Università degli studi di Torino
Scuola di scienze della natura
Facoltà di Fisica

A simulation study of the EUSO-SPB trigger and reconstruction performance

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JEM-EUSO
- Scientific objectives
- Observational principle
- The JEM-EUSO Program

EUSO Super Pressure Balloon (SPB)
- Objectives
- Detector

Study of the EUSO-SPB trigger performance
- ESAF: the EUSO simulation and analysis framework
- Trigger logics for EUSO-SPB
- Trigger response varying simulation parameters (detector efficiency, background, cloudy coverage)

Study of the EUSO-SPB reconstruction performance
- The reconstruction algorithm
- Estimation of the fractions of reconstructed events and energy resolution
- Reconstruction algorithm optimization

Estimation of the number of events detected by EUSO-SPB
- Number of expected events according to a minimal amount of detector operating time and a study of the cloudy coverage that will occur on the EUSO-SPB trajectory

Integration and calibration of the EUSO-SPB detector (Erasmus Traineeship at APC, Universitè Paris Diderot)(backup slide)
- PMT sorting
- Non uniform detector simulation

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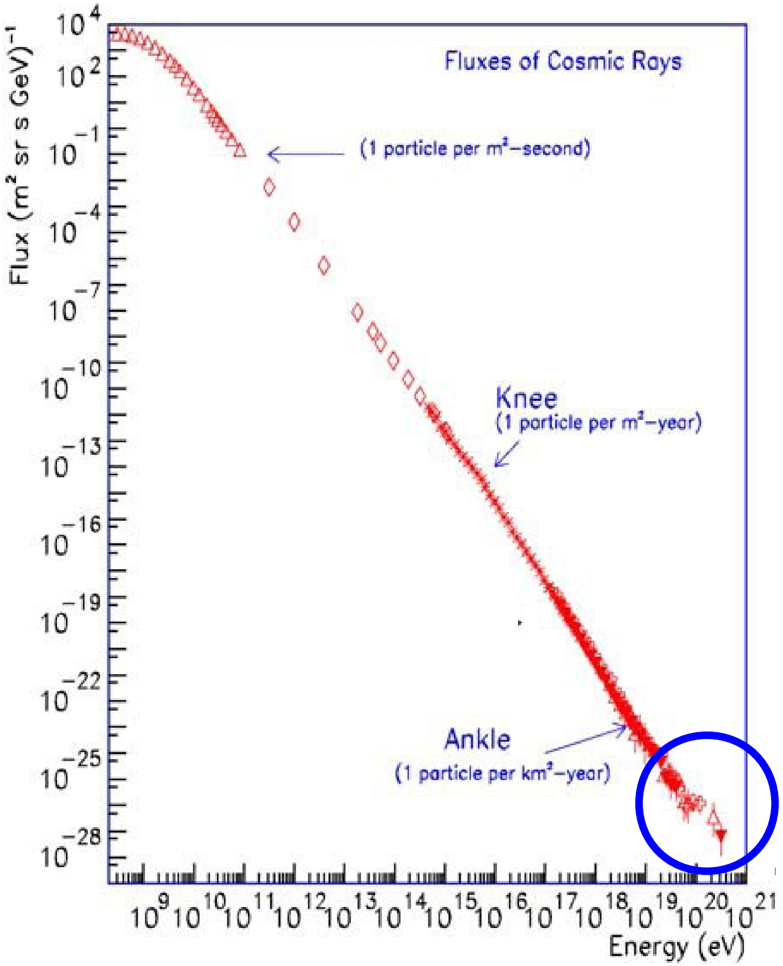
The JEM-EUSO experiment : investigation of the nature and origin of extreme energy cosmic rays at E ≳ $5 \cdot 10^{19}$ eV



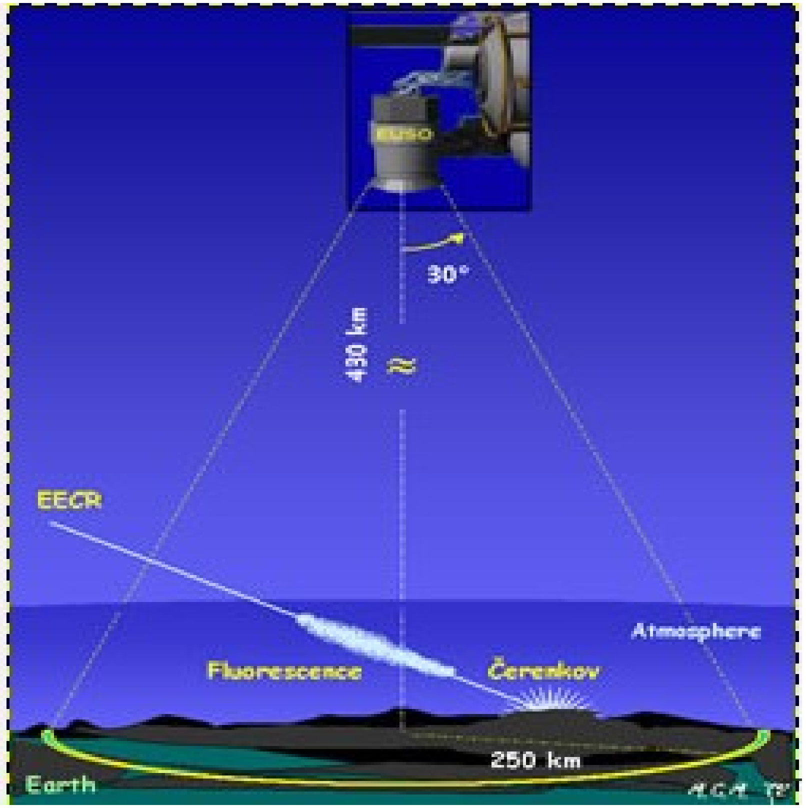
Scientific objectives

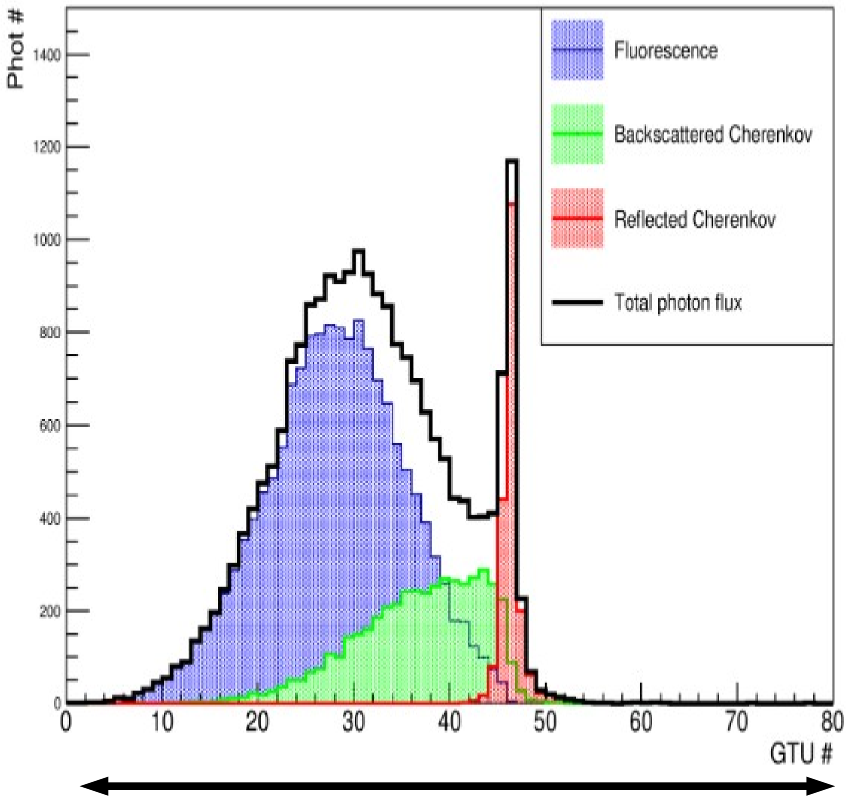
- high statistics measurement of the spectral shape above the GZK cut-off (flux ~ 1 particle/km^2/cen)
- identification of CR sources
- measurement of the energy spectra in a few sources
- Study of extragalactic magnetic field

Explorative objectives

- study of the UHE neutrino component
- discovery of UHE Gamma-rays

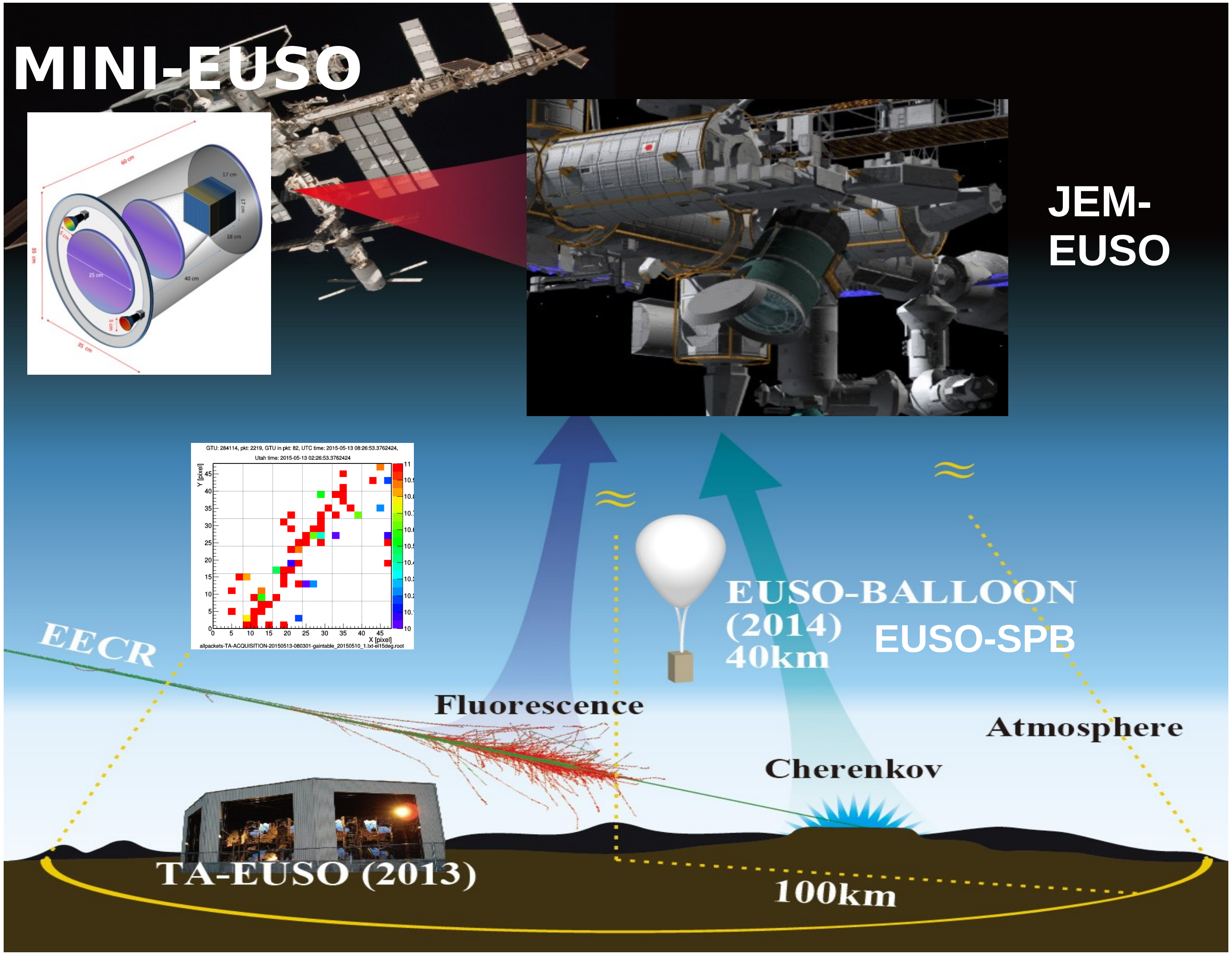
The JEM-EUSO observational principle



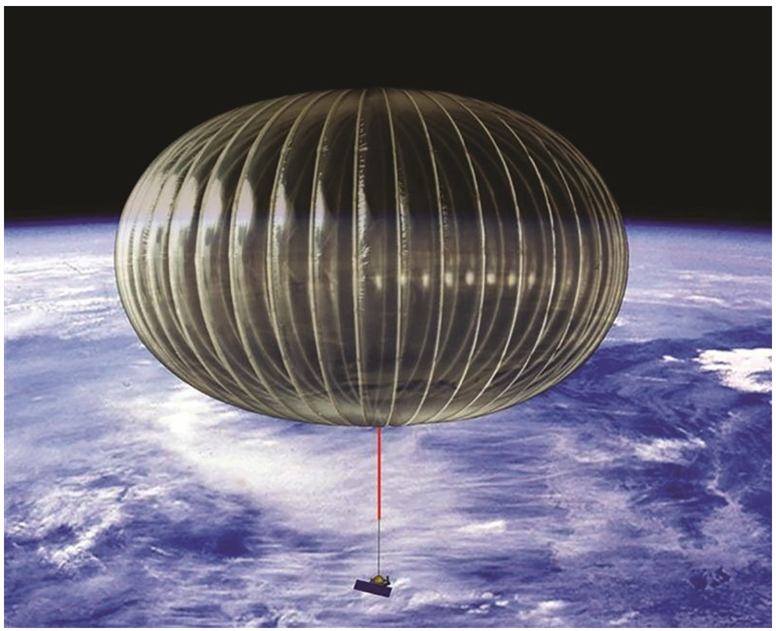


200 μs
(1GTU=2.5 μs)

The JEM-EUSO program



EUSO SUPER PRESSURE BALLOON (EUSO-SPB)



Objectives

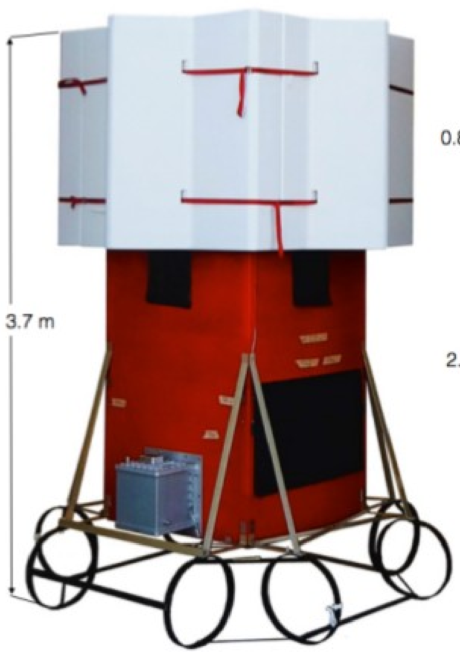
- **Detection of cosmic ray events for the first time from the top of the atmosphere using the fluorescence tecnique**
- **full end-to-end test of the entire technological system for temporal scale ≈ 1 month**
- **Measures of the diffused UV emission in several observative conditions**

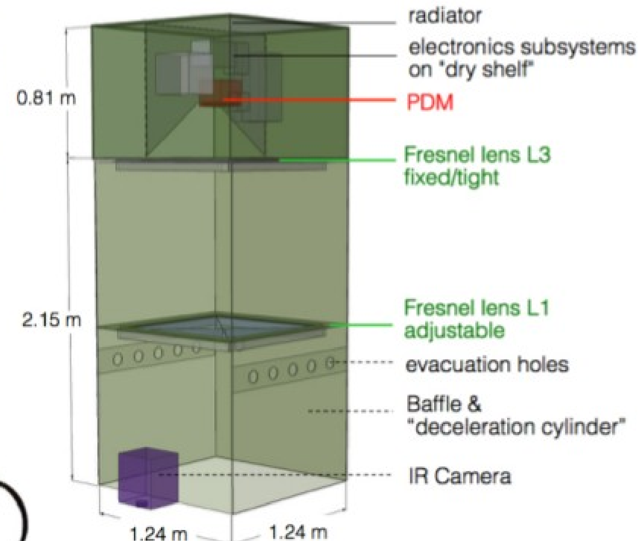
Main flight parameters

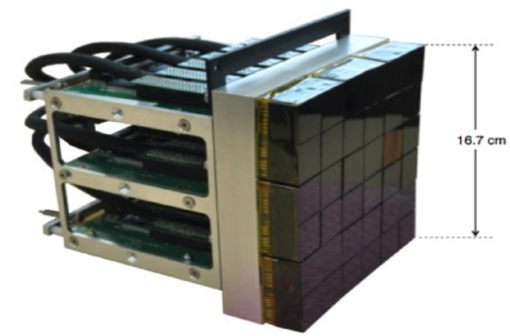
- **Altitude ~ 35 km**
- **Mission duration > 1 month (until 100 days)**

SPB flight (2015)

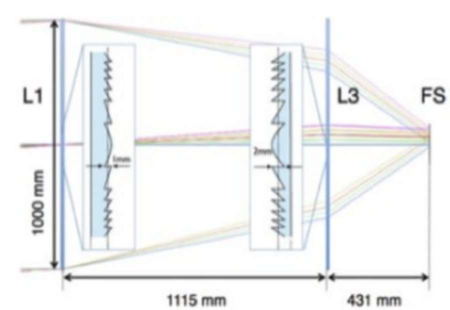
The EUSO-SPB detector

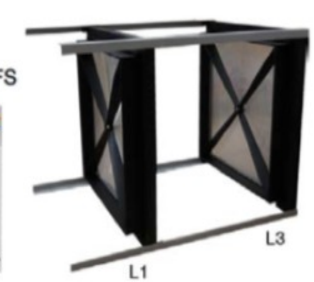






36 MAPMTs x 64 pixels





THE EUSO SIMULATION AND ANALYSIS FRAMEWORK (ESAF)

ESAF

Simu

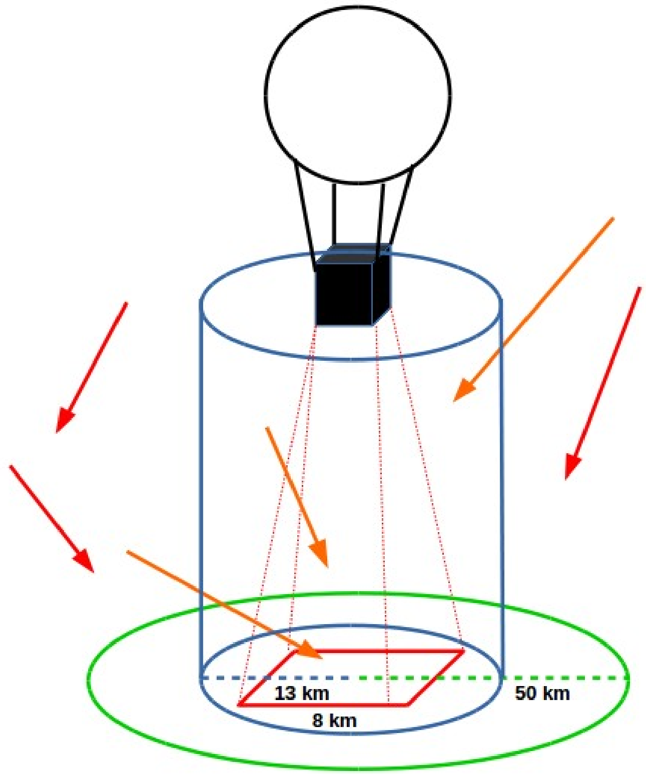
- **Shower propagation**
- **Optics simulation**
- **PMT electric signal treatment**
- **Trigger logic**

Reco

- **Recognition of the track signal on the focal surface**
- **Reconstruction of the shower parameters**

Generation of cosmic ray events

- **Need to generate events using an injecting area >> of the telescope field of view to avoid border effects**
- **Huge fracion of events has not any chance to enter the field of view**
- **Most of ESAF iterations wasted to generate not relevant events.**



- **SOLUTION: preselection of showers initial parameters (externally to ESAF)**

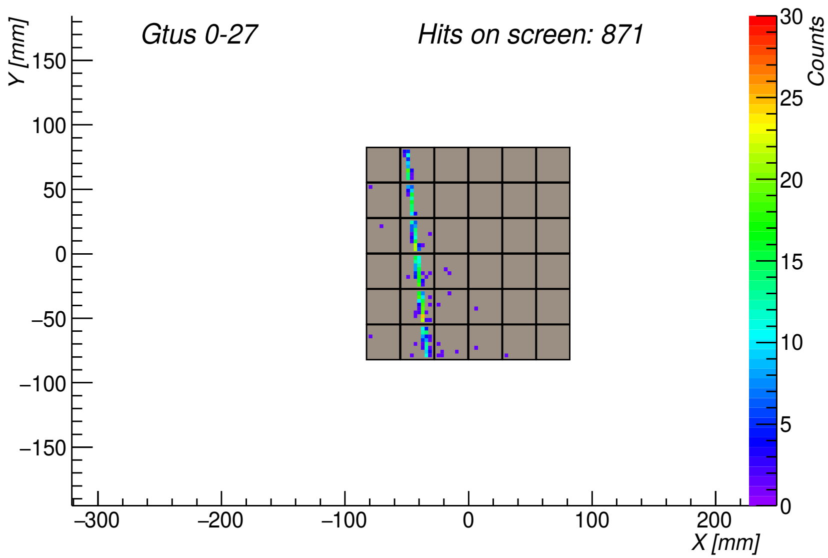
$$k = \frac{N_{cyl}}{N_{tot}}$$

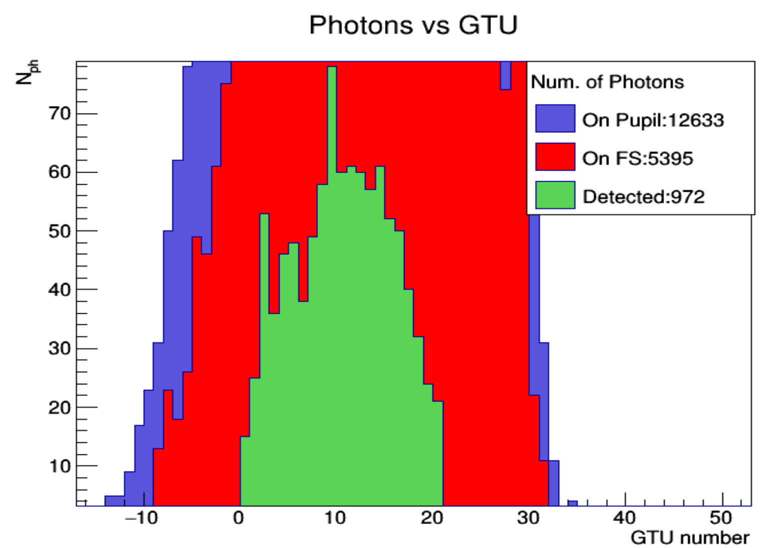
- **Without preselection: N_{tot} iteractions to have N_{cyl} events**
- **With preselection: N_{cyl} events are directly processed**

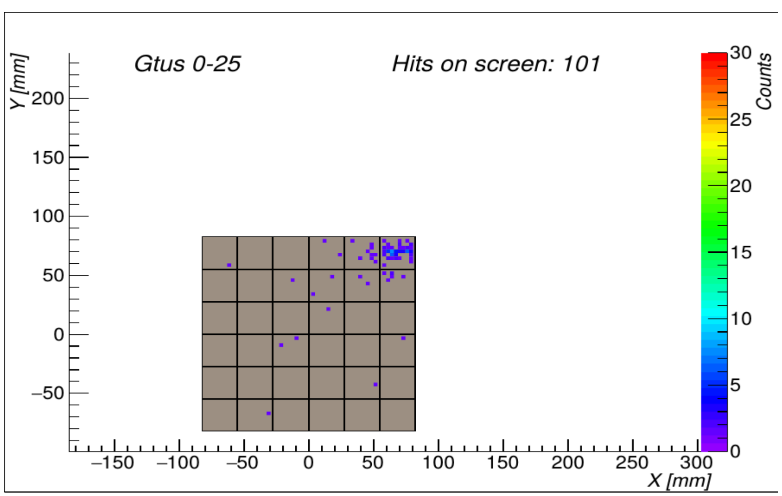
Saved time ~ 1-k ~ 90%

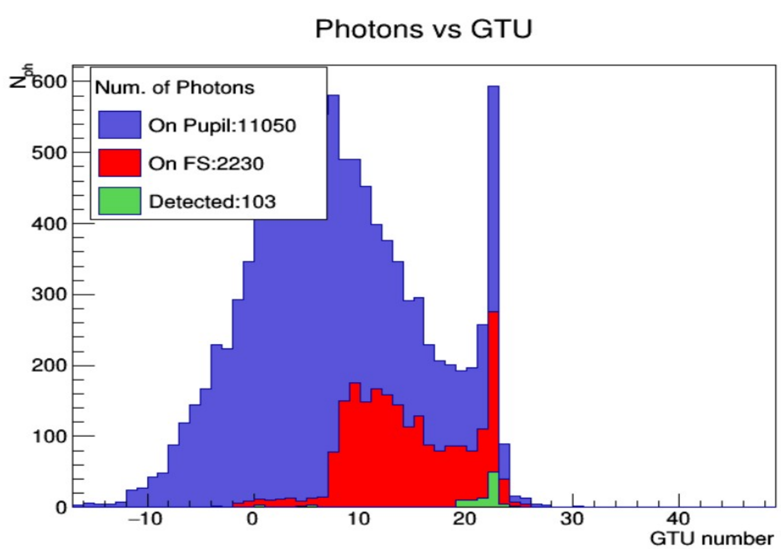
- **Detection efficiency** $\varepsilon(E) = \frac{N_{trigg}(E) \cdot k}{N_{cyl}(E)} \cdot \frac{A_{simu}}{A_{fov}}$

Examples of EAS signal

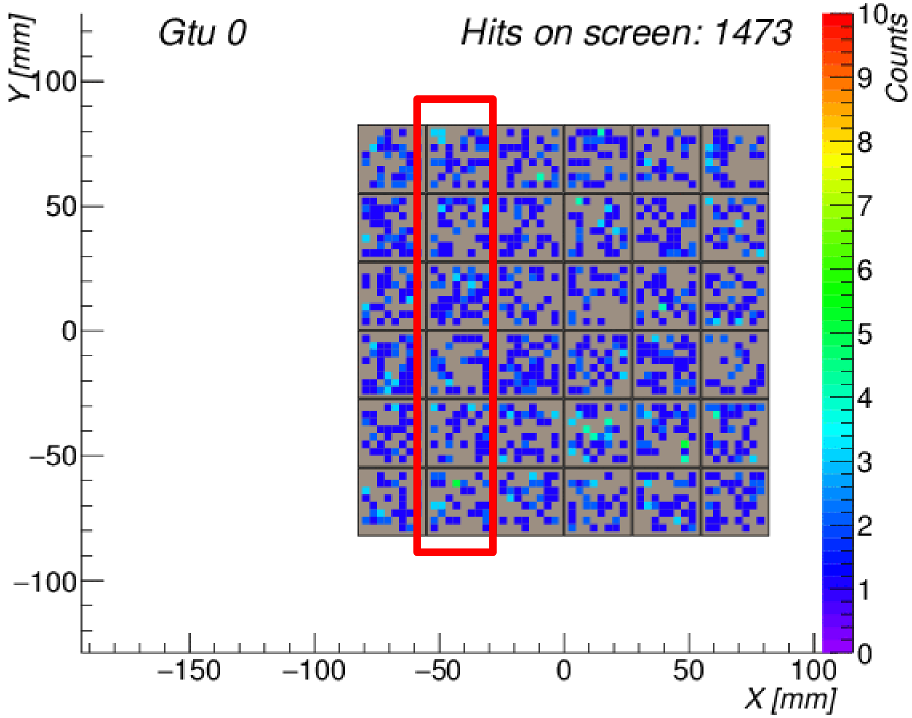








Need of a trigger to reject background events



- **Amount of data per second:**

  8 bit/pixel x 2304 pixels x 4 x 10^5 GTU/s

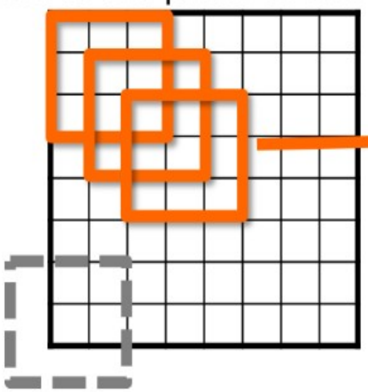
  ~ 73 Gb/s

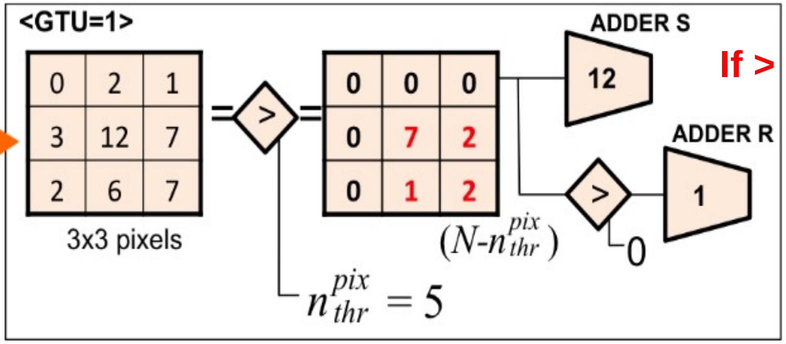
Trigger looking for a persistent and localized signal

- **Electronics requirement:**

  trigger rate on UV background plus cosmic ray events < 2 Hz

Trigger : Method 1 (baseline)



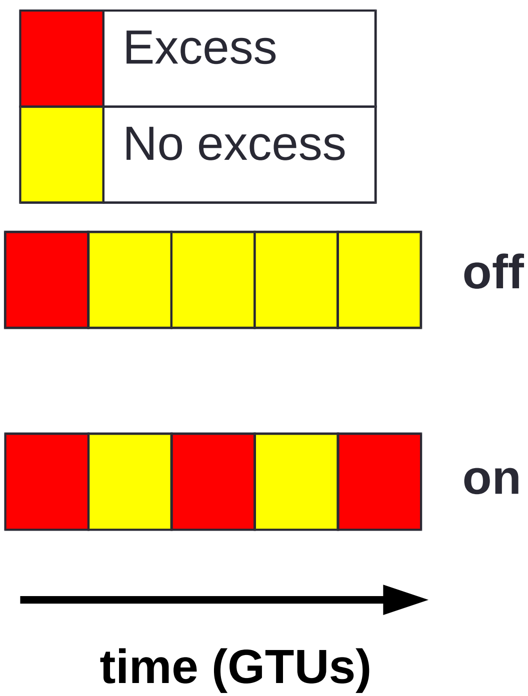


If > N^{cell}_{thr} → **Trigger yes**

Trigger parameters are set according to the background level

Background (counts/μs/pixel)	N^{pix}_{thr}	N^{cell}_{thr}
0.25	3	12
0.50	4	16
0.75	4	25

Trigger : method 2a and 2b



- **lower value of the N^{cell}_{thr} parameter (7 for method 2a and 6 for method 2b) $\rightarrow$ decreasing of the energy threshold of detected events**
- **Trigger as for method 1 becomes a pretrigger**
- **In at least 3/5 GTU (not necessary consecutives) over the entire EC at least 1 pixel shows an excess higher than N^{cell}_{thr}**

Triggered spectra calculation

- **Trigger performances evaluated in term of events collected in a spectrum**

- **Number of events per energy bin** → $$\Delta N(E) = \frac{d\Phi(E)}{dE} \cdot \Delta(E) \cdot \Psi(E)$$
- **Differential flux** → $$\frac{d\Phi(E)}{dE}$$ **(Auger flux – ICRC 2013)**
- **Detector exposition** → $$\Psi(E) = \epsilon(E) \cdot A_{fov} \cdot \pi \cdot t \cdot DC$$
- **Parameters**
  - **DC = 0.16**
  - **t = 60 days**
  - **A_{fov} = 64 km^2**

→ **Big uncertainty on parameters**

↓

Results must be seen in a relative way

Main simulation parameters

- **Detector efficiency (still to be defined)**
  - **0.15** → **Goal of the collaboration**
  - **0.05** → **First balloon efficiency (conservative case)**

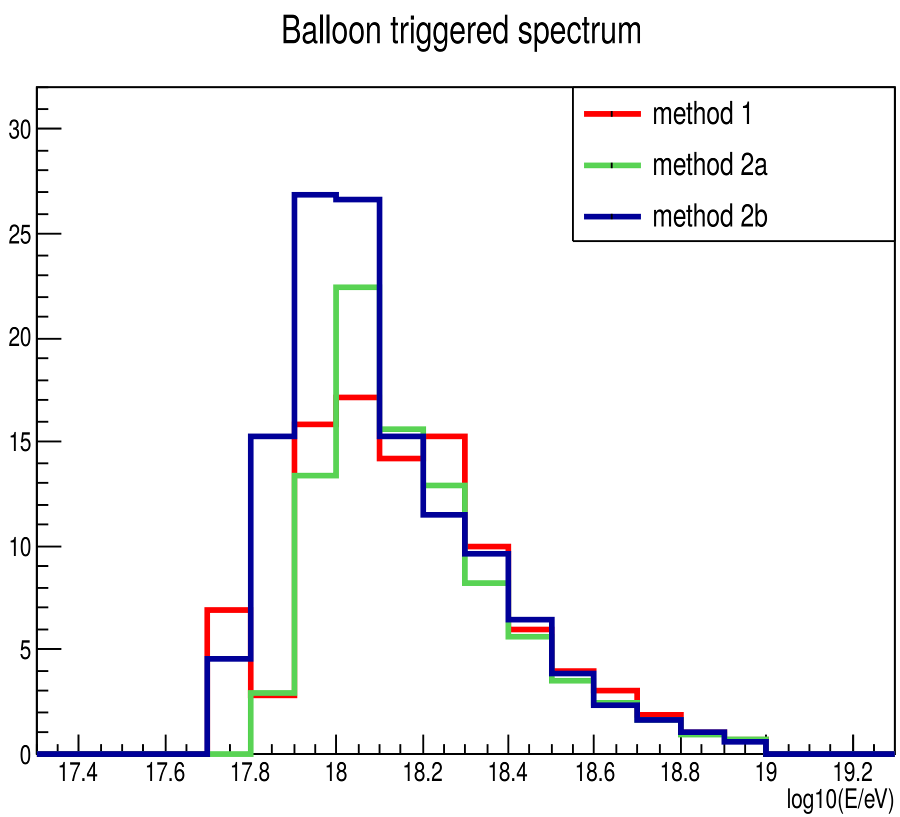
- **Background level** → **0.25 counts/μs/pixel 0.50 counts/μs/pixel 0.75counts/μs/pixel**

- **Clouds parameterized with**
  - **Optical depth (OD)** → **1 5**
  - **Altitude** → **2km 5km 10km**

Simulation provided a relative comparison beetwen spectra obtained varying these parameters

Comparison between the 3 methods – clear sky condition

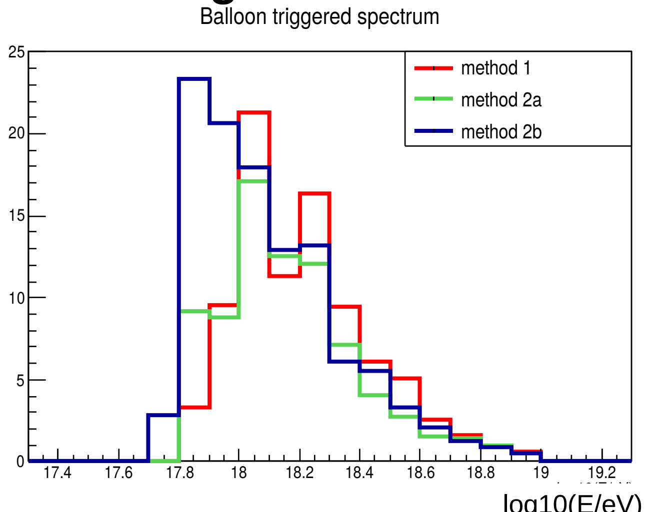
- **Detector efficiency 0.15**
- **Background 0.25 counts/μs/pixel**

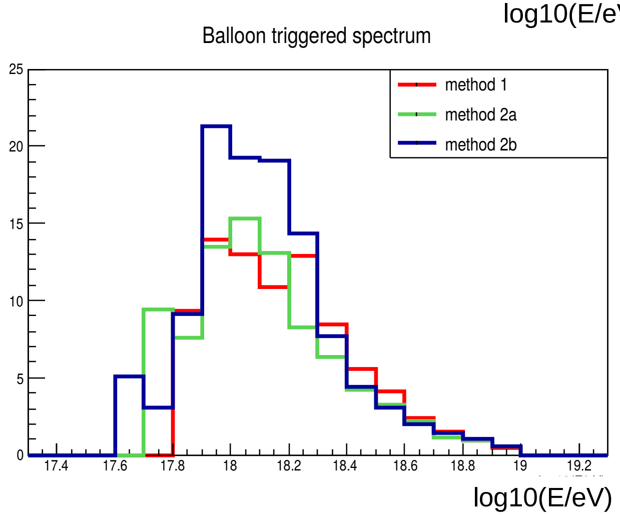


	Triggered Events
METHOD 1	99 ± 7
METHOD 2a	90 ± 6
METHOD 2b	126 ± 9

Comparison between the 3 methods – thin clouds (O D = 1)

- **Detector efficiency 0.15**
- **Background 0.25 counts/μs/pixel**





H = 2 km

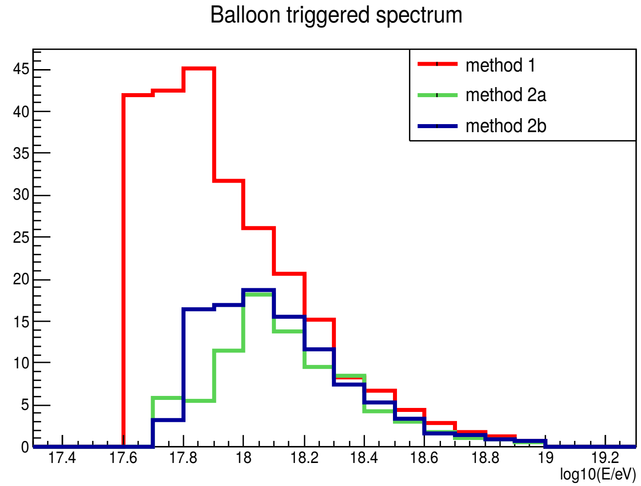
	Triggered Events
METHOD 1	88 ± 6
METHOD 2a	78 ± 7
METHOD 2b	111 ± 10

H = 5 km

	Triggered Events
METHOD 1	83 ± 7
METHOD 2a	86 ± 9
METHOD 2b	111 ± 10

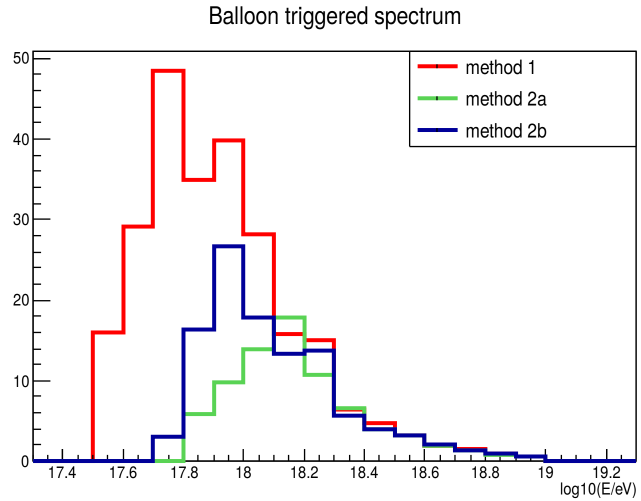
Comparison between the 3 methods – thick clouds (O D = 5)

- **Detector efficiency 0.15**
- **Background 0.25 counts/μs/pixel**



H = 2 km

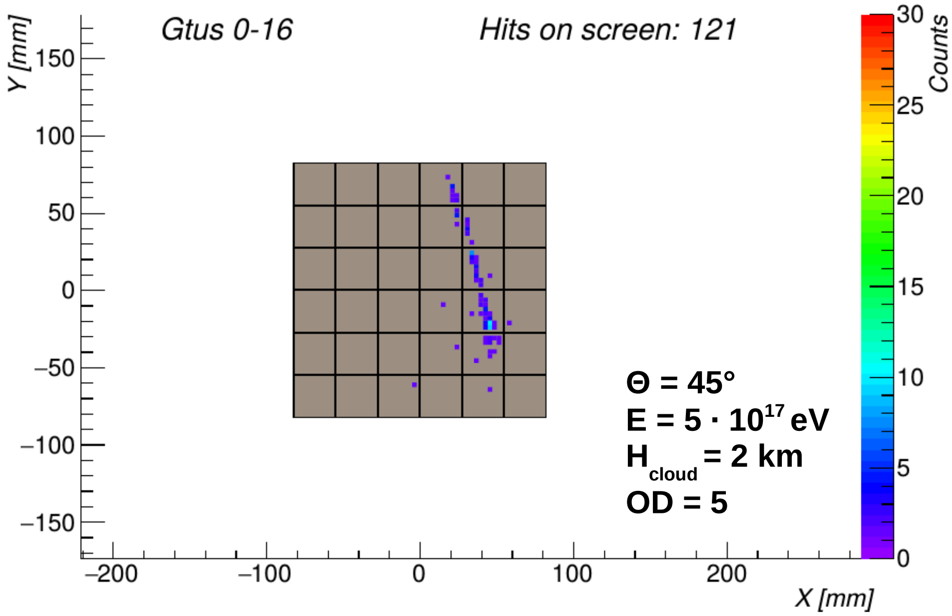
	Triggered Events
METHOD 1	249 ± 21
METHOD 2a	84 ± 8
METHOD 2b	103 ± 9

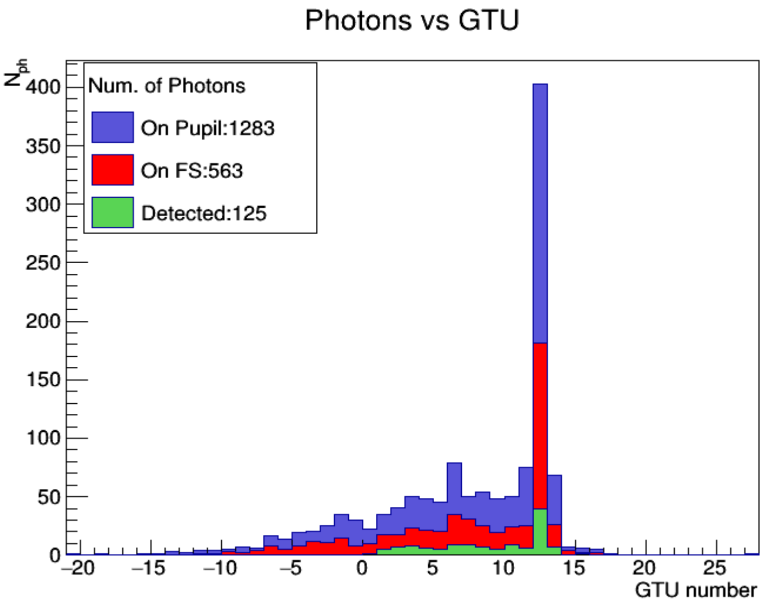


H = 5 km

	Triggered Events
METHOD 1	247 ± 24
METHOD 2a	76 ± 6
METHOD 2b	109 ± 9

Method 1 : detection of Cherenkov events reflected on the top of the cloud





Low efficiency detector

- **Detector efficiency 0.05**
- **Background 0.25 counts/μs/pixel**

Optical depth	Altitude (km)	Triggered events (method 1)	Triggered events (method 2b)
//	//	9.9 ± 0.8	14.4 ± 1.0
1	2	10.2 ± 1.1	10.9 ± 0.9
1	5	8.9 ± 0.7	11.4 ± 1.1
5	2	32.4 ± 2.7	12.7 ± 1.1
5	5	26.1 ± 2.8	11.2 ± 0.9

We chose method 1 :

- **Is still the most efficient in thick cloudy contidions**
- **Is suitable to detect Cherenkov events reflected on the top of the cloud (impossible for ground based experiments)**

Study of different detector performances – clear sky condition

- **low performance** **Detector efficiency = 0.05** **Background = 0.25 counts/μs/pixel**
- **high performance** **Detector efficiency = 0.15** **Background = 0.75 counts/μs/pixel**

Triggered events (low performance)	Triggered events (high performance)
9.9 ± 0.8	21.4 ± 1.7

The number of events increases by a factor ~ 2

Trigger performances assuming a background of 0.50 counts/μs/pixel

- **Detector efficiency = 0.05**

Optical depth	Altitude (km)	Triggered events (0.5 counts/μs/pix)	Triggered events (0.25 counts/μs/pix)
//	//	3.2 ± 0.3	9.9 ± 0.8
1	2	3.6. ± 0.3	10.2 ± 1.1
1	5	3.9 ± 0.4	8.9 ± 0.7
5	2	17.0 ± 1.5	32.4 ± 2.7
5	5	17.5 ± 2.1	26.1 ± 2.8
1	10	0	0
5	10	0	0

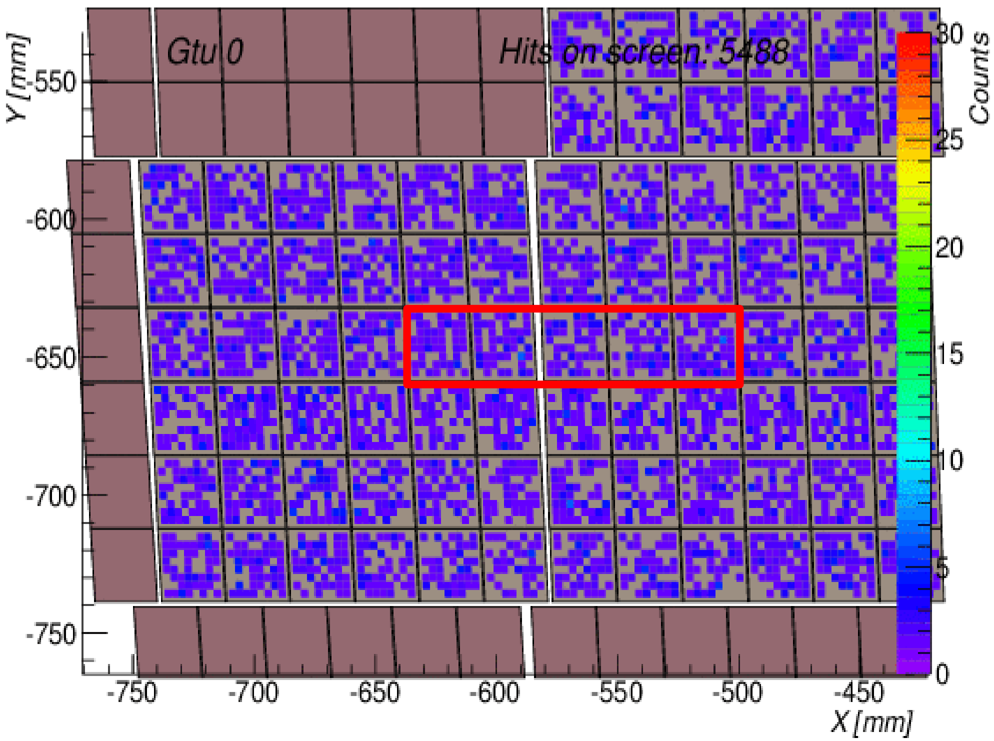
Number of triggered events drops by a factor ~ 2-3 compared to the case with 0.25 counts/μs/pixel (higher trigger thresholds)

Study of the reconstruction performance of EUSO-SPB

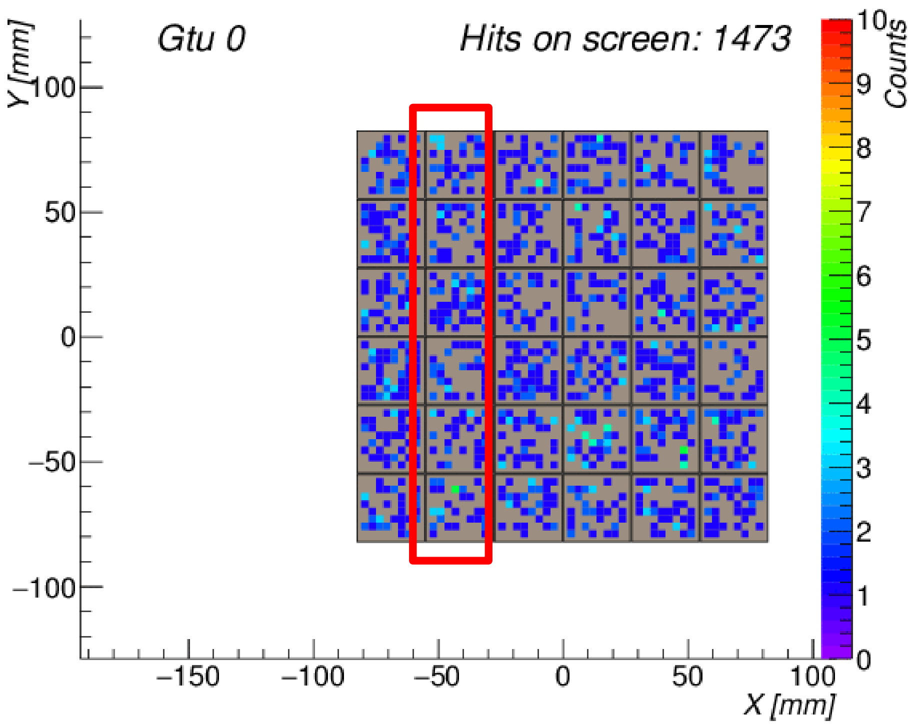
- **EUSO-SPB is not expected to provide a reconstructed spectrum**
- **Reconstruction performance is evaluated in terms of reconstructed fraction of triggered events**
- **An estimation of the average energy resolution is given**
- **A work aimed to improve the performance of the reconstruction algorithm was developed in this thesis**

Comparison between the JEM-EUSO signal and the EUSO-SPB signal

JEM-EUSO



EUSO-SPB



Reconstruction algorithm tuned on the JEM-EUSO signal features

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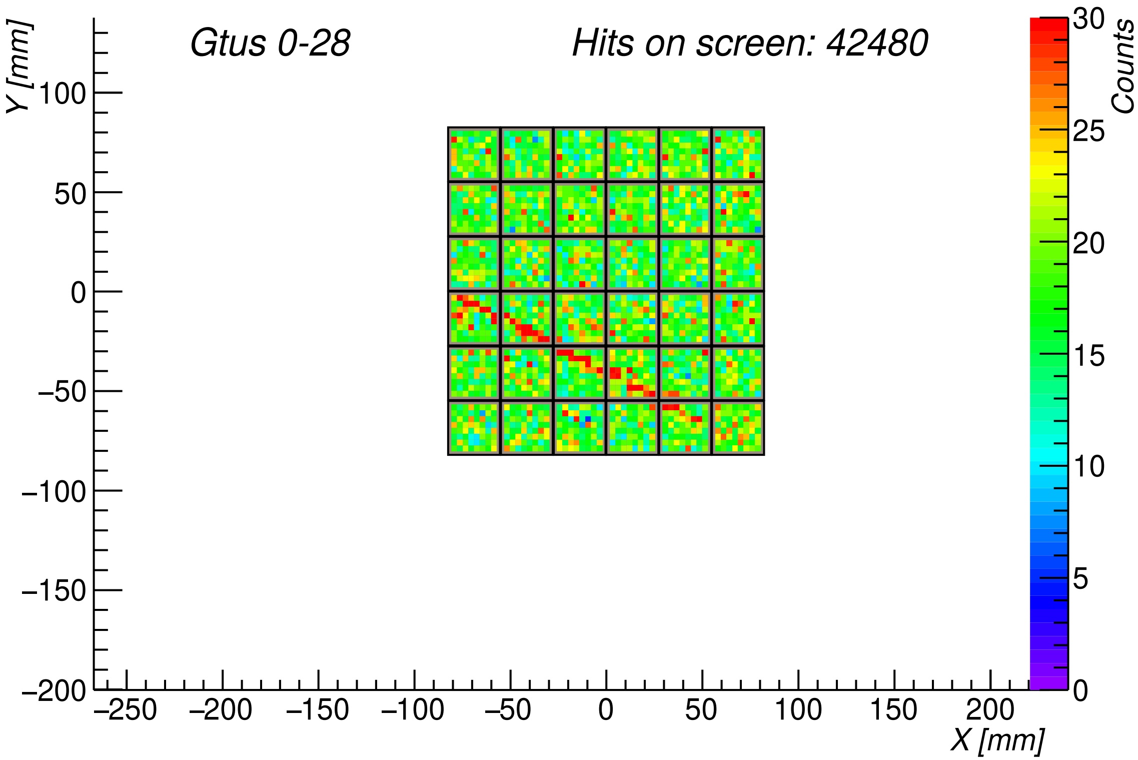
In principle bad reconstruction performances are expected

The pattern recognition algorithm



SIGNAL IDENTIFICATION

- **Signal is integrated for 5 GTUs in 3x3 pixels boxes on the entire PDM**
- **Highest integral choosen as initial condition**
- **A box integrates along several directions on the phocal plane**

$$\Delta S_{box,ground} = V_{box} \cdot t$$

$$\Delta S_{box,fs} = \frac{\Delta S_{box,ground}}{d_{pixel,ground}}$$

- **The direction with highest integration is chosen**

Reconstruction of the shower profile

Identification of the track

↓

Background subctration

↓

Detector correction

↓

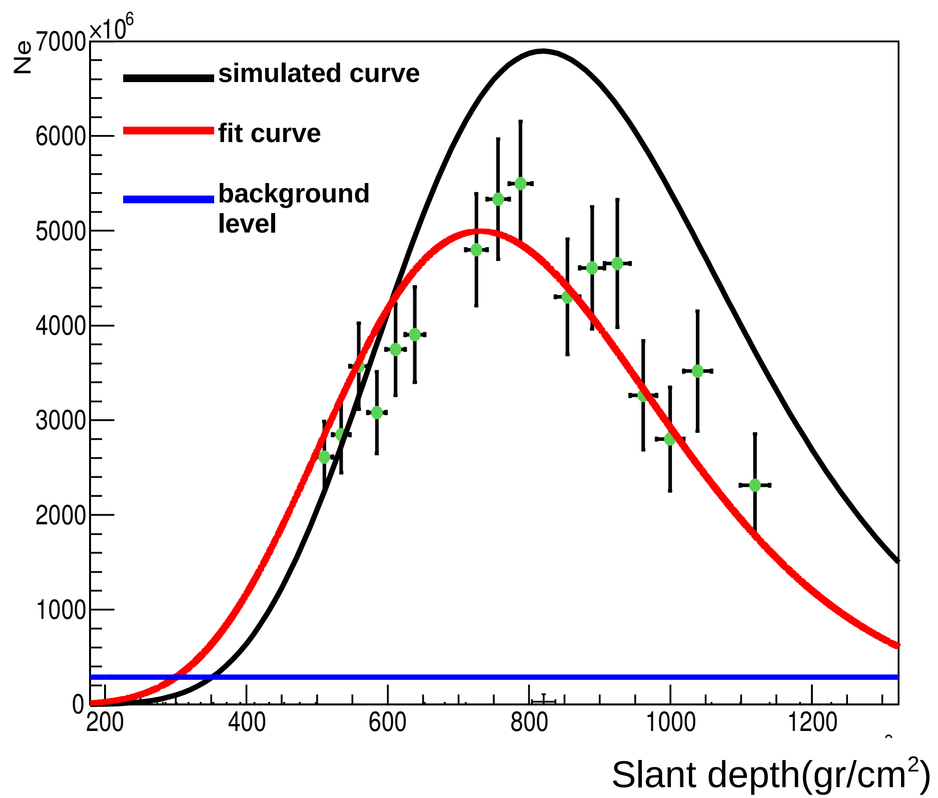
Photons in shower

↓

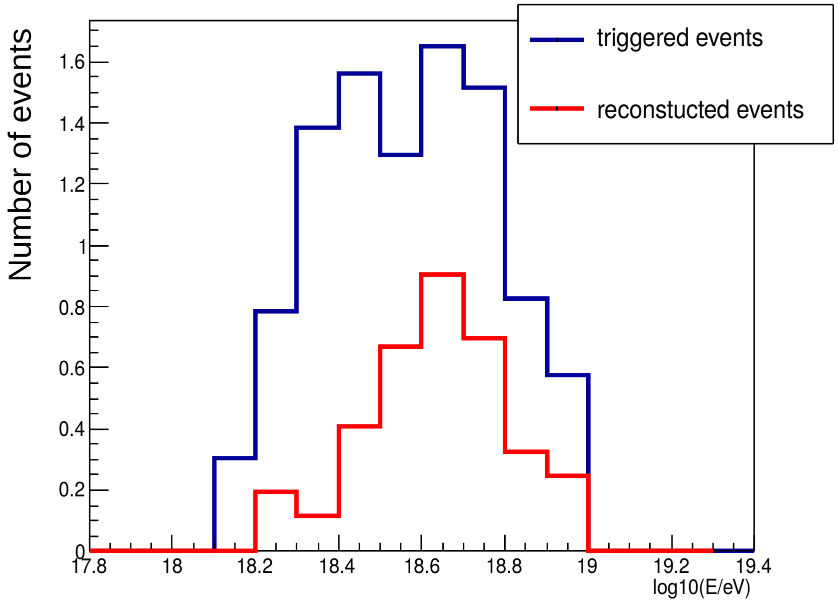
Electrons in shower

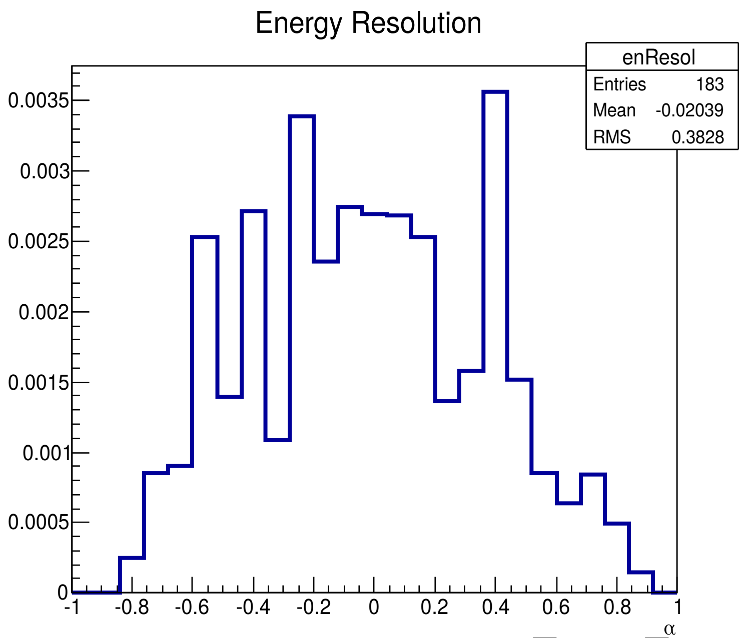
↓

Energy reconstruction



Fraction of reconstructed events and average energy resolution





$$\alpha = \frac{E_{rec} - E_{simu}}{E_{simu}}$$

Reconstruction performances

- **Detector efficiency 0.05**
- **Background 0.25 counts/μs/pixel**

Optical depht	Altitude (km)	Triggered events	N_{rec}/N_{trig}	RMS_{α}
//	//	9.9 ± 0.8	0.36	0.38
1	2	10.2 ± 1.1	0.36	0.48
1	5	8.9 ± 0.7	0.27	0.39
5	2	17.0 ± 1.5	0.25	0.39
5	5	17.5 ± 2.1	0.11	0.34

An average of 29% of the events can be reconstructed

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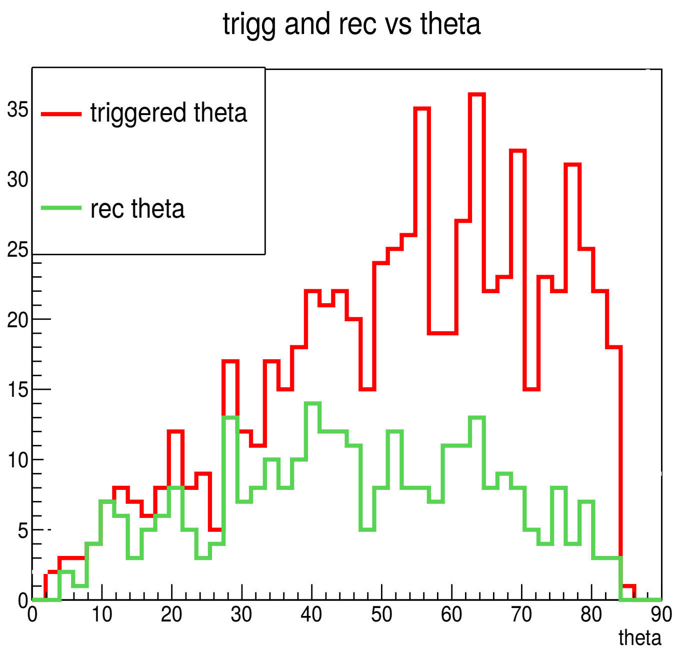
Optimization of the pattern recognition algorithm parameters



Optimization of the pixel size

- **Signal too fast for our integration box**

$$\Delta S_{box,ground} = V_{box} \cdot t \quad \Rightarrow \quad \Delta S_{box,fs} = \frac{\Delta S_{box,ground}}{d_{pixel,ground}}$$

Choice of the initial condition of the integration

- **Maximum on the 3x3 pixel box on single GTU (reduces the probability to integrate on background fluctuations)**

Performance after optimization

- **Detector efficiency 0.05**
- **Background 0.25 counts/μs/pixel**

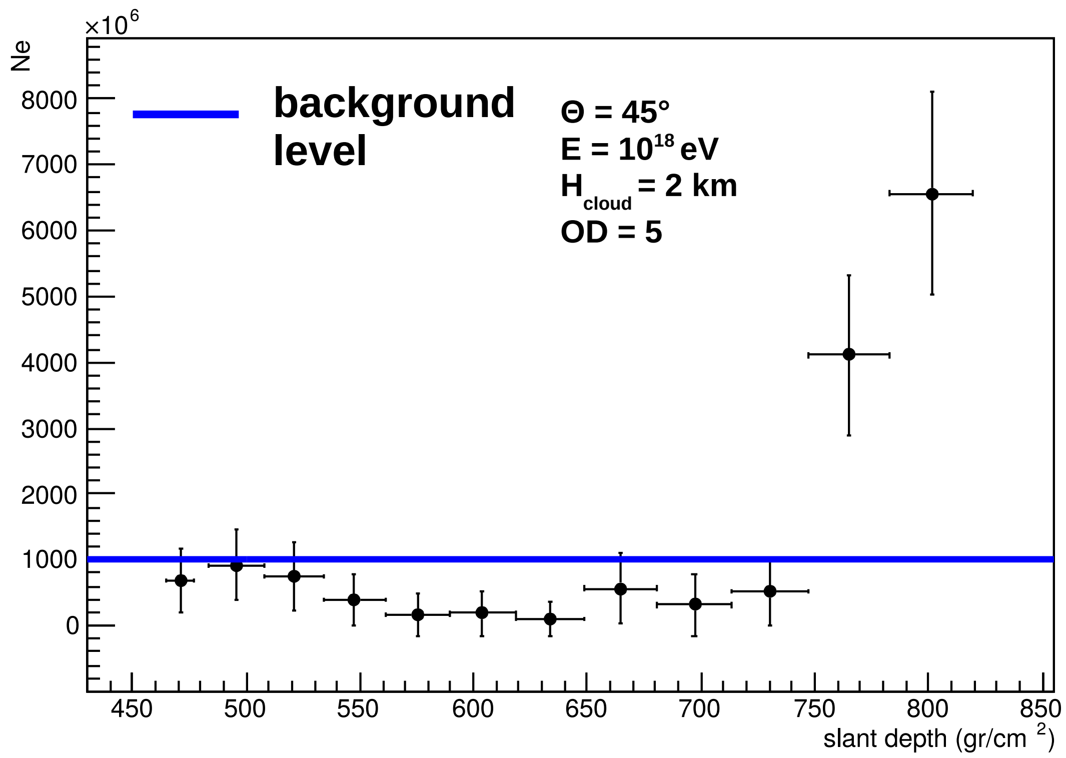
Optimized algorithm

O D	Altitude (km)	N_{rec}/N_{trig}	RMS_{α}	N_{rec}/N_{trig} (Optimized algorithm)	RMS_{α} (Optimized algorithm)
//	//	0.36	0.38	0.61	0.37
1	2	0.36	0.48	0.51	0.36
1	5	0.27	0.39	0.56	0.31
5	2	0.25	0.39	0.42	0.40
5	5	0.11	0.34	0.25	0.37

- **Improvment of the reconstructed events in clear sky from 36% up to 61% (no Cherenkov events)**
- **Average improvement by a factor 1.7**
- **Still low performance in thick cloud condition: most are Cherenkov events**

→ **algorithm thought to recognize the fluorescence bell**

Example of not reconstructed Cherenkov event



Estimation of the absolute number of expected triggered events

- **Assumtion of detector efficiency of 0.05 (we want to be conservative)**
- **The number of events is calculated considering a primary target observation time of 118 hours**
- **A factor of 10% of detector dead time is assumed**
- **The number of triggered events of spectra obtained in different cloudy conditions is weighted with the estimated percentages of different cloud coverage occurred on the EUSO-SPB trajectory**

First time slot for EUSO-SPB flight

date UTC	hrs dark	start UTc	stop UTC
2017 Mar 19	2:08	8:38 (twilight)	10:46 (moon 62%)
2017 Mar 20	2:52*	8:36 (twilight)	11:28 (moon 52%)
2017 Mar 21	3:40*	8:34 (twilight)	12:15 (moon 42%)
2017 Mar 22	4:34*	8:32 (twilight)	13:07 (moon 32%)
2017 Mar 23	5:34*	8:30 (twilight)	14:04 (moon 23%)
2017 Mar 24	6:38*	8:28 (twilight)	15:06 (moon 14%)
2017 Mar 25	7:46*	8:26 (twilight)	16:12 (moon 7%)
2017 Mar 26	8:51*	8:24 (twilight)	17:15 (twilight)
2017 Mar 27	8:54*	8:22 (twilight)	17:16 (twilight)
2017 Mar 28	8:57*	8:20 (twilight)	17:18 (twilight)
2017 Mar 29	9:01*	8:18 (twilight)	17:19 (twilight)
2017 Mar 30	9:04*	8:26 (twilight)	17:20 (twilight)
2017 Mar 31	8:40*	8:41 (moon 14%)	17:22 (twilight)
2017 Apr 1	7:57*	9:25 (moon 24%)	17:23 (twilight)
2017 Apr 2	7:08*	10:16 (moon 35%)	17:24 (twilight)
2017 Apr 3	6:12*	11:13 (moon 46%)	17:25 (twilight)
2017 Apr 4	5:12*	12:14 (moon 58%)	17:27 (twilight)
2017 Apr 5	4:09*	13:19 (moon 69%)	17:28 (twilight)
2017 Apr 6	3:04*	114:24 (moon 79%)	17:29 (twilight)
2017 Apr 7	2:00*	15:30 (moon 87%)	17:31 (twilight)

118 moon down hours
(1 lunar cycle)

Estimation of the absolute number of triggered events

Cloud altitude (km)	Percentage	Average optical depht
clear sky	23 ± 7	
h < 2 (low cloud)	37 ± 6	4.6 ± 1.1
2 < h < 6 (middle cloud)	25 ± 4	4.6 ± 1.1
h > 6 (high cloud)	15 ± 2	4.6 ± 1.1

*** results from Andrea Veneziani, student in stage at ARPA - Piemonte**

Assumption :

- **Background of 0.25 counts/us/pixel for clear sky**
- **Background of 0.50 counts/us/pixel for clouds**

Absolute number of expected events
- **7.3 ± 1.4 (1 lunar cycle)**
- **≥ 22 (3 lunar cycles)**

Conclusions

- **two different trigger logic were tested for EUSO-SPB varying simulation parameters such as detector efficiency, background level and cloudy coverage.**
- **method 1 (base line trigger) was the most suitable to detect Cherenkov events reflected on the top of thick clouds.**
- **Reconstruction performance were evaluated in terms of fractions of reconstructed events (N_{rec}/N_{trgg}) and energy resolution.**
- **An optimization of the reconstruction algorithm allowed to improve the fraction of the reconstructed events from 36% up to 61% (clear sky) with an average improvement of a factor 1.7 (no significant worsening of the energy resolution).**
- **The fraction is still low for thick clouds becouse of Cherenkov events (need of a new algorithm)**
- **The expected number of triggered events varies from 7.3 ± 1.4 (per lunar cycle).**
- **An increasing of the number of triggered events by a factor ~2 is expected in case of an high performance detector.**

Acknowledges

Sincere thanks to :

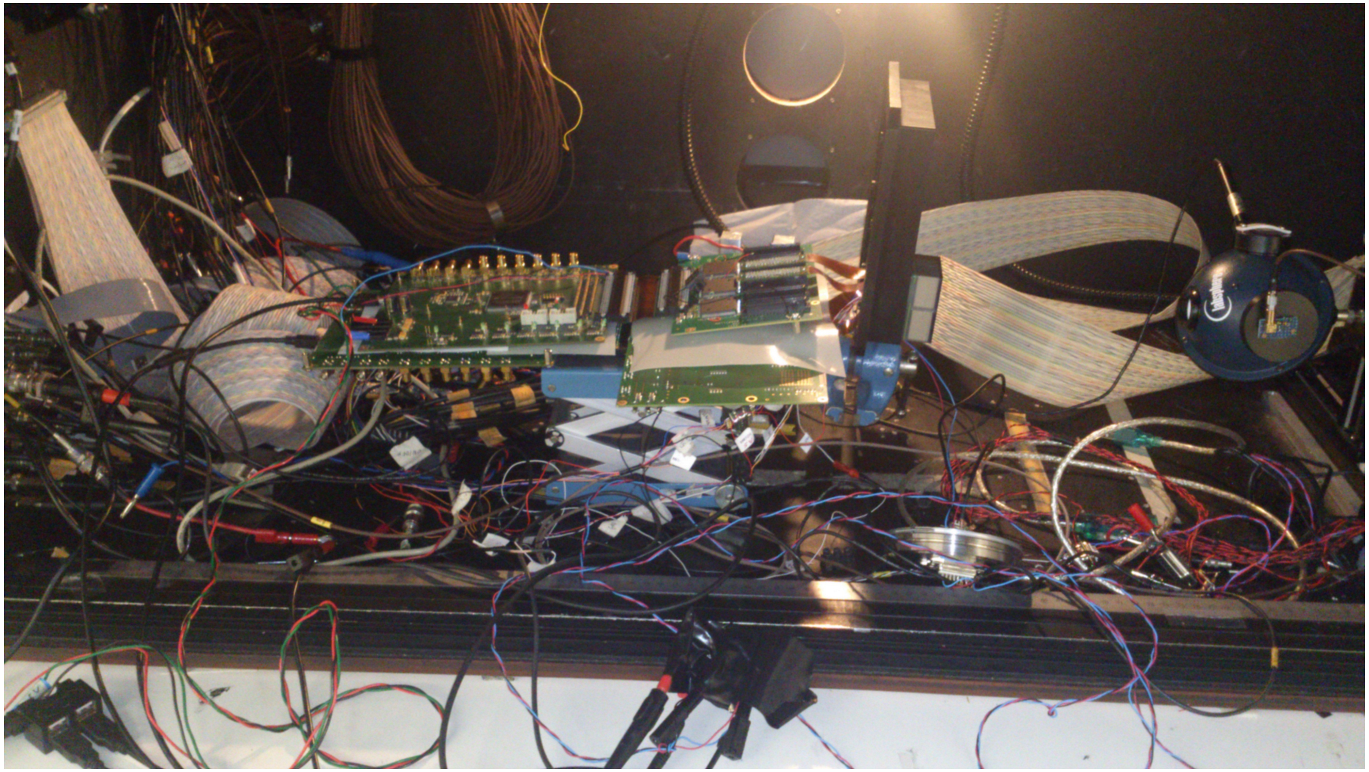
Prof. Mario Edoardo Bertaina

Dott. Francesco Fenu

Calibration aspects of the EUSO-SPB PDM

- Measumerements on a sample of 100 PMTs
- PMTs with more pixels uniform efficiency were selected
- Further selection operated on PMTs with best average gain
- Best 36 PMTs will be integrated on the EUSO-SPB PDM

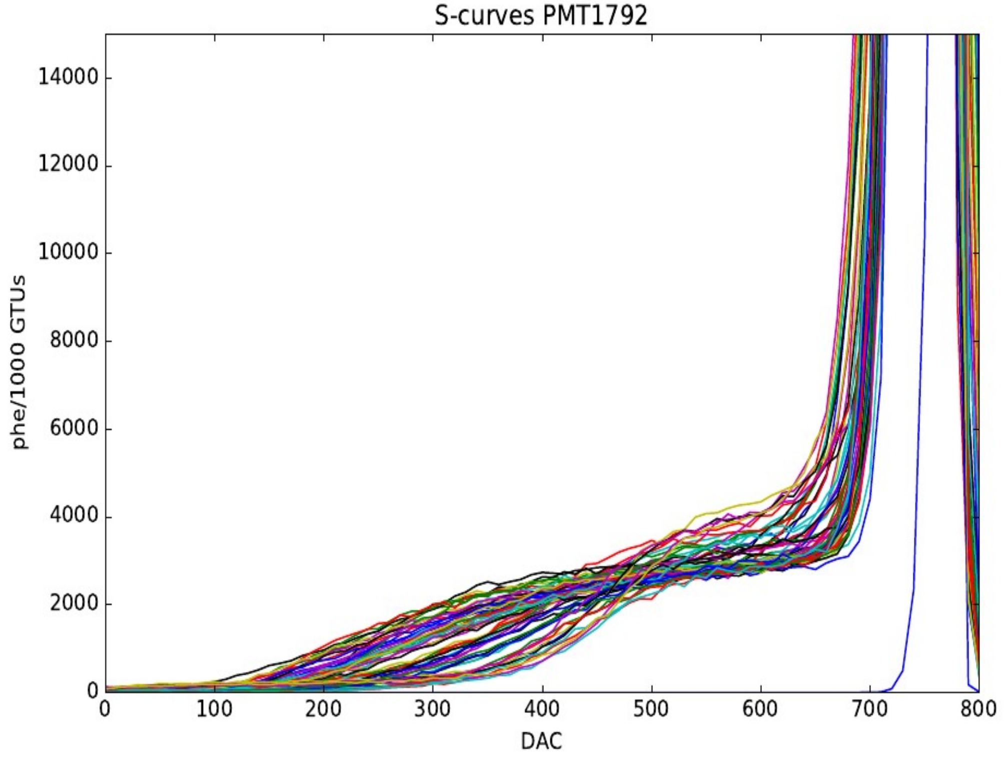
Experimental setup



- **Integrating sphere**
- **ASIC board**
- **Test board**
- **LabVIEW software**

PMTs operated in single photon counting mode

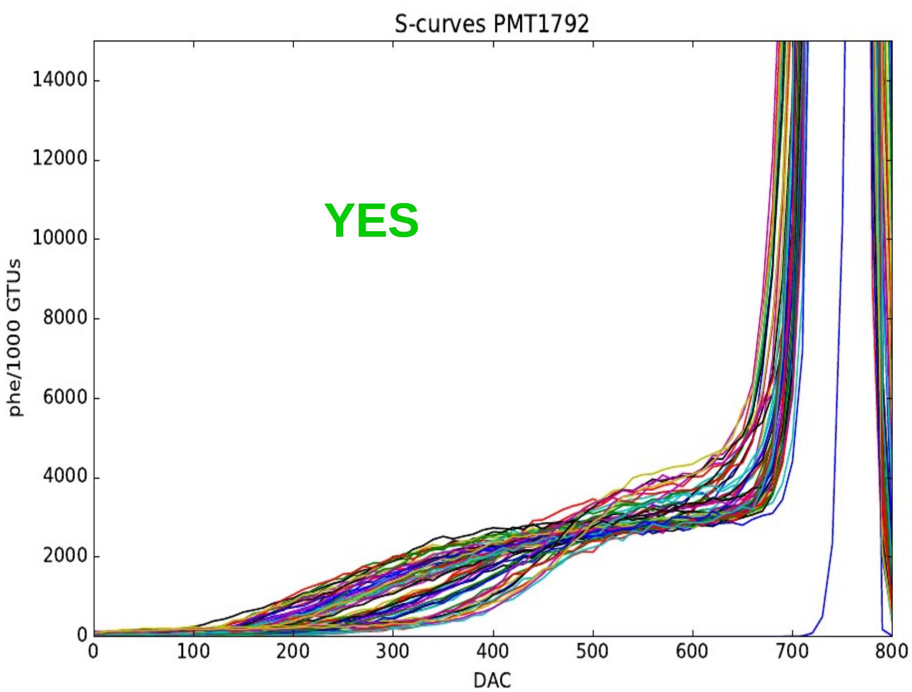
The S - curve

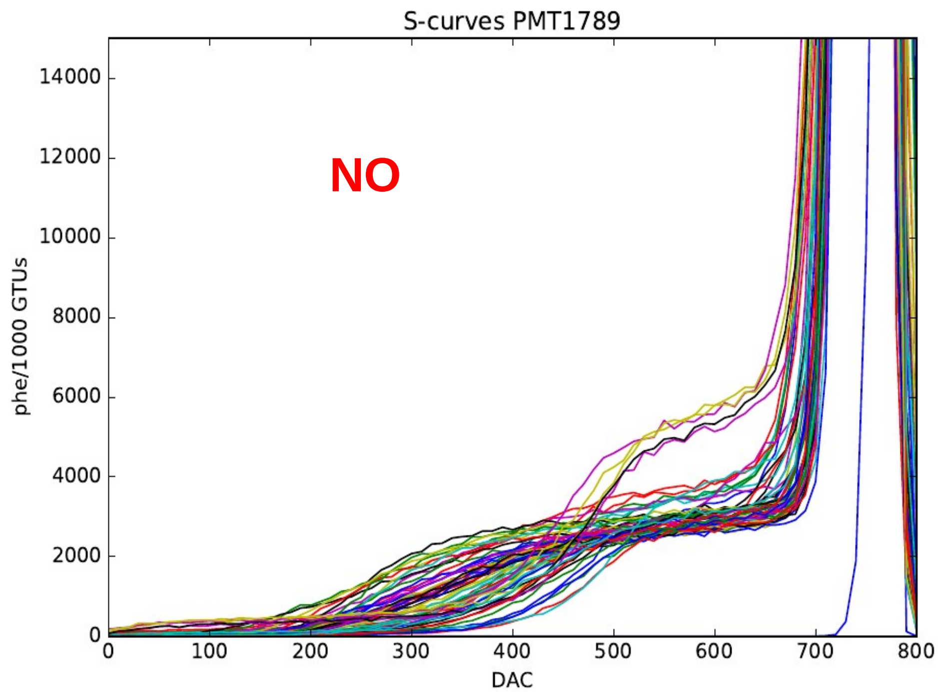


- **Count rate vs DAC threshold curve**
- **Efficiency : the value of the plateau**
- **Gain : difference between the DAC value of the pedestal and the inflection point**

PMTs sorting

- **Two class of PMTs were seen**





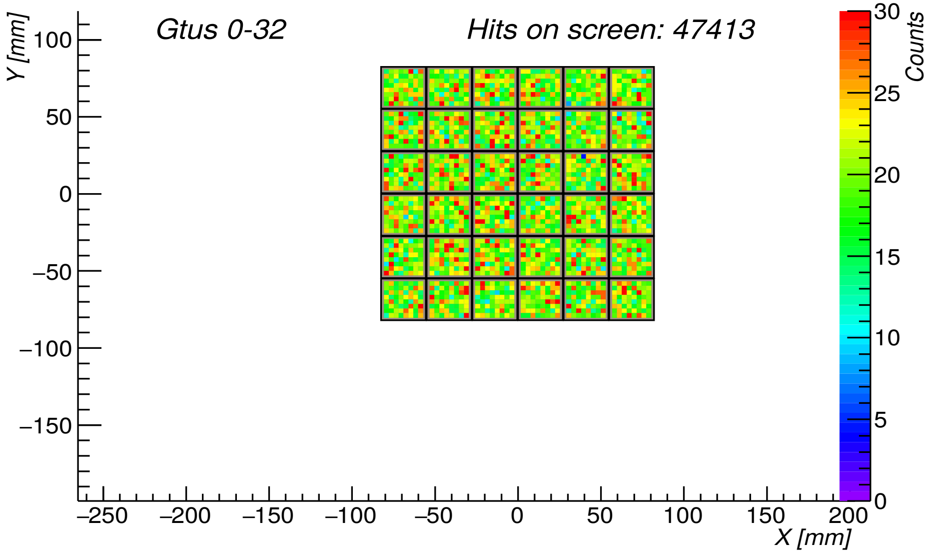
Pixels of a PMT must have uniform efficiecy
(trigger thresholds in a EC are set according to the pixel with higher counts)

- **Further selection on PMTs with best average gain**

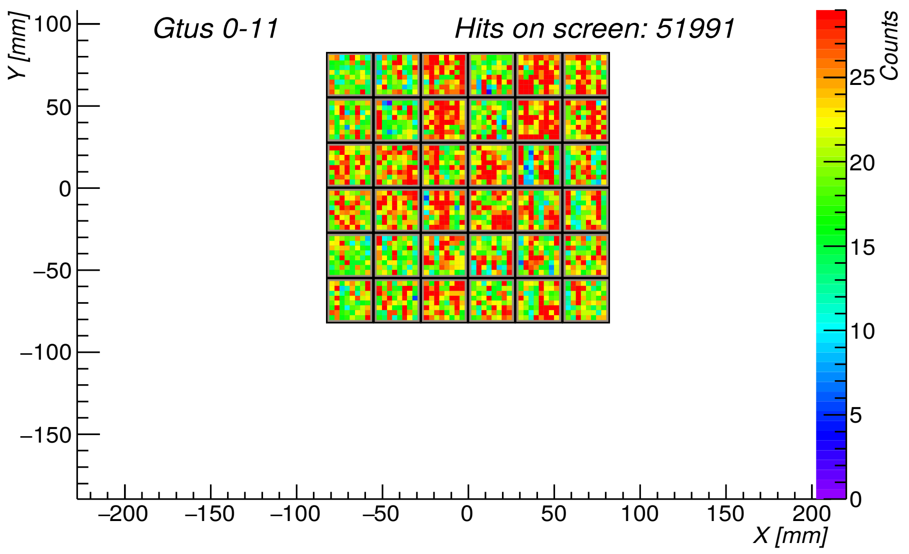
→ **Definitive PDM configuration**

Implementation of the PDM in ESAF

Uniform PDM

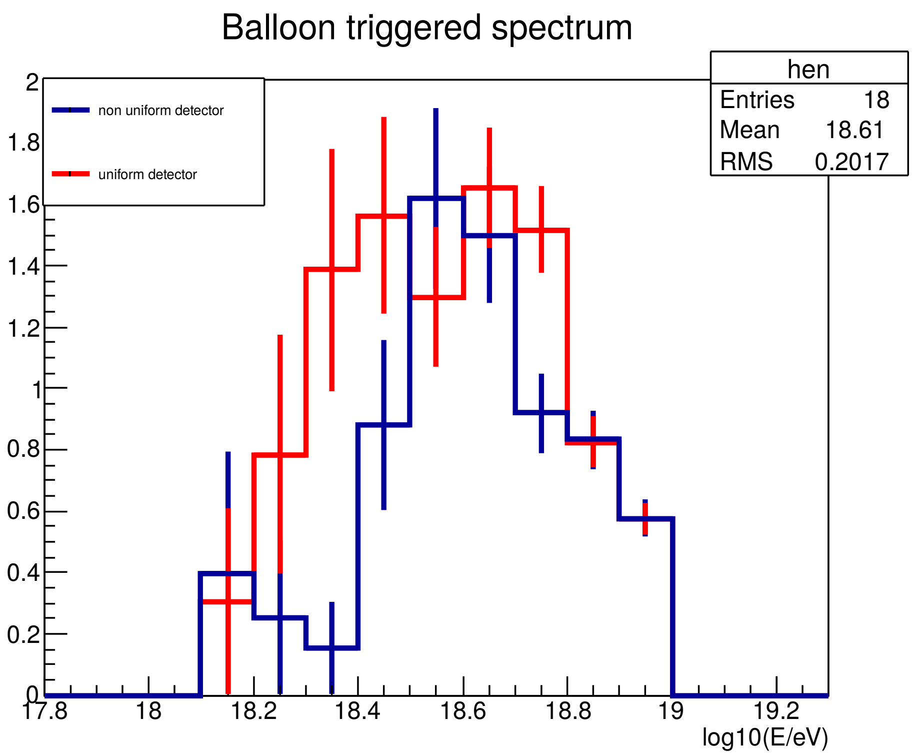


Non uniform PDM



Simulation with a non uniform detector (clear sky)

- **Average detector efficiency = 0.05**
- **Average background = 0.25 counts/μs/pixel**



Triggered events (uniform detector)	Triggered events (non uniform detector)
9.9 ± 0.8	7.1 ± 0.7

In case of a non uniform detector the number of events is reduced by ~ 30%

Background simulation (0.25 counts/μs/pixel)

Trigger rate (Hz) (method 1)	Trigger rate (Hz) (method 2a)	Trigger rate (Hz) (method 2b)
1	1	3

- **Trigger rate for method 1 and 2a is < 2 Hz**
- **Trigger rate for method 2b is slightly higher than 2 Hz**
- **We analyze method 2b anyway in order to see if its performance is better than the others**