BEAM MEASUREMENTS FOR LUMINOSITY OPTIMISATION IN DAΦNE

F. Sannibale, C. Biscari, M. Boscolo, G. Di Pirro, A. Drago, A. Gallo, A. Ghigo, S. Guiducci,
F. Marcellini, G. Mazzitelli, C. Milardi, M. Preger, M. Serio, A. Stecchi, A. Stella, C. Vaccarezza,
G. Vignola, M. Zobov, INFN-LNF, Frascati, Italy

Abstract

The optimisation of the DAΦNE interaction region for luminosity performances passes through a number of beam measurements that allow to set the proper overlap of the colliding beams and to minimize the beam-beam effects that degrade luminosity. Most of the machine diagnostics systems are involved in this process and in particular a machine dedicated luminosity monitor, the tune measurement system, the synchrotron light monitor and the orbit acquisition system play a fundamental role. In the present paper a description of the most significant measurements is presented.

1 INTRODUCTION

Among the existing factories, DAΦNE†[1] has the lowest energy (0.51 GeV/beam). The KLOE experiment detector, placed in one of the two interaction regions, makes use of a solenoid magnet whose integrated field is about 2.1 Tm. This combination of low energy beam and strong solenoidal field in the interaction region (IR) induces a large coupling that must be carefully compensated in order to improve the luminosity performance. In fact commissioning experience and beam-beam simulations [1], have indicated the existence of a very bad synergism between beam-beam effects and coupling. In particular, the presence of even modest values of coupling can significantly enhance the vertical beam blow-up with consequent luminosity reduction. For this reason the coupling, generated in the KLOE IR and in any other source along the machine, must be corrected as much as possible. At present time emittance ratios as low as 0.2% have been obtained (the design value is 1.0%).

At the same time the other parameters at the interaction point (IP) (optical functions, vertical crossing angle, vertical overlap, ä) that, in a flat beam machine such as DAΦNE, play an important role in the beam-beam game must be tuned with a great accuracy.

The optimisation of these machine parameters needs accurate measurements. Because of the KLOE requirement of a large material free region around the IP, very little space was left for the IR diagnostics, which has a reduced configuration, particularly for what concerns the number of beam position monitors. The optimisation of the IP parameters passes through indirect measurements performed by basically all the DAΦNE diagnostic systems [2]. The synchrotron light monitor, the orbit acquisition system and the tune measurement system [3, 4, 5], play an important role, but the fine tuning of the beam-beam affecting parameters is obtained by a machine dedicated luminosity monitor†[6]. This is a high counting rate monitor, able to perform fast measurements with small fluctuation, in 2 or 3 seconds, allowing a real time optimisation of the machine parameters.

This paper deals with the most significant beam measurements performed in the final tuning phase. Table 1 shows the DAΦNE parameters, while a complete update of the present performances can be found in [1].

Table 1: DAΦNE Design Parameters

Energy	0.51 GeV/beam
Phase 1 Luminosity (30 bunches)	1.3 10^{32} cm^{-2} s^{-1}
Final Luminosity (120 bunches)	5.2 10^{32} cm^{-2} s^{-1}
Beta Functions @ IP (V/H)	4.5/450 cm
Natural Emittance	10^{-6} m rad
Emittance Ratio	0.01
Particles/Bunch (Max)	8.9 10^{10}
Beam-beam Tune Shift (Max) (V/H)	0.04/0.04
Horizontal Crossing Angle	10-15 mrad
r.m.s. Bunch Length	3 10^{-2} m
Natural Relative Energy Spread	4 10^{-4}
Number of Bunches (Max)	120
Ring Length	97.69 m
RF Frequency	368.263 MHz

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The IR parameters are first optimised in a condition of negligible beam-beam effects. Such a situation is achieved when very small currents per bunch are stored in both rings (typically less than 1 mA/bunch). Multibunch mode is preferred in order to increase the counting rate at the luminosity monitor improving the measurement accuracy.

Most of the measurements make use of the luminosity parameter scan technique where a machine parameter is systematically varied and the effects on luminosity are recorded.

2.1 Overlap at IP of the Colliding Beams

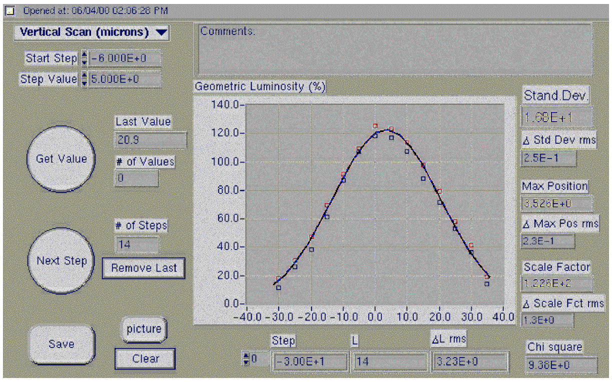
Among the possible scans, the ones concerning the mutual beam position at IP are very useful. They allow to directly measure the quantities Σ_y and Σ_x:

$$\Sigma_w = \sqrt{\sigma_{w+}^2 + \sigma_{w-}^2} \qquad w = x, y \tag{1}$$

that appear in the luminosity formula:

$$L = f_R \frac{N^+ N^-}{2\pi \Sigma_x \Sigma_y} \tag{2}$$

Figure 1 shows an example of a vertical position scan. With the beams in collision, the electron beam vertical position at IP is changed with a 5 µm step and the related luminosity is measured. Data are fitted by a gaussian function that gives Σ_y, the best overlap position y_{max} and the luminosity maximum value. Luminosities are normalised to the product of the colliding currents and referred to the design value of 2.27 10^{27} cm^{-2} s^{-1} mA^{-2}.



Comments:

Start Step: -6.000E+0

Step Value: 5.000E+0

Last Value: 20.9

# of Values: 0

# of Steps: 14

Stand.Dev.: 1.68E+1

Δ Std Dev rms: 2.5E-1

Max Position: 3.526E+0

Δ Max Pos rms: 2.3E-1

Scale Factor: 1.226E+2

Δ Scale Fct rms: 1.3E+0

Step: 0 -3.00E+1

L: 14

ΔL rms: 3.23E+0

Chi square: 9.36E+0

Figure 1: Luminosity vs. Vertical Position@IP.

Luminosity and the Σ parameters are measured and their consistency with the expected values calculated by equations (1) and (2) can be checked. Any discrepancy, taking into account the experimental errors, is an indication of a non-properly set IP: presence, for example, of relative transverse tilt between the colliding beams, vertical dispersion, different optical functions. In Figure†1, the measured Σ_y of 16.8 µm is, using the values of Table 1, a clear indication of a well-overlapped IP consistent with a coupling corrected down to 0.3 % in both beams.

2.2 Best IP Position and Vertical Crossing Angle Correction.

DAΦNE is a separate ring collider with independent e^+ and e^- RF cavities. By changing the RF phase of one of these cavities it is possible to move the longitudinal position of the IP. If vertical position scans are performed at different IP positions, then the dependence of Σ_y and of y_{max} with respect to the IP position can be measured. By using the first set of data and assuming zero vertical dispersion at IP and negligible effects due to bunch length, than equation (1) gives a quadratic dependence of the square of Σ_y with respect to the IP position s_{IP}:

$$\Sigma_y^2 = a_2 s_{IP}^2 + a_1 s_{IP} + a_0 \qquad (3)$$

By equation (3) it is possible to fit the data and find the IP position where Σ_y assumes its minimum value. In separated rings machines where the optical functions at the IR and in particular the vertical beta waist position, can be different in the two rings, this minimum Σ_y identifies the IP position that gives the best luminosity performance obtainable with that IR configuration.

Figure 2 shows an example of such a measurement.

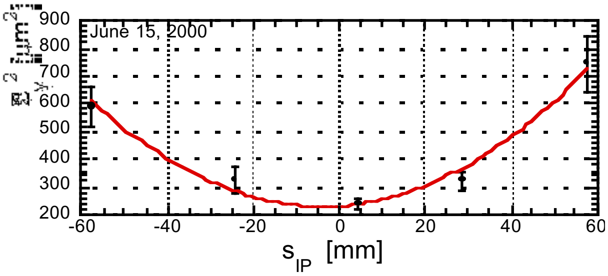


Figure 2: IP Best Longitudinal Position Measurement.

The detector solenoidal field introduces a coupling between the coordinates of the transverse plane. A rotation of the reference frame proportional to the field integral along the longitudinal direction decouples the transverse plane again. It can be shown that in this rotated reference frame (RRF) the difference between the vertical trajectories of the beam center of mass of the colliding beams is, with a very good approximation:

$$\Delta y_{c.m.} = \left(y_{IP}'^{+} - y_{IP}'^{-} \right) s_{IP} \qquad (4)$$

Any position scan, including the vertical, is performed in RRF, thus the best overlap position y_{max} is a measurement of $\Delta y_{c.m.}$. If y_{max} vs. the IP position s_{IP} is fitted by equation (4) then the slope of the fit is a measurement of the beam vertical crossing angle at IP.

Figure 3 shows a measured vertical crossing angle of ~†230 µrad (dashed line) and a residual angle of less than 70 µrad (solid line) after the correction performed by a vertical angle bump localized at IP.

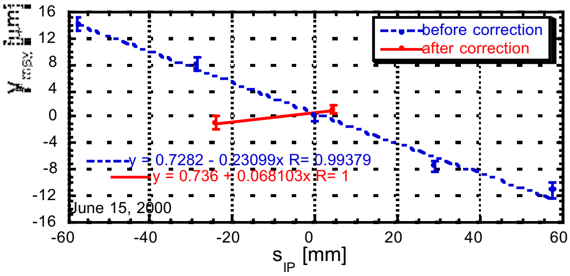


Figure 3. Vertical Crossing Angle Measurement

2.3 Vertical Dispersion and Transverse Plane Coupling at IP.

The y_{max} value, obtained by a vertical position scan, can also be used for estimating the vertical dispersion and the transverse plane coupling at IP.

In the first case a vertical scan is taken and the related y_{max} value is recorded. After that, the beam energy is changed by applying a RF shift Δf_{RF} and a new vertical scan is performed. The difference between the two values of y_{max} obtained at the different energies is a measurement of the vertical dispersion at IP. Actually, because of the common RF source, such a measurement does not give the absolute value of the vertical dispersion but just the difference between the dispersions of the two beams at IP.

In the transverse coupling case, the measurement starts with two scans, one vertical and the other horizontal, in order to get the initial values of y_{max} and x_{max}. The second step consists in powering in one of the rings, outside the IR, a horizontal corrector. The corrector kick must be strong enough to generate a horizontal closed orbit distortion at IP of the same order of the horizontal beam size. New vertical and horizontal position scans are finally performed and the ratio between the differences of the new and old values of y_{max} and x_{max} gives a measure of transverse plane coupling at IP.

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When the current of the colliding bunches increases the beam-beam effects become more and more important up to limit the maximum achievable luminosity. An exhaustive beam-beam theory does not exist, simulations can address the choices, but the final tuning must be performed by beam measurements.

3.1 Beam-beam Tune Shift.

The knowledge of the beam-beam tune shift vs. the single beam colliding currents gives a clear picture of the beam-beam scenario. This quantity can be evaluated by measuring, in the tune monitor, the associated coherent tune shift. The ratio between the coherent and incoherent tune shifts is a function that depends on a number of parameters [7] and its evaluation is often tricky. Additionally, at present time, the DAΦNE rings have different working points. This situation not only changes the mentioned ratio [8] but, reducing the beam-beam induced coherent oscillation, also makes the measurements difficult. An alternative way to obtain the tune shifts is given by the expressions:

$$\xi_y^{\pm} = \frac{2r_e}{\gamma f_R} \beta_y^* \frac{L}{N^{\pm}} \qquad \xi_x^{\pm} = \frac{r_e}{2\pi\gamma} \frac{N^{\mp}}{\varepsilon} \qquad (5)$$

that hold for flat and equal beams. In DAΦNE the vertical tune shift is evaluated at each luminosity measurement, allowing, for example, a run time measurements of the maximum tune shift achievable with that machine configuration.

3.2 Beam-beam Blow-up.

In a flat beam collider the beam-beam induced vertical blow-up is the ultimate limit to luminosity. The intensity of this effect depends on several parameters as, tune resonances, lattice non-linearities and all the coupling components. In collision, these quantities can be tuned by moving the proper knob (working point for tunes resonances, sextupoles strength for non-linearities, skew quadrupoles strength for coupling) and maximizing the luminosity or, equivalently, minimizing the beam-beam vertical blow-up. In DAΦNE it is possible to put the beams in and out of collision, in a very clean way, by applying or removing a RF phase jump of 2, 3 or 4 π in one of the cavities. The roundness values R (ratio between the vertical and horizontal beam dimensions at the synchrotron light monitor) in and out of collision are recorded at each knob variation step. The ratio R_{in}/R_{out} is a measure of the blow-up and its minimum indicates the best setting for that knob. Figure 4 shows an example of such a measurement where the current of a positron skew is varied and the related luminosities (dashed line) and positron roundness ratios (solid line) are recorded.

Additional information on single beam non-linearities minimization in DAΦNE can be found in†[9].

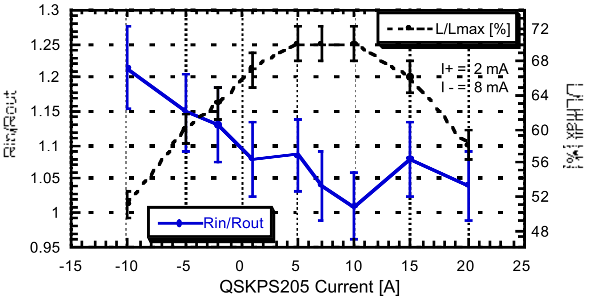

Figure 4: Positron Skew Quadrupole Scan.

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