UNIVERSITÀ
DEGLI STUDI
DI TORINO

INFN

Tesi di Laurea Triennale in Fisica
BSc. Thesis in Physics

"Performance del trigger e ricerca di eventi di tipo EAS con Mini-EUSO"

"Trigger performance and search for EAS-like events with Mini-EUSO"

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Stage presso/at *INFN* – Istituto Nazionale di Fisica Nucleare

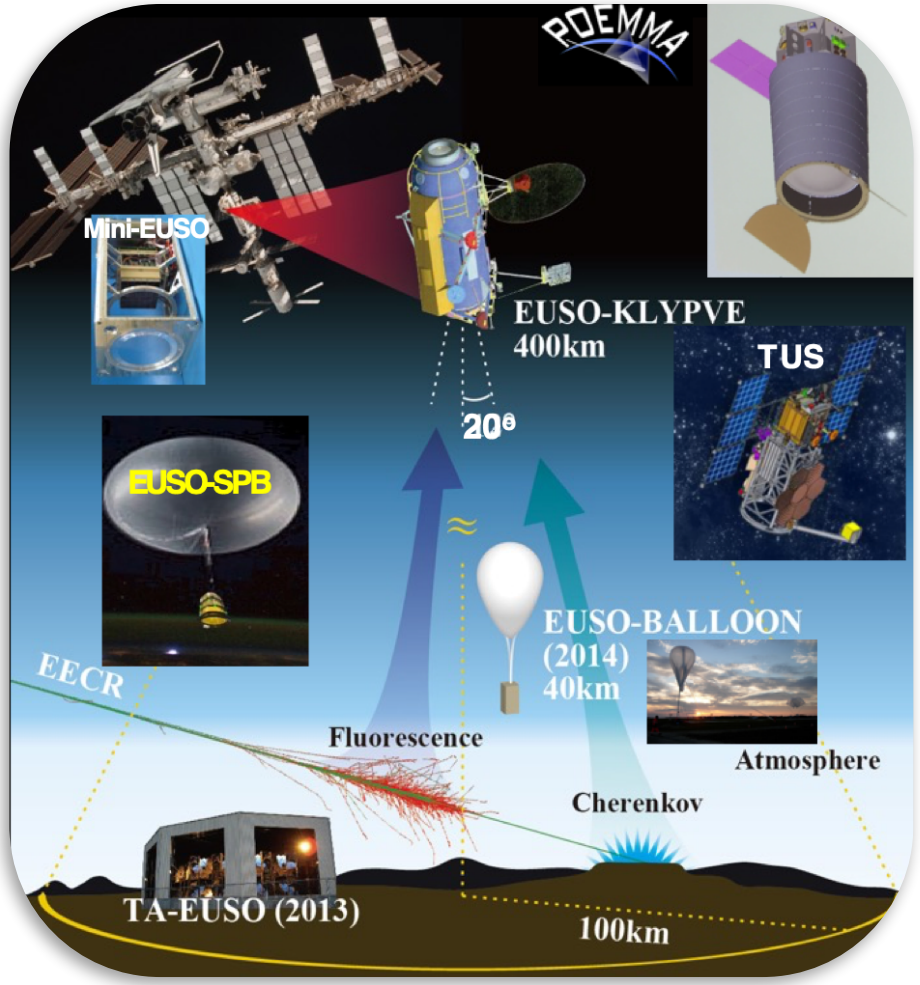
«*National Institute of Nuclear Physics*»

a.a. *2019-2020*

Summary

- ***Origin of EAS*** *(Extensive Air Showers)*
- ***JEM-EUSO program*** *(Joint Experiment Missions for Extreme Universe Space Observatory)*
  - Mini-EUSO & TUS
- ***Mini-EUSO -*** *Trigger, Data Acquisition Module & Data Analysis*
- ***Search Asymmetric Gaussian -*** *EAS-like events*
- ***Results***
- ***Conclusions***
- ***References***

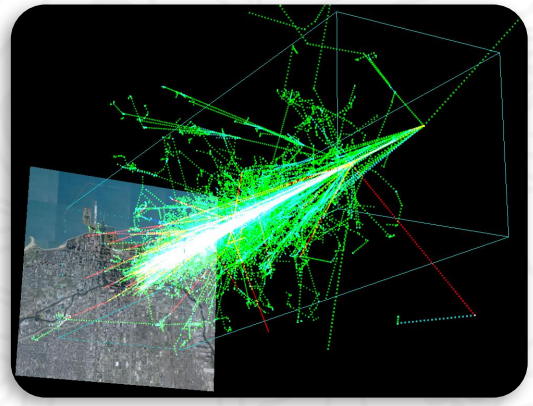
Introduction



JEM-EUSO program

Origin of EAS *(Extensive Air Showers)*

- ***EECRs***: *Extreme Energy Cosmic Rays*, particles *(protons, α particles, nuclei of C, O, Fe)* with $E \geq 5 * 10^{19} eV$ produced by extreme astronomical phenomena *(γ-ray bursts, starburst galaxies, black holes, etc…)*.
- Interaction with the high Earth's atmosphere yields *EAS,* creating a cascade of secondary particles.
- The streak of fluorescence and Cherenkov light.
- Flux of *1 event/km²/century*.



simulation of EAS

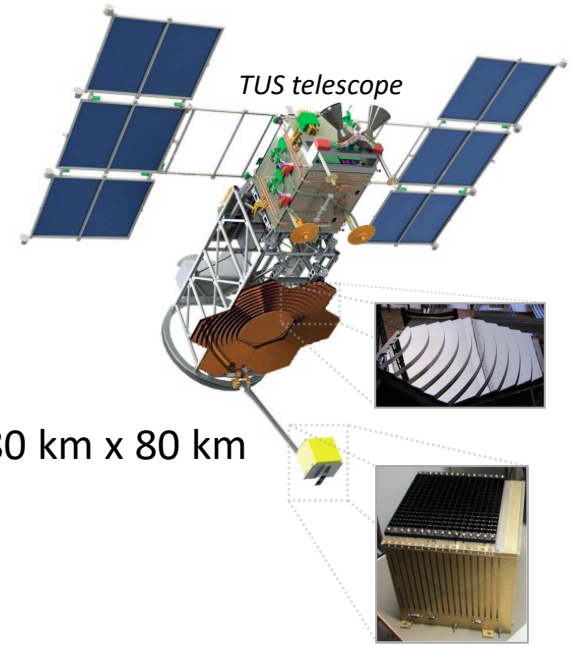
JEM-EUSO *(Joint Experiment Missions for Extreme Universe Space Observatory)*

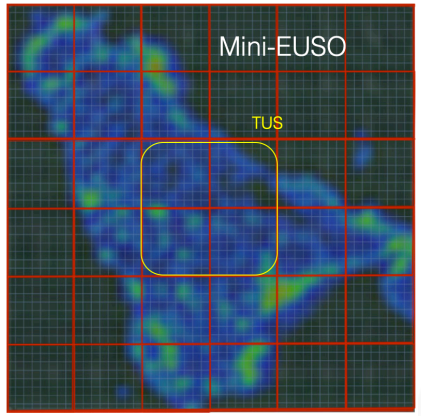
- Observe *EECRs* from space using fluorescence detectors.
- Collaboration of *16* countries and more than *300* researchers.
- Mission:
  - *EUSO-TA (2013 -)*
  - *EUSO-Ballon (2014)*
  - *TUS (2016 - 2017)*
  - *EUSO-SPB1 (2017)*
  - *Mini-EUSO (2019 -)*
  - *and more in the future…*

TUS & Mini-EUSO

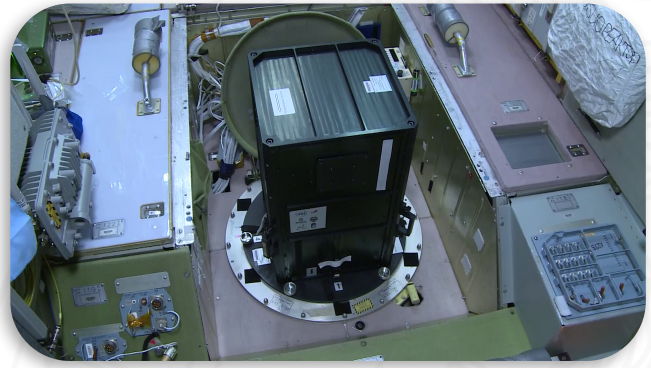
TUS *(Tracking Ultraviolet Set-up)*

- World's first orbital detector of EECRs.
- Consists of two main parts:
  - Fresnel mirror-concentrator.
  - 256 PMTs arranged 16x16 channels.
- Field of view ≃ 9°
- The full area observed on the ground ~ 80 km x 80 km from ~ 500 km orbit height
- Time resolution: 0.8 μs





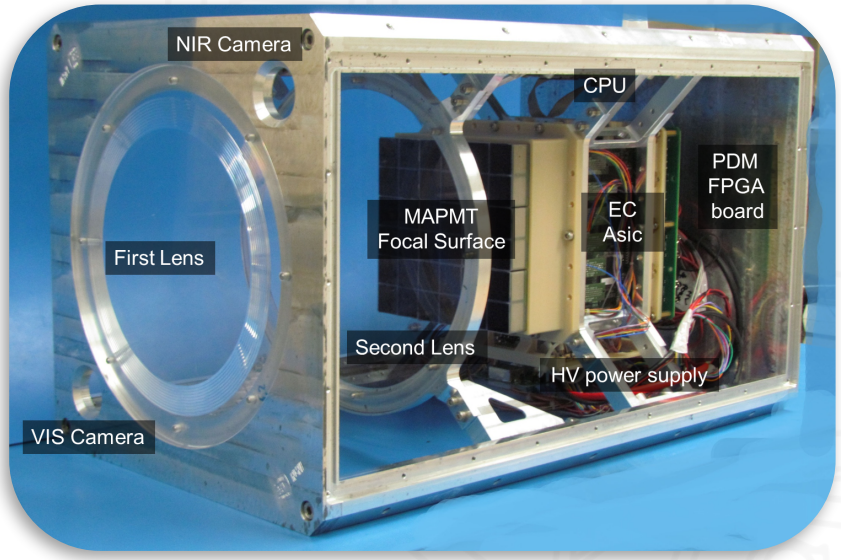
Comparison of FoV: Mini-EUSO and TUS



Mini-EUSO installed aboard the ISS

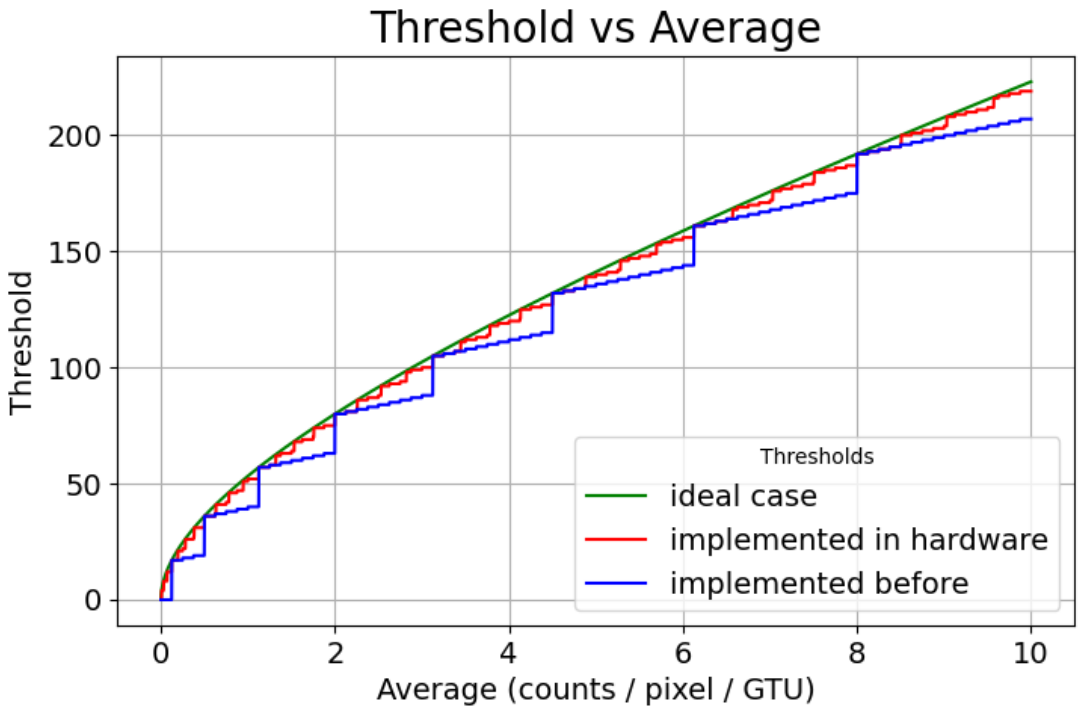
Mini-EUSO *(Multiwavelength Imaging New Instrument for the Extreme Universe Space Observatory)*

- A telescope in the UV range was installed on the nadir-facing in the Russian Zvezda module of *ISS (International Space Station).*
- Optical system: two Fresnel lenses diameter ≃ 25 cm.
- PDM consists of 36 MAPMTs, 64pixel each, able to detect a single photon.
- Field of view ≃ 44°
- The full area observed on the ground ~ 350 km x 350 km.
- Time resolution: 2.5 μs



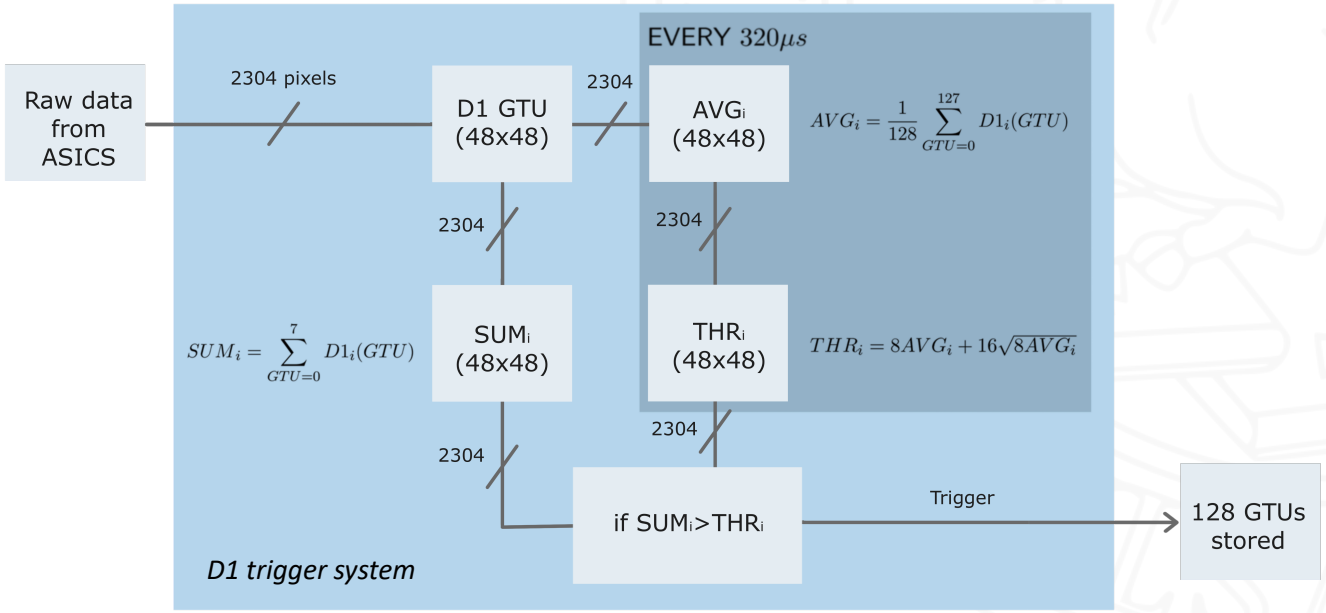
The Mini-EUSO's components

Mini EUSO Trigger – *Data Acquisition Module*



- Three different types of data acquisition stored:
  - **D1**: *2.5 μs*, timescale for *EECR*-like events.
  - **D2**: *320 μs*, timescale for fast atmospheric events.
  - **D3**: *40.96 ms*, *128* times D2.
- *2.5 μs = 1 GTU* (*Gate Time Unit*).
- up to *4* events saved every *5.2 s*.

- Internship at *INFN* (*National Institute of Nuclear Physics*).
- Mini-EUSO works with a *48 x 48* pixels matrix (*PMD*).
- Each pixel is considered independent with a field of view ~ *6 km*.
- The light takes ~ *20 μs* to cross one pixel.
- Pixel signal is integrated over *8* consecutive *GTUs*.
- The ground-level is determined by averaging over *128 GTU*.
- If the signal is *16 σ* over the background the event is triggered.

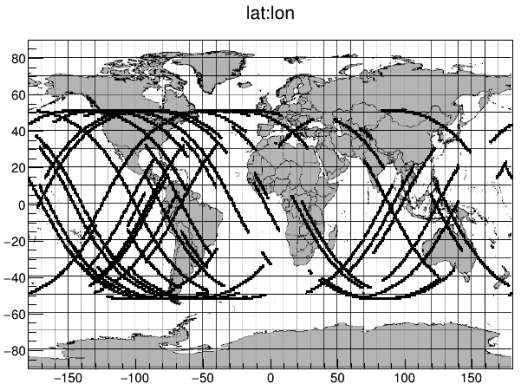


Data Analysis: *Timestamps, repeat events, dead time*

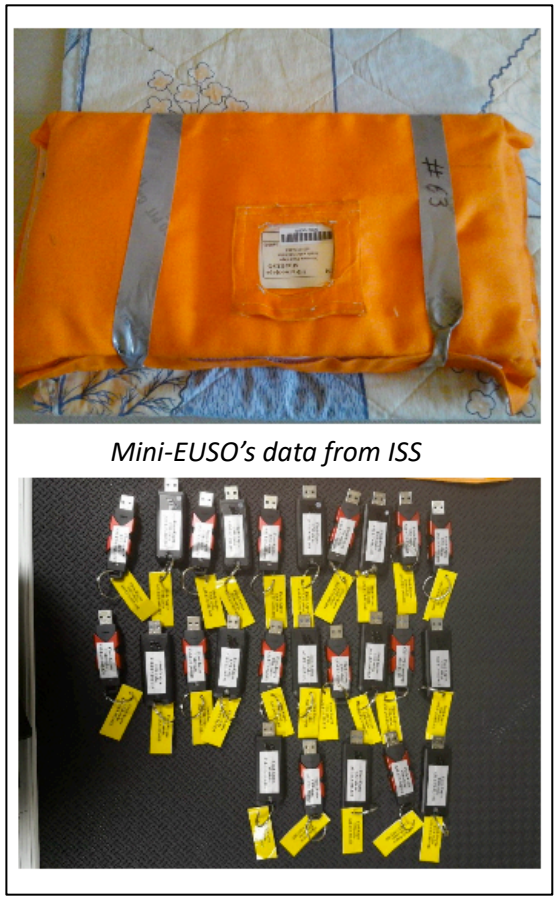
- The internship was also focused on the subdivision and organization of the new data acquired (January 2021) by Mini-EUSO.
- It was essential to locate the "repeat packages" in the available data and the dead time between the data acquisitions to start the data analysis

D1 GTU (file)	Timestamp	D3 GTU (orbit)	D3 packet (orbit)	Start of the packet (ms)	Time from previous trigger (ms)	Dead time (ms)
0	797990.97	19226	150	786432.00	11558.97	
128	800589.33	19289	150	786432.00	2598.36	
256	800781.83	19294	150	786432.00	192.50	0.00
384	804961.24	19396	151	791674.88	13286.36	0.00
10624	913543.37	22047	172	901775.36	11768.01	
10752	913553.35	22047	172	901775.36	9.98	
10880	913563.33	22047	172	901775.36	9.97	
11008	913573.30	22048	172	901775.36	9.97	3930.70
11136	917596.57	22146	173	907018.24	10578.33	
11264	918182.63	22160	173	907018.24	586.06	
11392	921297.45	22236	173	907018.24	3114.83	
11520	922248.47	22259	173	907018.24	951.02	498.41

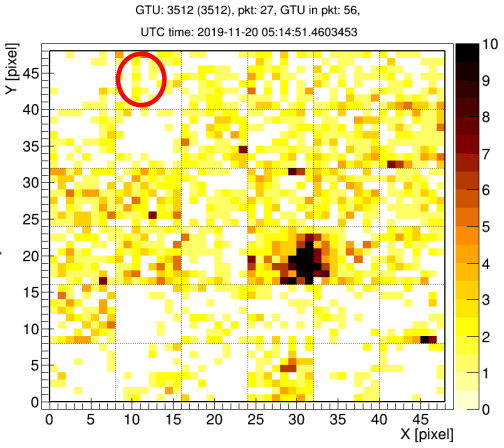
data analysis table



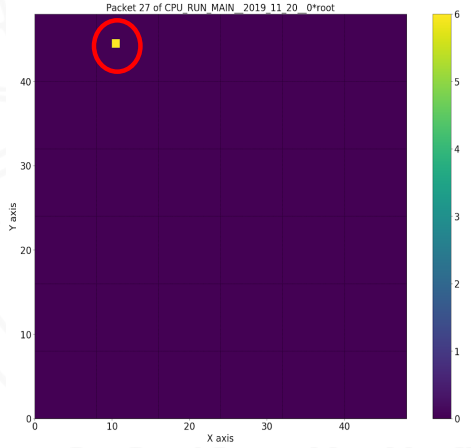
ISS orbits



Mini-EUSO's data from ISS



ETOS program

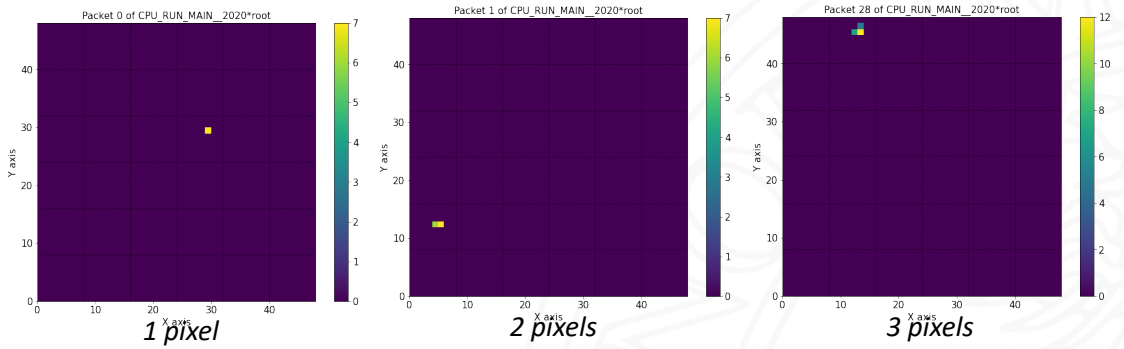


Visual data analysis

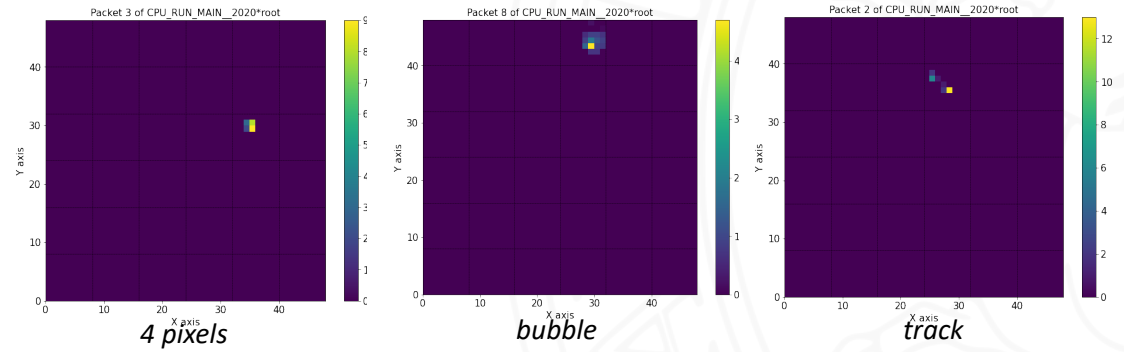
Event categorization (*manual*)

RESULTS OF 2 SESSIONS		
category	**freq. ass.**	**freq. perc.**
1 pixel	*1569*	*61.12%*
2 pixels	*318*	*12.39%*
3 pixels	*86*	*3.35%*
4 pixels or more	*78*	*3.04%*
bubble	*43*	*1.68%*
track	*18*	*0.70%*
no trigger	*220*	*8.92%*
ring	*6*	*0.23%*
sunrise and atmospheric events	*229*	*8.92%*
TOTAL EVENTS	**2567**	**100%**

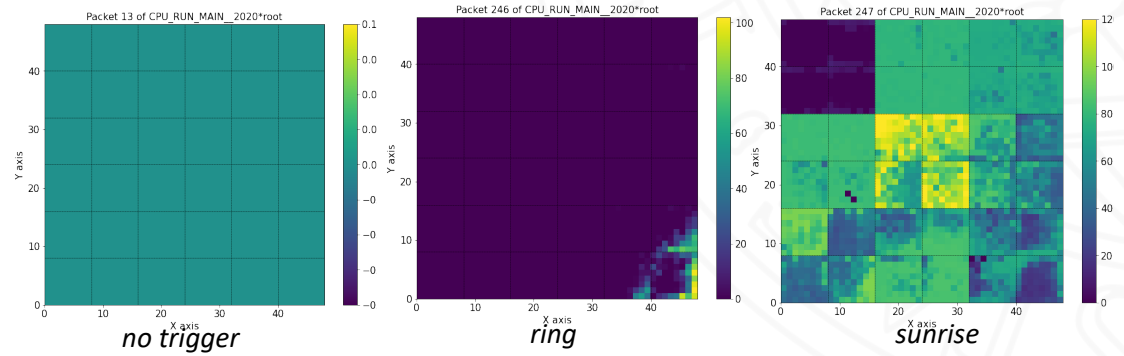
- After splitting and organizing the data, a large part of the stage work was to categorize the pixel's behavior of all events one by one.
- Two sessions with *2567* images were analyzed manually in this part of the internship work.



1 pixel *2 pixels* *3 pixels*

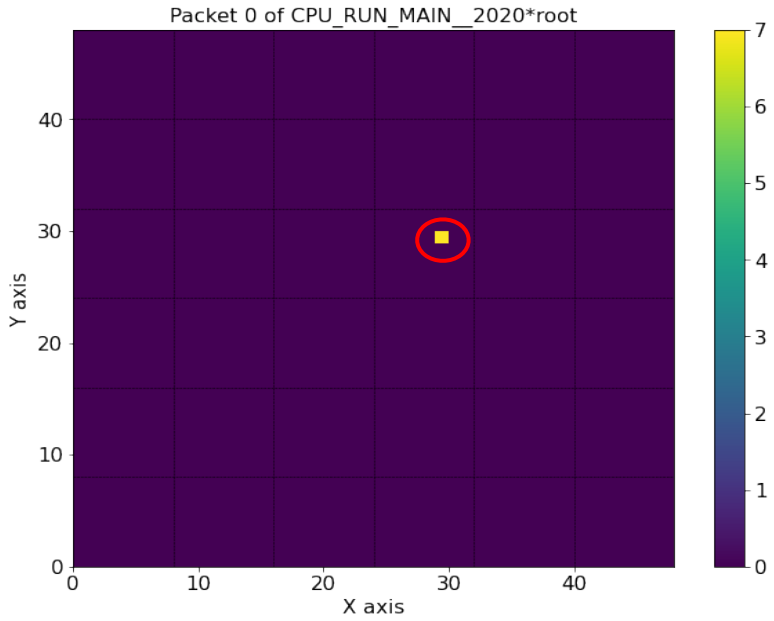


4 pixels *bubble* *track*

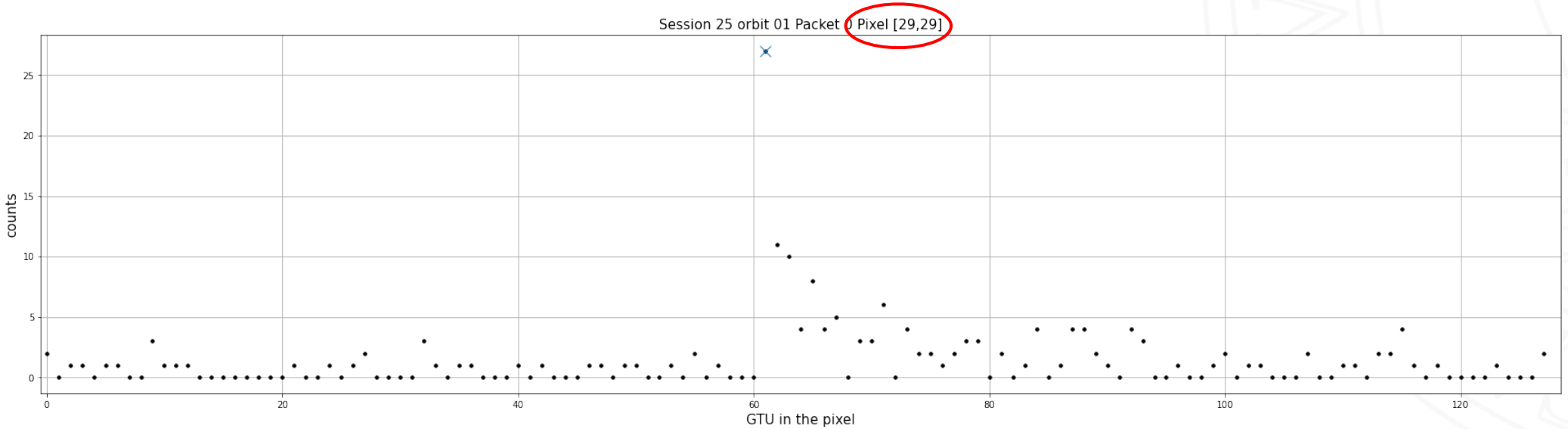


no trigger *ring* *sunrise*

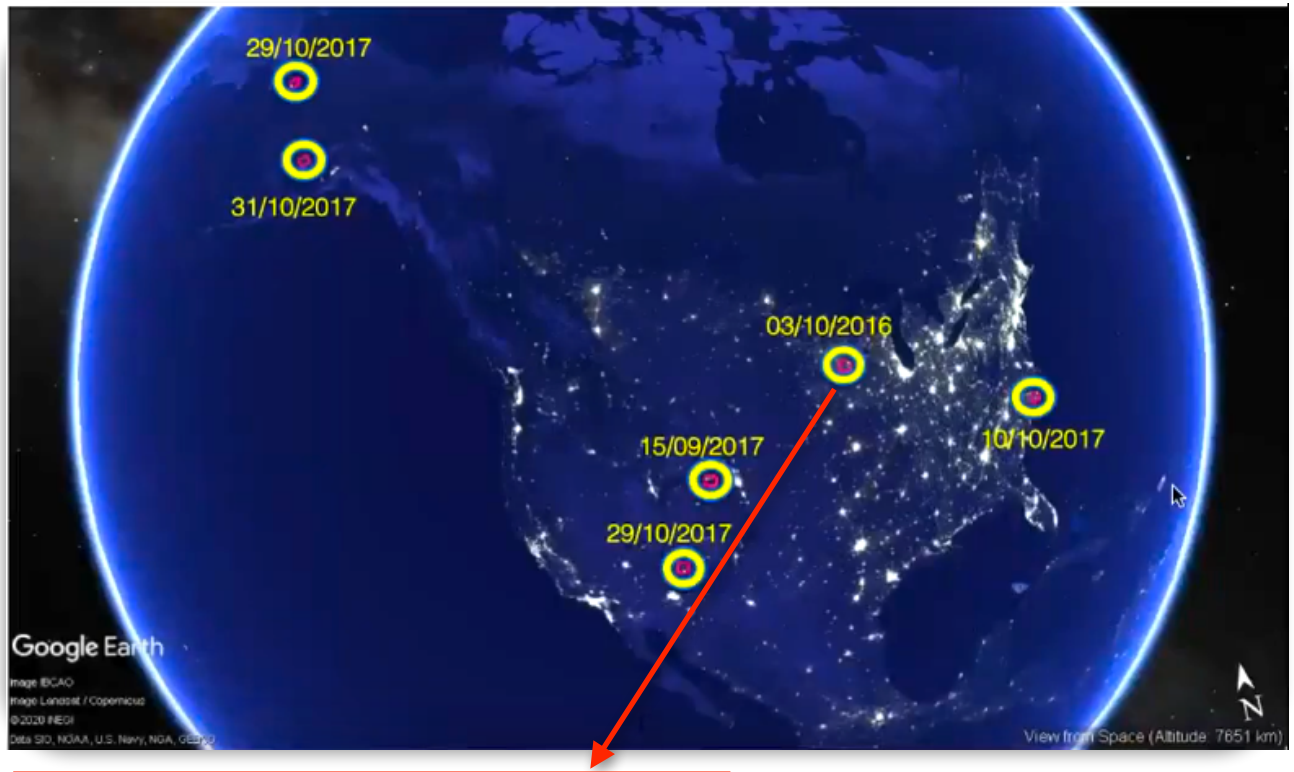
Event categorization (*software*)



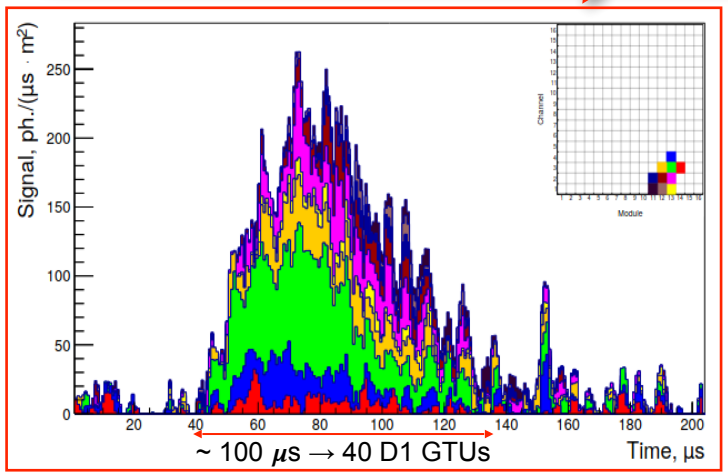
- After all the analysis done by hand, I created a program able to:
  - identify all packets containing *1, 2, 3,* and *4* pixels.
  - Show the position of the brightest pixel.
  - Plot its light curve (for future in-depth analysis)



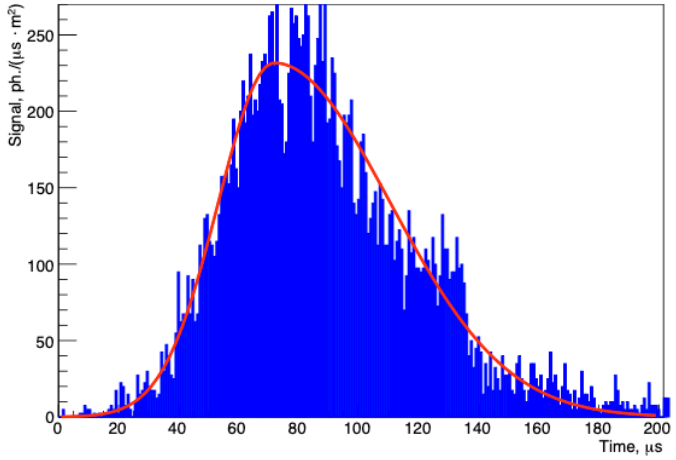
"Minnesota Event" - TUS



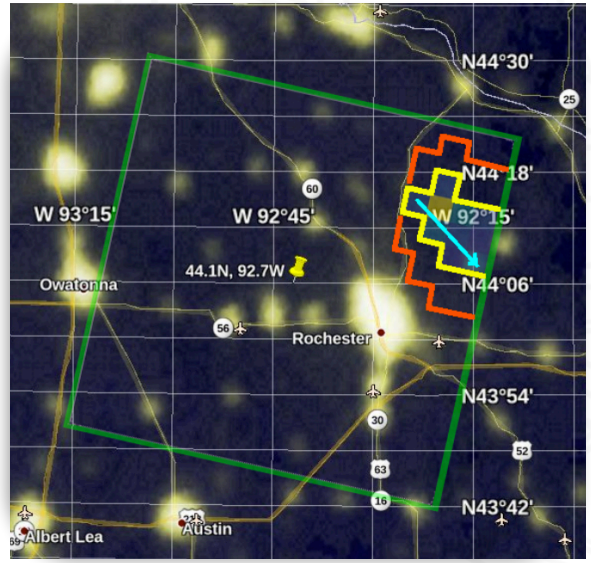
- *6* events were identified as *EAS*-like in a research carried out by *TUS* in *2016-17*.
- All of them are located in the United States showing «movement-like» pixels.
- *5* events are compatible by few degrees with the runway direction of nearby airports.
- Except the "*Minnesota Event*" (*TUS161003*), it's far from light sources and cities.
- *TUS* has a dead time of *1 min* and orbits the Earth with a speed of *7.5 km/s*.



"Minnesota event" light curve

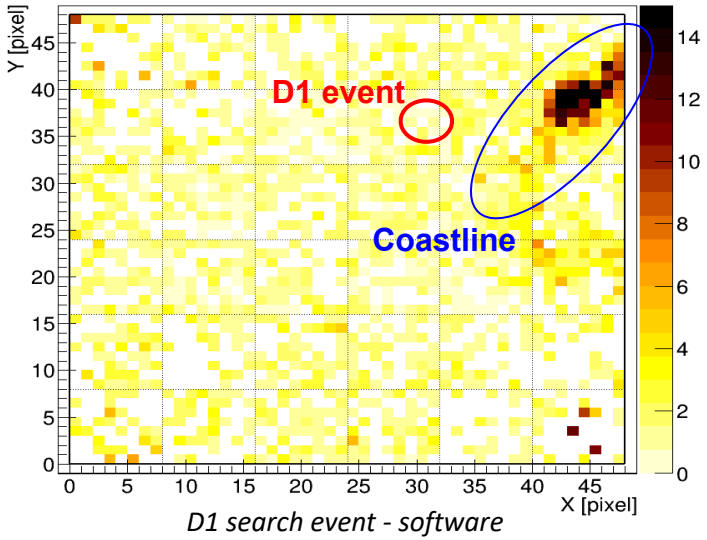


EAS simulation from 10^{21} eV proton at the zenit θ=60°

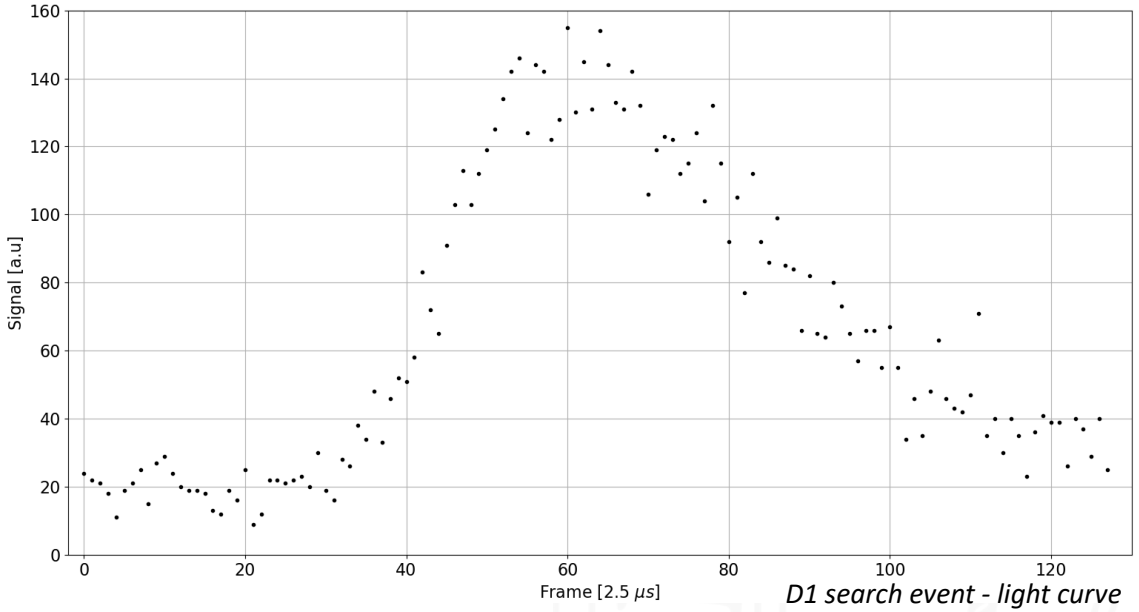


"Minnesota Event"

Search Asymmetric Gaussian with Mini-EUSO



D1 search event - software



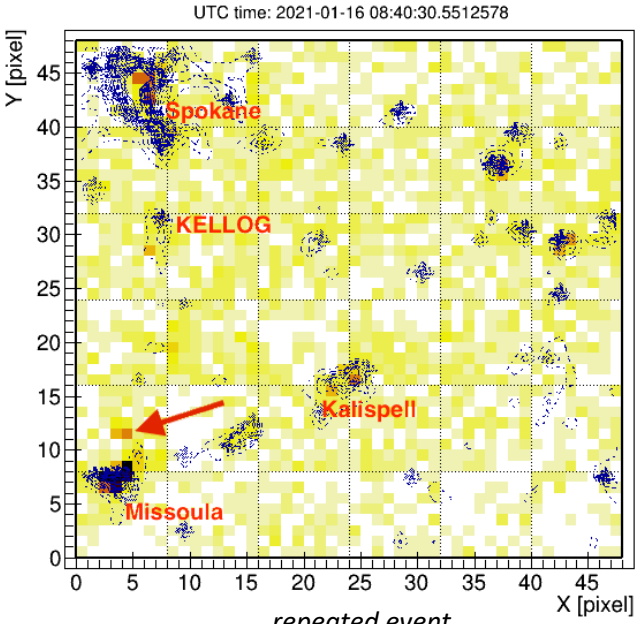
D1 search event - light curve

sessions over North America

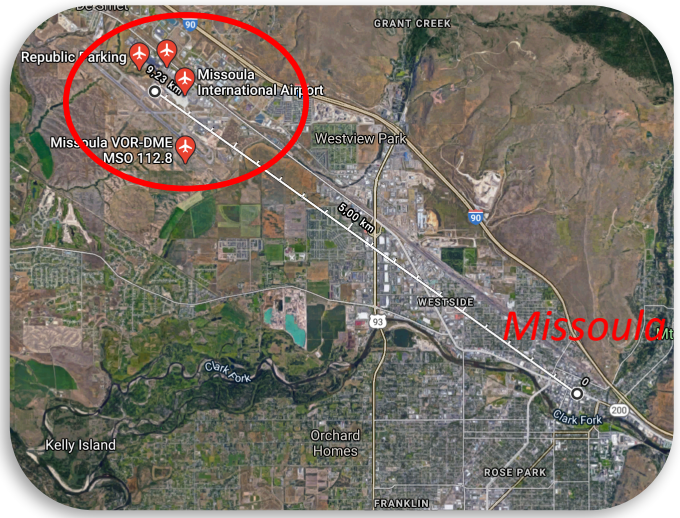
Session	# events	special events
25	1320	30
30	1288	29
31	1232	1
32	1247	24
33	773	1
total	**5860**	**85**
	rate	1,45%

- The program has selected only events with *1, 2, 3* and *4* pixels above the threshold with a total of *5860* packets for the five interesting sessions.
- Only *85* packages have been selected by hand (there is still no program capable of identifying the geometric shape of the affected light curve).
- *1.45%* of the data are interesting for an in-depth analysis.
- The analysis was focused on sessions that pass over North America at some point.

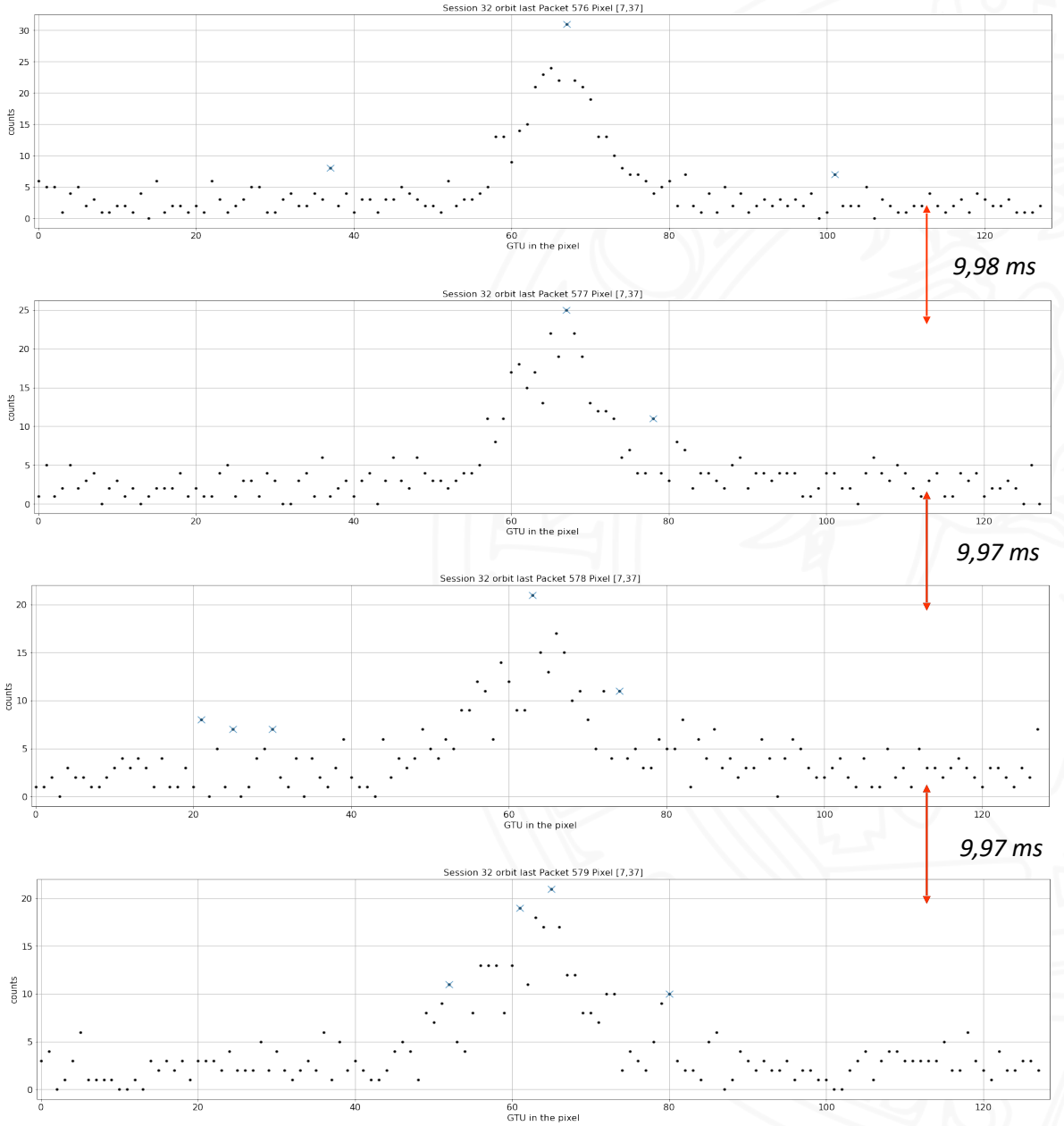
Missoula Event – *Montana*



repeated event

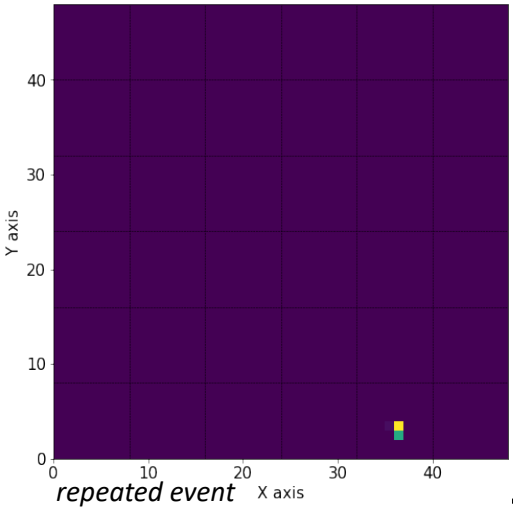


approximate geographical location - Missoula

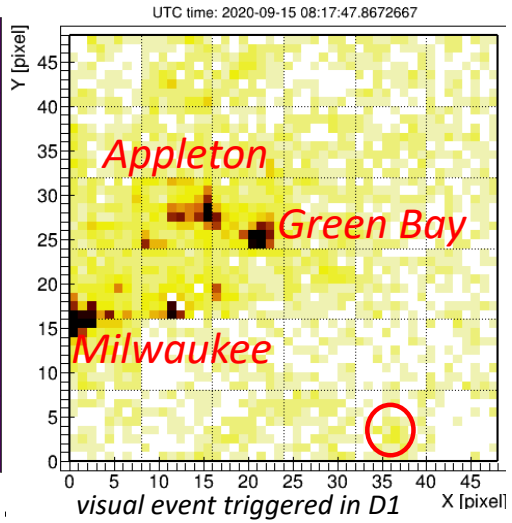


- A curious event has been triggered by the Mini-EUSO four times in the same pixel on *January 16th, 2021*.
- The event has been happened in the proximity of the Missoula City - Montana (USA), near the International Airport.
- The interval between the light curves is about *9.97 ms* with a frequency of *100 Hz*.

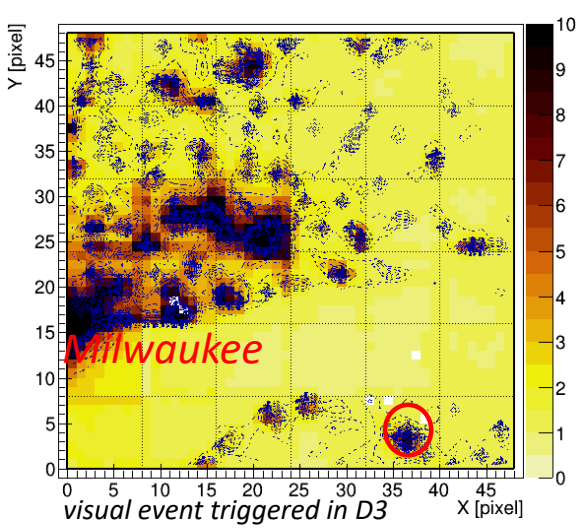
Michigan Lake Event – Traverse City



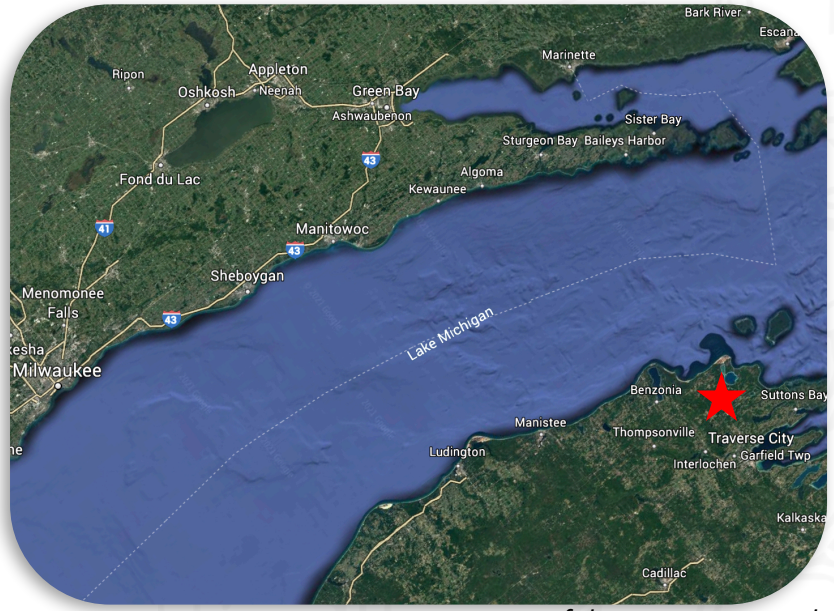
repeated event



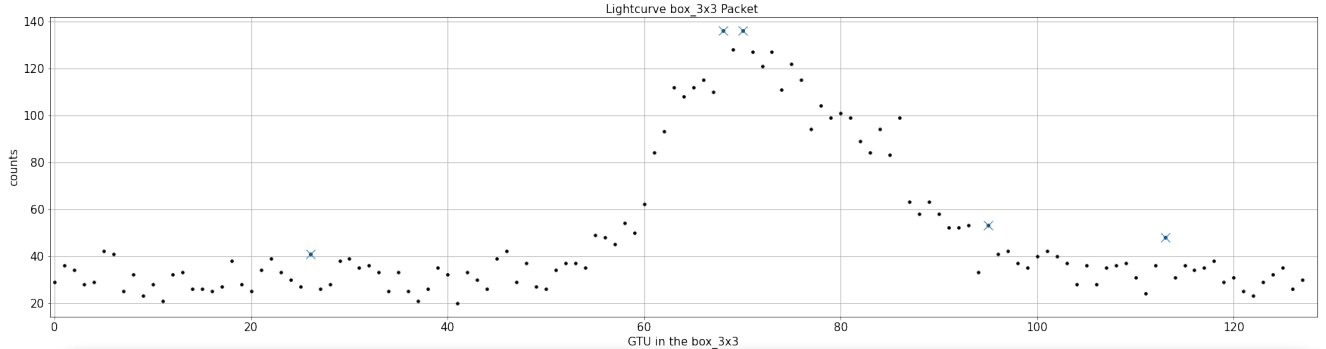
visual event triggered in D1



visual event triggered in D3

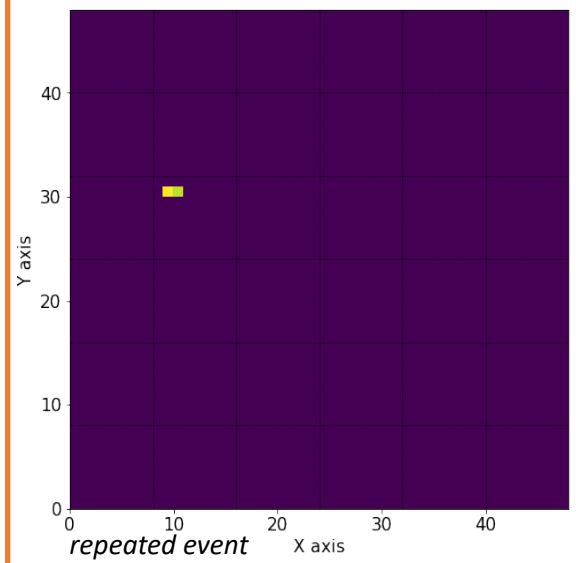


area of the event concerned

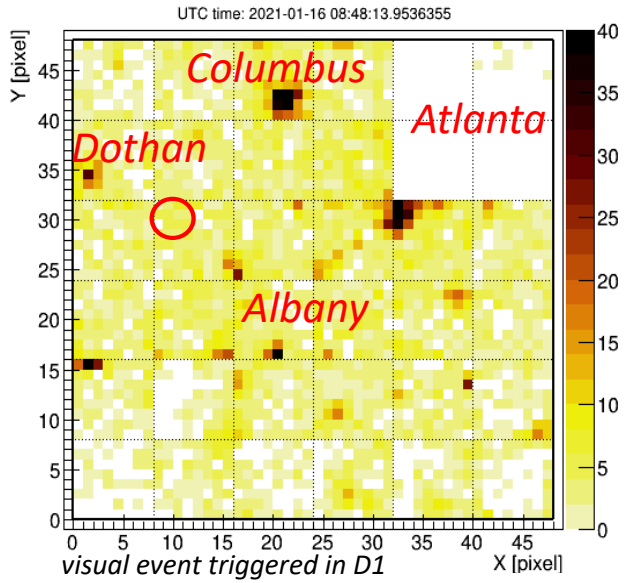


- Another particular event repeated for four times in the same pixel and with the same light curve on *September 15th, 2020*.
- *Δt ~ 32 ms* with frequency of *30 Hz*.
- With the same previous analysis, it was possible to certify the location in the proximity of the City Traverse on Lake Michigan (USA).
- At the down-left image can be noticed that the area is cupped by airports as usual.

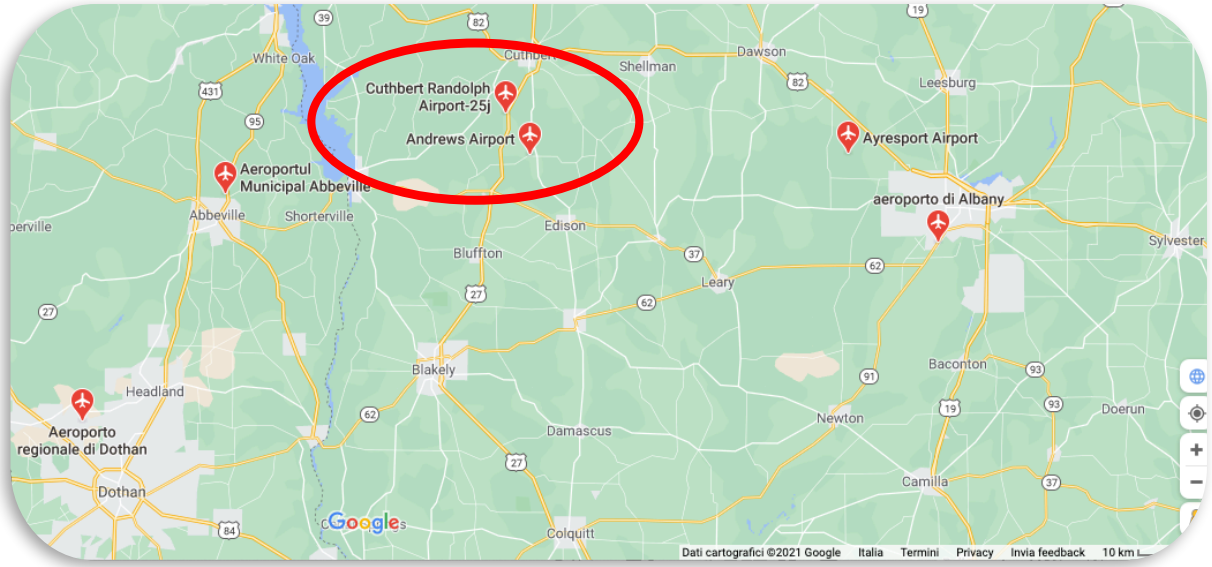
Alabama Event – *USA*



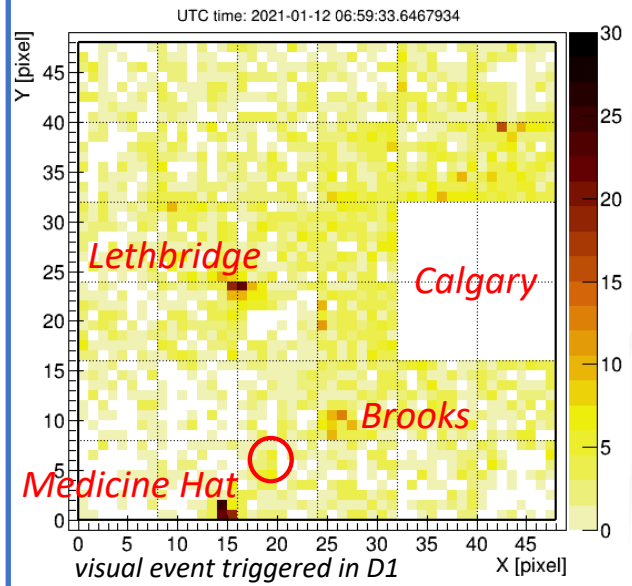
repeated event



visual event triggered in D1

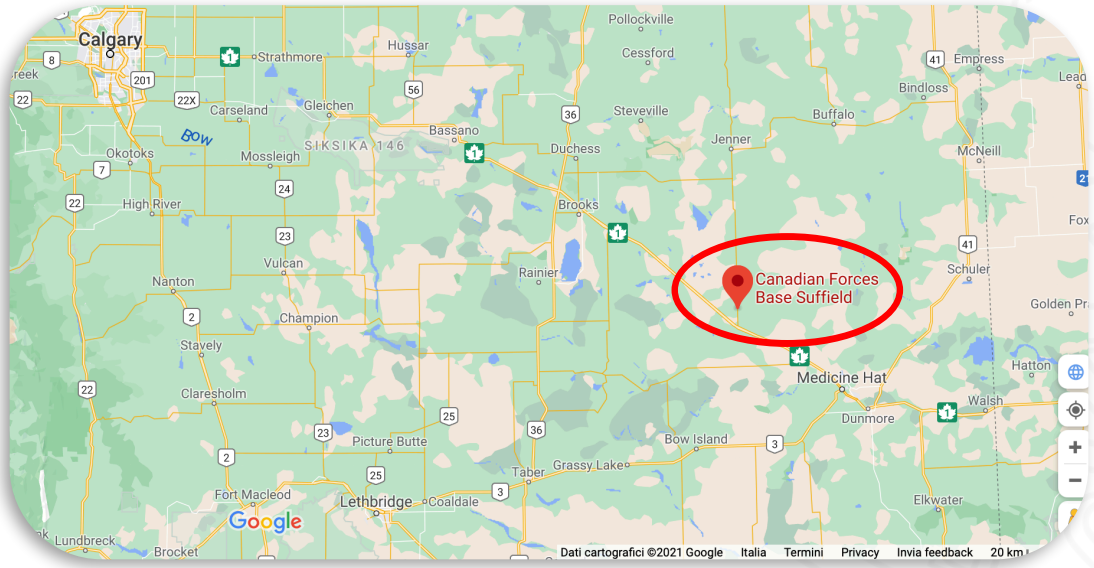


Suffield Event – *Canada*

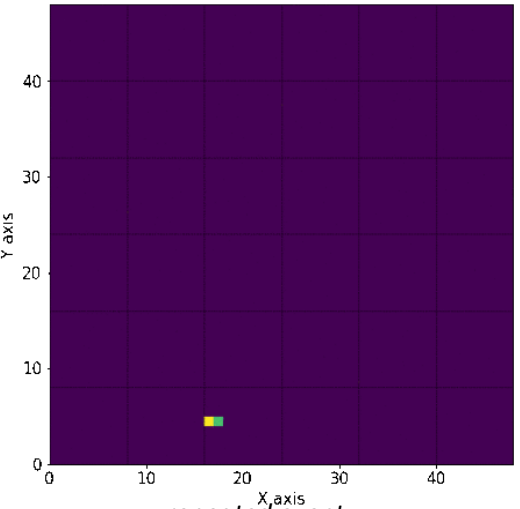


visual event triggered in D1

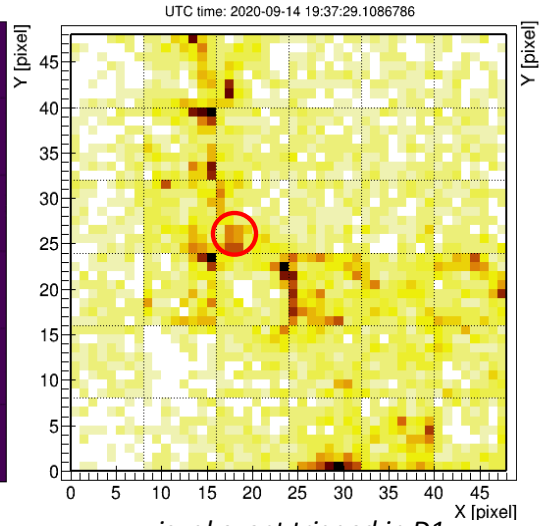
Canadian Forces Base Suffield



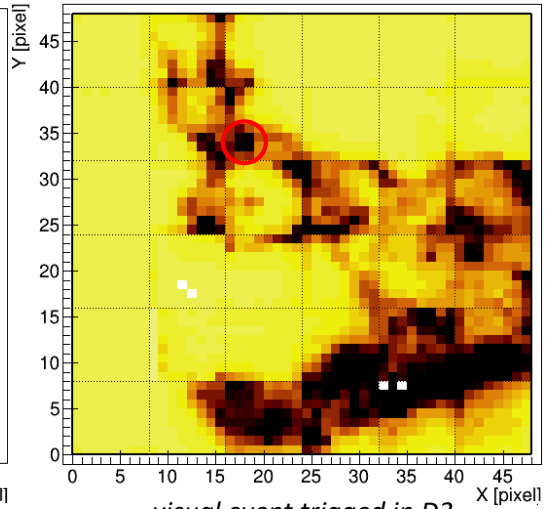
Lamezia Terme Event – Italy



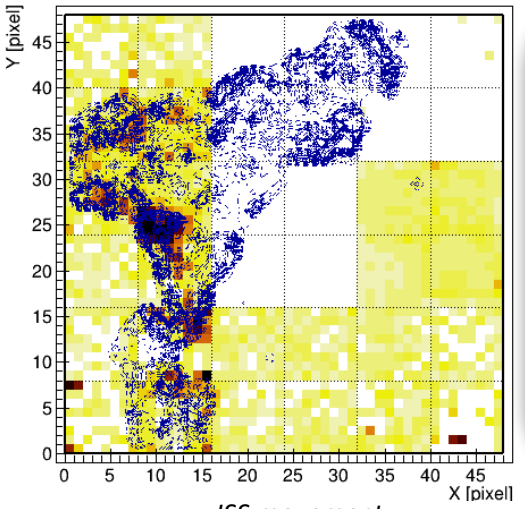
repeated event



visual event trigged in D1

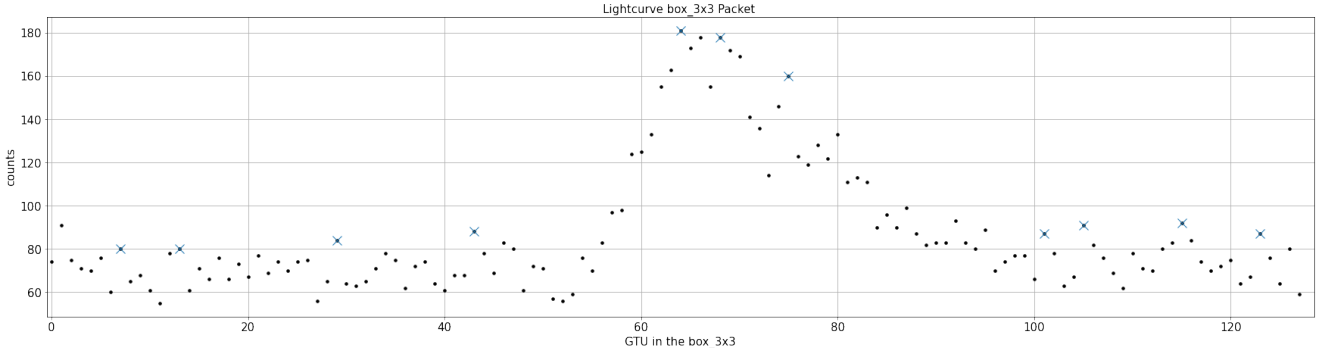


visual event trigged in D3



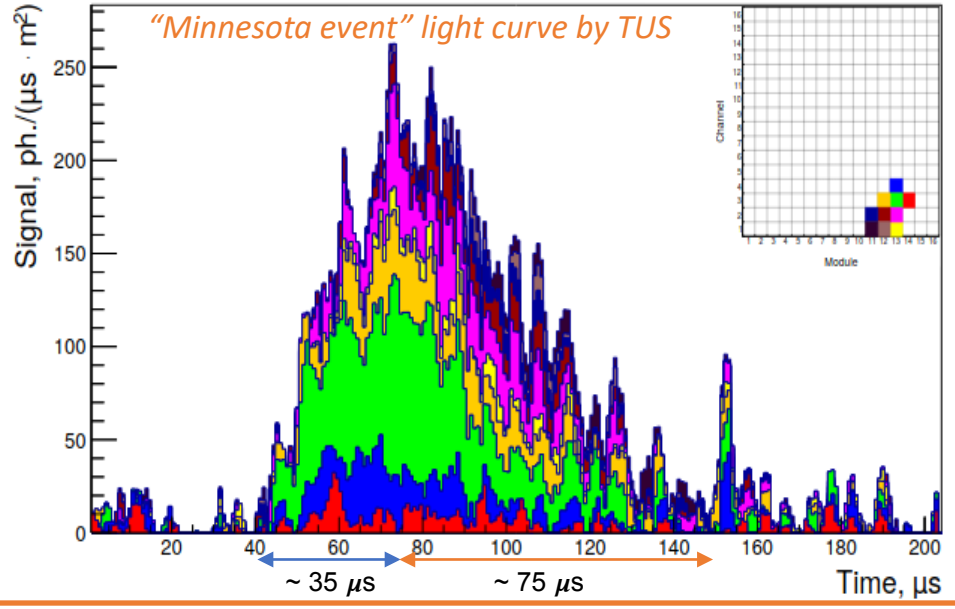
ISS movement

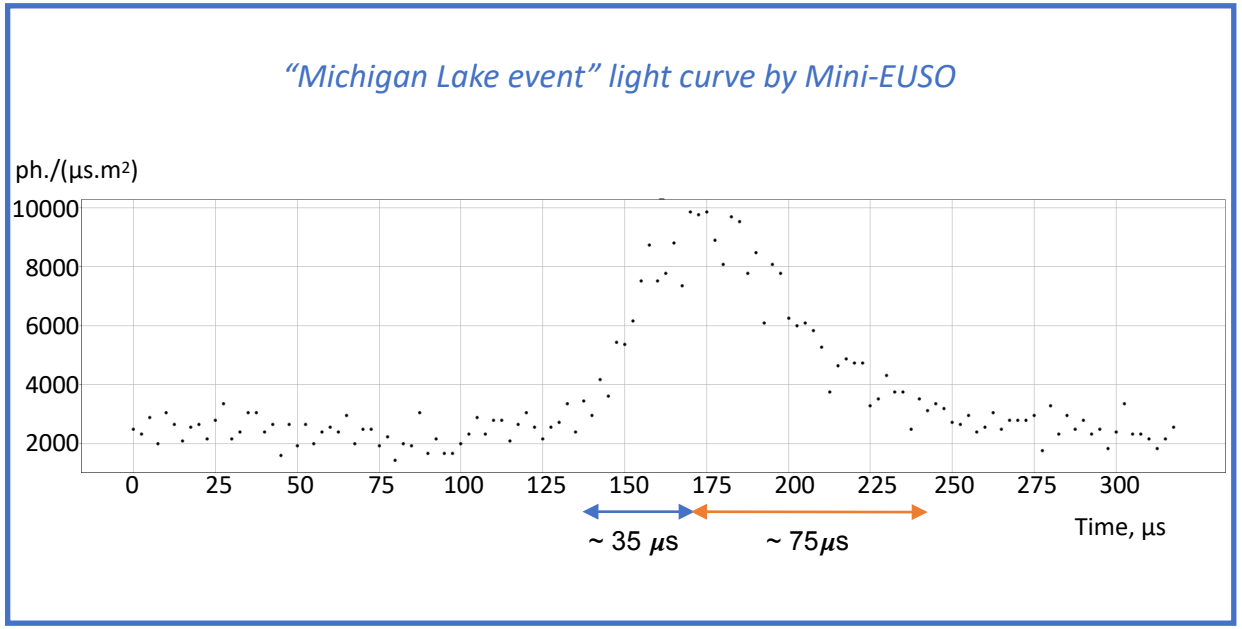
South Italy



- These events have not been seen only over North America.
- A particular example is this event repeated several times with the same light curve on *September 14th, 2020*.
- With an in-depth analysis and the location of the *ISS*, it was possible to find the approximate geographic location of the event.
- The event with *ETOS* software and the *DMSP* map were superimposed and it was possible to see that it's clearly displayed around *Lamezia Terme International Airport* (*Calabria*) in Italy.

TUS vs Mini-EUSO

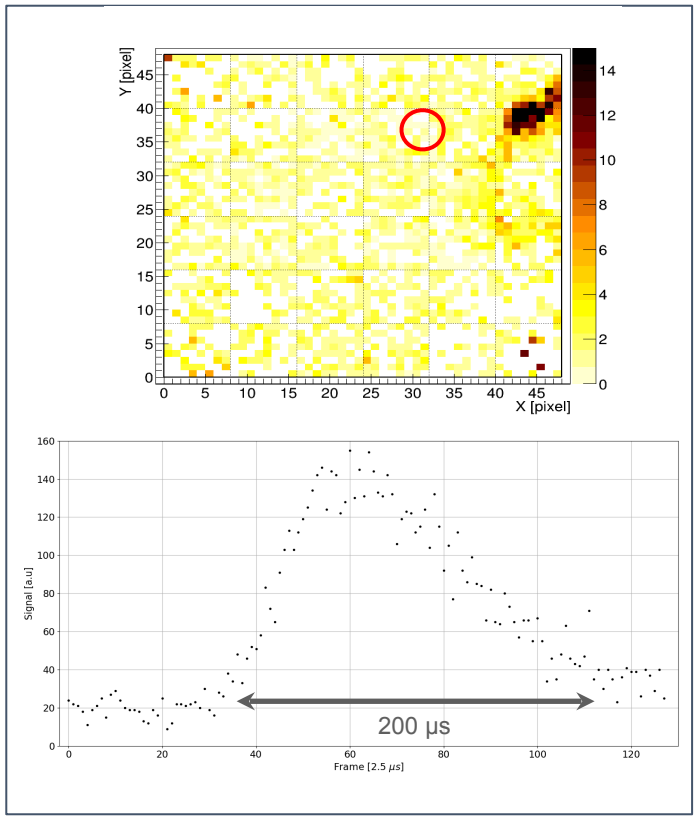




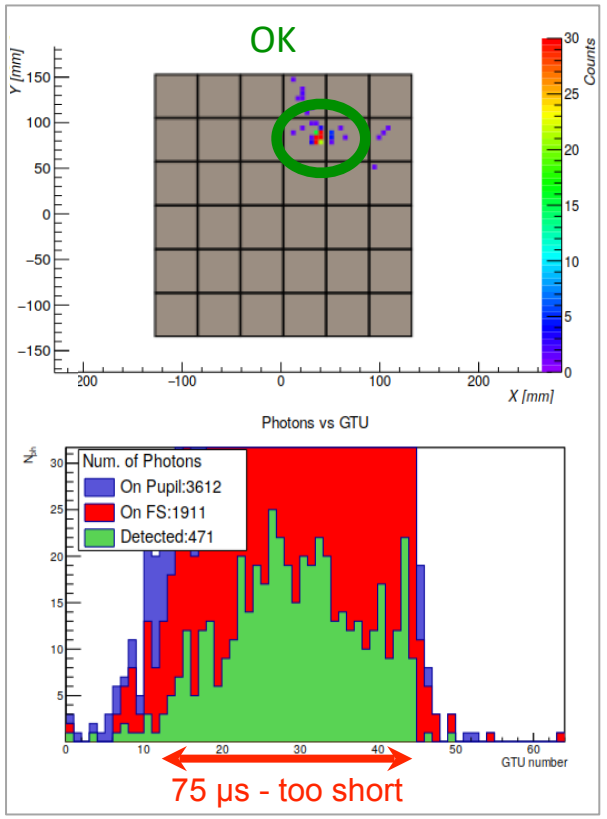
- Comparing the event seen by *TUS* and *Mini-EUSO*:
  - The events found by *Mini-EUSO* have similar characteristics to the "*Minnesota event*".
  - *Mini-EUSO's* events are up to *40x* brighter than TUS's events.
  - The length of time of ascent and descent seems to be reasonably comparable.
  - For all events with this feature, they have been located nearby airports.

Conclusions

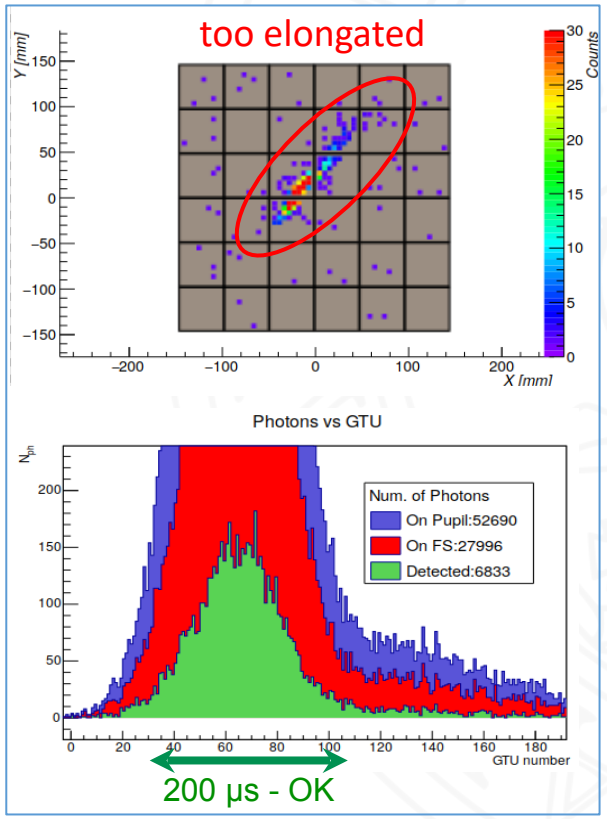
- *Mini-EUSO EAS*-like simulation with energy $\sim 2 * 10^{22}$ *eV*:
  - The temporal form, as expected, does not match with a *Cosmic Ray*.
  - Since it would be a *Cosmic Ray* with an elongated shape and with many pixels crossed.
  - It is not possible to associate the signal's temporal development with its spatial extension.



Mini-EUSO data



CR simulation Zenith = 50°

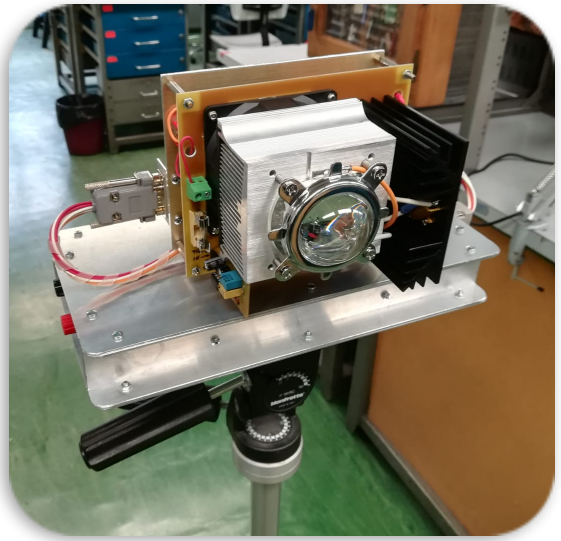


CR simulation Zenith = 80°

Conclusions

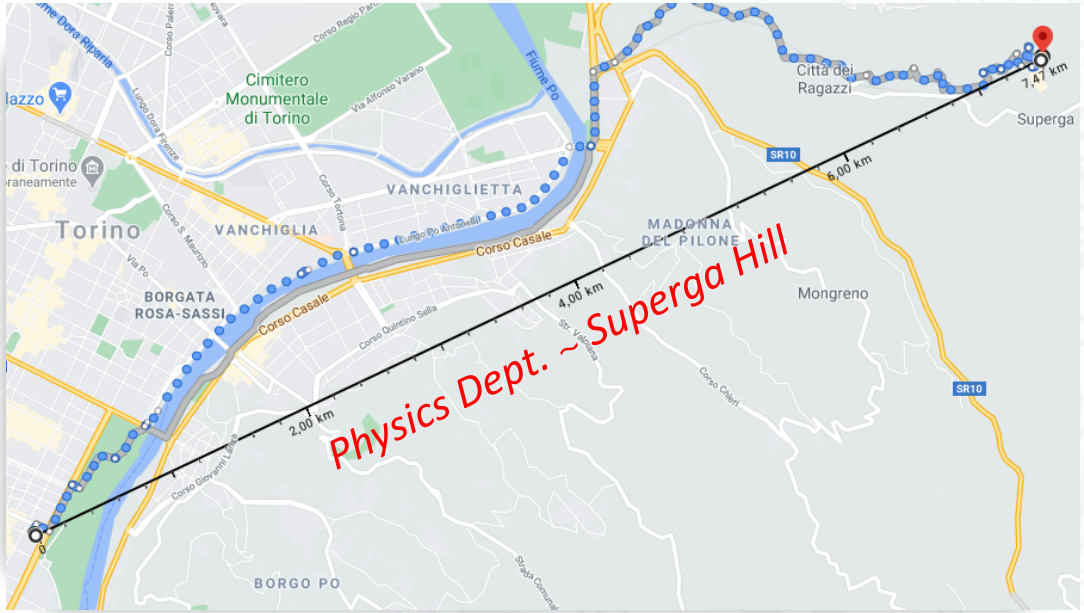
- During the internship period, the *Mini-EUSO* trigger's hardware implementation was introduced in the data analysis program to have a faithful representation onboard trigger logic's response.
- An analysis of the *Mini-EUSO* events was carried out by selecting the triggers according to the number of pixels that were triggered in each event.
- We focused on the *1* to *4* pixels events observed by *Mini-EUSO* in North America, looking for events with time profiles similar to that of *TUS*.
- It has been noticed that events with time profiles similar to those of *TUS* exist and all of them are associated with the presence of airports.
- The possible origin of the *TUS* event could be compatible with ground flasher signals typical of those observed in airports, although the *TUS* experiment did not show a clear correlation with an airport.
- By other hand, the typology of the events observed by *Mini-EUSO* demonstrates that the light profile is not compatible with a *Cosmic Ray*.

Bonus Stage

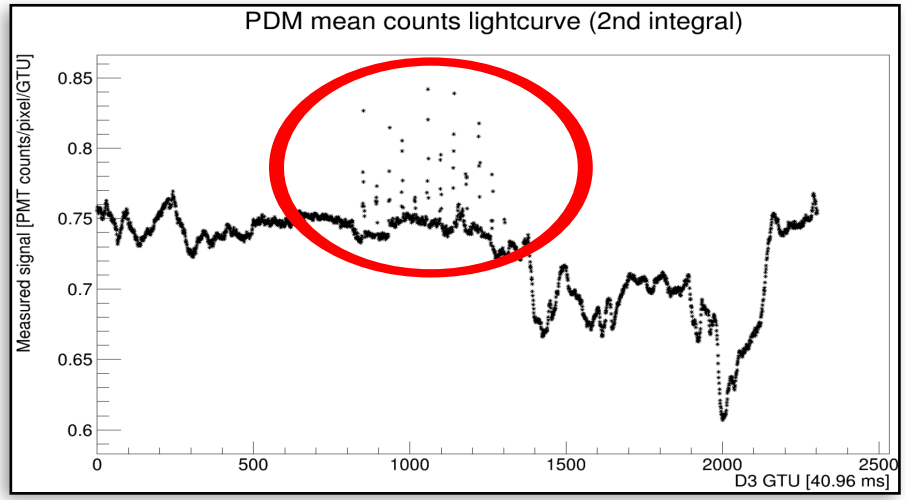


flasher used on the experiment

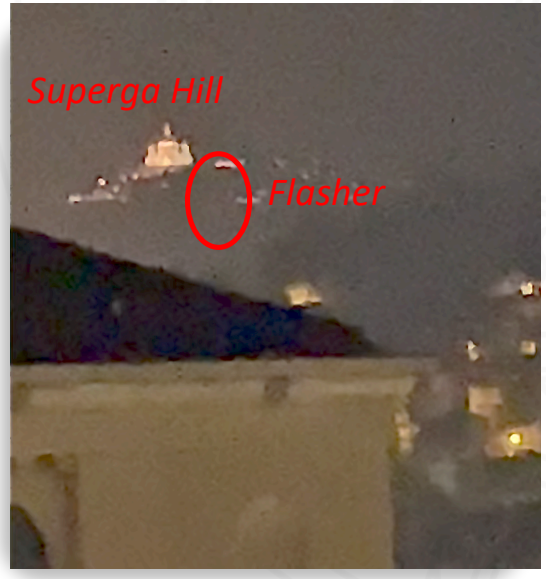
- Concurrently we are producing a set-up of flasher which can serve as calibration for Mini-EUSO.
- Observing how the signals are seen from the Superga Hill.
- Experience “outside” laboratory
- Superga – Physics Dept.’s roof



software D1 viewing



flasher’s light curve



experiment’s video

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- **online global meetings** about "*Mini-EUSO arguments", 1 December 2020 / 21 January 2021 / 18 February 2021 / 18 March 2021*

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  - *All collaborators on the Mini-EUSO project*

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