# ASDEX Johann Spectrometer

Status Report

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IPP III/127 November 1987

**MAX-PLANCK-INSTITUT FÜR PLASMAPHYSIK**

**8046 GARCHING BEI MÜNCHEN**

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*Die nachstehende Arbeit wurde im Rahmen des Vertrages zwischen dem Max-Planck-Institut für Plasmaphysik und der Europäischen Atomgemeinschaft über die Zusammenarbeit auf dem Gebiete der Plasmaphysik durchgeführt.*

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## INTRODUCTION

A Johann spectrometer is a curved crystal instrument whereby X-ray photons are focused by a crystal onto a position sensitive detector. The geometrical relationship betwen the slit, the crystal and the detector is a circle known as the Rowland circle /1/, see Figure 1. Focusing is achieved by bending the crystal such that its radius of curvature is equal to the diameter of the circle. There are many spectrographic devices which utilize the Rowland arrangement, such as the grazing incidence grating spectrographs, to enhance instrument photon collection efficiency. In a Johann arrangement, however, a physical slit at the entrance to the spectrometer is not required, being replaced by a "virtual" slit determined by the dispersion properties of a crystal. Crystal dispersion is given by the well known Bragg law

$$2d \cdot \sin(\theta) = m\lambda$$

where d is the spacing of the crystal dispersion planes, $\theta$ is the photon angle of incidence with wavelength $\lambda$ and m is the diffraction order (m=1, 2 etc.). As a consequence of Eq. 1, the angular range, $\Delta\theta$, over which the Bragg condition can be satisfied is $\Delta\theta = \tan\theta \cdot \Delta\lambda/\lambda$. The factor $\lambda/\Delta\lambda$ is the resolving power of a crystal ~20.000 or more for quartz in the soft X-ray region. Thus the nominal virtual slit width for a R = 1500 mm spectrometer is about 100 µm at $\theta_B \sim 60^o$ (effective slit width $\sim R \cdot \tan\theta \cdot \sin\theta \cdot \Delta\lambda/\lambda$). This also places an upper limit on the detector position resolution for optimal results to about 100 µm.

## CRYSTAL HOLDER

The heart of a Johann spectrometer is the bend crystal. A uniform curvature over the entire collecting area of the crystal must be achieved for proper focusing. Many bending techniques have been used for Johann spectrometers on tokamaks, such as four bar bending /2/, vacuum holders /3/, /4/.

On ASDEX, crystal bending is achieved by pressing a flat 0.5 mm x 10 mm x 70 mm crystal between two accurately machined holders to a radius of 1500 mm (see Fig. 2). The concave and convex curvatures on the stainless steel crystal holders (here called ASDEX holders) were made with computer controlled milling process followed by hand polishing to mirror-like finish. Accurate contact measurements of the final holders revealed that the radius of curvature has not being maintained over the entire range of the crystal collecting area (see Fig. 3). Deviations of ±15 mm from the desired radius of curvature exist for the outer portion of the holder. Testing in the optical (using He/Ne laser) with aluminized crystals have revealed structures in the focal spot related to the nonuniform radius of curvature.

An attempt was made to obtain the best possible finish without resorting to hand polishing. R. Rhorer and E. Baumgartner of the Los Alamos MEC-6 group have micromachined (commonly called diamond turned) two complete aluminium holder units for testing purposes. The concave and convex curvatures were made by computer controlled fly-cutting technique with diamond tools.

The focusing quality of the curved crystals was first evaluated in the visible by an arrangement similar to the schematic of Figure 1. A R=1500 mm near normal incidence (~85°) Rowland circle assembly with point light source (He-Ne laser light focused to about 50 µm by a microscope objective), aluminized bend crystal (<1000 Å Al), and a translational exit slit (~4 µm) were set up on a test bench. The "best focus" was obtained by adjustments of the R parameter to obtain the narrowest line focus. Actual recordings were made by scanning the slit/photomultiplier assembly across the image. Figure 4 shows the results for three different holders for the full 50 mm crystal collection length. The evaluated assemblies are the Los Alamos micromachined aluminium holder with QZ 203 crystal (LANL 1), stainless holder with Si111 crystal (ASDEX 10) and stainless holder with LiF 220 (ASDEX 9). It should be noted that the stainless holders have been hand-polished for the final finish while the Los Alamos holders were not.

The micromachined holders have clearly produced superior focusing qualities than the hand-polished holders (see Figure 4). Both the LiF220 and Si111 crystals have problems in maintaining a proper radius of cur vature. On the other hand, an aluminized quartz crystal was not available during the measurements shown here. We would like to explore the focusing properties of different types at crystals in the near future.

In X-ray diffraction, the Bragg condition must be adhered to and hence the allowed deviation from the Bragg angle is about ~3.3x10$^{-2}$ degrees for a good quartz crystal. This range is indicated by the small arrows in Figure 4. Therefore only a small portion of the bend crystal can satisfy the diffraction condition. We have estimated this to be about 65% of the LANL2 crystal length and considerable less for the ASDEX holders (~10% - 20%). The estimates were made by masking the outer portions of the crystal during optical evaluation while maintaining the same central peak value.

A summary of the measured FWHM for the optical test is given below. The theoretical limit should be about 50 μm (the estimated spot size):

BEST FOCAL SPOT (visible)

| Crystal | Holder | FWHM (full length) | FWHM (central 1/3) | R |
|---|---|---|---|---|
| Si 111 | ASDEX 10 | 100 μm$^{+}$ | 100 μm | 1480 mm |
| LiF 220 | ASDEX 9 | 160 μm$^{++}$ | 160 μm | 1480 mm |
| Qz 203 | LANL 1 | 70 μm | 70 μm | 1513 mm |

$^{+}$ best of the serrated peaks

$^{++}$ two smaller peaks far from the central peak have been ignored

## ASDEX PLASMAS

Initial operation with the first holder assembly micromachined by Los Alamos, LANL 1, with QZ $11\bar{2}0$ crystal has been in operation on ASDEX since the recent startup (since November 18, 1987). All indications are that the new curve crystal is superior to the previous attempts. We caution that quantitative information is not possible at this time. The reason is that the collected helium-like Cl X-rays ($\lambda$ = 4.44 Å) has been too intense for the detector to handle (maximum count rate ~20,000 c/s). This can result either from dirty machine (usual startup condition) or better crystal collection efficiency. We are presently utilizing only the central one-third portion of the crystal and this is still too bright for the inner half of the plasma (i.e. $r/a < 0.5$). A qualitative comparison of the two types of holders for the same crystal is shown in Figure 5 for the helium-like Cl lines. The maximum counts for the resonance line, w, is about the same in both cases, however, the collection length of the crystals is different in these two cases (old and new assemblies utilized full and central 1/3 length of the crystals, respectively). But we can say that the new assembly has produced better profiles of the resonance line (Gaussian profile) and hence a better ion temperature fit has resulted. Not only is the profile better (see arrows in Fig. 5), the maximum peak of the resonance line is much sharper for the new bent crystal.

Figure 6a shows a typical ion temperature fit for 200 ms integration time. The measured ion temperature here is 1.3 keV. Time dependence of the ion temperature is shown in Figure 6b. The data before and during the NBI were not usable. The limit of resolution is about 0.5 keV.

## SUMMARY

Initial results of test and evaluation of the crystal holders have shown that the micromachined aluminium holders are far superior to the hand-polished stainless steel holders. The best focus is 70 μm FWHM in the visible with central 65% of the crystal in proper focus. We would like to improve the collection efficiency to > 80% in the near future.

Recent plasma operation has shown that ion temperature measurements will produce acceptable results. We are currently limited by the count rate of the detector. A high count rate position sensitive proportional counter (similar to the Princeton crystal X-ray detectors) should be deployed at the earlier possible opportunity.

## ACKNOWLEDGEMENT

We would expecially like to thank R. Rhorer and E. Baumgartner of the Los Alamos National Laboratory for their collaboration in this project and thus making the micromachine technology available to us.

## Reference

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## Figure Captions

Fig. 1) Typical plan view of a Johann spectrometer. Photons of different wavelength form virtual slits at different positions on the Rowland circle.

Fig. 2) Crystal holder assembly. A 0.5mm x 10mm x 10mm crystal is pressed between the holders and bend to a radius of curvature of 1500mm.

Fig. 3) Measured profile of a polished holder, +. The curves are fit to data indicating different radii of curvature along the holder.

Fig. 4) Focal plane image in the visible for three different crystal holder assemblies. The full 50 mm crystal length was used for this measurement.

Fig. 5) Cl He-like spectra measured with (a) old holder assembly, ASDEX 8 and (b) micromachined crystal holder assembly, LANL 1. The arrows indicate imperfection in the resonance line, w, profile. The caviat here is that (a) used full crystal and (b) used central 1/3 of the crystal.

Fig. 6) (a) Typical ion temperature fit to measured data. The HWHM here is 6.8 pixels equivalent to $T_i$=1.3 keV. The instrumental HWHM ~3.5 pixels or $T_i$~0.5 keV.

(b) Ion temperature measured during and after NBI.

Fig. 1

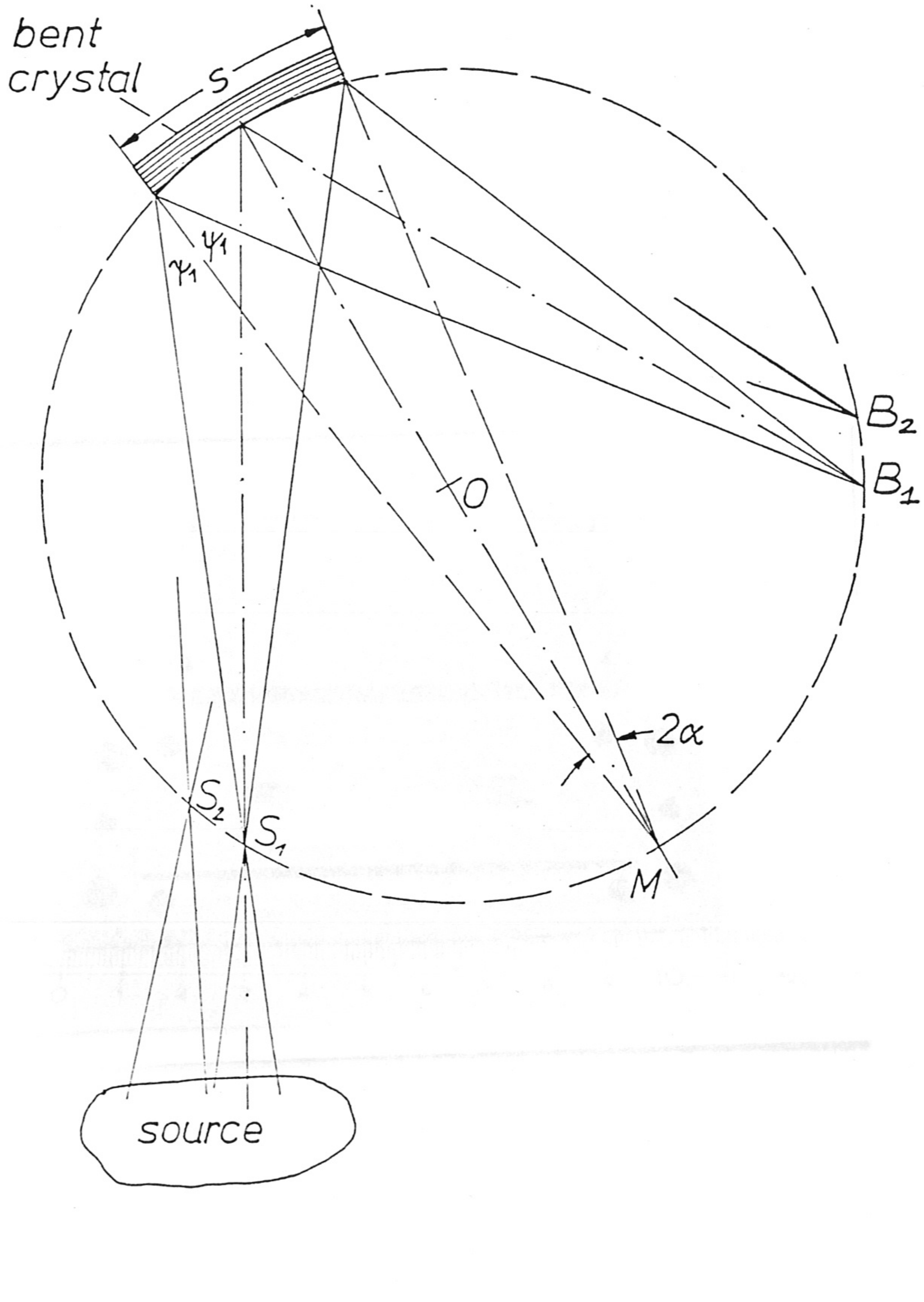


Fig. 2

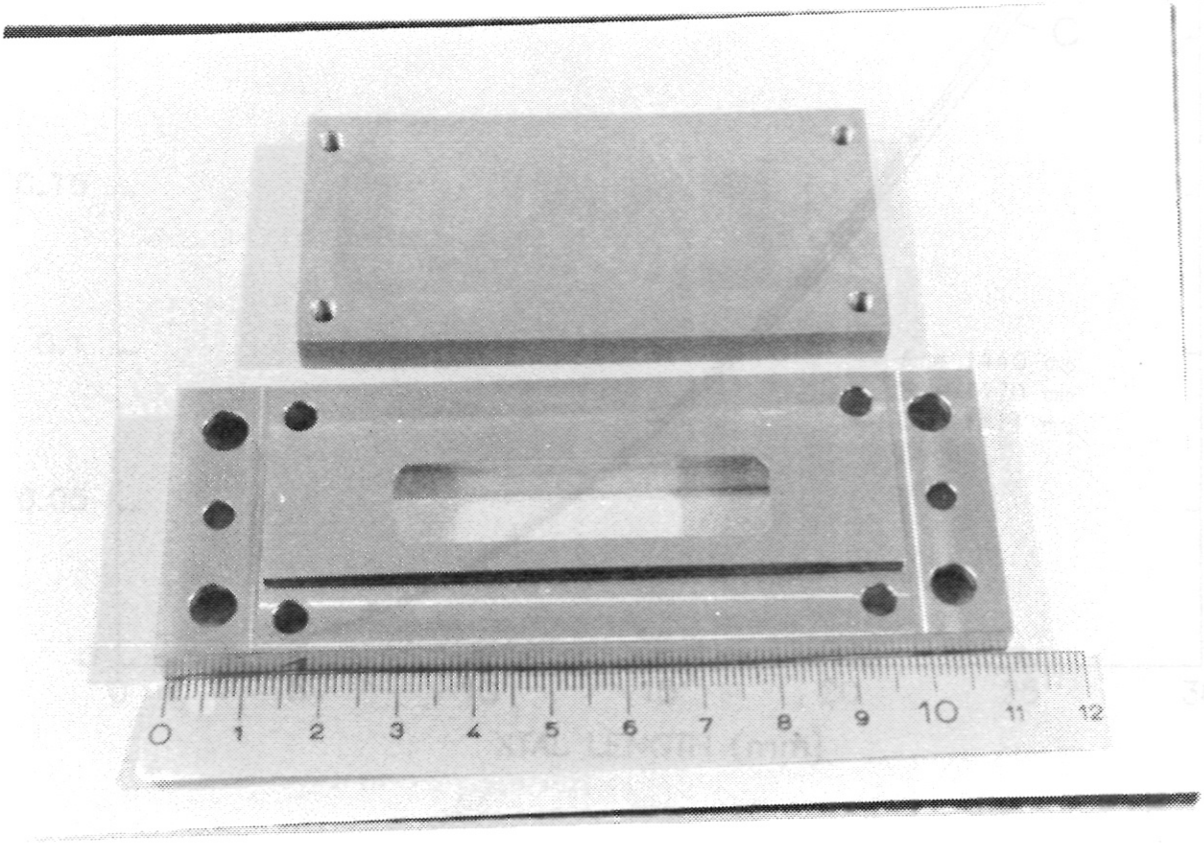


Fig. 3

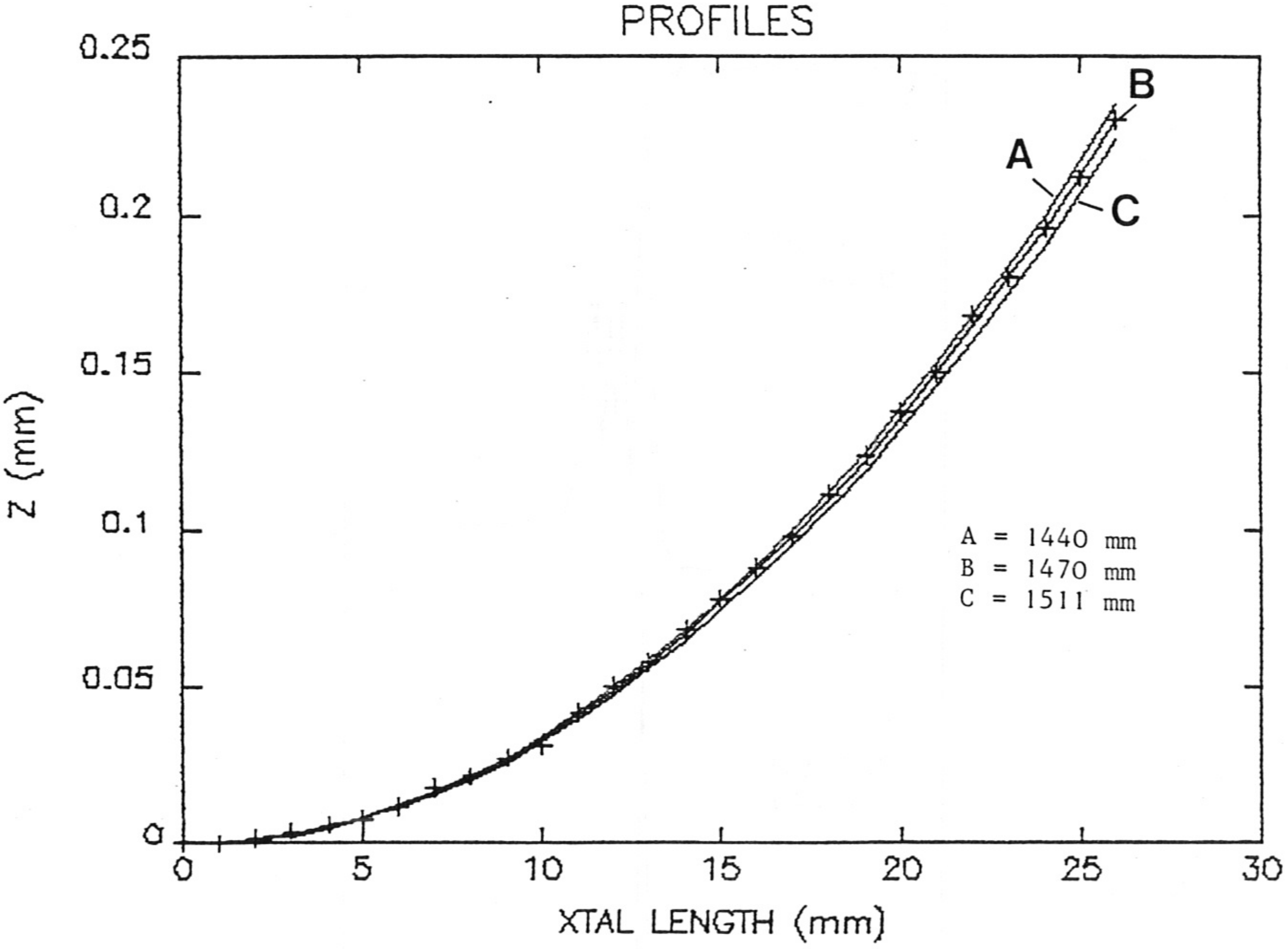

PROFILES
0.25
0.2
0.15
0.1
0.05
0
Z (mm)
0
5
10
15
20
25
30
XTAL LENGTH (mm)
A
B
C
A = 1440 mm
B = 1470 mm
C = 1511 mm

Fig. 4

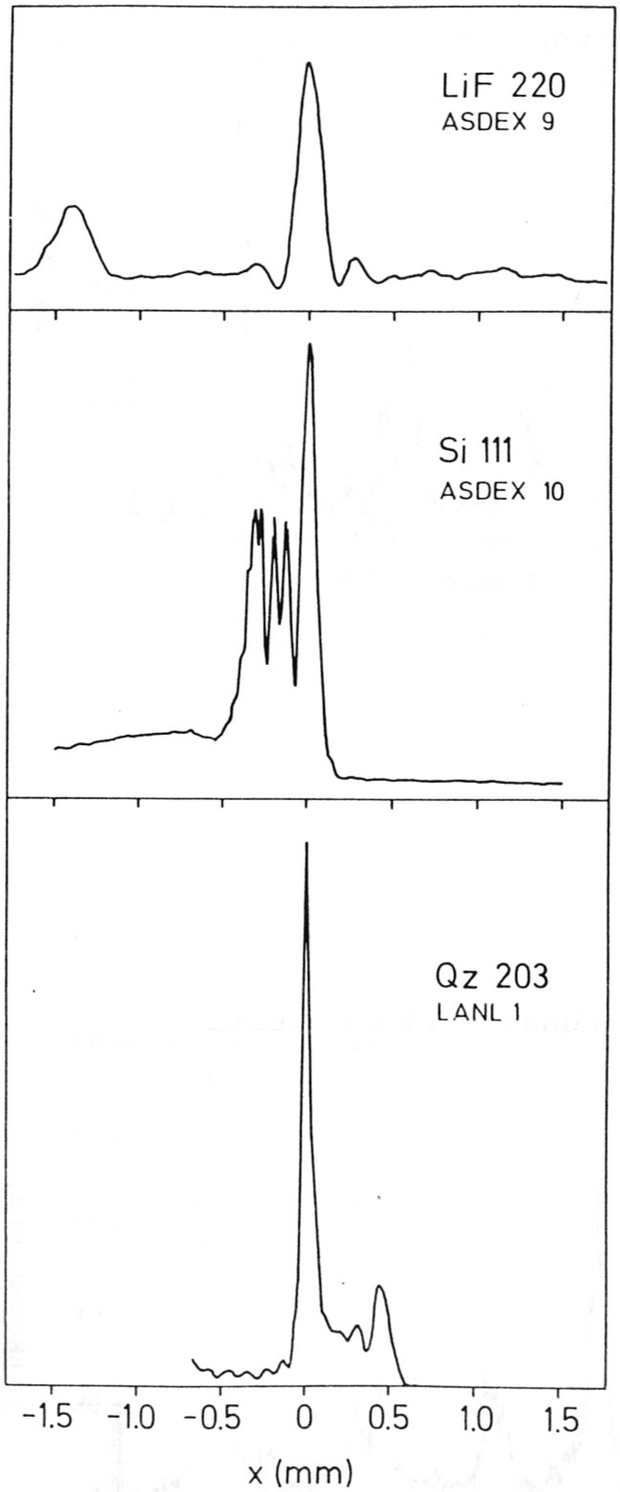
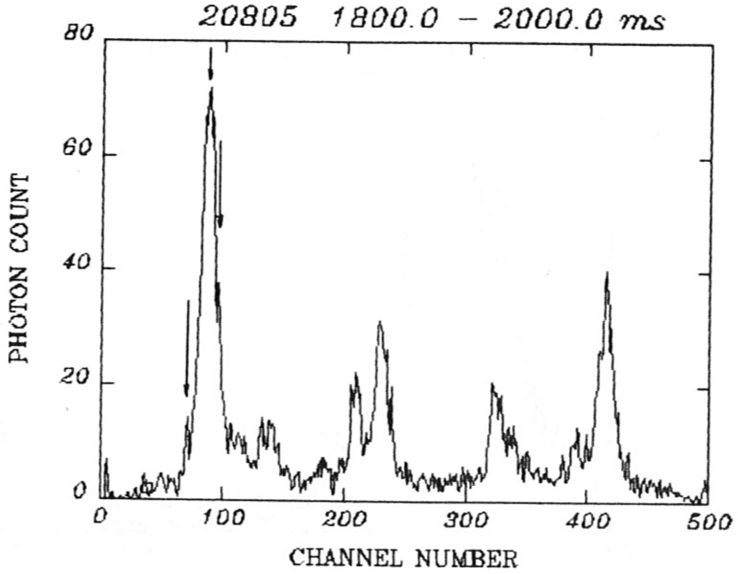

LiF 220
ASDEX 9
Si 111
ASDEX 10
Qz 203
LANL 1
-1.5
-1.0
-0.5
0
0.5
1.0
1.5
x (mm)

Fig. 5

(a)


20805 1800.0 – 2000.0 ms
80
60
40
20
0
PHOTON COUNT
0
100
200
300
400
500
CHANNEL NUMBER

(b)

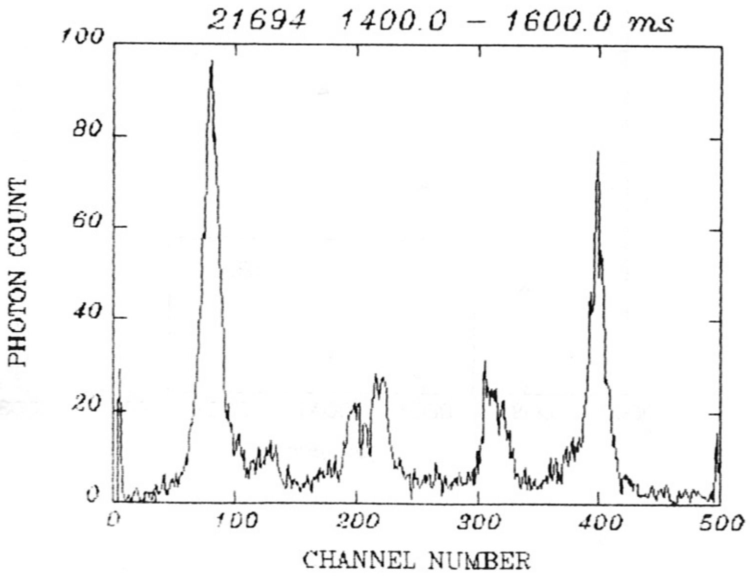
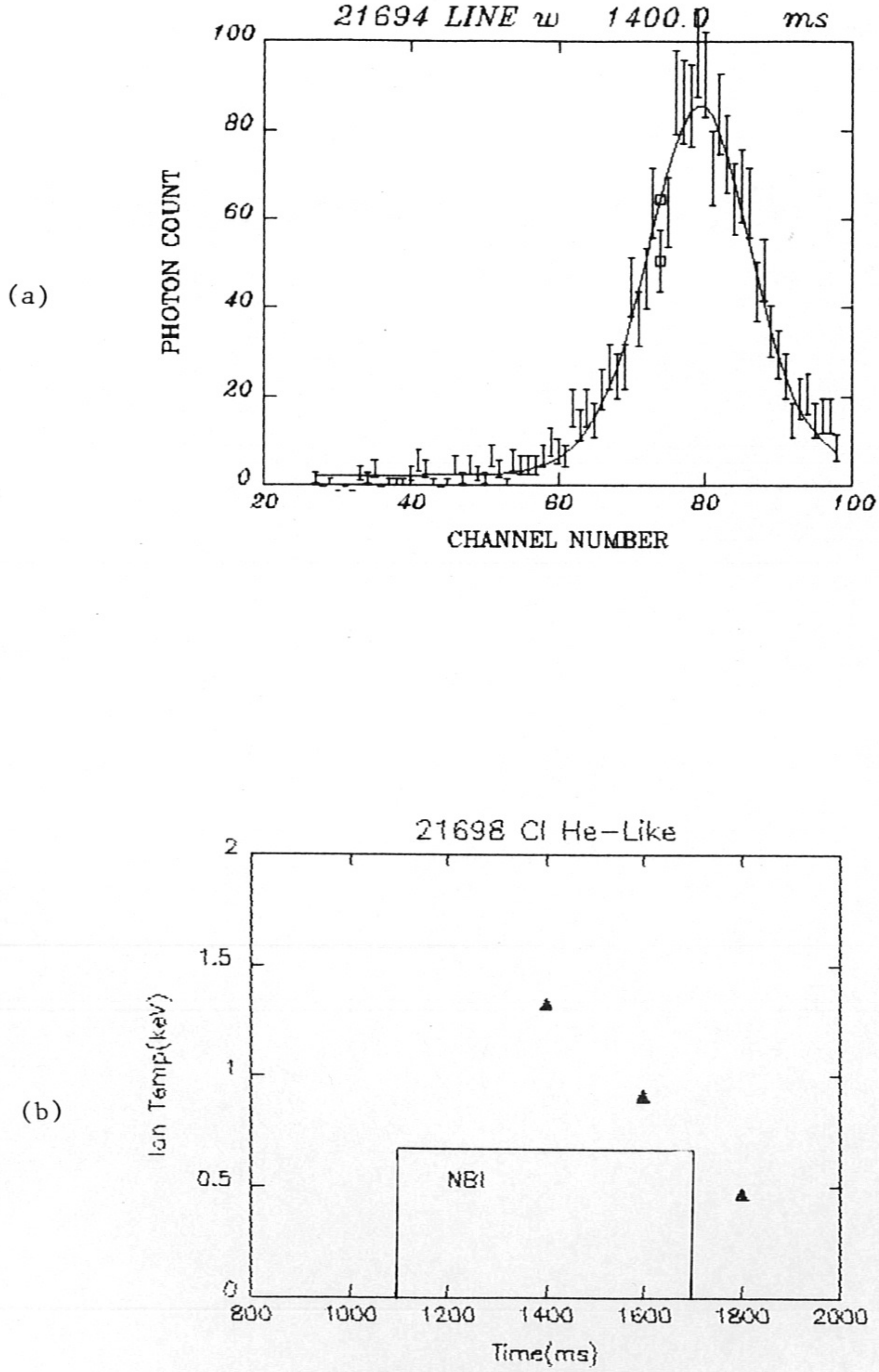

21694 1400.0 – 1600.0 ms
100
80
60
40
20
0
PHOTON COUNT
0
100
200
300
400
500
CHANNEL NUMBER

Fig. 6


(a)
21694 LINE w 1400.0 ms
PHOTON COUNT
0
20
40
60
80
100
20
40
60
80
100
CHANNEL NUMBER
(b)
21698 Cl He-Like
Ion Temp(keV)
0
0.5
1
1.5
2
800
1000
1200
1400
1600
1800
2000
Time(ms)
NBI