100 BUNCH DAΦNE OPERATION

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Abstract

The DAΦNE collider has been operating by filling 100 consecutive buckets out of the available 120 with a gap to avoid ion trapping in the electron beam. To reduce the effect of the parasitic crossings the crossing angle has been increased up to 29 mrad and the horizontal beta function at the interaction point lowered down to 1.7 m. Moreover both transverse and longitudinal feedbacks have been optimized for this more demanding mode of operation. Comparison between 100 and 50 bunches operation in 2002 runs is presented.

INTRODUCTION

DAΦNE is a e^+/e^- collider, with center of mass energy 1.02 GeV (Φ-Factory). It has two symmetric main rings and two IP's: KLOE detector is in IP1, DEAR detector is in IP2. The harmonic number is 120 and this is the maximum number of storable bunches. The minimum bunch distance is 2.7 nsec, corresponding to ~80 cm, and the maximum single bunch design current is 44 mA (achieved > 200 mA).

The peak luminosity can be expressed as function of number of bunches (n_b) and single bunch currents (I^+ and I^-)

$$L = \frac{n_b I^+ I^-}{4\pi f_{rev} e^2 \sigma_x \sigma_y} \quad (1)$$

where f_{rev} is the revolution frequency, e is the electron charge, σ_x and σ_y are the horizontal and vertical r.m.s. sizes of the bunch.

The peak luminosity is proportional to the number of colliding bunches and to the product of the single bunch currents. We want to increase the luminosity and this can be done also increasing the number of colliding bunches and the single bunch currents.

Since the tune shift (ξ) is proportional to the bunch current (I) and tends to saturate when the current increases (up to now $\xi < 0.03$), it is not effective to inject the single bunch current over a threshold, so we have increased the number of colliding bunches.

An ion clearing gap is necessary for the e^- beam: it can be between 15% and 25% of the ring. Usually a uniform train of bunches followed by one gap is stored: every bunch of the train can be separated from the following one by N empty buckets (N=0,1,2,…).

Different bunch patterns have been used for collision in the past. In the year 1999 the collision bunch pattern was composed by a train of 23 bunches separated by 3 empty buckets and followed by ¼ ring gap.

During the year 2000 the collision bunch pattern was 30 bunches separated by 2 empty buckets and followed by ¼ ring gap.

In the year 2001 and 2002 the collision bunch pattern was 50 bunches separated by 1 empty bucket and followed by 1/6 ring gap.

In the last 2 months of the year 2002, in the IP2, for DEAR detector, the bunch pattern used for collision was 100 contiguous bunches followed by 1/6 ring gap. In Fig.1 a sketch of the colliding pattern in the years 1999-2002 is presented.

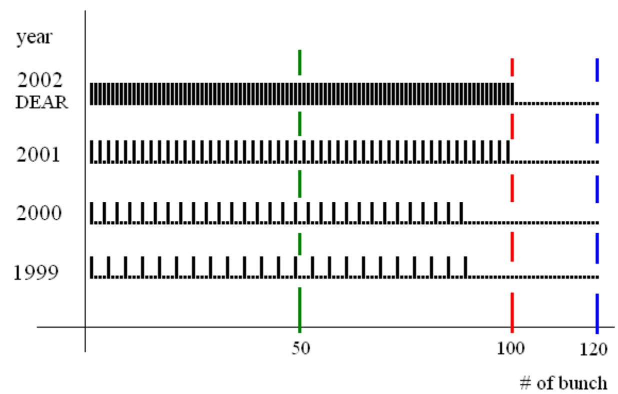

Fig. 1: – Colliding bunch patterns, years 1999-2002.

OPTICS DEVELOPMENTS

With the aim to bring into collision 100 contiguous bunches, some modifications to the optic layout have been implemented to minimize the effects of the parasitic crossings:

1) a lower horizontal beta in the Interaction Region (see Fig. 2);
2) a larger Crossing Angle at the IP, from 12.5*2 mrad to 14.5*2 mrad;
3) a smaller horizontal emittance.

With these modifications the first parasitic crossing horizontal separation (@40 cm from IP) has increased from 5 σ_x to 12 σ_x.

Minimizing of the horizontal size (see points 1 and 3 listed above) gave also a single bunch luminosity increase.

In order to reduce the non-linearities, three octupole magnets have been installed in each ring. Tuning correctly the machine non-linearities, it has been possible to reach better lifetimes, dynamic apertures and improve beam-beam performance. A machine model has been developed to study the linear and non-linear behaviour [1].

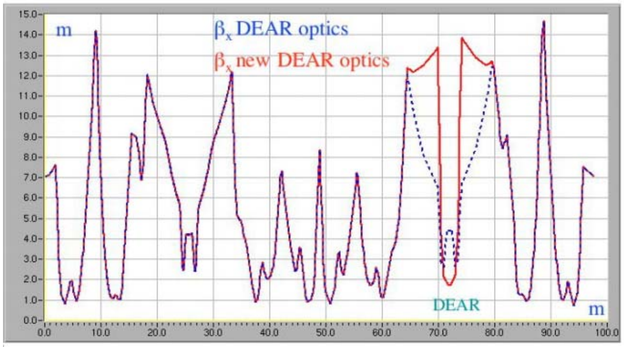

Figure 2: The horizontal beta at IP2 has been lowered: 4.4m at December 2001(blue), 1.7m after April 2002 (red).

The Piwinski's angle is evaluated as a "badness factor". It is given by the formula

$$\theta = \frac{\sigma_z \phi}{\sigma_x} < 1 \qquad (2)$$

where σ_z and σ_x are the longitudinal and horizontal r.m.s. sizes of the bunch and ϕ is the crossing angle.

Table 1: Piwinski's angle θ for different DAΦNE setup.

	σ_z cm	βx, m	β_y, m	ε_x, 10^{-6}	σ_x mm	σ_y μ	ϕ mrad	θ
Design	3	4.5	.045	1	2.12	20	12.5	.18
KLOE	2.5	2.7	.026	.74	1.41	20	11.5	.20
DEAR, Decemb. 2002	2	2.54	.040	.78	1.13	20	13.5	.24
DEAR, After April 2002	2	1.7	.030	.62	1.03	20	14.5	.28

In Table 1 are reported several machine parameters applied to four different machine setup: design, collision for Kloe, collision for DEAR before and after April 2002. β_x and β_y are the horizontal and vertical betatron functions, ε_x is the horizontal emittance, ϕ is the crossing angle at the IP, and θ is the Piwinski's angle.

As it can be seen, in order to bring into collision 100 bunches, the crossing angle and, as consequence, Piwinski's angle have been increased. However, this practically does not affect the single bunch luminosity.

BEAM DYNAMICS

The DAΦNE longitudinal dynamics is affected by strong coupled bunch synchrotron dipole oscillations well damped by the feedback developed with SLAC/LBL.

Besides in both rings, at high currents, harmful longitudinal quadrupole instabilities need to be cured.

In Fig. 3 a positron beam power spectrum measured by a powerful real time FFT analyzer HP3587s is shown. The beam spectrum, recorded with 100 bunches, 900mA, in collision, shows a large longitudinal quadrupole instability on the mode #76.

The Longitudinal feedback, built to damp the synchrotron dipole oscillations, is able, using a special setup, to damp the quadrupole motion [2].

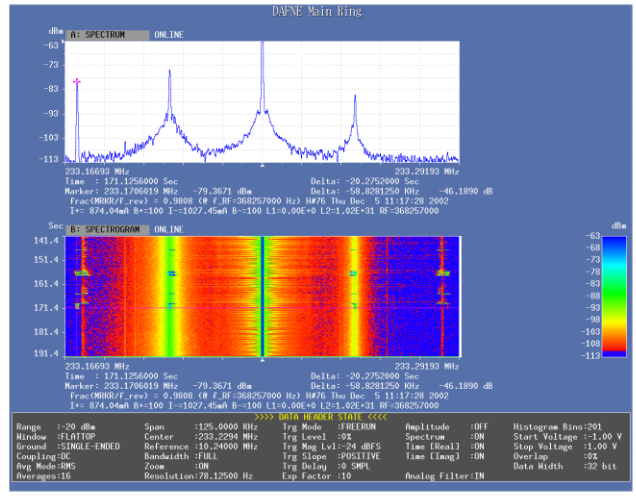

Fig.3: - e^+ beam power spectrum measured by a real time FFT analyzer HP3587. The beam spectrum, (100 bunches, 900mA, in collision) shows a large longitudinal quadrupole instability.

Vertical and horizontal instabilities require powerful feedback systems.

In the year 1999 the collision bunch pattern was 23 bunches each separated by 3 empty buckets. Only the longitudinal feedback was installed at full power (3x250W), without any transverse feedbacks.

During the year 2000 the collision bunch pattern was 30 bunches each separated by 2 empty buckets. The vertical feedbacks were added with reduced power (2x100W). In the year 2001 the collision bunch pattern was 50 bunches separated by 1 empty bucket. The vertical feedbacks were working at full power (2x250W) and the horizontal ones with reduced power (2x100W).

In the last 2 months of the year 2002 the bunch pattern was 100 contiguous bunches colliding in IP2 (DEAR) and the complete control of longitudinal quadrupole in both rings was successfully achieved.

With the new layout, it has been possible to store more than 1.8A with stable e^- beam in 90 contiguous bunches (single beam not colliding, >20mA per bunch), while in 50 bunches separated by 1 empty bucket, the maximum current achieved was smaller (~1.250A).

To achieve this, it has been necessary a very accurate transverse and longitudinal feedback setup and a complete separation of the signal of contiguous bunches in the feedbacks.

RESULTS

In this section we present the results obtained in the October–December 2002 shifts with 100 bunches colliding. In Fig.4 signals coming from two longitudinal pickups and showing the e^+ and e^- bunch train during collision, are monitored by an oscilloscope.

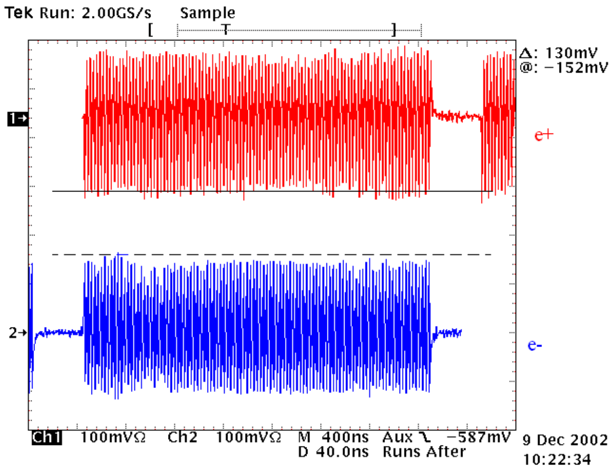

Fig.4: - Signals from two longitudinal pickups show the e^+ and e^- bunch train during collision monitored by an oscilloscope.

During the collision shifts more than 2 Ampere have been usually stored in two beams with acceptable background and lifetime.

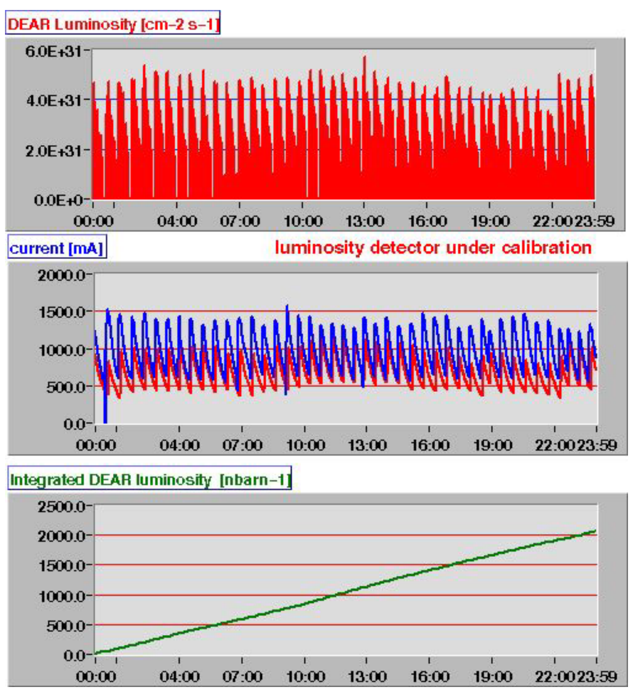

Fig.5: – Peak and integrated luminosity in 24h (12/8/02).

The collider has shown a very good reliability: in Fig. 5 the peak luminosity, currents and integrated luminosity are presented for one of the best 24 hours of data taking (12/8/2002, IP2). With 100 bunches a DEAR peak luminosity of $7*10^{31}$ cm-2 s-1 has been achieved while with 50 bunch it was $4.5*10^{31}$ cm-2 s-1. With 100 bunches a DEAR integrated luminosity of 2 $pbarn^{-1}$ per day has been reached while with 50 bunches the maximum value was 1.1 $pbarn^{-1}$. This has allowed completing the physics program for the DEAR experiment.

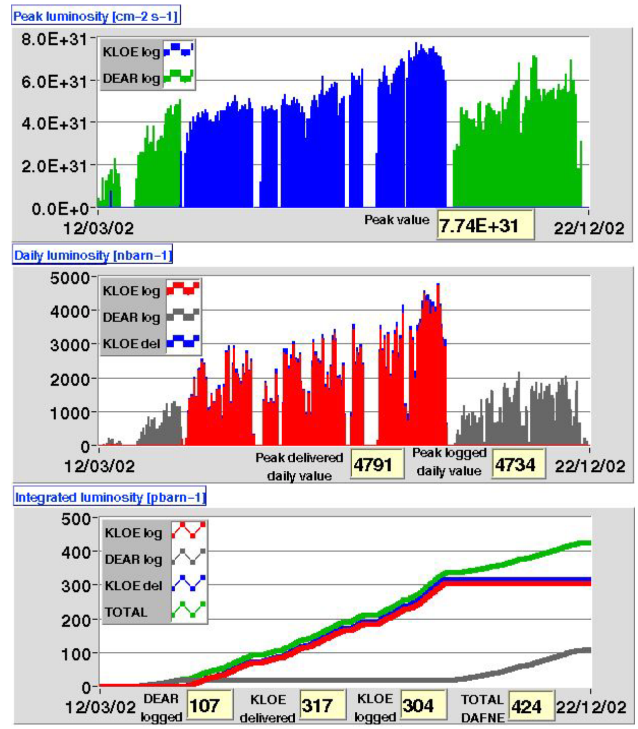

Fig. 6: – Year 2002 peak and integrated luminosity.

CONCLUSION

During 2002 it has been possible to collide with 100 contiguous bunches (out of 120) by implementing a new machine setup, lowering the horizontal beta at the IP, increasing the crossing angle and decreasing the horizontal emittance.

Storing high current in 100 bunches has become possible using powerful active feedback systems necessary to damp longitudinal dipole oscillations, longitudinal quadrupole, horizontal and vertical instabilities.

As result both peak and integrated luminosity have grown and there is still margin for further improvements increasing the currents up to 20mA per bunch; these results have been obtained in only two months.

With these shifts, DEAR experiment has completed the data taking. New IR's for KLOE and FINUDA detectors have been designed taking in mind this approach and are ready for the next shifts.

REFERENCES

[1] Milardi et al. "Developments in Linear and Non-Linear DAΦNE Lattice", RPAG025, these proceedings.

[2] A. Drago et al. "Longitudinal quadrupole instability and control in the Frascati DAΦNE electron ring", Phys. Rev. ST-AB, Vol.6, I5, 052801 (2003).