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DAΦNE STATUS REPORT

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Abstract

DAΦNE, the Frascati Φ-factory [1], is providing an increasing peak and integrated luminosity for the KLOE experiment [2,3]. Such improvements, together with a background reduction in the KLOE detector, have been obtained after continuous machine studies. An increase of the single bunch luminosity has been achieved essentially by the reduction of the effects of machine non-linearities. The integrated luminosity was improved by the capability of topping up the beam currents while keeping the KLOE detector on, together with an increase of the stored currents.

1 INTRODUCTION

DAΦNE is a high luminosity and low energy electron-positron collider, working at the center of mass energy of the Φ resonance (1.02 GeV). Two independent rings are 97 m long and cross at a small horizontal angle (25 mrad) in two interaction regions (IR's), where the two experiments KLOE and DEAR are placed. KLOE aims at measuring the CP violating parameter Re(ε'/ε). The second experiment is small and non-magnetic, it studies the properties of kaonic atoms and will eventually be replaced by the magnetic detector FINUDA, for the study of hypernuclear physics.

The installation of DAΦNE was completed at the end of summer '97. In the first commissioning phase, called "DAY-ONE", the KLOE detector was not installed and the low-β_y at the interaction point (IP) was obtained by 7 quadrupoles in a symmetrical arrangement with the central one on the IP. In November '98 a single bunch peak luminosity of $1.6 \cdot 10^{30}$ cm^{-2}s^{-1} was obtained with 20 mA per beam; the corresponding tune shifts were ≈0.03. In multibunch mode a luminosity of $1 \cdot 10^{31}$ cm^{-2}s^{-1} was reached with 13 bunches per beam.

In Spring '99 the KLOE detector was installed in one IP. It consists of a large superconducting solenoid with a field integral of 2.4 Tm, that gives a strong perturbation to the machine optics at its relatively low beam rigidity (Bρ=1.7 Tm). The betatron plane is rotated by ≈41°. The strong coupling introduced by the solenoid is compensated by two other solenoids with the same field integral but opposite direction, placed symmetrically with respect to the IP before the splitter magnets.

Commissioning after KLOE installation started in April '99 and historical luminosity performances at KLOE IP are summarized in figure 1. Particular care was dedicated to tuning coupling by using skew quadrupoles and solenoid compensators. At the end of year '99 a peak luminosity of $5 \cdot 10^{30}$ cm^{-2}s^{-1} with 30 bunches and currents of ≈300-400 mA was measured. The single bunch (SB) luminosity was $\approx 0.2 \cdot 10^{30}$ cm^{-2}s^{-1} with a bunch current of ≈10 mA.

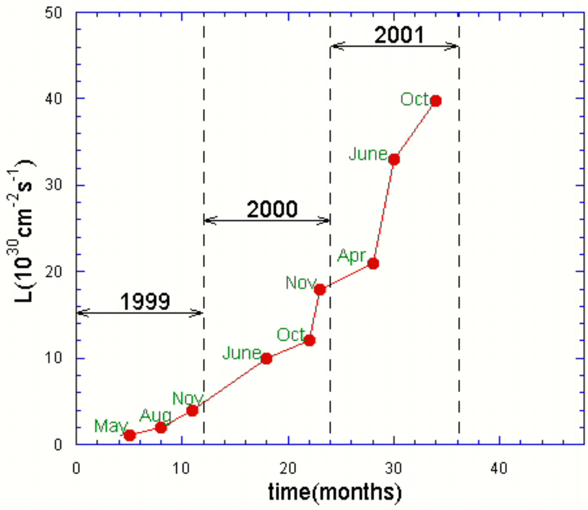

Figure 1: Peak Luminosity in DAΦNE.

The peak luminosity increase obtained last year (2000), shown in Figure 1, was obtained by further reducing coupling below the design value (less than 0.5%) and tuning collision parameters in multibunch operation. The SB luminosity was $\approx 0.5 \cdot 10^{30}$ cm^{-2}s^{-1} (with a bunch current of about 15 mA). An improvement in the maximum stored current was obtained in May '00 by setting different betatron tunes for the two colliding beams. In this configuration in November '00 a luminosity of $1.8 \cdot 10^{31}$ cm^{-2}s^{-1} with 45 bunches and ≈600 mA current in each beam has been achieved. The present tunes are (5.15;5.21) for positrons and (5.12;5.17) for electrons.

As shown in figure 2, ≈30 pb^{-1} were delivered to KLOE last year. However in July '00 data taking was affected by high rates of beam induced backgrounds. Data acquisition was switched off during injection because of unacceptable background rates. In fact, the luminosity lifetime is typically half an hour and injection had to be performed every 15 minutes. A great increase of data taking efficiency was obtained after the optimisation of the closed orbit, of the scrapers positions and of the optical functions, making possible to inject the beams with the

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[1] D.Alesini, G.Benedetti, S.Bertolucci, C.Biscari, R.Boni, A.Clozza, G. Delle Monache, S. Di Mitri, G. Di Pirro, A.Drago, A.Gallo, A.Ghigo, S.Guiducci, F.Marcellini, G.Mazzitelli, C.Milardi, L.Pellegrino, P. Raimondi(SLAC), M.A.Preger, R.Ricci, C.Sanelli, F.Sgamma, F.Sannibale, M.Serio, A.Stecchi, A.Stella, C.Vaccarezza, M.Vescovi, M.Zobov.

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drift chamber on. This led to a great improvement in average and integrated luminosity.

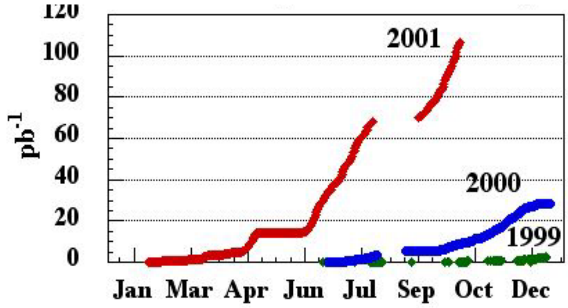


Figure 2: KLOE integrated luminosity.

2 PRESENT PERFORMANCE

A further improvement of the peak luminosity has been achieved by increasing the single bunch luminosity, the total beam currents and the number of bunches. Figure 1 shows that a peak luminosity of $4{\cdot}10^{31}\mathrm{cm}^{-2}\mathrm{s}^{-1}$ has been reached in multibunch mode.

The present collision parameters of DAΦNE operation for KLOE are listed in Table 2.

2.1 Single Bunch Luminosity

To increase the single bunch (SB) luminosity, many machine development shifts have been dedicated to working point tuning, coupling correction, measurement and reduction of the effects of non linearities [4].

A non-linear term in the wiggler magnet field has been detected in November 2000, so machine time has been dedicated to systematic studies of the effect of non linearities, as discussed in more detail in section 4.

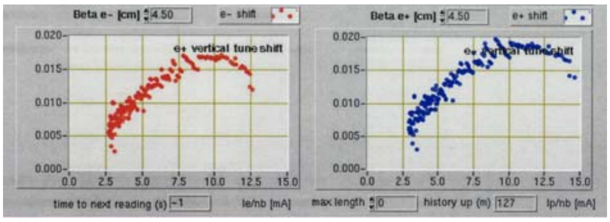
Table 2: DAΦNE Collision Parameters.

Beam Energy [GeV]	0.51
Half Crossing Angle [mrad]	12.5
Luminosity [$\mathrm{cm}^{-2}\mathrm{s}^{-1}$]	$4.0{\cdot}10^{31}$
Number of bunches	47
Longitudinal separation [RF buckets]	2
Harmonic number	120
e+ current [A]	≈0.9
e- current [A]	≈0.8
β_y/β_x @IP [m]	0.030/5.5
Emittance [10^{-6} m]	0.8
Rms beam size σ_y/σ_x @IP [mm]	0.011/19
Damping time N_{dx}[rev. turns]	$1.1{\cdot}10^{5}$
Injection time [min]	3
Max integrated luminosity/day [pb^{-1}]	2.1
Total integrated luminosity [pb^{-1}]	≈130

A new optics, called ‘detuned’, with no low-β in the DEAR IR, has been applied to DAΦNE [5]. With this structure the machine is tuned to collide only at the KLOE IP. As a consequence, the lattice has lower chromaticity, so smaller sextupole strengths are needed to compensate it. Since a large vertical separation at the second IP is introduced, parasitic interactions at the second IP are avoided. Moreover, the 'detuned' lattice is adjusted to have smaller β-functions in the wigglers, decreasing the effect of their octupole terms. As this optics is less sensitive to machine nonlinearities, it has been possible to obtain, in March 2001, a single bunch luminosity of $10^{30}\mathrm{cm}^{-2}\mathrm{s}^{-1}$ at currents of ≈20 mA per bunch.

Last September this 'detuned' optics has been slightly changed, as β_y at the IP has been reduced by about 30%. This reduction yielded an increase of the luminosity by the same factor, as expected.

The electron tune shift calculated from the luminosity saturates at a value of $\xi^{-}\approx0.02$ for a positron bunch current of $I^{+}\approx10$ mA, as reported in figure 3. The positron tune shift saturates at a somewhat smaller value $\xi^{+-}\approx0.018$ for an electron bunch current of $I^{-}\approx8.5$ mA. This asymmetry is due to different beam blow-up in the two beams: the electron beam is larger than the positron one, both due to different working point and to ion trapping effect.


Beta e- [cm] 4.50
Beta e+ [cm] 4.50
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max length 0
history up (m) 127

Figure 3. Tune shifts calculated from luminosity. *Left*: ξ_y^{+} versus electron bunch current; *Right*: ξ_y^{-} versus positron bunch current.

2.2 Multibunch Operation

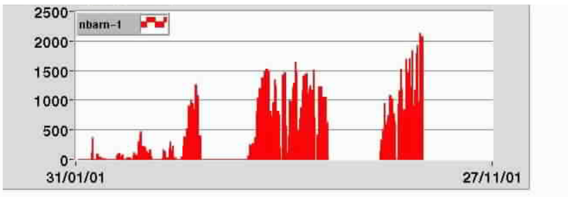

Figure 4: Daily integrated luminosity in KLOE since January 2001.

The average luminosity is maintained close to the peak value by a frequent refill of the currents.

Improvement of average luminosity and beam lifetime has been obtained by carefully tuning working point, machine coupling and setting of sextupoles.

The peak luminosity is usually obtained with total currents of 800-900 mA per beam, corresponding to currents per bunch slightly lower than those delivering the maximum SB luminosity.

The maximum positron beam current is limited to ≈0.9 A by the KLOE detector background. Above such current we also observe beam blow-up and lifetime decrease due to beam-beam effects. The pattern used for

KLOE runs 47 bunches spaced by 2 RF buckets with a 20% gap limited by ion trapping in the electron ring.

3 BACKGROUND

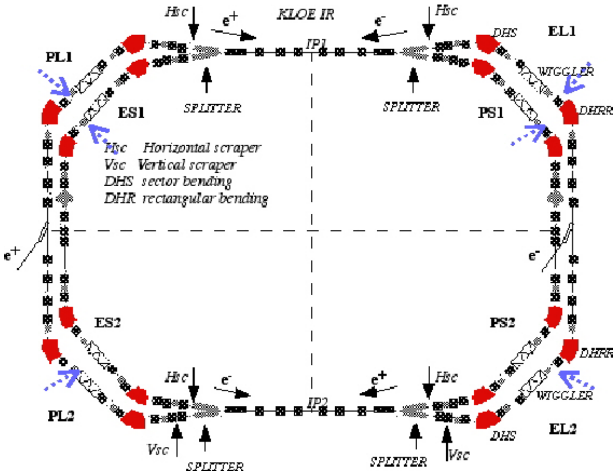

Figure 5: DAΦNE layout with black arrows showing the position of collimators. Blue dashed arrows indicate three future additional scrapers per ring.

In a low energy machine like DAΦNE the machine induced background arises mainly from the Touschek effect. In particular, background reduction has been obtained by tuning orbits and optical functions in the IR's and by adjusting the sextupoles strengths and the β_x value upstream the IR's. The remaining backgrounds have been reduced by optimising the scraper configuration [6]. Present KLOE background rate is nearly the same as in July 2000 but with a five times larger daily-integrated luminosity.

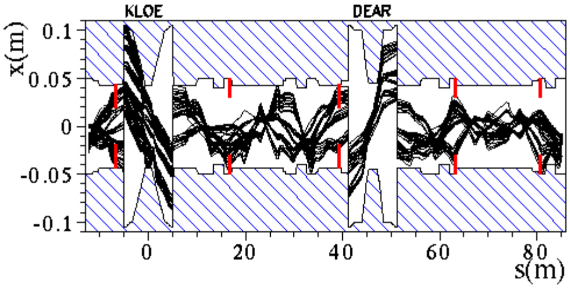

Figure 6: Touschek particles trajectories simulated along positron ring; in red are indicated all collimators, existent and planned ones.

Touschek background simulations indicate that three additional scrapers per ring (positions pointed by blue dashed arrows in figure 5) would be very helpful to further reduce machine induced background into the KLOE experiment. These scrapers are tungsten blocks of 55 mm thickness with a shape that optimises particle rejection. In figure 6 is reported a plot showing simulated Touschek scattered particles that have been tracked along the ring. Collimators stop their trajectories and additional collimators in non-dispersive regions are expected to further reduce KLOE induced background.

4 NON-LINEARITIES

Non-linearities have been intensively studied in order to improve dynamic aperture, beam-beam performance and Touschek background.

The presence of non linear terms in the magnetic structure had been observed looking at the behaviour of the betatron tunes versus energy, as they have a non linear shape with all sextupoles off; wigglers turned out to be the largest source of non-linearity.

A closed orbit bump was performed in each wiggler by means of the 4 nearest horizontal correctors, switching off the sextupoles near the wiggler. The beam position was perturbed only in the region between the correctors and the induced energy change (as the wiggler region is not dispersion-free) was carefully corrected by changing the RF frequency. Since the bump includes other possible sources of linear and non linear terms in the dependence of the tune on beam position, the measurement was repeated with a different lattice with wigglers off: although the vertical focusing of the wigglers is strong, an effort has been made to make the optical functions in the wiggler region as similar as possible to those with wiggler on.

The tune shift data with wigglers off have been subtracted from those with wigglers on and the resulting behaviour of the horizontal and vertical tune shifts versus amplitude of the closed orbit bump in the wigglers are two quadratic functions with the same center and the ratio of the two quadratic terms $(\Delta Q_x/\Delta x^2)/(\Delta Q_y/\Delta x^2)$ is, as expected, $\approx -\beta_x/\beta_y \approx -3$. The result is typical of an "octupole-like" term. It cannot be demonstrated that it is a real octupole term as the measurement of the tune shift versus vertical beam displacement in the wigglers cannot be performed, due to the limited aperture of the vacuum chamber.

An integrated third order term of $0.8 \cdot 10^3 \mathrm{m}^{-3}$ per wiggler fits well the measured tune shift on horizontal amplitude, which is in agreement with field measurements at the center of the wiggler poles. This nonlinearity is originated by the combination of a decapole term in the wiggler field and the oscillating beam path, leading to a large cubic non-linearity.

The impact of cubic non-linearity on beam-beam performance has been studied [7] and measured using a dynamic tracking system [8]: a single bunch is excited horizontally by pulsing one of the injection kickers and the dynamic tracking system allows to store and analyse the position of the kicked bunch turn-by-turn. The decoherence signal envelope at small currents decays with time in the following way [9]:

$$S(t) \propto \exp\left(-\frac{t^2}{2\tau^2}\right)\exp\left(-\left(\frac{\partial\omega_x}{\partial E}\frac{\sigma_E}{\Omega_S}\right)^2\left(1-\cos\Omega_S t\right)\right)$$

where $\tau = \left(2 \frac{\partial \omega_x}{\partial A_x^2} \Delta x \sigma_x \right)^{-1}$.

The cubic nonlinearity can be determined from τ if the kick amplitude Δx and the horizontal beam size σ_x are known at the pick-up position. $\partial \omega_x / \partial E$ is the chromaticity, σ_E the energy spread and Ωs the synchrotron frequency. The coefficient c_{11} is related to the cubic non-linearity $\partial \omega_x / \partial A_x^2$ by the following relation: $c_{11} = (\partial \omega_x / \partial A_x^2)(\beta_x / \omega_0)$, where β_x is the horizontal beta function at the pick-up position and ω_0 is the angular revolution frequency, and it is found directly from the signal envelope by fitting it by an exponential function.

It has been found that the cubic non linearity can change widely depending on lattice functions and orbit. In fact values of c_{11} have been measured between $-6 \cdot 10^2$ and $+4 \cdot 10^2$, as reported in Table 3. It is worth remarking that the sign of the non-linearity changes when the wigglers are switched off. From the analysis on the measurements reported in Table 3 we conclude that the highest negative contribution to c_{11} comes from the wigglers and its effect depends strongly on the β-value at the wiggler position; the sextupoles give a negative contribution to c_{11}, but less than the wigglers.

The combined effect of the cubic non-linearities and the beam-beam interaction depends on betatron tunes, on beam-beam tune shifts, on the non-linearity strength and on the sign of c_{11}. It has been found experimentally in DAΦNE that the best situation from the beam-beam point of view is with c_{11} negative and in absolute value less than $\approx |2 \cdot 10^2|$, as the highest value of SB luminosity (10^{30} cm^{-2}s^{-1}) has been measured with $c_{11} \approx -1.7 \cdot 10^2$.

The new 'detuned' optics presently used reduces the effect of non-linearities in wigglers by reducing β_x inside them. The reduction of the wiggler octupole contribution helps to increase the single bunch luminosity, but at the same time the Landau damping needed to suppress transverse multibunch instabilities is reduced.

In order to correct and optimise the effect of the octupole term on beam-beam and instabilities the installation of octupole magnets in foreseen in January 2002.

Table 3. Measured non-linear coefficient for different lattice configurations.

Optics	$c_{11} \cdot 10^2 [m^{-1}]$
last year KLOE runs	-6
Wigglers off and sextupoles off	+4
Wigglers off	+2
Wiggler's B field reduced by 15%	-3
'detuned'	-3

5 CONCLUSIONS

Peak luminosities of 10^{30} cm^{-2}s^{-1} and of $4.0 \cdot 10^{31}$ cm^{-2}s^{-1} have been reached in single and multi-bunch mode respectively. The maximum daily integrated luminosity is 2.1 pb^{-1}. Measurements and simulations have been performed in order to understand and control nonlinearities. The lattice of DAΦNE has been modified to reduce their impact on luminosity performance.

The optimisation of beam-beam behaviour with nonlinearities will be carried out when tunable octupoles will be installed on the two main rings in January 2002.

According to simulations, tunable octupoles are also expected to increase the dynamic aperture, decrease the beam losses in the experiments and improve beam lifetime.

Long term plans foresee major hardware modifications: wiggler nonlinearities are planned to be corrected locally by means of pole shimming, after precise magnetic measurements that will determine the best shim shape.

ACKNOWLEDGMENTS

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