MUCH: AN IMAGING ČERENKOV TELESCOPE FOR VOLCANO MUOGRAPHY

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Introduction

Particles seen by current muon telescopes are not only muons coming from the target. Indeed, muography can be affected by a huge particle background due to scattered low energy muons, charged particles from extensive air showers, random coincidences of different particles and upward-going particles entering the back of the detector[1]. The background can be reduced by increasing the number of detector planes and lead radiation shields. This solution increases the weight and dimensions of the instrument, limiting its portability. In order to overcome this problem, muography with Imaging Atmospheric Čerenkov Telescopes (IACTs) has been recently proposed[2][3]. Despite IACTs can observe only at night, none of the previously mentioned source of background is expected to affect the observed muon flux.

The feasibility of muography with IACTs has been demonstrated by our team using GEANT4 simulations for muon transportation and the ASTRI-Horn telescope simulator for optical ray tracing[4][5]. Simulation results of the muography of a volcano toy-model have shown an angular resolution better than a few tenths of degree and a muon collection area greater than the telescope aperture area.

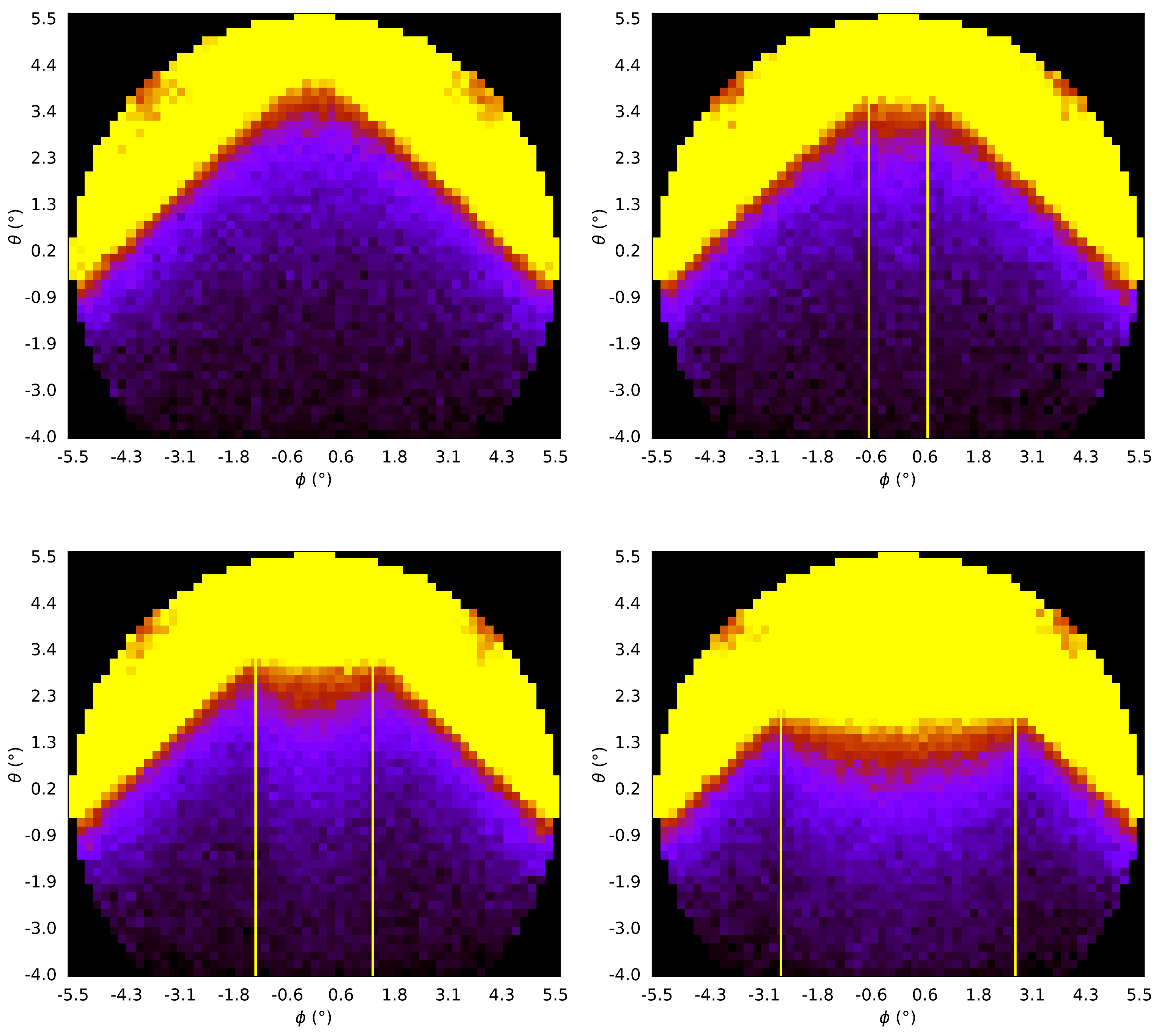


Fig. 1: 30 nights muography simulation of a volcano toy-model (a cone of base 500 m and height 240 m) with conduit of different diameters (0 m, 35 m, 70 m and 140 m) using the 4.3 m aperture ASTRI-Horn telescope simulator. The conduit position is highlighted by vertical lines.

Muon detection with IACT

A charged particle induces Čerenkov radiation when it passes through a refractive medium at a speed greater than the speed of light in that medium. This implies a process energy threshold of about 4.5 GeV for muons at sea level. Photons are emitted in a cone with a constant opening angle around the particle travel direction. As IACTs image in angular space, the Čerenkov light focused onto the camera forms a ring-shaped image centred at a distance from the focal plane centre corresponding to the angle of incidence of the muon and 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.

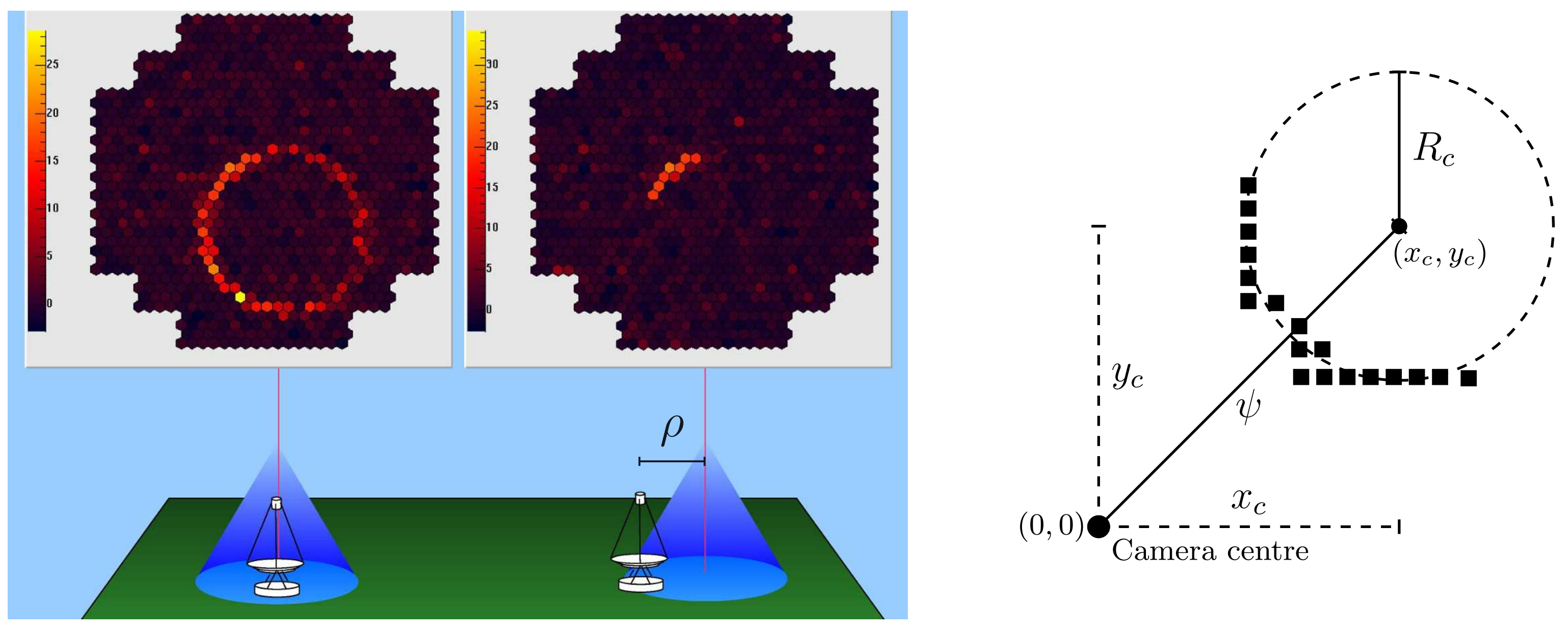
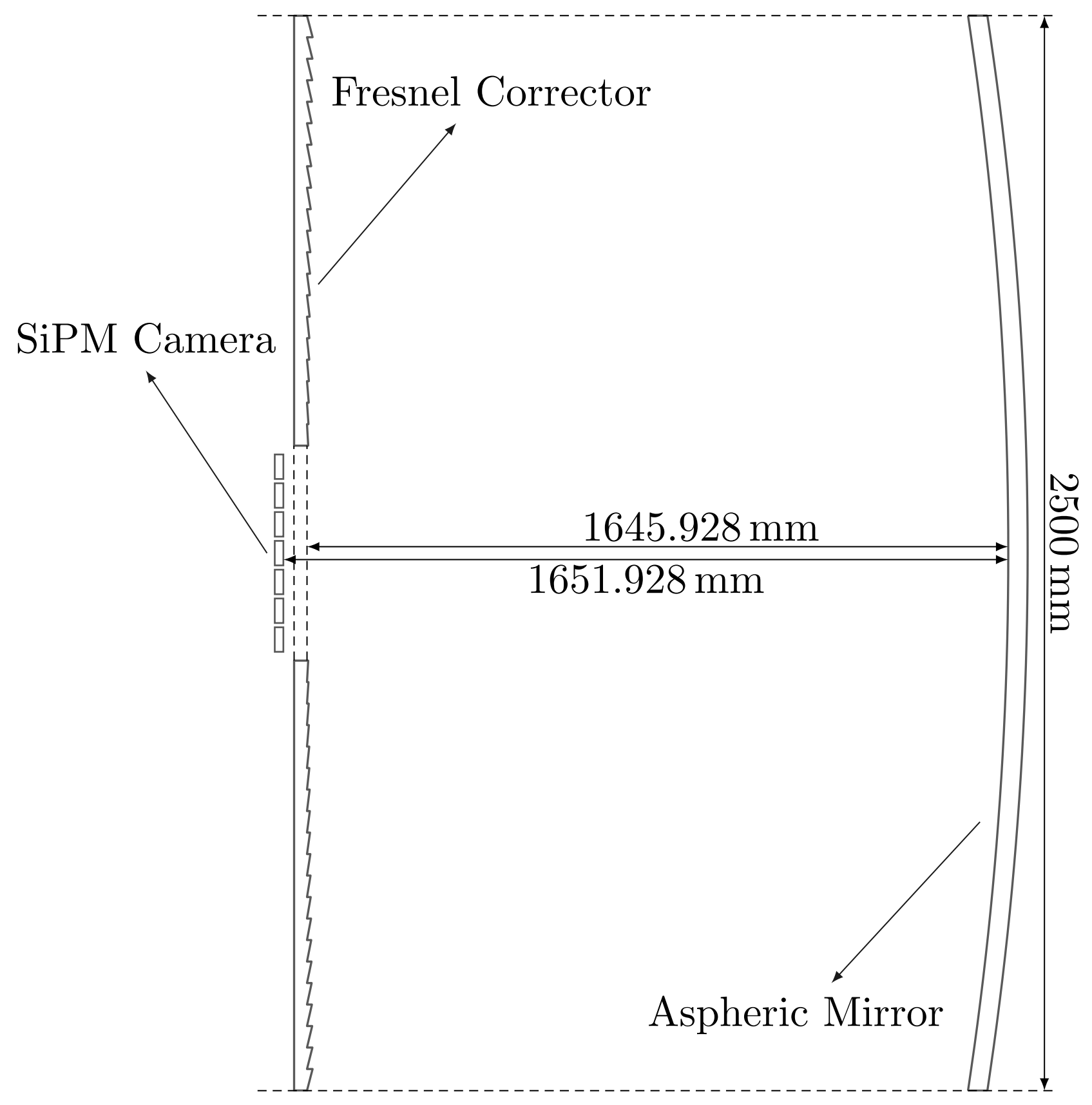


Fig. 2: **Left)** Muons hitting an IACT aperture plane in the center and at a distance ρ (credit:[6]). When the muon passes through the aperture plane the ring appears complete, otherwise its angular extent decreases with increasing ρ. **Right)** Reconstruction of muon direction and Čerenkov angle from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

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 280nm-900nm wavelength band.



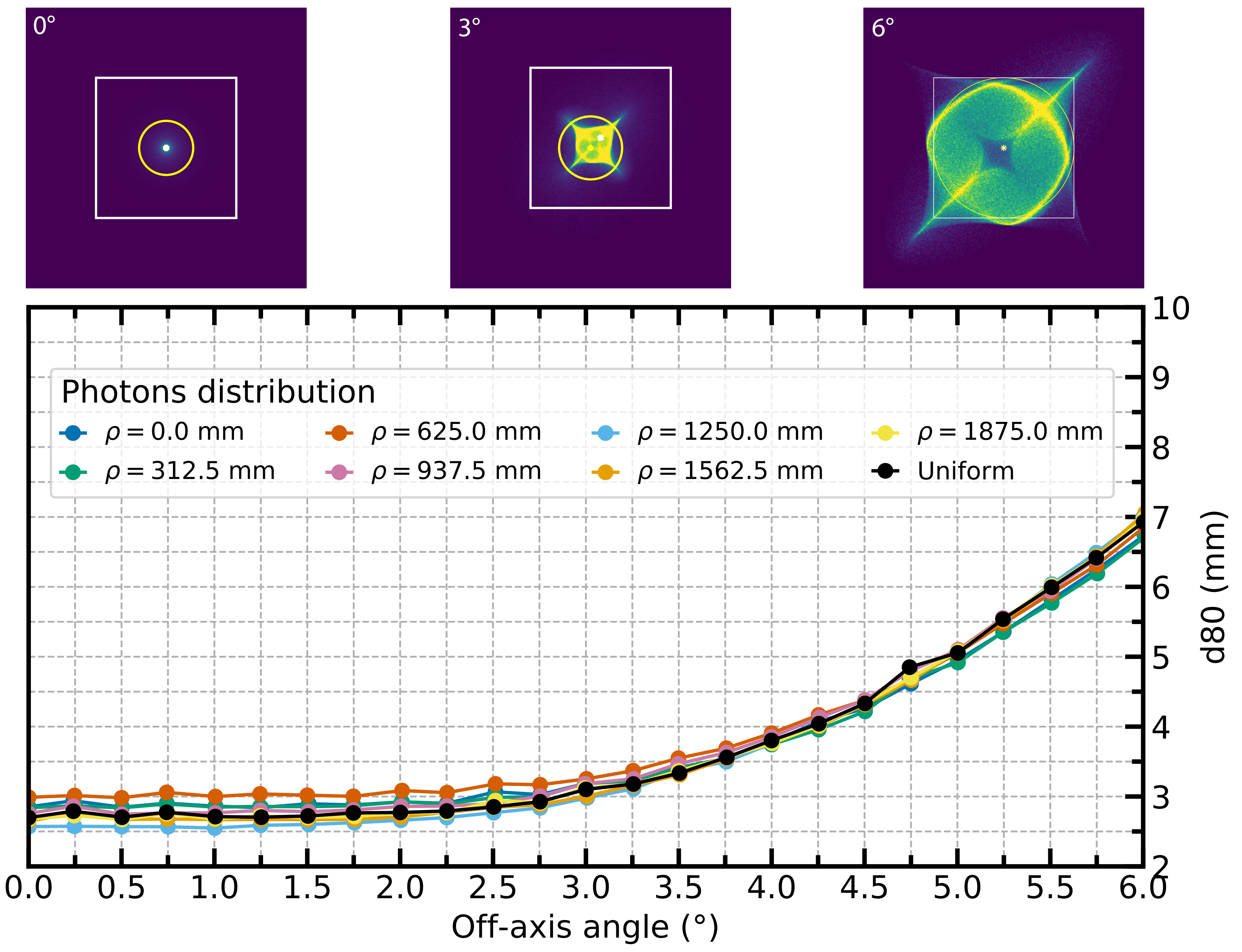


Fig. 4: **Above)** Optical system spot diagram at 0°, 3° and 6° off-axis angle. The white box is 7 mm×7 mm. **Below)** 80 % encircled photons diameter (d80) as a function of off-axis angle and with different photons distributions on the aperture: uniform and induced by muons with different ρ. Simulations have been performed with a dedicated GEANT4 simulator.

Electronics

An innovative fast front-end electronics will be used for the SiPMs readout. The Application-Specific Integrated Circuit (ASIC) designed, the RADIOROC (RADIOgraphy Read Out Chip)[7], is an improvement of an existing ASIC, used in the ASTRI-Horn project. RADIOROC is capable to operate SiPMs both in charge integration and in single photon counting (150 MHz). The latter is essential for acquire the brief muon signal minimizing the night sky background.

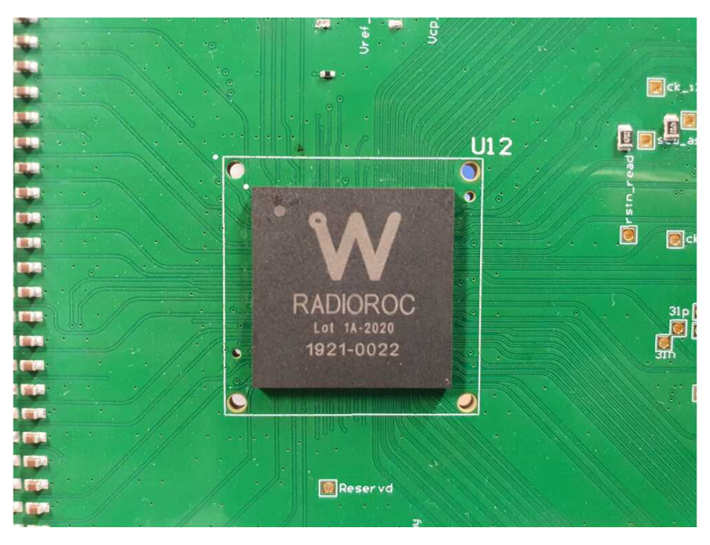


Fig. 5: RADIOROC

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 minimizing optical background signals. An international patent has been registered (PCT/IB2016/056937).

References

[1] J. Peña Rodríguez, H. Asorey, and L. Alberto Núñez. "Characterization of the muography background using the Muon Telescope (MuTe)". In: *40th International Conference on High Energy Physics*. Apr. 2021, p. 984.

[2] O. Catalano et al. "Volcanoes muon imaging using Cherenkov telescopes". In: *Nuclear Instruments & Methods in Physics Research Section A* 807 (2016), pp. 5–12.

[3] M. Del Santo et al. "Looking inside volcanoes with the Imaging Atmospheric Cherenkov Telescopes". In: *Nuclear Instruments and Methods in Physics Research Section A* 876 (Dec. 2017), pp. 111–114.

[4] D. Mollica et al. "Cherenkov muography for studying the internal structure of volcanoes". In: *AGU Fall Meeting Abstracts*. Dec. 2018.

[5] *The* ASTRI *telescope*. `http://www.ifc.inaf.it/index.php/projects/the-astri-telescopes/`.

[6] H. J. Völk and K. Bernlöhr. "Imaging very high energy gamma-ray telescopes". In: *Experimental Astronomy* 25.1-3 (Aug. 2009).

[7] G. Contino et al. "An ASIC front-end for fluorescence and Cherenkov light detection with SiPM for space and ground applications". In: *Nuclear Instruments and Methods in Physics Research Section A* 980 (2020).