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A measurement of the tau lifetime

Preliminary

DELPHI Collaboration

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Abstract

The tau lifetime has been measured with different techniques using data taken up to and including 1995 in the DELPHI detector at LEP. Combining these new measurements with previously published DELPHI results provides an estimation of the tau lifetime of $292.7 \pm 1.7 \pm 1.3$ fs.

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1 Introduction

Two new preliminary determinations of the tau lepton lifetime by the DELPHI collaboration are presented.

In the channel in which a tau decays into a final state containing three charged particles it is possible to reconstruct the decay vertex and measure the decay distance from the centre of the interaction region of the LEP beams. An analysis of the whole sample of three-prongs tau decays collected in DELPHI from 1991 to 1995 is described.

When a tau decays into final states with only one charged particle, the lifetime information is carried by the impact parameter of that particle with respect to the centre of the interaction region. The same analyses methods applied to 1991–1993 data [1, 2], exploiting the correlation between the impact parameters of the two charged tracks in one-prong vs. one-prong tau decays, were applied to the data collected during the 1994 LEP running.

2 Selection

The same event selection applied in the measurement of tau polarisation [3] was used to preselect tau pairs candidates. Further cuts were envisaged to increase the quality and purity of the samples used in the lifetime analyses.

In the three-prong channel the event is divided in two hemispheres by a plane perpendicular to the thrust axis. Events are selected in which there are three charged tracks in one hemispheres and up to three in the opposite one. In each hemisphere the invariant mass of the system of charged tracks was required to be less than 2 GeV/c^2. Such a cut drastically reduces the contamination from low multiplicity hadronic events which are the main source of background for this channel. The background contamination in the data sample used in this analyses was $0.4 \pm 0.1\%$.

In the one-prong vs. one-prong channel, events were required to have one and only one track per hemisphere with hits in the Vertex Detector. To reduce background from $\mu^+\mu^-$ and e^+e^-, events containing an identified electron or muon with momentum larger than 40 GeV/c were discarded. Also additional quality requirements should have been satisfied by both track: a transverse momentum greater than 1 GeV/c, having associated points in at least two VD layers, 11 associated points in the TPC and a probability of increase in the χ^2 when adding VD points to TPC segments greater than 0.1% (this cut is tightened to 1% for identified electrons). These criteria select 19189 events in the 1994 data sample. Residual background in the sample consists of $0.8 \pm 0.1\%$ and $0.5 \pm 0.1\%$ from e^+e^- and $\gamma\gamma$ events respectively.

3 Decay vertex lifetime determination

For selected three-prong tau decay candidates, a vertex is formed with the tracks in the hemisphere and the event is kept in the lifetime determination if the χ^2 probability of the vertex fit is larger than 0.5%. The typical resolution on the decay length from the vertex fit is 750 μm.

On the 11651 surviving events a maximum likelihood fit is performed, using as probability density function the convolution of the exponential decay time distribution with a resolution function describing errors on vertex reconstruction.

The observed decay length distribution compared with the fitted one is shown in figure 1. The result of the fit is

$$\tau_\tau(3 \text{ prong}) = 292.6 \pm 3.3(\text{stat.}) \pm 2.9(\text{syst.}) \text{ fs.} \tag{1}$$

Systematic errors are due to selection, 0.7 fs, knowledge of the resolution function, 2.1 fs, and alignment, 1.8 fs.

4 One-prong lifetime determination

In events where both taus decay into final states with only one charged particle, the impact parameters of the two tracks are combined to provide an estimation of the lifetime.

The algebraic sum of the impact parameters, called the miss distance, is equivalent to the separation of the two tracks at the production point. The lifetime is determined by an unbinned maximum likelihood fit to the observed distribution. The probability density function is given by the convolution of a physics function and a resolution function. The physics function is the distribution of miss distances expected from the decay length of taus. It is described by a convolution of the sum of two exponential functions and a Gaussian function. The resolution function describes the effects of track reconstruction in the detector. For each reconstructed track it is given by a double Gaussian according to the particle type (e, μ or π) and momentum.

The result of the fit (figure 2), is

$$\tau_\tau(\text{miss dist.}) = 293.6 \pm 2.8(\text{stat.}) \pm 2.7(\text{syst.}) \text{ fs.} \tag{2}$$

Main sources of systematic errors are the description of the physics function (0.6 fs), knowledge of the resolution function (0.7 fs), fit range (2.0 fs), background (1.1 fs), tau decay branching ratios and tau polarisation effects (0.7 fs).

The difference of impact parameters can be related with the projected acoplanarity of the decay products [4]:

$$\langle d_+ - d_- \rangle = \gamma\beta c\tau_\tau \sin\theta_\tau \Delta\varphi. \tag{3}$$

In such a case the impact parameter difference error is strongly affected by the size of the interaction region ($\approx$ 110 μm in the horizontal plane), but the information from the direction measurement can be used. An event by event weighted χ^2 minimisation is performed fitting the linear dependence of the impact parameter difference on the projected acoplanarity. An out-lier rejection is performed removing 0.4% of the events.

The impact parameter difference versus projected acoplanarity is shown in figure 3, together with the result of the linear fit. The lifetime estimate is

$$\tau_\tau(\text{IPD}) = 292.1 \pm 4.5(\text{stat.}) \pm 2.3(\text{syst.}) \text{ fs} \tag{4}$$

where the main contributions to the systematic error are the effect of radiative $\tau\tau\gamma$ production (1.3 fs), the trimming procedure (1.0 fs), selection (1.2 fs), and background (0.8 fs).

The two above measurements can be averaged taking into account a 30% statistical correlation [2] and fully correlated alignment and selection systematic errors. This provides a combined result of

$$\tau_\tau(1 \text{ prong}) = 293.1 \pm 2.7(\text{stat.}) \pm 2.1(\text{syst.}) \text{ fs} \tag{5}$$

5 Combination of results and conclusions

The tau lifetime determination in the three-prong channel provides an updated measurement of

$$\tau_\tau(\text{3-prong}) = 292.6 \pm 3.3(\text{stat.}) \pm 2.9(\text{syst.})\ \text{fs}, \tag{6}$$

which supersedes the 91–93 DELPHI published results [1, 2] with this channel.

In the one-prong versus one-prong channel, the combined result,

$$\tau_\tau(\text{1-prong, 94}) = 293.1 \pm 2.7(\text{stat.}) \pm 2.1(\text{syst.})\ \text{fs} \tag{7}$$

can be averaged with previously published DELPHI results,

$$\tau_\tau(\text{1-prong, 91}) = 298 \pm 7(\text{stat.}) \pm 4(\text{syst.})\ \text{fs}, \tag{8}$$

$$\tau_\tau(\text{1-prong, 92–93}) = 291.8 \pm 3.3(\text{stat.}) \pm 2.1(\text{syst.})\ \text{fs}, \tag{9}$$

to provide the result

$$\tau_\tau(\text{1-prong}) = 292.7 \pm 2.0(\text{stat.}) \pm 1.4(\text{syst.})\ \text{fs}. \tag{10}$$

The one- and three-prong measurements were averaged taking into account the common systematic uncertainties arising from the alignment procedure. This gives a preliminary DELPHI estimate of the tau lepton lifetime of

$$\tau_\tau = 292.7 \pm 1.7(\text{stat.}) \pm 1.3(\text{syst.})\ \text{fs}. \tag{11}$$

References

[1] DELPHI Collaboration, Phys. Lett. **B302** (1993) 356.

[2] DELPHI Collaboration, Phys. Lett. **B365** (1996) 448.

[3] DELPHI Collaboration, Zeit. Phys. **C67** (1995) 183.

[4] ALEPH Collaboration, Phys. Lett. **B279** (1992) 411.

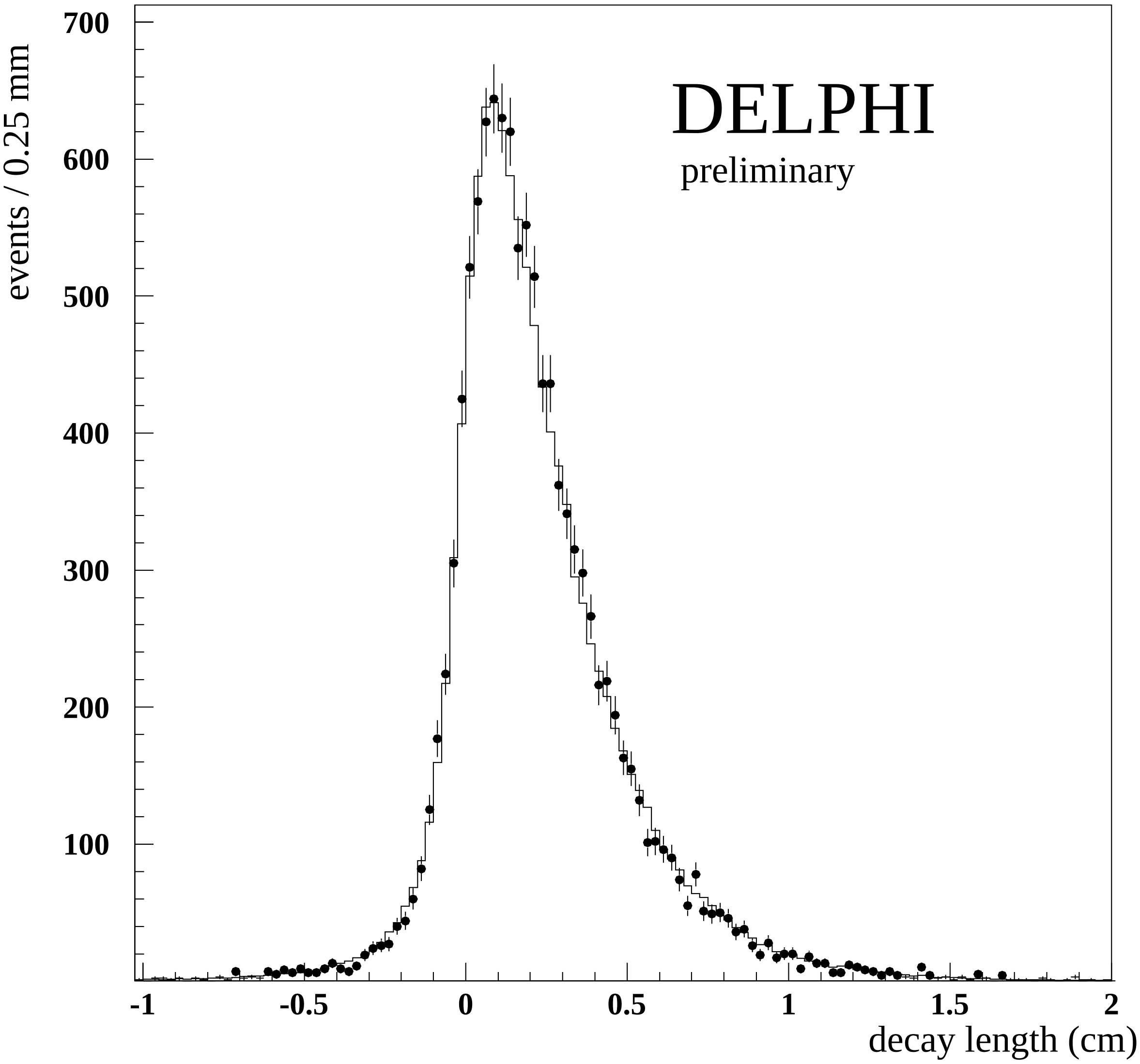

Figure 1: Decay length distribution for three-prong tau decays. The points are data and the continuous line is the result of the fit.

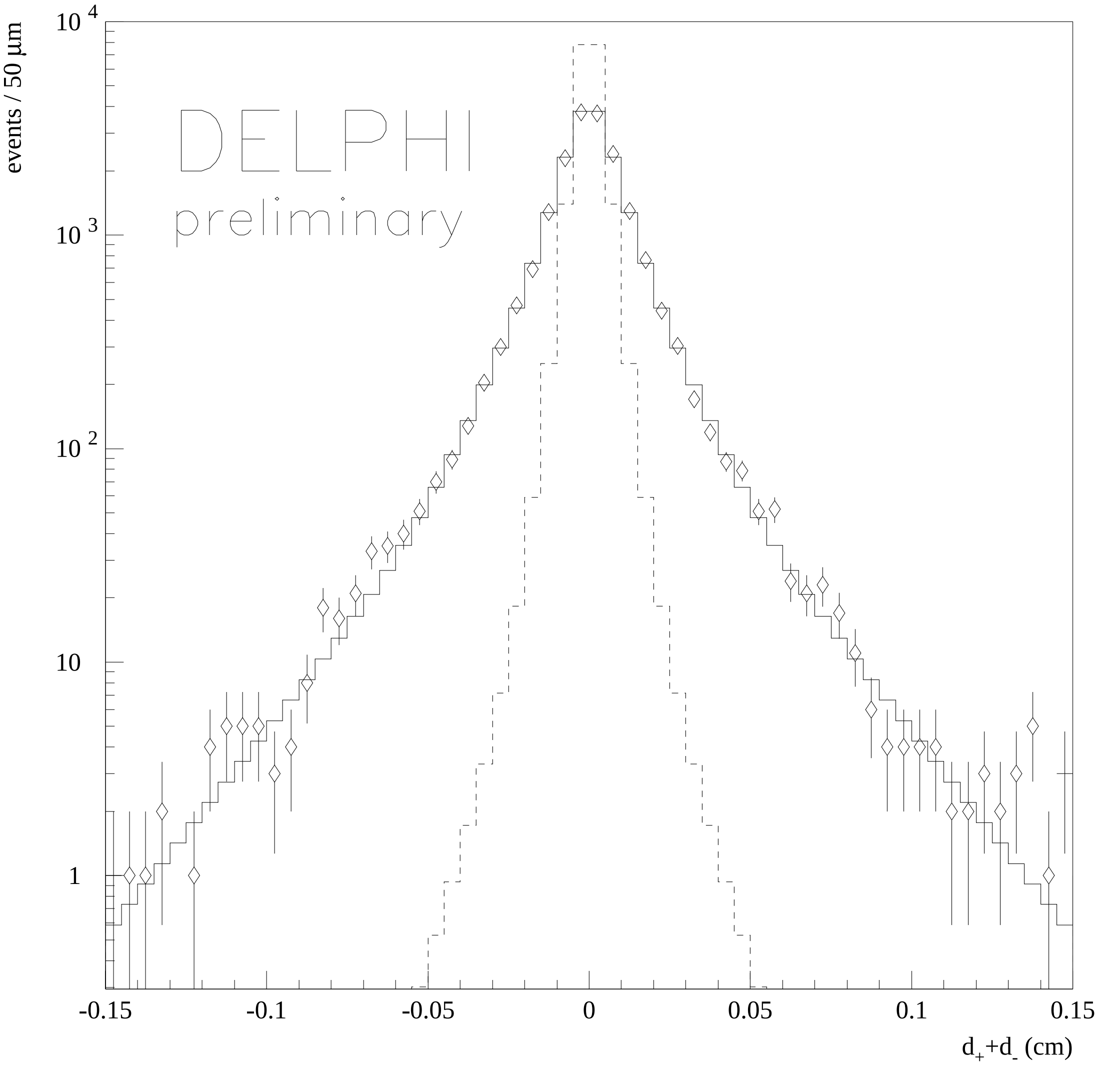

Figure 2: Distribution of the miss distance; diamonds are data, the full line the fitted distribution and the dashed line the distribution corresponding to tau pairs simulated with zero lifetime (i.e. showing resolution effects only).

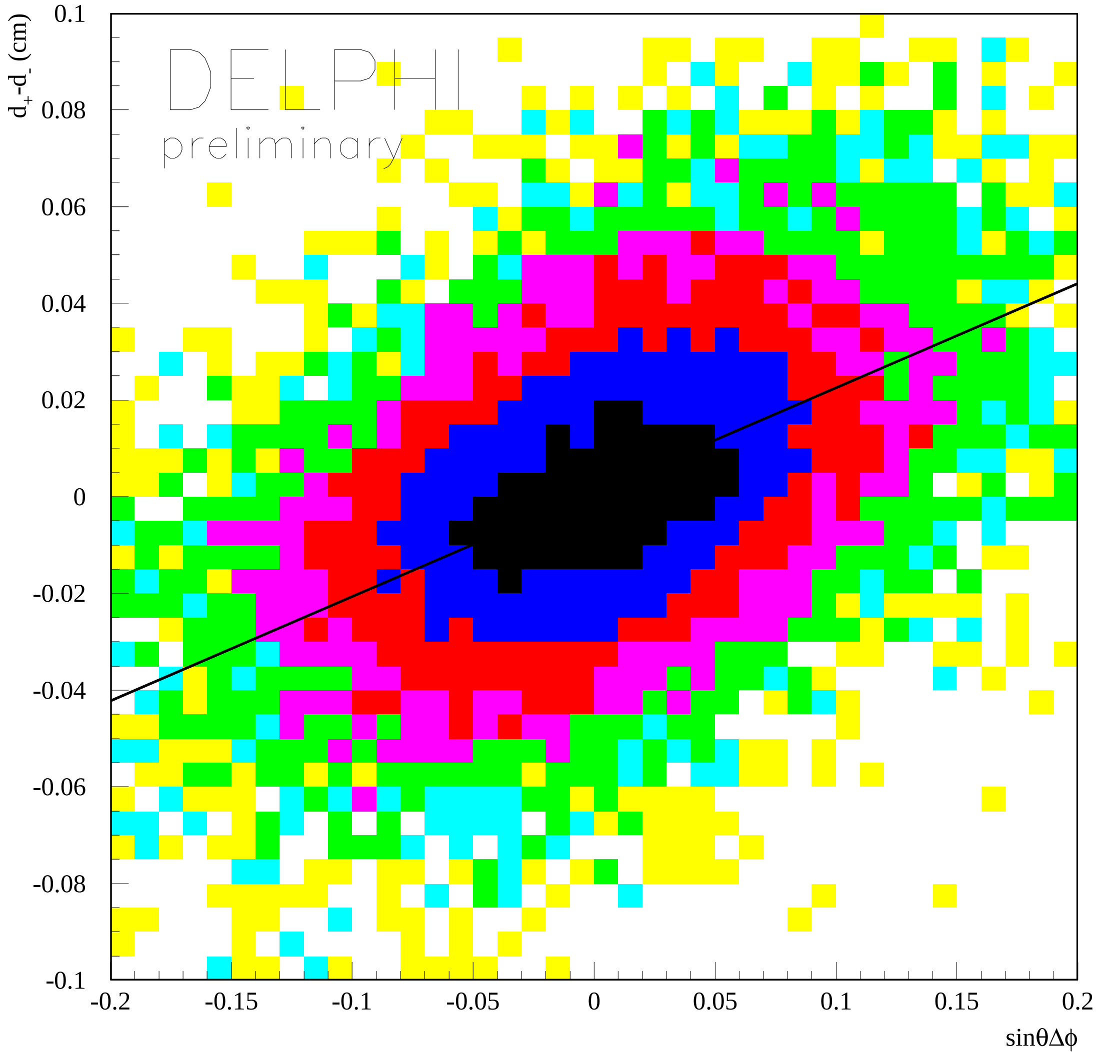

Figure 3: Distribution of the difference of impact parameters versus the projected acoplanarity; the slope of the fitted line is the mean decay length, which, after correction for biases due to reconstruction and background, is translated into the lifetime measurement as explained in the text.