Measurements of Collision Offsets and Difference in Vertical Dispersion at the LEP Interaction Points

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Abstract

The beam overlap at the LEP interaction points is optimized by monitoring the change in the Bhabha rate during the variation of an electrostatic bump amplitude. A new method has been developed and implemented to measure the difference of the residual vertical dispersion of electrons and positrons at the interaction points based on beam separation measurements at two different beam energies.

1 INTRODUCTION

LEP was operated for the first time in 1995 in "bunch train" mode [1]. Each beam consist of four equally separated trains of three bunches (families) 74 m apart. The bunches are vertically separated before and after the collision points to avoid unwanted encounters. Electrostatic separation generates opposite sign vertical beam dispersion and a residual offsets from long range beam-beam forces at the separated encounters. Both effects lead to a center of mass energy shift of several MeV at the interaction points (IP) [2]. This effect is illustrated schematically in figure 1.

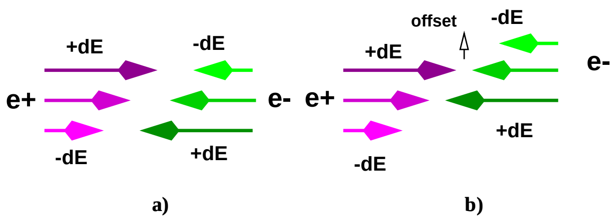

Figure 1: Schematic view of the collision of two bunches with opposite sign vertical dispersion. The nominal CM energy is unaffected in absence of offset (a) while it is shifted in the opposite case (b). Size of arrows indicates particle energy inside a bunch.

The CM energy shift ΔE_{CM} at each IP [2] is:

$$\Delta E_{CM} = -\frac{1}{2} \cdot \frac{\delta y}{\sigma_y^2} \cdot \frac{\sigma_E^2}{E} \cdot \Delta D_y^* \qquad (1)$$

where the collision offset δy is the distance between the centers of the positron and the electron bunches, σ_y the individual bunch vertical beam size, ΔD_y^* the vertical dispersion difference ($D^*_{y\_e^+} - D^*_{y\_e^-}$) and E, σ_E the beam energy and energy spread.

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In view of a precise determination of the CM beam energies and a reduction of the error of the Z mass and width [3], a procedure to control the vertical collision offsets of the beams [4] was developed, based on relative luminosity measurements using the high rate LEP Bhabha monitors [5] while scanning one beam against the other with closed electrostatic bumps. The luminosity was separately measured for every family to have a complete control of the beam separation at the IP. Frequent adjustments of the beam separation and some dispersion measurements are required to determine and reduce the energy shifts. The optimal collision offset, the vertical dispersion difference and the individual beam size in collision are extracted from the separation scans.

2 BEAM SEPARATION SCANS

For a complete beam scan the amplitude of the electrostatic separator bump was changed typically 8 times by 2 μm. At every separator setting the luminosity was recorded for 27 seconds and the whole scan lasted 8 minutes. An online program fits a gaussian function to the data for the three families and returns the optimal separator bump amplitude for each family as well as the average optimal position (fig. 2). The evaluated optimal position was used to adjust the separator settings and therefore to control the offsets. Beam separation scans were done at each LEP IP (fig. 2) and typically twice in a fill. The origin of the separation corresponds to the theoretical beam axis. The three families do not overlap exactly for the same value of the separator field, which is in agreement with simulations [6]. The maximization of the luminosity is done by averaging the three individual measurements.

The error of the offset determination for a single family is of the order of 0.2 μm. This error is mainly dominated by the statistical error of the luminosity measurement. The very accurate gaussian distribution (fig. 3) with rms of 1.0 of the difference between two successive luminosity measurements normalized to their combined error verifies the statistical origin of the luminosity error.

The beam separation technique can also be used to measure the beam size variation during the scan (fig. 4). During the IP 4 scan the luminosity is varying at the other three IPs. The beam size blow up in a non-scanned IP is measured by the ratio between the luminosity when both beams are colliding head-on and the actual luminosity. In this particular case the three families show a 30% different blow up of the beam size in the second half of the scan.

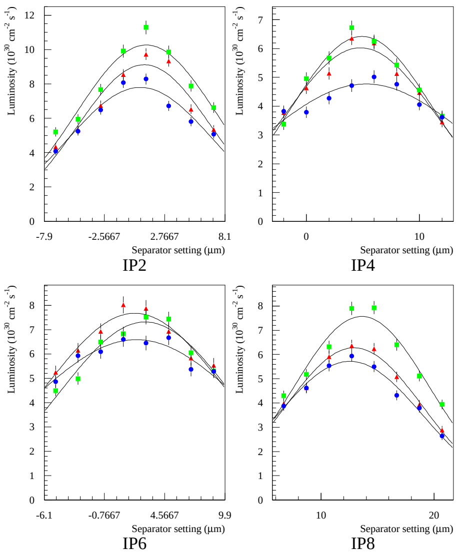

Figure 2: Luminosity as a function of the beam separation at the four LEP IPs. The offsets are separately extracted by applying a gaussian fit to the luminosity data of each family.

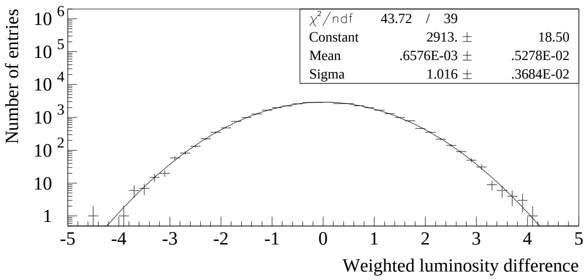

Figure 3: Distribution of the difference between two consecutive luminosity measurements, normalized to the combined error of both luminosity readings.

The mean blow up is affecting all IPs, including the IP where the separation scan is performed. The luminosity determination at the non-scanned IPs can be used to correct for the luminosity variation caused by beam size changes at the scanned IP. It could be shown that this correction has negligible influence on the determination of the optimal beam position. Beam separation scans are also a unique way to measure the mean vertical beam size at the IP. The beam size varies between 4 and 5 μm and is determined with a typical precision of 0.2 μm by including the mean beam blow up correction from the luminosity measurements at the non-scanned IPs.

3 TIME DEPENDENCE OF THE SEPARATION BUMP AMPLITUDE

Beam separation scans were performed during the 60 days of the 1995 LEP running period. The time evolution of the optimal separation bump amplitude is shown in figure 5 for the two operation energies (44.7 GeV and 46.5 GeV).

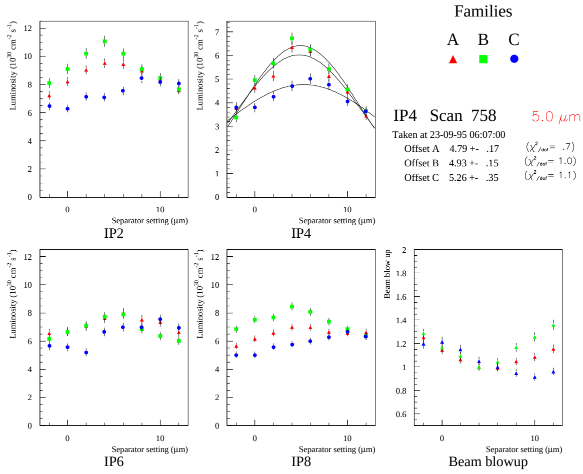

Figure 4: Luminosity at all IPs and the mean beam blow up as function of the beam separation at the interaction point 4. The beam size change due to the scan in IP4 affects the luminosity in the non-scanned IPs. In this case the blow up in the second half of the scan is different for the three families.

The rms of the optimal position is between 0.8 and 1.4 μm for different IPs and energies. The difference of the relative bunch positions, an expected feature of the bunch train scheme [6], was measured to be almost constant during the 60 day running period (fig. 6). The rms variation of the differences is between 0.4 and 0.6 μm, indicating that the larger rms variation of the optimal position is due to real drifts. This statement is supported by measurements of the reproducibility (rms between 0.2 and 0.4 μm) and by the rms of 0.26 μm of the difference for scans in opposite directions.

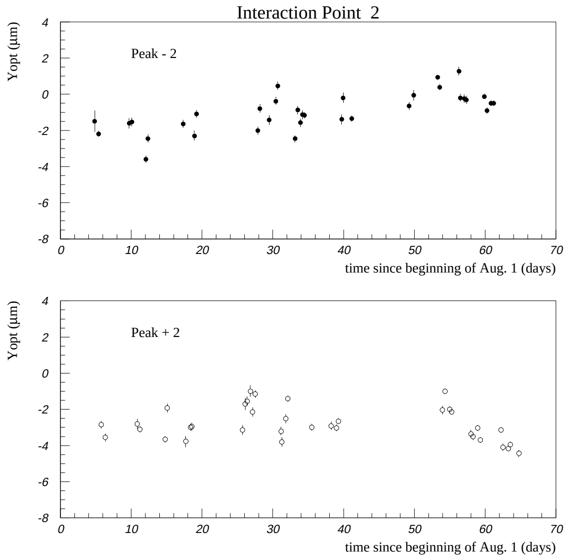

Figure 5: Stability of the separation bump amplitude at IP2 during a 60 days operation period.

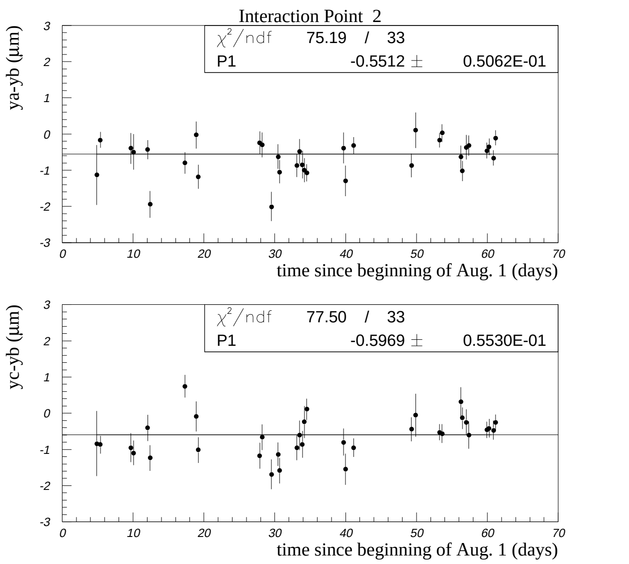

Figure 6: Difference between the optimal beam vertical positions at the IPs for the different families. Family B compared to A (top) and to C (bottom).

4 DISPERSION MEASUREMENTS

The vertical dispersion difference ΔD_y^* was directly measured by monitoring the variation of the optimal beam overlap over a relative energy change of $\pm 4.0 \times 10^{-4}$ produced by changing the RF frequency. Figure 7 shows a dispersion

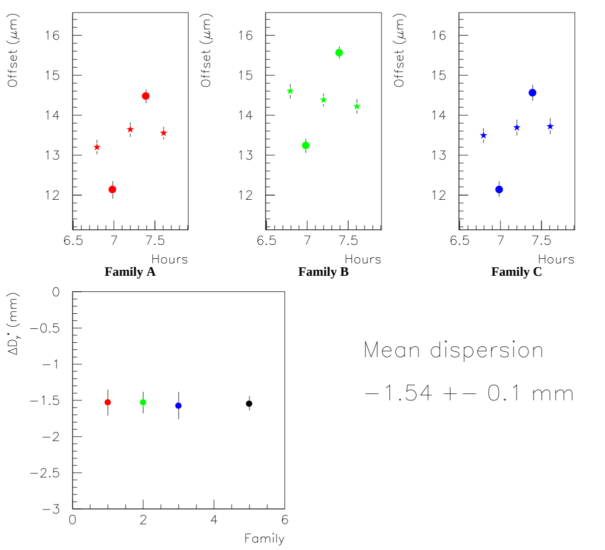

Figure 7: Dispersion measurements at one IP. Top: optimal offset for the different bunch families. The second and fourth measurement are taken at lower and higher beam energy. Bottom: mean dispersion differences for each family and their average (shown as a fifth family).

measurement. The top three plots show the optimal position for the three families. The first, third and fifth measurement are taken at nominal energy, the second and the fourth at lower and higher beam energy. The dispersion difference (bottom plot) is proportional to the shift in vertical position induced by the energy variation. The redundancy in this procedure allows for checks of the reproducibility and of systematic effects.

5 CONCLUSION

Beam separation scans were frequently performed during the 1995 LEP physics runs to optimize the beam overlap at the IPs. The optimal beam separation bump amplitudes were used to minimize the center of mass energy shifts. The luminosity was in parallel measured at the non-scanned IPs to derive the beam size The mean collision offsets were on average less than 0.3 μm and the dispersion differences at the IPs were measured to be $\sim$ 2 mm in absolute. This procedure ensured a small correction to the center of mass energy and a low additional contribution to the error of Z mass and width.

6 REFERENCES

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