$Z^0 \rightarrow \tau^+\tau^-$
Prospects for hadronic τ efficiency determination in first data

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Schedule

Motivation for $Z^0 \rightarrow \tau^+\tau^- \rightarrow had\,\ell$

Selection Strategy

OS-SS Asymmetry for $W \rightarrow \ell\nu$

Efficiency determination

First look into Pileup

Summary and Outlook

$Z^0 \to \tau^+\tau^- \to had\,\ell$

- in first data $Z^0 \to \tau^+\tau^- \to had\,\ell$ is useful (τ) channel for (τ) trigger studies
- most important control channel (together with $W \to \tau\nu$ and $t \to \tau\nu b$) to control the tau reconstruction
- Challenge to suppress the backgrounds due mainly to QCD and $W \to \tau\nu$, $W \to \mu\nu$ and $W \to e\nu$ channels
- Comparison with $Z^0 \to \mu^+\mu^-$ or $Z^0 \to e^+e^-$ allows efficiency determination using Z-Resonance

Used data sets

- Rel. 14 Tertiary DPDs used
- event weight corrosponds to luminosity $\mathcal{L}$ = 100 pb^{-1}
- cross section σ for LO $\longrightarrow N_{expect.events}$ = $\mathcal{L} \cdot \sigma$

Signal	Number events	event weight
Ztautau	109917	1.3

BG	events	weight	**BG**	events	weight
DiJet(8-17)GeV	1,68 Mio	696167	**Zee**	169099	0.67
DiJet(17-35)GeV	338777	253687	**Zmumu**	148029	0.7
DiJet(35-70)GeV	247796	23030	**Wenu**	340457	3.5
DiJet(70-140)GeV	134073	245	**Wmunu**	290073	4.1
DiJet(140-280)GeV	15031	123	**Wtaunu**	563719	2
DiJet(280-560)GeV	19678	25	**ttbar**	14685	3.4

- all muons in selected (Tau-Jet, Tau-Muon) combinations are truth matched muons $\Rightarrow$ Jet samples including truth lepton filter needed $\Rightarrow$ could decrease the effective event weight to $\mathcal{O}(1)$
- in general more statistic is needed!

Selection cuts

Trigger:

Electron: e10_medium
Muon: mu10i

Event Cuts:

Missing $E_T > $ 12 GeV (QCD BG reduction)
Sum $P_T <$ 400 GeV (QCD BG reduction)

general cuts for single particle:

$P_T >$ 12 GeV (for Tau-Jet or Lepton candidate)
$|Charge|$=1
$|\eta|$ <2.5
m_T <30 GeV (supresses semileptonic events from W decay)

general cuts for Tau-Jet,Tau-Lepton combinations:

$1 < |\Delta\Phi_{TauJet,Lepton}|$ <2.9 (rejects back to back jets)
opposite minus same sign charge (OS-SS)
37 GeV<invariant Mass<75 GeV

Selection cuts for particle identification

tau identification:

track multiplicity: 1 or 3
TauLikelihood $>$ 2 (τ-Jet/QCD-Jet separation)
TauElTauLikelihood $>$ -4 (τ/e separation)
Δ R(Jet,Tau-Jet) $>$0.4

electron identification:

IsEM=0
El_EtCone20 $<$ 5 GeV
Δ R(Electron,Tau-Jet) $>$0.4

muon identification:

Mu_EtCone20 $<$ 5 GeV
Δ R(Muon,Tau-Jet) $>$0.4

Number of combinations for signal and background ($\mathcal{L}$ = 100 pb^{-1})

Tau-Jet,Lepton	Signal	Background
$1 < |\Delta\Phi| <$2.9	300	257
opposite sign	278	182
37 GeV <invMass-OS<75 GeV	208	94
same sign	22	75
37 GeV <invMass-SS<75 GeV	15	50
Tau-Jet,Electron	**Signal**	**Background**
$1 < |\Delta\Phi| <$2.9	133	60
opposite sign	120	38
37 GeV <invMass-OS<75 GeV	86	20
same sign	13	22
37 GeV <invMass-SS<75 GeV	4	15
Tau-Jet,Muon	**Signal**	**Background**
$1 < |\Delta\Phi| <$2.9	167	197
opposite sign	158	144
37 GeV <invMass-OS<75 GeV	122	74
same sign	9	53
37 GeV <invMass-SS<75 GeV	11	35

Final Number of Tau-Jet,Lepton Comb. for signal $\&$ bg ($\mathcal{L}$ = 100 pb^{-1})

- after all cuts within "invariant mass window" 37 GeV $< M_{inv} <$ 75 GeV

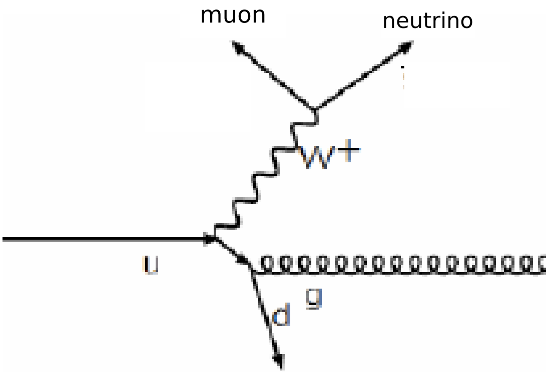
Sample	# OS (Tau-Jet,Lepton)	# SS (Tau-Jet,Lepton)	σ_{OS-SS}
$\mathrm{Z}^0 \rightarrow \tau\tau$	208	15	
DiJet (8-560)GeV [1]	0	0	-
$\mathrm{Z}^0 \rightarrow ee$	2	2	0
$\mathrm{Z}^0 \rightarrow \mu\mu$	6	4	1.2
$\mathrm{W} \rightarrow \tau\nu$	29	13	2.1
$\mathrm{W} \rightarrow \mu\nu$	28	18	1.7
$\mathrm{W} \rightarrow e\nu$	21	11	1.9
ttbar [2]	7	3	0.6

- **2 effects:**
  - intrinsic charge asymetry in $\mathrm{W} \rightarrow \ell\nu$ because of initial $pp \rightarrow W$ production which is slightly dominated by W^+
  - W production is dominated by an associated opposite charged quark

[1] not realistic because of event weight

[2] OS-SS asymmetry because of small statistic

dominant process for W production



- W production is dominated by an associated opposite charged quark
- $\to$ Fake-τ's have (mostly) opposite charge compared with μ from W-decay

Discussion of charge asymmetry for W channel

- $W \to \mu\nu$ (splitted in 0 partons to 5 partons)
- $\to$ different number of final state partons
- normalised to $\mathcal{L}$ = 100 pb^{-1}

Sample	exp. events	mc events	event weight
Np0	1012500	272560	3.71
Np1	215500	60580	3.55
Np2	67400	77708	0.87
Np3	20200	42740	0.47
Np4	5500	11900	0.46
Np5	1650	3500	0.47

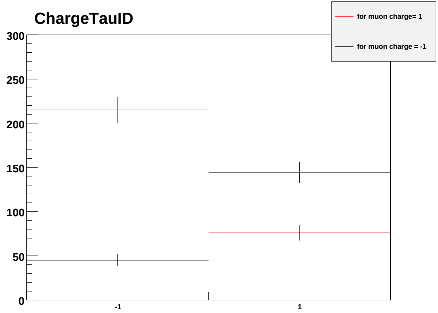
Determine W charge asymmetry

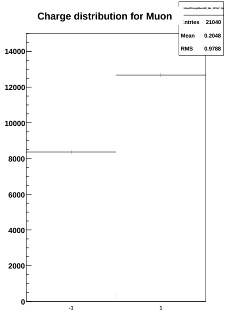
- Cut flow (again for $\mathcal{L}$ = 100 pb^{-1}) for $\mathrm{W} \rightarrow \mu\nu$ as BG for $\mathrm{Z}^0 \rightarrow \tau^+\tau^-$ analysis
- OS-SS asymmetry dominated by production with less final state partons

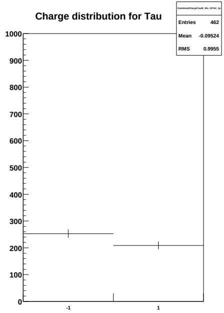
	m_T<30 GeV		m_T>30 GeV	
sample	OS	SS	OS	SS
0 partons	14,8	11,1	240,1	102,3
1 parton	10,7	3.6	510,7	100,4
2 partons	11,3	10,28	201,5	136,3
3 partons	2,4	3,3	70,0	31,7
4 partons	0	0	18,4	17,0
5 partons	0	0	2,8	2,8
All	**28,3**	**18,3**	**642**	**241**

Determine W charge asymmetry

- compare Tau charge distribution with respect to muon charge
- test with $W \to \mu\nu$ (**1 parton final state**, not normalized, no cuts!)
- for muon charge = 1 $\to \frac{\tau^+}{\tau^-}$ = 2,5 -for muon charge = -1 $\to \frac{\tau^+}{\tau^-}$ = 3







Determine W charge asymmetry

- $\mathrm{W} \to \mu\nu$ has also combinations of truth μ's and fake τ's
- find out "real" $\mathrm{W} \to \mu\nu$ charge asymmetry $\to$ use $\mathrm{W} \to \mu\nu$ as signal

Cut	Signal: $\mathrm{Z} \to \tau\tau$	Signal: $\mathrm{W} \to \mu\nu$
E_{tmiss}	>12 GeV	>20 GeV
m_T	< 30 GeV	>30 GeV
$M_{inv.}$	37 GeV<$M_{Z,vis.}$<75 GeV	22 GeV<$M_{W,vis.}$<55 GeV

- m_T > 30 GeV $\to$ μ from W decay
- use all Tau-ID cuts
- $\to$ combine μ's with fake τ's!

Determine W charge asymmetry

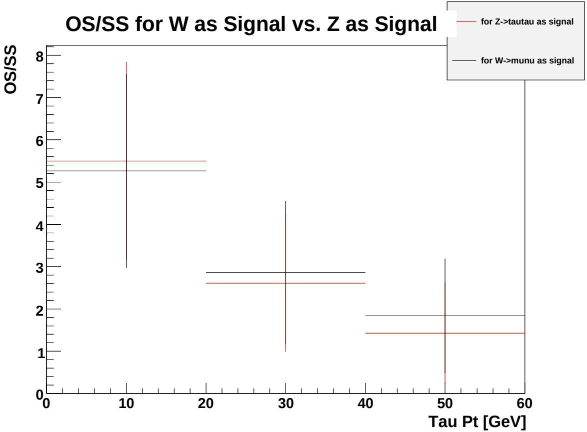
- Current cut flow for Signal $W \to \mu\nu$ ($\mathcal{L}$ = 100 pb^{-1}):

sample	OS	SS
$W \to \mu\nu$	**214,3**	**42,0**
$Z \to ee$	0	0
$Z \to \mu\mu$	12,2	12,2
$Z \to \tau\tau$	1	1
$W \to \tau\nu$	12,6	8,7
$W \to e\nu$	0	0

- relatively easy to select $W \to \mu\nu$
- OS/SS asymmetry of about 5 (factor 2 for Signal: $Z \to \tau\tau$)
- Reason: OS/SS is dominant for low p_T taus

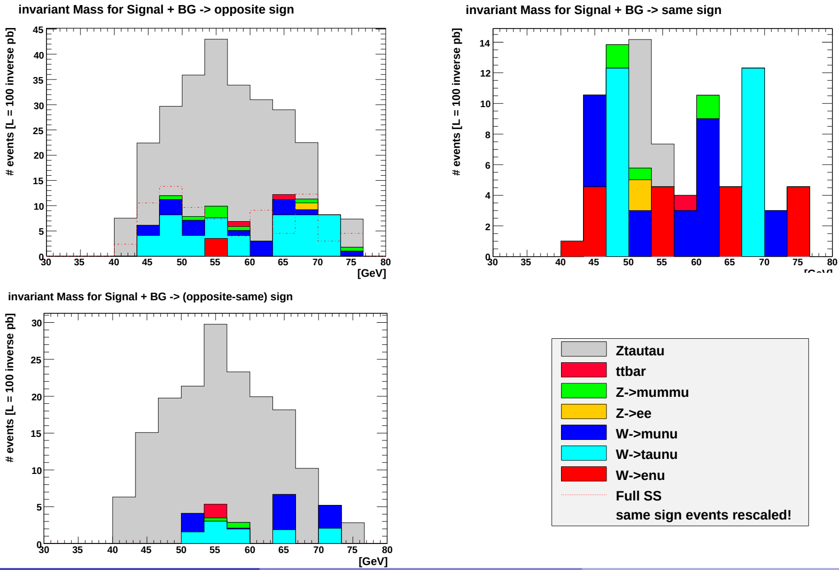
Compare OS/SS

- Compare OS/SS relation for $W \to \mu\nu$ as signal with OS/SS for for $W \to \mu\nu$ in original selection



back to $Z \rightarrow \tau\tau$.....

visible invariant Z mass for signal + BG



τ-efficiency

hadronic τ Efficiency is defined as:

$$\epsilon_{\tau\rightarrow had} = \frac{N^{sel}_{Z^0\rightarrow\tau^+\tau^-}}{N^{ini}_{Z^0\rightarrow\tau^+\tau^-} \cdot BR_{\tau\rightarrow had} \cdot BR_{\tau\rightarrow lep} \cdot \epsilon^{kin}_{Z^0\rightarrow\tau^+\tau^-} \cdot \epsilon_{\tau\rightarrow lep}} \tag{1}$$

possible to substitute $N^{ini}_{Z^0\rightarrow\tau^+\tau^-}$

with

$$\frac{N^{sel}_{Z^0\rightarrow\mu^+\mu^-} \cdot \frac{BR_{Z^0\rightarrow\mu^+\mu^-}}{BR_{Z^0\rightarrow\tau^+\tau^-}}}{\epsilon^{kin}_{Z^0\rightarrow\mu^+\mu^-} \cdot \epsilon^2_{\mu}} \tag{2}$$

Finally for efficiency calculation:

$$\epsilon_{\tau\rightarrow had} = \frac{\epsilon^{kin}_{Z^0\rightarrow\mu^+\mu^-}}{\epsilon^{kin}_{Z^0\rightarrow\tau^+\tau^-}} \cdot \frac{N^{sel}_{Z^0\rightarrow\tau^+\tau^-} \cdot BR_{Z^0\rightarrow\mu^+\mu^-} \cdot \epsilon_{\mu}}{N^{sel}_{Z^0\rightarrow\mu^+\mu^-} \cdot BR_{\tau\rightarrow lep} \cdot BR_{\tau\rightarrow had} \cdot BR_{Z^0\rightarrow\tau^+\tau^-}} \tag{3}$$

Parameter

- all BR available from PDG
- kinematic efficiencies (systematic studies for uncertainties of kin. efficiencies upcoming! Assume error $\mathcal{O}(10\ \%)$ just in order to check whether this would lead to acceptable order of magnitude of overall error)

$$\epsilon^{kin}_{Z^0\to\mu^+\mu^-} = 0.26 \pm 0.026$$

$$\epsilon^{kin}_{Z^0\to\tau^+\tau^-} = 0.0230 \pm 0.002$$

- selected number of events

$$N^{sel}_{Z^0\to\tau^+\tau^-} = 219 \pm 14$$

$$N^{sel}_{Z^0\to\mu^+\mu^-} = 21517 \pm 147$$

- Muon efficiency (uncertainty from ATLAS Note)

$$\epsilon_\mu = \sqrt{\frac{\frac{N^{sel}_{Z^0\to\mu^+\mu^-}}{\sigma_{Z^0\to\mu^+\mu^-}\cdot 100pb^{-1}}}{\epsilon^{kin}_{Z^0\to\mu^+\mu^-}}} = 0.85 \pm 0.05$$

Current values for hadronic efficiency

- Tau-Jet,Tau-Lepton combinations for $\mathcal{L}$ = 100 pb^{-1}
- SS events for background rescaled! (from MC events)

Signal	**OS**	**SS**	**OS-SS**
selected taus	208	11	197
selected taus truthmatched	201	2	199
Background	**OS**	**SS**	**OS-SS**
selected taus	96	91	5

- **hadronic efficiency** ϵ_{had} **for (OS-SS)** (uncertainty with error propagation)
  ϵ_{had} (Signal) = 0.537 $\pm$ 0.0642
  ϵ_{had} (Signal (truth)) = 0.542 $\pm$ 0.0654
  ϵ_{had} (Signal + BG) = 0.550 $\pm$ 0.073
- effects from selection uncertainties have to be studied in detail

First look into $Z \rightarrow \tau\tau$ with Pileup[3]

- up to now: only "clean samples"
- $\rightarrow$ Pileup due to high luminosity
- problem with underlying events (pp interactions with small energy values)
- number of tracks increases $\rightarrow \sum E_T$ increases $\rightarrow \sum E_T$ cut of 260 GeV (or 400 GeV) reduces the Tau efficiency
- $\epsilon_{had} \sim 1.4 \cdot \epsilon_{had,Pileup}$ (in my samples, preliminary)
- a looser $\sum E_T$ cut $\rightarrow$ effects the DiJet BG rate
- more detailed analysis (including BG) needed

[3] Sample from Katharina Fiekas

First look into $Z \rightarrow \tau\tau$ with Pileup

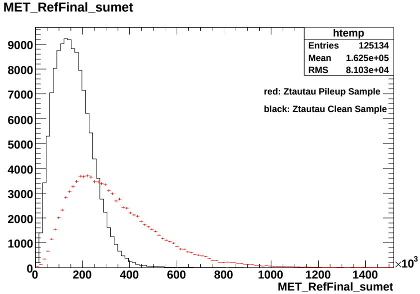


Figure: Sum of E_T and Number of tracks without any cut

- Lumi: $10^{32} cm^{-2} s^{-1}$
- Bunch spaces: 450 ns (4 collisions per bunch crossing)
- not yet looked into Trigger information....

Conclusion:

It's a long way to determine the hadronic tau efficiency

current (known...) challenges:

- a) QCD Background $\Longrightarrow$ truth filter
- b) Charge Asymmetry in W channels $\surd$
- c) Pile up (underlying events) $\Longrightarrow$ needs to be done
- d) determine the kinematic efficiencies for $\mathrm{Z}^0 \rightarrow \tau^+\tau^-$ and $\mathrm{Z}^0 \rightarrow \mu^+\mu^-$ with respect to detector effects $\Longrightarrow$ use method from M. Schumacher, Wisconsin et al.

Summary and Outlook

Summary:

- efficiency determination works in principle (with uncertainty of about 14 $\%$ if systematic in kinematic efficiency is at level of 10 $\%$)
- need to control systematics of $\frac{\epsilon^{kin}_{Z^0 \to \mu^+\mu^-}}{\epsilon^{kin}_{Z^0 \to \tau^+\tau^-}}$ at 10 $\%$ level
- current hadronic τ efficiency is 0.550 $\pm$ 0.073
- asymmetry in OS-SS for $\mathrm{W} \to \ell\nu$
- much more statistic for better description of W and Jet BG needed

Outlook:

- start with detailed systematic studies
- use and check specific cut optimization to improve the selection (purity...)
- higher statistic of QCD background $\longrightarrow$ truth filter for lepton
- can be used for first data

Backup

Number of tau candidates

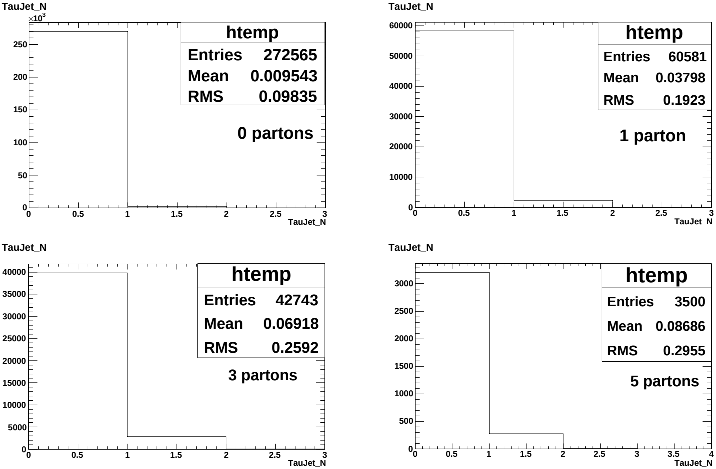


Figure: For Number of partons = 0 and 1 (top) and 3 and 5 (bottom)

Charge distribution for tracks

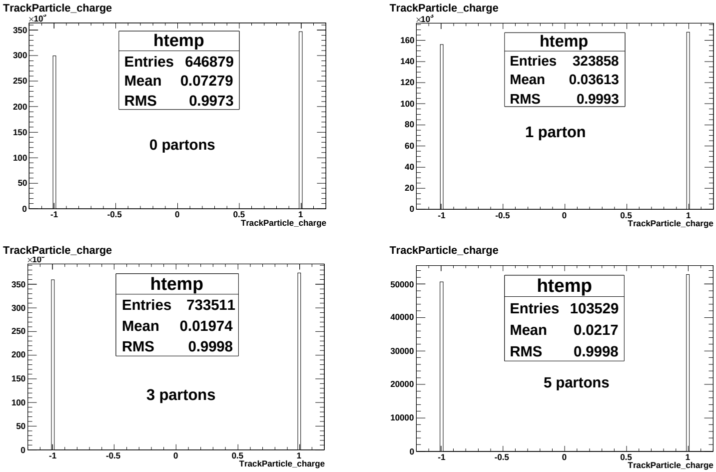


Figure: For Number of partons = 0 and 1 (top) and 3 and 5 (bottom)

recipe for kinematic efficiency determination from data

- don't know all detector (and trigger) effects in detail
- challenge to determine $\frac{\epsilon^{kin}_{Z^0\to\mu^+\mu^-}}{\epsilon^{kin}_{Z^0\to\tau^+\tau^-}}$
- not possible to use only data (help from MC sample (as less as possible) needed
- **Idea:**[4] take μ's from reconstructed $Z^0 \to \mu^+\mu^-$ events $\to$ remove μ hits and run the simulation (with Tauola) with τ's again (require: $E_\tau \sim E_\mu$)

[4]Markus Schumacher et al.