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DAΦNE COMMISSIONING FOR SIDDHARTA-2 EXPERIMENT

C. Milardi*, D. Alesini, O. R. Blanco-García, M. Boscolo, B. Buonomo S. Cantarella, A. De Santis, C. Di Giulio, G. Di Pirro, A. Drago, A. D'Uffizi, L. Foggetta, G. Franzini, A. Gallo, S. Incremona, A. Michelotti, L. Pellegrino, L. Piersanti, R. Ricci, U. Rotundo, L. Sabbatini, A. Stecchi, A. Stella, A. Vannozzi, M. Zobov, INFN - Laboratori Nazionali di Frascati, Italy
J. Chavanne, G. Le Bec, P. Raimondi, ESRF, Grenoble, France

Abstract

DAΦNE, the Frascati lepton collider, has completed the preparatory phase in order to deliver luminosity to the SIDDHARTA-2 detector. DAΦNE collider rings rely on a new interaction region, which implements the well-established Crab-Waist collision scheme, and includes a low-β section equipped with newly designed permanent magnet quadrupoles, and vacuum components. Diagnostics tools have been improved, especially the ones used to keep under control the beam-beam interaction. The horizontal feedback in the positron ring has been potentiated in order to achieve a higher positron current. Luminosity diagnostics have been also updated so to be compatible with the new detector design. The commissioning was initially focused on recovering the optimal dynamical vacuum conditions, outlining alignment errors, and optimizing ring optics. For this reason, a detuned optics, featured by relaxed low-β condition at the interaction point and Crab-Waist Sextupoles off, has been applied. In a second stage a low-β optics has been implemented to test collisions with a preliminary setup of the experiment detector. Machine preparation and the first luminosity results are presented and discussed.

INTRODUCTION

The DAΦNE accelerator complex [1] consists of a double ring lepton collider working at the c.m. energy of the ϕ-resonance (1.02 GeV) and an injection system. The collider includes two independent rings, each about 97 m long. The two rings share a purpose-built Interaction Region (IR), where a detector is installed. A full energy injection system, including an S-band linac, 180 m long transfer lines and an accumulator/damping ring, provides fast and high efficiency electron–positron injection also in topping-up mode while delivering luminosity. DAΦNE powers 4 synchrotron radiation beam lines too, and the DAΦNE LINAC provides beam to a beam test facility, which has been recently upgraded [2].

Presently DAΦNE is completing the commissioning phase for the pilot run, dedicated to delivery about 100 pb^{-1} to the SIDDHARTINO experiment [3]. Pilot run is intended to optimize the collision conditions and the experimental acquisition system in view of the physics run with the SIDDHARTA-2 apparatus [4], aimed at collecting 800 pb^{-1} to perform the first ever measurement of kaonic deuterium X-ray transitions to the fundamental level [5].

The SIDDHARTINO setup contains a reduced (1/6) SDD [6] array number and the whole setup is slightly lifted from the nominal position, in order to avoid interference with the dedicated DAΦNE luminosity monitor.

DAΦNE, a Φ-Factory built in the years 90', is a unique machine in the world for physics studies requiring low-energy charged kaons with momenta below 140 MeV/c. Moreover, at DAΦNE, a new approach to collisions: the Crab-Waist collision scheme [7] has been developed and successfully tested, with different kind of detectors [8, 9], allowing to increase the machine luminosity up to a factor of 3. As a matter of fact, luminosity achieved at DAΦNE is one order of magnitude higher than the one measured in colliders working at the same energy, and Crab-Waist has become the main approach to collision for present and future lepton colliders [10–14]. DAΦNE is, therefore, ideally suited for studying particle and nuclear physics in the sector of low-energy QCD with strangeness, even more as collisions at lepton machines naturally assure the minimal possible level of background on the detector with respect to hadron beam based experiments. A broad international community is preparing proposals for kaonic atoms and kaon-nuclei interactions measurements to be performed after the end of SIDDHARTA-2 run [15].

MAIN RING OPTICS

Several new optics configurations have been developed for the DAΦNE main rings and sequentially applied. This has been necessary because, during the preparatory phase for the KLOE-2 run in 2009, the wiggler magnets, installed in each arc of the two colliding rings, had been modified [16]. Contextually, several steering magnets had been repositioned in order to ease the closed orbit correction process. The longitudinal position of many electromagnetic quadrupoles had been also modified in order to achieve, with optimized quadrupole strengths, the required phase advance in the long and in the short straight sections, used for beam injection, and for adjusting ring tunes respectively.

In the very first stage of the DAΦNE commission a detuned optics has been applied. It had rather large betatron oscillation amplitudes at the Interaction Point (IP): $\beta_x^* = 0.27$ m, and $\beta_y^* = 0.049$ m. Detuned optics has been essential to inject the beams and to test the magnets alignment in the two branches of the new IR. In fact, during the preparatory phase for the SIDDHARTA-2 run, [17], the low-β section has been equipped with new defocusing quadrupoles based on permanent magnet technology, the IR beam pipe has been redesigned, and new BPM's have been added on both sides of the IP. Detuned optics has also been funda-

* catia.milardi@lnf.infn.it

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mental in improving the ring optics model reliability, and to store suitable beam currents, after closed orbit and feedback systems preliminary optimization, in order to start vacuum conditioning.

Afterwards, a low-β optics has been implemented, having $\beta_x^* = 0.28$ m, and $\beta_y^* = 0.009$ m at the IP. In this configuration the transverse betatron coupling has been corrected to the values of about $k \sim 0.3\%$ in both rings, non-linear optics has been improved, and the first collision at low currents have been tested. Eventually, the Crab-Waist optics, providing $\beta_x^* = 0.26$ m, and $\beta_y^* = 0.008$ m at the IP and the proper phase advance between the IP and the Crab-Waist sextupole magnets has been applied in order to start the pilot run.

Machine studies finalized to non-linear optics tuning of the Crab-Waist configuration are still under way. Beam based measurements outlined non-negligible alignment errors for three chromatic sextupoles in the positron ring, which have been corrected thus eliminating tune shifts and horizontal dispersion distortion when switching those sextupoles on.

Chromaticities of the two beams have been set to the highest possible positive values, compatible with the smallest values of second order dispersion and second order chromaticity as well.

Crab-Waist Sextupoles have been aligned in the transverse plane relying, even then, on beam-based measurements, they do not perturb beam parameters as, for instance, the transverse beam dimensions as can be seen from Fig. 1.

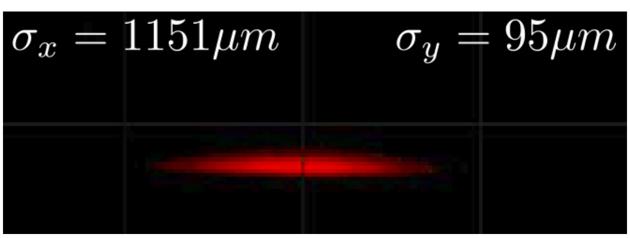

Figure 1: Electron beam profile as measured at the SLM, for a current of 500 mA stored in 100 bunches, after setting the Crab-Waist Sextupoles at 1/3 of the nominal strength. The beam vertical size is at the level of the diagnostics resolution.

BEAM DYNAMICS

Vacuum has a relevant impact on beam dynamics through, for instance, ion trapping and e-cloud effects influencing the electron and positron beams respectively. For this reason in the first stage of the commissioning dedicated beam conditioning runs, periodical sublimation, and beam scrubbing have been fundamental in progressing toward high intensity, stable, beam currents. E-cloud activity is quite evident looking at the measurements from vacuum gauges. In Fig. 2 the vacuum rise as a function of the stored current is shown for different bunch patterns. The 40 bunches pattern, being the most harmful, in terms of e-cloud activity, has been adopted for scrubbing runs.

At DAΦNE, ions related effects are kept under control by introducing a suitable gap in the batch, presently only 100

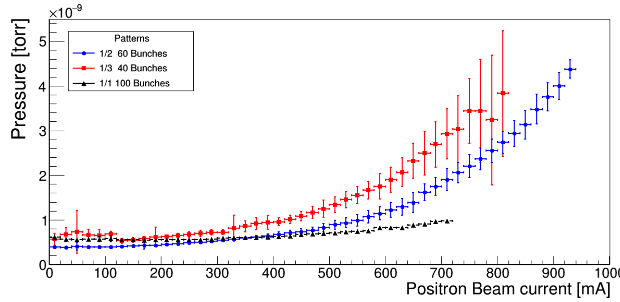

Figure 2: Positron ring vacuum rise as a function of the stored current for different bunch patterns. Each series represent the average (markers) and RMS (bars) over several hours of running.

bunches are filled out of the 120 available. E-cloud effects are thwarted by means of solenoids winded around the beam pipe of the straight sections, powerful transverse feedback systems, and by properly tuning positron beam parameters. In fact, e-cloud induced effect are considerably mitigated by moving beam chromaticities toward higher positive values, lengthening the bunch by reducing the RF voltage, adding Landau damping by tuning octupole magnets.

In a low energy machine as DAΦNE, operating with beams having long damping times, high current performances significantly depend on bunch by bunch feedback systems. Three independent feedback systems are installed in each DAΦNE ring, one dedicated to cure longitudinal instabilities and two dedicated to damp horizontal and vertical oscillations. During the pandemic shutdown, a general survey of the feedback systems was performed. The maximum currents stored so far are 1800 mA for the electron beam and 900 mA for the positron one, see Fig. 3.

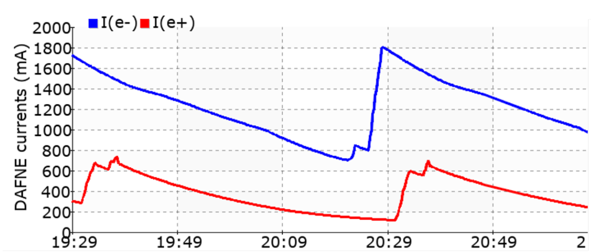

Figure 3: Maximum electron (blue) and positron (red) beam currents stored so far in the DAΦNE main rings.

The maximum electron current was obtained by adjusting the timing parameters and feedback setup (FIR filter parameters) of the iGp Signal processors [18]. Presently, the maximum achievable electron beam current is limited by injection efficiency, beam lifetime, and by the onset of longitudinal instabilities.

Differently, the maximum positrons beam current is limited by mode-0 instabilities and longitudinal quadrupole instabilities. The first one shows a clear dependence on the RF-Cavity feedbacks tuning, proper setup optimization is ongoing. The latter is going to be cured by a special tech-

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nique [19] developed at DAΦNE consisting in detuning the QPSK modulation in the feedback back-end in order to damp dipole and quadrupole beam motions at the same time.

COLLISIONS WARM-UP

Diagnostic Tools

A reliable luminosity measurements usually comes from a coordinated effort between collider and experiment experts. In the case of the SIDDHARTA-2 setup, the luminosity determination relies on charged kaon flux measurement having a low expected rate (10 Hz @ 10^{32} cm^{-2}s^{-1}) due to detector acceptance and a strong dependence on the collider center of mass energy.

To cope with such limitations, a low angle luminometer collecting Bhabha scattering events has been realized by converting the CCAL-T calorimeter [20], originally designed to increase the angular acceptance of the KLOE-2 setup, to an independent detector capable to measure energy and time of impinging particles. The energy resolution is expected to be very large due to geometrical factors (e.g., leakage), but it is mandatory to measure the scale of the threshold used to discriminate the signals for time coincidence. Rate of coincidence is proportional to the luminosity, as already demonstrated in a test run of a partial setup during KLOE-2 physics run [21].

In Fig. 4 the observed rate of coincidence is show as a function of the calculated geometrical luminosity. A good linearity is observed as expected.

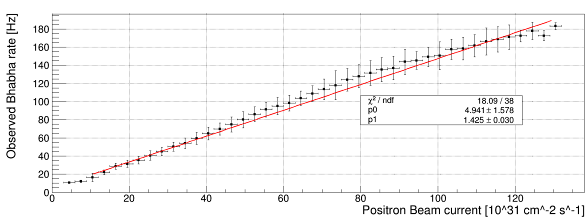

Figure 4: Observed Bhabha scattering events rate versus geometrical luminosity. The geometrical luminosity is evaluated taking into account measured beam sizes and hourglass.

The calibration of the energy scale is not yet completed and the corresponding luminosity is evaluated as the product of the Bhabha measured rate and the effective cross section as obtained from Monte-Carlo simulation based on GEANT4 using BABAYAGA@NLO [22] as event generator. Despite the effective cross section is systematically underestimated (on purpose), the online measurement provides constant feedback to the machine optimization as shown in Fig. 5. The Full chain of data acquisition, handling and visualization is managed by a novel DAQ/Control system concept developed in our laboratory: !CHAOS [23].

Beam Interaction Setup

After a systematic optimization of beam overlap, the Crab-Waist Sextupoles have been set at moderate strength, almost 1/3 of their nominal value. Then, the convoluted vertical size

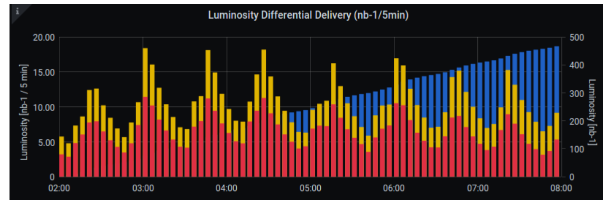

Figure 5: Luminosity (differential and integrated) during 6hr of SIDDHARTA-2 pilot run.

Σ_y^* of the interacting beams has been evaluated by scanning one beam through the other, at low current, while recording the luminosity trend, see Fig. 6. The vertical bunch size at the IP, σ_y, has been deduced with the assumption that the two beams have same sizes at the IP. The obtained σ_y is of the order of 5.2 µm, such value is consistent with the one evaluated by the Synchrotron Light Monitor, as well as the one computed on the basis of the nominal beam optics parameters. Moreover it is quite close to the one obtained, after a long optimization period, at the end of the SIDDHARTA run in 2009, when a σ_y of the order of 3.5 µm was measured.

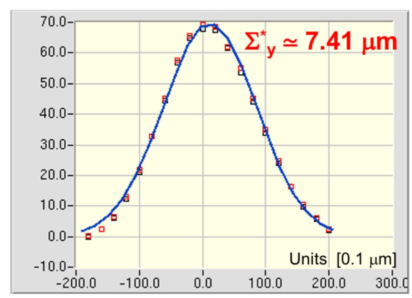

Figure 6: Vertical beam-beam luminosity scan.

CONCLUSION

DAΦNE is restarting after a long shunt down period mainly due to the lockdown imposed by the pandemic. Despite the adverse circumstances several positive results have been achieved: Crab-Waist Optics has been extensively characterized and assures a reliable control on beam parameters, transverse betatron coupling has been efficiently corrected, beam dynamics allows to store rather high stable beam currents, and DAΦNE Luminosity monitor characterization is almost completed. DAΦNE activity in the next months will be finalised to improve the quality of data delivery in view of the experiment data taking for pilot run.

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REFERENCES

[1] G. Vignola *et al.*, "Status report on DAFNE", *Frascati Phys. Ser.*, vol. 4, pp. 19-30, Oct. 1996.

ISBN: 978-3-95450-214-1 ISSN: 2673-5490 doi:10.18429/JACoW-IPAC2021-TUPAB001

[2] L. Foggetta *et al.*, "The Extended Operative Range of the LNF LINAC and BTF Facilities", presented at IPAC'21, Campinas, Brazil, May 2021, paper THPAB113, this conference.

[3] M. Skurzok *et al.*, "Characterization of the SIDDHARTA-2 luminosity monitor", *Journ. of Instr.*, vol. 15, p. 10010, Oct. 2020. doi:10.1088/1748-0221/15/10/P10010

[4] C. Curceanu *et al.*, "The modern era of light kaonic atom experiments", *Rev. Mod. Phys.*, vol. 91, p. 025006, 2019. doi:10.1103/RevModPhys.91.025006

[5] M. Bazzi *et al.*, "A New Measurement of Kaonic Hydrogen X rays", *Phys. Lett. B*, vol. 704, p. 113, 2011. doi:10.1016/j.physletb.2011.09.011

[6] M. Miliucci *et al.*, "Silicon Drift Detectors system for high precision light kaonic atoms spectroscopy", *Meas. Sci. Technol.*, to be published.

[7] M. Zobov *et al.*, "Test of crab-waist collisions at DAFNE Phi factory", *Phys. Rev. Lett.*, vol. 104, p. 174801, 2010. doi:10.1103/PhysRevLett.104.174801

[8] C. Milardi *et al.*, "Experience with DAFNE upgrade including crab waist", in *Proc. PAC'09*, Vancouver, Canada, May 2009, paper MO4RAI01, p. 80.

[9] C. Milardi *et al.*, "A Review of DAFNE Performances during the KLOE-2 Run", in *Proc. IPAC'18*, Vancouver, Canada, Apr.-May 2018, paper TUYGBD2, pp. 624-627. doi:10.18429/JACoW-IPAC2018-TUYGBD2

[10] KEK press release: SuperKEKB collider achieves the world's highest luminosity, https://www.kek.jp/en/newsroom/2020/06/26/1400/.

[11] A. Abada *et al.*, "FCC-ee: The Lepton Collider: Future Circular Collider conceptual design report. Volume 2", *Eur. Phys. Jour. ST*, vol. 228, p. 261, 2019. doi:10.1140/epjst/e2019-900045-4

[12] CEPC Study Group, "CEPC Conceptual Design Report: Volume 1 – Accelerator", IHEP, Beijing, China, Rep. IHEP-CEPC-DR-2018-01, 2018.

[13] A. E. Bondar *et al.*, "Project of a Super Charm factory at the Budker Institute of Nuclear Physics in Novosibirsk", *Phys. Atom. Nucl.*, vol. 76, p. 1072, 2013. doi:10.1134/S1063778813090032

[14] Q. Luo *et al.*, "Progress of conceptual study for the accelerators of a 2-7 GeV Super Tau Charm facility in China", in *Proc. IPAC'19*, Melbourne, Australia, May 2019, p. 643. doi:10.18429/JACoW-IPAC2019-MOPRB031

[15] C. Curceanu *et al.*, ""Fundamental physics at the strangeness frontier at DAΦNE. Outline of a proposal for future measurements", arXiv:2104.06076

[16] S. Bettoni *et al.*, "Beam Based Measurements with the Modified Wigglers in DAFNE", in *Proc. IPAC'11*, San Sebastián, Spain, Sep. 2011, paper WEPC077, p. 2196.

[17] C. Milardi *et al.*, "Preparation activity for the SIDDHARTA-2 run at DAFNE", in *Proc. IPAC'18*, Vancouver, Canada, May 2018, paper MOPMF088, pp. 334-337.

[18] A. Drago *et al.*, "Commissioning of the iGp Feedback System at DAΦNE", in *Proc. of EPAC08*, Genoa, Italy, Oct. 2008, paper THPC116, p. 3251.

[19] A. Drago *et al.*, "Longitudinal quadrupole instability and control in the Frascati DAΦNE electron ring", *Phys. Rev. ST Accel. Beams*, vol. 6, p. 052801, May 2003. doi:10.1103/PhysRevSTAB.6.052801

[20] M. Cordelli *et al.*, "CCALT: A Crystal CALorimeter with Timing for the KLOE2 upgrade", *Nucl. Instr. and Meth. A* vol. 718, p. 81. doi:10.1016/j.nima.2012.11.074

[21] A. De Santis *et al.*, "DAΦNE luminosity monitor", in *Proc. IBIC'18*, Shangay, PRC, 2018, paper MOPB06, pp. 81-84.

[22] G. Balossini *et al.*, "Matching perturbative and Parton Shower corrections to Bhabha process at flavour factories", *Nucl. Phys. B*, vol. 758, pp. 227, 2006. doi:10.1016/j.nuclphysb.2006.09.022.

[23] L. Catani *et al.*, "Introducing a new paradigm for accelerators and large experimental apparatus control systems", *Phys. Rev. ST Accel. Beams*, vol. 15, p. 112804, 2012. doi:10.1103/PhysRevSTAB.15.112804