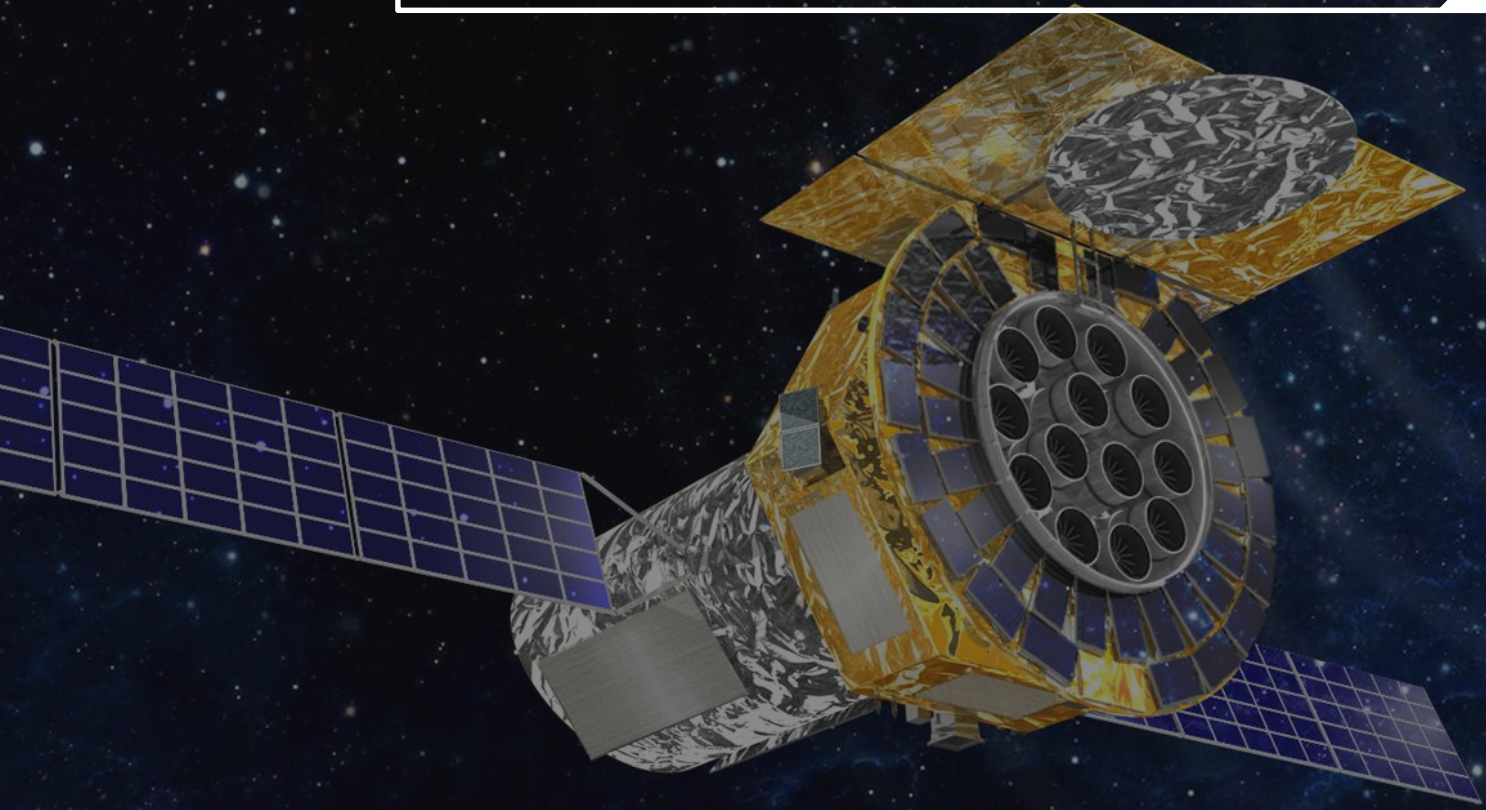
16th Marcel Grossmann Meeting

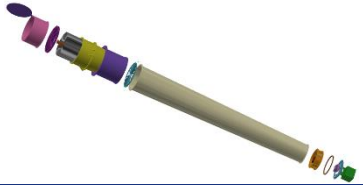
Design of the SFA and PFA instrument onboard eXTP

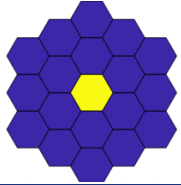
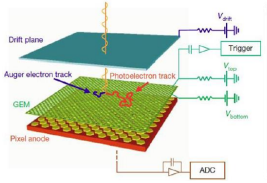


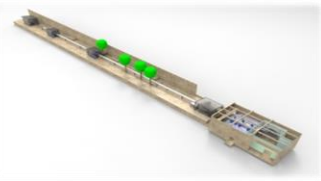
Yusa Wang

IHEP, CAS, China

On Behalf of SFA and PFA Teams

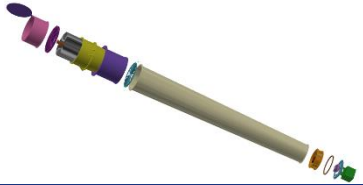



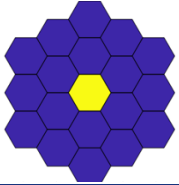
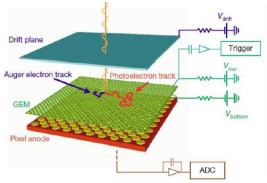



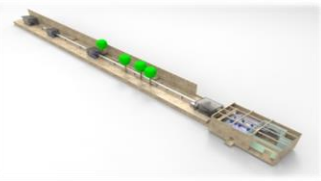


Outline

1. SFA&PFA requirements
2. SFA design and development status
3. PFA design and development status
4. Test facilities and calibration plans



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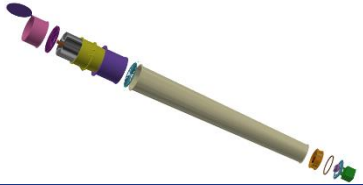
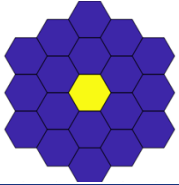
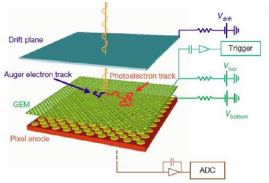
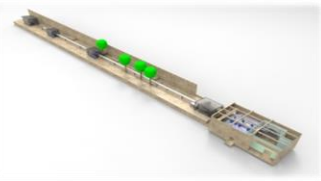
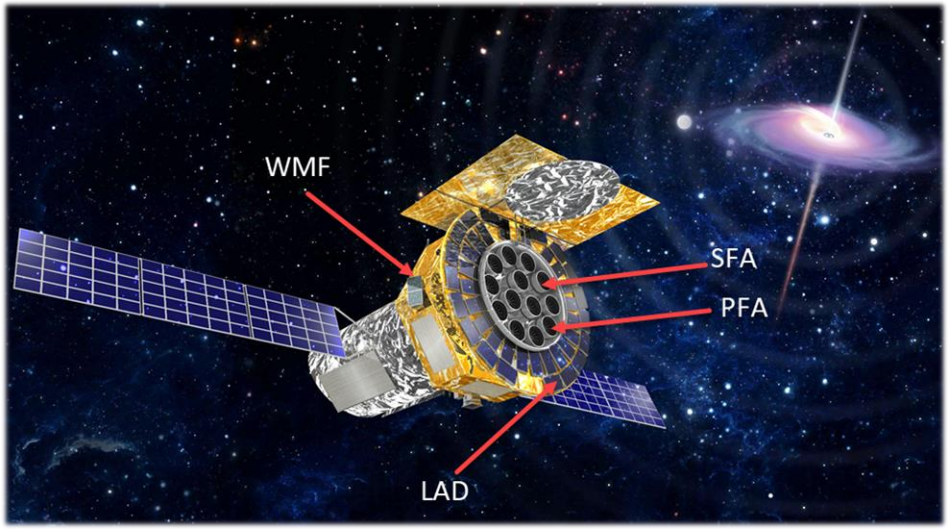




Introduction to eXTP

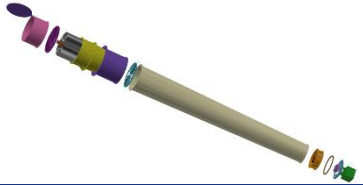
eXTP: enhanced X-ray Timing and Polarimetry Mission

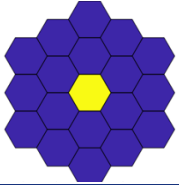
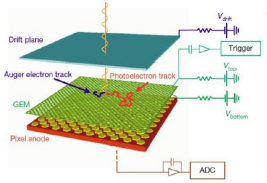


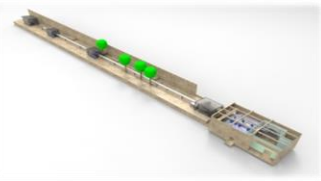
Scientific goal: eXTP is a science mission designed to study the state of matter under extreme conditions of density, gravity and magnetism.

Operation: Pointing observation with high accuracy and stability.

Payload	Configuration	Optics	Detector	Eff. area (m^2)
Spectroscopy Focusing Array (SFA)	9 telescopes	Wolter-I, nickel	SDD, 0.5-10 keV 180 eV @ 6 keV	0.6 m^2(1-2 keV)
Large Area Detector (LAD)	40 modules	MCP	SDD, 2-30 keV 180 eV @ 6 keV	3.1 m^2 (2-10 keV)
Polarimetry Focusing Array (PFA)	4 telescopes	Wolter-I, nickel	GPD, 2-8 keV 1.8 keV @ 6 keV	380 cm^2 @ 3 keV
Wide Field Monitor (WFM)	6 cameras	Coded mask	SDD, 2-50 keV 500 eV @ 6 keV	3 Sr (FOV)



SFA&PFA requirements – SFA1/3

Successfully passed the review of SFA requirement, including the requirement of science, instrument, platform and calibration.

Performance	Requirement	Goal
Energy range	0.5-10 keV	0.3-12 keV
Effective area	6000 cm^2 (1-2 keV) 4400 cm^2 @ 6keV	6600 cm^2 (1-2keV) 4800 cm^2 @ 6keV
Angular resolution	≤1 arcmin (HPD) ≤3 arcmin (W90)	30 arcsec (HPD)
Energy resolution	≤180 eV @ 6 keV	≤150 eV @ 6 keV
Time resolution	10 μs	6 μs
Absolute time accuracy	2 μs	1 μs
Dead time	≤ 5% @ 1Crab	≤ 3% @ 1Crab
Sensitivity	4×10^{-15} erg/cm2/s	


eXTP Requirement Specification eXTP-IHEP-SYS-RS-0001 1/77

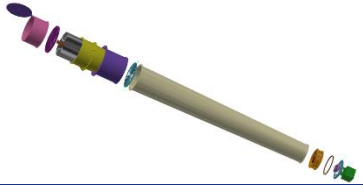
eXTP

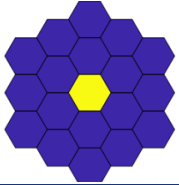
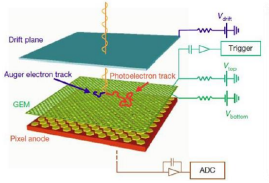
Requirement Specification

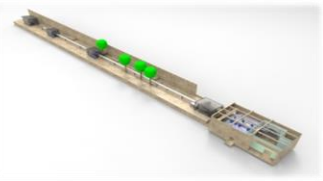
eXTP Science Requirements Document

Reference name	eXTP-IHEP-SYS-RS-0001
Version	2.2
Date	2020-09-23

Prepared by	eXTP Science Team
Checked by	Shuang-Nan Zhang
Approved by	Shuang-Nan Zhang
Contact	zhangsn@ihep.ac.cn

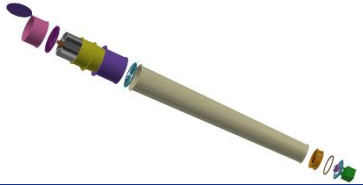


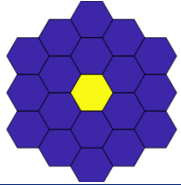
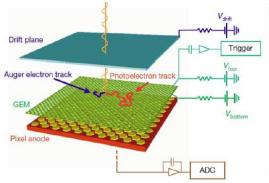
SFA&PFA requirements – SFA2/3

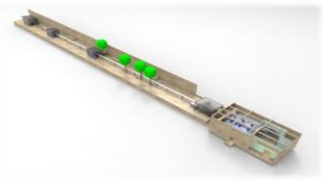
The requirement of pointing, stability are analyzed.

	Definition	Description	Error
Pointing accuracy of SFA	Mirror assembly	The contribution of MA	5″
		The uncorrected contribution after thermal/vibration test	5″
	Measurement accuracy	The measurement accuracy of the pointing	6″
	Platform	Satellite platform	44″ (TBC)

Stability	Time range	Stability of effective area (3σ)		Measurement
		nearly periodic	per octave	
<1 Hz	>1s	<0.2%	<0.5%	from the star tracker, ⩾8Hz
1-100 Hz	1s – 10ms	<0.02%	<0.5%	From platform
>100 Hz	<10ms	Low is better	Low is better	From the plat form

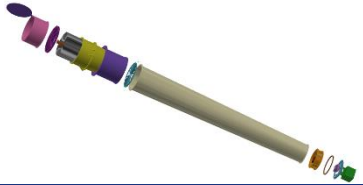



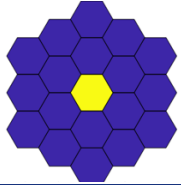
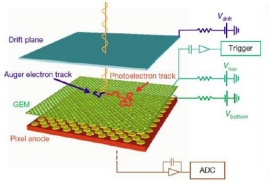



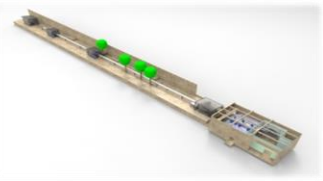


SFA&PFA requirements – SFA3/3

Device	Process	Content	Description
telescope	reflection	effective area (E,φ)	collecting area, reflectivity, vignetting function
		point spread function (E,φ)	mirror quality
		field of view	focal length, detector geometry
		boresight	alignment
filter	absorption	transmission	filter thickness, pinhole
SDD	charge release	edge effect	the lost of the part of one event
		low energy threshold	
		quantum efficiency	
		energy resolution	
	charge drifting	Timing	drift time
			time resolution
			time stability
	charge readout	readout noise/amplitude	nonlinearity
firmware	signal processing	mode exchange	depending different x-ray sources
		background evaluation	

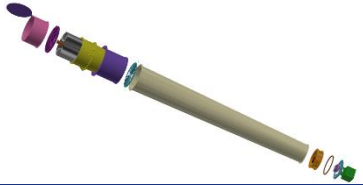



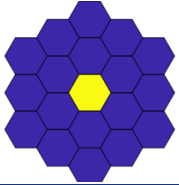
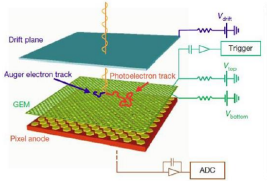


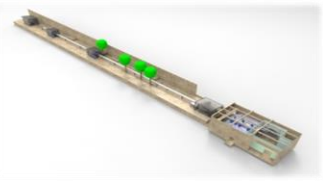
SFA&PFA requirements – PFA1/2

Successfully passed the review of PFA requirement, including the requirement of science, instrument, platform and calibration.

Performance	Requirement	Goal
Energy range	2-8 keV	1.5-12 keV
Effective area @3keV	380 cm^2	420 cm^2
Field of view@3keV	8×8arcmin	
Angular resolution	≤30 arcsec (HPD)	≤15 arcsec (HPD)
Energy resolution@5.9 keV	25%	20%
Time resolution	10 μs	8 μs
Absolute time accuracy	4 μs	
Dead time	≤ 10% @ 1Crab	≤ 3% @ 1Crab
Response stability (△p/p)	5%	2%
Point source localization	5 arcsec (1σ)	
Maximum flux	≥1Crab	≥2Crab
Polarimetric sensitivity(2-8keV)	3% (10^6s, 1mCrab)	2%
Spurious polarization	1%	

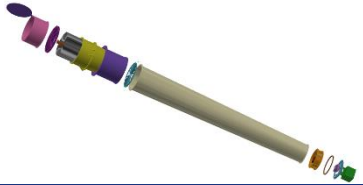



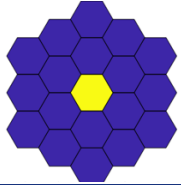
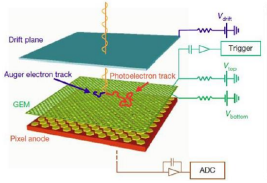



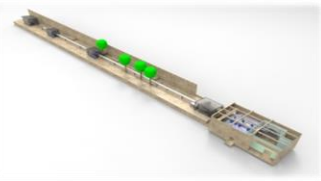


SFA&PFA requirements – PFA2/2

Device	Process	Content	Description
telescope	reflection	effective area (E,φ)	collecting area, reflectivity, vignetting function
		point spread function (E,φ)	mirror quality
		field of view	focal length, detector geometry
		boresight	alignment
GPD	charge release	Spatial resolution	for imaging
		Dead time	
		quantum efficiency	
		energy resolution	
	charge emission	Polarization	event direction
			time of arrival
			energy
	charge readout	Timing	nonlinearity
firmware	signal processing	mode exchange	depending different x-ray sources
		background evaluation	



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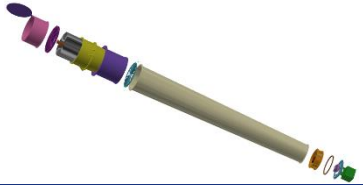
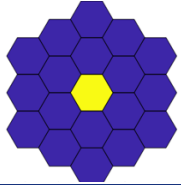
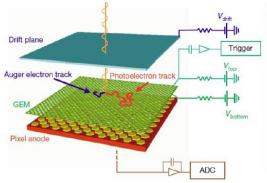
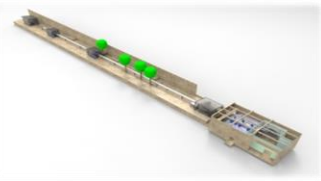
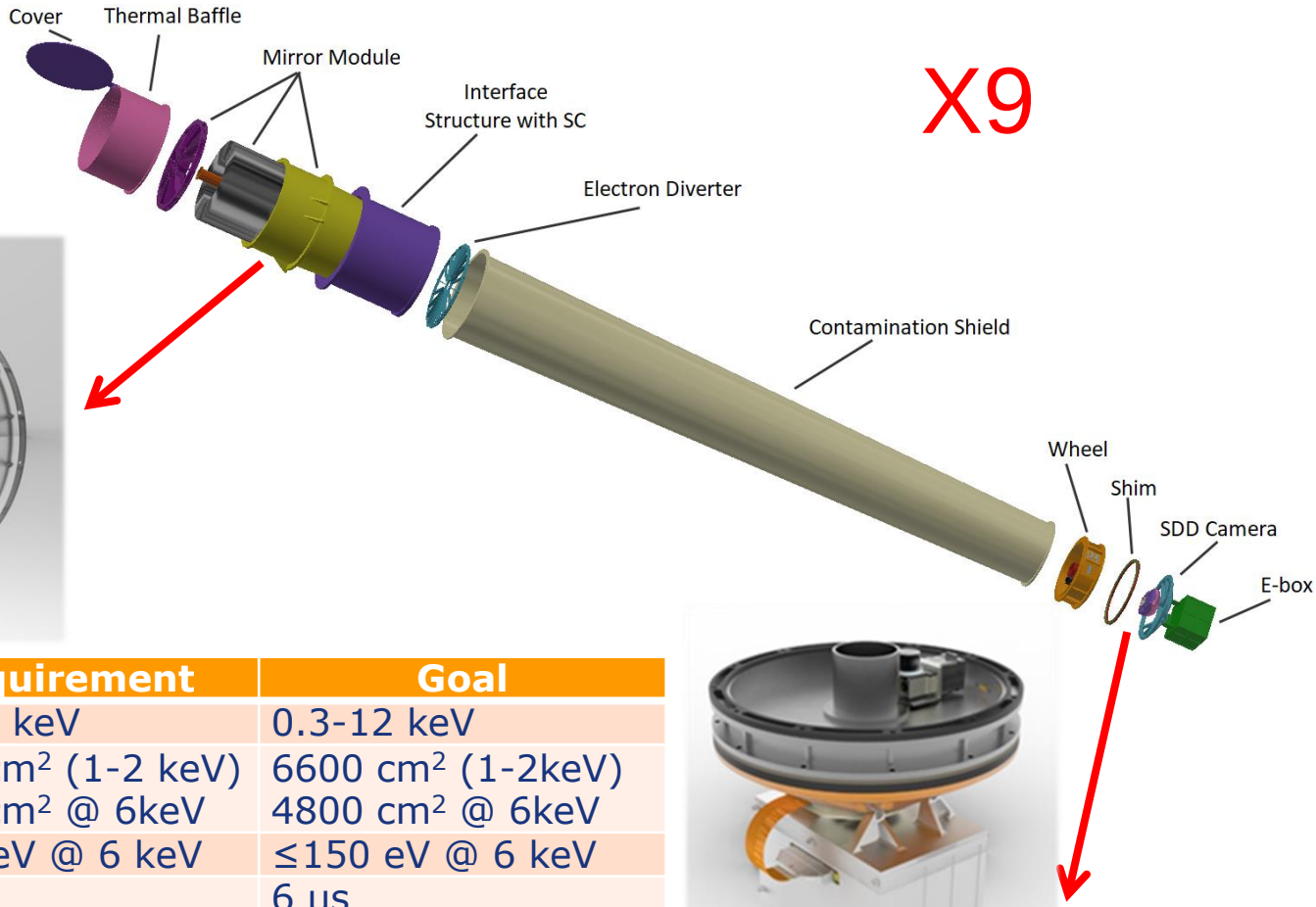




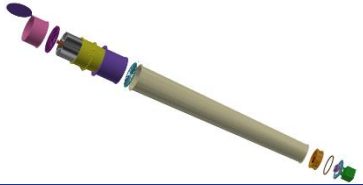
SFA design and development status - introduction

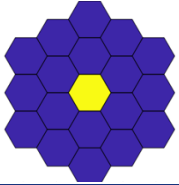
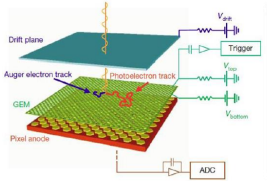
SFA: Spectroscopy Focusing Array instrument

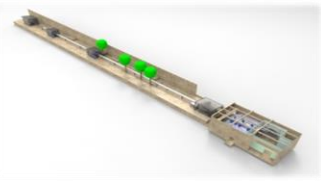


X9

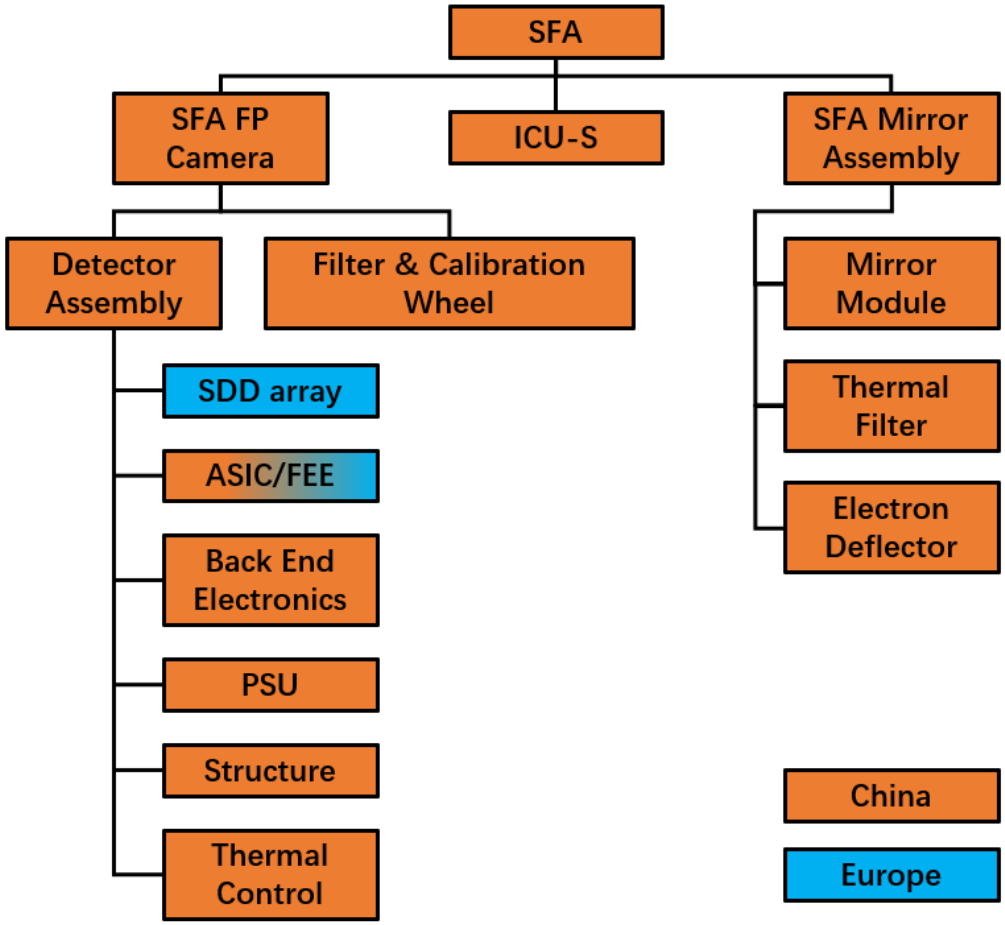
Item	Requirement	Goal
Energy range	0.5-10 keV	0.3-12 keV
Effective area	6000 cm^2 (1-2 keV) 4400 cm^2 @ 6keV	6600 cm^2 (1-2keV) 4800 cm^2 @ 6keV
Energy resolution	≤180 eV @ 6 keV	≤150 eV @ 6 keV
Time resolution	10 μs	6 μs
Absolute time accuracy	2 μs	1 μs
Dead time	≤ 5% @ 1Crab	≤ 3% @ 1Crab

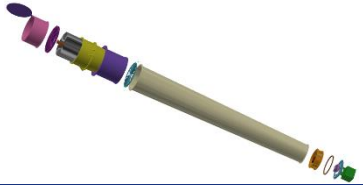



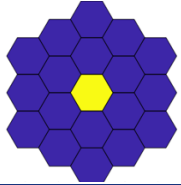
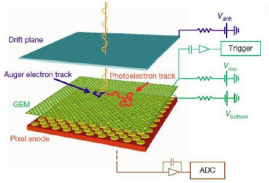



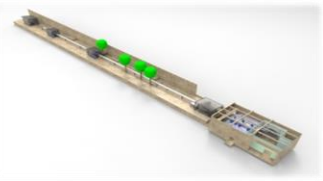


SFA design and development status - collaboration



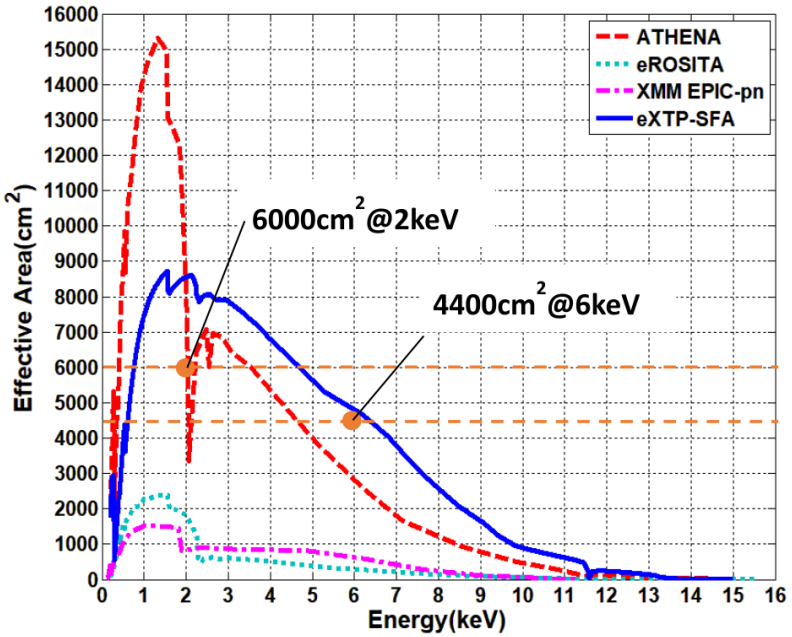



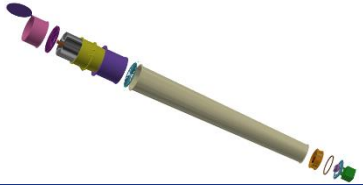


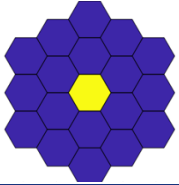
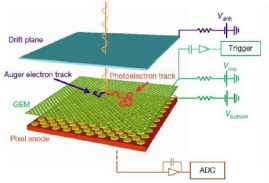
SFA design and development status – optics1/3

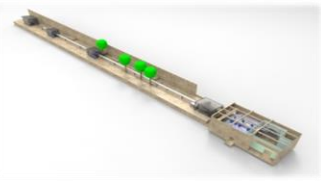
According to the requirement of SFA, the requirement of SFA optics was confirmed.

Performance	Value
Number of mirror modules	9
Focal length	5.25m
Envelope	≤600mm (diameter)
Effective on axis	≥820cm²@2keV ≥550cm²@6keV
Energy range	0.5-10keV
Field of view	≥12′
Angular resolution (HPD)	＜30″ (15″)
Mass budget	≤130kg
Operation temperature	20±1℃



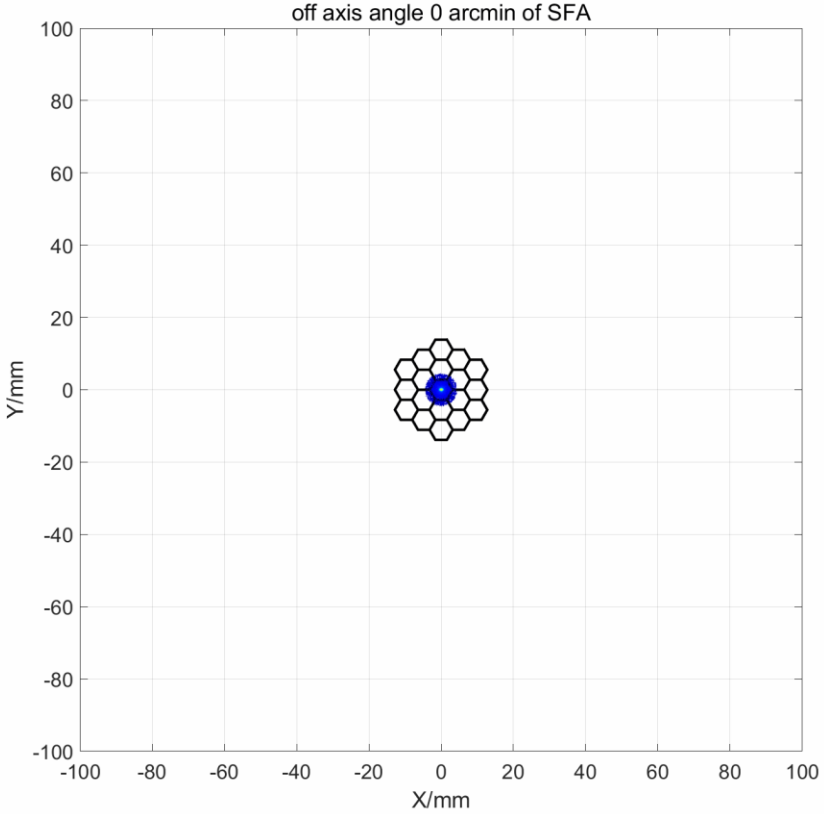



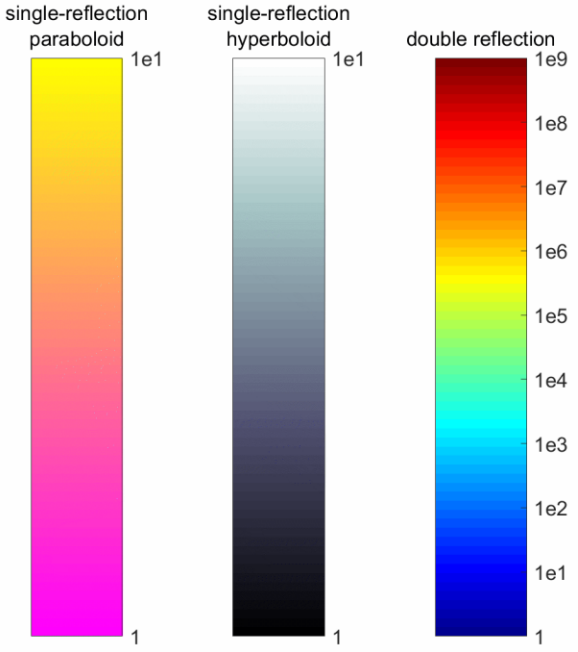





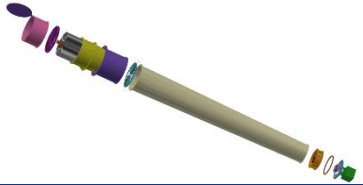
SFA design and development status – optics2/3

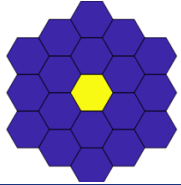
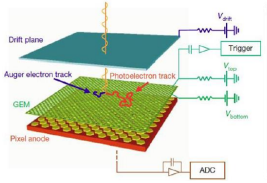
The off-axis performance of SFA was simulated. Especially focused spot on the 19-elements SDDs is shown. The stray light of the single-reflection of hyperboloid is not the x-ray from interested source, but from the contamination source.

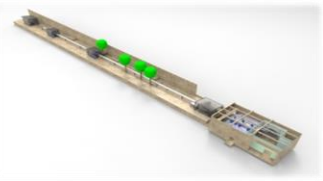




Yuxuan Zhu 2020



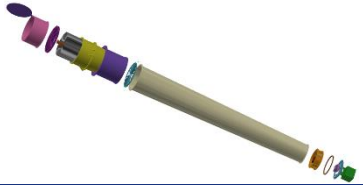
SFA design and development status – optics3/3

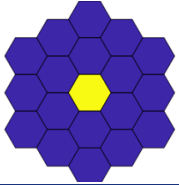
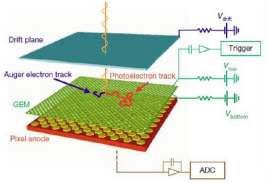
Baseline solution

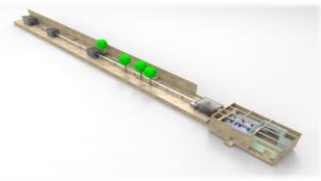
- Manufacture at Media Lario (under contract with IHEP), with supervision from OAB
- Status: optical design and preliminary thermal and mechanical analysis, mature technology of electroforming, carbon overcoating under investigation.

Parallel solution

- Technology development and partial modules manufacture in China. Manufacture in Harbin Institute of Technology (HIT), with support from XIOPM and IHEP, CAS
- Status: optical design and preliminary thermal and mechanical analysis, demonstration module under development, optical or UV metrology under investigation.

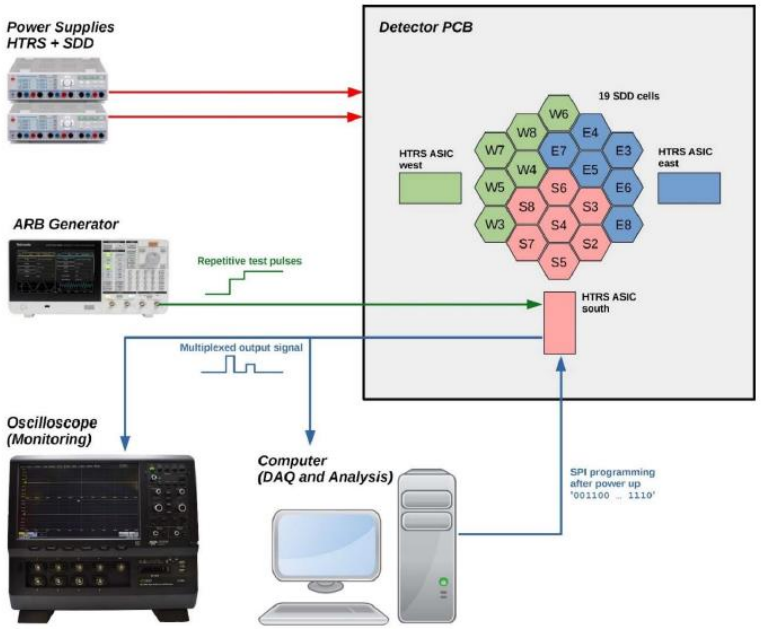



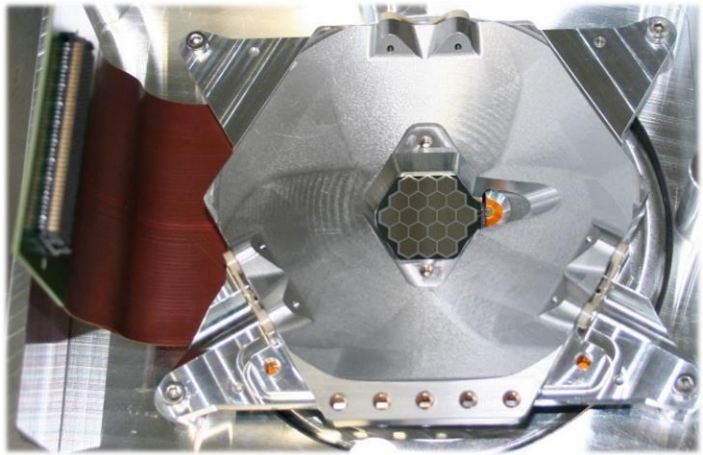





SFA design and development status – focal plane1/2

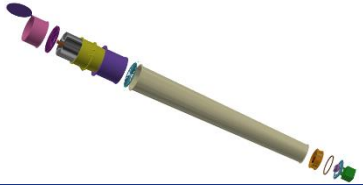
The 19-cell SDD was tested in MPE soon. The performance of the SDD and ASIC are obtained. Especially the temperature effect is Important to the SFA thermal design.

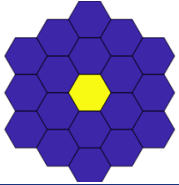
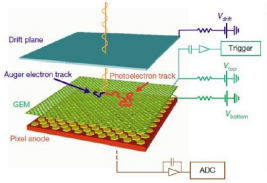


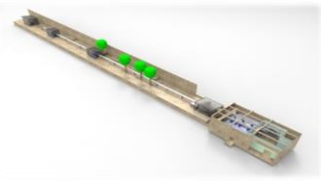


MPE 2021

The current operating temperature of SDD is -55℃, which is not optimal temperature for one stage TEC. According to the result and the next proton irradiation test, the operation temperature of SDD will be confirmed. The optimal temperature is -20~-30 ℃(*Lothar Strüder, 2020*).

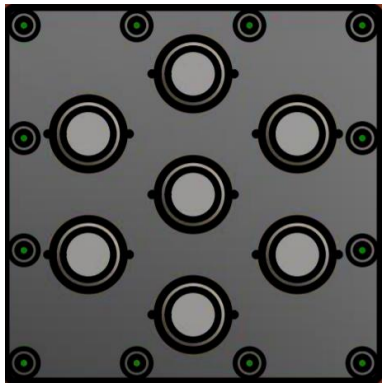
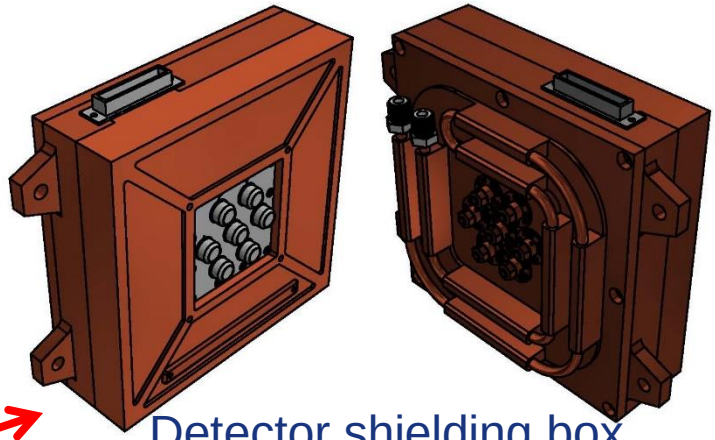
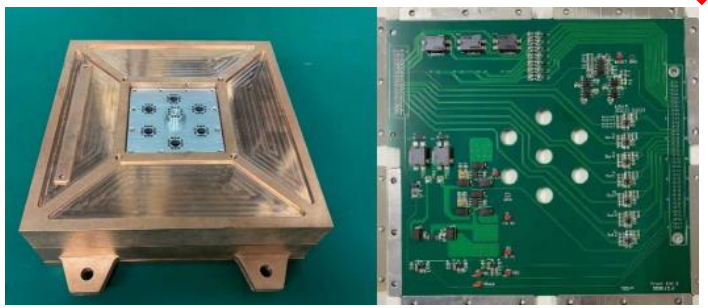



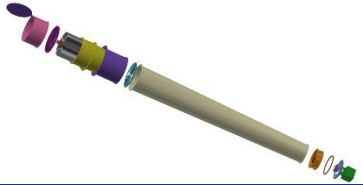


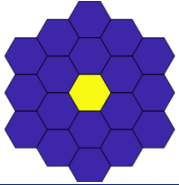
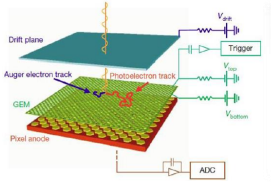
SFA design and development status – focal plane2/2

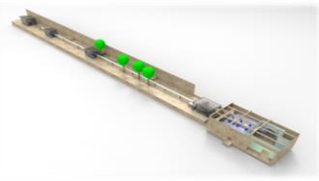
Since delivery of 19-cell SDD will not be confirmed until IHEP and MPE sign a MOU. To verify the design of FP, we are integrating a 7 SDDs array to test the performance of the whole optical design with SFA, especially the number of needed cell to background rejection.




Detector shielding box



The time performance under high flux can also be tested.

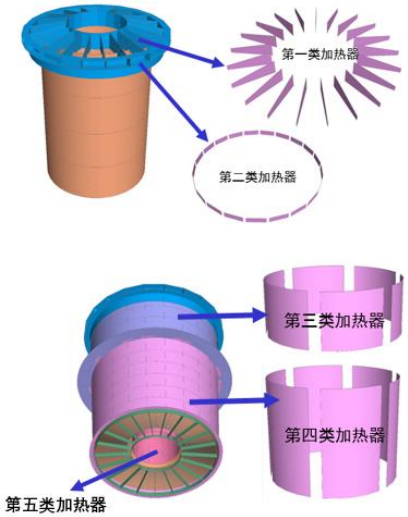



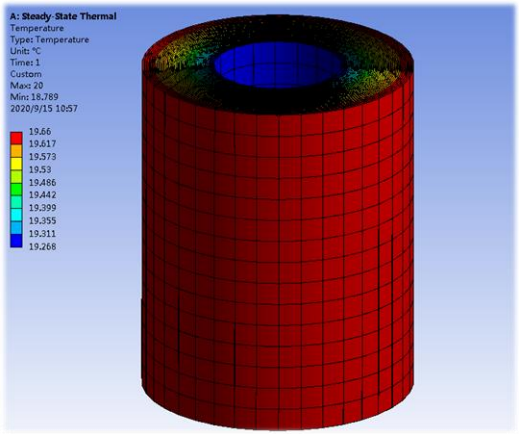





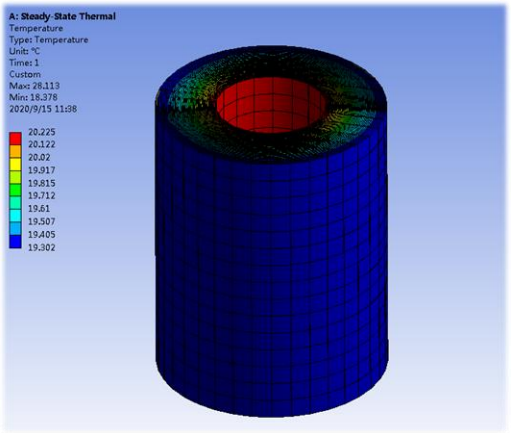
SFA design and development status – thermal

The temperature of mirror assembly is controlled by accurate heating

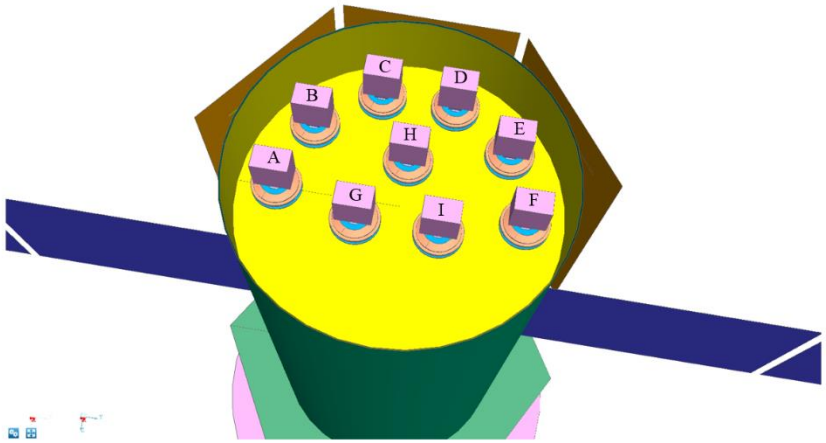


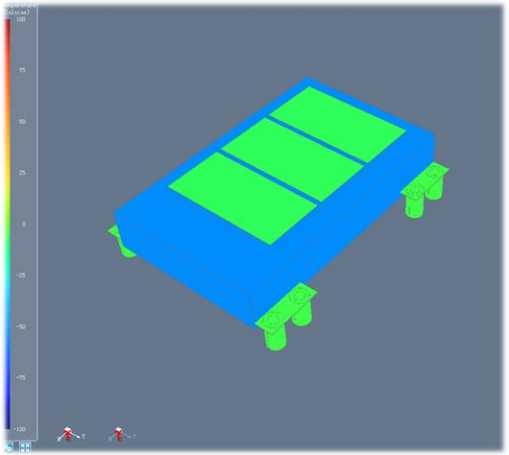


Hot case

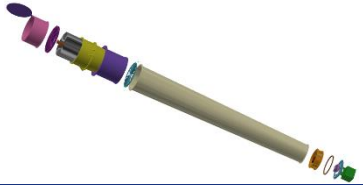


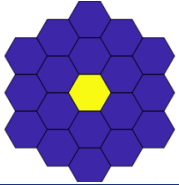
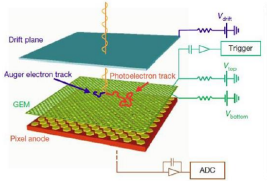
Cold case

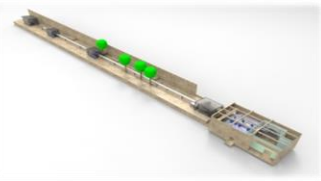




The temperature of focal plane camera is controlled by TEC and radiator

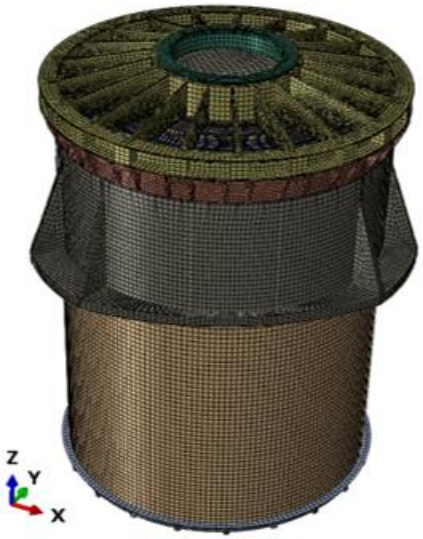



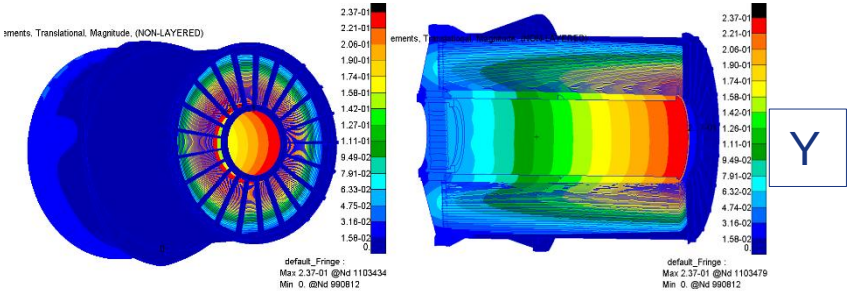


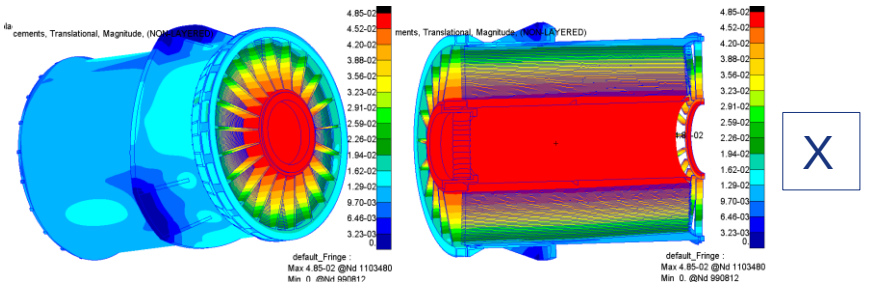
SFA design and development status – structure

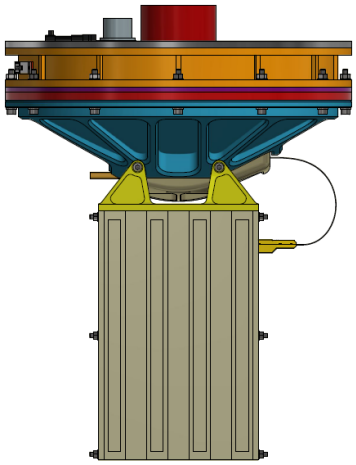
The structure design of MA is reasonable under the current vibration conditions

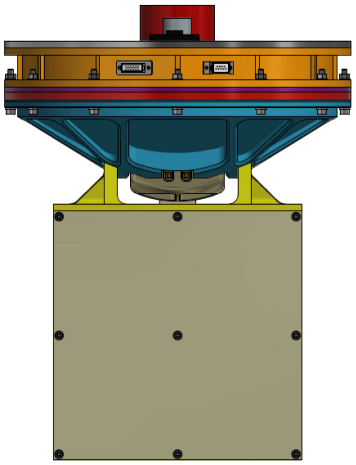


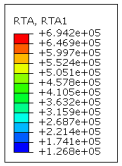
频率（Hz）	功率谱密度
20-100	+3dB/oct，1.0055e-4
100-160	0.0005
160-300	0.006
300-600	0.014
600-2000	-9dB/oct，3.827e-4
总均方根	2.99g

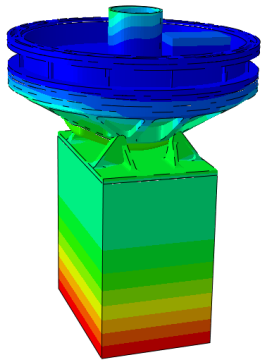




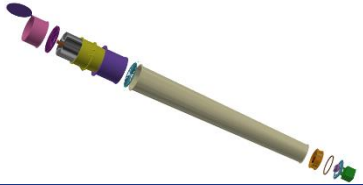


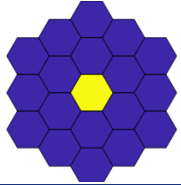
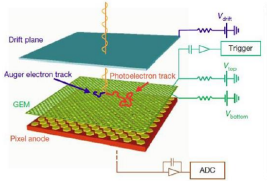


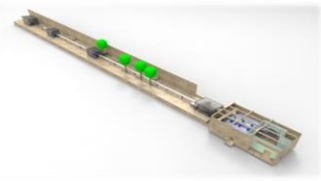




The structure of focal plane camera is also reasonable

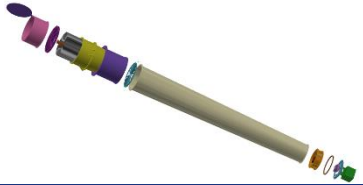



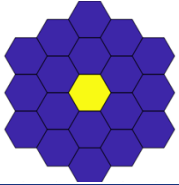
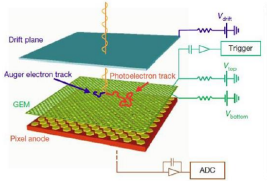



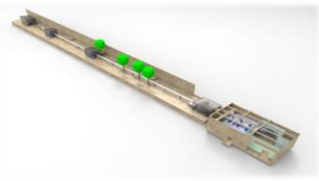


Outline

1. SFA&PFA requirements
2. SFA design and development status
3. PFA design and development status
4. Test facilities and calibration plans

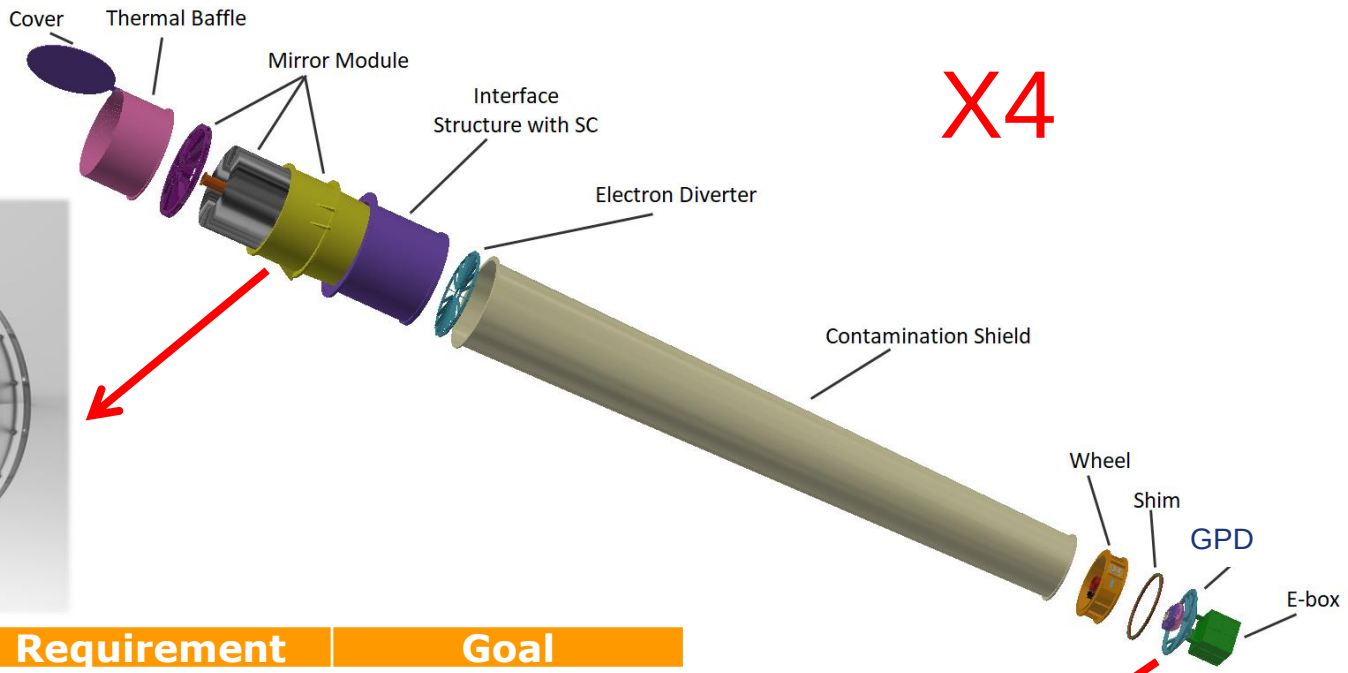





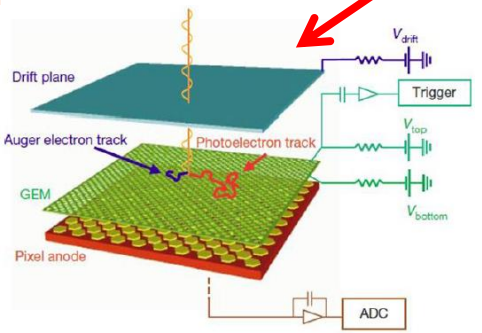
PFA design and development status - introduction

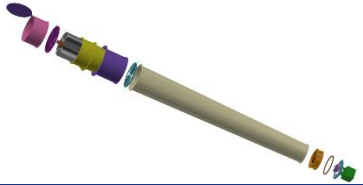
PFA: Polarimetry Focusing Array instrument

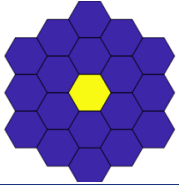
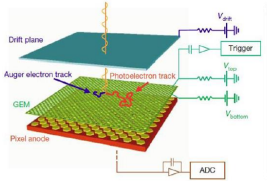


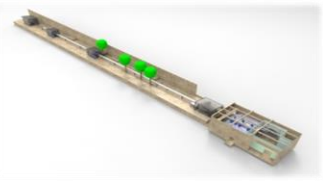
X4

Item	Requirement	Goal
Energy range	2-10 keV	1.5-12 keV
Effective area	380 cm^2 3keV	420 cm^2 3keV
Energy resolution	25% @ 5.9 keV	20%@ 5.9 keV
Time resolution	10 μs	8 μs
Absolute time accuracy	4 μs	
Dead time	≤ 10% @ 1Crab	≤ 3% @ 1Crab
Polarization sensitivity	≤3% (10^6s, 1mCrab)	2%
Spurious polarization	≤1%	





PFA design and development status - collaboration

The PFA is a China-Italy joint payload led by CAS/IHEP.

Partners(hardware only, limited to China and Italy only):

- The Institute of High Energy Physics , Chinese Academy of Sciences (CAS/IHEP)
- ASI and Istituto Nazionale di Fisica Nucleare (INFN)
- Tsinghua University

Contributions:

IHEP contribution

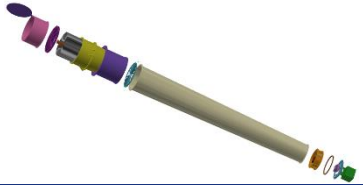
- lead the PFA instrument development.
- PFA mirror assembly developments (Optics)
- develop the PFA focal plane camera with the GPD module
- conduct PFA instrument assembly integration test (AIT) and calibration

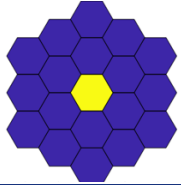
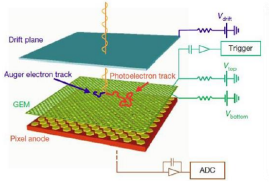
INFN contribution （Confirmed agreements with ASI and INFN）

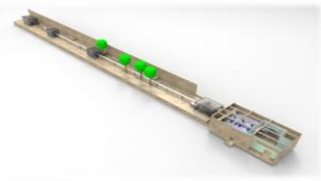
- develop the new ASIC XPOL-III ASICs for QM and FM
- Develop, qualify and define new-design GPD (jointly with China)
- Support to Back End Electronics (BEE)
- Participation in calibrations
- Simulation and analysis packages
- Expertise

Tsinghua contribution

- physical design of the instrument
- GPD assembly, testing and calibration

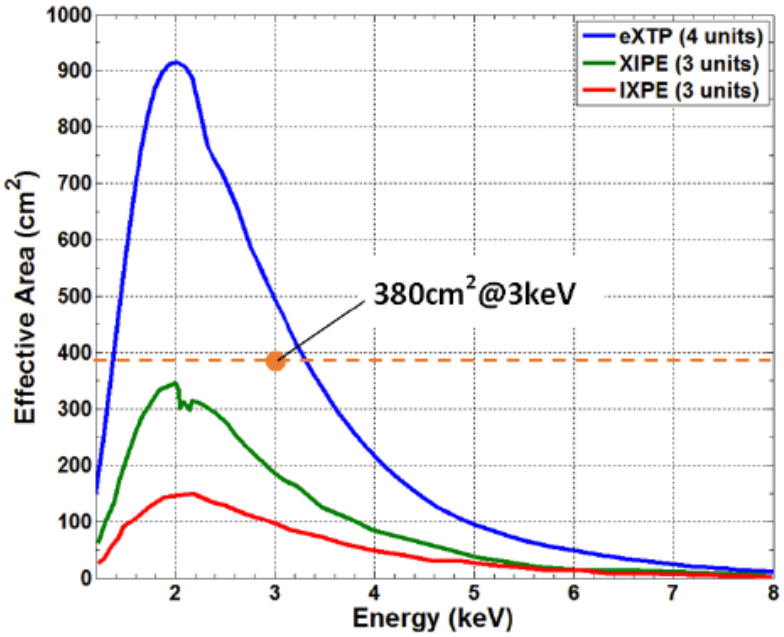



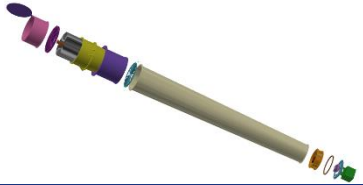


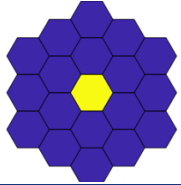
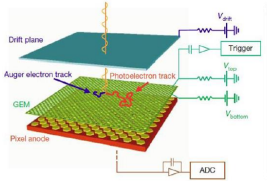
PFA design and development status – optics

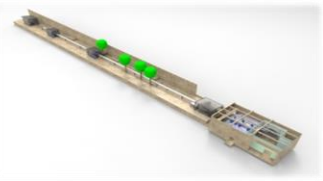
According to the requirement of PFA, the requirement of PFA optics was confirmed. Almost same to that of SFA, making the design of two instruments identical.

Performance	Value
Number of mirror modules	4
Focal length	5.25m
Envelope	≤600mm (diameter)
Effective on axis	≥890cm²@3keV
Energy range	2-10keV
Field of view	≥12′
Angular resolution (HPD)	< 30″ (15″)
Mass budget	≤130kg
Operation temperature	20±1℃



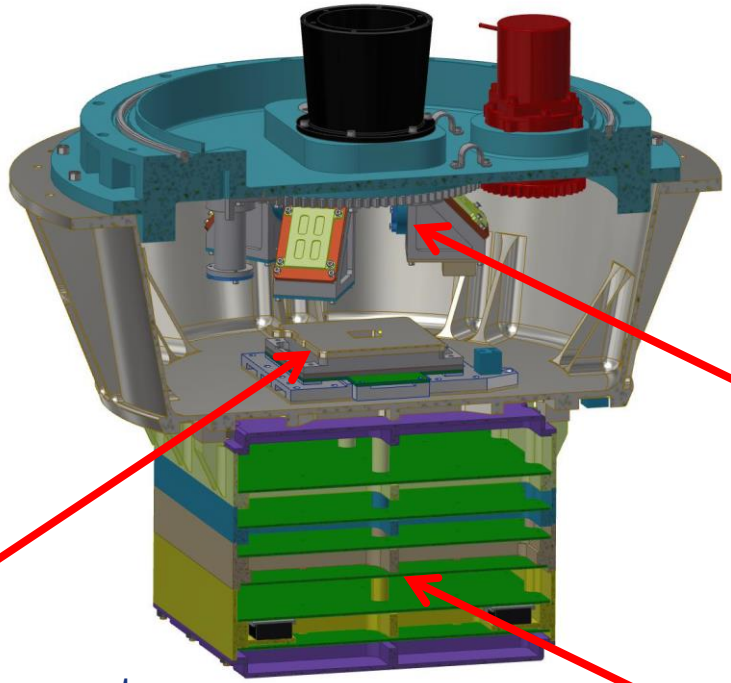



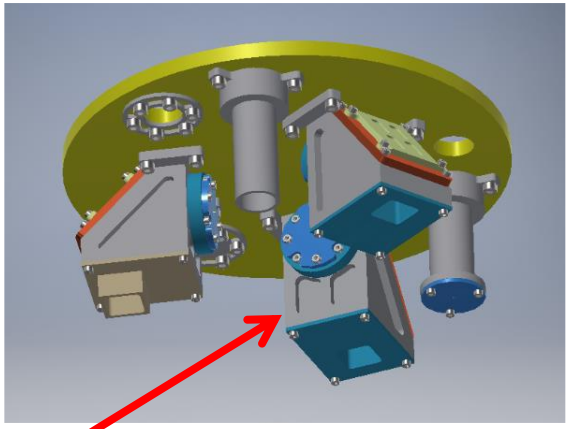





PFA design and development status – focal plane1

Design for PFA focal plane camera

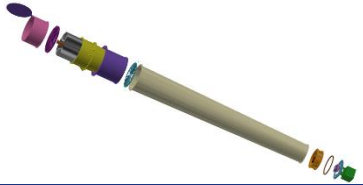


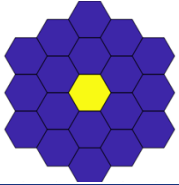
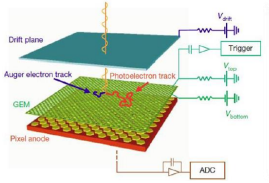


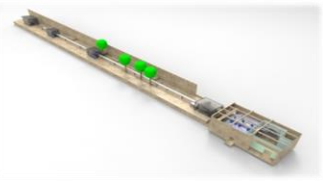
Filters and calibration set

GPD:
Operating temperature
(15~25)±1℃

PFA electronics
DAQ
Thermal control
LV supply
HV supply

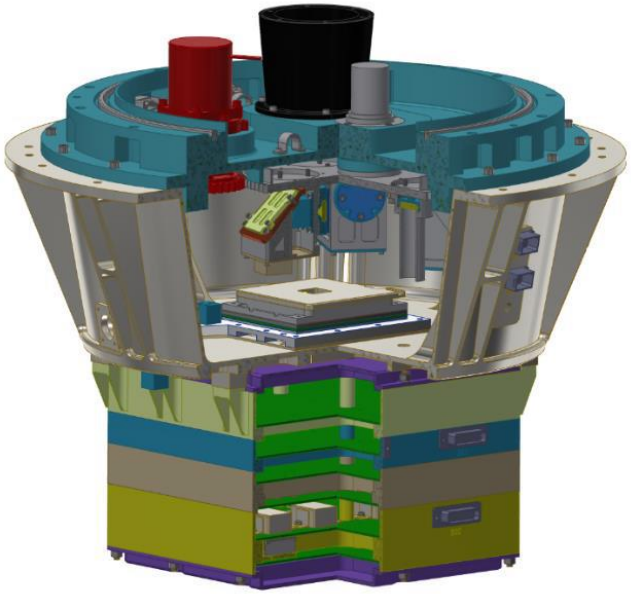



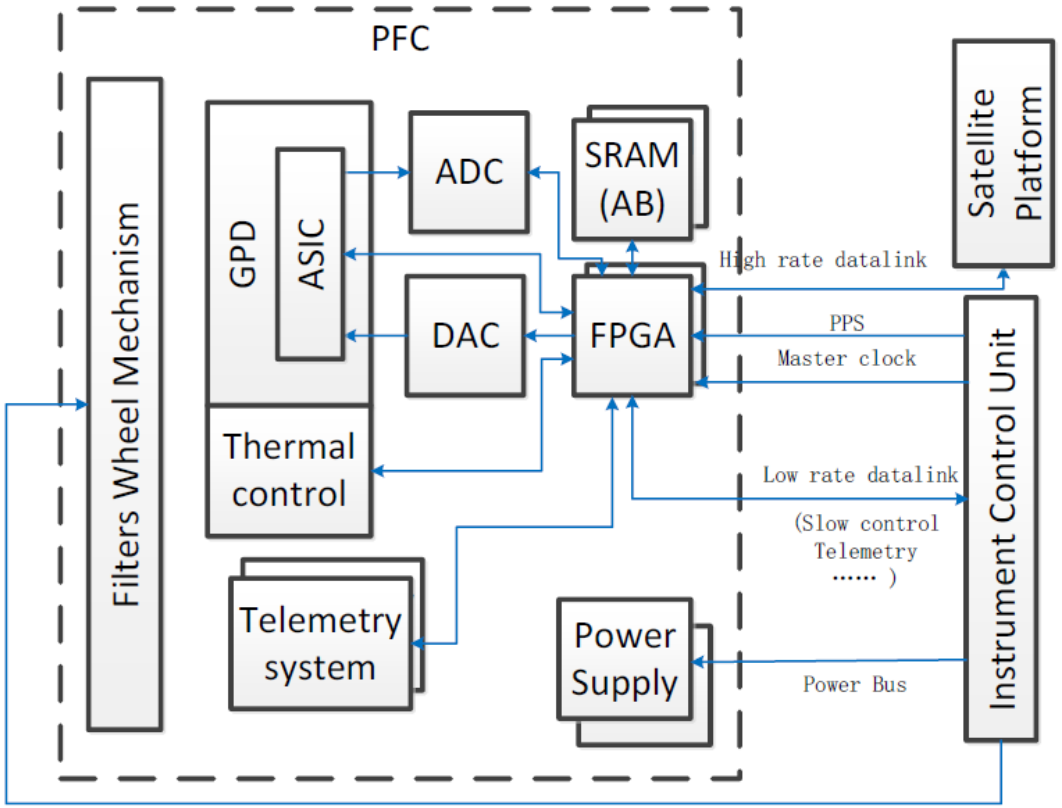



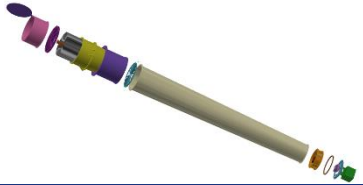


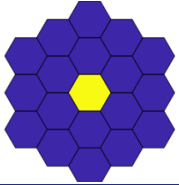
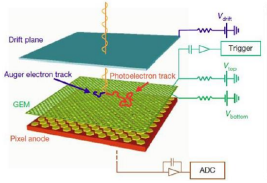
PFA design and development status – focal plane2

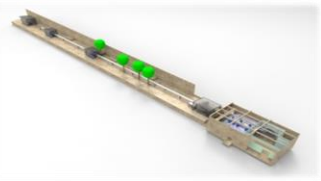
Functional diagram for PFA focal plane camera





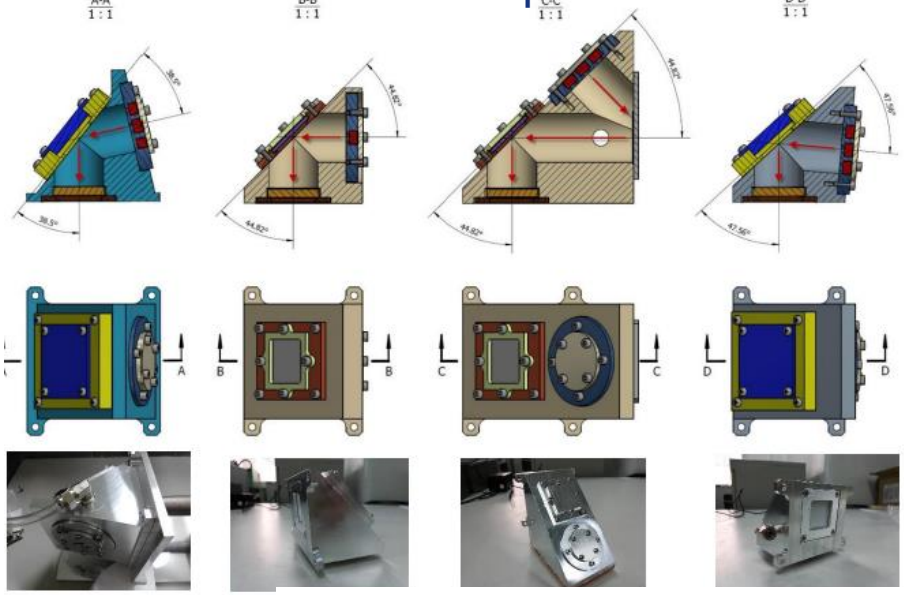



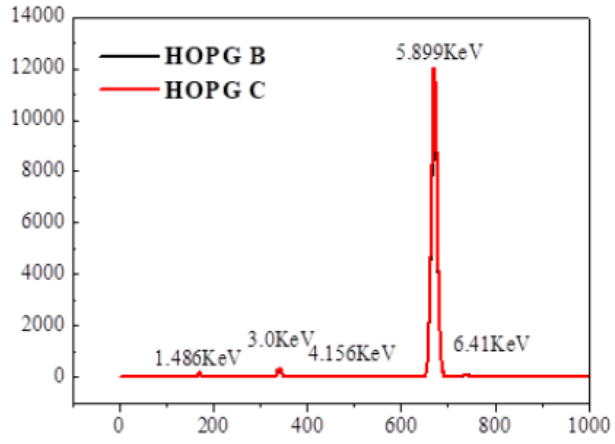





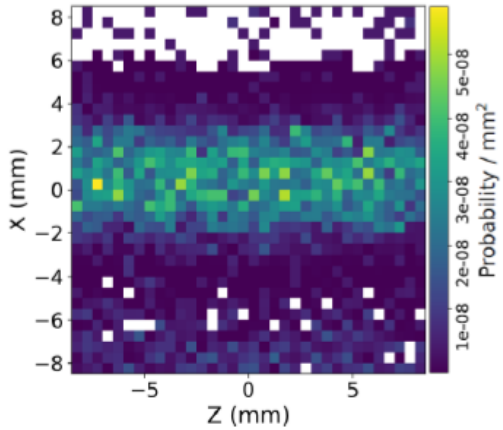
PFA design and development status – focal plane3

Performance of the in-orbit polarization source was tested.

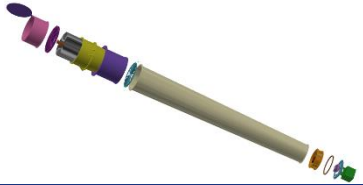


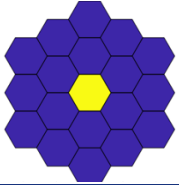
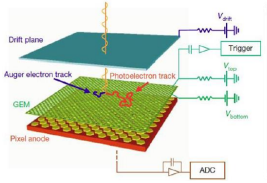


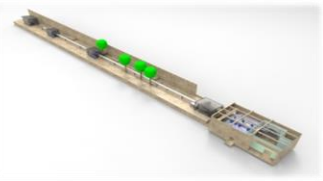
Test results of source1



Simulation results of source1

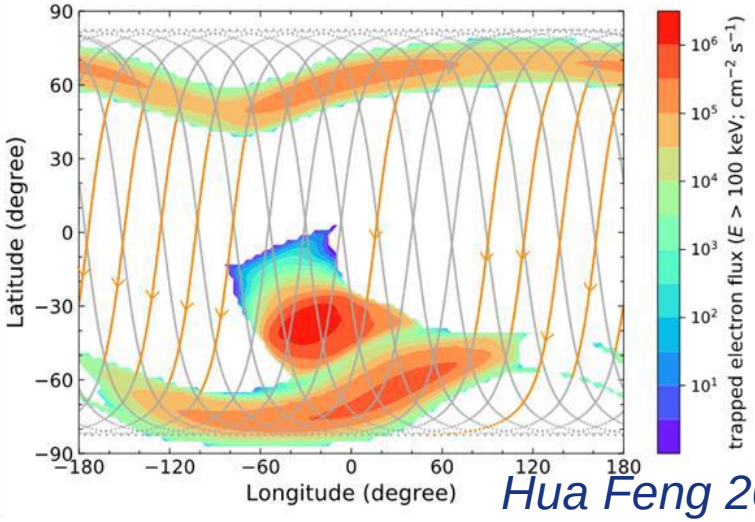





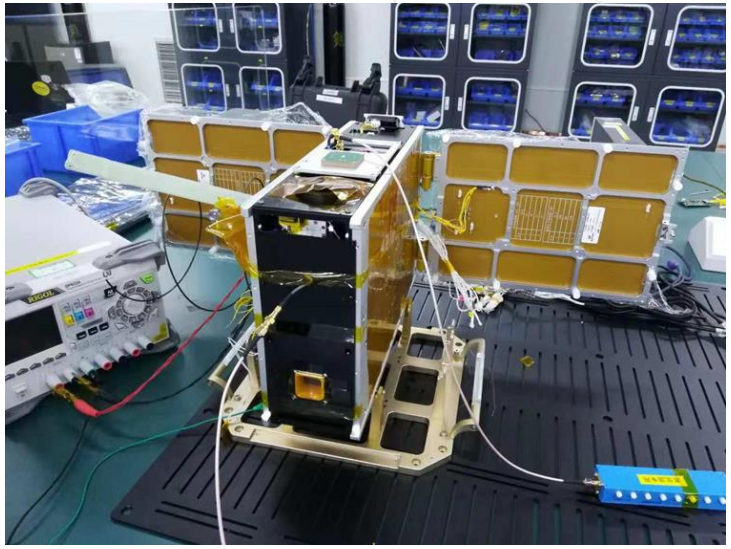
PFA design and development status – focal plane3

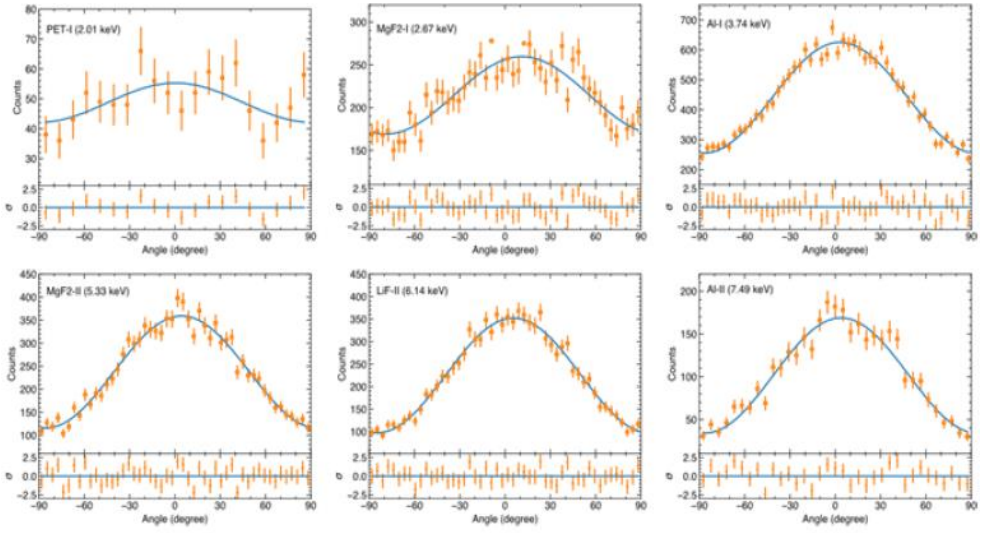
Performance of GPD was verified onboard the “PolarLight”.

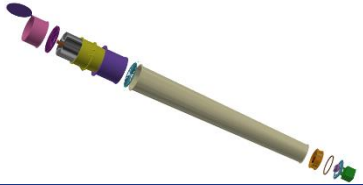
Launched in Oct.2018, works well now.

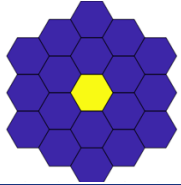
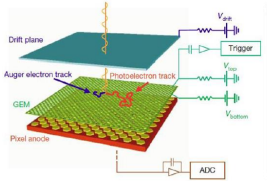


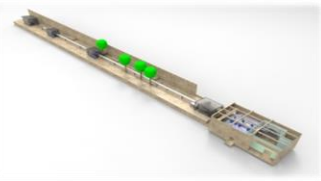
Hua Feng 2019





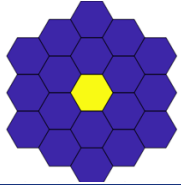
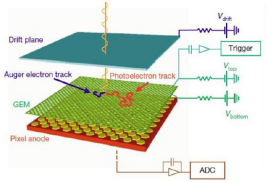



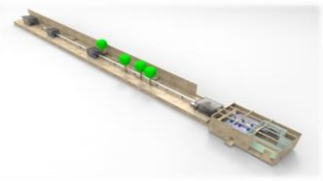


Outline

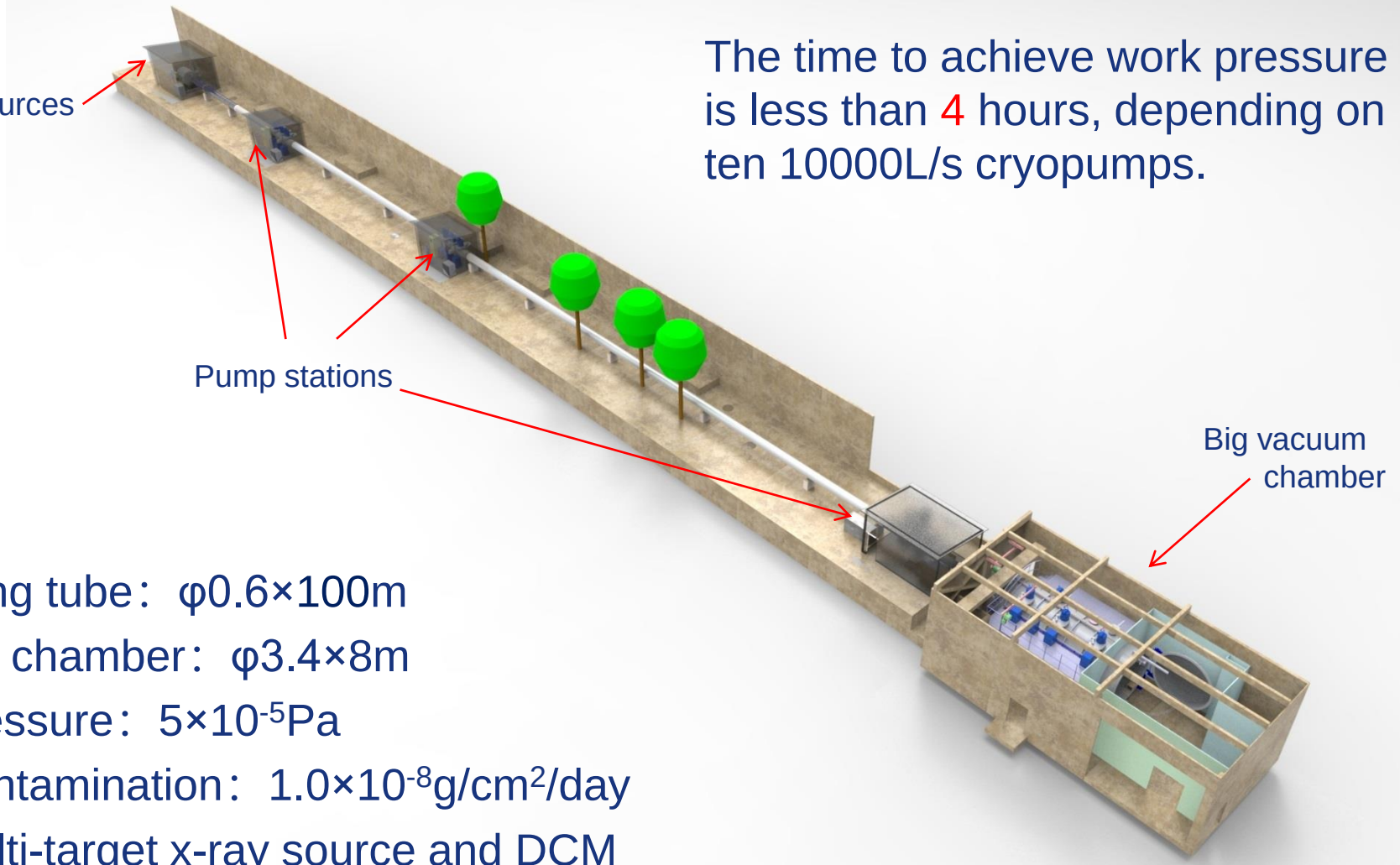
1. SFA&PFA requirements
2. SFA design and development status
3. PFA design and development status
4. Test facilities and calibration plans





Test facilities: 100m X-ray test facility



The time to achieve work pressure is less than 4 hours, depending on ten 10000L/s cryopumps.

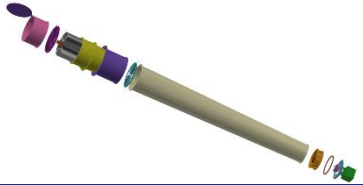
Long tube：φ0.6×100m

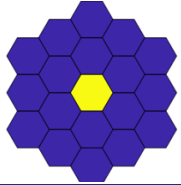
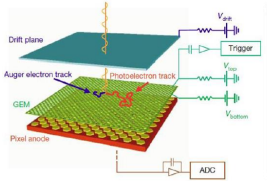
Big chamber：φ3.4×8m

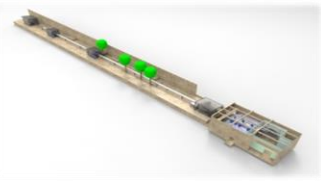
Pressure：5×10^{-5}Pa

Contamination：1.0×10^{-8}g/cm^2/day

Multi-target x-ray source and DCM

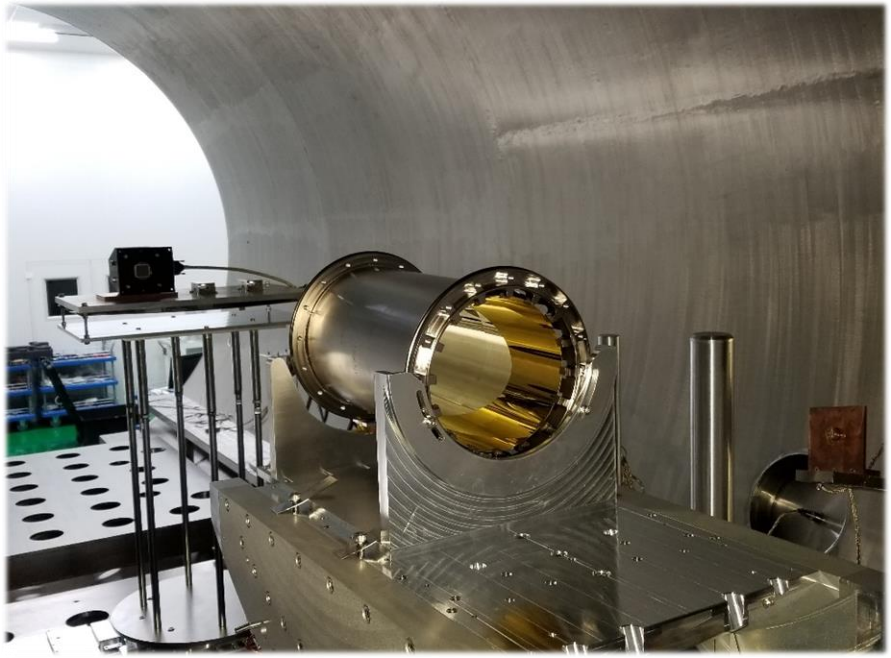



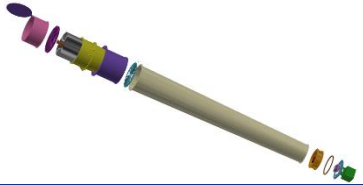


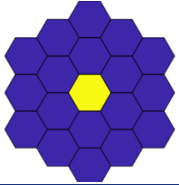
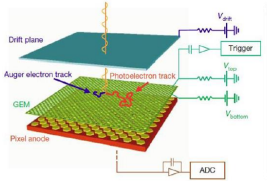
Test facilities: 100m X-ray test facility

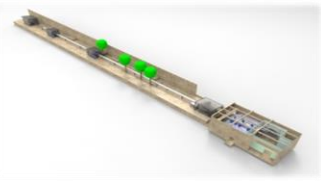
Inside the big vacuum chamber




This facility is mainly for the calibration of
X-ray mirror and mirror assembly.



Test facilities: 8m X-ray test facility

There is another 8m x-ray test facility at IHEP, which can meet the requirements of x-ray detectors, electronic boxes.

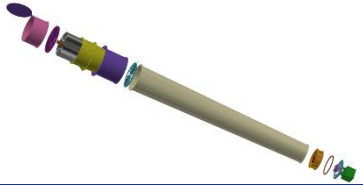
Long tube：φ0.1×8m

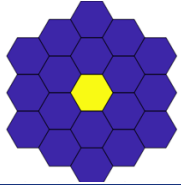
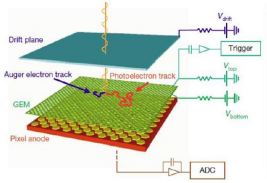
Vacuum chamber：φ2×2m

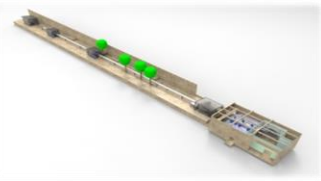
Pressure：5×10^{-5}Pa

Contamination：3.0×10^{-8}g/cm^2/day

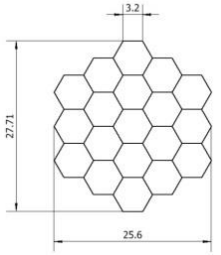
Multi-target x-ray source and DCM

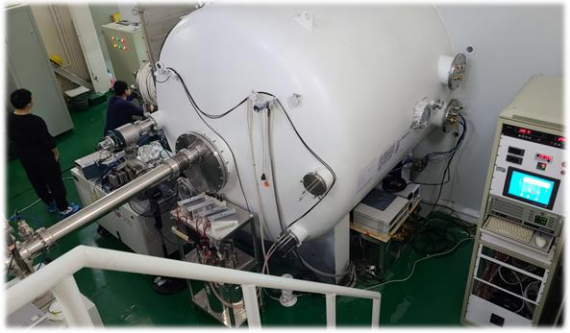


Test and calibration plan for SFA FPD



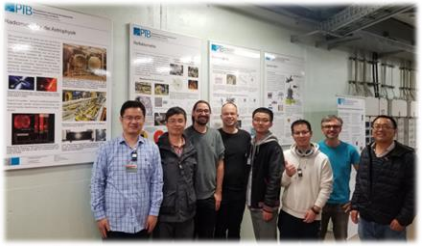
SFA FPD at 8m facility

- Performance under low temperature
- Energy response (0.3-12keV) and low energy threshold
- Energy resolution
- Time accuracy and time resolution
- Split events between cells and optimization
- The effect or electron on SDD.
- The performance of electron deflector
- Performance of background rejection with multi-cells

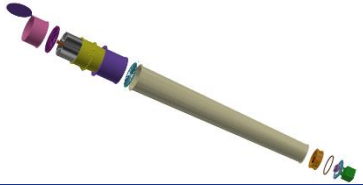


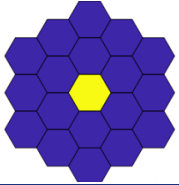
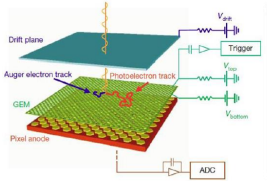
SFA FPD at synchrotron light source

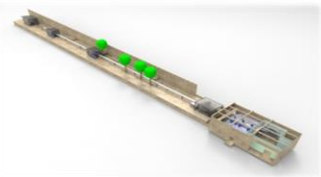
- SDD QE measurement at PTB
- Transmission of kinds of filters at HEPS



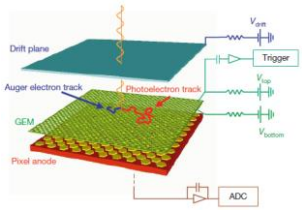




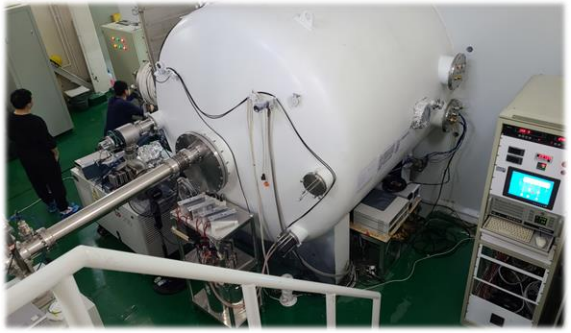


Test and calibration plan for PFA FPD



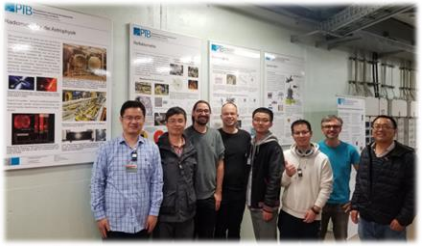
PFA FPD at 8m facility

- Performance under different temperature
- Energy response (1.5-12keV) and low energy threshold
- Energy resolution
- Time accuracy and time resolution
- The effect or electron on GPD.
- The polarization performance

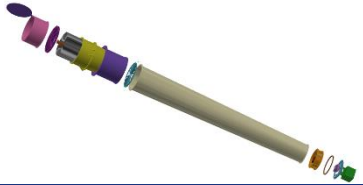


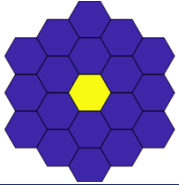
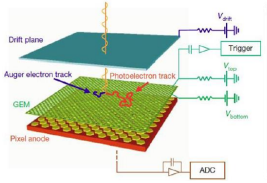
PFA FPD at synchrotron light source

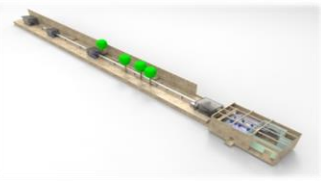
- GPD QE measurement at PTB



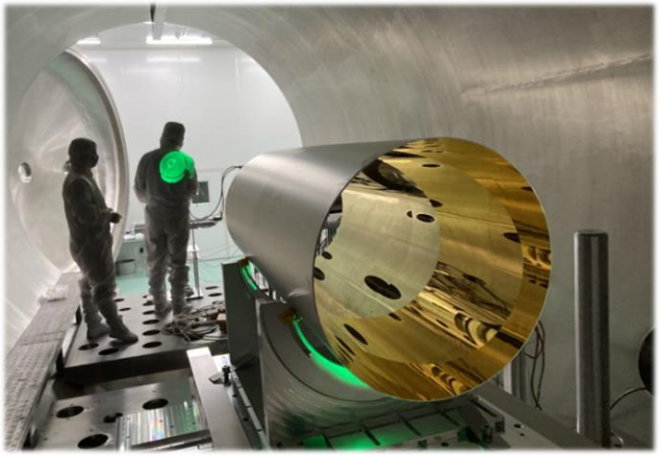






Test and calibration plan for SFA&PFA mirrors

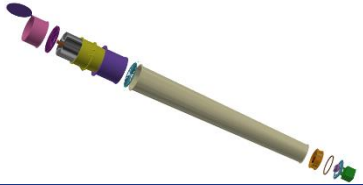


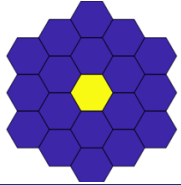
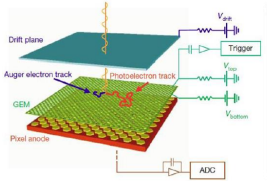
Mirror at 100m facility, with CXC

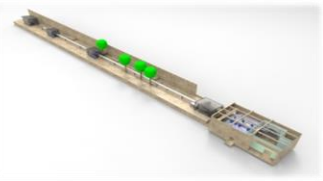
- Filed of view and PSF
- HPD at Al-K, Cu-K, C-K
- Effective area at Al-K, Cu-K , C-K
- Measurement of focal length and Pointing
- W90 and Off-axis performance
- Checking the performance of stray light(background)
- The performance of mirror depending on the temperature

Mirror at other facilities

- Proton irradiation

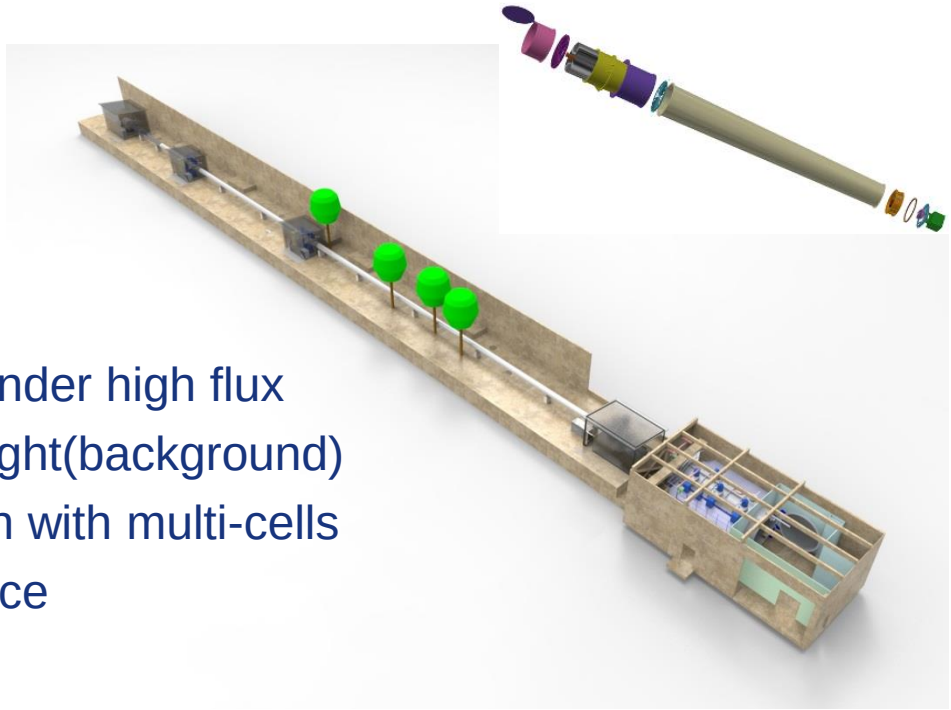





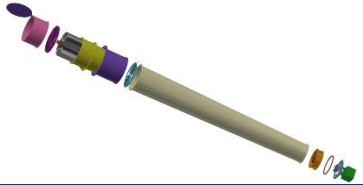
Test and calibration plan for SFA telescopes

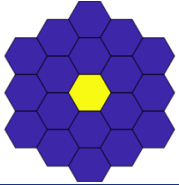
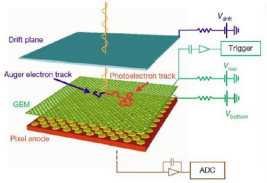
SFA&PFA at 100m facility, supported by integrated structure

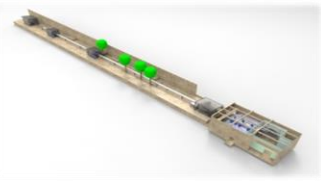
- Filed of view and PSF
- Effective area at Al-K, Cu-K , C-K
- Verification of focal length
- Off-axis performance
- Optical axis alignment and guide
- Time accuracy and time resolution under high flux
- Checking the performance of stray light(background)
- Performance of background rejection with multi-cells
- Checking the polarization performance



The SFA&PFA will do the end-to-end at100m facility, checking every function and performance one by one.

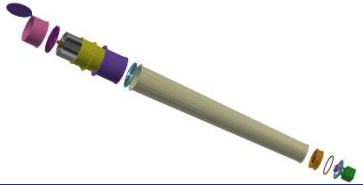



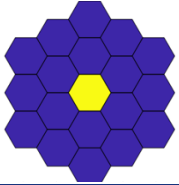
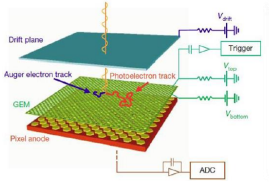





Summary

- The SFA and PFA are designed well even under preliminary design phase.
- The development of SFA and PFA are ongoing on critical technologies.
- The test facilities are available and ground calibration plans are given.



Drift plane
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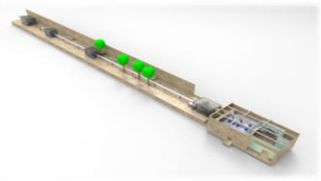
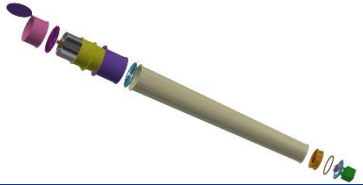
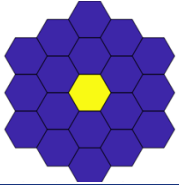
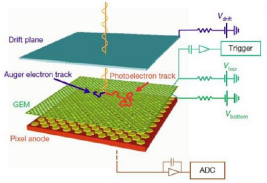
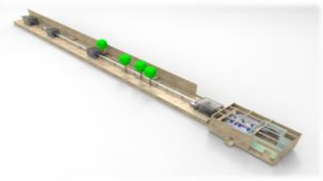
Auger electron track
Photoelectron track
GEM
Pixel anode
ADC


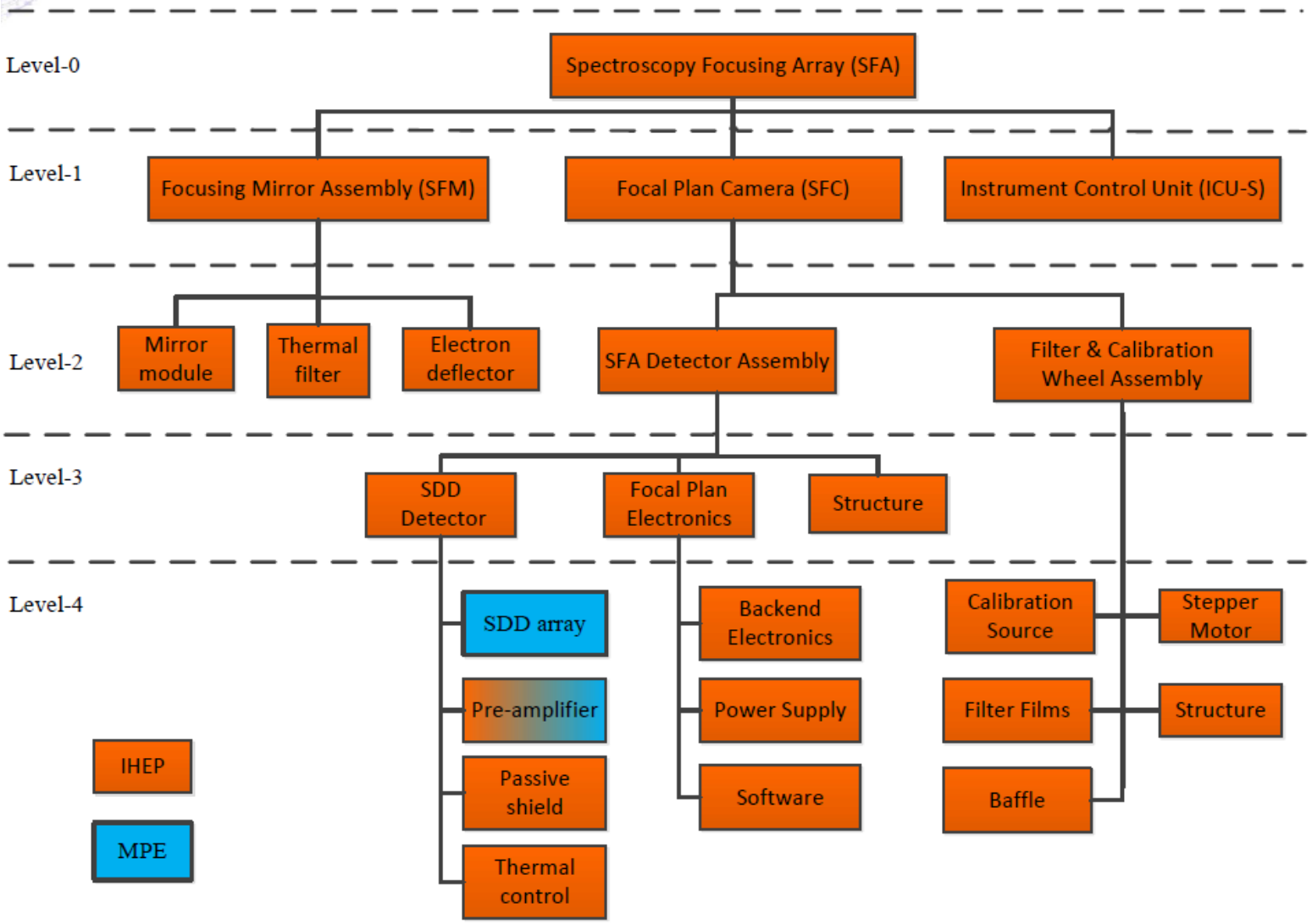
Thank you!

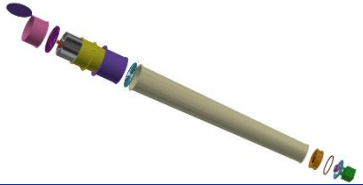



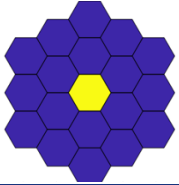
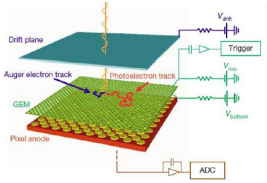



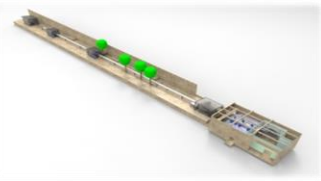


Backup slides





Backup slides

eXTP is still in preliminary design, depending on the thermal and interface design.

Schedule in 2021&2022

The conceptual design of SFA is completed, the review will be organized, May 2021

There are some verification and test after conceptual design review, June 2021

The qualification design review of SFA will be completed in August 2021

Some STM will be delivered to MICROSAT June 2022