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Update of tau lifetime analysis with the decay length method in 1992 data

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Abstract

Decay length method is used for tau lifetime determination in 1992 data sample. Small differences with previou analysis are shown. A (preliminary) result of $\tau_\tau = 291.9 \pm 5.8(\text{stat.}) \pm 2.4(\text{syst.})\,\text{fs}$ is obtained.

1 Decay length method

The analysis presented here was already used in 1991 data sample, and gave a published [1] result of $\tau_\tau = 298.0 \pm 10.6(stat.) \pm 4.5(syst)\,\text{fs}$. The method was already described in a previous note [2], and is recalled here: three prong tau decays are selected, and the secondary vertices are found with a minimum χ^2 fit; then the decay length is calculated event by event from the decay vertex and beam positions, using the reconstructed tau direction; mean tau lifetime is extracted from observed decay lengths. Main changes are in event selection criteria: this year we used **tslt01** instead of SELTAU: this gives higher efficiency and lower background. Some attention has been paid to the tau axis reconstruction, and to the problem of track confusion.

2 Events selection

The runs used were the ones simultaneously selected by the "VDET", "Heavy flavour ECAL" and "Heavy flavour HCAL" groups, with the rejection of 17 of them, which had some particular subdetector problem. These runs correspond to an integrated luminosity of about $21.5\,\text{pb}^{-1}$. Events were selected from class 24, asking no online error, LLUMOK or SLMUOK true, and r.c. from **tslt01** equal to 0 or 100: this gives 25679 events. Montecarlo used is a sample of $287K$ events produced with GALEPH version 255.1 and JULIA 271.7: $235K$events pass **tslt01** selection criteria.

3 Tau axis reconstruction

Errors on reconstructed tau direction should in principle have small effect on decay length analysis. The effect of this uncertainty is taken into account at lowest order enlarging beam size in the plane transverse to tau direction, so that in long lived taus the extrapolation from decay vertex does not fail too much the beam spot, thus avoiding biases in the analysis. However, a more subtle effect is present: not a big one, but clearly visible in data and Montecarlo. What happens is that events with unrealistic small reconstructed resolution have too short reconstructed decay length.

The problem was traced back to events with high acollinearity were tau axis reconstruction was dominated by tracks in the hemisfere opposite to the one analized, so that vertex covariance matrix was not cut along his major axis, and the projection of real tau path along this wrong axis resulted always in a smaller decay length value.

To avoid such problems, instead of the sphericity axis of the whole event, a slightly different defintion has been used for the tau direction and for three prong selection criteria. Firstly, the event sphericity axis is determined. Then reconstructed energy flow objects which form with this axis an angle greater than 18° are thrown away, and the sphericity axis is re-calculated. Only three prong jets inside this cone are used in the analysis. This method does not improve very much the resolution on tau direction (the r.m.s. of the angle between the two axis goes from 15 to 14 mrad) but eliminates very badly reconstructed events (with a sphericity axis more than 300 mrad away from true tau direction). The number of three track jets with unitary total charge satisfying these requirement found in the sample is 7879.

4 Three prong decay selection

Selection for three prong decays is very similar to last year's one: each track in jet should have:

1. At least 8 TPC points;
2. At least 1 VDET point (z or $r\phi$);
3. momentum larger than $0.5\,\mathrm{GeV}/c$;
4. $|d_0| < 0.5\,\mathrm{cm}$;
5. $|z_0| < 4.\,\mathrm{cm}$.

Moreover, the sum of the χ^2 for degree of freedom of the tracks must be less than 12. In order to reject background from gamma conversions, no track must be identified as an electron. Hadronic events are rejected requiring a jet invariant mass less than $2\,\mathrm{GeV}$.

5 Vertex reconstruction

The program used for vertex reconstruction is the same of last year (a private modification of $V0$ ALEPH routines). In Fig. 1 is shown the distribution of the fit probability. The cut at 0.04 (the same as last year) was choosen again looking at the behaviour of the tails of the resolution function (measured by the κ factor in lifetime fit, see following sections). This cut is the less efficient one: it rejects 37.7% of events in data and 31.3% in Montecarlo. Resolution along tau direction, projected

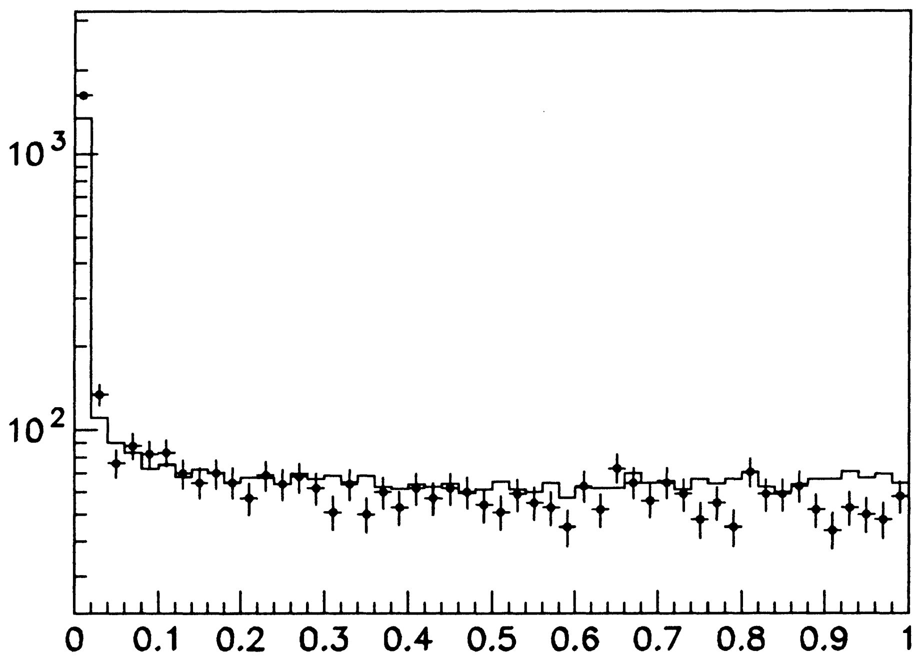

Figure 1: Probability of vertex fit distribution for data (points) and Montecarlo (histogram). Prob(χ^2) > 0.04 is required.

into xy plane, is about 530 μm (from Montecarlo).

6 Decay length reconstruction

A second minimum χ^2 fit is performed to reconstruct the decay length event by event searching for two point along the tau axis near the production and decay vertices. The beam position and the Y and Z beam size were taken from GET_BP by Dave Brown. For the X size, however, instead of using a single value for the whole year, we used the values which were calculated on meta-chunk of about 300 events and are used in Montecarlo to generate a more realistic beam spot (see [3]): these measurements are available by courtesy of S. Wasserbaech (for more details, see the note on IPD analysis [4]). This reduces the possibility of biases coming from long lifetimes giving a bad χ^2 . In Fig. 2 is shown the distribution of the χ^2 probability. A loose cut (at 0.4% probability) is put, since only very low probability events are badly reconstructed. No bias is introduced with this cut. Moreover, events with reconstructed error greater than 3 mm were rejected (only one event in data). In

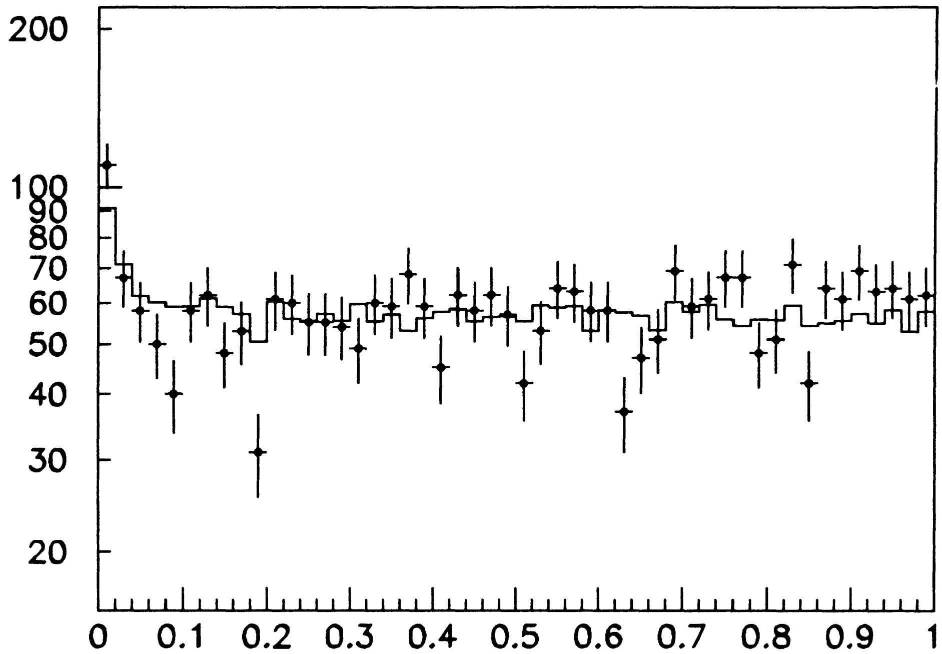

Figure 2: Probability of Decay Length fit distribution for data (points) and Montecarlo (histogram). Prob(χ^2) > 0.004 is required.

Fig. 3 the decay length distribution is shown: there is one event in data and four in Montecarlo with decay length greater than 3 cm: they are not used in the mean lifetime calculation. So final sample is of 2835 decays (30023 in Montecarlo). In table 1 is summarized the number of decays passing each cut.

7 Tau lifetime calculation

A maximum likelihood fit is performed on decay length distribution in order to extract the mean decay length. As last year, an overall scale factor κ for errors is left free in the fit. The results in data and Montecarlo are:

$$\ell_0 = .2209 \pm .0044\,\mathrm{cm} \quad \kappa = 1.22 \pm 0.04 \quad \text{Data}$$
$$\ell_0 = .2250 \pm .0014\,\mathrm{cm} \quad \kappa = 1.12 \pm 0.01 \quad \text{Montecarlo}$$

with a Montecarlo input lifetime of 296 fs, corresponding to a generated decay length of .2261 cm (initial state radiation included).

In Fig. 4 is shown the comparison between the fit and the original distribution for both data and Montecarlo.

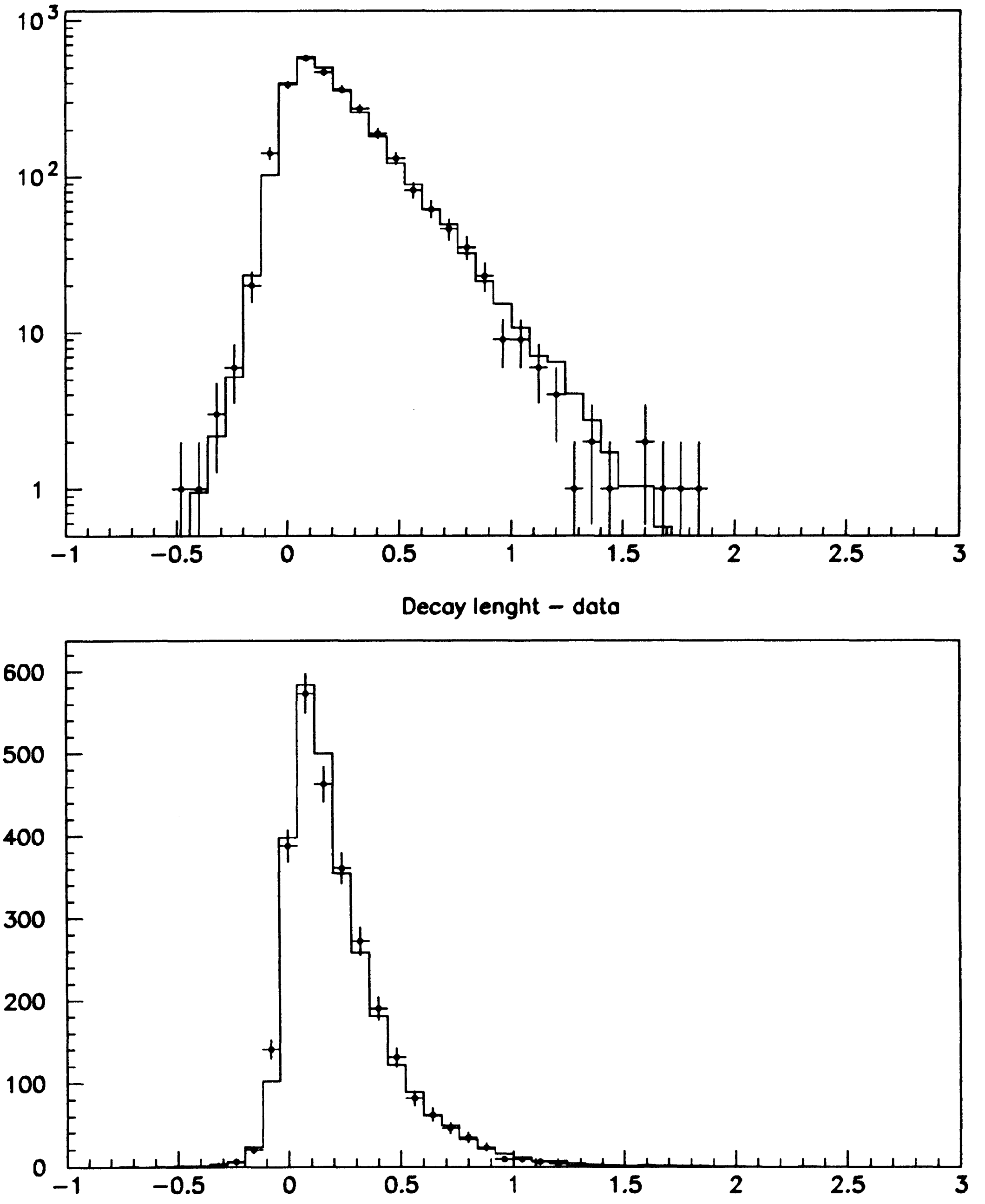

Figure 3: Decay Length distribution for data (points) and Montecarlo (histogram) in linear and logarithmic scale. One event in data and four on Montecarlo have decay length greater than 3. cm. They are not used in the final fit.

Table 1: Decays passing cuts

Cut	Data	ϵ	Montecarlo	ϵ
Tau pairs	25679		234436	
Three track jets	7998	0.312	74238	0.317
8 TPC points	7542	0.943	70000	0.943
1 VDET point	5569	0.738	51534	0.736
$P > 0.5\,\mathrm{GeV}$, $\lvert d_0\rvert < 0.5\,\mathrm{cm}$, $\lvert Z_0\rvert < 4.\,\mathrm{cm}$	5388	0.967	50023	0.967
$\Sigma\chi^2\ /ndf < 12.$	5307	0.982	49566	0.990
No electron	4648	0.878	44222	0.893
Inv. Mass less than 2 GeV	4645	0.878	44217	0.893
Vertex Prob(χ^2) > 0.04	2893	0.623	30379	0.687
Decay Length fit Prob(χ^2) > 0.04	2837	0.981	30068	0.990
Error < .3 cm	2836	1.000	30027	0.999
Decay Length < 3 cm	2835	1.000	30023	1.000

8 Systematic biases and uncertainties

Systematic errors are calculated as last year. First, there is the effect due to residual hadronic events. From Montecarlo, the number of events present in final sample is 6.8 ± 1.6, which correspond to an effect of $0.24 \pm 0.11\%$. The effect of gamma conversions faking three prong decays is already contained in Montecarlo: however this correction has fluctuations of the order of 0.06%. The effect of a wrong beam position was studied varying this quantity of one sigma in data: the variation obtained is small ($< 0.1\%$) and within statistical expectations. A variation of 10% on beam size gives a similar result.

Several checks has been made in order to verify the stability of final likelihood fit: a different parametrization for errors has been tried, using $\sigma^2 = k^2\sigma_t^2 + \rho^2$, were σ_t is the tracking error from Julia, and k, ρ are parameters left free in the fit (see last year IPS analysis): in both cases, the fit gives ρ equal to zero well within errors. Another check was made degrading Montecarlo resolution so as to reproduce the value ok κ found in data. The mean tau lifetime change is unobservable.

Then the correction on beam spot size due to tau direction uncertainty is removed: since in this way we are introducing a lifetime-dependent bias, Montecarlo events were weighted so as to reproduce data lifetime. The change in the ratio is $0.20 \pm 0.24\%$.

The problem of track confusion was studied again varying the cut on the vertex fit probability. Ratio between data and Montecarlo is constant within 0.4% when going fron zero to 0.2,as can be seen in Fig. 5. Another check was made using more tight requirements on tracks: the analysis was restricted to decays in which each track had one hit in outer layer, or one hit in each layer, or one complete ($r\phi$ and z) hit in each layer. In each case, the differences found were compatible with statistical fluctuations and of the same order of the quoted systematics (about 0.3%).

The only try which gives trouble is the dependence of decay length on jet opening angle, which in principle could be connected with track confusion. Data sample was divided into two bins containg roughly the same number of events, depending wether

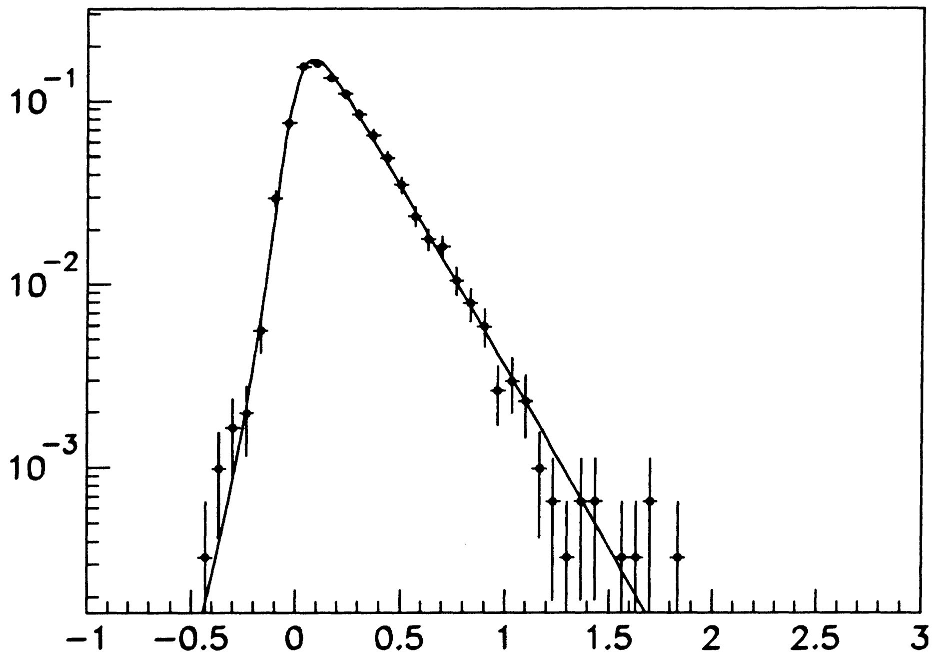

Figure 4: The decay length distribution compared with the result of the fit (data).

the jet opening angle (projected into $r\phi$ plane) was less or more than 70 mrad. The fit on first bin (small angles) gives a mean decay length of 0.2070 ± 0.0060 cm, while the other gives 0.2336 ± 0.0065 cm: this correspond to a 3σ difference. In Montecarlo, a smaller difference (15 μm) of the same sign is observed. Note however that:

1. The division into two equal events bins is the one were the biggest difference is seen;
2. This difference seems not to be related with track confusion: indeed, it remains unchanged in size if the analysis is restricted to events with one complete VDET hit in each layer for each track, and when a minimum $r\phi$ or z distance among track on VDET inner surface greater than 300 μm is requested;
3. There is no increasing decay length with increasing angle: events with opening angle less than 20 mrad have a decay length 0.054 ± 0.024 cm higher than the ones with opening angle between 20 and 60 mrad;
4. The effect should not be reproduced by Montecarlo: but this is the only case in which such a big difference is seen. In particular, opening angle distributions in data and Montecarlo agree quite well.

For these reasons, a very bad statistical fluctuation is assumed.

The effect of a d_0 or z_0 offest correlated with decay angle has been studied too. The effect of the correlation among d_0 offset and ϕ cancels out averaging over the full

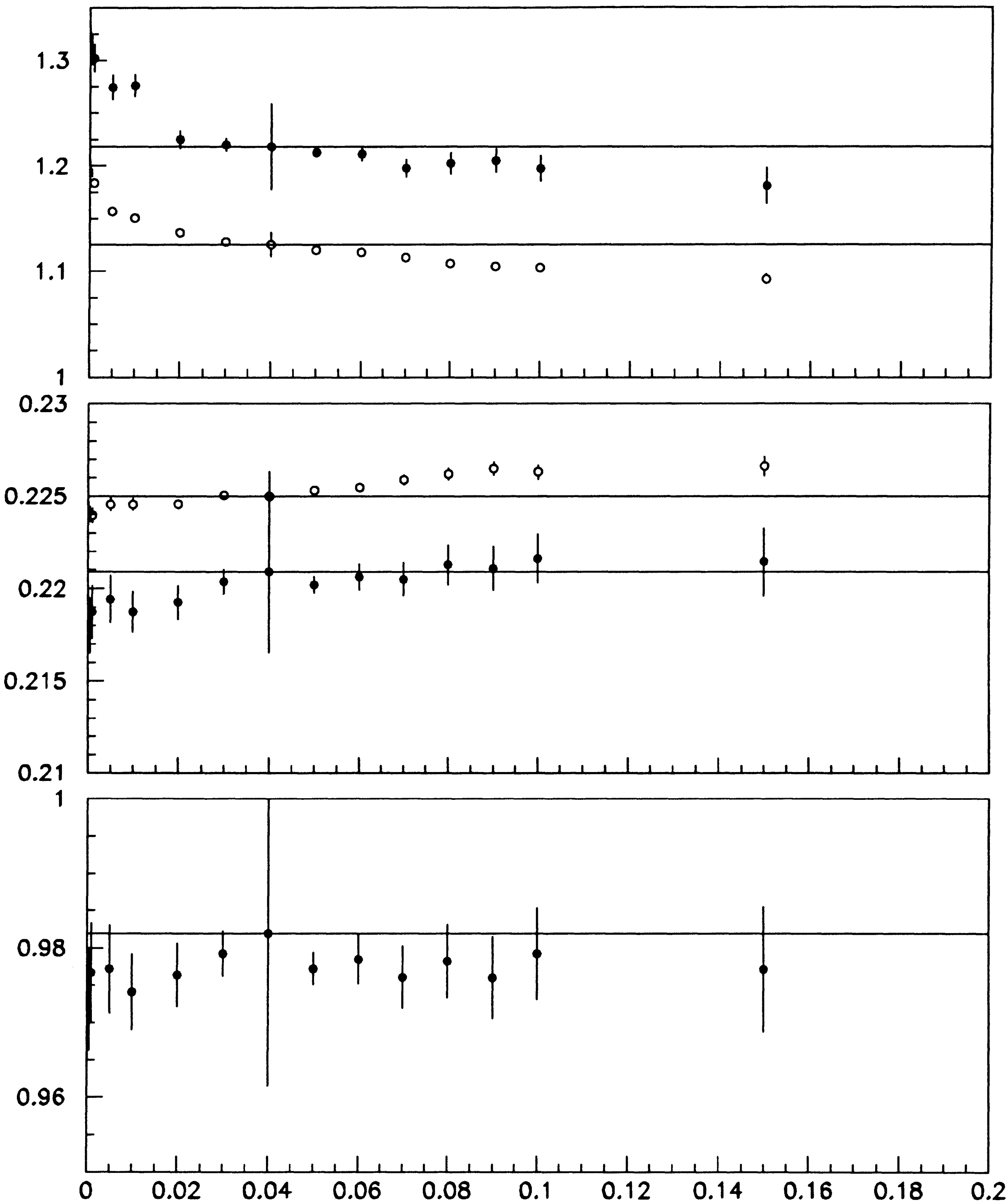

Figure 5: Variation of κ (upper plot) and of the mean decay length (middle plot) as function of the vertex probability cut for data (points) and Montecarlo (open circle). Lower plot is the ratio of data and Montecarlo Decay lengths. Errors at 0.04 are the full statistical uncertainties, while others error bars show the expected statistical differences with respect to that point.

azimuthal angle (see [5]), so it is not important. The effect of a z_0 offset correlated with the polar angle has not this nice feature,and is then worth to be studied in detail, using tracks in hadronic events. The difficulties in evaluating a z_0 offset arise mainly from z beam spot dimension, which is very large (7 mm). To overcome this problem,two classes of tracks have been selected in $q\overline{q}$ events: the first one consists of the best measured tracks (with at least one z VDET hit, more than 15 TPC hits, momentume greater than 5 GeV, d_0 less than 0.5 mm), well measured tracks (the ones not falling in the former class, but with one z VDET hit, a good number of TPC hits, and a good χ^2 for degree of freedom). The second class is used to measure event by event the mean z_0, which gives an estimate of the z position of the interaction point. The z_0 of individual best measured tracks are then measured with respect to this $\langle z_0 \rangle$. At least nine tracks must be used in the evaluation of the mean, otherwise the event is rejected. In this way, a global z_0 offset escapes measurement, while the angle dependence remains clearly visible. To estimate the sesitivity of the method, tracks were artificially distorted with a shift of the form: $\Delta z_0 = 100\,\mu\text{m} \cdot \tan\lambda$. This effect was cleraly visible in the plot of $z0 - \langle z0 \rangle$ vs. $\tan\lambda$, with small effects (less than $10\,\mu$m) on the $\langle z_0 \rangle$ evaluation: so the correlation of z_0 and $\langle z_0 \rangle$ is less than 10%. In fig 6 the plot of $z_0 - \langle z_0 \rangle$ as function of $\tan\lambda$

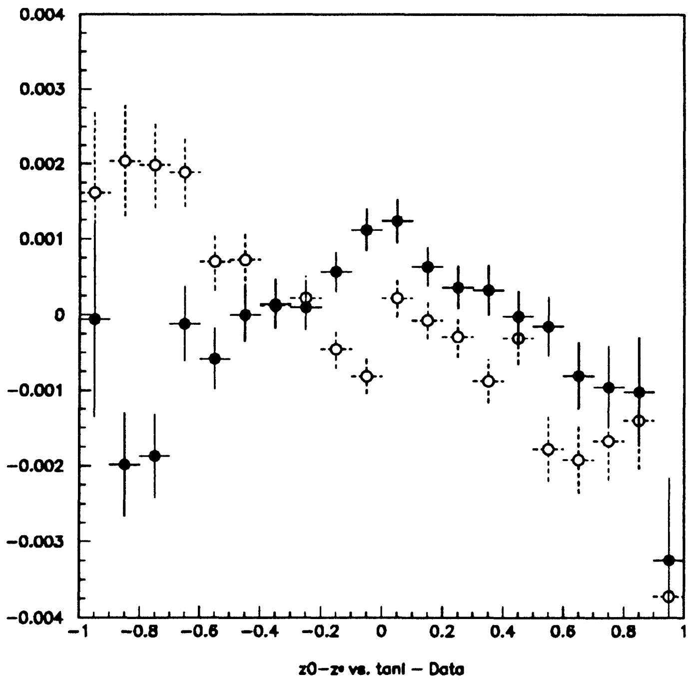

Figure 6: z_0 of best measured tracks minus the mean z_0 of others well measured tracks in the same event as function of $\tan\lambda$ for data (points) and Montecarlo (open circles)$q\overline{q}$ events.

is shown for data (points) and Montecarlo (open circles). On the rigth side of the plot the shape is similar, while on the left side has a different sign. As a further check, the z_0 of all tracks in tau Montecarlo with respect to the true production point has been calculated, and plotted against $\tan\lambda$: the plot obtained is identical within statistical errors to the one for $q\bar{q}$ Montecarlo. Both sides have been fitted with straigth line, taking into account the possibility of a discontinuity around zero, and both data and Montecarlo have been refitted with the appropriate correction. The shift in the ratio found is -0.36%. Since this effect is rather small, and only roughly evaluated, a conservative estimate has been used, correcting only for half of the shift observed, and adding the whole 0.36% to the systematic error.

Table 2: Contributions to the systematic error.

Source	Error
	%
Montecarlo statistics	-0.52 ± 0.61
$q\bar{q}$ background	-0.24 ± 0.11
Conversions	± 0.06
Pattern rec. errors	± 0.40
Beam size & position	negligible
z_0 offset	-0.18 ± 0.36
Total	-0.94 ± 0.81

Correcting for systematic biases and uncertainties (see table 2) the final result is:

$$\tau_\tau = 291.9 \pm 5.8(\text{stat.}) \pm 2.4(\text{syst.})\,\text{fs}.$$

References

[1] D.Buskulic *et al.*,Phys. Lett. B 297 (1992) 432.

[2] M.Carpinelli *et al.* ALEPH 92 - 25, PHYSICS 92 - 22.

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[4] S.Wasserbaech, Measurement of the τ lifetime with the impact difference method: 1992 data,ALEPH 95 - 026 PHYSIC 95 - 024.

[5] S. Wasserbaech, Systematic biases in particle lifetime measurements, Phys. Rev. D48, 4216-4223, 1993.