Joint Experiment Missions-
Extreme Universe Space Observatory

Mini-EUSO

Implications of Mini-EUSO measurements for a space-based observation of UHECRs

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for the JEM-EUSO Collaboration

6th UHECR symposium, L'Aquila

JEM-EUSO

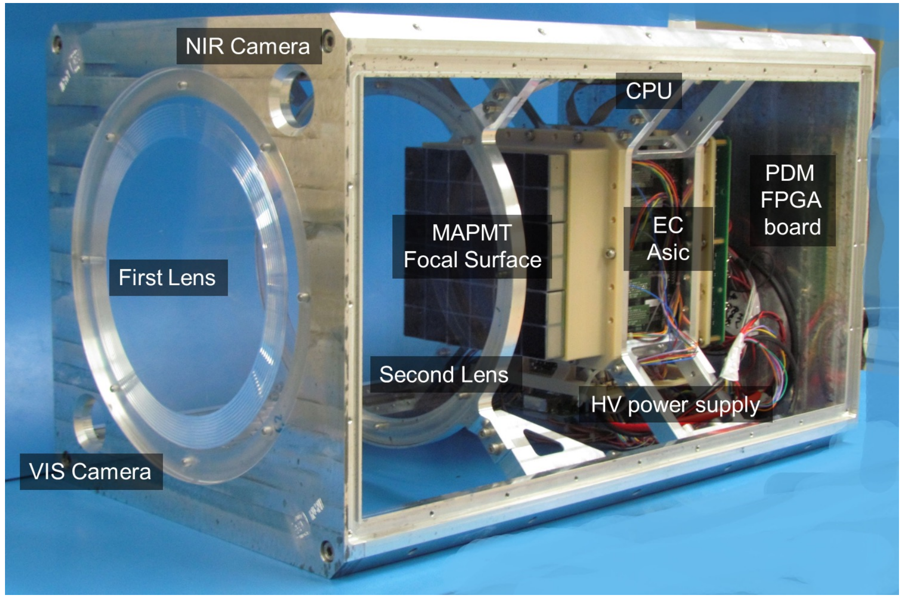
Introduction

In the following JEM-EUSO will be considered for comparisons as Mini-EUSO was designed as a small scale version of JEM-EUSO.

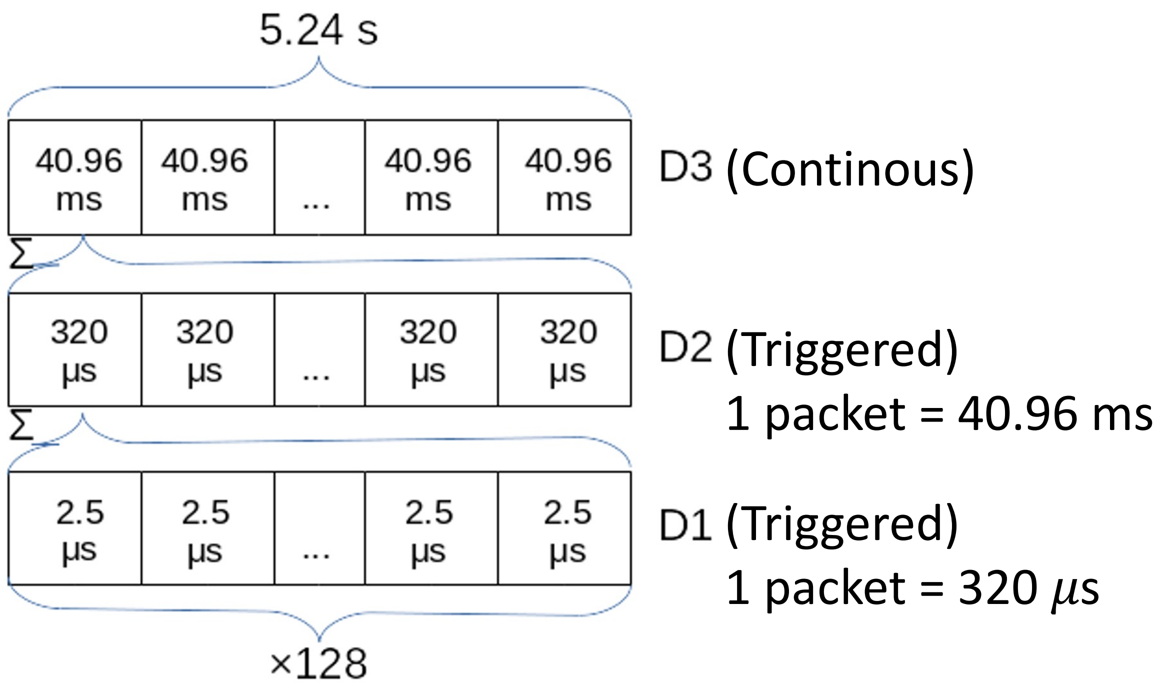
The results apply to K-EUSO and POEMMA as well as the exposure curves and the EAS detection principle of these two instruments have been obtained using the same approach and tools (ESAF simulation and reconstruction framework) originally developed for JEM-EUSO.

The results presented in the following have to be considered still PRELIMINARY (limited data sample and still on going analyses).

Data acquisition system of Mini-EUSO



Used in the following discussion



Mini-EUSO time resolution

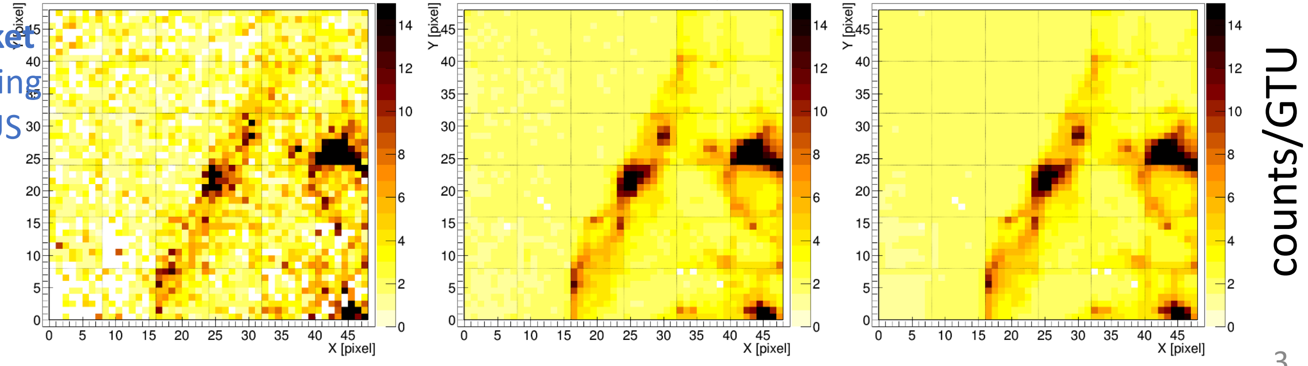
Single GTU / packet resolution assuming ~1 count/pix/GTUS

Views of the Indian coast

Stat. error ~100/10%

Stat. er. ~10/1%

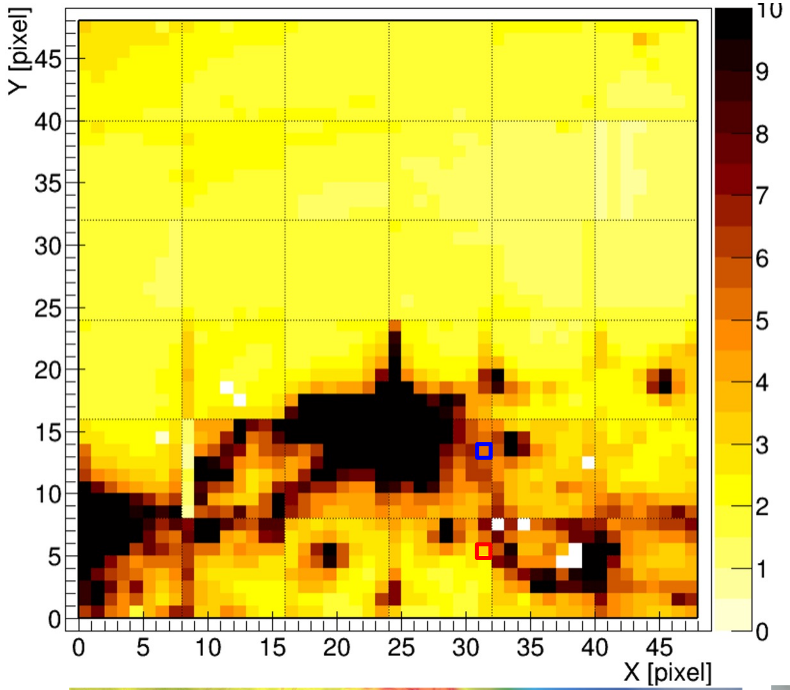
Stat. er. ~1/0.1%



M. Battisti D1 D2 D3

Mini-EUSO end-to-end calibration

See poster H. MIYAMOTO



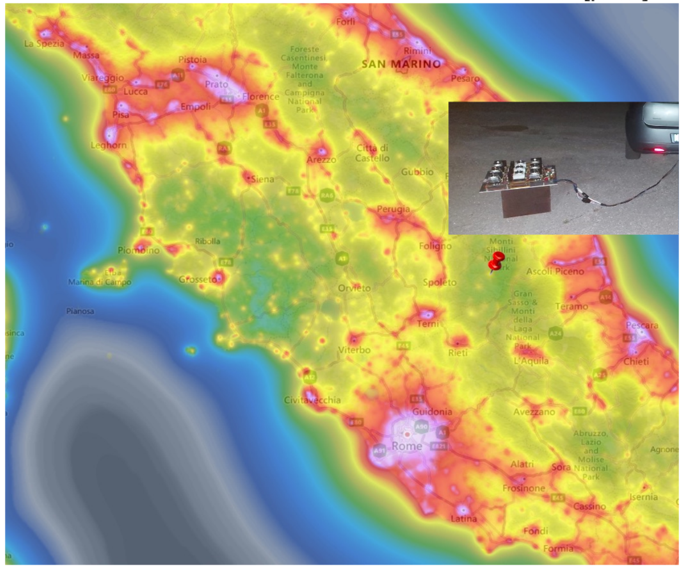
Considered in the following

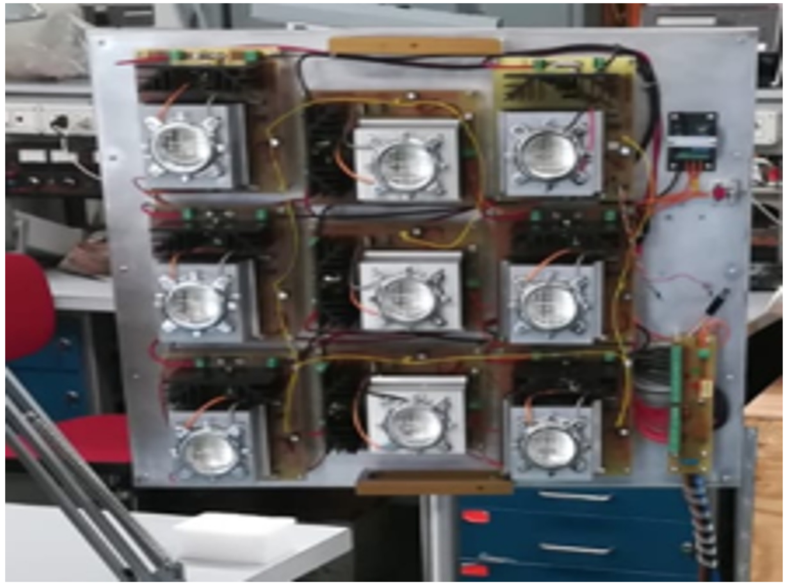
$$Eff_{ME} = \frac{n_{phe}^{detected}}{n_{photons}^{window}} = \frac{9.7}{120.4} = (8.0 \pm 1.5)\%$$

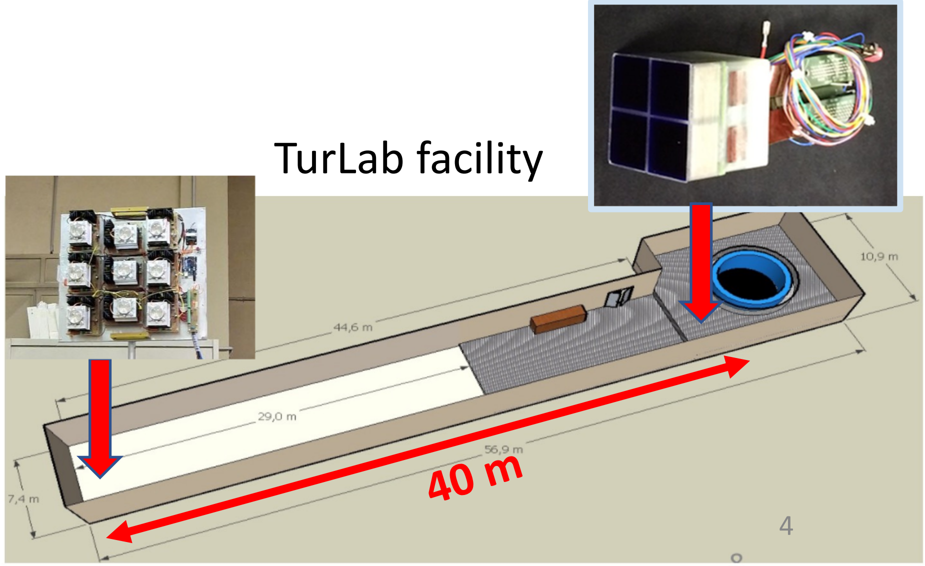
PRELIMINARY

$$Eff_{ME} = \frac{n_{phe}^{detected}}{n_{photons}^{window}} = \frac{8.3}{139.3} = (6.0 \pm 1.1)\%$$

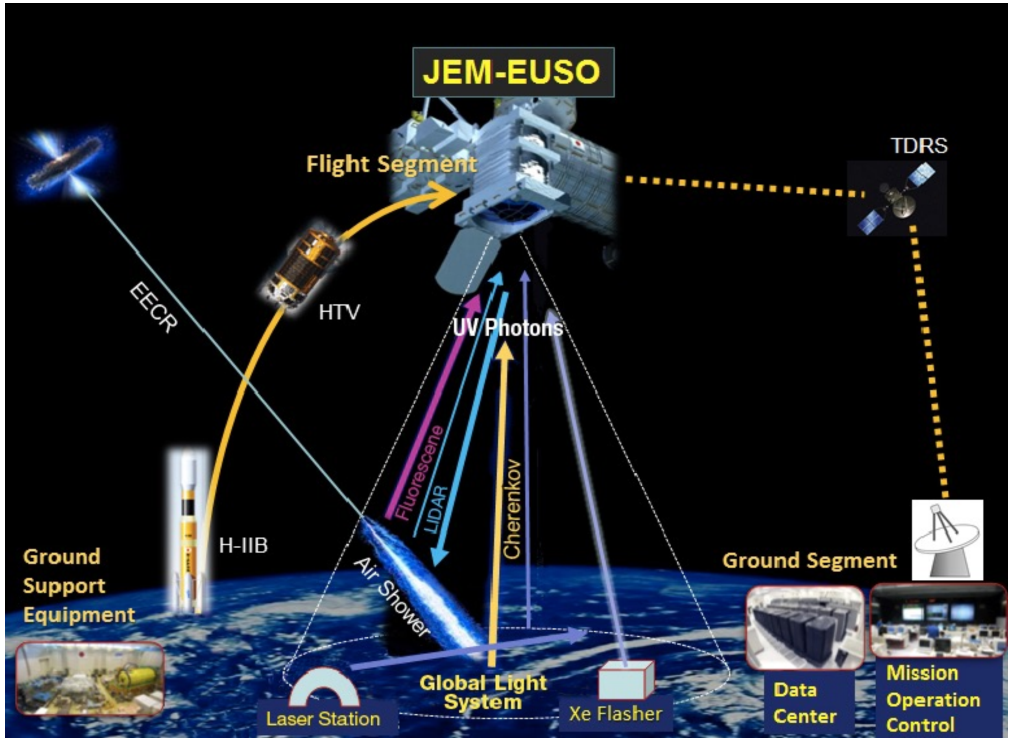
$$n_{photons}^{window} = n_{photons}^{TurLab} \times Angular_{lens} \times Abs_{atm} \times \frac{Area(ME)}{Area(To\text{-}EC)} \times \left(\frac{Distance(To\text{-}EC)}{Distance(ME)}\right)^2 \times cos(\theta)$$

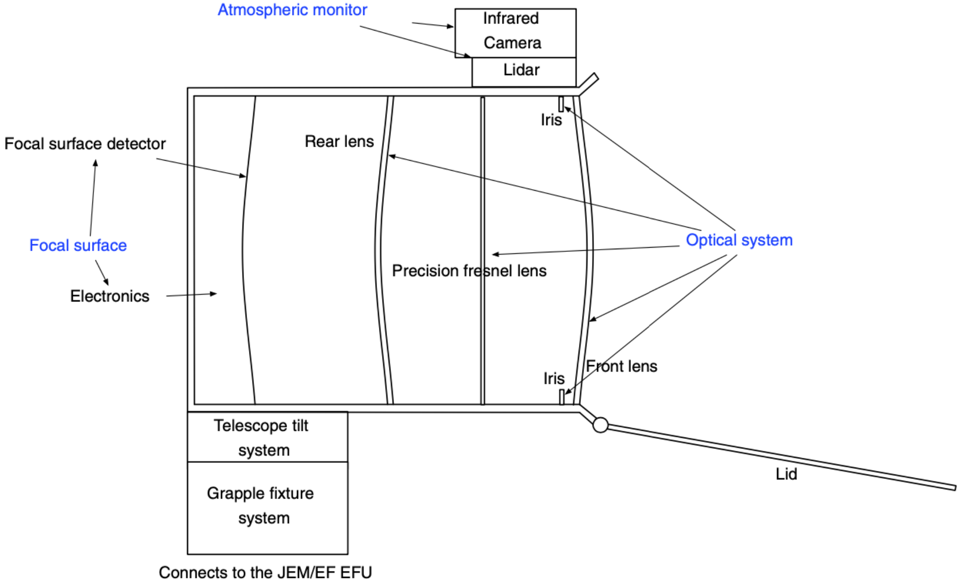


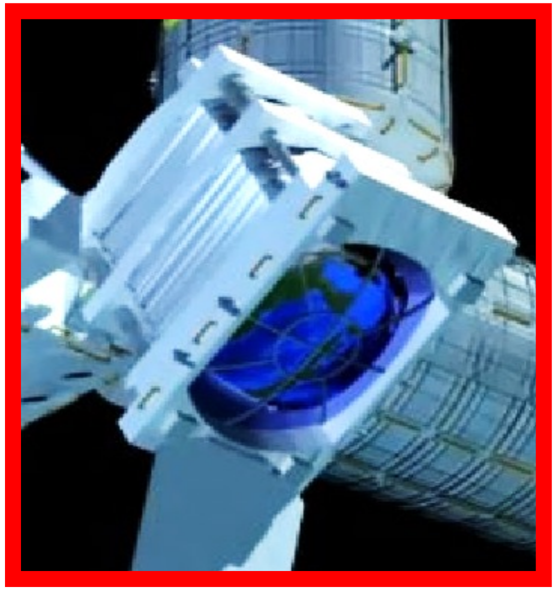




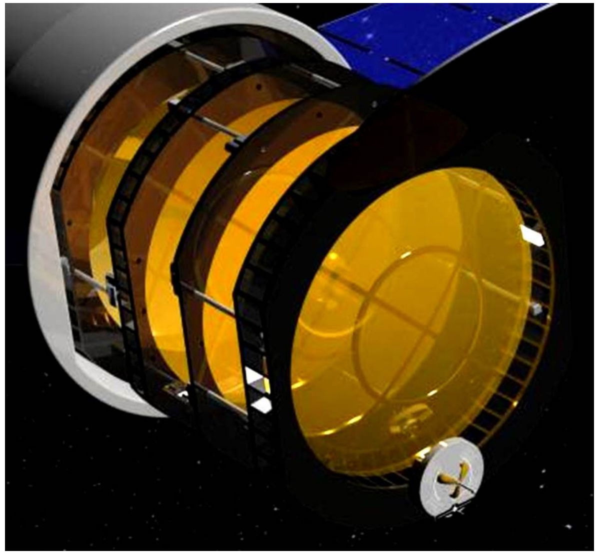
JEM-EUSO



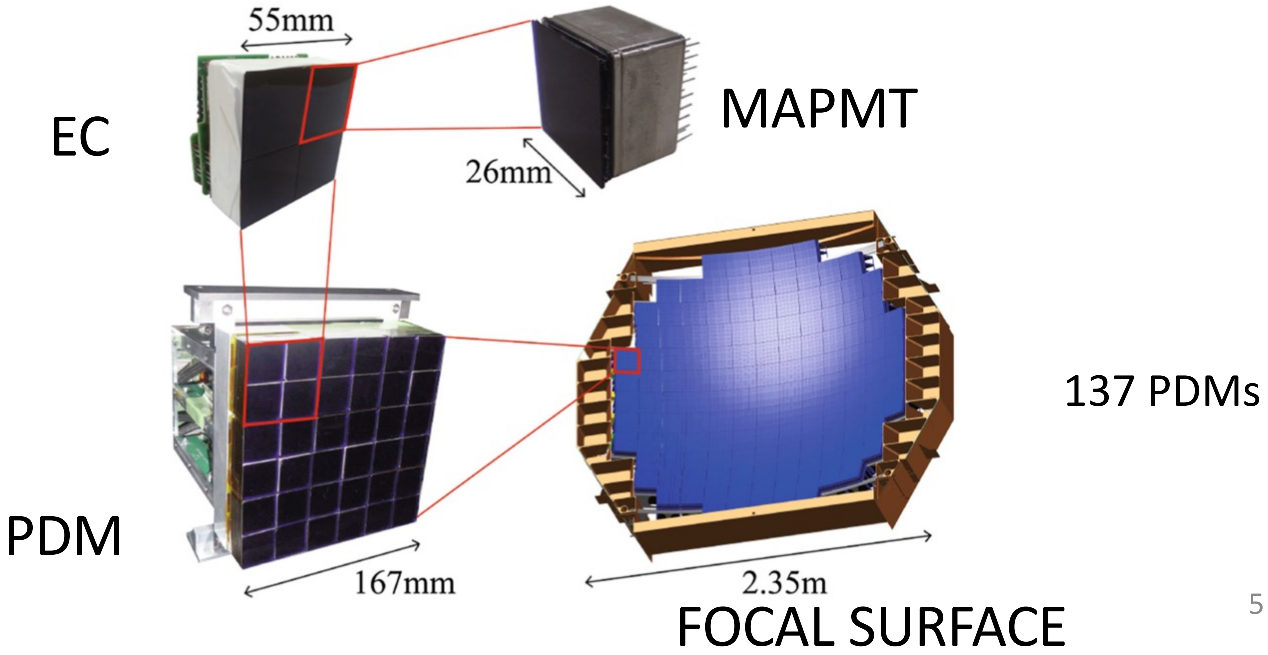




HTV configuration

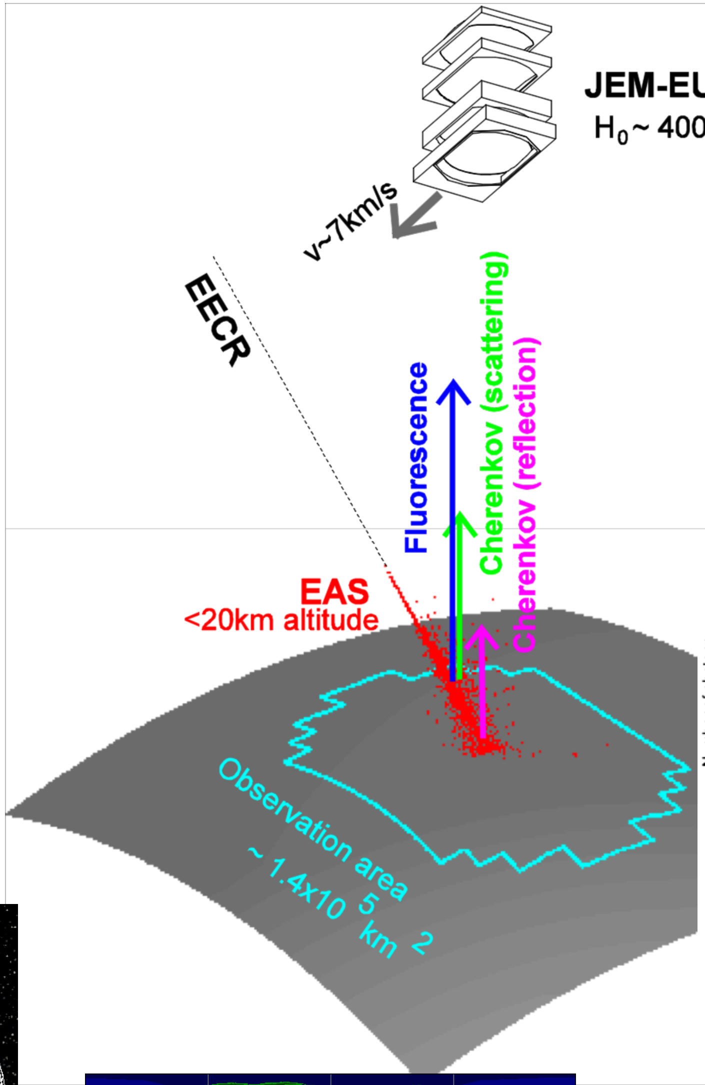


Dragon configuration

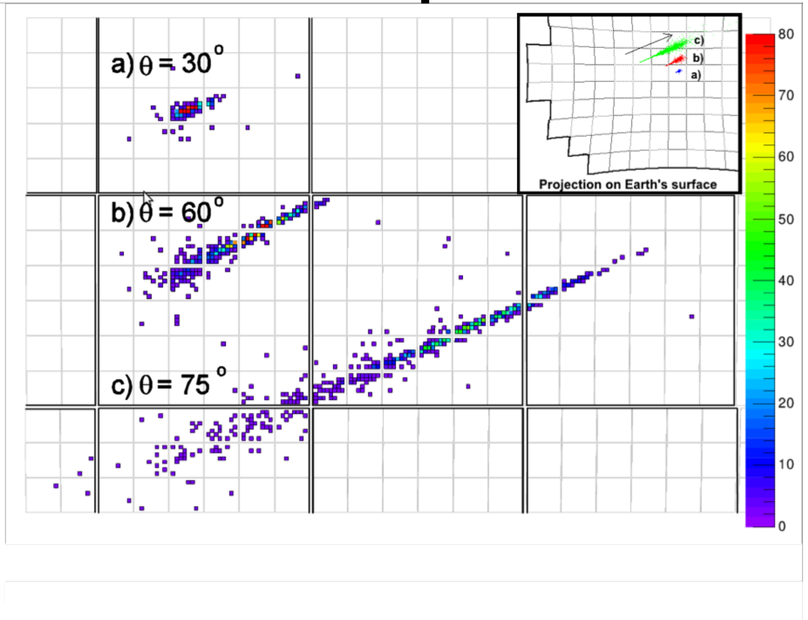


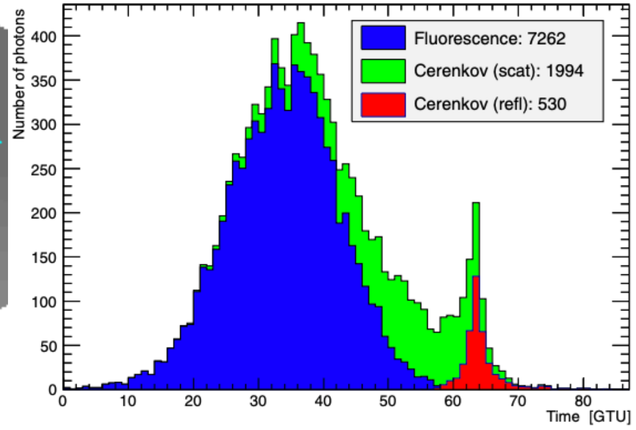
JEM-EUSO Observation Principle

JEM-EUSO Coll.
Astrop. Phys.
44 (2013) 76

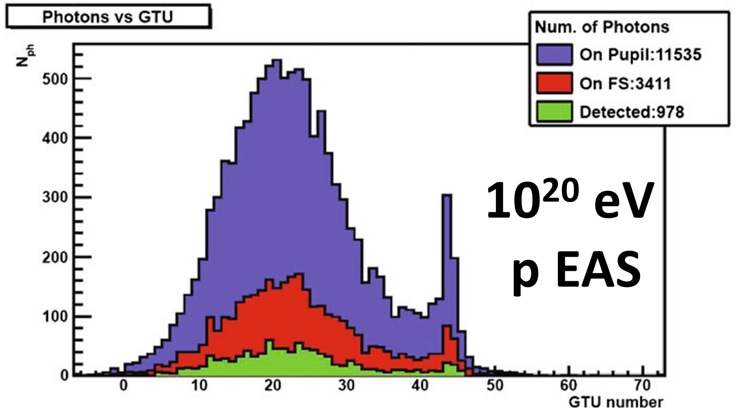


Counts/GTU





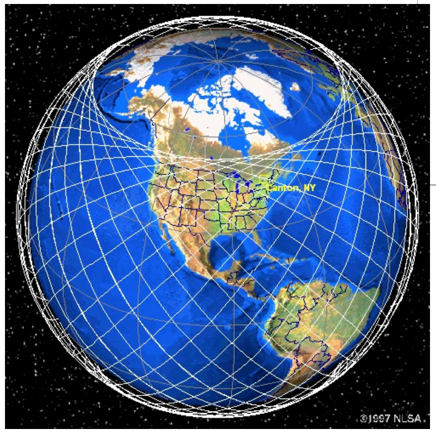
Δt ~ 50 - 150 μs

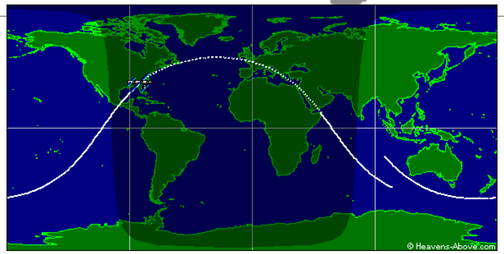


10^{20} eV
p EAS

Δt ~ 20 - 60 GTUs

(1 GTU = 2.5 μs)



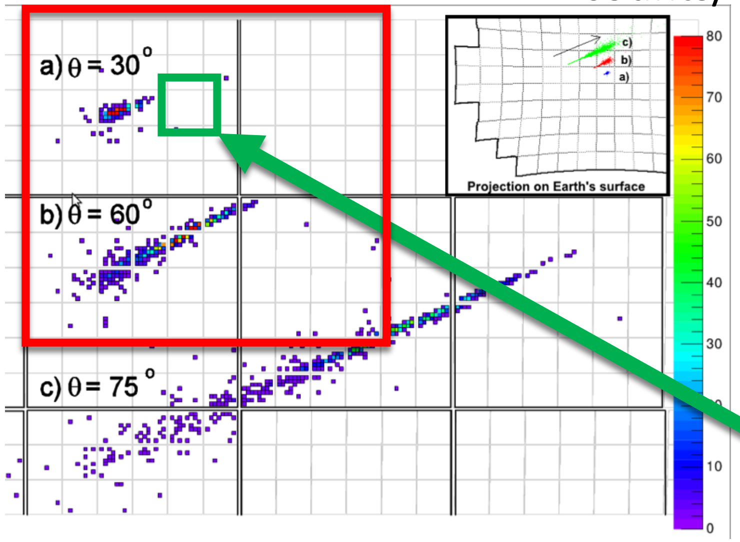


JEM-EUSO & Mini-EUSO

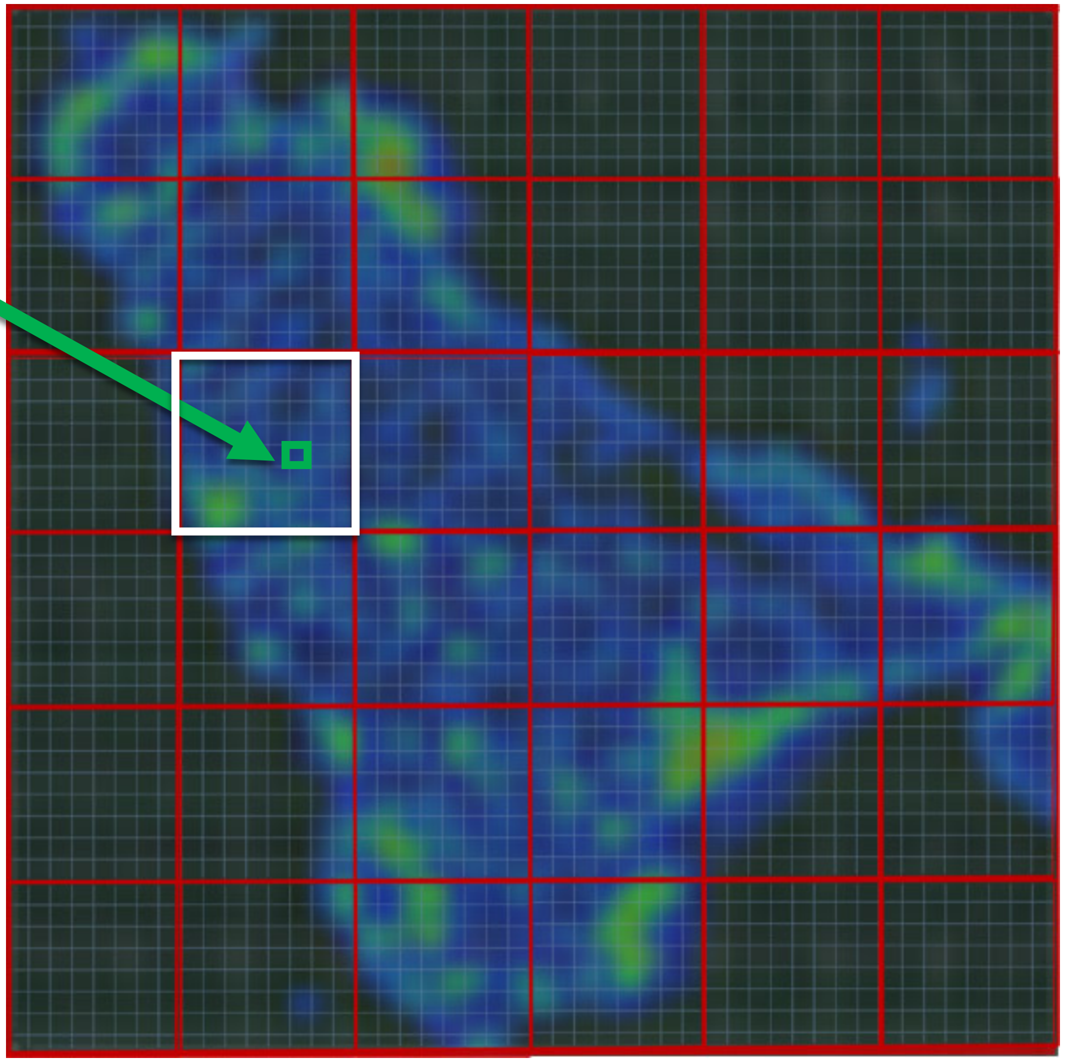
JEM-EUSO

FoV

counts/GTU



Mini-EUSO



Simulation pre-flight

Comparison @ order of magnitude level

	Mini-EUSO	JEM-EUSO
	~1 pixel	~ 1.5 MAPMT
	~1 PMT	~ 3 PDM
Spatial resolution	**~6.3 km**	**~0.55 km**
Optics aperture	**~0.05 m²**	**~4.5 m²**

Similar counts/pixel from diffuse light in JEM-EUSO & Mini-EUSO

x100 light in JEM-EUSO from point-like sources

K. Shinozaki

Expected diffused UV light ratio between JEM-EUSO and Mini-EUSO by means of ESAF simulations

- JEM-EUSO: expected performance according to J.H. Adams et al. Astrop. Phys. 44, 76-90 (2013)
- Mini-EUSO: overall efficiency **(8.0 ± 1.5)% @ 397 nm for point-like source** (see H. Miyamoto's poster)
- Flat diffused UV emission in the range λ = 300 – 400 nm

JEM-EUSO @ 500 photons/(ns sr m²)
0-60 degrees simulation: 1.31 CTS/pixel/GTU
0-30 degrees simulation: 1.02 CTS/pixel/GTU

Mini-EUSO @ 500 photons/(ns sr m²)
0-60 degrees simulation: 1.33 CTS/pixel/GTU
0-22 degrees simulation: 0.98 CTS/pixel/GTU

$$\chi = \frac{N_{CTS}}{N_{ph}} \frac{\Omega_{simu}}{\Omega_{det}} \frac{A_{simu}}{A_{det}}$$

From simulations: ratio of single pixel counts (N_{CTS}) to photon number on pupil (N_{ph}).

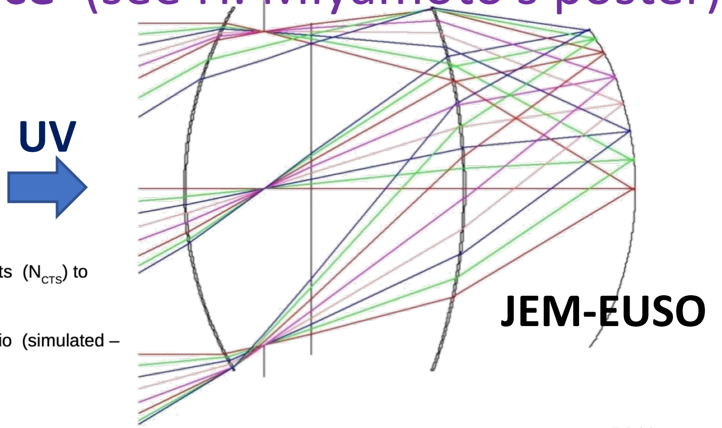
Normalization with solid angle and area ratio (simulated – Ω_{simu} vs. detector – Ω_{det})

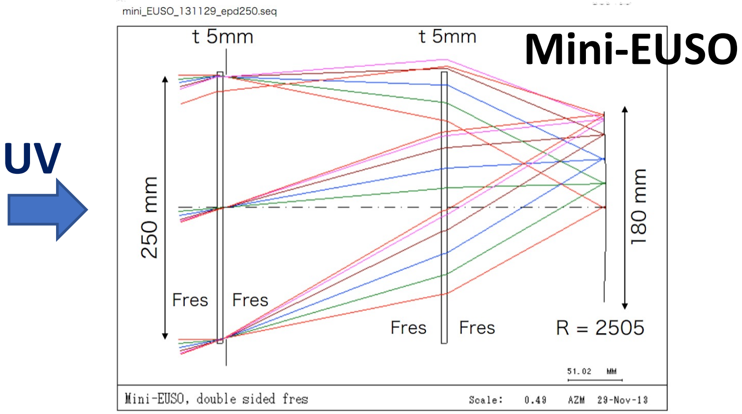
$$N_{expect} = \chi * R * \Delta t * A_{det} * \Omega_{det}\, \eta$$

Expectation of count number
R: Radiance
Δt: time
A: area of pupil
Ω_{det}: solid angle field of view

$$\eta = \frac{\int d\theta \sin(\theta)\cos(\theta)}{\int d\theta \sin(\theta)}$$

Correction to account for planarity of the lens

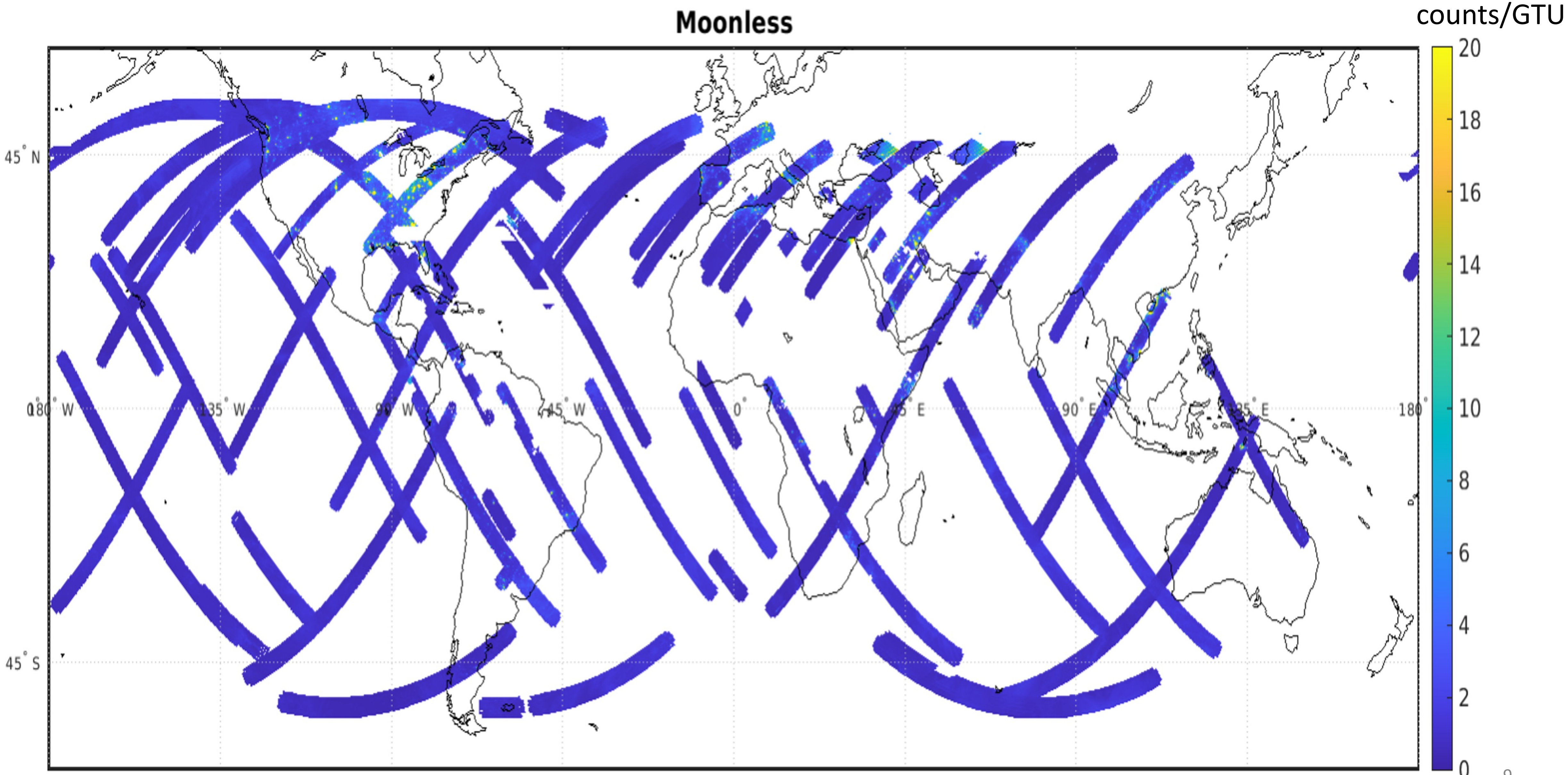




F. Fenu

Very similar UV background expected for Mini-EUSO and JEM-EUSO

UV maps: moonless conditions



K. Bolmgren

The real-time atmospheric conditions

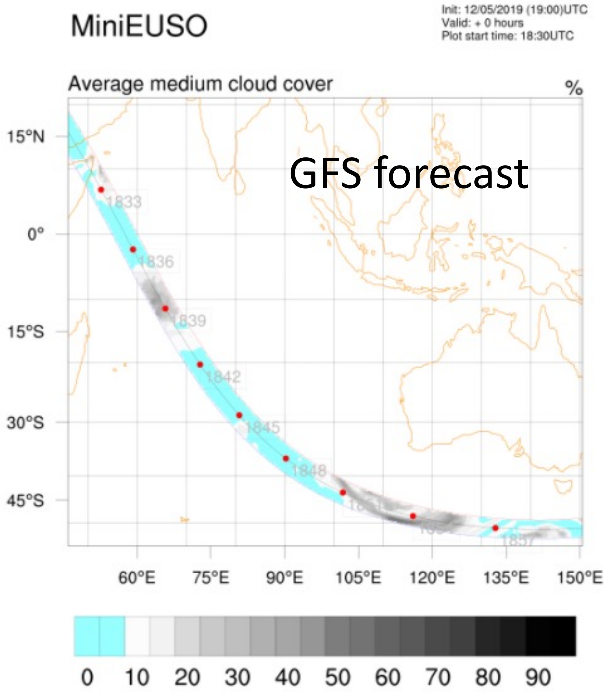
The analysis is the state of the atmosphere at a defined time (e.g. 12 UTC of 16th June 2020). The global model data assimilation system builds the analysis, collecting all the atmospheric observations (satellite, weather stations, boats, airplanes, …) in the previous 3 to 6 hours. The **Global Model is trained** during this period, and afterwards, it starts from the analysis to calculate the weather foreca

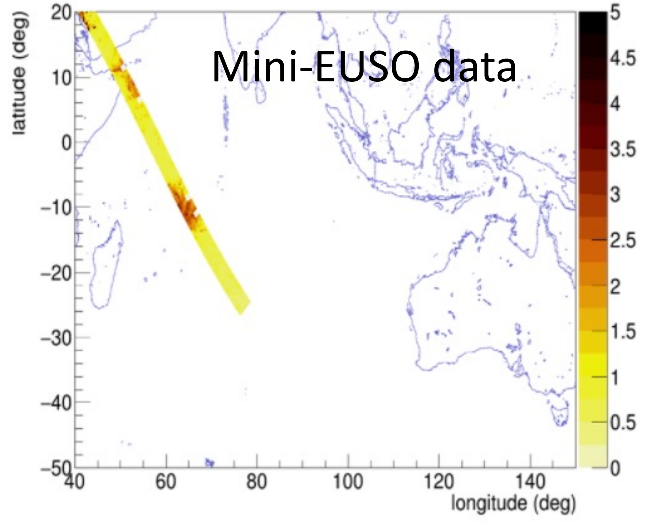
GFS Global Forecast System

Initial time:
18 UTC and 0 UTC

Forecasts Each 1 hour

Analysed data available at 10 UTC of the flight day (4 hours after the end of acquirement)





A. Golzio

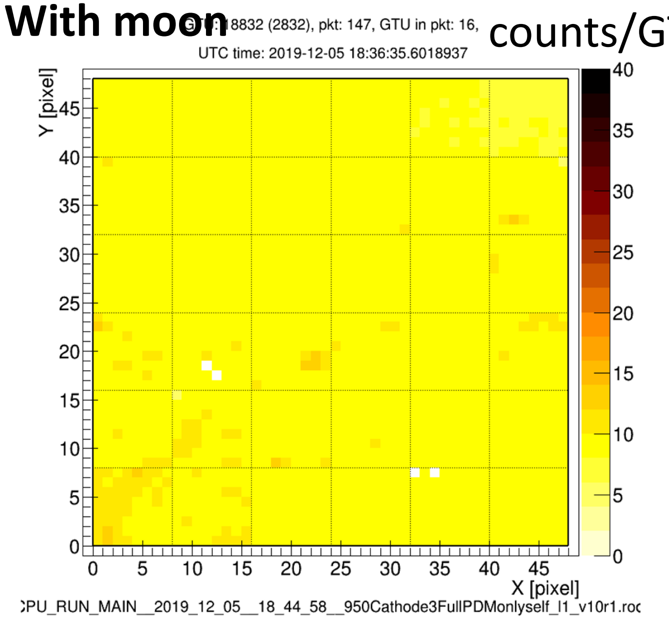
Atmospheric quantities

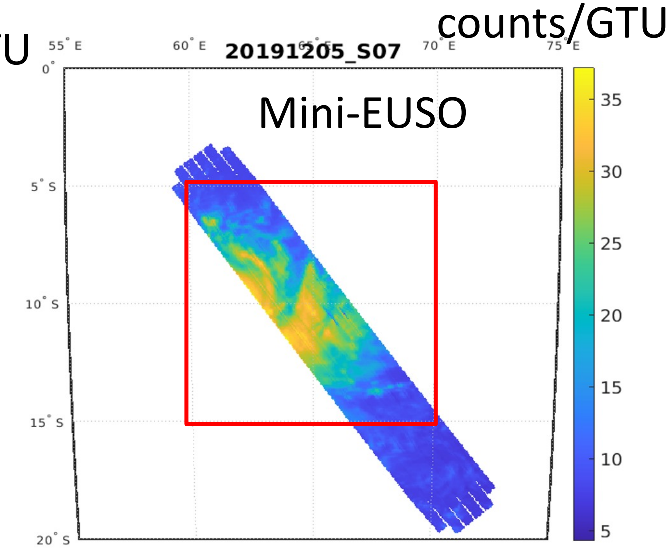
1. Thermodynamic profiles of the atmosphere
2. Spatial maps of the neighbourhood zones

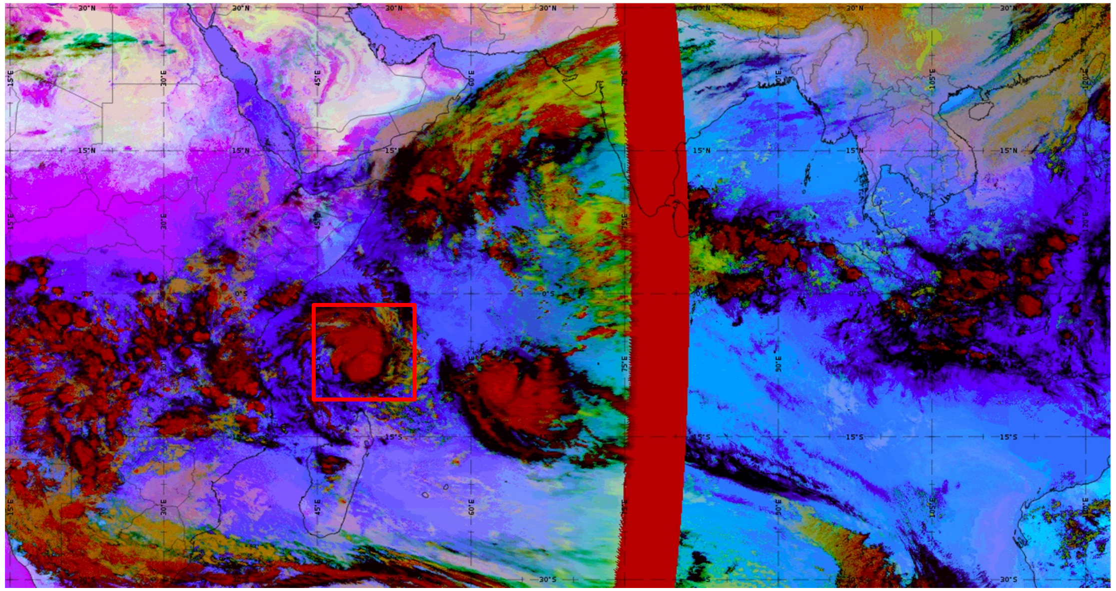
Potential temperature profile, humidity, optical depth
Cloud fraction, CAPE, Cloud-top temperature, convection

Cloud monitoring → Important for exposure estimation

With moon

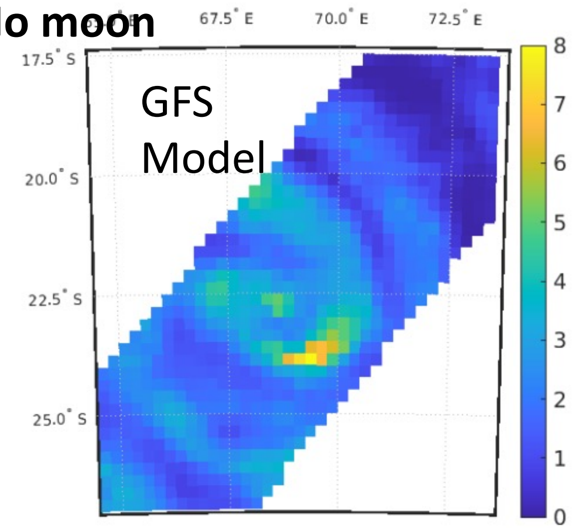


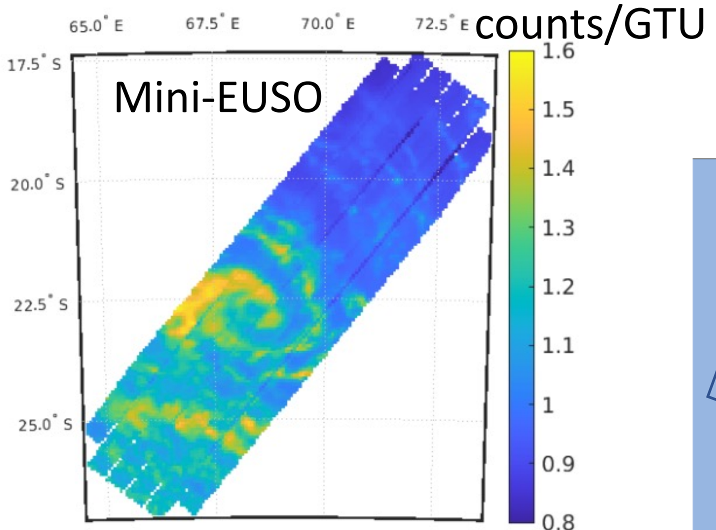




Circular cloud event over the Indian Ocean. Satellite data from *Himawari* satellites.

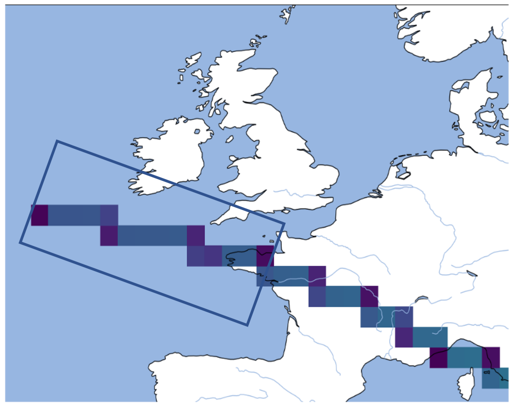
No moon

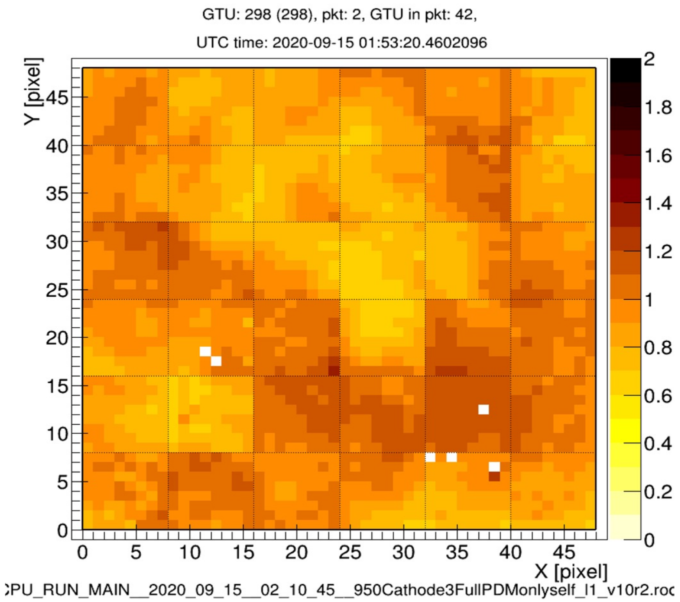




Cyclon near Mauritius Islands.

Celtic sea, off the coast of England





M. Battisti, K. Bolmgren, A. Golzio

Moonless conditions

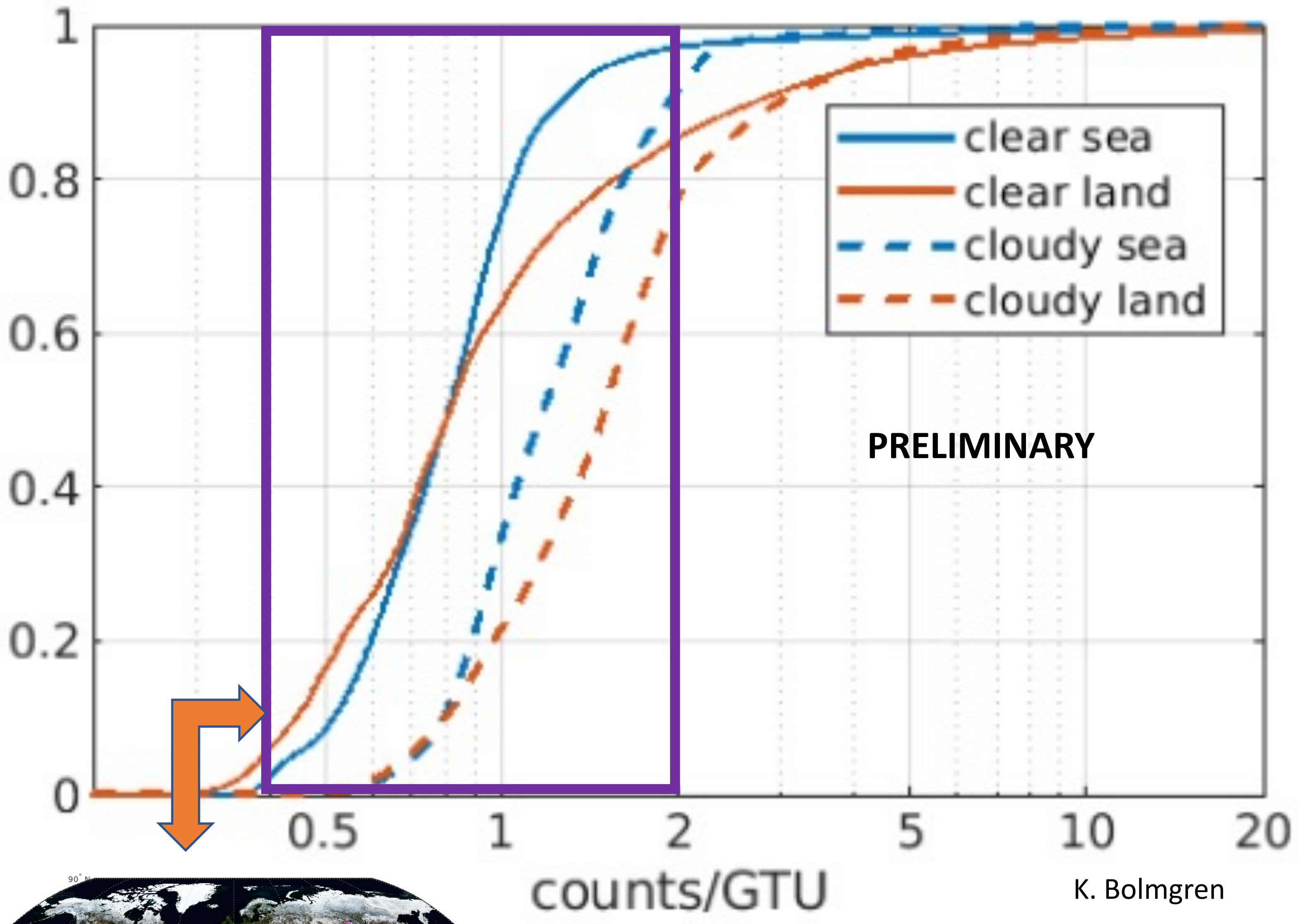
From literature UV background in 300 – 400 nm:
300 – 1000 ph/m^2/ns/sr

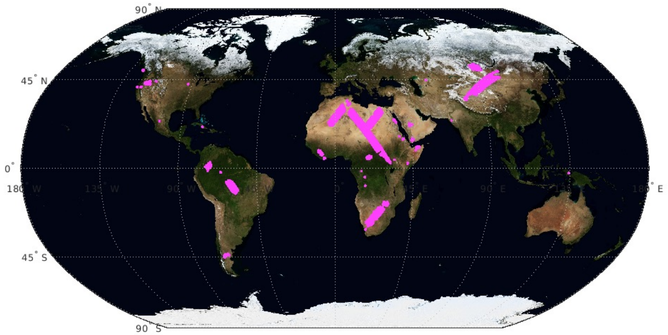
In Mini-EUSO >90% of the time in clear sea conditions **[0.4;2.0]** counts/pix/GTU; **median ~0.8 counts/pix/GTU** (for clear sea/land).
This is consistent with:
~0.8-1 count/pix/gtu → 500 ph/m^2/ns/sr

In clear land conditions higher chance of very low counts. These are associated with deserts and forests

If we assume that >2 counts in cloudy land means presence of city lights: ~20% time. 20%x30% land coverage: ~6% city light contribution

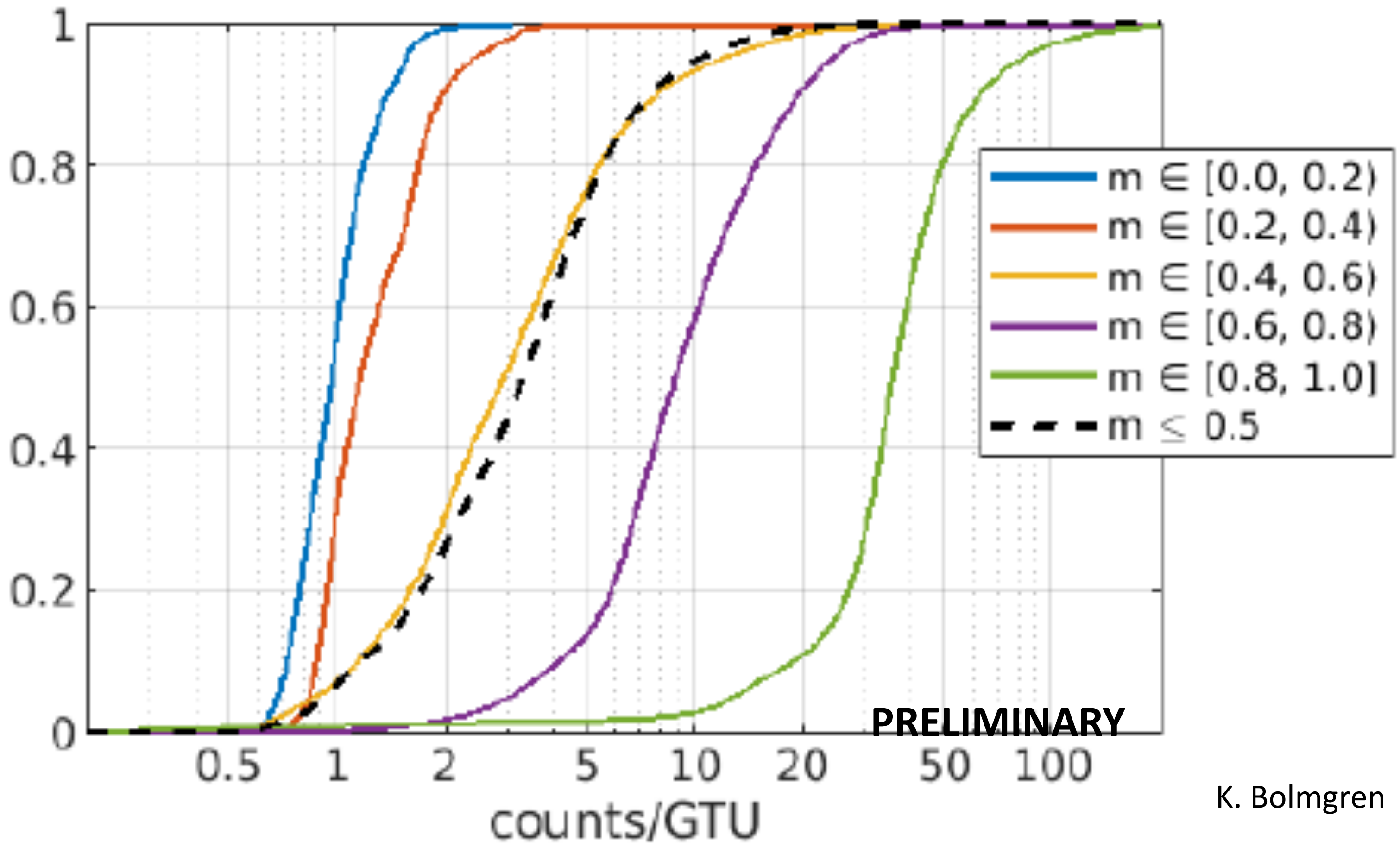
Cloudy conditions typically shift curves by 1.5 (sea) – 2 (land) the curves
(already seen in EUSO-Balloon/SPB1)





From Mini-EUSO estimations:
@ λ= 395 nm, 1 count/pix/GTU = (620 ± 110) ph/m^2/ns/sr

With Moon:

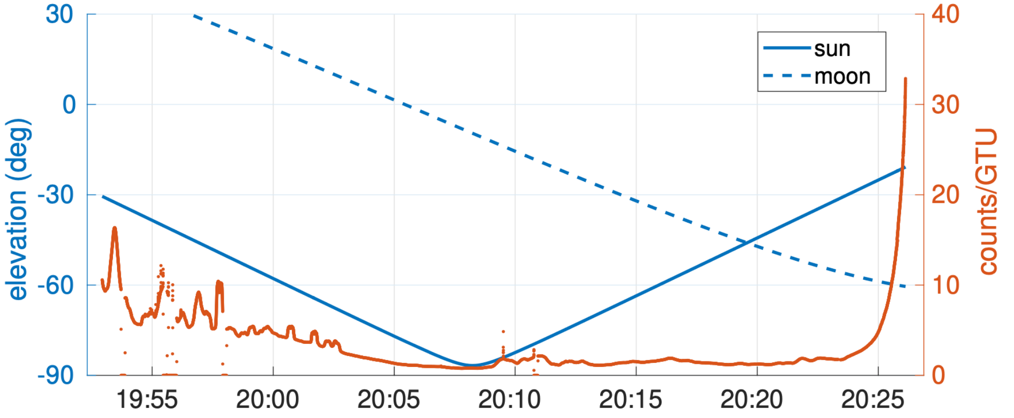


K. Bolmgren

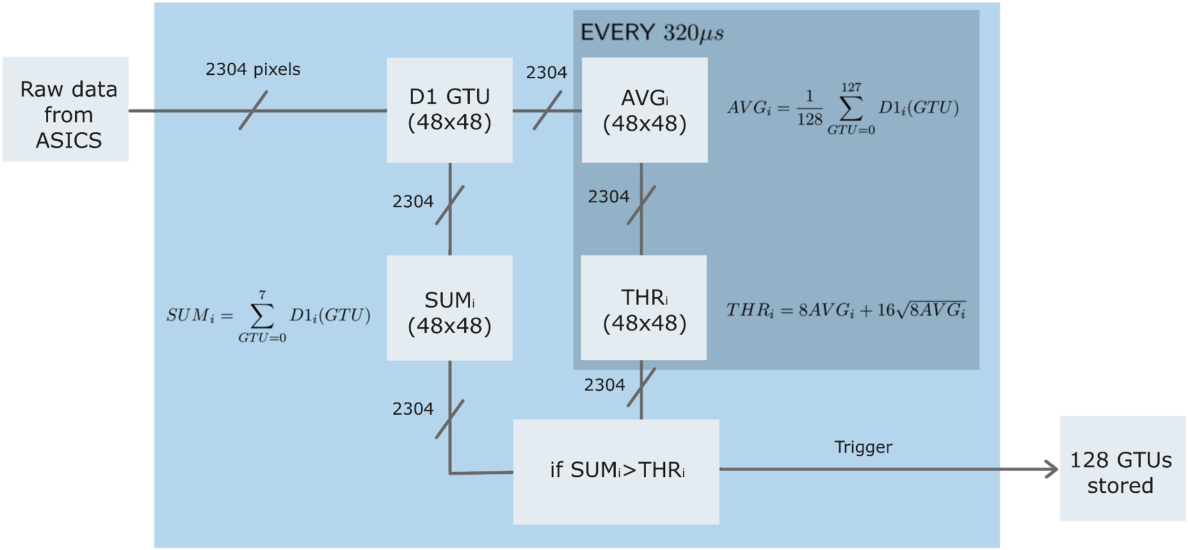
- With moon fraction [0.2,0.4], only moderate increase of UV counts
- With moon fraction < 0.5 still possible to accumulate exposure at the highest energies

Duty cycle (VERY PRELIMINARY):

- Fraction of time in which Sun position is below -109° [A]: 0.34
- UV background < 10 counts/pix/GTU & [A] = 0.84 x 0.34 = 0.28
- UV background < 2 counts/pix/GTU & [A] = 0.58 x 0.34 = **0.19**

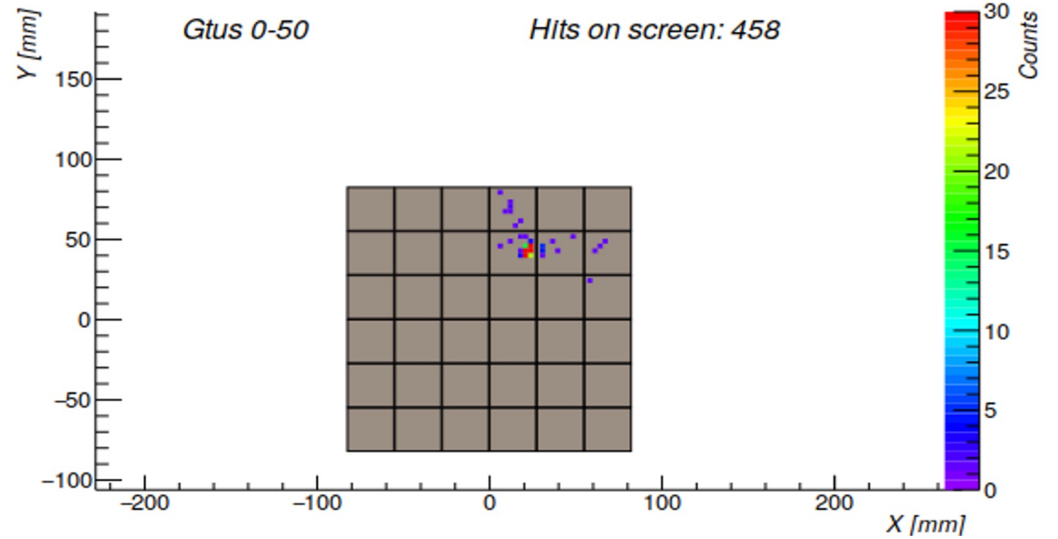


D1 trigger logic

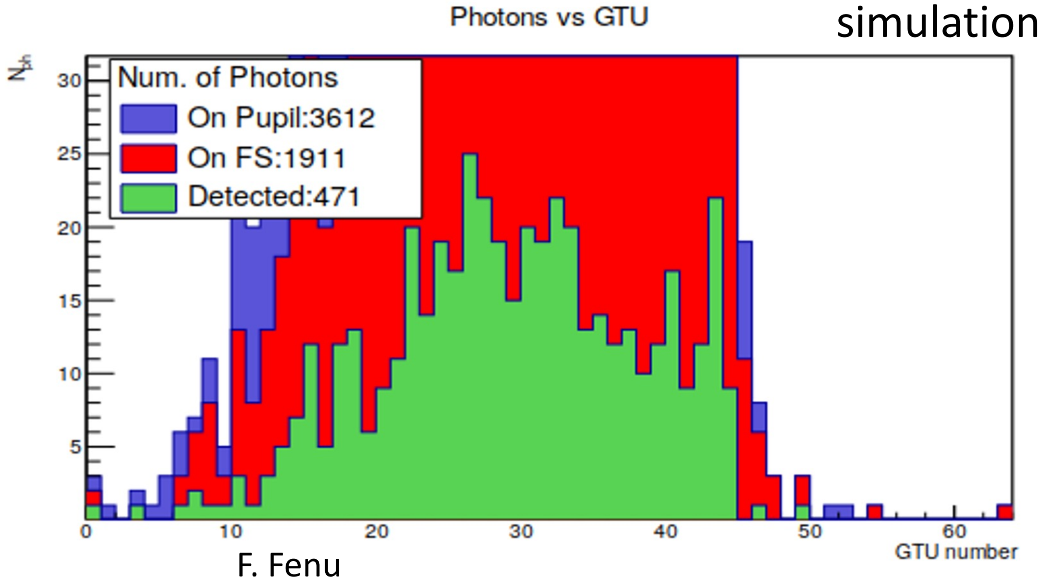


D1 trigger logic

Proton E = 5x10[21] eV, 50°



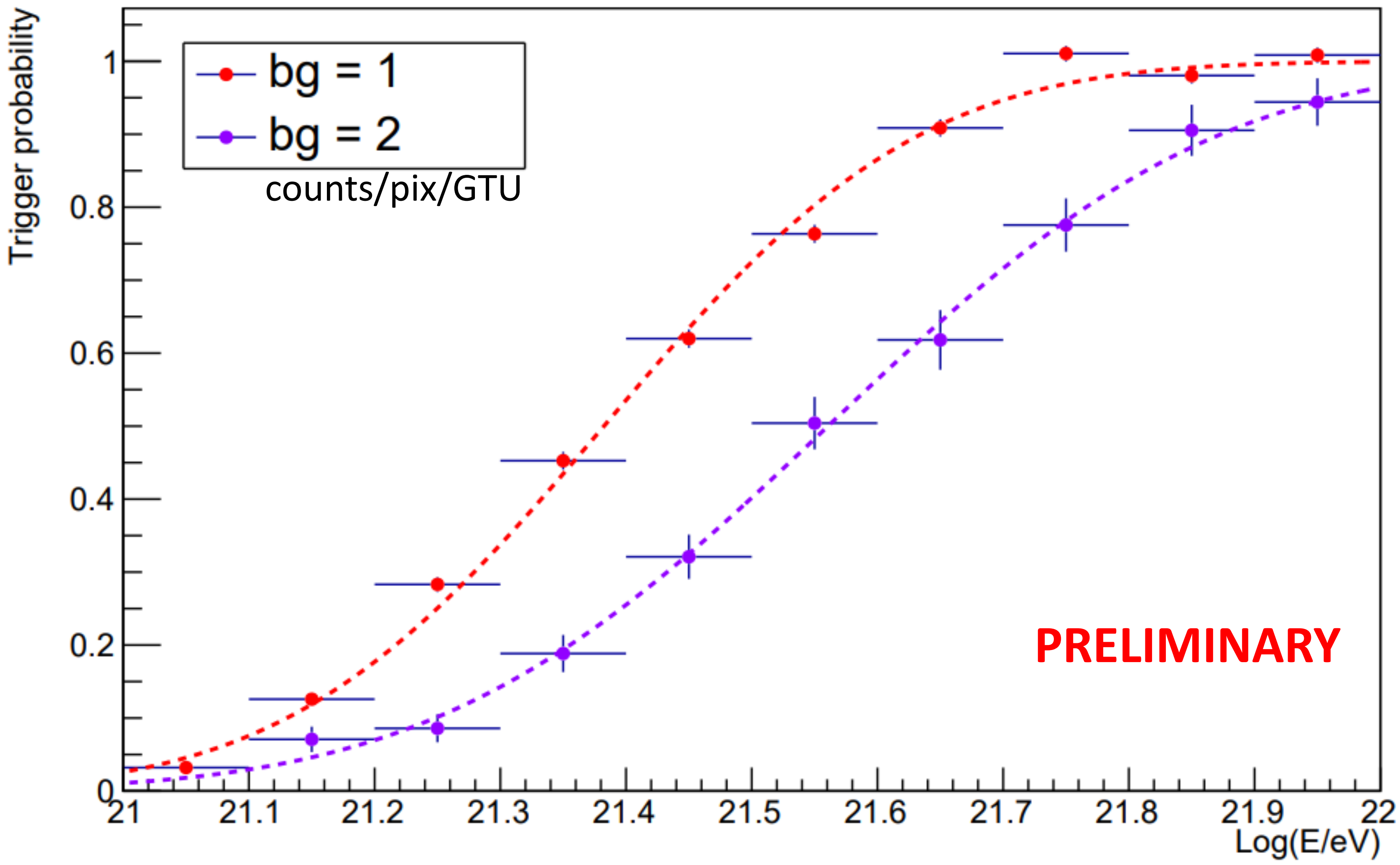
ESAF simulations



F. Fenu

- Each pixel is independent
  - Each pixel has its own threshold
  - A pixel over threshold is enough to issue a trigger
- The thresholds are updated every 128 D1 GTUs (320 μs)
  - Thresholds are set 16**σ** above the average value of the pixel (background)
- The logic looks for an excess of signal over 8 consecutive GTUs in the same pixel

Mini-EUSO EAS trigger probability



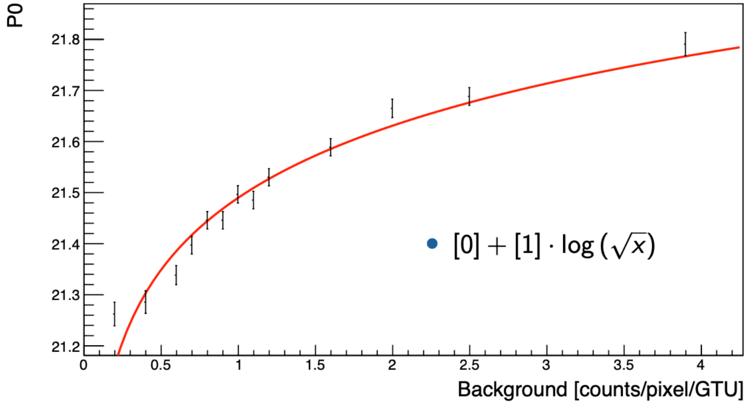
Obtained using ESAF simulations

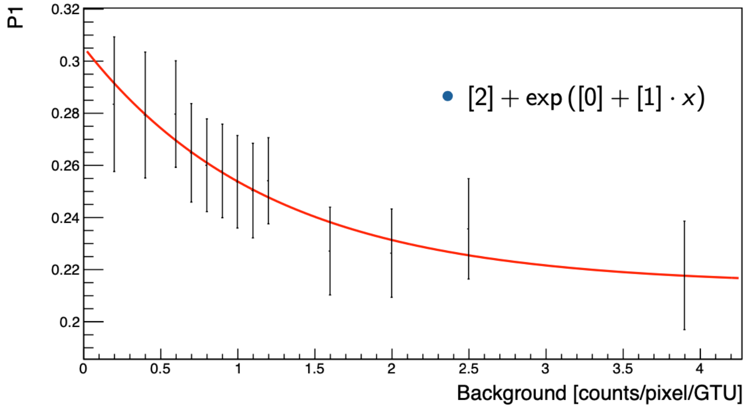
Proton EASs

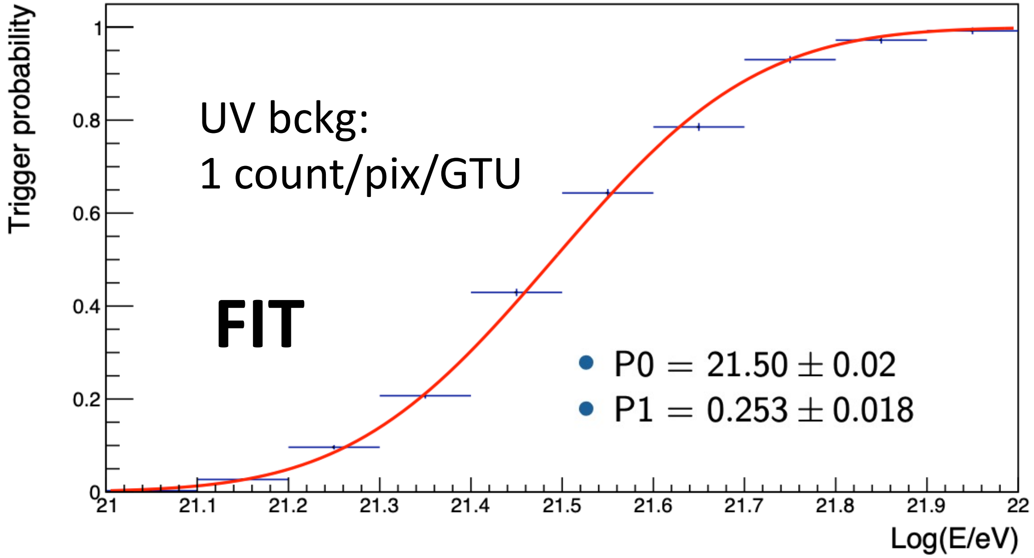
M. Bianciotto

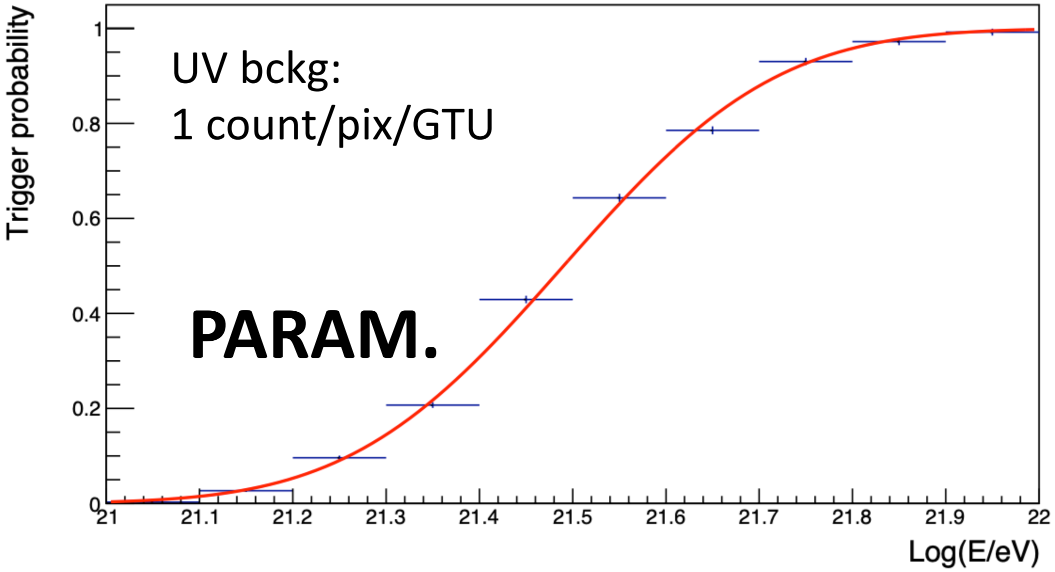
Convolving bckg distrib. and efficiency curves: the integrated exposure curve

- $\epsilon(E) = \frac{N_{trigg}}{N_{simu}}(E)\frac{A_{simu}}{A_{fov}} \Longrightarrow \frac{1}{2}[1 + erf(\frac{log_{10}(E/eV) - P0}{P1})]$
- P0 = threshold
- P1 = slope



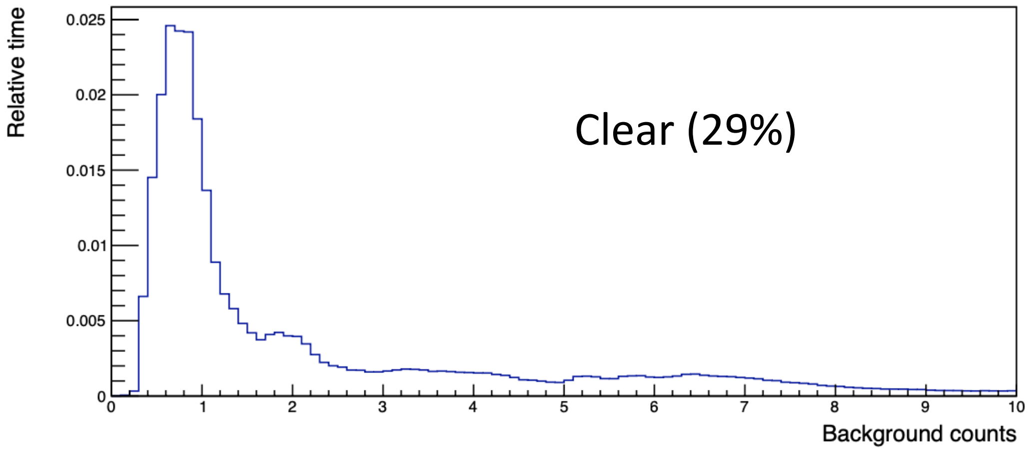


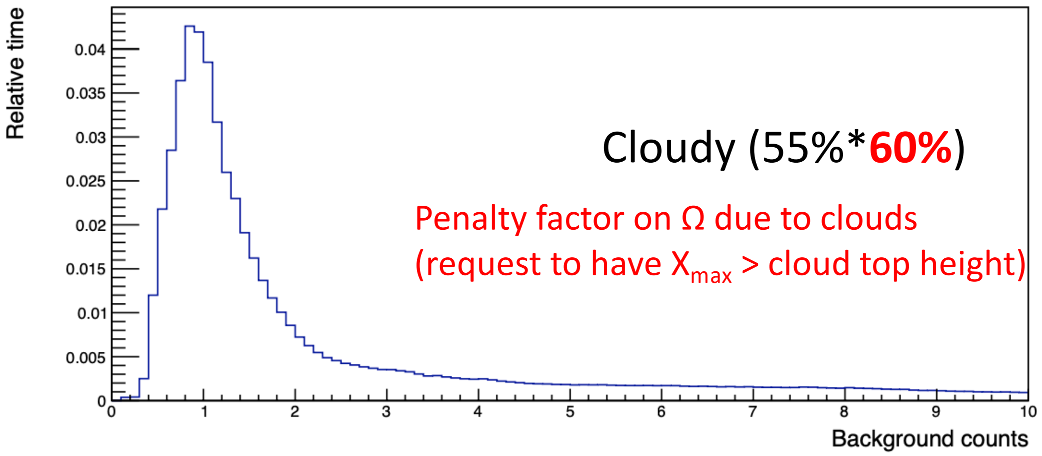




M. Bianciotto

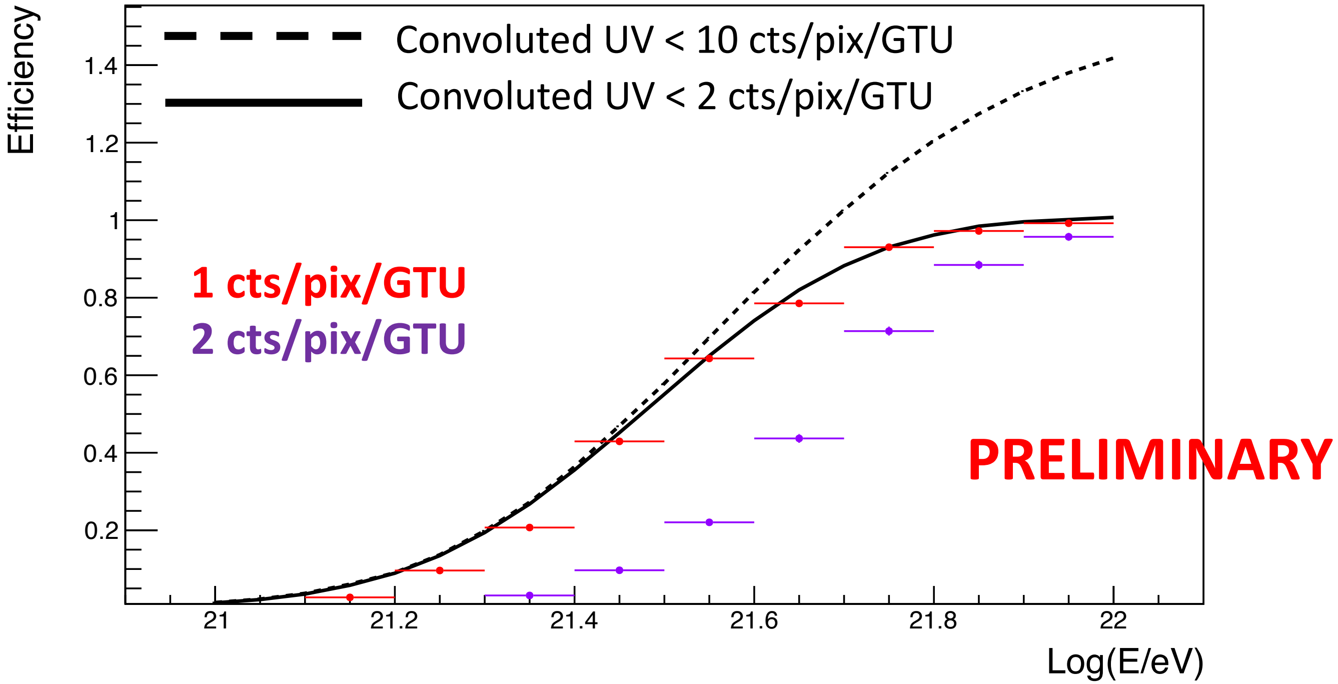
Convolving bckg distrib. and efficiency curves: the integrated exposure curve





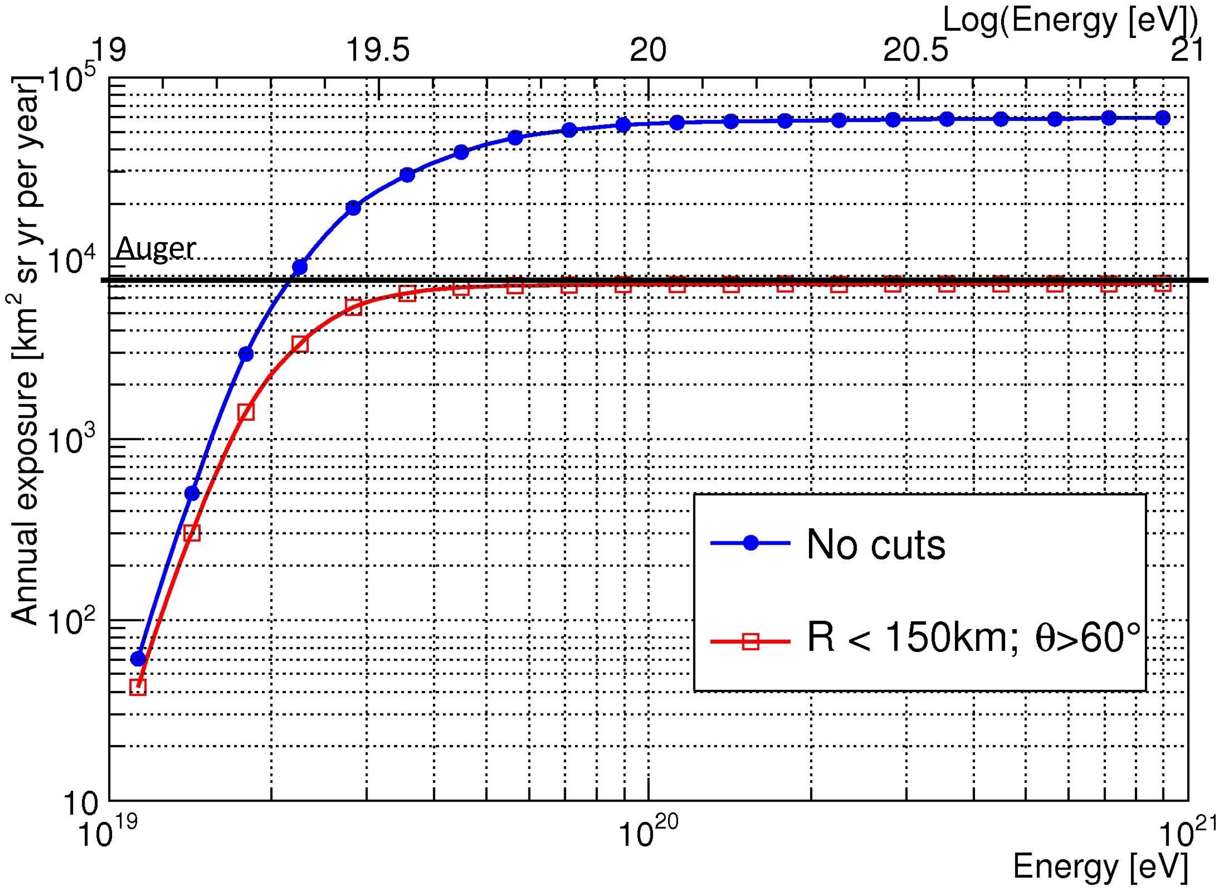
Cloudy atmosphere with a weight 60% to include EAS reconstruction like in JEM-EUSO

- $\mathcal{E}(E) = (\sum_i \epsilon_i(E) \times \eta_i \times t_i) \times A_{fov} \times \Omega \times t_{tot}$
- $_i$ = i-th background condition [counts/pixel/GTU]
- $\epsilon_i(E)$ as described by erf.
- η_i = e.g. effect of clouds
- t_i = relative time fraction
- A_{fov} = area of the FoV
- Ω = solid angle
- t_{tot} = time over which the exposure is calculated



The nominal efficiency curve (1 cts/pix/GTU) is well representative of the convoluted curve

JEM-EUSO Annual Exposure nadir mode



~60,000 km^2 sr yr

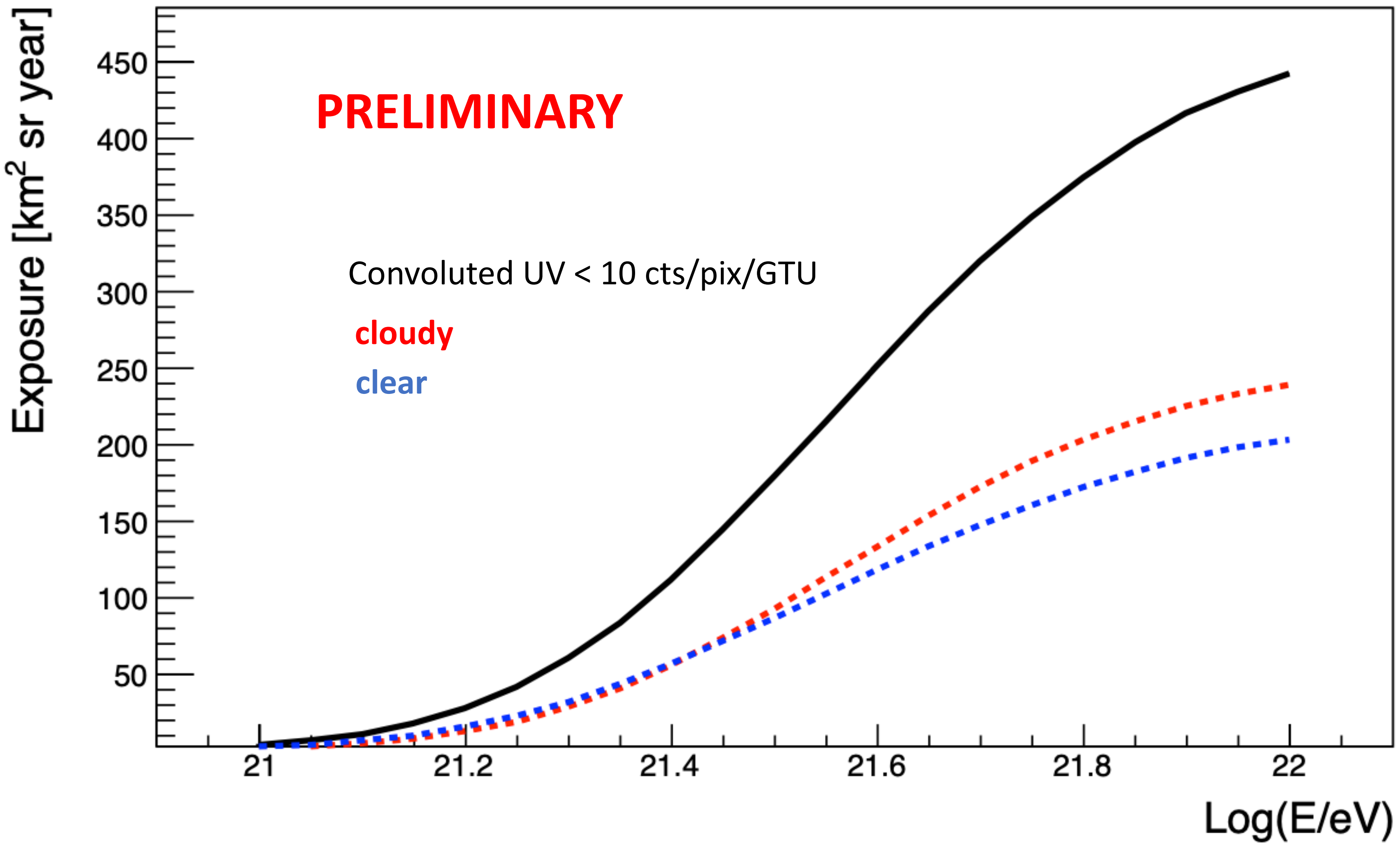
~7,000 km^2 sr yr

- Observational duty cycle (brightness of the sky does not hamper UHECR measurements): ~20%
- Role of clouds: ~72%
- City lights inefficiency: ~7%
- Lightning ineff.: ~ 2%
- Aurorae ineff.: ~1%

0.2 x (1-0.07-0.02-0.01)= 0.18

- Conversion factor between Aperture and Exposure: ~13%

Assumptions in J.H. Adams et al. Astrop. Phys. 43, 76-90 (2013):
500 photons/m^2/ns/sr → 1.1 counts/pix/GTU ✓



Extrapolating to all good recorded data the expected cumulated exposure for UHECRs is **~2000 L** at the highest energies

This exposure is comparable to those collected so far by UHECR experiments in fluorescence light.

- Auger exposure in hybrid mode @10 EeV ~**3000 L**
- TA exposure in hybrid mode @ 10 EeV **~200 L**

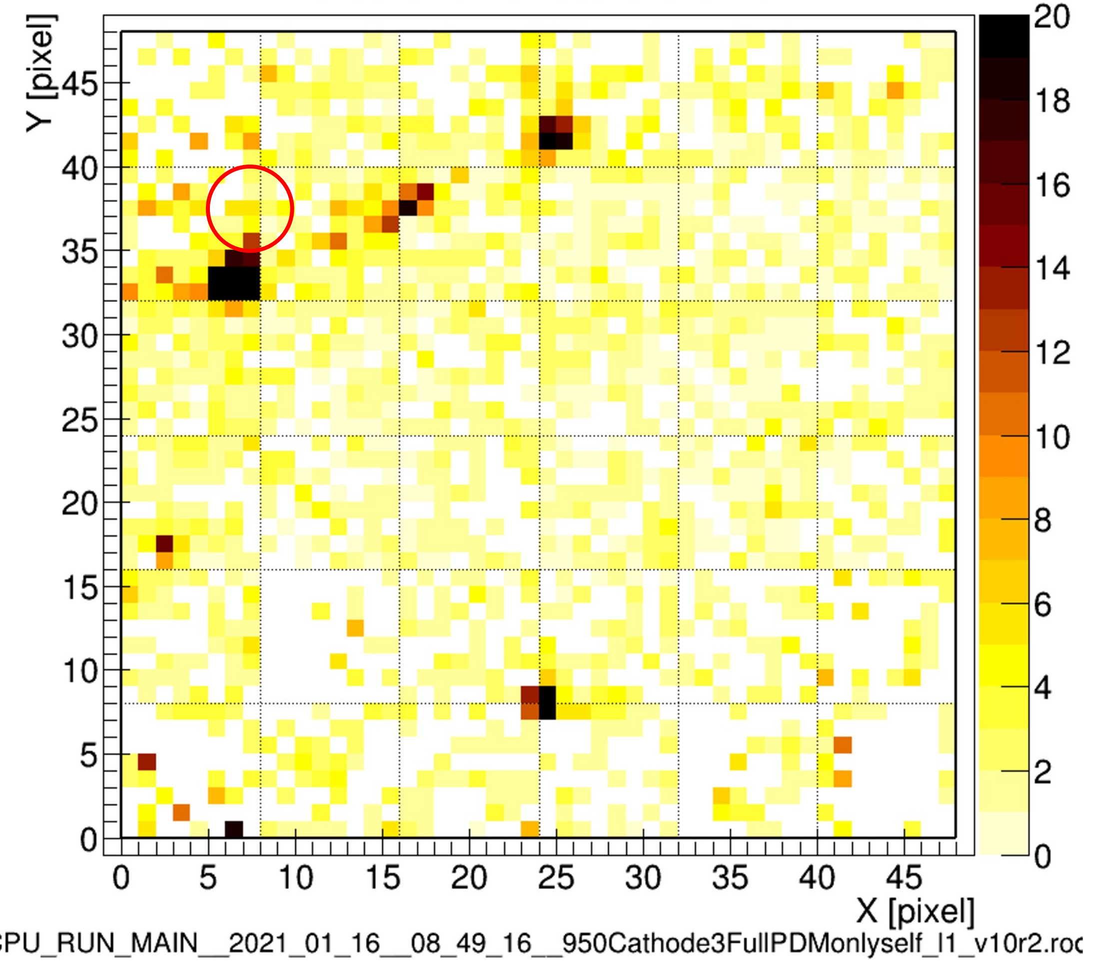
(from private comm.)

Repeated ground flashers

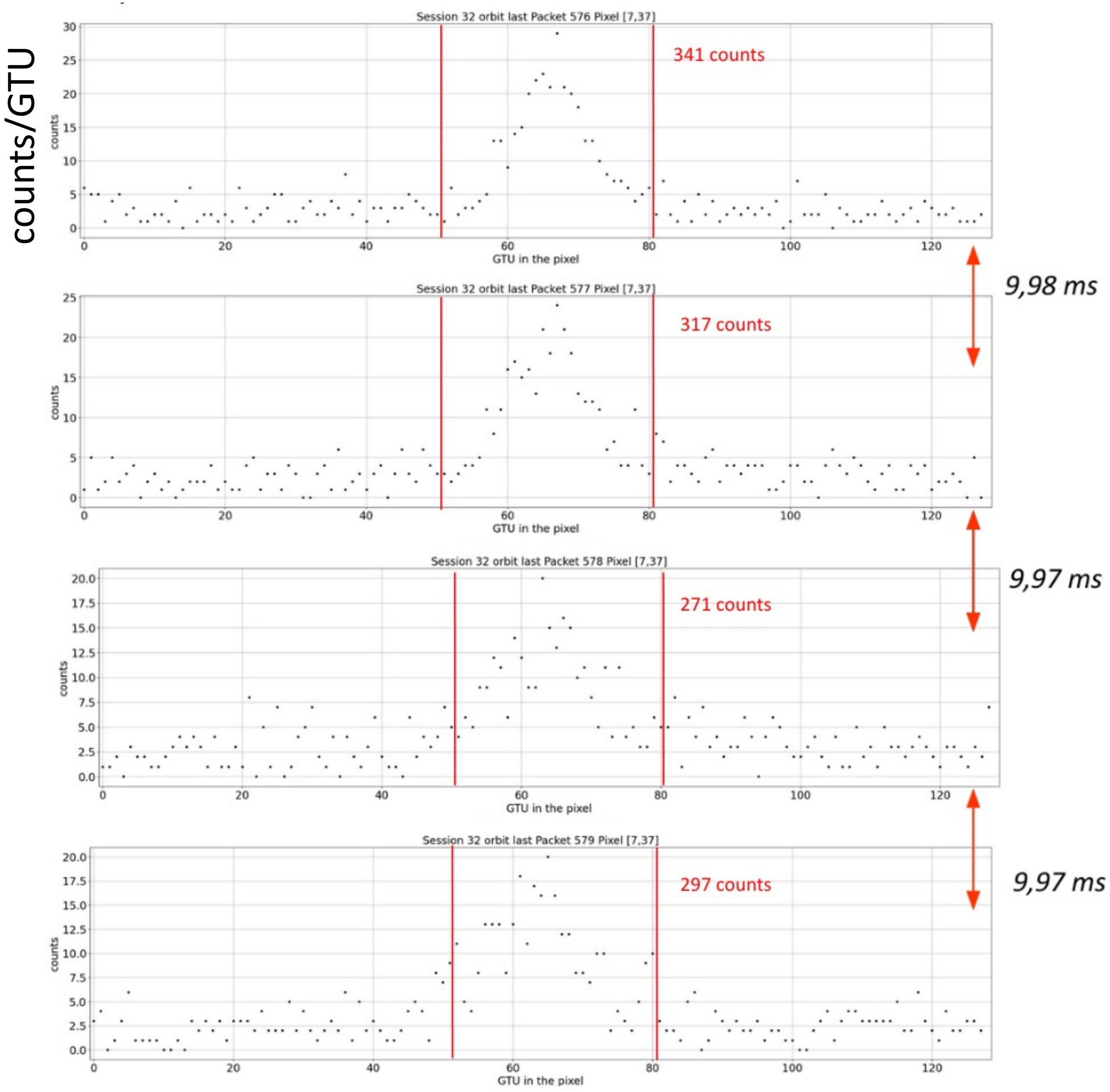
Michigan, US

GTU: 74034 (10930), pkt: 578, GTU in pkt: 50,

UTC time: 2021-01-16 08:29:13.184145



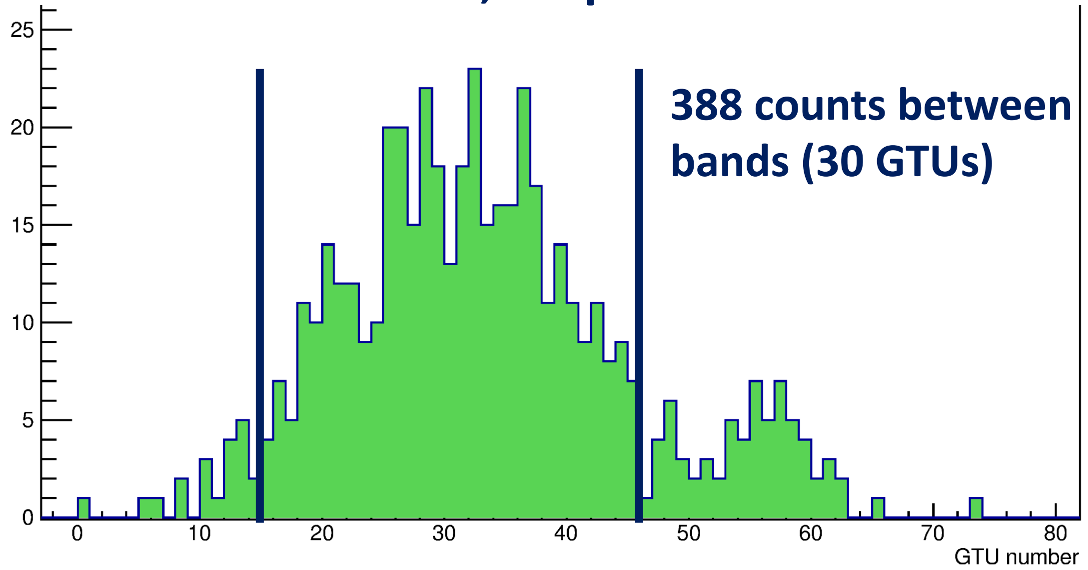
Mini-EUSO ground flashers



M. Battisti

UHECRs in JEM-EUSO & ground flashers in Mini-EUSO

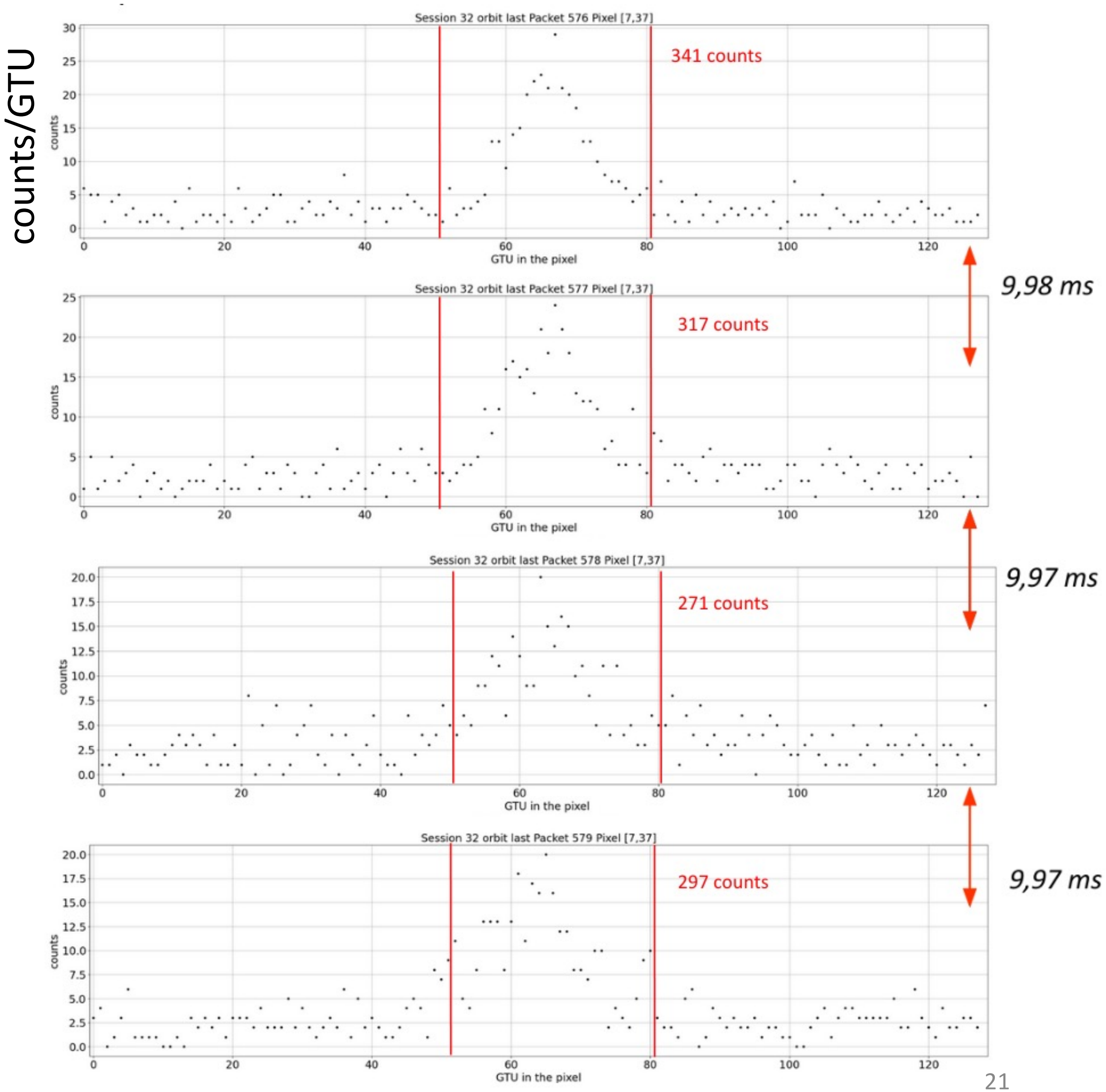
JEM-EUSO
$5x10^{19}$ eV, 60° p with ESAF



F. Fenu

Average counts: 307 counts
Semi dispersion: 35 counts
Relative error: 35/307 = 0.11
Expected Poissonan fluct.: 17 counts (5.5%)

Mini-EUSO ground flashers

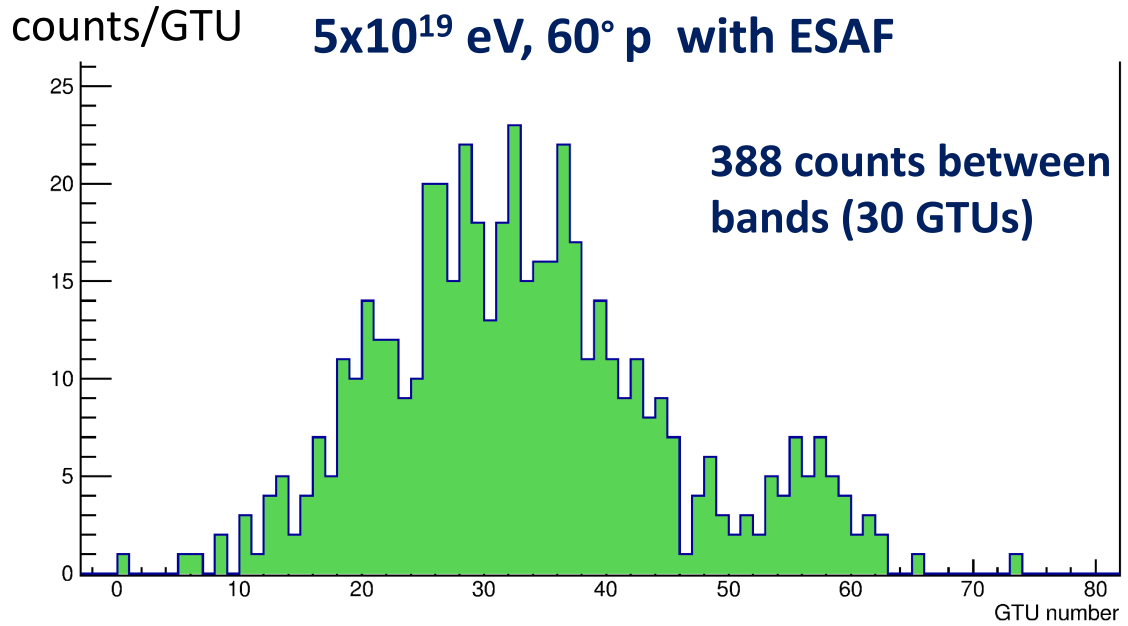


M. Battisti

UHECRs in JEM-EUSO & ground flashers in Mini-EUSO

JEM-EUSO

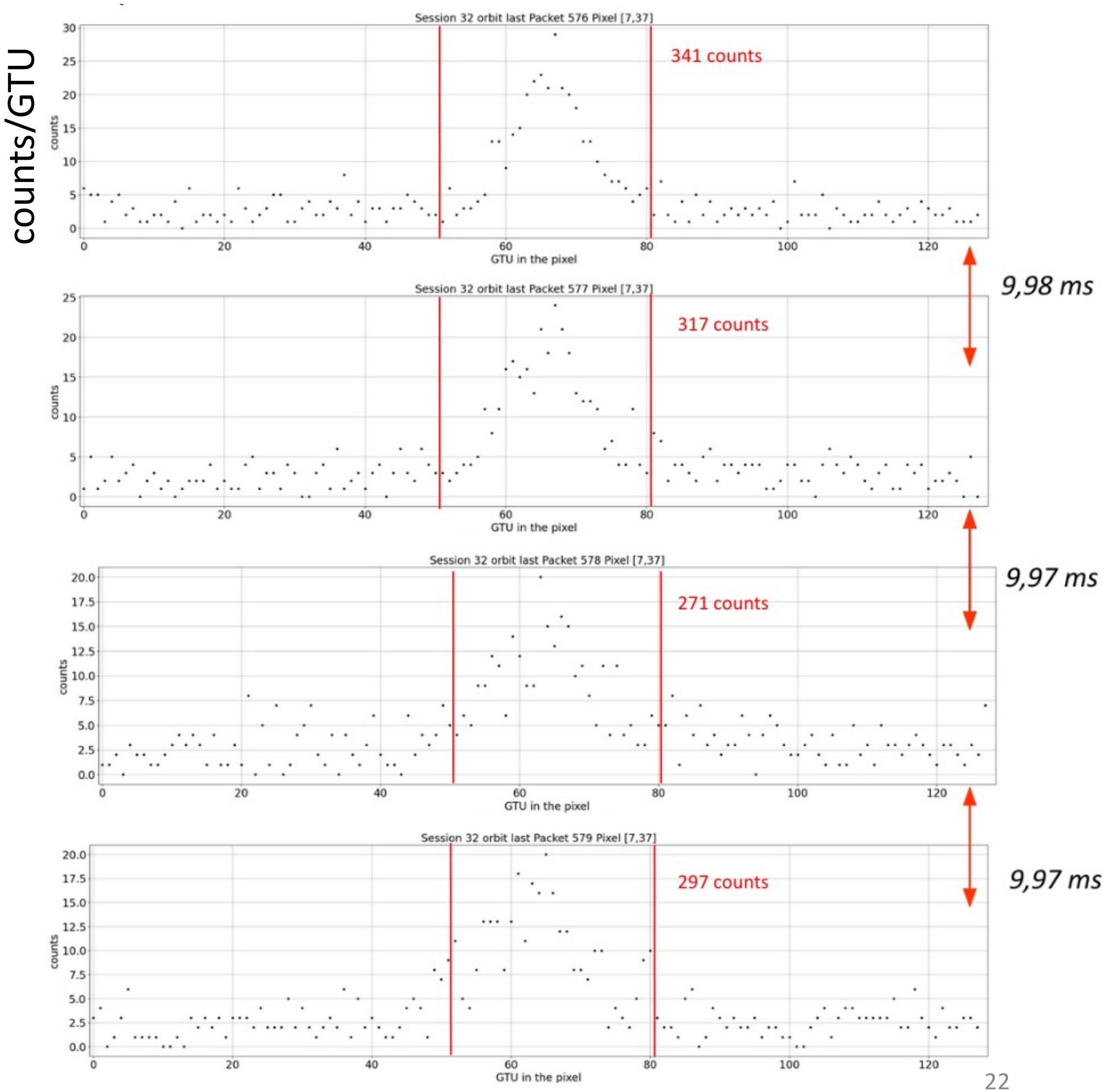
5×10^{19} eV, 60° p with ESAF



F. Fenu

Proof of the detection principle of UHECRs from space with signals in Mini-EUSO similar to those expected in JEM-EUSO

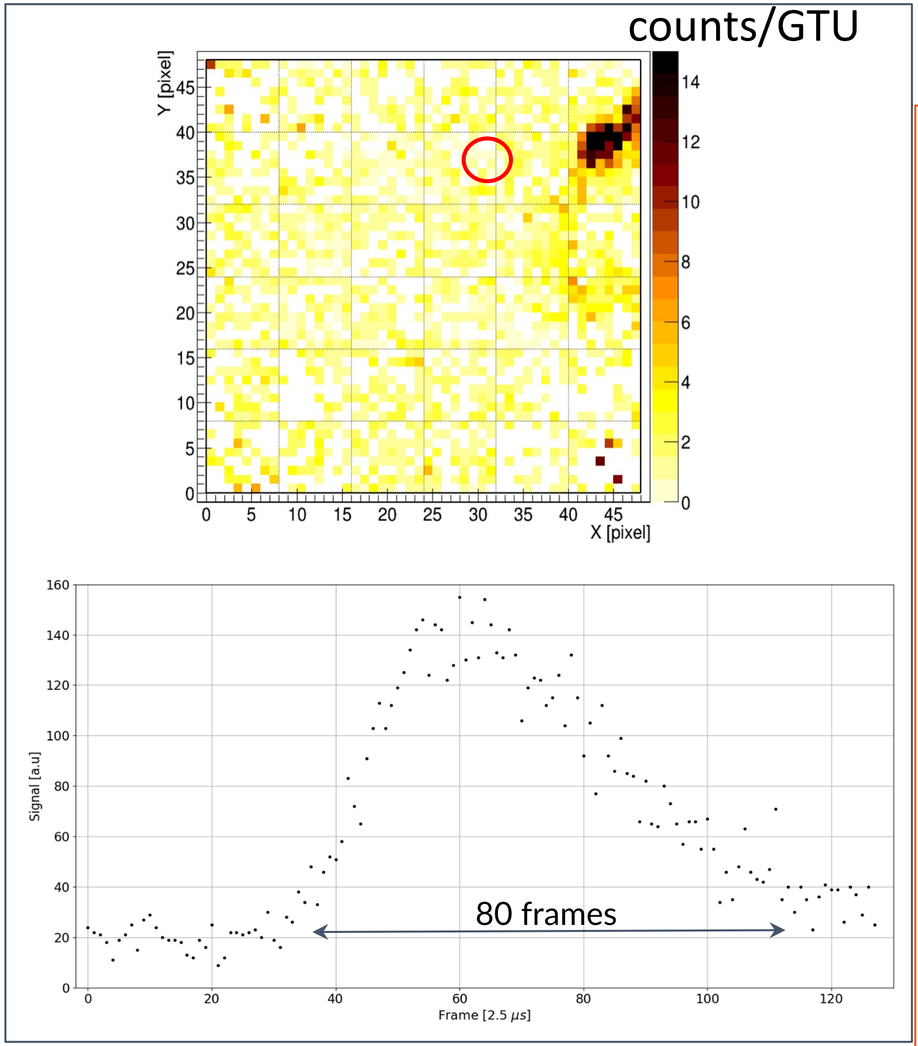
Mini-EUSO ground flashers



M. Battisti

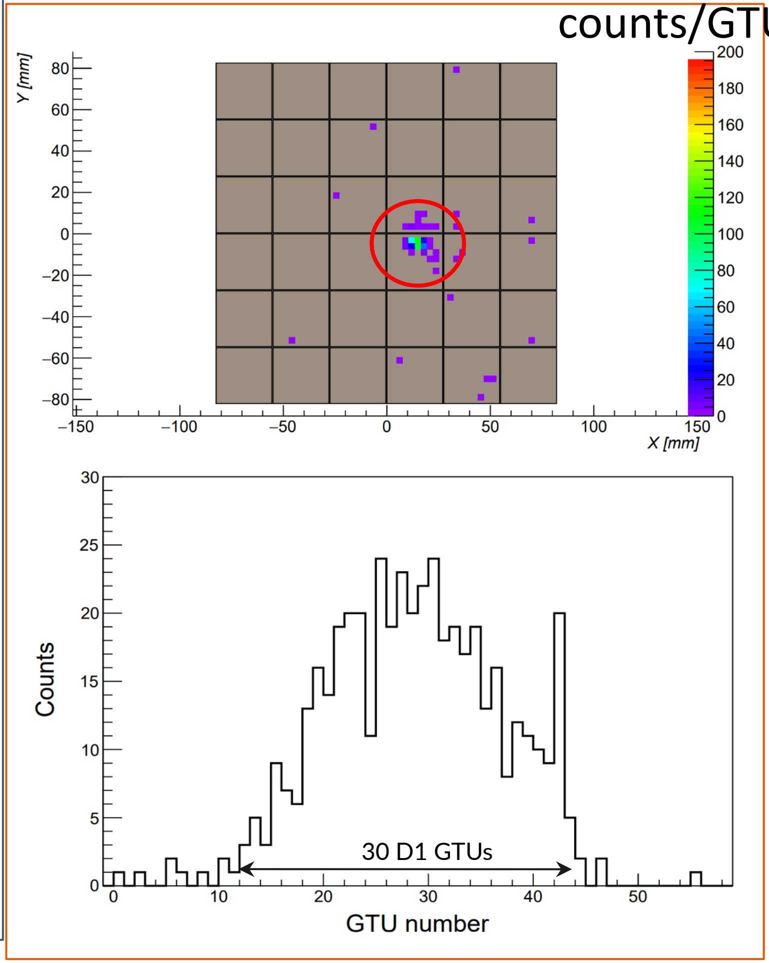
Mini-EUSO – non repetitive ‘EAS-like’ signal

Mini-EUSO data

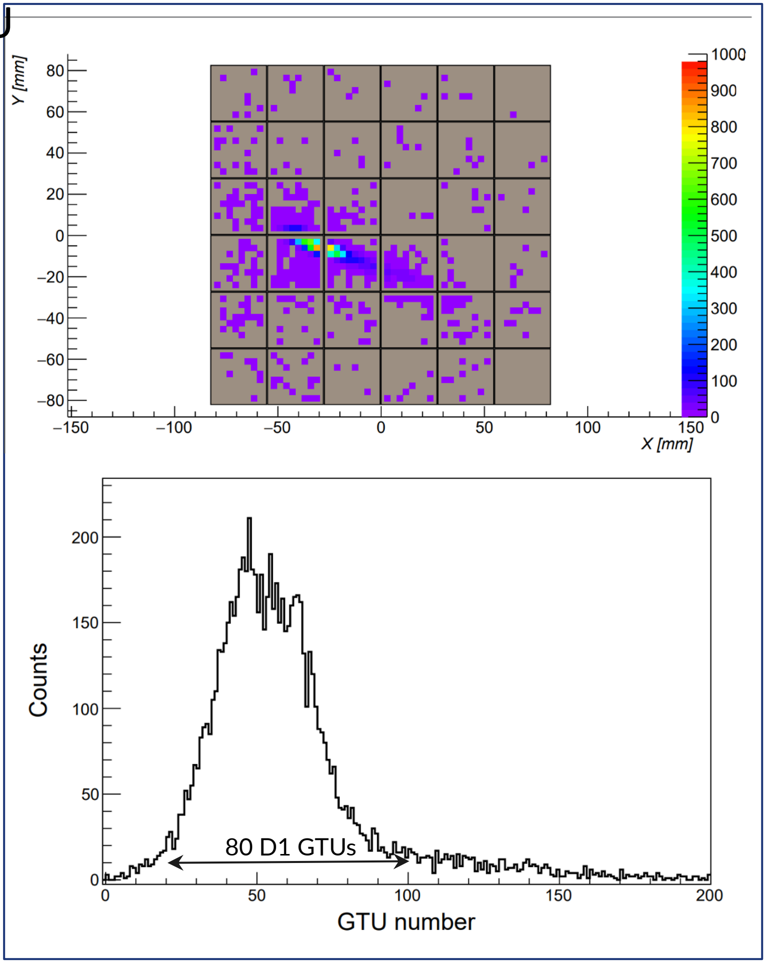


Focal plane view and lightcurve of the detected signal

ESAF p, E = 5x10^{21} eV Zenith = 50°

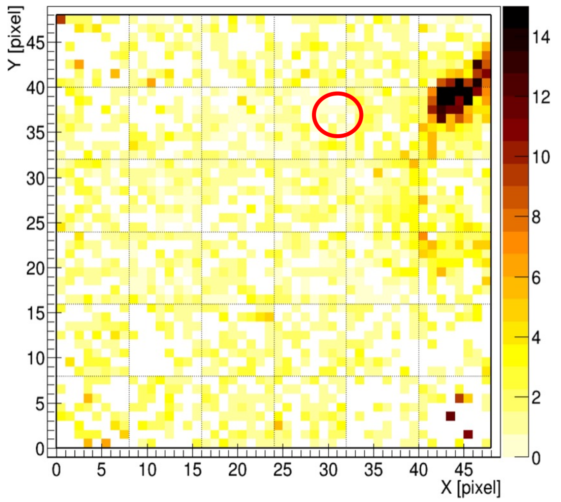


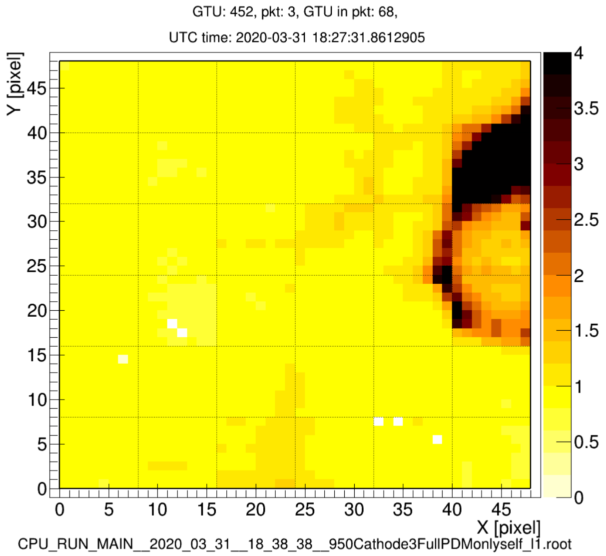
ESAF p, E = 2x10^{22} eV Zenith = 80°

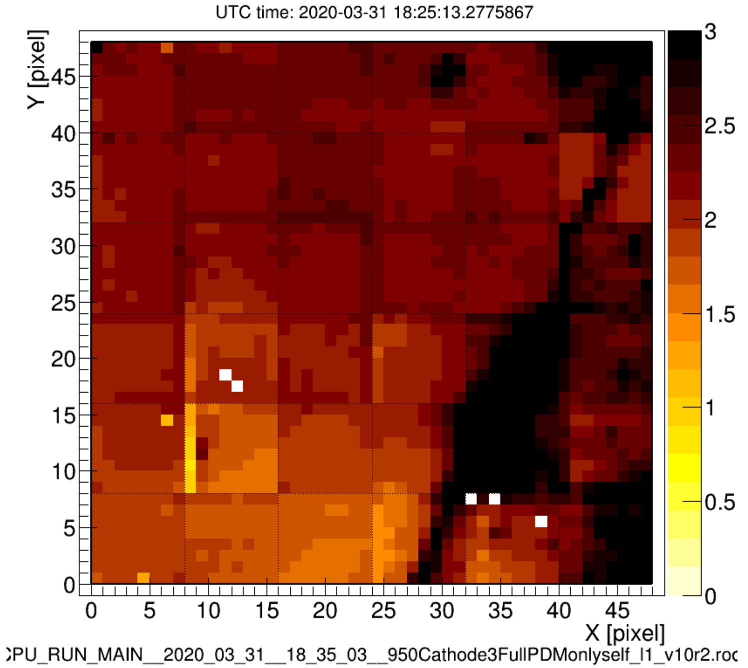


Cosmic ray simulations. Top: focal plane view. Bottom: lightcurves. Left: Zenith angle = 50°. Right: Zenith angle = 80°

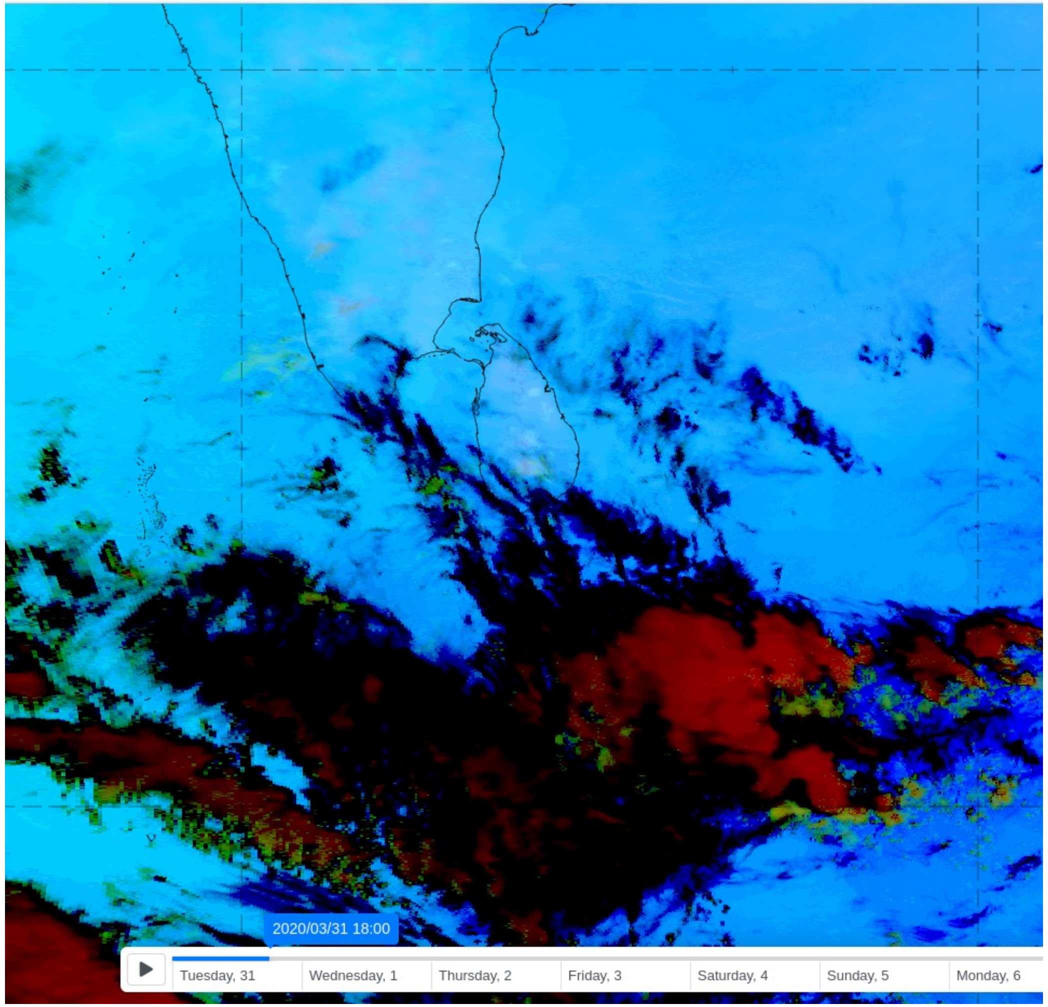
Weather conditions at the time of the event





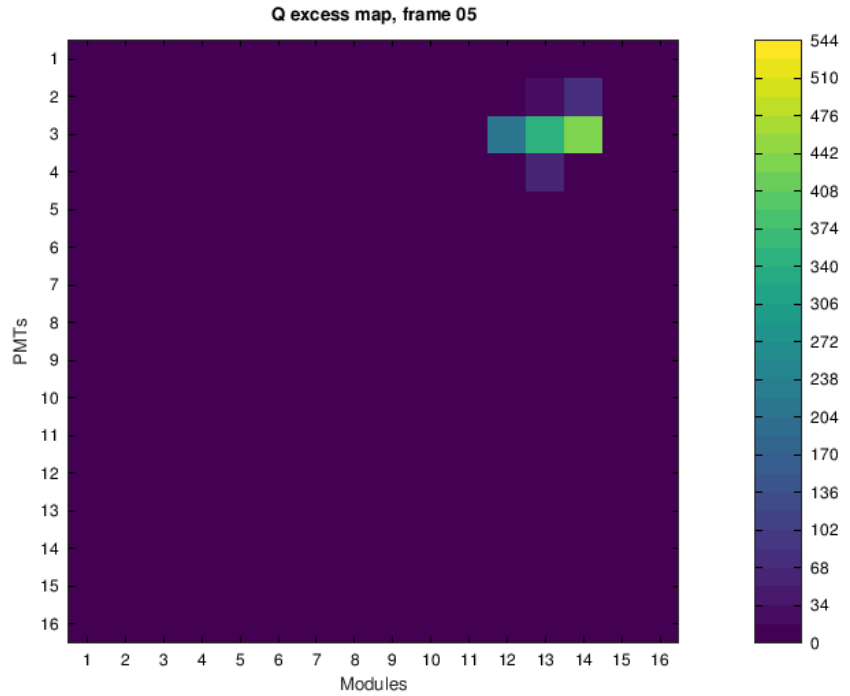


Mixture of clear and
cloudy conditions.
To be further investigated



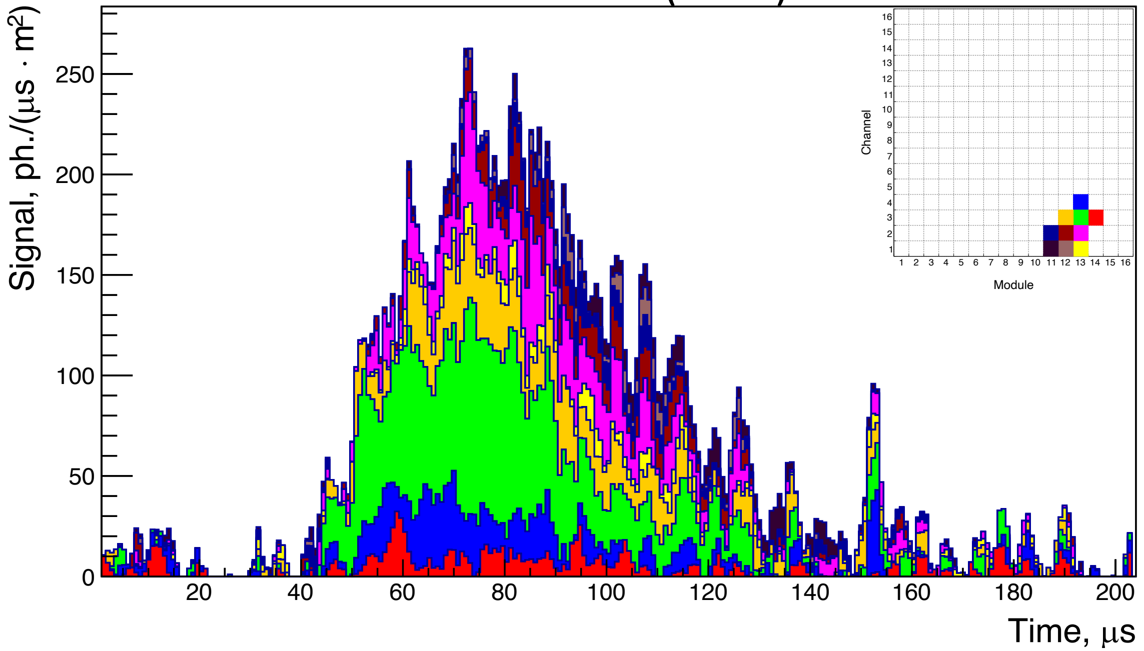
M. Battisti, A. Golzio

TUS & Mini-EUSO

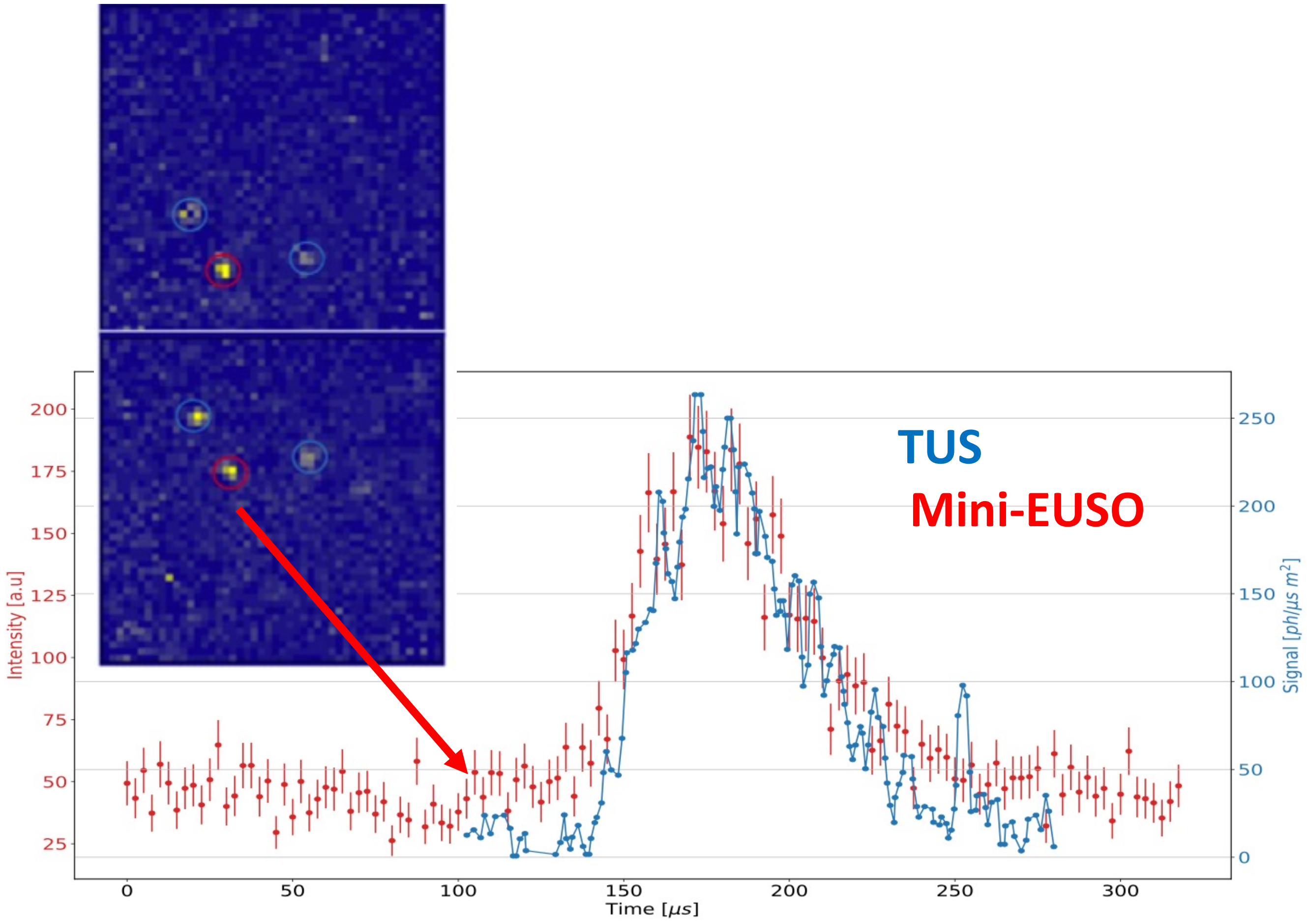


TUS Minnesota event

B.A Khrenov et al. JCAP 03 (2020) 033



Mini-EUSO sees ground flashers with signal in shape similar to the TUS Minnesota event. However, in TUS event an apparent movement is visible while in Mini-EUSO the signal is static.



M. Battisti

CONCLUSIONS

- Mini-EUSO on ISS for almost three years and observes events of different nature showing the broader impact of an UHECR detector in space.
- It proves that it is possible – with larger detectors – to perform UHECR observation from space.
- Preliminary results indicate that measurements are in agreement with predictions from simulations performed for JEM-EUSO.
- These results can be extrapolated directly to K-EUSO and POEMMA and support the indication of the expected performance of a large space-based mission for UHECR studies.