b)	516548 ± 8684	0.0019 ± 0.0006	981 ± 176	
J1F+J2F OS (b)			1215 ± 182	886 ± 626
J1F SS (b)	116952 ± 7198	0.0019 ± 0.0006	222 ± 42	
J2F SS (b)	493626 ± 8489	0.0019 ± 0.0006	938 ± 169	
J1F+J2F SS (b)			1160 ± 174	1178 ± 659

(a) = selection of the complete analysis except tau ID
(b) = selection of the complete analysis except tau ID and lepton isolation
*J1F = J1 dijet sample with 1 electron filter
*J2F = J2 dijet sample with 1 electron filter

⇒ difficult comparison due to low statistics, but one can assume a good agreement according to the factorization results for "loose" or "medium" on two previous pages