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Spatially and Temporally Resolved Crystal Spectrometer for Diagnosing High Temperature Pinch Plasmas on Z

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ABSTRACT

We have developed a spatially and temporally resolved crystal spectrometer for analyzing a variety of pinch experiments on Z. The spectrometer uses a convex curved crystal to disperse spectra onto a flat microchannel plate framing camera detector. A single wide, 1 cm, strip on the MCP is gated to provide temporal resolution. The spectral range governed by the 4 cm length of the MCP strip varies with the central Bragg angle and crystal. For a KAP crystal a typical range is 1500 to 2000 eV. This range can be shifted by translating the crystal along the optical axis to access different Bragg angles. The spectrometer can therefore measure K shell spectra of a wide variety of elements such as Al, Ti, and Fe. The short 1 cm width of the strip is spatially resolved with an imaging cross slit. With a 500 μm cross slit and magnification 1 the spatial resolution at the pinch is 1 mm. The instrument may also be fielded with 7 time frames using a 7 strip-line microchannel plate as the detector by sacrificing the spatial resolution. We will present data obtained from an aluminum pinch on Z.

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I. Introduction

Crystal spectroscopy may be used to measure a variety of z-pinch plasma parameters. (1,2,3) The electron temperature is most easily recognized through the ionization state of detected lines and can also be measured by the slope of free-bound continuum. Electron density can be estimated from line ratios as well as the absolute magnitude of lines and/or continuum. With temporal and spatial resolution these quantities can be measured as a function of space and time to study z-pinch dynamics and compare with the results of z-pinch computational modeling. (4) Information is also available in the line widths which on Z are due opacity or Doppler broadening.

If the plasma is LTE, as in dynamic hohlraum experiments, the temperature may be estimated using tracer spectroscopy. (5) For instance with dynamic hohlraum temperatures in excess of 150 eV the He-alpha lines of sodium and fluorine will be measurable and can be used to determine a hohlraum temperature.

In this paper we present the parameters of a spatially and temporally resolving crystal spectrometer which may be used the record lines and continuum in the range of 800 to 8000 eV from the pulsed power driver Z, a 20 MA, 100 ns pulsed power driver. (6) We will also present some sample data recorded by the instrument on Z.

II. Instrumentation

A schematic of the instrument is shown in figure 1. X-rays from the z-pinch are dispersed by a crystal onto a 4 cm long microchannel plate. Typically we use KAP and mica crystals. We also plan to use lead stearate with a 2d spacing of 100 Å for measuring spectra below 1 keV.

A thin light-tight filter, typically beryllium, is used to shield the instrument against large amounts of visible emission. Other filters may also be used. For instance a thicker filter such as 1 mil of kapton may suppress continuum in the 1 to 2 keV range in favor of measuring lines and continuum above 2 keV.

A single wide, 1 cm, strip on the MCP is gated to provide temporal resolution. The gating pulse can vary between 1 and 8 ns. The instrument may also be fielded with 7 time frames using a 7 strip-line microchannel plate as the detector by sacrificing the spatial resolution.

The spectral range governed by the 4 cm length of the MCP strip varies with the central Bragg angle and crystal. For KAP a typical range is 1500 to 2000 eV. This range can be shifted by translating the crystal along the optical axis to access different spectral ranges. The instrument has been designed to access Bragg angles between 6 and 56 degrees by translating the crystal with a vacuum feedthrough manipulator. We note that the deflection angle shown in figure 1 is equal to twice the Bragg angle.

The dispersion may be estimated analytically using the Bragg equation. We can express the distance, x, along the MCP and wavelength, λ, in terms of the Bragg angle, θ, the angle of the MCP with respect to the optical axis, $\alpha = 30$ degrees, the Bragg angle to the center of the MCP, θ_0, and the distance from the center of the MCP to the optical axis, $jog = 12$ cm. For a crystal spacing $2d$, we have

$$\lambda = 2d \sin\theta \qquad (1)$$

and

$$x = jog(\tan(2(\theta - \theta_0))/\sin 2\theta_0 \cos(2(\alpha - \theta)) \qquad (2)$$

Figure 2 shows the spectral range in eV parametric in central Bragg angle for a KAP crystal. For other crystals or other orders the curves of figure 2 are simply multiplied by a constant. The spectrometer can therefore measure K shell spectra of a wide variety of elements such as F, Na, Al, Ti, and Fe. It also may be used to detect continuum from very high Z radiators such as W.

The short 1 cm width of the strip is spatially resolved with an imaging cross slit. With a 500 μm cross slit and a magnification of 1 the spatial resolution at the pinch is about 1 mm. The instrument is protected from z-pinch debris by the imaging cross slit and a fast valve. To date this instrument has been fielded on the side of Z, with the imaging slit 300 cm from the pinch and the detector 300 cm from the slit. It may also be fielded on axis for tracer spectroscopy measurements on dynamic hohlraums.

III. Data Recorded on Z Shot 171

As an example of the capability of this instrument we present results from Z shot 171. The load for this shot was 260 aluminum wires on a 5 cm diameter with a mass per unit length of 1 mg/cm. In figure 3 we show the timing of the crystal spectrometer gate with respect to the x-ray diode signal in the 250 eV band. The crystal gate is about 5 ns wide while the x-ray pulse is about 10 ns wide. The gate is over the first half of the x-ray pulse width.

In figure 4 we show the image recorded by the spatially and temporally resolved crystal spectrometer. The spatial range is about 1 cm and the spatial resolution is about 1 mm. The image is resolved in the pinch radius, and integrates over most of the 2 cm length of the pinch. The spectrometer records the alpha , beta, and gamma lines of He-like aluminum and the alpha line of H-like aluminum. The Lyman alpha line extends to over 1 cm in diameter because of its large optical depth. One also sees continuum from a core about 3 mm in diameter. This continuum is due to free-bound recombination on aluminum L shell ions. It comes from a hotter and denser region than the lines because it has lower opacity. One also notices that the widths of the Lyman and Helium alpha lines are a decreasing function of radius, and this width is due to opacity broadening. Using the Al K shell power as measured by filtered photoconducting detectors, the image can be converted from units of film density to units of kJ/keV/mm averaged over the time gate. (4)

Line-outs through this image averaging over the core 3 mm in diameter and over $4<r<6$ mm are shown in figure 5. The continuum has dropped to below the noise level at large diameter. The lines however remain strong emitters at large diameter, particularly Lyman alpha, which dominates the spectrum.

Line-outs may also be taken along radii, averaging over a spectral window. In figure 6 we show the spatial dependence of Helium alpha radiation and of nearby continuum. One sees that the continuum, which is optically thinner than the line, comes from a 3 mm diameter core, while the line comes from a much larger 6 mm diameter.

IV. Summary

We have developed a spatially and temporally resolving crystal spectrometer for measuring pinch plasma parameters on Z. The instrument may be used with a variety of different crystals and crystal positions to tune the spectral range to record lines of interest. One may also sacrifice the spatial resolution in favor of recording seven time frames. The spectrometer may be used to measure dynamic hohlraum temperature via tracer spectroscopy or to measure plasma pinch parameters in K shell emitters such as aluminum. We have shown data from an aluminum pinch on Z indicating a dense core region emitting free bound continuum surrounded by a halo of optically thick line emission.

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Figure Captions

1. Schematic of the curved crystal spectrometer . The crystal may be translated to access different spectral regions. Bragg angles from 6 to 53 degrees are accessible. The spectrum may be spatially resolved perpendicular to the plane of the figure.

2. Dispersion of the crystal spectrometer parametric in Bragg angle at the center of the detector for a KAP crystal which had a 2d spacing of 26.6 Å. The center of the detector is

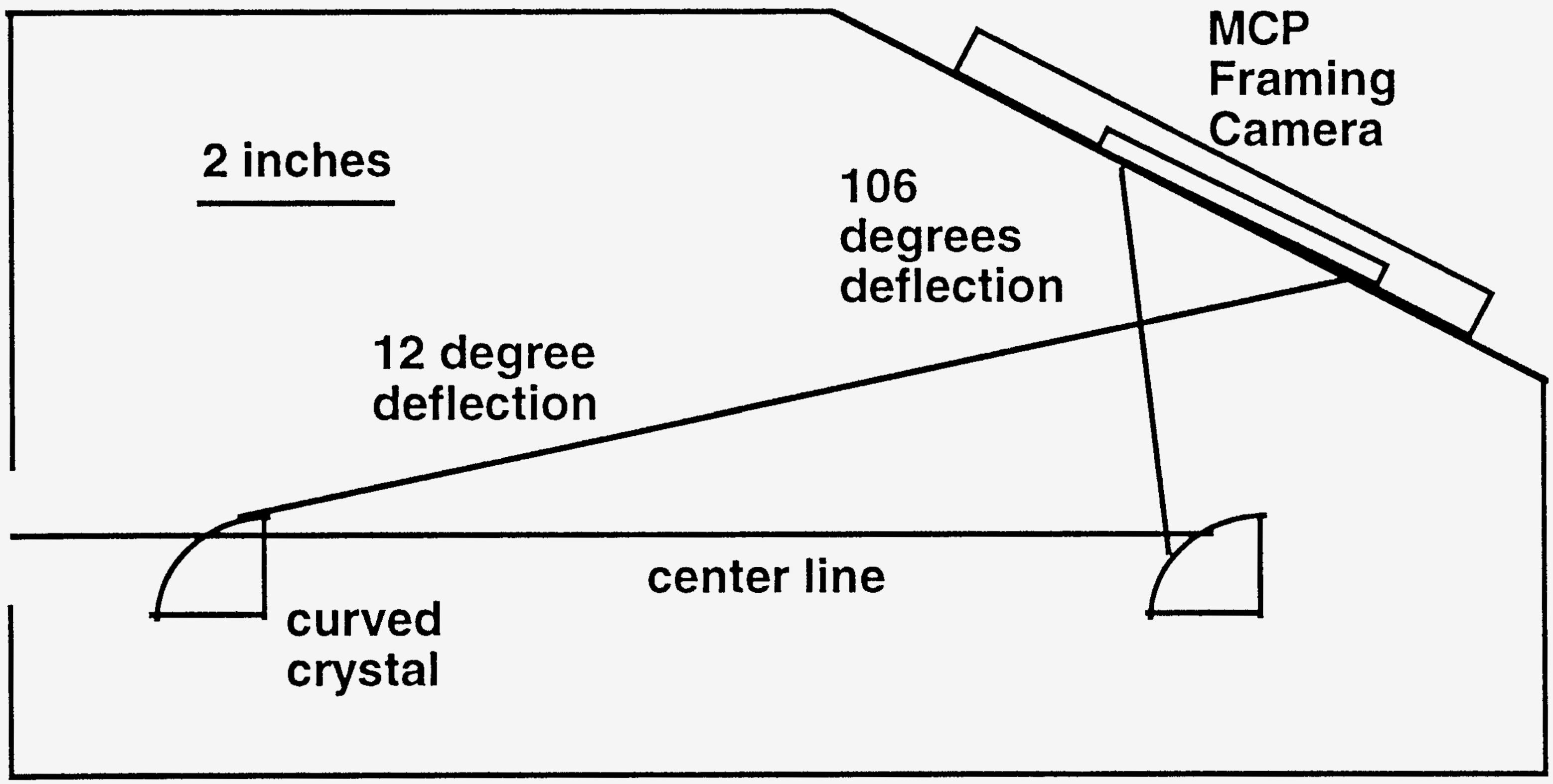
12 cm from the optical axis, and the detector is oriented at a 30 degree angle with the optical axis.

3. Temporal gate of the crystal spectrometer with respect to the x-ray signal for Z shot 171.

4. Image recorded by the spatially and temporally resolved crystal instrument for Z shot 171. K shell lines of aluminum extend to large diameter, while continuum is isolated to a smaller core.

5. Spectral line-outs over the core 3 mm and the pinch halo at $4<r<6$ mm. The continuum exists only in the core while the Lyman alpha line of aluminum is thick over a 1 cm diameter.

6. Spatial line-outs over the He-alpha line and over nearby continuum. As in figure 5 the continuum is seen to come from a 3 mm diameter core, while the Helium alpha line has a 6 mm spatial fwhm.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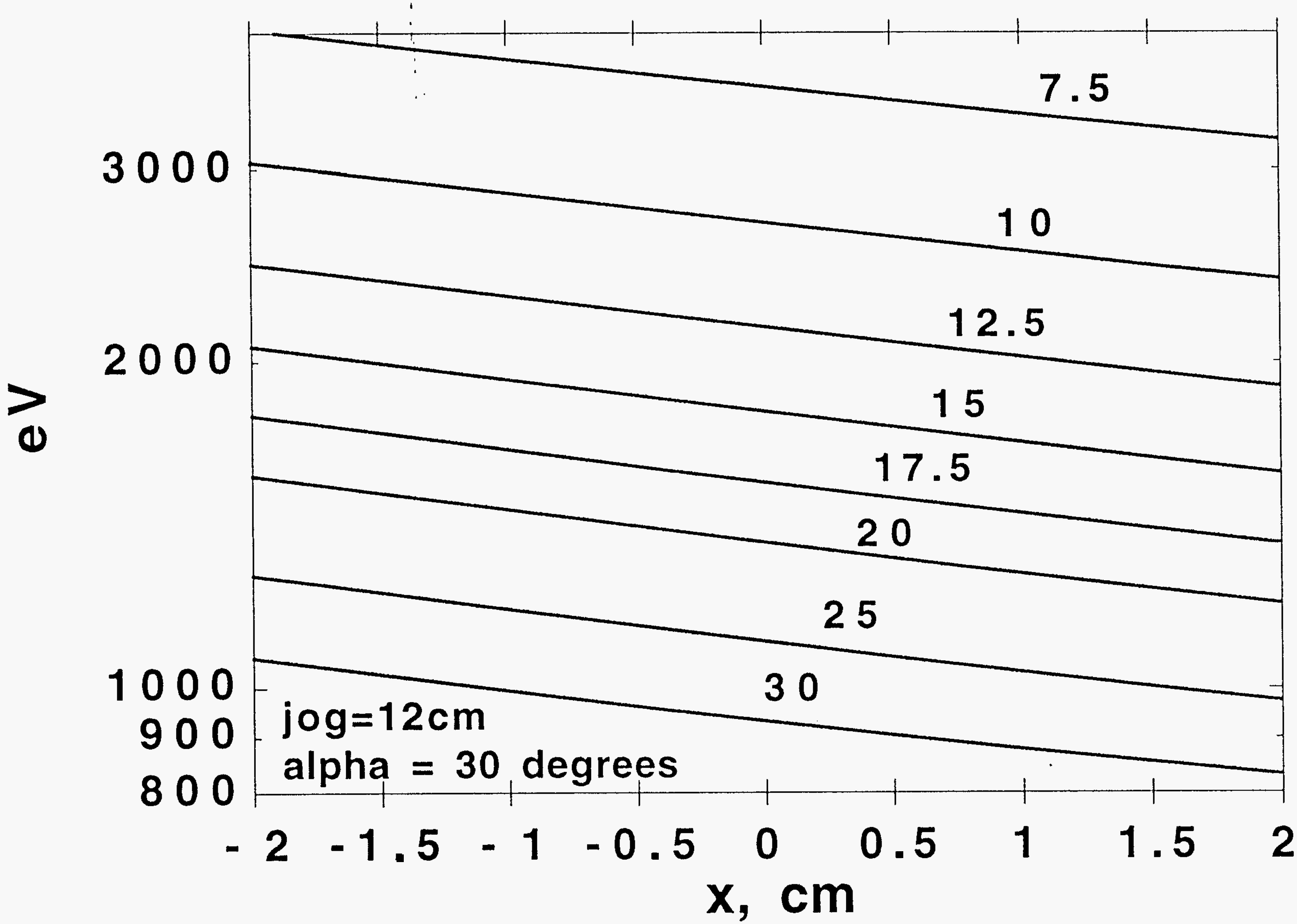
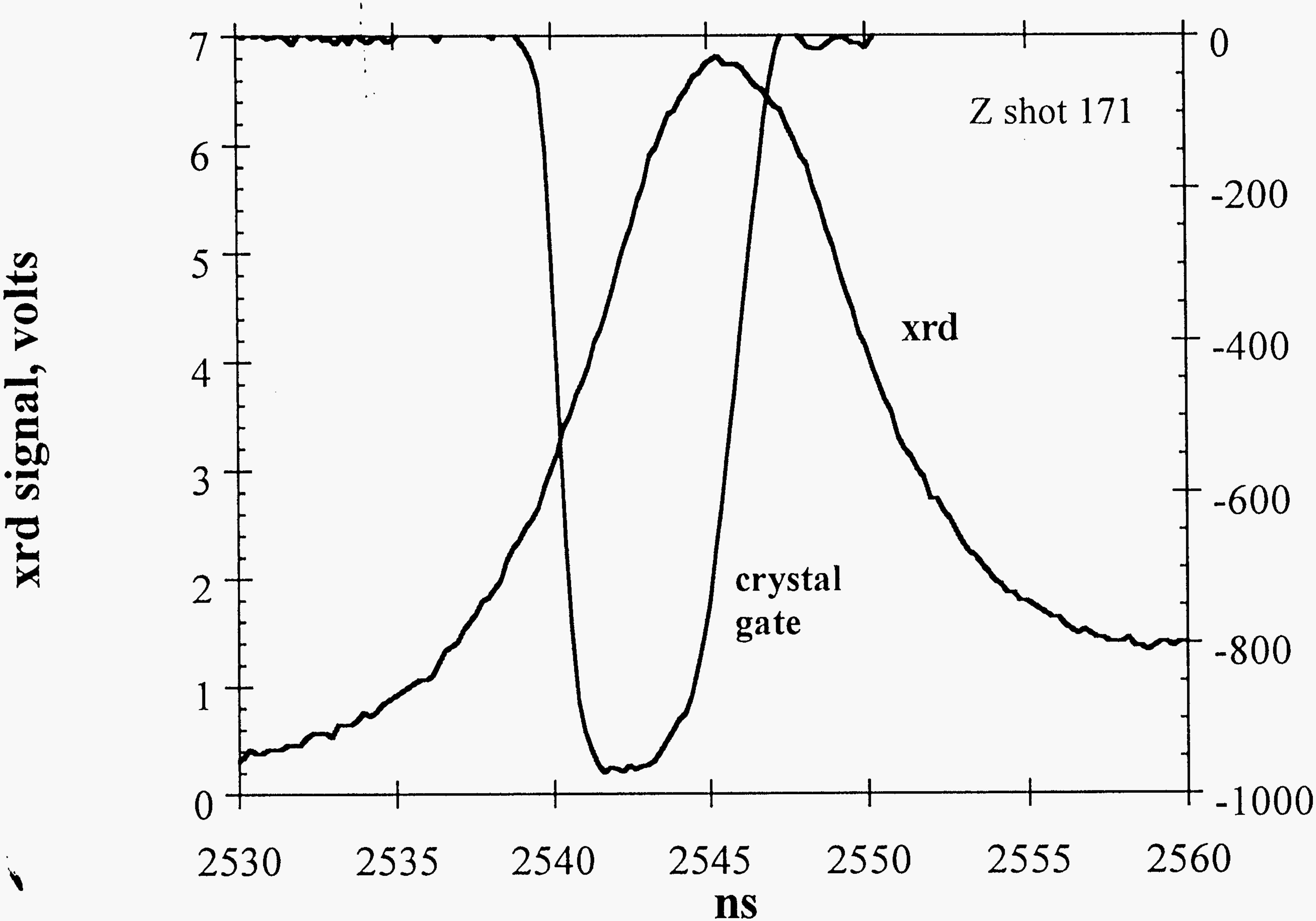
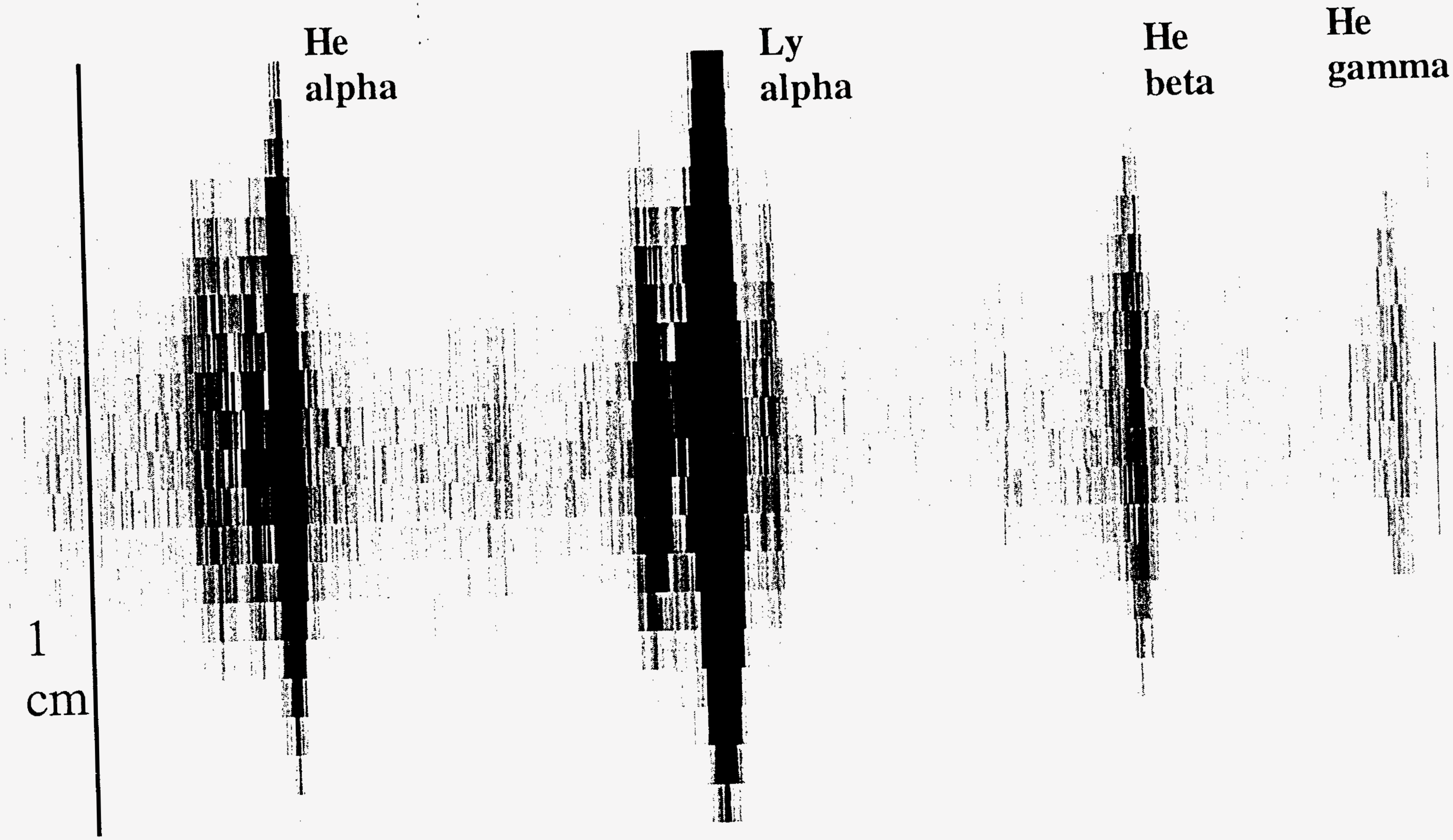
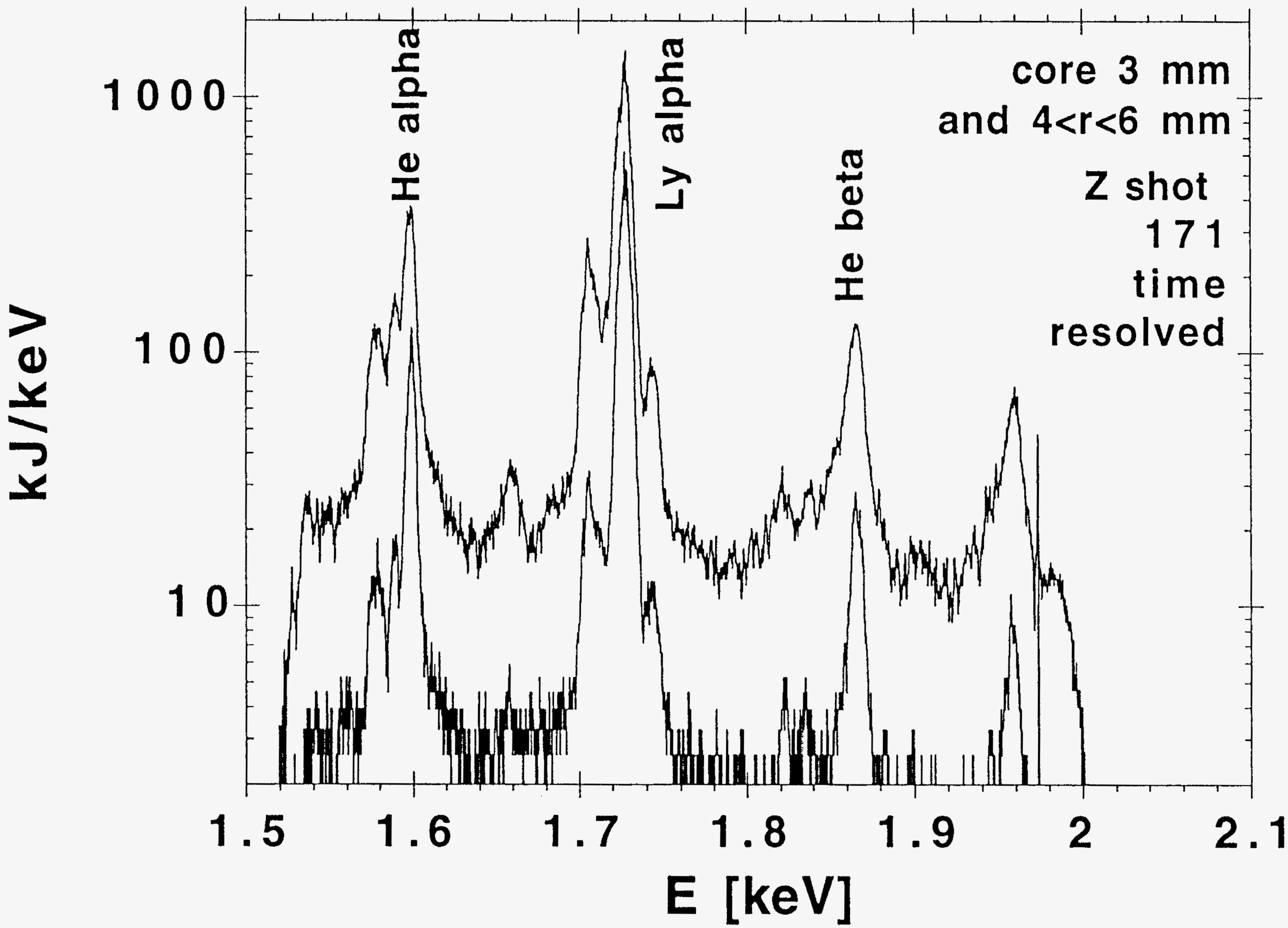
Framing
Camera
2 inches
106
degrees
deflection
12 degree
deflection
center line
curved
crystal

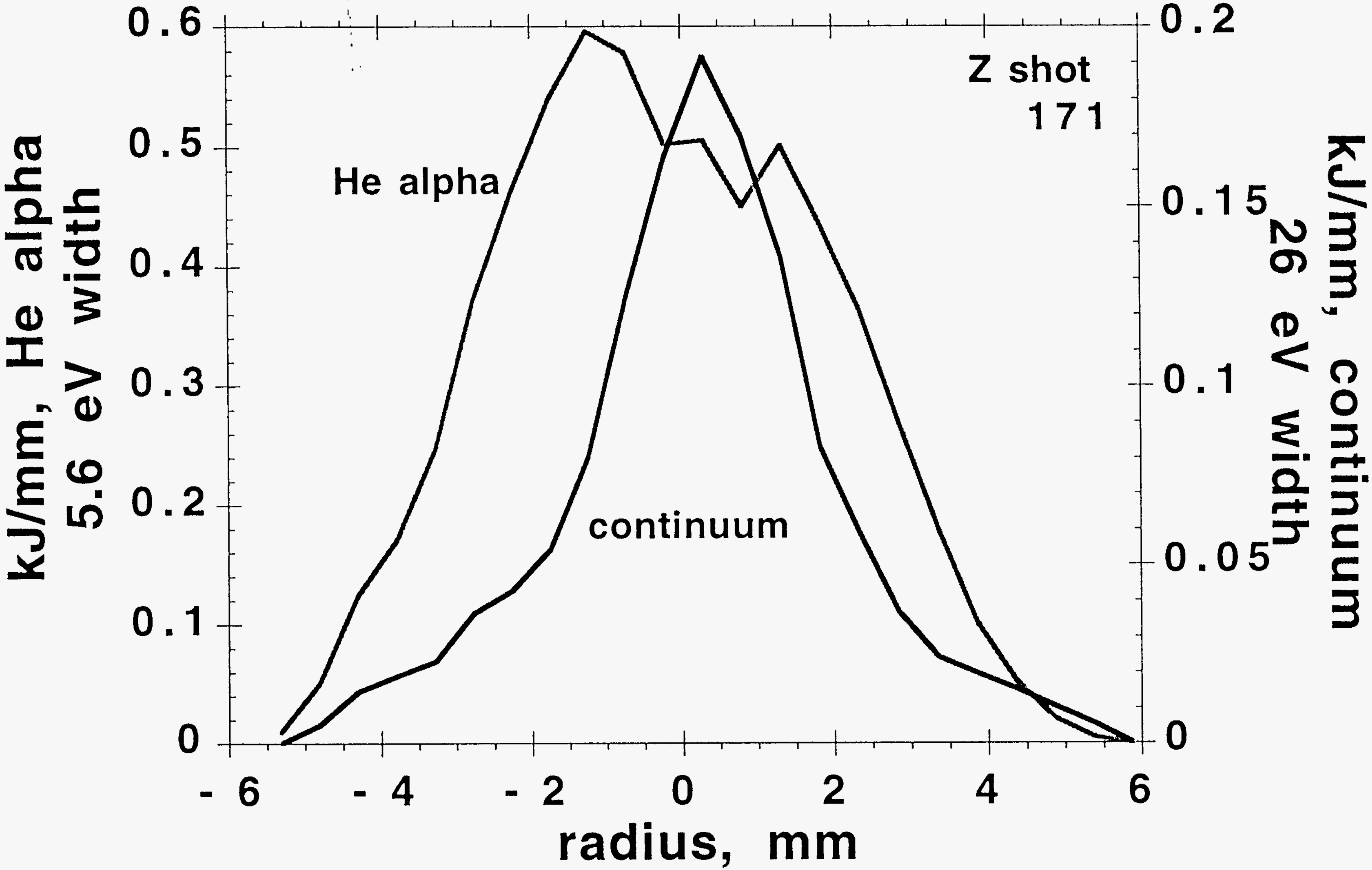

7.5
10
12.5
15
17.5
20
25
30
jog=12cm
alpha = 30 degrees
eV
3000
2000
1000
900
800
-2
-1.5
-1
-0.5
0
0.5
1
1.5
2
x, cm


Z shot 171
xrd
crystal
gate
xrd signal, volts
crystal spectrometer gate, volts
ns
7
6
5
4
3
2
1
0
0
-200
-400
-600
-800
-1000
2530
2535
2540
2545
2550
2555
2560


He alpha
Ly alpha
He beta
He gamma
1 cm



He alpha
Ly alpha
He beta
core 3 mm
and 4<r<6 mm
Z shot
171
time
resolved
1000
100
10
kJ/keV
1.5
1.6
1.7
1.8
1.9
2
2.1
E [keV]


kJ/mm, He alpha
5.6 eV width
kJ/mm, continuum
26 eV width
Z shot
171
He alpha
continuum
radius, mm
0.6
0.5
0.4
0.3
0.2
0.1
0
0.2
0.15
0.1
0.05
0
- 6
- 4
- 2
0
2
4
6

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