MUCH: an imaging Čerenkov telescope for volcano muography

D. Mollica[1]; O. Catalano[1]; M. Capalbi[1]; G. Contino[1]; P. Conconi[2]; G. Cusumano[1]; F. D'Anca[3]; M. Del Santo[1]; C. Gargano[1]; V. La Parola[1]; G. La Rosa[1]; M. C. Maccarone[1]; T. Mineo[1]; G. Pareschi[2]; G. Sottile[1]

[1]INAF/IASF Palermo, Italy; [2]INAF/O.A. Brera, Italy; [3]INAF/O.A. Palermo, Italy

Introduction

Current muography can be affected by a huge particle background due to scattered low energy muons and charged particles from extensive air showers [1]. This background can be reduced using several detector planes and lead radiation shields, increasing the telescope weight and dimensions and consequently limiting its portability. In order to overcome this problem, muography with Imaging Atmospheric Čerenkov Telescopes (IACTs) has been recently proposed [2][3] and its feasibility has been demonstrated by our team using GEANT4 simulations for muon transportation and the ASTRI-Horn telescope simulator for optical ray tracing [4][5].

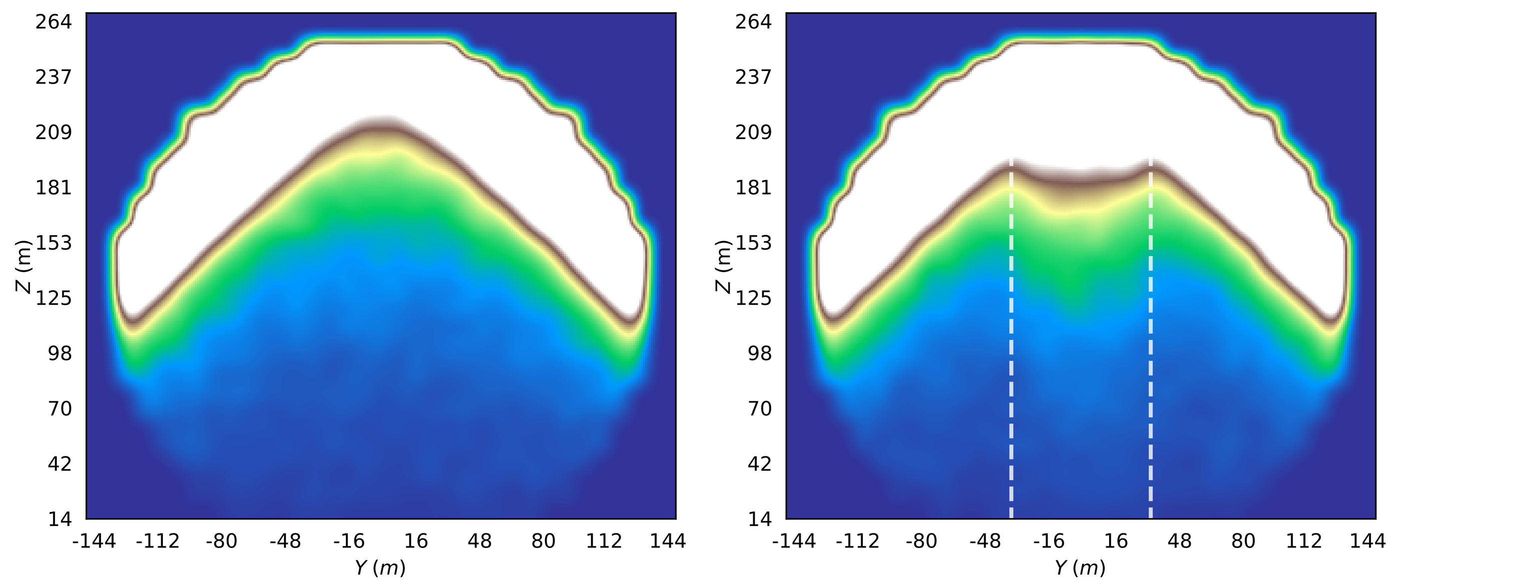


Fig. 1: 30 nights muography simulation of a volcano toy-model (a cone of base 500 m and height 240 m) with no conduit (left) and a conduit of 70 m (right) using the 4.3 m aperture ASTRI-Horn telescope simulator.

Muon detection with IACT

The Čerenkov threshold at sea level is about 4.5 GeV, and increases with altitude. Therefore, despite IACTs can observe only at night, none of the previously mentioned sources of background is expected to affect the observed muon flux. The Čerenkov light focused onto the focal plane forms a ring-shaped image, centred at the muon arrival direction, with an angular extent that decreases as the *impact parameter* ρ increases. With a 2.5 m telescope aperture only the photons emitted in about the last 100 m can be seen, resulting in a signal of few ns. After a cleaning procedure on the image, the muon arrival direction can be measured with a mere geometrical analysis. In addition, from the ring radius one can infer the muon energy up to about 20 GeV; above this energy the Čerenkov angle saturates at about 1.4° at sea level.

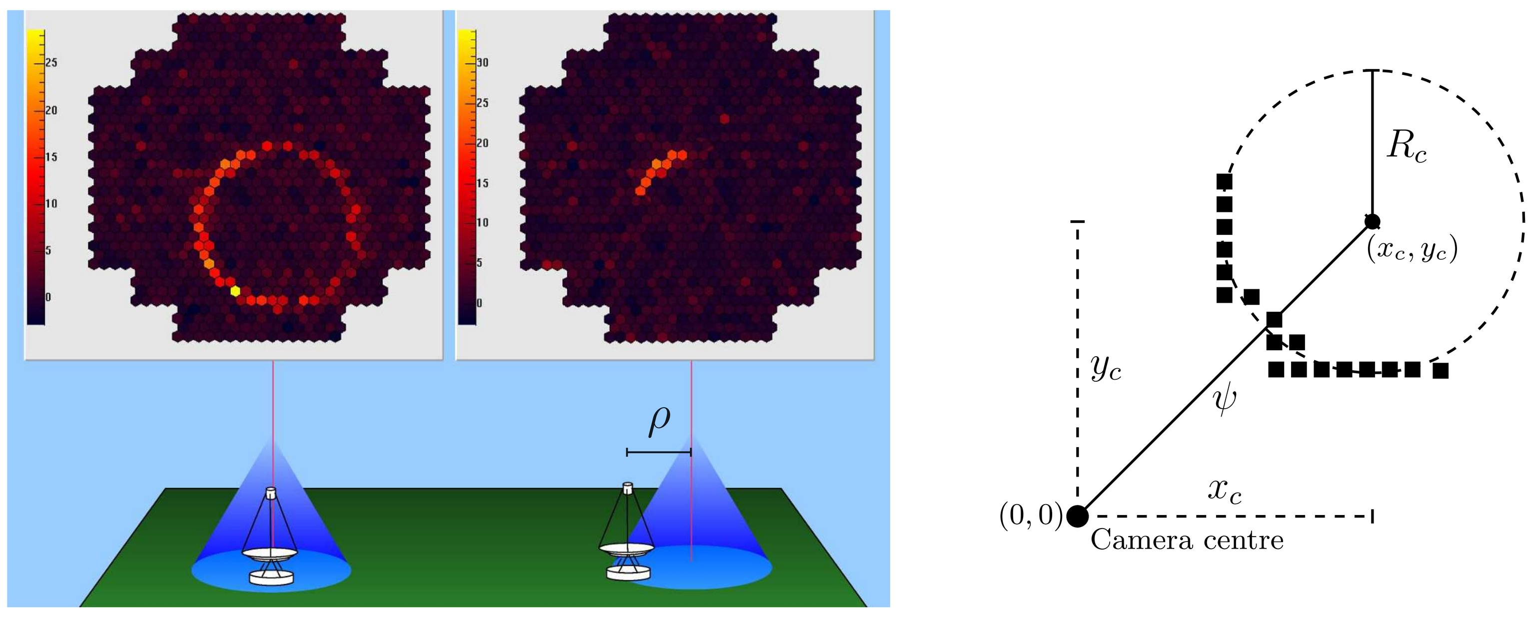


Fig. 2: Left) Muons hitting an IACT aperture plane at the center and at a distance ρ (credit:[6]). When the muon passes through the aperture plane the ring appears complete, otherwise its angular extent decreases with increasing ρ. Right) Reconstruction of muon direction and Čerenkov angle from radius and center of a IACT muon image.

GEANT4 simulator

A dedicated GEANT4 simulation framework is currently being developed. The main classes are:

- `MuchFresnelLens` class, that allows for creation of customisable Fresnel lenses taking into account major manufacturing errors;
- `MuchCamera` class, that allows for creation of customisable cameras composed of square SiPM modules arranged on a flat or spherical focal plane;
- `MuchStandardLens` class, that allows for creation of customisable "aspherical shell" solids. To this purpose, a new Geant4 CSG solid has been implemented.

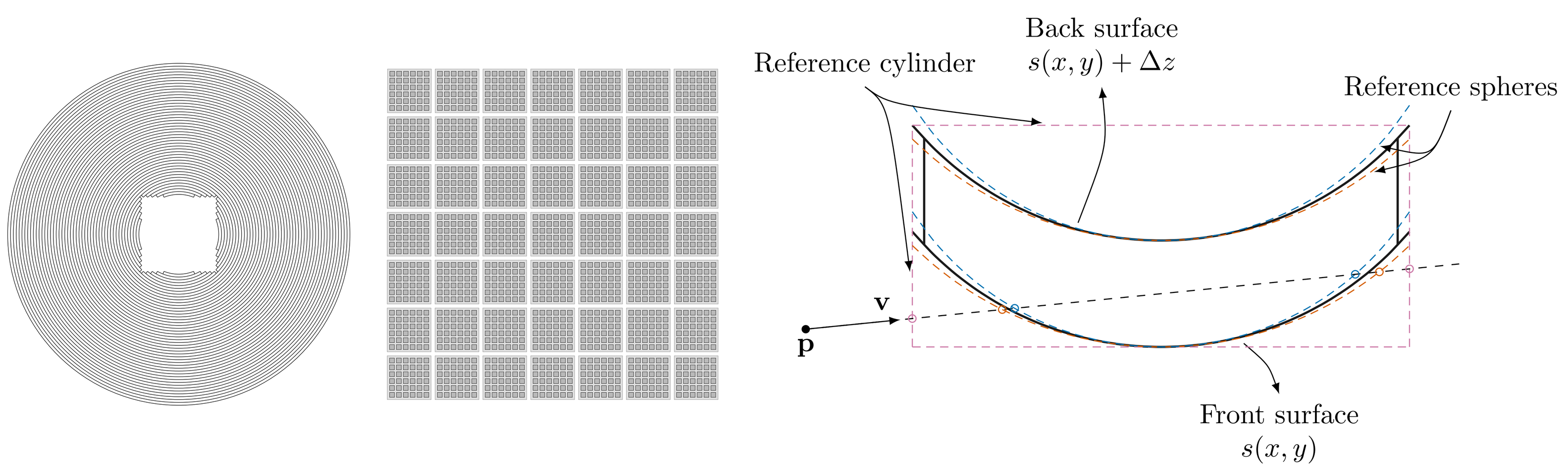
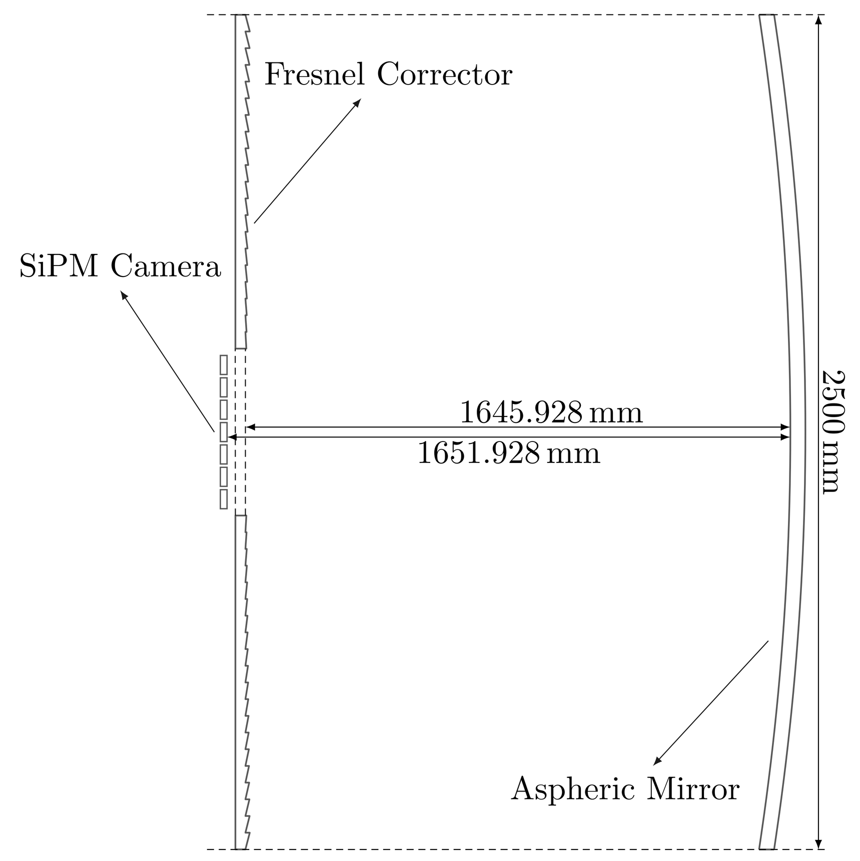


Fig. 3: Example of the geometry of a circular Fresnel lens with a squared central hole (left), a 7×7 modules (6×6 pixels) SiPM camera (center) and an aspherical shell (right). Grooves size, pixels separation and shell thickness and curvature are overemphasized for visualization purposes.

MUography CHerenkov telescope

Optical and detection system

The Schmidt-like optical system of MUCH consists of three optical surfaces: a Fresnel corrector, an aspheric mirror and a flat focal plane. The diameter of both corrector and mirror is 2500 mm and the distance between them is 1645.9 mm. The effective focal length of the system is 1800.6 mm and the telescope plate-scale is 32.4 mm/°. The focal plane is covered by a matrix of 7×7 Photon Detection Modules (PDMs), each one composed of a matrix of 8×8 Silicon PhotoMultiplier (SiPM) sensors with a 6.95 mm×6.95 mm active area working in the 280 nm-900 nm wavelength band.



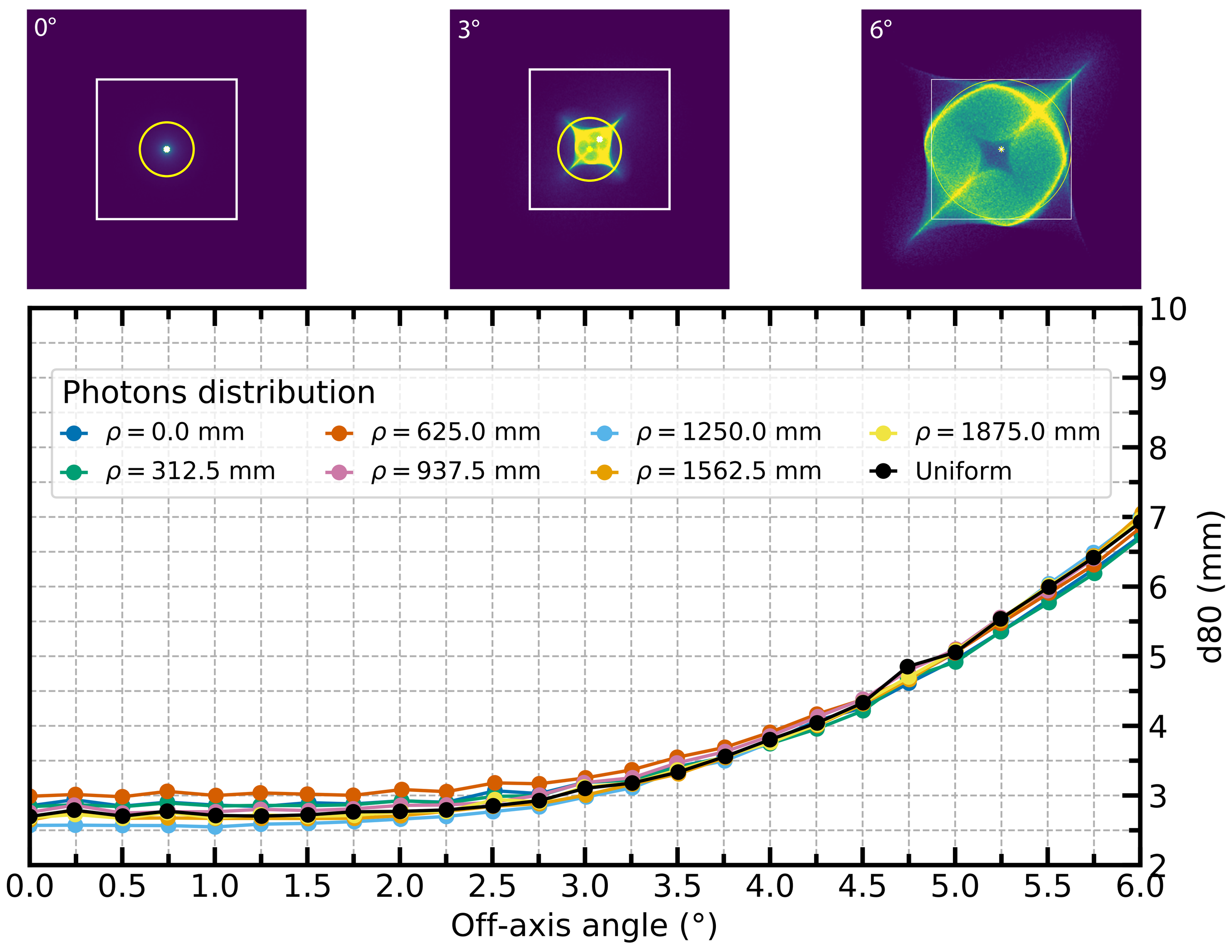


Fig. 5: Above) Optical system spot diagram at 0°, 3° and 6° off-axis angle. The white box has the same size of a pixel.Below) 80 % encircled photons diameter (d80) as a function of off-axis angle and with different photons distributions on the aperture: uniform and induced by muons with different ρ. Simulations have been performed with a dedicated GEANT4 simulator.

Electronics

An innovative fast front-end electronics will be used for the SiPMs readout. The designed Application-Specific Integrated Circuit (ASIC), named RADIOROC (RADIOgraphy Read Out Chip) [7], is an improvement of an existing ASIC, used in the ASTRI-Horn project. RADIOROC is a 64-channel chip, capable to operate SiPMs both in charge integration and in single photon counting (up to 200 MHz, thanks to a programmable pole zero cancellation circuit). The latter is essential for acquire the brief muon signal minimizing the night sky background contamination.

Conclusion

Muography with IACTs is a novel promising technique that exploits the muon-induced Čerenkov radiation in the atmosphere in order to perform muon detection. Due to IACTs image capability and high Čerenkov energy threshold, negligible background, muon collection area greater than the telescope aperture and an angular resolution better than a few tenths of degree are expected. MUCH, a compact Schmidt-like IACT designed for muography, has been presented. The design provides an angular resolution better than 0.21° (pixel angular size) over the entire FoV of 12°. The SiPM camera will be equipped with a new fast front-end electronics capable to acquire the brief muon Čerenkov flash reducing optical background signals. An international patent has been registered (PCT/IB2016/056937).

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