CONF-9510119--7

LBL-37815
UC-410

Lawrence Berkeley Laboratory
UNIVERSITY OF CALIFORNIA

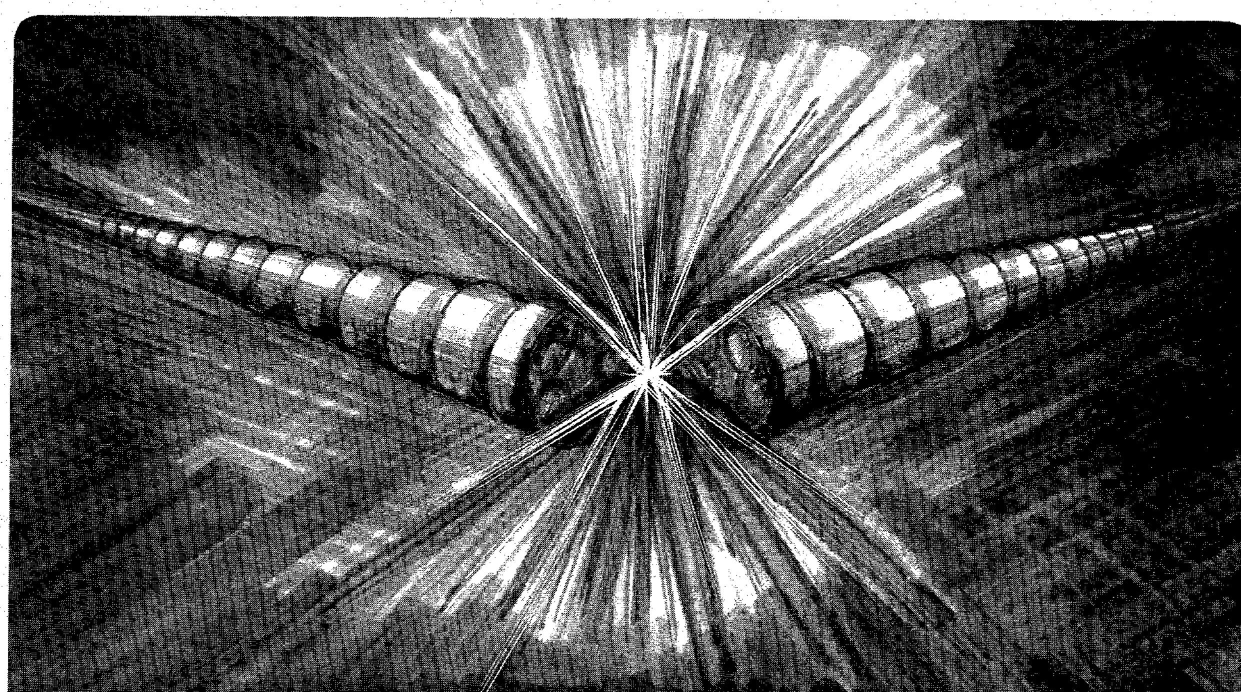
Accelerator & Fusion Research Division

Presented at the National Conference on Synchrotron Radiation Instrumentation '95, Argonne, IL, October 15–20, 1995, and to be published in the Proceedings

An Elliptical Wiggler Beamline for the ALS

V.V. Martynov, W.R. McKinney, and H.A. Padmore

October 1995



Prepared for the U.S. Department of Energy under Contract Number DE-AC03-76SF00098

LBL-37815
LSBL-289
UC-410

AN ELLIPTICAL WIGGLER BEAMLINE FOR THE ALS*

V.V. Martynov[a,b], W.R. McKinney[a], H.A. Padmore[a]

Advanced Light Source
Accelerator and Fusion Research Division
Lawrence Berkeley National Laboratory
Berkeley, CA 94720, USA

Institute of Microelectronics Technology
142432 Chernogolovka
Russia

Submitted to the National Conference on Synchrotron Radiation Instrumentation, Argonne, IL, October 1995

*This work was supported by the Director, Office of Energy Research, Office of Basic Energy Sciences, Materials Sciences Division, of the U.S. Department of Energy, under Contract No. DE-AC03-76SF00098.

An Elliptical Wiggler Beamline for the ALS.

V. V. Martynov[*,†], W. R. McKinney[*], H.A. Padmore[*]

[*]*Accelerator and Fusion Research Division, Lawrence Berkeley Laboratory, CA 94720*
[†]*Institute of Microelectronics Technology, 142432 Chernogolovka, Russia*

(Presented on 20 October 1995)

A beamline for circularly polarized radiation produced by an elliptical wiggler has been designed at the ALS covering the broad energy range from 50 eV to 2000 eV. The rigorous theory of grating diffraction efficiency has been used to maximize transmitted flux. The nature of the elliptical wiggler insertion device creates a challenging optical problem due to the large source size in the vertical and horizontal directions. The requirement of high resolving power, combined with the broad tuning range and high heat loads complicate the design. These problems have been solved by using a variable included angle monochromator of the "constant length" type with high demagnification onto its entrance slit, and cooled optics.

1. INTRODUCTION

The use of circularly polarized light is increasingly being exploited at many synchrotrons. The technique is now at the cutting edge of research on properties that are dependent on electron spin. For example, the magnetic properties of solids in thin films are of academic interest and of considerable economic importance to the magnetic recording industry. Similarly, in the life sciences, several critical biological processes are catalyzed by enzymes containing metals with active spin systems.

To address these problems, research with circularly polarized synchrotron radiation is moving rapidly toward the use of insertion devices to provide the higher flux and/or higher brightness needed. Based on input from the user community an elliptical wiggler and associated beamlines to cover the wide photon energy range from 50 eV to 2 keV are under development at the Advanced Light Source (ALS).[1]

The elliptical wiggler has been designed to produce circularly polarized light. The light can be produced on axis through the use of a periodic horizontal magnetic field shifted longitudinally 90° relative to vertical field. The horizontal field deflects the electron beam vertically as it passes through the wiggler, providing an on-axis effect equivalent to viewing the radiation from successive poles first from above the mid plane and then from below, so that the circular polarization components from poles of opposite polarity add rather than cancel. The polarization can be switched from right to left by reversing the horizontal field with frequency 1-10 Hz. The elliptical wiggler can be optimized by changing the horizontal and vertical magnetic field strength.

In this paper we present a solution to the problems caused by the large phase space of the source, and the design requirements of a wide tuning range, high heat loads and high resolving power.

2. COMPARISON OF FIXED AND VARIABLE DEVIATION ANGLE MONOCHROMATORS

In Padmore et al.[2] we have shown that a monochromator should have a variable deviation angle to achieve maximum grating efficiency at all energies. This is of particular importance when covering a large energy range so that the flux integrated by a beamline's acceptance is maximized. The optimum deviation angle changes from 150° to 177° for the range from 50 eV to 2000 eV for groove densities from 300/mm to 2100/mm.

In this paper we compare the fixed and variable deviation angle design schemes for this particular beamline. As a basis for comparison we take the geometry of a fixed deviation spherical grating monochromator (SGM) currently in use at ALS beamline 9.3.2.[3]

The goal of any monochromator design is to accept the most possible radiation from the source. We define a merit function by defining the monochromator output:

$$M_{out} = M_a \times \delta \times Eff \qquad (1)$$

where M_a is a merit function, defined as flux multiplied by the square of the degree of circular polarization integrated over the vertically collected aperture and over the whole source size. Delta (δ) is the entrance slit transmission factor and *Eff* is the diffraction efficiency of the grating.

To calculate the diffraction efficiency of the grating, we use a rigorous method developed by M. Neviere.[4] It calculates the diffraction efficiency of the grating for a given line density, groove width, groove depth, and deviation angle. We now have all the parts necessary to evaluate the next function and can now apply this to assess existing designs, and to optimize new designs.

Let us divide the energy range into three parts and take the energies 100 eV, 700 eV, and 1500 eV as basic points for optimization. The optimum demagnification will be fixed for all future calculations, because it is fixed in the real beamline, and we will keep resolving power constant and equal to 3500. We will consider a fixed angle monochromator first. Optimizing at 700 eV, assuming the geometry of the SGM from ALS 9.3.2 gives a demagnification of 13, and a deviation angle of 175°. For this angle the optimum line density of the grating for 100 eV is 100 l/mm, and at 1500 eV is equal to 1100 l/mm. The merit function for this case is shown in Fig. 1 by a solid line. One can see from the graph that the performance in the low and high energy ranges is poor. This is entirely due to the inappropriate deviation angle. The diffraction efficiency of the grating for deviation angle 175° is rather poor above 1500 eV and below 200 eV. The deviation angle should be smaller at the low energies and larger at the high energies. This is clearly seen from the next optimization. Now we optimize the deviation angle and line density for 100 eV, with the result 150.6°, 2600 l/mm; and for 1500 eV, with the result 177°, 500 l/mm respectively.

From Fig. 1 it can be seen that the merit function becomes much higher after this multi-angle optimization. This leads to a second type of monochromator, one with three fixed angles for low, medium and high energies, and the parameters above. The performance of such a design is shown by the dashed lines (solid line for the medium energy range). The parameters in this case are: low energy range: 150.6°. 2600 l/mm: medium energy range: 175°, 350 l/mm: high energy range: 177°, 500 l/mm. One can see from the figure that this segmental variable angle type is much better then the fixed angle type, but the merit function still varies sharply between the peaks, especially in the low energy range. By changing energies selected for optimization, the peaks can be moved, providing smoother performance, but it would likely require four gratings to produce the adequate smoothness. The third type of monochromator would be one with a completely variable deviation angle, and would cover the entire energy range with one grating (the line with white circles in Fig. 1).

3. BEAMLINE DESCRIPTION

One can see from the comparison of fixed and variable included angle monochromators (Fig. 1), that the monochromator should have a variable deviation angle to cover the entire energy range 50 eV—2000 eV.

The beamline layout is presented in Fig. 2. An elliptical wiggler source produces circularly polarized light. The beamline covers the energy range 50 eV—2000 eV providing a resolving power of 3500. The first mirror focuses the beam horizontally. It accepts 5 mrad of the source radiation, and deflects the beam four degrees horizontally. The second mirror focuses the beam vertically to the entrance slit of the monochromator with high demagnification 13:1, due to the large vertical source size $\approx$ 200 µm To obtain this resolving power, the entrance slit operates within the range from 15 µm at the low energies to 8 µm at the high energies.

The monochromator is a "constant length" instrument[5,6] in the sense that the slits do not move a large distance to keep the monochromator in focus as they must do in an SGM design. Due to high vertical divergence of the beam inside the monochromator (≈5 mrad), we face significant aberrations of the grating. These aberrations can be eliminated by following the exact Rowland circle conditions.[7] Non-Rowland circle geometries such as the SX-700[8] or the SGM can not be used. Rowland circle conditions can be satisfied by moving the plane pre-mirror and the spherical grating as a whole unit back and forth, and by a small movement of the exit slit. Simultaneously with these movements the grating rotates to tune the energy. Three spherical gratings of different radii and different line densities as well as three pre-mirrors under different angles of incidence are used to cover the entire energy range. (see fig. 3). The beamline components are presented in the table.

Component	**Description**	**Component**	**Description**
Horizontal focusing mirror	Water-cooled spherical 200x8 cm^2 R=286.54m	Monochromator	Constant length SGM Monochromator length=6m pre-mirror 40x5 cm^2 gratings 17x5 cm^2 water cooled
Glancing angle	2°		
		50 eV—500 eV	
		Deviation angle	160°
		Grating	R=17.32m; 2000 l/mm
		1000 eV—2000 eV	
		Deviation angle	175°
		Grating	R=68.78m; 700 l/mm
		1000 eV—2000 eV	
		Deviation angle	177°
		Grating	R=114.61m; 500 l/mm
		Exit slit	a small movement about 40 mm

Vertical focusing mirror	Water-cooled Elliptical 20x10 cm^2	Refocusing mirror	Toroidal 40x10 cm^2
	semi-major axis 1075cm		Major radius 6367.49 cm
	semi-minor axis 19.115cm		Minor radius 11.63 cm
	semi-focal length 1074.83cm	Glancing angle	2°
	Eccentricity 0.99984		
Glancing angle	2°		

4. CONCLUSION.

The large source size and divergence from an elliptical wiggler source together with the demand for a very large energy range produce difficult optical problems when trying to design a high flux, high throughput monochromator. By using a modification of the constant length monochromator concept and a high demagnification onto the entrance slit together with a rigorous system optimization has led to a highly efficient, high resolving power, high resolution design that should also have application elsewhere.

ACKNOWLEDGMENTS.

We would like to thank S. Marks for help with source merit function calculations and T. Young for useful discussions. This work was supported by the Director, Office of Energy Research, Office of Basic Energy Sciences, Materials Sciences, of the US Department of Energy, under contract No. DE-AC03-76SF00098.

REFERENCES

1 S. Marks, "Optimization design study for the ALS Elliptical Wiggler", LSBL-207, June 17, 1994.

2 H. A. Padmore, V. Martynov, K. Holis, "The use of diffraction efficiency theory in the design of soft X-ray monochromators.", Nucl. Instr. and Methods, A 347(1994), 206-215

3 Zahid Hussain, W.R. Anthony Huff, Scot A. Kellar, Edward J. Moler, Philip A. Heimann, Wayne McKinney, Howard A. Padmore, Charles S. Fadley, David A. Shirley, "High Resolution Soft X-Ray Bending Magnet Beamline 9.3.2 with Circularly Polarized Radiation Capability at the Advanced Light Source," Submitted to VUV 11, Aug. 27, 1995, Tokyo.

4 M. Neviere, P. Vincent and R. Petit, Nouv. Rev. Opt. 5 (1974) 65.

5 E. Ishiguro, M. Suzui et all, "Constant deviation monochromator for the range 100Å $\leq \lambda \leq$ 1000Å", Rev. Sci. Inst., Vol. 60, No. 7, July 1989, pp. 2105-2108.

6 F. Senf, H. Lammert, V. Flechsig, T. Zeschke and W.B. Peatman, "Precision demanded of a Rowland circle monochromator: its realization.", Rev. Sci. Instrum., 66(2), February 1995.

7 W.R. McKinney and M.R. Howells,"Design Optimization of 'Straight Groove' Toroidal Grating Monochromators for Synchrotron Radiation," Nuclear Instruments and Methods, 1980, Vol. 172, pp. 149-156.

8 H. Petersen, M. Willmann, F. Schafers and W. Gudat, "Circularly polarized soft X-rays in the photon energy range 30—2000 eV at BESSY SX700/3," Nucl. Instr. and Meth., A 333 (1993) 594-598.

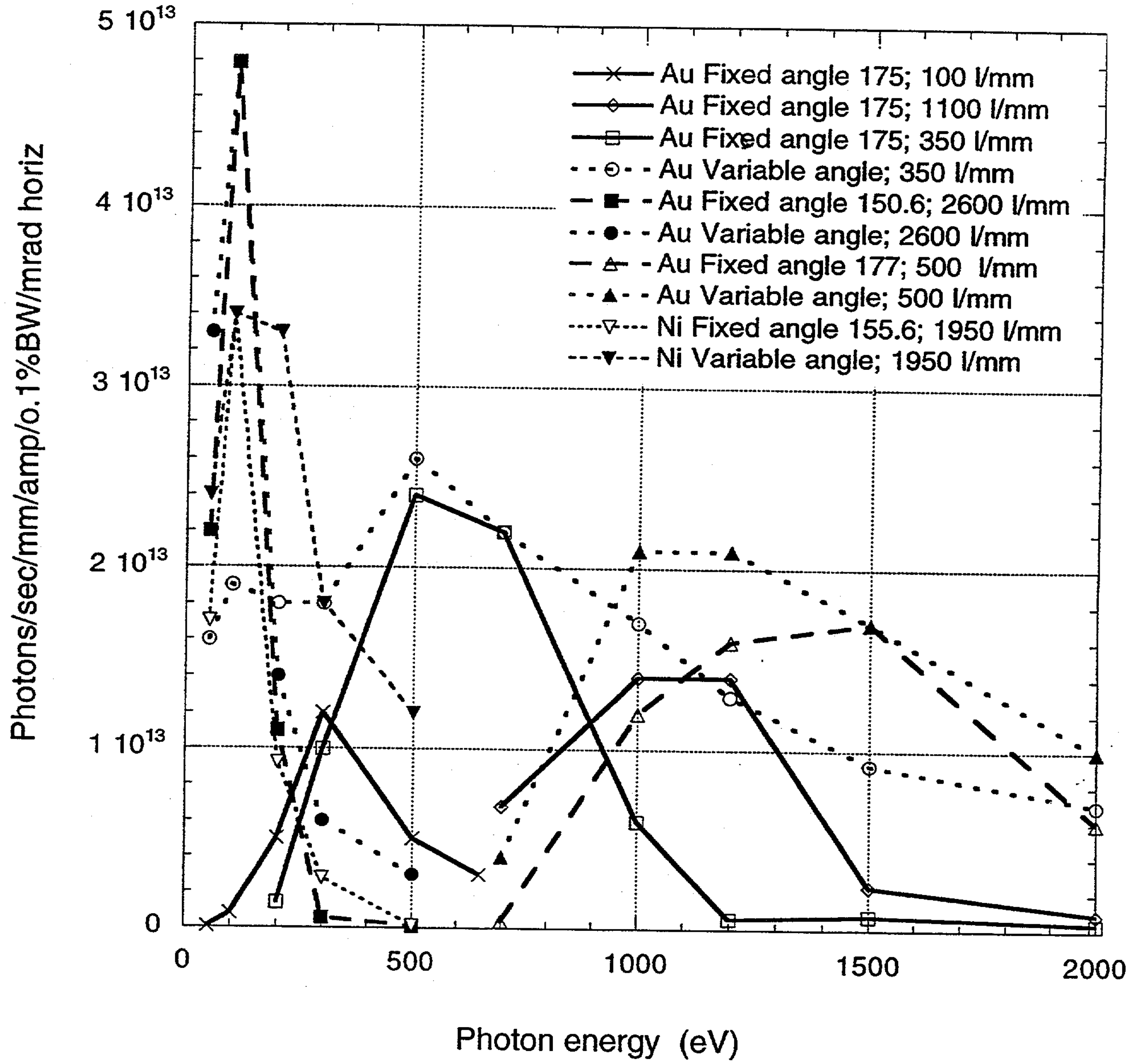
FIGURES

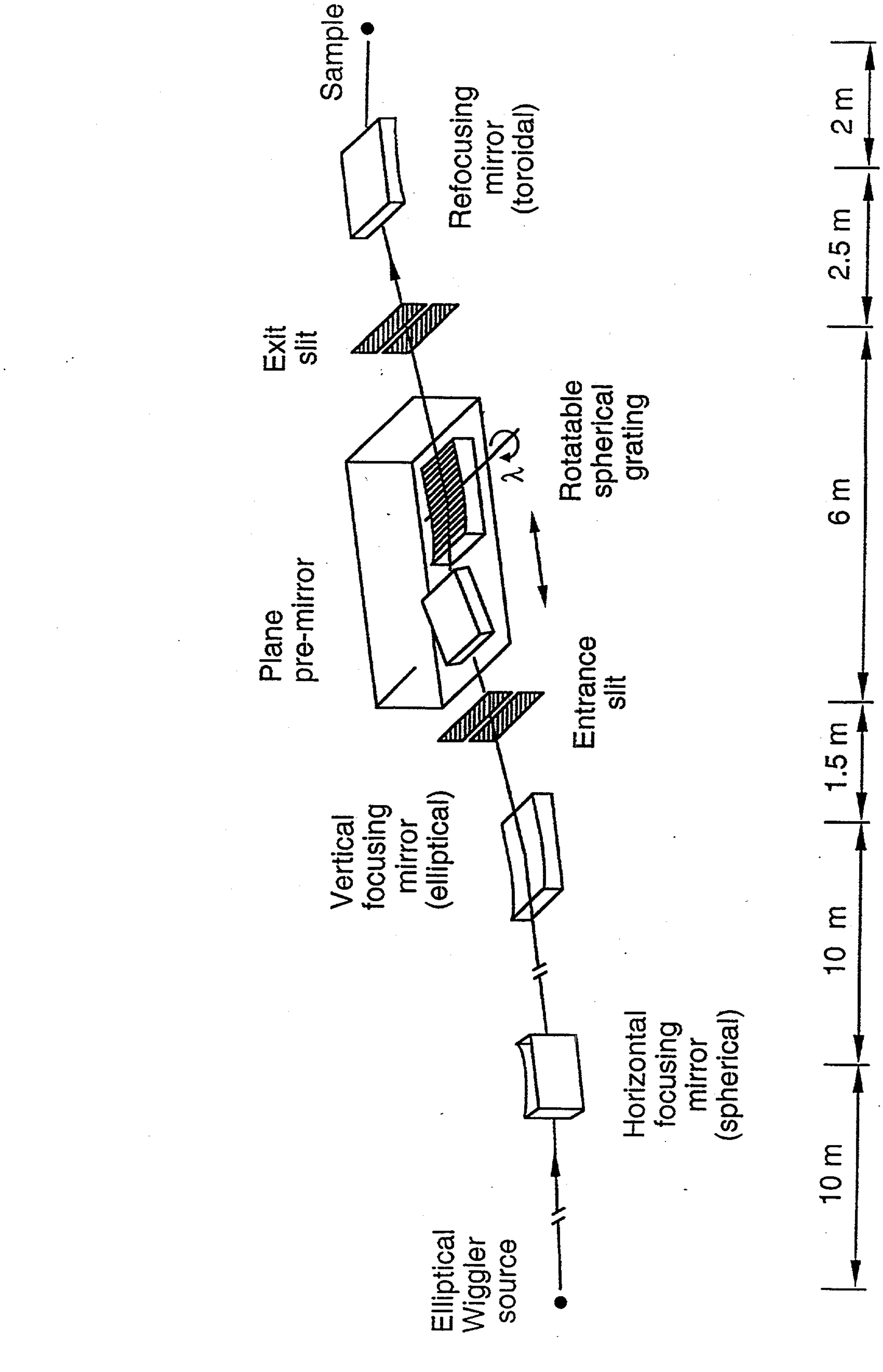
Fig. 1. Comparison of fixed, segmental variable and completely variable deviation angle monochromator performance. The y axis is in units of our chosen merit function. Resolving power is equal to 3500 over the whole energy range. The first number in the key insert is the deviation angle in degrees, the second one is the line density of the grating.

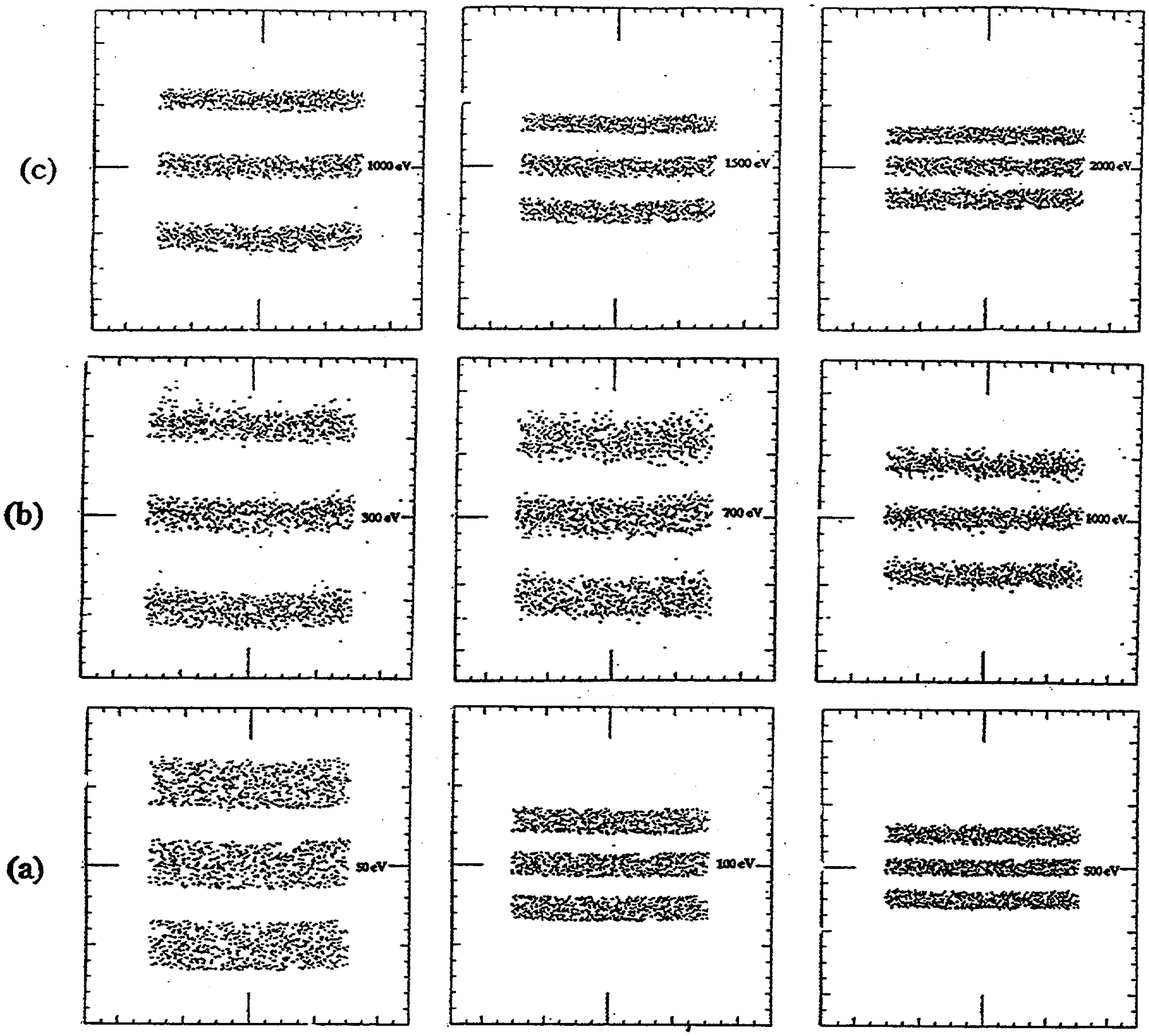
Fig. 2. Layout of the beamline.

Fig. 3 Ray-tracing of the constant length 6m monochromator with a small movement of the exit slit to satisfy Rowland circle conditions exactly. Pictures of the beam at the exit slit are calculated for energies $E = E_0 \pm \Delta E$, $E/_{\Delta E}$=3500: (a) 2θ=160°, grating radius =17.28m, N=850 l/mm; (b) 2θ=175°, grating radius = 68.78m, N=700 l/mm; (c) 2θ=177°, grating radius = 114.61m, N=500 l/mm.

Resolving power 3500




Elliptical
Wiggler
source
Horizontal
focusing
mirror
(spherical)
Vertical
focusing
mirror
(elliptical)
Entrance
slit
Plane
pre-mirror
λ
Rotatable
spherical
grating
Exit
slit
Refocusing
mirror
(toroidal)
Sample
10 m
10 m
1.5 m
6 m
2.5 m
2 m



(c)
1000 eV
1500 eV
2000 eV
(b)
300 eV
700 eV
1000 eV
(a)
50 eV
100 eV
500 eV