LUMINOSITY PERFORMANCE OF DAΦNE

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Abstract

Since the last EPAC2000 Conference, both the peak and integrated luminosity of the e^+e^- collider DAΦNE, Italian Φ–factory, have grown by an order of magnitude. In this paper we describe the steps that have led to the luminosity increase and discuss our plans for further luminosity upgrade.

1 INTRODUCTION

The Φ–factory DAΦNE is an e^+e^- collider designed to provide luminosity in the order of 10^{32} cm^{-2}s^{-1} at the energy of the Φ–resonance (1020 MeV in the centre of mass) [1]. The first experimental detector KLOE [2], aimed at the study of for CP violation, was installed in the Interaction Region 1 (IR1) of DAΦNE in March 1999. Since then DAΦNE alternates machine study and physics data taking shifts. Later, another experiment DEAR [3], for exotic atoms studies, was installed in the second interaction region (IR2). The peak luminosity growth in time for the KLOE experiment is shown in Fig. 1.

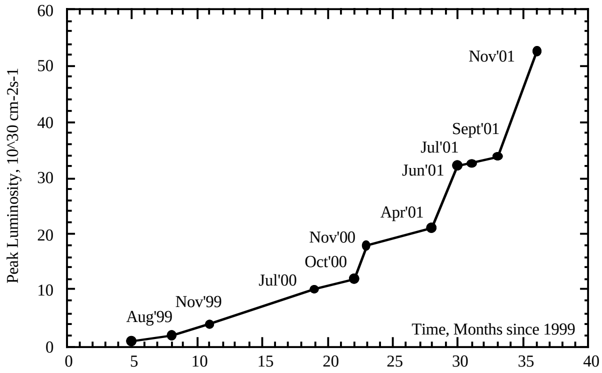

Figure 1: DAΦNE peak luminosity.

The peak luminosity was increased by more than a factor of 10 during the past two years (from November 1999 to November 2001) reaching a maximum value of 5.2 10^{31} cm^{-2}s^{-1}. As shown in Figure 2, during last year the peak luminosity is steadily increasing, while the integrated luminosity per day grows faster, indicating an improvement of the overall efficiency and at present its peak value is 3 pb^{-1}/day. About 200 pb^{-1} have been logged by the KLOE experiment. December 2001 and 3 months after a shut down in January/February 2002 were dedicated to the collider tuning and data taking for the DEAR experiment. The experience gained with the KLOE lattice helped in reaching practically the same luminosity of 5.0 10^{31} cm^{-2}s^{-1} at IR2 in a short time and to substantially reduce the background that was of a crucial importance for the DEAR experiment. About 20 pb^{-1} were logged by this experiment and, due to both machine and detector improvements, the signal-to-noise ratio has been enhanced by a factor of 40 with respect to the DEAR shifts in May 2001. An important contribution to the background reduction came from the decrease of the horizontal beta function at the interaction point.

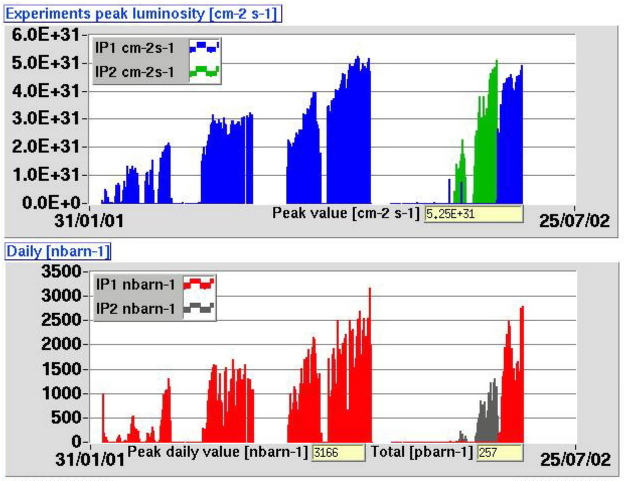

Figure 2: DAΦNE peak and daily integrated luminosity.

In May 2002 data taking shifts for KLOE resumed with slightly lower luminosity, but with a background reduction by a factor 3 with respect to December. In this paper we describe our experience on the DAΦNE luminosity performance optimisation and discuss our future plans.

2 LUMINOSITY OPTIMISATION

The above described significant luminosity progress was realized by means of continuous machine physics study. The major items leading to the luminosity performance improvement can be summarised as follows:

- Working point choice.
- Coupling correction.
- Nonlinear beam dynamics study.
- Linear optics improvements.
- Single- and multibunch instability cures.
- Collider parameters fine tuning during data taking.

A dedicated work on background reduction including orbits and optical functions correction, working point fine tuning, sextupole strengths and scraper positions optimisation allowed to operate the collider in the “topping up” mode without switching off the KLOE drift chamber during injection. This resulted in a significant average and daily integrated luminosity increase.

2.1 Working Point Choice

Analytical estimates and numerical simulations [4] have shown that the only working point on the tune diagram above integers, where the project luminosity parameters with $\xi_x = \xi_y = 0.04$ can be met, is a small area around (ΔQ_x=0.09, ΔQ_y=0.07). However, during collider commissioning the working point (0.15; 0.21) was chosen for collisions. Despite some expected reduction in luminosity, this point has a number of advantages with respect to (0.09; 0.07), of particular importance during machine tuning: the dynamic aperture is larger, the second order chromaticity terms are smaller, coupling correction is easier, the closed orbit is less sensitive to magnetic element errors and so on. An intensive numerical study has been carried out for this working point [5], considering different factors affecting the luminosity performance such as the separation at the second interaction point, vertical crossing angle, parasitic crossings and others. At present the positron ring is tuned at this working point. Instead, we had to shift the electron ring working point from (0.15; 0.21). There are two main reasons for that:

- Performing the tune scan it was found that the lifetime for this working point was low even without beam-beam collisions. This was attributed to nonlinear lattice resonances.
- At high currents a strong vertical instability in the e+ ring is transmitted to the e- ring if the tunes are equal. Separating the tunes the instability is eliminated by the Landau damping due to the nonlinear beam-beam interaction.

Experimentally, after gradual optimisation of collision parameters, the working point of the electron ring was set to (0.11; 0.14). Actually, according to numerical simulations this is yet another “safe” working point in the tune area above integers where the beam blow up is relatively small and tails induced by the beam-beam interaction are well confined within the dynamic aperture.

2.2 Coupling Correction

In a storage ring different sources can excite coupling between vertical and horizontal betatron oscillations: skew magnets, vertical dispersion, solenoids, off-axis sextupoles etc. Depending on the coupling sources and their distribution along the ring, the normal betatron modes can propagate in a different way down to the interaction point (IP). As a consequence, the two beams can have different sizes and rotations at the IP resulting in different core blow up and tail growth. Numerical simulations have shown that for the nominal coupling of 1% the beam core blow up in DAΦNE may vary in a wide range. This was a clear indication of the necessity of deeper coupling study and correction below the design value. Details of this work are described elsewhere [6]. Here we list the main steps that led to coupling reduction:

- KLOE detector solenoid and compensator magnet current variation
- Global coupling correction with skew quadrupoles.
- Residual vertical dispersion correction.
- Nonlinear terms minimization.
- Working point fine tuning.

As a result, coupling was reduced down to 0.2% for both rings and the luminosity in single bunch collisions increased by, at least, a factor of 2.

2.3 Nonlinear Dynamics Study

Nonlinear dynamics study was considered as a crucial task for luminosity increase. Three main techniques were adopted for this study: tune scans, localized orbit bumps inside critical magnetic elements and beam decoherence measurements. The tune scan was used to define safe areas for beam-beam collisions on the tune diagram not affected by nonlinear lattice resonances. By changing the tunes we observed the lifetime and blow up of a single bunch at the synchrotron light monitor. We found that for some tunes the lifetime was strongly reduced or the beam size increased. By analyzing the results we found that nonlinear resonances up to 6th order were responsible for these effects. Since such resonances can be driven only by strong nonlinear magnetic elements, dedicated orbit bumps were performed and tune shifts versus bump amplitude were measured in order to recognize such elements. In particular, it was found that the wigglers are a strong source of octupole-like terms providing a cubic nonlinearity [7]. By means of a dynamic tracking system [8] we performe beam decoherence measurements and estimate directly the coefficient c_{11} of the horizontal tune shift versus amplitude. Numerical simulations carried out taking into account the measured cubic nonlinearity have shown that they have a dramatic impact on the collider luminosity performance [9]. Beam blow up and tails growth could be observed in the simulations if the coefficient $|c_{11}|$ characterizing the cubic nonlinearity exceeded 2 10^2 m^{-1}. This limit should be compared to the measured value for some lattice configurations as high as 6 10^2 m^{-1}. In the multibunch regime the maximum achievable luminosity is mainly limited by the combined effect of parasitic crossings and nonlinearities.

Experimentally, a strong correlation between the luminosity and the measured cubic nonlinearity was observed. Indeed, the present peak luminosity of 5.2 10^{31} $cm^{-2}s^{-1}$ was obtained when $|c_{11}|$ was reduced below 2 10^2 m^{-1} in both rings. In this case the luminosity scales linearly with the number of bunches.

2.4 Lattice Improvements

An important step leading to luminosity increase was obtained for KLOE by means of a new “detuned” lattice without low beta insertion at the second interaction point [10] where the beams are separated during KLOE runs.

The main advantages of this lattice can be summarised as following:

- The separation of the beams at the second IP is be larger; therefore the second IP has no influence on luminosity.
- The low beta insertion at the second IP has been eliminated thus reducing the chromaticity. This allowed to reduce β_y at the KLOE IP keeping the same sextupole strengths. β_y has been reduced from .06 m to .03 m.
- The beta functions in the wigglers are lower. As a consequence, the lattice is less sensitive to the cubic nonlinearity in comparison with the "old" KLOE lattice.

In the DEAR case the situation is worse, since the permanent magnet KLOE quadrupoles do not allow to eliminate the low β in KLOE interaction region. At the KLOE IP a β_y =.07 m has been realized, while at the DEAR IP the value of β_y is .03 m. Switching off the couple of quads nearest to the IP allowed to decrease also β_x at the IP from 4 m to 1.5 m, with a significant reduction of chromaticity and background in the experiment and luminosity improvement.

2.5 Instabilities

Stable high current multibunch beams are necessary to reach high luminosity. At present the single bunch design current of 44 mA (in interaction) has been largely exceeded. About 200 mA were stored in a non interacting single bunch in both rings without observing harmful instabilities. In the multibunch regime more than 2 A were accumulated in the electron storage ring and about 1.3 A in the positron one. Details of the high current beam dynamics are presented at this Conference [11, 12].

3 LUMINOSITY UPGRADE PLANS

Analysis of numerical simulations and experimental data together with the experience acquired during commissioning provide us with guidelines for future luminosity upgrade. In particular, the following steps will be undertaken in the near future:

- Change of the e- beam working point. Strong-strong beam-beam simulations show that the luminosity can increase by almost a factor of 2 by shifting the electron beam tune to the working point (0.15; 021). This can be done if the problem of the low lifetime for this working point in the e- ring is solved and the vertical instability is effectively damped.
- Increase of the number of bunches by filling each RF bucket. The problem of parasitic crossings (PC) in this case can be solved by increasing the separation at the PCs in terms of the horizontal beam size by providing larger horizontal crossing angle, reducing the horizontal beta function at the PC positions and decreasing the horizontal emittance. The first attempt to work with 90 consecutive bunches in the DEAR lattice has been successfully made [13].
- Further current increase both in single bunches and in multibunch beams. Deeper beam dynamics study and elimination of instability sources will accomplish this task.
- Theoretical and experimental study of nonlinear optics with recently installed octupole magnets. The octupoles give a possibility to vary the cubic nonlinearity in a wide range thus affecting beam-beam interaction. Background, dynamic aperture and lifetime improvements are also expected [14].
- Measurement and correction of the nonlinear magnetic terms on a new wiggler prototype by means of pole shimming. By applying the correction to all wigglers, the contribution to the lattice non linearity will be strongly reduced.
- Installation of a new interaction region for KLOE(IR) providing independent rotation of the permanent magnet quadrupoles. Transformation of the present triplet structure into a doublet with the goal of reducing β_x at the IP and chromaticity. Insertion of masks for backgrounds reduction is also foreseen. We expect better coupling correction within the IR and the possibility of colliding at the second IP with the KLOE solenoid off.

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