

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

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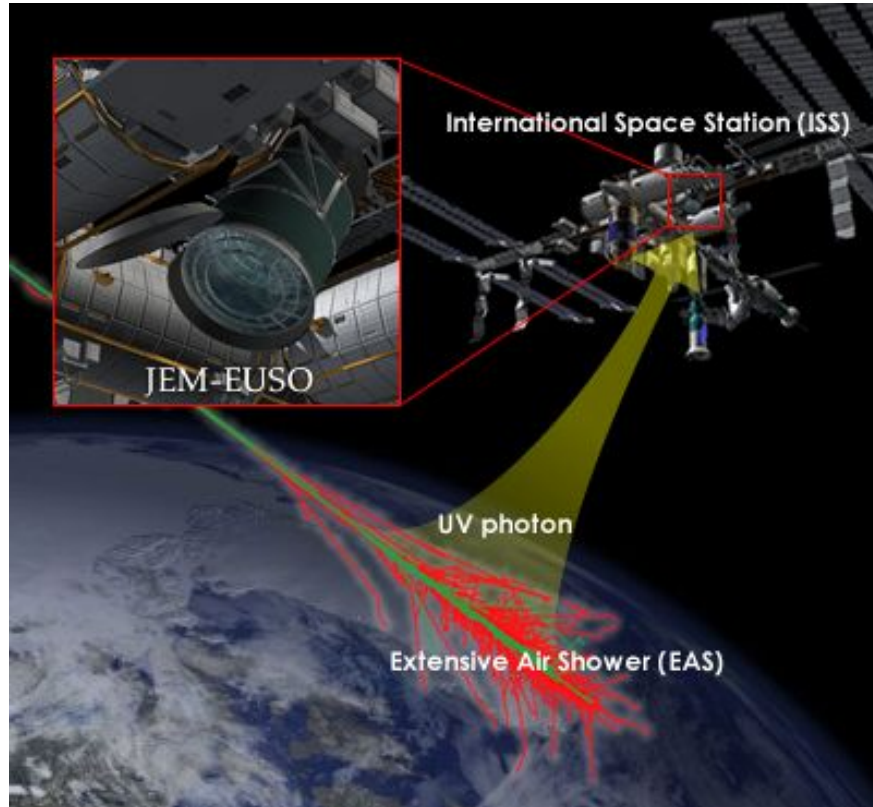
University of Torino

Discussione Tesi di Laurea

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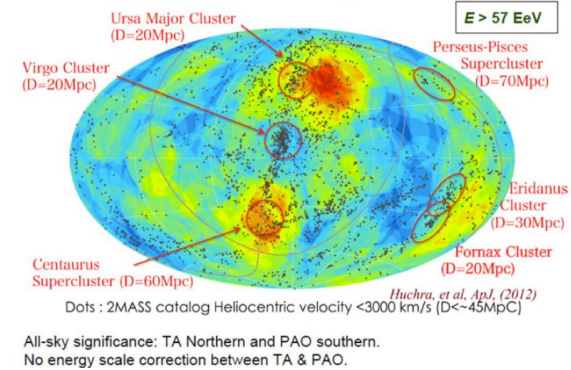
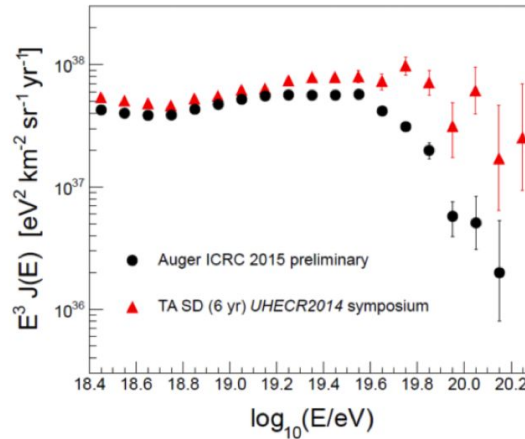
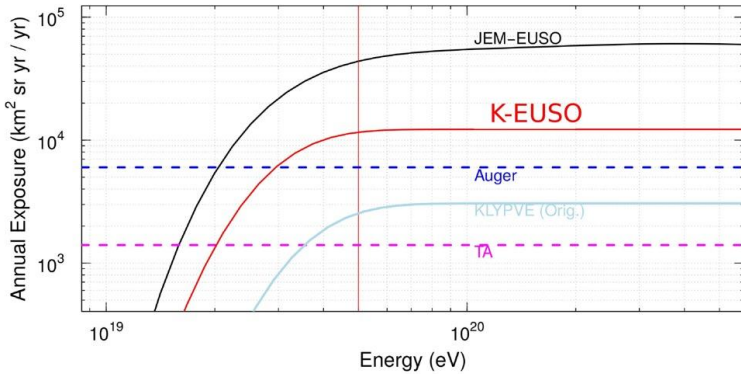
April 11, 2018

JEM-EUSO general idea



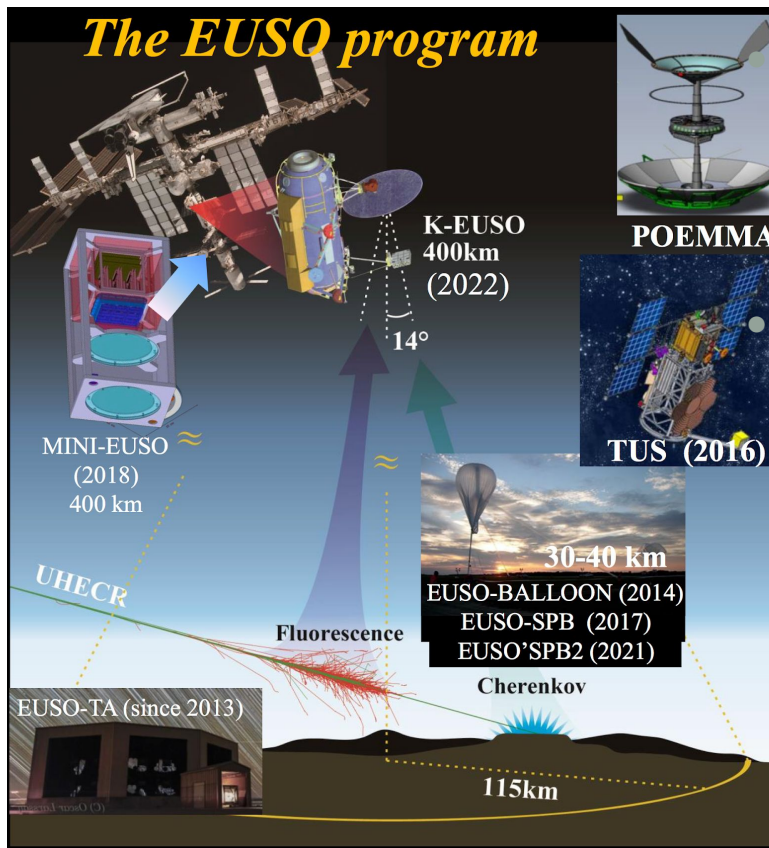
- **J**oint **E**xperiment **M**issions for **E**xtrême **U**niverse **S**pace **O**bservatory
- Very large exposure space-based detector looking at the fluorescence light produced by EECR ($E > 5 \times 10^{19}$ eV) interacting in the atmosphere

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

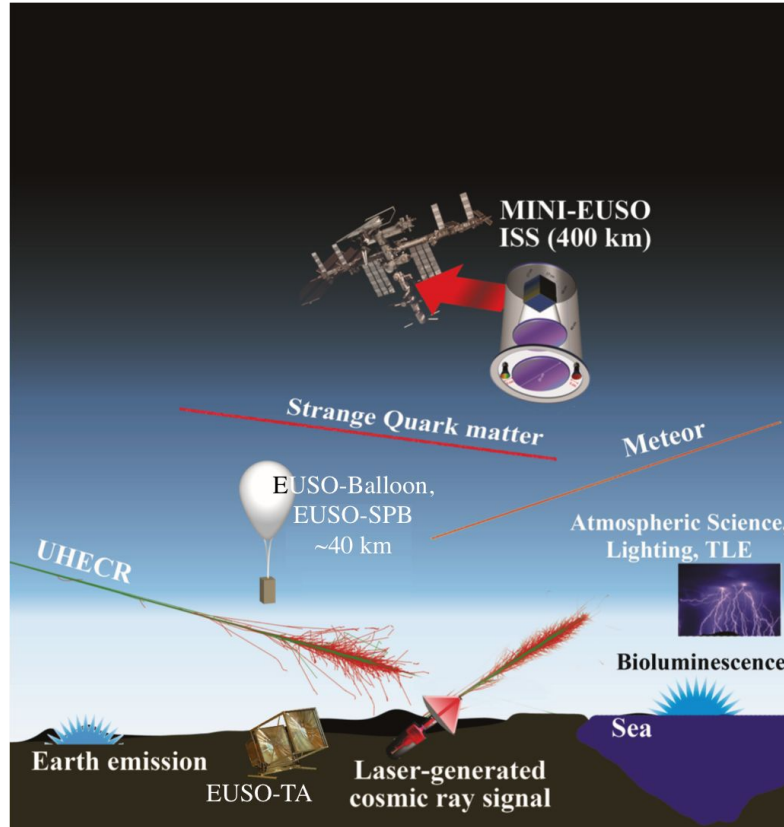


EUSO -TA (2013):
ground detector
installed at
Telescope Array site:
currently operational.

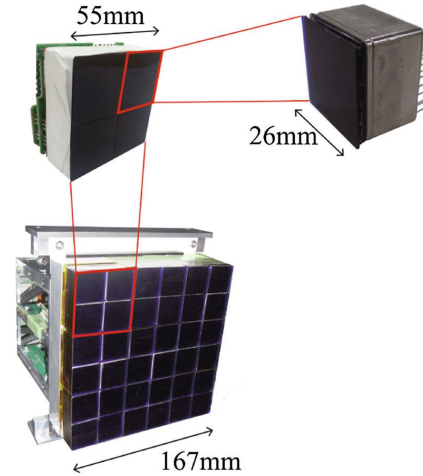
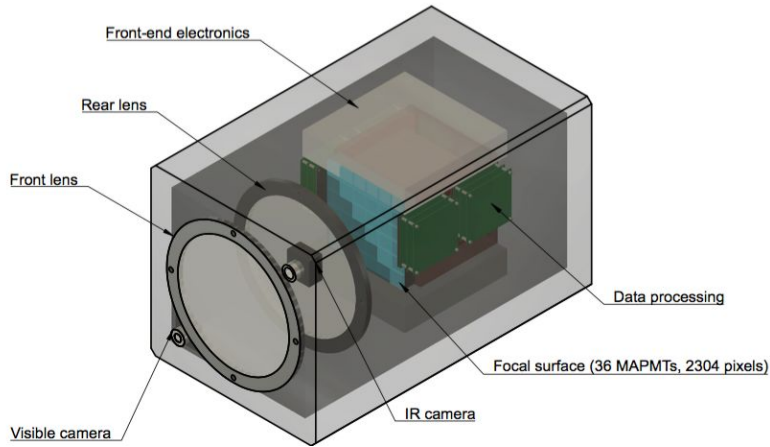
EUSO Balloons: first
balloon flight from
Timmings (Canada)
2014;
NASA SPB1: 2017;
NASA SPB2 2021

- 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



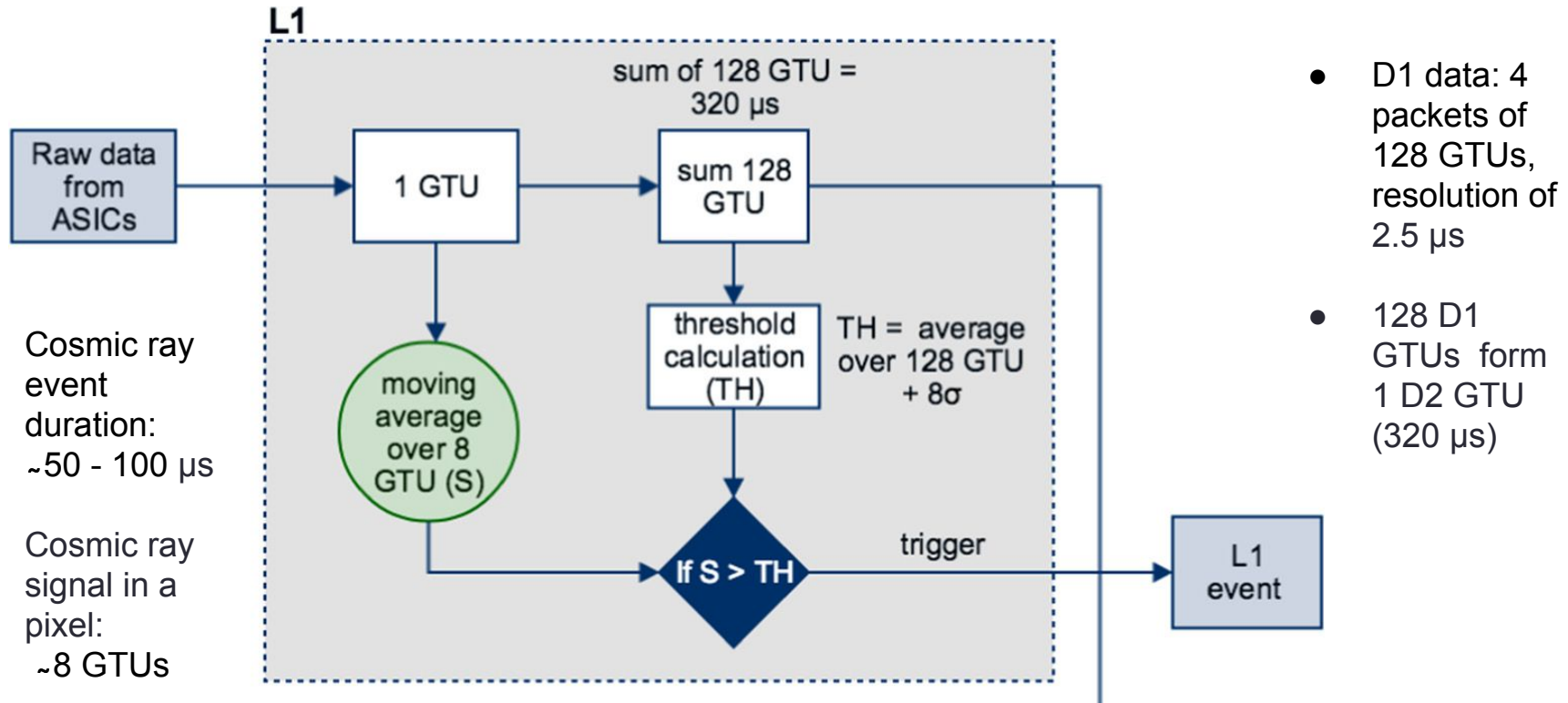
Mini-EUSO (2018)



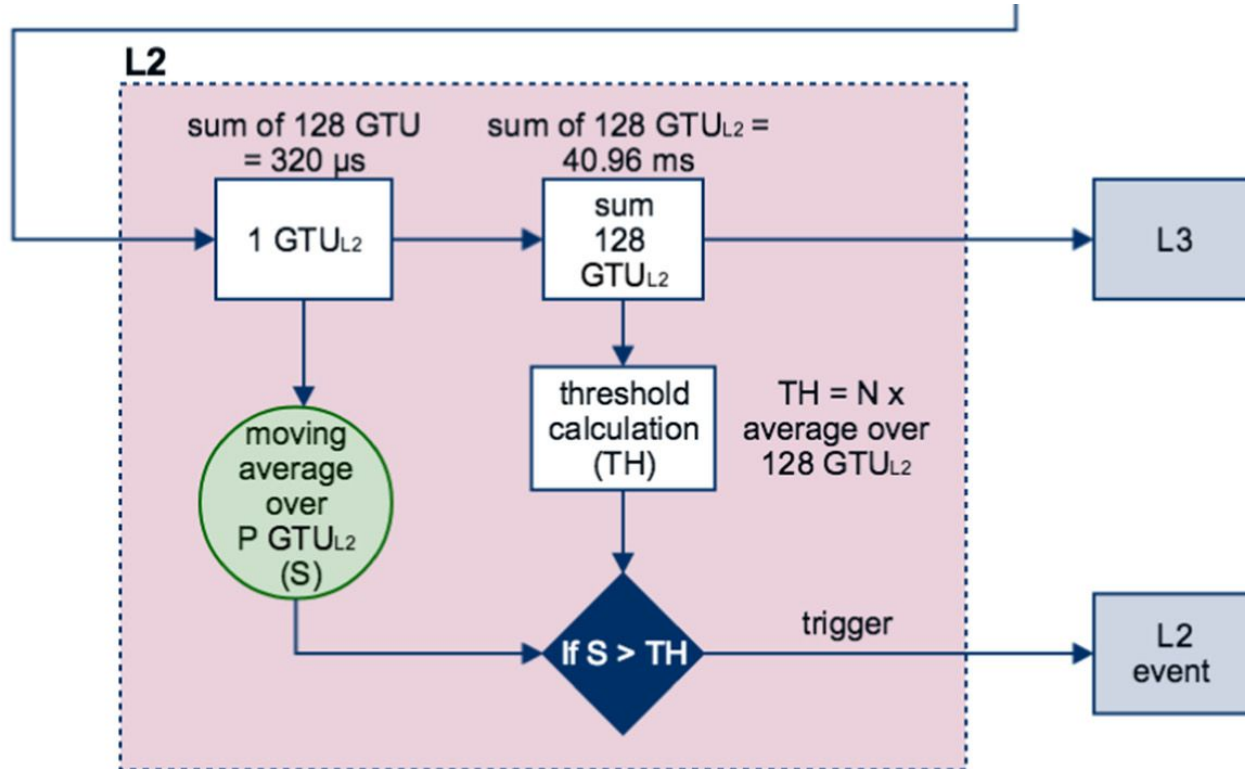
- Onboard of the ISS
- Wavelength: UV (300-400 nm)
- Time resolution: 2.5 μ s
- Mass: 25 kg

- Volume: 35 × 35 × 60 cm³
- Power: 50 W
- Large FOV ($\pm 19^\circ$)
- Pixel size at sea level: 5 km
- Multi-level trigger system

Mini-EUSO trigger logic: L1

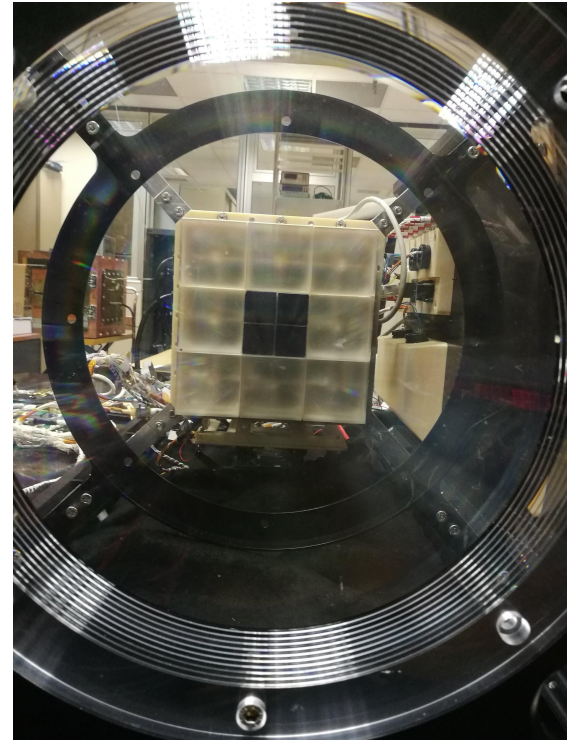
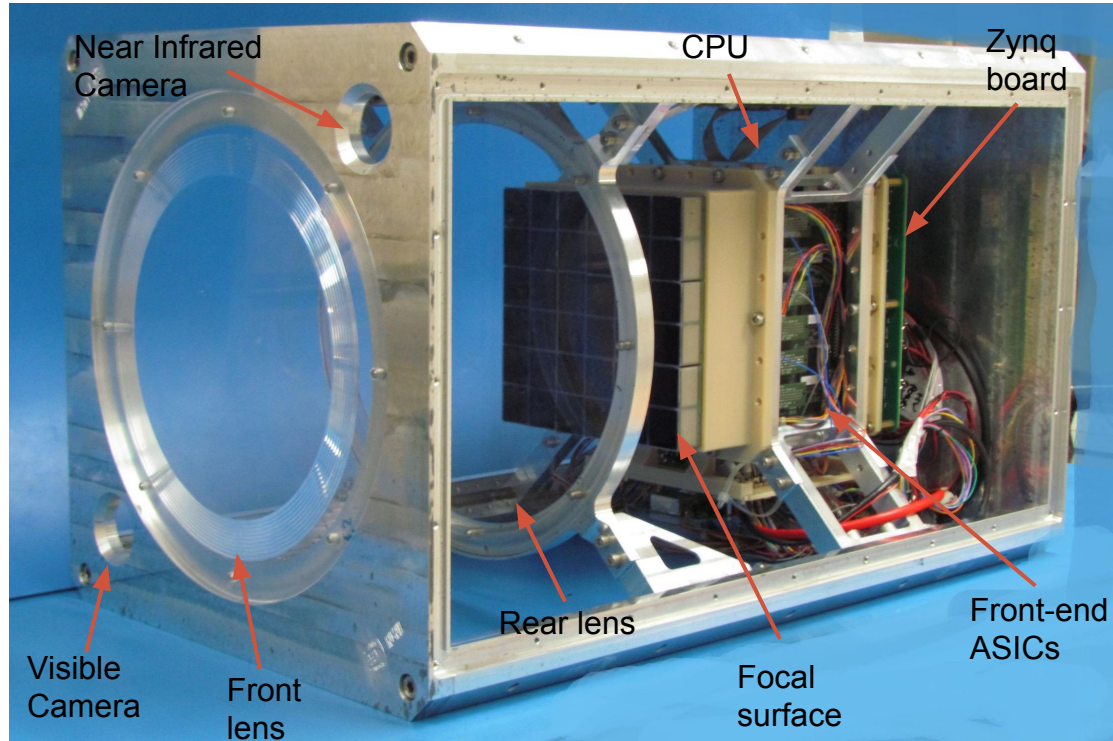


Mini-EUSO trigger logic: L2

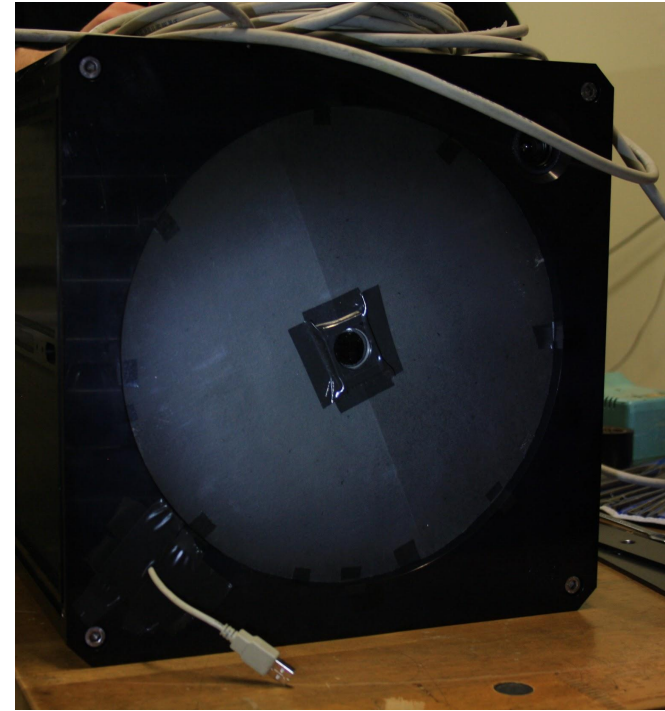
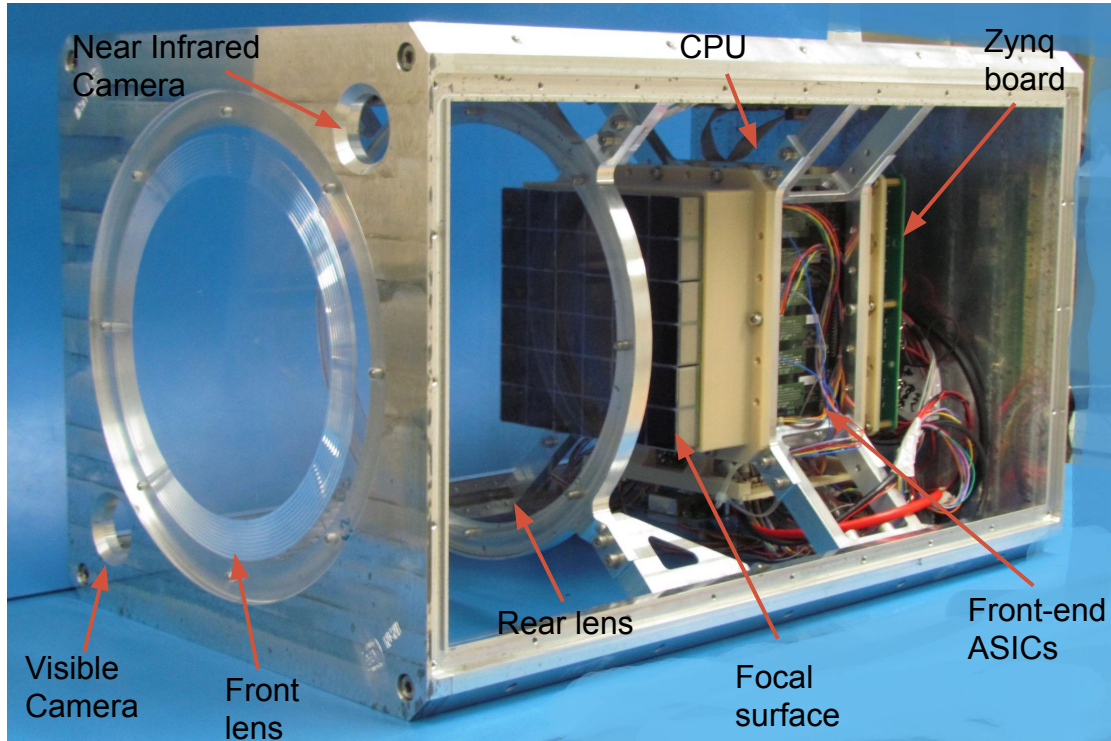


- D2 data: 4 packets of 128 GTUs, resolution of 320 μs
- 128 D2 GTU form 1 D3 GTU (40.96 ms)
- D3 data analysed offline

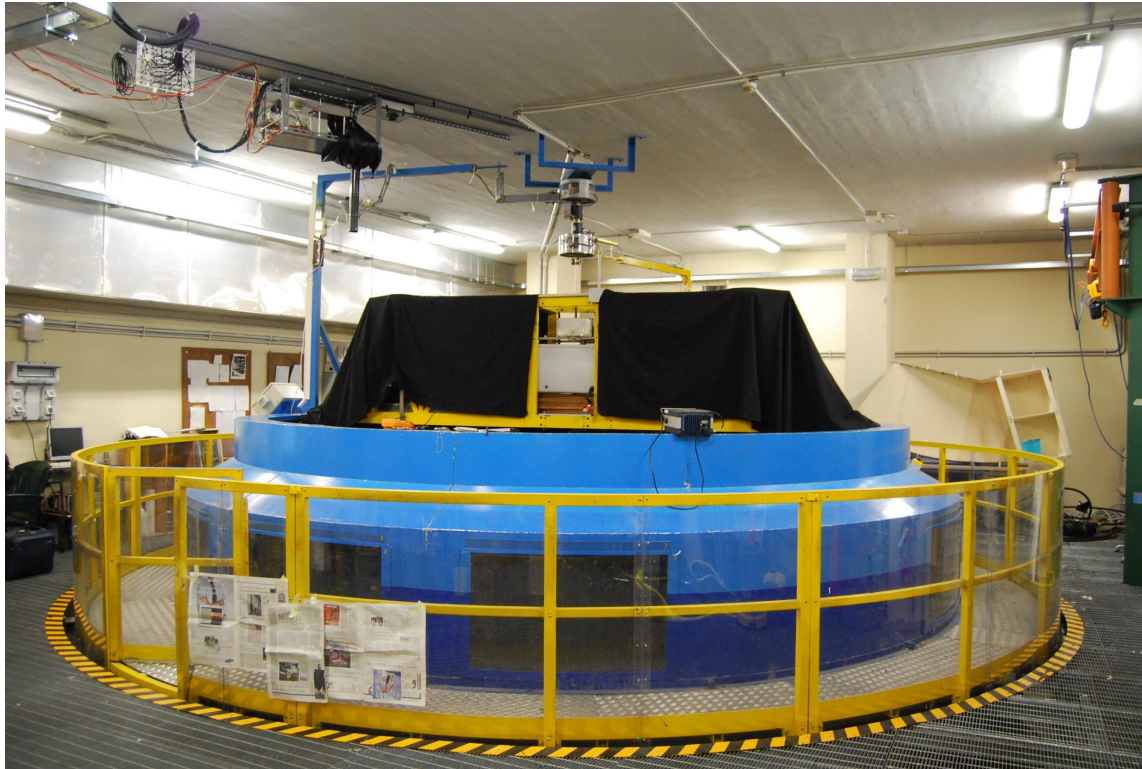
Mini-EUSO engineering model



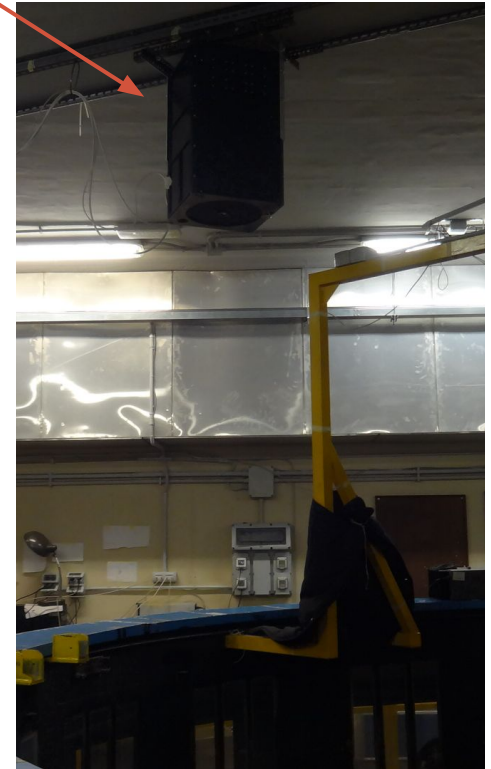
Mini-EUSO engineering model



Mini-EUSO@TurLab



Mini-EUSO

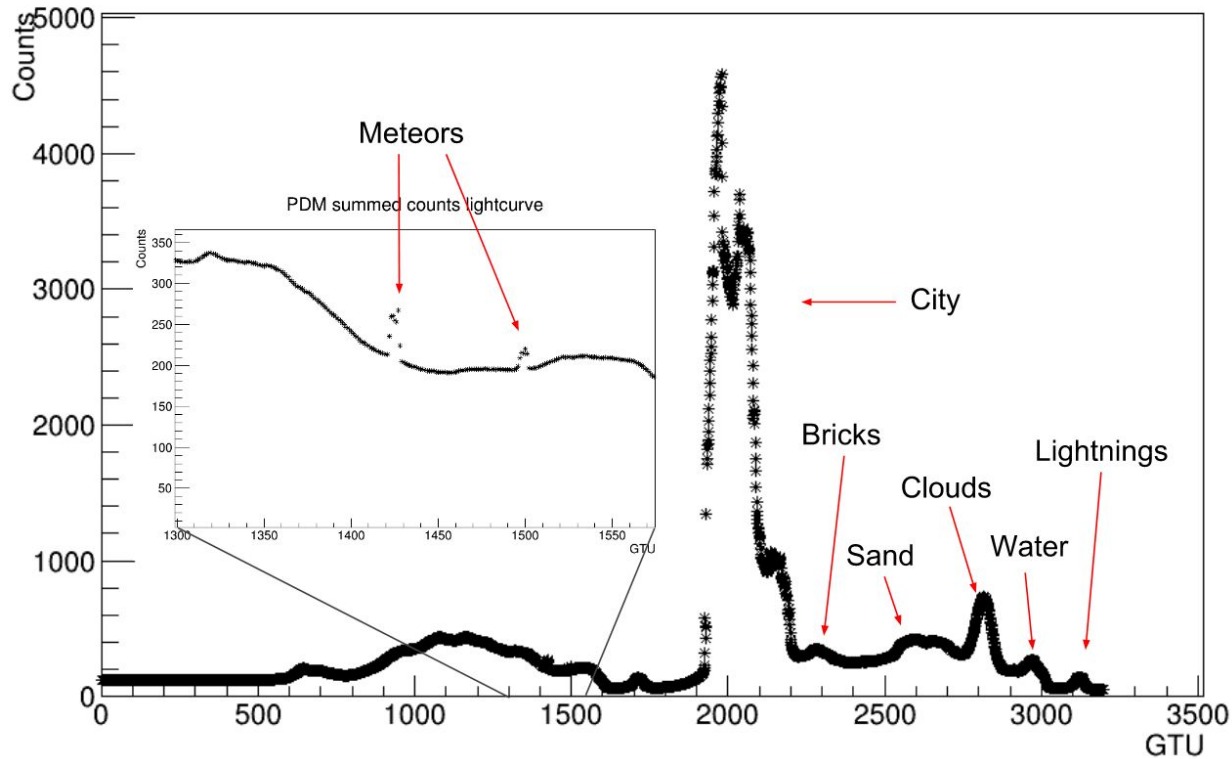


TurLab: materials and light sources

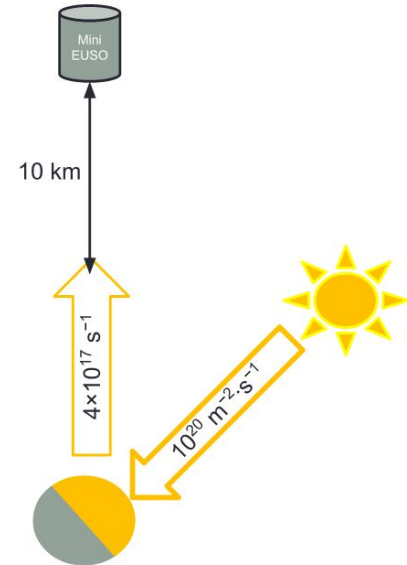


Mini EUSO @ TurLab

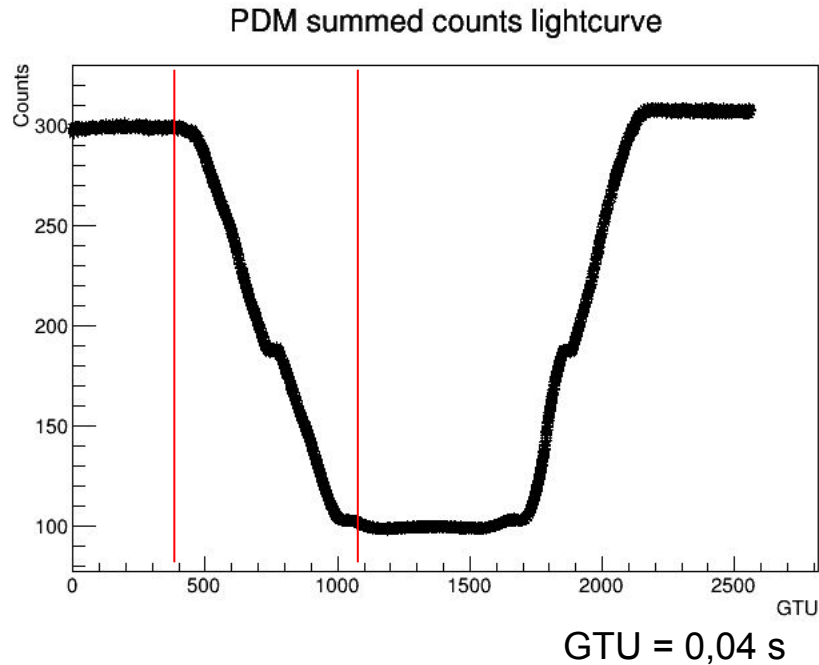
PDM summed counts lightcurve



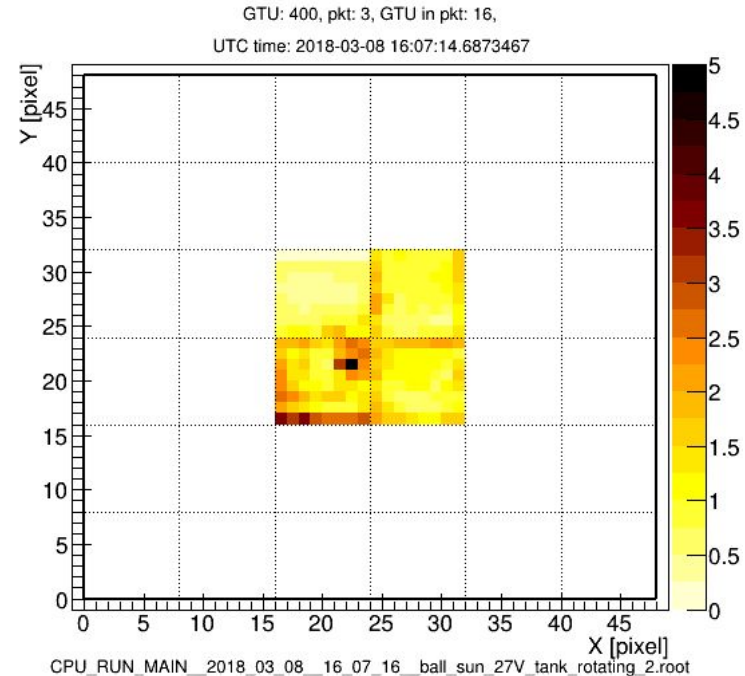
Space debris: setup



Debris light curve

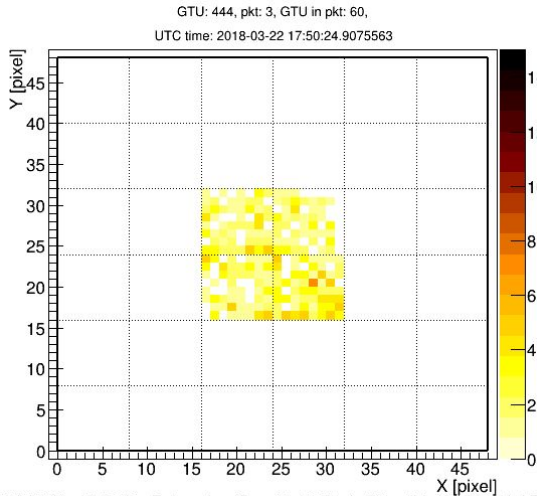


3rd level GTUs from 400 to 1100 reproduced also in animated color plot

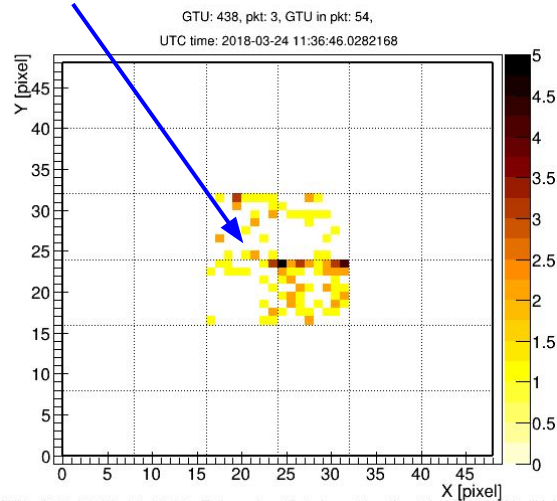


L1 trigger

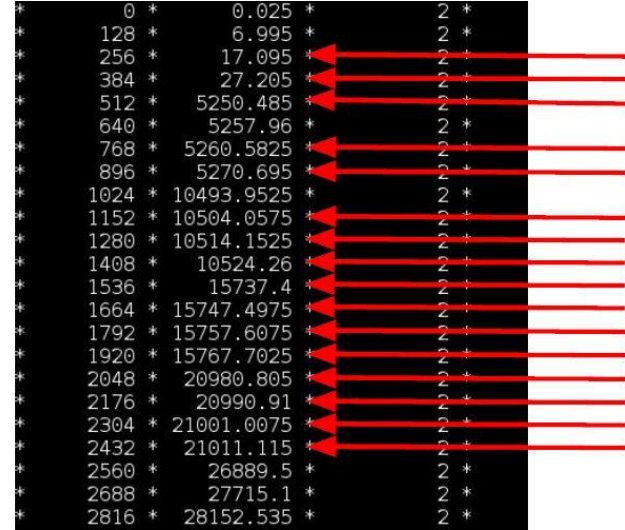
Pixel responsible
for the first trigger



2018_03_22_17_50_29_Torino_minus4F_run14_dv3950_dac500_self_led2p65Vpp_bkgLED2



MAIN_2018_03_24_11_36_51_Torino_minus4F_tank_run11_self_rotation_Bkg17p3V_allLigh

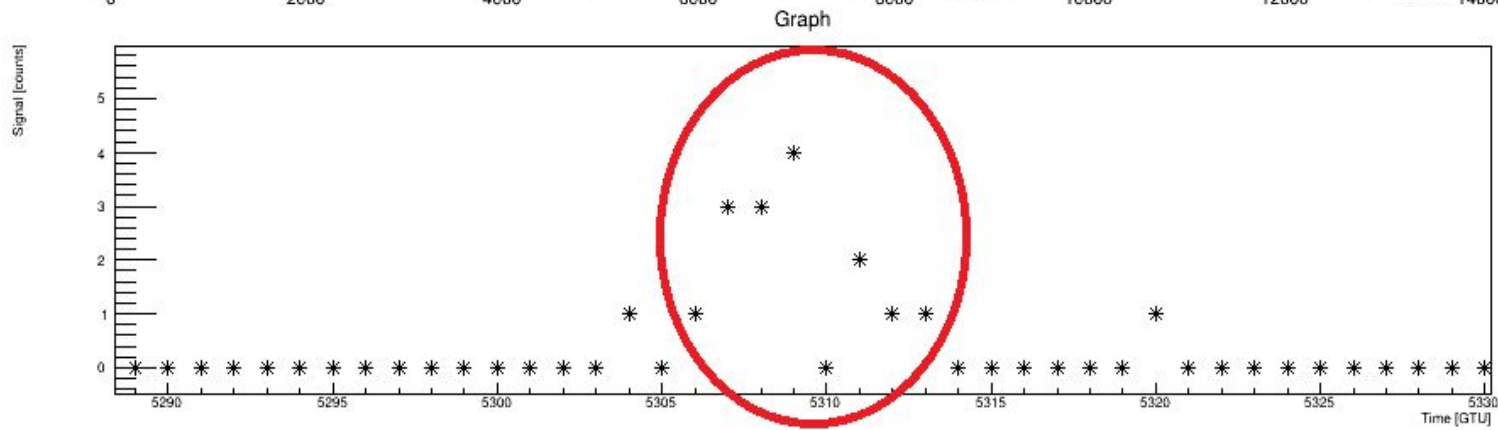
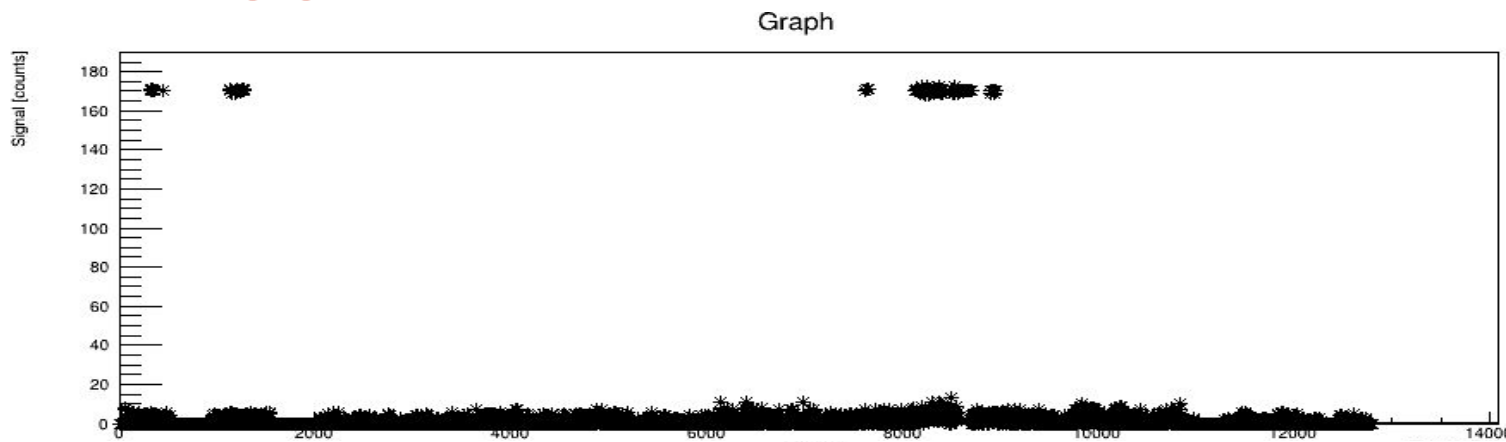


Triggers issued by the Arduino
driven LEDs (10 ms)

Static conditions: blue LED
blinking in the field of view

Dynamic conditions: Arduino
driven white LEDs

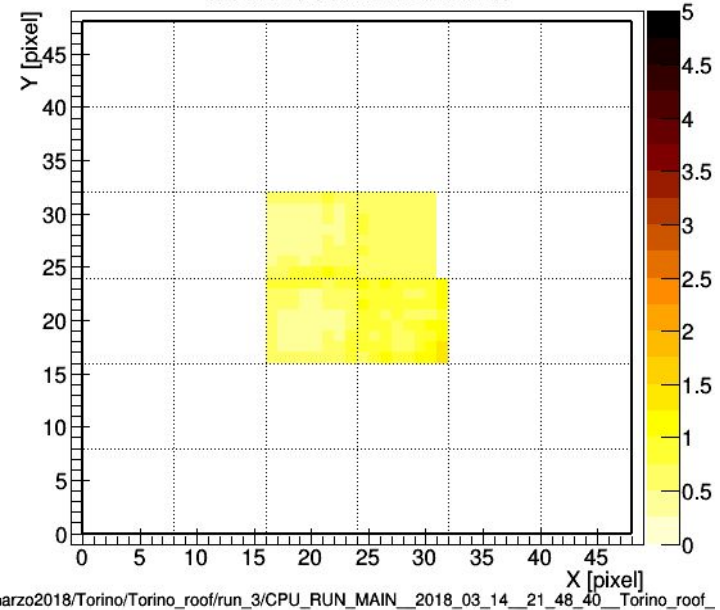
L1 trigger: front-end electrical problem



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

Plane

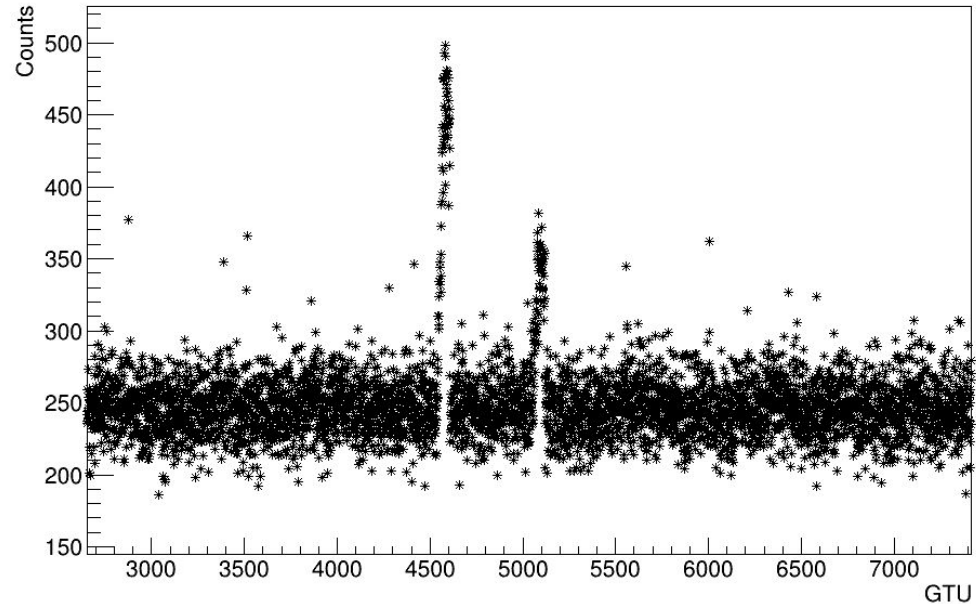
GTU: 15600, pkt: 121, GTU in pkt: 112,
UTC time: 2018-03-14 21:49:02.0402269



marzo2018/Torino/Torino_roof/run_3/CPU_RUN_MAIN_2018_03_14_21_48_40_Torino_roof_

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

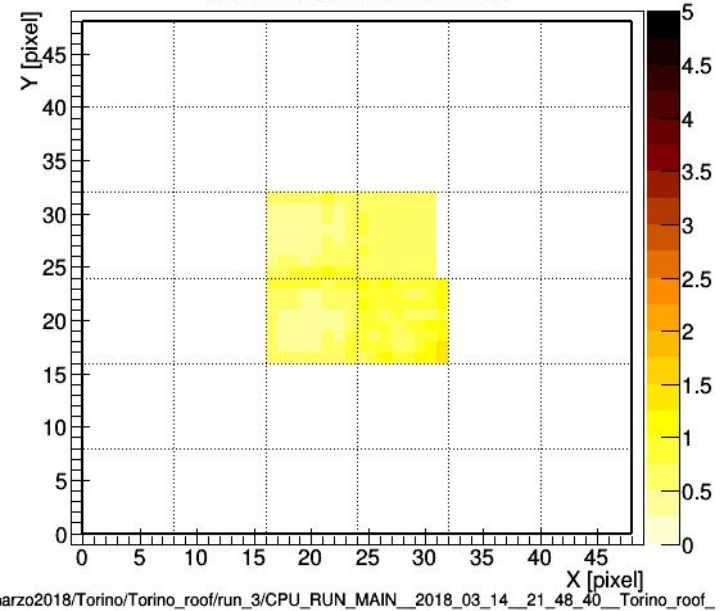
PDM summed counts lightcurve



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

GTU: 15600, pkt: 121, GTU in pkt: 112,
UTC time: 2018-03-14 21:49:02.0402269

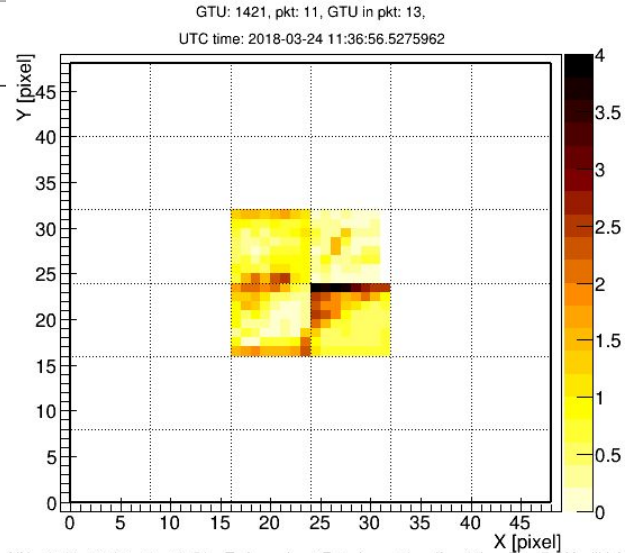
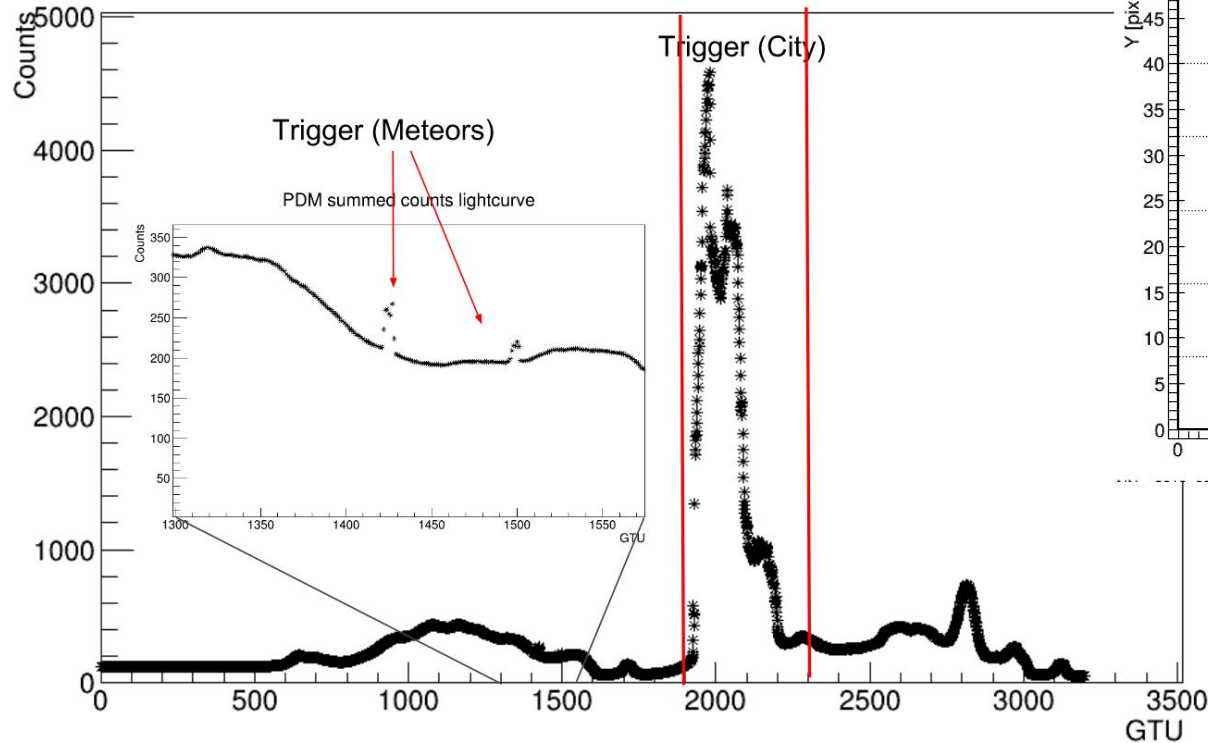


Plane crossing the field of view
(frame duration 40.96 ms)



L2 trigger

PDM summed counts lightcurve



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

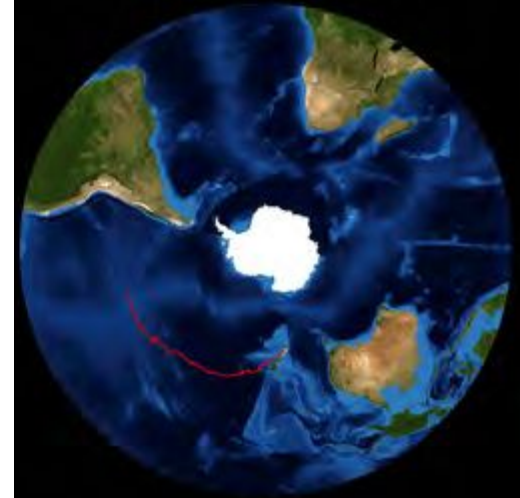
Requirements

- First Level Trigger has to be implemented in a FPGA
- Fake trigger rate should be $\sim 1\text{Hz}$

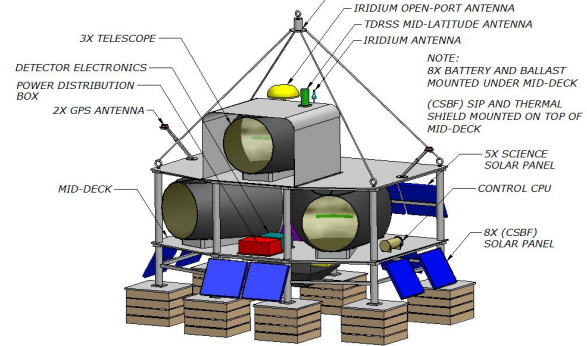
EUSO pathfinders



2017: 12 d 4 h



EUSO



GONDOLA ASSEMBLY

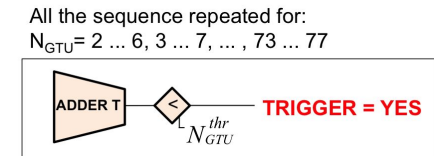
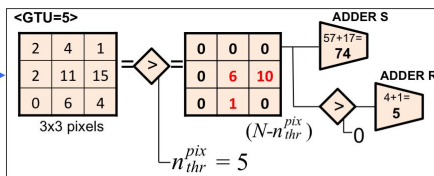
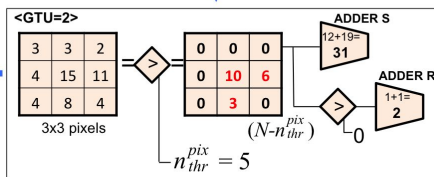
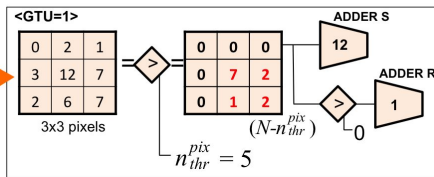
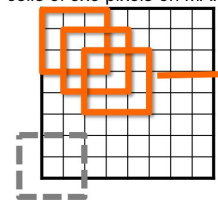


New trigger logics: general idea

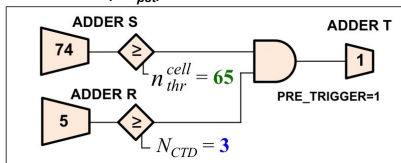
- Multi-level trigger
- Every pixel is independent
- Average computed every 128 GTU for each pixel
- Threshold distant n_σ sigma from the mean value (poissonian background)
- Simpler logic with respect to the previous algorithm

PTT algorithm

cells of 3x3 pixels on MAPMT



At GTU=5 ($=N_{pst}$):



All the sequence repeated for:

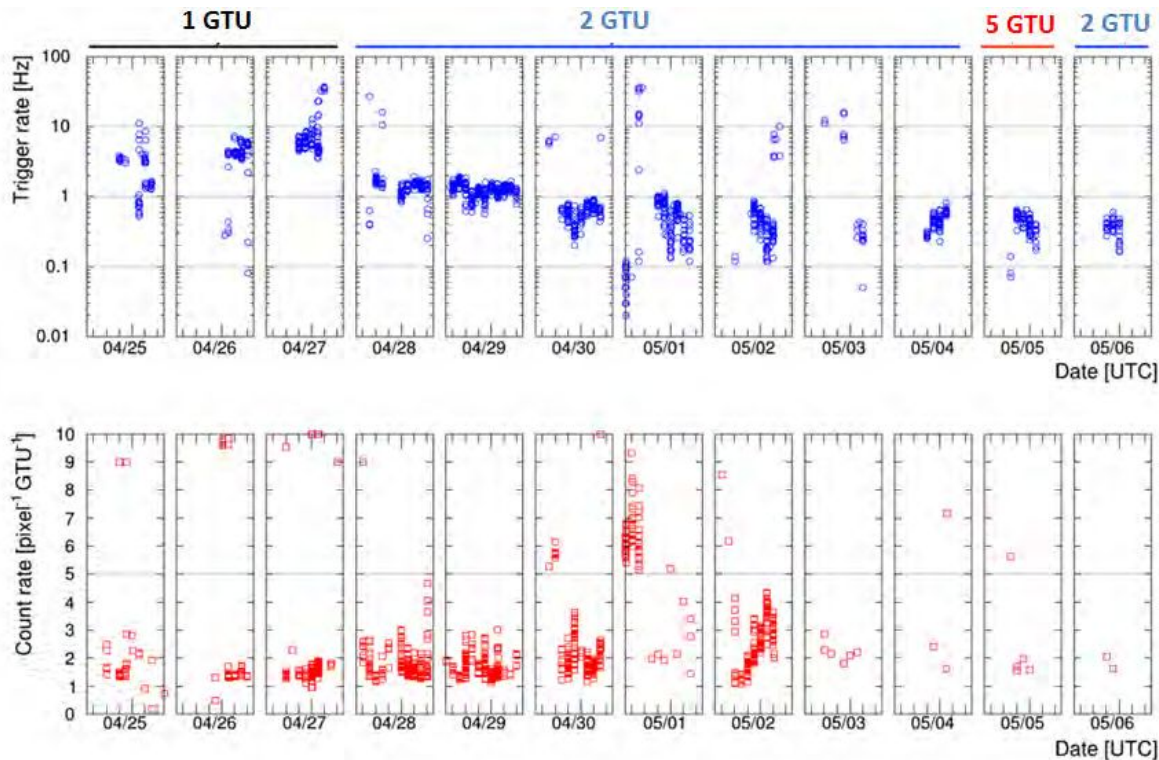
$N_{GTU} = 2 \dots 6, 3 \dots 7, \dots, 73 \dots 77$



Persistence Tracking Trigger

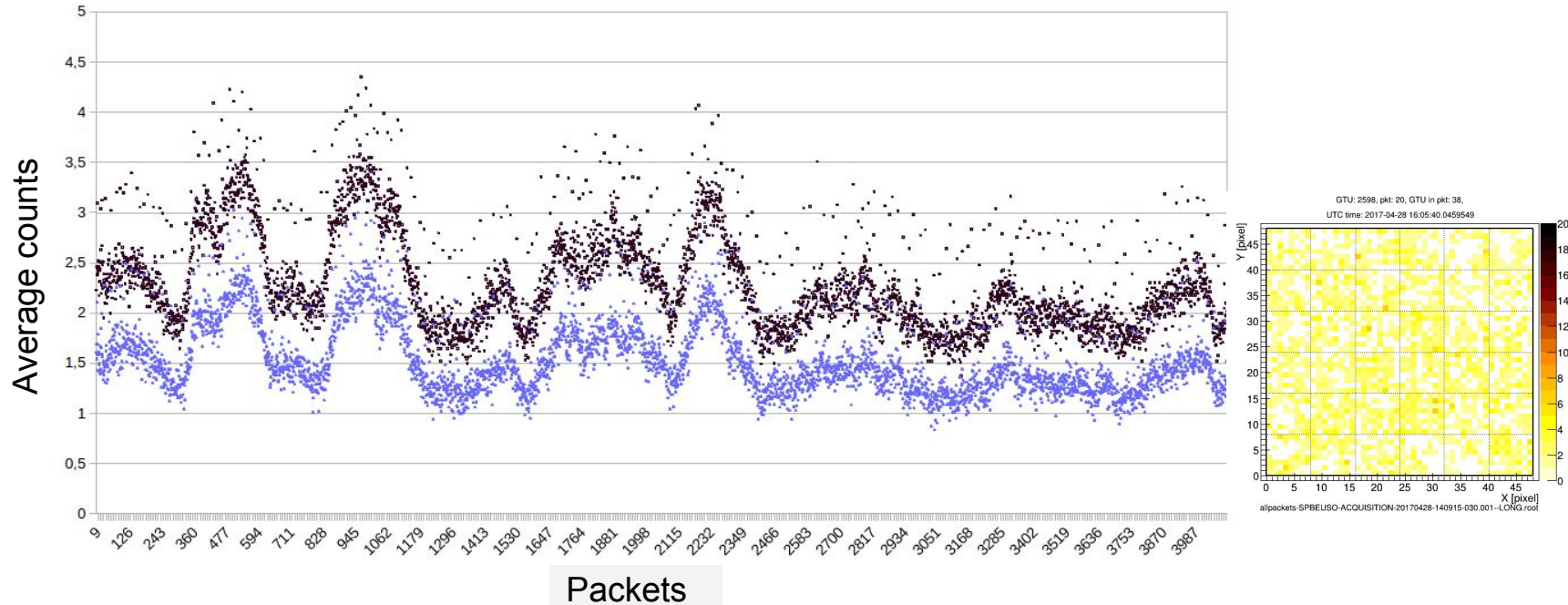
- Sets the same threshold for the all the pixels in a PMT
- Checks for an excess of signal in a 3x3 pixels box

PTT algorithm



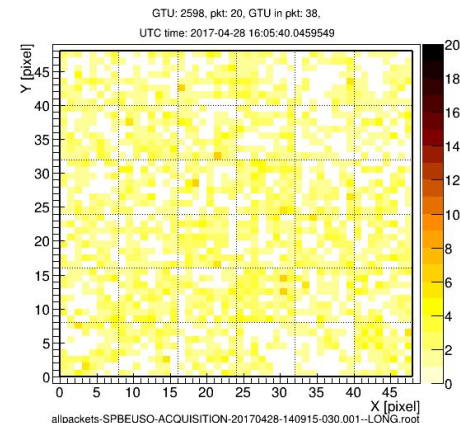
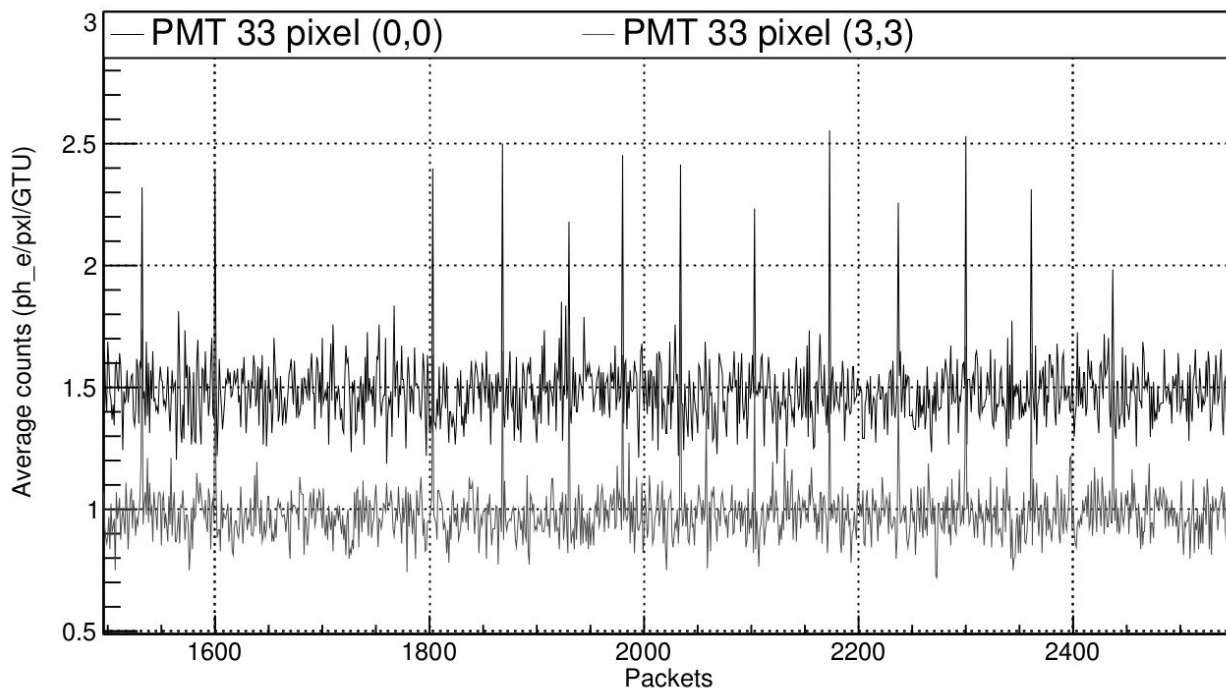
PTT performances during SPB1 flight

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



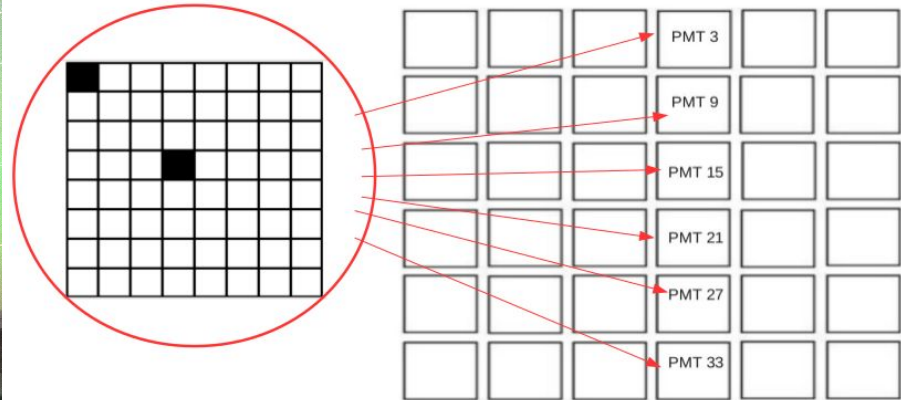
Background's trend over time: SPB1 campaign, 26/04 (clear sky)

Trend over time



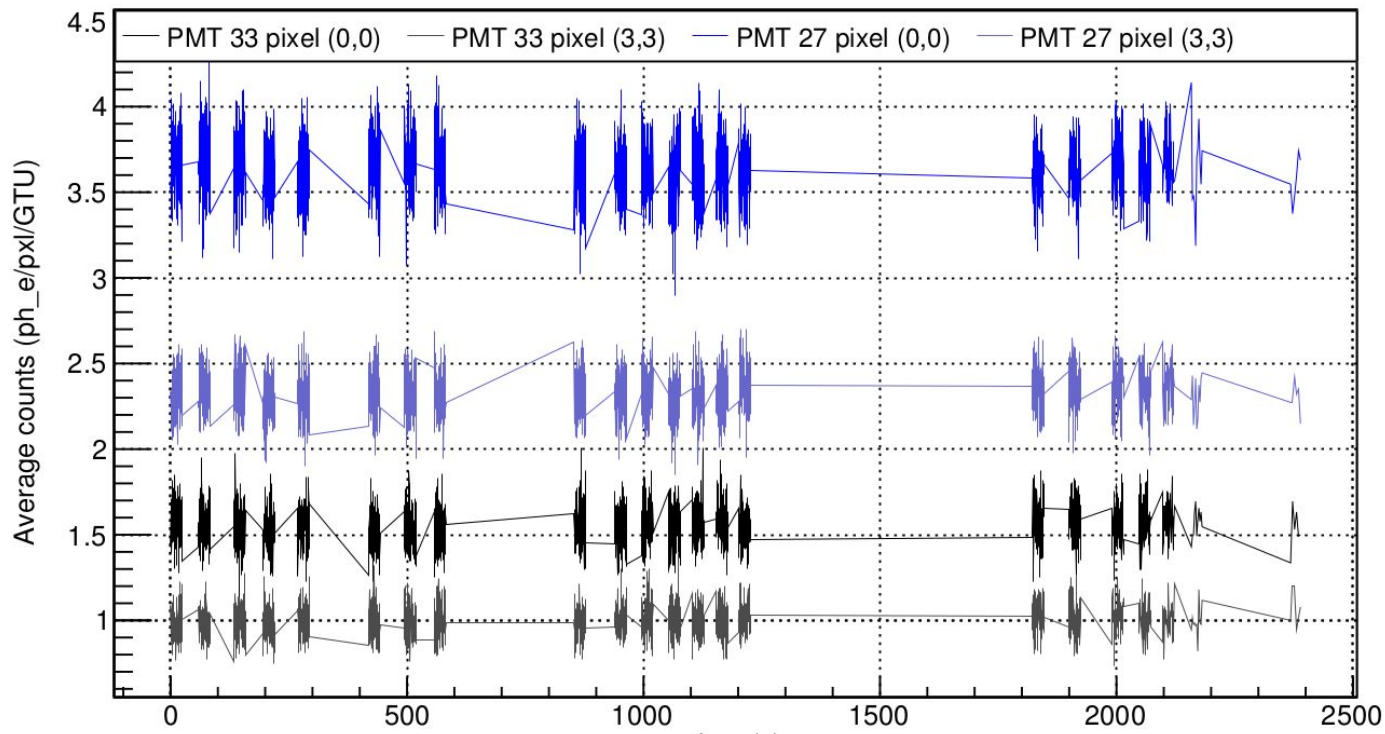
Background's trend over time: SPB@Utah (2016)

Laser shots crossing the field of view vertically.



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

Temporal behaviour



New trigger logics

- Compute the mean value every 128 GTUs (320 μ s) 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

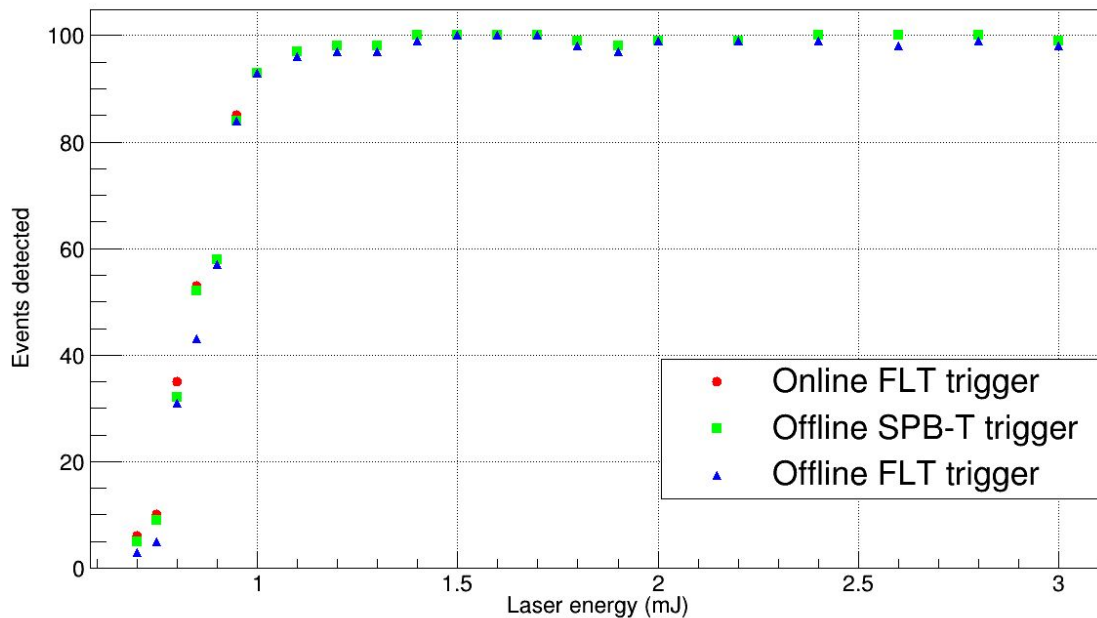
EUSO-SPB-T fake trigger rate estimated on SPB1 flight dataset in two different ways:

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

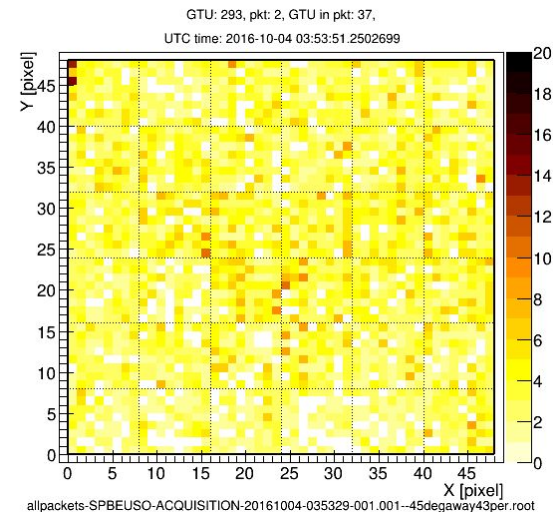
EUSO-TA-T fake trigger rate difficult to estimate (electrical noise, malfunctioning pixels, laser shots...)

- 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

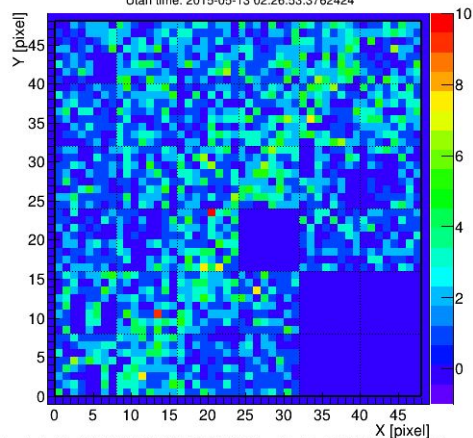


- 100 laser shots at fixed energy
- Only detected events were stored and therefore analysed

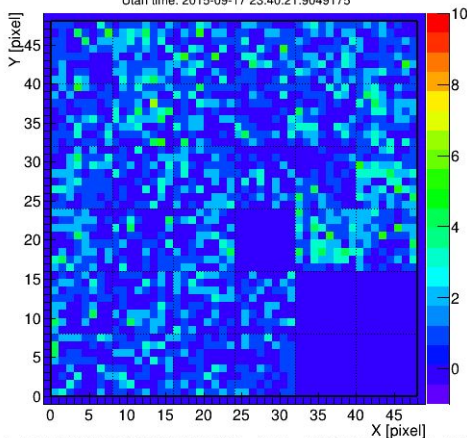


EUSO-TA: TA triggered data - Detected by TA-Trigger

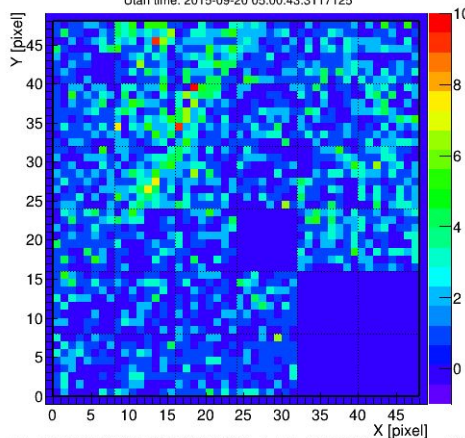
GTU: 284114, pkt: 2219, GTU in pkt: 82, UTC time: 2015-05-13 08:26:53.3762424,
Utah time: 2015-05-13 02:26:53.3762424



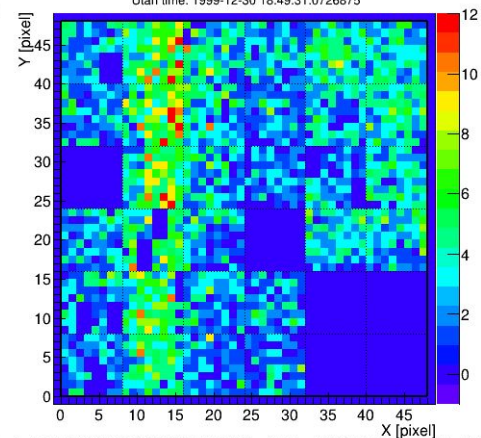
GTU: 22608, pkt: 176, GTU in pkt: 80, UTC time: 2015-09-18 05:40:21.9049175,
Utah time: 2015-09-17 23:40:21.9049175



GTU: 11712, pkt: 91, GTU in pkt: 64, UTC time: 2015-09-20 11:00:43.3117125,
Utah time: 2015-09-20 05:00:43.3117125



GTU: 39873, pkt: 311, GTU in pkt: 65, UTC time: 1999-12-31 01:49:31.0726875,
Utah time: 1999-12-30 18:49:31.0726875



\\packets-TA-ACQUISITION-20150513-080301-gaintable_20150510_1.txt-el15deg.ror ackets-TA-ACQUISITION-20150918-053906-gaintable_20150516.txt-Laser20deg053rackets-TA-ACQUISITION-20150920-105658-gaintable_20150516.txt-CLF10deg1056. ickets-TA-ACQUISITION-20151107-091314-gaintable_20150516.txt-Cosmic15degTA

$\log(E/eV) = 18.06$
 $R_p = 2.5 \text{ km}$

$\log(E/eV) = 18.51$
 $R_p = 9.1 \text{ km}$

$\log(E/eV) = 18.38$
 $R_p = 6.7 \text{ km}$

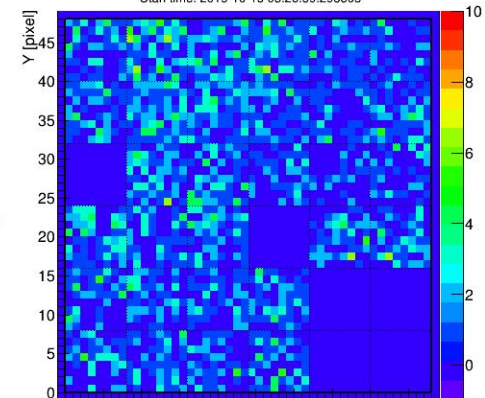
$\log(E/eV) = 18.42$
 $R_p = 2.6 \text{ km}$

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

$\log(E/eV) = 18.52$ $R_p = 9.0$ km

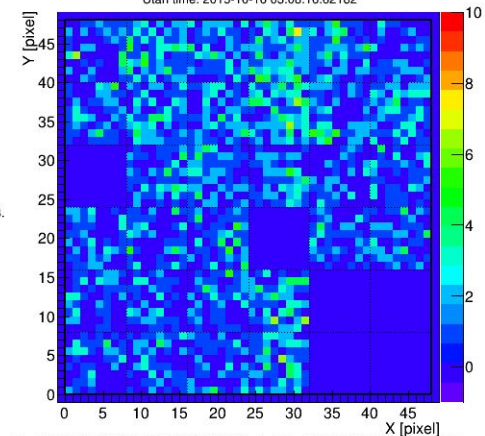
GTU: 83524, pkt: 652, GTU in pkt: 68, UTC time: 2015-10-15 09:26:39.298805,

Utah time: 2015-10-15 03:26:39.298805



GTU: 59331, pkt: 463, GTU in pkt: 67, UTC time: 2015-10-16 09:08:16.62182,

Utah time: 2015-10-16 03:08:16.62182

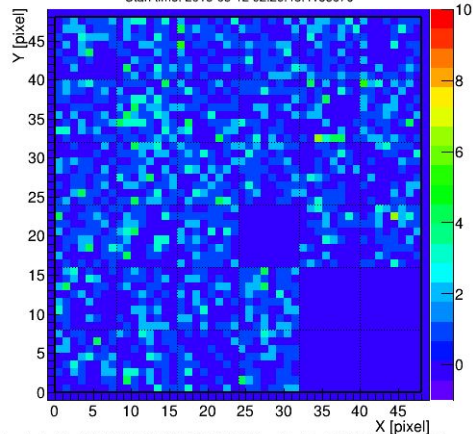


kets-TA-ACQUISITION-20151016-090337-gaintable_20150516.txt-TA_EXT_10Degre

$\log(E/eV) = 17.71$ $R_p = 1.7$ km

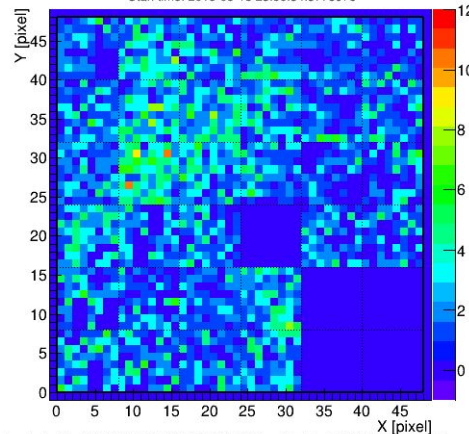
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Utah time: 2015-05-12 02:26:48.4158676



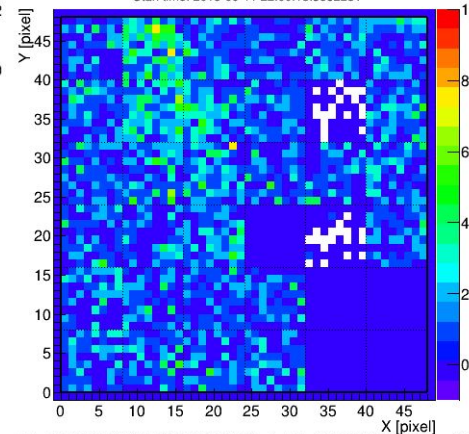
GTU: 203603, pkt: 1590, GTU in pkt: 83, UTC time: 2015-05-16 05:56:34.3773975,

Utah time: 2015-05-15 23:56:34.3773975



GTU: 75475, pkt: 589, GTU in pkt: 83, UTC time: 2015-09-12 04:00:13.3582251,

Utah time: 2015-09-11 22:00:13.3582251



llpackets-TA-ACQUISITION-20150512-081249-gaintable_20150510_1.txt-el25deg.ror llpackets-TA-ACQUISITION-20150516-054449-gaintable_20150510_1.txt-el25deg.rorackets-TA-ACQUISITION-20150912-035814-gaintable_20150516.txt-CLF21deg0358.

$\log(E/eV) = 18.69$

$R_p = 8.3$ km

$\log(E/eV) = 18.20$

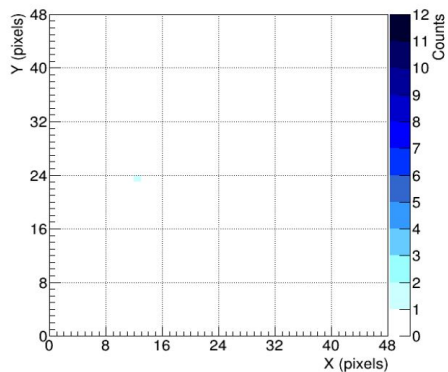
$R_p = 0.8$ km

$\log(E/eV) = 18.05$

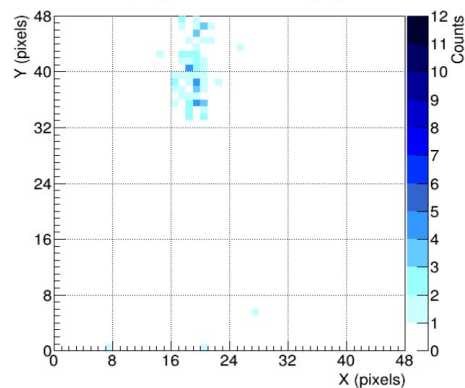
$R_p = 5.0$ km

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

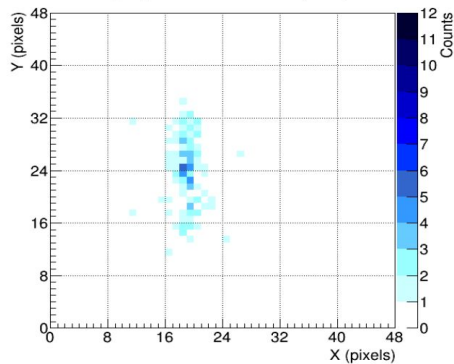
pe per frame = 0 (1)



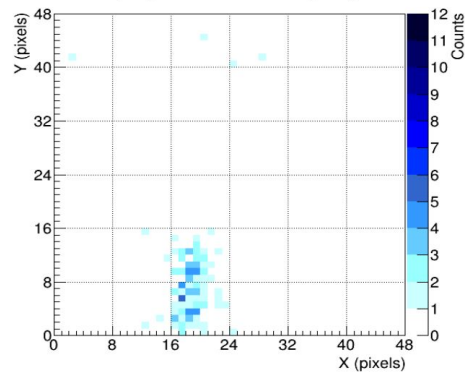
pe per frame = 79 (79)



pe per frame = 117 (118)

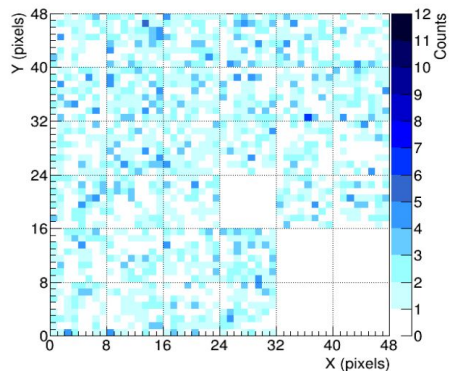


pe per frame = 123 (123)

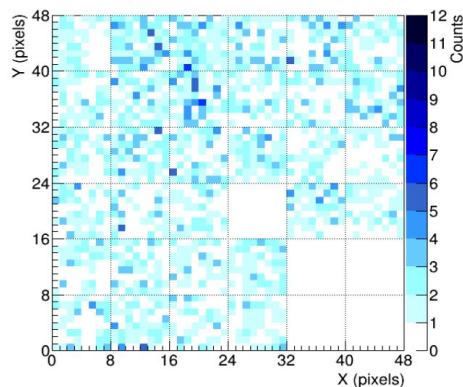


Energy $10^{18.5}$ eV , distance 12 km: partially detected

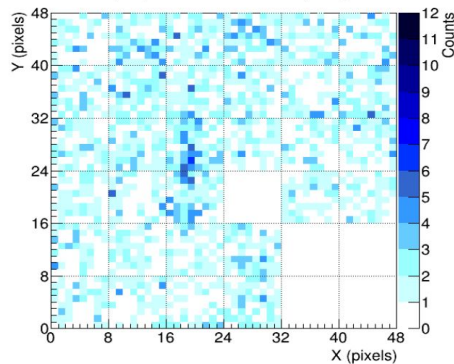
pe per frame = 0 (1)



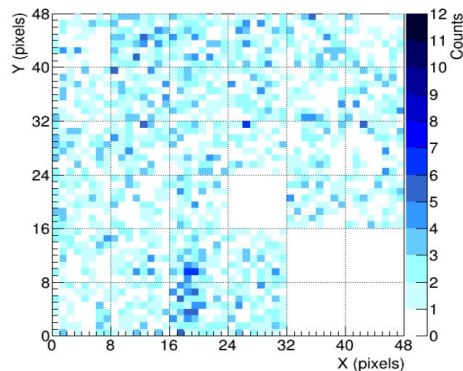
pe per frame = 79 (79)



pe per frame = 117 (118)



pe per frame = 123 (123)



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
