A new trigger logic for the future EUSO-like space missions

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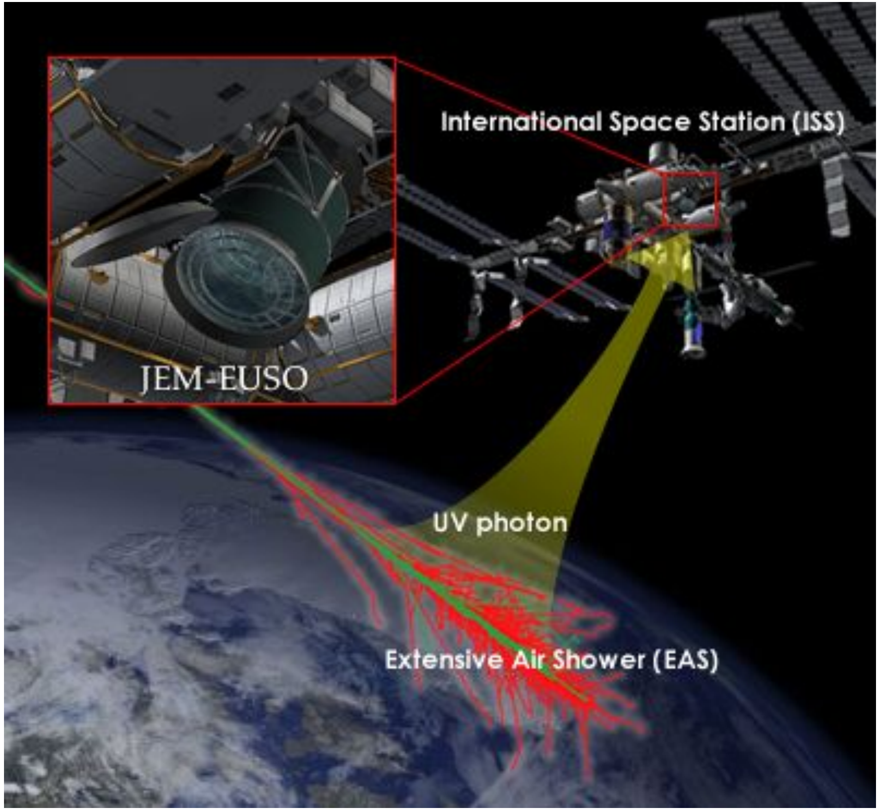
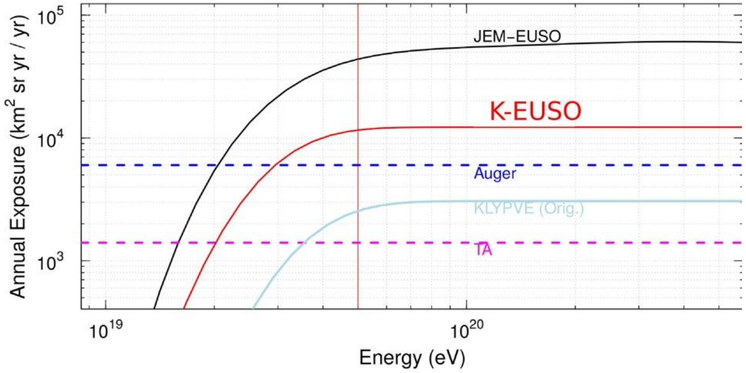
JEM-EUSO general idea

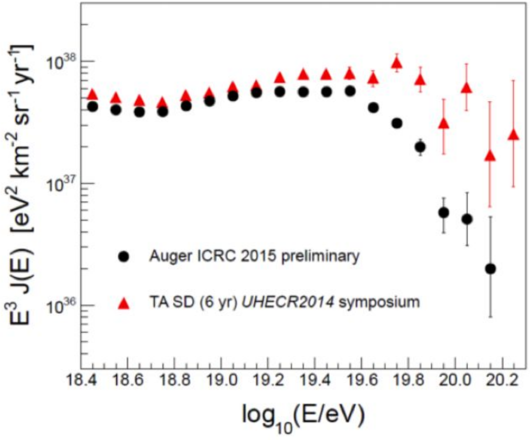


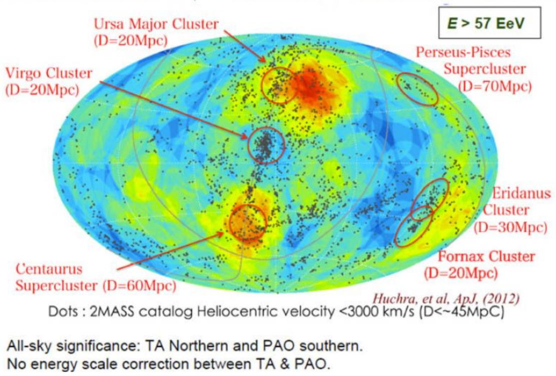
- **J**oint **E**xperiment **M**issions for **E**xtreme **U**niverse **S**pace **O**bservatory

- Very large exposure space-based detector looking at the fluorescence light produced by EECR ($E>5x10^{19}$ eV) interacting in the atmosphere

Advantages of a space-based detector

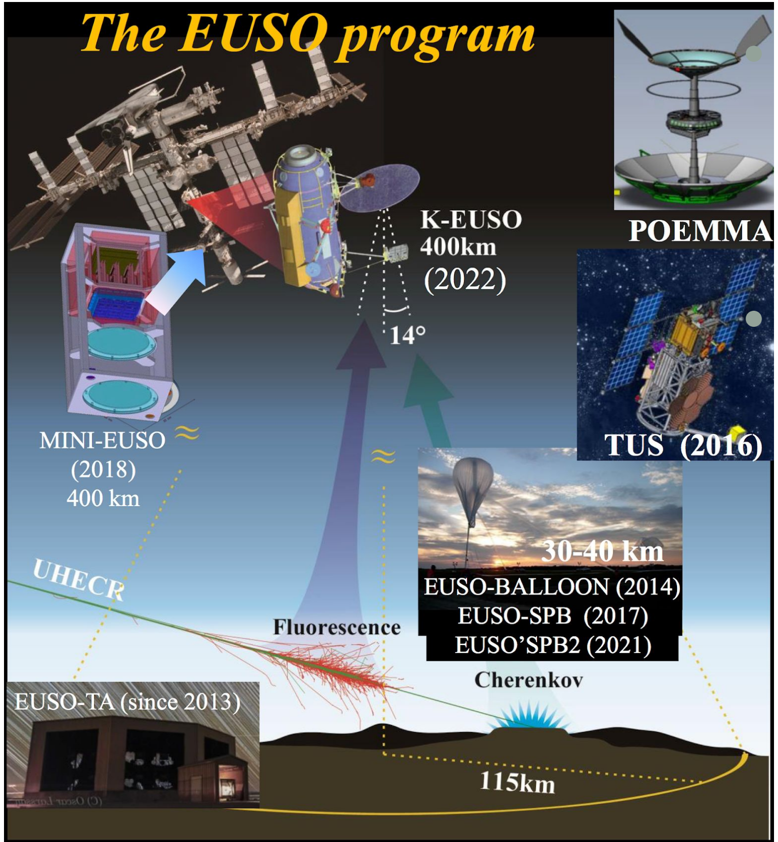






- Very large exposure → higher statistic
- Auger and Telescope Array show different spectra at high energy
- Hot spots in the Northern (TA) and Southern (Auger) sky

JEM-EUSO program

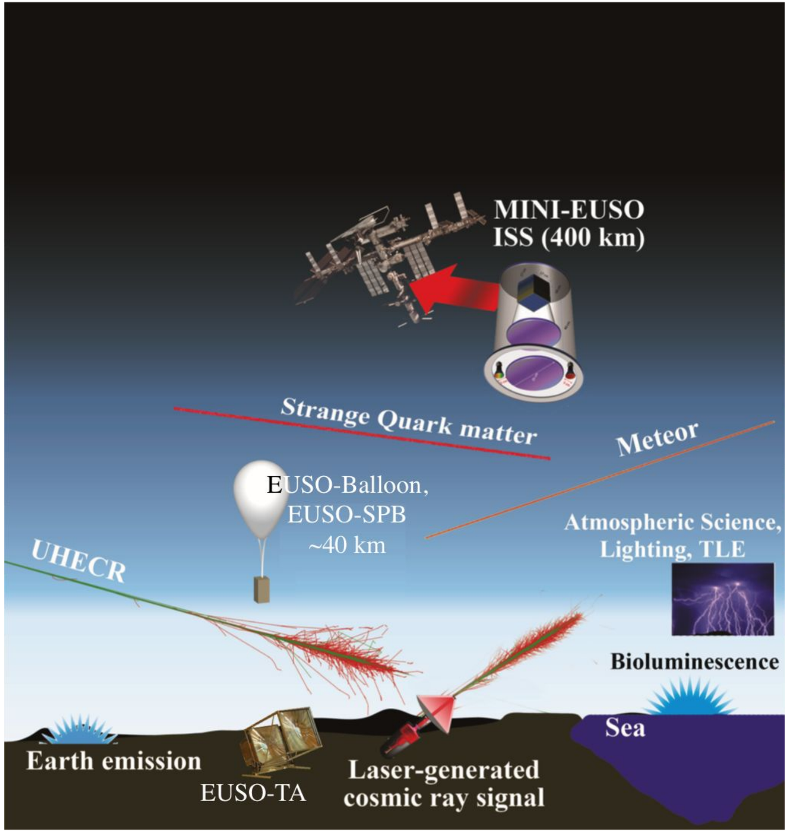


EUSO -TA (2013): ground detector installed at Telescope Array site: currently operational.

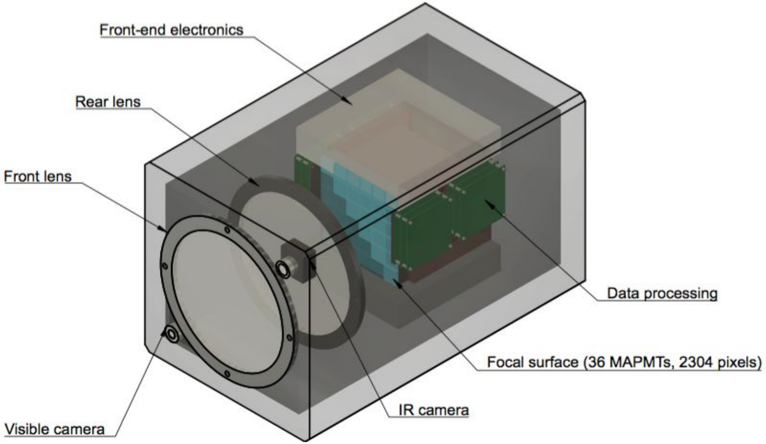
EUSO Balloons: first balloon flight from Timmins (Canada) 2014;
NASA SPB1: 2017;
NASA SPB2 2021

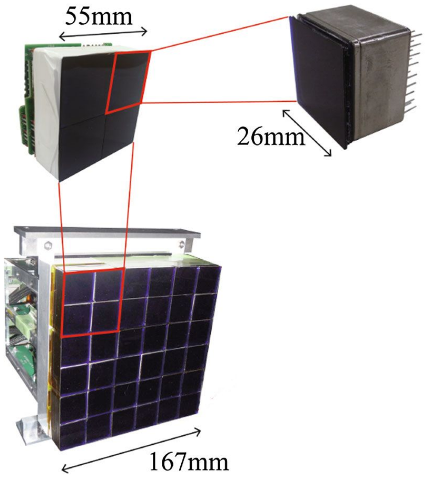
- TUS (2016): free-flyer (Roscosmos)
- Mini-EUSO (2018): Inside the ISS (ASI and Roscosmos)
- K-EUSO (2022): Outside ISS
- POEMMA (2023+): NASA twin free-flyer

Mini-EUSO scientific goals



Mini-EUSO (2018)





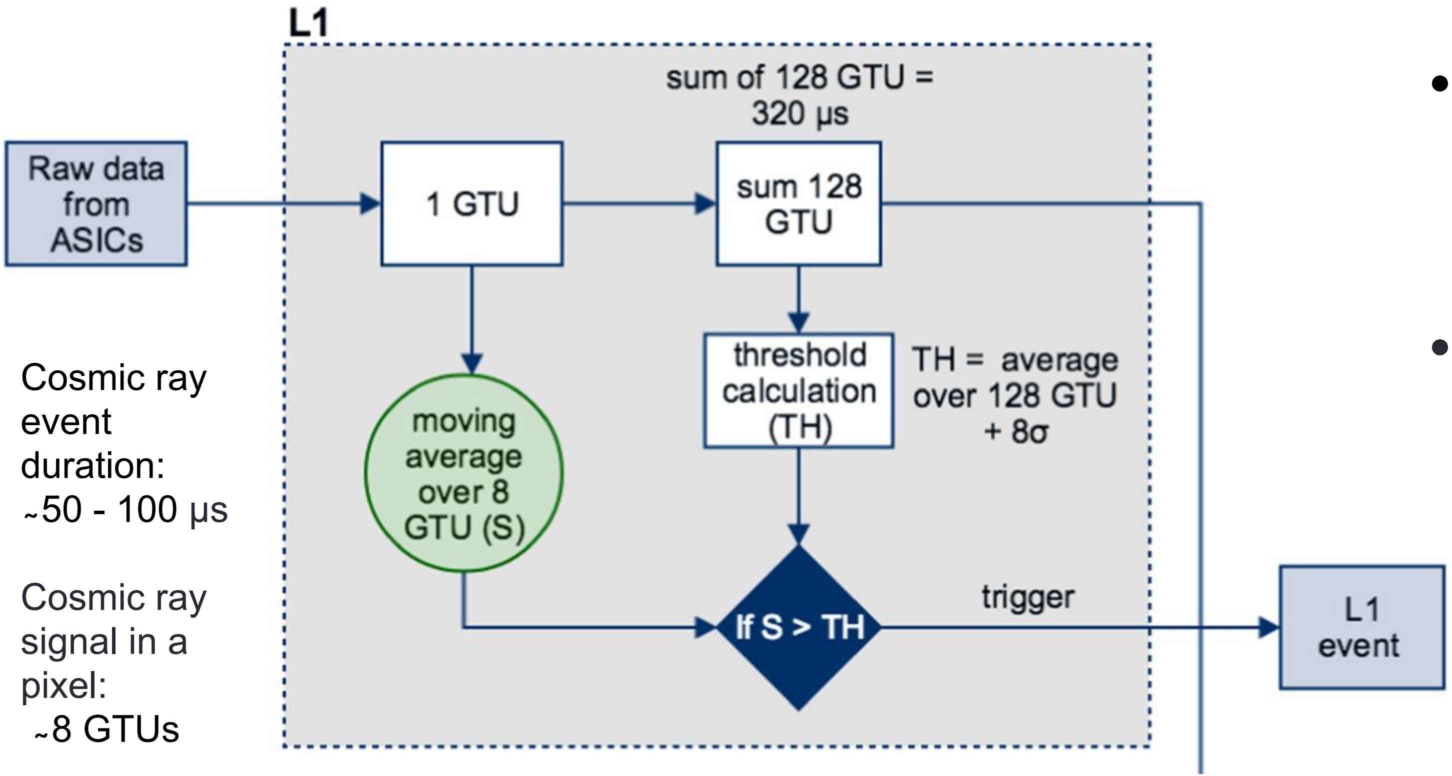
- Onboard of the ISS
- Wavelength: UV (300-400 nm)
- Time resolution: 2.5 μs
- Mass: 25 kg

- Volume: 35 × 35 × 60 cm^3
- Power: 50 W
- Large FOV (±19°)
- Pixel size at sea level: 5 km
- Multi-level trigger system

Mini-EUSO trigger logic: L1

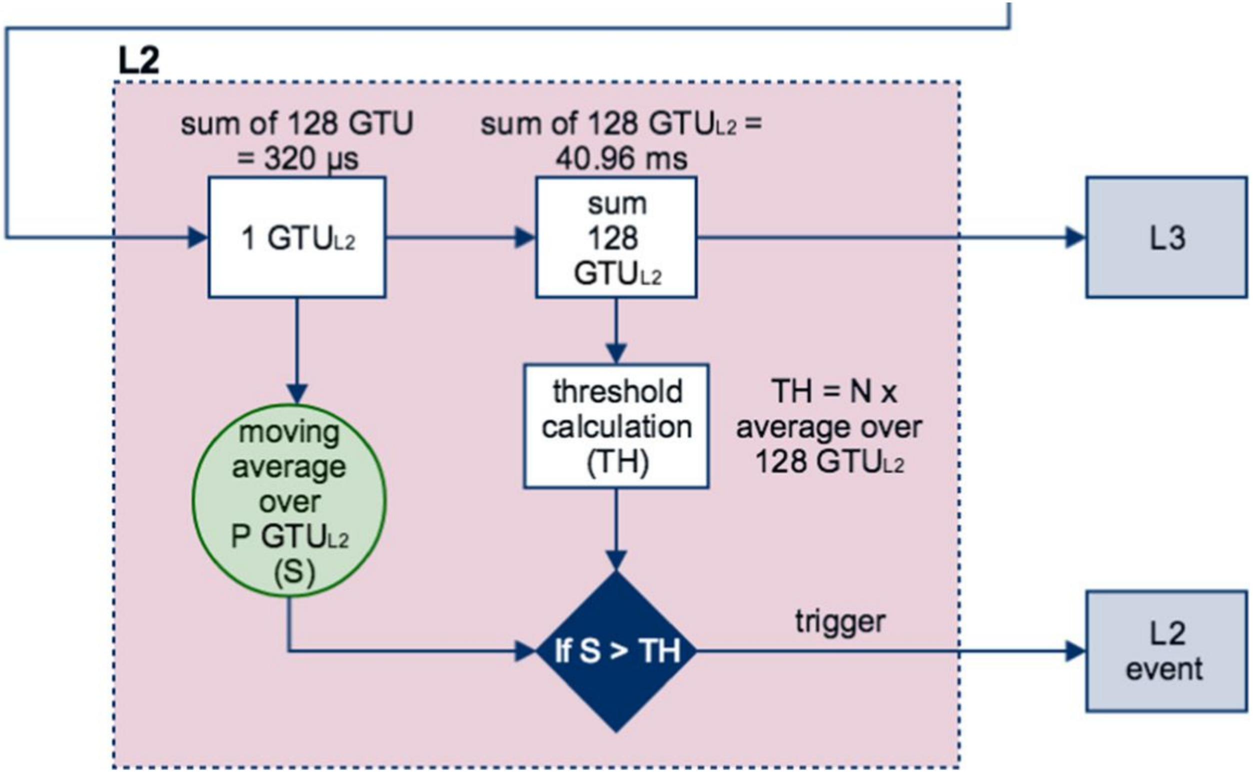
Cosmic ray event duration: ~50 - 100 μs

Cosmic ray signal in a pixel: ~8 GTUs



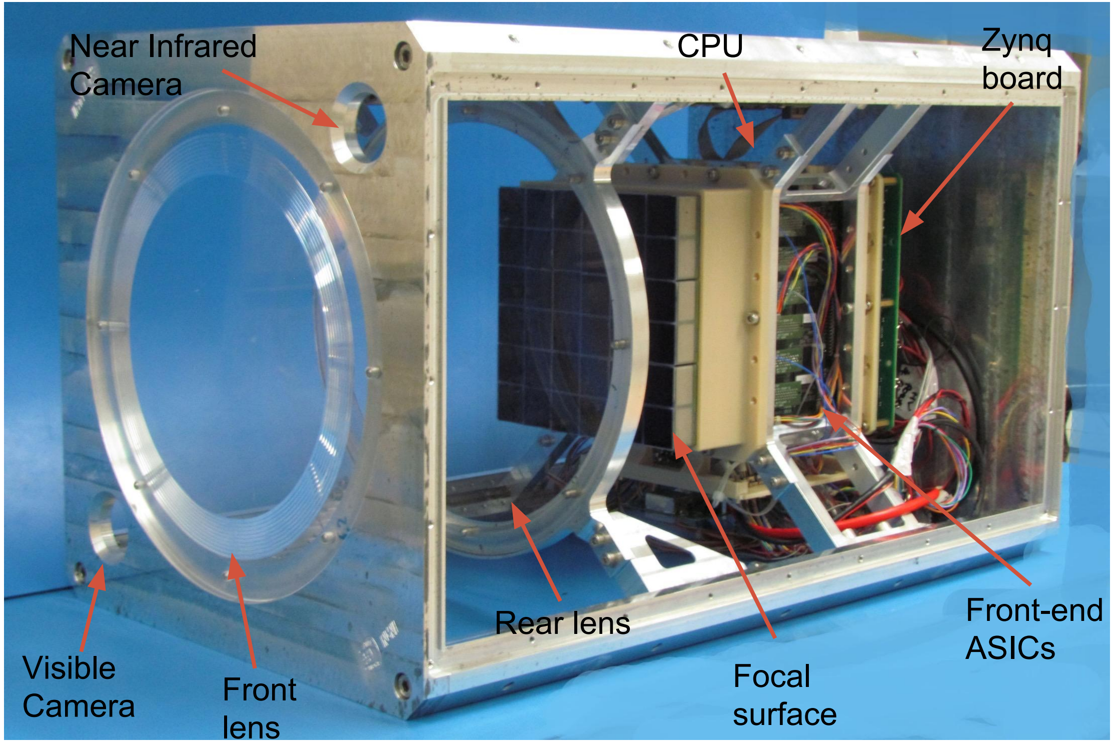
- D1 data: 4 packets of 128 GTUs, resolution of 2.5 μs
- 128 D1 GTUs form 1 D2 GTU (320 μs)

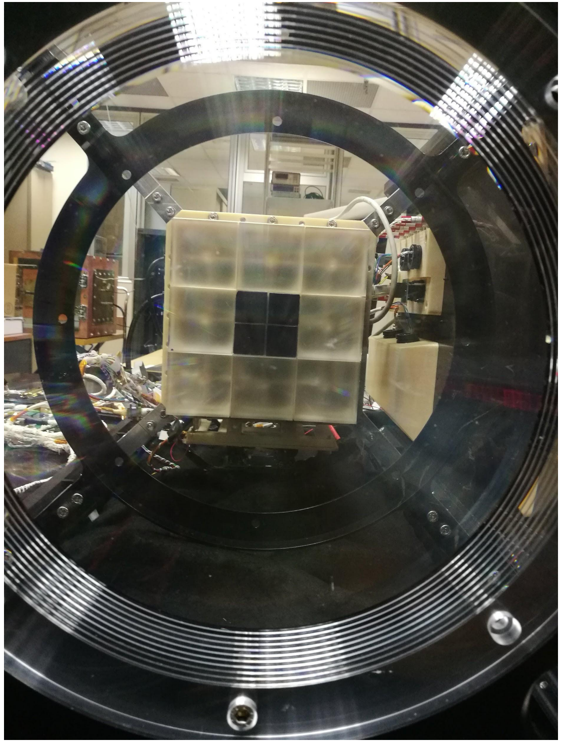
Mini-EUSO trigger logic: L2



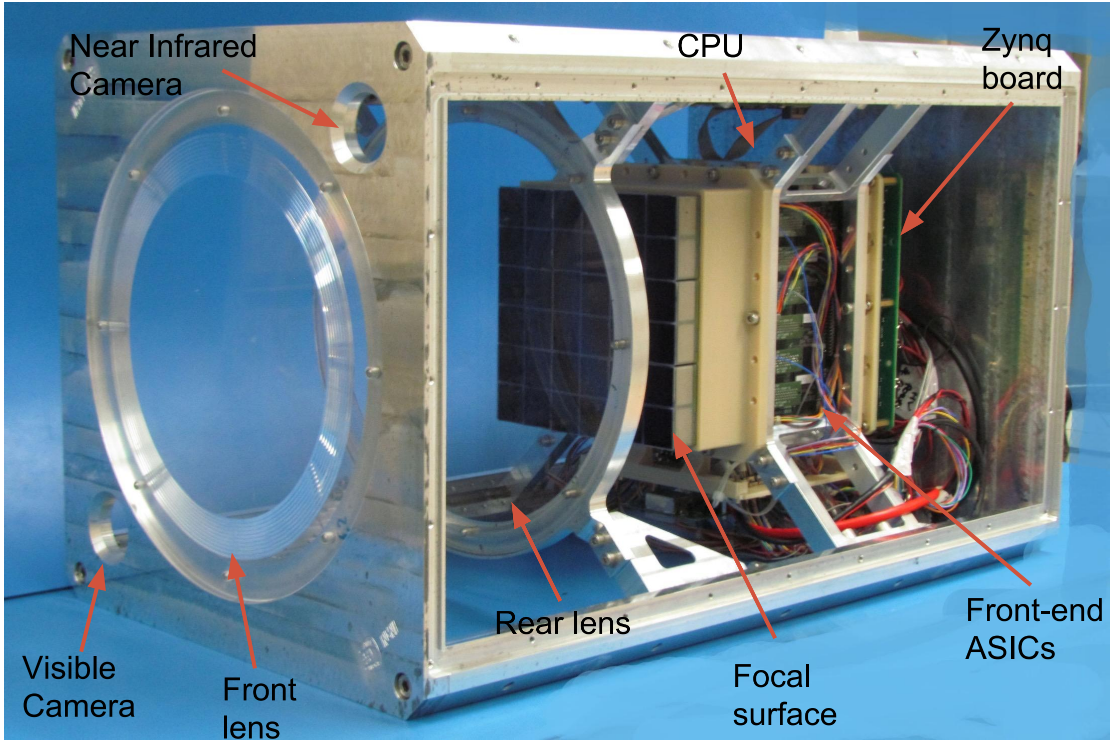
- D2 data: 4 packets of 128 GTUs, resolution of 320 µs
- 128 D2 GTU form 1 D3 GTU (40.96 ms)
- D3 data analysed offline

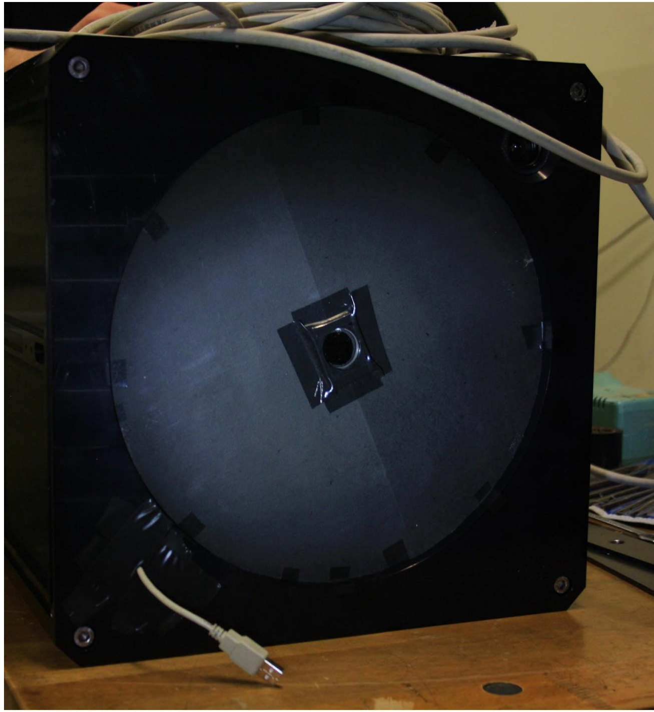
Mini-EUSO engineering model



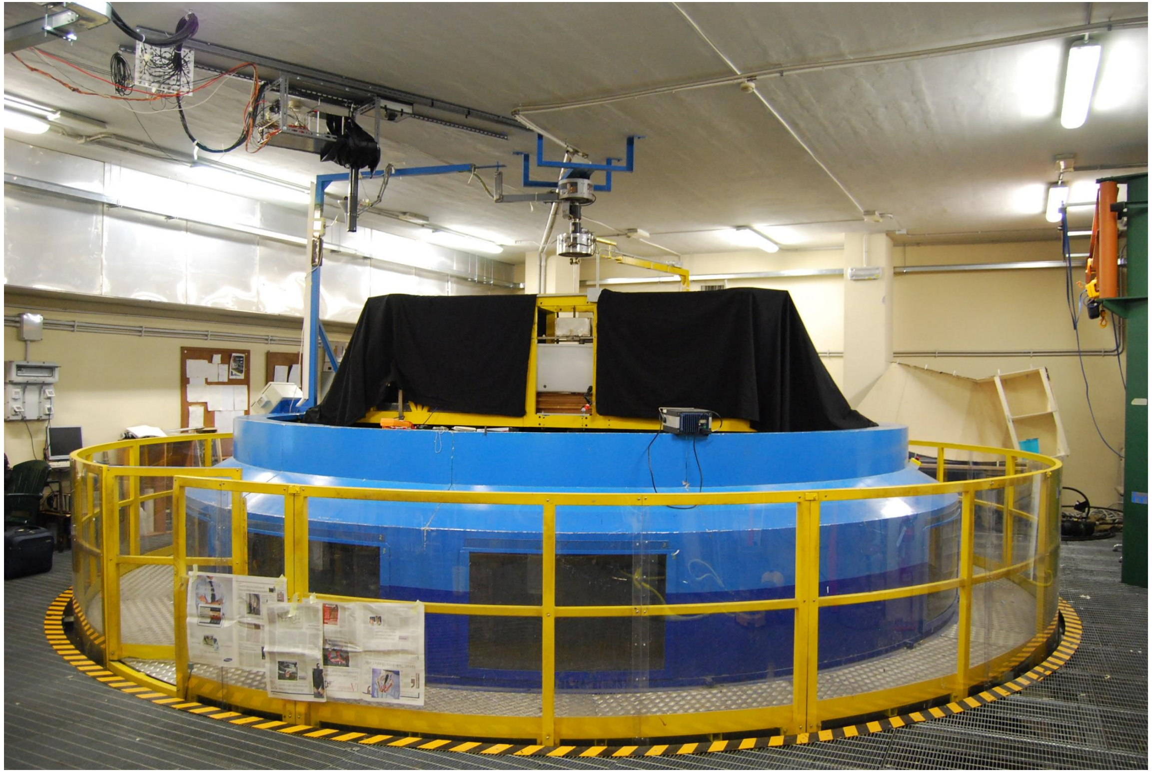


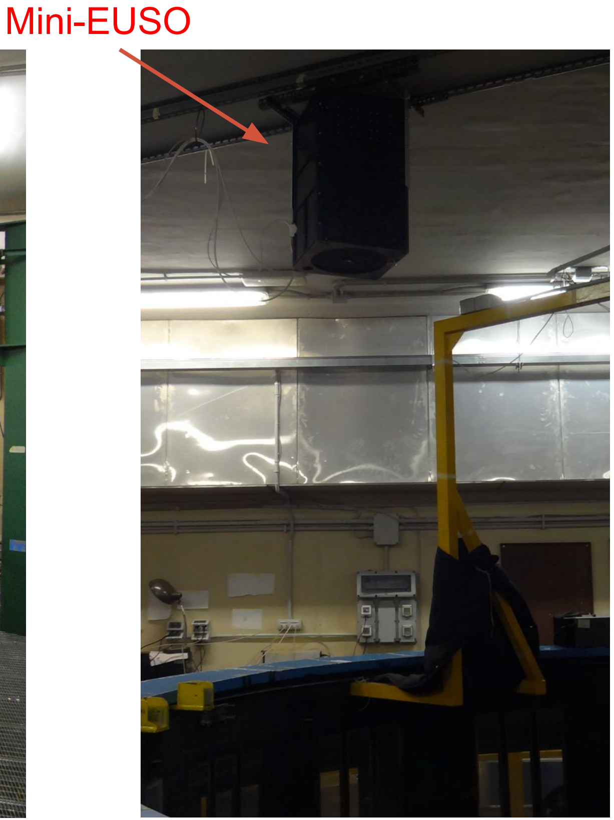
Mini-EUSO engineering model





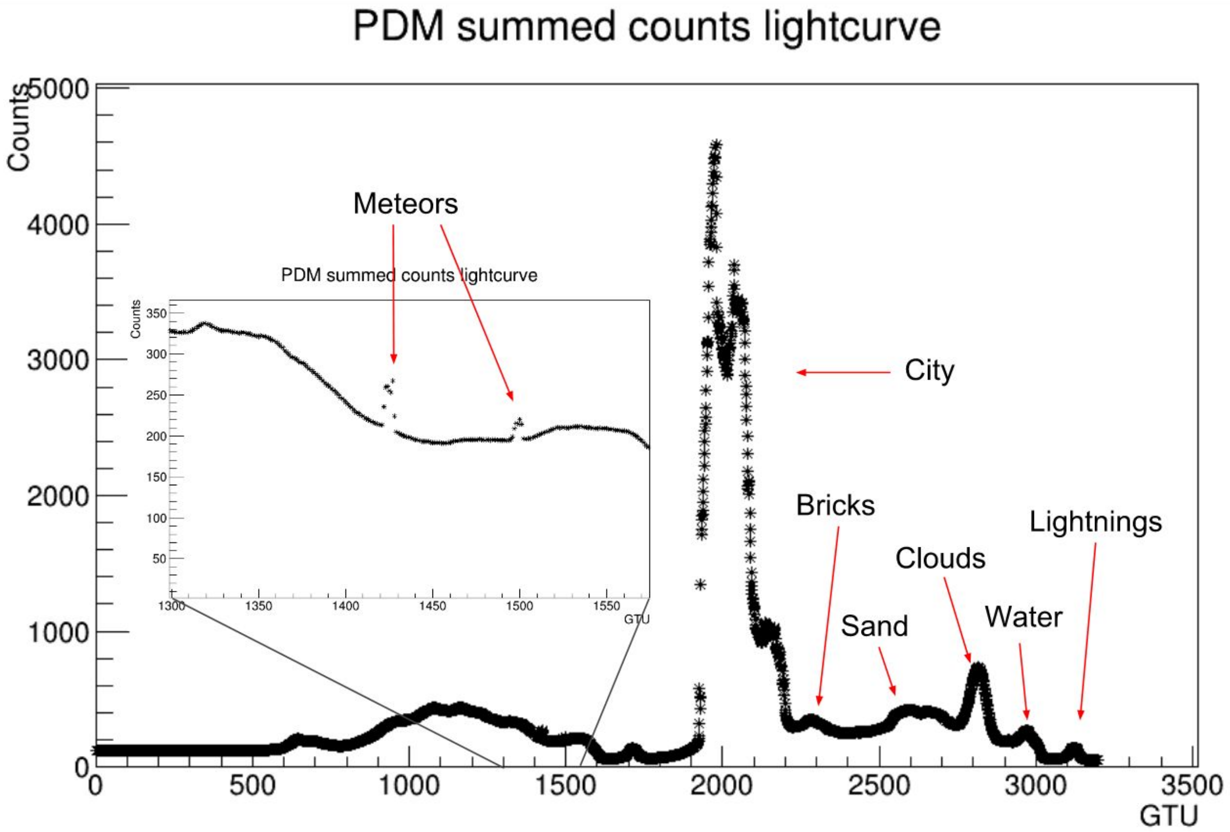
Mini-EUSO@TurLab



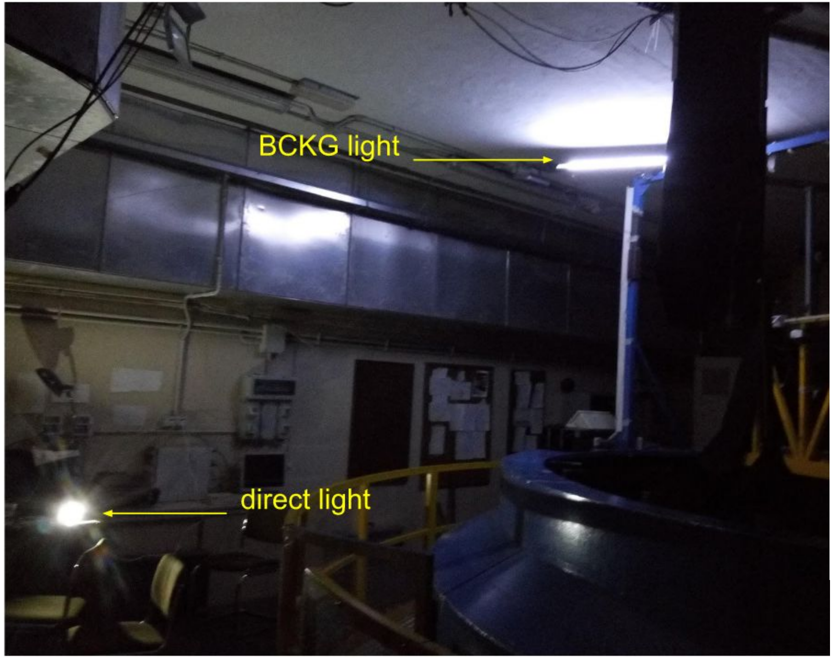


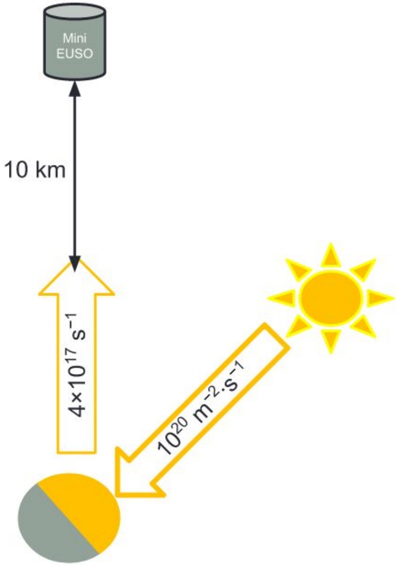
TurLab: materials and light sources

Mini EUSO @ TurLab

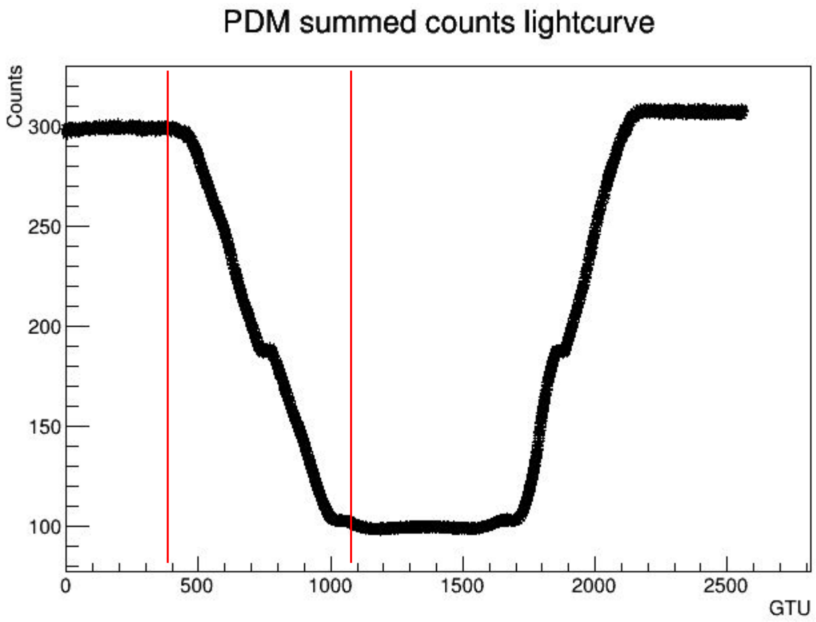


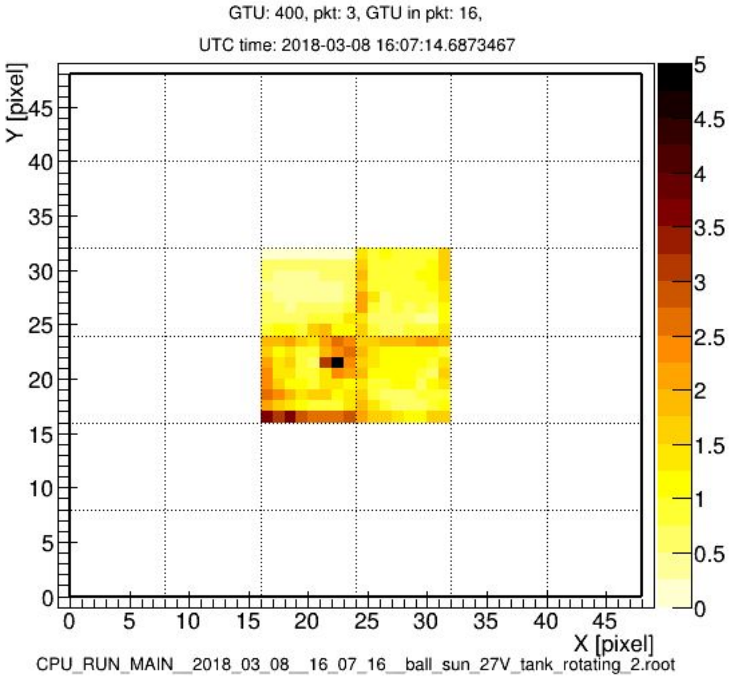
Space debris: setup





Debris light curve



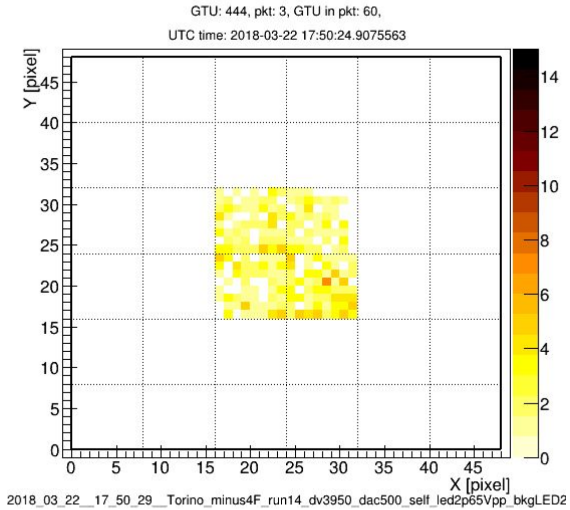


GTU = 0,04 s

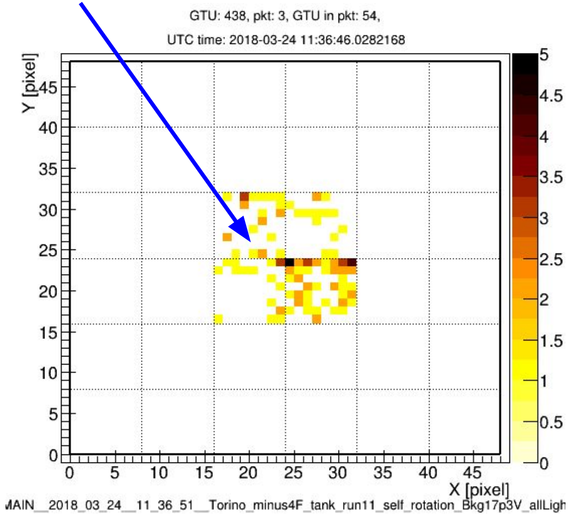
3rd level GTUs from 400 to 1100 reproduced also in animated color plot

L1 trigger

Pixel responsible
for the first trigger



Static conditions: blue LED blinking in the field of view

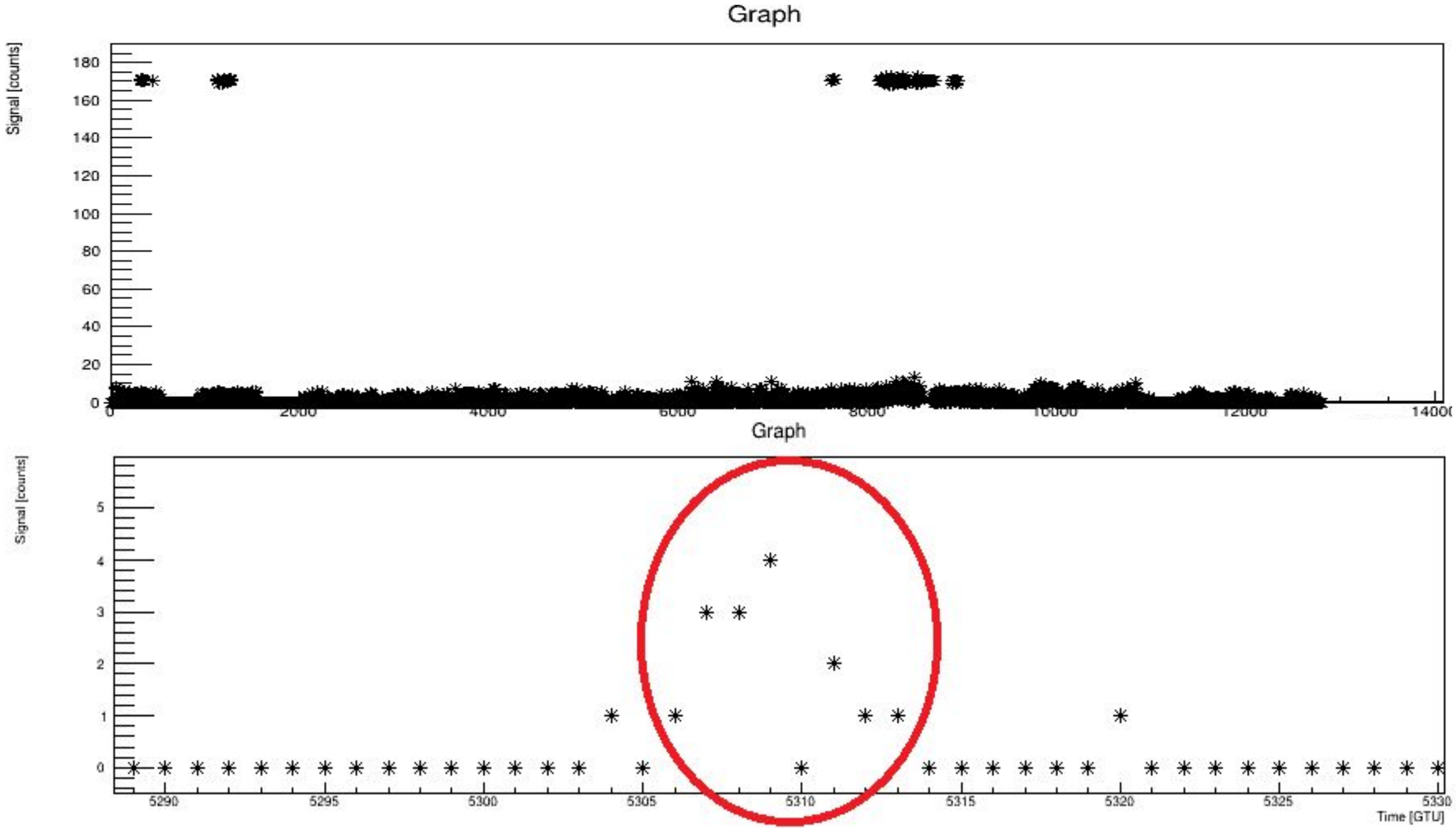


Dynamic conditions: Arduino driven white LEDs

*	0	*	0.025	*	2	*
*	128	*	6.995	*	2	*
*	256	*	17.095	*	2	*
*	384	*	27.205	*	2	*
*	512	*	5250.485	*	2	*
*	640	*	5257.96	*	2	*
*	768	*	5260.5825	*	2	*
*	896	*	5270.695	*	2	*
*	1024	*	10493.9525	*	2	*
*	1152	*	10504.0575	*	2	*
*	1280	*	10514.1525	*	2	*
*	1408	*	10524.26	*	2	*
*	1536	*	15737.4	*	2	*
*	1664	*	15747.4975	*	2	*
*	1792	*	15757.6075	*	2	*
*	1920	*	15767.7025	*	2	*
*	2048	*	20980.805	*	2	*
*	2176	*	20990.91	*	2	*
*	2304	*	21001.0075	*	2	*
*	2432	*	21011.115	*	2	*
*	2560	*	26889.5	*	2	*
*	2688	*	27715.1	*	2	*
*	2816	*	28152.535	*	2	*

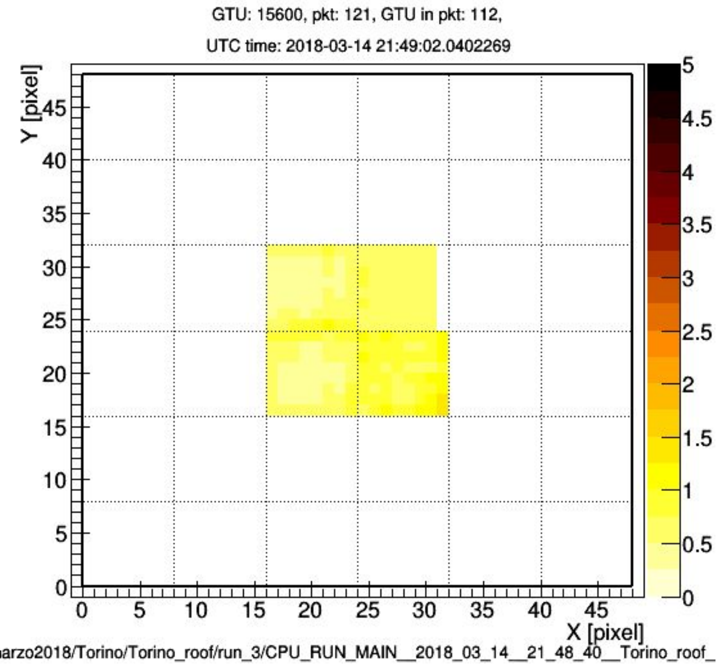
Triggers issued by the Arduino driven LEDs (10 ms)

L1 trigger: front-end electrical problem

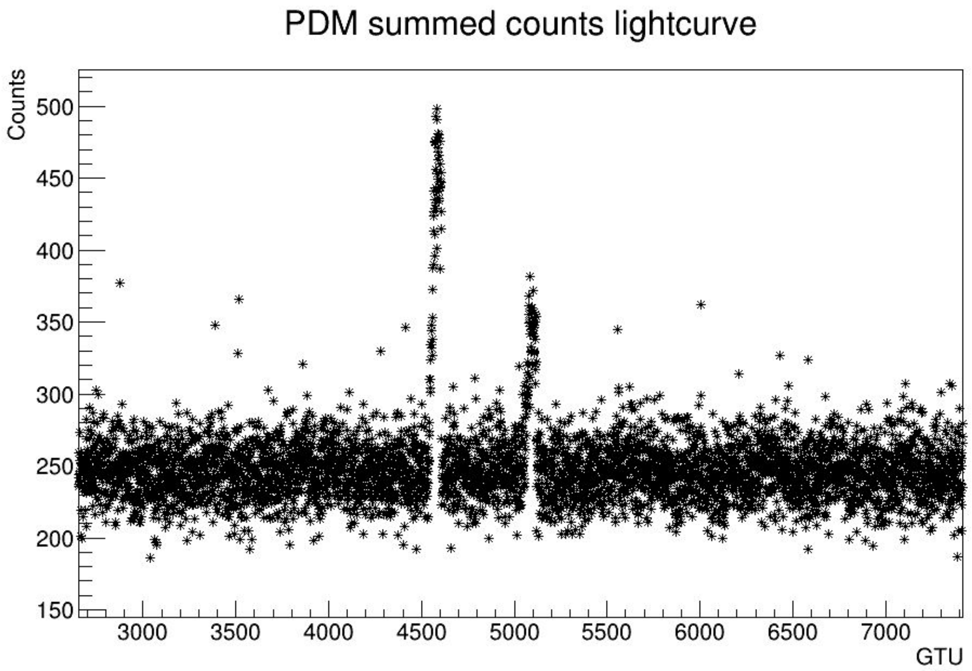


In the circle: 15 counts integrated over 8 GTUs. Enough to issue a trigger when the average over the previous 320 μs is lower than 0.3 counts/GTU

Plane

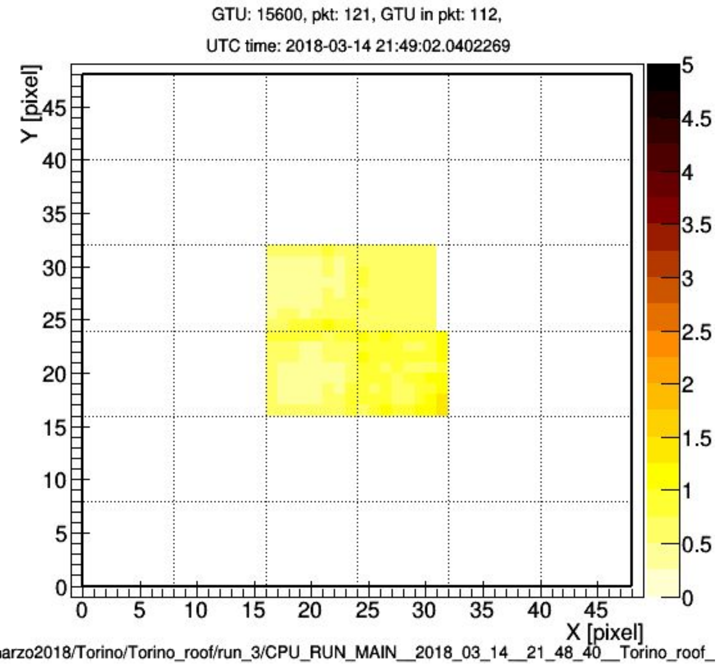


Plane crossing the field of view
(frame duration 40.96 ms)



D1 lightcurve in self trigger mode. The system detects the two peaks coming from plane flashers. The same event was triggered by the L2 as well

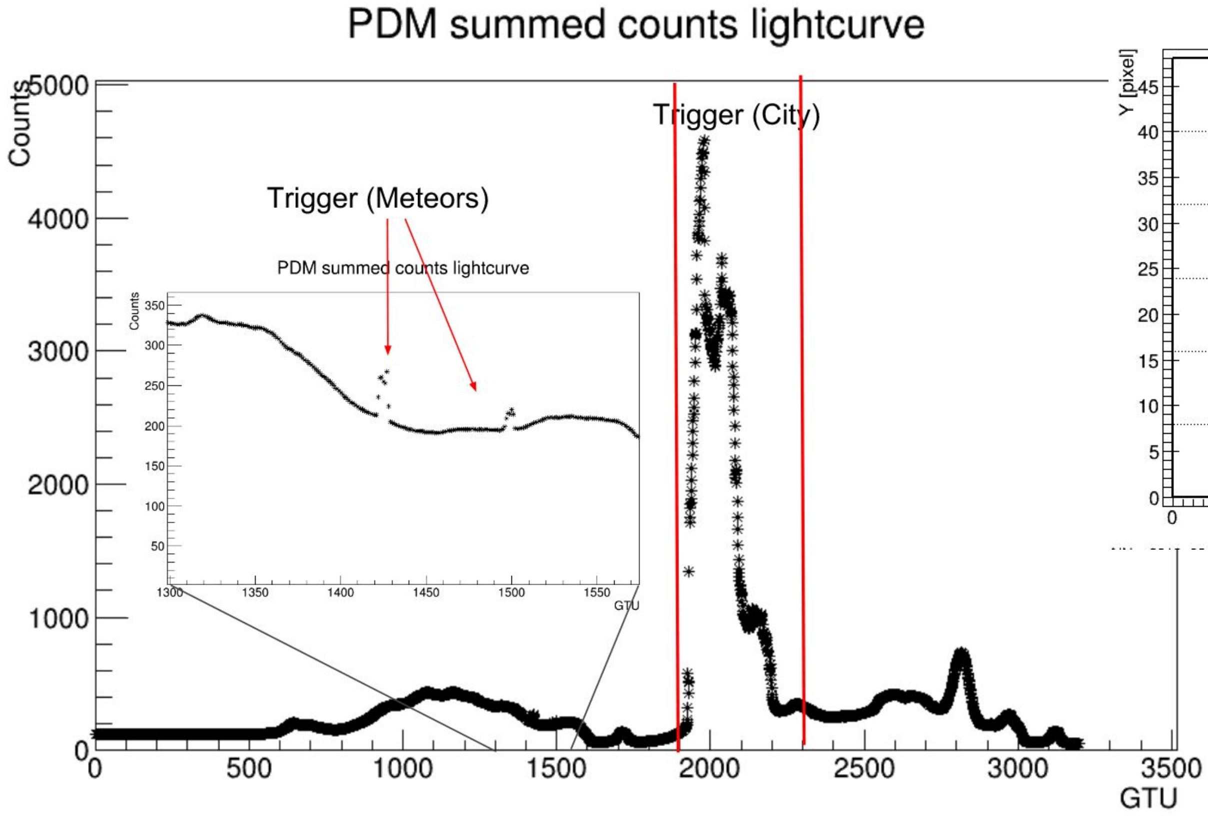
Plane

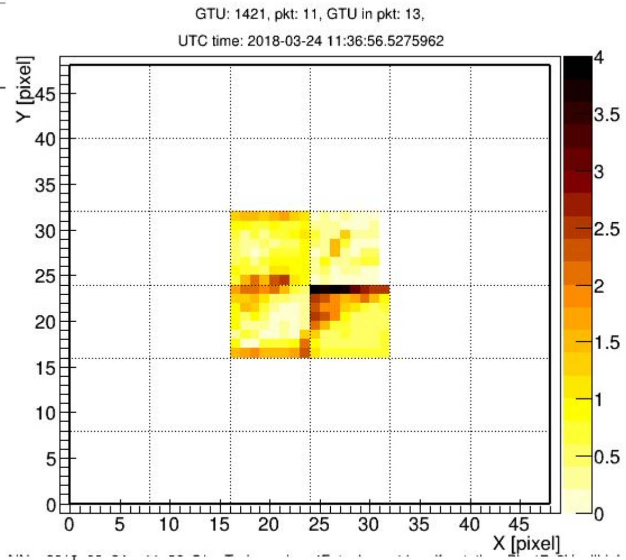


Plane crossing the field of view
(frame duration 40.96 ms)

Roof setup

L2 trigger





Meteor-like signal
(frame duration 40.96 ms)

New triggers goals and requirements

Goals

- Design an (adaptable, if possible) new FLT for EUSO-like experiments (SPB2, EUSO-TA)

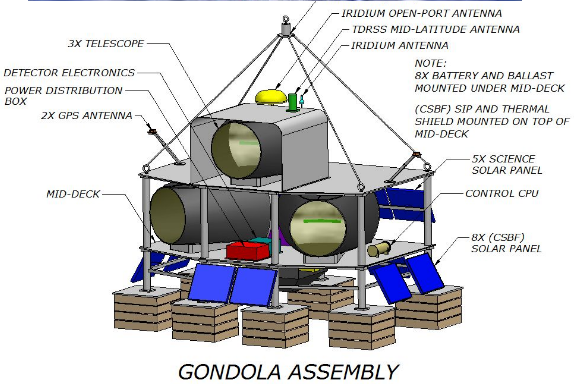
- Test the FLT on simulations and available data

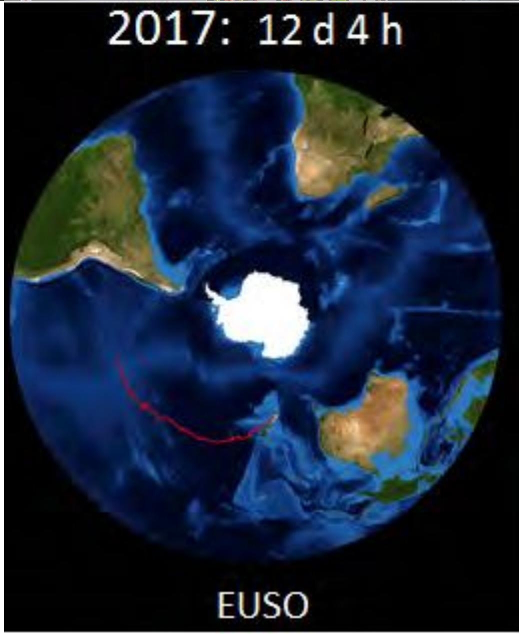
Requirements

- First Level Trigger has to be implemented in a FPGA

- Fake trigger rate should be ~ 1Hz

EUSO pathfinders

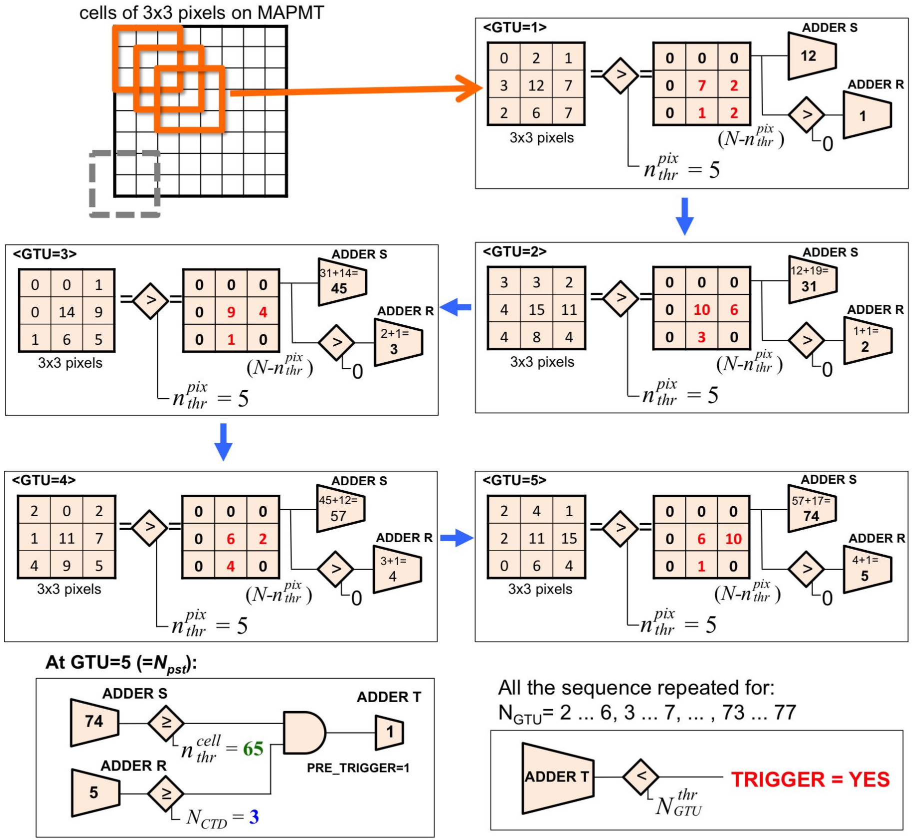




New trigger logics: general idea

- Multi-level trigger
- Every pixel is independent
- Average computed every 128 GTU for each pixel
- Threshold distant n_σ sigma from the mean value (poissonian background)
- Simpler logic with respect to the previous algorithm

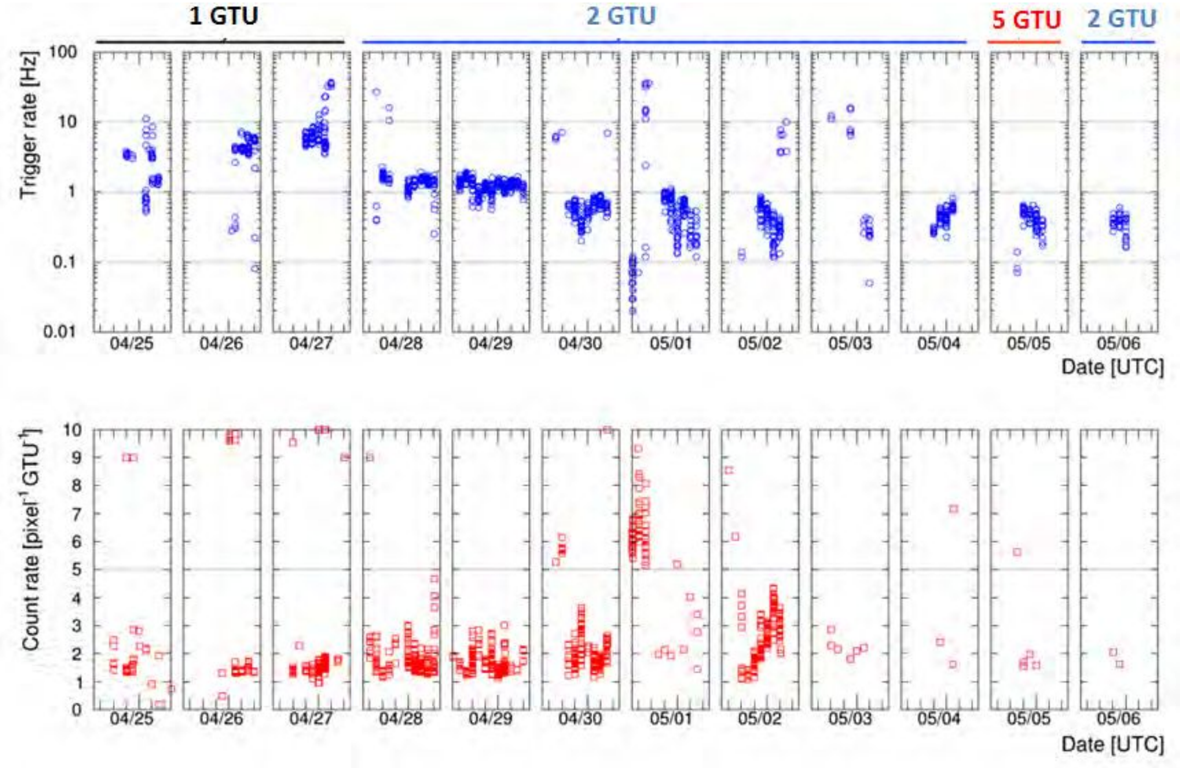
PTT algorithm



Persistence Tracking Trigger

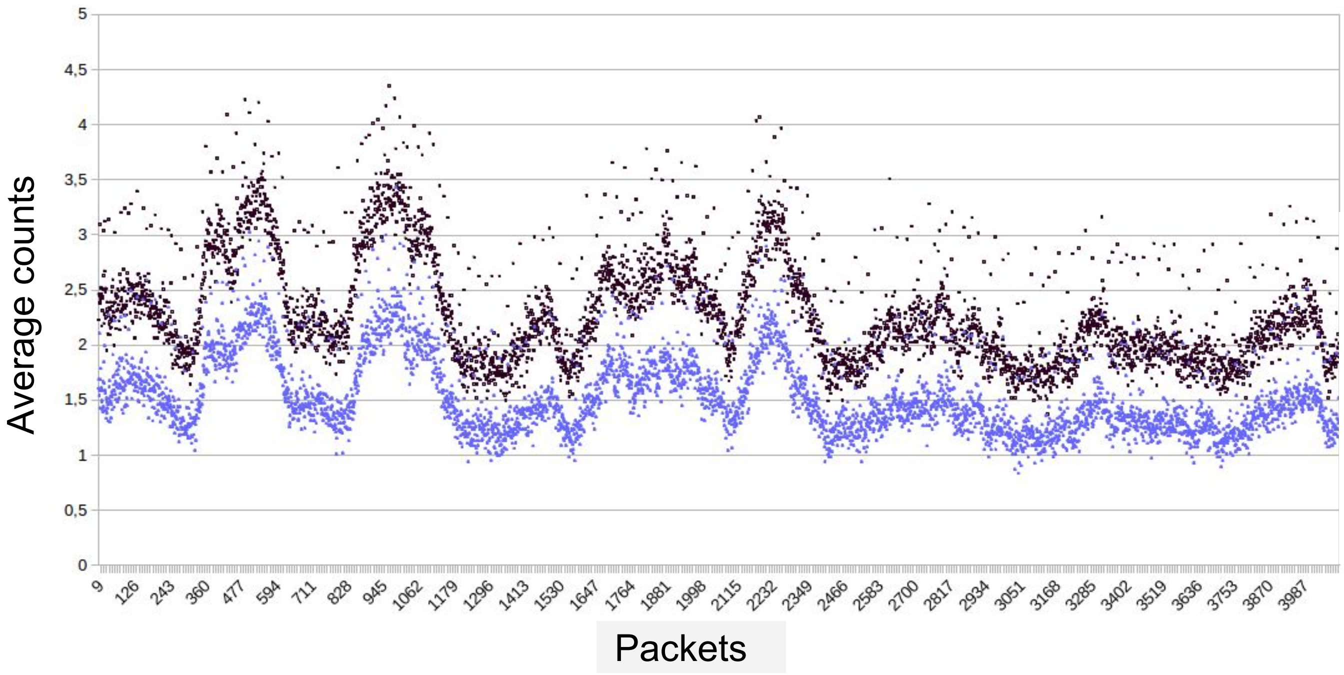
- Sets the same threshold for the all the pixels in a PMT
- Checks for an excess of signal in a 3x3 pixels box

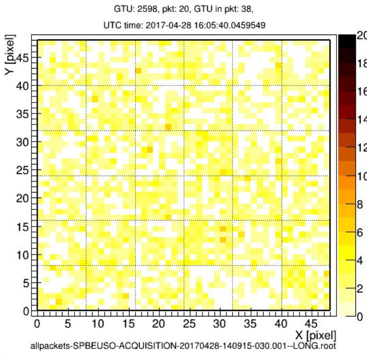
PTT algorithm



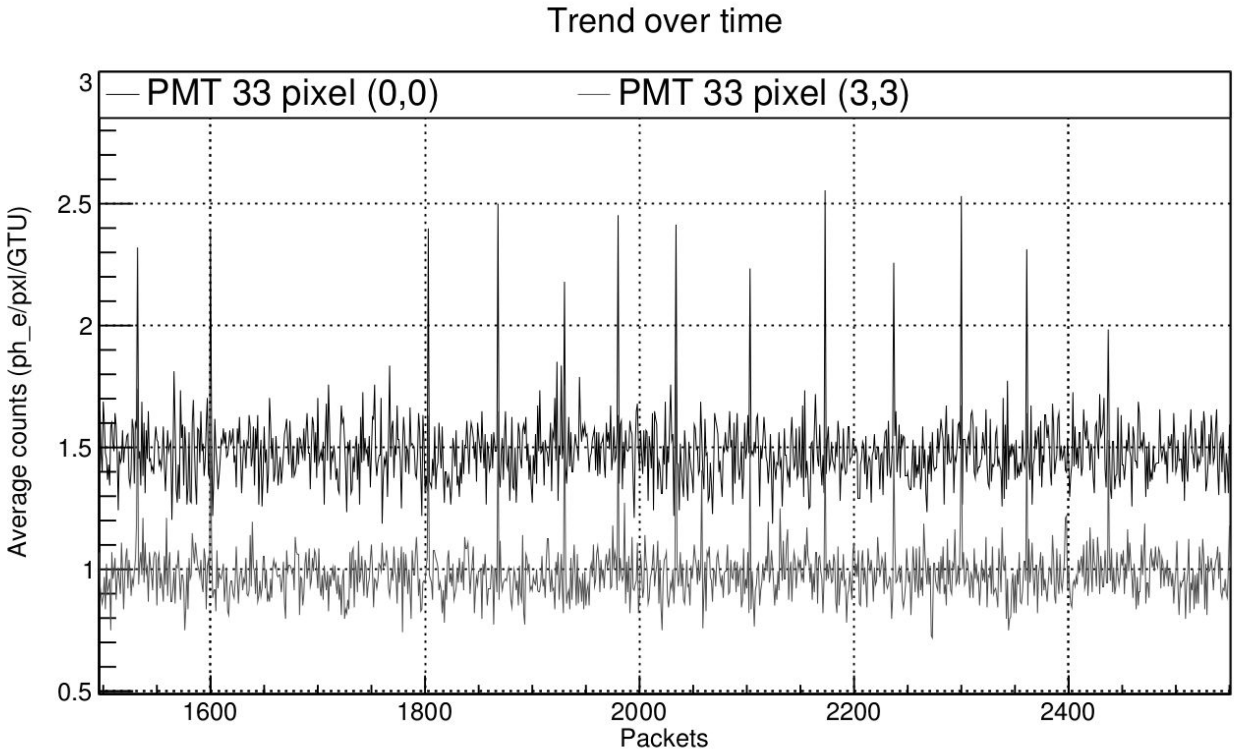
PTT performances during SPB1 flight

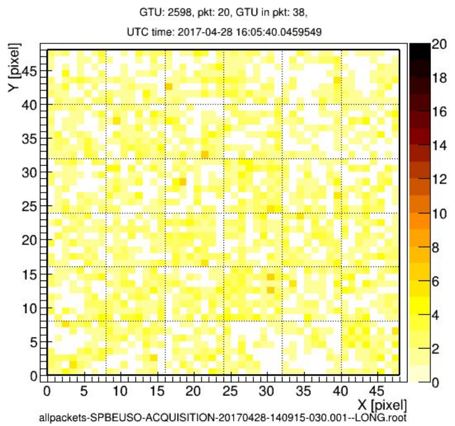
Background's trend over time: SPB1 campaign, 28/04 (partially cloudy night)





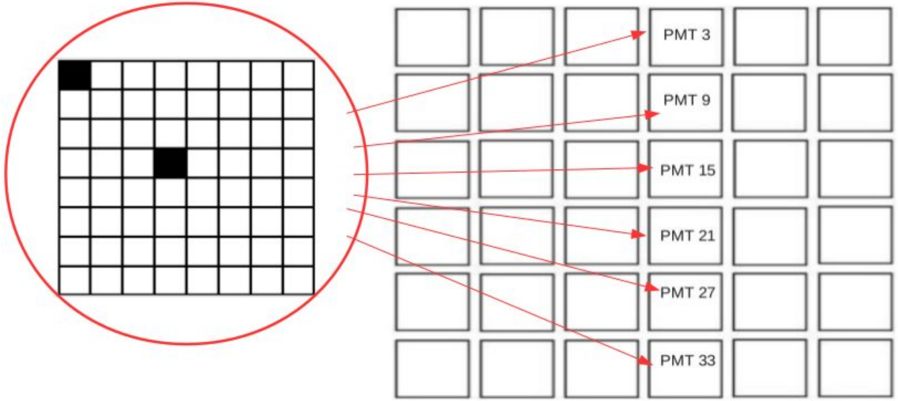
Background’s trend over time: SPB1 campaign, 26/04 (clear sky)



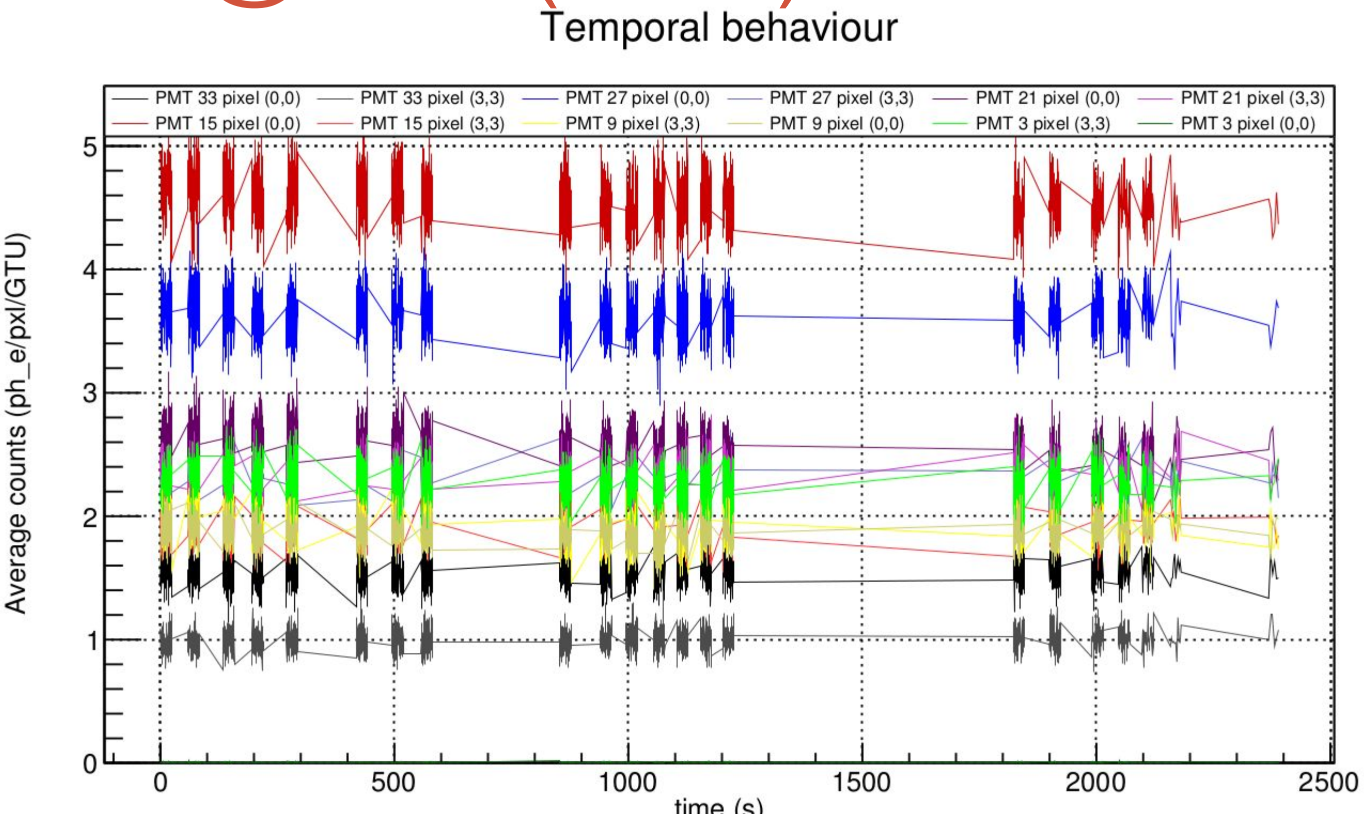


Background's trend over time: SPB@Utah (2016)

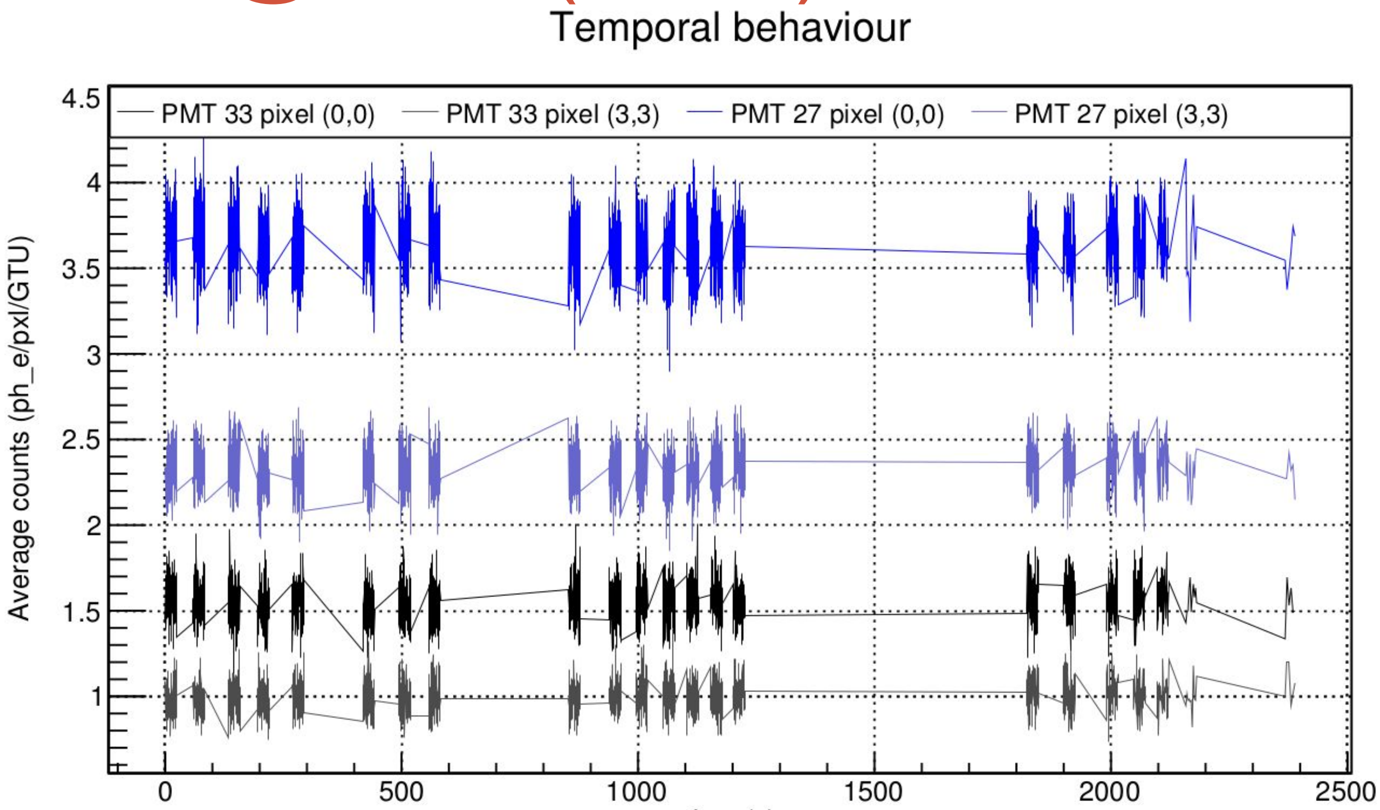
Laser shots crossing the field of view vertically.



Background's trend over time: SPB@Utah (2016)



Background's trend over time: SPB@Utah (2016)



New trigger logics

- Compute the mean value every 128 GTUs (320 μs) for every pixel
- Threshold distant n_σ- (4) sigma from the mean value (poissonian background)

EUSO-SPB-T trigger logic

- at least n_{Pixel} (3) pixels above threshold in the same PMT
- the same PMT active for at least 2 consecutive GTUs

EUSO-TA-T trigger logic

Requires at least one of the following:

- n_{PMT1} (i.e. 5) pixels above threshold in the same PMT in a single GTU
- n_{EC1} (i.e. 8) pixels above threshold in the same EC in a single GTU
- n_{PMT2} (i.e. 6) pixels above threshold in the same PMT integrating over 2 GTUs
- n_{EC2} (i.e. 10) pixels above threshold in the same EC integrating over 2 GTUs

Fake trigger rate estimation

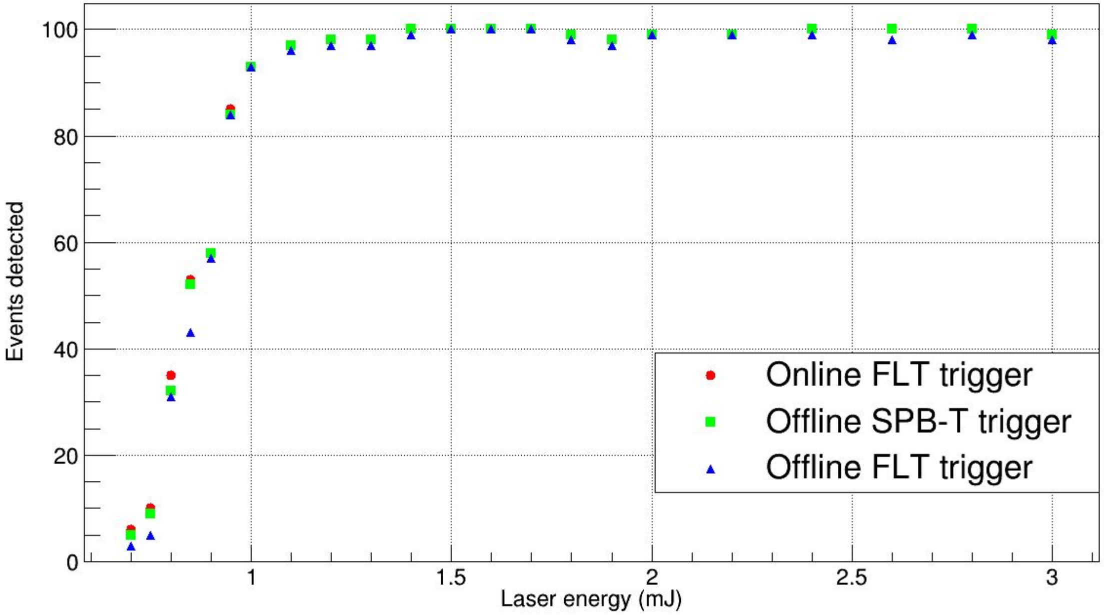
EUSO-SPB-T fake trigger rate estimated on SPB1 flight dataset in two different ways:

- 2.5 Hz (method 1) and 4.7 Hz (method 2)
- On-line PTT algorithm trigger rate between 1 Hz and 2 Hz

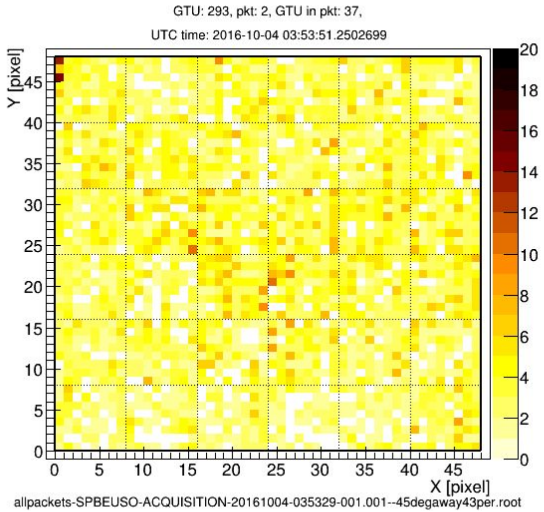
EUSO-TA-T fake trigger rate difficult to estimate (electrical noise, malfunctioning pixels, laser shots...)

- One "background" file of ~ 0.5 s equivalent time analysed, no fake triggers detected
- Despite low statistics, fake trigger rate well below 10 Hz

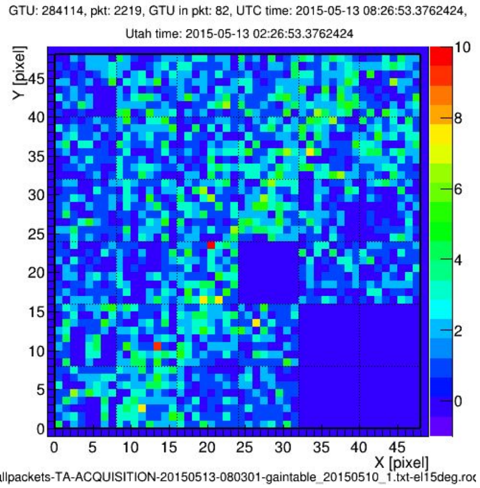
SPB-T trigger efficiency



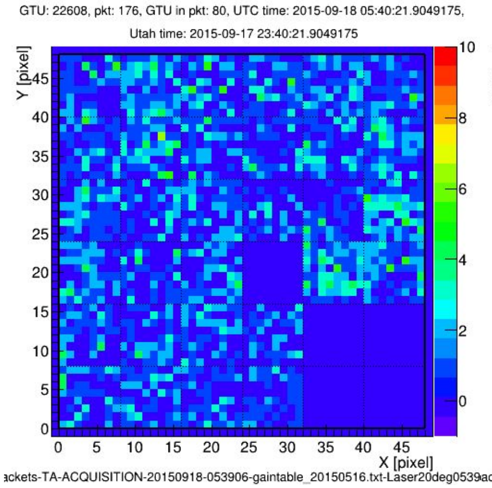
- 100 laser shots at fixed energy
- Only detected events were stored and therefore analysed



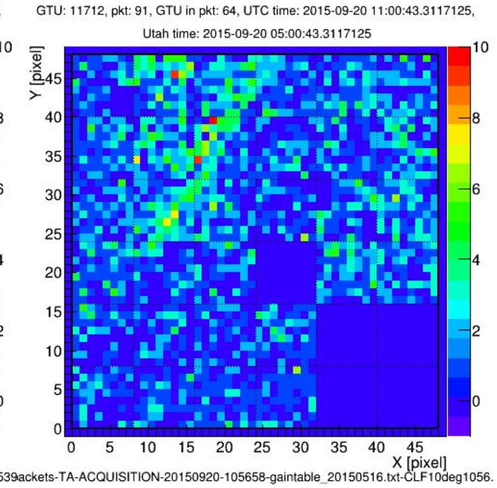
EUSO-TA: TA triggered data - Detected by TA-Trigger



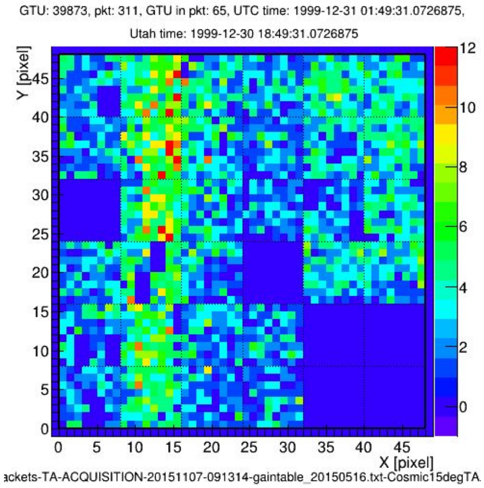
log(E/eV) =18.06
Rp = 2.5 km



log(E/eV) =18.51
Rp = 9.1 km

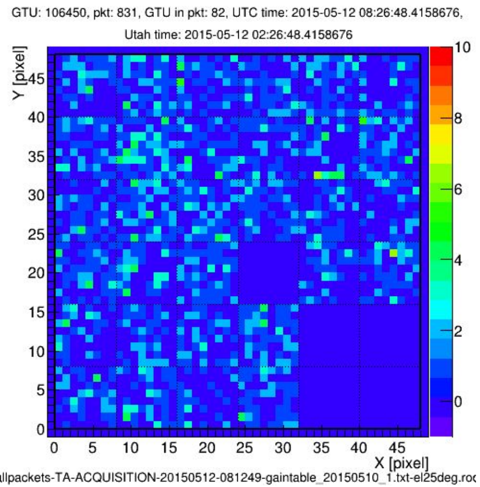


log(E/eV) =18.38
Rp = 6.7 km

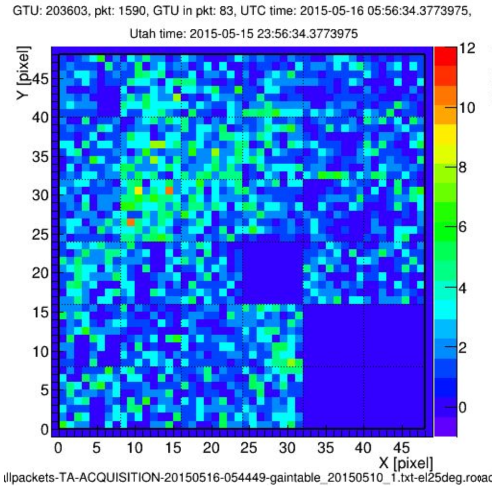


log(E/eV) =18.42
Rp = 2.6 km

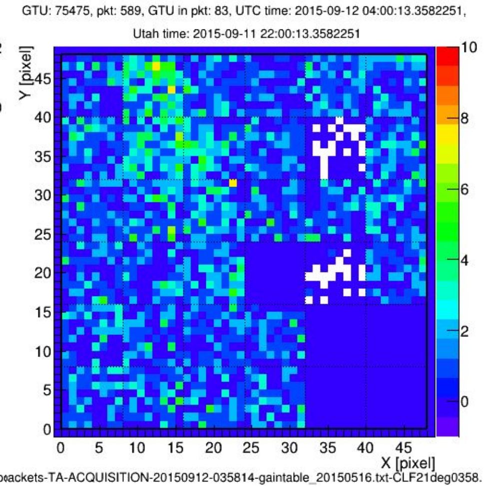
EUSO-TA: TA triggered data - Undetected by TA-Trigger



log(E/eV) =18.69
Rp = 8.3 km

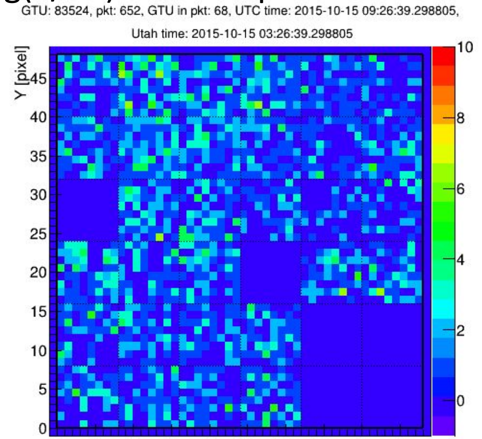


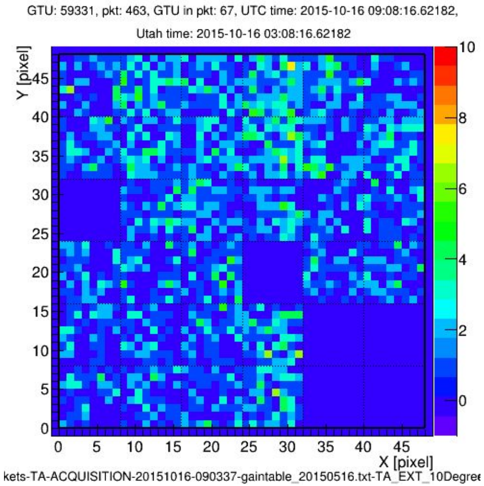
log(E/eV) =18.20
Rp = 0.8 km



log(E/eV) =18.05
Rp = 5.0 km

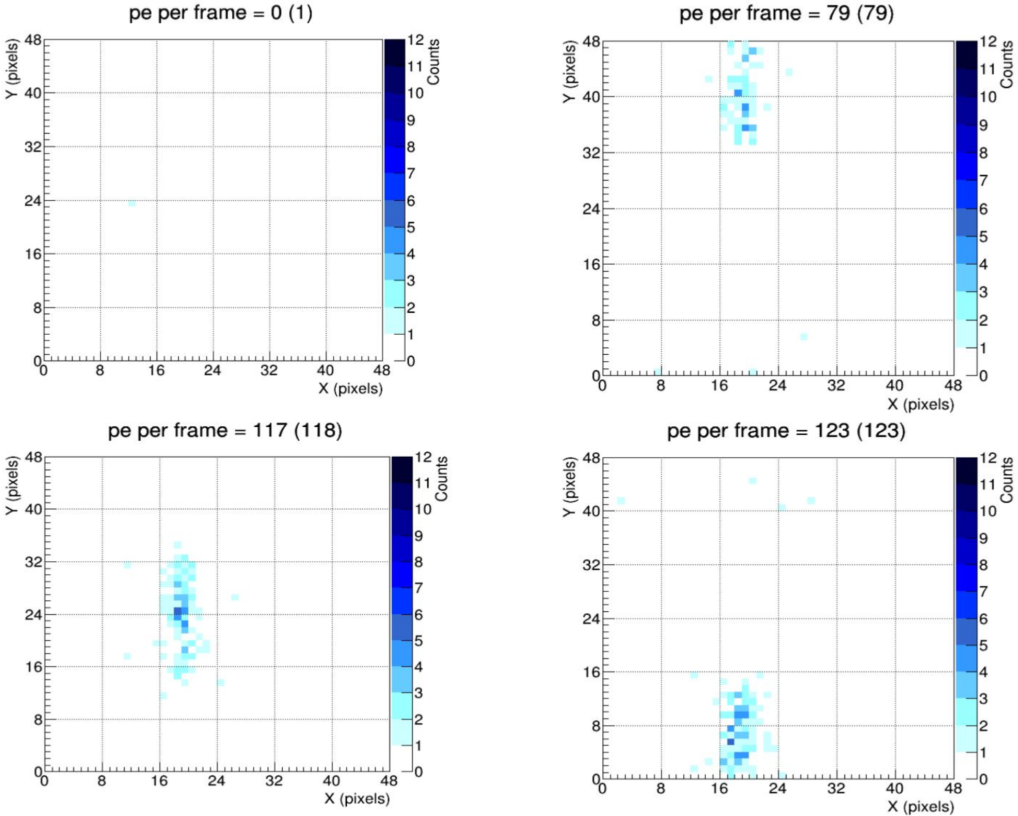
log(E/eV) =18.52 Rp = 9.0 km



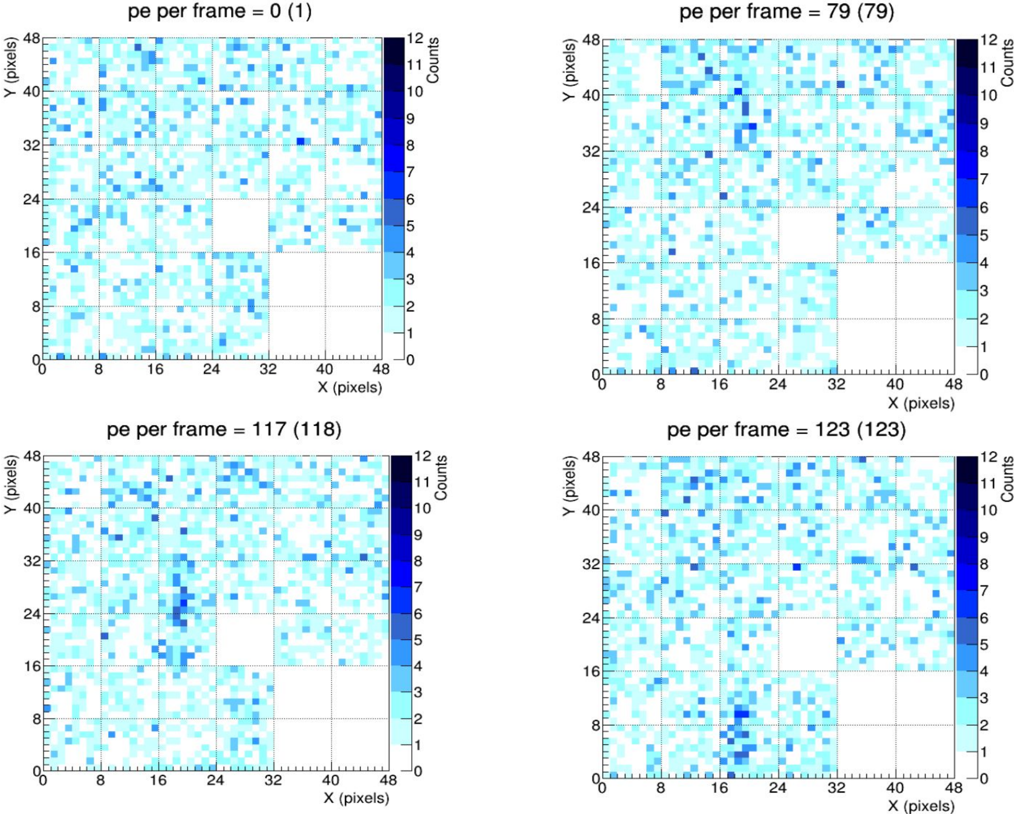


log(E/eV) =17.71 Rp = 1.7 km

Energy $10^{18.5}$ eV , distance 12 km: partially detected



Energy $10^{18.5}$ eV , distance 12 km: partially detected



Conclusion

- Mini EUSO engineering model extensively tested
  - Acquisition and trigger logic properly working
- EUSO-SPB-T logic tested
  - more efficient but slightly less robust compared to the previous algorithm
- EUSO-TA-T logic tested
  - able to trigger all the events immediately recognised as cosmic rays
  - unable to detect any of the cosmic ray events that required further offline analysis
  - difficult to estimate the fake trigger rate, anyway it should be well below 10 Hz
  - TA-trigger logic is suitable to be implemented in a FPGA via VHDL code

Thank you for your attention