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Measurement of the beam parameters during the 1995 Z^0 scan with the DELPHI VSAT

Ch. Zacharatou Jarlskog
Lund University

Abstract

The beam parameter variations during the 1995 Z^0 scan obtained by the Very Small Angle Tagger (VSAT) luminometer are presented. The results are compared with the VD and TPC measurements.

1 Introduction

The Very Small Angle Tagger (VSAT) is one of the luminosity monitors of DELPHI [1]. It is an electromagnetic sampling calorimeter consisting of four rectangular modules called F1, F2 in the forward region and B1, B2 in the backward region. The distance of the modules from the DELPHI origin is approximately 7.7 m. The luminometers are placed symmetrically around a short elliptical section of the beam pipe as shown in fig. 1. The process seen by the detector is Bhabha scattering, i.e. electrons and positrons emitted back-to-back carrying approximately the beam energy. We therefore look for coincidences of signals between a module in the forward region and a module in the backward region, defining two diagonals for the trigger: diagonal 1 (modules F1-B2) and diagonal 2 (modules F2-B1).

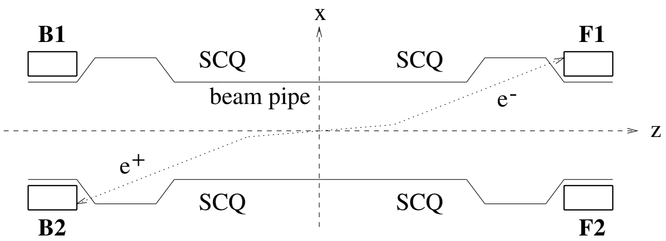

Figure 1: *Layout of the VSAT modules in the (x,z) plane.*

The dimensions of the calorimeters are 3 cm in x, 5 cm in y and approximately 10 cm in z. Each module contains 12 tungsten absorbers interspaced with 12 silicon planes for energy measurement (FADs). The center of the electromagnetic shower is given by three silicon strip planes with 1 mm pitch placed close to the shower maximum at 5, 7 and 9 r.l.; the second plane is used for the y coordinate measurement and the other two planes for the x coordinate measurement.

The detector has an azimuthal coverage of ± 45 degrees. The polar angles seen by the modules are from 5 to 7 mrad, a region of high Bhabha cross section. This allows the monitoring of the variation of beam parameters with high statistics.

In section 2, we give a short description of the variables used in the analysis, as more detailed accounts have been given in previous reports [2,3]. In sections 3 and 4, the determination of the x and z beamspot is discussed, respectively. The variations of the beam tilts and of the acollinearity are presented in section 5. Finally, section 6 presents beam parameter results for individual minibunches.

2 Measurement in the (x,z) plane

The analysis is based on the measurements of the x and y coordinates of the impact points of the outgoing particles on the four modules. In this section, we will see how these measurements are affected by the various beam parameters in the (x,z) plane.

In the general case, the beam has a displacement both in x and in z equal to x_b and z_b, respectively. Moreover, the incoming electron and positron are expected to have directions at nonzero angles with respect to the z axis. These angles are called tilts and are denoted by θ_+^x for the positron and by θ_-^x for the electron. If the production angle of the outgoing particles in diagonal 1 (2) is θ_1^x (θ_2^x), the x coordinates of the impact points on the modules will be

$$x_{F1} = f_x(x_b - z_b(\theta_1^x + \theta_-^x)) + l_x(\theta_1^x + \theta_-^x) \qquad x_{B2} = f_x(x_b - z_b(\theta_1^x + \theta_+^x)) - l_x(\theta_1^x + \theta_+^x)$$
$$x_{B1} = f_x(x_b + z_b(\theta_2^x - \theta_+^x)) + l_x(\theta_2^x - \theta_+^x) \qquad x_{F2} = f_x(x_b + z_b(\theta_2^x - \theta_-^x)) - l_x(\theta_2^x - \theta_-^x) \tag{1}$$

In the derivation of the above equations, we have represented the trajectories of the outgoing particles as straight lines. This entails the introduction of an effective distance, $l_x = (12.60 \pm 0.02)\ m$, of the front face of the modules from the DELPHI origin. This distance is larger than the real one because of the defocusing effect of the superconducting quadrupoles in the (x,z) plane. This effect is also reflected in the magnification factor $f_x = 2.1 \pm 0.1$, which multiplies the x beamspot value.

The electron and positron tilts can be rephrased in terms of two new beam parameters, the average tilt, θ_x, and the acollinearity, ϵ_x. We define them as

$$\theta_x = \frac{\theta_+^x + \theta_-^x}{2} \qquad \epsilon_x = \theta_-^x - \theta_+^x \tag{2}$$

Eqs. 1 can now be combined into the two following measures

$$\Delta x_1 = x_{F1} + x_{B2} = 2 \cdot f_x(x_b - z_b(\theta_1^x + \theta_x)) + \epsilon_x l_x$$
$$\Delta x_2 = x_{F2} + x_{B1} = 2 \cdot f_x(x_b + z_b(\theta_2^x - \theta_x)) + \epsilon_x l_x \tag{3}$$

With a view to extracting information on x_b and z_b separately, we introduce the variables

$$\Delta x = \frac{\Delta x_1 + \Delta x_2}{2} = 2 \cdot f_x x_b + \epsilon_x l_x + f_x z_b(\theta_2^x - \theta_1^x - 2\theta_x) \tag{4}$$

$$\delta x = \Delta x_2 - \Delta x_1 = 2 \cdot f_x z_b(\theta_1^x + \theta_2^x) \tag{5}$$

The production angles in the two diagonals have essentially equal values (5.5 $mrad$ approximately) and since the mean tilt is generally small this allows for the third term in eq. 4 to be neglected. Δx thus reflects the variations of both the x beamspot and the acollinearity. The two parameters cannot be separated with VSAT information only. On the other hand, eq. 5 provides us with a very efficient way to measure the z beamspot, the sum of the production angles being calculated directly from our data, as explained in section 4.

Before we proceed to the beam parameter calculation, it must be noted that the variables Δx_1 and Δx_2 are averages over the time required to write one cassette of data (about 15 minutes). As the corresponding distributions are affected by the variation of beam parameters, the average values Δx_1 and Δx_2 must be corrected in order for this variation to be taken into account. FASTSIM simulation runs have shown that the correction for the effect of the beam width and divergence variations can be parametrized in terms of the widths of the Δx_1 and Δx_2 distributions, $R\Delta x_1$ and $R\Delta x_2$, while the correction for the y tilt can be achieved by using the Δy_1 and Δy_2 variables (defined for the (y,z) plane in a similar way to eqs. 3) [4]:

$$\Delta x_{1C} = \Delta x_1(1 + 0.1(R\Delta x_1 - 2.6)) - 0.1(\Delta y_1 + 7)$$
$$\Delta x_{2C} = \Delta x_2(1 + 0.1(R\Delta x_2 - 2.8)) - 0.05(\Delta y_2 + 8)$$

where all quantities are measured in mm. Consequently, the variables Δx and δx should be replaced by the quantities $\Delta x_C = (\Delta x_{1C} + \Delta x_{2C})/2$ and $\delta x_C = \Delta x_{2C} - \Delta x_{1C}$, respectively.

3 Variation of the x beamspot

As was mentioned in the previous section, the x beamspot and acollinearity cannot be disentangled. We can, nevertheless, apply eq. 4 for the corrected value, Δx_C, in order to obtain an estimation of the variations of the x beamspot. If we define the approximate value of the x beamspot as $x_{VSAT} = \frac{\Delta x_C}{2f_x}$, eq. 4 will give

$$x_{VSAT} = x_b + \epsilon_x \frac{l_x}{2f_x} + x_0 \tag{6}$$

where the term x_0 corresponds to the third term of eq. 4 and is thus negligible. The distribution of x_{VSAT} and its variation with fill number are given in fig. 2. One entry in the plots corresponds to one cassette. The mean value for the scan is (0.162 ± 0.055) mm. The accuracy for the measurement per fill is (28 ± 12) μm.

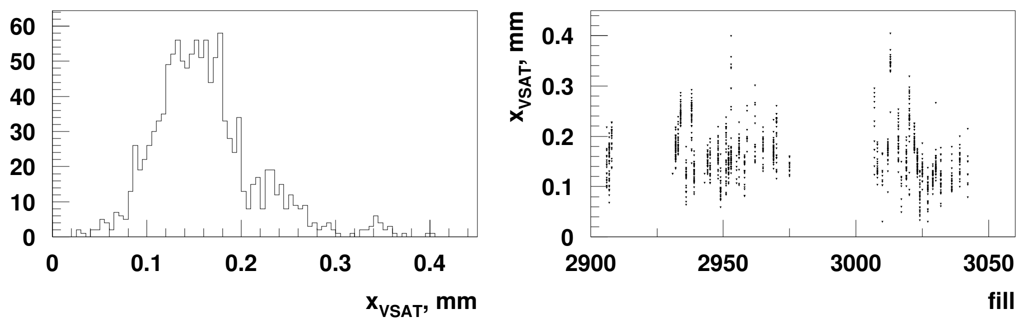

Figure 2: *x_{VSAT} with corrections for the beam width, divergence and y-tilt. The x-acollinearity effect is neglected.*

We can confirm the variation of our estimate by comparing with the x beamspot determination done by VD. The correlation plot is given in fig. 3(a). The linear relation is evident. The presence of the undetermined acollinearity term is clearly evidenced by fig. 3(b), which shows the normalized difference of the two measurements having an rms value significantly larger than unity.

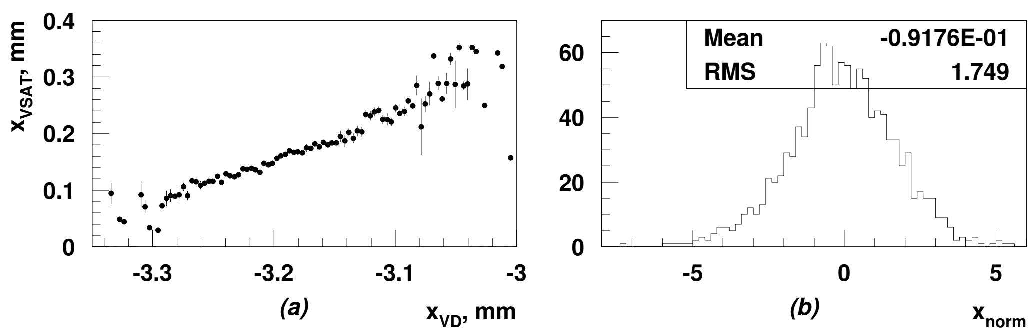

Figure 3: *(a) Correlation plot for the x_{VSAT} and x_{VD} measurements and (b) their normalized difference.*

4 Determination of the z beamspot

The advantage of eq. 5 over eq. 4 is that the acollinearity terms of eqs. 3 have been eliminated. If we substitute δx_C for δx and z_{VSAT} for z_b in eq. 5 we obtain

$$z_{VSAT} = \frac{\delta x_C}{2f_x(\theta_1^x + \theta_2^x)} \tag{7}$$

Eqs. 1 can provide us with the sum in the denominator

$$\theta_1^x + \theta_2^x = \frac{x_{F1} - x_{B2} - x_{F2} + x_{B1}}{2 \cdot l_x} \tag{8}$$

The resulting distribution for z_{VSAT} and its variation are shown in fig. 4. The overall mean value is (-47.8 ± 4.4) mm. The accuracy per fill is (2.4 ± 0.6) mm.

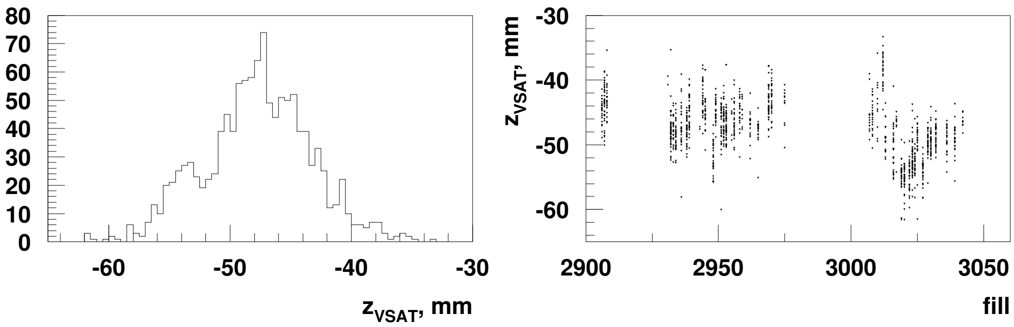

Figure 4: z_{VSAT} *with corrections for the beam width, divergence and y-tilt.*

The comparison with the TPC result is illustrated in fig. 5. The correlation plot demonstrates the qualitative agreement of the two measurements. The rms of the normalized difference confirms that there are no unaccounted effects.

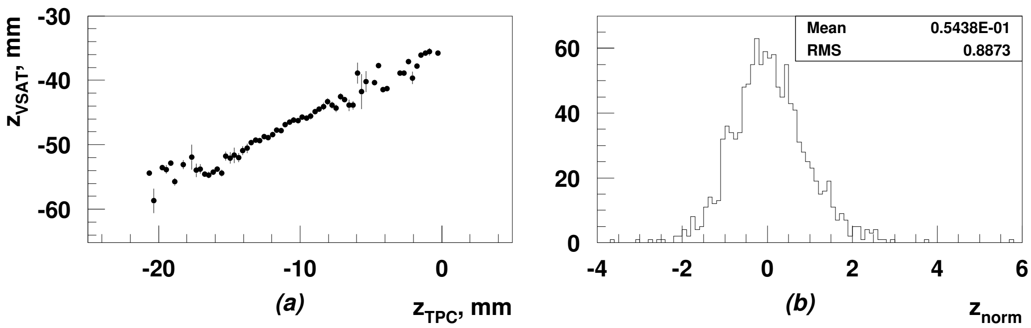

Figure 5: *(a) Correlation plot for the* z_{VSAT} *and* z_{TPC} *measurements and (b) their normalized difference.*

5 Variations of acollinearity and tilt

The VD and VSAT measurements can be combined to extract the values of the acollinearity in the (x,z) and (y,z) planes. Neglecting the third term of eq. 4, we obtain

$$\epsilon_x \approx \frac{\Delta x_C - 2f_x \cdot x_{VD}}{l_x} \tag{9}$$

A similar equation holds in the vertical plane. In eq. 9, we have replaced Δx by Δx_C and introduced the VD measurement for the x beamspot. The variations of ϵ_x and ϵ_y are given in fig. 6. The mean values are (0.905 ± 0.012) $mrad$ and (-2.101 ± 0.023) $mrad$, respectively.

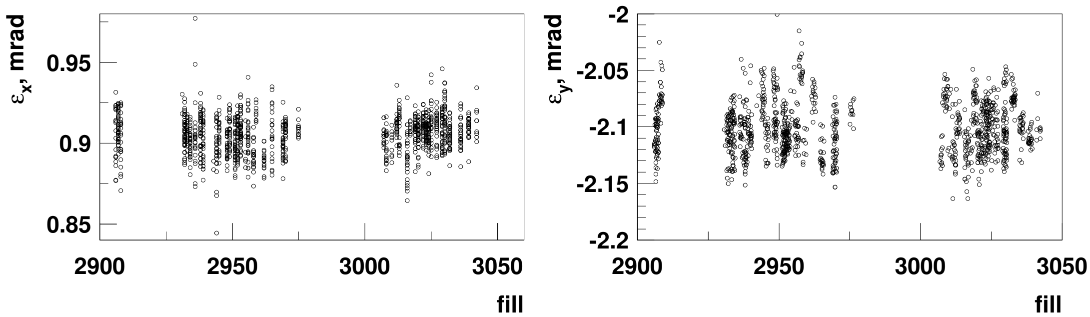

Figure 6: *Variations of* ϵ_x *and* ϵ_y*.*

Another measurement that can be performed by the detector is that of the mean beam tilts in the two planes, θ_x (eq. 2) and θ_y. Simulations with FASTSIM have established a relation between the x tilt and the asymmetry [4], A_D,

$$\theta_x\ (mrad) = 1.75 \cdot A_D \tag{10}$$

where the asymmetry is defined as the fractional difference of the number of Bhabha events in the two diagonals of the detector. Moreover, the y tilt is extracted directly from the y coordinates of the impact points on the four modules:

$$y_{F1} + y_{F2} - y_{B1} - y_{B2} = 2f_y z_b(\theta^y_+ - \theta^y_-) + 2l_y(\theta^y_1 - \theta^y_2 + \theta^y_- + \theta^y_+) =$$

$$= -2f_y z_b \epsilon_y + 2l_y(\theta^y_1 - \theta^y_2) + 4l_y\theta_y \approx 4l_y\theta_y$$

and therefore

$$\theta_y \approx (y_{F1} + y_{F2} - y_{B1} - y_{B2})/4l_y \tag{11}$$

Fig. 7 shows the results of eqs. 10 and 11. The average value of θ_x is (-0.082 ± 0.038) $mrad$, whereas θ_y has a mean value of (0.462 ± 0.076) $mrad$.

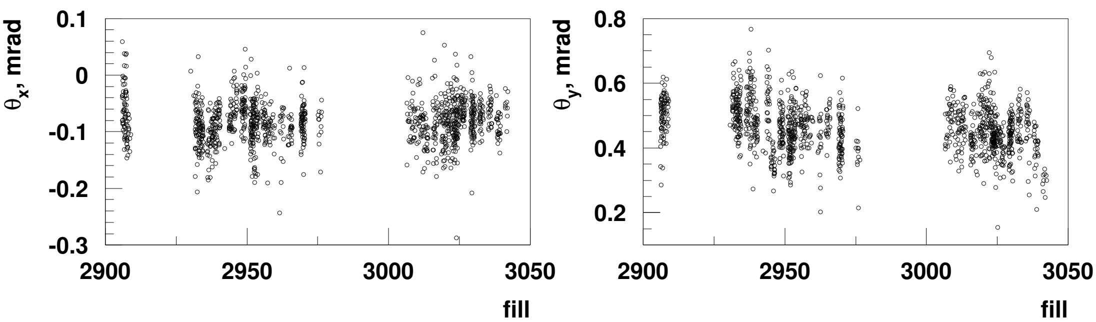

Figure 7: *Variations of* θ_x *and* θ_y*.*

As the tilt values above represent only average beam directions, it is useful to determine also the spread around these directions, i.e. the beam divergence. This measurement is not possible in the vertical plane because of the quadrupole effect. On the other hand, eq. 4 can give the variations of the divergence in the horizontal plane through the dispersion $\sigma_{\Delta x}$ of the Δx distribution. This result is shown in fig. 8.

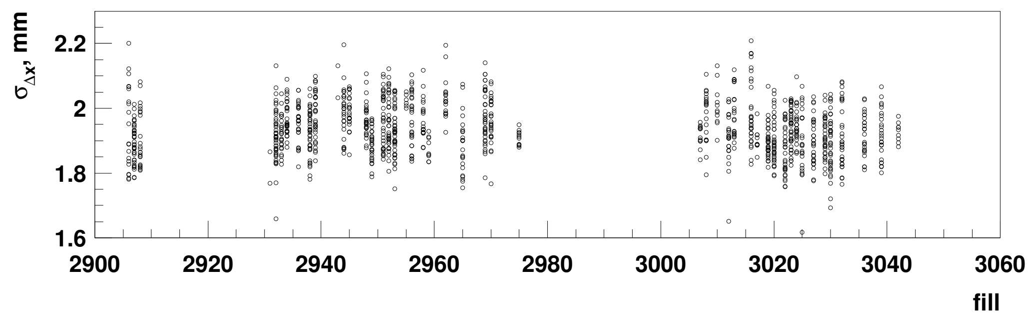

Figure 8: *Variation of* $\sigma_{\Delta x}$.

6 Beam parameters for minibunches

As 1995 was the first year LEP ran in the minibunch scheme, it is of interest to examine whether the three minibunches exhibited differences in their beam parameter characteristics. Since the VD has not supplied beamspot information per minibunch, we cannot perform the calculation of the acollinearity. However, the distributions of x_{VSAT} and z_{VSAT} as well as the mean tilts in the two planes can be extracted from VSAT data alone for the three minibunches. The results are shown in fig. 9. We observe no dependence on minibunch number.

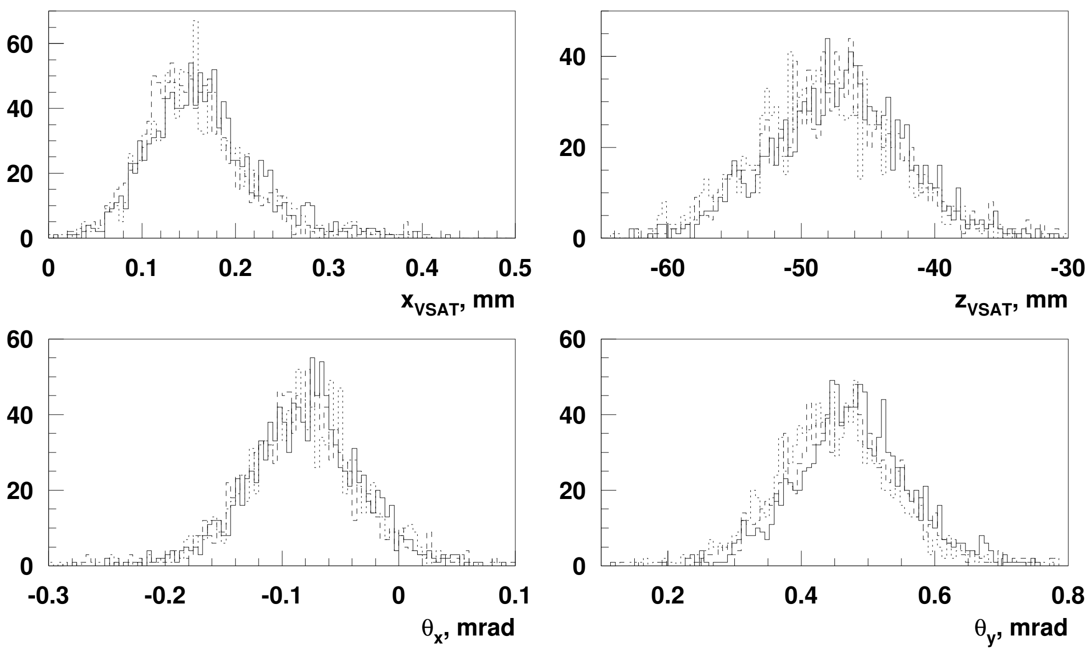

Figure 9: *VSAT beam parameters for minibunch one (solid lines), two (dashed lines) and three (dotted lines).*

7 Conclusions

The x and z beamspot variations have been successfully measured and compared with the results of VD and TPC. The average beam directions have also been calculated in the horizontal and vertical planes. The combination of VD and VSAT data has provided information on beam acollinearities. Beam parameters per minibunch have also been determined. These results have been used for the luminosity analysis [5].

References

[1] Almehed et al., *A silicon tungsten electromagnetic calorimeter for LEP*, Nucl. Instr. Meth. A305 1991.

[2] Almehed et al., *Measurement of the beam parameter variations in DELPHI with the VSAT*, DELPHI 95-150 LEDI 2.

[3] Ch. Jarlskog, *Interaction point estimation and beam parameter variations in DELPHI with the VSAT* , LUNFD6/(NFFL-7110)1995.

[4] S. Almehed, private communication.

[5] DELPHI note in preparation.