DAΦNE Φ-FACTORY UPGRADE FOR SIDDHARTA RUN

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Abstract

An upgrade of the DAΦNE Φ-Factory [1] at LNF is planned in view of the installation of the Siddharta detector [2] in fall 2007. A new Interaction Region suitable to test the large Piwinski angle and *crab waist* (CW) collision schemes will be installed. Other machine improvements, such as new injection kickers, bellows and beam pipe layouts will be realized, with the goal of reaching luminosity of the order of 10^{33}/cm^2/s. The principle of operation of the new scheme, together with hardware designs and simulation studies, are presented.

DAΦNE PERFORMANCES

DAΦNE is an electron-positron collider working at the c.m. energy of the Φ resonance (1.02 GeV) to produce a high rate of K mesons. The collider complex consists of two independent rings having two common Interaction Regions (IR) and an injection system composed of a full energy linear accelerator, a damping/accumulator ring and transfer lines. Since 2000 DAΦNE has been delivering luminosity to three experiments, KLOE [3], FINUDA [4] and DEAR [5] steadily improving performances in terms of luminosity, lifetime and backgrounds. The DEAR experiment was performed in less than 5 months in 2002-2003, collecting about 100 pb^{-1}, with a peak luminosity of 0.7x10^{32} cm^{-2}s^{-1}. The KLOE experimental program has been completed in year 2006, acquiring more than 2 fb^{-1} on the peak of the Φ resonance, more than 0.25 fb^{-1} off-resonance and performing a high statistics resonance scan. The best peak luminosity obtained during this run was 1.5x10^{32} cm^{-2}s^{-1}, with a maximum daily integrated luminosity of about 10 pb^{-1}. In April 2006 started the second run of FINUDA [6], which collected 0.96 fb^{-1}. During this run a peak luminosity of 1.6x10^{32} cm^{-2}s^{-1} has been achieved, while a maximum daily integrated luminosity similar to that in the KLOE run has been obtained with lower beam currents, lower number of bunches and higher beta functions at the collision point. Fig.1 shows the daily peak luminosity for KLOE, DEAR and FINUDA runs. In fall 2007 a new setup will be installed for the Siddharta experiment, and a test of the new CW collision scheme will be performed. Beam-beam, backgrounds and dynamic aperture studies have been performed, showing the possibility of very good luminosity performances.

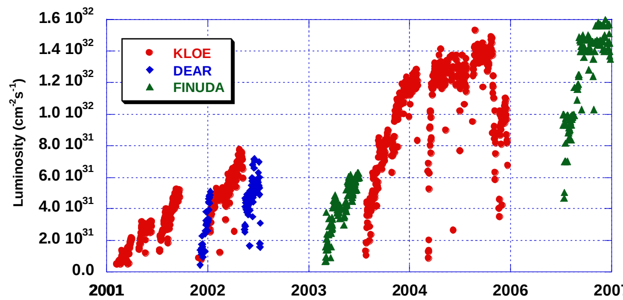

Figure 1: DAΦNE peak luminosity for KLOE (red), DEAR (blue) and FINUDA (green).

A NEW COLLISION REGIME

One of the key requirements in high luminosity colliders is a very small β_y^* at the IP. However, β_y^* cannot be much smaller than the bunch length without incurring in a “hourglass" effect, and this sets a stringent requirement on the bunch length σ_z. Indeed it is very difficult to shorten σ_z in a high current ring, as proposed in standard upgrade plans for Factories, without the problems of HOM heating, coherent synchrotron radiation, excessive power consumption and instabilities. The recently proposed CW scheme for collisions holds the promise of increasing the luminosity of storage-ring colliders by more than two orders of magnitude beyond the current state-of-the-art, without any significant increase in beam current and without reducing the bunch length. Moreover parasitic collisions (PC) become negligible because of the higher crossing angle and smaller horizontal beam size, which makes the beam separation at the PC large in terms of σ_x.

The main features of the CW scheme can be summarized as:

1. use of a large Piwinski angle, to decrease the length of the overlap area;
2. smaller β_y^* (of the same order of the length of the overlap area): this is the main source of the luminosity increase;
3. CW sextupoles to suppress the synchro-betatron resonances arising from the large crossing angle, which allow for significant ξ_y and luminosity increase, and avoiding vertical beam-beam blow-up.

A more detailed description of the principle can be found in [7, 8] this Conference.

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The DAΦNE upgrade beam parameters are listed in Table 1: those corresponding to the KLOE run in 2006 are shown in parenthesis. With this new scheme it will be possible to reach a luminosity of the order of 10^{33} cm^{-2} s^{-1}, with very little modifications of the machine and beam currents similar to the already operational ones.

Table 1: DAΦNE Upgrade Beam Parameters

β_x^*(m)	0.2 (1.7)	**β_y^* (cm)**	0.65 (1.7)
σ_x (mm)	0.2 (0.7)	**σ_y (μm)**	2.6 (7)
ε_x (mm.mrad)	0.2 (0.3)	**Coupling**	0.5%
σ_z (mm)	20 (25)	**θ_{cross} (mrad)**	50 (25)
I_{bunch} (mA)	13 (13)	**$N_{bunches}$**	110 (110)
L x10^{32} (cm^{-2} s^{-1})	10 (1.5)	**N_{part}/bunch**	2.65x10^{10}

BEAM-BEAM STUDIES

Beam-beam studies have verified the validity of the CW idea [1, 8]. The effect of the betatron resonances suppression by the CW becomes obvious when looking at the luminosity scan versus betatron tunes. Fig. 2 shows a luminosity scan in the tunes plane performed for DAΦNE in the Siddharta configuration [1]. The scan on the left is with the CW sextupoles, the right one without. The red color corresponds to the maximum luminosity, the blue one to the minimum. With the CW many X-Y betatron resonances disappear or become much weaker, so the good working area is significantly enlarged, and the maximum luminosity is increased: a peak of 2.97x10^{33} cm^{-2} s^{-1} compares with L_{max} = 1.74x10^{33} cm^{-2} s^{-1} without CW.

Moreover in the CW collision a high luminosity can be obtained at the working points presently used at DAΦNE, like (0.09, 0.16). It should be noted that the worst luminosity value obtained in the CW collisions, 2.52x10^{32} cm^{-2} s^{-1}, is still higher than the present best luminosity obtained at DAΦNE.

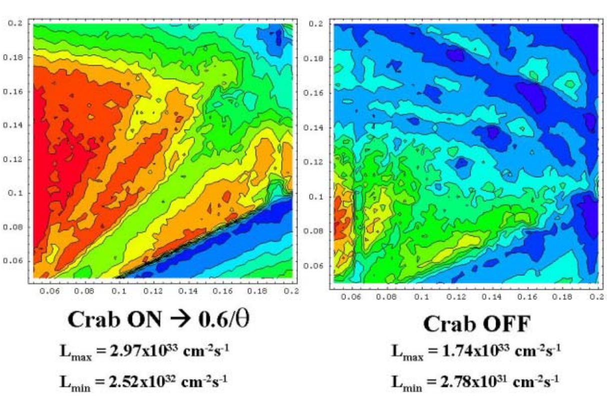

Figure 2: Luminosity vs tunes scan. CW ON, 0.6/θ (left). CW OFF (right).

An important limitation arising from the beam-beam interaction is the lifetime reduction. The beam-beam collisions create non-Gaussian tails in the transverse beam charge distributions. If the tails reach the physical or dynamic aperture the particles get lost, leading to lifetime degradation. In order to simulate the beam-beam induced tails the numerical code LIFETRAC [9] has been used. The CW sextupoles have been inserted in an implicit way, as lattice elements satisfying the CW conditions, i.e. having the required strength and betatron phase advances. Fig. 3 shows the beam distribution contour plots in the space of the normalized transverse amplitudes A_x/σ_x and A_y/σ_y. For all the plots the maximum horizontal amplitude A_x is 12σ_x and the vertical one 160σ_y. The successive contour levels are at a constant ratio of $e^{1/2}$ between each other. Each column contains plots for different strengths of the crabbing sextupoles K: K = 1 means the exact crabbed waist condition, for K = 0 the crabbing sextupoles are off.

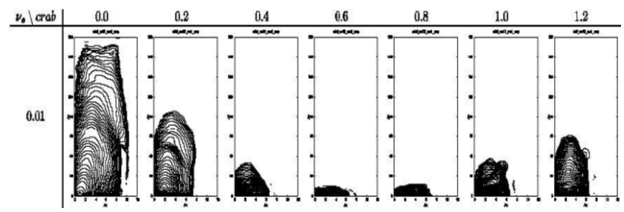

Figure 3: Distribution tails vs crabbing sextupole intensity.

A peak luminosity of about 3x10^{33} cm^{-2} s^{-1} is achieved. The maximum luminosity is obtained for slightly lower sextupole strengths (K=0.6÷0.8) than required for the "exact" CW condition (K=1). The luminosity optimum corresponds also to the shortest distribution tails. With stronger or weaker sextupoles the tails start growing indicating possible lifetime problems. It is worth remarking that even without crabbing sextupoles (see the plots with K=0), a peak luminosity higher than 1.0x10^{33} cm^{-2} s^{-1} can be achieved. Clearly the tails are much longer in this case. However, the lifetime can be improved with dynamic aperture optimization or by using slightly lower bunch currents.

BACKGROUND STUDIES

Machine backgrounds and lifetime will be dominated by the single Touschek scattering, as it is for the DAΦNE present configuration. Simulations of the Touschek effect with the CW scheme have been performed [10]. Particle losses due to Touschek effect are expected to be quite high with the Siddharta optics, mainly due to the smaller emittance. However, the longitudinal position of collimators has been optimized for the new optics and they are expected to be very efficient, even if a good compromise between losses and lifetime has necessarily to be found experimentally. In addition, careful design of the detector shielding is underway.

DYNAMIC APERTURE STUDIES

Dynamic aperture studies have been performed with the Acceleraticum code developed at BINP [11], where a numerical algorithm is used to choose "the best" pairs of sextupole magnets in order to optimize the chromaticity correction. Moreover a tune working point was chosen which satisfies the requirements of high luminosity and large dynamic aperture. The "best pair" optimization method provides a dynamic aperture ≥20 σ_x off-coupling and >250 σ_y full coupling, with an energy acceptance of ~1%. These values seem quite satisfactory to provide high luminosity and a successful experimental run. It is worth noting that one of the promising tune points {5.105, 5.16} practically coincides with the present operational values. Fig. 4 shows the optimized DA for three different working points, corresponding to good areas in the luminosity versus tunes plot.

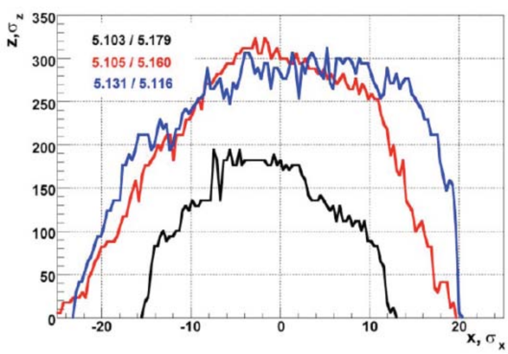

Figure 4 - Optimized DA for different working points.

HARDWARE MODIFICATIONS

A layout of the upgraded DAΦNE is shown in Fig. 5, and the main hardware changes are briefly illustrated in the following. Details are available in the papers presented at this Conference [12,14].

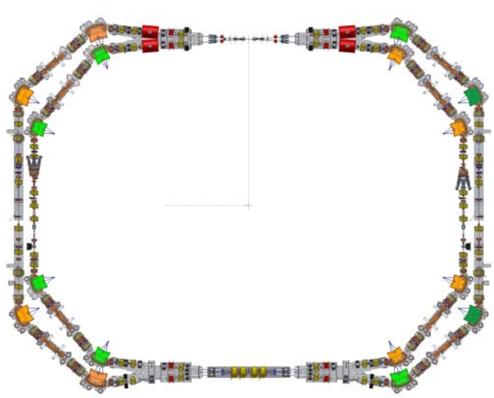

Figure 5: Upgraded DAΦNE layout.

Interaction Regions layout

IR1 has been modified [12] for the installation of the Siddharta experiment, and equipped with new quadrupoles to be able to lower β^* at the IP. The total crossing angle has been increased from 30 mrad to 50 mrad. Existing sextupoles will be used as CW sextupoles. New beam pipes have been designed for this scheme. In IR2 the beams will travel through vertically separated vacuum chambers without low-β focusing.

IR1 quadrupoles

Two new permanent magnet quadrupole doublets are needed in order to focus the beams to the smaller β^* at the IP. The first quadrupole of the doublet is horizontally defocusing, common to both beams in the same vacuum chamber: it provides a strong separation of the beams. The following QFs are particularly small, in order to fit separated beam pipes for the two beams.

Fast Injection kickers

New, fast kickers have been designed and built [13], based on a tapered strip with rectangular vacuum chamber cross section. The deflection is given by both the magnetic and the electric fields of a TEM wave traveling in the structure. Compared to the present DAΦNE injection kickers the new ones have a much shorter pulse (~12 ns instead of ~150 ns), better uniformity of the deflecting field, lower impedance and the possibility of higher injection rate (max 50 Hz).

New bellows

Four new bellows [14] are placed in each sector, connecting pipes with circular cross section (D = 88 mm). A RF shield is necessary to hide the chamber discontinuity to the beam. The coupling impedance of the structure has been evaluated in a frequency range from DC to 5 GHz and comes out to be very low.

CONCLUSIONS

Past approaches of collider optimization, followed over several decades, have now run into a dead end. The novel collision scheme with large crossing angle and CW uses hitherto frozen variables in parameter space to ascend to a new luminosity scale, by effectively exchanging the roles of the longitudinal and transverse dimensions. A new IR layout for the Siddharta run, compatible with the new scheme, has been designed and built. Operation will start in fall 2007. The predicted luminosity boost is based both on geometric and beam dynamics considerations, fully supported by extensive beam-beam simulations. With the test of the new idea at DAΦNE top-of-the-line accelerator physics should be at reach.

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