Size of the Luminous Region
at LEP Interaction Point 4
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Abstract

In this memo I describe my measurement of the size of the luminous region at LEP point 4. I use the $d_0$ and $z_0$ measurements from the Aleph ITC and TPC for muon tracks in $Z^0 \rightarrow \mu^+\mu^-$ events. The technique yields the apparent dimensions of the luminous region, i.e., the effects of errors on the beam position and motion of the beam within a fill are not removed. This apparent size is relevant for certain physics analyses. The results are $\sigma_x = 156 \pm 4 \mu$m, $\sigma_y = 33^{+10}_{-14} \mu$m, and $\sigma_z = 9.85 \pm 0.12$ mm, where the errors are statistical only. The systematic uncertainty on $\sigma_y$ is large.

I have measured the apparent size of the luminous region in Aleph using $Z^0 \rightarrow \mu^+\mu^-$ events. Before showing the data I will briefly outline the method.

First I will consider the situation in the $xy$-plane. Suppose that, for a particular event, the $Z^0$ decay occurs at the point $(\delta_x, \delta_y)$, measured with respect to the centroid of the luminous region. Then we have for the $\mu^+$ and $\mu^-$ tracks

\[
d_+ = \delta_x \sin \phi_+ - \delta_y \cos \phi_+ + \delta_+,
\]
\[
d_- = \delta_x \sin \phi_- - \delta_y \cos \phi_- + \delta_-,
\]

where $d_\pm$ are the reconstructed $d_0$'s with respect to the beam axis (standard Aleph sign convention) and where $\delta_\pm$ represent the tracking errors for this event. If the tracks are back-to-back, we obtain

\[
d_+ + d_- = \delta_+ + \delta_-
\]

and

\[
d_+ - d_- = 2\delta_x \sin \phi_+ - 2\delta_y \cos \phi_+ + \delta_+ - \delta_-.
\]

If the $\delta$ are uncorrelated we find, for a particular value of $\phi_+$,

\[
s_2(d_+ - d_-) - s_2(d_+ + d_-) = 4s_x^2 \sin^2 \phi_+ + 4s_y^2 \cos^2 \phi_+,
\]

where $s_x$ and $s_y$ are the rms dimensions of the luminous region.
The determination of $\sigma_z$ is much simpler. Let $z_\pm$ denote the measured $z_0$'s. Again considering the deviations $\delta$ for the $Z^0$ decay point and tracking errors in a particular event, we have

$$z_+ = \delta_z + \delta_+, \quad z_- = \delta_z + \delta_-,$$

so

$$z_+ + z_- = 2\delta_z + \delta_+ + \delta_-, \quad z_+ - z_- = \delta_+ - \delta_-,$$

and

$$\sigma^2(z_+ + z_-) - \sigma^2(z_+ - z_-) = 4\sigma_z^2.$$

For the measurements I used the dimuon events given in MUMU90 EDIR (1990 data only) in the EDIR area. This file refers to the standard DSTs which were produced in the DST-to-DST reprocessing which was completed in December, 1990. The $d_0$ values were computed using the revised (April 1991) fill-by-fill average beam positions and "offsets" from the T. Burnett method. The $z_0$ values were taken from QZB in ALPHA. I selected events which contained exactly two good\(^1\) charged tracks with total charge zero. I further required $|\cos \theta| < 0.8$ for both charged tracks, and I made acollinearity cuts at $\pm 0.01$ in $\Delta (\cos \theta)$ and $\pm 1^\circ$ in $\Delta \phi$.

My sample contained 4105 events. The results of the $d_0$ analysis were $\sigma_x = 156 \pm 5 \mu m$ and $\sigma_y = 44_{-10}^{+8} \mu m$ (statistical errors only). But I found evidence that something was wrong: $\sigma^2(d_+ + d_-)$, which should be related to the tracking resolution only, was found to depend on $\phi$.

I looked for systematic defects in the $d_0$ measurements by plotting $(d_0)$ as a function of $\cos \theta$, $\phi$, track charge, location in the ITC cells, and various combinations of these quantities. Even with the revised beam positions these plots show significant structure at the level of 50 $\mu m$. An effort was made to remove the most serious biases by parametrizing the observed $(d_0)$ offsets given in my plots. The offsets were parametrized over 12 bins in $\phi$ versus 4 bins in $\cos \theta$. Additional ITC-related biases were computed over 10 bins in mod$(\phi, 360^\circ/96)$ versus 8 bins in $\phi$. (The inner ITC layers each have 96 cells.)

After these "corrections" $\sigma^2(d_+ + d_-)$ still has some $\phi$ dependence. My plots of $(d_+ - d_-)^2$ and $(d_+ - d_-)^2$ vs. $\phi$ are shown in Figs. 1(a) and (b). The difference is shown in Fig. 1(c). The fit results are\(^2\) $\sigma_x = 156 \pm 4 \mu m$ and $\sigma_y = 33_{-11}^{+10} \mu m$.

To make an estimate of the systematic uncertainty on $\sigma_y$, I have fitted a horizontal line to the data of Fig. 1(b), obtaining $\sigma^2(d_+ + d_-) = (204 \pm 3 \mu m)^2$. If this value is subtracted from the data of Fig. 1(a) (rather than the bin-by-bin values), one concludes that $\sigma_y = 0$. In summary, some unexplained defects are degrading the resolution in $(d_+ + d_-)$ for certain values of $\phi$. If defects of the same magnitude are present in $(d_+ - d_-)$, we wouldn’t be able to tell and $\sigma_y$ could be zero. (I suppose that the defects could lead to an underestimate of $\sigma_y$ as well.)

\(^1\)A track was "good" if it had at least one ITC hit, at least four TPC hits, $|d_0| < 2 \text{ cm}$, $|z_0| < 10 \text{ cm}$, $|\cos \theta| < 0.95$, and $p > 0.1 \text{ GeV}$.

\(^2\)The fit function is a sinusoid whose mean, amplitude, and phase are free to vary. The dimensions of the luminous region are derived from the mean and amplitude; the $\phi$ angle of the major axis of the beam ellipse is $-3^\circ \pm 2^\circ$. 
Figure 1. Measured means-squared (cm²) versus \( \phi \) (degrees) for dimuon events: (a) \( (d_+ - d_-)^2 \) vs. \( \phi \); (b) \( (d_+ + d_-)^2 \) vs. \( \phi \); (c) \( (d_+ - d_-)^2 - (d_+ + d_-)^2 \) vs. \( \phi \). The curve in (c) is the result of the fit described in the text.

Figure 2. (a) \( z_+ + z_- \) (cm); (b) \( z_+ - z_- \) (cm). (Notice the different horizontal scales.) The curves are the results of gaussian fits.
The distributions of $z_+ + z_-$ and $z_+ - z_-$ are shown in Fig. 2. The fitted resolutions are $19.86 \pm 0.24$ mm and $2.52 \pm 0.03$ mm, respectively, from which we obtain $\sigma_z = 9.85 \pm 0.12$ mm.

I performed the same analysis on a dimuon sample from the 1989 data. Large (and different) systematic defects are seen, and the statistics are poor. The 1989 data doesn't add much to the story. For the record, the results were $\sigma_x = 145 \pm 16$ $\mu$m, $\sigma_y = 48^{+20}_{-15}$ $\mu$m, and $\sigma_z = 9.72 \pm 0.35$ mm.

Finally, I checked the method using a sample of Monte Carlo dimuon events. The dimensions of the luminous region input to the generator were $\sigma_x = 350$ $\mu$m, $\sigma_y = 12$ $\mu$m, and $\sigma_z = 12.8$ mm. From 6066 reconstructed events I calculated $\sigma_x = 351 \pm 4$ $\mu$m, $\sigma_y = 31^{+8}_{-10}$ $\mu$m, and $\sigma_z = 12.70 \pm 0.11$ mm. It is disturbing to note that the Monte Carlo tracking resolution in $d_0$ is 110 $\mu$m, whereas the value obtained from the data is 144 $\mu$m. Moreover, the $z_0$ resolution is 0.86 mm in the Monte Carlo and 1.78 mm in the data. Notice that these values are completely independent of assumptions about the size, shape, and position of the luminous region.

In conclusion, the apparent dimensions of the luminous region in the 1990 data are $\sigma_x = 156 \pm 4$ $\mu$m, $\sigma_y = 33^{+10}_{-11}$ $\mu$m, and $\sigma_z = 9.85 \pm 0.12$ mm (statistical errors only). The systematic uncertainty on $\sigma_y$ is large. Fill-by-fill beam positions were used and an attempt was made to remove the systematic tracking errors. A slightly larger value of $\sigma_y$ is obtained when the uncorrected track parameters are used. The resolutions on the reconstructed $d_0$ and $z_0$ are not accurately simulated in the Monte Carlo.

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3The sample was generated with GALEPH 238 and reprocessed to remove the ITC wire sag problem.