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# BEAM WAIST MANIPULATIONS AT THE ATF2 INTERACTION POINT*

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*Abstract*

The ATF2 project is the final focus system prototype for ILC and CLIC linear collider projects, with a purpose to reach a 37nm vertical beam size at the interaction point. Techniques developed based on simulations are described to adjust the horizontal and vertical beam waists independently in the presence of errors, at two different IP locations where beam sizes can be measured with different accuracies. During initial commissioning, larger than nominal IP β-functions are used, to reduce effects from higher-order optical aberrations and hence simplify the optical corrections needed. First measurements in such intermediate β-configurations are reported.

## ATF2 BEAM SIZE MEASUREMENTS

ATF2 is a test facility for ILC and CLIC type final focus systems. It aims to reach a final beam size of 37 nm. To measure such a small beam size, a “Shintake” monitor based on colliding the beam with the interference pattern from lasers is used [1]. In addition, post-IP wire scanners with diameters 10 and 5 µm, respectively in tungsten and carbon, are placed 40 centimeter behind the nominal IP to measure the beam sizes during initial tuning, with resolutions of about 2.5 and 1.25 micron [2]. During the first commissioning in March 2009, a large β optics configuration was used at the IP, with 20 and 800 times the nominal values for $\beta_x$ (0.08m) and $\beta_y$ (0.08m), respectively. Sextupoles were turned off to reduce the sensitivity to misalignments. In April 2009, $\beta_y$ was reduced to 100 times the nominal value (0.01m). For these optics, expeted beam sizes were large enough to be measured with the post-IP wire scanners.

## SIMULATIONS OF WAIST SCANS

Simulations using the nominal optics with $\beta_x = 0.004$ m and $\beta_y = 0.0001$ m were done to test adjusting the beam waists at the IP in the presence of errors independently in horizontal and vertical planes. QD0 and QF1 strengths were found fitting with the MAD program to get:

1) $\alpha_x= 0.1, \alpha_y=0.0$ $\delta_{QD0} = 1.00$ e-4 m$^{-1}$, $\delta_{QF1} = -3.57$e-4 m$^{-1}$
2) $\alpha_x= 0.0, \alpha_y=0.1$ $\delta_{QD0} = 6.41$ e-3 m$^{-1}$, $\delta_{QF1} = -5.22$e-5 m$^{-1}$

For waist errors of reasonable magnitudes, adjustments can be computed efficiently scaling these coefficients linearly. A first application study was done with random relative field errors in all ATF2 quadrupoles, with RMS of 0.001. Fig. 1 and 2 show the effect of correcting 100 seeds using the defined $\alpha_{x,y}$ multiknobs. The red and blue histograms show the beam sizes before and after scans to find the minimum values. Residual horizontal dispersion is generated by the above procedure for quadrupole errors in the non-dispersive parts of ATF2. The corresponding contribution to the horizontal beam size was however found small enough to be neglected for this set of errors.

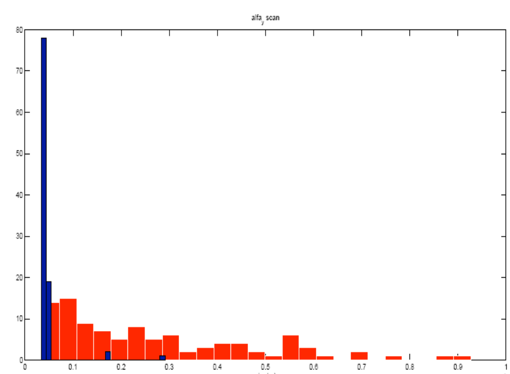

Figure 1: $\alpha_y$ orthogonal IP waist scan with nominal optics.

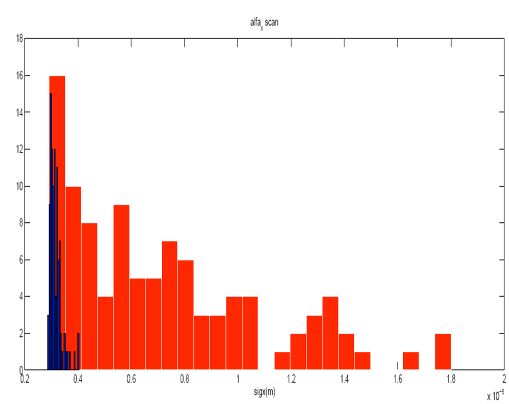

Figure 2: $\alpha_x$ orthogonal IP waist scan with nominal optics.

Waist scans using QF1 and QD0 were also simulated for both cases of large β optics used in the commissioning. Fig. 3 shows the beam size variations predicted for the 20 times $\beta_x$ (0.08m) and 100 times $\beta_y$ (0.01m) configuration. Since QF1 does not affect $\sigma_y$ at the IP much at all, while QD0 has a strong effect. QD0 could

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be used alone to vary both beam sizes at the post IP wire scanner locations.

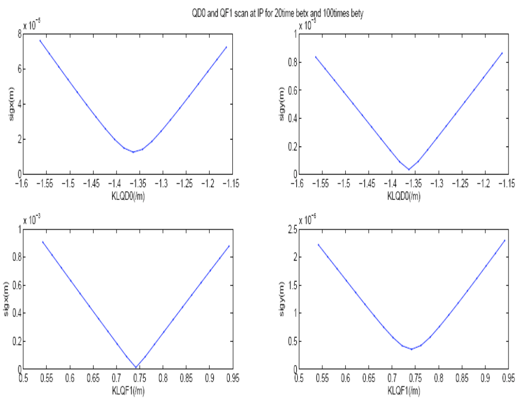


Figure 3: Horizontal & vertical IP beam sizes *vz* QD0 & QF1 strengths for the 20,100 times $\beta_{x,y}$ ATF2 optics.

## MEASURED WAIST SCANS

First measurements of horizontal and vertical beam sizes at the IP were done with the post-IP tungsten wire during the commissioning in March and April, to exercise the procedures and get initial estimates of the dispersion, emittance and β functions, and as part of tuning in preparation for Shintake monitor commissioning work. Two examples are shown below.

### *Vertical Waist Scan on April 9*

In this shift period, a 20 pm vertical emittance had been measured in the extraction line. For $\beta_y$ at the IP aimed to be 0.01m (100 times the nominal value), the vertical beam size was predicted to be less than one micron after optical corrections. To avoid possible destruction of the tungsten wire scanner, QK1, a skew quadrupole which had been adjusted close to its maximum value of -20A to correct x-y coupling effects measured in the extraction line, was set back to zero. Without this correction, the vertical emittance measured in the extraction line was 40 pm. Table 1 displays the vertical beam sizes measured as a function of QD0 current.

Table 1: Vertical Beam Size Measured with Post-IP Wire Scanner on April 9, 2009

| $I_{QD0}$ (A) | $\sigma_y$ (m) | ERROR_$\sigma_y$ (m) |
|---|---|---|
| 116.08 | 1.55e-05 | 2.0e-07 |
| 113.58 | 1.17e-05 | 1.0e-07 |
| 111.08 | 7.7e-06 | 1.0e-07 |
| 108.58 | 4.8e-06 | 1.0e-07 |
| 107.58 | 4.0e-06 | 1.0e-07 |
| 106.08 | 4.8e-06 | 1.0e-07 |
| 103.58 | 8.2e-06 | 1.0e-07 |
| 101.08 | 1.17e-05 | 1.0e-07 |

In the thin lens approximation, beam sizes squared can be shown to have a parabolic dependence on the strength of QD0, with parameters from which the emittance, ε and β functions can be computed [3]. Fig. 4 shows the squares of the vertical beam sizes measured on April 9 after correcting for the contributions from the wire size and anomalous vertical dispersion at the waist. The wire size correction amounts to subtracting 2.5 micron in quadrature, corresponding to a quarter of the wire diameter [4]. The vertical dispersion was measured in the same shift, recording vertical position shifts on the wire scanner for different settings of the damping ring momentum ramp, see Fig. 5. The vertical dispersion, emittance and β function obtained fitting respectively first and second order polynomials to the data were:

$$D_y = -3.0 \pm 0.6 \text{ mm}$$
$$\beta_y = 0.026 \pm 0.002 \text{ m}$$
$$\varepsilon_y = 141 \pm 9 \text{ pm}$$

Both the vertical emittance and β function were larger than expected, the latter by about a factor of 2 ($\beta_y$ is slightly enlarged at the post-IP wire location compared to the nominal IP). The larger $\varepsilon_y$ may be explained in part because anomalous angular dispersion was not measured during the waist scan and could thus not be corrected. Residual x-y coupling was also not corrected and can hence also be part of the explanation.

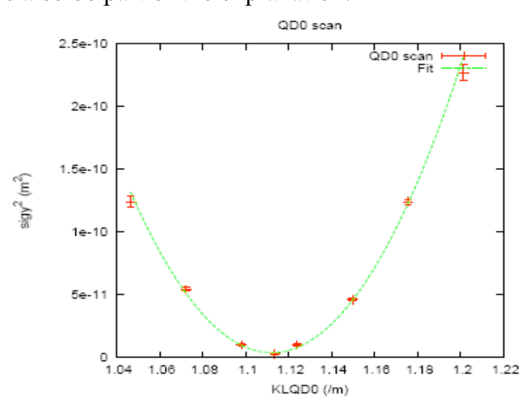


Figure 4: Vertical beam size as a function of KLQD0.

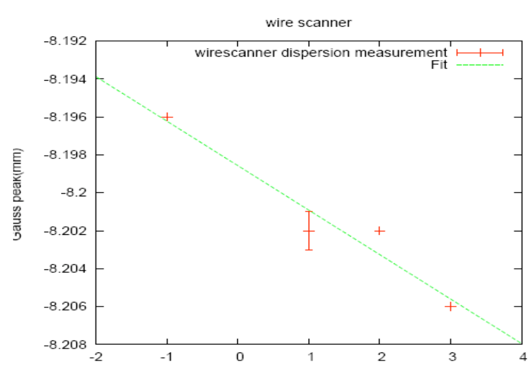


Figure 5: Vertical beam position shift measured at waist using post-IP wire scanner vz DR RF frequency shift.

### *Horizontal and Vertical Waist Scans on April 23*

Similar results obtained in both planes at the end of April are shown in Table 2 and in Figs. 6 and 7.

Table 2: Horizontal and Vertical Beam Sizes Measured with Post-IP Wire Scanner on April 23, 2009

| $I_{QD0}$ (A) | $\sigma_y$ (m) | $\Delta\sigma_y$ (m) | σx (m) | $\Delta\sigma_x$ (m) |
|---|---|---|---|---|
| 145.34 | | | 4.16e-05 | 1.2e-06 |
| 140.34 | | | 3.18e-05 | 1.0e-06 |
| 135.34 | | | 2.85e-05 | 1.0e-06 |
| 132.84 | | | 3.9e-05 | 1.4e-06 |
| 127.84 | | | 4.59e-05 | 1.7e-06 |
| 125.34 | | | 4.84e-05 | 1.5e-06 |
| 122.84 | 3.07e-05 | 1.3e-06 | | |
| 117.84 | 1.76e-05 | 1.1e-06 | | |
| 112.84 | 1.54e-05 | 3.0e-07 | | |
| 107.84 | 9.6e-06 | 4.0e-07 | | |
| 105.34 | 7.0e-06 | 4.0e-07 | | |
| 102.84 | 6.6e-06 | 1.0e-07 | | |
| 100.34 | 6.0e-06 | 5.0e-07 | | |
| 97.34 | 7.7e-06 | 2.0e-07 | | |
| 92.84 | 1.31e-05 | 4.0e-07 | | |

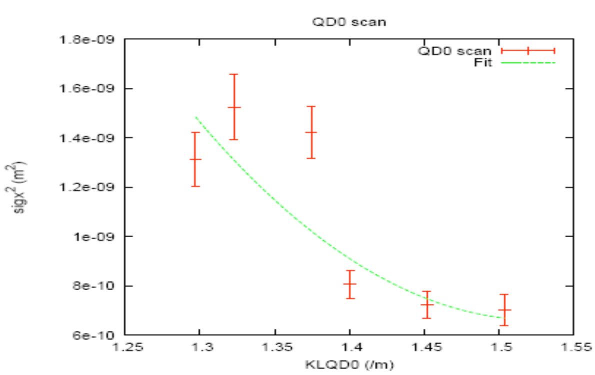


Figure 6: Horizontal beam size as a function of KLQD0.

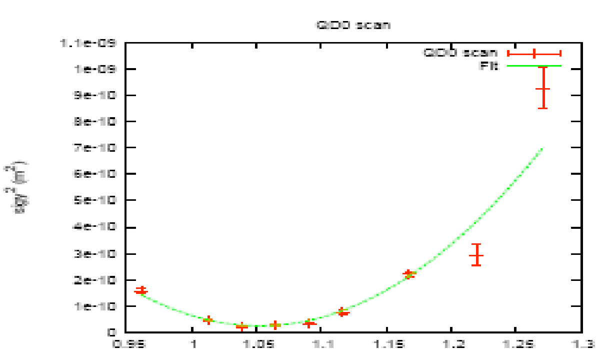


Figure 7: Vertical beam size as a function of KLQD0.

The horizontal dispersion was measured both at the minimum, where a value compatible with zero was found, and close to the edges of the scan, allowing also the angular component to be calculated. The latter confirmed the nominal $D_{x'}$ = 0.14 rad angular dispersion, but since QF1 and QD0 settings were not exactly those needed nominally to produce a horizontal waist at the wire scanner, some horizontal dispersion mismatch could be inferred. Correcting the measured beam sizes for the wire size and measured dispersion significantly displaced the minimum of the beam size, as shown in Fig. 6, indicating a large horizontal betatron mismatch. The values for the emittance and β function obtained from fitting a second order polynomial to the corrected beam size data were:

$$\beta_x = 0.6 \pm 0.3 \quad \text{m}$$
$$\varepsilon_x = 1.1 \pm 0.8 \text{ nm}$$

The large uncertainties account for the large beam size errors and for the fact that only one side of the parabola remained after the dispersion correction. It would clearly have been desirable to measure more distant points. Nonetheless, the result for the emittance is compatible with the design value of about 1.2 nm while the β function was much larger than the expected value of about 9 cm at the post-IP wire, confirming a significant betatron mismatch of the horizontal plane.

The results in the vertical plane were:

$$\beta_y = 0.098 \pm 0.007 \quad \text{m}$$
$$\varepsilon_y = 255 \pm 14 \text{ pm}$$

In this case the dispersion measurement did not give consistent values below and above the waist and could not not be accounted for meaningfully. The results shown are thus corrected only for the wire size, and can hence unfortunately not be compared with expectations.

### *Summary and Prospects*

Orthogonal waist scans can adjust the horizontal and vertical beam waists independently in the presence of errors, at two different IP locations. More studies are planned to check the orthogonality in realistic condition with several other types of errors, inducing e.g. vertical dispersion and x-y coupling. By adjusting the waists at the post-IP wire scanner location, the beam can be prepared with coarse tuning before measurements with the Shintake monitor. First measurements to exercise the corresponding procedures were presented in this paper.

## REFERENCES


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[4] Beam Size Measurements by 7 μm Carbon Wire Scanner. ATF Internal Report, ATF-02-04 2002/11/29