τ-Polarization in H/Z-Decays

Michaela Roggendorf
(Supervised by Juergen Kroseberg & Thomas Schwindt)

Physikalisches Institut
Rheinische Friedrich-Wilhelms-Universität Bonn

11th Workshop of the mtautau Analysis Working Group
23.09.2013

Introduction

- τ-lepton is the heaviest of the leptons $(1{,}777\,\mathrm{GeV})$
  $\Rightarrow$only lepton that can decay into hadrons
  (hadronic decays: $\sim 65\%$, leptonic: $\sim 35\%$)

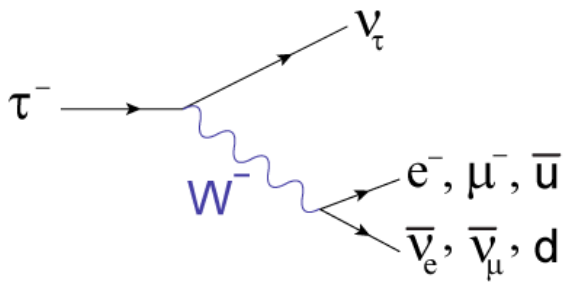


Figure: *tau*-decay modes

- also due to hadronic decay mode the τ-lepton decay is a good spin analyser
- can use previous work as starting point, e.g. master thesis "Measurement of the Tau Polarization in $Z \longrightarrow \tau\tau$ Decays with the ATLAS Detector" by Ingrid Deigaard
  http://discoverycenter.nbi.ku.dk/teaching/thesis_page/MasterThesis_Ingrid.pdf

Introduction

- possible application: distinction between $H \longrightarrow \tau^+\tau^-$ (total spin 0) and $Z \longrightarrow \tau^+\tau^-$ (total spin 1)

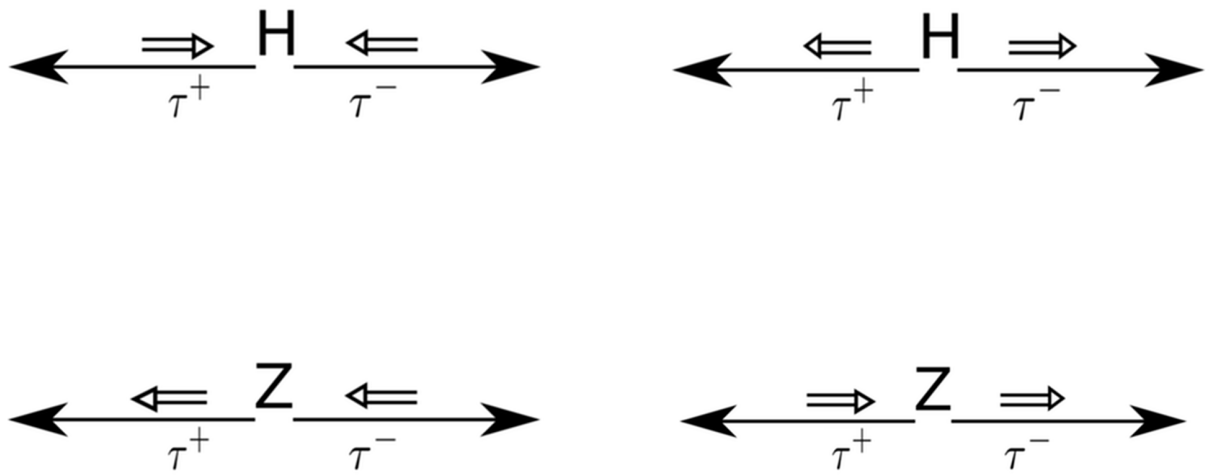


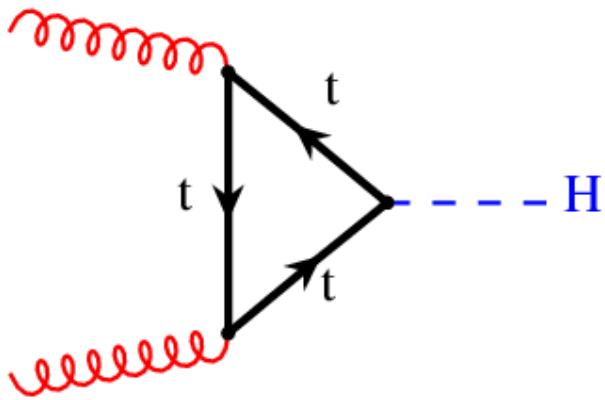
Figure: *tau*-helicities in H/Z decays

Helicity/Polarization in ATLAS MC

- In ATLAS simulation tau-decays are e.g. handled by TAUOLA, which assigns helicity to the taus and decays them accordingly.
- **BUT** tau helicity was not saved
  $\Rightarrow$ no truth information available
- estimation: **TauSpinner-Tool**:
  - "TauSpinner program for studies on spin effect in tau production at the LHC" by Z. Czyczula, T. Przedzinski, Z. Was
    arXiv:1201.0117 [hep-ph]
  - using polarimetric vectors (can be obtained from kinematics) to calculate weights for spin-configurations
    $\Rightarrow$ returns for each event a variable called "polari" with value -1 or 1 based on probability
  - Input: four-vectors of
    - mother particle (H/Z)
    - τ^+
    - τ^-
    - τ^+-decay products (pion or kaon endstate)
    - τ^--decay products (pion or kaon endstate)
  - for Z/γ^*-decays polari is equal to the helicity of τ^-

Samples (Monte Carlo 2012):

- H
  - $gg \rightarrow H \rightarrow \tau^+\tau^-$
  - $m_{\mathrm{H}} = 125\,\mathrm{GeV}$
- Z
  - π^0 reconstruction from 01.07.2013 (no latest versions)
- due to preselection of H analysis
  - $p_T(e) \geq 17\,\mathrm{GeV}$
  - $p_T(\mu) \geq 17\,\mathrm{GeV}$
  - $p_T(\tau_{\mathrm{vis}}) \geq 20\,\mathrm{GeV}$ ($p_T(\tau_{\mathrm{vis}})$ for each π^0 algorithm separately)
  - BDT medium tau



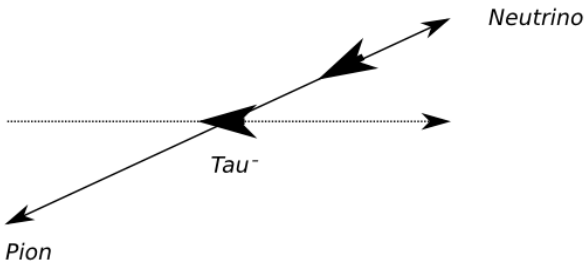
gluon-gluon-fusion

Measurement of Helicity/Polarization for Single Tau Leptons

- Fraction Of Visible Energy
  - π-Channel
    $\longrightarrow$ best distinction power
  - l-Channel
    $\longrightarrow$ no other observable available in reconstruction
- Charged Energy Asymmetry
  - ρ-Channel
    $\longrightarrow$ best distinction power
- Polarimetric Vector
  - Hadronic Channels

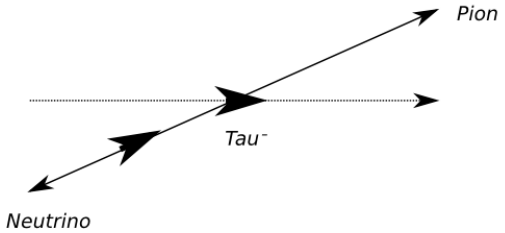
Reminder: Fraction Of Visible Energy: π-Channel: $\tau^- \longrightarrow \pi^- \nu_\tau$

tau: negative helicity



tau rest frame, low-energy pion

tau: positive helicity



tau rest frame, high-energy pion

$$\Rightarrow x = \frac{E_\pi}{E_\tau} \text{ is a spin sensitive quantity}$$

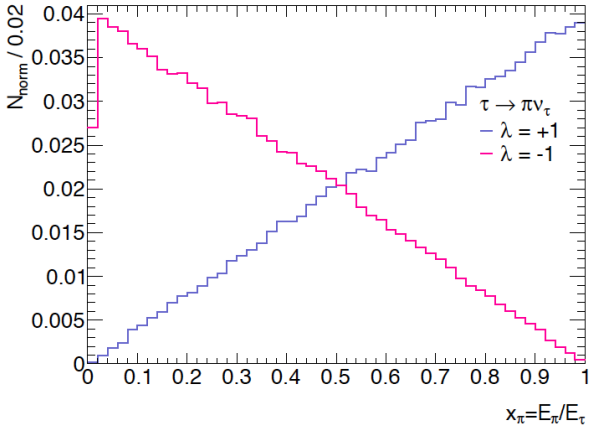


Figure: Distribution of fraction of visible energy, x, for τ^- in pion decays divided into left-handed (pink) and right-handed (blue) samples.[Ingrid Deigaard]

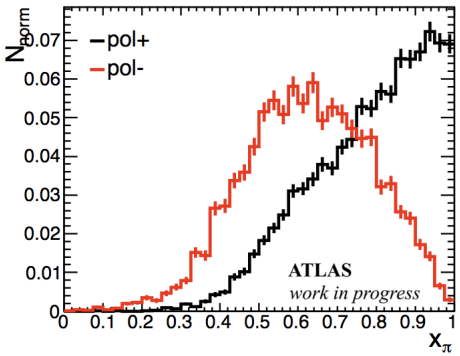
Reminder: Truth x and Reconstruction of x

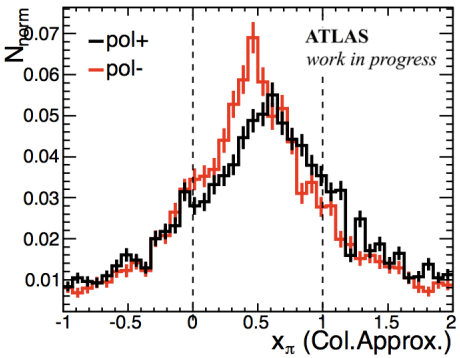
truth :
Monte Carlo samples without detector simulation

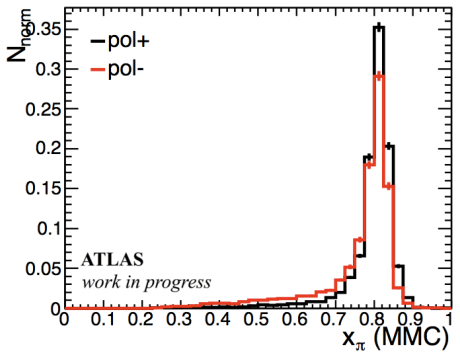
reconstruction:
using detector simulation

- Collinear Approximation
  - neutrinos go in the same direction as the visible decay products
  - all the missing energy is due to neutrinos from tau decays
- Missing Mass Calculator (MMC)
  - complex tool to reconstruct the mass of the original resonance (H/Z)
  - requirement: mutual orientations of the neutrinos and other decay products are consistent with the mass and decay kinematics of a τ lepton
  - minimizing likelihood functions

Truth x_π and Reconstruction of x_π, Z sample







Truth

- preselection deforms distributions of τ^- with positive helicity / τ^+ with negative helicity due to low $\pi^\pm$ energy

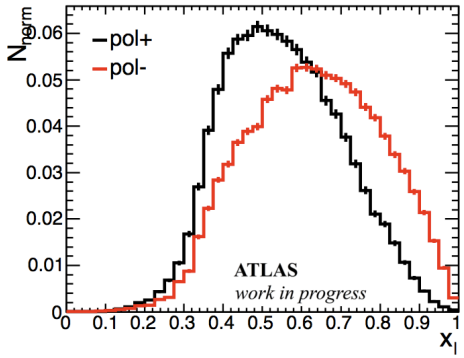
Collinear Approximation

- curves are shifted towards smaller values of x

MMC

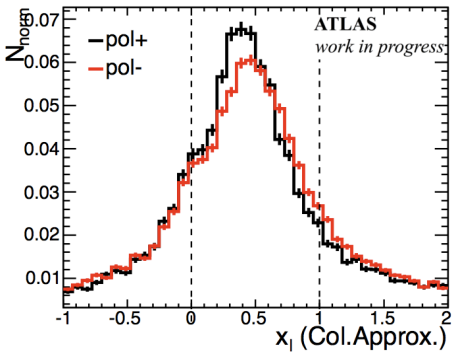
- curve peaks are at $x \approx 0.8$ independent of helicity (caused by internal PDFs/parametrization)

Truth x_l and Reconstruction of x_l, Z sample



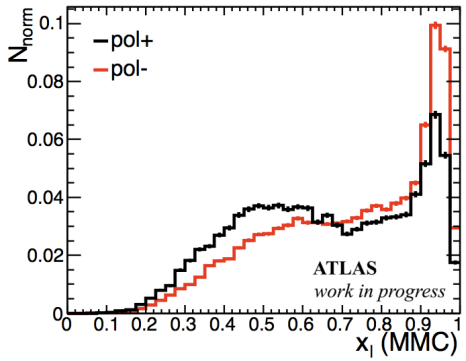
Truth

- preselection deforms distributions for both helicites
- less distinction power than for x_π



Collinear Approximation
(neutrino sum reconstruction)

- curves look similar to x_π curves



MMC
(neutrino sum reconstruction)

- curves very deformed (caused by internal PDFs/parametrization)

Charged Energy Asymmetry Υ

E_{π^0} not directly accessible in the data $\Rightarrow$ use $E_{\mathrm{T}}^{\pi^0} = E_{\mathrm{T}} - p_{\mathrm{T}}^{\mathrm{Trk}}$

$$\Upsilon = \frac{E_{\mathrm{ch}} - E_{\pi^0}}{E_{\mathrm{ch}} + E_{\pi^0}} \quad (1)$$

$$= \frac{p_{\mathrm{T}}^{\mathrm{Trk}} - (E_{\mathrm{T}\tau} - p_{\mathrm{T}}^{\mathrm{Trk}})}{p_{\mathrm{T}}^{\mathrm{Trk}} + (E_{\mathrm{T}\tau} - p_{\mathrm{T}}^{\mathrm{Trk}})} \quad (2)$$

$$= \frac{2p_{\mathrm{T}}^{\mathrm{Trk}}}{E_{\mathrm{T}\tau}} - 1 \quad (3)$$

$\Rightarrow$ not usable for lepton or single pion channel (no π^0)

definitions:

- **truth upsilon** (1)
  from truth information
- **upsilon** (3) from transverse calorimeter energy and transverse momentum of the charged tracks
- **upsilon using π^0 reconstruction** (1)
  from tracks and reconstructed π^0
  - cluster based π^0 reconstruction algorithm: Michel Trottier-McDonald
  - cell based π^0 reconstruction algorithm: Benedict Winter

Υ in ρ-decays

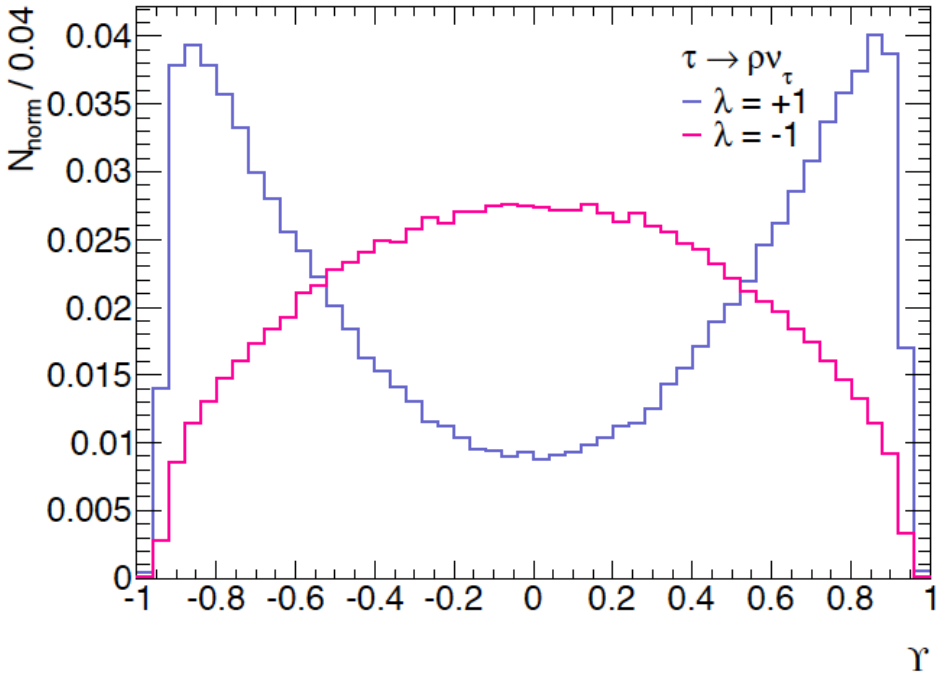
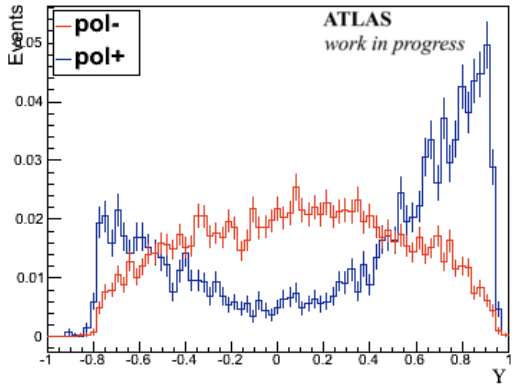


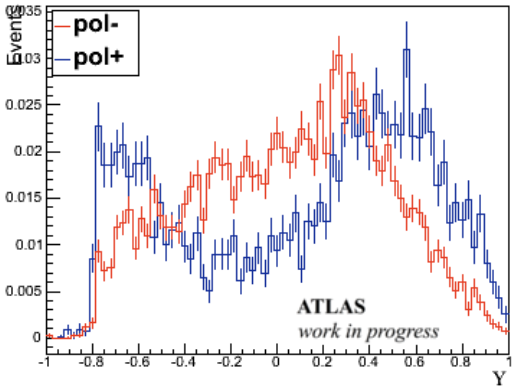
Figure: The distribution of the charged energy asymmetry Υ from rho decays divided into left-handed (pink) and right-handed (blue) samples. Each sample is normalized to one. [Ingrid Deigaard]

Υ in ρ-decays



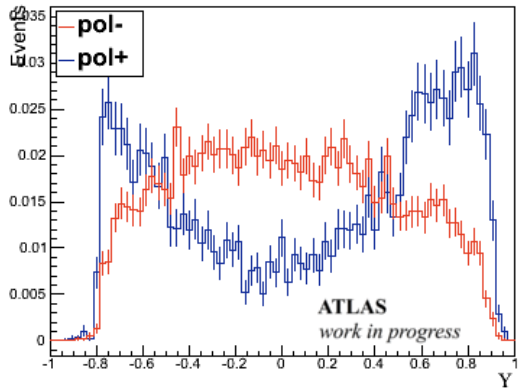
Truth

- asymmetry due to preselection
- overlap $(61 \pm 2)\%$



Cluster Based

- default π^0 reconstruction method
- overlap $(75 \pm 2)\%$



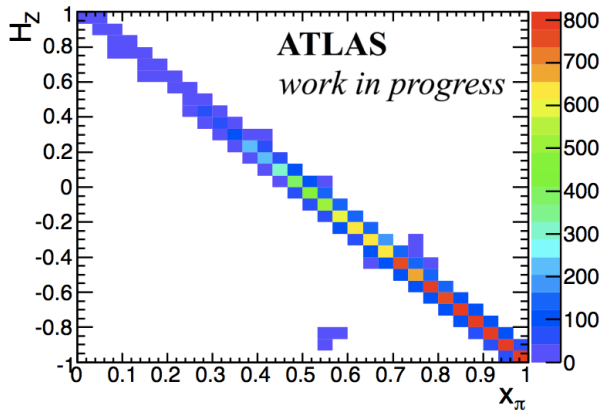
Cell Based

- overlap $(71 \pm 2)\%$
- performs better than cluster based algorithm (see Backup)

Reminder: Relation Between Matrixelement and Polarimetric Vector

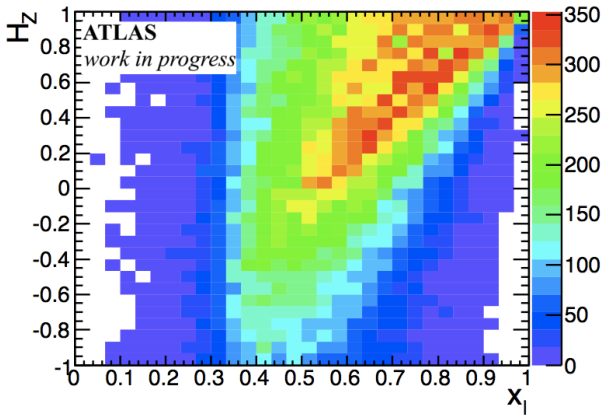
- spin vector S, polarimetric vector H
- partial decay width for any decay mode $d\Gamma \propto (1 + S \cdot H)$
  $\Rightarrow$ most likely configuration for a given S is H pointing in the direction of S
  best estimate of spin direction ist the direction of H for which $d\Gamma$ is maximal
- helicity estimation (H/Z rest frame)
  - $H_z < 0$: right-handed τ^- (lh τ^+)
  - $H_z > 0$: left-handed τ^- (rh τ^+)

Correlation of H_z with x and Υ, Truth Information



Single Pion Channel

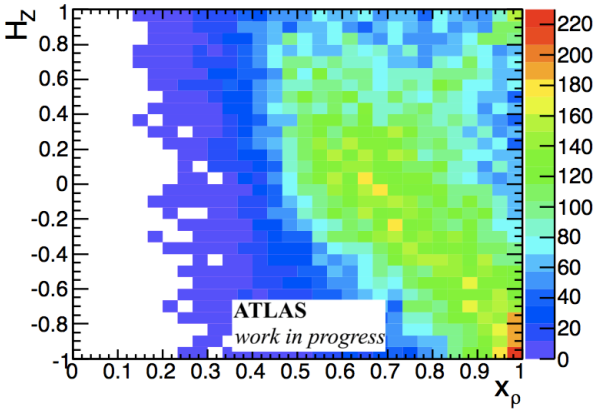
- strong correlation between H_z and x
- preselection suppresses events with high H_z values

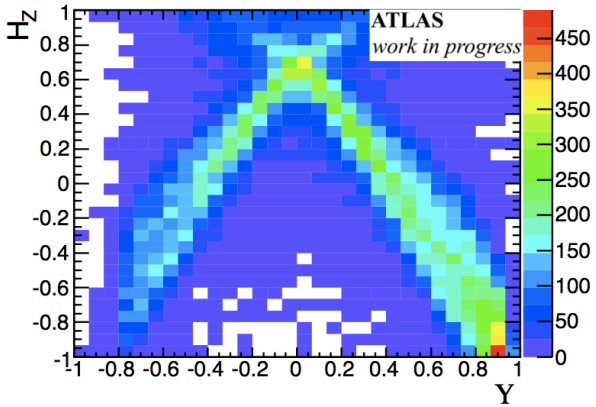


Lepton Channel

- only low level correlation betweeen H_z and x
- preselection suppresses events with high negative H_z values

Correlation of H_z with x and Υ, Truth Information





Rho Channel

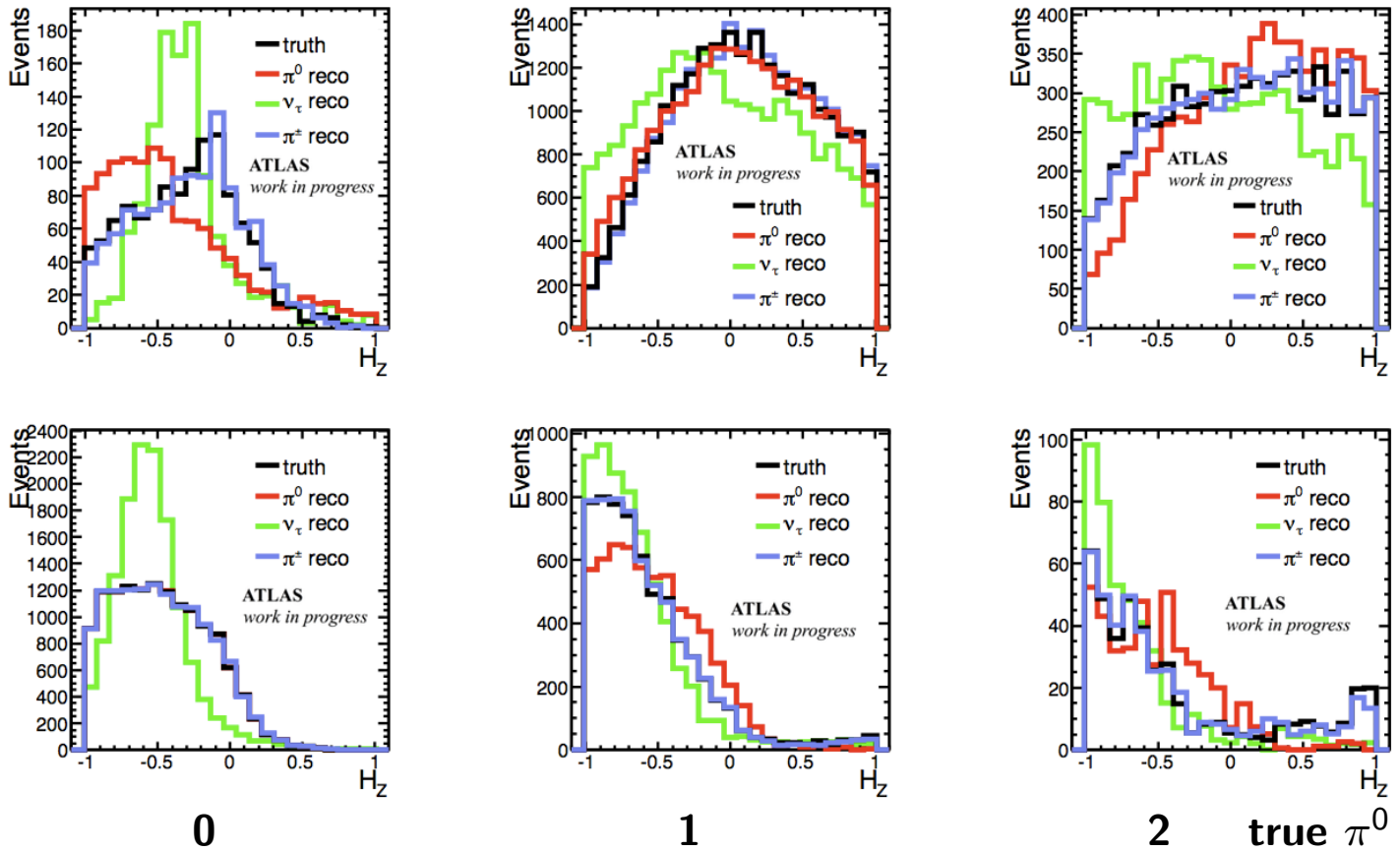
- due to ρ spin spin information splitted between x and Υ
  $\Rightarrow$correlation between H_z and x not as strong as in single pion channel
  $\Rightarrow$ clear correlation between H_z and Υ
- influence of preselection on H_z more difficult identify

Reconstruction of H_z - Needed Information

- Hadronic τ decay
  - track four-vector
  - π_0 four-vector $\longrightarrow$ π_0 reconstruction algorithms
  - ν_τ four-vector $\longrightarrow$ MMC
- Leptonic τ decay
  - track four-vector
  - ν_τ AND ν_l four-vector
    $\Rightarrow$ not available $\Rightarrow$ H_z can only be calculated on truth level

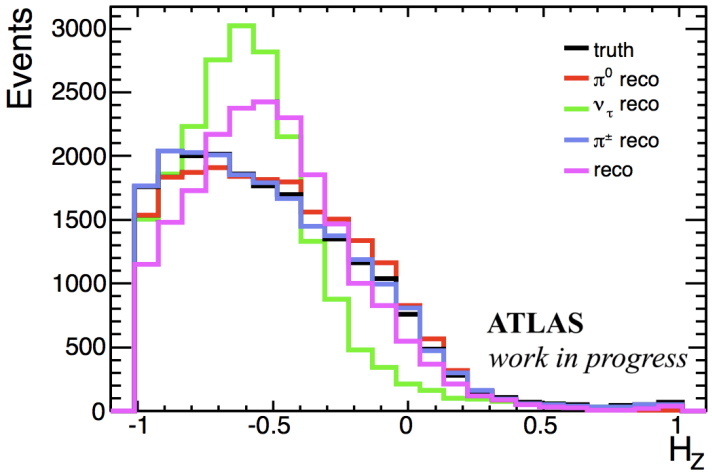
H_z in Hadronic Decays: Reconstruction of Particles (using Z sample)

reco π^0

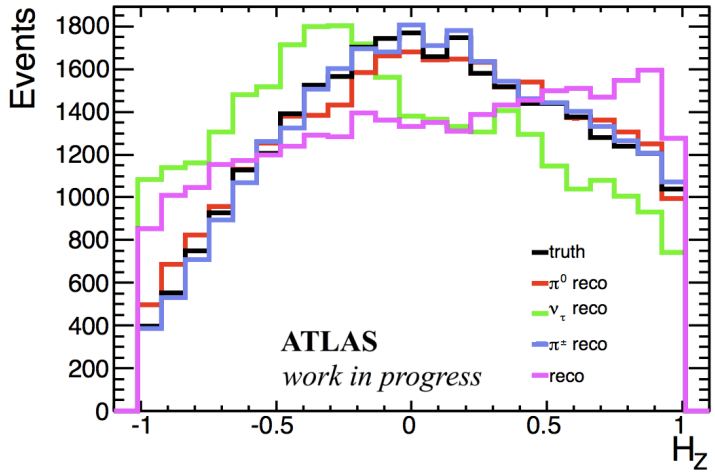


truth
reco π^0 (cluster based), true neutrino & track
reco ν_τ (MMC), true π^0 & track
reco track ($\pi^\pm$), true π^0 & ν_τ
(all decay modes: 1 track)

H_z in Hadronic Decays: Reconstruction (using Z sample)



(a) reconstructed single pion decay



(b) reconstructed rho decay

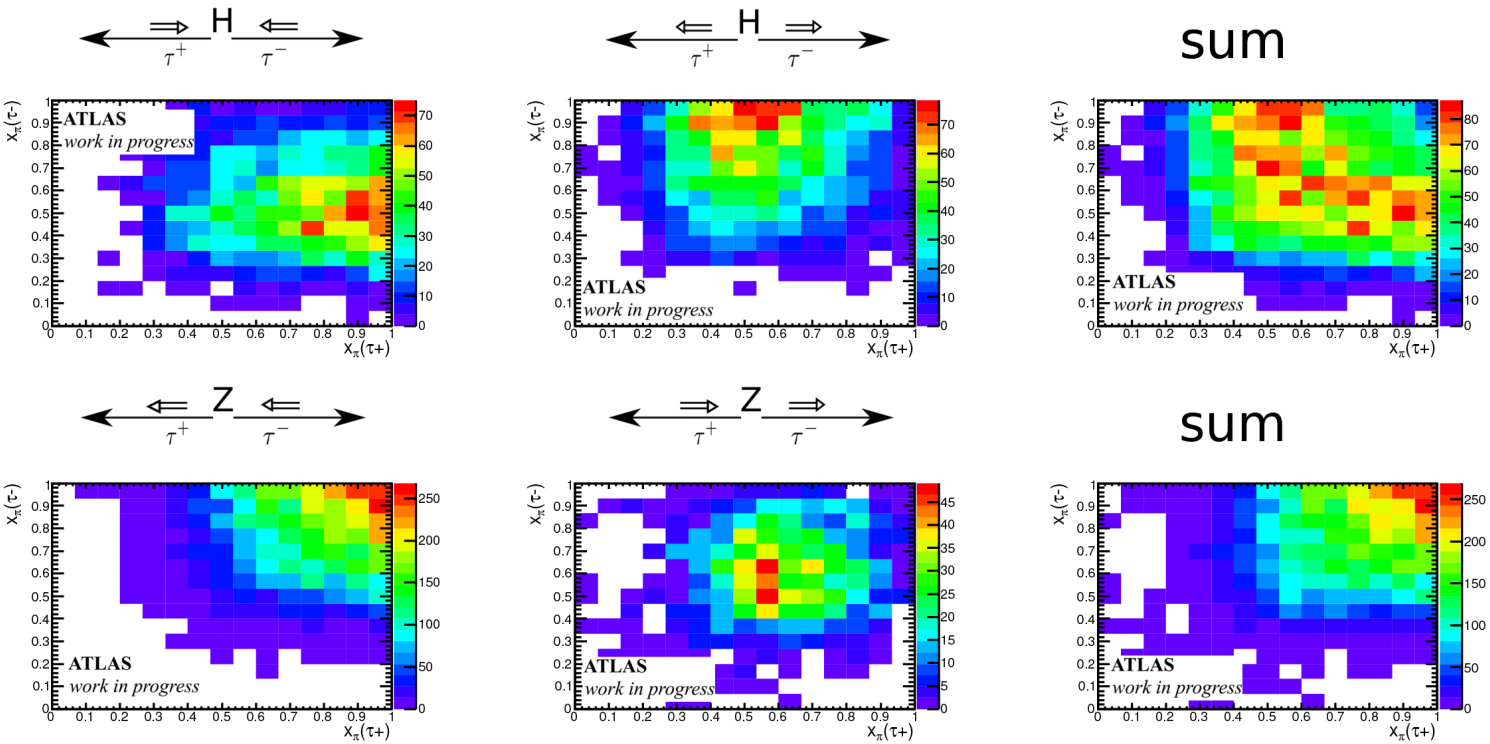
truth
reco π^0 (cluster based), true ν_τ & track
reco ν_τ (MMC), true π^0 & track
reco track ($\pi^\pm$), true π^0 & ν_τ
all components reconstructed
(all decay modes: 1 track)

- combination of reconstruction effects leads to contortions not seen in single particle reconstruction
- not only shape deviations but event-by-event deviations are important for H/Z distinction (Backup)

Helicity/Polarization Correlation between the Tau Leptons on Truth Level

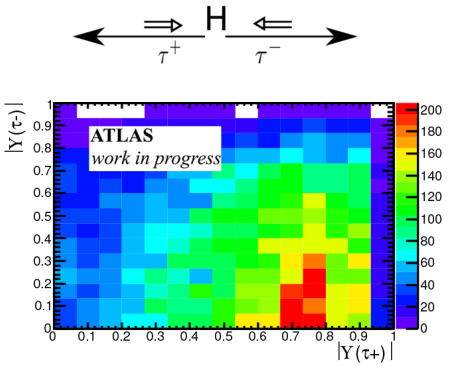
- Fraction Of Visible Energy
  $\longrightarrow \pi\pi$-Channel
- Charged Energy Asymmetry
  $\longrightarrow \rho\rho$-Channel
- Polarimetric Vector

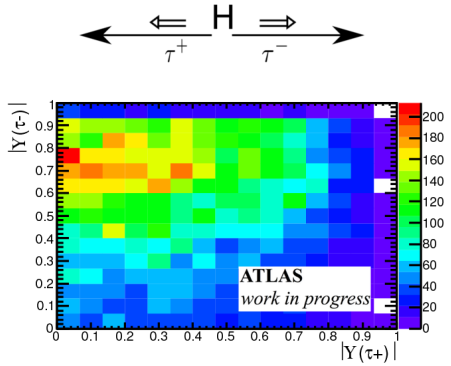
Correlation of Xs for H/Z on Truth Level ($\pi\pi$-Channel)



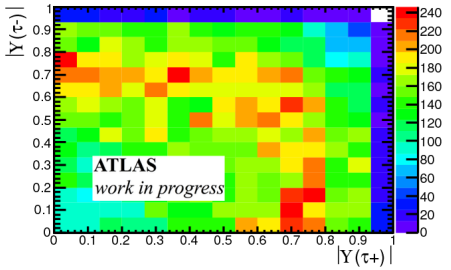
x axis: x of τ^+, y axis: x of τ^-

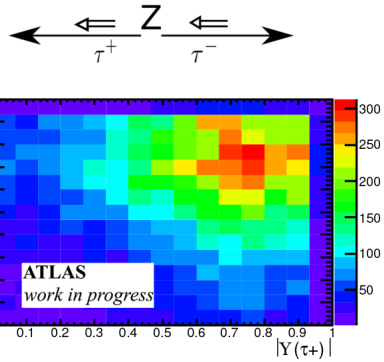
Correlation of Υs for H/Z on Truth Level ($\rho\rho$-Channel)

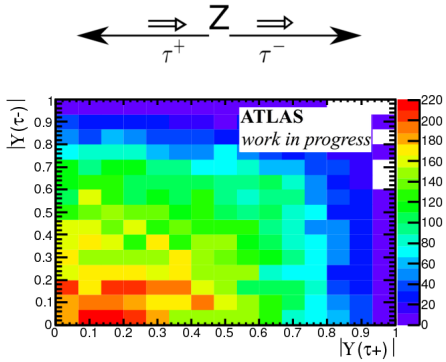




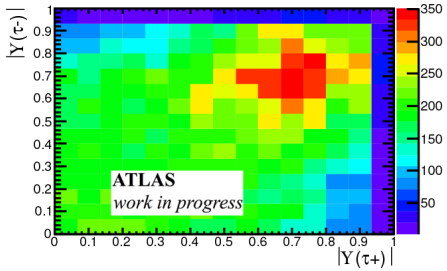
sum





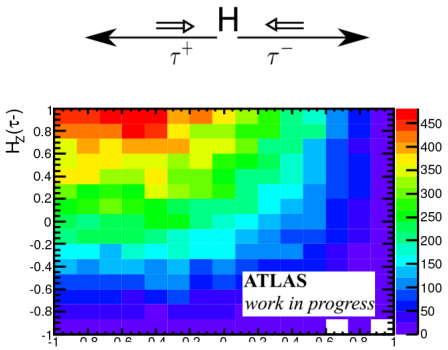


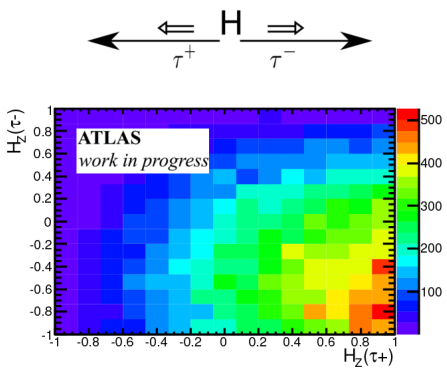
sum



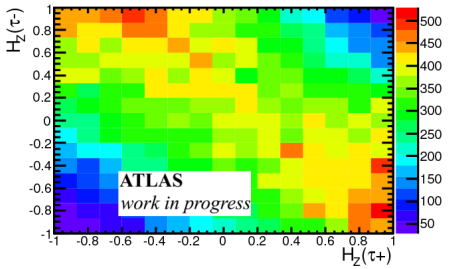
x axis: Υ of τ^+, y axis: Υ of τ^-

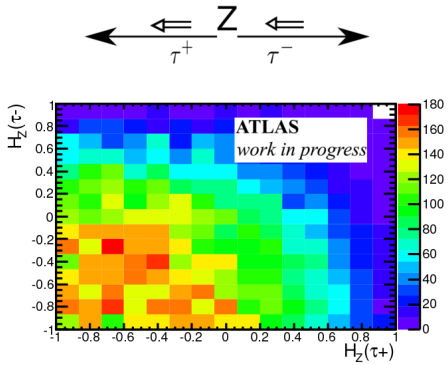
Correlation of Polarimetric Vectors for H/Z on Truth Level (lephad-Channel)

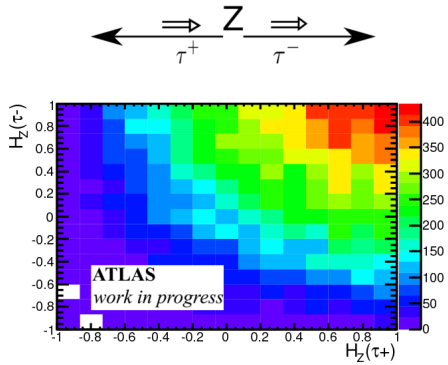




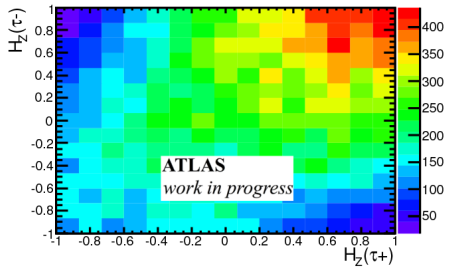
sum







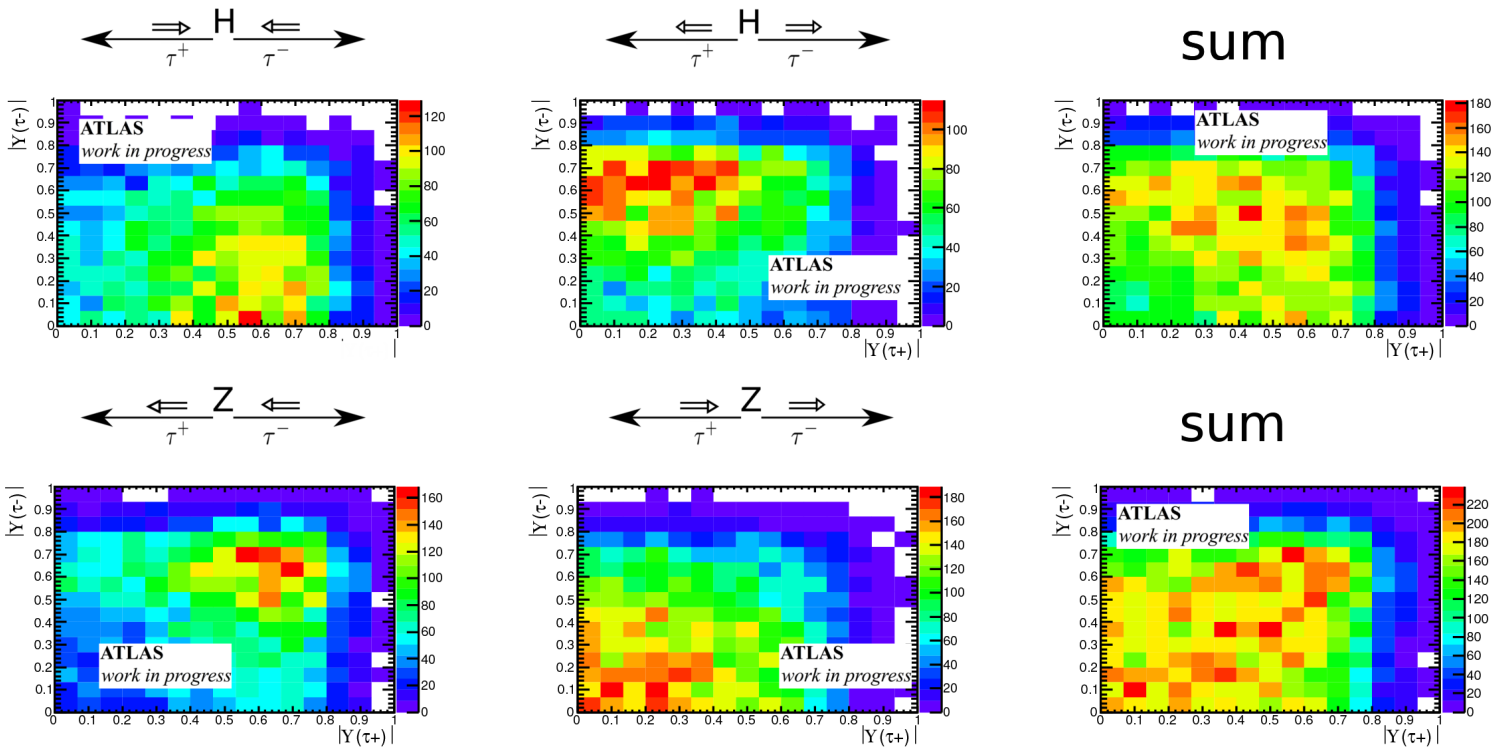
sum



x axis: H_z of τ^+, y axis: H_z of τ^-

Correlation of Υs for H/Z on Reconstruction Level ($\rho\rho$-Channel)

using cluster based π^0 reconstruction algorithm



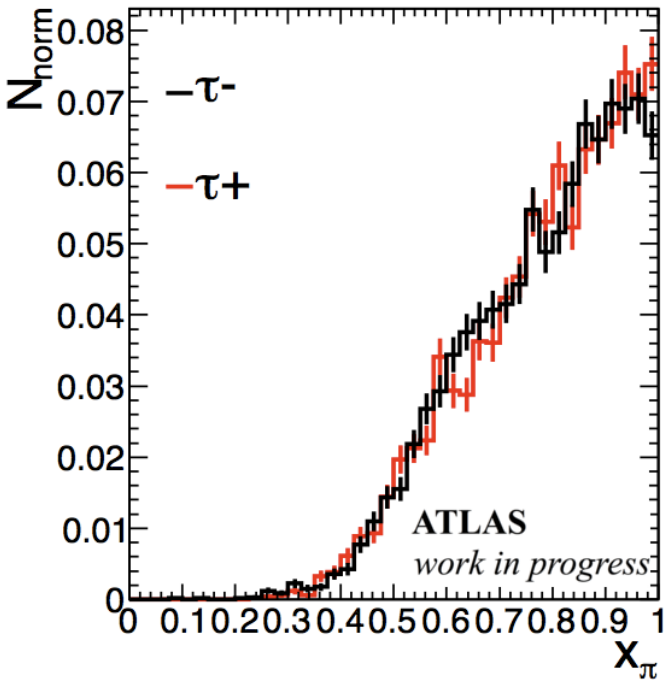
x axis: Υ of τ^+, y axis: Υ of τ^-

Conclusion / Outlook

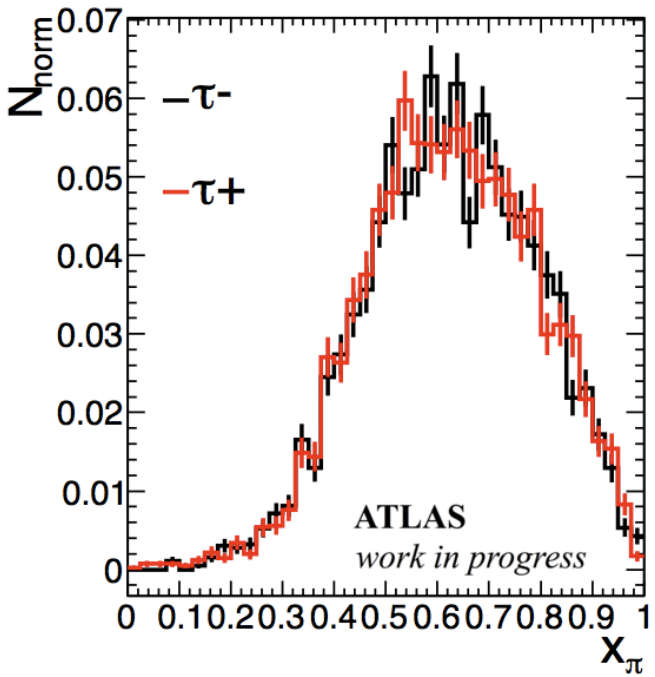
- TauSpinner Tool
  - can be used to get polarimetric vectors
    $\Rightarrow$ estimator for spin direction
- studied most promising polarization variables
  - fraction of energy x for $\pi^{\pm}$-channel
    BUT reconstruction with MMC or Col. Approx. very difficult
    only choice for reconstruction in the lepton-channel
  - charged energy asymmetry Υ for ρ-channel
    also looks more promising than x after reconstruction (several methods available)
    improved π_0 reconstruction (e.g. cell based - Benedict Winter (Bonn), pantau - Christian Limbach (Bonn))

Backup

x_π after preselection, Z sample



(c) τ^- with positive helicity, τ^+ with negative helicity

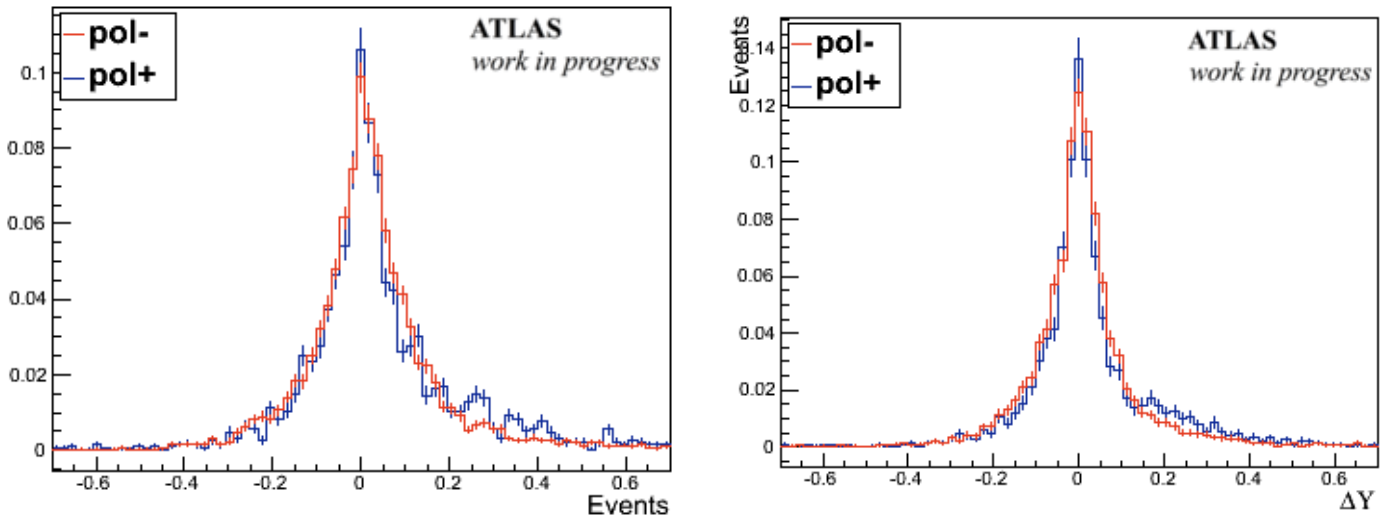


(d) τ^- with negative helicity, τ^+ with positive helicity

Figure: Fraction of visible energy for $\tau \longrightarrow \nu_\tau \pi$ decays

$\Rightarrow$ preselection deforms distributions of τ^- with positive helicity / τ^+ with negative helicity due to low $\pi^\pm$ energy

Υ Reconstruction Difference, Z sample



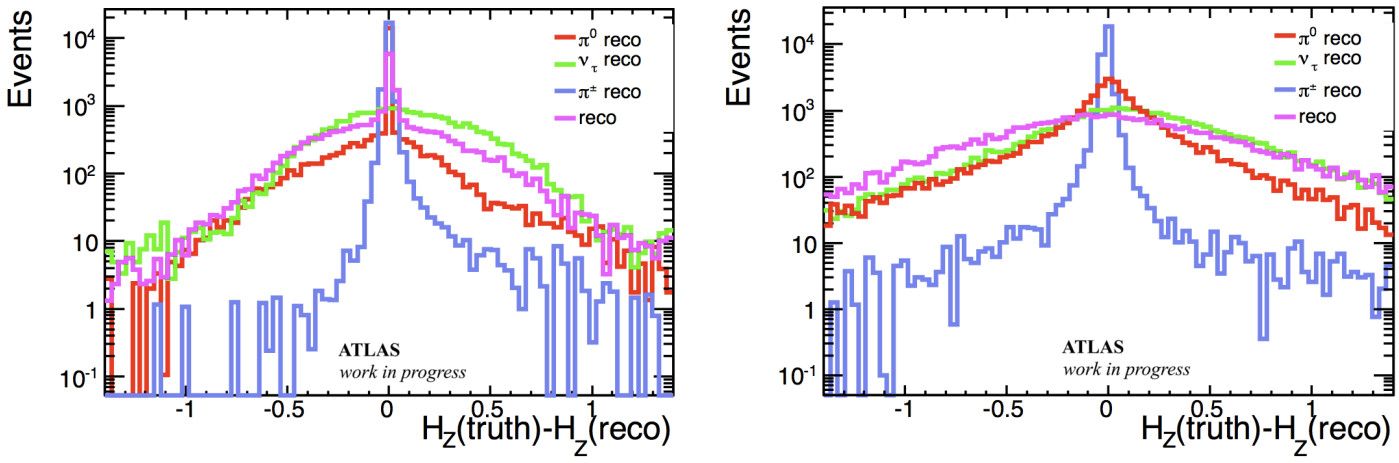
(a) Cluster Based

(b) Cell Based

Figure: Differences $\Upsilon_{truth} - \Upsilon_{reco}$ for reconstructed rho decays

- only small differences between Υ_{truth} and Υ_{reco}
- Cell Based better than Cluster Based

H_Z Reconstruction Difference, Z sample



(a) reconstructed single pion

(b) reconstructed rho

Figure: Differences $H_{Z,\,\mathrm{truth}} - H_{Z,\,\mathrm{reco}}$ for reconstructed decay modes

- larger reconstruction differences than for Υ
- main differences due to neutrino reconstruction
- single pion channel looks slightly better