Implementation of the First Level Trigger of JEM-EUSO: Results of the First Tests

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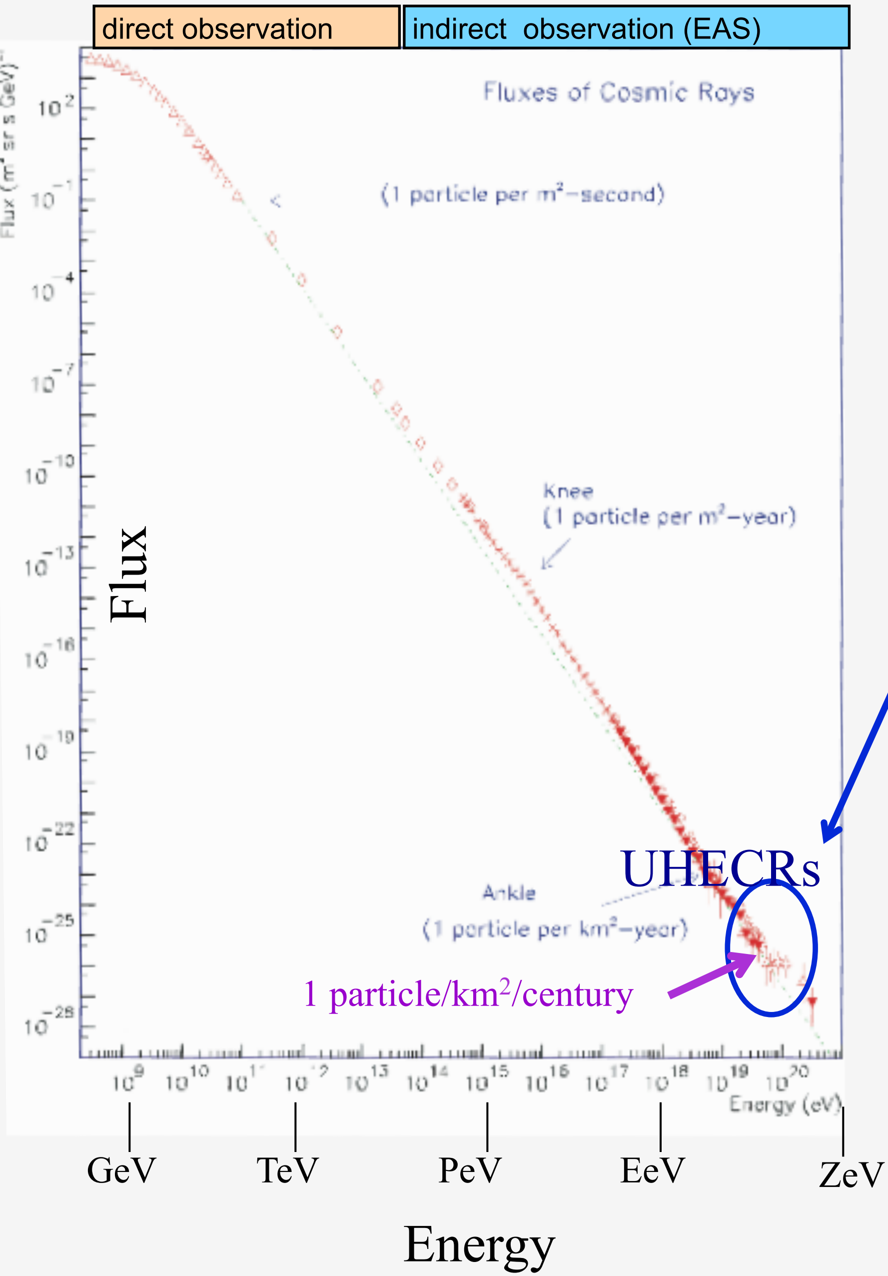
Contents

- The JEM-EUSO program for ultra-high-energy cosmic ray detection from space
- Electronics of the JEM-EUSO pathfinders, definition and implementation of the first level trigger (L1)
- Tests of the L1 Trigger
- Summary

01 What are cosmic rays?

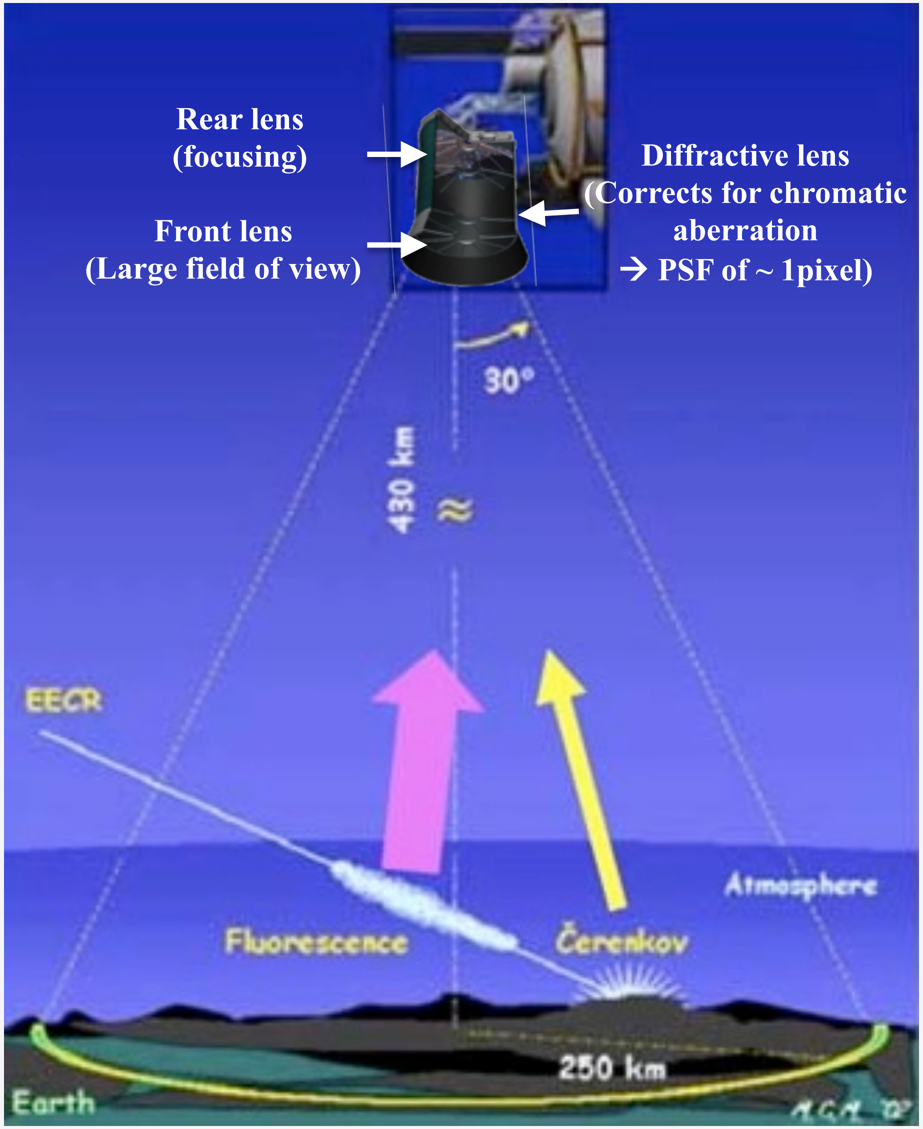


- High-energy particles in the Galaxy (protons and nuclei)
- Wide energy range, up to macroscopic energies (10^{20} eV → several Joules!)
- The flux decreases very rapidly with energy
- Ultra-high-energy cosmic rays (UHECRs) are very interesting
  - Most energetic particles in the universe
  - Challenging for astrophysics
  - Unknown sources
  - Unknown acceleration mechanism
  - Low magnetic rigidity → smaller deflections → point towards sources?
- But very low flux (1 part/km²/century)

  → **Huge detectors needed!**

  → Go to space → JEM-EUSO collaboration

The detection principle



- High energy cosmic rays produce "atmospheric showers": cascades of secondary particles
- Up to hundreds of billions of secondary particles!

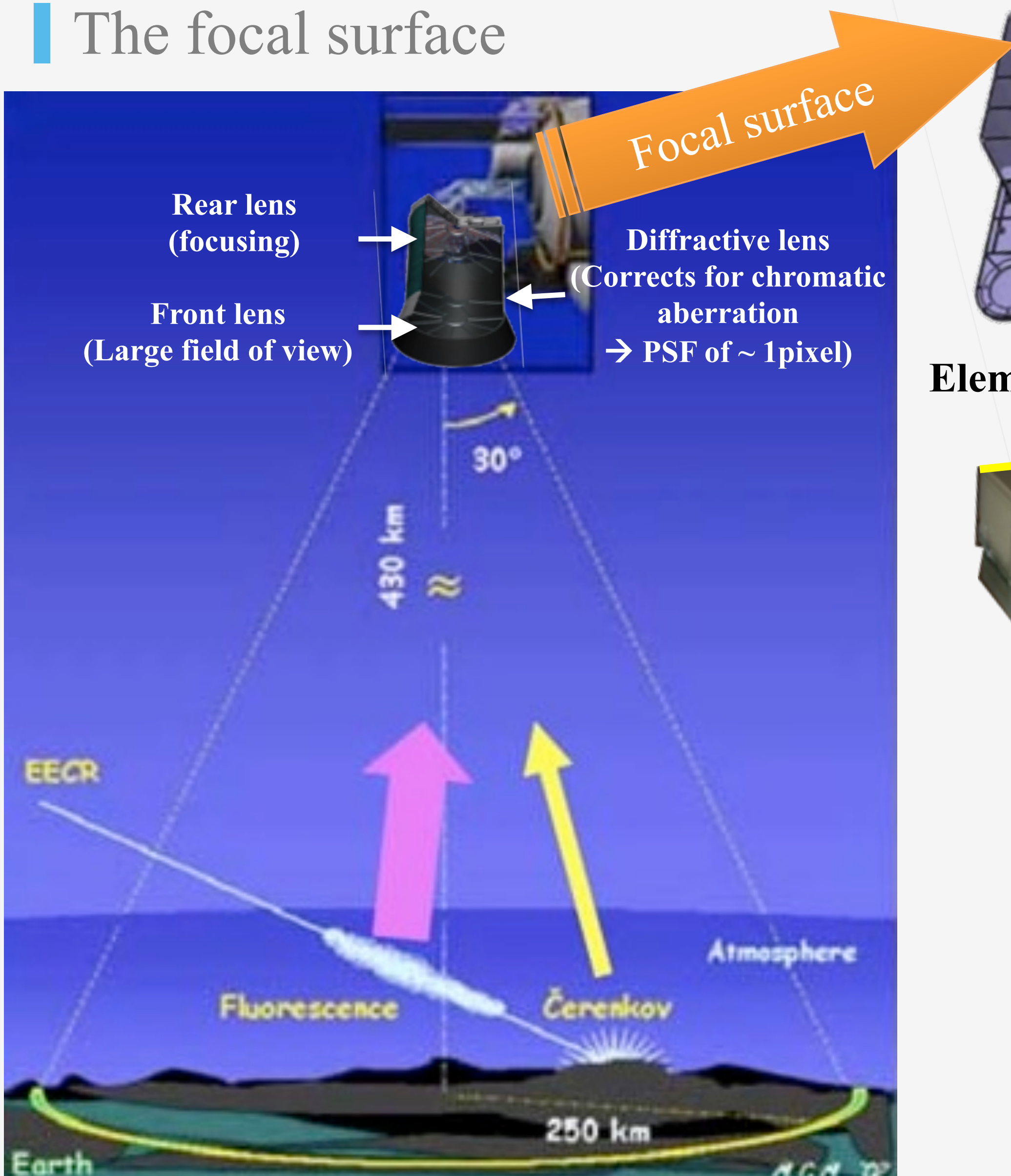
→ excitation of air molecules
→ de-excitation by fluorescence emission (UV light, isotropic)
→ Cherenkov emission (along shower axis)

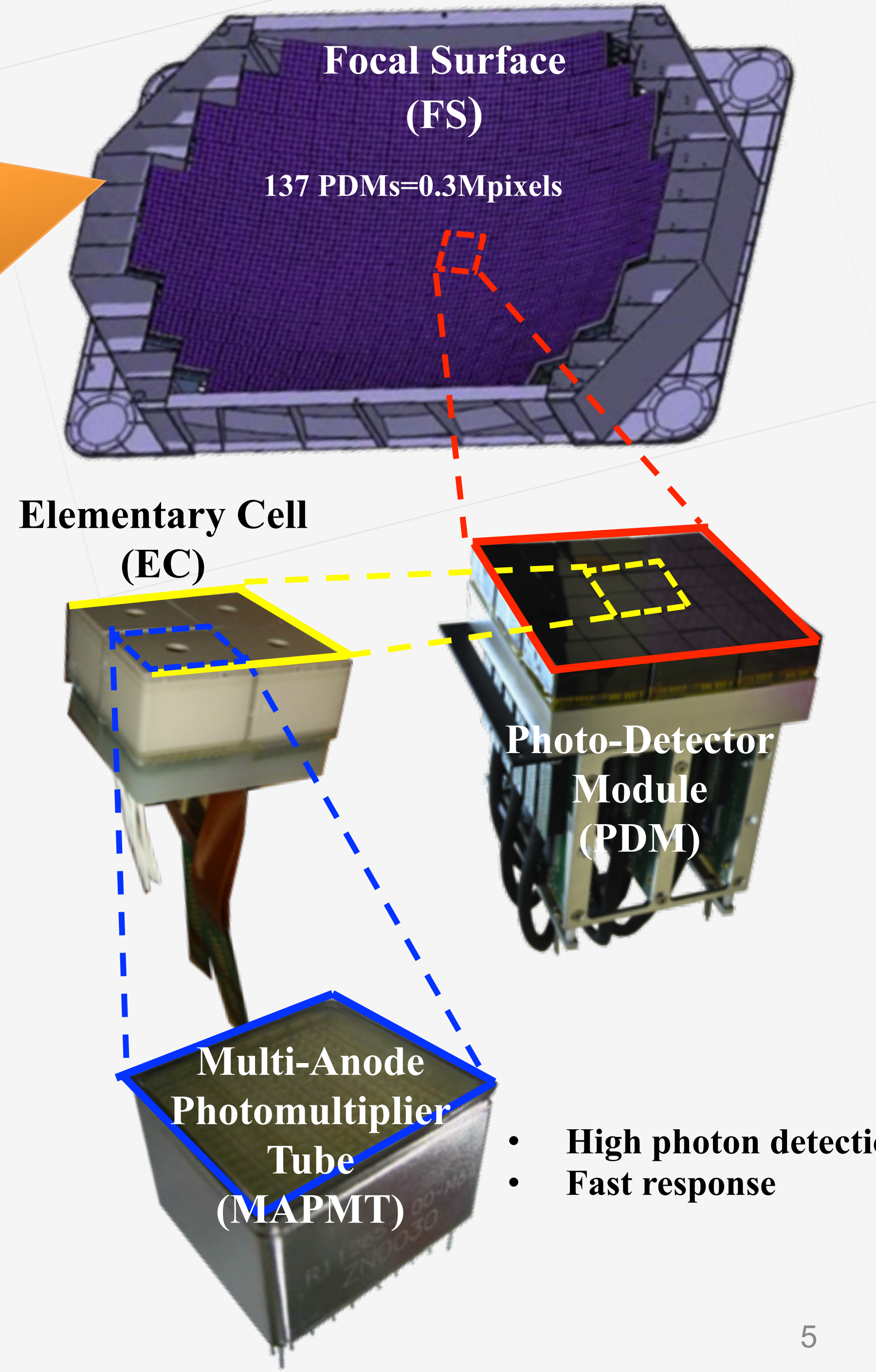
- Detection of UV light from the shower, with large field-of-view telescope (2.5 m ∅ Fresnel lens optics, ±30° FoV)

→ Reconstruction of the energy and arrival direction of the incoming cosmic ray

01 JEM-EUSO

The focal surface





- High photon detection
- Fast response

01 **JEM-EUSO (Japanese Experiment Module – Extreme Universe Space Observatory)**

JEM-EUSO pathfinders

Space

Balloon

Ground (looking up)

02 Data encoding

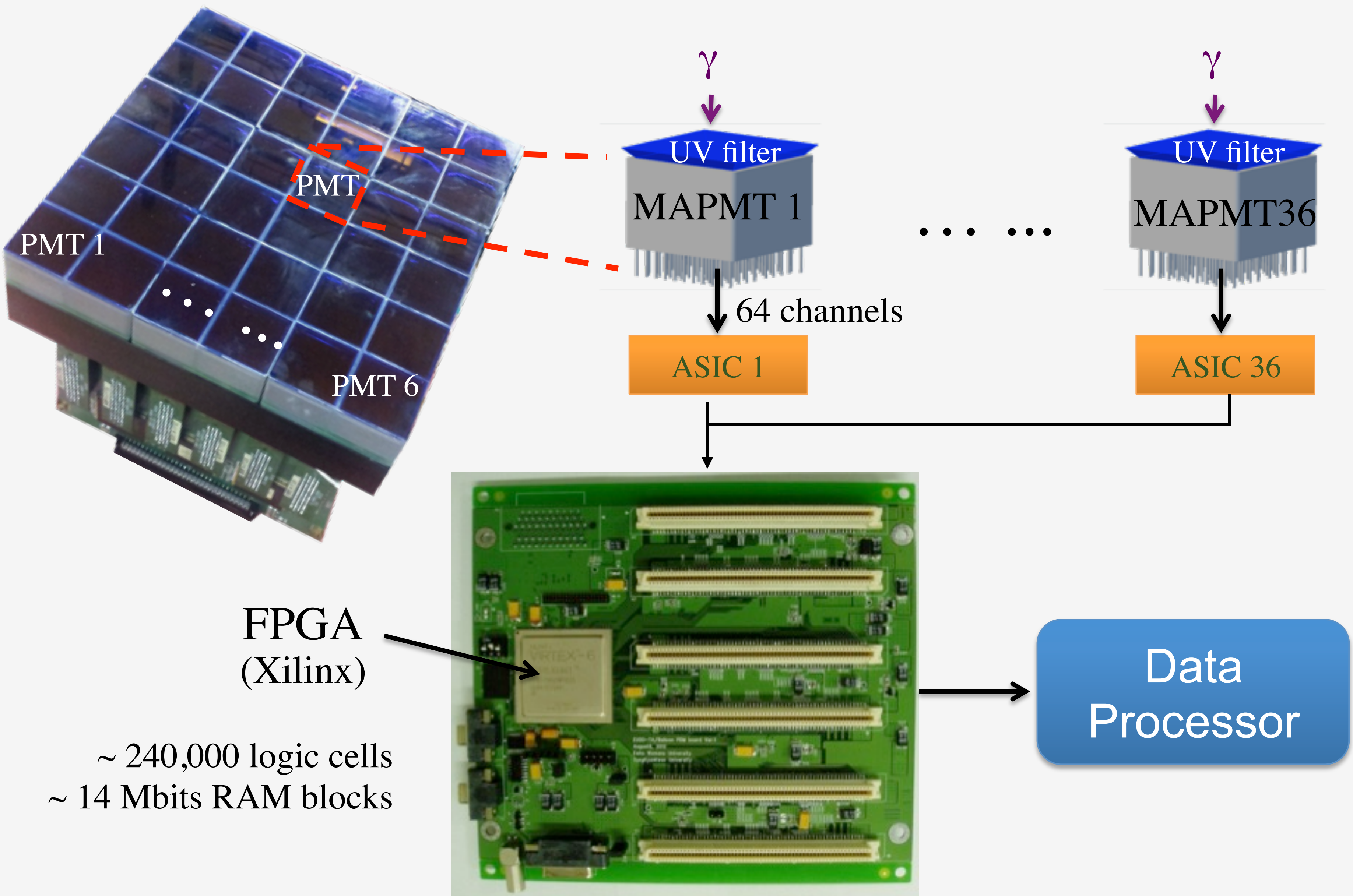
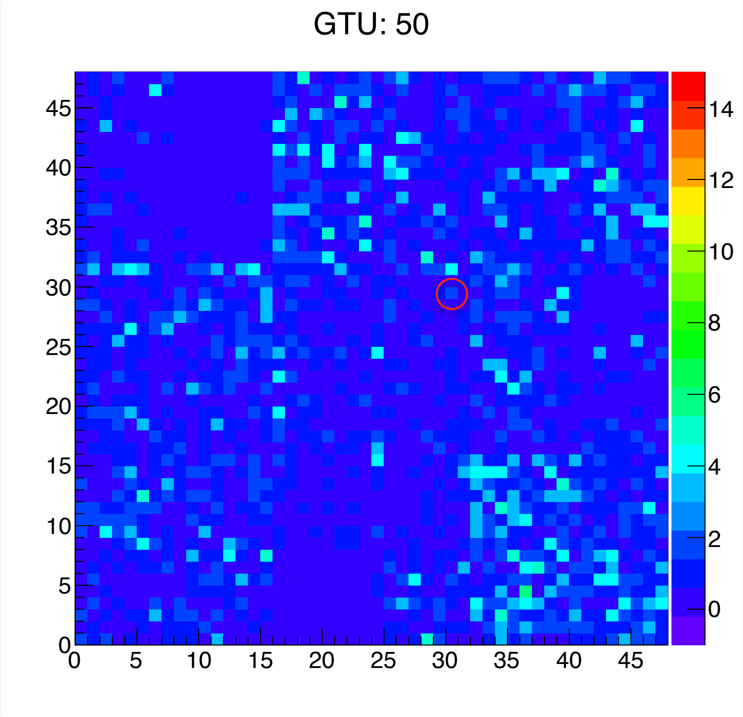


Photo-Detector Module board

Basic information:
Number of photo-electrons recorded in each pixel during a time unit of 2.5 μs

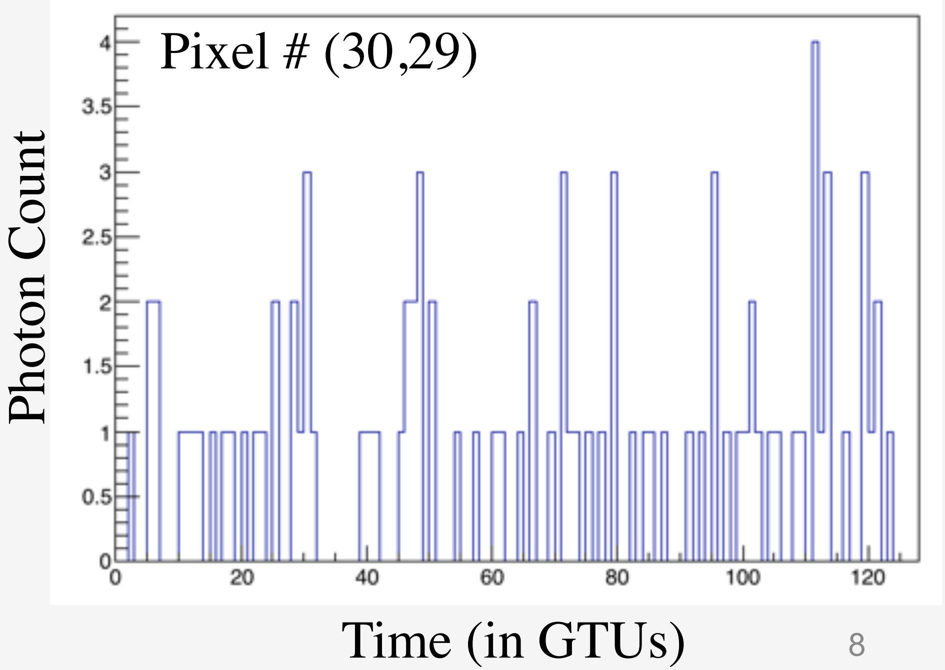
"Gate Time Unit": 1 GTU = 2.5 μs

Photon count over the entire PDM (2304 pixels) during 1 GTU



- Data organized by "packets" of 128 GTUs

Photon count for 1 pixel
as a function of time (discrete values)



02 **Trigger algorithm**

Goal: 1) trigger on cosmic-ray showers, but not on other atmospheric phenomena

→ Discrimination based on the timescale and structure of the signal

2) The L1 trigger parameters will adjust themselves such that the false trigger rate is lower than 1 per second.

	Event region	Event frequency	Event size	Event duration	Light spectrum	Event energy
Meteors	Atmosphere	5~100 or more /hour	0.5~2 m	0.5 ~ 3 s	Violet to red	variable
Lightning	Troposphere	3/min	Some km	0.1 s	Violet to red	10^{12} W
Sprites	Mesosphere	unknown	Some km	Some ms	red	10^{7} W
Jets	Stratosphere Troposphere	unknown	Tens of km	0.4 s	blue	10^{4} W
Elves	Mesosphere	unknown	200 km	< 1ms	red	
Noctilucent clouds	Mesosphere	variable	Some tens of km	hours	solar	
Aurorae	Mesosphere to atmosphere limit	variable	Some hundreds of km	From minutes to hours	Violet to red	10^{10} W
Space debris	Atmosphere	5/day	0.5 ~ 2 m	0.5 ~ 3 s	Violet to red	variable
Cosmic ray		variable		50 ~ 150 us	UV	variable

→ Level 1 trigger (L1): select events with fast signal variations

→ Level 2 trigger (L2): select events with space-time structure compatible with a cosmic-ray shower ("tracks" developing at the speed of light)

L1 Trigger conditions

"Gate Time Unit": 1 GTU = 2.5 μs

CONDITION 1: "Local signal"

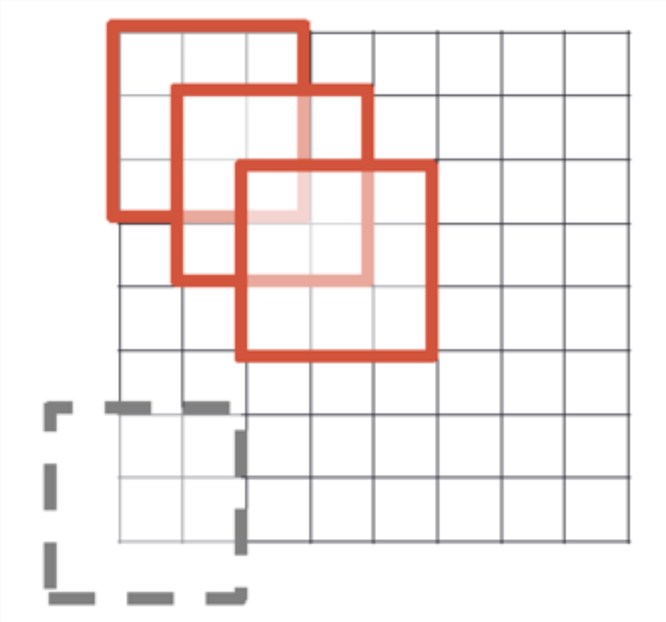
At least 1 pixel in a **3x3 pixels cell** with photon count ≥ N (in 1 GTU)

CONDITION 2: "Persistency"

CONDITION 1 must be met by the same cell during P consecutive GTUs

CONDITION 3: "Global signal"

The total number of p.e. in the cell during P consecutive GTUs must be ≥ S

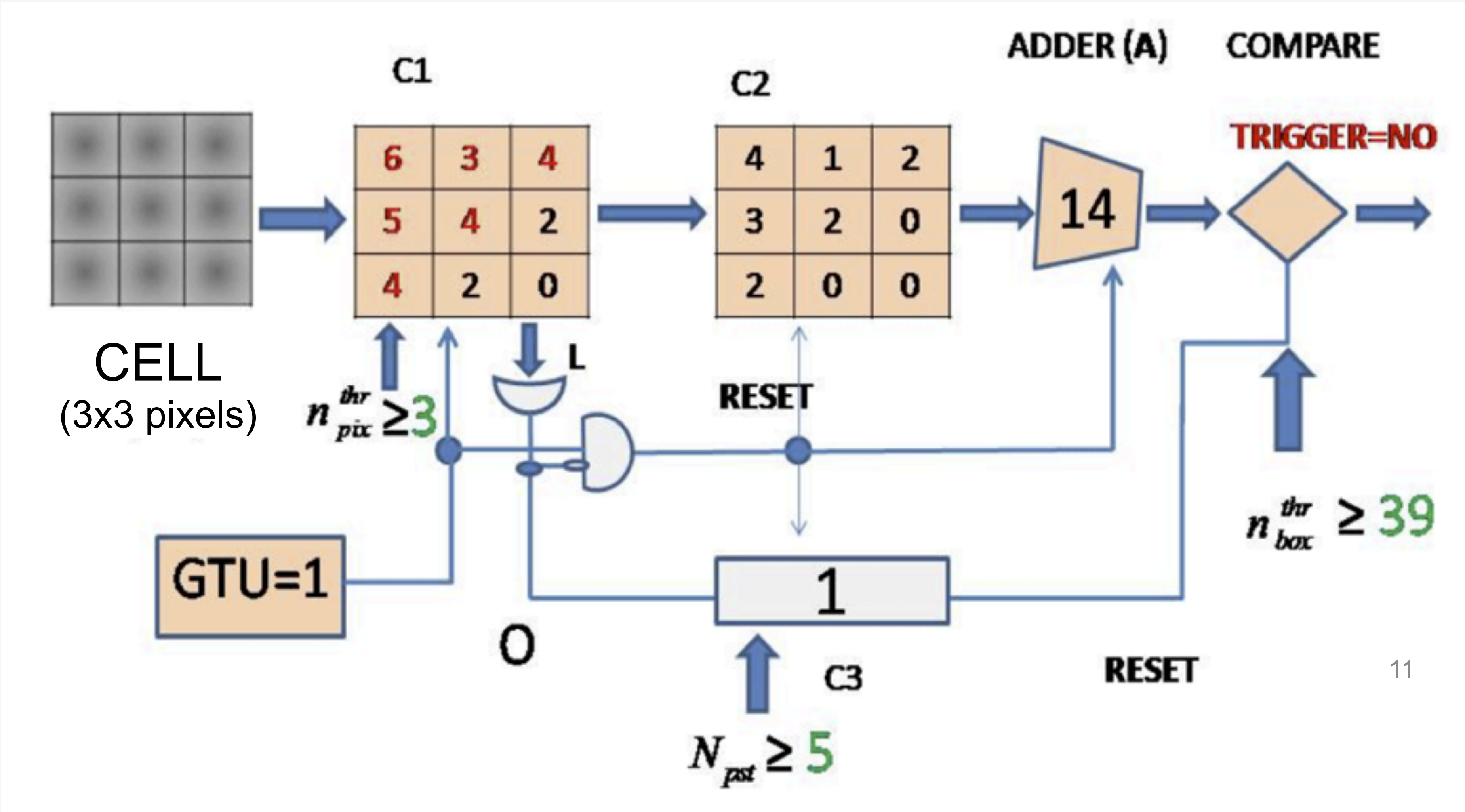


Essentially the signal has to be stronger than N for longer than P GTUs and sum to more than S.

02 **Example of a trigger sequence**

“Gate Time Unit”: 1 GTU = 2.5 μs

Local threshold: N = 3 photoelectrons (in 1 pixel)
Minimum persistency: P = 5 GTUs
Total global signal threshold: S = 39



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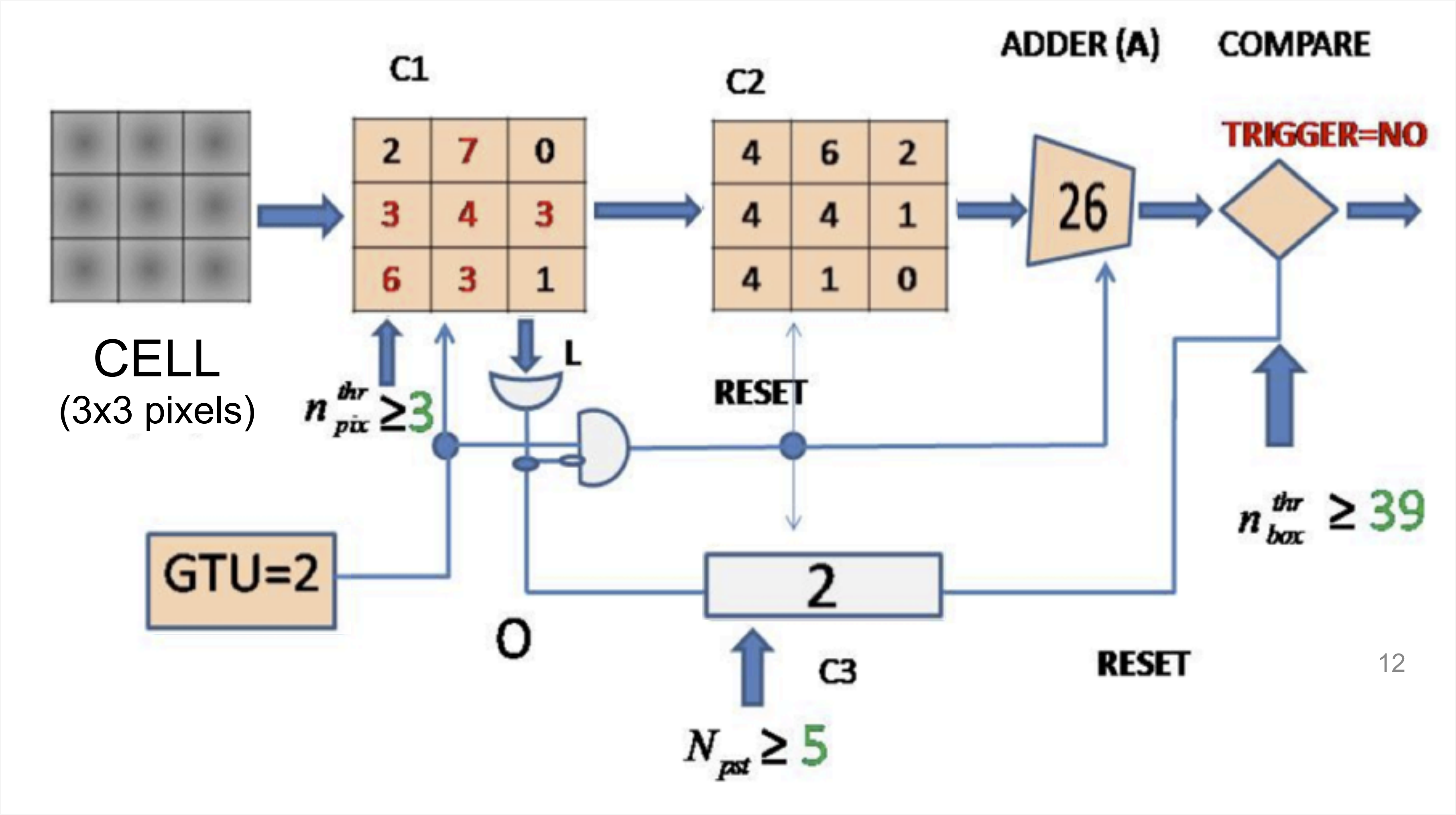

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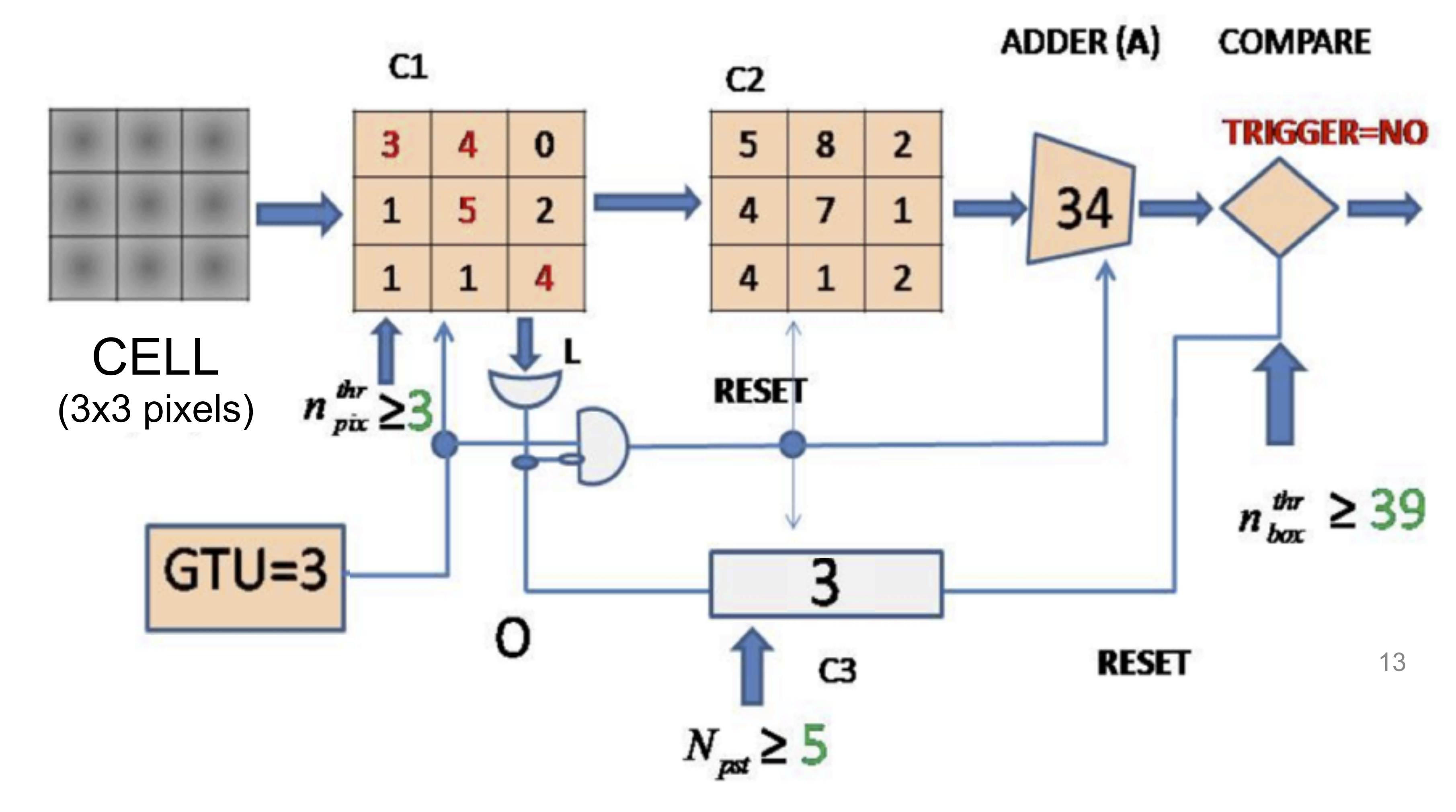

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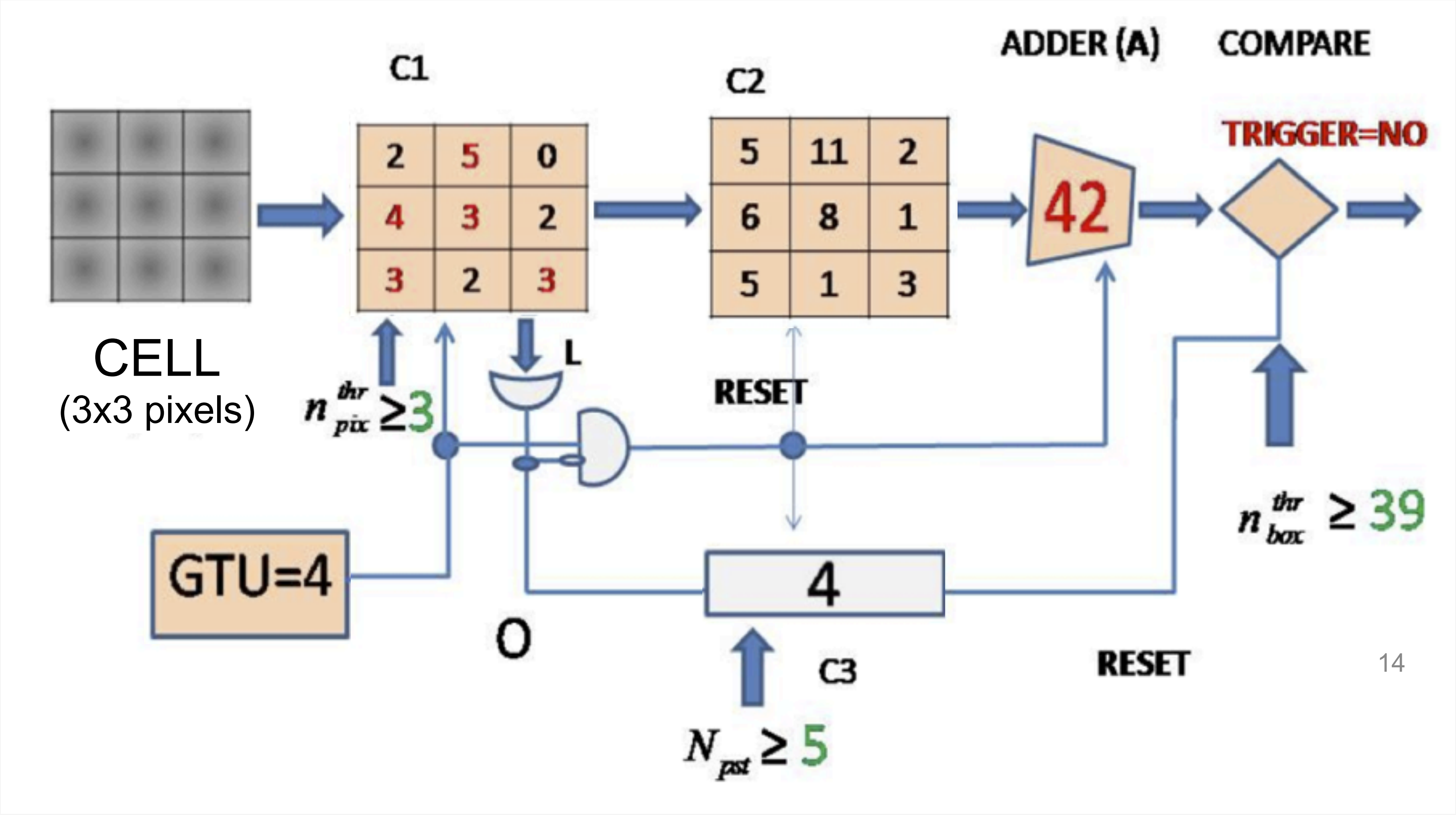

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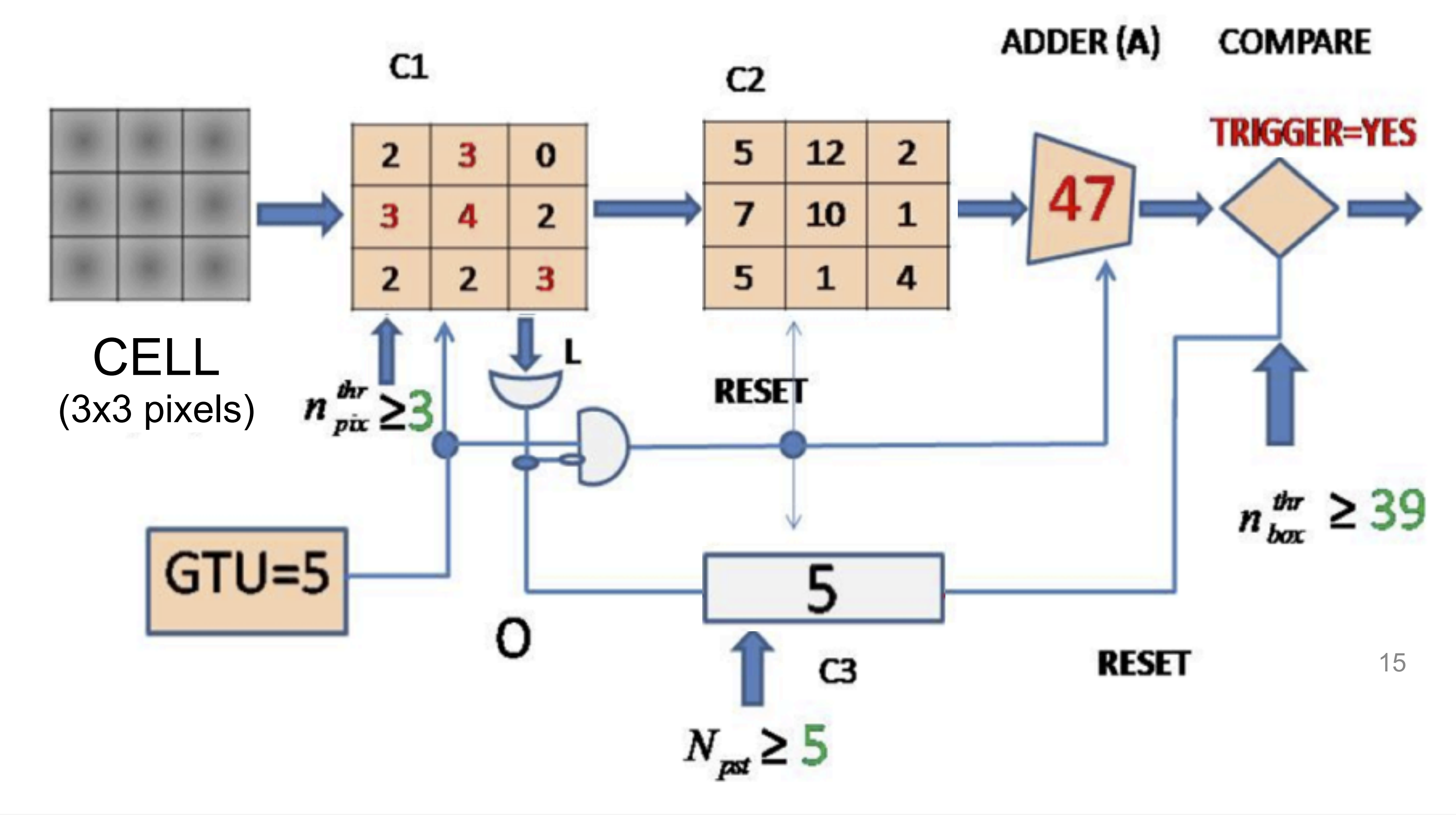

03 Tests of the trigger algorithm

Series of tests of the internal Level1 trigger at the level of 1 elementary cell (EC)

1st test: at Laboratoire Astroparticule & Cosmologie (APC) in Paris, France

- Internal Level 1 (L1) trigger functionality using dark box, with LED light

2nd test: at TurLab in Torino, Italy

- July 19th~28th, 2015 and August 23rd ~ 29th, 2015
- Internal Level 1 (L1) trigger with different kinds of emulated light sources

3rd test: EUSO-TA site in Delta, Utah, USA

- October 6th ~ 19th, 2015
- First field test for internal Level 1 (L1) trigger

The L1 tests were successful

=> The L1 trigger is now implemented in the EUSO-SPB instrument

(Long-duration flight operated by NASA, scheduled on April 2017)

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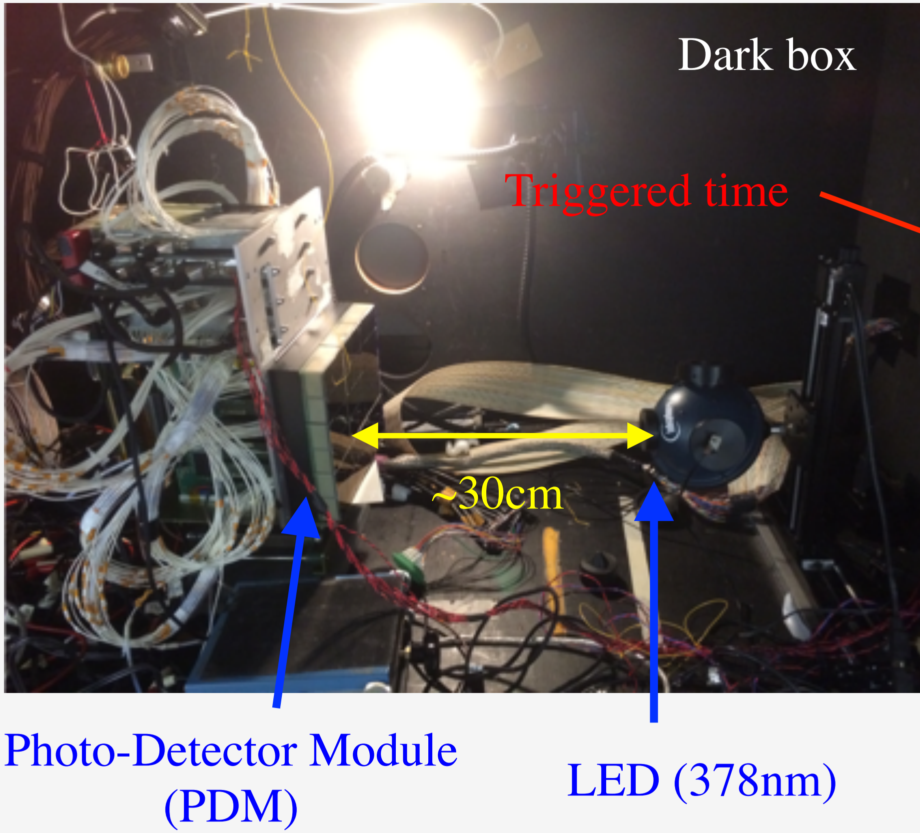
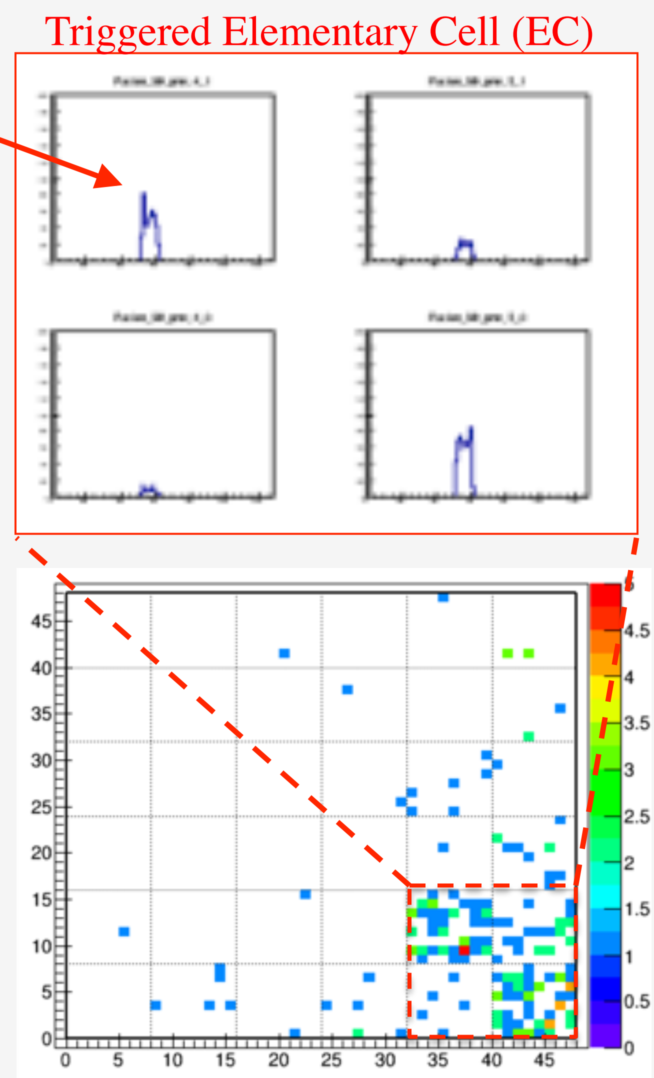
03 Results of L1 trigger test | At APC (Paris, France)

- Test Internal L1 trigger functionality using a dark box and a pulse signal using LED





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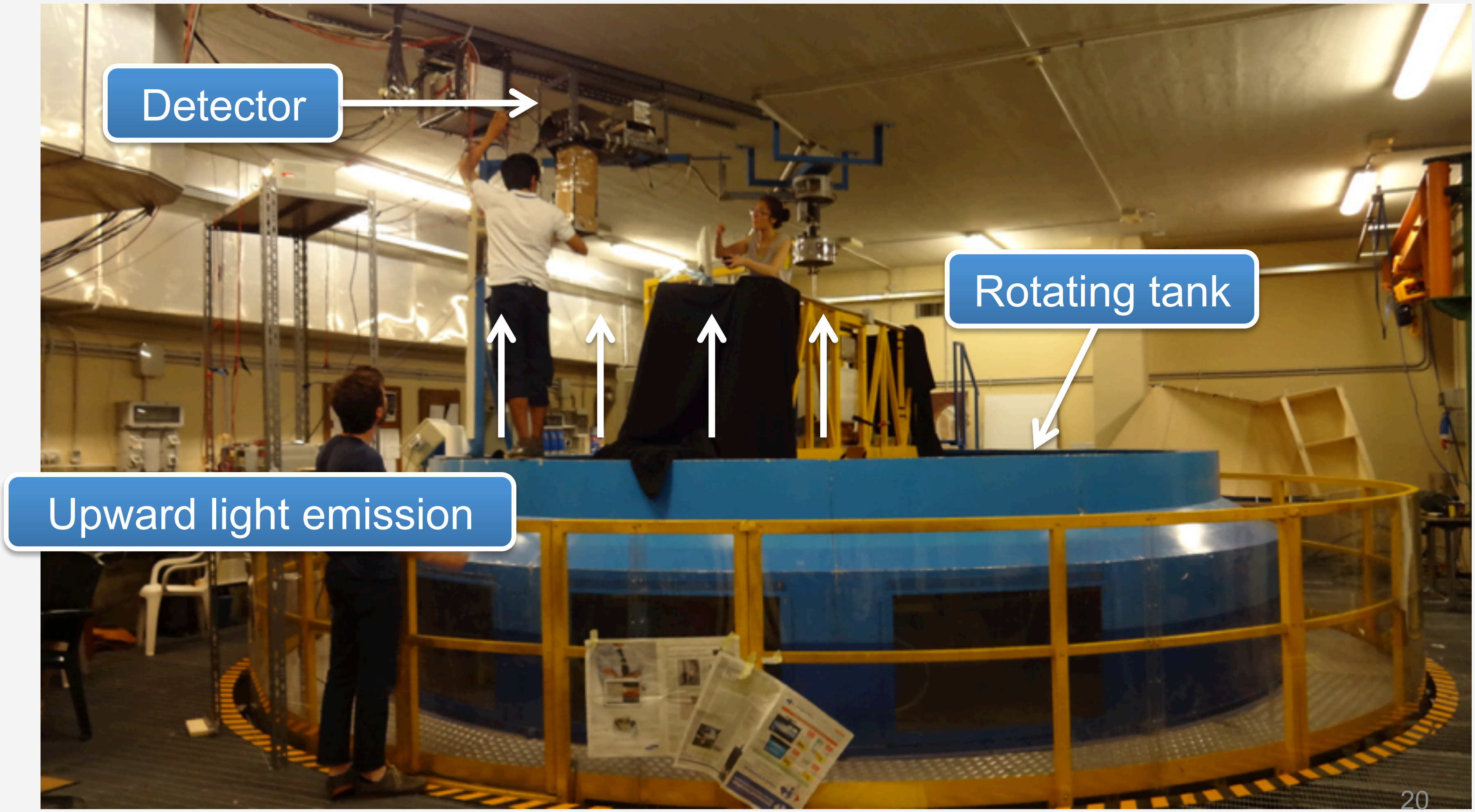
Results of L1 trigger test | At the Turlab facility (Torino, Italy)

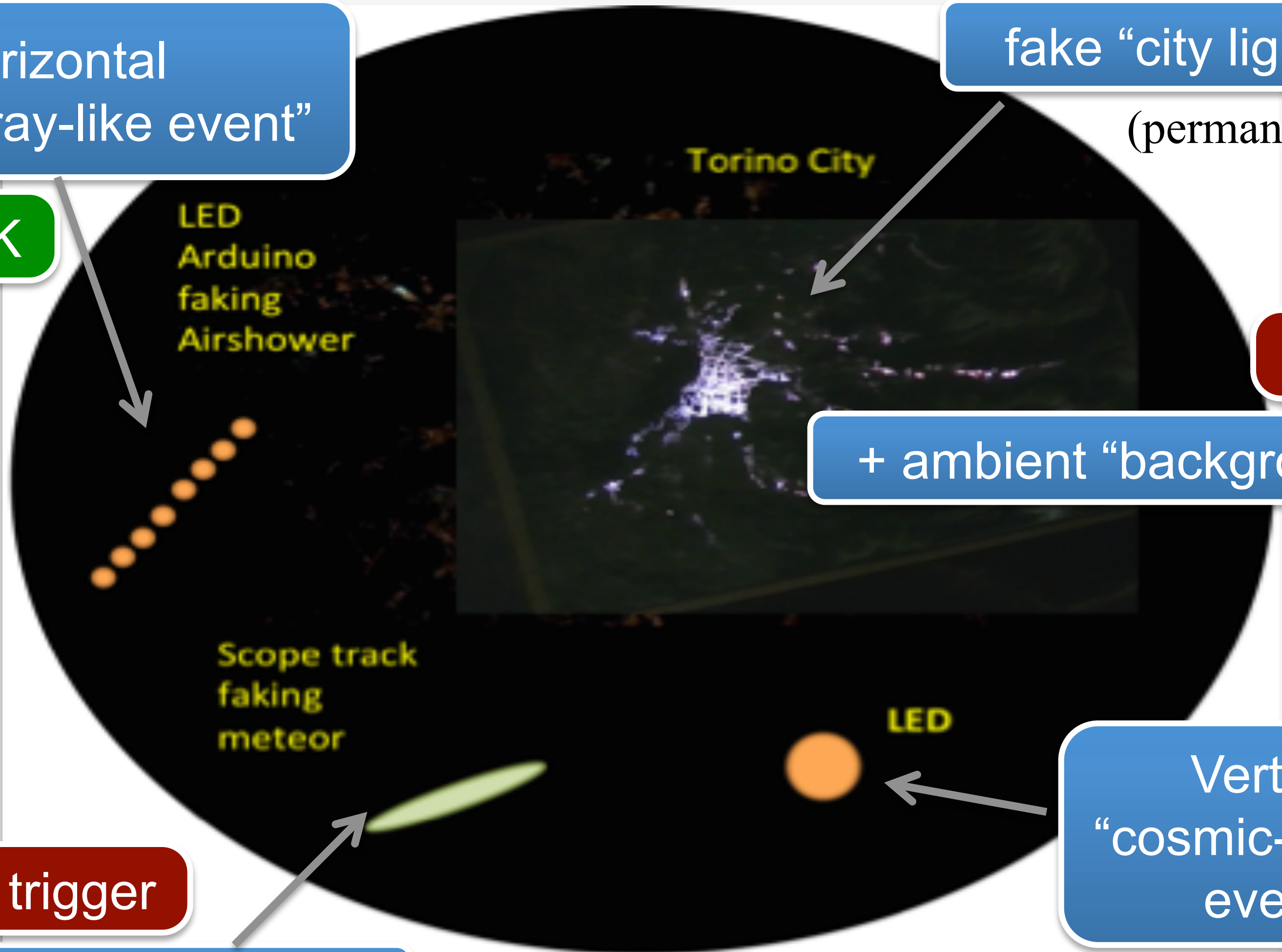
• The TurLab facility is used for oceanic and atmospheric physics experiments (in the Physics department of the University of Torino). It is equipped with a 5 m diameter rotating tank.

• Tank rotation → light sources pass in the field of view of the detector (1 EC + lens)



03 Results of L1 trigger test | At the Turlab facility (Torino, Italy)

- Light sources inside the tank, to mimic various physical phenomena



Horizontal "cosmic-ray-like event"

trigger OK

fake "city light"

(permanent emission)

NO trigger

+ ambient "background light"

NO trigger

"meteor-like event"

(longer timescale)

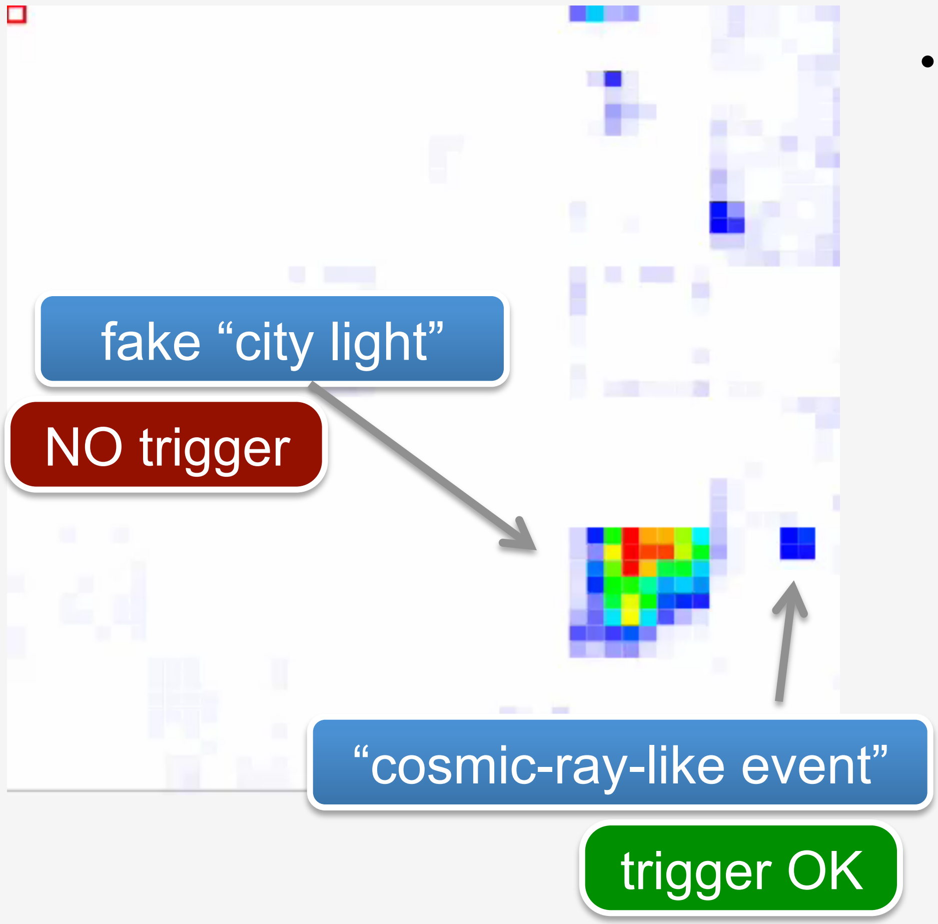
NO trigger

Vertical "cosmic-ray-like event"

trigger OK

Results of L1 trigger test | At the Turlab facility (Torino, Italy)

- Successful test: trigger on the cosmic-ray like events only
- Additional test: trigger on cosmic-ray-like event near to a city-like background



- Level 1 trigger on the cosmic ray track, even though the MAPMT next to it is contaminated by intense city-lights

➔ PMTs can work independently, even within the same elementary cell (EC)

NB: This is crucial to maximize the duty cycle and acceptance of the instrument: in the presence of a city, the rest of the field of view can still be used to detect cosmic rays!

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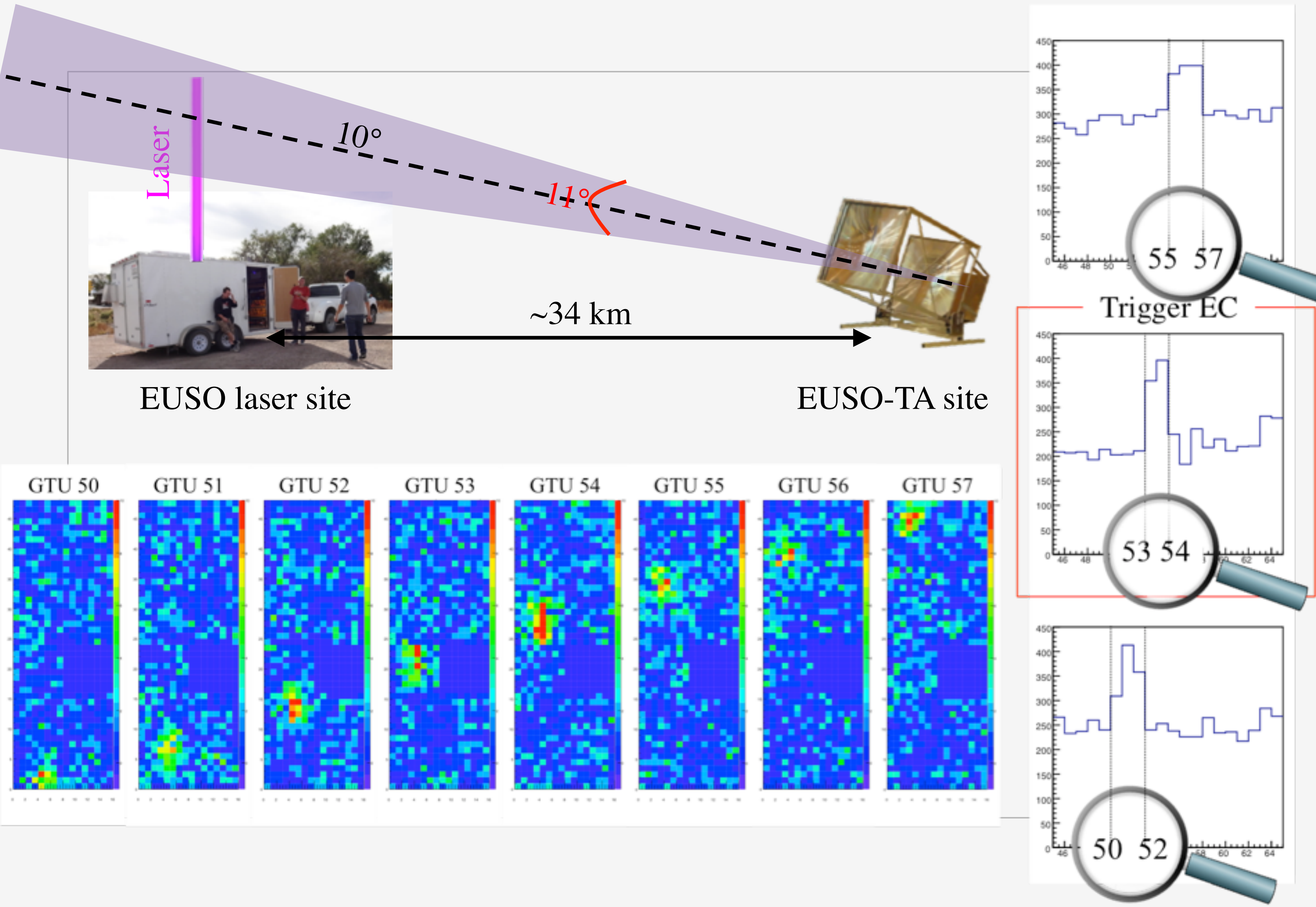
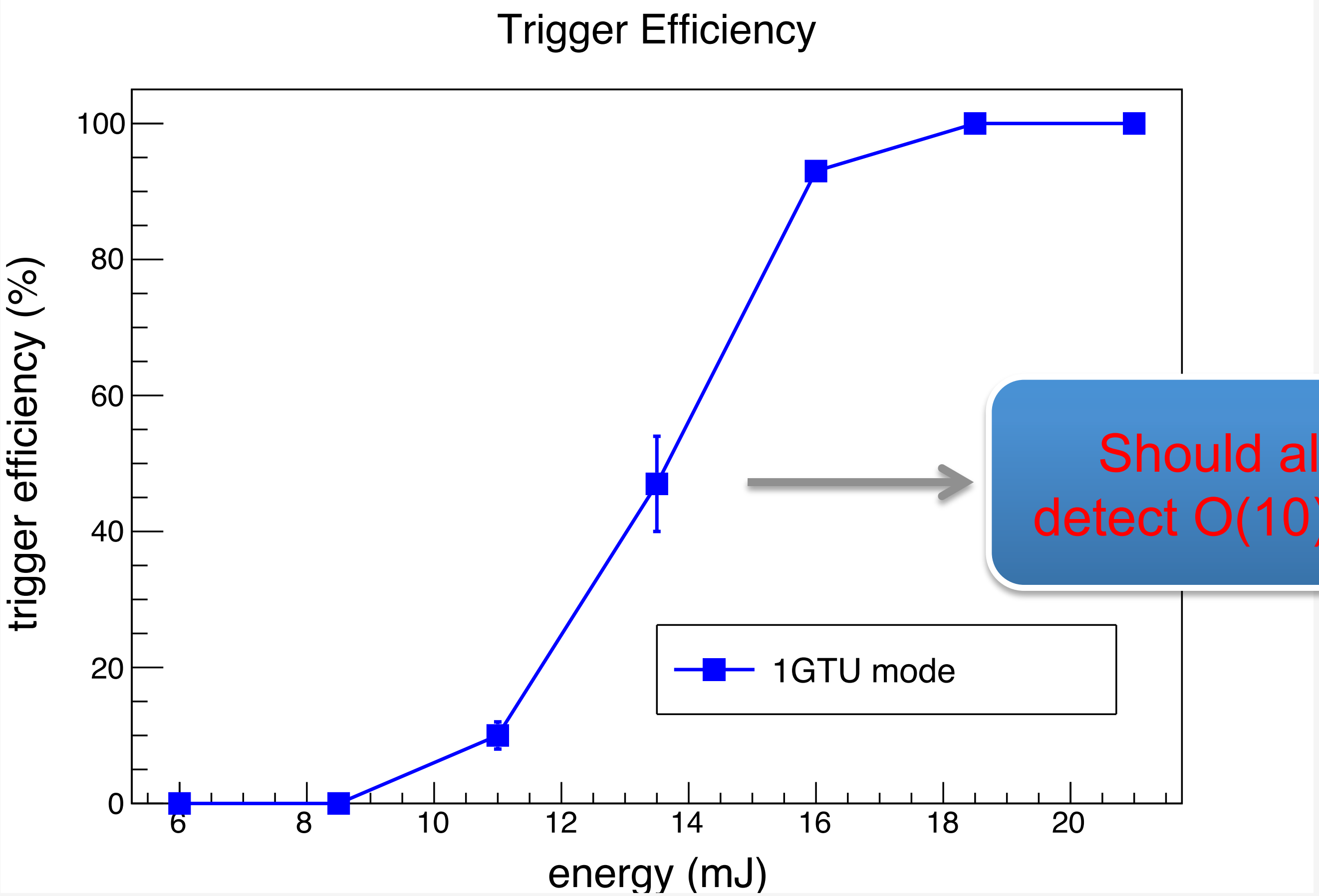
03 **Results of L1 trigger test | At TA-EUSO site (Utah, USA)**



03 Results of L1 trigger test | At TA-EUSO site (Utah, USA)

Trigger efficiency as a function of laser intensity (mimicking a cosmic-ray shower)



Should allow EUSO-SPB to detect O(10) cosmic-ray showers

The trigger efficiency decreases as the laser energy is lowered.

04 **Summary**

→ I was in charge of L1 level trigger and PDM board.

→ We have implemented the L1 trigger algorithm in the PDM board of the JEM-EUSO pathfinders for cosmic ray detection from space.

→ We successfully tested the L1 trigger functionality in Turlab Torino (triggering on air showers and not on other lights)

→ We are studying the behavior as a function of light intensity on EUSO-TA (in Utah, USA)

→ We have implemented the L1 trigger in the EUSO-SPB balloon instrument to be flown on an ultra long duration balloon flight in 2017 (NASA)

→ The SPB balloon should be able to detect, for the 1st time, a cosmic ray shower from above by UV light

→ Longer term: full JEM-EUSO mission for UHECR study from space, with an unprecedented effective acceptance (much larger than on the ground)