DAΦNE SETUP AND OPERATION WITH THE CRAB-WAIST COLLISION SCHEME

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Abstract

In the second half of 2007 a major upgrade has been implemented on the Frascati DAΦNE collider in order to test the novel idea of *Crab-Waist* collisions. New vacuum chambers and permanent quadrupole magnets have been designed, built and installed to realize the new configuration. At the same time the performances of relevant hardware components, such as fast injection kickers and shielded bellows have been improved relying on new design concepts.

The collider has been successfully commissioned in this new configuration. The paper describes several experimental results about linear and non-linear optics setup and optimization, damping of beam-beam instabilities and discusses the obtained luminosity performances.

INTRODUCTION

DAΦNE [1] is the Frascati lepton collider working at the c.m. energy of the Φ meson resonance (1020). It came in operation in 2001 and till summer 2007 provided luminosity, in sequence, to three different experiments which logged a total integrated luminosity of ~ 4.4 fb^{-1}.

During these years the collider reached its best performances in terms of luminosity and background (L_{peak}=1.6x 10^{32} $cm^{-2}s^{-1}$ $L_{\int day}$~10 pb^{-1}) by means of several successive upgrades, relying on the experience gathered during the collider operations and implemented exploiting the shutdowns required for the experiment change over [2, 3, 4].

PHYSICAL BASIS FOR THE UPGRADE

Pushing the peak luminosity beyond the achieved limit of 1.6 10^{32} $cm^{-2}s^{-1}$ required a drastic change of the collision scheme. In fact the value of the betatron function at the Interaction Point (IP) was comparable with the longitudinal bunch length and the maximum storable current in collision was affected by the non-linear effects induced by the 24 parasitic crossing [5] occurring in each one of the two Interaction Regions (IRs).

A new collision scheme with a large Piwinski angle, obtained by increasing the horizontal crossing angle and reducing the transverse horizontal beam size at the IP, has been proposed and implemented at DAΦNE [6]. The large Piwinski angle provides several advantages: it reduces the beam-beam tune shift in both planes, shrinks the longitudinal size of the overlap between the colliding bunches, thus allowing for a lower β_y at the IP, and cancels almost all the parasitic crossings: in fact it becomes possible to completely separate the vacuum chambers of the two beams just after the first low-beta quadrupole in the IR. Moreover a couple of *Crab-Waist* (CW) sextupoles, installed in symmetric position with a proper phase advance with respect to the IP, suppresses the betatron and sinchrobetatron resonances coming from the vertical motion modulation due to the horizontal oscillation [7].

The second unused IR has been eliminated by separating vertically the two vacuum chambers. Some devices, such as bellows and injection kickers have been redesigned in order to improve their performances and to reduce their contribution to the total coupling impedance of the rings.

The new *Crab-Waist* collision scheme [8] and the collider mechanical and magnetic layout evolution [9] have been already extensively described in many papers.

DAΦNE UPGRADE COMMISSIONING

DAΦNE operation restarted at the end of November 2007 with the aim to optimize the collider performance, test the new devices, verify the *Crab-Waist* collision scheme and provide luminosity to the SIDDHARTA experiment preliminary setup.

Main Ring Optics

In the early stage of the commissioning a detuned optics, with ν_x slightly above 5, ν_y above 4, and without *Crab-Waist* sextupoles has been applied to both rings in order to speed up beam injection, put the diagnostics in operation and perform a satisfactory machine modeling. Beam closed orbit has been minimized together with the steering magnet strengths relying also on beam based procedure to point out and fix misalignment errors. Vertical dispersion has been minimized by global vertical orbit correction and by centering the beam vertical position in the arc sextupoles.

Once a reliable machine model has been defined, the ring optics has been moved progressively towards the nominal one with both tunes above 5. The β functions are now $\beta^*_{y/x}$ ~ 0.01/0.25 m at the IP, slightly larger than the *Crab-Waist* design values ($\beta^*_{y/x}$ ~ 0.0065/.20 m). The present main ring optics is shown in Fig. 1. Finally the

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Crab-Waist sestupoles have been switched on, at half their nominal strength, however five times higher than the strength of the ordinary sextupoles used for chromaticity correction. Beam orbit deviations in the CW sextupoles have been carefully corrected to avoid tune changes.

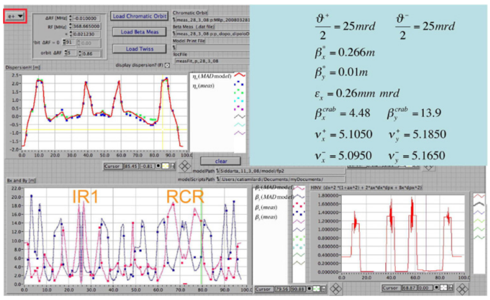

Figure 1: DAΦNE model compared with beam measurements – up left: dispersion function; down left: betatron functions; down right: betatron invariant.

In January two electromagnetic quadrupoles have been added symmetrically with respect to IP1 on each ring, in order to finely tune the phase advance between the CW sestupoles and the IP.

The transverse betatron coupling has been corrected mainly by correcting rotation errors in the low-β focusing quadrupoles, now independent for the two rings. The best value obtained so far is $\kappa \sim 0.4\%$ for both beams measured at the synchrotron light monitor after a careful calibration.

The nonlinear optics has been optimized by finely tuning the sextupole configuraton to minimize the dependence of the betatron functions on energy and to improve the dynamic aperture and, therefore, the beam lifetime.

Coupling Impedance

The ring coupling impedance is responsible for several harmful effects to the beam dynamics, and to the luminosity as well, as it has been pointed out during the last FINUDA run [4]. Coupling impedance affects bunch length and has to be kept as low as possible to avoid geometric luminosity reduction due to the hourglass effect.

The coupling impedance in the two rings has been reduced [10] by adopting new injection kickers and new shielded bellows and, on the e^- ring, by removing some broken ion clearing electrodes. A bunch length of 1.7 mm has been measured for both beams at 10 mA/bunch, which, for the e^- beam, is consistent with a 20% bunch length reduction.

High Currents Issues

Machine operation at high current strongly depends on vacuum conditions. The new vacuum chambers installed on the IR and in the opposite ring crossing region (RCR), as well as the new bellows and injection kickers required a careful and time consuming beam conditioning.

After three months of operation a reasonable vacuum condition has been obtained. However no more than 95 e^- bunches can be stored, so far, in collision instead of the 110 used during the past DAΦNE runs.

In turn the e^+ beam is affected by fast transverse instability leading to partial or total beam loss. Such instabilities have been cured by tuning the transverse and longitudinal feedback systems. The four e^- e^+ transverse feedbacks have been upgraded by adopting the new iGP (Integrated Gigasample Processor) feedback unit [11]. Beyond its ordinary stabilization function, this system allows to build a variety of diagnostic tools ranging from the single bunch tune to the single turn beam position measurement, a feature which has been extensively used in the injection induced transient analysis aimed at reducing the impact of the injection kickers on the maximum storable current, especially for the e^+ beam.

A further e^+ current improvement has been obtained installing solenoid windings (Bsol ~ 45 Gauss) in long section of the IR and of the RCR in the e^+ ring. Solenoids have been effective especially in the first commissioning phase, in fact they reduce the transverse instability rise-time boosting the action of the transverse feedbacks.

High current operations also profited from the lower coupling impedance introduced by the new bellows and injection kickers. A more relevant contribution is expected when the fast high voltage pulsers (5 ns, 40kV), perturbing only one bunch during injection, will replace the old ones (200 ns, 25kV) presently feeding the new stripline kickers.

As an overall result the highest currents stored by now are in single beam: $I^- = 1.8$ A (95 bunches), $I^+ = 1.15$ A (120 bunches) and in 95 colliding bunches: $I^- = 1.2$ A, $I^+ = 1.1$ A.

Luminosity Measurement

Three different monitors are used to evaluate the luminosity. The γ monitor measures the photons emitted at small angle (≈1 mrad) in the e^+ e^- inelastic scattering by means of two detectors aligned along the direction of each beam at the IP. It is used essentially for relative measurements aimed at optimizing the luminosity since its acceptance cannot be easily defined. An absolute luminosity measurements is provided by a Bhabha calorimeter [12] with a large acceptance (17÷27 degrees). The kaon counting rate is yielded by the SIDDHARTA experiment trigger system.

The Bhabha and Kaon monitors are in agreement within 15%.

NEW COLLISION SCHEME TESTS

Several measurements and qualitative observations of the beam-beam behaviour have confirmed the effectiveness of the new collision scheme.

The convoluted vertical size Σ_y of the interaction region can be measured by scanning a beam through the other one at low current looking at the luminosity; the vertical bunch size at the IP σ_y can be obtained by taking into account the hourglass effect. At DAΦNE $\sigma_y \sim 4$ μm has been obtained (see Fig. 2) consistent with the value measured at the Synchrotron Light Monitor.

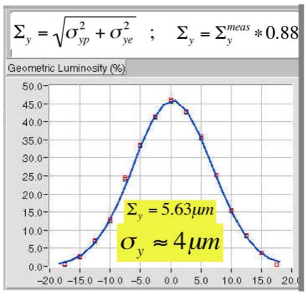

Figure 2: Vertical beam-beam luminosity scan.

A simple test of the new collision scheme consists in switching off the Crab-Waist sextupoles of one beam in collision. As a consequence the growth of both horizontal and vertical transverse sizes can be observed together with a luminosity reduction recorded by all the monitors. Such a behaviour is compatible with the appearance of beam-beam resonances when the CW sextupoles are off.

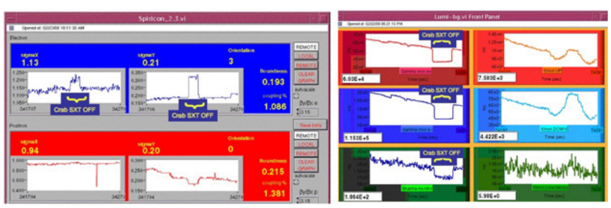

Figure 3: Transverse size (left) and luminosity dependence (right) on the CW sextupole excitation in the e^- ring.

The geometric luminosity, defined as the luminosity divided by the product of the total currents in the two beams (taking into account also the number of colliding bunches), exceeds by 3÷4 times the best value measured during the past DAΦNE runs, and the beam-beam tune shift exhibits a fairly linear behaviour as a function of current per bunch in the opposite colliding beam.

Collisions involving 10 bunches per beam have been studied both in the low and high current regimes. Such a situation avoids the effects due to the multi-bunch longitudinal beam dynamics. The maximum measured luminosity is consistent with the numerical simulations of the Crab-Waist collision scheme with the present low-β parameters.

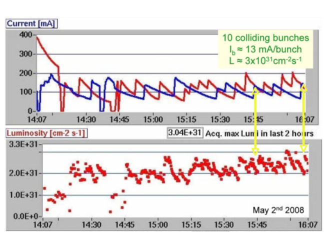

Figure 4: 10 bunches luminosity run.

LUMINOSITY RESULTS

The most relevant results of the commissioning concern the luminosity. So far the maximum measured peak luminosity is in excess of $L_{peak} = 2.2\ 10^{32}\ cm^{-2}s^{-1}$, the best daily integrated luminosity is $L_{\int day} \sim 8\ pb^{-1}$ and the highest integrated luminosity in one hour is $L_{\int 1hour}$ ~0.5 pb^{-1} averaged over a two hours run (see Fig. 5).

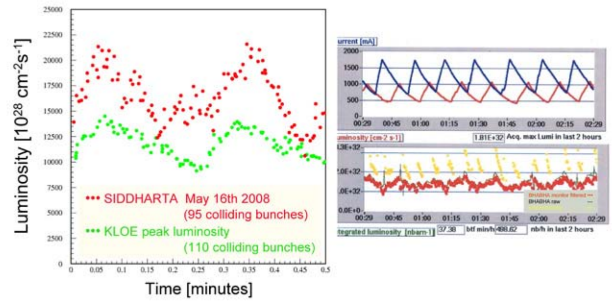

Figure 5: Peak luminosity (left) and integrated luminosity (right) over 2 hours.

However these results have been obtained without reaching the low beta parameters and the CW sextupole strength to their nominal values. As a matter of fact it is reasonable to foresee a 10% reduction in β^*_y and a 20% increase in the CW sextupoles strength in the near future. Moreover the number of colliding bunches, due to the recovered vacuum conditions and to the recent developments on the transverse and longitudinal feedback systems, can be raised from 95 to 110, as during the past DAΦNE runs. The average luminosity can also profit from speeding up the switch electron and positron injection. With all these improvements the peak luminosity is expected to reach 4.0 $10^{32}\ cm^{-2}s^{-1}$ and the monthly integrated luminosity ~ 0.5 fb^{-1}.

CONCLUSIONS

The DAΦNE collider has been successfully commissioned in the new configuration. The CW sextupoles proved to be effective in controlling transverse beam blowup and increasing luminosity.

DAΦNE is presently delivering luminosity to the SIDDHARTA prototype detector to establish the best background rejection configuration. Peak and average luminosity are already sufficient to perform the experiment in few months.

Further improvements of machine operation are likely to fulfill the requirements for a future physics experiments at DAΦNE.

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