


# JEM-EUSO and its Pathfinders
# Technicalities

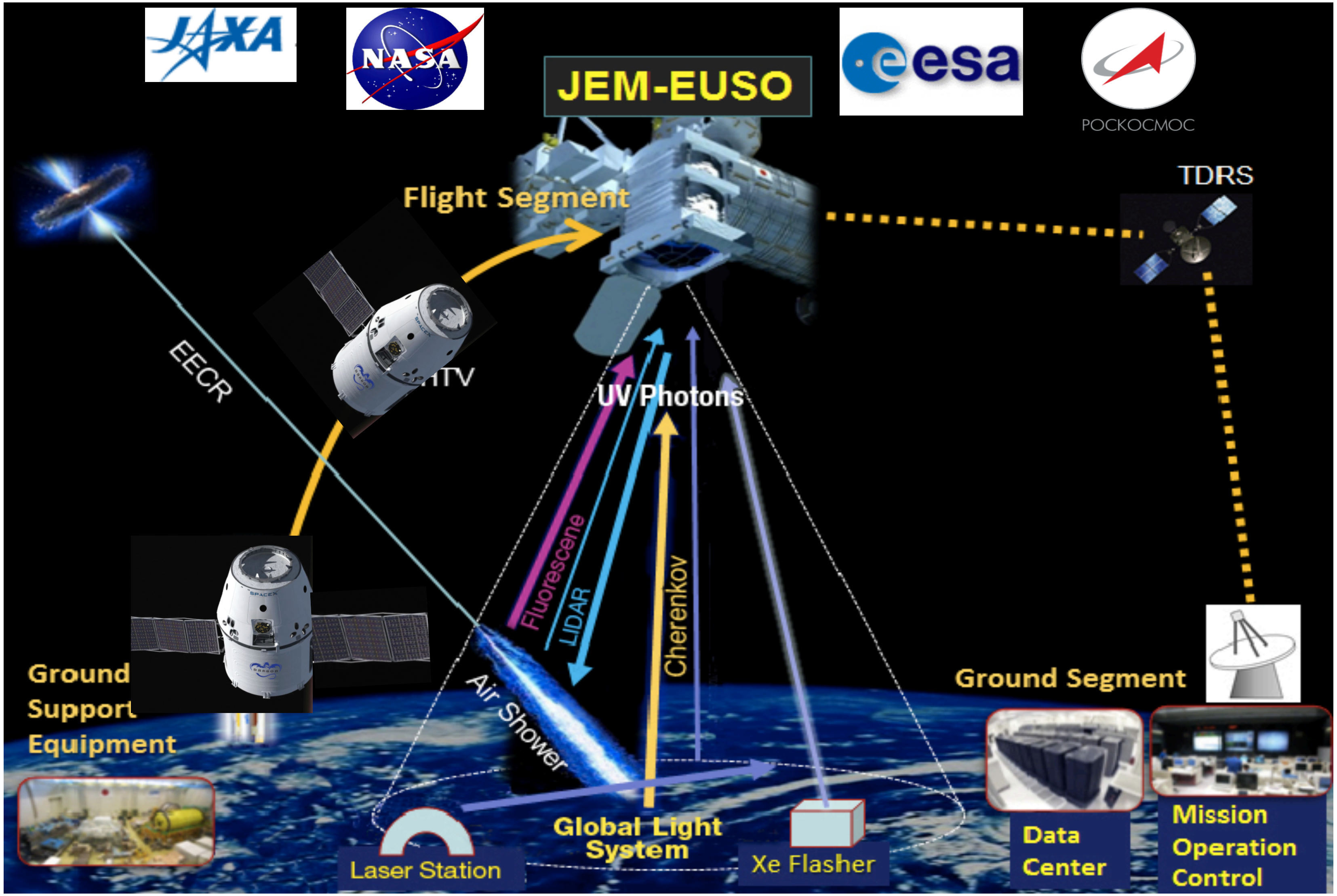
Philippe Gorodetzky* for the JEM-EUSO collaboration, especially Lech Piotrowski whose talk is included here.

* APC lab, Paris 7 / Paris-Diderot University and CNRS, Paris, France

**The outline of this talk:**

- JEM-EUSO
- EUSO-Balloon (Timmins)
- EUSO-TA
- EUSO-SPB
- Mini-EUSO
- K (Klypve)-EUSO

This approach is purely Fluorescence (and Cerenkov). No need here for hadronic models (thanks Alan).
Surface on ground is critical (thanks again).
Resolution in Xmax actually not so good, but will be much improved in the future.
Electronics: only photo-electron counting. No ADC.



# LIGHT FOCUSSING

Remember large Field of View are required !
2 methods:

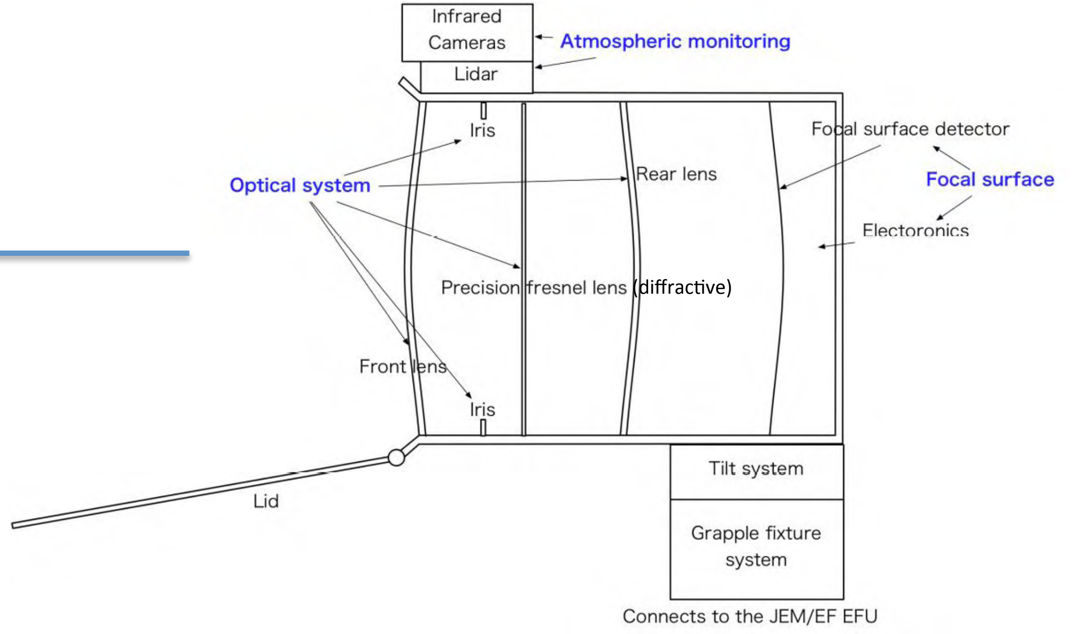
a) Mirrors
   2 Lightweight: good
   3 Very small FoV (a few degrees): bad. Needs a lens (Schmidt system), then FoV still small (< 20°)
   4 Obscurancy by detector: bad

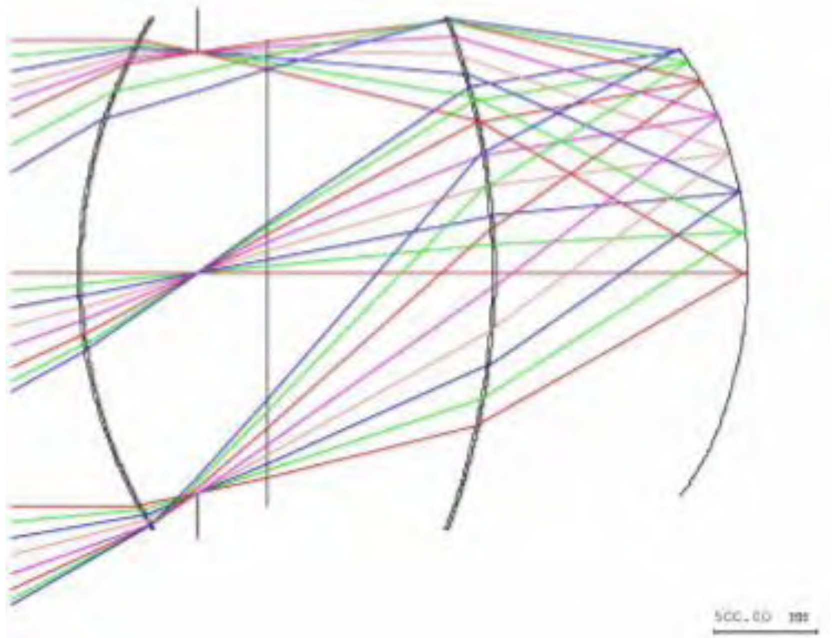
b) Lenses
   1 More heavy, but Fresnel OK
   2 Wide FoV (up to ± 50°, fish-eye telescope ?). Why? **Lenses have an index, mirrors do not**.
   3 Some diffracted light (but with Fresnel mirror + Schmidt lens, same)

Choice: lenses. Furthermore, Japan has the largest lathes to cut the Frenel grooves (> 3 m)

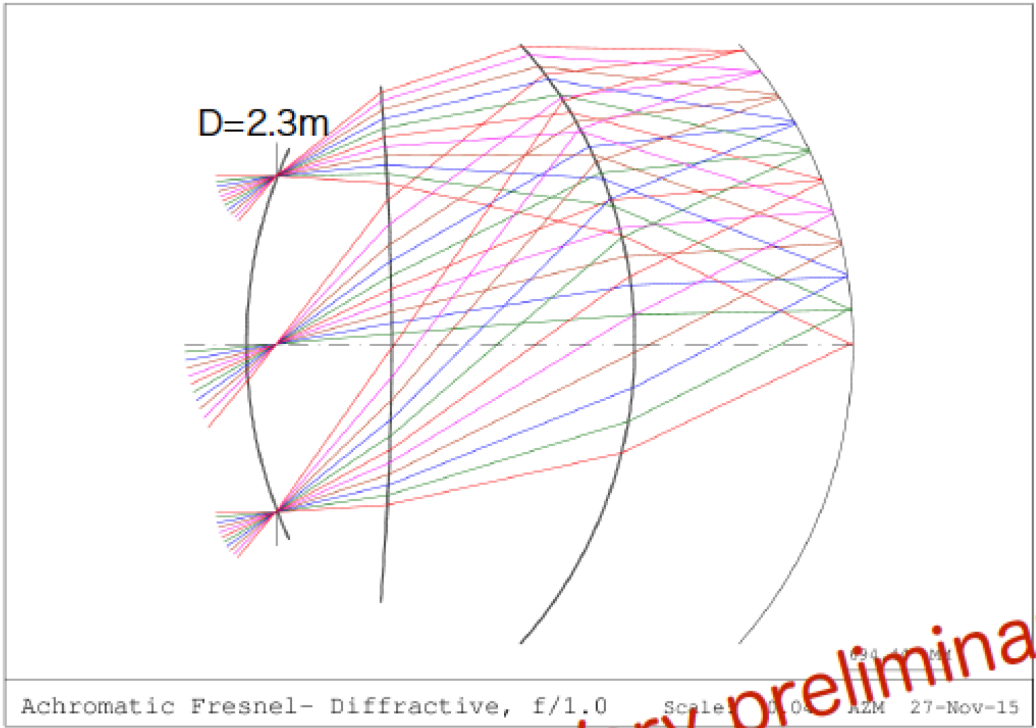
# Jem-Euso

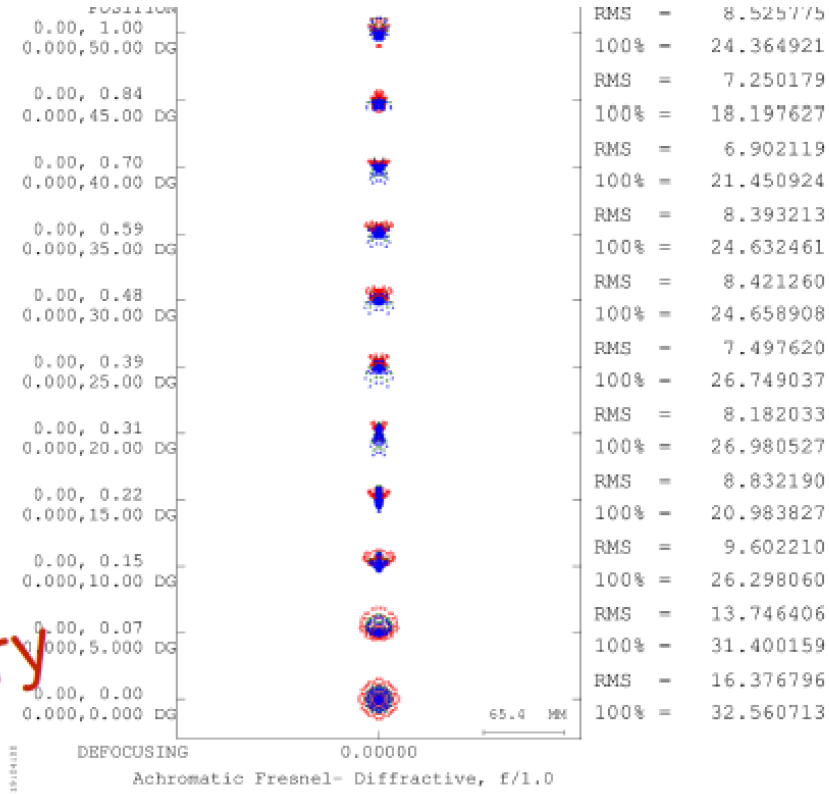
Earth



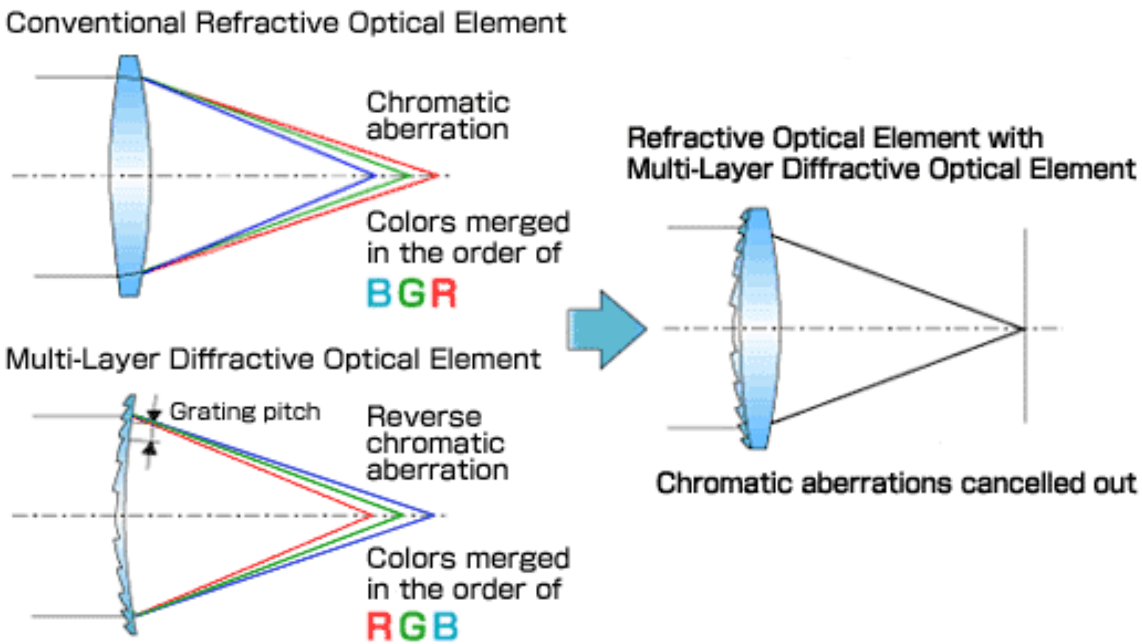



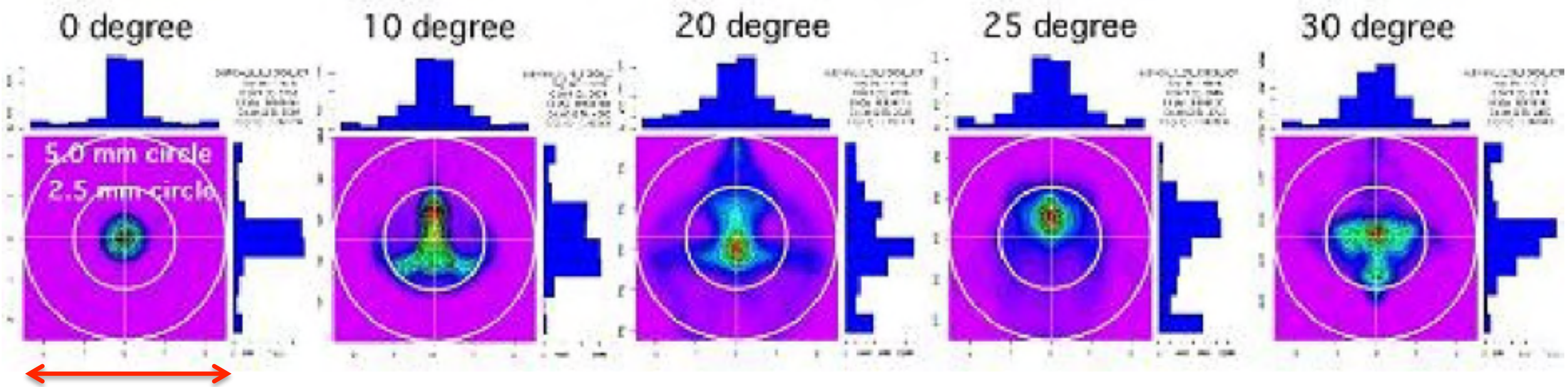
# ± 50° design by Takky ! Yes, 50 !




Very preliminary




5 mm

From this PSF, we choose to have pixels of 3 x 3 mm, hence PMTS with 8 x 8 pixels of 2.88 mm.

# Photodectors

a) Up to now, photomultiplier tubes

b) Recently, SiPM (Wavelength bandwidth [300-400 nm] only in last months)

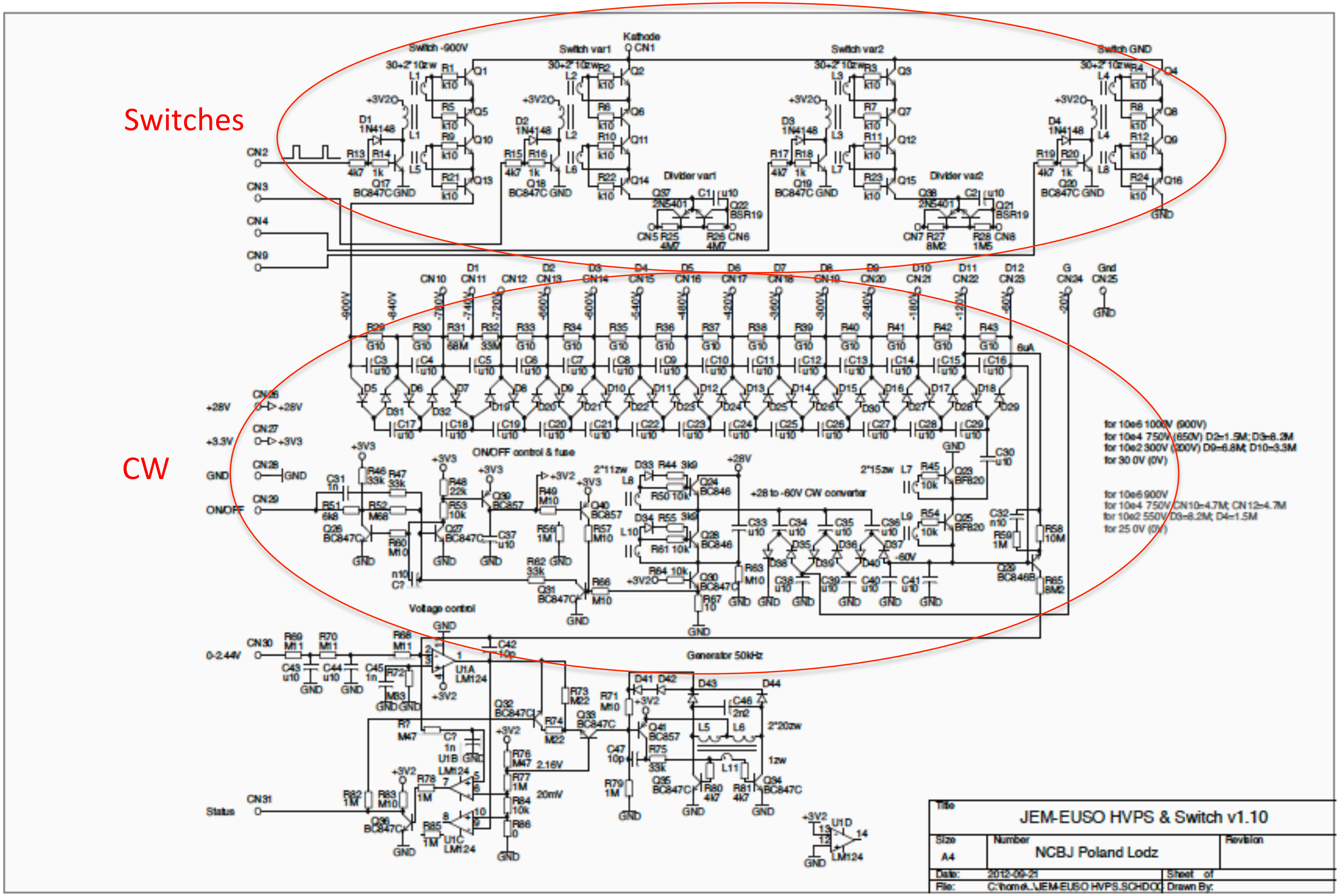
So we are using now PMTs for the photons detector.

SPB and Mini-Euso have in addition some SiPM (O. Catalano from Palermo, the CTA design in Mini-Euso and A. Haungs from KIT with a preliminary design) to test them in "Space".

The chosen PMTs are Hamamatsu 64 (8 x 8) pixels of 2.88 x 2.88 $mm^2$
Their gain varies from 1.5 to 4 $10^6$ at a maximum voltage of -1100 V
Their QE is about 36 %, the collection efficiency about 70 % (square phototube), for an overall efficiency of 25 %.

Furthermore, High Voltage power supply: classical (resistor divider) requires for Jem-Euso 5 kW and we cannot spend more than 75 W (99% goes in the divider).
With a Cockroft-Walton (CW), each dynode is polarized with a low impedance: you consume only for what you use, so that the 5 kW reduces to less than 50 W.
Also, the dynamics are much greater than with a divider.

Cockroft-Walton

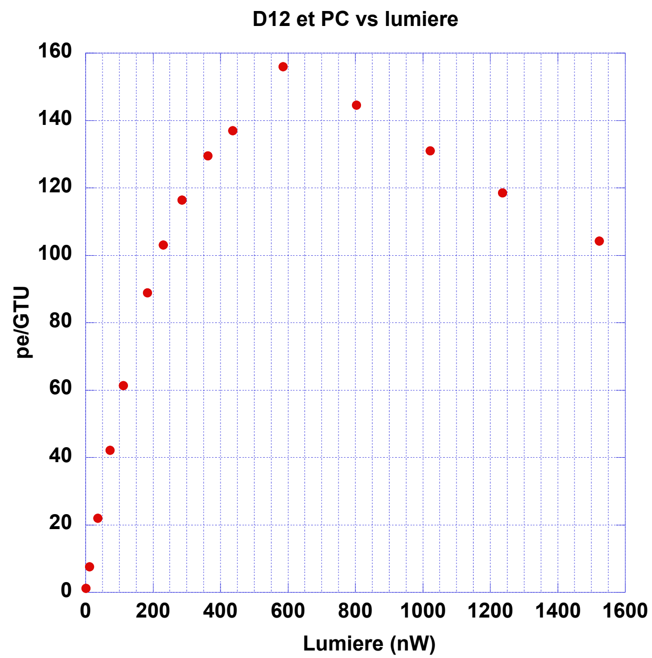





We have 9 of these, and each has 13 outputs (13 dynodes), so we have 117 white cables

# What are these switches ?

The dynamics of the light are > $10^6$ (from 1pe / µs for the background to more than $10^6$ pe / µs for a lightning).
As the normal dynamics of a PMT are around 100, we have built a set of switches which lower the cathode voltage, while all other dynodes stay at their nominal voltage (determined for the PMT gain).
Then if we have the nominal voltage of thePMT (let say -1100 V for a gain of 2 $10^6$, then with the cathode at the D1 voltage (-850 V), the collection efficiency is reduced by a factor 100. If the cathode is set at 0 V, then the collection efficiency is further reduced by another factor of 100.
That way we reach dynamics of $10^6$.
Commands of switches: the front end ASIC (Spaciroc 3), has only photo-electron counting (discriminator) facility. The output pulse is 5 ns wide. For random pulses we can go up to 140 pulses in one Gate Time Unit (GTU) of 2.5 µs before pile-up makes the counting rate decrease. This chosen time interval corresponds to 750 m for light, equal to the pixel separation on ground, as Jem-Euso is a TPC with a drift velocity equal to c.




Pe/GTU taken from the S-curves plateau versus light intensity measured on a NIST photodiode located at the second exit of an integrating sphere (hence proportional to the light impinging on the illuminated pixel).

# How to use the photon counting to trigger the switches (old 30 ns ASIC)

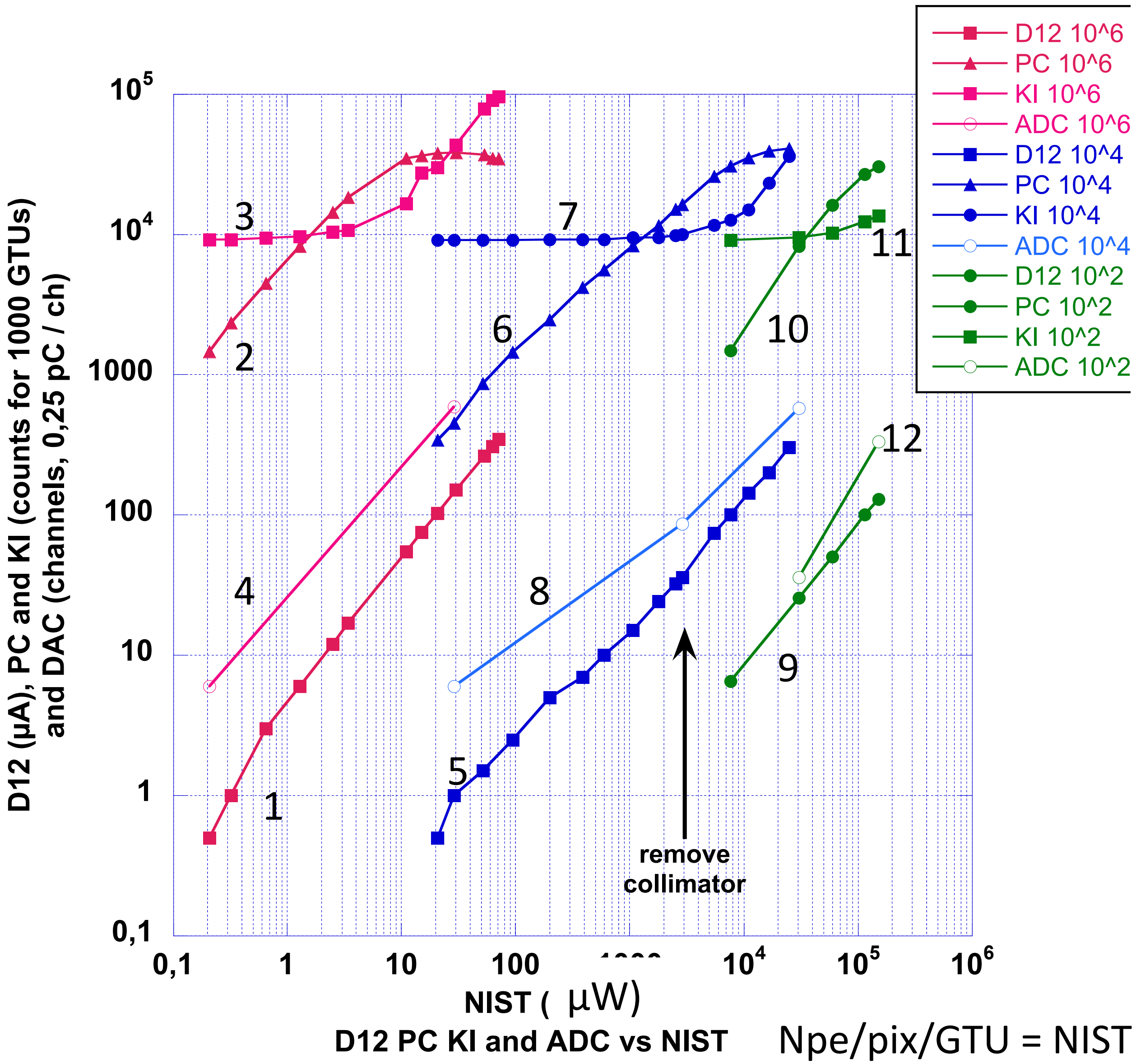
Red: G = 10^6, 1000 V on K, 822 V on D1

Blue: G = 10^4, 821 V on K, 822 V on D1

Green: G = 600, 10 V on K, 822 V on D1

Curves are numbered from 1 to 12 for reference in the next slides.

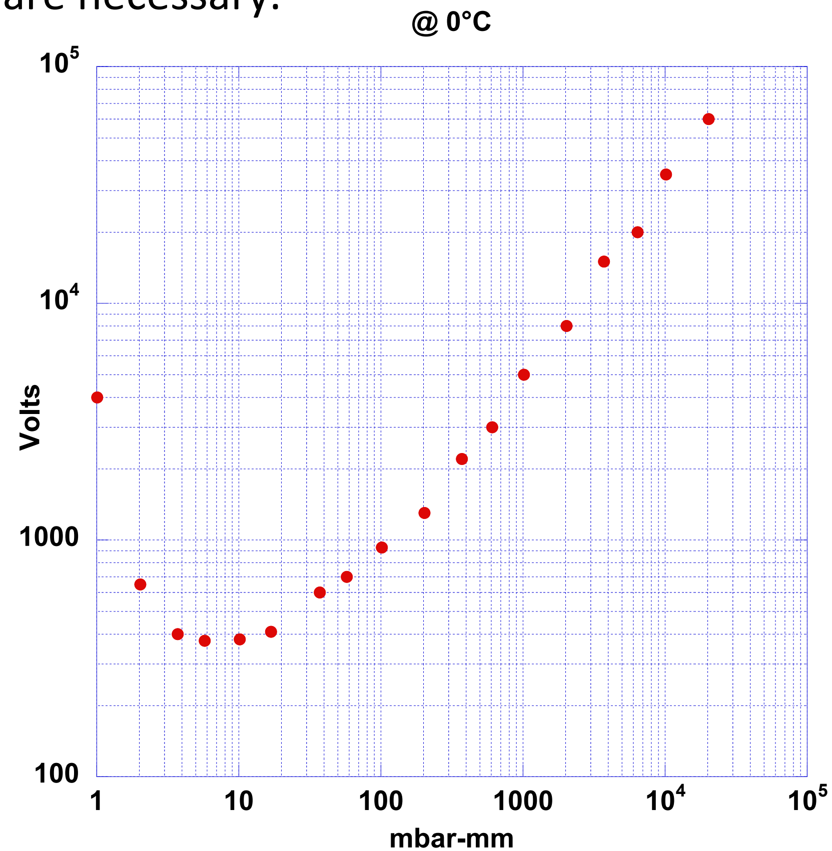
Up to NIST 80µW, we were using the normal Hamamatsu voltage repartition with K at 1000 V and D1 at 822 V (red curves) for a 10^6 gain.
Above, up to 30000 µW, we had 821 V on K, only change, for a 10^4 gain (blue curves)
From 8000 to 150000 µW we had 0V on K for a gain of about 600 (green curves)

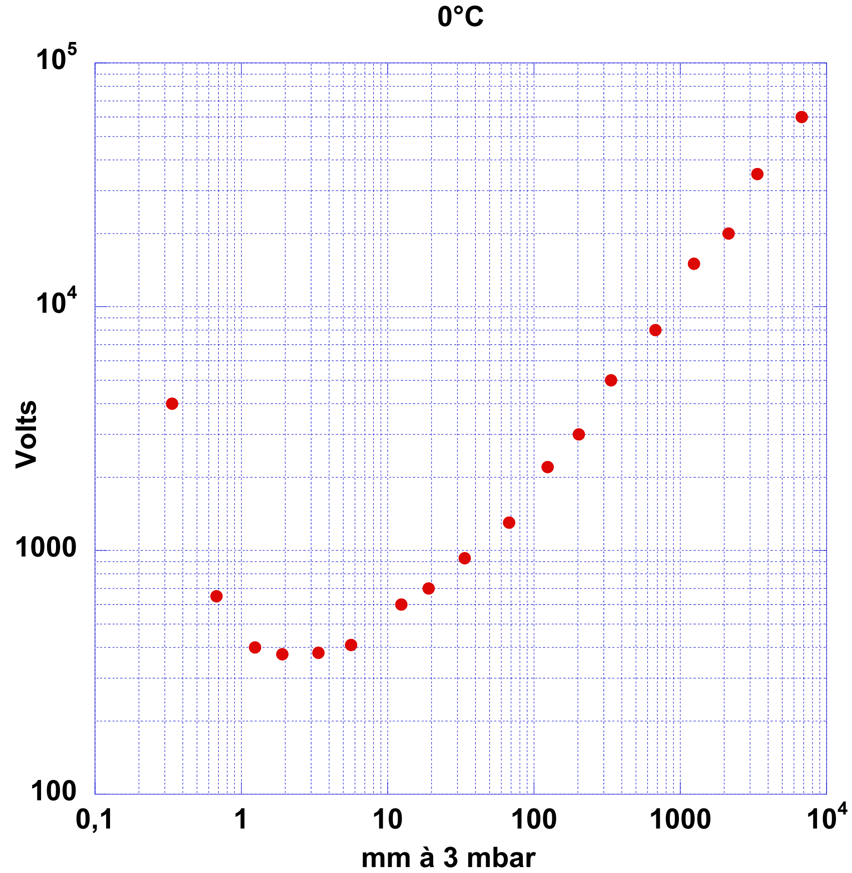



Npe/pix/GTU = NIST

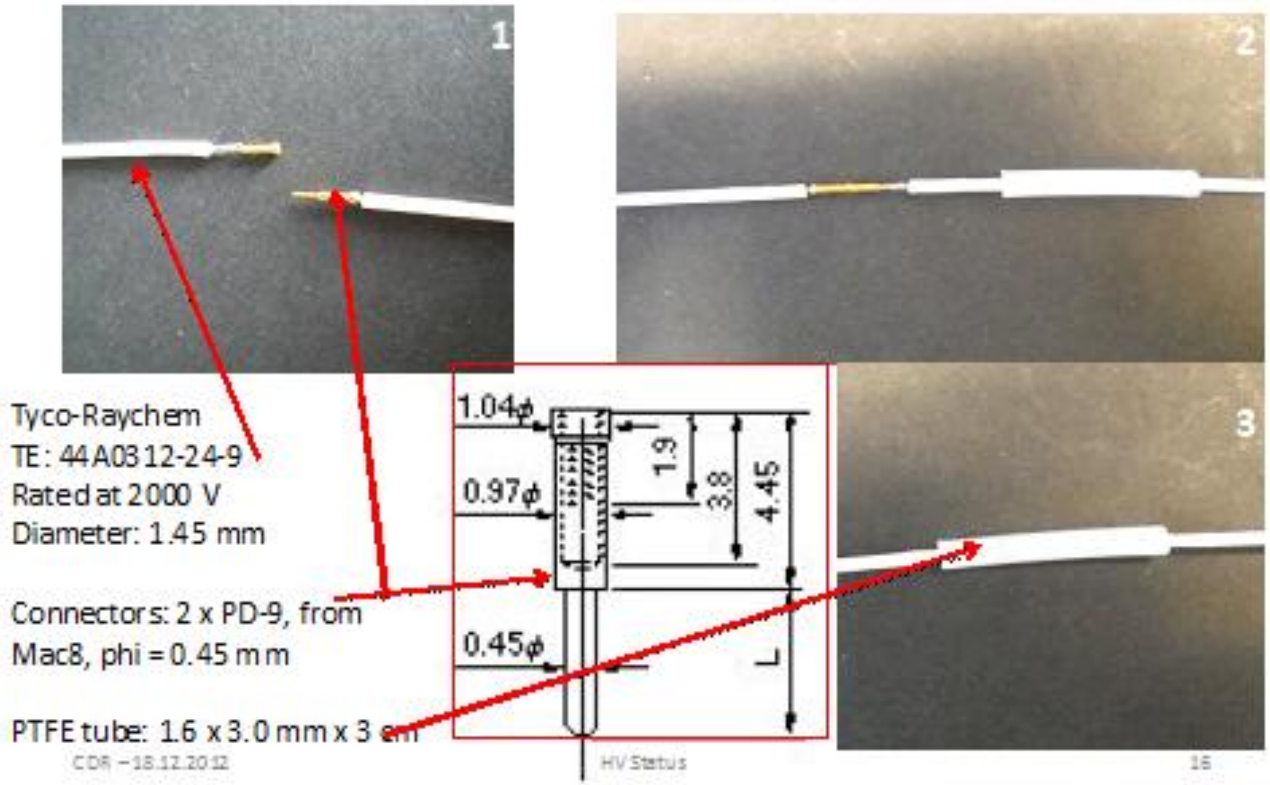
# First pathfinder
# Timmins Balloon (August 2014)

Paschen-Back effect: voltage limit of discharge, here in air, when pressure and distance between electrodes vary. This problem is only for balloons, Timmins and SPB, because at 30 - 40 km, p = 8 - 3 mbar. At 1000 V, and 1000 mbar, 0.5 mm is sufficient. At 3 mbar, 30 mm are necessary.



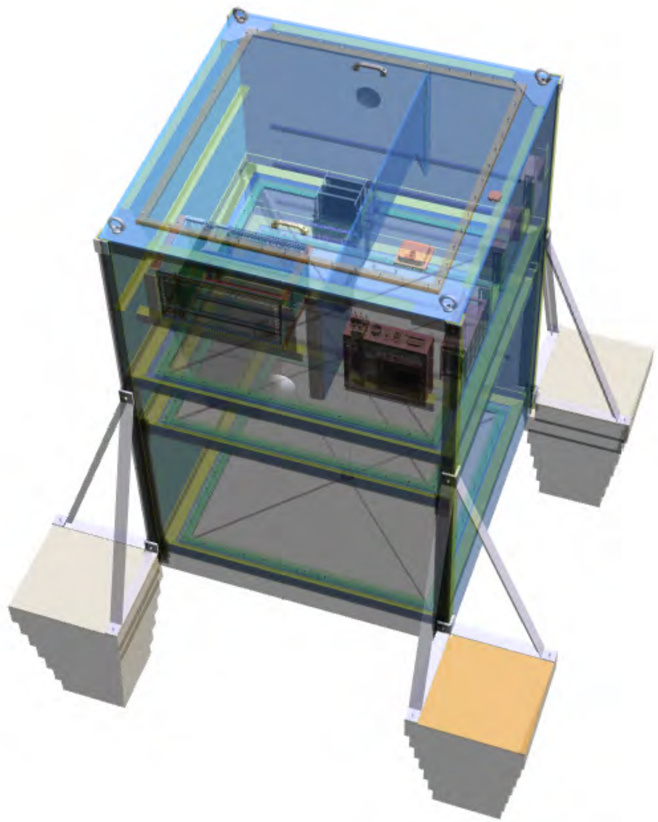
Cables between potted HVPS and potted PMT pins. These cables need to be opened to build the instrument.




These are called the white cables, and there are 117 of them.
These white cables were the cause of having only 1/3 of the pixels having a correct efficiency (we could not go above 950 V, then the distance between pedestal and pe peak is too small.

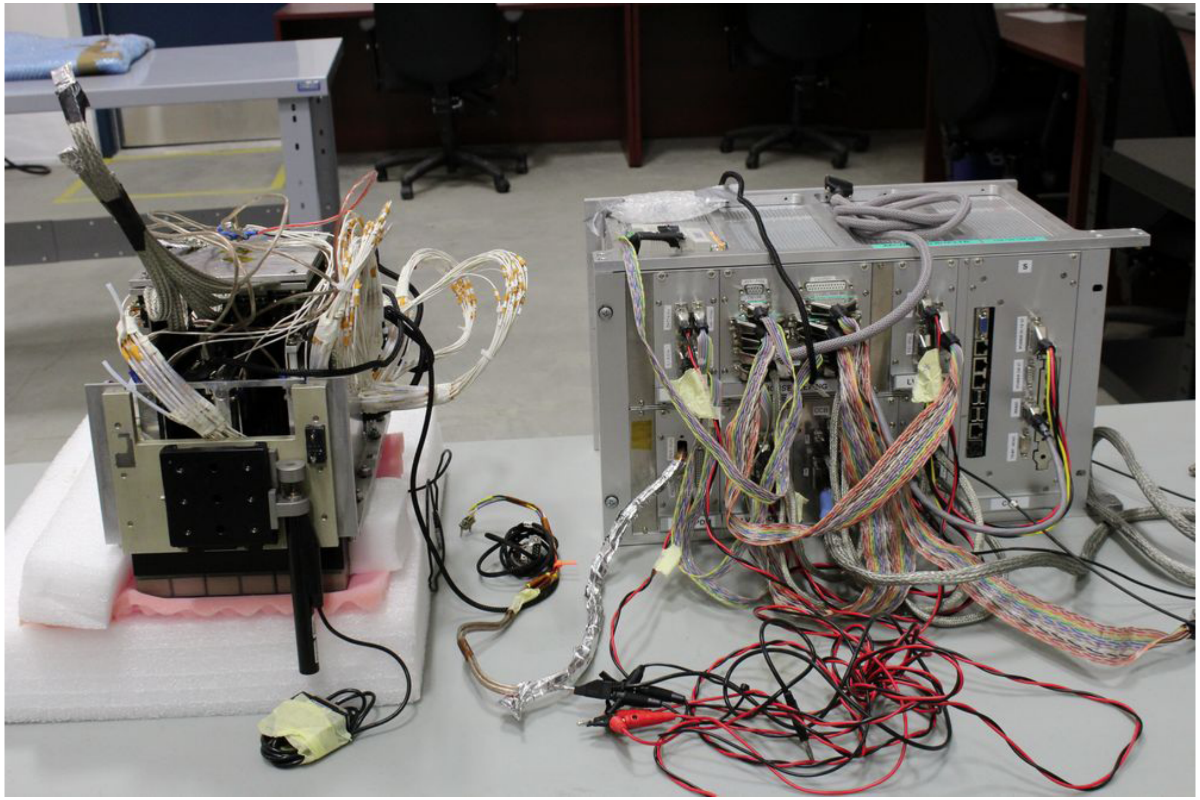
Even with this design, it was impossible to put more than -950 V on the PMTs, hence 2/3 of the pixels did not have enough efficiency due to this low gain.

You will see soon that we have now suppressed these white wires.



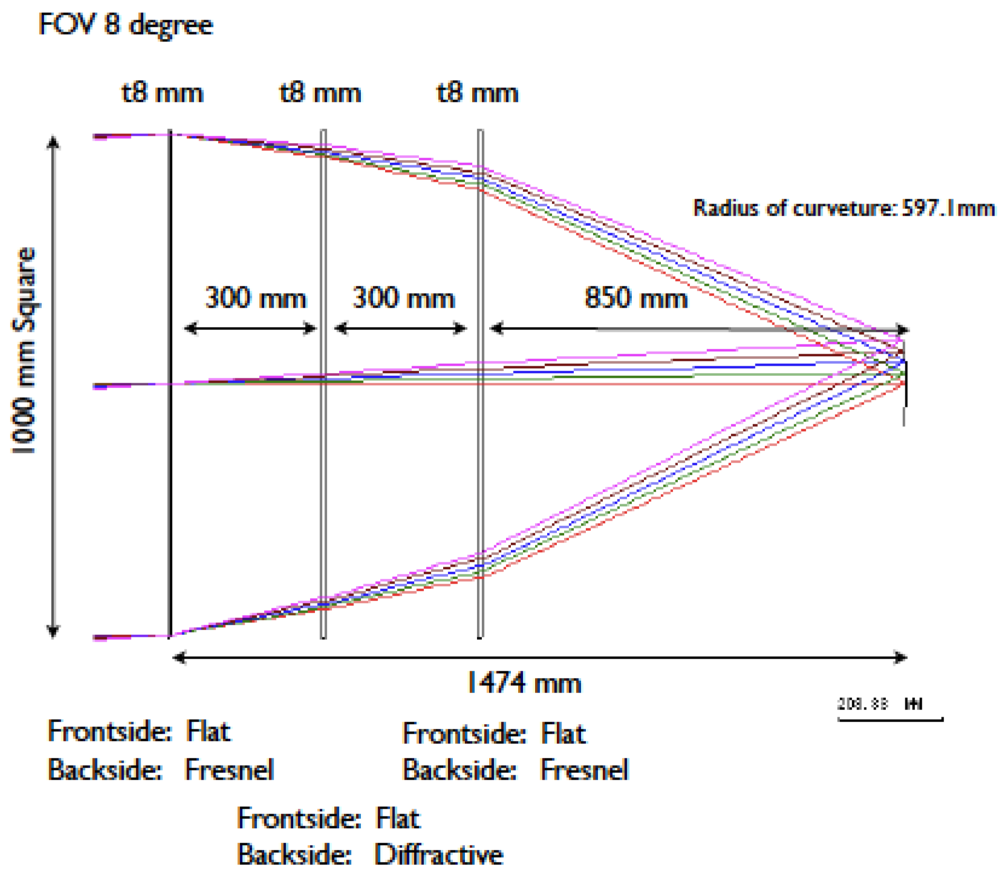
The Timmins gondola

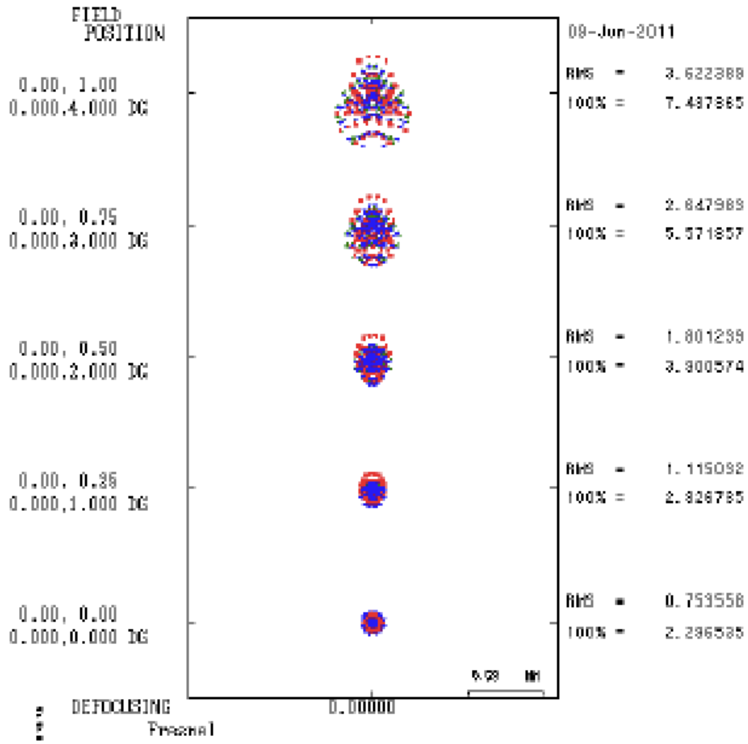
The PDM (look at all the white cables) and the Digital Processor (from Napoli)



# Balloon optics

Timmins



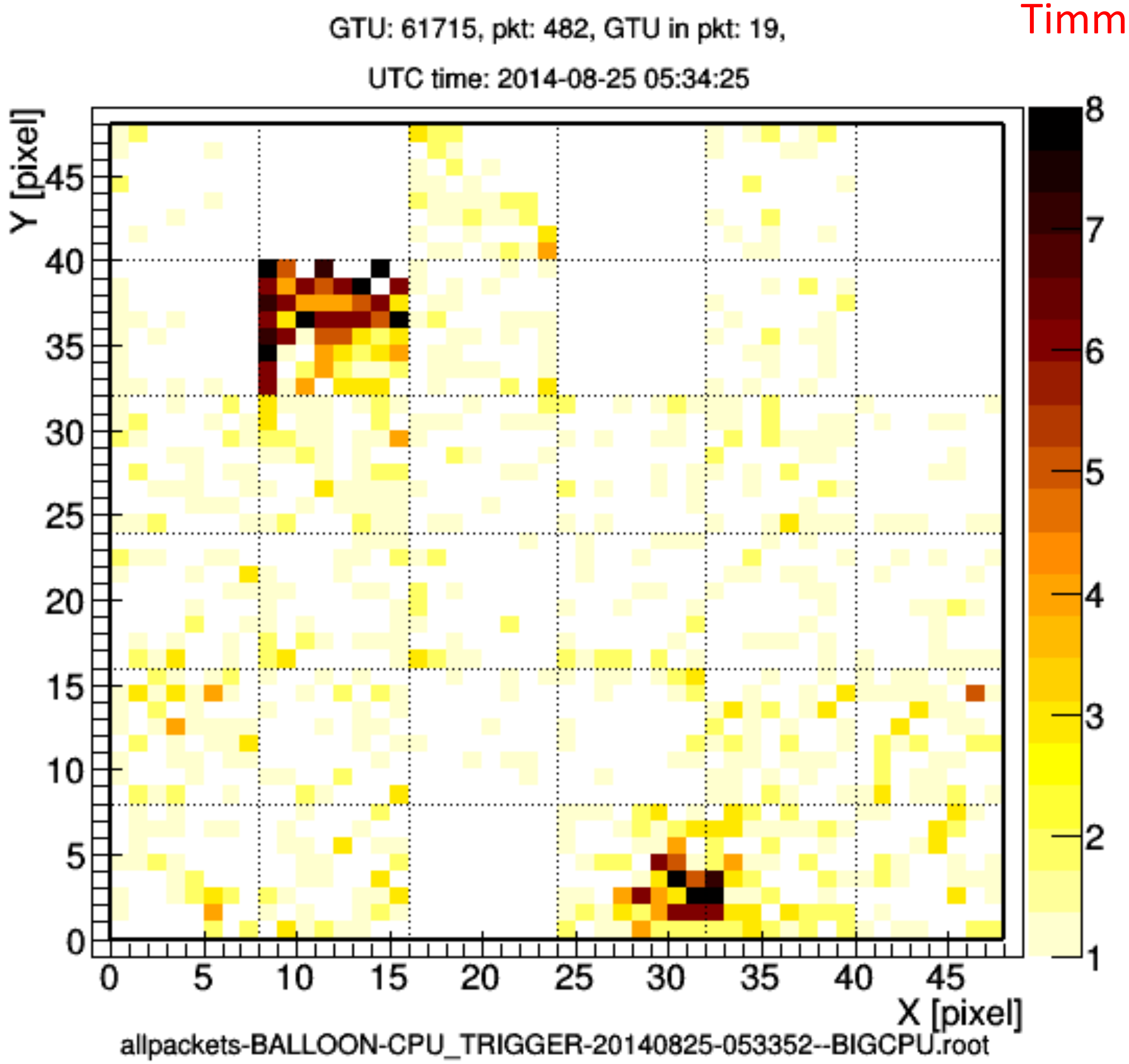

These are the very good optics we were supposed to have. However, a miscalculation on the code written to engrave the refractive lens made it impossible to use. So we had two lenses only, exactly like in TA-EUSO (see slide 17) . So our PSF was 2-3 pixels in diameter instead of one. This is corrected in the future balloon (SPB).

But we were able to see what we wanted: next slide:

Timmins

The balloon was at about 40 km altitude.
An helicopter was hovering under at 3 km altitude. It was equipped with a laser (355 nm) shooting horizontal very short pulses of light.
They travel at the speed of light and emit Raylegh scattering which is observed by the balloon.
Every GTU (2.5 μs), the pulse of light had moved 750 m.
This mimics a track (and we can measure c !)

So we proved this camera is indeed fast enough to see photons emitted by showers.



# Second pathfinder TA-EUSO

## See Valentina's excellent poster

Location    Black Rock Mesa

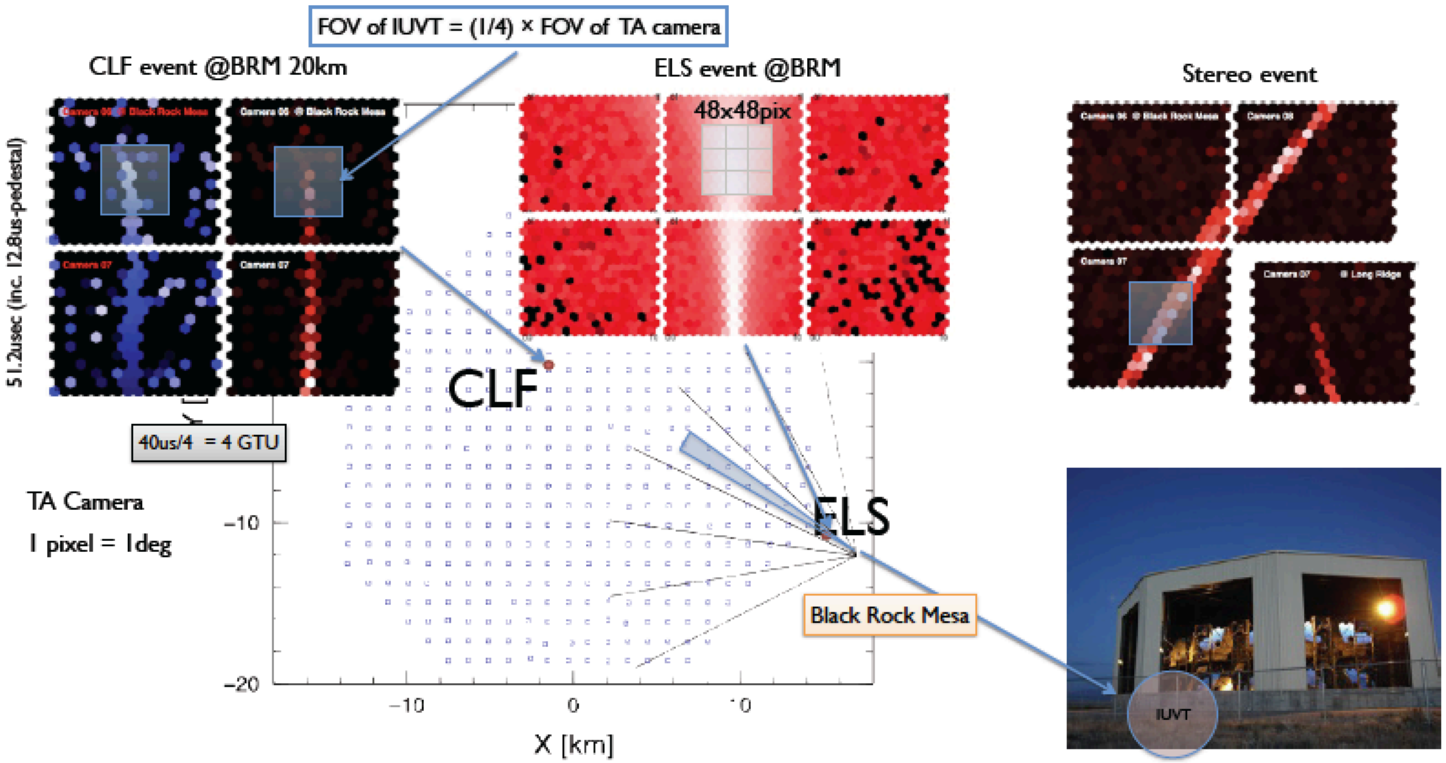
IUVT is able to observe CLF and ELS.

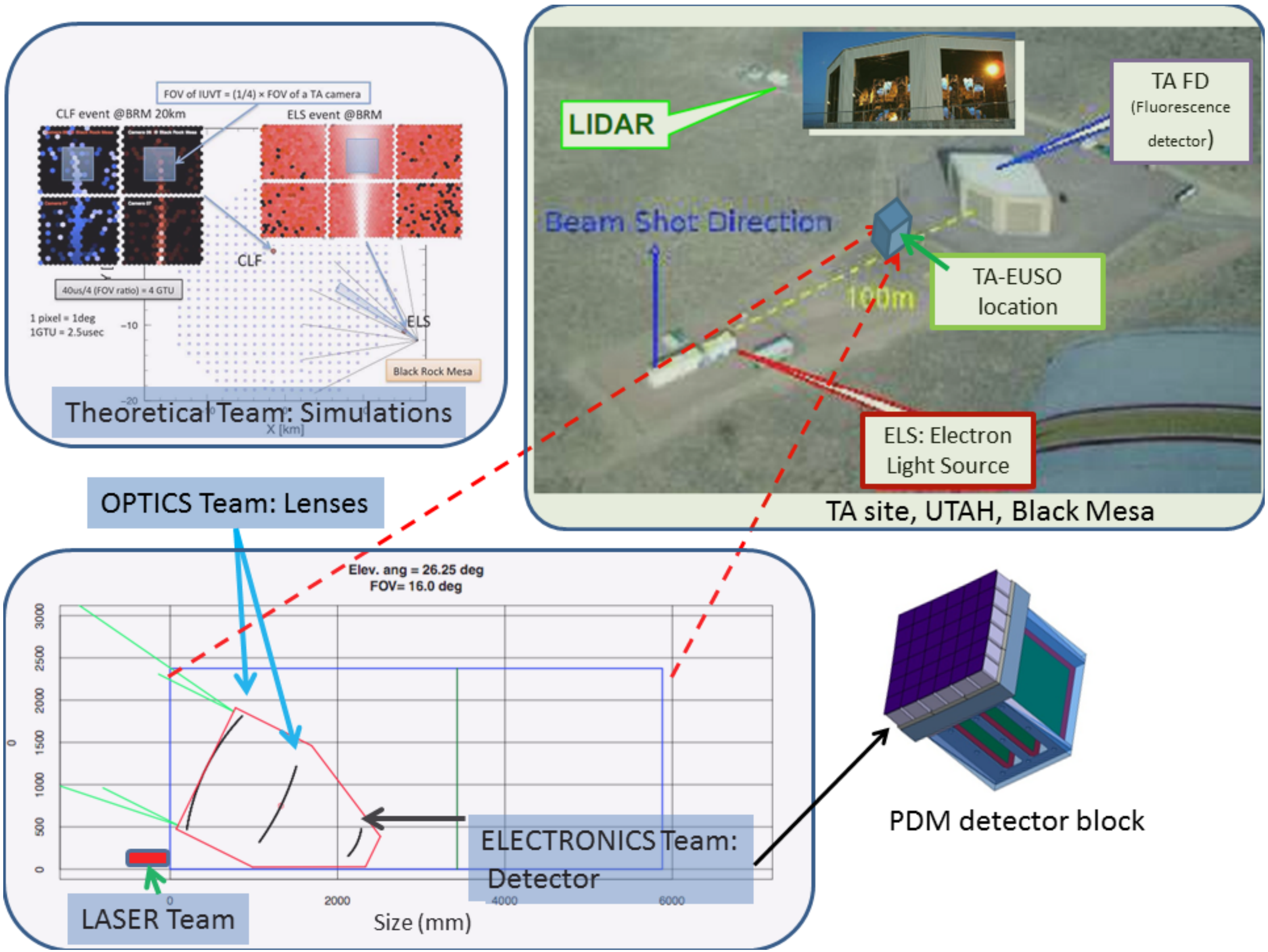
Time: March. 2012   → The second half of 2012

Synchronize between TA and IUVT: GPS time

(If possible, we want to use Trg. Signal from TA elec.)

IUVT should have a mechanism to change its elevation.




FOV of IUVT = (1/4) × FOV of a TA camera
CLF event @BRM 20km
ELS event @BRM
CLF
ELS
40us/4 (FOV ratio) = 4 GTU
1 pixel = 1deg
1GTU = 2.5usec
Black Rock Mesa
X [km]
Theoretical Team: Simulations
LIDAR
TA FD (Fluorescence detector)
Beam Shot Direction
100m
TA-EUSO location
ELS: Electron Light Source
TA site, UTAH, Black Mesa
OPTICS Team: Lenses
Elev. ang = 26.25 deg
FOV= 16.0 deg
ELECTRONICS Team: Detector
LASER Team
Size (mm)
PDM detector block

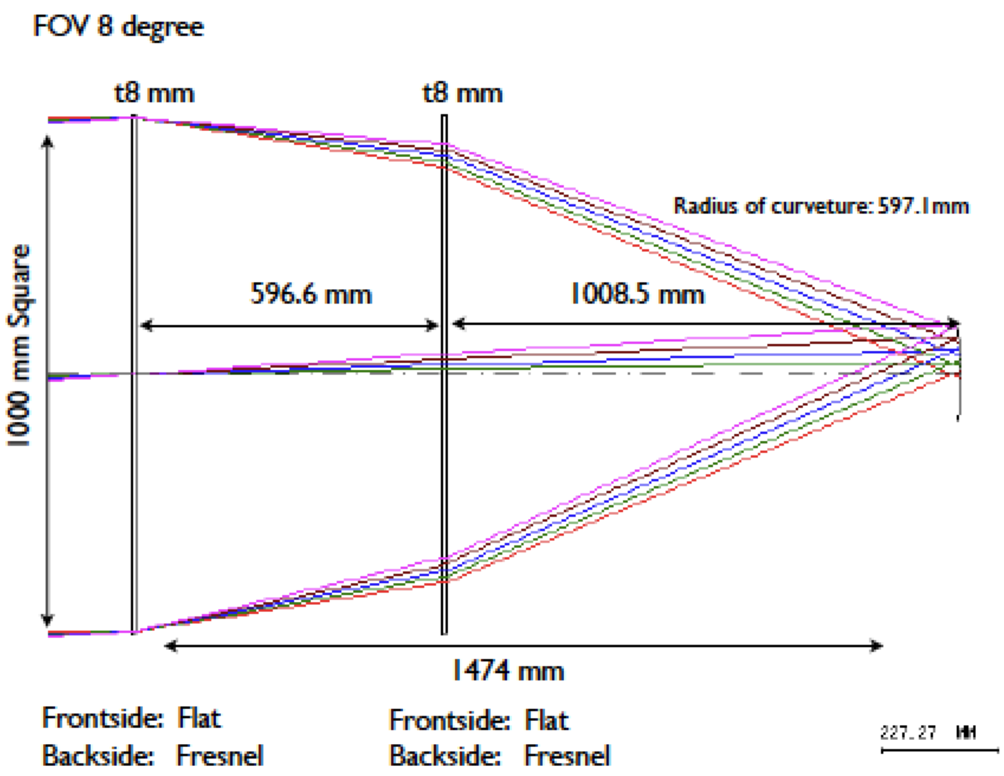
The goal of TA-EUSO is to analyze with a finer resolution, the inside of a shower seen by the TA UV telescopes .

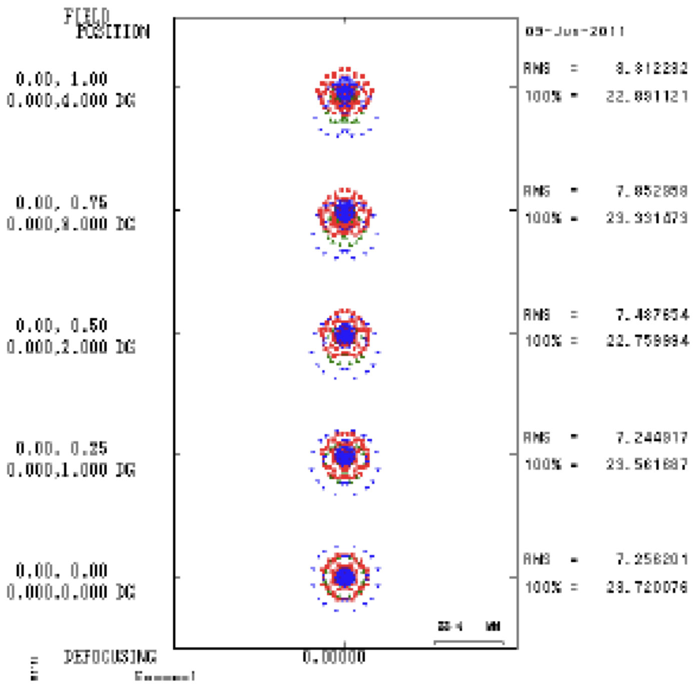
It’s FoV englobes the laser facility (CLF) and the vertical electron beam (ELF).

There are two Fresnel lenses only (and no diffractive), because here we do not require a very small PSF.

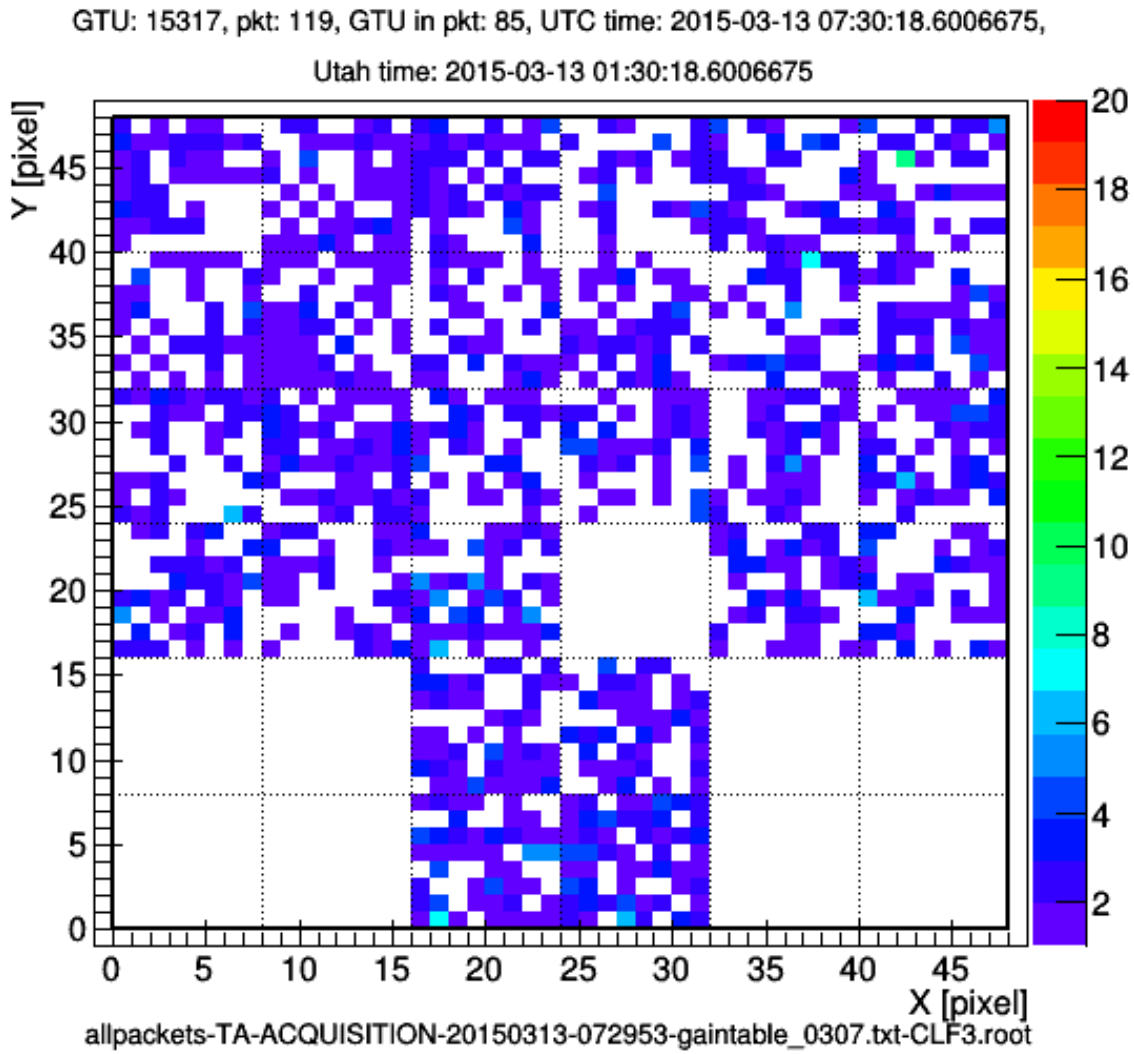
TA-EUSO

# TA optics

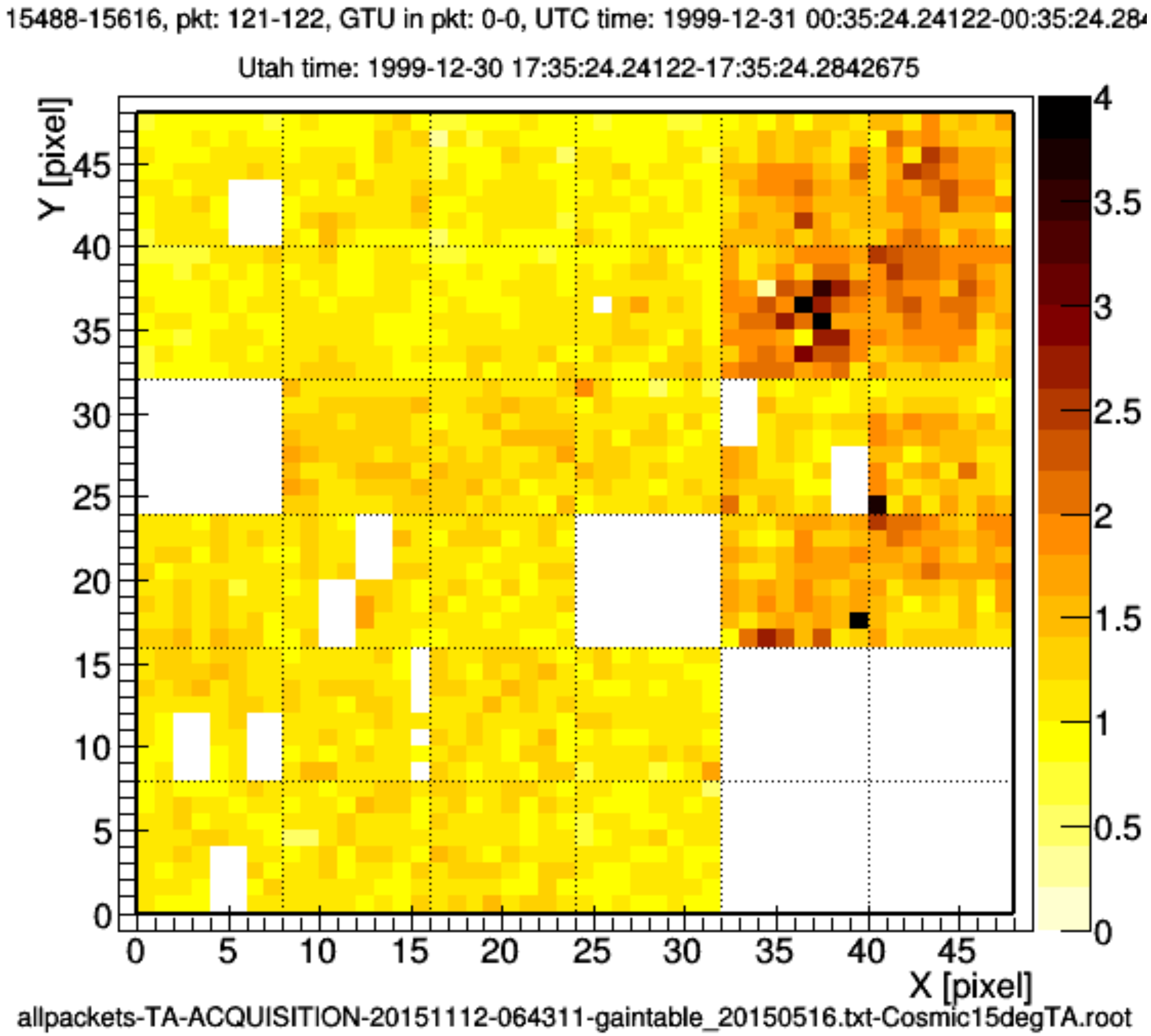


Central laser facility seen by TA-EUSO



And here, a meteor (much slower).

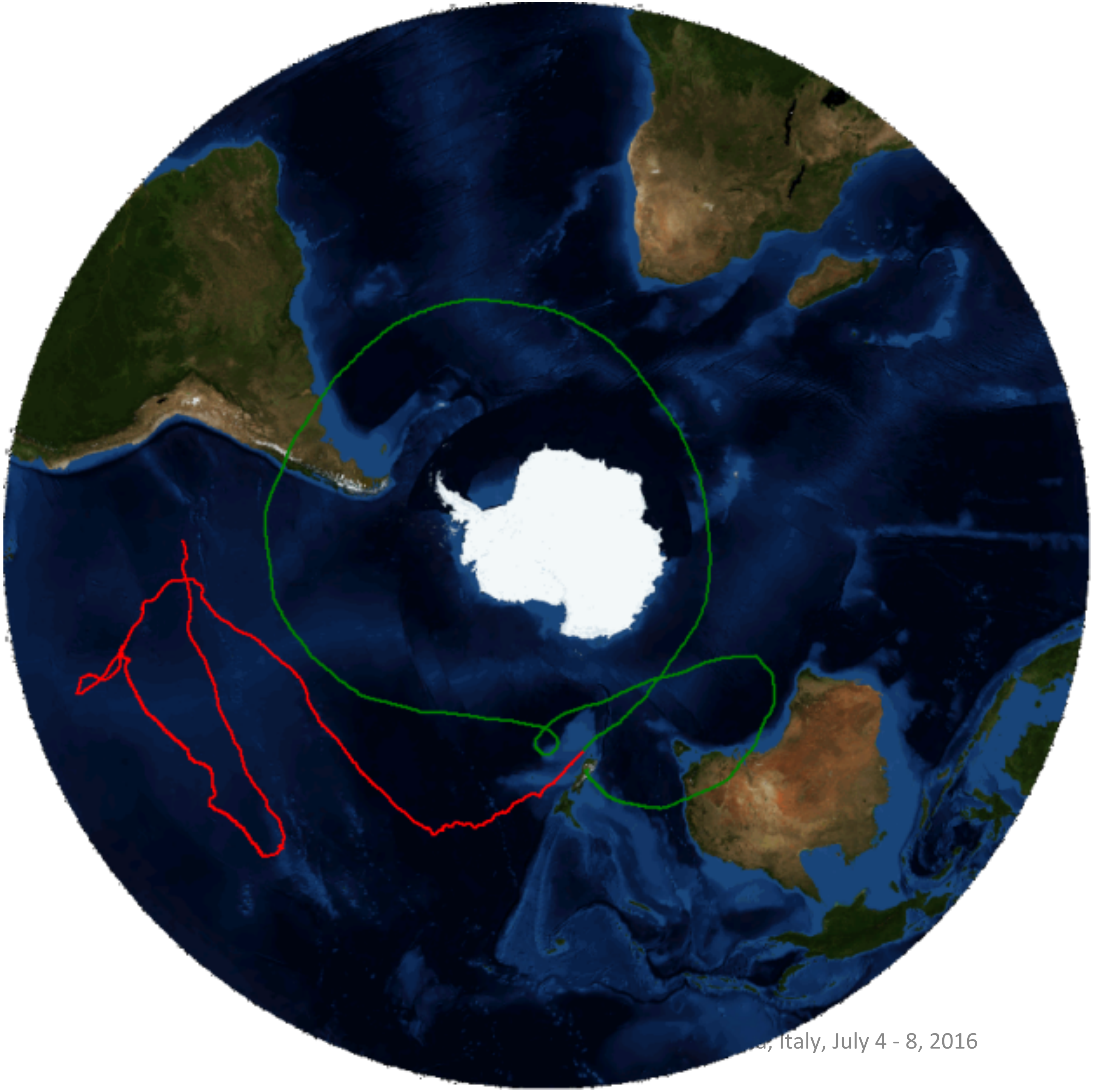


# Third Pathfinder:
# the Super Pressure Balloon (EUSO-SPB)

Special envelope balloon such that it keeps its original He pressure.
Can fly for a few months.

Goals: see $10^{18}$ eV (and above ?) first showers from Space.
At 30 km altitude, with 1.0 $m^2$ lenses, we predict one shower per night.

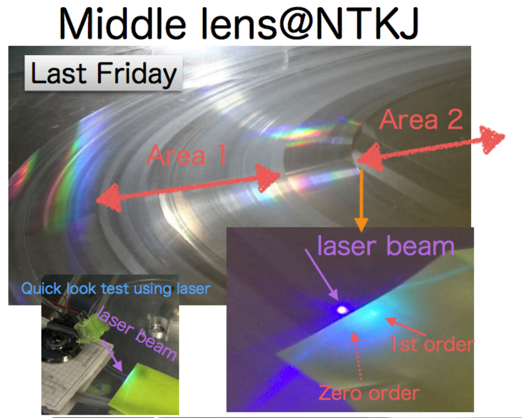
Will fly in one year from Wanaka and will circle around the south pole.



SPB

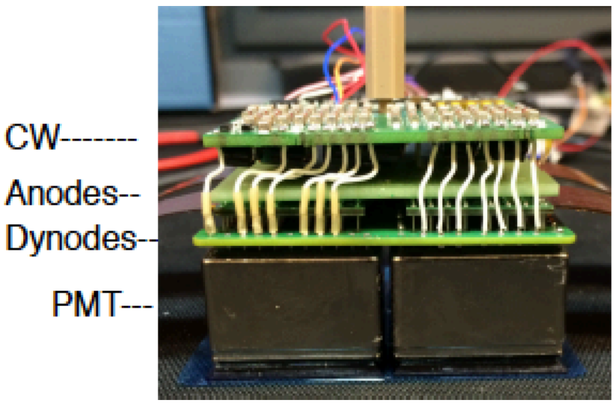
First prototype of SPB is COSI which flew from May 16 (Wanaka, NZ) to landing July 2 (Peru), that is close to 80 days.

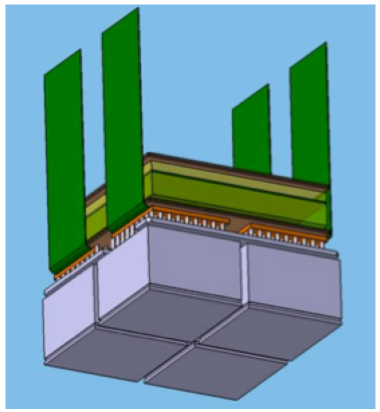
# What's new in SPB, compared to Timmins balloon ?

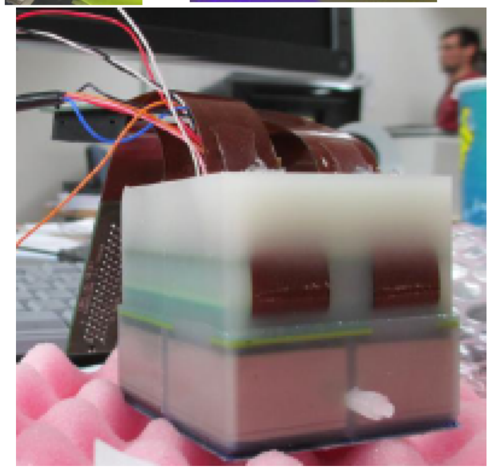



1) Second lens: diffractive: here being engraved. See the rainbow! With 3 lenses, PSF is very good.

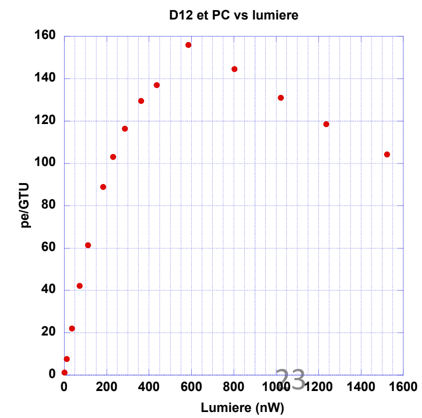
2) White cables (between potted HVPS and potted PMT base) removed by having the High Voltage part of the HVPS (the Cockroft-Walton) next to the PMT pins, having then only one potting instead of two. Tests at 3 and 8 mbar successful.





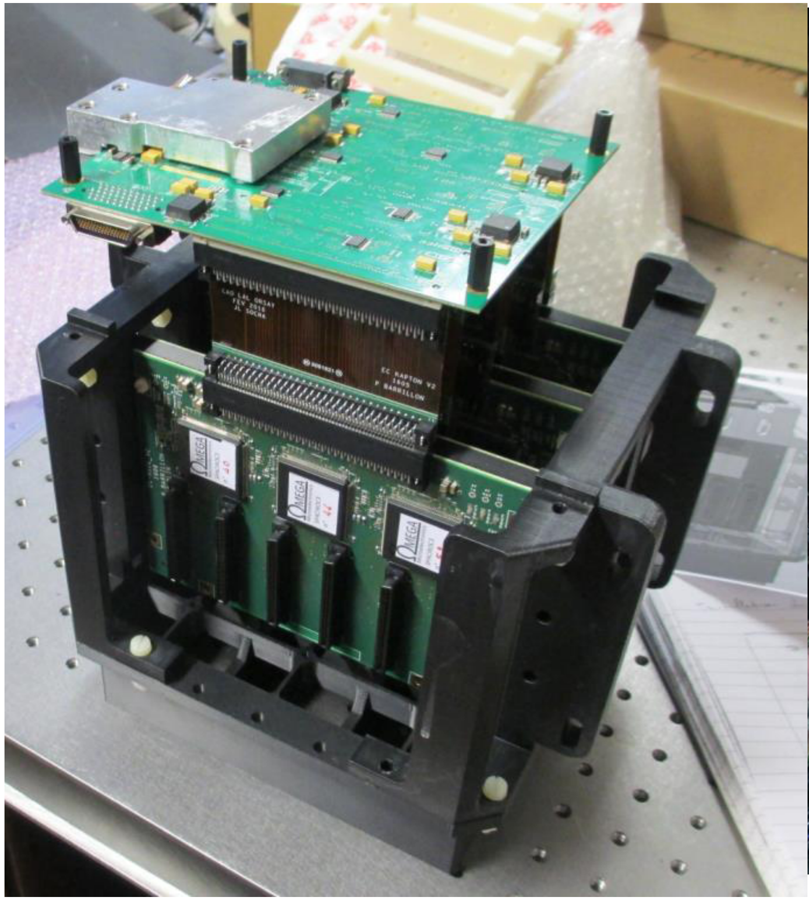
3) Plastic frame (3D printer) instead of aluminum for good grounding (next slide)

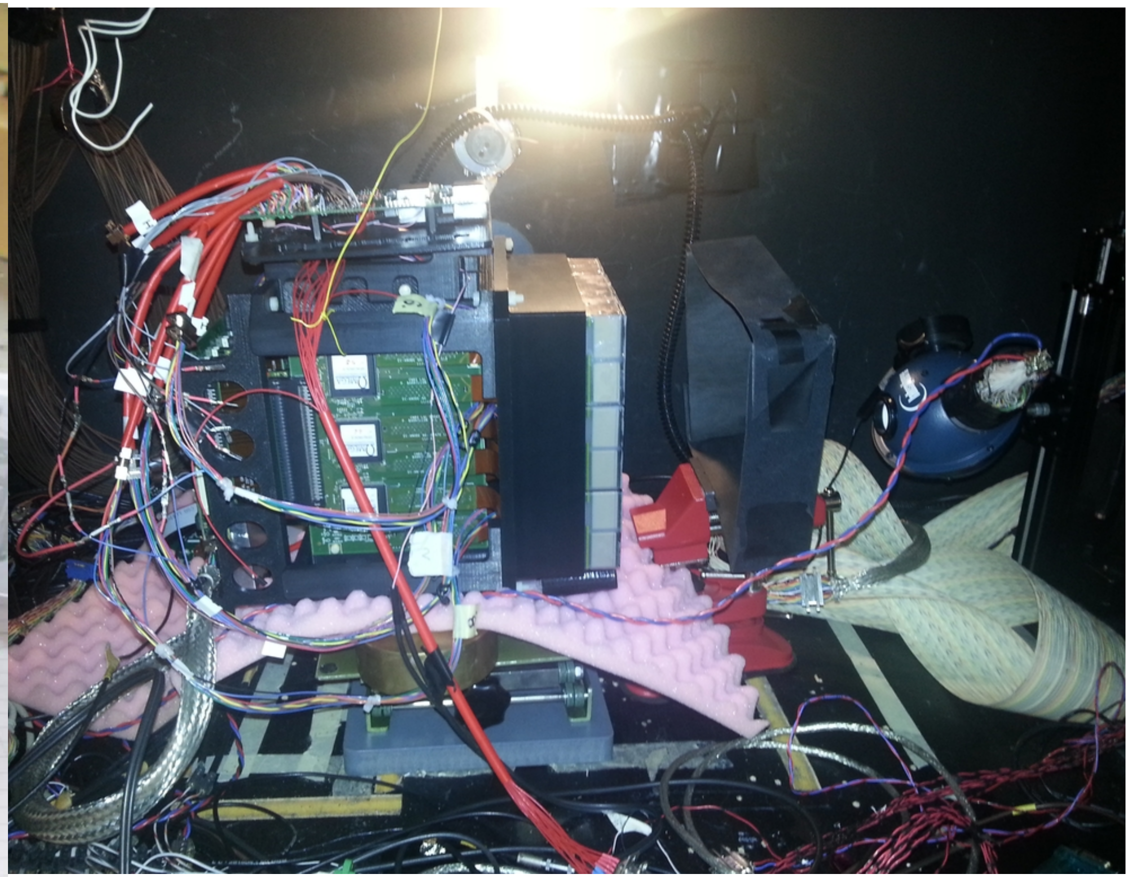



4) New ASICs, with 5 ns (instead of 30), where counting of pe can go up to 140 (instead of 30) per GTU. Then the HVPS switches will be commanded from the pe counting in each EC (256 pixels). If the counting rate of any pixel in the 256 goes above 100, then the cathode voltage is reduced in less than 3 μs.

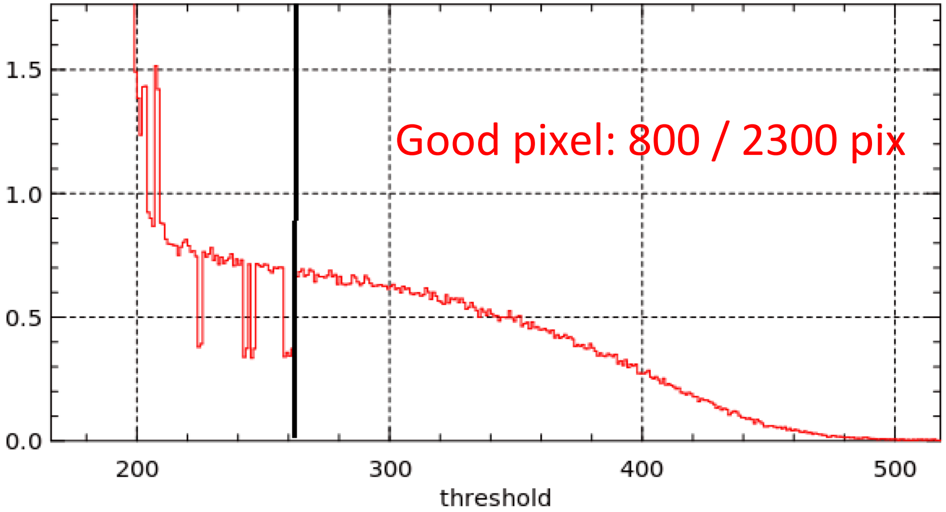
The new PDM frame with most cables ( but no white).
From right to left: the light source (integrating sphere), the PMTs, the ASIC boards and finally the PDM board.

Without cables

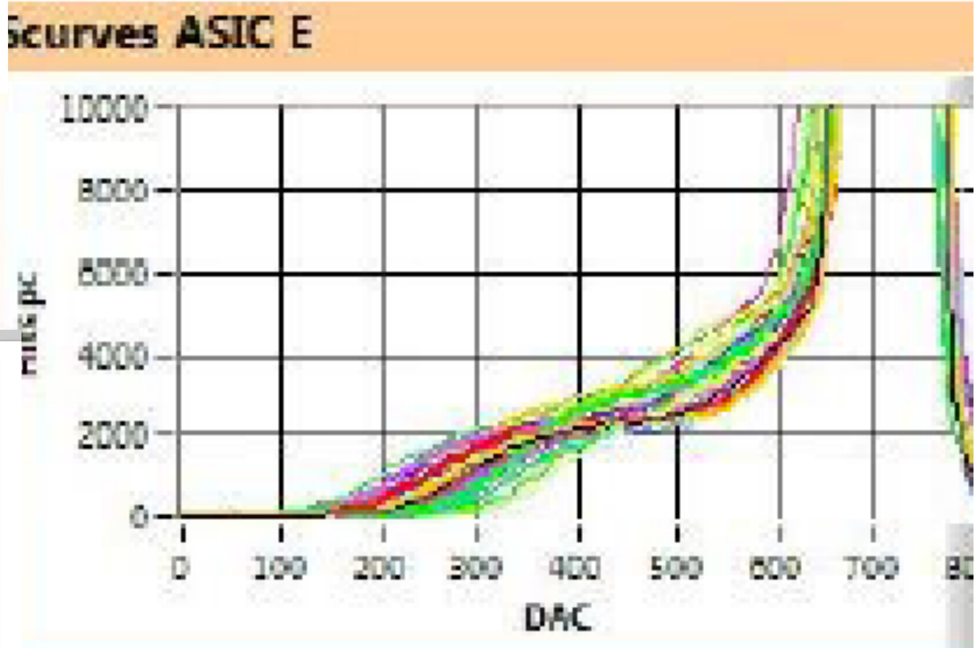




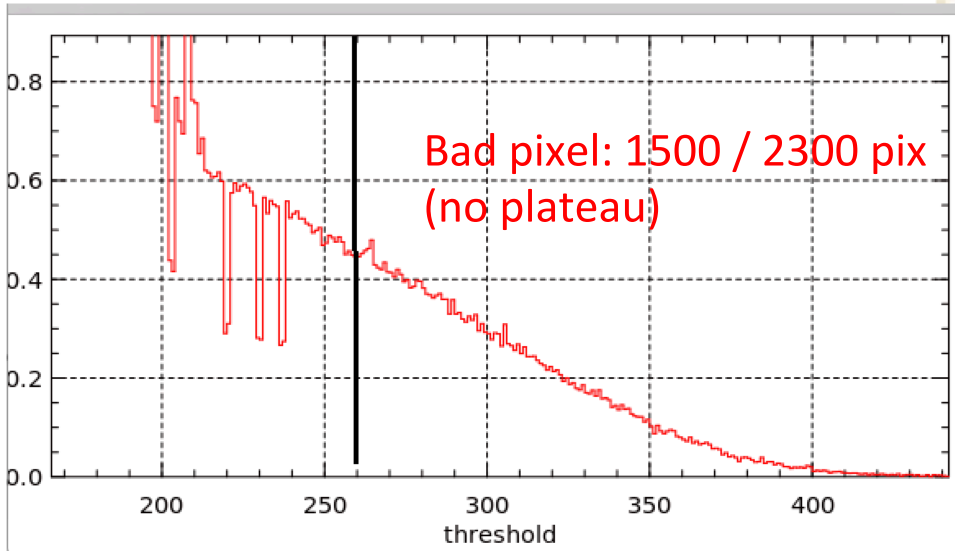
SPB




These curves: S-curves, are obtained by increasing the threshold of the discriminator set on anode pulses. These curves are the integral of the more usual charge spectra. The efficiency is the height of the plateau.




**Timmins balloon**




**SPB: one of the worst PMT**

The S-curves are reversed because of the new ASICs

# Fourth Pathfinder: Mini-Euso

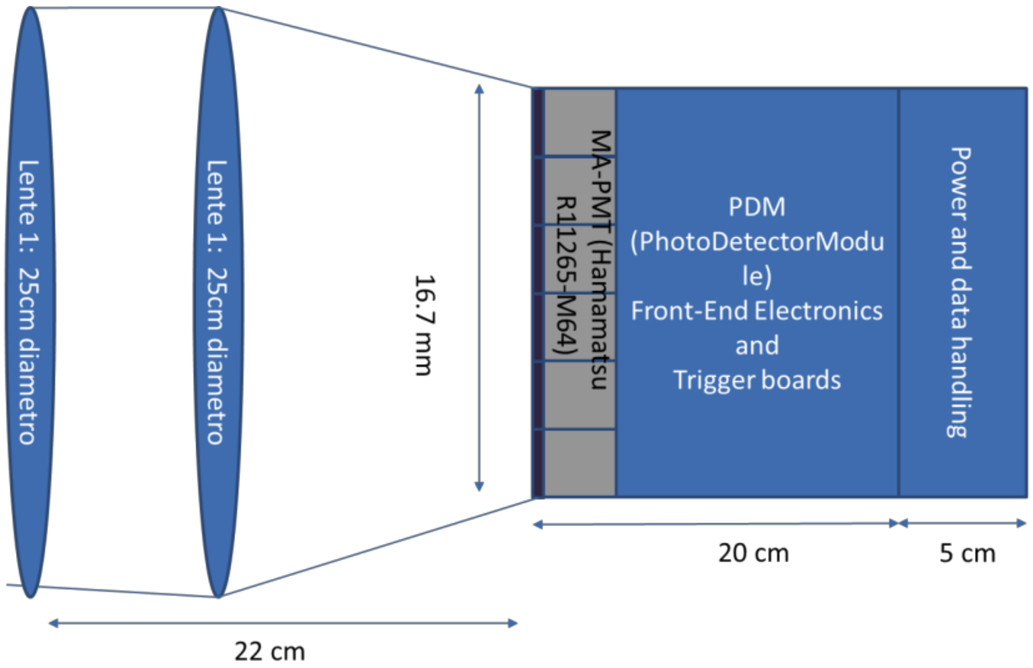



Figure 1 MINI-EUSO block scheme: Optical system with two Fresnel Lenses (25 cm diameter) focalizes UV light on a focal surface of 1 PDM, 36 multi-anode PMTS, total 2304 pixel

PDM same dimensions as SPB, but different DAQ.
Located inside ISS (p = 1 bar) next to a UV window looking at earth.
The lenses (25 cm) are too small to see showers.
Accepted by Energia and Roscosmos and ASI.
Will go to ISS end of 2017.
Both PDMs (SPB and Mini-Euso) are made, tested and calibrated at APC (Paris).

## Scientific objectives

- a.1) UV emissions from night-Earth
  *6.5 km resolution, from 2.5mus and above +-51°*
  *Noise from different lightning conditions, moon phase*
  *Noise from different inclinations*
- *a.2) Map of the Earth in UV*
- *a.3) Study of atmospheric phenomena*
- a.4) Bioluminescence of Animal and vegetal organisms
- *a.5) Study of meteors*
  - *Search for Strange quark matter*
  - *Space Debris assessment*

## Technological objectives

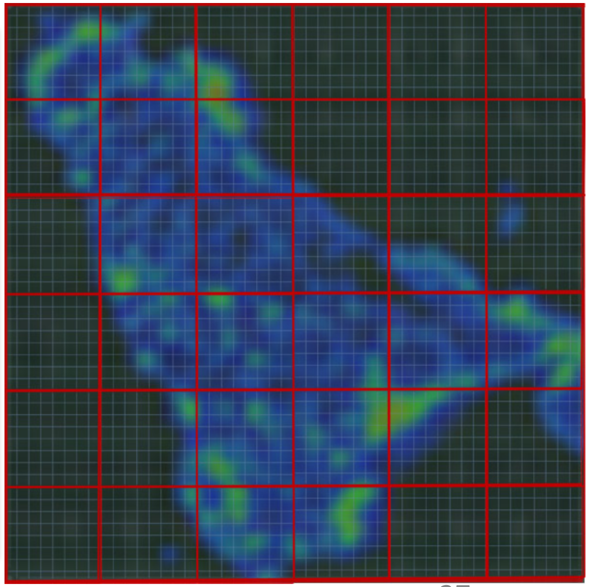
*b.1) First use of Fresnel lenses in space*

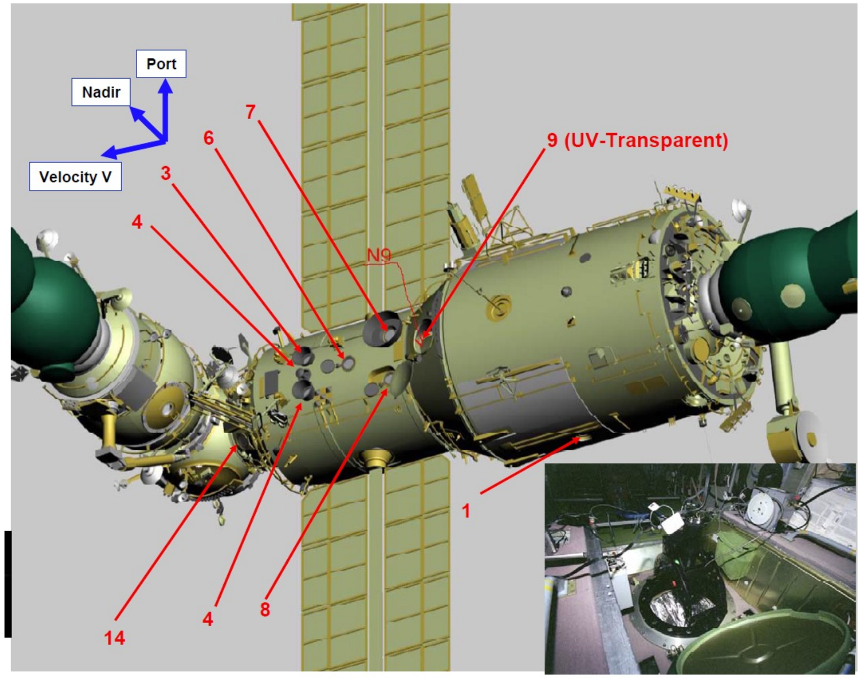
*b.2) Optimization of characteristics and performances of EUSO*

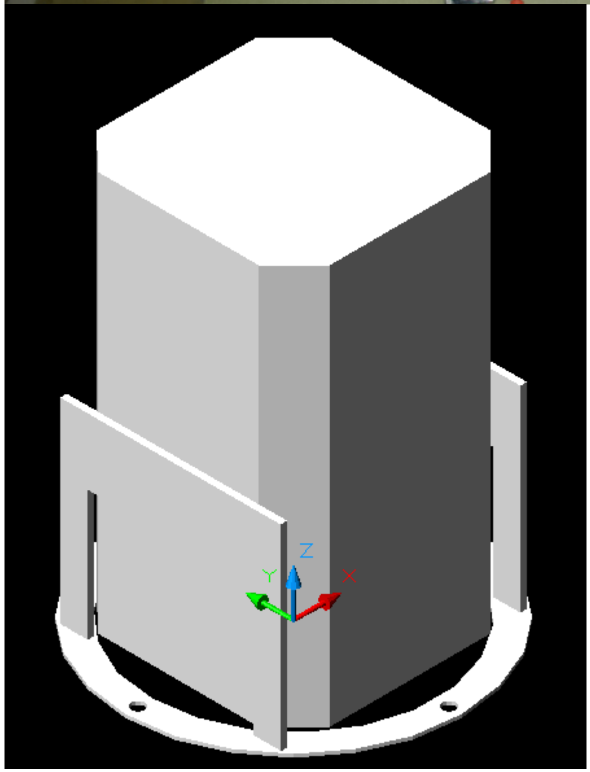
*b.3) Raise the technological readiness level of the Hardware*

For our south Italy friends
The details of a.1) UV.
*(from Marco Casolino)*

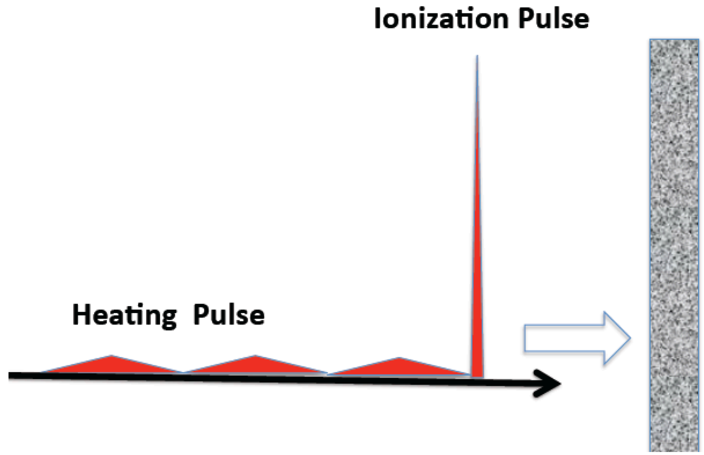
- Nessuna mappa UV notte
- Tatiana 1 pixel
- Fluttuazioni spaziali e temporali ms ms, s
- Trigger su μs e ms
- Variazioni a lungo periodo
  - Terreno
  - Fase lunare
  - Nadir / Tilt (0-4 gradi)




Port
Nadir
Velocity V
7
6
3
4
9 (UV-Transparent)
N9
1
14
4
8


Z
Y
X

# Debris
## In collaboration with Gerard Mourou from école polytechnique




Very powerful very fast fiber laser
Fiber very good in terms of cooling
10000 fibers, all with their own phase control.

A very wide FoV telescope detects 1 < dia < 10 cm (like Jem-Euso) from 100 km, calculates the trajectory, feeds these data to a Cassegrain normal telescope and the lasers fire to slightly change the debris momentum, which will then go to earth.

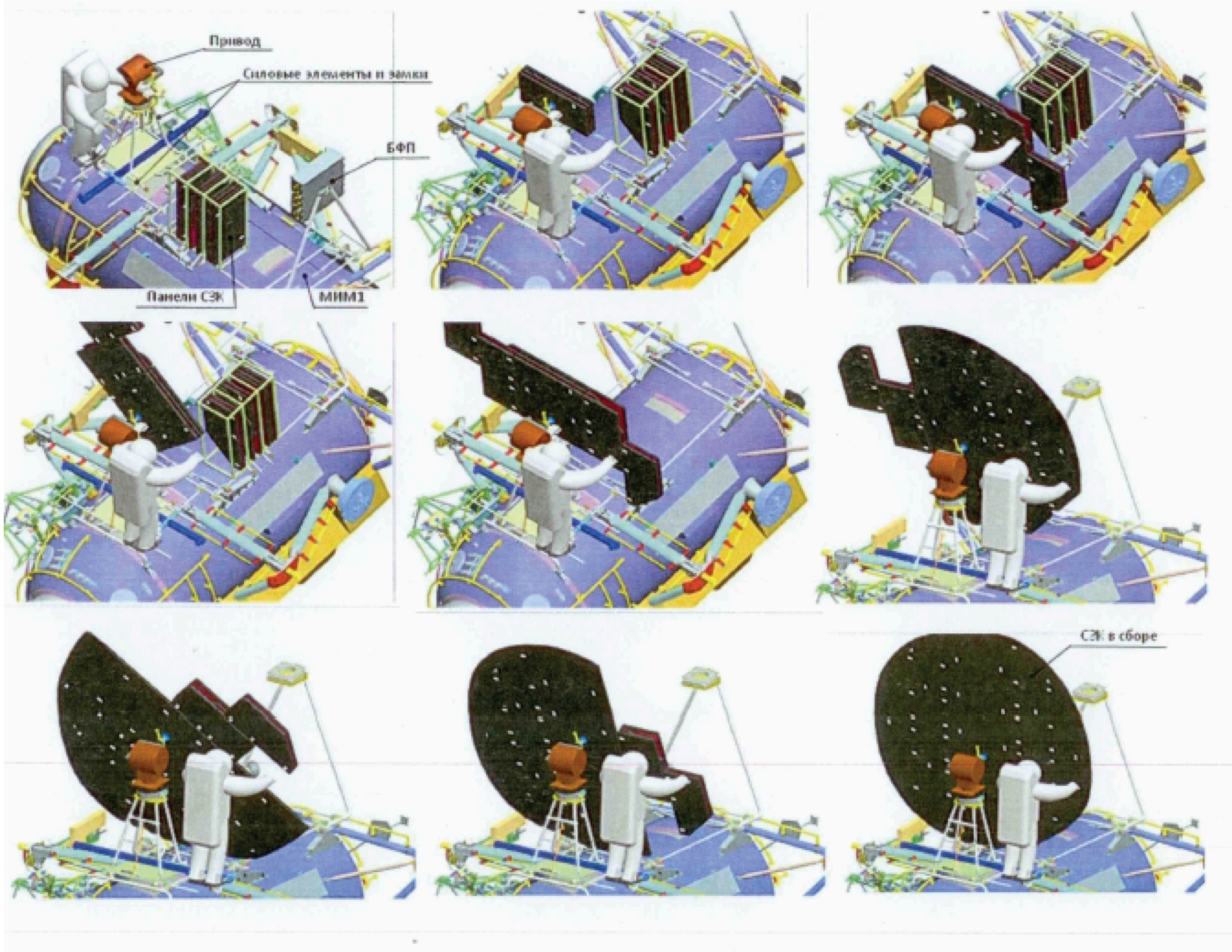
Prototype can be Mini-Euso to detect during the twilight (8 minutes every 90) these debris from as far as 50 km.

A laser could then be installed together with K-Euso (see next slides)

Finally, a dedicated free flyer with the big laser and a dedicated "Jem-Euso" could swipe the debris from 300 to 100 km altitude in a couple of years operation.

# Fifth and probably last pathfinder before the big Jem-Euso : Klypve (K)-Euso

3 years ago the Russians from MSU (Michael Panasiuk, Pavel Klimov…) who are part of the Jem-Euso collaboration, proposed to us to help them by improving a project: KLYPVE, the following project after TUS on Lemonosov.
Klypve was only made of a mirror (large: 3.5 m diameter), a small focal surface and a very narrow FoV (± 7°)
We accepted the deal, and began to argue about the mirror, telling that large FoV means refractive. They said Roscosmos insisted on the mirrors for later applications. However, we finally agreed on a mirror with a correcting lens, going then from ± 7° to ± 14°. The new name: K-Euso. It is to be attached to the ISS, transported by Soyouz, and delivered through a small hatch (< 1 $m^2$) so that the mirror has to be cut in many pieces to be assembled by cosmonauts. However, MSU said that when Roscosmos will realize how expensive that is, they hope to be allowed to use lenses, and then K-Euso becomes Jem-Euso with a FoV of ± 30°.
This is mainly a Japan-Russia collaboration, with the Japanese building the lens, the laser head for the Lidar and buying the Hamamatsu 64 pixels PMTs. The Russians do everything else.
New electronics will be tested on Mini-Euso.

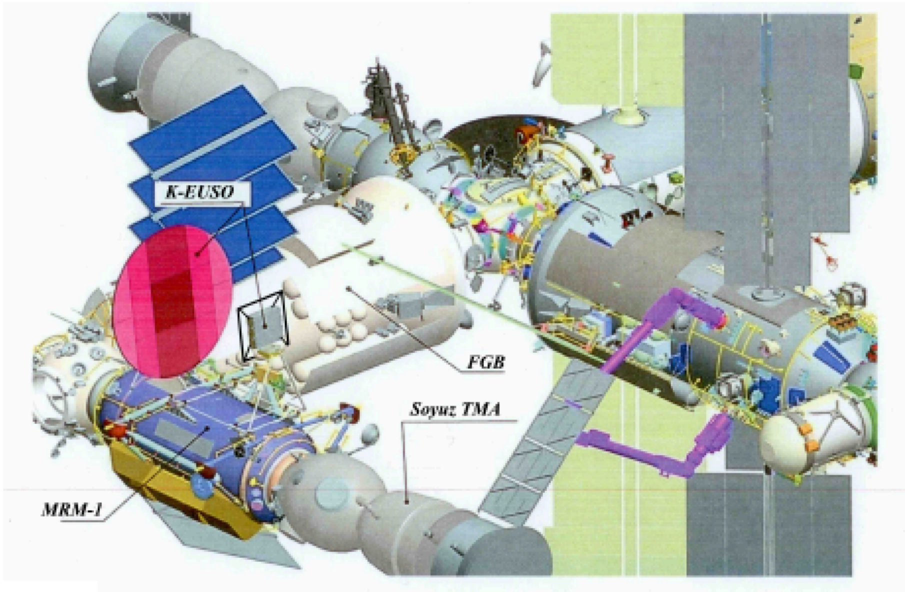


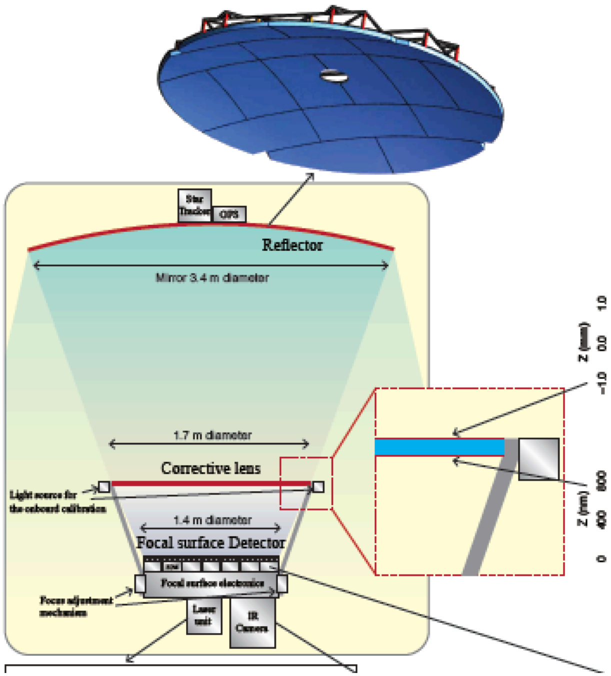

This deployment of the mirror looks like a Tex Avery cartoon. Not a very healthy solution, certainly very expensive.

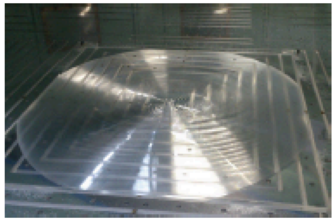
A new cargo to go to the ISS is under study.

## K-Euso

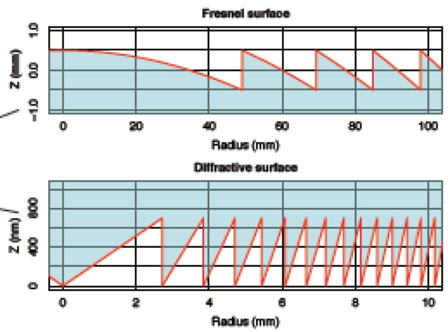
Attachment the ISS.
The telescope can be tilted up to 60°
(can see the horizon, test for τ neutrinos)



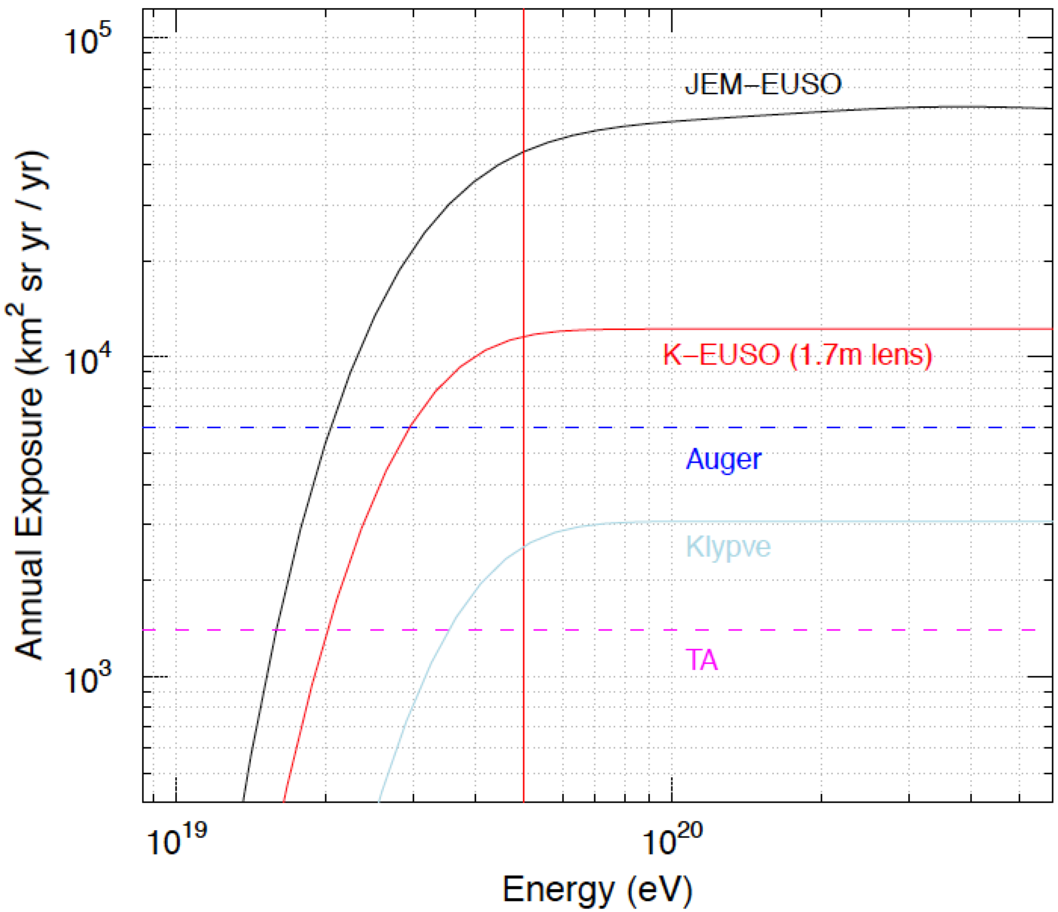
LENS




The mirror is Fresnel, and the lens is Fresnel one face and diffractive the other.

# Scientific goals of K-Euso

As you see, K-Euso is about 2 AUGER and 1/5 of Jem-Euso. However its threshold is low enough to see the same energies than TA (energies where they see the Hot Spot). The goal #1 is to have this 2 AUGER instrument going all around the globe, and confirm this hot spot seen by TA in the North.
A secondary goal is to check the relative calibrations of TA and AUGER with a unique instrument.
All other Jem-Euso goals are still valid, especially the study of intense atmospheric lights.



# How we see the future now ?

a) The big Euso should be at least 4 times bigger than the "present" one (to account for the AUGER increase in statistics when it is launched) for CR
   1 Very large mirror (we have theoreticians in our coll.)
   2 Lenses: ± 50°make a ground surface 4.25 greater than ± 30° for the same altitude.

b) Detect neutrinos: looking at earth horizon so that very energetic τ neutrinos have only a small portion of the earth to cross.

c) 2 ways to maybe make this project real:
   1 ESA M5 (A. Santangelo…)
   2 NASA Mission of Opportunity with a good chance if SPB is a success, (Angela Olinto).

d) Free flyer with a large elliptic (from 400 to 800 km) orbit. Low energy CR at low altitude and high energy at high altitude (we have another factor of 4 in ground surface between the two altitudes).

When? Probably after my death !