



Joint Experiment Missions- Extreme Universe Space Observatory

Status of the K-EUSO Orbital Detector of Ultra-High Energy Cosmic Rays

**M. Bertaina – Univ. & INFN Torino
for the JEM-EUSO Collaboration
COSPAR 2022**

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COSPAR 2022

44th SCIENTIFIC ASSEMBLY

16-24 July 2022, Athens, Greece

aMUSEd by the Athenian **URANIA**

JEM-EUSO PROGRAM

EUSO-TA (2013-)

EUSO-Balloon (2014)

TUS (2016-17)

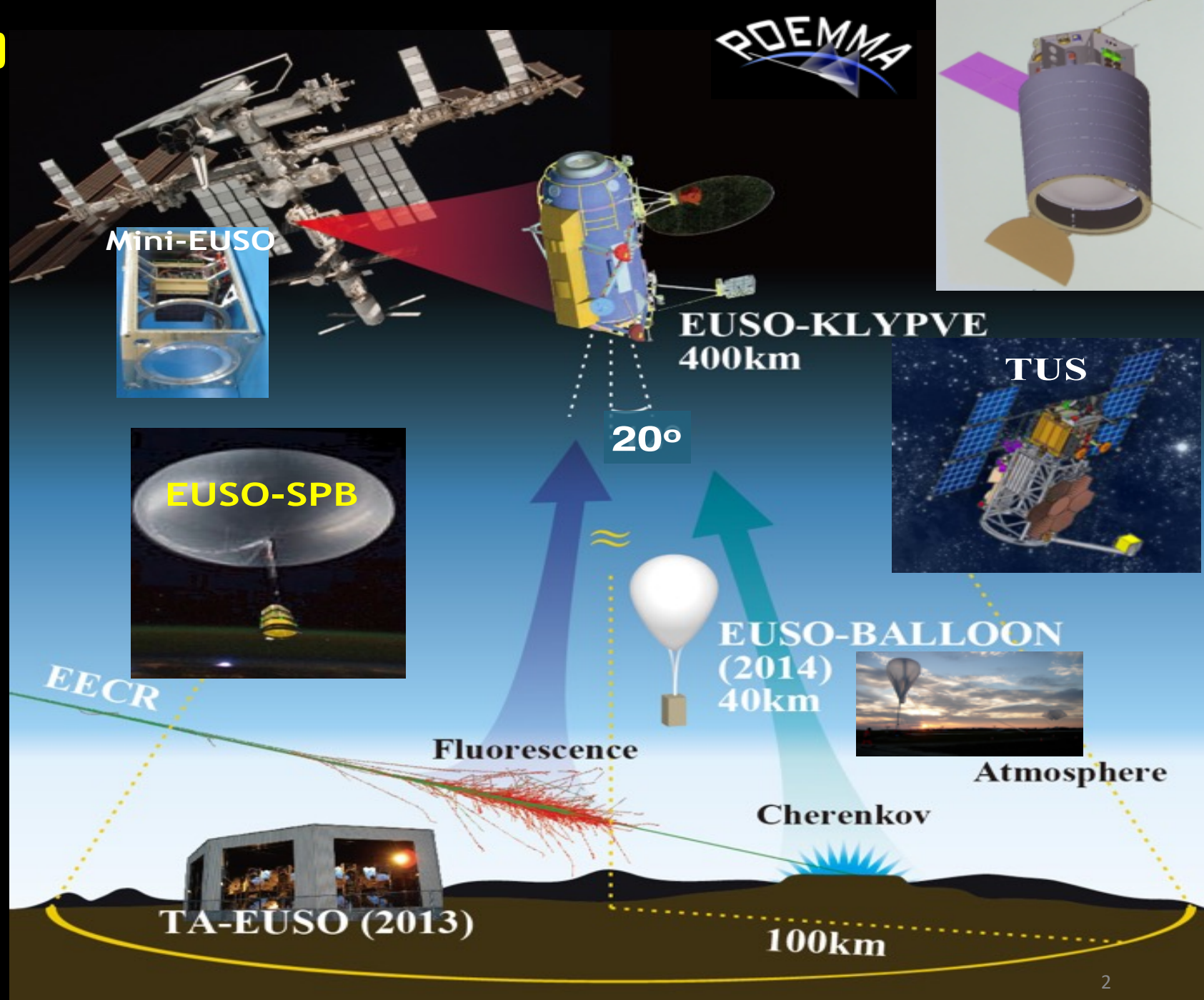
EUSO-SPB1 (2017)

Mini-EUSO (2019 -)

EUSO - SPB2 (2023)

K-EUSO (2025+)

POEMMA (2029+)

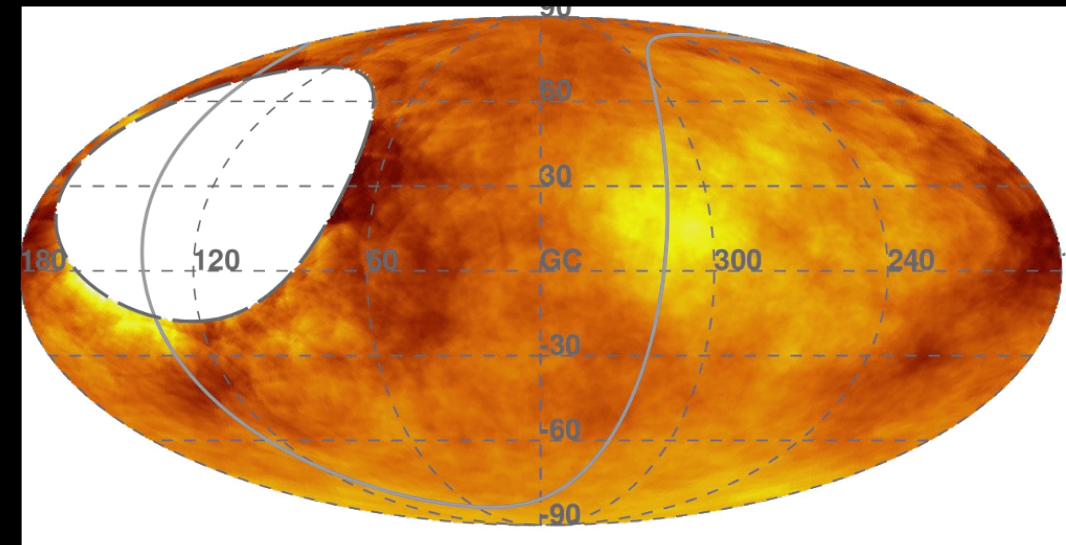
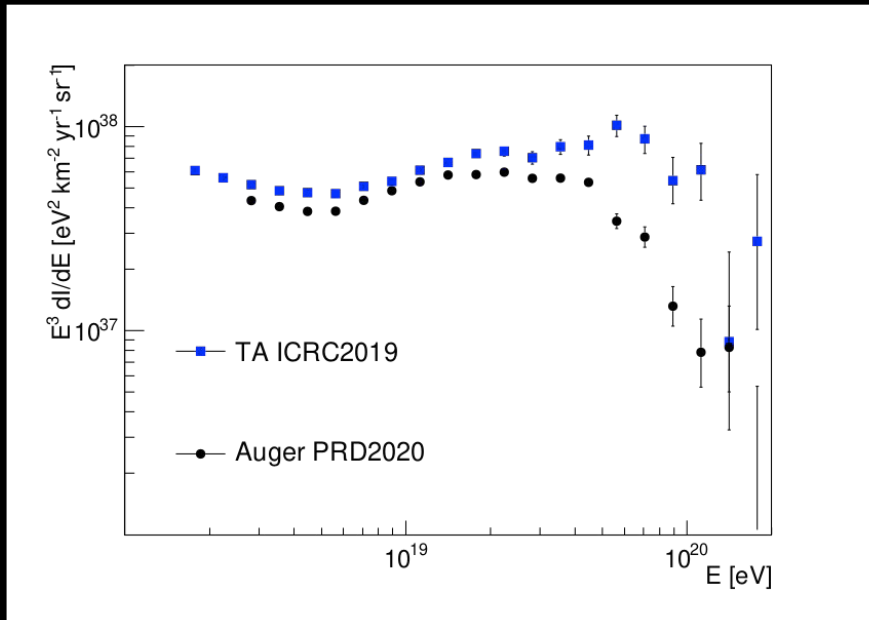
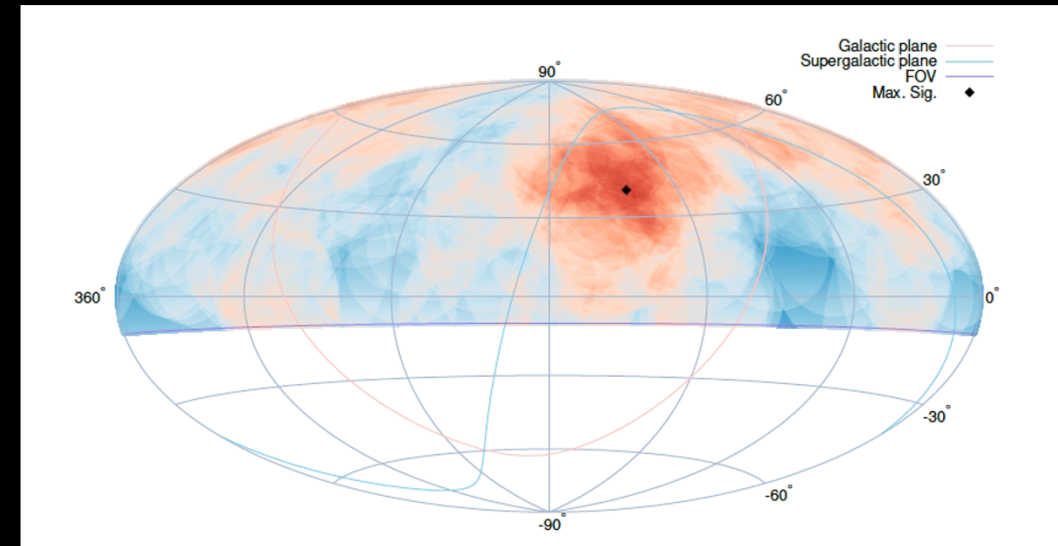


The origin of UHECRs still requires an answer....

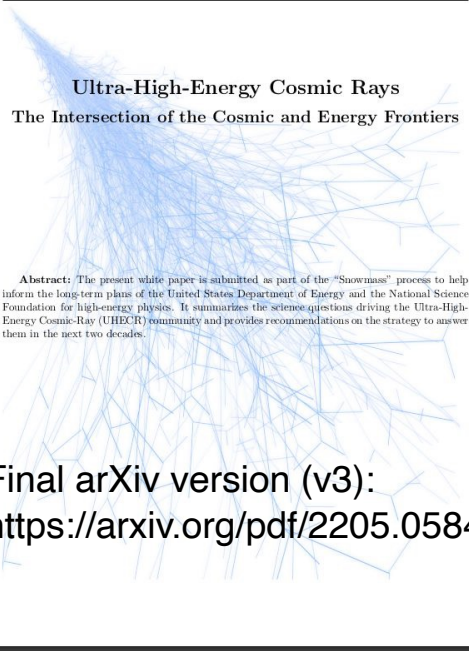
A significant increase in exposure is needed

Space offers the following opportunities:

- a) Complementarity to ground-based observation
- b) Potential 10x annual exposure vs ground-based observatory
- c) Full sky coverage



Submitted to the US Community Study
on the Future of Particle Physics (Snowmass 2021)



Ultra-High-Energy Cosmic Rays

The Intersection of the Cosmic and Energy Frontiers

Abstract: The present white paper is submitted as part of the "Snowmass" process to help inform the long-term plans of the United States Department of Energy and the National Science Foundation for high-energy physics. It summarizes the science questions driving the Ultra-High-Energy Cosmic-Ray (UHECR) community and provides recommendations on the strategy to answer them in the next two decades.

Final arXiv version (v3):
<https://arxiv.org/pdf/2205.05845>

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Snowmass 2021



The Key Recommendations

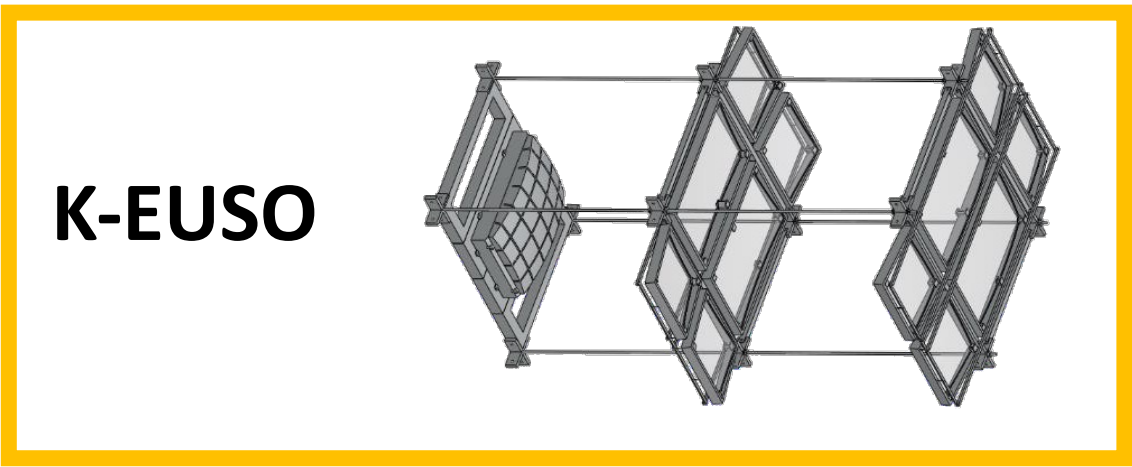
- The next-generation experiments (GCOS, GRAND, and POEMMA) will provide complementary information needed to meet the goals of the UHECR community in the next two decades. They should proceed through their respective next stages of planning and prototyping.
- At least one next-generation experiment needs to be able to make high-precision measurements to explore new particle physics and measure particle rigidity on an event-by-event basis. Of the planned next-generation experiments, GCOS is the best positioned to meet this recommendation.
- As a complementary effort, experiments with sufficient exposure ($> 5 \times 10^5 \text{ km}^2 \text{ sr yr}$) are needed to search for Lorentz-invariance violation (LIV), SHDM, and other BSM physics at the Cosmic and Energy Frontiers, and to identify UHECR sources at the highest energies.
- Full-sky coverage with low cross-hemisphere systematic uncertainties is critical for astrophysical studies. To this end, next generation experiments should be space-based or multi-site. Common sites between experiments are encouraged.**

Experiment	Feature	Cosmic Ray Science*	Timeline
Pierre Auger Observatory	Hybrid array: fluorescence, surface e/μ + radio, 3000 km ²	Hadronic interactions, search for BSM, UHECR source populations, $\sigma_{\text{p-Air}}$	AugerPrime upgrade
Telescope Array (TA)	Hybrid array: fluorescence, surface scintillators, up to 3000 km ²	UHECR source populations, proton-air cross section ($\sigma_{\text{p-Air}}$)	TAx4 upgrade
IceCube / IceCube-Gen2	Hybrid array: surface + deep, up to 6 km ²	Hadronic interactions, prompt decays, Galactic to extragalactic transition	Upgrade + surface enhancement IceCube-Gen2 deployment IceCube-Gen2 operation
GRAND	Radio array for inclined events, up to 200,000 km ²	UHECR sources via huge exposure, search for ZeV particles, $\sigma_{\text{p-Air}}$	GRANDProto 300 GRAND 10k GRAND 200k multiple sites, step by step
POEMMA	Space fluorescence and Cherenkov detector	UHECR sources via huge exposure, search for ZeV particles, $\sigma_{\text{p-Air}}$	JEM-EUSO program POEMMA
GCOS	Hybrid array with X_{max} + e/μ over 40,000 km ²	UHECR sources via event-by-event rigidity, forward particle physics, search for BSM, $\sigma_{\text{p-Air}}$	GCOS R&D + first site GCOS further sites

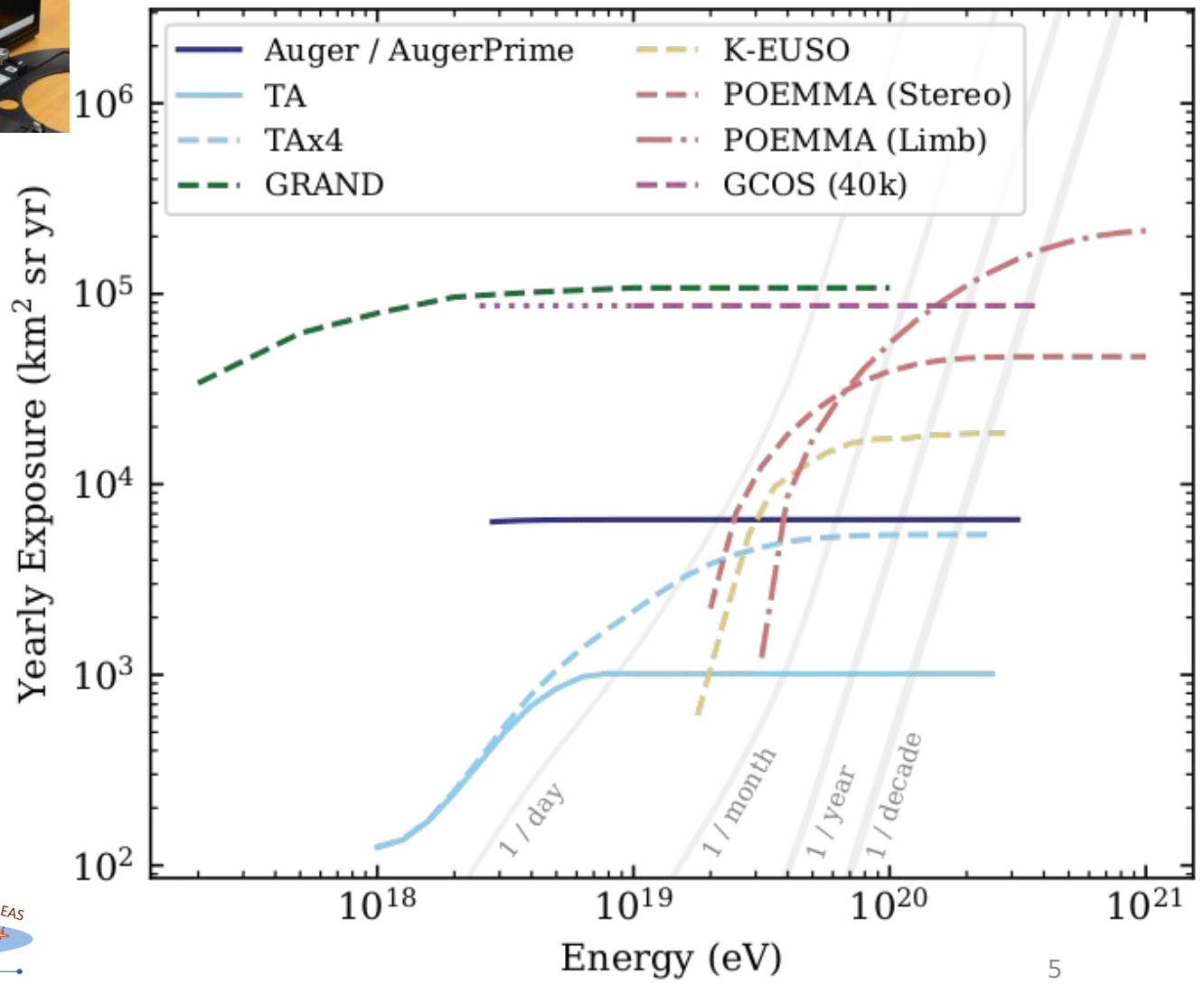
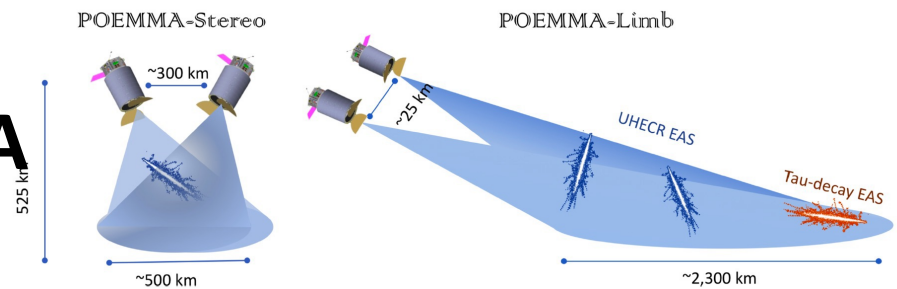
*All experiments contribute to multi-messenger astrophysics also by searches for UHE neutrinos and photons; several experiments (IceCube, GRAND, POEMMA) have astrophysical neutrinos as primary science case.

K-EUSO an intermediary step between pilot missions from space & balloons and POEMMA

EUSO-Balloons
TUS
Mini-EUSO



POEMMA



Article

Status of the K-EUSO Orbital Detector of Ultra-High Energy Cosmic Rays

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Abstract: K-EUSO (KLYPVE-EUSO) is a planned orbital mission aimed at studying ultra-high energy cosmic rays (UHECRs) by detecting fluorescence and Cherenkov light emitted by extensive air showers in the nocturnal atmosphere of Earth in the ultraviolet (UV) range. The observatory is being developed within the JEM-EUSO collaboration and is planned to be deployed on the International Space Station after 2025 and operated for at least two years. The telescope, consisting of $\sim 10^5$ independent pixels, will allow a spatial resolution of ~ 0.6 km on the ground, and, from a 400 km altitude, it will achieve a large and full sky exposure to sample the highest energy range of the UHECR spectrum. We provide a comprehensive review of the current status of the development of the K-EUSO experiment, paying special attention to its hardware parts and expected performance. We demonstrate how results of the K-EUSO mission can complement the achievements of the existing ground-based experiments and push forward the intriguing studies of ultra-high energy cosmic rays, as well as bring new knowledge about other phenomena manifesting themselves in the atmosphere in the UV range.

Keywords: ultra-high energy cosmic rays; fluorescence telescope; orbital experiment; K-EUSO; JEM-EUSO

1. Introduction

It was back in 1961 that cosmic rays with energies $\gtrsim 50$ EeV—henceforth called ultra-high energy cosmic rays (UHECRs)—were first registered [1]. However, the nature and origin of these most energetic particles in the Universe still remains a puzzle. One of the main difficulties in UHECR studies is their extremely low flux, of the order of a few particles

This communication reports the latest hardware developments and performance studies of K-EUSO as published in:

P. Klimov et al., Universe 2022, 8, 88
<https://doi.org/10.3390/universe8020088>



Citation: Klimov, P.; Battisti, M.; Belov, A.; Bertaina, M.; Bianciotto, M.; Blin-Bondil, S.; Casolino, M.; Ebisuzaki, T.; Fenu, F.; Fuglesang, C.; et al. Status of the K-EUSO Orbital Detector of Ultra-High Energy Cosmic Rays. *Universe* **2022**, *8*, 88. <https://doi.org/10.3390/universe8020088>

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Since February 24th 2022 the project is on hold

Scientific motivations

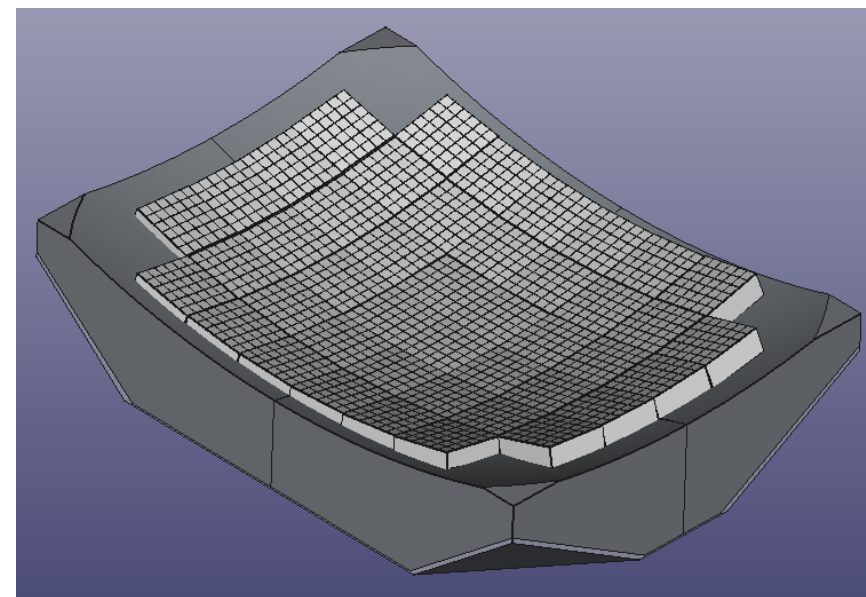
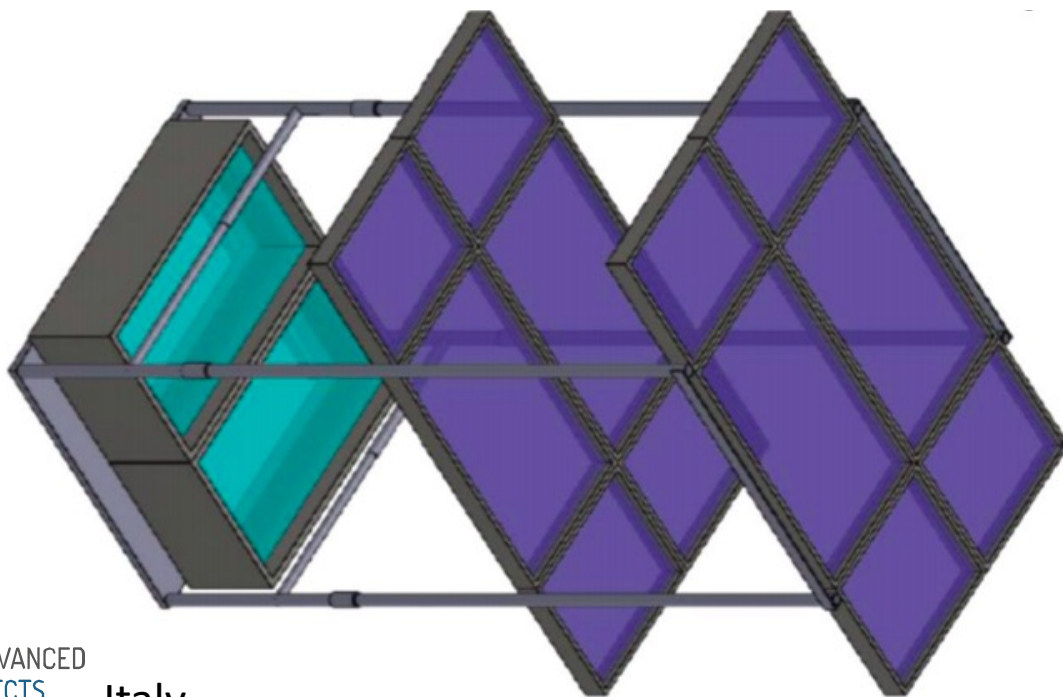
- Demonstrate that the JEM-EUSO program has reached the required TRL for a space mission.
- Measure first Ultra-High Energy Cosmic Rays ($E > 5 \times 10^{19}$ eV) from space.
- Provide an exposure curve at UHECR energies from space.
- Study the origin of the discrepancy between Auger and TA energy spectra above GZK.
- Perform anisotropy studies with a full-sky coverage.

Telescope configuration

Technical parameters of K-EUSO.

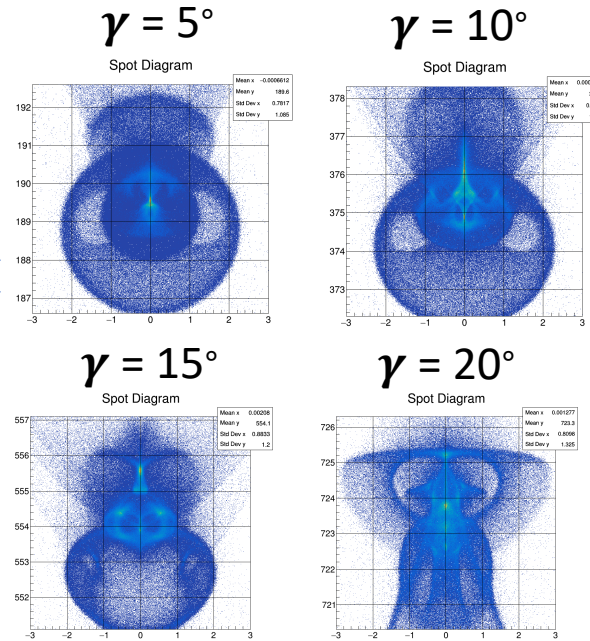
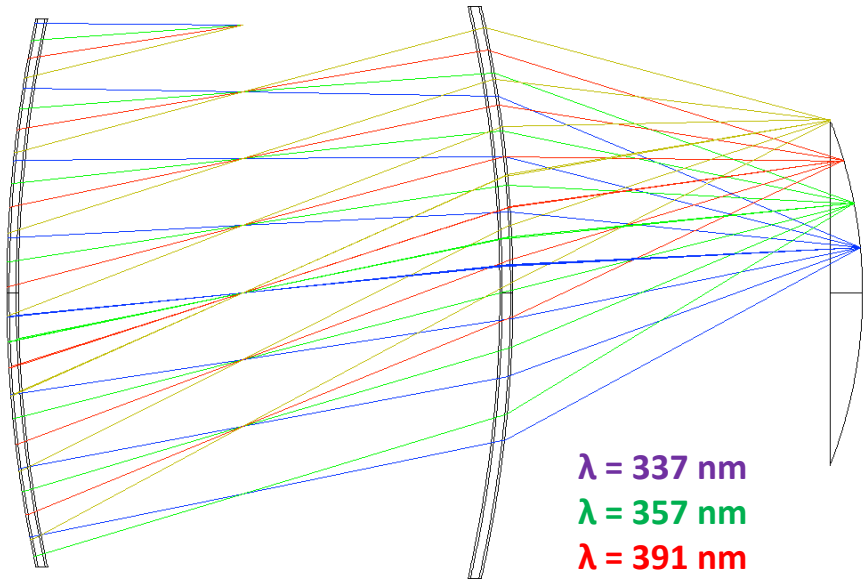
Altitude	≈ 400 km
Field of view	0.3 sr (48,000 km ²)
Pixel size	3 mm $\times$ 3 mm
Spatial/temporal resolution	0.6 km (pixel)/2.5 μ s (GTU)
Entrance pupil area	~ 3 m ²
Number of PDMs/channels	44/101,376
Dimensions (unfolded)	$\approx 125 \times 250 \times 400$ cm ³

Current configuration to fit launch & installation constraints on Russian module of ISS



MSU

Optics Performance & Manufacturing

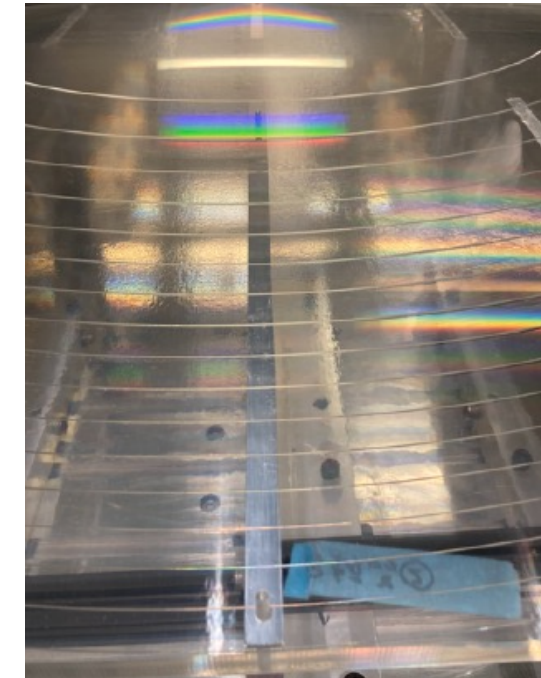
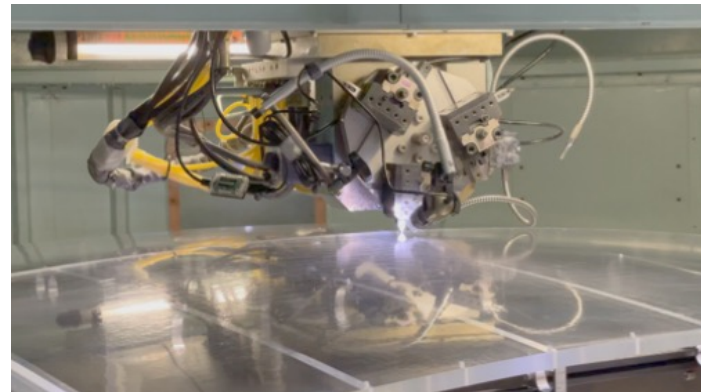


Zemax ray-tracing model

Table 2. K-EUSO optics performance: image size d_{RMS} , effective area S_{eff} and ensquared energy EE as a function of field angles γ, ϕ .

γ	5°		10°		15°		20°	
ϕ	0°	90°	0°	90°	0°	90°	0°	90°
$d_{\text{RMS}}, \text{mm}$	2.61	2.68	2.84	2.95	3.11	3.10	3.86	3.32
$S_{\text{eff}}, \text{m}^2$	1.53	1.49	1.30	1.34	0.98	1.22	0.56	0.94
EE	0.79	0.78	0.76	0.74	0.71	0.71	0.47	0.65

γ = zenith angle, ϕ = azimuth angle

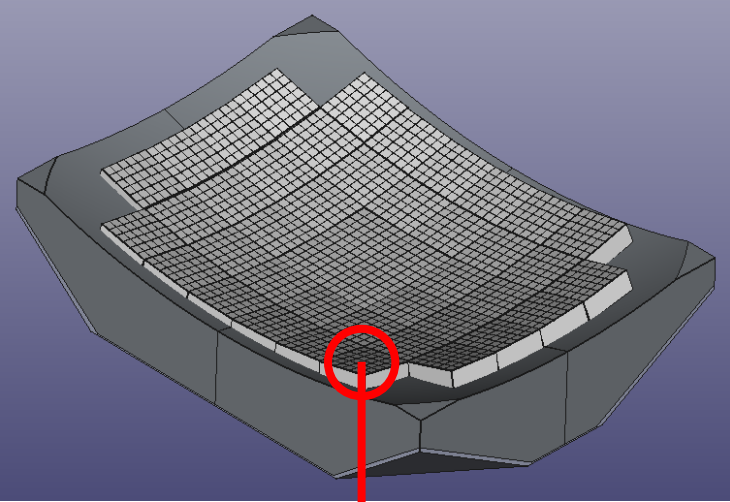


Fresnel lenses based on PMMA-000
(Mitsubishi Chemical Corporation product)

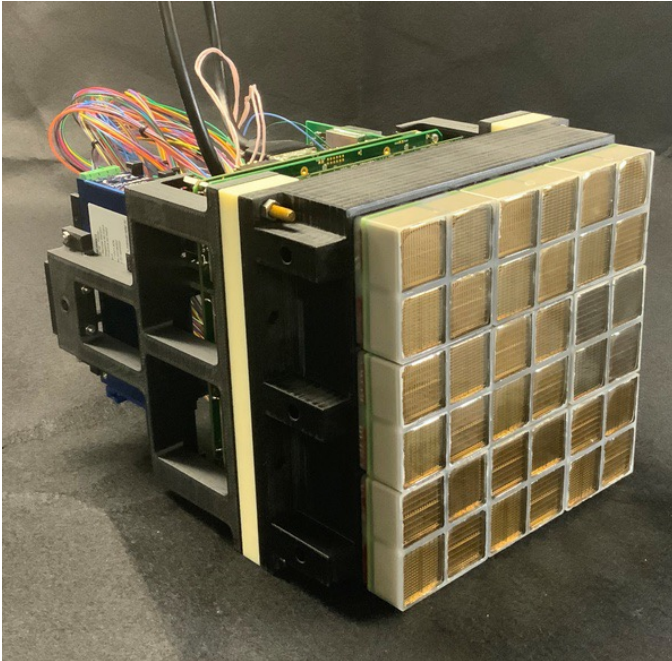
Lens manufacturing @ RIKEN (Japan)

Focal Surface Electronics

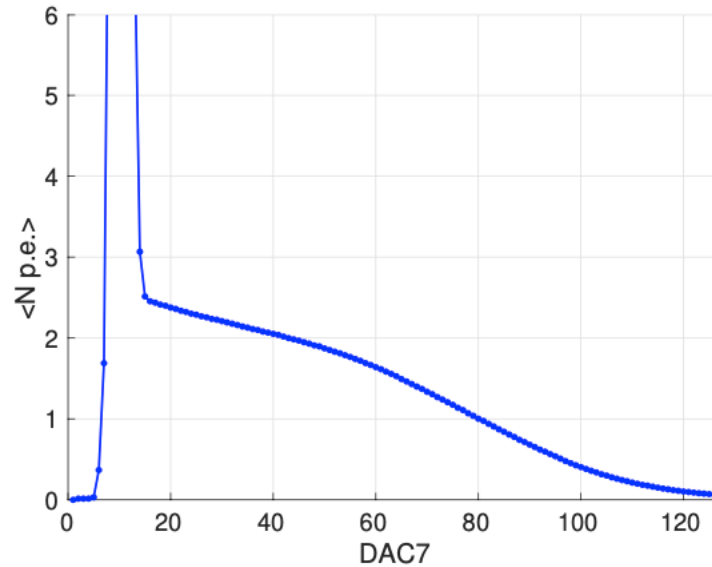
Layout: 44 PDMs



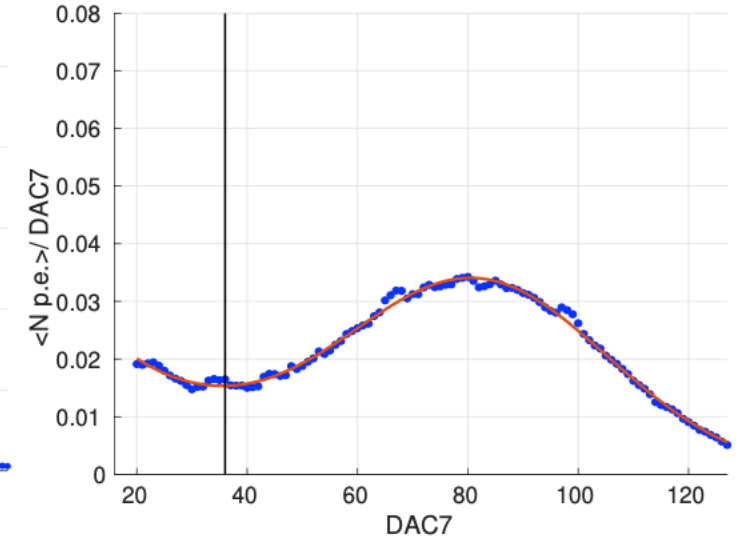
PDM



S-curve



Single Photo-electron spectrum

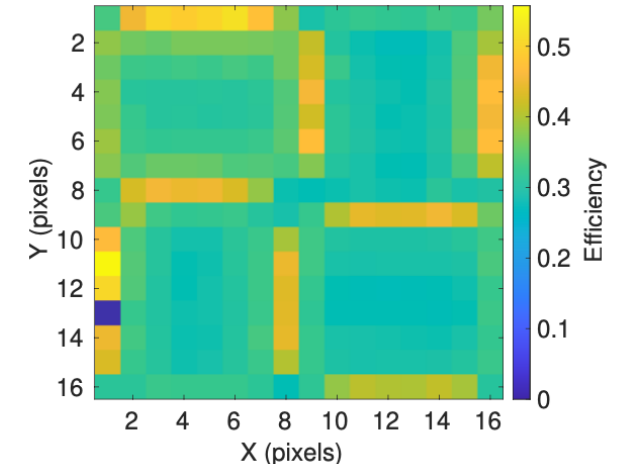


Measurements done @ APC (France)

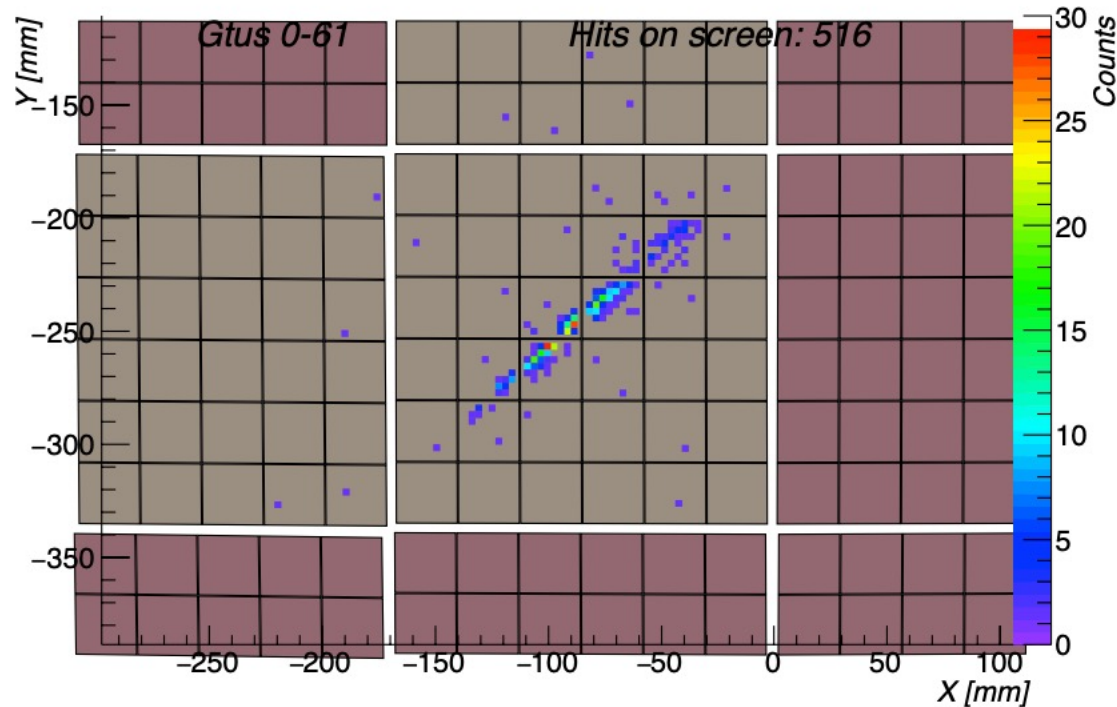
Photo Detector Modules (PDMs) developed for EUSO-SPB2 (heritage of EUSO-Balloons and Mini-EUSO)

- 36 MAPMTs, 64 ch each, Hamamatsu R11265-103-M64
- SPACIROC3 ASICS (Omega & APC, France)
- Zynq Board containing Xilinx Zynq 7000 FPGA with an embedded dual core ARM9 CPU processing system (MSU)
- Cockroft-Walton power supply (NCBJ, Poland)
- Gate Time Unit (GTU) = 1 - 2.5 μ s

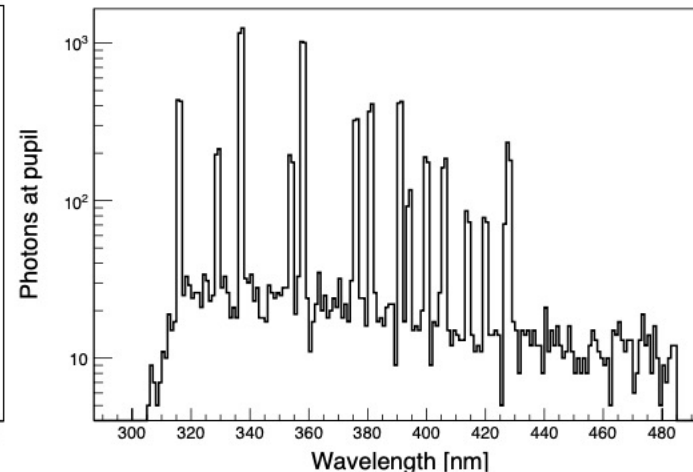
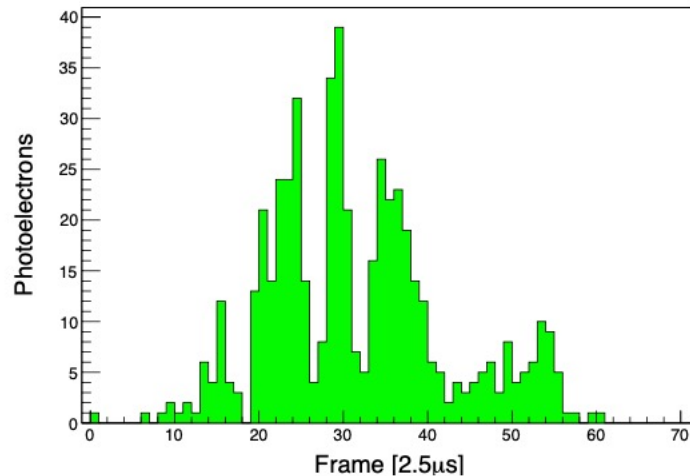
Efficiency map of 1 Elementary Cell (4 MAPMTs)



Performance Studies using ESAF

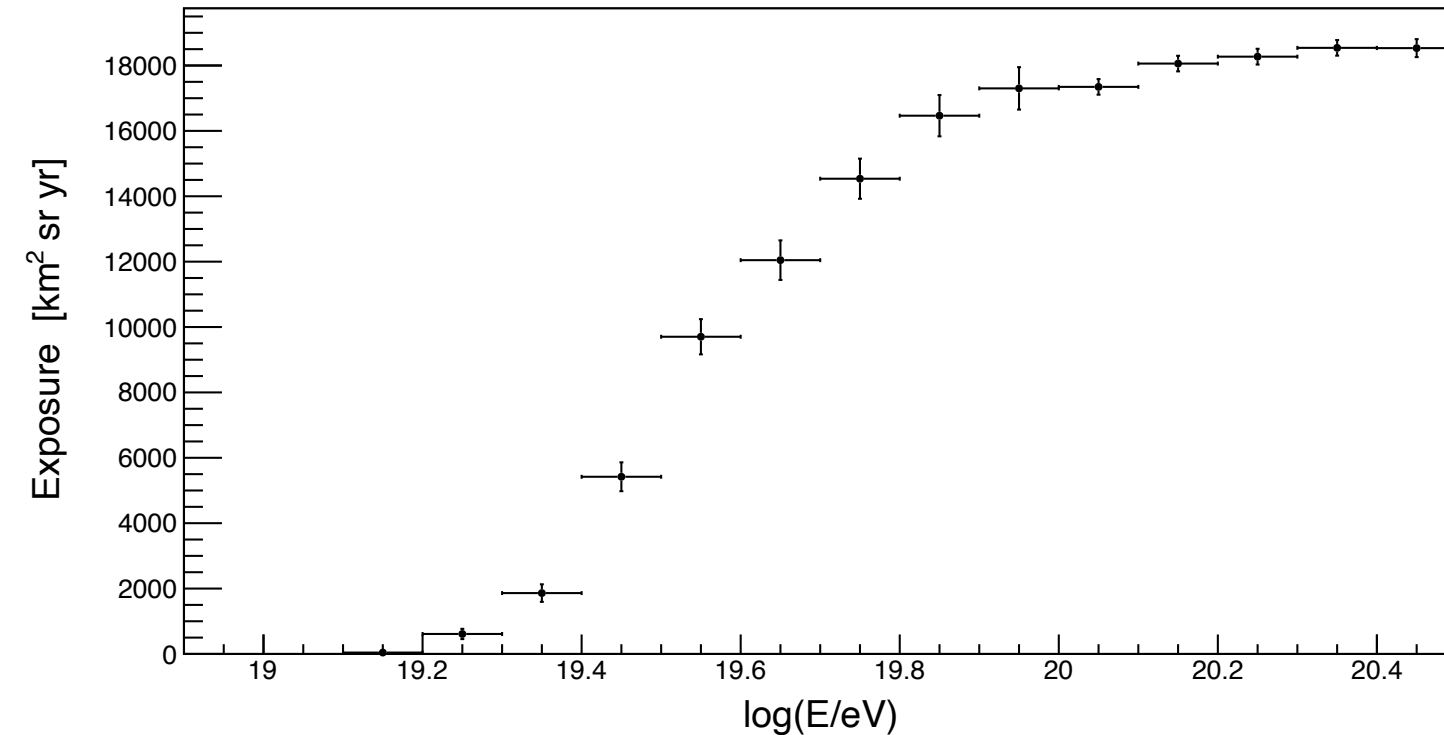


- K-EUSO configuration implemented in ESAF (Euso Simulation and Analysis Framework) like for other missions of the JEM-EUSO program
- Trigger logic and reconstruction algorithms heritage from JEM-EUSO mission



Proton $E = 10^{20}$ eV, $\Theta = 60^\circ$

Annual Exposure estimation



Based on similar assumptions used for JEM-EUSO:
J.H. Adams et al, Astrop. Phys. v.44, pp.76-90 (2013)

$$\mathcal{E}(E) = \frac{N_{\text{trigg}}}{N_{\text{simu}}}(E) \times A_{\text{simu}} \times \Omega \times \eta \times \eta_{\text{clouds}} \times \eta_{\text{city}} \times t.$$

$\mathcal{E}$ = exposure , E = energy

N_{trigg} = triggered events, N_{simu} = simulated events

A_{simu} = Area of injected events, Ω = solid angle

$\eta = 0.2$ (astronomical D.C.), $\eta_{\text{clouds}} = 0.72$ (cloud eff.)

$\eta_{\text{city}} = 0.9$ (artificial lights eff.), $t = 1$ year

Annual exposure:

~18000 km² sr yr @ $E > 10^{20}$ eV

Expected triggered events (assuming Auger spectrum):

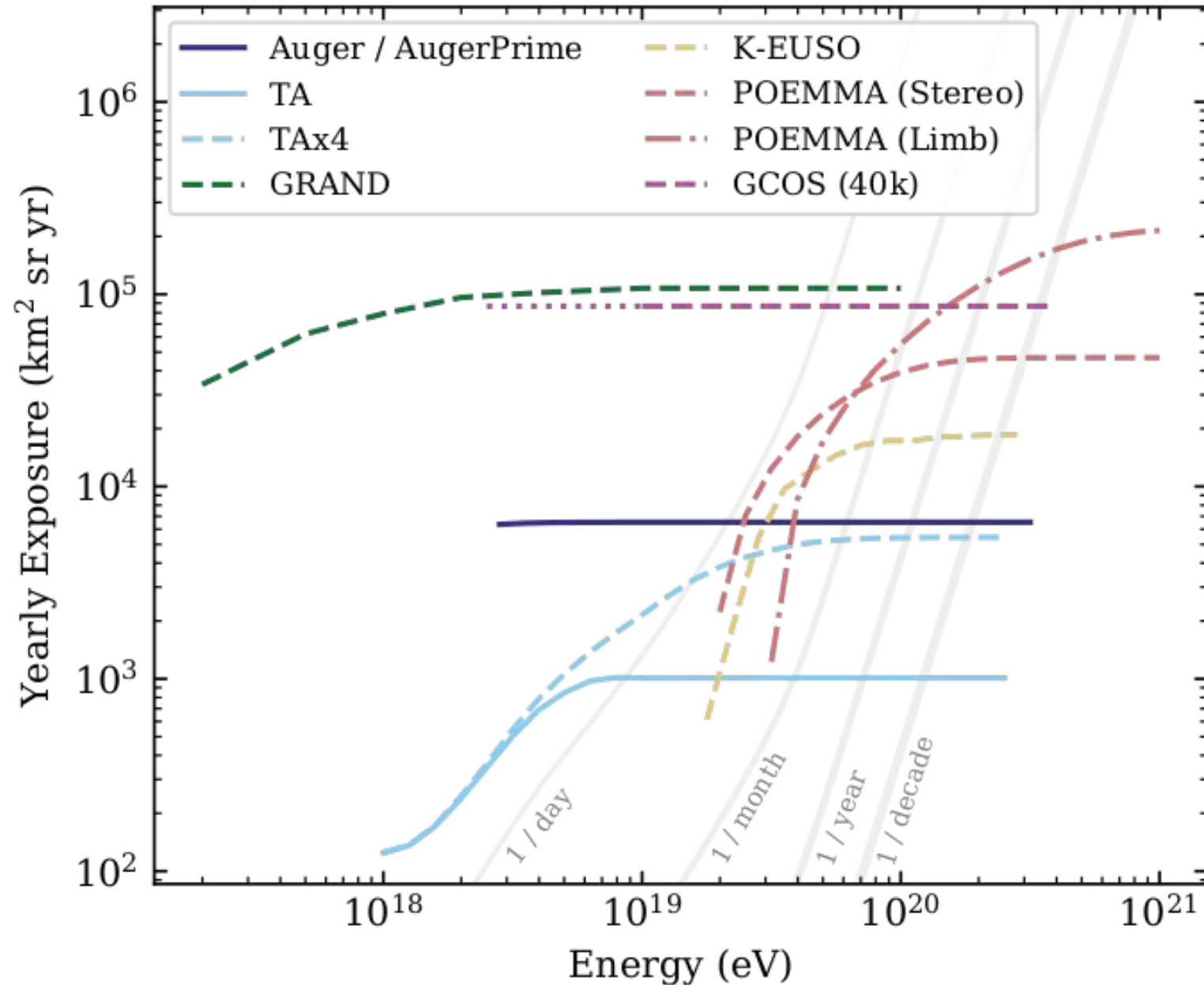
65 ev./yr @ $E > 5 \cdot 10^{19}$ eV, 4 ev./yr @ $E > 10^{20}$ eV

To be compared with:

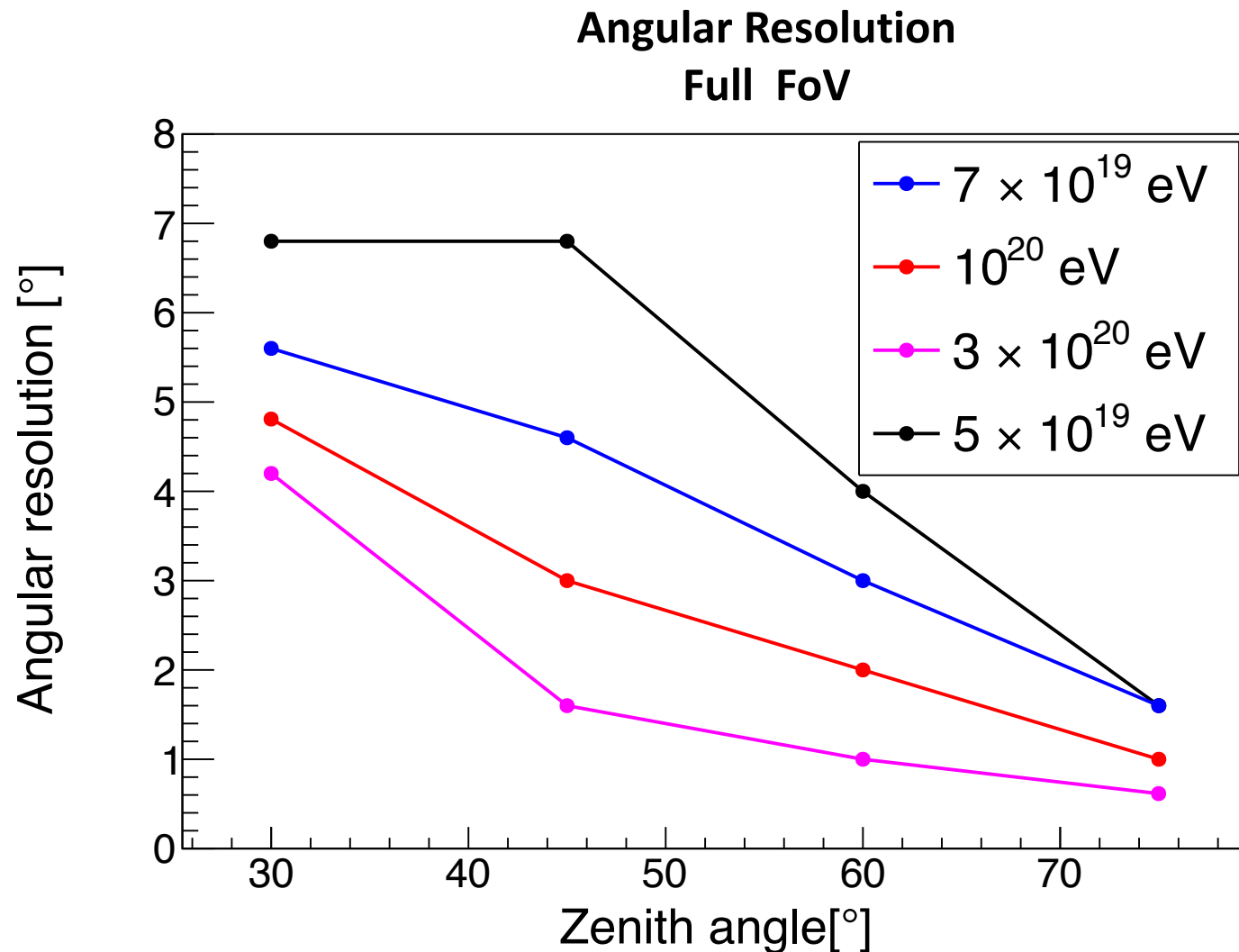
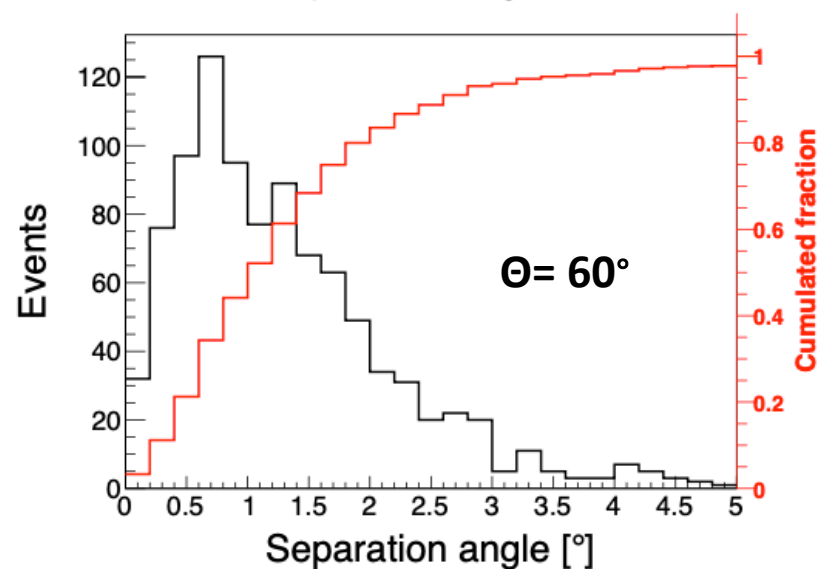
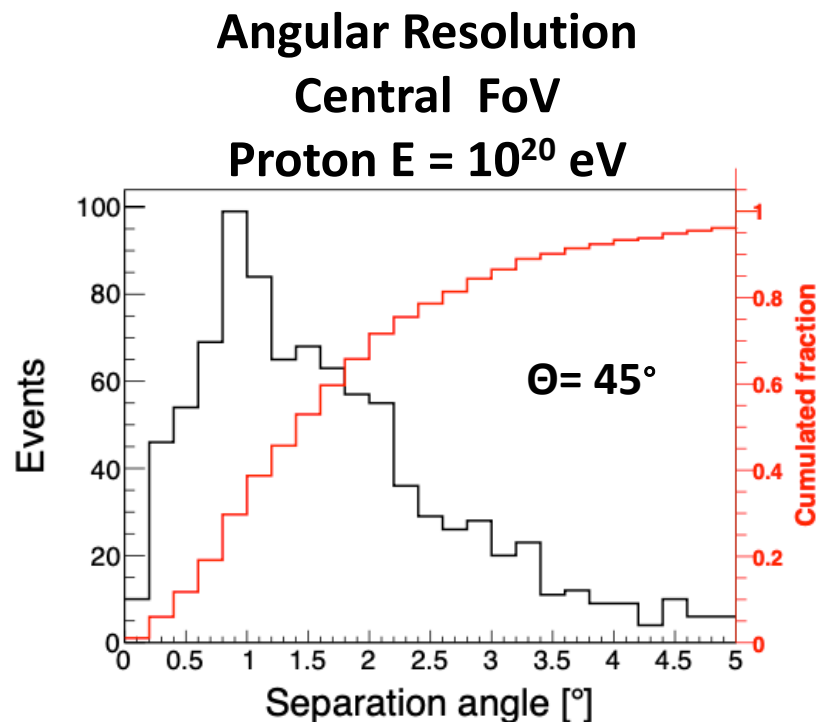
~7000 km² sr yr of Auger

~5000 km² sr yr of TAx4 (expected)

Comparison of exposures

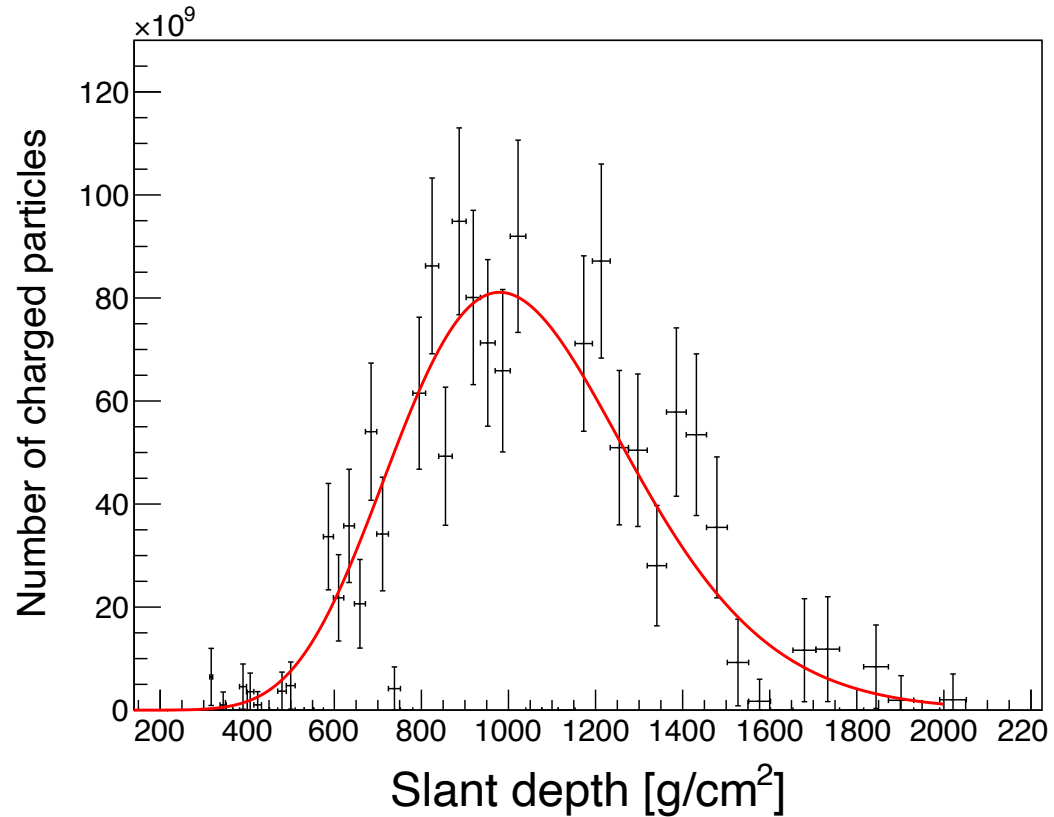


Angular resolution

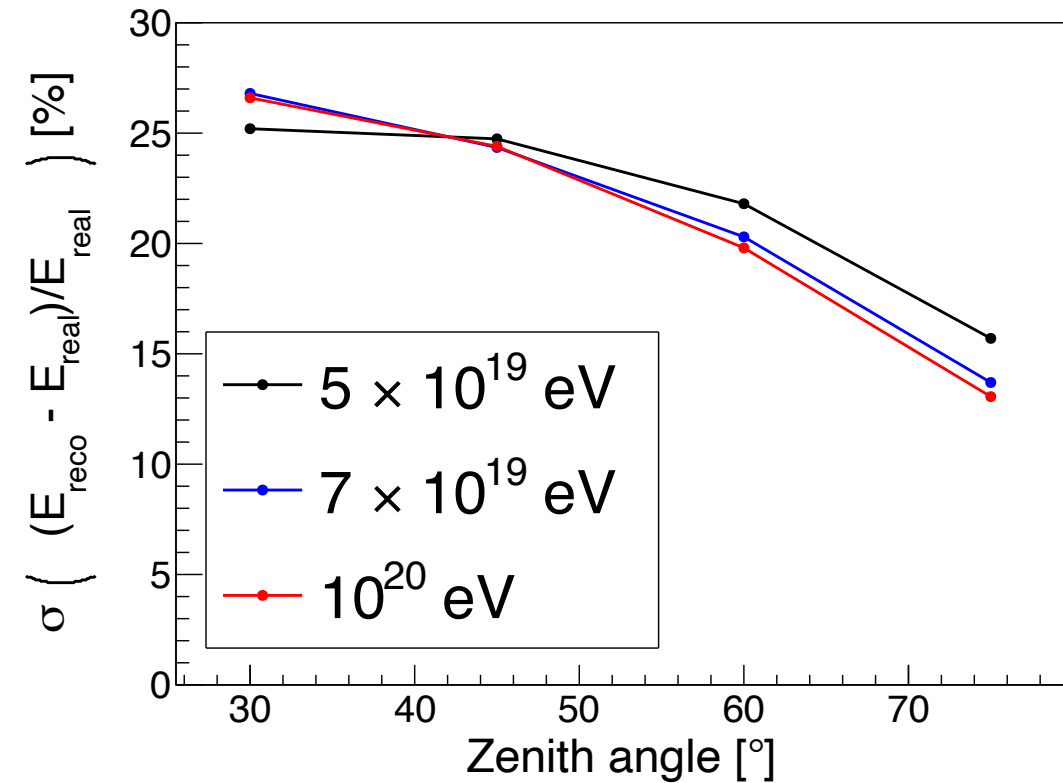


Angular resolution is good for medium & large scale anisotropy studies

Energy resolution



Proton $E = 10^{20}$ eV, $\Theta = 60^\circ$



Full FoV

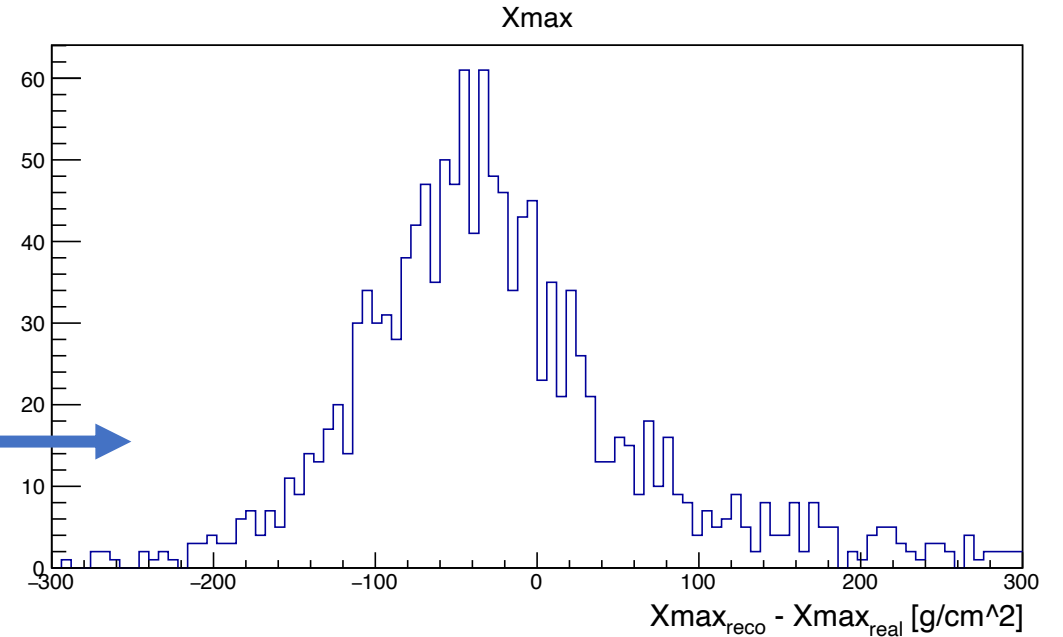
Energy resolution is better (15%) or comparable (25%) to TAx4

$X_{\max}$ resolution

$X_{\max}$ Resolution
Center FoV
Proton $E=2 \cdot 10^{20}$ eV

Table 3. $X_{\max}$ resolution of the K-EUSO detector in the center of the field of view.

Energy [EeV]	Zenith Angle [°]	Resolution [g/cm ²]
70	30	83
70	45	94
100	30	69
100	45	75
200	30	50
200	45	66



$$\sigma(X_{\max}) \sim 66 \text{ g/cm}^2$$

Modest $X_{\max}$ resolution on individual events

Improved sensitivity on average values:

x10 @ $5 \cdot 10^{19}$ eV and x3 @ 10^{20} eV with 3 years data taking

CONCLUSIONS

- A huge effort has been done in the past years to re-shape the K-EUSO mission in order to fit launch & installation constraints on the Russian module of the ISS.
- K-EUSO possesses the sufficient technical parameters to study the origin and nature of UHECRs.
- With an annual exposure at plateau of $\sim 18000 \text{ km}^2 \text{ sr y}$ and an expected rate of $\sim 65 \text{ ev./year @ } E > 5 \times 10^{19} \text{ V}$ with energy resolution $\sigma(E) \sim 15 - 25\%$, K-EUSO will allow us to shed light on the discrepancy between Auger and TA at the highest energies and will provide an opportunity to test the dependence of the energy spectrum on the declination reported by TA.
- With its full-sky exposure, it will provide the first complete map of the sky in UHECRs obtained in a consistent way by one single instrument.
- The angular resolution of the telescope will be good enough to explore anisotropies at medium and large scales. Combined with high statistics of events, it will provide a chance to verify the existence of the hot spot observed by TA and the warm spot found by Auger.
- Despite the large uncertainty on the depth of the shower maximum on individual events, the uncertainty on the average composition will be reduced by the statistics collected in each energy bin and will allow to extend the X_{max} measurements employing fluorescence technique at energies above those reached by Auger so far.
- **Since February 24th 2022 the K-EUSO mission is on hold and its future is unpredictable right now.**

THANK YOU

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