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DAΦNE Status

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CONTENTS

STATUS REPORT ON DAΦNE

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Abstract

DAΦNE, the Frascati LNF Φ-factory [1], is providing luminosity for the KLOE experiment since July 2000. A steady increase of daily integrated luminosity in KLOE has been obtained, due to interspersed machine physics studies. The main results are: increase of single bunch luminosity by reduction of the effects of nonlinear terms in the machine, background reduction, refill of the colliding beams while keeping the KLOE detector taking data and increase of stable stored current. A fraction of machine time has been used to tune luminosity and reduce background in the DEAR configuration. The luminosity delivered to DEAR was sufficient to conclude the first phase of the experiment.

1 INTRODUCTION

DAΦNE is an e^+e^- double ring collider at the Φ centre of mass energy. The KLOE experiment, dedicated to CP violation, is installed in Interaction Region 1 (IR1) since March 1999. The DEAR experiment, for exotic atoms studies, is installed in IR2.

A peak luminosity of 2.8 10^{31} cm^{-2} s^{-1} with currents of 730 mA e^+, 670 mA e^- in 47 bunches has been achieved. The maximum daily integrated luminosity is 1.4 pb^{-1}/day. The total luminosity delivered to KLOE since July 2000 is 50pb^{-1}. Time has been shared between KLOE (27%), DEAR (13%), Machine Development (30%), Shutdown (23%) and Maintenance (7%).

The collision parameters achieved in DAΦNE operation for KLOE are listed in Tab. 1. Continuos operation for KLOE started in July 2000 after machine development shifts dedicated at increasing the single bunch luminosity [2]. Thanks to strong reduction of machine coupling single bunch luminosity of 5-6 10^{29} cm^{-2} s^{-1} was obtained with a total luminosity of 10^{31} cm^{-2} s^{-1} with 350 mA in 30 bunches. At the beginning of operation the maximum luminosity could not be delivered to KLOE due to the high background level which limited the stored current below 250 mA per beam. From July to December machine shifts where interspersed with KLOE runs in order to optimise machine performance. In particular background reduction was obtained by tuning orbits and optical functions in the IRs and by optimising the scrapers configuration [3]. Improvement of peak luminosity and beam lifetime was obtained by tuning working point, machine coupling and sextupole configuration.

As soon as background was reduced, the stored currents were brought close to 1A, due to the good performance of the longitudinal and transverse feedback systems [4] as well as to the optimisation of the injection procedure. Furthermore all these actions allowed KLOE to stay fully operational during injection. This feature brought to a large increase in integrated luminosity because the average can be kept very close to the peak one by frequent refill of the rings.

In Fig. 1 currents and luminosity within two hours in a typical run are shown.

Table 1: DAΦNE Collision Parameters

Beam Energy [GeV]	.51
Crossing angle [mrad]	12.5
Luminosity [$cm^{-2}s^{-1}$]	2.8 10^{31}
Number of bunches	45
Harmonic number	120
e^+ current [mA]	730
e^- current [mA]	670
β_y*/β_x* [m]	.045/4.5
Minimum Coupling	0.3 %
Emittance ε_x [mm mrad]	0.8 - 0.9
IP rms beam size σ_y/σ_x [μm]	11/1900
Σ_y (low current) [μm]	12
Damping time τ_E/τ_x [ms]	17.8/36
Injection time (1full beam) [min]	3
Detector solenoid field integral [Tm]	2.4
Max integrated luminosity 24h [pb^{-1}]	1.3
Total integrated luminosity [pb^{-1}]	50

In November a nonlinear term in the wiggler magnets was measured [5]. After winter shutdown machine time has been dedicated to systematic studies of nonlinearities [6]. A new "detuned" optics (without low-β in the DEAR IR), allowing better separation in the second IP, has been designed [7]. This optics is less sensitive to machine nonlinearities and has achieved a single bunch luminosity of 10^{30} cm^{-2} s^{-1} at currents of ~ 20 mA.

Since April KLOE is taking data with the new optics and after ten days the daily integrated luminosity reached 1.3 pb^{-1}. The daily integrated luminosity since July 2000 is shown in Fig. 2. A continuous increase is evident.

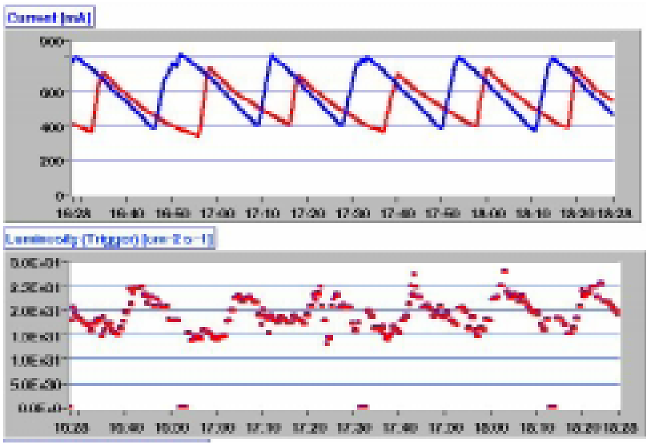

Figure 1: Luminosity and currents over 2 hours. Peak luminosity 2.8 10^{31} cm^{-2} s^{-1}, integrated luminosity 136 nb^{-1}.

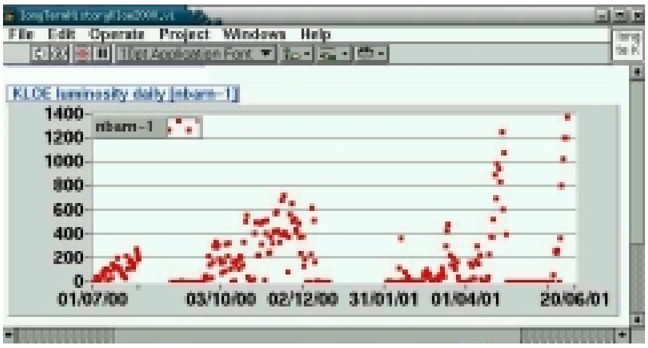

Figure 2: Daily KLOE Integrated Luminosity since July 2000

In the same period a smaller fraction of time has been dedicated to tune the DEAR optics. Due to the IR2 layout, to keep the chromaticity reasonably low the vertical β at the IP2 is twice the value used for KLOE.

A peak luminosity of 10^{31} cm^{-2} s^{-1}, with 600-800 mA in 45 bunches, has been achieved. The total integrated luminosity of 2.9 pb^{-1} has been sufficient to produce physics results and to conclude the first phase of the experiment.

During the winter shutdown, dedicated to maintenance of DAΦNE subsystems and cryogenic plant, some upgrades have been performed: remote helium refill of the compensating solenoids, scrapers upgrade [3] and new power amplifiers for the transverse feedback [4].

2 SINGLE BUNCH LUMINOSITY

To increase single bunch luminosity machine physics runs have been dedicated to measurement and reduction of the effects of nonlinearities, coupling reduction and working point tuning.

2.1 Machine Nonlinearities

Nonlinearities have been intensively studied in order to improve the beam lifetime (determined by dynamic aperture) and beam-beam performance.

A nonlinear term in the wiggler of the four arc achromats has been measured.

The measured tune shift on amplitude shows a parabolic well reproduced by an octupole term [5]. Tracking and simulation studies have been done to understand the effect of this octupole term on dynamic aperture[6] and beam-beam performance [8]. An optics with wigglers off has been designed and applied to both rings, and single bunch collisions have been performed. This optics had quite poor single bunch luminosity but was important for a better understanding of machine performance. The strong radiation damping of the wigglers is needed in DAΦNE to improve beam-beam performance and beam lifetime. Moreover the octupole term in the wigglers introduces a strong Landau damping which suppresses multibunch instabilities. Once turned off the wigglers a nonlinear component in the "C" corrector magnets was clearly individuated and found in agreement with magnetic measurements. This was responsible for the coupling introduced by the vertical separation orbit bump.

The new optics has been designed to reduce the effect of wigglers and "C" nonlinearities. In the wiggler this is obtained by lowering the β-function. The reduction of the octupole term increases the single bunch luminosity but reduces also the Landau damping which helps in suppressing multibunch instabilities.

In order to correct and optimise the effect of the octupole term on beam-beam and instabilities the installation of octupole magnets is foreseen for fall 2001.

2.2 Coupling and Working Point

To achieve the optimum luminosity performance the coupling has to be reduced as much as possible. The strong coupling introduced by the KLOE solenoid is compensated by two antisolenoids and by a rotation of the low β quadrupoles immersed in the solenoid field [9]. This system has demonstrated a strong efficiency in reducing the global coupling of the machine [10]. A further coupling reduction has been obtained by reducing the strengths of the "C" corrector magnets placed near IR2. Different working points have been tried, after tune scans. Small changes with respect to the working point adopted in June 2000 have given the best performance. Optimum luminosity, both for KLOE and DEAR, is obtained with (e^-: 5.12, 5.17; e^+: 5.15, 5.21).

3 MULTIBUNCH PERFORMANCE

A continuous improvement has been obtained by increasing total currents and number of bunches. At the beginning 1 bunch was filled every 3 buckets, injecting 30 bunches in non colliding buckets and bringing them into collision by "RF phase jump". The maximum number of bunches with this pattern would be 40 but a gap to avoid ion trapping in the e- ring is needed. At present we inject in collision 1 bunch every 2 buckets for a total of 49 bunches.

3.1 Feedback Systems

A longitudinal bunch-by-bunch feedback system has been operating in DAΦNE since the beginning of commissioning. A transverse bunch-by-bunch feedback system working in the vertical plane has been implemented in both rings. This produced an increase of the stable stored currents. A record of 1 A stable stored current in each ring, with the bunch pattern used in collision, has been achieved [4]. A similar system for the horizontal plane is ready to be installed when needed.

3.2 Vacuum System

The vacuum has been continuously improving because the high current operation for the experiments is very effective for beam conditioning. Desorption coefficient as a function of the integrated stored current is shown in Fig. 3. It can be seen that two vacuum breaks were rapidly recovered.

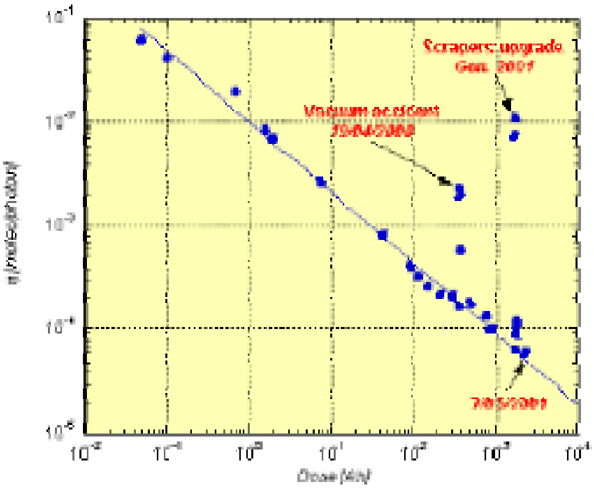

Figure 3: desorption coefficient vs. integrated stored current

3.3 Machine Background

Measurements and simulations have been performed to reduce the machine background in the detectors. A first reduction has been obtained by tuning orbits and optical functions in the IRs and by optimising the sextupole strengths. A further reduction is obtained by inserting the scrapers, thick tungsten targets, in the horizontal plane, to intercept large aperture particles upstream the two interaction regions. When the background is reduced stored currents and luminosity are increased.

At present KLOE is taking data with the same background level as in July 2000 but with an integrated luminosity per day 5 times larger.

For DEAR the signal to background ratio in September 2000 was 1/150, now has been reduced to 1/30.

The background reduction is both due to detector shielding upgrade and to improvement of machine performance.

5 FUTURE PLANS

We plan to deliver to KLOE 200 pb^{-1} by the end of the year. With the present integrated luminosity of 1.4 pb^{-1} most of machine time will be dedicated to KLOE, nevertheless a small fraction of time will be dedicated to machine physics studies on background reduction, beam lifetime increase and suppression of transverse instabilities. This has proven to be fruitful in increasing average luminosity. In autumn octupole magnets will be installed. They will be used to control tune shift on amplitude in order to find the best compromise between increase of single bunch luminosity and suppression of transverse instability.

Long term plans foresee major hardware modifications: correction of wiggler nonlinearities by means of pole shimming, installation of a third harmonic RF cavity to increase bunch length [11], and therefore beam lifetime and realisation of a new IR for KLOE.

The new mechanical design of the KLOE IR foresees independent rotation of the three low-β quadrupoles between zero and the design angle, in order to allow machine operation with the KLOE solenoid turned off. The same scheme is used for the design of the IR for the FINUDA experiment, which is planned for IR2 after the conclusion of DEAR.

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NON LINEAR BEAM DYNAMICS AT DAΦNE

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Abstract

Studies and measurements have been performed at DAΦNE to improve dynamic aperture, beam lifetime and beam-beam performance. Measured tune scans for different working points are presented. After the measurement of an octupole-like term in the wiggler field, decoherence measurements with wigglers on and off have been performed. The effect of this cubic term on the chromaticity and dynamic aperture is presented.

1 INTRODUCTION

In the past year of DAΦNE running [1-3] machine-studies have been interspersed with experiment data-taking. Mainly the machine development has been devoted to beam-beam studies [4], characterisation of the machine non-linear behaviour, and background reduction for both the installed experiments [5]. At present the peak luminosity has reached $L \approx 2.9\times10^{31} cm^{-2}s^{-1}$ with about 600 mA per beam, with an average integrated luminosity of $L_i \approx 1.4\, pb^{-1}/day$. The Kloe experiment is routinely collecting data. The non-linearities present in the machine play a major role affecting the dynamic aperture, the beam lifetime, (with relation to the background and the integrated luminosity), and the beam-beam behaviour (single bunch luminosity). The study moved from extensive beam lifetime measurements vs. betatron tunes in both rings resulting in a high sensitivity of the machine to high order resonances (section 2). The decoherence measurements, (dynamic tracking), with the wigglers powered on and off show the effect of a strong dependence of the tune on the betatron amplitude oscillation, (section 3). The presence of a cubic term in the wiggler is accounted for the residual non-linear chromaticity of the machine even with sextupoles off. The strength of the octupole thin lens to be taken into account in each pole, found from the chromaticity measurements, agrees with the value obtained from the measurements of the betatron tunes vs. the localised orbit bumps inside the wiggler [6]. The effect on the dynamic aperture is described in section 5.

2 TUNE SCANS

Tune scan measurements have been performed on both electron and positron rings to find the best working point for the DAΦNE machine. The beam lifetime, normalised to the beam current and coupling, is an indication of the strength and width of resonances.

The obtained results for the lifetime show a high sensitivity of the machine even to high order resonances, (sixth order). Figure1 shows the scan around the standard working point (WP), $Q_x = 5.15$, $Q_x = 5.21$, adopted for the positron ring of the collider, the sixth order resonance is clearly seen.

In Figure 2 the beam roundness, $R = \sigma_y/\sigma_x$, measured at the Synchrotron Light Monitor, is reported in the tune footprint. It is clearly affected by the presence of two difference resonances, ($2Q_x - Q_y$, $Q_x - Q_y$).

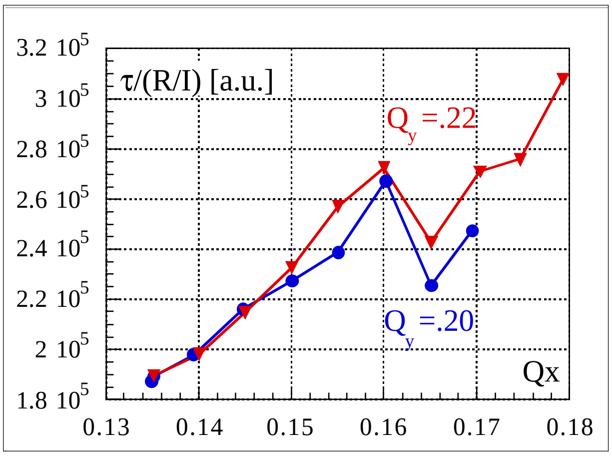

Figure 1: The normalised lifetime of the positron beam, vs. the horizontal betatron tune.

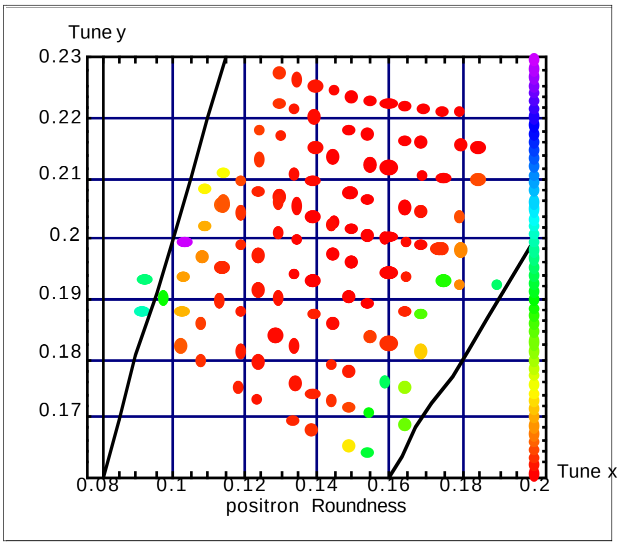

Figure 2: The positron beam roundness in the betatron tune plane. From red (lowest value) to violet (highest).

An extensive exploration around the half-integer has also been carried on, namely close to $Q_x = 4.73$, $Q_x = 5.08$, where no significant improvements on the lifetime come out, confirming the good choice for the adopted WP.

3 DYNAMIC TRACKING MEASUREMENTS

With the DAΦNE dynamic tracking acquisition system [7], it is possible to restore the beam trajectory in the transverse phase space; in particular the betatron tune dependence on amplitude is found fitting the decay of the coherent signal, which is proportional to the beam transverse displacement, vs the number of turns.

Figure 3 shows the measurements performed for two different lattices with wigglers on and off respectively. They have a different decay time of the signal and also different reconstructed phase space deformation. The non-linear coefficient C_{11} [8] defined as:

$$\Delta Q_x = 2 c_{11} J_x$$

where J_x is the betatron action variable, depends on the non-linear element strengths, optic functions at their position and relative phase advance.

Lattices with wigglers on have negative values of C_{11} (values ranging from –200 to –1000 have been measured) depending on the value of the horizontal betatron function at the wiggler position). Lattices with wigglers off have positive values of C_{11}, which means that there are other non-linearities in the machine, whose overall contribution is compensated by the wiggler non-linearity. One of these is a sextupolar term in the “C” corrector magnets [6].

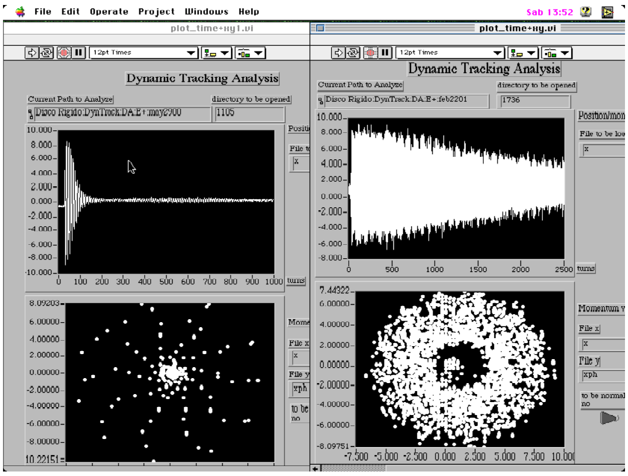

Figure 3: Dynamic tracking measurements of the beam transverse displacement vs number of turns (above), and phase space trajectory (below). The case with wiggler on is shown on the left, wiggler off on the right.

To counteract the effect of the octupole-like a new “detuned” optics (Mar 2001) has been applied on both thepositron and electron ring [9]; lowering the β-functions in the wiggler reduces the effectiveness of the octupole-like term.

4 CHROMATICITY

The measured non-linear terms have been included in the model, which now fits satisfactory the chromaticity behaviour. As an example the natural chromaticity of the positron ring with wiggler on and wiggler off are shown in Figs.4-5.

Figure 4 shows the measured chromaticity together with the model predictions with the cubic term. For the lattice with wigglers off the chromaticity is linear (Fig. 5).

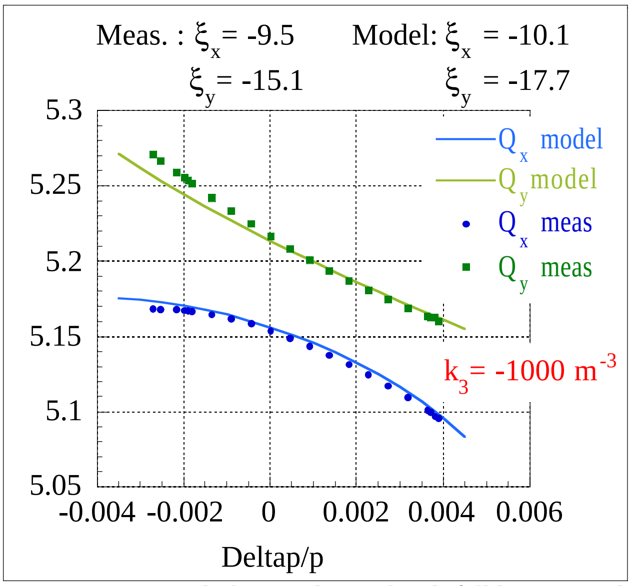

Figure 4: Measured (dots) and (simulated (full line) natural chromaticity with wiggler on for the positron ring.

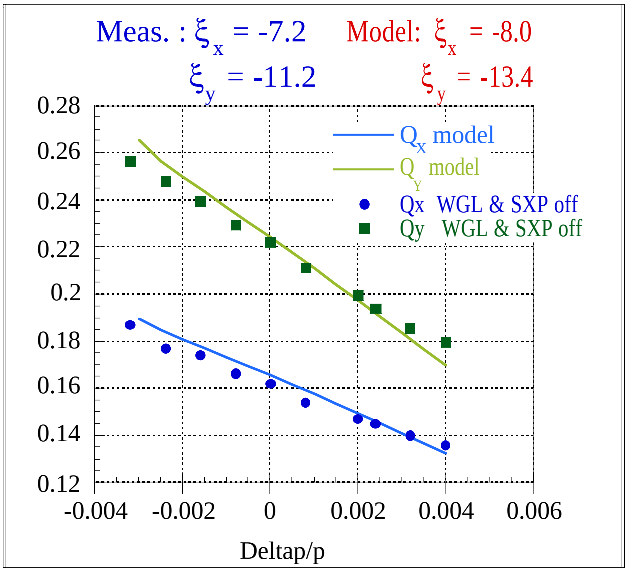

Figure 5:Measured (dots) and simulated (full line) natural chromaticity with wiggler off for the positron ring.

5 DYNAMIC APERTURE

The dynamic aperture has been calculated with the MAD code for the old optics for the Kloe experiment. The on energy dynamic aperture reduction, for the error free machine, is about 30%, see Fig. 6.

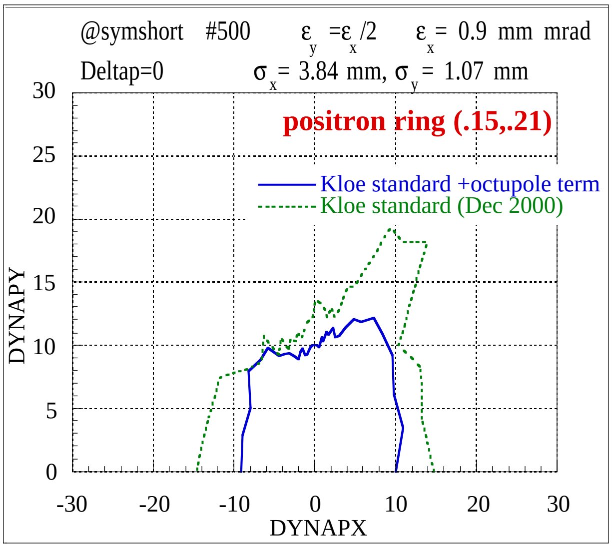

Figure 6: Dynamic aperture calculation for old (Dec 2000), expressed in number of beam σ's, with and without considering the octupole-like term in the wiggler.

The effect of the octupole-like term on the dynamic aperture is less severe in the case of the present optics, see Fig. 7.

The tune shift on amplitude is reduced, in agreement with the model prediction shown in Fig. 8. Further the beam-beam performance is positively affected as confirmed by the results obtained so far.

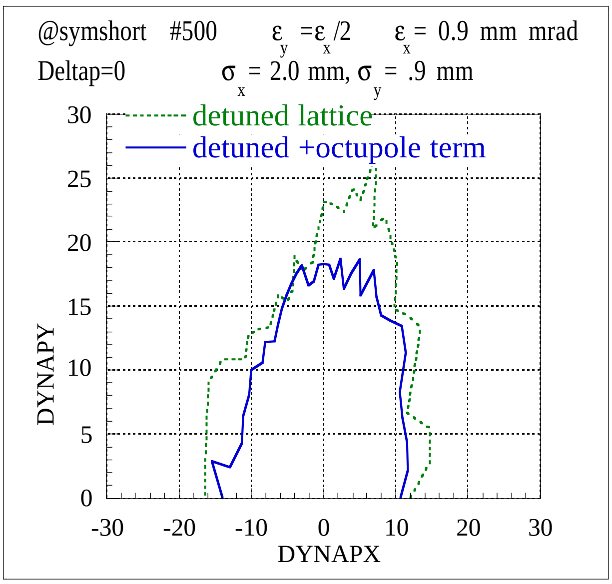

Figure 7: Dynamic aperture calculation for the DAΦNE actual optics (Mar 2001) expressed in number of σ's, with and without the wiggler octupole-like term.

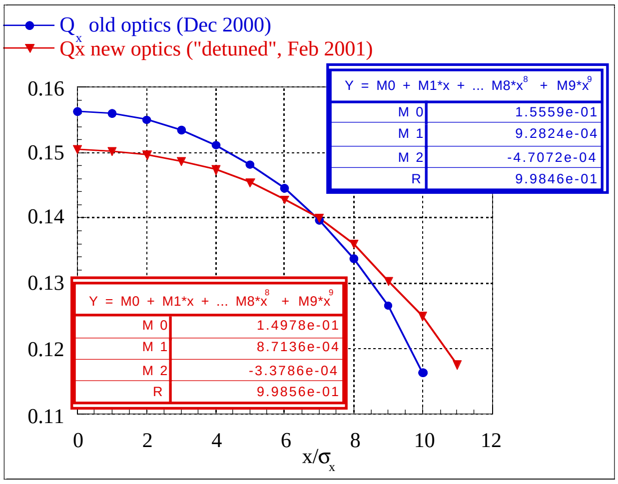

Figure.8: Tune shift on amplitude as predicted by the model for the old and present optics.

6 CONCLUSIONS

The installation of octupole magnets in the DAΦNE rings is underway [10] to optimise the octupole term benefits (Landau damping) and drawbacks.

Dynamic aperture improvements on the new optics are in progress with a six-dimensional phase space study by tracking a high number of particles, on and off energy, together with a betatron tune plane analysis. At the same time an empirical, way to optimise sextupole sets, with the trial and error method, is used. The sextupole strength distributions, calculated for constant chromaticity, are applied looking for beam lifetime and the background improvements.

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THE DAΦNE 3RD HARMONIC CAVITY

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Abstract

The installation of a passive 3rd harmonic cavity in both the e^+ and e^- rings of the Frascati Φ-factory DAΦNE has been decided in order to improve the Touschek lifetime by increasing the bunch length. The implications of the RF harmonic system on the beam dynamics, in particular those related to the gap in the bunch filling pattern, have been carefully studied by means of analytical and numerical tools. A single-cell cavity incorporating a ferrite ring for the HOM damping has been designed through the extensive use of MAFIA and HFSS simulation codes. One cavity prototype has been built and extensively bench tested, while the fabrication of the two final cavities is almost completed. A description of the design and construction activities, and a set of experimental measurements are reported in this paper.

1 INTRODUCTION

The installation of a passive 3rd harmonic cavity [1] in each DAΦNE ring has been decided to increase the Touschek lifetime by lengthening bunches [2], and to weaken the coherent instabilities by increasing the Landau damping due to the non-linearity of the longitudinal potential well.

The most relevant parameters related to the machine longitudinal phase space are summarized in Table 1.

Table 1: DAΦNE parameters

Energy	E	510 MeV/ring
Single bunch current	I_b	20 mA (present operation) 44 mA (nominal)
Maximum total current	I_M	0.8 A (present operation) 1.5 A (mid-term goal) 5 A (nominal)
Synchrotron losses	V_s	9.3 keV/turn
Parasitic losses	V_p	≈2 keV/turn(@ I_b=20 mA)
RF frequency	f_{RF}	368.29 MHz
RF voltage	$_{RF}$	120÷170 kV (present operation) 250 kV (nominal)
harmonic number	h	120
momentum compaction	α	≈ 0.025
natural bunch length (@ I_b≈ 0)	σ_{z_0}	≈ 1.4 cm (@ V_{RF}= 120 kV) ≈ 1.0 cm (@ V_{RF}= 250 kV)

The actual DAΦNE bunch length depends on the single bunch current, since the machine runs in the bunch lengthening regime.

This means that bunch lengths exceeding 2 cm are normally obtained in the present standard operating conditions (I_b = 20 mA, V_{RF} = 120 kV).

The implementation of a high harmonic RF system will allow to approach a bunch length value $\sigma_z \approx 3$ cm in the lengthening regime with the main RF voltage larger than the present operational value. Thus the Touschek lifetime will be recovered mainly from the bunch lengthening, but also due to the RF acceptance increase.

The parameters of a 3rd harmonic RF system matching these specifications are summarized in Table 2.

Table 2: DAΦNE 3rd harmonic RF system parameters

3rd harmonic RF frequency	f_{RF_H}	1104.9 MHz
main RF voltage	V_{RF}	200 kV
3rd harmonic RF voltage	V_{RF_H}	57 kV
natural bunch length (@ I_b≈ 0, V_{RF}= 200 kV)	σ_{z_0}	≈ 2 cm
bunch length @ I_b≈ 20 mA	σ_z	≈ 2.8 cm
operational beam current	I	0.3 ÷ 1.5 A

Under these specifications we estimate that the Touschek lifetime improvement, with respect to the present operating conditions, will be about 50% [2].

Due to the peculiarity of the DAΦNE parameters (low RF voltage, high beam current), powering the cavity in the passive way appears to be the simplest and the most effective choice. The required harmonic voltage can be obtained with a modest cavity shunt impedance and over a wide range of beam currents. The choice of the harmonic number 3 is a compromise between beam dynamics requirements and constraints related to the space available for the cavity installation.

2 BEAM DYNAMICS REMARKS

The implications of the harmonic voltage on the beam dynamics have been carefully considered. The most worrying issues are the shift of the frequency of the coupled bunch (CB) coherent motion and the effects of a non-uniform filling pattern in the multibunch configuration (bunch trains with gaps in the filling pattern).

The coherent frequency shift of the CB modes for a passive harmonic cavity calls for low R/Q and high Q values. In this case the cavity can deliver the required harmonic voltage over a wide range of stored currents being always tuned far enough from the coherent synchrotron lines located near the revolution harmonics $3h$ and $3h+1$.

The presence of a gap in the bunch filling pattern generates a bunch-to-bunch spread of the parasitic losses. Since the total RF voltage derivative at the bunch center is considerably reduced by the harmonic voltage contribution, the parasitic loss spread produces a large spread of the bunch synchronous phases. The higher is the stored current and the larger is the gap in the filling pattern, the larger is the synchronous phase spread. This effect sets the ultimate current value I_{Max} corresponding to the maximum acceptable spread. Beyond this value the bunch-by-bunch feedback systems loose their synchronism and some bunches may collide too far from the nominal Interaction Point (IP).

Since we normally need a gap of 1/3rd of the ring in the e^- bunch filling pattern to avoid ion trapping, we estimate that in our case $I_{Max} \approx 1.5$ A.

The harmonic voltage can be almost completely "switched-off" by tuning the cavity as far as possible from the harmonic $3h$. In order to minimize the coherent effects, it is worth tuning the cavity at $(3h + n + 0.5) f_{rev}$, with the integer n as high as the tuning system allows. This is the so-called "parking option", that can be used to recover approximately the operating conditions obtained before the harmonic cavity installation. In our case n can be chosen in the range from -1 to +2.

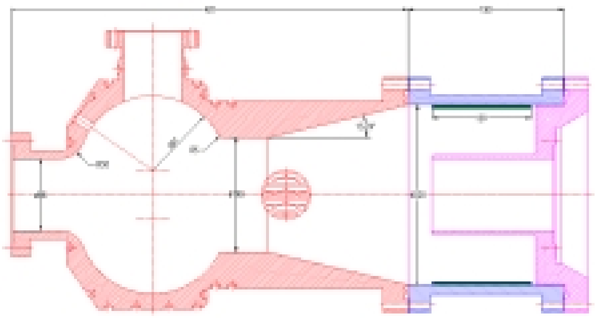

Figure 1: Sketch of the 3rd harmonic cavity

3 DESIGN OF A HOM DAMPED 3RD HARMONIC CAVITY

A mechanical sketch of the DAΦNE 3rd harmonic cavity is shown in Fig. 1. The assembly can be divided into 3 main parts connected together with flanges. In the first part the contour of a rounded cell is recognizable, connected to a short flanged beam tube on the left side and to a longer tapering-out section on the right. On the cell top there is a port for the insertion of a tuning plunger. This cavity has been designed to be passively powered by the beam itself, so that no port for the RF coupler has been foreseen. Three small RF probes have been inserted in the structure to measure the beam induced field allowing the low-level control and diagnostics.

The rounded cell is the volume where the fundamental mode resonates. It is connected through the tapered section to an HOM damper. The damper consists in a ring made of a special ferrite (IB-004) bonded on a flanged stainless steel support with the Hot Isostatic Pressure (HIP) method. This device has been designed and fabricated as one of the HOM dampers for the superconducting cavities of the KEK B-factory [3], the so called SBP (Small Beam Pipe) HOM load. The KEK laboratory kindly supplied us 3 dampers taken from the B-factory spares.

The DAΦNE 3rd harmonic cavity has been designed to incorporate this kind of damper. In this way we could simplify the project considerably, ending-up with a design having basically a 2D symmetry and taking advantage of the good experience of two-years operation of these kind of dampers. The general properties of a rounded cell with large openings well match the requirements of our passive cavity (high Q and low R/Q values).

The only significant adaptation of the SBP HOM load to our requirements is represented by the coaxial shield which avoids direct exposure of the ferrite to the beam charge, which is the third flanged object shown in the assembly of Fig. 1. The shield prevents direct heating of the ferrite that in this case can interact with the beam only through the cavity HOMs. The shield then avoids the risk of degradation of the DAΦNE broadband impedance associated with the direct beam-ferrite interaction. This risk cannot be easily evaluated by means of simulations or analytical estimate.

In spite of the apparent simplicity of the proposed geometry, a huge simulation activity based on MAFIA and HFSS codes had been necessary to define the final dimensions of the cavity. The task of this job was to obtain a strong coupling of all the cavity modes with the damper, except the fundamental one, with a limited total length available for allocating the structure in the ring.

4 EXPERIMENTAL MEASUREMENTS

The fabrication of one cavity prototype and two final devices all made of Aluminium has been decided. The prototype, whose picture is shown in Fig. 2, has been delivered to the LNF at the end of last year, while the fabrication of the two final cavities is almost completed and their delivery is scheduled by the end of June 2001.

Figure 2: Picture of the harmonic cavity prototype

Three tuning plungers (including one spare) made of Copper and fully equipped with bellows, stepping motors and encoders have been fabricated separately and have been already delivered to LNF. Although Copper has a better conductivity, we chose Aluminium for the cavity body fabrication in order to reduce both the cost and the delivery time. This choice implies a reduction of the fundamental mode Q by ≈ 15÷20%.

Table 3: cavity modes (simulations and measurements)

	SIMULATIONS			MEASUREMENTS	
	f[MHz]	Q	R/Q	f[MHz]	Q
M1	1105	23000	26 Ω	1105	18500
M2	1335	12	16 Ω	---	---
M3	1600	27	6 Ω	---	---
M4	1650	55	2 Ω	1650	168
M5	1899	52	4 Ω	---	---
M6	2094	115	7 Ω	2100	224
M7	2270	117	9 Ω	2289	60
M8	2495	167	3 Ω	2466	140
M9	2524	226	10 Ω	2507	278
D1	1089	438	66 Ω/m	1070	450
D2	1244	35	26 Ω/m	---	---
D3	1445	158	22 Ω/m	1400	139
D4	1618	158	29 Ω/m	1560	175
D5	1797	266	37 Ω/m	1725	163
D6	1886	283	24 Ω/m	1865	190

The impedance and Q values of the cavity longitudinal (M=monopole) and transverse (D=dipole) modes, as given by simulations and as measured on the prototype, are reported in Table 3. With the exception of the fundamental mode M1, all the other modes are substantially damped by the ferrite load. Considering the bunch always longer than 2 cm, the HOMs show effective impedances lower than 800 Ω (monopoles) and 25 kΩ/m (dipoles). We believe that this contributions will not change significantly the present scenario of the DAΦNE beam dynamics [4]. On the contrary we expect beneficial contribution to the beam dynamics from the Landau damping which will be strongly emphasized by the non-linearity of the harmonic voltage.

Some modes, calculated with the simulations, where not measurable port-to-port on the prototype. The low Q value of these modes and the presence in the measurements of high polarity modes (quadrupoles, sextupoles, etc.) are possible explanations for this lack. We also performed longitudinal and transverse impedance measurements on the prototype based on the wire method. After a careful interpretation of these measurements we conclude that they confirmed the values reported in Table 3. The fundamental mode shunt impedance ($R_s = V_{acc}^2 / 2P_d$) is about 0.5 MΩ, a value fully compatible with the Table 2 specifications.

The power required to sustain the harmonic voltage is $P_{fund} \approx 3.5\ kW$. The maximum power delivered by the beam to the cavity HOMs is about the same ($P_{HOM} \approx 3.5\ kW \quad @I = 1.5A$ into 60 bunches), accordingly with our prudent estimate. The fundamental mode power is dissipated on the cavity walls, while the HOM power is dissipated in the ferrite damper. All this power is supplied through the main RF system and corresponds to an increase of the beam parasitic losses.

5 CAVITY ENGINEERING

The final cavities will be ready by the end of June, while all other equipments (dampers, tuners, vacuum feedthroughs) are already in house. Presently, the SBP HOM loads are undergoing a 60-day baking process at 55 °C, accordingly to a procedure suggested by KEK [5].

The RF power wasted on the cavity walls is limited to only 3.5 KW, but water cooling is still necessary. A plot of the expected temperature along the cell profile for an overrated RF dissipation of 5 KW is shown in Fig. 3. Other 3 separated water circuits will cool the damper, the tuner and the tube connecting the tuner port to the cell.

The passive harmonic cavities will not be installed during the shut-down period of August 2001, since a vacuum opening is not compatible with the machine schedule for the year 2001. The next shut-down (January 2002) is a more convenient period for such installation.

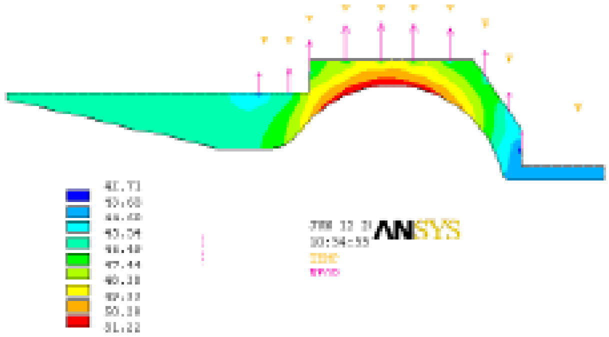

Figure 3: Temperature map along the cell profile

ACKNOWLEDGMENTS

We wish to warmly thank Dr. Takaaki Furuya and the KEK laboratory for supplying us three SBP dampers giving us all the information necessary to put them in operation.

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EFFECTS OF NONLINEAR TERMS IN THE WIGGLER MAGNETS AT DAΦNE

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Abstract

Analysis of the experimental observations and comparison with magnetic measurements have pointed out relevant nonlinear terms in the DAΦNE wigglers and in the "C" corrector magnets. Different optics configurations aimed at reducing the impact of nonlinear terms have been studied and their effects on the collider performances are presented.

1 INTRODUCTION

Nonlinerities at DAFNE [1, 2] appeared since the very beginning of commissioning, already from the measured chromaticity which exhibits a nonlinear shape even switching off all sextupole magnets. Wigglers and dipoles have been indi-cated as a possible source of those nonlinearities and studied in detail.

Experimental observations showed also a dependence of coupling on the beam position at both interaction regions, hinting the presence of some coupling source nearby.Nonlinearities have been investigated measuring: chromaticity, tunes versus closed orbit bumps, beam dynamic tracking and compared with numerical simulation.

2 WIGGLERS

Wigglers in DAΦNE are used to increase the synchrotron radiation emission and are integral part of each ring lattice.

The horizontal and vertical tunes as a function of horizontal closed orbit bumps have been measured at each wiggler, by means of four correctors whose induced energy change has been cancelled by varying the RF frequency. The sextupole magnets, obvious source of nonlinearities, were switched off.

Results are presented in Fig. 1 and Fig. 2 for electron and positron ring respectively. The horizontal tunes exhibit a clear quadratic behavior whose average value, over all wigglers, is comparable in the two rings. The different curve maxima are displaced with respect to each other and from the bump origin, due to residual orbits in each wiggler.

Repeating the orbit bump scans switching off the wigglers, gave a further confirmation about the source of the observed nonlinearities, since the quadratic shape disappeared. Figure 3 shows the comparison between the two different situations.

The vertical tunes versus horizontal bump amplitude are reported in Fig. 4 for the positron ring. They show a quadratic term due to the small vertical b values in the wigglers and a linear term coming from a residual orbit displacement in the dipoles adjacent to each wiggler. This last assumption has been confirmed by subtracting corresponding measure-ments performed with wigglers off and on, that resulted in an almost flat vertical tune. Same behaviour has been de-tected in the electron ring. The tune measurements can be fitted introducing a cubic term in each wiggler pole.

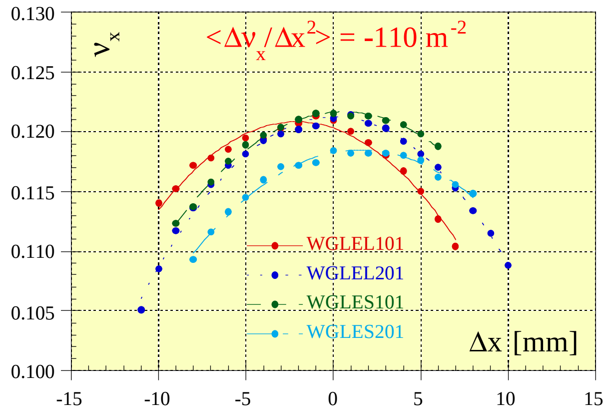

Figure 1: Horizontal tunes versus horizontal closed orbit bump at each wiggler in the electron ring.

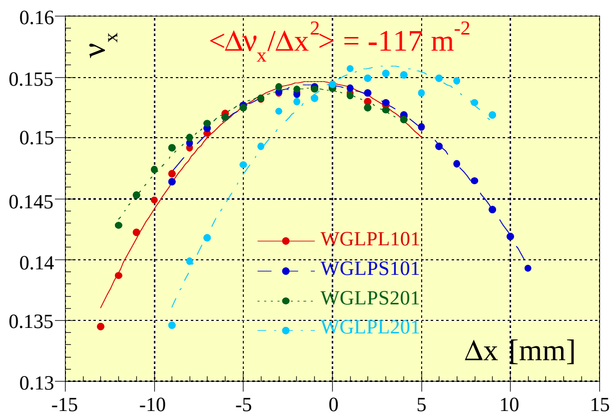

Figure 2: Horizontal tunes versus horizontal closed orbit bump at each wiggler in the positron ring.

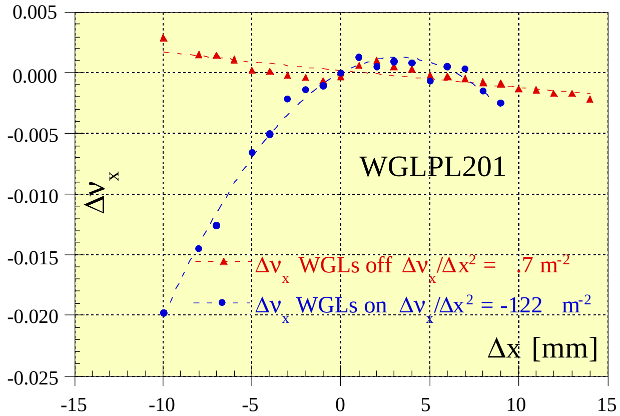

Figure 3: Horizontal tune shift versus horizontal closed orbit bump measured with the wigglers off and on.

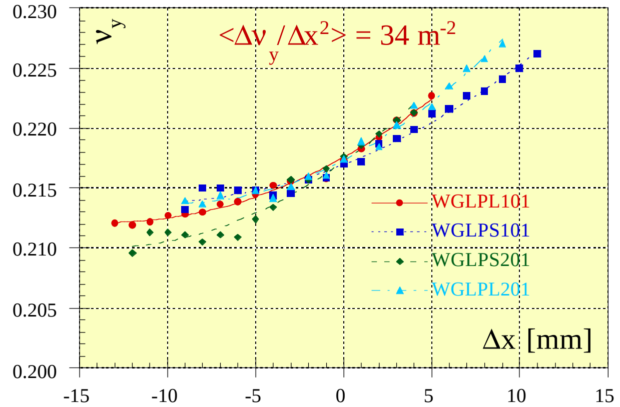

Figure 4: Vertical tunes versus horizontal closed orbit bump at each wiggler in the positron ring.

Figure 5 presents a comparison between simulated and measured horizontal tune versus horizontal closed orbit bump for a wiggler in the positron ring.

The integrated strength of the octupole-like term used in the simulation is K^3= -1000 m^{-3}. It fits also the chromaticity measurements [3].

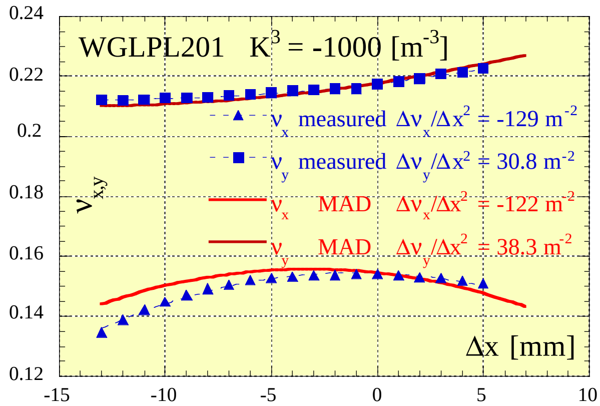

Figure 5: Comparison between measured and simulated tunes versus horizontal closed orbit bump.

Corresponding tune measurements while moving the vertical orbit can not be done due to the limited aperture of the vacuum chamber. An accurate analysis of the wiggler magnetic meas-ure-ments has shown how the cubic contribution rises from the superposition of a fourth order term in the wiggler field and the "wiggles" (~ 25 mm peak-to-peak) in the beam trajec-tory.

The same analysis by closed orbit bumps has been done at dipole location. Comparing simulated and measured tune shifts no unexpected nonlinear term has been observed.

Beam dynamic tracking [4] consists in exciting a free transverse betatron oscillation by kicking the beam and re-cording the transverse displacement turn by turn. This method allows to restore trajectory in the transverse phase space and can be used to measure the nonlinear coefficient C_{11} [5] relating the tune shift $\Delta\nu_x$ to the betatron oscillation amplitude J_x

$$\Delta\nu_x = 2c_{11}J_x$$

C_{11} depends on nonlinear element strengths, on betatron function at their position and on relative betatron phase advance between each other.

In DAΦNE, changing the lattice configuration, it varies in a wide range: $-6 < C_{11}\cdot 10^{-2} < 4$, see Table 1.

Table 1: Measured nonlinear coefficient for different main ring lattice configuration.

Optics	$C_{11}\cdot 10^{-2}$
KLOE optics	-6
Wigglers & Sextupoles off	+4
Wigglers off	+2
Wiggler's field 15% reduction	-3
KLOE detuned optics	-3

The DAΦNE optics used for the KLOE experiment data taking during year 2000 had a large negative C_{11} term. Re-ducing the wiggler field by a 15% lowers C_{11} by a factor two, while switching off the wigglers C_{11} changes sign; this circumstance suggests the presence of other contributions than wigglers to the overall DAΦNE nonlinearities. The sextupole magnets also affect C_{11} introducing a small negative contribution. Its worth remarking that negative C_{11} values provide Landau damping beneficial to coherent beam instabilities.

3 "C" CORRECTOR MAGNETS

The "C" corrector magnets are placed at both side of each interaction region. They are used to vary the horizontal crossing angle and the relative vertical position of the colliding beams.

The observed dependence of the beam coupling on beam position at the interaction point is explained if skew magnetic terms are added in the "C" correctors.

A polynomial fit [6] of the "C" corrector magnetic measurements [7] pointed out the presence of a sextupole and a skew sextupole term when the horizontal and the vertical winding are respectively excited. By including this contribution in the “C” corrector model it was possible to fit the chromaticity and the tune shift measurements versus closed orbit bumps, see Fig. 6, as well as the coupling dependence with the beam position at the interaction point.

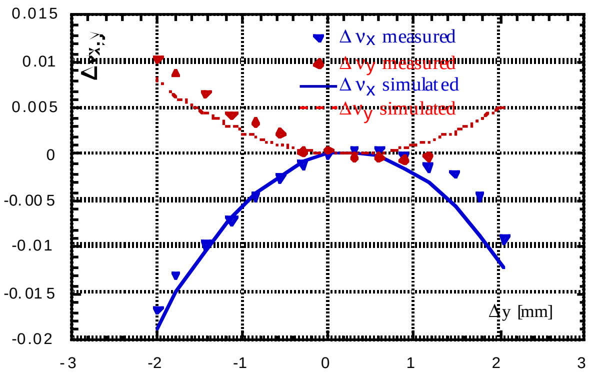

Figure 6: Tune shift dependence on displacement, using the "C" correctors, at the second interaction region.

4 OPTICS

During machine studies many different lattice configurations have been explored in order to quantify the impact of nonlinearities on beam dynamics. In this context an optics without wigglers has been computed and used for collision.

The maximum single bunch luminosity obtained was of the order of $7 \cdot 10^{28}$ cm^{-2} s^{-1}, with a maximum current of 5÷6 mA a bunch. As expected this lattice was much more sensitive to the transverse beam instabilities because the Landau damping, due to the cubic term, was removed and the damping time was 2-3 times larger than in the case of the optics with wigglers. It was clear that C_{11} positive value affects the beam-beam behaviour causing beam blow-up and lifetime degradation [8]. In this framework a new DAΦNE optics, called “detuned” [9], has been introduced with the idea of increasing the beams separation at the second interaction point and to lower the horizontal betatron function at the wigglers. This in order to have a smaller C_{11} given by the cubic terms in the wiggler, while still providing a reasonable amount of Landau damping. To implement those conditions, keeping the usual general constraints on lattice parameters, the vertical betatron function has been changed in the second interaction region removing the low-β condition. The detuned optics allowed a better coupling correction, since once eliminated the coupling contribution due to the "C" correctors, the only coupling source is the KLOE sole-noid, that is locally compensated in the interaction region.

Different lattice configurations were explored looking for the best condition of: single bunch luminosity, beam lifetime, injection efficiency and background [10] seen by the KLOE detector.

During these machine studies the detuned lattice performed definitely better from the point of view of beam–beam effects. Horizontal transverse instabilities, which in principle could expect to be stronger with this optics, were kept under control by a careful tuning of the feedback systems [11].

A single bunch luminosity of $1 \cdot 10^{30}$ cm^{-2} s^{-1} has been obtained, with a colliding current of the order of 18 mA per bunch. It was the first time that such results were achieved, in a reproducible way and with a reasonable lifetime (~2000 s), since the installation of the KLOE detector. Moreover high single bunch current up to 44 mA, that is the design value [1], has been let colliding, both for electron and positron, even if against lower current.

Detuned optics is currently used for KLOE data taking and is providing a peak luminosity of $2.8 \cdot 10^{31}$ cm^{-2} s^{-1} with a peak integrated luminosity of 1.4 pb^{-1} a day.

5 CONCLUSIONS

Nonlinearities at DAΦNE have been singled out and understood in detail. A wide set of measurements able to quantify their effects has been defined. Their impact on the collider luminosity performances has been reduced by modifing the DAΦNE optics.

Studies on a spare wiggler have been planned, in the next future, in order to suppress cubic nonlinearities by pole shimming. At the same time octupole magnets are under construction [12] to be installed in both rings in order to have predictable knobs to tune nonlinearities.

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EXPERIENCE WITH BEAM INDUCED BACKGROUNDS IN THE DAΦNE DETECTORS

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Abstract

DAΦNE is a high luminosity double ring electron-positron collider working at the energy of the Φ resonance (1.02 GeV c.m.) [1]. Two experiments, KLOE [2] and DEAR [3] are presently taking data at DAΦNE. At the beginning of data taking, both experiments suffered from large beam induced background, mainly due to Touschek scattering. Measurements of the background rates in different configurations as well as simulations and tracking studies have been performed in order to find the proper actions that allow reducing these rates. In particular measurements and simulations on the collimation efficiency of the scraper system and the consequent modifications adopted to improve the system are presented.

1 INTRODUCTION

Reduction of beam induced background is a particularly difficult task in a short machine like DAΦNE. In a low energy machine background arises mainly from the Touschek effect. Off-momentum particles can exceed the momentum acceptance given by the RF bucket, or may hit the aperture when displaced by dispersion. In addition, a betatron oscillation is excited if the momentum change happens in a dispersive region.

Machine induced background at the two experiments KLOE and DEAR has been reduced by adjusting several optical parameters like the orbits at the interaction points (IP), the strength of sextupoles or the β_x value upstream the IR's [4].

In the following efforts to reduce the remaining particle backgrounds by adjusting scraper positions are described, as well as simulations of Touschek particles through collimators, that led to the choice of more efficient scraper surfaces. Furthermore the modelling of Touschek induced background particles in DAΦNE is discussed.

2 SCRAPERS

To protect the detectors of the experiments from off-momentum particles remote controlled scrapers have been installed for the incoming beams on either side of each experiment. They are placed before the splitter magnets, about 7.0 m from the interaction point (IP), as shown in Fig.1. Two horizontal jaws per scraper, external and internal, are used to intercept the two off-energy particle families. Until December 2000 the scrapers consisted of rectangular tungsten blocks of 35 mm thickness, which corresponds to 10 r.l.

They were shielded by 150 μm of copper to minimize the discontinuity in the vacuum chamber.

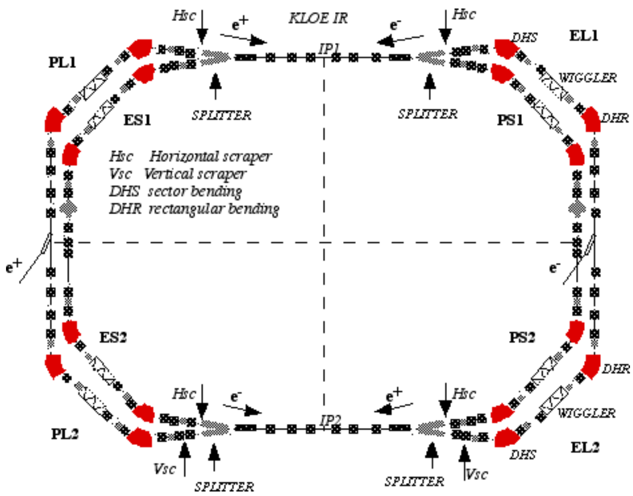

Figure 1: Layout of the DAΦNE main rings.

2.1 Scraper scans

Scraper scans have been performed both with colliding beams during physics data taking and with single beams [5]. Rates of the two forward calorimeters in KLOE have been taken as a function of the opening of the horizontal scrapers upstream IR1. The two rates from the calorimeters ECM2 and ECM4 integrate the signals over the four innermost sectors of the west and east forward calorimeters each. In order to compare measurements with different beam parameters, the calorimeter rates are given per 1 mA bunch and are scaled for a roundness of 0.1, as the beam lifetime (dominated by the Touschek effect) in DAΦNE is proportional to σ_y. The roundness parameter is the ratio of the vertical to horizontal beam size measured at the location of the synchrotron light monitor.

The background rate measured by KLOE for an electron beam versus the KLOE scraper setting is shown in Fig. 2 (dashed blue line) and can be taken as a typical behaviour. It appears that the external jaw reduces the background by about a factor 2.3 at a distance of ≈25 mm from the beam axis, while the closed orbit was measured at -2.7 mm from the center of the chamber. However, a steep increase of the background rate is observed when the scrapers are closed to less than about 23 mm ($9\sigma_x$) from the closed orbit position. Apparently, from this moment on, the scrapers are producing more background particles than they are stopping.

In an effort to understand the unveiled inefficiency of the used scrapers, simulation of Touschek particles in the accelerator, as well as tracking 510 MeV electrons through the scraper blocks have been performed.

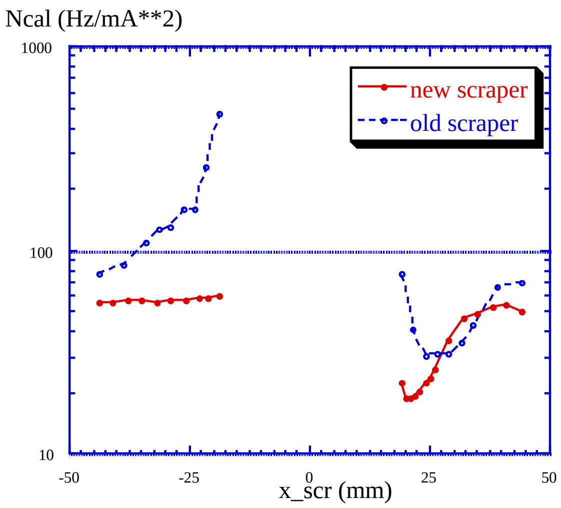

Figure 2: Scan of the normalized background rate versus the position of the inner scraper edge. The scraper openings are measured from the central beam axis.

3 SIMULATIONS

The home-developed tracking code STAR (Simulation of Touschek pARticles) [7] has been upgraded and was run with the present optics conditions; it is used to understand the source of the machine induced background and the locations where most of the off-energy particles get lost.. The main beam parameters used for these simulations are summarized in Table 1.

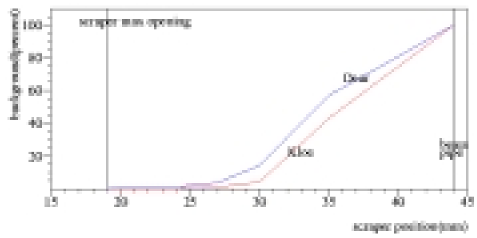

Figure 3: Simulated scraper efficiency for KLOE and DEAR scrapers, assuming completely absorbing scrapers.

Simulations of edge effects of the scrapers have been performed with STAR and GEANT3 [8]. It has been found that with the rectangular shape most of the particles are scattered by the thin copper layer above the tungsten, instead of being absorbed, thereby producing additional background to the experiments.

These calculations resulted in the proposal of new modified scrapers, which were constructed and installed in the DAΦNE rings during January 2001. The inner surface of the new scraper block has been divided into two flat parts. A first 10 mm long section has a slope of 100 mrad towards the beam, in order to increase the impinging angle into the block for most particles. This is followed by a second section of 45 mm length which slopes by 10 mrad in the opposite direction to avoid foreward scattering of electrons back into the beam pipe. A vertical slit has been introduced into the copper shield to ensure that all incident particles only see the tungsten absorber. The total scraper thickness of now 55 mm (about 16 r.l.) is reducing the punch-through probability of 500 MeV electrons to below 10^{-6}.

Table 1: Relevant beam parameters used for Touschek simulations.

Particles/bunch	$2 \cdot 10^{10}$
Hor. Emittance[m rad]	10^{-6}
Coupling factor	0.01
Bunch length [cm]	1.9
Relative energy spread	$4 \cdot 10^{-4}$
RF Voltage [KV]	100

The behaviour of the new scraper is shown in Fig. 2 (full red line). The external jaw reduces the background by a factor 2.9 at a distance of ≈20 mm from the chamber axis. No background reduction is found when moving in the internal jaw (full line), however, the previously observed strong increase is no longer present (dashed line), indicating an improved stopping efficiency of the scraper blocks.

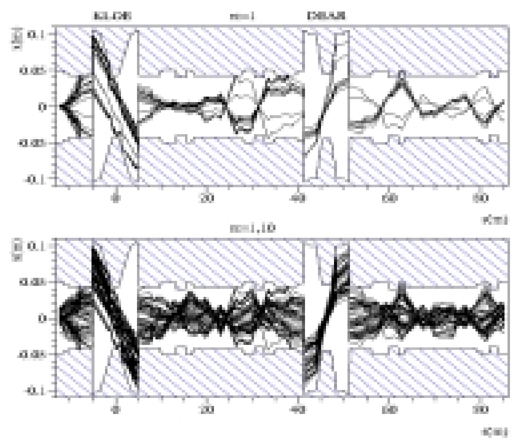

Figure 4: Touschek scattered particles generated in arc PL1 are tracked along the DAΦNE ring with sextupoles included. The upper plot shows the trajectories in the first turn, the lower plot over ten consecutive turns.

The simulated scraper efficiency, for an ideal scraper, which completely absorbs all intercepted particles, is shown in Fig. 3. As was measured, the KLOE scrapers appear to be more effective than the ones around DEAR. In the simulations only Touschek particles produced along the first arc upstream the experiment are included and counted as background when being lost inside the IRs. Touschek lifetime is determined by the momentum acceptance and bunch volume integrated over the lattice structure [6]. In the DAΦNE rings we distinguish two regions: straight sections with vanishing dispersion and arcs with high dispersion. Particles scattered in the straight sections undergo a momentum deviation, but gain no additional betatron oscillation, and will therefore not add to the background. However, particles scattered in the arcs suffer additional horizontal betatron oscillations and can therefore get lost on the vacuum chamber inside the interaction regions, hence producing background at the experiments.

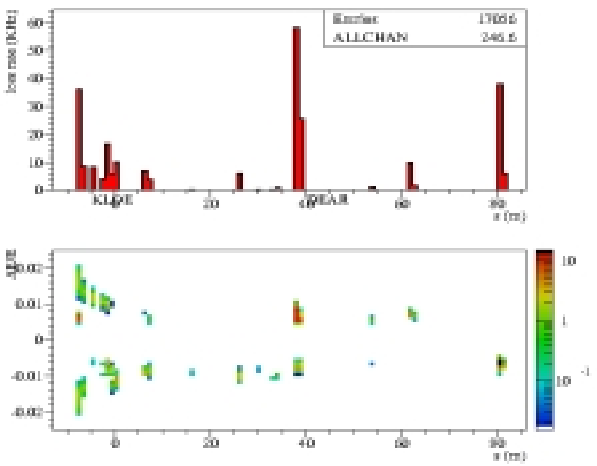

Figure 5: Upper plot: distribution of lost particles at the vacuum chamber along the ring, starting from arc PL1. Lower plot: corresponding energy distribution of lost particles.

In a second phase tracking has been extended to include the whole ring and to track over many turns. Touschek scattered particles are generated separately in the four arcs as shown in Fig. 1: PL1, PL2, PS2 and PS1 for the positron beam (and similarly EL1, EL2, ES2, ES1 for the electron beam). This way the different contributions from each arc to the two experiments as well as to the total beam loss can be separated. Simulations have been performed, both with and without sextupoles. When sextupoles are included a lifetime reduction of 40% is found. Preliminary results are presented below.

An example of the horizontal trajectories of Touschek scattered particles along the ring is shown in Fig. 4. The presently adopted optics for KLOE data taking for the positron beam was used. The discontinuity at the ends of the IRs is due to the change of the reference system in the splitter magnets, as the trajectory of the reference particle passes off-axis in the IR quadrupoles due to the horizontal crossing angle. Only Touschek particles with a relative energy deviation between 0.003 and 0.02 have been included, as particles with higher energy deviation get lost locally and do not contribute to the experimental background. The simulations clearly show the evident role played by the betatron phase and how this is changed when sextupoles are included. In fact, without sextupoles only off-energy particles generated in the arc upstream of IR1 get lost in KLOE and only in their first turn. With sextupoles included also particles generated in the arc PS1 reach IR1 and are lost at the second and third turn. The distribution of loss points around the ring and the corresponding energy of lost particles is shown in Fig. 5. The total loss rate as well as the KLOE background rate as function of the number of turns show that losses appear only over the first few turns.

Table 2 summarises the contributions of the four arcs to Touschek losses around the ring and to the background rates in the two experiments. 10^4 particles have been tracked over ten machine turns. with sextupoles excited or not (in parenthesis).

Table 2: Expected losses with and without sextupoles

BKG(KHz)	All ring	KLOE	DEAR
PL1	246.6 (198.4)	44.6 (30.6)	0.0 (0.0)
PL2	884.4 (251.8)	0.0 (0.0)	0.0 (0.0)
PS2	232.6 (254.3)	0.0 (0.0)	19.2 (19.2)
PS1	310.2 (271.0)	2.5 (0.0)	0.0 (0.0)
Total BKG	1673.8 (975.5)	47.1 (30.6)	19.2 (19.2)

Although these results do not yet allow to fully explain the observed amount and behaviour of the background rates in KLOE and DEAR, good progress has been made in this direction. Further systematic measurements and detailed simulations will be needed to reach the required level of understanding that will allow for further reduction of the background rates.

5 CONCLUSIONS

Important progress has been made in understanding the machine induced background. New, more efficient scraper blocks have been introduced. Progress in the modelling of the origin of background will further help actions to reduce background, which might be at the end the limiting factor for luminosity improvements.

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BEAM-BEAM EXPERIENCE AT DAΦNE

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Abstract

This paper summarizes the results of experimental observations and measurements of beam-beam interactions in DAΦNE, the Frascati Phi-factory. The achieved results are reported with analysis of present limitations in both single and multibunch operation modes and compared with numerical simulations.

1 INTRODUCTION

DAΦNE is a double ring electron-positron collider, designed to provide very high luminosity at the energy of the Φ resonance of 1.02 GeV c. m., the Φ-factory built at the Frascati National Laboratories of INFN (Italy) [1, 2]. After storing the first beam in fall 1997 and the successful commissioning without solenoidal detectors, the experimental detector KLOE [3] was rolled-in and the collider operation in the present configuration started in spring 1999. Since then DAΦNE alternates machine study and physics data taking shifts. Recently, peak luminosity of 10^{30} $cm^{-2}s^{-1}$ in single bunch collisions and $2.8\cdot10^{31}$ $cm^{-2}s^{-1}$ in the multibunch regime have been measured by the KLOE detector. A maximum integrated luminosity of 1.4 pb^{-1} per day has been registered, while the total luminosity integrated by the KLOE experiment amounts to about 50 pb^{-1}. In Section 2 we summarize the luminosity achievements and discuss measures that have allowed to improve gradually the collider luminosity performance. Section 3 describes the results obtained in single bunch collisions, compares the experimental data with numerical simulations and discusses present single bunch luminosity limitations. Section 4 is dedicated to the multibunch luminosity operation with analysis of the achieved results.

2 LUMINOSITY HISTORY

Figure 1 shows DAΦNE luminosity achievements, the maximum peak luminosity and the integrated luminosity per day, since the KLOE detector installation in spring 1999. The steady improvement is accounted by continuous machine study. Indeed, the first two years of collider runs were dedicated mainly to machine development, with limited time allocated for experimental physics. Much effort in this period was devoted to measurements and careful analysis of machine optics necessary to create an adequate linear model and to perform coupling correction. Now coupling is corrected down to 0.3%, much better than the design value of 1%.

As experience has shown in agreement with numerical simulations, the coupling reduction has improved substantially the luminosity performance [5].

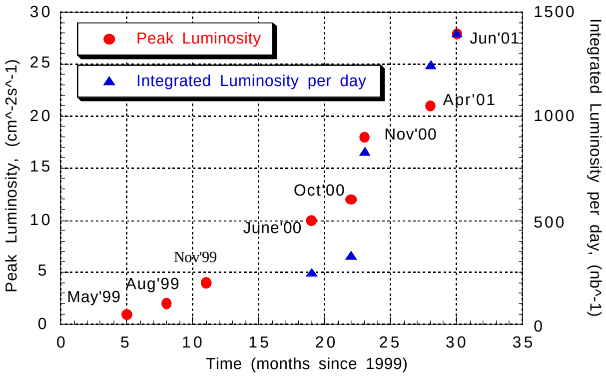


Figure 1: DAΦNE peak and daily integrated luminosity.

Together with machine modelling, the measures for optimization of the collision point parameters, such as bunch overlap in time and in both transverse planes, correction of the vertical crossing angle and residual dispersion at the IP etc., were studied [6].

The most intensive study of nonlinear dynamics was performed during last year. A dynamic tracking system was implemented in the main rings. This system allows to estimate trajectories in the transverse phase space and to measure the lattice cubic nonlinearity. As we will see later, the crosstalk between beam-beam effects and nonlinearity affects strongly the luminosity and the lifetime. By performing dedicated localized bumps and measuring the betatron tune, it was found that wigglers give a strong octupole term [7], while the "C" corrector magnets have non-negligible sextupole component [8] influencing the beam dynamics.

A real break-trough in single bunch luminosity has been obtained when the newly proposed "detuned" structure [9] has been applied to DAΦNE. This new lattice avoids the low beta scheme at the second interaction point when the machine is tuned to collide only at the IP for the KLOE experiment. As a consequence, the lattice has lower chromaticity and smaller sextupole strengths are necessary to compensate the chromaticity. Moreover, it accepts a large vertical separation at the second IP decreasing therefore the problem of parasitic interactions at the second IP.

Besides, the separation bump at the IP is performed with very low currents in the nonlinear “C” correctors magnets, thus minimizing their contribution to the overall machine nonlinearity and coupling. Another important point is that the “detuned” lattice can be adjusted to have smaller beta functions in the wiggler decreasing the effect of their octupole terms. All these features allowed to achieve for the first time since KLOE installation a single bunch peak luminosity of 10^{30} cm^{-2} s^{-1} with currents of the order of 18mA per bunch and reasonable lifetimes. For the first time it has been possible to increase the bunch currents in collision up to the nominal value (44mA), with no drastic reduction of lifetime, even if the beam-beam blowup not only limits but even reduces the luminosity.

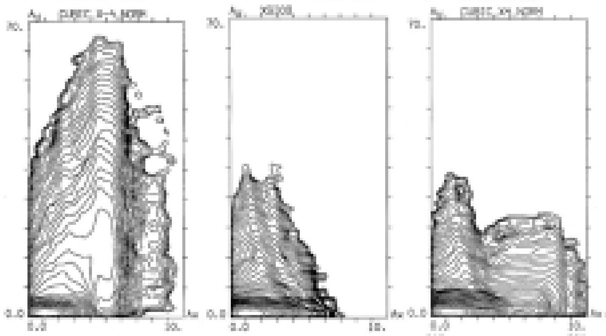
The steep jump in the integrated luminosity per day in November 2000 and its further increase in April 2001 was due to the possibility of performing the “topping up” procedure without switching off the experimental detector. Careful tuning of lattice, orbit, and scrapers positions for the background reduction made this possible. non-linearities in the machine, whose overall contribution is compensated by the wiggler non-linearity. One of these is a sextupolar term in the “C” corrector magnets [6].

3 SINGLE BUNCH LUMINOSITY

For a long time the single bunch luminosity could not exceed 4-5·10^{29} cm^{-2} s^{-1}. And only recently, we managed to increase the luminosity to 10^{30} cm^{-2} s^{-1}.

During collider tune up for collisions it has been found that the cubic nonlinearity can change in a wide range depending on lattice functions and orbit. Moreover, the sign of the nonlinearity can even change, as it is when wigglers are switched off [7]. The coefficient of the cubic nonlinearity as measured by the dynamic tracking system, varies between - 600 < c_{11} < + 400. Besides, we have found correlations between the nonlinearity strength and sign and the attainable luminosity. Numerical simulations with the weak-strong code LIFETRAC [10] that allows including implicitly the cubic nonlinearity coefficient c_{11} have been undertaken to explain the crosstalk between the beam-beam effects and nonlinearity. We have assumed that the tune shift parameters are equal in both transverse planes $\xi_x = \xi_y = 0.03$ and the working point is at (0.15; 0.21). The examples of equilibrium density distributions in the space of normalized betatron amplitudes are shown in Fig. 2. Table 1 summarizes the beam-beam blow up factors in the both transverse planes and the lifetime as a function of c_{11}. We should remark here that in the simulations the lifetime is limited only by beam-beam effects and the dynamic aperture is considered to be rectangular with boundaries at $A_x = 10\sigma_x$ and $A_y = 70\sigma_y$ (or $10\sigma_y$ at full coupling). As it is seen in Fig. 2, both positive and negative nonlinearities are harmful for beam-beam effects. Above $|c_{11}| > 200$ the distribution tails start growing and the bunch core blows up.

So, it is difficult to say which sign of the nonlinearity is more preferable. For positive c_{11} the horizontal tails reach the horizontal dynamic aperture and the horizontal size is blown up, while for negative c_{11} the tails expand in both transverse directions and the bunch blows up vertically.



C_{11} = - 400 C_{11} = 0 C_{11} = 400

Figure 2: Equilibrium distributions for different cubic nonlinearities in space of normalised betatron amplitudes.

Table 1: Beam-beam blow up and lifetime

c_{11}	σ_x/σ_{x0}	σ_y/σ_{y0}	τ
- 600	1.064	2.431	2.4 h
- 400	1.053	1.300	9.9 h
- 200	1.075	1.038	∞
0	1.067	1.047	∞
+ 200	1.110	1.055	∞
+ 400	1.160	1.044	7.7 h
+ 600	1.400	1.108	4 min

According to the simulations, the nonlinearity strength can be considered acceptable when c_{11} remains within the range – 200 < c_{11} < + 200. Within this range the tails are well confined inside the dynamic aperture and blow up is negligible. This agrees well with experimental observations: the highest single bunch luminosity of 10^{30} $cm^{-2}s^{-1}$ was reached in a reliable way when both collider rings were adjusted at the working point (0.15; 0.21) and the measured c_{11} was equal to – 170. Instead, during collisions in the KLOE IP in November – December 2000 the measured c_{11} was about – 600 and the maximum achievable single bunch luminosity was at a level of 5x10^{29} $cm^{-2}s^{-1}$. As it is seen in Table 1, such a strong cubic nonlinearity leads to both beam-beam blow up and lifetime reduction. In the present collider configuration, the electron ring has c_{11} = - 300 and the positron one has c_{11} = - 350. The nonlinearity is higher for this configuration due to the increase of the horizontal beta functions in the wigglers, which was necessary to cope with background problems and to damp horizontal transverse instability. However, c_{11} values of the order of – 300 are still acceptable giving relatively small blow up and moderate tail growth and in fact the measured single bunch luminosity in this case is again of the order of 10^{30} $cm^{-2}s^{-1}$.

Therefore, the present lattice can be considered as a reasonable compromise between beam-beam performance and allowable background level. From this point of view, beam-beam and background problems can be separated if we use an independent (and variable) source of cubic nonlinearity. Additional octupoles could play this role and they will be installed in fall 2001.

4 MULTIBUNCH LUMINOSITY

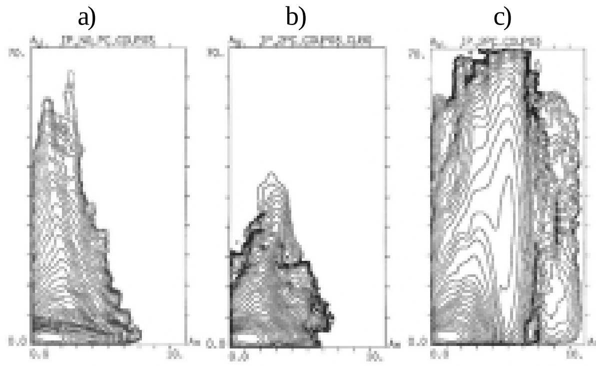
Passing from single bunch to multibunch collisions the luminosity does not scale linearly with the number of bunches. One of the reasons is that the maximum beam currents $I^{\pm}_{max}$ cannot be stored simultaneaosly, since both rings are filled by the same injector chain. Few minutes are necessary to convert the injector between the two beams and the lifetimes are of the order of 2000 sec. Presently the I^{-}_{max} is limited to ~ 850 mA by vacuum, and does not reach the beam-beam limit of positrons. The I^{+}_{max} is limited to ~ 800 mA by KLOE background acceptable rate and is near to the e- beam-beam limit. The optimum number of bunches, taking into account all these considerations and the gap which limits ion trapping, is found during the luminosity shifts.

The peak luminosity is usually obtained with total currents of 600 to 700 mA per beam, with 45 : 49 bunches, corresponding to currents per bunch lower than the one giving the maximum luminosity. The maximum measured peak luminosity, $2.8 \cdot 10^{31}$ $cm^{-2}s^{-1}$, has been achieved with 47 bunches in each beam, i.e. with the luminosity of $6 \cdot 10^{29}$ $cm^{-2}s^{-1}$ per each bunch. Another limit could come from parasitic crossings (PC) reinforced by the cubic machine nonlinearity.

There are some experimental observations confirming that the PC effect is significant for the multibunch collider performance. In particular, when injecting one beam out of collision in the nearby bucket, the already stored opposite beamlifetime drops. Yet another observation is that it has been possible to scale the luminosity with the number of bunches with bunches separated by 3 empty buckets. In order to clarify the situation we have simulated with LIFETRAC the beam-beam interaction with two parasitic crossings at either side of the interaction point (IP) and taking into account the measured cubic nonlinearity c_{11} = -350. The PCs were at a distance of 81 cm from the IP, which corresponds to the actual fill pattern with 1 empty bucket between bunches. We have also considered that the coupling has been corrected down to 0.3%. The simulations have been carried out a bunch current of 25 mA. Figure 3 compares the results of the following simulation runs taking into account:

- Only IP without PCs and without nonlinearity;
- IP with two PC and without nonlinearity;
- IP with two PCs and with cubic nonlinearity.

As it is clearly seen, the PCs reinforced by the nonlinearity strongly affect the bunch tails and, as a result, the lifetime drops. So, one of the solutions aimed at increasing the luminosity in the multibunch regime is further reduction of the nonlinearity. Installation of additional octupoles capable of controlling the nonlinearity would be extremely useful.



a)	b)	c)
σ_x/σ_y = 1.076	σ_x/σ_{x0} = 1.097	σ_x/σ_{x0} = 1.099
σ_y/σ_{y0} = 1.449	σ_y/σ_{y0} = 1.954	σ_y/σ_{y0} = 2.498
$\tau = \infty$	$\tau = \infty$	τ = 36 sec

Figure 3: Equilibrium distributions taking into account parasitic crossing and cubic nonlinearities.

5 CONCLUSIONS

Obtaining high luminosity in the low-energy range of a Φ-factory is an interesting challenge. Beams are extremely sensitive to nonlinearities, instabilities and coupling. The beam-beam effect is a strong perturbation of the bunch distributions. Long damping times ask for very efficient feedback system.

The design DAΦNE luminosity is an ambitious number, but with the present results the integrated luminosity needed by the experiments to reach their physics goals is a reachable aim..

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HIGH CURRENT MULTIBUNCH OPERATION AT DAΦNE

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Abstract

At present the Frascati Φ-factory DAΦNE is operating in multibunch regime with stored currents in the range of 0.5-1 A in both e+ and e- rings. A longitudinal bunch-by-bunch feedback system has been operating in each DAΦNE main ring since the beginning of the machine commissioning. The transverse bunch-by-bunch feedback system working in the vertical plane has been implemented last year in both rings. This paper describes the performance of the feedback systems and reports the instability observations and the rise-time measurements. The present current limitations and the plans aimed at further current increase are also discussed.

1 INTRODUCTION

DAΦNE is a Φ-factory in operation at the Laboratori Nazionali di Frascati of I.N.F.N. Two detectors, Kloe and Dear are currently taking data and a synchrotron light facility is under development. At present the Frascati Φ-factory DAΦNE is operating in multibunch regime with stored currents in the range of 0.5-1 A in both e^+ and e^- rings. The achieved peak luminosity is $2.79 \cdot 10^{31}$ cm^{-2} sec^{-1} in the IP1 (Kloe detector) while the reached integrated luminosity is 1.4 $pbarn^{-1}$ per day [1].

A longitudinal bunch-by-bunch feedback system, developed in collaboration with SLAC and LBL, has been operating in each DAΦNE main ring since the beginning of the machine commissioning.

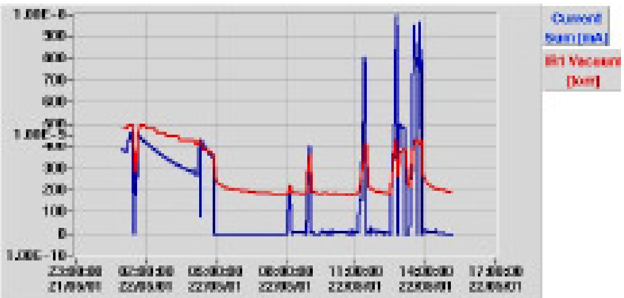

Figure 1: E- machine development shift plot.

Last year transverse bunch-by-bunch feedback systems in the vertical plane were implemented. These new systems have become necessary to increase the electron and positron current, the number of colliding bunches and to pass from a filling pattern of one bunch every three buckets, to one every two. This has allowed typical collisions with 800mA of electrons against 700 mA of positrons. In single beam more than 1 Ampere has been stored in each ring.

In Fig. 1 a machine development run with 1015 mA of a stable electron beam is shown.

2 LONGITUDINAL DYNAMICS

The longitudinal dynamics in DAΦNE has to cope with three kinds of effects limiting the maximum stored currents and the luminosity: synchrotron (dipole) oscillations, quadrupole longitudinal oscillations and mode-0 oscillations. Different actions have to be taken to damp or stop these undesired instabilities.

The synchrotron oscillations are rigid movements of every bunch backwards and forwards. In the DAΦNE main rings are damped by a bunch-by-bunch longitudinal feedback described in the next subsection.

The quadrupole internal bunch motion is a kind of oscillation appearing at the double of synchrotron frequency and changing the charge distribution, i.e. the longitudinal bunch shape. It can not be damped by the longitudinal feedback. In DAΦNE this instability is stronger in the electron ring. The ways we cure the instability are following: increasing the momentum compaction, RF voltage variation and appropriate orbit correction (since the impedance depends on the bunch orbit).

The mode-0 oscillations can appear at frequency equal to the synchrotron one or at lower frequencies. The mode frequency decreases for higher currents. The beam gets unstable when the frequency reaches zero. We damp these oscillations by a zero mode feedback that corrects the common mode signal through the main RF cavity.

2.1 Bunch by bunch longitudinal feedback

A longitudinal bunch-by-bunch feedback system has been operating in each DAΦNE main ring since the beginning of the machine commissioning. A large collaboration between laboratories has allowed to test the system first on the Advanced Light Source main ring and then to install it on many other storage rings without modifications [2]. In DAΦNE the very high synchrotron frequency requires the use of one Digital Signal Processor every two bunches. The power stage has been upgraded and now three 250 W amplifiers are installed for each system. High pass filters at 1.5MHz on the input signal have allowed avoiding crosstalk effects with the mode-0 oscillations. Usually FIR (Finite Impulse Response) filters are running in the DSP's but also IIR (Infinite Impulse Response) filters [3] have been tested successfully. The IIR filters show a better rejection to the mode-0 signal and a flatter phase response in the frequency range selected.

2.2 Characteristics and performances

Up to the achieved currents the longitudinal feedback damps the instabilities very well. Turning off for a while the correction signals makes possible to measure the growing and the damping time. The electron beam with a ~500mA current shows the presence of mode 21 with a growing time of 800 μsec, while the feedback gives a damping time of 90 μsec. In the positron ring the same mode 21 shows a growing time of 600 μsec at 214mA, while the feedback shows a damping time of 220 μsec. A correct comparison should be done at the same total currents. Both measurements have been done storing a bunch every two buckets.

3 TRANSVERSE DYNAMICS

One year ago transverse bunch-by-bunch feedback systems working in the vertical plane have been implemented in each ring.

At the beginning of commissioning this systems was considered not strictly necessary. Moving toward more populated filling patterns and increasing the stored currents, the need of a vertical system became clear. In the present situation during collisions a horizontal feedback is not mandatory, but the installation is foreseen in the next future.

3.1 Vertical bunch-by-bunch feedback

The vertical feedback is designed completely at Frascati, but similar systems are well known, see as an example the PEP-II transverse feedback [4].

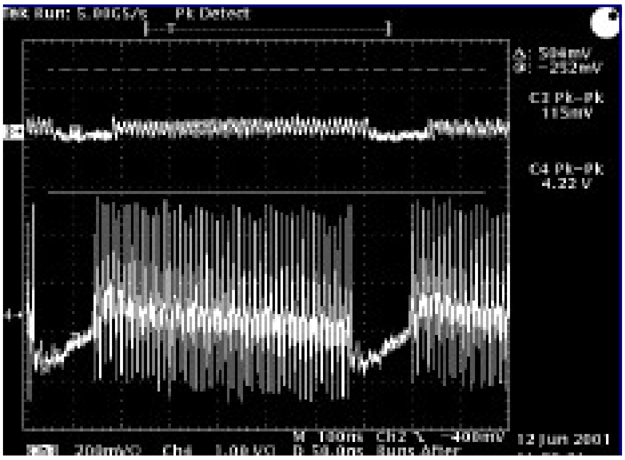

Figure 2: E- correction signal and stripline output at 750mA.

The DAΦNE vertical feedback system allows to select offline a suitable beam position monitor in order to assure the 90 degrees phase advance between monitor and kicker.

An operative comparison between a baseband front end receiver and another working at 4*RF has made to prefer the first system for a smaller crosstalk between adjacent bunches.

An 8 bits analog-to-digital converter samples at the radiofrequency (368MHz) the input received signal without discarding any samples. The digital signal can be inverted or put at zero. The beam position offset gives a spurious input signal that has to be minimized by a local bump in the orbit. An improvement in the offset management is on the way, by adding to the feedback system a digital bunch by bunch offset corrector. A digital-to-analog converter produces a bunch by bunch correction signal that is sent to the power stage. The sampler timing is done digitally phasing the RF clock, while in the back end a programmable delay line for analog signals is used. The power stage is composed by two 250W amplifiers for each ring. In Fig.2 it is plotted the correction signal and the stripline output for an electron beam of 750mA with 49 over 60 bunches.

3.2 Characteristics and performances

The analysis of the correction signal of the vertical instability has shown that the oscillation is stronger toward the end of the bunch train as shown in Fig. 3. This is true for both beams.

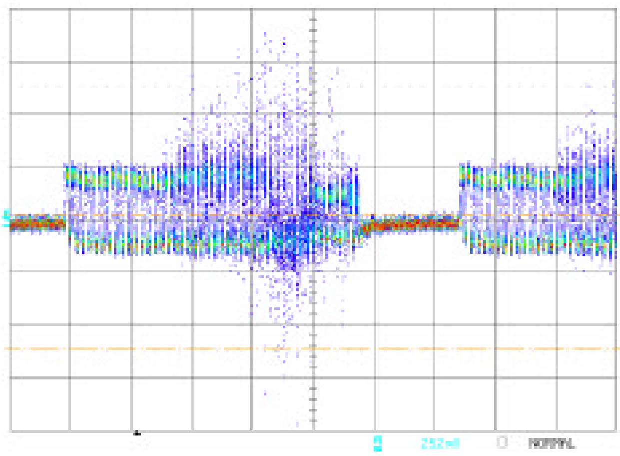

Figure 3: E+ correction signal with 45/60 bunches (~400mA)

The analysis shows also a frequency spread of 20KHz in the betatron oscillation on both beams, while the electron beam requires a feedback gain at least 3dB higher than positron. In both rings the instability threshold is proportional to the distance between contiguous bunches (lower threshold for closer bunch pattern). For example with 45/60 bunches and feedback off the vertical instability in the e- ring starts at ~100mA, while in the case with 32/40 bunches it starts at ~300mA.

In both rings the unstable mode is 100 or 101 which seems related with the longitudinal mode 21 considering that the harmonic number is 120. The growing time of the modes is around 125 μsec at 500mA for the positron beam with 45/60 bunches. The damping time measured of the feedback was 83 μsec with the old reduced power of 200 W. A preliminary measurement with the new 500 W power amplifiers evaluates the damping time <40 μsec.

In Fig. 4 it is shown the vertical oscillation in the electron ring with the vertical feedback off, and in the Fig. 5 the same situation after the feedback turning on. The beam current is ~400mA with 45/60 bunches.

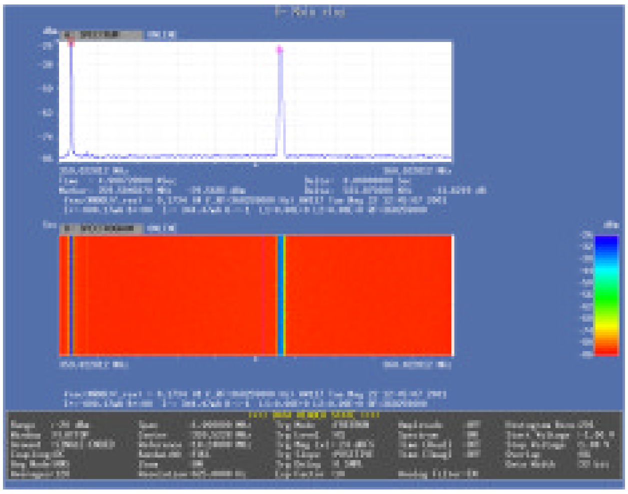

Figure 4: E- beam: vertical oscillation (feedback off)

4 CONCLUSIONS

DAΦNE collider requires powerful feedback systems to achieve the high stored currents needed to reach the high luminosity. At present the longitudinal and the vertical feedback systems are adequate to store more than 1 Ampere in each ring.

In the next future we are considering to double the power amplifiers for the longitudinal feedback systems, feeding all the six ports of the "cavity" kicker [5] (now only three ports are fed).

For horizontal transverse instabilities we are preparing a system identical to the vertical feedback: pickups, kickers [6] and cables are already installed and the electronics is ready. Two 100 Watts amplifiers for each ring are installed. We have to tune the betatron phase advance between monitor and kicker, some optics modifications could be necessary to make the system operative.

For the vertical feedback we have planned to improve the management of the beam position offset, upgrading the feedback system with a digital bunch by bunch offset corrector now in fabrication at the Frascati laboratory.

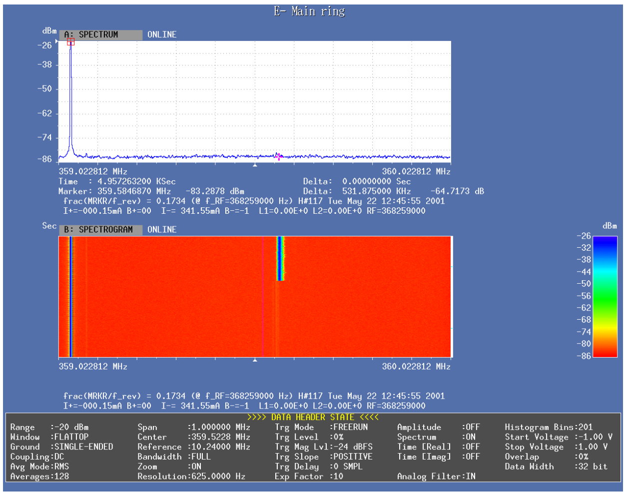

Figure 5: E- beam: no vertical oscillation (feedback on)

5 ACKNOWLEDGEMENTS

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