Positron Annihilation Imaging high-Resolution Spectrometer

PAIRS
Instrument Development Plan

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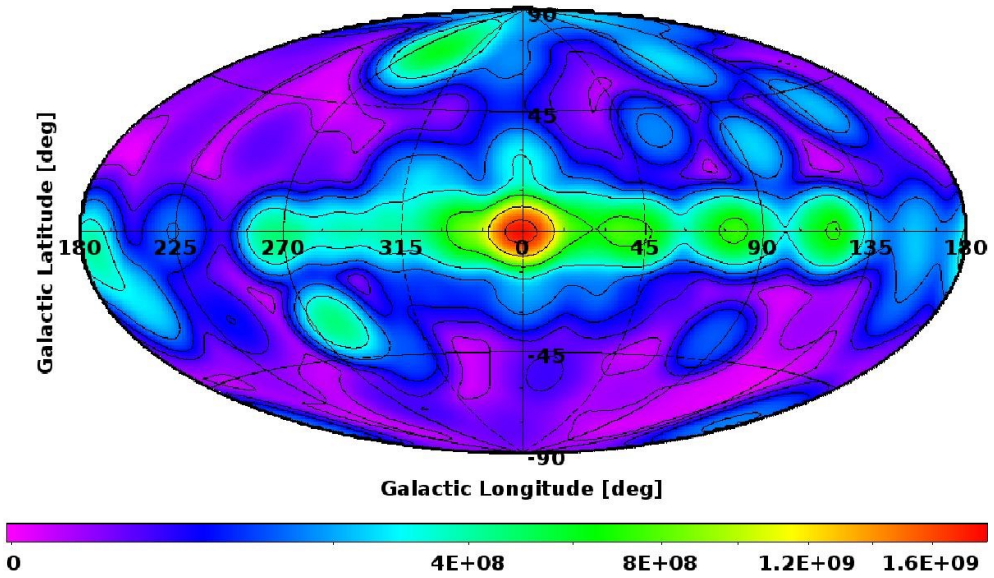
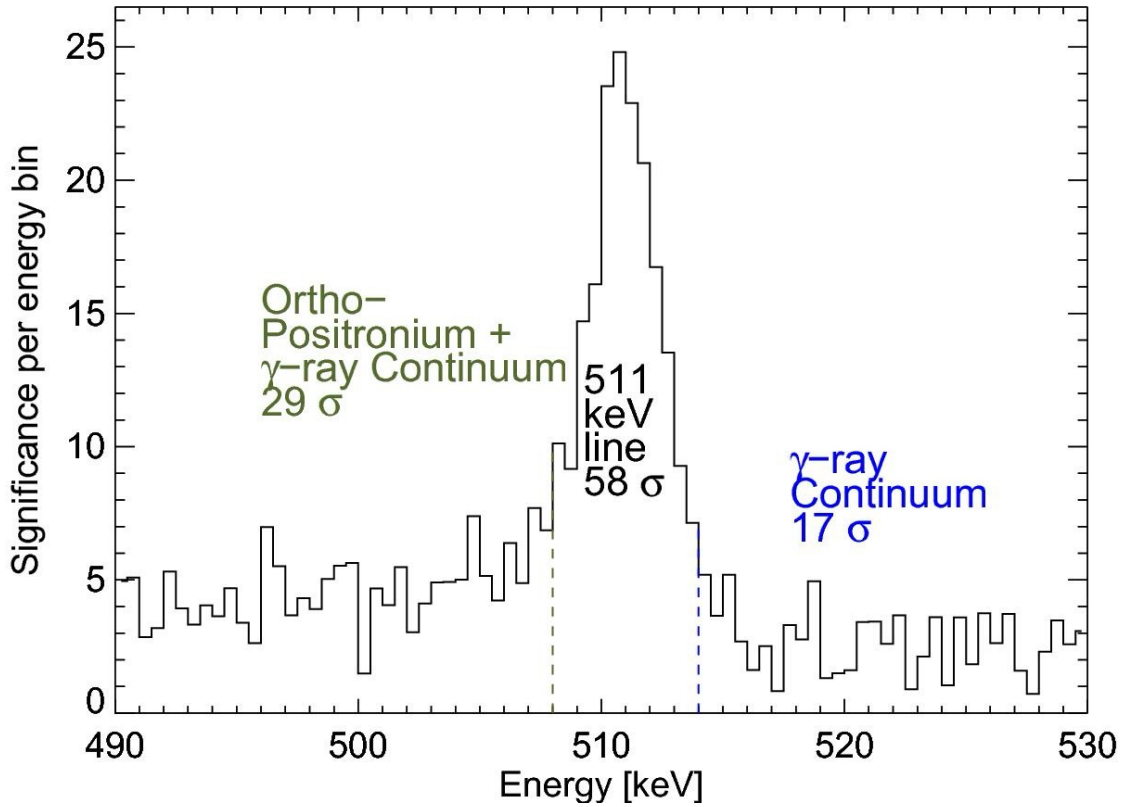
Science motivation

Latest result from INTEGRAL/SPI (2023)

- Rate of positron annihilation： $>5\times10^{43}$ s^{-1}
- Bulge-to-disk ratio： 1.0 ± 0.1
- Positronium fraction： 1.080 ± 0.029



Siegert, 2016



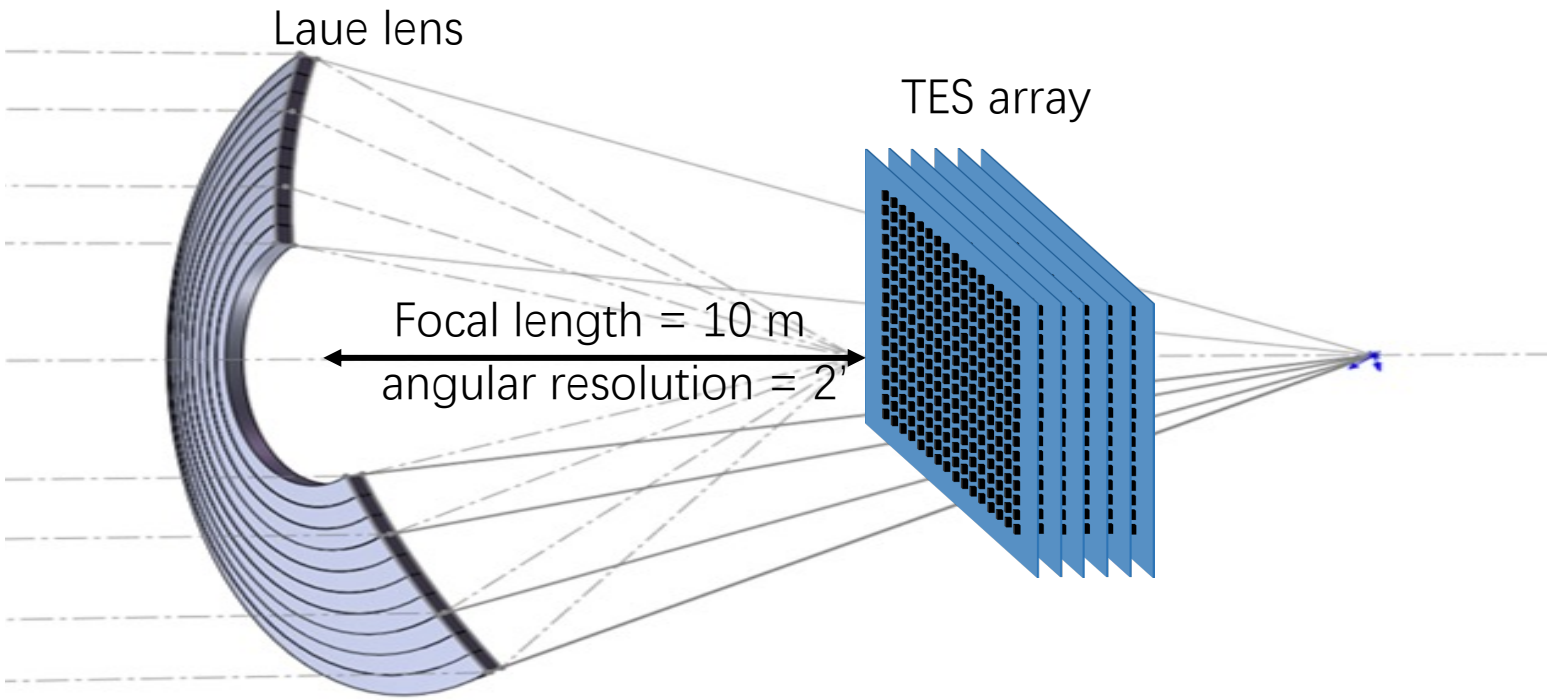
Attracting results, and more to be discovered with higher spacial resolution and higher energy resolution

PAIRS balloon project

Positron Annihilation Imaging high-Resolution Spectrometer

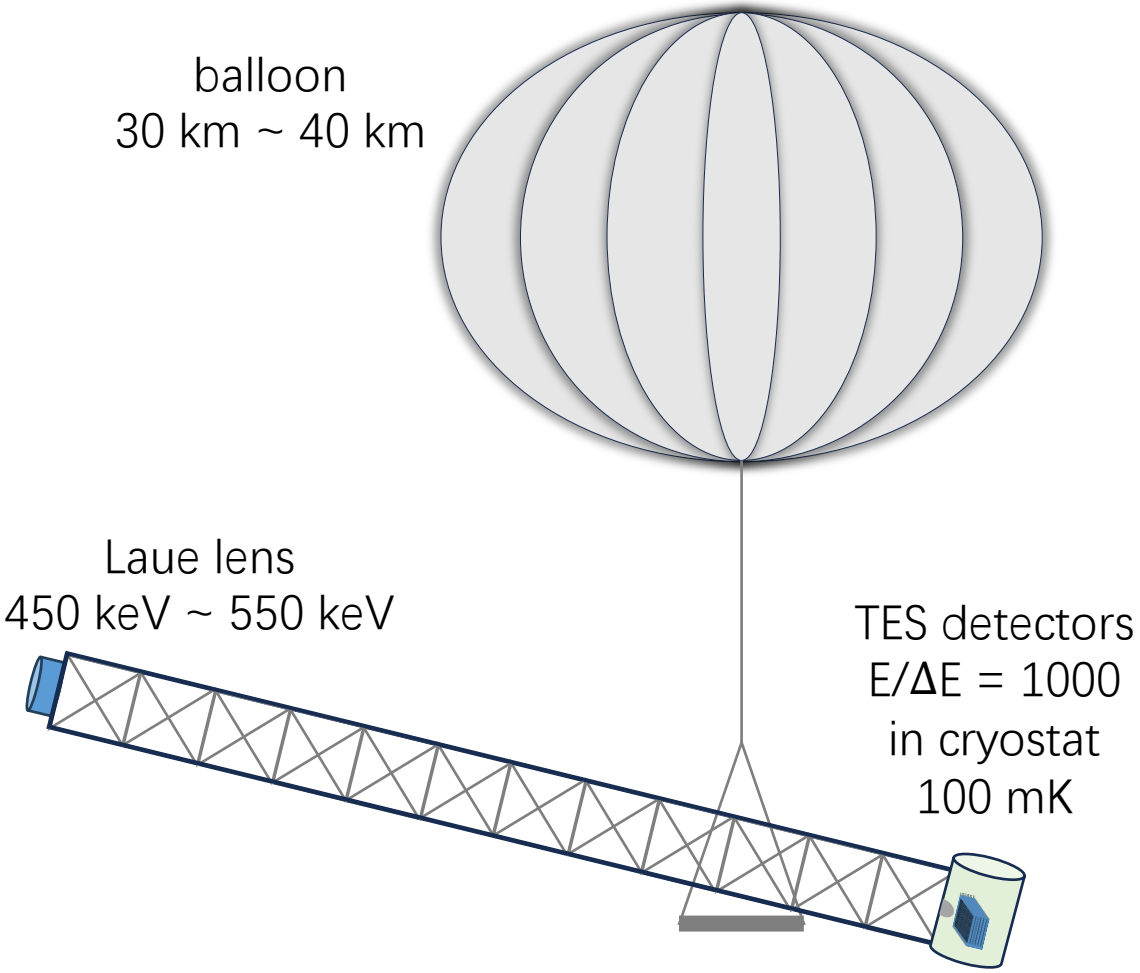
Observation time: 12 days
- continuous flight around Southpole
- or multiple 24h~48h flights in China

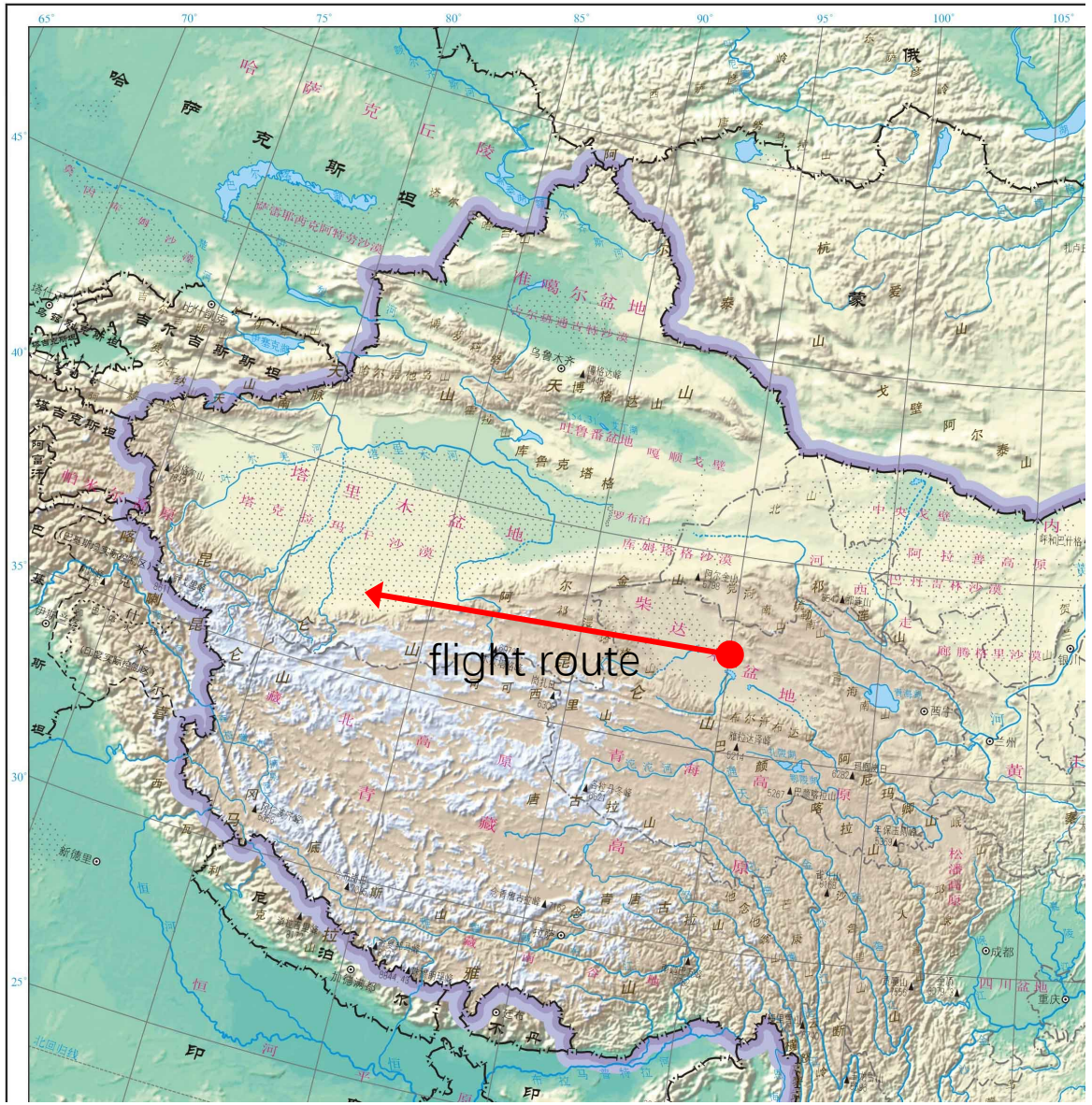
Altitude: 30 km ~ 40 km



Laue direct imaging + superconducting microcalorimeter

PAIRS balloon project

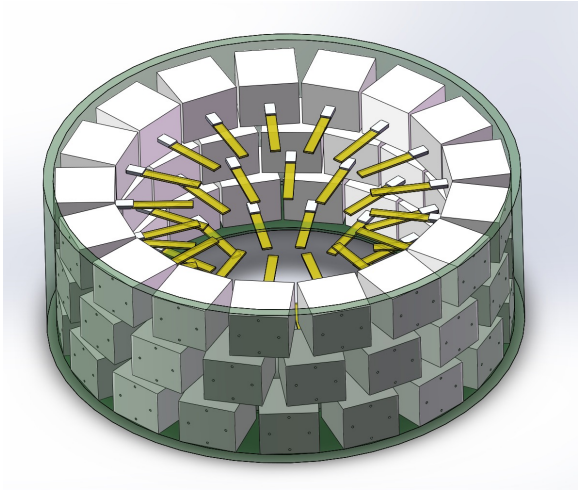


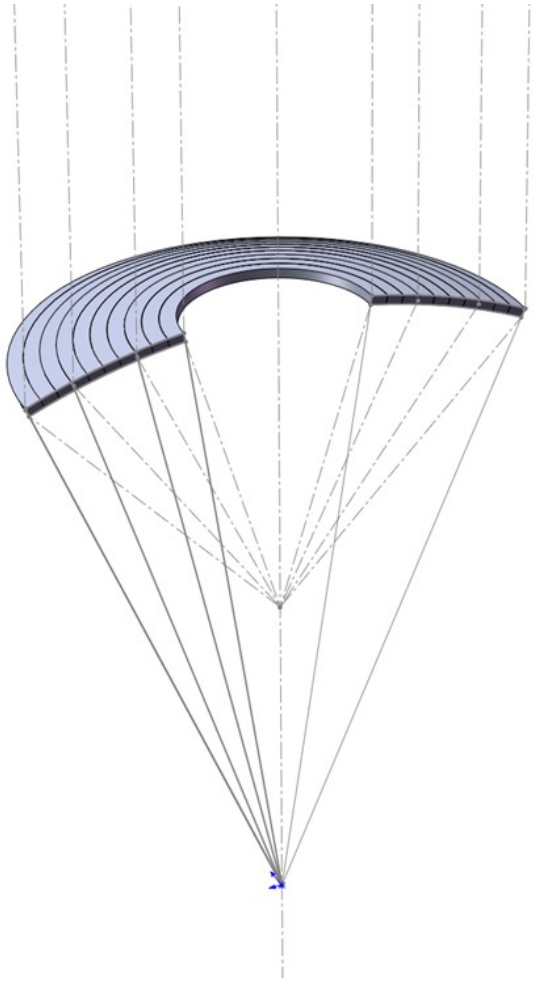


Laue lens

Design

- Material of focus lens: Ge (111)
- Energy range: 450 keV ~ 550 keV
- Field of view: 5 arcmin
- Spatial resolution: 2 arcmin (5.8 mm)
- Pointing accuracy: 15 arcsec
- Pointing stability: 10 arcsec
- Focus area: 100 cm2
- Focus length: 10 m
- Size: diameter 40 cm * 30 cm
- Working temperature: 20±5℃





Current status

- Completed active optics design
- Mastered anodic bonding technique, ready to implement on Laue bent cyrstals

Laue lens: plan

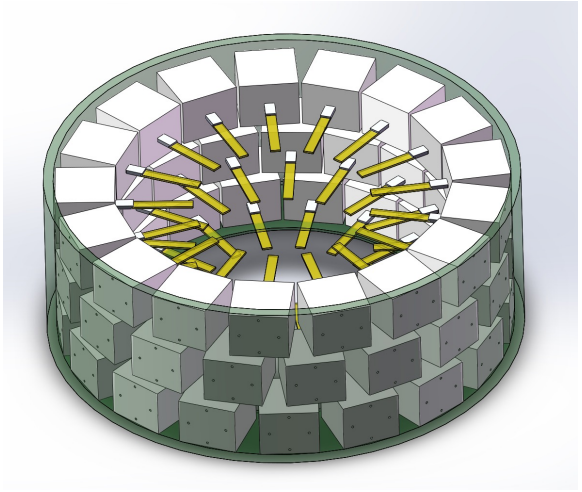
1st year: make development plan, complete Laue optics simulation software, produce the 1st version bent crystal, complete the prototype of the active optics control system, design and fabricate the optics (wide energy range) module substrate;

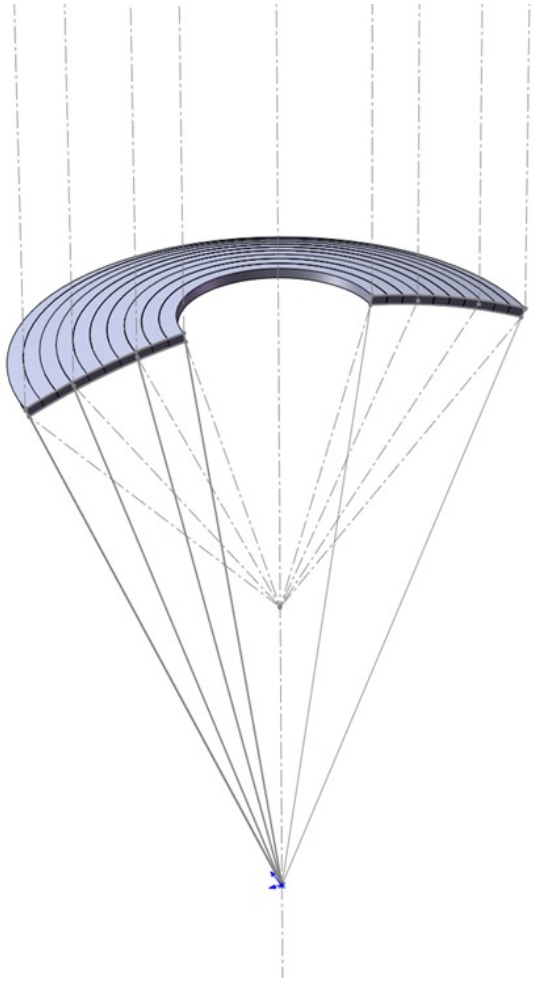
2nd year: measure the precision of the crystal curvature radius, optimize crystal produce technique, produece the prototype of the 511 keV Laue lens, start to test the high-precision crystal gluing technology, study the high-precision assembly technology of optics module;

3rd year: finish the development and calibration of the balloon-borne 511 keV Laue lens;

4th year: balloon flight experiment;

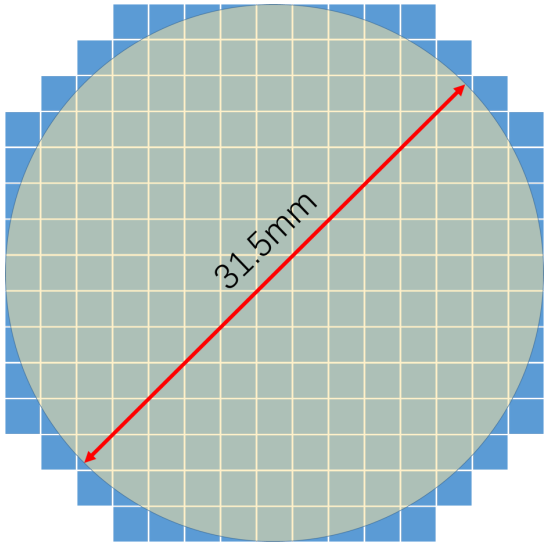
5th year: mission accomplished

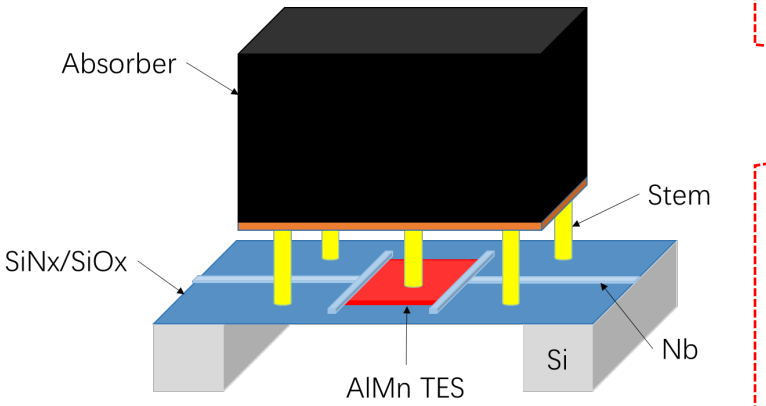


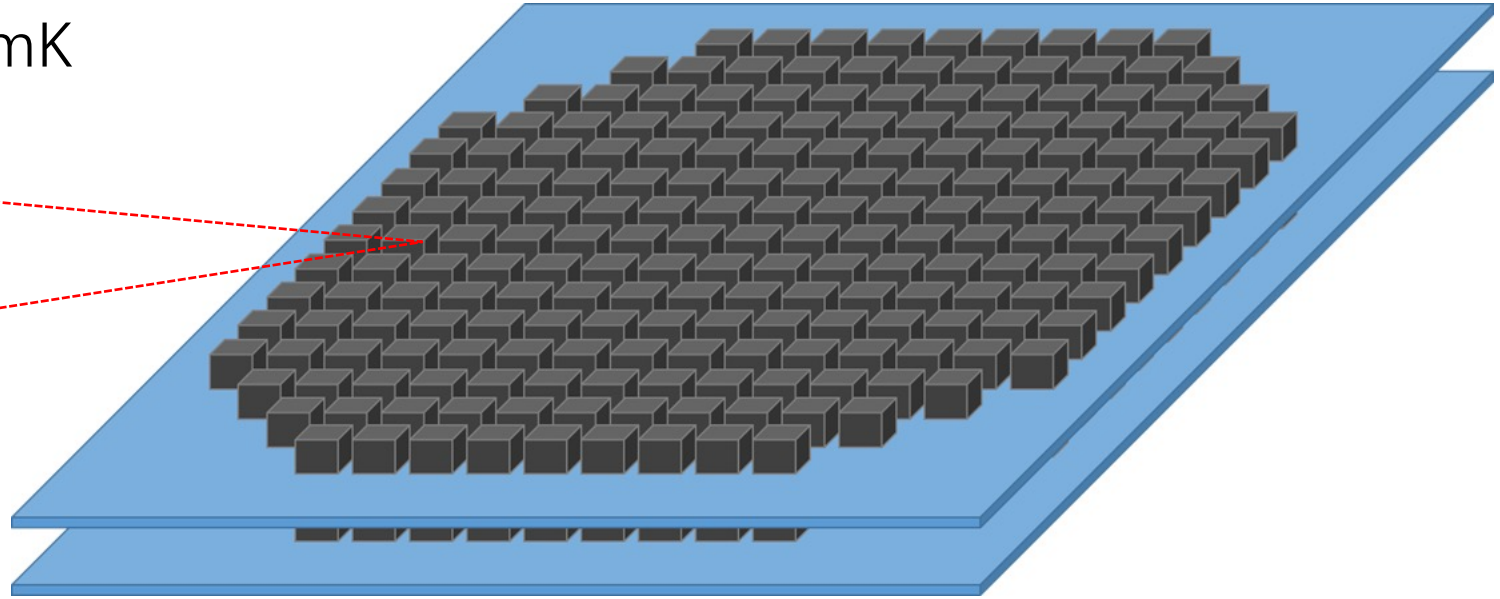


TES microcalorimeter: design

- TES material: AlMn alloy
- Absorber material: Ta, Pb, Bi or other heavy metals
- Absorber size: 2 mm × 2 mm × 2 mm (2’ anglar resolution)
- Geometry: 201 pixels per layer, 2 layers (402 pixels in total)
- Effective area: 8 cm^2 per layer
- Resolution: 0.5keV @ 511 keV (E/ΔE = 1000)
- Total QE: 50% @ 511 keV
- Working temperature: ~100 mK

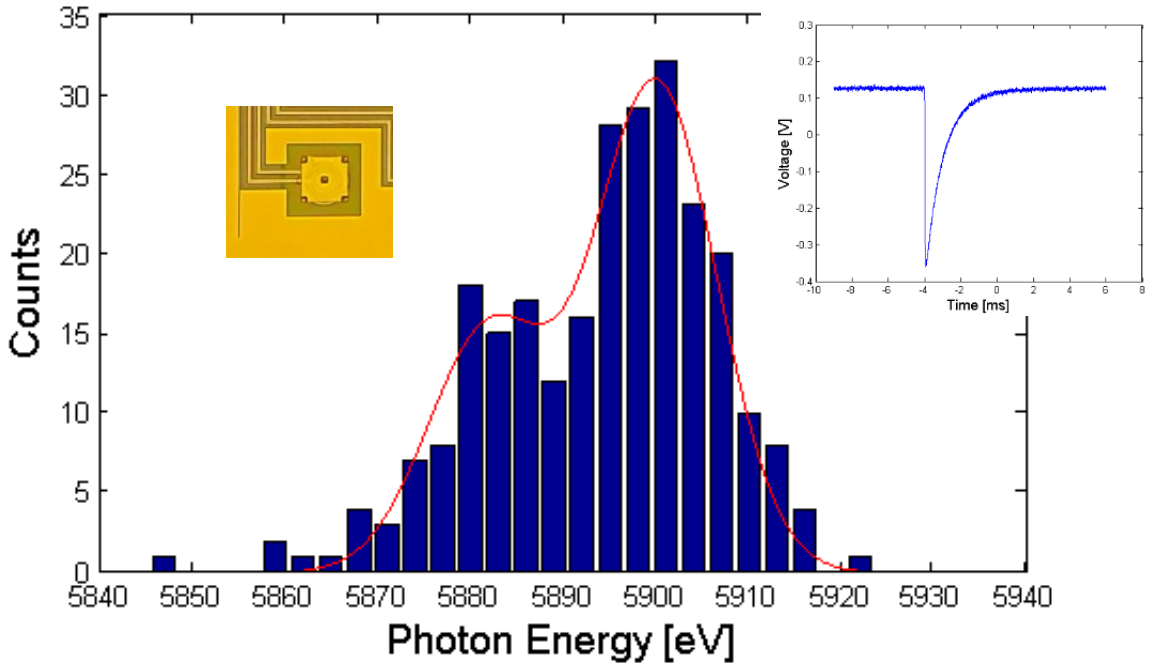


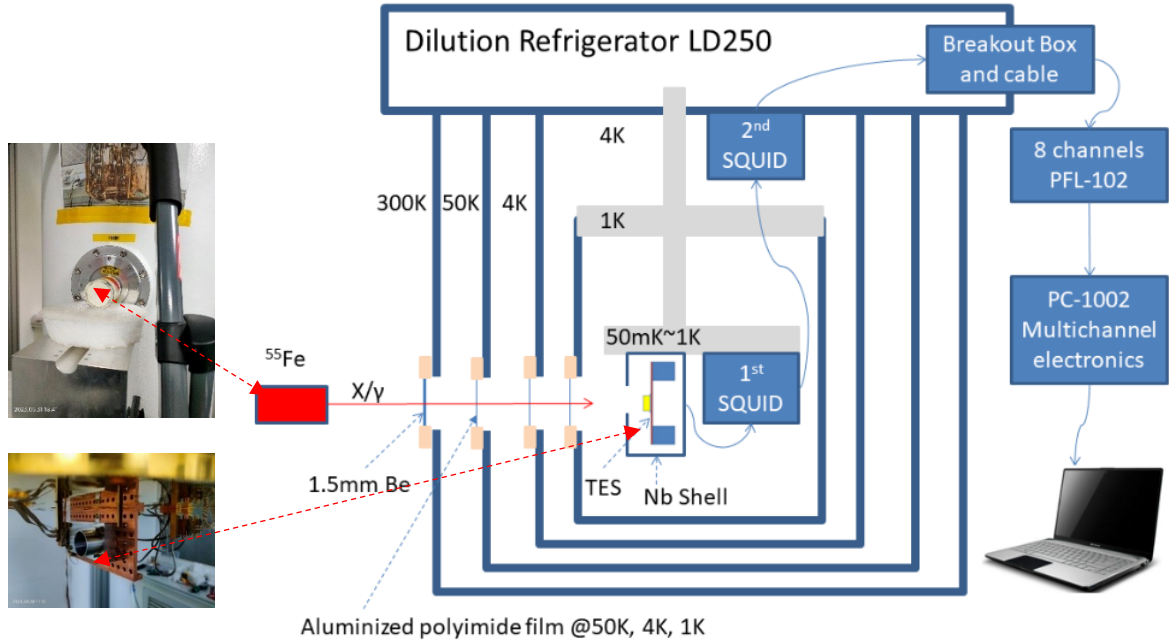




TES: current status

- 2018-2020：TES fabrication technique exploration
- 2021：finished 1st version X-ray TES
- 2022.3：ΔE = 106eV@5.9keV (E/△E=56)
- 2023.4：2nd version TES, ΔE = 27eV@5.9keV (E/△E=219)
- 2023.9：3rd version TES, ΔE = 11.0eV@5.9keV (E/△E=536)
- 2024.4：3rd version TES, ΔE = 28eV@17.48keV (E/△E=624)





TES: plan

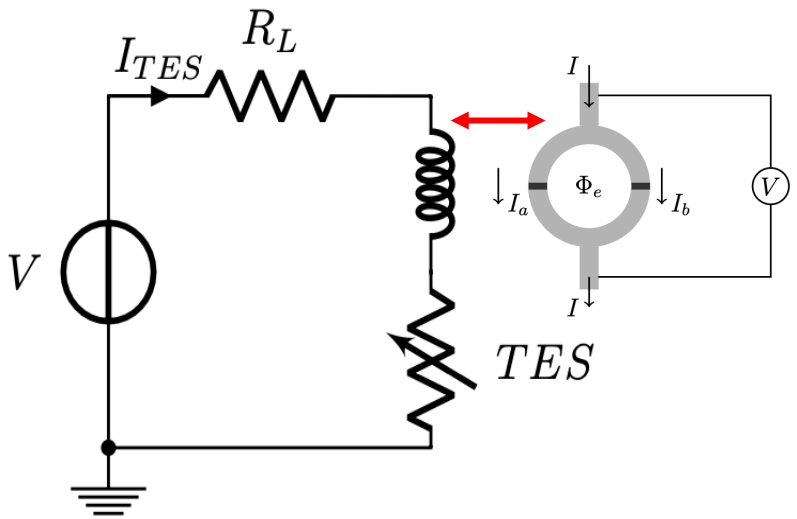
YEAR	TASK	TARGET	DEADLINE
1st	simulation, design, fabrication	complete single pixel design, complete multipayer assembly design, fabricate single pixel devices	2025-12-31
2nd	single pixel TES characterization and optimization	single pixel ΔE reaches 2keV @ 511keV	2026-12-31
3rd	TES array optimization and fabrication	TES array ΔE reaches 0.5keV @ 511keV	2027-12-31
4th	TES array fabrication and calibration	TES array ΔE reaches 0.5keV @ 511keV , finish integration and calibration	2028-12-31
5th	Integration and assembly characterization	pass comprehensive test	2029-12-31

SQUID

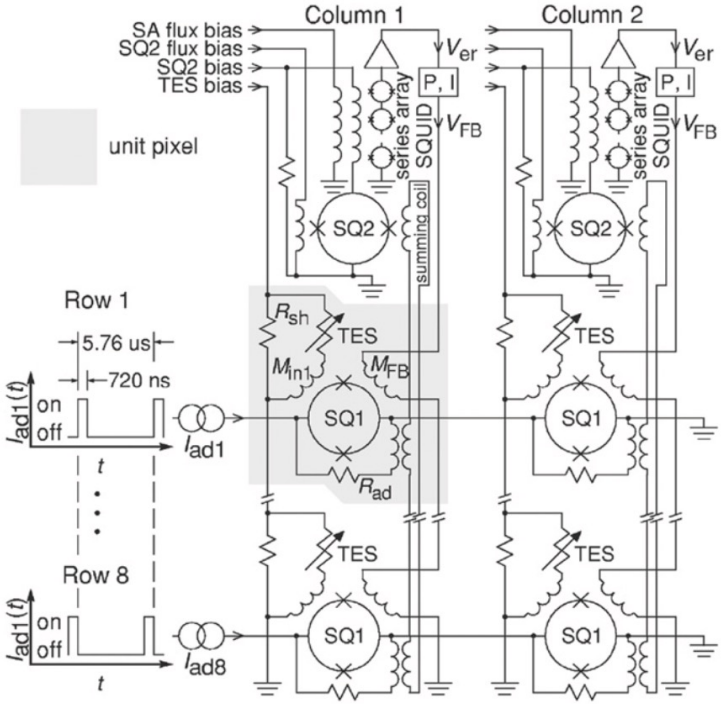
We use SQUID as low-temperature signal amplifiers for TESs for two reasons:

- impedance matching
- multiplex readout for less wiring

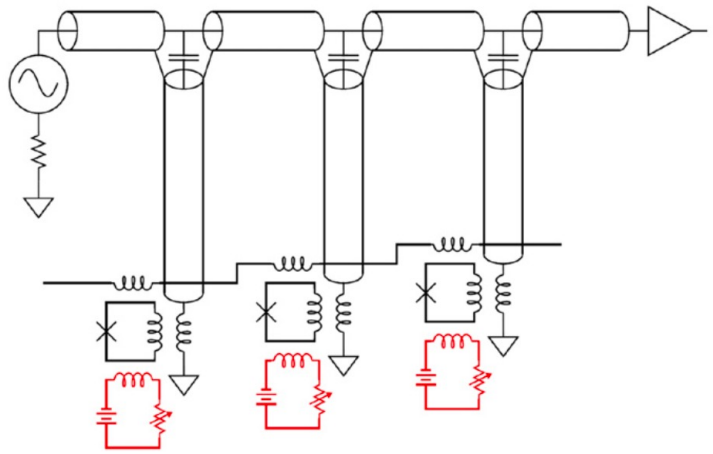
TES – SQUID coupling



Time Domain Multiplexing



μmux Multiplexing



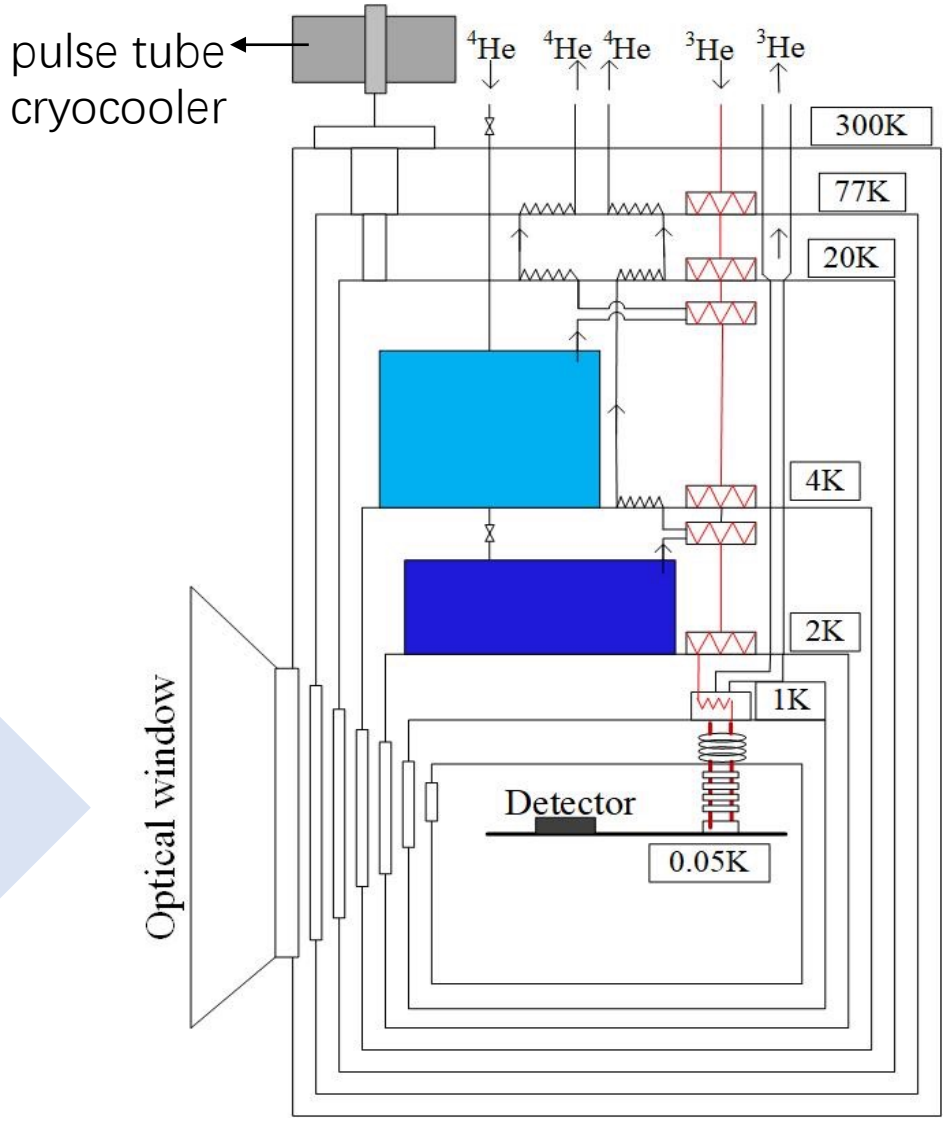
J N Ullom and D A Bennett， Supercond. Sci. Technol. 28 (2015) 084003

SQUID

	TDM	μmux
Design	20 : 1 multiplexing ratio	78 : 1 multiplexing ratio
SQUID status	achieved 2 : 1 multiplexing ratio	resonator Q_i factor ⩾ 100,000
	optimazing 2 : 1 wafers	optimizing Josephson Junction fabrication
Room temperature electronics status	analog feedback board completed	working on 500-channel, 250 kHz BW RFSoC
	working on digital feedback board	

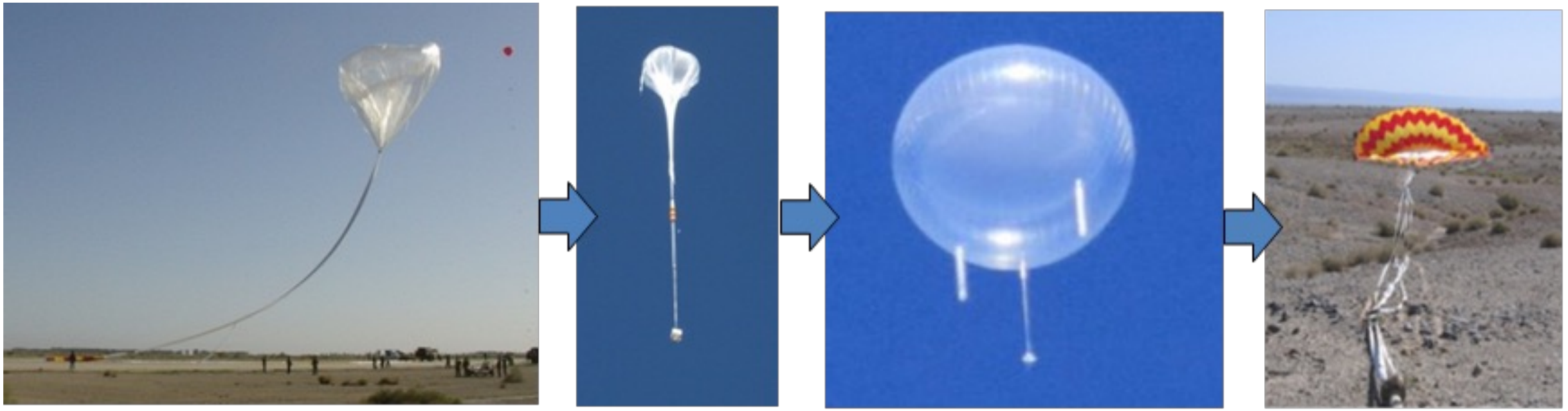
Cryostat

X-ray, Gamma-ray



Picture credit: Technique Institute of Physics and Chemistry, Chinese Academy of Sciences

Balloon



Launch

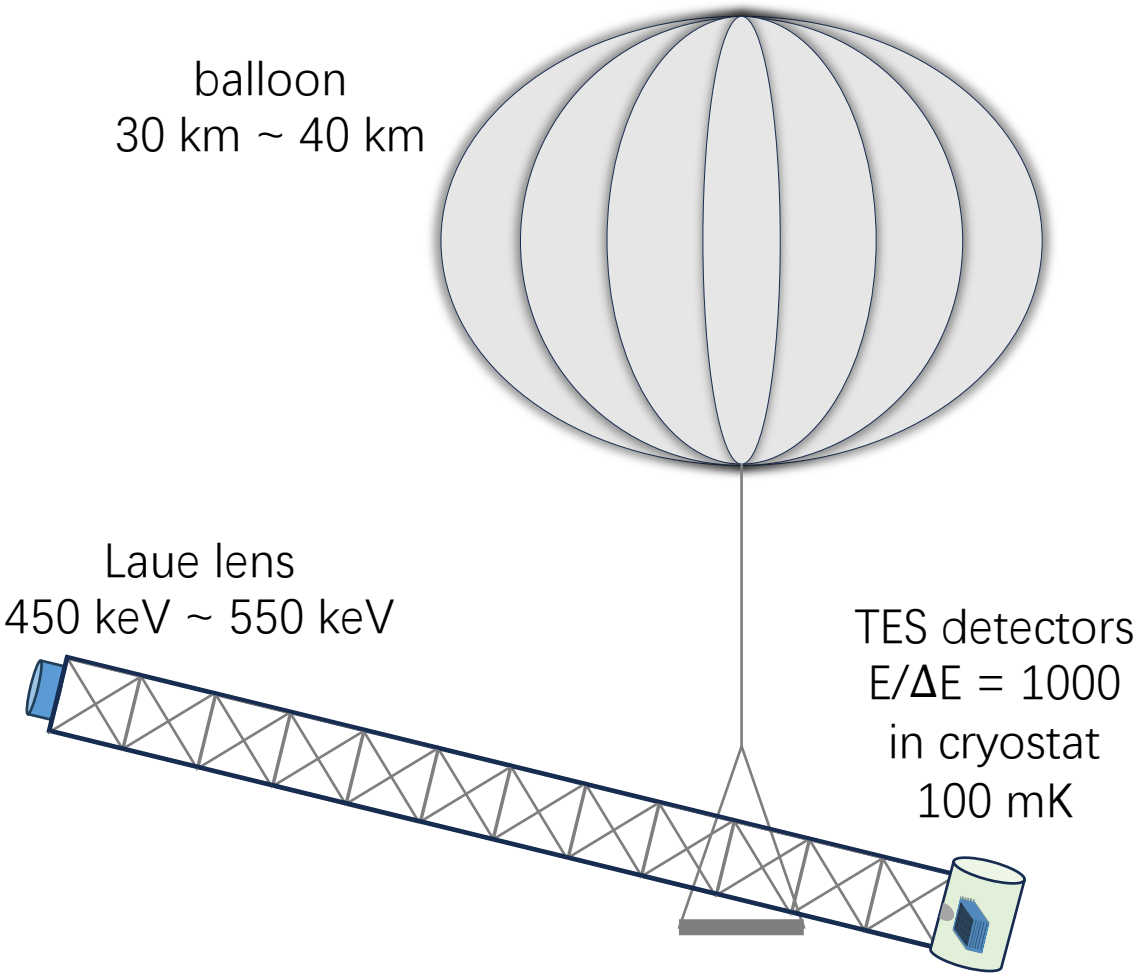
Ascend

Level flight

Descend
and recovery

Picture credit: Aerospace Information Research Institute, Chinese Academy of Sciences

PAIRS balloon project



YEAR	PLAN
1st	- finish single pixel design - start array assembling design
2nd	complete whole single pixel readout chain
3rd	- finish large array production - complete large array detector production - optics test flight
4th	detector system reach all parameter targets
5th	whole system balloon flight