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Laboratori Nazionali di Frascati

LNF–93/027 (IR)
14 Giugno 1993

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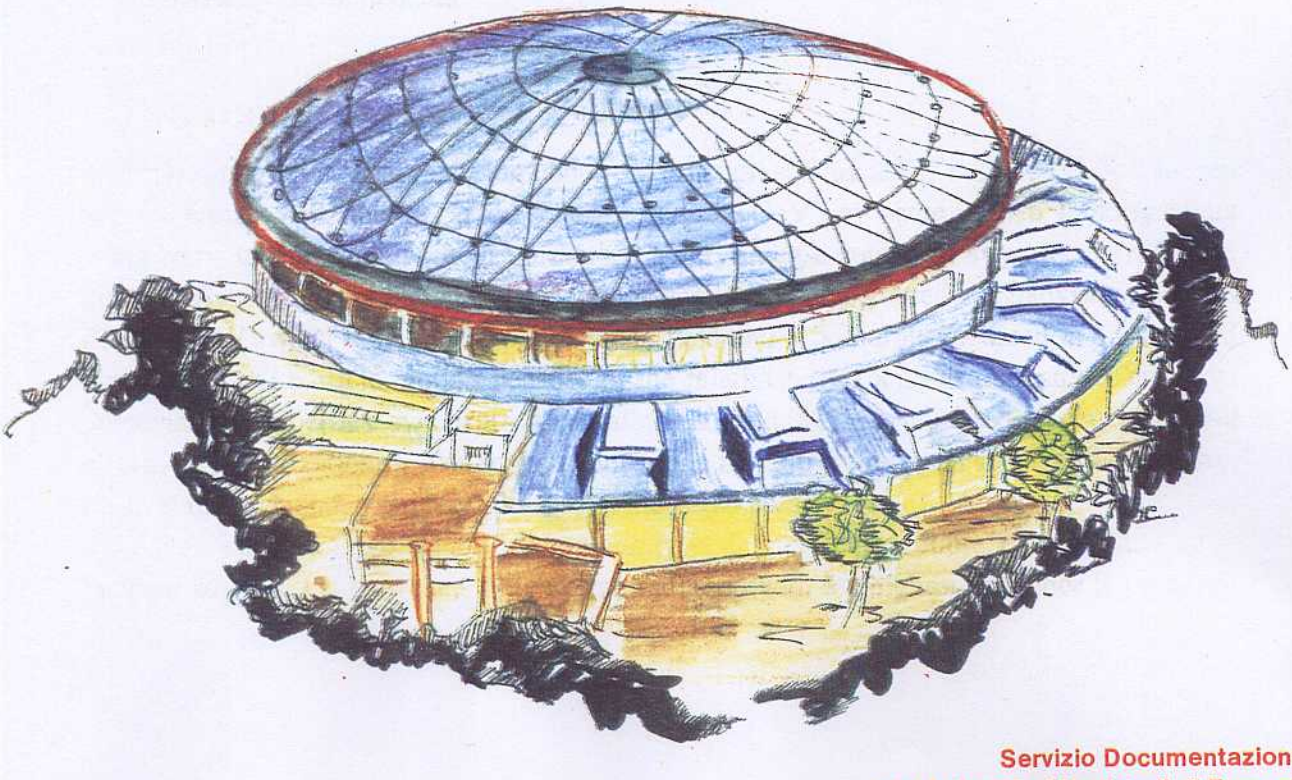

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DAΦNE - A NEW TUNABLE AND INTENSE SOURCE OF SYNCHROTRON RADIATION IN THE INFRARED DOMAIN

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ABSTRACT

The construction of the new DAΦNE machine, at the Laboratori Nazionali di Frascati, addresses the question if competitive synchrotron radiation applications can be figured out for this non dedicated storage ring and which valuable or new research fields can be considered at least for the next five-ten years. Starting from the design parameters, some general considerations concerning the synchrotron radiation source requirements are outlined. Finally the extraction of synchrotron radiation for experiments in the infrared energy range (5-5000 μm) is discussed in more detail.

1 - INTRODUCTION

DAΦNE the new storage ring under construction at Frascati, is designed to be a meson factory which will operate at the energy of 0.51 GeV per beam. When looking at its parameters, it represents without no doubts, a very intense source of synchrotron radiation (SR). [1] Synchrotron radiation is the electromagnetic radiation emitted by relativistic electrons (E>100 MeV) when they move in a magnetic field and it is sharply focussed in the forward direction of the particle motion because of the relativistic velocity of this latter. Due to its outstanding properties synchrotron radiation is used world-wide for the structural and electronic investigation of matter. Its applications range from material science to chemistry, medical research and, more recently, also to industrial uses. [2]

Nowadays, a large scientific community is demanding for more effective and more brilliant sources. [3] However, synchrotron radiation with the highest brilliance is produced only by special insertion devices as undulators and wigglers. [2] Unfortunately, only a few such devices are available, so that users must wait longtime for the allocation of beamtime at these powerful sources. Even when looking only at the Italian synchrotron radiation community, the potential availability of a new storage ring, like DAΦNE, as a synchrotron radiation source for infrared (IR), vacuum ultraviolet (VUV) and soft x-ray range (SXR) will be extremely useful. For the international community, DAΦNE could also represents a powerful source of applications.

Currently, there are no third generation sources in operation in the VUV and in the SXR range, if we exclude SuperACO at LURE, which can be probably considered the prototype of the new dedicated synchrotron radiation sources and which operate at an energy of 0.8 GeV. However, more than ten new rings are under construction or approved, (see TABLE I which however does not include all the projects at energy greater then 1.5 GeV like ALS in USA, ESRF in France or Spring-8 in Japan) all these storage rings will operate at energies over 1 GeV and will be optimized for the x-ray range. If we look at the *scenario* of the storage rings planned or under consideration, and we neglect all compact sources, only the DAPS machine (UK) is designed specifically to produce lower energy photons at an operating electron energy less then one GeV. In addition, if we consider the 1.5 GeV (or higher energy) machines, none of them is planned or designed to operate also at lower energy. (see TABLE I) [3] On the contrary, several are planned to be stretched to higher energies in an attempt to increase the higher energy photon flux. As a consequence, also in this larger *scenario* DAΦNE is situated in a niche of possible applications which other sources cannot cover completely or at their best.

TABLE I

Ring	**Site**	**Status**	**Energy** (GeV)	**Emittance** (m rad 10^{-9})
DAPS	Daresbury	Under consid.	0.5 (1.2)	5 (15)
Max-1	Lund	In operation	0.55	40
ASTRID	Aarhaus	In constr.	0.6	160
VEPP 2M	Novosibirsk	In operation	0.7	205
NSLS VUV	Brookhaven	In operation	0.75	150
UVSOR	Okasaki	In operation	0.75	160
SuperACO	Orsay	In operation	0.8	37 (h) 18 (v)
BESSY-I	Berlin	In operation	0.8	50
HESYRIL	Hefei	Commiss.	0.8	170 (h) 2.7 (v)
Aladdin	Wisconsin	In operation	1.0	4 (v)
LNLS	Campinas	In constr.	1.15	60 (h) 6 (v)
SRRC	Taiwan	In constr.	1.3	19
HiSOR	Hiroshima	Planned	1.5	83
Max-2	Lund	Approv.	1.5	6-9
ALS	Berkeley	In constr.	1.5	3.4
Elettra	Trieste	In constr.	1.5 (2)	4 (h) 0.4 (v)
BESSY-II	Berlin	Under consid.	1.7	5

We would stress here that DAΦNE cannot be considered in competition with any high brilliance source under construction, like for example Elettra in Trieste. Indeed, Elettra is a dedicated storage ring designed to operate at the energies of 1.5-2 GeV and optimized for higher energy emission from wigglers and bending magnets. However, it will be able to cover the DAΦFNE energy range with highest brilliance by undulator emission only. We will show that the expected performances of DAΦNE in dedicated runs are extremely interesting for synchrotron radiation application and very similar to the design characteristics of DAPS, [4] which can be considered, really a next generation source being it now under design. In Fig. 1 the flux emitted by DAΦNE is compared with other synchrotron radiation sources.

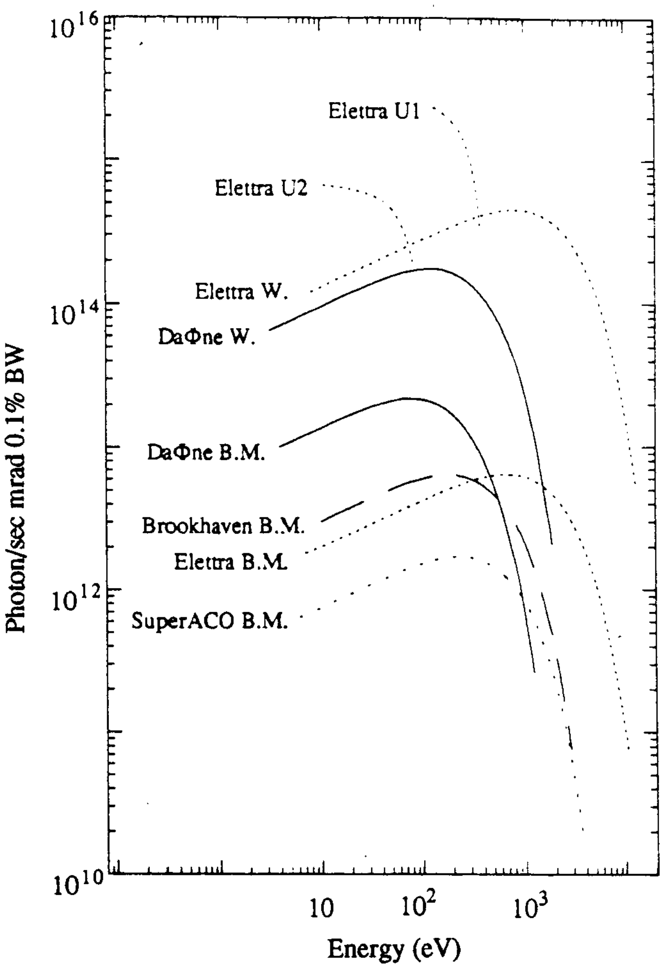

FIG. 1 — Comparison between the flux emitted by some storage rings in operation and the estimated flux of the rings under construction in Italy. Calculations are referred to average currents. For the Elettra undulators, the emission is in a central cone of width less then 1 mrad. By collecting more then 25 mrad from the DAΦNE wiggler is possible to get comparable flux but with lower brilliance.

If DAΦNE will be dedicated also to synchrotron radiation applications, the Italian community will take benefit from two completely new machines. One dedicated to VUV and soft x-ray applications (DAΦNE), while the other one (Elettra) specially designed for x-ray, or for experiments demanding the highest brilliance from undulators, in the VUV energy range. In for experiments demanding the highest brilliance from undulators, in the VUV energy range. In addition to these two machines, a large low emittance storage ring at 7 GeV is under construction at Grenoble (ESRF) under a joint agreement of several European countries, including Italy. ESRF is expected to cover (starting from the early 1993) the x-ray and hard x-ray range with the highest performances.

United Kingdom should go towards a similar *scenario*. In fact, the DAPS project has been finally shelved but at Daresbury they are now studying two new rings. A low energy ring, SIMBAD, of 700 MeV and a higher energy ring called DIAMOND of about 3 GeV which will cover the intermediate range from VUV and SXR to the hard x-rays delivered by the ESRF european machine.

We can conclude this section by stressing that the strategy of covering the wide range of synchrotron radiation emission by different storage rings, appears to be the most suitable, promising and convenient for users.

2 – DAΦNE STORAGE RING DESIGN

All DAΦNE design is based on conventional technology. The machine layout is shown in Fig. 2. The two rings cross in the horizontal plane in two points and have a symmetry axis so that the two interaction regions, designed to locate two large apparatus for the detection of the particles, produced by the interaction between e^+ and e^-, have the same magnetic structure and the same optical functions. Each ring consists of two symmetric parts which have similar structure: an inner one named "*short*" and an outer one named "*long*". The Φ-factory storage rings will be located in the existing ADONE hall and oriented in such a way as to illuminate an experimental hall for synchrotron radiation experiments. Photon beams for synchrotron radiation applications can be extracted by the "*long*" arc section, shown in Fig. 3. The sources planned for this application are a wiggler and two bending magnets, as shown in detail in Fig. 4. Table II reports some of the design parameters of the DAΦNE project as reprinted by the latest Technical Notes on the lattice. [5].

The storage ring lattice can be divided into three regions: the low-b insertions, the achromats and the zero dispersions. The ring magnetic lattice of the achromat is a four-period modified Chasman-Green type with a 1.8 Tesla conventional wiggler magnet inside the achromat. [5] This last choice allows sample emittance tunability and at the same gives strong radiation damping. Conventional wigglers are used to avoid the strong field non linearities created by short bending radius of superconducting devices.

The coupling coefficient design value has been chosen to be k=0.01. Achieving such a very low value for the coupling coefficient it is certainly not an easy task. The orbit has to be measured and corrected with great precision and the vertical dispersion function has to be carefully minimized. However, other storage rings in operation have already obtained k values less than 1%. In particular the Brookhaven 750 MeV VUV ring has reached k=0.0017.

The third generation synchrotron radiation sources, either under construction or planned in the next years, are associated with very low beam emittance (i.e. in 10^{-9} m rad range). This requirement makes necessary a careful design of the electron beam optics including the chromatic corrections. A typical example of low emittance optics is the modified Chasman-Green lattice (i.e. ESRF lattice). In the DAΦNE design the emittance e, due to the requirement physical and dynamical aperture which is necessary for a reasonable beam lifetime. On the contrary for synchrotron radiation applications the e value has to be small. All considered, a reasonable and conservative choice for the DAΦNE design emittance is $\epsilon = 10^{-6}$ m rad. In any case this storage ring is designed to be tunable over a wide range with the possibility of further improvements. Actually, the storage ring lattice is substantially the same as used for low emittance, high periodicity machines. Its main limitation comes from the chromaticity correction that, due to the small value of the dispersion function, requires strong sextupoles and produces rather small dynamic apertures.

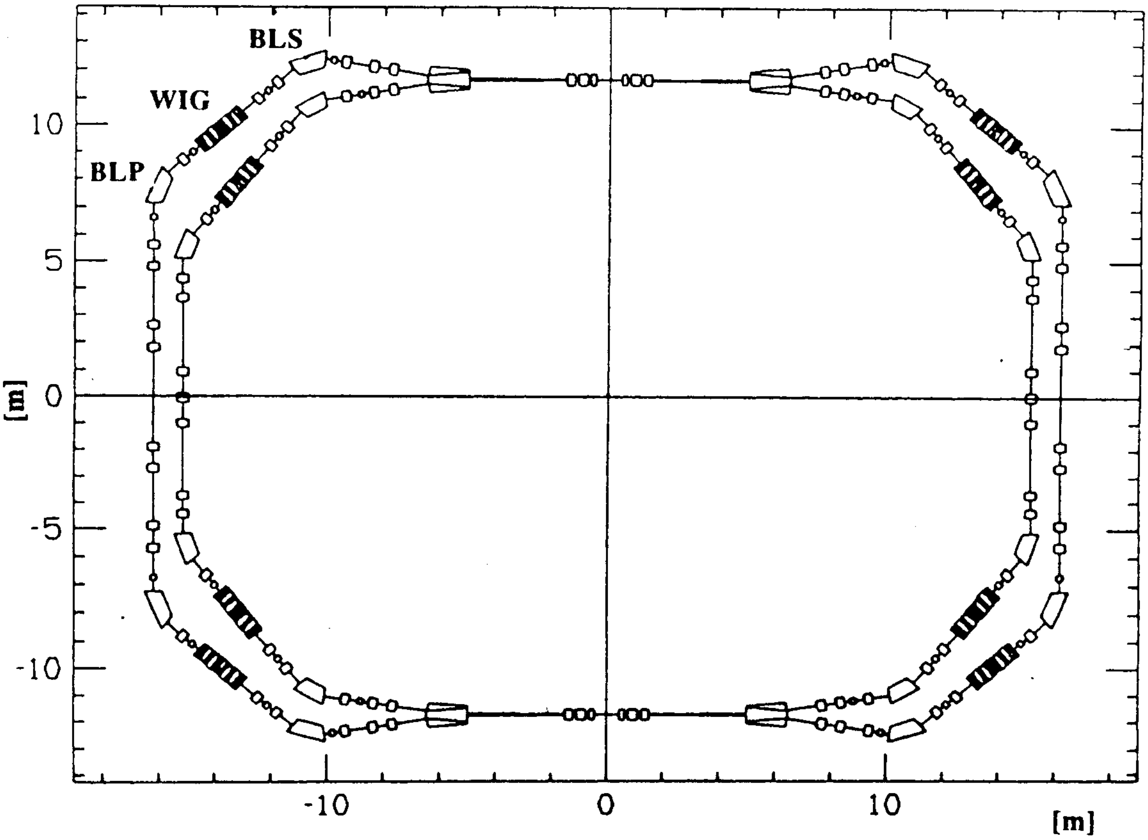

FIG. 2 — Layout of the DAΦNE storage rings. The possible sources of SR are indicated as BLS, WIG and BLP.

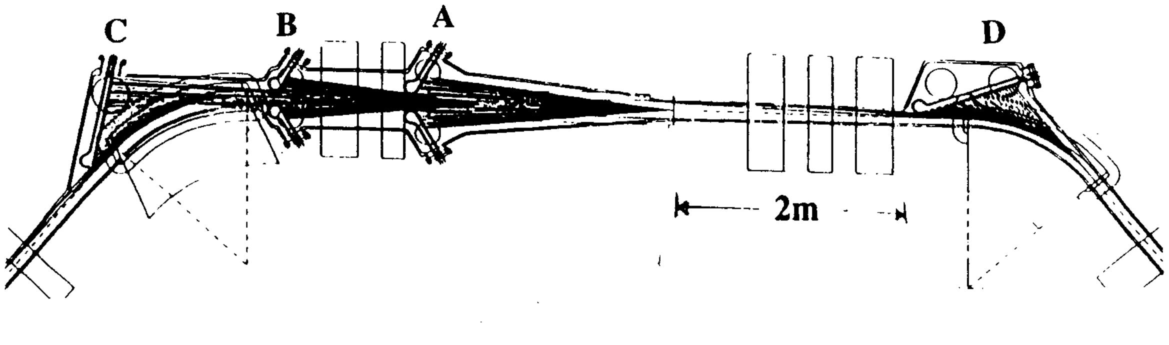

FIG. 3 — Sketch of the *long* arc section of DAΦNE. The SR emission and the absorbers are shown. Extraction of VUV and SXR can be obtained opening windows in the absorbers located at C and D positions.

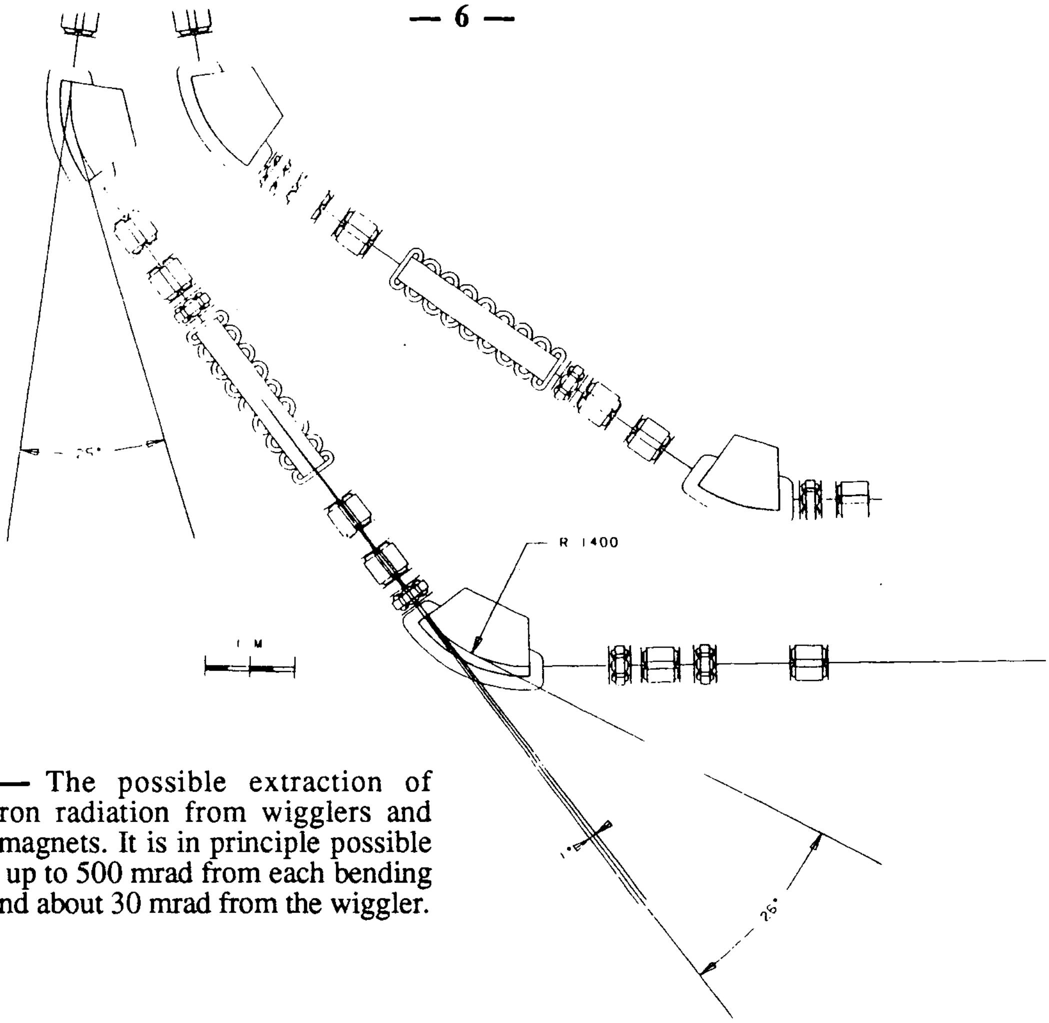

FIG. 4 — The possible extraction of synchrotron radiation from wigglers and bending magnets. It is in principle possible to accept up to 500 mrad from each bending magnet and about 30 mrad from the wiggler.

TABLE II: DAΦNE single ring parameters

Energy E	510 MeV	$(\gamma=E/mc^2=10^3)$
Circumference	97.69 m	
Dipole bending radius	1.400 m	$\epsilon_c=208$ eV
Dipole magnetic field	1.2 T	
Dipole bending angle	0.8 rad	
Wiggler bending radius	0.94 m	$\epsilon_c=311$ eV
Wiggler magnetic field	1.8 T	
Wiggler length	2.0 m	
Wiggler period length	0.64 m	$N_{period}=3$
Horizontal b-tune	4.87	
Vertical b-tune	4.85	
Momentum compaction	0.017	
Energy loss/turn (U_0)	9.3 KeV	
Natural Horizontal Emittance	10^{-6} m rad	
Vertical Emittance	1.82 10^{-11} m rad	
Natural Horizontal chromaticities	-6.9	
Vertical chromaticities	-16.9	
Coupling coefficient k	0.01	
Natural Bunch length s_z	0.81 cm	

Anomalous bunch length s_z	3.0 cm
Bunch separation	4.2 m
Number of particles/bunch	$9\ 10^{10}$
Number of bunches	1÷120
Max. total average current	5.3 Amp
RF freq	368.25 MHz
Harmonic number	120
Max. Synchrotron Radiation Power/beam	49 kW
Relative rms Energy spread	$3.97\ 10^{-4}$
Anomalous Relative rms Energy spread	$1.46\ 10^{-3}$
Damping Time	τ_s=17.8 τ_x=36 τ_y=35.7 msec
Total single beam lifetime	156 min

Due to low energy of the beam, the main effect which limits the beam lifetime τ is the single Touscheck scattering, which gives a lifetime proportional to the third power of the energy. At this stage of the design, the DAΦNE beam lifetime τ is expected to be greater than 2 hours. In view of this τ value, topping off injection from an accumulator ring will take place. This is highly desirable for luminosity consideration but also for synchrotron radiation applications in order to keep current at high values during the operation. Refilling time can be predicted to be very short in the case of DAΦNE design, where a system "Linac + accumulator" has been considered.

The value of current foreseen for DAΦNE operation is 1.3 Amps/ring into 30 bunches as short-term goal. The maximum average current is 2.5 Amp, but the final goal is to push up the current over 5 Amp/ring with an energy loss per turn up to U_0=9.3 keV. Nowadays, high current values have been already reached at storage rings in operation (i.e. 1.3 Amp has been accumulated in the BNL-VUV ring that runs routinely with stored currents of 0.8÷0.9 Amp) so that the final goal too can be considered as realistic. With such current values, the photon flux will be higher than those shown in Fig. 1, thus satisfying even the most photon hungry experiments. However, as the beam stability at such high currents is critical, this is both one of the most challenging topics of the project and one of the most demanding issues for synchrotron radiation applications.

Moreover, any movement of the ground or any local temperature changes may produce movement of the magnet support structure which are additional source of movement of the electron beam and of emitted photon beam. The severity of the photon beam stability problem scales like the square of the photon brilliance. [6] The major effects of the photon beam movement depend on the detail of the beamline but basically are position change which means loss of photon flux and angle change which means both loss of photon flux and wavelength shift.

If we consider the positional stability of a beamline with entrance slit, high throughput stability address high photon stability. Calculation can show that the beam center-mass stability has to be within a 10% of the transverse electron beam size in any source regions. For DAΦNE, the beam centre-mass stability has to fulfil this requirement also in the interaction region where the vertical size of the beam is estimated to be about 20 mm. (see TABLE III)

As far as the vacuum system is concerned, no matter of what 10^{-9} torr, with ~100 kW of synchrotron radiation power must be obtained in the aluminium chamber of the DAΦNE storage rings. To fulfil this requirement an accurate design of the vacuum chamber by CAD is being developed, with special emphasis on the wiggler regions where maximum heating of the chamber wall is expected due to the synchrotron radiation. To reduce the latter effect, special slots are designed in the beam pipe. In fact, the light will hit on special absorber placed in antechambers, located on the external side of the pipe in the bending magnet regions and on both side for the wiggler case. Special apertures on the absorbers will allow synchrotron radiation to be collected outside (see Fig. 5). Their dimension substantially determines the minimum distance at which the first optical elements can be placed in order to focus or deflect the radiation.

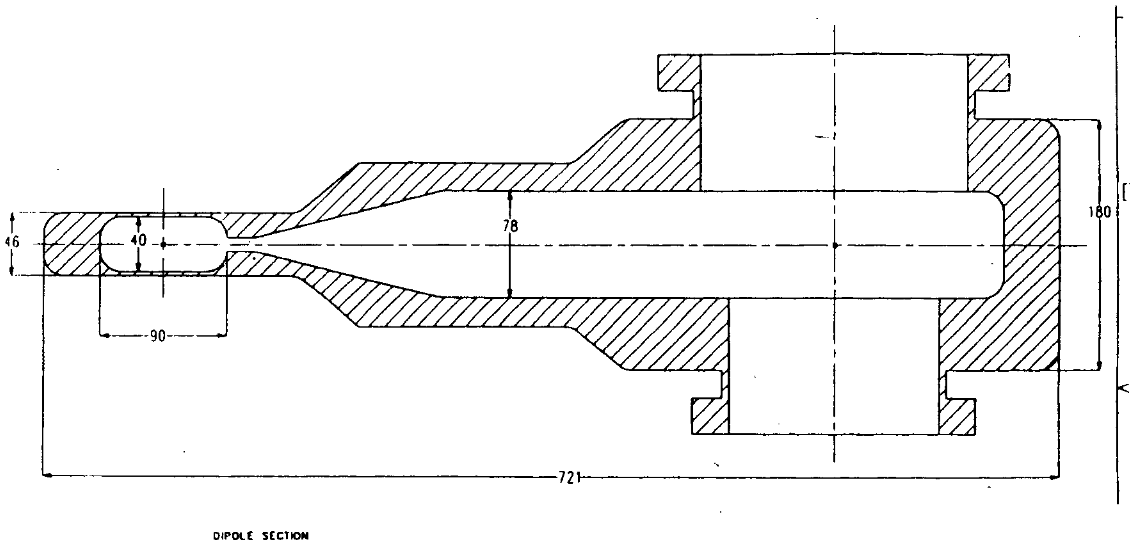

FIG. 5 — A preliminary antechamber design in the dipole section for the *long* arc vacuum chamber. (Figures are in mm)

3 - DAΦNE LATTICE AS RADIATION SOURCE

The particle beam emittance in an electron storage ring is determined by the competition between quantum excitation that causes individual particles to oscillate transversally and damping of the betatron oscillations. The natural horizontal beam emittance of any storage ring lattice is determined only by the beam energy and the values of standard lattice functions within the bending magnet. In the vertical plane, there is radiation damping but ideally no dispersion and hence no quantum excitation, so that in a *perfect* machine the vertical emittance is zero. The vertical emittance is determined only by coupling between the horizontal and vertical planes due to magnet imperfections, misalignments, etc.

The minimum possible beam emittance can be estimated for any lattice. [7,8] In particular for a Chasman-Green structure [9] the minimum emittance is given by the formula [7,9]

$$e_{x(\min)} = C_q \gamma^2 \Theta^3 / (J_x 4\sqrt{15}) \qquad (1)$$

where C_q=3.84 10^{-13} m, γ is the relativistic factor, Θ the bending angle per dipole and J_x is the horizontal damping partition number. In a practical storage ring it is difficult to reach the minimum emittance, therefore for actual lattice, a more realistic estimate would increase this estimated emittance value by a factor of two or three.

For the Chasman-Green lattice of DAΦNE, by using the conservative values (in terms of synchrotron radiation applications) of TABLE II, the horizontal damping partition number can be calculated by standard formulas which relate the J_i with the damping factors τ_i. As we obtain a J_x value of 0.993, with $\gamma=10^3$ and Θ=0.8 rad, the estimated emittance minimum value is about 15 10^{-9} m rad, which represents a reasonably low emittance value for a ring working at 0.51 GeV.

Actually a double bend achromat [10] as DAΦNE produces the same minimum emittance as given by eq. 1 but it is in fact more flexible in terms of emittance than simple Chasman-Green lattices. This is due to the presence of additional quadrupoles within the achromat cell. With this value of emittance DAΦNE is going to have similar or even better performances than other rings of similar energy (see TABLE I).

As in the DAΦNE lattice there will be several wigglers, the additional radiation produced in the insertion device will tend to increase the quantum fluctuations and also to lower the damping time. Depending on the value of the dispersion at the insertion device location (including the self-generated dispersion), either effects will tend to dominate. This means that wigglers can be used also to reduce the emittance. In the DAΦNE lattice, in the wiggler straight section the dispersion function has a non-zero value so that the emittance should be tuned to a final value lower than the minimum estimated in a lattice without damping wigglers. (see ref. [10] eq. 41).

4 - CALCULATION OF ELECTRON BEAM DIMENSIONS AND SOURCE CHARACTERISTICS

To calculate the beam dimensions σ_i (i = x, y where x is referred to the horizontal axis) and the divergences σ'_i we use the standard equations for the emittances (ε_i) and the dispersion (β_i) functions. The theoretical values for σ_x and σ'_x are given by:

$$\sigma_x = \sqrt{\beta_x \varepsilon_x} + (\eta_x \, \Delta p/p)^2 \qquad (2)$$

$$\sigma'_x = \sqrt{(\varepsilon_x/\beta_x)} + (\eta'_x \, \Delta p/p)^2 \qquad (3)$$

while for the theoretical value of σ_y and σ'_y we have:

$$\sigma_y = \sqrt{(\beta_y \varepsilon_y)} \qquad (4)$$

$$\sigma'_y = \sqrt{(\varepsilon_y/\beta_y)} \qquad (5)$$

here η_x and η'_x are the dispersion function and its derivative while $\Delta p/p$ is the relative r.m.s. energy-spread in the anomalous bunch lengthening regime (1.46 10^{-3}). By using eqs. 2-5 and the parameter listed in ref. [5] we can calculate the beam dimensions and the beam divergences at three different sources point of the half-*long* section and in the center of the very long straight section where the interaction point (IP1) is located. The other points are the two bending magnets BLS and BLP and the wiggler WIG. (see Fig. 2) Values reported in TABLE III, are obtained by using the design emittance $\epsilon = 10^{-6}$ m rad (a very conservative choice) and the design coupling coefficient k=0.01.

If we exclude the interaction region IP1, which is dedicated to the detector and where we have small vertical size but a large divergence, the vertical beam size and the divergences are nice for the two bendings but in particular for the emission of the wiggler (about 100 μm and 100 μrad). In fact the vertical beam sizes of the bending are more than two times larger. On the contrary all the horizontal parameters are quite large. However, it is important to note that at the second bending BLP, the horizontal divergence is three times smaller than at BLS.

TABLE III

Source	σ_x (mm)	σ'_x (mrad)	σ_y (mm)	σ'_y (mrad)
IP1	2.12	0.471	0.021	0.471
BLS	2.21	1.57	0.280	0.036
WIG	4.13	0.341	0.109	0.091
BLP	2.17	0.534	0.313	0.032

If the machine will work with a lower emittance all of these values can be reduced and by taking benefit by the very low coupling value, a reduction of about a factor of 3 in terms of beam size can be reasonable expected. However, detailed beam parameters cannot be obtained without a table of optical functions for the lower emittance lattice.

In summary, even if this storage ring is not specifically designed for, can be usefully applied to synchrotron radiation applications, for its small beam dimensions and divergences in the vertical plane. This coupled to the high design current is really interesting for all the experiments who mainly need high fluxes. The vertical emittance will be further improved if in dedicated runs the machine, taking benefit of the large flexibility of the lattice will work around emittance values of about 20 nm rad. In that case a consistent increase of the brilliance is expected.

From these electron beam dimensions we can calculate now the vertical source characteristics at different wavelength. The angular spread of the radiation in the vertical plane is

$$\sigma'_Y = \sqrt{(\sigma^2_{y'} + \sigma^2_c)} \qquad (6)$$

where σ_c is the natural synchrotron radiation angular width. This can be calculated and is a function of the ratio ϵ/ϵ_c. To DAΦNE, for $\epsilon/\epsilon_c \ll 1$ as in the case of infrared and VUV emission, the σ_c rms is given by this formula [6]

$$\sigma_c \,(\mathrm{mrad}) = 0.816\, (\epsilon/\epsilon_c)^{-0.354} / E\,(\mathrm{GeV}) \qquad (7)$$

For example, at the wavelength of 10 μm, the rms angular spread is greater then 20 mrad (and increases with the wavelength) and this makes the $\sigma_{y'}$ contribution negligible when compared to the contribution of the divergences for both bending magnets and wiggler of Table III. Actually, this is a desirable situation because both the effective source divergence angles in the horizontal and vertical plane: σ'_X and σ'_Y are as minimum as possible and are determined by the characteristic synchrotron emission.

5 - SR INFRARED EMISSION

The interest in IR emission dates 1966, when a Solid State Panel of the National Research Council of USA address the significance of the synchrotron radiation sources as IR sources in particular in the far IR. Since then we have to wait for a study of Stevenson *et al.* [11] in 1973. The first paper on synchrotron infrared emission cames only in 1976 [12] but only in 1985, the first infrared synchrotron radiation beamline became operational at UVSOR (Okazaki, Japan). [13] This new source has been progressively considered by spectroscopists as a useful alternative to black bodies in far-IR spectroscopy. Further IR beamlines from synchrotron dipolar magnets have been built (or are under construction) at Brookhaven (USA), Berlin (Germany), Daresbury (UK), Lund (Sweden). At Brookhaven and at Okazaki the infrared beamlines are currently used for spectroscopic applications. They usefully replace black bodies (mercury and globar lamps) wherever high brilliance in the far-infrared is requested.

The first infrared SR line which utilizes as a source an undulator is now performing final tests at LURE (Orsay, France). This device is named SIRLOIN and will be described here in some detail both for its interesting project performances and its original constructing solutions. [14] A schematical view of the line is shown in Fig. 6. Its extracting mirrors are assembled on one of the straight sections of the 800 MeV SuperACO storage ring, which contains a variable gap undulator. This latter has a length of 3096 mm, a magnet period λ_o=12.9 cm, a maximum B_o=0.57 T, and is used in the wiggler mode with K=6.9. At about 1 m from the exit of the undulator, two gold-coated, water-cooled plane mirrors M_1 and M_1' form in the vertical plane an angle of 45° with respect to the particle beam. They can be moved at will in order to vary their separation D. This separation is maximum during the phase of beam injection and is minimum (24 mm) when the particle beam is stable. As the divergence of synchrotron radiation is much larger in the infrared than in the VUV and SXR domain, the mirrors collect the infrared while letting the particle beam and the high energy radiation pass by. (see Fig. 7) Cylindrical mirrors M_2 and M_3 focus the infrared on the diamond, 1-cm in diameter, window W, which separates the ultra-high vacuum section of the line from the low-vacuum section. Radiation is finally focussed on the input slit of an interferometer, in such a way that infrared SR follows the same optical path as the internal sources of the spectrophotomer. This will facilitate comparisons and line calibration. All tests performed with mirrors M_1 and M_1' in final position have shown that, after a few hours of working which are necessary for degassing, their insertion in no way affects the beam lifetime, which at SuperACO is about eight hours in standard situation. Computer simulation has shown also that the radiation which can be extracted from SIRLOIN is more intense (not just more brilliant) than that of a black body at 2000 K in all the infrared domain (Fig. 8). Analogous calculations show that SIRLOIN radiation should be also more intense than that one can extract from a bending magnet of the same ring. Nevertheless, first tests performed after the assembling of the line (June 1992) have not met these predictions yet. The discrepancy is mainly attributed to difficulties in the simultaneous alignment of the cylindrical mirrors and to an imperfect parallelism between M_1 and M_1' which is a key element of this optical layout. The insertion of a dynamical alignment system should solve this problem.

It is clear that the experience which is being accumulated at SIRLOIN is precious for anybody would project further infrared SR lines which extract radiation from wigglers and undulators. In view of this, one of us (P.C.) is participating to the entire testing procedure of the SIRLOIN beamline.

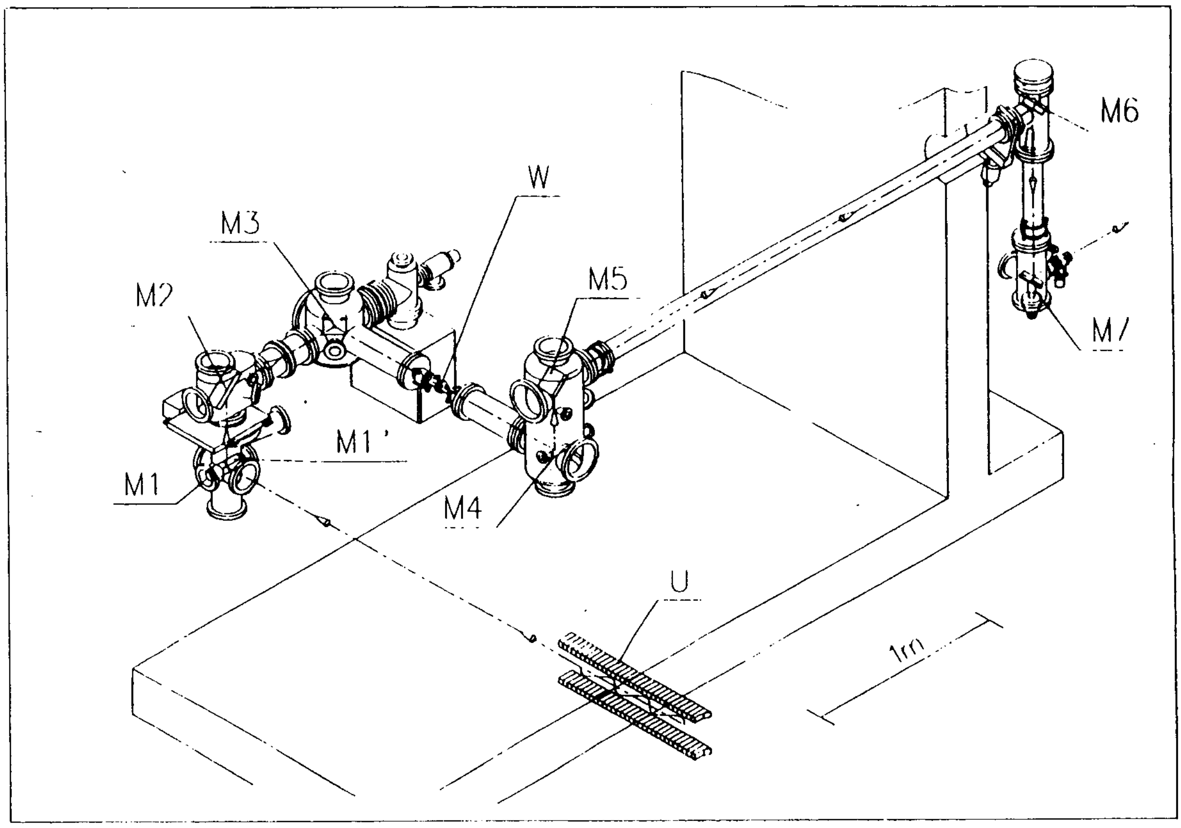

FIG. 6 — Schematic view of SIRLOIN (courtesy from ref. [14]). The extracting mirrors are assembled on a straight section of SuperACO storage ring, which contains the variable gap undulator SU3. Two water-cooled plane mirrors M_1 and M_1' can be moved at will in order to vary their separation in order to collect the infrared while letting the particle beam and the high energy radiation pass by. The beam is then focussed by the cylindrical mirrors M_2 and M_3 on the diamond window W, which separates the ultra-high vacuum section of the line from the low-vacuum section, and matched to the entrance optics of the interferometer by mirrors M_4 to M_7.

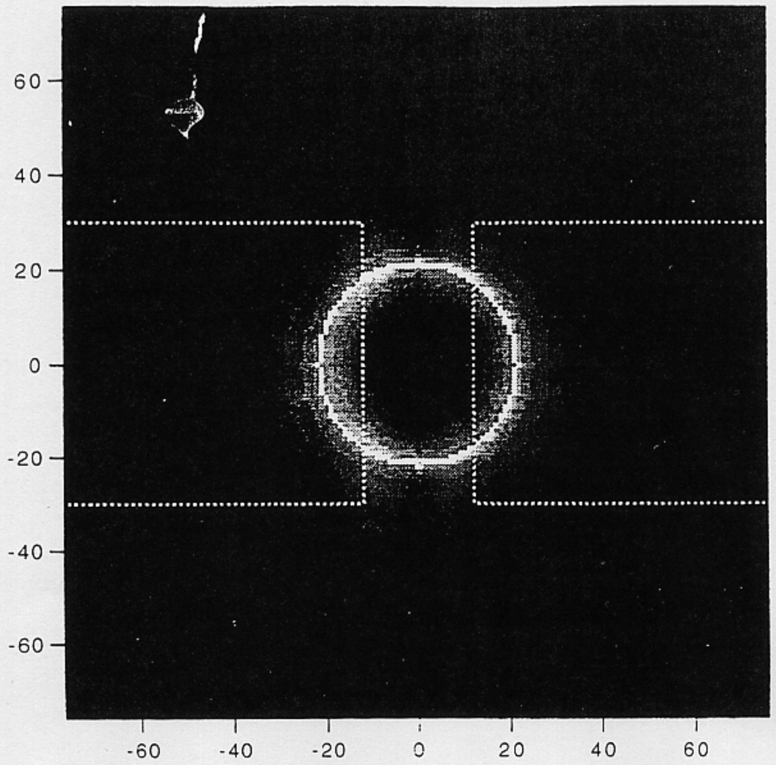

FIG. 7 — Distribution of the photon flux on mirrors M_1 and M_1' (represented by dotted lines) at a wavelength of 100 μm and for a typical gap D=16 mm. Each tone of grey from white to black corresponds to a 12.5% loss with respect to the maximum intensity. (courtesy from ref. [14]).

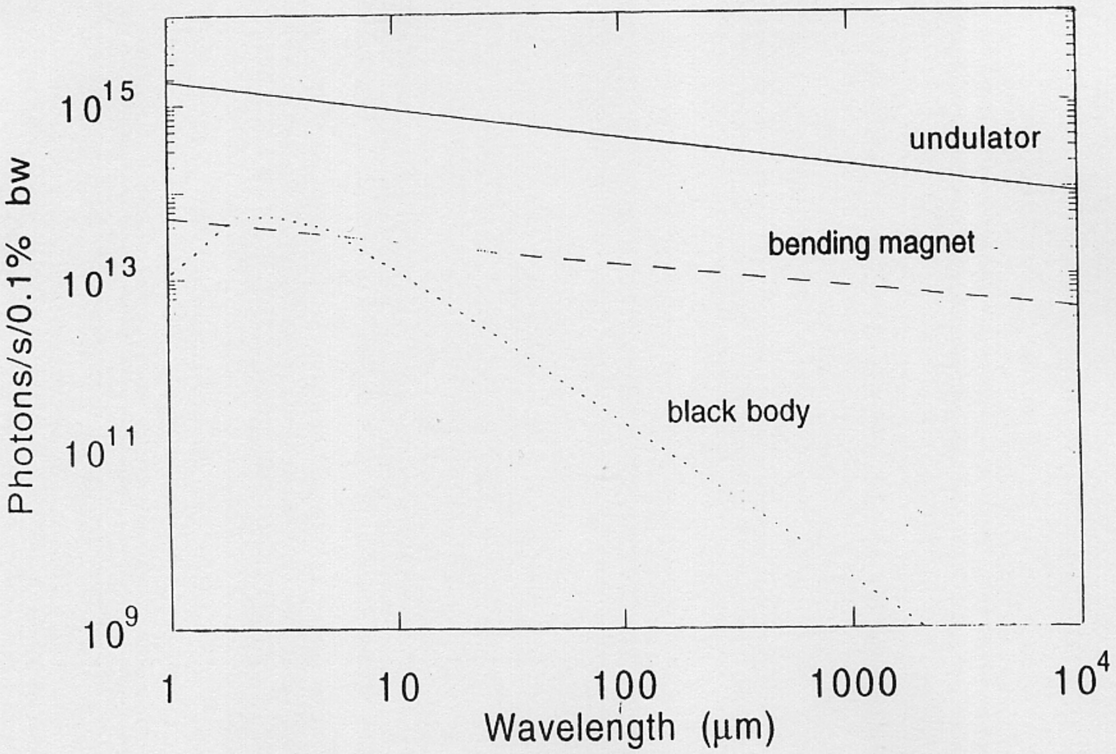

FIG. 8 — Infrared photon flux, as calculated for a black body at 2000 K (dotted line), produced by the SuperACO bending magnet collecting 50 mrad (dashed line) and for the undulator working at K=6.9 (solid line). (courtesy from ref. [14]).

Calculations for the infrared flux have been performed with the parameters of the bending magnet of DAΦNE and are reported in Fig. 9 (at 100 μm) and in Fig. 10 (at 10 μm) for both polarized components (σ, π) of the SR. They show that infrared radiation from DAΦNE, collecting 50 mrad in the horizontal plane at a current of 2 Amps, will be in the range $10^{14}\div10^{15}$ photon/sec per 0.1% bandwidht. Expected values are roughly the same as for SIRLOIN.

The possible use of IR radiation from a bending magnet are then extremely promising and challenging both for the intensity of the radiation delivered and the power load that the optical elements have to withstand without to be deformed and limiting the aberrations.

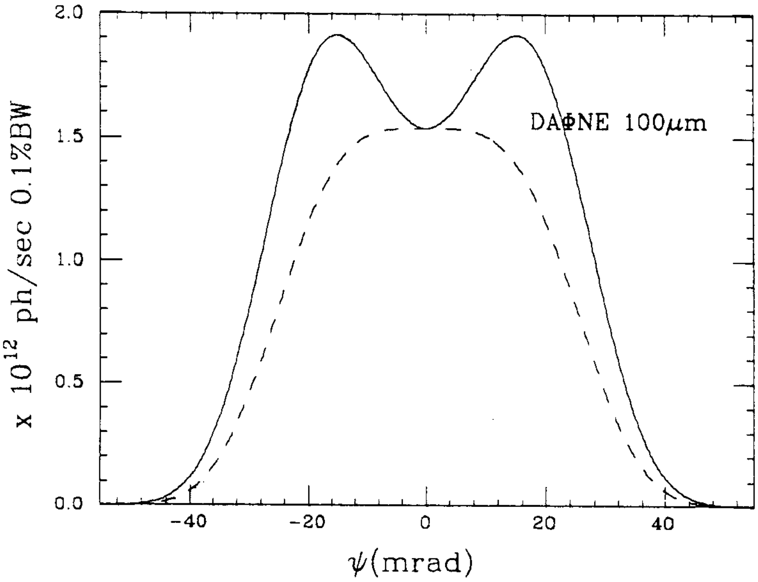

FIG. 9 — Plot of the flux emitted by the bending magnet of DAΦNE at a wavelength of 100 μm, collecting 50 mrad of radiation in the horizontal plane and with 2 Amp of current (solid line). The dashed line is the component of the radiation polarized in the plane of the ring (s) while the dotted one is the perpendicular component (p).

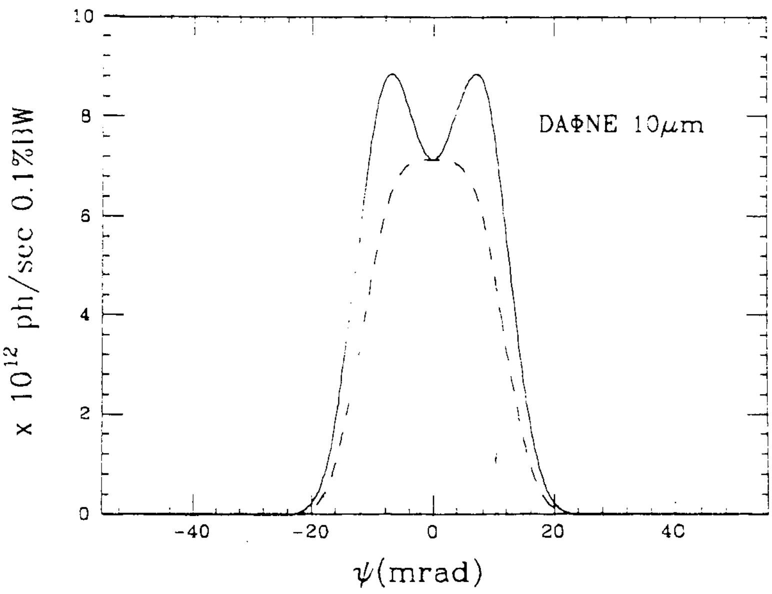

FIG. 10 — The same as in Fig. 9 but at a wavelength of 10 μm.

A design similar to SIRLOIN can be considered for extracting radiation for a wiggler of DAΦNE. The extraction system for the radiation can be located at about 0.5 m from the wiggler, where two Ni-coated, water-cooled plane mirrors made by Cu OHFC, form in the vertical plane an angle of 45° with respect to the particle beam direction. They can replace (or can be placed after) the absorbers (A) shown in Fig. 3. The two mirrors have to be moved at will in order to vary their position to avoid problems during the beam injection. As the divergence of synchrotron radiation is much larger in the infrared than in the VUV and SXR domain, the mirrors collect the infrared while letting the particle beam and the high energy radiation pass by, strongly reducing thermal problems due to the heat load. (see Fig. 7)

The optical system necessary to transfer radiation to the spectrometer can be realized with two parabolic off-axis mirrors that will focus the infrared radiation on a diamond window. It will be used to separate the ultra-high vacuum section from the low-vacuum section of the beamline. Radiation will be finally focussed on the entrance slit of an interferometer with appropriate optical elements.

Alternatively, it is possible to consider the emission of a DAΦNE bending magnet and collect about 50 x 50 mrad (see Fig. 9 and Fig. 10). As before a first plane mirror is located close to the orbit (~0.6 m). This mirror set at 45° deflects on top the radiation and withstand the maximum power load. Focusing of the radiation onto a diamond window which will separate the UHV section with the low vacuum section will be performed by a separate optical setup which have to transport the radiation in the experimental area. Ray tracing calculation for the focusing optics are in progress to compare the performance of different setup.

6 - CONCLUSION

The SR DAΦNE sources (i.e. wiggler and bending magnets) are more intense and more brilliant than black body sources of radiation both in the far and the mid infrared as confirmed now by several works. The insertion devices sources (i.e. undulators and wigglers) are certainly more attractive for several reasons:

i) the intensity is greater by a factor of 2N where N is the number of periods

ii) smaller horizontal mirrors are required, indeed, a large angle port from bending magnet subtending about 50 mrad of orbit, intercepts a segment of several centimetres;

iii) the design of the optical components for the radiation transfer line is easier (less elements) and less expensive (smaller mirrors) as shown by the design of SIRLOIN [14];

iv) in general the extraction of the radiation from these devices involves less constraints to the physical environment.

However, the last IR beam time becoming operational now at Daresbury extract the radiation from a bending magnet. [15]. The use of bending magnet sources still remain extremely competitive both for the absence of constraints induced on the machine (i.e. gap of the mirrors which is correlated with the beam lifetime) and for the reduced damaging of the first optical elements associated to x-rays and beam particles impinging on it.

The availability of an infrared facility on DAΦNE will open large scientific opportunities to solid state physics, surface and interface physics and physical chemistry. In particular, several kinds of reflectivity measurements, because of the high flux, will be replaced by transmission experiments allowing to obtain more accurate and direct information. Moreover, high resolution spectroscopy could be extended to all the infrared range, with the substantial advantage to work with the experimental apparata in low vacuum environment when UHV is not required.

In addition, due to the high flux available, in the case of bending magnet, the peculiar polarization properties of the SR (see Figs. 9 and 10) could be exploited for studies on anisotropic systems without use of polarizers.

Finally, the time structure of the SR represents a potential great opportunity for the investigation of relaxation times in molecular and/or collective systems.

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