

# DAΦNE TUNE-UP FOR THE KLOE-2 EXPERIMENT\*

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## Abstract

In its continuous evolution DAΦNE, the Frascati lepton collider, is starting a new run for the KLOE-2 detector, an upgraded version of the KLOE one.

A new interaction region, based on the high luminosity Crab-Waist collision scheme, has been designed, built and installed. Several machine subsystems have been revised according innovative design concepts in order to improve beam dynamics. Collimators and detector shields have been upgraded in order to minimize the background hitting the experimental apparatus during coasting as well as in injection operation. A wide measurement campaign has been undertaken to verify and quantify the effect of the modifications and to tune-up the collider in view of the 3 years long data-taking that should deliver  $\sim 5 \text{ fb}^{-1}$  to the KLOE-2 experiment.

## INTRODUCTION

The relevant results obtained during the test of the Crab-Waist collision scheme [1] opened new perspectives to the KLOE-2 experiment [2]. A detector taking data at DAΦNE can now acquire a daily integrated luminosity of the order of  $15 \text{ pb}^{-1}$ , 50% higher than in the past. However the integration of the new high luminosity collision scheme with a large detector required a completely new Interaction Region (IR) design, implemented during a shutdown, which offered a good opportunity to improve several other collider components [3].

DAΦNE operations restarted during fall 2010, but they were seriously slowed down by several technical faults that, finally required an unscheduled shut-down in May 2011.

Problems in the cryogenic plant due to a leakage of He at 4 °K toward the insulation vacuum prevented from energizing the detector till the end of October.

On January 2011 the 34° injection septum of the positron ring got permanently damaged due to a water leakage together with a fault in the alarm system. Since no spare part was available it has been impossible to store the  $e^+$  beam for three months. However the accident had a positive drawback: the new septum coil has been optimized by reducing the coil gap and changing the geometrical dimension of the conductor, thus achieving a 50% reduction in the wall plug power with respect to the original device. As a consequence all the four 34° degree installed on DAΦNE are being replaced.

The Linac had several problems concerning the D-modulator system, essential for positron production and

the gun cathode, which required several replacements till to run out of spare parts.

Although the collider uptime has been very limited, especially for the  $e^+$  ring, some meaningful work has been done to test the upgraded systems and to tune collisions.

## MAIN RINGS TUNING

### Optics

The first phase of the main ring commissioning has been done with the KLOE detector off. The lack of focusing from the solenoid has a strong impact on the ring optics, which had to be deeply modified. A specific magnetic configuration with solenoid off, but with compensators on has been computed and used to store up to 1.0 A and 0.5 A in the positron and electron ring respectively. This optics prevents beams from colliding at the IP and has been used to check all the ring subsystems, to start the vacuum conditioning with the beam as well as to optimize the ring model by adjusting the parameters of the wiggler magnets, which had been deeply modified.

Thanks to the preliminary work, the nominal optics suitable for Crab-Waist collisions with the solenoid on has been quickly implemented, after minor model refinements involving, mainly, the parameters of the low-beta quadrupoles, which are immersed in the detector solenoidal field. Beam measurements show a quite good agreement with the model in terms of linear optics. Betatron functions are presented in Fig. 1. The chromaticities, measured switching off all the electromagnetic sextupoles, are  $\xi_1 = -11.7$  and  $\xi_2 = -14.0$ , quite close to the theoretical ones:  $\xi_1^{\text{model}} = -11.0$  and  $\xi_2^{\text{model}} = -14.6$ . The low- $\beta$  parameters at the IP are:  $\beta_1 = 0.24 \text{ m}$ ,  $\beta_2 = 0.009 \text{ m}$ ,  $\alpha_1 = \alpha_2 = 0.0$ ,  $\eta_x = \eta'_x = 0.0$ .

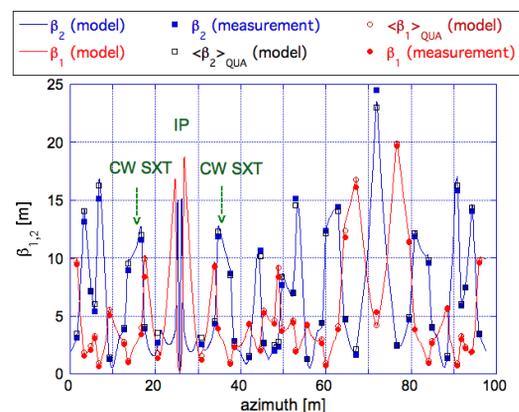


Figure 1: Pseudo-horizontal (red) and pseudo-vertical betatron functions (blue): computed values (lines), measurements (full markers), and theoretical average values at each quadrupole (hollow markers).

The Crab-Waist sextupoles have been aligned on the beam to avoid any effect on the betatron tunes and coupling when switching them on and off.

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### Closed Orbit

Closed orbit and steering magnet strengths have been minimized, by using an iterative approach, based on the measured response matrix from the horizontal and vertical correctors, aimed at finding and fixing alignment errors in the layout of quadrupole and sextupole magnets. Closed orbit adjustment gives a relevant contribution in achieving a good agreement between linear model and beam measurements by reducing the impact of non-linear elements and avoiding dispersion errors. Vertical dispersion around the ring has been reduced by more than a factor 2, see Fig. 2. Low  $\eta_y$  at IP is a main prerequisite in achieving minimum vertical beam size in collision, it is now of the order of  $\approx 7.0$  mm in the  $e^-$  ring, while in the  $e^+$  one, still to be optimized, is  $\sim 2$  cm. A smoother beam orbit had also a relevant impact in reducing the background shower hitting the experimental detector and in improving the collimator efficiency.

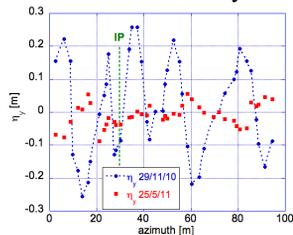


Figure 2: Vertical dispersion in the  $e^+$  ring before (dots) and after (squares) correction.

### Transverse Betatron Coupling

The new high luminosity IR for KLOE-2 requires a careful transverse betatron coupling compensation, not interfering with the Crab-Waist sextupoles. For this purpose a sophisticated scheme has been implemented [4] exploiting two anti-solenoids for each beam and rotation of one of the two permanent magnet quadrupoles of the low-beta doublet and of the three electromagnetic quadrupoles in each one of the four IR branches. This approach, after a preliminary debugging that outlined few installation errors concerning quadrupole rotations, proved to be quite effective. The lowest coupling achieved by now is  $\kappa = 0.14\%$ . This value has been measured on the electron ring in single beam operation mode; it does not show any meaningful dependence on the bunch number, and is lower than the corresponding value,  $\kappa = 0.2 \pm 0.3\%$ , attained during the past KLOE run.

## TESTS ON THE UPGRADED SYSTEMS

### Wiggler

The new configuration of the wiggler magnets, based on shifted poles has proved to be effective in reducing the non-linear terms in the magnetic field (B) [5].

The field quality has been tested by measuring the beam tune shift induced by a horizontal closed orbit bump at the wiggler place. This bump, including the two dipoles adjacent to the wiggler, slightly changes the ring energy: this effect has been carefully compensated tuning the frequency of the RF cavity. The orbit position at the

wiggler centre has been obtained by averaging the readout from two beam position monitors (BPM) placed at the magnet end side. For large values of the bump the BPMs non-linearity have been taken into account and properly corrected. The measured horizontal and vertical tune shifts exhibit a clear linear behaviour, see Fig. 3.

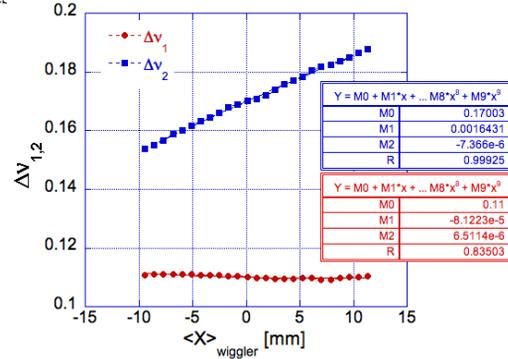


Figure 3: Tune shifts versus horizontal closed orbit bump in the wiggler.

A small sestupole-like dependence can be still observed in the vertical tune only, which is likely to be originated in the nearby dipoles. Wiggler nonlinearities have been affecting in a relevant way dynamic aperture and energy acceptance, mainly due to the interference of a decapole term with the beam trajectory, showing up in the measurements as a third order multipole. The original strength of this term was  $K^3 = 800 \text{ m}^{-3}$  in 2001, value which has been reduced to  $K^3 = 360 \text{ m}^{-3}$  in 2004 by adding longitudinally and horizontally shimmed plates on the poles, while now it almost negligible.

### Ring Impedance

The ring impedance has been estimated relying on bunch length measurements as a function of bunch current.

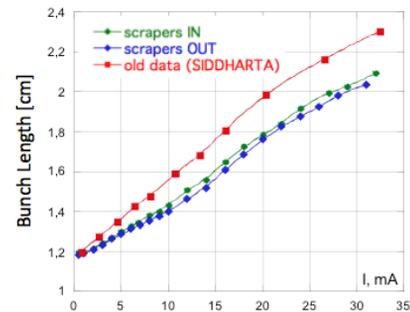


Figure 4: Bunch length measurements in the  $e^-$  ring.

Results, presented in Fig. 4 for the electron ring, show a bunch lengthening reduction of the order of 10% at a current of 20 mA with respect to the values attained during the test run with the SIDDHARTA detector. Measurements taken on the positron ring exhibit the same behaviour. Bunch length is neither affected by the insertion of the beam collimators nor, on the positron ring, by the presence of the new electrodes for electron clearing. Numerical fits based on potential well as well as microwave regime converge to a ring coupling impedance of  $0.3 \Omega$ ; it was  $0.4 \Omega$  during the previous run.

### Bunch by Bunch Feedback

The three independent bunch-by-bunch feedback systems installed on each DAΦNE ring have been successfully tested with the beam [6]. The new hardware proved to be flexible and backward compatible with respect to the old diagnostic tools. Preliminary measurements concerning longitudinal feedback have already shown a reduced noise level in detecting and damping longitudinal oscillations. In the transverse vertical feedback a clear reduction of the quantization noise on the system gain has been measured, as expected from the new 12-bit ADC based hardware. The new features of the transverse feedback units can be used to implement decoherence measurements by applying a proper anti-damping signal to the beam and recording its turn by turn response to the perturbation. The measurement accuracy profits from the high resolution of the system and from its data storage capability compatible with the beam damping time. The system has made it possible to measure vertical decoherence for the first time at DAΦNE.

## LUMINOSITY RESULTS AND BACKGROUND

The luminosity has been optimized by storing 100 bunches in collision at low current.

Firstly the betatron coupling has been minimized in single beam operation mode, then the colliding beam overlap has been tuned in the transverse and longitudinal planes using a fast monitor based on beam-beam bremsstrahlung. The transverse overlap is performed by means of closed orbit bumps changing independently the position and angle of one beam through the opposite one. In the first stage of the commissioning bumps were implemented by using four correctors, two called “C” and two “Lambertson”. They are installed in the IR branches where the two rings are separated, but the coupling due to the detector solenoid is not compensated. As a consequence there is a cross-talk between closed orbit bumps in the two main betatron planes. In order to minimize perturbation on the beam trajectory and to avoid large kick values, which might introduce non-linear effects interfering with the beam-beam process it has been decided to rotate the “C” correctors by an angle suitable to achieve horizontal closed orbit bumps which do not require any additional vertical steering. The last issue is intended to preserve the vertical overlap, which is very demanding since DAΦNE works with flat beams. The “Lambertson” correctors could not be rotated due to mechanical reasons, and so the bumps were realized with the so called “skew” correctors installed at the end of each IR branch. Now the “Lambertson” correctors are going to be replaced by small rectangular devices fulfilling the previous criteria and providing a better field quality as well. The single bunch specific luminosity, defined as the single bunch luminosity divided by the product of the single bunch currents, at low currents, is of the order of  $\sim 4.5 \cdot 10^{28} \text{ cm}^{-2} \text{ s}^{-1}$ , see Fig. 5, the same as the one measured during the Crab-Waist test without the

detector solenoid. The vertical size of the colliding bunches at the IP measured by vertical beam-beam scan is  $\sigma_y = 3.0 \text{ } \mu\text{m}$ , 14% lower than the best measured in the past after a long optimization period.

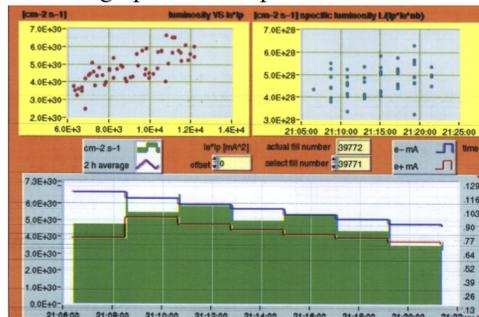


Figure 5: Luminosity versus product of colliding currents (top left), specific luminosity versus time (top right) and colliding currents and luminosity evolution (bottom).

An efficient data taking requires not only high luminosity, but also very low background rates on the detector. At DAΦNE the main source of noise is due to low beam lifetime stemming from Coulomb scattering between couples of particle inside the bunch (the “Touschek effect”). The new collimators installed in each one of the four IR branches proved to be effective in reducing the background shower on the experimental apparatus as predicted by numerical simulations [7]. However after careful orbit optimization and collimator tuning it was evident that the background level on the electromagnetic calorimeter was not acceptable. For this reason, on February 2011 an additional 1.0 cm thick lead screen has been added around the inner layer (QCAL) of the KLOE-2 detector. Preliminary measurements have shown a significant reduction in the background hitting the detector. Background counting rate from the  $e^-$  beam is now compatible with data taking, while the  $e^+$  one, being a factor 3.0 higher, still needs further optimization.

## CONCLUSIONS

DAΦNE operation and uptime have been affected by many severe faults. Although the beams have been available for short periods only, and rarely at the same time, a not negligible work has been done to tune-up the main rings and collisions. Preliminary results about luminosity at low current are quite encouraging. However operation at high current must still be explored. In order to grant reliable machine operation and a fruitful data taking to the KLOE-2 experiment a detailed plan has been undertaken aimed at maintaining and consolidating several parts of the accelerator complex. Operations with the beam are expected to restart by the end of September.

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