BSc. Thesis in Physics
Tesi di Laurea Triennale in Fisica

Search and analysis of cosmic-ray events in Mini-EUSO data

Ricerca ed analisi di eventi di raggi cosmici nei dati di Mini-EUSO

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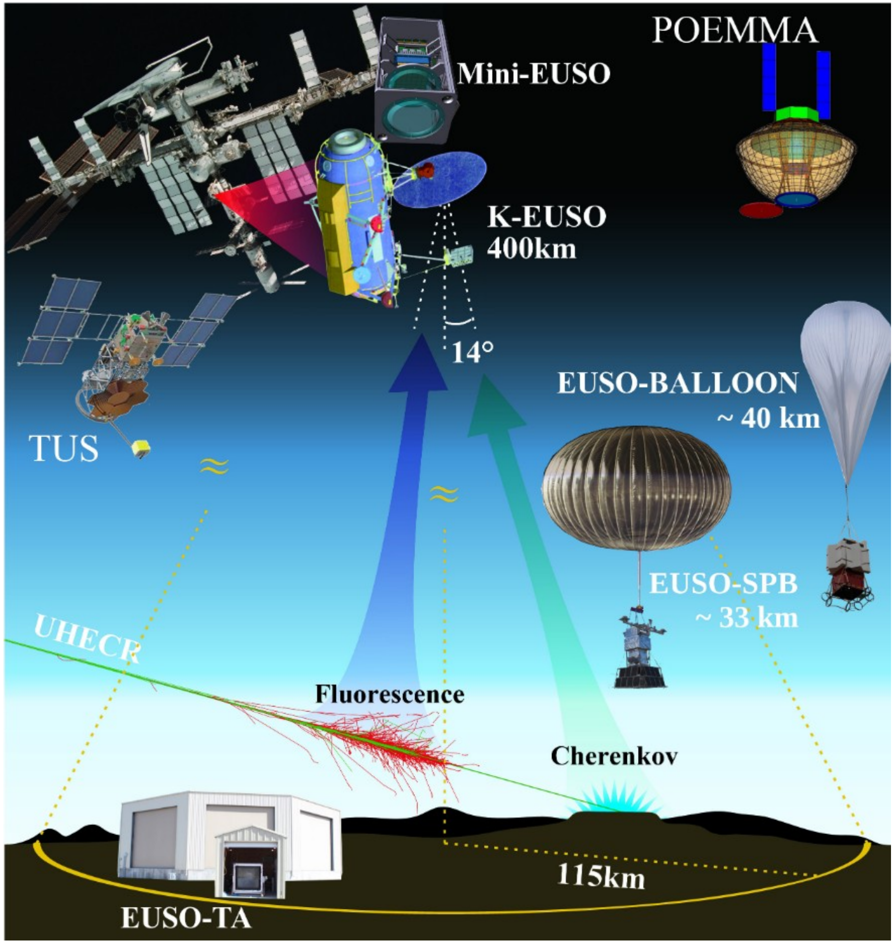
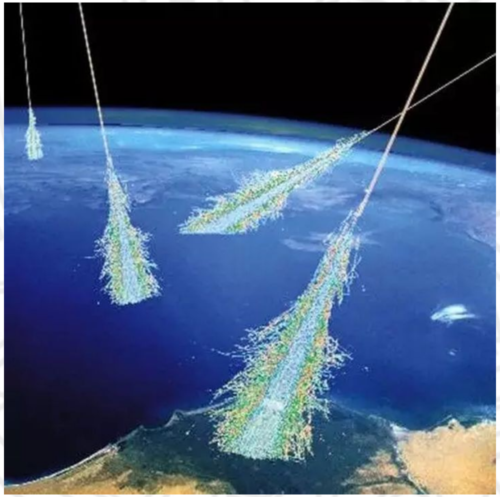
Introduction

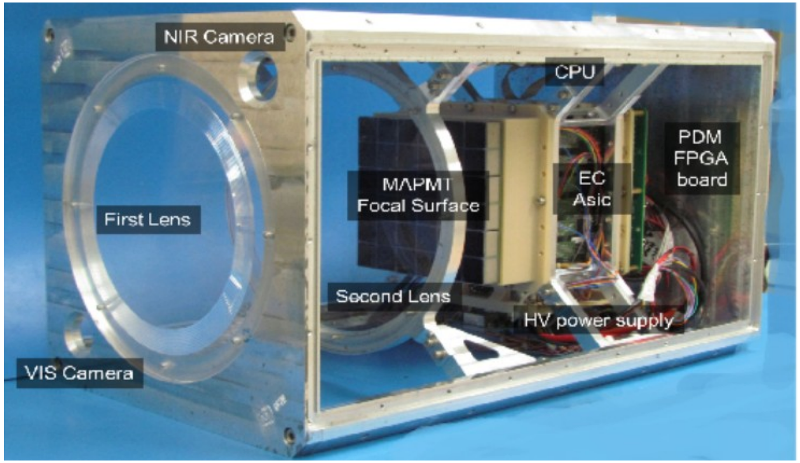


- JEM-EUSO (*Joint Experiment Missions for Extreme Universe Space Observatory*) is a program started with the objective of studying Ultra High Energy Cosmic Rays (~ 10^{18} eV).
- When this rays reach the atmosphere they generate a shower of particles and emit UV light isotropically in the process.

- This fluorescence light and the reflection of Cherenkov light from the ground are the object of study of JEM-EUSO.

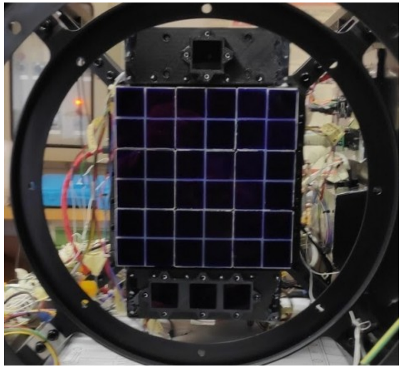


Mini-EUSO



- Mini-EUSO is a scale model of the original JEM-EUSO telescope. It's installed in the Russian Zvezda module of ISS (International Space Station).
- It's the first detector of the JEM-EUSO program that observes the Earth from the ISS.
- Mini-EUSO stands for *Multiwavelength Imaging New Instrument for the Extreme Universe Space Observatory.*

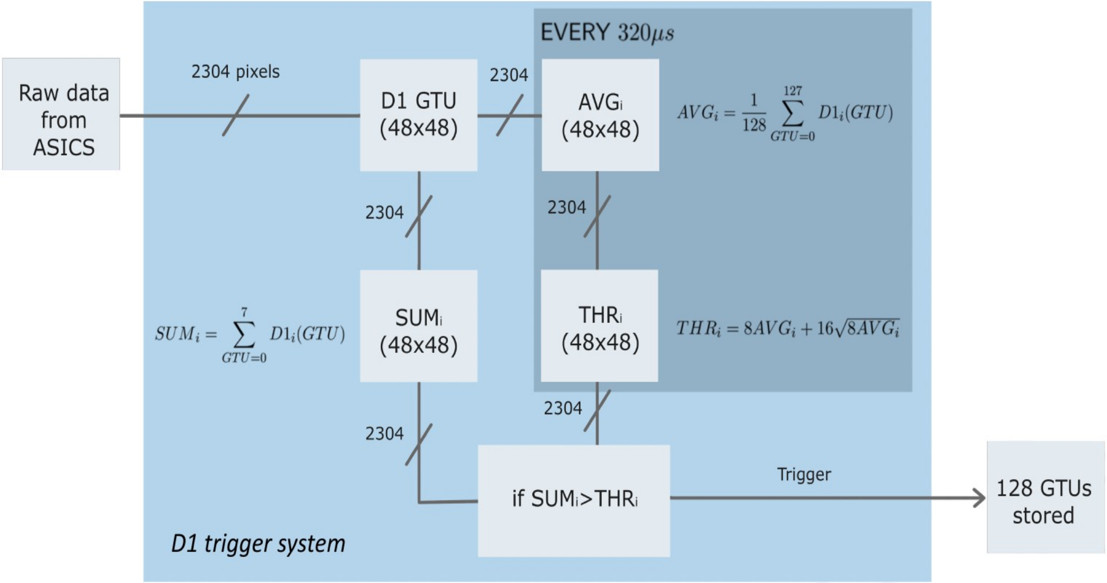
Mini-EUSO in his position on the ISS



Pixel Matrix

- The optical system consists in two Fresnel Lens of ~25 cm of diameter.
- The PDM is composed of 36 MAPMTs of 64 pixel each, sensitive to single photons in the 290nm-430nm band.
- The field of view is around 42° and cover 350x350 km^2 on the ground.

Time scales & trigger



Mini-EUSO D1 trigger logic

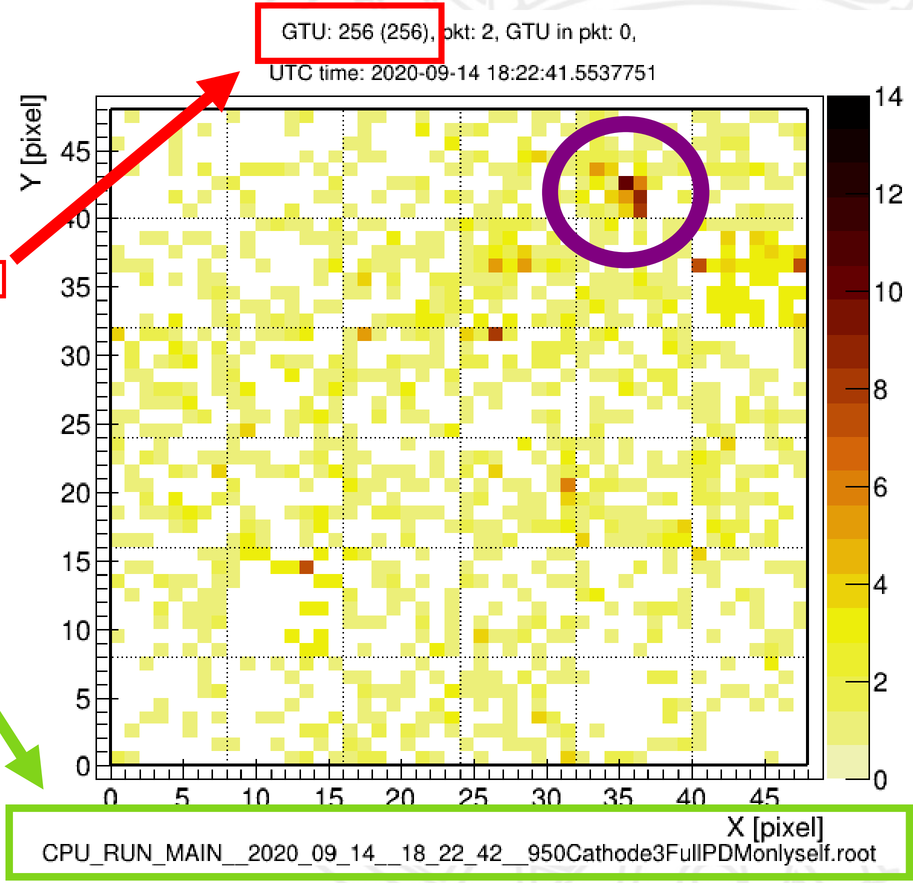
- Mini-EUSO store data in three different time resolutions:
  - **D1:** *2.5 μs,* scale for *Extreme Energy Cosmic Ray* events
  - **D2:** *320 μs,* scale for atmospheric events
  - **D3:** *40.96 ms,* this timescale get saved continously.
- The frame duration of every timescale is called GTU (*Gate Time Unit*).
- 128 GTUs form a packet.

- D1 and D2 have a trigger system:
- The threshold is determined by averaging over 128 GTUs.
- The signal from the pixel is integrated over 8 consecutive GTUs.
- If the signal is 16σ over the threshold the event triggers and get memorized.

Labeling data

	A	B
1	**Session (S25)**	**D1 GTU (orbit)**
2	Session_25_20200914/Orbit_01/CPU_RUN_MAIN__2020_09_14__18_22_42__950Cathode	0
3		128
4		256
5		384
6		512
7		640
8		768
9		896
10		1024
11		1152
12		1280
13		1408
14		1536
15		1664
16		1792
17		1920

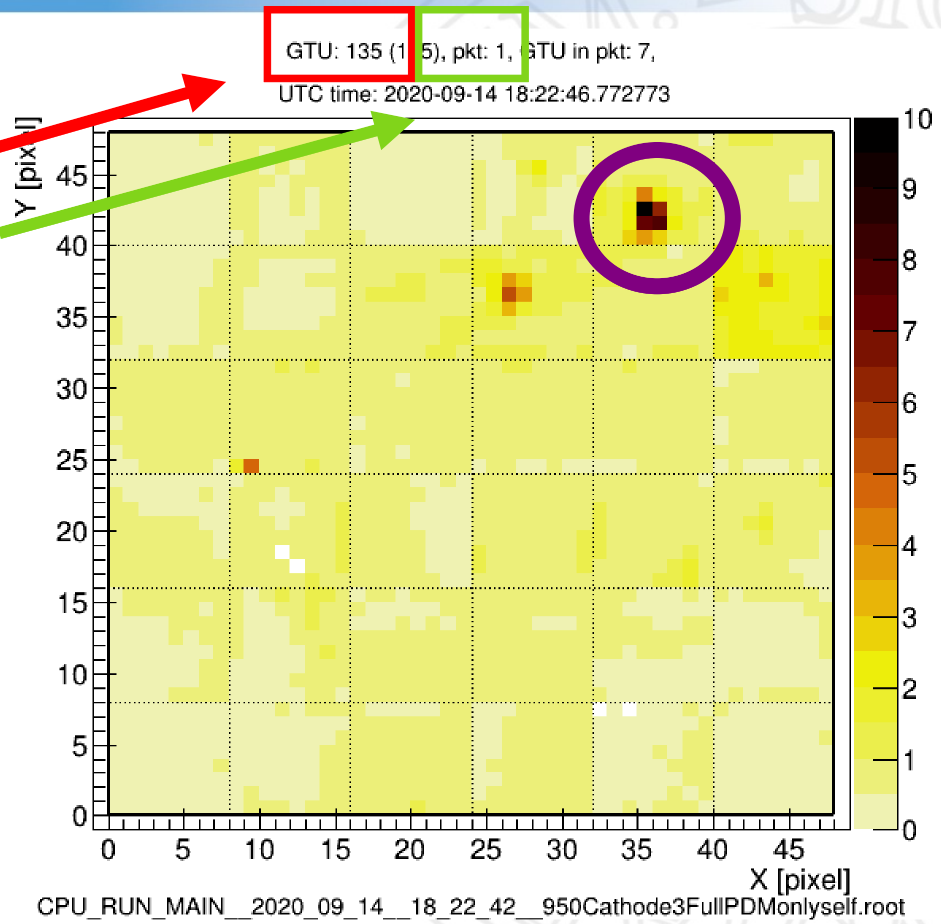
Orbit_01 | Orbit_02 | Orbit_flasher | Orbit_last



Labeling data

1	D1 GTU (orbit)	D1 GTU (file)	Timestamp	D3 GTU (orbit)	D3 GTU (file)	D3 packet (orbit)
2	0	0	1250.38	30	30	0
3	128	128	3770.12	92	92	0
4	256	256	5553.78	135	135	1
5	384	384	6069.81	148	148	1
6	512	512	8654.02	211	211	1
7	640	640	8977.24	219	219	1
8	768	768	10594.56	258	258	2
9	896	896	10841.55	264	264	2
10	1024	1024	11229.05	274	274	2
11	1152	1152	13127.26	320	320	2
12	1280	1280	15989.36	390	390	3
13	1408	1408	17752.52	433	433	3
14	1536	1536	18059.04	440	440	3
15	1664	1664	19547.01	477	477	3
16	1792	1792	21904.55	534	534	4
17	1920	1920	23647.77	577	577	4

Orbit_01 | Orbit_02 | Orbit_flasher | Orbit_l



A first analysis

Time from previous trigger (ms)	Dead time (ms)	Total dead time (s)	Total Time (s)	Relative dead time (%)
1250.38		59.21	870.32	6.80%
2519.74				
310.90				
516.03				
2584.21				
323.22	1508.52			
108.80				
246.99				
387.50				
1898.21	2601.39			
260.72				
1763.16				
306.51				
1487.97	1424.51			
933.03				
1743.22				

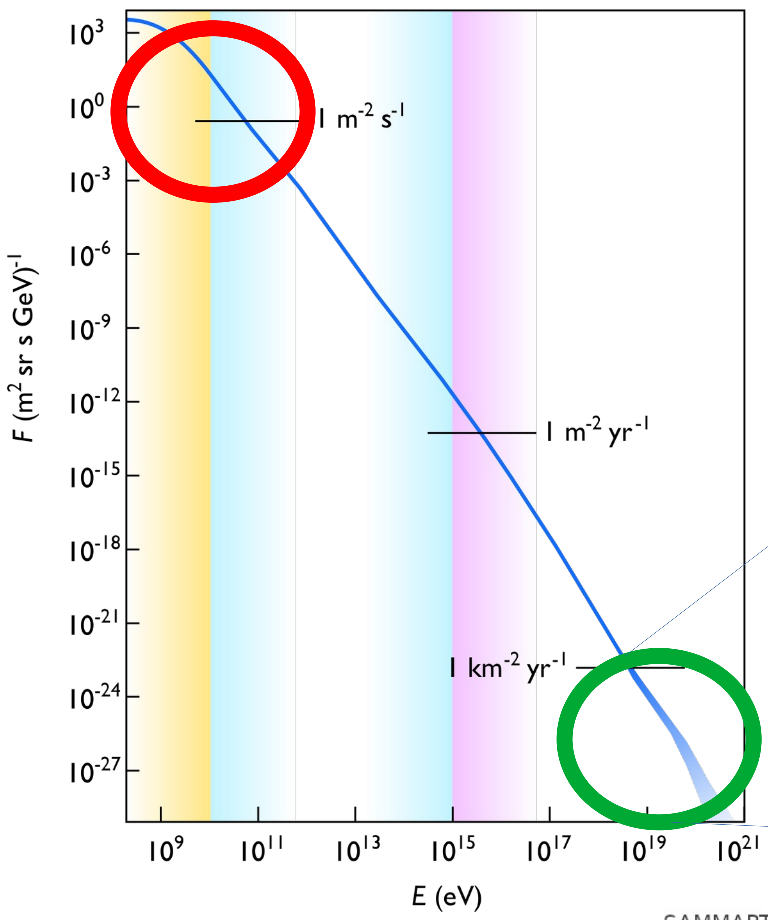
- Mini-EUSO can save up to 4 events per 5.24 seconds (namely the duration of a D3 packet, 128*40.96 ms).
- When the fourth event is stored the telescope is blind to triggers until the end of the current packet.
- This is considered *dead time*, it's useful to evaluate the duration of these periods relatively to the working time of Mini-EUSO.

Duration of the entire orbit

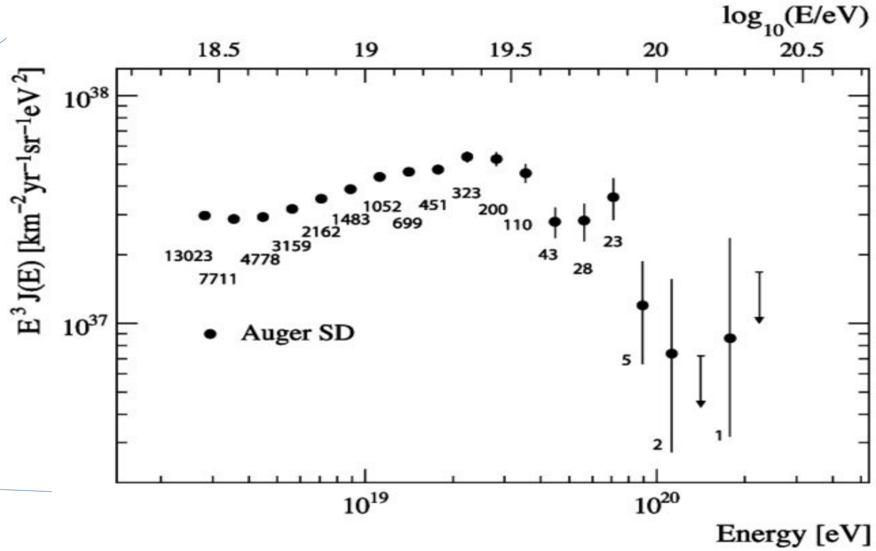
The total dead time during the orbit

Dead time after the memorization of the 4th trigger

Direct cosmic rays



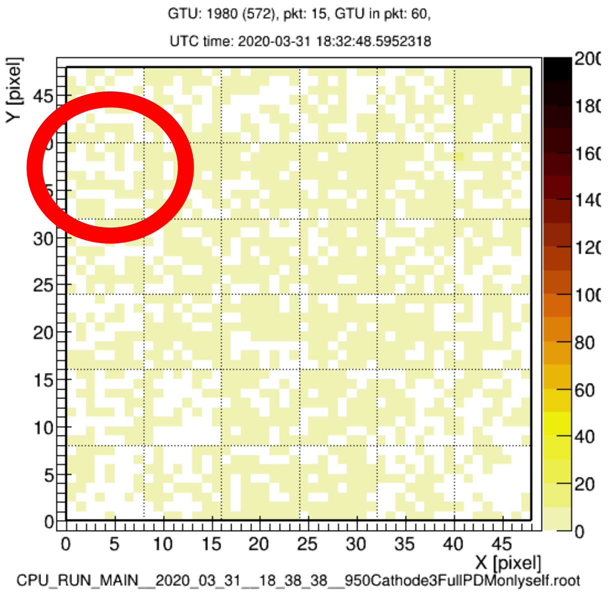
- The energy level of the cosmic rays searched by JEM-EUSO is showed in GREEN.
- When a charged particle hit the PDM before reaching the atmosphere is called a *Direct Cosmic Ray* and it's considered background in the scope of the data.
- There still isn't a theoric model for these particular particles, but they are expected to be in the range of energy showed in RED.

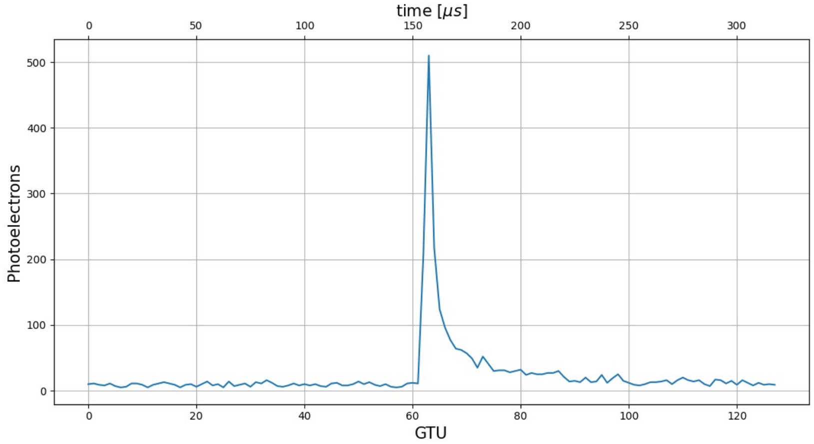


Auger data

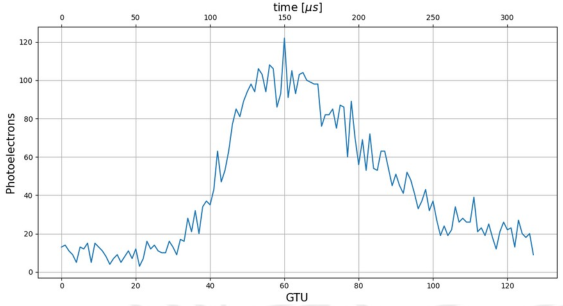
Cosmic-ray light curve

- When cosmic rays interact with Mini-EUSO directly they trigger and cause the memorization of an event.
- These events are not the objective of JEM-EUSO experiment and are considered background.
- In order to analyze these light curves it's useful to automatize the filtering of non-interesting events, reducing the time involved in the analysis.



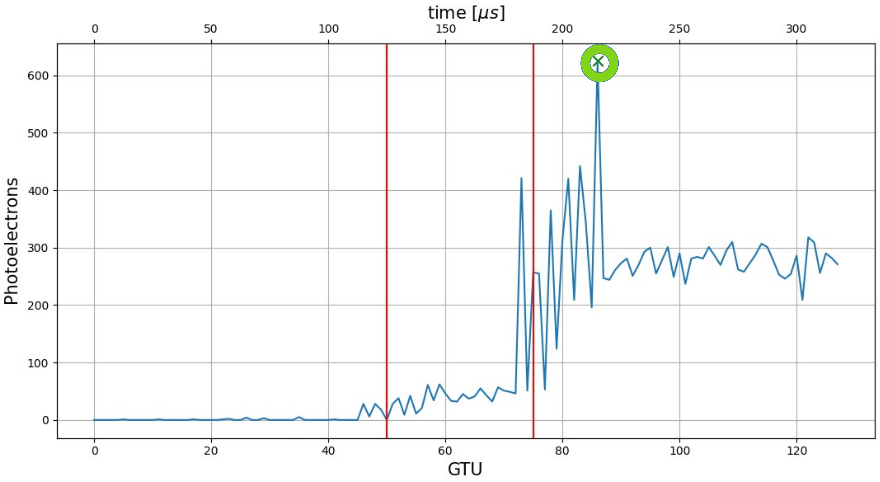


Direct Cosmic Ray Light curve

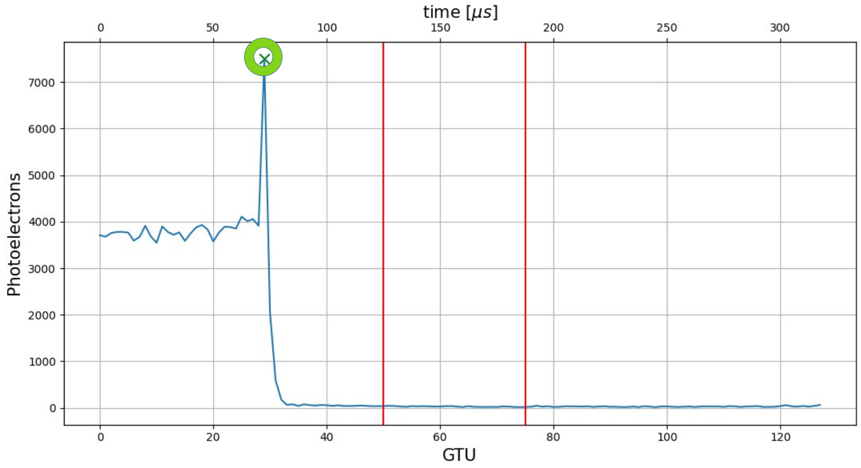


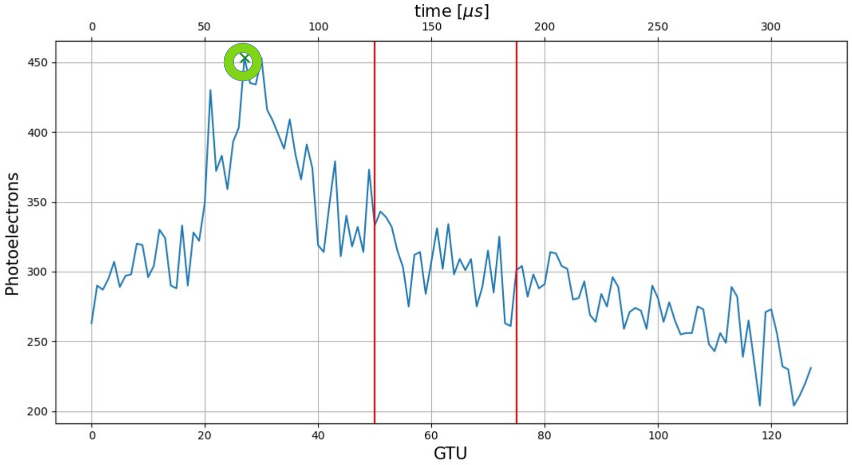
Flasher event with similar light curve to a real cosmic ray event

Cut by position of maximum

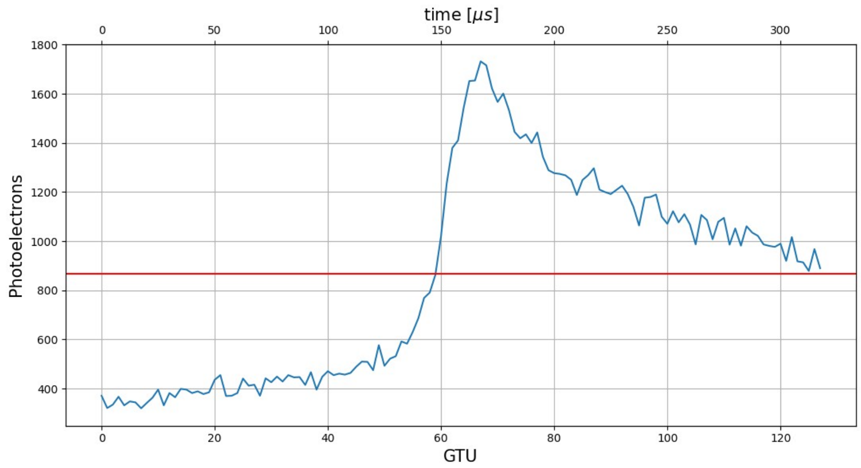


- The way that Mini-EUSO electronics works makes it save an event simmetrically.
- When something triggers it gets saved from a certain time *before* and the same time *after*.
- Light curves with a non-centered maximum are almost certainly not Direct Cosmic Rays events.

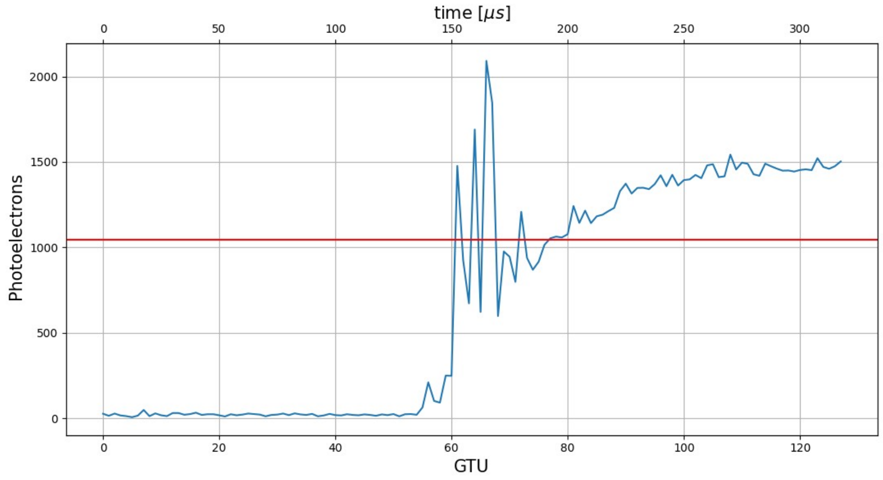


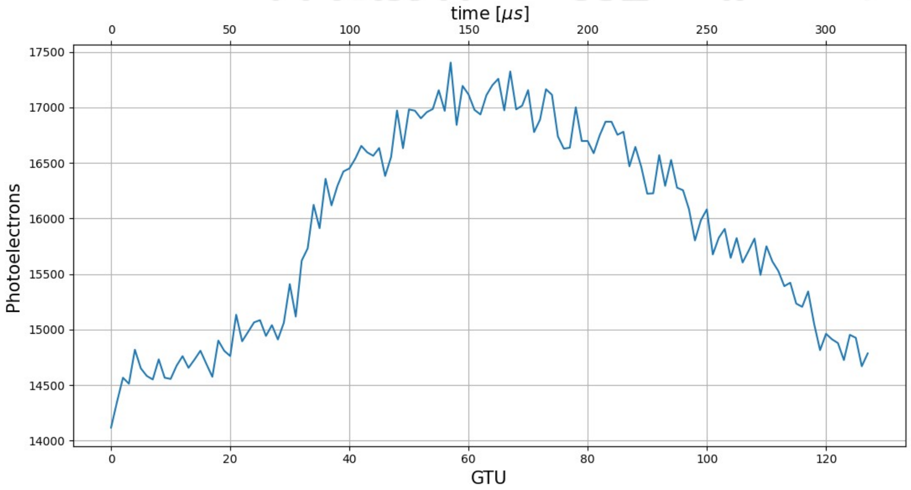


Cut by average height

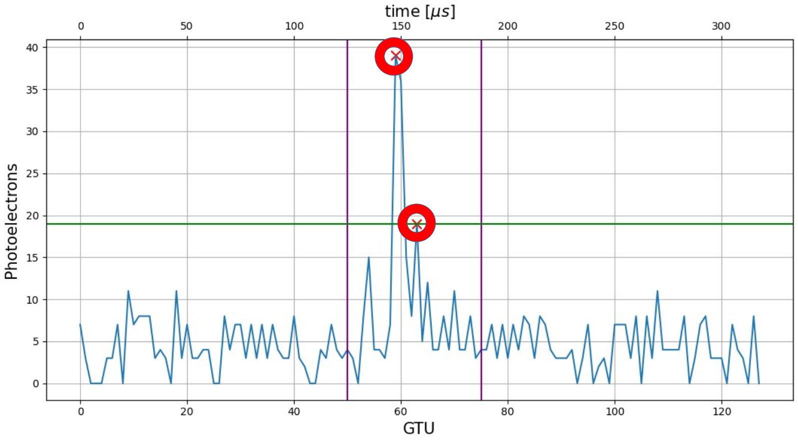


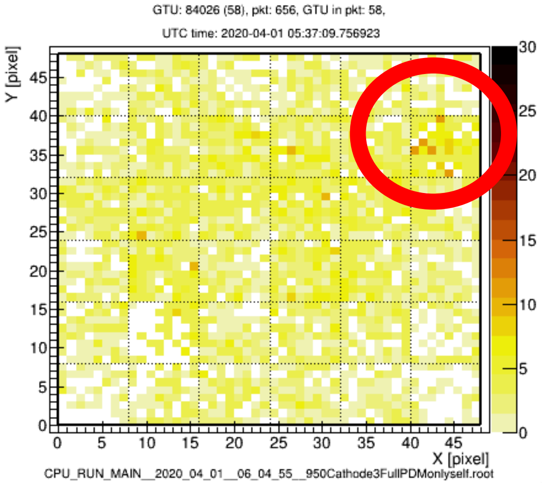
- Some phenomena other than cosmic rays can emit ultraviolet light and trigger Mini-EUSO.
- These include things like lightnings or any sun reflection when approaching of the dawn.
- They are very bright and long, in order to cut them out the filter checks and removes curves that stays high for a relatively long time.



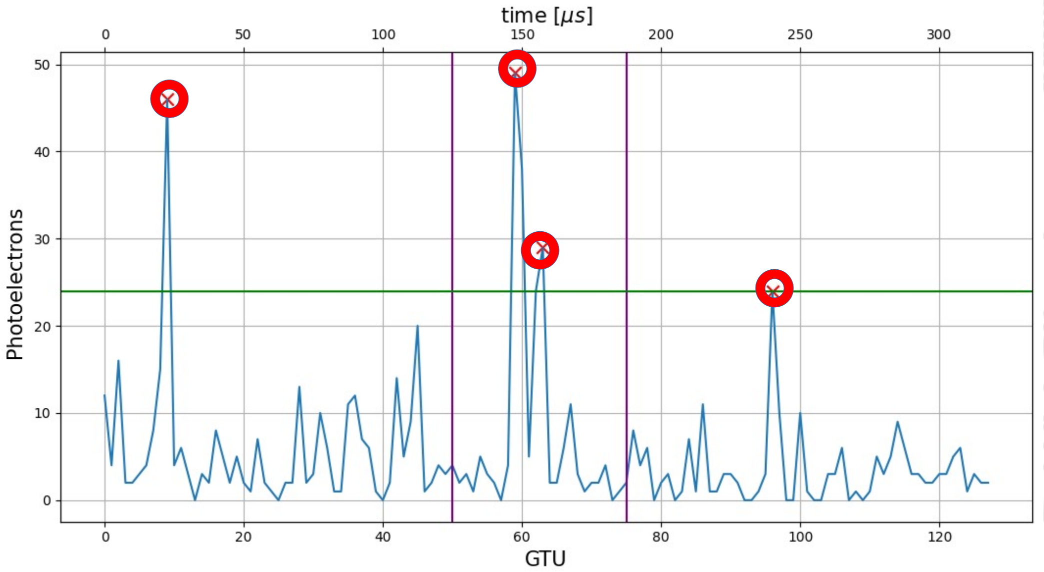


Cut by number of peaks

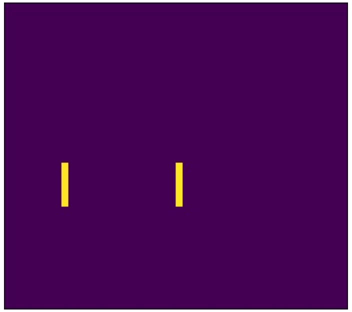




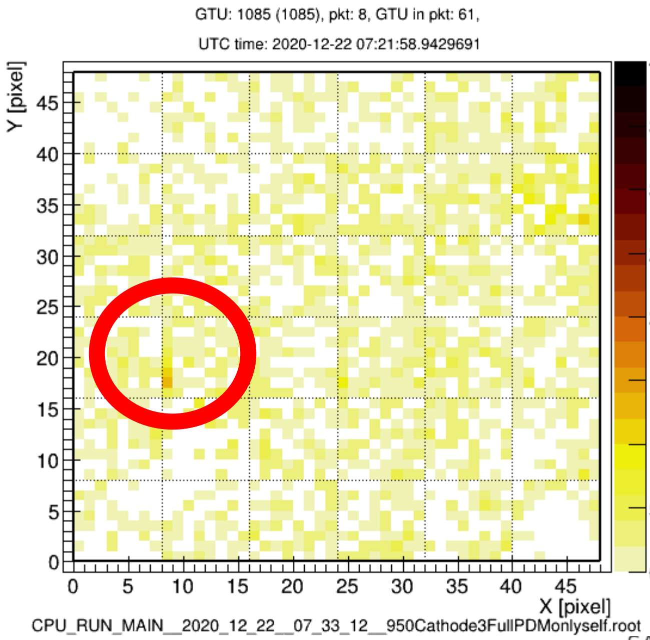
- The light curves of real events are expected to show a single peak localized in the center, the events with more than one are usually noise.
- As a relaxed assumption the filter is set to cut curves only with decentered and relativey high peaks.
- These peaks are found automatically using an algorithm.

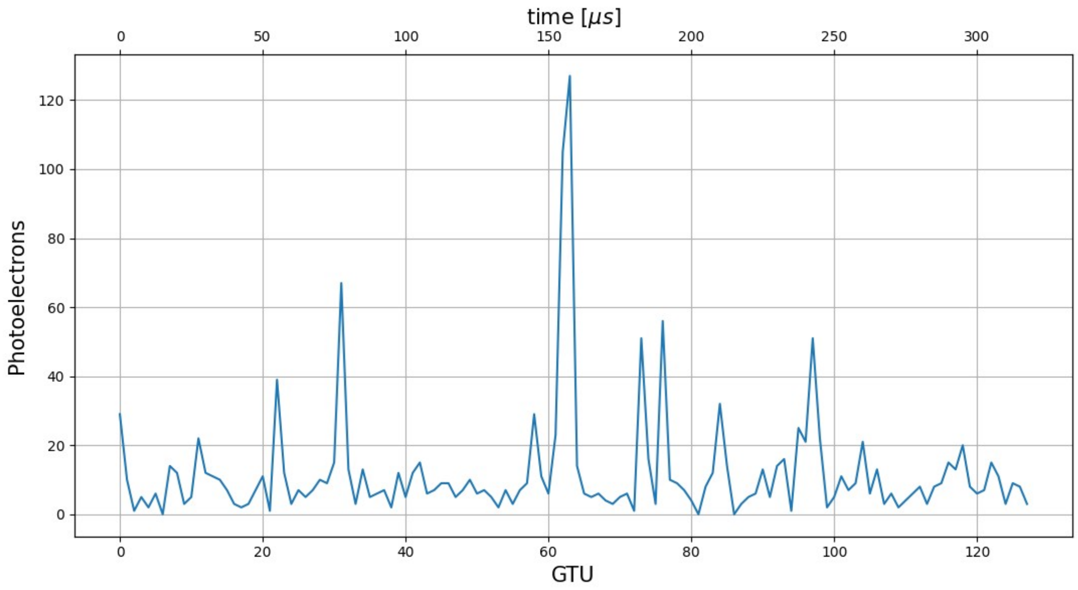


Cutting noisy pixels

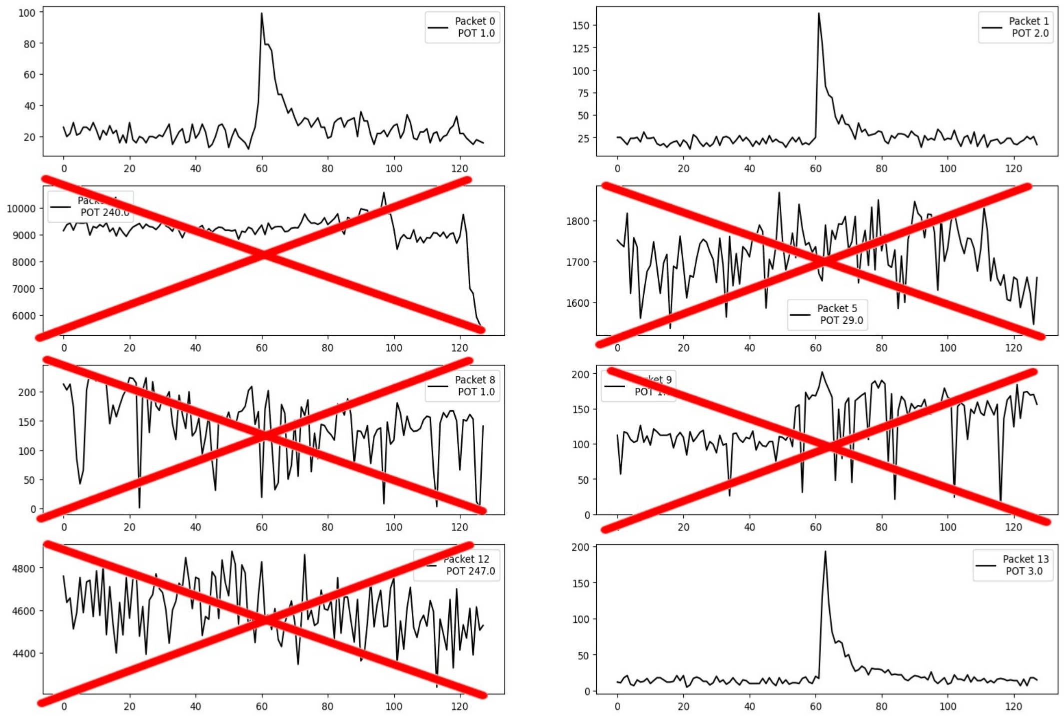


- Some of the pixels of Mini-EUSO showed anomalous behaviour and cannot be trusted in finding events.
- It’s possible to selectively filter out triggers coming from these pixels assuming that none of them are interesting.
- In the worst case scenario the loss of real cosmic rays would be of 0.6% (area of the pixel matrix occupied by these pixels).



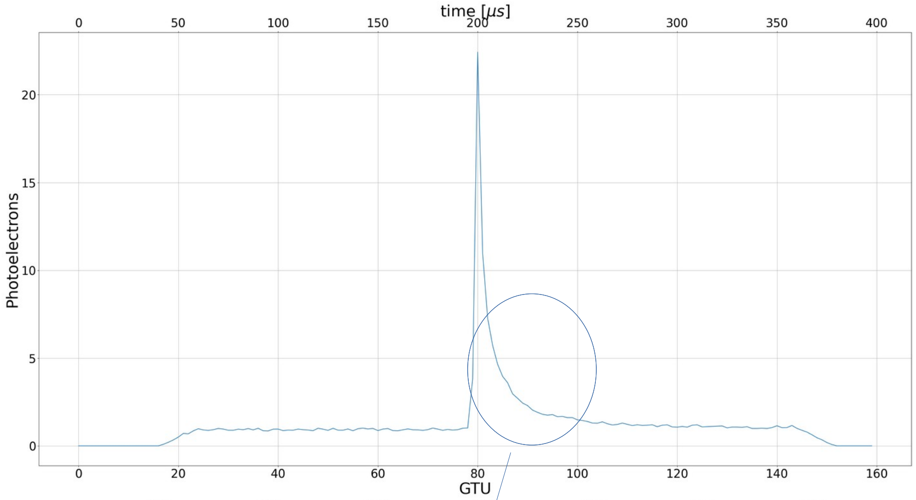


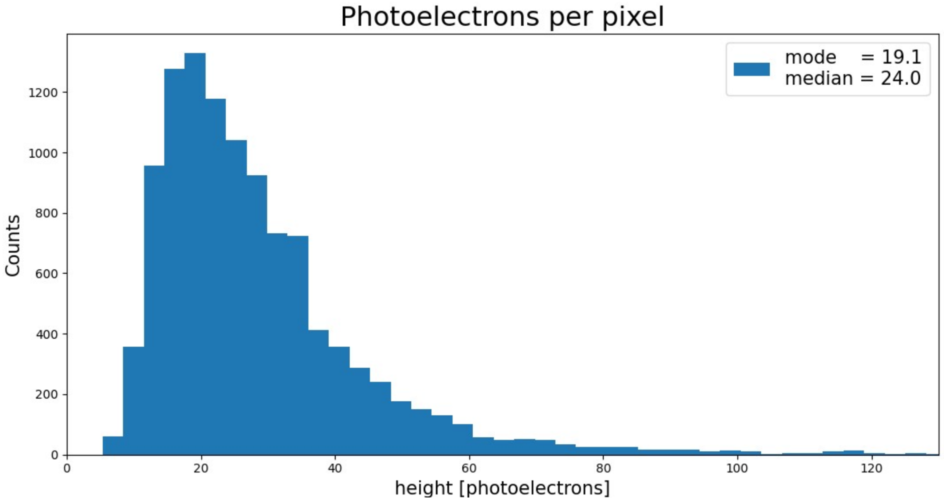
Results

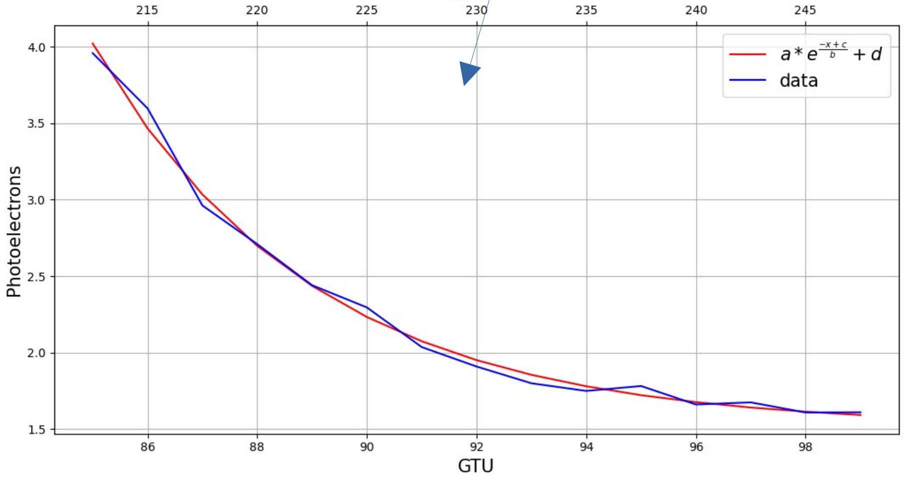


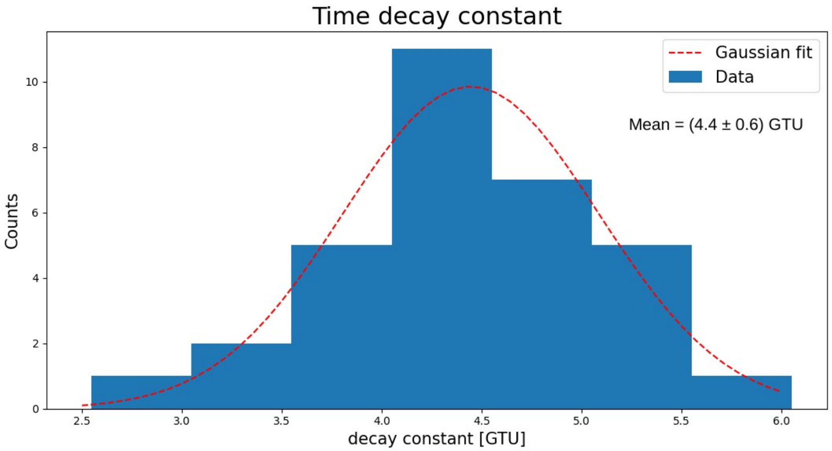
- Using these simple filters the amount of work needed to manually select the events is reduced greatly.
- On a particular data session known to be composed totally of electronic noise the filters manage to cut out 99.6% of the data.
- Some sessions with a more generic distribution of noise and interesting events have been tested and showed cuts for around 32-33% of total data.
- Applying the filters provides a relatively specialized dataset that can be used for the study of Direct Cosmic Rays.

Further analysis









Conclusions

- During the internship period, the transcription of the data from ISS into an excel sheet has been automated by the use of a program. The same program splits events in their respective packets and computes dead time.

- Direct cosmic rays lightcurves have been analyzed in order to extrapolate their distinctive characteristics and possibly select them from other events.

- The introduction of specific filters carries out efficiently this selection, thus introducing an automatic method for obtaining a set of data containing only Direct Cosmic Rays.

- This dataset may be used to study the distribution of these events, and its dependence from geomagnetic latitude.

- Further informations about Direct Cosmic Rays can be learned from their lightcurves, such as the average photoelectron number and the time costant of the exponential decay

References

- **A. Belov et al.** *“The integration and testing of Mini-EUSO multi-level trigger system”* https://doi.org/10.1016/j.asr.2017.10.044

- **JEM-EUSO Program** website, *“Missions: Mini-EUSO”* http://jem-euso.roma2.infn.it

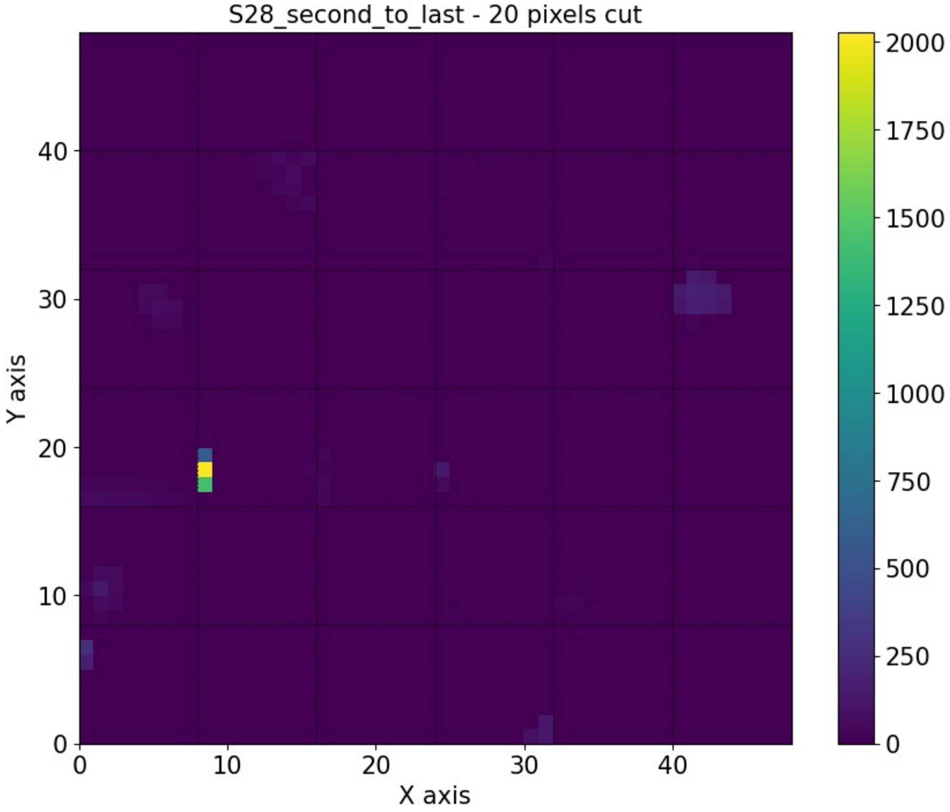
- **M. E. Bertaina** website, *“Research activity and other projects”* http://personalpages.to.infn.it/~bertaina/index-e.html

- **M. Battisti et al.** *“The onboard performance of the Level 1 trigger of Mini-EUSO telescope”,* private communication

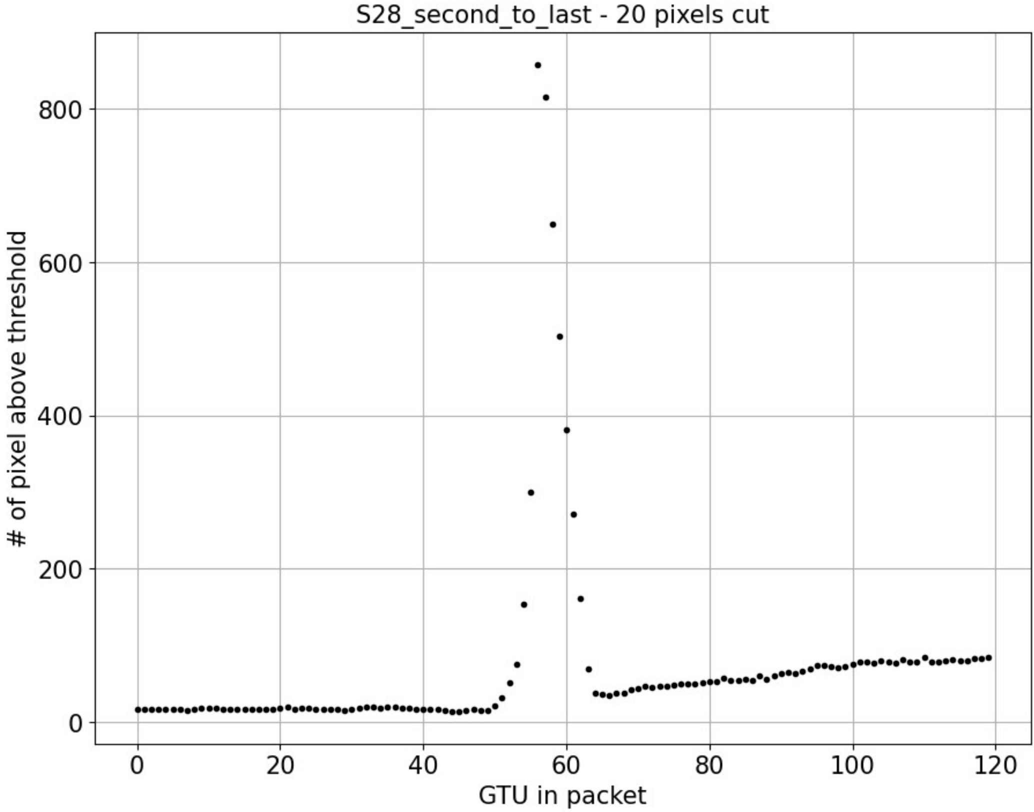
- **S. Bacholle et al.** *“Mini-EUSO mission to study Earth UV emissions on board the ISS”* *https://arxiv.org/abs/2010.01937*

Thanks for your attention

“Noisy orbit”

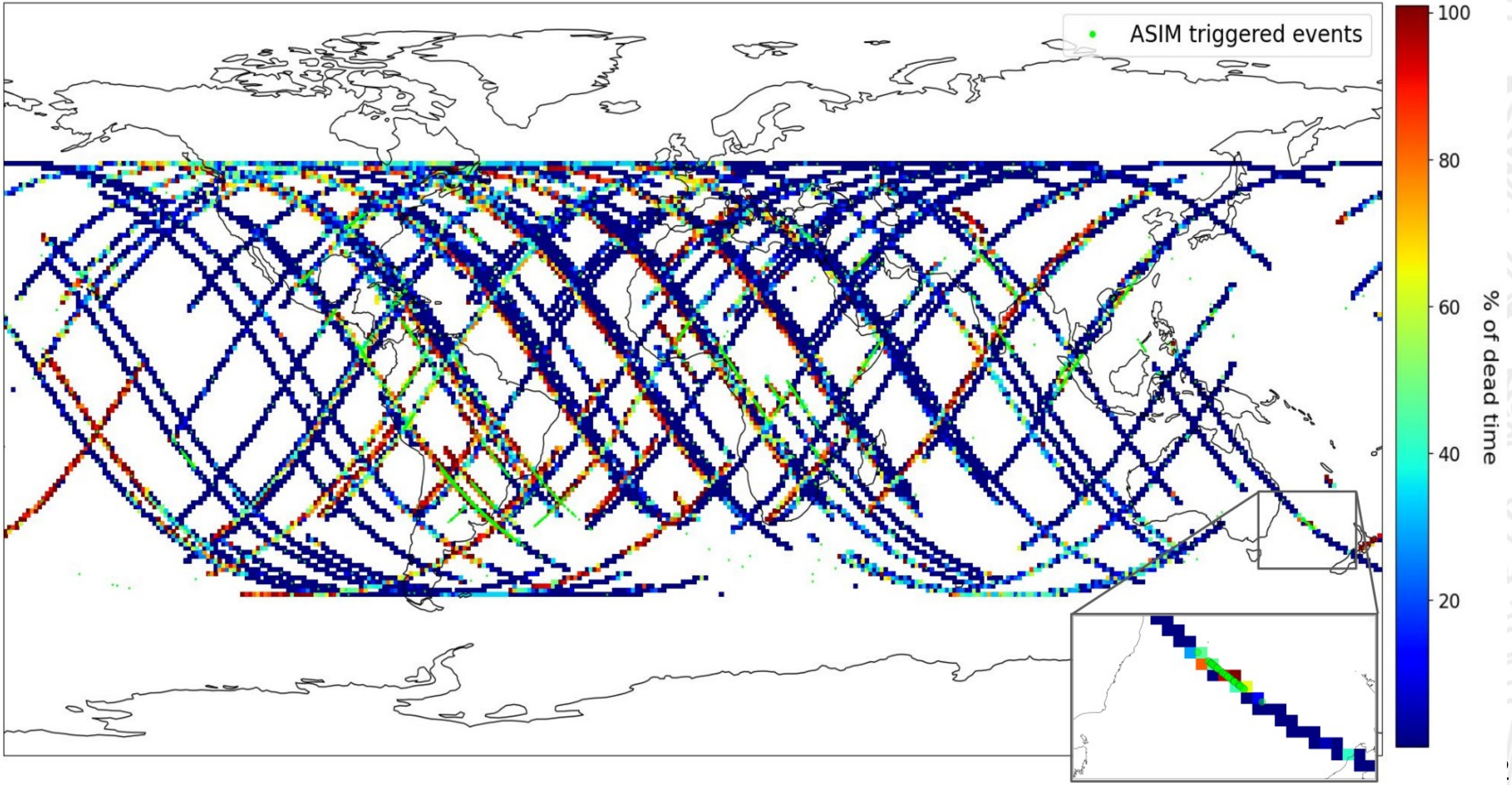


S28_second_to_last - 20 pixels cut
Y axis
X axis
0
10
20
30
40
2000
1750
1500
1250
1000
750
500
250
0



S28_second_to_last - 20 pixels cut
# of pixel above threshold
GTU in packet
0
200
400
600
800
20
40
60
80
100
120

Dead time distribution



Cosmic rays distribution