A study of $e^+e^- \to \tau^+\tau^-$ at 500 GeV

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Introduction

The $e^+e^- \to \tau^+\tau^-$ process is of particular interest because the tau lepton polarisation can be reconstructed, allowing its chiral nature to be proved.

The tau lepton, with its rather short lifetime 2.9×10^{-13} s allows reconstruction of its spin direction by the distribution of its decay products.

Maximum sensitivity to the spin orientation requires reconstruction of the tau decay mode and the kinematics of its decay.

Outline

- Event selection
- Identification of tau decay mode

  $\tau \to \pi\nu$

  $\tau \to \rho\nu$

  $\tau \to a_1\nu$
- Measure polarization in $e^+e^- \to \tau^+\tau^-$
- Compare two models of the ILD detector

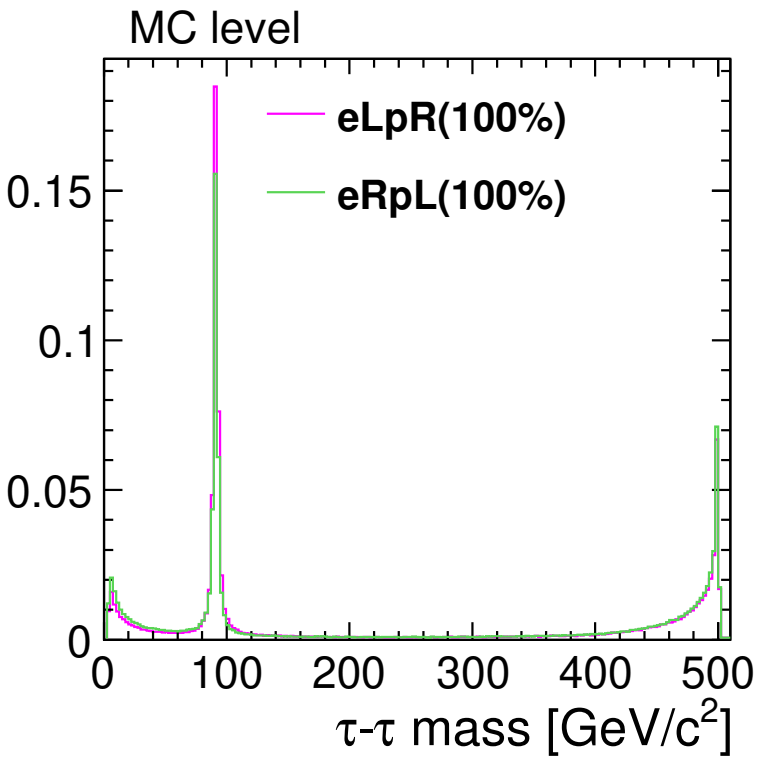
  IDR-L

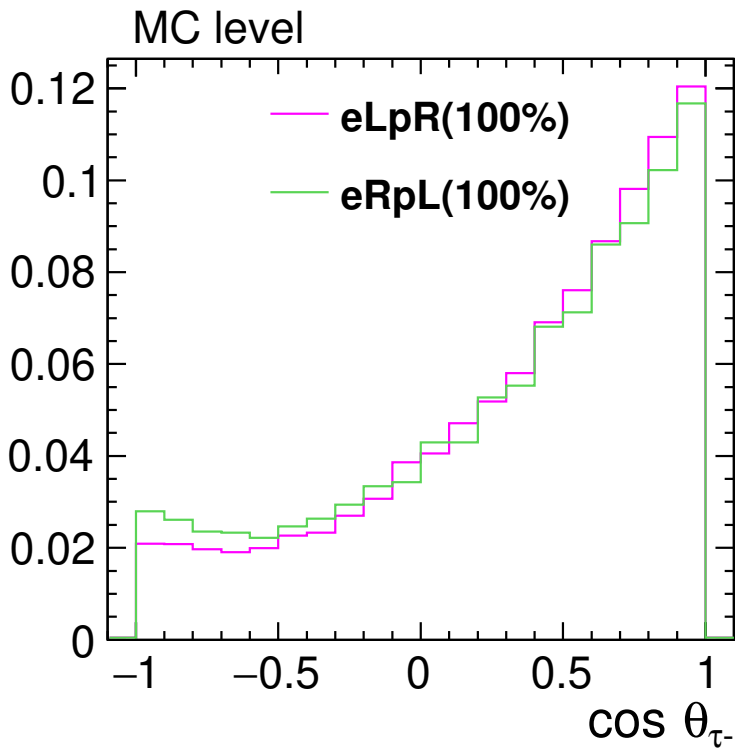
  IDR-S

Simulation setup

- Signal events sample were generated using WHIZARD ver 1.95
- The decay of the polarized tau was done using TAUOLA
- Two samples were used

  100% polarised $e^-_L e^+_R$ and $e^-_R e^+_L$

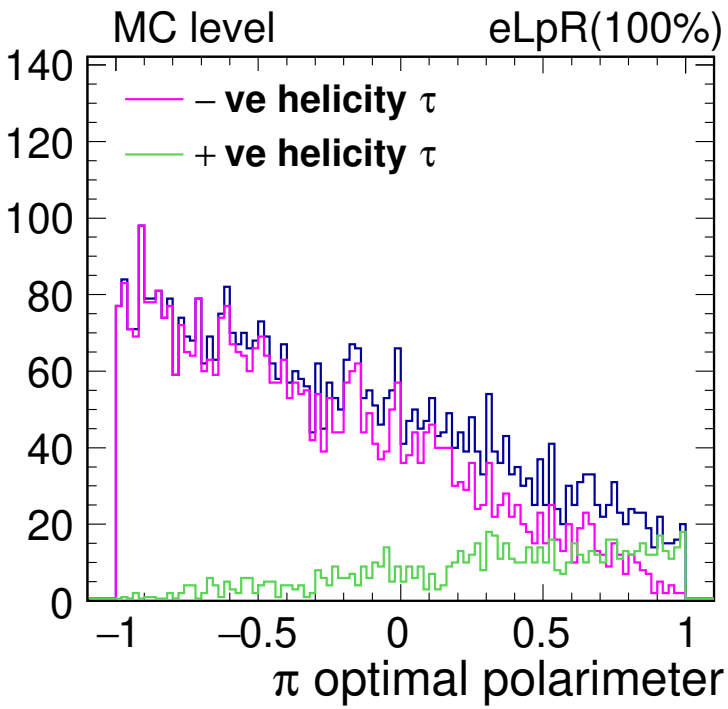


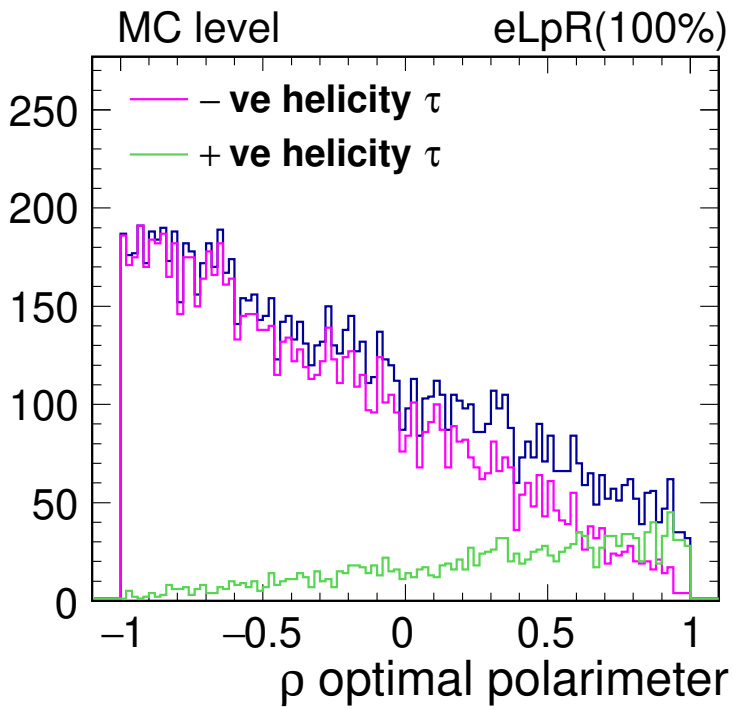


Polarimeters

The polarimeter vectors including the momenta of neutrino, charged and neutral pions.

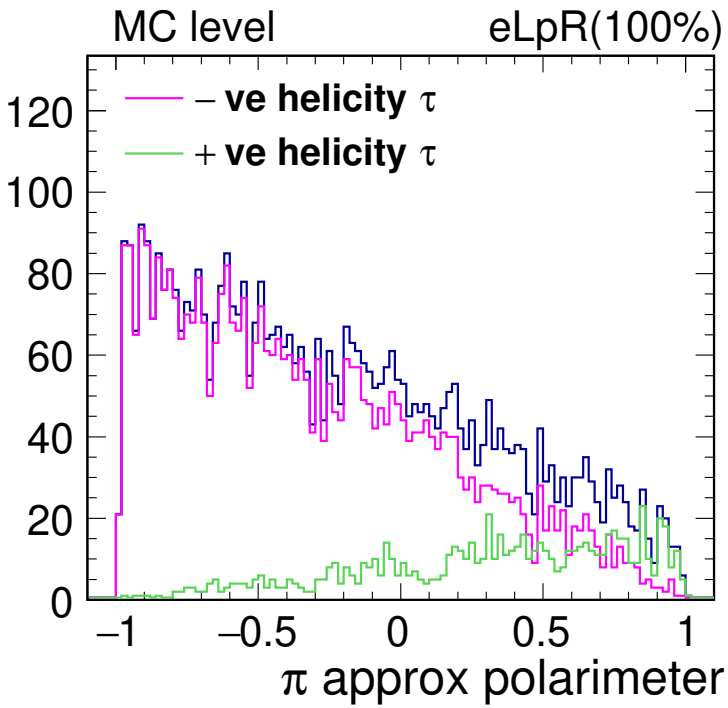
We refer to this form of the polarimeter as "optimal" tau polarimeter.

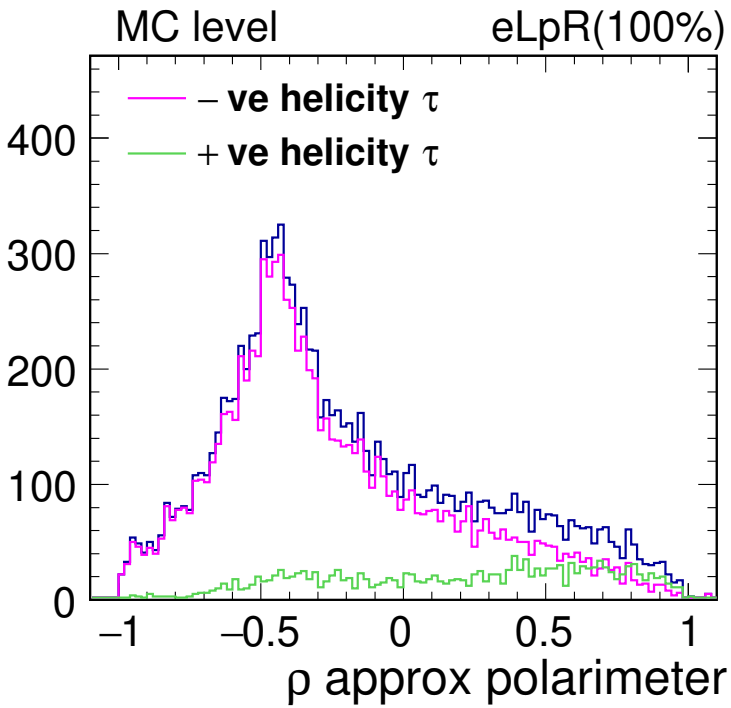




Polarimeters

"Approximate" tau polarimeter are reconstructed
based only on the momenta of visible tau decay products.

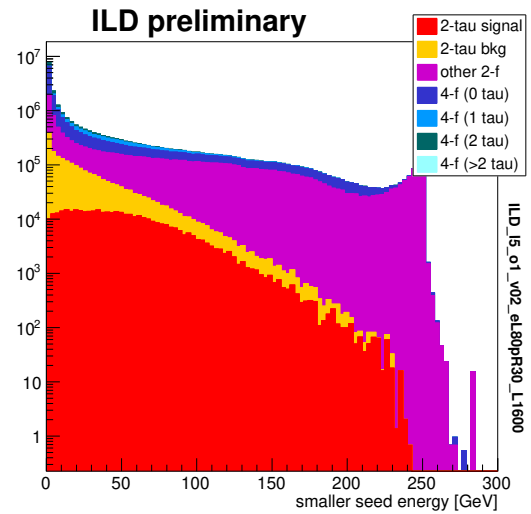




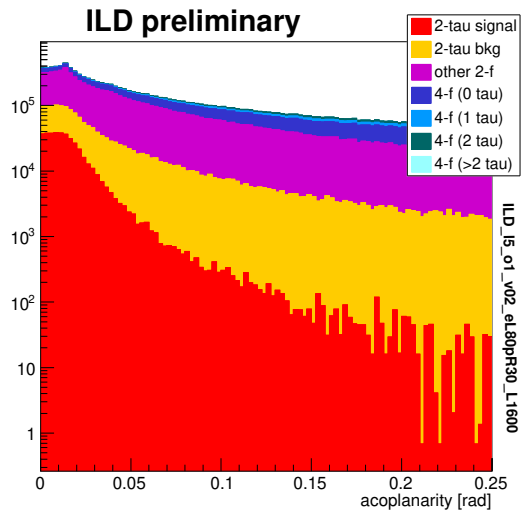
Event selection

- **(a)** the second seed PFO energy
- **(b)** the outside energy of PFOs
- **(c)** Jet acoplanarity
- **(d)** Jet acolinearity
- **(e)** no ISR photon
- **(f)** no isolated leptons
- **(g)** the shower shape

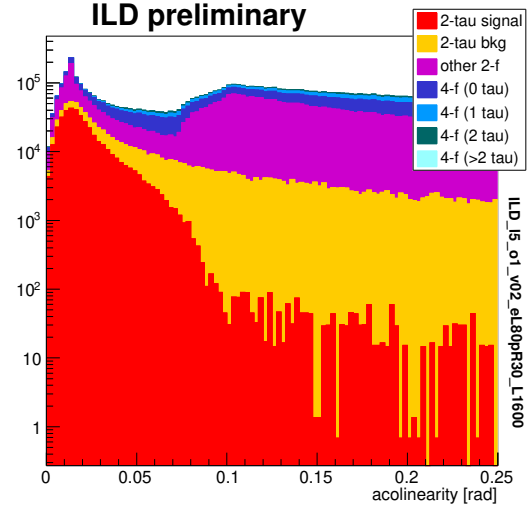
(a)



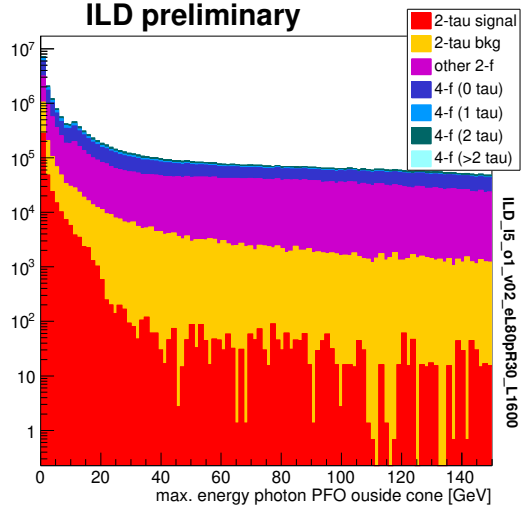
(c)



(d)



(e)



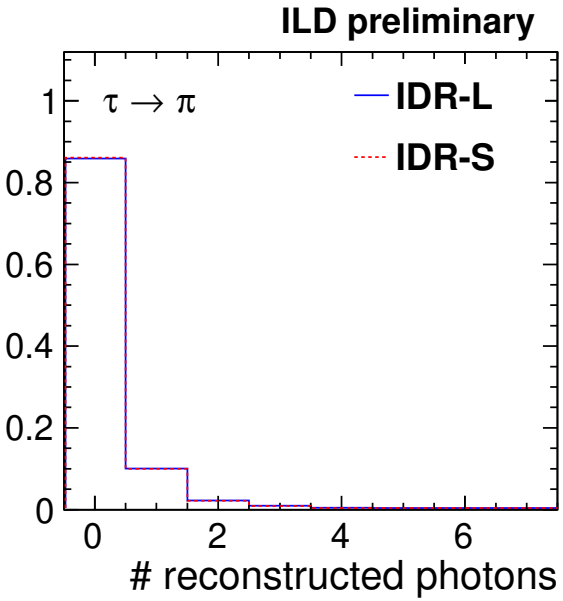
τ decay mode selection

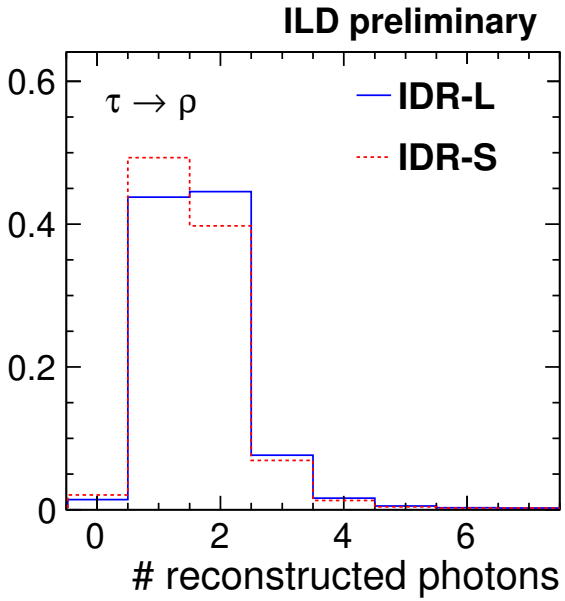
To decide whether a jet originates from $\tau^{\pm} \to \pi^{\pm}\nu$ or $\tau^{\pm} \to \pi^{\pm}\pi^{0}\nu$
First, we require that it contains a single charged PFO.

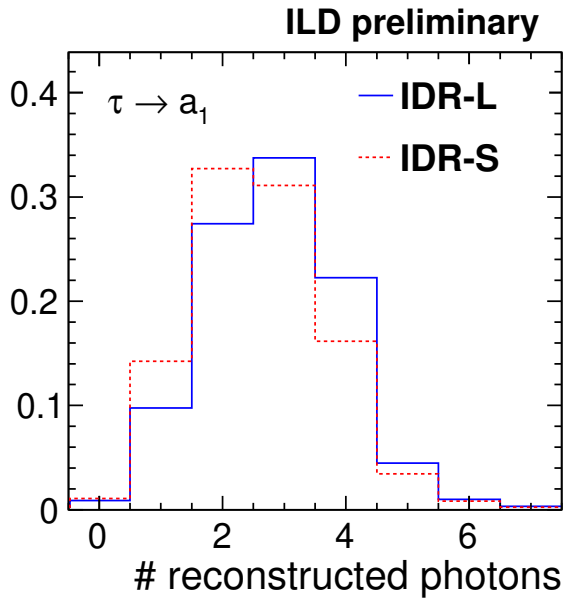
A cut-based selection is based on 3 observables of particle in the candidate jet

- number of identified photon PFOs
- total invariant mass of all visible particles
- total invariant mass of all neutral visible particles

τ decay mode selection







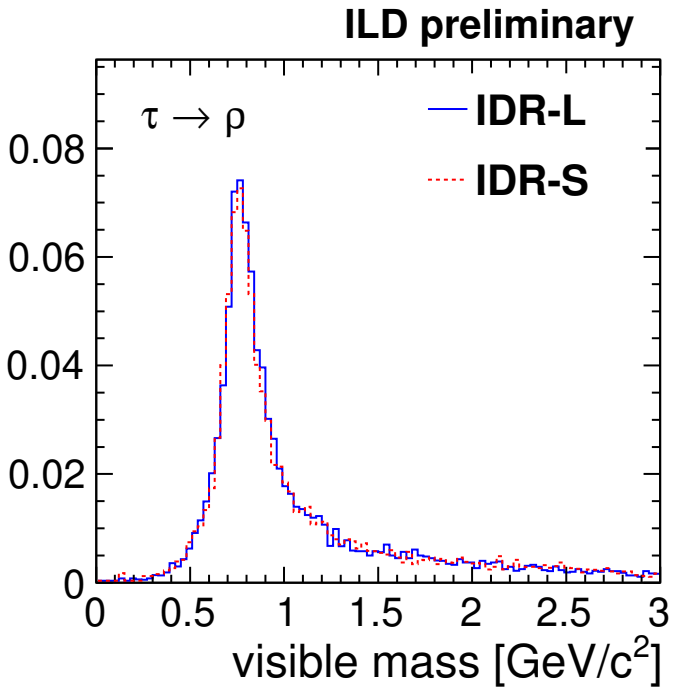
γ-like PFOs identified within the cone matched to various decay modes.

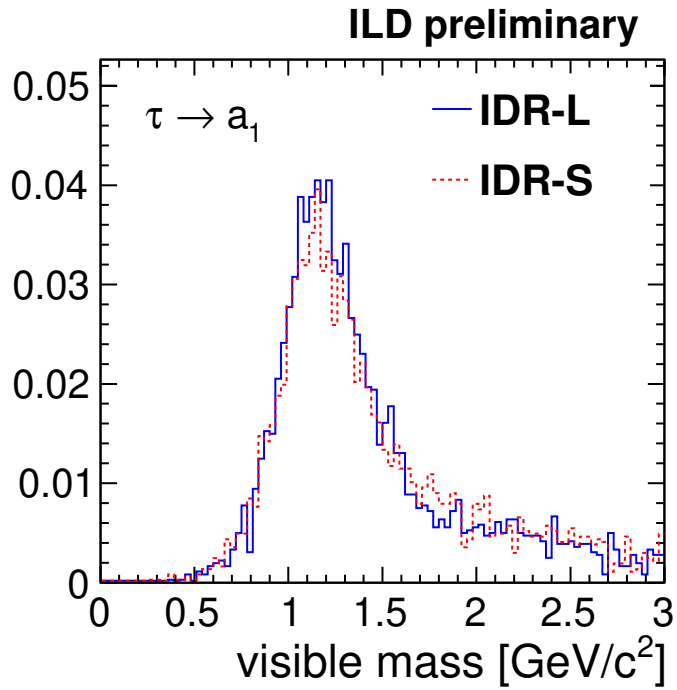
In the case of ρ decays, $50\ \%$ of tau jets only a 1-γ cluster is reconstructed.

IDR-L model is better than IDR-S model to count photons

τ decay mode selection

Signal-only comparisons after general event selection





visible invariant mass in ρ (left) and single-prong a_1 (right) decays
There is no significant difference between IDR-L and IDR-S model

τ decay mode selection

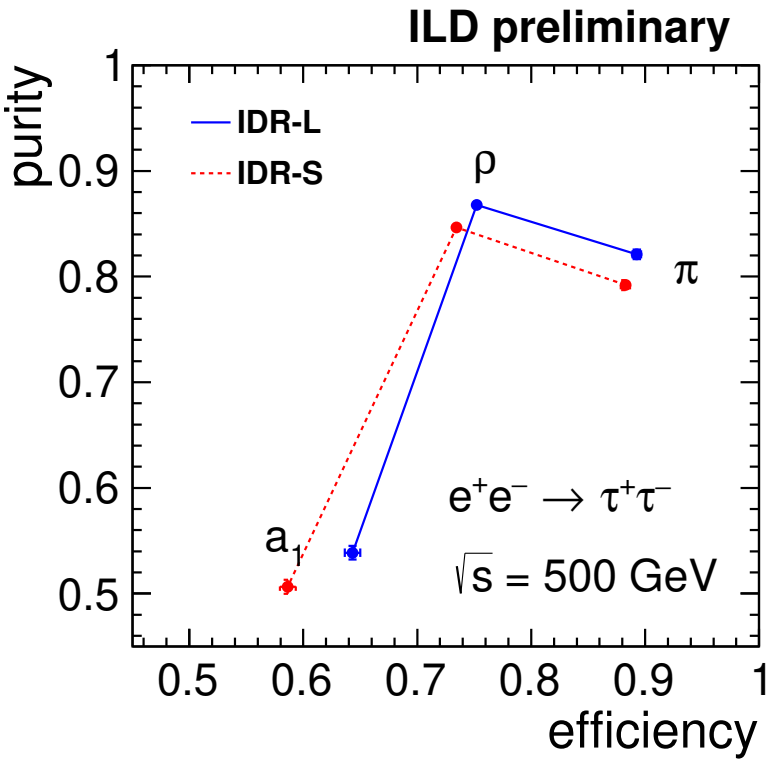
Selected 1-prong tau candidates in signal events

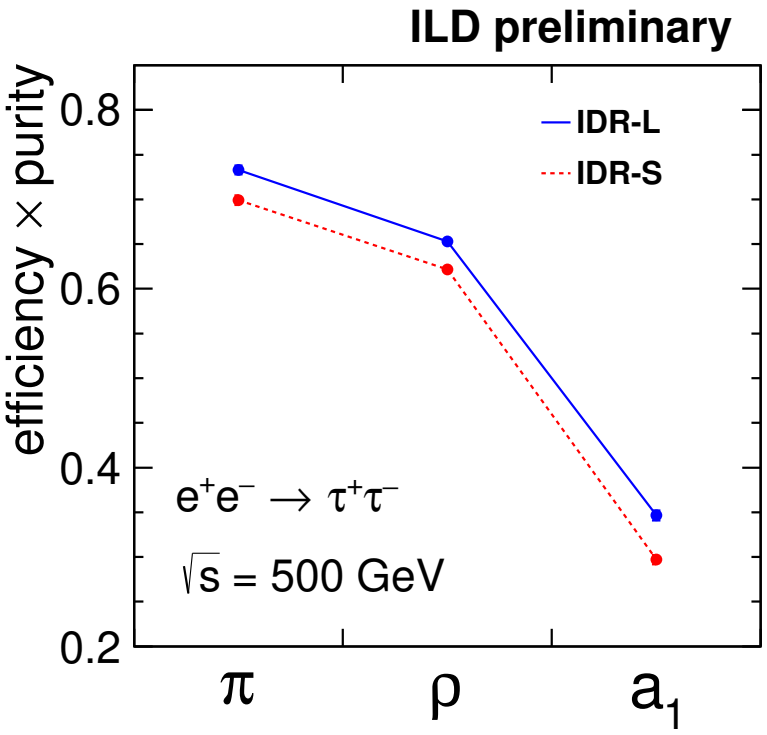
	true MC decay				purity
	$\tau^\pm \to \pi^\pm\nu$	$\tau^\pm \to \pi^\pm\pi^0\nu$	$\tau^\pm \to \pi^\pm\pi^0\pi^0\nu$	$\tau^\pm \to$ other	
	IDR-L				
selected as $\tau^\pm \to \pi^\pm\nu$	89.27 ± 0.38	2.06 ± 0.12	0.87 ± 0.13	9.22 ± 0.29	82.11 ± 0.45
selected as $\tau^\pm \to \pi^\pm\pi^0\nu$	6.47 ± 0.30	75.21 ± 0.36	13.32 ± 0.48	5.81 ± 0.23	86.79 ± 0.30
selected as $\tau^\pm \to \pi^\pm\pi^0\pi^0\nu$	2.20 ± 0.18	13.03 ± 0.28	64.32 ± 0.68	6.74 ± 0.25	53.86 ± 0.65
	IDR-S				
selected as $\tau^\pm \to \pi^\pm\nu$	88.28 ± 0.40	3.16 ± 0.15	1.11 ± 0.15	9.93 ± 0.30	79.20 ± 0.47
selected as $\tau^\pm \to \pi^\pm\pi^0\nu$	7.56 ± 0.33	73.45 ± 0.37	17.14 ± 0.54	5.92 ± 0.23	84.64 ± 0.32
selected as $\tau^\pm \to \pi^\pm\pi^0\pi^0\nu$	2.18 ± 0.18	13.82 ± 0.29	58.64 ± 0.70	6.33 ± 0.24	50.65 ± 0.66

decay mode identification efficiency in large and small models,
and the purity considering only backgrounds from other high mass di-tau events.

τ decay mode selection

Separation of single prong tau decay modes



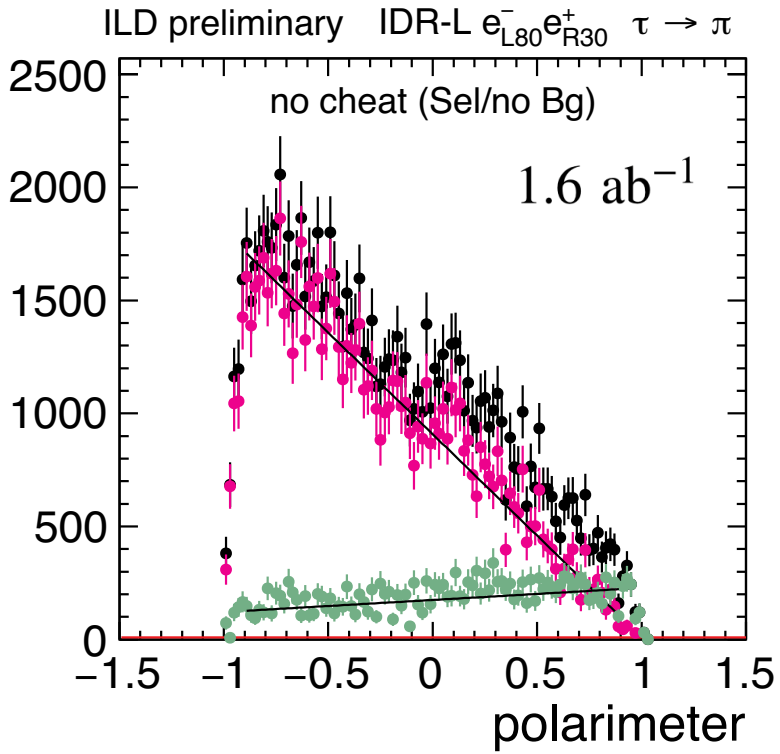


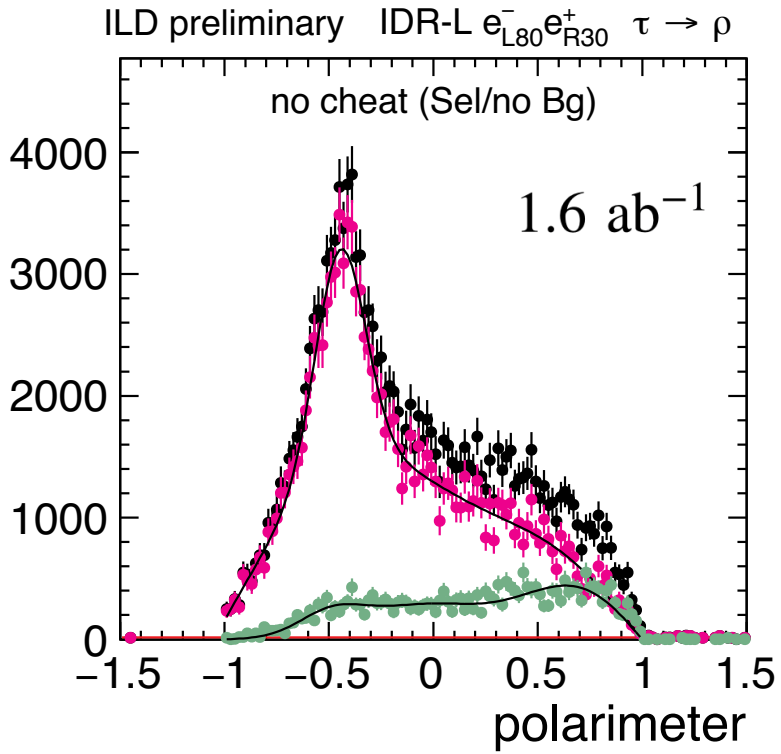
the efficiency and purity (left) and their product (right) of the decay mode selection

IDR-L has slightly better eff $\times$ pur than IDR-S

Polarimeter estimation

Reconstructed polarimeter templates for $\tau^{\pm} \to \pi^{\pm}\nu$ and $\tau^{\pm} \to \pi^{\pm}\pi^{0}\nu$ decays in the IDR-L model
scaled to the expected integrated luminosity in the $e^{-}_{L80}e^{+}_{R30}$ and $e^{-}_{R80}e^{+}_{L30}$

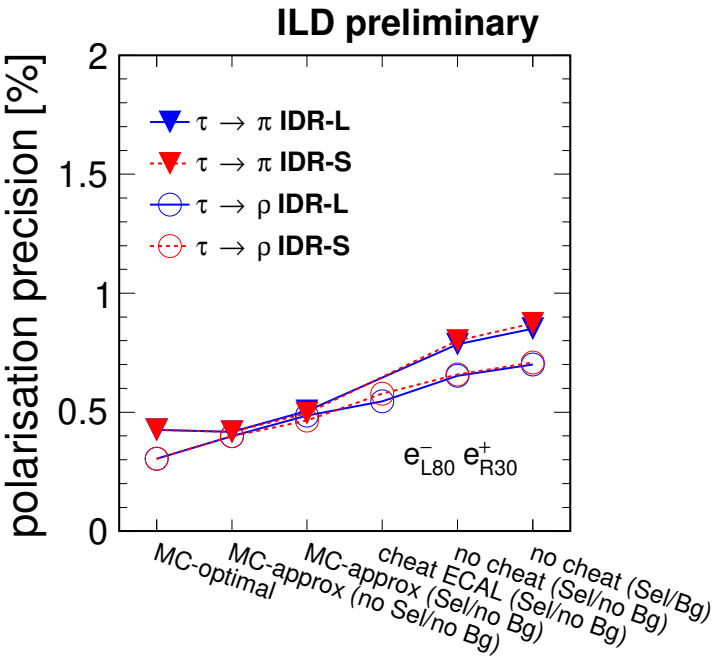




We use them as templates for pseudo-experiments.

τ polarisation measurement

Estimated tau polarisation precision at different level of "cheating" for different decay modes, detector models, and polarisation sets



cheat ECAL: using MC photon momentum

MC-approx: using MC photon & pion momentum

MC-approx(no Sel/Bg): all events

The $\tau^{\pm} \to \pi^{\pm}\pi^{0}\nu$ decay mode has somewhat better precision than $\tau^{\pm} \to \pi^{\pm}\nu$

Conclusion

- The reconstruction and selection of high mass pairs of tau leptons at ILC-500 was investigated
- Polarimeters were reconstructed in the $\tau^{\pm} \to \pi^{\pm}\nu$ and $\tau^{\pm} \to \pi^{\pm}\pi^{0}\nu$
- At ILC-500, tau polarisation precision is better than 1%
- The performance of two detector models, IDR-L and IDR-S were compared.
- IDR-L model performed somewhat better at reconstructing the number of photon and at identifying tau decay modes.
- The final precision on the tau polarisation measurement of the two models is very similar

Backup

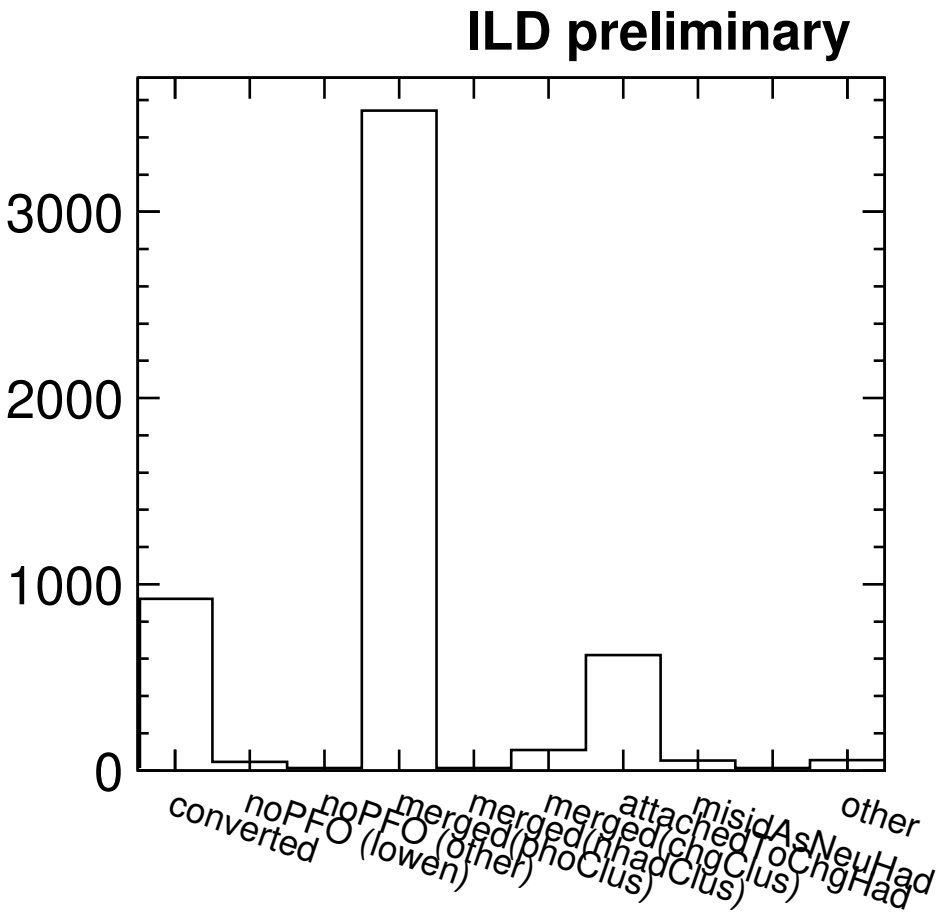


Figure: Reason for which only a single photon PFO was found in $\tau \to \rho$ decays

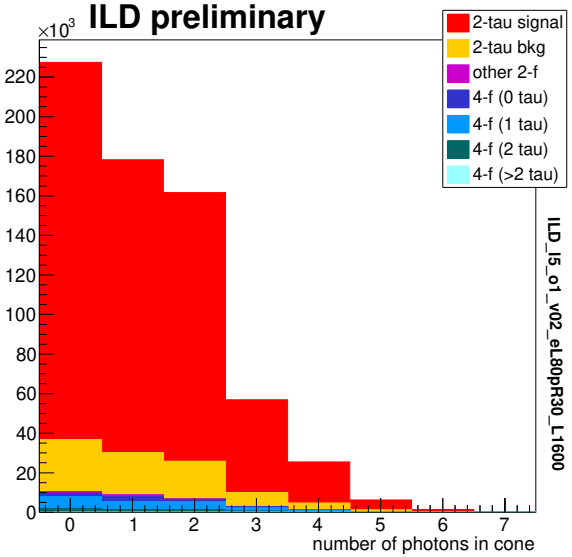
The most common reason for mis-counting the number of photons is that the two photons have been merged into a single photon-like cluster.

Event selection

- energy of the second seed PFO less than 200 GeV [to remove di-lepton events(ee, $\mu\mu$)]
- sum of the energy [p_T]of PFOs lying outside the two cones less than 40 [20] GeV [to remove hadronic events]
- acoplanarity between candidate jet directions less than 0.05 rad [remove fully leptonic WW events]
- acolinearity between candidate jet directions less than 0.075 rad [remove Z return events]
- no photon-like PFO with energy larger than 10 GeV located outside the two cones [remove events with seen ISR]
- no isolated leptons identified by the IsolatedLeptonTagging processor [remove di-lepton events, fully leptonic tau decays]
- the smallest and largest eigenvalues of the shower ellipsoid must respectively lie in the range 3.2→63 mm and 6.3→100 mm

τ decay mode selection

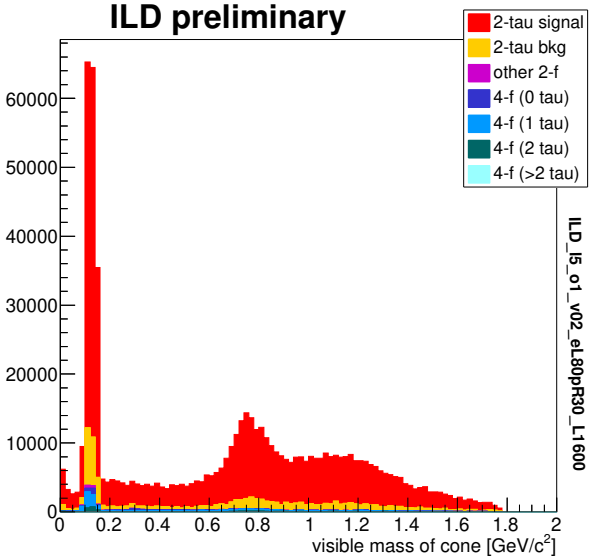
Distributions after the event selection, before decay mode identification.

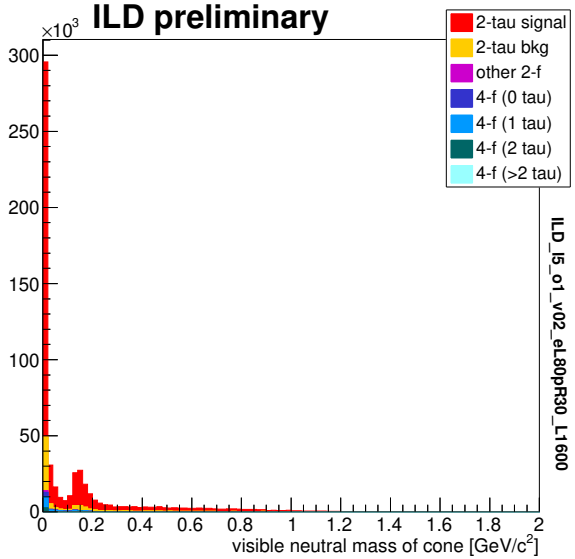


the number of photon PFOs(top)

the invariant mass of all(left) and

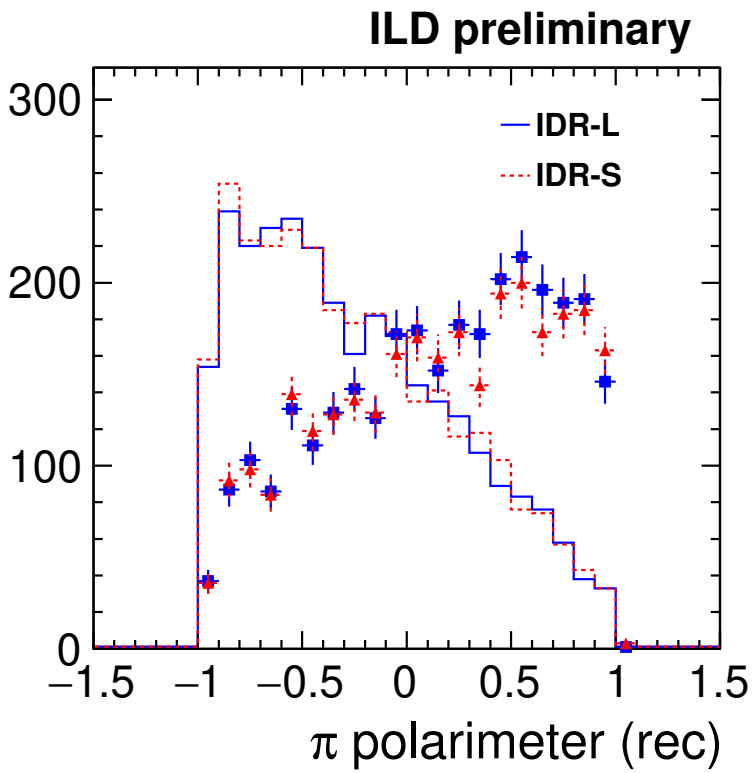
all neutral (right) PFOs inside jet

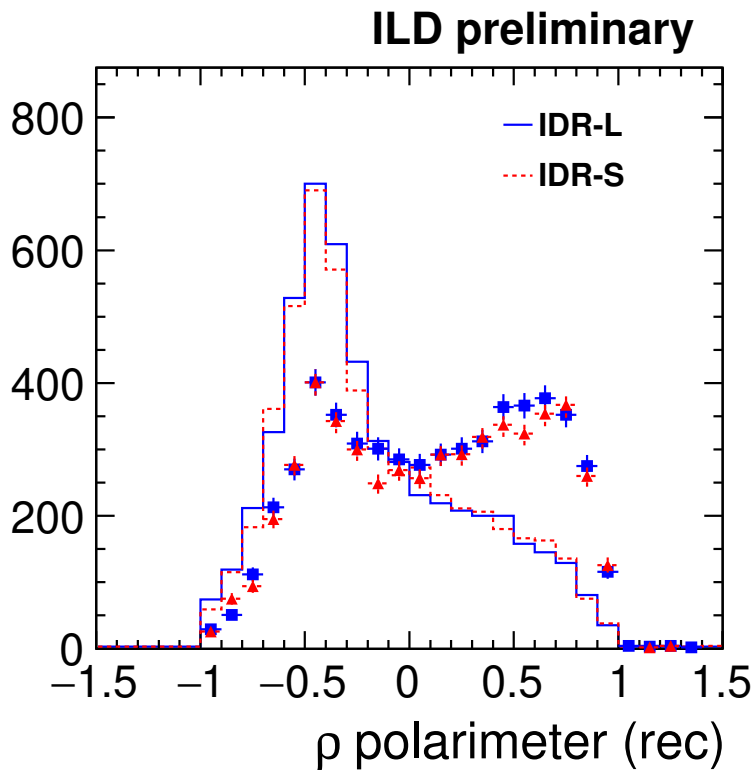




Polarimeter estimation

"Approximate" polarimeters in selected and correctly identified tau jets.





the line : for 100 $\%e_L^-e_R^+$

the markers with error bars : for 100 $\%e_R^-e_L^+$

Event selection

(a) the second seed PFO energy

(b) the outside energy of PFOs

(c) Jet acoplanarity

(d) Jet acolinearity

(e) no ISR photon

(f) no isolated leptons

(g) the shower shape