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A method to estimate the boson mass and to optimise sensitivity to helicity correlations of $\tau^+\tau^-$ final states

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Abstract: In proton-proton collisions at LHC energies, Z^0 and low mass Higgs bosons would be produced with high and predominantly longitudinal boost with respect to the beam axis. This note describes a new analysis tool devised to handle this situation in cases when such bosons decay to a pair of τ-leptons. The tool reconstructs the rest frame of the $\tau^+\tau^-$ pair by finding the boost that minimises the acollinearity between the visible τ decay products. In most cases this gives a reasonable approximation to the rest frame of the decaying boson. It is shown how the reconstructed rest frame allows for a new method of mass estimation. Also a considerable gain in sensitivity to helicity correlations is obtained by analysing the τ-jets in the reconstructed frame instead of using the laboratory momenta and energies, particularly when both τ-leptons decay hadronically.

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Contents

1 Introduction

Experimental precision data strongly suggest that the Higgs boson should be relatively light. While experimental data exclude Standard Model Higgs, H, masses below 114.4 GeV/c^2, the lightest neutral supersymmetric Higgs can have a mass as low as 92.8 GeV/c^2 [1], which is very close to the mass of the Z^0. In the mass range below 160 GeV/c^2 the $\tau^+\tau^-$ decay mode is of particular importance in searches for neutral H, as demonstrated in Tevatron searches [2]. In this mass region, H production in proton-proton (pp) collisions at LHC energies is dominated by gluon-gluon fusion [3], and a search for $gg \to H \to \tau^+\tau^-$ production at the LHC is very important, as emphasised in [4].

Together, these facts strongly motivates a careful study of the $\tau^+\tau^-$ system as produced at the LHC, and the development of analysis tools that enhance sensitivity to measure properties of H bosons. Furthermore, since Z^0 production is an irreducible background for this channel it is also important to fully understand the behaviour of $Z^0{\to}\tau^+\tau^-$ events and to look for possible contributions from other processes in a selected sample of $\tau^+\tau^-$ pairs. The sensitivity of such a study can be enhanced by exploiting the fact that the parity violating τ decays carry helicity information. Thus, τ-leptons can be used as spin analysers, and provide information that could be helpful in distinguishing the existence of a scalar H in a background of Z^0 decays.

In [5] some variables that could be used for a spin analysis are proposed. However, these are all defined in the rest frame of the decaying boson, a frame that cannot be found in any straight forward manner because of the escaping neutrinos produced in the τ-decays.

Methods have been proposed to assign the measured missing transverse energy, $\not{E}_{\mathrm{T}}$, to the neutrinos to obtain unbiased estimates of $\tau^+\tau^-$ mass [6, 7]. The resulting estimates of the neutrino momenta also gives access to an approximation of the rest frame of the decaying boson, but implications of this beyond mass estimation is not discussed. Further, these methods only work in a fraction of the events with a suitable topology whereas the technique proposed in this paper is applicable for all event topologies.

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This note presents a new simple algorithm that finds an approximation to the rest frame of the decaying boson. This will be shown to result in an improved sensitivity to spin, and to an alternative variable that could be of use for the estimation of the mass of the decaying boson.

2 Reconstructing the $\tau^+\tau^-$ rest frame

Because of their short life time τ-leptons are typically studied indirectly through their decay products. Due to the one or two neutrinos produced in the decay, the 4-momentum of the visible τ-decay products, the τ-jet, has a broad spectrum, often carrying less that half the energy of their mother τ. Therefore, reconstructing the rest frame, RF, of a particle decaying into a $\tau^+\tau^-$ system is in principle not possible.

However, for a sufficiently massive particle decaying into a $\tau^+\tau^-$ pair, the directions of the τ-jets are expected to be close to that of their mother τ-leptons. Thus, one expects the τ-jet pair to have only a slight deviation from being back-to-back in the rest frame of the massive particle. It is useful to define the *acollinearity* — the angular deviation of the τ-jets from being back-to-back. This acollinearity is a well defined positive number in any frame of reference. Henceforth, α will denote the acollinearity between two τ-jets, and furthermore α_{RF} the acollinearity in the heavy particle rest frame.

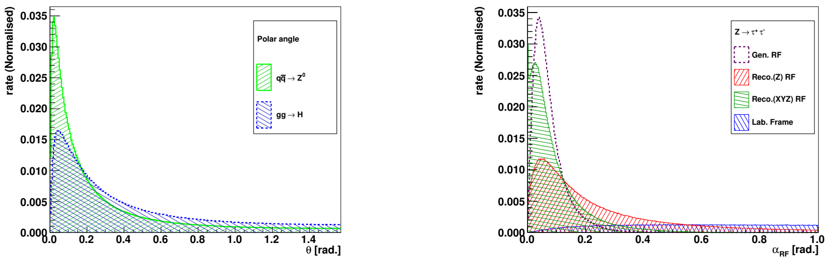
Simulations show that at 7 TeV pp-collisions, the Z^0 and a light H, are mostly produced with a high and predominantly longitudinal boost, β_{z}. Thus, measured 4-momenta will deviate significantly from those in the heavy particle RF. Exploiting that α_{RF} should be small and assuming that β_{T} is small, the method proposed in this paper consists in searching for the β_{z} that minimises α. When restricting β to be parallel to the beam axis, the α as a function of β has a single minimum and hence can be reliably minimised.

The method can also be extended to look for the transverse component of the boost if one has a good estimate of the direction of the heavy particle in the transverse plan. The transverse direction of the heavy particle, can be estimated by summing up the transverse momenta of the τ-jets and the reconstructed missing transverse energy, $\not{E}_{\mathrm{T}}$. Our algorithm minimises α in two steps; first, by varying the longitudinal boost, β_{z}, secondly when a suitable minimum is found, the transverse boost is varied along the found transverse direction. In both steps the α is 1-dimensional function with a single global minimum and no secondary minima.

In this paper, we will denote the two search strategies as the Z- or XYZ-method depending on whether we only will try to estimate the longitudinal component of the boost of the heavy particle or estimate the transverse component as well.

Since particle directions are well measure quantities these methods are robust and can be applied in every collision event for any pair of measured particles or jets.

Performance. The performance of the methods were studied using $\tau^+\tau^-$ pairs from simulated Z^0 and 114 GeV/c^2 gluon-gluon fusion H events produced in 7 TeV pp-collisions. Anticipating that backgrounds could be difficult to handle in multi-prong τ decays, only decays with exactly one charged particle in the final state were considered here. However,



(a) Polar angle, θ, of the Z^0 and 114 GeV/c^2 H bosons. Typically the bosons are produced at small angles close to the beam axis.

(b) Acollinearity, α, for $Z^0 \to \tau^+\tau^-$ in the generated and reconstructed RFs and in the laboratory frame of the Z^0.

Figure 1. Angular distributions for simulated heavy boson decays.

the inclusion of τ decays with more than one charged hadron is not expected to change the performance of this method significantly. 10^7 Z^0 and H events were generated with `Pythia8` [8] and subsequent τ-decays were done with `TAUOLA` [9] to correctly include spin and polarisation effects. Detector resolution effects were not included. However, an angular cut requiring the two jets to have $|\eta| < 2.5$ was imposed to match the acceptance of a typical tracker in an LHC experiment.

As shown in figure 1(a) the polar angle distributions for both H and Z^0 decays are predominantly parallel to the beam axis. Therefore, assuming a boost direction parallel to the beam seems to be a reasonable guess for a very large fraction of the events and we therefore only expect the XYZ-method to be slightly better in reconstructing the rest frame than the Z-method for these events. In figure 1(b) it is seen that the true α_{RF} is concentrated at small values, with $\langle\alpha_{\mathrm{RF}}\rangle = 4.5°$ for Z^0 events, while the acollinearity distributions in the reconstructed frames are peaked towards low acollinearities as expected. The effect of working in the collinear frame ($\alpha = 0$) instead of in the true RF should have a small effect if the direction of the boost is correctly estimated. In the collinear frame closest to the true RF, the momenta of the two τ-jets will deviate with a factor $\cos(\alpha_{\mathrm{RF}})$ from the truth, meaning a typical deviation of 0.3%.

Since the α is always positive, it is easy to minimise with respect to the applied $\beta_{\mathrm{z,T}}$ of the two tau jets. For a selection of ranges in the generated β of a produced Z^0-boson, figure 2 shows how, on average, α varies as a function of an applied longitudinal boost to the two jets. The minimal acollinearity is always at a longitudinal boost that is close to the generated one. The actual value of α is reflecting to which extent there might be a transverse boost present, ignored in figure 2.

To estimate the goodness of the reconstruction of the RF, the vectorial difference $|\beta_{\mathrm{gen}} - \beta_{\mathrm{reco}}|$ is shown in figure 3(a) for both reconstruction methods. The reconstructed RFs are seen to be closer to the generated RF for the XYZ-method as expected. Figure 3(b) shows the difference in magnitude between the generated and reconstructed boost with a FWHM of the distribution of 0.010 for the XYZ-method.

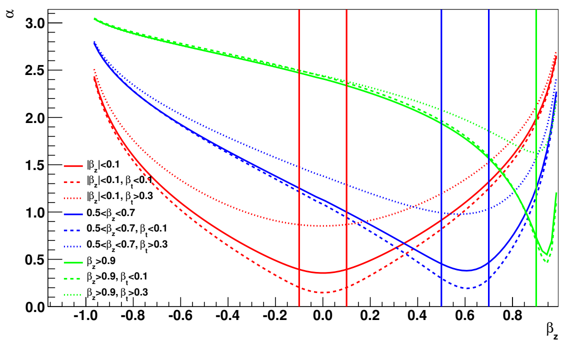
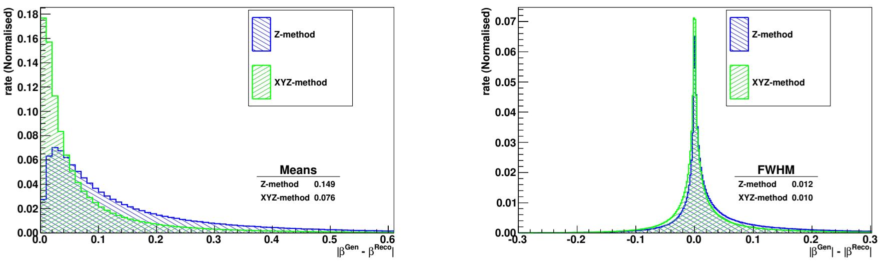


Figure 2. Average acollinearity as a function of attempted longitudinal boost for various ranges of true boost.



(a) Vectorial difference between the generated and reconstructed RF.

(b) Difference in magnitude between the generated and reconstructed β.

Figure 3. Comparisons of both reconstructed and generated rest frames in $Z^0 \to \tau^+\tau^-$ events.

In conclusion both methods reconstructs the boost very reasonably, with a distribution around the true value with a mean deviation around 0.076 for the XYZ-method and 0.149 for the Z-method, when averaging over all events. Due to the exclusion of the transverse component, a small offset away from zero in the most probable value is seen in the Z-method. Although figure 1(a) shows that the bosons are mostly boosted longitudinally, improvements are found when also estimating the transverse components of the boost. However, these improvements will be very dependent on the ability to estimate the transverse direction of the bosons correctly in the detector. Therefore the two methods act complementary; for events with a small transverse boost and low precision on the $\not{E}_{\mathrm{T}}$ the Z-method should be applied, whereas for events with good precision in $\not{E}_{\mathrm{T}}$ and a high transverse boost, improvements will be gained by using the XYZ-method.

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3 Estimating the boson mass

Due to the neutrinos in the τ decays, the visible invariant mass, M_{vis}, distribution peaks far below the real mass of the resonance produced. A method correcting for this is the so called *collinear approximation* [6]. This method assumes the neutrinos are collinear with the decaying τ-lepton, and includes $\not{E}_T$ by projecting it to the τ-jets. However, this projection is only possible and reliable in a fraction of events with large transverse boost and well aligned $\not{E}_T$ [10, 11].

In [7] the performance of a likelihood based technique is presented for simulations of Higgs and Z^0 events in antiproton-proton collisions at 1.96 TeV, and also for data collected by the CDF experiment. For fully hadronic decaying *tau*-leptons, unsmeared simulations show a mass reconstruction resolution of 8%, and more realistic simulation shows a mass resolution of 14%, and finally the CDF $Z^0 \to \tau^+\tau^-$ events show a resolution of 16% with this technique. The smeared results are obtained for events within $|\eta| < 1$, smearing of hadron momenta of 10% and of $\not{E}_T$ of 5 GeV in each of the transverse components.

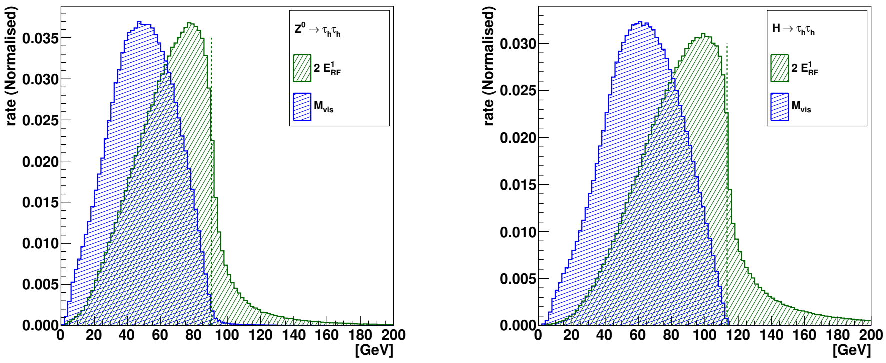
At the LHC the events are much more boosted, and the experiments have larger η coverage. In [12], CMS expects a likelihood mass resolution of 21% for a 130 GeV Higgs (for leptonic and semi-leptonic τ-decays), in an analysis covering $|\eta| < 2.3$ for hadronic τ decays. This is approaching the width of the the M_{vis} distribution which is reported to be 24%. A possible explanation for the poorer resolution in CMS could be that $\not{E}_T$ measures a smaller fraction of the full neutrino energies for τ-jets with large η than for transverse ones. Hence, estimates of the full neutrino energies from $\not{E}_T$ arises from correspondingly larger scale factors.

Another mass variable for τ pairs is the effective mass, $M_{eff} = \sqrt{(p_{\tau^1} + p_{\tau^2} + \not{p}_T)^2}$, where p_τ are the visible τ-jet 4-momentum, and $\not{p}_T$ is the missing transverse momentum vector. In addition to the M_{vis} and M_{eff} recent result from the ATLAS collaboration [13] has also used a likelihood based method, whereas the recent result from the CMS collaboration [14] simply uses M_{vis} in the analysis.

In the following an alternative variable for mass estimation is described and for simplicity comparisons have been made to distributions of M_{vis} which is a straightforward robust alternative in use by all experiments.

Finding the kinematic edge. The mass of a particle decaying to $\tau^+\tau^-$ could be inferred by determining the kinematic endpoint of the distribution of twice the leading τ-jet energy in the boson RF. This quantity will henceforth be named as $2E^1_{RF}$. As opposed to the collinear approximation this quantity can be calculated for all events. In figure 4 distributions of $2E^1_{RF}$ are compared to M_{vis} distributions.

This way of estimating the mass becomes particularly useful when both τ-leptons decay into hadrons, where only one neutrino is present in each τ decay. Figure 4 suggests that a first guess to the shape of $2E^1_{RF}$ could be a triangle convoluted with some resolution function, although it is clear that the inclusion of effects like the Z^0/H width and helicity effects modifies such an assumption. Still the kinematic edge can be found be determining the point of steepest slopes of the distribution.



(a) Distributions for Z^0 events.

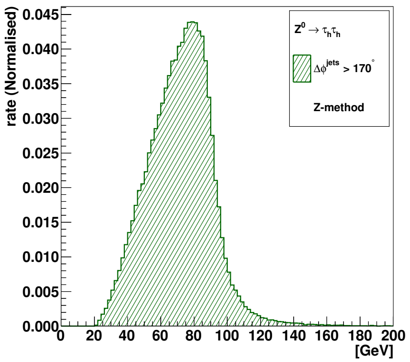
(b) Distributions for H events.

Figure 4. Distributions for $2E^1_{\mathrm{RF}}$ calculated using the XYZ-method and invariant mass of the visible τ-jets, $\mathrm{M_{vis}}$, for $\tau^+\tau^-$ pairs both decaying to single charged hadrons. The dotted line marks the position of the steepest slope for the $2E^1_{\mathrm{RF}}$ distribution.

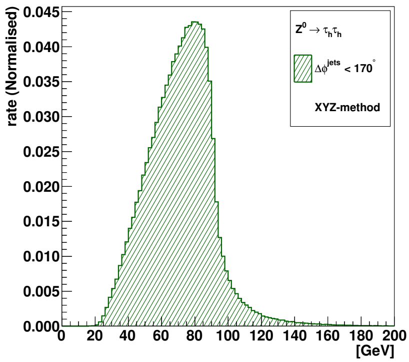
Figure 4 is the result for *all* hadronic decaying events without any selection. As mentioned earlier, the decision on which boost reconstruction method to use should depend on the magnitude of the transverse boost. Therefore, the events have been divided into two classes; one with a large difference in azimuthal angle between the two jets, $\Delta\phi^{\mathrm{jets}}$, compatible with no transverse boost, where the Z-method were used, and one with the rest of the event where the XYZ-method were applied. Here a threshold of $\Delta\phi^{\mathrm{jets}} = 170°$ were chosen to separate the two classes. The criterion for the choice of boosting method would have to be subject to study in a true experimental environment. Furthermore, a cut of 10 GeV on the p_{T} for both τ-jets were applied to both classes. In figure 5, it is shown that 24% of the Z^0-boson and 16% of the Higgs events can be reasonably subjected to the Z-method. Hence, without any use of $\not{E}_{\mathrm{T}}$ an approximation of the centre of mass system is still available of these events.

Since the distributions of $2E^1_{\mathrm{RF}}$ are clearly asymmetric and non-gaussian, the spread of the distributions calculated from the most likely value are therefore also asymmetric. For Higgs events with $\Delta\phi^{\mathrm{jets}}$ above 170°, the spread from the peak position is found to be $^{+17}_{-25}\%$.

To evaluate the precision of retrieving the boson mass by finding the kinematic edge, M_{boost}, pseudo-experiments were performed. From the $2E^1_{\mathrm{RF}}$ distribution shown in figure 4(a) several pseudo-distributions were generated with varying number of events and for each distribution the kinematic edge was found as the point of the steepest decent. In table 1, the found values and spread of M_{boost} are listed as a function of the number of events in the pseudo-experiment for the two classes of events, where class 1 refers to the events in which the Z-method has been used, and class 2, refers to the events where the XYZ-method were used. For the simple kinematic edge-finder implemented for this analy-



(a) Class 1: Distributions for Z^0 events with $\Delta\phi^{\rm jets} > 170°$.



(b) Class 2: Distributions for Z^0 events with $\Delta\phi^{\rm jets} < 170°$.

Figure 5. Distributions for $2E^1_{\rm RF}$ calculated for the two event classes using the Z and XYZ-method for $\tau^+\tau^-$ pairs both decaying to single charged hadrons.

	Obtained values of $M_{\rm boost}$	
Number of events	Class 1	Class 2
250	88.3 ± 5.3	88.5 ± 4.7
500	89.3 ± 3.1	89.3 ± 2.5
1000	90.3 ± 2.3	89.7 ± 1.7
2000	90.6 ± 1.8	89.9 ± 1.3
4000	90.8 ± 1.4	90.0 ±1.1

Table 1. Mass estimation $M_{\rm boost}$ as a function of number of events $n_{\rm evt}$ as obtained from pseudo-experiments for the two classes of Z^0 events. Class 1 consists of events with $\Delta\phi^{\rm jets} > 170°$ where the Z-method have been applied and class 2 consists of events that has been subject to the XYZ-method.

sis the $M_{\rm boost}$ converges to 90.8 ± 1.4 GeV for 4000 events (for class 1 events). These values indicates that the method could be of interest to investigate further in experimental data.

For a triangle function convoluted with a gaussian, numerical calculations have shown that taking the kinematic edge to be the point of the steepest slope overestimates the edge value. For a gaussian width of 7-10 GeV, the systematic shift is found to be 0.5-1.0 GeV. For an experimental analysis including backgrounds a more sophisticated edge finding method, e.g. template fitting, should be deployed.

Intuitively, constructing a mass variable that accumulates towards the real mass should help distinguishing different masses. One way to distinguish distributions is to compare the largest difference of the cumulative distributions, D_L which is input to the Kolmogorov-Smirnov test. It is found that while D_L between the calculated $2E^1_{\rm RF}$ distributions (using

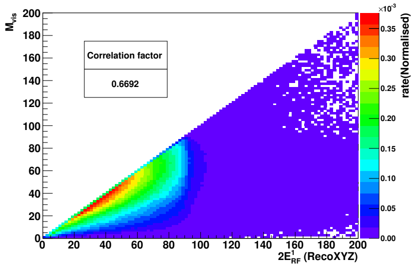


Figure 6. Correlations between $\mathrm{M_{vis}}$ and $2E^1_{\mathrm{RF}}$ using the XYZ-method in $Z^0 \to \tau^+\tau^-$ events with all decay channels of the τ-leptons included.

the XYZ-method) for Z^0 and H events is 0.35, it is only 0.24 when comparing the two $\mathrm{M_{vis}}$ distributions. It is not clear if the tails towards high values of $2E^1_{\mathrm{RF}}$ seen to be more important in figure 4 than figure 4(a) is helpful in a search scenario, because clearly the Z^0 contribution is non-negligible for values well beyond the kinematic edge. At present, it cannot be concluded that this variable will be better than any of the other proposition in a real experiment. However it seems to be worthwhile to consider the use this variable in an experimental search for the Higgs boson.

In figure 6, the correlation between $\mathrm{M_{vis}}$ and $2E^1_{\mathrm{RF}}$ is shown for Z^0 events. Thus, since the correlation is significantly lower than 1, the $2E^1_{\mathrm{RF}}$ variable is adding information, and it should be studied for use in a search scenario.

4 Helicity correlations

Several powerful variables for studying τ polarisation in Z^0 decays were developed for the LEP experiments [15]. These variables are defined in the rest frame of the decaying boson. While this is close to identical to the laboratory frame at LEP, this is not true at the LHC, and this paper proposes to study these variables in a reconstructed RF instead.

For $\tau^\pm \to \pi^\pm \nu_\tau$ events, the distribution of the decay angle in the τ-lepton rest frame, that is the angle between the direction of the τ-lepton and its visible decay product, is determined by the τ helicity. In the rest frame of the heavy boson producing a $\tau^+\tau^-$ pair this translates to a well determined distribution in the fraction of τ energy carried by π. The quantity used in the following figures is the energy of visible particles in the decay, E^{vis}, normalised to the kinematic endpoint (half the mass of the decaying boson). Weaker energy-energy correlations also shows for the $\tau^\pm \to \ell^\pm \nu_\tau \bar{\nu}_\ell$ and $\tau^\pm \to h^\pm \nu_\tau \, nh^0$ modes.

The E^{vis} distributions for single π decay modes shown in figure 7 for the generated and reconstructed heavy boson RFs show that the true correlations are partly recovered in the reconstructed RF using the XYZ-method proposed in section 2. Furthermore, it is shown that these correlations are much weakened in the laboratory frame.

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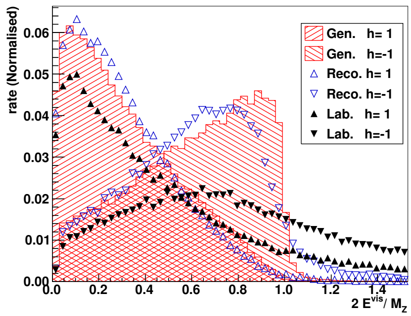
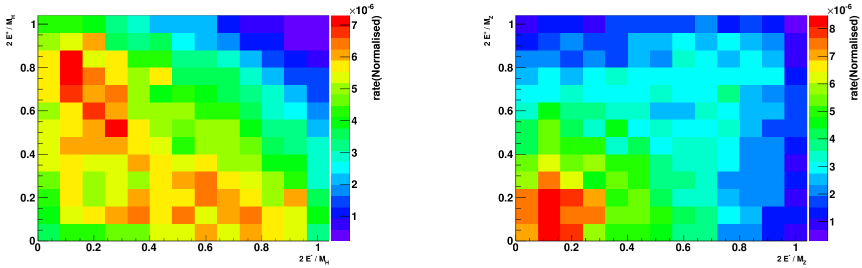


Figure 7. $2E^{\text{vis}}/M_Z$ for τ-leptons with positive and negative helicities decaying into $\pi^{\pm}\nu_\tau$ shown in the generated and reconstructed RF using the XYZ-method as well as the laboratory frame.



(a) Spin 0 (H sample).

(b) Spin 1 (Z^0 sample).

Figure 8. Energy correlations in the reconstructed RF using the XYZ-method of a $\tau^+\tau^-$ pair with both τ-leptons decaying to $h^{\pm}\nu_\tau$. To avoid effects coming from the mass differences all energies are scaled with the mass of the decaying boson.

4.1 Analysis of the sensitivity to spin

Conservation of angular momentum leads to distinctly different helicity configurations when comparing the final states of Z^0 and H decays in their rest frames. While the spin components along the direction of flight of the τ^+ must add up to ± 1 for the Z^0, the sum must be 0 for the H decays. Thus the spin effects can be studied by looking at the correlations in E^{vis} of the two τ-leptons as shown in figure 8.

To quantify the observed difference between spin 0 and spin 1 particles, the Z^0 and H samples were split into training and test samples. Probability density functions for both spins, $P_0(E_{\tau^-}, E_{\tau^+})$ and $P_1(E_{\tau^-}, E_{\tau^+})$, were constructed as the fraction of events in a bin of (E_{τ^-}, E_{τ^+}) in the corresponding training sample. From this a likelihood, $\mathcal{L}$, is created for N events from both training samples by

$$\log \mathcal{L} = \sum_{i=0}^{N} \left(\log(P_1^i) - \log(P_0^i) \right) / N \tag{4.1}$$

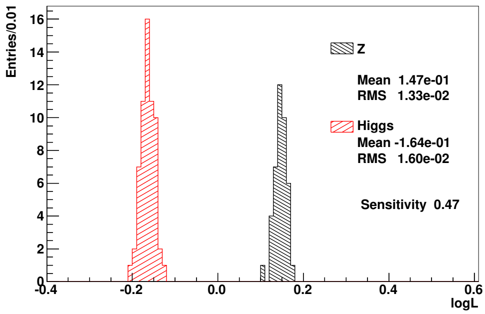


Figure 9. Log likelihood plot for energy-energy correlations in the reconstructed RF using the XYZ-method when both τ-leptons decays into $h^\pm \nu_\tau$.

τ decay mode		Sensitivity			
τ_1	τ_2	Reco.RF(Z)	Reco.RF(XYZ)	Lab.	True RF
$\ell^\pm \nu_\tau \overline{\nu}_\ell$	$\ell^\pm \nu_\tau \overline{\nu}_\ell$	0.13	0.09	0.06	0.08
$\ell^\pm \nu_\tau \overline{\nu}_\ell$	$h^\pm \nu_\tau$	0.17	0.13	0.06	0.15
$\ell^\pm \nu_\tau \overline{\nu}_\ell$	$h^\pm \nu_\tau\ nh^0$	0.15	0.07	0.05	0.13
$h^\pm \nu_\tau$	$h^\pm \nu_\tau$	0.42	0.47	0.23	0.51
$h^\pm \nu_\tau$	$h^\pm \nu_\tau\ nh^0$	0.21	0.15	0.10	0.18
$h^\pm \nu_\tau\ nh^0$	$h^\pm \nu_\tau\ nh^0$	0.19	0.13	0.09	0.18

Table 2. Sensitivity to spin of the boson for different decay modes of the two τ-leptons shown in the true and reconstructed RFs as well as in the laboratory frame.

The test samples of Z^0 and H events are divided in sub-samples of N events and the likelihood is calculated for each sub-sample. The distribution of $\log \mathcal{L}$ when $N = 1000$ and when both τ-lepton decays to $h^\pm \nu_\tau$ is shown in figure 9.

Inspired by [15], a *sensitivity*, S, is defined such that the number of standard deviations between the means of the two distributions, n_σ, is given by

$$n_\sigma = S\sqrt{N}\,. \tag{4.2}$$

Table 2 shows values obtained for S in the reconstructed RFs using the Z- and XYZ-method as well as in the laboratory frame for the different τ decay modes. For all decay channels sensitivity is gained when using the reconstructed RF over the laboratory frame. When just applying the Z-method, differences in the transverse momentum of the bosons are kept in the distributions, while the XYZ-boost approximates the RF more correctly. The Z-method thus analyses a combination of the two effects, the boson p_T and spin, while the sensitivities determined using the XYZ-method are largely only due to differences in spin.

Finally, further sensitivity would be gained by using ratios between neutral and charged energy for $h^{\pm}\nu_{\tau}\ nh^0$ final states. An exhaustive analysis of spin should probably make use of these ratios. These ratios remain almost unchanged in any boosted frame. The purpose of this note is to discuss the advantages of finding an approximate rest frame, so the sensitivities when using these variable are not reported here.

5 Conclusions and discussion

By minimising the acollinearity, two methods to reconstruct the rest frame of boosted heavy particles decaying to two τ-leptons have been proposed, and it has been demonstrated that they both find the rest frame reasonably well. Whereas the XYZ-method requires an estimate of the transverse direction of the heavy particle, the Z-method can be used for analyses where one does not have a good estimate of this direction.

A new technique for mass estimation has been proposed using the end-point of the leading τ-jet energy in the reconstructed rest frame. This technique does not introduce assumptions on transfer functions or production mechanisms of the heavy particle as more elaborate reconstruction techniques, and it can be applied to *all* events within the geometrical acceptance of the experiments. The method is complementary to existing methods in the sense that it can be applied without using information on the measured $\not{E}_{\mathrm{T}}$, and since it is not directly correlated with the visible mass it adds information, and thus the two can be combined to gain further sensitivity.

Furthermore, a scheme for an event-wise spin analysis of the $\tau^+\tau^-$ system has been outlined, and it has been shown that enhanced sensitivity to spin is gained when transforming the 4-momenta as proposed in this paper. Both boost methods presented enhance sensitivity to spin when compared to an analysis in the laboratory frame. Which method to use depends on whether or not differences in production mechanism of the boson should be taken into account.

In summary, a tool has been developed to approximate the rest frame of $\tau^+\tau^-$ systems, and two applications thereof have been illustrated. These applications could prove to be helpful in the analyses of Z^0 decays or in searches for new particles like H, Z' or SUSY particles. Additionally, it is possible that a transformation to the rest frame could be beneficial to other variables used in the study of $\tau^+\tau^-$ systems.

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