EXPERIMENTAL OBSERVATIONS AND E-CLOUD SIMULATIONS AT DAΦNE

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Abstract

At the design stage of the DAΦNE e^+e^- collider, preliminary simulations predicted significant e-cloud induced beam instabilities in the positron ring for the design machine parameters. Such calculations were not refined to simulate e-cloud instabilities using more realistic parameters (i.e. chamber geometry, measured secondary emission yield (SEY), photon reflectivity and actual beam conditions). DAΦNE has been routinely operated with more than 1A of circulating positron current, without clear evidence of the predicted e-cloud limitations. We describe some experimental observations and report the preliminary simulation results of the e-cloud build-up evaluation, obtained with the more recently developed computer codes. In this framework, the role played by the approximations used to describe the machine geometry and the material behaviour is discussed.

INTRODUCTION

DAΦNE is an electron-positron collider with 1.02 GeV centre of mass energy (Φ-factory). For each circulating beam the maximum design current value is 5 A over 120 bunches, at an average dynamic pressure of 1 nTorr; up to now the maximum achieved current value is about 2A for the electron beam and 1.3 A for the positron one. Since the early commissioning preliminary simulations have predicted severe e-cloud induced beam instabilities in the positron ring for the design parameters. Such calculations did not include the use of realistic parameters (i.e. chamber geometry, measured SEY and actual beam conditions), DAΦNE has nevertheless been routinely operated with more than 1A of circulating positron current, without clear evidence of the predicted e-cloud limitations. The design value for the maximum beam current has not been reached yet and the more recently developed computer codes can be used to simulate the e-cloud build-up in the DAΦNE machine and can be benchmarked against the observed behaviour to extrapolate it to higher current. It is worth to be noticed that, due the symmetry of the electron and positron ring, the DAΦNE machine offers a reliable tool for the comparison of the observations performed on the two beams. In the following section we present a brief description of the collider and a sketch of the Main Rings vacuum chamber. Next an overview of the machine achievements is given together with the beam parameters for the different colliding configurations. Experimental observations are also reported, together with the very preliminary results of the e-cloud build-up simulations.

THE DAΦNE Φ-FACTORY

The accelerator complex of the DAΦNE Φ-factory consists of a double ring collider, a linear accelerator (LINAC), an intermediate damping ring, and about 180 m of transfer lines connecting these machines [1]. The collider consists of two symmetric main rings, about 100 m long, laying in the same horizontal plane, sharing two Interaction Regions (IR), in which the e^-/e^+ beams cross at a small tunable angle of ± 12.5 mrad, see Fig. 1. Two experiments can be installed in the IRs and share the operation: three detectors have been actually realized so far, KLOE, DEAR and FINUDA [2-4]. KLOE (IR1) and DEAR (IR2) have taken data until December 2002, while FINUDA has been installed in September 2003 in the IR previously occupied by DEAR (IR2). For the momentum analysis of the decay particles the detectors of KLOE (IR1) and FINUDA (IR2) are surrounded by large superconducting solenoid magnets, whose length is about 4 m and 2.2 m, respectively, the magnetic field value being about 0.5 T for KLOE and 1.1 T for FINUDA, with about the same integrated B field.

The DAΦNE Main Ring Vacuum Chamber

The Main Ring vacuum chamber is designed in such a way that most of the Synchrotron Radiation that is emitted in the four arcs is stopped in the antechambers by water-cooled copper absorber. Each arc is a one-piece

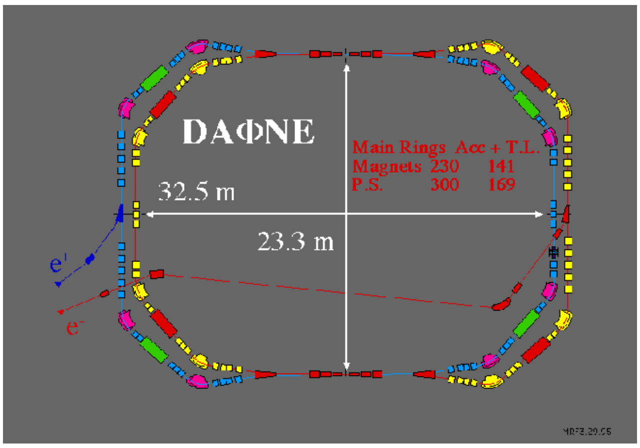

Figure 1: DAΦNE collider schematic layout.

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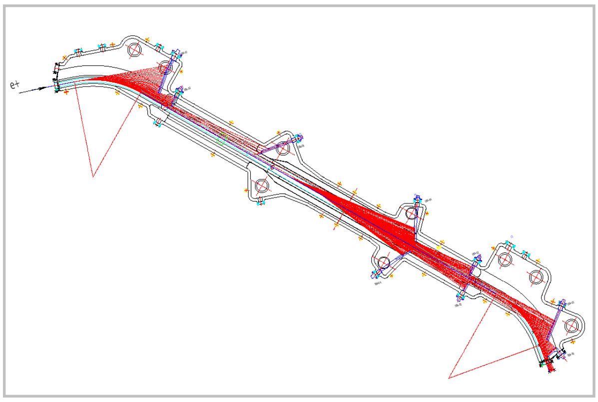

Figure 2: The DAΦNE Main Ring arc vacuum chamber (top view). The Synchrotron Radiation distribution is shown in red.

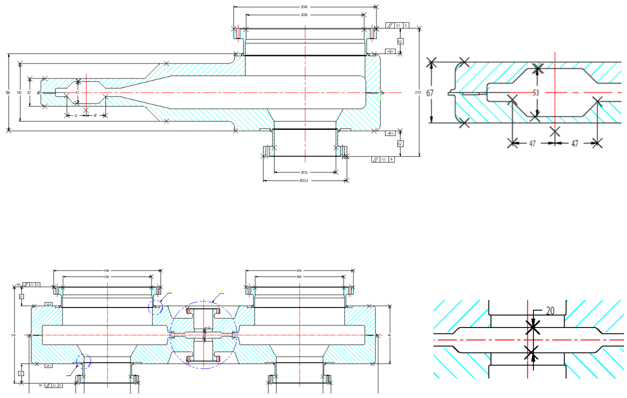

Fig. 3: Arc vacuum chamber cross sections: dipole and wiggler magnets with beam chamber detail (right).

only vacuum chamber, about 10 m long, where two dipoles and a wiggler magnet are embedded, together with three quadrupoles and two sextupoles. A design, similar to ALS, has been adopted for the vacuum vessel inside the arc, consisting of two chambers connected through a narrow slot [5]. The beam circulates in the first chamber, while the synchrotron radiation photons hit a system of copper absorbers located in the second one (antechamber) in such a way that more than 95% of the photon flux is intercepted in the antechamber, see Fig. 2-3. The arc vessel is made by two halves of Al alloy 5083-H321 plates, which, after machining, are welded along the middle plane. The inner surface is mirror finished (roughness = 0.2 Ra). Close to each copper absorber there is a pumping station based on Ti sublimation pump (TSP). In addition, sputter ion pumps are used to pump down CH_4 and noble gases. The total pumping speed installed in each storage ring is ~ 125000 l/s. The straight sections were made by extrusion of the same aluminum alloy, with a round cross section of Ø=88 mm. Four splitter dipoles bend the electron and positron beams nearby the entry/exit of the two interaction regions; the splitter chambers, 1.5 m long, were machined from the same Al alloy, with normal finishing. For the KLOE and FINUDA detectors two beryllium alloy (ALBeMet) vacuum thin chambers are provided, 70 cm and 50 cm long respectively.

The DAΦNE Main Ring Vacuum Chamber

The Main Ring vacuum chamber is designed in such a way that most of the Synchrotron Radiation that is emitted in the four arcs is stopped in the antechambers by water-cooled copper absorber. Each arc is a one-piece only vacuum chamber, about 10 m long, where two dipoles and a wiggler magnet are embedded, together with three quadrupoles and two sextupoles. A design, similar to ALS, has been adopted for the vacuum vessel inside the arc, consisting of two chambers connected

Table1: DAΦNE parameter list for three experiment configurations

		KLOE 2002	DEAR 2002	FINUDA 2003
Beam energy	E (GeV)	.51		
Harmonic number	h	120		
RF frequency	f (MHz)	368.264		
Number of bunches per beam	N_b	49	95	100
Horizontal emittance	ε_x (mm mrad)	.74	.62	.45
Coupling factor	κ	0.003÷0.01	0.003÷0.01	0.003÷0.01
Horizontal beta function at crossing	β_x (m)	2.7	1.7	2.0
Vertical beta function at crossing	β_y (m)	.026	.038	.027
Vertical beam-beam tune shift per crossing	ξ_y	~0.02	~0.016	~0.015
Bunch length (lengthening regime)	σ_z (mm rms)	15÷25	12÷20	10÷20
Maximum stored current e^-/e^+	I_{tot} (A)	1.8/1.1	1.3/1.1	2.0/0.8
Maximum achieved luminosity	L_{peak} ($cm^{-2}s^{-1}$)	0.8 x 10^{32}	0.7 x 10^{32}	0.6 x 10^{32}

through a narrow slot [5]. The beam circulates in the first chamber, while the synchrotron radiation photons hit a system of copper absorbers located in the second one (antechamber) in such a way that more than 95% of the photon flux is intercepted in the antechamber, see Fig. 2-3. The arc vessel is made by two halves of Al alloy 5083-H321 plates, which, after machining, are welded along the middle plane. The inner surface is mirror finished (roughness = 0.2 Ra). Close to each copper absorber there is a pumping station based on Ti sublimation pump (TSP). In addition, sputter ion pumps are used to pump down CH_4 and noble gases. The total pumping speed installed in each storage ring is ~ 125000 l/s. The straight sections were made by extrusion of the same aluminum alloy, with a round cross section of Ø=88 mm. Four splitter dipoles bend the electron and positron beams nearby the entry/exit of the two interaction regions; the splitter chambers, 1.5 m long, were machined from the same Al alloy, with normal finishing. For the KLOE and FINUDA detectors two beryllium alloy (ALBeMet) vacuum thin chambers are provided, 70 cm and 50 cm long respectively.

The DAΦNE Operation

From November 1999 to October 2002 the DAΦNE operation has been devoted to the KLOE experiment (IR1). In three years the peak luminosity steadily increased reaching a value of about $L_{peak} \approx 0.8\text{x}10^{32}$ $cm^{-2}s^{-1}$ in 2002 (KLOE), with 5 pb^{-1}/day of integrated luminosity. The last four months of 2002 were dedicated to the DEAR (IR2) data taking and a maximum value of $L_{peak} \approx 0.7\text{x}10^{32}$ $cm^{-2}s^{-1}$ was reached, with 2.2 pb^{-1}/day integrated luminosity [6]. After a six-months shutdown for the FINUDA detector installation (IR2), the FINUDA data taking took place until March 2004 and the best peak value was $L_{peak} \approx 0.6\text{x}10^{32}$ $cm^{-2}s^{-1}$, with 3.5 pb^{-1}/day integrated luminosity [7]. The KLOE experiment is presently running (April 2004) with dedicated machine operation. In Table 1 the main parameters are reported for the three experimental configurations.

EXPERIMENTAL OBSERVATIONS

At the end of 2003, during the FINUDA experiment operation, the maximum current we could store in the positron ring was significantly lower (0.6÷0.8 A) than the one obtained in the previous KLOE and DEAR data taking. To investigate the positron beam behaviour we performed "grow-damp" measurement of the transverse instability observed on the positron beam when the current limit was reached. A transverse, vertical and horizontal, bunch-by-bunch feedback system (V-HFB) has been implemented in each DAΦNE ring in 2001-2002, besides the broadband bunch-by-bunch Longitudinal Feedback (LFB) operating since 1998 [8,9]. The analysis of the feedback input signal, namely the bunch-by bunch beam position offset, was performed switching on and off the horizontal feedback. The circulating beam current was I~500 mA, and the

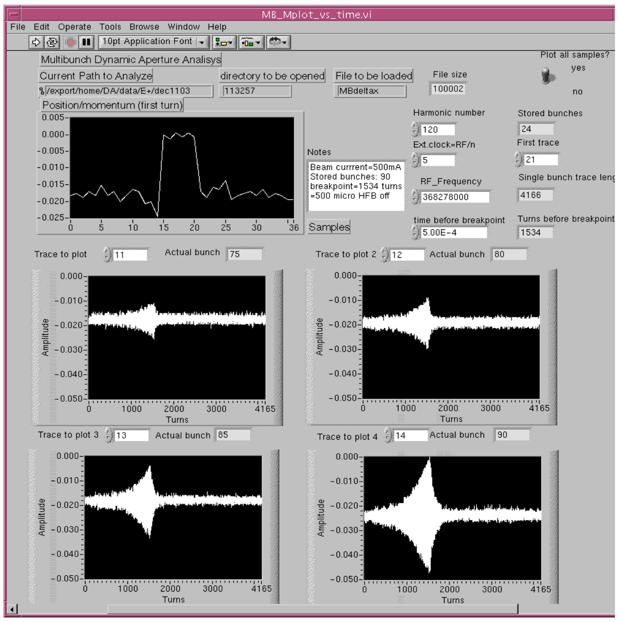

Figure 4: The bunch-by-bunch beam position offset, namely the positron HFB input signal, reported as function of the turn number for four different bunches along the train, (four lower pictures), namely #75-#80-#85-#90, with a 500 µs off-time of the HFB itself.

horizontal feedback, HFB, off time was 500 µs, during which the horizontal oscillation amplitude grows, as a function of turn number as shown in Fig. 4, with a growth time of about 70 µs for I≈500 mA and 35 µs at I≈535 mA. F. Zimmermann et al predicted a similar behaviour in presence of e-cloud build-up [10]. A comparison between different bunch filling patterns was performed and the results are shown in Fig. 5, where a vacuum gauge reading and the positron current value are reported for the cases with 90 and with 45 filled bunches (same gap), namely with the bunch spacing one the half

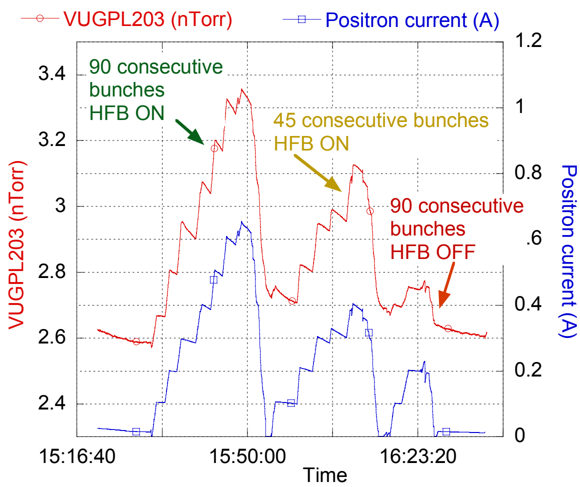

Figure 5: Total positron current and VUGPL203 vacuum gauge reading plotted as a function of time for the patterns of 90 and 45 filled bunches (same gap), with 80 cm and 160 cm of bunch spacing respectively. The third peak corresponds to the HFB off case.

of the other, and for HFB switched off. It can be seen that with the double bunch spacing the maximum stored current is slightly more than one half, while the case with HFB OFF shows a current threshold due the transverse instability. Looking at the vacuum gauge reading, plotted vs. the positron current, Fig. 6, it seems that the two different filling patterns do not significantly affect the slope of the pressure reading. For the 90 bunches configuration we also measured the tune shift of both

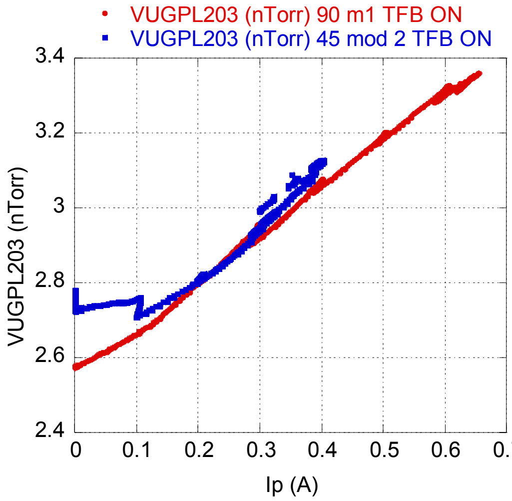

Fig 6: The same vacuum gauge reading of the previous figure plotted vs the total positron current for the two different bunch spacing cases.

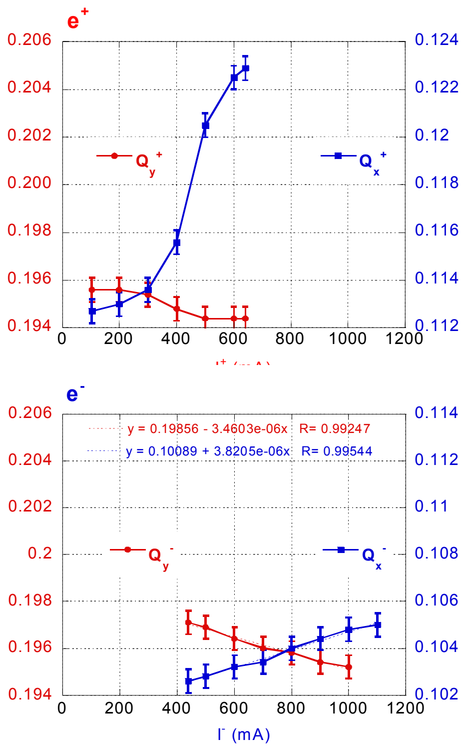

Figure 7: The horizontal and vertical tune shift plotted as a function of the total current for positrons (above) and electrons (below).

positron and electron beam as a function of the total current; the results are shown in Fig. 7. There is a clear difference of the horizontal tune, Q_x, behaviour for the two beams. For the electrons the slope of the current induced tune shift is equal (opposite sign) for the two planes, while for the positrons the growth of the horizontal tune is clearly steeper than the vertical one. The electron beam behaviour can be related to the resistive wall effect due to a rectangular vacuum chamber cross section [11]. It is conceivable that an electron cloud may have contributed to the observed horizontal instability and tune shift of the positron beam.

PRELIMINARY SET OF SIMULATION RESULTS

We started a simulation study of the electron cloud build-up using the Ecloud code [12]. The first zones we considered were the second arc dipole, the drift at the arc exit, and the splitter magnet close to the IRs. The second arc dipole was chosen because, due to its location downstream a 2 m long wiggler, in this arc section a higher photon flux hits the edges of the antechamber slot. The drift at the exit of the arc, (Ø=88 mm cross section), receives about 9 degrees of the synchrotron radiation emitted by the upstream dipole, not intercepted by the slot. Finally the splitter magnet is a bending section, with a curvature radius ten times lower than the arc dipoles, but where no antechamber is provided. The simulation parameter list is reported in Table 2, and the preliminary simulation results are shown in Fig. 8-10. Only the results with a 50 % reflectivity are here reported, (for the 15% reflectivity case the obtained photoelectron density is about one half); in the meantime an experimental activity is foreseen to measure the actual Al 5083 photon reflectivity. Two different values of the maximum secondary emission yield (SEY) were considered as

Table 2: Ecloud simulation parameter list

Bunch population	N_b	$3.4 x 10^9$
Number of bunches	n_b	90
Missing bunches	N_{gap}	30
Bunch spacing	L_{sep}	.8 m
rms bunch length	σ_z	1.1 cm
rms horizontal size	σ_x	1÷2.5 mm
rms vertical size	σ_y	0.1÷0.25 mm
Max sec. emission yield SEY	δ_{max}	1.5÷1.9
Energy at max at SEY	ε_{max}	250 eV
Al eff. photoelectron yield	y_{eff}	0.1
Vac. chamber hor. aperture	2 h_x	88÷120 mm
Vac. chamber ver. aperture	2 h_y	20÷88 mm
Bending field	B	0÷1.2 T
Primary electron rate	$d\lambda_e/ds$	0.003÷0 .131
Photon reflectivity	R	15-50-80 %
Elastic electron reflection	Cimino-Collins [13]	

indicated. For the elastic electron reflectivity we assume that the results obtained for Cu [13], with the so-called Cimino-Collins low energy distribution, can hold also in Al case. The simulated electron cloud build-up turns out

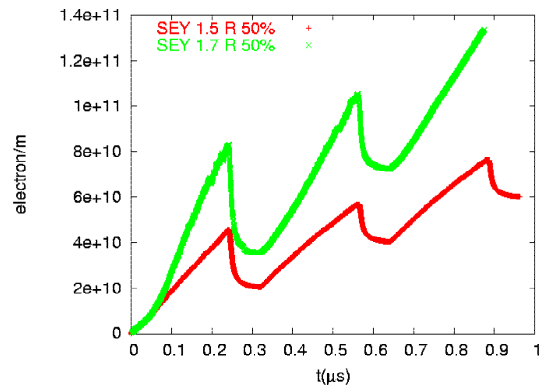

Figure 8: Photoelectron linear density build-up for the drift zone at the arc exit: σ_x~ 2.5 mm, σ_y~ 1.5 mm, vac. chamber aperture Ø= 88 mm. Three complete turns are plotted.

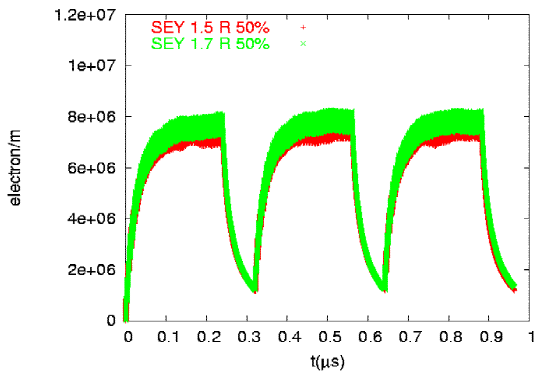

Figure 9: Photoelectron linear density build-up for the downstream arc dipole case: σ_x~ 1.2 mm, σ_y~ 0.7 mm, B≈1.2 T, 2 h_x= 120 mm, 2 h_y= 20 mm. Three turns.

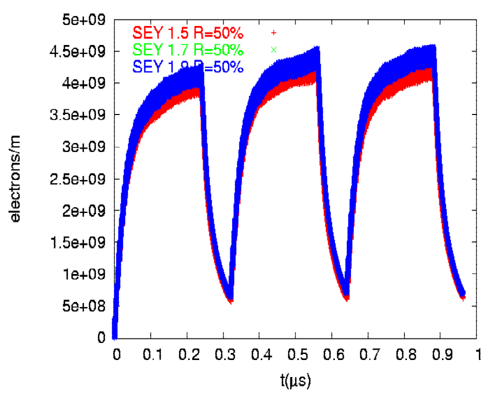

Figure 10: Photoelectron linear density build-up for the splitter dipole case: σ_x~ 2.5 mm, σ_y~ 1.5 mm, B≈0.18 T, 2 h_x= 88 mm, vac. chamber 2 h_y= 54 mm. Three turns.

to be severe especially in the drift chamber where a significant photoelectron density arises even for a total beam current of 150 mA, Fig. 8. Anyway a more detailed analysis will be carried out considering the presence of the fringe field due to the nearby magnetic elements. It has to be noticed that the stray magnetic field plays a relevant role for DAΦNE, due to compactness of the machine and the cross talk between the elements of the two rings, preventing an easy approach to a quantitative study of the electron cloud effect. In the case of the arc dipole and the splitter the photon density obtained is much lower, see Fig. 9 and 10, and the overall effect seems to be confined in the straight sections. A more extensive study is foreseen, based on parameters such as the SEY and the real surface condition of the beam pipe, in order to arrive at a more accurate scenario.

CONCLUSIONS

More than 1A of positron current has been stored up to now in the DAΦNE collider without clear evidence of e-cloud limitations. Nevertheless recent experimental observations encouraged a simulation study that takes advantage of the recently developed codes using more realistic parameters, (chamber geometry, measured secondary emission yield, photon reflectivity and so on). The objective is to predict the observed behaviour and to extrapolate it to higher current, while testing the code's validity. A dedicated laboratory activity is foreseen in the near future to investigate the actual surface parameters, together with a program of measurements on the DAΦNE machine, compatible with the experiments' data taking.

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