ILD benchmark: tau tau at 500 GeV

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February 21, 2019

Abstract

Analysis of $ee \to \tau\tau$ for detector benchmarking.

1 Introduction

Di-tau production at high COM. Polarisation of tau lepton is reconstrutable thanks to its relatively short lifetime and "clean" decays.

We study the selection of such events and how their spin can be reconstructed. We compare the results in the two ILD detector models (large and small).

2 What we need to measure

The tau decay gives us sensitivity to its spin, and therefore to the left and right handed couplings of whatever intermediate particle produced them. In the $ee \to \tau\tau$ process, we plot a few relevant observables in Fig.1. These are shown at MC level, separately for samples with (100%) eLpR and eRpL beam polarisations: the polar angle of the τ^- direction, and the polarimeters in the case of $\tau^\pm \to \pi^\pm\nu$ and $\tau^\pm \to \pi^\pm\pi^0\nu$ decays. The polarimeter vectors are defined in the tau rest frames as follows: for $\tau^\pm \to \pi^\pm\nu$, it is the direction of the neutrino momentum, while for $\tau^\pm \to \pi^\pm\pi^0\nu$ it is the direction of the vector $\mathbf{P} = 2(\mathbf{q} \cdot \mathbf{p}_\nu)\mathbf{q} - m_q^2\mathbf{p}_\nu$, where $\mathbf{q} = \mathbf{p}_{\pi^\pm} - \mathbf{p}_{\pi^0}$, and $\mathbf{p}_\nu, \mathbf{p}_{\pi^\pm}, \mathbf{p}_{\pi^0}$ are respectively the 3-momenta of the neutrino, charged and neutral pions. To distinguish left and right handed taus, we look at the cosine of the angle this polarimeter vector makes to the tau flight direction.

Our job in the current analysis is basically to see how well we can reconstruct these distributions in the large and small ILD models.

3 Event selection

It is the semi-leptonic tau decays (in which the tau decays to a single neutrino plus hadrons) which are most seneitive to tau polarisation (fully leptonic modes suffer from the presence of 2 neutrinos per tau decay). We therefore emphasise hadronic decays, in particular $\tau^\pm \to \pi^\pm\nu$ (the cleanest decay) and $\tau^\pm \to \pi^\pm\pi^0\nu$ (whcih has the largest BR). These two decay modes both allow full extraction of polarisation information. We concentrate out efforts on events in which the tau pair invariant mass is close to the nominal collision energy of 500 GeV.

From the detector point of view, the most sensitive aspect is probably the reconstruction and measurement of the π^0 decay products in the highly boosted tau decays.

We use the "DistilledPFOs" collection, in which some pairing of photons into π^0 and η (and others?) has been done. We first apply a simple preselection, requiring that between 2 and 11 charged PFOs have been reconstructed.

We then look for jet directions. We first identify the highest momentum charged PFO ("first seed"). Once this has been found, we look for the higehst momentum charged PFO which is separted from the first seed by at least $\pi/2$ in the $x - y$ plane. This selection makes use of the fact that the two taus in signal events are emitted back-to-back in the $x - y$ plane in the case of no ISR or collinear ISR. If no second seed is found, the event is rejected.

We then look in narrow cones (opening angle 0.1 rad) around these two seed directions. PFOs within these cones are associated to tau jet candidates. We then apply the following selection:

- Energy of the second seed less than 200 GeV. [to remove di-lepton events.]
- Sum of the energy (p_T) of particles lying outside the two cones less than 40 (20) GeV. [remove hadronic events.]

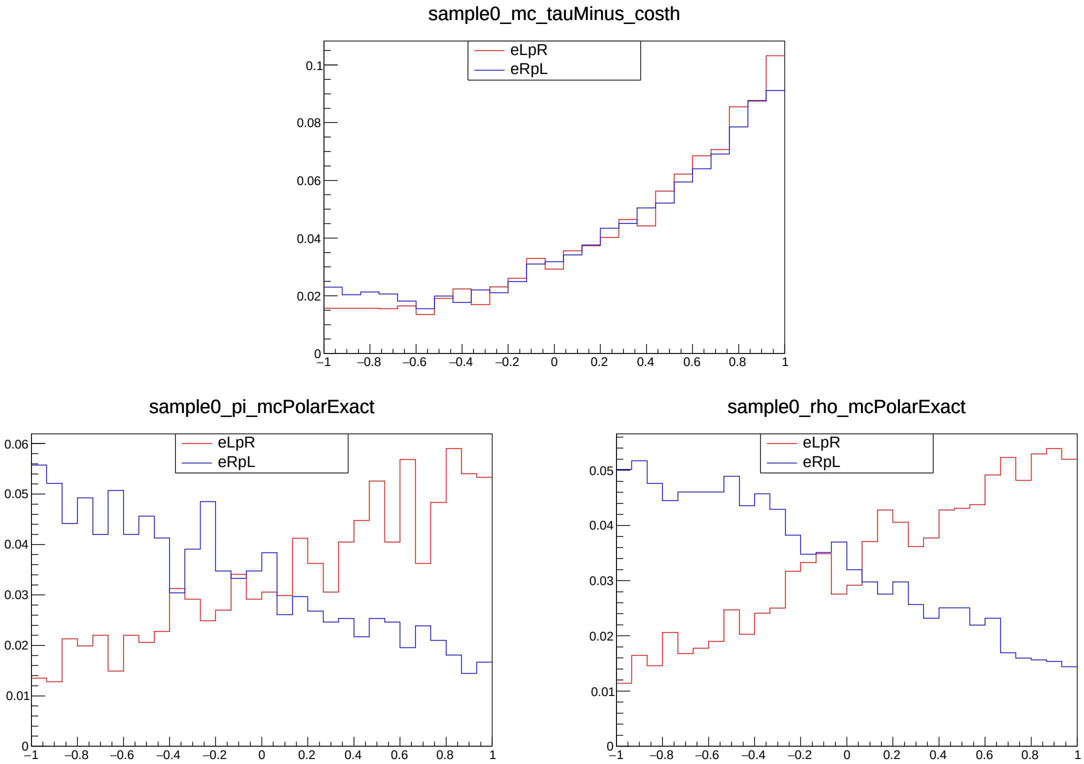

Figure 1: MC distributions, for $ee \rightarrow \tau\tau$ with $M_{\tau\tau} > 480GeV$. Top: cosine of the τ^- polar angle; Bottom: polarimeter distributions for $\tau^\pm \rightarrow \pi^\pm\nu$ (left) and $\tau^\pm \rightarrow \pi^\pm\pi^0\nu$ (right) tau decays.

- acolinearity between seed directions less than 0.07 rad. [remove Z return events.]
- acoplanarity between seed dricetions less than 0.04159 rad. [remove fully leptonic WW events]
- No photon-like PFO (as tagged by PandoraPFA) with energy larger than 10 GeV lying outside the two cones. [remove events with seen ISR]
- No isolated leptons identified by the IsolatedLeptonTaggingProcessor. [remove dilepton events, fully leptonic tau decays]
- Energy-to-momentum ratio of seeds less than 0.85, and for seed PFOs with an momentum of at least 25 GeV associated calorimeter energy of at least 15 GeV. [remove dilepton events, fully leptonic tau decays]

We then look in more detail at the two jet cones. We observe that neutral hadrons are often reconstructed within the cones. This is almost always the result of fragmentation of the calorimetric shower induced by a charged hadron. The number of long-lived neutral hadrons produced in tau decays is rather small, so we remove such neutral hadron PFOs from the event. If the total charge of the jet is zero, we remove the charged particle furthest from the jet's initial seed direction. After removing these PFOs from consideration, we calculate the invariant mass of the jet. We ask that this mass is less than 2 GeV, and also that one jet has charge $+1$ amd the other -1.

4 Tau decay mode selection

To decide whether a jet originates from $\tau^\pm \rightarrow \pi^\pm\nu$ or $\tau^\pm \rightarrow \pi^\pm\pi^0\nu$, we first require that it contains a single charged PFO. A cut-based selection is based on 3 observables of the trimmed candidate jet: the number of identified photon PFOs, the total invariant mass of all visible particles, and the total invariant mass of all neutral visible particles. The performance of this identification is shown in table 2.

5 Polarimeter estimation

In the case of single pion decay, the optimal polarimeter is very simple: the ratio of the pion energy to the beam energy (assuming that the taus are exactly back-to-back). In the case of rho decay, full sensitivity requires

final state	$ee \to \tau\tau$			2f	4f
	SIGNAL		OTHER		
	efficiency [%]	expected events/1000			
preselection	88.3	222	2011	8833	18309
two seeds identified	88.0	221	1933	8391	16175
energy outside cones	84.0	211	1392	2078	6618
acolinearity	82.4	207	412	15	334
acoplanarity	74.5	187	358	6	100
photons outside cones	72.6	183	344	6	96
no isolated leptons	72.2	182	258	4	26
seeds' calorimeter energies	57.1	143	35	3	1
tau jets' invariant mass	50.3	127	28	0	1
tau jets' charge	48.8	123	27	0	1

Table 1: Selection efficiencies and expected event numbers at different stages of the selection (see text for details). Large detector, 1.8 ab-1 in the eLpR polarisation. SIGNAL refers to $ee \to \tau\tau$ events with $\tau\tau$ invariant mass greater than 480 GeV, and in which neither τ decays leptonically.

ILD_l5_o1_v02	MC-pi	MC-rho	MC-a1p	MC-other	purity
SELECTED AS PI	91.5 ± 0.5	2.1 ± 0.2	0.8 ± 0.2	9.2 ± 0.4	82.5 ± 0.7
SELECTED AS RHO	4.9 ± 0.4	77.4 ± 0.5	13.4 ± 0.8	5.9 ± 0.4	87.5 ± 0.5
SELECTED AS A1P	1.8 ± 0.2	12.5 ± 0.4	62.5 ± 1.1	5.9 ± 0.4	54.3 ± 1.0

ILD_s5_o1_v02	MC-pi	MC-rho	MC-a1p	MC-other	purity
SELECTED AS PI	91.6 ± 0.5	3.1 ± 0.2	1.2 ± 0.2	10.5 ± 0.5	79.5 ± 0.7
SELECTED AS RHO	5.1 ± 0.4	75.8 ± 0.6	17.0 ± 0.9	5.5 ± 0.3	86.6 ± 0.5
SELECTED AS A1P	1.7 ± 0.2	13.2 ± 0.4	57.2 ± 1.1	5.3 ± 0.3	50.4 ± 1.1

Table 2: Selected 1-prong tau candidates in signal events: decay mode identification efficiency in large and small models (100% eLpR only)

reconstruction of the neutrino momenta. In the case of back-to-back taus, the momenta can be estimated by constraining the tau lepton energies (250 GeV), their being back-to-back, and imposing the known tau mass. Zero or two (possibly identical) possible solutions occur. Tau impact parameters are used to choose one of these solutions. Intersection of cones around jet momenta. Results to follow.

6 Conclusion

Acknowledgements

References