Plans and status for X-rays generation via Channeling with 50 MeV electrons

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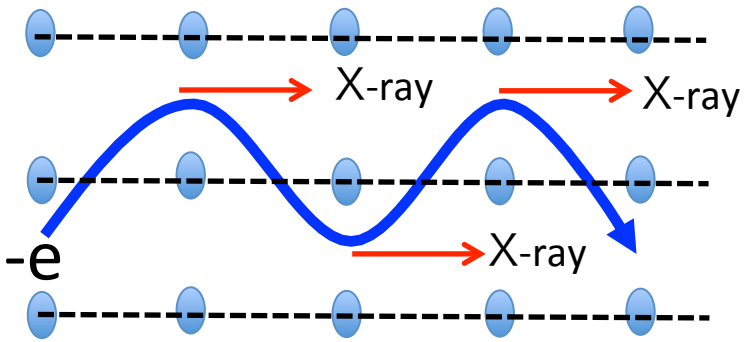
Outline

1. Introduction
2. Beam optics for high-brightness CR
3. Expected X-ray spectrum including bremsstrahlung
4. Compton scattering for X-ray detector
5. Conclusion

Channeling Radiation (CR)

CR is emitted when a relativistic electrons pass through a single crystal.



○ Incident angle < critical angle

Critical angle : $\theta_c = \sqrt{\frac{2\gamma V_{\max}}{mc^2\left(\gamma^2 - 1\right)}} \propto \frac{1}{\sqrt{\gamma}}$

○ Below 100 MeV electron energy, discrete and quasi-monochromatic X-rays

CR Features

1. quasi-monochromatic
2. Hard X-rays
3. High intensity

Expected applications

1. X-ray imaging (Phase contrast)
2. Medical treatment
3. Crystal structure analysis

Now, almost coherent X-rays sources are large-scale facilities.
(XFEL, Storage ring)

We want

compact high intensity coherent X-rays source.

Channeling Radiation (CR)

Brightness equation of CR

$$B_{av} = \frac{I_{av}}{e} \frac{\gamma^2 Y \cdot \sigma_e'^2 \times 10^{-3}}{\varepsilon_n^2 \cdot \Delta E_\gamma / E_\gamma} Erf\left[\frac{\psi_c}{\sigma_e'}\right]$$

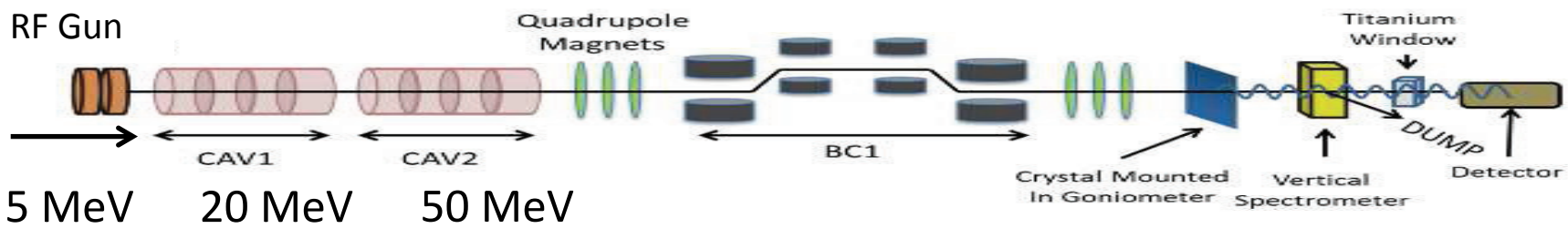
$$photons / s - (mm \cdot rad)^2 - 0.1\% BW$$

For high brightness

1. Low emittances
2. High charge

FAST's Injector !!

～FAST's Injector～



Parameter	Value
Beam Energy	20, 50 MeV
Bunch charge	1 - 200 pC
Bunch frequency	3 MHz

Parameter	Value
Normalized emittance	0.2 μm･rad (20pC)
Bunch length	3 ps
Energy spread	< 1 %

Our purpose

Our goals

1. To emit high brightness coherent X-rays (40 keV - 110 keV) with low emittance electrons beam.
2. To demonstrate that CR is compact high brightness coherent X-ray source.

Today's topics (only simulation)

1. Beam optics for high brightness at 20 pC
2. CR spectrum including background
3. Compton scattering for X-ray monitor

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Beam parameters to simulate optics

These parameters were generated with ASTRA

✔ Bunch energy and charge: 43 MeV and 20 pC

✔ Normalized emittances : $\varepsilon_x = \varepsilon_y = 0.2$ mm-mrad

✔ Initial twiss parameters

$$\rightarrow \begin{cases} \alpha_x = \alpha_y = -3.80 \\ \beta_x = \beta_y = 21.3 \text{ m} \end{cases} \qquad \begin{cases} \eta_x = 0 \\ \eta_y = 0 \end{cases}$$

✔ Momentum spread: $\Delta P/P = 0.1\%$

<u>For high brightness</u>

Brightness of CR

$$B_{av} \propto \frac{1}{\sigma_e^2}$$

➡ Minimum beam sizes

At the crystal

At the crystal
beam divergences

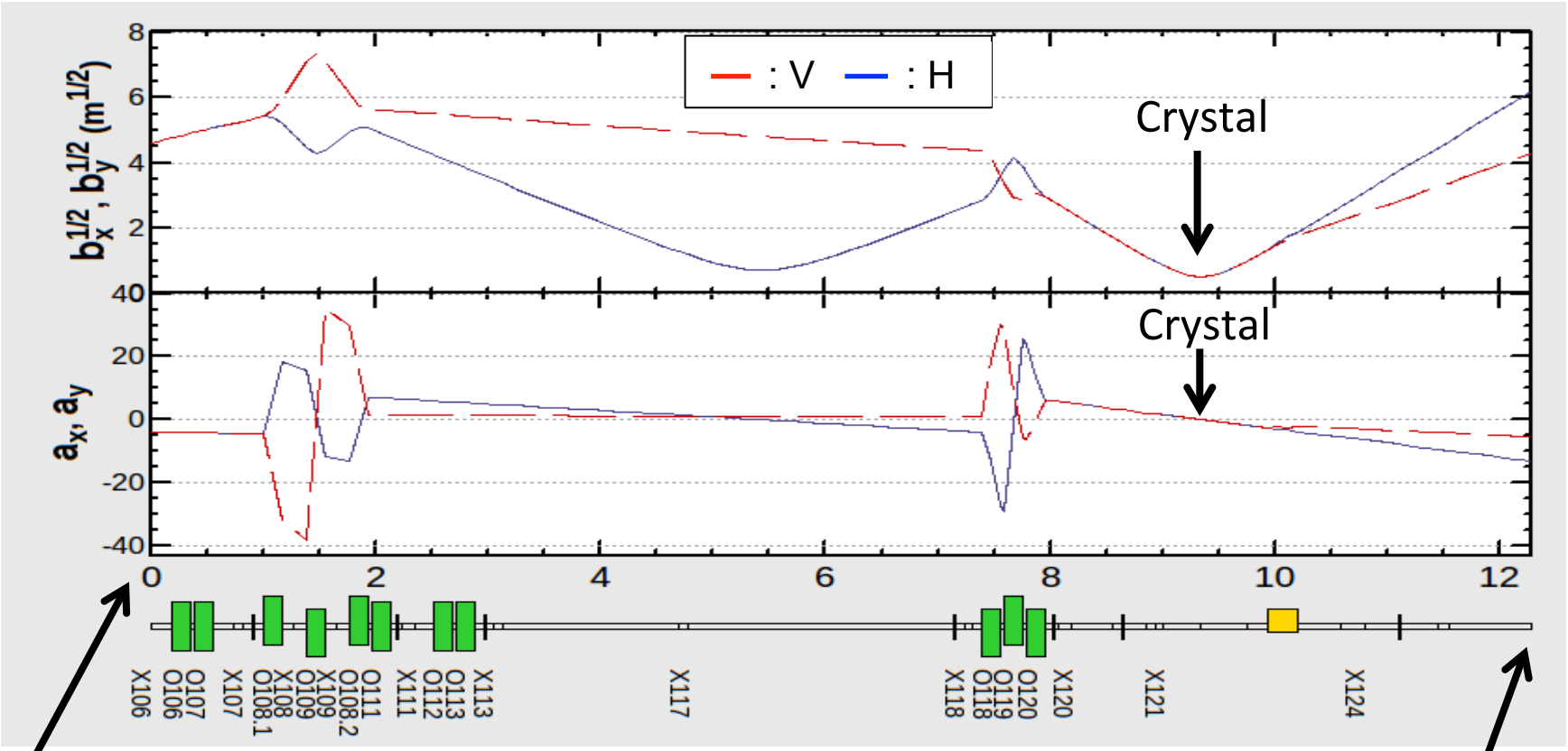
$$\sigma'_e = 0.1\, mrad \left(< \theta_c = 1.1 mrad \right)$$

@43 MeV

Beam optics at 20 pC

Beam sizes =22um at divergences of 0.1mrad @crystal

Path length vs Twiss parameters



Start point
(8 m from cathode)

:Q-magnet

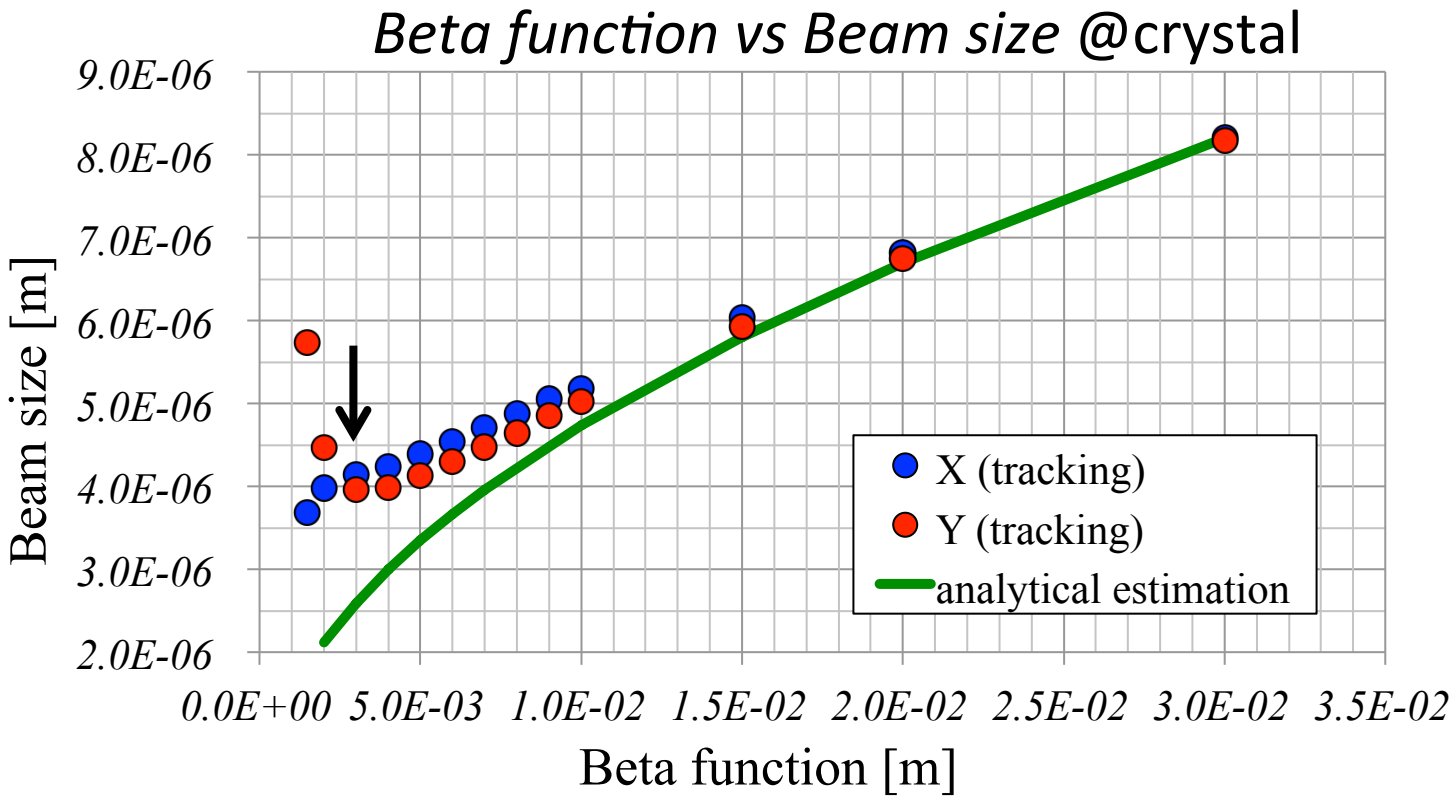
:Bending magnet

dump

Expected minimum beta functions at crystal

Minimum beta functions and beam sizes @ crystal

$$\begin{cases}\beta_x \approx 3mm \\ \beta_y \approx 3mm\end{cases} \qquad \begin{cases}\sigma_x \approx 4.14\,\mu m \\ \sigma_y \approx 3.96\,\mu m\end{cases}$$



➡ At low beta function, chromatic aberrations increase the beam size above the simple analytic estimation

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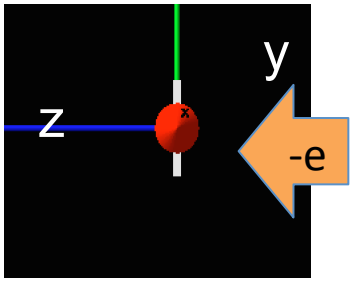
Expected spectra of CR and bremsstrahlung

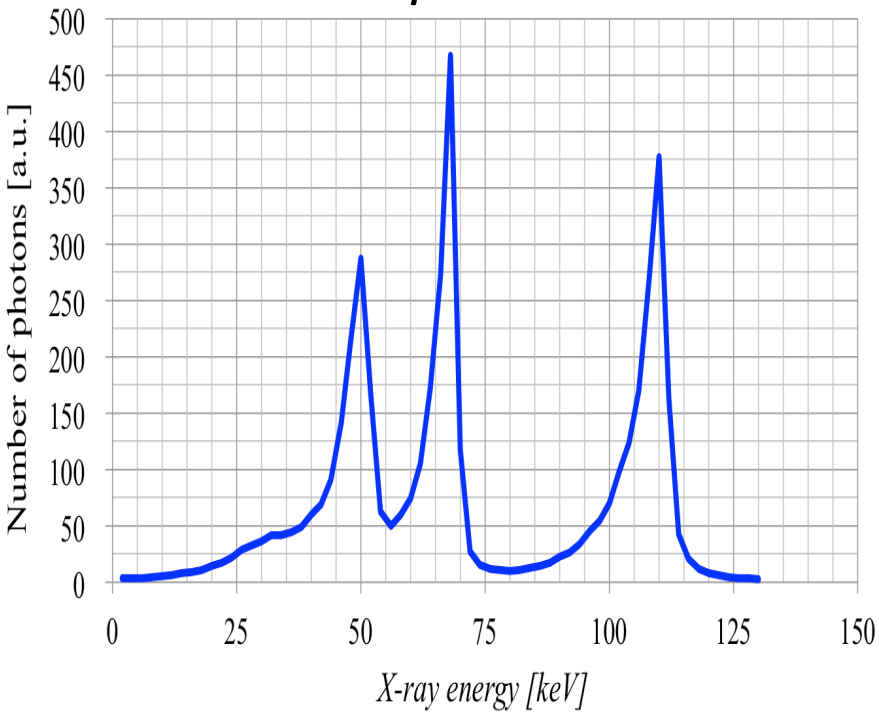


Crystal: Diamond, plane: (110), thickness: 168um

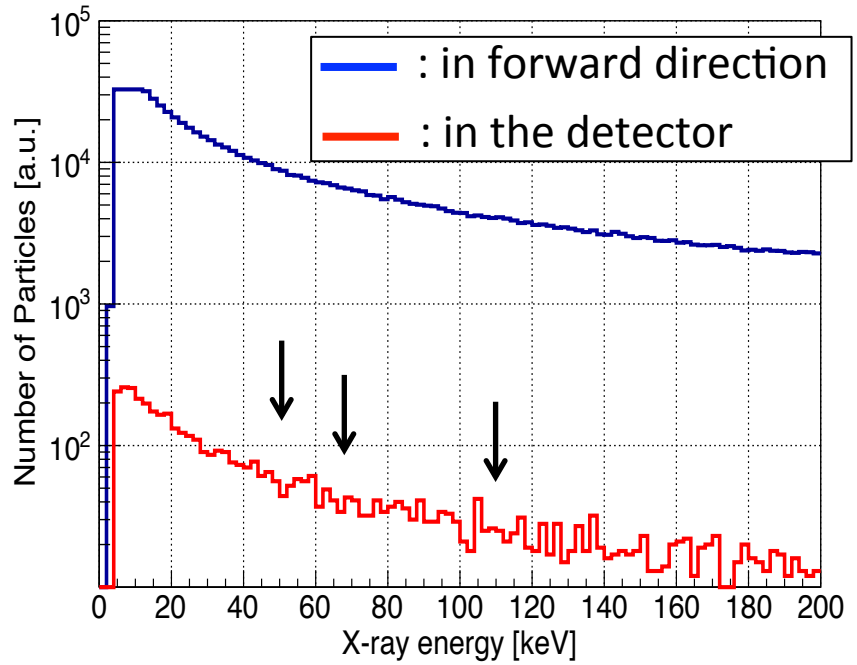
detector acceptance : 2 mrad

Bremsstrahlung were simulated with Geant4.

CR spectrum



Bremsstrahlung spectrum

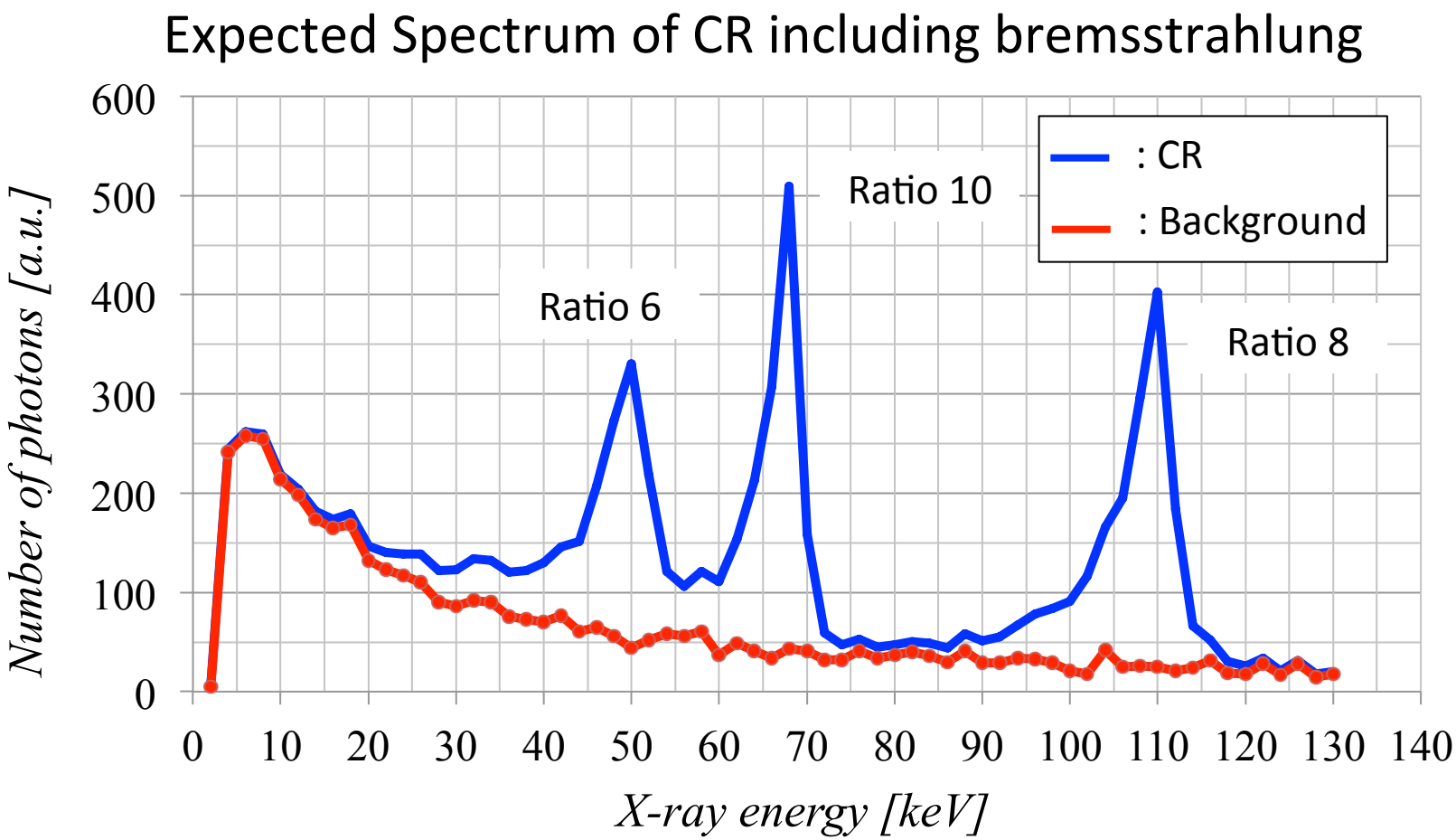


CR energy for 43 MeV electrons : 50 keV, 68 keV, 110 keV, $\delta E/E$ = 10%

Spectrum of CR including Bremsstrahlung

Electrons Energy : 43 MeV, Electrons Number : 10^8, Crystal : Diamond (168 μm)

Signal to background ratio : 6, 10, 8 for 50 keV, 68 keV 100 keV



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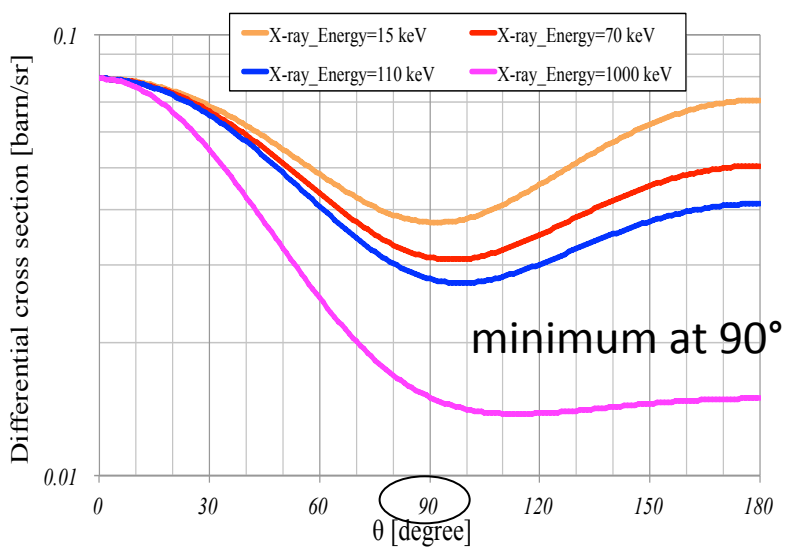
X-ray detector

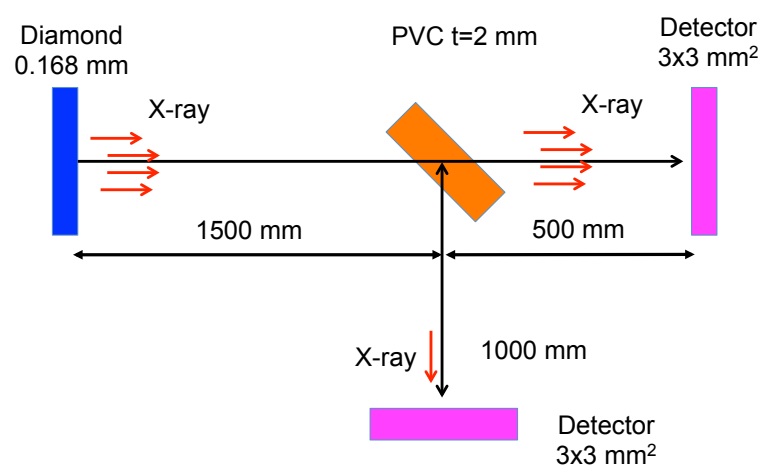
- CdTe detector
  →Pile-up effect for high intensity !!
- To avoid pile-up effect, reduce the number of photons in the detector ⟶ Compton scattering

Klein-Nishina's formula (cross section)

$$\frac{d\sigma}{d\Omega} = \frac{r_e^2}{2}\frac{1}{\left[1+\gamma(1-\cos\theta)\right]^2}\left(1+\cos^2\theta+\frac{\gamma^2(1-\cos\theta)^2}{1+\gamma(1-\cos\theta)}\right)$$



The second CdTe detector at 90°

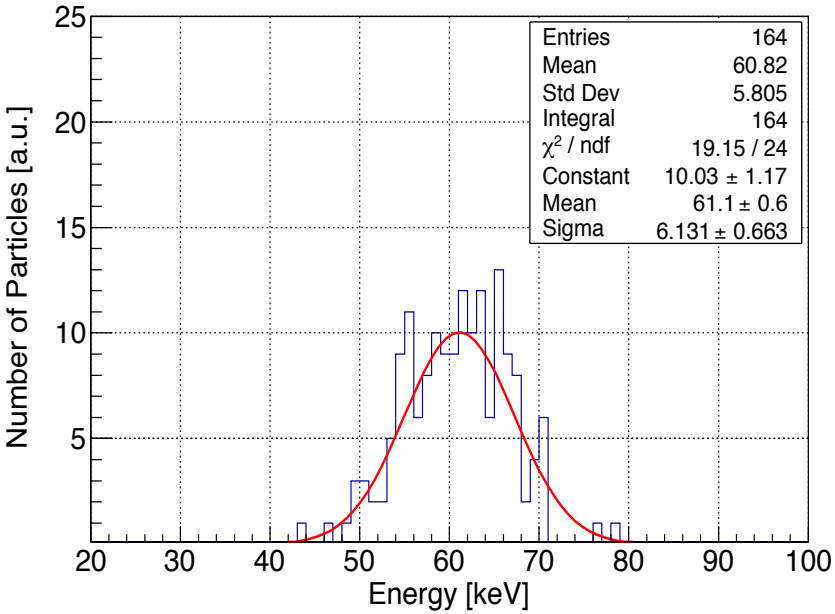


Compton Scattering at 90 degrees

X-ray energy : 70 keV, dE/E=10%, Number of photons : 1×10^9

detector acceptance : 8 mrad

PVC C_2H_3Cl t=2 mm



～ second detector～

Number of photon :～170

X-ray Energy : 61 keV

The photon number at 90 degrees is reduced by about seven order.
This will be sufficient to measure X-rays without pile-up.

Conclusions

1. Beam optics for high-brightness CR
   → Minimum Beam sizes at the crystal are about 4um.
2. Expected X-ray spectrum including background
3. Compton scattering to avoid pile-up effect

We can produce the high-brightness CR with low emittances beams at FAST.

The average brilliance in our experiment is expected to be about one order of magnitude higher than that in previous experiments.

Thank you for your attention