MEASUREMENT OF CESR EMITTANCE AND SEARCH FOR DYNAMIC EFFECTS

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Abstract

We have developed techniques that allow simultaneous measurements of the spatial size of the luminous region and the angular spread of the $e^+e^- \; -\!\!\rightarrow \mu^+\mu^-$ events from the CLEO interaction point of the Cornell Electron-Positron Storage Ring, CESR. These techniques take advantage of the small and well understood resolution of the CLEO tracking system. We use these measurements to extract the horizontal beta, horizontal emittance and the vertical emittance as functions of specific luminosity.

1 INTRODUCTION

The measurement of the emittance of colliding beams is a difficult problem. Here we present a method that relies on the tracking system of a high energy physics experiment, CLEO. Two recent results [1] [2] have shown the resolution of the CLEO tracking system to be small and well modeled by simulation. The basic technique is to select $e^+e^- \; -\!\!\rightarrow \mu^+\mu^-$ events, measure the total momentum of the two observed tracks, and unfold from this the contribution from the momentum resolution of the tracking system and the underlying difference caused by the angular spread of the beam particles. Combining the angular spread of the beam with the spatial spread of the beam, measured with our box method [2], we can simultaneously extract β_x^*, the horizontal beta function at the CESR–CLEO collision point, β_y^*, the vertical beta function at the CESR–CLEO collision point, ϵ_x, the horizontal emittance, and ϵ_y, the vertical emittance. By considering the data as a function of specific luminosity we can search for dynamic changes of emittance.

The beam parameters β_x^*, β_y^*, ϵ_x, and ϵ_y are related to the physical observables σ, the Gaussian width of the spatial spread of the beam at the CLEO interaction point, and σ', the Gaussian width of the angular spread of the beam at the CLEO interaction point by the following equations

$$\sigma_x = \sqrt{\beta_x^* \epsilon_x} \quad (1)$$

$$\sigma_y = \sqrt{\beta_y^* \epsilon_y} \quad (2)$$

$$\sigma'_x = \sqrt{\epsilon_x / \beta_x^*} \quad (3)$$

$$\sigma'_y = \sqrt{\epsilon_y / \beta_y^*}. \quad (4)$$

A simultaneous measurement of σ and σ' in the collision region would yield measurements of β^* and ϵ via the obvious algebraic manipulation. This simultaneous measurement is possible using the method described below.

The effect of the angular spread of the approaching beams in CESR is depicted in the diagram shown in Figure 1. Particles constituting the colliding beams do not interact head on, but at an angle to one another. This gives rise to a non-trivial distribution of the angle between the two tracks in $e^+e^- \; -\!\!\rightarrow \mu^+\mu^-$ events even before a finite resolution is taken into account.

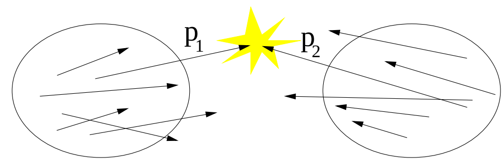

Figure 1: Particles in the beam do not collide head on, but at some angle. The width of this angular distribution, or the angular spread, is σ'.

2 METHOD

We measure the angle between two colliding tracks by first dividing the sum of the momenta of the two tracks by the beam energy to obtain a non-trivial value called the peculiar momentum. The peculiar momentum is equivalent to the minor arc between the colliding tracks, given by $\sin\theta$, where θ is the central angle between the colliding tracks. For small angles use the approximation $\sin\theta \approx \theta$. Thus the small angle between the two tracks in the horizontal and vertical directions is determined. This method is schematically shown in Figure 2. The width of the distribution of the angles between tracks, θ, is related to the width of the angular distribution of the beam, σ'.

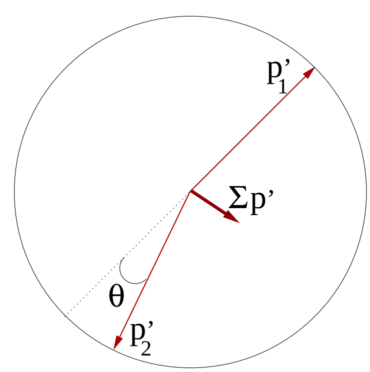

Figure 2: The peculiar momentum of the two tracks is obtained by taking the sum of the momenta of two tracks and dividing by the beam energy. This defines the central angle, θ, giving the minor arc, $\sin\theta$. The minor arc defined by θ is equivalent to the peculiar momentum of the two tracks.

The key to this method is knowing the resolution on the central angle. We study the resolution on the central angle with a simulated sample of $e^+e^- \;-\!\to \mu^+\mu^-$ events with no momentum spread in the incoming beam particles. Recent examples show that, for high momentum tracks, the simulation of the tracking accurately models the data [1] [2]. The resolution depends on global properties of the event, such as the size of the luminous region, restricted to optimize the resolution. This resolution also depends on the hit pattern in the $r\phi$ and z views of the silicon vertex, or SVX, detector. Thus the data is divided accordingly. For each of these subsamples, the resolution is parametrized as

$$A + B/Nhits = \mathrm{Resolution} \tag{5}$$

where $Nhits$ is the total number of tracking hits on both tracks. To determine A and B for each SVX hit pattern, we fit the two dimensional distribution of central angle versus $Nhits$ to a Gaussian with a width given by the resolution plus a flat background. To display the results of this fit, we show the width of the resolution as a function of $Nhits$, determined by selecting on a range of $Nhits$ and performing a one dimensional fit to a Gaussian plus a flat background. Figures 3 and 4 show the resolution for a pattern of 6 $r\phi$

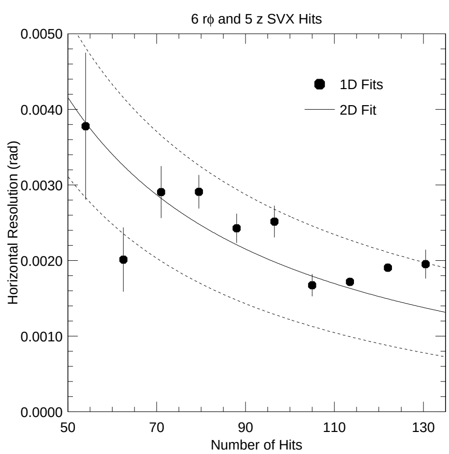

Figure 3: For the horizontal central angle, the resolution in $e^+e^- \;-\!\to \mu^+\mu^-$ events with an SVX hit pattern of (6$r\phi$, 5z) as a function of $Nhits$ as predicted by the simulation. Also shown is the resolution parametrized as $A+B/Nhits$ with the central value as a full line and the dashed lines showing the one standard deviation uncertainty due the errors on the A and B parameters.

and 5 z hits in the horizontal and vertical directions, respectively. These figures show that our parameterization of the central angle resolution is a reasonable match to the prediction of the simulation.

The width of the spatial spread of the CESR beam is determined using the box method, depicted in Figure 5. A hypothetical box is centered on the measured center of the luminous region and the average position of tracks passing through the box are used to measure the size and shape of the luminous region. We choose an ensemble of tracks

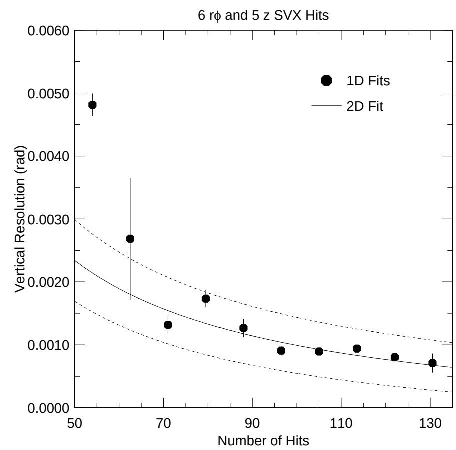

Figure 4: For the vertical central angle, the horizontal resolution in $e^+e^- \;-\!\to \mu^+\mu^-$ events with an SVX hit pattern of (6$r\phi$, 5z) as a function of $Nhits$ as predicted by the simulation. Also shown is the resolution parametrized as $A + B/Nhits$ with the central value as a full line and the dashed lines showing the one standard deviation uncertainty due the errors on the A and B parameters.

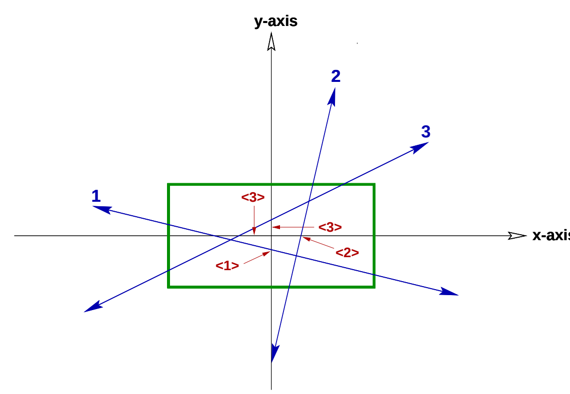

Figure 5: An ensemble of stiff tracks passing through the box allow for a precision measurement of the beam spot.

that pass through the box at a small angle, as these are most useful for making a measurement. We have previously used this technique to measure β^*_y and observe the hourglass effect at the CESR-CLEO interaction point [2].

The vertical spatial width of the luminous region is not measured, only the resolution on the position. Therefore we take σ_y to be the resolution on the position. For this reason, dynamic measurements of β^*_y cannot be extracted. A constant measured value, $\beta^*_y = 17910 \pm 170$mm [2], is used in this analysis to extract ϵ_y.

3 RESULTS

Using the methods described above, we measure σ_x, σ_y, σ'_x, and σ'_y as functions of the specific luminosity. From this data and algebraic manipulation of Equations 1, 2, 3 and 4 we extract β_x^*, ϵ_x and ϵ_y.

The extracted β_x^*, shown in Figure 6, agrees well with expectations based on a previous analysis done on dynamic beta [3].

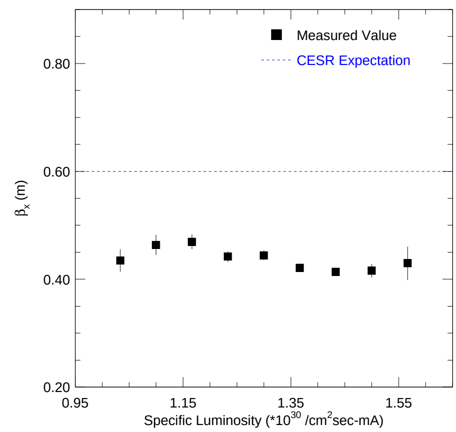

Figure 6: The extracted horizontal beta as a function of specific luminosity.

Figure 7 shows the extracted horizontal emittance, ϵ_x, as a function of specific luminosity. Here we also see good agreement with our expectations. We clearly do not see any dynamic effects.

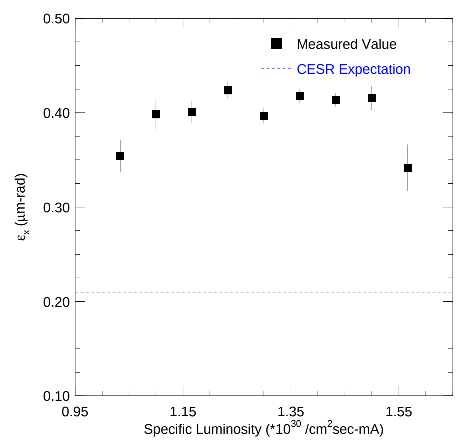

Figure 7: The extracted horizontal emittance as a function of specific luminosity.

The extracted vertical emittance in Figure 8, ϵ_y, appears to have dynamic effects, but when a χ^2 fit to a first order polynomial is applied to this data, the obtained slope is not significant. Therefore there are no visible dynamic effects on vertical emittance. Moreover, a true expectation value of ϵ_y is not known, though these results agree with an earlier observation.

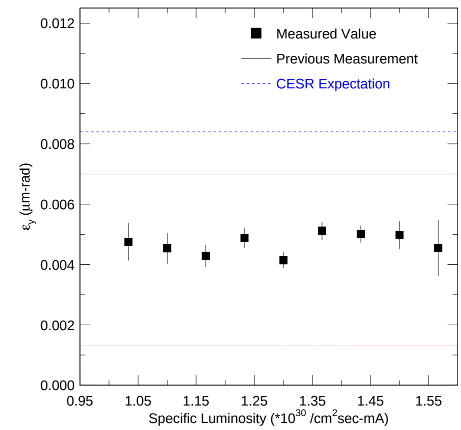

Figure 8: The extracted vertical emittance as a function of specific luminosity.The red dotted line represents the lowest expected value based on the previous measurement.

4 CONCLUSION

We have developed a method of measuring the emittance of colliding CESR beams at the CLEO interaction region without any additional input beyond the resolution of the CLEO tracking system. We measure the width of the angular distribution of $e^+e^- -\!\!\to \mu^+\mu^-$ events from the luminous region of CESR at the CLEO interaction point. The very good and well understood resolution of the CLEO tracking system allows us to extract the underlying width caused by the angular spread of the beam. This method, combined with the box method, allows us to make simultaneous measurements of the spatial and angular spreads of the CESR beam. These simultaneous measurements lead to the extraction of the beam parameters β_x^*, ϵ_x and ϵ_y as functions of specific luminosity. No dynamic effects for ϵ_x and ϵ_y are visible.

5 REFERENCES

[1] hep-ex/0102007, *First Measurement of* $\Gamma(D^{*+})$, T.E. Coan, *et al*, CLEO Collaboration.

[2] physics/0011075, *Novel Method of Measuring Electron-Positron Colliding Beam Parameters*, D.Cinabro, *et al*.

[3] ”Observation of the Dynamic Beta Effect at the Cornell Electron-Positron Storage Ring with the CLEO Detector”, D. Cinabro *et. al.*, *Phys. Rev.* E57 (1998): 1193.