LUMINOSITY OPTIMIZATION IN DAΦNE

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Abstract

DAΦNE the Frascati Φ-factory, started the two beams commissioning on March 1998. Since then a relevant amount of experience concerning the techniques and procedures for optimizing the luminosity has been acquired. All the schemes used are strongly based on the use of various diagnostic systems including a dedicated luminosity monitor, orbit measurement, tune monitor, synchrotron light monitor and others. A summary of the used techniques, with accent on the diagnostic aspects, is presented.

1 INTRODUCTION

DAΦNE is an electron-positron collider with separated vacuum chamber rings and two interaction regions (IR) with horizontal crossing angle [1]. The main design parameters are listed in Tab. 1, while a general lay-out is shown in Fig. 1.

Table 1: DAΦNE Design Parameters

Energy	510 MeV/beam
Single Bunch Luminosity	4.4 10^{30} cm^{-2} s^{-1}
Multibunch Lum. (30/120 bunches)	1.3/5.3 10^{32} cm^{-2} s^{-1}
Beam-beam Tune Shift (H/V)	0.04/0.04
Ring Length	97.69 m
Dipole Bending Radius	1.4 m
Natural Emittance	10^{-6} m rad
Coupling	0.01
Natural Relative Energy Spread	4 10^{-4}
r.m.s. Bunch Length	3 10^{-2} m
Damping Times (L/T)	17.8/36.0 ms
Beta Functions @ IP (V/H)	4.5/450 cm
Horizontal Crossing Angle	10-15 mrad
Particles/Bunch	8.9 10^{10}
Number of Bunches	30÷120
RF Frequency	368.26 MHz

The center of mass energy of the beams is tuned on the mass of the Φ meson in order to study the rare phenomenon of the CP violation that can appear when the Φ's decay in neutral kaons. In order to collect sufficient statistics a very high integrated luminosity is required.

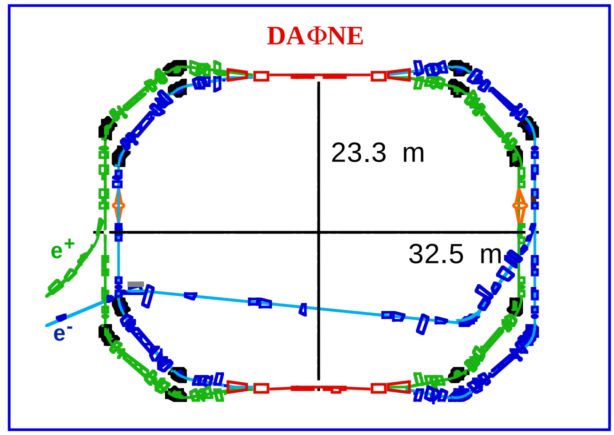

Figure 1: DAΦNE Main Rings Lay-out.

The luminosity commissioning of DAΦNE was organized in two different phases. During the first period, that started on March 1998 and ended on November 1998, the main goal was to obtain a single bunch luminosity of 10^{30} cm^{-2} s^{-1} as a test of the machine capabilities. In order to gain enough comprehension and operational experience, the IR was equipped with a provisional insertion in which all the quadrupoles in the low-beta triplets were normal conducting, instead of permanent magnet type, the vacuum chamber was instrumented with a beam position monitor (BPM) just at the IP and with additional BPM's of electrostatic (button) and directional (strip-line) types. No experiment detector was present at that time. A four months shutdown period followed, during which the CP violation experiment KLOE [2] was installed with its. detector totally immersed in the magnetic field of a ~6 m diameter superconducting solenoid. The second phase of the two beams commissioning started few weeks ago, on April 1999, with the solenoidal magnetic field (2.4 Tm) of the detector on. At the low energy of DAΦNE, this field creates a strong perturbation that must be carefully compensated. The compensation operation was successfully performed in few days and since April 14, the KLOE detector is collecting Φ events, making of DAΦNE the first factory running physics. Table 2 shows the main results so far obtained.

Table 2: DAΦNE Achieved Results

Single Bunch Luminosity	1.4 10^{30} cm^{-2} s^{-1}
Multibunch Luminosity (13 bunches)	1.5 10^{31} cm^{-2} s^{-1}
Particles/Bunch	2.3 10^{11}
30 bunches Stored Current (e^+/e^-) (design: 1.1 A)	0.56/0.54 A
Integrated Luminosity to KLOE Experiment (May 12, 1999)	30 nb^{-1}

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Table 3: Luminosity Parameters and Diagnostic Systems Matrix.

	Tune Measurement System	Orbit Acquisition System	Synchrotron Light Monitor	Oscilloscope Monitor	Longitudinal Feedback	Stored Current Monitor	Luminosity Monitor
IR Orbit		**o**					
Longitudinal Position@IP				**o**			**o**
IP Vertical Position		**o**					**o**
IP Vertical Angle		**o**					**o**
IP Horizontal Position		**o**					**o**
IP Horizontal Angle		**o**					**o**
IP Transverse Tilt			**x**				**o**
IR Optical Functions	**o**	**x**					**o**
Coupling &Emittance	**x**		**o**			**x**	
Working Point	**o**						
Beam-Beam Effects	**o**	**o**	**x**			**x**	**o**
Instabilities	**o**		**x**	**x**	**o**		
Dynamic Aperture						**o**	

The luminosity tuning up passes through the optimization of several machine parameters. This operation is performed by means of the continuous and intensive use of most of the different diagnostic systems present in DAΦNE. Table 3 indicates these machine parameters and the diagnostic systems that are used for their optimization. In the table the dots indicate the primary importance regulations while the crosses the secondary ones.

The machine parameters, relevant in the luminosity optimization, can be separated in two main categories. The first one concerns the optimization of the interaction point (IP) 'geometry', or in other words, of the mutual position of the two beams at IP. The second category includes those parameters that allow to increase the maximum beam-beam tune shift and then to maximize the number of particles able to stay in collision steadily. The quantities in the upper half of Tab. 3 belong to the first category, while the remaining parameters belong to the second one.

The typical luminosity optimization process in DAΦNE consists in a number of steps. First of all, the single beam parameters are tuned. That includes, for example, the optimization of the coupling and of the transverse tilt by the synchrotron light monitor, of the working point and of the betatron functions at IP by the tune measurement system, of the IP geometry by the orbit acquisition system. Once one of the beams has been properly tuned, the whole operation must be repeated for the other one. At this point, if everything has been done correctly, the beams are ready for the last phase of the luminosity optimization. Few mA of each beam are stored and brought into collision. By using the luminosity monitor it is now possible to fine tune the geometry at the IP. Vertical position and angle, longitudinal position, horizontal position and angle and transverse tilt can be now adjusted in order to maximize the luminosity. Actually these adjustments affect each other and some iterations are necessary to achieve the best result. It is worth to remark the importance of this optimization phase performed with the luminosity monitor. To be efficient this monitor must be independent from the experiment detectors and completely available to the machine personnel. Additionally, it must be fast enough to permit real time adjustment of the machine parameters. The next paragraph will include a brief description of the diagnostic systems together with some examples of the measurements used for luminosity optimization.

2 DIAGNOSTIC SYSTEMS FOR LUMINOSITY OPTIMIZATION

2.1 Tune Measurement System

Figure 2 shows the two different systems used in DAΦNE for measuring the fractional part of the horizontal and vertical betatron tunes.

The first one uses a 'classic' scheme where the RF output of a network analyzer (HP 4195A 10 Hz - 500 MHz), amplified up to 100 W by class A amplifiers, generates the sweeping excitation for a transverse kicker. The beam response is then picked-up by BPM's whose signals, properly combined, are sent back to the network analyzer, where a simultaneous analysis of the tunes in both the planes is performed. The single measurement takes the time necessary for a complete sweeping cycle, making this system not suitable for real time monitoring of the tunes. Fast measurements are instead possible by means of the second system, where the excitation is now provided by a white noise generator. The beam response signal is sent to a spectrum analyzer (HP 70000 system) operating as a detector in zero span mode. The spectrum analyzer IF is then down-converted by a HP 89411A module and finally processed by a FFT signal analyzer, HP 3587S, with 23 bits resolution and 10 MHz sampling rate. The two systems can be used for both the beams indifferently.

The tune measurement system plays a primary role in the luminosity optimization process. Measurements such as tune plane working point, tune shifts induced by quadrupole strength variations for evaluating the beta functions at IR, coupling measurements by the closest tune approach, coherent beam-beam tune shift are some of the fundamental measurements that are heavily used during the luminosity optimization. Moreover the spectrum analyzer combined with the real time signal analyzer is very powerful and useful in identifying and in the observation of instabilities.

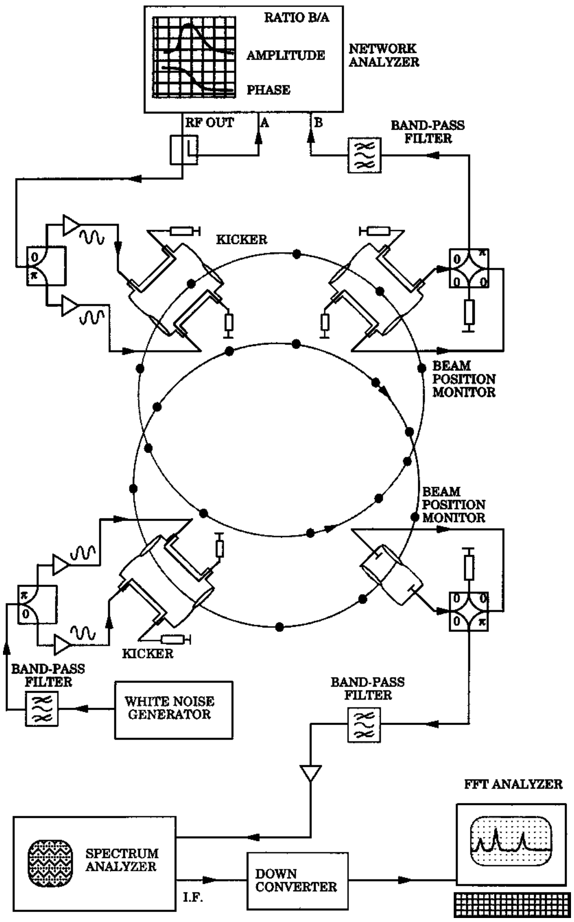

Figure 2: Tune Measurement System Schematic

Figure 3 shows an example of a coherent beam-beam tune shift measurement performed on the positron beam with the real time system.

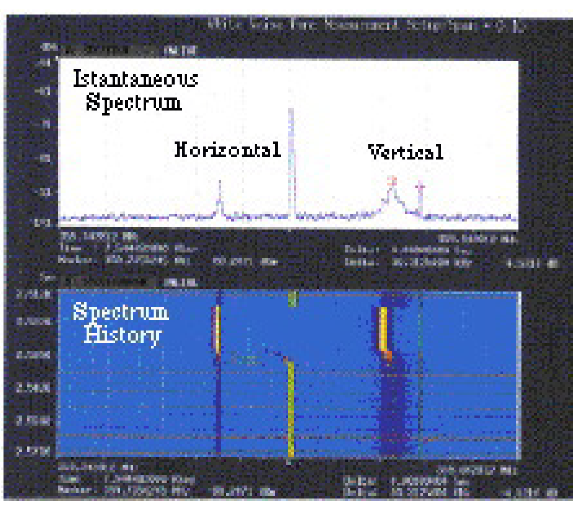

Figure 3: Coherent Beam-beam Tune Shift

2.2 Orbit Acquisition System

The 45 beam position monitors (BPM), of the button type, distributed along each of the Main Rings allow efficient closed orbit measurements in DAΦNE [3]. The electronic detector, one per each BPM, is a commercial board by BERGOZ built according to DAΦNE specifications. The scheme is based on a super heterodyne receiver, which converts the beam spectrum selected harmonic into an intermediate frequency before the amplitude detection. The board analog outputs are then sent to four VME acquisition systems, one per machine quarter. Each of these systems is composed by a bank of HP1352 FET Multiplexers connected to a HP1326B Digital Multimeter. The hardware control and the data acquisition are performed by the DAΦNE Control System processor board [4], based on a Motorola 68030 CPU, which runs a purpose built LabView application. The whole orbit acquisition rate is 5 Hz, the rms resolution is about 20 μm and stable measurements can be performed down to 1 mA of stored current.

The orbit acquisition system is a very important tool during luminosity optimization. In fact the geometry of the interaction region, in all its degrees of freedom, must be first tuned by this system. Moreover, as Fig. 4 shows, global orbit measurements when the beams are in collision can evidence beam-beam deflection effects. By minimizing this collision induced orbit, by local bumps at the IR, it is possible to optimize the overlap at the IP.

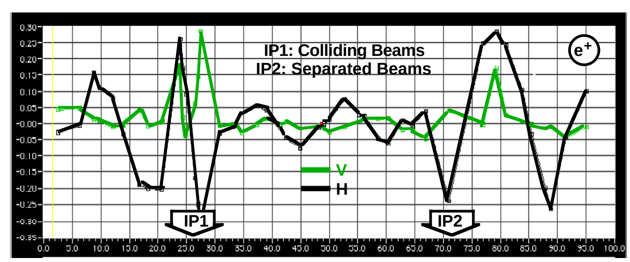

Figure 4: Beam-Beam Deflection Orbit. Horizontal scale 5 m/div, vertical scale 50 μm/div.

2.3 Synchrotron Light Monitor

Two synchrotron light monitors (SLM) are present in DAΦNE, one in each of the rings. In order to be able to perform beam emittance measurements, the source points have been chosen in dipoles with very small horizontal dispersion. Because of the large emittance, the transverse beam dimensions in DAΦNE remain relatively large even down to a coupling factor smaller than 0.01. This situation allows the use of the visible portion of the synchrotron radiation maintaining, at the same time, the monitor resolution sufficiently small. In the present configuration a water cooled 45° aluminum mirror, placed inside the vacuum chamber, deflects the light through a vacuum window and a slit into a CCD camera. In the final configuration [5] the light will be transported to a dedicated laboratory outside the controlled area by an achromatic optical channel, aberration free up to the second order, to extend the measurement capabilities of the monitor and provide the maximum flexibility of use.

From the point of view of the luminosity, the most relevant measurements that can be performed by the SLM include emittance, coupling and transverse tilt.

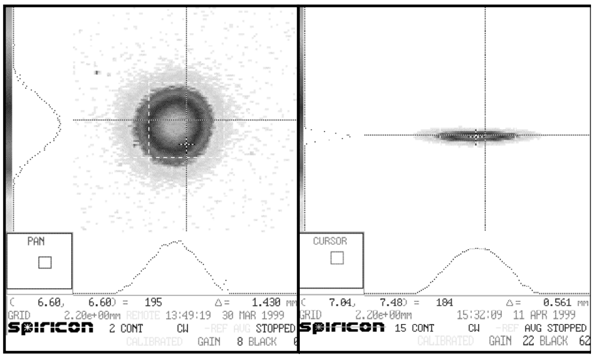

Figure 5: Coupling Measurements by the DAΦNE SLM

Additionally, from the simple observation of the beam spot, some useful indications can be derived concerning beam-beam effects such as tails, distribution variations, induced instabilities and so on. The example in Fig. 5 shows coupling measurements performed on April 99 when, left side, for the first time the positron beam was stored with the KLOE field on (45% of coupling) and, right side, when after few days the field effects were properly compensated and the coupling was reduced to 1.1%.

2.4 Oscilloscope System

This system is based on a 4 channel 2.5 Gsamples/s 500 MHz oscilloscope and on a hierarchical (1.3 GHz) RF MUX tree housed on VME crates and controlled by a CPU running under the DAΦNE Control System which provides also a friendly user interface able to select each of the signals connected to the lower level of the multiplexer tree and, additionally, the proper timing system signal for triggering the oscilloscope. Several beam pickups, including wall current monitors, together with a variety of other useful signals, such as the ones from the injection kickers, can be monitored by this system.

As already mentioned, DAΦNE is a collider with separated vacuum chambers. Each of the beams runs through a different magnetic structure and has its own RF cavity driven by the same master RF generator. This situation requires a very fine tuning of the times of arrival at the IP. This delicate operation is performed by selecting the couple of BPM's placed just at the ends of the IR, equally spaced from the IP, and by measuring the difference in time between the passage of the 2 beams in each of the 2 BPM's. By varying the RF phase of one of the cavities it is possible to make these time differences equal, which imply that the beams cross each other exactly at the IP. The resolution offered by this scope based adjustment is about 100 ps. The system is also used during the multibunch luminosity optimization. In fact, if the signal coming from a pickup is observed on the scope on a long time base, it is then possible to verify the multibunch filling pattern. Even filling patterns are important because they make the longitudinal feedback operation more efficient allowing to increase the stored current.

2.5 Longitudinal Feedback

The DAΦNE bunch-by-bunch longitudinal feedback has been developed in collaboration with SLAC and LBL [6]. The system, see Fig. 6, is composed by a front end that extracts, from a pick-up signal, the phase of the bunch center of mass by a phase detector working at 6 times the DAΦNE RF (368 MHz).

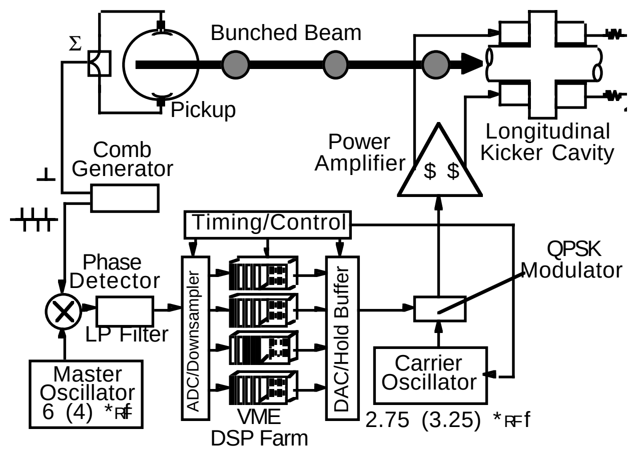

Figure 6: Longitudinal Feedback Schematic

The phase error signal is then sent to an ADC, with clock at 368 MHz, that converts the signal for the feedback digital part, where a FIR filter is implemented by the real time software. The digital part is based on a fast VME Digital Signal Processor farm of 60+60 ATT DSP1610 processors. The FIR filter type, gain and phase are run time programmable. The chain is then completed by a DAC that sends the correction signal to RF class A power amplifiers and to a 'cavity-type' longitudinal kicker that finally performs the phase correction on the bunch.

The main task of this system is, of course, to maximize the luminosity with more than one bunch in the rings, by damping the instabilities that can limit the total beam current, decrease the beam lifetime, and make the currents between different bunches strongly unequal. Additionally the feedback front end can be used as a powerful diagnostic tool. In fact a purpose built software application allows to perform instability mode analysis and bunch by bunch current measurements.

2.6 Stored Current Monitor

The beam current monitor system is based on a toroidal DCCT sensor by BERGOZ, a signal conditioning apparatus, a VME digital voltmeter (DVM) and a VME processor. The DCCT connected to the signal conditioning electronics provides a voltage output proportional to the average value of the stored beam current. The DVM, triggered at 50 Hz, performs the conversion of the analog voltage over an integration time of 2.5 ms and stores the value into an internal register accessible through the VME bus. The VME processor is again the DAΦNE Control System processor board, based on a Motorola 68030, running an application written in LabView. The processor performs the on-line acquisition of the 2 DCCT's (one for each of the rings) and after an immediate conversion stores the floating point values into two circular buffers on VME RAM, each one holding the last 2000 acquisitions. The processor calculates and updates also the average current for the last 10 s of run for both the rings. Lifetime calculation is also performed.

In the single bunch mode, luminosity is proportional to the product of the currents of the colliding beams. By means of current and luminosity measurements it is possible to evaluate this very important proportionality constant, that gives a clear and direct measurement of the degree of optimization of most of the quantities related to luminosity: the higher the constant value, the better the optimization. Moreover beam lifetime measurements during collision give useful information about beam-beam effects and dynamic aperture of the machine. DAΦNE is a collider with flat beams with lifetime dominated by the Touschek effect. This situation implies that the lifetime value is with a good approximation proportional to the square root of the coupling factor. By the 'lifetime method' it is possible to measure coupling values smaller than the ones allowed by the synchrotron light monitor which is resolution limited to ~ 0.005.

2.7 Luminosity Monitor

DAΦNE is equipped with 2 independent luminosity monitors [7], one for each of the interaction regions. The electromagnetic reaction at IP used for measuring the luminosity is the single bremsstrahlung (SB) where an electron and a positron scatter with the emission of a gamma photon. Luminosity is proportional to the gamma photon counting rate. The monitor detector consists of a high resolution "spaghetti calorimeter" proportional counter, where thin layers of lead and scintillating fibers are alternately packed together in order to obtain a very efficient configuration for photon detection in the gamma range. The calorimeter is equipped with a photomultiplier read-out whose output signal is sent to the electronic chain visible in Fig. 7. During collisions the very high rate and sharp angular distribution of the SB process allow an on-line luminosity measurement within an overall accuracy of 10÷15%. The system and electronic chain are calibrated by measuring the energy spectra of the well-known gas bremsstrahlung process (GB), scattering between beam particles and residual gas molecules with the emission of a gamma photon.

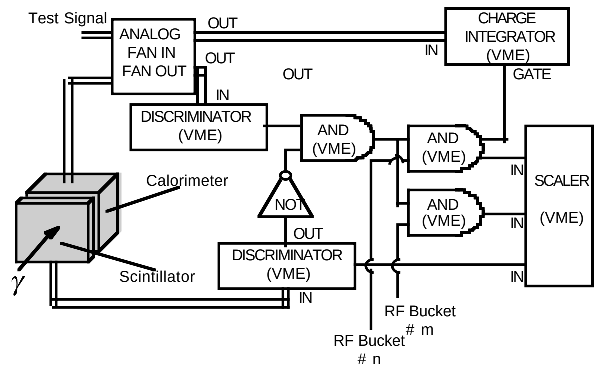

Figure 7: Luminosity Monitor Block Diagram

The system, as previously pointed out, has shown its fundamental role in the fine tuning of the IP geometry during the luminosity optimization. Figure 8 shows, as example, the luminosity monitor read-out window, during a luminosity relative measurement dedicated to the optimization of the vertical overlap of the beams at IP. Vertical position bumps at IR were performed looking for the SB counting rate relative maxima (peaks in the clear trace of the figure).

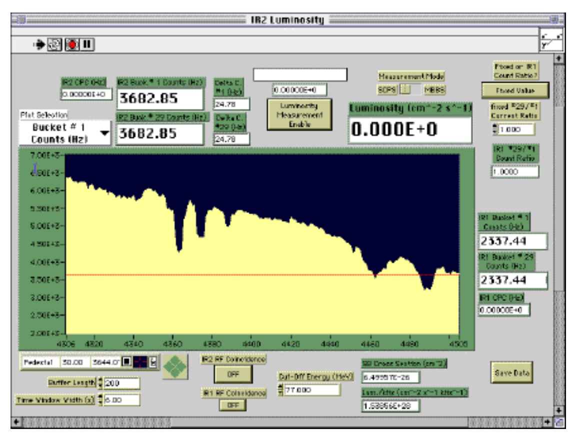

Figure 8: Luminosity Monitor Read-out Window

REFERENCES

[1] "DAΦNE operating Experience", S. Guiducci, DAΦNE Commissioning Team, PAC 99, New York, March-April 1999.

[2] "KLOE a general purpose detector for DAΦNE", The KLOE Collaboration, LNF-92/019(IR), April 1992.

[3] "Beam Position Monitor System of DAΦNE ", A.Stella et al., BIW 98, Stanford, May 1998.

[4] "Integration of Diagnostics in the DAΦNE Control System", G. Di Pirro et al., DIPAC97, Frascati, October 1997.

[5] "Synchrotron radiation monitor for DAΦNE", A. Ghigo, F. Sannibale, M. Serio, BIW 94, Vancouver, October 1994.

[6] "Multibunch longitudinal dynamics and diagnostics via a digital feedback system at PEP-II, DAΦNE, ALS and SPEAR", J.D. Fox et al., EPAC 98, Stockholm, June 1998.

[7] "The DAΦNE luminosity monitor", G. Di Pirro et al., BIW 98, Stanford, May 1998.