Preliminary study on the observation of Transient Luminous Events (TLE) by means of the JEM-EUSO experiment.

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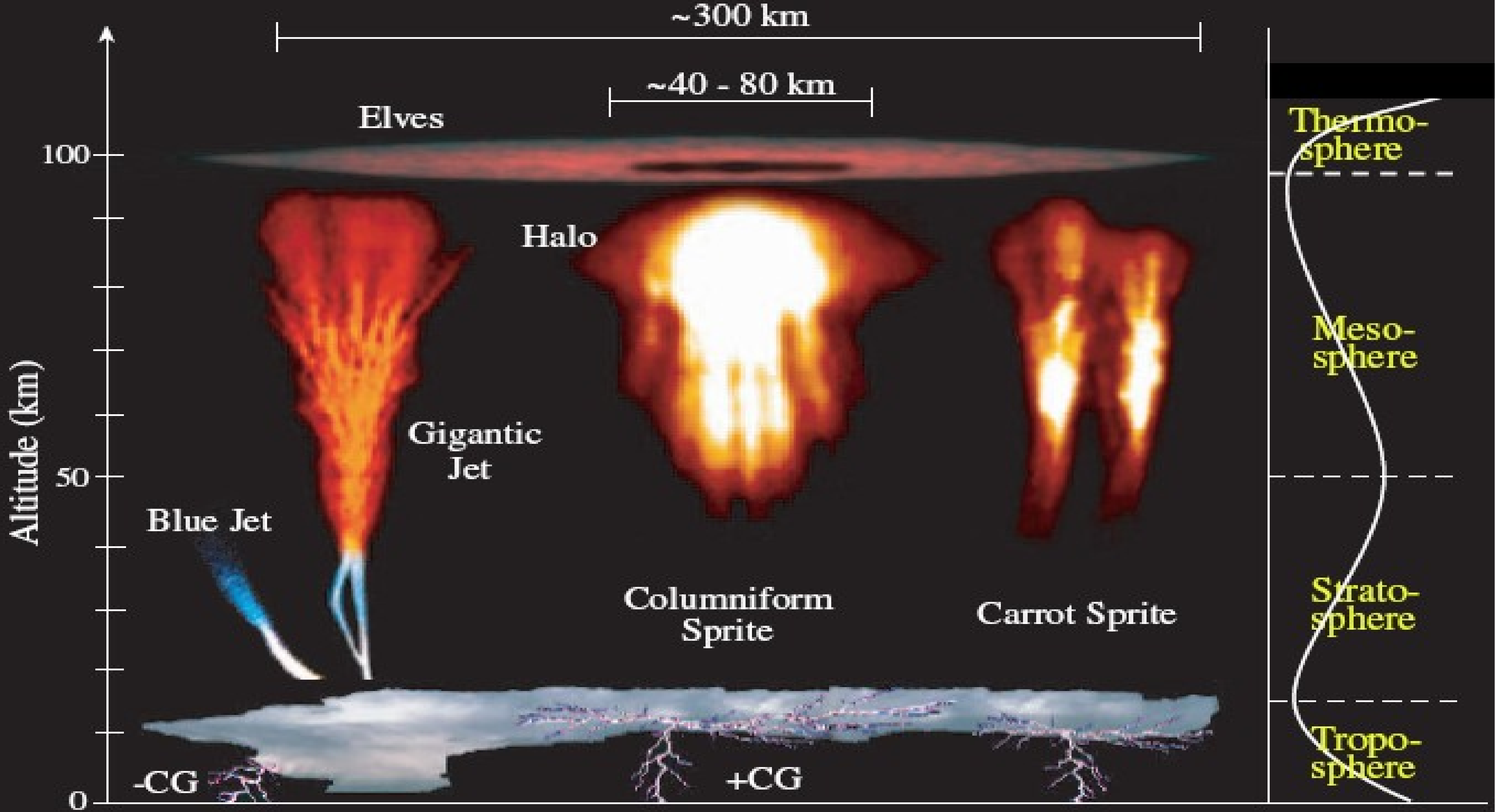
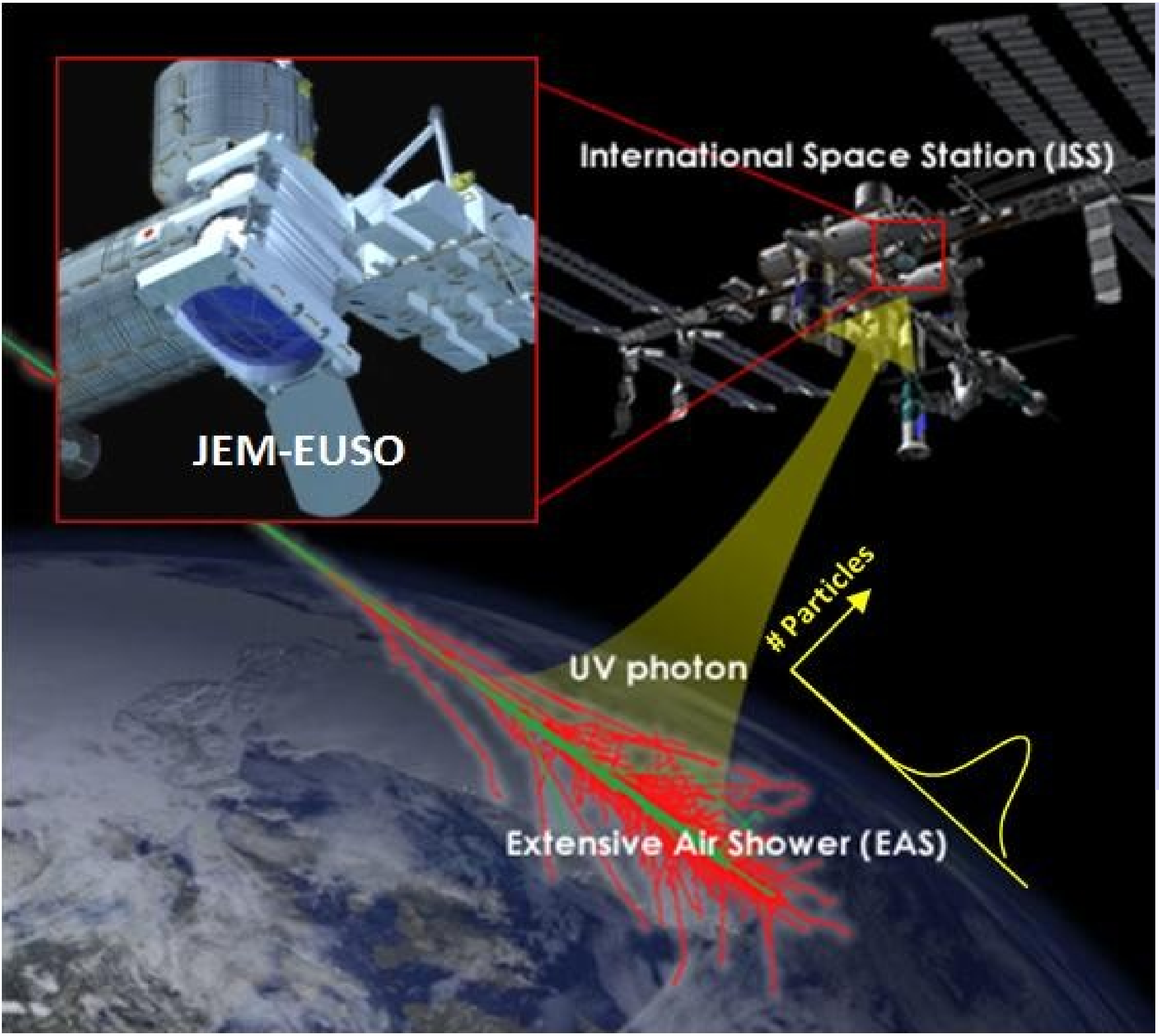
TRANSIENT LUMINOUS EVENTS



TLEs are upper atmospheric optical phenomena associated with thunderstorms

What is JEM-EUSO telescope

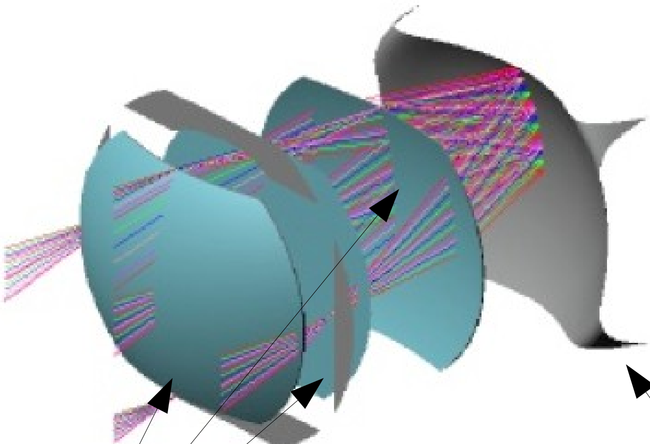


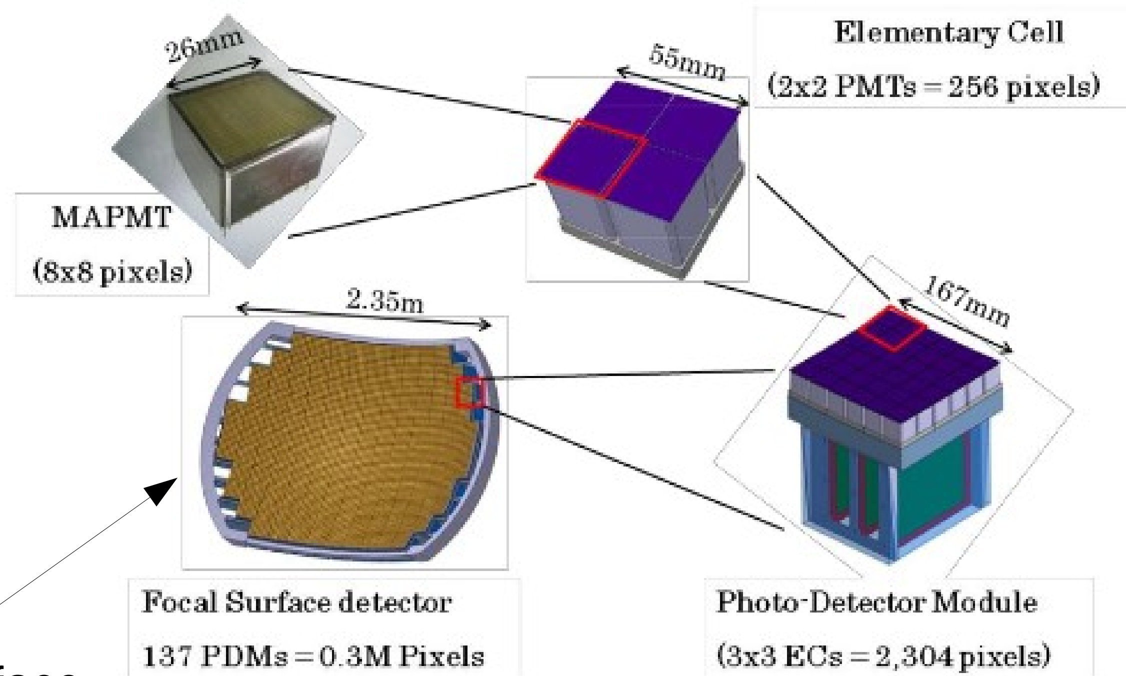
INSTRUMENTS PARAMETERS

- Field of view: ±30°
- Aperture diameter: 2.5 m
- Optical bandwidth: 330 – 400 nm
- Angular resolution: 0.1°
- Pixel size: 2.9 mm
- Number of pixels: $\sim 3.0 \times 10^5$
- Pixel size at ground: 560 m
- Duty cycle: ~20%
- Event time sampling: 2.5μs = 1GTU
- Observational area: $>1.9 \times 10^5$ km^2
- ISS flight height: 430km
- PMT Gain: 10^6 (0.16pC/phe)
- Detector efficiency: 0.12
- KI partition: rectangular 4pix x 2pix

- LARGE DETECTOR → LARGE STATISTICS
- 2.5μs = VERY PRECISE TLE OBSERVATION

JEM EUSO OPTICS & ELECTRONICS





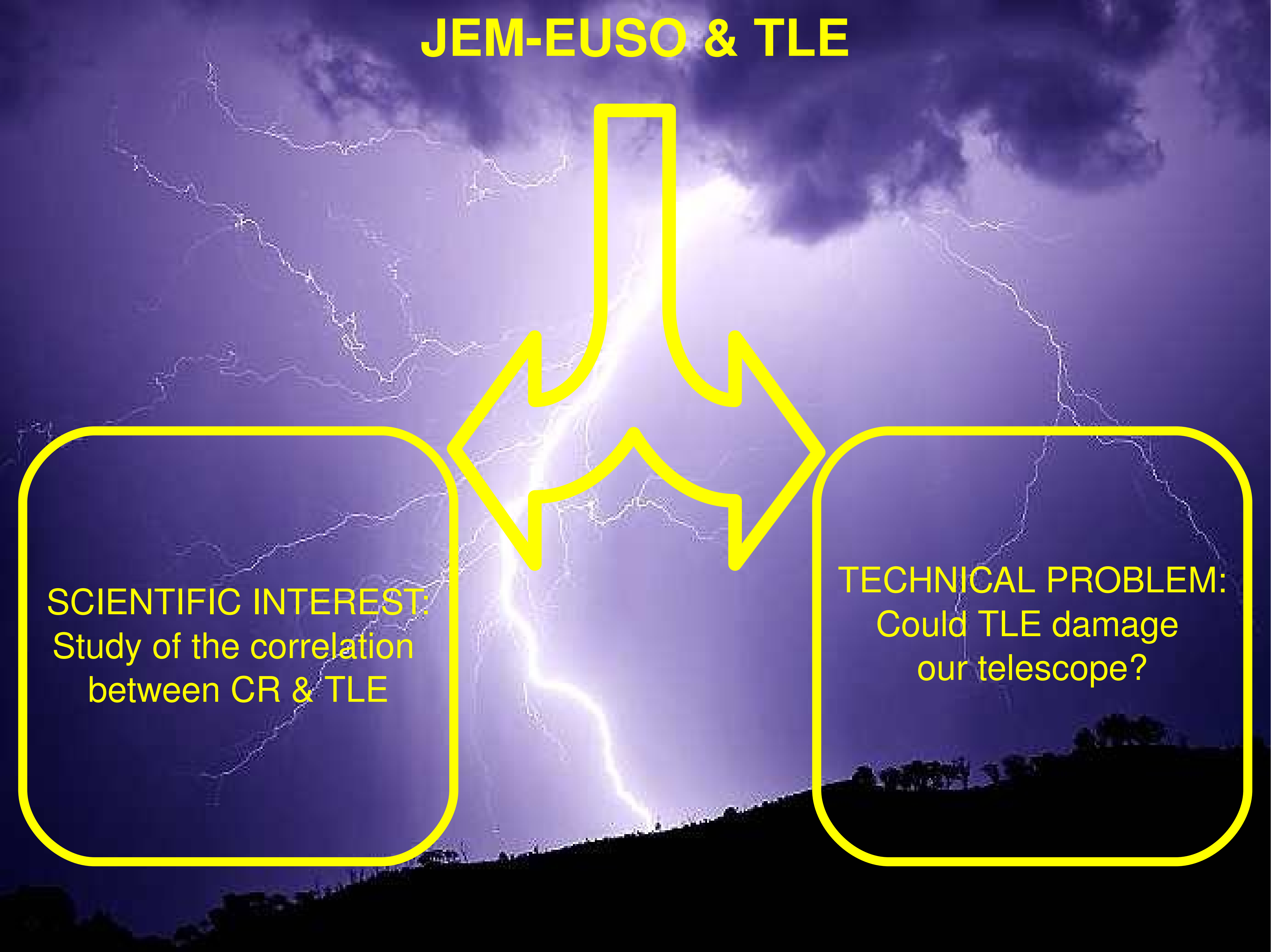
3 Fresnel lenses

Detector Focal Surface

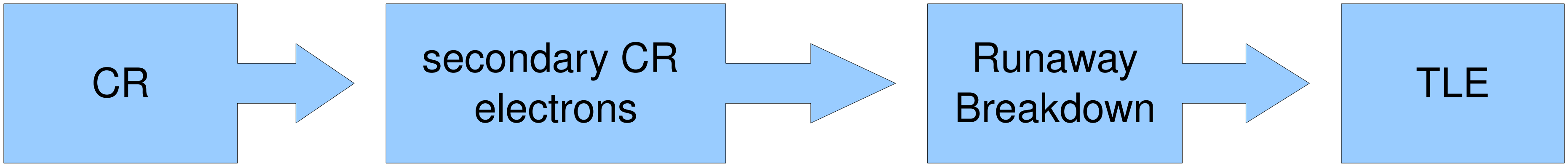
Figure 4.3.1-1. *Focal surface detector and its structure.*

2 working mode at the same time:

1. DIGITAL → single photon counting → single pix → CR events
2. ANALOG → charge integration → KI (4x2 pix) → CR & TLE


JEM-EUSO & TLE
SCIENTIFIC INTEREST:
Study of the correlation
between CR & TLE
TECHNICAL PROBLEM:
Could TLE damage
our telescope?

CR – TLEs INTERACTION: RUNAWAY BREAKDOWN THEORY



RUNAWAY BREAKDOWN CONDITIONS:

1. electric field $E > E_c$
   (in air at atmospheric pressure $E_c \cong$ 200 kV/m)

2. spatial scale of electric field $L > l_a \sim 50$m
   l_a = length of exponential growth of the runaway avalanche

3. fast seed electrons with $\varepsilon > \varepsilon_c \geq 0.1 – 1$MeV

ATMOSPHERIC CONDITIONS:

1. electric field $E > E_c$ in case of discharges in thunderclouds

2. clouds' length $>> l_a$

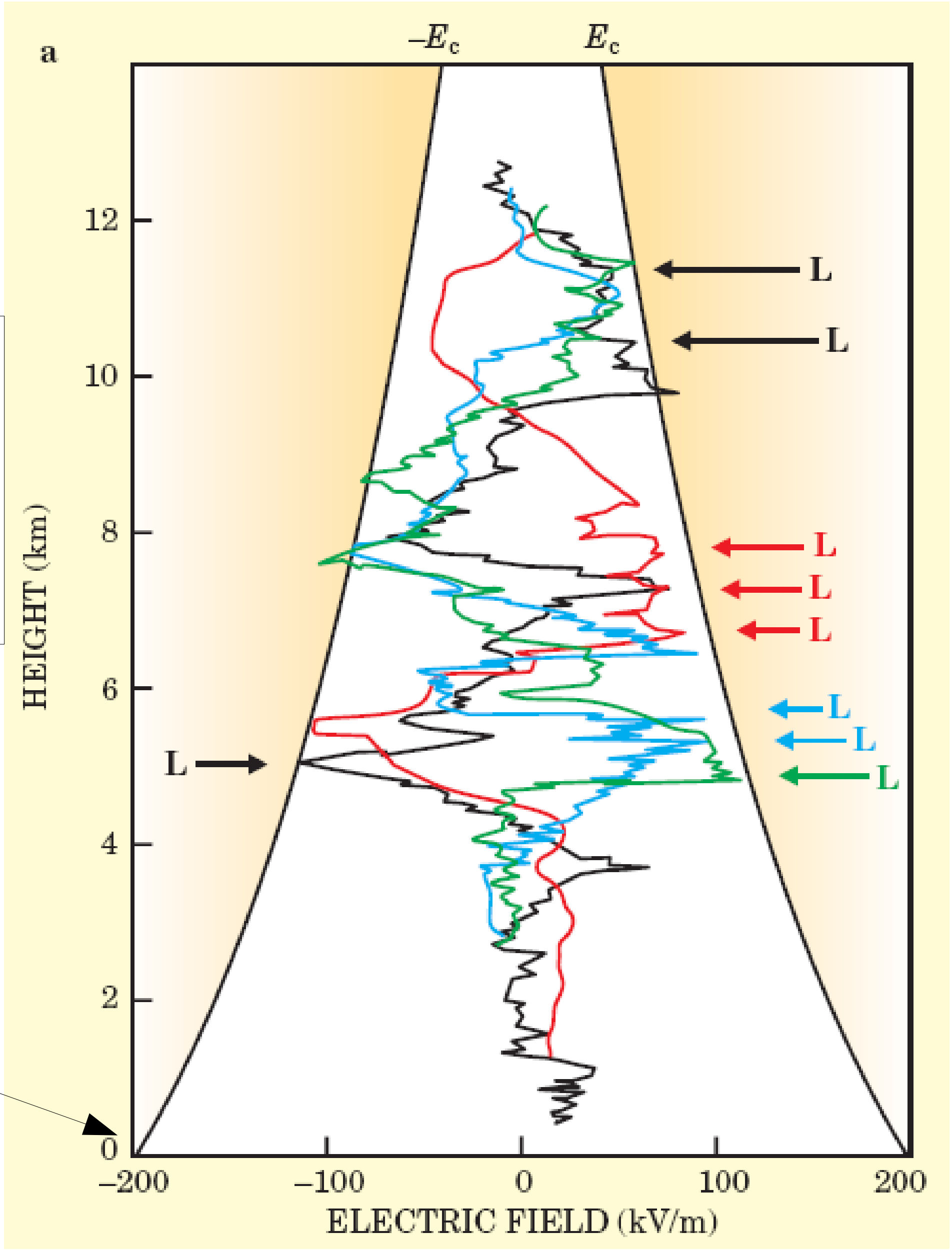
3. lots of electrons from secondary CR with energy >1 MeV: $\phi \cong 10^3\ m^{-2}s^{-1}$ at 4-8 km (primary CR energy = 10^{15-16} eV)

An avalanche of runaway electrons can be created in atmosphere!

CR – TLEs INTERACTION: EXPERIMENTAL OBSERVATION

Lightning phenomena were observed in various atmospheric electric field measurements, corresponding to an electric field value $E \cong E_c$ = RB threshold.

$E_c \cong$ 200 kV/m at atmospheric pressure



Main TLEs - emitted photons - signal order of magnitude

NAME	EVENT REGION	POWER	DURATION	EXTENSION	SPECTRUM
LIGHTNING	Troposphere	$\sim 10^{12}$W	~0.1s	Some km	Violet to red
SPRITE	Mesosphere	$\sim 10^{7}$W	Some ms	Some km	Red - blue
ELVE	Mesosphere	$\sim 10^{10}$W	<1ms	~200km	red
JET	Stratosphere Troposphere	$\sim 10^{4}$W	~0.4s	Tens of km	blue
AURORA	From mesosphere to atm. limit	$\sim 10^{10}$W	From minutes to hours	Some hundreds km	Violet to red

- P = power
- D = duration
- h = Planck's constant
- ν = mean photon frequency
- Ac = absorbtion coefficient
- Sc = spectrum coefficient
- d = telescope diameter
- D = telescope-event distance

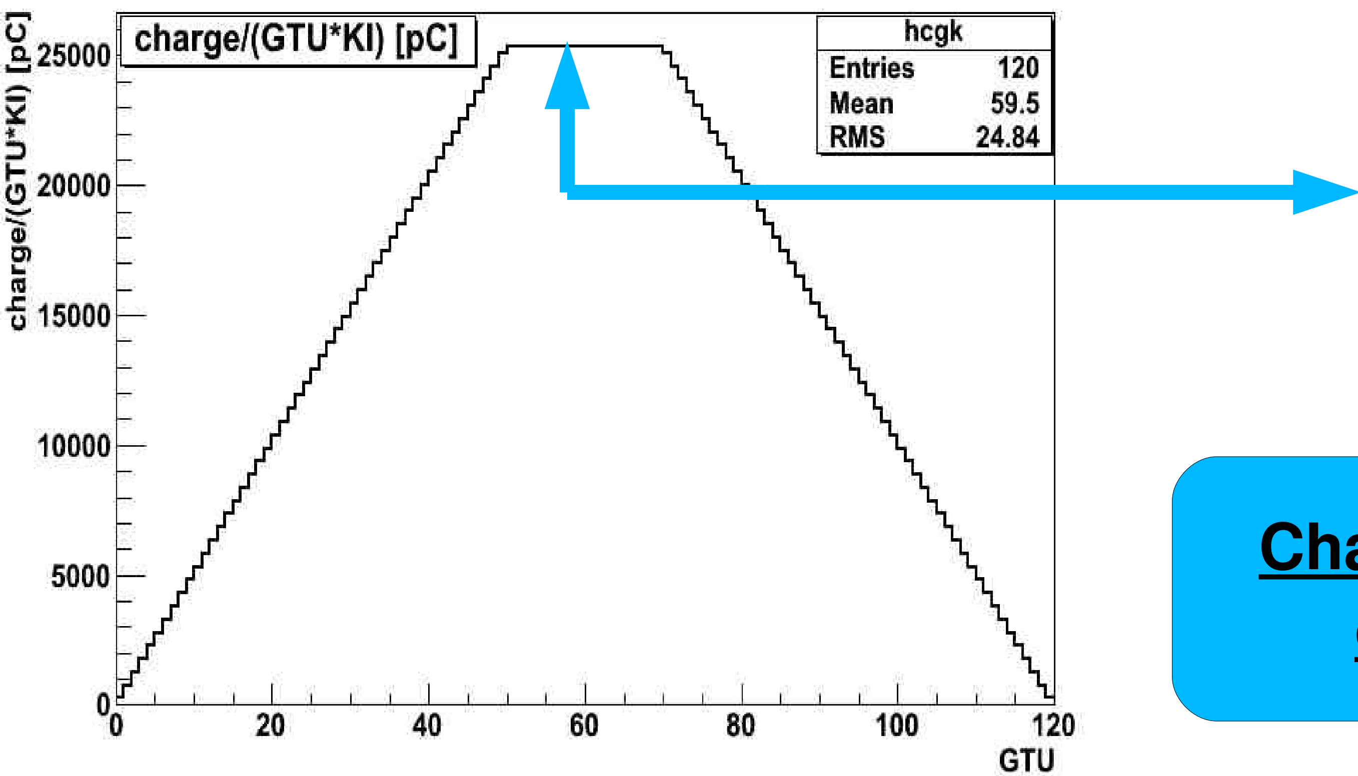
$$Nph = \left(\frac{(P*D)}{(h*\nu)}\right)*Ac*Sc*\left(\frac{(\pi*(d/2)^2)}{(4*\pi*D^2)}\right)$$

<u>We want just an estimate of the order of magnitude of the signal received by the telescope!</u>

Our assumptions for a TLE profile:

- **Total photon number of the whole event: 1.2×10^{12}**
- **Duration of the event: 300 μs = 120 GTU**
- **Shape of the light curve: isosceles trapeze**
- **Raise time – fall time: 50 GTU**
- **Radius of the event: 100km**
- **Event height: 10km (420km from ISS)**
- **Average background: 2 phe/(GTU*pix)**

data by M. Sato, Y. Takizawa, Y. Kawasaki, M. Bertaina, T. Ebisuzaki, Y. H. Takahashi, D. Lebrun & EUSO collaboration

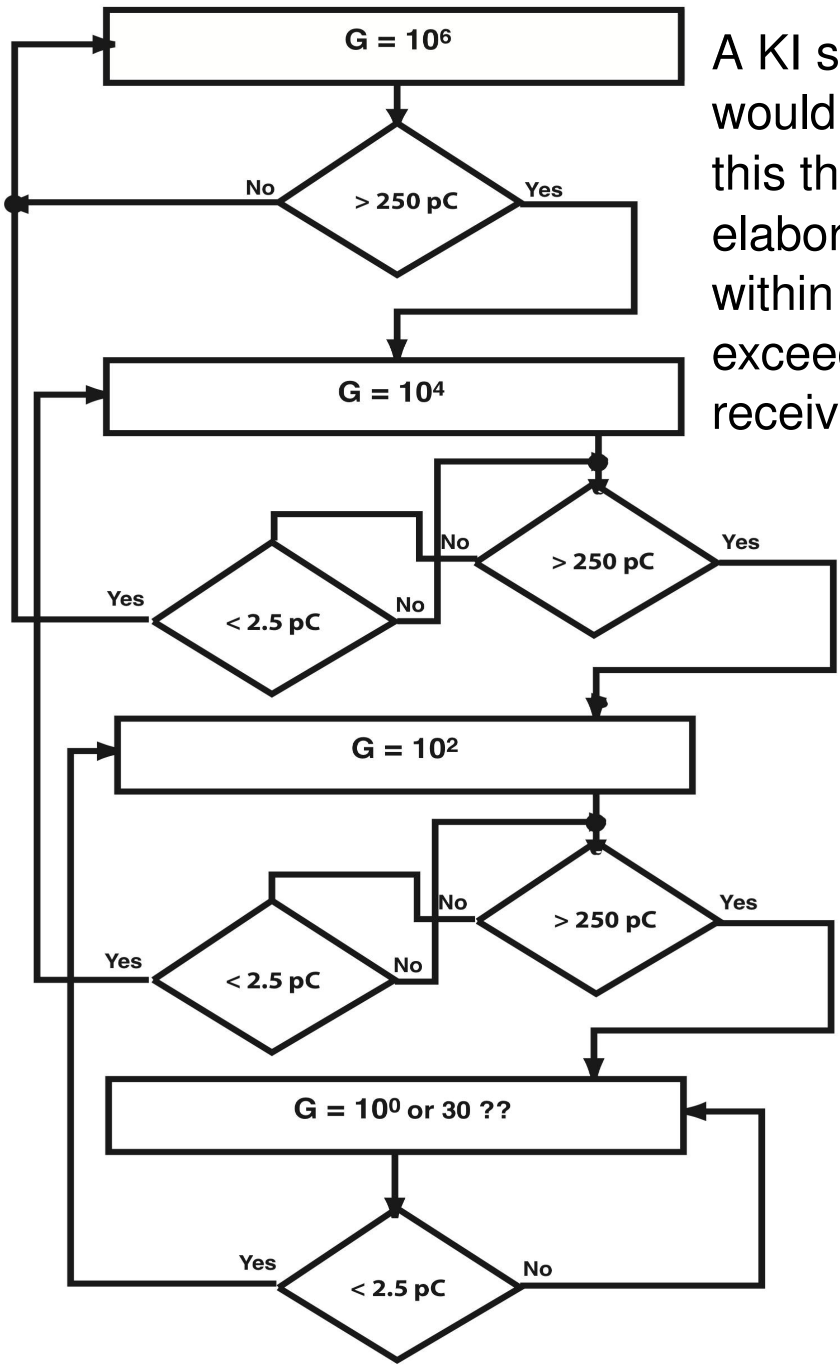


25000 pC/(GTU*KI)

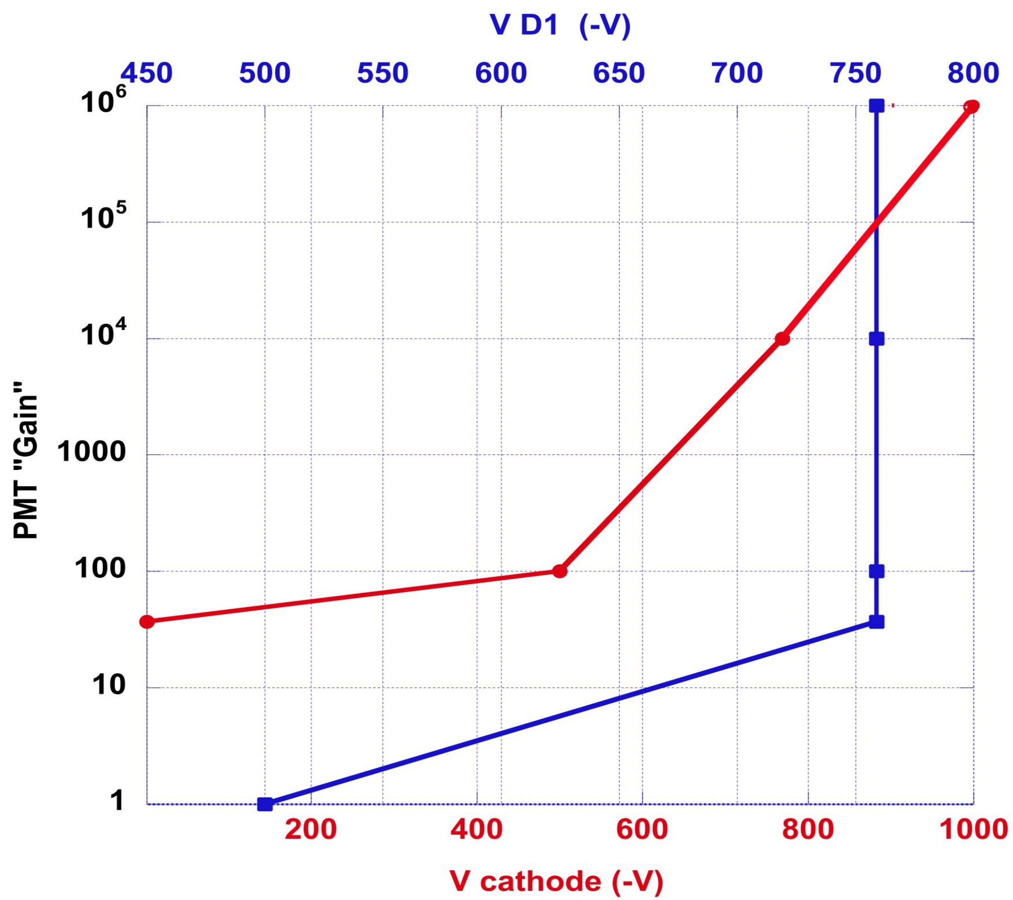
Charge signal seen by one KI of a PDM

SWITCH-LOGIC

A way to protect from very luminous events



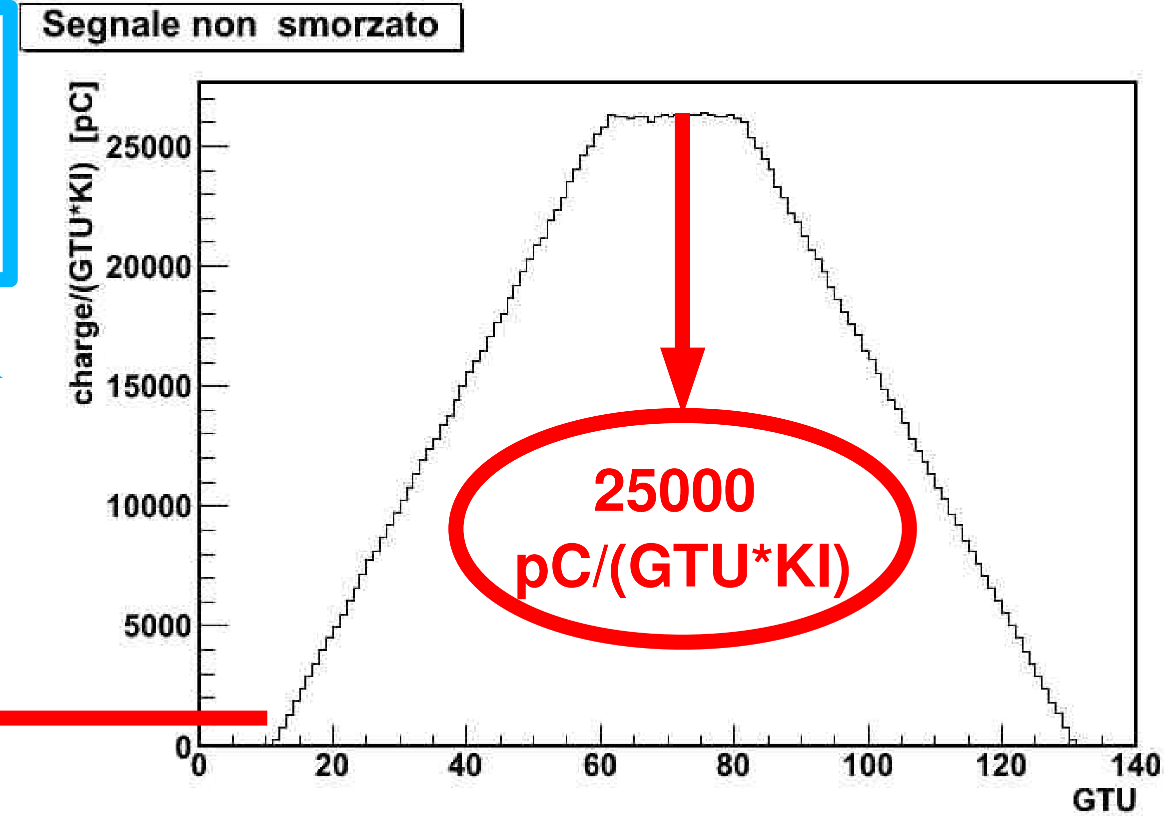
A KI should not have more than 250 pC/gtu because it would start saturating the electronics. In case of such events this threshold is strongly exceeded**.** With the *switch-logic* elaborated by P. Gorodetzky we manage to reduce the gain within 2 GTUs of a factor 100 as soon as the threshold is exceeded in just one KI of the PDM. Only when every KI receives less than 2.5 pC the gain can be increased again.



For a better simulation of reality we introduce some statistical draws:

DRAW	KIND OF DRAW	MEAN VALUE	STANDARD DEV.
# background phe	Poisson	16 phe/(GTU*KI)	4 phe/(GTU*KI)
# TLE-born phe	Poisson if mean value <50	Calculated for each GTU with the trapeze model	Square root of the mean value
//	Gauss if mean value >50	Calculated for each GTU with the trapeze model	Square root of the mean value
Gain value for PMT	Gauss	0.16 pC/phe	0.016 pC/phe
Gain value for KI	Gauss	PMT gain value	0.002 pC/phe
Charge value for KI	Gauss if # of phe is >50	KI gain * # phe of the KI	$\frac{0.08(pC/phe) * KIgain * phe\ of\ the\ KI}{\sqrt{phe\ of\ the\ KI}}$
//	Draw each phe from single phe distribution if # of the phe <50	0.16 pC/phe	0.08 pC/phe

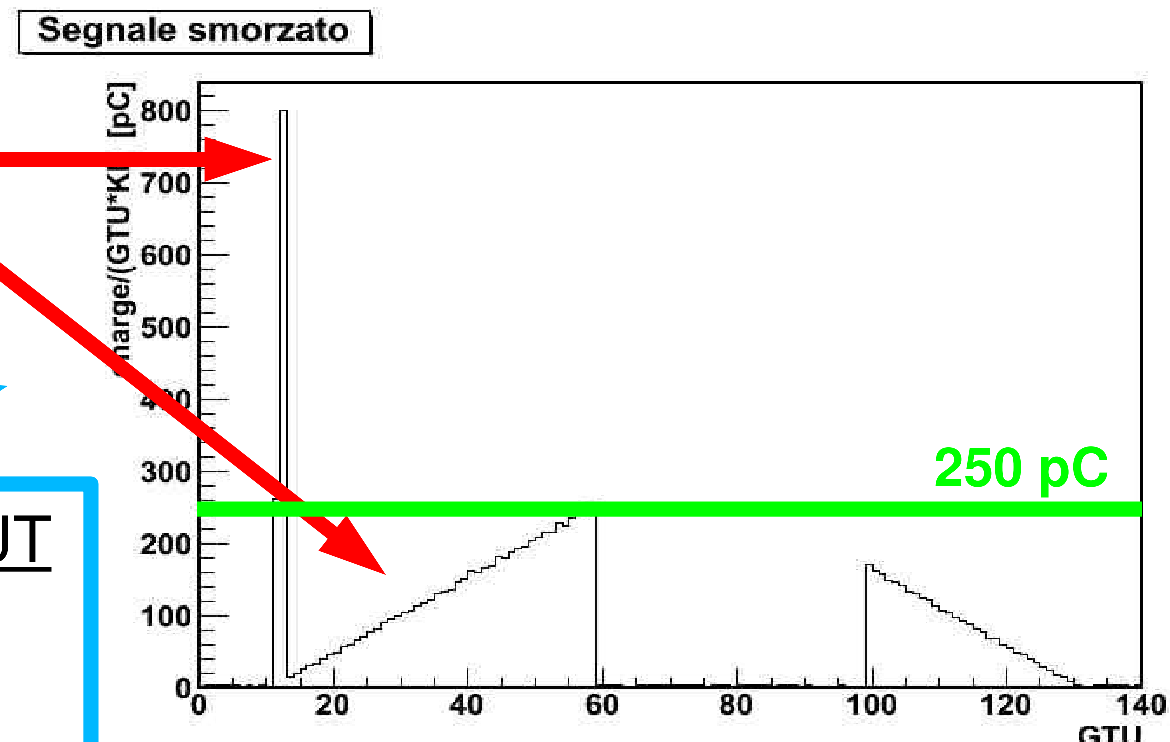
SIGNAL REGISTERED WITHOUT SWITCH-LOGIC



250 pC exceeded!

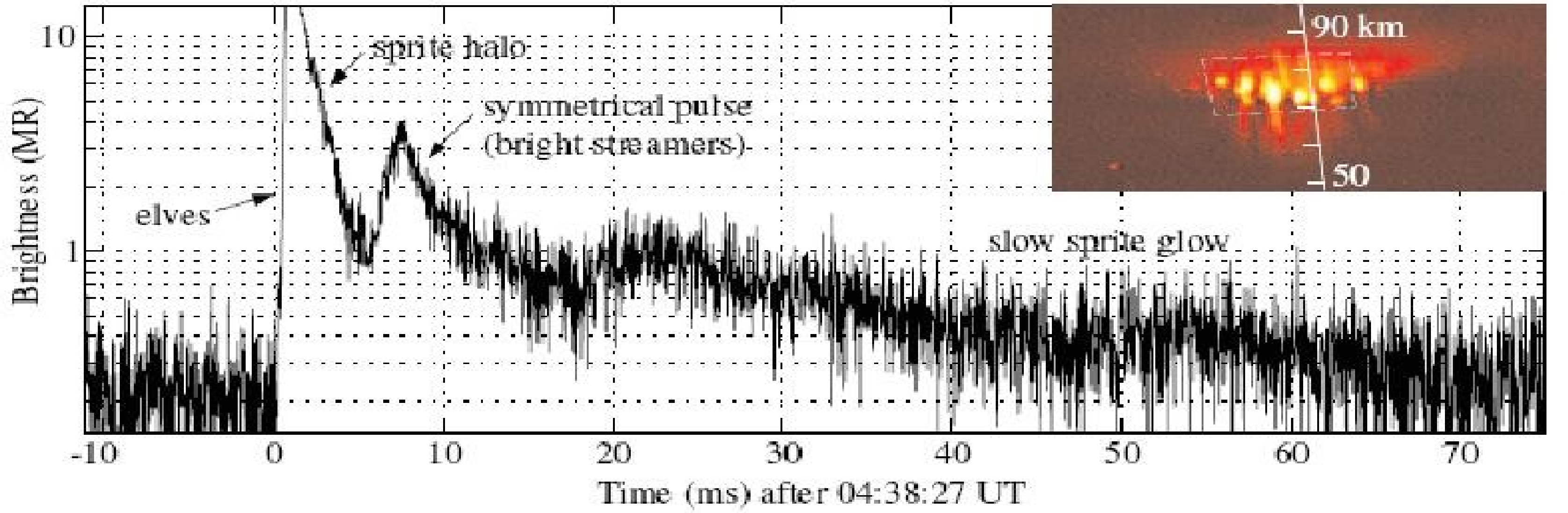
GAIN DECREASED

From 10^6 to 10^4



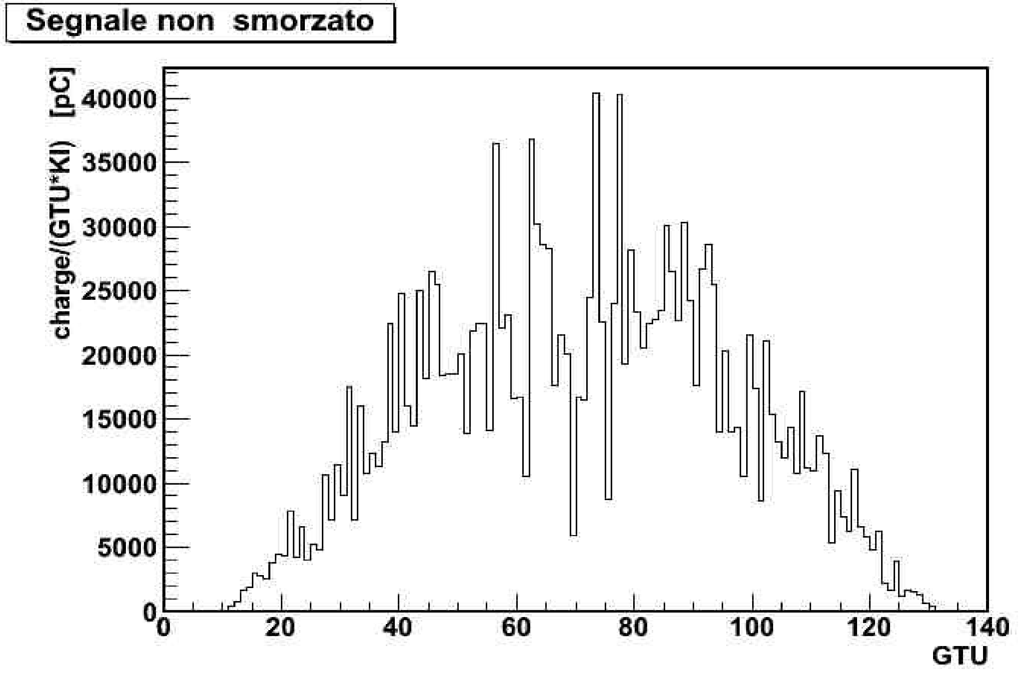
SAME SIGNAL AS ABOVE BUT REGISTERED WITH SWITCH-LOGIC

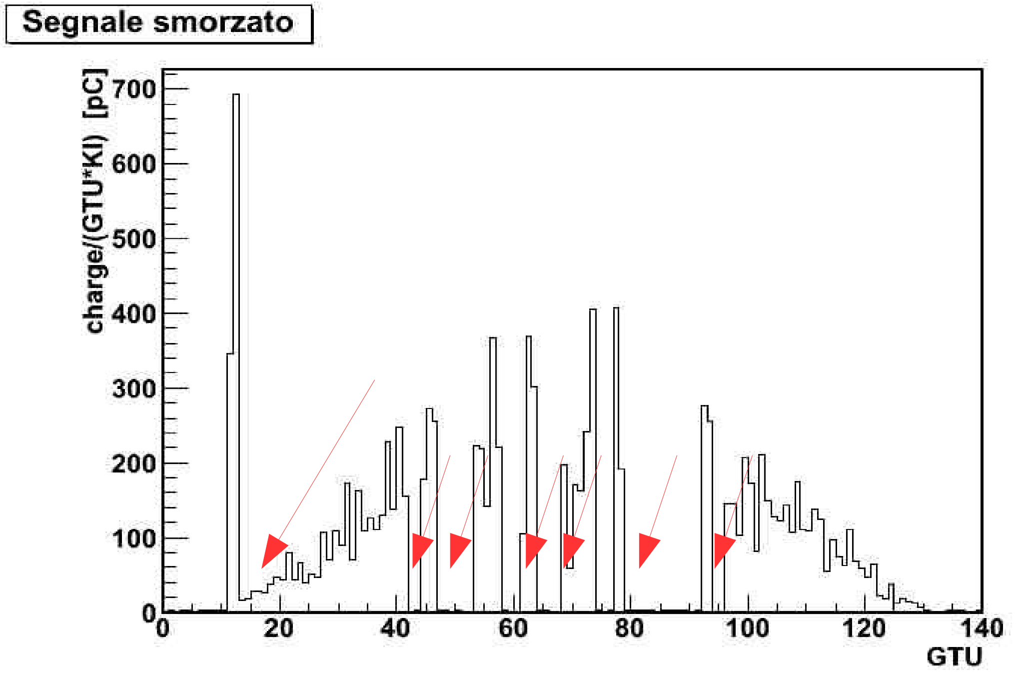
….JEM-EUSO Phase A study...



Report on the Phase A Study 2010 (Purple Book)

On the basys of this graphic we introduced a bigger oscillation to the signal origin:
MORE OSCILLATION MORE SWITCHES!!!





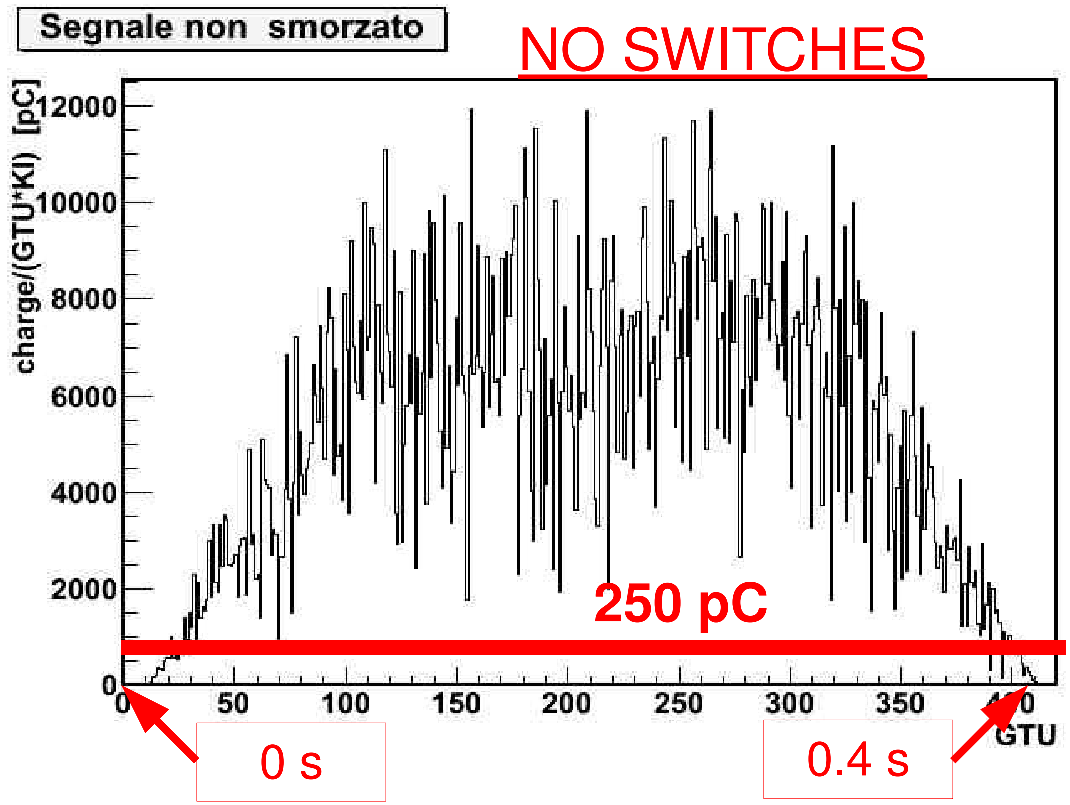
TLEs SIMULATION: **JET**

TLEs SIMULATION: JET

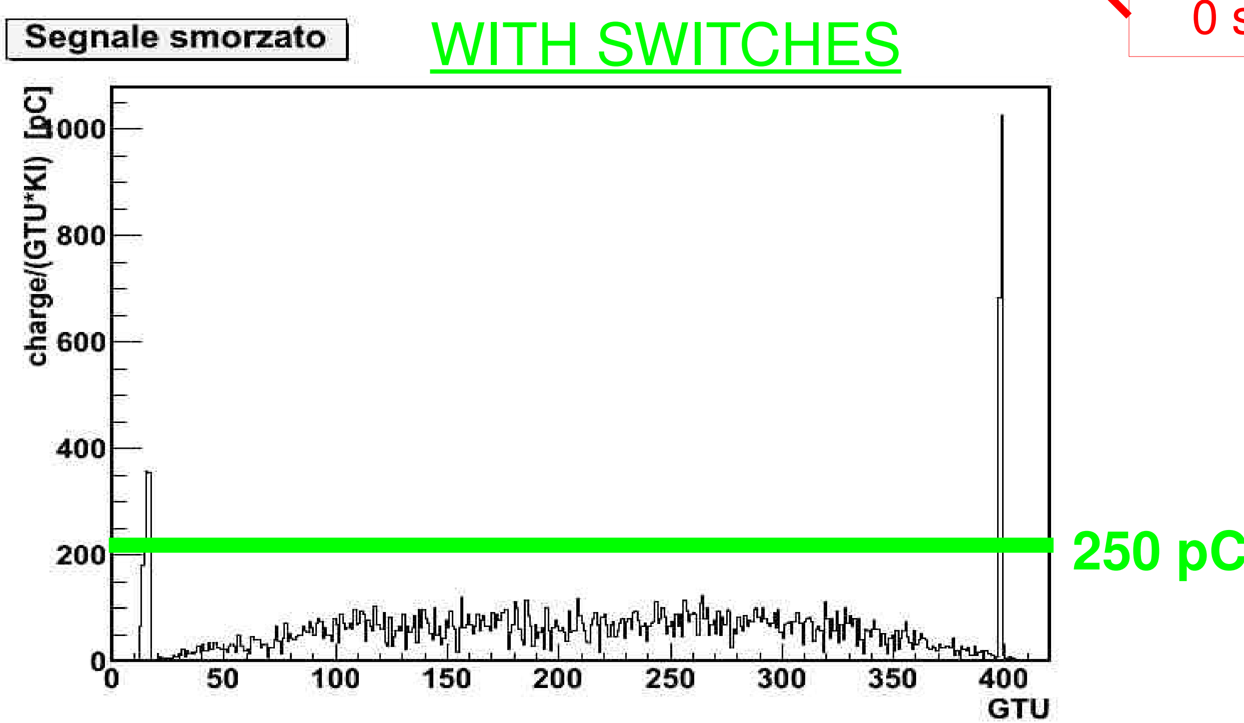
TLE	jet
Power	10^4 W
Duration	0.4 s
Radius	40 km
Height in atm.	Troposphere

THE SIGNAL HAS BEEN SAMPLED: THE INTERVAL BETWEEN 2 GTUs IS 1 ms!!!

NO SWITCHES



WITH SWITCHES



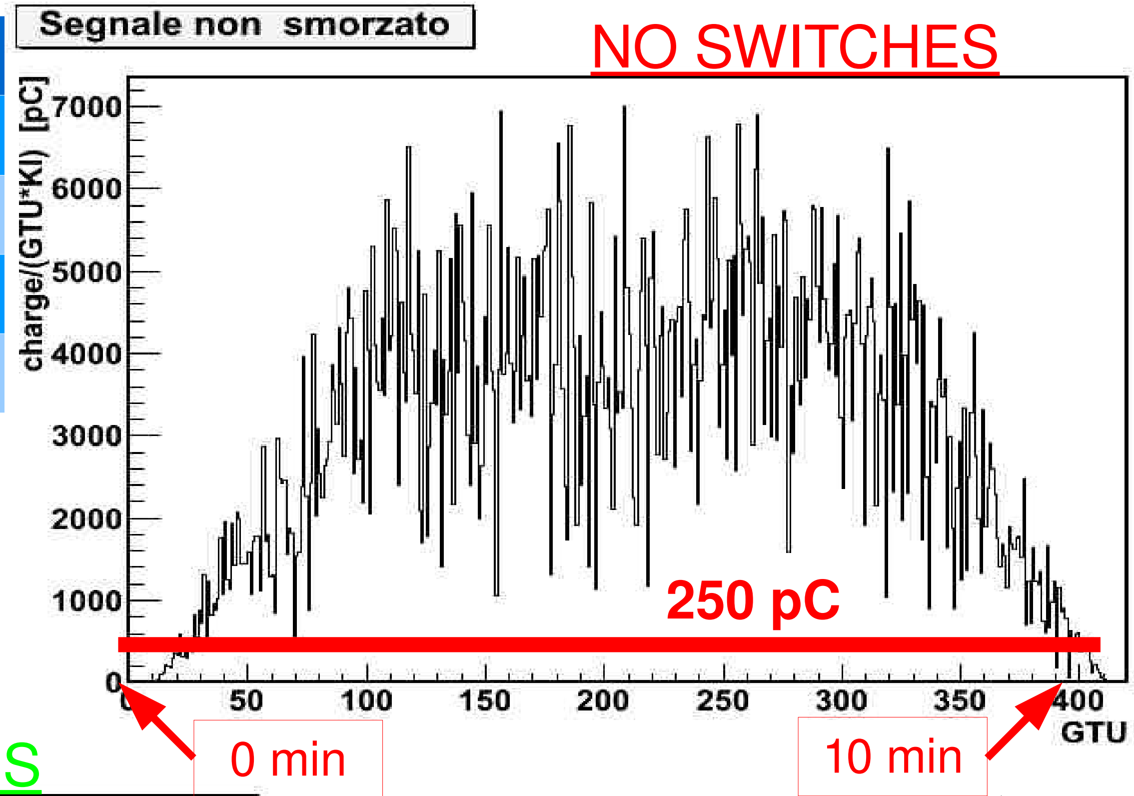
SWITCH-LOGIC WORKS!

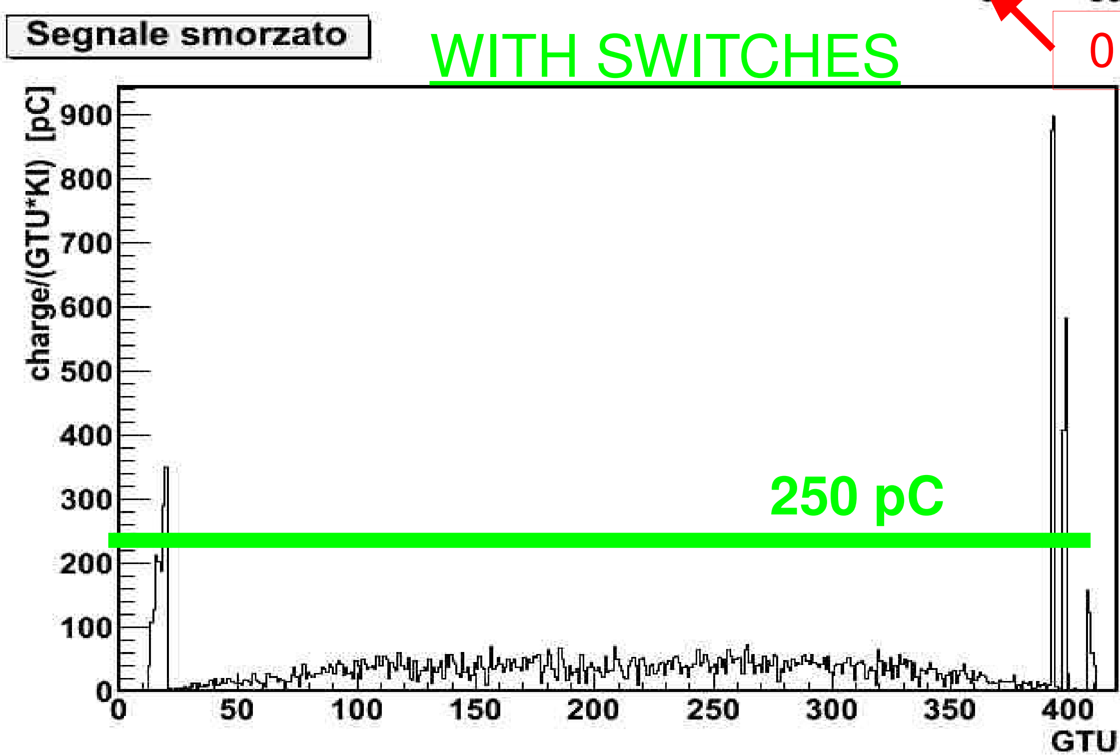
TLEs SIMULATION: **AURORA**

TLEs SIMULATION: AURORA

TLE	aurora
Power	10^{10} W
Duration	10 min
Radius	300 km
Height in atm.	Mesosphere

THE SIGNAL HAS BEEN SAMPLED: THE INTERVAL BETWEEN 2 GTUs IS 1.5 s!!!

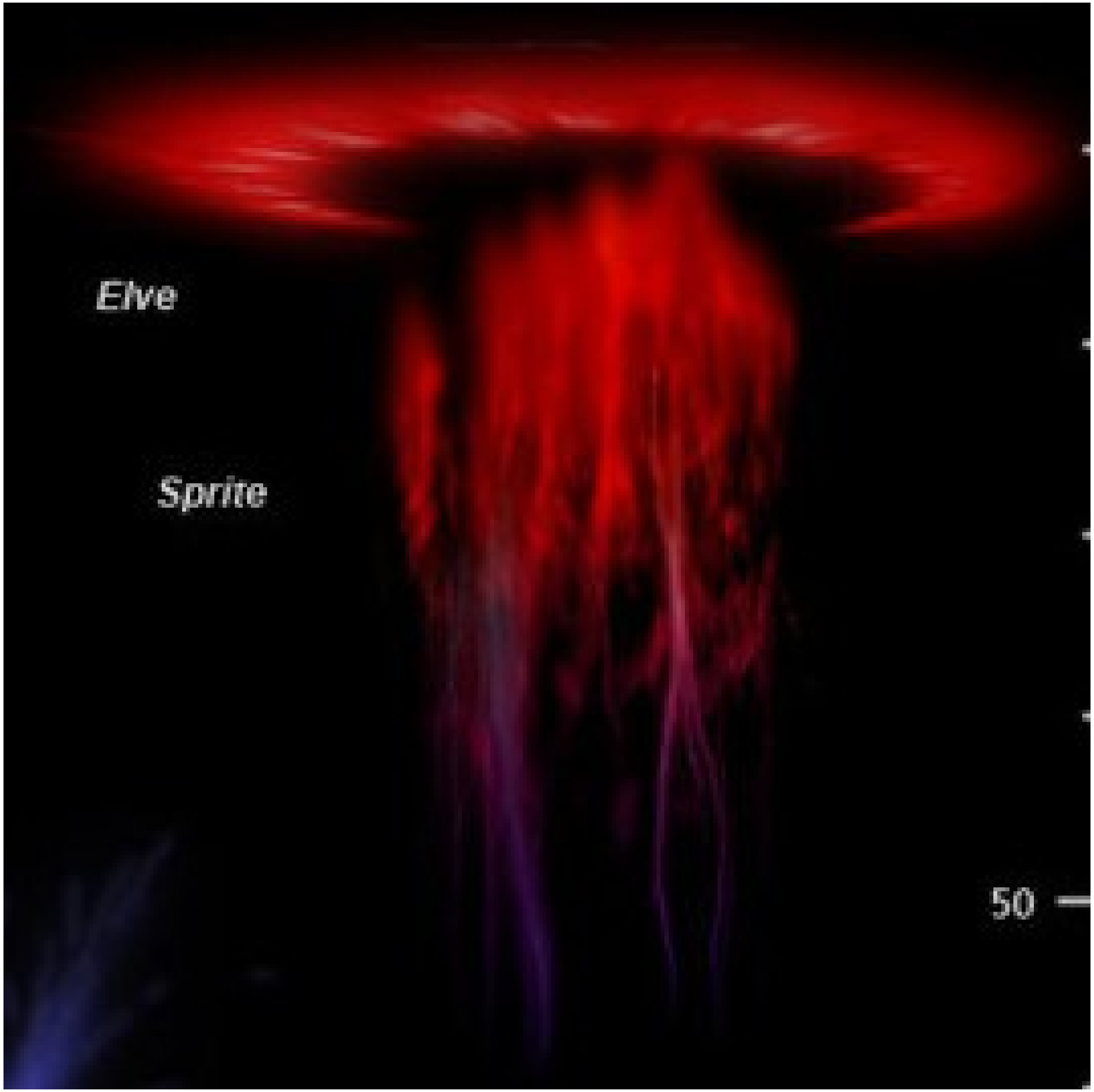




SWITCH-LOGIC WORKS!

Very long event =
All the FoV calls lots of current!
Could it be a problem?

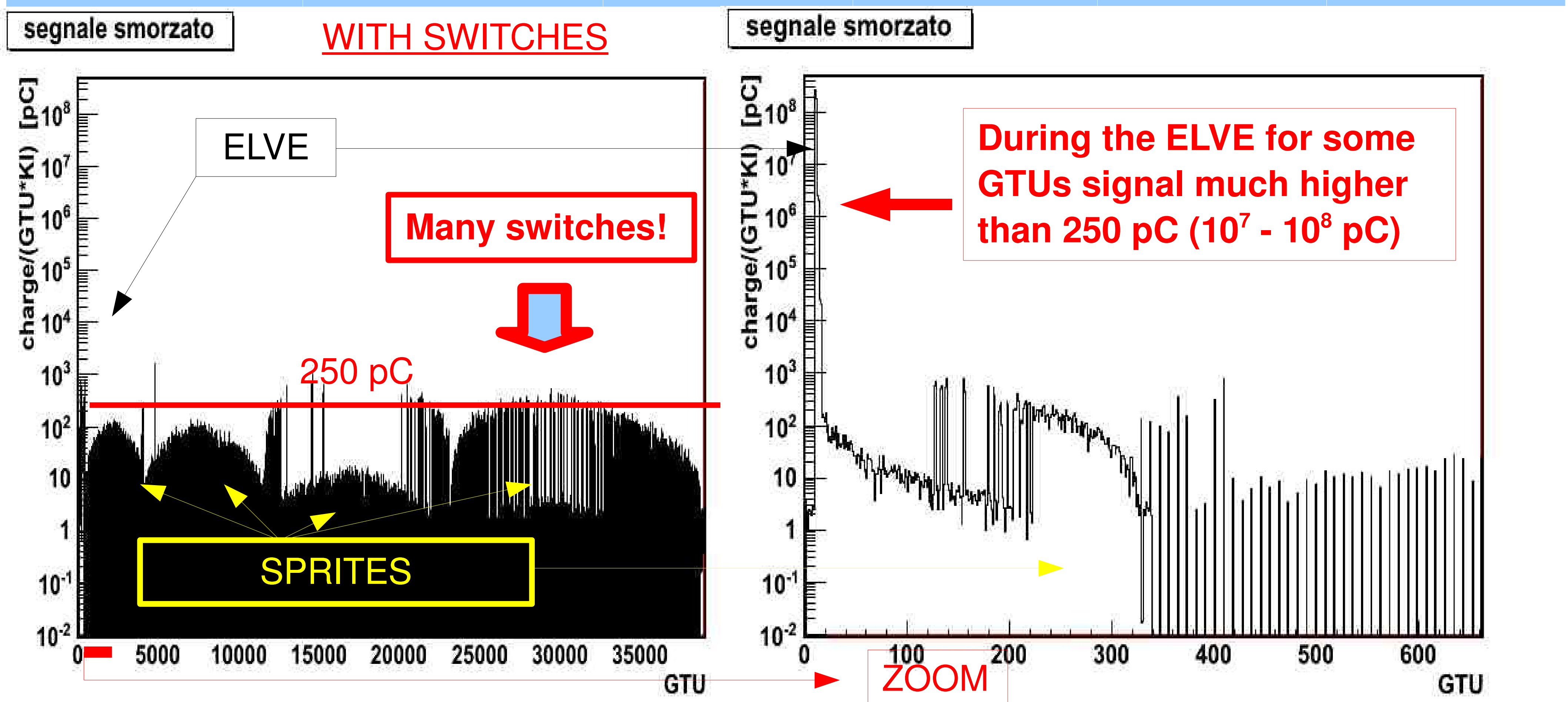
TLEs SIMULATION: **ELVE & SPRITES**



TLEs SIMULATION: ELVE & SPRITES

Sprites often happen in groups of some units, following an elve...

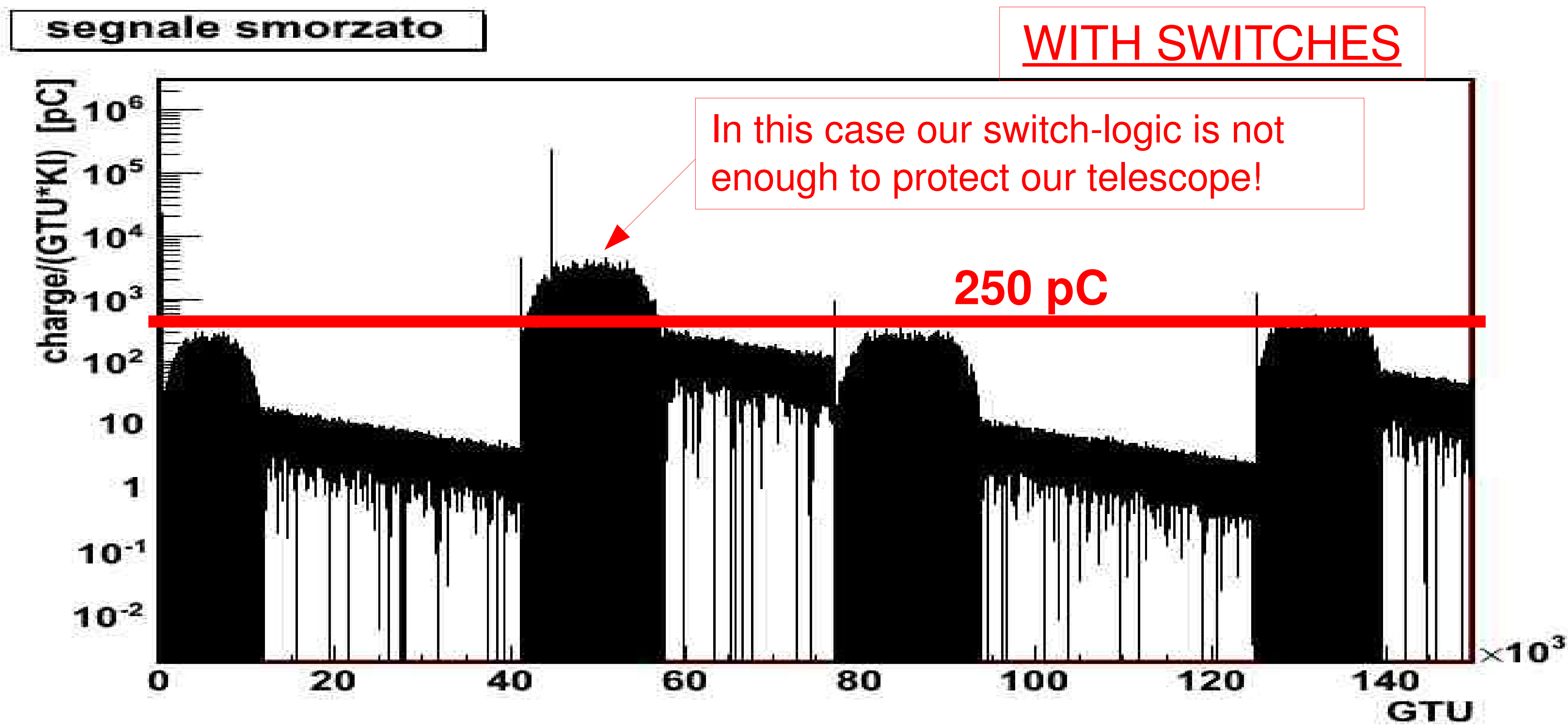
TLE	elve	sprite 1	Sprite 2	Sprite 3	Sprite 4
Power	10^{10} W	~10^{7} W	~10^{7} W	~10^{7} W	~10^{7} W
Duration	0.008 s	0.01 s	0.02 s	0.03 s	0.04 s
Radius	200 km (R max)	9.8 km	5.8 km	8.6 km	8.0 km
Height in atm.	Mesosphere	Mesosphere	Mesosphere	Mesosphere	Mesosphere



TLEs SIMULATION: **4 DISCHARGES LIGHTNING**

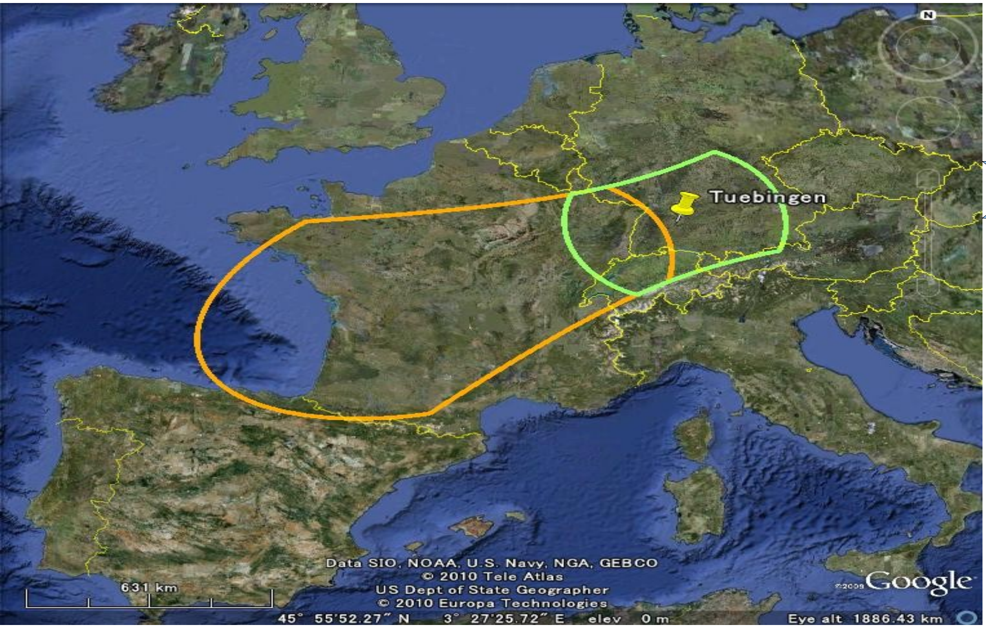
TLEs SIMULATION: 4 DISCHARGES LIGHTNING

Discharge #	1	2	3	4
Power	~10^{11} W	~10^{11} W	~10^{11} W	~10^{11} W
Duration	0.03 s	0.04 s	0.04 s	0.03 s
Radius	19 km	4 km	15 km	12 km
Height in atm.	Troposphere	Troposphere	Troposphere	Troposphere



The shape of the profiles are rough approximation but what we were interested in was just testing the efficacy of the *switch-logic* on this kind of events!

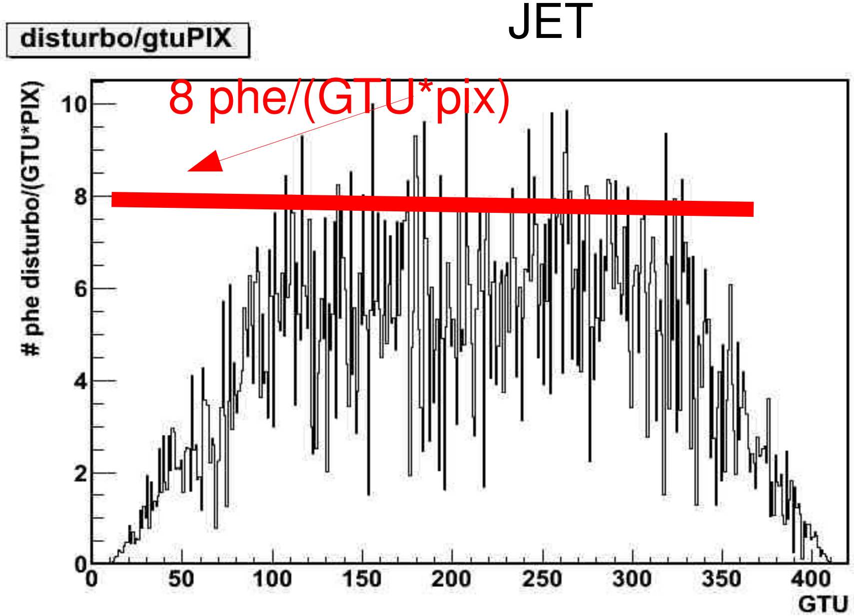
DISTURB PHOTONS:
ANOTHER PROBLEM RELATED TO VERY LUMINOUS EVENTS



BIG FOV! Covers areas with different weather condition at the same time

Because of optics difects we'll have some photons scattered all around the focal surface, even on PDM covering areas without luminous events!!!

NORMAL BACKGROUND = 2phe/(GTU*pix)



A number of scattered photons of the order of 2% is enough to disturb CR detection also in case of not very intense phenomena such as the JET previuosly presented!

CONCLUSIONS

It has been explained how JEM-EUSO can describe TLEs, therefore it will be possible to test the theory about the correlation between CR and TLEs.

The effect of the switch-logic to protect the telescope has been tested on simulated TLEs events.
In general the technique works and the gain is rapidly decreased below problematic levels.

However, in few cases this technique is not enough.
Second, some hysteresis seems to be needed ato avoid series of switches due to signal fluctuations.

Finally, it has to be assessed if the intense light in one part of the FoV could prevent the measurement in the rest of the FoV.


THE END!

TLES

LIGHTNING are intra-cloud or cloud-to-ground (less common) discharges that happen in presence of a strong d.e.p., as soon as the electric resistance of air is overcome. Most of the lightnings bring negative charges to/towards the groud but lightnings produced by positive charges do exist too.
Such events are composed by a series of disharges, in average four.
SPRITES are correlated with CG or intra-cloud lightning. Once a negative region is created on the cloud top, electrons can be accelerated towards the ionosphere exciting atmospheric molecules, wich coming back to their fundamental state emit electromagnetic radiation.
ELVES are correlated with strong lightning discharges and can happen before sprites. They appear as small flat disk expanding at speed of light up to a 200km diameter disk.
JETS are phenomena of still unknown origin. They are blue colored beams expanding in conical form with velocity of about 100km/s.
AURORAE are generated by the interaction of solar-wind particles and atoms of the ionosphere after that some charged solar-wind particles has penetrated the atmosphere along magnetic field lines near the poles.

RUNAWAY BREAKDOWN vs NORMAL BREAKDOWN

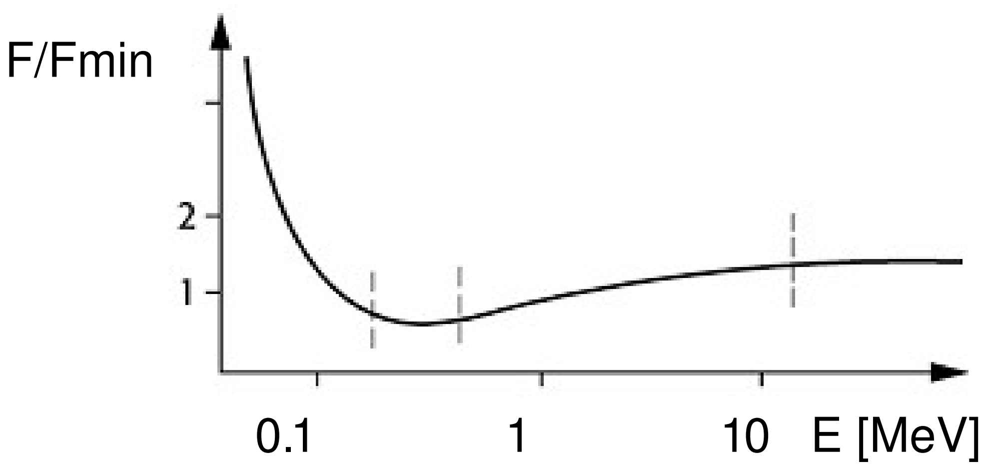
Both phenomena need the presence of intense electric fields that can be generated in clouds by:

1. Cloud to Ground discharges
2. Capture of charged particles by cloud boundaries

The best condition for the creation of such electric field are in clouds because there the conductivity is low and the relaxation time of the electric field is high ($\tau \sim \sigma^{-1}$).

RUNAWAY BREAKDOWN

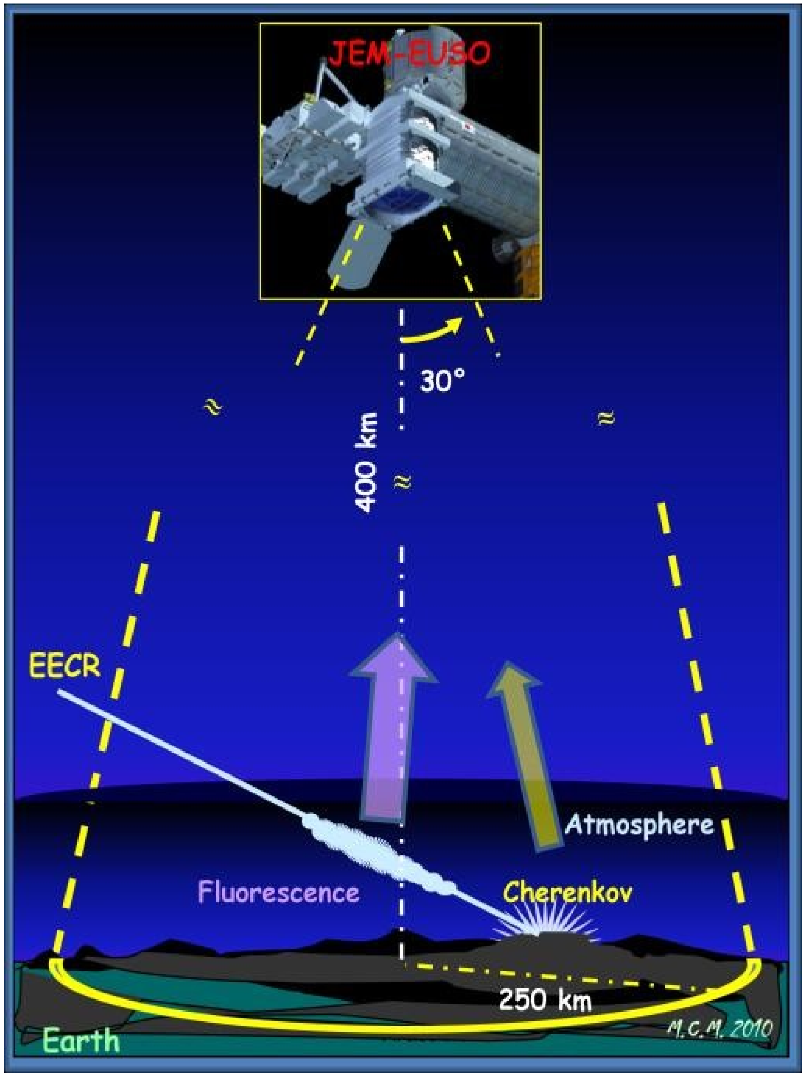
If this electric field is more intense than the threshold value = 216kV/m, electrons of energies 0.1-1 MeV which are under the influence of a weak braking force, can be accelerated by the E field and generate other electrons with a higher energy than the critical value. The avalanche is also increased by electrons coming from ionization.

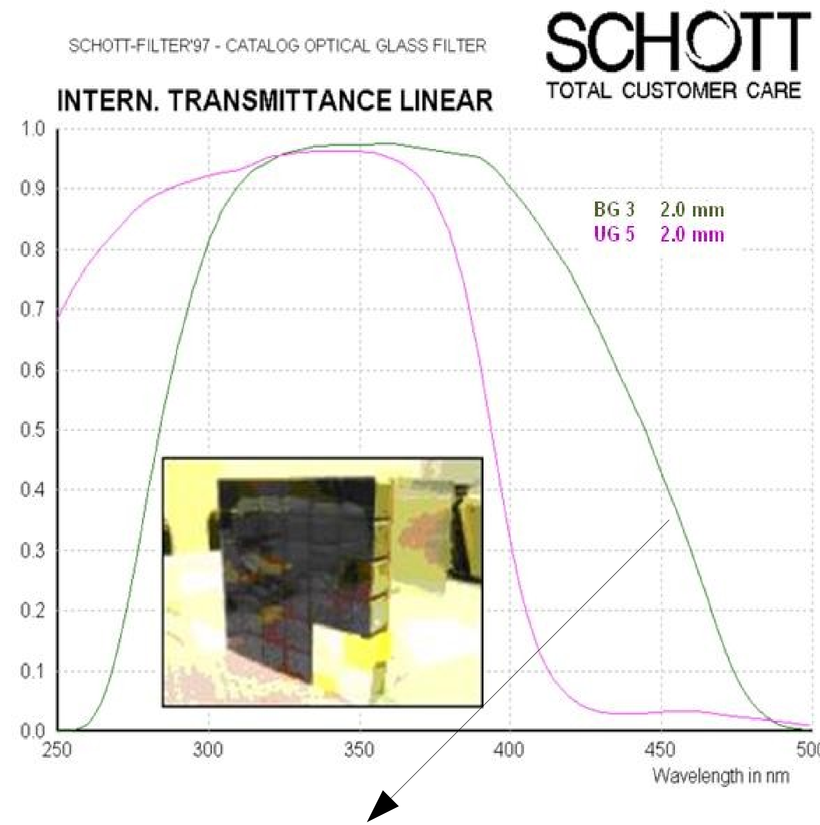


NORMAL BREAKDOWN

If the electric field is more intense than the threshold value = 2300kV/m, electrons can be heated. If such electrons get energy values of the order of 10-20 eV they will be able to ionize matter and create new electrons.
Such process can generate a very large number of free electrons.

JEM EUSO – CR PHOTONS





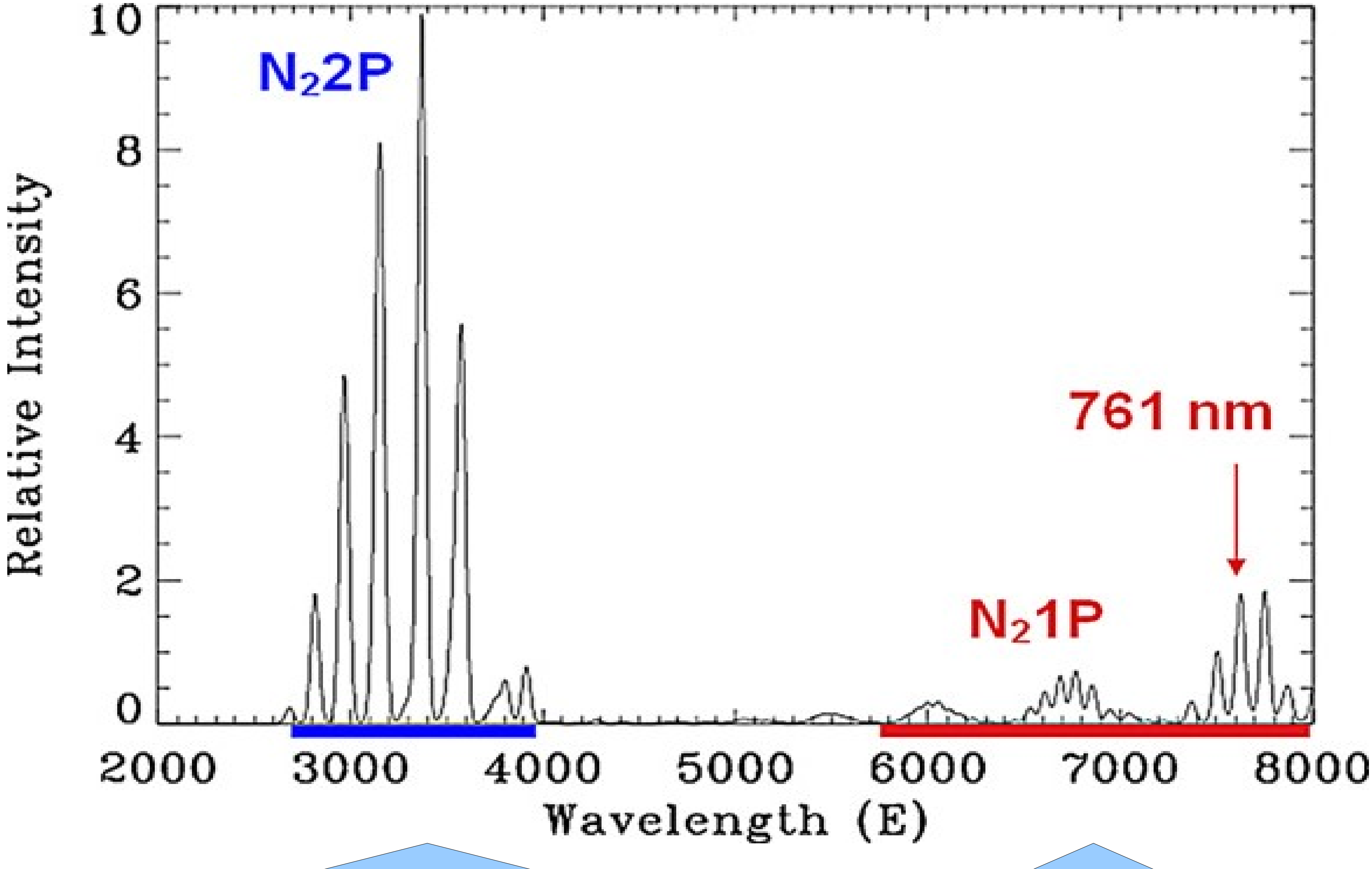
BG3 band-pass filter

EECR → EAS →

Fluorescence photons from secondary CR-Nitrogen interaction

Cherenkov photons from Earth's albedo

SPRITE SPECTRUM



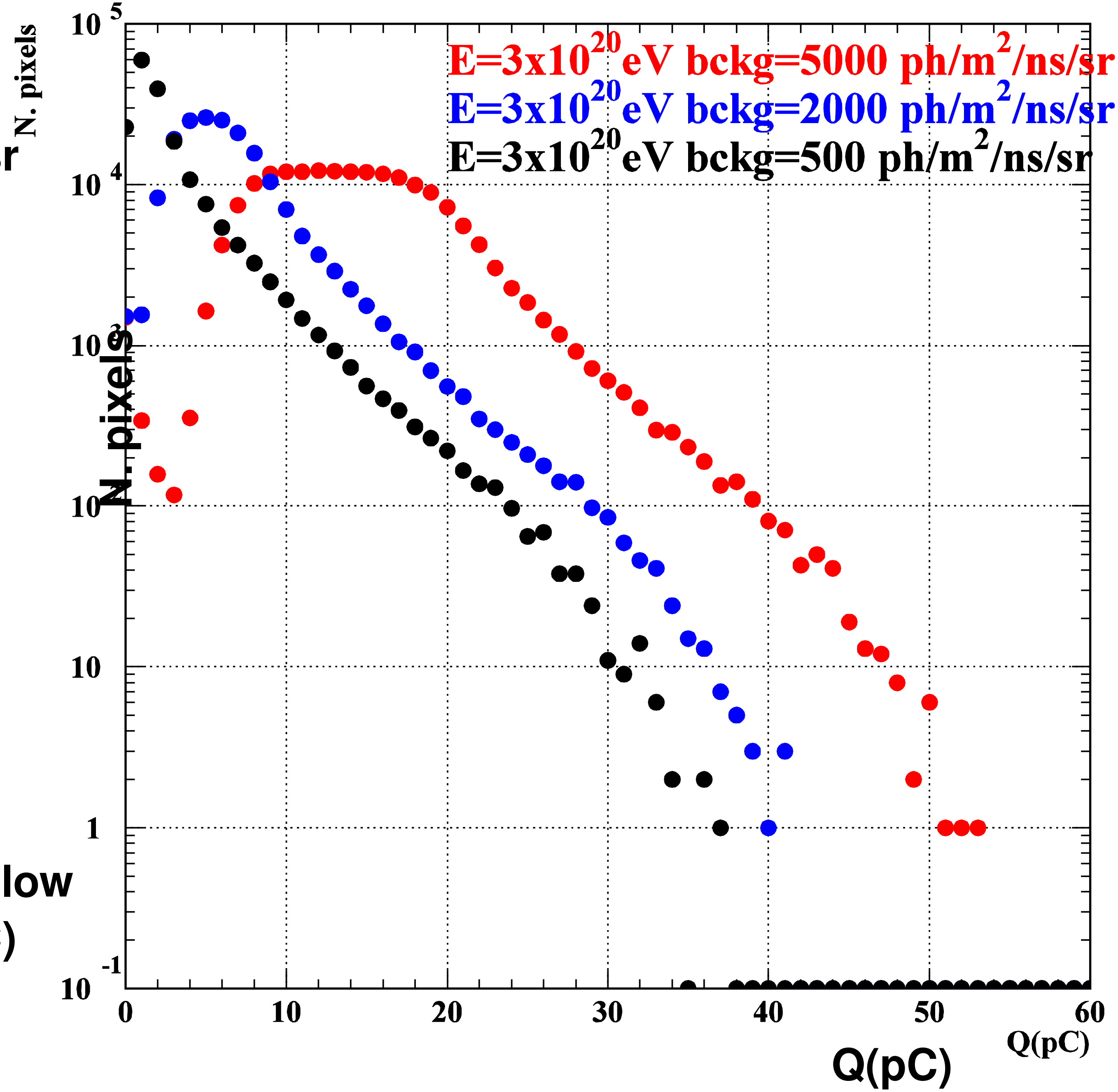
BLUE PART SEEN BY EUSO: ~70%

UNDETECTED PART: ~30%

Air Showers & KI

~2500 ev. @ 3x10e20 eV

Bckg variable:
500 – 5000 ph/m²/ns/sr



We can expect that
@ 1e21eV we are still below
switch threshold (250pC)