# Development of Advantage X-ray Imaging Crystal Spectrometer Utilizing a Large-area Proportional Count for KSTAR


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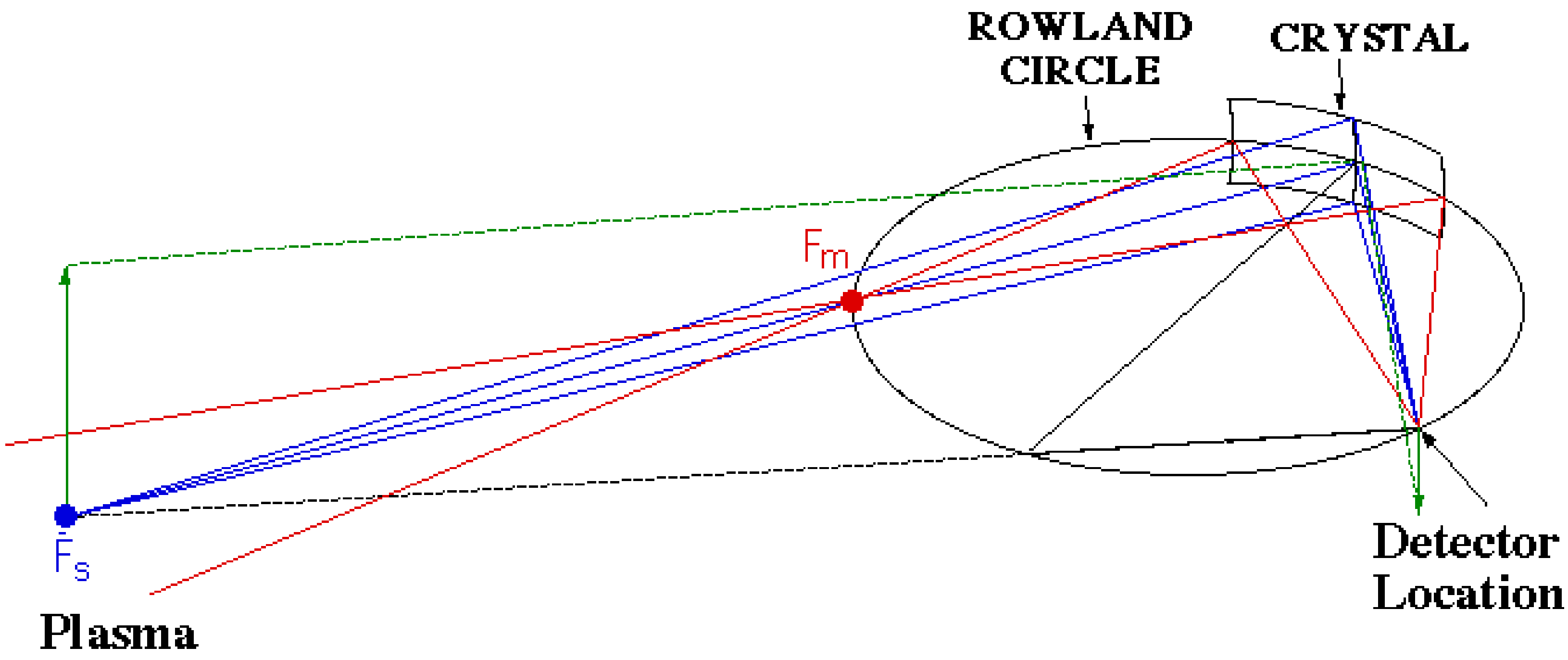
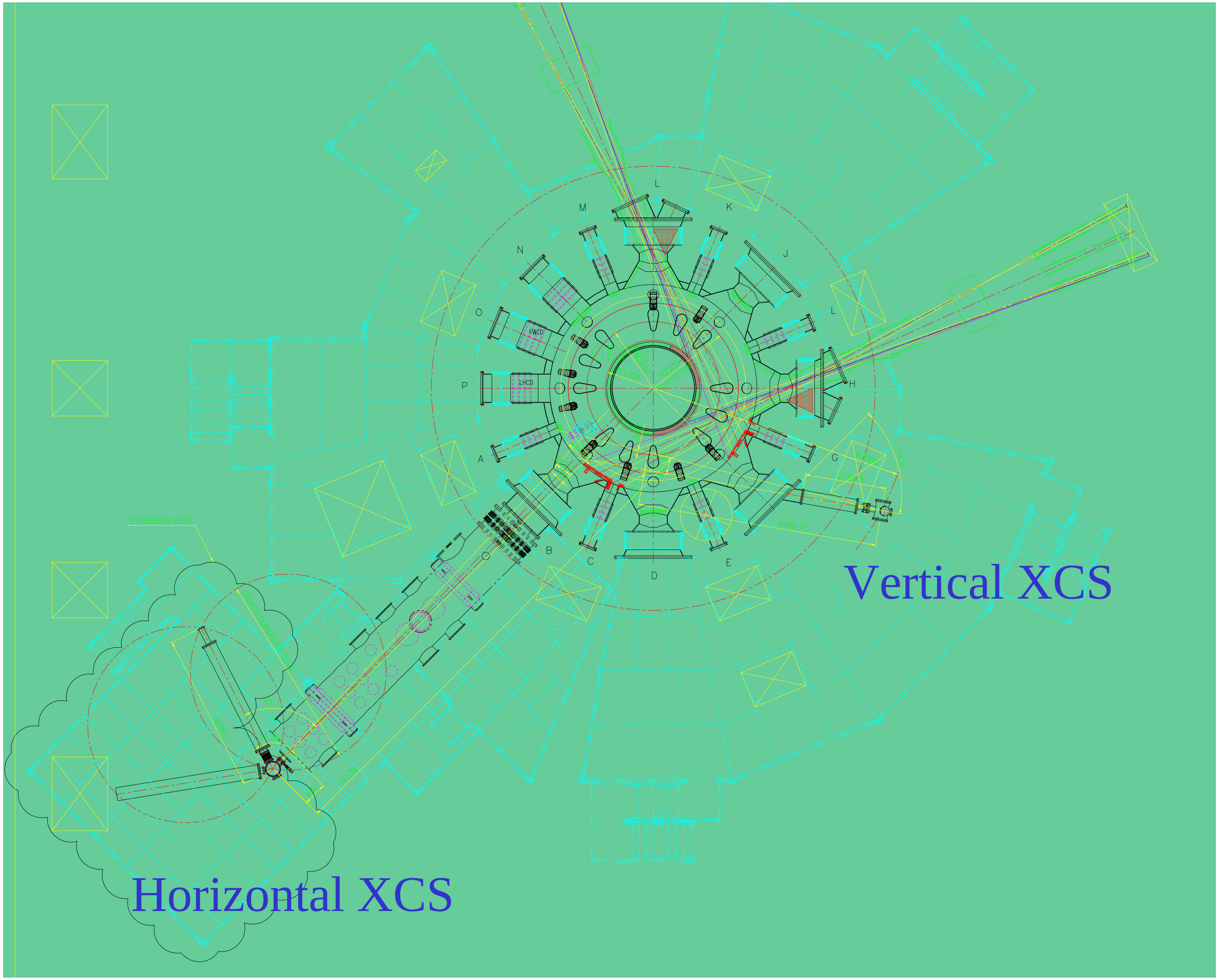
# KSTAR Advanced X-ray Imaging Spectrometer




Due to the astigmatism of a spherical crystal two images, $\mathbf{F_m}$ and $\mathbf{F_s}$, of a point source *located on the Rowland circle at the position of the detector* are formed by the meridional and sagittal rays. For a Bragg angle of 45°, $\mathbf{F_s}$ is at infinity, so that - if the rays are reversed - a parallel bundle of X-rays emerging from the plasma is focused to a point on the detector. Parallel bundles, which are oblique to the main (horizontal) diffraction plane, are focused to points above or below the horizontal plane.

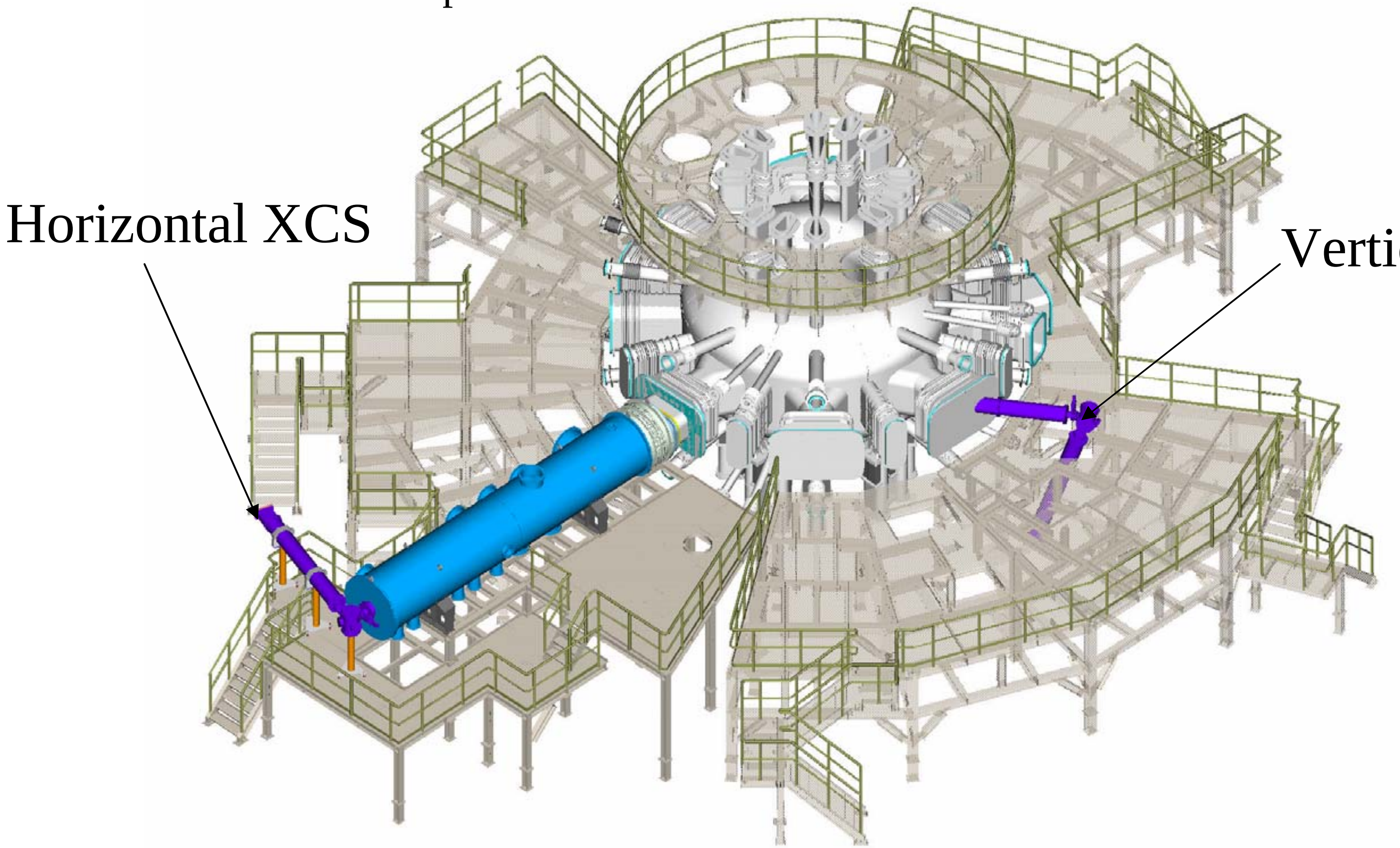
# X-ray Crystal Spectrometer (XCS)



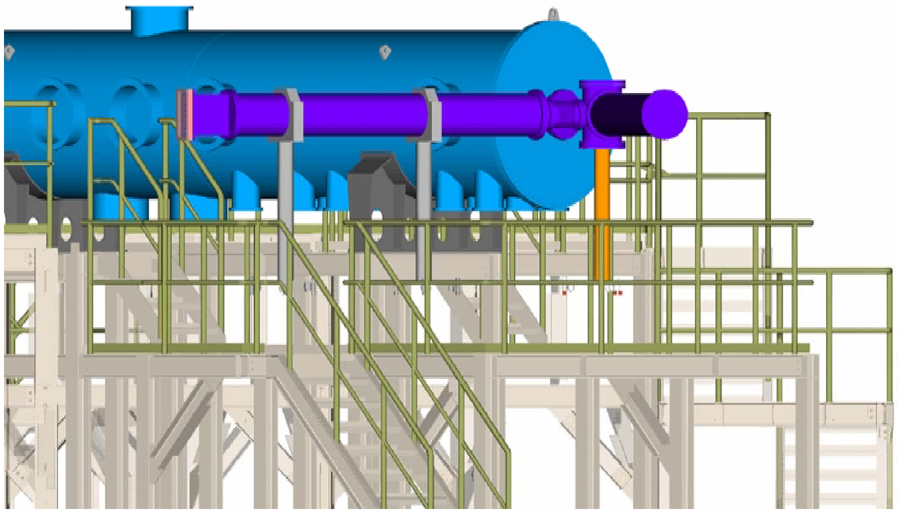
# KSTAR XCS

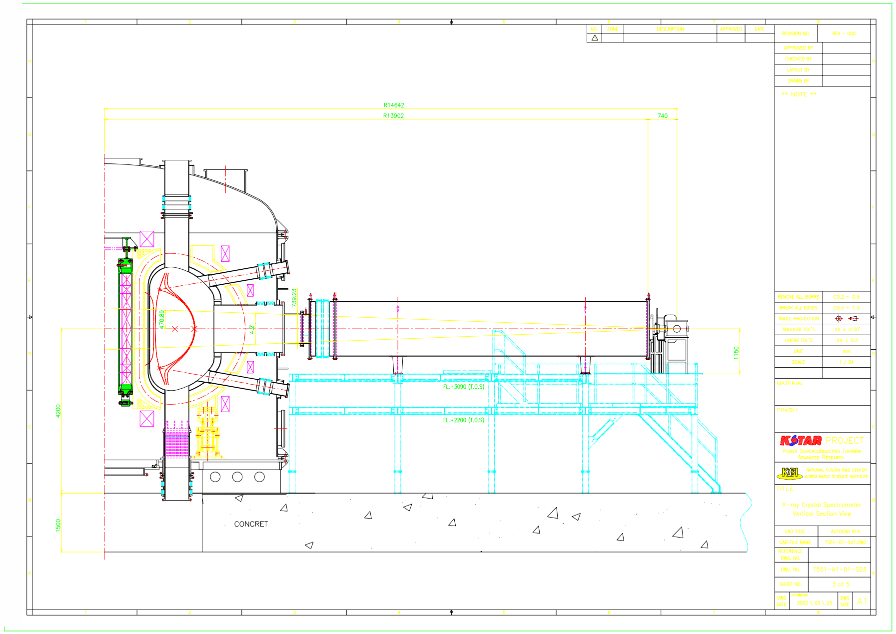
Horizontal XCS
- Bay B
- Spatial resolution perpendicular to the horizontal mid-plane

Vertical XCS
- Bay F
- Spatial resolution in the horizontal mid-plane



# Horizontal XCS





Maximum viewing vertical cross section : ± 47 cm

Plasma center – crystal distance : 14.6 m

Many detail drawings were generated

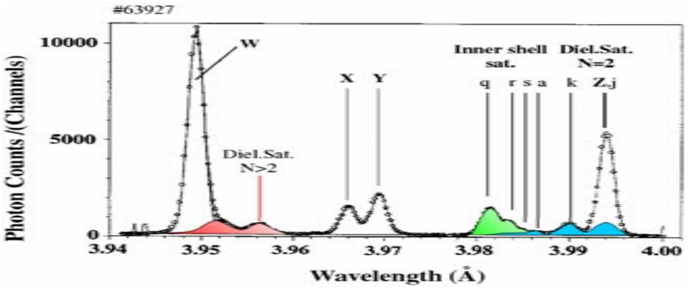
2d-spacing of 110 quartz crystal : 4.913 Å

$\lambda_w = 3.9494$ Å $\qquad \theta_w = 53.50°$

$\lambda_z = 3.9944$ Å $\qquad \theta_z = 54.392°$

$\theta_{avg} = 53.946°$ $\qquad \Delta\theta = \theta_z - \theta_w = 0.892°$

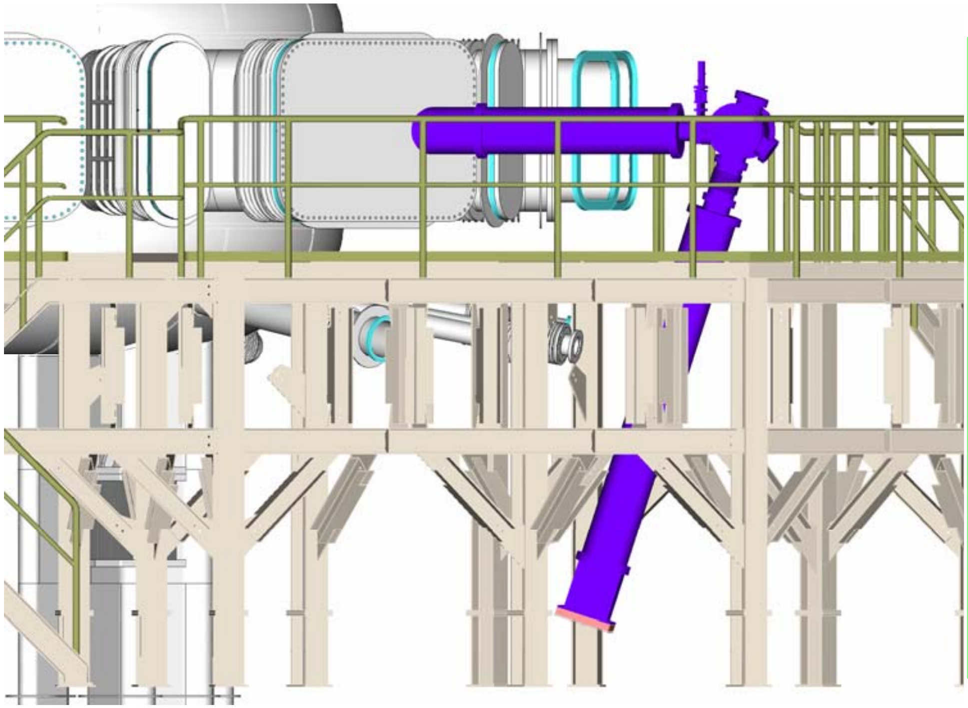
Radius of crystal curvature : 5294 mm

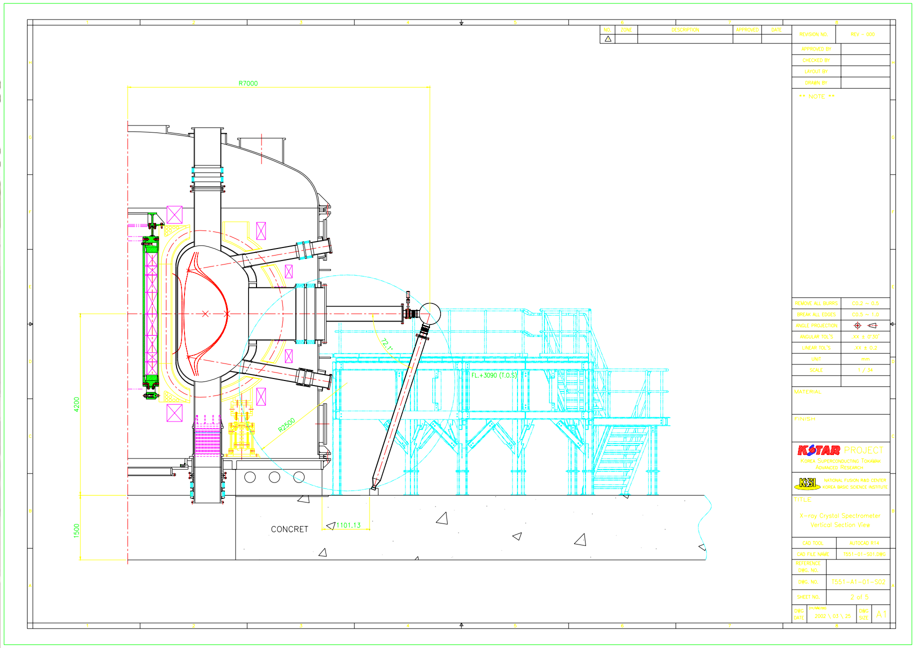



| Key | Transition | Wavelength (Å)* |
|---|---|---|
| W | $1s^2\,{}^1S_0 - 1s2p\,{}^1P_1$ | 3.9494 |
| X | $1s^2\,{}^1S_0 - 1s2p\,{}^3P_2$ | 3.9661 |
| Y | $1s^2\,{}^1S_0 - 1s2p\,{}^3P_1$ | 3.9696 |
| q | $1s^22s\,{}^2S_{1/2} - 1s2s2p\,({}^1P)\,{}^2P_{3/2}$ | 3.9815 |
| r | $1s^22s\,{}^2S_{1/2} - 1s2s2p\,({}^1P)\,{}^2P_{1/2}$ | 3.9836 |
| a | $1s^22p\,{}^2P_{3/2} - 1s2p^2\,{}^2P_{3/2}$ | 3.9860 |
| k | $1s^22p\,{}^2P_{1/2} - 1s2p^2\,{}^2D_{3/2}$ | 3.9901 |
| j | $1s^22p\,{}^2P_{3/2} - 1s2p^2\,{}^2D_{5/2}$ | 3.9941 |
| Z | $1s^2\,{}^1S_0 - 1s2s\,{}^3S_1$ | 3.9944 |

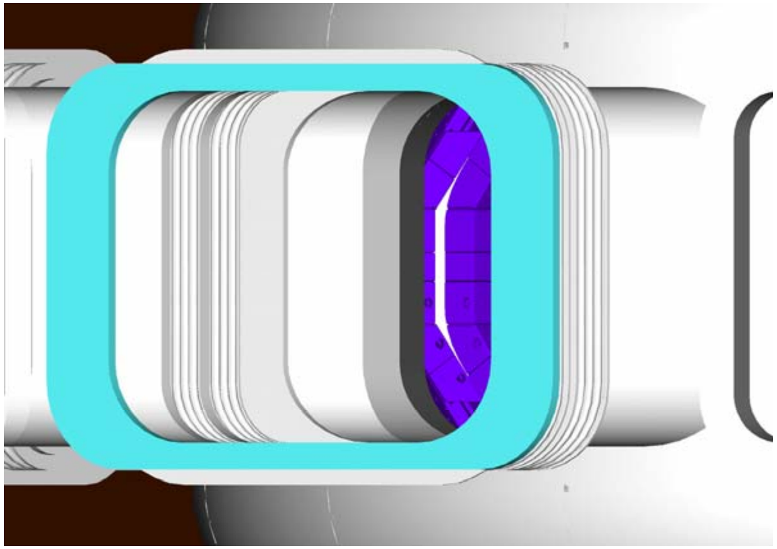
* Theory by Vainshtein and Safranova

# Vertical XCS



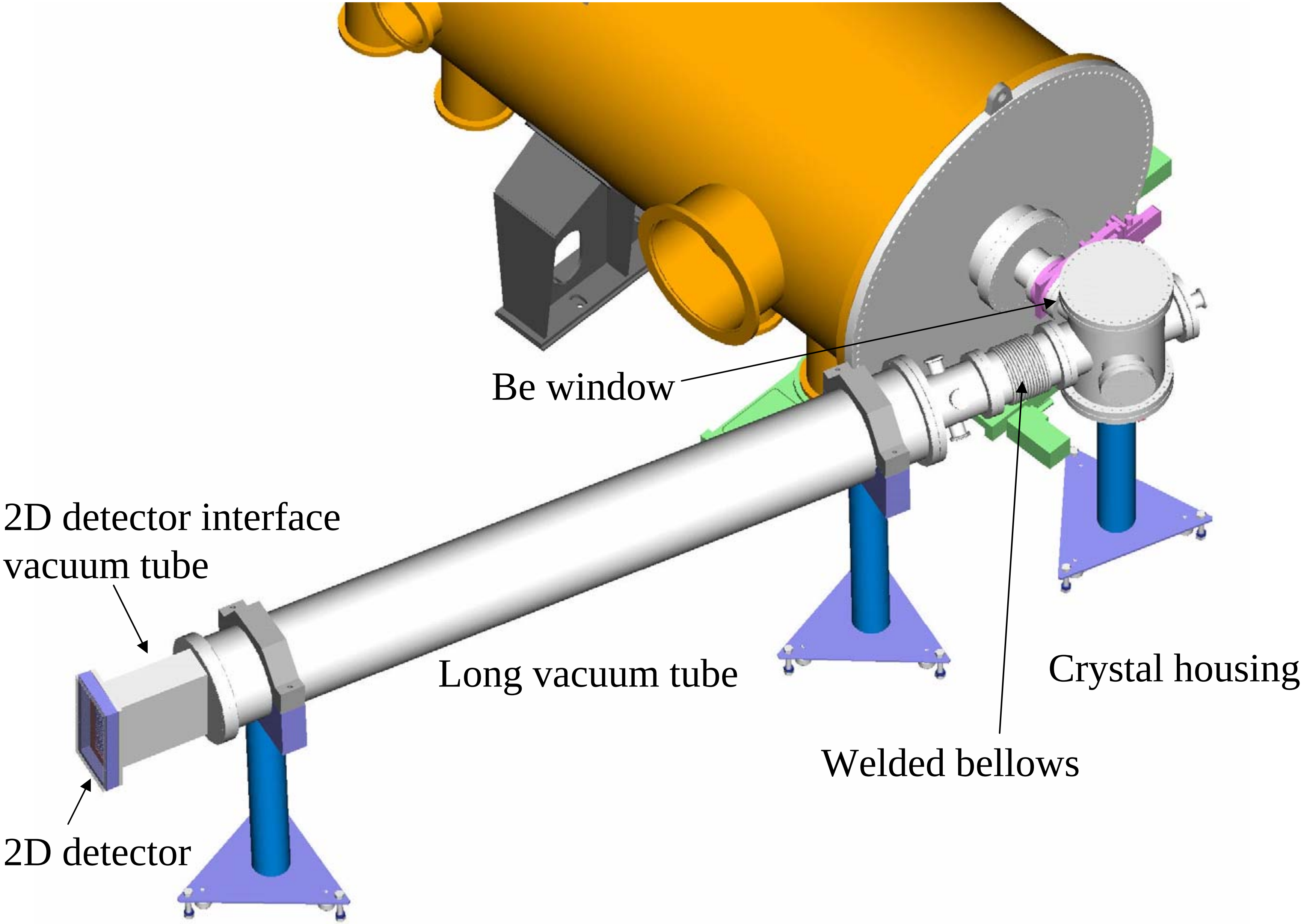



Vertical viewing cross section : ± 50 cm
Plasma center – crystal distance : 7.0 m

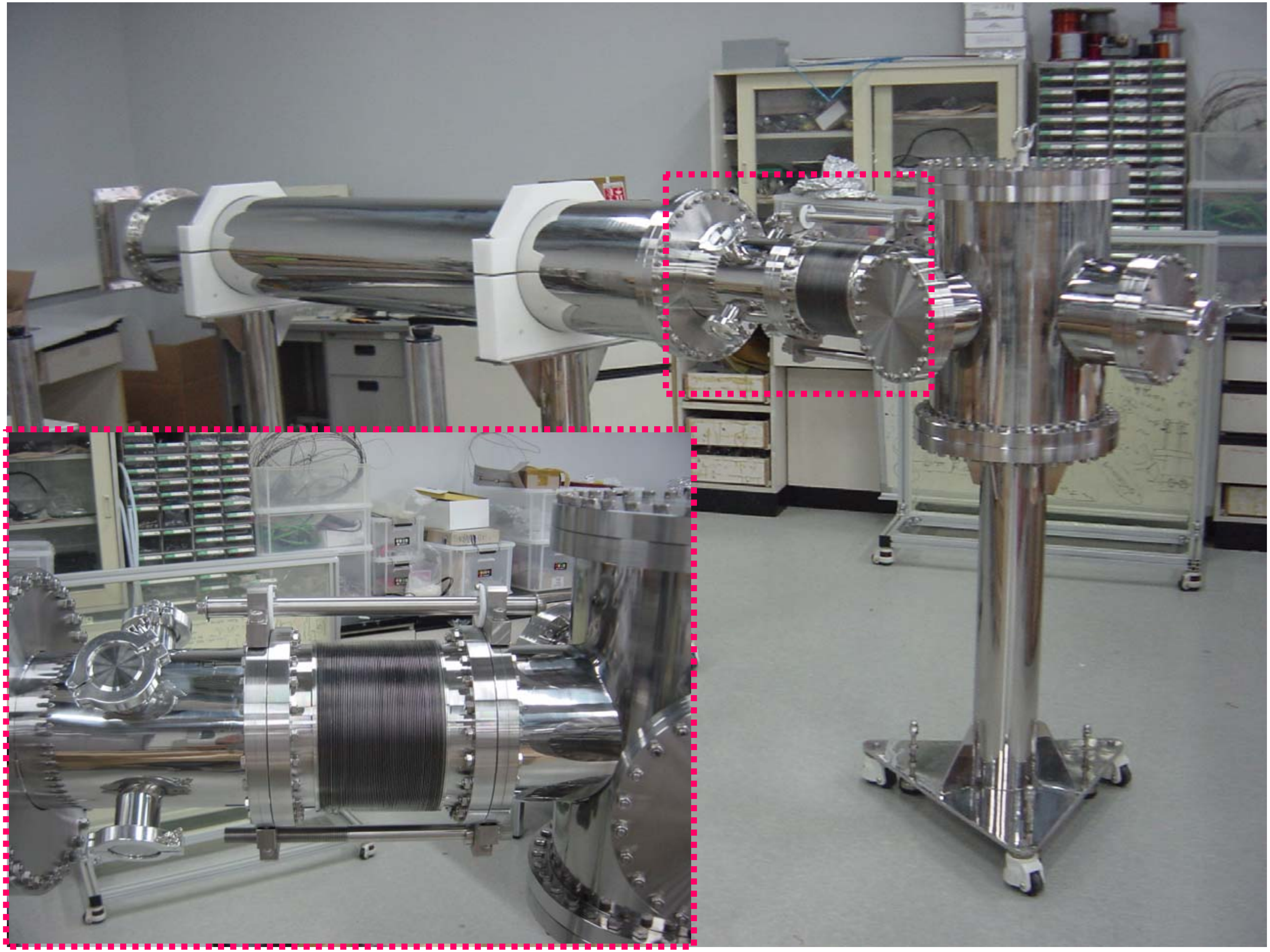


Inside view from crystal

# Horizontal XCS Layout



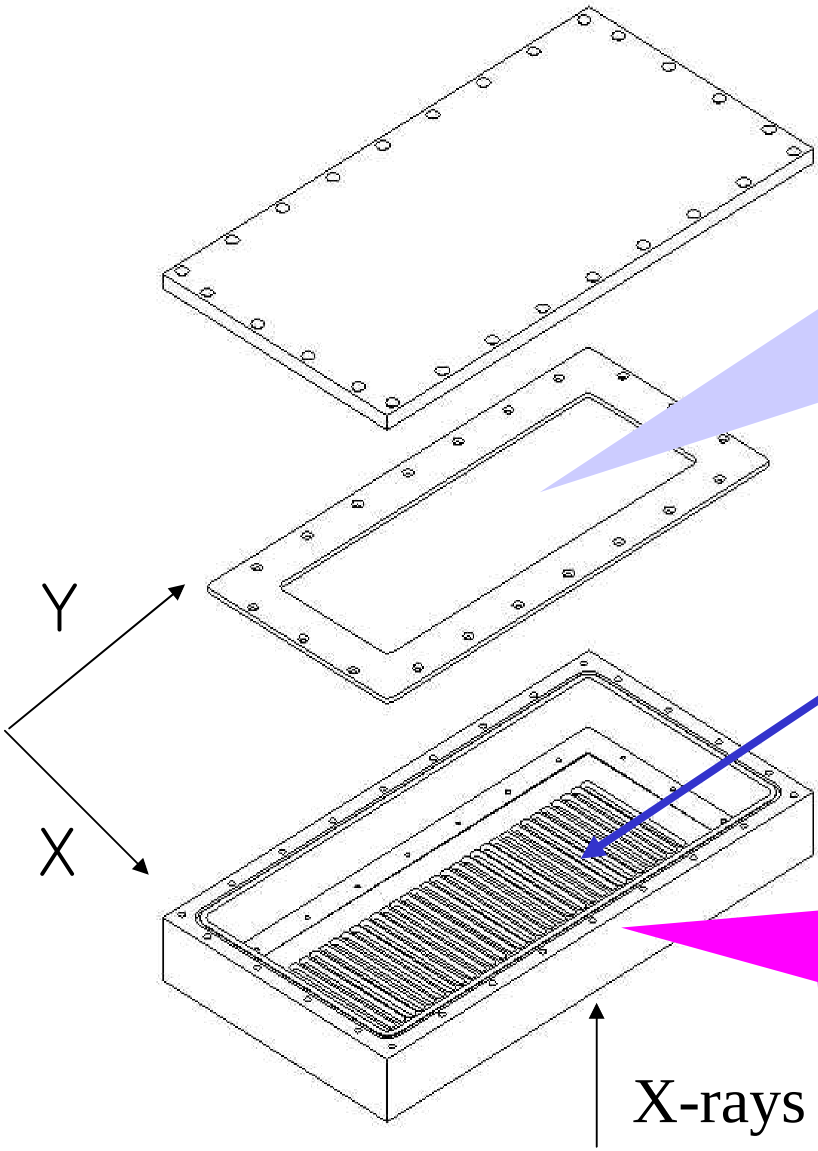
# KSTAR Fabrication Status of Horizontal XCS



# Vacuum Leak Test of XCS


The measured leak rate of the spectrometer was below
5.0 x 10-10 mbar liter/s, which satisfies the KSTAR vacuum requirement.

# Design of 2D detector




Upper cathode - Cu strips

spectral resolution on X-axis

Anode - wires

Lower cathode – wires

spatial resolution on Y-axis

Be window

0.1 mm thick

110 mm by 330 mm

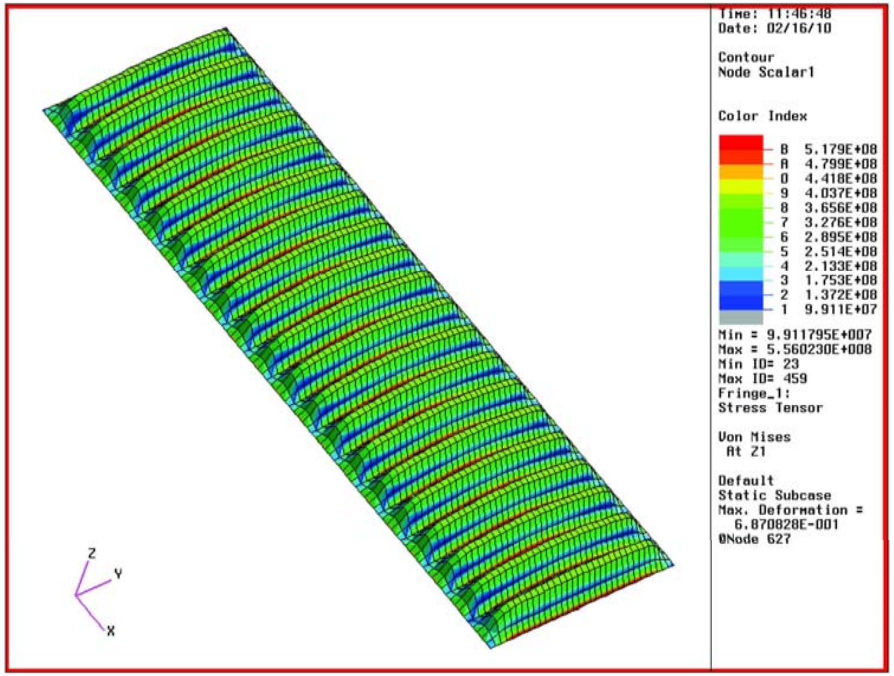
1 atm gas : Xenon 78%

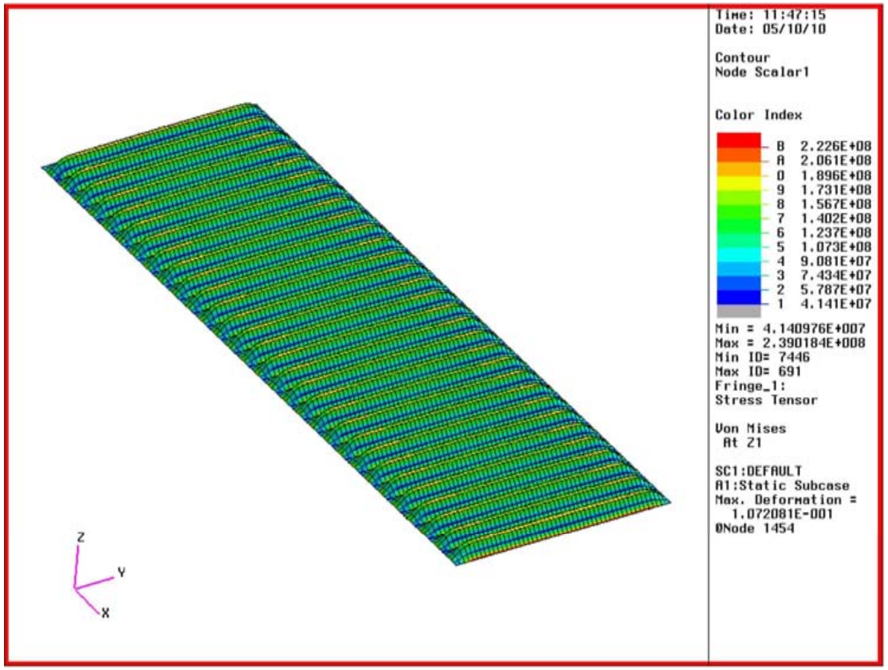
$C_2H_6$ 20%

$CF_4$ 2%

# Stress analysis – Be window

0.1 mm thick 110 mm by 330 mm Be window

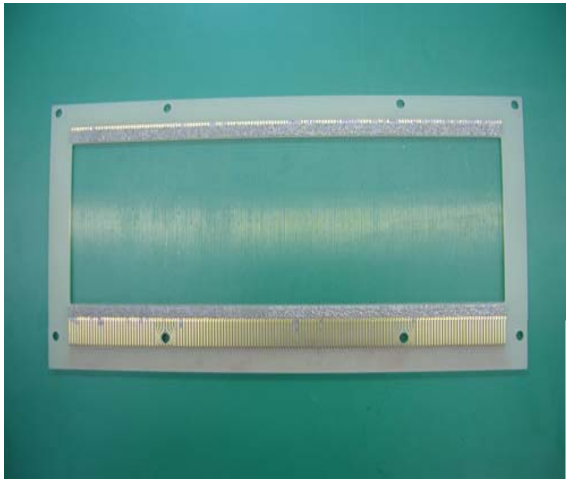


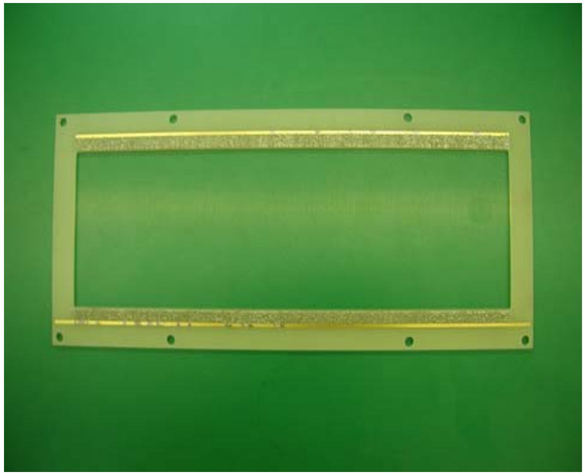

19 ribs 2 mm wide x 5 mm thick, Maximum stress 556 Mpa > 300 Mpa (limit) - not allowed

29 ribs 2 mm wide x 5 mm thick, Maximum stress 239 Mpa < 300 Mpa (limit) - allowed

# Components of 2D Detector



Lower cathode



Anode

Upper cathode

**Gold coated tungsten wire**

**30 μm in diameter**

**2 mm in separation**

**total number: 150**

**each 2 wires were tied and**

**total 75 delay lines**

**Total delay : 290 ns**

**Gold coated tungsten wire**

**10 μm in diameter**

**2 mm in separation**

**total number:150**

**1.7 mm wide copper strip**

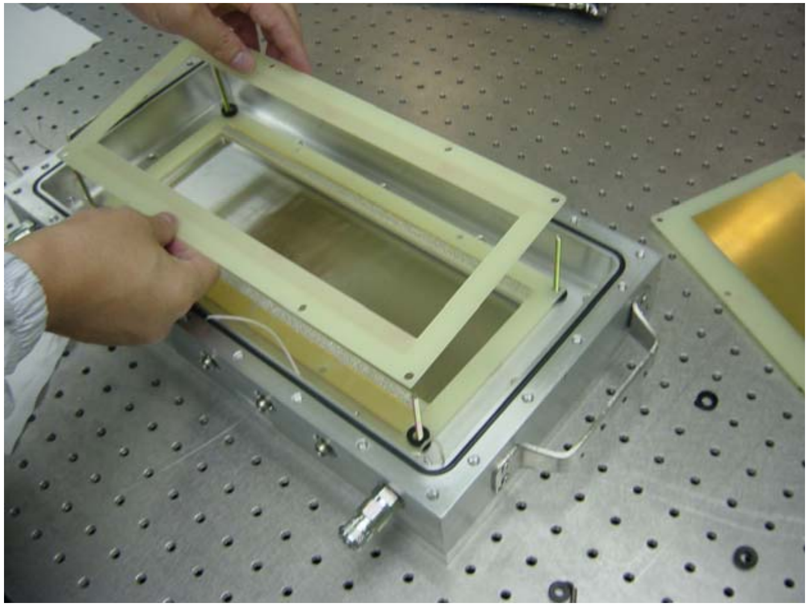
**2 mm in separation**

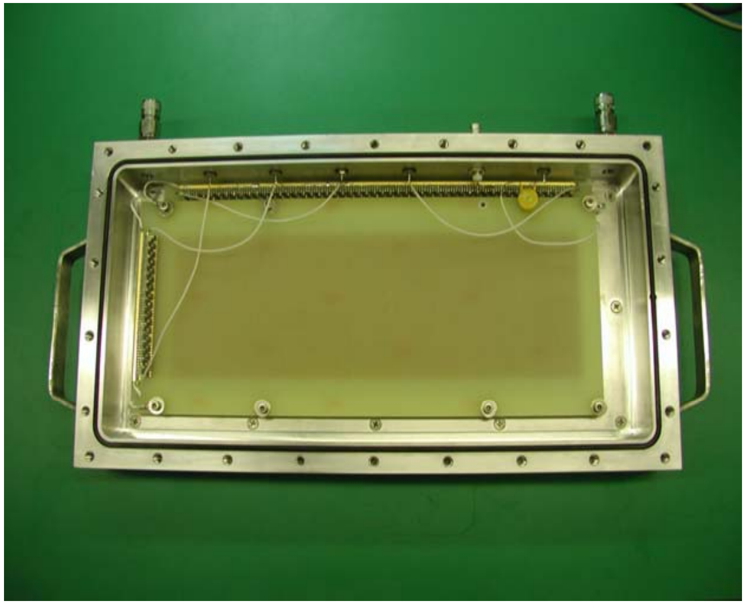
**total 50 strips**

**total 50 delay lines**

**Total delay : 290 ns**

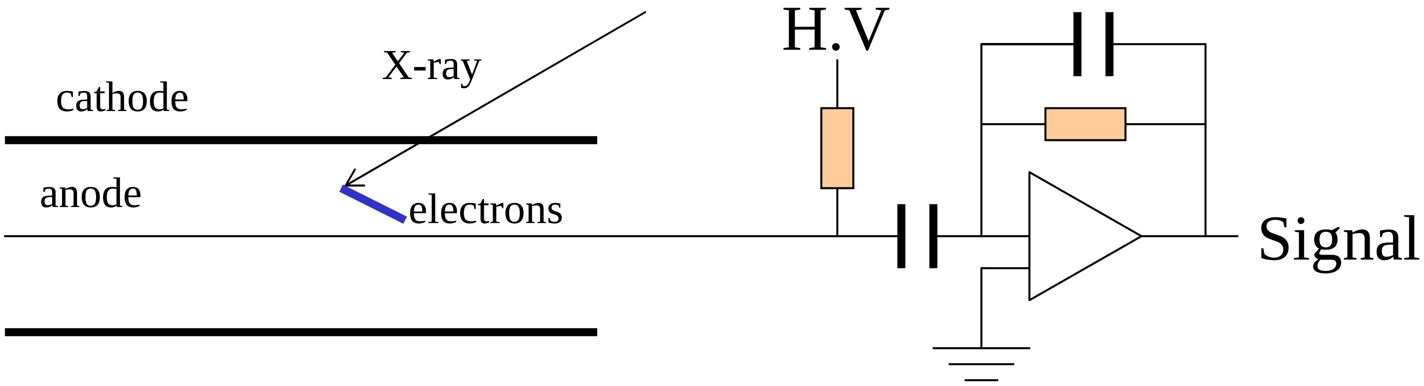
# Fabricated 2D Detector





Sensitive area: 100 mm (X-axis)
300 mm (Y-axis)
Entrance window : 100 μm Be foil
29 supporting ribs : 2 mm wide
5 mm thick
Gas mixture : Xenon 78%
$C_2H_6$ 20%
$CF_4$ 2%

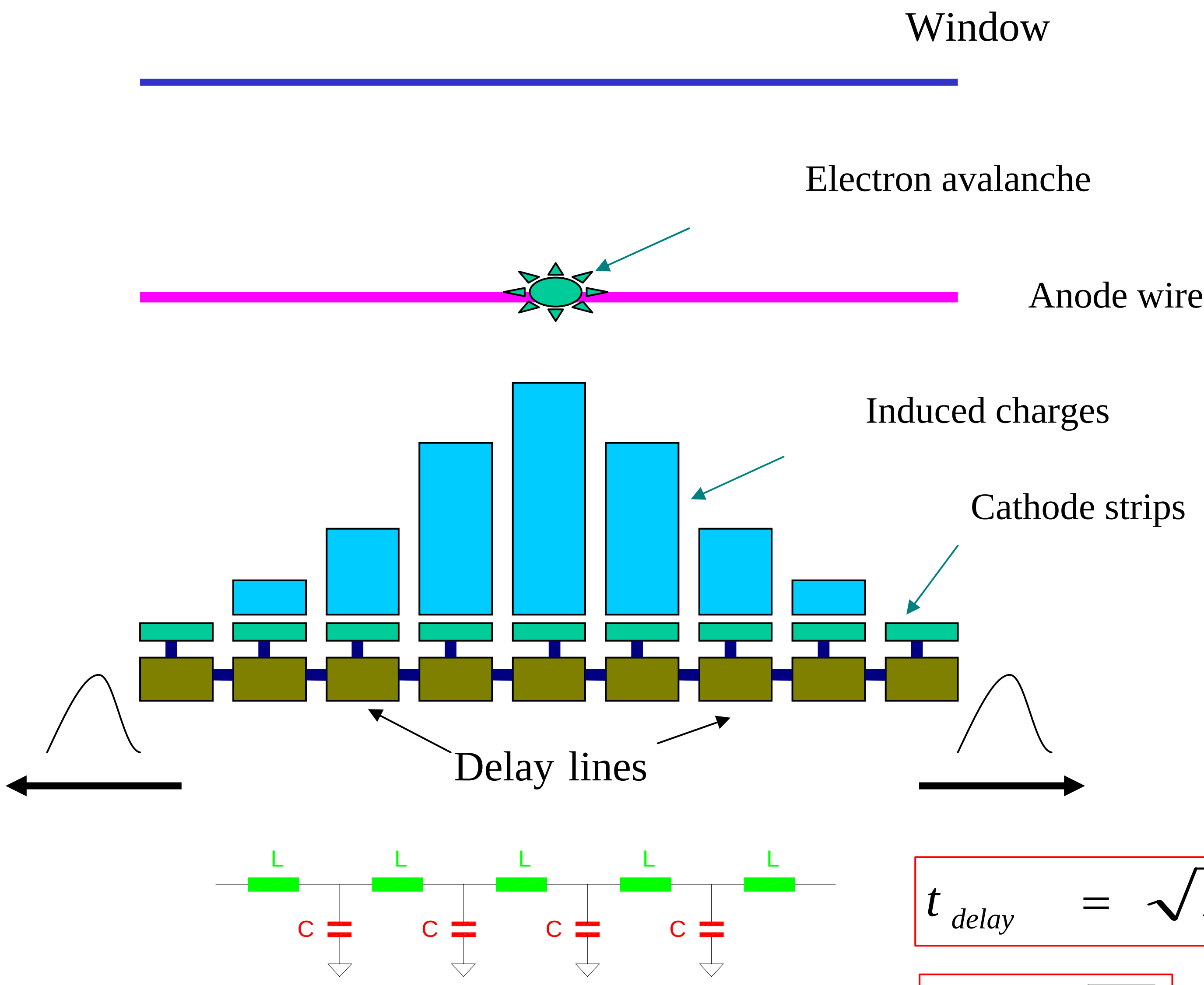
# X-ray Detection Principle




Mainly photo-electric effect
(low energy X-ray)

~300 ions and electrons produced per 8keV X-ray
(Ar, Kr, Xe gases for X-rays)

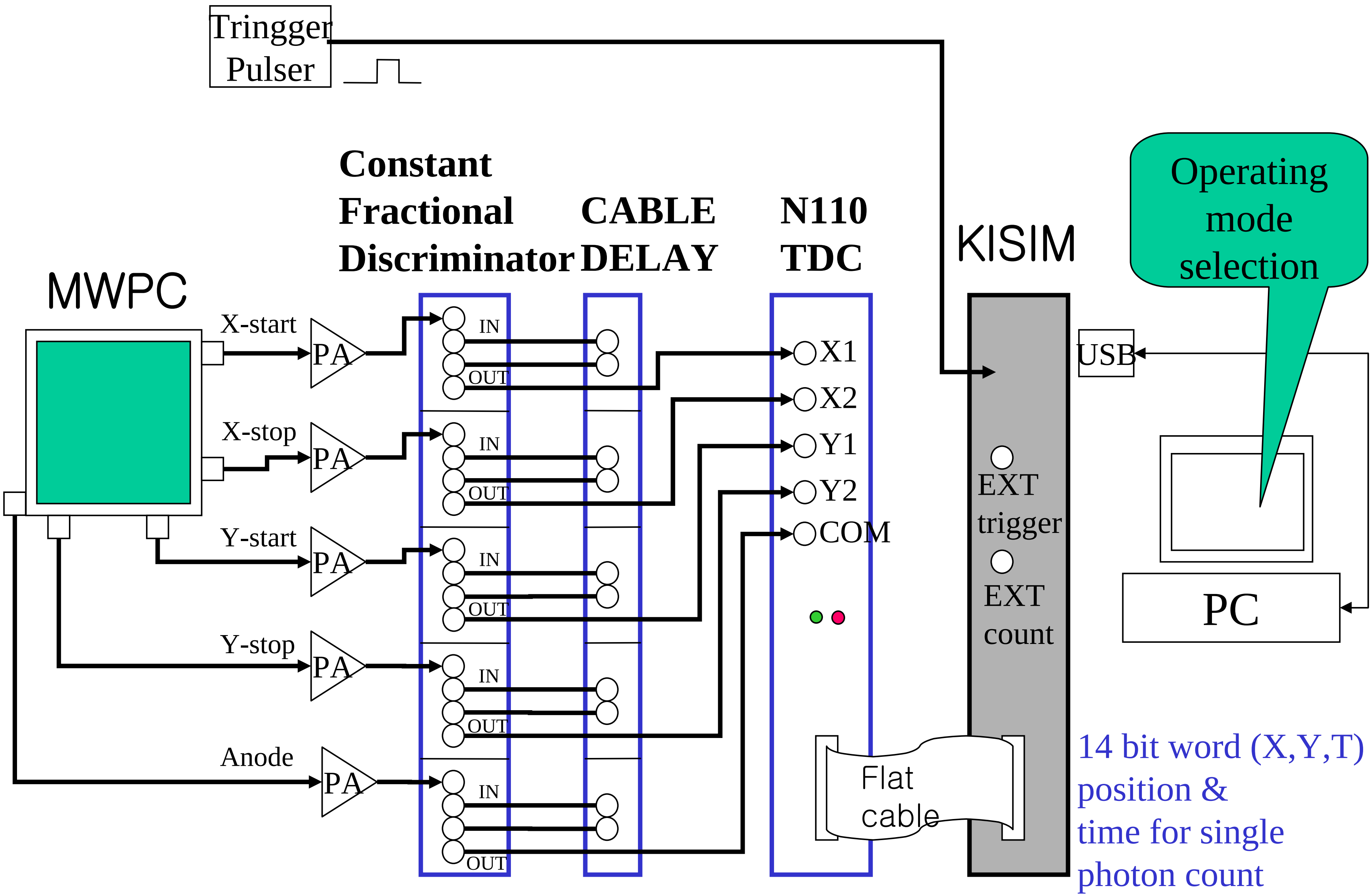
# Principle of Position Readout



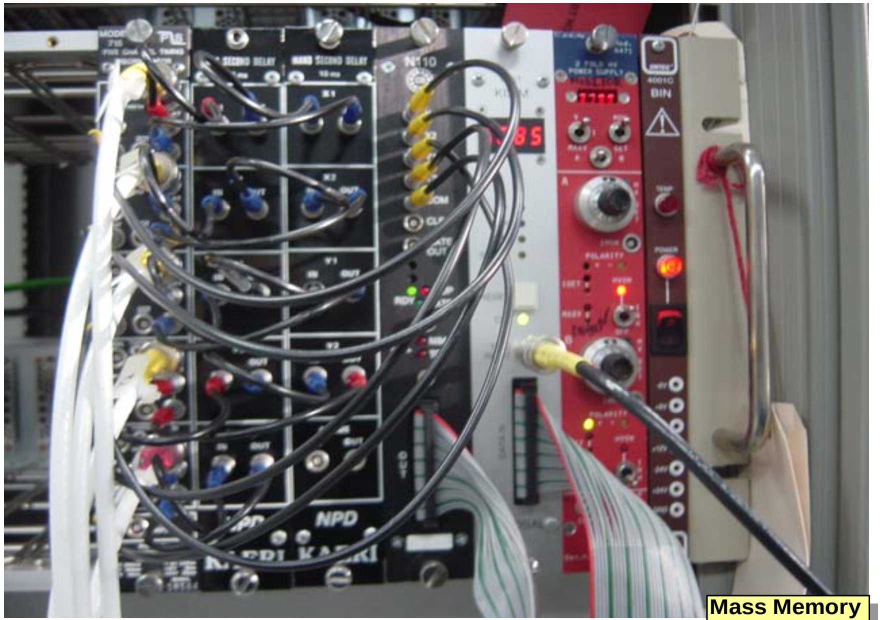

$$t_{delay} = \sqrt{LC}$$

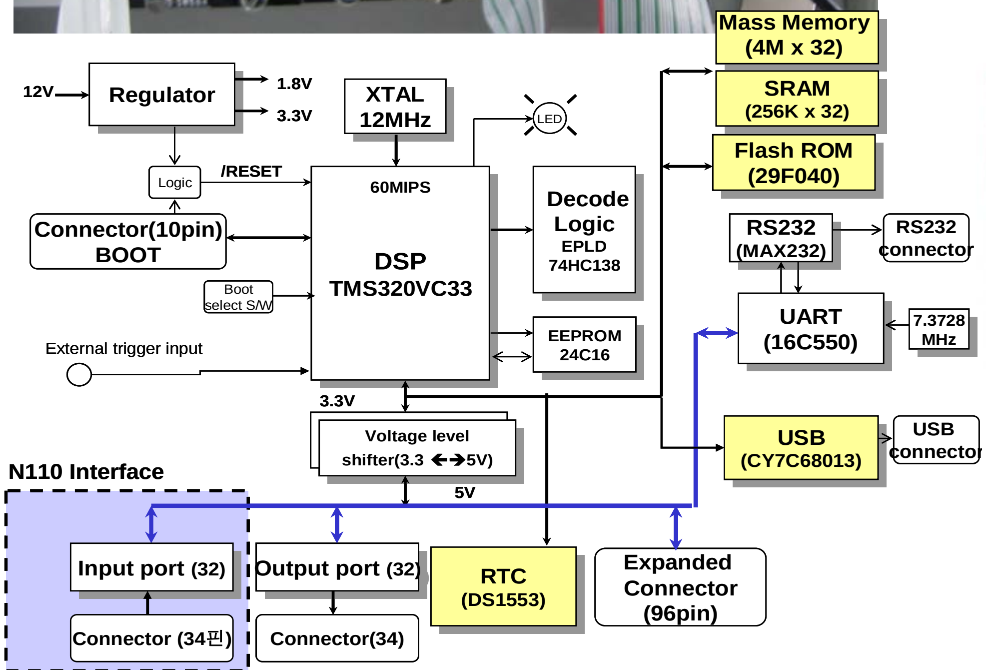
$$Z = \sqrt{\frac{L}{C}}$$

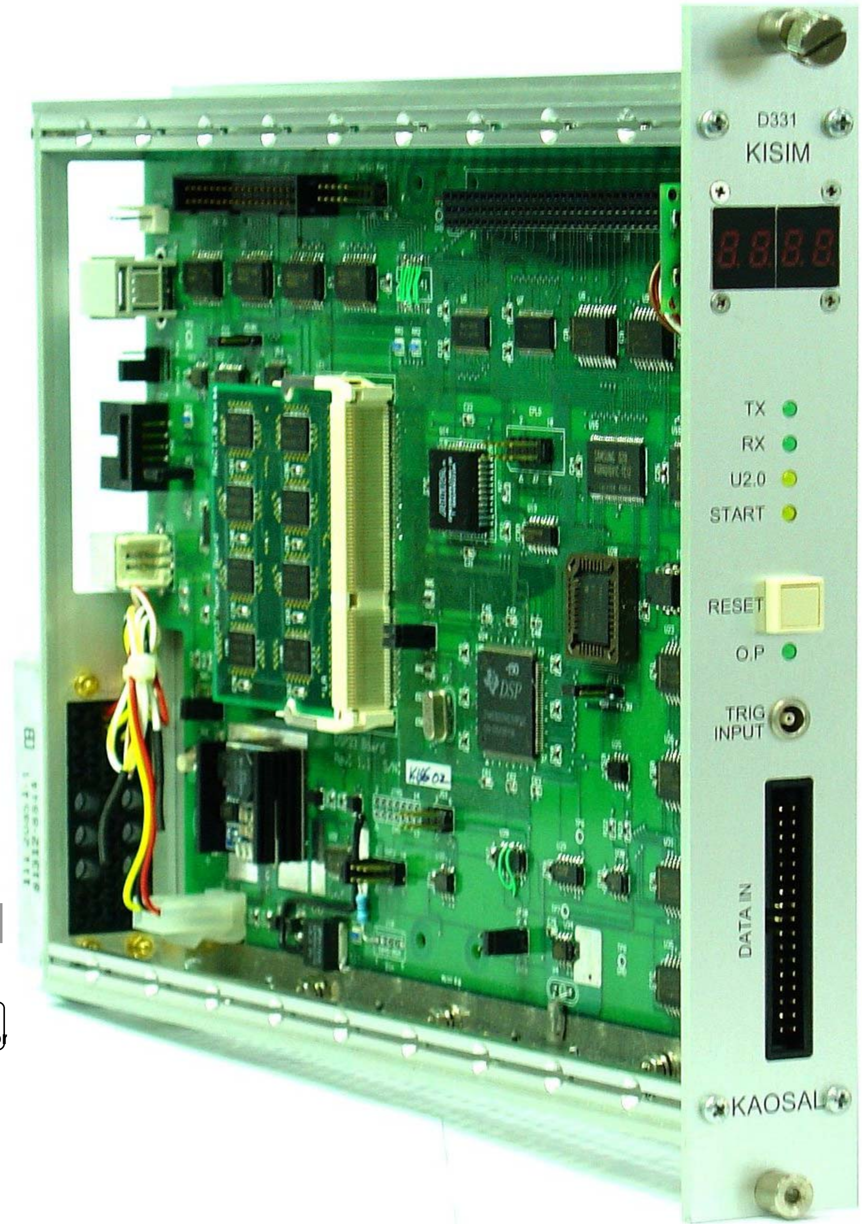
# Configuration of Data Acquisition



# Fabricated Electronics

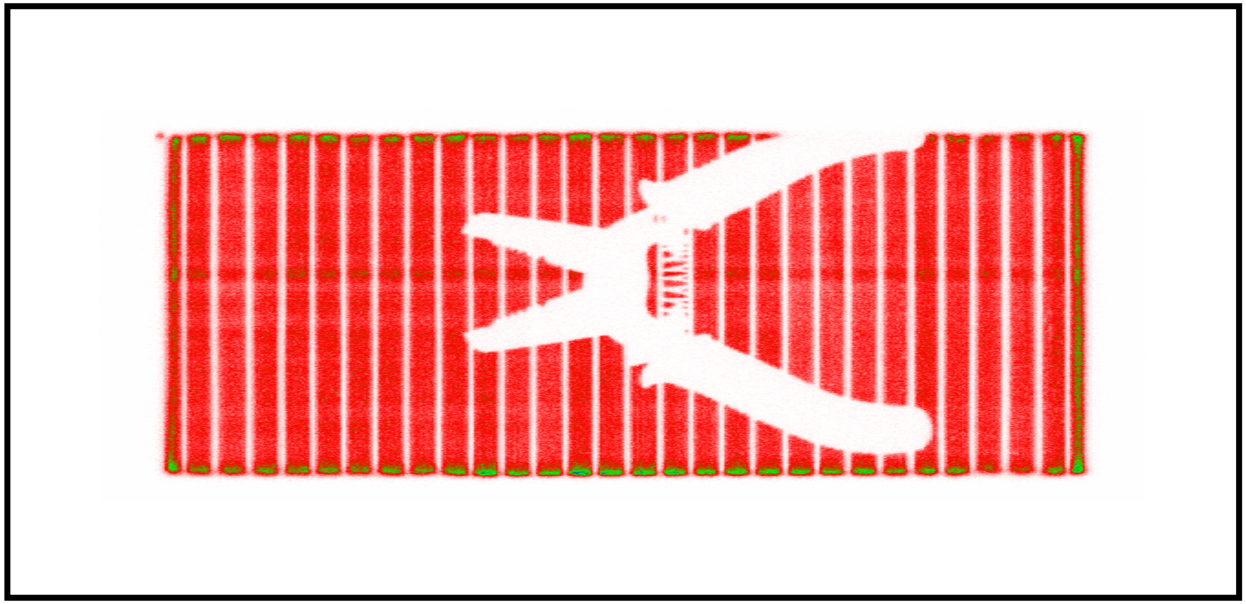




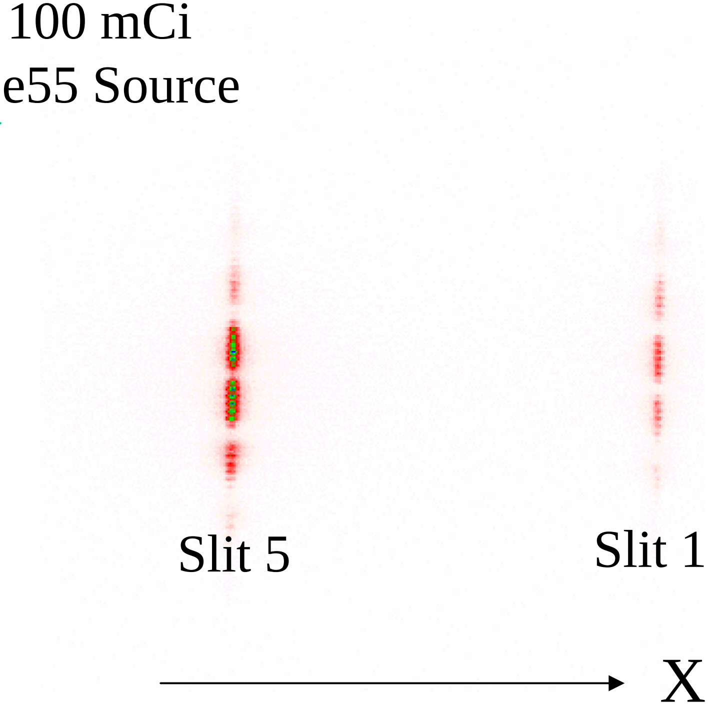
# Image Test of 2D Detector

An image test was done by illuminating the whole detector with a Fe55 source.



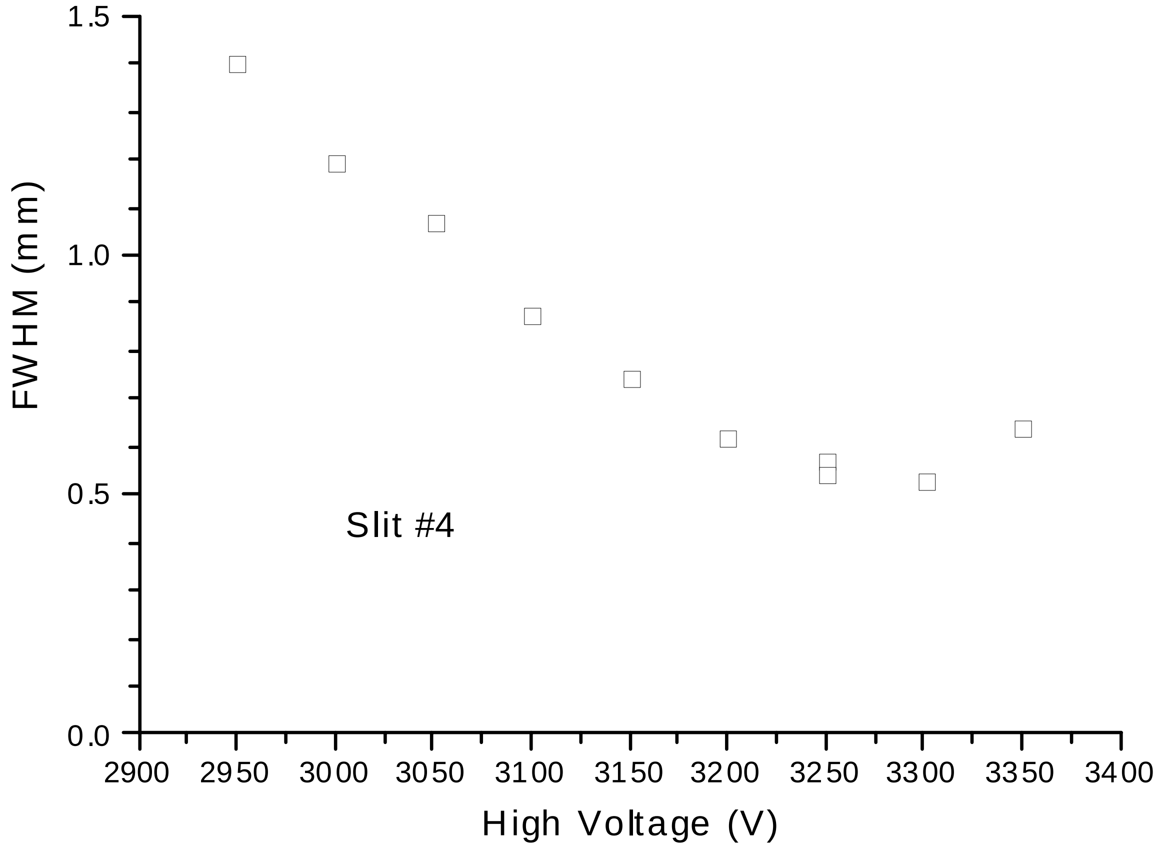
The nipper image on the detector is clearly shown.

# Detector Calibration Measurement

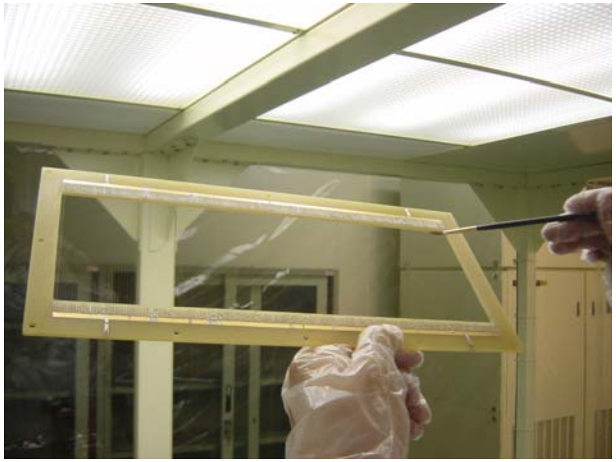
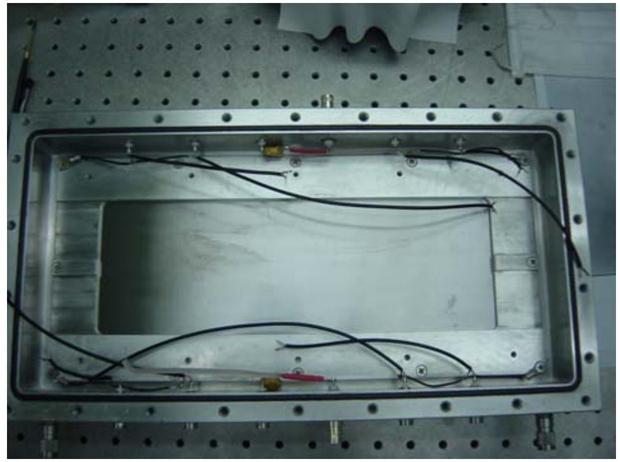
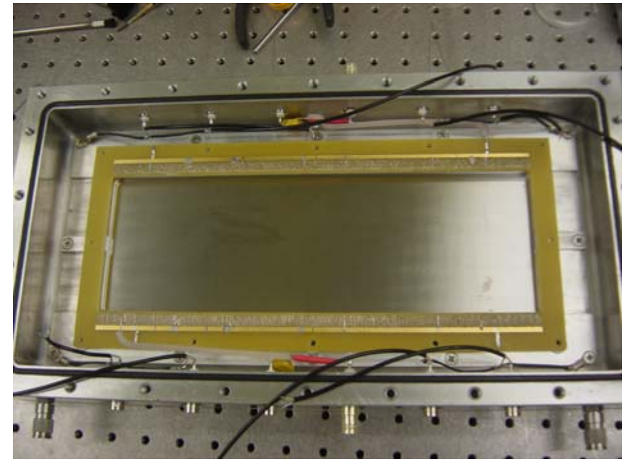
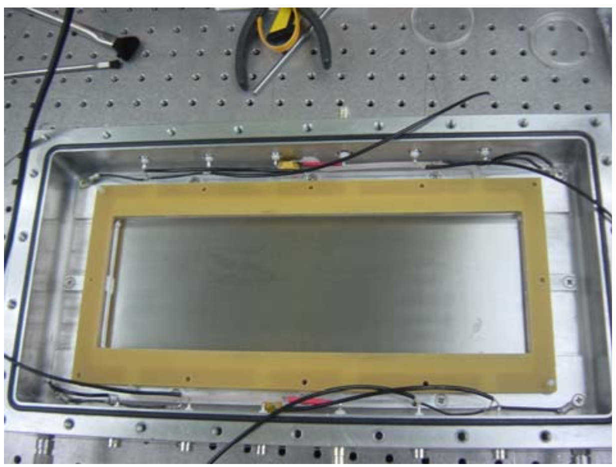
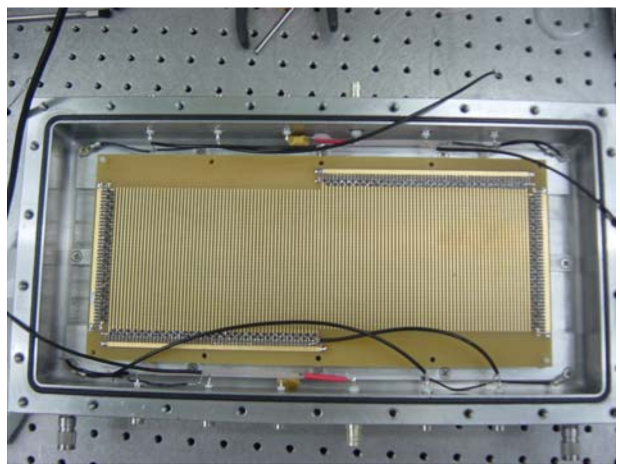

Fe55 source is placed on a slit between toolbits above the detector
Center channel numbers of slit 1 and 5 are 1405.4 and 716.82, respectively
The distance between two slits is 38.1 mm
The conversion factor = 0.0553 mm/channel

# Spatial Resolution




- 100 m Ci Fe55 source is placed on a 0.05 mm wide slit above the detector
- For each high voltage value, we accumulated the data from 20 shots
- Each shot was 25 sec long
- FWHM decreased from 1.4 to 0.53 mm when the high voltage was varied from 2950 to 3300 V

# Improvement of 2D Detector

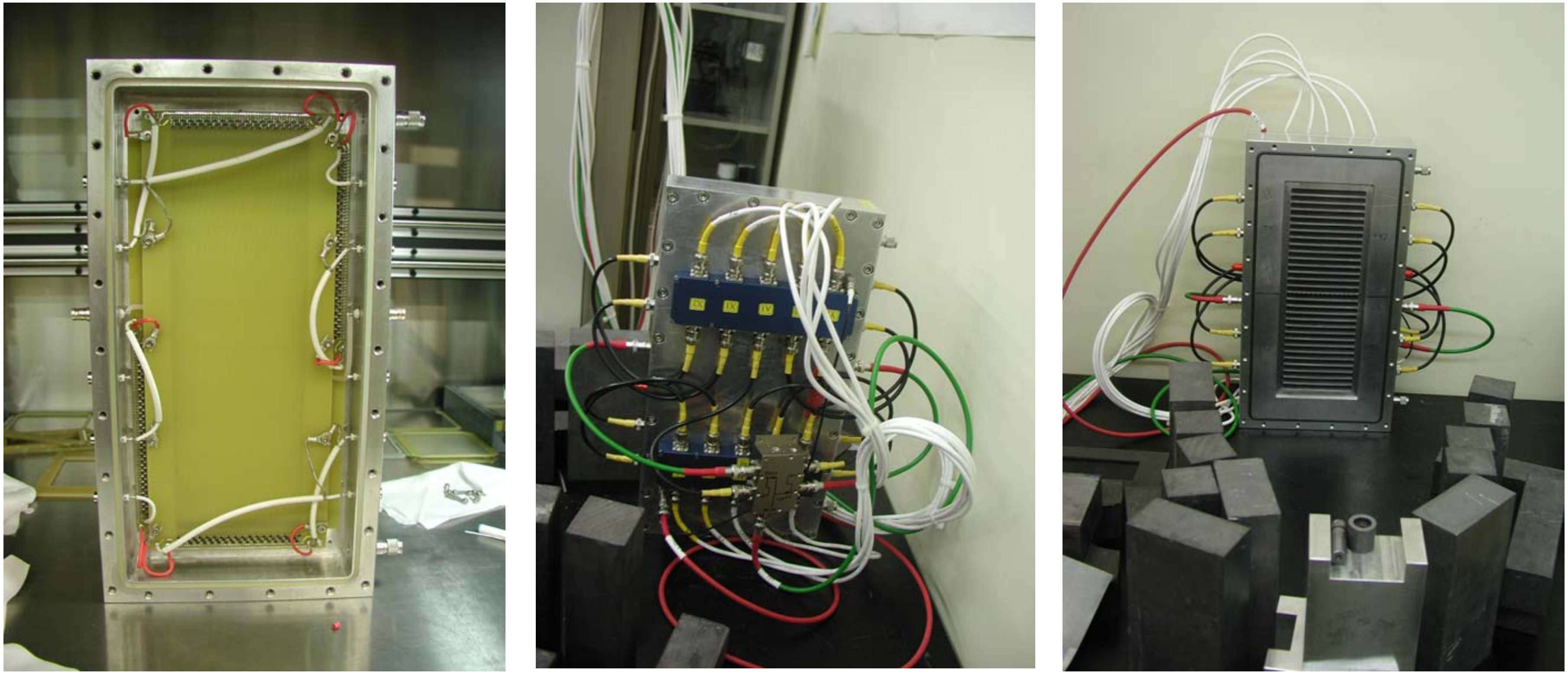







A new improved segmented-detector

Count rate capability is factor of 2 better than before

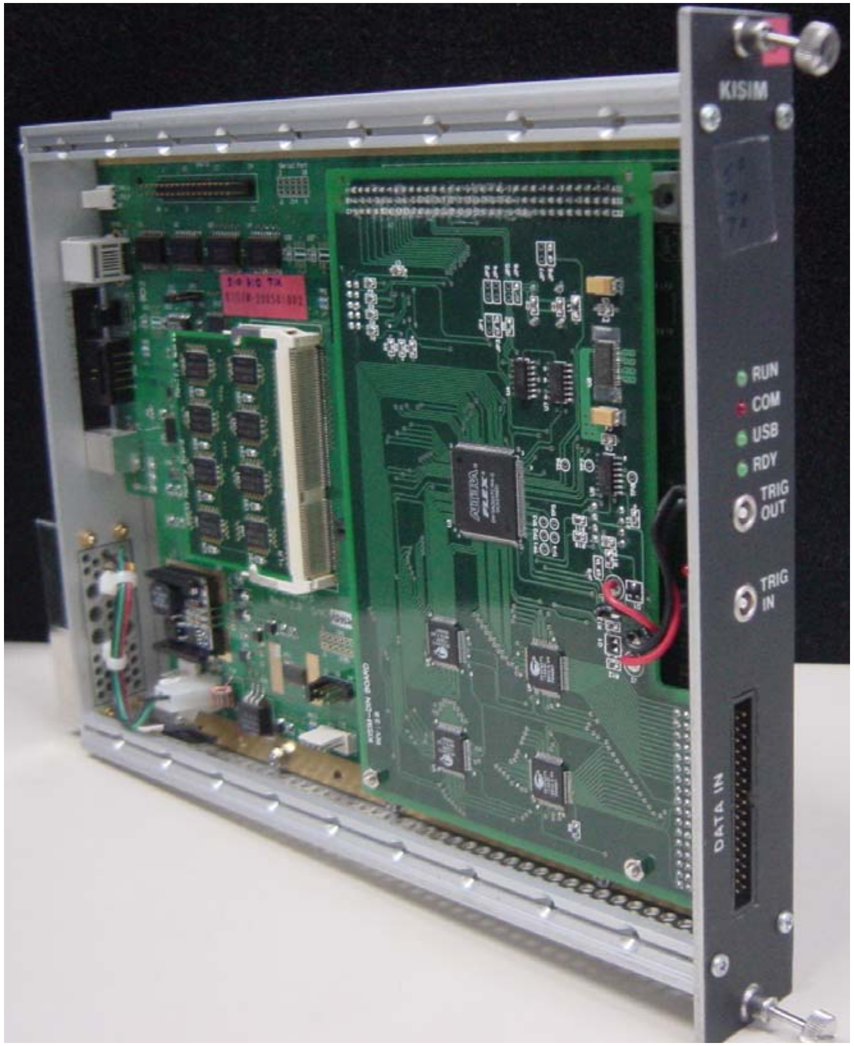
# Upgraded Segmented 2D Detector

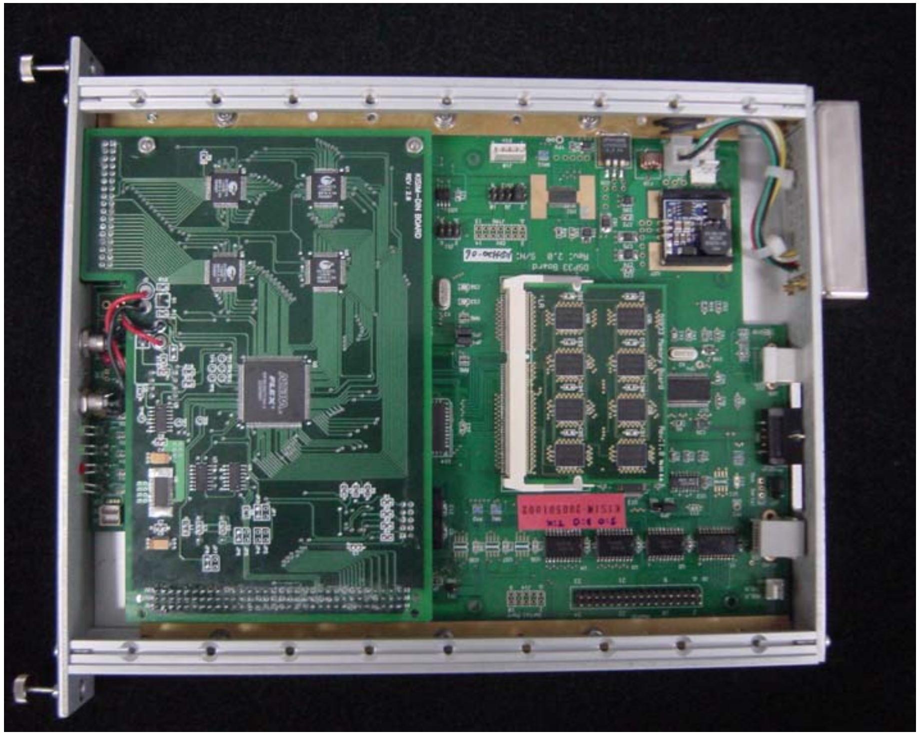
(a) (b) (c)



(a) An inside view of the segmented 2D detector.
(b) An outside view of the segmented 2D detector.
(c) A layout of the uniformity test of the fabricated segmented 2D detector.

# Upgraded Interface with New TDC

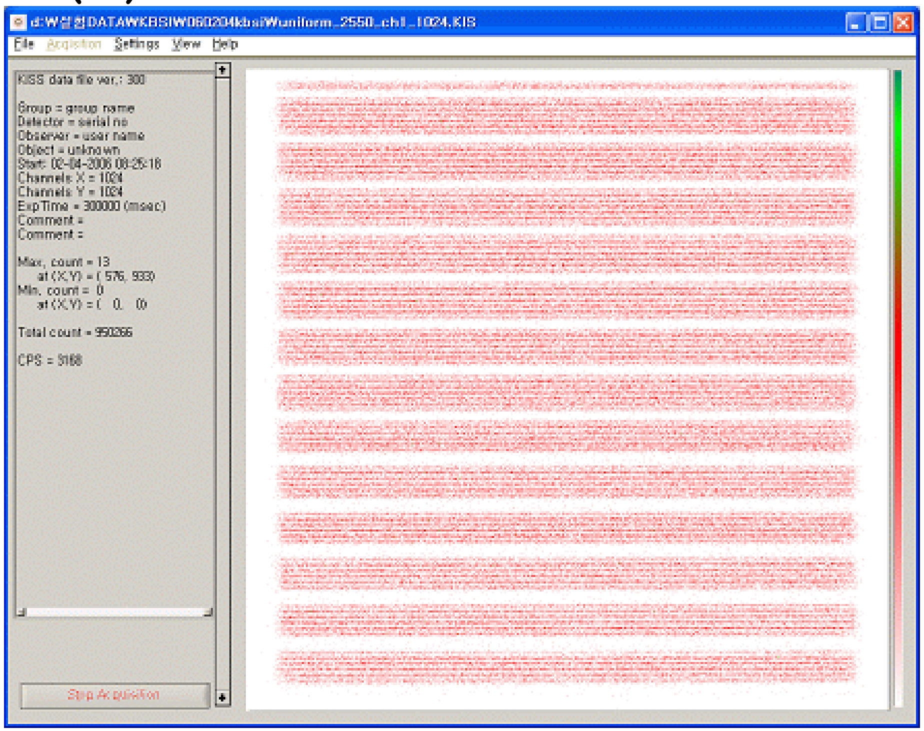


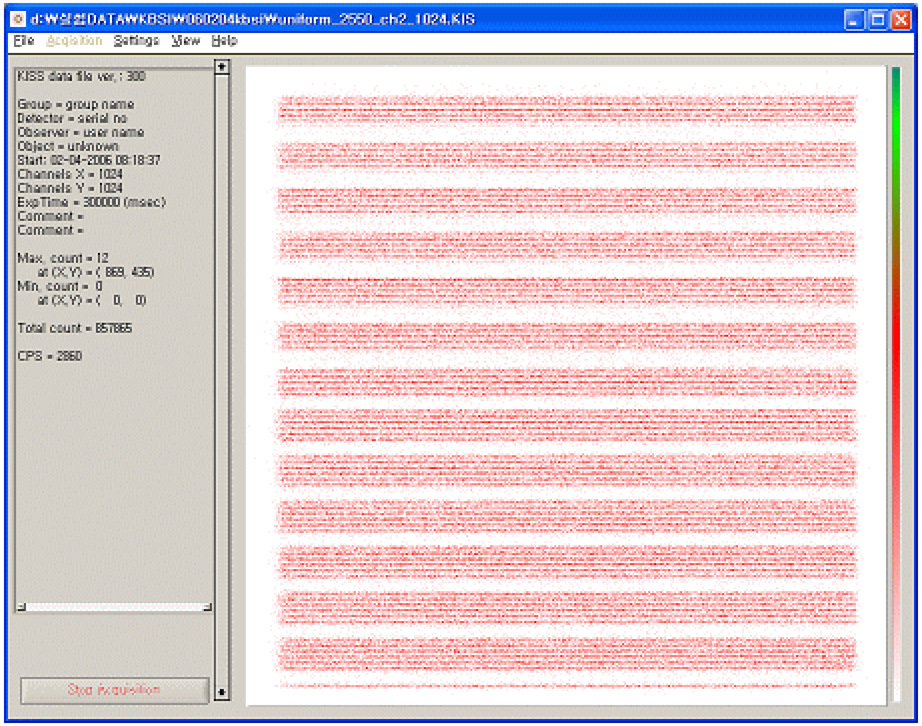
Count rate capability: 800 kHz

# Uniformity Test

(a)



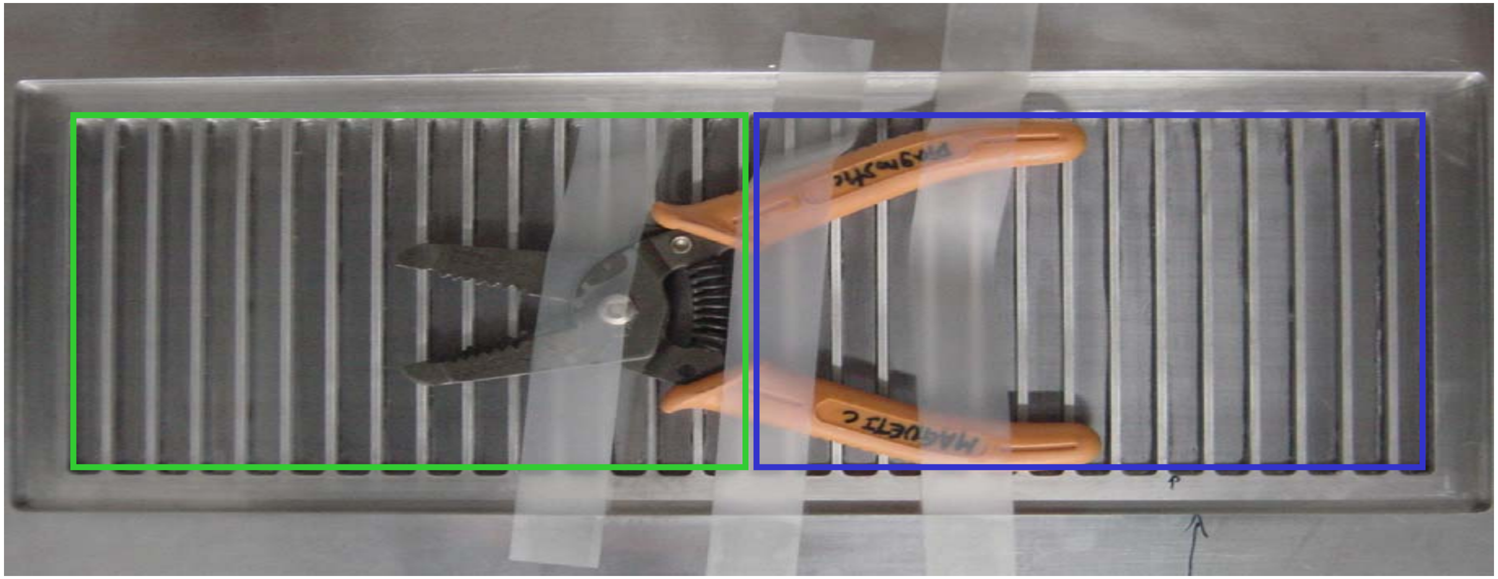

(b)

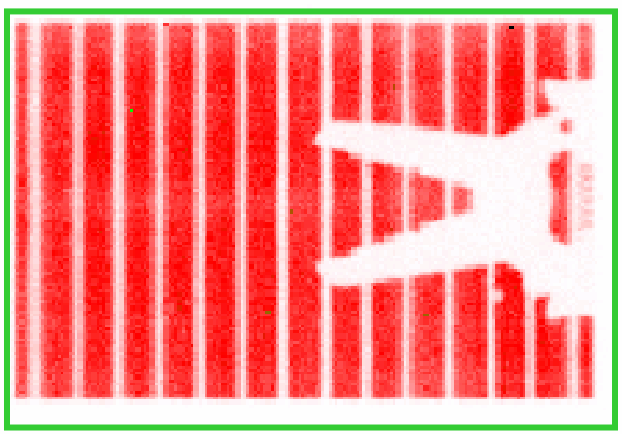


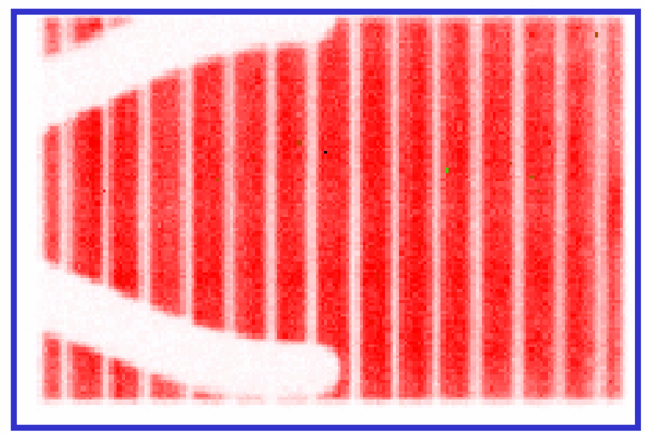

(a) The uniformity of the detector 1.
(b) The uniformity of the detector 2.

- The anode wire images of both detectors are clearly shown.
- The shadows in the horizontal direction are caused by the supporting ribs on the Be-window.

# KSTAR Image Test of Segmented 2D Detector





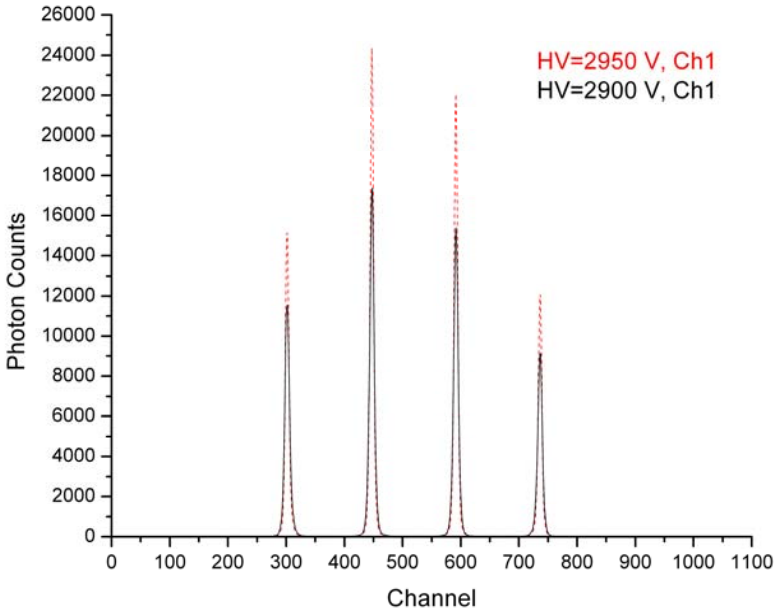


256 resolution display -> real image will be much better

# KSTAR Spatial Resolution of Segmented 2D Detector

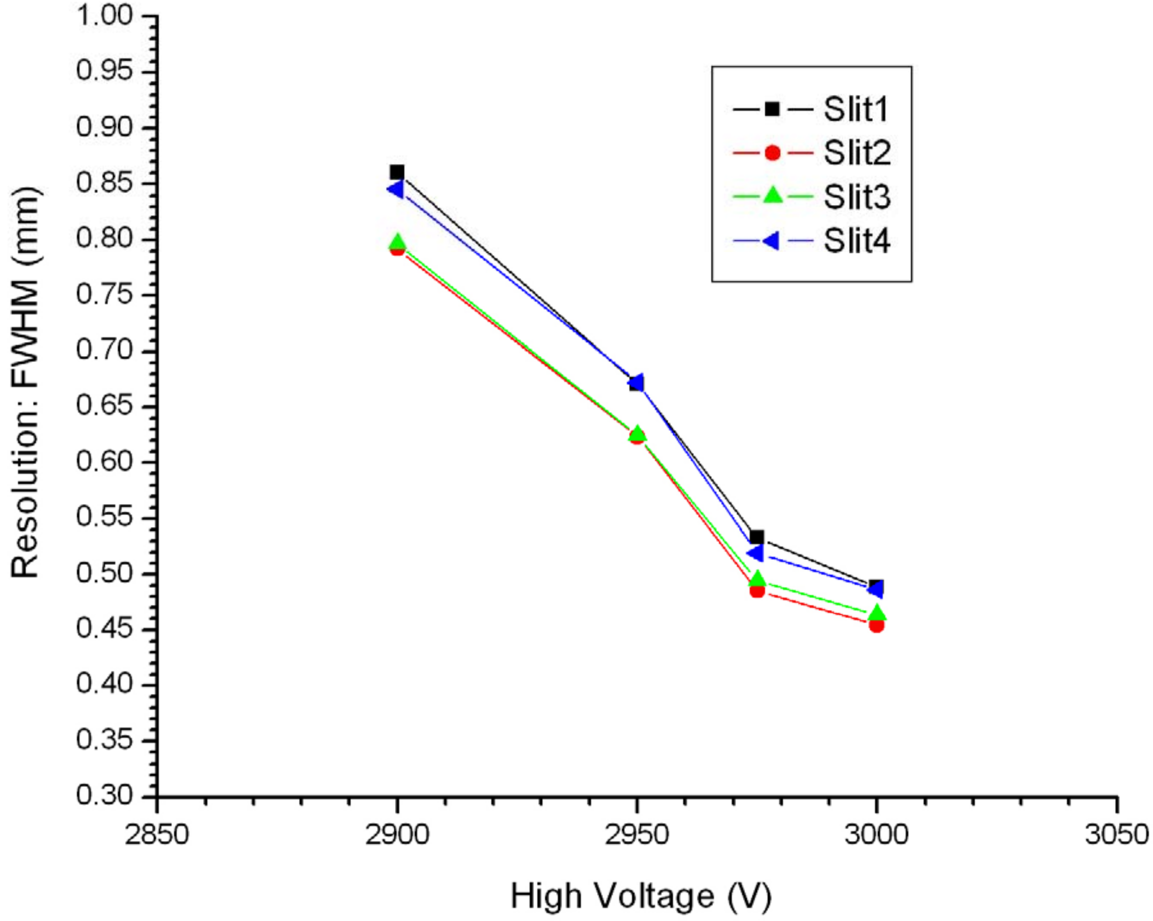
(a)


(b)




- The spatial resolution of the segmented 2D detector was further studied.
- For this spatial resolution measurement, the Fe-55 x-ray source was placed on a slit between tool bits above the detector as shown in Fig. (a).
- The tool bits consist of four 50 micron wide slits and the separation between the slits is 15 mm.
- Figure (b) shows the obtained peak profiles from each slit on the detector 1.
- The peak profiles are similar to a Gaussian.

# Spatial Resolution of Segmented 2D Detector




- The measured full width at half maximum (FWHM) of each slit on the detector.
- The FWHM changes from 0.85 mm to 0.45 mm when the high voltage is varied.
- The best spatial resolution of the detector is approximately 0.45 mm.
- The measured spatial resolution of detector 2 is very similar to that of detector 1.

# Summary and Future Works

- The engineering design for KSTAR imaging XCS has been finished.

- Horizontal XCS for the KSTAR has been fabricated.

- It is expected that the imaging XCS will provide many contributions to KSTAR experiments.

- A 2D detector and associated electronics were fabricated and tested.

- An upgraded new segmented 2D detector was fabricated and tested.

- The performance of the segmented detector and electronics will be improved.