CTA 報告 48: ROOT ベースの光線追跡シミュレータの開発とその応用

奥村 曉

名古屋大学 太陽地球環境研究所

他 The CTA Consortium

2012 年 9 月13 日

日本物理学会 2012 年秋季大会 @ 京都産業大学

A. Okumura *et al*. (2011) ICRC 2011
A. Okumura (2012) *Astropart. Phys.*

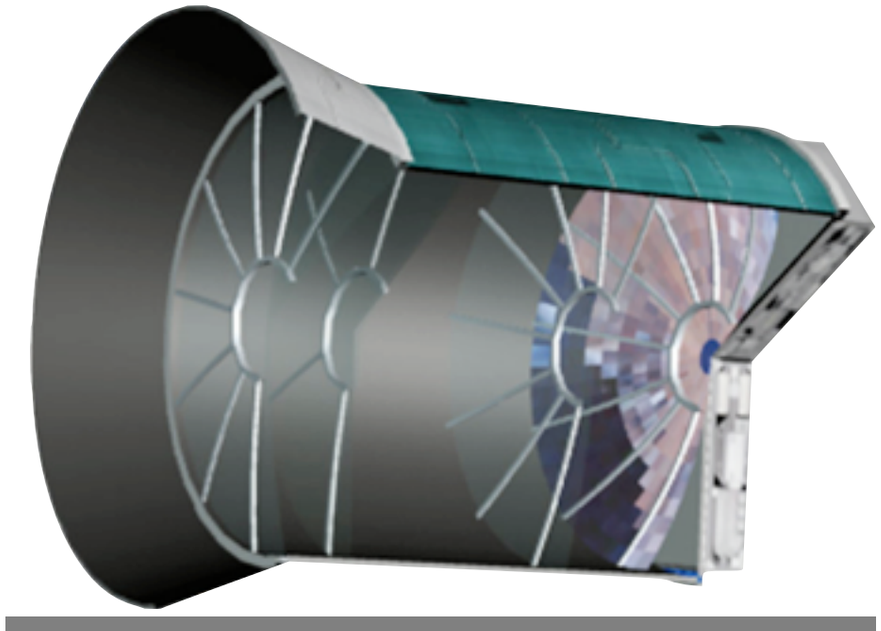
“Optical” Cosmic-ray Telescopes

H.E.S.S. II
http://pic.twitter.com/XQDY6d26

MAGIC
http://magic.mppmu.mpg.de

STACEE
http://www.astro.ucla.edu/~stacee/

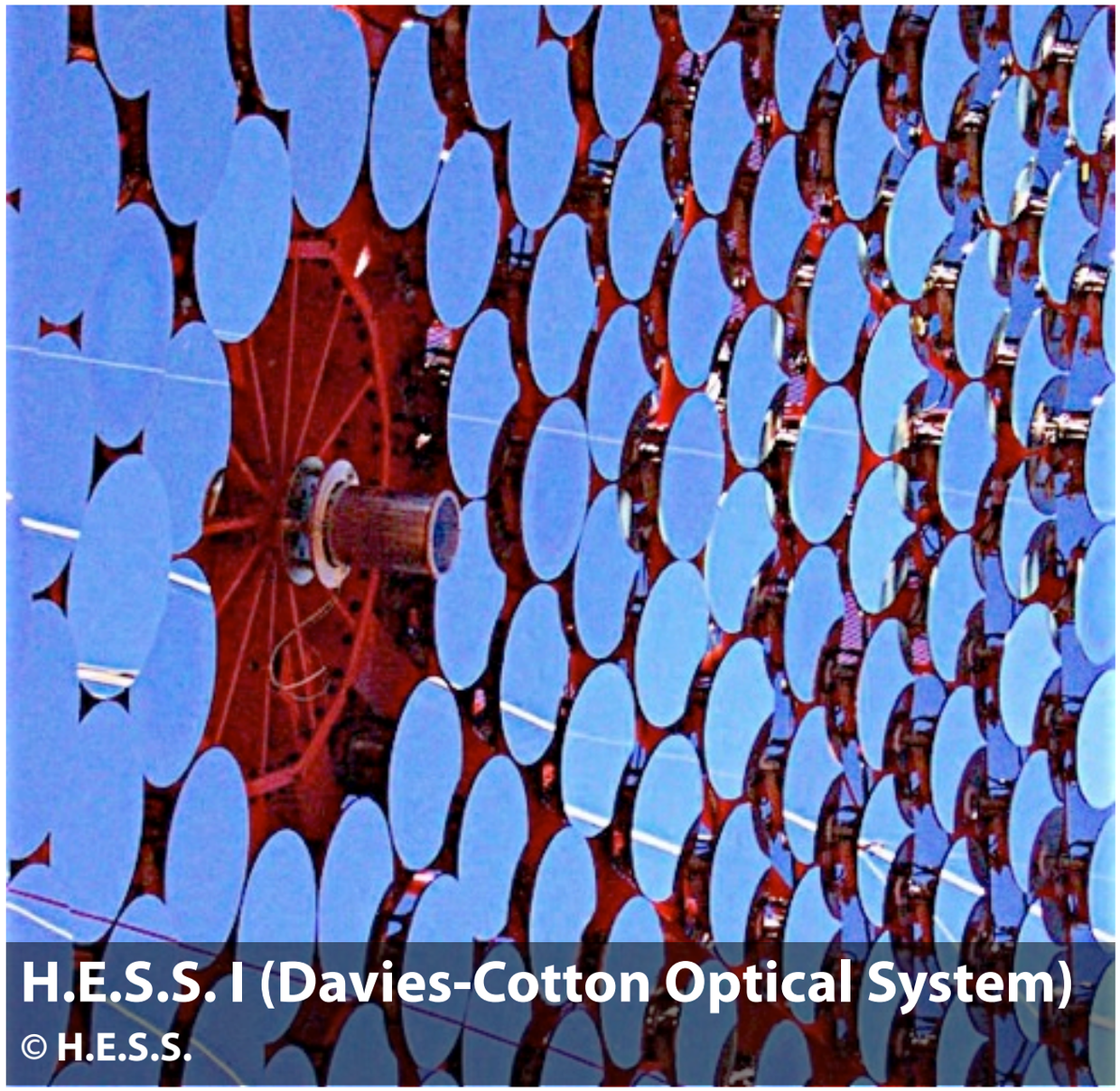
Pierre Auger Observatory
http://www.auger.org



JEM EUSO
http://jemeuso.riken.jp

Ashra
Final Optics Design by A. O.

Segmented Mirrors with Complex Configurations



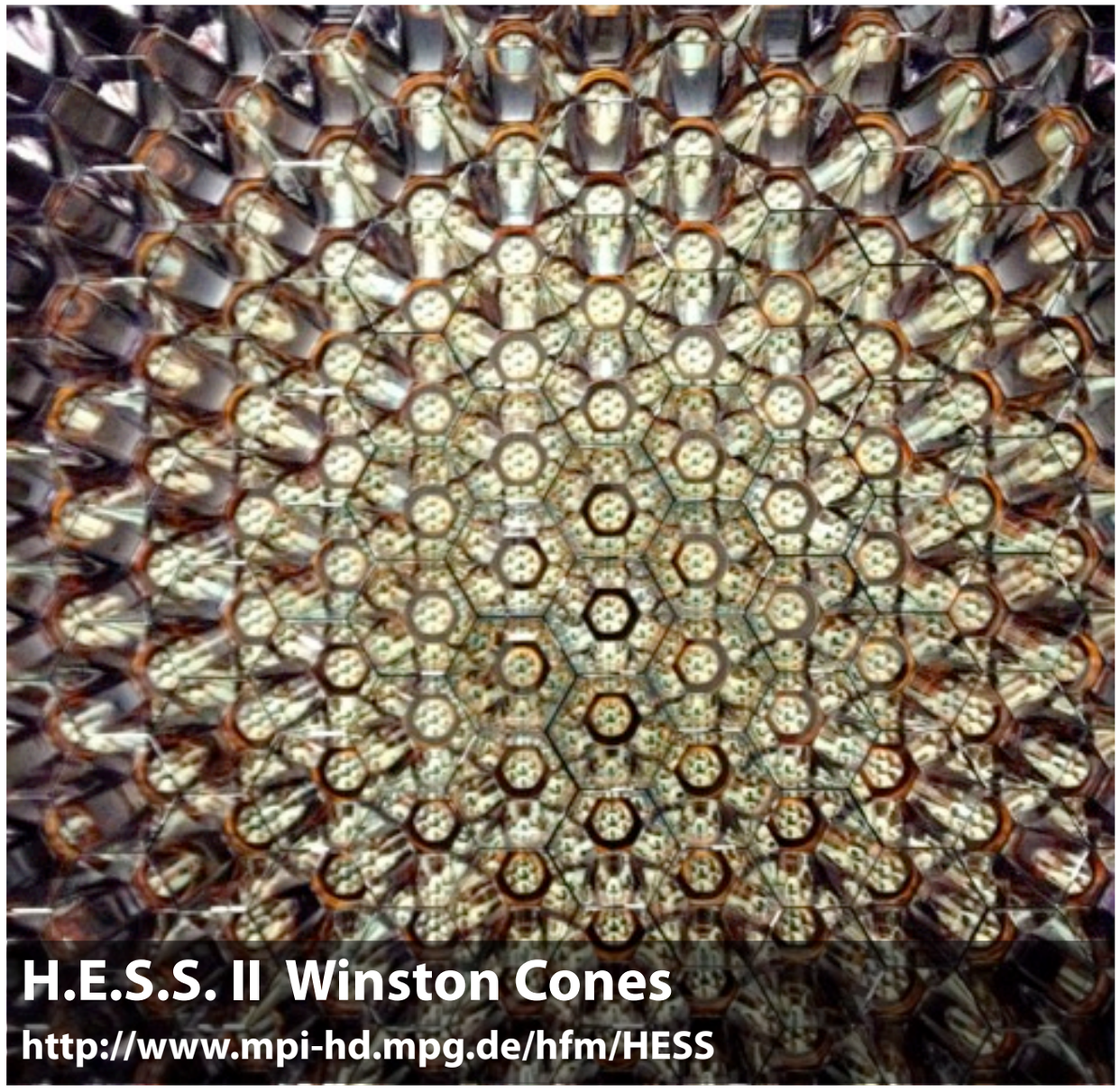
H.E.S.S. I (Davies-Cotton Optical System)
© H.E.S.S.

STACEE (Heliostats)
http://www.astro.ucla.edu/~stacee/

- Need a large and complex optical system with segmented mirrors
- Building the geometry and tracking photons in “non-sequential” mode are not easy
- Existing programs’ functions are not adequate

Pixelated Focal Planes and Light Collectors

H.E.S.S. II Camera
http://www.mpi-hd.mpg.de/hfm/HESS



H.E.S.S. II Winston Cones
http://www.mpi-hd.mpg.de/hfm/HESS

- The focal plane of a typical cosmic-ray telescope is pixelated with PMTs
- Hexagonal Winston cones and similar ones are used to reduce dead area
- Pixel information and multiple reflection on light collectors are important

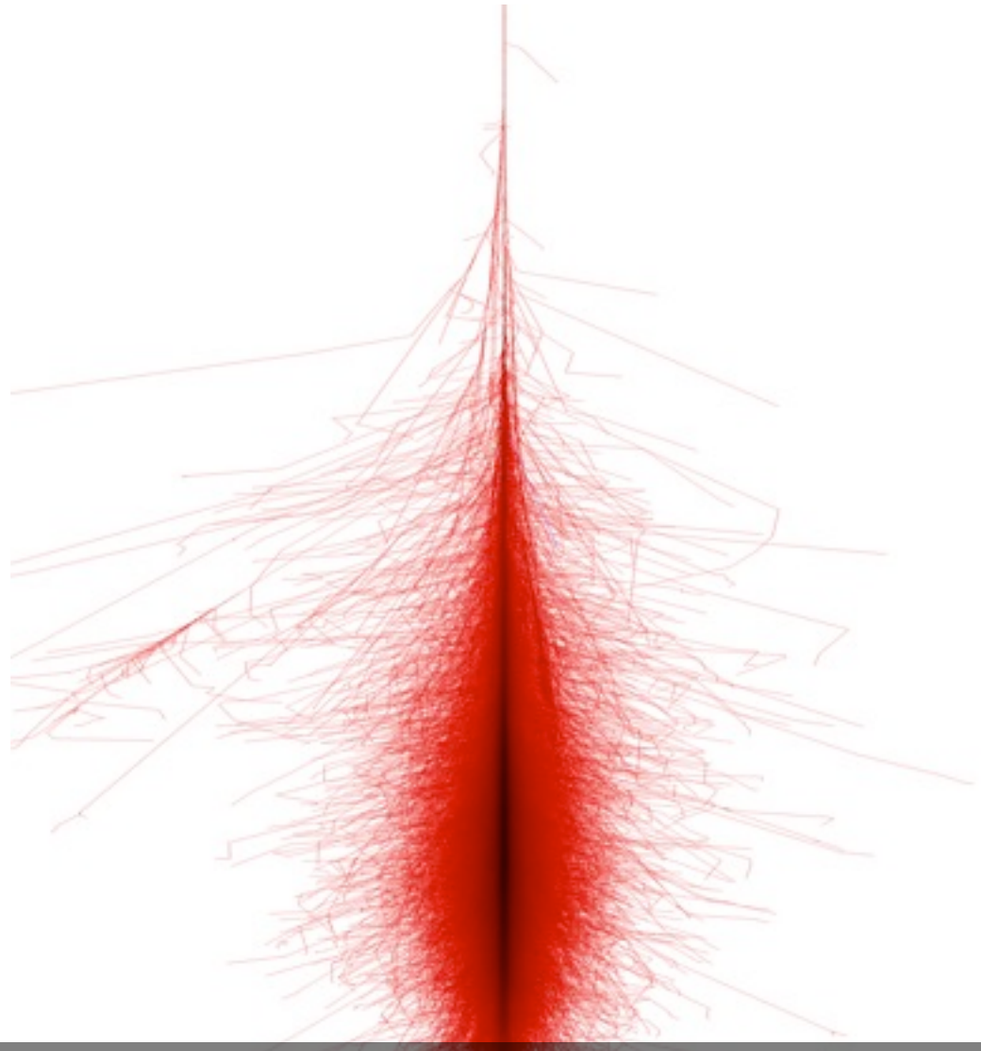
Photon Timing Analysis for Large Dishes

MAGIC (Parabolic 17-m Dish)
http://magic.mppmu.mpg.de

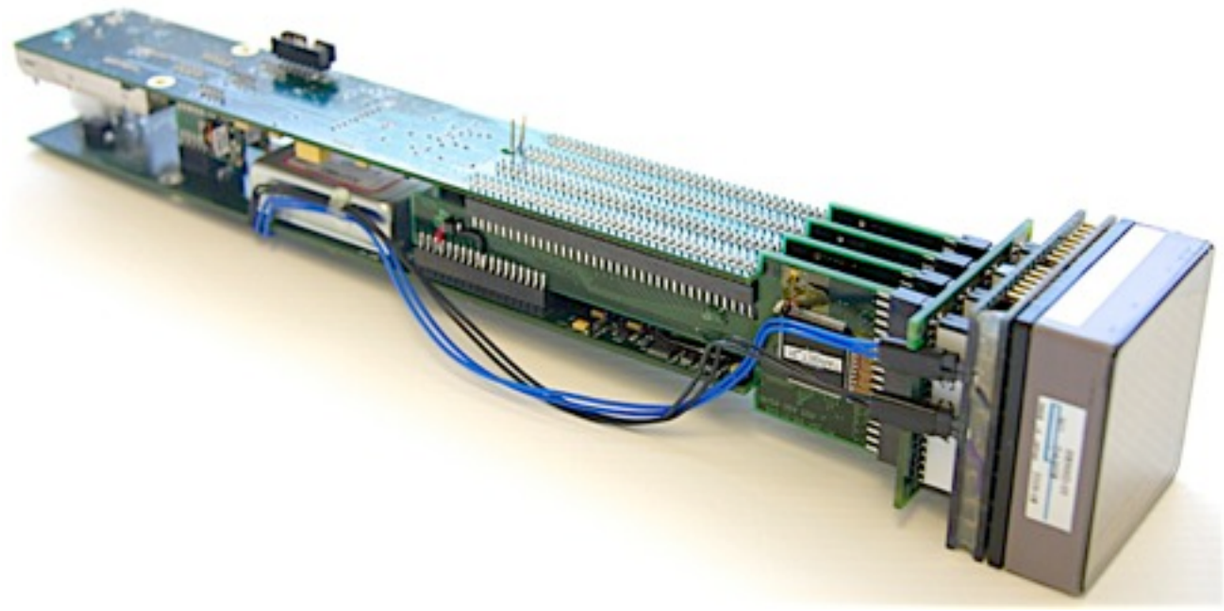
H.E.S.S. II (Parabolic 28-m Dish)
http://www.mpi-hd.mpg.de/hfm/HESS

- Signal timing is important information for gamma-ray detection
- Parabola Cherenkov signal ~5 ns
- Optical path difference of a 10-m Davies Cotton telescope is $\Delta t \sim 5$ ns

Connection to Air-shower and Electronics Simulations



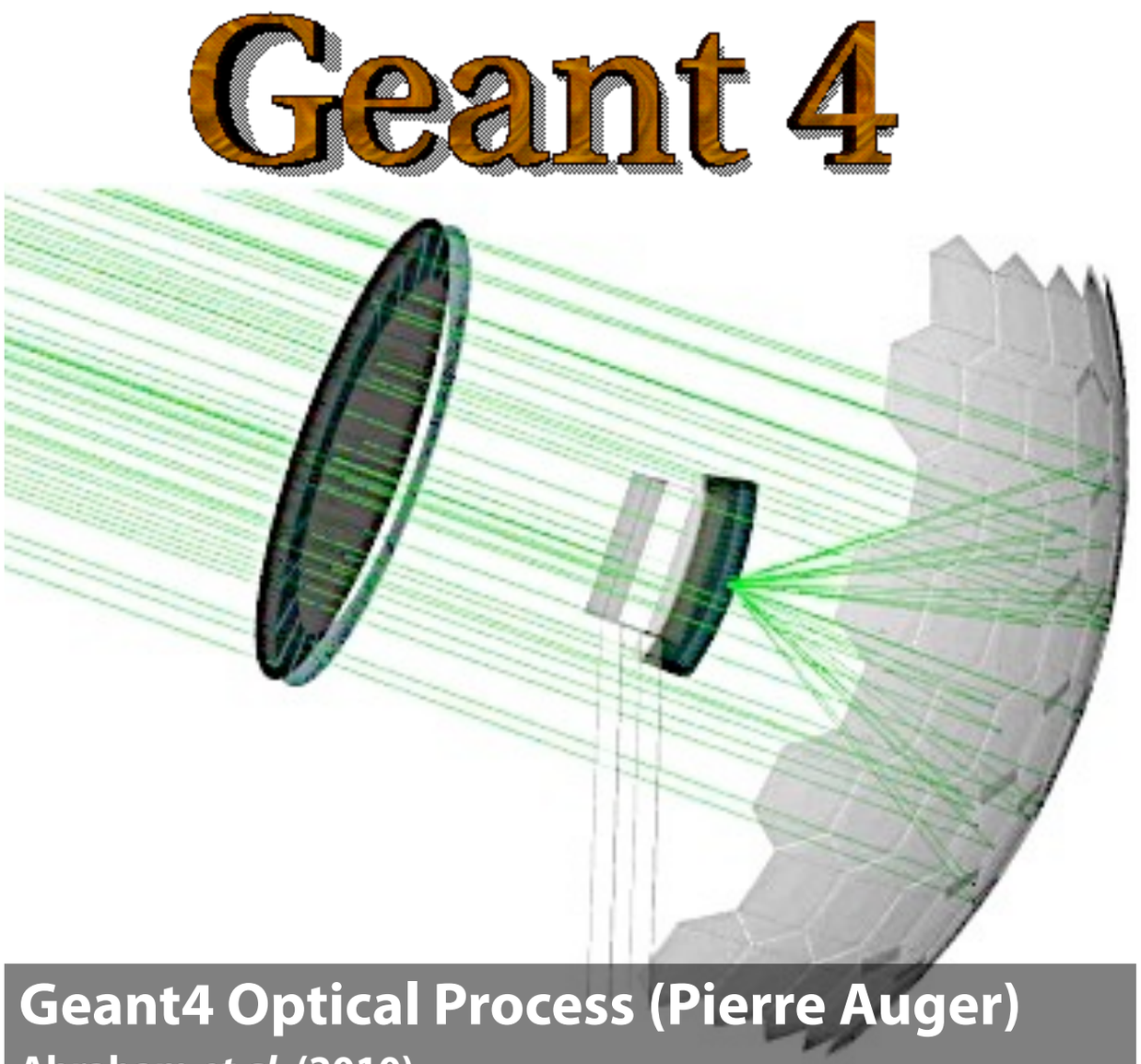
CORSIKA MC (1 TeV Photon)
http://www.ast.leeds.ac.uk/~fs/photon-showers.html



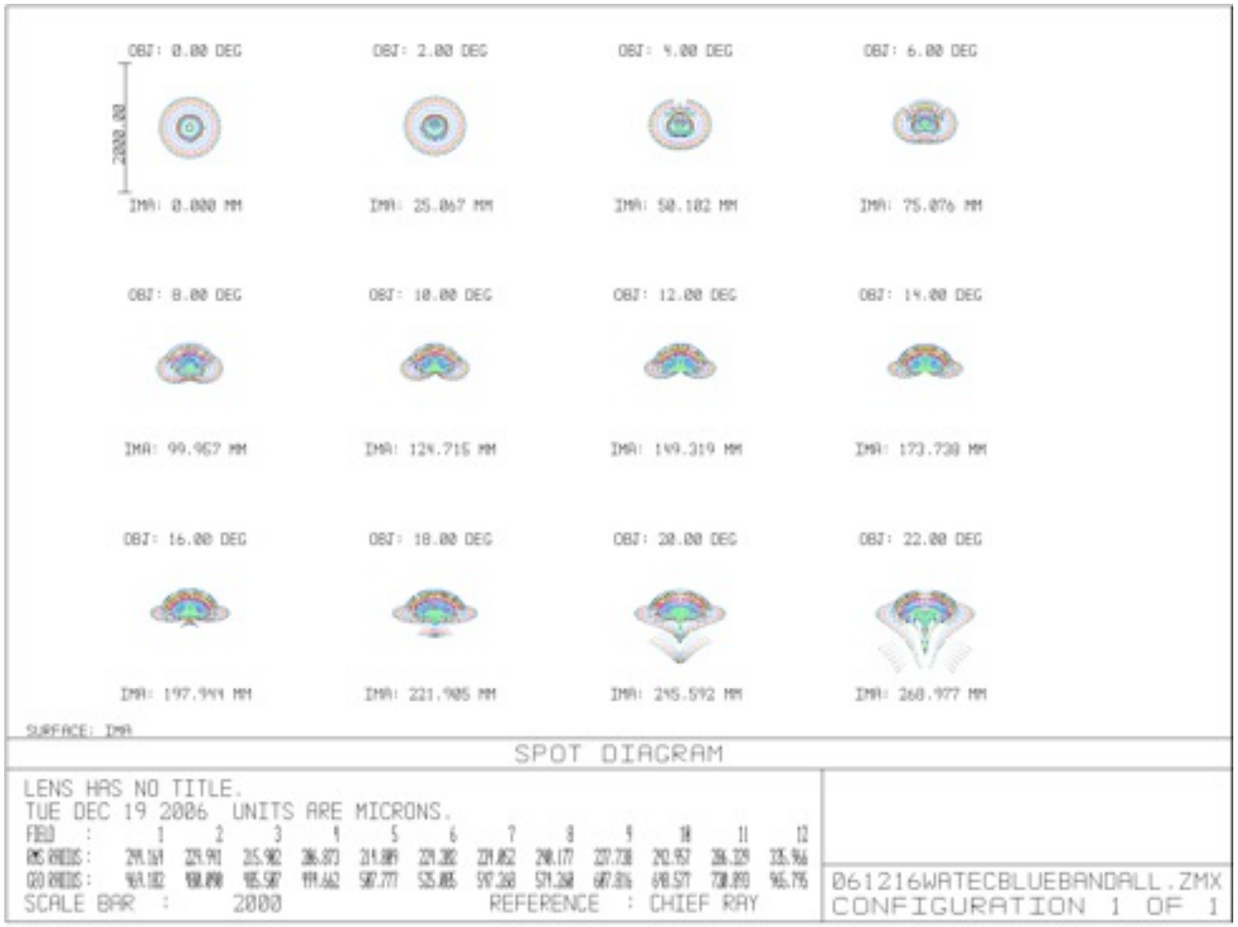
TARGET (ASIC Developed for CTA)
Bechtol *et al*. (2012)

- Used along with an air-shower simulator and an electronics simulator
- No “Windows Only” software allowed (Linux and OS X preferred)
- C++ and Python preferred

Existing Ray-tracing (Particle Tracking) Software



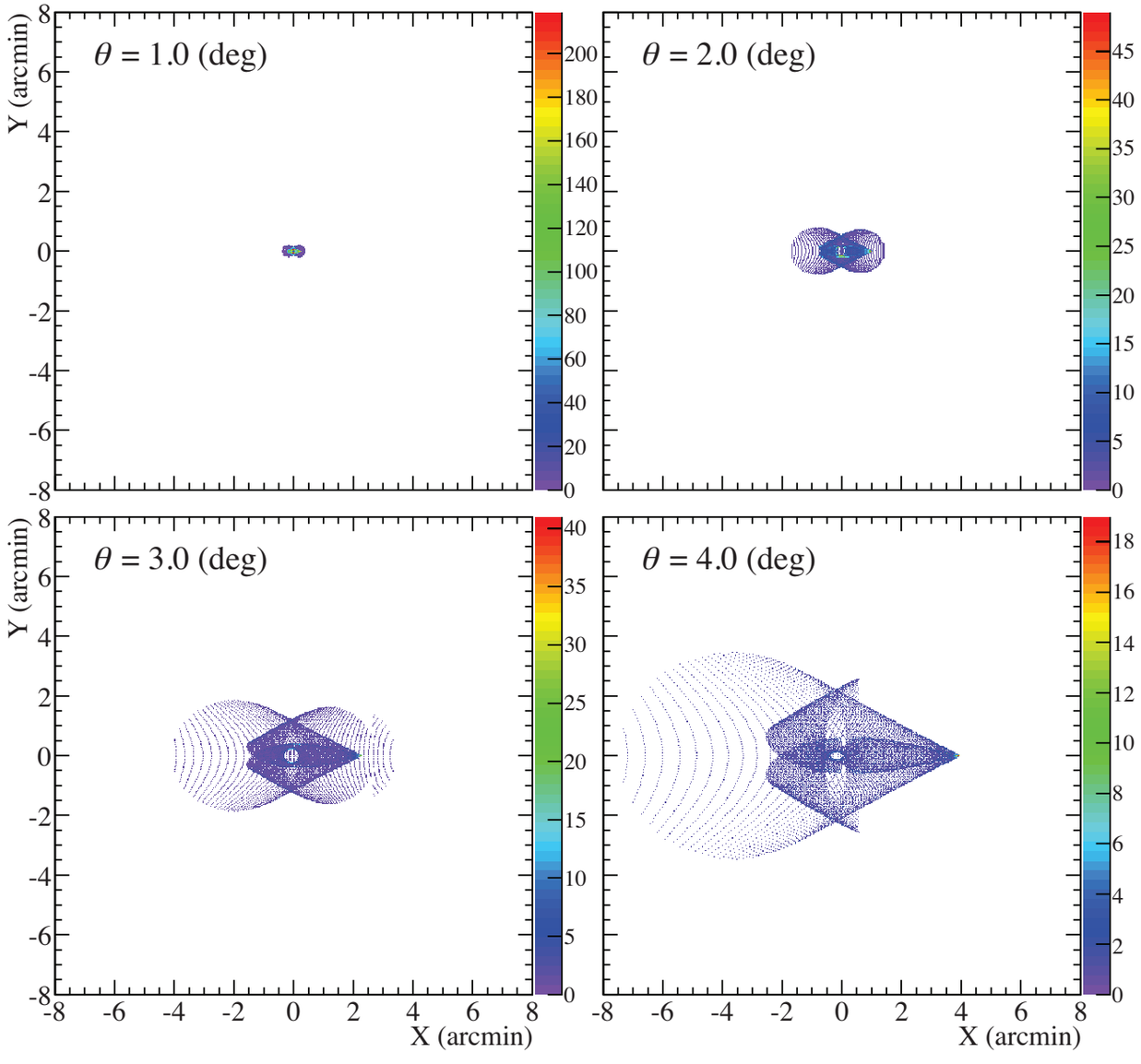
Geant4 Optical Process (Pierre Auger)
Abraham *et al*. (2010)

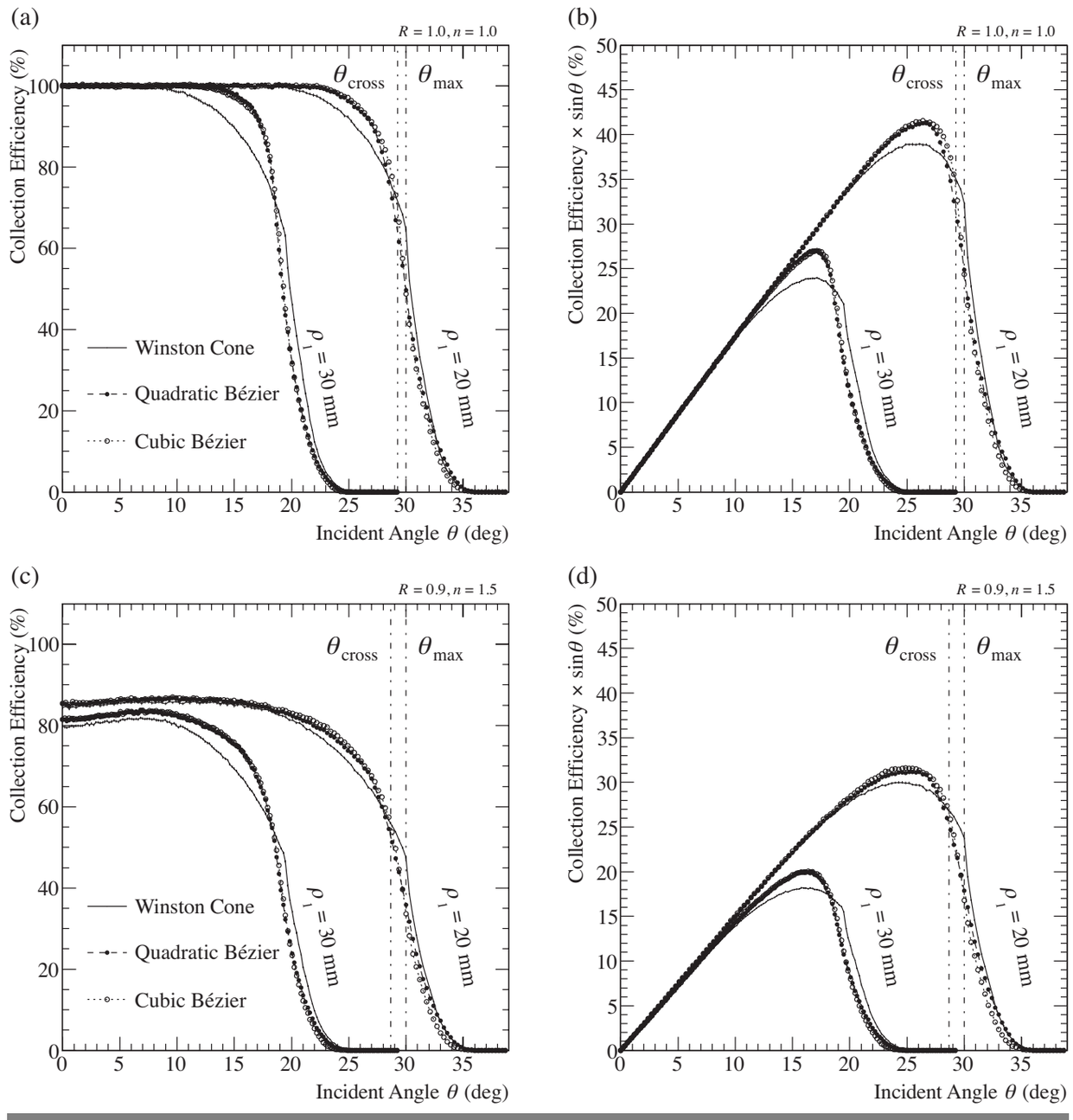


Zemax for Optimization Study (Ashra)
by A. Okumura

- Geant4 is famous and powerful, but can you use it? Very hard for C++ beginners
- Zemax is a standard commercial software with a fast optimization engine, but expensive and Windows only

Analyses with ROOT





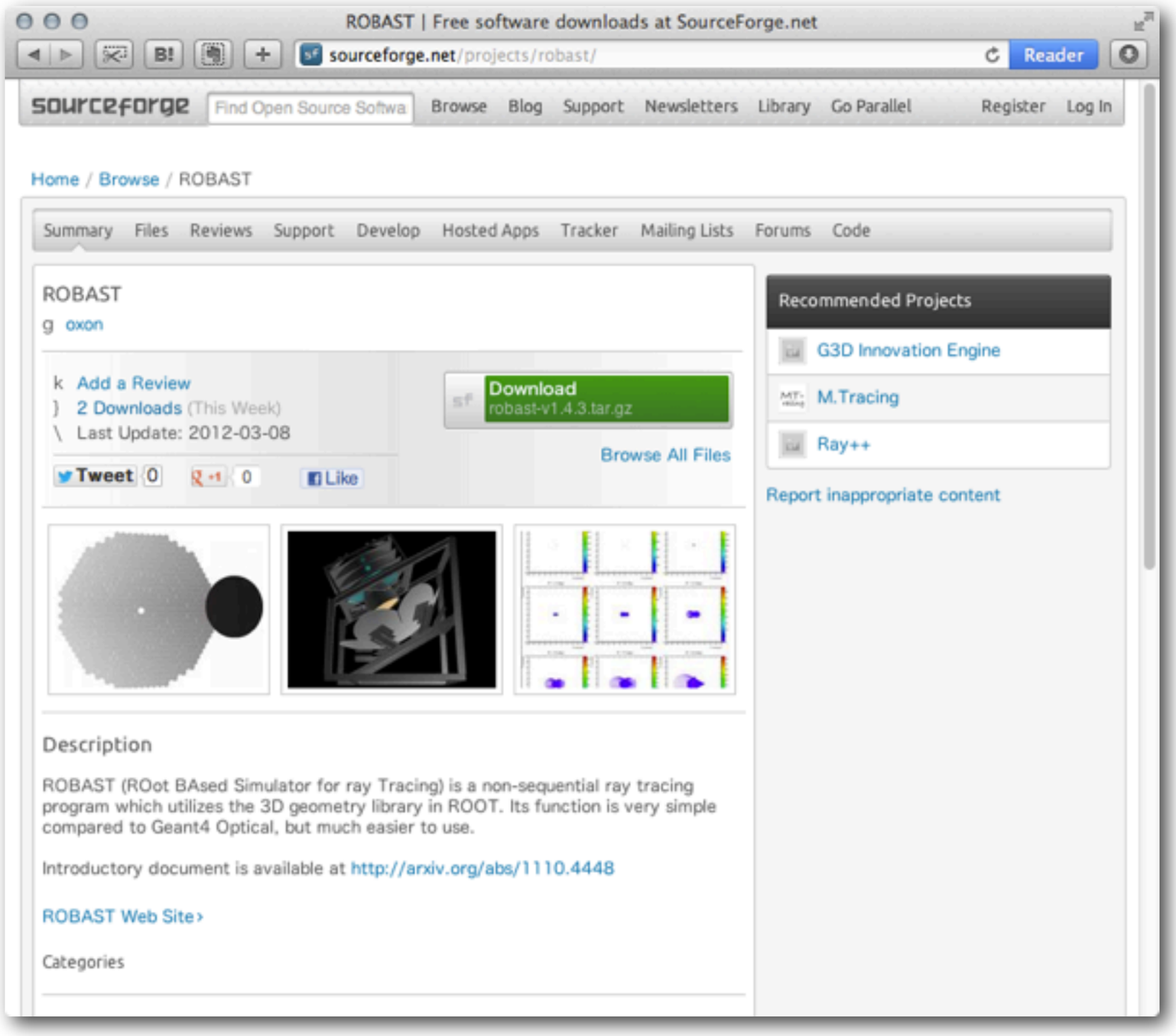
PSF of Schwarzschild-Couder Telescope

A. Okumura *et al*. (2011) ICRC

Collection Efficiencies of Light Collectors

A. Okumura (2012) arXiv:1205.3968

ROot-BAsed Simulator for ray Tracing (ROBAST)



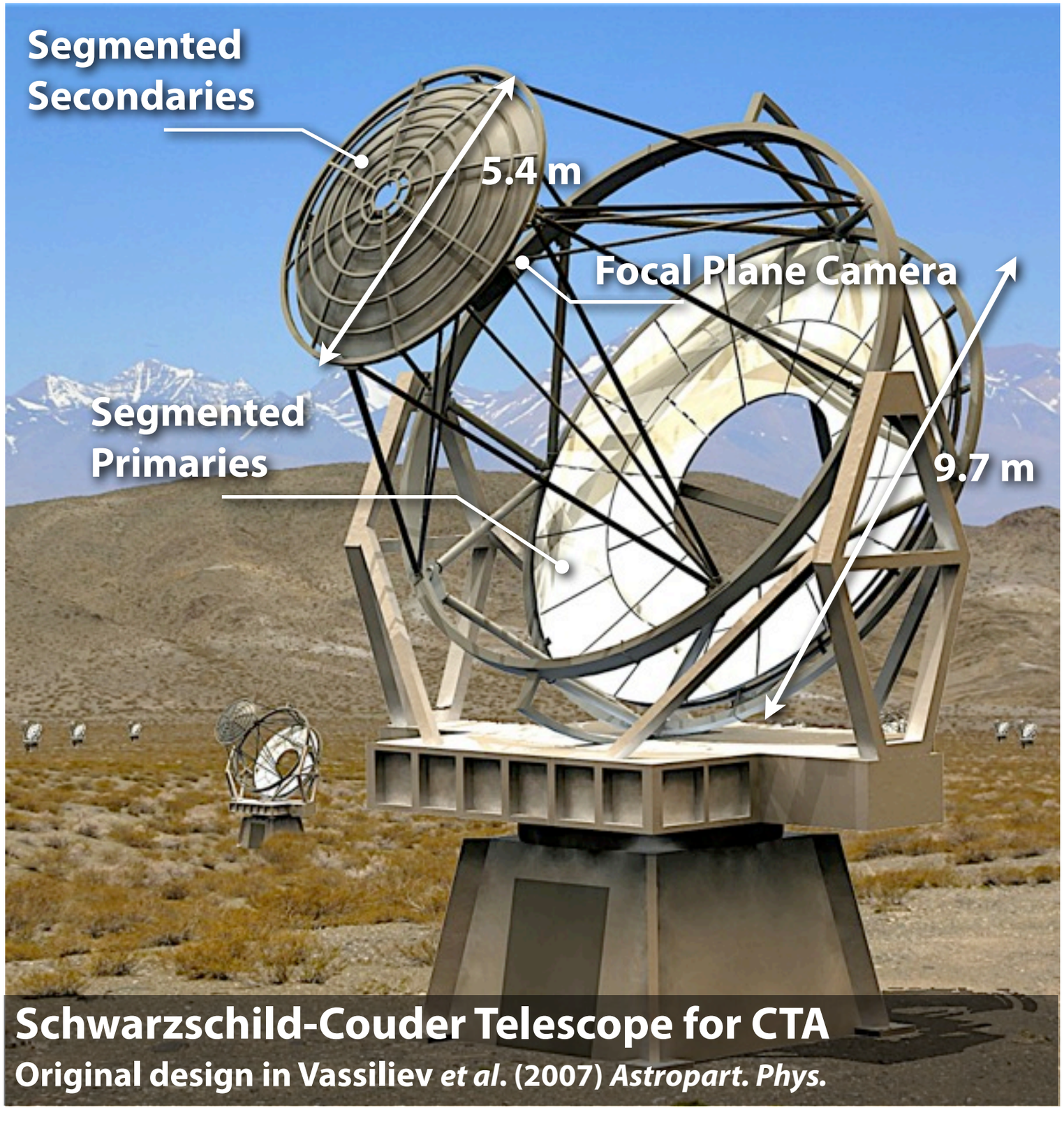
- ROOT geometry library for particle tracking and complicated geometry construction
- Open source software
- http://sourceforge.net/projects/robast/
- Runs in C++/CINT/Python

A. Okumura *et al.* (2011) ICRC 2011

The First Application (The Ashra Optical System)

- A good example to show how complex geometries can be built with ROOT
- Lens parameters were optimized with Zemax
- Realistic effective area of the optical system can be estimated by considering shadows
- Study on alignment of non-ideal segmented mirrors

CTA Application 1: Schwarzschild-Couder (SC) Optical System

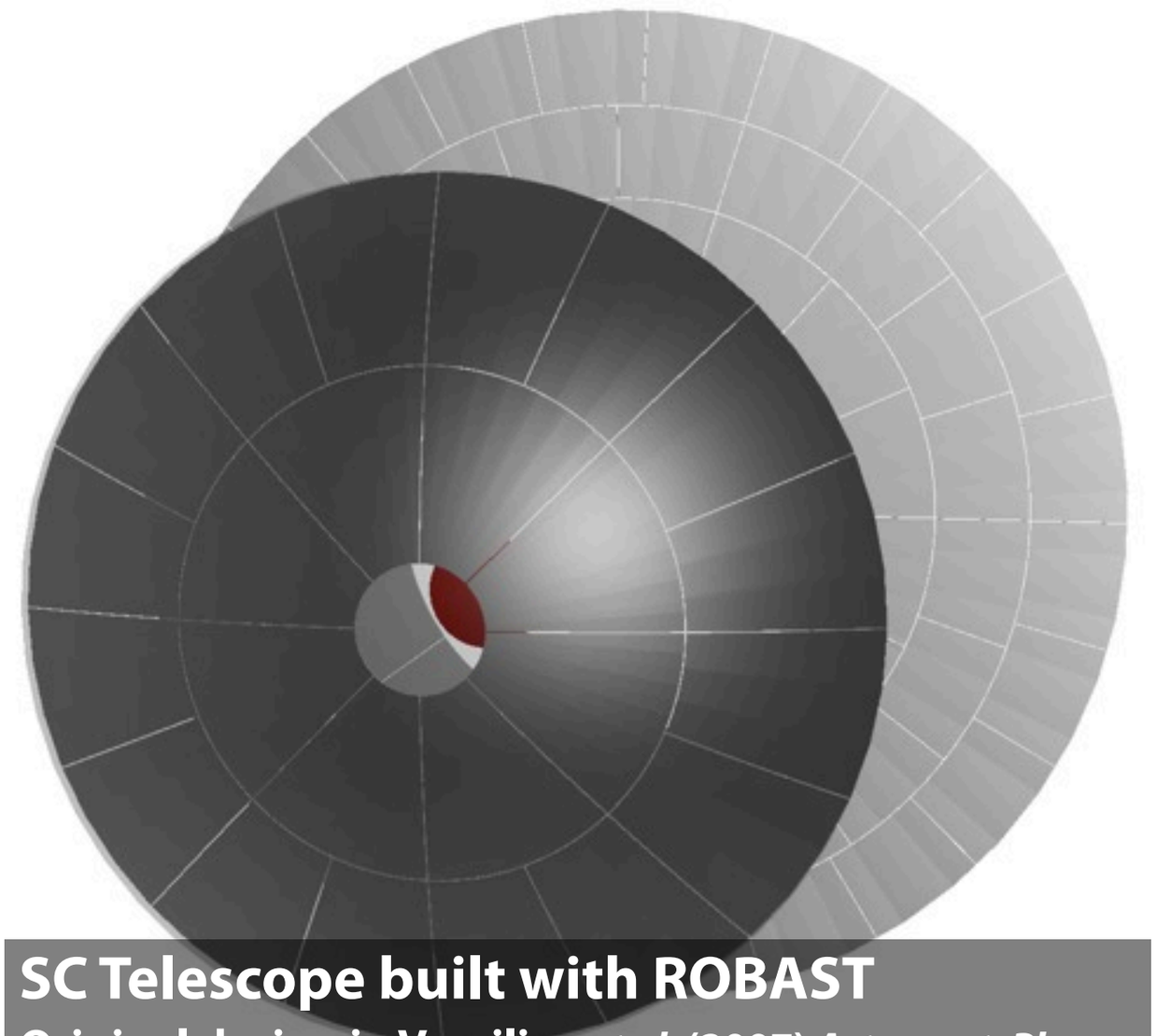


Schwarzschild-Couder Telescope for CTA

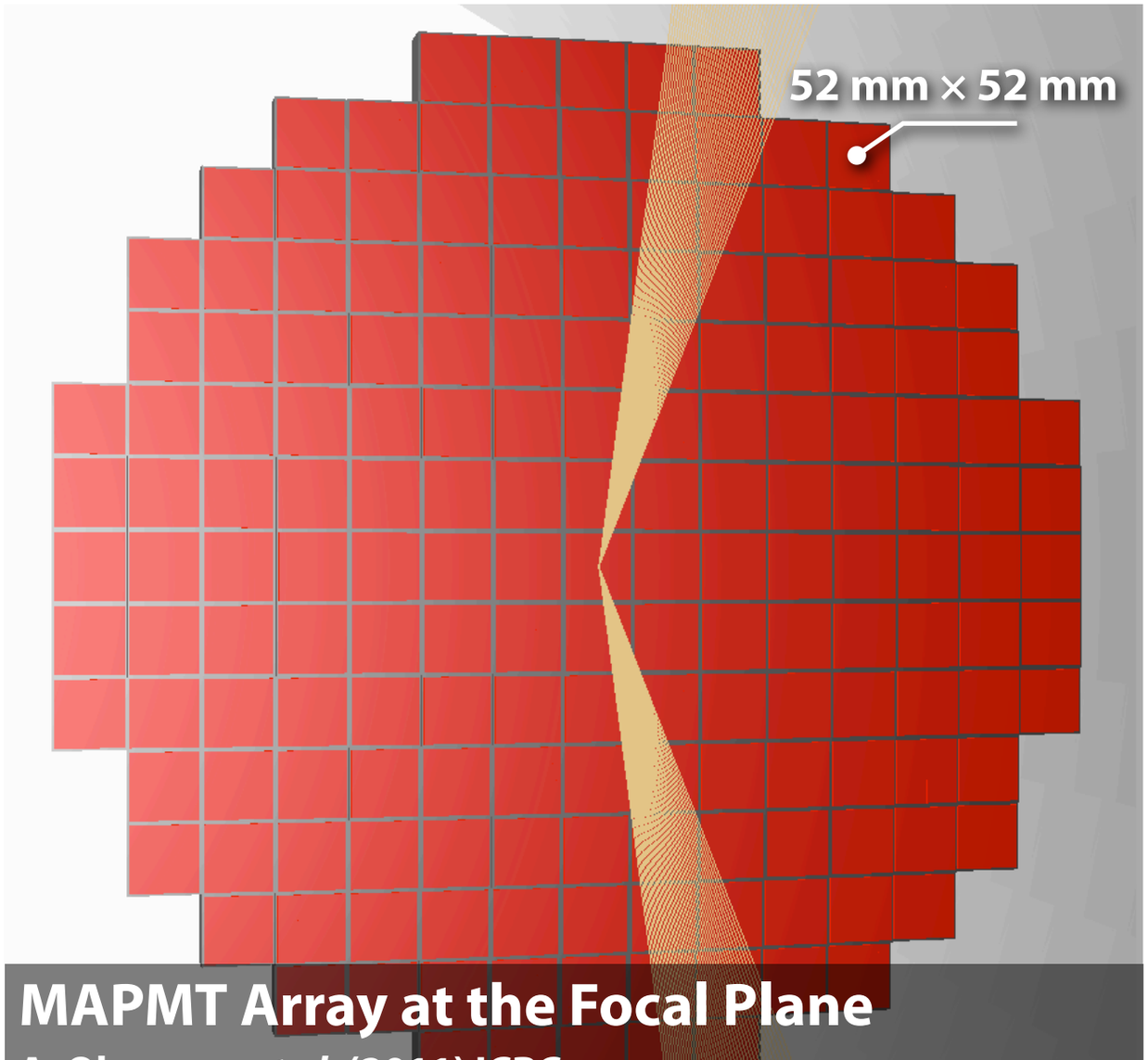
Original design in Vassiliev *et al*. (2007) *Astropart. Phys.*

- The first dual-mirror design in VHE
- Proposed by CTA US and Europe groups
- Aspherical segmented mirrors for primaries and secondaries
- Multi-anode PMT (MAPMT) or multi-pixel photo counter (MPPC) array

CTA Application 1: Schwarzschild-Couder Optical System



SC Telescope built with ROBAST
Original design in Vassiliev *et al*. (2007) *Astropart. Phys.*

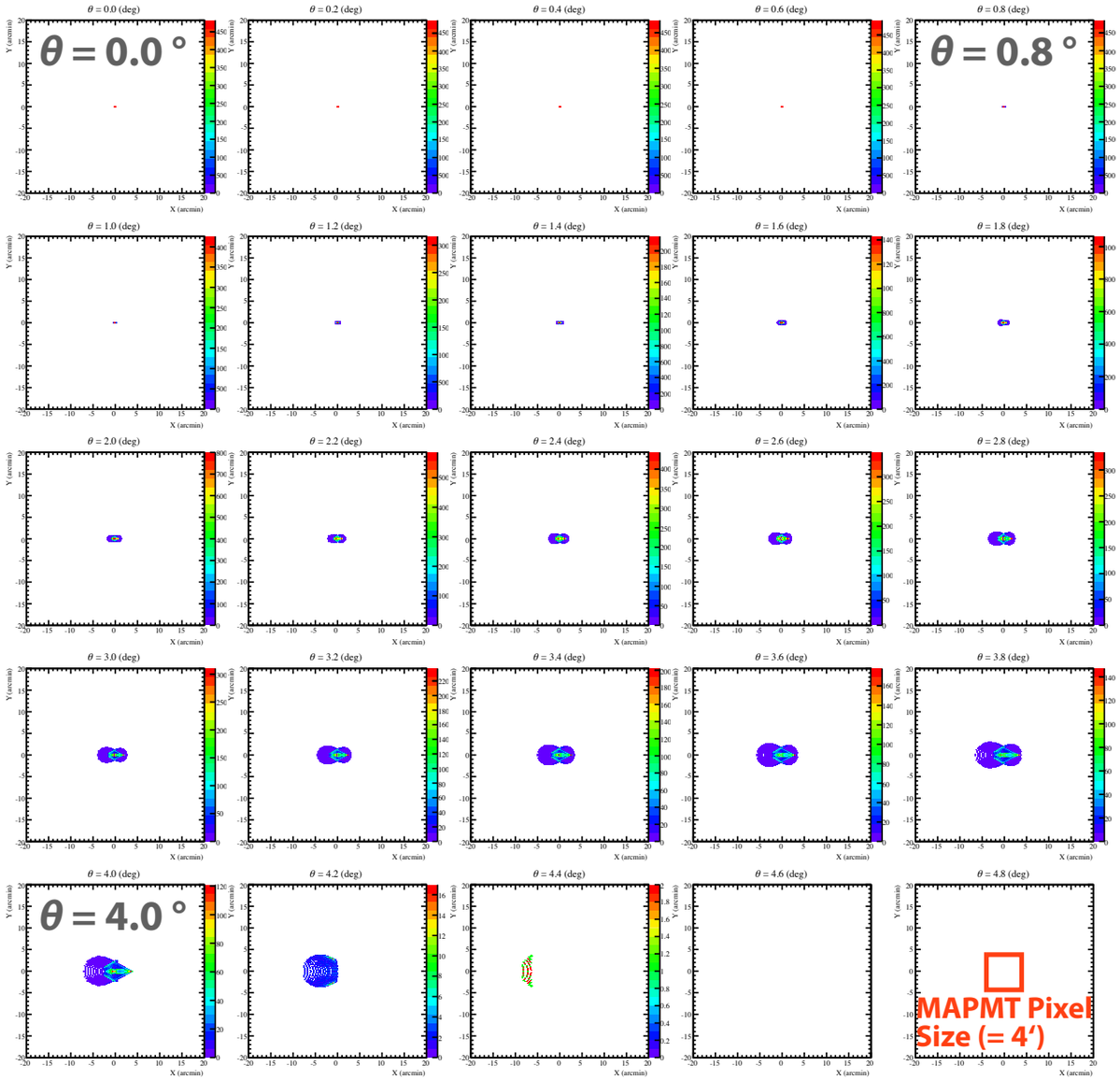


MAPMT Array at the Focal Plane
A. Okumura *et al*. (2011) ICRC

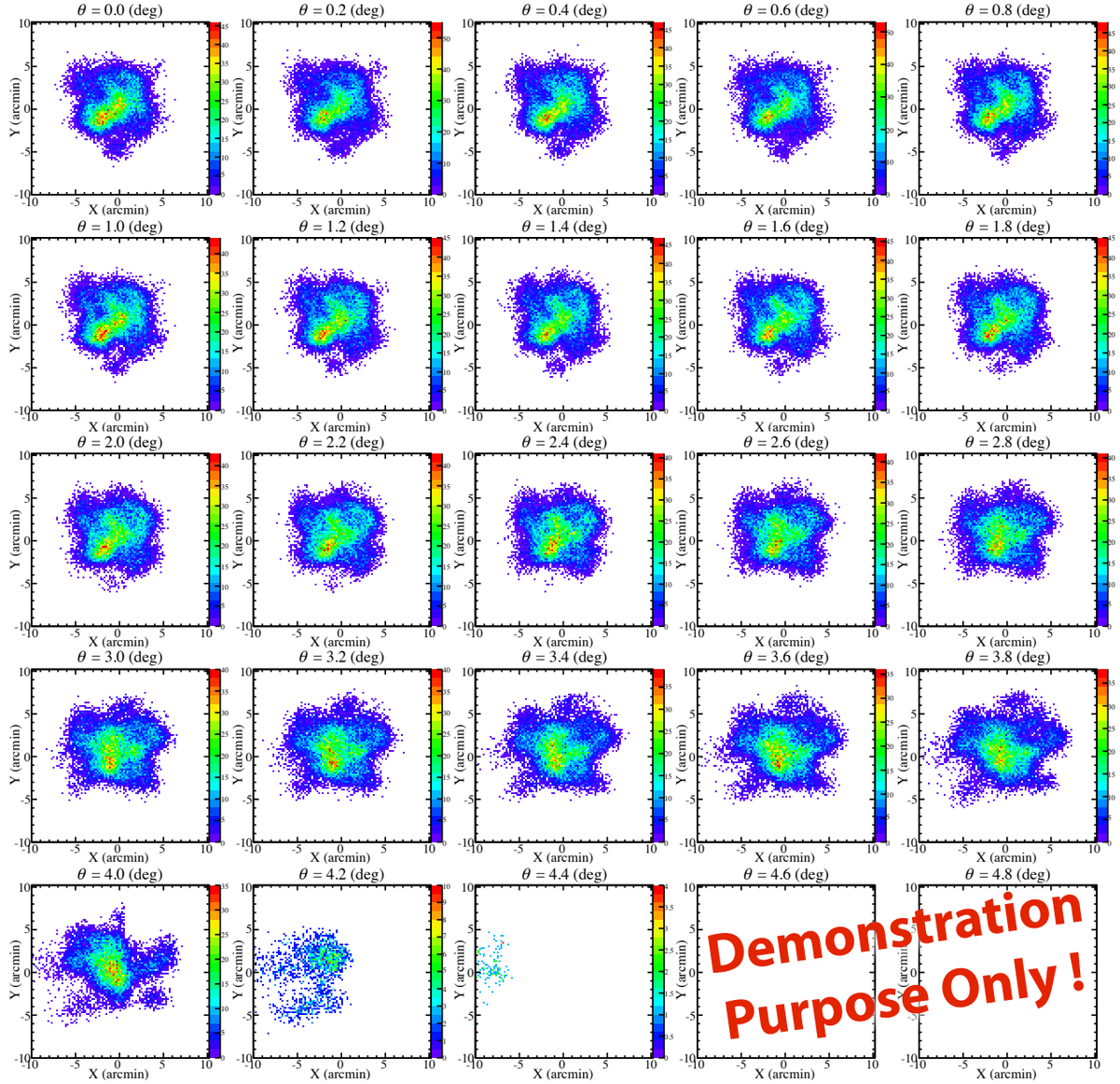
- Easy to build aspherical segmented mirrors and a photodetector array
- The ROBAST library is currently used inside the MC code developed by the CTA-US group

CTA Application 1: Schwarzschild-Couder Optical System

Ideal Mirrors and Alignments

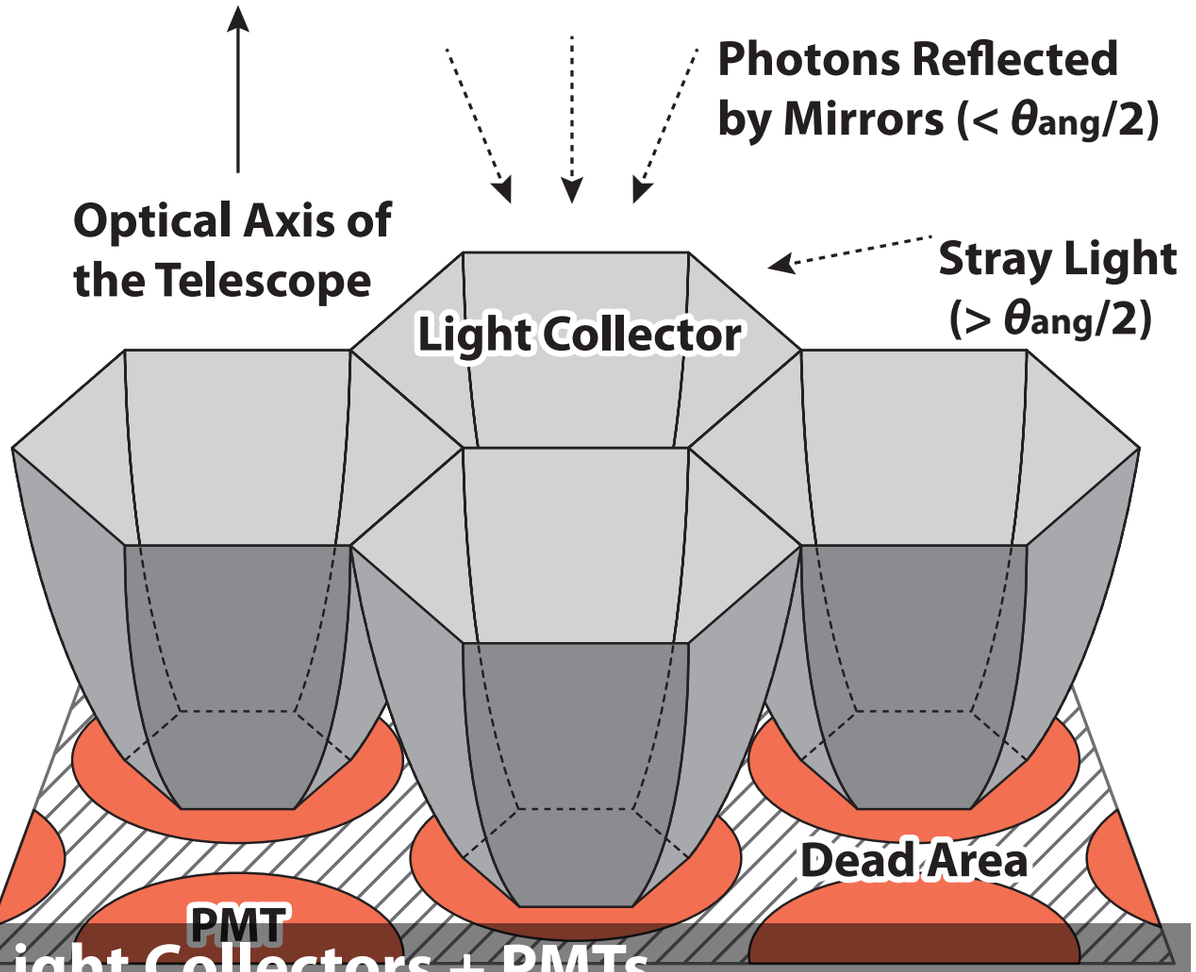


Rough Mirrors + Misalignments



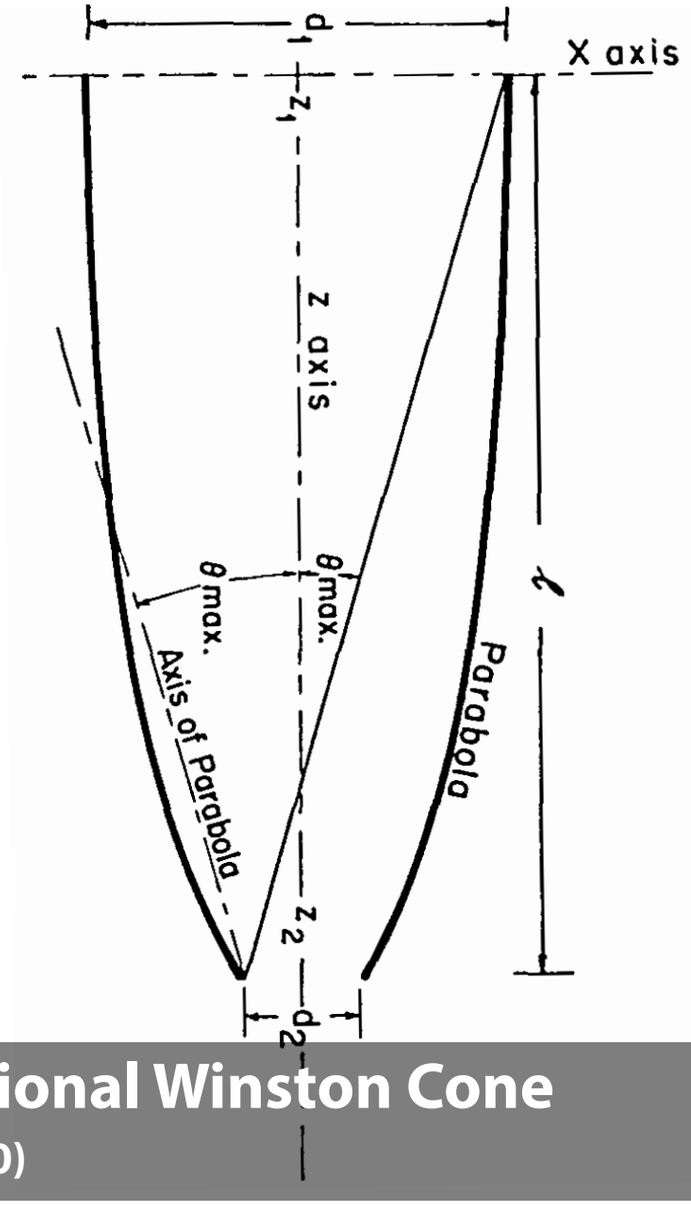
- Translation and rotation matrices in the ROOT geometry library are useful to evaluate the PSF worsening from mirror misalignments
- Studies on tolerance analysis and mirror alignment are on going

CTA Application 2: Hexagonal Light Collector



Light Collectors + PMTs

A. Okumura (2012) *Astropart. Phys.*

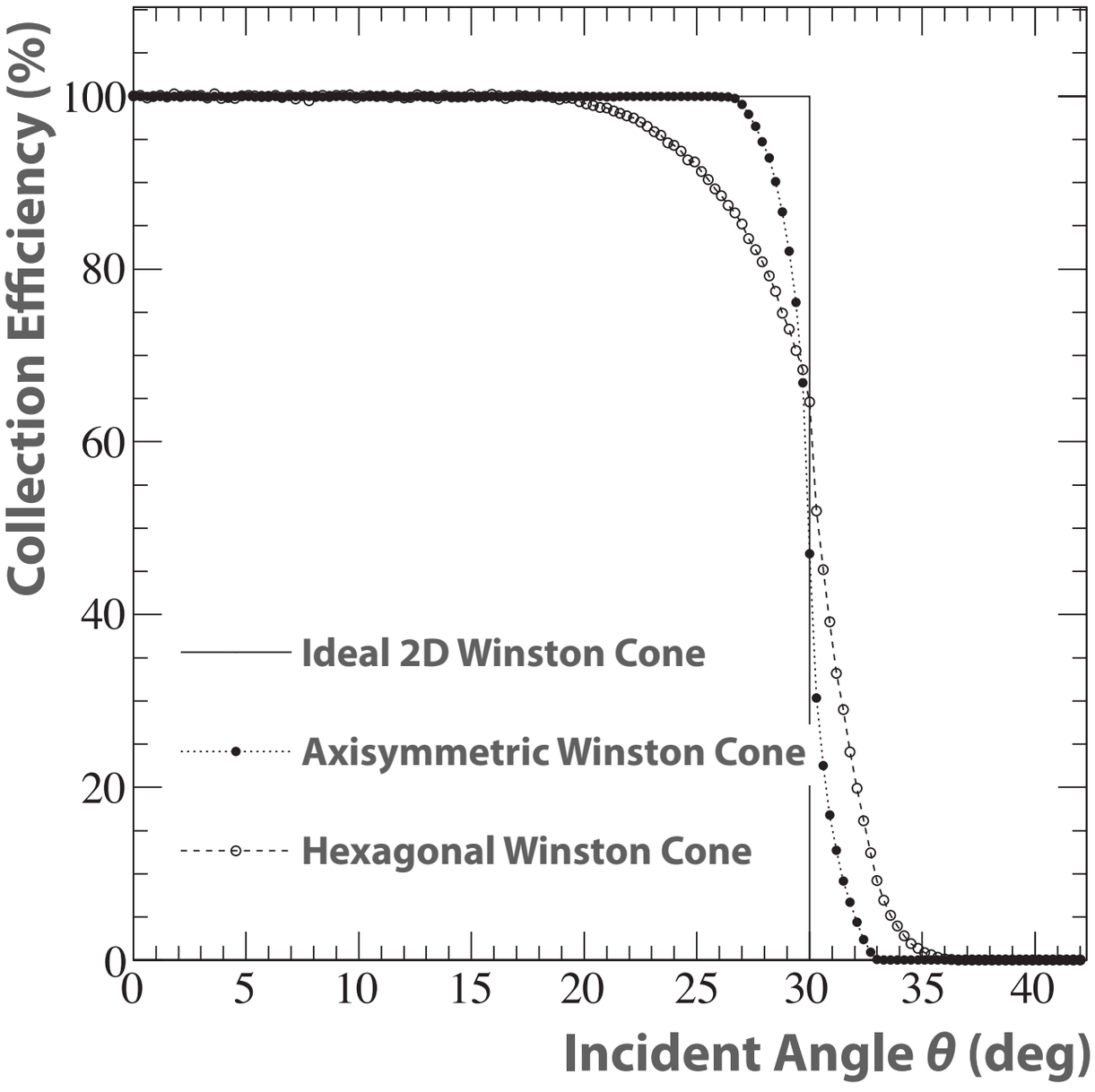


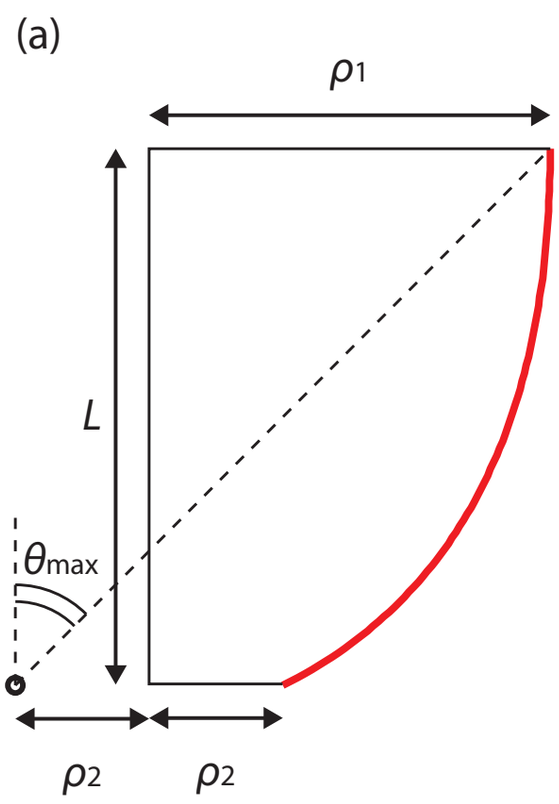
2-dimensional Winston Cone

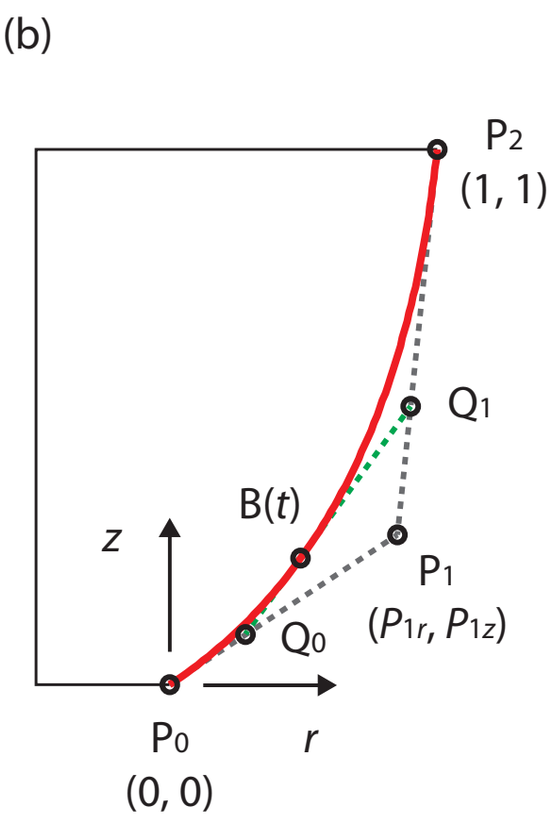
Winston (1970)

- Hexagonal light collectors are widely used in Cherenkov telescopes to increase the effective area of the focal plane, and to reduce background stray photons
- The traditional design is based on Winston's idea (so-called Winston Cone)

CTA Application 2: Hexagonal Light Collector



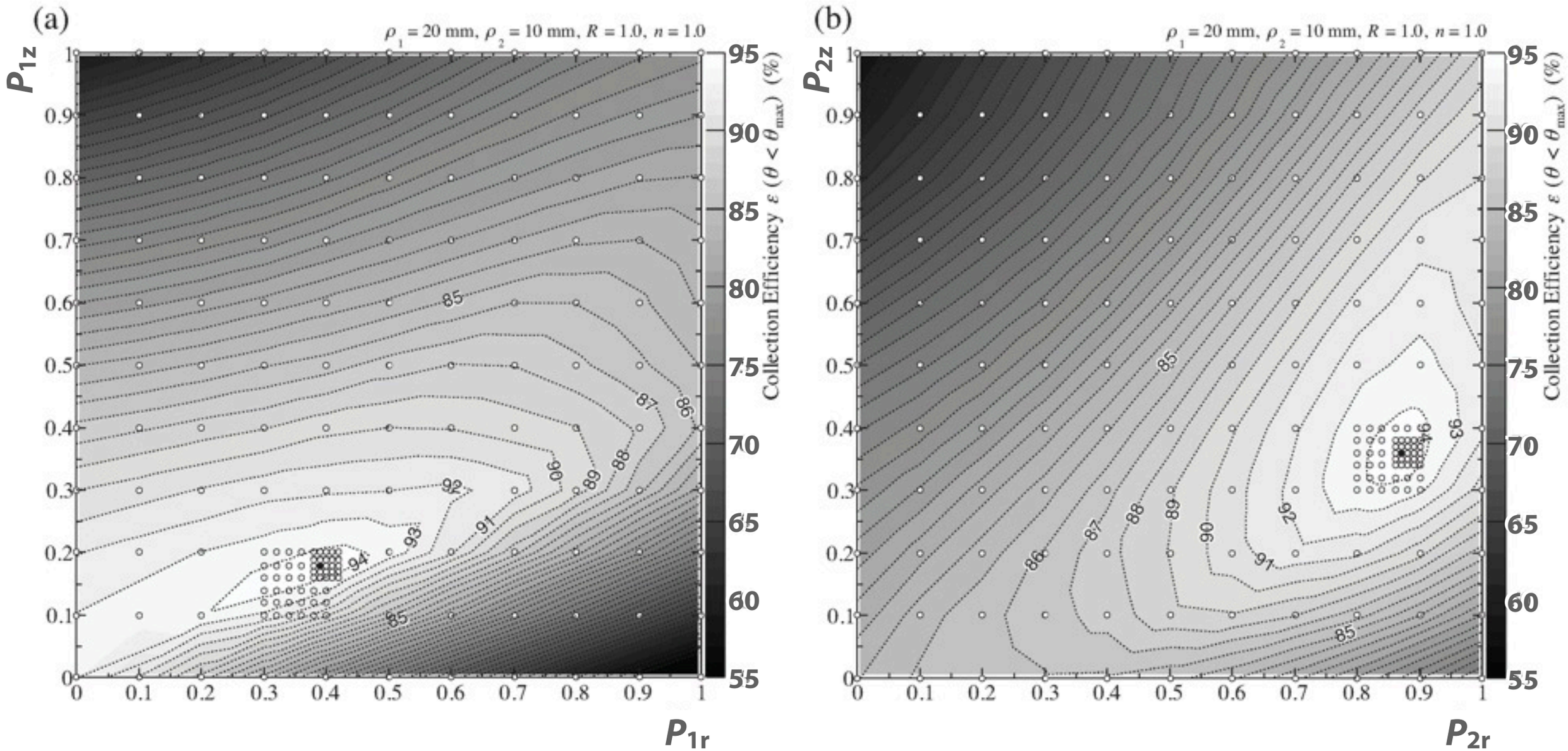




Paraboloid & Bézier Curve (Bézier 1978)
A. Okumura (2012) *Astropart. Phys.*

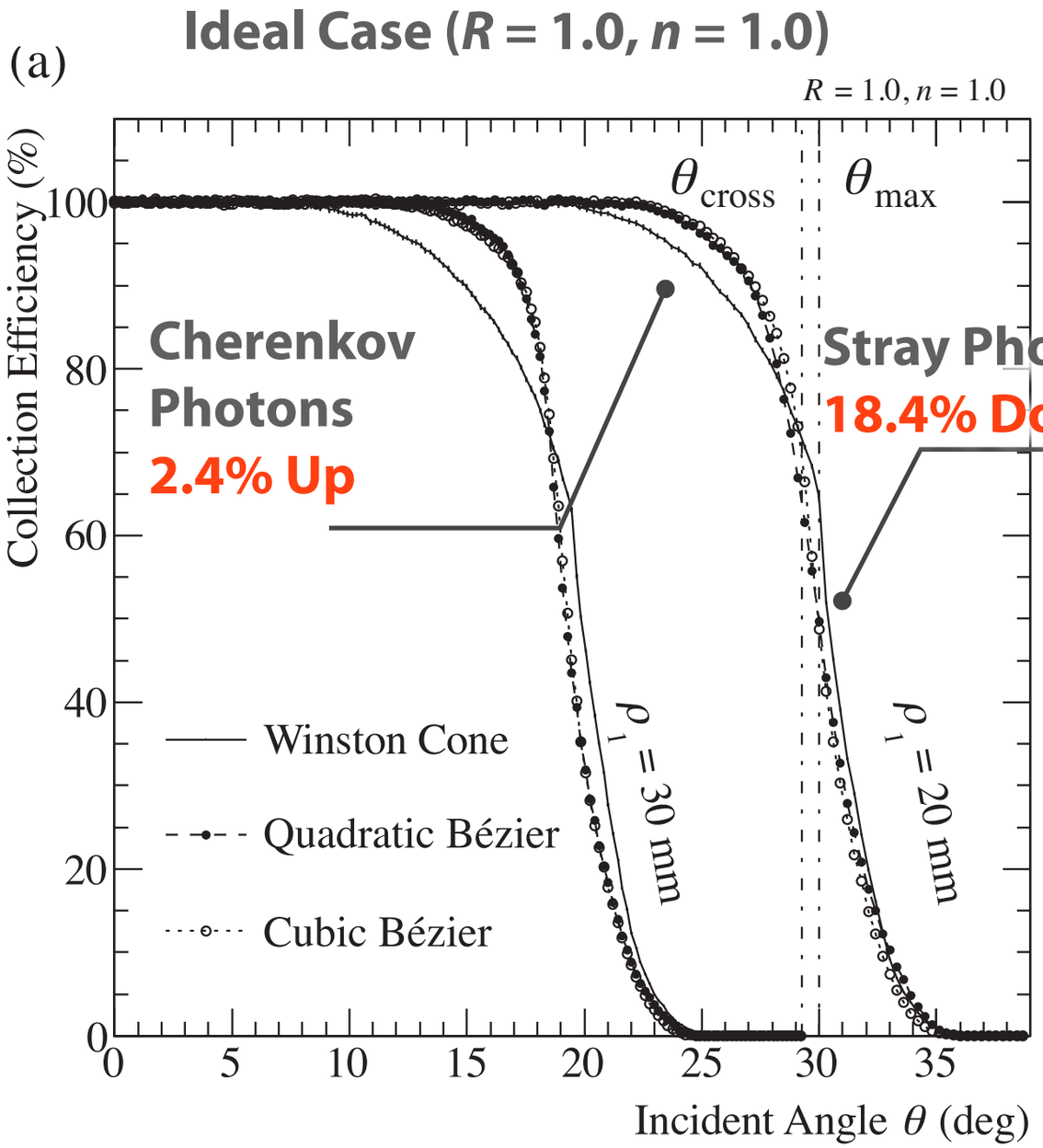
- Winston cone is optimized in the 2D space
- Known to have **good** performance in the 3D space, but need **better** ones
- Use Bézier curves instead of paraboloids

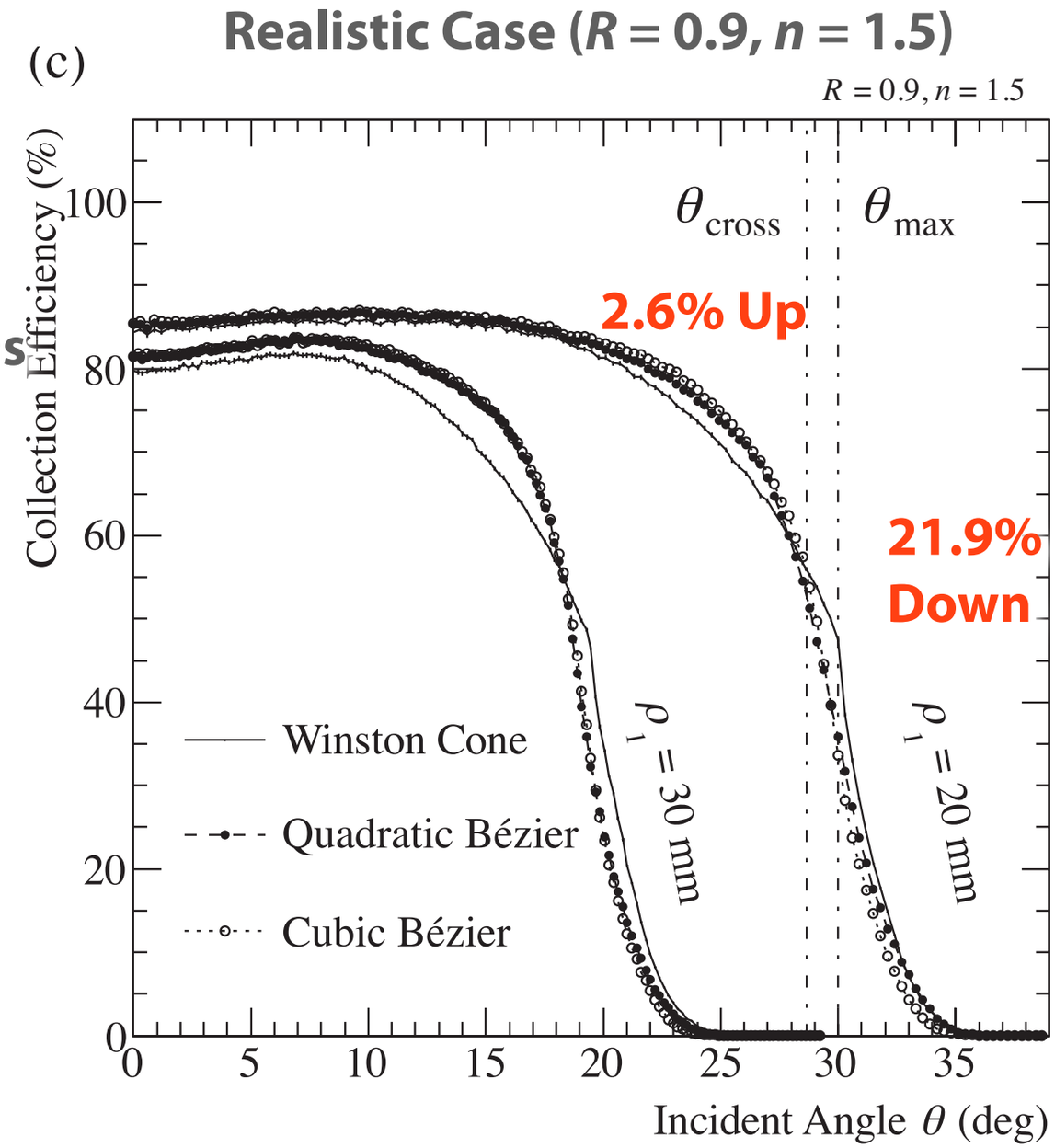
CTA Application 2: Hexagonal Light Collector



- Maximize the collection efficiency (contour) of a cone within the cutoff angle
- The coordinates of two control points (P_{1r}, P_{1z}, P_{2r}, P_{2z}) are scanned in 4-parameter space

CTA Application 2: Hexagonal Light Collector





- Achieved higher collection efficiency and BG reduction rate
- **~3% increase** of Cherenkov photons, **~20% decrease** of stray BG photons in the case of cut-off angle of 30 deg

Summary

- We have developed ROot-BAsed Simulator for ray Tracing (ROBAST) for optics simulations of cosmic-ray telescopes
- First used in Ashra, currently used in CTA
- Simulations of Schwarzschild-Couder telescope are on going in the CTA-US team
- A hexagonal light collector was successfully optimized using ROBAST

- New users are very welcome!