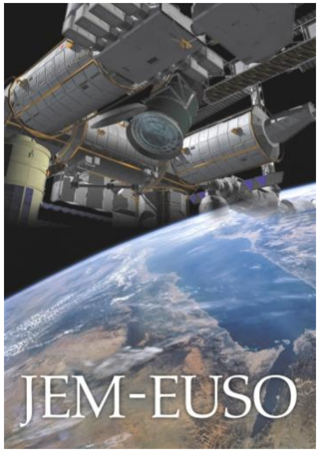
3rd International Conference on Technology and Instrumentation in Particle Physics

2-6 June / Amsterdam, The Netherlands

The EUSO-Balloon instrument

Valentina Scotti
University of Naples Federico II
INFN Naples

- The JEM-EUSO project
- The EUSO-Balloon pathfinder
- Description of the instrument
- Instrument integration and tests
- Status and plans



The JEM-EUSO project

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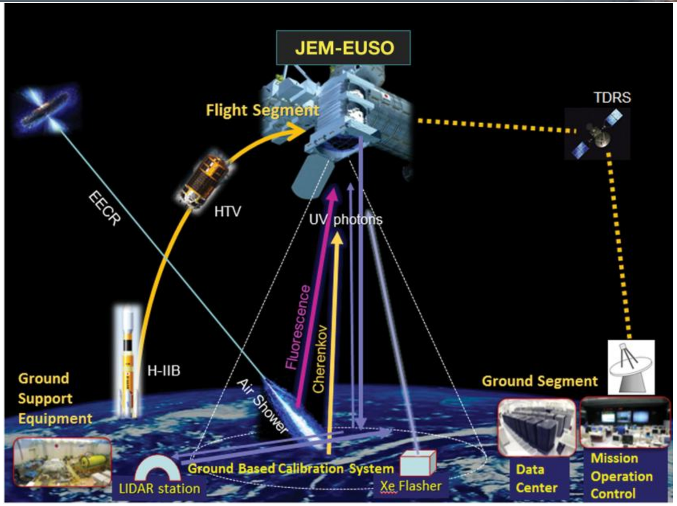

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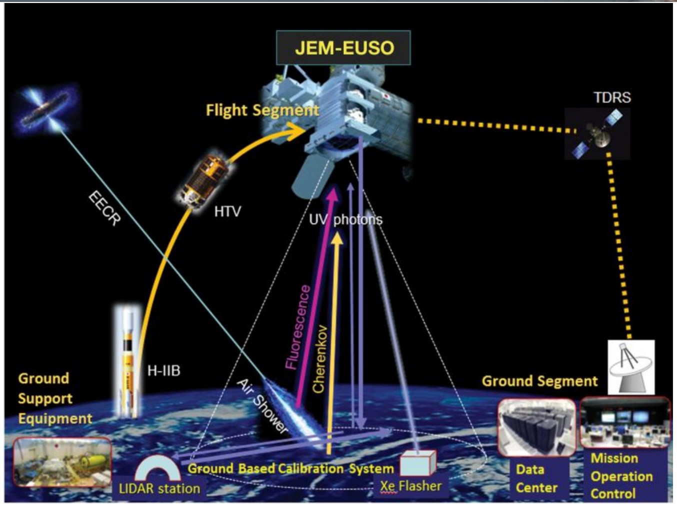

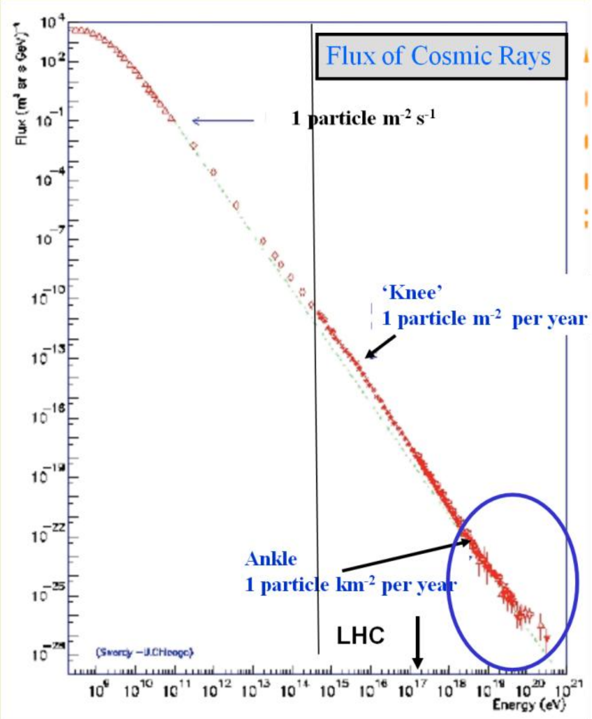

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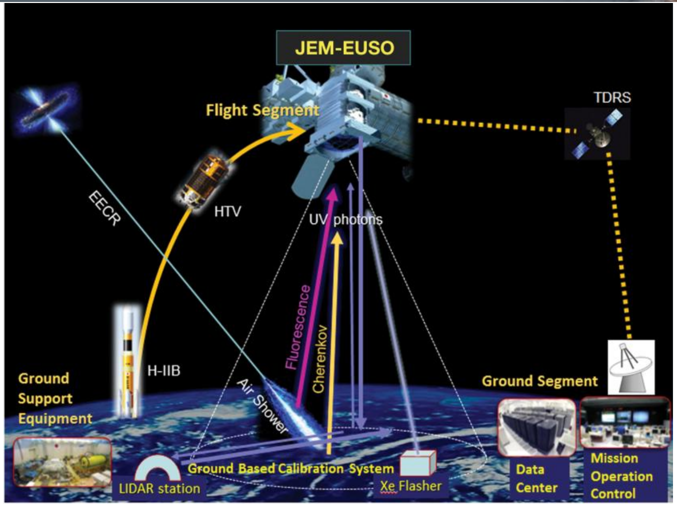
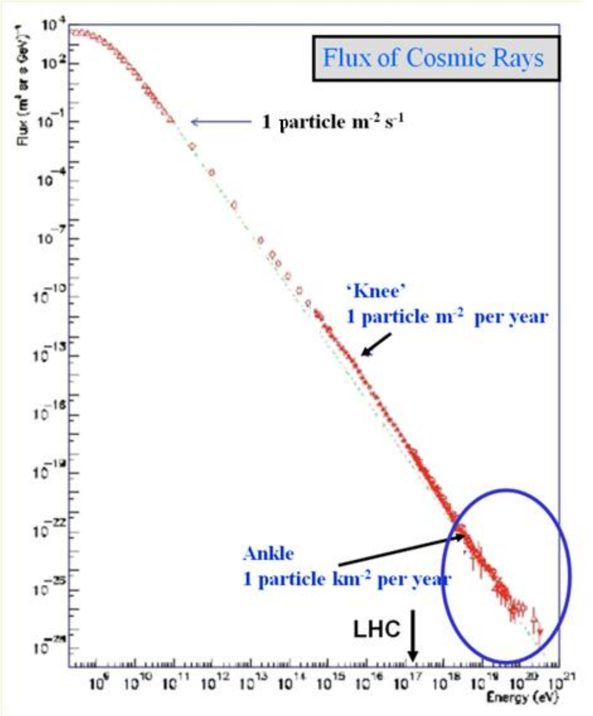
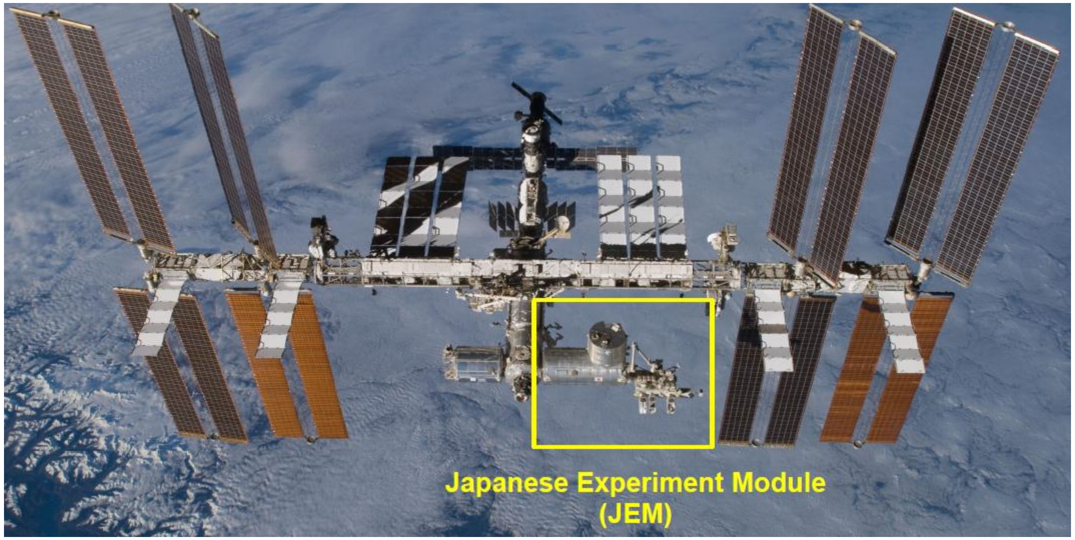
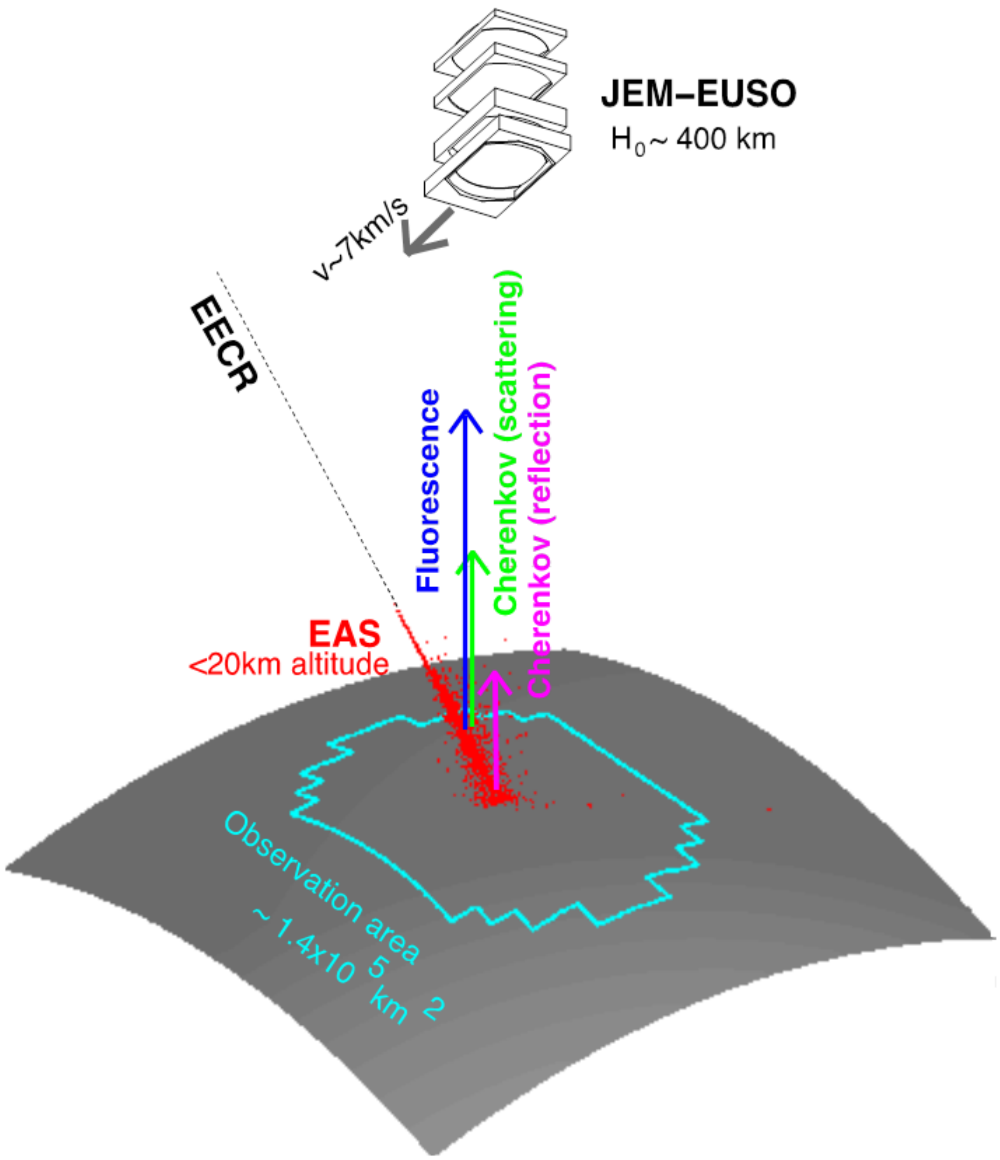




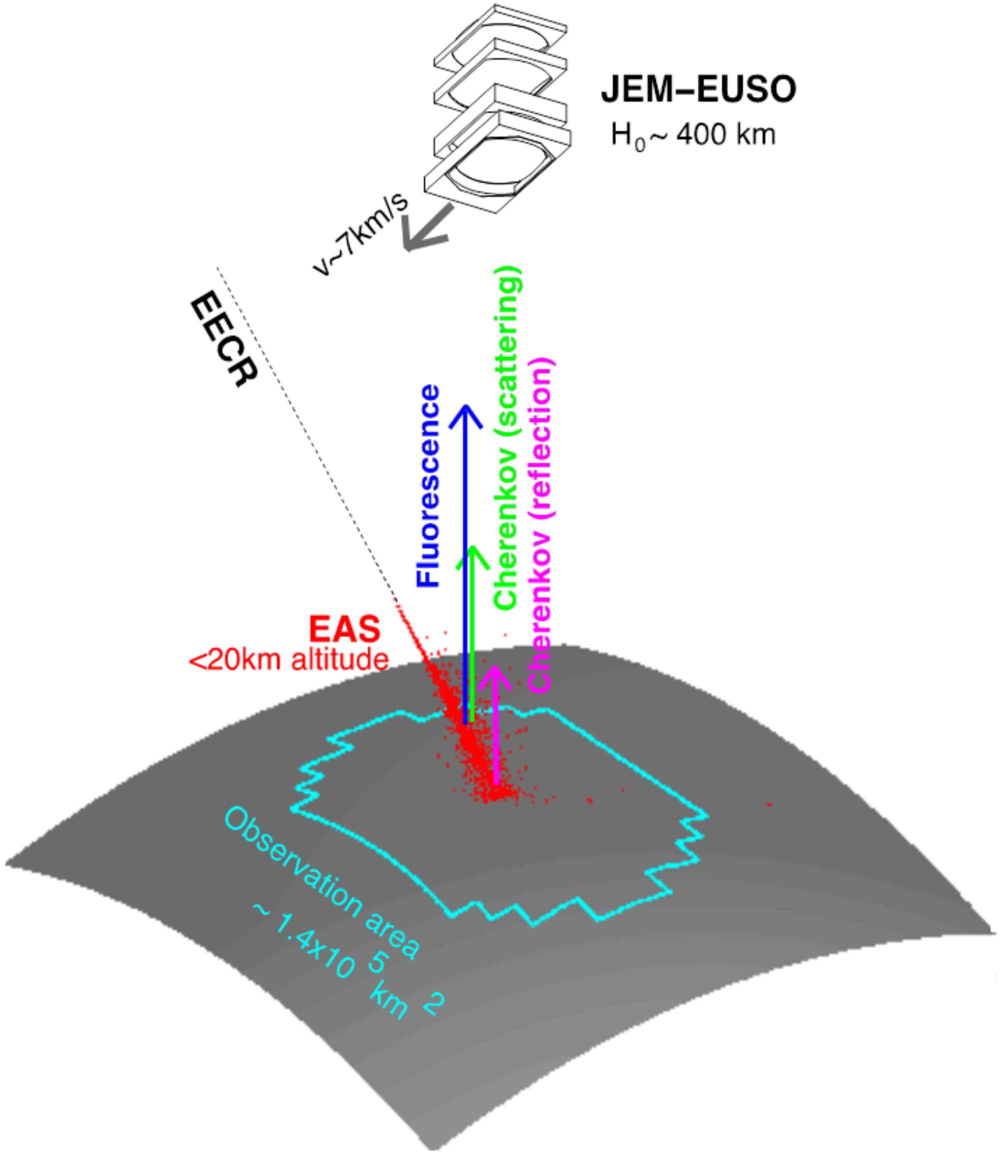
The instrument is planned to be attached to JEM/EF of ISS in 2017 for a 3 years long mission.



The observation principle of JEM-EUSO



JEM-EUSO telescope will observe fluorescence and Cherenkov UV photons generated by Extensive Air Showers created by EECR.



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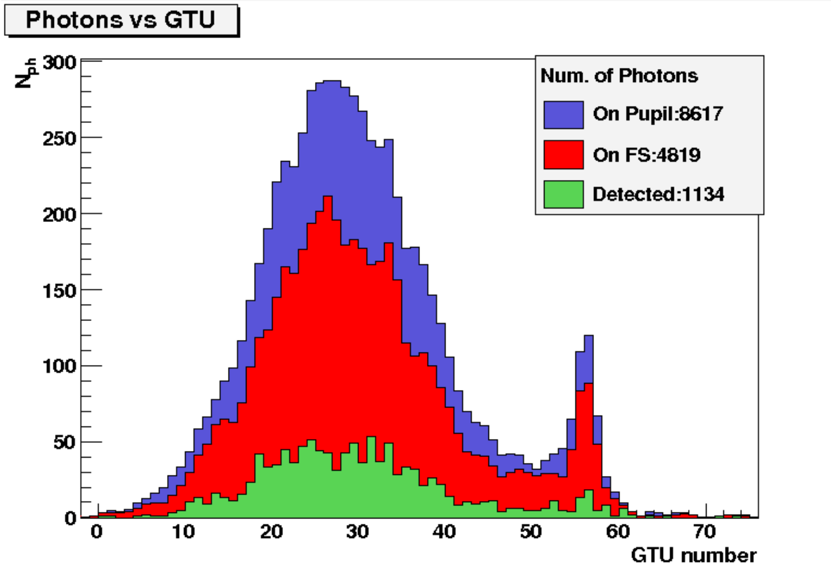

EAS development time ~ 50 – 150 ms

Simulation of the light profile observed at the entrance pupil and through the instrument.

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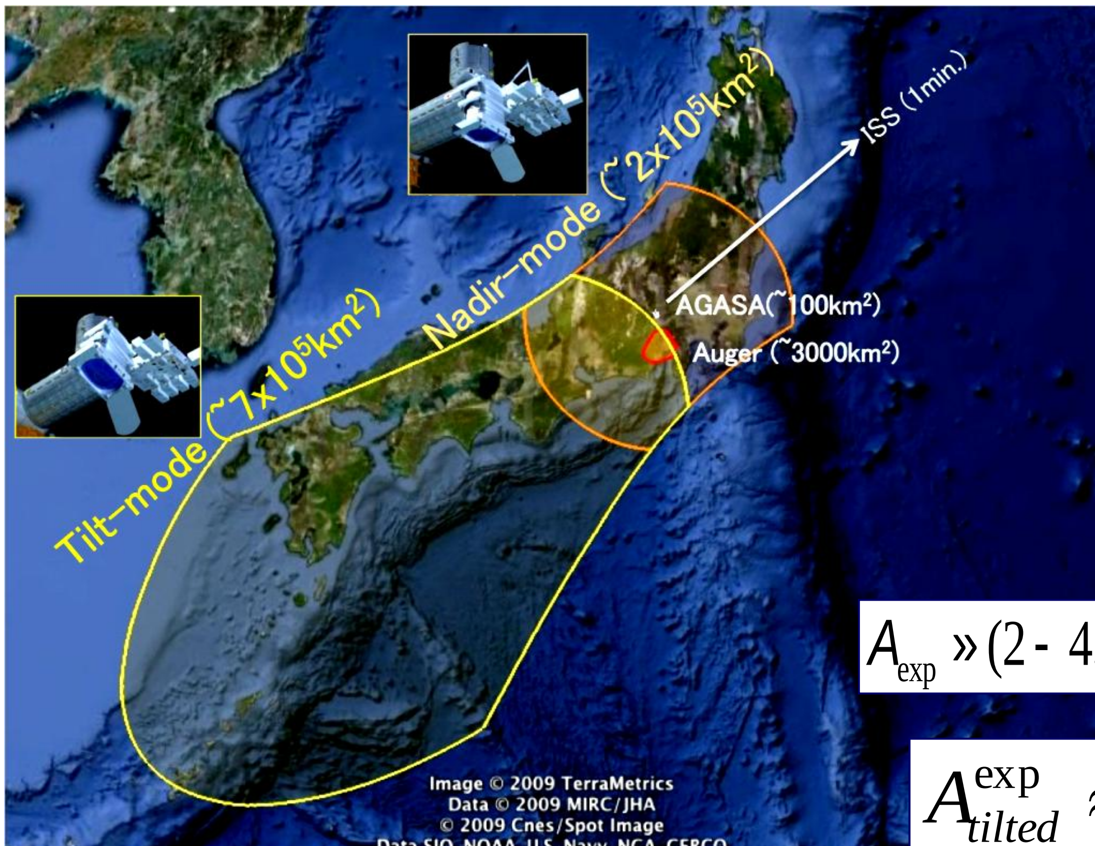
Two main advantages:

1. The target volume is far greater than possible from the ground



$$A_{exp} \approx (2-4.5)\times 10^5\ km^2 \cdot sr \cdot yr$$

$$A^{exp}_{tilted} \approx 10^6\, km^2\, sr\ yr$$

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2. Full sky coverage

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Physics and Astrophysics from $E > 5 \times 10^{19}$ eV focusing at $E \sim 10^{20}$ eV (and above)

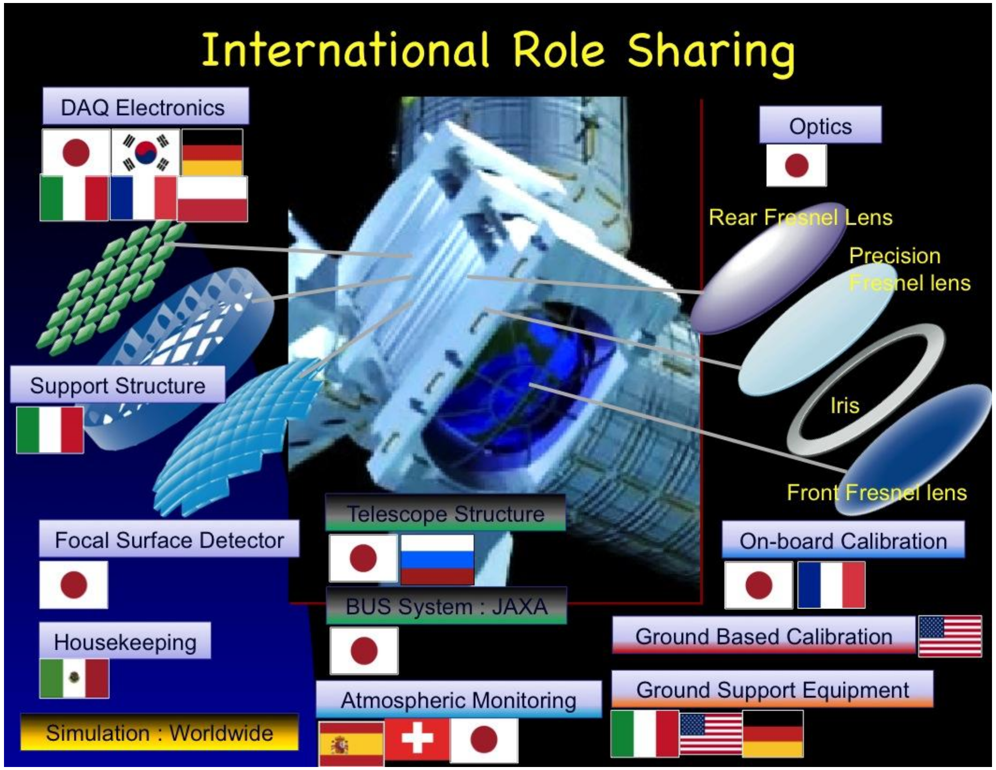
JEM-EUSO Collaboration

JEM-EUSO is a worldwide collaborating effort of 80 research groups from 15 Countries:

Japan, USA, Korea, Mexico, Russia, Algeria

Europe: Bulgaria, France, Germany, Italy, Poland, Slovakia, Spain, Sweden, Switzerland

RIKEN: Leading institution



The JEM-EUSO instrument

The telescope is an extremely-fast and highly-pixelized (~3×10^5 pixels) digital camera with a large diameter (2.35 m) and a wide-FoV (±30°).

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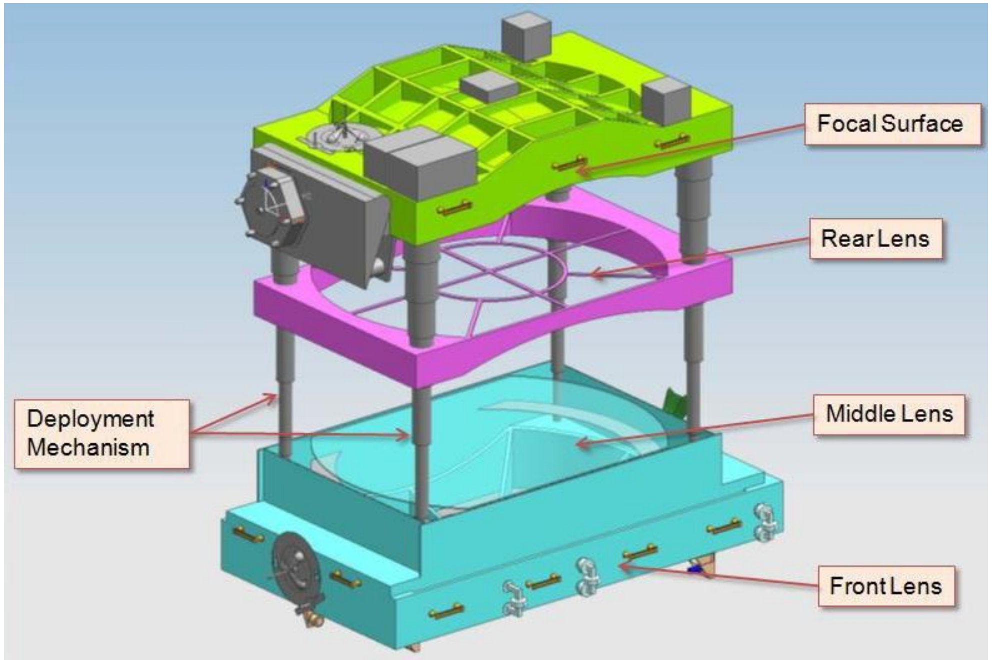

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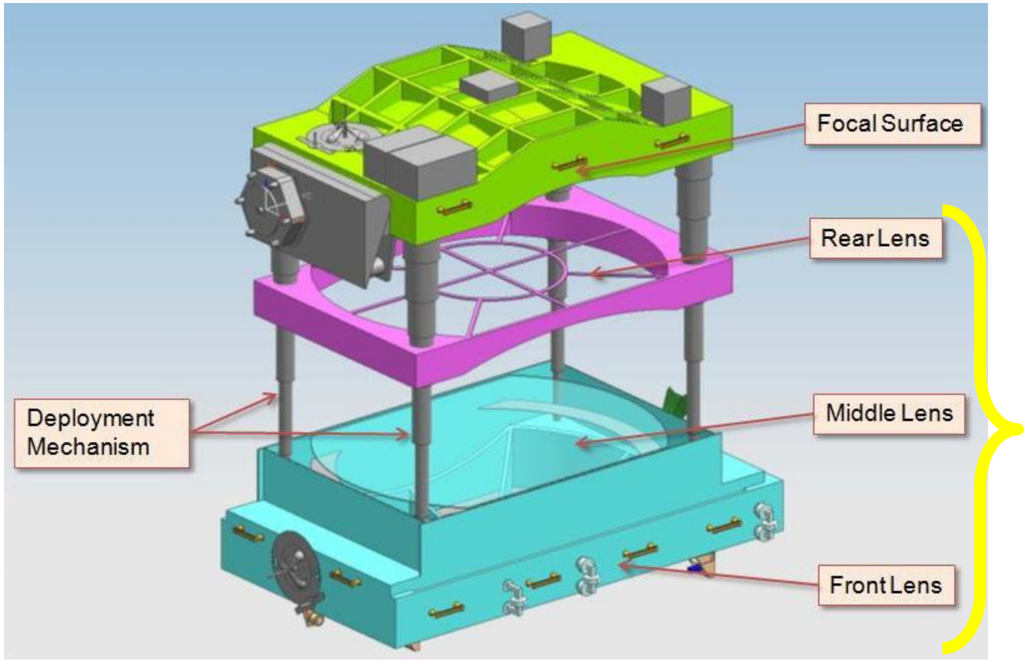

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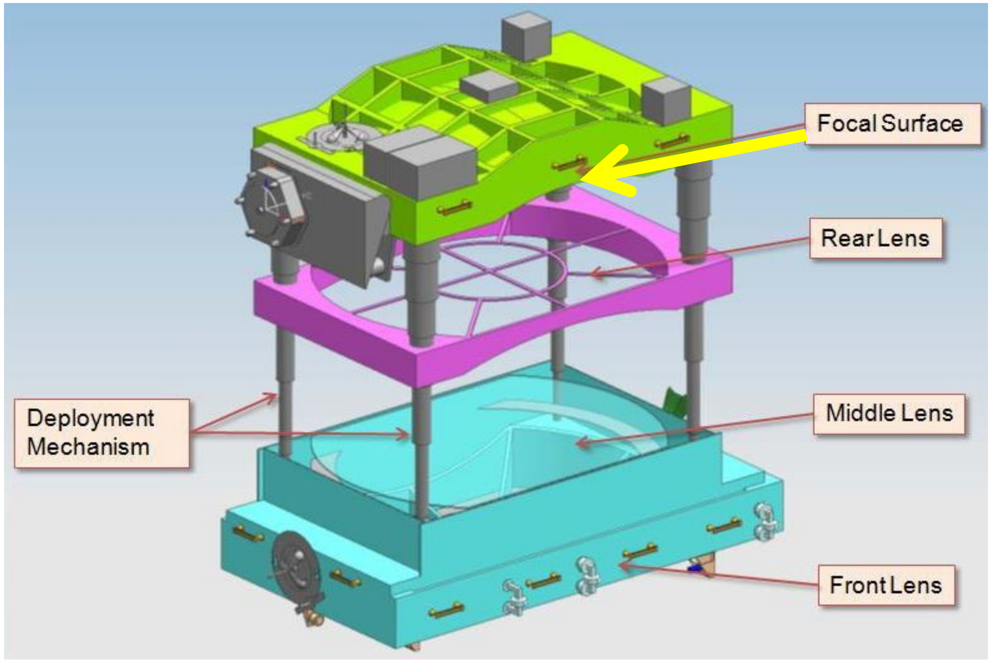

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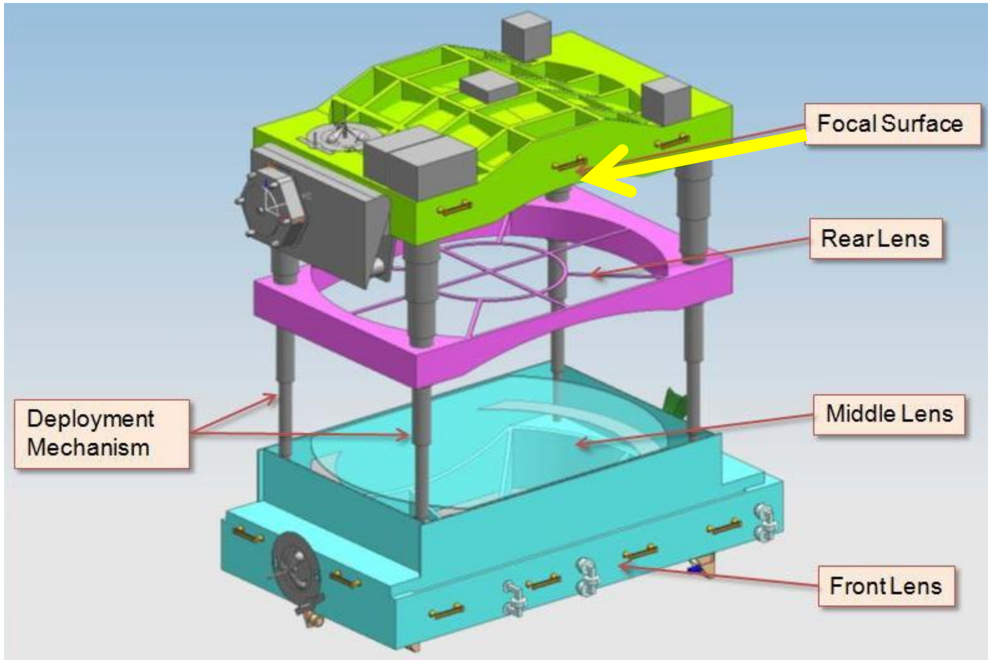

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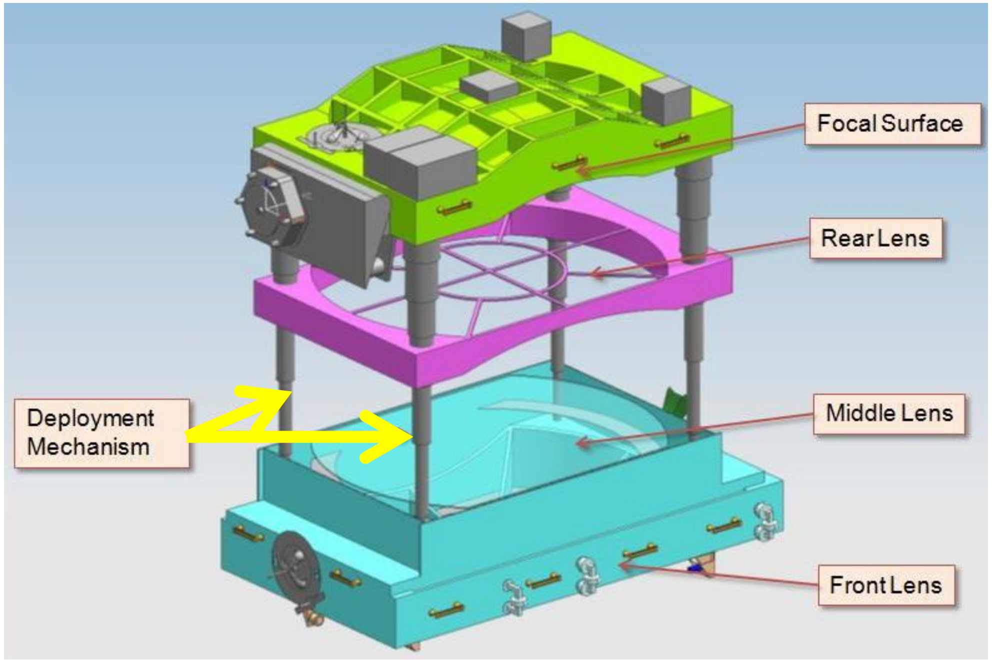

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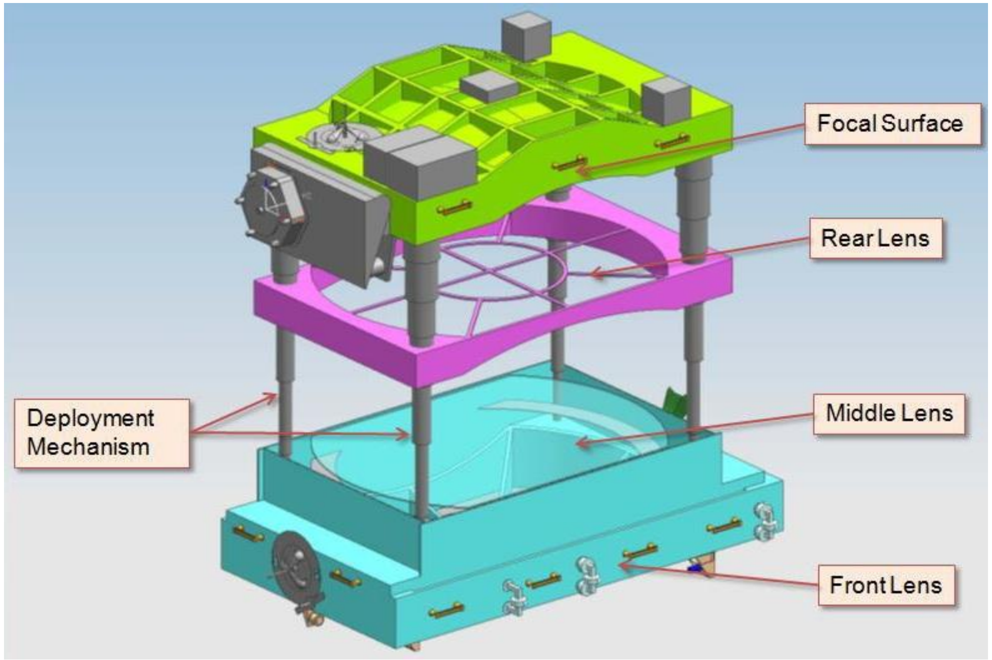
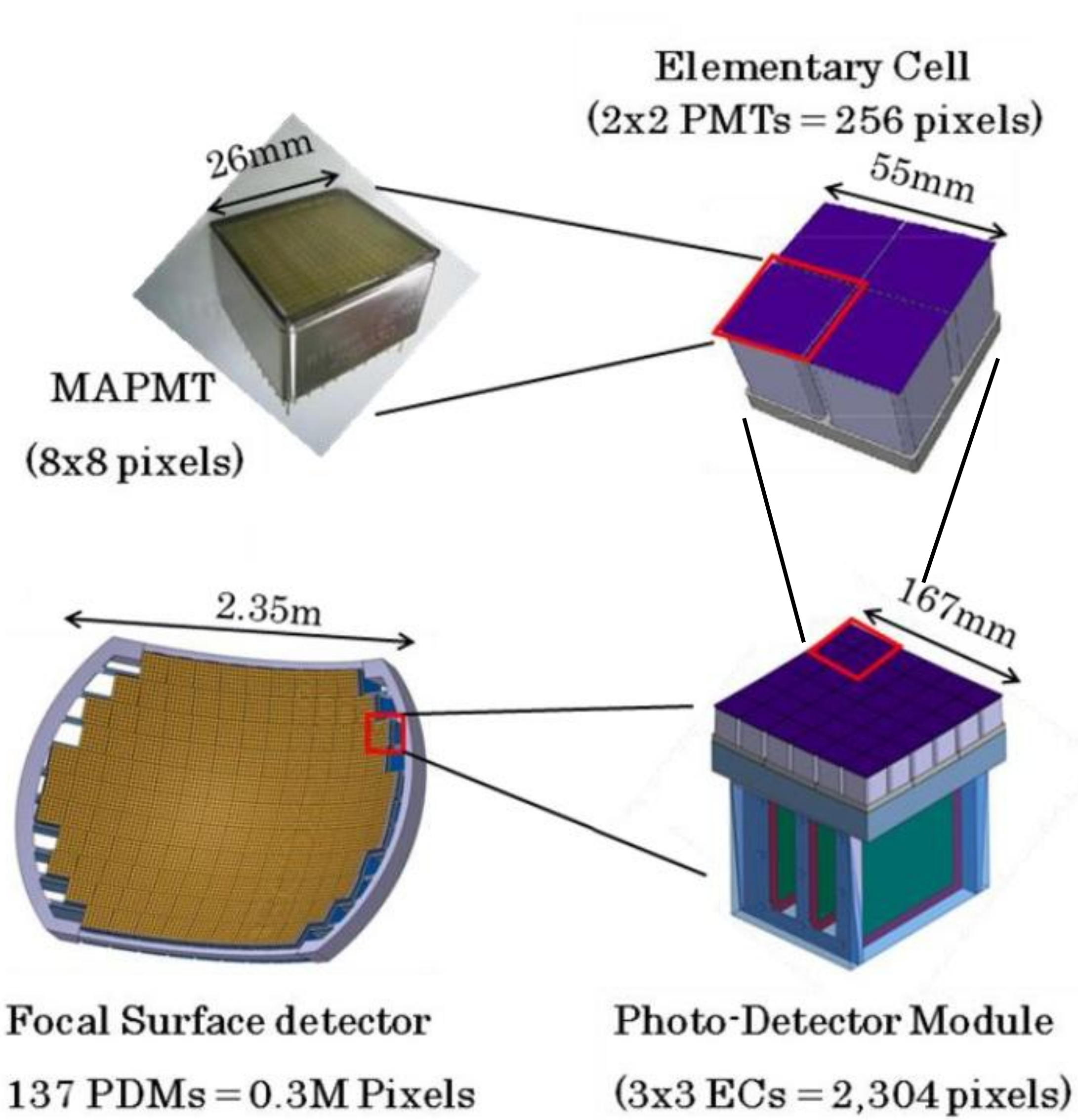


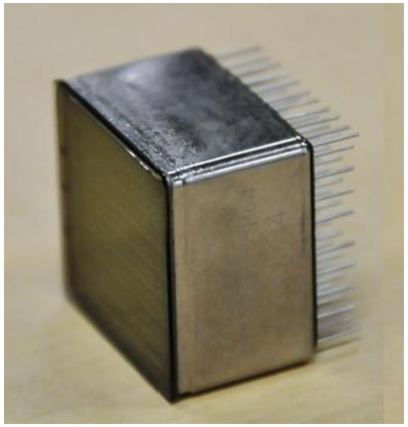
An atmosphere monitoring system (Infra-Red camera and Lidar) and a calibration system complete the apparatus.

The Focal Surface detector



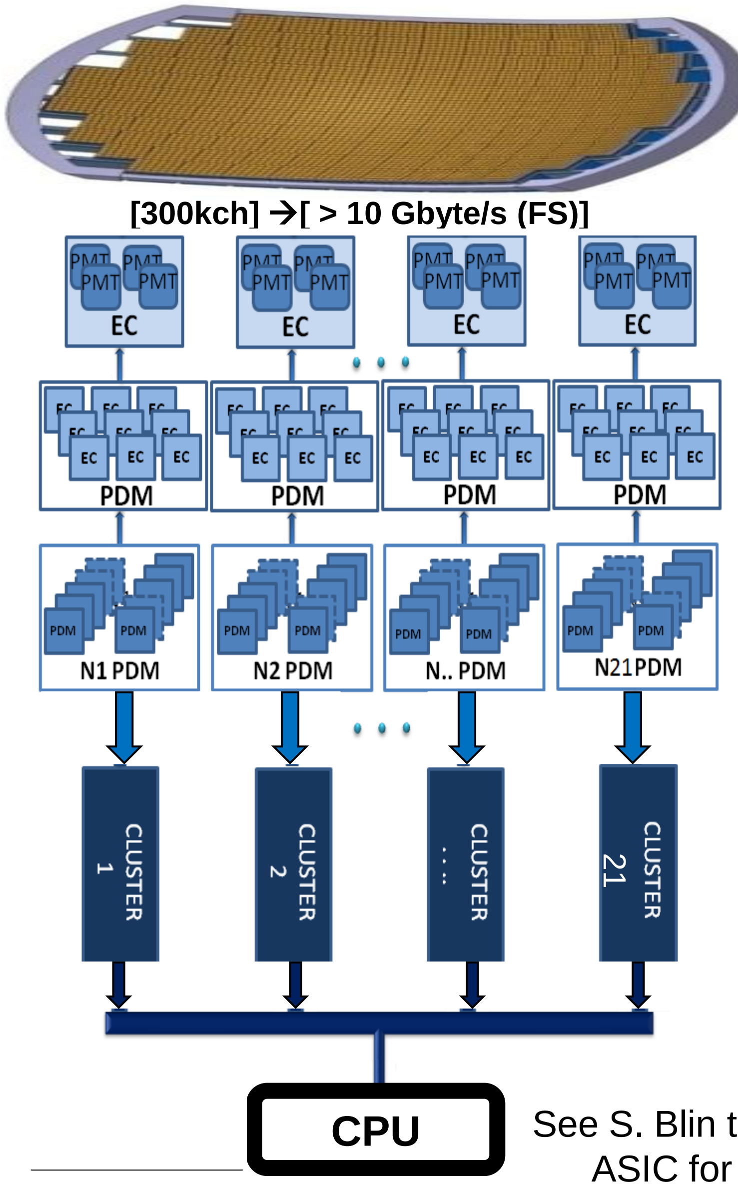
The FS detector has a curve surface of about 2.35 m of diameter, totally covered by ~5000 MAPMT:

- 137 Photo-Detector Modules (PDM) on the Focal Surface
- 36 MAPMT for every PDM



Hamamatsu R11265-03- M64

The data acquisition chain



Photons coming from EAS are converted into electric pulses by MAPMTs.

Signals from every MAPMT are discriminated from noise and digitalized by a front-end ASIC.

The ASIC counts the number of photo-electrons in a fixed time window for each pixel (Gate Time Unit = 2,5 μs).

The data electronics issues a trigger for EAS events and saves data.

4932 MAPMT of 64 pixels

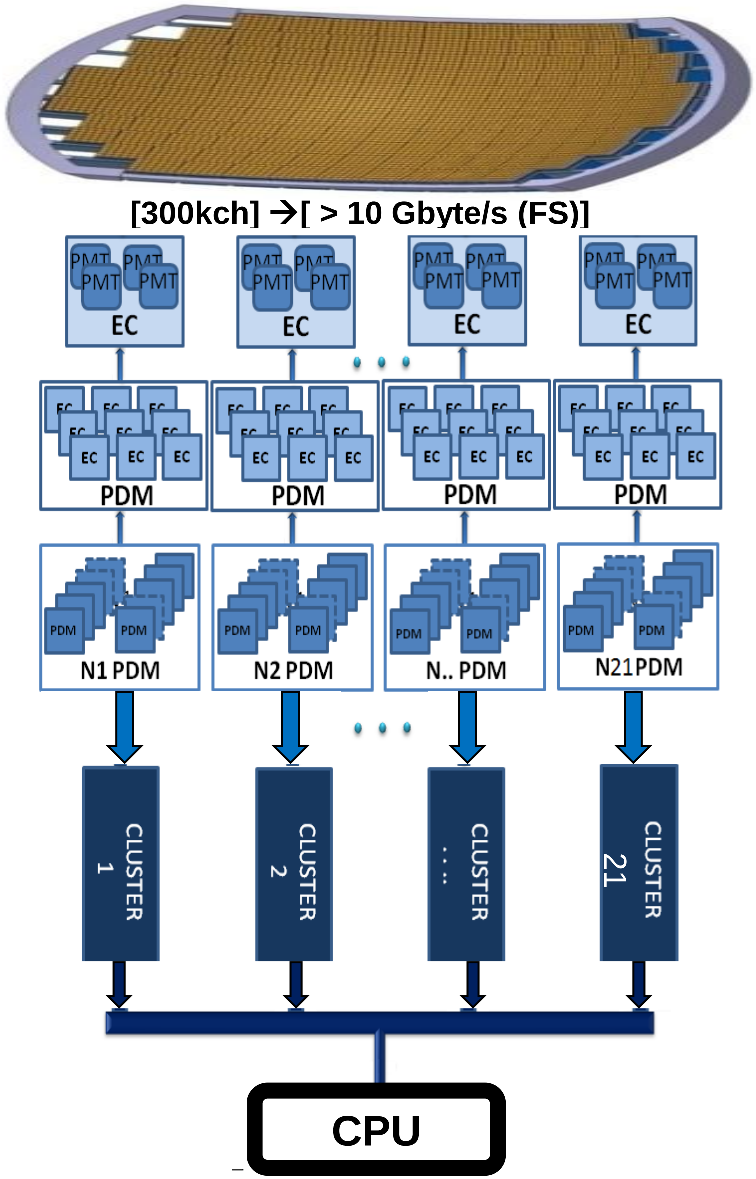
300 Kchannels

4932 front end ASIC

~300 FPGA

See S. Blin talk: SPACIROC3: A Front-End Readout ASIC for JEM-EUSO cosmic ray observatory

Trigger scheme



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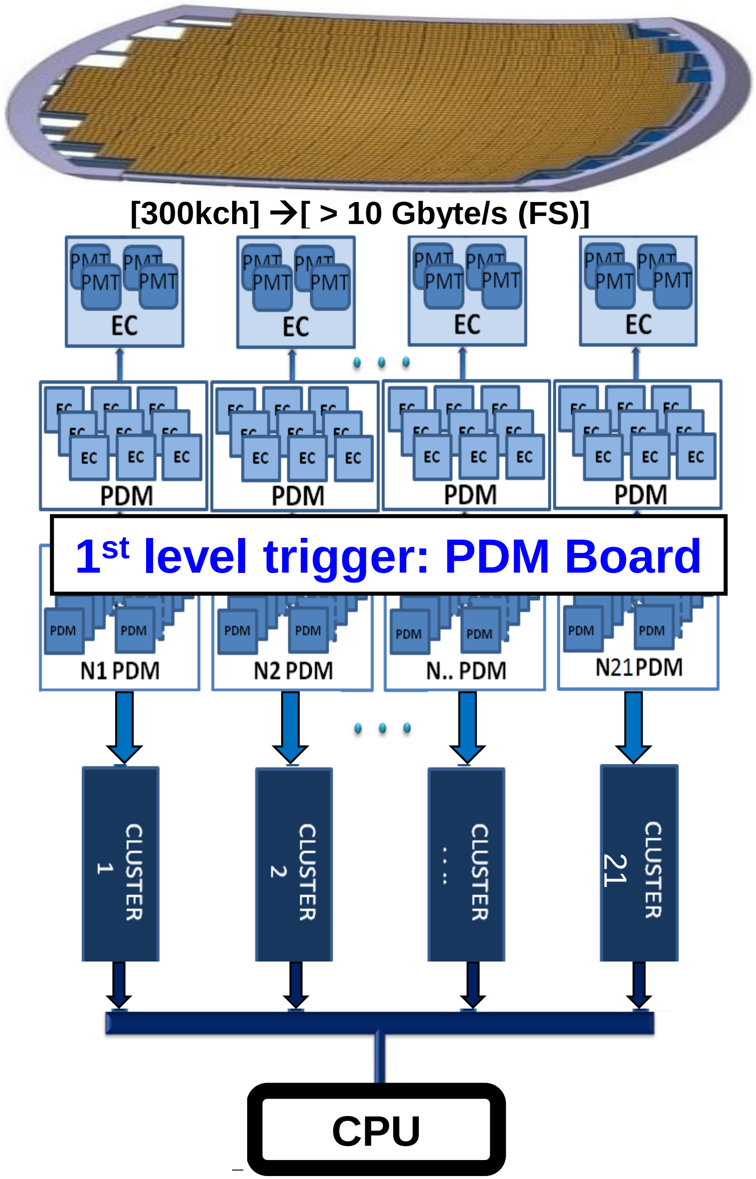

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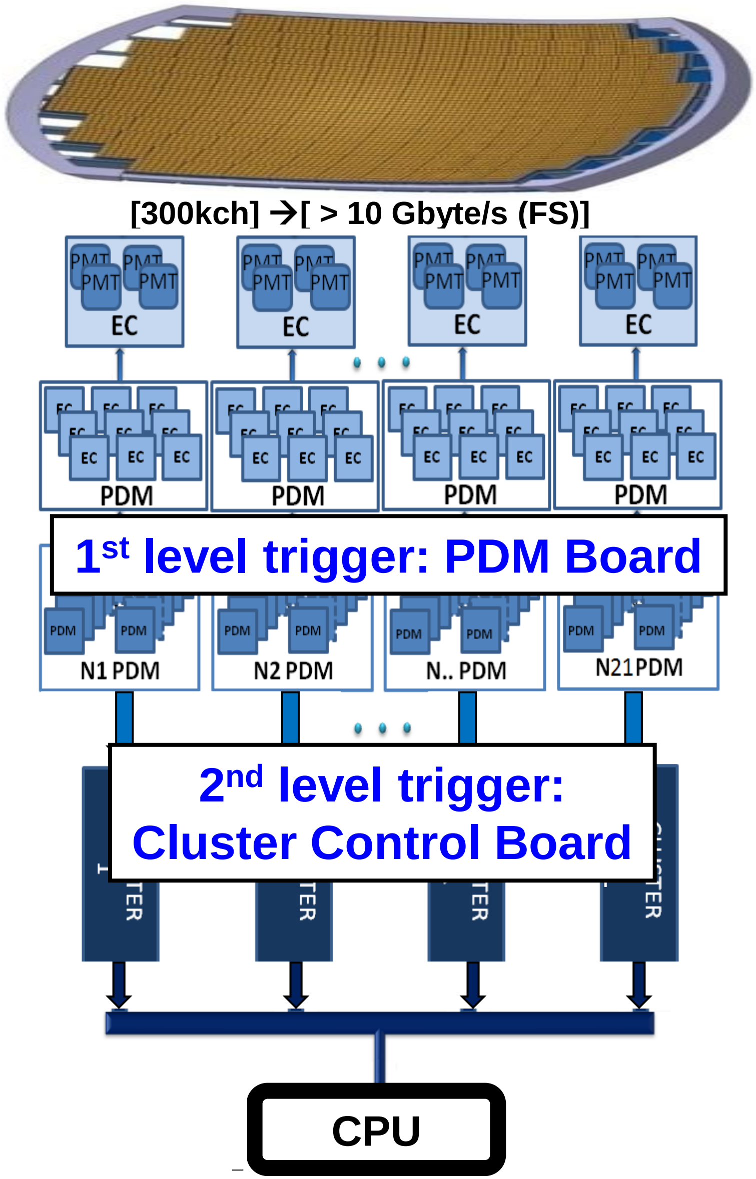

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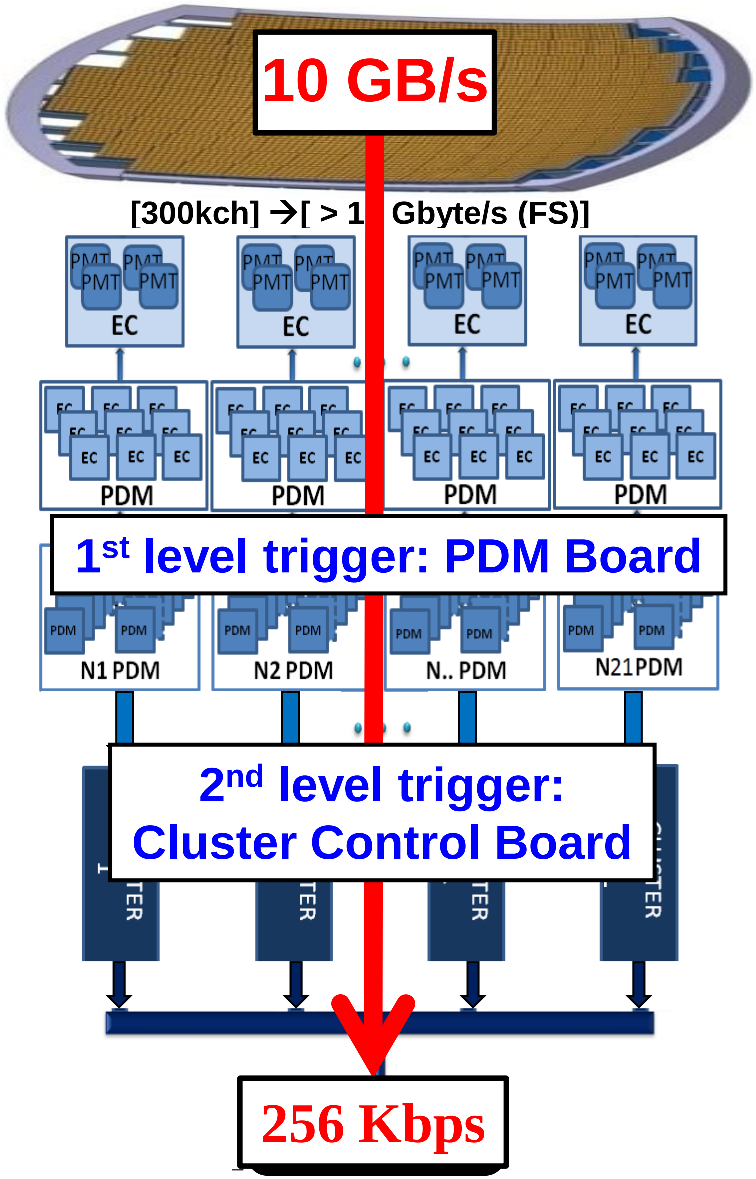

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This system is
- hierarchical and highly parallel
- intrinsically redundant

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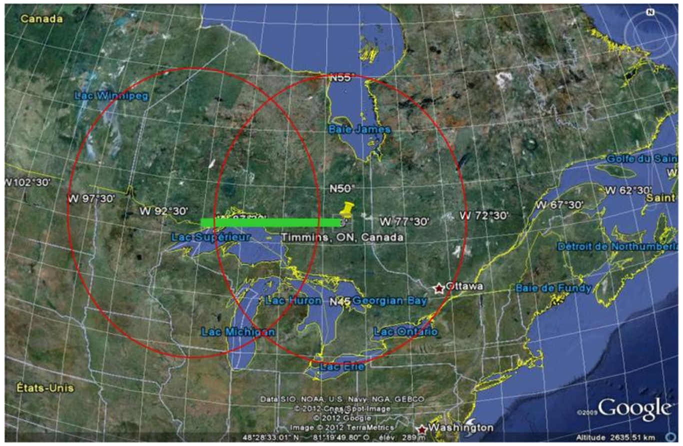
EUSO-Balloon: a balloon-borne instrument which will fly to an altitude of about 40 km.



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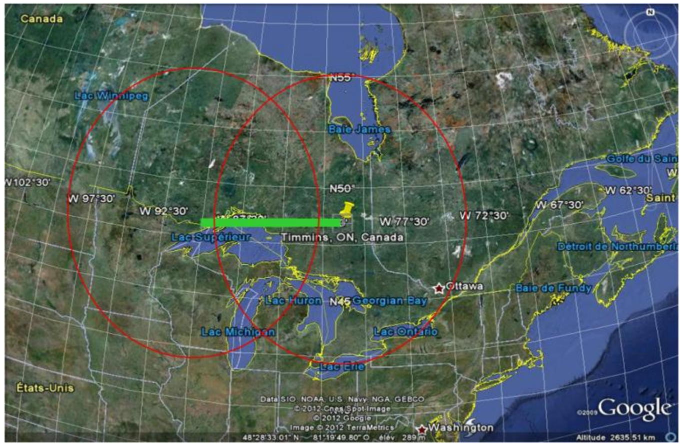
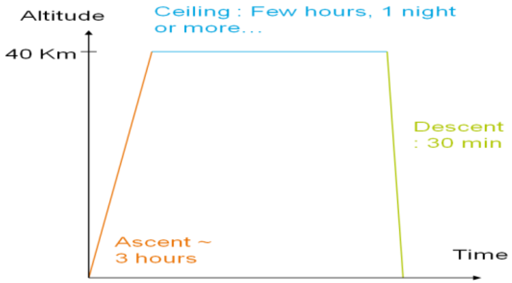
EUSO-Balloon: a balloon-borne instrument which will fly to an altitude of about 40 km.

- 3 flights mission (approved by CNES)
- 1st flight: August 2014 from Timmins (Canada)
- the instrument will monitor a 12°×12° wide FoV





Environmental constrain:
Low pressure (3 mbar)
Thermal range: -30°C +50°C

Objectives for EUSO-Balloon

1. Technology demonstrator for JEM-EUSO:
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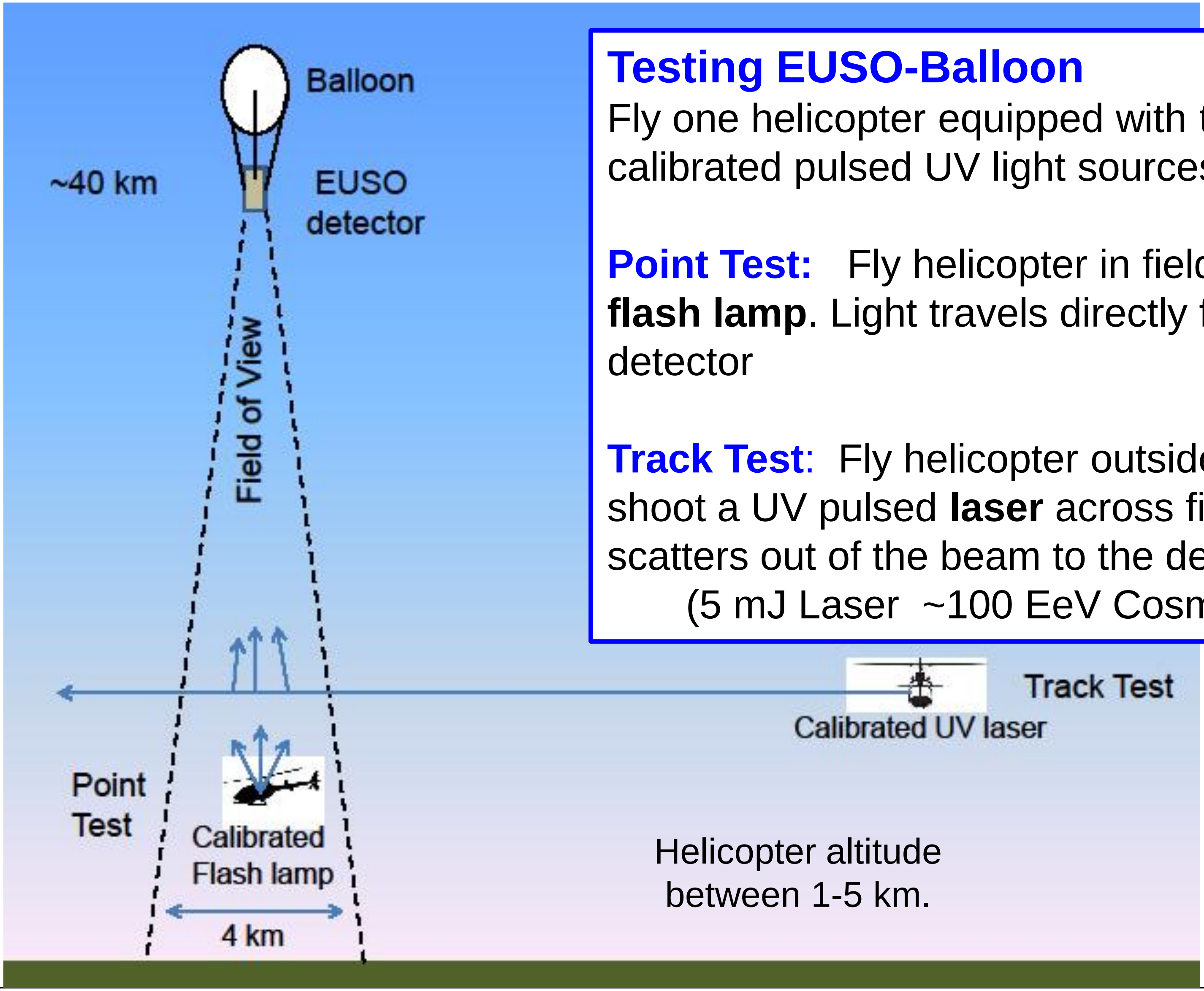
5. Pioneering JEM-EUSO: 1st detection of EAS by looking down from the edge of space

EUSO-Balloon “in flight” calibration



Testing EUSO-Balloon

Fly one helicopter equipped with two types of calibrated pulsed UV light sources.

Point Test: Fly helicopter in field of view and fire **flash lamp**. Light travels directly from lamp to detector

Track Test: Fly helicopter outside field of view and shoot a UV pulsed **laser** across field of view. Light scatters out of the beam to the detector.
(5 mJ Laser ~100 EeV Cosmic Ray)

Helicopter altitude between 1-5 km.

EUSO-Balloon Vs JEM-EUSO

	JEM-EUSO	EUSO-Balloon
Height (km)	420	40
Diameter (m)	2.5	1
FoV/pix (deg)	0.08	0.25
Pixel@ground (km)	0.580	0.175
FoV/PDM (deg)	3.8	12
PDM@ground (km)	28.2	8.4
Signal Ratio	1	17.6
BG Ratio	1	0.9-1.8
$S/\sqrt{N}$	1	20-10
E_{thr} (eV)	3×10^{19}	$1.5\text{-}3 \times 10^{18}$
Number of PDM	137	1

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Maximize performance of EUSO-Balloon keeping parameters as close as possible to JEM-EUSO

EUSO-Balloon instrument

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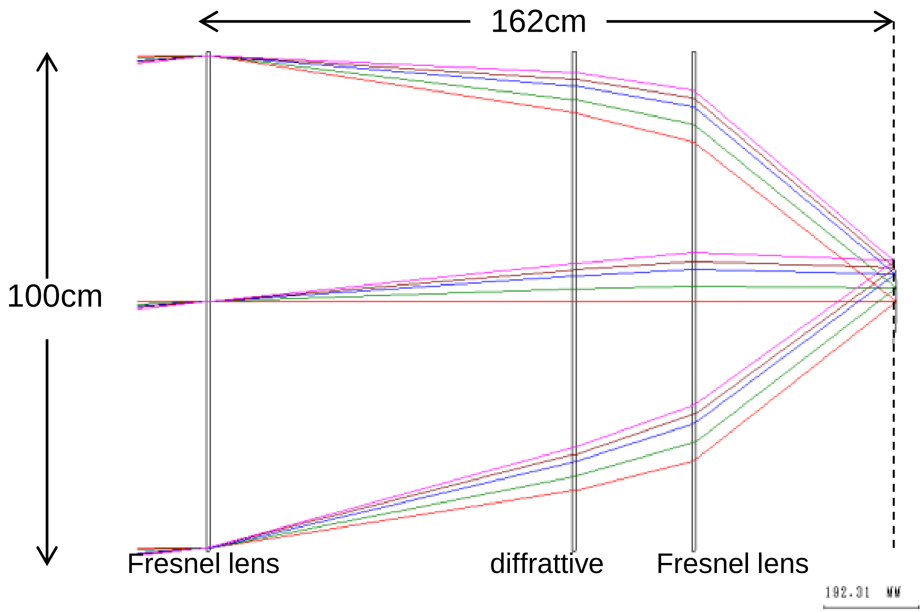
- Optical system: 3 PMMA flat-type
  Fresnel lenses



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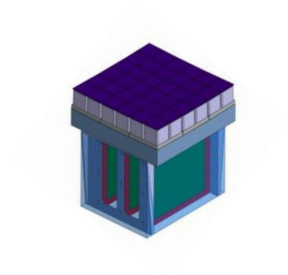
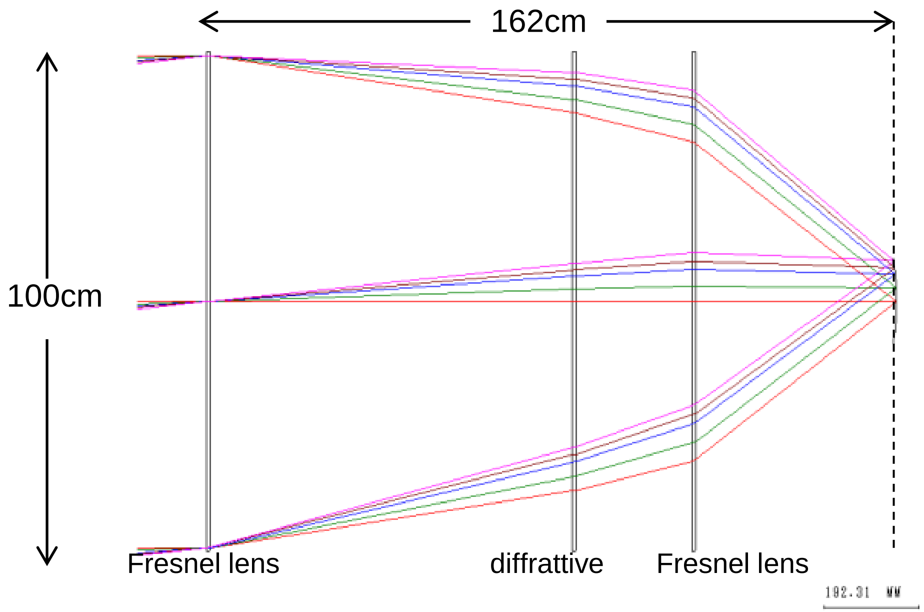
- PDM: 2304 pixels





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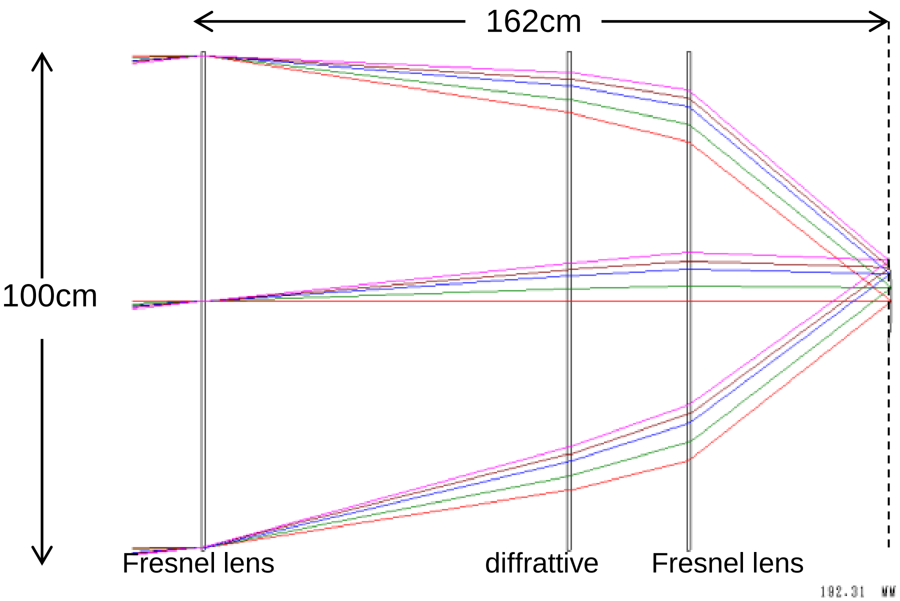

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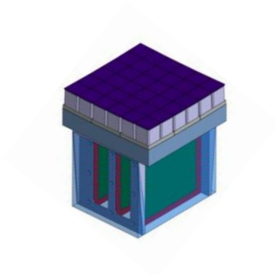
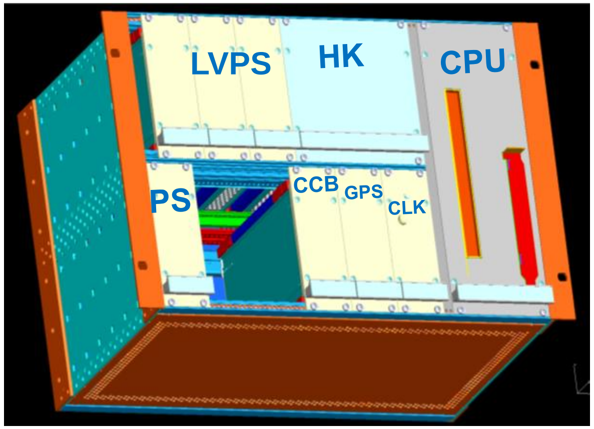


- Data Processor



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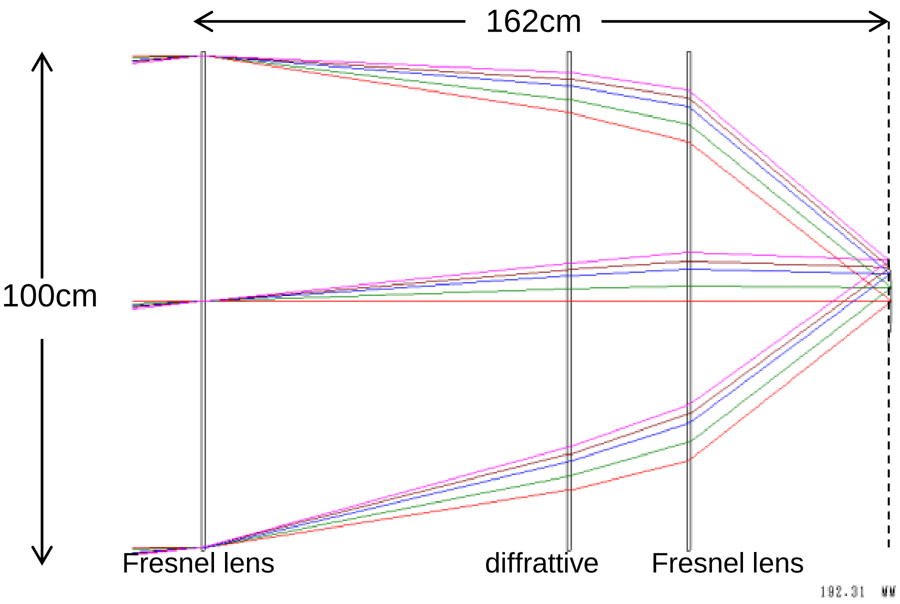
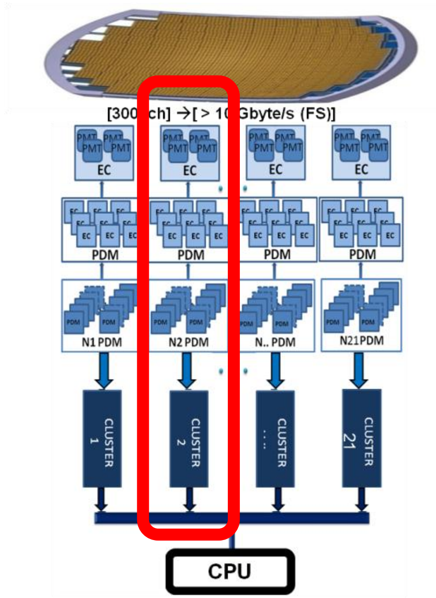


- PDM: 2304 pixels



- Data Processor

EUSO-Balloon instrument

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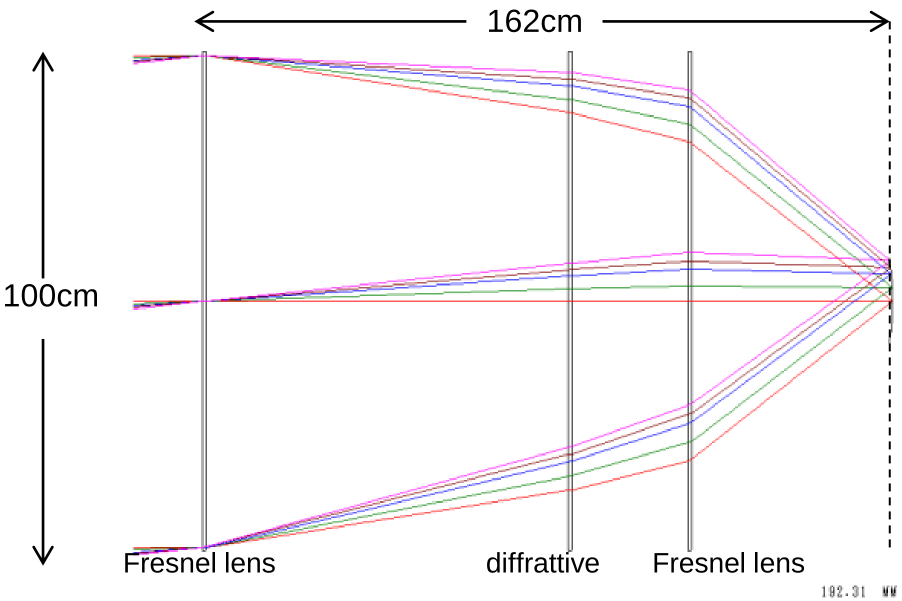

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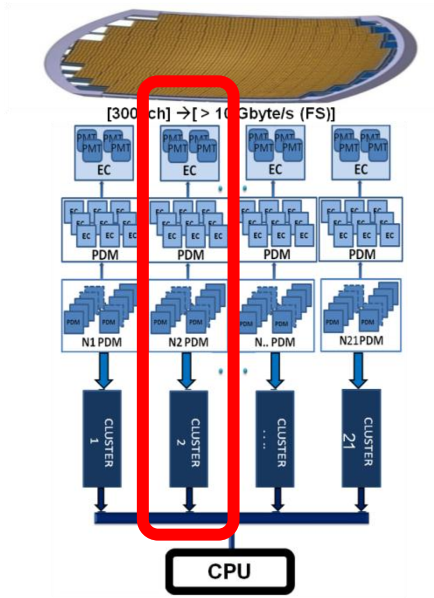

- Data Processor

- Telescope structure

EUSO-Balloon instrument

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- PDM: 2304 pixels
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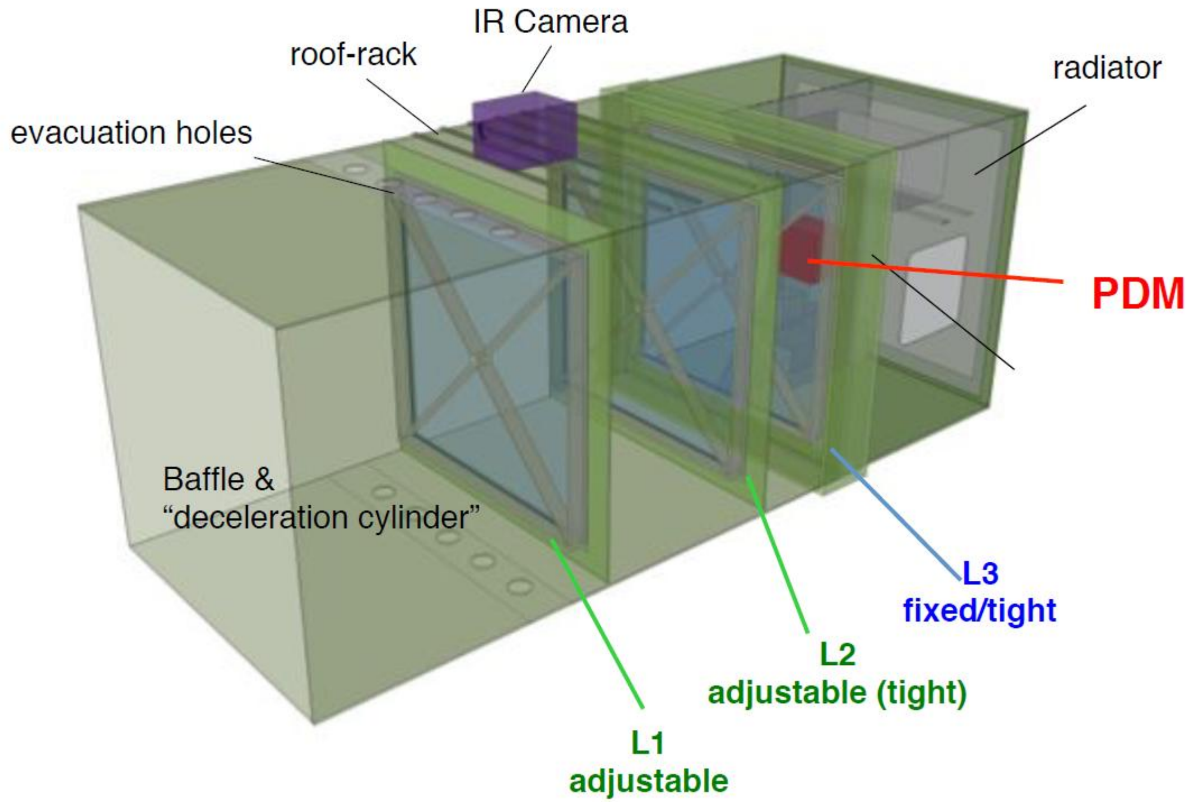
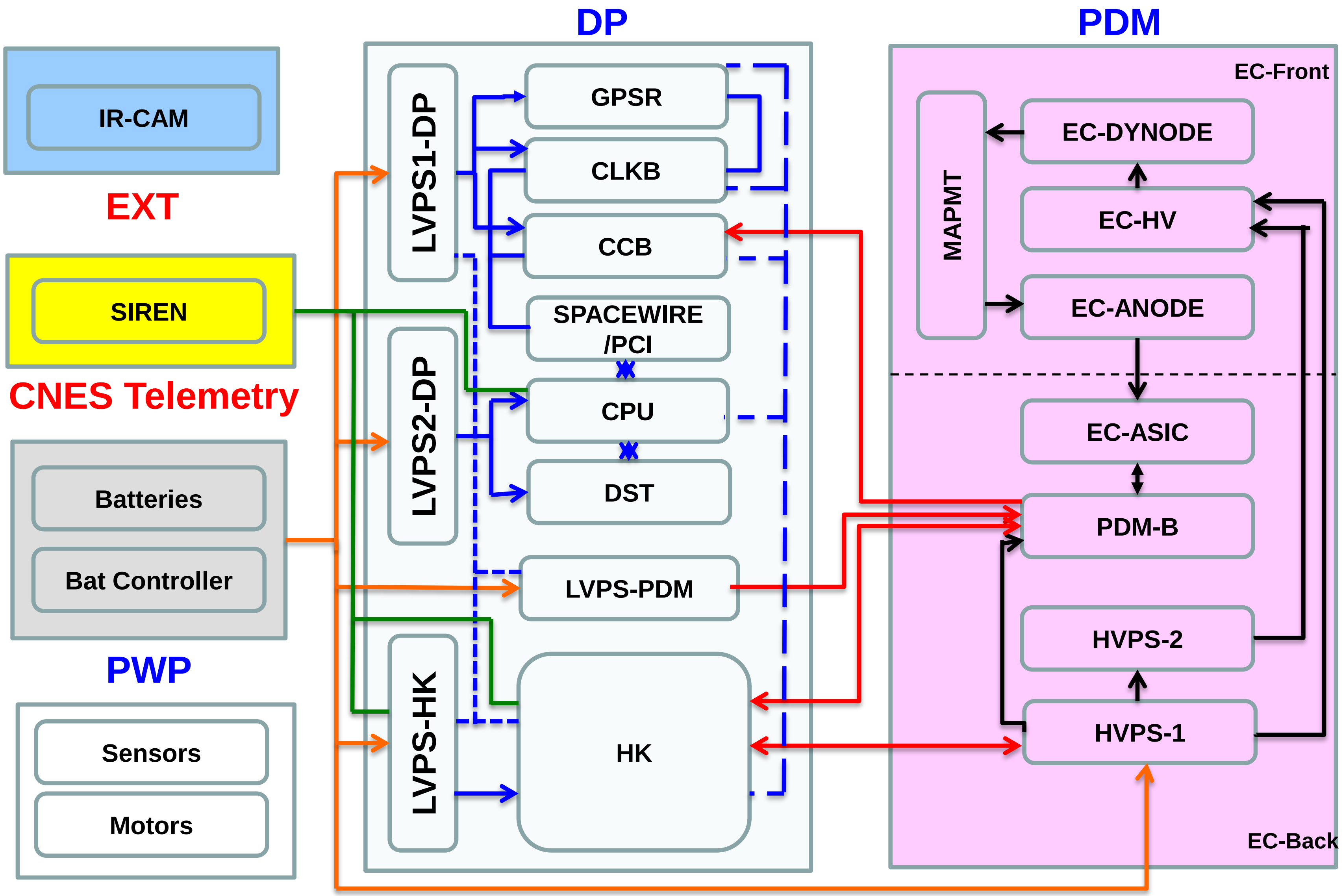
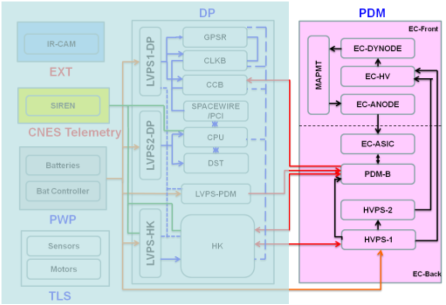


EUSO-Balloon instrument block diagram



A global view of the PDM

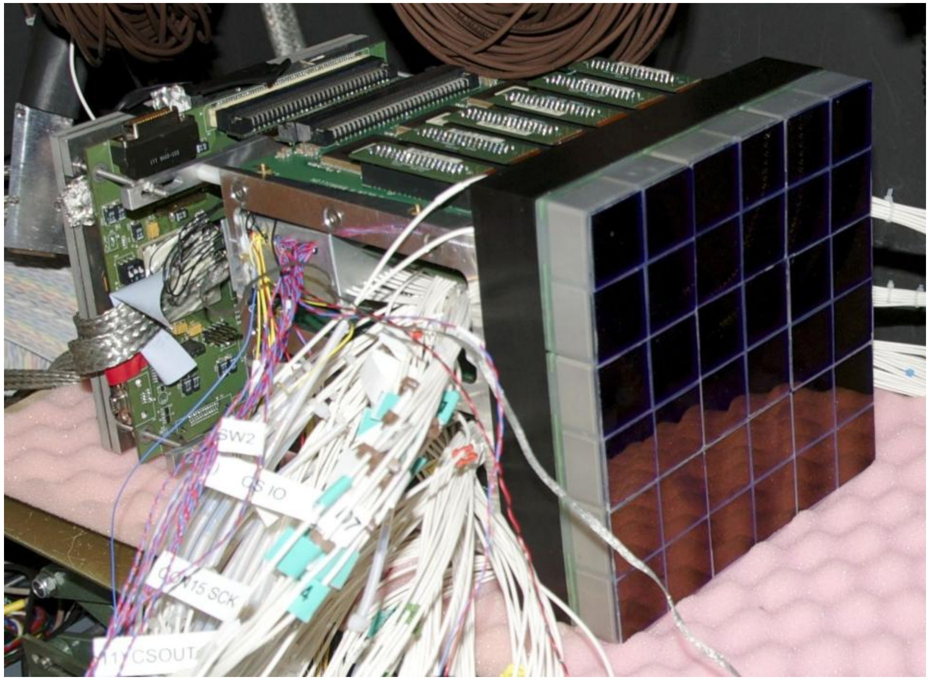


The PDM has to detect the UV photons coming from the optics, digitalize the data and perform the 1st level trigger.

It is an assembly of several components:

- 1 mechanical structure
- 9 Elementary Cell front units
  - 36 Multi-Anode Photomultipliers
  - Front end electronic
- 6 ASIC boards
- 2 High Voltage Power Supplies
- 1 PDM board

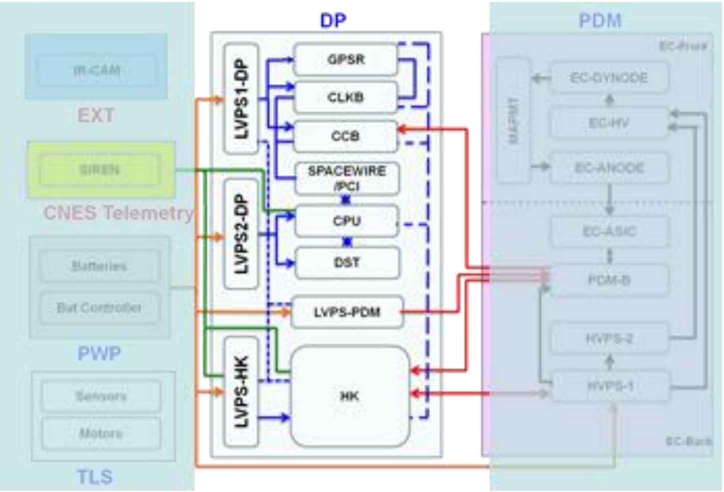
Budgets:
- Mass ~ 3.6 kg
- Power ~ 20 W
- Size given by the mechanical structure: 167 x 167 x 160 mm



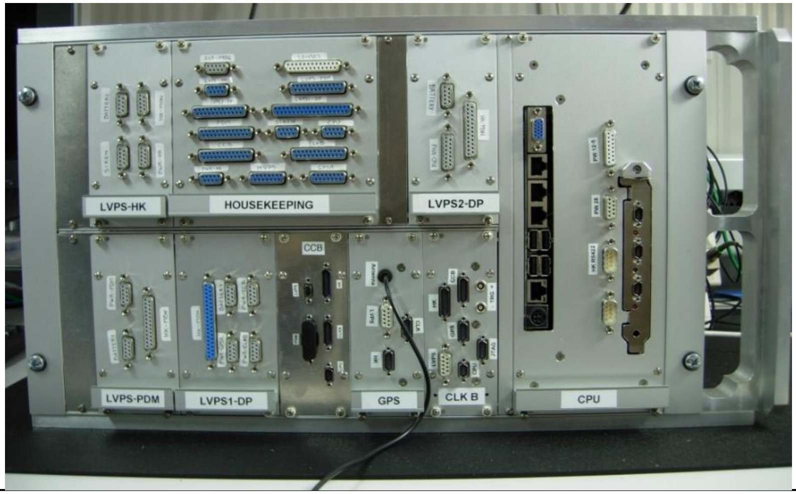
Data Processor functional requirements

The Data Processor has to:

- Control the data acquisition
- Control the front-end electronics
- Perform 2nd level trigger filtering
- Tag the events with arrival time and position
- Manage the Mass Memory for data storage
- Measure live and dead time of the instrument
- Provide signals for time synchronization of the event
- Perform housekeeping monitor
- Handle interface to tele-commands and to telemetry system



Budgets:
- Mass < 20 kg
- Power < 50 W
- Data acquisition: 2304 channels → 330 kB/event



Components of the DP

The DP functionality is obtained by connecting different specialized items, which form a complex system.

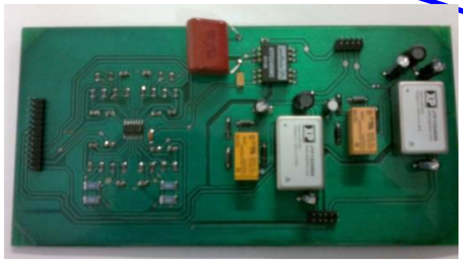
The main subassembly items are:

- Control Cluster Board (CCB)
- Main processing unit (CPU)
- Data Storage (DST)
- Housekeeping system (HK)
- Clock Board (CLKB)
- GPS receiver (GPSR)
- Data Processor Power Supplies (DP-LVPS1-2-3)
- PDM Power Supply (PDM-LVPS)

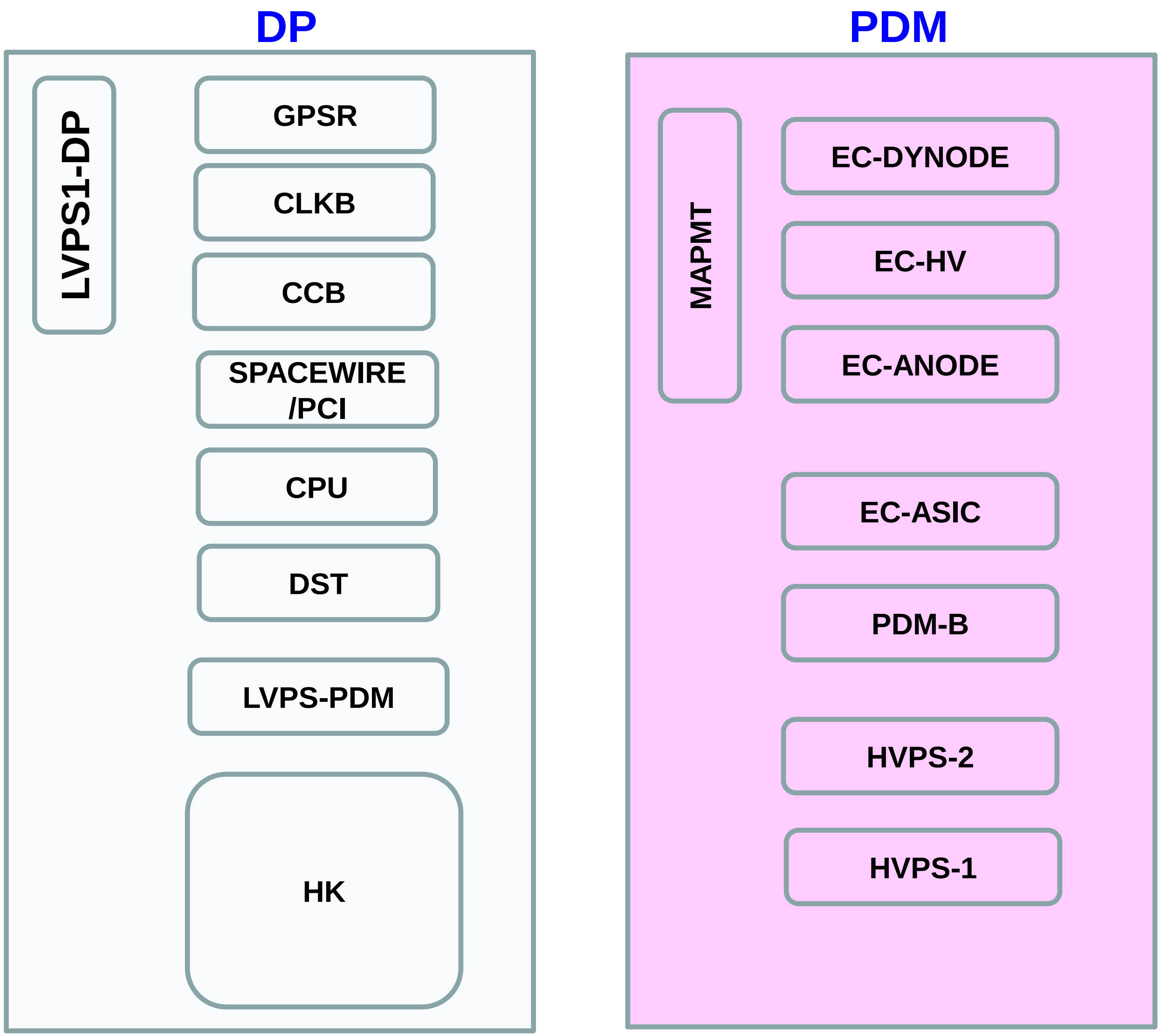
Arbor iTX-i2705

2 x OCZ 512 GB SSD disk

SpaceWire PCI Mk2



DP-PDM Interfaces



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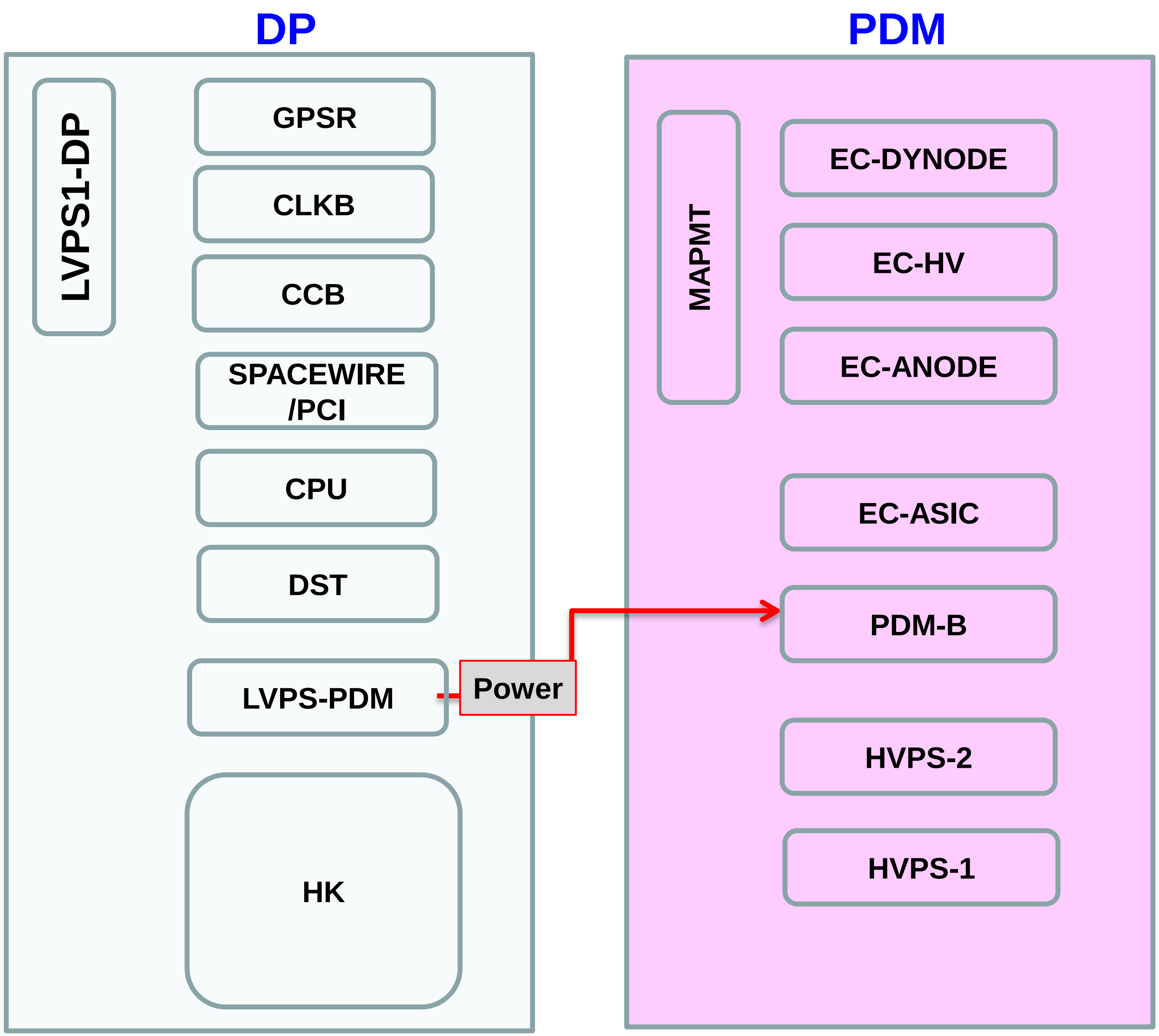
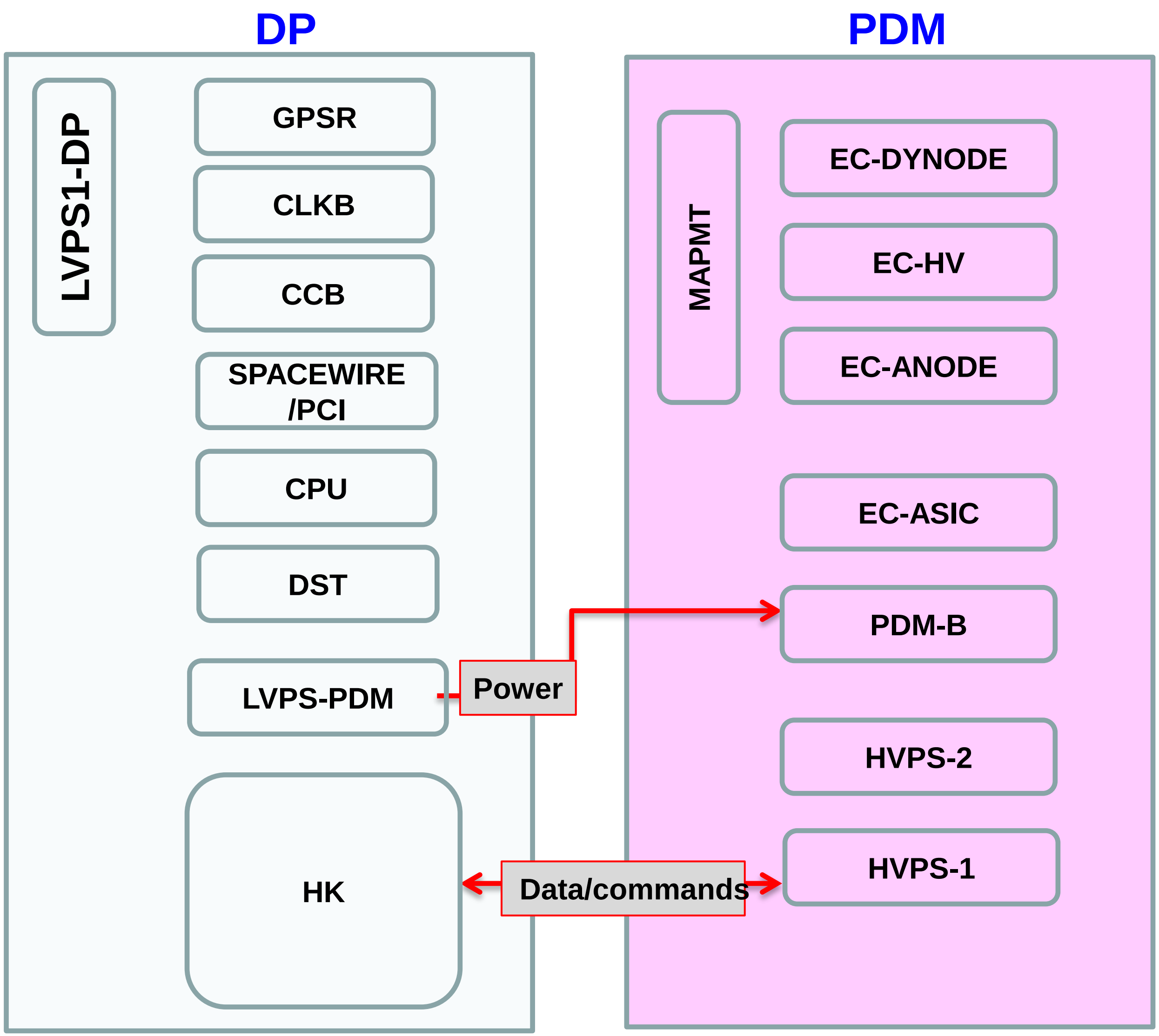


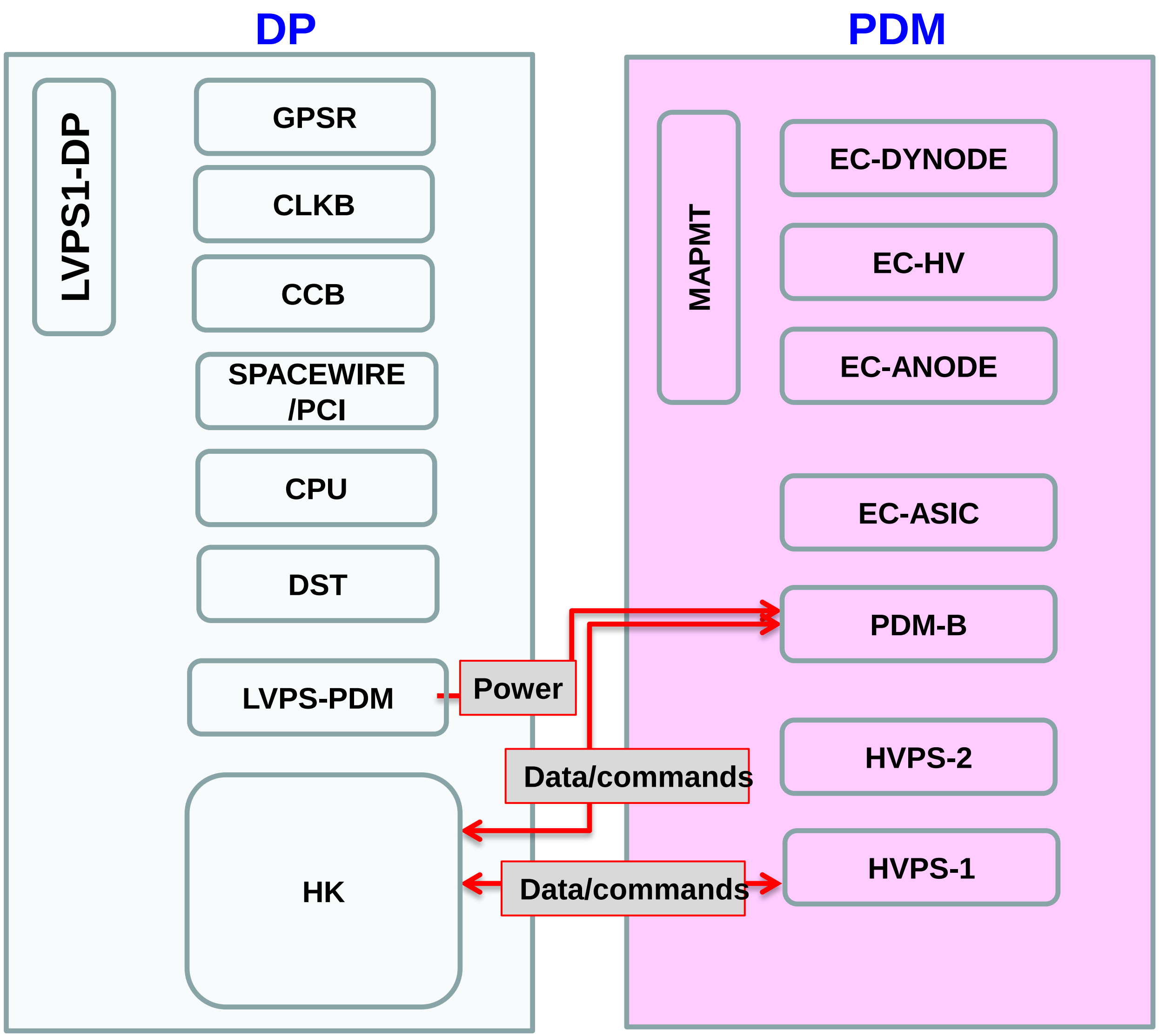
The PDM-Board is powered by LVPS from DP

DP-PDM Interfaces



HK controls HVPS and can send several commands: On/Off, interrupt, HV settings

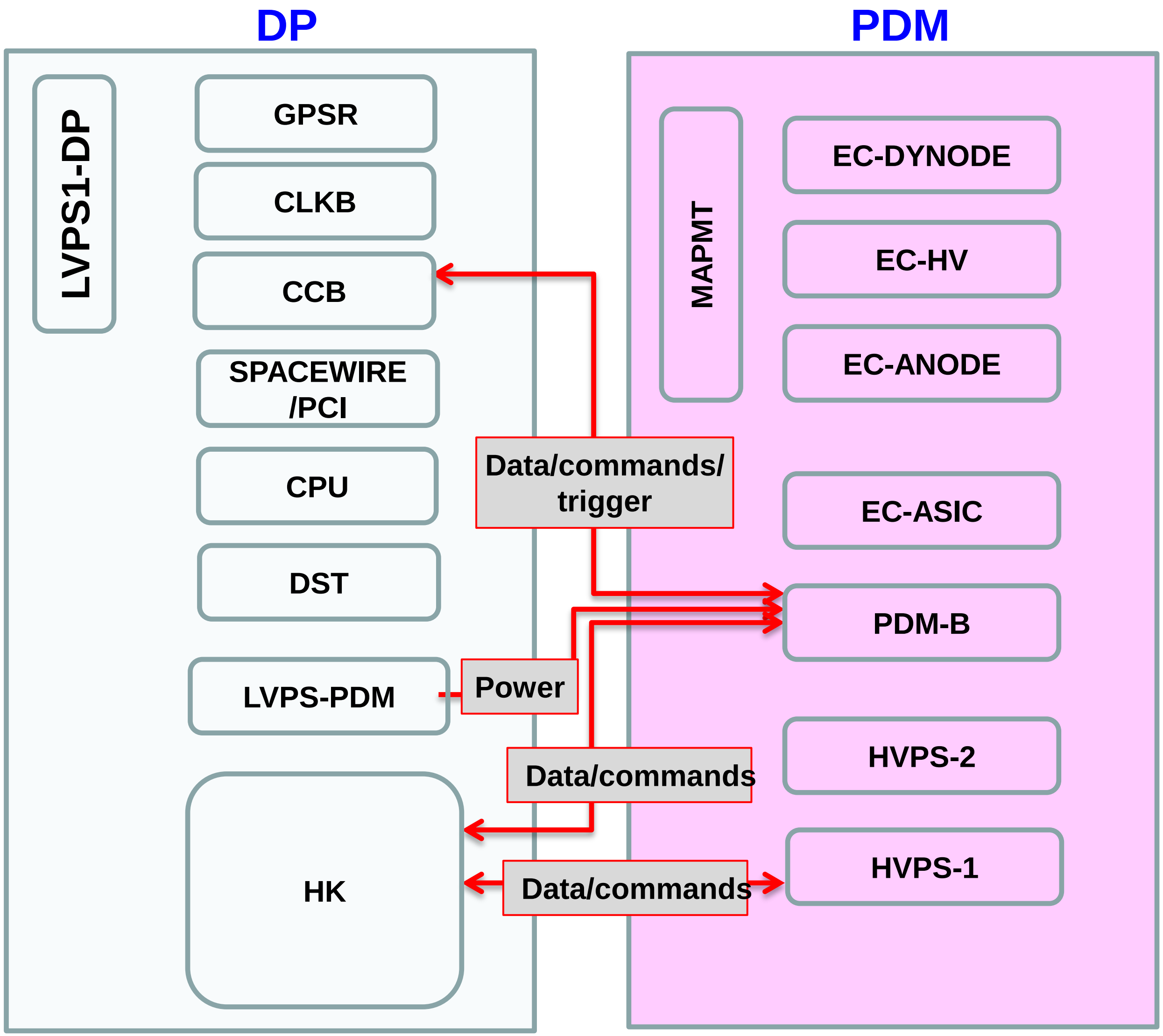
DP-PDM Interfaces



The HK can send commands to the PDM board (On/Off, reset,…).

The PDM sends data and information (telemetry, alarms,…) to the HK through a SPI interface.

DP-PDM Interfaces

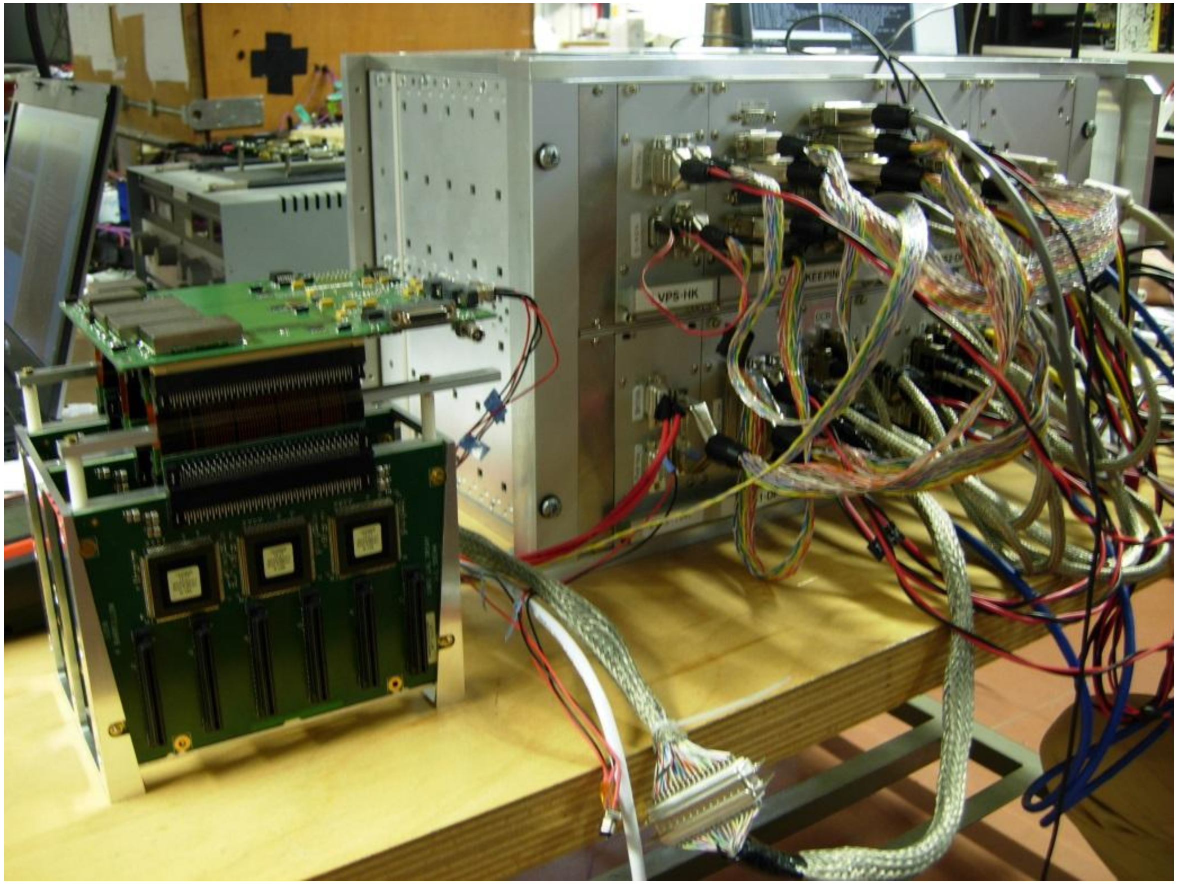


Commands and configuration parameter are sent from CPU to CCB via Space-Wire link and then from CCB to PDM Board trough a serial SPI link.

The PDM Board, on request, sends data to CCB trough a parallel bus.

DP-PDM Integration

The first successful test of the whole electronics chain (PDM + DP) took place in March 2014 at APC (Paris). The complete PDM was in the black box connected to the complete DP via a feedthrough.



DP-PDM Integration

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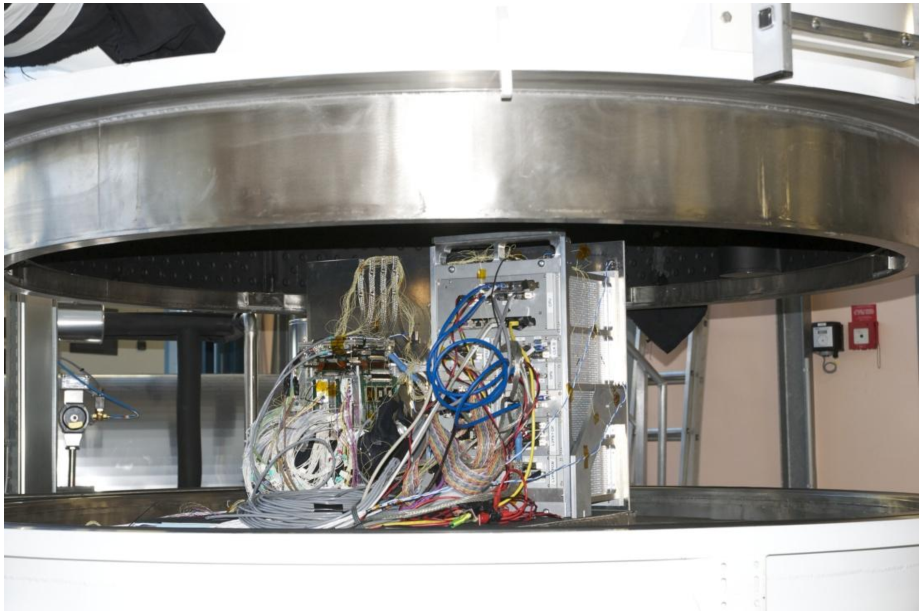
We also performed the same tests in a thermo-vacuum Siméon cuve at CNES (Toulouse).



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Results:

- Commands both from HK and CPU were properly served
- Configuration of the ASICs was properly performed.
- Data request commands were properly served and information sent were meaningful
- Data transfer of thousands of events was successfully performed

Full integration tests

In May 2014, the whole system was assembled at IRAP, in Toulouse:
Optics + PDM + DP + Power Pack

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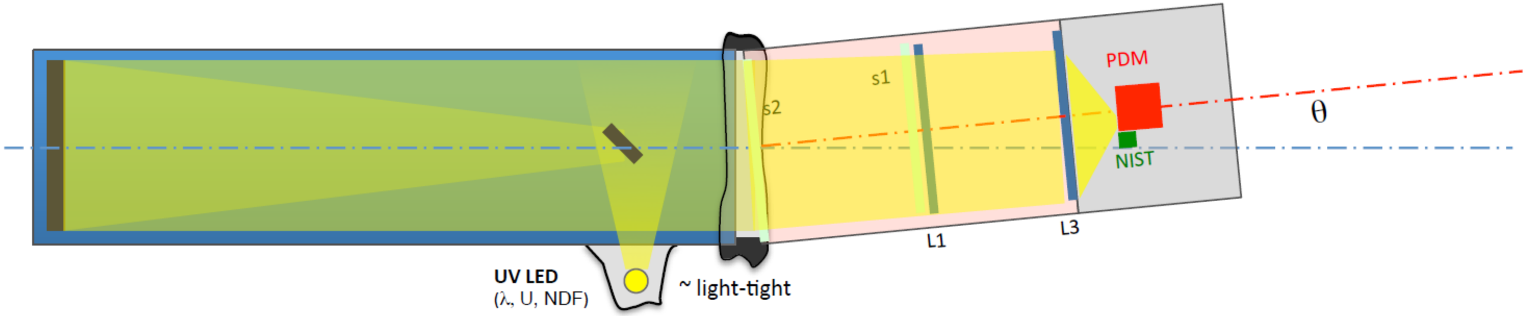
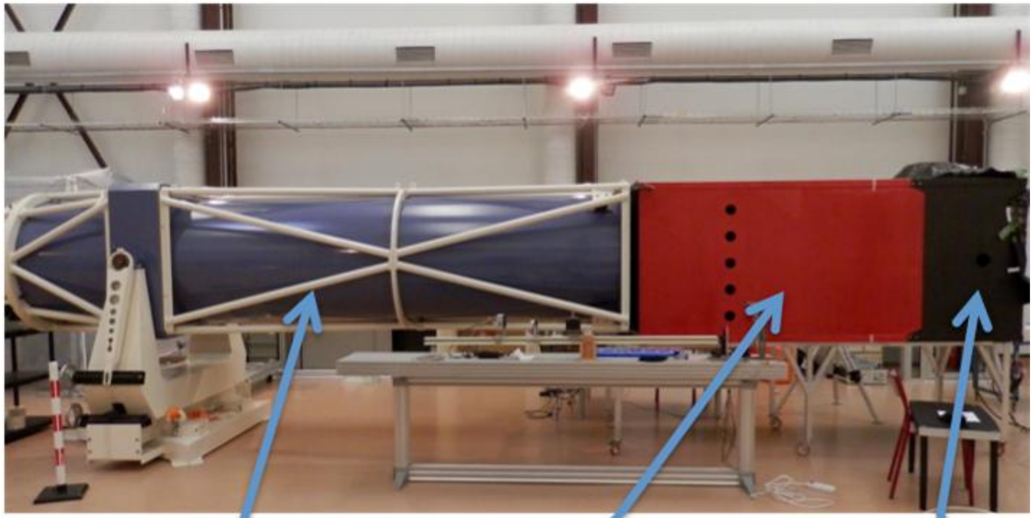
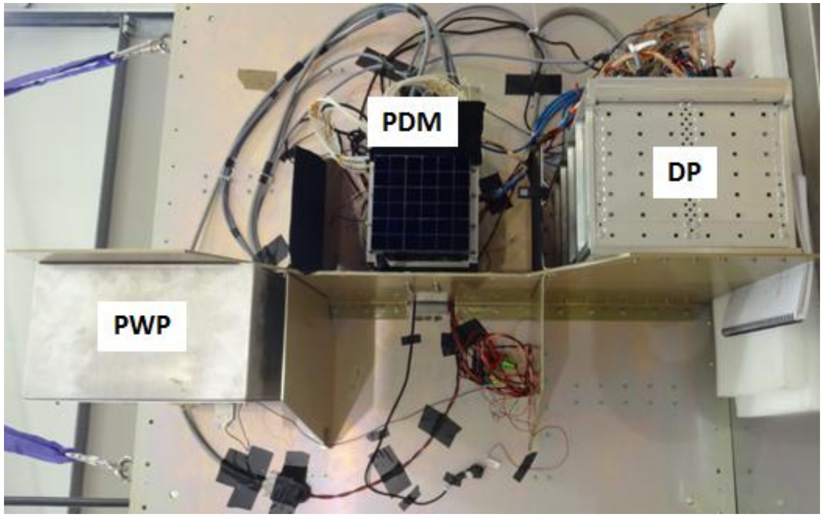




Collimator Optical system PDM



PDM, DP and Power Pack fixed to the radiator plate.

Full integration tests results

We performed end-to-end tests and we successfully managed to:

✓ Operate the instrument from flight batteries with flight-plug

✓ Measure the width of the PSF as a function of z (distance L3-PDM) for several wavelengths in order to find the best focal spot

✓ Map the PSF's at different wavelengths and incident angles

✓ Measure the overall (end-to-end) efficiency for 375 nm

✓ Test the system with pulses and pulse-intensities to match the dynamic range

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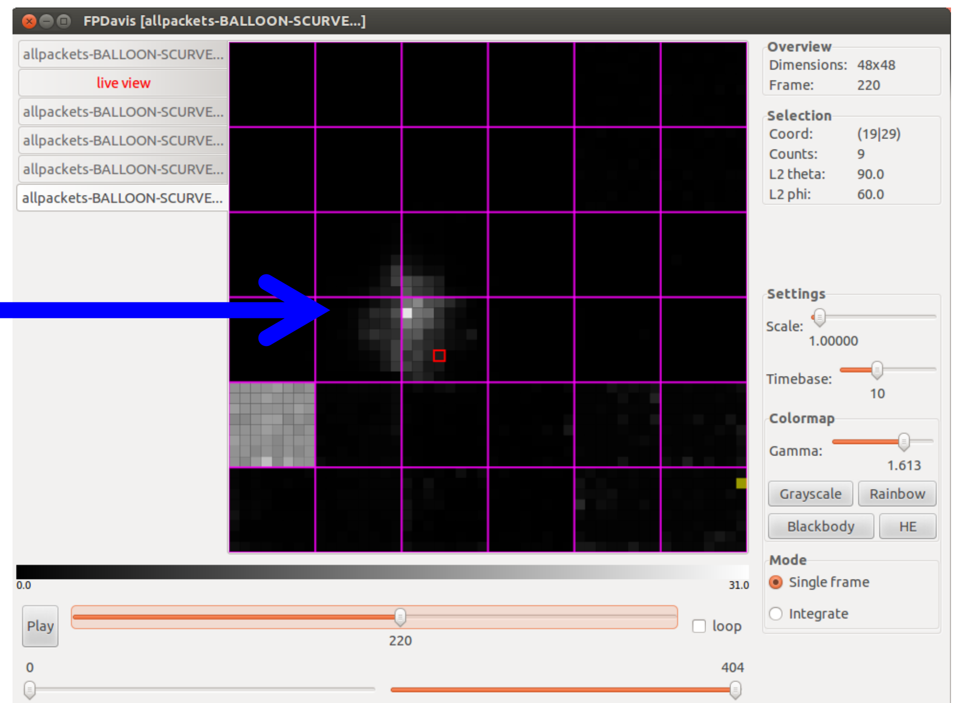
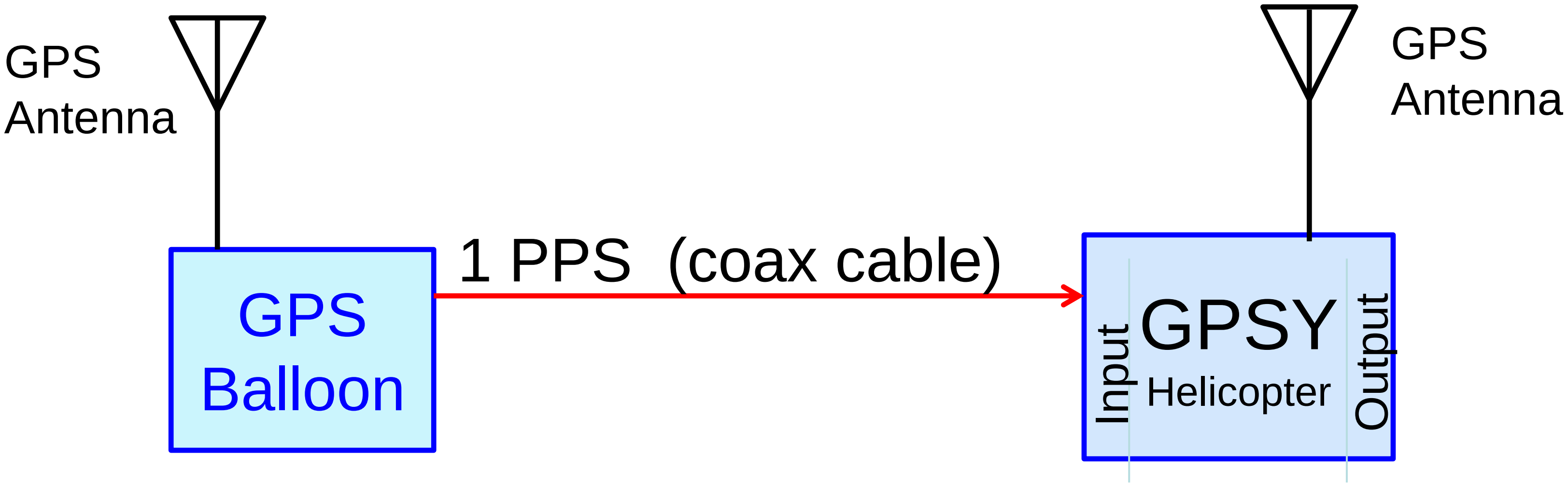
Our first light!



See H. Miyamoto poster: Performance of the EUSO-Balloon UV camera

Flasher tests 1: clock synchronization

The 1 Pulse Per Second (PPS) output signal of the DP GPS clock was time stamped by the helicopter GPS clock system.



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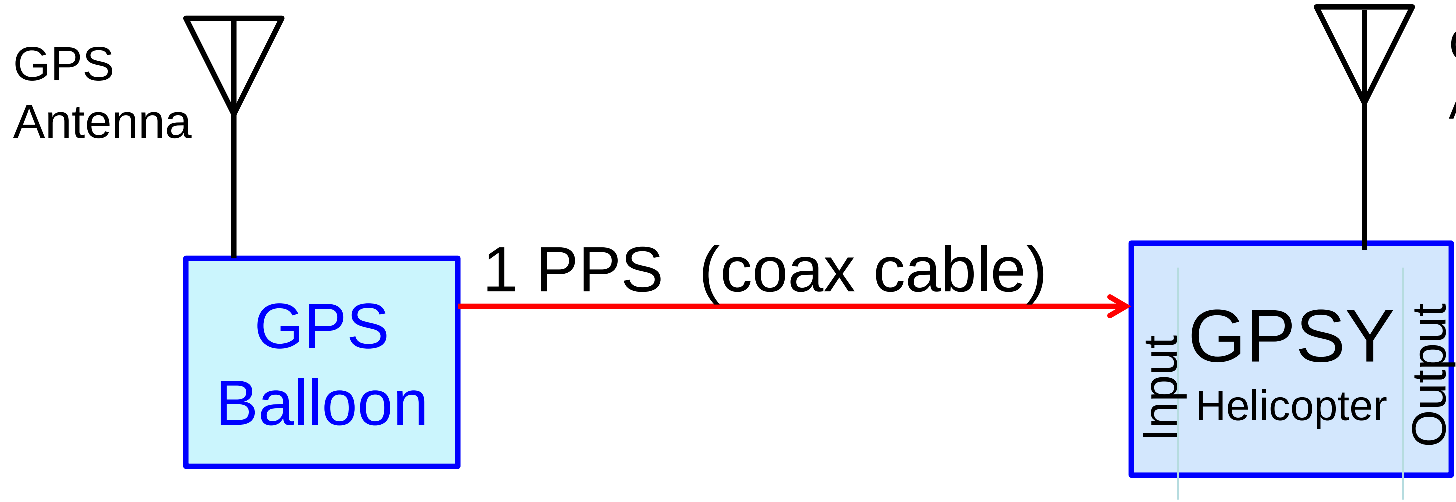
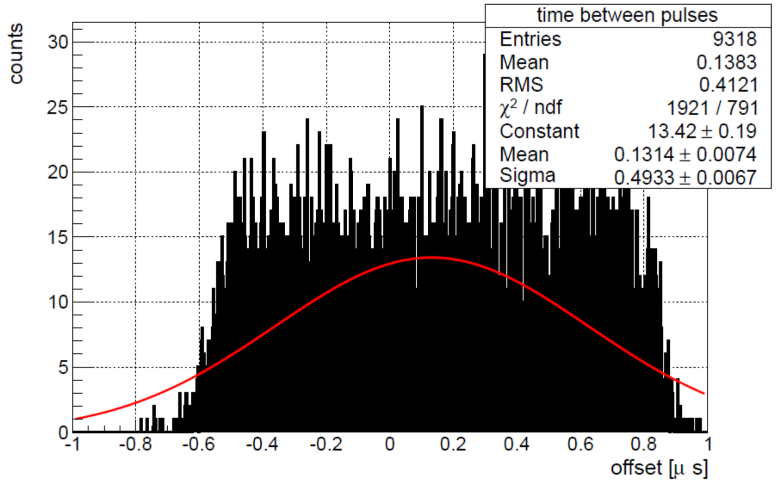




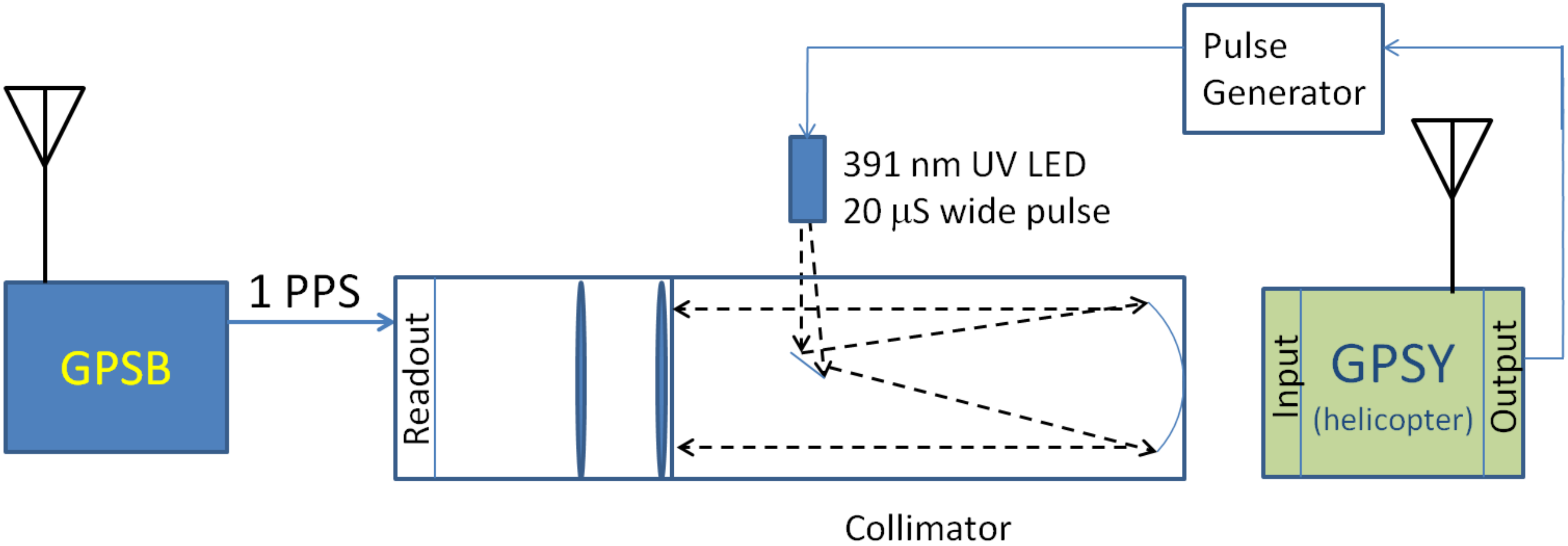
Difference between DP GPS clock (1PPS) and Helicopter GPS clock.

GPS clocks are synchronized:
the DP GPS and helicopter GPS clocks are synchronized with an RMS <0.5 µS

Flasher tests 2:1PPS signal from GPS as external trigger

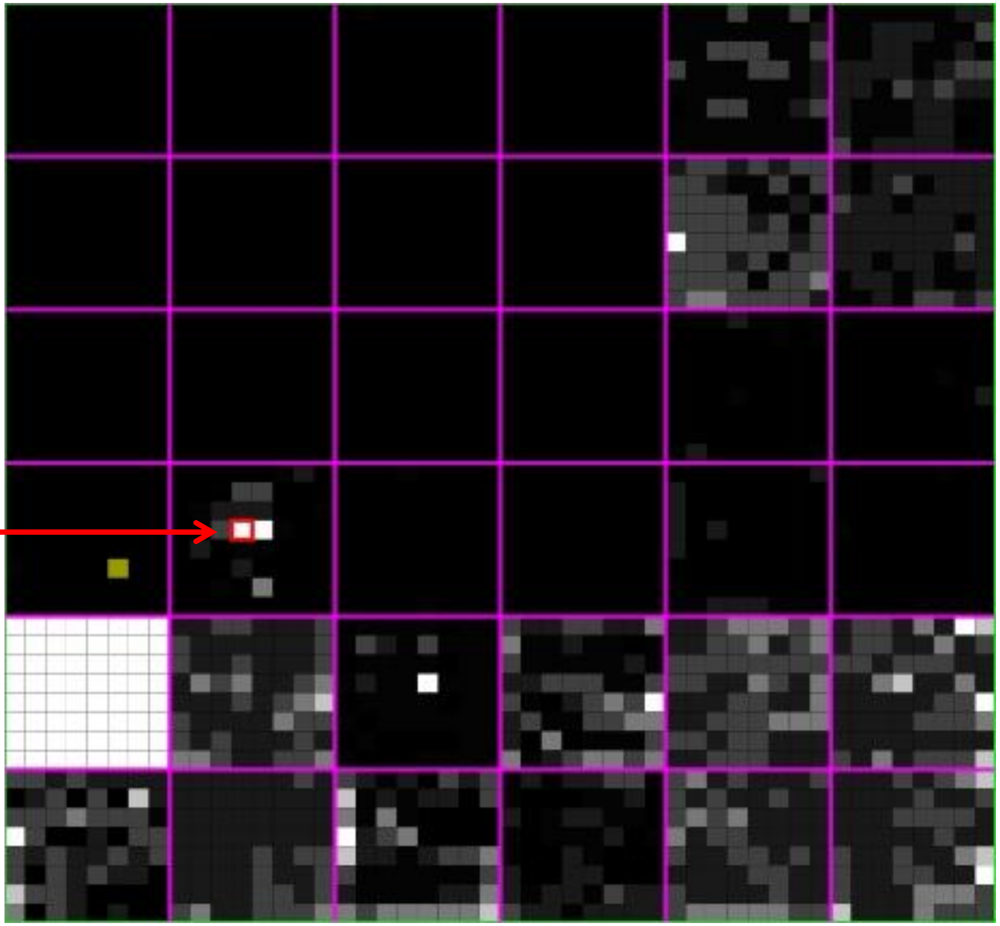
The EUSO-Balloon instrument was triggered externally by the 1PPS signal from DP GPS while an UV LED was triggered by the helicopter GPS.

Does the pulse appear in the 128 GTU readout window of EUSO-Balloon?



Flasher tests 2:1PPS signal from GPS as external trigger

Light spot
From 391 nm LED

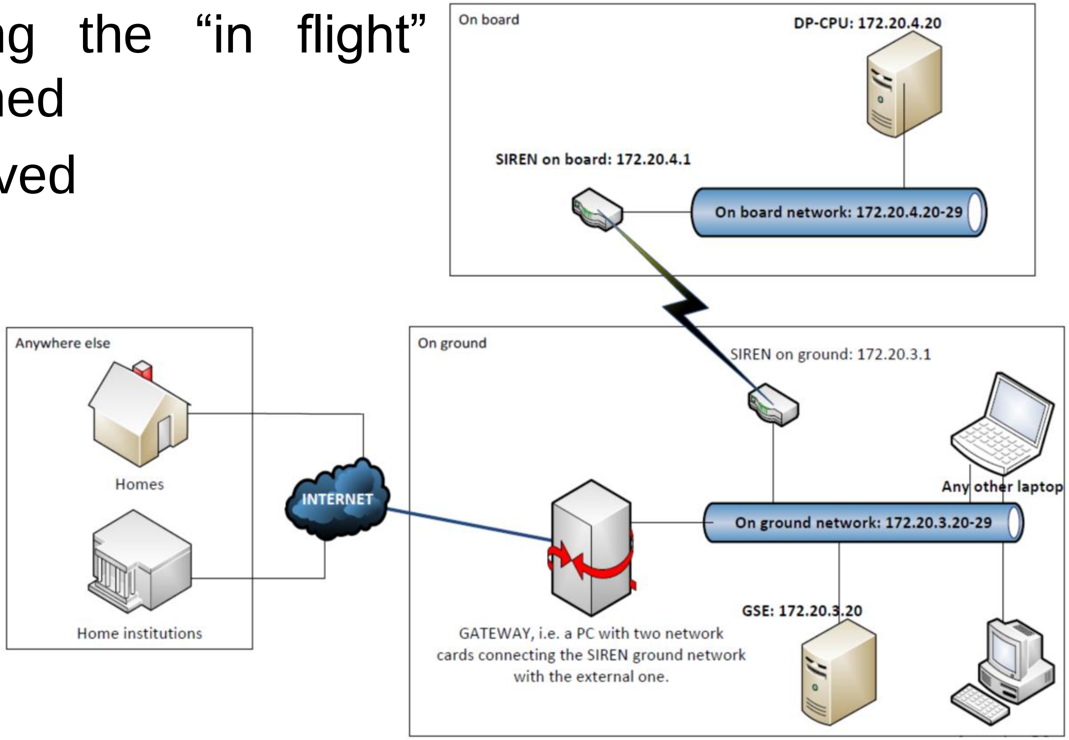


External GPS trigger technique works: we captured the flashes from the LED triggered by the helicopter GPS clock using the PPS from GPS board as external trigger.

Interface tests with SIREN CNES telemetry

The interface between the DP system and SIREN system has been tested:

- The SIREN system has been connected to the apparatus by using flight cables and connectors
- Test of all the interfaces were successfully performed
- Test of sequence simulating the "in flight" operations successfully performed
- Telemetry data correctly received



Status and plans

- The whole EUSO-Balloon Instrument has been assembled and tested:
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    - Efficiency measurement of the whole chain performed
    - Flasher tests successful
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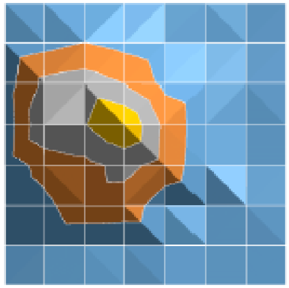
- Everything is on schedule for the first launch from Timmins in August 2014.

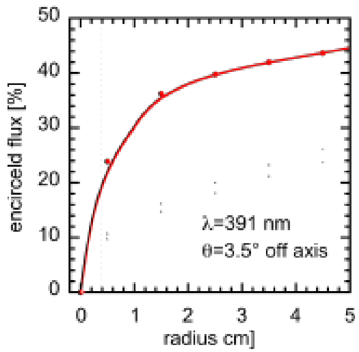
Thank you for your
kind attention!

Backup Slides

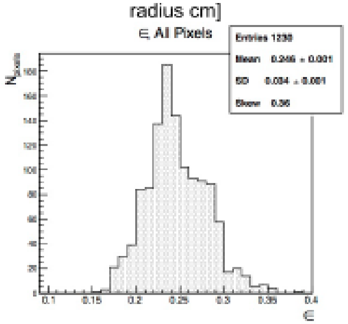
Performance synthesis (preliminary)



PSF has a width of 9 mm (FWHM)



ε_{opt} = 22 ±2.2 % (3 x 3 pixels, i.e. 0.75 cm^2)



ε_{fs} = 23±2.3% (average on the entire PDM)

fig. of merit

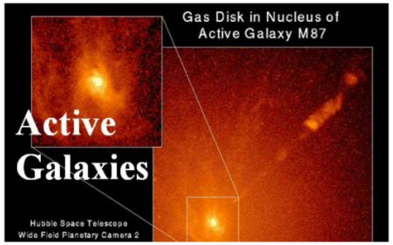
$$\boldsymbol{\varepsilon_{tot} = \varepsilon_{opt} \cdot \varepsilon_{fs} \approx 5.3 \pm 1.1\%}$$

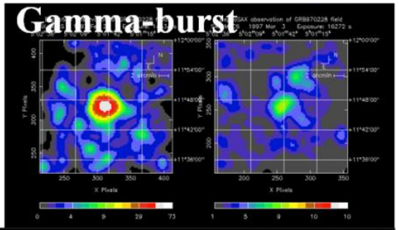
JEM-EUSO Science

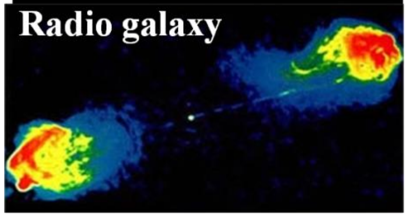
Astrophysics and Cosmology:

Main science objectives:

- **identification of EECR sources**
- **measurement of the energy spectra of individual sources**
- **measurement of the trans-GZK spectrum**





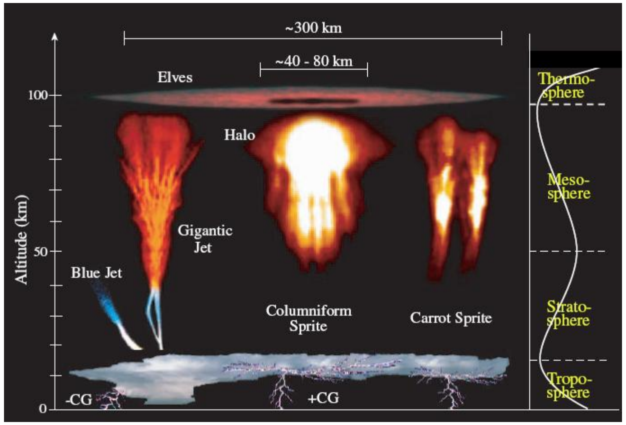


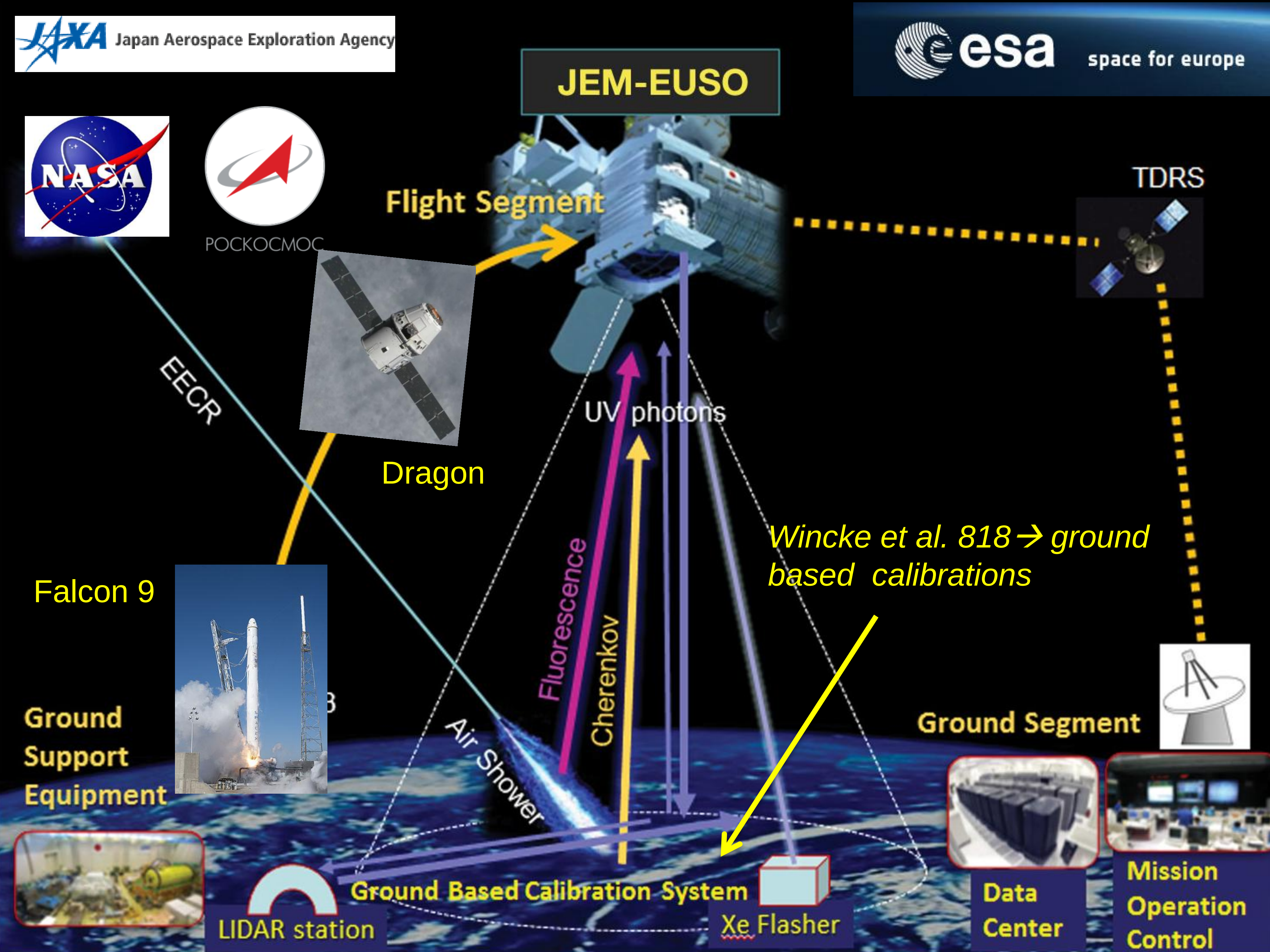
Exploratory objectives:

- discovery of UHE neutrinos
- discovery of UHE Gamma-rays
- study of the galactic and local extragalactic magnetic field

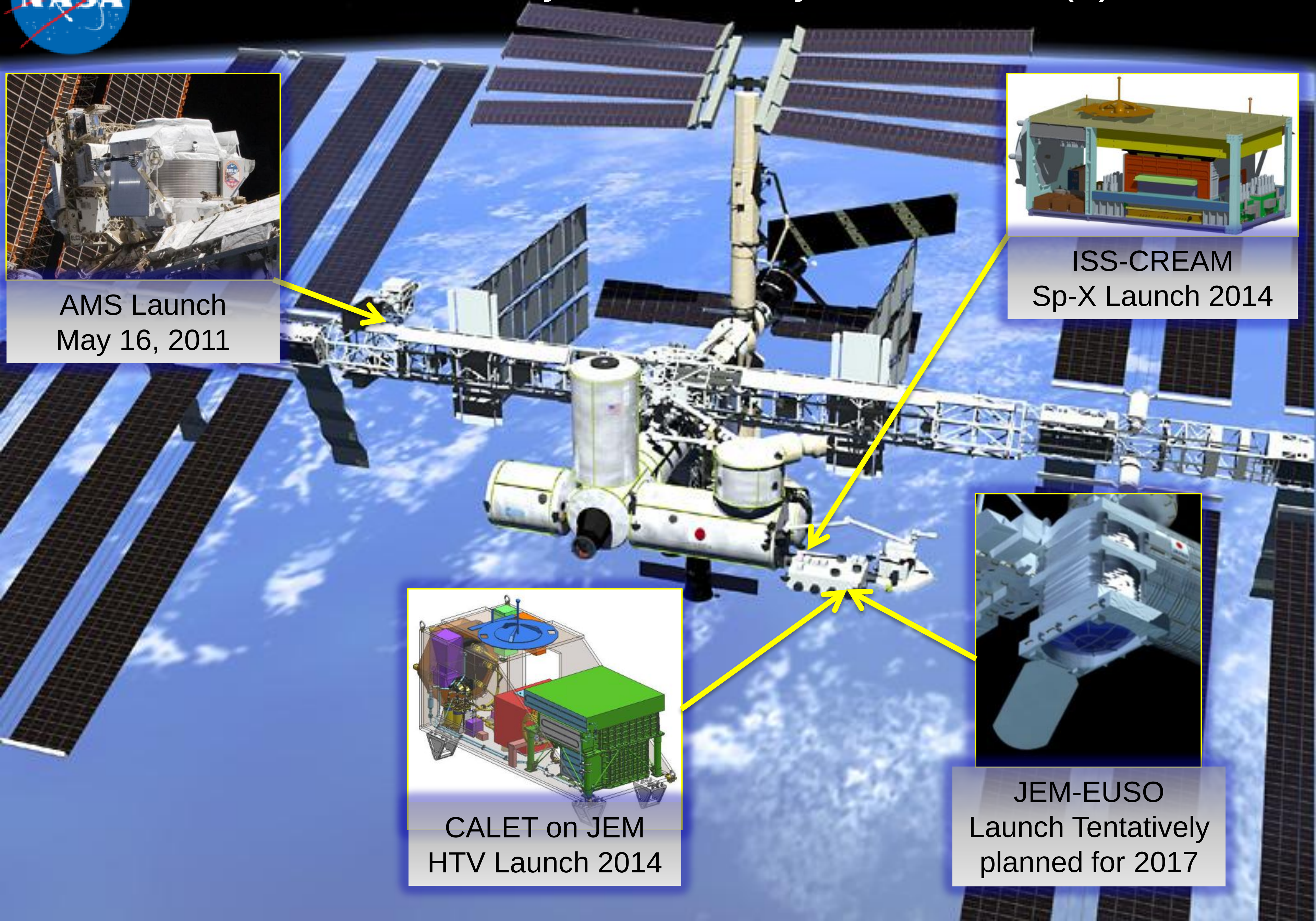
Atmospheric Science:

- nightglow
- transient luminous events (TLE)
- meteors and meteoroids




JAXA Japan Aerospace Exploration Agency
JEM-EUSO
esa space for europe
NASA
РОСКОСМОС
Flight Segment
TDRS
EECR
Dragon
UV photons
Fluorescence
Cherenkov
Wincke et al. 818→ ground based calibrations
Falcon 9
Ground Support Equipment
Air Shower
Ground Segment
Ground Based Calibration System
LIDAR station
Xe Flasher
Data Center
Mission Operation Control

“Cosmic Ray Observatory on the ISS” (?)



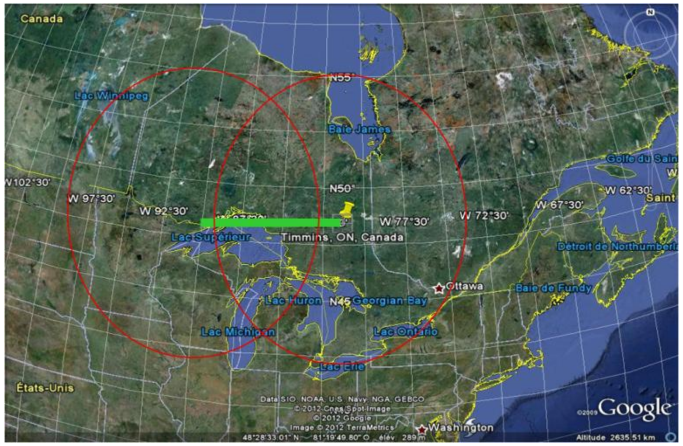
EUSO BALLON mission

Three flights mission (recently approved by CNES)

Balloon size for EUSO :

400 000 m^3 -> 40 Km altitude

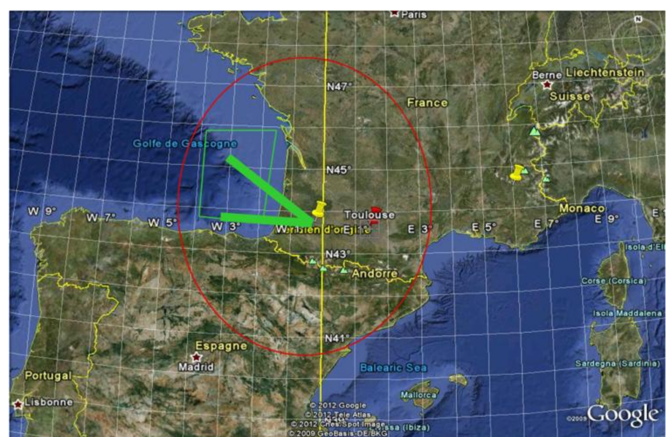
First flight : 2014 Timmins.



0.2-0.3 CR events/10hr

Second flight : 2015 Kiruna?

Third flight : 2016 Aire sur l'Adour?



Environmental constrain:
Low pressure (3 mbar)
Thermal range: -30°C +50°C

EUSO-Balloon mass budgets

- PDM: 6.94 kg
- DP: 25.6 kg
- Radiator (with PDM, DP, PWP, Cables onto): 127 kg
- Mechanical structure: 171 kg
- Total mass: 439 kg

Sub systems	Mass (kg) without contigency
Siren (CNES)	3.2
ICDV (CNES)	1
Hub (CNES)	1
Battery (CNES)	3.9
Radiator – Radiator and stiffeners – PDM + Micrometric stage (without motor): 6.940 (weight) – DP 25.66 (weight) – PWP – Cables – Outillage 25 (CAO)	152 (weight)
IR Camera	25
Mechanical structure – Lens with frame + mechanical structure – Interface IRCam	171 (weight)
Foam roll	72 (weight)
Crash pads	35
Total	464 -25 = **439**

EUSO-Balloon power budgets

- PDM: 18.2 W
- DP: 52.3W

- IRCam: 30W

- Total power budget: 70.5 W

Interface	Power Consumption in W for PWP	Power Consumption in W for PWP-IR
IR Camera		30
High Voltage Power Supply	1,0	
PDMB (FPGA)	7,2	
PDMB-EC-ASIC	10,0	
TOTAL PDM	**18,2**	
LVPS DP1	2,1	
LVPS DP2	5,0	
Housekeeping	6,0	
LVPS-PDM	2,5	
CPU	15,0	
CCB	5,0	
Data Storage	10,0	
GPS	1,5	
CLK	4,0	
LVPS-HK	1,2	
TOTAL DP	**52,3**	
Total	70,5	30

Optics

Main requirements for EUSO-BALLOON optics are:

- a large optical system to increase the number of photons collected and thus lower the threshold for minimum energy detection of UHECR.
- a large Field-of-View (FoV) to increase the number of events observed.

This results in a wide-field optics, with a low focal ratio (the ratio between the optics aperture and the focal length) f# = 0:72.

Fresnel lenses realized in UV-grade Poly(Methyl MethAcrylate) - PMMA allows to build a refractor telescope capable to meet these requirements with the constraints posed by space borne experiments.
Furthermore, the reduced thickness of the lenses allows to reduce the mass of the optics resulting in a light system capable to withstand launch vibration and thermal expansion.

Focal spot size

The size of the focal spot is important for:
(a) the determination of the spatial structure of the background
(b) shower detection and reconstruction

• The size of the focal spot **is not important for the determination of the intensity of the background.**

Since the definition of scientific success of the first flight is not the detection of a CR shower, we center on point (a).
The spatial structure of the background should be characterized at least down to the scale of the **footprint of the pixel of JEM-EUSO (~ 3 pixels of EUSO-Balloon).**

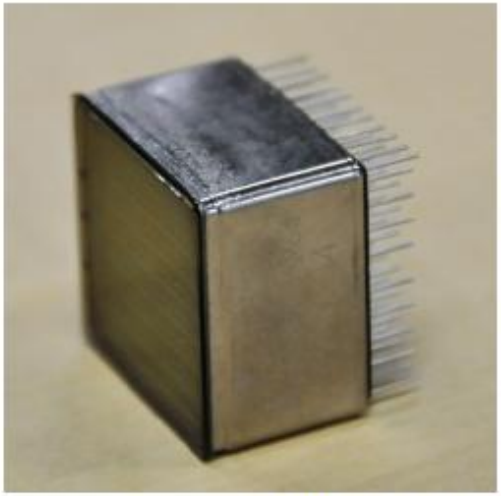
Therefore, **3 pix is still a focal spot size that would have no impact on** the scientific performance.

The MAPMT

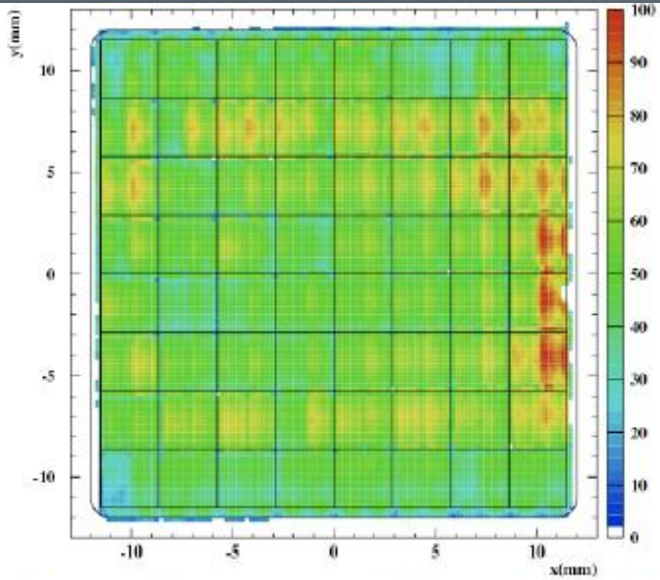
The main specifications of R11265-03-M64 are as follows:

•pixels side	2.88 mm
•maximum sensitive area	23.04 mm × 23.04 mm.
•physical dimension of the MAPMT	26.2 mm × 26.2 mm (length is 20.25 mm).
•weigth	27.3 g.
•photo-cathode	ultra-bialkali
•window material/thikness	UV glass/ 0.8 mm
•quantum efficiency	higher than 35% (maximum 40%) for wavelengths from 330 nm to 400 nm.
•dynode structure	metal channel with 12 stages,
•gain	10^6 at 0.9 kV with a tapered voltage divider.
•anode pulse rise-time I	1.5 ns.
•transit time spread	about 0.3 ns.
•cross talk	about 1%.
•gain non-uniformity (anodes)	1:3.
•gain non-uniformity (MAPMT)	within 1:2.
•anode dark curr. (30 min. storage)	1 nA.

The MAPMT



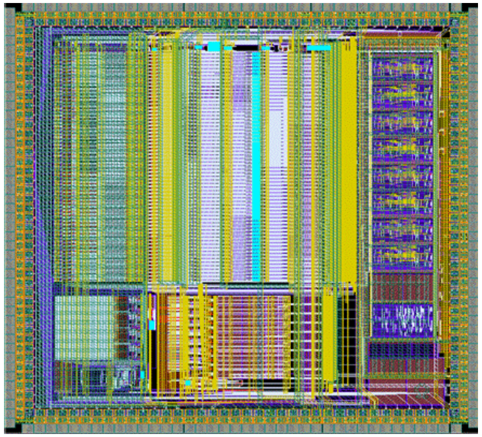
Hamamatsu R11265-03- M64
64 pixel MAPMT



Gain uniformity of the MAPMT

- Uniformity of the gain meets the requirements.
- Single photoelectron peaks can be seen for all of the pixels.
- Gain of each channel can be adjusted by HV and frontend electronics.

SPACIROC ASIC



- 64 channels ASIC in AMS 0.35 µm SiGe technology designed by Omega group at LAL
- Requirements:
  - ✓ Readout of MAPMT (charge or current input)
  - ✓ Gain adjustment (preamplifier)
  - ✓ Photo-electron counting (Fast Shaper + discriminator)
  - ✓ Estimation of the charge (Q to T converter)
  - ✓ Radiation hardness
  - ✓ Low consumption (<1 mW/ch)
- All achieved with the first version of the ASIC