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THE DAΦNE INTERACTION REGIONS

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ABSTRACT

The DAΦNE Φ-factory has two interaction regions where three experiments (KLOE, FINUDA and DEAR) will be allocated in different time periods. The design of a Φ-factory interaction region is determined by the requirements of very high luminosity and by severe constraints posed by the detectors. The description of the interaction regions design for the three different DAΦNE experiments is given. To evaluate machine background the rates of particles lost in the interaction regions have been calculated for the three detectors. A strong reduction of the machine background is obtained by increasing the vacuum chamber apertures inside the detectors and installing horizontal and vertical beam scrapers.

1. Introduction

DAΦNE is a double ring e^+e^- collider at the Φ resonance energy (E = 510 MeV/beam). The commissioning of the main rings started in September 1997 [1].
The main objective of the Φ-factory is to measure the CP-violating quantity ε'/ε in neutral K decays. To perform this measurement with good accuracy it is required a high luminosity ($L = 5\ 10^{32}\ \mathrm{cm}^{-2}\mathrm{s}^{-1}$) and a very precise detector.
DAΦNE has two 10 m long Interaction Regions (IRs) where the beams, which cross with an angle, travel horizontally separated in the same vacuum chamber [2]. The former, IR1, 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 on IR2 at an early stage of machine operation, before FINUDA installation. The DEAR detector has a small size and does not interfere with machine elements.
To achieve high luminosity DAΦNE is designed to have a large current and many bunches. To allow a small bunch spacing a horizontal crossing angle has been chosen, so that the two beams cross only in two Interaction Points (IPs) and are separated elsewhere in the rings. To keep more flexibility the half crossing angle can be varied between 10 and 15 mrad.

To avoid excitation of synchrobetatron resonances in the beams, without a crab cavity, it is convenient to have a small value for the normalized crossing angle defined as:

$$\phi = \frac{\sigma_l}{\sigma_x}\theta$$

where θ is the horizontal half crossing angle, σ_l and σ_x are the longitudinal and horizontal rms beam sizes respectively.
As a consequence a scheme with flat beams has been adopted. The DAΦNE luminosity parameters are shown in Table I.

Table I: *DAΦNE Design Luminosity Parameters*

Energy (MeV)	510.	L ($cm^{-2} s^{-1}$)	5. 10^{32}
I (A)	5.2	Bunch distance (m)	.81
Revolution Freq. (MHz)	3.07	Max. number of bunches	120
Emittance (m rad)	10^{-6}	Coupling factor	.01
Half cross. angle (mrad)	10÷15	σ_x* (m)	2.1 10^{-3}
β_y* (m)	.045	σ_y* (m)	2.1 10^{-5}
ξ	.04	σ_l (m)	.03

A relatively high value of the vertical beta function at the IP, as compared with other projects, has been chosen to reduce the beta-function at the first parasitic crossing (.41 m from the IP). Anyway the apertures and the lattice flexibility will allow a further reduction to obtain a β_y* value equal to the design bunch length σ_l.
The choice of the IRs vacuum chamber apertures has been object of a careful study. Beam lifetime and background calculations recommend the largest beam stay-clear apertures, but the large solid angle required by the detectors poses stringent constraints on the space available for the low-β quadrupoles. Due to the crossing angle the two beams are separated in the IR vacuum chamber, so requiring a large horizontal aperture. The vertical aperture allows for orbit separation of the beams, in case it is required to operate with only one IP.

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 commissioning IR lattice on the other side. To make compatible all the different configurations the IR lattices have been designed with very similar transfer matrices and can be matched to the arcs with small adjustments of the arc optical functions.

KLOE uses a superconducting solenoid with a field of .6T, 4m long, and requires the maximum free solid angle around the IP. For this reason a solution with permanent magnet low-β quadrupoles inside the detector has been adopted. They are confined inside a 9° cone around the IP and the solid angle available for the detector is 99%. There are three of these quadrupoles on each side of the IP, supported by the detector. They can be rigidly moved with 5 degrees of freedom (displacement and tilt in the x and y plane and rotation around the axis) by means of a cam system. A schematic view of the KLOE IR with the detector is shown in Fig. 1.

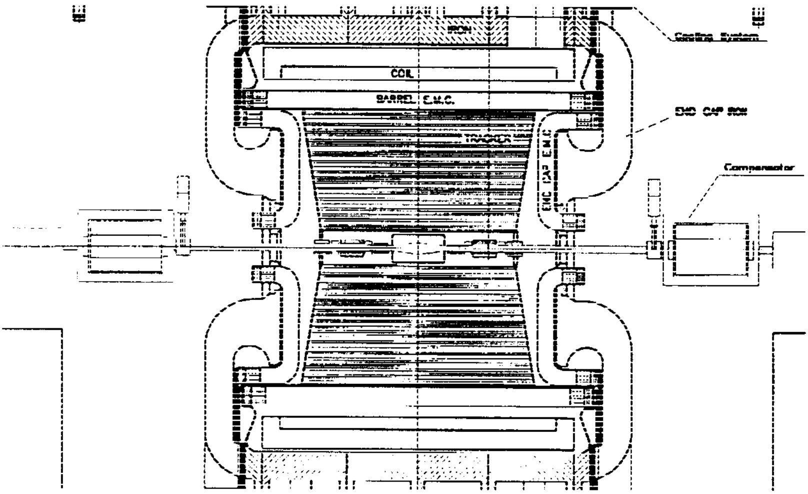

Figure 1: *Schematic view of KLOE IR.*

The beam pipe around the IP has to be as transparent as possible for the outcoming particles, therefore a 500 μm Be pipe will be used. To avoid K^0_S regeneration, it is required that the K^0_S decay before hitting the pipe. Therefore the cylindrical pipe around the IP will be welded to a Be sphere with a 10 cm radius. A cylindrical Be shield 50 mm thick will be welded inside the sphere to assure the electrical continuity of the beam pipe for the beam. An R&D project for the fabrication of this pipe has been issued.

The FINUDA detector has a solenoid with the same integrated field as KLOE but a shorter length. Inside the detector will be installed two permanent magnet quadrupoles on each side of the IP, with a cam system for fine alignment. Other two electromagnetic quadrupoles will be placed outside the detector on each side of the IP.

The field of the KLOE and FINUDA solenoids is a strong perturbation for a 510 MeV beam. To cancel the coupling introduced by the solenoids a new compensation scheme, the Rotating Frame Method proposed by M. Bassetti [6], has been adopted. This scheme requires two superconducting compensating solenoids on both sides of the IR and a rotation of the low-β quadrupoles.

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

The DEAR experiment has no solenoid and does not need a special IR design. It will adopt the DAY-ONE IR configuration, once eliminated the central quadrupole situated at the IP, which is now used to reduce the chromaticity and to make the commissioning easier.

Special diagnostics has been foreseen for the IRs: directional striplines and button monitors with unconventional design to detect the position of each beam in the common chamber. Beam loss monitors and scrapers (upstream the IRs) are used to control beam background.

A single bremsstrahlung luminosity monitor has been placed in each IR. The vertical beam size at the IP is very small and to have a sensitive monitor of the superposition of the two beams it is planned to measure the separation at the IP by means of the beam-beam deflection.

3. Detector Backgrounds

To obtain a high luminosity DAΦNE has been designed with large beam currents (I_{MAX} = 5A per beam). The beam lifetime τ is of the order of two hours. The total rate of particles lost all along the ring is:

$$\dot{N} = \frac{N}{\tau} \cong 10 MHz / bunch$$

where N = 9 10^{10} is the number of particles per bunch and the number of bunches varies from 30, in the initial phase, up to a maximum of 120. To evaluate the machine background rates, the fraction of particles hitting the vacuum chamber inside the detectors has been calculated for the different loss processes.

The beam lifetime is calculated with the parameters given in Table I, assuming a gas pressure p = 10^{-9} torr (biatomic gas, Z=8) and an RF voltage V_{RF} = 250KV. The different contributions to the single beam lifetime are shown in Table II.

Table II: *Single Beam Lifetime (biatomic gas Z = 8, p = 10^{-9} torr)*

Quantum lifetime	$4.5 \cdot 10^{31}$ hours
Gas bremsstrahlung	$2.0 \cdot 10^{3}$ min
Coulomb gas scattering	$1.9 \cdot 10^{3}$ min
Touschek scattering	160 min
Single beam total lifetime	135 min

The background calculations for DAΦNE have been initiated by M. Sullivan [7] who evaluated the synchrotron radiation effects and installed DECAY-TURTLE [8] giving the first estimate of beam-gas interactions. The synchrotron radiation background is negligible for DAΦNE due to the low beam energy and the large bending radius of the splitter, the nearest magnet to the IR.

Due to the relatively low energy of the machine the Touschek scattering is the main contribution to the beam lifetime. Its effect on machine background will be described in the next Section.

An evaluation of the rates of particle losses due to beam-gas interaction has been done for KLOE [9,10,11] and DEAR [12] using DECAY-TURTLE. The rates and distributions of particles lost inside the detector have been used by the KLOE group in the Monte Carlo to evaluate the machine background and its influence on the trigger system performances.

The IRs vacuum system is specially designed to get a low local gas pressure and reduce the gas scattering background.

DEAR will run in the initial period of machine operation, when a higher value of the residual gas pressure in the vacuum chamber is expected. The beam gas background calculations for DEAR will be described in more detail in Section 3.2.

3.1. Touschek Scattering Background

Touschek scattering is an elastic Coulomb scattering between pairs of particles within a bunch. One particle loses and the other gains the same fraction of energy δ.

The particles scattered at the azimuth s_i with horizontal dispersion D_i, start to oscillate around an orbit displaced by $\delta D(s)$ with a maximum horizontal amplitude:

$$\hat{x}_\beta(s) = \delta\sqrt{H_i \beta(s)}$$

where:

$$H_i = \gamma_i D_i^2 + 2\alpha_i D_i D'_i + \beta_i D'^2_i$$

is the invariant quantity which appears in the emittance calculation.

The particles scattered where H is small are lost when δ exceeds the RF acceptance, and have a negligible probability to be lost in the IRs, where $D(s)$ is nearly zero.

The particles scattered in the arcs (between the two dipoles), where H is high, are lost when $\hat{x}_\beta$ exceeds the vacuum chamber aperture and have a high probability to be lost inside the IRs, producing background for the experiments.

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

To strongly reduce the machine background rates it has been chosen to increase the vacuum chamber aperture inside the detectors and to install two horizontal beam scrapers upstream the splitter magnets of each IR.

The scrapers can be inserted independently on both sides of the vacuum chamber reducing the aperture to cut the large amplitude particles upstream the IR. They are 3.5 cm thick tungsten targets, corresponding to nearly ten radiation lengths and covered by a special copper-beryllium shield to taper the discontinuity and reduce the vacuum chamber impedance for the beam.

The horizontal scrapers help also in reducing the background coming from gas bremsstrahlung in the arcs. Moreover a vertical scraper will be installed in each ring to reduce the number of lost particles generated by Coulomb gas scattering.

The rates of particles lost on the vacuum chamber due to Touschek scattering, calculated for KLOE, FINUDA and DEAR [13], are shown in Tables III as a function of the scrapers aperture. When the scrapers aperture is reduced, the beam lifetime decreases as shown in the last column. For each experiment the scrapers aperture has to be adjusted to obtain a low machine background in the detector together with the optimum beam lifetime.

Table III: *Rates of Touschek scattered particles hitting the vacuum chamber inside the detectors* - $N=9\cdot 10^{10}$ *part/bunch;* $\theta = 12.5$ *mrad*

A_{SC}/σ_x	KLOE	FINUDA	τ_{tot} (min) K & F	$\dot{N}$ (s^{-1}/bunch) DEAR	τ_{tot} (min) DEAR
no scrap.	$1.47\ 10^5$	$1.76\ 10^5$	135.	$8.77\ 10^4$	97
10	695.	$1.55\ 10^4$	117.	$7.45\ 10^3$	96
9	0.	$4.1\ 10^3$	101.	725.	90
8	0.	756.	84.	35.	77

For KLOE and FINUDA the rates of lost particles have been calculated for the vacuum chamber region covered by the detector. Due to the horizontal crossing angle, the layout of the machine is not symmetric with respect to the IP: in the KLOE IR the beams come from the external (LONG) ring, while in the FINUDA IR they come from the internal (SHORT) one. Therefore the effect of the scrapers is different for the two IRs, in particular they are more efficient for KLOE. Anyway the FINUDA detector is less sensitive to the background and can accept a higher rate.

The DEAR target is placed 10 cm above the vacuum chamber and extends for a small region (15 cm) around the IP. The rate of lost particles has been calculated in the region between the two quadrupoles next to the IP. Only the particles with $\delta < 0$ are given in the table because they are lost in the quadrupole before the IP, and are the main source of background, while those with $\delta > 0$ are lost in the quadrupole after the IP and can be neglected. The different beam lifetime for DEAR is due to the different lattice.

3.2. Beam-Gas Background in DEAR

The beam-gas interaction is the main source of background for DEAR, because in the initial stage of machine operation the synchrotron radiation produces desorption of gas molecules from the vacuum chamber and gives a high residual gas pressure.

The DEAR experiment uses a CCD as soft X-ray detector. The pixels are read and cleared with an appropriate time interval: CCD's cannot tolerate more than 5% of the pixels hit by background particles. The evaluation of the background rate is then particularly important to determine the operating conditions for the detector.

A preliminary version of the DEAR experiment will be dedicated to background measurements at an early stage of machine operation. This will allow to tune the machine parameters to achieve the highest average luminosity at low background rates.

Using DECAY-TURTLE the rates of particles which hit the vacuum chamber after beam-gas interaction have been calculated [12]. The simulation has been done for the entire ring and for IR2 in the DEAR configuration, with a half crossing angle $\theta = 12.5$ mrad and a scrapers aperture $A_{SC} = 9\sigma_x$.

The region of the IR near the IP is divided into 9 segments (A to I), as shown in Fig. 2, to get the longitudinal distribution of the lost particles, which is required as an input for the DEAR Monte Carlo to evaluate the background level on the detector. Regions F and G are just below the DEAR target.

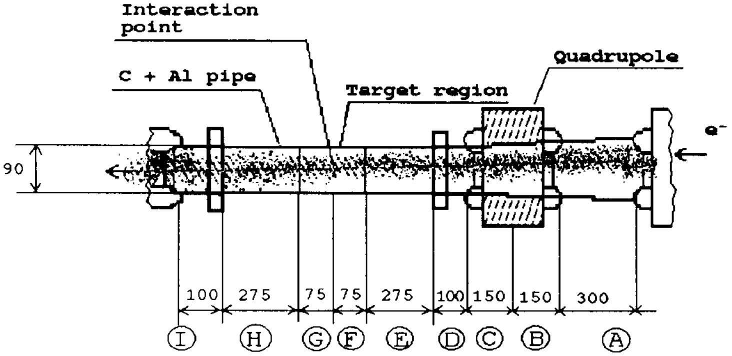

Figure 2: *Segments of the DEAR IR considered in the simulation (sizes in millimeters).*

Table IV: *Normalized rates of lost particles after 1000 Ah of beam conditioning. (30 bunches - $9 \cdot 10^{10}$ part/bunch)*

Losses	**A** (KHz)	**B** (KHz)	**C** (KHz)	**D** (KHz)	**E** (KHz)	**F** (KHz)	**G** (KHz)	**H** (KHz)	**I** (KHz)
C.S.el	41.3	8.7	6.1	3.57	10.9	3.78	5.9	31.5	16.2
H.Br.el	6.79	2.02	1.1	0.55	1.66	0.53	0.53	2.2	0.89
H.Br.ph	.225	0.06	0.07	0.04	0.1	0.03	0.03	0.12	0.05

The rates of lost particles in the different segments of IR2, normalized with the local gas pressure for a total current $I_{tot} \approx 1$ A, after 1000 Ah of vacuum chamber conditioning with beam, are shown in Table IV for Coulomb scattering and hard bremsstrahlung electrons and photons. The contribution of Hard Bremsstrahlung photons is negligible and that of Hard Bremsstrahlung electrons is small because it comes mainly from the IR itself. In fact Hard Bremsstrahlung electrons, having a large momentum deviation, are quickly lost after passing through a bending magnet. The major contribution to the total rate comes from Coulomb scattering.

4. Conclusions

The DAΦNE design is based on many bunches, i.e. large currents, horizontal crossing angle and flat beams. The requirements posed by the high luminosity and by detector constraints have been satisfied by using small permanent magnet quadrupoles inside the detector solenoids and two superconducting compensating solenoids on each side of the IR.

The background rates calculated for the three experiments have been strongly reduced by increasing the aperture of the IR quadrupoles and inserting two horizontal beam scrapers and a vertical one, for each ring, in order to cut the large amplitude particles.

Background measurements will be performed at the beginning of DAΦNE operation by the DEAR group using a dedicated target.

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