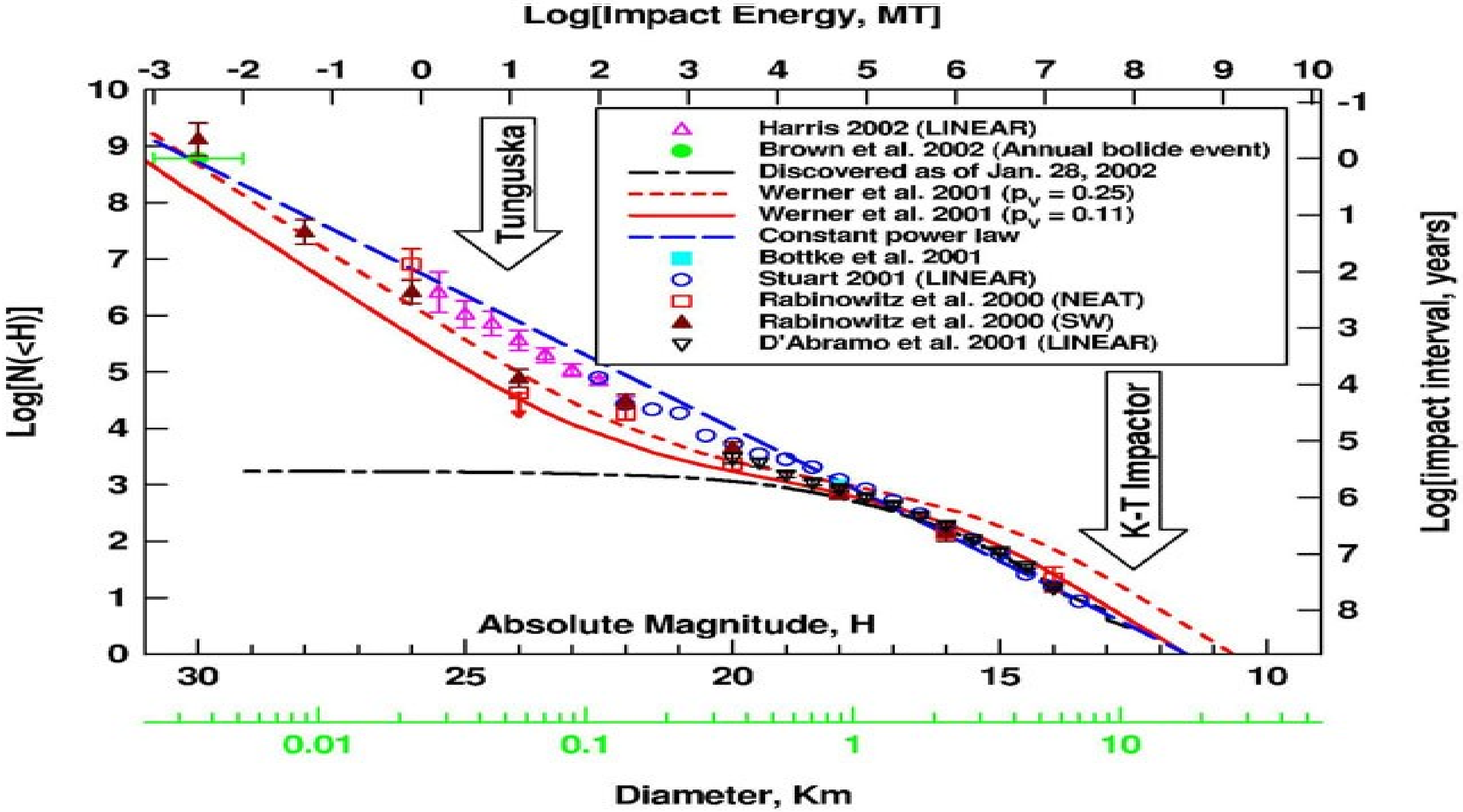
SIMULATION OF METEORS FOR THE JEM-EUSO EXPERIMENT

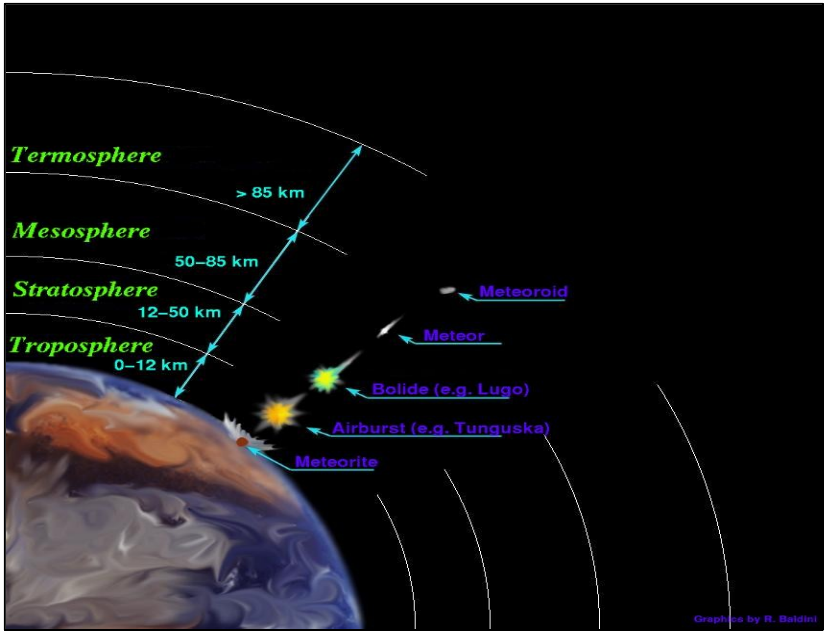
CANDIDATO: Fabrizio Gola
RELATORE: dott. Mario Edoardo Bertaina
CORRELATORE: dott. Alberto Cellino

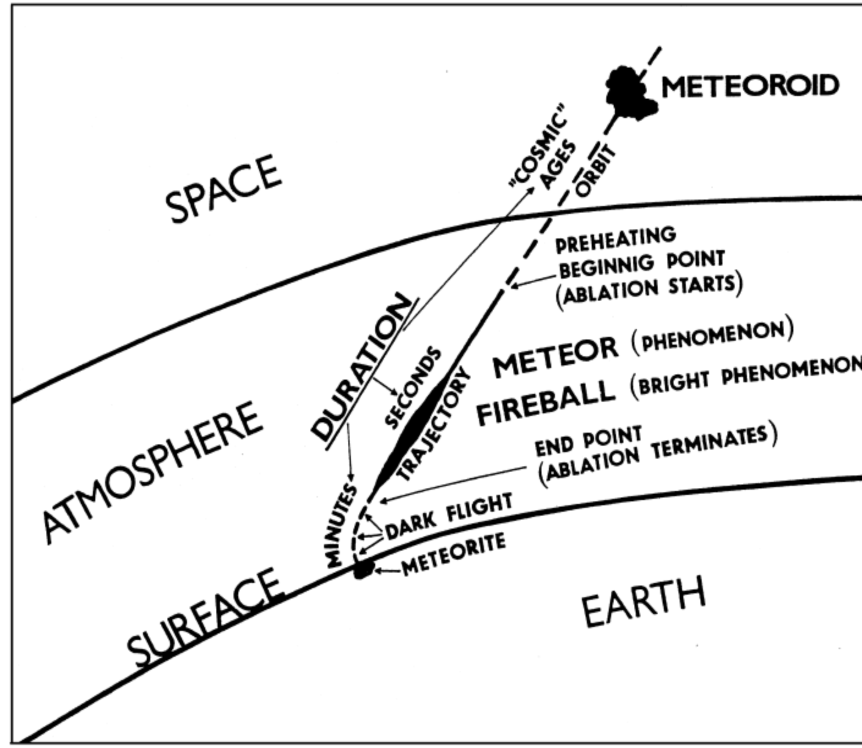

Meteor of the Perseids
observed from ISS (Aug. 2011)
JEM-EUSO on ISS

There are good reasons to study the so-called Near-Earth Objects (NEOs)



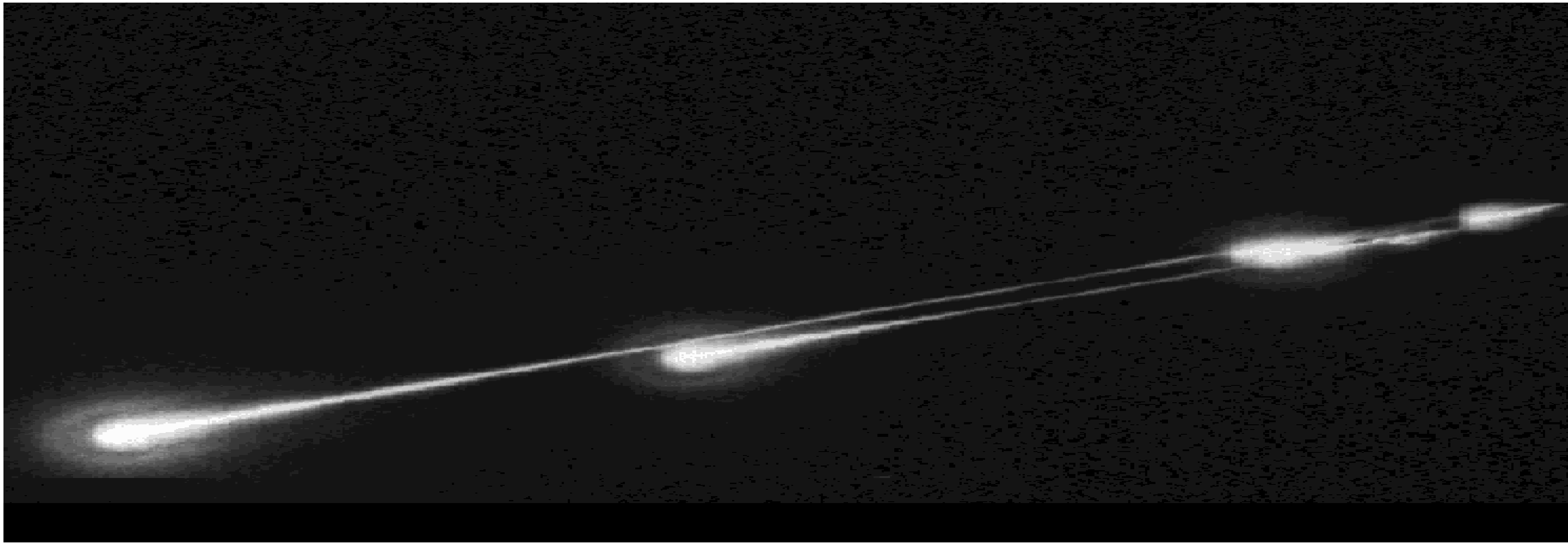
1 MT ~ 4.18 * 10^{15} J





- **Beginning point:** ~ 75 ÷ 120 km
- **End point:** ~ 30 ÷ 70 km
- **Duration:** ~ 0.5 ÷ 3 s
- **Length:** ~ 10 ÷ 20 km
- **Type:** sporadic, showers (~ 25% obs. meteors)
- **Frequency:** ~ 5 ÷ 100 per hour (up to thousands during meteor storms)

Visual meteors ⇒ **meteoroids with D > 2 mm**



The Peekskill fireball (Oct. 9, 1992)

$m < -8$ bolide or fireball **(meteoroid mass 10 ÷ 100 kg)**
$m < -17$ superbolide **(meteoroid mass > 1000 kg)**

Fireball precursors, between 10 m and 100 m in size, are the least known population of minor bodies in our Solar system

What we need to know about meteoroids

- Mass
- Density → Luminosity, deceleration, ablation equations
- Structure → Beginning and terminal heights
- Composition → Spectra + analysis of recovered meteorites
- Orbit → Velocity vector
- Flux → Direct observation

We want to obtain data on largest bodies observable in the atmosphere, filling in the missing data between 10^3 and 10^6 kg mass interval

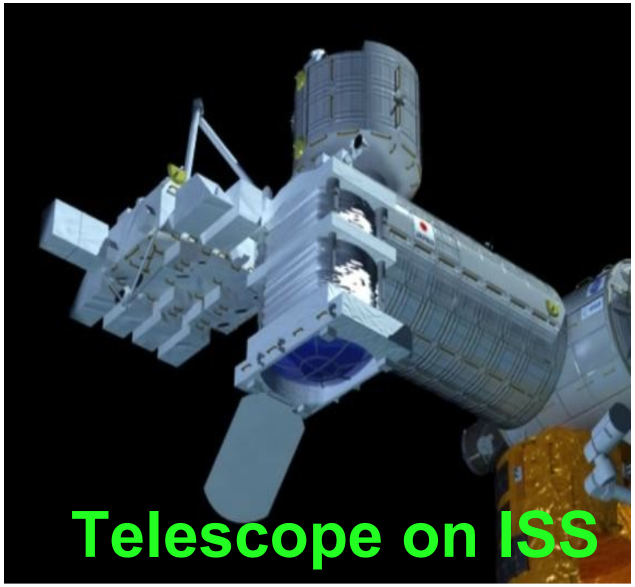
FONT: JEM-EUSO Meteor Observation by Watanabe, Ishiguro, Sato (13/06/2009)

ABSOLUTE MAGNITUDE	U-BAND FLUX (erg/s/cm^2/A)	FLUX (ph/s)	FLUX (phe/GTU) [1 GTU = 2.5 μs]	MASS (g)	COLLISIONS IN THE FIELD OF VIEW OF JEM-EUSO
+7	$6.7*10^{-12}$	$4.3*10^{7}$	11	0.002	1/s
+5	$4.24*10^{-11}$	$2.7*10^{8}$	68	0.01	6/min
0	$4.24*10^{-9}$	$2.7*10^{10}$	6750	1	0.27/orbit
-5	$4.24*10^{-7}$	$2.7*10^{12}$	675000	100	6.3/year (duty cycle 0.2)

flux=flux from Magnitude/Flux Density Converter of Spitzer Science Center (photometric system Johnson UBVRI+ in the U-band)

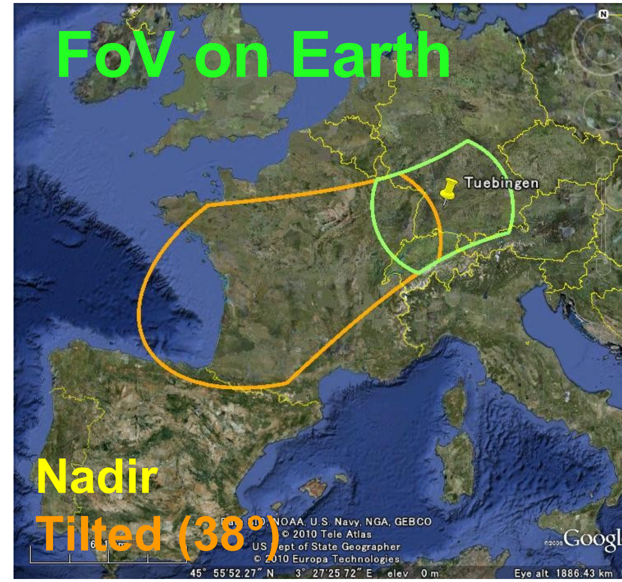
ph = photons phe = photoelectrons

What is JEM-EUSO telescope



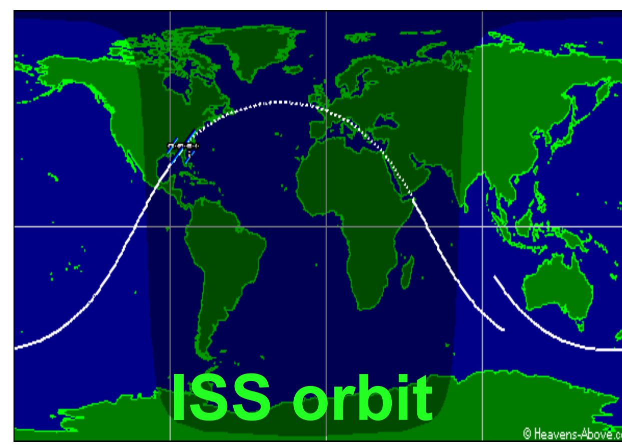
MISSION PARAMETERS

- **Time of launch:** year 2017
- **Operation period:** 3 years (+2 years)
- **Launching Rocket:** H2B
- **Transportation to ISS:** un-pressurized Carrier of H2 Transfert Vehicle (HTV)
- **Site to Attach:** Japanese Experimental Module/Exposure Facility #2
- **Height of the Orbit**: ~ 400 km
- **Inclination of the Orbit:** 51.64 °
- **Latitude and longitude:** 51.6° N – 51.6° S (for all longitudes)
- **Power:** 926 W (operative), 352 W (non-operative)
- **Mass**: 1983 kg
- **Data Transfert Rate:** 285 kpbs + on-board storage
- **Period of the Orbit:** 90 mins

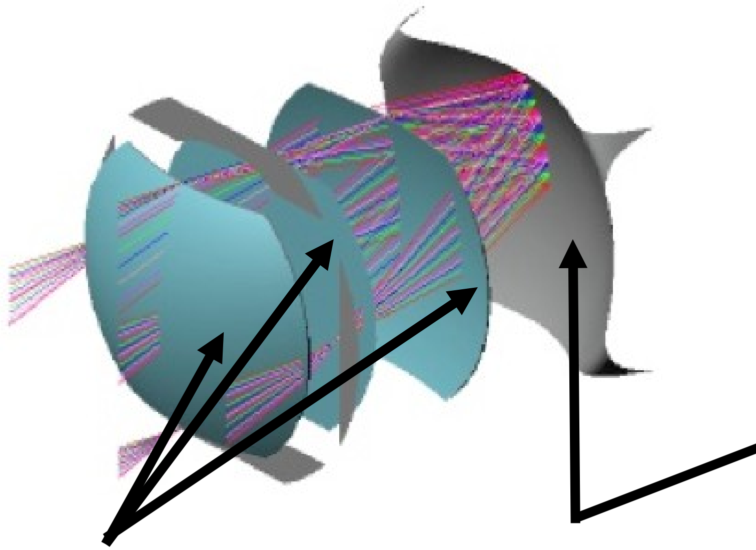


INSTRUMENT PARAMETERS

- **Field of view:** ± 30°
- **Aperture diameter:** 2.5 m
- **Optical bandwidth:** 330 ÷ 400 nm
- **Angular resolution:** 0.07°
- **Pixel size:** 2.9 mm
- **Number of pixels:** ~ 3.0×10^5
- **Pixel size at ground:** 560 m
- **Event time sampling:** 2.5 μs = 1 GTU
- **Observational area:** > 1.9×10^5 km^2 (depending on the pointing angle)
- **PMT Gain:** 10^6 (0.16 pC / phe)
- **Detector efficiency:** 0.12
- **KI partition:** rectangular (4 x 2 pixels)



Optics and electronics



3 Fresnel lenses

Detector Focal Surface

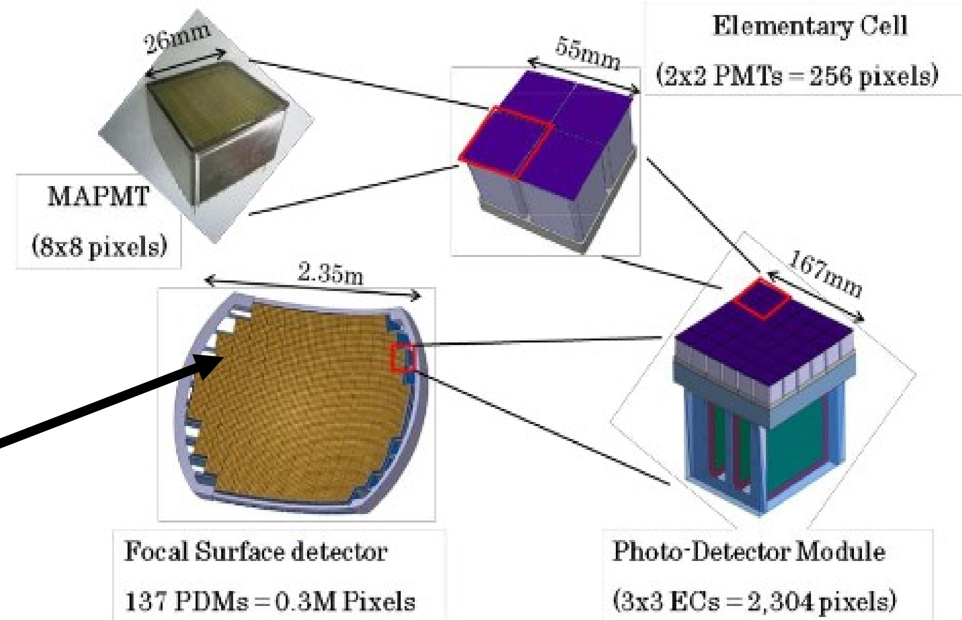
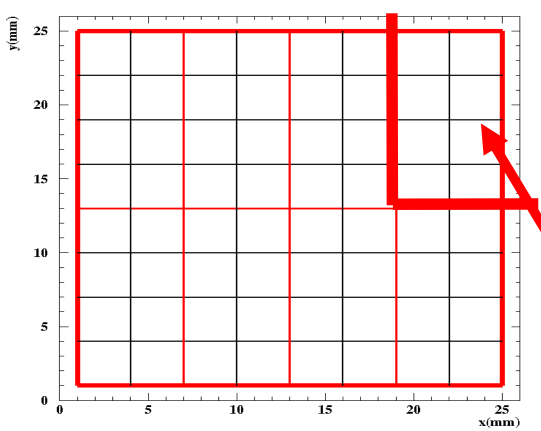


Figure 4.3.1-1. *Focal surface detector and its structure.*



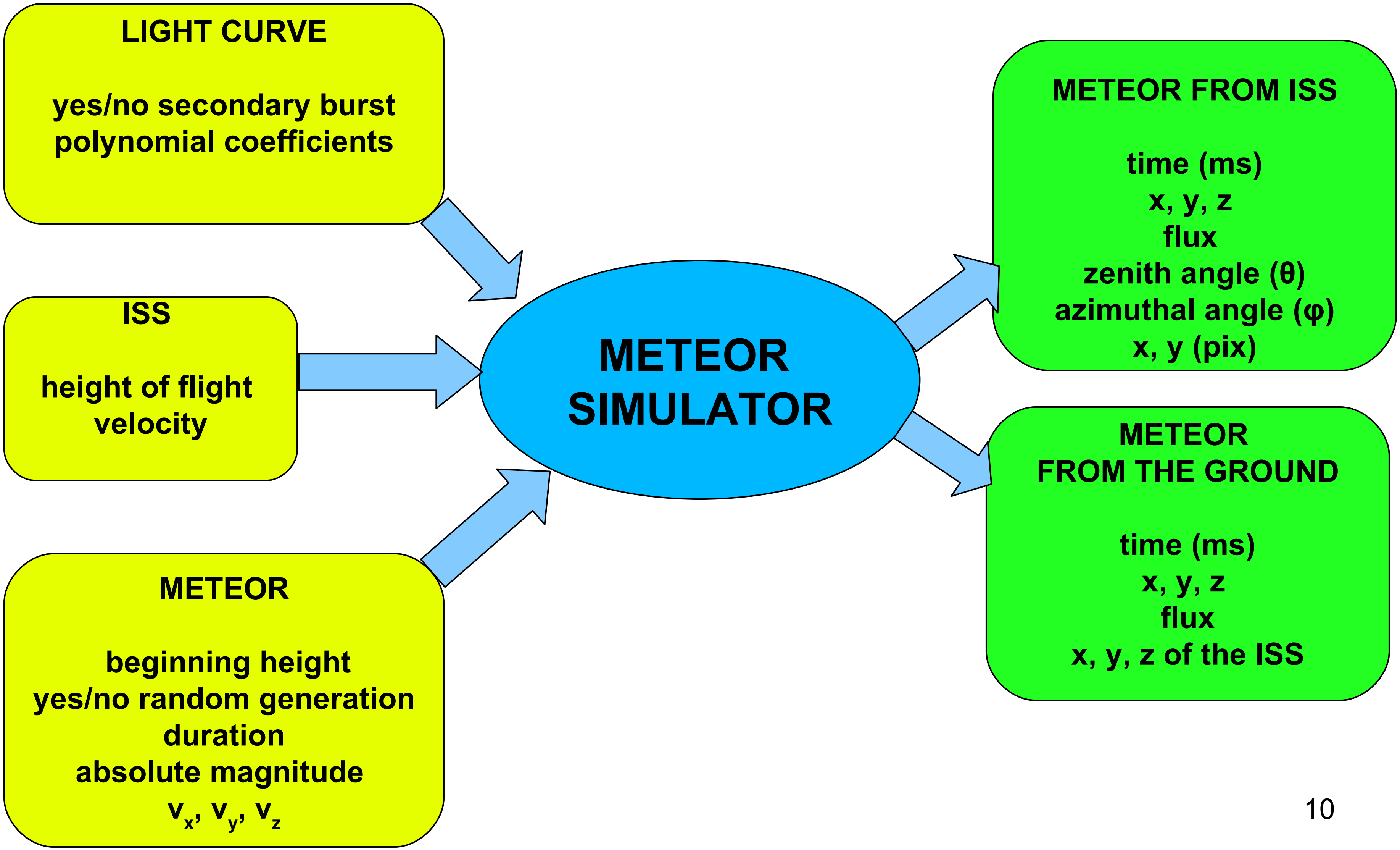
single KI pixel

MAPMT

Working mode:

ANALOG (charge integration)
KI pixels = 4 X 2 MAPMT pixels

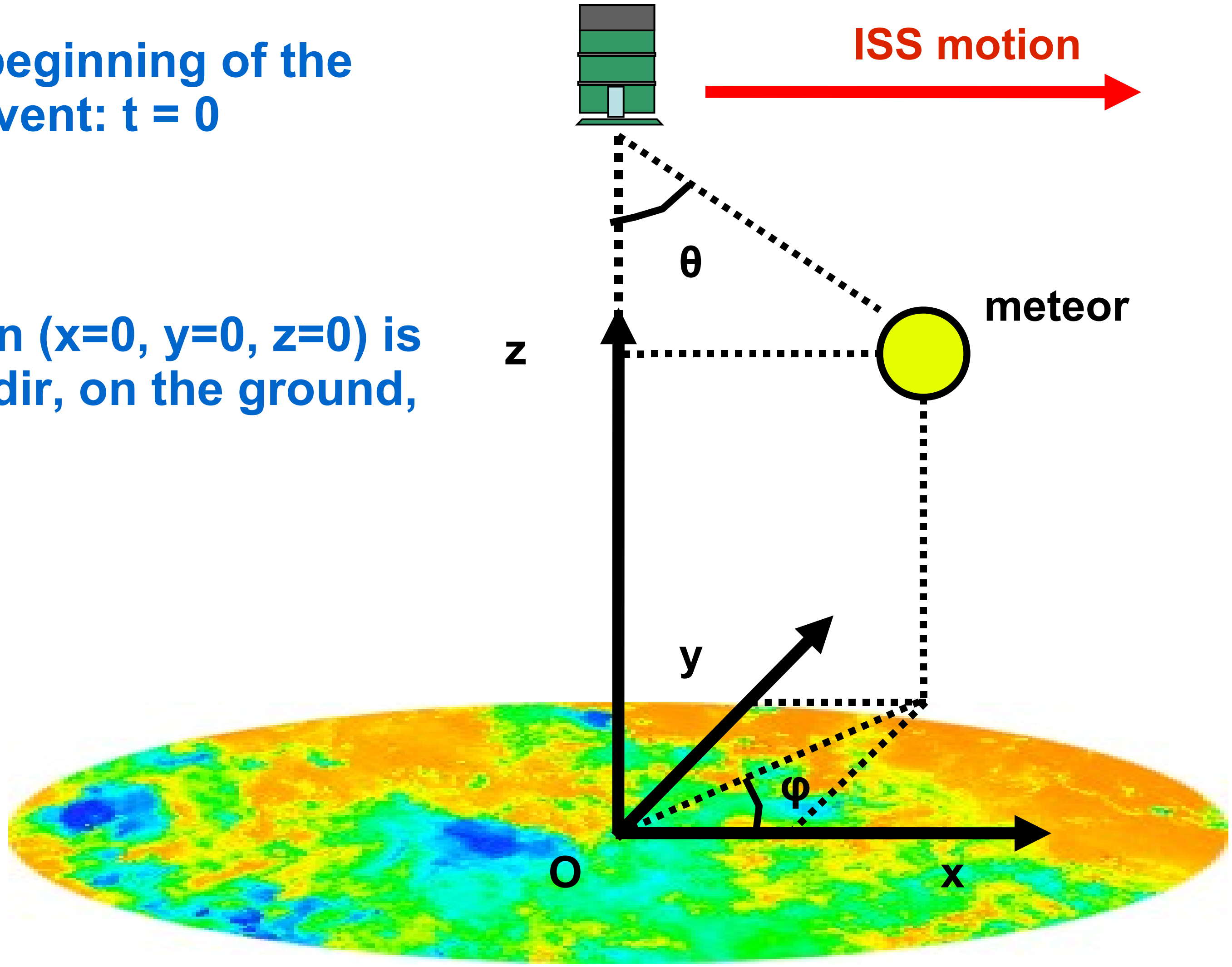
Meteor simulation



Reference system

Time of beginning of the meteor event: t = 0

The origin (x=0, y=0, z=0) is at the nadir, on the ground, at t=0



Meteor simulation: magnitude

Absolute magnitude $M = -2.5 * \log_{10}(\text{flux}) + C$

$C = 2.5 \log_{10}(6750) \sim 9.57$

Apparent magnitude $m = M - 10 + 5 * \log_{10}(\text{dist})$

1 GTU = 2.5 μs

[flux] = phe / GTU **[dist] = km**

Our assumptions for a meteor profile (input parameters)

All simulated meteors have a secondary burst

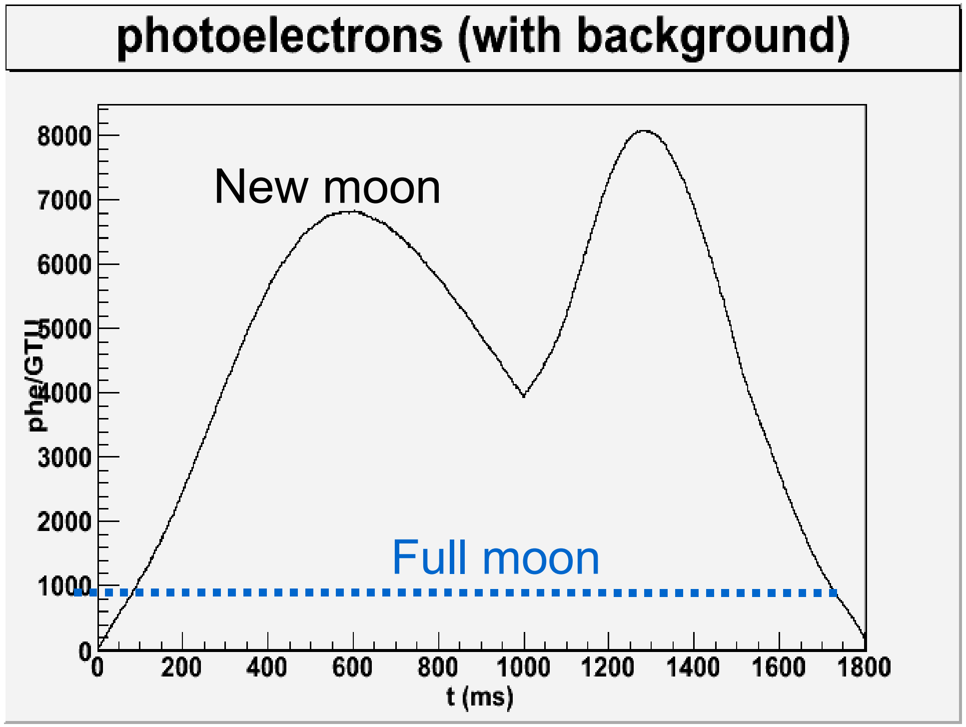
- **Height of the ISS:** 400 km
- **Velocity of the ISS :** 7.8 km/s
- **Beginning height of the meteor:** 100 km
- **Duration of the main event:** 1.5 s
- **Duration of the secondary burst:** 0.8 s
- **Beginning time of secondary burst:** 1 s
- **Duration of meteor:** 1.8 s
- **Shape of the light curve:** 8th degree polynomial (the same for both the main event and the secondary burst)
- **Event time sampling:** 1 GTU = 2.5 μs

The signal is modulated for every ms and integrated for a single GTU, in a single KI

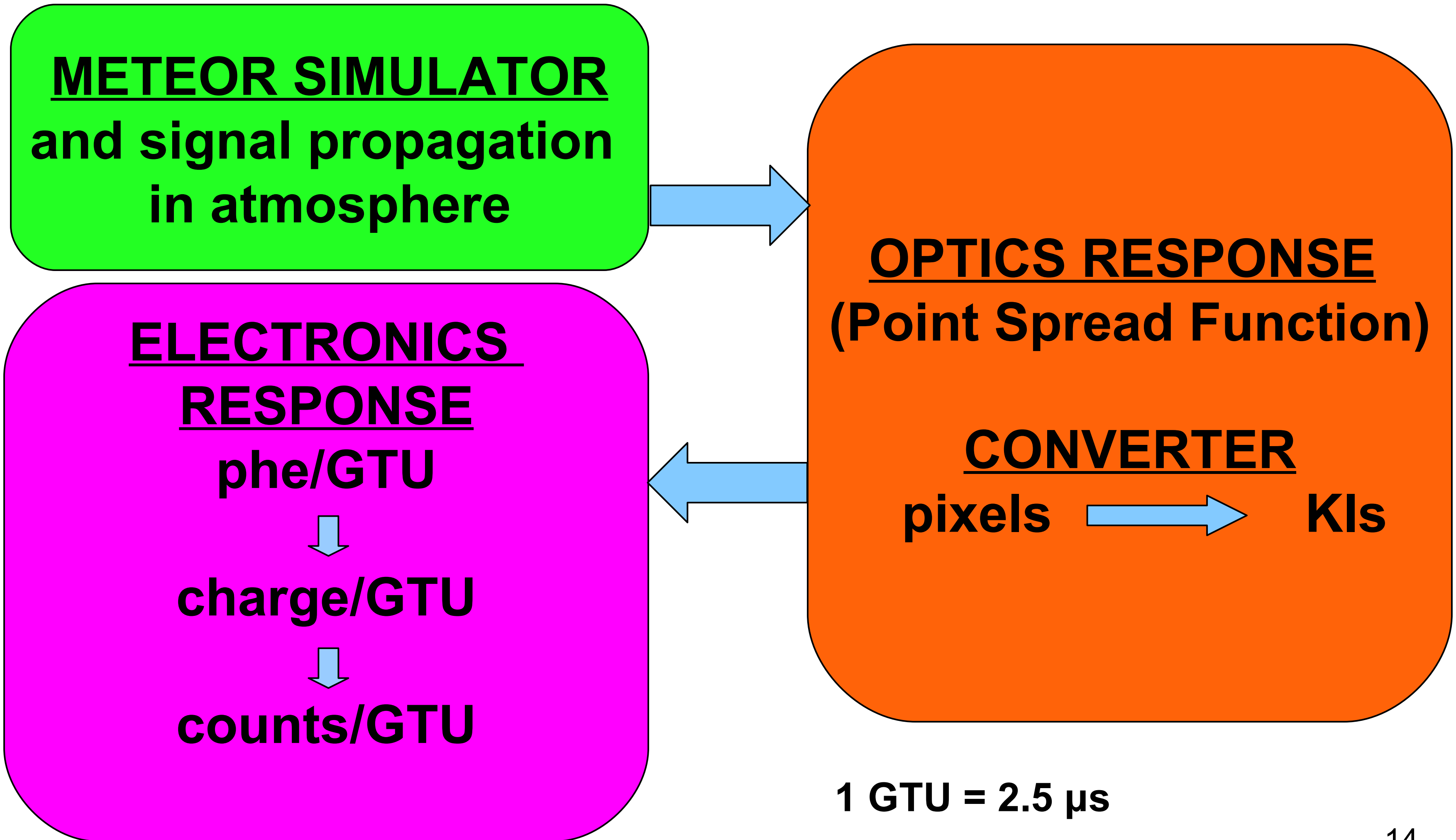
Approximations:

- NO PERSISTENCE
- NO DECELERATION
- NO ABSORPTION COEFFICIENT OF THE AIR
- POINT- LIKE SOURCE
- LIGHT CURVE = UV LIGHT CURVE

METEOR LIGHT CURVE (M=0)



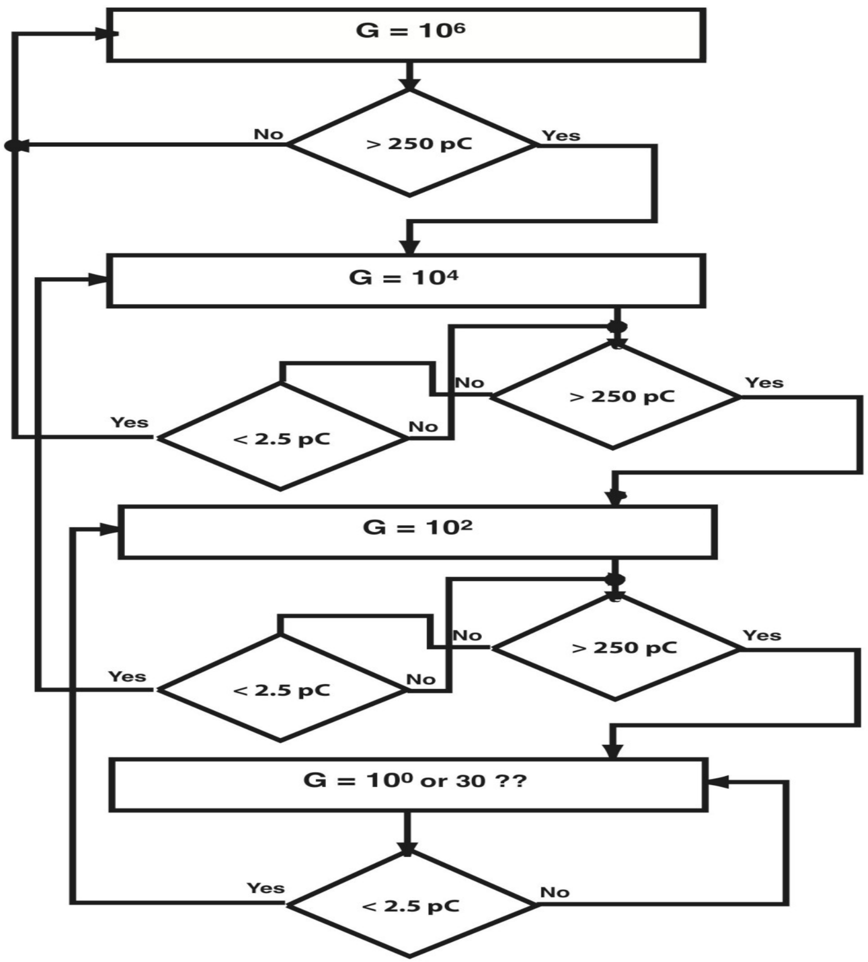
From meteor simulation to the recorded signal



1 GTU = 2.5 µs

HV protection logic for intense signals

To avoid too strong currents in the MAPMT, a KI should not have more than 250 pC/GTU. The *switch-logic* elaborated by P. Gorodetzky reduces 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.



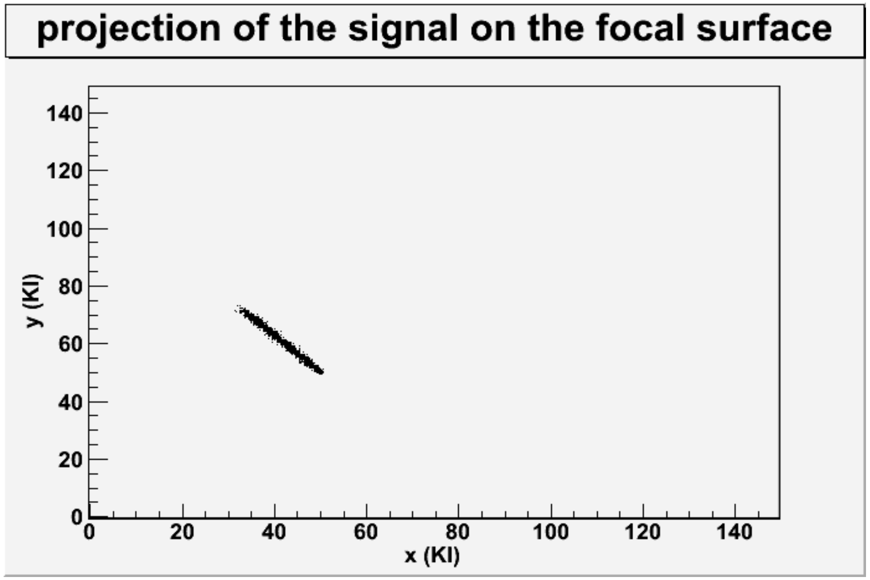
Level	Gain
0	10^6
1	10^4
2	10^2
3	1

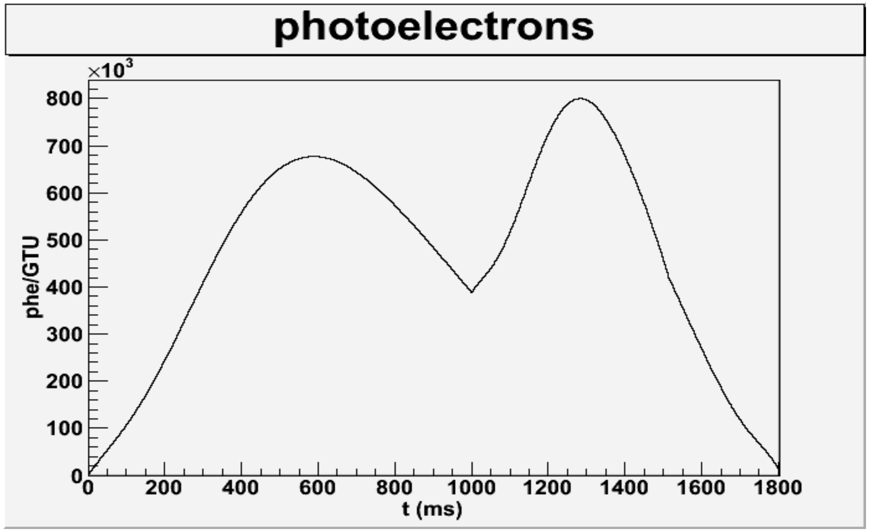
COMPLETE METEOR PROFILE

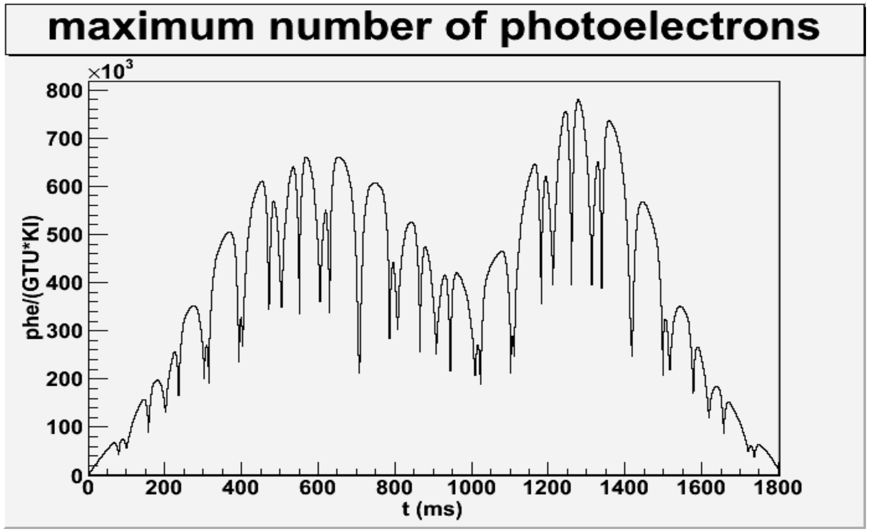
$v_x = v_z = 0$ km/s

$v_y = 20$ km/s

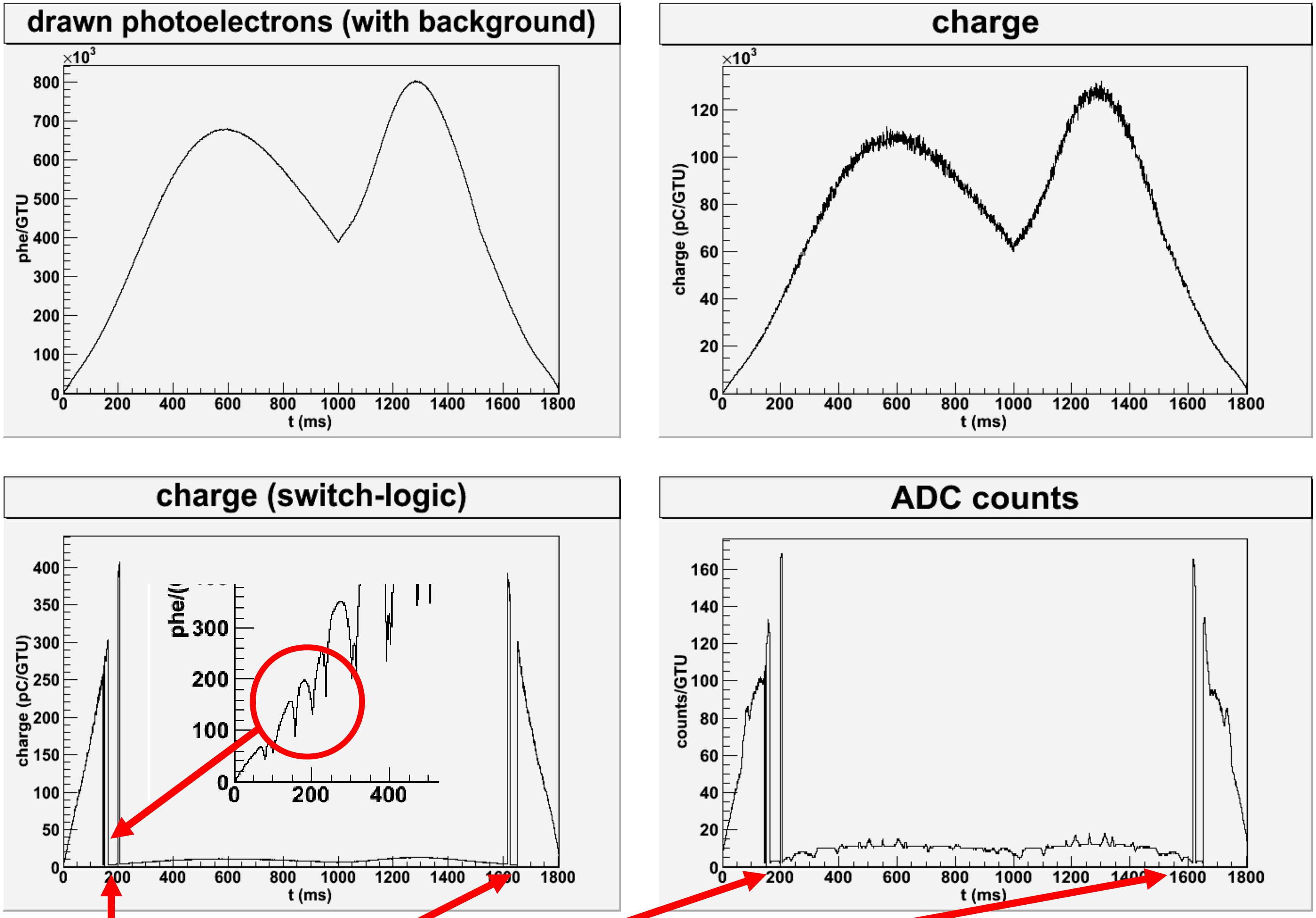
M = -5







1 GTU = 2.5 μs



Effects of the switch logic

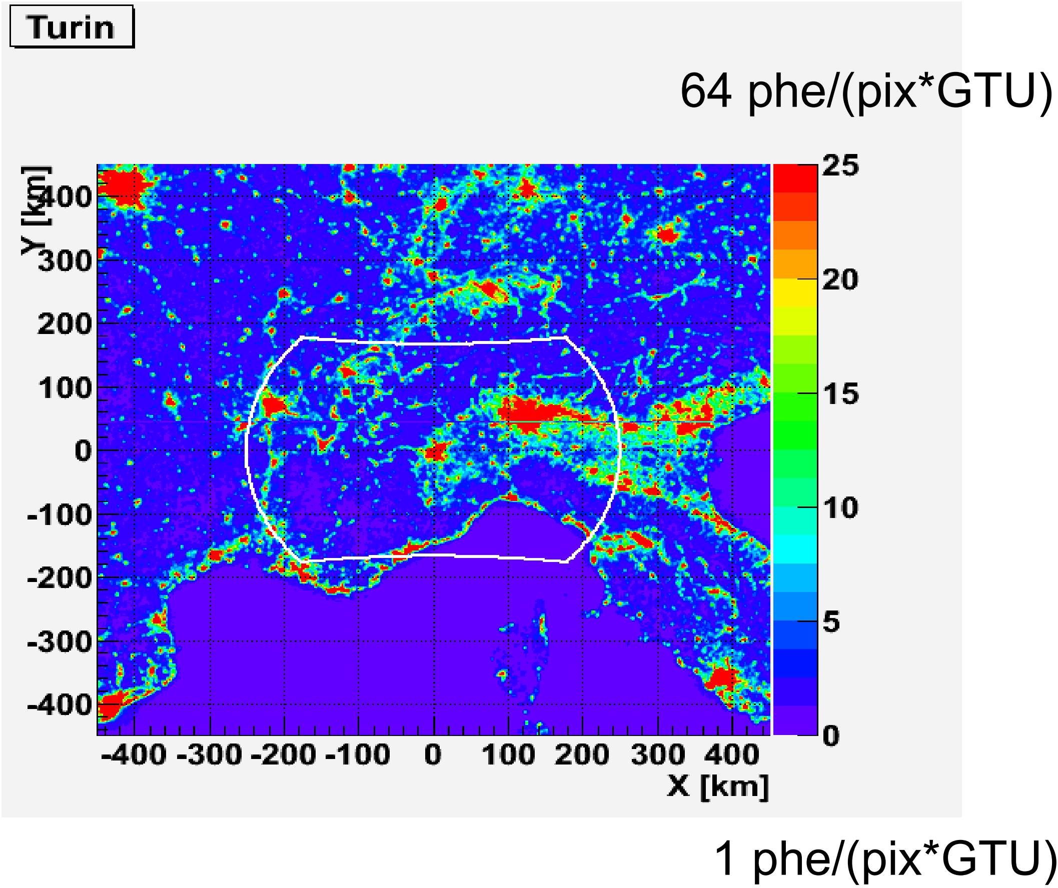
1 GTU = 2.5 μs

Cities

ASSUMPTIONS (INPUT PARAMETERS)

CITY = METEOR with:

- Beginning height = 0 km
- Constant light curve
- Circular shape
- No secondary burst
- M ~ 5.06 (flux = 64 phe/(pix*GTU))
- $v_x = v_y = v_z = 0$ km/s



SIMULATION OF CITIES: PSF

SIMULATIONS

CITIES
(r = 10 km; r = 3 km)

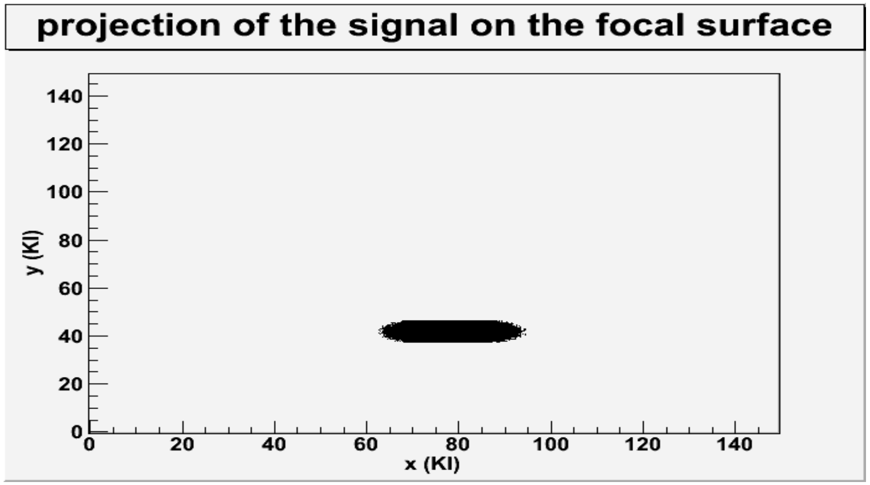
"MOSAIC"
POINT – LIKE SOURCES

VILLAGE

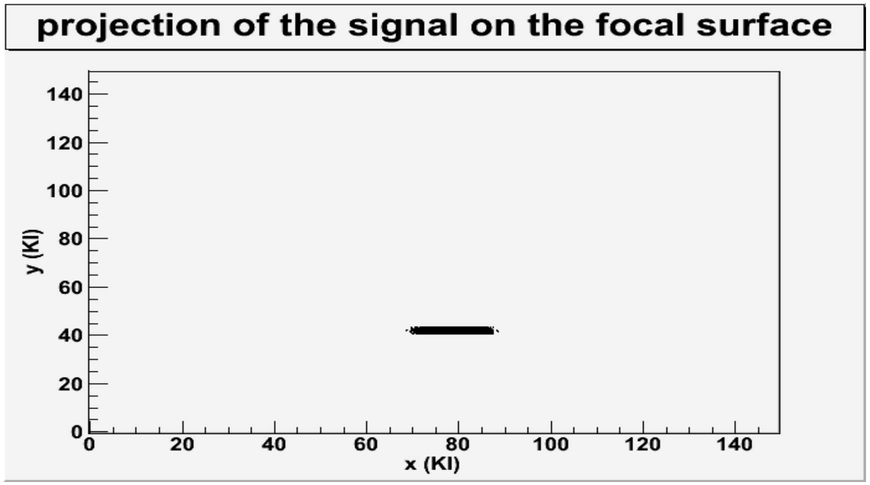
POINT – LIKE SOURCE

Cities vs vertical meteor (M ~5.06; v_z= -11.2 km/s)

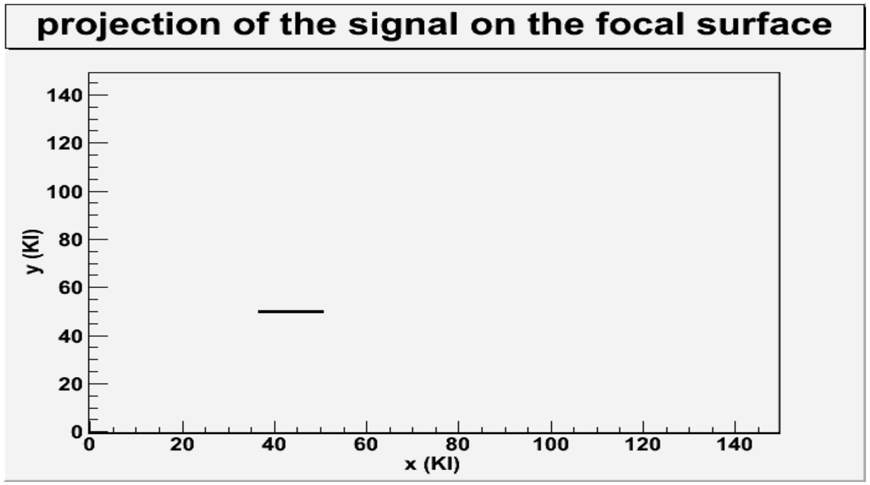
r = 10 km



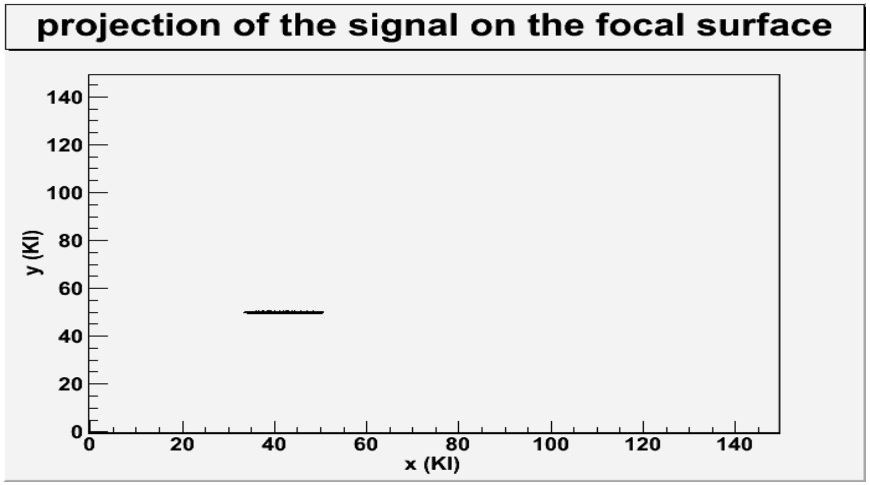
r = 3 km



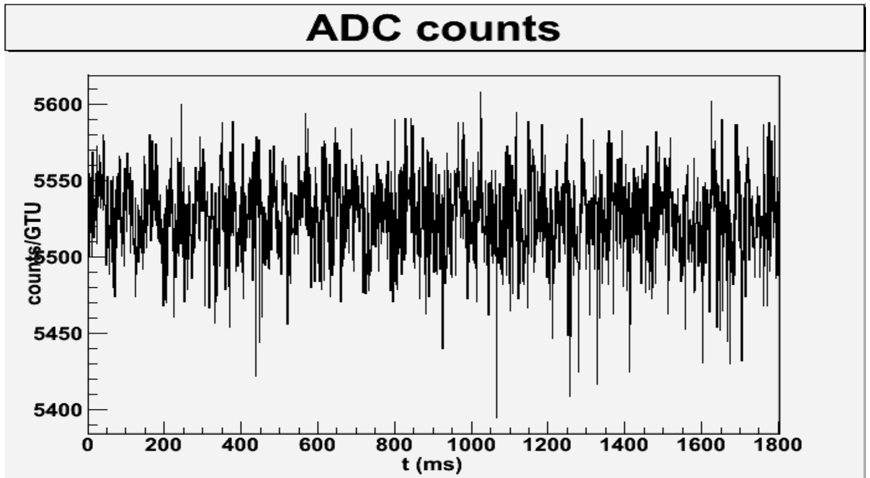
Village



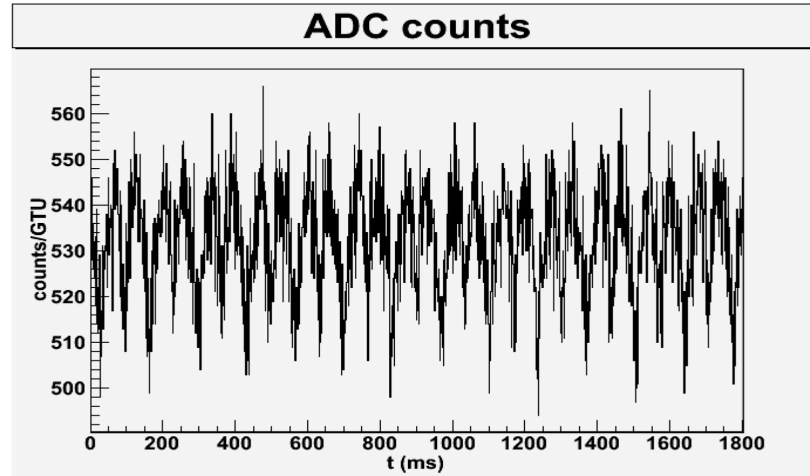
Vertical meteor



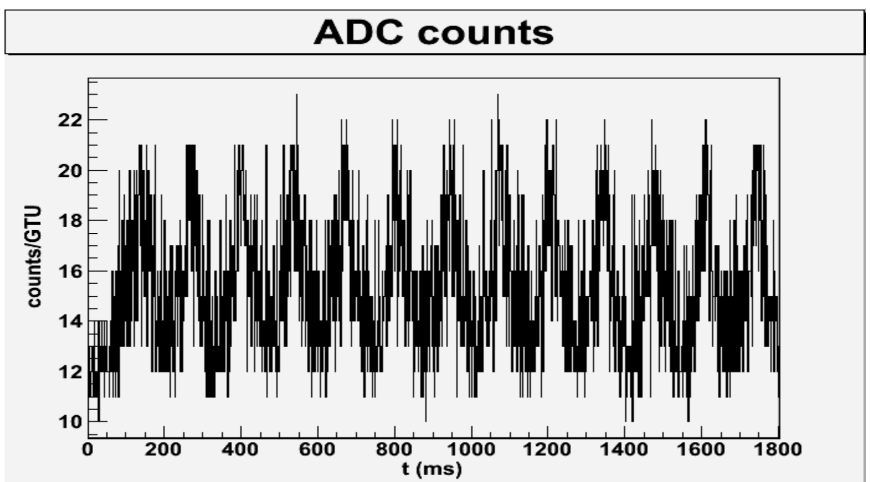
r = 10 km



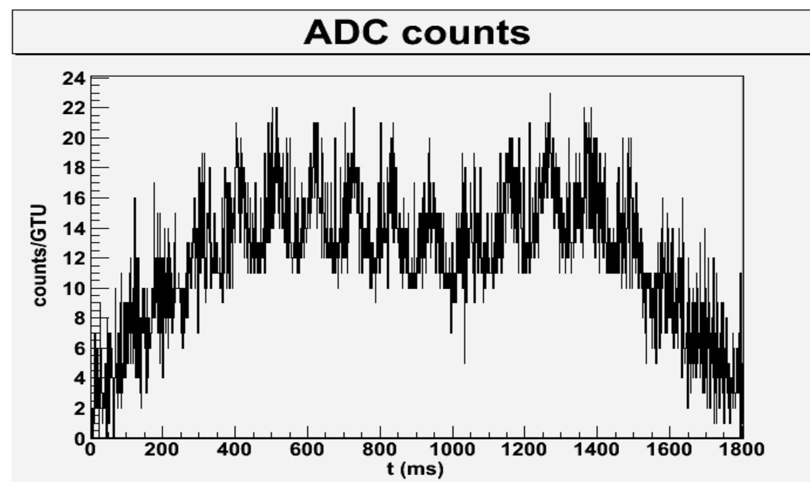
r = 3 km



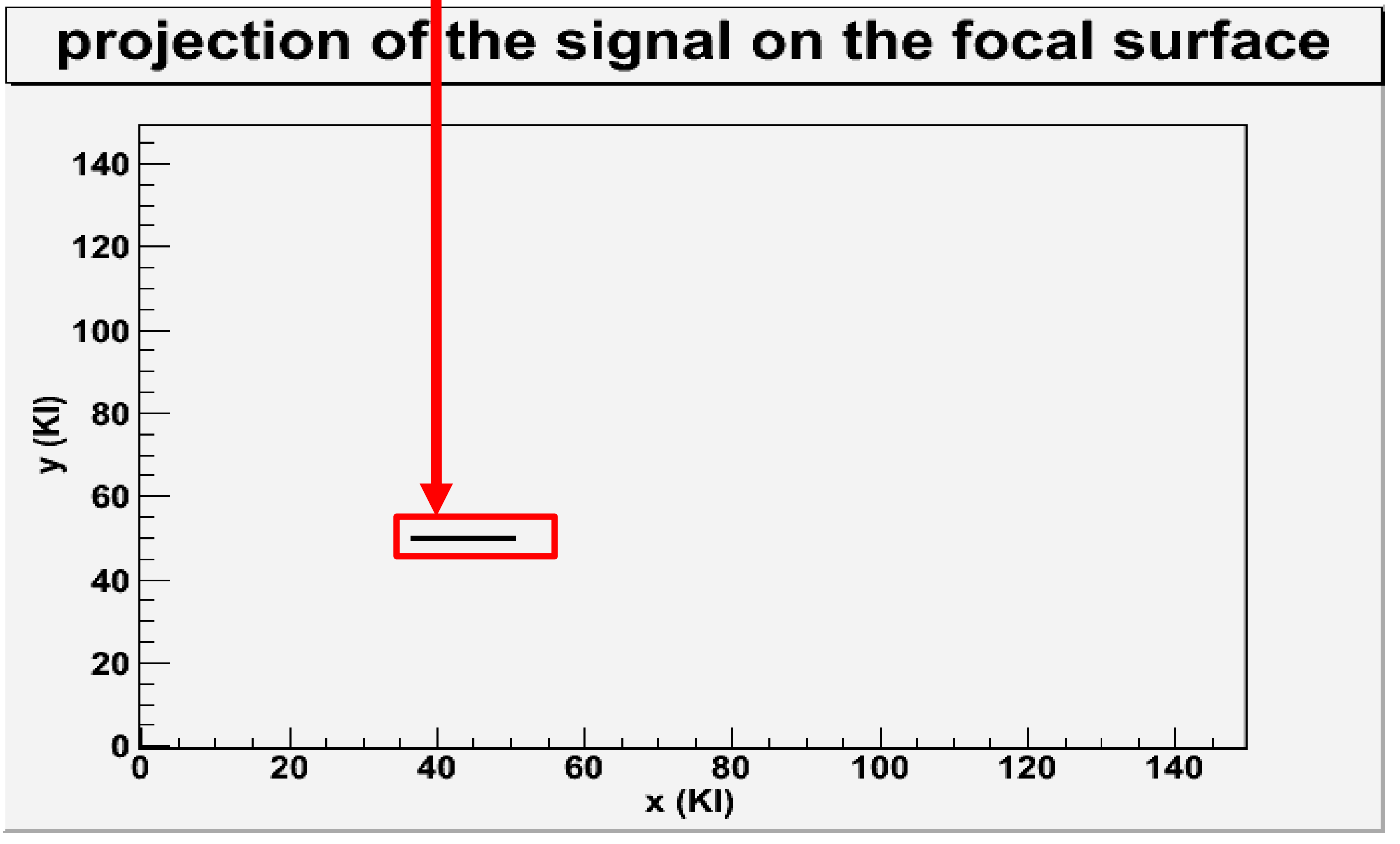
Village



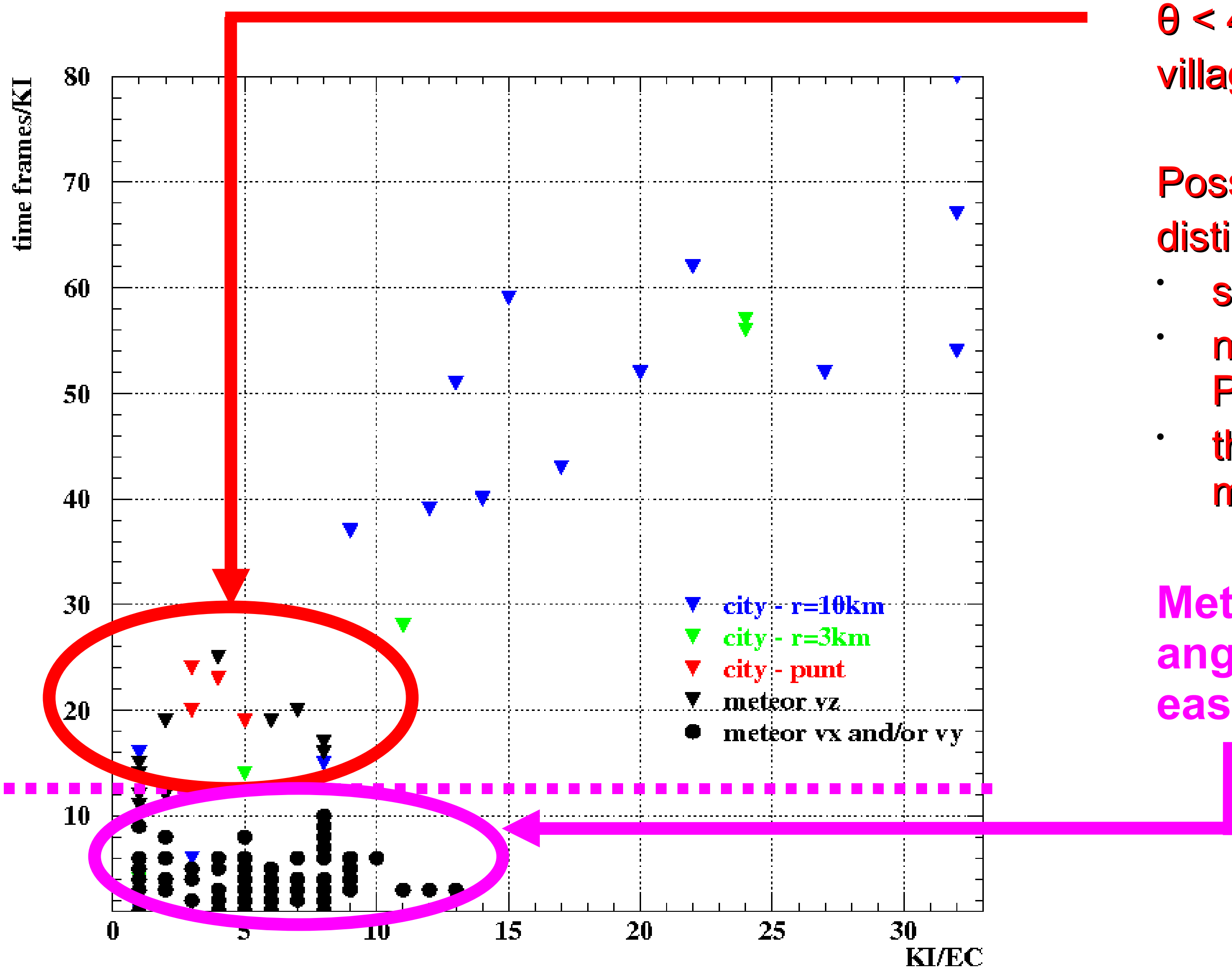
Vertical meteor



PDM size: 48 X 48 pixels



Cities vs meteors: criteria



Meteors with zenith angle θ < 45° and villages look similar

Possible criteria to distinguish them :

- shape of the light curve
- number of enlightened PDMs
- threshold on the magnitude

Meteors with zenith angle θ > 45° are easily detectable

1 EC = 32 KIs

Fireballs and HV protection logic

M < -13.5 → PMT Gain = 1

M < -13.5 → charge > 250 pC (at least in a KI)

$M < -13.5$

↓

number of events on Earth:

$< 2*10^{-3}$ / day ~ 0.73 / year

Number of events on JEM-EUSO FoV at ground

(duty cycle 0.2):

$< 5.4*10^{-5}$ / year

HV switch-logic protects the telescope from very luminous fireballs

Conclusions

Main results:

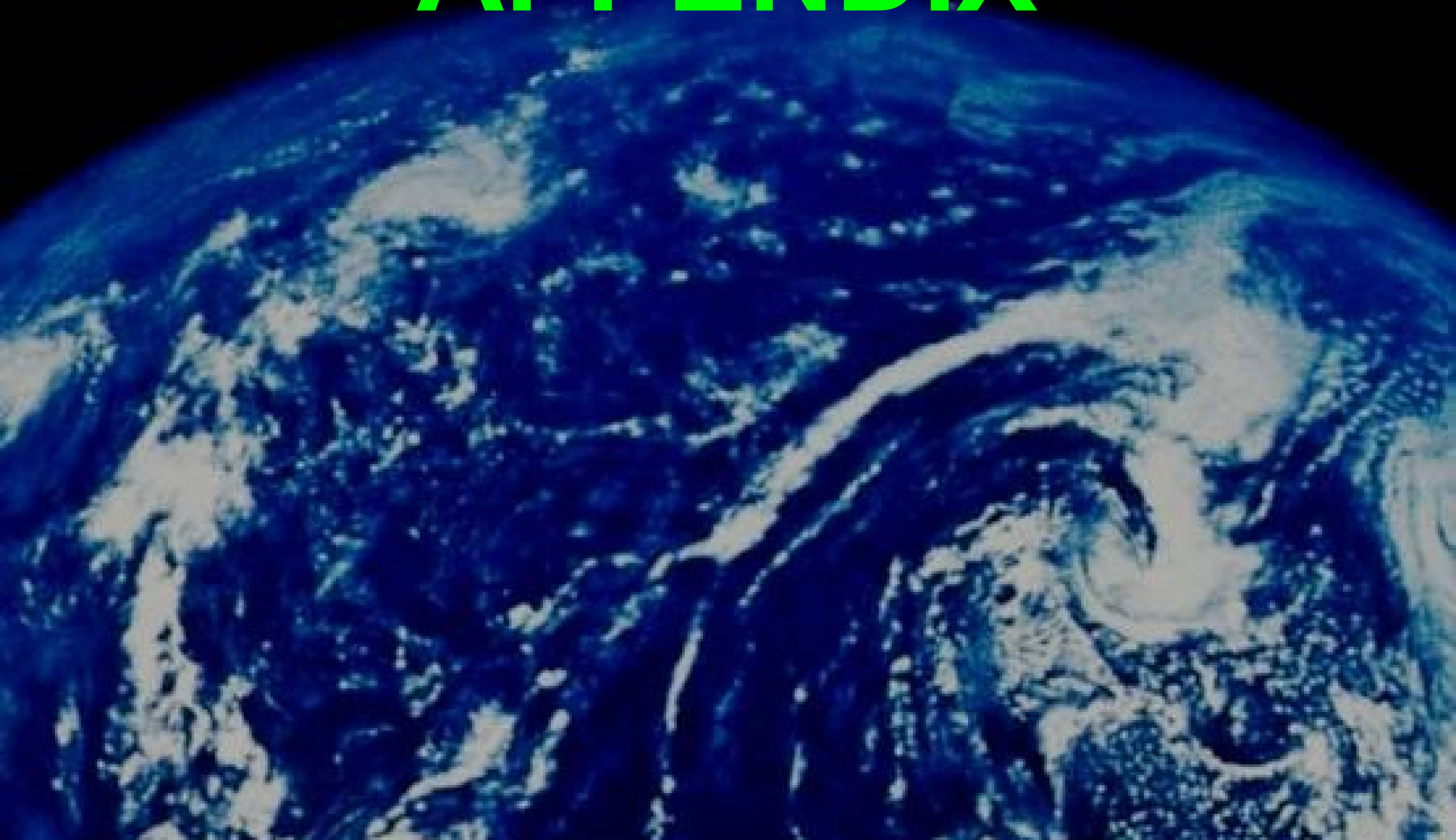
1) **a simulator of meteors has been developed;**
2) **a simple simulator of the response of JEM – EUSO detector has been developed.**

By – products of the work:

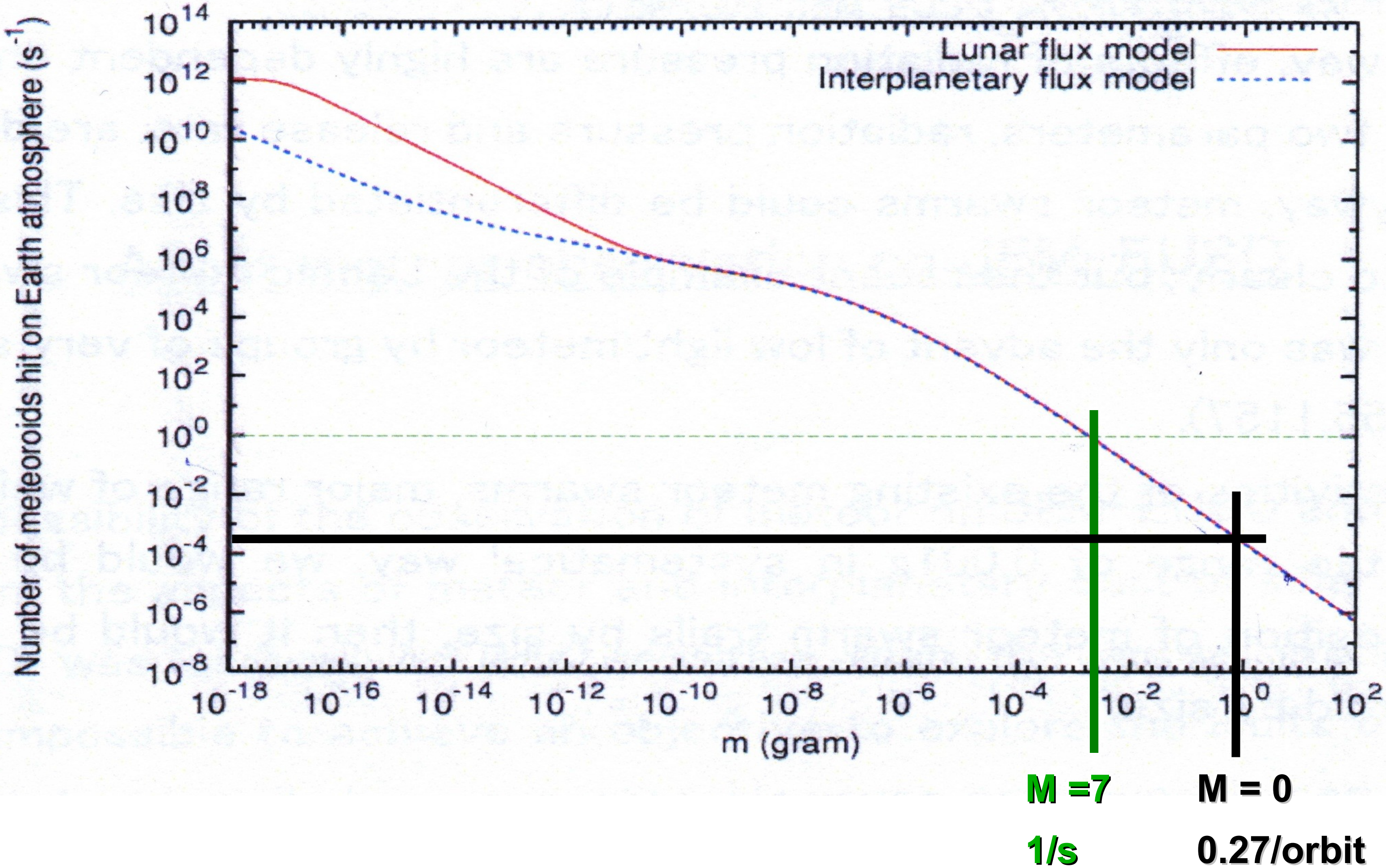
1) **simulations of cities;**
2) **a first criterion to distinguish meteors from cities;**
3) **an analysis of the switch-logic that confirms its capability to protect the telescope from extremely bright objects such as fireballs.**


THANK YOU !!!

APPENDIX

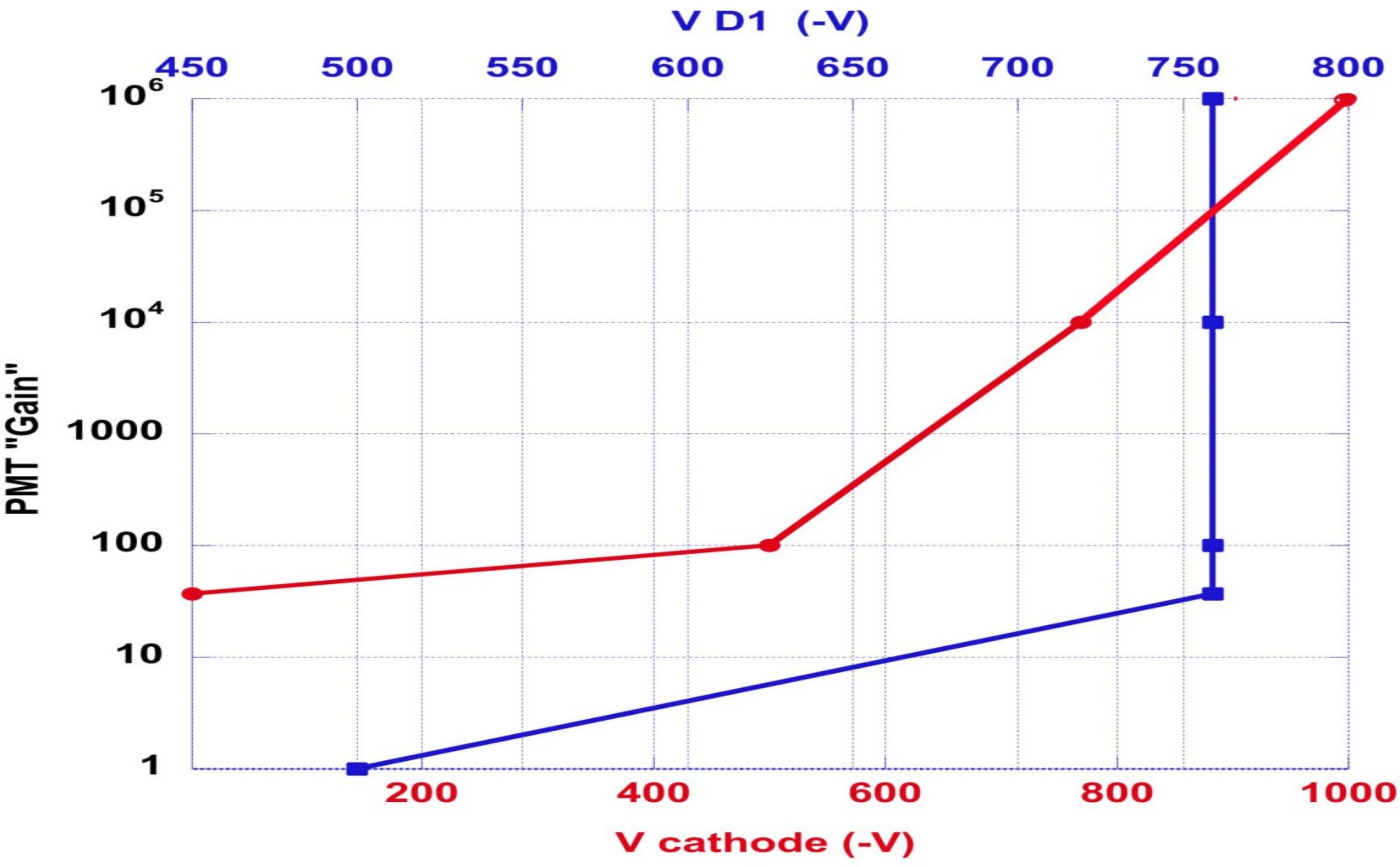


Cumulative number of collisions of meteoroids with the Earth's atmosphere in JEM-EUSO FoV



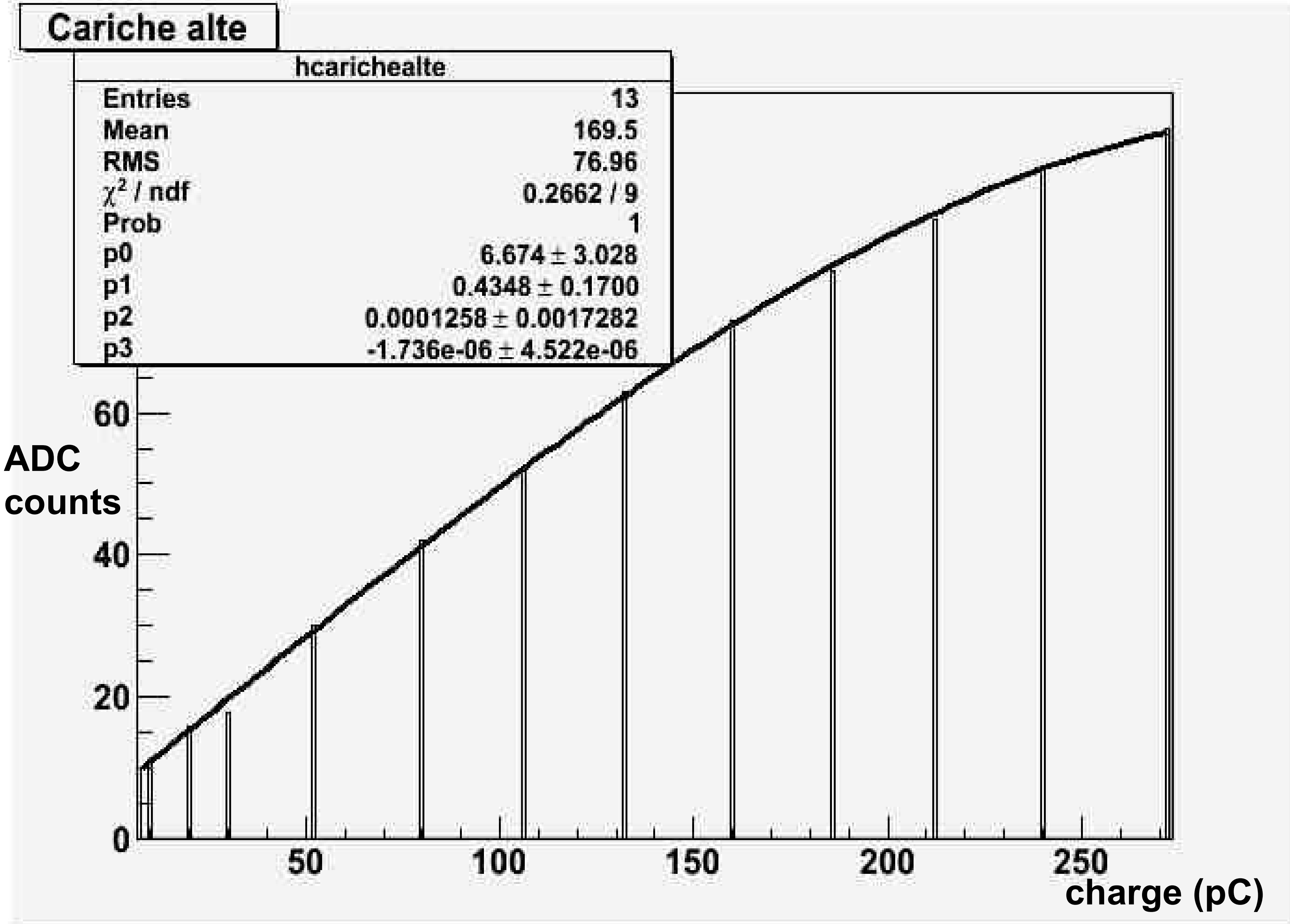
DRAW / VARIABLE	SYMBOL	CONDITION	KIND OF DRAW	MEAN VALUE	STANDARD DEVIATION	COMPUTATION
Integer simulated flux	ncts	m < (flux-int (flux))	Random (m; 0-1)	/	/	int (flux)+1
//	//	m >= (flux-int (flux))	//	/	/	int (flux)
Radius of the PSF	r	/	Gauss	0 mm	1.25 mm	abs (r)
Angle of the PSF	angle	/	Random (0 - 2π)	/	/	/
x in KI of the single photoelectron	xKI	/	/	/	/	int (Xpix/2) + C
y in KI of the single photoelectron	yKI	/	/	/	/	int (Ypix/4) + C
Flux of photoelectrons in (xKI, yKI)	ICount	/	/	/	/	Sum of all the photoelectrons spreaded in (xKI, yKI)

Switch-logic and PMT potentials

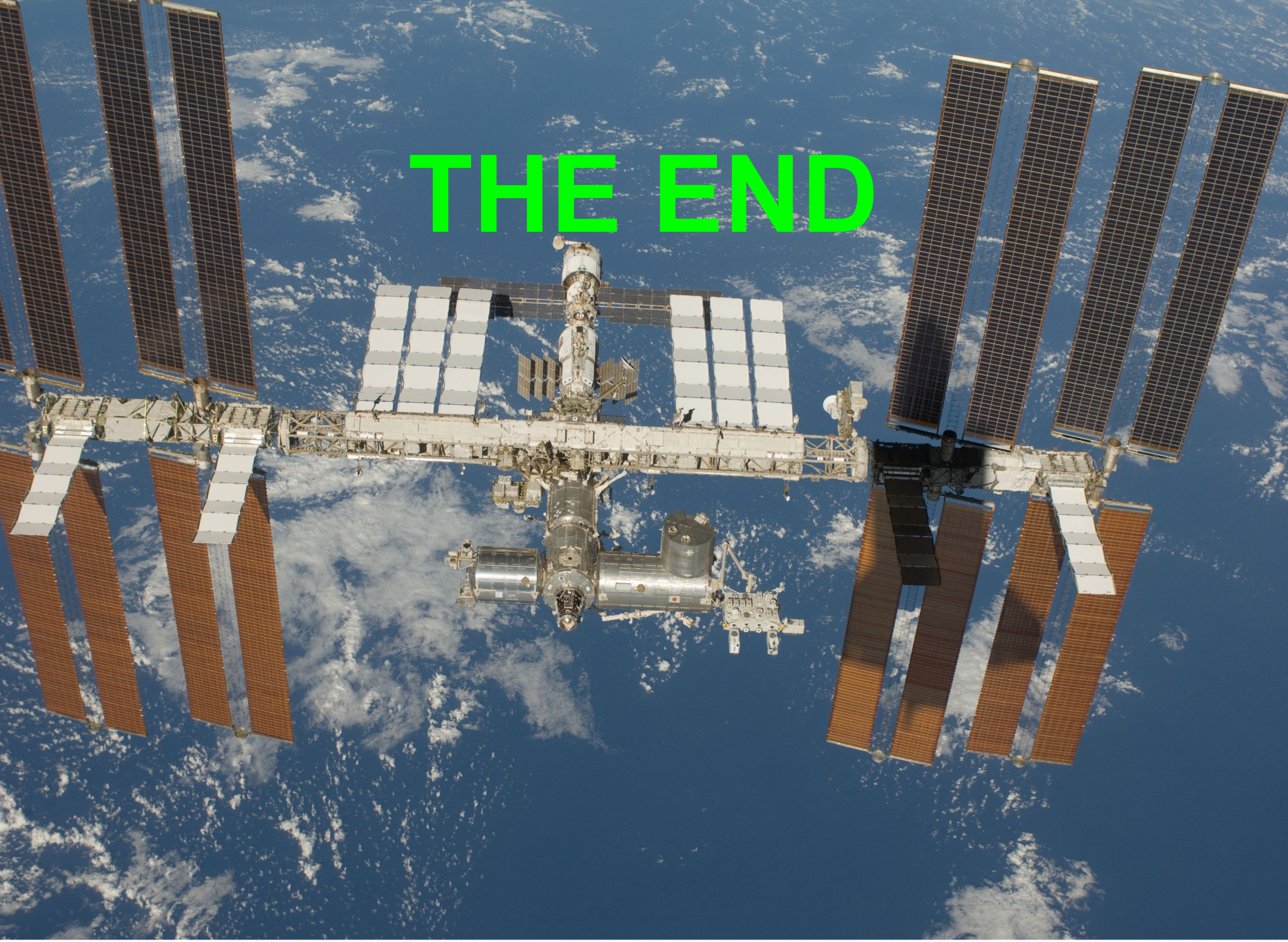


DRAW / VARIABLE in (xKI, yKI)	SYMBOL	CONDITIONS	KIND OF DRAW	MEAN VALUE	STANDARD DEVIATION	COMPUTATION
Flux of photoelectrons with background	ICOUNT	ICount > 0	Poisson (nphebkg)	16 (960) phe/(KI*GTU) [new (full) moon]	Square root of the mean value	ICount + nphebkg
Gain	GKI	/	Random (0.152-0.168 pC/phe)	/	/	/
Drawn flux of photoelectrons	pheest	0<ICOUNT<50 phe/GTU	Poisson	ICOUNT	Square root of the mean value	/
//	//	ICOUNT>=50 phe/GTU	Gauss	ICOUNT	Square root of the mean value	/
//	//	ICOUNT<=0	/	/	/	0

DRAW / VARIABLE in (xKI,yKI)	SYMBOL	CONDITIONS	KIND OF DRAW	MEAN VALUE	STANDARD DEVIATION	COMPUTATION
Charge	ca	pheest < 50 phe/GTU	/	/	/	Subsequent gaps
//	//	pheest >= 50 phe/GTU	Gauss	pheest*GKI	0.5*GKI* sqrt(pheest)	/
Gain (switch-logic)	G	gu value (integer 0-3; indicates the level of switch)	/	/	/	$GKI*10^{-2*gu}$
Charge (switch-logic)	caatt	/	/	/	/	ca*G
Charge (control)	ca	ca<0	/	/	/	0
Charge (switch-logic; control)	caatt	caatt<0	/	/	/	//


Cariche alte
hcarichealte
Entries 13
Mean 169.5
RMS 76.96
χ² / ndf 0.2662 / 9
Prob 1
p0 6.674 ± 3.028
p1 0.4348 ± 0.1700
p2 0.0001258 ± 0.0017282
p3 -1.736e-06 ± 4.522e-06
ADC counts
0
20
40
60
50
100
150
200
250
charge (pC)

DRAW / VARIABLE in (xKI,yKI)	SYMBOL	CONDITIONS	COMPUTATION
Counts	cts	0 < caatt <= 10 pC/GTU	-2.644 + 1.839*caatt
//	//	10 pC/GTU < caatt <= 300 pC/GTU	Polynomial curve in the previous slide
//	//	caatt > 300 pC/GTU	100
ADC counts	CTS	cts-int (cts) >= 0.5	cts+1
//	//	cts-int (cts) < 0.5	cts
ADC counts (control)	//	CTS < 0	0



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