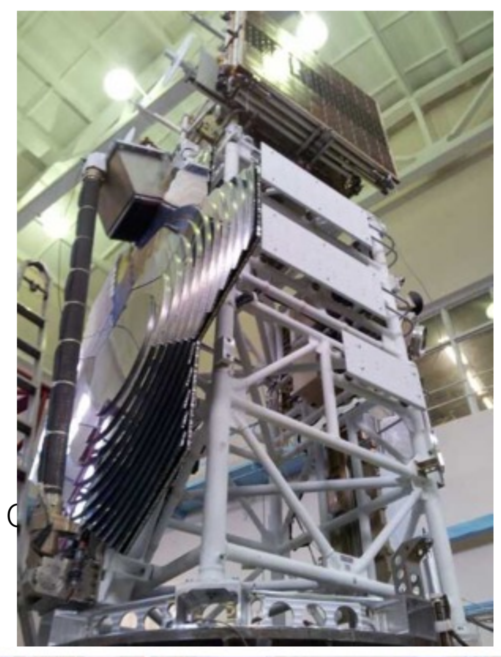
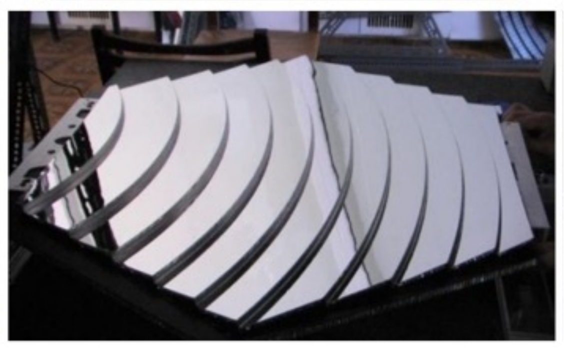
Lomonosov Moscow State University

TUS: Tracking Ultraviolet Setup





In orbit since April 28th 2016 on Lomonosov satellite

Telescope & Detector Parameters:

Orbit Altitude: ~ 500 km
Monitored area: ~ 6400 km^2
FoV: = ±4.5°
Fresnel Mirror: ~1.9 m^2
Focal Surface: 16 x 16 PMTs
Pixel FoV at ground: ~ 5 km
Time resolution: ~ 0.8 μs
Data acquisition: 256 time bins
Acquisition mode: Charge Integration

Search for Extreme Energy Cosmic Rays with the TUS orbital telescope and comparison with ESAF

M. Bertaina[1], A. Castellina[2], F. Fenu[1], P. Klimov[3], A. Salsi[1,4], S. Sharakin[3], S. Shinozaki[1] & M. Zotov[3]
for the Lomonosov-UHECR/TLE Collaboration

1) Department of Physics, University of Torino, Italy
2) INAF, Astrophysical Observatory of Torino, Italy
3) Lomonosov Moscow State University, Skobeltsyn Institute of Nuclear Physics, Russia
4) Lagrange Laboratory, Nice Cote d'Azur Observatory, France

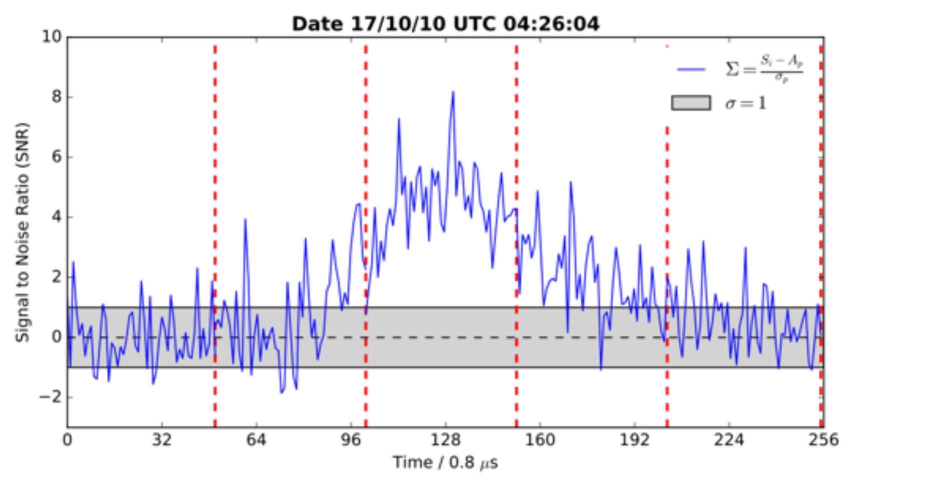
Abstract:

The Track Ultraviolet Setup (TUS) detector was launched on April 28, 2016 as apart of the scientific payload of the Lomonosov satellite, for a 5 years mission. TUS is a path-finder mission for future space-based observation of Extreme Energy Cosmic Rays (EECRs, E > 5x10^{19} eV) with experiments such as K-EUSO. TUS data offer the opportunity to develop strategies in the analysis and reconstruction of the events which will be essential for future space-based missions. During its operation TUS has detected about 80 thousands events which have been subject to an offline analysis to select among them those that satisfy basic temporal and spatial criteria of EECRs. A few events passed this first screening. In order to perform a deeper analysis of such candidates, a dedicated version of ESAF (EUSO Simulation and Analysis Framework) code as well as a detailed modelling of TUS optics and detector have been developed.

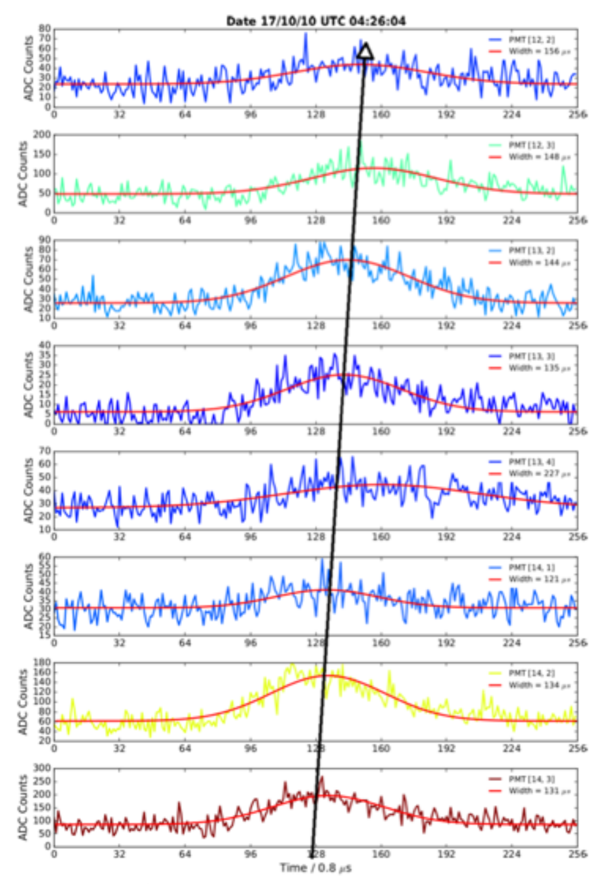
Signal selection in the ADC time track

(Plot refers to event: TUS171010)

Signal significance: substracting average and dividing by RMS, we get:

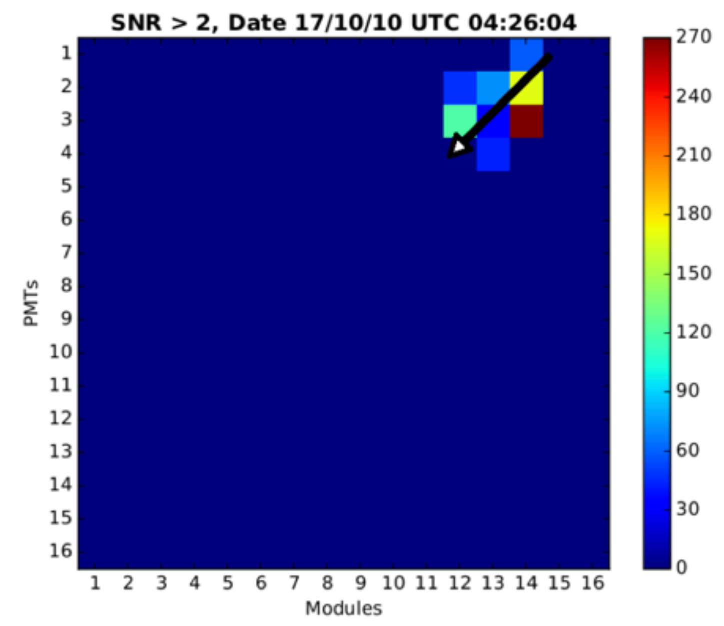


We divided the signal into **five windows** and we determined the SNR average value in each window
→ If there is a window with average SNR > 2 ⇒ **signal**



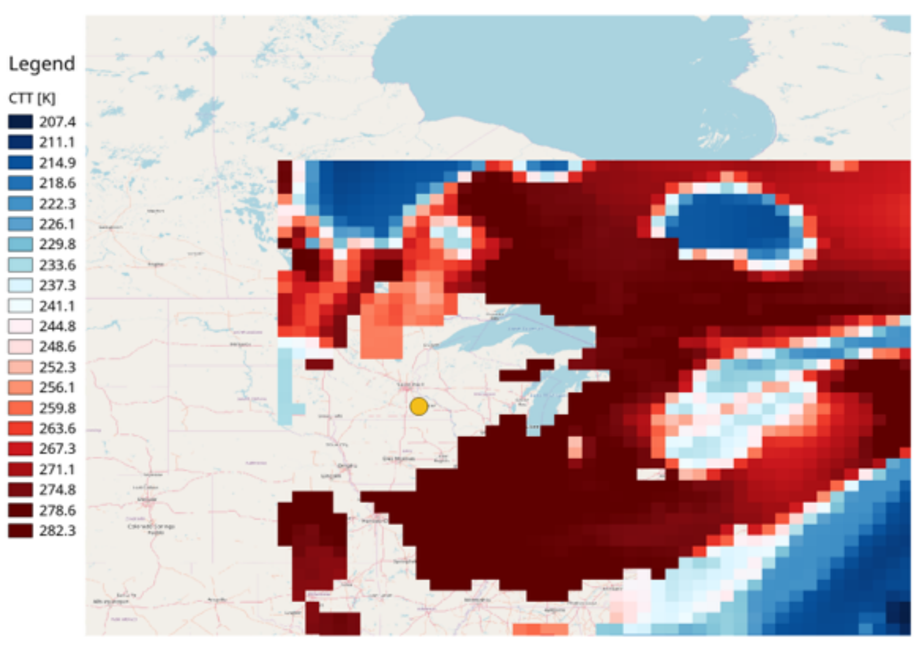
Selection of tracks & identification of movement

(Plots refer to event: TUS171010)



The search for UHECR signals in the data require different steps. First of all the signal selection in the ADC time track is performed. In this work the signal significance is used. The signal in one packet of 256 time ticks is divided in 5 parts and the average SNR value is determined in each time window. If there is a window with average SNR > 2, the pixel is assumed to have a signal excess. This procedure is applied for each pixel. In case of a UHECR event it is expected that several pixels show similar behaviour with a signal excess shifted in time in a consistent way. Simulation of EASs should reproduce similar time evolution of the signal, as well as the light intensity in the pixels.
Other important aspects to be considered are the atmospheric conditions as well as the geographical area of the event. For this reason we used the data from MERRA-2 model to understand the possible presence of high clouds which would hamper the detection of UHECRs. In parallel we use DMSP data to check the possible presence of anthropogenic lights which raise the energy threshold of detectable UHECRs and can indicate the possible presence or artificial pulsed lights, such as laser shots, strobe lights, etc… like near airports. Several triggers are indeed coming from areas near airports. A more detailed description of the most interesting UHECR candidates detected by TUS can be found in: P. Klimov et al. PoS(ICRC2017) 1098.
A part from comparing the signal of UHECR simulated events, we also simulate light sources of different origin such as laser pulses. Such pulses could be direct towards TUS if generated by a laser beam on ground, but could also point downward like in case of an airplane lidar. First simulations of waveforms obtained with laser pulses look different from those of EAS candidates, but more simulations and analyses are needed.

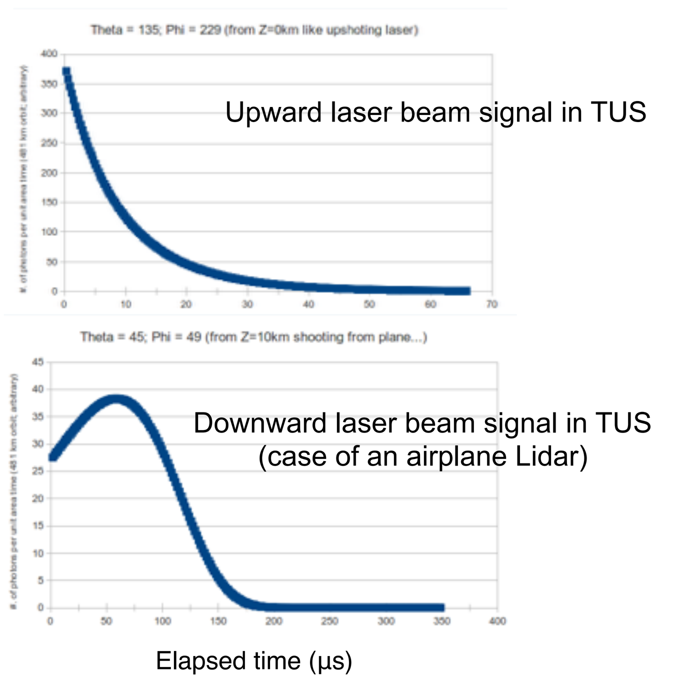
Evaluation of weather conditions on selected events with satellite data & models (MERRA-2)



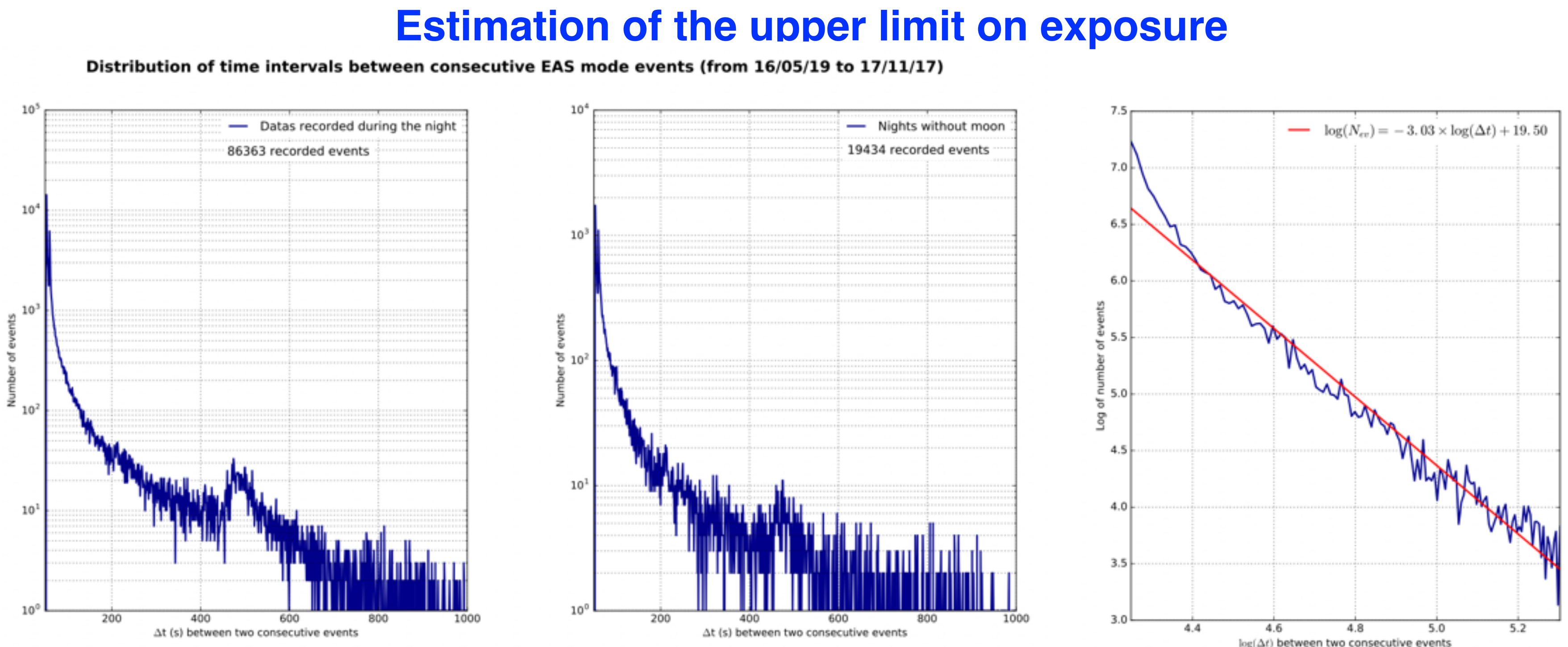
Localization of events (areas subject to anthropogenic lights should be excluded)

(Plots refer to event: TUS161003)

Simulation of possible anthropogenic sources of light like laser pulses



Estimation of the upper limit on exposure



Time = 38.25 days
A = 6400 km^2

Upper limit on Exposure: 2100 km^2 sr yr

(if we apply the penalty factors due to presence of high clouds, lightnings, anthropogenic lights, etc.. assuming JEM-EUSO values, the exposure reduces to 1360 km^2 sr yr)

The upper limit on the exposure can be simply derived by looking at the time difference between consecutive events collected in EAS mode and by considering only the nights without moon. The number of triggered events reduces from 86363 to 19434 (23%) when this selection is applied. We notice that the peak of the time difference between consecutive events is located around 53 s. This has to be assumed as the dead time of the instrument. Other penalty factors come from the presence of high clouds that block the detection of the events, the presence of artificial lights, mainly on continents as well as lightnings, aurorae, etc…

ESAF: EUSO Simulation and Analysis Framework

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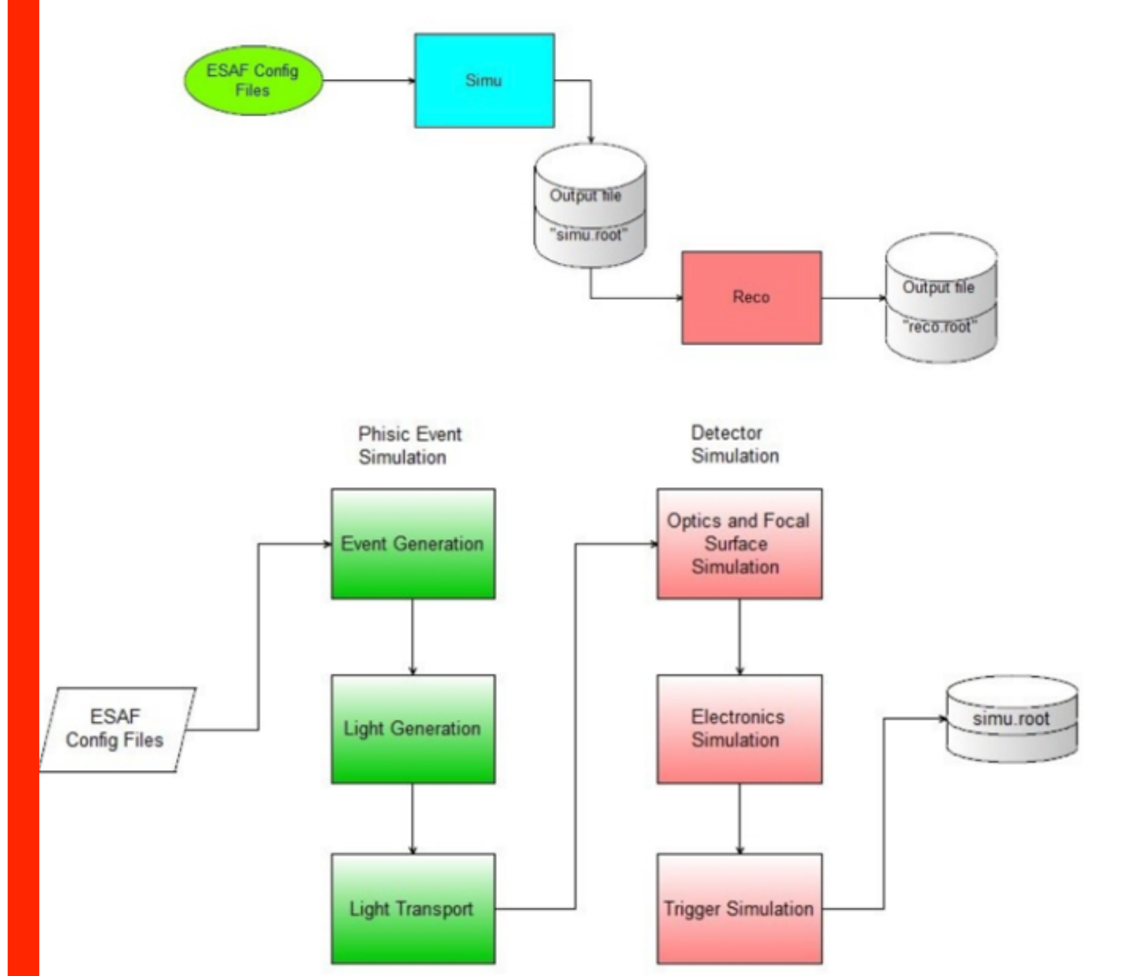
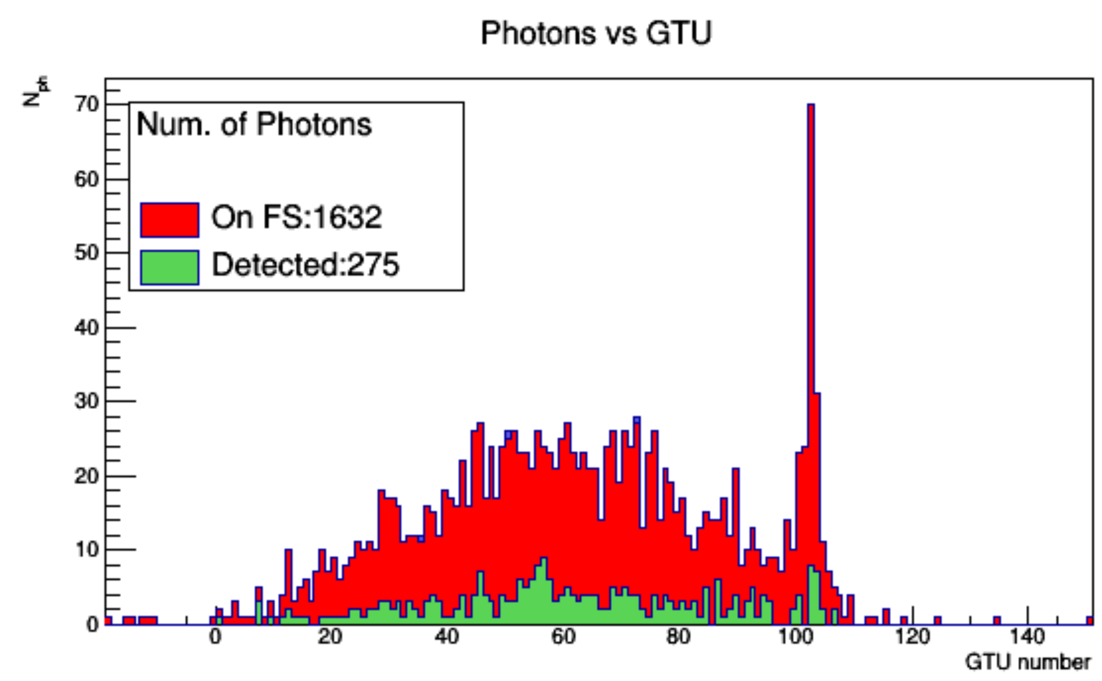
- Software developed specially for EUSO missions.
- Monte Carlo simulation framework based on ROOT (realized with C++ object oriented language).
- Event generation, photons production and their transport to the detector, optics and electronics response.

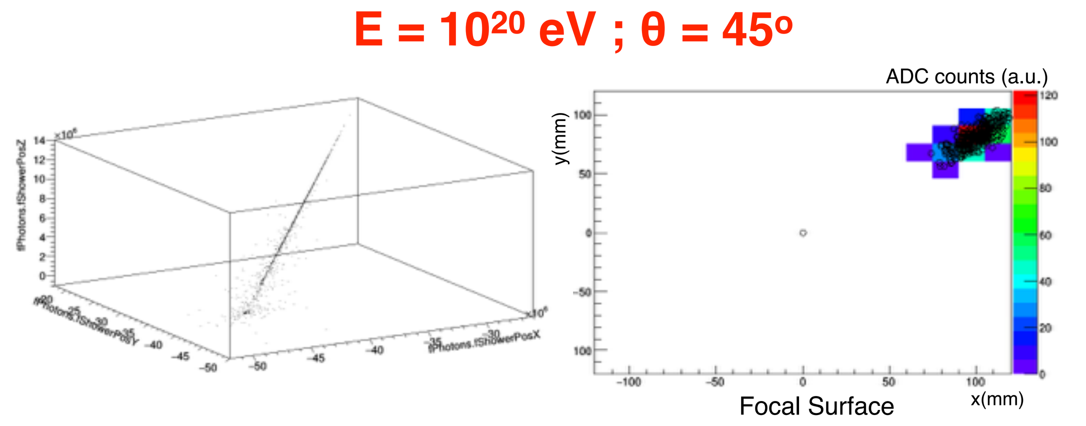


The ESAF framework is used to compare experimental results of TUS with simulated EAS. ESAF is one of the official analysis packages for the evaluation of JEM-EUSO performance. Currently, the detector configuration of TUS is being implemented. The key points are the optics response (mirror instead of lenses) and the ADC counts (TUS uses a charge integration approach instead of photon-counting like in JEM-EUSO).

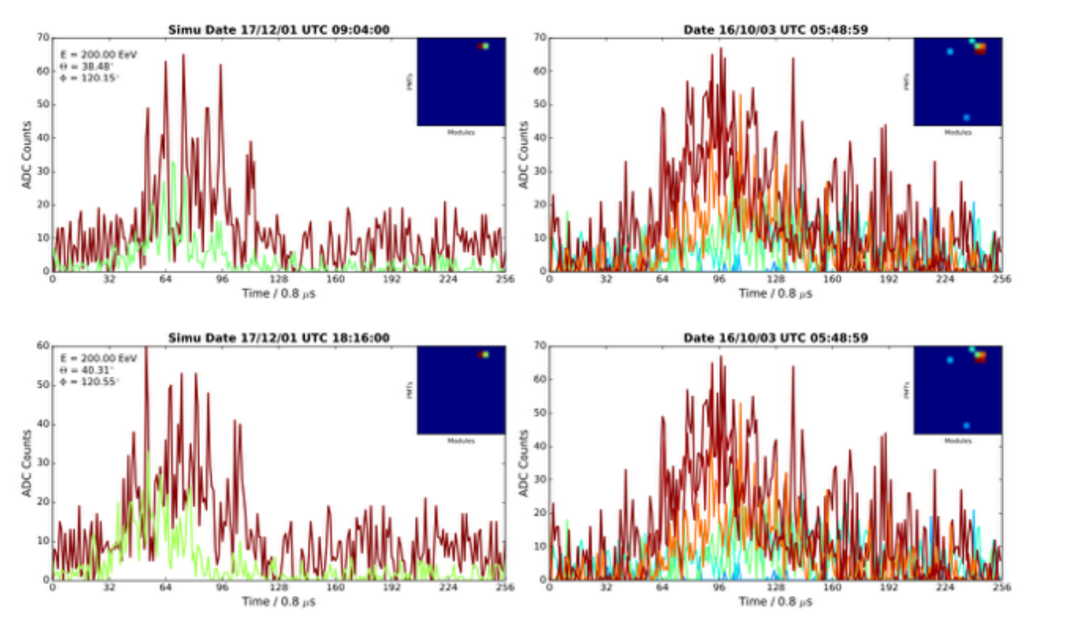
EAS Simulation in ESAF: Implementation of the TUS detector & optics response in progress



E = 10^{20} eV ; θ = 45°



Simulations **Real data**



Arbitrary response of TUS detector is assumed to match signal intensity in simulations and experimental data. Same EAS with two different zenith angles is simulated and compared to the same experimental event.

The modelling of the conversion between photo-electrons and ADC counts is in progress. This requires an absolute calibration of the detector which is being performed using data acquired in flight. The second aspect is the modelling of the PSF of the optics. Currently a Gaussian shape is assumed, while a proper modelling of the Fresnel mirror response is under development.