STATUS OF DAΦNE

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Abstract

DAΦNE is a double ring electron-positron collider, designed to provide very high luminosity at the energy of the Φ resonance (1.02 GeV c.m.). After storing the first beam in fall 1997, the collider was commissioned without solenoidal detectors until the end of 1998, reaching a single bunch luminosity of 1.6×10^{30} cm^{-2}s^{-1} with 20 mA in each beam, corresponding to a beam-beam tune shift of ≈0.03. A longitudinal bunch-to-bunch feedback has been implemented, allowing the storage of more than 0.5 A in 30 bunches for both electrons and positrons. The KLOE detector, embedded into a superconducting solenoid with strong longitudinal field integral (2.4 Tm, to be compared to a magnetic rigidity of 1.7 Tm) compensated by two other solenoids of opposite field, was installed in winter 1999 and commissioning resumed with a careful correction of the coupling effects. Particular effort has been dedicated to the reduction of background in the experiment, which led to the possibility of injecting the beams in interaction without switching off data taking. The total stored current has reached more than 1 A in each beam, while a transverse feedback system has been realized to counteract vertical instabilities occurring during injection. The collider is now running in the multibunch mode for KLOE data taking with peak luminosity up to 1.8×10^{31} cm^{-2}s^{-1} and integrated luminosity larger than 0.8 pb^{-1} per day.

1 INTRODUCTION

DAΦNE has been already described in detail [1,2,3,4]. Let us just recall here that it is a high luminosity electron-positron collider working at the center of mass energy of the Φ resonance (1.02 GeV) to produce a high rate of K mesons to study CP violation. Two 97 m long independent rings lay in the same horizontal plane, crossing at a small horizontal angle (25 mrad) in two interaction regions (IR). The first one hosts a large detector (KLOE [5]) surrounded by a superconducting solenoid with a field integral of 2.4 Tm; its main physics goal is the measurement of the CP violating parameter Re(ε'/ε). A small non-magnetic experiment for the study of the properties of kaonic atoms (DEAR [6]) is presently installed on the second IR, which will host in the near future a second magnetic detector (FINUDA [7]) with the same field integral as KLOE, devoted to the study of hypernuclei.

Up to 120 bunches can be stored in each ring, leading to a very large design total current of 5A. The design luminosity is 5×10^{32} cm^{-2}s^{-1}, based on the assumption of reaching equal tune shifts of 0.04 in both planes with a flat beam (1% coupling, 4.5 cm vertical β at the crossing point (IP) and 1 mm.mrad emittance).

A powerful injection system [8] has been realized to cope with the large stored current and short, Touschek limited, lifetime. The system, consisting of a Linac and an intermediate damping ring, is designed to deliver single bunches with the design charge at full energy to the collider at a repetition rate of 1 Hz. In such way, operating in a "top off" mode, or from scratch, it is possible to refill the rings in less than 5 minutes.

Figure 1 shows a schematic layout of the double ring collider in the final configuration with both magnetic detectors installed. Presently, the DEAR detector occupies the IR at the bottom of the figure. The low vertical β is obtained by means of two symmetric quadrupole triplets, realized with permanent magnets in KLOE and with conventional ones in DEAR.

2 HISTORY

The installation of DAΦNE was completed at the end of summer 1997. The first electron beam was stored in September and the positron one followed two months later. The first interactions were obtained in March 1998 and at the end of November a single bunch peak luminosity of 1.6×10^{30} cm^{-2}s^{-1} was obtained, with 20 mA in each beam. The corresponding tune shifts, estimated from the luminosity measurement, beam currents and sizes, were ≈0.03.

Only a few attempts to run the machine in the multibunch mode were tried, reaching a luminosity of $\approx 1 \times 10^{31}$ cm^{-2}s^{-1} with 13 bunches in each beam. During this first commissioning phase (called "DAY-ONE") the low vertical β at the interaction points (see Fig. 1) was obtained by a symmetric arrangement of 7 quadrupoles, with the central one sitting on the IP.

The design single bunch current (44 mA) was largely exceeded, reaching 110 mA in both rings. Ion trapping was observed in the electron ring and cured with a distributed system of clearing electrodes.

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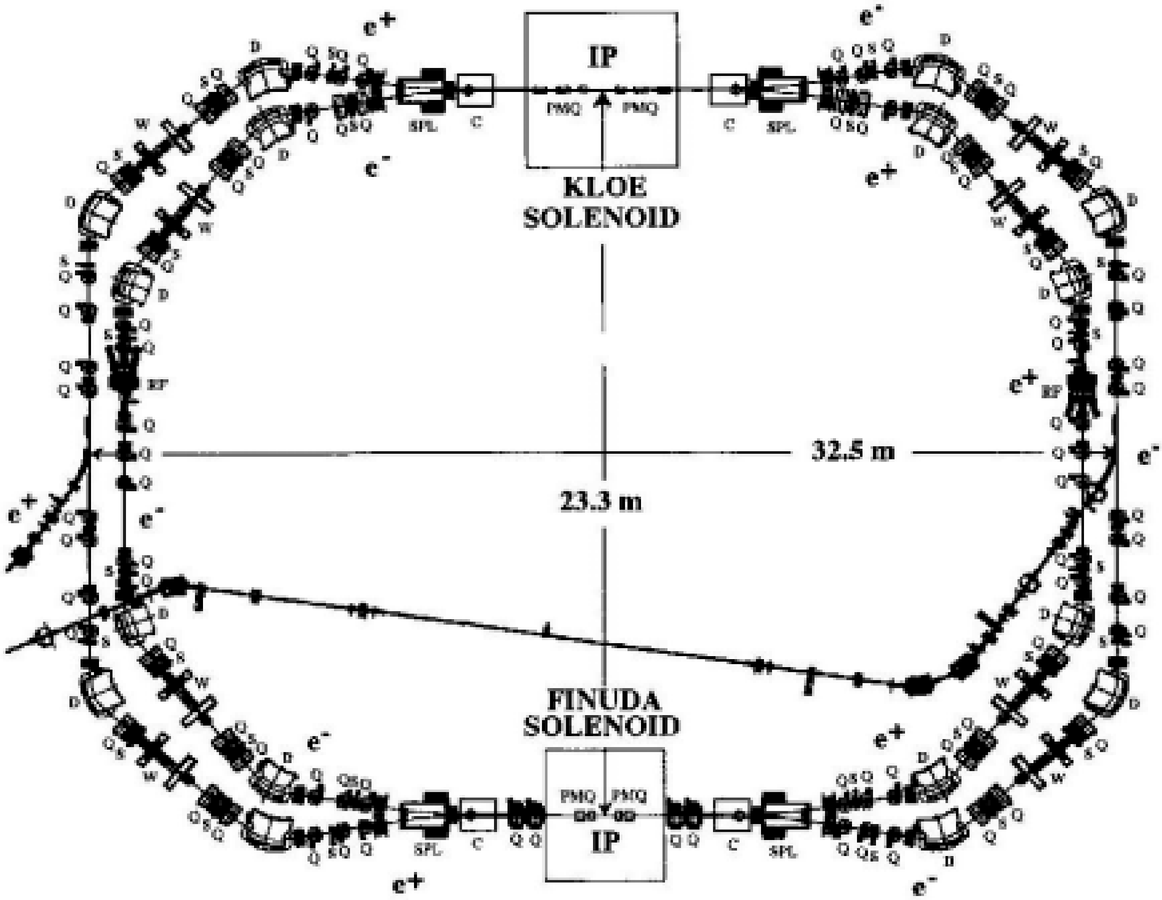

Figure 1: The double ring collider layout (symbols indicate quadrupoles Q, sextupoles S, permanent magnet quadrupoles PMQ, compensating solenoids C, splitters SPL, dipoles D, wigglers W).

Up to 0.3 A were stored without feedback. A bunch-to-bunch longitudinal feedback [9] was implemented, allowing the storage of more than 0.5 A in ≈30 bunches in both rings.

During a long shutdown in winter 1999 the KLOE detector was installed on the IR on the top of Fig. 1. The structure of the IR changed drastically with respect to the "DAY-ONE" layout with seven quadrupoles: the strong field integral necessary for the experiment is realized by means of a superconducting solenoid with a field integral of 2.4 Tm. This field rotates the betatron oscillation plane by ≈41 degrees. In order to compensate the strong coupling created by this solenoid, two compensators are placed near the splitters (see Fig. 1) with the same field integral of opposite direction. A sophisticated assembly containing two permanent magnet quadrupole triplets and a thin special vacuum chamber was inserted inside the detector: the last step was to move the whole setup (solenoid magnet, detector and vacuum chamber) on the beam line. At the same time the DEAR experiment was prepared on the other IR, with two conventional quadrupole triplets around a carbon fiber straight section on the IP.

The introduction of KLOE was a strong perturbation to the lattice of the two rings for the following reasons:

- The field created by the detector solenoid, although compensated, strongly couples the betatron motion, calling for a sophisticated compensation scheme [10] where the quadrupoles of the two focusing triplets are rotated by different angles following the rotation of the betatron plane inside the magnet.
- The quadrupole sitting on the IP was removed, reducing to 6 the number of IR quads.
- A Beam Position Monitor (BPM) placed exactly on the IP in the first commissioning phase, which made the superposition of the two beams at the IP straightforward, was no more available.
- The symmetry of each ring with respect to the major axis in Fig. 1 was lost.

Commissioning of the collider after KLOE installation was resumed in April 1999, exploiting the well-known working point of the "DAY-ONE" structure, with particular attention to the problem of coupling correction. The vertical beam size was minimized by tuning the main

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solenoid field, the compensators and skew quadrupole correctors inside the ring, reaching coupling values well below the design one (1%). However, the single bunch luminosity was less than $2x10^{29}$ $cm^{-2}s^{-1}$, much smaller than the results obtained in the "DAY-ONE" configuration.

Since the main change with respect to the "DAY-ONE" configuration was the introduction of the solenoids, particular care was dedicated to the problem of coupling, also because simulations had shown that even small relative angles between the two beams in the plane perpendicular to the trajectory could seriously affect the limit on attainable luminosity. This angle cannot be directly measured at the IP. However, by making vertical scans of one beam on the other one at the IP and detecting the corresponding luminosity, it was checked that the effective vertical beam size was consistent with the size observed on a synchrotron radiation detector in the arcs.

At the end of the year a period of approximately one month was dedicated to KLOE: working with stored currents of 300÷400 mA in 30÷40 bunches, with peak luminosity in the range of $5x10^{30}$ $cm^{-2}s^{-1}$ and beam lifetime in the order of 1 hour, ≈2.5 pb^{-1} were delivered to the experiment.

After the modification of the KLOE IR an unstable quadrupole mode was observed in both rings, with a threshold strongly dependent on bunch length. This problem was fixed by increasing the momentum compaction and reducing the cavity voltage.

A rather strong vertical instability was also observed in the positron beam at currents larger than ≈200 mA. This instability is not harmful to colliding beams operation, because it is damped by the beam-beam interaction. A transverse feedback system was also developed to further improve the instability threshold.

3 PRESENT PERFORMANCE

Collider operation was resumed in March 2000, after a long shutdown, with particular attention to multibunch operation and coupling optimization. Total currents in excess of 1 A were stored separately in each ring. The single bunch luminosity was carefully tuned by adjusting collision parameters and further reducing the coupling to ≈0.5%, reaching $5÷6x10^{29}$ $cm^{-2}s^{-1}$. In multibunch mode the maximum luminosity was $1x10^{31}$ $cm^{-2}s^{-1}$ with 30 bunches and ≈0.35 A per beam. It was empirically found that setting the two beams on different betatron tunes (5.10/5.14 for the electron beam, 5.15/5.21 for the positron one) improved machine performance significantly. At this point the machine was dedicated to data collection by KLOE for the whole month of July, delivering an integrated luminosity of ≈4 pb^{-1}. However, data collection was affected by high rates of beam induced backgrounds and short luminosity lifetime (typically half an hour). Injection had to be performed frequently with data acquisition switched off because of unacceptable background rate which tripped the KLOE drift chamber, leading to poor average luminosity.

At the beginning of September two weeks were dedicated to DEAR: this experiment is particularly sensitive to the signal to background ratio, which was larger by two orders of magnitude than the minimum required to start the experiment. By changing the optical functions near the IR, improving closed orbit correction and optimizing the position of 4 couples of scrapers placed upstream the IR's in both rings it was possible to decrease the backgrounds by a factor 5.

The following period, from mid-September to the end of November, was shared (at typically 50% each) between KLOE data taking and machine development dedicated at improving the background situation and the average luminosity. The first important result of this work was that the beam losses during injection were reduced to a level which allowed injection without switching off the drift chamber, only inhibiting data acquisition for 50 ms at each injection pulse. In this way the average luminosity can be kept close to the maximum one by frequently refilling the stored beams to the maximum currents allowed by the beam-beam interaction.

The machine is now operated with 45÷48 bunches. The filling pattern interleaves one empty bucket with a full one, with a ≈20% gap to avoid ion trapping. The typical positron current is 15 mA per bunch, limited by beam-beam interaction. The corresponding threshold for electrons is ≈12 mA per bunch: at higher currents the lifetime of the positron beam becomes very poor. The peak luminosity obtained so far is $1.8x10^{31}$ $cm^{-2}s^{-1}$, with ≈0.75 A in the positron beam and ≈0.55 A in the electron one. The luminosity per bunch in multibunch operation is therefore ≈30% smaller than the best obtained in the single bunch mode, due to non perfectly uniform filling patterns and parasitic crossing effects. The collider runs with the beams separated in the DEAR interaction region.

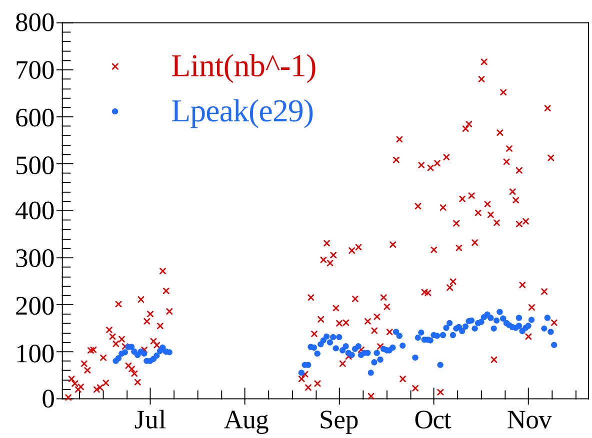

Figure 2: Peak luminosity (dots, in units of 10^{29} $cm^{-2}s^{-1}$) and integrated luminosity (crosses, nb^{-1}) per day.

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In 2.5 months 24 pb^{-1} were delivered to the experiment. Figure 2 shows the integrated and peak luminosity per day. The former changes significantly between different days because of variable beam time dedicated to machine development, while the latter exhibits a smooth improvement with time. It can be seen from Fig. 2 that the envelope of the integrated luminosity improves with time more rapidly than the peak one. This may be attributed to the fact that, during this period of data taking, no major improvements in the single bunch luminosity were obtained, but at the same time there has been a significant increase in the overall efficiency of machine operation.

The last two weeks of December 2000 were dedicated again to DEAR: by reinforcing the shielding around the detector and further optimizing the optical functions and closed orbit, another factor 4 was gained in the signal to background ratio. With a new experimental setup, which is already installed on the second IP and exploiting a new shape for the scrapers (see next section) it should be possible to start data acquisition. In addition, a new luminosity monitor based on the detection of charged kaons from the decay of the Φ resonance was also brought into operation. A trial to work with the beams crossing in KLOE and DEAR at the same time led to a substantial reduction in luminosity. Studies are under way to find a suitable working point with two crossings.

4 BACKGROUND STUDIES

During the time allotted to machine development at the end of last year a careful study of the behavior of the scrapers installed upstream the IR's has been carried out [11]. Each one of the 4 scrapers, placed before the splitters (see Fig. 1) in the direction of the incoming beams, consists of a couple of remote controlled rectangular tungsten blocks of 35 mm thickness, which can be moved in the horizontal direction from the walls of the vacuum chamber towards the beam. The position of the scrapers is chosen in such a way that they intercept Touschek-scattered particles from the arcs before hitting the vacuum chamber inside the IR's. The background rate measured by KLOE for an electron beam as a function of the scraper position is shown in Fig. 3: it can be seen that the external scraper reduces the background up to a distance of ≈25 mm from the beam, while the internal one has only a harmful effect.

The dynamics of Touschek-scattered particles has been simulated by means of tracking programs and GEANT3: it was found that most particles are scattered by the tungsten instead of being absorbed and that a different shape is necessary to improve background rejection. New scrapers have been built and installed on the rings with the thickness increased to 55 mm. This thickness is divided into two flat surfaces: the first one is 10 mm long and bent by 100 mrad with respect to the beam trajectory in order to increase the impinging angle for most particles, the second one (45 mm in thickness) is bent by 10 mrad in the opposite direction to avoid scattering the electrons towards the center of the beam pipe. First results show an increased efficiency of the scrapers.

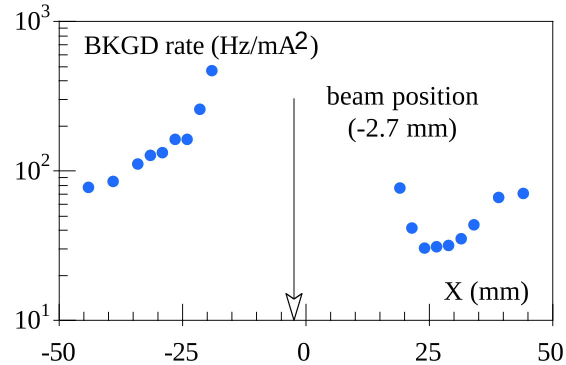

Figure 3: Normalized background versus position of scraper edge.

5 NON LINEARITIES

Another important result from the machine development shifts was the discovery of a strong "octupole-like" term in the wigglers (see Fig. 1). The presence of non linear terms in the magnetic structure was already known from the behavior of the betatron tunes versus energy (obtained by changing the RF frequency) shown in Fig. 4, which exhibits (with wigglers on) a non linear shape even with all sextupoles off in the ring. In a different lattice with all wigglers off, instead, the tunes are linear.

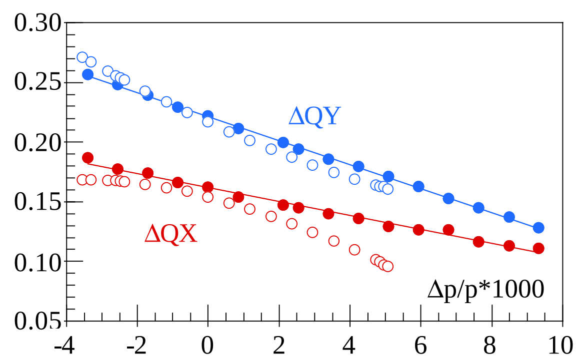

Figure 4 - Betatron tunes versus energy with sextupoles off (full dots = wigglers off, empty dots = wigglers on).

A closed orbit "bump" was performed in each wiggler by means of 4 horizontal correctors. The currents were adjusted in such a way that the beam position was perturbed only in the region between the first and last corrector. The energy change induced by the correctors was carefully corrected by changing the RF frequency. Fig. 5 shows the dependence of the betatron tunes on the amplitude of the closed orbit bump in the wiggler. The horizontal tune fits well with a quadratic behaviour, typical of an "octupole-like" term. The peak of the curve is slightly displaced from the origin because of a residual orbit displacement in the wiggler.

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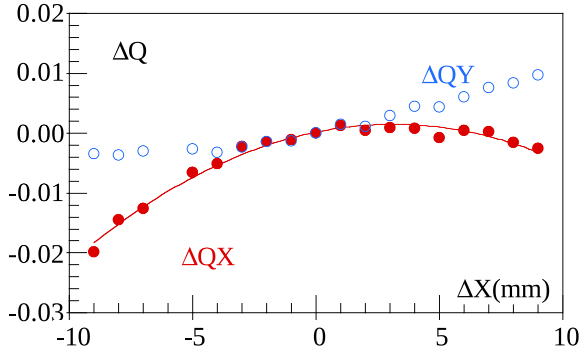

Figure 5: Change in tune versus horizontal bump amplitude (full dots = horizontal, empty dots = vertical).

Since the correctors required for a closed symmetric bump are at least four, the beam is displaced in the two dipoles of each achromat as well as in the wiggler (see Fig. 1). The horizontal β function is larger than the vertical one by a factor ≈3 in the wiggler, while the situation is opposite in the dipole.

We have therefore attributed the dependence of the vertical tune on bump amplitude to the displacement in the dipole. To verify this assumption, a lattice with wigglers off and similar functions in the achromat has been realized and the measurement of tunes with bump amplitude repeated. By subtracting the measurement with wigglers off from the corresponding one with wigglers on, the result shown in Fig. 6 has been obtained,

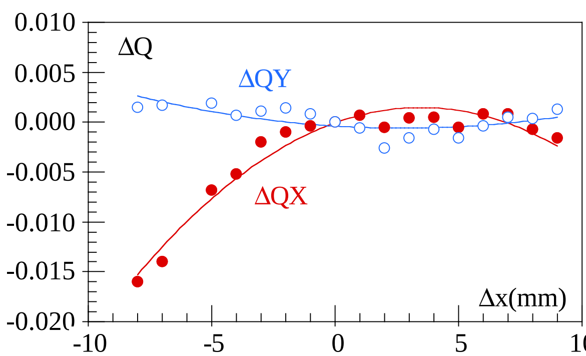

Figure 6 - Tune dependence on bump amplitude after subtracting measurements with wigglers off full dots = horizontal, empty dots = vertical).

This result is compatible with an "octupole-like" term. We cannot demonstrate that it is a real octupole since the measurement with a vertical beam displacement could not be performed due to the limited aperture of the vacuum chamber. The chromatic behavior of the tunes is linear and the decoherence time measured by applying a transverse kick to the beam by means of the injection kickers also improves in the lattice with wigglers off.

The measured tune shift on amplitude corresponds to an integrated third order term of $0.8x10^3$ m^{-3} per wiggler, and comes from the combination of the beam trajectory inside the wiggler (≈25 mm peak-to-peak) with a fourth order term in the field. The measured value is in agreement with the field measurement at the center of the wiggler poles.

After a shutdown in January 2001 for the maintenance of the cryogenic systems a new "detuned" optics (with high vertical β value in DEAR, ≈12 m) has recently been tested to better separate the beams at the second IP. A single bunch luminosity of $1x10^{30}$ $cm^{-2}s^{-1}$ has been measured at the first attempt. However, this detuned lattice has lower horizontal β values at the wigglers, thus decreasing the effect of the octupole term. Work is in progress to establish to which amount the improvement in luminosity comes from better separation in DEAR and from reduced non linearity effects, and to set up multibunch operation with this new lattice in order to substantially improve DAΦNE luminosity performance.

6 CONCLUSIONS

Data collection for the KLOE experiment has started at the end of year 2000 with an integrated luminosity per day approaching 1 pb^{-1}. Recent improvements on machine lattice have doubled the single bunch luminosity, opening the way to a substantial improvement of the overall machine performance. Studies are in progress on the effects of nonlinearities on the luminosity and their cures; we are also working on the limits on stored current to cope with the larger total current expected from the improved single bunch operation, on beam lifetime and on the level of background in the experiments.

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