

# EUSO



Vincent Van Gogh, "The starry night"

# EUSO: the focal surface photo-detector

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## Provisional EUSO parameters

Desired pixel size at the Earth surface	0.5 km $\div$ 1.0 km
ISS average orbit height	$\approx$ 380 km
Observation duty cycle	0.1 $\div$ 0.15
Orbital period	$\approx$ 1.5 hours
Maximum diameter of the apparatus	$\approx$ 2.5 m
Optics aperture (entrance pupil diameter)	$\approx$ 2.0 m
Optics f/#	$\approx$ 1.25
Optics field of view (half-angle)	$\approx$ 30 degrees
Provisional geometry of the focal surface (from the provisional design of the main optics)	Paraboloid: $z - \alpha r^2$ ( $\alpha = 0.3 \text{ m}^{-1}$ ; maximum $r = 1.13 \text{ m}$ )

## Requirements for the photo-detector

- The photo-detector must have single photon sensitivity in the 330 nm  $\div$  400 nm wavelength range, to detect as faint as possible EAS by observing the fluorescence and diffusely reflected Cherenkov light.
- The photo-detector must have a fast time response (well below 0.1  $\mu$ s) to follow the space-time development of the EAS, and to be able to determine the EAS direction from one single observation point. On the other hand only a modest spatial resolution (of the order of one mm) is required, due to the desired pixel size.
- The photo-detector must have a low noise and good signal to noise ratio to detect the faint signal produced by the less energetic EAS and to discriminate it from the background. Small cross-talk and after-pulse rate as well as a good and uniform detection efficiency are required.
- The photo-detector must have a large area (of the order of a few square meters), due to the large field of view required to the optics, and it must cover the focal surface with a sensitive area as large as possible, reducing dead or inefficient areas. The curved focal surface can be more easily covered by a mosaic of small units.
- The large field of view and the desired spatial granularity require a large number of pixels (hundreds of thousands) and therefore a complex read-out electronics, capable to handle such a large number of channels, is required.
- Low power consumption, low mass, mechanical robustness and small dimensions are also required.
- The photo-detector has to be compatible with the requirements imposed by a space mission which include space radiation tolerance, low sensitivity to magnetic fields of the order of the gauss and high reliability and operating stability over a period of a few years.

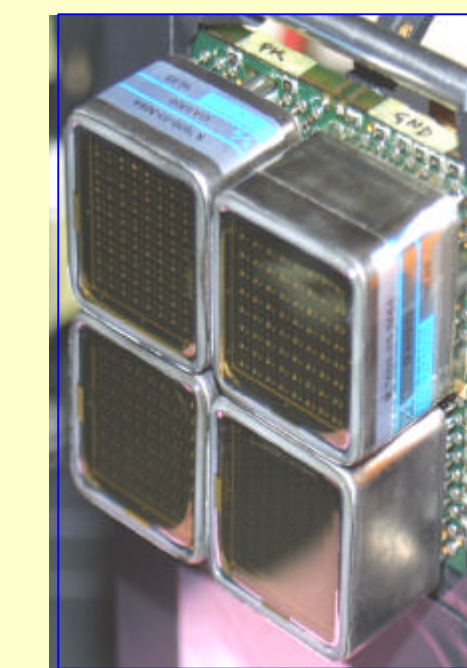
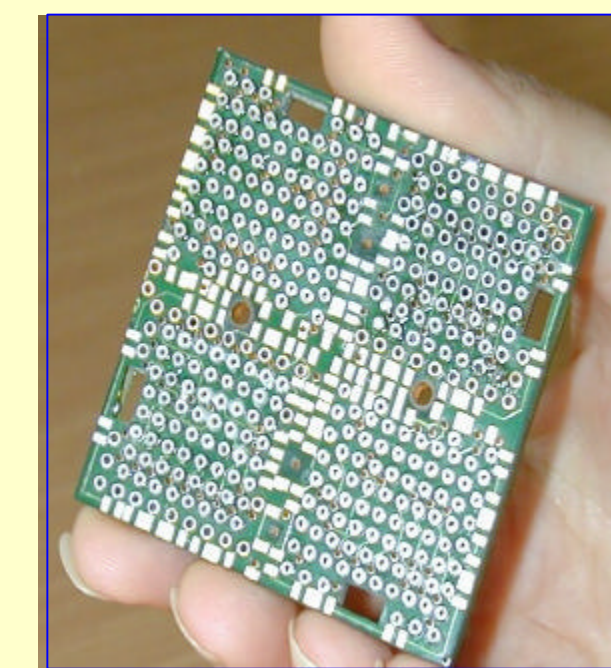
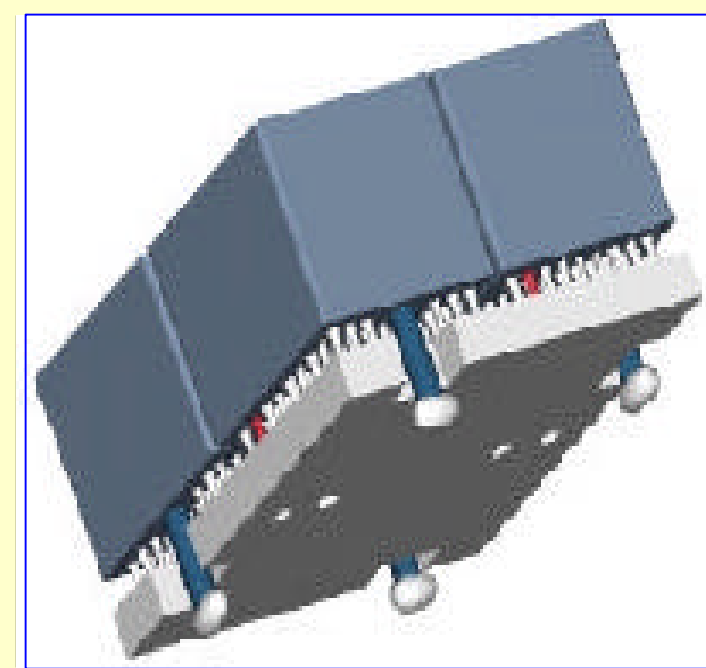
## The photo-detector

The photo-detector has to be able to detect the EAS by observing the nitrogen fluorescence light produced during the EAS development and the Cherenkov light diffused from the Earth. It must be able to determine the position of the arriving photons as a function of time, to be able to follow the space-time development of the EAS. It includes the following components:

- the sensors;
- the front-end electronics;
- the optical interface to the sensors on the focal surface (the light collection system);
- the focal surface structure, layout and engineering, its integration with the support structure and with the space vehicle;
- the ancillary systems required for the proper functioning and control of the photo-detector and for data acquisition.

## The elementary cell

The photo-detector elementary-cell must provide the housing and close-packing of the MAPMTs and support for the front-end electronics and all the ancillary systems. A base-board was designed and prototyped for four MAPMTs. This elementary unit features one single HV connection and one resistive bleeder circuit per MAPMT. It was attempted to close-pack the MAPMTs with a one mm pitch between adjacent MAPMTs. It was avoided to use any additional space along the edges of the board to allow close packing of different boards, again with one mm clearance. The removal of the heat produced by the bleeder circuit was accomplished by inserting a copper layer inside the PCB to be thermally connected to the cooling system. The board allows for mounting of the front-end chip on the same board as the voltage divider, on the opposite side with respect to the MAPMT. In this way the front-end electronics is close to the photo-detector in a compact structure which minimize cabling. The three figures below show the design of the elementary cell for four MAPMTs, a photo of the base-board (without the electronics components) and a photo of one elementary cell in a laboratory setup.



## The sensor: multi-anode photomultipliers (MAPMT)

The use of commercial Multi-Anode PhotoMultipliers Tubes (MAPMT) for the EUSO photo-detector was proposed as the most viable option based on existing and reliable devices. In fact MAPMTs fulfill most of the requirements and they are a well-established technology, available from shelf, with characteristics which are easily quantified. The Hamamatsu Photonics R7600 series provides a viable solution.

And R&D program was carried on to validate this choice and to find possible solutions to a few open items which might limit the usefulness of the device in EUSO, the most important of which appears to be the low overall geometrical acceptance of the bare device. Operational issues, such as power consumption, were also preliminarily investigated. All the characteristics were found to be compatible with the presently known constraints and requirements.

## The focal surface layout

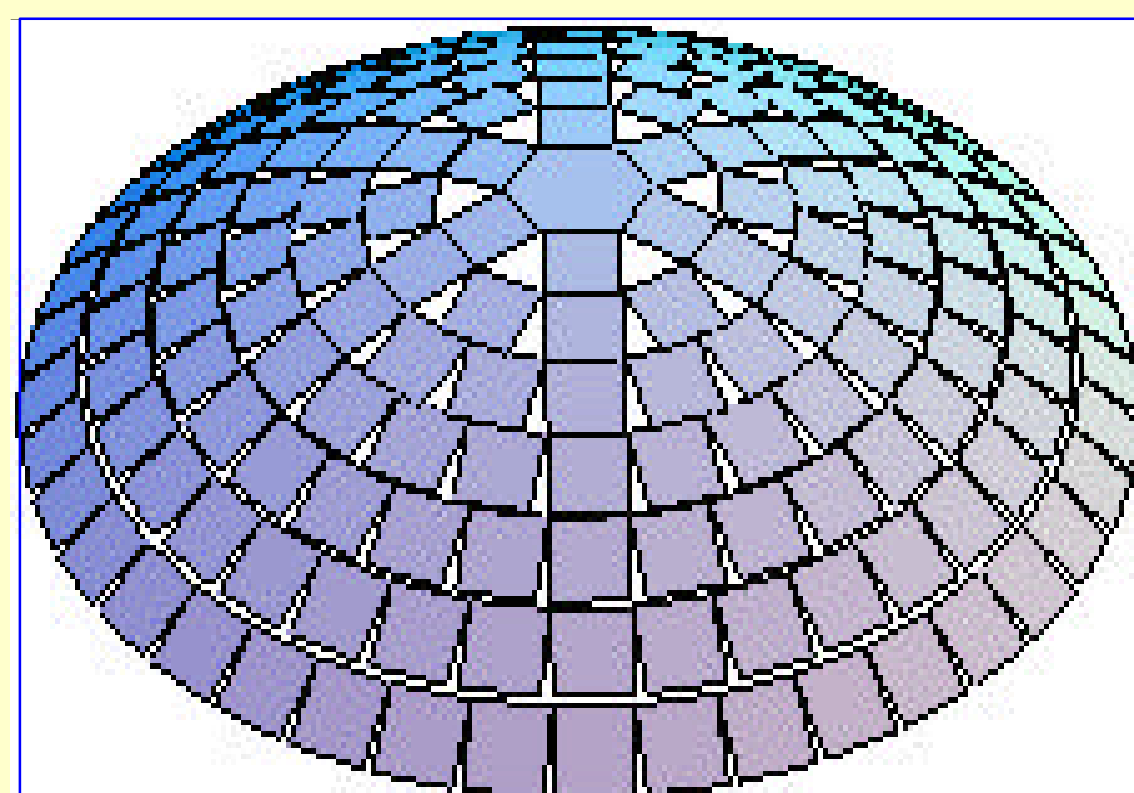
As the focal surface will be most probably curved, the packing of the devices has to be optimised to reduce losses in the geometrical acceptance and defocusing effects. A curved focal surface requires a modular structure. The overall structure should consist of small functional units (*elementary cells*) assembled in super-modules.

The elementary modules consist of a limited number of MAPMTs installed on the same Printed Circuit Boards (PCB) base-board and sharing some common resources. All of the front-end electronics plus as much as possible of the following readout electronics should be integrated in the module.

The elementary cells can be thick multi-layered PCB, as described in another panel. A number of these modules, each one making an essentially autonomous system, are then assembled to make a super-module. These are independent structures tied to each other by the support structure and having a shape determined by the layout of the focal surface.

The focal surface can be fitted with rectangular flat panels. The layout of any surface with cylindrical symmetry can be built by a segmentation in polar angle, producing circular coronas, filled with rectangular flat panels. This arrangement, can make use of identical rectangular super-modules only, thus greatly simplifying the geometry, the logic and structure of the trigger and readout electronics. A curved surface cannot be filled exactly with rectangular shapes, but holes will unavoidably remain.

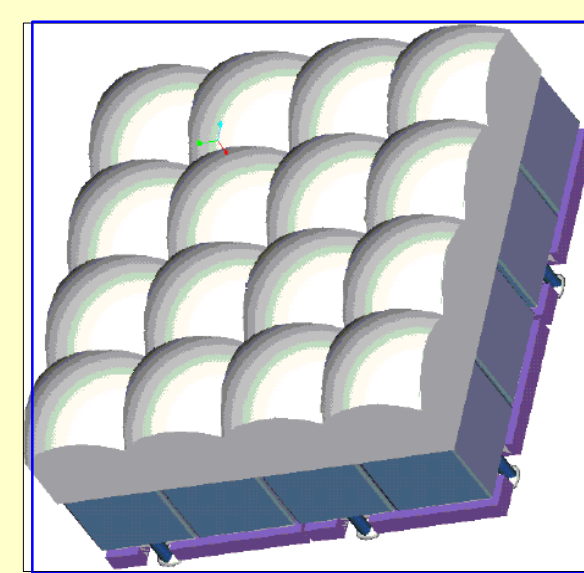
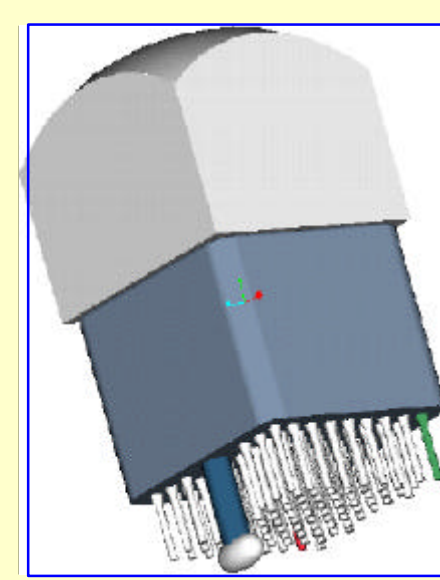
A view of one possible layout of the focal surface having a six-fold symmetry and based on square modules made of 6x6 MAPMTs. It features 168 modules, a filling factor of 0.84 and a maximum discrepancy of any module from the focal surface of about 2 mm. About six thousands MAPMTs are needed.



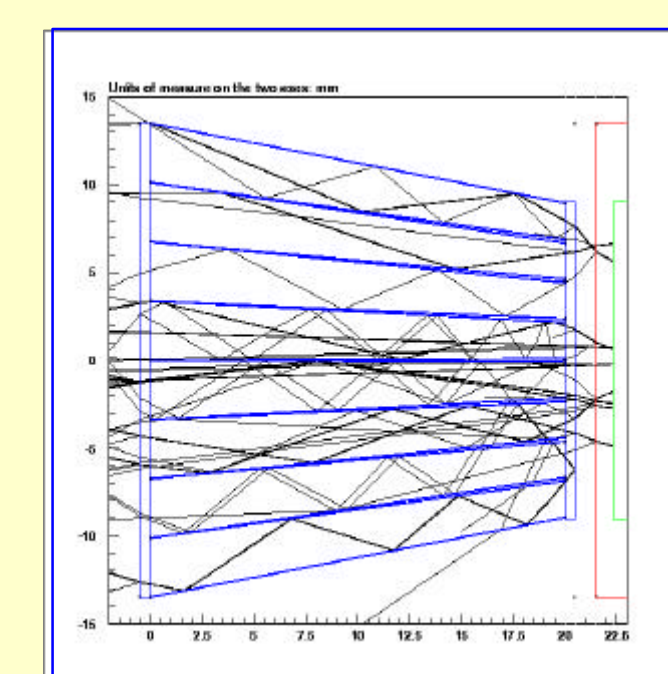
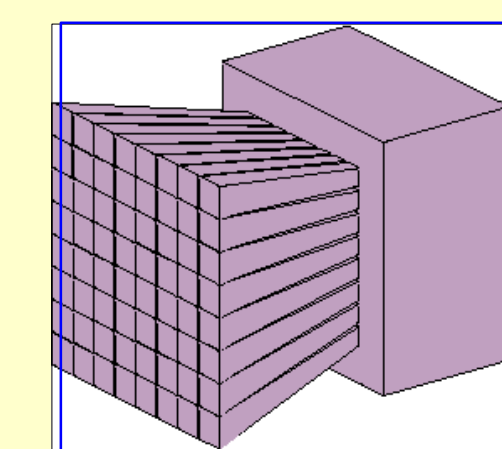
## Light collector systems for the MAPMT

The geometrical acceptance of the bare MAPMT (less than 0.45) can be improved by means of a suitable light collector system, placed in front of each device, performing the required demagnification onto the MAPMT sensitive area. This system might consist of a lens system, a system made of a bundle of tapered light pipes (working either by normal reflection or by total internal reflection inside a transparent pipe) or a fiber optic taper. Its importance is not only to improve the overall geometrical acceptance but also to make it more uniform on the focal surface. Detailed simulations of the performance of the different systems were carried on with the conditions expected in EUSO and with assumptions based on the requirements and constraints known as of today.

One possible lens system consists of a plano-convex hemi-spherical lens located in front of the MAPMT with the plane face in optical contact (or separated by a small gap) with the MAPMT input window and coincident with the original focal surface, as shown in the two figures. Simulations show that an overall efficiency of about 0.7 can be reached after the lens inclusion. This takes into account all the reflection losses and the inefficient inter-pixel region but ignores the bulk absorption because it depends on the material. It was assumed, conservatively, no anti-reflection coating and no optical coupling to the MAPMT input window. The lens introduces a degradation of the spatial resolution corresponding to about one pixel (for the 64 channel MAPMT) for about one third of the reconstructed rays.



A bundle of tapered light pipes, one per pixel, might be used in front of the MAPMT, exploiting either the total internal reflection inside a refractive and transparent light guide or normal reflection on the walls of an empty pipe. One possibility is to assemble a system made of square section tapered slanted light pipes, in such a way that each pipe has an exit face with the same dimensions of the MAPMT pixel. A conceptual view of the system is shown in figure as well as ray tracing for total internal reflection light pipes. Simulations of the total internal reflection light pipes show that an overall efficiency up to about 0.7 can be reached with a 30 mm long pipe. This takes into account all the losses but those coming from the bulk absorption, which cannot be carefully estimated at present as they depend on the material. It was assumed, conservatively, no anti-reflection coating on the entrance and exit faces and no optical coupling to the MAPMT input window. In the simulations of reflective light pipes a constant reflectivity on the walls, equal to 0.9, was assumed, independent of the incidence angle and wavelength. The results show that an overall efficiency up to about 0.55 can be reached.



## The front-end electronics

The front-end electronics is needed to preamplify the signals from the sensors, to discriminate these signals with a programmable threshold, to mask noisy channels, to provide information to the trigger system, possibly performing a first level trigger, and to store the information until readout is done. The most important and critical features are the optimal gain and input impedance to match the photo-detector signal, the double hit resolution (required to be of the order of 10 ns), the time information (with precision of the order of 10 ns) and the low power consumption allowed. One should consider a highly integrated front-end chip for signal readout and possibly first level trigger. Required features are a very compact design with minimal distance between the sensors and the front-end electronics, a completely modular system with minimal cabling and self-triggering capabilities. The design of a dedicated front-end chip is going on, carefully designed to comply with the EUSO requirements. A preliminary feasibility study shows that a design compatible with the EUSO requirements is possible. A preliminary design was carried on for the front-end section which matches the presently known constraints and requirements. Prototypes are being built.

## References

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## Conclusions

A realistic baseline design for the EUSO photo-detector, based on the presently known information and constraints, was developed. The most critical issues related to the MAPMTs and the overall photo-detector design were preliminarily investigated. Possible solutions to some open issues were studied and proposed.

See also the related posters: HE178, HE179, HE180 and HE181.

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