How an ERL might benefit our understanding of elementary excitations in condensed matter?

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Acknowledgments

APS:

H. Sinn, W. Sturhahn, T. Toellner,
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IXS-CAT

J. Hill (BNL), C. Burns (Western Michigan),
P. Stephens (Stony Brook), E. Isaacs (Lucent)

Why Inelastic X-Ray Scattering?

Static structure: elastic scattering
Dynamical behavior: inelastic scattering

Energy integrating x-ray scattering and quasi-elastic scattering lose most of the dynamical information.

For condensed matter systems, dynamical information is needed to describe the ground state and the excitations from the ground state.

For soft condensed matter, propagation of sound waves and other density fluctuations determine the response of the system to time varying probes – a key aspect of their material's properties.

For biological systems, understanding the vibrational modes of molecules is as central to the understanding of their function as determining their structure is.

Intensity of Bragg reflection

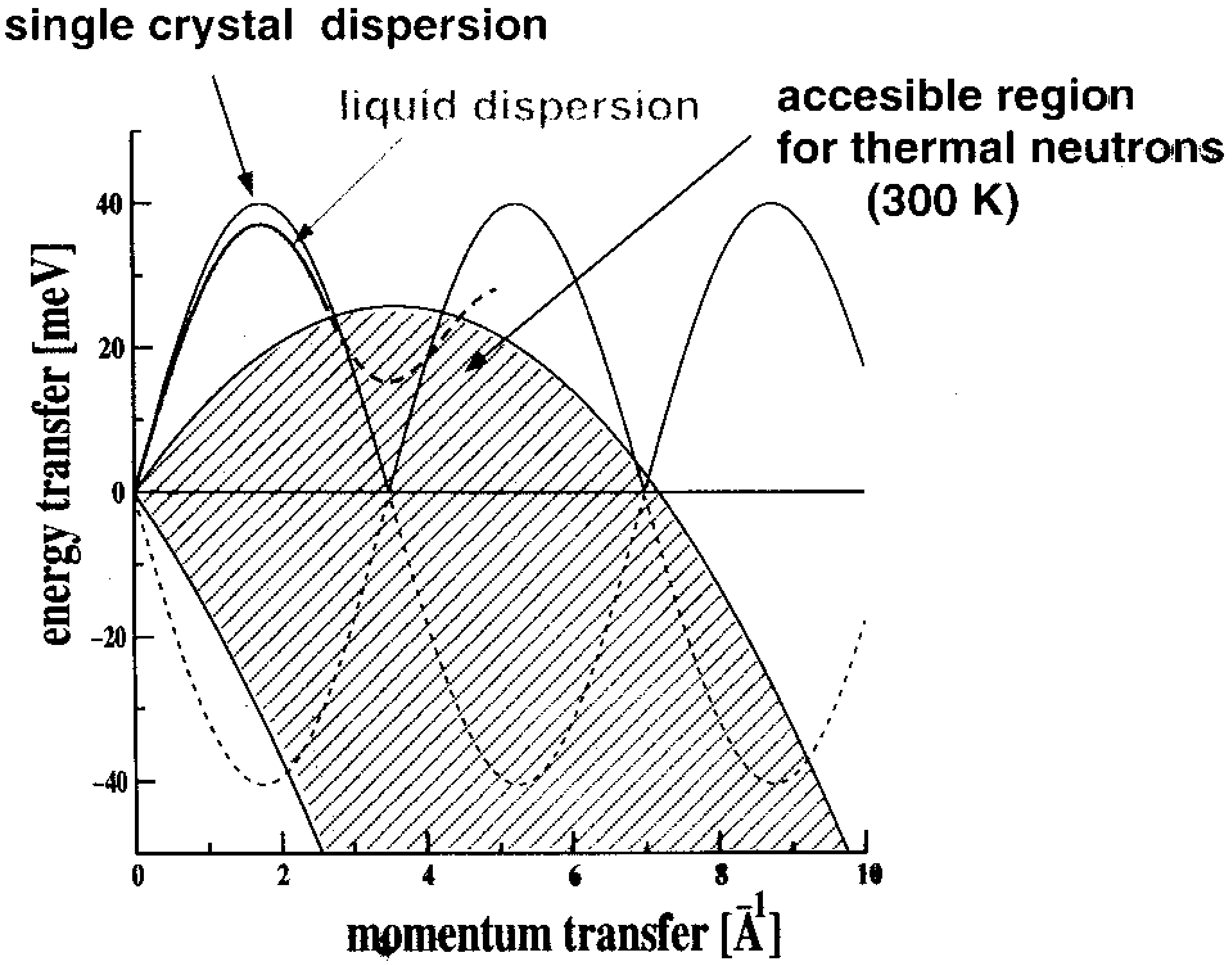
$$I(\mathbf{Q},\omega) \sim \left|f_s(Q)e^{-W}\right|^2 \delta(Q-\tau)$$

Intensity of phonon

$$I(\mathbf{Q},\omega) = \left|\Sigma_s^{unitcell} f_s(Q)e^{-W}\sqrt{m_s}e^{i\mathbf{Q}.\mathbf{r_s}}[\mathbf{Q}.\mathbf{e}(s|{}^{q}_{j})]\right|^2$$

$$\frac{<n>+\frac{1}{2}\pm\frac{1}{2}}{\omega_{\mathbf{q},j}}\delta(\omega \mp \omega_{\mathbf{q},j})$$

what physics ?



single crystal dispersion

liquid dispersion

accesible region for thermal neutrons (300 K)

- high sound velocity simple liquids, liquid metals
- molecular liquids, alloys, molten salts
- phonons under high pressure
- quantum crystals (H_2 , He-3)

Lattice Dynamics

A unified understanding of thermodynamics, optical and dielectric properties of materials, both at the classical and quantum mechanical level.

It can be perceived as simple as study of small oscillatory vibrations of atoms in solids, and in liquids, too. However, since it involves an accurate knowledge of forces acting on each atom, it provides a direct measure and test of interatomic potential, which is at the heart of **modern solid state physics.**

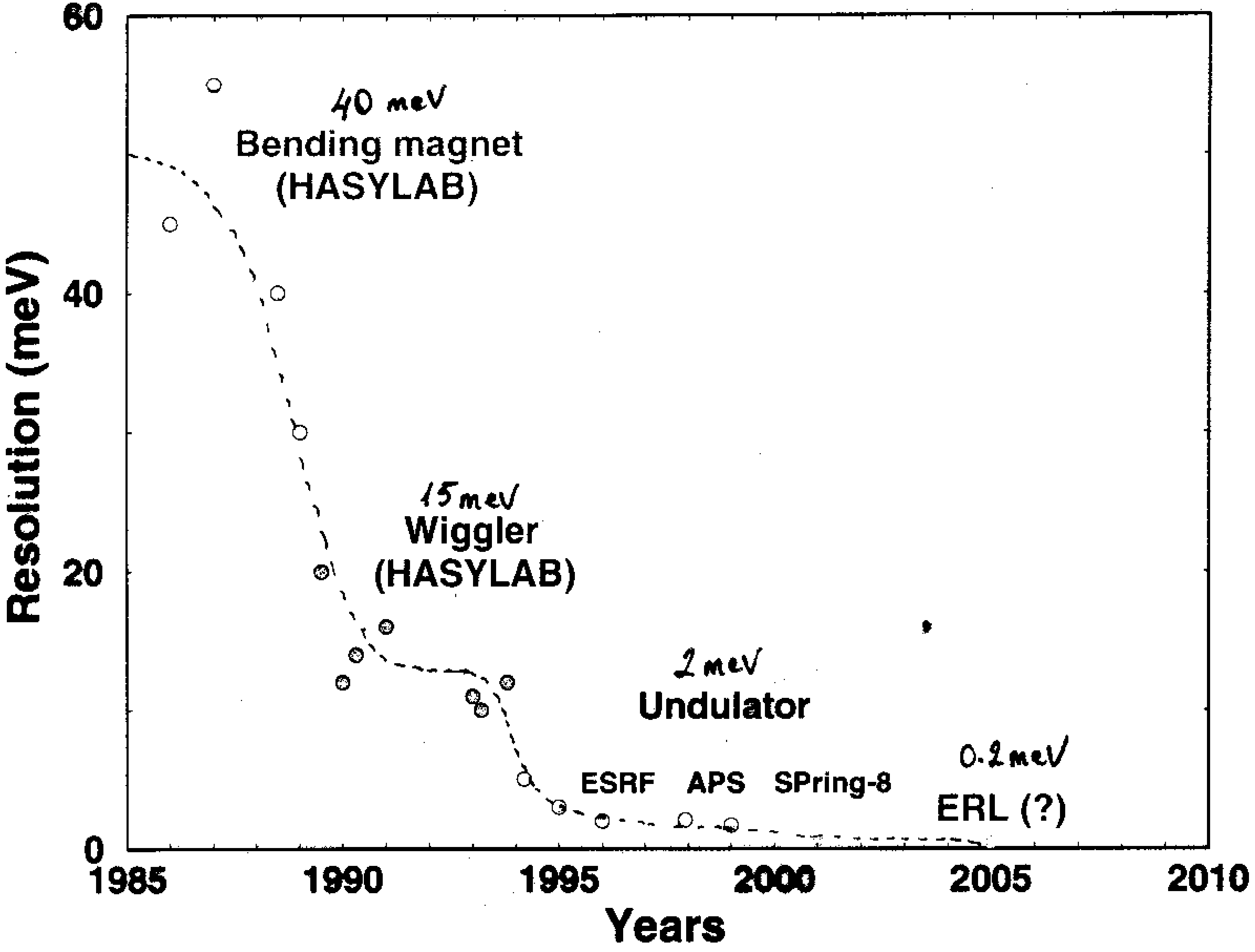
Lattice dynamics ➠ **PHONONS**

➠ **dispersion relations**
➠ **form factors**
➠ **density of states**

➠ **specific heat**
➠ **Debye temperature**
➠ **thermodynamics**

Inelastic X-Ray Scattering in the Synchrotron Era

source: E. Burkel, Rep. Prog. Phys. 63 (2000) 171, (modified)



Why Energy Recovery Linac?

* Flux,

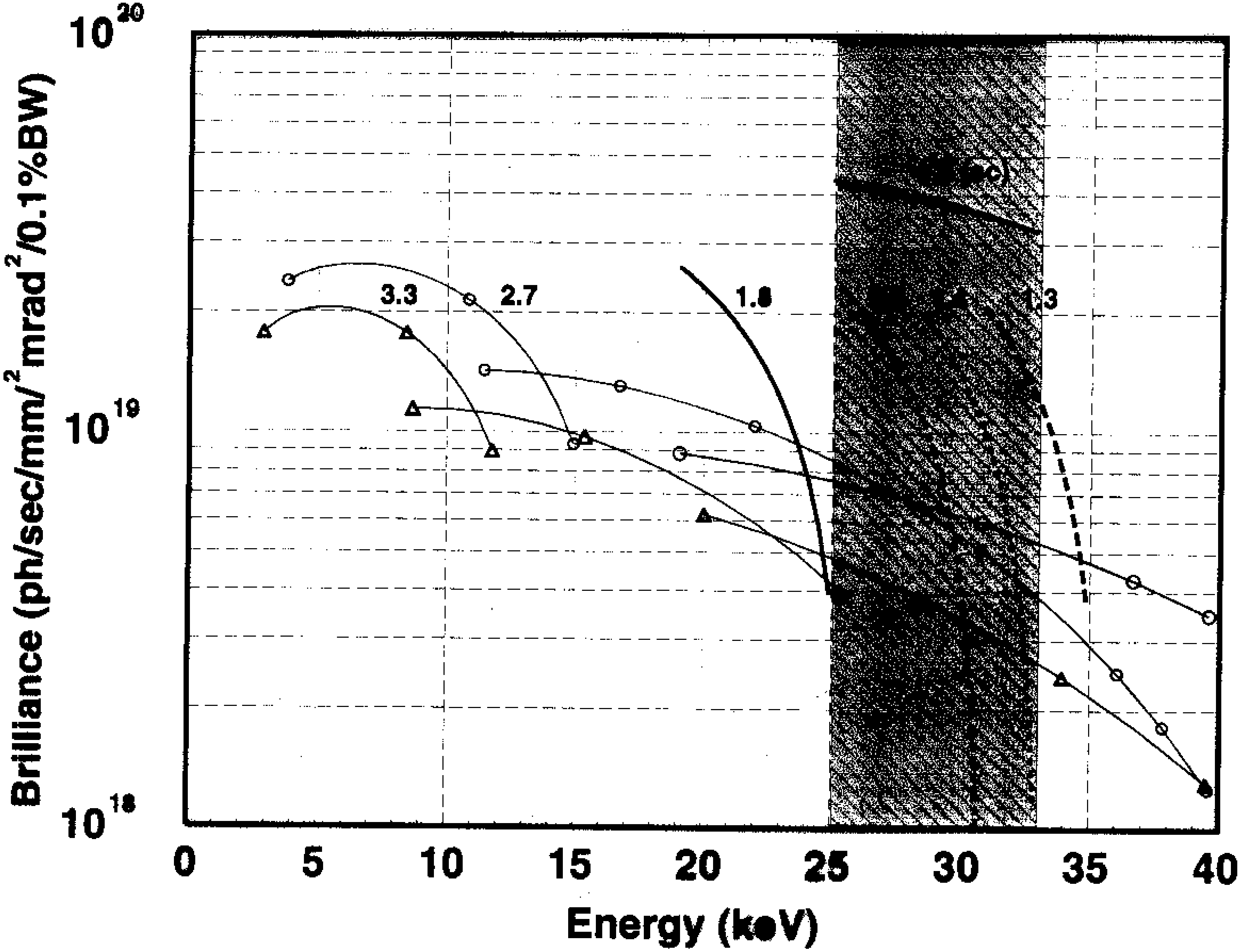
* Brilliance,

* High Energy X-Rays

* *Flux:*

better resolution,
difficult sample geometry,
thin films,
high pressure,
containerless liquids,
microfocusing applications.

Tunability range of the APS undulators with different periods



* *Brilliance*

High throughput monochromator at high energies,

Better resolution function

3rd generation machines in 2000 : $\Delta\theta = 8-12\,\mu rad$
What is needed @ 30 keV : $\Delta\theta \sim 2-4\,\mu rad$

} dictated by angular acceptance of high resolution monochromator

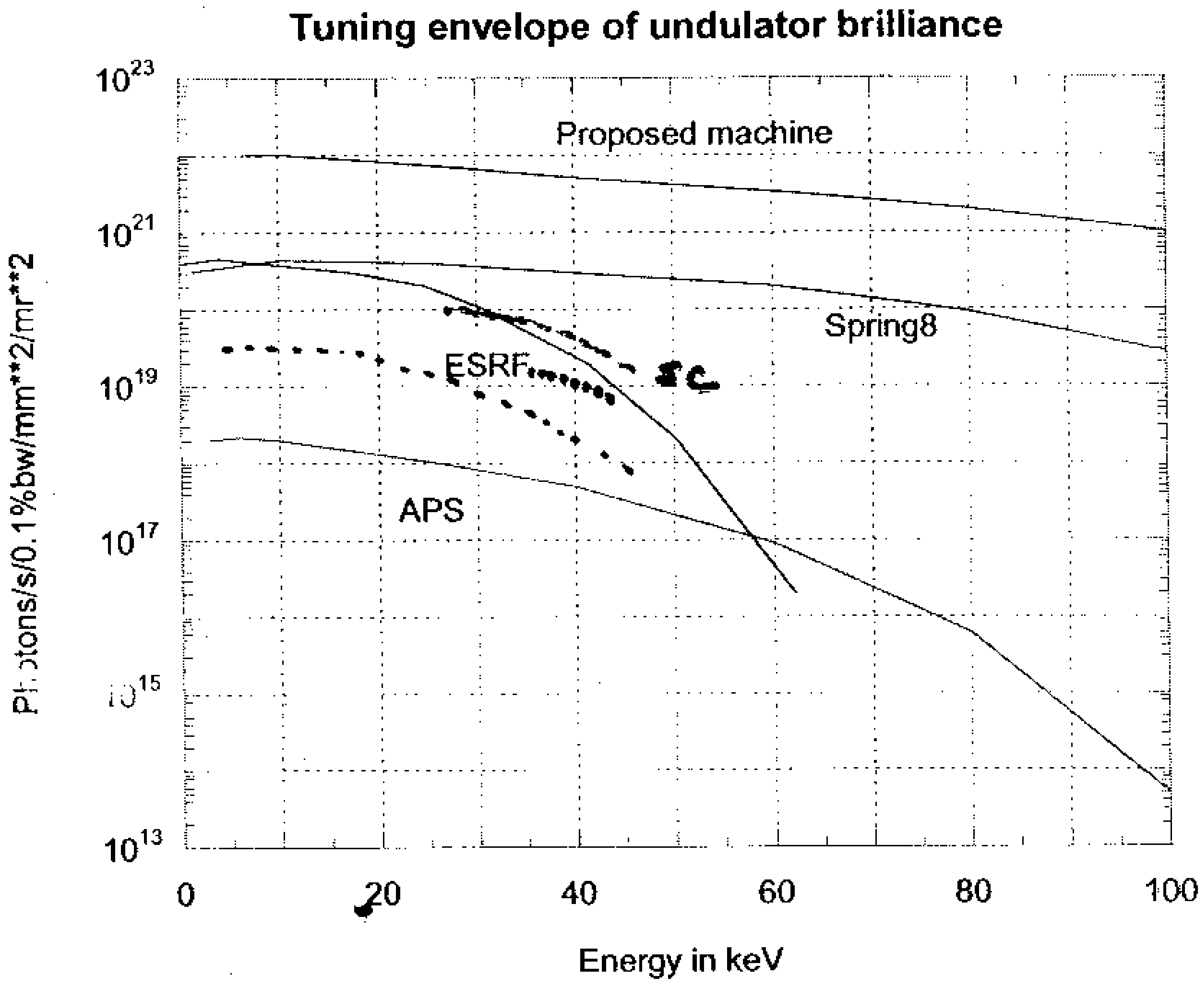


Figure 2. Tuning envelope of undulator brilliance for various undulator sources -- See explanation following the Tables. (Note: Per Dr. Dennis Mills, the peak APS brilliance value has been increased to 10^{19}, as given in Table 1, but not shown in this figure.)

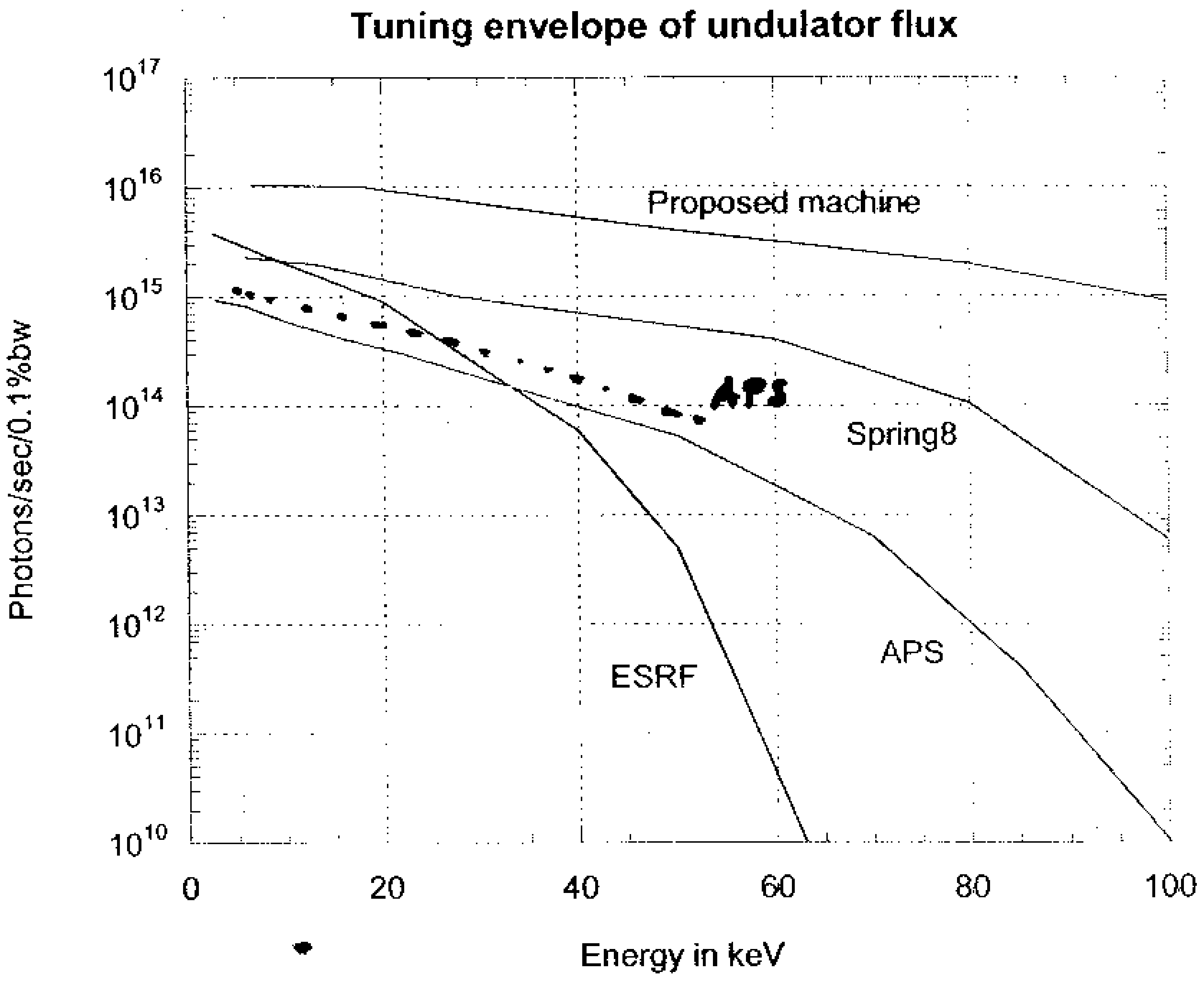
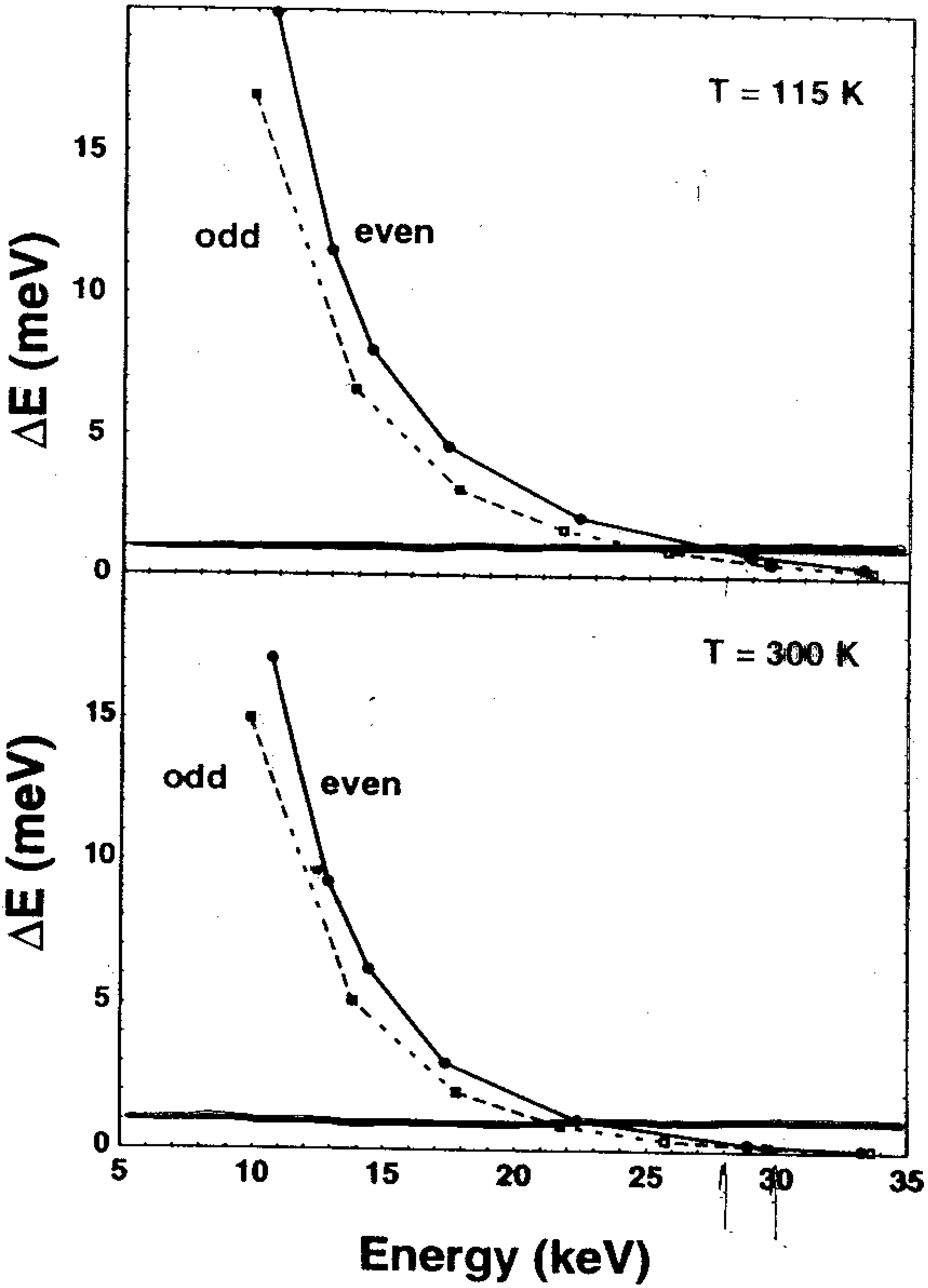


Figure 3. Tuning envelope of undulator flux for various undulator sources -- See explanation following the Tables.

Si back-scattering crystals intrinsic energy resolution



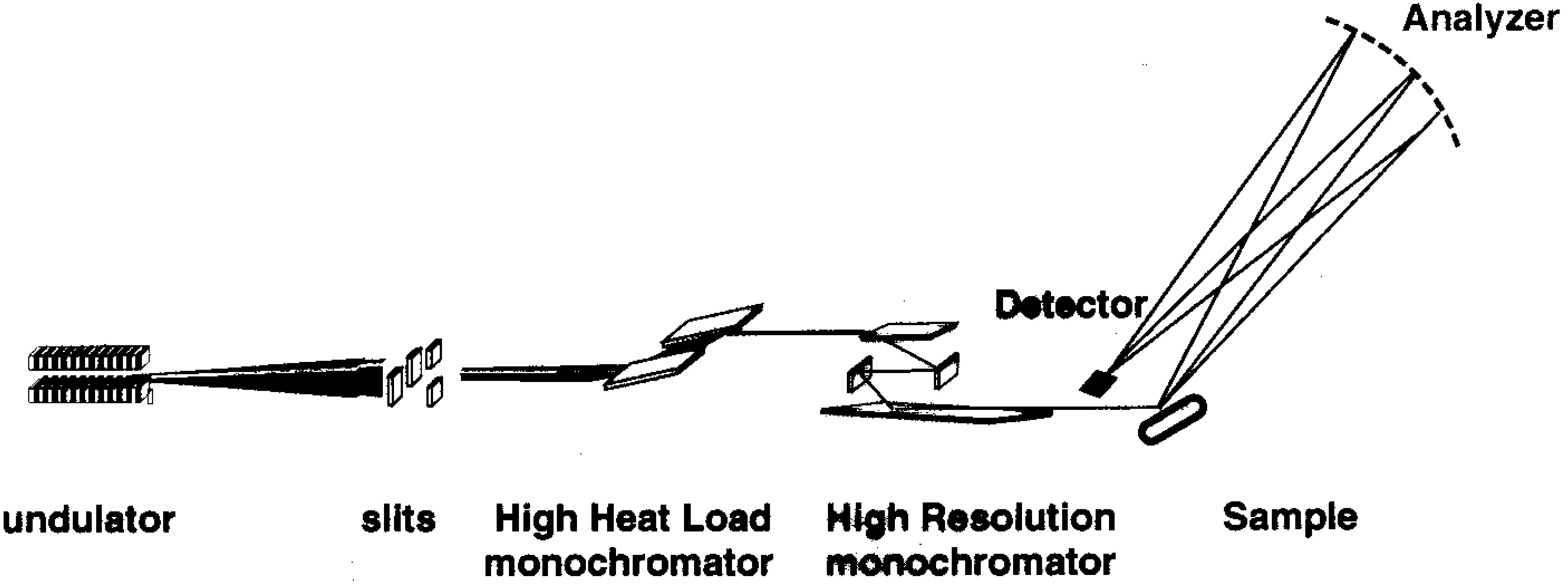
* *High Energy X-Rays*

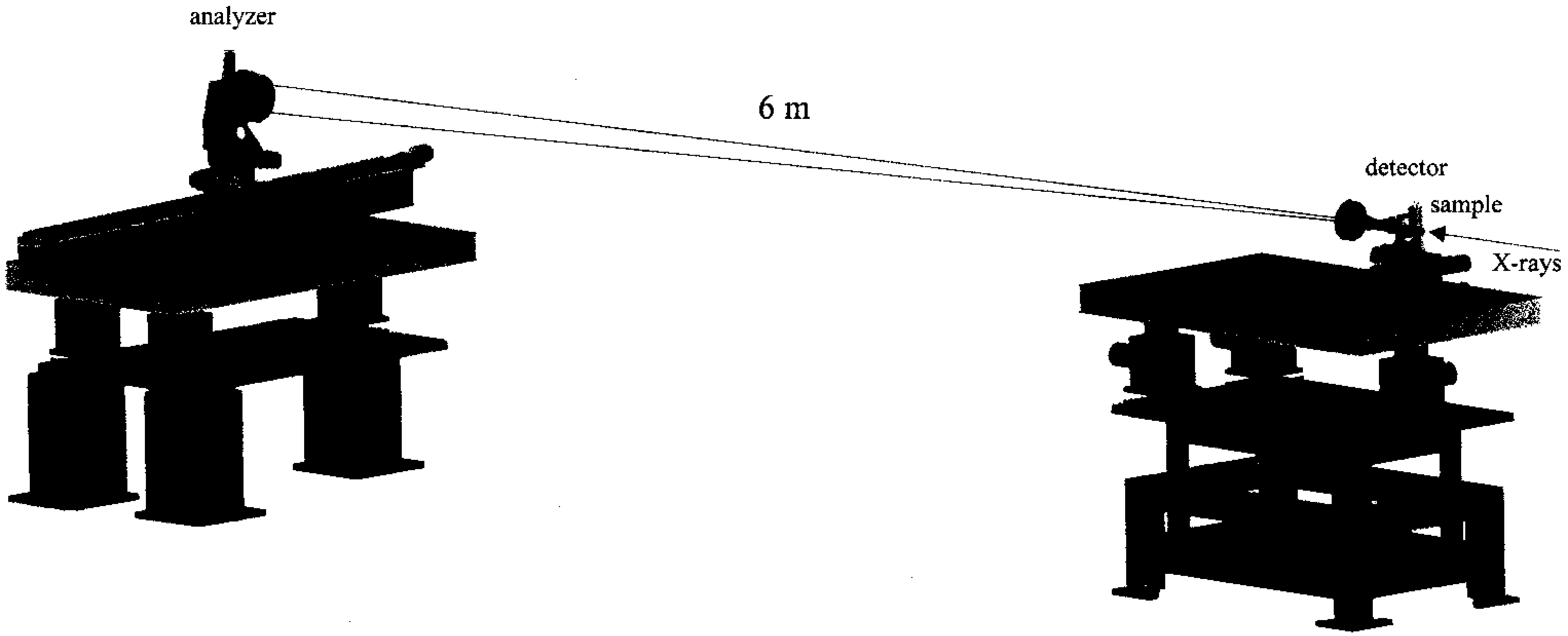
Sub-meV spectrometer,

Thicker samples,

Higher Z-elements accessible

Measuring Excitations with Inelastic X-ray Scattering





3-ID-C 6m-radius inelastic X-ray spectrometer

J. Barraza
9/20/99

Table 1. The relationship between incident energy E, temperature T, resolution ΔE, angular acceptance $\Delta\theta$, peak reflectivity R, extinction depth τ, absorption length l, and temperature stability $\Delta E/\Delta T$ for various reflections of Si at a fixed Bragg angle 89.98°, a practical value for today's instruments. The probable energy for a new sub-meV spectrometer are highlighted, both for odd and even reflections.

E (keV)	$h\ k\ l$	T (K)	ΔE (meV)	$\Delta\theta$ (μrad)	R	τ (μm)	l (μm)	$\Delta E/\Delta T$ (meV/10mK)
9.885	5 5 5	300	15.5	1,949	0.83	13	125	-0.25
9.888		120	17.6	1,933	0.86	12		0.00
13.839	7 7 7	300	5.1	1,202	0.80	41	335	-0.36
13.843		120	6.6	1,226	0.85	32		0.00
17.793	9 9 9	300	2.0	910	0.76	106	697	-0.46
17.798		120	3.0	953	0.84	70		0.00
21.747	11 11 11	300	0.85	117	0.70	250	1,244	-0.56
21.753		120	1.59	253	0.83	132		0.00
25.701	13 13 13	300	0.37	41	0.60	580	1,992	-0.66
25.708		120	0.88	102	0.82	241		0.01
29.655	**15 15 15**	**300**	**0.15**	**15**	**0.46**	**1,427**	**2,936**	**-0.76**
29.663		**120**	**0.48**	**47**	**0.79**	**442**		**0.01**
33.609	17 17 17	300	0.08	7	0.24	3,790	4,058	-0.86
33.618		120	0.25	21	0.79	842		0.01
14.438	12 4 0	300	6.2	1,167	0.86	34		-0.37
14.442		120	8.2	1,121	0.91	26	379	0.00
21.657	18 6 0	300	1.2	117	0.78	173		-0.56
21.663		120	2.3	852	0.89	92		0.00
28.876	**24 8 0**	**300**	**0.25**	**25**	**0.61**	**840**	**2,736**	**-0.74**
28.884		**120**	**0.76**	**78**	**0.85**	**277**		**0.01**
33.239	28 8 0	300	0.1	9	0.39	2,437	3,948	-0.85
33.248		120	0.38	33	0.81	560		0.01

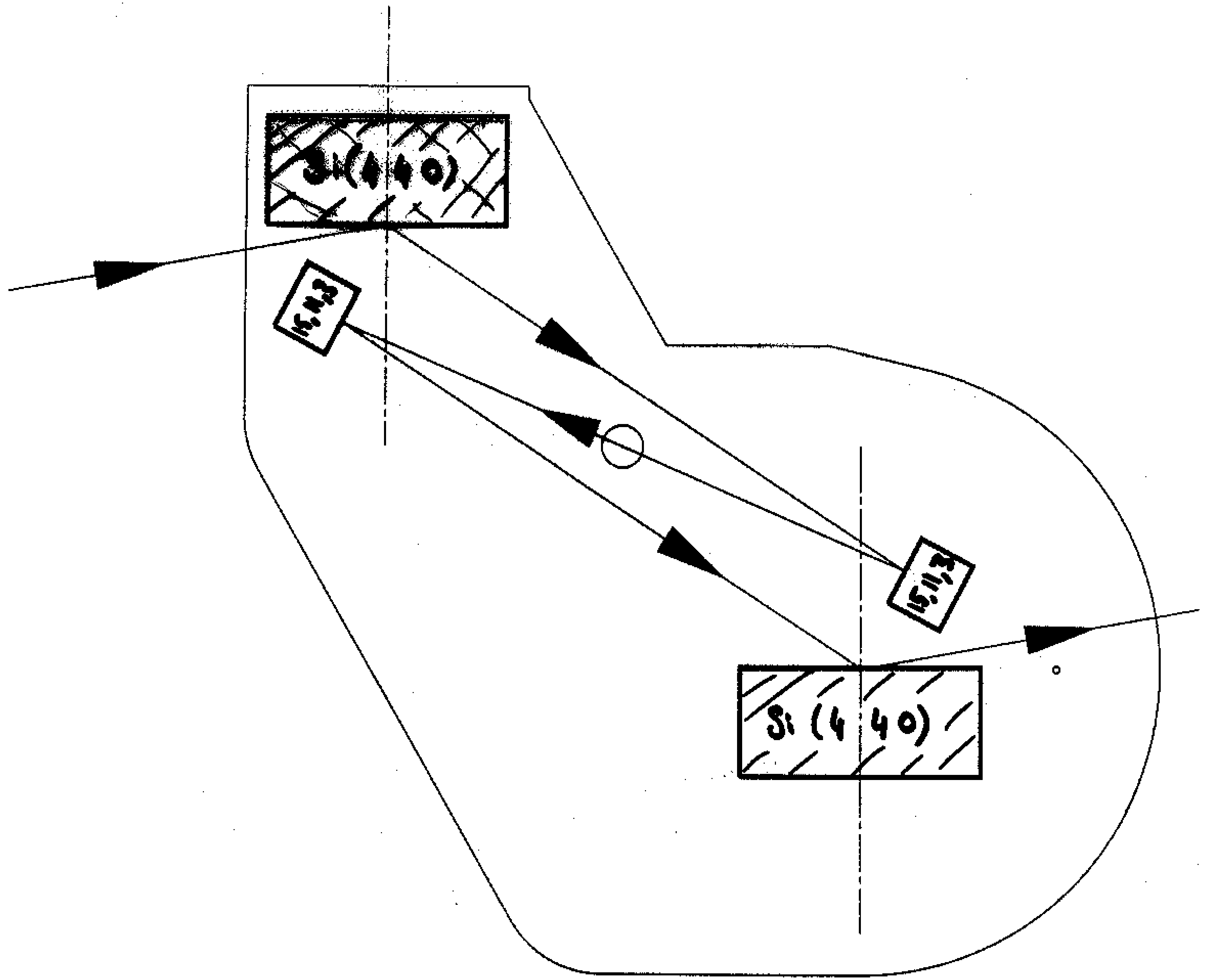


Fig. 3. Four Crystal Monochromator Using Artificial Channel-Cut Crystal

HIGH ENERGY RESOLUTION, HIGH ANGULAR ACCEPTANCE CRYSTAL MONOCHROMATOR

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ABSTRACT

The design principles, construction and characterization of a 4-bounce dispersive crystal monochromator is discussed. This monochromator is designed to reduce the bandpass of synchrotron radiation to 10-50 meV level, without sacrificing angular acceptance. This is achived by combining an asymmetrically-cut, low order reflection with a symmetrically-cut, high order reflection in a nested configuration. This monochromator is being used as a beam conditioner for nuclear resonant scattering of synchrotron radiation to produce x-rays with μeV-neV resolution in the hard x-ray regime.

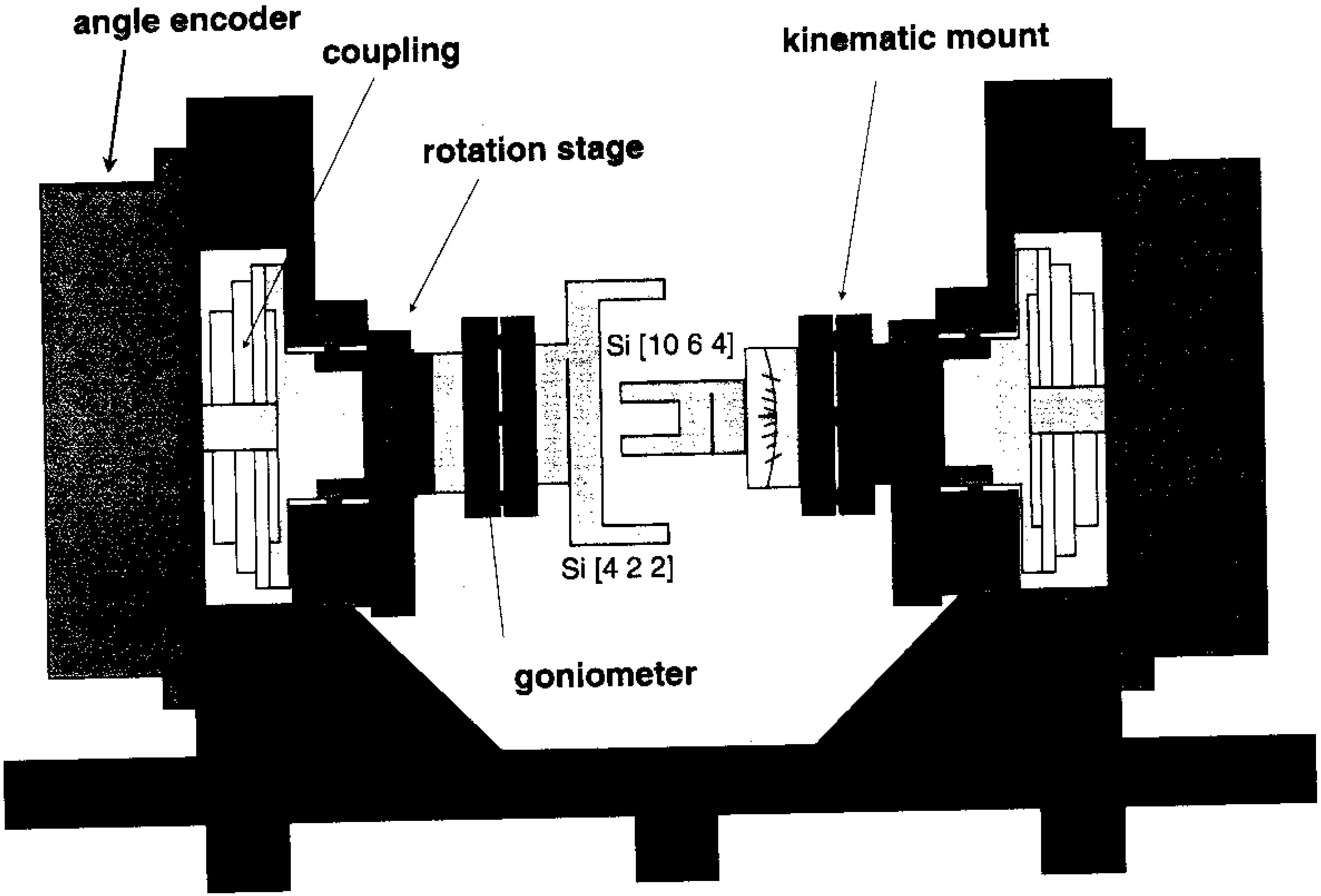
1. INTRODUCTION

Monochromatization of the hard x-ray component (5-30keV) of synchrotron radiation down to the ueV-neV level may be achieved via coherent nuclear resonant scattering. (1,2) This technique involves a nuclear resonant medium whose coherent response can produce an energy band-pass of μeV-to-neV. However, the nuclear resonant medium also has a non-resonant response (viz. Rayleigh scattering) which, if not suppressed, would normally overwhelm the detection system and lead to a prohibitively poor signal-to-noise ratio. Despite available techniques to suppress non-resonant scattering, it is extremely beneficial to reduce the energy bandpass of the x-ray beam as much as possible before it is incident on the nuclear resonant medium. After preliminary remarks, we present the design and testing of a high-resolution monochromator with large angular acceptance for the ^{57}Fe Moessbauer resonance (E=14.413keV). This monochromator, which is suitable for wiggler and undulator insertion devices, has a band-pass of 11 meV and an acceptance of 4.5 arcseconds.

2. APPROACH

The high brightness of undulators provide high flux in the resonant band-width in the form of a very low-divergence beam. This low divergence (vertical divergence ≈ 5 arcsec) makes high resolution ($\Delta E/E \approx 10^{-6}$) monochromatization in the hard x-ray regime with single-crystal silicon practicable. The reason for this is essentially that the beam divergence of these insertion devices approaches the Darwin width of single-crystal reflections. As a result, one can accept an appreciable fraction of the diverging x-rays in the resonant band-width.

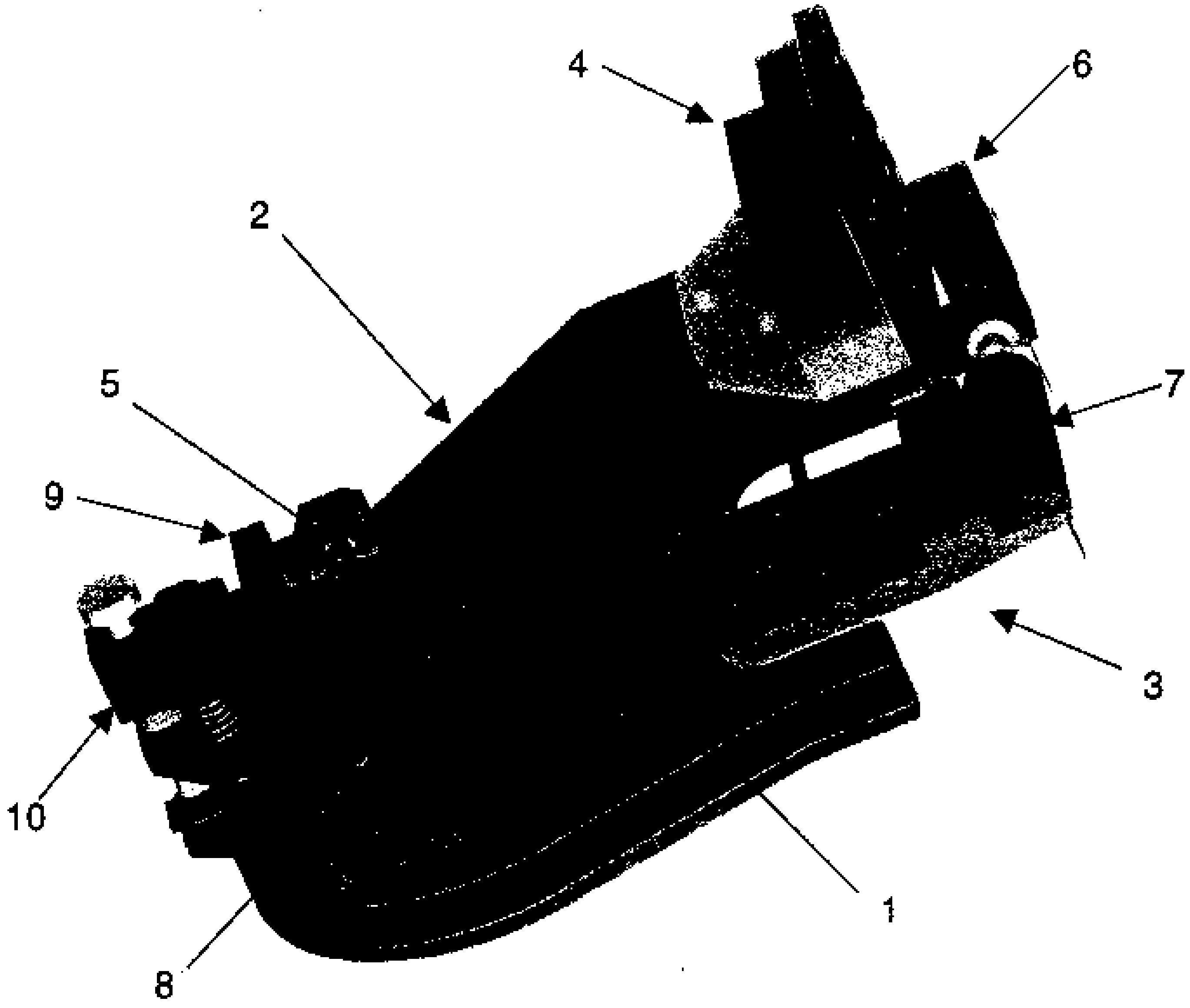
0-8194-0913-8/93/$4.00


angle encoder
coupling
rotation stage
kinematic mount
Si [10 6 4]
Si [4 2 2]
goniometer

Ultraprecision Motion Control Technique for High-Resolution X-ray Instrumentation

High-stiffness Weak-link Mechanism

- Structure Design

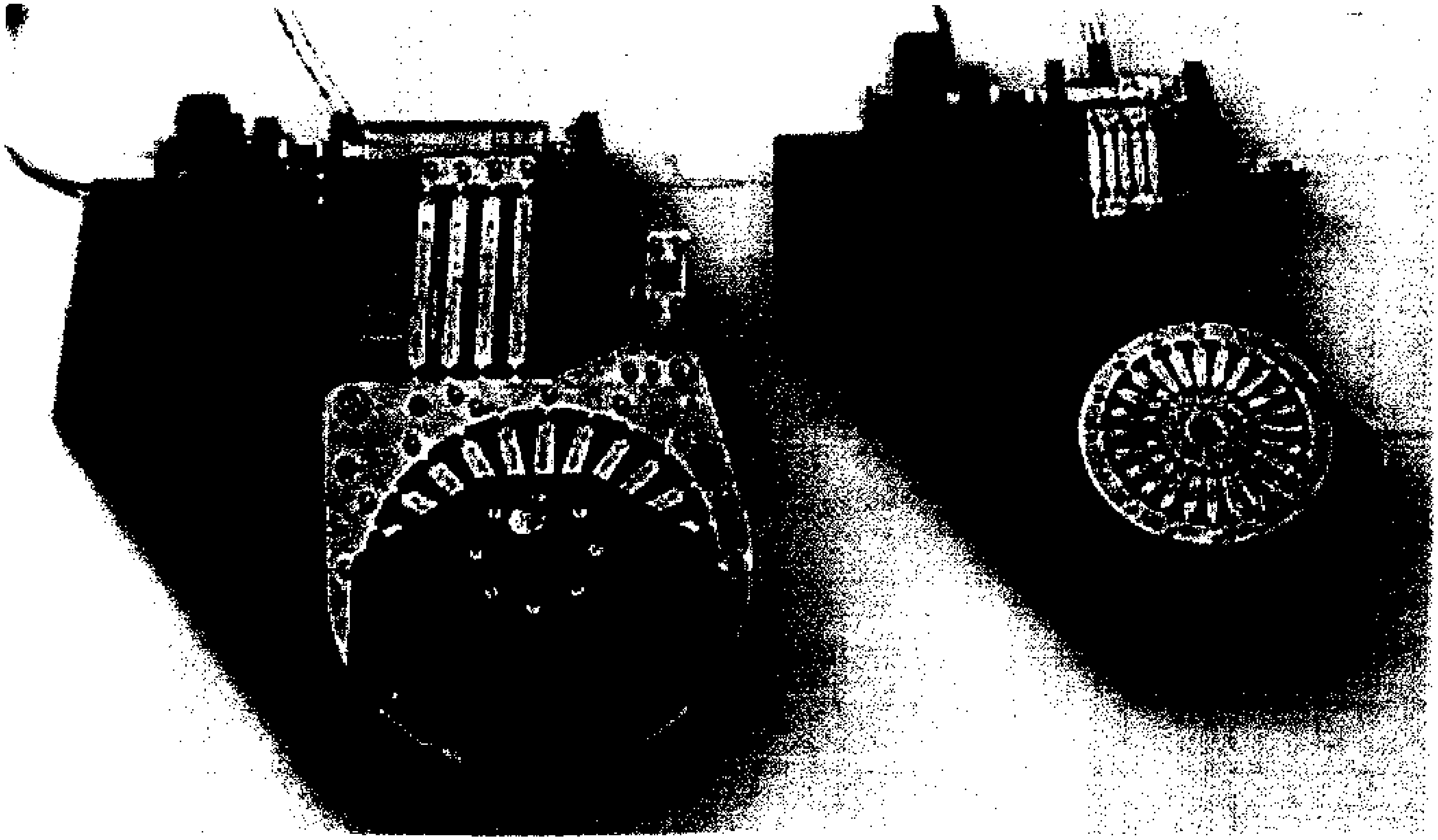


The base mechanism includes a compact sine-bar driving structure for the crystal pitch alignment, which is the key component of the whole mechanism. There are two groups of stacked thin metal weak-link structures (1) mounted on each side of the base plate (2). A sine-bar (3) is installed on the center of the planar rotary shaft for the pitch alignment between the two (4 4 0) single crystals (4, 5). Two linear drivers are mounted on the base plate serially to drive the sine-bar. The rough adjustment is performed by a Picomotor™ [10] (6) with a 20-nm to 30-nm step size. A Queensgate™ [11] closed-loop controlled PZT (7) with capacitance sensor provides 1-nm resolution for the pitch fine alignment.

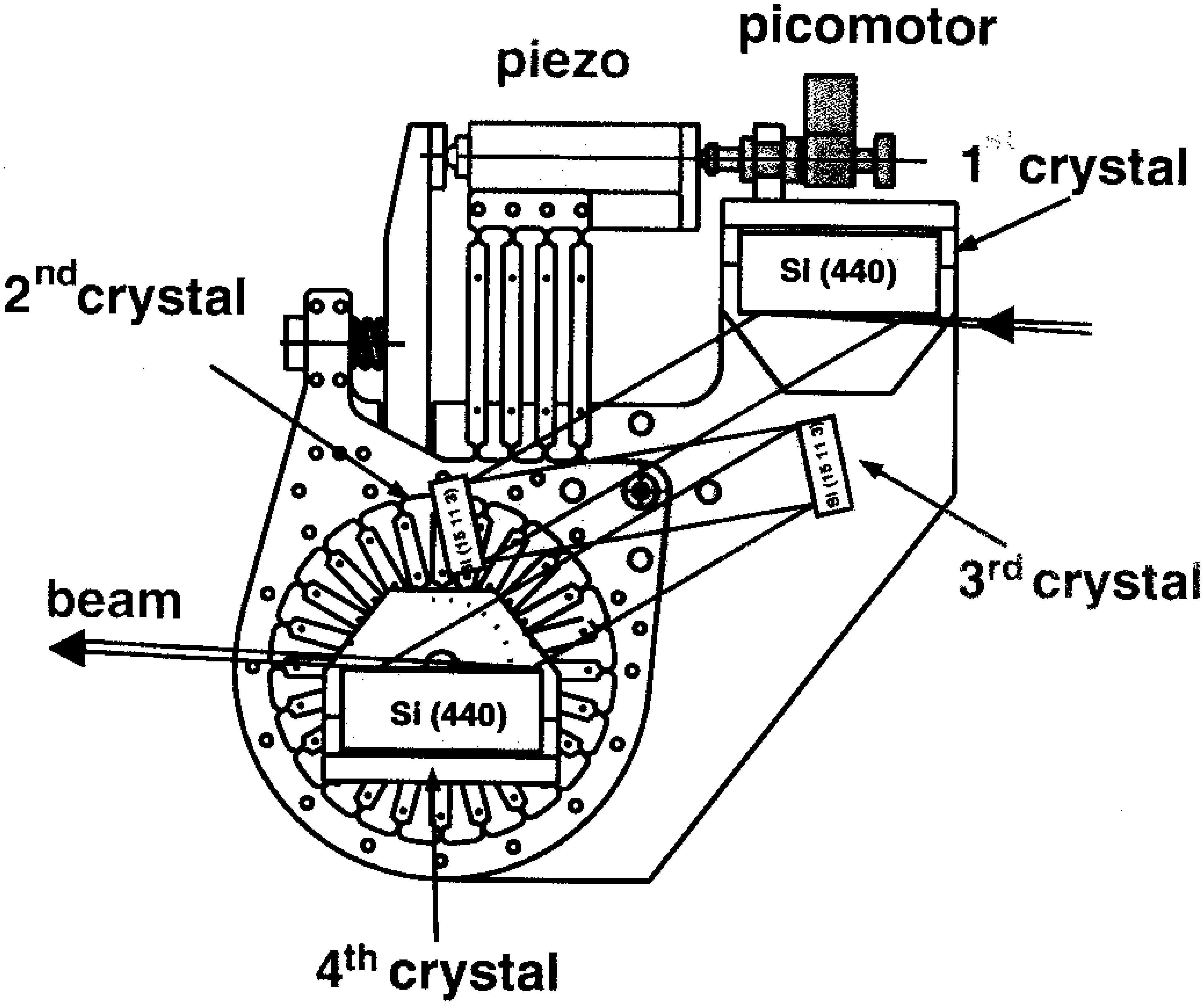
Ultraprecision Motion Control Technique for High-Resolution X-ray Instrumentation

Discussion and Conclusion

Photograph of the high-stiffness weak-link mechanisms. Left side is the first prototype of the overconstrained weak-link mechanism. Right side is a new prototype for a modular design

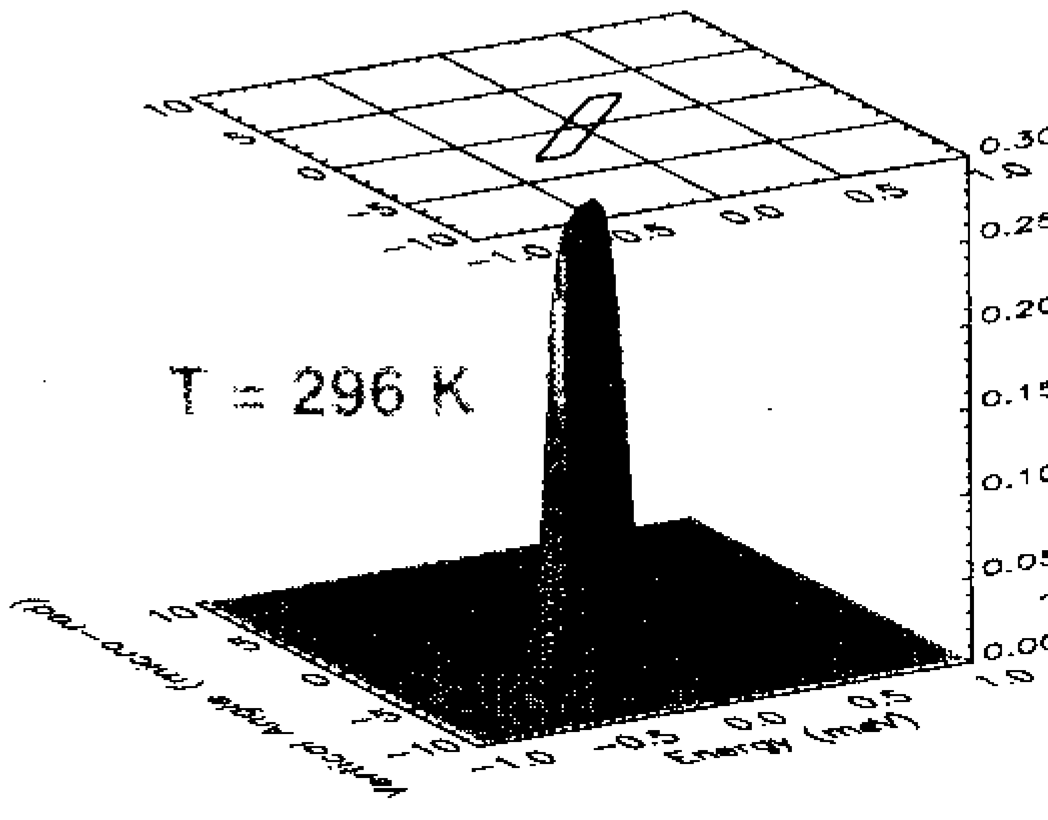


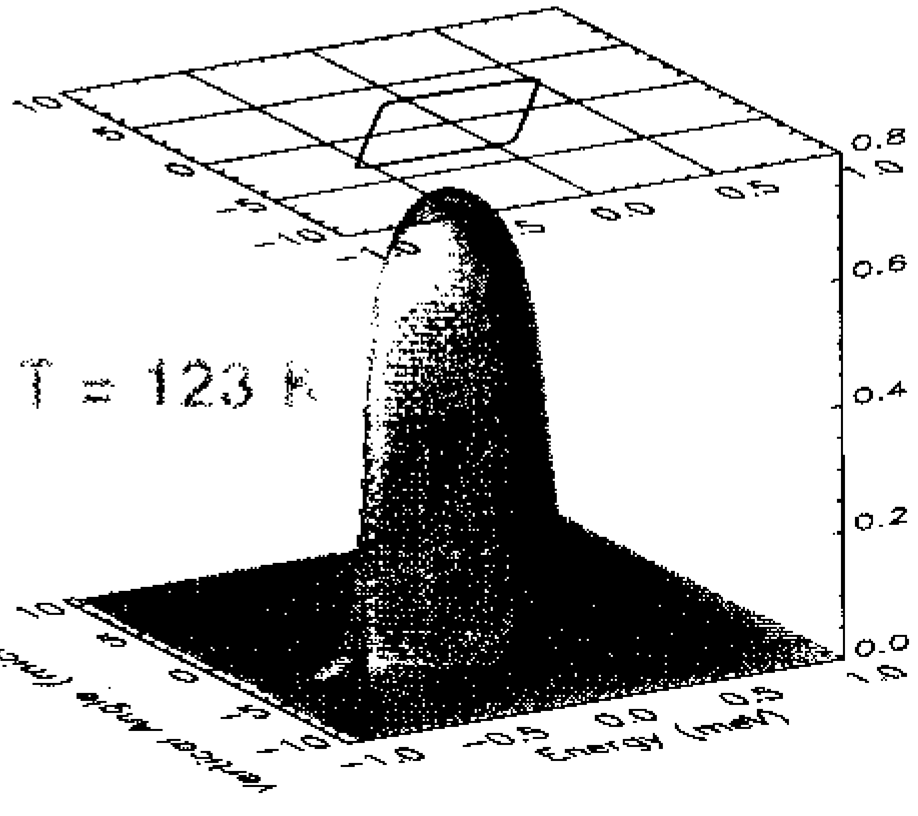
Artificial channel-cut monochromator

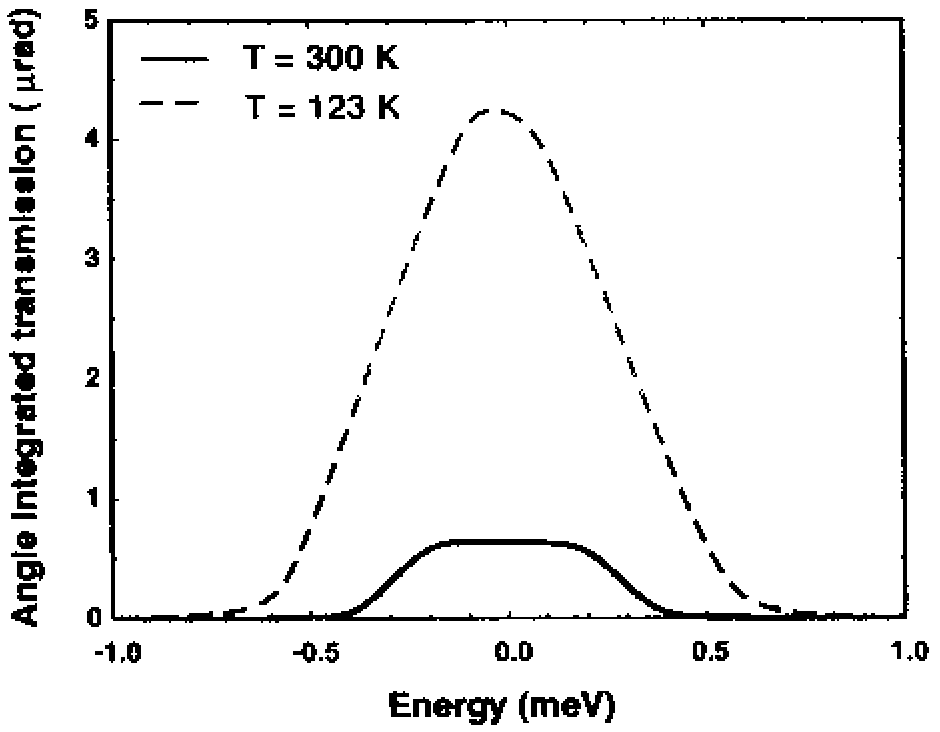


HERIX Monochromator

Si (4,4,4)-(20,16,4) @ 29.655 keV



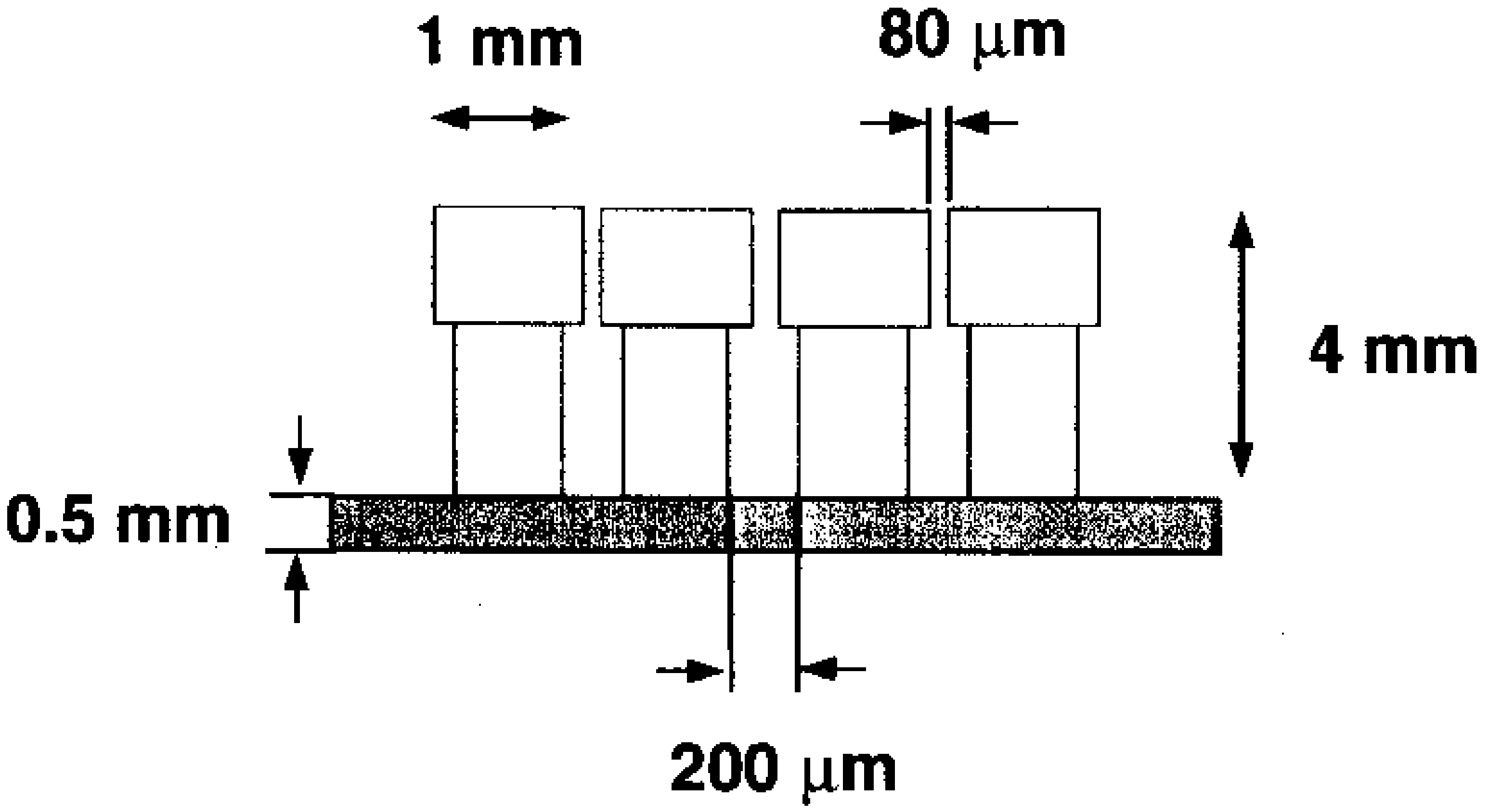




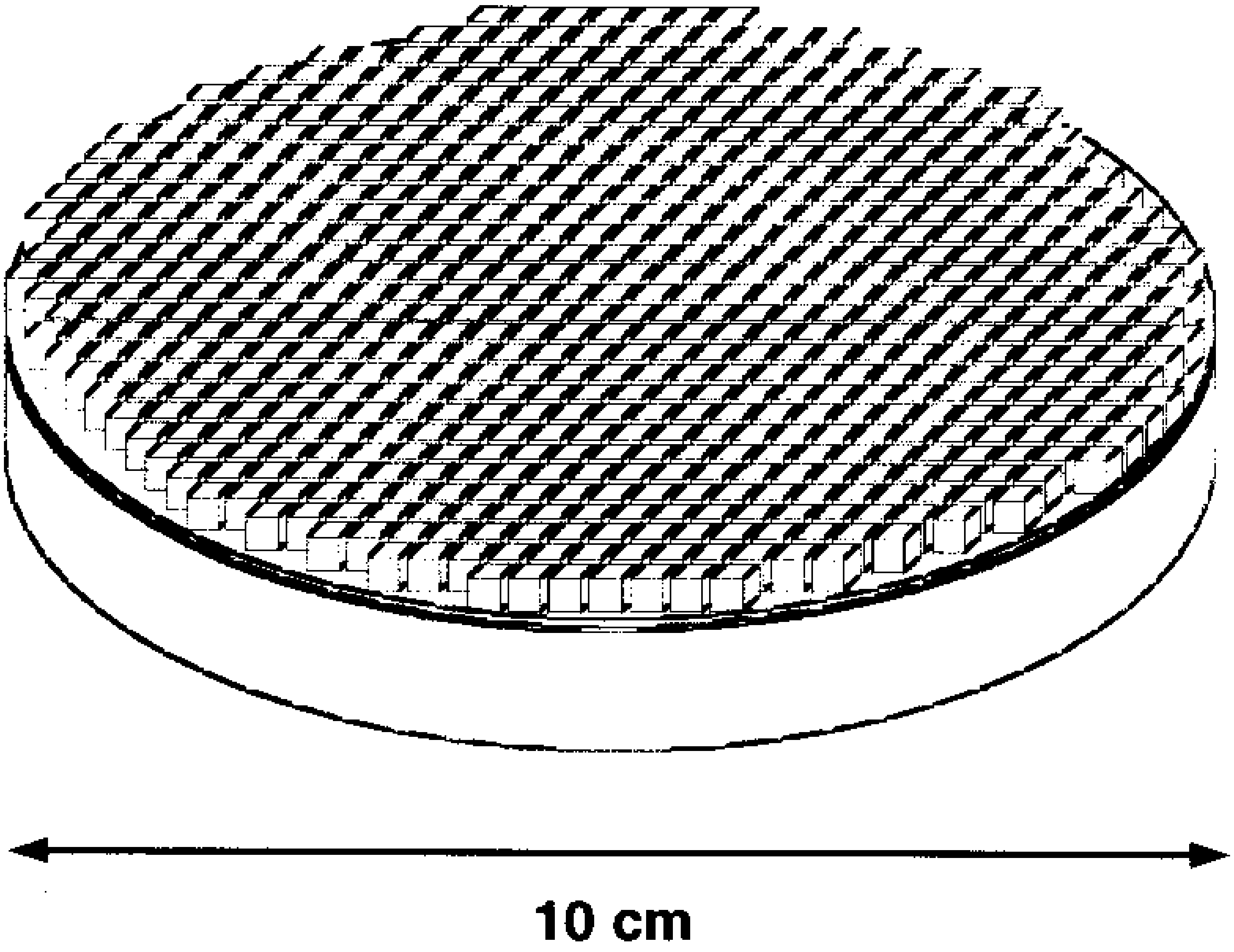
Temperature	ΔE (meV) (FWHM)	Flux (Hz)
296 K	**0.57**	**5.5×10^{8}**
123 K	**0.65**	**4.1×10^{9}**

Bent crystal analyzer for inelastic x-ray scattering with meV resolution

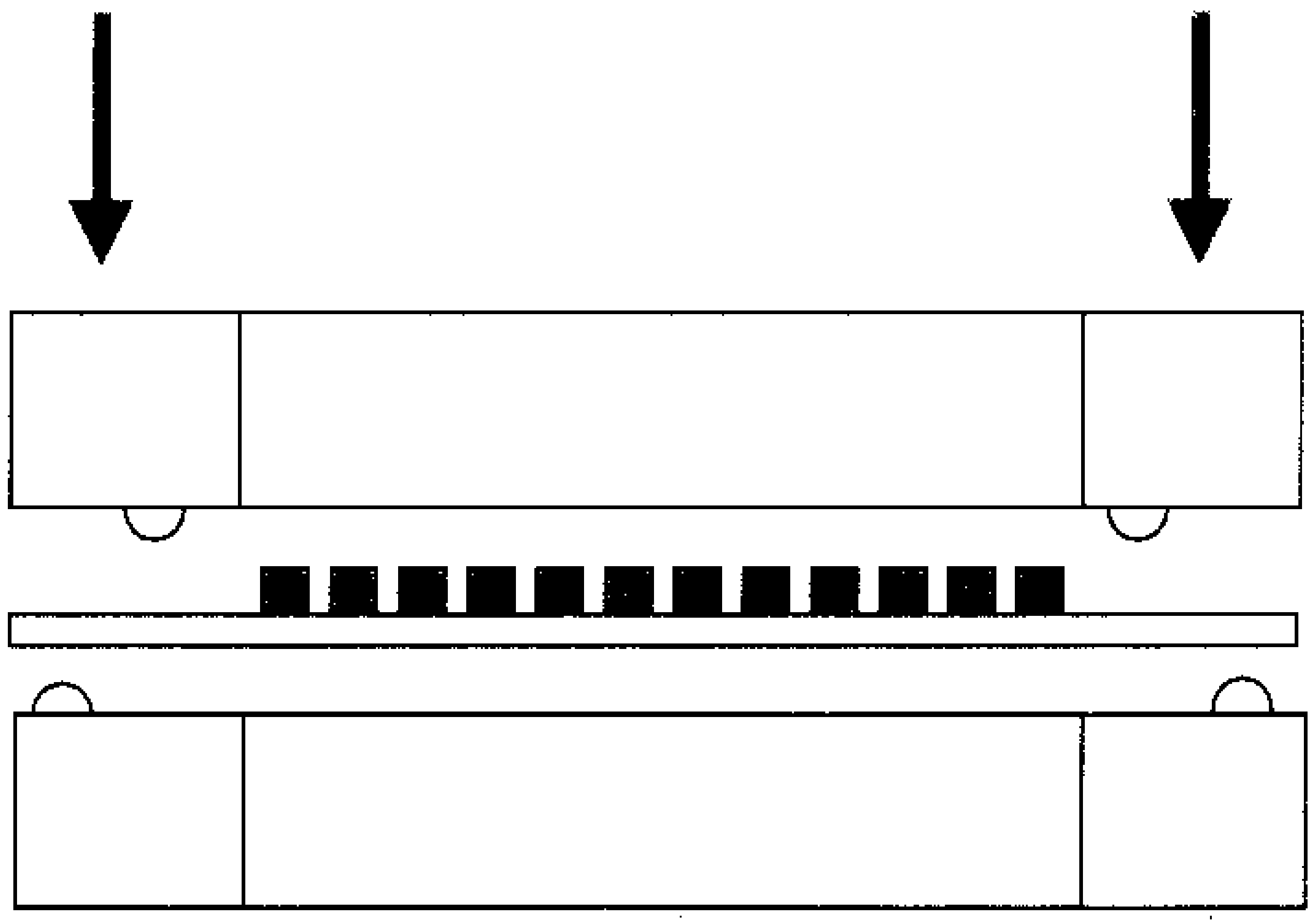
a.)



b.)



2 – dimensional bender



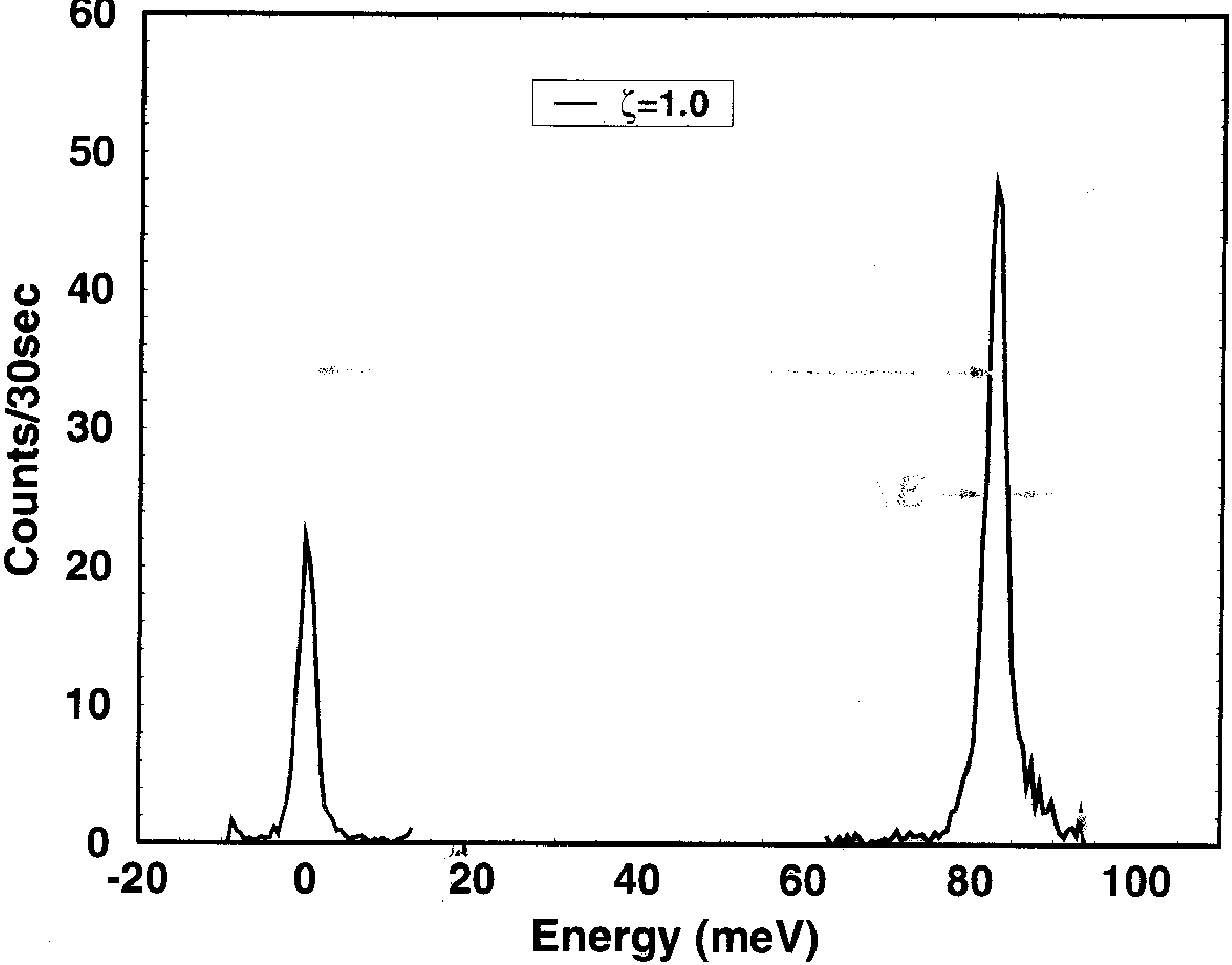
- Adjustable Radius
- Better figure
- Flexibility

H. Sinn (APS)

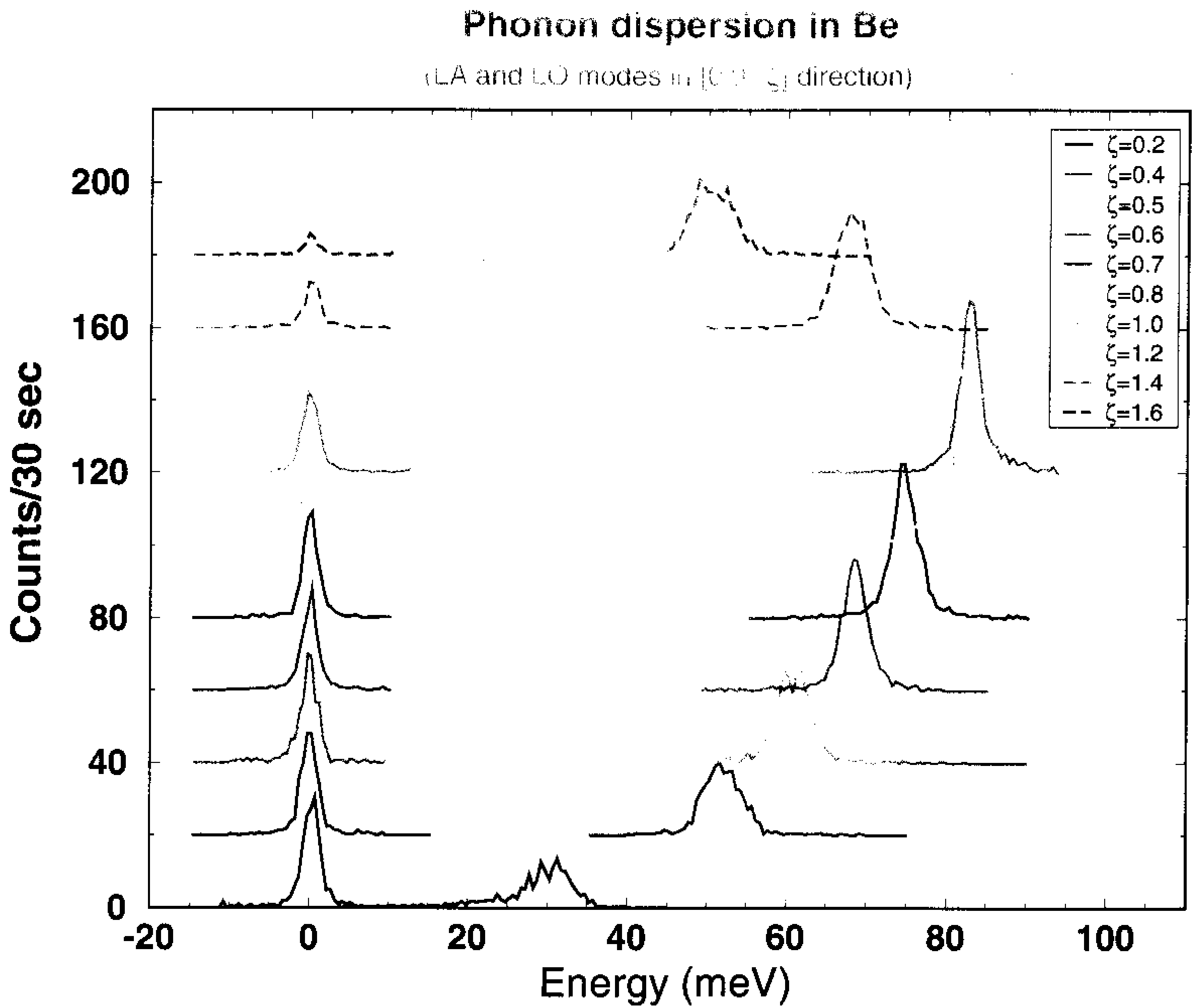
Y. Fujii et.al, SSRL Report (1982) p.145 : flat crystal bender

Energy scans in Be

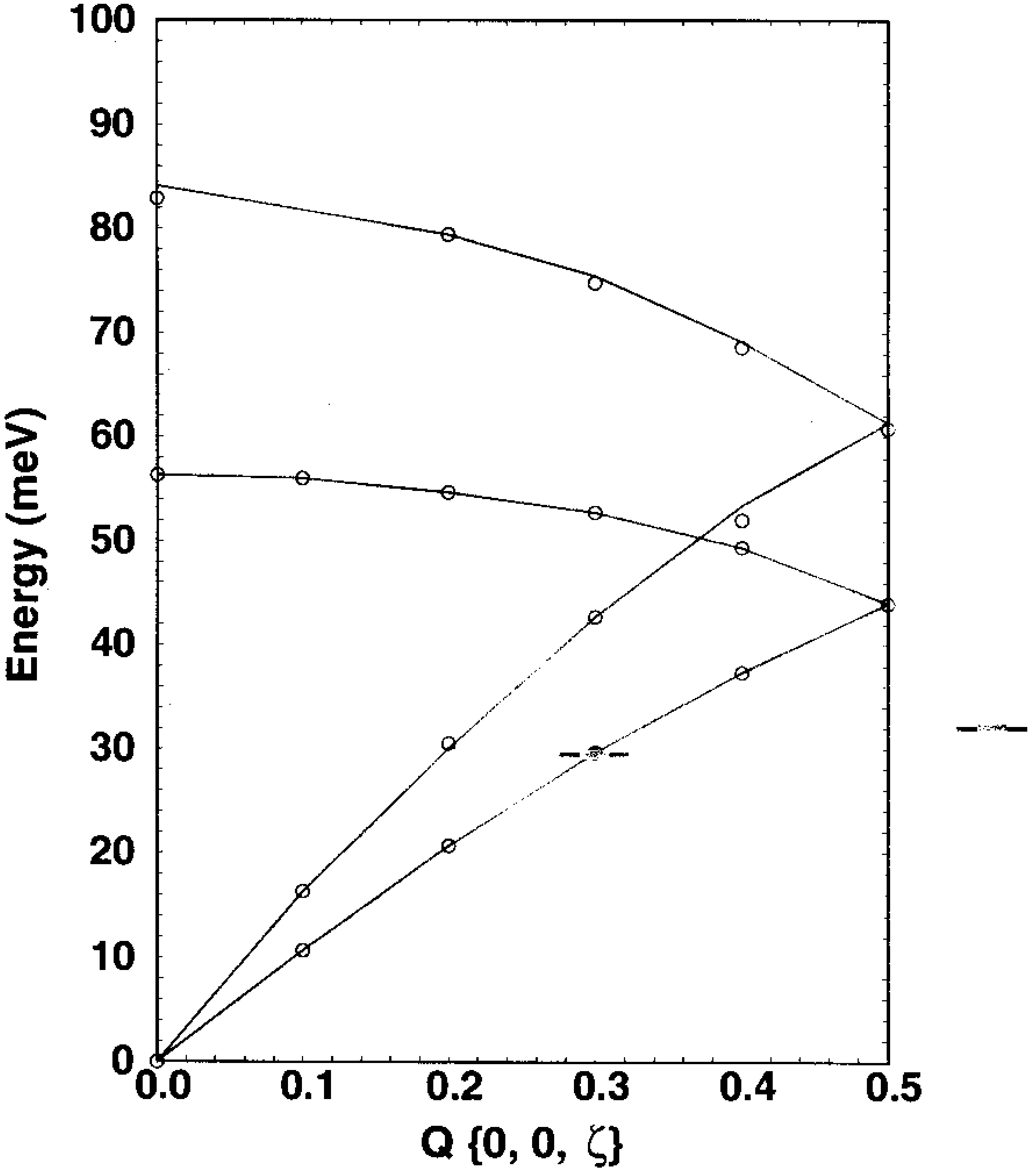
(LA and LO modes in [0 0 ζ] direction)



EEA/SINN/Be/SampleScan.ps


Phonon dispersion in Be
(LA and LO modes in [0 0 ζ] direction)
Counts/30 sec
0
40
80
120
160
200
-20
0
20
40
60
80
100
Energy (meV)
ζ=0.2
ζ=0.4
ζ=0.5
ζ=0.6
ζ=0.7
ζ=0.8
ζ=1.0
ζ=1.2
ζ=1.4
ζ=1.6

Dispersion relation in Be for logitudinal and transverse modes along {0,0, ζ) direction



EEA/SINN/Be/Dispersion.ps

Figure-of-merit

$$\frac{\text{counts / sec}}{\text{energy bandpass}} = \text{Hz / meV}$$

measured at $S(q = 1\,\text{Å}^{-1}, \omega = 0)$ for plexiglass

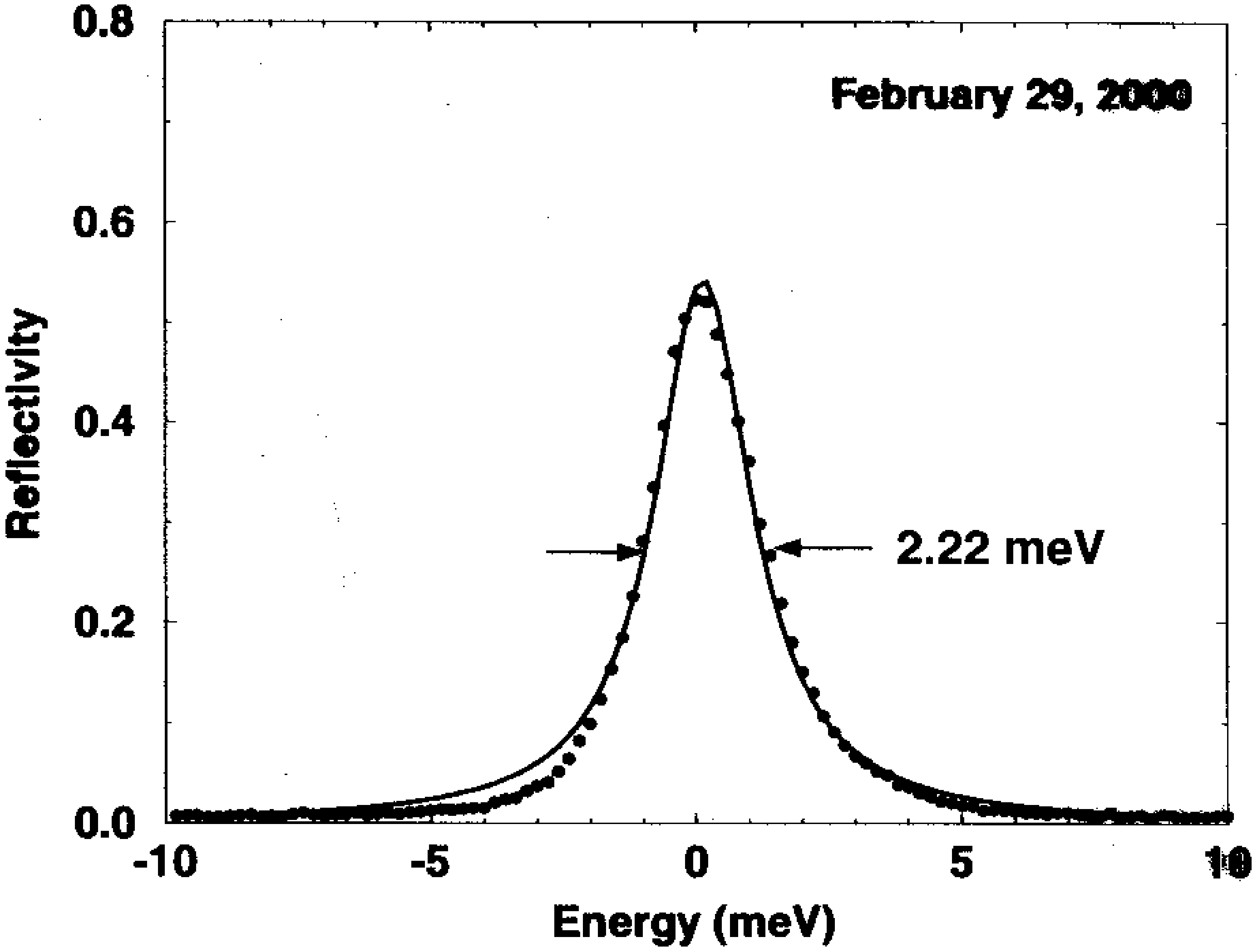
Today : 500 Hz / meV ($\Delta E = 2$ meV)

Goal : 10,000 Hz / meV ($\Delta E < 1$ meV)

What is possible @ ERL ? $\boxed{50{,}000 \text{ Hz} / 0.2 \text{ meV}^{*}}$

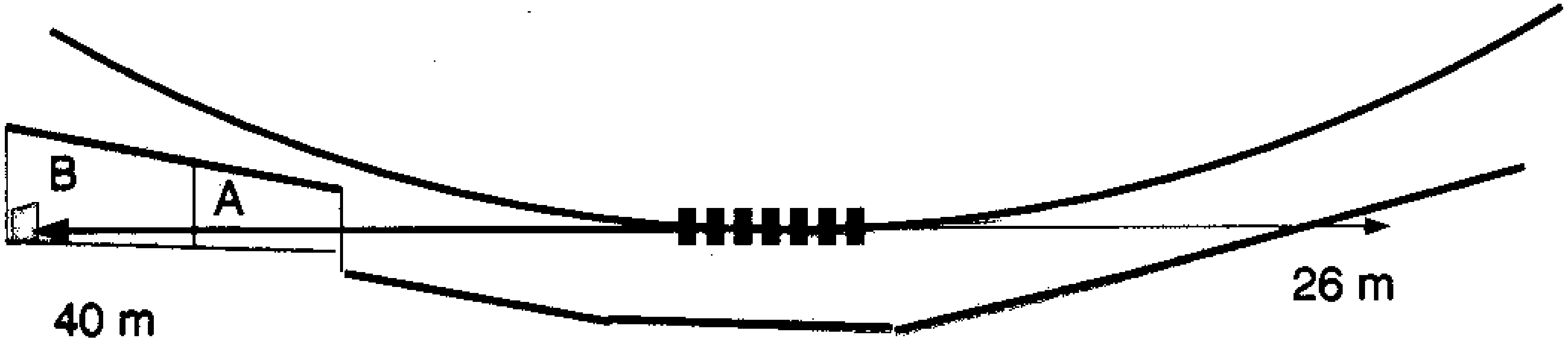
(*) in combination with improvements in cryogenically cooled monochromaters, dynamically bent analyzers, and, of course source improvements.

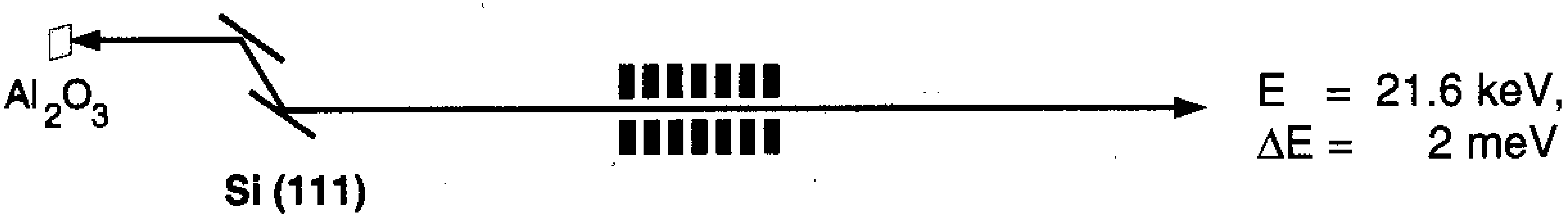
The energy response of Al2O3 (1 1 45) reflection at E= 21630.6 eV measured at exact back-scattering geometry

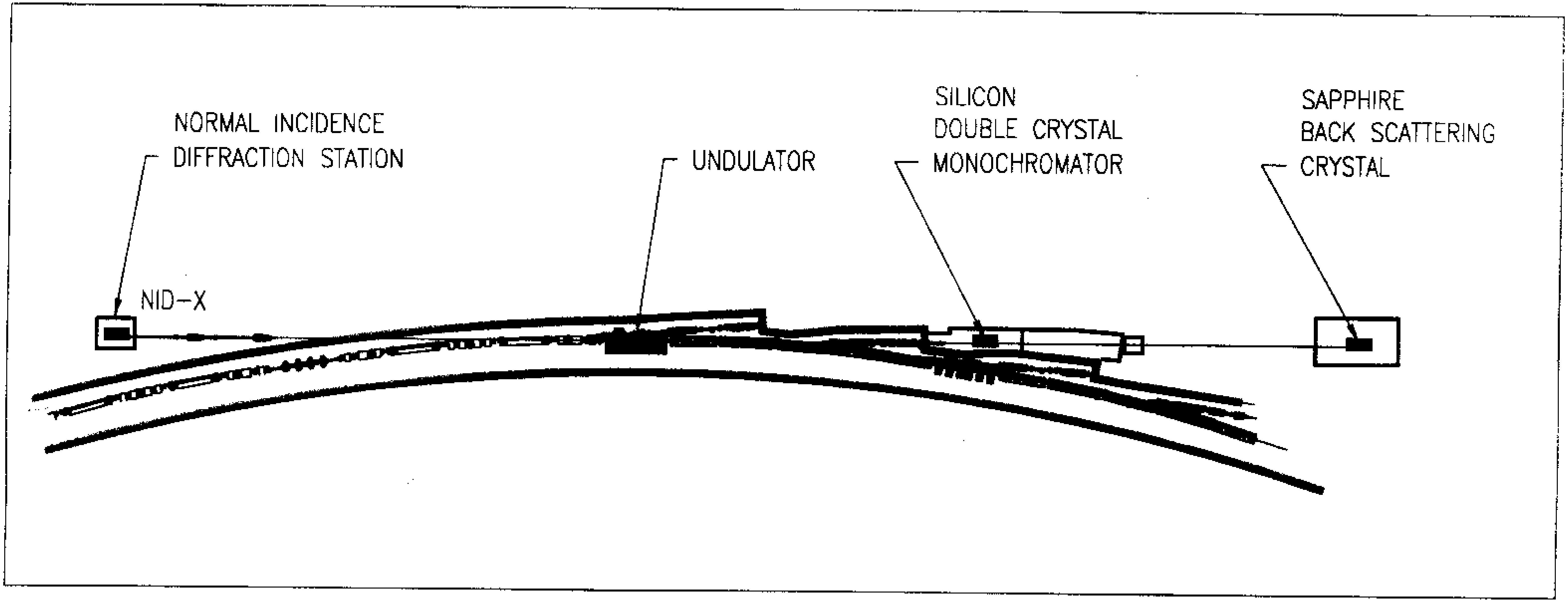


scan # 360, Ercan 2, C61 crystal

Proposed experiment at 1-ID for September 2000






NORMAL INCIDENCE
DIFFRACTION STATION
NID-X
UNDULATOR
SILICON
DOUBLE CRYSTAL
MONOCHROMATOR
SAPPHIRE
BACK SCATTERING
CRYSTAL

First beam in the
Normal Incidence Diffraction Beamline, NID-X
3:10 am, October 1, 2000

E. Ercan Alp

Yuri Shvyd'ko

John P. Sutter

Wolfgang Sturhahn

Harald S

John B Stoffel

Deming Shu

John Wright

S.D. Shastri

Yong ZHAO

Dean R. Haeffner

Kurt Goetze

Nick Friedman

Jack Harbeson