



中国科学院
CHINESE ACADEMY OF SCIENCES



WXT Calibration

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On behalf of EPSC and WXT team

2024 April 24th

7th CAS-ESA-MPE-CNES Joint Workshop on Einstein Probe



中国科学院国家天文台
NATIONAL ASTRONOMICAL OBSERVATORIES, CAS

Outline

- * A brief review on the ground calibration of WXT
- * Overview of the in-flight calibration of WXT
- * Key performance goals
- * In-flight calibration status
 - * PSF and angular resolution
 - * Positioning accuracy
 - * Energy band
 - * Effective area
 - * Energy response
- * Future plan
- * Summary

A brief review of the ground calibration of WXT instrument

Effective Area, PSF
Source Positioning Accuracy



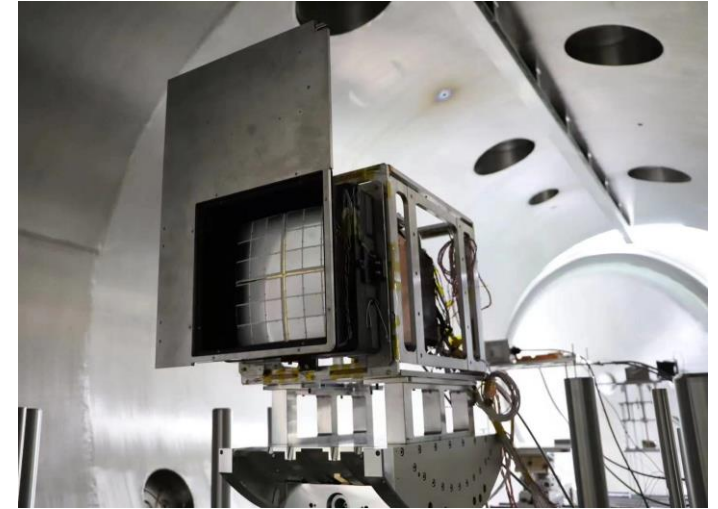
12 assemblies calibration
@NAOC-XIB, 2022-04 to 2023-04

Effective Area, Focus Search
Focal Plane Mapping



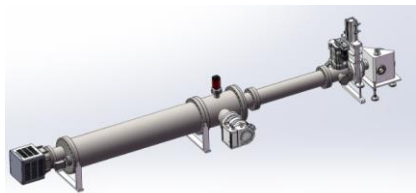
1 assembly calibration
@MPE-Panter, 2022.10

Effective Area, PSF
Source Positioning Accuracy



3 modules calibration
@IHEP, 2022.8 & 2023.5

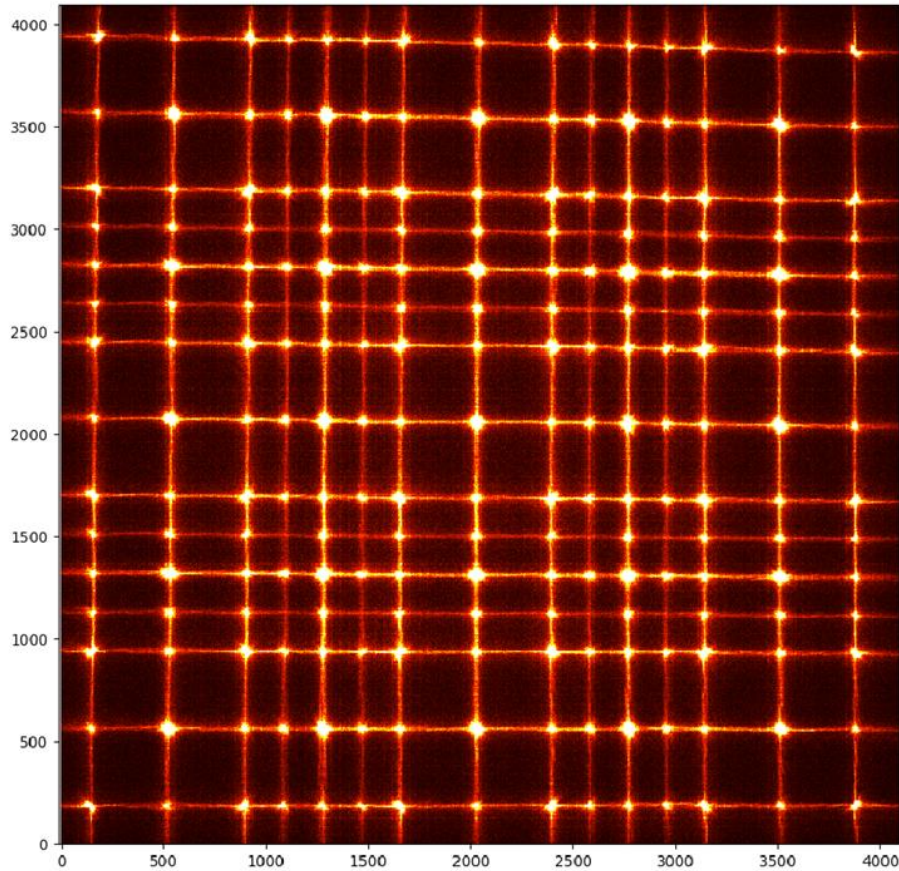
Credit: Dr. Yanfeng Dai



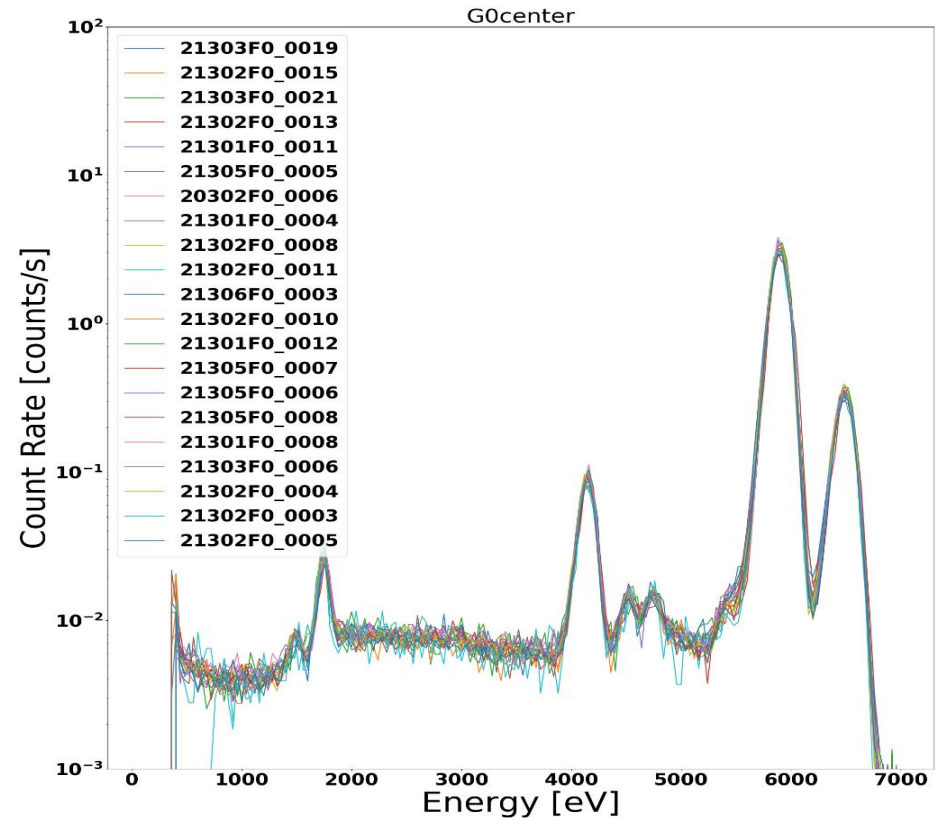
NAOC/XBC

Meanwhile, 54 CMOS chips (including 6 backups) were calibrated at NAOC.

Calibration at NAOC



FM MA Focal plane mapping
(209 test points for each FoV quadrant)



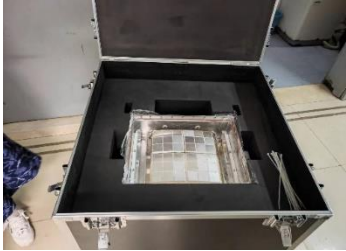
Fe55-illuminated spectra for
CMOS FM chips

Credit: Dr. Chen Zhang, Dr. Zhixing Ling

Detailed calibrations on MA and CMOS chips before integration to complete modules.

MA calibration at MPE/Panter facility

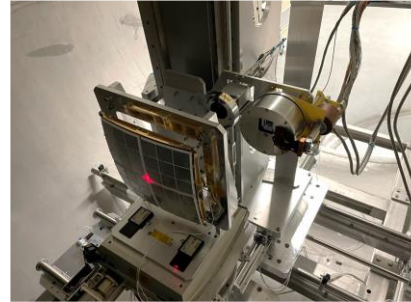
Credit: Dr. Yanfeng Dai



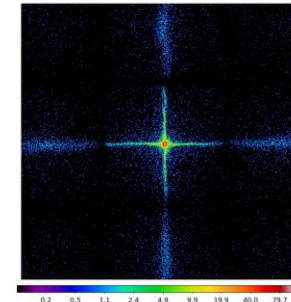
Sep. 5 2022 OFM5@NAOC



Sep. 20 2022@MPE



OFM5@PANTER

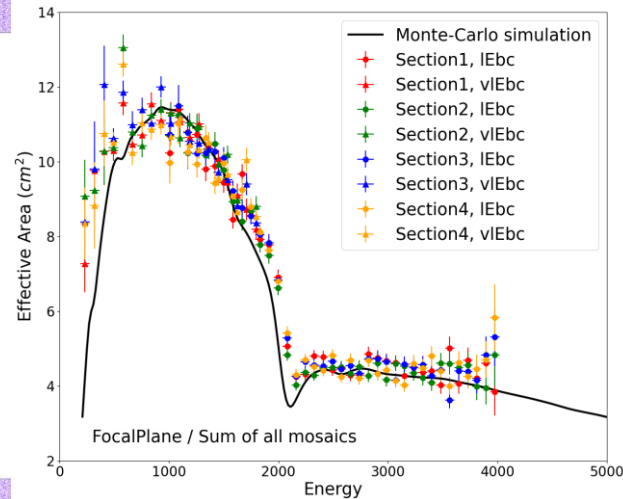
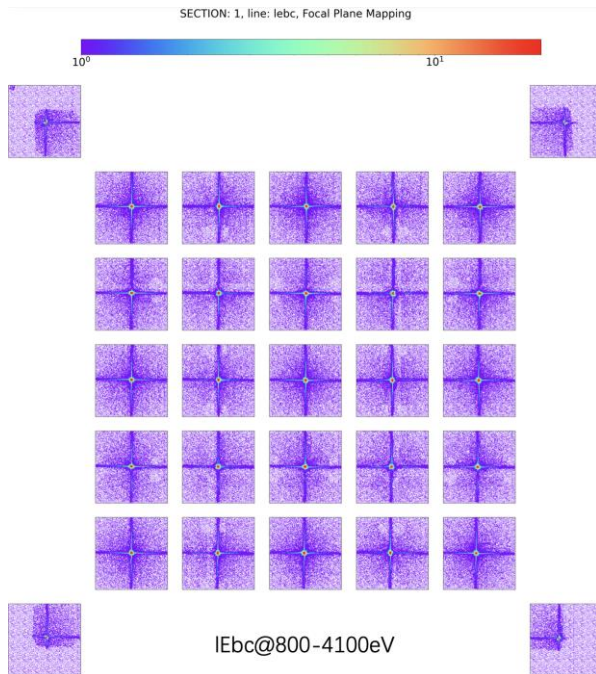


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Dec. 29 2022 Back to NAOC

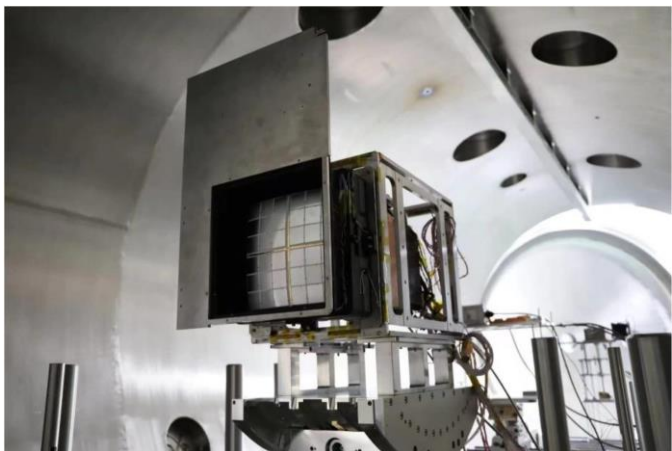
Optics Assembly Calibration@Panter



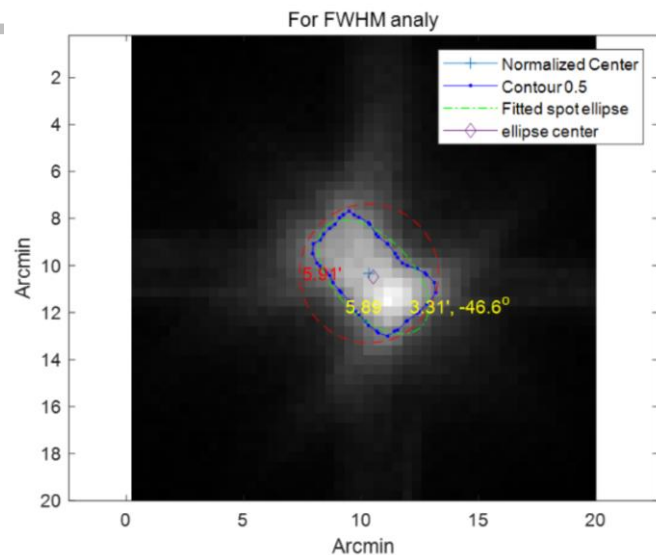
	LEIA(OQM3)	EP OFM5
Focal Length	375mm	375mm
FOV	>18*18	>18*18
Angular Resolution	Best 4' Arg<5'	Best 3', Arg<4.5'
Effective Area	>95%	>95%

MPE paper: Rukdee et al. 2023, <https://doi.org/10.1117/12.2677479>

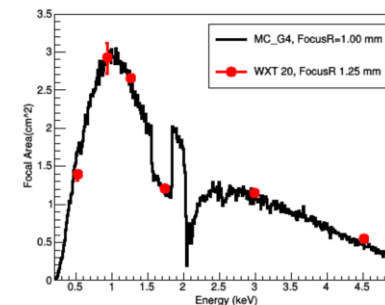
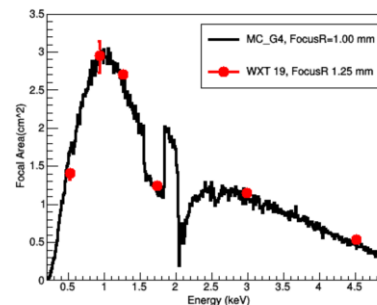
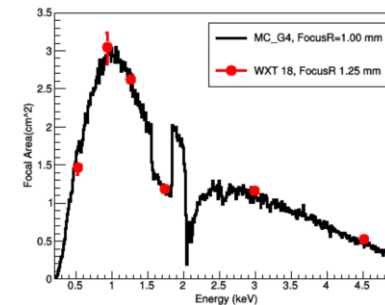
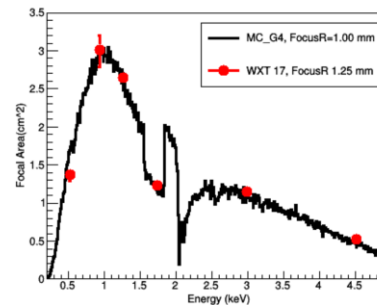
Calibration at IHEP



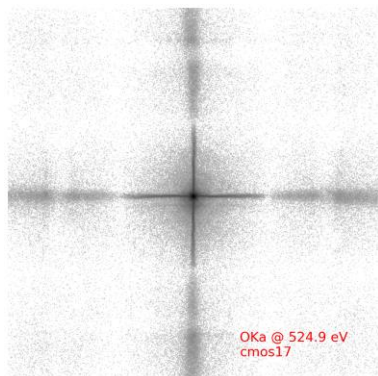
FM1 @IHEP 100m facility, 2023.8



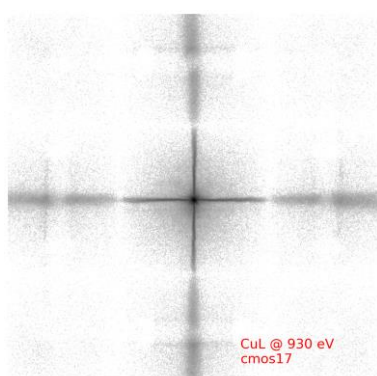
PSF, FWHM~3-4'



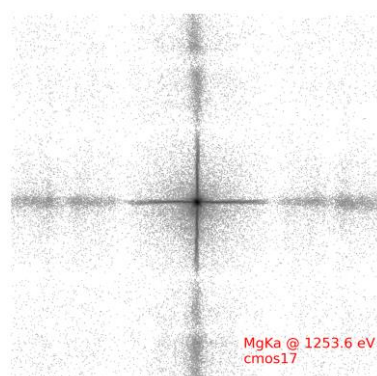
Effective area of FM5 at IHEP



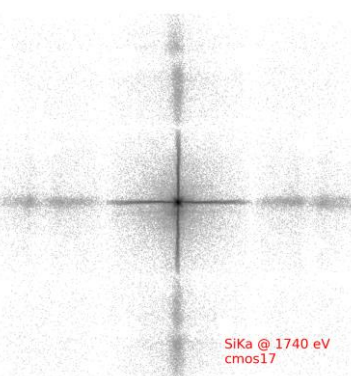
O K α



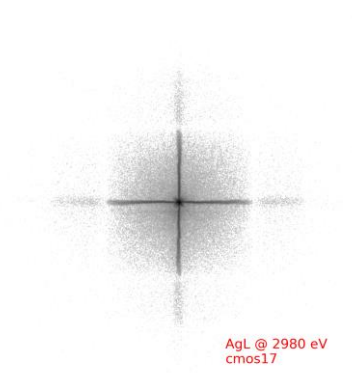
Cu L



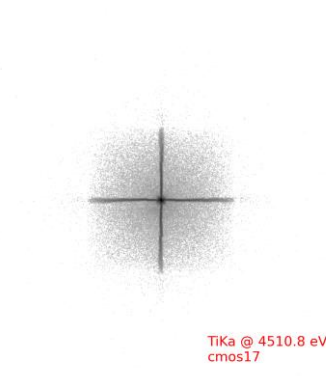
Mg K α



Si K α



Ag L



Ti K α

PSF shape at different energies of characteristic emission lines

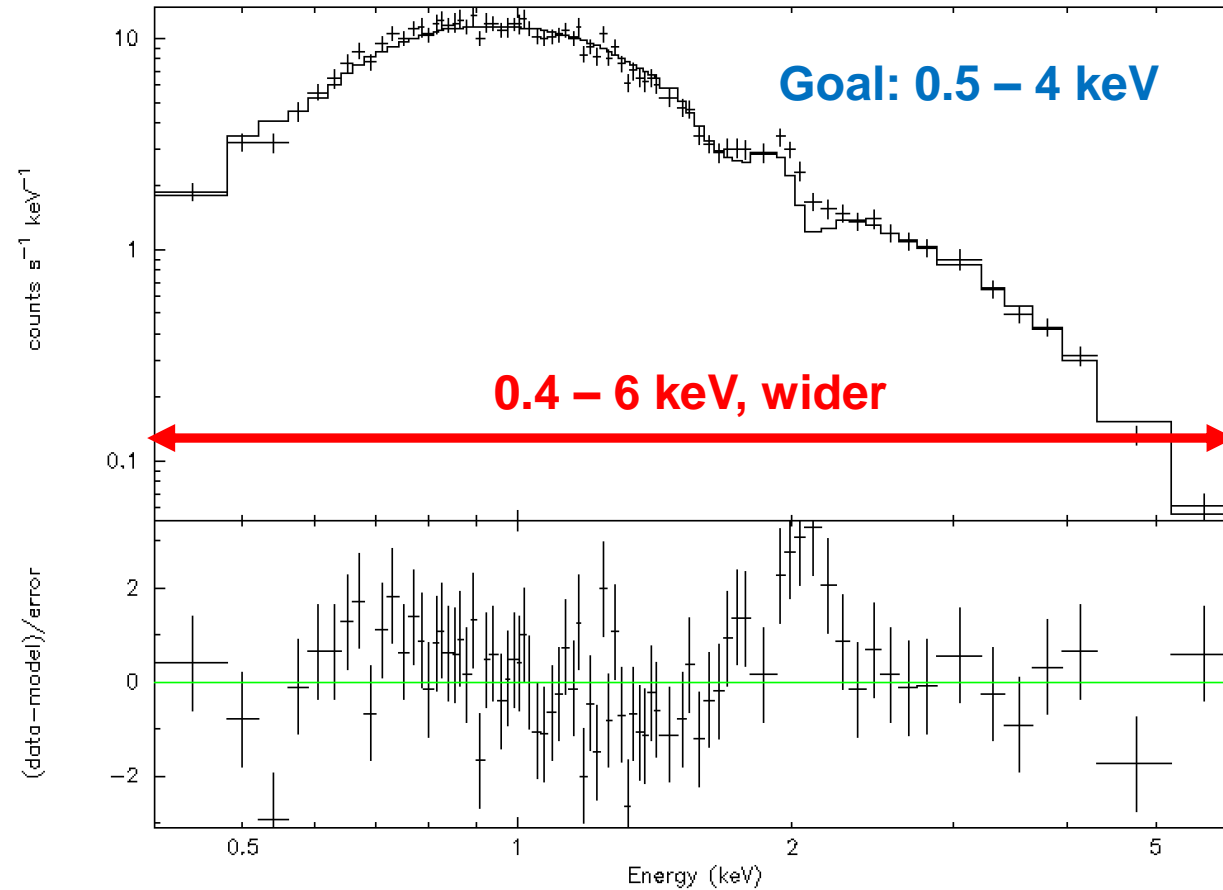
In-flight calibration observations

Round	Calibration term	Target	Calibrated module	Observational date
1	Energy response	CAS A, Tycho	4, 10	2024/1/19 - 2024/1/25
	PSF, angular resolution	Crab	10 modules (except Module 3 & 9)	2024/1/25 - 2024/3/8
	Positioning accuracy			
	Energy band			
	Effective area			
2	PSF, angular resolution	Sco X-1	3,9	This week (plan)
	Positioning accuracy			
	Energy band			

Key Performances Goals

No.	Calibration item	Goal	Requirement of systematics/precision
1	Positioning Accuracy	≤ 2 arcmin (J2000, 90% C.L.)	-
2	Energy band	0.5 – 4 keV	-
3	Effective area	≥ 2 cm ² @1keV	$\leq 20\%(1\sigma)$
4	Angular resolution	≤ 5 arcmin @1keV	-
5	Energy resolution	≤ 170 eV @1.25 keV	$\leq 20\%(1\sigma)$

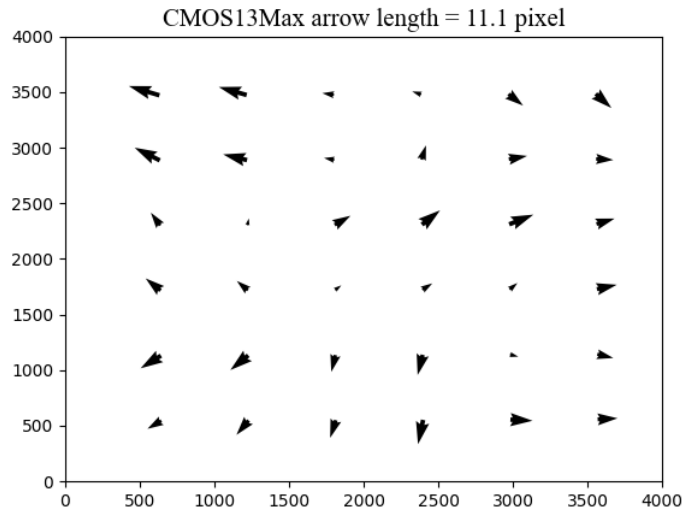
Energy band



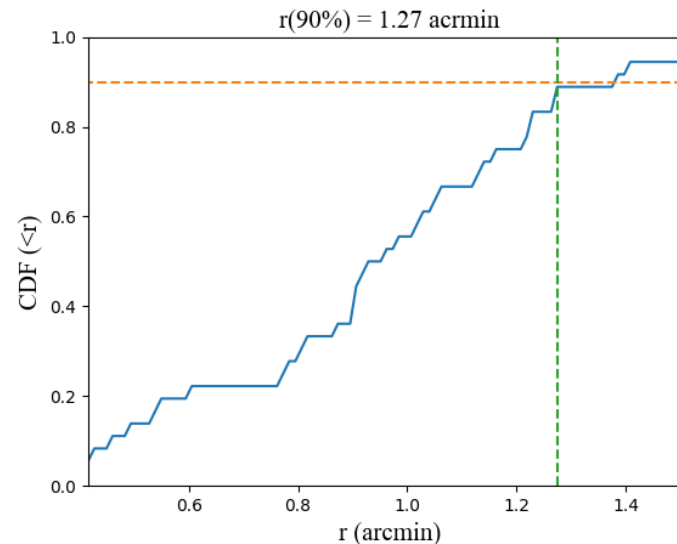
Spectral analysis of the Crab nebula
(along the center direction, FM1, CMOS3)

Positioning Accuracy

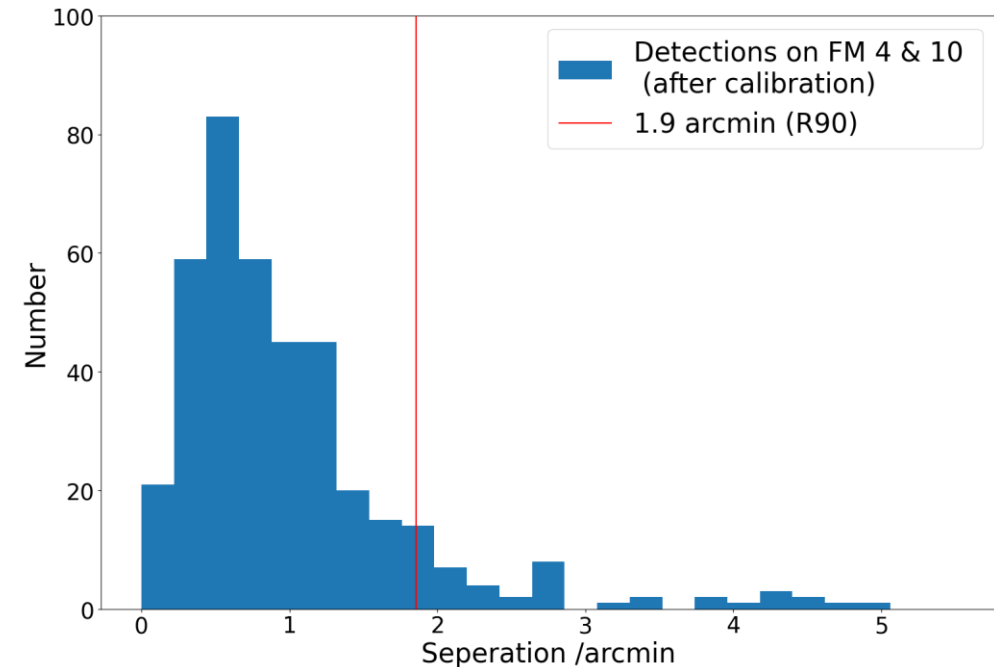
- ★ 10 modules (except 3 & 9) calibrated via Crab observations **Highest priority!**
- ★ Goal: better than 2 arcmin (J2000, 90% C.L.)
- ★ Method: calibration of the rotation matrix and non-linear corrections with a PSF scan in 6x6 mesh grid



Pos. offset of the PSF within FoV quadrant



CDF of non-linear residual

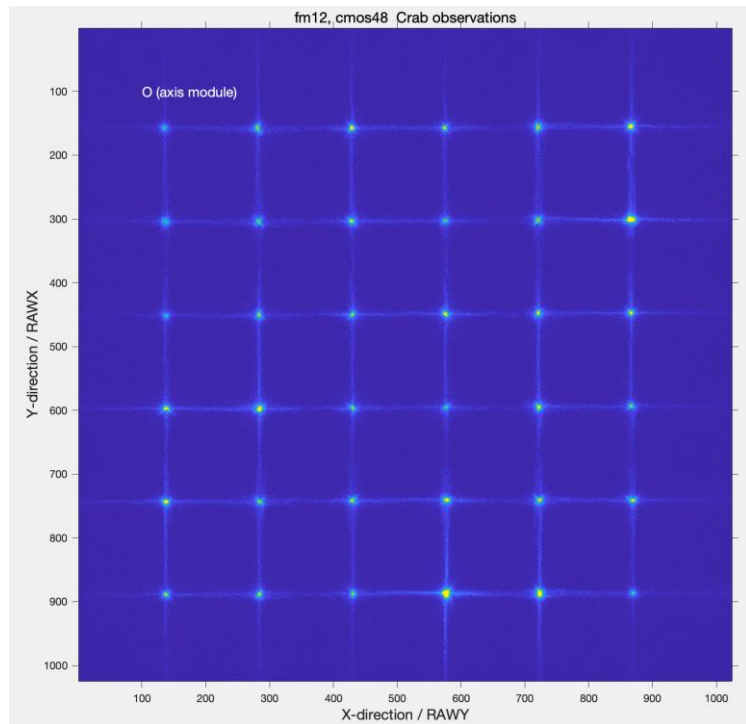


Assessing pos. accuracy with real observational data after calibration

By now positioning accuracy better than 2 arcmin (J2000,90% C.L.)

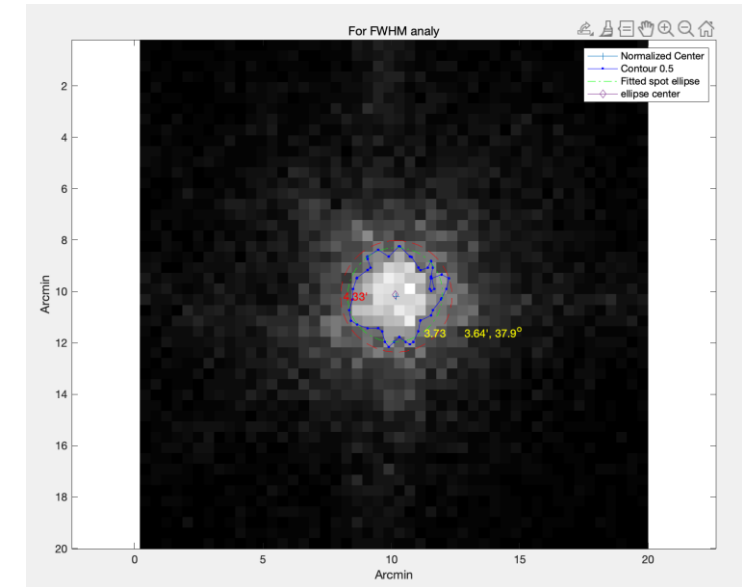
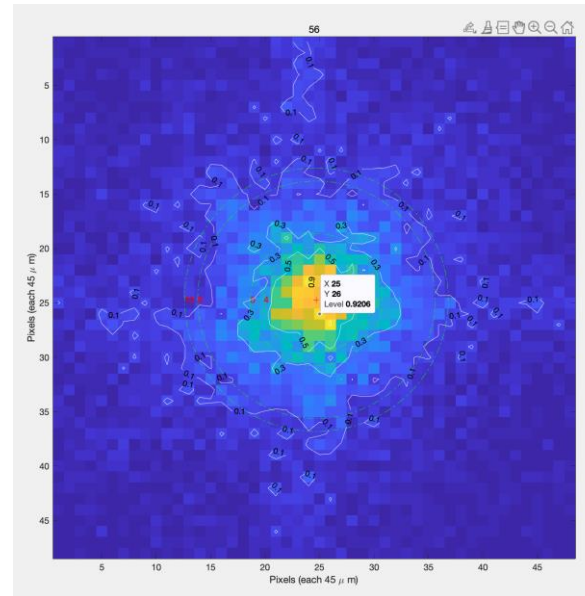
PSF and angular resolution

- ★ 10 modules (except 3 & 9) calibrated via Crab observations
- ★ Goal: angular resolution ≤ 5 arcmin@1keV
- ★ Method: PSF extraction and analysis with elliptical function



PSF 6x6 scanning array(FM12, CMOS48)

Crab is not a point source

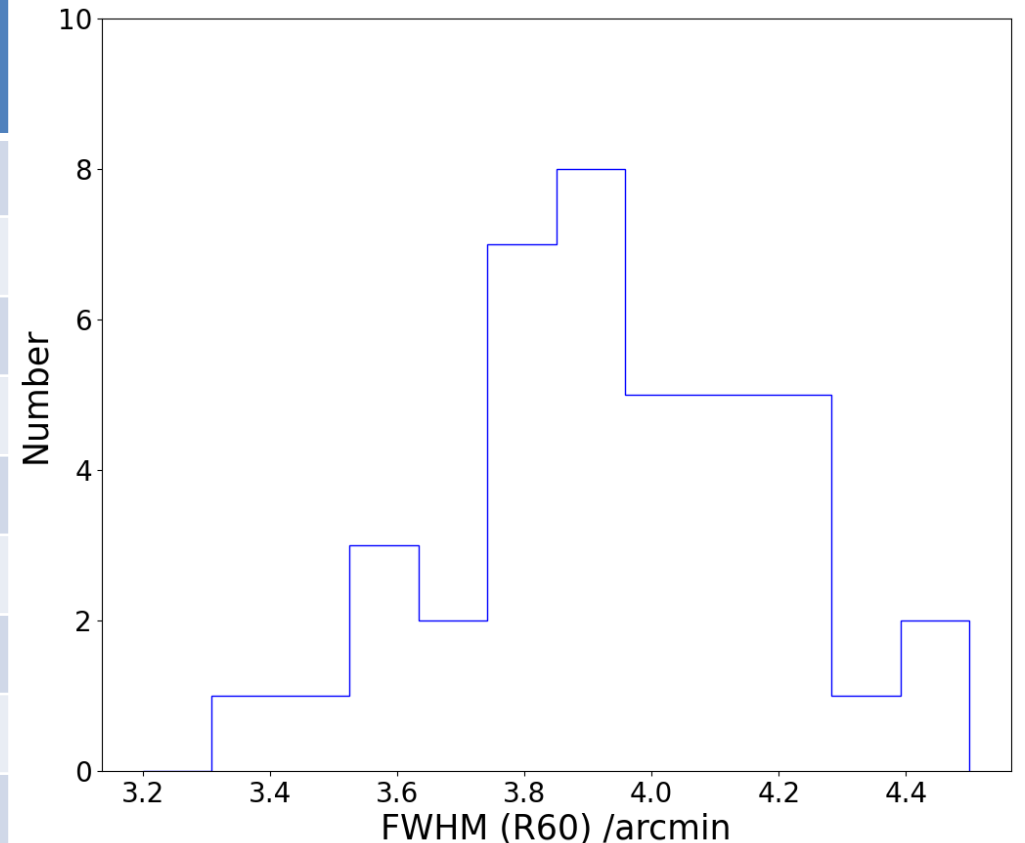


PSF analysis

(elliptical fitting, method identical to that employed on ground)

PSF: angular resolution

FM ID	Detector 1 (R60)	Detector 2 (R60)	Detector 3 (R60)	Detector 4 (R60)
1	4.1	4.0	4.0	3.9
2	4.2	4.1	4.2	3.8
4	4.0	4.0	3.7	4.4
5	4.3	4.1	4.0	4.3
6	3.8	3.8	4.0	3.5
7	3.8	4.2	3.9	3.8
8	3.7	3.9	3.6	3.8
10	4.4	4.2	3.6	4.2
11	3.9	3.6	3.3	3.9
12	3.9	4.3	3.9	3.8

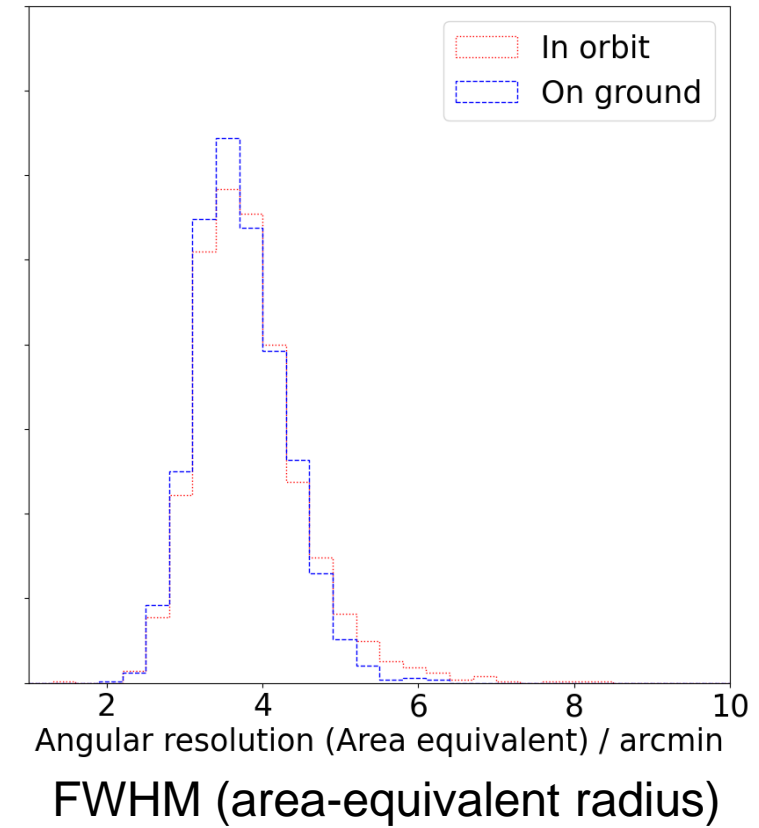
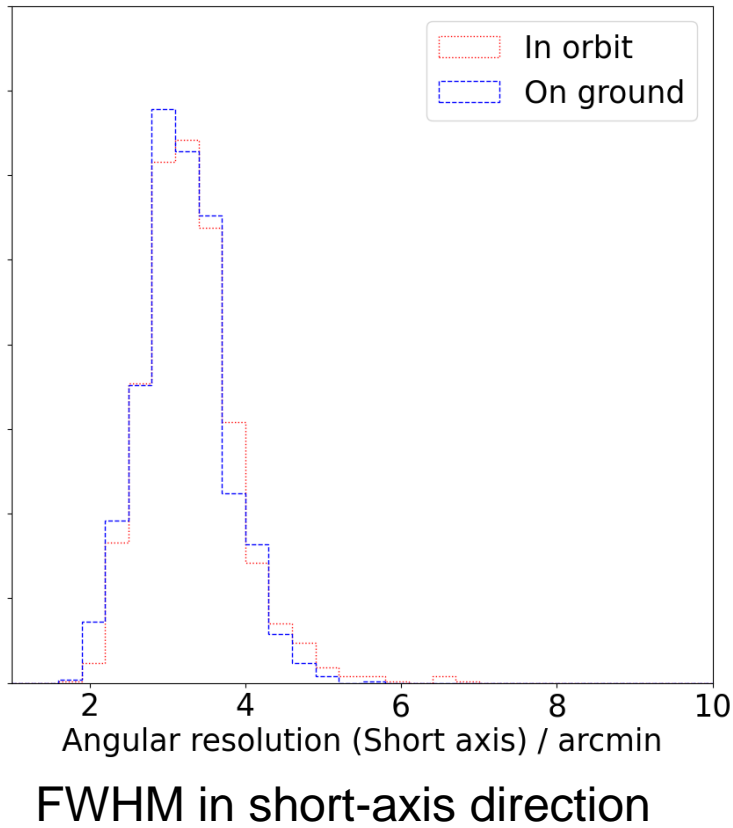
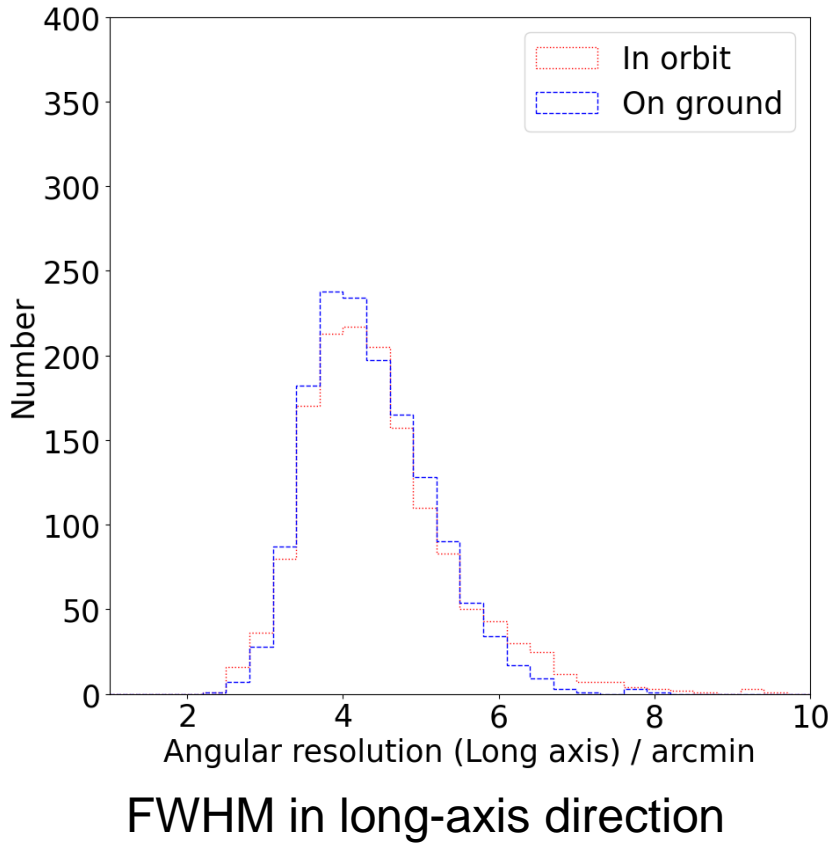


Distribution of the FWHM R60 value

Summary of the FWHM
(R60: upper limit of the 60 percentile)

The angular resolutions mostly fall within 5 arcmin, fulfilling our goals.

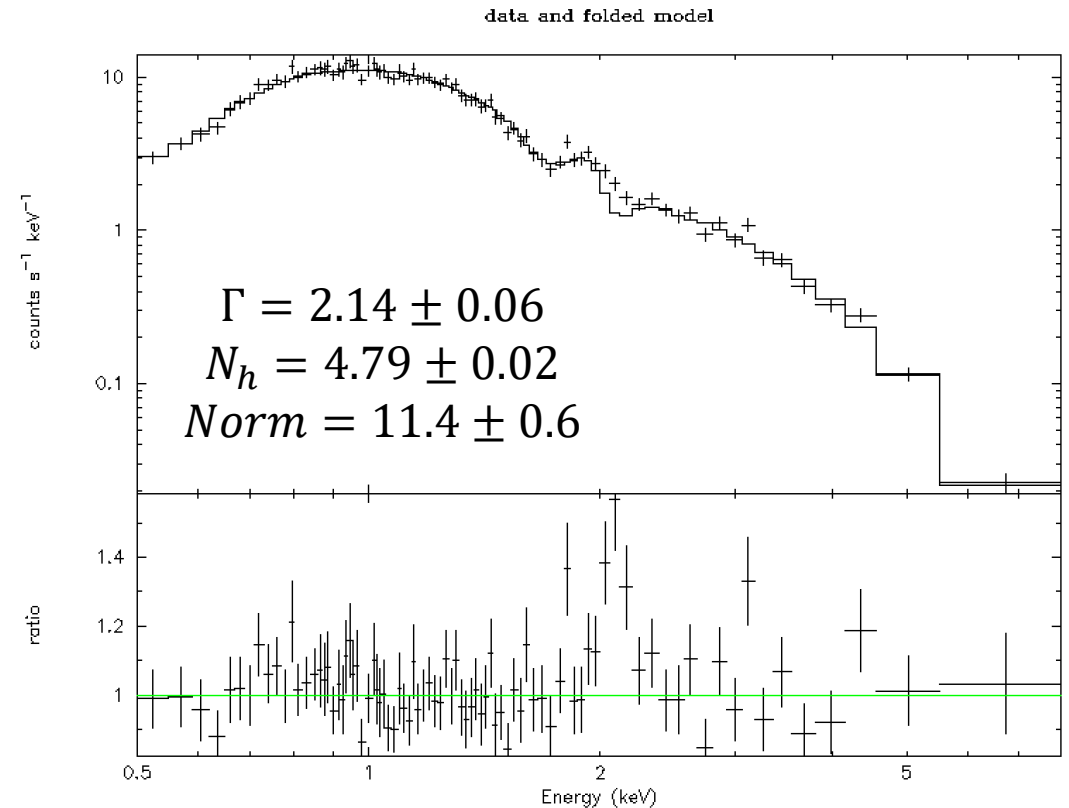
In-flight angular resolution vs. Ground values



No noticeable degradation in the imaging quality was found after launch.

Effective Area

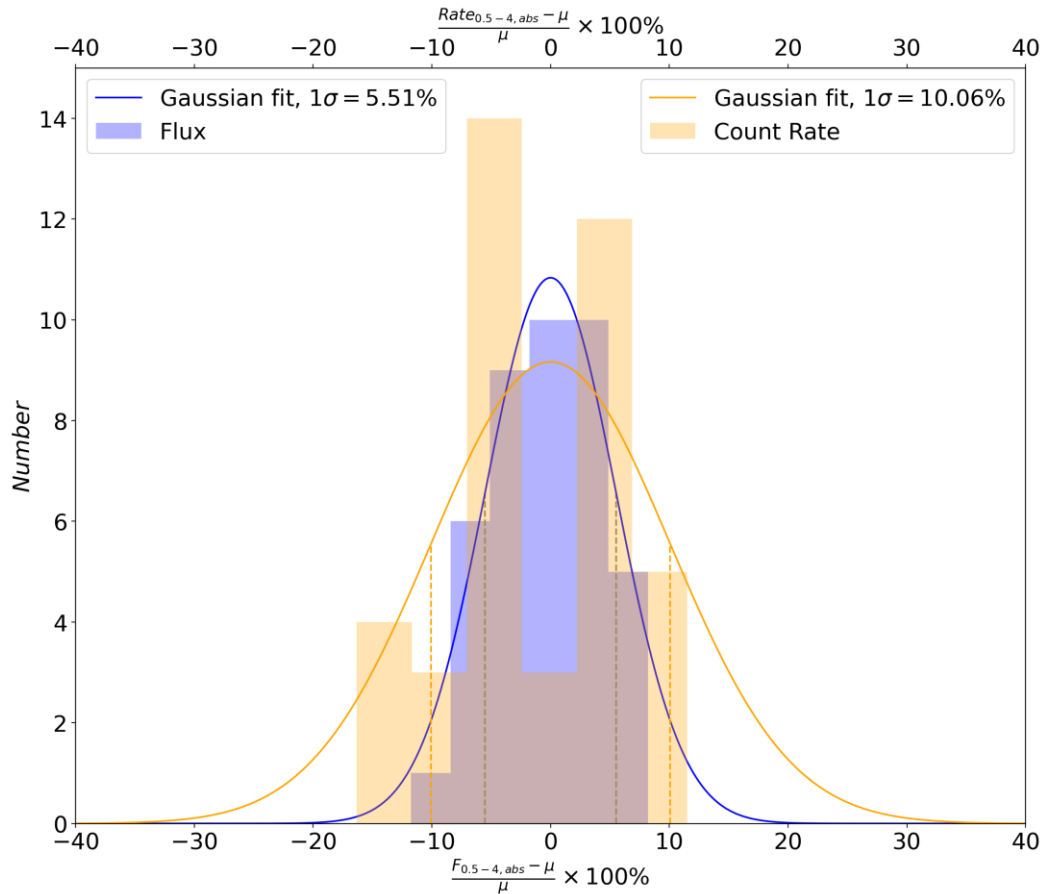
- ★ Modules: 10 modules (except 3&9)
- ★ Goals:
 - ★ Absolute effective area $\geq 2 \text{ cm}^2 @ 1 \text{ keV}$
 - ★ Precision (systematics) better than 20% (1σ)
- ★ Method:
 - ★ Estimate the absolute effective area via on-axis observations
 - ★ Estimate the systematics via on-axis and off-axis observations



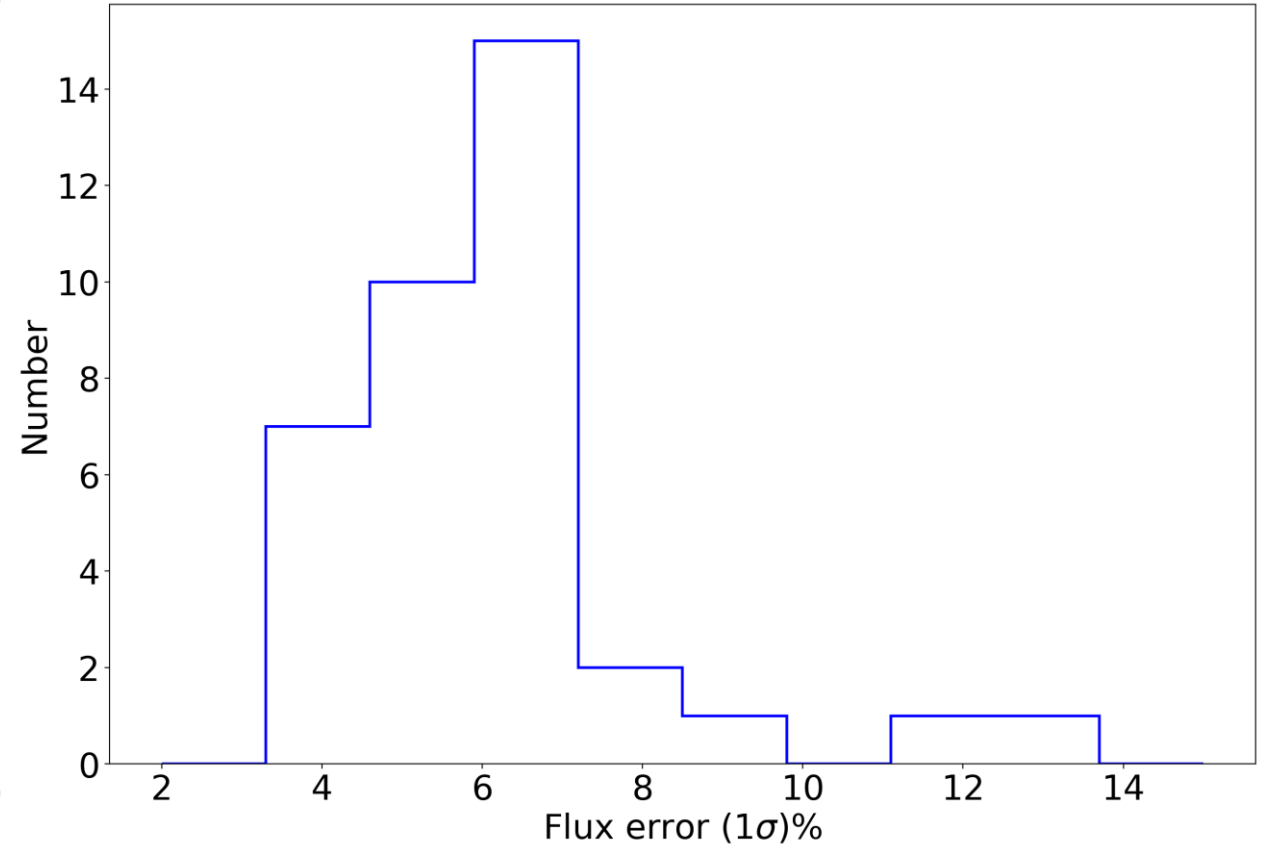
**Crab spectral fitting along center direction
(FM1, CMOS3)**

The simulated effective area curve (built based on ground calibration) provides a reasonable description to the in-flight effective area, i.e. $\sim 3 \text{ cm}^2 @ 1 \text{ keV}$ (ground values)

Effective Area: systematics



Count rate and derived flux of Crab
(FM2, CMOS5)



Distribution of flux error (systematics) of the
effective area

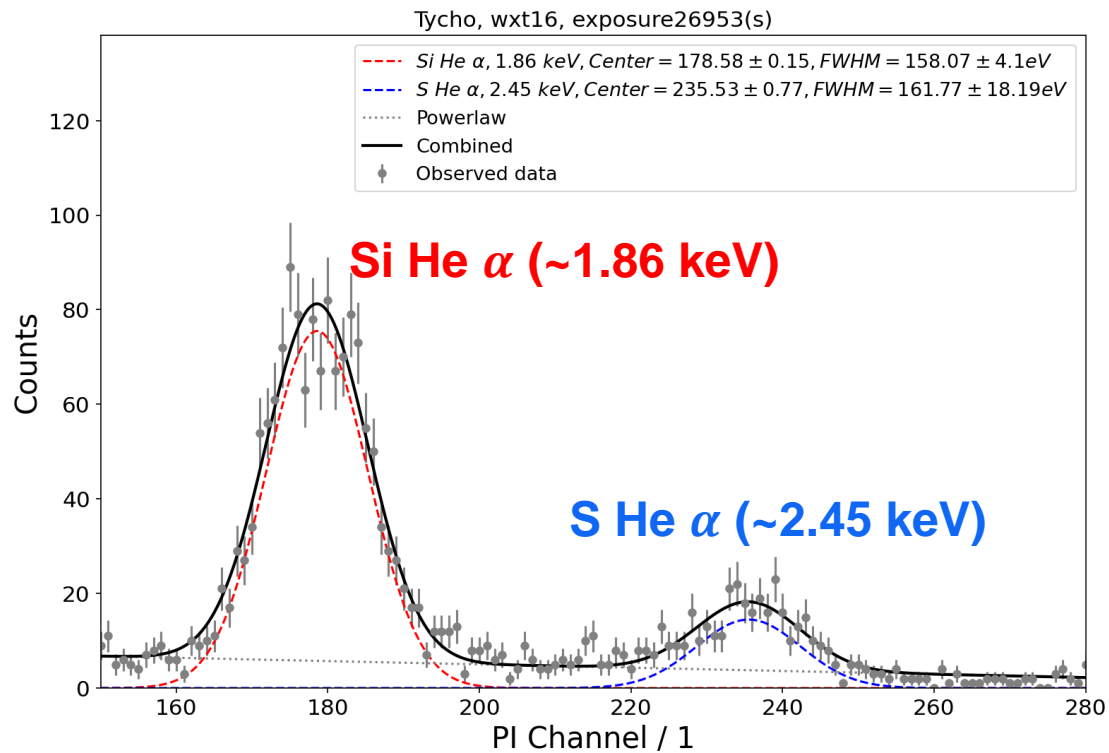
The systematics of the effective area is generally less than 10%(1 σ).

Energy response of the CMOS detectors

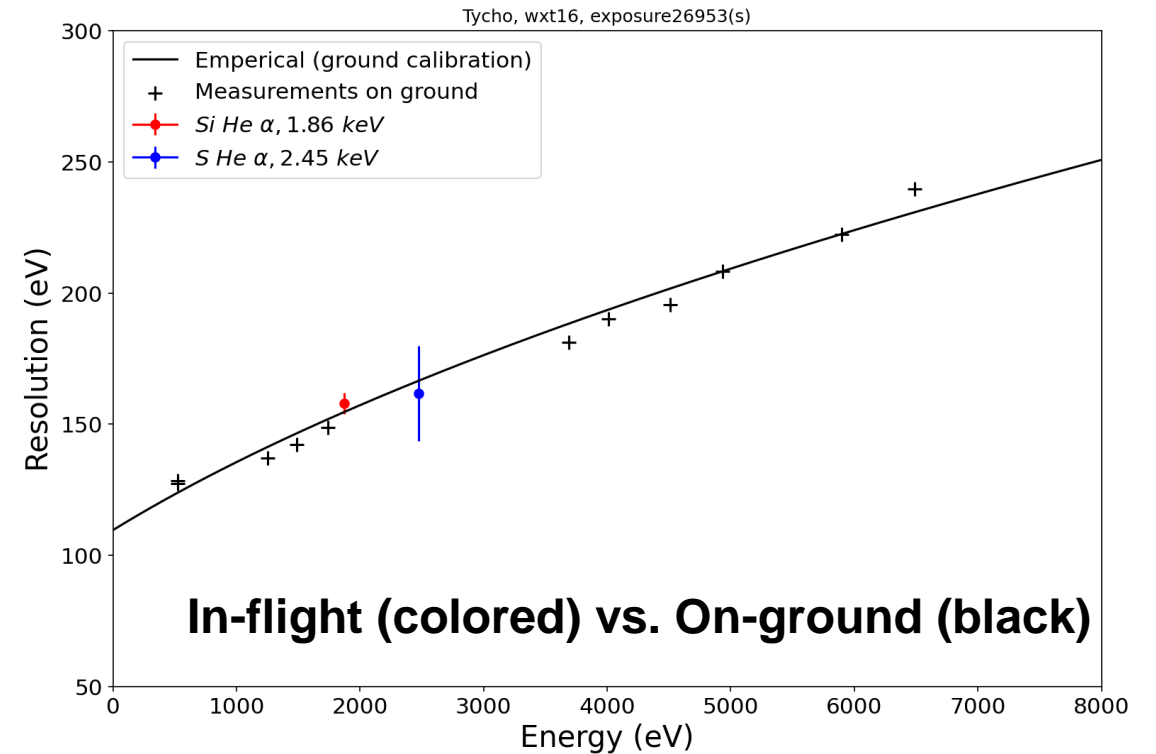
- * Modules: 4&10
- * Goals:
 - * Energy resolution ≤ 170 eV @1.25 keV (Mg $K\alpha$)
 - * Measurement precision better than 20% (1σ)
- * Method:
 - * Perform emission line analysis to Tycho spectra
 - * Estimate the resolution at 1.25 keV by extrapolation

Energy response of the CMOS detectors

* Spectral analysis of Tycho spectrum



Spectral analysis of (stacked) spectrum of Tycho (FM4, CMOS16)



Energy resolution (compared with ground measurements, FM4, CMOS16)

No obvious variations in GAIN and energy resolution after launch.

Energy response: energy resolution

- * Extrapolate from 1.86 keV and obtain the resolution @ 1.25 keV

Flight Model No.	CMOS	Resolution @ 1.25 keV	Precision(1σ) %
4	13	134.1+/-1.9	1.4
4	14	131.7+/-1.6	1.2
4	15	120.2+/-1.9	1.6
4	16	129.6+/-3.4	2.6
10	17	119.1+/-1.5	1.3
10	18	121.6+/-1.7	1.4
10	19	121.6+/-2.4	2.0
10	20	130.7+/-2.0	1.5

The energy resolution @1.25 keV is in range of 120-140 eV with a precision of 1-3% (1σ)

Future plans

- * The observation of Sco X-1 will be carried out later (planned to be in this week) for the calibration of FM 3 & 9 concerning PSF, spatial resolution and positioning accuracy.
- * Summary of the calibration and paper publication.

Summary

- * Extensive tests and calibrations were carried out before the launch of EP.
- * First round of in-flight calibration has been conducted from 2024/01/19 to 2024/03/08 and **the second round begins in this week.**
- * Preliminary analysis of the WXT data shows
 - * Positioning accuracy: less than 2 arcmin (J2000, 90% C.L.)
 - * Angular resolution: 3.3 - 4.4 arcmin (FWHM, R60)
 - * Effective area: $\sim 3.0 \text{ cm}^2 @ 1 \text{ keV}$, systematics $\sim 4\text{-}13\%$ (1σ)
 - * Energy resolution: $\sim 120 - 140 \text{ eV} @ 1.25 \text{ keV}$, Precision $\sim 1\text{-}3\%$ (1σ)
 - * Detected band: 0.4 – 6 keV
- * **The in-flight performances fulfill design goals, without noticeable degradation after launch until now!**

A solid foundation for scientific discovery!

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