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STATUS OF DAΦNE

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ABSTRACT

The DAΦNE commissioning, in the day-one configuration, was completed at the end of 1998. In the following three months the KLOE experiment and the new Interaction Regions have been installed. Machine operation was resumed in March of the same year and in few weeks a luminosity of 10^{30} cm^{-2}s^{-1} has been reached: this result has been improved and the average maximum luminosity in KLOE during last month of operation is 3.5 10^{30} cm^{-2}s^{-1} with peak value 5 10^{30} cm^{-2} s^{-1}. All luminosity data are obtained in multibunch collisions with a beam lifetime better than one hour suitable for experiment data collection. However the maximum multibunch luminosity obtained in the first stage of commissioning without KLOE (L =10^{31} cm^{-2}s^{-1}) has not yet been reproduced. In the following an overview of all possible issues limiting DAΦNE luminosity performance will be given, together with the plans to push luminosity up to the nominal value.

1 Introduction

DAΦNE is the Frascati electron positron collider operating at the energy of 510 MeV, a rather low energy with respect to the other existing factories (KEK, SLAC), that makes this machine much more sensitive to beam instabilities and beam current related problems. DAΦNE is based on two different rings sharing two Interaction Regions (IR) where the counter rotating beams collide with a horizontal angle of 25 mrad in order to allow multibunch operation and minimize, at the same time, parasiting crossing effects. The rings rely on a novel lattice scheme [1], including a wiggler in each arc, allowing short damping times and beam emittance tuning over a wide range.
DAΦNE is a small and compact collider (see Fig. 1) ~ 100 m long, the two rings are very close and for this reason stray fields and cross talk between different magnetic elements are very important in tuning up the machine.
The KLOE experimental solenoid, due to its strong integrated magnetic field (2.4 Tm) with respect to the low machine energy must be considered as an integral part of the machine.
DAΦNE is designed to work with high beam currents, 5 A arranged in 120 bunches in each colliding ring.

2 Luminosity Relevant Issues

2.1 Working Point

The Working Point for a collider is carefully chosen in order to provide a wide region of stable betatron tunes suitable to accommodate the beam-beam induced tune shift in collision.
During the first phase of commissioning a set of betatron tunes ($\nu_x = 5.15, \nu_y = 5.21$), slightly different from the design one, has been adopted to overcome multibunch transverse instabilities in the positron ring as well as to operate in a less critical situation in terms of dynamic aperture and closed orbit distortion. Exhaustive numerical simulations of luminosity [2] and beam beam lifetime [3] supported this decision [4].

[0]D. Alesini, C. Biscari, R. Boni, M. Boscolo, A. Clozza, G. Delle Monache, G. Di Pirro, A. Drago, A. Gallo, A. Ghigo, S. Guiducci, F. Marcellini, G. Mazzitelli, C. Milardi, L. Pellegrino, M.A. Preger, R. Ricci, C. Sanelli, F. Sannibale, M. Serio, F. Sgamma, A. Stecchi, A. Stella, C. Vaccarezza, M. Vescovi, G. Vignola, M. Zobov

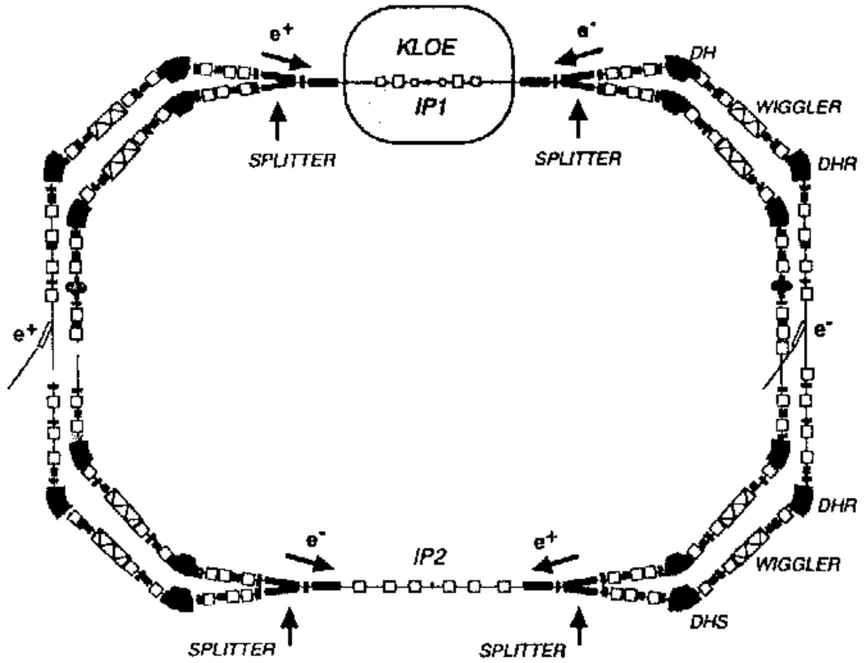

Figure 1: *DAΦNE Layout.*

2.2 Beam Current and Vacuum Related Items

Vacuum has an indirect influence on luminosity since it limits the maximum storable current and affects beam lifetime.

During KLOE installation the four straight sections close to the IRs have been baked and a powerful NEG pumping system has been installed in the KLOE IR. As a matter of fact, at the beginning of machine operation the average vacuum in both rings was 10^{-9} Torr, reasonably close to the design value, but the maximum circulating current was 0.4A. In few months, due to beam conditioning, up to 0.7A of electrons and 0.8A of positrons, both in multibunch configuration, have been stored. In the electron ring the ion trapping effect is minimized by introducing a gap in the multibunch filling. It is worth reminding how before KLOE roll-in a single bunch current as large as 110 mA has been stored in both rings with no evidence of vacuum or instability limitation.

2.3 Coupling

The coupling factor is defined as the ratio of the vertical to horizontal beam emittances.
The design value for DAΦNE is 1% but it may increase due to quadrupole tilt errors, vertical orbit deviation in sextupoles, vertical dispersion and errors in the compensation of the experiment solenoidal field, all circumstances which may transfer oscillation amplitude from the horizontal to the vertical plane since DAΦNE is working with flat beams having horizontal beam size much larger than the vertical one.
Coupling induces two harmful effects: it increases the beam transverse size and changes the beam tilt angle in the transverse plane, both resulting in a final luminosity reduction. Especially the tilt angle is a critical item for DAΦNE since the colliding beams are stored in two different rings and follow different trajectories. In this context different tilt angles between electron and positron bunches may change the relative orientation angle, resulting in a relevant reduction of the beam overlap.
Before KLOE installation coupling values down to 0.2% have been observed, both for electrons and positrons, measured at a synchrotron light monitor (SLM).
The KLOE induced coupling has been taken carefully into account during the main rings design. The KLOE Interaction Region includes two superconducting compensating solenoids whose fields balance the experimental one, and the six low-β quadrupoles are rotated by the corresponding average rotation induced by the KLOE solenoid at their azimuth [5].
After KLOE installation the beam coupling has been kept within 1% by slightly changing the KLOE and compensator solenoids with respect to the nominal values. Tuning up all other machine parameters like energy, tunes, beam separation on the DEAR IP and so on in order to improve luminosity led to a slight coupling increase, and this has been fixed by means of the closest tune approach method [6]. The effectiveness of the coupling reduction has been checked by measuring the decrease in beam lifetime, due to the Touschek effect, which is proportional to the beam density.

2.4 Beam Dynamics

The single bunch dynamics in DAΦNE is essentially dominated by the wake field coupling impedance [7]. The contributions from the different ring components have been simulated extensively and the result have been verified by means of bunch length measurements. Before KLOE installation dipole and quadrupole instabilities have been observed below 100 kV RF voltage and this limit has been overcome by pushing up the RF voltage above 150 kV in agree-

ment with the microwave instability theory. After the new IR insertion an unexpected single bunch quadrupole mode appeared in both rings, showing a different threshold dependence with the RF cavity voltage, just the opposite with respect to the behaviour without KLOE. This fact may be explained assuming that a new high frequency impedance has been introduced with the new IRs installation. This is why the instability threshold depends on the bunch length, and this has been demonstrated by changing independently the momentum compaction factor. To cope with this instability the RF voltage has been kept below 100 kV corresponding to a quadrupole threshold of 24 mA. However this arrangement presents two unpleasant drawbacks, since it limits the lifetime and the single beam current to the half its nominal value. The plans for the long term foresee a higher momentum compaction optics, allowing bunch length tuning, as well as studies about the insertion of a high harmonic RF cavity.
Up to now no experimental evidence of single bunch transverse instability has been observed. The measured head-tail threshold without sextupoles is 13 mA. Special attention has been devoted from the beginning of theDAΦNE project to long range bunch by bunch longitudinal instabilities. A complex longitudinal feedback system has been developed within a worldwide collaboration [8]. This system succeeded in damping the coupled bunch instabilities from the first phase of DAΦNE commissioning as can be seen from the comparison between Fig.2 (left) and Fig.2 (right) showing the multibunch spectrum around the revolution harmonic with the feedback off and on respectively; both spectra are taken with 100 mA positron current stored in 20 bunches. Recently, due to the RF voltage lower than the nominal one, the negative shift of the synchrotron frequency from beam loading is much larger than its design value. This effect offsets the working point of the longitudinal feedback and has been cured by improving the RF cavity feedback loop.

Since the first stage of DAΦNE commissioning a transverse multibunch instability limiting the maximum positron current has been observed. After careful analysis the instability source has been localized in the injection kickers with a threshold depending on the vertical orbit in that point. The change in the betatron tunes from $\nu_x = 5.09$ $\nu_y = 5.07$ to $\nu_x = 5.15$ $\nu_y = 5.21$ has reduced the impact of this mode. Nevertheless new injection kickers equipped with a high order mode damper have been designed and built and will be installed during the next machine shutdown.

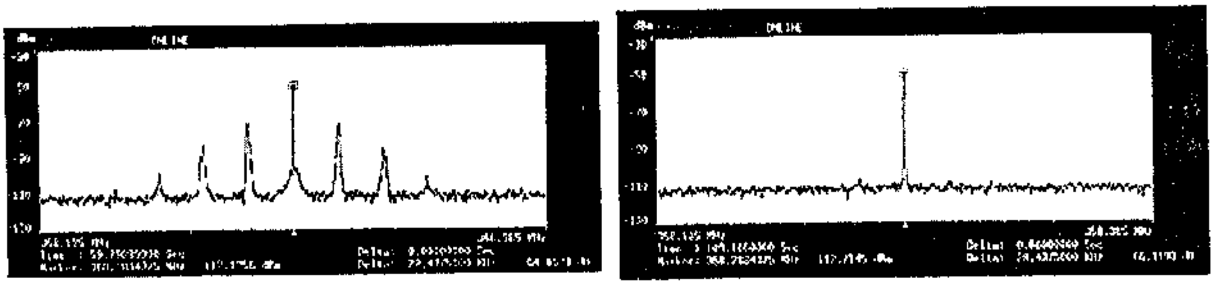

Figure 2: *Longitudinal spectrum of 30 bunches. Left: feedback off. Right: feedback on*

3 Understanding Luminosity Results

At DAΦNE the luminosity is measured by means of the beam-beam single bremsstrahlung. Two monitors have been installed one for each IR, both looking at the incoming positron beam [9]. Since the experimental requirements concerning the solid angle aperture do not leave room for beam-beam diagnostic and since the IR beam position monitors are not able to resolve the positions of the two counter rotating beams at the same time, the luminosity monitor is the only indirect diagnostic tool to perform beam measurements in colliding mode.
DAΦNE is a double ring collider, so a slight difference in beam trajectory, position of the vertical betatron waists, longitudinal position of the actual beam crossing point and beam coupling may degrade luminosity. All these parameters are finely tuned by optimizing the normalized luminosity, defined as the ratio between the measured luminosity and the design luminosity scaled with the measured beam currents. All scannings are performed with stored currents below 2 mA per bunch to stay far from beam-beam effects on the luminosity measurements.
The vertical beam overlap is sampled by moving the electron beam vertical position with respect to the positron one in steps of 5 μm. By recording the normalized luminosity at each step, it is possible to measure the vertical size

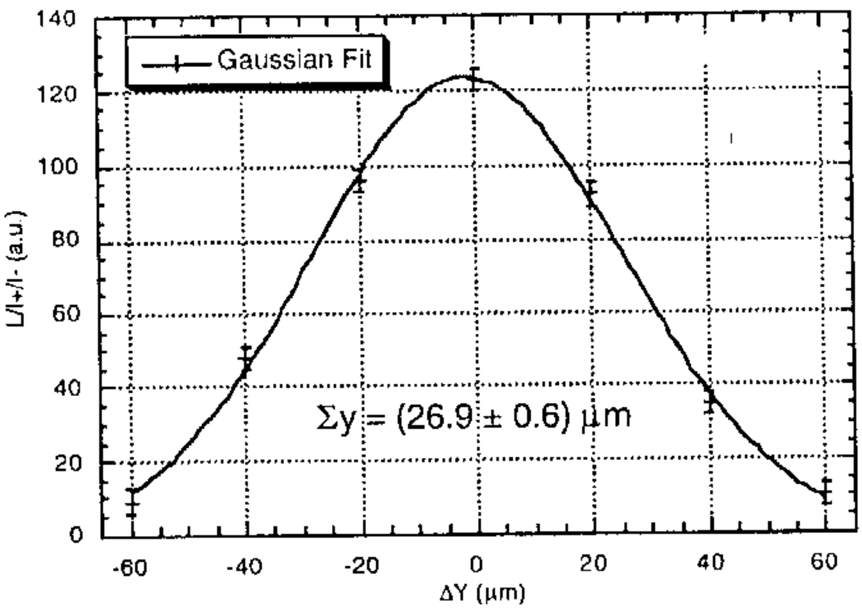

Figure 3: *Luminosity Vertical Scan.*

Σ_y of the convoluted beam envelope. The result of this analysis that gives a Σ_y = a value very close to the theoretical one evaluated on the basis of the measured beam parameters is reported in Fig.3.

The longitudinal position of the beam crossing point can be scanned by changing the phase difference between the two RF cavities; a typical longitudinal scan is shown in Fig.4, where the maximum gives the optimum RF phase for luminosity.

The optimum working point has been searched by analyzing beam lifetime and aspect ratio measured at the SLM (roundness), as a function of the colliding beam currents in a grid of 0.01 steps both in horizontal and vertical tunes. Results are presented in Fig. 5: the working point $\nu_x = 5.16$, $\nu_y = 5.21$ is the best one in terms of lifetime and beam blow-up, in agreement with numerical simulations.

In spite of the accurate optimization, DAΦNE luminosity results show some evident limits. Taking into account the requirements of the KLOE experiment in terms of lifetime and background in the detector, the single bunch cur-

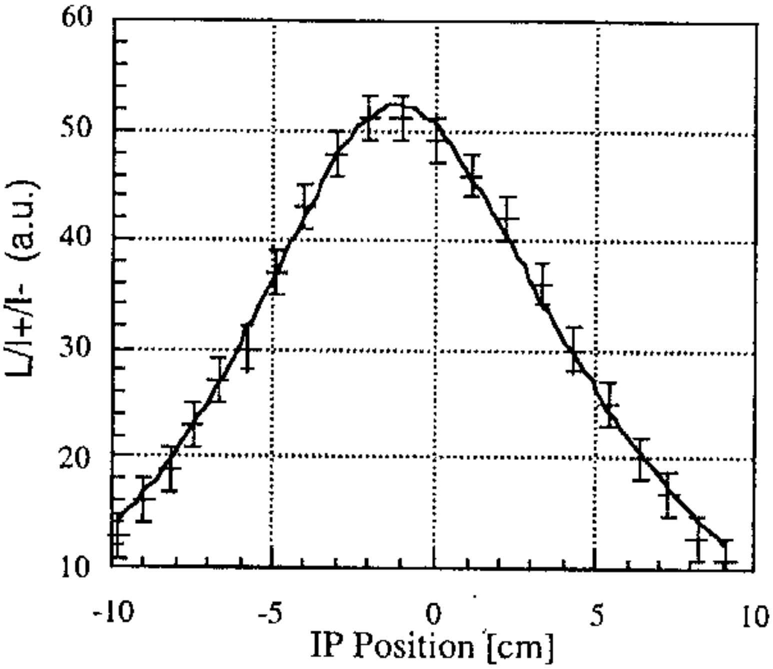

Figure 4: *Luminosity Longitudinal Scan.*

rent in interaction cannot exceed ~ 10 mA, corresponding to a maximum single bunch luminosity of 2 $10^{29}cm^{-2}s^{-1}$. In multibunch operation the positron current is limited to ~ 300 mA by the multibunch transverse instability; for this reason the maximum luminosity is obtained when the current is stored in ~ 30 bunches, with an electron current of ~ 400 mA. The peak luminosity reached in this configuration is 3.5 10^{30} $cm^{-2}s^{-1}$.
During about one month of continuous operation for KLOE in November 1999 the collider has provided an average integrated luminosity of 100 nb^{-1} per day with good background conditions.
Few days of operation have been dedicated to collision on the second IR and a luminosity of the order of 1030 have been delivered to DEAR.
Operation with two collision points at the same time has not yet been attempted. Simulations are being performed to find the optimum working point and betatron phase advances between the two interaction points.

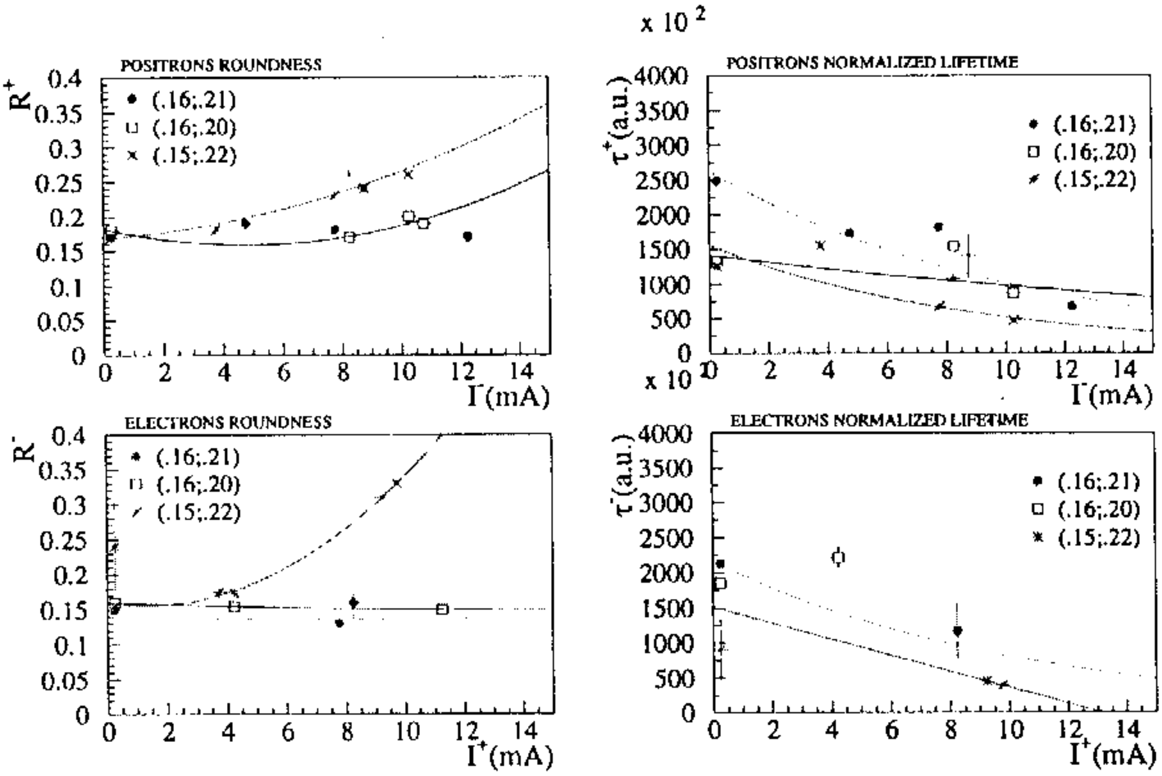

Figure 5: *Working point scans with beam-beam effects.*

4 Conclusions

Presently DAΦNE is facing two main challenges, to increase the stored beam current in the multibunch mode and the luminosity in the single bunch one.
The big amount of work done so far about machine dynamics has explained the present current limitation due to beam instabilities and suggested the proper cures. The injection kickers have been rebuilt with damping antennas for the offending parasitic modes, a high order mode cavity is under study as well as a transverse feedback to cope with unexpected instabilities that could appear at higher currents.
The correlation between beam-beam interaction and coupling at the IP is being studied to possibly explain the present limitation on single bunch luminosity. Work is under way to improve lattice modeling in order to better control the coupling in the rings.

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