DESY SR 85-10
September 1985

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ISSN 0723-7979

NOTKESTRASSE 85 · 2 HAMBURG 52

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After almost ten years of successful operation at a bending magnet beamline of HASYLAB the FLIPPER monochromator was transferred to a 32-pole wiggler/undulator. With new grazing incidence optics the original energy range of 15 - 450 eV could be extended to more than 1500 eV. The gain in intensity is approximately two orders of magnitude. Undulator effects are observed between 36 eV and 900 eV and contribute considerably to this intensity gain. Monochromators of the FLIPPER type are ideally matching the emission characteristics of undulators. The main problem with wigglers at high energy storage rings is the heat load on the optical elements.

- presented at SRI 85 in Stanford, CA, USA, July 29th - Aug. 2nd, 1985 to be published in Nucl. Instr. & Meth.

During recent years it became obvious that wigglers/undulators used in high energy storage rings (from 2 GeV upward) are not only excellent sources of x-rays but also deliver more photons in a small solid angle (i.e. more brightness) in the vacuum ultraviolet (VUV) than wigglers/undulators installed in low energy storage rings. Moreover, much simpler technical solutions are possible and the influence on the storage ring is small. When the installation of a 32-pole wiggler was planned at the 5.3 GeV storage ring DORIS (see P. Gürtler, /1/) it was therefore decided to split off a VUV beam with a 2.2° grazing incidence mirror alternatively to the x-ray beam. The FLIPPER monochromator with its angular acceptance of roughly 0.2 mrad vertically and 0.8 mrad horizontally almost perfectly matches the emission cone of this special wiggler W1 /1/. Furthermore it turned out that the undulator peak in first order of the HASYLAB wiggler can be tuned via the gap height over the whole energy range of the FLIPPER monochromator (see Table 1).

The FLIPPER /2/ was successfully operated at a bending magnet beamline for almost a decade. Its optical design originates from the GLEISPIMO mounting invented at DESY in 1968 /3/. The optical layout of the FLIPPER has the inherent property to reduce higher order radiation by taking advantage of the cut-off of total reflection. Six alternatively used plane mirrors S1 ... S6 (see Table 2) cover the energy range 15 to 450 eV. An additional mirror S_0 which is illuminated at 1.2° grazing angle was added for the set-up at the wiggler line (see Fig. 1) and covers the energy range up to above 1000 eV. As a matter of fact the Al K edge at 1560 eV can be observed in absorption. There the level of "good" light roughly equals that of stray light. A plane grating (1.5° blaze, 1200 lines/mm) disperses the prefiltered radiation and a paraboloid illuminated at now 2° grazing angle (formerly at 5.7°) focusses a beam of fixed direction into the exit slit. An experimental chamber suitable for photoemission and other surface sensitive techniques is mounted behind the exit slit.

A critical element for a successful use of a VUV undulator beam from a high-energy storage ring is the first mirror S_{-1}. It has to take a heat load of up to 600 watt when the wiggler gap is completely closed (see Table 1). This power is concentrated in an angular interval of roughly 0.7 mrad horizontally and 0.25 mrad vertically taking into consideration an angular divergence of the electron beam of 0.5 x 0.07 mrad^2 (FWHM) at the source point. Due to the grazing angle of 2.2° most of the power is distributed over a strip of 10 x 100 mm^2 on the surface. The plane mirror S_{-1} can be remotely aligned in two degrees of freedom. From its active position it can be retracted completely to allow the beam to pass to the x-ray station. The re-insertion of the mirror is reproducible.

The mirror itself is a copper block with dimensions 200 x 50 x 50 mm^3 covered with Kanigen and polished to high accuracy (90 % of reflected intensity in an angular intervall of ± 2"). It is pressed on a water cooled support with a layer of indium in between providing good metallic contact. The rise in temperature of the mirror block is only some ten degrees measured about halfway between the irradiated surface and the cooled bottom. In order to keep the temperature of this mirror low the Kanigen coating of the backside had to be removed partly for better thermal contact. Without this measure the temperature rose up to 200°C. But even in the new configuration we observe large effects on the intensity of the monochromator output when the wiggler gap is small and thus the power high. We found that these losses originate from mirror S_{-1}. A drop in intensity of up to a factor of three is observed in the first 20 seconds after opening the beam stop. The performance of the monochromator appears to be otherwise unaffected. Our present hypothesis

is that the surface of the mirror reversibly develops a bump due to a large surface temperature decreasing rapidly with a high gradient into the inner of the the copper block. Due to the elongated shape of the illuminated part of the surface this bump will act as a cylindrical convex horizontally defocussing mirror which deflects part of the incident radiation in such a way that it is lost at the horizontal apertures. Any additional horizontal divergence added this way to the beam does not pose serious problems to the monochromatization since the spectral resolution of the monochromator depends mainly on vertical imaging. Such distortions of heavily loaded mirrors have been treated theoretically /4/. We have not yet attempted to do a similar model calculation on our special arrangement.

It is possible to avoid this effect by operating the wiggler at large gaps. The heat load on the mirror S_{-1} is then drastically reduced. The wiggler still provides a gain of roughly a factor of 40 compared to a bending magnet. The undulator peak in first order, however, is shifted to 929 eV at 3.7 GeV and W = 168 mm (see Table 1). With the completely closed gap, W = 34 mm, the undulator peak is lowered in energy to 36 eV at 3.7 GeV. As will be shown below, the gain of intensity in the undulator peaks can be appreciable. It can, nevertheless, be advantageous for low photon energies at high currents in the storage ring to sacrifice this option in order to avoid the distortions of S_{-1} and the subsequent losses.

A choice of other materials, other shapes for the mirror S_{-1}, larger distances from the source, and maybe even more grazing angles for the first mirror may solve this problem. To find the optimum solution a fundamental investigation of this problem is necessary.

For 3.7 GeV about 10 % of the radiated power is reflected by mirror S_{-1}. This is incident in mirror S_0 which is made of $AlMg_5$ coated with Kanigen. This mirror has no water cooling. Due to a large reduction in the apparent aperture a maximum of about 2 % of the total power hits the grating if S_0 is illuminating the grating directly and about 4 % of the total power hits the mirrors S_1 to S_6 in the other mode. We have detected serious distortions of the mirrors S_1 to S_6 which were fabricated from glass (BK7). The heat load resulted in a convex curvature of the flat mirrors probably due to both a bump at the surface and a bending of the whole mirror. This was an especially serious problem for the less grazing incidence mirrors S_3 to S_6 where most of the incident radiation is also absorbed. The distortion was observed as a defocussing stemming without doubt from these mirrors. It could be compensated by changing the focus of the paraboloid. In May 1985 these mirrors were replaced by all-metal mirrors (AlMg5 covered with Kanigen) and this problem is now solved. Small warm-up effects still occur on S_0 and on the grating which is etched on glass and coated with gold. We have attempted to measure the power incident on S_3 by directly measuring the rise in temperature of this mirror with a thermocouple. The first result, namely 1.5 watt at 5.3 GeV storage ring energy and 30 mA is too low by roughly a factor of 3. A more detailed analysis is needed.

The main information on the performance of the FLIPPER monochromator is condensed in Fig. 2. The old bending magnet version was actually operated until August 1984 but no characterisation of the output was made immediately before the transfer to the wiggler line. Therefore the status as of December 82 is given. Each of the mirrors S_0 to S_1 is typically used in an energy range between its high-energy cut-off and half that energy in order to avoid second and higher order contributions. With the new arrangement some problems with second order light appear to occur in certain regions covered by S_1 and S_0 although this is not fully investigated yet. As a possible remedy special coatings can be selected or the undulator peak can be shifted to influence the relative strength of first or second order radiation (in this case attention has to be given to the second order undulator peaks). It should be mentioned here that the mirrors S_1 to S_6 are usable at two different sections of the surfaces which can have different materials on the surfaces (see Table 2).

The curves have been measured at typical currents around 60 mA in DORIS. DORIS is capable, however, to operate at 100 mA in main user shifts. Therefore the intensiti es were linearily extrapolated to this value. To what extend this linearity holds for small gaps could not yet be tested in dedicated runs at 3.7 GeV after improving the cooling of the mirror S_{-1} in spring 1984. A similar investigation for the operation at 5.3 GeV, 35 mA of DORIS in summer 1985 is not yet completed.

The most striking feature is the appearance of the undulator peak in first order and also in higher orders (see ref. /1/). It shifts according to the theoretical calculation given in Table 1. The additional intensity gain in this peak amounts to as much as 6. For the common photon energy ranges of the two FLIPPER versions a maximum gain of 200 over the December 82 performance was observed at the undulator. This must not be completely attributed to the undulator since all optical elements and the arrangement of the pre-mirrors have been changed in between.

An analysis of the shape of the undulator peak is given by Gürtler /1/. The analysis is based on the solid angle accepted by the FLIPPER optics and yields an excellent agreement between theory and experiment. It is well known that undulator effects are spatially confined to the immediate neighbourhood of the forward direction of emission. By deflecting the beam with the help of the remote control of mirror S_{-1}, the undulator peaks decay rapidly as soon as the central ray of the beam is outside of the entrance aperture. It has to be taken into account that the emittance of the electron beam in DORIS and subsequently its angular spread causes a spread of "forward directions". This distribution has the following dimensions at the entrance aperture of the FLIPPER, namely 18 mm horizontally and 2.5 mm vertically (FWHM). Thus the undulator perfectly matches the aperture of the FLIPPER (see Fig. 3). Taking into consideration the properties of undulators /5/ it becomes obvious that the FLIPPER monochromator installed at one of the newly proposed low emittance storage rings could use smaller apertures without intensity loss in the undulator peak.

Since the storage ring DORIS is almost unaffected by the wiggler/undulator /1/ a mode of operation of the FLIPPER monochromator is planned where the undulator gap would follow the wavelength scan in such a way as to keep the selected wavelength always at the undulator maximum.

There is still another advantage of observing the undulator peaks. This provides a perfect criterion to align the monochromator in such a way that it looks "head-on" at the undulator. This minimizes any apparent increase of the source size due to an oblique projection of the 2.15 m long radiating path.

The theoretical resolution as calculated for a 200 µm slit width is indicated in Fig. 2. How far this can be scaled down for smaller slit widths depends on the quality of the alignment of the monochromator, the influence of the source size, the imaging errors of the paraboloid due to the fact that the source is not at infinity, the slope errors of the paraboloid, and the

astigmatism due to the change of the vertical divergence at the grating. The latter leads to a different aparent source distance for vertical and horizontal focussing /3/. This effect is especially important for the mirrors S_1 and S_2 where the ratio of the angles of incidence and take-off at the grating φ_0/φ deviates considerably from 1. While the distance of the source for horizontal focussing stays fixed at 36.555 m with a horizontal image from the paraboloid (focal length 1000 mm) at b = 1028 mm, the distance of the virtual source for vertical focussing varies between 36.555 m and almost infinity. This leads to a vertical image point between 1028 mm and 1000 mm from the paraboloid. In the vertical plane the image of the source is geometrically demagnified as 1 : 36. On the other hand outside the horizontal focus the intensity distribution resembles a sickle resulting in a coupling of the horizontal beam width to the vertical dispersion plane /6/. Since we have to keep the exit slit fixed we have to find a compromise position. We choose 1013 mm which gives a greater weight to good resolution at high photon energies. As expected, the resolution is very much improved by reducing the horizontal aperture. Figure 3 shows an example of ray tracing calculations.

Figure 4 shows as an example for the performance of the FLIPPER set-up a total yield spectrum of a clean Cu sample in the region of the Cu L edges. The spectrum was obtained by measuring the total current leaving the sample with a DC ampere-meter in the 10^{-10} A range. The signal is normalized to the photon flux measured by a diode. Such photoelectric yield curves reproduce the absorption in a layer of about 50 Å below the surface. Many possible applications of monochromatic beams with such high intensity are obvious. The main research fields for the FLIPPER will be surface and atomic physics.

We want to thank P. Gürtler for many fruitful discussion about the properties of the wiggler/undulator. Thanks are also due to W. Jark for many discussions on the optics of the monochromator and for helping with the ray-tracing calculations. Further, we wish to thank H. Maack for his help during the planning stage of the project and L. Incoccia for her collaboration during the improvement program in 1985. The work done by the technical staff of HASYLAB and the workshops of DESY and the II. Institut für Experimentalphysik der Universität Hamburg was decisive for the rapid commissioning of the FLIPPER only 6 weeks after it had taken its last spectrum on the old beamline. The work was supported by the BMFT under contract no. 05 248 KU.

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Table 1

Parameters of the HASYLAB wiggler/undulator W1. Gap = W, maximum field on orbit = B, photon energy of first order undulator radiation = hν_1, total emitted power = P.

Gap W (mm)	B (Tesla)	K	3.7 GeV h $_1$(eV)	5.3 GeV h $_1$(eV)	3.7 GeV 100 mA P(Watt)	5.3 GeV 50 mA P(Watt)
33.8	0.567	7.10	36.2	74.3	609	625
40.0	0.493	6.08	48.7	99.9	446	458
50.0	0.382	4.71	78.5	161	268	275
60.0	0.295	3.64	124	254	160	164
70.0	0.229	2.82	191	392	96	99
80.0	0.176	2.17	283	581	57	59
90.0	0.137	1.69	391	802	35	36
100	0.104	1.28	522	1071	20	21
120	0.063	0.777	729	1496	7.3	8
140	0.036	0.444	864	1773	2.4	2.5
160	0.022	0.271	916	1880	0.9	0.9
168	0.017	0.210	929	1906	0.5	0.6

Table 2 Optical components. For the mirrors S1 - S6 only the coating of position 1 is given, position 2 is blank kanigen.

	function	dimensions (length,width,heigth) (mm)	material	coating	angle of incidence	manufacturer
S_{-1}	cooled pre-mirror	200 x 50 x 50	Cu	kanigen	2.2°	Zeiss
S_o	premirror	250 x 50 x 50	$AlMg_5$	kanigen	1.2°/2.7°	"
S_1	"	100 x 88 x 25	"	kanigen /+200Å Cr	4°	"
S_2	"	100 x 88 x 25	"	kanigen +300Å C	7.5°	"
S_3	"	60 x 88 x 12	"	kanigen +300ÅC	12°	"
S_4	"	60 x 88 x 12	"	kanigen +300Å C	20°	"
S_5	"	60 x 88 x 12	"	kanigen +300Å C	33°	"
S_6	"	60 x 88 x 12	"	kanigen +300Å C	50°	"
G	plane grating, 1200l/mm, 1.5°blaze	65 x 40 x 15	quartz glass	250Å Au	var.	Astron
P	paraboloid, 2° grazing, f = 1000 mm	250 x 60 x 35 usable area 200 x 36	Zerodur	Au	2°	Zeiss

Figure Captions

Fig. 1 Schematic arrangement of the optical components in the FLIPPER set-up at the wiggler/undulator beamline at HASYLAB. The angles are somewhat distorted. S_x are deflecting mirrors (see Table 2), G = Grating, ES = exit slit. Mirror S_0 can reflect either to S_1 ... S_6 or directly on G.

Fig. 2 Intensity behind the 200 μm exit slit at the wiggler/undulator (Oct. 84) and at the bending magnet (Dec. 82). The resolution as marked by arrows can be improved by about 1/3 by reducing the slit width (see also Fig. 3), W_{xx} marks the wiggler gap (see Table 1).

Fig. 3 Results of ray-tracing calculations for image planes at different distances b from the center of the paraboloid. b = 1013 mm is the standard position of the exit slit. A slit width of 50 μm is indicated. The source size was zero.

Fig. 4 The L edges of Cu observed on a clean Cu sample in total electron yield. The spectrum was obtained with a horizontal aperture of 10 mm and a slit width less than 30 μm.

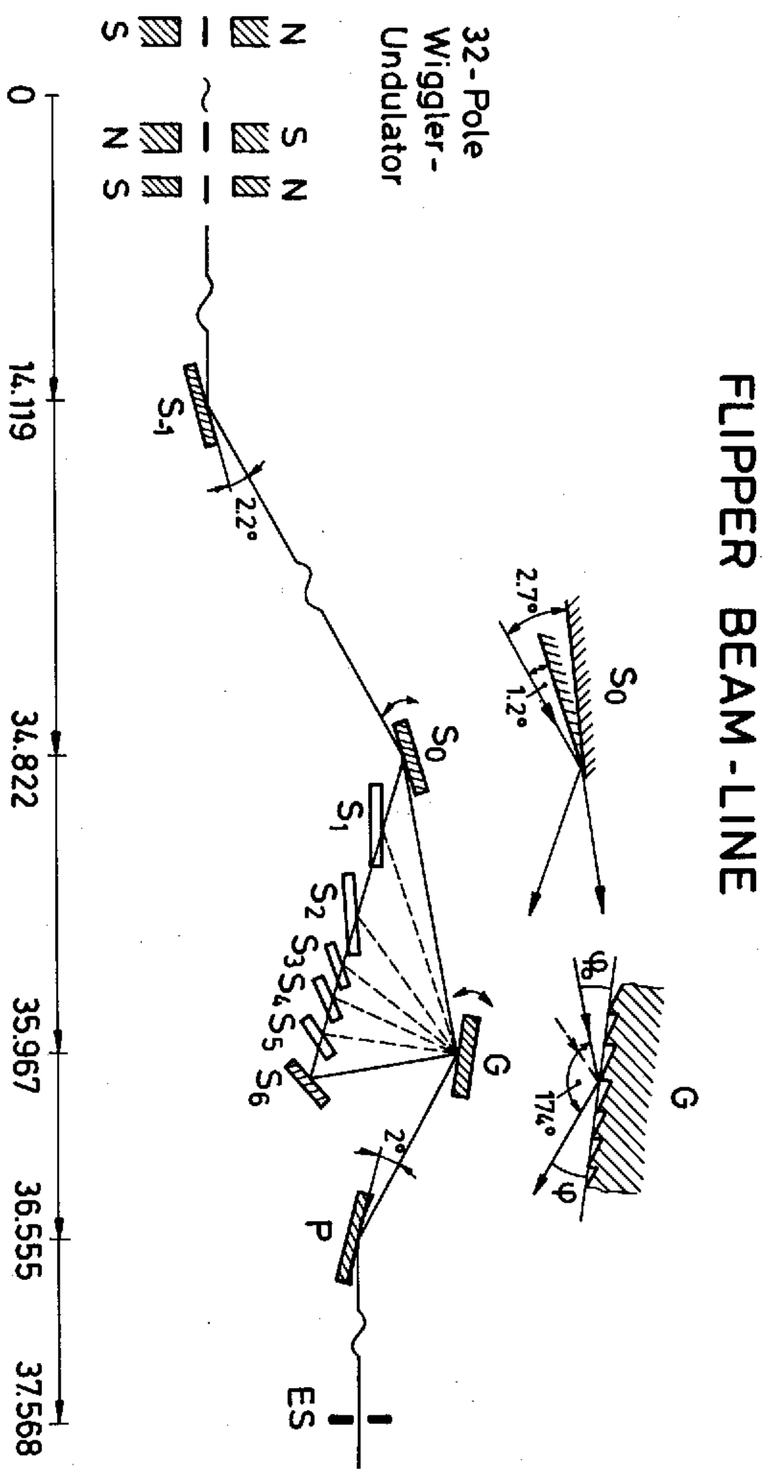

Fig. 1

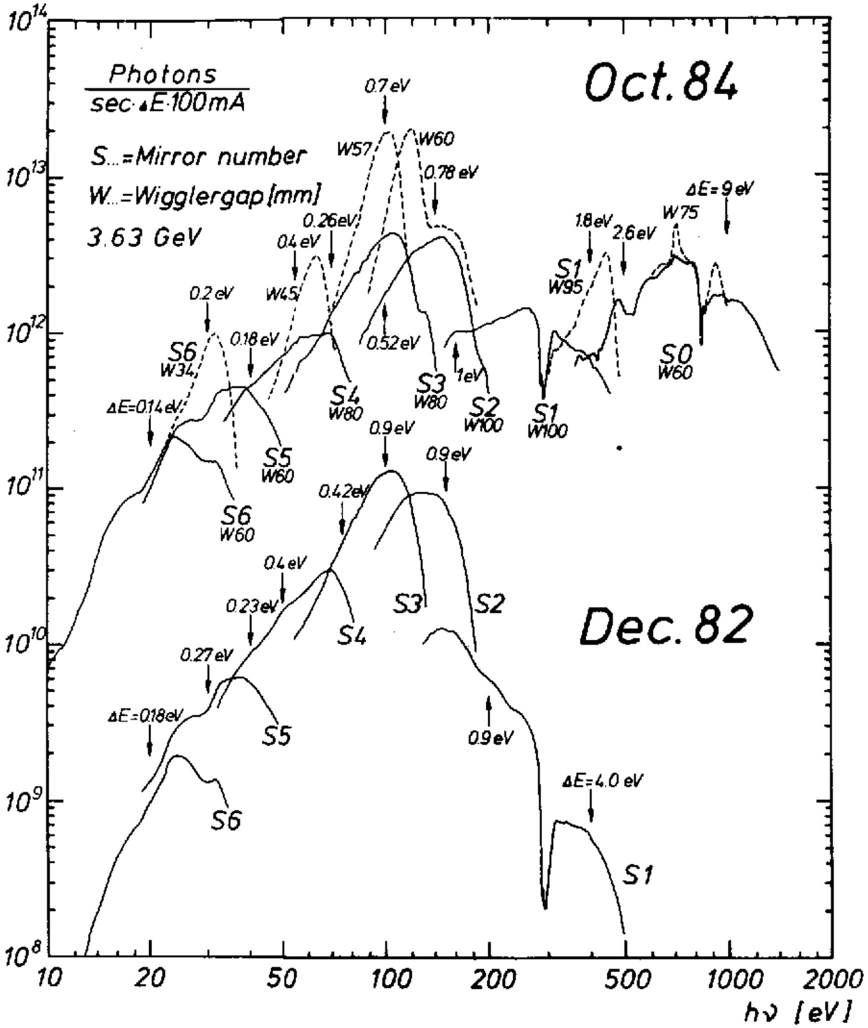

Fig. 2

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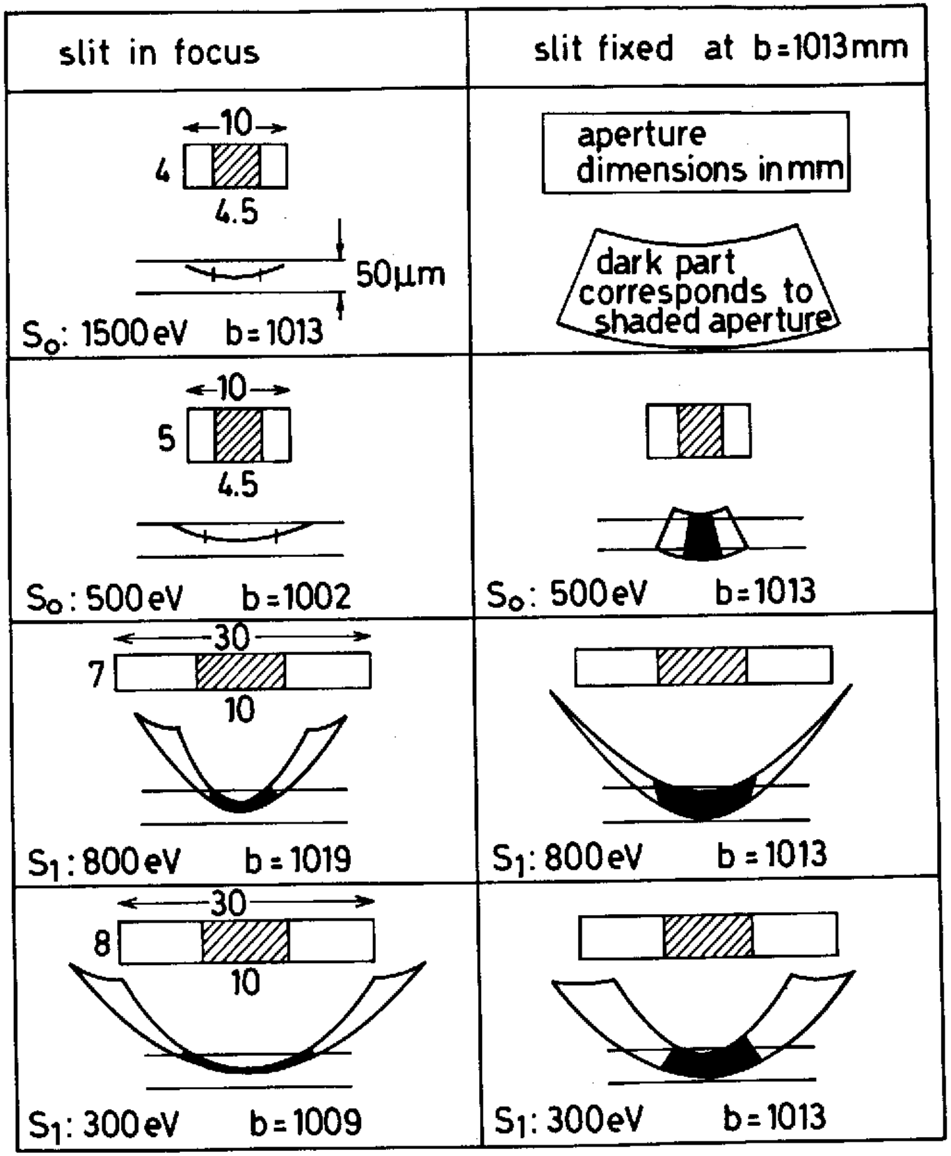

Fig. 3

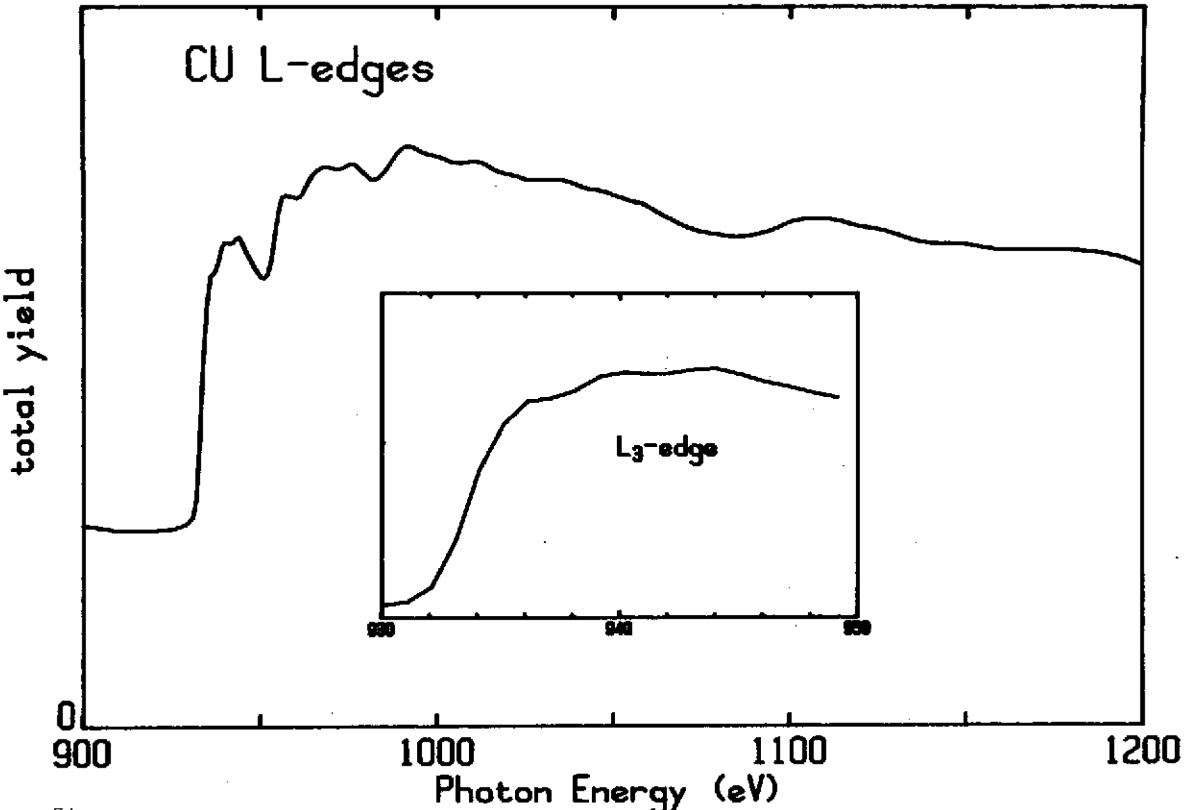
CU L-edges
total yield
0
900
1000
1100
1200
Photon Energy (eV)
L_3-edge
930
940
950

Fig. 4