$Z^0 \rightarrow \tau^+\tau^- \rightarrow$ Method to determine hadronic tau efficiency

Gordon Fischer

Deutsches Elektronen Synchrotron - DESY

Summer school Rathen 2009

Schedule

What do I have to do?

Efficiency determination

Embedding method

Summary and Outlook

What do I have to do?

"....determine the hadronic tau selection efficiency from channel $\mathrm{Z}^0 \rightarrow \tau^+\tau^- \rightarrow had\,\ell$ in first data at ATLAS...."

- Why?
- How?

Why Tau Leptons?

Why Tau Leptons? Higgs search!

- Higgs boson couples to mass favouring the decay to the heavier tau-leptons
- for light Higgs masses $\rightarrow \tau\ \tau$ final state becomes important
- $b\bar{b}$ is difficult to measure
- third generation is very useful for new physics!

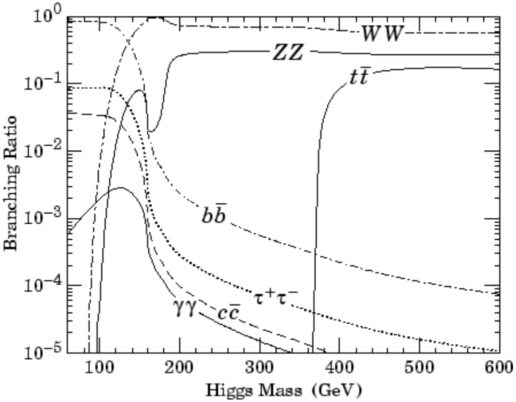


Figure: BR for different possible Higgs masses

Why Tau Leptons? SUSY search!

- τ leptons often final state in SUSY models
- $\tilde{\tau}_L$, $\tilde{\tau}_R$ mixing $\rightarrow \tilde{\tau}_1$, $\tilde{\tau}_2$ $\rightarrow \tilde{\tau}_1$ and τ production enhanced
- BR for $\tilde{\chi}_2^0 \rightarrow \tilde{\tau}_1\ \tau$ larger than for e or μ decays
- τ final states provide information for e.g. $\tilde{\tau}$ masses
- tau decay offers opportunity to measure tau polarization $\rightarrow$ $\tilde{\chi}_1^0$,$\tilde{\chi}_2^0$, $\tilde{\tau}_1$ coupling

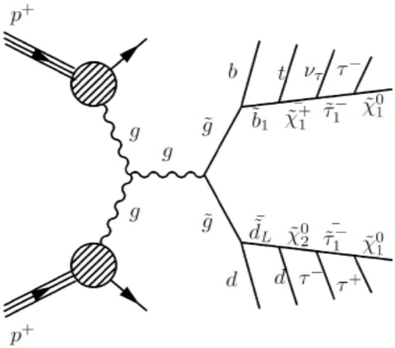


Figure: typical SUSY chain with τ's in the final state

Motivation for the channel $\mathrm{Z}^0 \rightarrow \tau^+\tau^- \rightarrow had\,\ell$

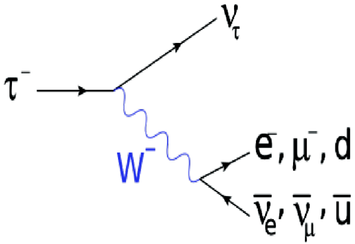
- in first data $\mathrm{Z}^0 \rightarrow \tau^+\tau^- \rightarrow had\,\ell$ is useful (τ) channel for (τ) trigger studies, with hadronic channel trigger studies not possible
- most important control channel (together with $\mathrm{W} \rightarrow \tau\nu$ and $t \rightarrow \tau\nu b$) to control the tau reconstruction
- Comparison with $\mathrm{Z}^0 \rightarrow \mu^+\mu^-$ or $\mathrm{Z}^0 \rightarrow e^+e^-$ allows efficiency determination using Z-Resonance

different τ decay channels $\rightarrow$ what does that mean?

- **three different $\tau\tau$ channels:**
- leptonic channel: two leptons (e, μ, τ)
- semileptonic channel: one lepton and one hadron (e.g. π...)
- hadronic channel: two hadrons

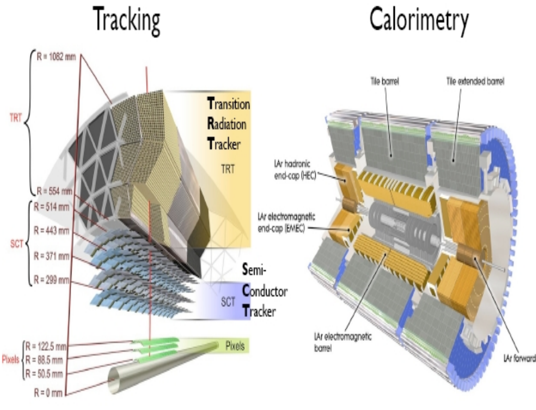
- τ-decay:

leptonic	(35.2 %)
$\tau \rightarrow e + \nu_e + \nu_\tau$	
$\tau \rightarrow \mu + \nu_\mu + \nu_\tau$	
hadronic	
1 Prong	(46.8 %)
$\tau \rightarrow \pi^\pm + \nu_\tau$	
$\tau \rightarrow \pi^\pm + n \cdot \pi^0 + \nu_\tau$	
3 Prong	(13.9 %)
$\tau \rightarrow \pi^\pm + \pi^\pm + \pi^\pm + \nu_\tau$	
$\tau \rightarrow \pi^\pm + \pi^\pm + \pi^\pm + n \cdot \pi^0 + \nu_\tau$	



important detector moduls for hadronic τ identification

- to select 1 prong and 3 prong decays $\rightarrow$ good tracking system
- τ Jets have a smaller EM-radius than QCD Di-Jets
  $\rightarrow$ for τ Jets and QCD Di-Jets separation good calorimeter system required
- QCD background is a big challenge!



Selection cuts

- **Event cuts**:
  - Missing E_T and Sum E_T (QCD BG reduction)
- **Particle cuts**:
  - trigger e10, mu10i
  - P_T for Tau-Jet or Lepton candidate
  - $|Charge|$ and η
  - m_T
  - different identification cuts
- **for τ,ℓ combinations:**
  - $|\Delta\Phi_{TauJet,Lepton}|$
  - invariant Mass window

  - **opposite minus same sign charge (OS-SS)**
  Assumption: for Background OS-SS $\approx$ 0 (for statistical reasons)
  $\Rightarrow$ good background rejection

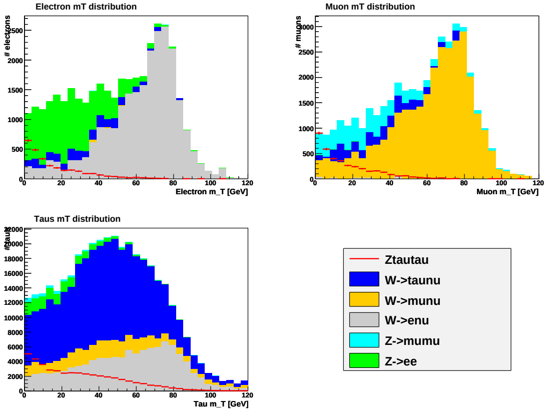


Figure: m_T distribution for final state leptons

τ-efficiency

hadronic τ efficiency is defined as:

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

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

with

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

Finally for efficiency calculation:

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

Parameter for $\mathcal{L}$ = 100 pb^{-1}

- 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)

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

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

- selected number of events

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

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

- Muon efficiency (uncertainty from ATLAS Note)

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

Current values for hadronic efficiency

- Tau-Jet,Tau-Lepton combinations for $\mathcal{L}$ = 100 pb^{-1}

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

Challenge: determine kinematic efficiency for $\mathrm{Z}^0 \rightarrow \tau^+\tau^-$ and $\mathrm{Z}^0 \rightarrow \mu^+\mu^-$

- don't know all detector (and trigger) effects in detail $\rightarrow$ challenge to determine $\frac{\epsilon^{kin}_{\mathrm{Z}^0\rightarrow\mu^+\mu^-}}{\epsilon^{kin}_{\mathrm{Z}^0\rightarrow\tau^+\tau^-}}$
- Idea [1]: select μ pairs from Z decay (in real data)
- kinematic behaviour of μ and τ (before decaying) is the same $\rightarrow$ allowed
- replace μ with τ
- let τ decay and run full reconstruction chain again
- compare number of (kinematic) selected τ and μ $\rightarrow$ no more initial information needed

[1] Markus Schumacher, Nicolas Möser (Uni Bonn), Martin Schmitz (Uni Bonn) et al.

recipe for kinematic efficiency determination from data

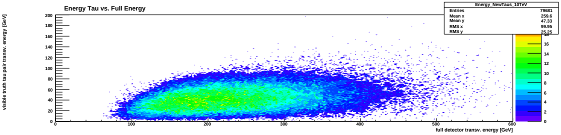
- select μ pairs from $\mathrm{Z}^0 \rightarrow \mu^+\mu^-$ with $p_T > 5$ GeV, opposite charge
- determine correction factor for lepton $p_T \longrightarrow \xi = \frac{E^2 - m_\tau}{|p|^2}$ and replace μ with τ
- let τ decay (TAUOLA) $\rightarrow$ digitisation $\rightarrow$ reconstruction $\rightarrow$ embedding $\rightarrow \mathrm{Z}^0 \rightarrow \tau^+\tau^-$
- Embedding $\rightarrow$ ΔR matching of τ to corresponding μ
- all track segments in muon spectrometer are deleted $\rightarrow$ track information from Z $\rightarrow \tau\tau$ events
- Track particles and tracks of μ are deleted and replecad by tracks from Z $\rightarrow \tau\tau$ events
- all higher-level objects and missing et will be reconstructed (Offline reconstruction (e.g. MuTag or STACO)
- run the kinematic selection and ratio $\frac{\epsilon^{kin}_{\mathrm{Z}^0 \rightarrow \mu^+\mu^- \, original}}{\epsilon^{kin}_{\mathrm{Z}^0 \rightarrow \tau^+\tau^- \, replaced}}$ yields the required efficiency!

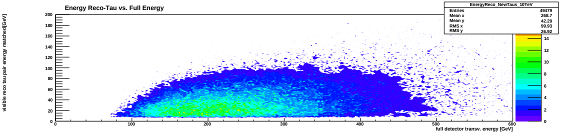
Performance plots

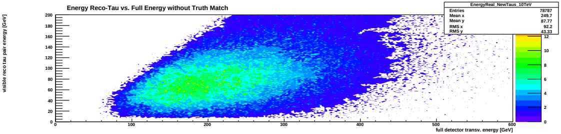
E_T for visible τ vs. Full detector energy on:

- case 1: truth level
- case 2: reconstruction level
  with truth match
- case 3: reconstruction level

  without truth match

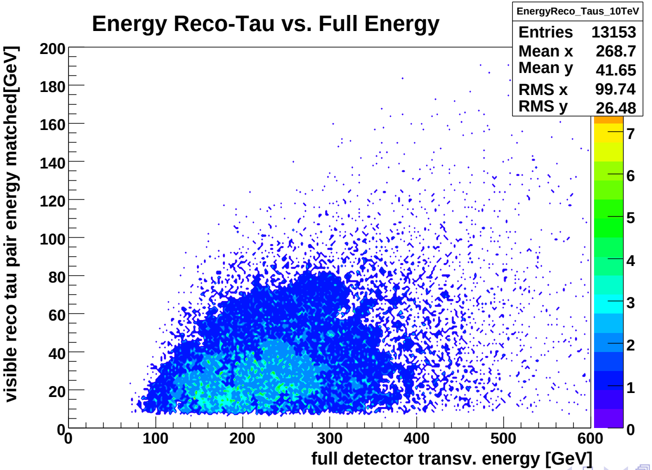






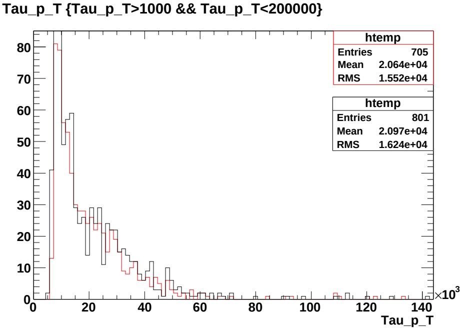
case 2: reconstructed (and truth matched) τ's

- $\Longrightarrow \tau$ pair energy contribution relative small



Performance plots → Embedding

- choose $Z^0 \to \mu^+\mu^- \to$ full embedding chain
- compare with regular $Z^0 \to \tau^+\tau^-$ sample (same production)
- plot p_T from reconstructed τ
- **compare R =** $\frac{\#\tau\ell}{\#\mu\mu}$ **for truth MC and Embedding:**



Sample	$events$	R	$\Delta R/R$
MC truth	$\frac{271\pm16}{2131\pm46}$	$\sim$ 0.120 $\pm$ 0.01	$\sim$ 0.08
Embedding	$\frac{13\pm4}{122\pm11}$	$\sim$ 0.106 $\pm$ 0,04	$\sim$ 0.40

Summary and Outlook

Summary:

- τ and μ kinematic well understood
- technical problems solved
- embedding method works fine (on this level)

Outlook:

- of course more statistic needed
- disussion of further uncertainties (e.g. μ selection, TAUOLA, effects from underlying events..)
- more detailed studies of embedding tool will be done
- .....

Backup

Embedding method in more detail

- $\mu\mu$ declared as $\tau\tau$ $\rightarrow$ four vectors together with four vector of Z boson are written in HEPEVT format
- ASCII file read in into TAUOLA ($\rightarrow$ lets τ decay) and PHOTOS ($\rightarrow$ final state radiation)
- fed into ATLAS detector simulation, digitisation, reconstruction
- Embedding $\rightarrow$ ΔR matching of τ to corresponding μ
- all track segments in muon spectrometer are deleted $\rightarrow$ track information from Z $\rightarrow$ $\tau\tau$ events
- Track particles and tracks of μ are deleted and replecad by tracks from Z $\rightarrow$ $\tau\tau$ events
- all higher-level objects and missing et will be reconstructed (Offline reconstruction (e.g. MuTag or STACO)

Embedding flow

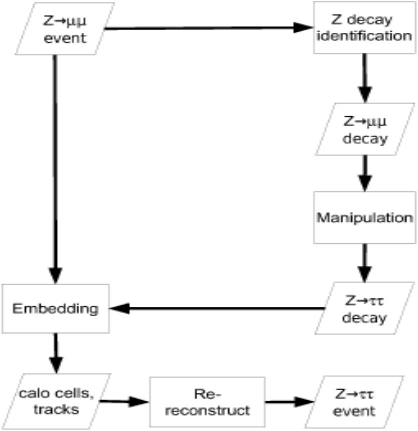


Figure 2: flowchart of the embedding procedure.