Discussion session 07 - CRI: Where to go in UHECR observations?

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ICRC 2021
THE ASTROPARTICLE PHYSICS CONFERENCE
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Jörg R. Hörandel, Angela Olinto

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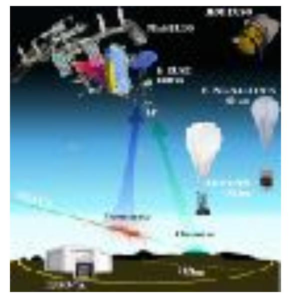
- Prospects for Cross-correlations of UHECR Events with Astrophysical Sources with Upcoming Space-based Experiments



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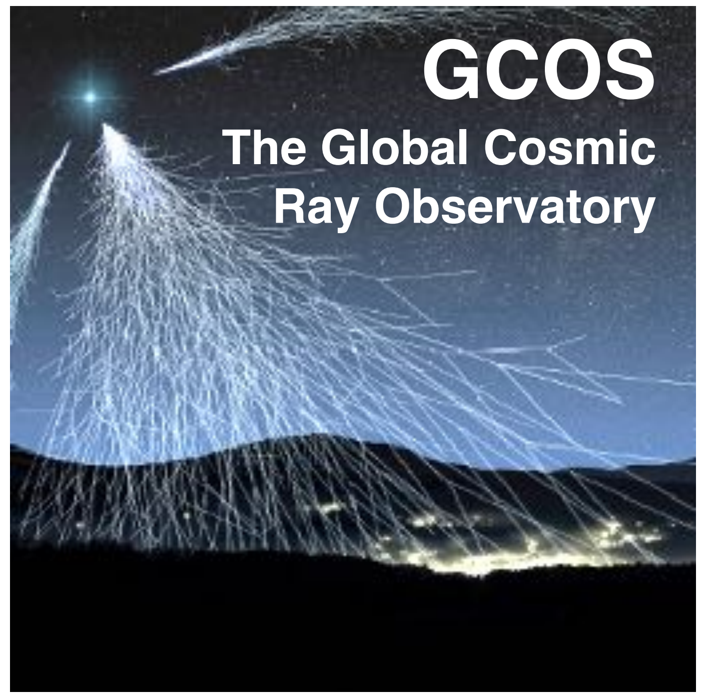
time

SWGO
The Southern Wide-field Gamma-ray Observatory

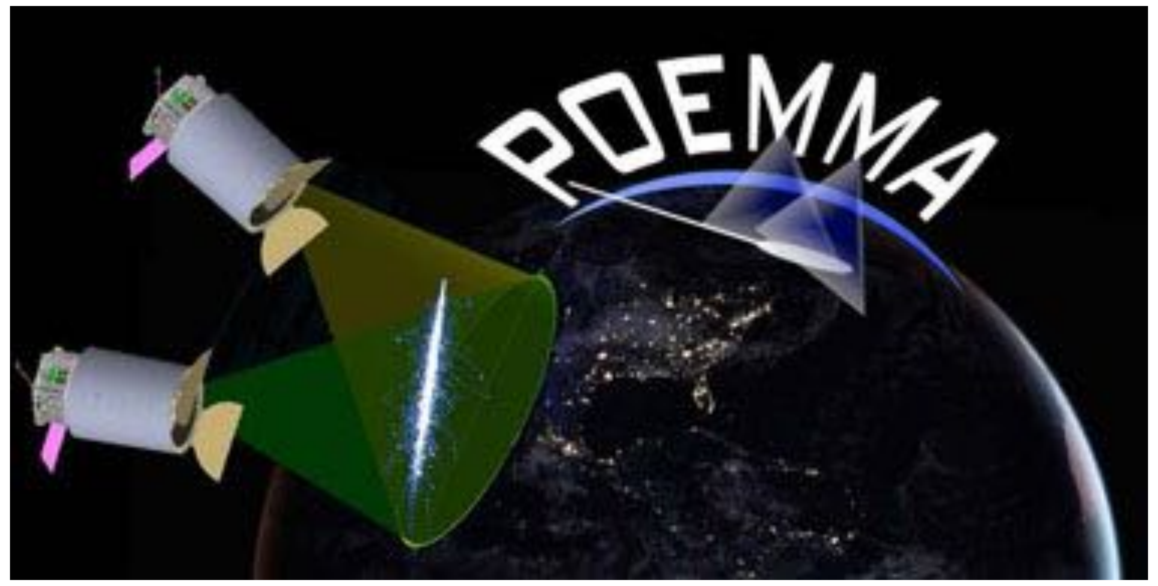
SKA
SQUARE KILOMETRE ARRAY

ICECUBE
SOUTH POLE NEUTRINO OBSERVATORY

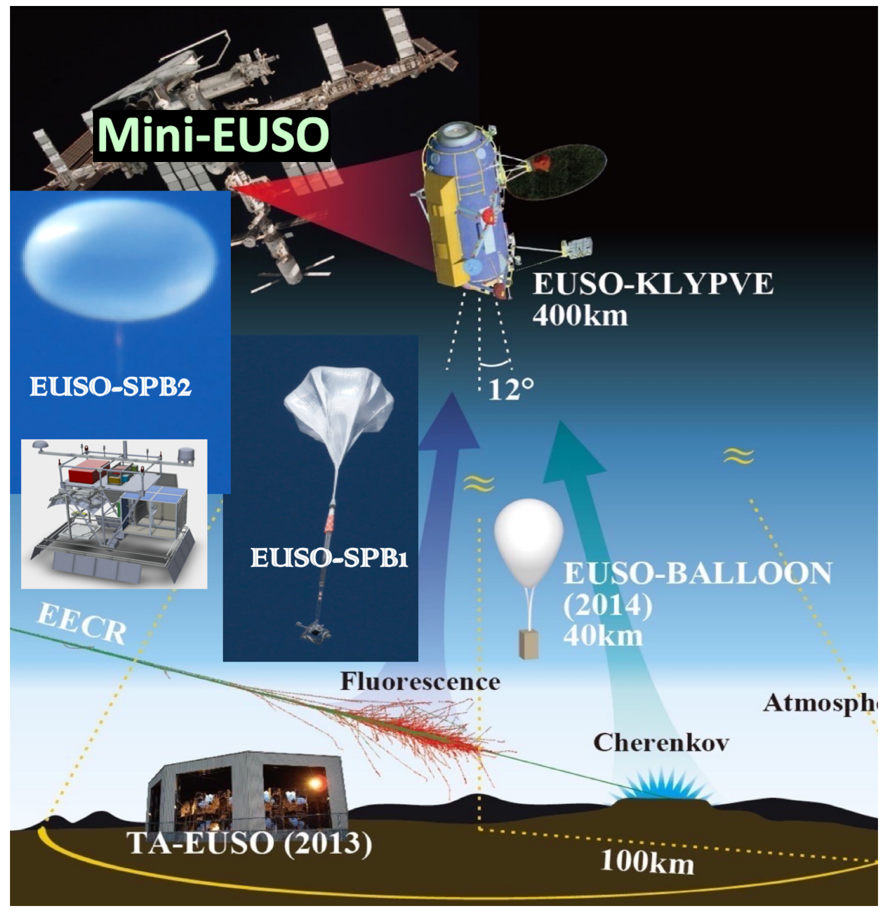


TELESCOPE ARRAY PROJECT

PIERRE AUGER OBSERVATORY



JEM-EUSO



TUS

energy

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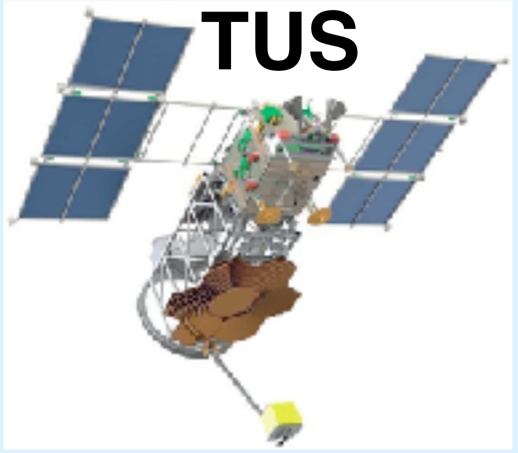
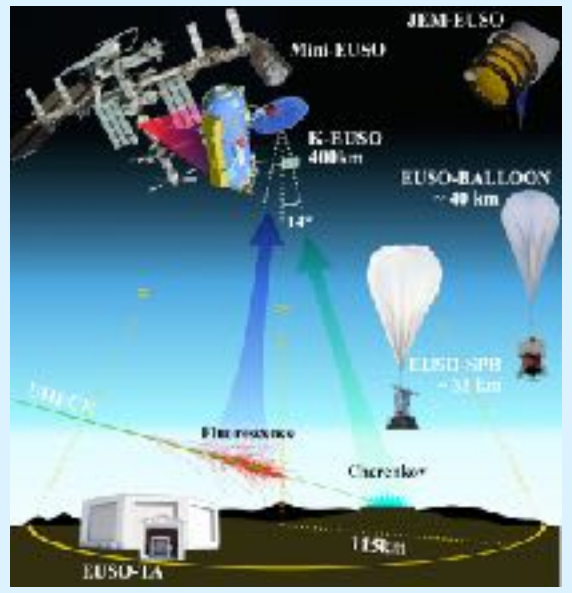
fluorescence telescopes

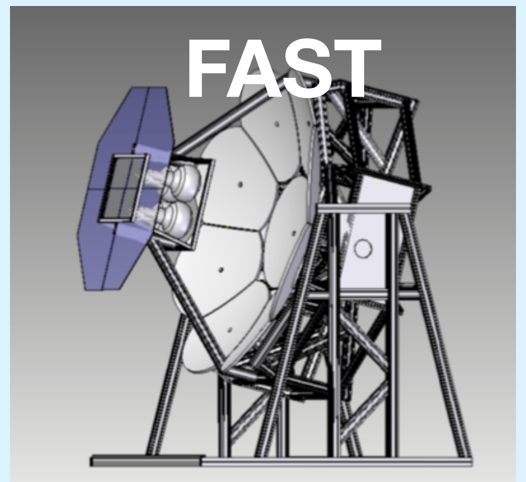
particle detectors

radio antennas



EUSO





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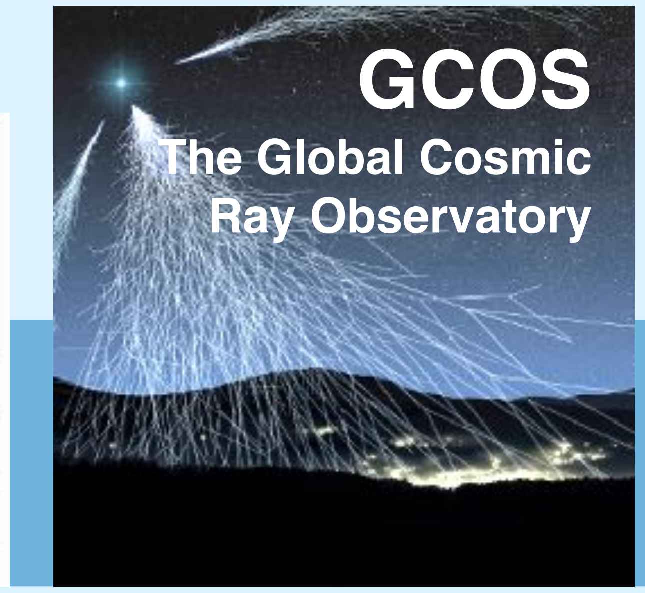

TELESCOPE ARRAY PROJECT

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- Detection of Above the Lim
- Prospects for Cross-correl

- each presenter has 1 min to explain the executive summary
- followed by ~5 min discussion/block
  with Q&A for each contribution and
  future plans for that „block“,
  what do you expect in the next decade?

- after this, we plan to have 30 min general discussion:
  how to proceed at the highest energies?
  * complementarity ground - space
  * what will be the most important questions in multi-messenger astroparticle physics in the next decade?
  * what will be the biggest challenges in the next decade?

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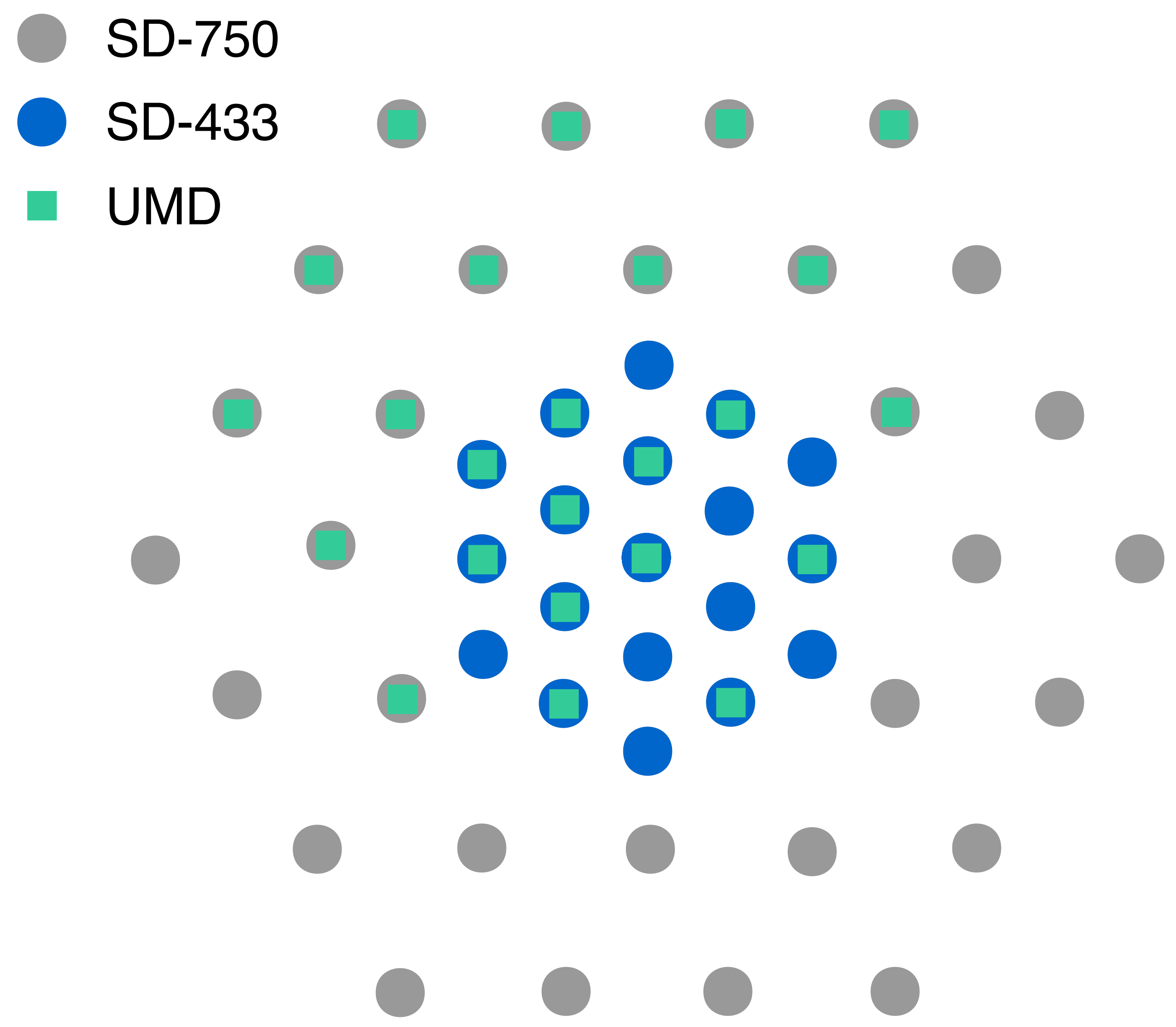
Performance of the 433 m surface array of the Pierre Auger Observatory

Executive Summary

Gaia Silli[a,b] for the Pierre Auger Collaboration[c]

[a] Instituto de Tecnologías en Detección y Astropartículas (CNEA, CONICET, UNSAM), Buenos Aires, Argentina
[b]Institute for Astroparticle Physics (IAP), Karlsruhe Institute of Technology, P.O. Box 3640, 76021 Karlsruhe, Germany
[c] Observatorio Pierre Auger, Av. San Martín Norte 304, 5613 Malargüe, Argentina

We present an array of 19 water-Cherenkov detectors spaced at 433-m that has been added to the Pierre Auger Observatory. The new array complements the existing 750-m and 1500-m ones by reaching energies down to 10 PeV thus giving Auger the capability to observe with a surface detector the second knee of the cosmic-ray spectrum, and search for ultra-high energy photons coming from the Galactic Center.



We present the first results of the 433-m array after seven years of data taking and an evaluation of its performance from simulations. We found from data the lateral distribution function, an optimal distance of 300 m to measure the energy, and the angular resolution as function of the energy. From simulations we determined that the array is fully efficient above 50 PeV for cosmic-rays arriving at less than 45° of zenith angle.

Status and performance of the underground muon detector of the Pierre Auger Observatory

Executive Summary

Ana Martina Botti[a,b] for the Pierre Auger Collaboration[c]

[a] Instituto de Tecnologías en Detección y Astropartículas (CNEA, CONICET, UNSAM), Buenos Aires, Argentina
[b] Department of Physics, FCEyN, University of Buenos Aires and IFIBA, CONICET, Buenos Aires, Argentina
[c] Observatorio Pierre Auger, Av. San Martín Norte 304, 5613 Malargüe, Argentina

What is this contribution about?

We describe the underground muon detector (UMD) of the Pierre Auger Observatory, an array of 219 buried plastic scintillators with an area of $10\,\mathrm{m}^2$ each.

Why is it relevant/interesting?

With the UMD, we can obtain direct measurements of muons in air showers initiated by primaries with energy between $\sim 10^{16.5}$ and $\sim 10^{19}$ eV to improve the mass composition analyses and shed light on the muon puzzle.

What has been done?

The end-to-end calibration was developed and is running smoothly. 35% of the array has been deployed.

What is the result?

The UMD will soon be ready to start physics analyses. The detector will be fully commissioned by 2022.

The upgrade of the Pierre Auger Observatory with the Scintillator Surface Detector

Executive Summary

Gabriella Cataldi[a] for the Pierre Auger Collaboration[b]

[a] INFN, Sezione di Lecce, via per Arnesano, 73100 Lecce, Italy
[b] Observatorio Pierre Auger, Av. San Martín Norte 304, 5613 Malargüe, Argentina

What is this contribution about?

One of the elements of the upgrade of the Pierre Auger Observatory: the new Scintillator Surface Detector (SSD) placed on top of the Water-Cherenkov stations.

Why is it relevant/interesting?

At the Observatory, the integration of the components and their deployment in the array is well advanced. The main challenges and characteristics of the construction and installation and the long-term performance of the detectors are presented.

What has been done?

In March 2019, a preproduction array of 77 SSDs started data acquisition with an adapted version of non-upgraded electronics. It is collecting events and proving the goodness of the design. Since December 2020, the upgraded electronics boards are being deployed in the field together with the photomultiplier tubes, increasing the number of detectors that are taking data continuously with good stability.

What is the result?

The data collected so far demonstrate the quality of the new detectors and the physics potential of the upgrade project.

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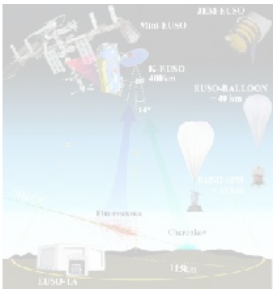


Current status and prospects of surface detector of the TAx4 experiment

Eiji Kido on behalf of the Telescope Array Collaboration
RIKEN Cluster for Pioneering Research

- Implications on anisotropy were obtained by the TA experiment.
  - Energy Spectrum
    - Declination dependence was claimed at **4.3σ** in the energy spectrum using TASD 11 years data
  - Anisotropy
    - **3.2σ** hotspot, oversampling radius: 25° E > **57** EeV was obtained using TASD 12 years data

- Arrangement of the TAx4 detectors:
  - **500 new** SDs with **2.08 km** spacing + TA SDs
    → Coverage of **4×** TA SDs ～2800 km^2 → **～4×TA SD** equivalent events for E > 57 EeV
  - **2 new** FD stations (4+8 HiRes Telescopes) → **～3×TA SDFD** equivalent hybrid events for E > 10 EeV
- More than half of new SDs (257 SDs) were deployed in 2019.
- Construction of new FDs was finished.
- Stable run of the data acquisition of the new detectors was started.

SD: from Nov. 2019, FD(north): from 2018 Jun. FD(south): from 2020 Sep.
Hybrid trigger runs from 2020 June.

- Global significance of the TA hotspot will reach about 6σ in 2025 by the TAx4 SDs (TASD 24.5 years equivalent data) from the simple expectation.

Monocular Energy Spectrum using the TAx4 FDs

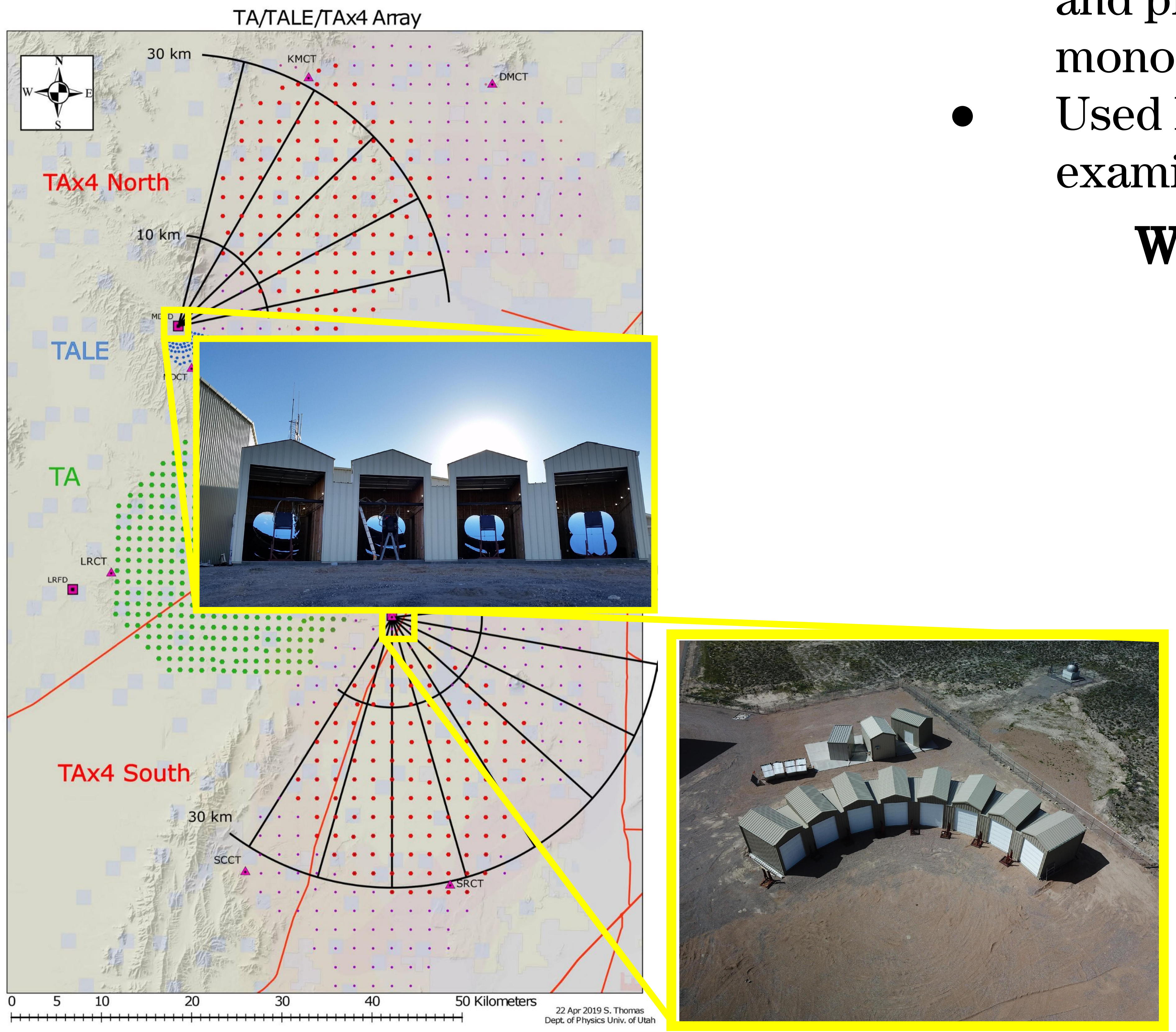
ICRC, July 2021

PoS(ICRC2021) 343

Mathew Potts for the Telescope Array Collaboration

What is TAx4?

- Fourfold increase in size of TA SD array.
    - 257 of 500 planned scintillator SDs are deployed at 2.08 km spacing
    - Added 2 FD stations, 12 telescopes



What have we done?

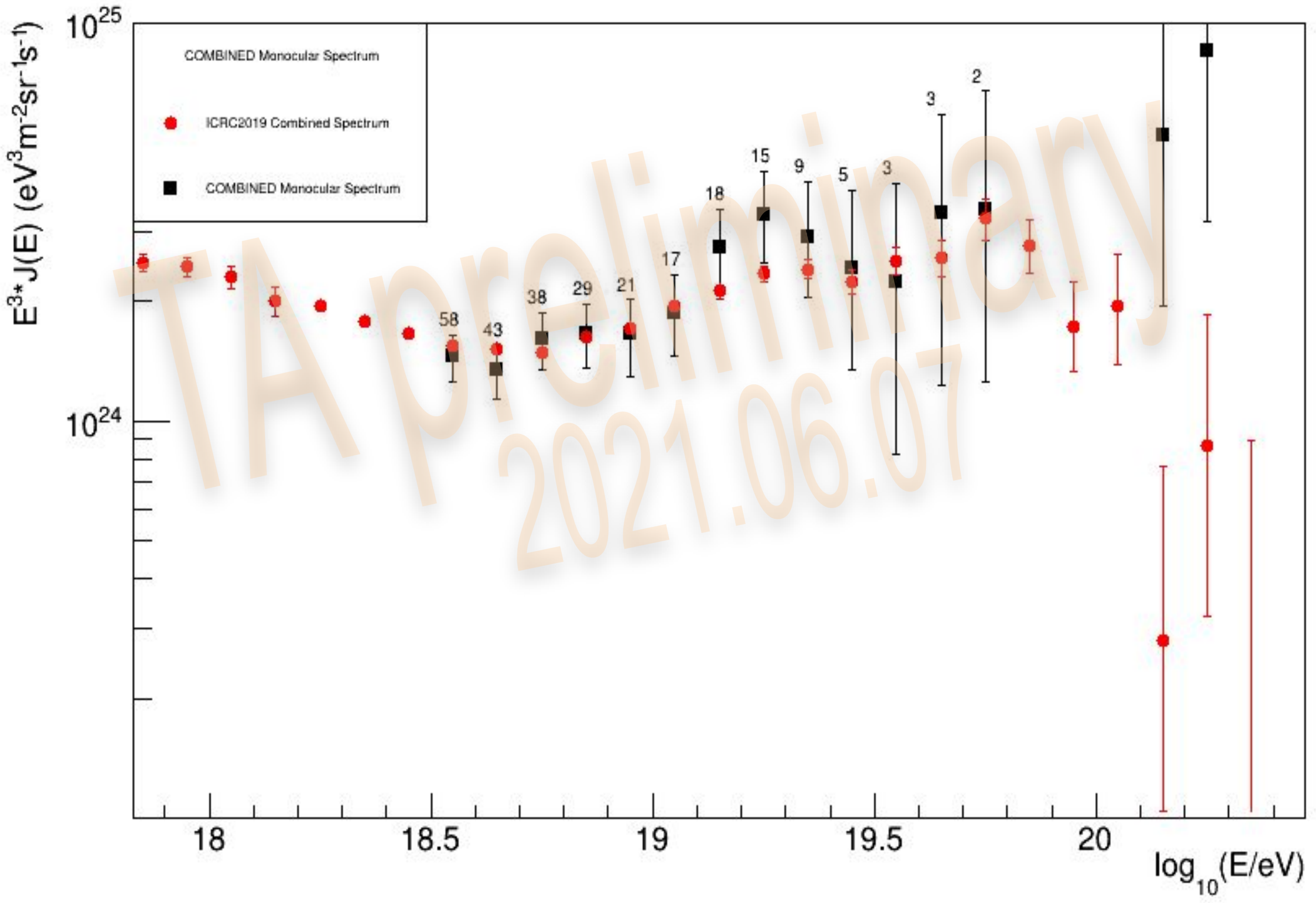
- Generated MC using QGSJetII-03 protons thrown at E^{-2} power law
- Reconstructed the energies and directions of UHECRs from the signals detected by the TAx4 FDs.
- Examined the TAx4 FD's performance and produced a preliminary monocular energy spectrum.
- Used hybrid reconstruction to examine data events.

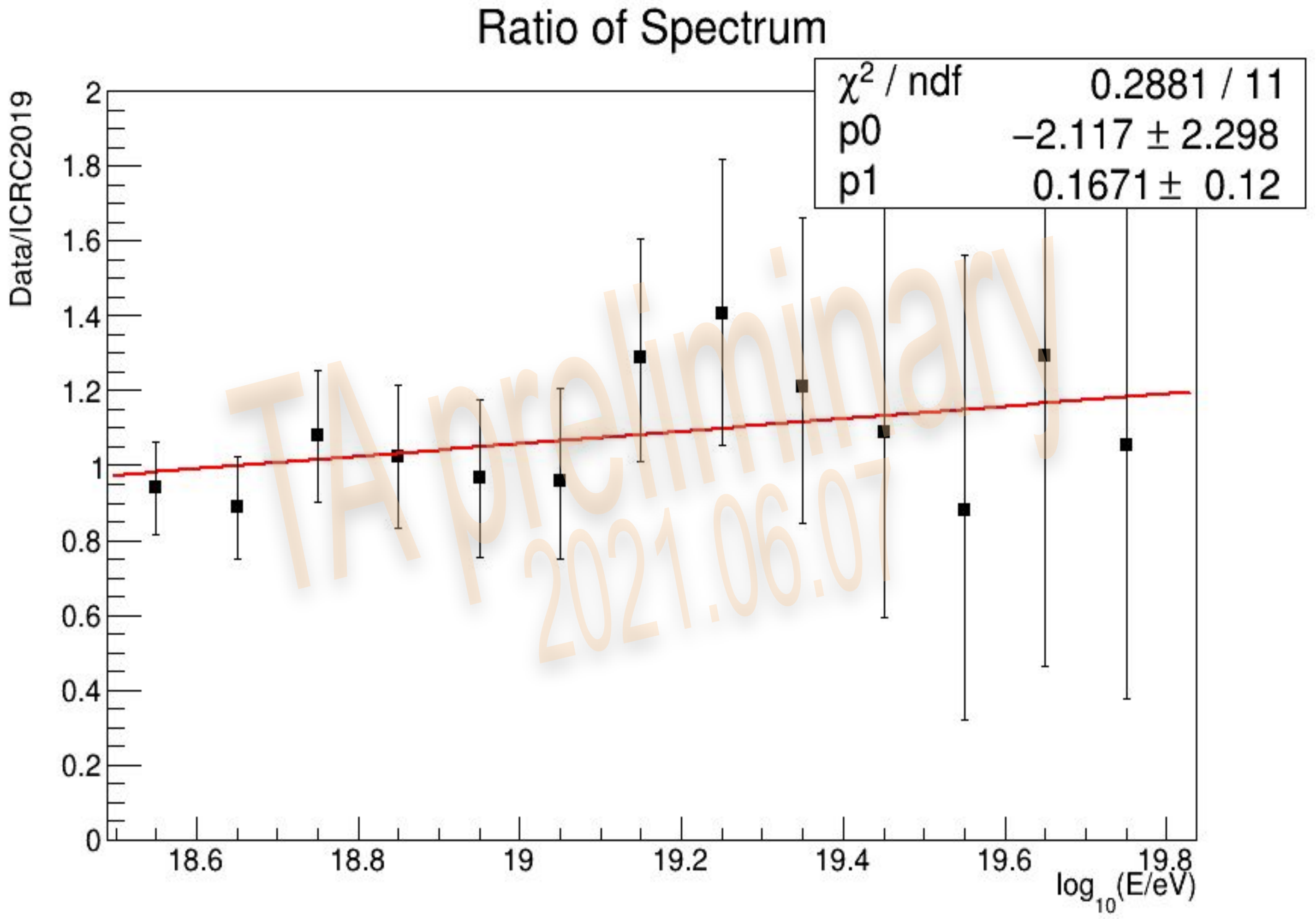
What are the future plans for TAx4?

- A monocular energy spectrum is the first step towards my goal of generating a hybrid energy spectrum using the TAx4 detector for my Ph.D thesis.
    - Using a parametric hybrid MC to estimate the hybrid aperture and detector resolutions
    - Implementation of full hybrid MC is in progress.
    - I plan on graduating next summer and will be looking for new research opportunities.
- TA will work on hybrid composition

What are the current results?

- The preliminary monocular energy spectrum measured by the TAx4 FDs is in overall agreement with the TA ICRC2019 combined spectrum.





One page executive summary

Introduction

The status of the TALE surface detector array and TALE infill project

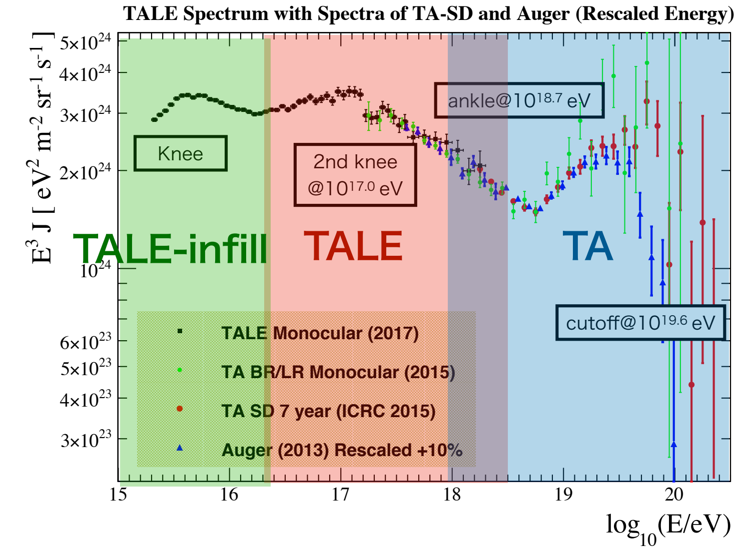
Shoichi Ogio for the Telescope Array Collaboration
Graduate School of Science, Osaka City University

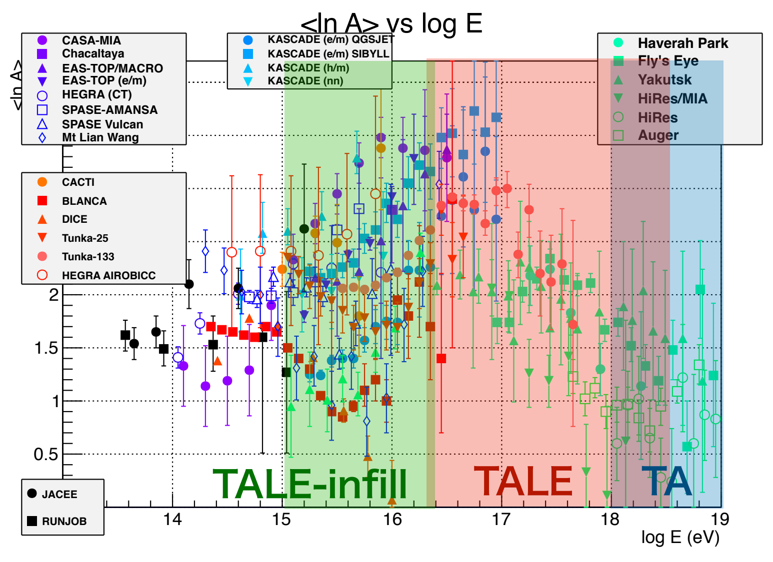
Summary

- TALE and TALE infill: covering with FD+SD over “knee” to “ankle”
- Routine operation of TALE hybrid for more than 2 years
- 54 SDs will be additionally installed in the TALE site in 2022

Extension of TALE: TALE-infill

Ap. J., 865, 74(2018), arXiv: 1803.01288





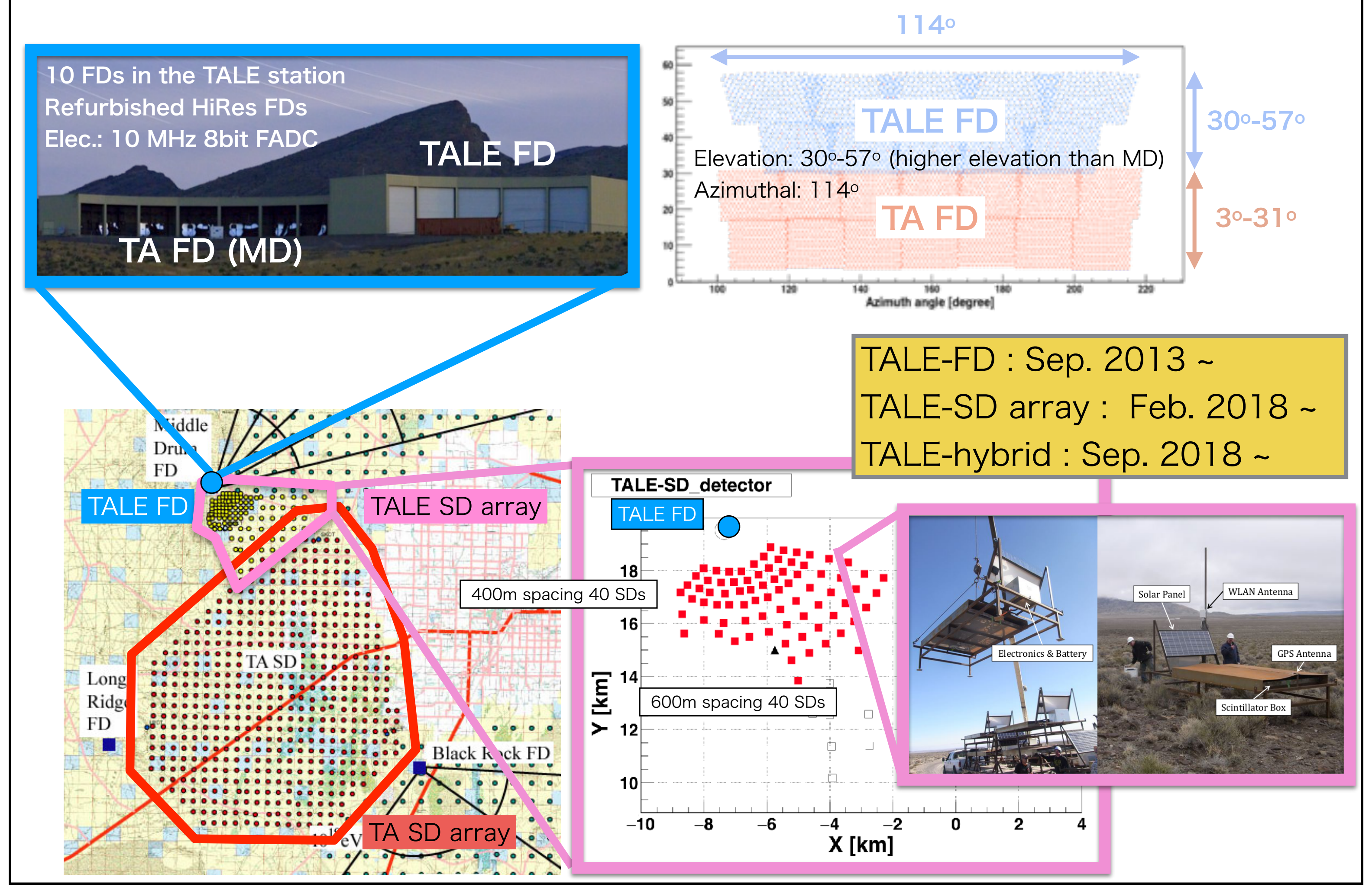
TALE + TALE-infill “hybrid” covering “knee” to “ankle”:

＊Detailed studies of spectrum and composition
<= Hybrid observation with FDs plus SDs
＊Anisotropy study
<= Uniform + high statistics with SD array

TALE hybrid

TALE hybrid

10 FDs + 80 SDs in TA site

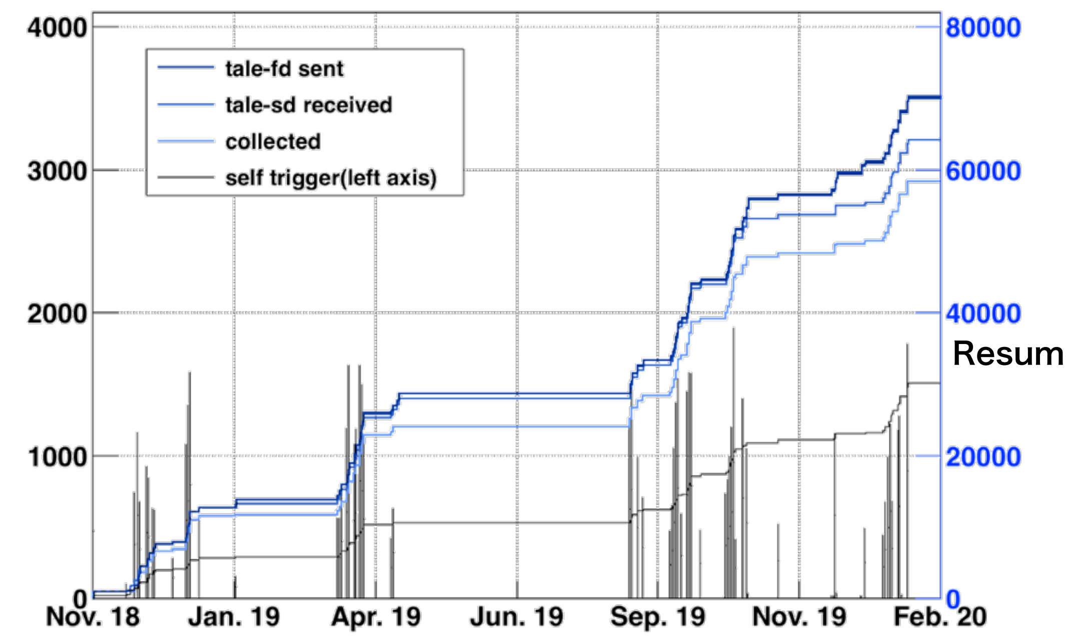


TALE-FD : Sep. 2013 ~
TALE-SD array : Feb. 2018 ~
TALE-hybrid : Sep. 2018 ~

TALE hybrid operation status

80 SDs covering about 20 km²
Routine operation from Oct. 2018
Triggering condition:
SDs of > 0.3 MIPs within +- 32us of TALE FD trigger

tale hybrid trigger events plot



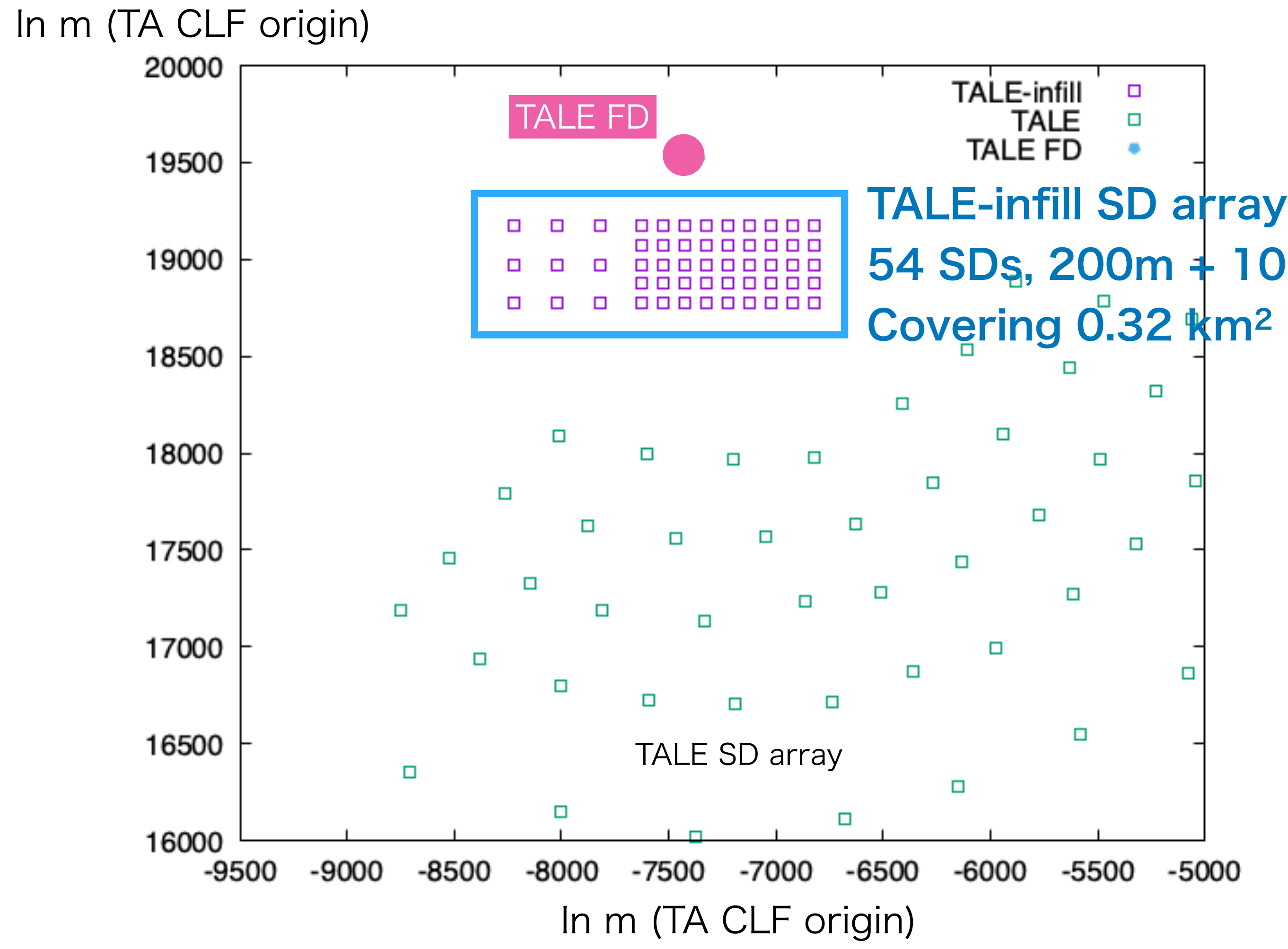
Nov. 2018 - Jan. 2020

2018/11/14-2020/01/28
Total obs. Days = 68
Total obs. Time = 390 hrs

Resumed hybrid obs. In Dec. 2020

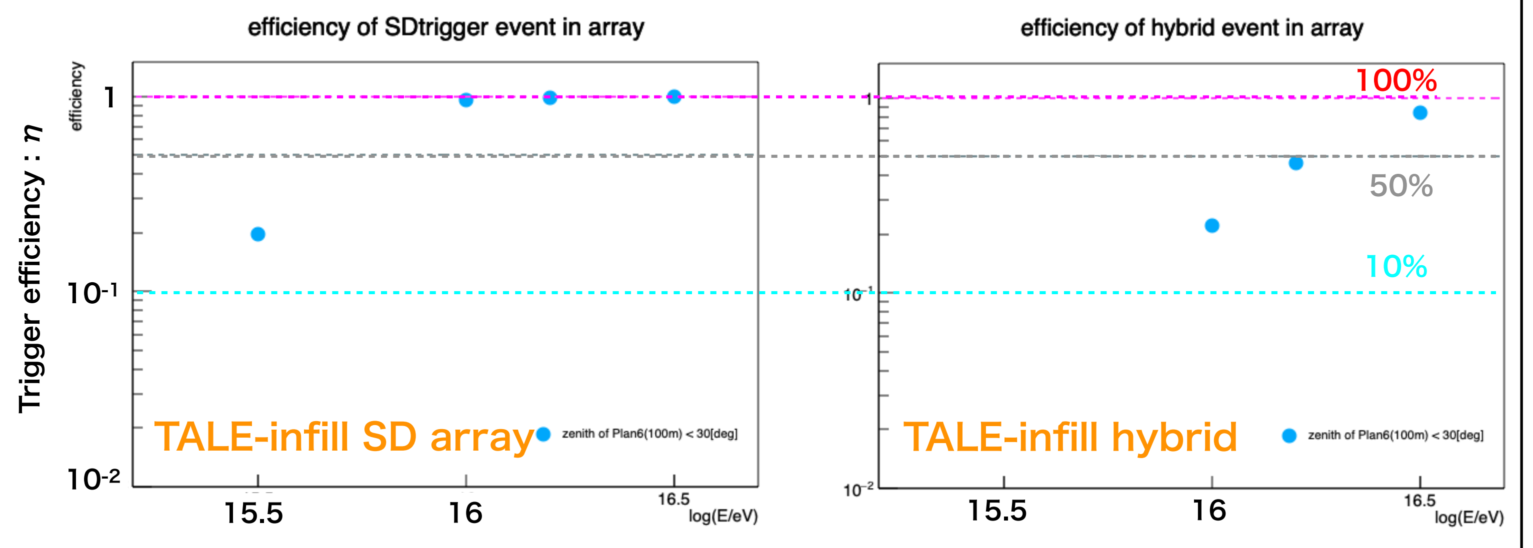
TALE-infill project

Extension of TALE: TALE-infill



TALE-infill SD array
54 SDs, 200m + 100m
Covering 0.32 km²

Triggering efficiency of TALE-infill hybrid



5% efficiency energy ~ mode energy :
TALE-infill SD array : logE ~ 15.3

TALE-infill hybrid : logE ~ 15.8

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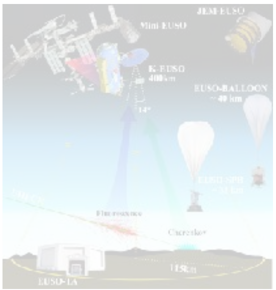


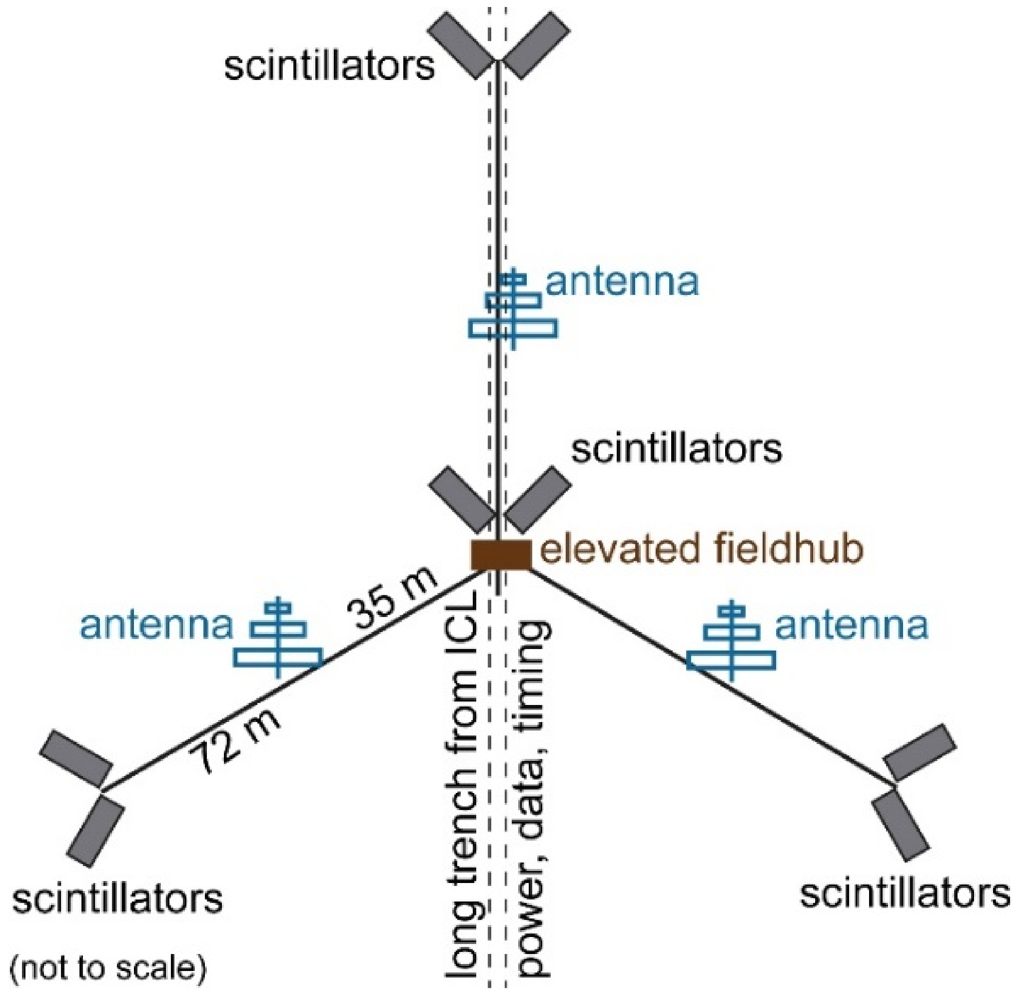
Future IceCube-Gen2 Surface Array

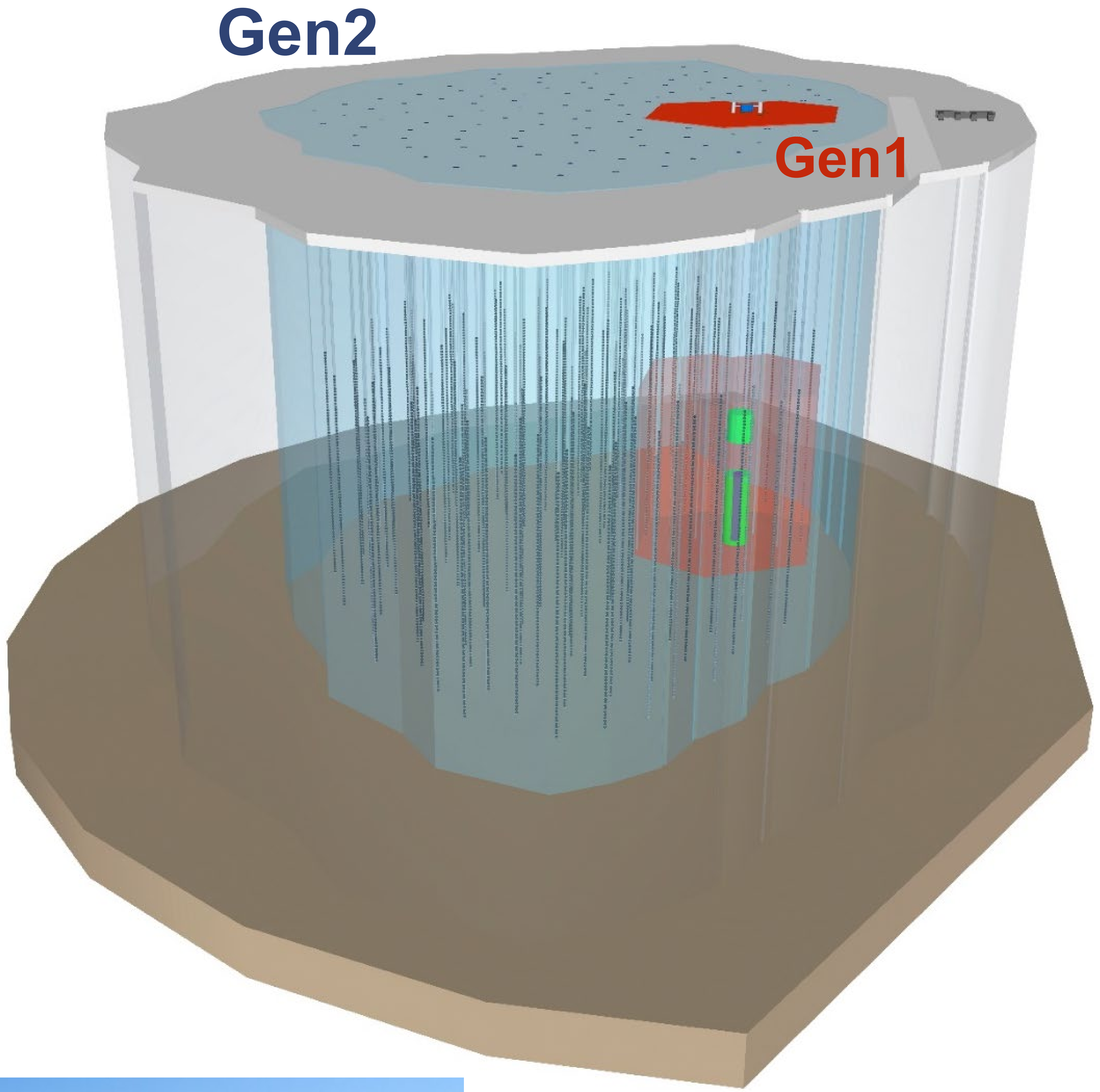
Key Features:

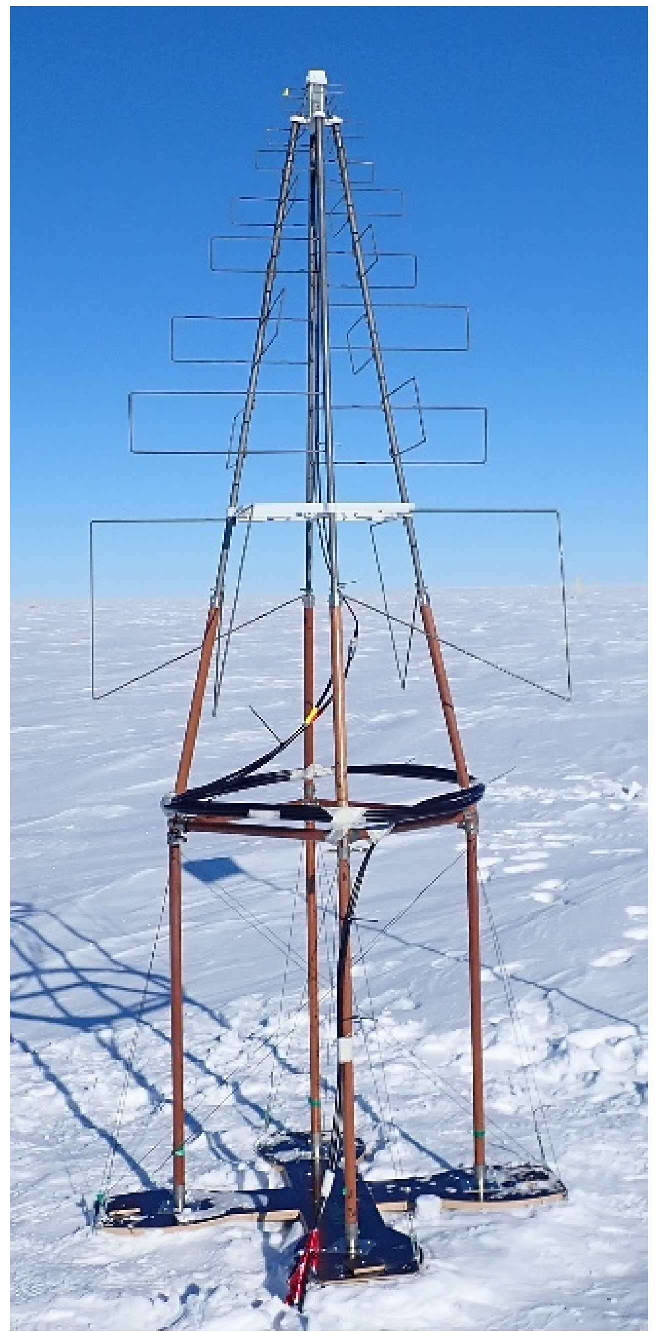
- Higher aperture than Gen1
  - 8−10× aperture surface only
  - > 30× aperture for coincidences with optical in-ice array
- Energy range: 0.5 PeV to Ankle
- Radio for increasing accuracy at galactic-to-extragalactic transition

Science Case (selection):

- Veto for neutrino detection
- Hadronic interactions
  - muon spectroscopy
  - prompt muons
- Most energetic *Galactic* CR
  - mass, anisotropy, search for photons







Surface Array Layout:

One station for each of the 120 optical strings.

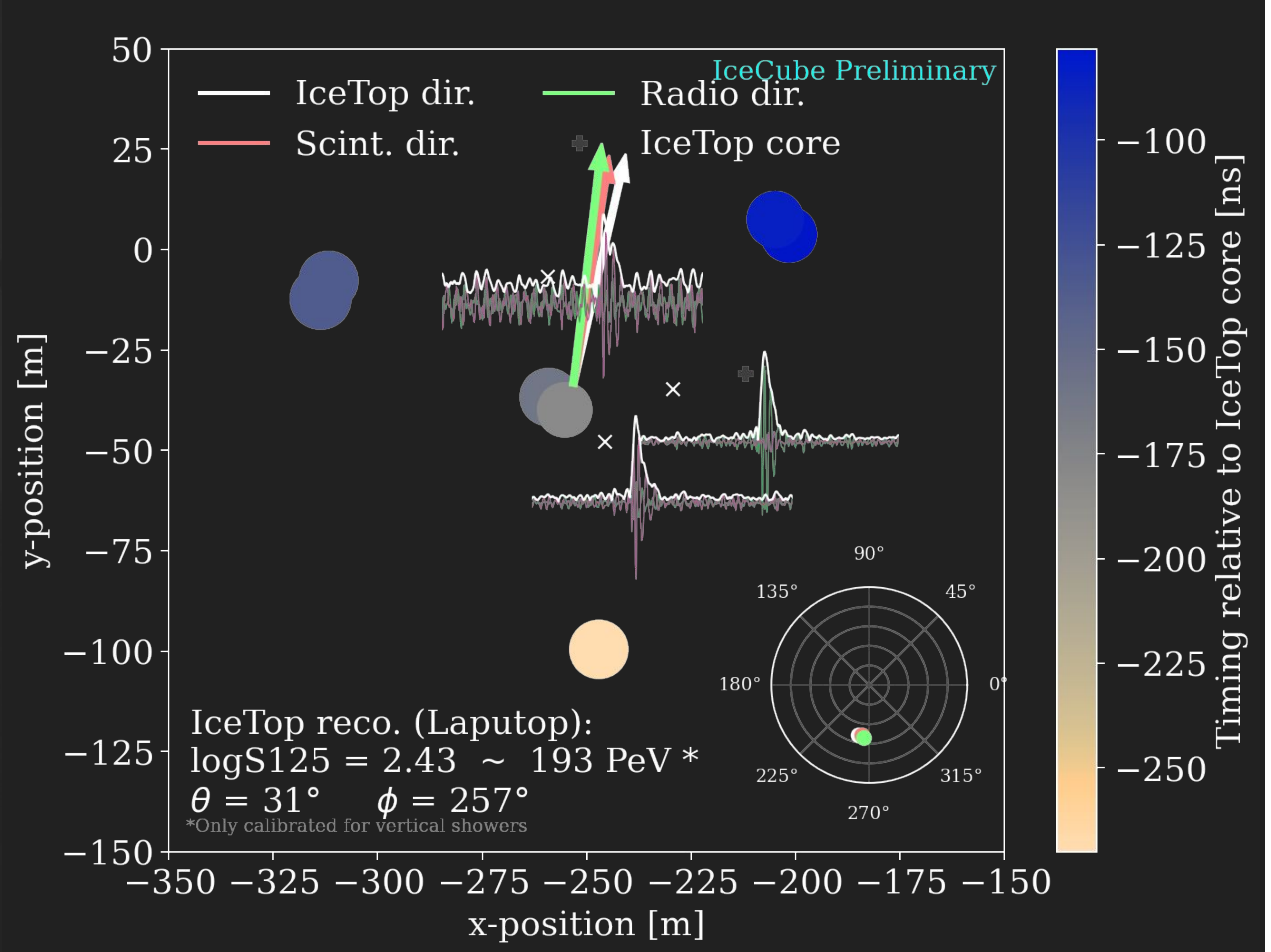
Each station has 4 pairs of scintillators + 3 antennas.

Frank G. Schroeder (IceCube-Gen2 Coll.), ICRC 2021

First air-shower measurements with the prototype station of the IceCube surface enhancement

Hrvoje Dujmović, Alan Coleman, Marie Oehler
ICRC 2021

- In the coming years, IceCube's cosmic-ray capabilities will be enhanced by adding scintillators and radio antennas to the surface array
- The design of the Encacement is being tested with a prototype station deployed to the Pole in Jan. 2020
- **First cosmic-ray air-showers with the prototype station have been measured**
- Basic event reconstructions are performed on the scintillator, radio and IceTop data individually
    - ○ The results agree with each other and the station seems to be performing as expected!
- Improved reconstructions and additional cross-checks are being worked on



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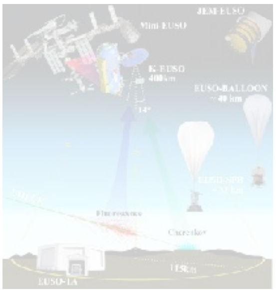
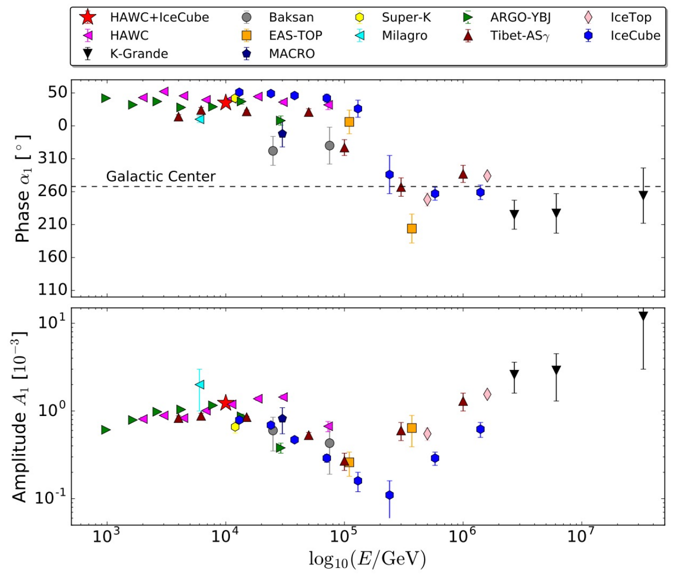


The Southern Wide-field Gamma-ray Observatory

Composition Sensitivity for the Cosmic Ray Anisotropy with SWGO

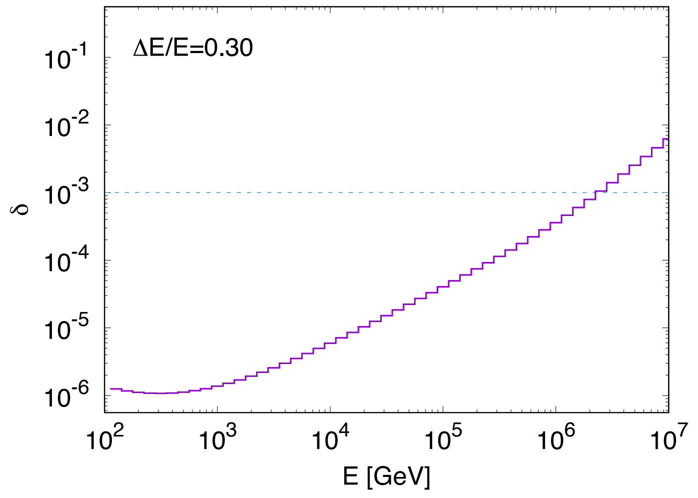
We investigate the potential sensitivity that the future instrument SWGO will offer for probing the evolution of the cosmic ray anisotropy in the two decades of energy below the knee.

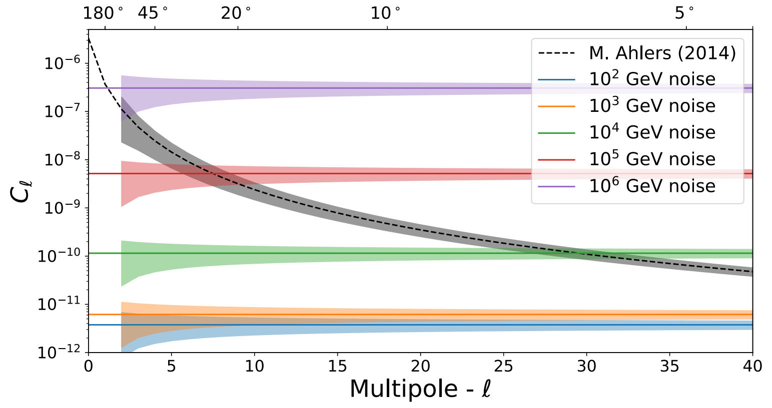


In the two preceeding energy decades below the knee (0.03-3 PeV), the dipole in the cosmic ray anisotropy exhibits a swing in its phase and a corresponding dip in its amplitude. This observational signal, however, has yet to be probed in terms of the underlying signal for different cosmic ray species groups.

Beyond the dipole, the multipole evolution in this energy range has also not been probed, nor broken down into the multipole signal for different species groups.

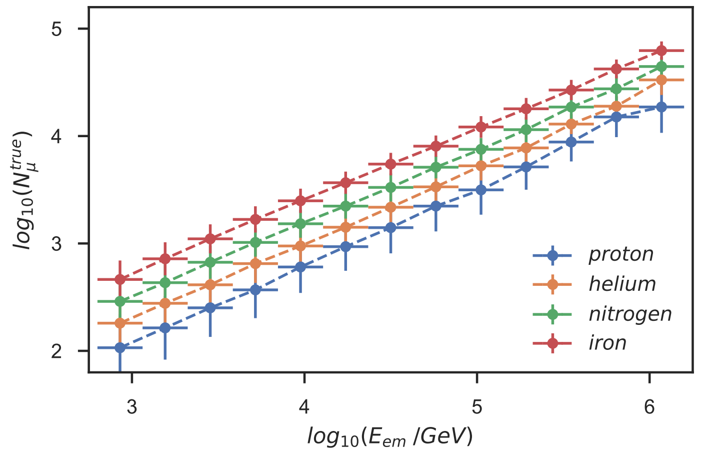
Utilising the large effective area of the planned instrument, and convolving it with the cosmic ray spectru, the detection rates per year are obtained. These indicate that a probe of the dipole, at its level of 10^{-3}, will be achievable up to energies of at least knee (3 PeV).





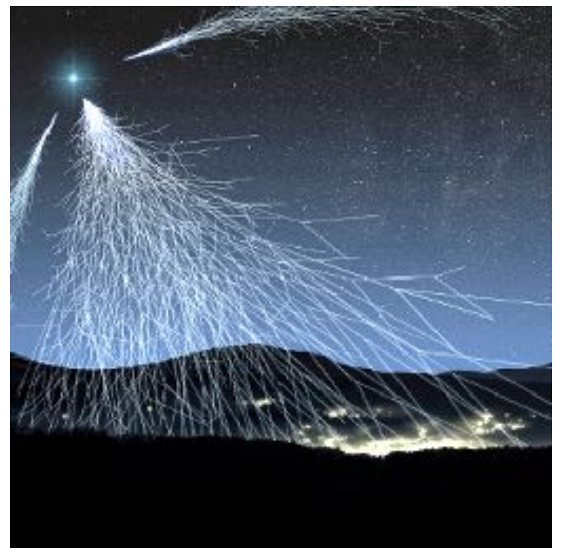
The same exercise applied for probing the weaker higher order cosmic ray multipole anisotropies, indicates that at an energy of 0.1 PeV, a probe of the multipole up to l=6 will be possible.

Taking advantage of the good muon counting capabilities of the SWGO instrument, a separation of the arriving cosmic rays into 4 equal logarithmically spaced mass groups between proton and iron (ie. $\sigma_{\ln A} \simeq 1$) is estimated to be possible above an energy of 3 TeV.



On behalf of the Cosmic Ray Task Force: Andrew Taylor, Gwenael Giacinti, Paolo Desiati, Juan Carlos Diaz-Velez, Andrea Chiavassa, Guiseppe Di Sciascio, Juan Carlos Arteaga Velazquez, and Samridha Kunwar

GCOS - The Global Cosmic Ray Observatory



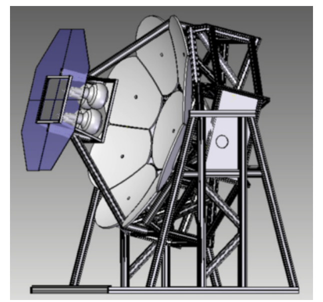
- World-wide initiative to conduct multi-messenger astroparticle physics beyond 2030

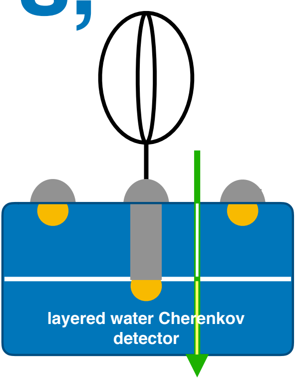
- MM-APP has started: GW sources, IceCube neutrinos, and follow-ups, …
  key results from Telescope Array & Pierre Auger Observatory (anisotropies, mass composition)

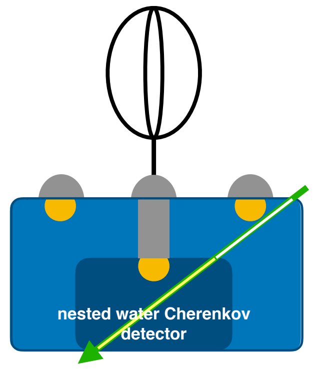
- building on this knowledge, it is time to prepare for a Global Cosmic Ray Observatory after 2030

- aim for multi-purpose observatory:
  sources of UHE particles (charged CRs, neutrinos, gamma rays), connection to GWs,
  dark matter searches, fundamental physics, particle physics, geophysics and atmospheric science

- considering different detection concepts, including layered/nested water Cherenkov detectors,
  radio antennas, and fluorescence light telescopes







- workshop with >200 participants in May 2021
  to discuss path to define physics case and develop concepts for detection technologies

- we plan a follow-up workshop at the end of 2021/begin of 2022 with the goal
  to write a roadmap for multi-messenger astroparticle physics (CRs, GAs, NUs, GWs) beyond 2030
  and a Global Cosmic Ray Observatory

→ theatre of dreams, 21 July

GCOS homepage: http://particle.astro.ru.nl/gcos

Progress and future prospect of the CRAFFT project for the next generation UHECR observation

Y. Tameda

1. What is this contribution about?

CRAFFT project is developing a low cost fluorescence detector (FD) to realize a huge observatory for ultra high energy cosmic ray (UHECR) observation.

2. Why is it relevant / interesting?

**It is expected that we will be able to identify the sources of UHECRs because of the straight propagation with such high energy.
We need a large detection area for a large statistics because of the low flux of UHECR and it is inevitable to reduce the cost to realize the next generation observatory with a large detection area.**

3. What have we done?

We developed the low cost FD resultant to the cost to be 1/10 of conventional FDs.

4. What is the result?

**We succeeded to detect UHECR air showers,
and we demonstrated the possibility of reconstruction with the low cost FD even with single pixel by waveform fitting.**

Fig1. Exterior of CRAFFT detector which consists of Fresnel lens, UV trans. Filter, 8 inc. PMT, FADC.

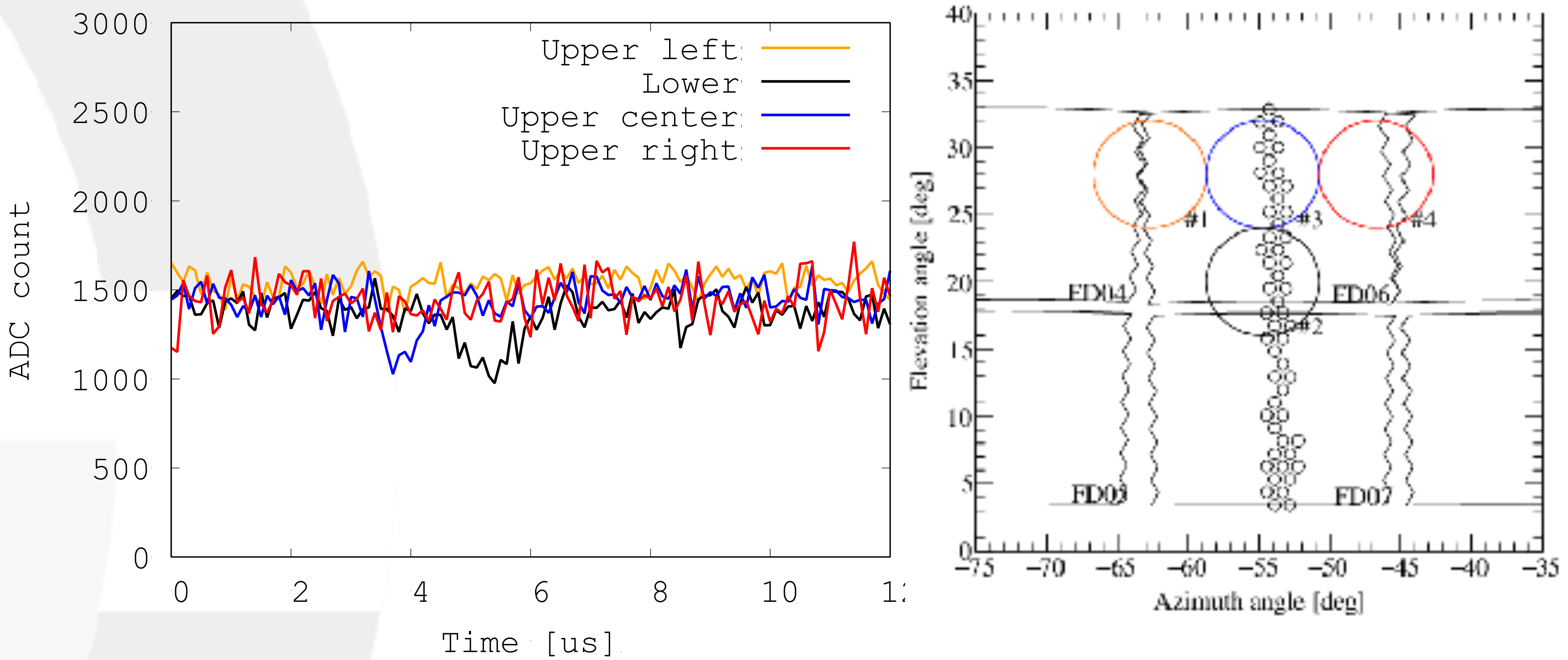


Fig2. Air shower event detected by CRAFFT at TA site.
(E=$10^{17.7}$ eV, 3.6 km apart from the detector analyzed by TA FD)

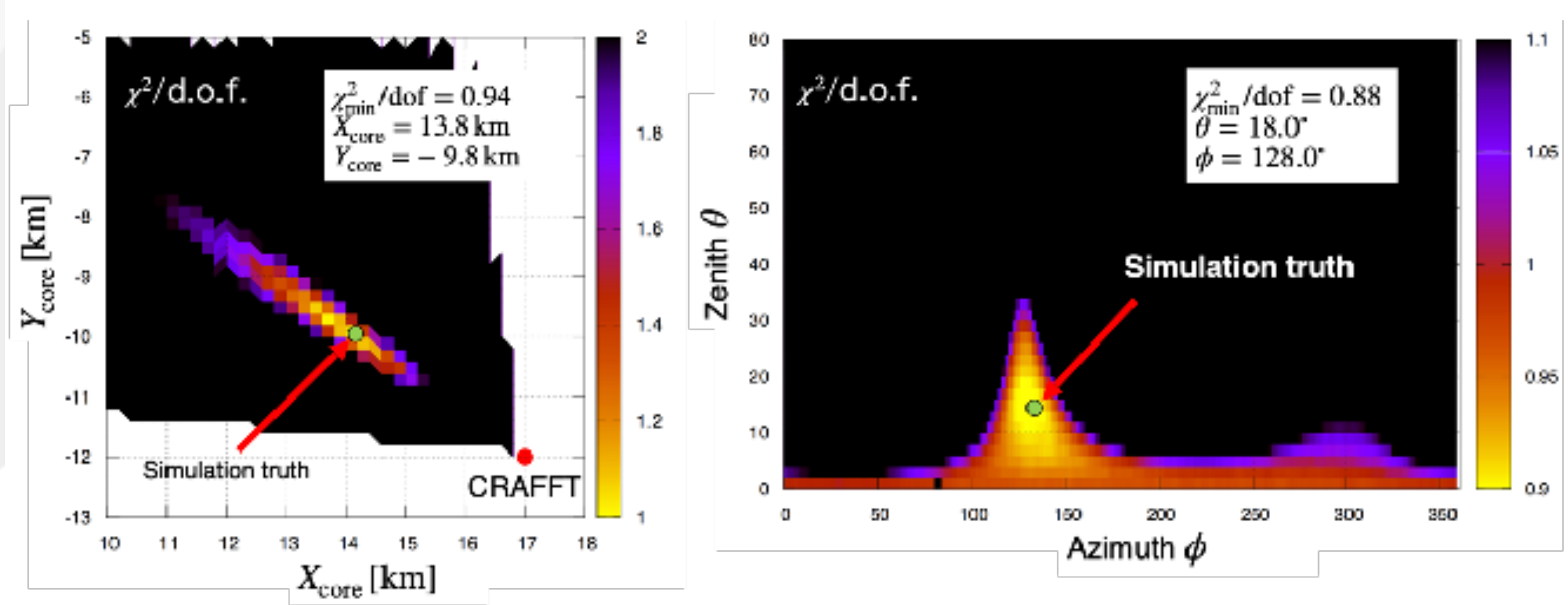


Fig3. Reduced chi^2 distribution for geometry reconstruction by waveform fitting. (Simulation study)
chi^2 is converged around true value.

Discussion session 07 - CRI: Where to go in UHECR observations?

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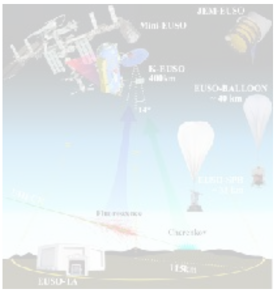


Title: An overview of JEM-EUSO program and results

M. Bertaina (Univ. & INFN Torino) on behalf of the JEM-EUSO Collaboration

- This contribution summarizes the status of the JEM-EUSO program aiming at realizing a large space-mission devoted to the observation of Ultra-High Energy Cosmic Rays from space with x10 annual exposure compared to ground-based observatories.

- This program includes 8 different missions: EUSO-TA (on ground), EUSO-Balloon, EUSO-SPB1 & EUSO-SPB2 (stratospheric balloons), TUS, Mini-EUSO, K-EUSO and POEMMA (in space).

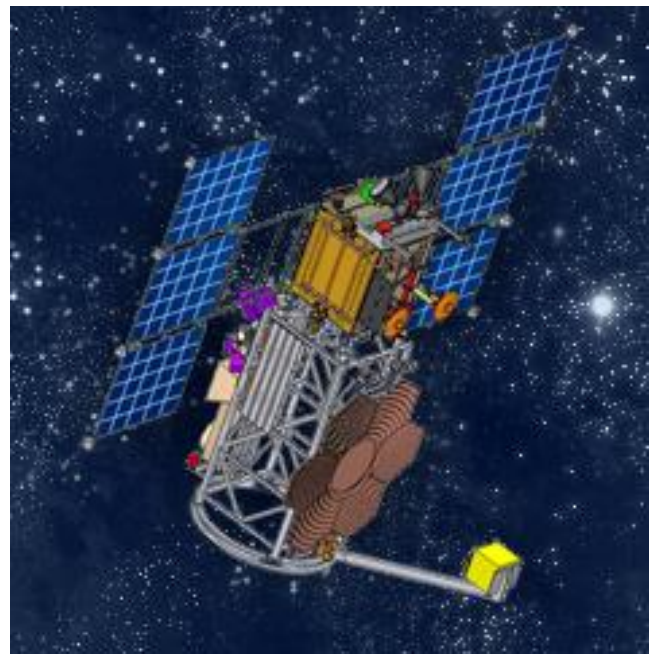
- Five of them (EUSO-TA, EUSO—Balloon, EUSO-SPB1, TUS & Mini-EUSO) have already been accomplished while the remaing three (EUSO-SPB2, K-EUSO & POEMMA) are at different development stage.

- This contribution will report on the results and expected performance of all the 8 missions highlighting some of the key information presented in the 25 contributions submitted to ICRC2021 in relation to this program.

Contribution: #389 - 15/7 @ 18:00

Main results of the TUS experiment on board the Lomonosov satellite

TUS is a first orbital fluorescent detector of ultra-high-energy cosmic rays

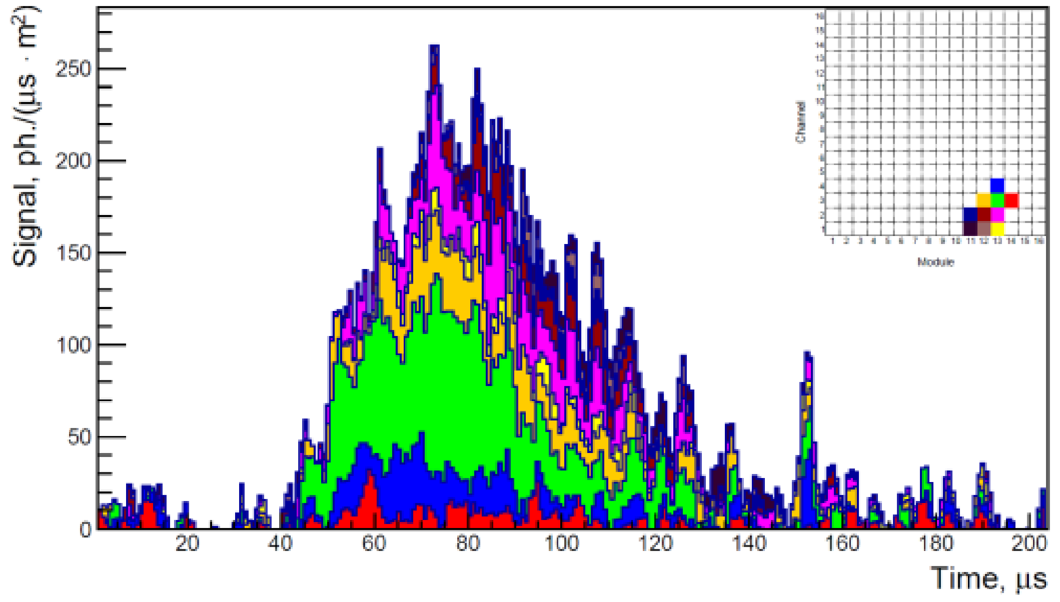


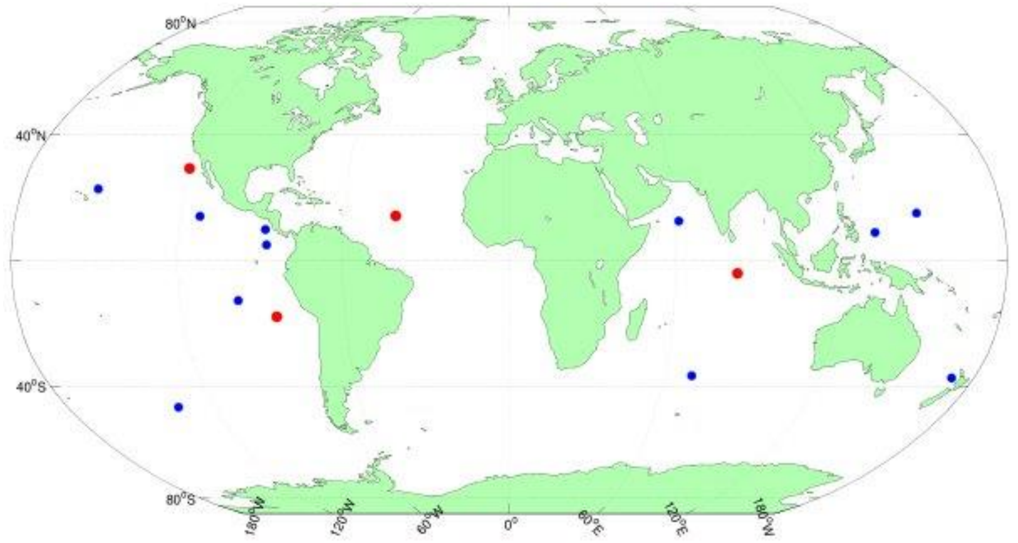
✓It was launched aboard the Lomonosov spacecraft on 04/28/2016. Time of operation until 12.2017 (with interruptions)

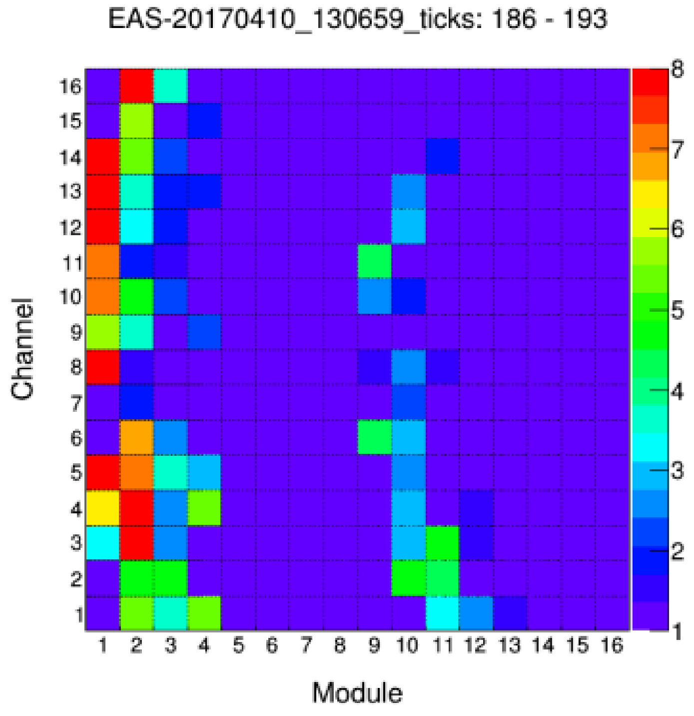
✓More than 200 thousand events registered

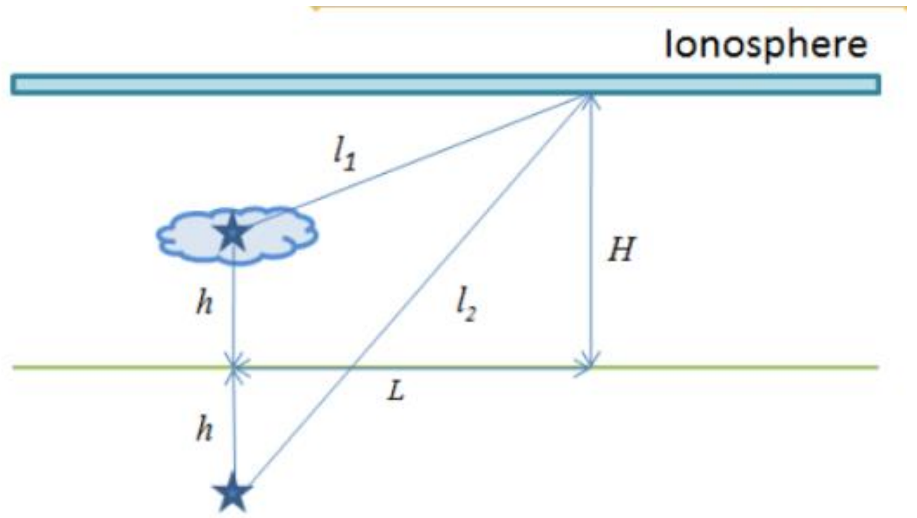
✓The total exposure ~ 1550 km^{2}sr yr.

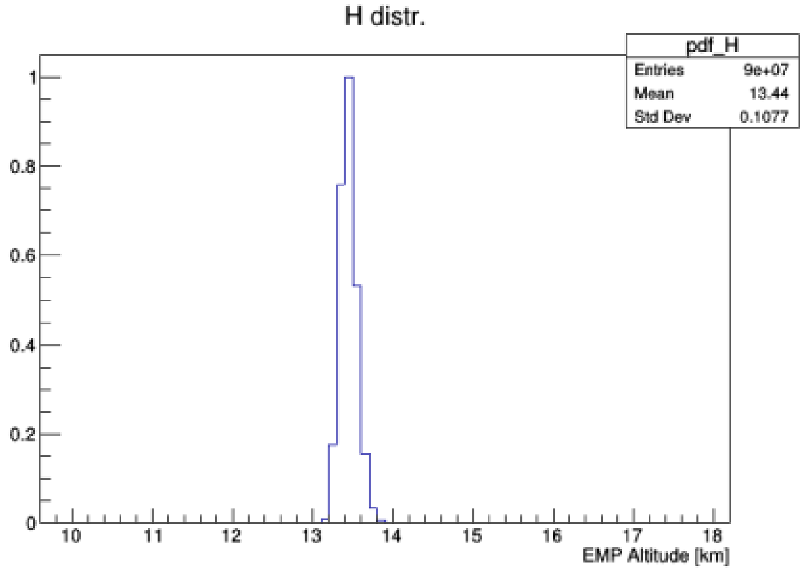
- ✓ EAS-like events are measured and analyzed. E>10^{21} eV – too high. Various hypotheses are discussed (man-made sources, relativistic dust grains …).
- ✓ Events above land are of anthropogenic origin. Number of flashes measured above oceans.



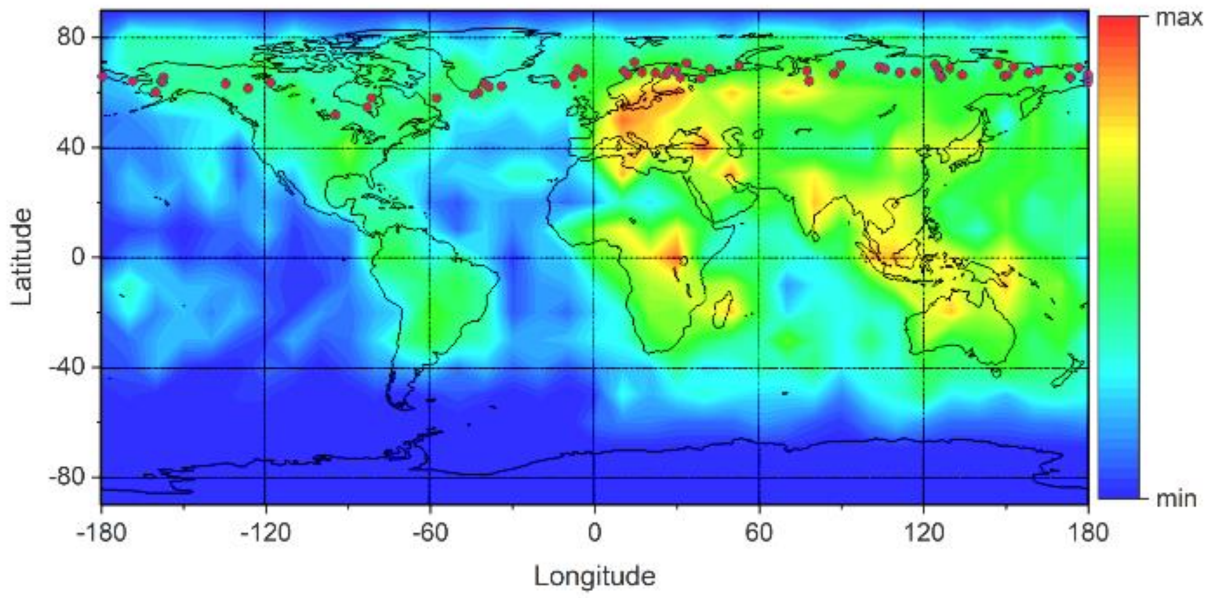


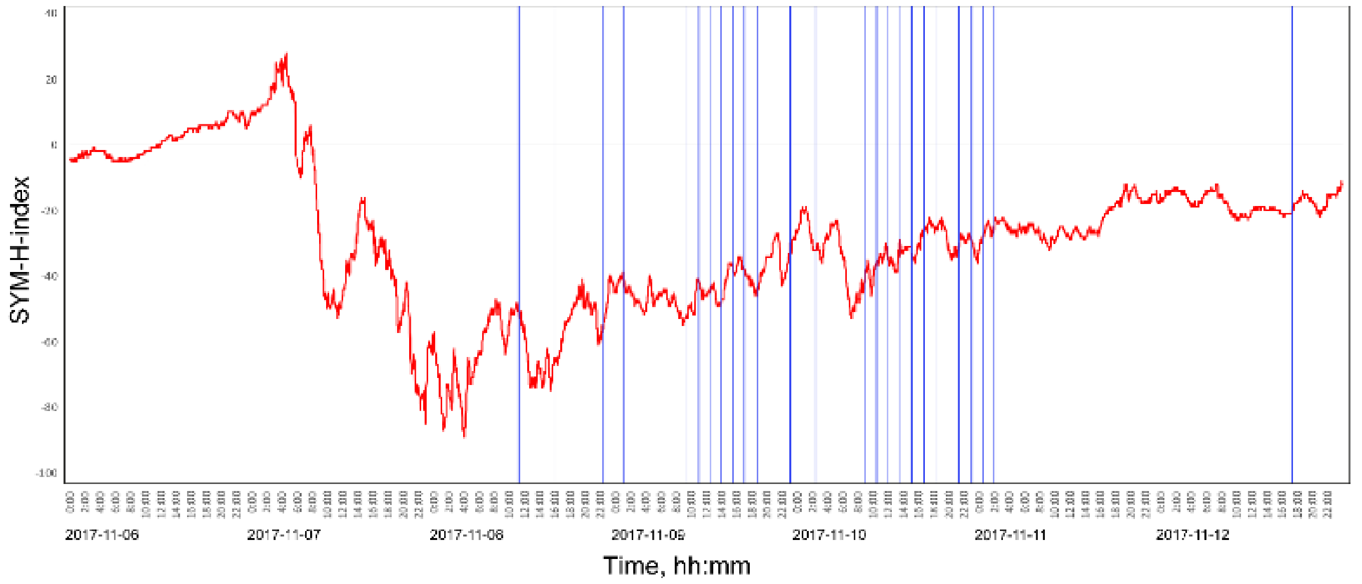






Transient atmospheric events double ELVES measured and studied





Pulsating Aurora events are observed with high temporal resolution.

- ✓ **The TUS detector has studied various UV phenomena which constitute the background for UHECR measurements.**
- ✓ **The technique proved a possibility to measure and recognize relativistic motion in the atmosphere, reconstruct direction and energy of the event.**
- ✓ **The TUS detector demonstrated multifunctionality of orbital fluorescent observatory and its usefulness for various astro- and geophysical studies.**

Discussion session 07 - CRI: Where to go in UHECR observations?

The-Mini-EUSO-telescope-on-board-the-International-Space-Station-Launch-and-first-results

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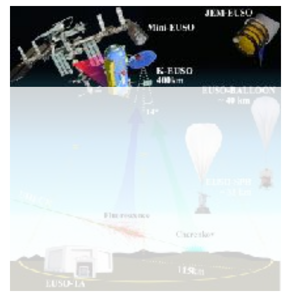


EUSO-SPB2: Overview

- *What is this contribution about?*

  We provide an brief overview of the EUSO-SPB2 instrument, discuss the science goals and the expected performance

- *Why is it relevant / interesting?*

  First time to measure UHECR via fluorescence technique from suborbital space and not only rise the Technical Readiness Level for future space missions but also measure for the first time the backgrounds for such an instrument.

- *What is the result?*

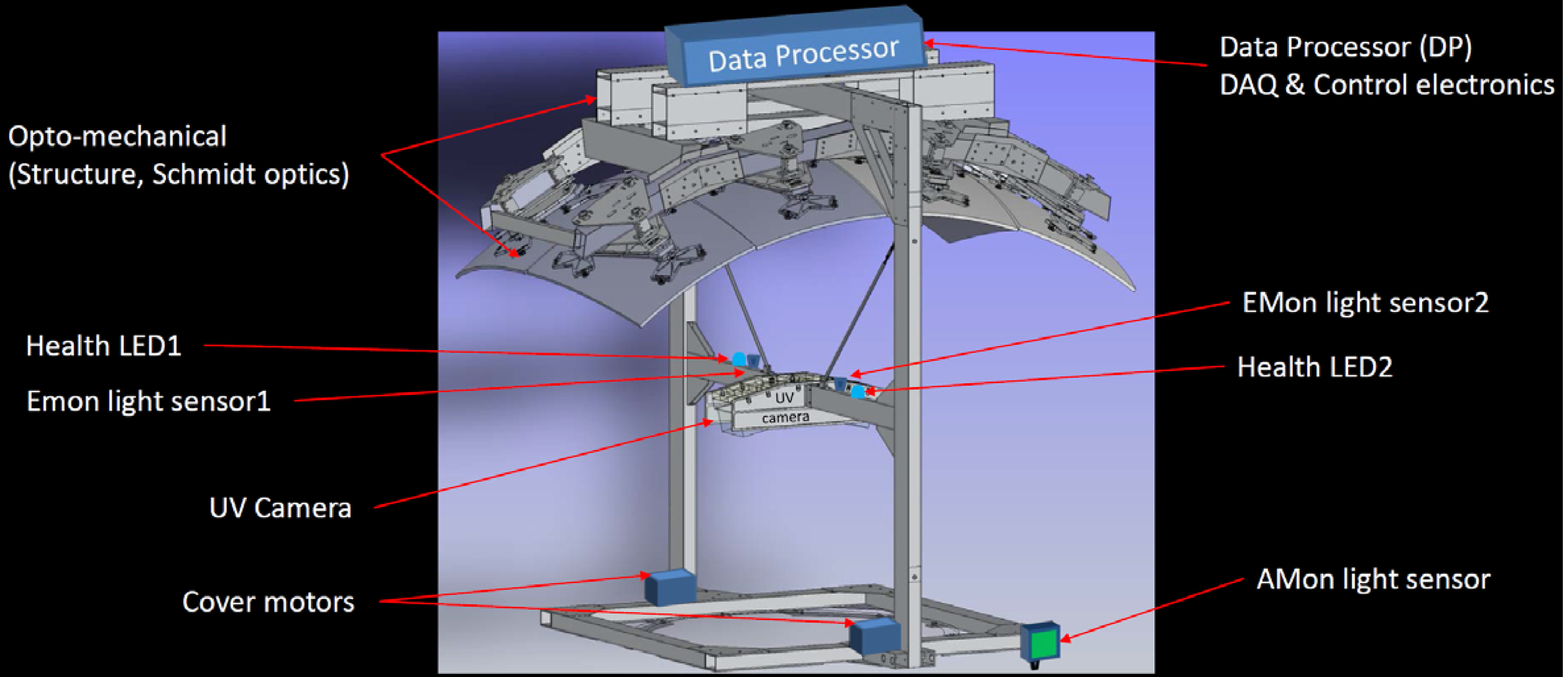
  We showed through simulation that we will be able to record 0.12 EASs with FT. We also could show that we will be able to record thousands of direct cosmic ray with the CT. In addition we could show that EUSO-SPB2 has sensitivity to neutrinos from astrophysical transient events.

- *Other contributions for EUSO-SPB2*

  389, 403, 330, 490, 614, 489, 867, 1002, 248

The Fluorescence Telescope on board EUSO-SPB2 for the detection of Ultra High Energy Cosmic Rays

- Second-generation instrument
- Status of the art for this kind of technology
- With respect to the telescopes which flew on previous missions, upgrades introduced on
  - Optics (Schmidt telescope) → lower energy threshold
  - Focal surface
    - 3 times larger → greater collection power
    - shorter temporal resolution 1 µs → lower energy threshold
  - General architecture (redundancy, lower dead time) → greater collection power
- The telescope should allow for the first observation of extensive air showers using the fluorescence technique from suborbital space
- It is an important step to demonstrate the possibility to study Ultra High Energy Cosmic Ray from Space.
- The construction of the telescope sub-systems is now underway and the whole instrument is on the way for a scheduled launch in early 2023 from Wanaka, New Zealand.



Discussion session 07 - CRI: Where to go in UHECR observations?

Detection of Above the Limb Cosmic Rays in the Optical Cherenkov

Prospects for Cross-correlations of UHECR Events with Astrophysical Sources with Upcoming Space-based Experiments

T. M. Venters[1] and A. Romero-Wolf[2] on behalf of the POEMMA and ZAP Collaborations

Background

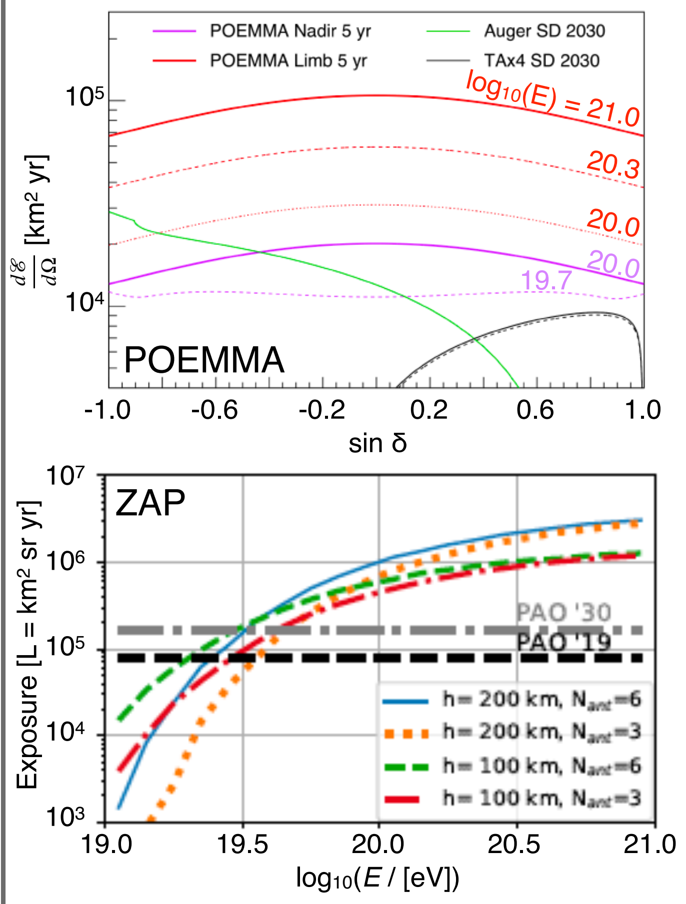
- Sources of ultra-high energy cosmic rays (UHECRs) remain elusive
- Magnetic fields that deflect UHECRs remain poorly understood, though expect weaker deflection at the highest energies
- Expect UHECR sky distribution to exhibit anisotropy suggestive of underlying source population and possibly even hotspots
- A common test for UHECR anisotropy cross-correlates UHECR arrival directions with astrophysical catalogs
    - ≥ 4.5σ correlation above ~40 EeV with nearby starburst galaxies reported by Auger
- POEMMA and ZAP will monitor large target volumes from space in order to detect UHECR showers:
    - ➢ *Unprecedented UHECR exposures with full-sky coverage*
    - ➢ *5σ discovery reach for many astrophysical scenarios*

Method

Objectives

- Objective 1: For a given number of UHER events and a given astrophysical scenario, determine average significance of cross-correlation with astrophysical catalog.
- Objective 2: For a given astrophysical scenario, determine the number of events needed to guarantee a 5σ detection of the cross-correlation.

Likelihood Test for Cross-correlations



- Construct mock UHECR datasets w/ params.$(N_{\rm ev}, f^*_{\rm aniso}, \Theta^*)$:
    - $N_{\rm ev}$ from exposure or left free
    - $f^*_{\rm aniso}$ fraction of aniso. events
    - Θ^* smearing angle
- Construct astrophys. hypothesis maps, $\mathscr{F}_{\rm sky}$, w/ params. $(f_{\rm sig}, \Theta)$:

exposure

UHECR flux from sources

$$\mathscr{F}_{\rm sky}(\hat{n}) = \frac{\omega(\hat{n})}{\mathscr{C}}\left[(1-f_{\rm sig})\frac{1}{4\pi} + f_{\rm sig}\mathscr{F}_{\rm src}(\hat{n})\right]$$

normalization

- Compute TS for each $(f_{\rm sig}, \Theta)$:

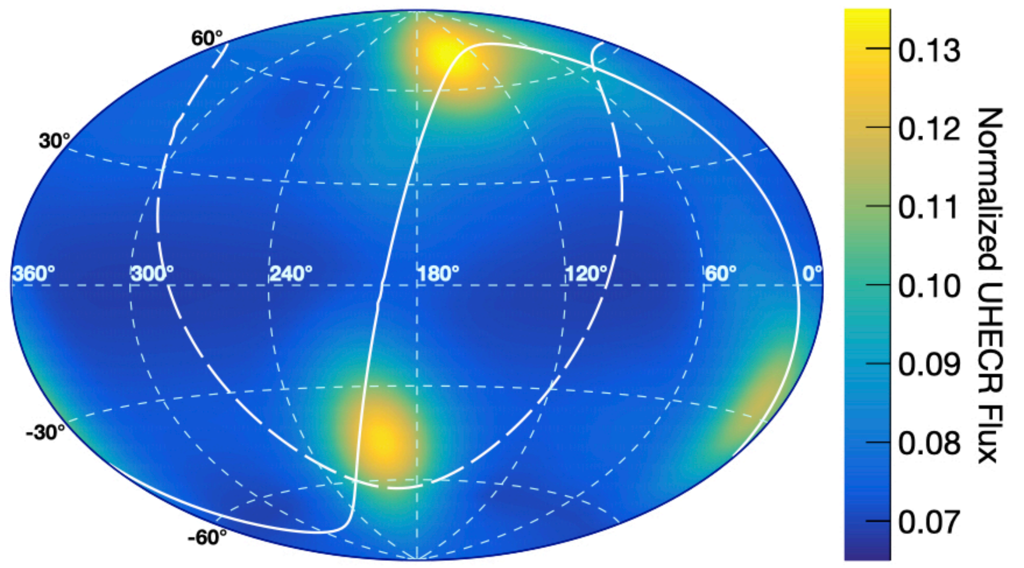
$$\mathrm{TS} = 2\ln\left(\frac{L(\mathscr{F}_{\rm sky})}{L(\mathscr{F}_{\rm iso})}\right)$$

likelihood

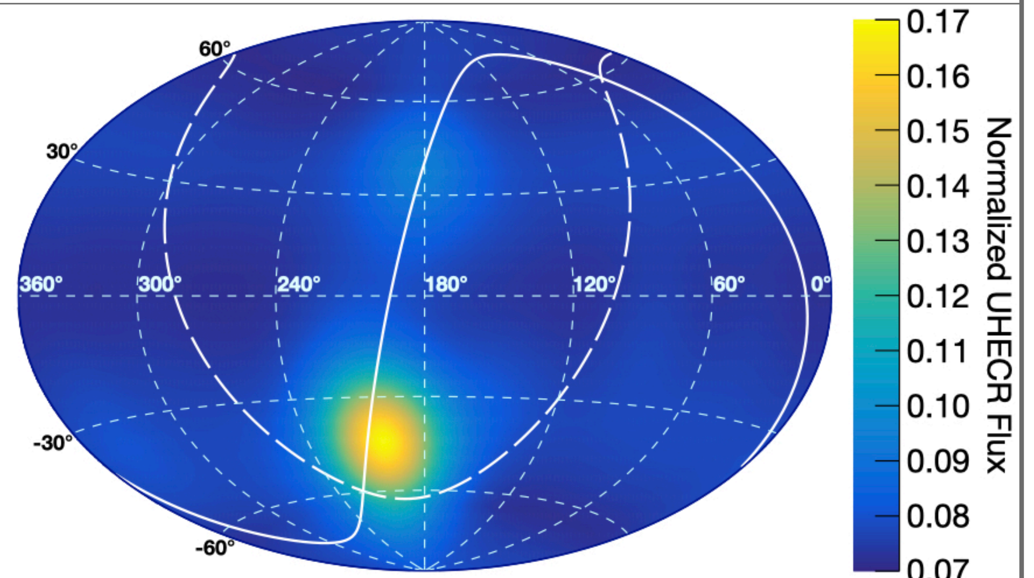
- Obj. 1: Compute average TS values, find maximum, compute significance
- Obj. 2: Construct TS distributions for mock and isotropic datasets; compute req. $N_{\rm ev}$ to distinguish at level of 5σ

Results

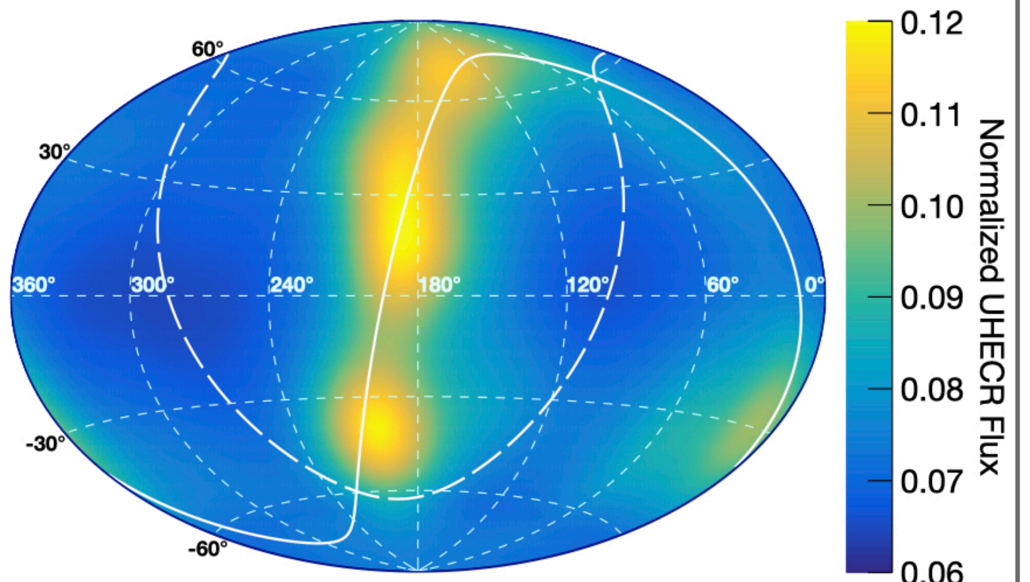
*UHECR Flux Sky Plots**



Starburst Galaxies



Swift-BAT AGN

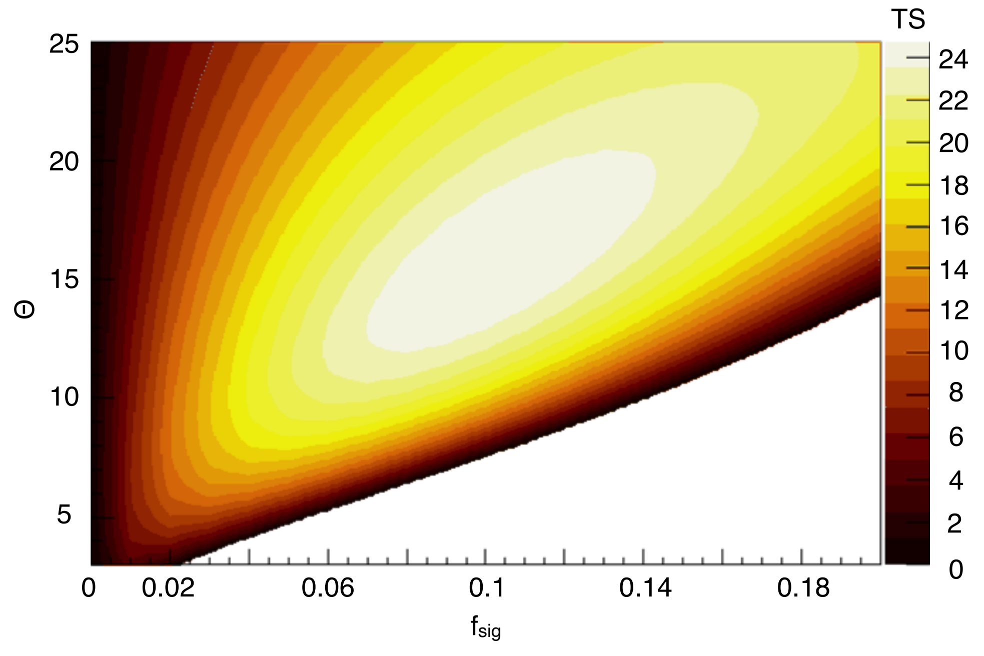


Distribution of UHECR flux for astrophysical scenarios motivated by maximum likelihood parameters reported by Auger.

*Sky Plots in Equatorial Coordinates

2MASS Redshift Survey

Cross-Correlation Significances



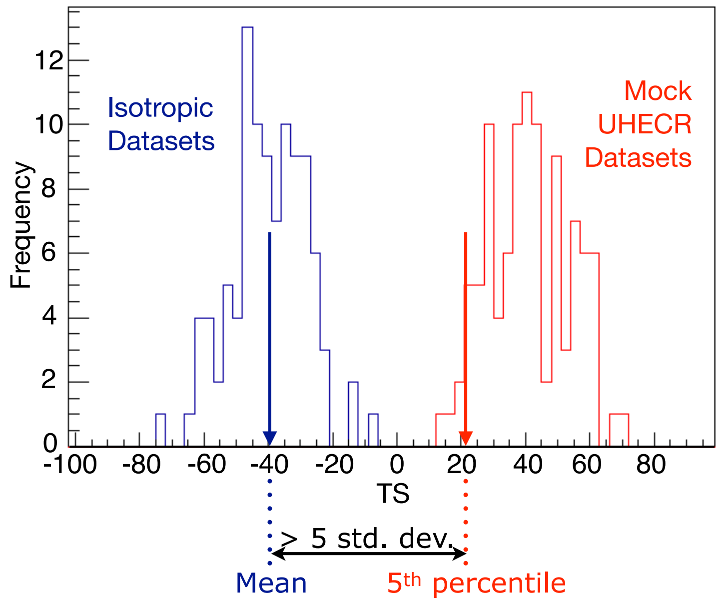
Example TS Map

Catalog	$f_{\rm sig}$	TS	σ
SBG	5%	6.2	2.0
	10%	24.7	4.6
	15%	54.2	7.1
	20%	92.9	9.4
2MRS	5%	2.4	1.0
	10%	8.7	2.5
	15%	20.0	4.1
	20%	35.2	5.6
Swift-BAT AGN	5%	10.4	2.8
	10%	39.6	6.0
	15%	82.4	8.8
	20%	139.3	11.6

TS and σ values for astrophysical scenarios w/ Θ = 15° and $N_{\rm ev}$ = 1400 (5 yrs. of POEMMA Stereo-precision)

Results (cont.)

Events Requirement



Parameter		$N_{\rm ev}$ Required		
$f_{\rm sig}$	Θ	AGN	SBG	2MRS
10%	20°	1240	2060	>5000
	15°	920	1910	4830
15%	20°	680	1000	2550
	15°	660	870	2280
20%	20°	<650	<650	1520
	15°	<650	<650	1320

Determine $N_{\rm ev}$ such that 5th percentile of mock dataset separated by more than 5 std. devs. from mean of isotropic datasets.

	POEMMA	ZAP
Energy Resolution	$\leq 18\%$ above 50 EeV	$< 30\%$
Angular Resolution	$< 1.5°$ above 40 EeV	$1° - 4°$

Parameter values represent astrophysical scenarios convolved with detector characteristics, such as ang. resolution and energy resolution. Different experiments can expect different parameter values, leading to different requirements for the number of events.

Conclusions

- POEMMA and ZAP will achieve unprecedented UHECR exposures in ~ few years.
- Both will have full-sky coverage, providing them access to regions of the sky that are inaccessible for ground-based expts.
- Both will achieve 5σ discovery reach for many plausible astrophysical scenarios.

References

[1] The POEMMA Collab., 2021, JCAP, 06, 007
[2] Romero-Wolf, A., et al., 2021, PoS (ICRC2021), 403
[3] Anchordoqui, L. A., et al., 2020, PRD, 101, 023012
[4] Pierre Auger Collab., 2018, ApJL, 853, 29
[5] Telescope Array Collab., 2018, ApJL, 867, 27
[6] Caccianiga, L., et al., 2019, PoS (ICRC2019), 206
[7] Verzi, V., et al., 2019, PoS (ICRC2019), 450

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[1]NASA Goddard Space Flight Center, [2]Jet Propulsion Laboratory/Caltech

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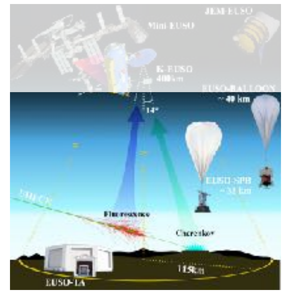

Discussion session 07 - CRI: Where to go in UHECR observations?

Discussion session 07 - CRI: Where to go in UHECR observations?

- **How to proceed at the highest energies?**
- **What is needed to find and study the sources of UHE particles?**
- **Complementarity ground - space**
- **What will be the most important questions in multi-messenger astroparticle physics in the next decade?**
- **What will be the biggest challenges in the next decade?**
  - **understanding the effects of Galactic and extragalactic B fields**
  - **interaction properties (extragalactic, Galactic, atmosphere)**
  - **multi messenger connections (CRs, GAs, NUs)**
  - **how to include GW sources?**
  - **….**
  - **….**