The DAΦNE Interaction Regions

S. Guiducci

INFN-LNF, C.P.13, 00044 Frascati (RM), Italy

ABSTRACT

DAΦNE is an e^+e^- Φ-factory under construction at the Frascati National Laboratories. The beams will circulate in a double ring collider and cross, with a small horizontal angle, in two Interaction Points (IPs). A description of the interaction regions design and of the related problems is given.

1. INTRODUCTION

DAΦNE is a double ring e^+e^- collider at the Φ resonance energy (E = 510 MeV). The project status is well advanced and commissioning of the main rings is foreseen for beginning of 1997 [1],[2].

The main objective of the Φ-factory is the measure of CP violation in neutral K decays. To achieve a high accuracy in the measure of the CP-violating quantity ε'/ε it is required a high luminosity ($L=5\ 10^{32} cm^{-2}s^{-1}$) and a very precise experiment.

DAΦNE has two 10m long IRs: one is dedicated to the KLOE detector, mainly to study CP violation [3], and the other will house the FINUDA detector for hypernuclei decays study [4]. A third experiment, DEAR, for exotic nuclear physics [5], will run at an early stage of machine operation in one of the two IRs.

To achieve a high luminosity crossing angle at the IP, low beta and low chromaticity interaction regions are necessary. It is a challenge to match these requirements with those posed by the detectors on the IRs design: large available solid angle and long interaction region free from machine elements, high integrated field solenoid, special vacuum chamber design and low background level. The solutions adopted for DAΦNE [6] are presented here in some details.

2. DESCRIPTION OF THE INTERACTION REGIONS

DAΦNE has four different IR lattices and many different configurations: in fact each experiment can run with another experiment or the day-one IR on the other side. To make compatible all the different configurations we have chosen to design the IR lattices with the same transfer matrix. This is achieved with quite good accuracy and the optical functions of the arcs are nearly the same for all the configurations.

For machine commissioning there will be a special design of the IR (DAY-ONE IR) with electromagnetic quadrupoles to allow tuning of the optical functions and without solenoids to perform a good orbit and coupling correction.

In the DAY-ONE configuration the two IRs, made by seven electromagnetic quadrupoles are equal.

The DEAR experiment has no special IR design but will adopt the DAY-ONE IR once eliminated the central quadrupole situated at the IP, which is used to reduce the chromaticity and make the commissioning easier.

Both KLOE and FINUDA IRs have high integrated field solenoids, small permanent magnet quadrupoles, which fit inside a small angle cone centered at the IP, and a compensating solenoid on each side of the detector to cancel the longitudinal field integral in the IR.

KLOE has three permanent magnet quadrupoles inside a cone of 9° half-aperture and a solenoid 5m long with a maximum field $B_z = .6T$. The free space around the IP is ±.45 m and the solid angle available for the detector is 99%.

FINUDA has two permanent magnets inside the solenoid field and two electromagnetic quadrupoles outside. The solenoid is 2.5 m long with a maximum field $B_z = 1.1$ T.

The optical functions and beams half separation from the IP to the entrance of the splitter magnet are shown in Figs. 1 and 2 for KLOE and FINUDA respectively.

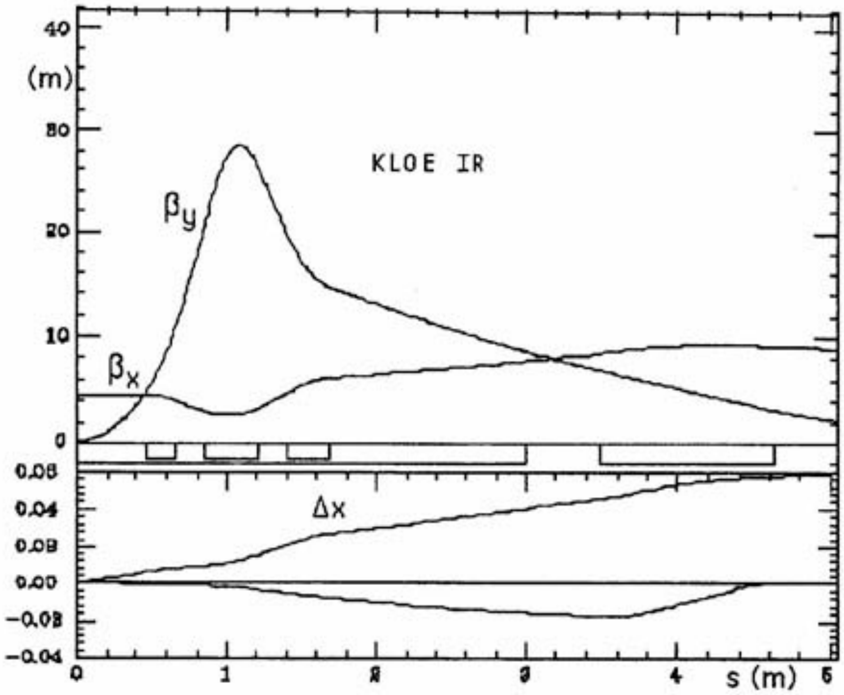

Figure 1 - Optical functions and half separation in half of the KLOE IR.

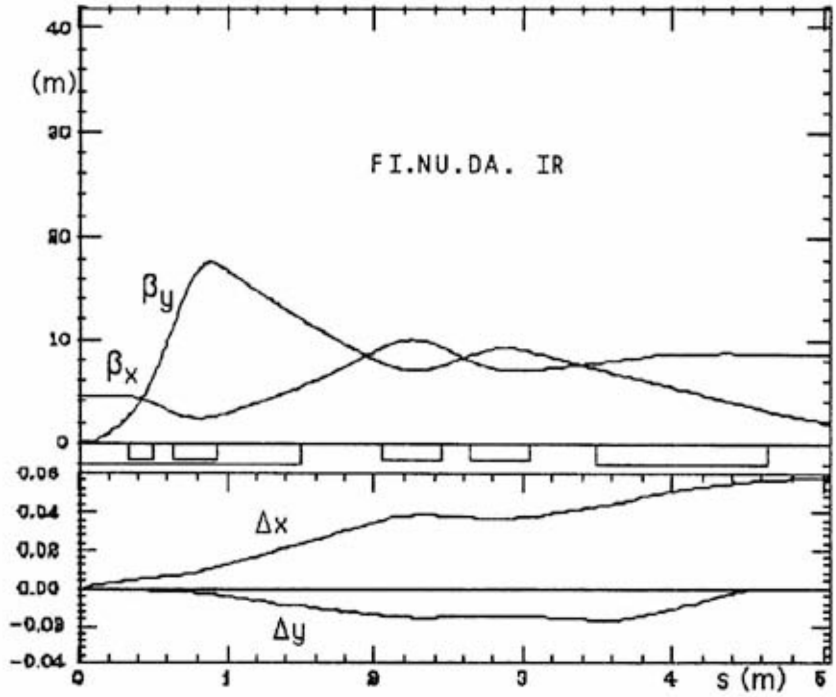

Figure 2 - Optical functions and half separation in half of the FINUDA IR.

Table II - First Parasitic crossings

		KLOE		FINUDA	
N_b	s (m)	$\Delta\nu_y$	d/σ_x	$\Delta\nu_y$	d/σ_x
120	.4	.0014	4.7	.0015	4.7
60	.8	.0023	9.8	.0023	11
40	1.2	.0012	16.9	.0005	17.1
30	1.6	.0002	20.9	.0002	20.8

4. SOLENOID COMPENSATION

At the DAΦNE energy the detector solenoids are a strong perturbation for the machine lattice.

Each solenoid has an integrated field B_z L =2.6T m, which, at E = .51 GeV, rotates the xy plane by an angle α=43.8°.

Moreover the low-β quadrupoles are immersed in the solenoid field and this makes the correction of the coupling effect due to the solenoids more difficult.

A new compensation scheme [6] suggested by Mario Bassetti has been adopted to achieve the low value of the design coupling κ=.01. These scheme is called Rotating Frame Method, RFM in the following. A description of the basic principles of the RFM is given and then its application to the DAΦNE IRs is presented.

To cancel the coupling of the horizontal and vertical betatron phase planes, due to the solenoid, the matrices of half IR on both sides of the IP must be made block diagonal .

The RFM block diagonalizes this matrix without inserting extra elements in the IR apart from the compensating solenoid.

To describe the RFM we consider the simplified structure shown in Fig. 3 made of a detector solenoid, a quadrupole and a compensating solenoid. All the following considerations hold when instead of one quadrupole is inserted a low-β triplet, as it is in real life.

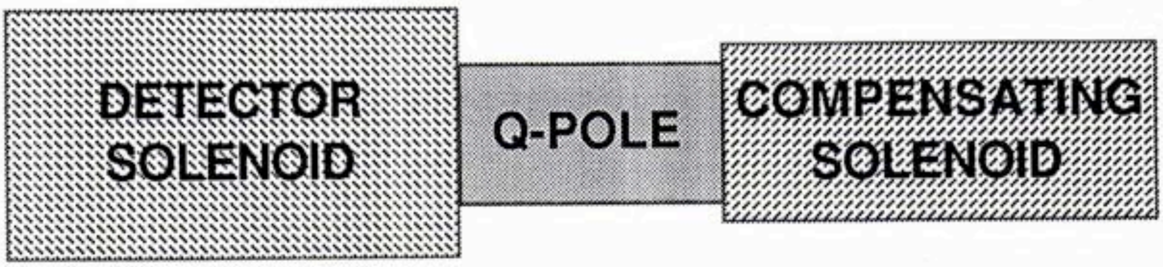

Figure 3 - Simplified scheme of half interaction region.

The matrix P of a uniform solenoid can be expressed as the product of a rotational part R and a focusing part F :

$$P = R(\alpha) \cdot F(\alpha, l)$$

where :

$$\alpha = k_z \cdot l \ ; \ \ k_z = \frac{B_z}{2B\rho},$$

B_z and l are the field and length of the solenoid.

$$R = \begin{pmatrix} I\cos\alpha & I\sin\alpha \\ -I\sin\alpha & I\cos\alpha \end{pmatrix}, \quad I = \begin{pmatrix} 1 & 0 \\ 0 & 1 \end{pmatrix}$$

$$F = \begin{pmatrix} A & 0 \\ 0 & A \end{pmatrix}, \quad A = \begin{pmatrix} \cos\alpha & \frac{1}{k_z}\sin\alpha \\ -k_z\sin\alpha & \cos\alpha \end{pmatrix}$$

The focusing part is block diagonal and the rotational one is responsible of the coupling. The two matrices F and R commute:

$$F \cdot R = R \cdot F$$

The transfer matrix M of the structure shown in Fig. 3 is not block diagonal due to the coupling effect of the solenoid. As an example of the RFM we show how it can be made block diagonal. We indicate with P_D and P_C respectively the matrix of the detector and compensating solenoid, which have equal and opposite rotation angle in order to get zero longitudinal field integral at the end of the structure; Q is the quadrupole matrix. The total matrix M can be written as:

$$M = P_C \cdot Q \cdot P_D = F_C \cdot R(-\alpha) \cdot Q \cdot F_D \cdot R(\alpha) =$$

$$F_C \cdot R(-\alpha) \cdot Q \cdot R(\alpha) \cdot F_D$$

where F_D, Q and F_C are block diagonal.

If the quadrupole is rotated by the angle α its matrix is replaced by Qr:

$$Q_r = R(\alpha) \cdot Q \cdot R(-\alpha)$$

and the total matrix M becomes block diagonal:

$$M = F_C \cdot Q \cdot F_D.$$

The rules of the RFM are two:

- The total rotating angle must vanish:

$$\int_{IR} B_z dz = 0$$

- each quadrupole must be rotated by the angle:

$$\alpha(z) = \int_0^z k_z dz$$

i.e. the rotation angle of the solenoid from the IP to the quadrupole longitudinal position.

The RFM cannot be applied exactly to the DAΦNE IRs because the low-β quadrupoles are immersed in the solenoid field. To satisfy the above relation the quadrupoles should be rotated continuously as an helix.

In practice each quadrupole is rotated by the angle corresponding to its midpoint.

To calculate the transfer matrix the quadrupoles immersed in the longitudinal field are modeled by alternating thin lenses and solenoid slices. The half IR matrix obtained exhibits a small residual coupling that can be made vanishing by adjusting four parameters:

- three independent supplementary rotations of the quadrupoles $\delta\alpha_i$
- a correction of the compensating solenoid rotation angle $\delta\alpha_C$.

In Table III the rotation angles needed to correct the coupling in the KLOE and FINUDA IRs respectively are shown.

Table III - Rotation angles used to correct the coupling in the IRs

	KLOE		FINUDA	
Elements	α	δα	α	δα
Q1	+5.58°	+0.29°	+7.84°	+1.31°
Q2	+10.28°	-0.02°	+14.50°	-0.48°
Q3	+15.20°	-0.27°	+22.10°	-0.16°
Q4	-	-	+22.10°	-0.16°
Compensating	-21.22°	+0.34°	-22.10°	+0.66°

The corrections respect to the simple RFM scheme are very small. Some small skew quadrupoles are installed in the ring to correct the coupling due to alignment and field errors out of the interaction regions.

5. DETECTOR BACKGROUNDS

The different contributions to the DAΦNE single beam lifetime and the related design parameters are listed in Table IV.

Table IV - Single beam lifetime and related parameters

Particles/bunch N	$8.9\ 10^{10}$
Emittance	10^{-6} m rad
Coupling factor	.01
Bunch length	.03 m
Relative energy spread	$5.5\ 10^{-4}$
RF Voltage	254 kV
Gas pressure (biatomic gas Z=8)	10^{-9} Torr
Quantum lifetime	$4.5\ 10^{31}$ hours
Gas bremsstrahlung	$2.0\ 10^{3}$ min
Coulomb gas scattering	$1.9\ 10^{3}$ min
Touschek scattering	160 min
Single beam total lifetime τ	135 min

Due to the high current, the number of particles per bunch lost per second all over the ring is quite large:

$$\dot{N} = \frac{N}{\tau} = 1.1 \cdot 10^7 \, s^{-1} \; / \; bunch \; / \; beam.$$

To evaluate the background rates the fraction of particles lost inside the detectors has been calculated.

Due to the relatively low energy of the machine the Touschek scattering is the main contribution to the background. The synchrotron radiation background is negligible [10], while gas scattering contributions remain below an acceptable level [10],[11] also because special care has been taken in the design of the vacuum system in order to reduce the residual gas pressure in the IRs.

The Touschek scattering is equivalent to an energy change. Each ring is divided in two regions: straight sections, where the dispersion is zero, and arcs where it is high.

The particles which undergo a Touschek scattering in the arcs reach the IR with a large horizontal oscillation amplitude and can be lost on the vacuum chamber.

The number of particles which hit the vacuum chamber has been evaluated by tracking the Touschek scattered particles inside the two IRs[12].

A solution to strongly reduce the background rates has been adopted:

- increase of the vacuum chamber aperture in the IRs
- installation of two beam scrapers upstream the splitter magnet of each IR.

The number of particles per bunch lost per second inside the KLOE and the FINUDA IR, respectively, is shown in Table V for different values of the scrapers' aperture A_{SC}, in units of the horizontal beam size. In the last column the value of the beam lifetime corresponding to the scrapers' aperture is given.

Table V - Particles lost due to Touschek scattering in the KLOE and FINUDA detectors $\dot{N} = 8.9\ 10^{10}$ part./s/bunch/beam $-\ \theta = 12.5$ mrad

A_{SC}/σ_x	$\dot{N}$, KLOE (s^{-1}/bunch/beam)	$\dot{N}$, FINUDA (s^{-1}/bunch/beam)	τ (min)
no scrapers	$1.47\ 10^5$	$1.76\ 10^5$	135.
10	695.	$1.55\ 10^4$	117.
9	0.	$4.10\ 10^3$	101.
8	0.	756.	84.

The vacuum chamber aperture is at least $10\sigma_x$ all over the ring and the corresponding single beam lifetime is two hours. Setting the scrapers' apertures at $10\sigma_x$ gives a drastic reduction of the Touschek scattering background without affecting the beam lifetime.

The number of particles lost in the KLOE IR is nearly zero; in the FINUDA IR it is high but well below the level which is acceptable for the experiment.

The horizontal scrapers help also in reducing the background coming from gas bremsstrahlung in the arcs. A vertical scraper will be installed downstream the splitter magnet in the FINUDA IR to reduce the number of lost particles generated by Coulomb gas scattering.

A preliminary version of the DEAR experiment will be dedicated to background measurements at a very early stage of machine operation. This will be very useful to improve the machine performance for all the experiments by adjusting the machine parameters to get a high average luminosity with low background rates.

REFERENCES

[1] 'DAΦNE the First Φ-Factory', G. Vignola, the DAΦNE project team, Proceedings of 5th European Particle Accelerator Conference, Sitges (Barcelona) 1996.

[2] 'Design and status of DAΦNE: the Frascati Φ-Factory', M.E. Biagini, these proceedings.

[3] 'KLOE, a General Purpose Detector for DAΦNE', KLOE Collaboration, LNF-92/019(IR), Apr. 1992.

[4] 'FINUDA a Detector for Nuclear Physics at DAΦNE', FINUDA Collaboration, LNF-93/021 (IR), May. 1993 .

[5] 'DAΦNE Exotic Atoms Research, the DEAR Proposal', DEAR Collaboration, LNF-95/055(IR), Oct. 1995.

[6] 'DAΦNE Interaction Region Design', M. Bassetti, M.E. Biagini, C. Biscari, M.A. Preger, G. Raffone, G. Vignola, Proceedings of 1993 Particle Accelerator Conference , Washington D.C, p. 2048.

[7] 'Satellite Resonances due to Beam-Beam Interaction', A. Piwinski, IEEE Trans. on Nucl. Sci. NS-24,1408 (1977)

[8] 'On Beam-Beam Limit with a Horizontal Crossing Angle at CESR', D. Rubin, A. Temnykh, Arcidosso 94 (1994)

[9] 'Beam-Beam Interaction study for DAΦNE', K. Hirata, M. Zobov, Proceedings of 5th European Particle Accelerator Conference, Sitges (Barcelona) 1996.

[10] 'Preliminary background calculations for DAΦNE', M. K. Sullivan, DAΦNE technical note IR-2, 1993.

[11] 'Beam-gas background calculations for DAΦNE', E. Gero, KLOE note 102, 1994.

[12] 'Background Calculations for the DAΦNE Experiments', S. Guiducci, Proceedings of 5th European Particle Accelerator Conference, Sitges (Barcelona) 1996.