Prospects of Measuring the Tau Polarization in Z'→ττ Events

Z. Czyczula, M. Dam

Introduction

- If a Z' is found at the LHC, a theoretical interpretation requires a measurement of its properties.
- First to be measure are xsect, BR to leptons, width, forward-backward asymmetry (A_{FB}).
- Additional info on its couplings from polarization P_τ
- Possible spin configurations:

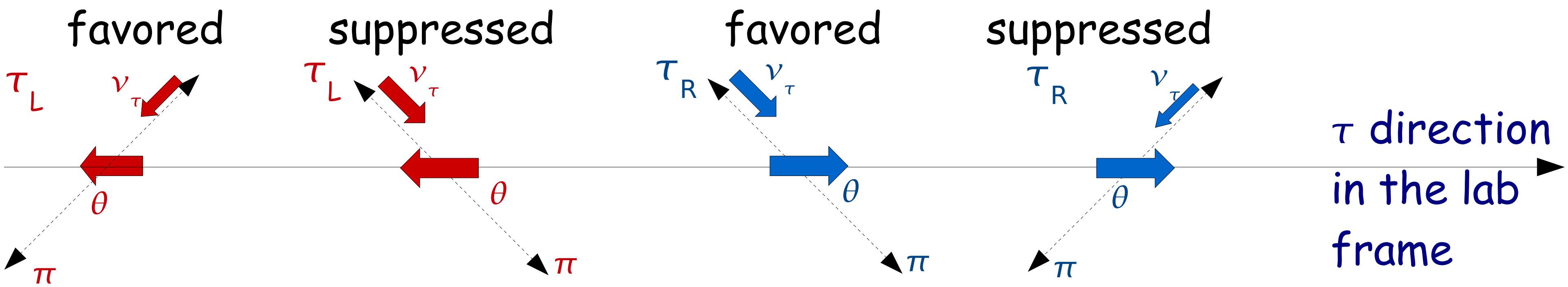
$$Z' \to \tau_L^- \tau_R^+ \text{ or } Z' \to \tau_R^- \tau_L^+$$

- Cross section: σ_L and σ_R
- Polarization: $P_\tau = (\sigma_R - \sigma_L)/(\sigma_R + \sigma_L)$
- P_τ non-zero if Z' couplings are parity violating.
- Tau short-lived : use decay product kinematics as spin analyzers.

Mode	BR %
leptonic	35.0
$\tau \to \pi/K\ \nu$	11.9
$\tau \to \pi/K\ \pi^0\ \nu$	27.3 (via rho, K*)
$\tau \to \pi/K\ n\pi^0 \nu$	10.7 (via a1, K*)
$\tau \to 3\pi/Kn\pi^0\ \nu$	14.6 (via a1, K*)
$\tau \to 5\pi/Kn\pi^0\ \nu$	0.3
others	0.5

Polarization observables (1)

- Helicity conservation:



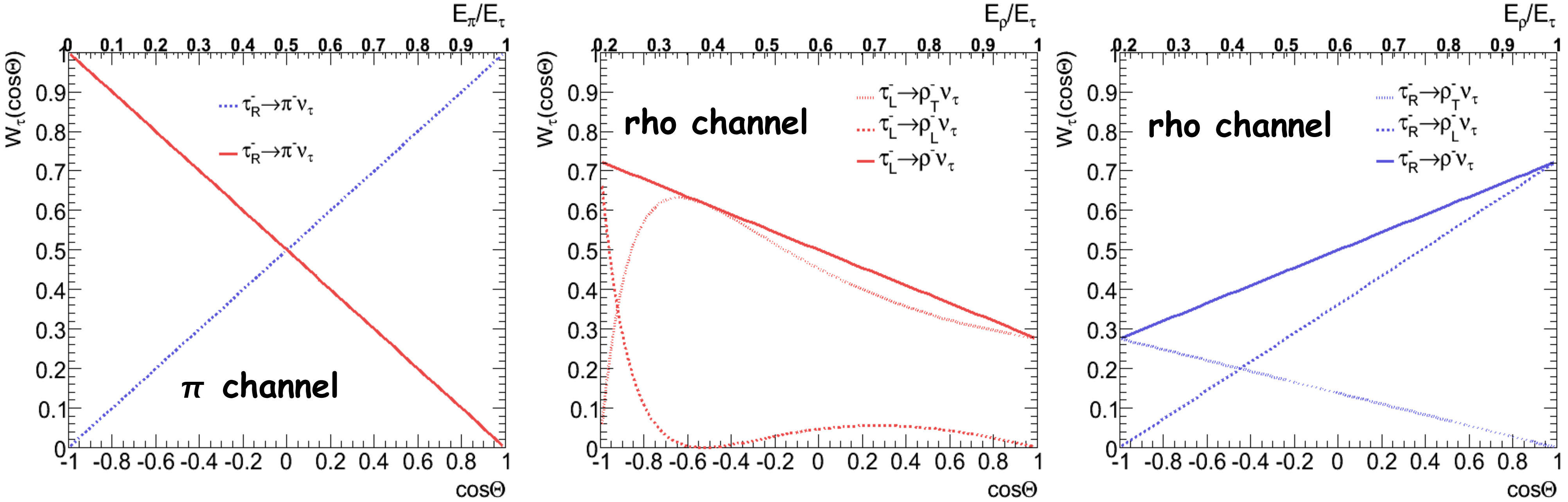
- The main observable is the angle θ
- Decay distribution in the π channel: $W(\cos\theta) \sim 1 - P_\tau \cos\theta$
- In the rho/a1 channel $W(\cos\theta)$ depends on helicity of the vector meson:
- $W(\cos\theta) \sim 1 - P\cos\theta$ - transversely (T) polarized state
- $W(\cos\theta) \sim 1 + P\cos\theta$ - longitudinally (L) polarized state
- If rho/a1 polarization states are treated inclusively sensitivity to polarization is suppressed by the factor: $\alpha = (m^2_\tau - 2m^2_\rho)/(m^2_\tau + 2m^2_\rho)$

  $\alpha = 0.46$ for the rho and $\alpha = 0.12$ for the a1 channel.

Polarization observables (2)

- Since the neutrino is not observed the angle θ cannot be reconstructed.
- In the lab frame the angle θ is related to energy fraction x carried by the hadronic system:

$$\cos\theta = (2x - 1 - m^2_\rho/m^2_\tau)/(1 - m^2_\rho/m^2_\tau)$$



Strong enhancement of hard L rho for R taus and soft T rho for L taus.

Polarization observables (3)

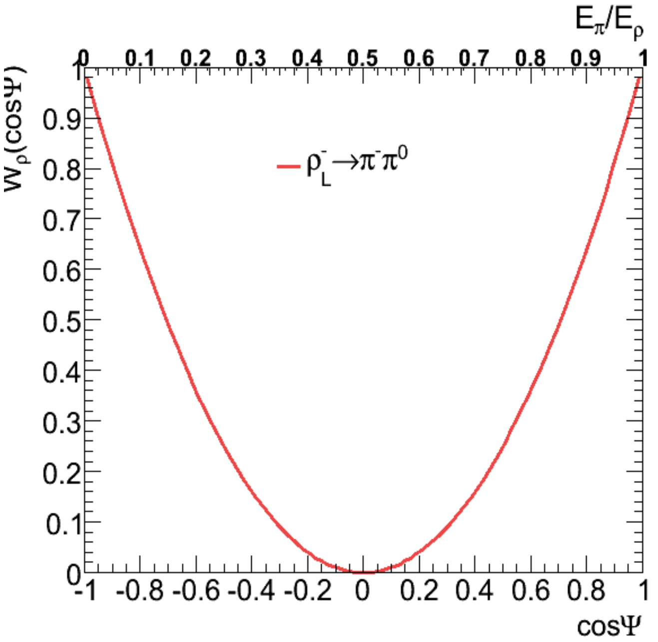
- Most of lost sensitivity can be regained if one uses information of helicity of intermediate resonance.
- Define Ψ as the angle between the charge pion and the rho initial direction.

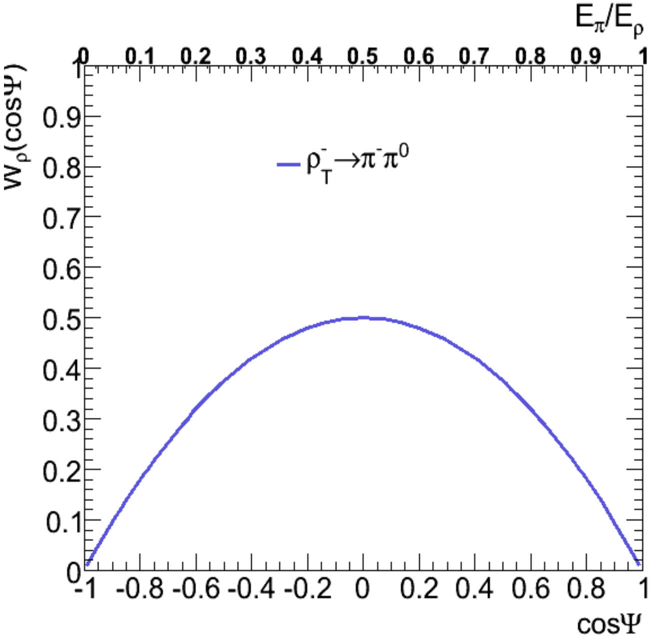
  In terms of the laboratory observables:

  $\cos\Psi = \{m_\rho / \mathrm{sqrt}(m^2_\rho - 4m^2_\pi)\}(E_{(\pi-)} - E_{(\pi 0)})/(|\mathbf{p}_{(\pi-)} - \mathbf{p}_{(\pi 0)}|)$

  which is ~ the energy asymmetry of the two pions.

- Due to conservation of total angular momentum longitudinally/transversely polarized rho favor non-equal /equal energy splitting between the two pions





MC samples (14 TeV)

Tauola tag: Tauola_i-00-01-49
Available in 14.5.1.1, 15.0.0
Thanks to V. Savinov,
and Azuelos G.

- **Generator Level** (Pythia, 200 kEvts)

· Z'(600 GeV) $\rightarrow \tau_L^- \tau_R^+ \rightarrow$hh (the τ_L sample)

· Z'(600 GeV) $\rightarrow \tau_R^- \tau_L^+ \rightarrow$hh (the τ_R sample)

Initial state coupling of Z' to quarks as in SSM model (same as to Z).

- **Full Simulation** (sim+digi with 14.2.23.1, reco with 14.2.25.2)

· the τ_L sample: 84853 Evts

· the τ_R sample: 83410 Evts

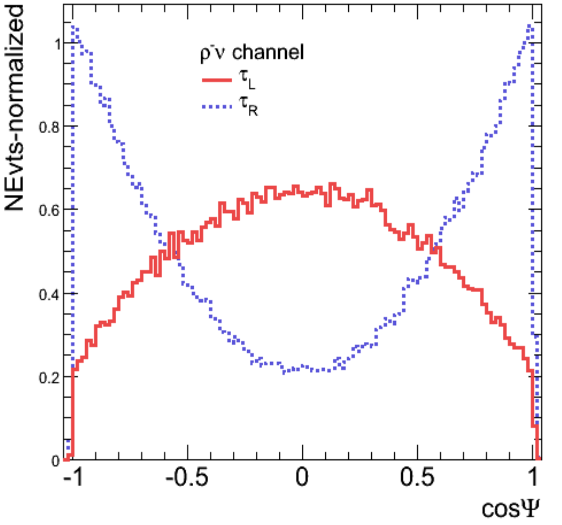
- Technical details, validation plots and sample location available at:
  https://twiki.cern.ch/twiki/bin/view/AtlasProtected/ZprimeTauTau

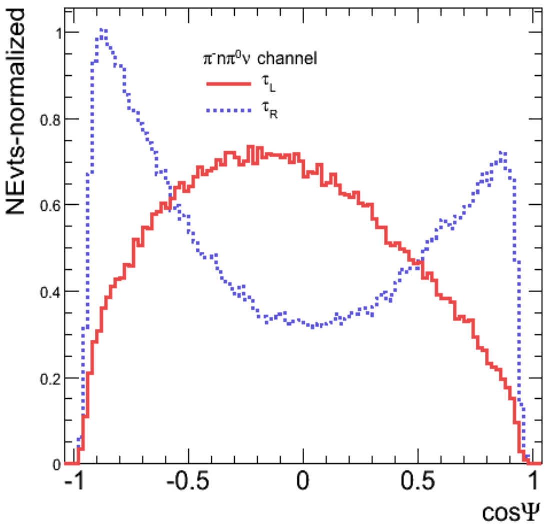
Observables at the LHC (1)

- At the high energies taus become very collimated -> experimental determination of number of final state π^0 becomes very difficult -> all tau decay modes which include π^0 are treated inclusively.
- The cos θ variable depends on the energy fraction x hence requires knowledge of the energy of decaying tau which is accessible only via collinear approximation.
- The collinear approximation reaches its limit when the two taus are back-to-back -> for heavy Z' its acceptance is only ~ 10 % -> considerable loss of statistics.
- The cosΨ variable depends on the energy sharing between the final state pions and does not rely on reco of the tau rest frame. Hence the use of collinear approximation can be avoided.

Observables at the LHC (2)

Sensitivity	$\cos\theta$	$\cos\Psi$	$\cos\theta$ & $\cos\Psi$
π^-	0.57	-	-
ρ^-	0.26	0.37	0.48
$\pi^- n\pi^0$	0.21	0.31	0.39
lep	0.22		-





- Experimentally measurement of mass of the hadronic state (rho/a1) is difficult -> **Use** instead:

$$\Upsilon = (E_{(\pi -)} - E_{(\pi 0)})/(E_{(\pi -)} + E_{(\pi 0)})$$

- 4-vector study:
  Sensitivity of Υ is identical to that of $\cos\psi$

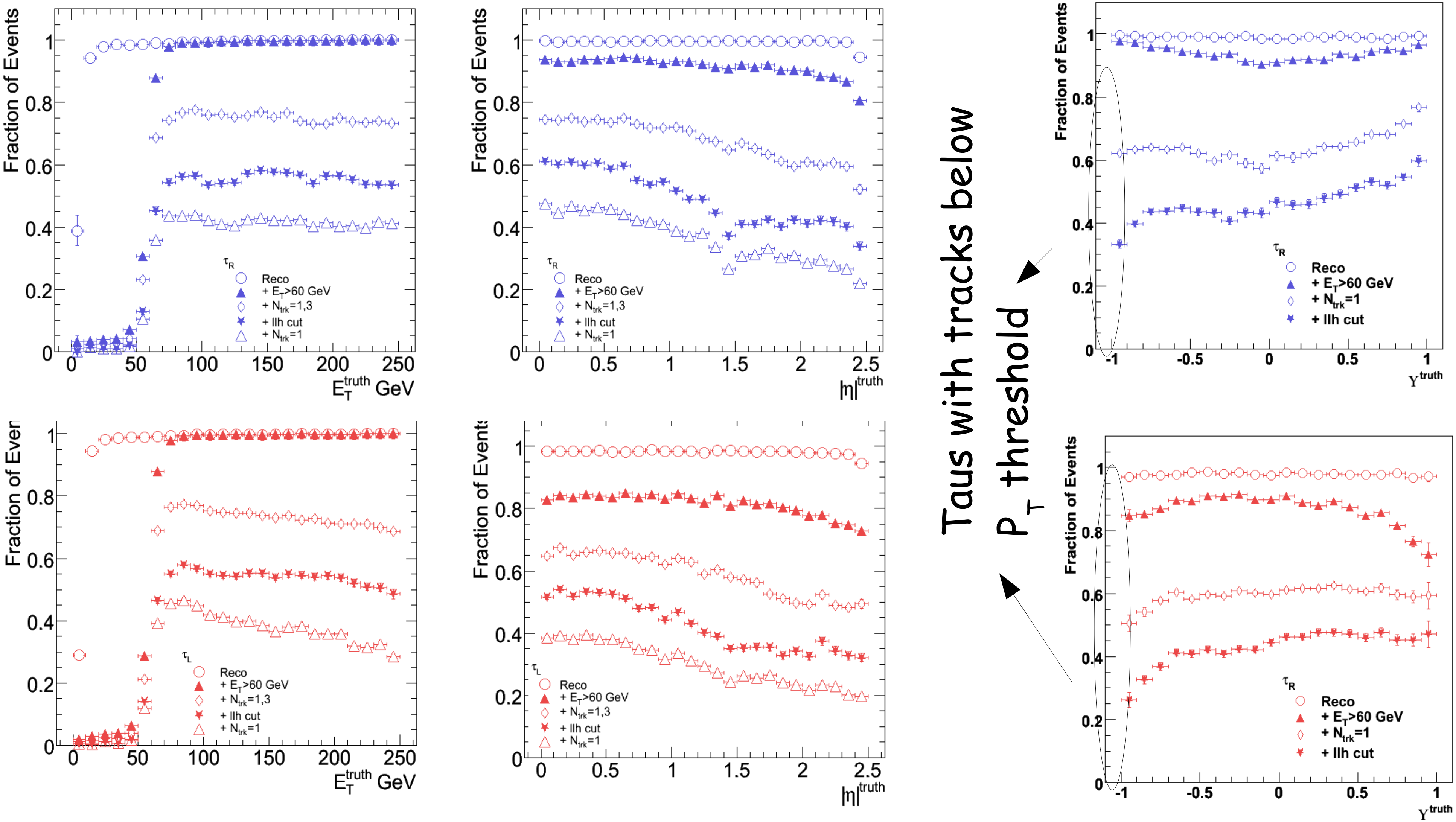
Tau Selection (1)

- Tau ID (ATL-INT-2008-038): calo-seed tauRec, E_T >60 GeV, Ntrk=1,3, E_T dependent llh cut

Efficiency %	τ_L			τ_R		
Channel	π^-	ρ^-	$\pi^-(2,3)\pi^0$	π^-	ρ^-	$\pi^-(2,3)\pi^0$
Reconstruction	92.6	99.4	99.7	99.2	99.5	99.5
E_T >60 GeV	54.1	83.3	94.6	88.9	90.6	95.3
Ntrk=1,3	47.0	64.1	66.8	78.7	70.2	67.4
llh cut	36.5	46.3	44.8	62.2	50.4	45.4

- Efficiency given wrt true taus in a given channel.
- Lower efficiency of L taus due to softer nature of visible decay products (especially in the pion channel)

Tau Selection (2)

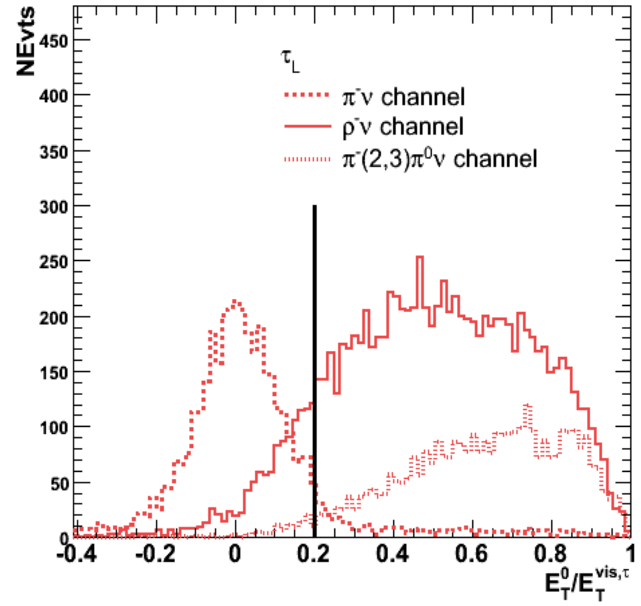


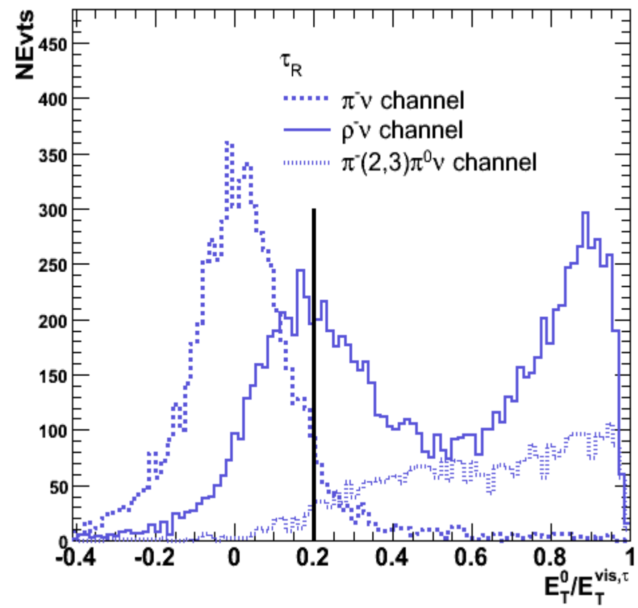
Selection of decays with neutrals

- Energy deposited by π^0 : $E_T^0 = E_T - p^{trk}_T$
- To select $\pi^- n\pi^0$ decays: TauID + $E_T^0/E_T > 0.2$

	τ_L			τ_R		
Channel	π	ρ	$\pi^-(2,3)\pi^0$	π	ρ	$\pi^-(2,3)\pi^0$
Ntrk=1	36.3	43.4	40.1	61.8	47.3	40.7
E_T^0/E_T	3.6	38.3	38.7	5.9	34.8	38.3

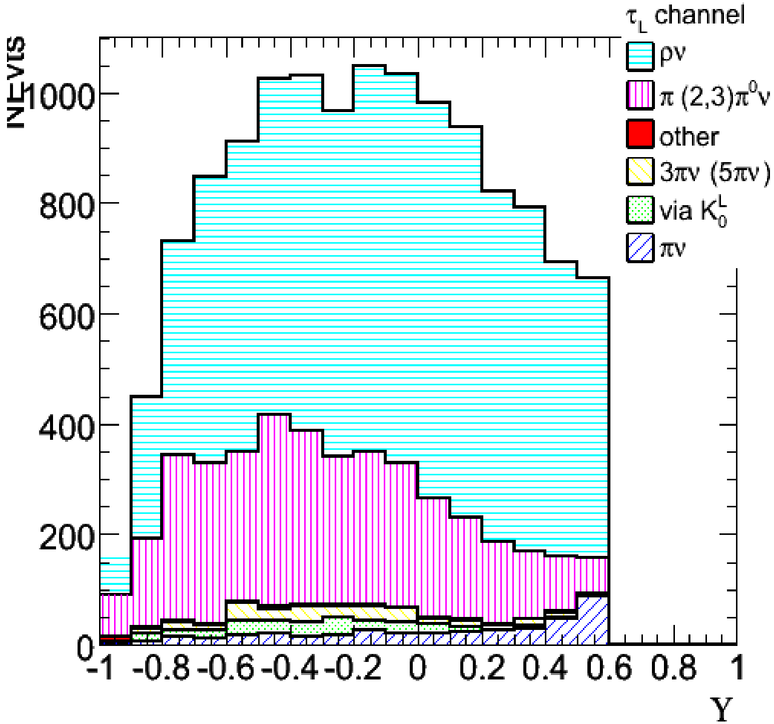
- In ρ channel the E_T^0/E_T reflects influence of tau polarization on tau kinematics.
- τ_R with soft π^0 tend to fake single π case ->lower efficiency for ρ and $\pi^-(2,3)\pi^0$

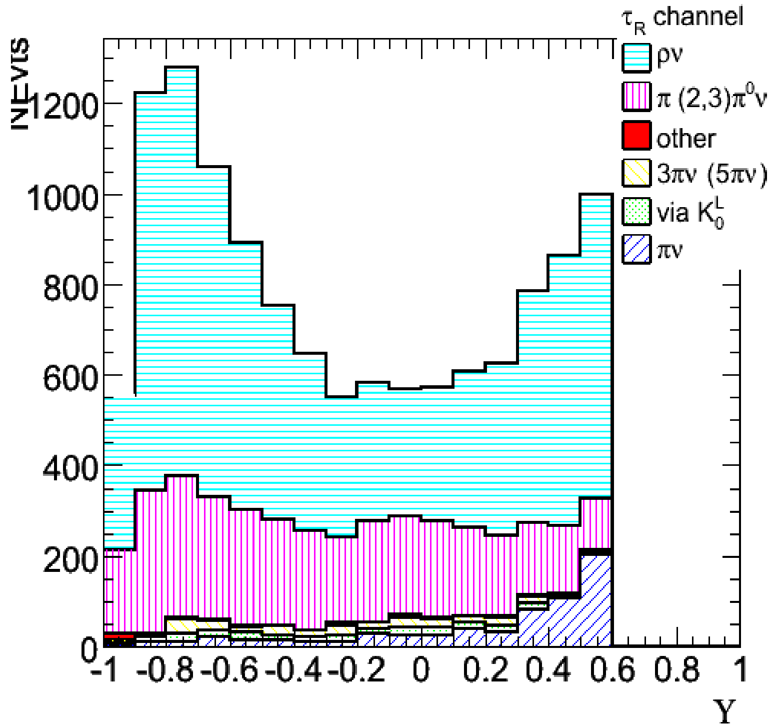




Υ distributions

Experimentally: $\Upsilon = (2p^{trk}_T - E_T)/E_T$

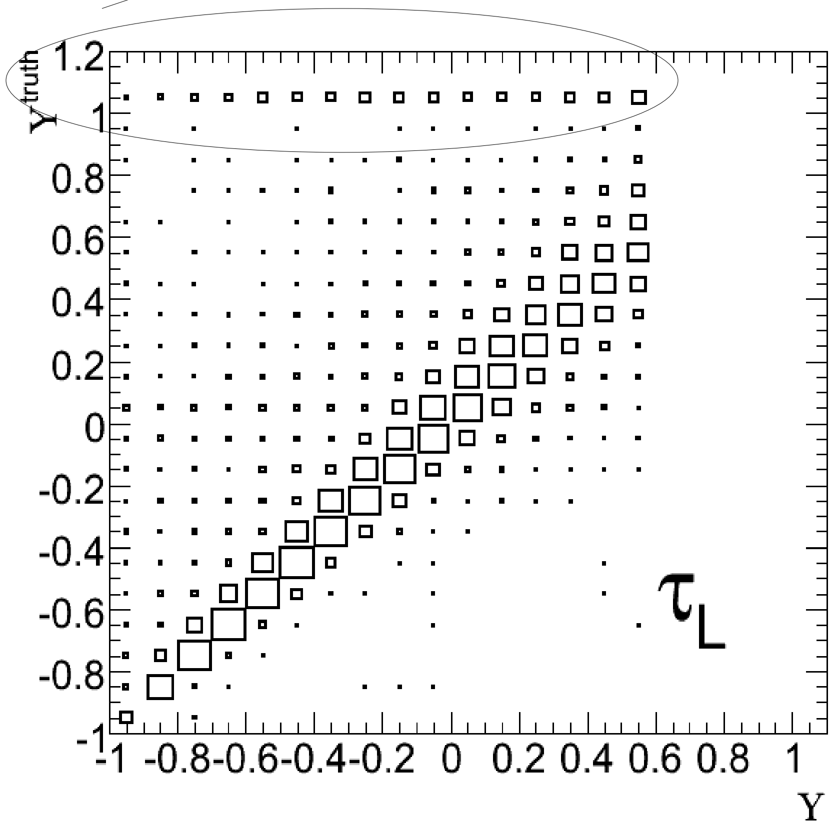


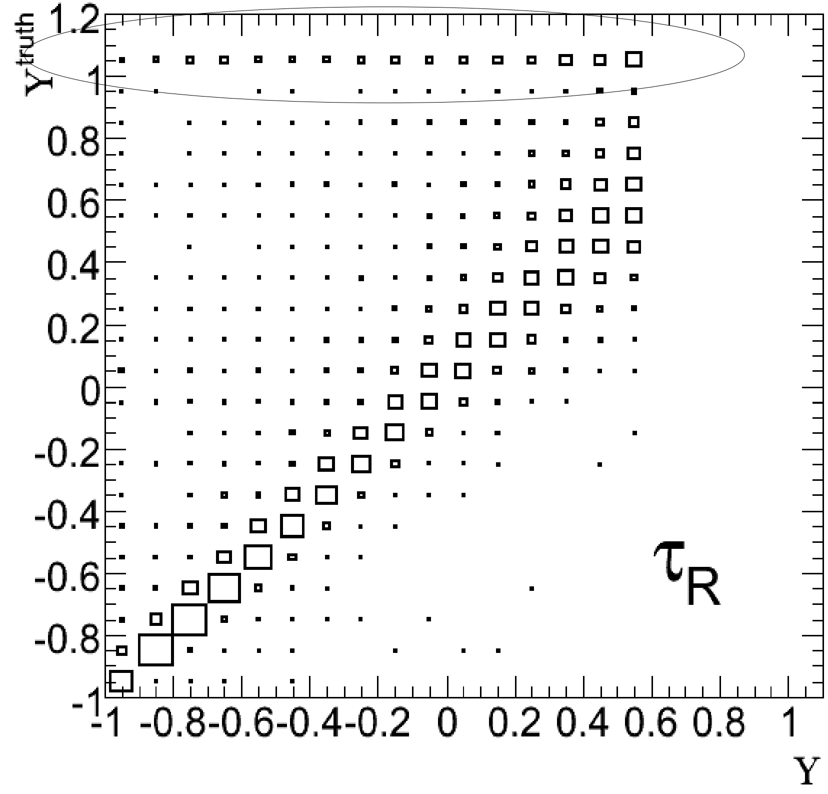


$E_T^0/E_T > 0.2$ correspond to $\Upsilon < 0.6$ by definition

Υ resolution

Bkg from the pion channel

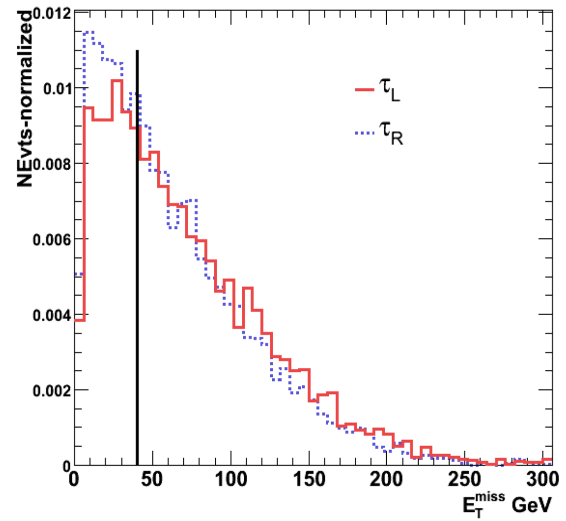


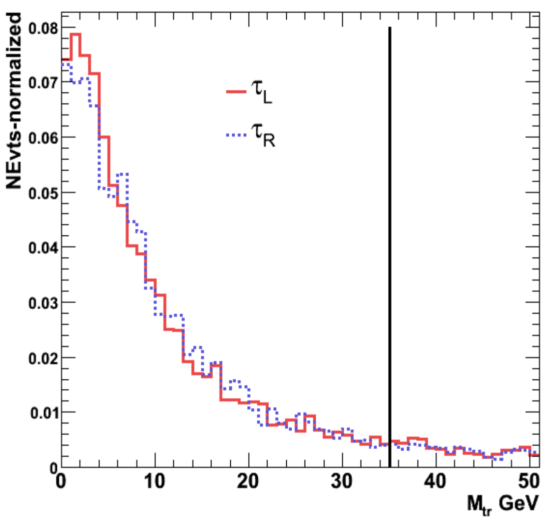


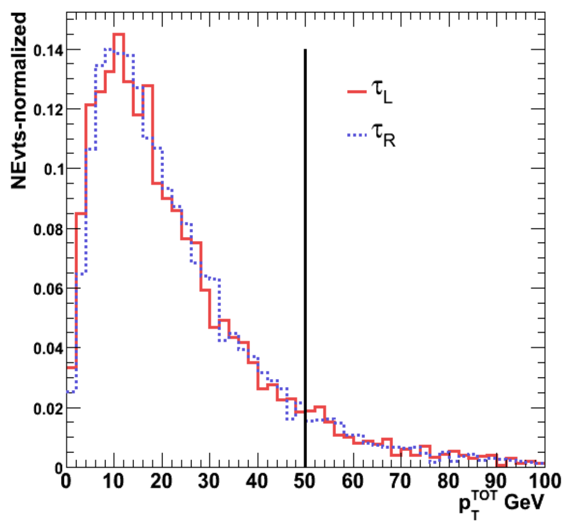
Full Event selection (1)

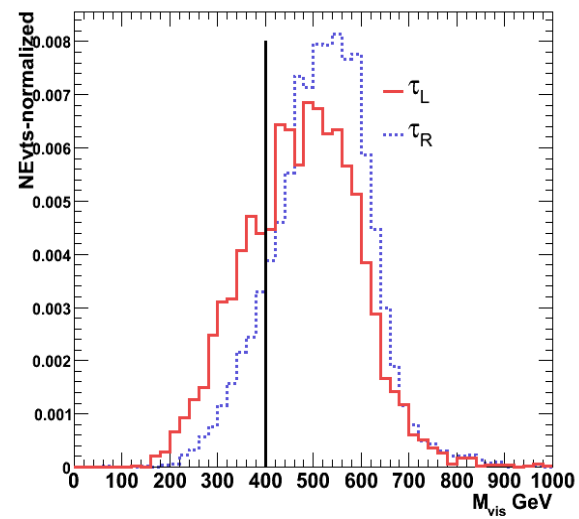
Event selection as in ATL-INT-2008-038

- 2 ID taus of opposite charge
  + MET > 40 GeV (against DY, QCD)
  + Mtr <35 GeV (against W+jets)
  + PtTOT<50 GeV (aganst ttbar, QCD)
  + Mvis >400 GeV
- S:B ~ 3:1 (no collinear approximation!)

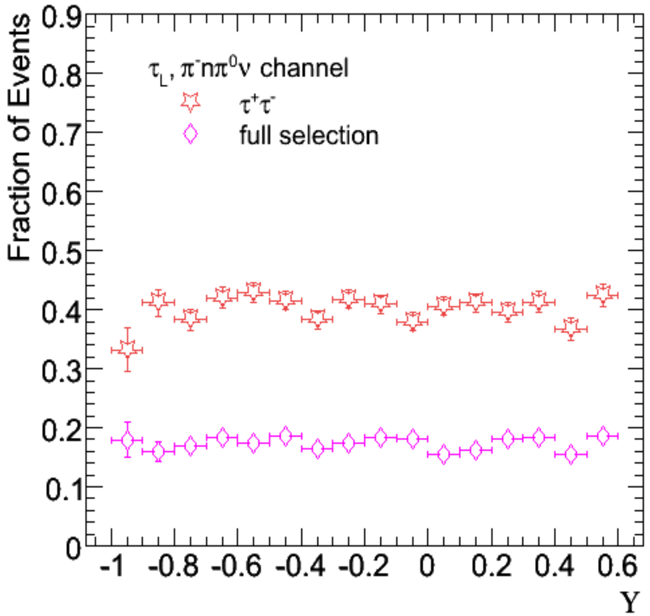


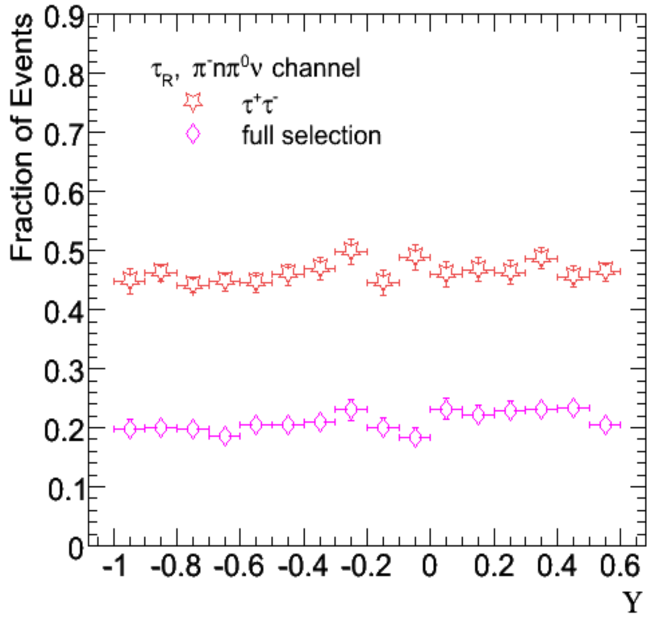






Full Event selection (2)





In the plots, true $\pi^- n\pi^0$ channel no $\pi^- n\pi^0$ decays selection

Due to correlation of spins the acceptance for event selection is different in a sample of τ_L and τ_R

TauID + $\pi^- n\pi^0$ decays selection +

Channel	π	ρ	$\pi^-(2,3)\pi^0$	π	ρ	$\pi^-(2,3)\pi^0$
2Tau	1.4	15.3	15.9	2.8	15.9	17.8
full selection	0.6	6.5	7.2	1.4	7.3	7.9

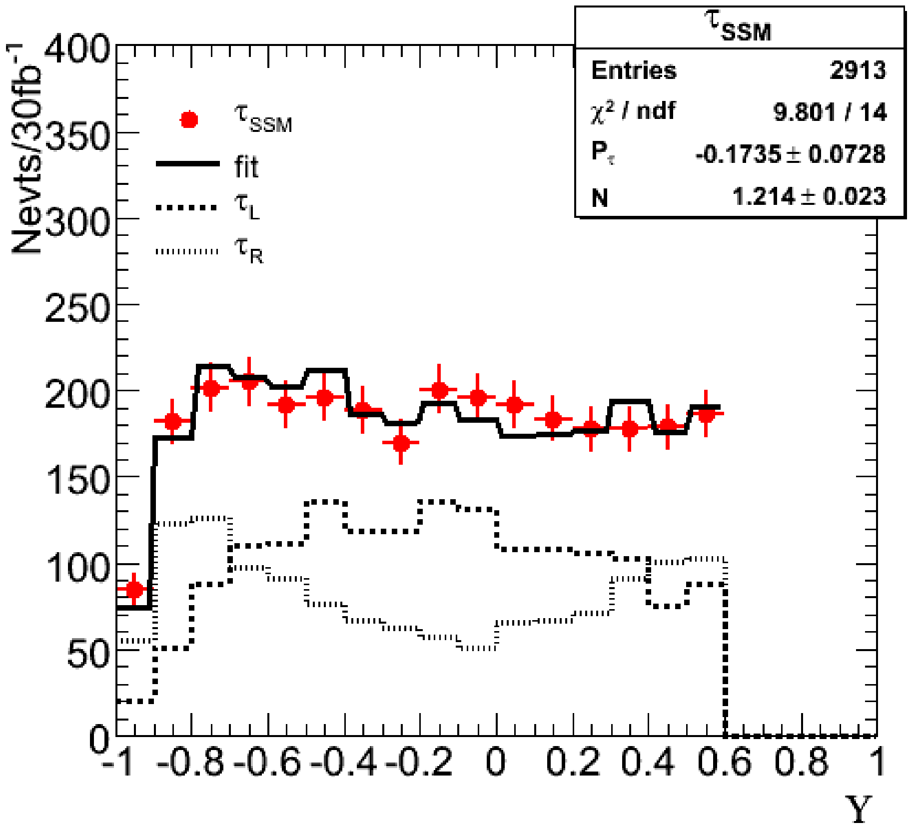
Extraction of Tau Polarization (1)

- 38700 kEvts (before selection) of τ_{SSM} events were used to emulate "data" (τ_{SSM}:the τ_L and τ_R samples were mixed assuming true polarization -0.15).

- 32 kEvts (before selection) from τ_L and τ_R samples were used for modeling of the "data".

- A binned log likelihood relating the simulated and "observed" Υ distributions (after full selection) is maximized wrt to P_τ .

Extraction of Tau Polarization (2)



Polarization can be well determined from the fit

P_τ = -0.174± 0.073

(P_τ true -0.15)

with good χ^2 value.

Amount of data correspond to 30 fb-1 of data.

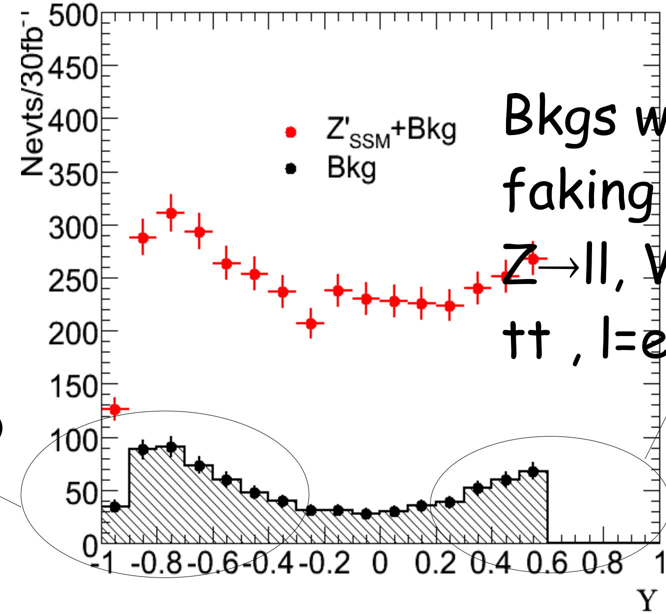
Systematic Uncertainty

- Dominant systematic uncertainty comes from mis-modeling of Υ distributions in the Monte Carlo as compared to the data.
- Consider systematic from τ energy (calorimeter) scale $\pm$ 5% and from τ energy resolution given by an extra smearing σ(E)=0.45 sqrt(E)
- Variation of τ energy scale and resolution results in different total acceptance as well as vary contamination of the pion background.

Source	tau scale +5%	tau scale -5 %	tau resolution
Systematic	0.071	-0.023	-0.031

External Background

- MC samples has not been produced in enough large numbers to to study the shape of the backgrounds (QCD and DY).
- Assume external backgrounds to be ~ R(Υ)
- Add external background with 3:1 , S:B ratio (ATL-INT-2008-038)
  Rather conservative since we concentrate only on 1P events and these backgrounds were evaluated inclusively for 1P and 3P.



QCD

Bkgs with lep faking tau, as Z→ll, W→lnu, tt , l=e,μ

- Bkg mis-modeling by ± 10 % in the MC as compare to "data" results in shift in polarization by ± 0.049

Total uncertainty

- **Statistical uncertainty**

  From the fit we get $\pm$ 0.07

- **Systematic uncertainty**

  Each of individual systematic error does not exceed statistical uncertainty likely that total systematics can be controlled to precision similar to statistical.

- **Total**

  A total error on the measurement ~ 0.10 would constitute an interesting measurement

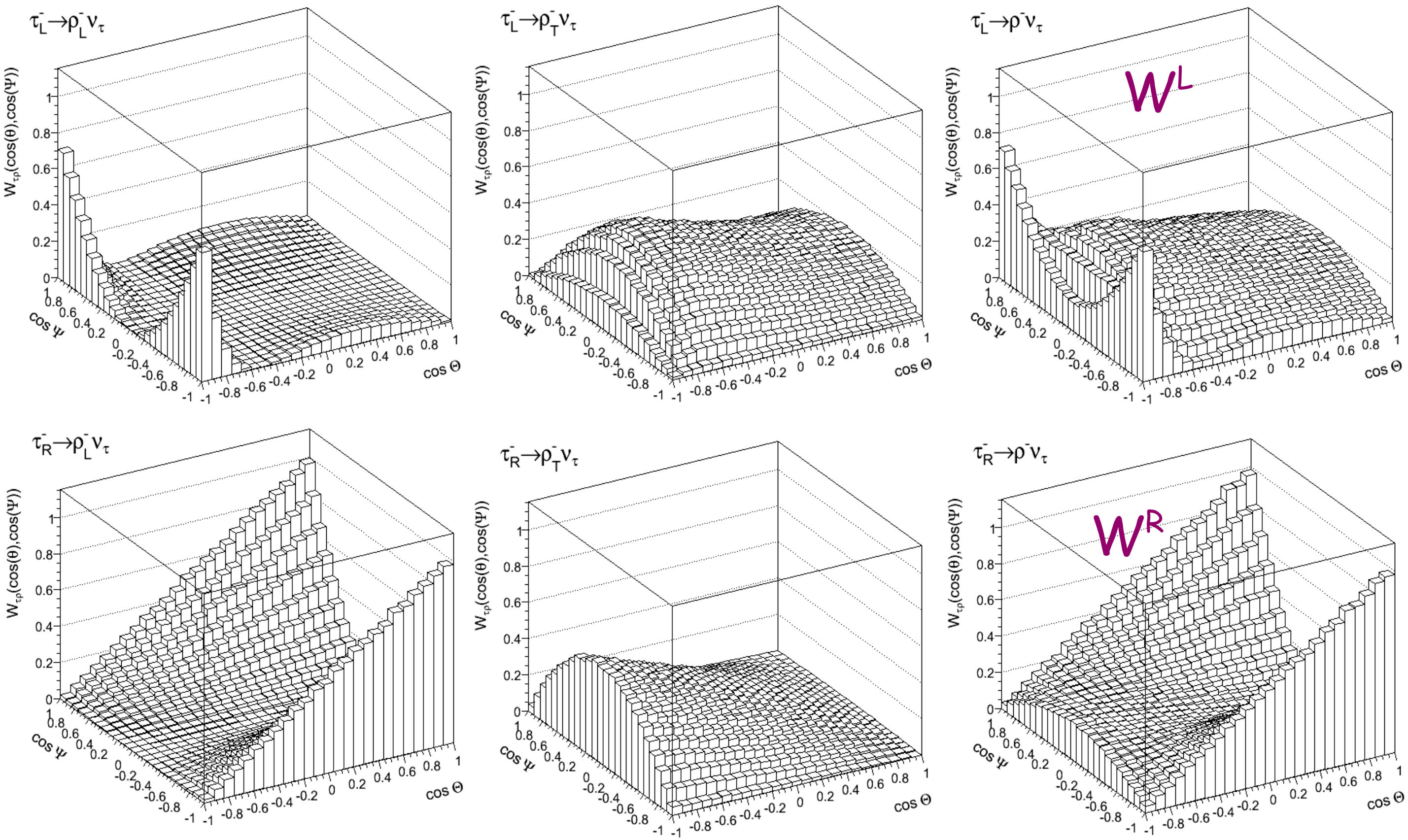
Summary and conclusion

- Assuming 30 fb^{-1} of data and SSM xsect tau polarization can be determined with ~ 0.1 uncertainty in the sample of taus before collinear approximation.
- The method does not need the tau rest frame what is especially useful for higher masses samples, where collinear approximation is very inefficient.
- Statistics can be enhanced by adding the lepton-hadron channel.
- Due to correlation of spin of the taus, one needs to assume a model for the parent resonance spin (spin-0/spin-1) to model the L and R distributions.
- We have just submitted an ATLAS note (ATL-COM-PHYS-2009-174) detailing the analysis and asked for approval.

Back-Up slides

The rho channel (2)

The general decay distribution for a spin 1 hadronic system $W = const\{(1+P)W^R + (1-P)W^L\}$



General formalism

Physics Letter B306

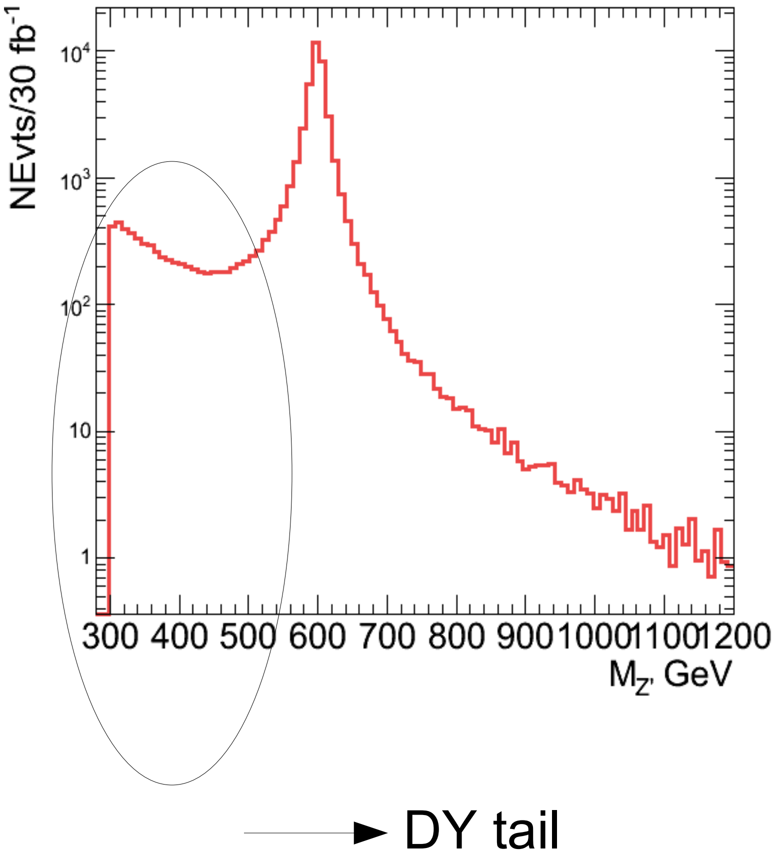
- Let ζ designate n available spin observable and p the true polarization (ζ = {cos(θ)} in the pion channel, ζ = {cos(θ), cos(ψ)} in the rho channel, ζ = {cos(θ), cos(ψ), cos(γ)} in the a1 channel)

- The decay distribution can be written as $W(\zeta) = f(\zeta) + p\, g(\zeta)$ where fand g satisfy: $\int f(z)\,dz=1$; $\int g(z)\,dz=0$; $f \geq 0$; $|g| \leq f$

- **Define $\omega = g(\zeta)/f(\zeta)$**
  It can be proven that ω carry all the information on the tau spin states which is encoded in multi dimensional distribution.

- In terms of ω we have: $\mathbf{W'(\omega) = f'(\omega)\,(1 + p\omega)}$

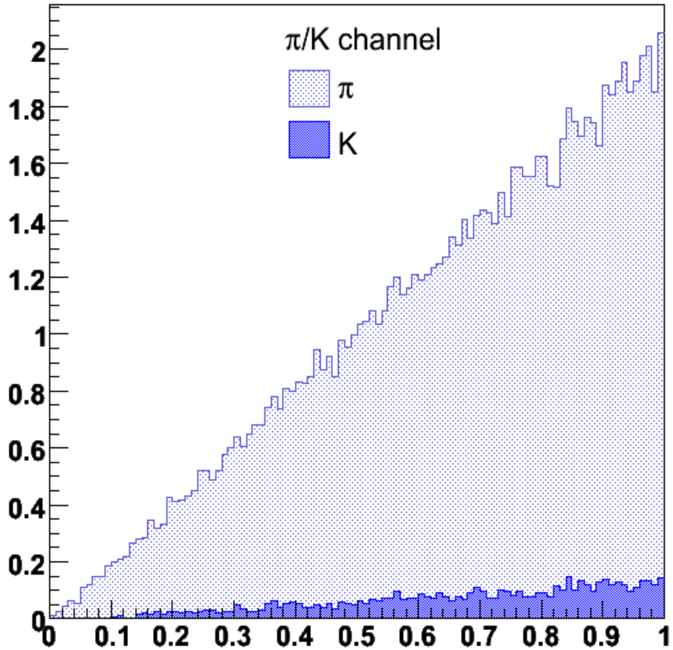
Invariant Mass

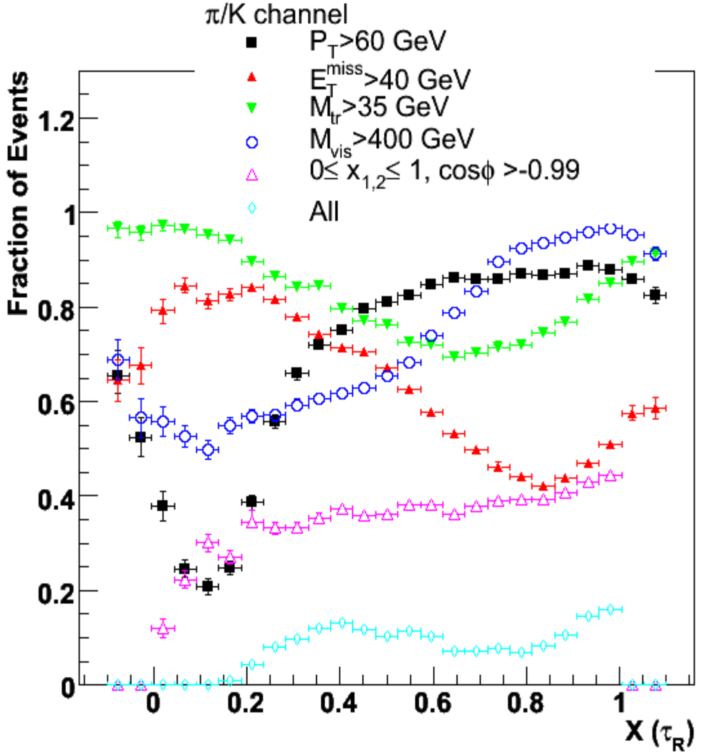


- In current version of Tauola interference with the Z is always On
- As a consequence 2% of events have opposite polarization.
- On the peak interference is negligible
  ⇒ Mass window : +/- 100 GeV.
  ~ 87% efficiency

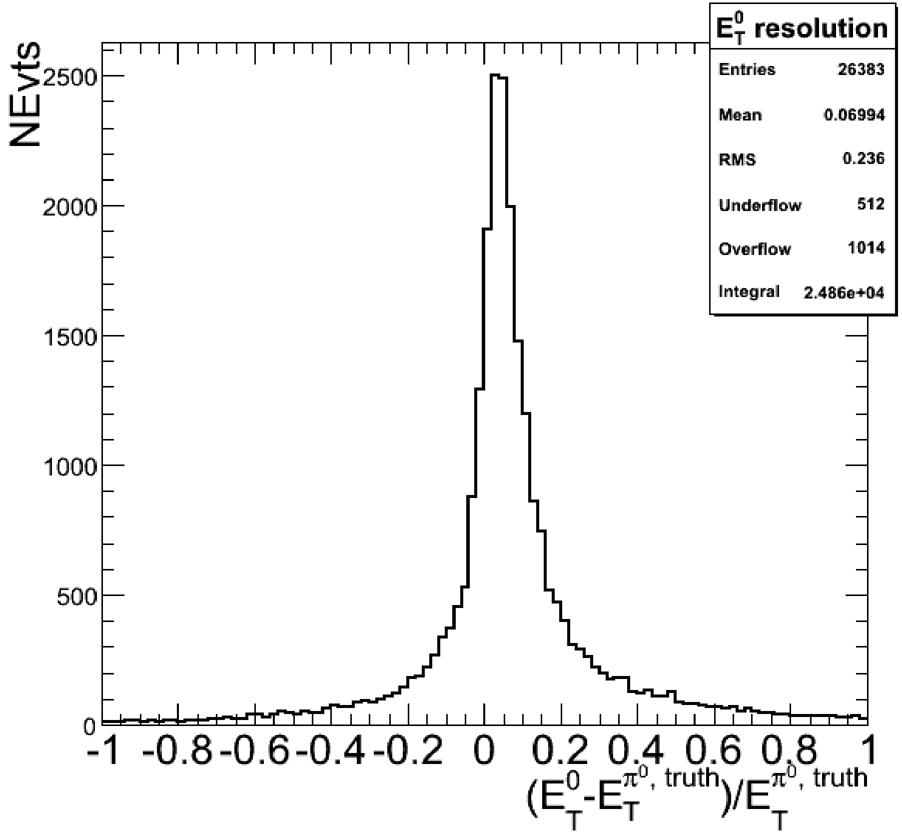
The pion channel

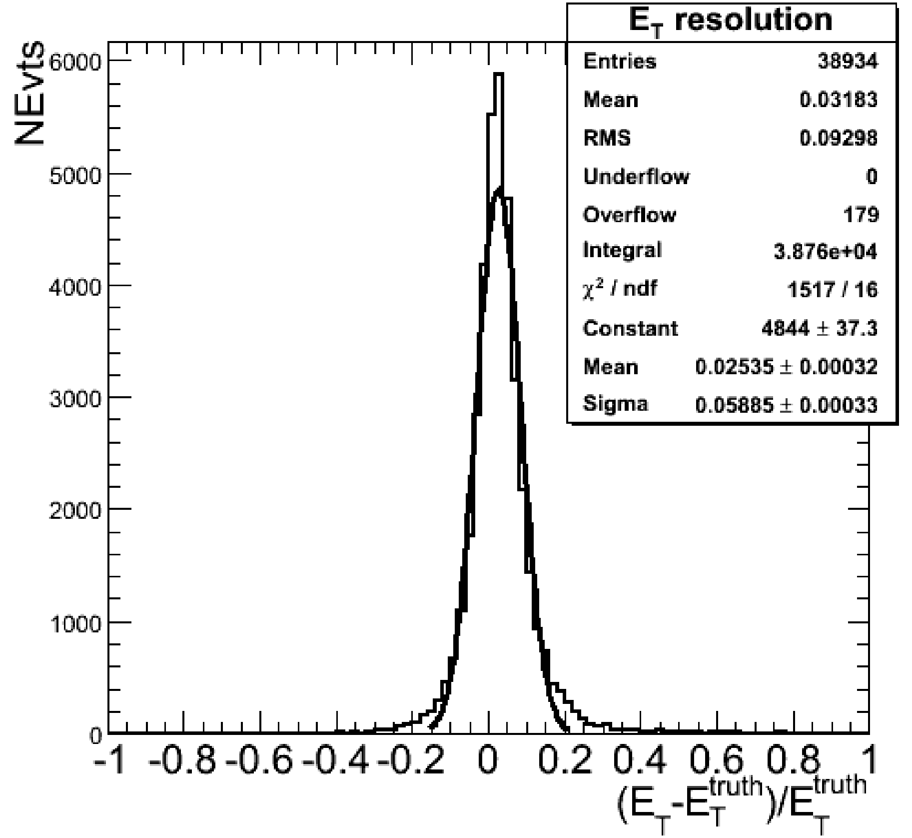
- Distribution of fraction of momentum taken by visible decay products of right handed taus and impact of event selection cuts at generator level





Neutral Energy and Tau Energy Resolution





Fit procedure

The predicted number of taus from MC in a given bin i: $M_i = C_i + W_i + B_i$;

- C_i – correctly ID taus; W_i – tau background; B_i – non-tau background;
- All P_τ dependance is carried by $C_i + W_i = S_i$

$$S_i = N\,(\,0.5\,(1 + P_\tau)\,S_i^R + 0.5\,(1 - P_\tau)\,S_i^L\,)$$

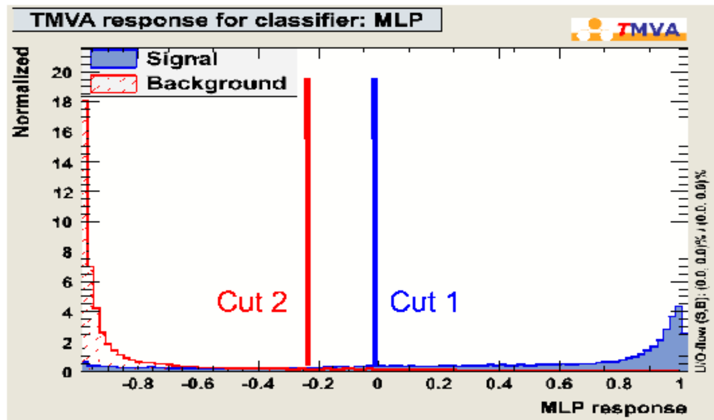
π^0 identification in tauRec

"Status of pi0 SubCluster Implementation and Validation in 14.4.x"
J.C.Dingfelder, tauWG meeting 06/11/08

Update on Performance: Efficiencies

Neural-Net discriminator for fake π^0 suppression (input: π^0 cluster shapes/moments)

$E_T^{\pi 0\ cand.} > 0.5$ GeV



Generated τ decay / # reco. π^0

Cut 1	$0\ \pi^0$	$1\ \pi^0$	$\geq 2\ \pi^0$
$\tau \to \pi\nu$	75%	22%	3%
$\tau \to \rho\nu$	11%	71%	18%
$\tau \to a_1\nu$	3%	50%	47%

Cut 2	$0\ \pi^0$	$1\ \pi^0$	$\geq 2\ \pi^0$
$\tau \to \pi\nu$	82%	17%	1%
$\tau \to \rho\nu$	16%	73%	11%
$\tau \to a_1\nu$	7%	59%	33%

- Efficiencies for π, ρ, a_1 can be adjusted by moving NN cut (see e.g. increase in a_1 efficiency for cut 1 → cut 2)