Investigation of a novel X-ray tube for the calibration of the X-ray crystal spectrometer in the KSTAR machine (P6-37)

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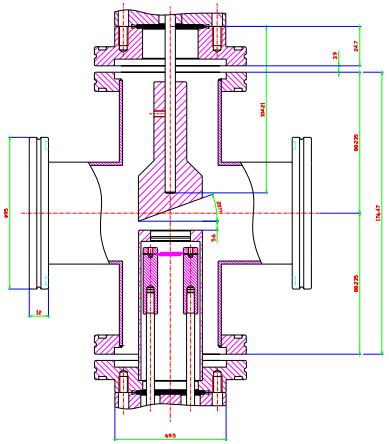
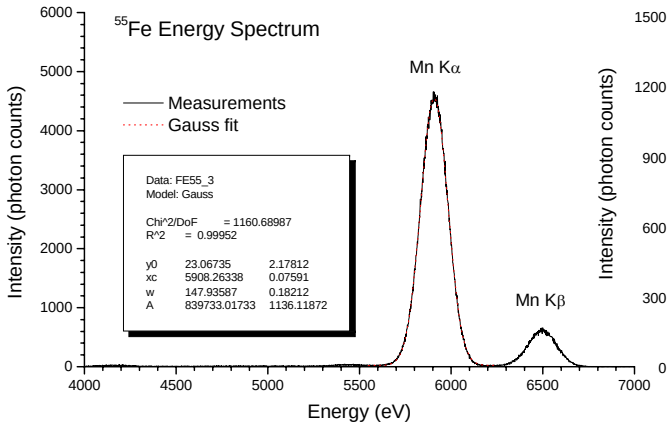
Abstract

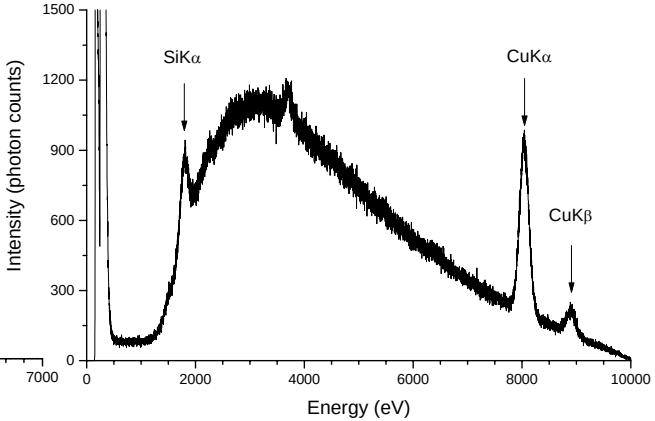
A novel x-ray tube with a line filament has been developed for the *in-situ* calibration of the x-ray crystal spectrometer (XCS) in the KSTAR machine. The characteristics of the x-ray tube are investigated from the x-ray images obtained by using a pinhole and a CCD detector. It is found that the image has the width of about 0.1 mm, which is much improved as compared with the previous experimental results. In addition, there is a uniform region around the center of the image within its full length of 13.5 mm. This work may lead to the development of a novel x-ray tube with a line focus, which is required for the calibration of the XCS. Experimental results from the investigation of the x-ray tube are presented and the technical issues in a design of the *in-situ* calibration system using the x-ray tube for the KSTAR XCS are discussed.

* Work supported by the Korea Research Council of Fundamental Science & Technology and the KSTAR project.

Fabricated X-ray tube and spectrum







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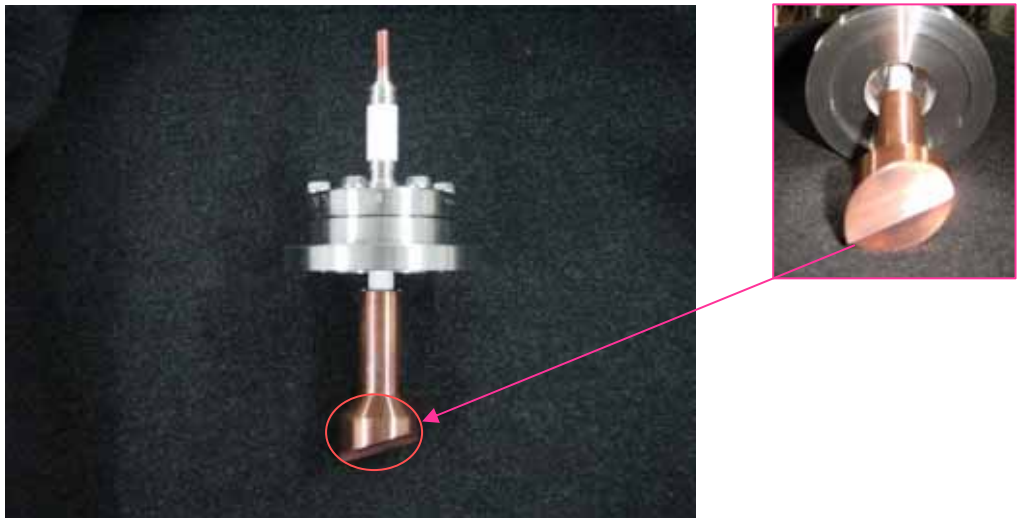
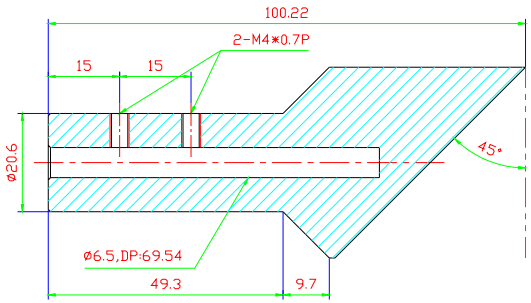
Various types of anode

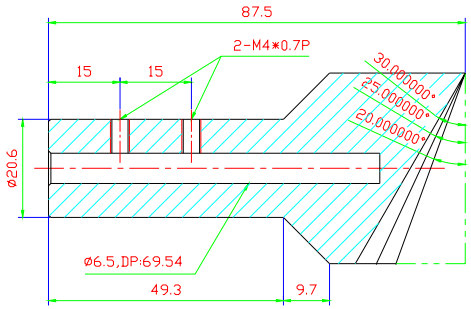
20º slanted flat anode



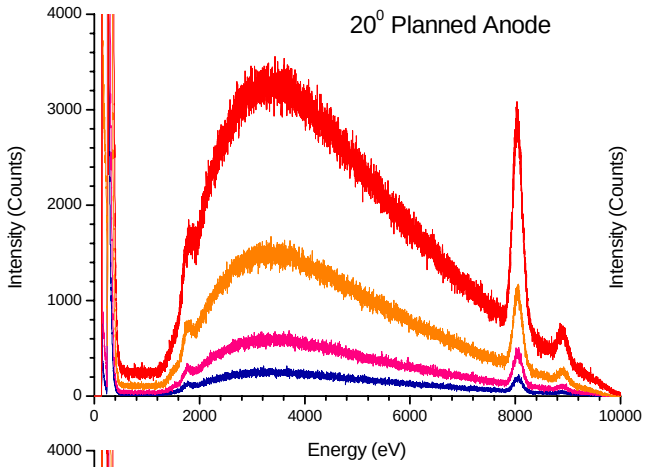
20º slanted focusing anode

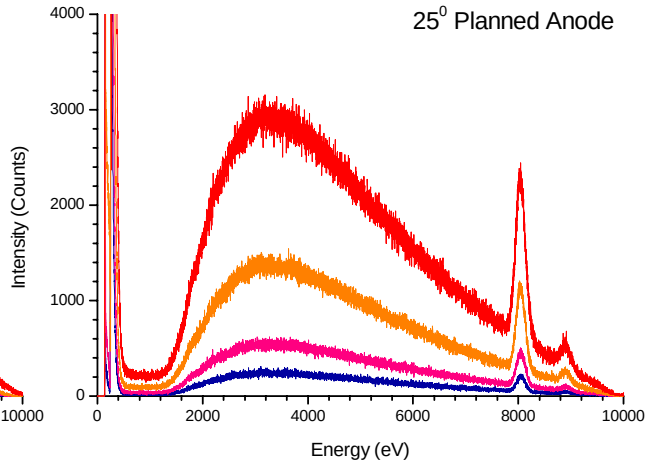
45º slanted flat anode

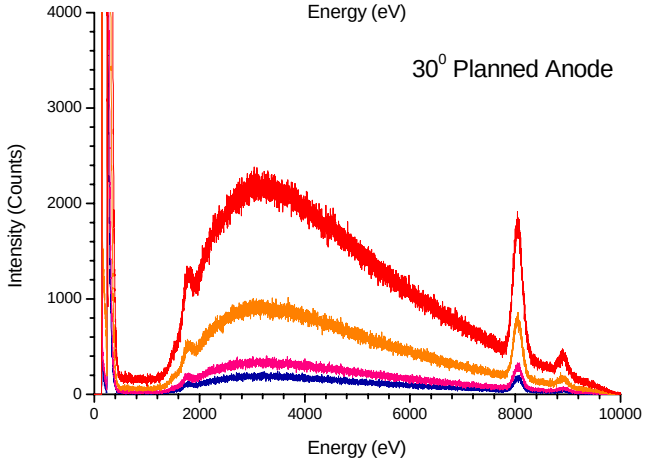




Measured intensity vs. anode angle

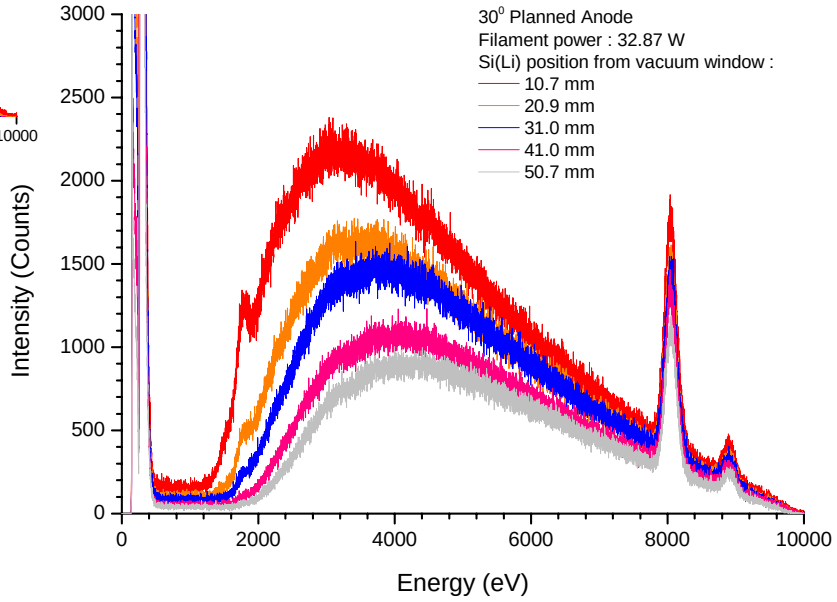






Si(Li) position : 10.7 mm from the window

- Filament power : ~ 28.67W
- Filament power : ~ 30.03W
- Filament power : ~ 31.29W
- Filament power : ~ 32.87W

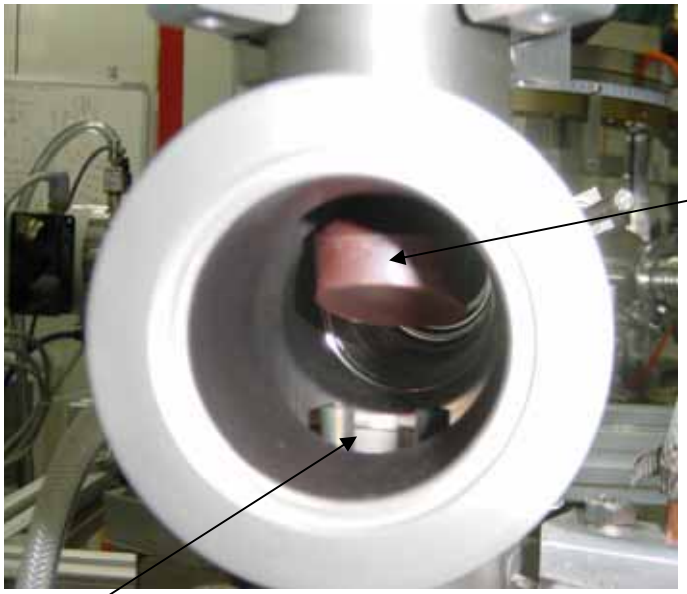


A 20º anode emits the highest x-ray intensity

The emitted intensity of the x-ray is strong as the filament current increases

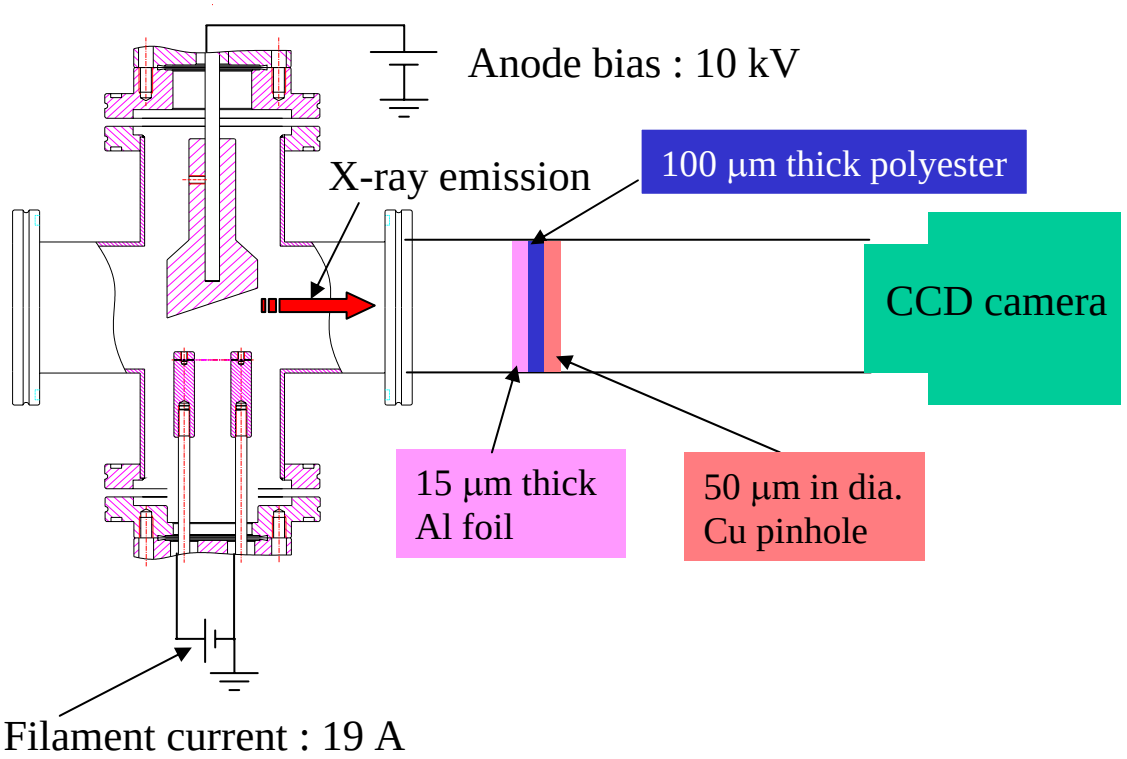
The low x-ray energies are strongly attenuated in the air

Trace observed on the anode after experiment



- The axis of the electron trace image on the anode is perpendicular to the direction of the filament.
- The line on the anode is due to the energetic electron beams from the filament and x-rays are emitted from the line.

X-ray pinhole camera for investigating x-ray images

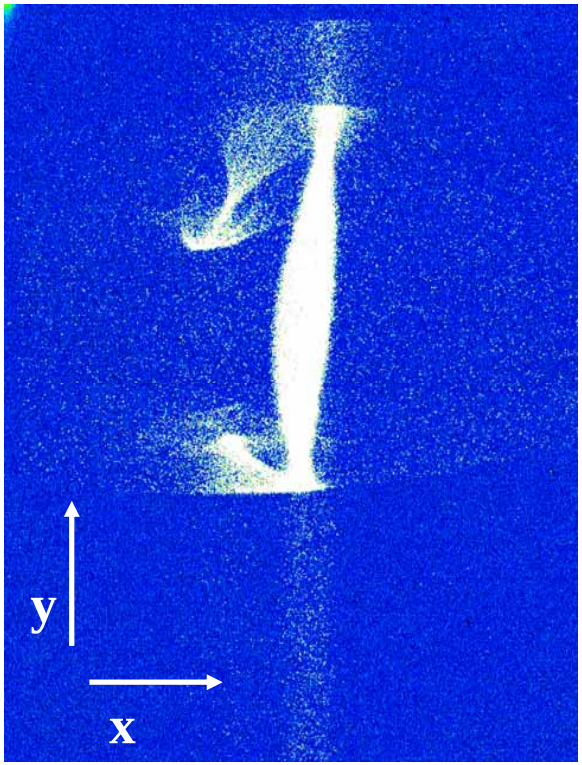


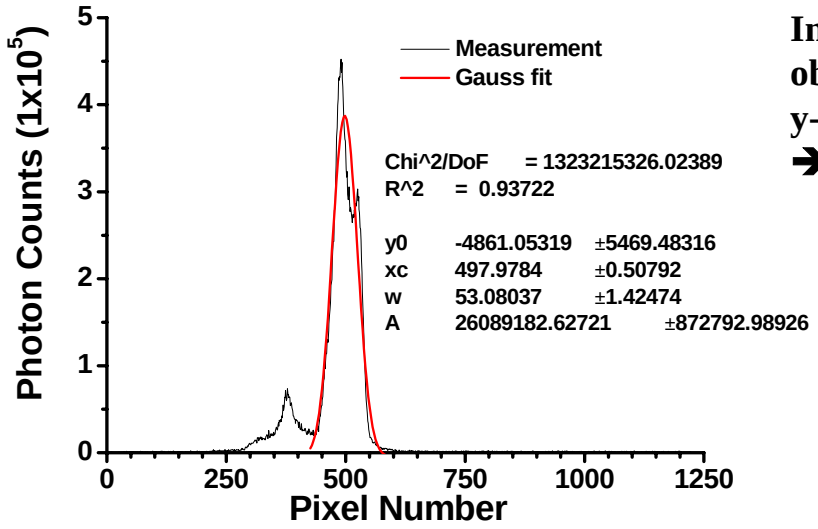
EEV CCD chip
1242 pixels by 1152 pixels
Pixels size : 22.5 μm by 22.5 μm
Dimension : 27.9 mm by 25.9 mm

- A pinhole was installed half way between the x-ray source and CCD camera
- Various types of anode were used
- Polarity of the filament was changed to see the effect of the polarity
  - space charge effect
  - magnetic field effect

X-ray image from a pinhole camera

CCD-421
Filament polarity : normal
20 degree plane anode

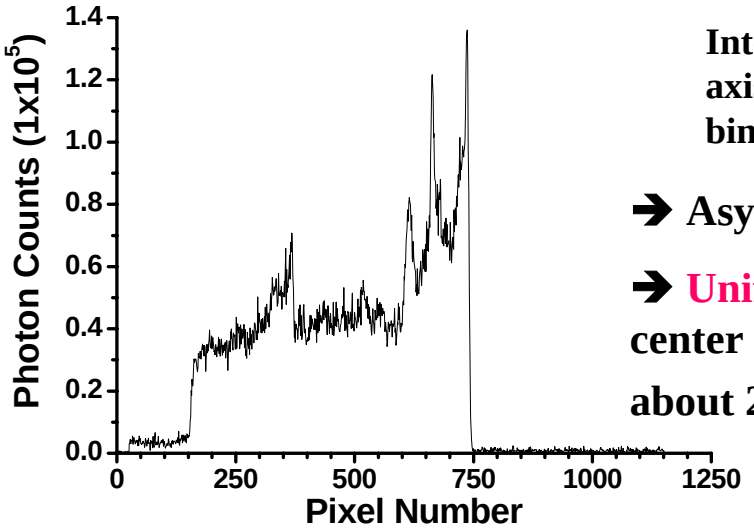




Intensity along the x-axis obtained by binning on the y-axis

➔ **FWHM : ~ 1.2 mm**

Note that
1 pixel = 22.5 μm



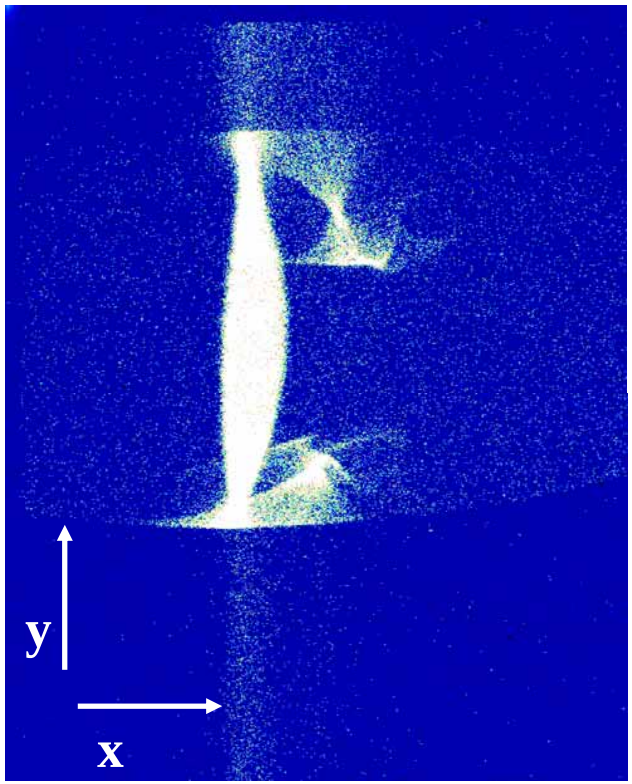
Intensity along the y-axis obtained by binning on the x-axis

➔ **Asymmetric**

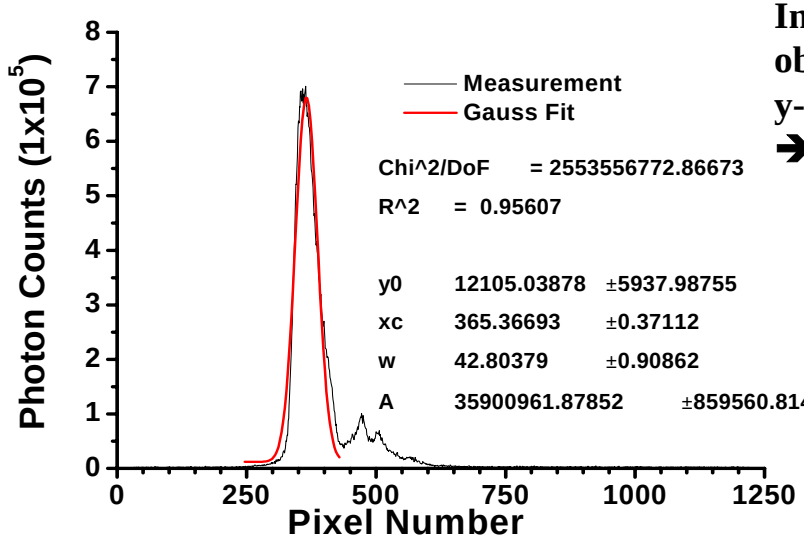
➔ **Uniform region around the center of the image : Width of about 200 pixels or 4.5 mm.**

X-ray image from a pinhole camera

CCD-424
Filament polarity : reversed
20 degree plane anode

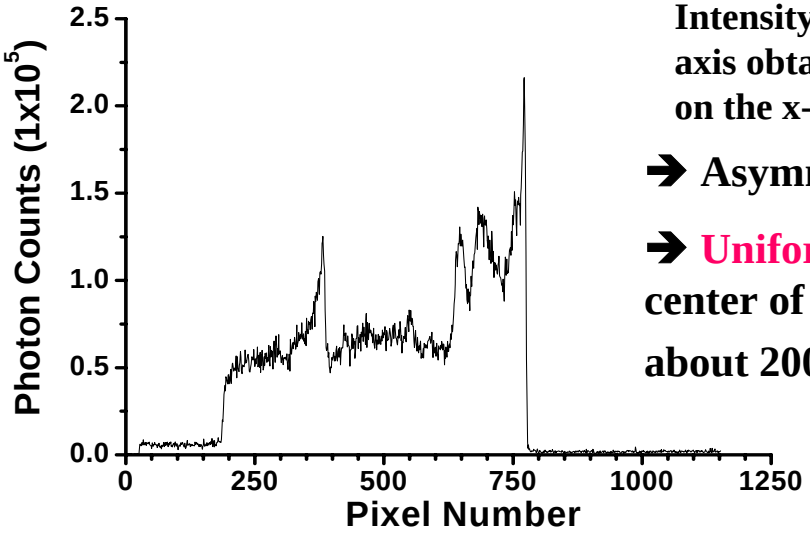


Ground — Filament — +



Intensity along the x-axis obtained by binning on the y-axis

➔ FWHM : **~ 0.96 mm**



Intensity along the y-axis obtained by binning on the x-axis

➔ **Asymmetric**

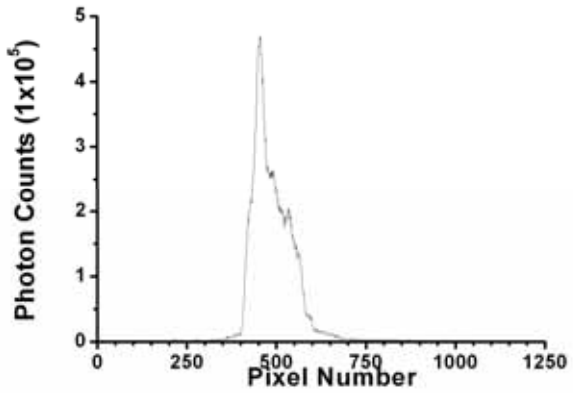
➔ **Uniform region around the center of the image : Width of about 200 pixels or 4.5 mm.**

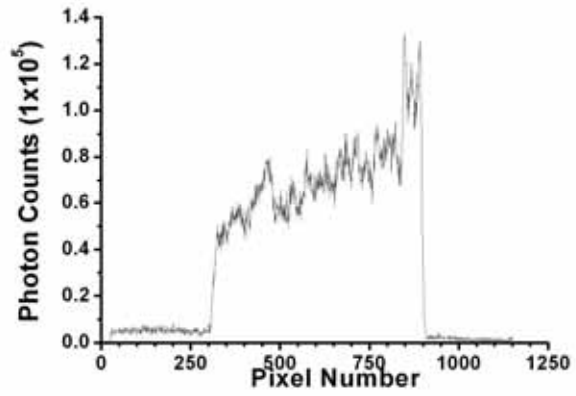
Intensity distribution in previous measurements

Intensity along the x-axis obtained by binning on the y-axis

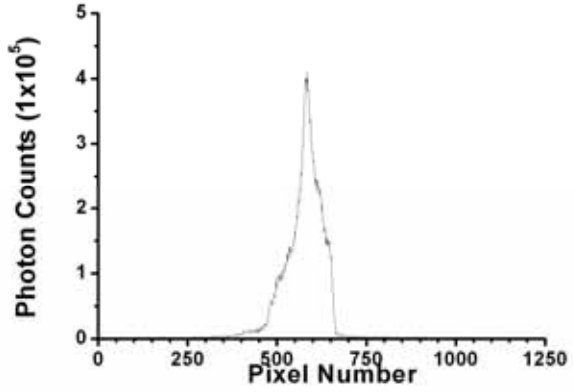
Intensity along the y-axis obtained by binning on the x-axis

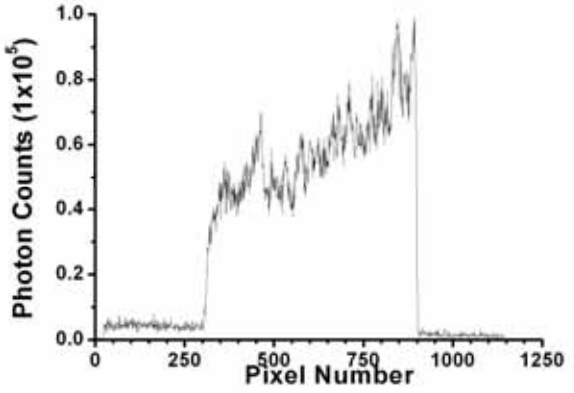
Filament polarity : normal
20 degree plane anode
FWHM : **~ 4 mm**





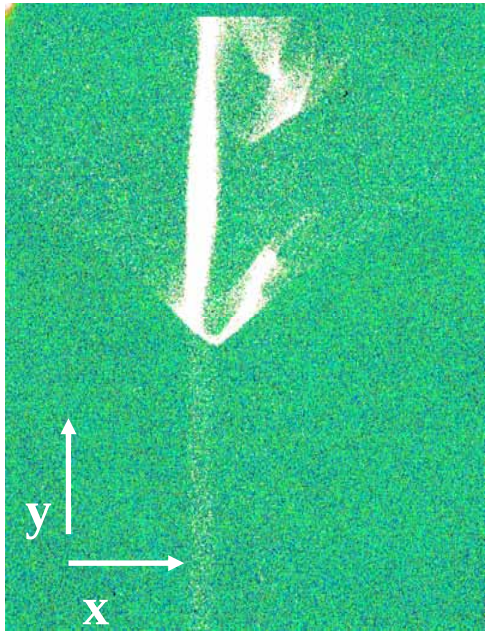
Filament polarity : reversed
20 degree plane anode
FWHM : **~ 4 mm**



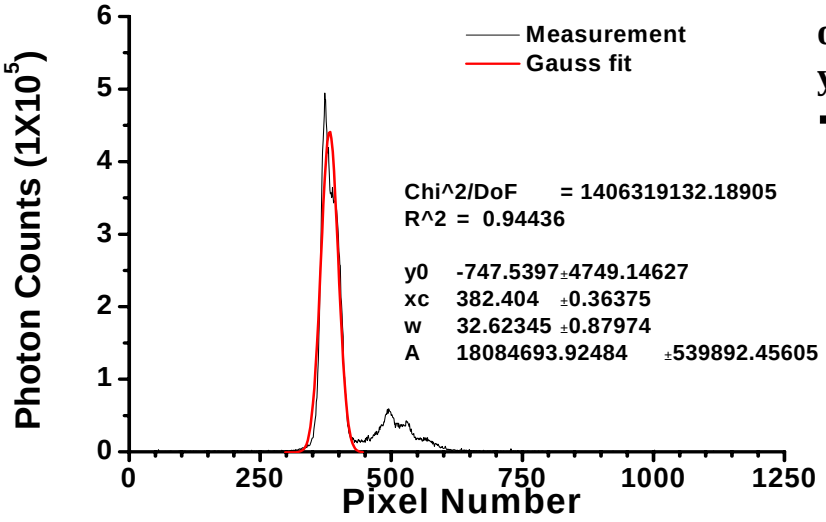


X-ray image from a pinhole camera

CCD-427
Filament polarity : reversed
20 degree focusing anode

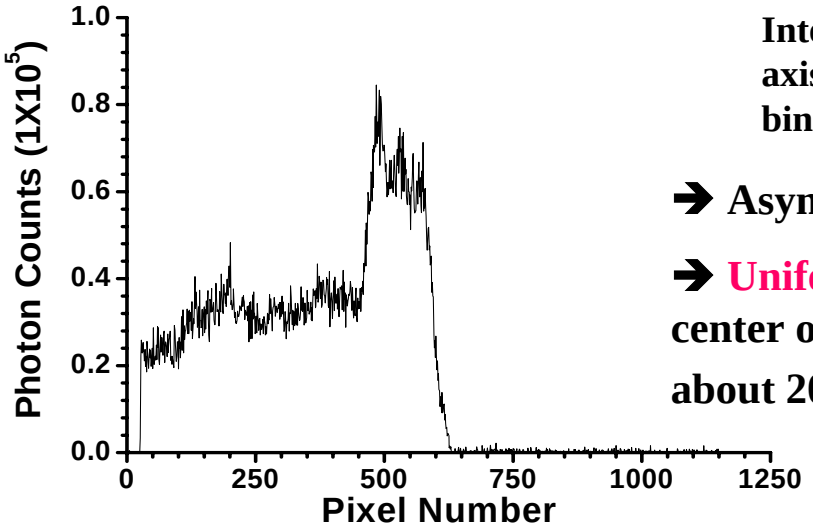


Ground + Filament



Intensity along the x-axis obtained by binning on the y-axis

➔ **FWHM : ~ 0.73 mm**

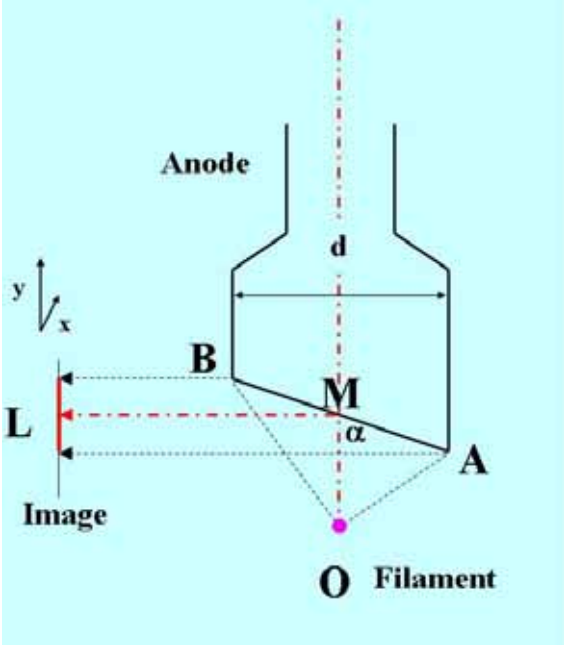


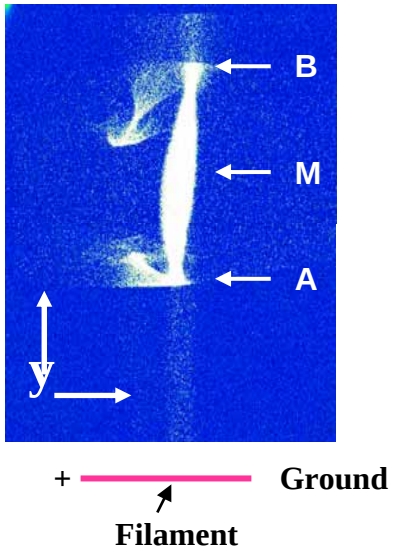
Intensity along the y-axis obtained by binning on the x-axis

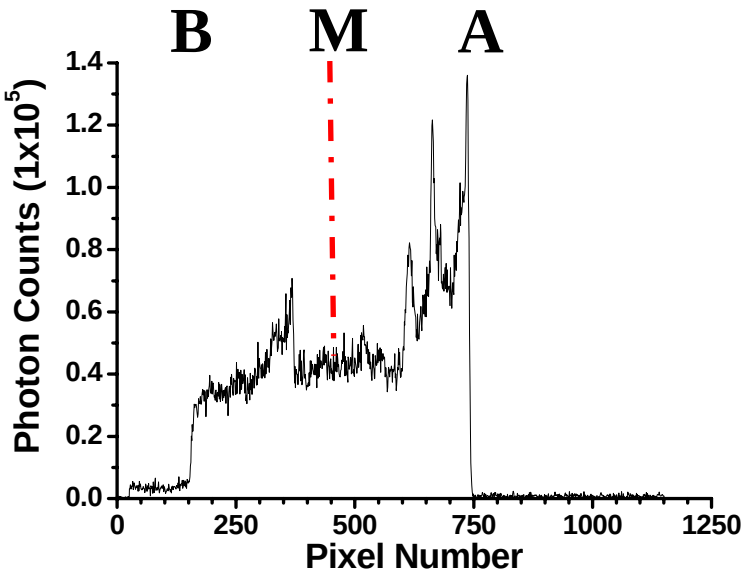
➔ **Asymmetric**

➔ **Uniform region around the center of the image : Width of about 200 pixels or 4.5 mm.**

Intensity distribution on the anode

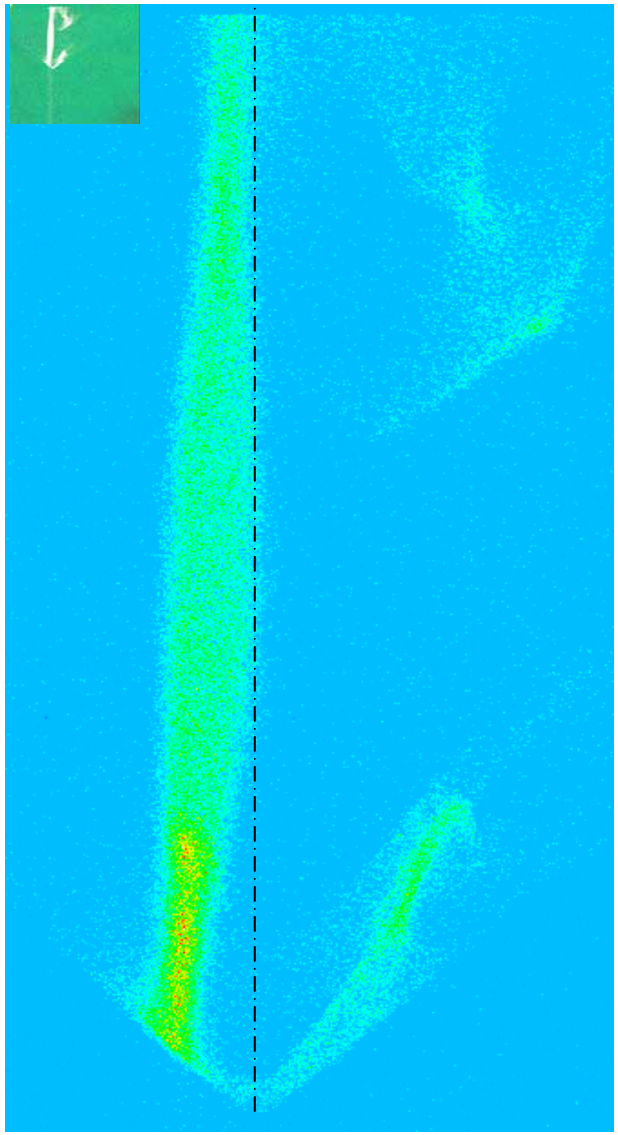




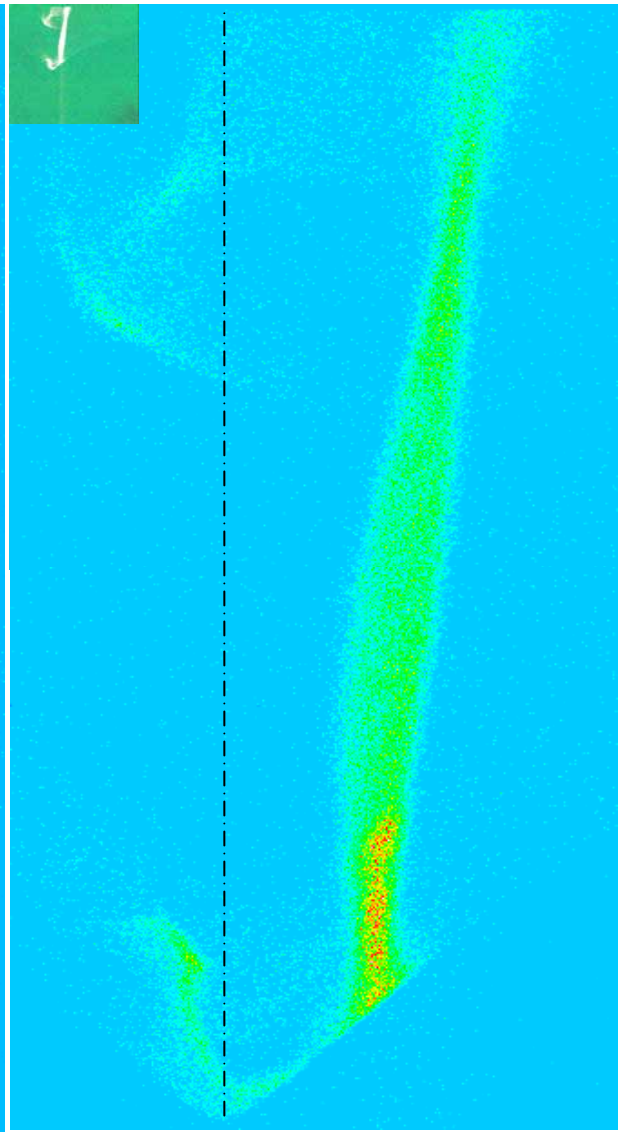


- The expected total length of the image is d· tan (α) = 14.6 mm, where d = 40 mm is the diameter of the anode and α = 20° is the angle of inclination of the anode surface.
- The measured length of the image is 13.5 mm

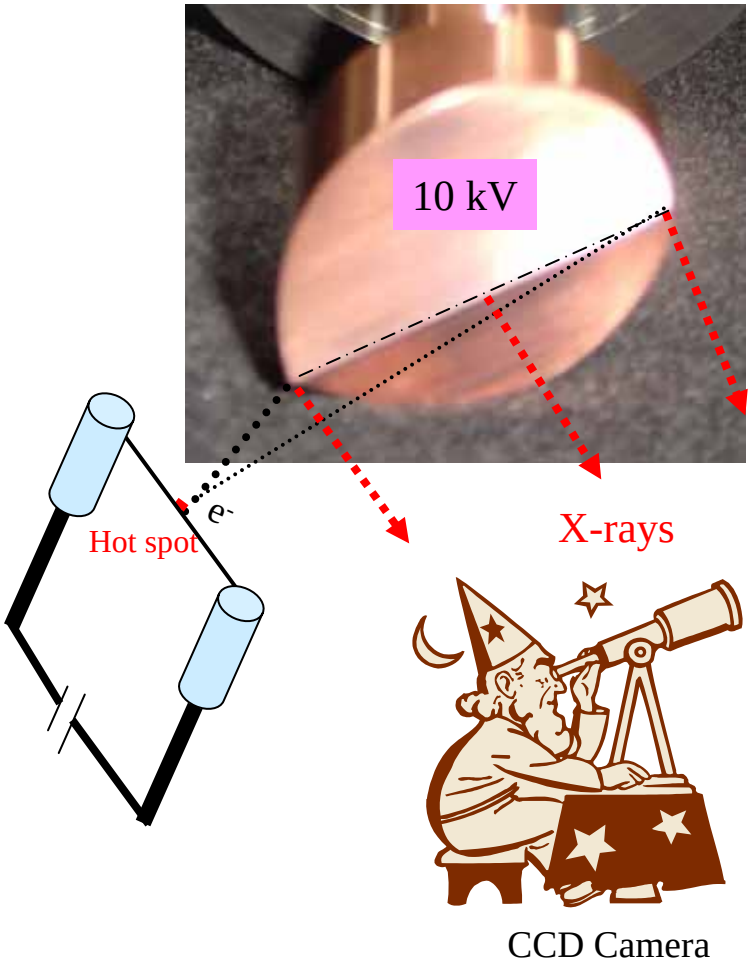
Detail view of the image for 20° focusing anode



Filament polarity : reversed

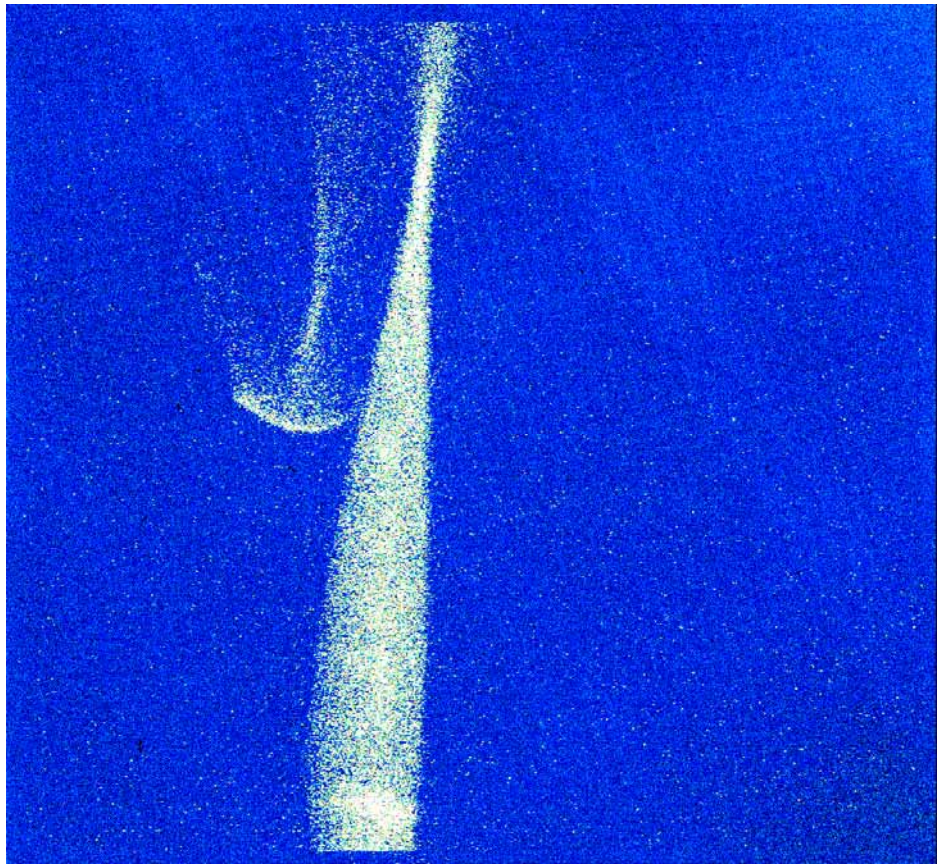


Filament polarity : normal

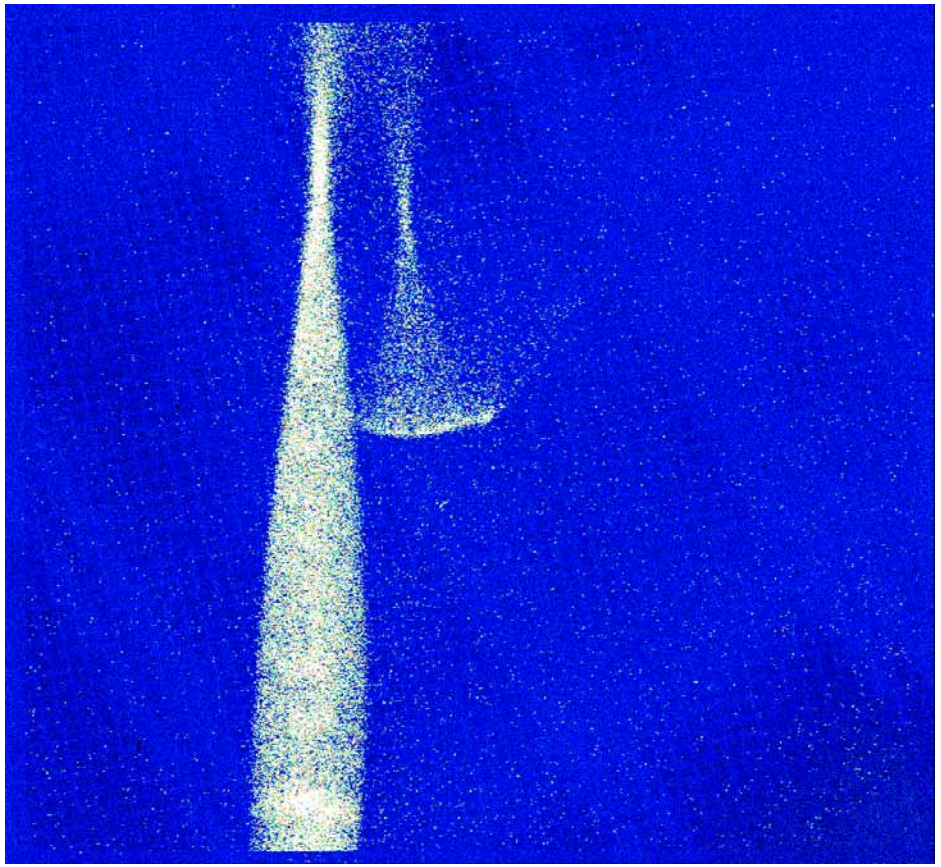


Electrons are emitted from narrow point at the center of the filament – hot spot

Detail view of the image for 45° planned anode



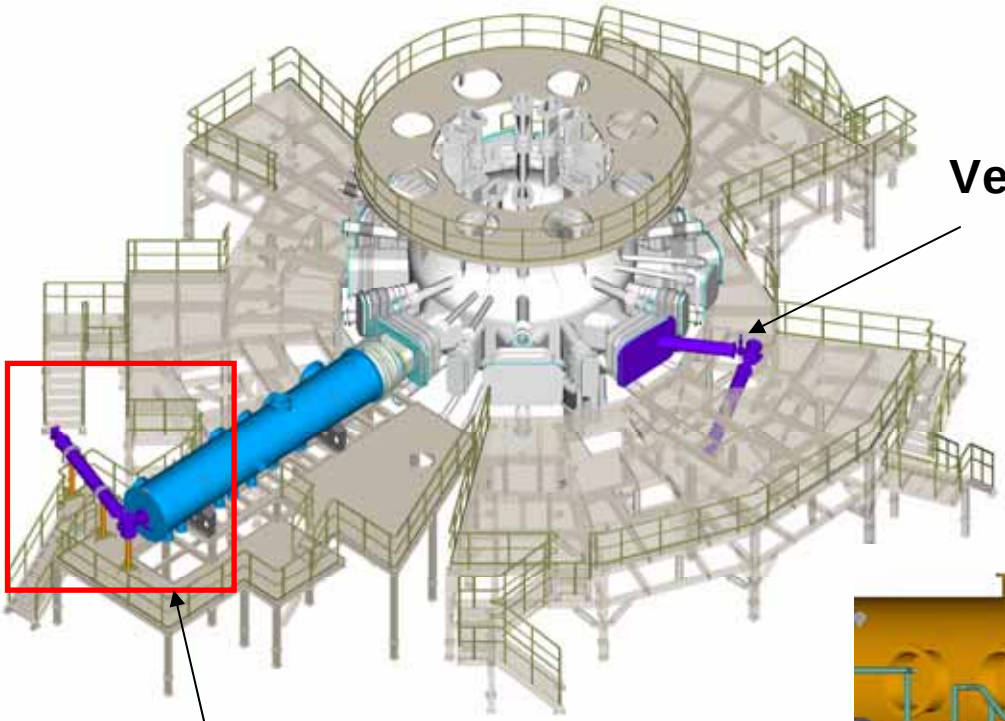
Filament polarity : normal

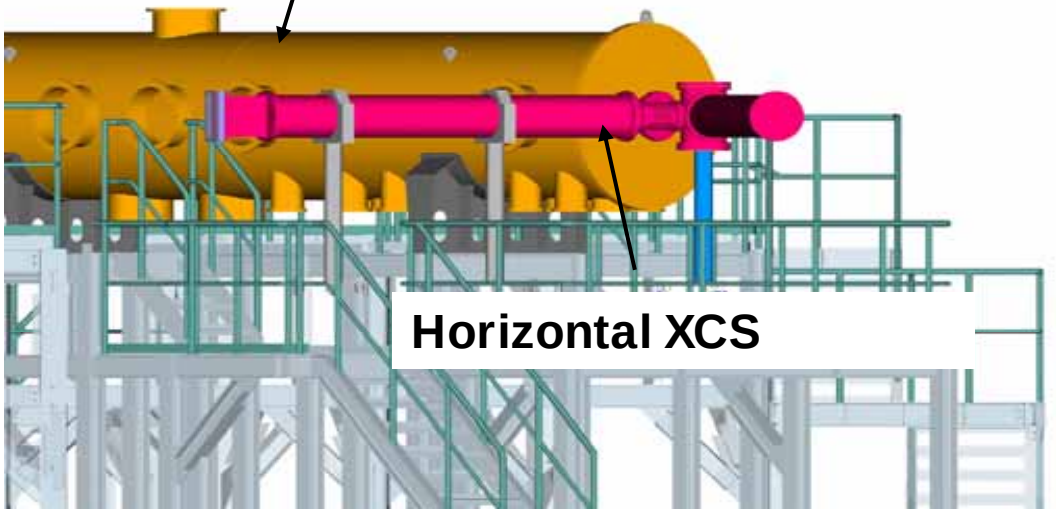


Filament polarity : reversed

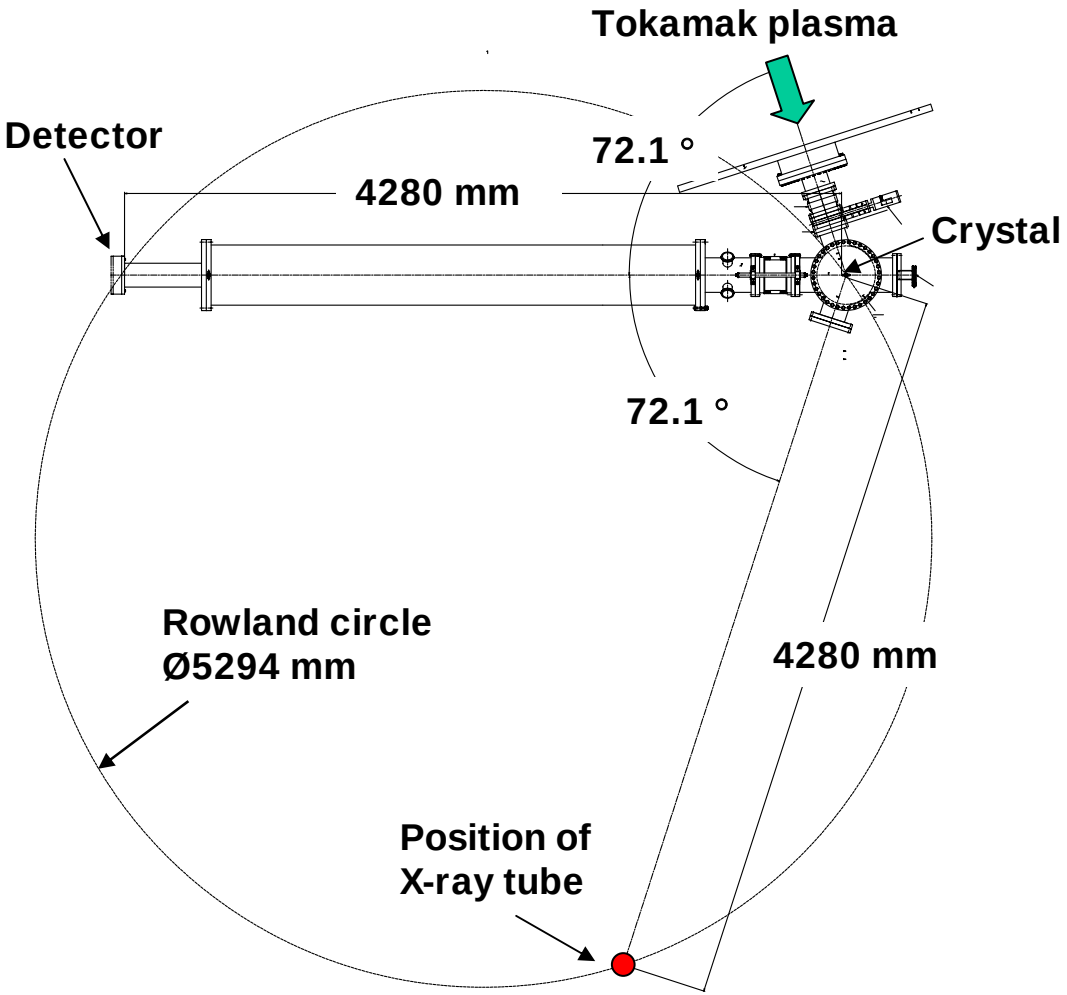
Expected total height of the anode image is d · tan (α) = 40 mm.
The height of the CCD chip is 25. 9 mm so that a full image of the anode from the pinhole camera can not be shown – upper half image is shown

Arrangement of Horizontal XCS in KSTAR





Horizontal X-ray Crystal Spectrometer



- Spherically bent quartz (1120) crystal
  - 2*d* spacing : 4.913 Å
  - Radius of curvature : 5294 mm
- 10 cm by 30 cm 2D detector
- Spectral parameters for heliumlike argon Ar XVII :
  - Resonance line λw :3.9494 Å
  - Forbidden line λz : 3.9944 Å
- Dimension of spectrometer
  - Bragg angle $\theta w = 53.594°$
  - Crystal to plasma center distance : 12842 mm
  - Length of crystal detector arm : 4280 mm
  - Demagnification : 3
  - Sagittal focal length : 13931 mm

Technical issues for calibration of the XCS

- 2D detector, the crystal and the x-ray source should be positioned on the Rowland circle in order to expose the best focused x-rays on the detector.

- To get the line focused x-ray source, a slit with a gap of about 50 μm is positioned in front of the x-ray tube, which experienced in the position calibration using a 55Fe source in a laboratory.➔ to investigate the spatial resolution in the detector required for the image measurement.

- Additional optic system for scanning x-rays is needed for the exposure of the line focused x-rays on the full area of the detector ➔ for both of the position calibration and the examination of the uniformity in the detector.

Summary and future work

- It was found that the x-ray image was a slightly curved line perpendicular to the filament, which is similar with the previous measurements.

- The orientation of the anode image changed with the polarity of magnetic field due to the filament current, which is similar with the previous measurements

- The x-ray image from the x-ray tube had a uniform region near the center region and the width of the image was reduced up to about 1.0 mm, which was much improved as compared with the previous experimental results.

- From experimental results, it was found that the width and the length of the image depended upon the thermionic emission current distribution along the filament and the diameter of the anode, respectively.

- The further study on the geometry between the filament and anode in the x-ray tube will be carried out to explain the improvements in the image characteristics of the x-ray tube, which is essential to get a further improved line focused x-rays for the calibration of the KSTAR XCS.