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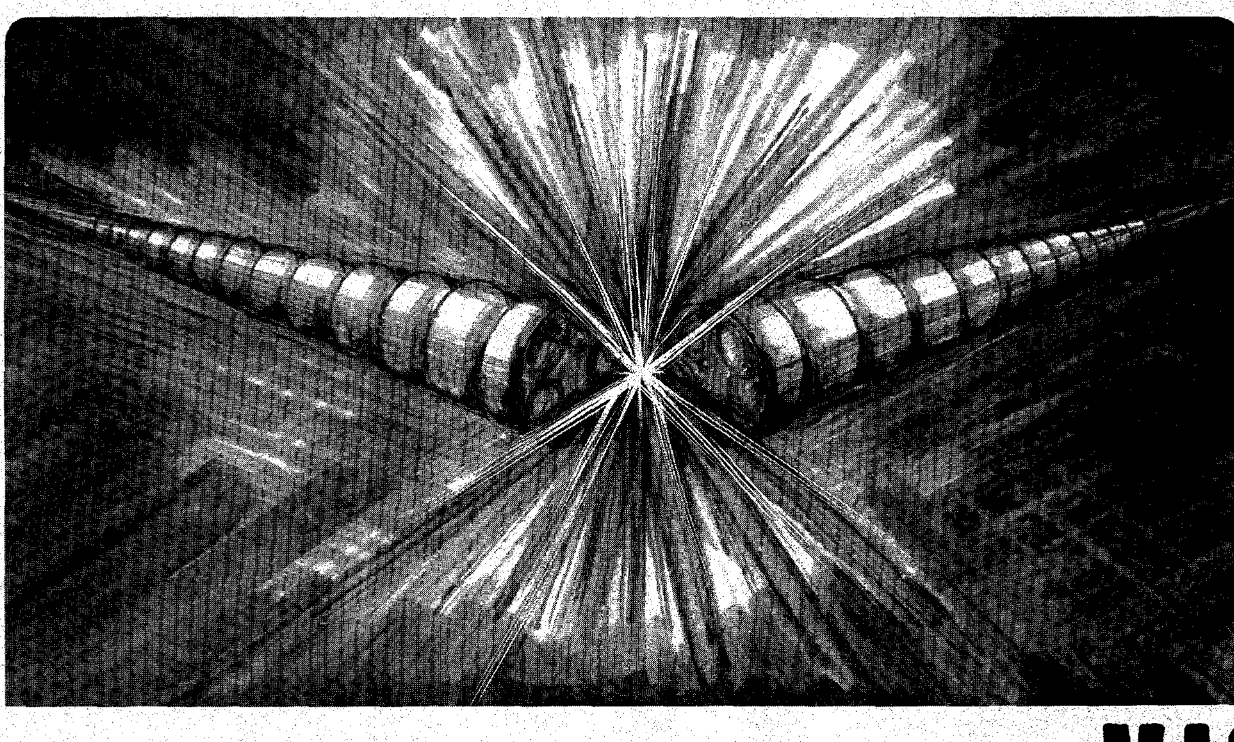

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Advanced Light Source
Accelerator and Fusion Research Division
Lawrence Berkeley National Laboratory
University of California
Berkeley, California 94720

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A. T. Young, E. Hoyer, S. Marks, V. Martynov, H.A. Padmore, D. Plate, and R. Schlueter

Advanced Light Source, Lawrence Berkeley National Laboratory, Berkeley, CA 94720

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Abstract

Circular polarization insertion devices and beamlines at the Advanced Light Source are described. The facility will consist of multiple undulators feeding two independent beamlines, one optimized for microscopy and the other for spectroscopy. The energy range of the beamlines will go from below 100 eV to 1800 eV, enabling studies of the magnetically important $L_{2,3}$ edges of transition metals and the $M_{4,5}$ edges of rare earths.

I. INTRODUCTION

The application of circularly polarized x-rays to studies of chemistry and physics has recently become a field of intense interest. Studies of systems as diverse as magnetic materials[1], biological molecules[2], and monolayer/thin film structures[3] have been performed using circularly polarized x-rays. From these studies, information such as the magnetic moment and the structural environment of the system can be measured. Circularly polarized x-rays have also been used to image magnetic structures. Magnetic microscopy has been used to create element specific images of the magnetic domains of interest to the semiconductor/magnetic recording industry.[4]

The Advanced Light Source at Lawrence Berkeley National Laboratory is designing and building a complement of insertion devices and beamlines to facilitate this research. Using undulators which directly produce circularly polarized light, high flux, high brightness beams of x-rays will be available at "application-specific" beamlines. Up to four undulators will be used to produce the radiation for two independent beamlines, one for high resolution spectroscopy and one for microscopy. This will allow the optical design to be optimized for the differing requirements of these two applications.

The insertion devices will be located in a single insertion device straight, where two "undulator stations" will be placed end-to-end. Small bending magnets will produce a "chicane" in the straight section, producing a 1.65 mrad angle between the two optical axes. Undulators can be operated at both stations simultaneously. In addition, at each station, a translation mechanism will allow either of two undulators to be placed in the beam. The output from either station can be directed to either of the two branchlines, or the output from both stations can be directed to the same branchline. Rapid changes in polarization can be produced in this operating mode by setting the two undulators for opposite polarization and alternating between the two beams with a mechanical chopper.

II. INSERTION DEVICE DESIGN

A. Magnetic design

To directly produce circularly polarized radiation, an undulator design similar to that of Sasaki[5] and Carr[6] has been adopted. The device is capable of producing polarized light of any ellipticity: horizontal, vertical, circular, or elliptical. Figure 1 shows a schematic of one period of the magnetic structure. The basic structure consists of four identical quadrants, or magnetic jaws. The helicity of the field is altered by shifting two diagonally opposed jaws axially relative to the other two. For example, jaws 1 and 3 are fixed, while jaws 2 and 4 move together. When all the jaws are aligned, or in phase, horizontal field components are canceled on-axis, and linear polarized light is produced in the horizontal plane. When the jaw phase is 0.5λ, vertical field components cancel on-axis, and vertical linearly polarized light is produced. When the jaw phase is between 0 and 0.5λ, the field is elliptical producing elliptically polarized radiation.

Each quadrant consists of two rows of permanent magnet blocks. The split magnetization orientations in each quadrant, as shown in Figure 1, increase the attainable on-axis field, thereby widening the accessible photon energy range. Having two blocks in each quadrant also allows for a thinner vacuum chamber wall, and thus a smaller magnetic gap, over the portion of the chamber directly above/below the beam axis. This smaller gap at the beam axis further increases the attainable peak on-axis field, decreasing the low energy limit.

The figure of merit considered for the evaluation of performance is defined as:

$$M = P_C^2 * F$$

where P_C is the degree of circular polarization, and F is the flux. The merit function brightness is also considered (where brightness is substituted for flux in the above equation). Flux, brightness, and degree of circular polarization have been calculated using the formalism described by Kim[7] for the planar and helical cases and generalized by Marks[8] for the elliptical case.

The first undulator to be installed in the ALS circular polarization facility will be a 5 cm period, 1.95 m long device with 37 full strength periods. The energy ranges of the various modes of polarization are summarized in Table 1. These correspond to an electron energy of 1.9 GeV. Figure 2 shows the calculated performance for merit function flux and brightness for this device for pure helical mode and for the 1st, 3rd, and 5th harmonics when the undulator is operated in an elliptical mode. As can be seen, operation in pure helical mode gives slightly higher merit function performance, but with a very restricted energy range, as pure helical mode produces no harmonics. In elliptical mode, this undulator produces usable output from 100 to 1800 eV. This energy range covers the important core levels for magnetic materials -- the $L_{(2,3)}$ edges of transition metals and the $M_{(4,5)}$ edges of rare earths. These calculations do not include electron beam energy spread, which will decrease the performance of the higher harmonics. For this reason, in determining the high energy performance, only the first and third harmonics have been considered. To reach even lower energies, a 7.5 cm period device has also been designed. With this device, energies as low as 20 eV will be available.

B. Mechanical Structure and Drive System Design

The basic layout features a three magnet chicane which provides the 1.65 mrad angle between the photon beams from the upstream and downstream undulator stations. Figure 3 shows a cross section of two of the undulators side-by-side. Each undulator will be supported by an "T" structure design. Two vertical columns are mounted to a common base with two horizontal members connecting them. The base is split to provide 200 mm of transverse motion. A second undulator can then be mounted to the same base and either device can be moved in and out of operation.

The vertical gap drive for a device is provided by a chain drive system connected to a motor and gear box arrangement and to the two roller screw assemblies, similar to all other ALS undulators. The longitudinal drive system will be a linear drive system . There will be two longitudinal drive systems, one for the upper magnetic structure and one for the lower magnetic structure.

The vacuum system design will be similar to existing designs on all ALS undulators. Pumping will be with both ion and titanium sublimation pumps. The chambers will be independently supported from the floor. Six sets of position monitors will be provided for electron beam position monitoring.

To achieve the required beam steering in the chicane, the field strength of the central magnet is reversed in direction from both the upstream and downstream magnets and has twice the field strength. These magnets are air cooled electromagnets of conventional construction. To control the fringe fields from these magnets, each is terminated with a pair of field clamps. These magnets are driven in series with a single DC power supply.

III. BEAMLINE DESIGN

A. General Description

The conceptual design of the circular polarization beamlines is shown in figure 4. Two main beamlines will be built for this facility. The optical design of each branchline is tailored to suit either microscopy or high resolution spectroscopy. For spectroscopy studies, a wide energy range will be covered, from 20 to 1800 eV, with a resolution of up to 10,000 at 100 eV. For the microscopy beamline, a higher-throughput, lower resolution monochromator has been designed. It is entrance-slitless, with an energy range of 100-1800 eV and a resolution of about 1500.

B. Beam Direction Mirrors

Emerging from the undulators, the two photon beams are separated by 1.65 mrad. After passing through the shield wall, the beams will enter a "mirror switchyard." Using this set of grazing incidence mirrors, the output from either (or both) undulator station(s) can be directed to either of the branchlines. In the "standard" mode, each undulator beam would be directed to one of the beamlines by a translating mirror. To send both beams to the microscopy branchline, the mirror for the spectroscopy line would be retracted and the beam allowed to propagate to a second mirror which would then direct the beam down the microscopy line. A similar procedure is used to direct both beams to the spectroscopy line.

C. Microscopy Beamline

A multiple grating spherical grating monochromator will be used for the microscopy line. Grating diffraction efficiency has been calculated using the differential method[9] and modal theory.[10] To cover the energy range 100-1800 eV, three gratings with rulings of 200, 400, and 600 l/mm will be used. Efficiencies up to 28% have been achieved.

Following dispersion by the grating the beams will pass through a mechanical chopper. The chopper is used for experiments in which the output from both undulator stations are sent to the beamline but with opposite helicity.

Before reaching the monochromator exit apertures, the x-rays are directed to one of two end stations by an "end station switchyard." As with the first switchyard, a system of retractable mirrors is used. These mirrors also provide horizontal focusing with a demagnification of about 6 at the exit plane. Each end station has its own exit aperture.

To minimize the defocus of the monochromator at the exit apertures, the source position, the radius of the grating, and the exit arm length have been carefully considered. In particular, the two undulator stations present different source positions. The ray tracing program SHADOW was used to study this problem. Figure 5a shows the beam focus at the exit aperture if the grating radius and the exit arm length have been chosen for an "average" source point between the two undulator stations, but with the source actually being 1.2 m farther away, corresponding to the center of the upstream undulator station. The photon energy is 850 eV Also shown are the spots from photons which are 0.57 eV above and below 850 eV, simulating a resolution of 1500. As can be seen, these spots are only marginally resolved.

To solve this problem, instead of using two plane mirrors in the mirror switchyard to direct the undulator beams to this beamline, one of the plane mirrors is replaced by a cylindrical mirror. The grating radius and exit arm length are optimized for the first station (the one using the plane mirror) while the cylindrical mirror is used to move the real source point of the second station to a virtual source point which coincides with the first station. Figure 5b shows that with the cylindrical mirror solution, the SHADOW images resulting from the upstream undulator station are now well resolved, in spite of the fact that the monochromator has been optimized for the downstream undulator station, 2.4 m away.

C. Spectroscopy Beamline

For the higher resolution requirements of this beamline, a monochromator with an entrance slit has been selected. The mirrors in the beamline switchyard for this beamline are spherical, and focus horizontally to the exit slit. The first optical element after the switchyard is a spherical mirror which focuses vertically to the entrance slit. After passing through a mechanical chopper and a translating exit slit, the x-ray beam is refocused to the end station with an ellipsoidal mirror.

A particular problem of the design of this beamline is the wide energy range required, 20-1800 eV. For optimum diffraction efficiency, the included angle of the monochromator needs to vary from 177 degrees at 1800 eV to <155 degrees at 20 eV.[11,12] This can be accomplished using a set of monochromator premirrors at fixed but differing angles. As the optimum grating is laterally translated into the beam, the appropriate premirror could also be translated into place. Work is continuing on the design of this beamline to select the optimum gratings and included angles.

IV. END STATIONS

The microscopy beamline will have provisions for two end stations, each with its own monochromator exit aperture. One end station will be a full field photoemission electron microscope (PEEM). Ultimate resolution of an advanced PEEM should be better than 20 nm. The other microscope end station will be equipped for scanning zone plate microscopy. Future advances in zone plate fabrication should lead to resolution approaching 10 nm.

The spectroscopy beamline will also have provisions for two end stations. For this beamline, a rotating experimental platform will allow two end stations to be attached and aligned to the beamline at a time. Typical end stations which will be used on this beamline will include UHV angle-resolved photoelectron spectroscopy chambers, superconducting magnet chambers for magnetic circular dichroism experiments, and general purpose chambers equipped for surface science and materials research.

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Table 1 Energy Range of a 5 cm period elliptically polarizing undulator

Mode	Peak Bx T	Peak By T	Min. Energy eV	Max. Energy eV
Elliptical	0.228	0.502	100	1500
Helical	0.424	0.424	140	680
Horizontal	0	0.793	85	1500
Vertical	0.502	0	180	1500

Figure Captions

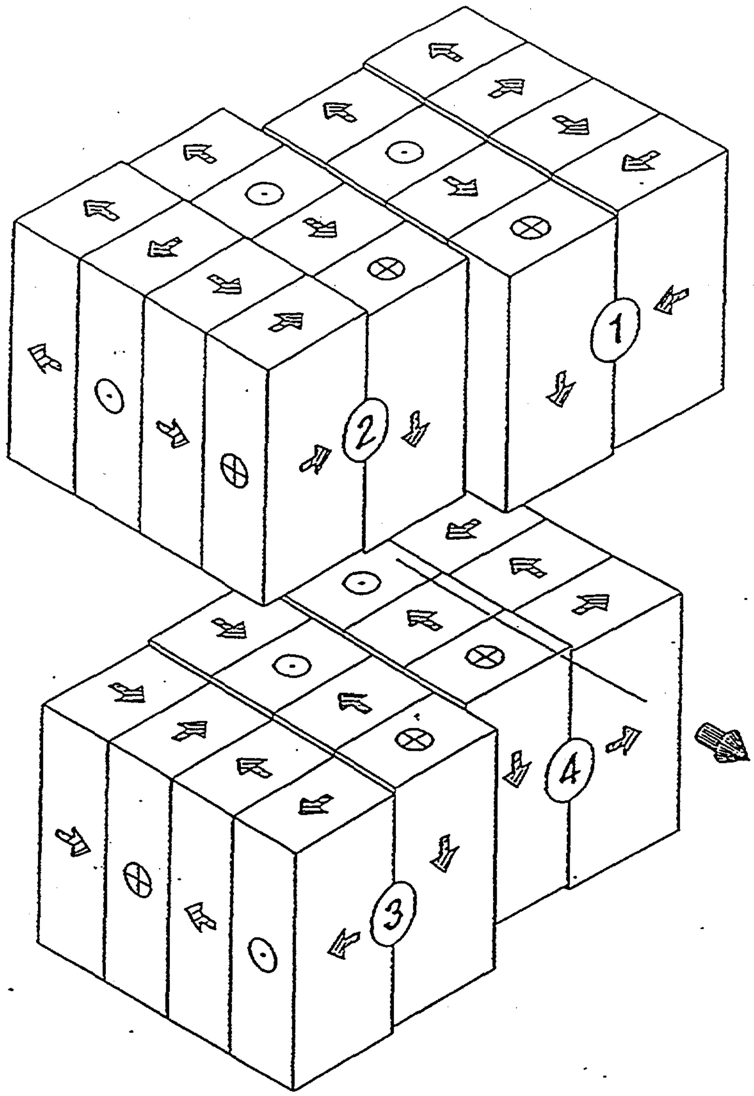
Figure 1 Schematic of the magnetic structure of the ALS elliptically polarizing undulator.

Figure 2 Calculation of the performance of a 5.0 cm undulator. The merit function is (the degree of circular polarization)^2 times the flux or the brightness

Figure 3 Cross sectional view of an undulator station illustrating that each station can hold two undulators.

Figure 4 Conceptual design of the LBL circular polarization beamlines. Both microscopy and spectroscopy can be performed at this facility.

Figure 5 Raytrace plots of the beamspot at the microscopy monochromator exit aperture. a) result with an optical design using plane steering mirrors b) result with a cylindrical steering mirror. See text.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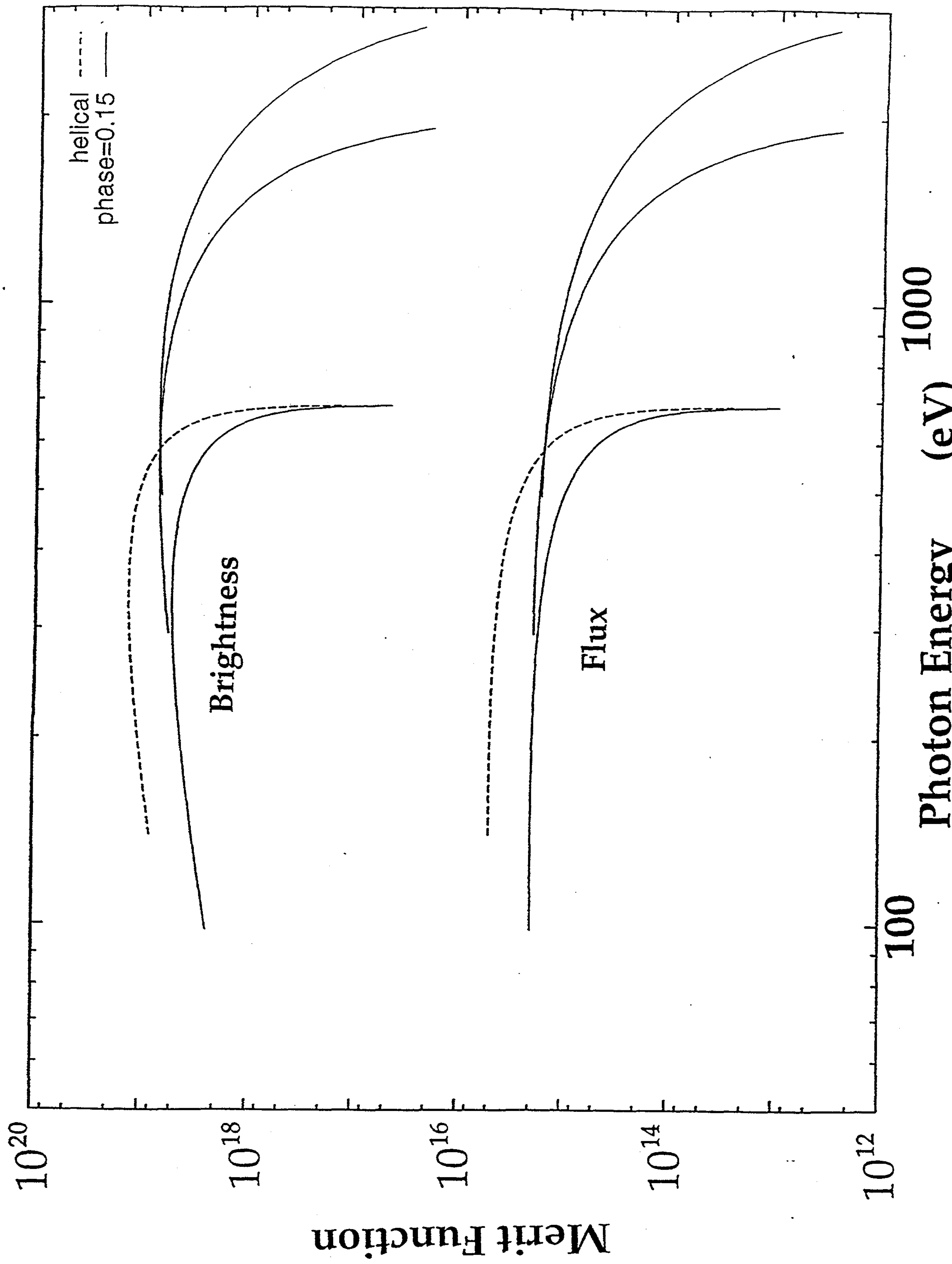
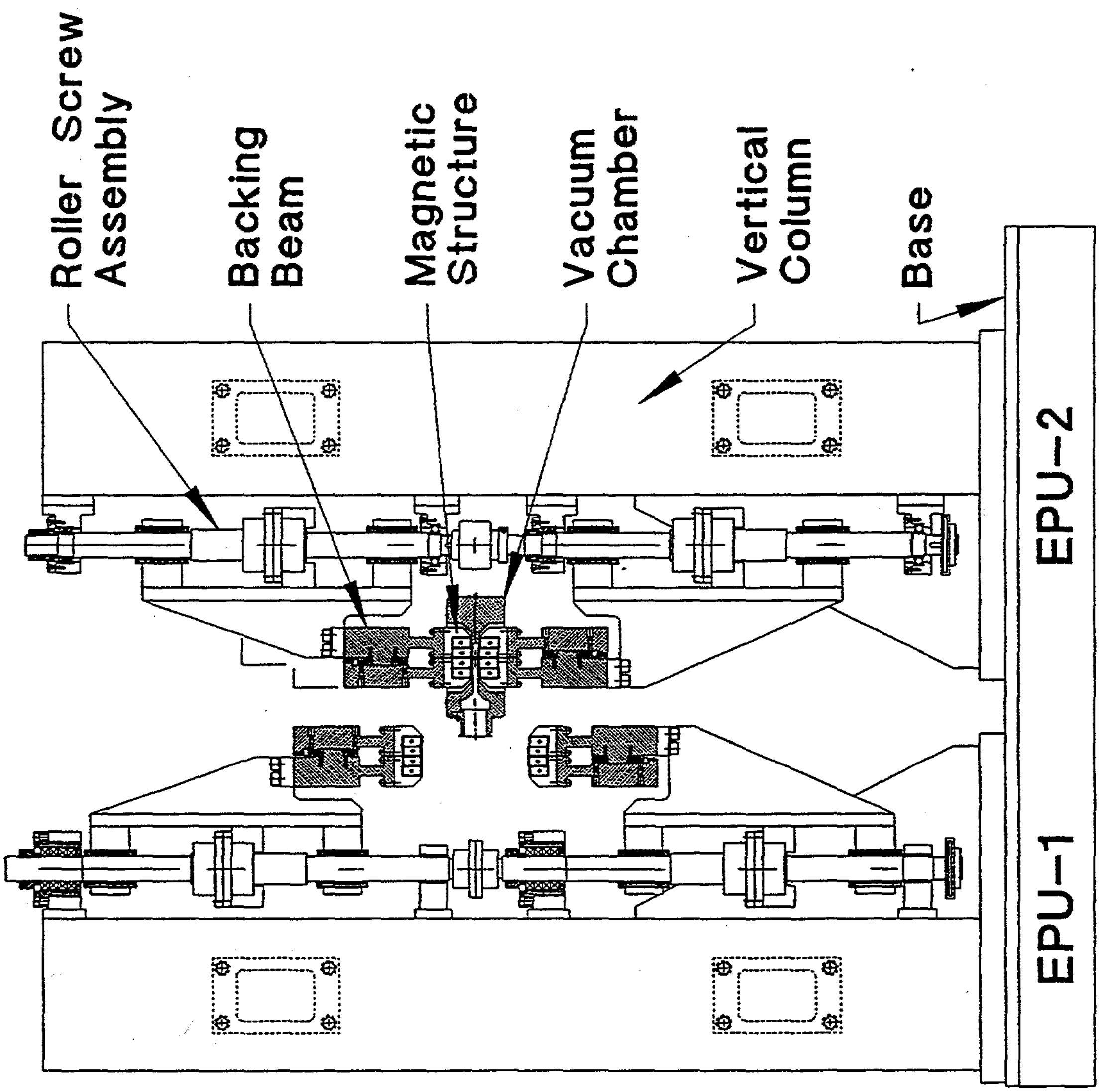
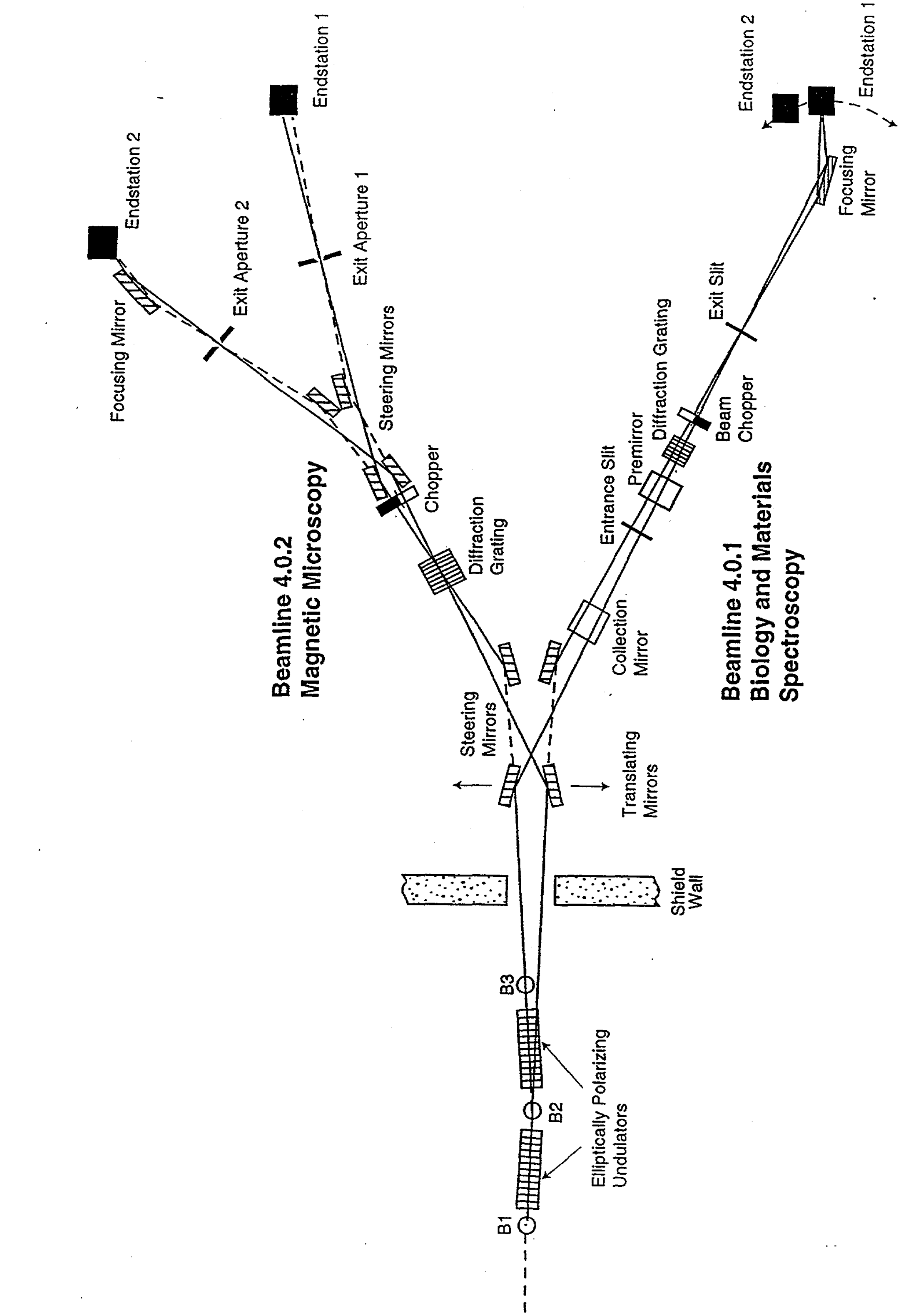
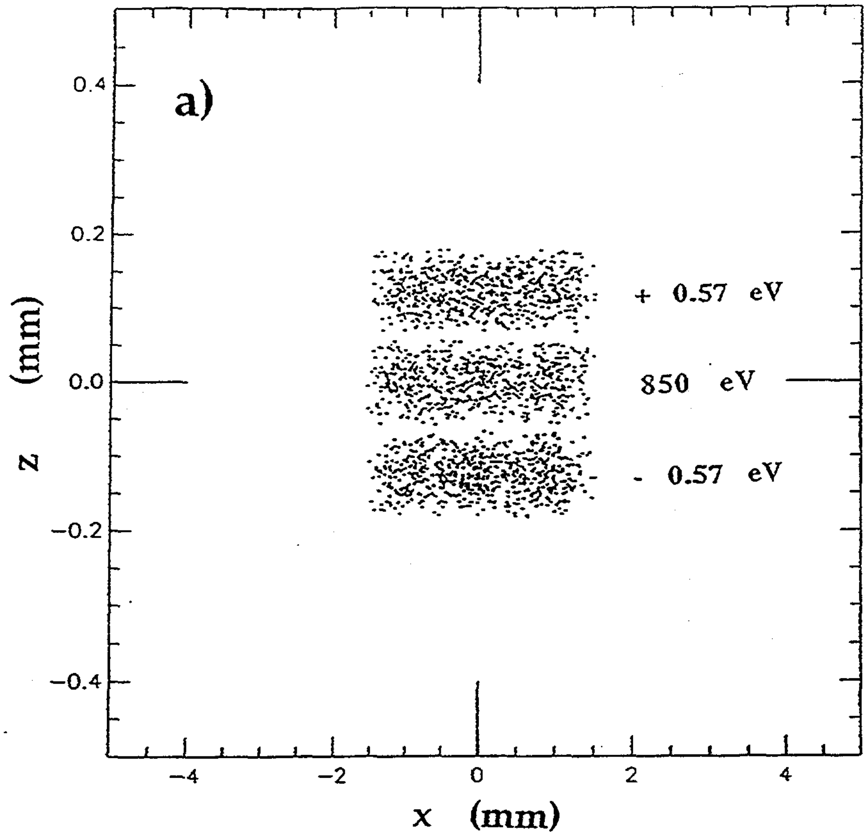
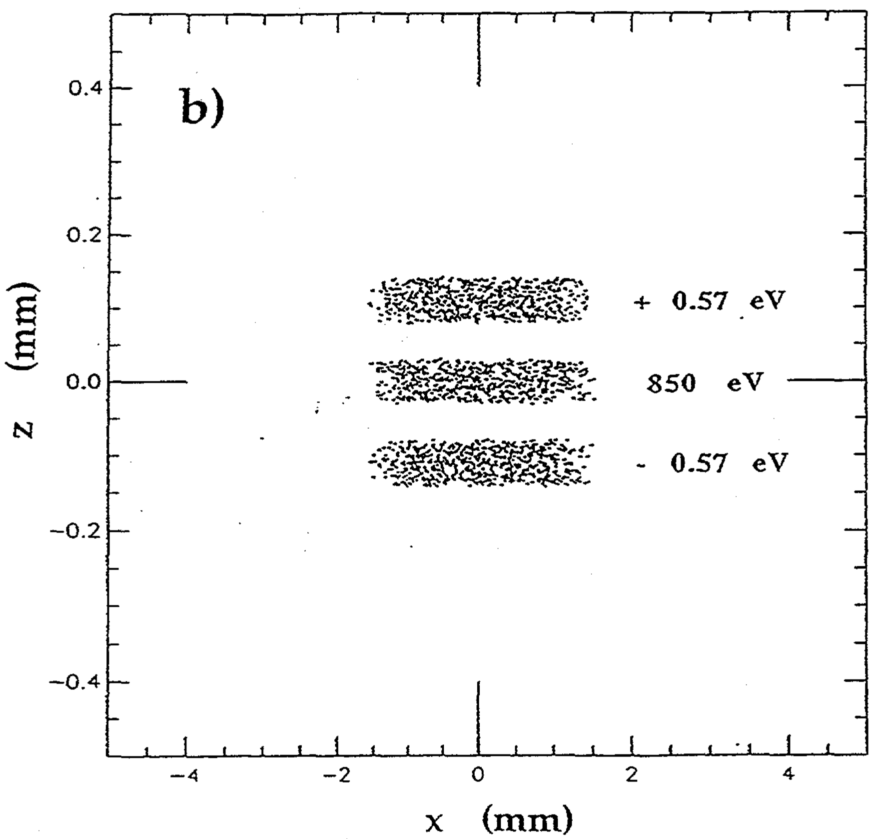

helical
phase=0.15
Brightness
Flux
Photon Energy (eV)
Merit Function
10^{20}
10^{18}
10^{16}
10^{14}
10^{12}
100
1000



Roller Screw Assembly
Backing Beam
Magnetic Structure
Vacuum Chamber
Vertical Column
Base
EPU-2
EPU-1


Beamline 4.0.2
Magnetic Microscopy
Beamline 4.0.1
Biology and Materials
Spectroscopy
Endstation 1
Endstation 2
Exit Aperture 1
Exit Aperture 2
Focusing Mirror
Steering Mirrors
Chopper
Diffraction
Grating
Steering
Mirrors
Translating
Mirrors
Shield
Wall
B1
B2
B3
Elliptically Polarizing
Undulators
Collection
Mirror
Entrance Slit
Premirror
Diffraction Grating
Beam
Chopper
Exit Slit
Focusing
Mirror
Endstation 2
Endstation 1


a)
+ 0.57 eV
850 eV
- 0.57 eV
0.4
0.2
0.0
−0.2
−0.4
z (mm)
−4
−2
0
2
4
x (mm)


b)
+ 0.57 eV
850 eV
- 0.57 eV
0.4
0.2
0.0
−0.2
−0.4
z (mm)
−4
−2
0
2
4
x (mm)