IL NUOVO CIMENTO Vol. 32 C, N. 3-4 Maggio-Agosto 2009
DOI 10.1393/ncc/i2009-10476-6

Colloquia: IFAE 2009

Results from the DAΦNE high luminosity test

C. Milardi on behalf of the DAΦNE Commissioning Team(*)
LNF-INFN - Frascati (Rome), Italy

(ricevuto il 19 Settembre 2009; pubblicato online il 24 Novembre 2009)

Summary. — In the second half of 2007 the Frascati DAΦNE collider has been upgraded in order to test an innovative collision scheme based on large Piwinski angle and providing for *Crab-Waist* compensation of the beam-beam interaction. In the following the main upgrade motivations are explained and the achieved results are presented and discussed.

PACS 29.20.-c – Accelerators.

1. – Introduction

DAΦNE [1] is an accelerator complex including a lepton collider working at the c.m. energy of the Φ-resonance (1.02 GeV) and an injection system. The collider consists of two independent rings, each 97 m long. In the original configuration the rings shared two, 10 m long, interaction regions (IR1 and IR2) where the KLOE and FINUDA or DEAR detectors were respectively installed. A full energy injection system, including an S-band linac, 180 m long transfer lines and an accumulator/damping ring, secures fast and high-efficiency electron-positron injection also during collisions. Collisions at DAΦNE, as well as at the other old generation factories, are provided by flat multi-bunch beams colliding under a horizontal angle θ and having a normalized crossing angle ψ (also known as Piwinski angle) smaller than 1, according to eq. (1) where σ_z and

(*) D. Alesini, M. E. Biagini, C. Biscari, A. Bocci, R. Boni, M. Boscolo, F. Bossi, B. Buonomo, A. Clozza, G. Delle Monache, T. Demma, E. Di Pasquale, G. Di Pirro, A. Drago, A. Gallo, A. Ghigo, S. Guiducci, C. Ligi, F. Marcellini, G. Mazzitelli, F. Murtas, L. Pellegrino, M. Preger, L. Quintieri, P. Raimondi, R. Ricci, U. Rotundo, C. Sanelli, M. Serio, F. Sgamma, B. Spataro, A. Stecchi, A. Stella, S. Tomassini, C. Vaccarezza, M. Zobov, INFN-LNF, Frascati; E. Levichev, P. Piminov, D. Shatilov, V. Smaluk, BINP SB RAS, Novosibirsk; S. Bettoni, CERN, Geneva; P. Valente, INFN-Roma1, Roma; K. Ohmi, KEK, Ibaraki; N. Arnaud, D. Breton, L. Burmistrov, A. Stocchi, A. Variola, B. F. Viaud, LAL, Orsay; M. Esposito, University La Sapienza, Roma; P. Branchini, INFN Roma3, Roma; D. Teytelman SLAC, Menlo Park, California.

σ_x^* are the r.m.s. longitudinal and horizontal bunch sizes at the interaction point (IP), respectively.

$$\psi = \frac{\sigma_z}{\sigma_x^*}\,\mathrm{tg}\frac{\theta}{2} \sim \frac{\sigma_z}{\sigma_x^*}\frac{\theta}{2} \ll 1. \tag{1}$$

This criterion is intended to cope with the synchro-betatron resonances arising from the horizontal angle required to minimize secondary bunch crossings around the IP. In this context, the only approach to get a higher luminosity consists in reducing the vertical betatron function β_y^* at the IP, increasing the beam intensity and tuning properly beam emittance and transverse beam sizes to keep under control the beam-beam effects.

2. – New collision scheme

DAΦNE started steady operations in 2001 and till summer 2007 provided luminosity, in sequence, to the experiments which logged a total integrated luminosity of $\sim 4.65\,\mathrm{fb}^{-1}$. In the same years the collider performances have been considerably improved achieving a peak luminosity $L_{\mathrm{peak}} \sim 1.6 \cdot 10^{32}\,\mathrm{cm}^{-2}\,\mathrm{s}^{-1}$ and a record daily integrated luminosity $L_{\mathrm{daily}} \sim 10.$ (pb^{-1}), by means of several successive upgrades implemented during the shutdowns for the experiment change over [2, 3]. However several factors were limiting any further relevant luminosity improvement. In fact the β_y^* was already 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 [4] occurring in each one of the two IRs. The new collision scheme based on large Piwinski angle and *Crab-Waist* compensation proposed and implemented at DAΦNE overcomes all these limitations [5]. The large Piwinski angle, obtained by increasing the horizontal crossing angle and by reducing the transverse horizontal beam size at the IP, provides several advantages. It lowers the beam-beam tune shift in the horizontal plane, and it allows for a lower β_y^* value by taking advantage of the shorter longitudinal overlap length between colliding bunches. It also cancels almost completely parasitic crossings because the vacuum chambers of the two beams can be separated just after the first low-beta quadrupole in the IR. A couple of *Crab-Waist* sextupoles, installed symmetrically and with a proper phase advance with respect to the IP, suppress the betatron and synchrobetatron resonances generated by the vertical motion modulation due to the horizontal oscillation. It is worth mentioning that with the DAΦNE upgrade several other accelerator components have been modified [6] including the second unused IR, the feedback systems and some devices such as bellows and injection kickers. The SIDDHARTA experiment [7], an evolution of DEAR, has been installed on the new IR. It is a compact device without solenoidal field providing a simple environment to test the effectiveness of the new collision scheme.

3. – Experimental results

3·1. *Crab-Waist compensation and luminosity.* – The impact of the *Crab-Waist* sextupoles has been studied and discussed in detail [8]. It can be recognized at a glance when comparing measurements corresponding to runs with *Crab-Waist* sextupoles on and off (see fig. 1 left). At low current the luminosity is the same in the two cases, and it is significantly higher than the one measured during the operation with the DAΦNE original collision scheme. As the product of the stored currents exceeds $0.3\,\mathrm{A}^2$ the luminosity measured with the *Crab-Waist* sextupoles off becomes lower and a corresponding

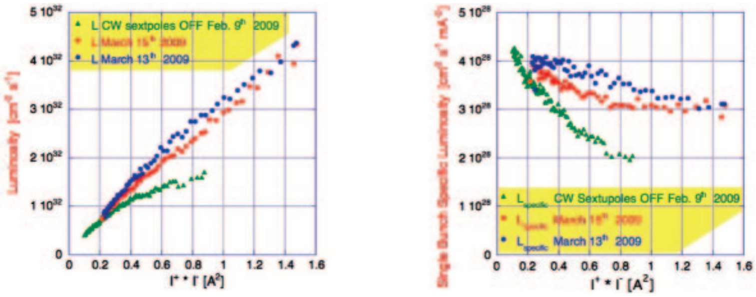

Fig. 1. – (Colour on-line) Left: luminosity *vs.* the product of the colliding currents during two of the best runs (blue and red dots) and with *Crab-Waist* sextupoles off (green triangles). Right: single bunch specific luminosity *vs.* the product of the colliding currents for two of the best run (blue and red dots) and for the *Crab-Waist* sextupoles off (green triangles).

transverse beam size blow up and beam lifetime reduction are observed as a consequence of the uncompensated beam-beam resonances. The effect is even more evident when looking at the single bunch specific luminosity with *Crab-Waist* sextupoles off (green triangles in fig. 1 right).

3·2. *Luminosity and beam-beam tune shift.* – In May 2008, after only six months dedicated to machine commissioning, values of luminosity considerably higher ($\sim 30\%$) than those achieved in the past were already measured. The peak luminosity, then, has been progressively improved by tuning the collider and increasing the beam currents; the maximum value achieved by now is $4.36 \cdot 10^{32}\,\mathrm{cm}^{-2}\,\mathrm{s}^{-1}$ measured in several runs (see blue and red dots in fig. 1 left) with good luminosity-to-background ratio. The present peak luminosity is satisfactorily close to the nominal one predicted by numerical simulations $5.0 \cdot 10^{32}\,\mathrm{cm}^{-2}\,\mathrm{s}^{-1}$. The highest single bunch luminosity achieved so far is $L_{\mathrm{sb}} \sim 5 \cdot 10^{30}\,\mathrm{cm}^{-2}\,\mathrm{s}^{-1}$ measured letting in collision 20 bunches, spaced by four empty buckets, instead of the usual 105. The single bunch specific luminosity, defined as the single bunch luminosity divided by the product of the single bunch currents, at low currents exceeds by 4 times the best value measured during the past DAΦNE runs (present values are red and blue dots in fig. 1 right). It gradually decreases with colliding beam currents. This reduction can be only partially explained by the growing beam size blowup due to the beam-beam interaction [9]. Another factor comes from the fact that in the large Piwinski angle regime the luminosity decreases with the bunch length, which in turn is determined by the ring coupling impedance. The beam-beam vertical tune shift evaluated from measured peak luminosity taking into account the hourglass effect is now $\xi_y = 0.042$, a factor ~ 1.5 higher than the maximum value achieved with the original collision scheme: $\xi_y = 0.025$ and $\xi_y = 0.029$ for the KLOE and the FINUDA runs, respectively. In weak-strong collision regime an even higher $\xi_y = 0.063$ has been attained. In this case a luminosity $1.31 \cdot 10^{32}\,\mathrm{cm}^{-2}\,\mathrm{s}^{-1}$ has been measured with $I^- \sim 2.0\,\mathrm{A}$ against $I^+ \sim 0.2\,\mathrm{A}$. Since the ring damping times are the same as in the past in the case of the FINUDA data, and they are even longer than in the case of the KLOE ones, the present tune-shift represents a further evidence of the *Crab-Waist* sestupoles effectiveness in compensating the bem-beam coupling resonances in strong-strong as well as in weak-strong regimes.

3·3. *Integrated luminosity.* – The best hourly and daily integrated luminosity measured, by now, during the SIDDHARTA run are $L_{\mathrm{hourly}} \sim 0.79$ (pb^{-1}) averaged over

TABLE I. – *DAΦNE present achievements.*

	Upgrade	KLOE run	FINUDA run
L_{peak} ($10^{32}\,\text{cm}^{-2}\,\text{s}^{-1}$)	4.36	1.5	1.6
L_{hourly} (pb^{-1})	1.03	0.44	0.5
L_{daily} (pb^{-1})	14.98	9.8	9.4
I^- at L_{peak} (A)	1.4	1.4	1.5
I^+ at L_{peak} (A)	1.0	1.2	1.1
N_{bunch}	105	111	106
ξ_y at L_{peak}	0.042	0.025	0.029

two hours, and $L_{\text{daily}} \sim 15.0$ (pb^{-1}). Daily integrated luminosity is a factor 1.5 higher than before the upgrade although it has been obtained in a moderate injection regime aimed at maximizing the experiment data taking, vetoed during injection due to the higher background. A much higher integrated luminosity can be delivered increasing the injection rate. In fact the time needed to switch the injection system from electrons to positrons and vice versa has been considerably reduced (a factor ~ 3) and is now less than a minute. A continuous switching regime provides a hourly integrated luminosity $L_{\text{hourly}} \sim 1.0$ (pb^{-1}) [10], this result opens significant perspectives for the KLOE experiment, which is intrinsically much less sensitive to background. Scaling this best integrated luminosity measured over two hours it is reasonable to expect a daily integrated luminosity larger than 20.0 (pb^{-1}), and assuming 80% collider uptime, as it was for the past runs, a monthly integrated luminosity of ~ 0.5 (fb^{-1}).

4. – Conclusions

The new collision scheme based on large Piwinski angle and *Crab-Waist* implemented on DAΦNE worked as predicted by the preliminary studies and numerical simulations. The present achievements are summarized and compared with the old ones in table I. The principle of *Crab-Waist* compensation has been widely recognized as a major advance in the field of the beam-beam interaction in lepton colliders. The present luminosity achievements have opened new perspectives for the DAΦNE collider, and a new run for the KLOE experiment has been planned for spring 2010. The new collision scheme is the main design concept for a new project aimed at building a Super-B factory [11] that is expected to achieve a luminosity of the order of $10^{36}\,\text{cm}^{-2}\,\text{s}^{-1}$.

REFERENCES

[1] VIGNOLA G. *et al.*, *Frascati Phys. Ser.*, **4** (1996) 19.
[2] GALLO A. *et al.*, *EPAC06, Edinburgh, UK*, pp. 604-606.
[3] MILARDI C. *et al.*, *PAC07, Albuquerque, USA*, p. 1457.
[4] MILARDI C. *et al.*, arXiv:0803.1544v3.
[5] RAIMONDI P. *et al.*, physics/0702033.
[6] MILARDI C. *et al.*, e-print: physics/0408073.
[7] SIDDHARTA COLLABORATION, *Eur. J. Phys. A*, **31** (2007) 537.
[8] MILARDI C. *et al.*, *Int. J. Mod. Phys. A*, **24** (2009) 360.
[9] ZOBOV M. *et al.*, *ICFA Newslett.*, **48** (2009) 34.
[10] MILARDI C. *et al.*, *ICFA Newslett.*, **48** (2009) 23.
[11] BOSCOLO M. *et al.*, these proceedings.