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DAΦNE OPERATION WITH THE UPGRADED KLOE-2 DETECTOR

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Abstract

The DAΦNE collider has been successfully commissioned after implementing major modification of the experimental detector and a general upgrade-consolidation program involving, although to a different extent, all the accelerator complex subsystems. This paper presents the Φ-Factory setup and the achieved performances in terms of beam dynamics, luminosity, detector background and related aspects.

INTRODUCTION

DAΦNE [1] is an accelerator complex consisting 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 ~ 97 m long. The two rings share an interaction region (IR), where the KLOE 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 during luminosity delivering. DAΦNE attained its maximum luminosity during the test of the new Crab-Waist collision scheme [2] achieving a peak luminosity, $L = 4.5 \cdot 10^{32}$ $cm^{-2}s^{-1}$, two orders of magnitude higher than the one measured by other colliders working at the same c.m. energy.

Operations for the KLOE detector have been organized in two stages. First the new IR [3] has been installed, tested and the luminosity, already measured in the pre-*CrabWaist* configuration, has been reproduced and slightly improved, $L = 1.52 \cdot 10^{32}$ $cm^{-2}s^{-1}$ [4]. Then, in the first seven months of 2013, the accelerator complex has been shut down again mainly to upgrade the detector, KLOE-2 [5], which in view of a higher luminosity had extended its physics search program, and to implement a general consolidation program concerning several machine subsystems [6].

The KLOE-2 setup includes tracking and calorimeter devices close to the IR. The major upgrade consists in a cylindrical GEM detector installed at 15 cm distance from the Interaction Point (IP).

Such upgrade imposed the extraction of the IR from inside the detector and the disassembly of the low-β section. As a consequence, before restarting operations, the collider had to be commissioned, once again, almost from scratch.

COMMISSIONING

The main commissioning phase started by the end of January 2014, but it has been severely slowed down by three main interruptions due to external circumstances and affecting the whole LNF laboratory. In fact a drastically reduction of the water supply first, and an electric blackout after imposed three shut-down costing, in total, two and half months of inactivity.

In general, operations received a very positive impulse from the consolidation activities undertaken during the 2013 shutdown [6, 7, 8]. Among all it is worth mentioning the working point stabilization, recovered by replacing broken bellows close to the IP, causing anomalous heating (up to 50÷60 ^{0}C) in the low-β defocusing quadrupole downstream the e^- beam.

The working points adopted by now are: $\nu_x^- = 5.098$, $\nu_y^- = 5.164$ and $\nu_x^+ = 5.1023$, $\nu_y^+ = 5.139$, which, according *LIFETRAC* [9] simulations should provide good luminosity and lay in a rather large stable area still to be explored.

Transverse Betatron Coupling Correction

Transverse betatron coupling has been optimized by tuning the rotations of the low-β focusing quadrupoles, now independent for the two rings, relying on transverse beam sizes evaluated by a calibrated synchrotron light monitor, as well as on the response matrix measured by varying corrector magnets. Presently a very good coupling correction has been achieved for the e^+ beam, $\kappa \sim 0.4\%$, with all the skew quadrupoles off, while a further optimization is needed for the e^- beam. Nevertheless by tuning the skew quadrupoles a transverse betatron coupling in the range 0.2% ÷ 0.3% can be achieved in both rings.

Beam Dynamics

Machine operation at high current strongly depends on vacuum conditions. Since the beam pipe has been opened in several main ring sections a quite long time has been spent to recover a reasonable dynamic vacuum level.

Highest currents stored, so far, in 98 contiguous bunches are 1.7 A and 1.15 A, for e^- and e^+ beam, respectively. These currents are the highest ever achieved after installing the new IR for the KLOE-2 detector, based on the *Crab-Waist* collision scheme.

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The three independent bunch-by-bunch feedback systems [10] installed on each DAΦNE ring are continuously working being essential for high current multi-bunch operations. The e^+ vertical feedback is now using a new ultra-low noise front-end module, designed in collaboration with the SuperKEKB feedback team, aimed at reducing the noise contribution to the transverse vertical beam size in collision.

Presently beam dynamics in the e^+ ring is clearly dominated by the e-cloud induced instabilities. These effects are suppressed by means of powerful bunch-by-bunch transverse feedback systems [10], by solenoids wound all around the straight sections and by on purpose designed electrodes [11] installed inside dipole and wiggler vacuum chambers. The electrodes have been already checked in 2012, during the KLOE preliminary run. Several measurements and tests demonstrated their effectiveness in thwarting the e-cloud effects [12]. These first studies have all been done by polarizing the stripline with a positive voltage in the range 0÷250 V. However simulations indicate that a factor two higher voltage is required to completely neutralize the e-cloud density due to a e^+ current of the order of 1 A. For this reason during the 2013 shutdown the electrode power supplies have been replaced with devices providing a maximum negative voltage of 500 V. The change of polarity was intended to limit the current delivered by the power supplies. The new setup has been tested storing a ~ 700 mA current in 90 bunches spaced by 2.7 ns, and measuring the horizontal and vertical tune spread along the batch with the electrodes on and off. Results show a clear reduction of the tune spread in both planes, but especially in the horizontal one [13].

It's worth mentioning that presently two out of the four electrodes installed in the wiggler magnets have been short-circuited since they were not working properly.

Another positive result in mitigating the detrimental effects induced by the e-cloud has been obtained lengthening the bunch by reducing the voltage of the RF cavity of the e^+ ring. Fig. 1 presents the behaviour of the pressure rise with the stored current, measured by two vacuum gauges installed on different arcs, as a function of the RF cavity voltage.

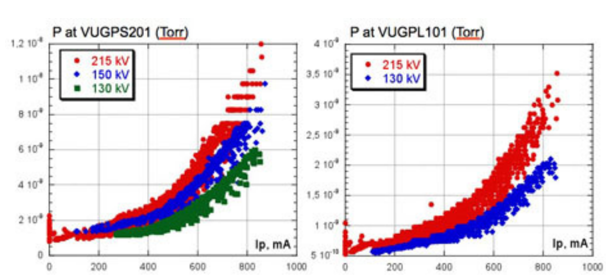

Figure 1: Pressure rise versus stored e^+ current in 2 different arcs of the e^+ ring as a function of the RF cavity voltage.

The e^- beam exhibits a microwave instability threshold (TMCI), appearing above a current of the order of ~10 mA per bunch, resulting in a widening of the transverse beam sizes. Such effect is quite moderate in single beam operation and becomes more harmful in collision due to the beam-beam interaction. The instability might be kept under control using an optics with higher momemtum compaction α_c. Beam dynamics also profited from replacing the bellows installed in the IR close to the low-β section. In fact some of them were seriously damaged and were causing random discharges.

LUMINOSITY

Luminosity in the present DAΦNE configuration is evaluated by using two different approaches.

A fast γ monitor measures the photon 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. They are used only for relative luminosity measurements, during collision optimization. The absolute luminosity measurement is provided by the experimental detector.

Luminosity Results

First luminosity has been optimized with the *Crab-Sextupoles* off. The overlap between colliding beams has been recovered, both in transverse and longitudinal plan, taking advantage from the two new beam position monitors installed around the IP [6]. The highest luminosity measured in large Piwinsky angle regime with the *Crab-Sextupoles* off has been slightly in excess of 10^{32} $cm^{-2}s^{-1}$. However in this configuration harmful effects have been observed such as: considerable reduction of the lifetime of one beam when injecting the other, transverse beam blow-up at high currents and deleterious background level. All these phenomena are expected, being correlated to the lack of a compensation mechanism for the synchro-betatron resonances affecting collisions in large Piwinsky angle regime.

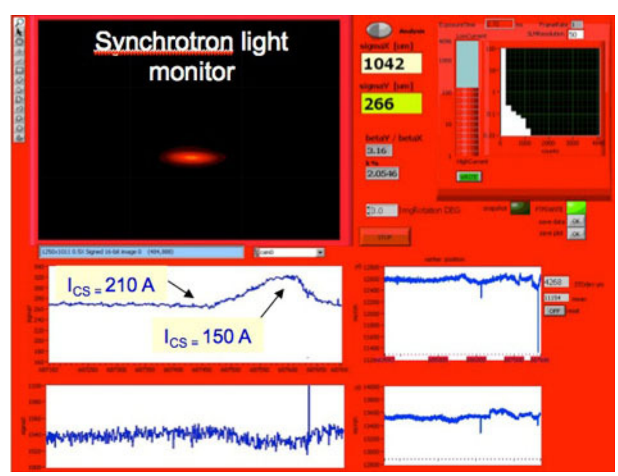

Figure 2: e^+ vertical beam size versus the *Crab-Sextupole* strengths.

After, the *Crab-Sextupoles* have been carefully aligned on the collision orbit, by using beam based alignment techniques, and their field increased progressively, while

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tuning collisions, till reaching strengths of the order of 70% and 50% of the nominal ones for e^+ and e^- respectively.

The effect of the *Crab-Sextupoles* has been clearly seen on the synchrotron light monitor, as well as on the luminosity monitors. For instance Fig. 2 shows the e^+ vertical beam size grows while reducing the *Crab-Sextupole* strengths and the opposite trend is observed restoring the initial conditions.

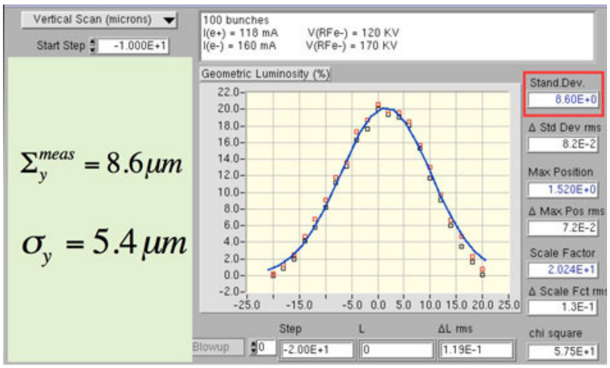

Figure 3: Vertical beam-beam luminosity scan.

Increasing bunch length for both beams appreciably contributed in enhancing peak luminosity.

The convoluted vertical sizes of the colliding bunches as measured by beam-beam scan at low current is $\sigma_y = 5.4\ \mu$m, due to the not yet optimized transverse coupling in the e^- beam, see Fig. 3.

The highest luminosity attained, so far, is $L = 1.7 \cdot 10^{32}\ cm^{-2}s^{-1}$ measured with current of the order of $I^- \sim 0.96$ A and $I^+ \sim 0.89$ A stored in 100 bunches. This value exceeds by a 13% the best luminosity ever achieved, at DAΦNE, during operations for an experimental apparatus including high field detector solenoid.

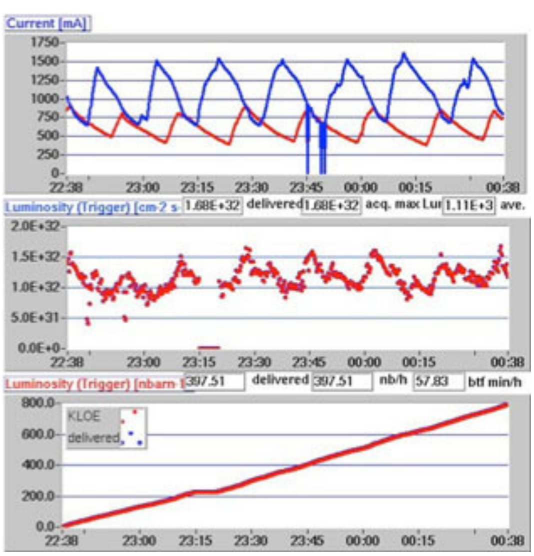

Figure 4: Hourly integrated luminosity .

Furthermore a rather promising hourly integrated luminosity has been recorded averaging over two hours, in moderate injection regime: $L_{\int 1hour} \sim 0.4\ pb^{-1}$, see Fig. 4. This measurement indicates that, having a reasonable uptime, a daily integrated luminosity at least of the order of $\sim 10\ pb^{-1}$ can be delivered to the experiment.

Background

Background hitting the experimental apparatus has been mitigated by the new shields inserted both side of the IP [6]. Presently it has been reduced to levels almost compatible with the detector data taking by adjusting: beam orbit, position of collimators (which have been advantageously modified) and making the beam injection process more efficient [7].

Pushing Luminosity Beyond the Present Values

A considerably higher luminosity might be attained by: transverse betatron coupling correction in the e^- ring, increase of stored currents and number of colliding bunches, rings optics and working point optimization, dynamic vacuum improvement. Further contributions might come also from exploring new optics configuration with higher α_c and from extensive beam dynamics studies.

CONCLUSION

The DAΦNE collider is operational again. Despite the adverse circumstances several clear results have been achieved: the instantaneous luminosity and the maximum stored beam currents are now the highest ever achieved in operations with an experimental apparatus including high field detector solenoid. Limiting factors have been well understood and still many parameters can be ameliorated to further improve the collider performances.

ACKNOWLEDGMENT

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