DAΦNE SETUP AND PERFORMANCES DURING THE SECOND FINUDA RUN

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Abstract

Beam operations at DAΦNE restarted in October 2006 after a four months shut-down to remove the KLOE experimental detector and to install the FINUDA one. This period has been also used for maintenance and implementation of several upgrades.

Already in the first two months of operation the peak and integrated luminosity exceeded the values obtained during the first FINUDA run by 20%, and have been steadily improving toward the end of the operation. By June 2007 ~ 1 fb^{-1} integrated luminosity has been logged by the experiment.

The collider performances during the run are presented together with the improvements obtained in terms of beam dynamics and beam-beam behaviour coming from several collider modifications.

INTRODUCTION

DAΦNE [1], the Frascati lepton collider, is now in its sixth year of operation. Since 2001 it has been delivering luminosity, at the energy of the Φ resonance (1.02 GeV c.m.), to three different experiments: KLOE, DEAR and FINUDA, one at a time.

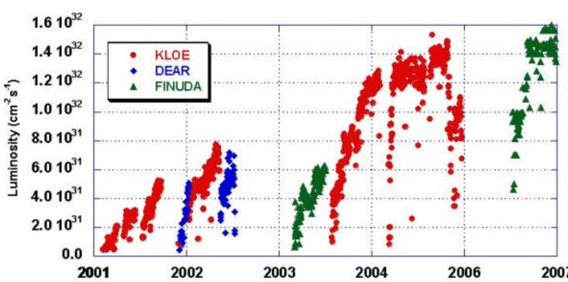

Figure 1: DAΦNE peak luminosity trend.

DAΦNE consists of two independent rings, each ~ 97m long, sharing two interaction regions IR1 and IR2 where the KLOE and DEAR or FINUDA detectors are respectively installed. An injection system, including a S-band linac, 180m long transfer lines and an accumulator/damping ring, provides the e^+ and e^- beams, with the required emittance and energy.

The DAΦNE complex runs also a beam test facility, providing e^-/ e^+ beams from the linac in the energy range 25÷725 MeV with tunable intensity from 10^{10} to a single particle per pulse.

Three independent beam lines, collecting the radiation emitted in one wiggler and one bending magnet of the e^- ring, provide a synchrotron radiation facility.

In these years DAΦNE has undergone several progressive upgrades [2], aimed at improving the collider performances (see Fig.1) which have been implemented exploiting the shut-downs required for detectors changeover.

DAΦNE SHUTDOWN ACTIVITIES

During the last shut-down, March 2006 ÷ July 2006, a maintenance program has been undertaken involving all the DAΦNE plants: electric, cooling and cryogenic, and all machine subsystems: linac, control system, magnet power supplies, RF system, vacuum system and wigglers. At the same time the FINUDA detector has been installed on IR2 while the KLOE one has been removed from IR1.

As usual several upgrades have been implemented relying on the experience gained during the last KLOE run [3].

The interaction region IR1 has been substituted with a straight section equipped with four electromagnetic quadrupoles, a much more flexible configuration to detune the optical functions in the unused IP, which does not contribute to betatron coupling.

Several broken Ion Clearing Electrods (ICE) and all those installed in the e^- ring wigglers have been removed, since theoretical studies [4] indicated the ICEs in the wigglers as the main source of the larger coupling impedance measured in the e^- ring with respect to the e^+ one.

Wires for beam-beam long range compensation (BBLR) [5] have been installed in IR2 following the successful tests done during the KLOE data taking.

New Beam Position Monitors (BPMs) [6], with turn by turn measurement capabilities, have been installed in the DAΦNE main rings in order to have fast and accurate linear and non linear beam optics measurements as well as to estimate driving terms impact on the main rings beam dynamics.

A new commercial processor (Pentium/Linux) has been implemented in the control system; this will progressively replace the original home designed front-end processors.

Third generation bunch by bunch feedbacks [7], based on field programmable gate array and developed for the Super B-factory in the framework of the SLAC-KEK-LNF collaboration, have been tested and implemented to stabilize the four transverse motions.

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FINUDA RUN

Commissioning & Main Ring Optics

DAΦNE operation for FINUDA [8] restarted in October 2006 with the goal to deliver 1 fb^{-1} integrated luminosity by mid June 2007.

The optimum vacuum conditions have been recovered in few weeks while commissioning the collider and in November the first luminosity has been delivered.

Commissioning included, as usual, ring optics tuning, closed orbit optimization, linear betatron coupling correction and feedback systems setup.

The bare beam orbit in both ring has been drastically reduced by beam based alignment involving the FINUDA detector solenoid.

The ring optics for the collision at FINUDA has been designed in order to have a beam emittance ε_x = 0.34 μ and low beta parameters at the main IP2 β_x^* = 2 m and β_y^* = 0.019 m. The vertical betatron function at IP1 has been tuned in order to trade off between an efficient beam-beam separation and the need to keep under control the blow-up due to beam-beam long range interaction; for this reason the β_y^{IP1} value after two months of operation has been halved and set to β_y^{IP1} = 11 m. Beam-beam simulations, showing the beam-beam blow-up dependence on parasitic crossings, for a given beam-beam separation, have been useful in this optimization process.

Betatron coupling compensation has been achieved by rotating the permanent quadrupoles inside the FINUDA solenoid, reaching an optimal value of ~0.3%

The magnetic field of the four wigglers installed in each DAΦNE ring to increase radiation damping has been reduced by 5% (1.68 T) with respect to the last KLOE run resulting in a ~1.5 MW total wall-plug power reduction since they were operated in the field saturation region. The new wiggler field setup produces a negligible effect on the damping times, improves the ring energy acceptance, reduces the non linear terms contribution in the tune shift on energy dependence and is compatible with the operation of the x-ray beam line being the critical energy, and consequently the photon flux, reduced by 10% only.

During the luminosity adiabatic tuning the main ring working points (asymmetric at DAΦNE) have been progressively moved toward the integer

$\nu^-_{x,y}$ = 5.086 , 4.156 -> 5.076 , 4.140

$\nu^+_{x,y}$ = 5.109 , 4.192 -> 5.096 , 4.168

to reduce the beam transverse dimension growth driven by the beam-beam interaction at high current, confirmed by experimental evidence and theoretical simulation.

Beam Dynamics

The ICE in the e^- ring wigglers have been removed since they were responsible for the factor 2 higher coupling impedance measured in the DAΦNE e^- ring with respect to the e^+ one (Z/n = 1.1 Ω and Z/n= .54 Ω respectively). This difference produced several observed detrimental effects on the e^- ring beam dynamics and collider luminosity as well.

The e^- bunch length was 30% longer than the e^+ one causing a geometric luminosity reduction due to the hour glass effect. For such a longer bunch synchro-betatron beam-beam resonances, due to the collision scheme based on crossing angle, were more harmful. Single bunch instabilities, mainly longitudinal quadrupole oscillations [9], depending inversely on the coupling impedance, appeared at lower bunch current in the e^- ring. Transverse beam size blow-up, mainly in the vertical plane, has been observed beyond the microwave instability threshold.

Beam measurements taken during commissioning confirmed that the e^- beam dynamics, after ICEs removal, is almost comparable to that of the e^+ beam [10]. The e^- bunch length is 25÷30 % shorter (see Fig.2) and there is no evidence of quadrupole instability threshold neither vertical beam blow-up at the operating bunch current (~ 15 mA).

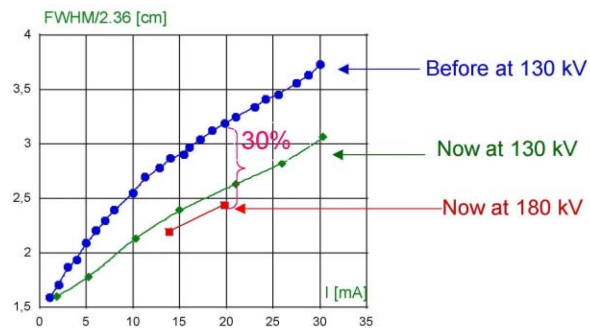

Figure 2: Bunch lengthening before (blue) and after (green) ICE removal.

Since the first phase of commissioning the e^+ beam showed a threshold in the maximum storable current due to a fast horizontal instability depending on the current and on the beam fill pattern, compatible with an e-cloud driven instability. The phenomenon had been observed even during the KLOE data-taking with 1.4 A current threshold in collision. During the FINUDA operation the threshold seemed to be much more harmful, in fact in November only 0.4 A e^+ current was storable in collision. This limit progressively increased by improving the injection process and the feedback systems.

The injection optimization was aimed at reducing the oscillation amplitude of the stored beam by moving the e^+ stored beam orbit closer to the injection septum, reducing strength and pulse length (150 ns to 90 ns) of the injection kickers, and tuning the phase advance between the injection kickers, by means of the newly installed BPMs with turn by turn orbit measurement capability.

The new feedback systems are based on a digital signal processing relying on a programmable gate array. It has enhanced diagnostics and remotization capabilities, can deal with any betatron and synchrotron tune, does not require fixed phase advance between pick-up and kicker and is much less sensitive to the injection oscillation amplitude transient. The new hardware has been implemented progressively for the two rings transverse feedbacks, giving a relevant contribution to the transverse beam dynamics control and to the enhancement of the e^+ maximum storable current.

Luminosity

Since the first two months of operation the luminosity has been significantly higher than during the previous 2003÷2004 FINUDA run, as shown in Table 1. The peak luminosity measured by the FINUDA detector has been almost doubled; correspondingly the maximum monthly integrated luminosity has been increased by a factor ~3.

This large gain is a direct consequence of the several implemented upgrades.

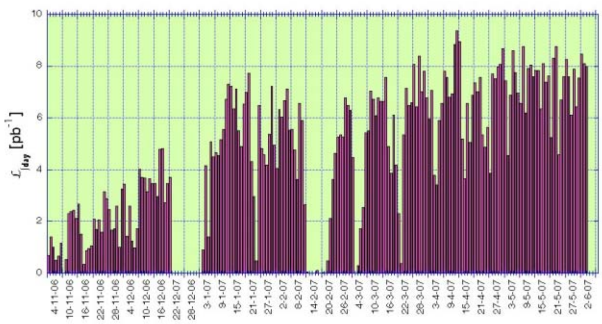

Figure 3: Daily integrated luminosity measured by FINUDA.

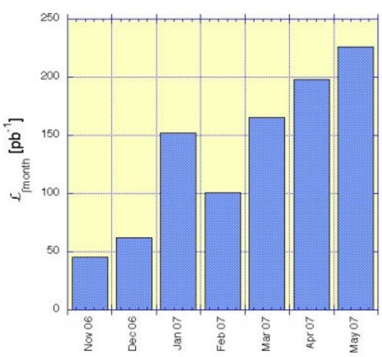

Figure 4: Monthly integrated luminosity.

An improvement can be noticed even with respect to the last KLOE run, with a peak luminosity increased by few percent, althogh the low beta parameters have not been pushed to the lowest possible values, due to the short time available for machine studies and tuning and putting in collision smaller currents and less bunches. This gain can be ascribed to the higher geometric luminosity due to the ICEs removal. Correspondingly 8% gain in terms of maximum monthly integrated luminosity (see Fig.4) has been obtained due to the higher collider uptime (> 80%), to the careful subsystems maintenance and upgrade and to the longer beam lifetimes obtained from the wires for BBLR compensation installed in both interaction regions.

The background rate seen by the FINUDA detector has been progressively reduced, by tuning the collider optics and adjusting the collimators, and made lower than during the 2003-2004 FINUDA run. Due to the higher luminosity and uptime and to the lower background the delivered luminosity and the statistical sample acquired by FINUDA have been 5 and 7 times larger with respect to the previous run in approximately the same data-taking time. Moreover these results have been obtained with ~30% reduction in the wall-plug power.

FUTURE PLANS

In the next months the FINUDA detector will be removed and the DAΦNE interaction regions will be replaced [11] in order to implement the 'crab waist' collision scheme [12], aiming at a luminosity of the order of $10^{33} cm^{-2}s^{-1}$ with beam currents similar to the present ones.

The operation restart is scheduled for the end of 2007 with the Siddharta experiment installed on IP1. The SIDDHARTA detector [13] is a compact table-top device without solenoidal field providing a suitable configuration to test the effectiveness of the 'crab waist' concept.

Table 1: DAΦNE luminosity performances and low-beta parameters at IP2 during the last runs.

	FINUDA Oct 03 Mar 04	**KLOE** May 04 Nov 05	**FINUDA** Nov 06 Jun 07
L_{peak} [$cm^{-2}s^{-1}$]	0.85	1.53	1.6
$L^{MAX}_{\int day}$ [pb^{-1}]	3.9	9.8	9.4
$L^{MAX}_{\int month}$ [pb^{-1}]	65	209	226
I^{-MAX}_{coll} [A]	1.1	1.4	1.5
I^{+MAX}_{coll} [A]	1.0	1.2	1.1
$n_{bunches}$	100	111	106
$L_{\int logged}$ [fb^{-1}]	0.192	2	0.966
β_x^* [m]	2.33	1.5	2.0
β_y^* [m]	0.024	0.018	0.019
ε_x [10^{-6} m rad]	0.34	0.34	0.34
κ (%)	0.3	0.3	0.3

CONCLUSIONS

DAΦNE has completed the run for the FINUDA experiment delivering ~ $1 fb^{-1}$ in six months of operation. All the upgrades have been effective in optimizing machine operation and uptime, as well as in providing efficient and accurate diagnostic tools. The e^- ring coupling impedance has been made comparable with the e^+ one resulting in improved e^- beam dynamics and geometric luminosity. The peak and integrated luminosity have reached the highest value ever obtained during the whole DAΦNE operation.

The run efficiency and the high quality of delivered data is raising the experiment groups interest for future physics enterprises at DAΦNE.

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