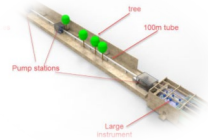
Ground calibration of FXT optics in IHEP

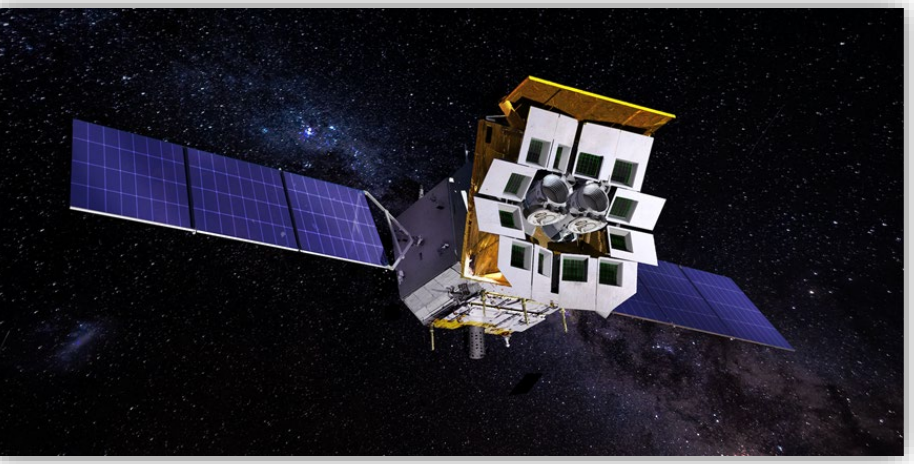
The Institute of High Energy Physics, Key Laboratory for Particle Astrophysics
Yuxuan Zhu
on behalf of the EP-FXT Team
2024， May 13th

Outline

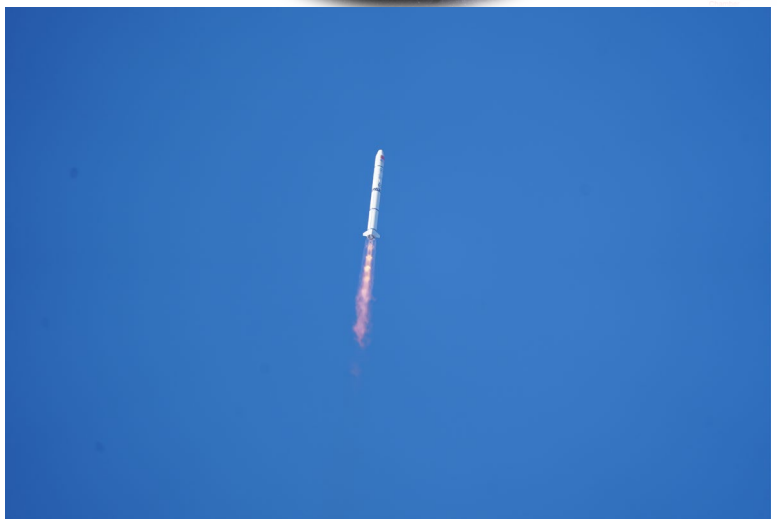


- Introduction of EP-FXT and calibration facility 100XF
- Installation and alignment
- Calibration results
  - ✓ Effective area
  - ✓ Vignetting
  - ✓ PSFs(Open filter, thin filter, medium filter, hole filter)
  - ✓ Angular resolution
  - ✓ Transmission of filters
  - ✓ Focal length measurement

1.1 EP-FXT



- ◆Size: 3000mm×3605mm
- ◆Stability: better than 0.0005 degree/s
- ◆Pointing accuracy: better than 0.05 °
- ◆Orbit altitude: 600 km
- ◆Inclination: ≤20°

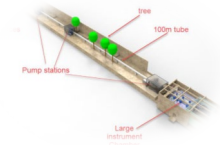


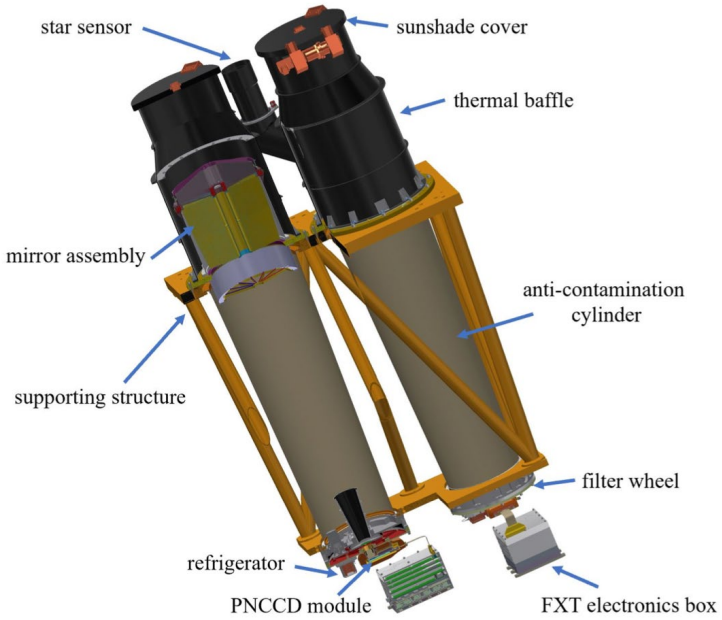
A Long March-2C carrier rocket carrying a new astronomical satellite named Einstein Probe (EP) blasts off from the Xichang Satellite Launch Center in southwest China's Sichuan Province, ***Jan. 9, 2024***. (Photo by: Zhang Jing/Xinhua)

Primary scientific objectives:

1. Discover and characterize cosmic **X-ray transients**, to reveal their properties and gain insight into their nature and underlying physics.
2. Discover and characterize **X-ray outbursts** from normally quiescent black holes, for better understanding of the demography of black holes and their origin and evolution, as well as accretion physics.
3. Search for X-ray sources associated with **gravitational-wave events** and precisely locate them.

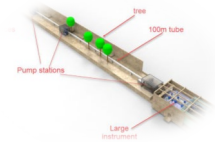
1.1 EP-FXT

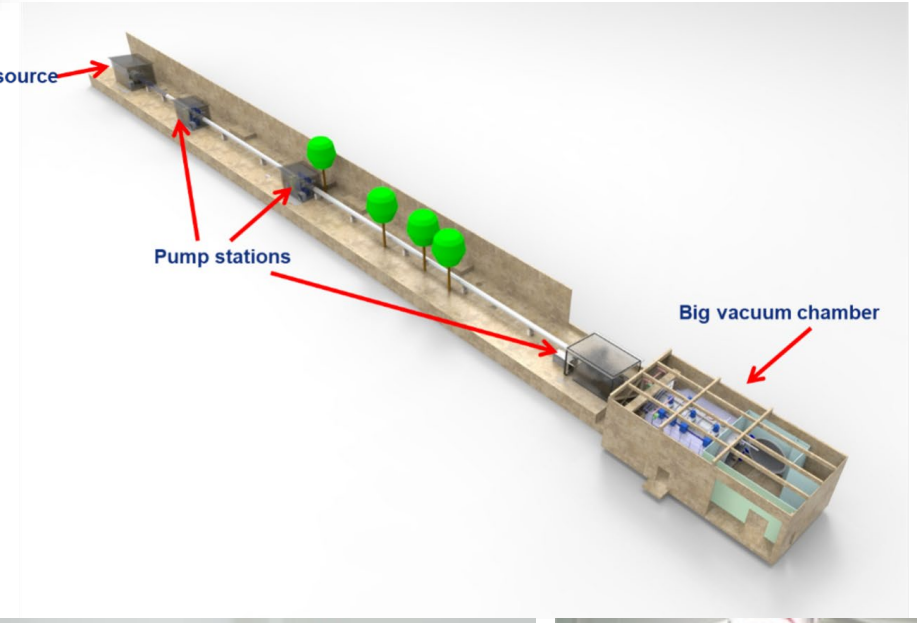




Items	Goal
Field of View (FOV)	60’
Source flux upper limit	≥ 5Crab; TM ≥ 200mCrab; PW
Effective area	≥ 600 cm2@1.25 keV, on axis
Angular resolution	HPD ≤ 30”
Energy resolution	FWHM ≤ 120eV@1.25keV
Energy band	0.3 - 10 keV
Location precision	≥ 4”
Frame frequency	20 fps; FF
Mass	276 kg
Mission duration	5 years

1.1 The 100m X-ray Test Facility (100XF)



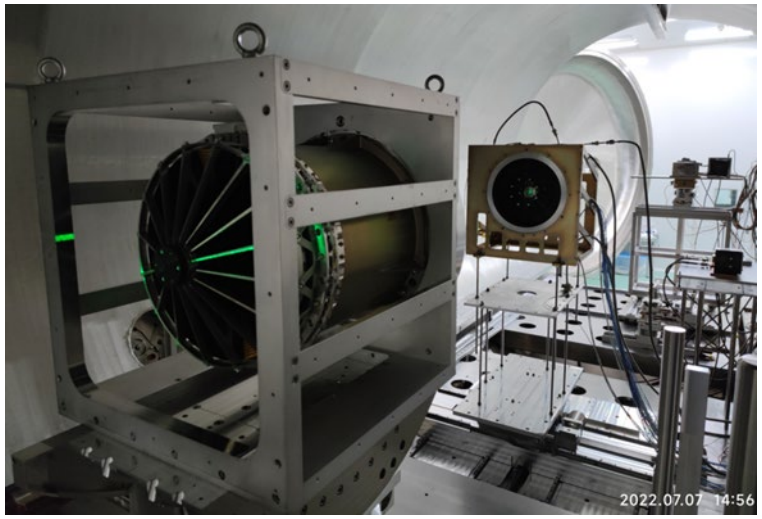


Items	Level
Vacuum level	Better than $5*10^{-5}$ Pa
Spot diameter	600 mm(divergence angle＜12′)
X-ray sources	➢ The multi-targets X-ray source ➢ Timing Calibration X-ray source ➢ Channel-cut DCM ➢ Secondary multi-targets X-ray sources ➢ The polarized X-ray ➢ source
Vacuum Chamber size	8 m (length)*3.4 m (diameter)
Cleanliness level	Class 1000

Details about the 100XF will be found in Prof Wang's presentation.

The 100XF overall schematic (up), Multi-target X-ray source (down left), EP-FXT is prepared for test in the vacuum chamber (down right)

2 Installation and alignment

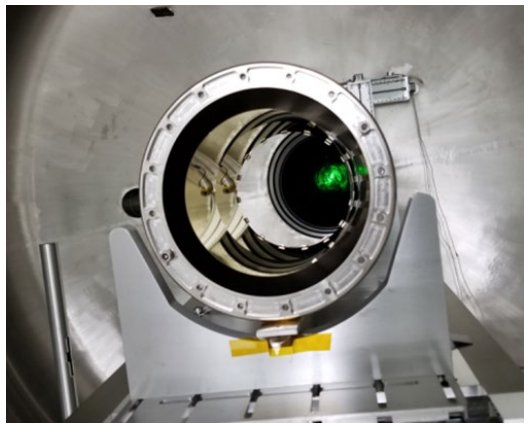


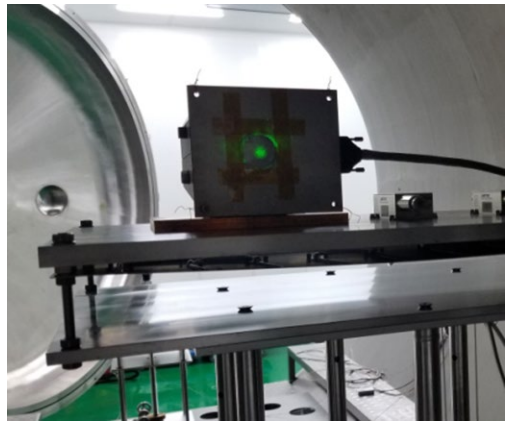
FXT FM1（contribution of ESA）calibration （left） & FXT-A Calibration （right）

The optical calibration is divided into two stages, the mirror assembly stage and the overall FXT stage:

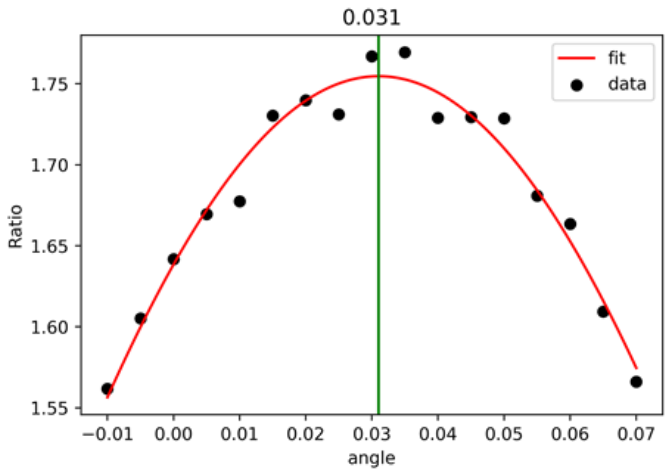
- In the mirror assembly stage, the focusing mirror and the camera are separately adjusted and can undergo various tests such as effective area (intra-foucs status), focal length, Vignetting, angular resolution etc.
- The whole FXT stage includes testing of PSFs, filter transmission, etc.

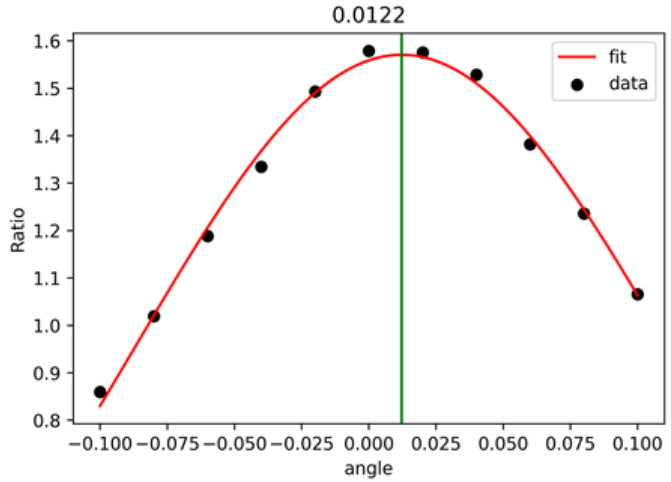
2 Installation and alignment





Laser rough alignment and spot

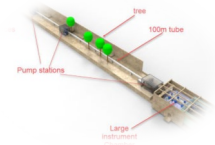


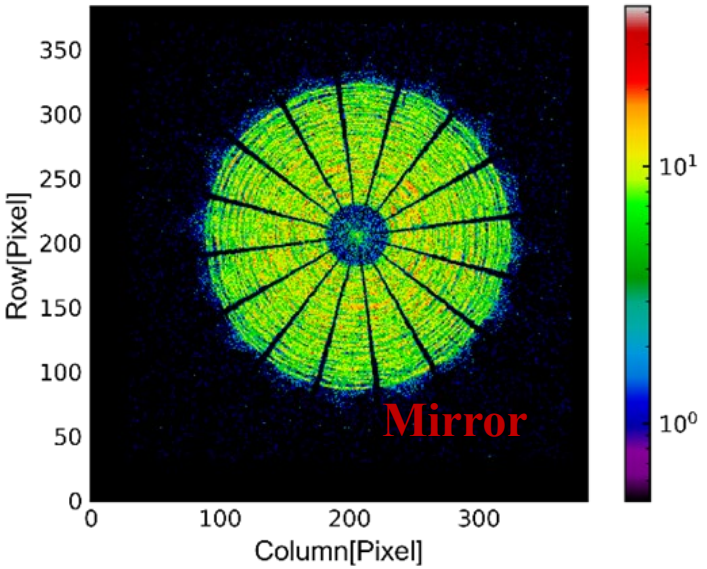


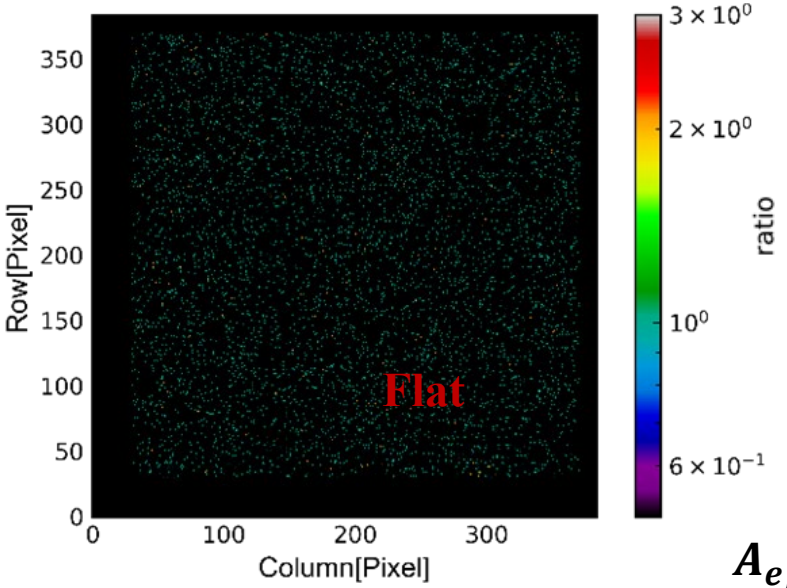
Using the X-ray counts rate to search the precise position of on-axis

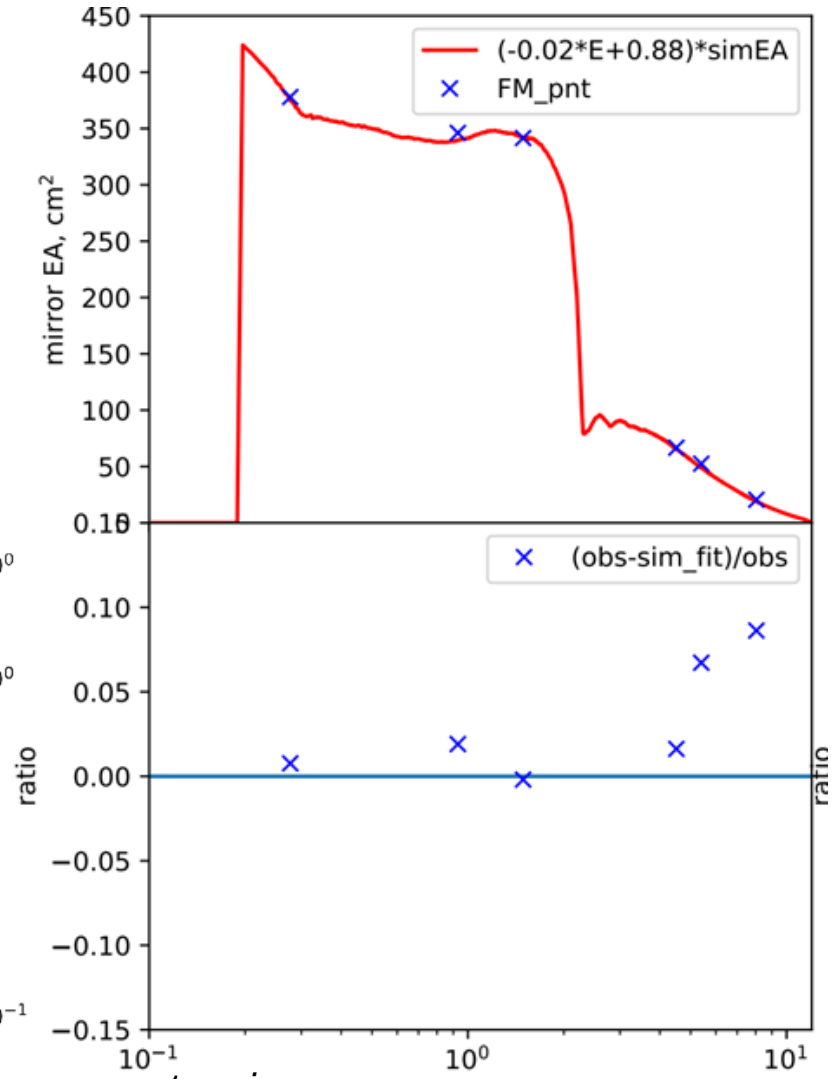
- First step of laser alignment is scan of the center of the exit port of the 100-meter pipe, and the laser spot aligned in the 100-meter tube will pass through the mirror module.
- Due to the deviation in position and attitude between the laser light source and the X-ray source, X-ray alignment needs to be performed after laser focusing by off-axis scanning to search maximum counts.

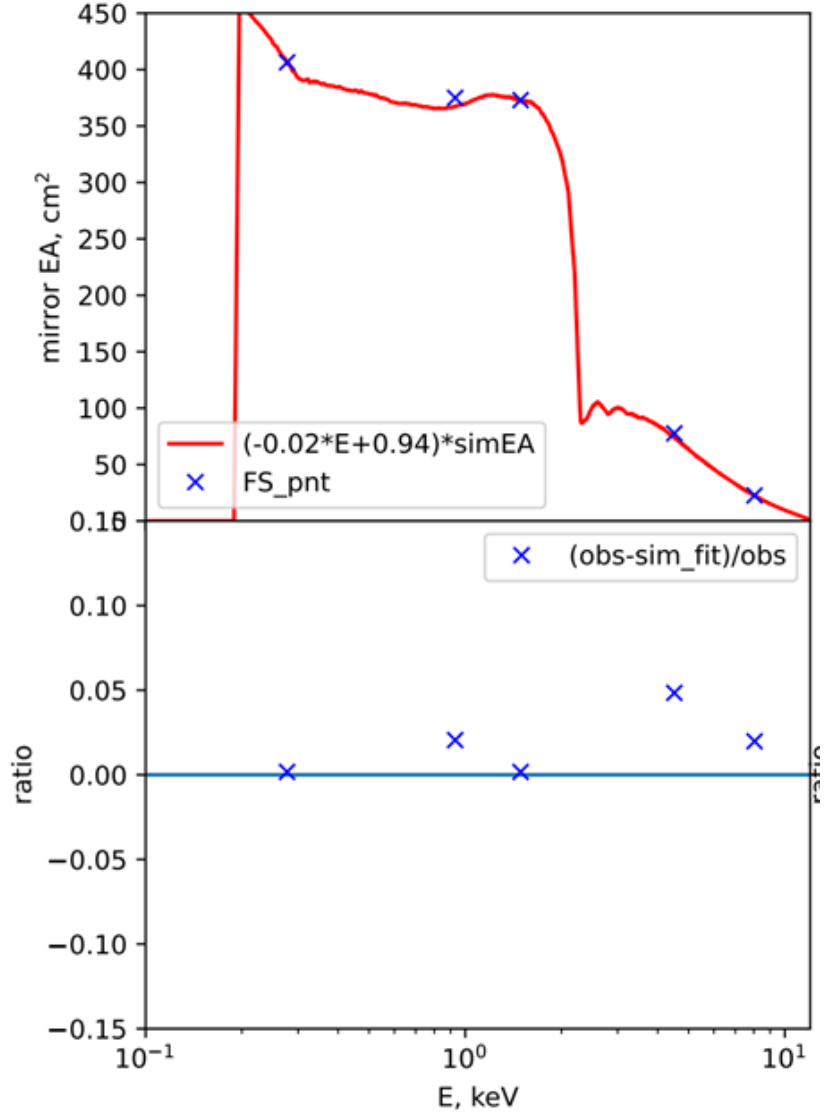
3.1 Effective area





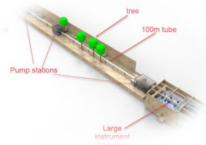






$$A_{eff} = \frac{cts\_mirror}{cts\_flat} * A_{det} * D * P$$

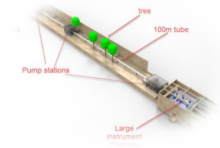
3.1 Effective area

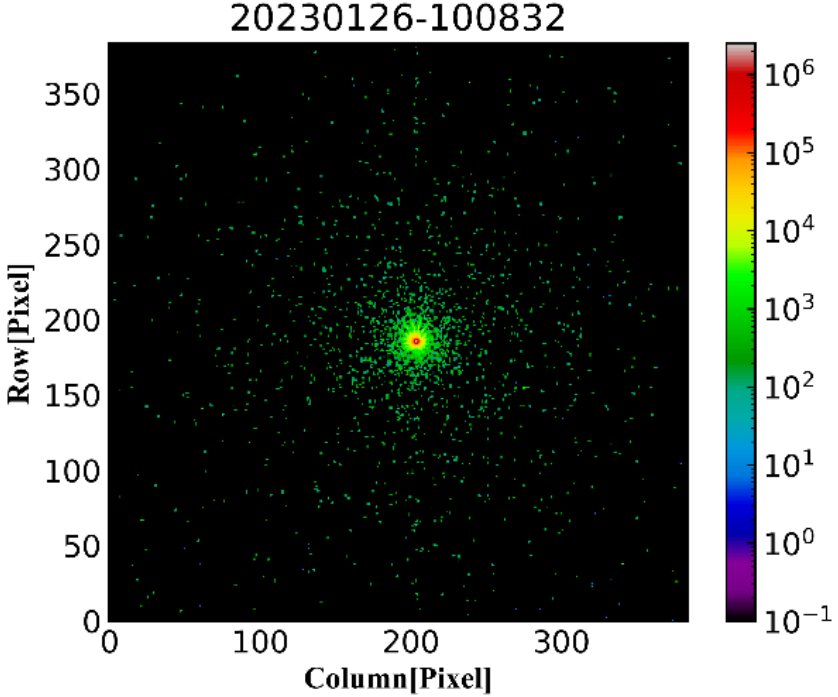


Items	EA of FXTA			EA of FXTB		
Energy (keV)	FXTA-open Corrected for divergence	PANTER mirror	IHEP mirror	FXTB-thin Corrected for divergence	PANTER mirror	IHEP mirror
Method	Standard	Gluckrad	Standard	Standard	Standard	Standard
pnCCD mode	Timing	Full frame	Full frame	Timing	Full frame	Full frame
C-K:0.28	134.4±2.7		391.3±7.6	61.8±1.0		406.4±4.5
Ti-L:0.45		396.3±2.3				
O-K:0.53	263.1±4.1			177.0±3.2		
Cu-L:0.93	325.3±5.1		356.8±5.6	288.4±2.8		375.0±3.6
Mg-K:1.25	323.3±1.7			329.8±1.8		
Al-K:1.49	324.8±1.7	360.7±3.4	363.3±1.9	346.3±4.4	389.6±20.5	373.0±4.7
Ag-L:2.98	86.2±1.0	94.6±1.1		86.4±1.0		
Ti-K:4.51	71.5±0.6	67.1±0.8	67.6±0.4	74.1±1.3		77.6±1.4
Cr-K:5.4			52.3±0.4			
Fe-K:6.4	33.8±0.3	33.7±0.3		37.6±0.5		
Cu-K:8.04	18.9±0.2	17.9±0.1	20.4±0.2	20.5±1.0	20.5±1.0	22.6±1.1

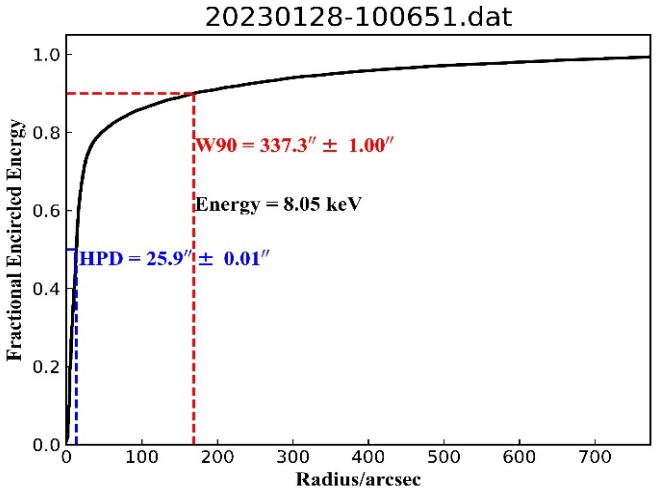
- Some significant deviation caused by the pile-up occurs while the flux is rather big @ C-K
- EA is about 320 cm^2@Mg-K, meeting the scientific requirements.

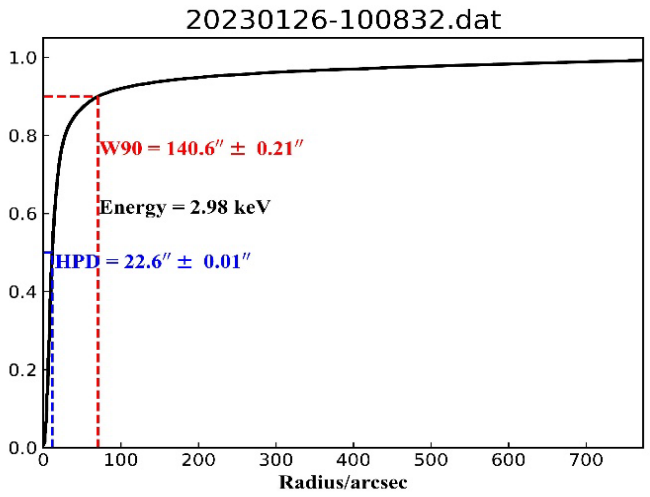
3.2 Angular resolution

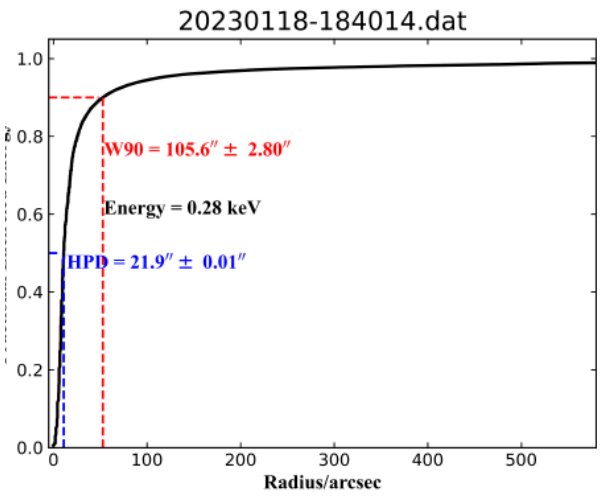


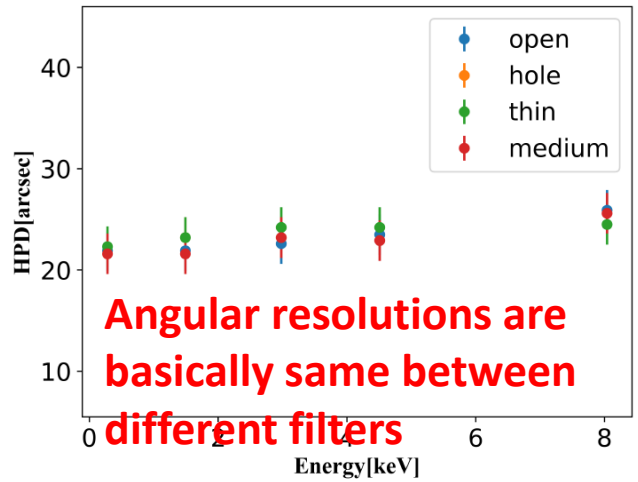


Energy/keV	FXTA		FXTB	
	HPD/″	W90/″	HPD/″	W90/″
C-K: 0.28	21.9±0.01	105.6±2.8	19.3±0.01	46.6±0.01
Al-K: 1.49	21.9±0.01	104.1±5.3	23.5±0.01	126.3±0.41
Ag-L: 2.98	22.6±0.01	140.6±0.2	23.2±0.01	129.7±0.29
Ti-K: 4.51	23.5±0.01	198.5±1.2	22.6±0.01	134.9±0.17
Cu-K: 8.04	25.9±0.01	337.3±1.0	19.7±0.01	154.0±0.77

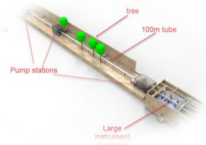


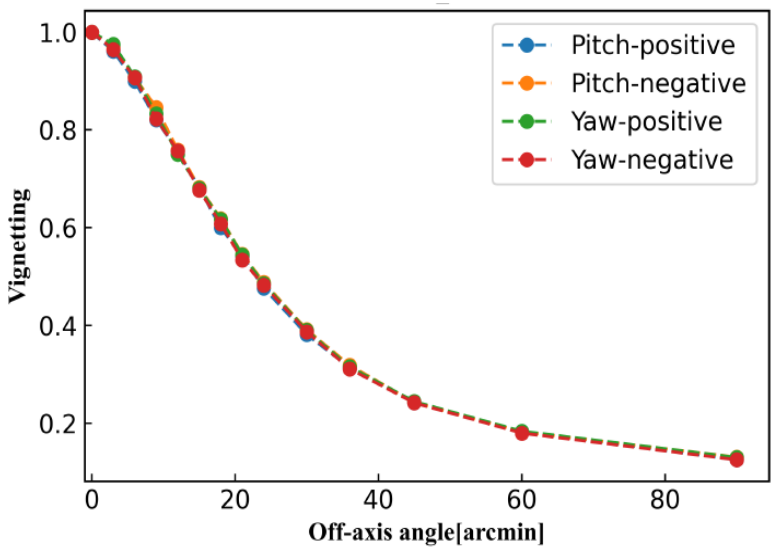




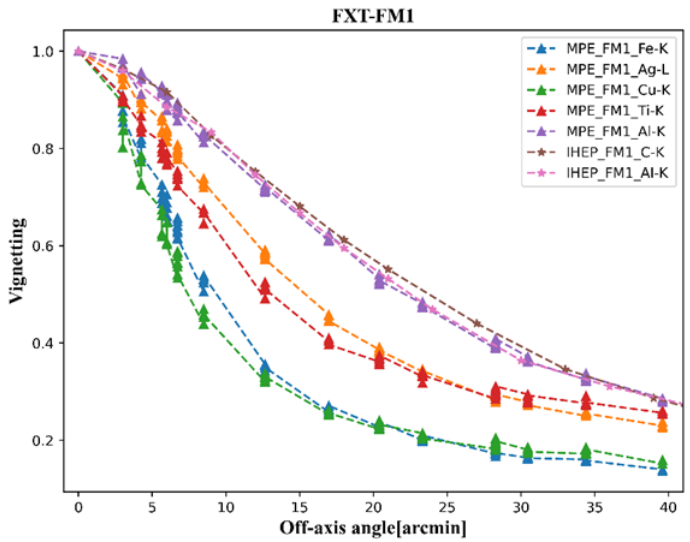


3.3 Vignetting

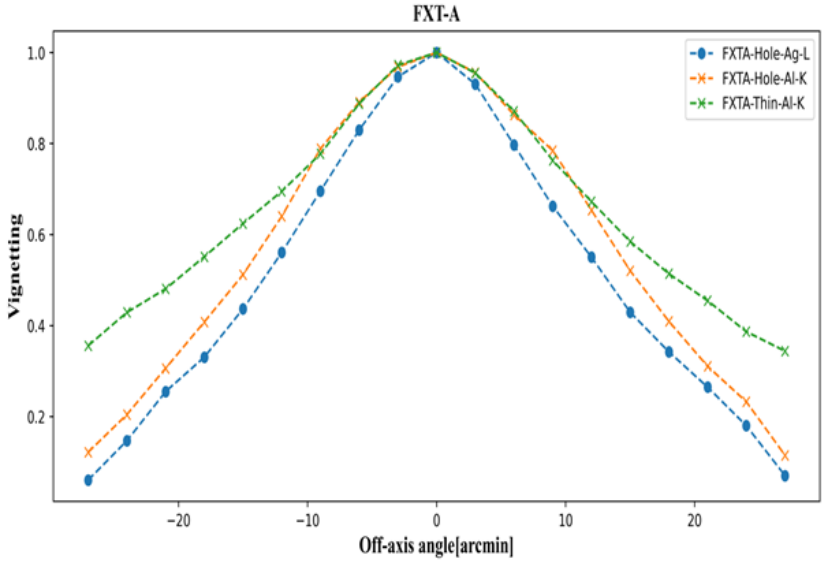




Off-axis symmetry



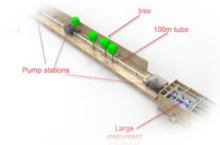
Vignetting function of FM1
（Mirror assembly stage）

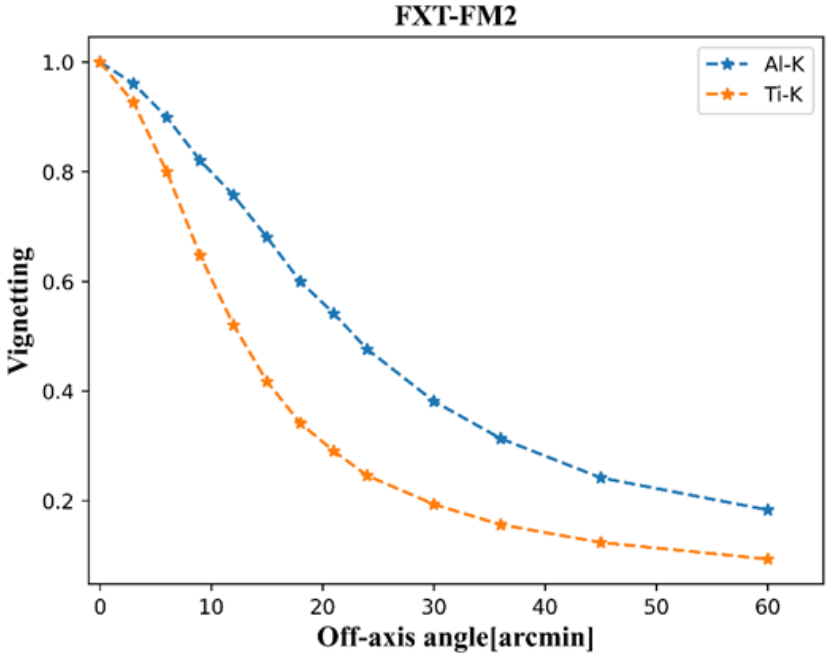


Vignetting function of FXTA
（ overall FXT stage）

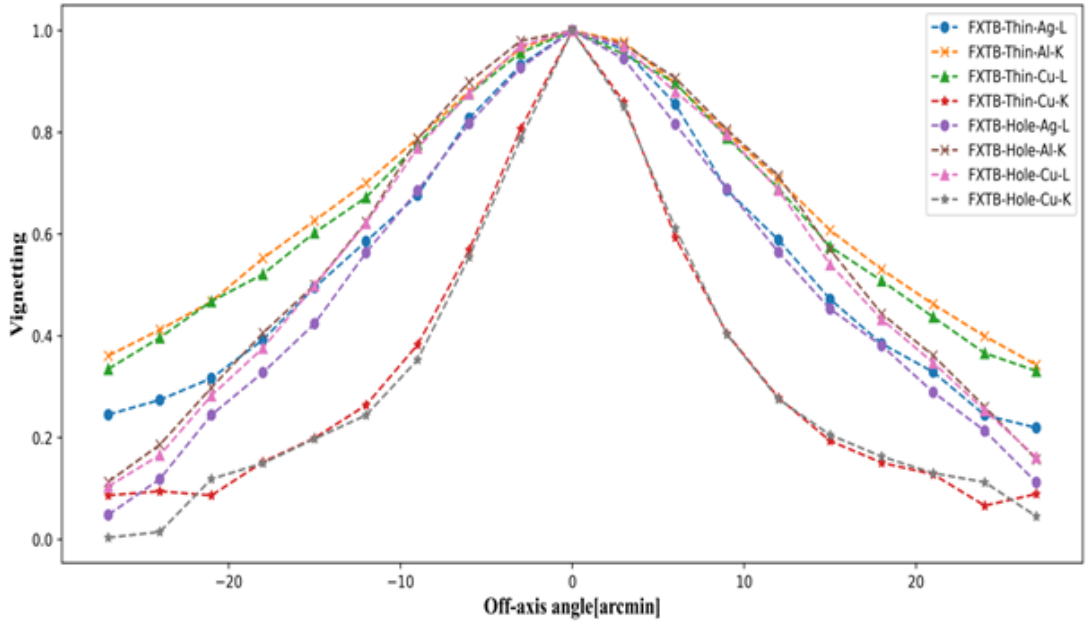
- The off-axis characteristics in all four directions exhibit excellent symmetry.
- The calibration results between PANTER and IHEP are consistent @Al-K.
- The influence of filter on vignetting is rather little while off-axis angle is rather small, which can be ignored. But for the hole position of the filter wheel, owing to the diameter of hole is smaller than thin filter, the vignetting drops faster after about 13′ than that of thin filter.

3.3 Vignetting



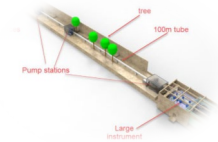


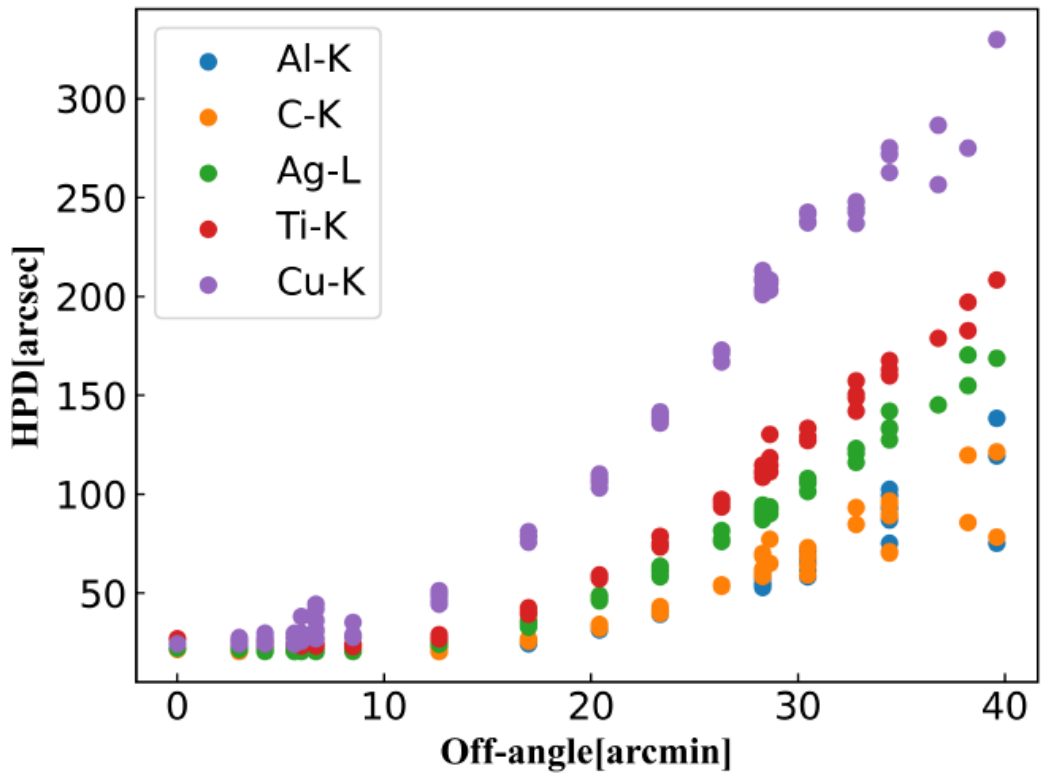
Vignetting function of FM2
（Mirror assembly stage）

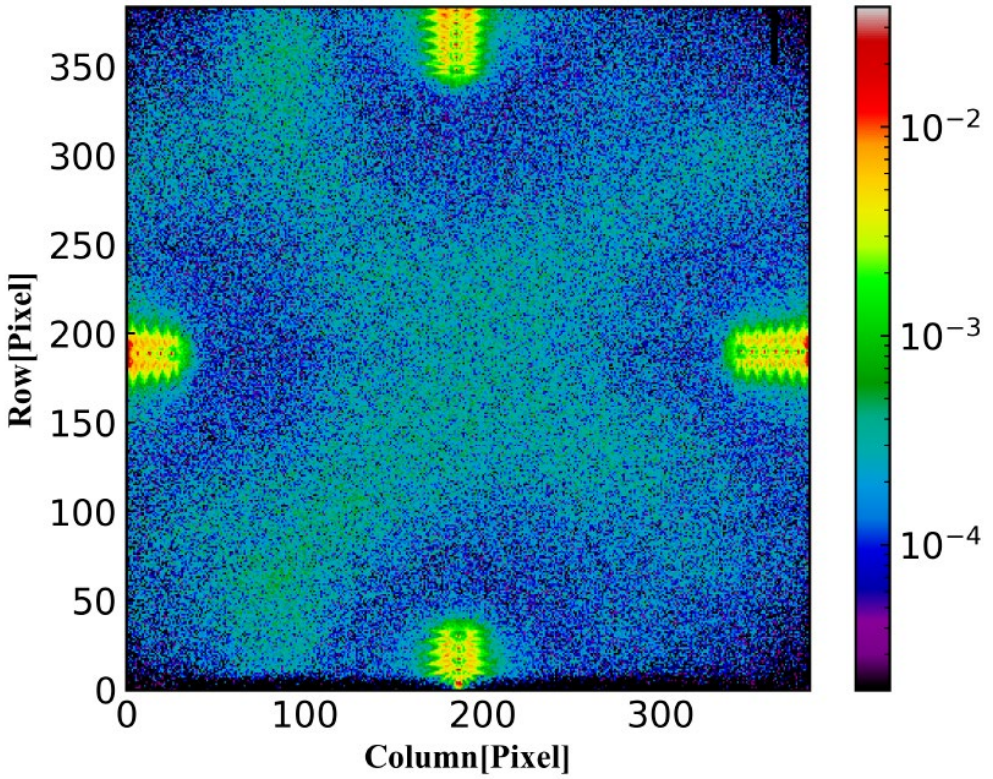


Vignetting function of FXTB
（ overall FXT stage）

3.3 Vignetting

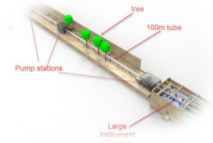


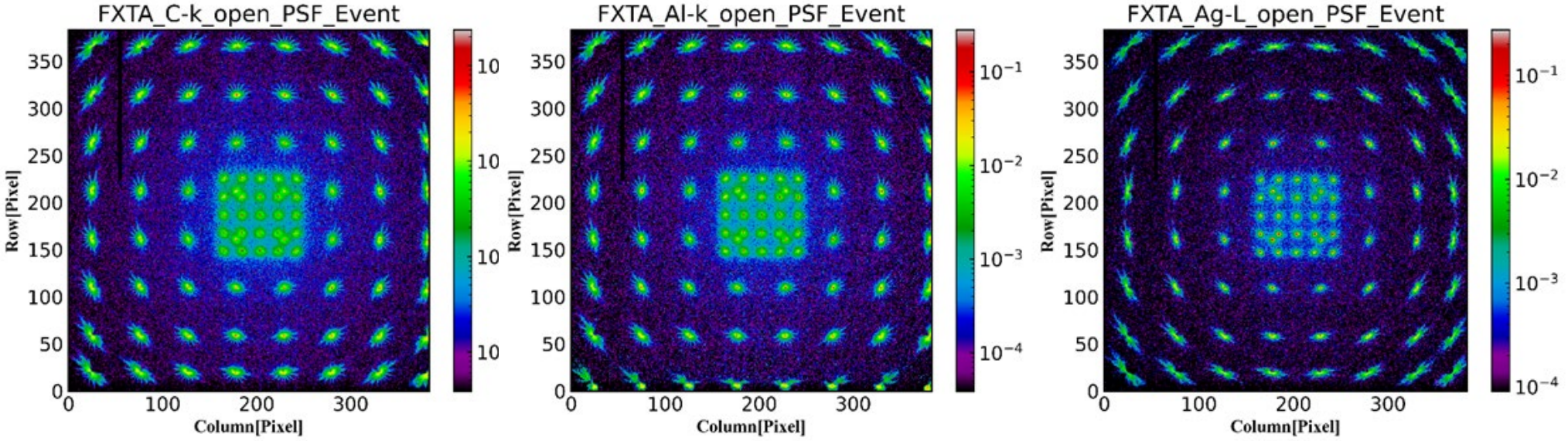


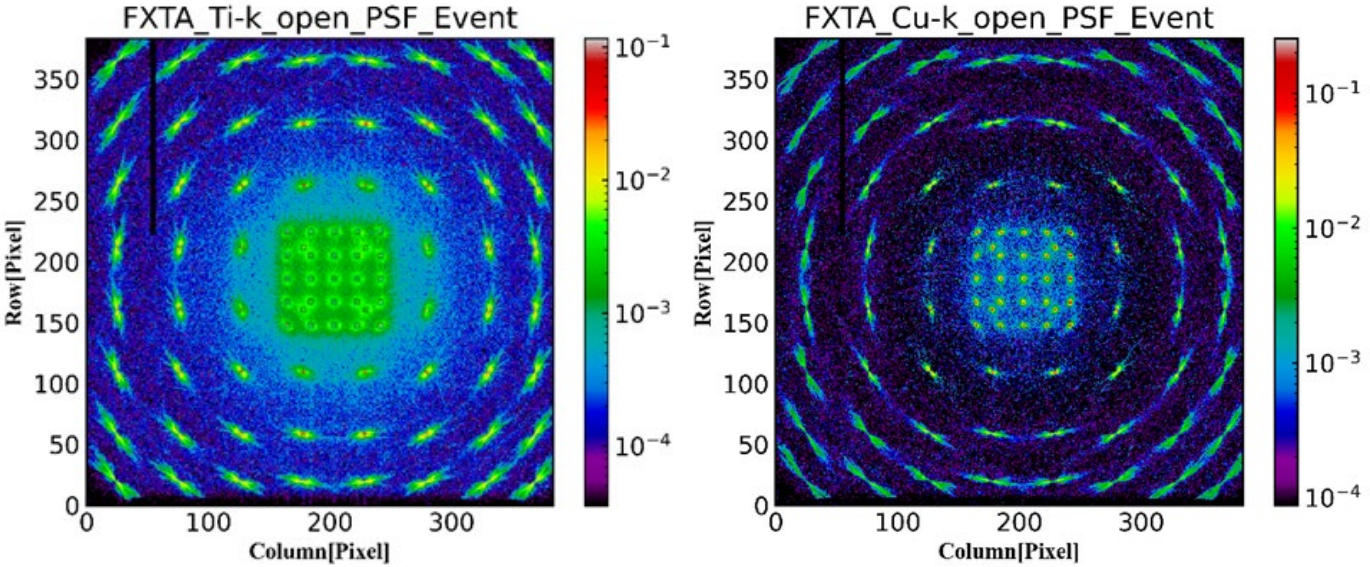


- Scanning along the edge of FoV shows： FoVs of FXT-A and FXT-B are 0.98° ×0.98° and 1.02° ×1.02° , respectively.

3.4 PSF mapping of FXTA open

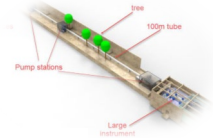


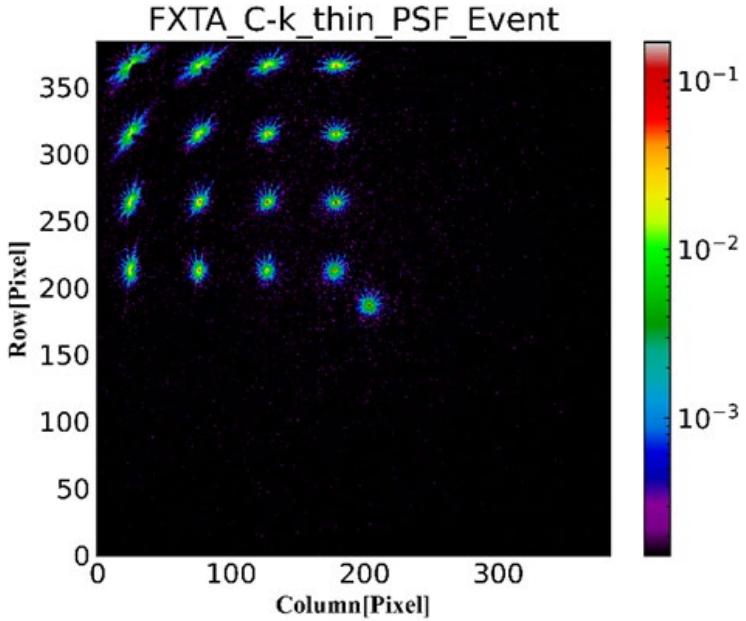


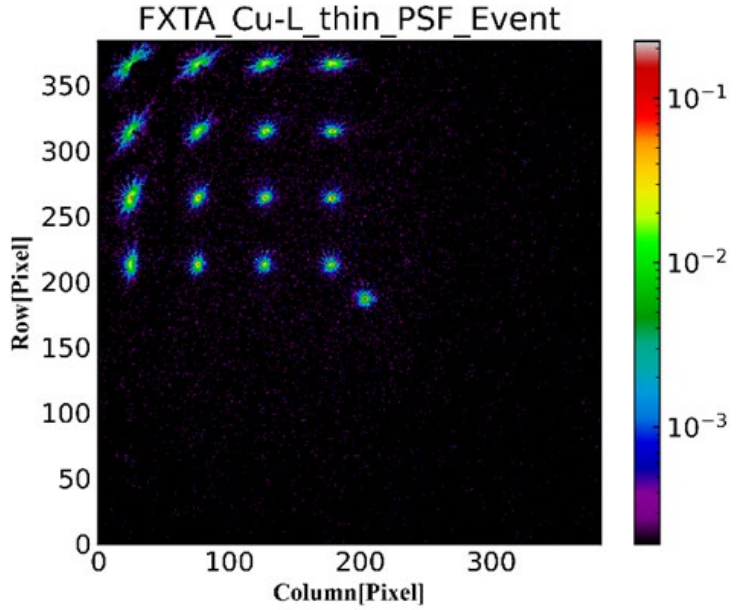


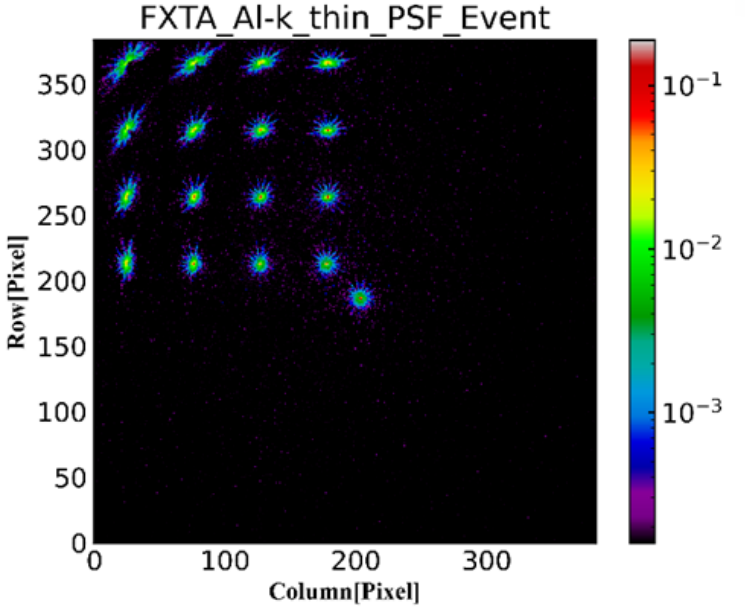
- In detail, point-by-point scanning is performed by an 8×8 matrix (interval 8′) for the whole FoV and a 5×5 matrix (interval 3′) for the central region.

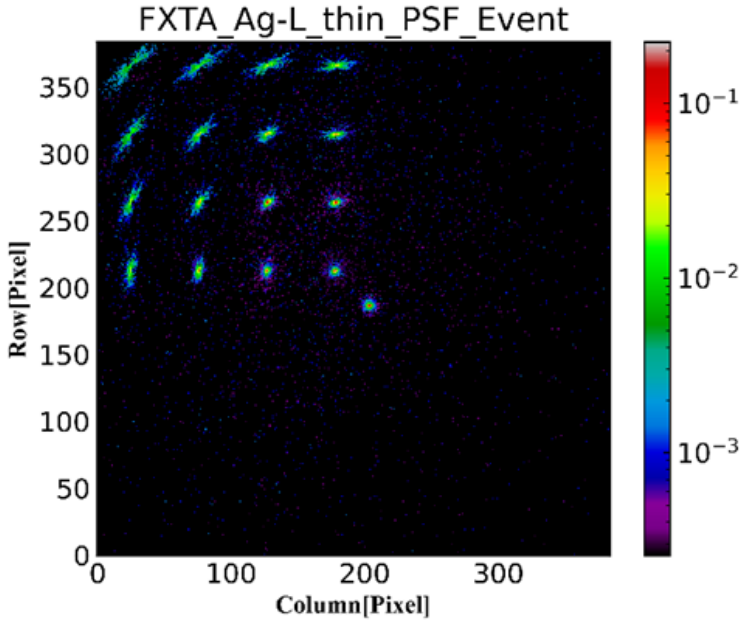
3.4 PSF mapping of FXTA thin filter

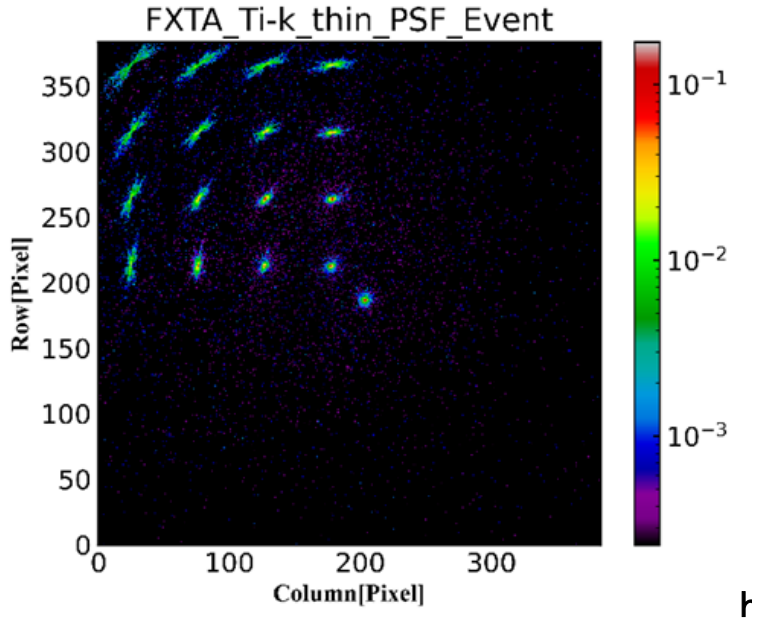


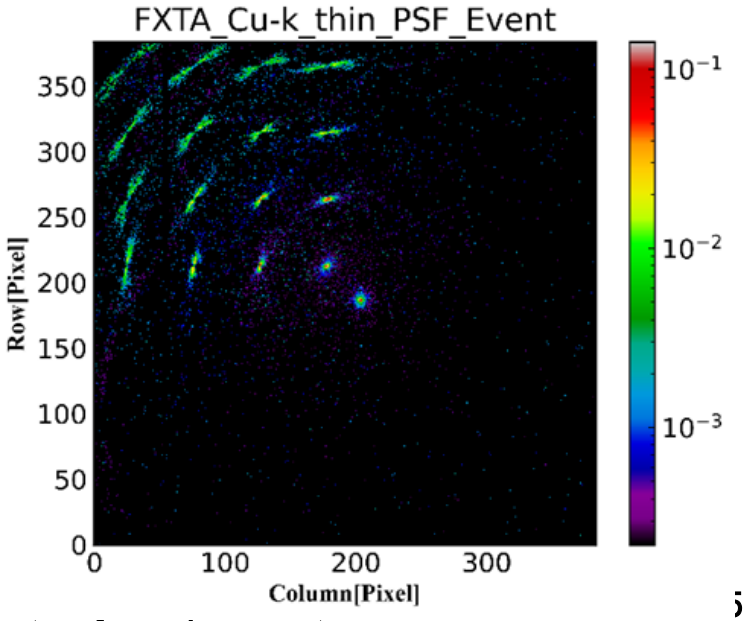




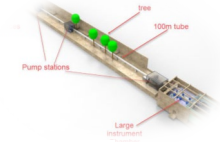


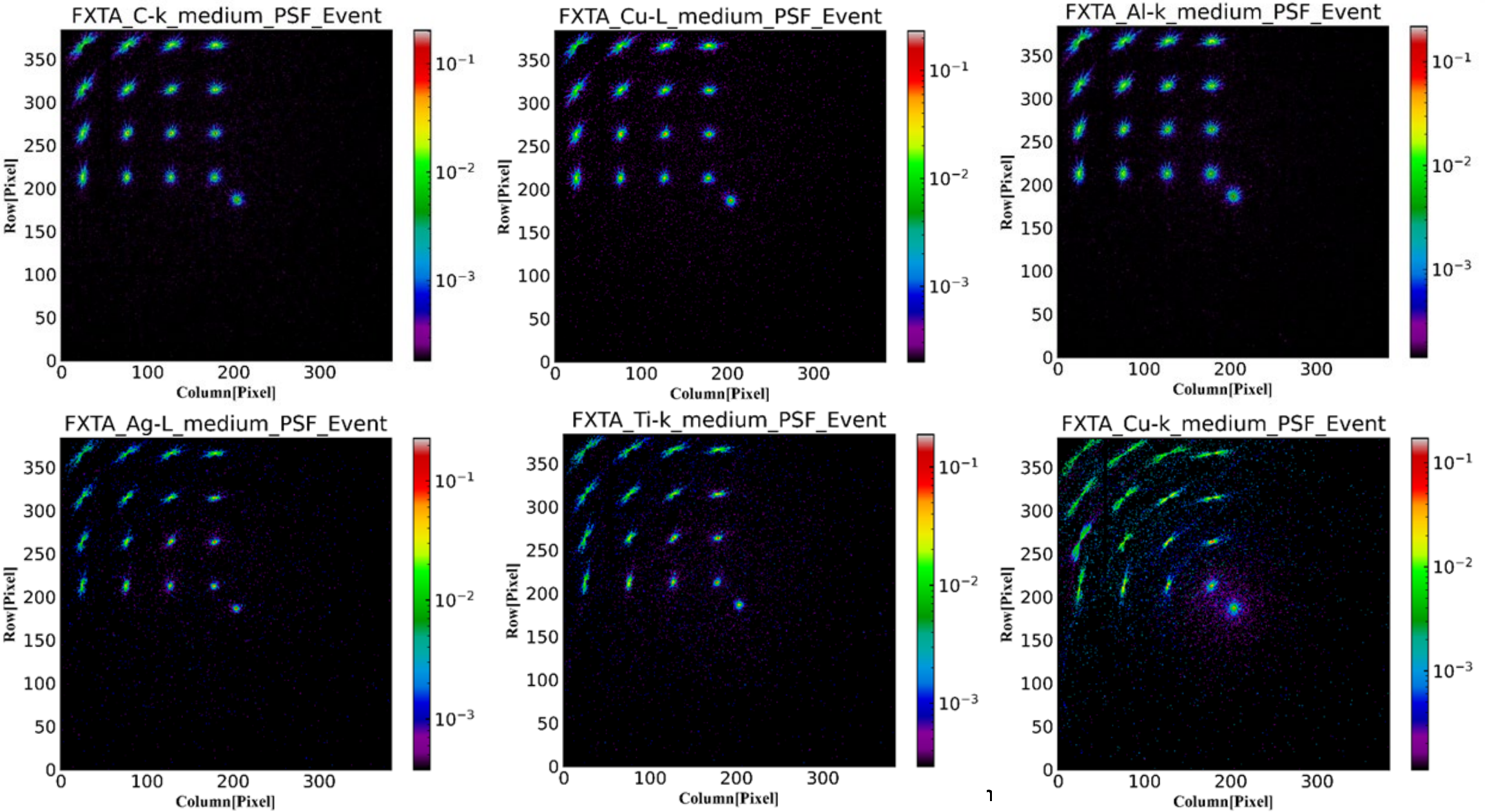




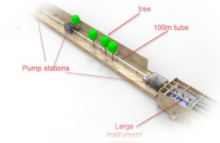


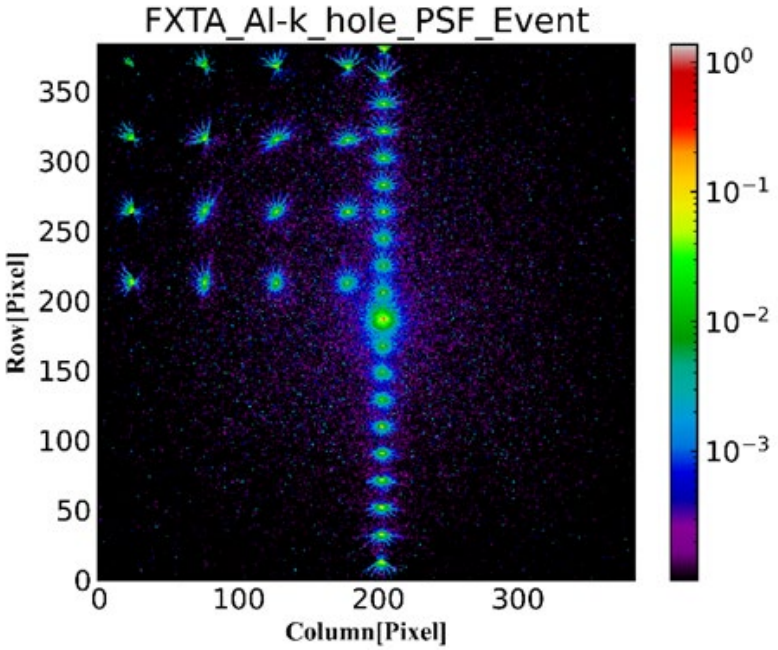
3.3 PSF mapping of FXTA medium filter

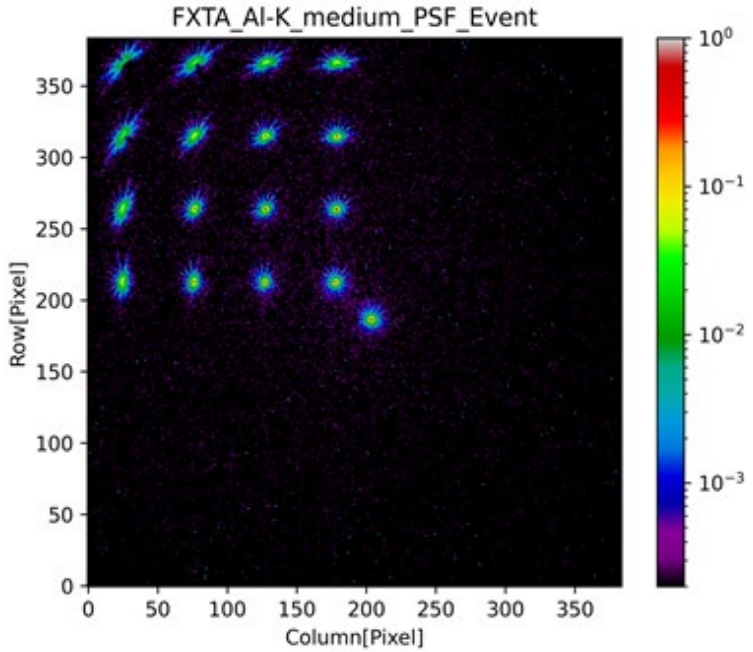


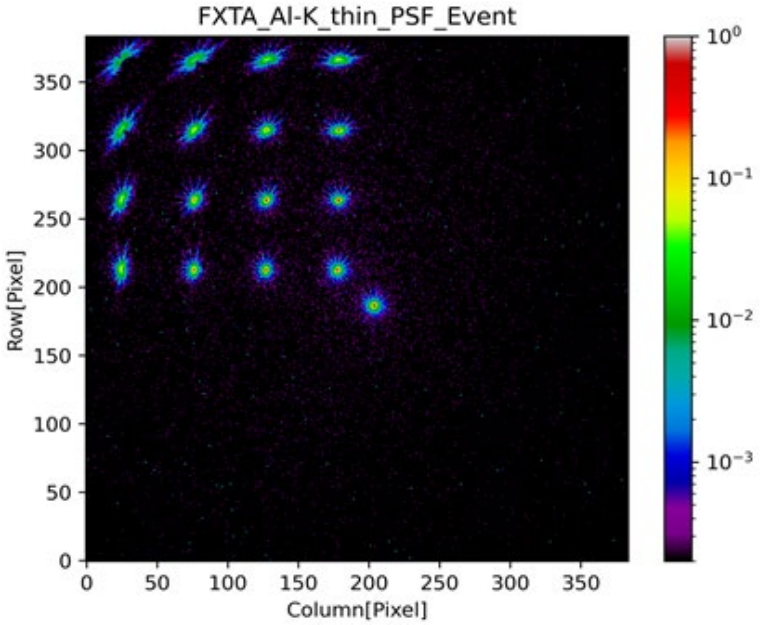


3.3 PSF mapping of FXTA hole filter



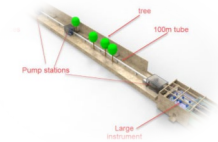


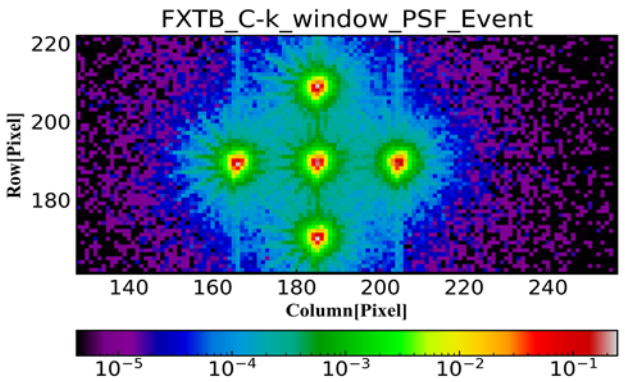


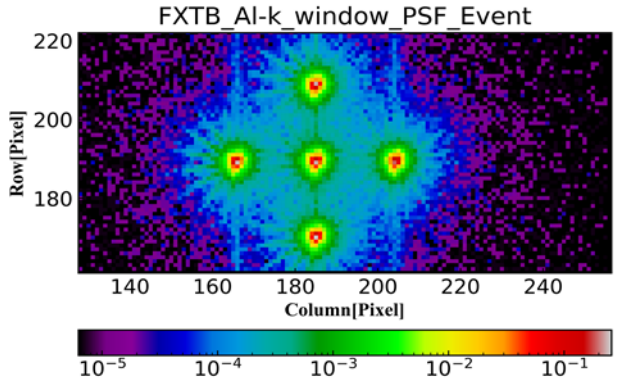


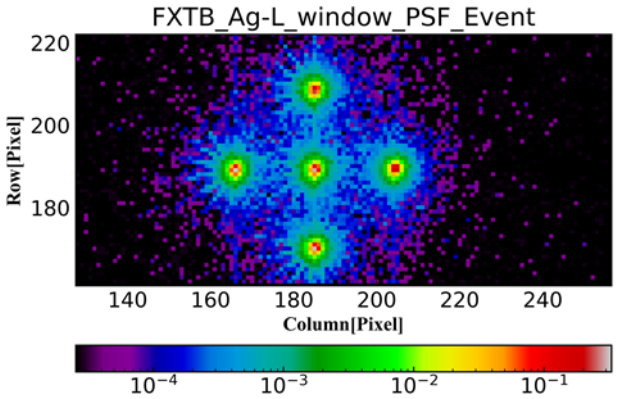
- PSF（HEW and W90） on-axis are essentially the same under four different conditions.
- Due to the significantly reduced diameter of the hole compared to the other operating conditions, the off-axis PSF shape is noticeably different from the other three conditions.

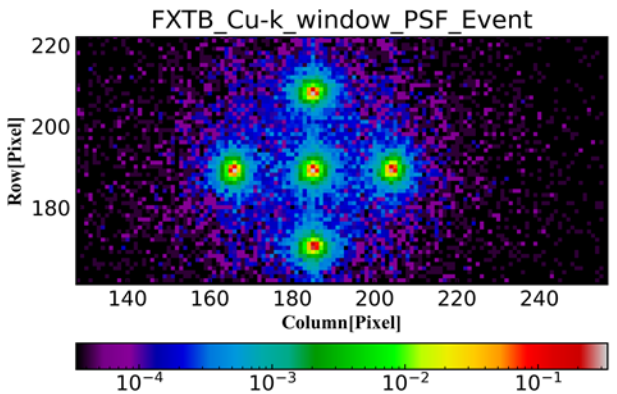
3.4 PSF mapping of FXTA hole filter





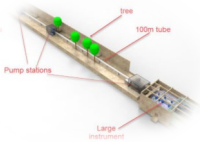


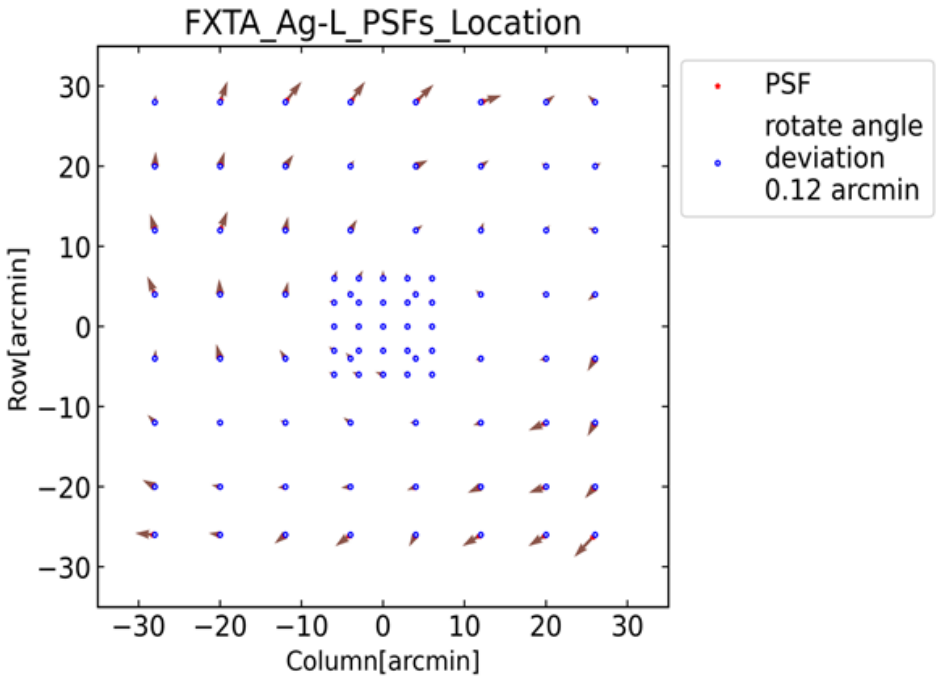


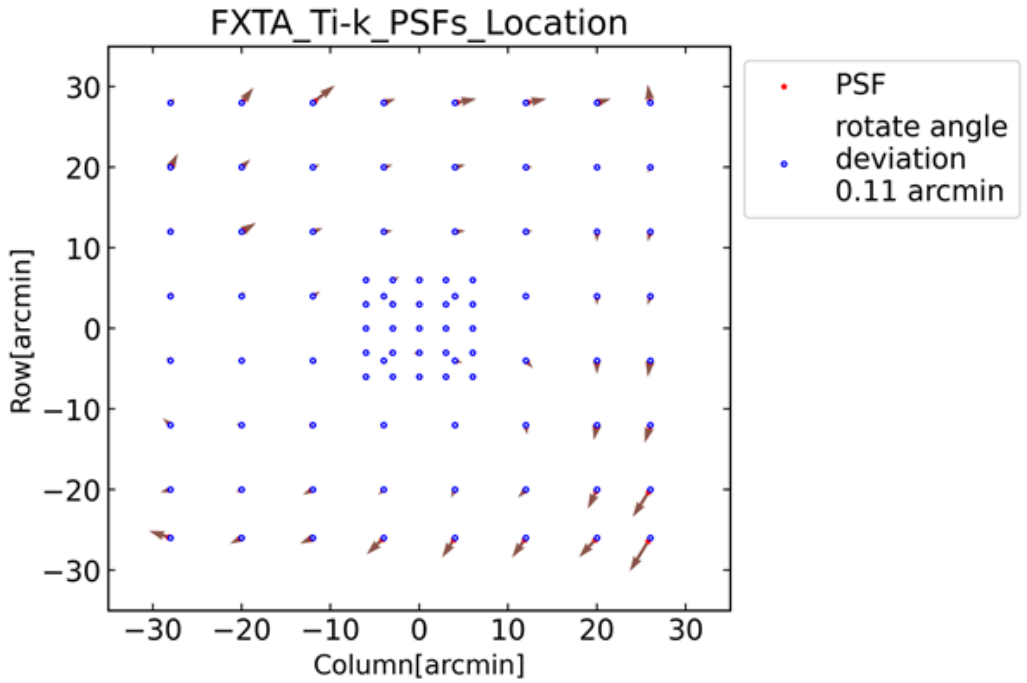


- PSFs of FXT-B for Partial window mode, the central PSF is on-axis, the angle of four symmetric off-axis position is 3’.
- In the PW of PSF of FXT-B, there are obvious out of time events because the incident flux is high.
- The HPD is 23.5” for C-K and Al-K, 20.8” for Ag-L and 19.7” for Cu-K. The HPD of PW is roughly consistent with Full Frame mode

3.4 PSF mapping of FXTA open filter

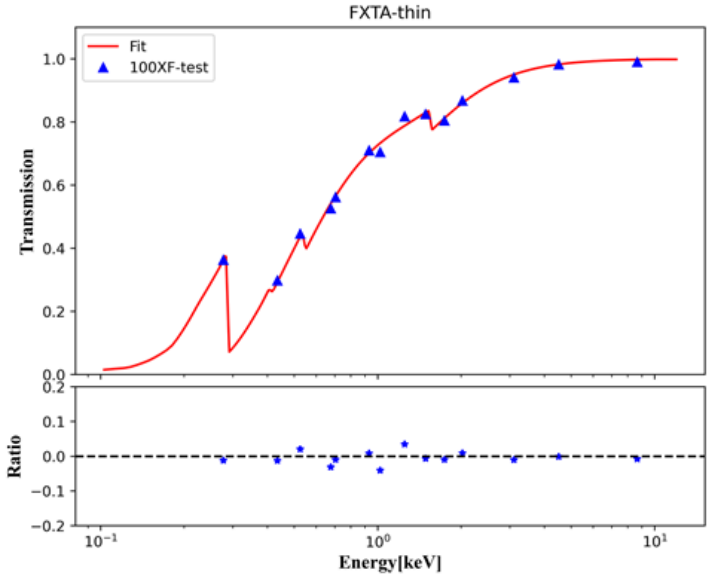


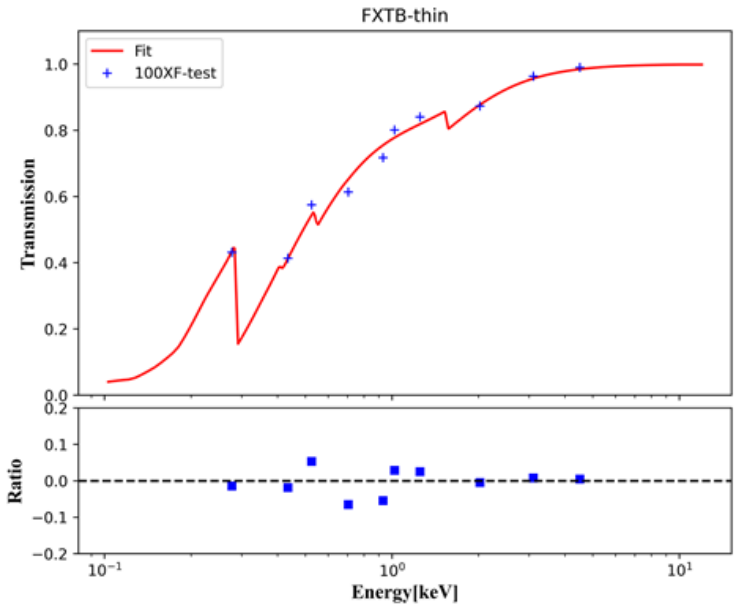




- Outer data points have larger deviations. The mean value of the deviations is 0.11′ for Ti-K and 0.12′ for Ag-L.
- It must be declared that the deviation will change when the telescope is in orbit for the change of the position of the pnCCD.

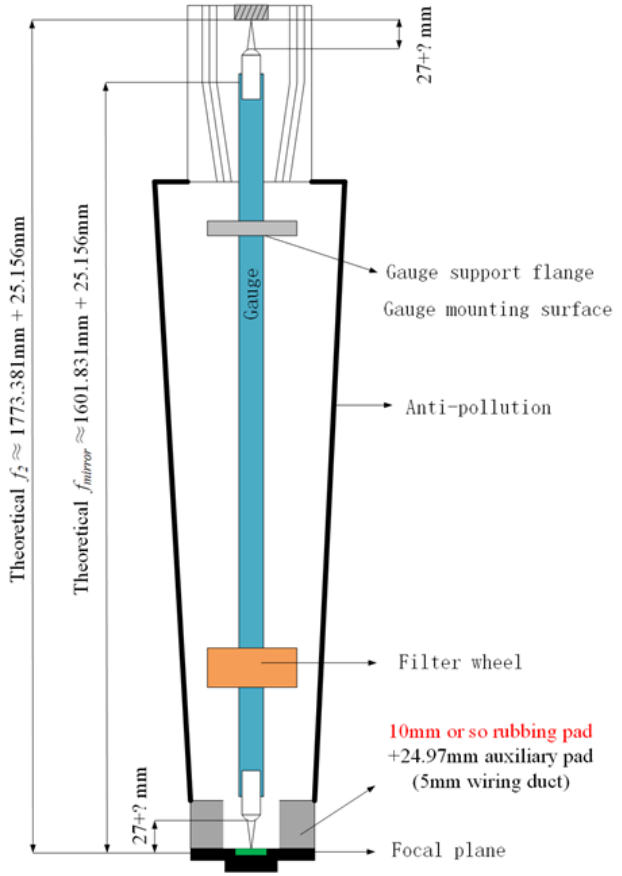
3.5 Transmission of filters

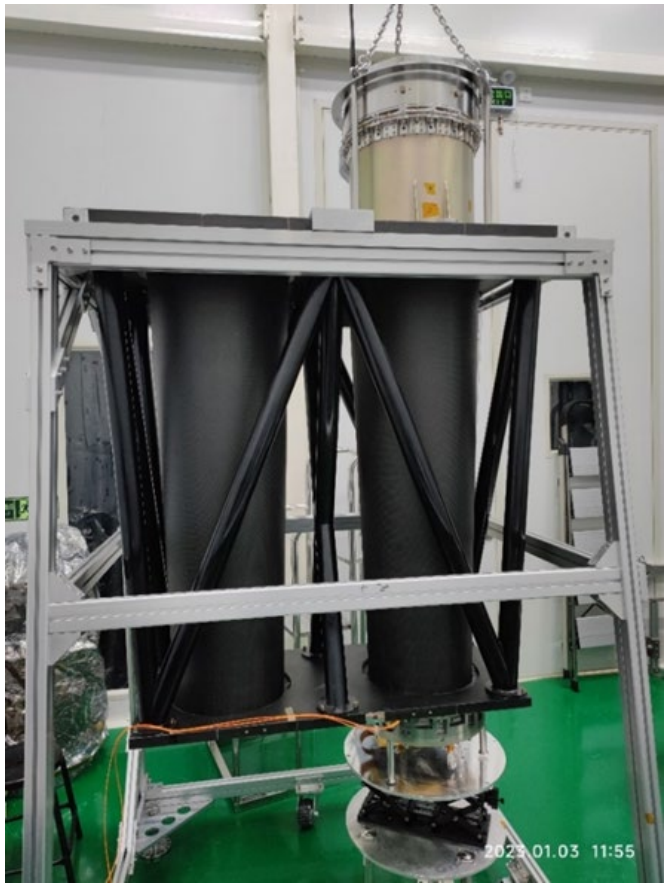


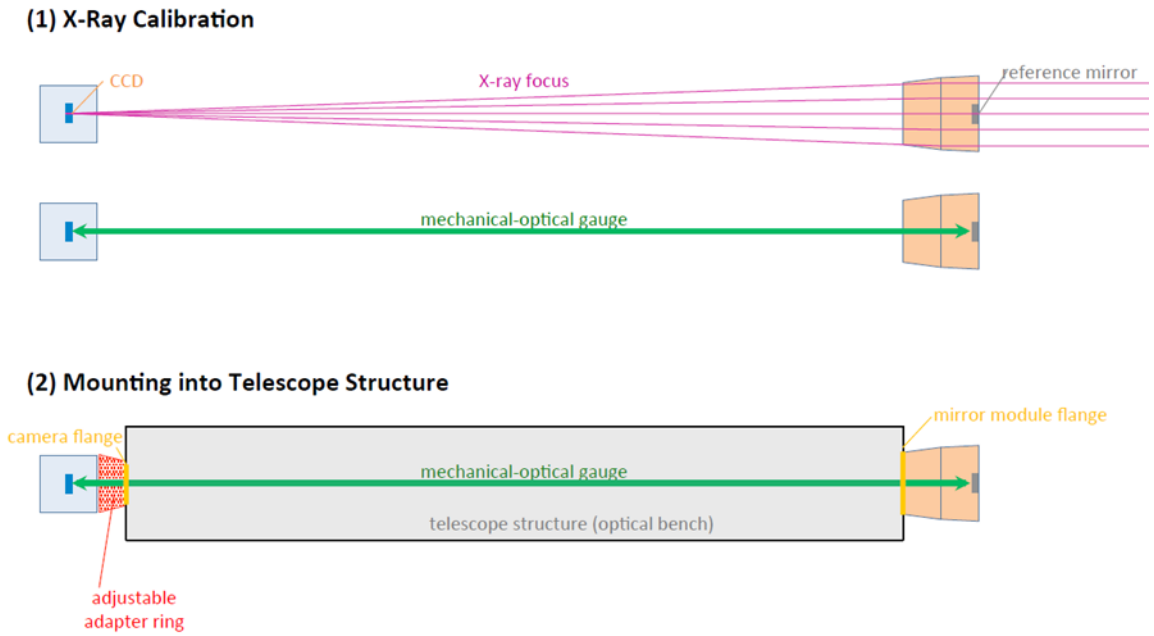


Energy/keV	FXTA			FXTB		
	thin	hole	medium	thin	hole	medium
0.277	0.36	0.41	0.15	0.43	0.43	0.16
0.434	0.30	0.40	0.19	0.41	0.42	0.21
0.525	0.45	0.55	0.33	0.58	0.59	0.39
0.704	0.53	0.63	0.46	0.61	0.62	0.47
0.93	0.56	0.66	0.49	0.72	0.73	0.61
1.02	0.71	0.79	0.68	0.80	0.80	0.72
1.25	0.71	0.79	0.69	0.84	0.86	0.80
1.487	0.82	0.87	0.80	--	--	--
1.74	0.83	0.85	0.80	--	--	--
2.02	0.81	0.85	0.73	0.87	0.88	0.78
3.1	0.87	0.89	0.78	0.96	0.96	0.86
4.5	0.94	0.94	0.87	0.99	0.99	0.91
8.64	0.98	0.98	0.91	--	--	--

3.6 Focal length measurement







- The focal length of FXT-A and FXT-B are 1601.970 mm and 1601.831mm, respectively.
- The measurement of focal lengths in IHEP aimed to install the mirror assembly correctly.

Thanks!