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Abstract

To improve the possibilities of synchrotron radiation research at HASYLAB in Hamburg, the storage ring DORIS II will be modified into DORIS III. One 65 m long straight section will be replaced by a new 73.6 m long arc which is built in such a way that space for seven insertion devices will be created. The scientific background and requirements on the wigglers and undulators are briefly mentioned. The optimization procedure leading to the parameters for the proposed devices is described. The requirements on vacuum chamber apertures in the insertion devices, especially for the high energy physics colliding beam operation mode at 5.3 GeV, is discussed.

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Introduction

At DESY, synchrotron radiation (SR) research has a long tradition since the sixties. The first SR experiments used the DESY I synchrotron. When DESY built the first electron storage ring DORIS in 1972, also a first beamline was constructed. Since then, the SR activities grew continuously: HASYLAB was founded in 1978 and a large experimental hall was built in the following years. In the meantime, the radiation of more than 1/4 of the DORIS dipole magnets is used for SR experiments. The first wiggler/undulator was installed in DORIS II in 1984 [1] and two more insertion devices optimized for VUV physics and high energy X-ray experiments [2] followed.

Research using SR is rapidly expanding, and new experimental possibilities for, e.g., inelastic photon scattering, magnetic surface scattering, time resolved studies became feasible with modern synchrotron radiation sources. The high flux, brightness and brilliance that can be obtained with insertion device technology stimulated these developments to a large extend. As a consequence, the demand on beamtime at insertion devices has increased dramatically.

At DORIS II, however, the space for wigglers and undulators is very limited due to geometrical constraints. In order to provide space for more devices, the idea of DORIS III was born. It will provide seven additional straight sections for insertion devices.

In this article we present a brief description of the planned DORIS III project and give some insight into the problems of adopting the insertion devices to the storage ring. The planned devices and their design criteria are described in detail.

The Project DORIS III

Until the end of 1986, two high energy physics experiments simultaneously used the storage ring DORIS at DESY in Hamburg (see Fig. 1). One, the Argus (A) detector is still collecting data. The other, the Crystal Ball (C), was removed from the ring in 1986. Consequently, one of the two 65 m long straight sections was available for new activities. In order to use this opportunity for the installation of wigglers and undulators several options were studied by a working group with the following result: Each of the two dipole magnets of 15° bending angle adjacent to the old Crystal Ball branch will be removed and replaced by three shorter magnets of 5° bending angle which are distributed along the new arc. In this way seven additional straight sections, most of them providing 4 m of free space for insertion devices, are created.

In Fig. 1 the old Crystal Ball branch is still visible. It will be dismantled but many of its components will be used for DORIS III. Fig. 2 shows the Bypass section in more detail. Using the insertion devices, seven new beamlines will become available.

Since high energy activities at ARGUS will be continued, DORIS III will also be operated in two different modes: one at 5.3 GeV energy with colliding beams of positrons and electrons stored for high energy physics (LUM mode), and the other with electrons at lower energy (4.5 GeV) for synchrotron radiation experiments (SYN mode).

Of course, design criteria for a ring that is compatible with LUM operation are different from that for a ring that is optimized for synchrotron radiation only. For synchrotron radiation operation the LUM option has two major drawbacks:

1. A special magnetic lattice and corresponding electron optics are needed to produce the interaction point for LUM operation. Consequently, less degrees of freedom are available to produce an electron optics when optimizing the synchrotron radiation requirements. In general, the electron optics will be a compromise between SR and LUM requirements.

2. The vertical aperture, that two circulating beams require, is for DORIS III roughly twice as large as that of only one beam. This is an important boundary condition for insertion devices.

During the past year, a magnetic lattice and electron optic were developed that allow for synchrotron radiation as well as for LUM operation [3]. It could be demonstrated that both operation modes are possible in a rather asymmetric ring like DORIS III.

The impact of the larger aperture requirements on the insertion devices is most severe. The consequences will be discussed in detail later in this paper.

Insertion Devices

The number of free parameters when designing the new part of the storage ring was very limited. Therefore electron source sizes and electron beam divergences represent compromises within the given emittance of DORIS. The energy for dedicated SR runs of DORIS III was chosen to be 4.5 GeV. Therefore the wigglers and undulators are optimized for this energy. A maximum current of 100 mA will be available. Numerous discussions helped to define the users requirements on the device parameters [4,5,6]. Due to geometrical constraints on one of the new beamlines at present only six of the seven straight sections are considered for insertion devices. Four of them will serve as sources in the X-ray region, one as an XUV- and one as an VUV- as well as an X-ray-source. The six devices proposed for the straight sections will be discussed in more detail in the following paragraphs. Their parameters are listed in table 1 together with relevant parameters of the straight sections. A comparison with existing devices in DORIS II is given as well.

X-Ray Undulator

The primary design goal for the X-ray undulator was high brightness at 8 keV photon energy. This will be realized with a short period length (λ_o = 3.14 cm) undulator in hybrid technology working on the third harmonic. The tunability will be rather limited.

The energy of the n-th harmonic on axis is given by

$$E_n\ [\mathrm{keV}] = 2.483 \times 10^{-7}\ \gamma^2 \cdot n\ /\ \lambda_o\ [\mathrm{cm}] \cdot (1 + 0.5\ K^2) \qquad (1)$$

Here γ is the electron energy in units of its rest mass and λ_o is the period length. The undulator parameter K is defined as

$$K = 0.934 \cdot \lambda_o\ [\mathrm{cm}] \cdot B_o\ [\mathrm{T}] \qquad (2)$$

B_o is the maximum magnetic field on the undulator axis. It can be estimated using Halbach's empirical formula [7] for hybrid devices:

$$B_o\ [\mathrm{T}] = 3.33 \cdot \exp(-g/\lambda_o(5.47-1.8\ g/\lambda_o)) \qquad (3)$$

with the undulator magnet gap g. Equation (3) is valid for $0.07 \le g/\lambda_o \le 0.7$. To be on the safe side, only 90 % of the value given by (3) were taken into account.

When inserting (3) into (1), E_n is a function of g and λ_o only, so g-λ_o pairs can be found that satisfy eq. (1) for a specific photon energy. This functional relationship for E_B = 8 keV is shown by the full curve in Fig. 3.

The total flux of the n-th harmonic is given by

$$I_n = e^2 \cdot \pi \cdot N \cdot F_n(K) \cdot (1+0.5\ K^2)/n \cdot c \qquad (4)$$

N is the number of periods, e the electron charge and c the speed of light. The function $F_n(K)$ is defined and reproduced in ref. 8. Above K = 1.5, the intensity I_n in the third harmonic reaches comparable or even higher values than that of the first one.

The brightness of this device can be calculated from eq. (4). Possible g-λ_o pairs are reproduced by the full curve of Fig. 3. The brightness values for these pairs are shown by the dashed curve. The number of periods N is restricted by the available length of the straight section (4 m) and increases continuously for decreasing gap since the period length λ_o decreases with the gap. Therefore, in order to obtain a reasonable brightness, low gap values are necessary. At present a magnetic gap of 11 mm seems possible employing a sophisticated vacuum chamber with a minimum vacuum aperture of 7-8 mm. Machine studies with DORIS demonstrated that in SYN-mode such a small aperture should be possible by choosing a low vertical β-function with a corresponding low vertical beam size at this device location.

The brightness of this undulator is strongly influenced by the electron beam divergence. The width of the radiation cone σ'_r is considerably smaller than the horizontal and vertical electron beam divergences σ'_x and σ'_z.

In order to maximize the brightness we also tried to minimize σ'_x when designing the electron optics. Numerical values for σ'_z and σ'_y are given in Table 1. σ'_z was already fixed by the requirement for a small vertical beam size.

X-Ray Wigglers

Many experiments use X-rays in the range up to roughly 20 keV. Experiments like, e.g., EXAFS, XANES, small angle scattering, protein crystallography, X-ray diffraction, powder diffraction, and inelastic X-ray scattering need a high photon flux, energy tunability, and imaging of the source rather than high collimation and brightness. To meet these demands, three identical standard wigglers have been proposed. Unlike for undulators the divergence of the radiation plays only a minor role. Most of the radiation of a wiggler is emitted incoherently, therefore the total opening angle is much larger and given by

$$\delta = 2\ K/\gamma \qquad (5)$$

Since the K-value can be quite large, δ can reach several mrad. In order to collect the radiation or to image the source, optical elements such as focusing mirrors will be used. The horizontal acceptance of these mirrors is limited to about ± 1.5 mrad thus limiting the K-value to 13.2 at 4.5 GeV. On the other hand, the emitted spectrum should not extend to too high photon energies in order to avoid background problems. A critical energy around 12-14 keV is sufficient which allows for X-ray experiments even well above 20 keV.

These facts are summarized and illustrated in Fig. 4. The allowed λ_o values that fulfil equ. (2) and (3) with K = 13.2 are shown by the full line. Again Halbach's formula minus 10 % was employed to calculate the maximum field. The maximum field on axis, the critical energy and the number of periods possible in a 4 m long straight section are also plotted. As one sees immediately, a wiggler with K = 13.2 allows for more periods, higher field and higher critical energy, the smaller the gap. It is obvious that the flux emitted by this device also increases at least proportional to N if the gap is decreased. Further the total power emitted by these wigglers increases dramatically proportional to B^2. The critical energy was chosen not to exceed 13.6 keV thus allowing for a maximum field of 1.01 T and a period length of 14 cm. The corresponding magnet gap is 3 cm, requiring a vacuum chamber aperture of 26 mm. This can be realized with vacuum chambers already in use at DORIS. The total power at 100 mA ring current will be 5.25 kW, a value considered tractable with modern state of the art SiC-mirrors [9].

We intend to standardize these wigglers as far as possible, e.g., mechanical drives as well as magnetic structures will be identical. This also allows for economic manufacturing. The magnetic structures can be easily dismounted from their drives in order to facilitate a quick exchange of magnetic arrays.

Asymmetric Wiggler

There is a rapidly increasing demand for circularly polarized radiation in the X-ray region for spin dependent photoabsorption, magnetic scattering, magnetic surface scattering, and magnetic inelastic scattering.

Plans are underway to build an asymmetric wiggler for DORIS III following the original idea of Goulon et al. [10], however, with a modified magnetic structure. A prototype based on a pure REC magnetic structure is already under construction [11].

For DORIS III an asymmetric structure that uses hybrid technology will be built. This will allow for high fields and consequently more polarized intensity at higher energies. Although a helical wiggler as proposed by Yamamoto and Kitamura [12] offers more polarized intensity for a given device length, we decided on the simpler asymmetric design which is mechanically fully compatible with the symmetric structures. This allows the construction of at least one structure that can be used alternatively at any X-ray wiggler beamline. The influence of possibly different optical elements on photon polarization can be either predicted theoretically [14] or determined experimentally [15].

Fig. 5a shows a magnetic flux line plot of the upper part of one half period of this device obtained with the PANDIRA program code. The field on axis is shown in the diagram below. The asymmetric field is obtaind by choosing different lengths for the two magnet blocks. In this way the asymmetry can be adjusted. Further, more periods can be installed in a given straight section than proposed by the design given in ref. 13. The field integral is kept zero since each flux line of one block crosses the midplane twice, thus causing no net deflection. If the length of both blocks is identical, a full period of a symmetric structure will be obtained. This case is shown for comparison in Fig. 5b which corresponds to a symmetric X-ray wiggler with λ_o = 14 cm. The periodicity is doubled in the latter case. The lengths of the first blocks are the same in the symmetric and asymmetric device and very similar values for the negative peak field are obtained. It can be shown by integration that the maximum beam deflection of both devices is also very similar so that both the symmetric and asymmetric wiggler require the same acceptance for the beamline optics.

VUV-Undulator / X-ray Wiggler

One beamline will be shared by a VUV and an X-ray experiment. An undulator is designed to deliver a high brightness photon beam for a high resolution plane grating VUV-monochromator in the range from 5 to 100 eV. For a first harmonic at 5 eV, a large period length and large K value of 18.5 is needed. This means high magnetic field and such a device is simultaneously a wiggler for the X-ray range. Due to the large period length, the magnetic gap can be fairly large and the device is built in pure REC technology.

The electron beam size in this wiggler is very small so that is is well suited for imaging optics. However, the length of the device is limited to 2.7 m due to two quadrupoles needed to produce a LUM optic for high energy physics.

XUV-Triple Undulator

SR-experiments on the K-shells of free atoms and molecules up to Silicon require very high resolution because the electronic excitation levels are very sharp. To cover this energy range a beamline tunable from 50 to 2000 eV that offers both very high resolution (up to 10000) and very high flux is planned. A new type of monochromator using a varied-space plane grating with self-focusing properties will be used, that allows for high photon throughput [16, 17].

In order to reach its design goals, this monochromator needs a highly collimated photon beam that can only be delivered by an undulator. Three magnet structures with different period lengths will be provided that can be alternatively used in a revolver type [18] device. The first harmonic of each can be tuned by changing the gap. In this way the full range from 50 to 2000 eV can be covered.

The optimization procedure for the three magnet structures is illustrated in Fig. 6. A conventional pure REC structure with four blocks per period is assumed. The lowest possible energies of the first harmonics of these structures at the minimum gap were set to 50, 200 and 800 eV. Possible g-λ pairs that satisfy this condition are also shown in Fig. 6. Generally, the smaller the minimum gap, the smaller the period length and the more periods can be used in a given device length, which in turn increases the obtainable intensity. The K-value also increases, but only slightly, and the tunability becomes larger.

On the other hand, the total power emitted by this undulator and correspondingly the power density on the first optical element increases dramatically when reducing the gap and this sets a lower limit. Fig. 6 demonstrates how relevant parameters change with design modifications. As a compromise between intensity and tunability considerations on one side and power load problems on the other side, we decided to use a minimum magnetic gap of 30 mm which allows to employ the same vacuum chambers as for the X-ray wigglers. The power load of 2.54 kW at 100 mA beam current is again considered to be tractable.

Spectra of the Insertion Devices

A comparison of brightness and flux for all insertion devices described in this paper is shown in Figs. 7a and b. Finite electron divergence was properly taken into account for the calculation of brightness. Undulator harmonics are reproduced by the dotted curves. The first in the case of VUV and XUV, the third in the case of the X-ray undulator.

The full lines correspond to the wiggler spectrum of the VUV-undulator/ X-ray wiggler. The X-ray wiggler spectra are shown by the dot-dashed curves. For comparison, the spectra of the already existing devices W1 and W2 as well as the spectrum of a dipole magnet for 1 mrad horizontal width are included. The highest brightness is delivered by the undulators especially in the XUV and VUV region. In the case of the XUV-1 undulator a gain of 40-50 in comparison with a wiggler is expected. This is due to the fact that for higher photon energies a smaller period length is required. But for a fixed gap the magnetic field on axis in then decreasing causing a rapid decrease in brightness. Because of this effect, undulators in the XUV spectral region are promising devices for a storage ring like DORIS. This is already shown with the existing wiggler/undulator W1 [19].

The total flux emitted by the undulators is considerably lower than that of the wigglers. This indicates that they are optimally used only when a highly collimated beam is needed. When flux is the figure of merit like in the case

of many X-ray experiments, wigglers are superior, especially if also a broad spectral range is required.

Figs. 8a-c show spectra of the asymmetric wiggler. Instead of reproducing the general brightness and flux curves, a direct comparison is made for an experiment on spin dependent photoabsorption made at HASYLAB [20]. This experiment uses the circularly polarized light emitted by a dipole magnet above and below the orbital plane. Fig. 8a shows a direct comparison of the total flux received at this experiment with an acceptance of ± 0.2 mrad horizontally and 0.14-0.18 mrad vertically for a dipole magnet (dot-dashed) and the asymmetric wiggler with 19 periods (full line). Fig. 8b gives the circularly polarized flux I_R-I_L where the positive and negative signs stand for right and left handed polarization, respectively. Electron beam divergence is taken into account. Only left handed polarized light is observed at a dipole. At the asymmetric wiggler a weak positive and a strong negative field contribute to the forward emission which always leads to a change of sign of the polarization at low energies. The photon energy at which this change occurs can be influenced by the magnet design, i.e. by choosing the proper ratio of lengths of the two magnet blocks in Fig. 5a. The gain in polarized intensity is roughly equal to the number of periods which is readily verified in Fig. 8b. This is different from symmetric wigglers where two poles contribute per period and consequently the intensity is increased by about 2 N when compared to a bending magnet.

The degree of polarization is given in Fig. 8c. Especially below about 3.0 keV it is lower than that of a dipole magnet. Above 5 keV there is practically no difference. Of course, the polarization characteristics can be strongly influenced by choosing appropriate different apertures. In the example given above they were kept fixed.

Aperture Requirements

In the preceding chapter it was pointed out that the minimum magnetic gap is essential for the optimization of a given device, since for most applications devices optimized at a smaller gap perform better. There are two constraints for the magnetic gap:

1. Photon emission characteristics like maximum radiated power, power density, or maximum critical energy of the radiated spectrum.
2. Vertical aperture requirement for the circulating electron beam, i.e. lifetime of the beam.

The needed aperture in a storage ring depends in a complex way on a number of machine parameters like electron energy, electron optics, beam size, vacuum pressure. Since it is difficult to predict the aperture requirement exactly, the information on a particular storage ring is obtained experimentally by using scrapers. For DORIS the main parameter that determines the lifetime was found to be the vertical source size. For SYN and LUM operation the following relationship was found [21]:

$$A_{1,SYN} = 27\ \sigma_z \tag{6a}$$

$$A_{2,SYN} = 36\ \sigma_z \tag{6b}$$

$$A_{LUM} = 64\ \sigma_z \tag{6c}$$

σ_z is the vertical source size. The A's in equs. (6a-c) are minimum apertures for the electron beam without shortening its lifetime. LUM operation generally requires almost twice as much vertical aperture as SYN operation for the same σ_z. Equ. (6b) and (6c) already contain a security factor for beam deflection by field errors. If the aperture can be adjusted to the electron beam, so that it passes right through the center, the smaller value (6a) can be taken. The aperture given by Equ. (6a-c) are reproduced in table 1 for SYN and LUM operation together with the minimum magnetic gaps for the insertion devices and the inner height of the planned vacuum chambers.

In SYN mode for all devices except the X-ray undulator the minimum magnetic gap was chosen on the basis of heat load considerations or the desired critical energy. In contrast, the X-ray undulator will fully use the aperture limit given by Equ. (6a). In order to obtain this small value (7.3 mm) a vacuum chamber with a variable gap has to be developed.

In the straight sections 2, 3, and 6 the LUM mode requires much more than twice the aperture as compared to the SYN case due to the electron optics. The consequence is that in these sections either vacuum chambers with the apertures given in Table 1 have to be interchanged when switching between SYN and LUM operation or variable vacuum chambers have to be employed. While the first alternative is a straightforward solution, it requires 3-4 changes per year, with the drawback of breaking the vacuum of the storage ring. The second alternative requires a considerable engineering effort. At present only one such chamber is in use worldwide [22]. A variable gap vacuum chamber has been designed at HASYLAB and a prototype is under construction and will be tested this fall.

Another solution has been successfully tried out at BESSY where the whole magnet structure is placed in a large vacuum vessel [23,24].

Time schedule

The time schedule for DORIS III is as follows:

Electron optics calculations are almost completed. The dipole, quadrupole, and sextupole magnets as well as correction coils are designed. First prototypes will be delivered during 1989. As far as possible types already existing in one of the four DESY storage rings were used or modified. The design of the ring vacuum chambers and exit chambers has started. There will be a conceptual phase for the mechanical drives of the insertion devices as soon as all geometrical boundary conditions are clarified. Test structures of the X-ray undulator, X-ray wiggler and asymmetric wiggler will be built during 1989 in order to check their magnetic properties. The full devices will be constructed in parallel. Civil construction including the new experimental areas, the modifications of the DORIS tunnel as well as a new experimental hall are planned for 1990.

In the beginning of 1991 DORIS III will become operational. At this time most of the insertion devices as well as several beamlines will be completed.

References

1 P. Gürtler, A. Jackson, Nucl. Instr. and Meth. 208 (1983) 163; P. Gürtler, Nucl. Instr. Meth. A246, 91 (1986)

2 W. Graeff, L. Bittner, W. Brefeld, U. Hahn, G. Heintze, J. Heuer, J. Kouptsidis, J. Pflüger, E.W. Weiner, T. Wroblewski, Proc. of the SRI-88, Tsukuba (Japan), Aug. 29 - Sept. 2, to be published in Rev. Sci. Instr.

3 W. Brefeld, H. Nesemann, J. Roßbach, Proc. of the European Accelerator Conf., Rome (Italy), June 7-10, 1988, to be published in Nuovo Cimento

4 P. Gürtler, Internal Report DESY-HASYLAB, September 1987, unpublished

5 P. Gürtler, Internal Report DESY-HASYLAB, January 1988, unpublished

6 J. Pflüger, P. Gürtler, Internal Report DESY-HASYLAB, August 1988, unpublished

7 K. Halbach, Journal de Physique, Colloque C1, Suppl. No. 2, Vol. 44 (1983)

8 S. Krinsky, M.L. Perlman, R.E. Watson in: Handbook of Synchrotron Radiation, ed. E.E. Koch, North Holland 1983, p. 151 ff.

9 S. Mourikis, W. Jark, E.E. Koch, V. Saile, Proc. of the SRI-88, Aug. 29-Sept. 2, Tsukuba (Japan), to be published in Rev. Sci. Instr.

10 J. Goulon, P. Elleaume, D. Raux, Nucl. Instr. and Meth. A254 (1987) 192

11 J. Pflüger, to be published

12 S. Yamamoto, H. Kitamura, Jap. Journ. Appl. Phys. 26 (1987) 1613

13 M. Barthès, C. Bazin, M.E. Couprie, A. Dael, C. Evesque, G. Humbert, Proc. of the 10th Internat. Conf. on Magnet Technology, Boston (USA), Sept. 21-15, 1987

14 M. Blume, D. Gibbs, Phys. Rev. B 37, 4 (1988) 1779

15 G. Schütz, unpublished data

16 T. Harada, T. Kita, M. Itou, H. Taiza, A. Mikuni, Nucl. Instr. and Meth. A246 (1986) 272

17 V. Saile, private communication

18 G. Isoyama, S. Yamamoto, T. Shiogu, to be published in Rev. Sci. Instr.

19 F. Senf, K. Behrens v. Rautenfeld, S. Cramm, C. Kunz, J. Lamp, V. Saile, J. Schmidt-May, J. Voss, Nucl. Instr. and Meth. A246, (1986) 314

20 G. Schütz, W. Wagner, W. Wilhelm, P. Kienle, R. Zeller, R. Frahm, G. Materlik, Phys. Rev. Lett. 58 7 (1987) 737

21 H. Nesemann, unpublished data

22 E. Hoyer, representing the Beam Line VI Design Group, Nucl. Instr. Meth. 208 (1983) 117

23 J. Pflüger, S. Bernstorff, W. Braun, W. Gudat, W. Heinen, G. Isoyama, E.E. Koch, C. Krauß, P. Kuske, R. Maier, W. Peatman, F. Schäfers, T. Schroeter, R. Weidemann, F.P. Wolf, Nucl. Instr. Meth. A266 (1988) 120

24 W. Gudat, J. Pflüger, J. Chatzipetros, W. Peatman, Nucl. Instr. Meth. A256 (1986) 50

Figure Captions

Fig. 1 Site plan of DORIS III. The old Crystal Ball branch (C) is still visible.

It will be dismantled and its components used for DORIS III.

Explanation of symbols:

A: Argus detector
C: Crystal Ball detector
D: DORIS main hall
Do: DORIS office building
E: EMBL building and laboratory
H: HASYLAB experimental hall
W: Wiggler hall

Fig. 2 Actual planning stage (January 1989) of DORIS III.

Fig. 3 The full line represents all possible λ_o-gap-values for an undulator that result in a third harmonic of 8 keV. Halbach's hybrid-formula minus 10 % is assumed. The dashed curve gives the brightness of the third harmonic corresponding to the full curve.

Fig. 4 Gap/λ values for the X-ray wigglers when K = 13.2 resulting in an opening angle of 3.0 mrad. For these pairs, the maximum field, the critical energy and the number of periods in a 4 m long straight section is also shown.

Fig. 5a Flux line plot of the asymmetric magnet structure obtained with the PANDIRA program code. The upper part of one half period is shown. The asymmetry of the field can be influenced by a proper choice of the lengths of the magnet blocks. The flux density on axis is shown in the lower diagram. Parameters: λ_o = 19 cm, Gap = 3.0 cm, NdFeB with B_r = 1.1 T.

5b If the lengths of both magnets are equal, a full period of a symmetric structure is obtained. The length of the first magnet is unchanged. The parameters of this figure are those of the X-ray wiggler (λ_o = 14 cm, Gap = 3.0 cm, NdFeB with B_r = 1.1 T).

Fig. 6 Optimization curves of the XUV-triple undulator. Gap-λ_o pairs are determined such that the resulting minimum energy of the first harmonic is 50, 200 and 800 eV for XUV I, II, and III, respectively. The resulting K-values are large enough to guarantee sufficient tuning range. The resulting maximum K-values and maximum power load is also shown. Since the number of possible periods increases with decreasing λ_o, more periods can be installed in a device that is optimized at lower gap. A good choice of parameters must be a balance between gain of intensity and tunability and tolerable power load on the first mirror.

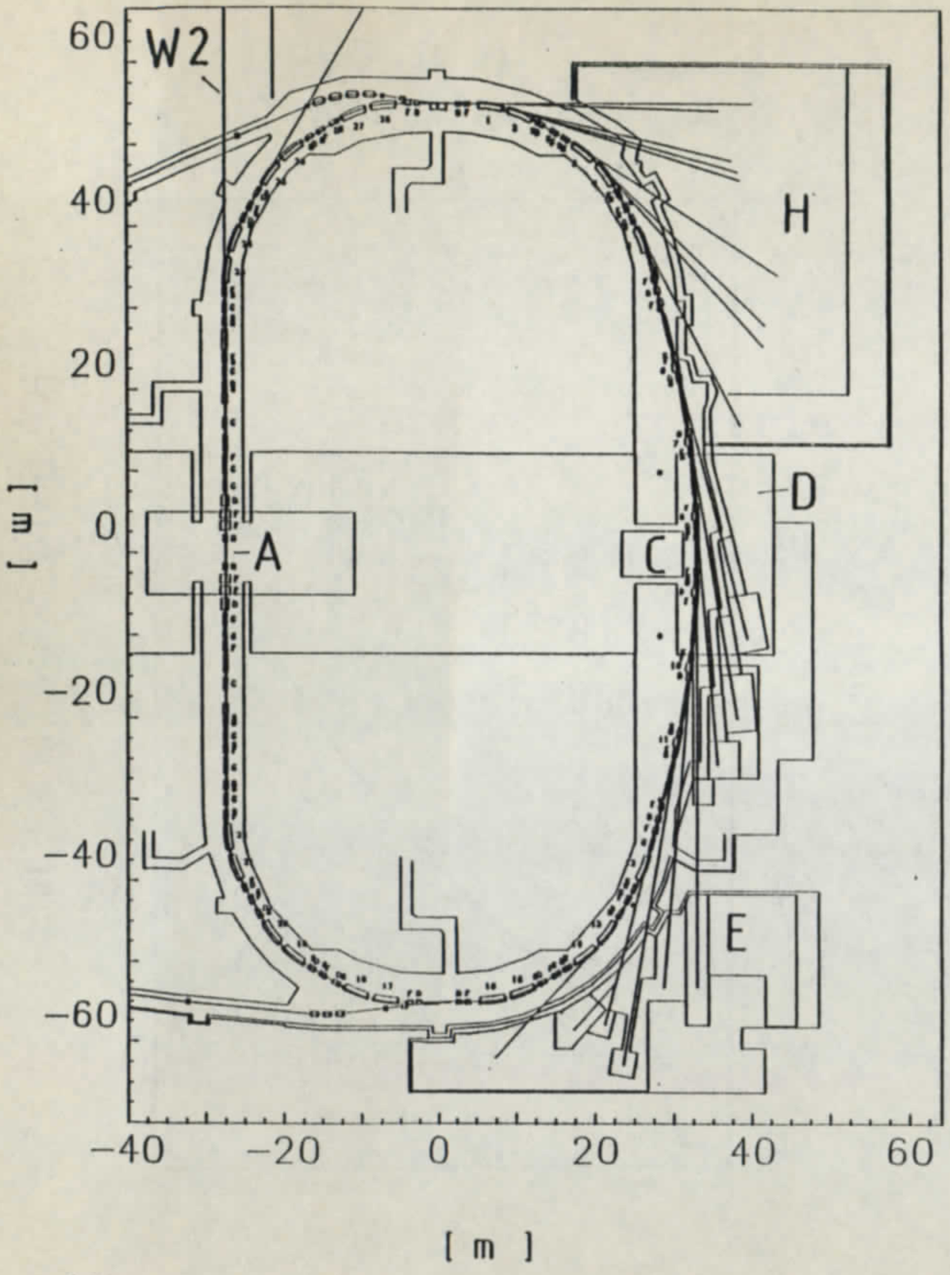
Fig. 7a,b Spectral brightness and flux of all DORIS III insertion devices. Dotted: the undulator harmonics of VUV and XUV I-III (1st) and X-ray undulator (3rd). Full: incoherent wiggler spectra of the VUV-undulator which is also a good X-ray wiggler. Dot-dashed: X-ray wiggler. Dashed: W1, W2 (already existing) and dipole magnet (1 mrad of orbit arc).

Fig. 8 Emission characteristics of the planned asymmetric wiggler. A comparison between an experiment using circularly polarized X-rays performed at HASYLAB on a dipole magnet (see ref. 20) and the intensities that would be possible with this device is made. The experimental aperture ± .18 mrad horizontal and 0.14-0.18 mrad vertical. Electron beam divergence is included. Full lines: asymmetric wiggler. Dashed lines: DORIS dipole magnet.

a Total intensity accepted by the experimental aperture.

b Circularly polarized flux accepted by this aperture. The maximum gain is about N times that of a dipole magnet. Below 3 keV the polarization of the asymmetric wiggler changes sign because of the small positive field present in forward direction. This behaviour can be influenced by the choice of the lengths of the magnet blocks.

c Degree of circular polarisation. Because positive and negative fields contribute, the polarization of the asymmetric wiggler is lower than the of a dipole magnet. But above 4 keV it is still larger than 0.7. Above 10 keV it is practically the same in both cases.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* Fig. 1

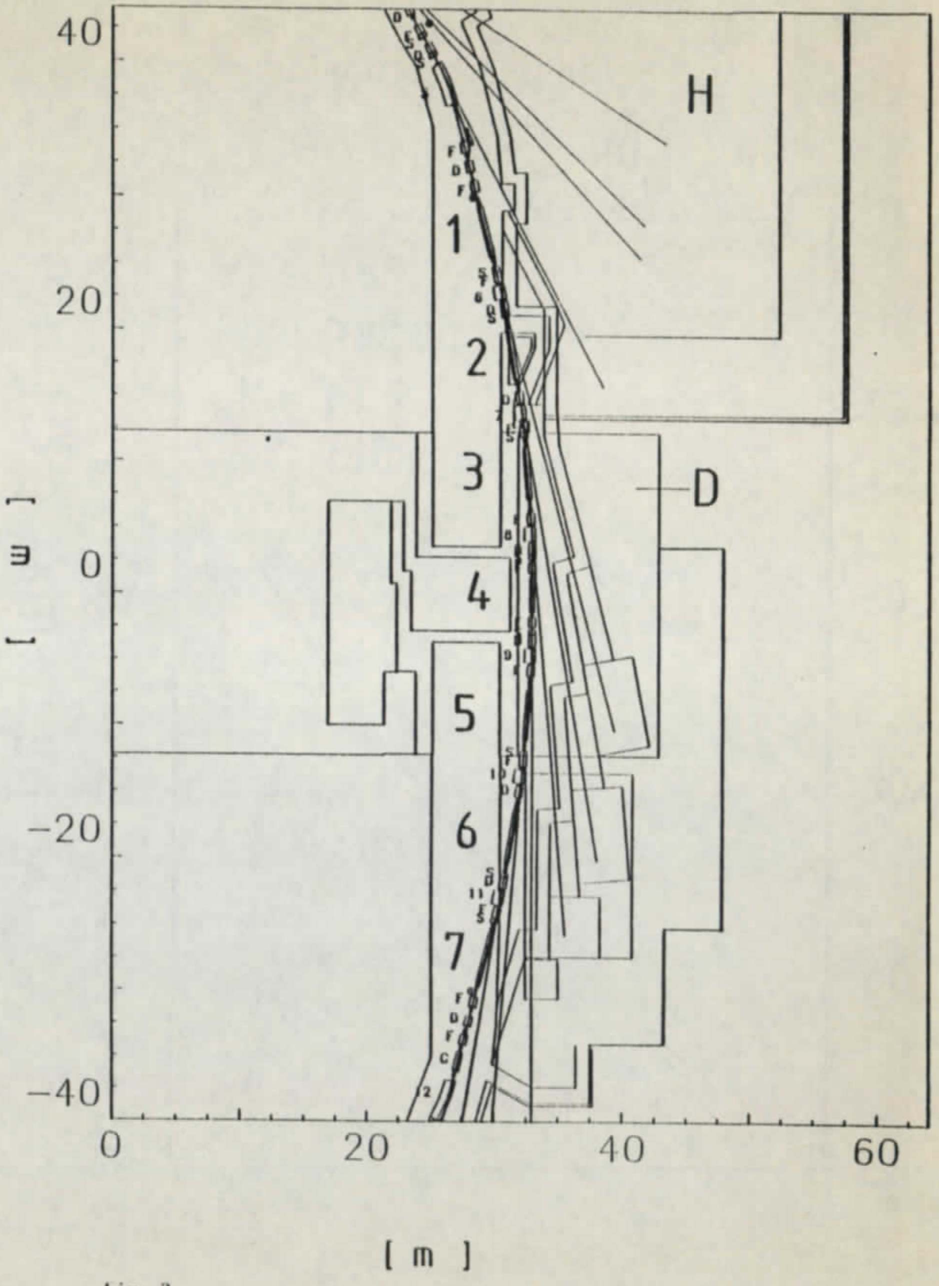
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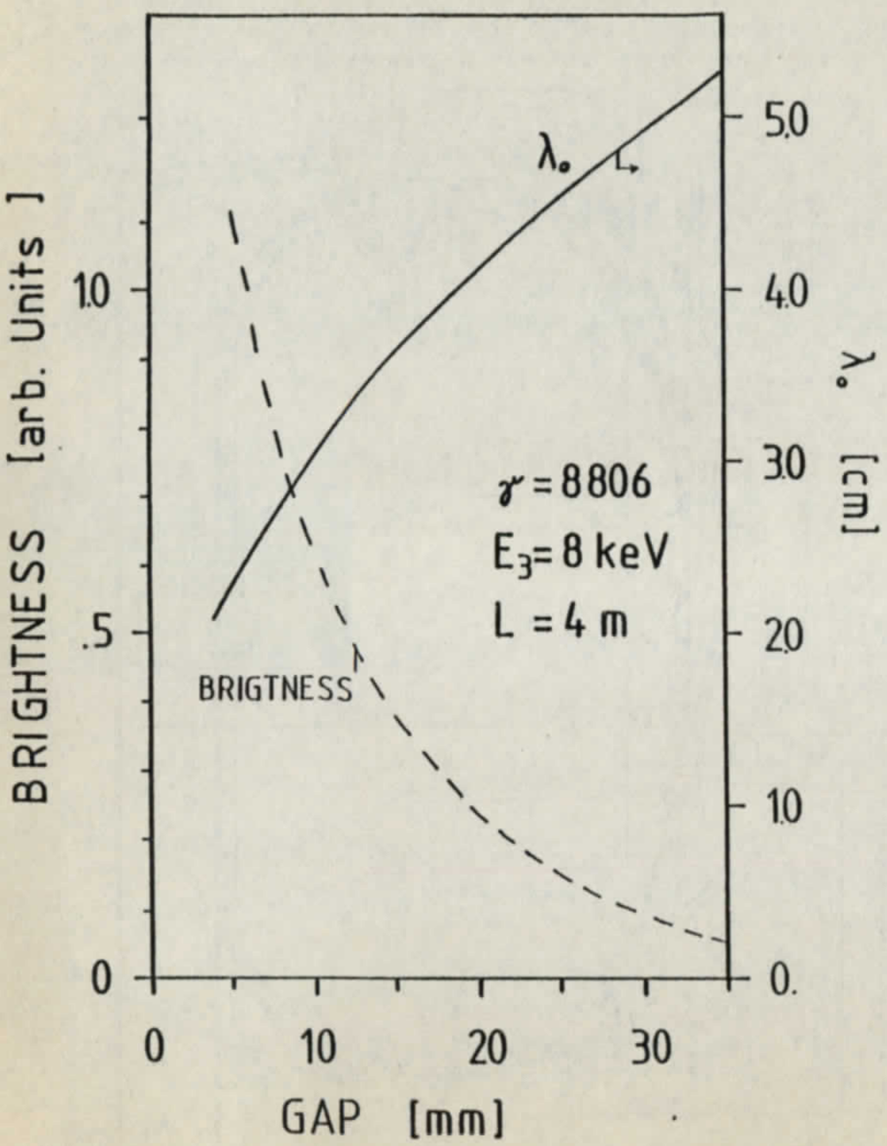
Fig. 2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γ = 8806
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L = 4 m

Fig. 3

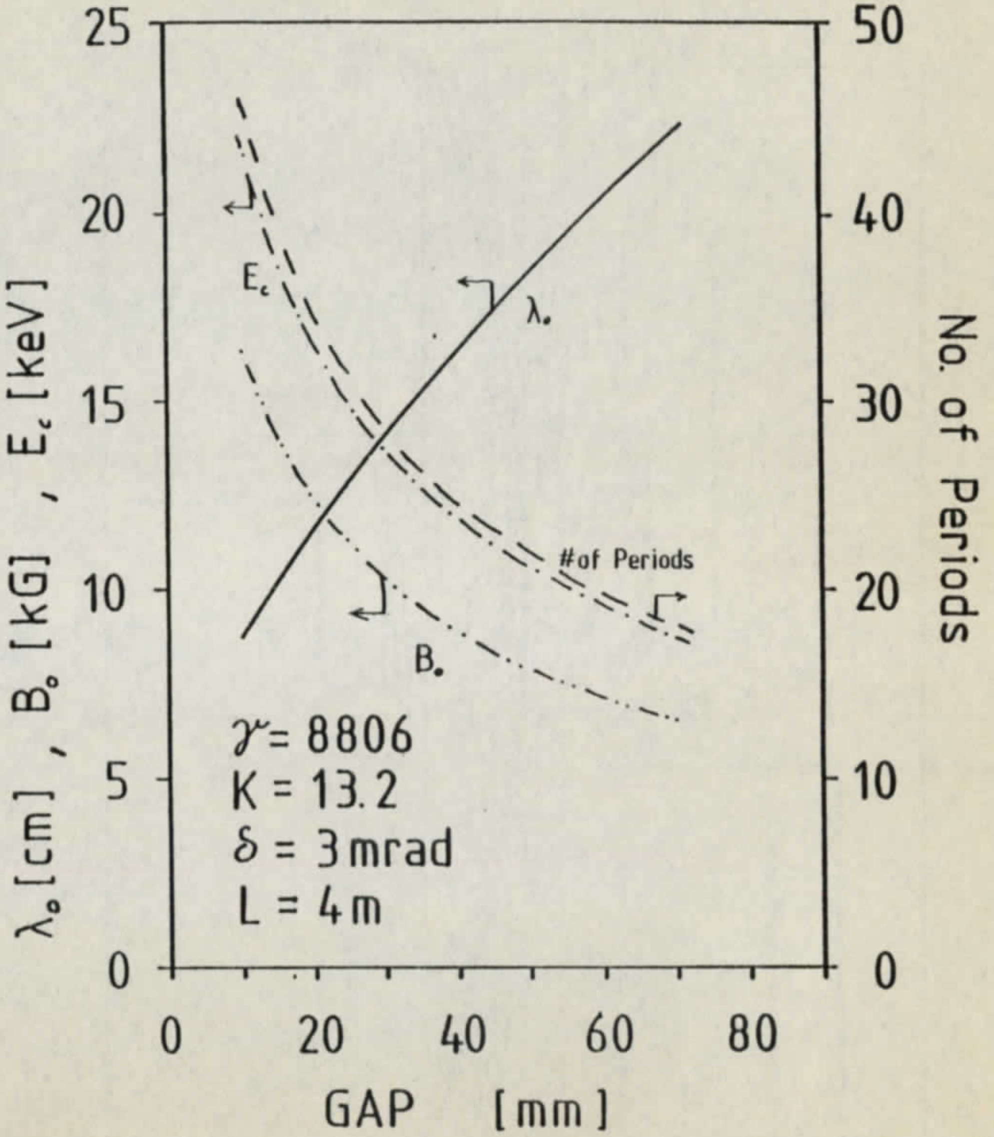
λ₀ [cm] , B₀ [kG] , E꜀ [keV]
25
20
15
10
5
0
No. of Periods
50
40
30
20
10
0
0
20
40
60
80
GAP [mm]
E꜀
λ₀
B₀
#of Periods
γ = 8806
K = 13.2
δ = 3 mrad
L = 4 m

Fig. 4

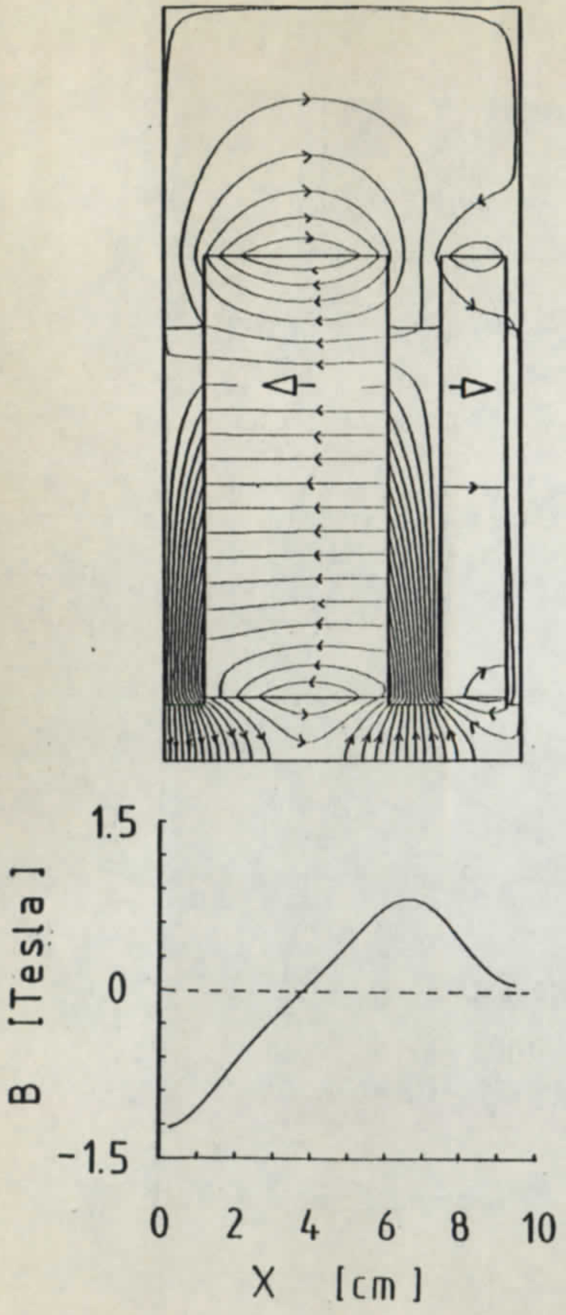

Fig. 5a

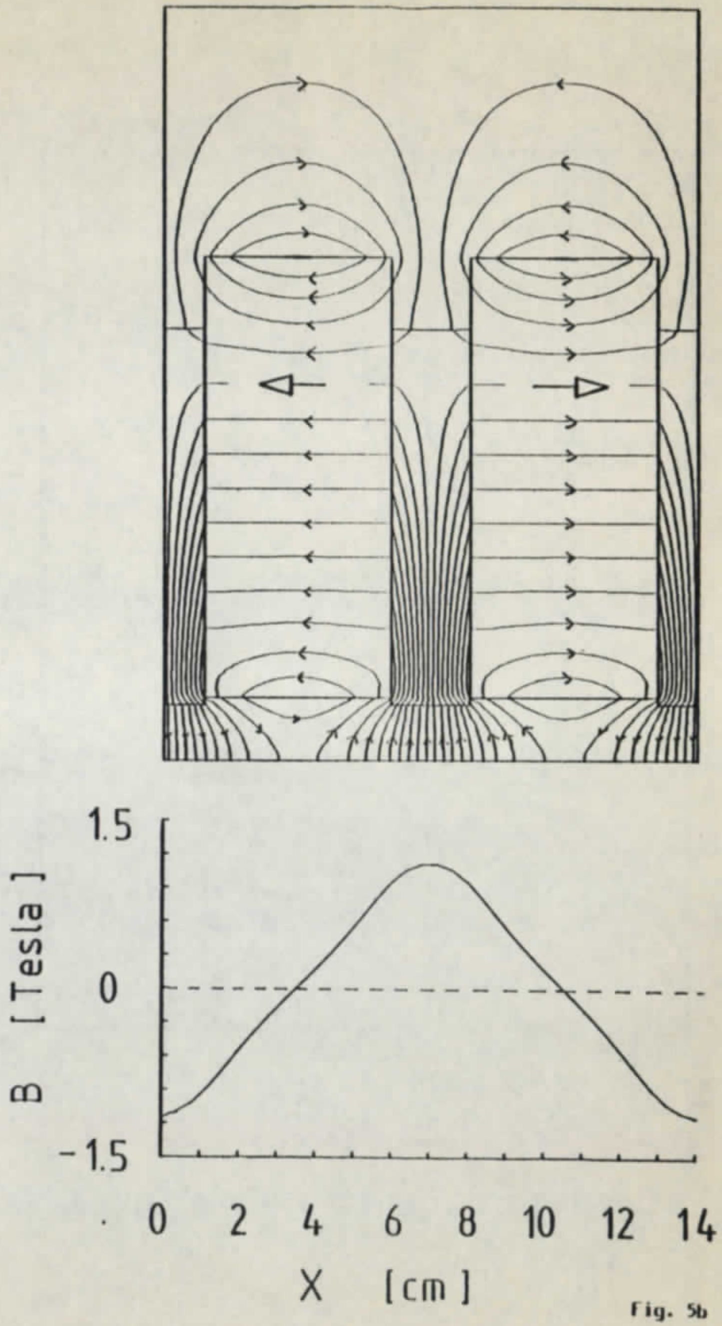

Fig. 5b

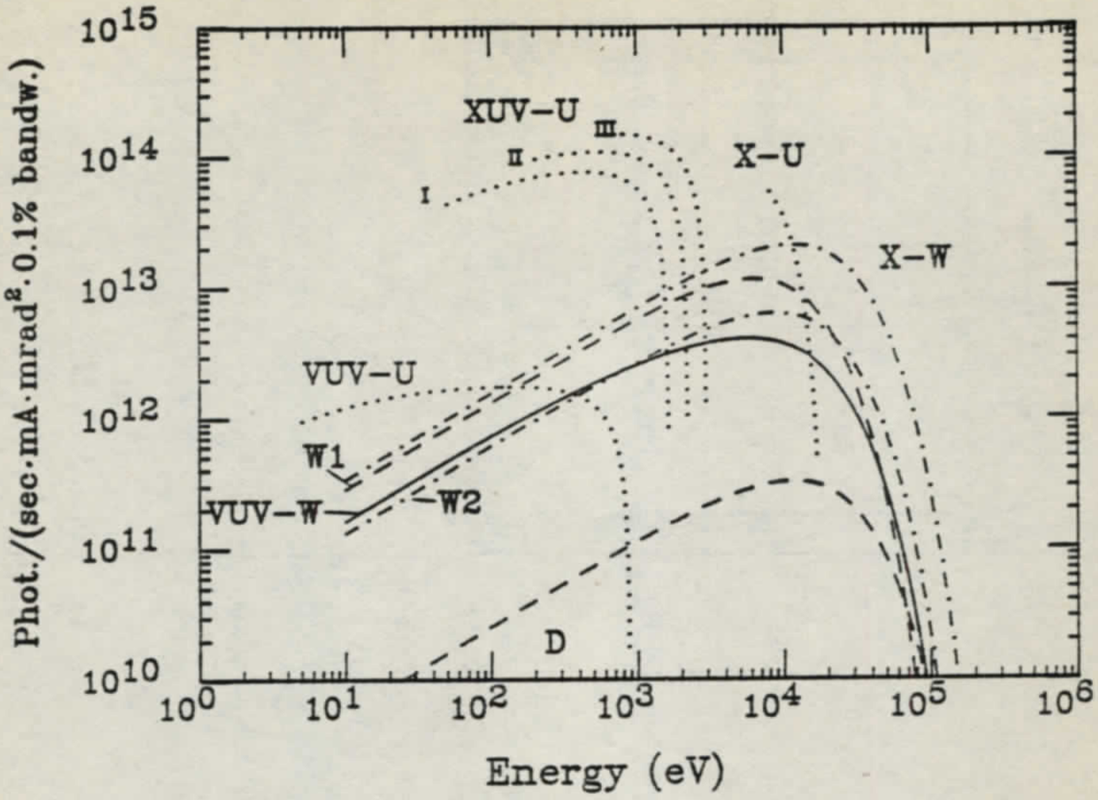
Phot./(sec·mA·mrad²·0.1% bandw.)
10^15
10^14
10^13
10^12
10^11
10^10
10^0
10^1
10^2
10^3
10^4
10^5
10^6
Energy (eV)
XUV-U
I
II
III
X-U
X-W
VUV-U
W1
VUV-W
W2
D

Fig. 7a

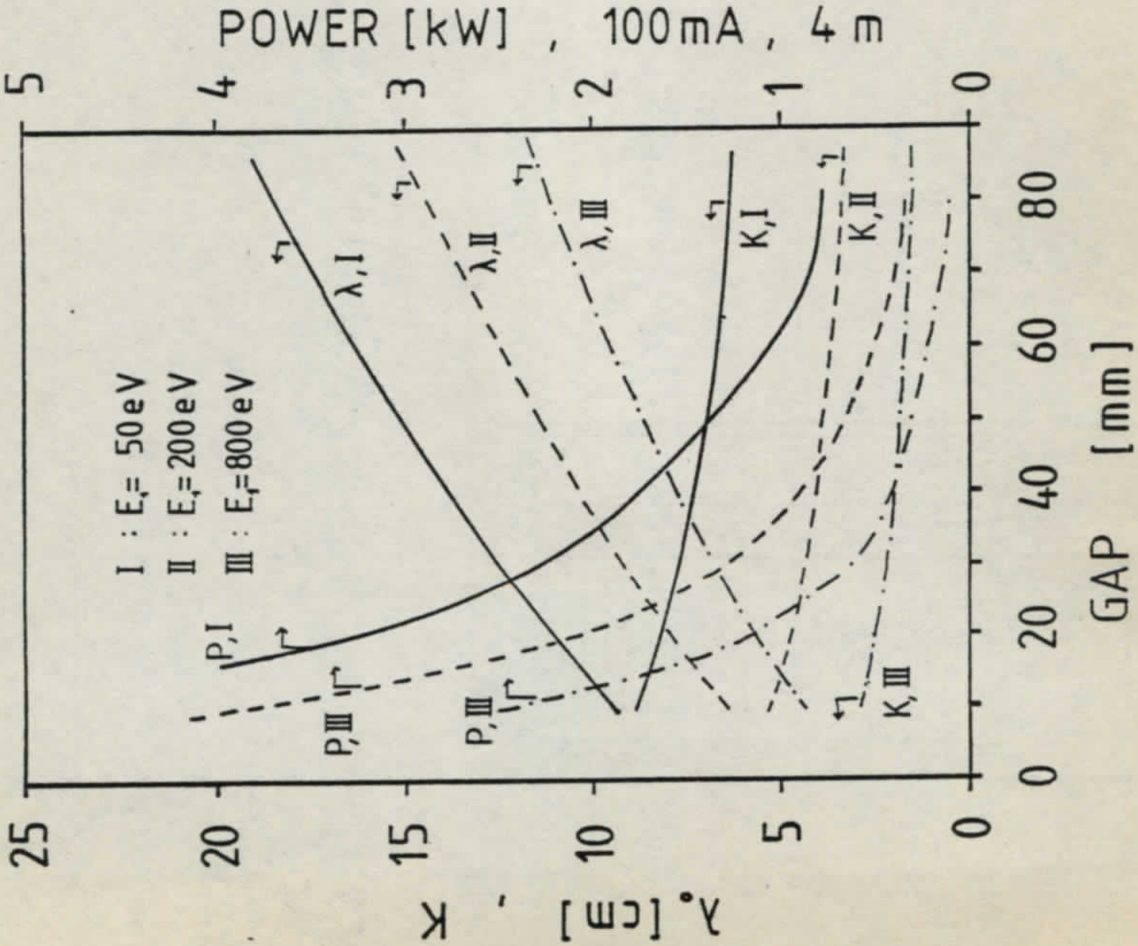
POWER [kW] , 100mA , 4m
5
4
3
2
1
0
λ₀ [cm] , K
25
20
15
10
5
0
GAP [mm]
0
20
40
60
80
I : E₁= 50eV
II : E₁=200eV
III : E₁=800eV
λ,I
λ,II
λ,III
K,I
K,II
K,III
P,I
P,II
P,III

Fig. 6

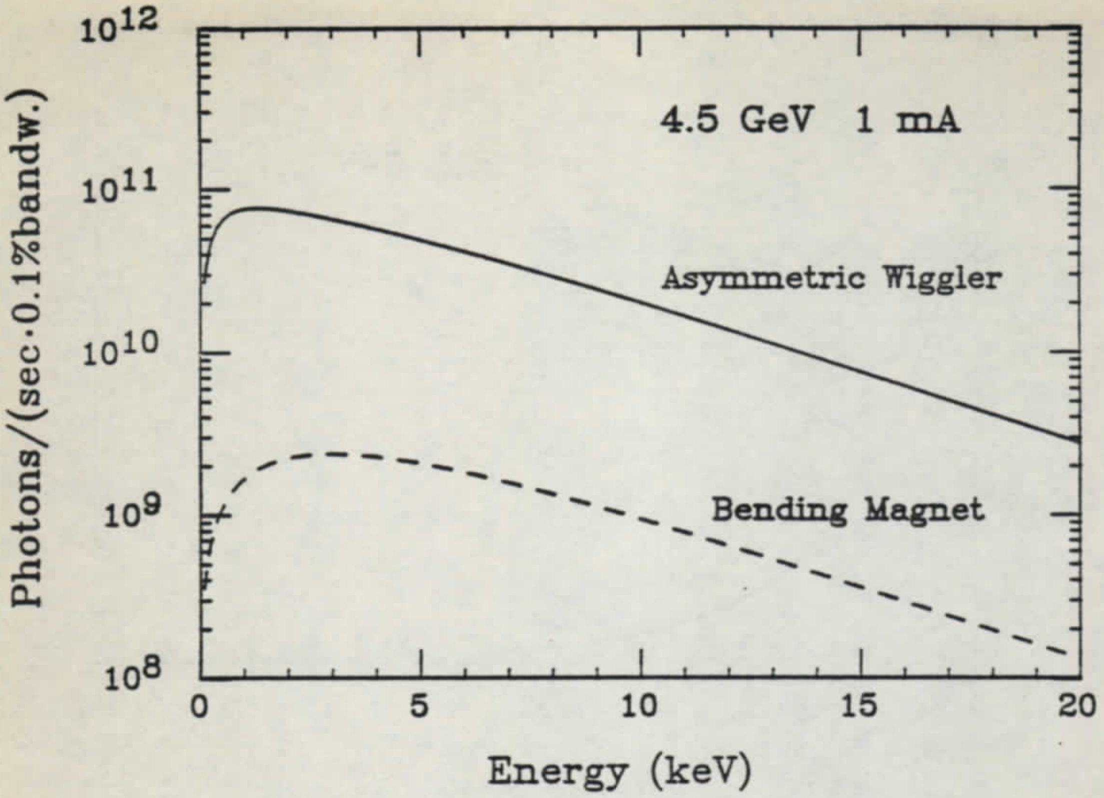
4.5 GeV 1 mA
Asymmetric Wiggler
Bending Magnet
Photons/(sec·0.1%bandw.)
10^{12}
10^{11}
10^{10}
10^{9}
10^{8}
0
5
10
15
20
Energy (keV)

Fig. 8a

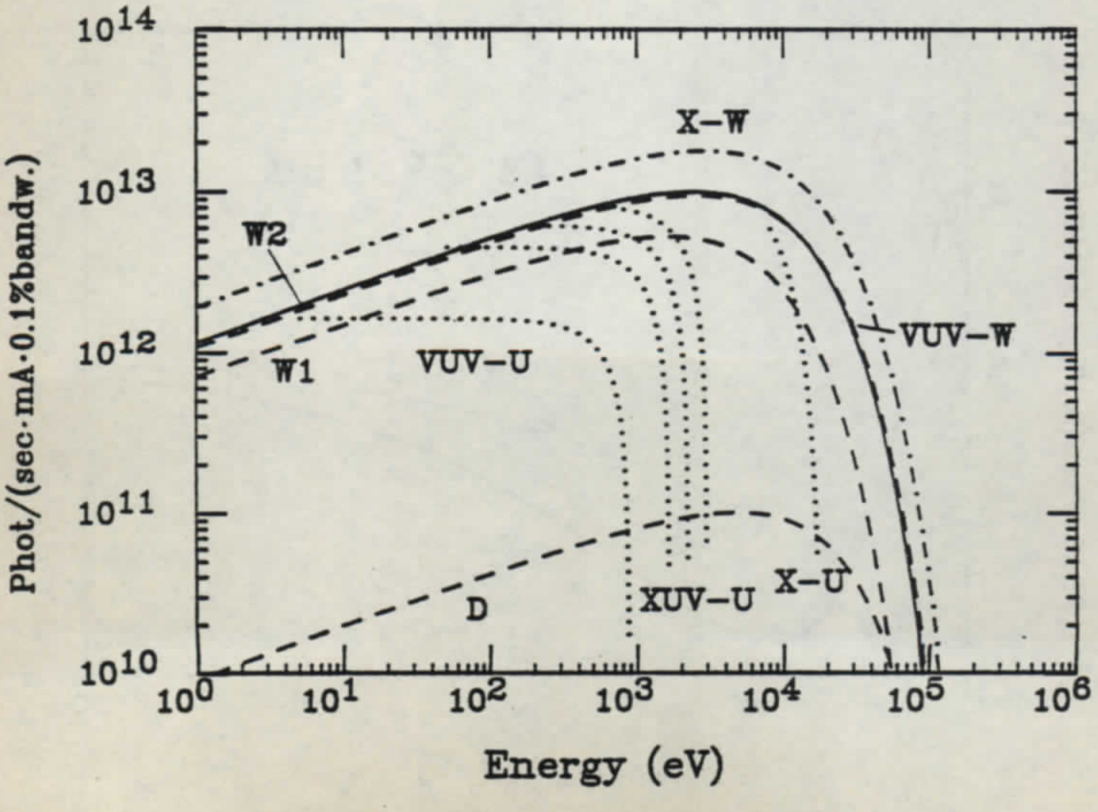
X-W
W2
VUV-W
W1
VUV-U
XUV-U
X-U
D
Phot/(sec·mA·0.1%bandw.)
10^{14}
10^{13}
10^{12}
10^{11}
10^{10}
10^{0}
10^{1}
10^{2}
10^{3}
10^{4}
10^{5}
10^{6}
Energy (eV)

Fig. 7b

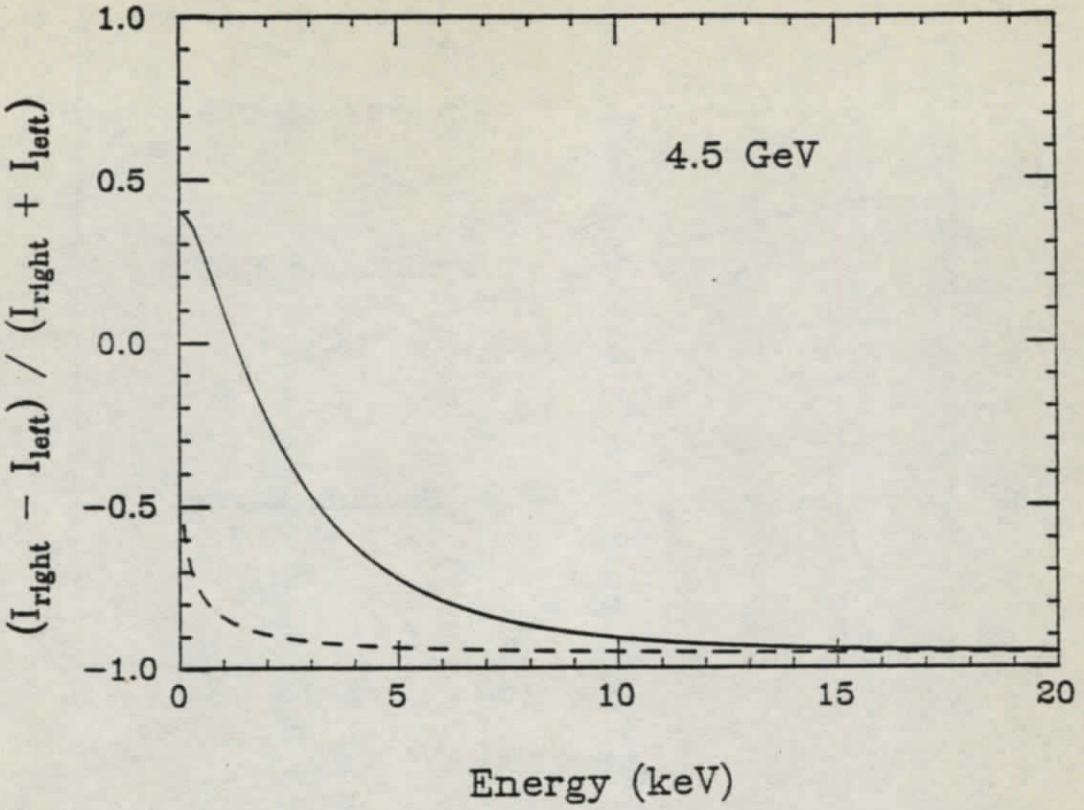
1.0
0.5
0.0
−0.5
−1.0
(I_right − I_left) / (I_right + I_left)
4.5 GeV
0
5
10
15
20
Energy (keV)

Fig. 8c

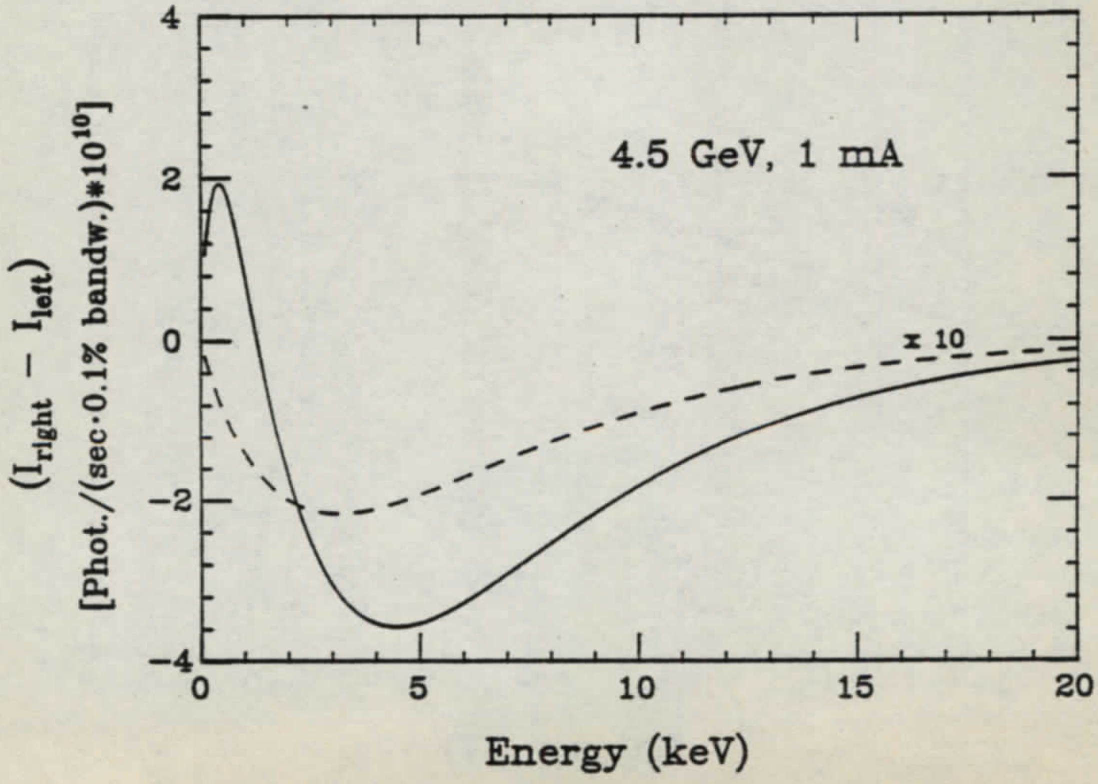
4
2
0
−2
−4
(I_right − I_left)
[Phot./(sec·0.1% bandw.)*10^10]
4.5 GeV, 1 mA
x 10
0
5
10
15
20
Energy (keV)

Fig. 8b

TABLE 1 : OVERVIEW OVER THE CHARACTERISTIC PARAMETERS OF THE PROPOSED AND EXISTING INSERTION DEVICES FOR THE DORIS - BYPASS (DORIS III) AND REQUIREMENTS OF SYN AND LUM OPTICS
ENERGY OF SYN OPTICS : 4.5 GEV , LUM OPTICS : 5.3 GEV

15.3.1989

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
PLACE NR	DEVICE	TYPE	LAMDA [CM]	N	L [M]	B [T]	K	2K/GAM [MRAD] 1)	PTOT [W/mA] 1)	POWER DENSITY [W/mA MRAD**2] 2)	EC [KEV] 1)	FORCE [KN] 3)	MIN. MAGN. GAP SYN/LUM [MM]	MIN. VACUUMGAP REQUIRED SYN/LUM [MM]	VACCUUMGAP PROVIDED SYN/LUM [MM]	SIGMAX SYN/LUM [MM]	SIGMAZ SYN/LUM [MM]	SIGXP SYN/LUM [MRAD]	SIGZP SYN/LUM [MRAD]
1	X-RAY UNDULATOR	HYBRID	3.14	127	4.0	0.55	1.61	0.37	15.5	112.6	7.47	24.0	11 / 25	4) 9.7/7.3 21/19	VARIABLE	2.9/3.7	.27/.33	.22/.29	.051/.072
2	X-RAY WIGGLER	HYBRID	14.0	28	4.0	1.01	13.20	3.0	52.5	119.0	13.60	91.0	30 / 52	20 / 48	26 / 48 5)	2.1/2.8	.55/.75	.21/.21	.022/.024
3	XUV - TRIPLE UNDULATOR I 50 - 400 EV II 200 - 1000 EV III 800 - 2000 EV	REC REC REC	11.91 8.83 6.58	33 45 60	4.0 4.0 4.0	0.71 0.54 0.38	7.91 4.45 2.30	1.80 1.01 0.52	25.4 14.7 7.1	96.6 92.2 64.9	9.60 7.29 5.06	39.4 23.1 11.3	30 / 52	12 / 48	26 / 48 5)	3.1/3.3	.34/.75	.13/.47	.039/.049
4	VUV UNDULATOR / X-RAY WIGGLER	REC	22.3	12	2.7	.89	14.50	4.21	26.9	40.1	12.0	42.2	30 / 30	12 / 16	26 / 26	1.4/3.5	.34/.25	.56/.21	.038/.162
5	FREE												--	12 / 48	48 / 48	3.1/3.3	.34/.75	.13/.47	.039/.049
6	X-RAY WIGGLER	HYBRID	14.0	28	4.0	1.01	13.20	3.0	52.5	119.0	13.60	91.0	30 / 52	20 / 48	26 / 48 5)	2.1/2.8	.55/.75	.21/.21	.022/.024
7	X-RAY WIGGLER	HYBRID	14.0	28	4.0	1.01	13.20	3.0	52.5	118.4	13.60	91.0	30 / 30	9.7 / 21	26 / 26	2.9/3.7	.27/.33	.22/.29	.051/.072
6)	ASYMMETRIC WIGGLER	HYBRID	21.0	19	4.0	1.10	15.00	3.4	30.0	<119.0	14.80	46.7							
W1 7)	WIGGLER-UNDULATOR ASYMMETRIC WIGGLER	REC REC	13.2 24.0	16 10	2.2 2.4	0.60 0.68	7.4 12.0	1.7 2.7	9.6	35.2	8.1	13.6	34 / 34	14 / 31	30 / 30	2.0/2.5	.39/.48	.25/.26	.031/.036
W2	HARMI-WIGGLER	HYBRID	24.0	10	2.4	0.94	21.1	4.81	27.2	38.2	12.7	63.3	42 / 42	18 / 36	38 / 38	3.5/3.9	.49/.56	.42/.61	.053/.153
W3	MINI-WIGGLER	REC	12.0	4	.48	0.31	3.5	0.8	0.62	2.4	4.2	1.01	58 / 58	16 / 34	49 / 49	1.2/1.4	.43/.53	.36/.50	.047/.054

1) VALUES ARE CALCULATED FOR 4.5 GEV
2) 4.5GEV AND SYN OPTICS ARE ASSUMED, ELECTRON BEAM DIVERGENCE IS INCLUDED
3) TO CALCULATE THE FORCE BETWEEN THE TWO STRUCTURES A MAGNEITIC WIDTH OF 10 CM IS ASSUMED FOR THE BYPASS DEVICES
THE WIDTHS OF EXISTING DEVICES ARE : W1 : 9CM , W2 : 15CM , W3 : 11CM
4) A VACUUM CHAMBER ADJUSTABLE TO THE ELECTRON BEAM IS REQUIRED TO OBTAIN THE SMALLER SET OF VALUES FOR THE X-RAY UNDULATOR
THE SMALLER VALUES ARE NECESSARY TO OBTAIN THE PLANNED PERFORMANCE
5) EITHER DIFFERENT VACUUM CHAMBERS FOR SYN AND LUM OPTICS OR A VARIABLE VACUUM CHAMBER ARE REQUIRED
6) EXCHANGEABLE MAGNET STRUCTURES ARE PLANNED, SIMILIAR TO W1 (SEE 7)), WHICH CAN BE OPERATED ALTERNATIVELY ON EITHER OF THE X-RAY WIGGLER BEAMLINES ON PLACES 2, 6 OR 7.
7) THE TWO MAGNETSTRUCTURES CAN BE MOUNTED AND OPERATED ALTERNATIVELY ON THE SAME MECHANIC DRIVE SYSTEM :
THE WIGGLER / UNDULATOR IS IN OPERATION SINCE 1984, THE ASYMMETRIC STRUCTURE IS A TEST AND PROTOTYPE STRUCTURE WHICH WILL BECOME OPERATIONAL BY SPRING 1989. THEY WILL SHARE THE SAME BEAMLINE.