地上ガンマ線望遠鏡 CTA のための高効率な集光装置の試作

奥村 曉

名古屋大学 宇宙地球環境研究所

Dang Viet Tan [A]、林田将明 [B]、Jim Hinton [C]、片桐秀明 [A]、
野田浩司 [B]、手嶋政廣 [B,D]、山本常夏 [E]、吉田龍生 [A]

茨城大理 [A]、東大宇宙線研 [B]、マックスプランク核物理 [C]、
マックスプランク物理 [D]、甲南大理工 [E]

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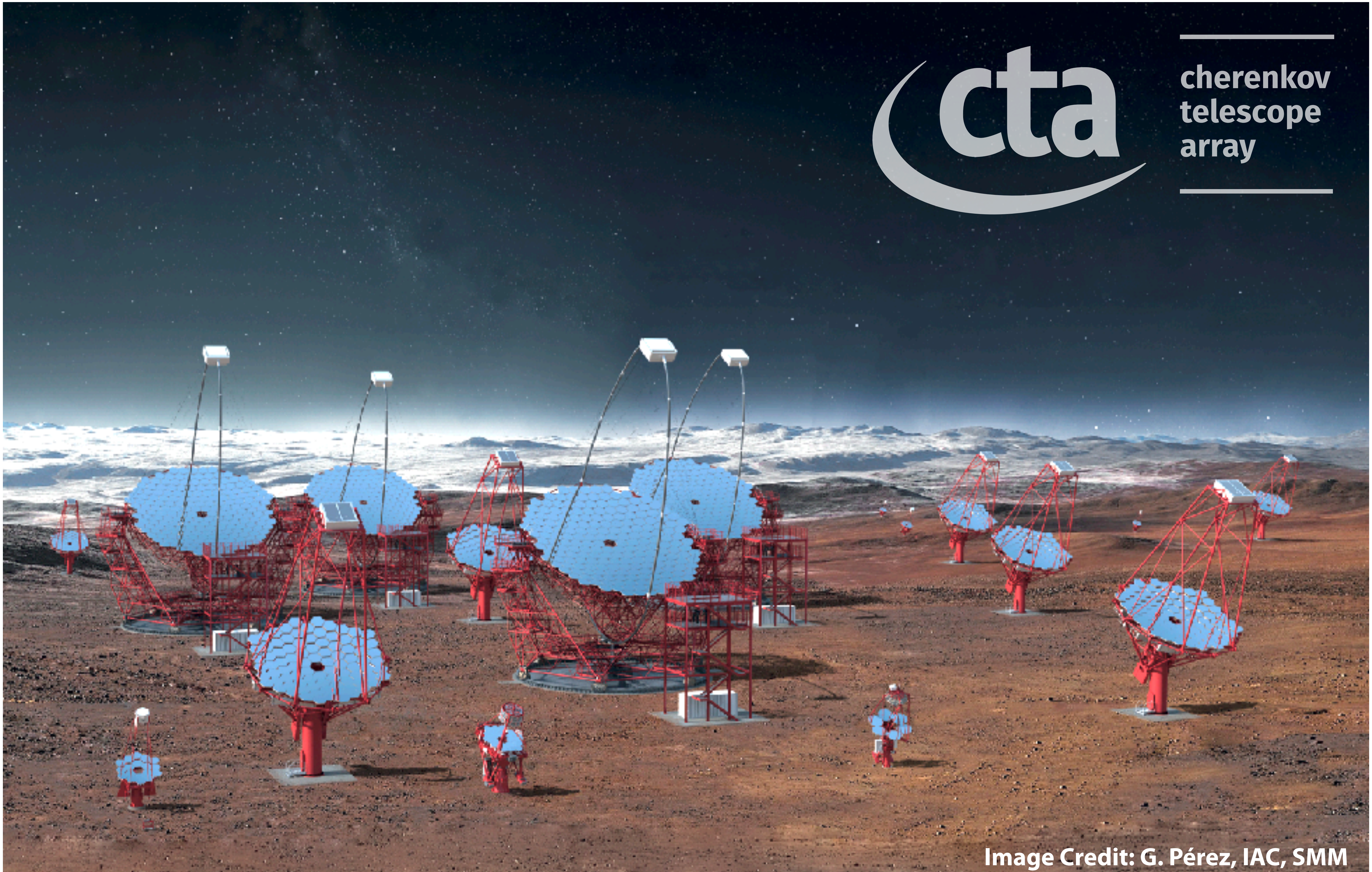
名古屋大学 NAGOYA UNIVERSITY

ISEE Institute for Space–Earth Environmental Research

oxon@mac.com

Cherenkov Telescope Array (CTA)



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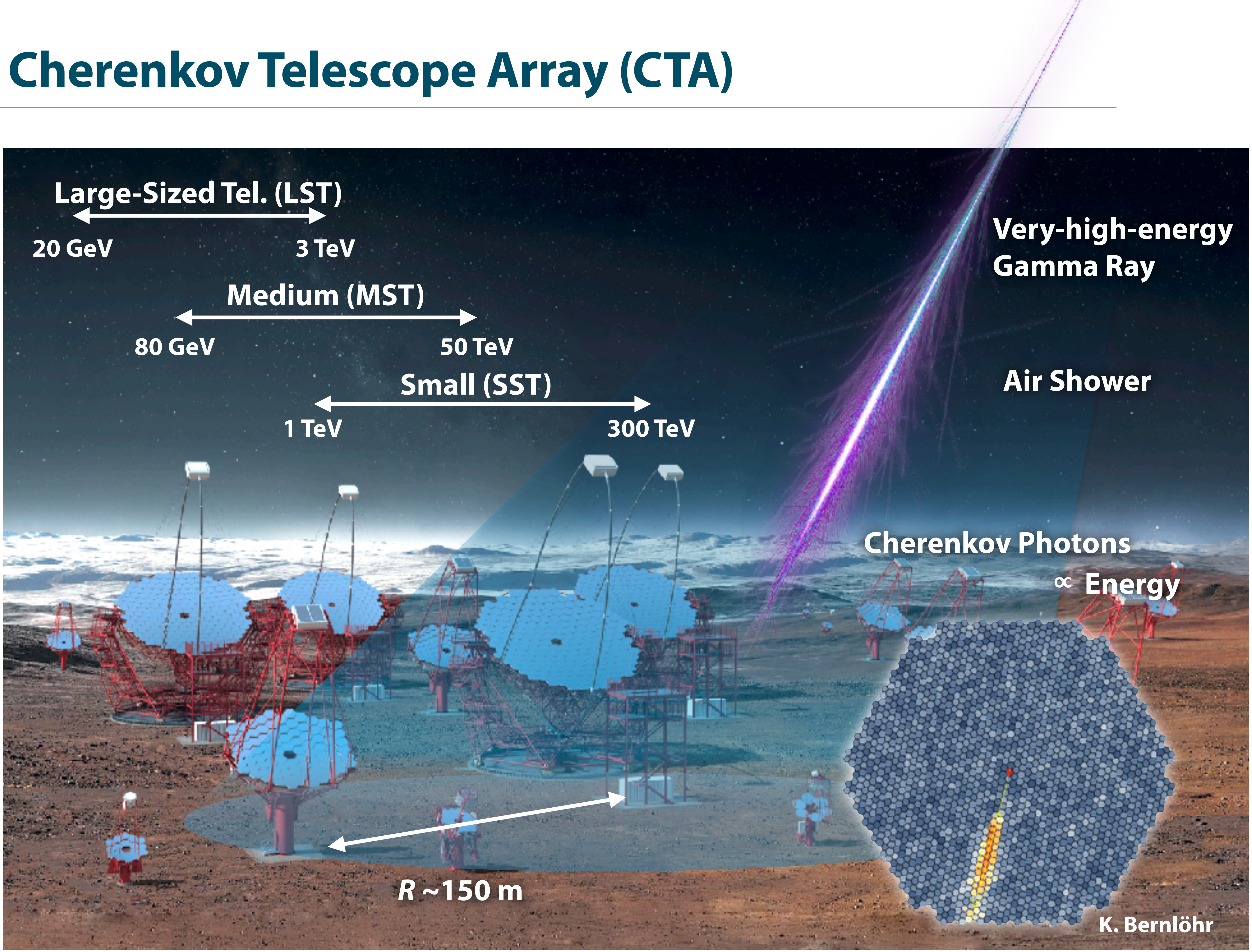
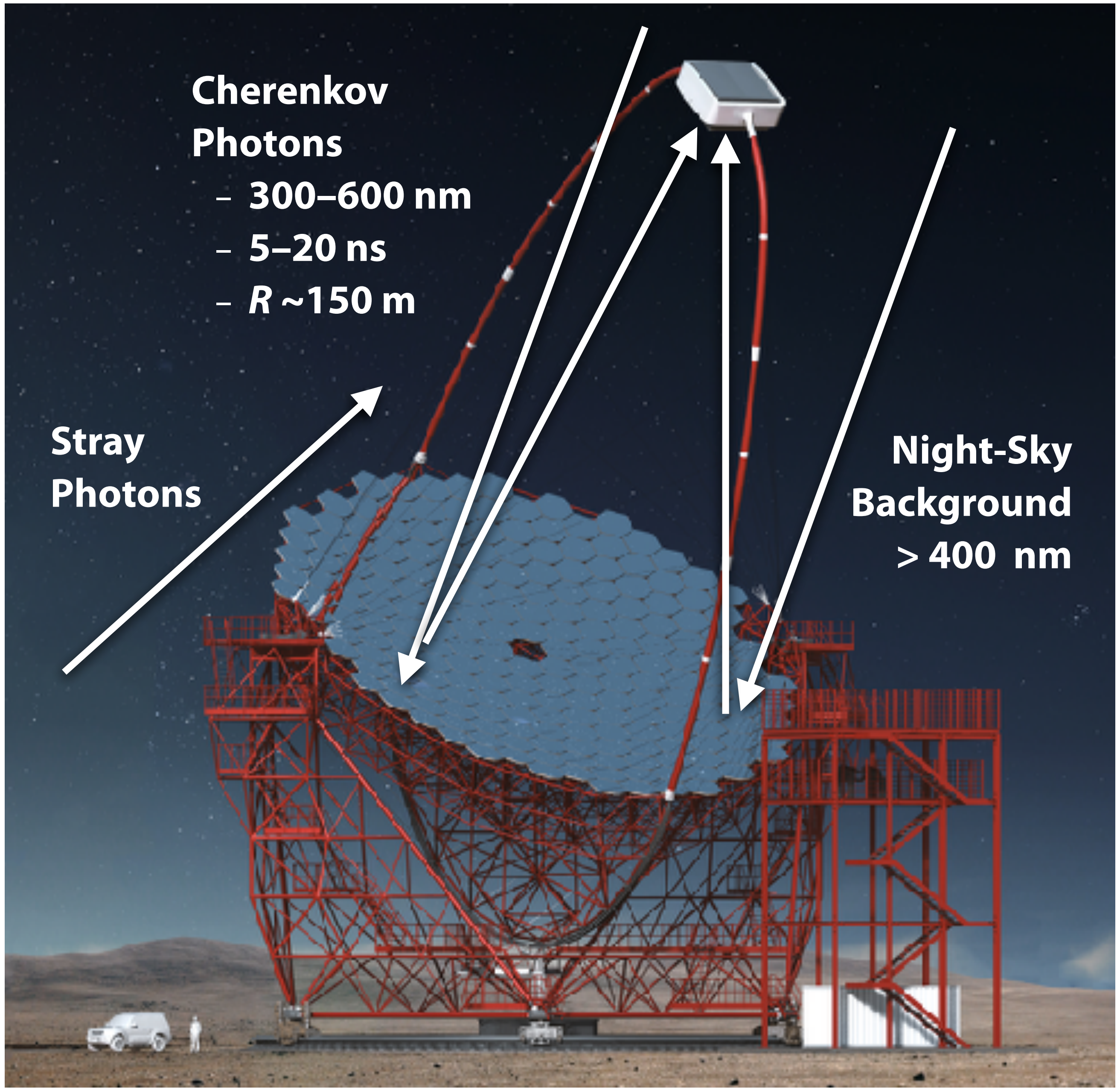
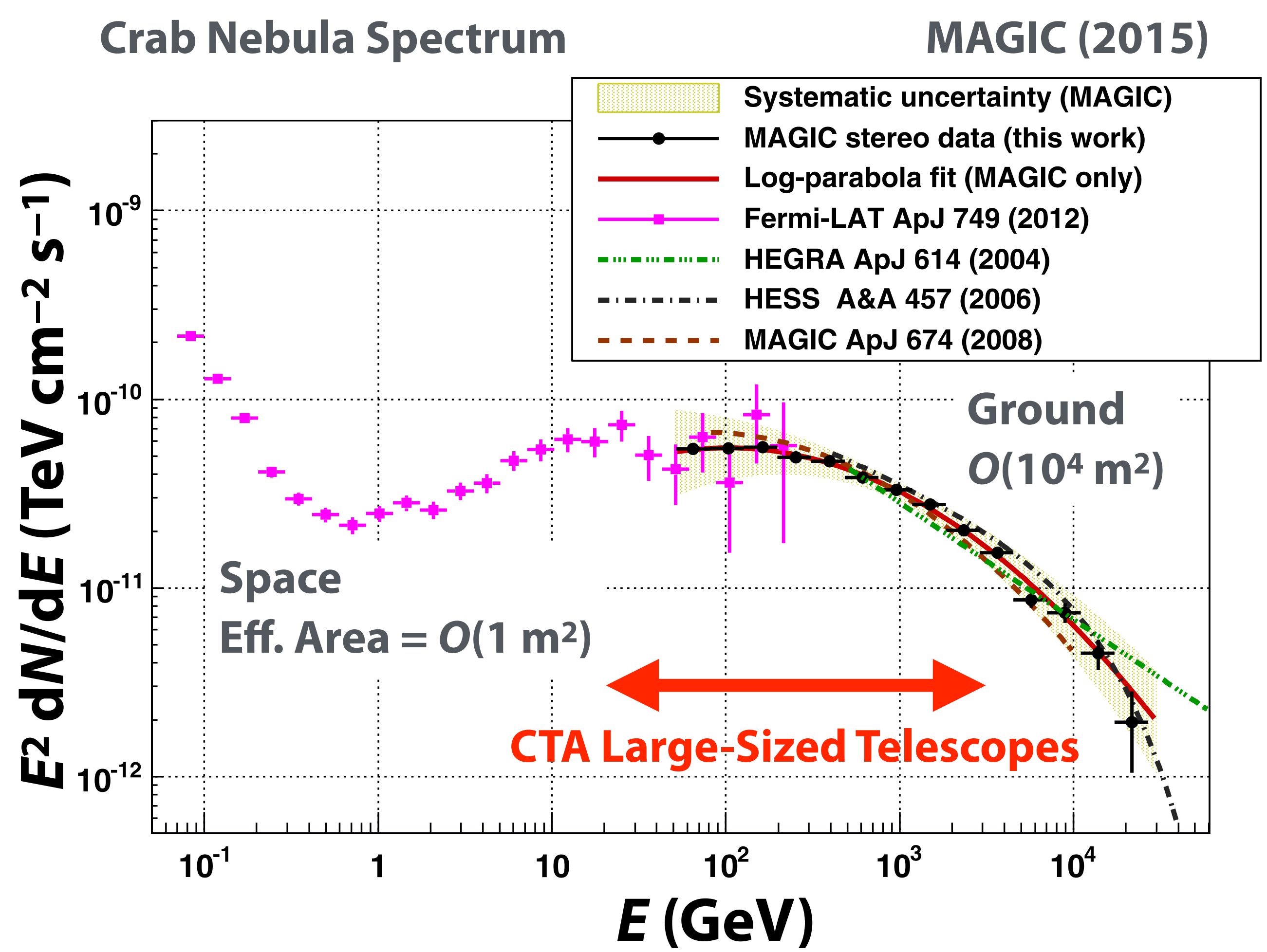


LST Status

- 1st LST is under construction for the CTA Northern Array at La Palma, Spain
- Camera, mirrors, and auxiliary systems are in the final development and testing phase
- LST First light is scheduled in 2018

The More Photons, the Lower Threshold & Higher Sensitivity



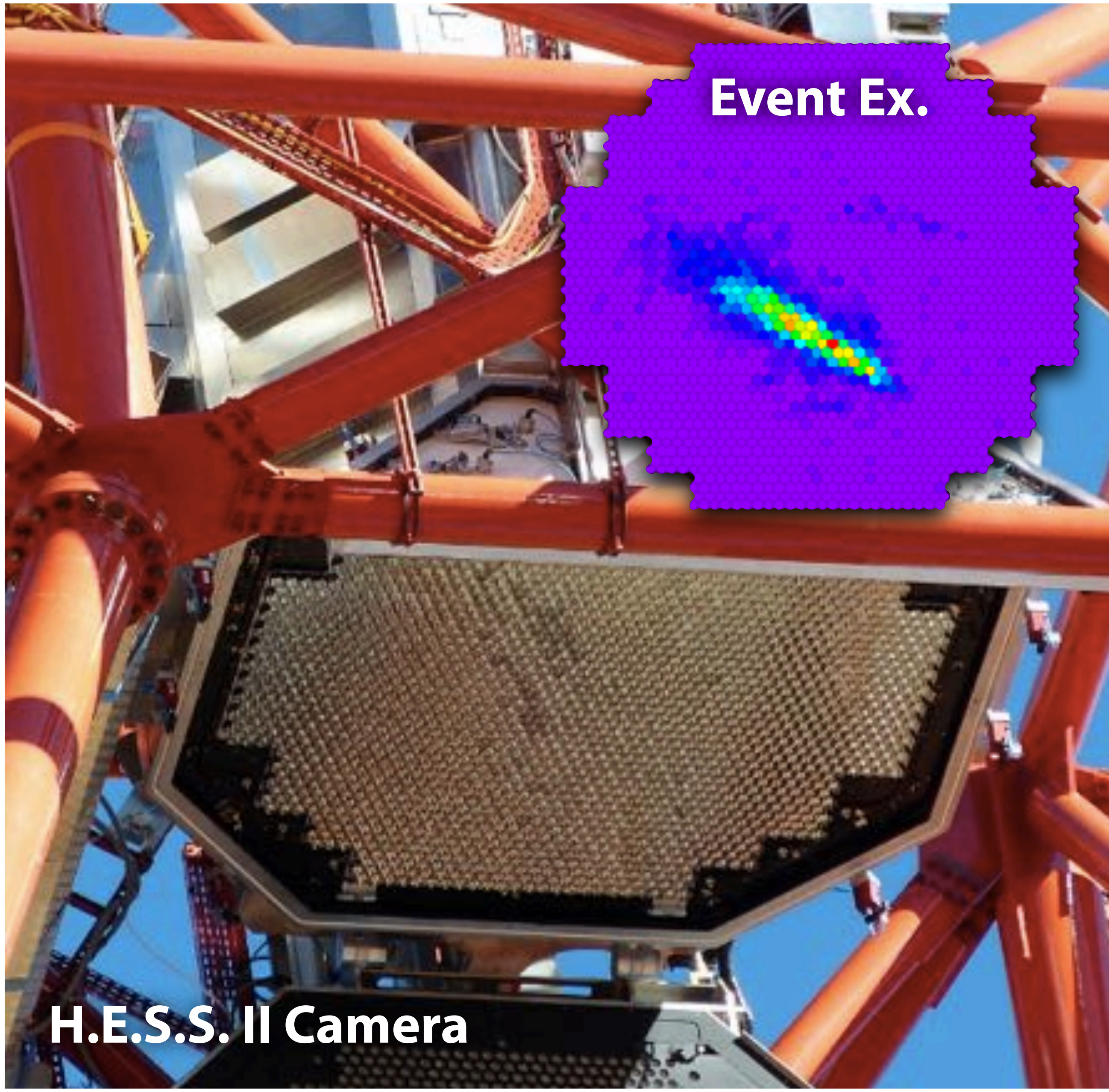


Typically dN/dE $\propto E^{-2} - E^{-3}$

- Night-sky background is dominant for lower-energy gamma rays
- Larger mirror area or higher photodetector efficiency lowers the trigger energy threshold → higher sensitivity

Winston Cones

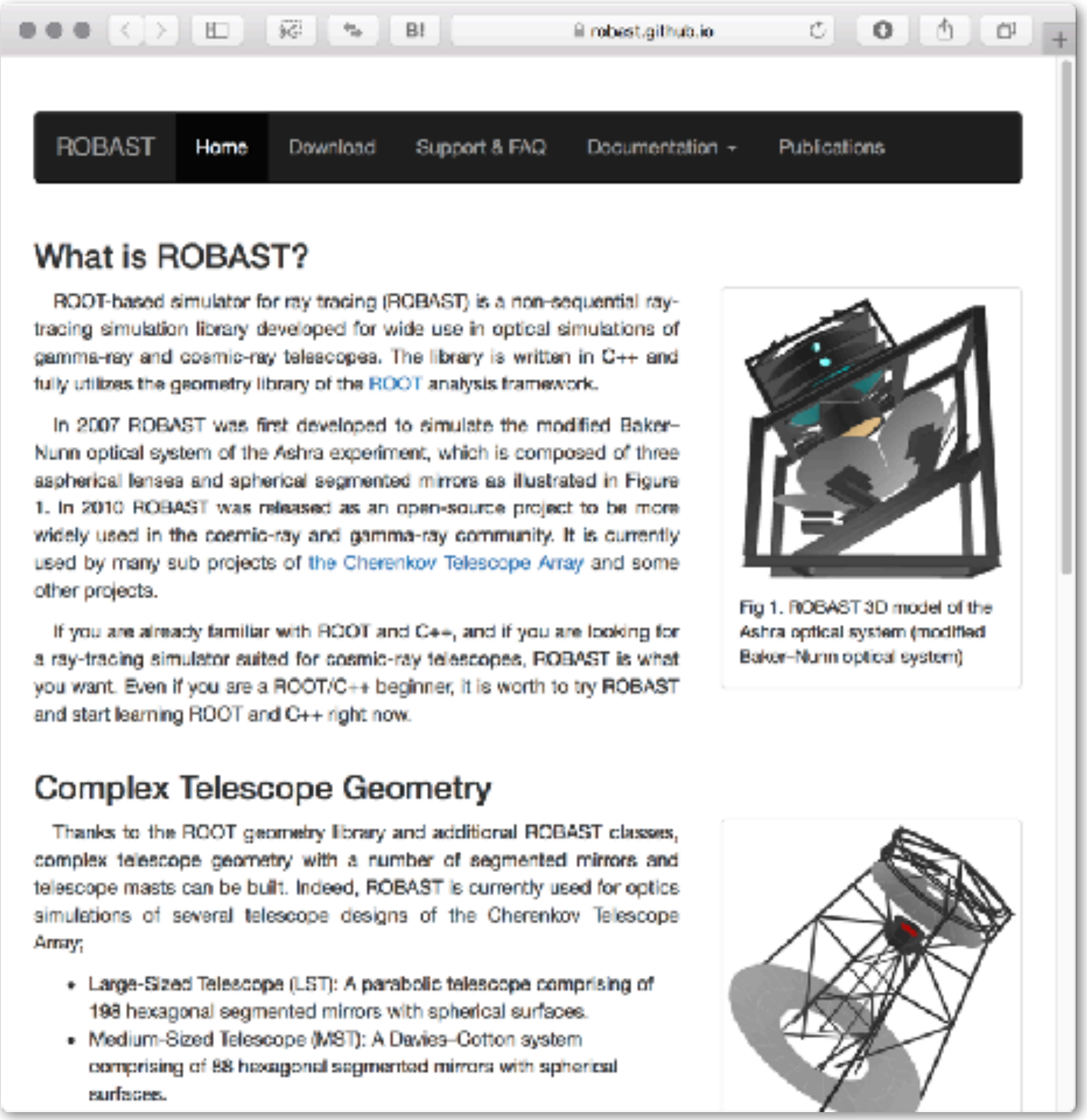
http://www.mpi-hd.mpg.de/hfm/HESS

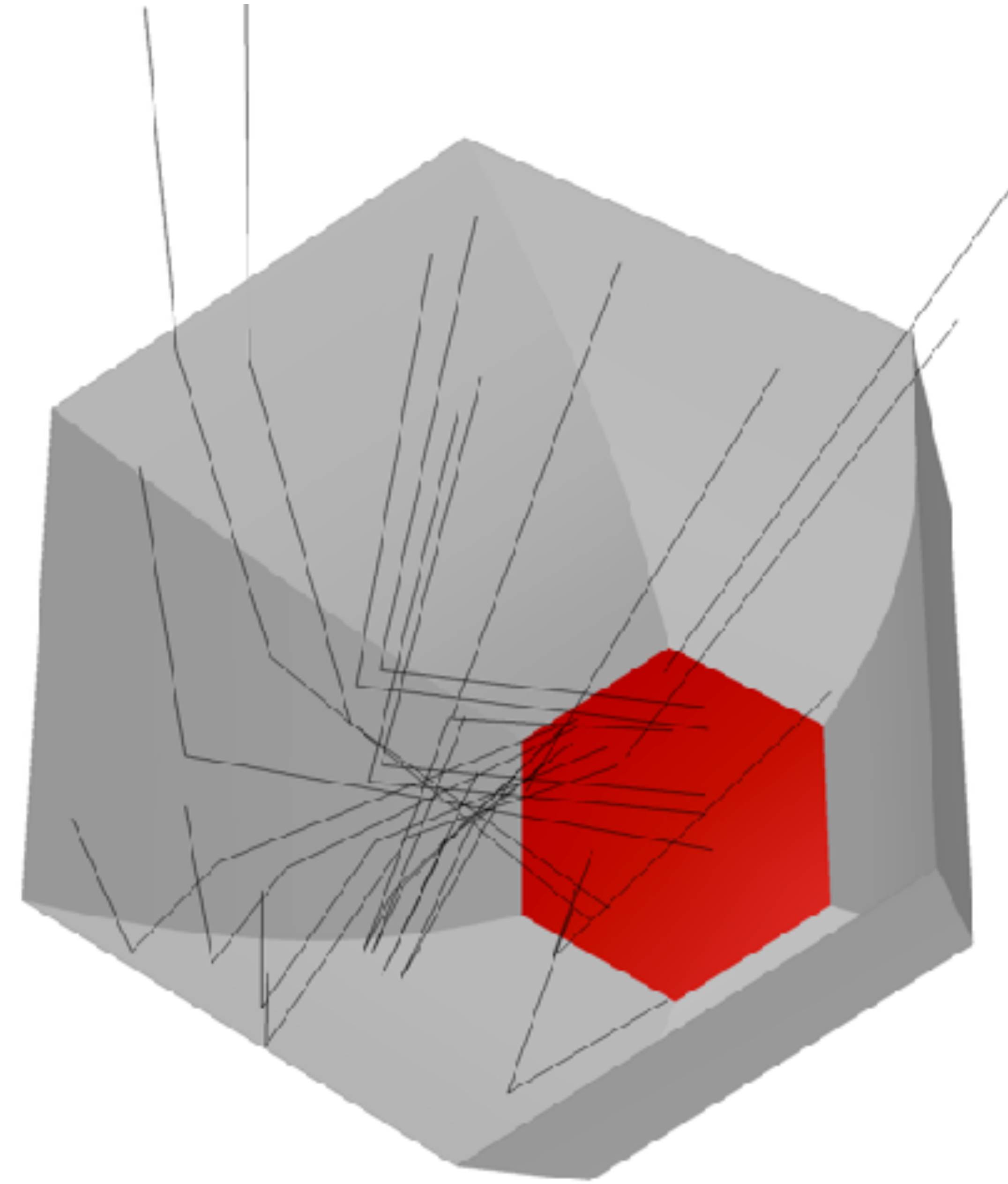


- Cherenkov camera = **Winston cones** + Photomultiplier Tubes (PMTs) + Front-end Elec. + Back-end Elec.
- Hexagonal Winston cones cover the whole camera to maximize the collection efficiency and to reduce BG photons

ROBAST

Okumura+ (2015) *Astropart. Phys.*

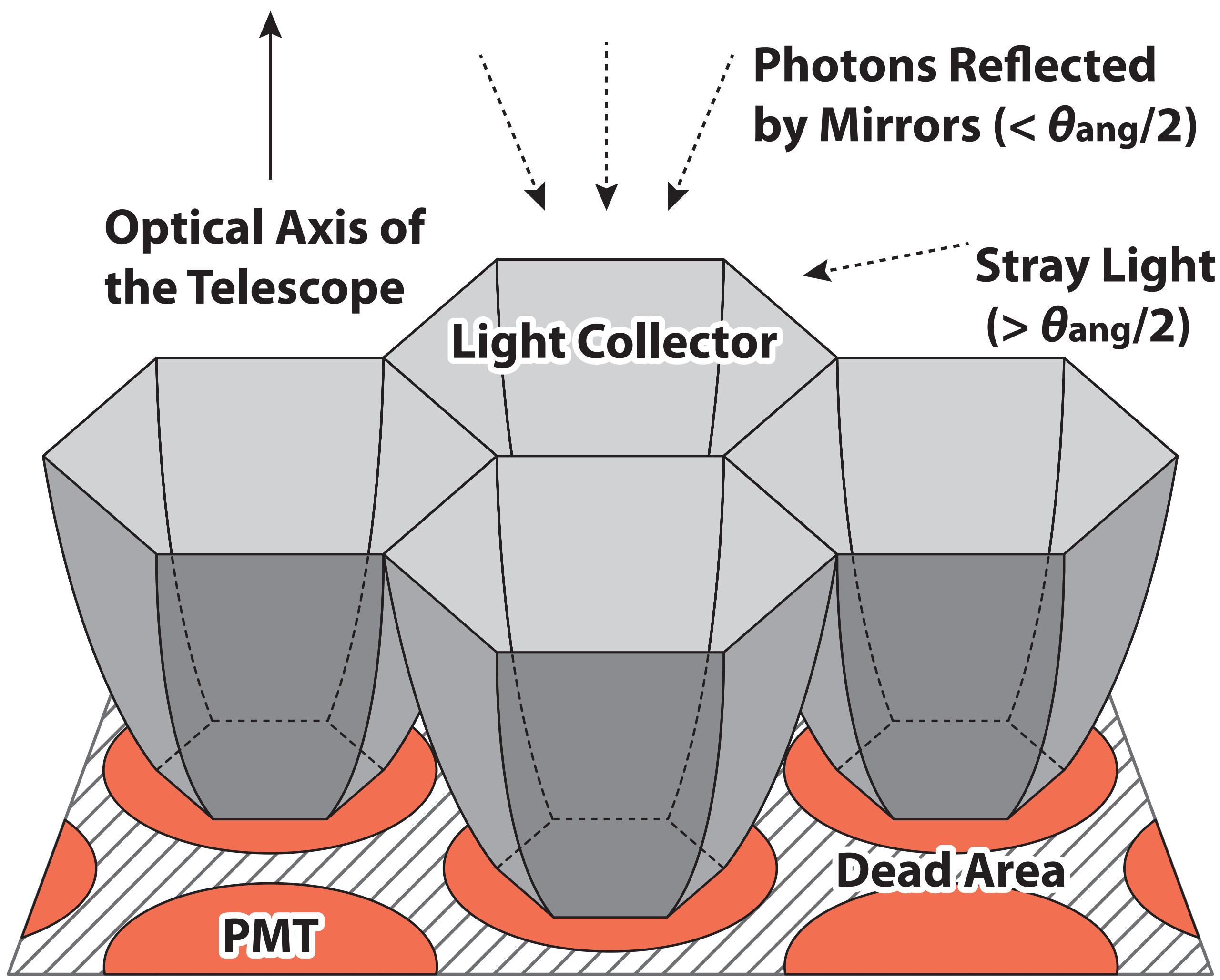


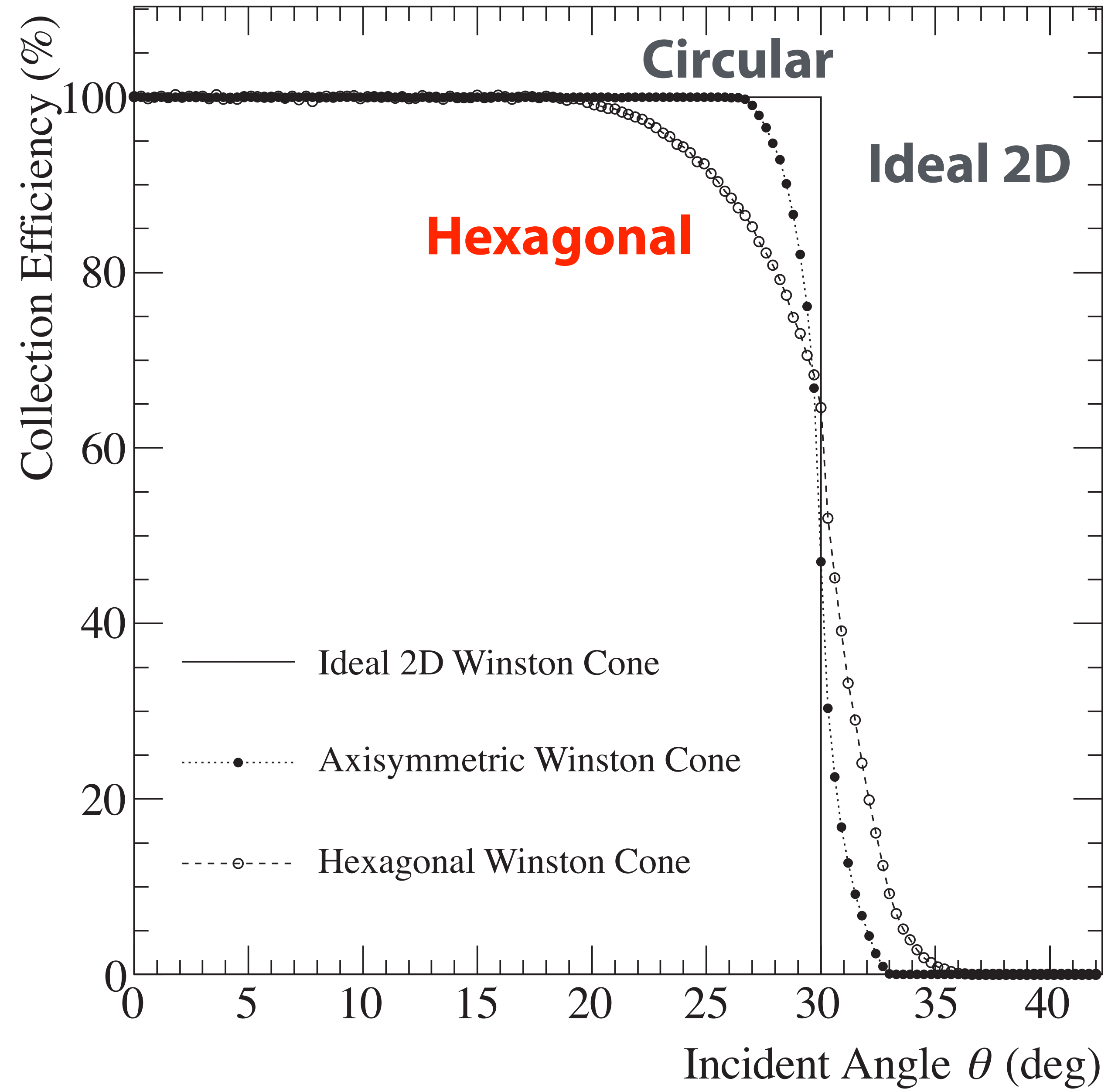


- **RO**OT-**ba**sed **s**imulator for ray **t**racing (ROBAST) https://robast.github.io
- Developed for cosmic-ray and gamma-ray telescopes with use of the ROOT Geom library
- Open source https://github.com/ROBAST/ROBAST

Winston Cones

Okumura (2012) *Astropart. Phys.*

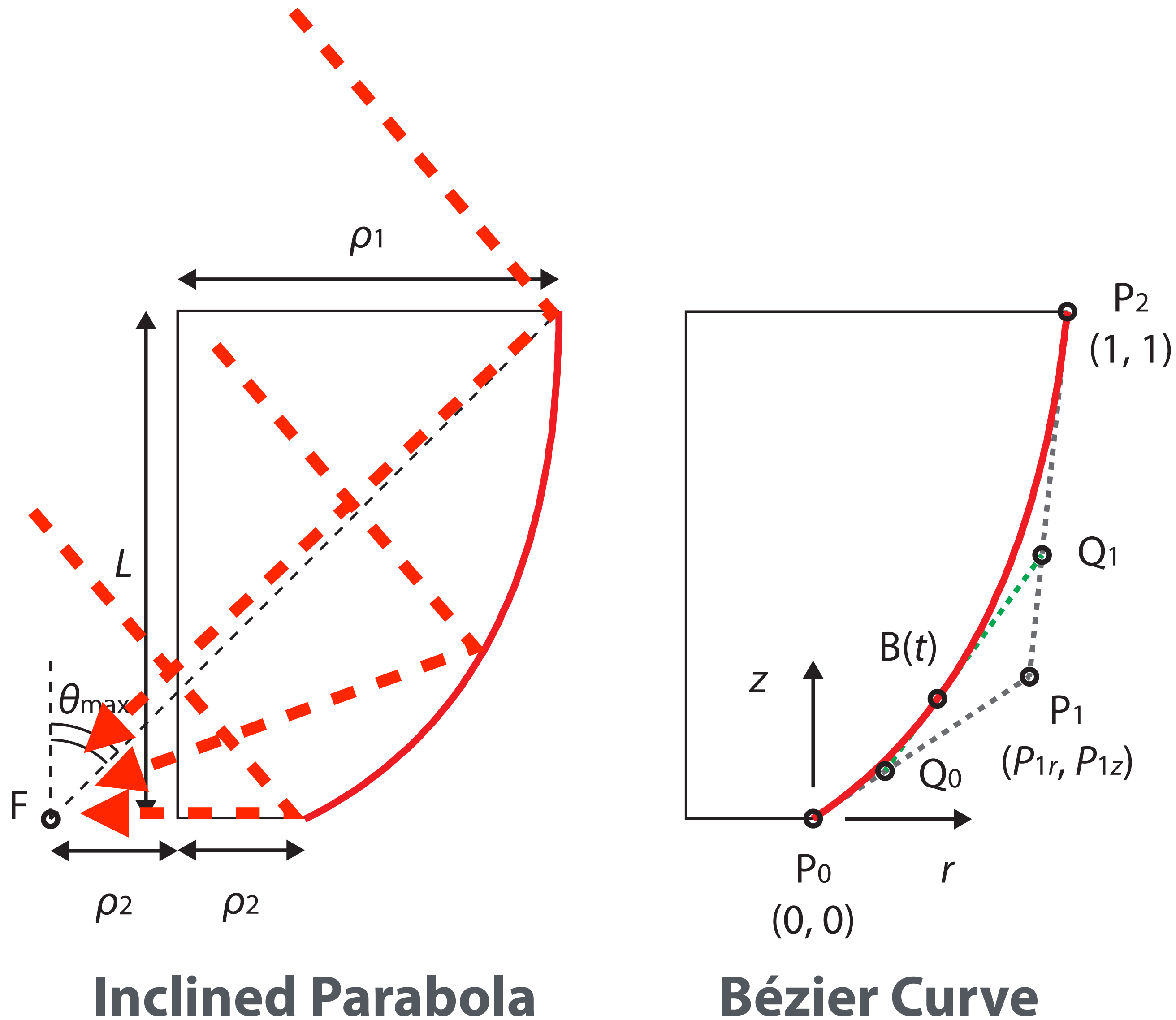


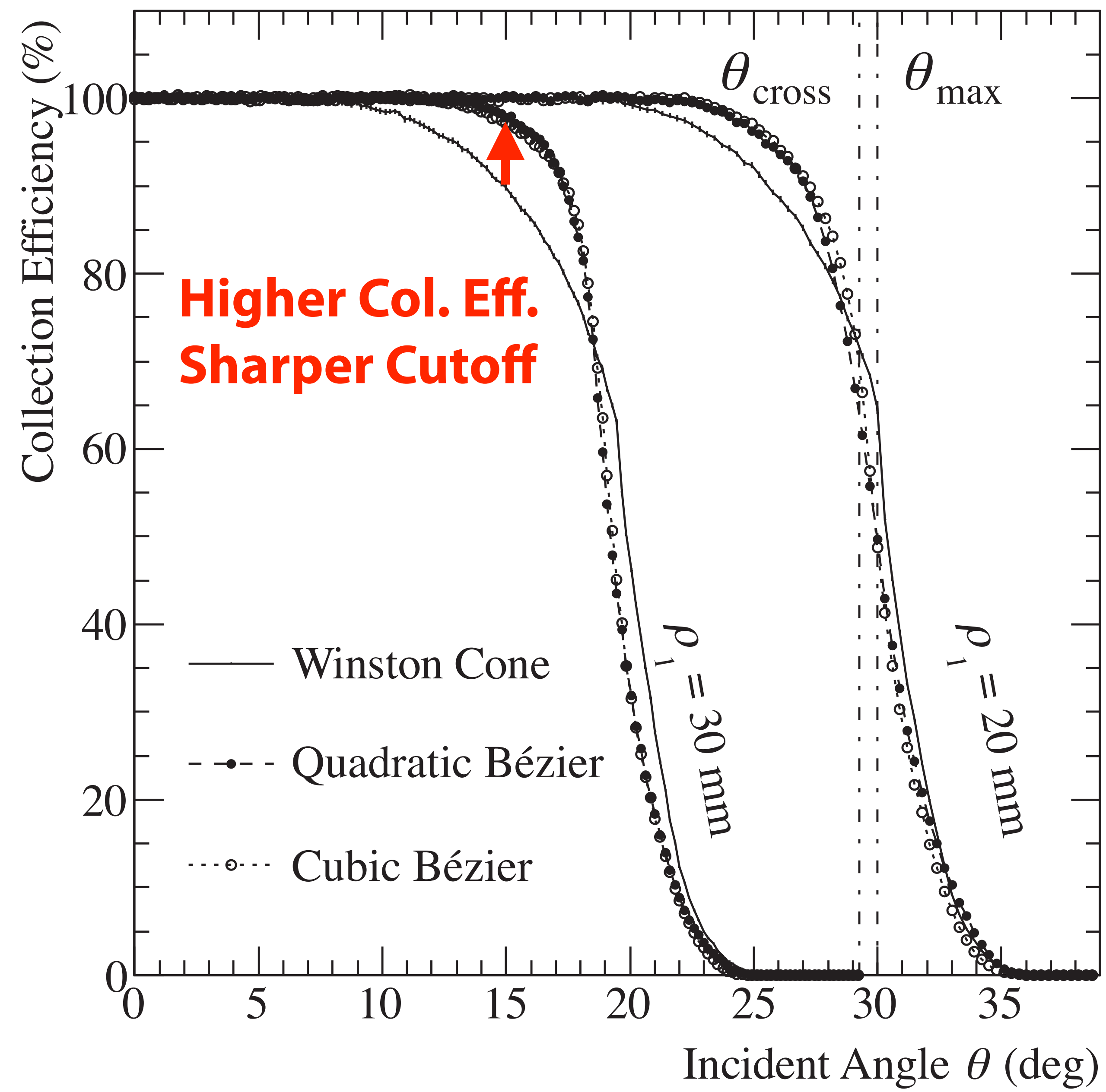


- Invented by Winston (1970) a.k.a. Compound Parabolic Concentrators (CPCs)
- In 2D space, Winston cones ideally work (100% for θ < cutoff, 0% for θ > cutoff)
- Not ideal for PMT arrays

Bézier-Curve Profile

Okumura (2012) *Astropart. Phys.*

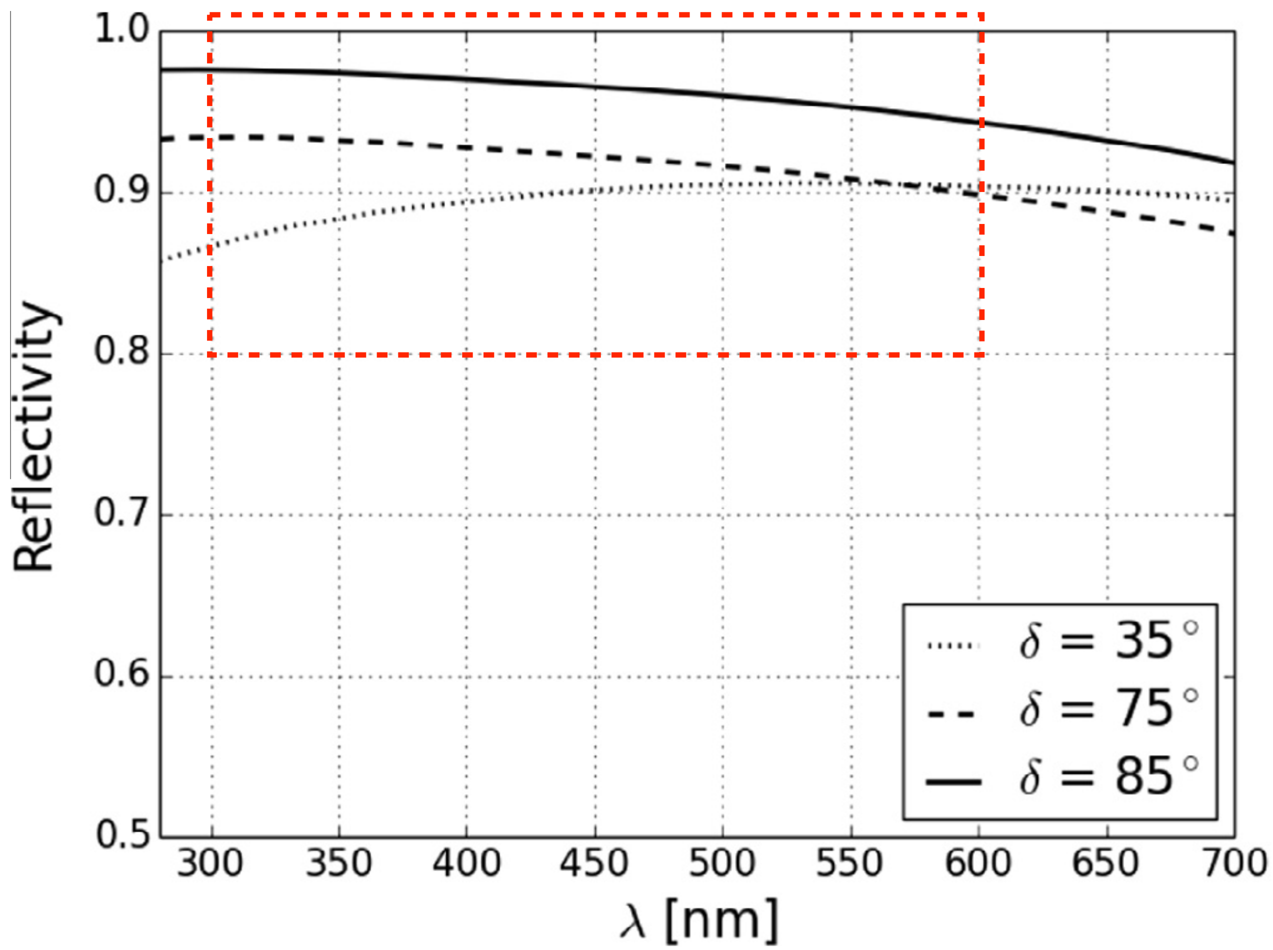




- Inclined parabola (conventional Winston cones) is not ideal for hexagonal pixels
- Use of a Bézier curve profile → higher collection efficiency & sharper cutoff

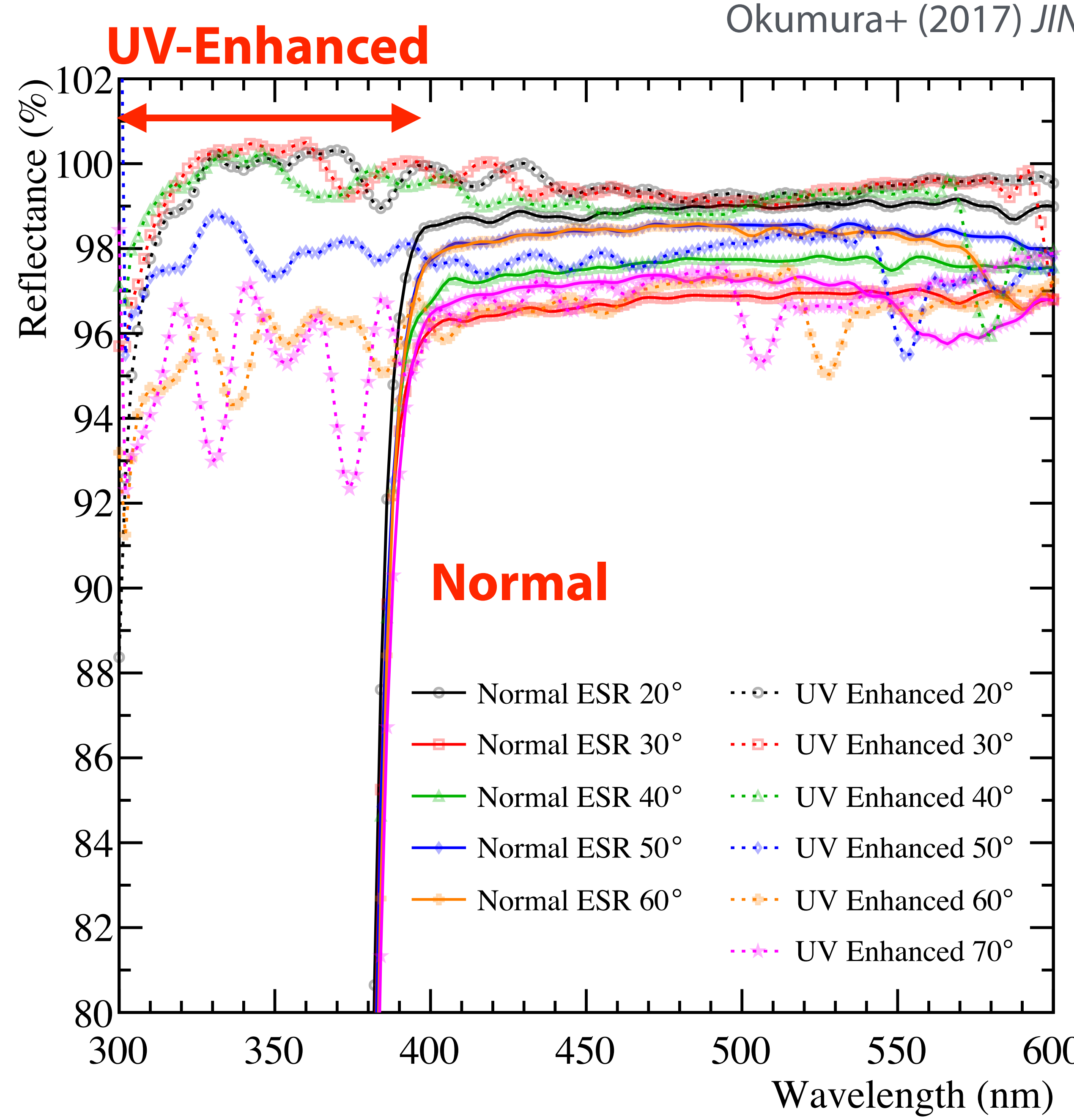
UV-Enhanced ESR

Aguilar+ (2015) *Astropart. Phys.*



Simulated Al Coating + 2 Layers

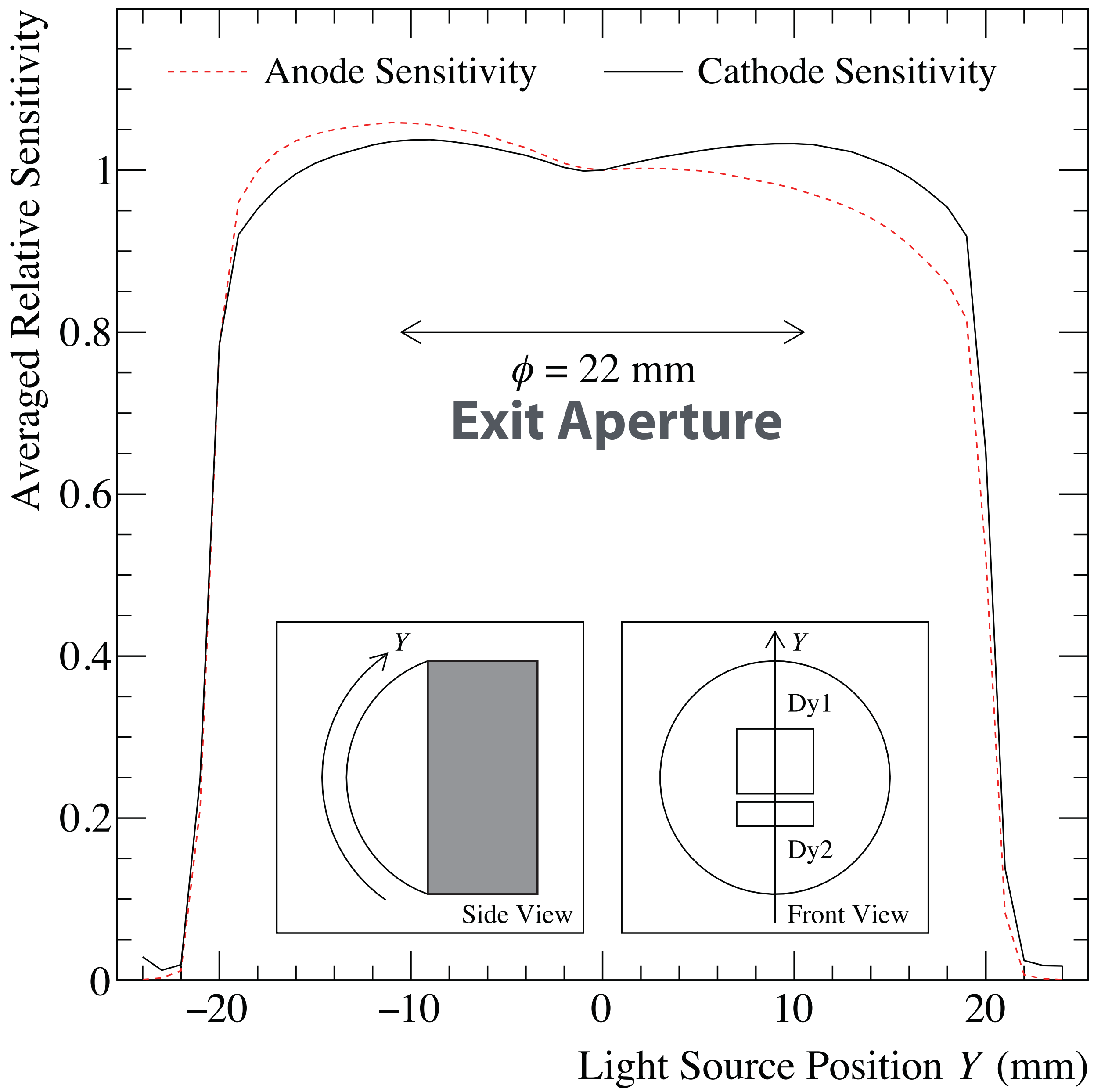
Okumura+ (2017) *JINST*

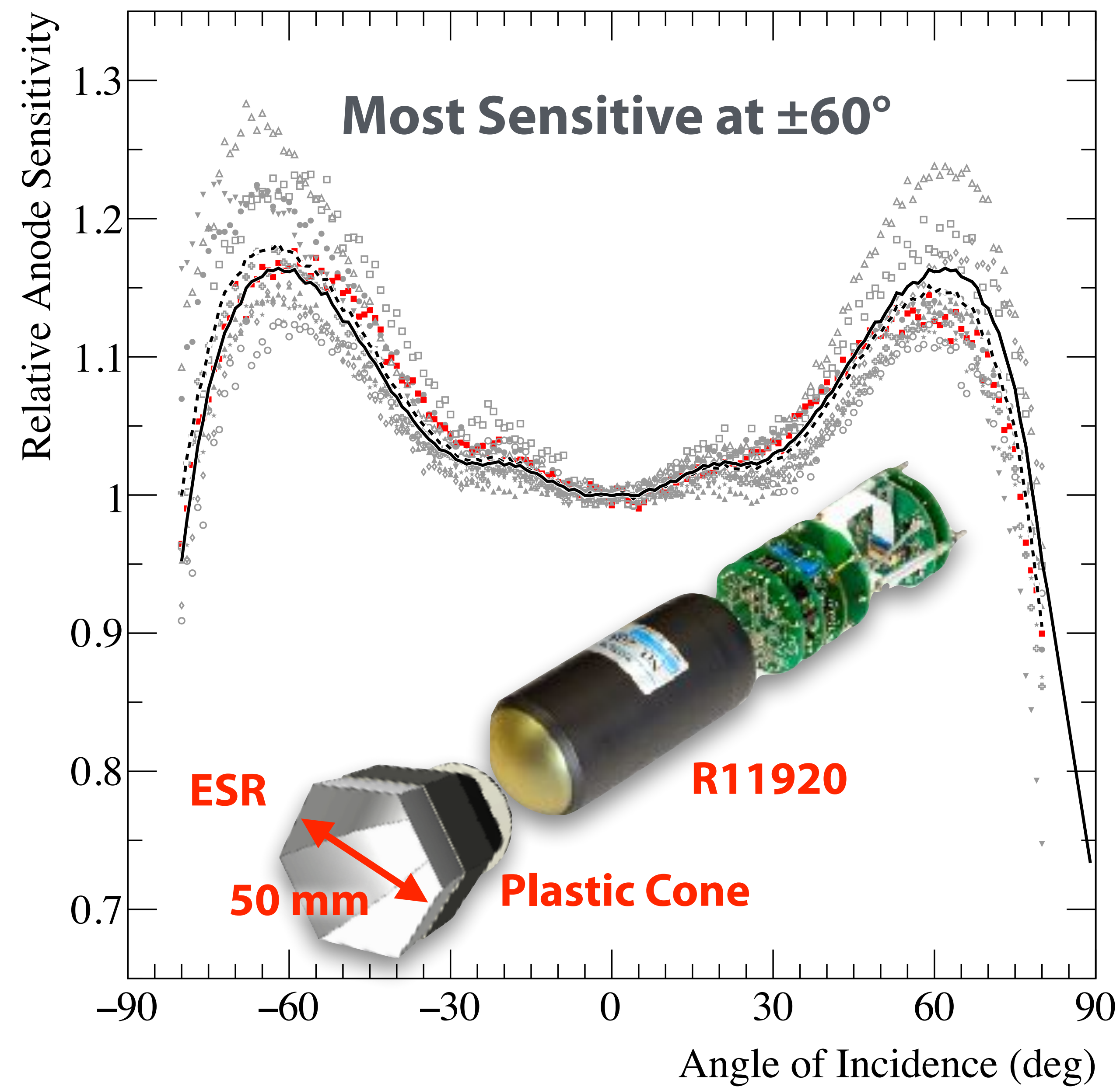


- 54 additional layers (Ta_2O_5 & SiO_2) on 3M Vikuiti *Enhanced Specular Reflector* (**ESR**, ~1000-layer polyester film)
- ~93% to almost 100% (w/ ~1% err.) in λ = 300–600 nm and θ = 20°–70°

PMT Characteristics

Okumura+ (2017) *JINST*

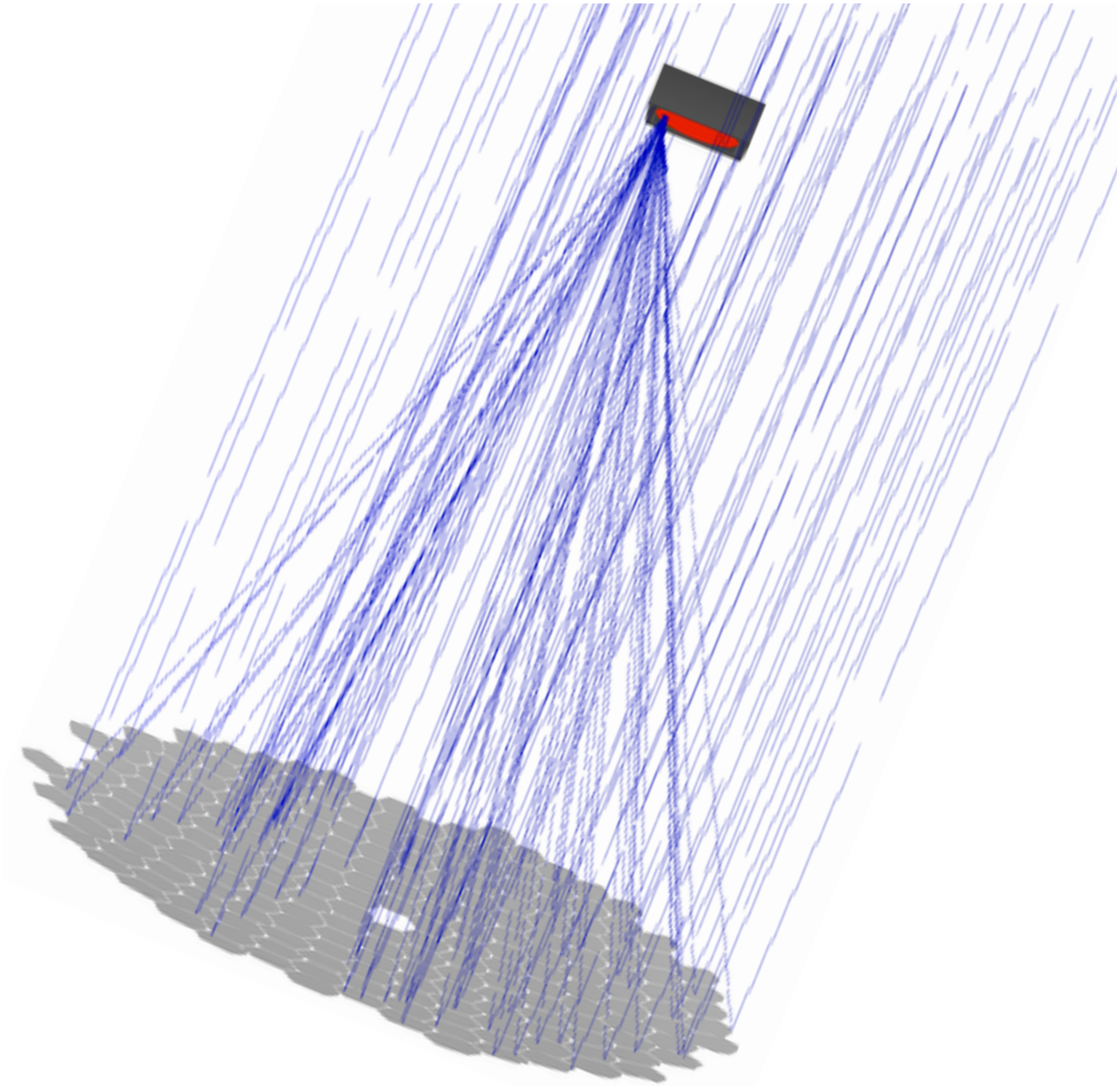


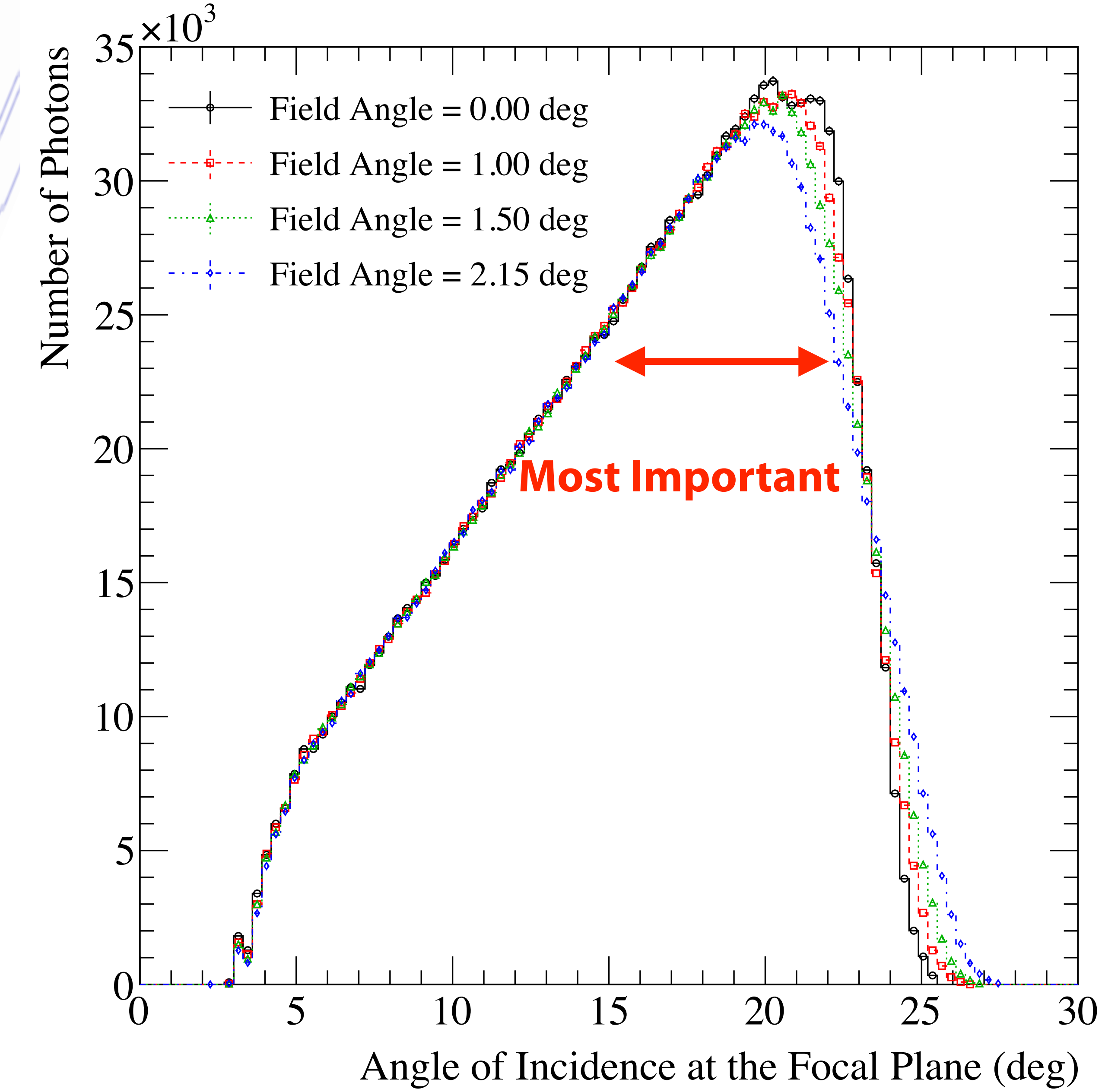


- CTA LSTs and MSTs will use Hamamatsu R11920-100-20 and R12992-100-05
- Spherical matte-surface photocathode
- Positional and angular dependence must be taken into account in the design

Angular Distribution of Incident Photons

Okumura+ (2017) *JINST*

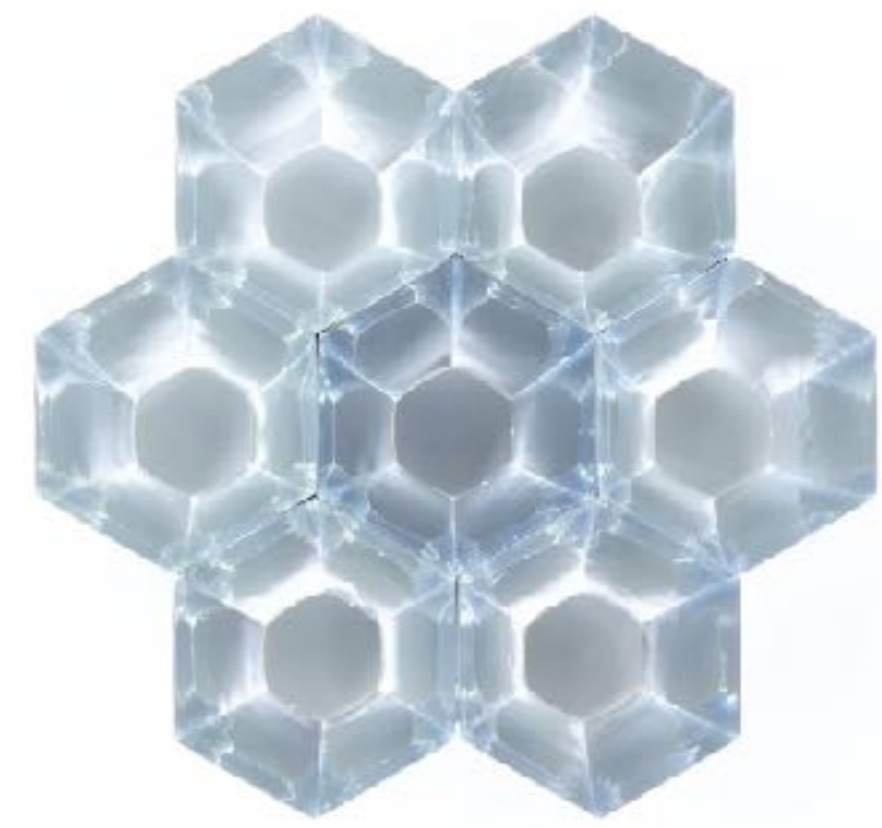


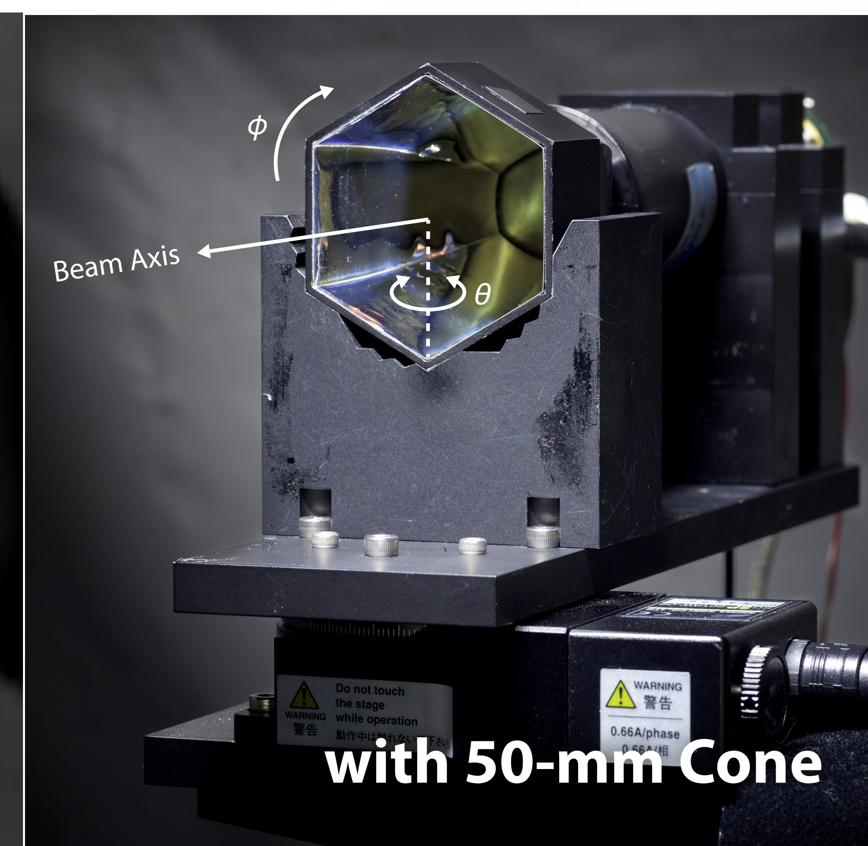


- Also need to consider the angular distribution of incident photons to maximize the collection efficiency

Prototype Production and Evaluation

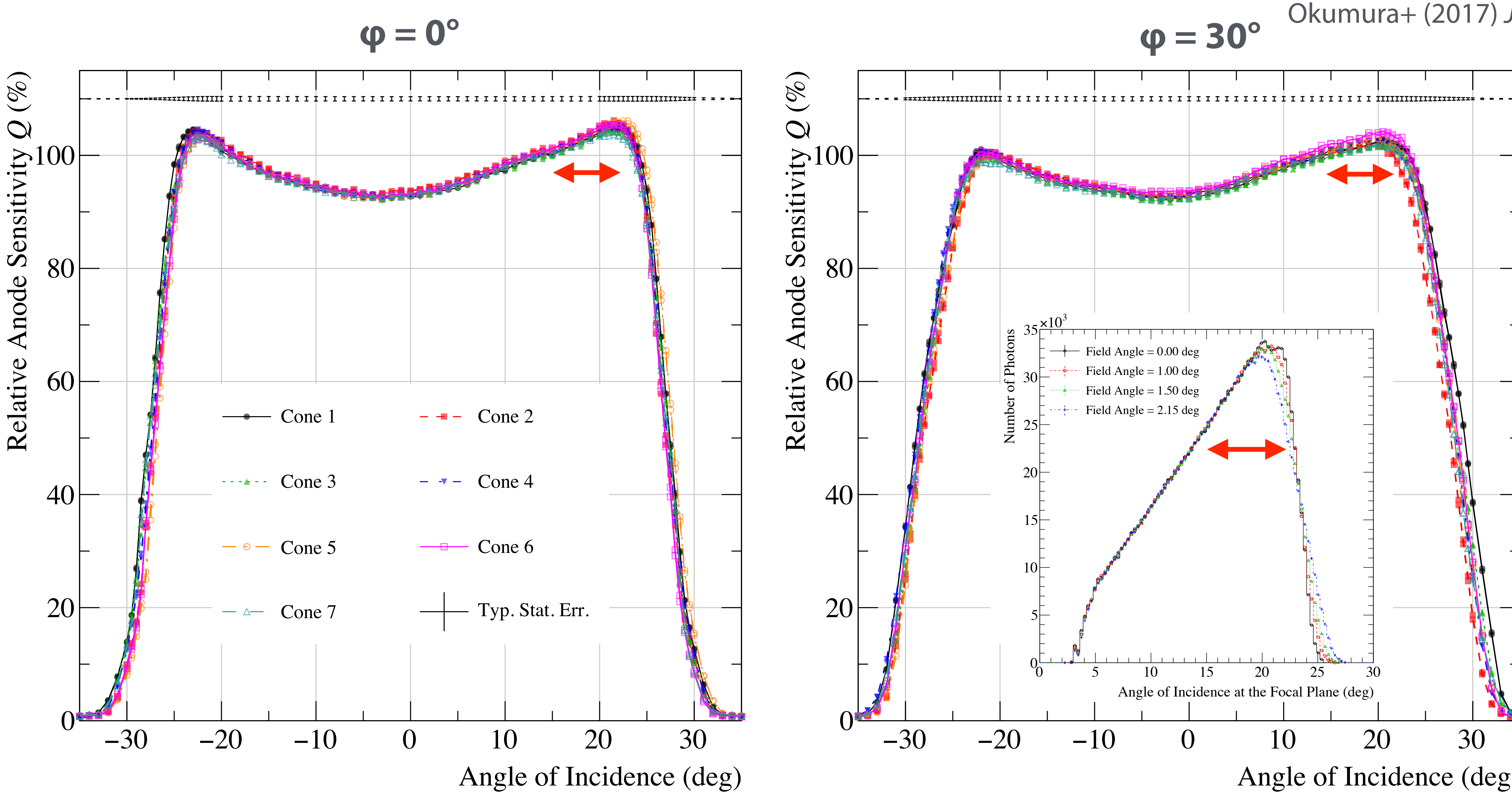
Okumura+ (2017) *JINST*





Results (465 nm)

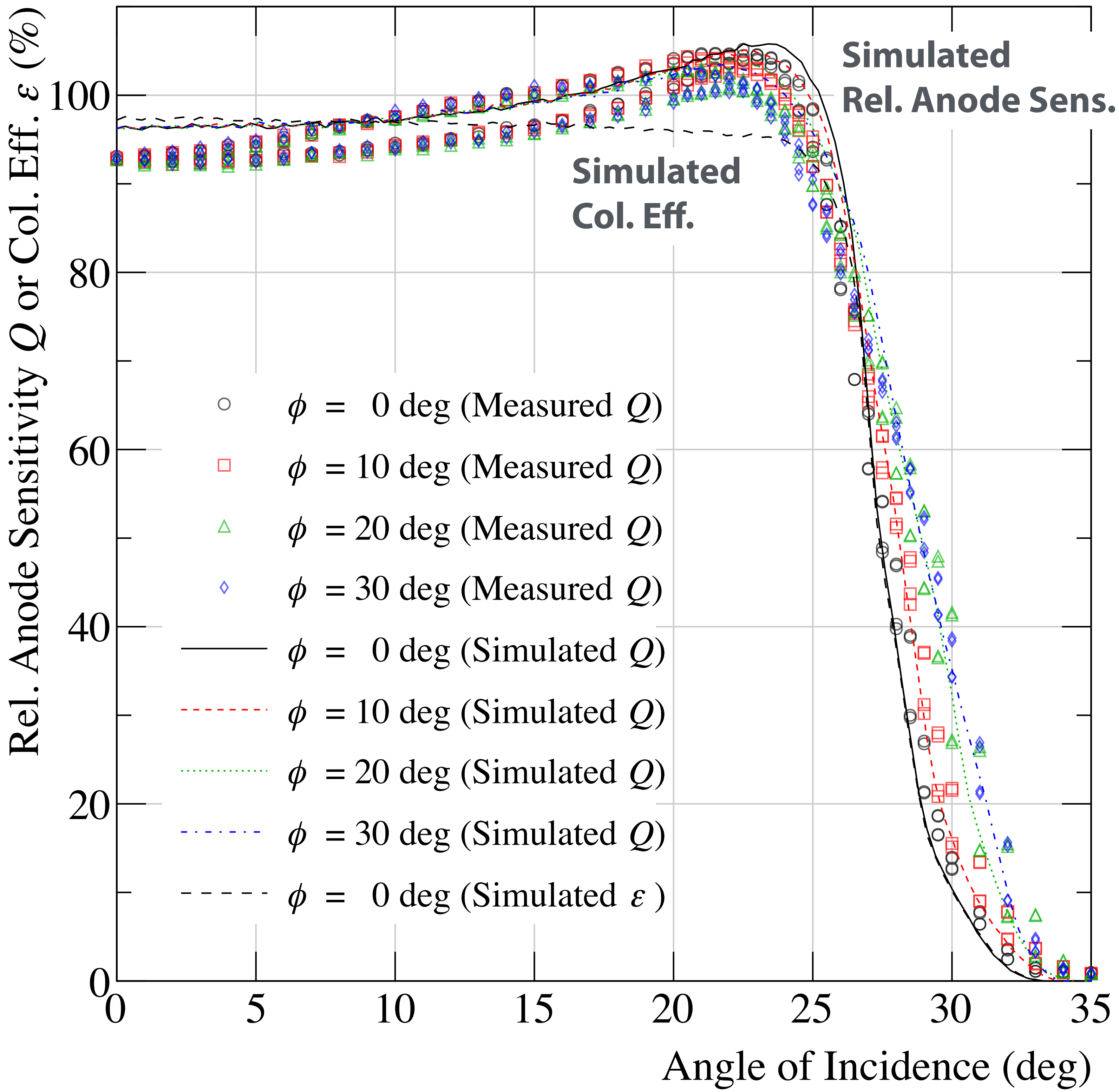
Okumura+ (2017) *JINST*



- Define **rel. anode sensitivity** (~ col. eff.) because col. eff. cannot be defined due to the angular and positional dependencies $Q = \frac{A_{\mathrm{LC}}(\theta)}{A_{\mathrm{mask}}} \times \frac{1}{3.7515 \times \cos\theta}$
- Reaches **100% and higher** in the most important angles

Measurement v.s. Simulation (465 nm)

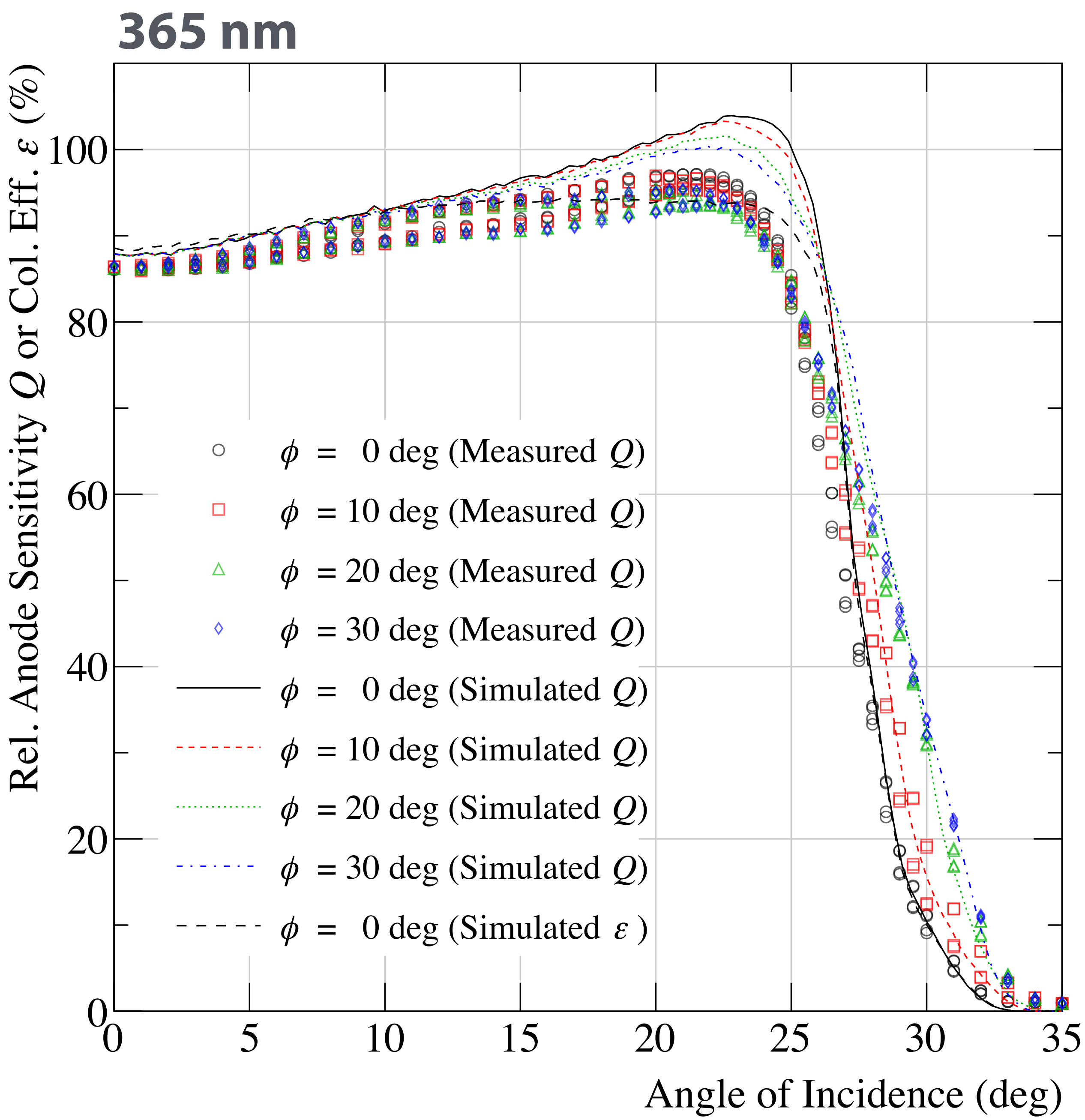
Okumura+ (2017) *JINST*

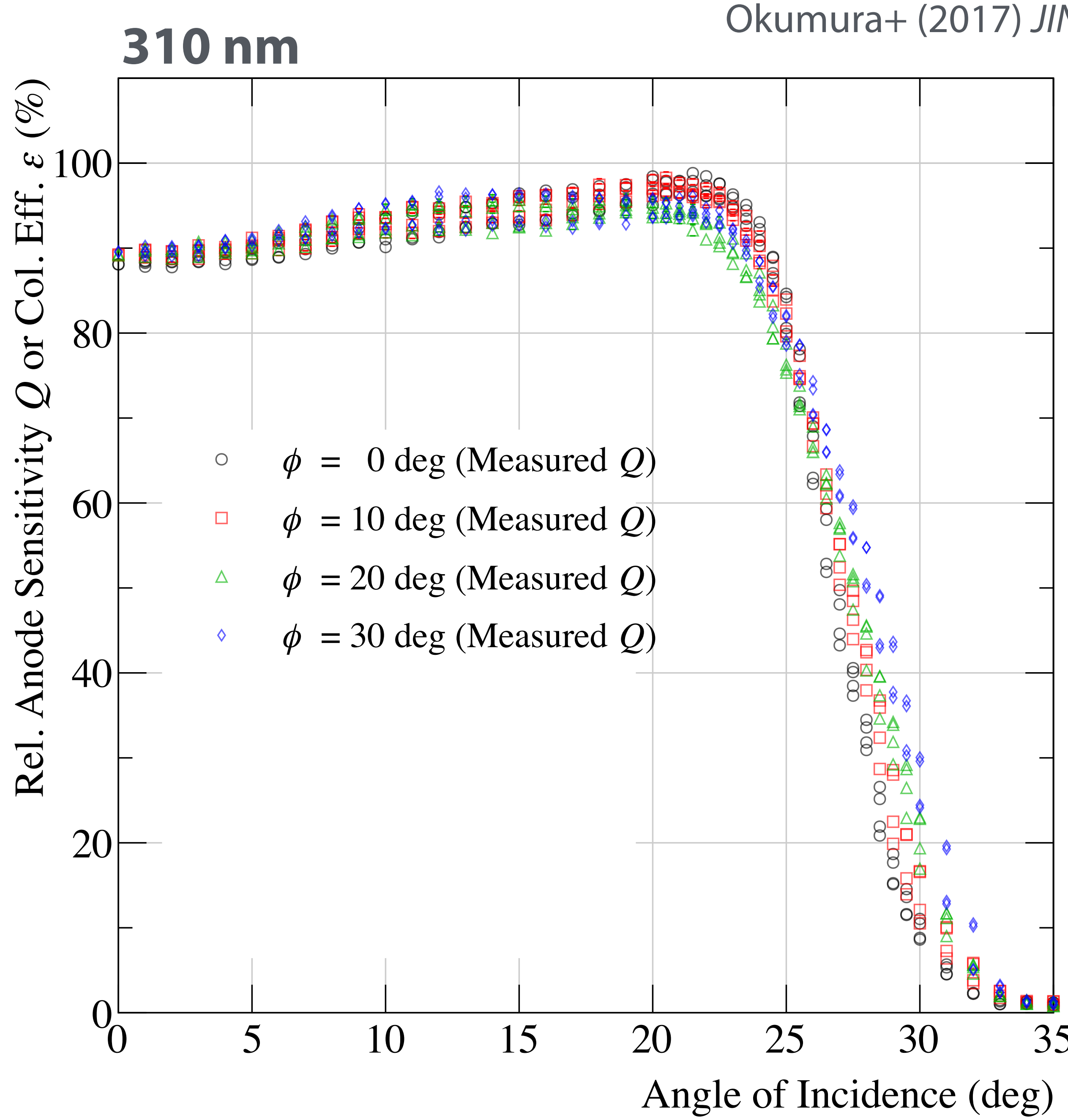


- ROBAST simulations
  - Rel. anode sensitivity
  - Collection efficiency
- Measured and simulated values are consistent within ~5% (points) for 465 nm
- Rel. anode sensitivity has a bump higher than 100% due to the angular dependence of the PMT sensitivity

365 nm and 310 nm

Okumura+ (2017) *JINST*





- Performance at 365 and 310 nm is worse than that of 465 nm presumably because lower reflectance (~93–100%) of UV-enhanced ESR
- Not very consistent with a simulation (PMT angular dependency is different?)
- But still better by 5–10 points than Al coating cones

Conclusion

- Developed new techniques to improve conventional Winston cones
  - ROBAST: New ROOT library for ray-tracing simulations
  - Use of Bézier-curve profile
  - UV-enhanced ESR (92–100% reflectance for 300–600 nm and 20–70°)
  - Take into account the PMT characteristics in simulation and design
- Measured performance at 465, 365, and 310 nm
  - Rel. anode sensitivity of ~95% to ~105% for the most important angles
  - Better by 5–10 points than Al-coating cones