Performance of the X-ray PSD based on the MWPC

Position sensitive detector (PSD)
Multi-wire proportional chamber (MWPC)

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Introduction – X-ray

In 1895, Wilhelm Conrad Roentgen (GE) discovered the X-ray.

Wilhelm Conrad Roentgen

X선(X-Rays)으로 처음 촬영한 뢴트겐 부인의 손 사진

What's the X-RAY?

wavelength :0.01 ~ 100 Angstrom

< general properties >

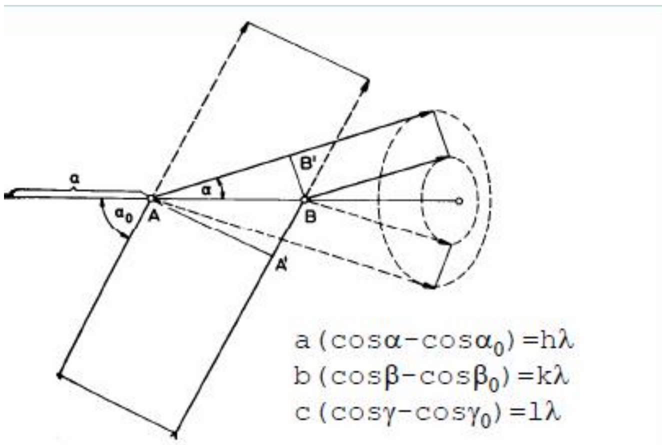
- X-ray detection method
  - Imaging
  - Fluorescence (ZnS, CdS, NaI)
  - Ionization

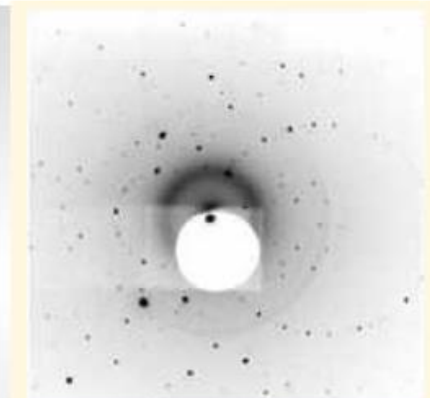
- Light speed in vacuum
- Diffraction like particle
- Reflection index ~ 1
  (impossible to focus the X-ray)

- medical imaging & material experiment due to the high transparency

Introduction – X-ray diffraction

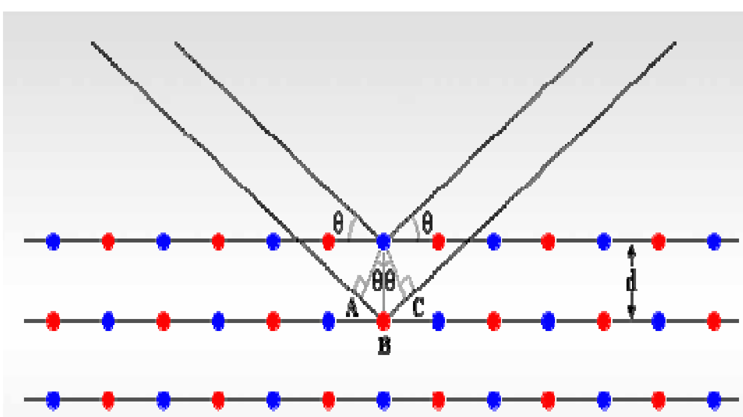
In 1912, Laue (GE) succeeded the X-ray diffraction experiment .
X-ray diffracts when its wavelength is same as the distance in between atoms.





Laue의 반점

In 1913, Bragg (UK) makes Laue's diffraction formula more simply.



Constructive interference: n = integer

AB = BC = d sinθ

n λ = 2d sinθ

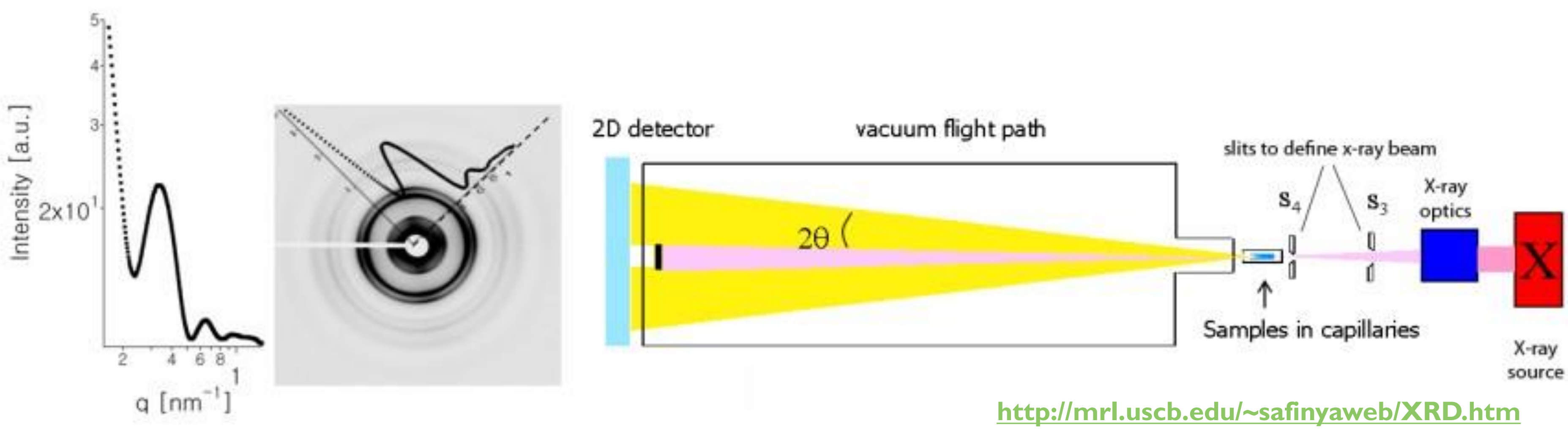
d: distance between the interface of atoms

λ : wavelength

Θ : incidence angle

Introduction - SAXS

- Small angle X-ray scattering (SAXS):
  - research the shape and size of the high molecular materials.
  - role of PSD: to measure the scattered pattern.



http://mrl.uscb.edu/~safinyaweb/XRD.htm

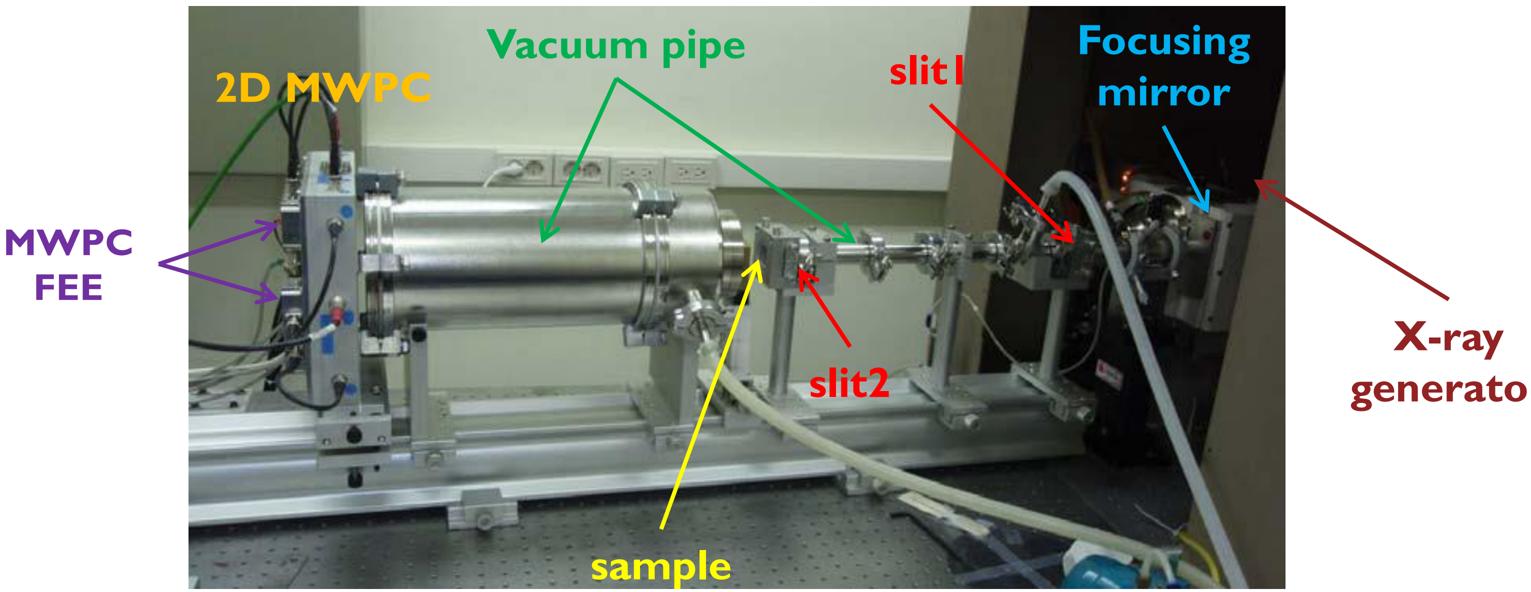
$$q = \frac{2\pi}{d} = \frac{4\pi \sin\theta}{\lambda}$$

q: scattering vector
d: distance between the surface of atoms
λ : wavelength
2Θ : scattering angle

SAXS at Hannam University

- Energy range of photon for diffraction and scattering experiment: 5 ~ 30 keV

Photo-electric effect
Wavelength of X-ray: 1.54 Å at 8.04 keV



< X-ray generator >
Rigaku rotating anode
3 kW filament
40 kV, 70 mA

< Focusing mirror >
Osmic
Confocal Max-Flux
Source-focus distance: 1200 mm

Introduction - PSD

Why is MWPC attracted than the semiconductor detector?

- Multi-wire proportional chamber (MWPC)

  - single counting method

  <strength>

  - high X-ray detection efficiency
  - good position linearity
  - geometrical flexibility
  - fast DAQ
  - low production cost

  <weakness>

  - relatively poor position resolution compared to SDAD.
  - poor rate capability

- Silicon diode array detector (SDAD) or charge-coupled device (CCD)

  - charge accumulation method

  <strength>

  - good rate capability
  - good position resolution

  <weakness>

  - high background
  - narrow dynamic range
  - poor time resolution
  - slow DAQ

Operation of X-ray PSD

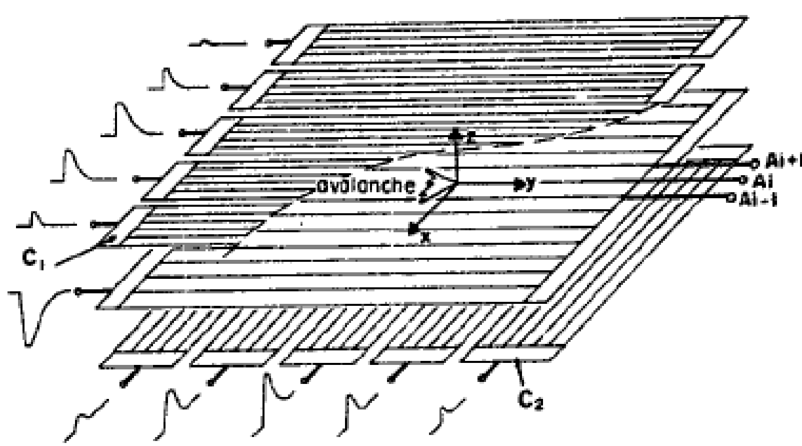
- Energy range of photon for diffraction and scattering experiment: 5 ~ 30 keV
- Photo-electrical effect creates the photo-electron or Auger electron.

- Average ionization energy of noble gas (Ar, Kr, Xe): ~ 30 eV

  - number of produced electron-ion pairs: ~160 at 5 keV
  ~267 at 8 keV
  ~1000 at 30 keV

<MWPC>

G. Charpak *et al.*, Nucl. Instr. and Meth. 62 262 (1968)
G. Charpak and F. Sauli, Nucl. Instr. and Meth. 162 405 (1979)



Incident X-ray

↓

Photo-electric effect

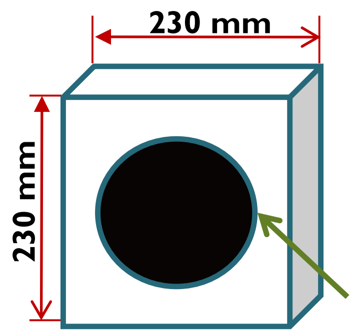
↓

Electron avalanche occurs toward the anode.
Collect the electrons on the anode.

↓

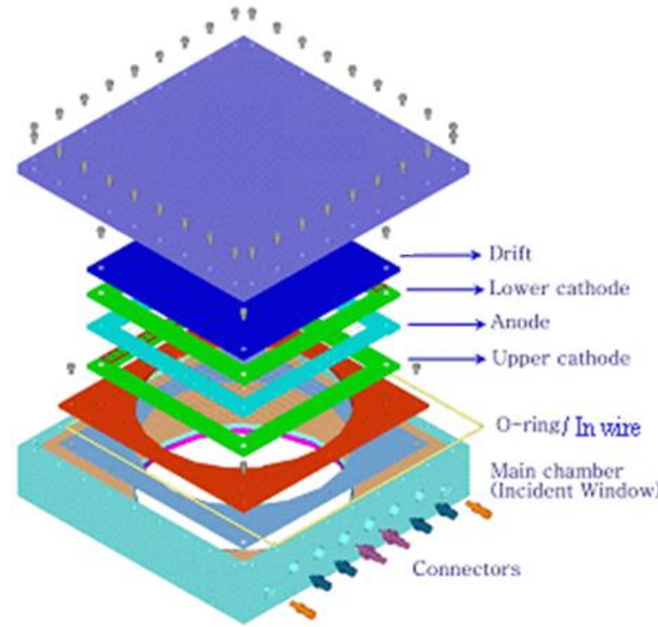
Positive ion drifts toward the cathode.
Induced signal on the cathode.

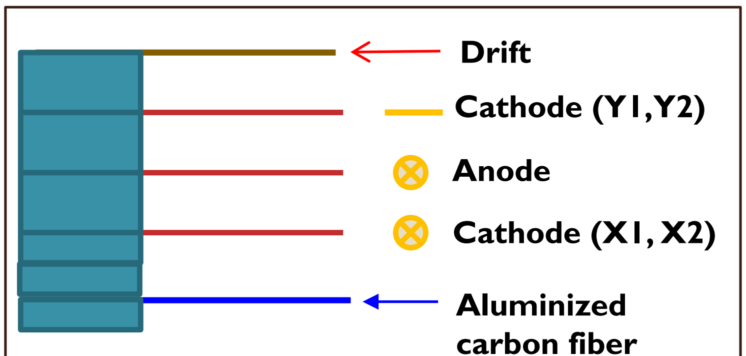
Detector configuration



Effective area : 120 x 120 mm

0.4 mm aluminized carbon fiber
~80 % transmittance at 8 keV (1.54 Å)
Ø150 mm





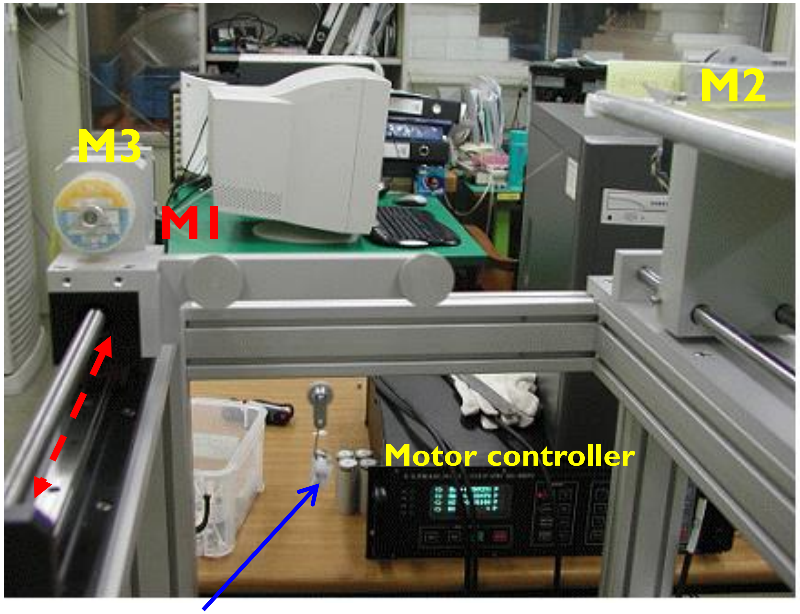
Anode: Ø10 ㎛, 1.25 mm spacing.
(Ø30 ㎛ used for 1st and 2nd wires at both end side.)

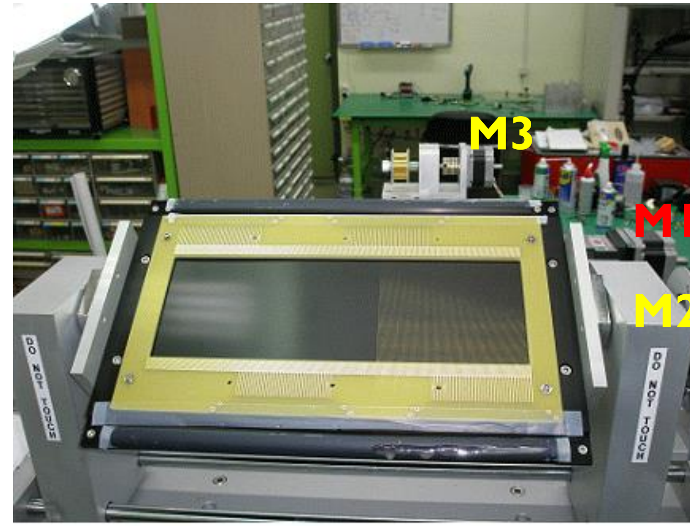
Dual Cathode: Ø30 ㎛, 1.25 mm spacing

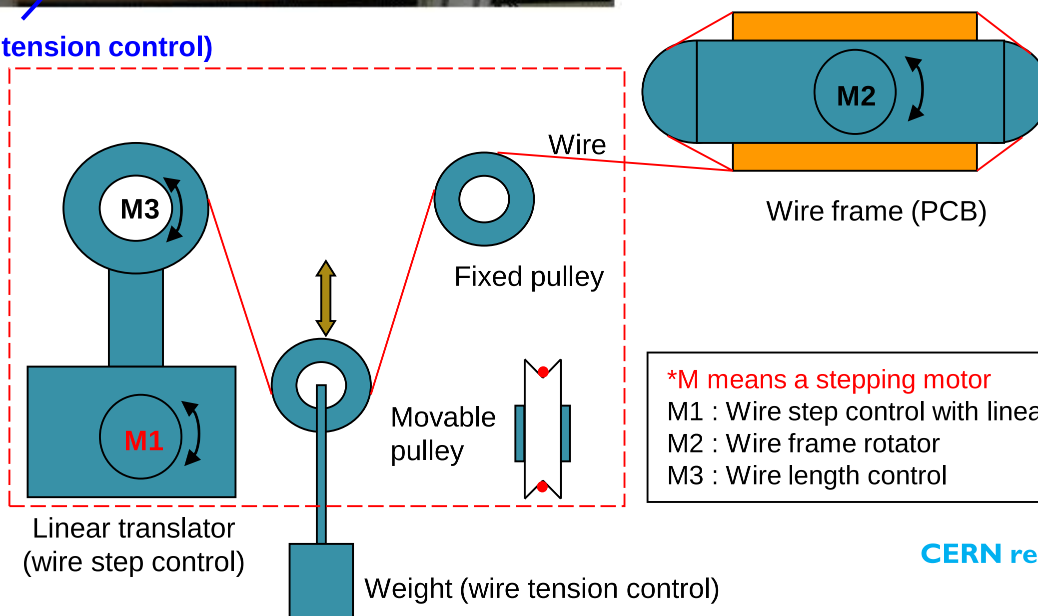
Drift plate

Anode-Cathode gap: 3.2 mm
Drift-Cathode gap: 3.2 mm

Winding Machine



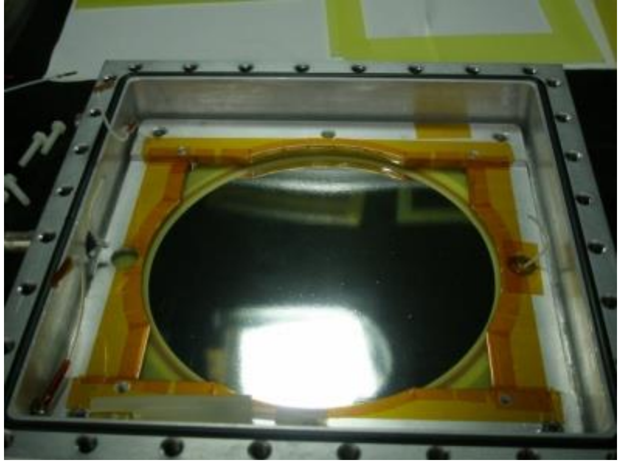


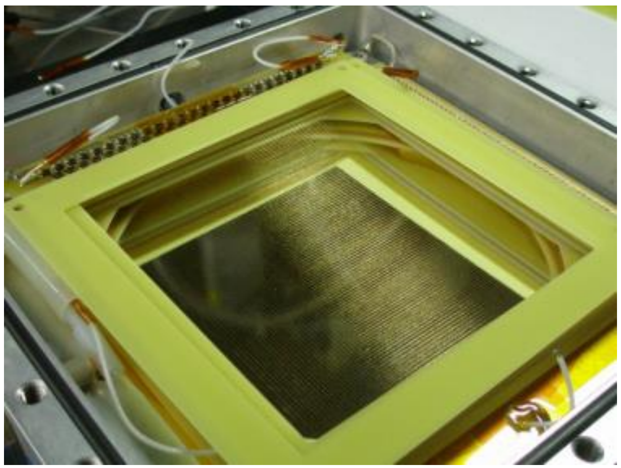


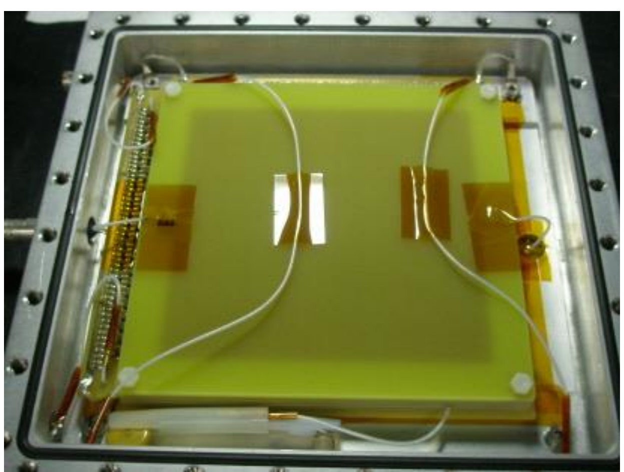
*M means a stepping motor
M1 : Wire step control with linear translator
M2 : Wire frame rotator
M3 : Wire length control

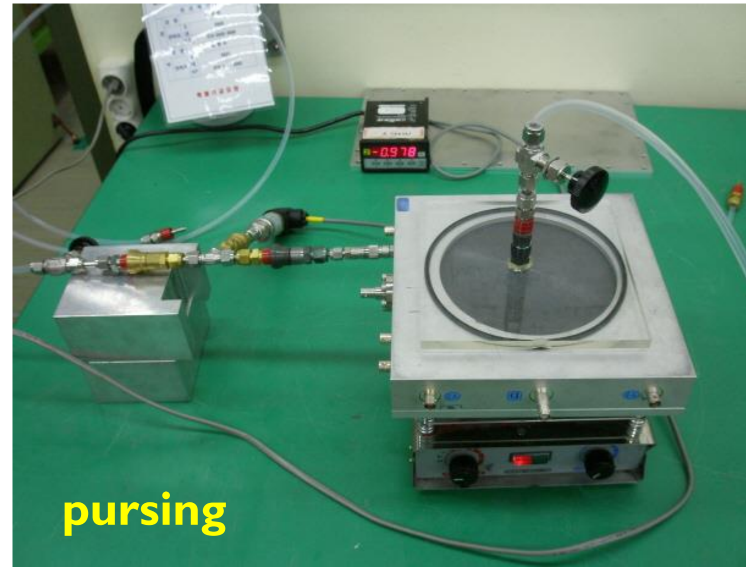
CERN report 77-09(1977)

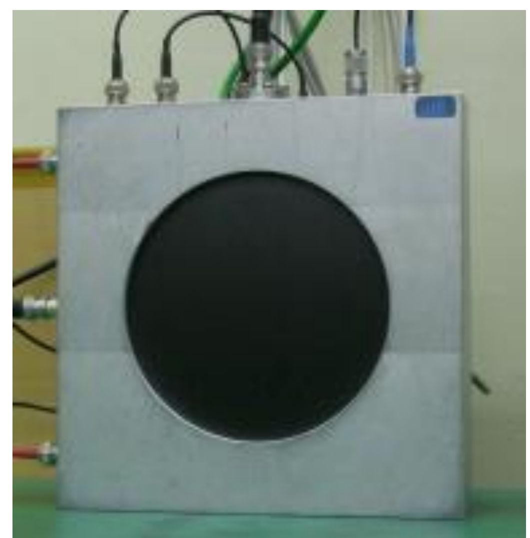
Picture of X-ray PSD



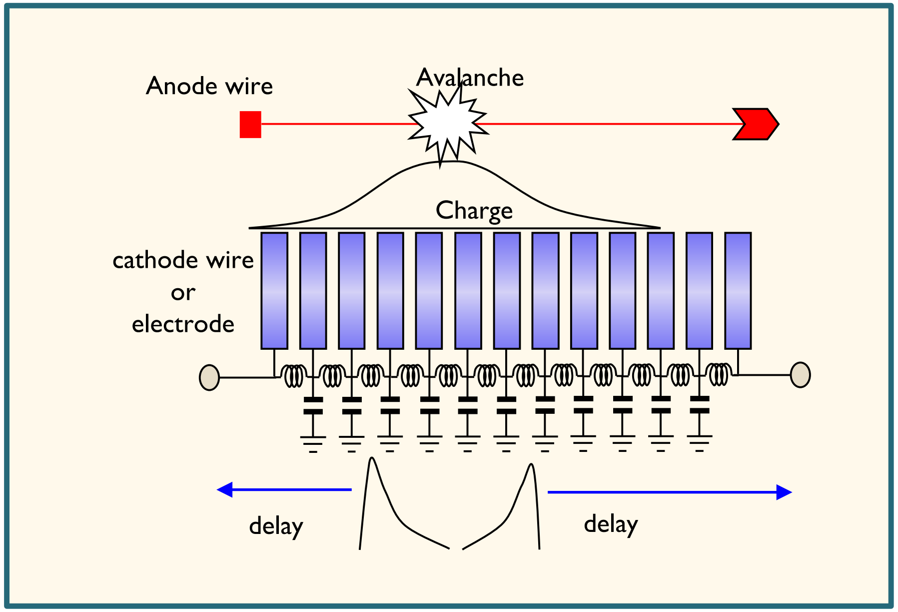


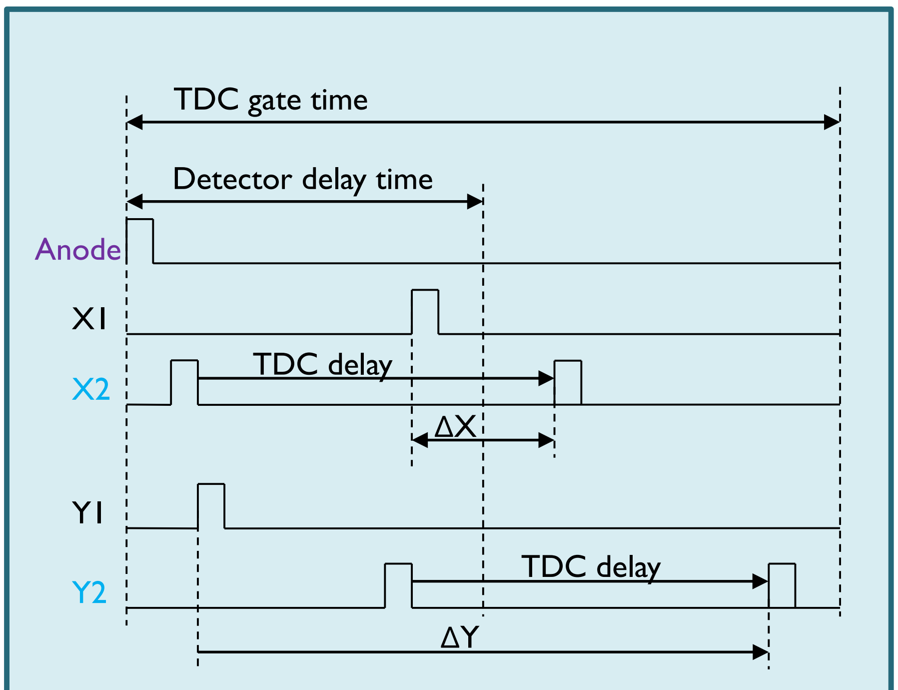






Delay-line readout method





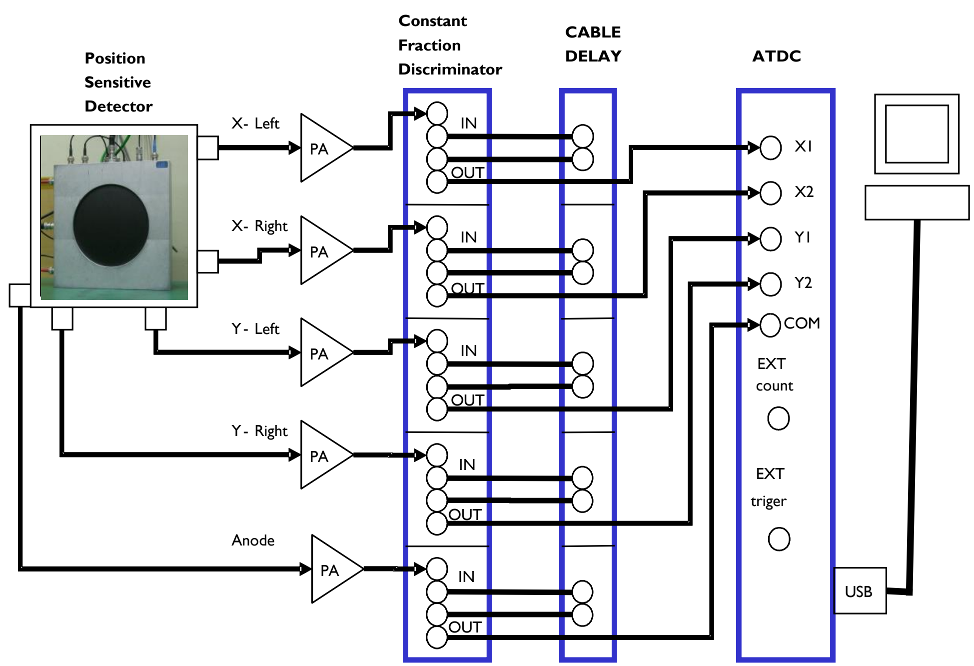
Data acquisition

- Inductor (145 nH) & capacitor (56 pF)

$$Z = \sqrt{\frac{L}{C}} = 51\Omega$$

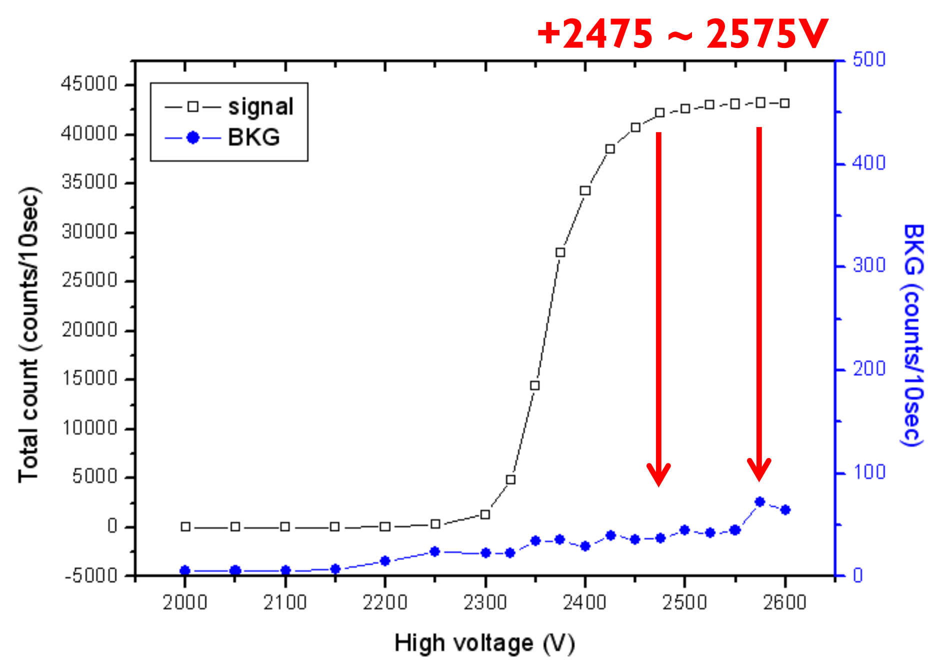
$$t = \sqrt{LC} = 2.85ns$$

- Total delay time: 170 ns



Operational region

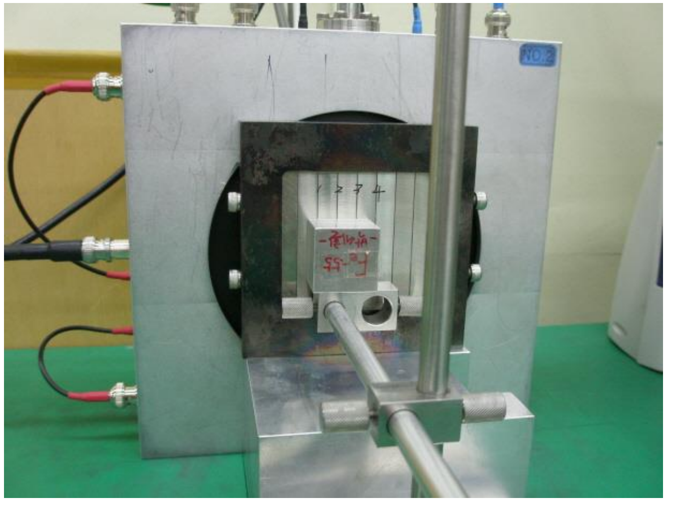
- Ar + C_2H_6 + CF_4 at 1.5 atm
- Drift voltage: -1200 V
- Fe-55: 6.4 keV, 10 mCi
  (half life time : 2.744 y)
- Source to PSD: 45 cm

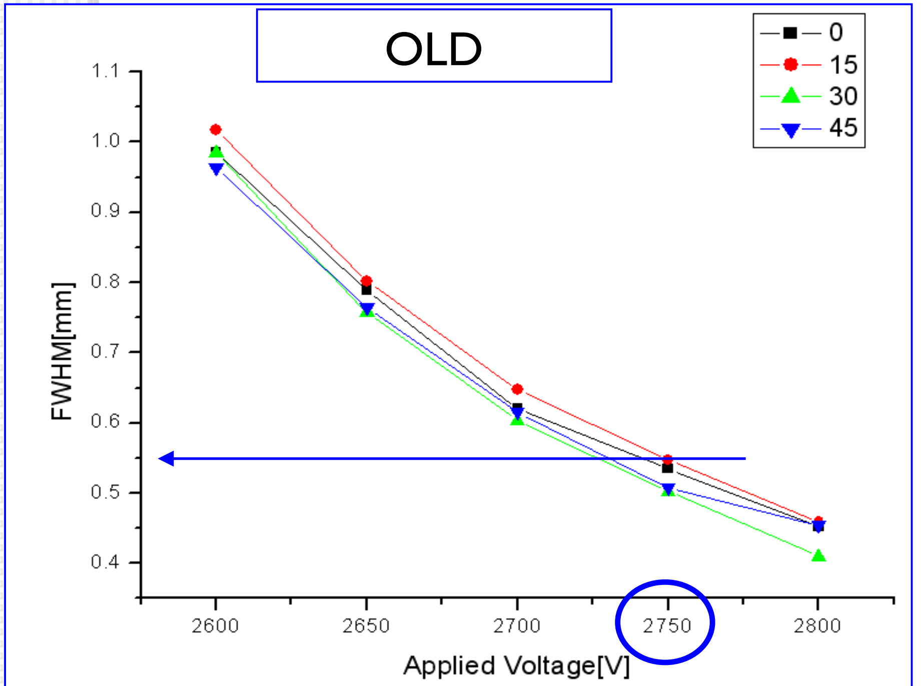


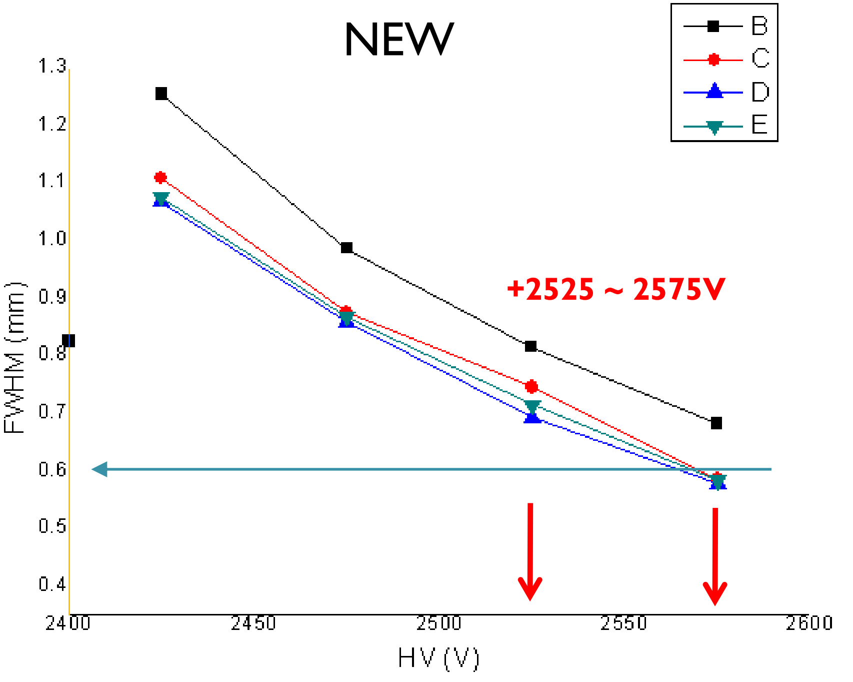
Position resolution

- Ar 1.5 atm
- Drift voltage: -1200 V
- High voltage: +2425 ~ 2575 V
- Voltage step: +50 V

- Fe-55 (KAERI)



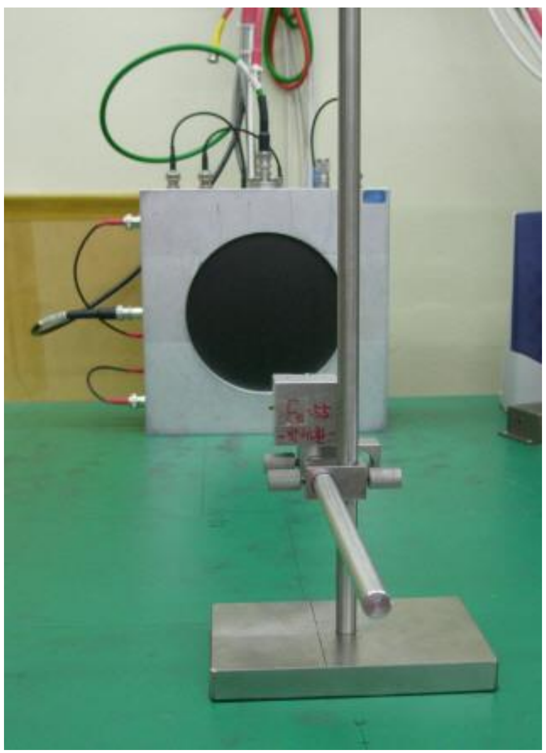


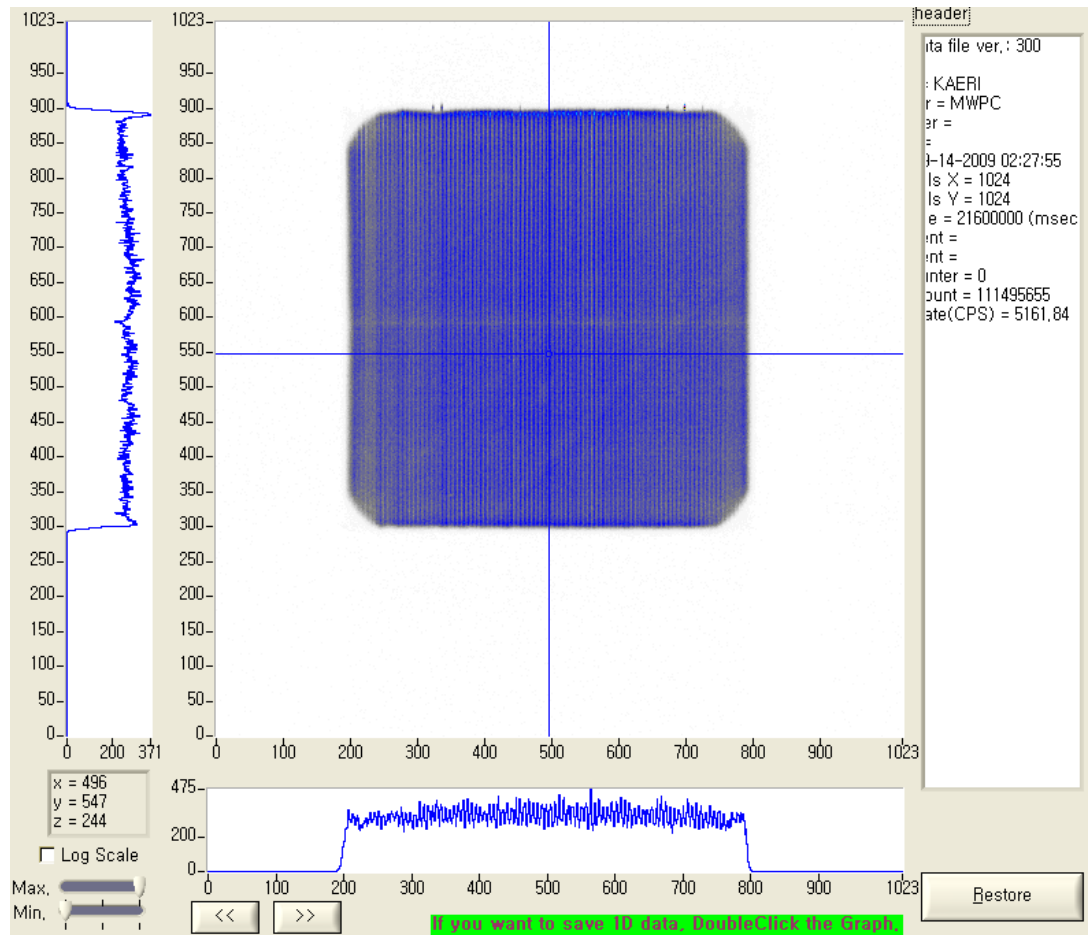


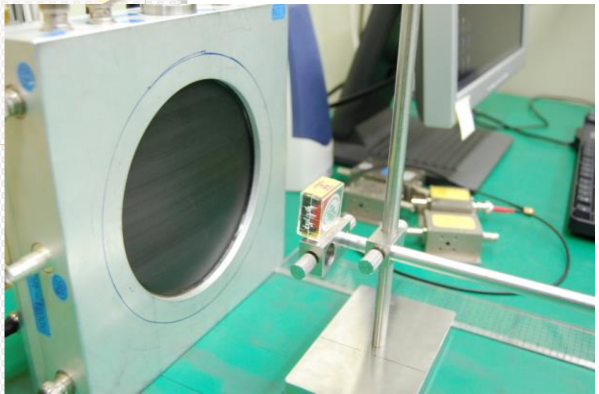
Uniformity

- **Ar 1.5 atm**
- **Drift voltage: -1200 V**
- **High voltage: +2525 V**

- **Fe-55 (KAERI)**
- **Source to PSD: 45 cm**
- **Time: 21600 sec (6 hours)**







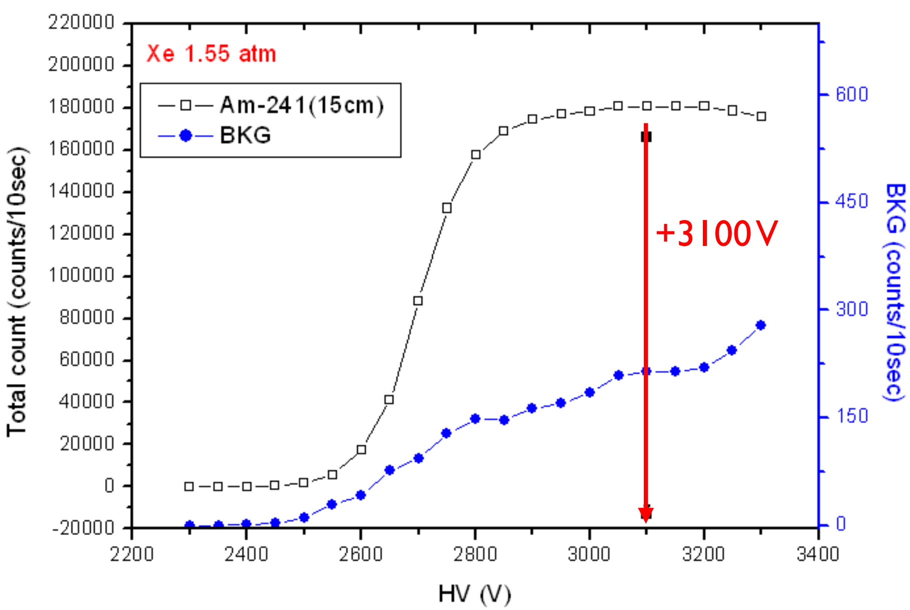
Operational region

Xe + C_2H_6 + CF_4 at 1.55 atm

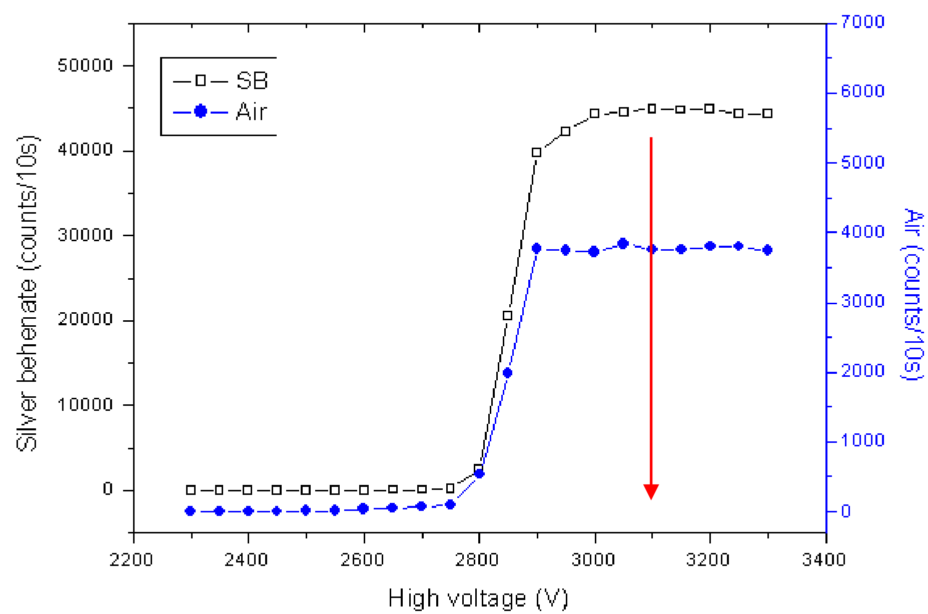
Silver behenate (SB): standard sample for SAXS

- **Am-241(103.4 uCi): ~14 keV (KAERI)**

(half life time : 432.6 y)



- **X-ray: 8.04 keV (Hannam Univ.)**



- Two plots are shown the equivalent trend.
- BKG rate has decreased and has been stable.

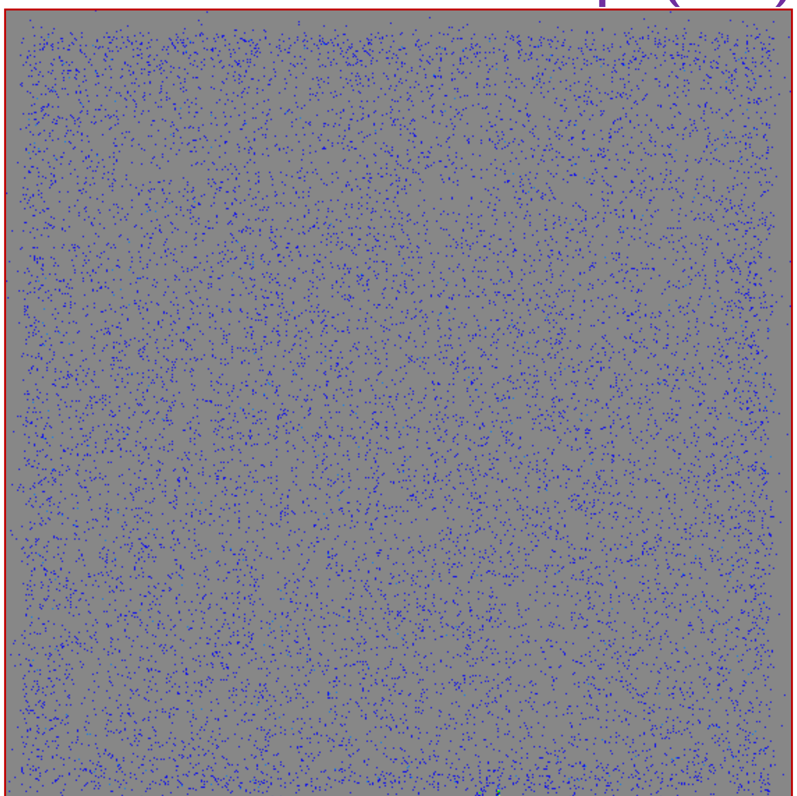
BKG & SB at SAXS

- **Xe 1.55 atm**
- **Drift voltage: -1200 V**
- **HV: +3050 V**

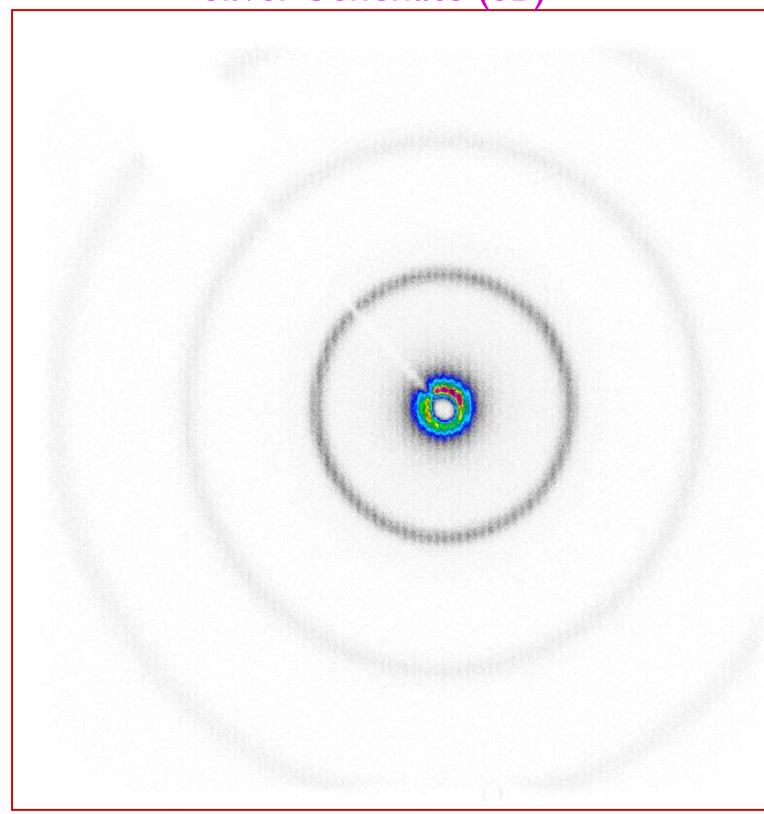
BKG rate has decreased.

18 cps at the beginning.
14 cps after 24 hours.
11 cps after 72 hours.

3600 sec **11.1 cps (BKG)**



Silver behenate (SB)



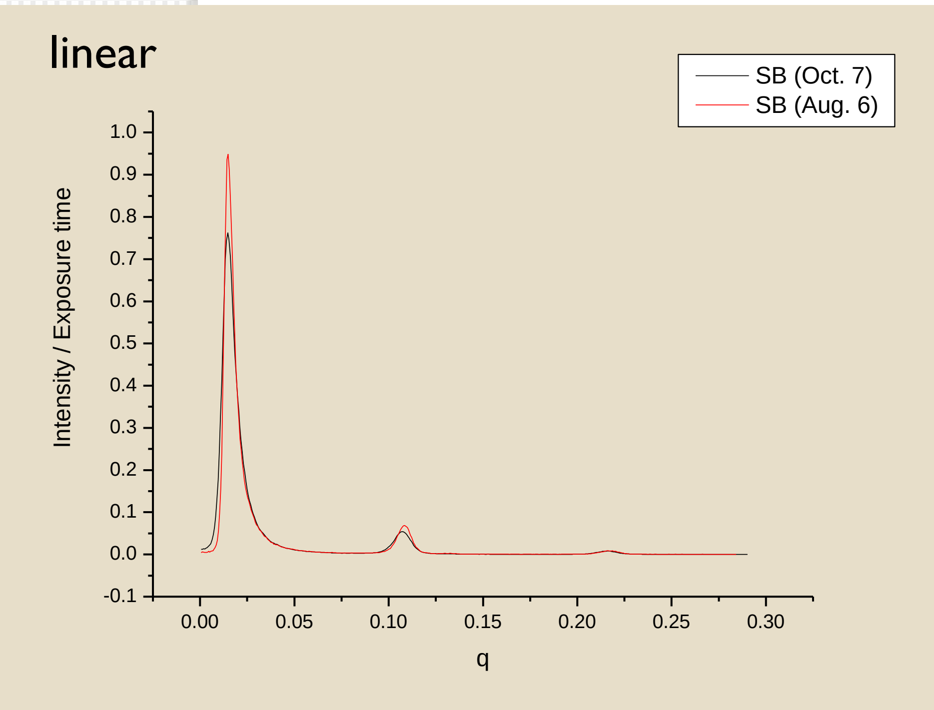
Comparison

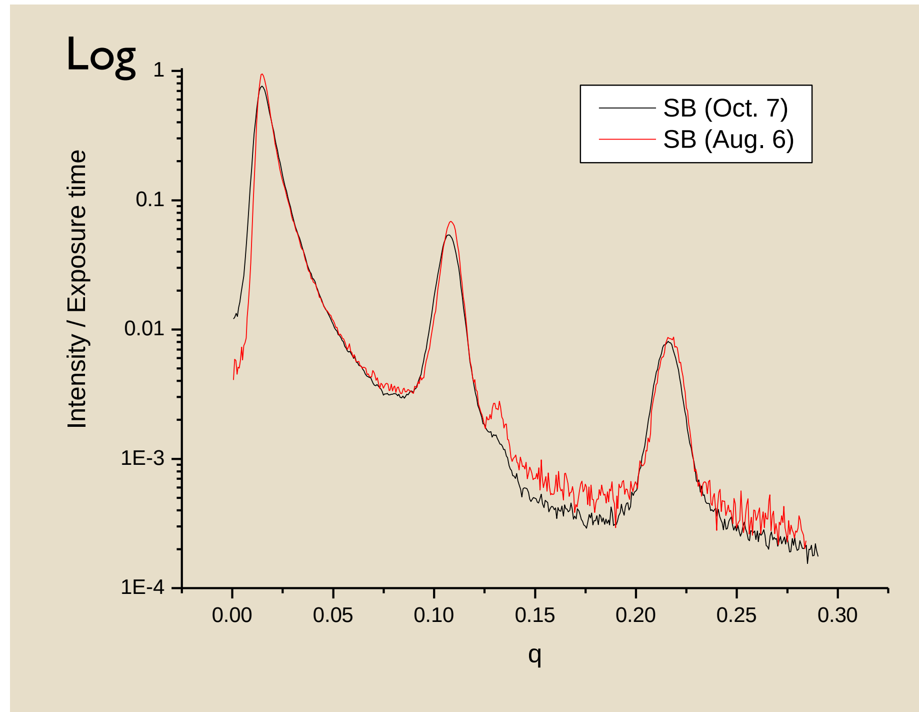
- **Aug. 6 (OLD)**

- **Drift voltage: -1200 V**
- **High voltage: +2750 V**

- **Oct. 7 (NEW)**
- **Xe 1.55 atm**

- **Drift voltage: -1200 V**
- **High voltage: +3050 V**





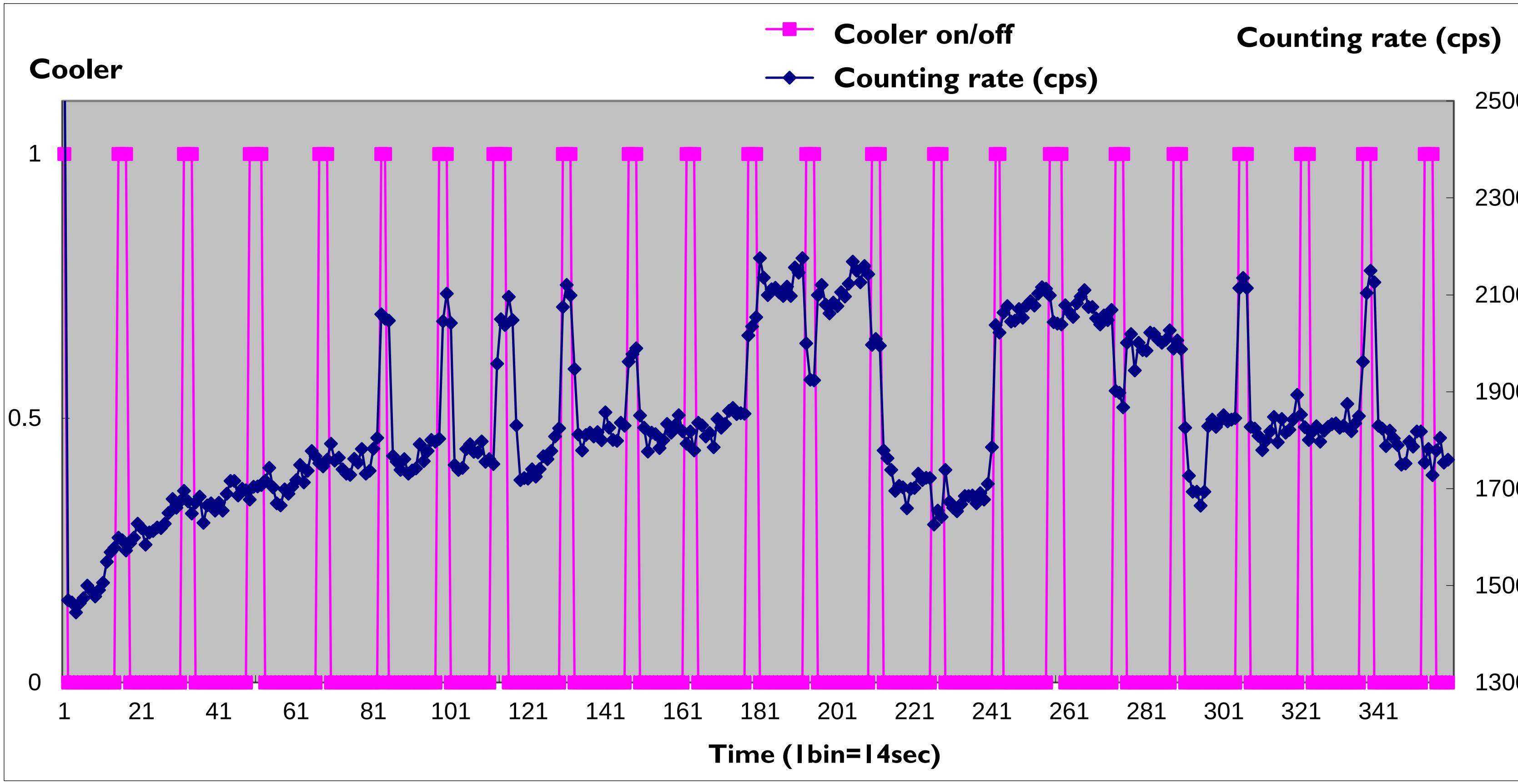
The first peaks can be different due to beam focusing and fluctuation of beam flux.

The second and third peaks correspond to the old data.

X-ray fluctuation

- Xe 1.55 atm
- Drift voltage: -1200 V
- 360 trial
- Total time: ~ 5040 sec (84 min)

- High voltage: +3050 V
- sample: LDPE



Counting rate shows not only some coincidence with the on/off of the cooler but also it presents unmatched period.

Introduction - XICS

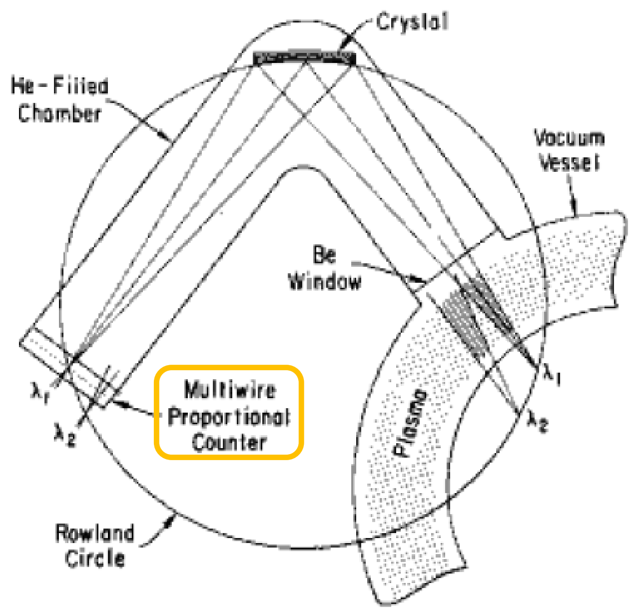
- **X-ray imaging crystal spectrometer (XICS)**

  - to measure ion temperatures in the tokamak device.

  Doppler-broadening

  Movement of the center wavelength (spherically bent crystal)

Johann configuration



Ar is injected in the tokamak.

He-like Ar (Ar XVII, Ar^{16+}) has only two electrons due to the high energy plasma.

Ar^{16+} and plasma thermally equilibrated.

Ar^{16+} emits the X-ray.

$$\Delta\lambda = \lambda_0 \sqrt{\frac{kT}{mc^2}}$$

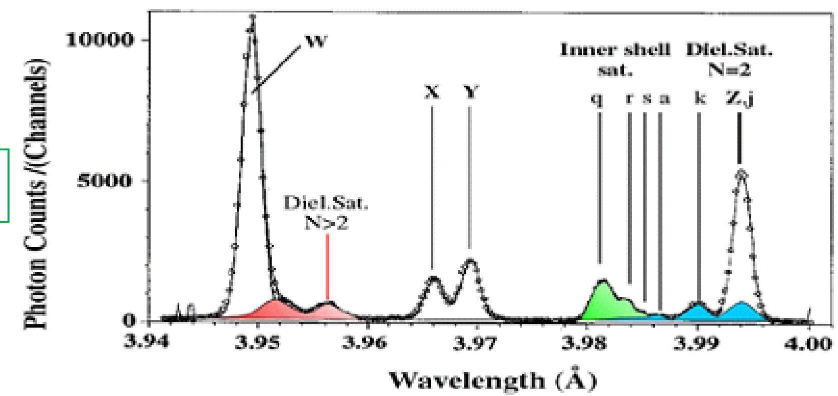
λ_0 : center wavelength of the spectrum
k : Boltzmann constant

Phys. Rev. Lett. 42 304 (1979) M. Bitter et al.
Rev. Sci. Instrum. 70, 1 (1999) M. Bitter et al.
J. K. Cheon, Ph.D. thesis, Kyungpook national university, (2008)

Doppler-Broadening: the spectral lines are broaden caused by a distribution of velocities of atoms or molecules.

4 segment PSD for XICS

X-ray spectrum of He-like Ar



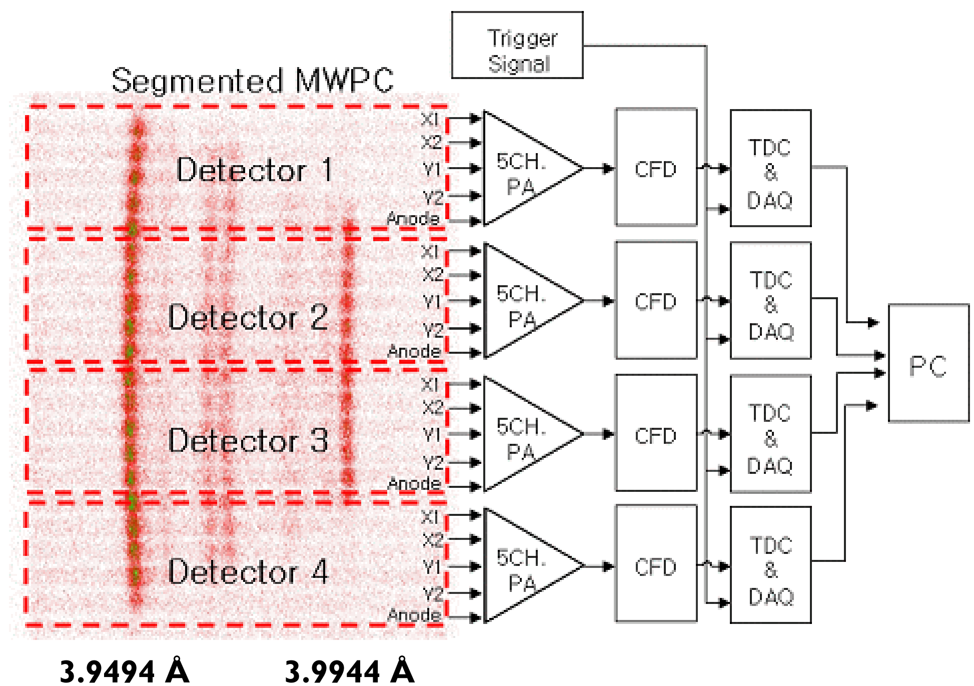
Ar^{16+} emits the X-ray (3.9494 ~ 3.9944 Å).

- **PSD requirements**

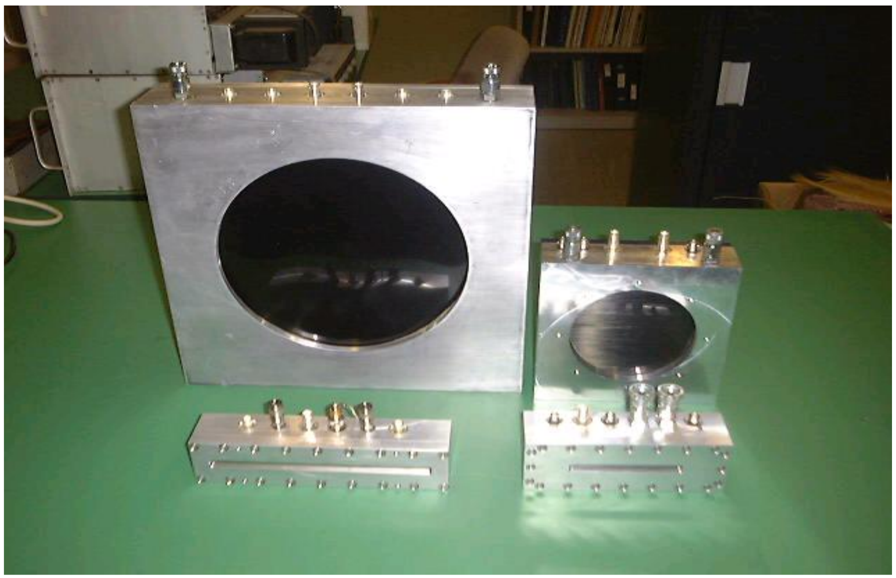
- Photon counting
- Enough rate capability
- Large area
- Fast DAQ

- position resolution (< 0.5 mm)

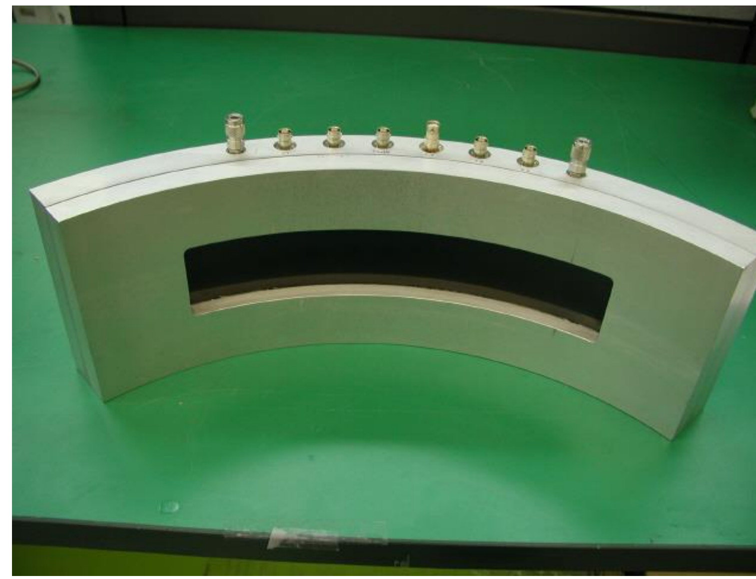
- Radiation hardened (fast neutron)



Fabricated PSD at KAERI: part I



1D & 2D X-ray PSD



2D curved X-ray PSD

Fabricated PSD at KAERI: part II

1D Neutron PSD

Neutron Monitor

2D Large Neutron PSD for SANS

Summary

- Many kinds of PSD have been producing at KAERI.
  - Small angle X-ray scattering (SAXS)
  - X-ray imaging crystal spectrometer (XICS)
  - Neutron monitor
  - Neutron diffraction
  - Small angle neutron scattering (SANS)

- PSD
  - Low production cost
  - Large effective area
  - Geometrical flexibility
  - Fast DAQ
  - Good position resolution
  - Sensitivity depending on gas and energy