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PROPOSAL OF A BUNCH LENGTH MODULATION EXPERIMENT IN DAΦNE

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Abstract

We propose an accelerator physics experiment in DAΦNE to prove the regime of bunch length modulation in storage rings, which has never been tested before in any existing accelerator. The result of the experiment can be of great interest for the future colliders and for the synchrotron light sources. The concept has been developed at the Divisione Acceleratori in the framework of super-factory studies. Collaborations with international groups interested in the experiment have been set-up.

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1 INTRODUCTION

The interest in high peak currents in electron and positron storage rings is strong both in the collider and in the synchrotron light source communities [1].

In the colliders the minimum betatron function value (β*) at the Interaction Point (IP) is limited essentially to the value of the bunch length, since the 'hourglass' effect degrades the luminosity if $\beta^* < \sigma_L$, see for example [2]. Future colliders, especially super factories, aim at lowering the vertical beam size at the collision point by increasing the RF voltage in order to minimize the bunch length in the whole ring. The limit on the minimum bunch length is given by the anomalous bunch lengthening associated with an energy spread growth above the microwave instability threshold. In the present generation of colliders the usual values for bunch length and β* are in the cm range.

The synchrotron radiation facilities are paying special attention to the possibilities for increasing the infrared spectral flux by production of Coherent Synchrotron Radiation (CSR). The latest ICFA BD 35th Newsletter [3] is dedicated to CSR in Storage Rings, showing how broad is the interest on this type of light sources. The experiments already done on some of the sources, as BESSY II, have been performed in regimes of quasi-isochronicity with very low currents.

Short bunches are also of increasing demand to generate short X-ray pulses for time resolved measurements.

Recently the strong RF focusing regime (SRFF) [4] has been proposed as a basic principle for the design of a super factory at the Φ energy. This regime is based on a high RF voltage and a high momentum compaction ring lattice which together produce a bunch length modulation along the ring. In principle the limits imposed by the microwave instability can be controlled by placing the high impedance objects in the ring zones corresponding to the longer bunch, with the IP placed at the shorter bunch position.

The same principle can be applied also to rings dedicated to CSR production. The CSR emission is induced by high peak currents. Stable CSR emission occurs only below the Microbunching Instability Threshold (MBI), which depends strongly on the bunch length[3]. If the MBI threshold is determined by the average bunch length along the ring, stable CSR could be produced in the bends placed in the ring zone where the bunch is shorter. Considering that the CSR power depends quadratically on the number of particles per bunch (N), the possibility of increasing the flux power with bunch length modulation is large. Studies of this principle are currently being performed.

An evolution of the SRFF principle has been recently proposed[5]: a ring magnetic structure where the dependence on energy of the longitudinal position of a particle in the bunch oscillates suitably between large positive and negative values along the ring, together with a high RF voltage, can give rise to a bunch length modulation. The synchrotron frequency can be controlled by means of the RF voltage and by the momentum compaction, down to the vanishing limit corresponding to the isochronicity condition. This regime overcomes one of the critical points of the SRFF principle, where due to the large synchrotron tune the particle motion is essentially 6D, and this has a negative impact on both the dynamic aperture and beam-beam effect [6].

No storage ring has been so far operated in such regimes. The DAΦNE magnetic structure is very flexible [7], and can be tuned both on the high and low synchrotron tune regimes, which can be experimentally explored with a new RF superconducting system at 1.3 GHz.

2 PRINCIPLE FOR THE BUNCH LENGTH MODULATION

In the absence of current dependent bunch lengthening the longitudinal dynamics in a storage ring can be described in a 2x2 formalism, where the longitudinal plane is defined by the vector $(\delta l, \delta E/E)$, δl being the longitudinal particle distance from the synchronous particle, and $\delta E/E$ its energy deviation. Elements acting on the longitudinal phase space are the RF cavities and the bending magnets.

The effect of one RF cavity with voltage V_{RF}, wavelength λ_{RF} on the bunch with energy E, is described by the thin lens focusing matrix:

$$\mathbf{M}_{RF} = \begin{pmatrix} 1 & 0 \\ -\dfrac{2\pi}{E/e}\dfrac{V_{RF}}{\lambda_{RF}} & 1 \end{pmatrix} = \begin{pmatrix} 1 & 0 \\ -U & 1 \end{pmatrix} \tag{1}$$

The parameter U corresponds to the voltage derivative at the synchronous phase.

The effect of a zone with dipoles between s_1 and s_2 is described by the 'drifting' matrix:

$$\mathbf{M}(s_2 - s_1) = \begin{pmatrix} 1 & \displaystyle\int_{s_1}^{s_2} \frac{D(s')}{\rho(s')} ds' \\ 0 & 1 \end{pmatrix} \tag{2}$$

where $D(s)$ and $\rho(s)$ are respectively the dispersion function and the bending radius at the s position.

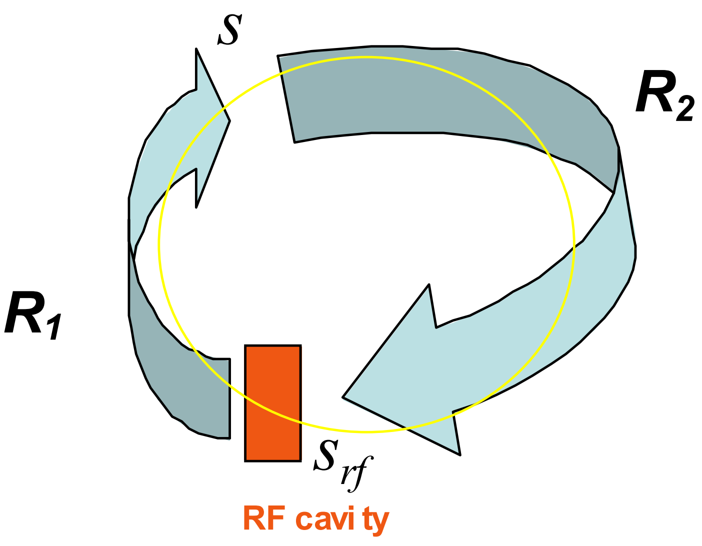

Figure 1: Sketch of a ring with one cavity.

In a ring with one cavity placed at s_{RF}, (see Fig. 1) the one-turn matrix at the point s is given by the product of the RF cavity and drifting matrices:

$$\mathbf{M}(s) = \mathbf{M}(s - s_{RF})\mathbf{M}_{RF}\mathbf{M}(s_{RF} - s) \tag{3}$$

Let's call

$$R_1(s)=\int_s^{s_{rf}}\frac{D(s')}{\rho(s')}ds' \quad \text{and} \quad R_2(s)=\int_{s_{rf}}^{s}\frac{D(s')}{\rho(s')}ds' \tag{4}$$

the distance in longitudinal phase advance from the cavity, defined in a clockwise direction along the ring, and related with the momentum compaction by:

$$R_1(s)+R_2(s)=\alpha_c L \tag{5}$$

The one-turn transport matrix (3) is then:

$$\mathbf{M}(s)=\begin{pmatrix}1-UR_2(s) & \alpha_C L-UR_1(s)R_2(s)\\ -U & 1-UR_1(s)\end{pmatrix}=\cos\mu\,\mathbf{I}+\sin\mu\begin{pmatrix}\alpha_L(s) & \beta_L(s)\\ -\gamma & -\alpha_L(s)\end{pmatrix} \tag{6}$$

and from it the longitudinal Twiss parameters can be written as:

$$\begin{aligned}\cos\mu&=1-\frac{\alpha_C L}{2}U\\ \beta_L(s)&=\frac{1}{\sin\mu}\left(\alpha_C L-R_1(s)R_2(s)U\right)\\ \gamma_L&=\frac{U}{\sin\mu}\end{aligned} \tag{7}$$

The longitudinal emittance ε_L is the ellipse area in the longitudinal phase space and is constant along the ring (see Fig. 2). The beam energy spread which is the ellipse height, defined by γ_L, is constant, while the bunch length is modulated by $\beta_L(s)$.

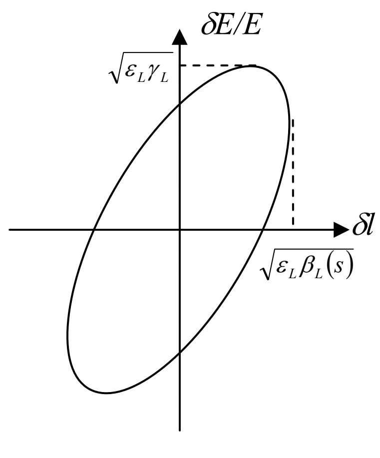

Figure 2: Longitudinal phase space in one point of the ring.

The synchrotron tune $Q_s=\mu/2\pi$ is defined by the momentum compaction and the RF voltage.

The longitudinal beta function modulation is determined by α_c, the behavior of $R_1(s)$, and the RF system. In order to increase the modulation a large voltage derivative at the synchronous phase (high U) as well as a strong variation of the function $R_1(s)$ are required.

The minimum β_{Lmin} appears at the position $s_{\min}$ where

$$R_1(s_{\min}) = \frac{\alpha_C L}{2} \tag{8}$$

and is equal to

$$\beta_{L\min} = \frac{\alpha_C L}{2\sin\mu}(1+\cos\mu) \tag{9}$$

which can be written as a function of the RF lens and momentum compaction:

$$\beta_{L\min} = \sqrt{\frac{\alpha_C L(4-\alpha_C LU)}{4U}} \tag{10}$$

The energy spread is defined by the eigenvalues of the matrix **M**(s)[8], taking into account radiation damping and energy emission.

$$\left(\frac{\sigma_E}{E}\right)^2 = \frac{\gamma_L}{2} C_L \frac{\gamma^5}{L\alpha_{\|}} \oint \frac{\beta_L(s)}{|\rho(s)|^3} ds \tag{11}$$

where $C_L = 2.15\ 10^{-19}\ m^{-2}\ sec^{-1}$, $\alpha_{\|}$ is the longitudinal damping decrement, defined by:

$$\alpha_{\|} = \frac{C_\alpha E^3}{L}(2I_2 + I_4) \tag{12}$$

with $C_\alpha = 2113.1 m^2/GeV^3/s$ and I_j the usual synchrotron radiation integrals[9]

The longitudinal emittance is

$$\varepsilon_L = \frac{1}{\gamma_L}\left(\frac{\sigma_E}{E}\right)^2 \tag{13}$$

The modulation in β_L and bunch length can be raised in two regimes:

a) the function $R_1(s)$ and consequently $R_2(s)$ are monotonic in s.

b) $R_1(s)$ is not monotonic, but has a positive derivative in one part of the ring and a negative one in the other.

The first corresponds to the strong RF focusing regime, as described in [4], and has a large synchrotron tune Q_s. The second one, as described in [5], corresponds to a low Q_s.

3 EXPERIMENT IN DAΦNE

Most storage rings work in regimes of almost fixed momentum compaction, with well defined behavior of the dispersion function in the dipoles. Testing the bunch modulation in an already existing ring needs in principle two conditions: flexibility in the lattice allowing to easily change the dispersion (see eqs.(4) and (7)) and powerful RF system in terms of the *U* parameter.

DAΦNE is an e^+e^- collider, working at the Φ-resonance, with 510 MeV per beam stored in two symmetric rings, 98 m long. The flexibility condition is fulfilled thanks to the initial design which foresaw independent power supplies for each quadrupole, while the present RF system is not dimensioned to go to such extreme regimes: the present *U* parameter is at maximum

$$U_{max} = 3.7\ 10^{-3}\ m^{-1} \qquad (14)$$

corresponding to 250 kV at 368 MHz, while an increase of at least one order of magnitude is needed to reach a measurable bunch length modulation regime.

The installation of a Tesla type super conducting RF cavity at 1.3 GHz, with a maximum voltage of 10 MV, would provide the necessary voltage derivative. Figure 3 shows the μ value as a function of the voltage for different values of momentum compaction in the ring with one RF system at 1.3 GHz.

The RF system is described in paragraph 4, while in the following the set-up of the ring and its parameters both for the high and the low synchrotron tune are described.

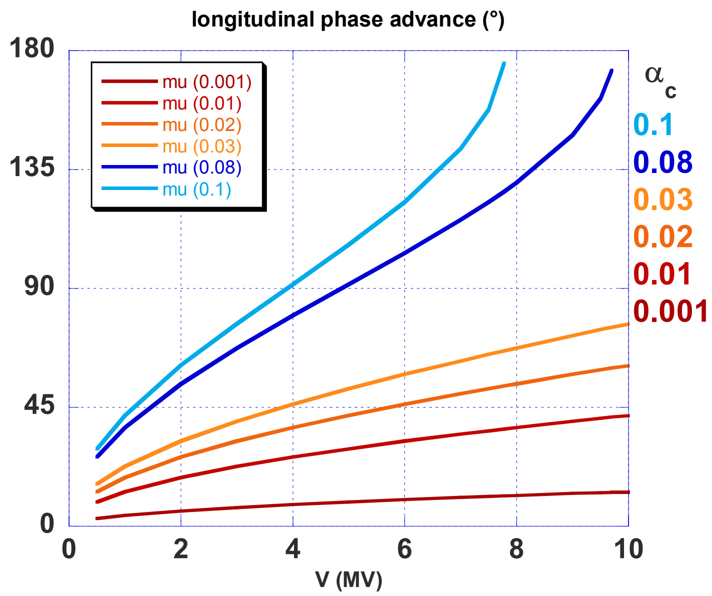

Figure 3: Longitudinal phase advance as a function of the RF voltage at 1.3 GHz, E = 510 MeV for different values of μ.

Each DAΦNE ring is composed of four arcs (two “short” and two “long”), and two Interaction Regions (IRs) shared with the other ring. The KLOE detector has been permanently installed in IR1 since 1999, while IR2 has housed in sequence DEAR, FINUDA, and a detuned IR with no low-beta quadrupoles. The new RF system can be installed in one of the IRs, so that it can be used by both rings, together or independently. In the following we assume to install it in IR2, keeping the KLOE detector on IR1, but all the considerations are valid also if the cavity is placed in the first IR.

The attainable momentum compaction range and variation of $R_I(s)$ are limited by the physical and dynamical aperture of the ring. The function $R_I(s)$ can be tuned by modifying the behavior of the dispersion in the dipoles bracketing the short and the long sections. In fact by keeping the dispersion vanishing together with its derivative at both Interaction Points, the dispersion behavior in the dipoles near the Interaction Regions is almost determined.

Limiting the maximum value of the dispersion to 5 m, the maximum value of the integral per arc of the function $|D/\rho|$ is of the order of 2m.

The regime of strong RF focusing – high Q_s – monotonic behavior of $R_I(s)$ - corresponds to equal contributions from the four arcs. Figures 4 show the corresponding betatron functions and dispersion, with $\alpha_c = 0.08$. We refer in the following to this magnetic structure as “structure A”.

The regime of low Q_s – non monotonic behavior of $R_I(s)$ - corresponds to positive contributions from the short arcs and negative from the long ones (or viceversa), with a very small α_c. Figures 5 illustrate the example of $\alpha_c = 0.006$ (“structure B”). Both cases correspond to horizontal emittances near 1 mm mrad, the design DAΦNE value.

The regime of low α_c can be obtained also with a small integral of D/ρ in all four arcs, and in this case the bunch is short all along the ring without bunch length modulation. Figures 6 shows the corresponding optical functions (“structure C”).

Table I summarizes the main parameters of the three regimes, with the present RF system at the maximum power (V_{RF} = 250 KV), and with the 1.3 GHz system at two different voltage values. The synchrotron radiation integrals which define the natural energy spread are

$$\begin{aligned} I_2 &= 10.14\, m^{-1} \\ I_3 &= 8.74\, m^{-2} \end{aligned} \qquad (15)$$

while the value of I_4 which depends on the dispersion function along the dipoles and therefore changes with the magnetic structure is reported in the Table.

Table I: Main parameters of DAΦNE in the three different experimental regimes

Structure	f_{rf} GHz	λ m	V_{rf} MV	α_c	I_4 m^{-1}	Q_s	σ_E/E 10^{-4}	ε_L 10^{-6}m rad	σ_L mm
A	0.368	0.84	0.25	0.079	- 4.284	0.0268	4.56	9.52	21
A	1.3	0.24	3	0.079	- 4.284	0.184	5.00	1.48	3-3.6
A	1.3	0.24	9	0.079	- 4.284	0.393	10.16	1.39	1.4-4.5
B	0.368	0.84	0.25	0.006	-0.680	0.0076	4.21	2.32	5.5-5.9
B	1.3	0.24	3	0.006	-0.680	0.050	7.13	1.02	1.4-3.5
B	1.3	0.24	9	0.006	-0.680	0.087	11.14	1.40	1.2-5.2
C	0.368	0.84	0.25	0.005	-0.654	0.007	4.11	2.05	5.
C	1.3	0.24	3	0.005	-0.654	0.046	4.17	0.32	.9
C	1.3	0.24	9	0.005	-0.654	0.080	4.29	0.19	.5

The synchrotron frequency, $f_s = Q_s f_o$, where f_o = 3.07 MHz is the revolution frequency, is presently of the order of 30 kHz, while in the above scenarios it goes for the high synchrotron tune up to 1.2 MHz and for the low one up to 270 KHz, thus meaning that the beam dynamics in multibunch operation at high currents would require a substantial modification of the feedback system, as will be shortly described in a dedicated paragraph.

Structure A – strong RF focusing – $\alpha_c = 0.08$

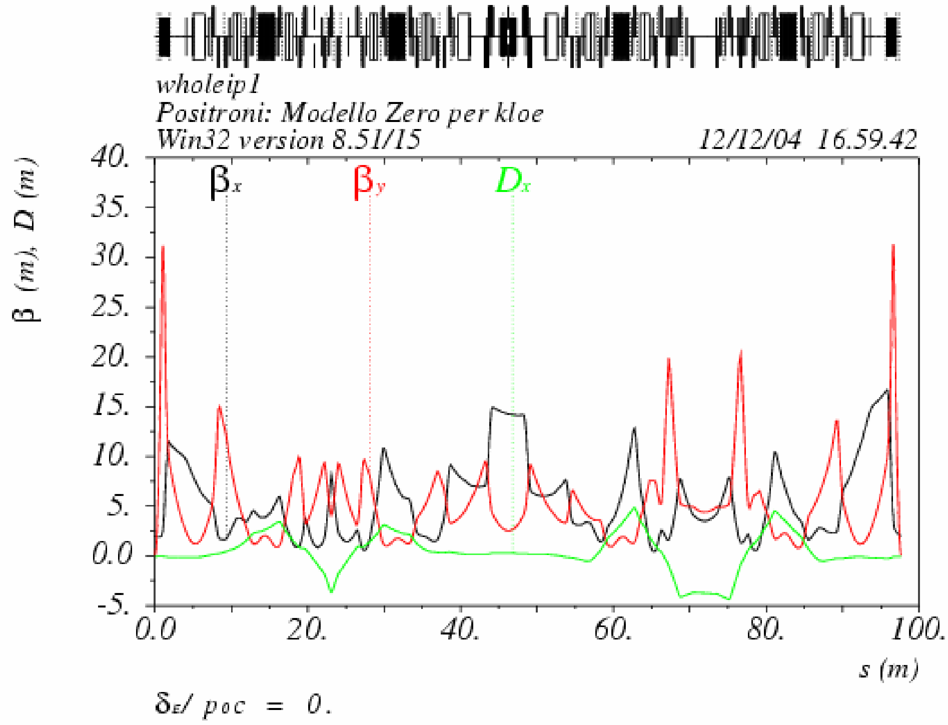

Figure 4a: Betatron functions along the DAΦNE ring starting from IP1

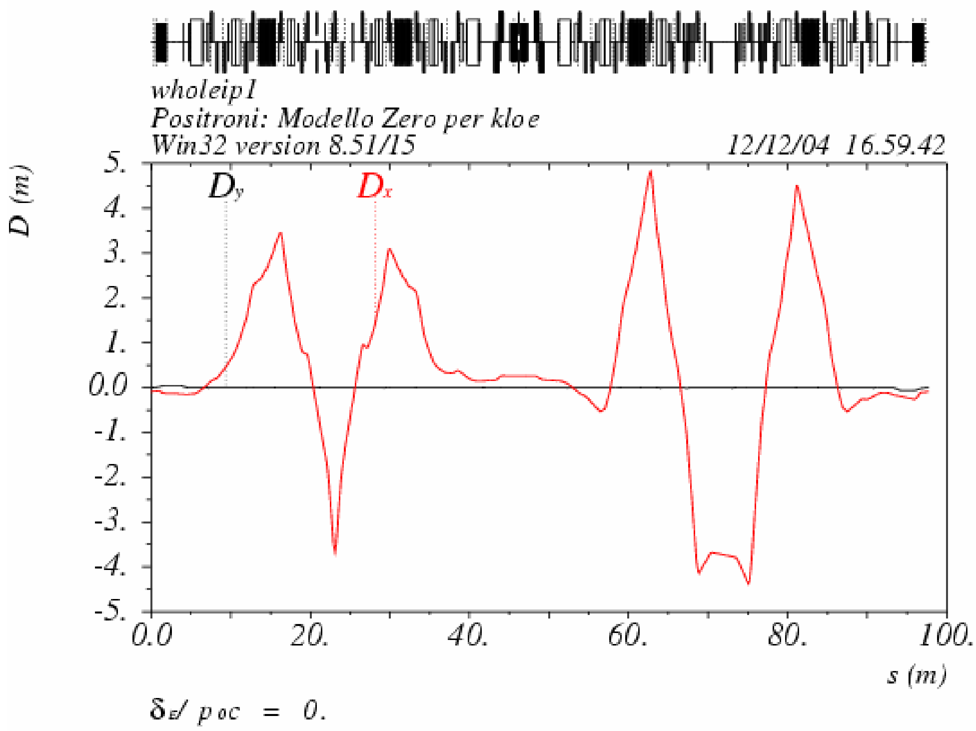

Figure 4b: Dispersion function along the ring

Structure B – strong RF focusing – $\alpha_c = 0.006$

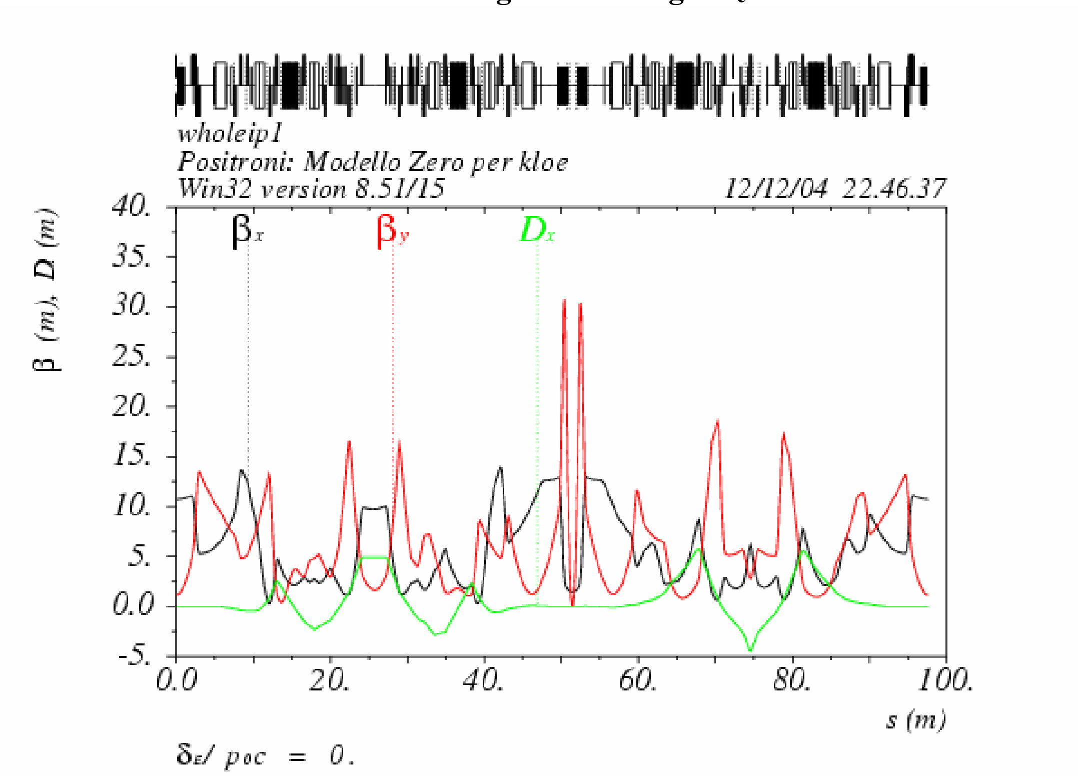

Figure 5a:: Betatron functions along DAΦNE starting from IP1

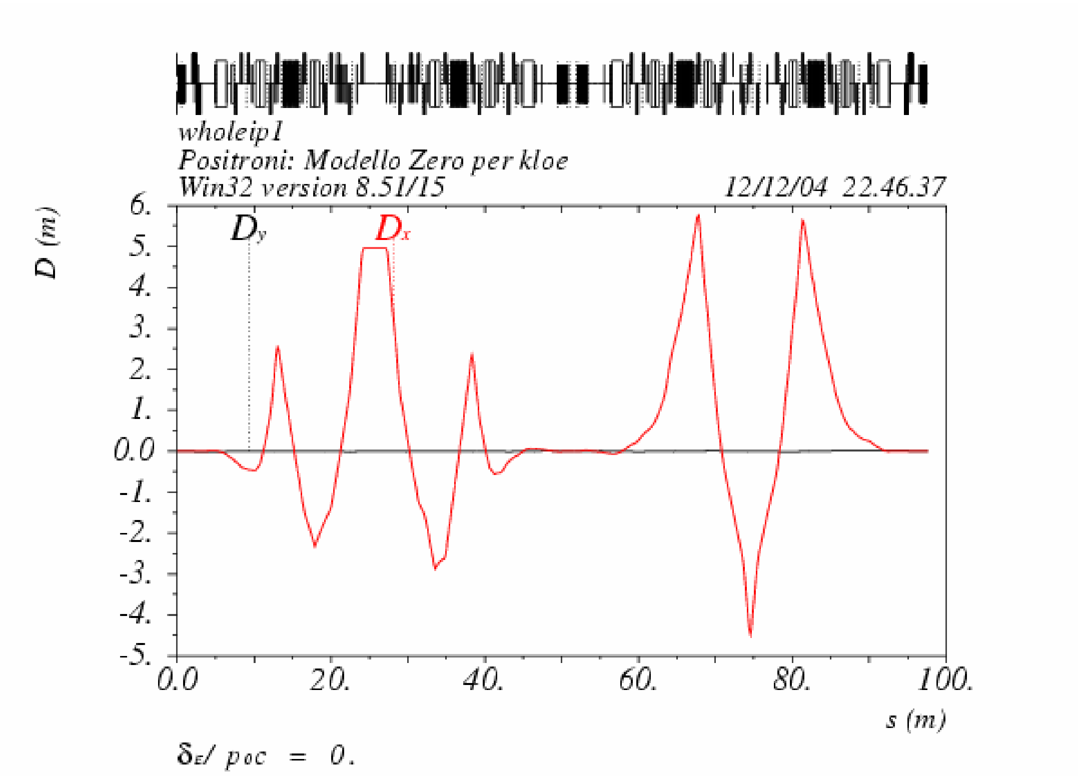

Figure 5b: Dispersion function along DAΦNE

Structure C – $\alpha_c = 0.005$ - small $R_1(s)$

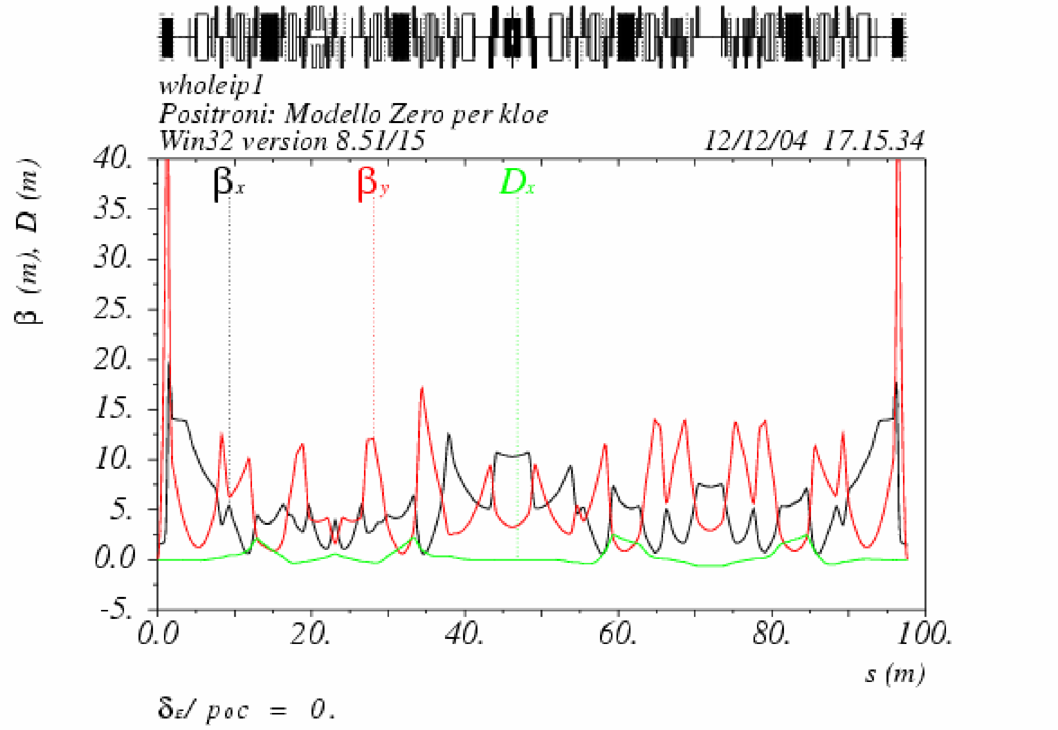

Figure 6a: Betatron functions along DAΦNE starting from IP1

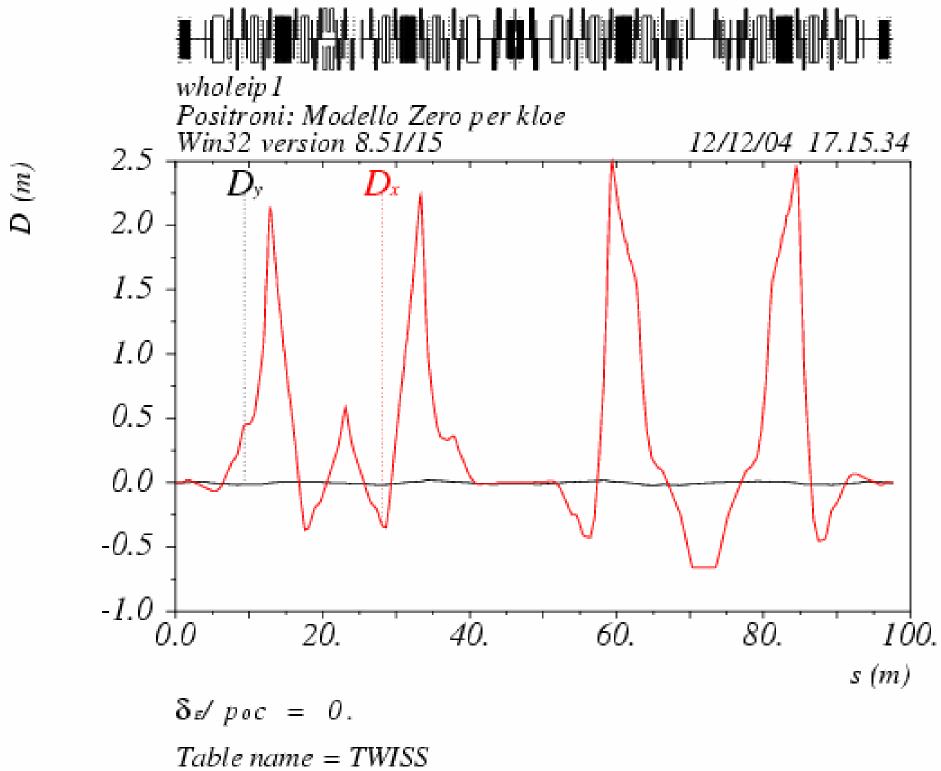

Figure 6b: Dispersion function along DAΦNE

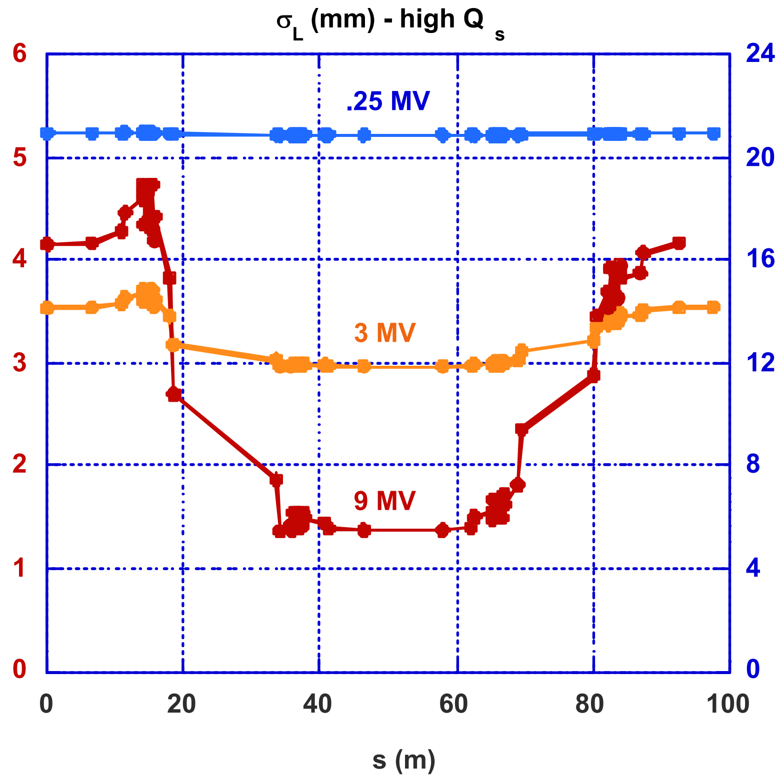

Figure 7: Bunch length along the ring starting from IP2 for the high momentum compaction – Structure A – for different RF voltages. The right vertical axis refers to the blue curve, the left to the red-orange ones

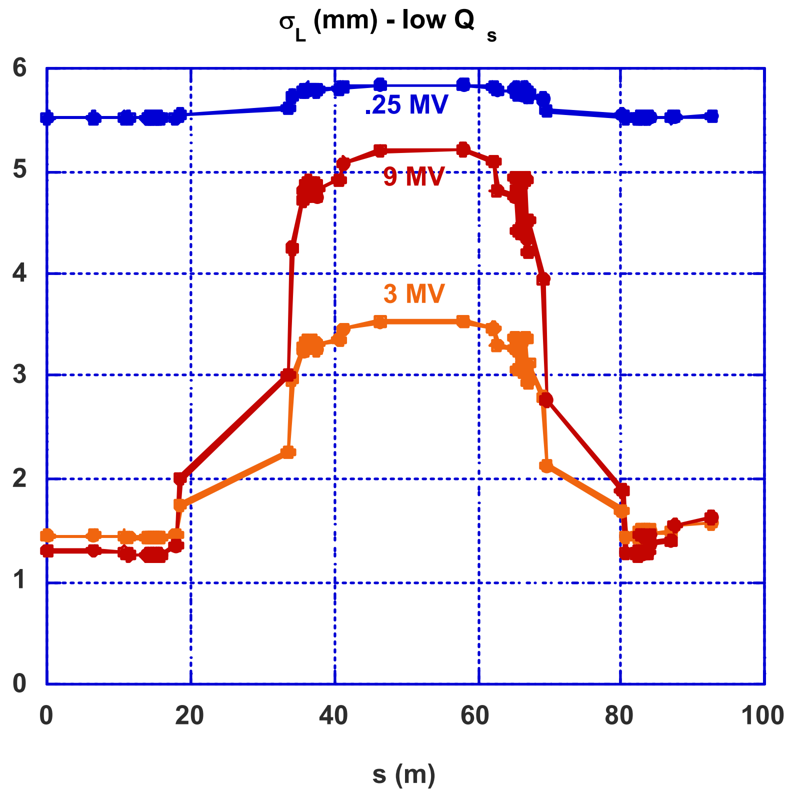

Figure 8: Bunch length along the DAΦNE ring starting from IP2 for the low momentum compaction – Structure B – for different RF voltages

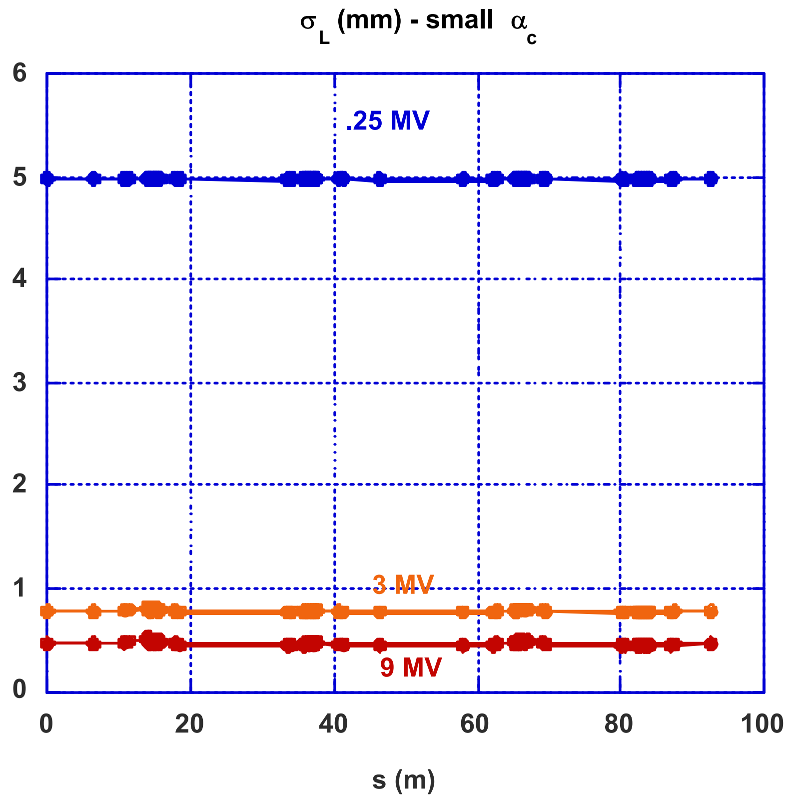

Figure 9: Bunch length along the DAΦNE ring starting from IP2 for the low momentum compaction – Structure C – for different RF voltages

Figures 7 through 9 show the bunch length in the different regimes and structures. In the first case with the present RF system at 368 MHz the bunch length along the ring is constant and of the order of 2 cm (right axis on Fig. 7). With the 1.3 GHz system at low voltage (3 MV) a small modulation appears but still difficult to measure. Going to the high voltage (9 MV) the modulation factor is about 3 and can be measured. The minimum of the bunch length occurs in the Interaction Region opposite to the cavity placement, in our case in the KLOE region. In the hypothesis of storing enough current in multibunch operation and in both rings, it can be envisaged to collide the beams in KLOE with the lowest β_y* compatible with the present KLOE IR vacuum chamber aperture, meaning about a factor of two lower than the present value, which is β_y* = 19 mm limited essentially by the hourglass effect.

In the low momentum compaction case (Fig. 8) the natural bunch length is of the order of some mm even with the present RF system, which lets already appear a small modulation. The modulation is measurable also with low RF voltage at 1.3 GHz, and while the minimum bunch length remains constant the modulation ratio and the average bunch length increase with the voltage. In this case the minimum of the bunch length appears at the RF cavity position. In the case the cavity is installed in IR2, this means that the bunch will be short in the electron ring in the position of the present synchrotron radiation ports, normally used for synchrotron light experiments. If an emission of CSR is obtained it could be measured by the LNF Synchrotron Light group.

The case of small momentum compaction and small $R_1(s)$ corresponds to constantly very short bunches all along the ring, as described in the proposal of using DAΦNE as a TeraHerz light source[10]. The comparison of the microwave instability threshold and the longitudinal distribution shape between this case and the previous one is of great interest for understanding the beam dynamics in the short bunch length regime.

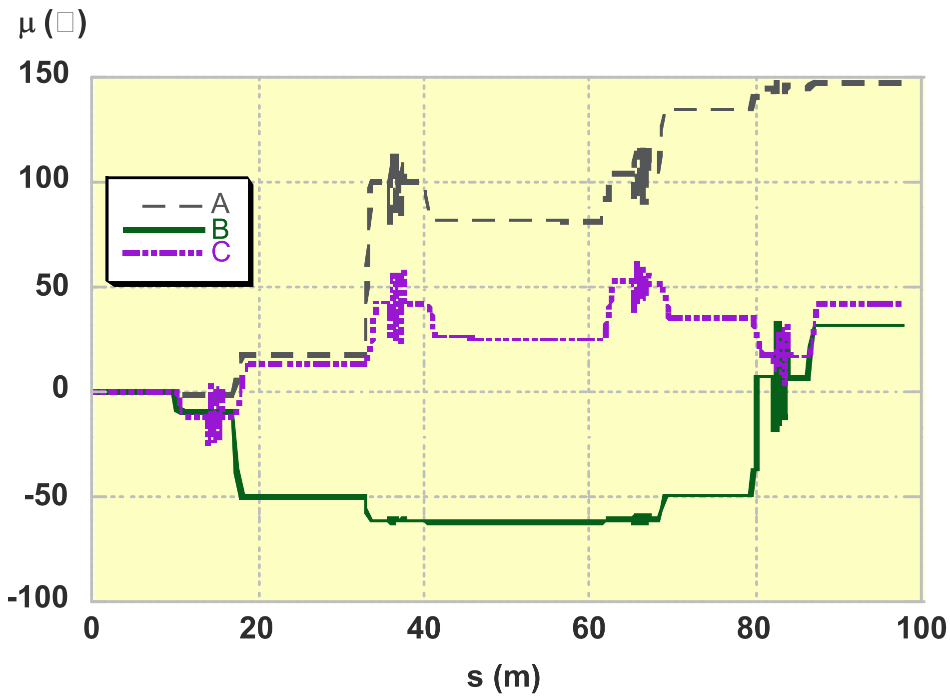

Figure 10: Longitudinal phase advance for the three structures with V = 9 MV starting from IP2

Figure 10 shows the longitudinal phase advance along the ring starting from IP2 for the three structures in the case of V = 9 MV. In the structure A the function has always positive derivative except in the splitter where the contribution to $R_l(s)$ is negative. In the structure B it goes to negative values in half of the ring and then increases in the other half. In the structure C the oscillations are small all along the ring. The value at of the function at $s = L$ determines the synchrotron tune.

4 RF SYSTEM

In order to produce a bunch length variation above a factor 2 along the ring in the SRFF regime (the one corresponding to the structure A described above), the ratio between the RF voltage and the RF wavelength (i.e. the RF slope) must be $V_{RF} / \lambda_{RF} \approx 30\ MV/m$. This very demanding specification can be relaxed by a factor of ≈2.5 if the structure B is used. In any case the required RF slope is very high (about 2 orders of magnitude with respect to the maximum attainable with the present RF system) and the use of SC technology is mandatory. The 1.3 GHz SC RF technology developed for TESLA is a suitable choice since it is absolutely mature and it provides the highest accelerating gradients. The requirements of all the scenarios described in this proposal can be largely fulfilled by a 1.3 GHz RF system providing an accelerating voltage up to 9 MV. A multi-cell TESLA-like cavity powered at a moderate gradient (< 12 MV/m) can safely provide the required voltage. This choice is convenient and very compact.

The parameters of the SC RF system to be installed in DAΦNE for the bunch length modulation experiments are listed in Table II.

Table II: RF system for the SRFF experiment

Cavity type		SC TESLA-like, 7 cells
Cavity frequency	f_c	1289 MHz
R/Q geometric factor	R/Q	390 Ω
Quality factor (@ 1.8 K)	Q_0	$1 \cdot 10^{10}$
Max RF voltage	$V_{RF_{Max}}$	9 MV
Max cavity wall power	$P_{cav_{Max}}$	10 W
Loaded quality factor	Q_L	$2.8 \cdot 10^7$
Cavity detuning due to beam loading	Δf_{cav}	- 60 kHz (@ 9 MV, I_b=1A)
RF generator power	P_{gen}	1 kW
Cavity length	L_{cav}	0.8 m

The frequency of the SC cavity is about 0.85% lower than the standard TESLA one (1.289 GHz against 1.3 GHz) in order to be tuned on the 420th bunch revolution harmonics. Since the NC RF system of DAΦNE is tuned on the 120th revolution harmonics, the two systems can operate simultaneously to store up to 60 equidistant bunches. In this way the standard NC RF system will provide the power to compensate the beam losses, while the SC system will act as a harmonic RF system to provide the large focusing voltage over the bunch. The input coupler needs also to be modified in order to increase the external Q value to $Q_{ext} \approx 2.8 \cdot 10^7$. An RF power source of 1 kW is sufficient to power the cavity in this case.

Other modifications of the TESLA multicell cavity design have been studied and implemented to decrease the number of the HOMs trapped in the structure, namely reducing the number of cells and enlarging the beam tubes. A 2D model of a 7-cells cavity with enlarged beam tubes is shown in Fig. 11. Only the 1st monopole band remains trapped in this case, while the other monopoles and the dipoles propagate in the beam tubes and can be damped by absorbing loads.

Concerning the monopoles of the 1st band, it is not obvious how to get rid of them without affecting the quality of the accelerating $TM_{010\text{-}\pi}$ mode. In any case the modes of this band show very low R/Q values, with the obvious exception of the accelerating one. Therefore the easiest way to treat them is to prevent their coupling with the bunch revolution harmonics and, possibly, with the unstable synchrotron sidebands. Since the exact frequency locations of these modes strongly depend on the fabrication tolerances and can be hardly predicted by simulations, our approach to this problem consists in tracking and, if necessary, displacing by a proper amount the frequencies of the first band modes during the cavity final tuning process to keep them safely away from the dangerous harmonics and sidebands. By doing that, a limited degradation of the accelerating mode field flatness could raise up.

The damped monopoles of the 2nd and 3rd band obtained with an HFSS simulation of the Fig. 11 model are reported in Fig. 12. In each band the mode damping efficiency increases with increasing cell-by-cell phase advance. This is because the energy of the modes with small cell-by-cell phase advance is more concentrated in the central cells, while the coupling with the beam tubes depends on the intensity of the fields in the two ending cells. The values of the loaded Q-factors of the less damped HOMs are of the order of few thousands. However, since the R/Q values of these modes are very moderate, the HOM impedance budget of the damped 7-cells cavity seems to be acceptable. More accurate evaluations of this item are under way. The goal is to keep the beam dynamics under control to store multibunch current up to 1 A in the bunch length modulation regime.

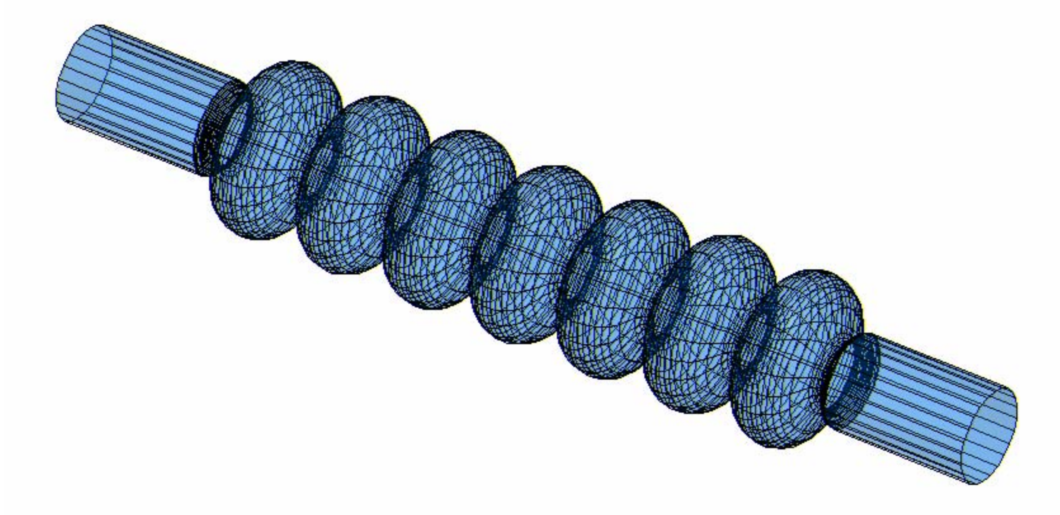

Figure 11: 7-cells structure with large beam tubes

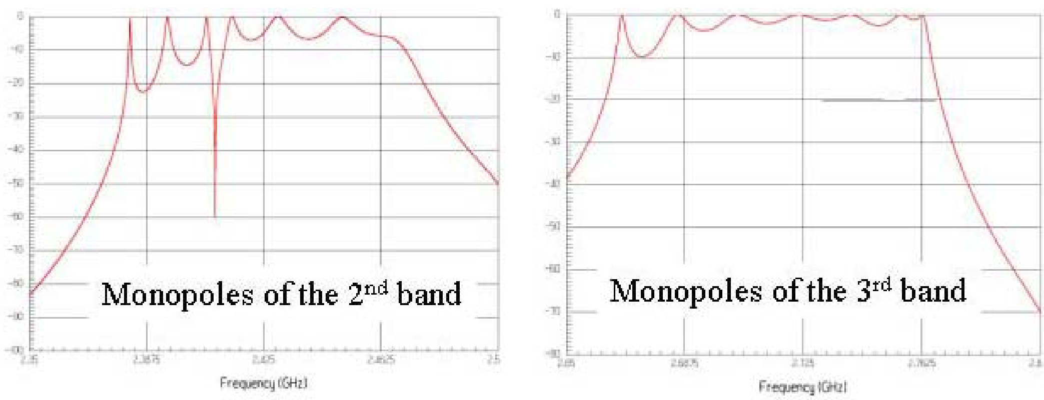

Figure 12: Damped propagating monopoles

The electromagnetic cavity design is well advanced and we intend to complete this phase in two months time. The design will be reviewed by the DESY SC RF group in the frame of a collaboration that has been set-up on this subject.

The cavity cryostat design will be based on the existing design of the TESLA Capture Cavity one, which is still compatible with the 7-cells cavity described above with just few adaptations on the supports.

Figure 13 shows the cut through view of the TESLA cryostat, which is unfortunately not available to be borrowed. However, the Orsay SC RF group has kindly provided us the drawings of this cryostat in order to realize a new one. No modification to the TESLA cryostat design is needed, apart from the adaptation for the new cavity and possibly a different design of the cryogenic interface, in order to simplify the fitting with the DAΦNE present cryoplant transfer lines. The cryostat installation is compatible with the DAΦNE interaction regions with minor impact on the machine layout.

The next steps, subject to the funding of the proposal, will be the engineering and fabrication of the cavity and cryostat. Thanks to the mentioned collaboration, the final chemical treatments, tuning and cold tests of the module will be made at DESY benefiting of the TESLA-TTF infrastructures.

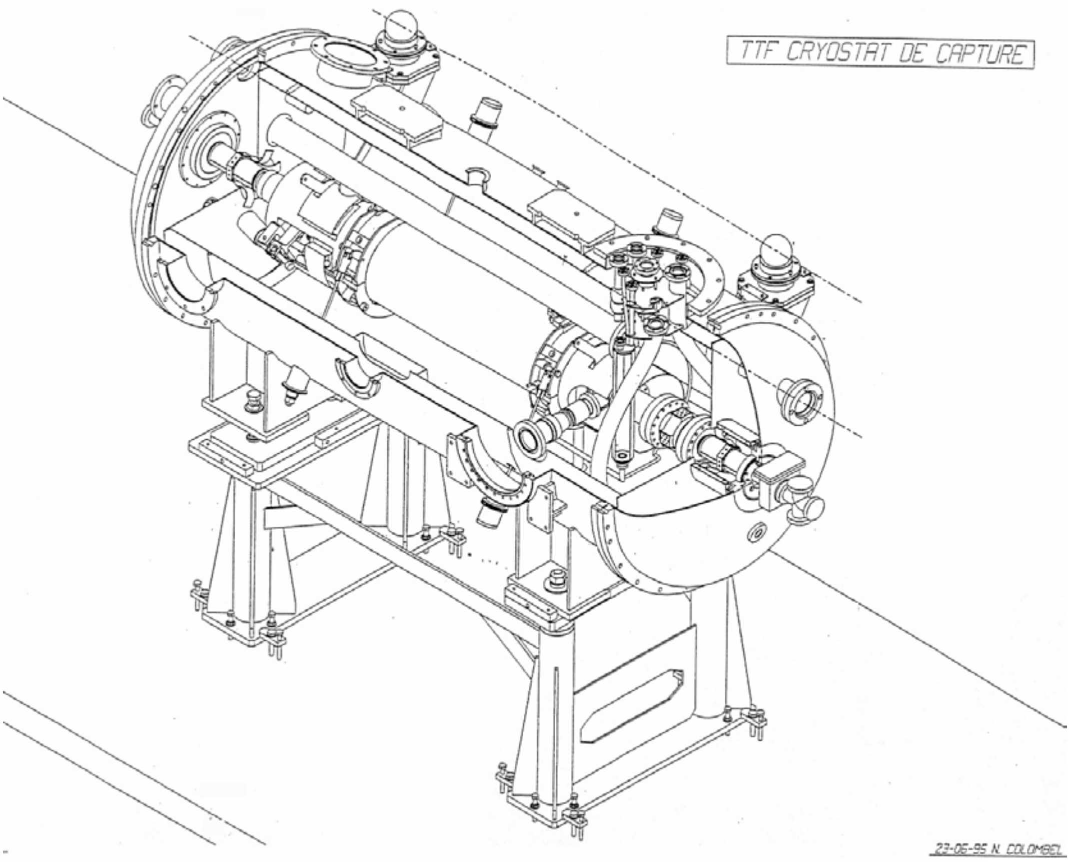

Figure 13: The TESLA Capture Cavity Cryostat

5 CRYOGENIC SYSTEM UPDATE

The TESLA cavities have to be cooled with superfluid Helium at 1.8 K temperature.

In the present configuration the DAΦNE cryogenic plant cools the SC solenoids of the KLOE and FINUDA detectors, and the 4 small-size compensating solenoids placed on both sides of the two experiments . The plant is a standard LINDE TCF 50. At present the cold box delivers to the valve box two cold He line (see Fig. 14):

- supercritical He T = 5.2 K P = 3 bar (99 W refrigeration + 1.4 g/s liquefaction)
- Cold gas T = 70 K P = 5 bar (800 W refrigeration)

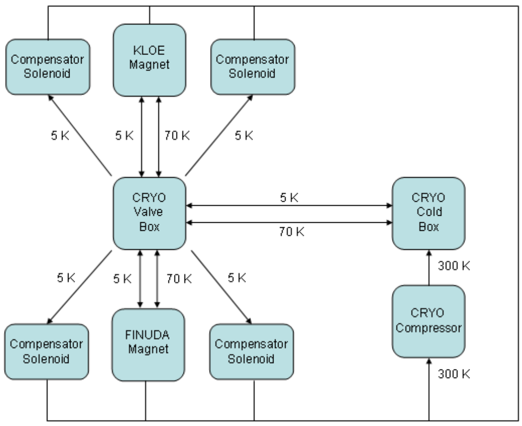

Figure 14: The present DAΦNE cryoplant schematic layout

The two Cryogenic loads are divided as follows:

Kloe:

1) 0.3 g/s LHe (current leads)
2) 55 W at 4.4 K (coil)
3) 530 W at 70 K (shields)

Finuda:

1) 0.4 g/s LHe (current leads)
2) 45 W at 4.4 K (coil)
3) 270 W at 70 K (shields)

Compensators:

1) 0.7 g/s LHe (coil + shield + current leads, one at a time)

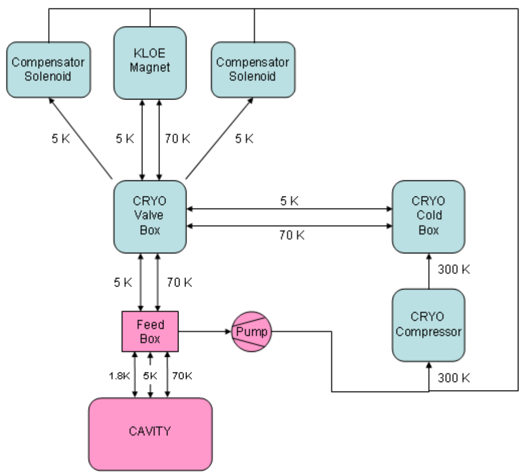

Figure 15: The layout after the cavity insertion at the Finuda place

In order to produce superfluid Helium the plant needs to be upgraded. The SC cavity and cryostat can occupy the place of the FINUDA or the KLOE magnet. Let’s make the hypothesis of using the FINUDA/IR2 for the experiment. The FINUDA transfer line, now transporting 5.2 K and 70 K cold Helium, will be used to supply an interface box. Here the 1.8 K superfluid Helium will be produced by means of a pumping system directly connected to the Helium bath.

The required cryogenic power for the experiment is

1) 10 W at 1.8 K (RF cavity)
2) 15 W at 4.4 K (shields)
3) 55 W at 70 K (shields)

By scaling the cryogenic powers with the Carnot efficiency we have checked that the rf cavity can be installed on any of the two IRs, still having enough power for the cryogenic operation of the remaining experiment with its compensators pair. In Fig. 15 the modified layout with the cavity in IR2 is shown.

The installation can take advantage of the existing transfer lines just by means of a proper extension. By pumping on the helium bath down to 16 mbar the desired 1.8 K temperature will be obtained. The vacuum pump must be set as near as possible to the cryostat to limit the suction pipes diameter.

A small feed box must be installed between the valve box and the cavity cryostat in order to enhance the thermodynamic efficiency of the process (see Fig. 16)

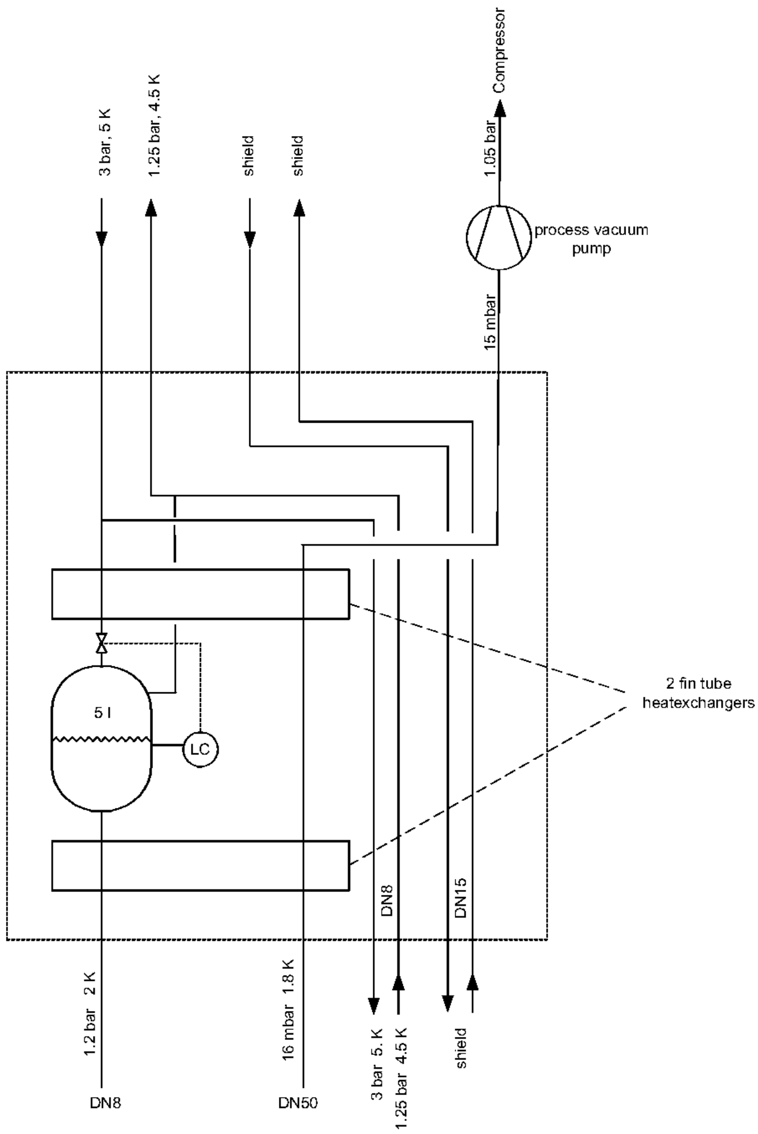

Figure 16: Scheme of the cryogenic feed box

6 DIAGNOSTICS

The role of diagnostics in the proposed machine experiment is to provide adequate means of observation for initial commissioning and optimization of the injection and stacking rate, measurements of the optics and comparison versus the machine model. Most of the existing diagnostics are adequate for the purpose, even under unusual operating conditions.

However, the crux of the experiment is to demonstrate the bunch length modulation in "very short" (~between 1 and 5 mm) bunch length regime, for which the existing diagnostics is hardly usable and must be improved and complemented by new devices.

Assuming gaussian shape, the bunch frequency spectrum has a gaussian shape extending to an rms width of ~48 GHz @ 1mm and ~9.5 GHz @ 5mm rms length. In such frequency region, the electromagnetic pickup's used in DAΦNE for transverse and longitudinal diagnostics are not usable to characterize the longitudinal distribution, because the transfer impedance is difficult to simulate and several narrow-band resonant peaks are present in the response.

6.1 Bunch length variation measurements with synchrotron radiation monitor

The longitudinal current distribution in the bunch is presently measured by looking at the time-modulation of the synchrotron radiation emitted in the bending magnets [11]. The visible light from a bending magnet is extracted from the vacuum chamber, after reflection on a water-cooled mirror, through a transparent window, transported by an optical system to an accessible laboratory and measured with a streak camera Hamamatsu C5680. The time resolution claimed by the manufacturer is 1.5 ps. At 1mm rms bunch length, this figure is still compatible with (nominally) 10 % resolution.

Additional ports can be activated with vacuum chamber minor modifications; the best measurement positions are close to the two interaction regions. We are studying the possibility to use the synchrotron radiation produced in the splitter magnets that are placed not far from the position in which the minimum and maximum of the bunch length occur. In the splitter vacuum chambers there are the luminosity monitor ports, two for each ring, that allow the γ-ray produced in the electron-positron collisions to reach the luminosity monitor calorimeters. Replacing the γ-ray ports, that are thin aluminum sheets, with optical windows (quartz ore fused silica) it is possible to extract the radiation produced by the trajectory curvature in the splitter magnets. New optical lines, composed by mirrors and achromatic lenses, will transport the synchrotron light extracted from these windows close to the interaction regions to the existing output ports. These lines must be connected to the existing lines in order to transport the light to the external lab; flip mirrors can be used to select the line for the measurements. Figure 17 shows the schematic layout of the existing and new transfer lines. Because of the dependence of the path length on the chromatic effects all achromatic lenses are foreseen.

The existing apparatus in the external lab consists of four large aperture mirrors and two achromatic lenses that focus the light coming from both beams on the streak camera input slits through a symmetrical mirror system placed on an optical bench.

The streak camera is used in synchro-scan mode operation; we use this acquisition mode to lock the measurement to the RF trigger that permits repetitive measurements also with long integration period with the drawback of a resolution reduction due to the input trigger jitter (3 ps r.m.s.). In the experiments the bunch length varies from 1 mm to 6 mm, therefore the use of single shot acquisition mode is foreseen using the standard plug in.

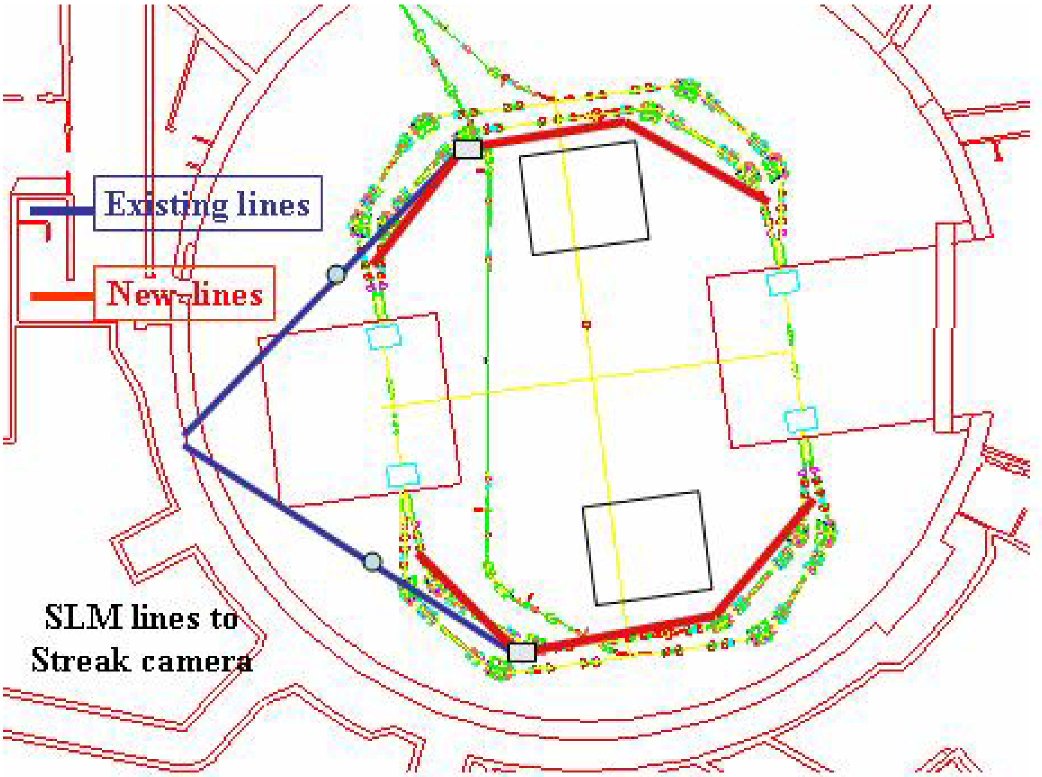

Figure 17: Sketch of diagnostics lines

6.2 Frequency domain measurements

Installation of new dedicated hardware is foreseen to improve the time resolution of the measurement.

A solution which does not have much impact on the vacuum system and on the present layout consists in picking up the beam signal by a rectangular waveguide connected transversally to the vacuum chamber through a slot of the same dimensions, as the one developed at CERN for the CTF2 project. The EM fields generated by the beam in the vacuum chamber and associated with the bunch longitudinal distribution are coupled by the fundamental mode of propagation of the waveguide (TE10 mode) [12]. To avoid possible mode conversions in the waveguide, only the frequency bandwidth between the TE10 cut off and the cut off of the first higher order mode is used. For this reason the slot-waveguide system behaves like a filter whose pass-band depends on the waveguide size. Several commercial waveguides covering half-octave band in the range 5-50 GHz are commercially available and can be easily welded on some section of the existing vacuum chamber.

A single waveguide pick up is not able to cover the frequency spectrum characterizing the bunch both where it is long and where it is short. A small size waveguide (WR-22, 33-50 GHz) could be used to measure short bunch lengths, while a greater size waveguide (WR-112, 7.05-10 GHz) to measure long bunch lengths.

The pickup-waveguide transfer function must be known by EM simulations and/or by laboratory calibration. Assuming gaussian shape, the bunch length can be inferred by comparison of the relative amplitudes of different harmonics of the bunch revolution frequency. The measurement can be done with a microwave spectrum analyzer or with super-heterodyne detectors. Two monitors per ring could be installed replacing short vacuum chamber regions close to the interaction point.

6.3 Energy spread measurement

In the SSRF regime the bunch length modulation is strongly correlated with an increase of the natural beam energy spread, whose measurement is therefore very useful. Furthermore the impedance due to the CSR and the coupling impedance due to the contribution of the vacuum chamber components can also increase the energy spread.

The most direct method to measure the energy spread is the observation of the beam horizontal size performed with a synchrotron radiation monitor placed in a non zero dispersion region, once the transverse emittance and the betatron functions are known.

The present synchrotron radiation monitor fits all the necessary requirements. The particle beam transverse distributions are reconstructed by storing the synchrotron radiation image with a CCD camera and frame grabber system and analyzing the image with the appropriate software.

6.4 CSR direct measurements

The direct observation of the coherent synchrotron radiation is an important feature in the region in which the bunch is shortened; the direct measurement of the CSR is feasible collecting the far infrared radiation in the synchrotron radiation monitor through a window.

A Z-cut quartz window, that permits high transmission from 1mm wavelength to visible range, can be placed as radiation output in the splitter magnet view port or in the first dipole after the interaction region. A wide band infrared radiation detector, for example a bolometer, can be used to measure the eventually emitted CSR and set up the minimum bunch length compatible with a reasonable low CSR emission.

7 FEEDBACK SYSTEM

The longitudinal feedback (LFB) used today at DAΦNE has been developed in collaboration with SLAC and LBL in the first half of the 90's. It is digital and works on the principle of down sampling. By this approach, the LFB uses less than a sample per bunch per turn and it can manage frequencies up to ~100 kHz. The value of this limit depend on the present feedback architecture and machine parameters (harmonic number = 120, etc.).

In the proposed experiment the synchrotron frequency is higher, and the maximum number of bunches is 60. In this case the LFB can be still effective using lower sampling frequencies (RF/2 or RF/4).

A more innovative and complete solution would be a new feedback system based on the "GBOARD" [13], currently under development at SLAC in the framework of the future factories development. This new system will be able to manage much higher frequency oscillations and suits therefore all the needs of the experiment. This new feedback system would give the capability for operating in a much extended longitudinal dynamics range; besides, the Gboard can be used for the transverse feedback systems too.

8 SCHEDULE

Since the experiment in DAΦNE implies vacuum chamber apertures both to install the rf cavity and to disinstall it after the experiment completion, its natural time collocation is in between two DAΦNE runs for experiments which also foresee vacuum chamber apertures.

The time needed for the design and construction of the rf system with its cryogenic part and the diagnostics is of the order of two years, as shown in Table III.

Table III: Experiment schedule

	2004	2005	2006
SC RF Cavity	Design	Final design and order	Construction, testing @DESY and delivery
Cryostat	Drawings	Final design and order	Construction and delivery
Cryogenic System Upgrade	Preliminary design and cost breakdown	Final design and order	Installation
Diagnostics		Project	Construction and delivery
MD on DAFNE	2 days	2 weeks	2 weeks

DAΦNE (see Table IV) will run for the KLOE experiment during 2005 and for FINUDA during 2006. At the end of the FINUDA run there will be the SIDDHARTA installation and therefore one possible time window for the experiment is the end of 2006, beginning of 2007, in between the FINUDA and the SIDDHARTA runs. The total DAΦNE time for the experiment is of the order of 6 months.

During the next two years Machine Development shifts dedicated to the experiment could be programmed, of the order of two weeks per year. The aim should be setting the optical structures defined above (A,B and C), for the linear and non linear beam dynamics optimization. First measurements on the minimum bunch length obtainable with the structures at very low momentum compaction could be carried out with the present hardware and some hints of the possibility of producing CSR could be obtained even with the present diagnostics.

Table IV: Proposal for the present and next future of DAΦNE schedule

	2004	2005	2006	2007
KLOE				
FINUDA				
SIDDHARTA				
Bunch length modulation experiment				

9 CONCLUSIONS

We propose an accelerator physics experiment in DAΦNE to prove a regime in storage rings which has never been tested before in any existing accelerator.
The concept has been developed at the Divisione Acceleratori in the framework of super-factory studies. Collaborations with international groups interested in the experiment have been set-up.

The experiment has an impressive panorama of different results. The measurement of the modulation factor is the first and essential result of the experiment, and it can be done even at very low current, single bunch operation and single beam.

Several evolutions are possible and some of them are here cited

- Measurement of microwave instability threshold in different regimes with very short bunches. The two DAΦNE rings have different impedance due to the presence in the e- ring of the ion clearing electrodes. The two IRs will have also different impedance since one will house the new rf cavity. The bunch length can be minimized both on the rf cavity position or in the opposite IRs, by changing the ring optics. The interaction of an intense peak current bunch with the surroundings can therefore be investigated in several different configurations.
- Test of multibunch configuration and high current regimes
- Measurement of Touschek effect as a function of the bunch length modulation
- Luminosity measurements with β^* lower than the present one
- Test of beam dynamics and dynamic aperture with high synchrotron frequency
- Localized production of stable CSR and comparison with the distributed production along the ring

The result of the experiment would be of great interest for the future colliders and for the synchrotron light sources. In the framework of keeping at Frascati the activity on particle physics with the construction of a superfactory in the low or intermediate range of energy, the proof of principle of the strong rf focusing regime is very important. If, on the contrary, the future of the LNF reverts to the synchrotron light research activity, the experiment is still very useful, since it can prove if DAΦNE can be used as a powerful CSR source.

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