CTA報告110：焦点面光検出器の光検出効率改善に向けた集光装置の開発

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cta cherenkov telescope array
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Cherenkov Telescope Array (CTA)

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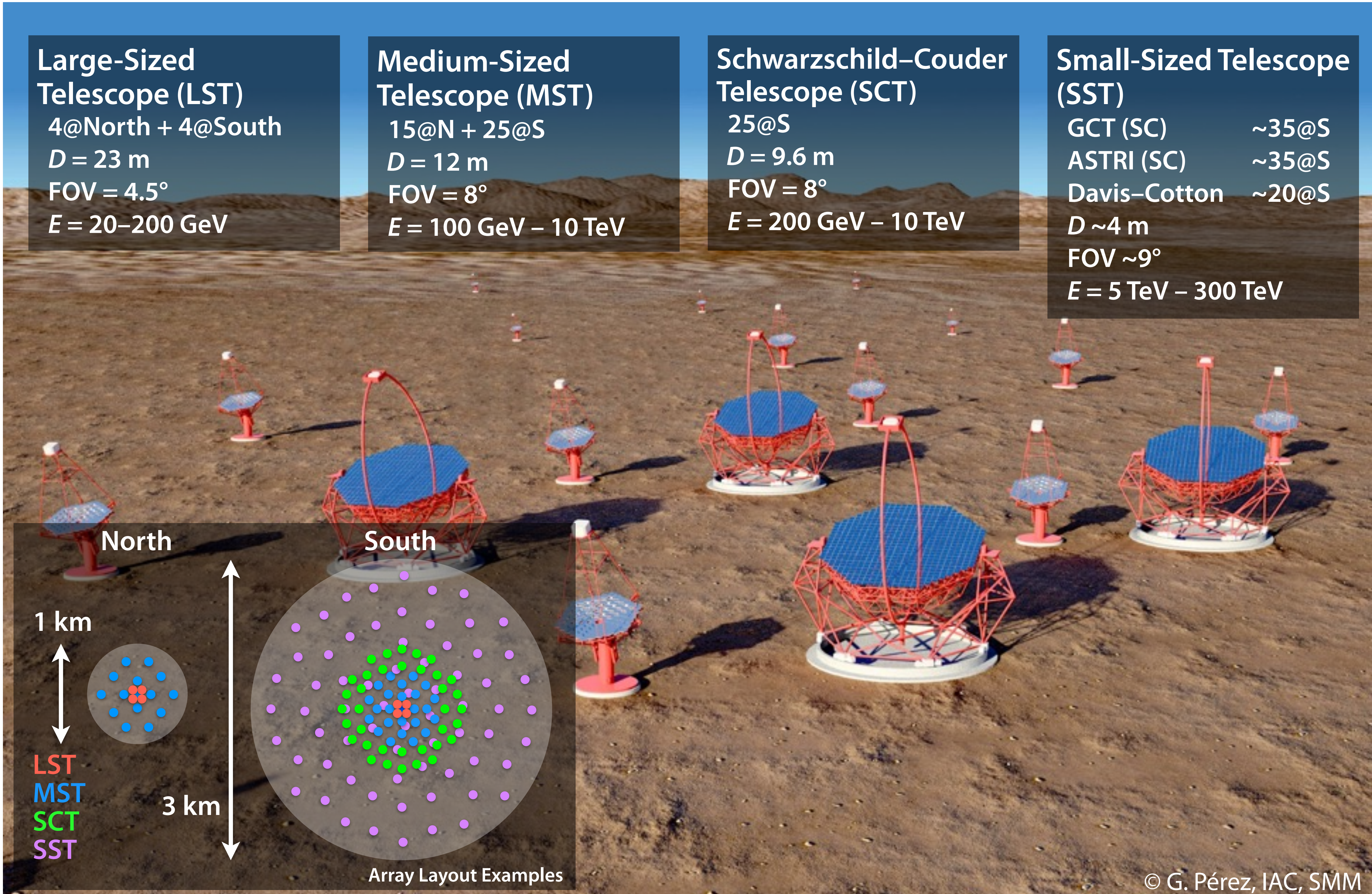
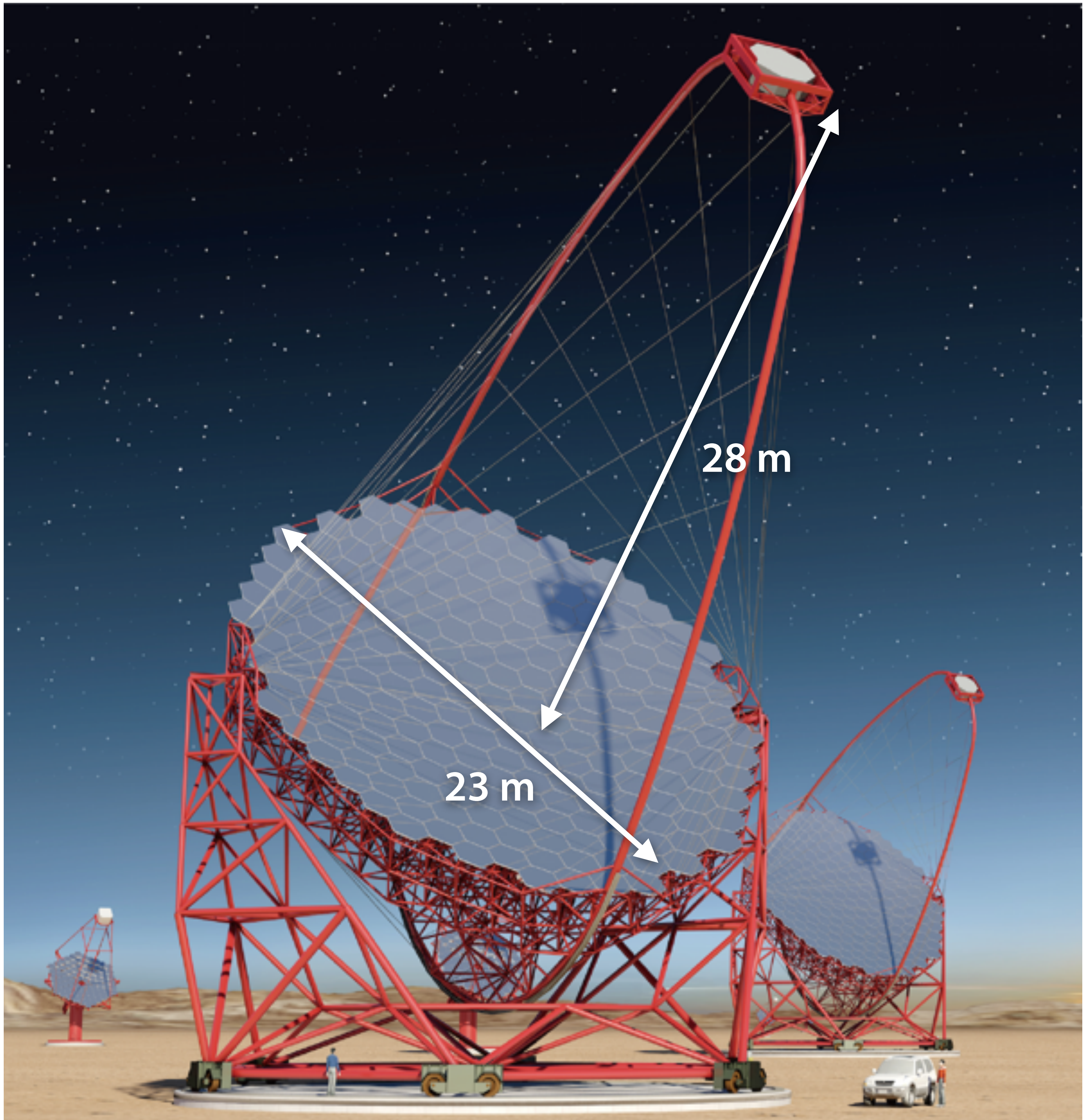
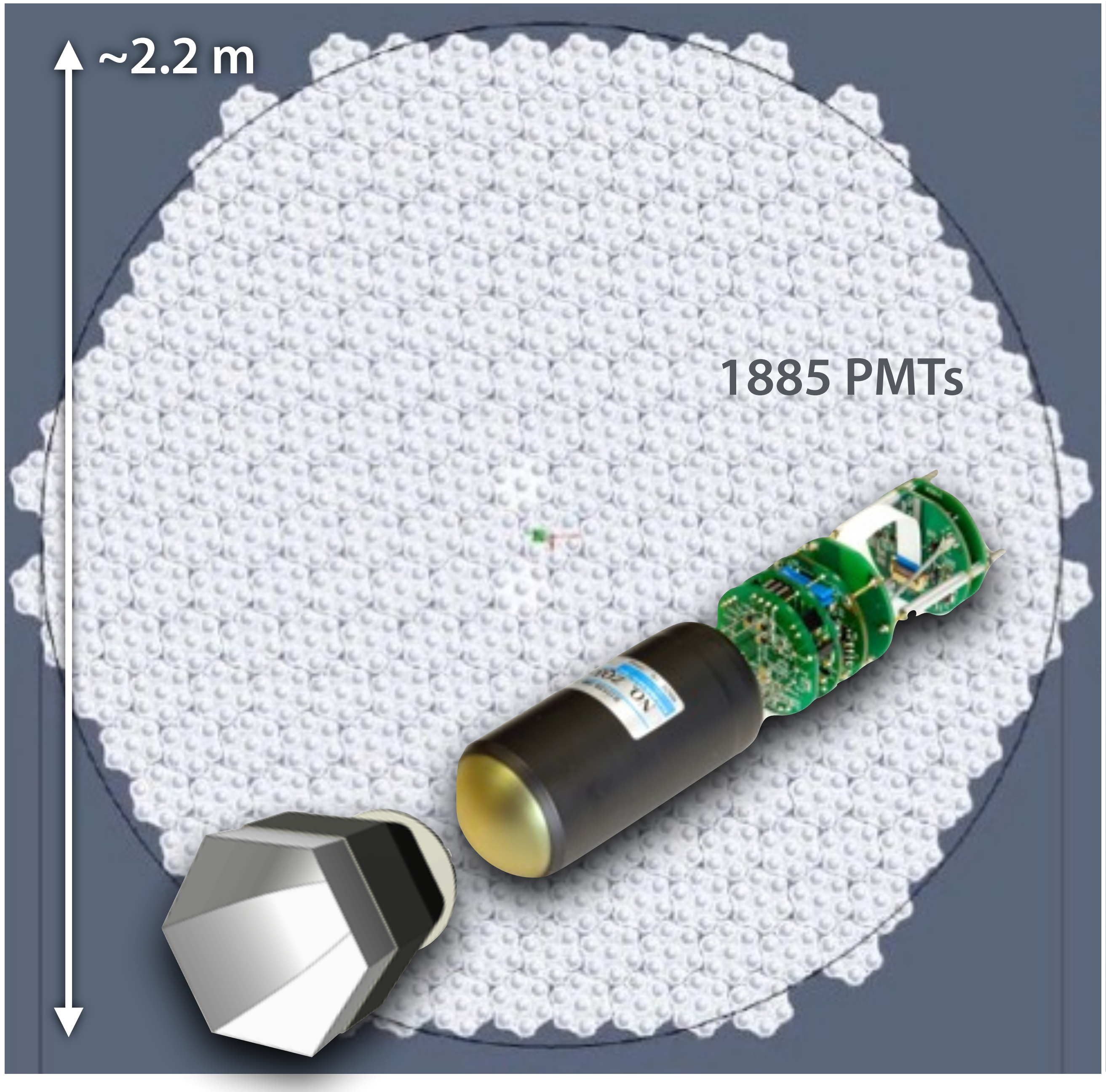


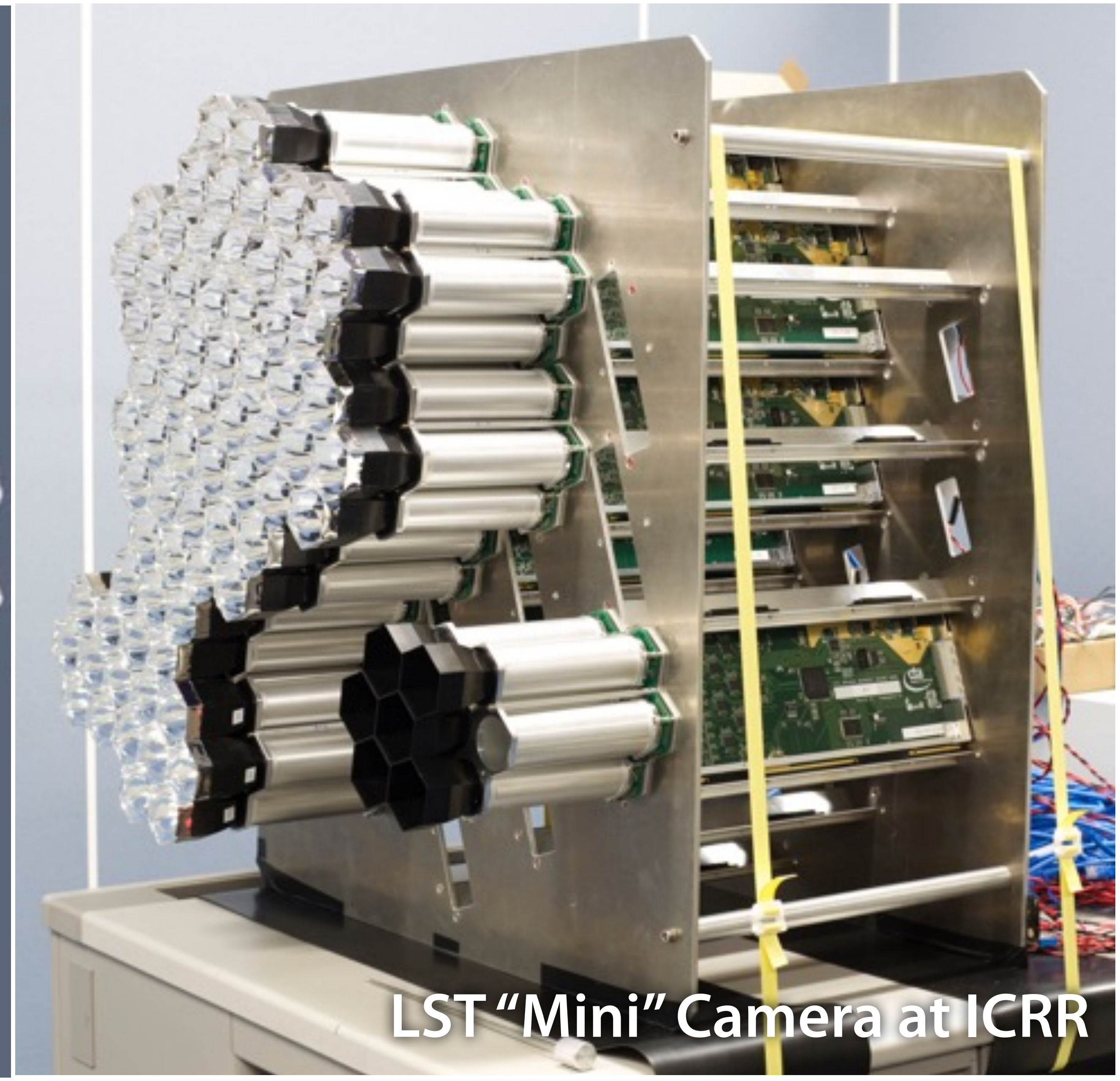
Large-Sized Telescope (LST)



- 23 m diameter × 4
- Will achieve 20 GeV energy threshold
- High statistics gamma-ray astronomy
  - Gamma-ray burst
  - AGN
  - Connection to *Fermi*/LAT (20–300 GeV)
  - Origin of extragalactic cosmic rays
- **The higher photon collection efficiency is the better**

The LST Camera





- Comprises 1855 high-QE PMTs (Peak QE ~40%) with hemispherical cathode
- Covered by hexagonal light concentrators to reduce ineffective area
- "Winston cones" have been used in Cherenkov telescopes

Ideas (1) – Bézier Curve Profile

2D Compound Parabolic Cone (CPC) or Winston Cone

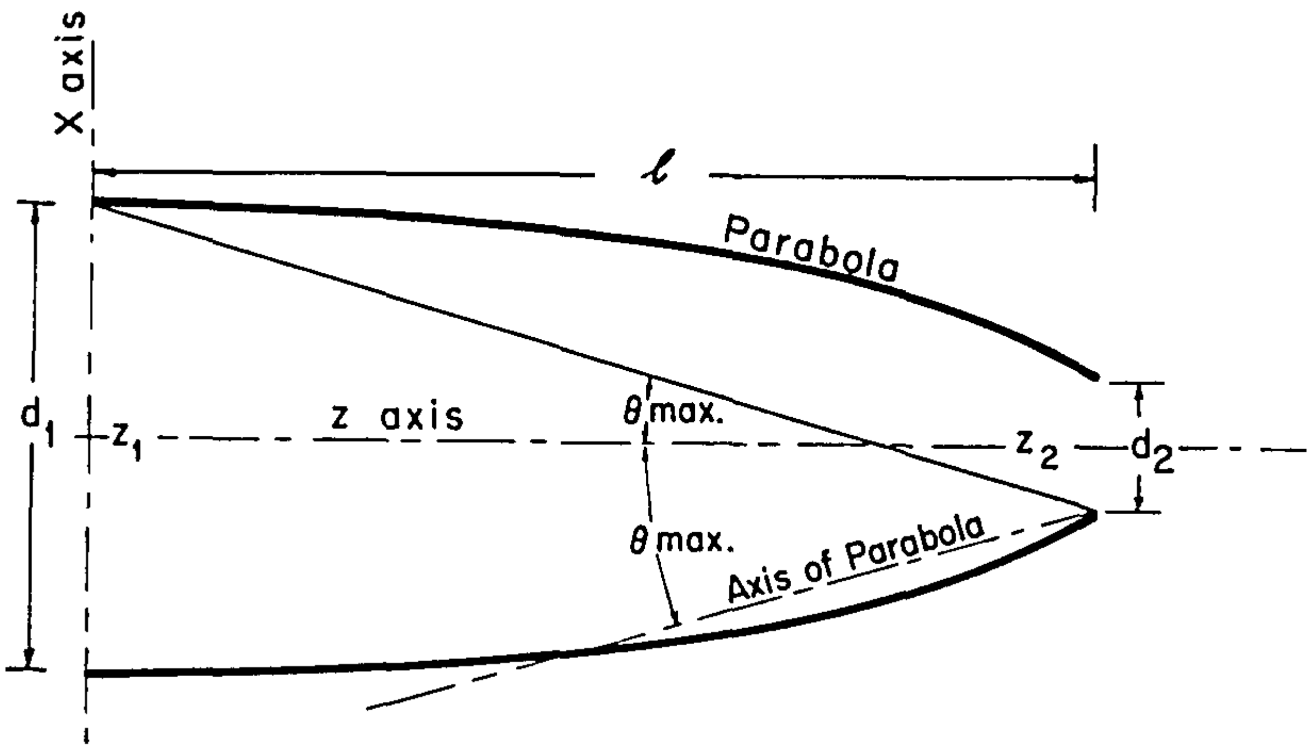
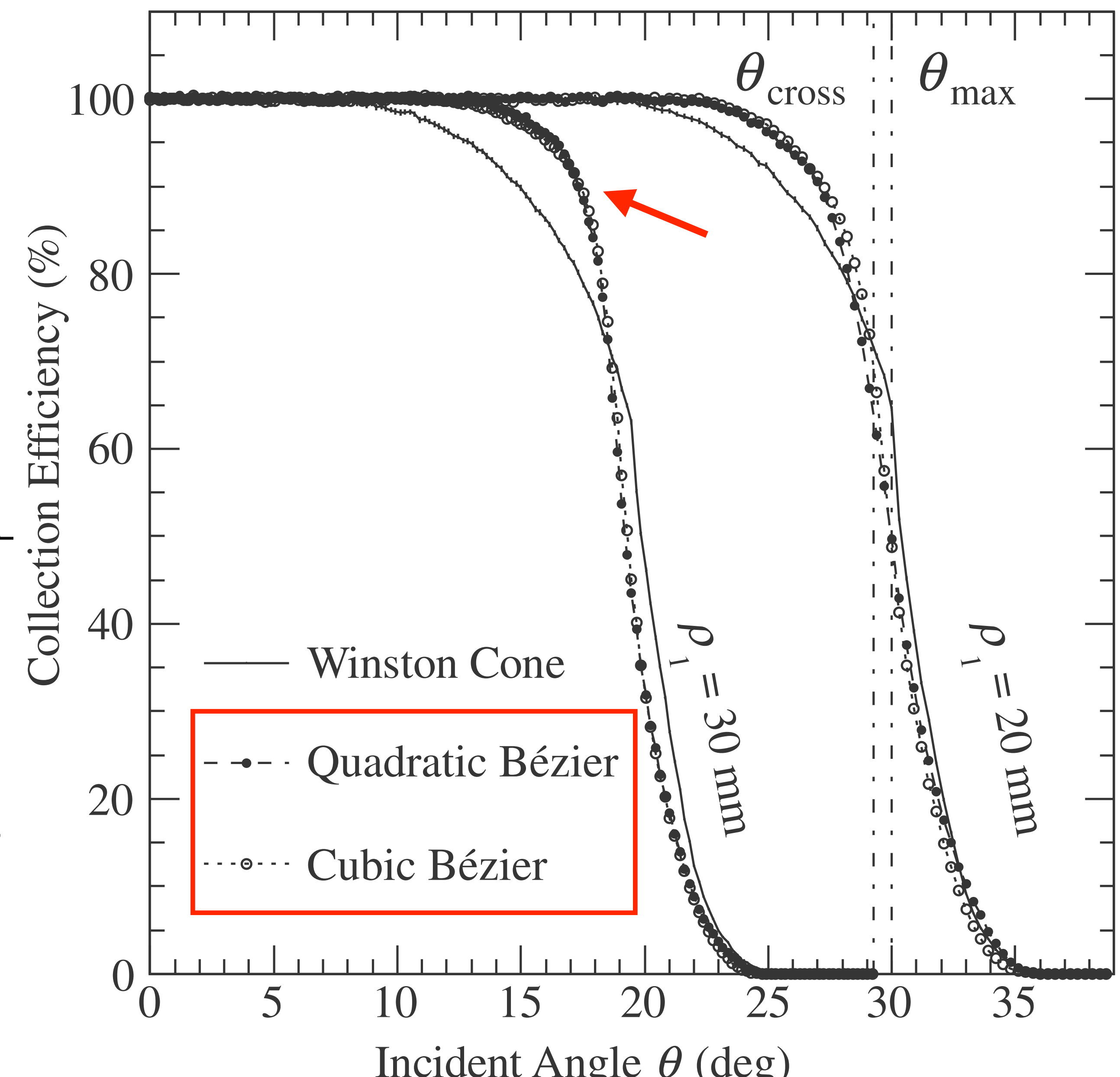


FIG. 2. Construction of an ideal light collector for the case of constant index of refraction. In this example, $\theta_{max} = 16°$.

Winston 1970

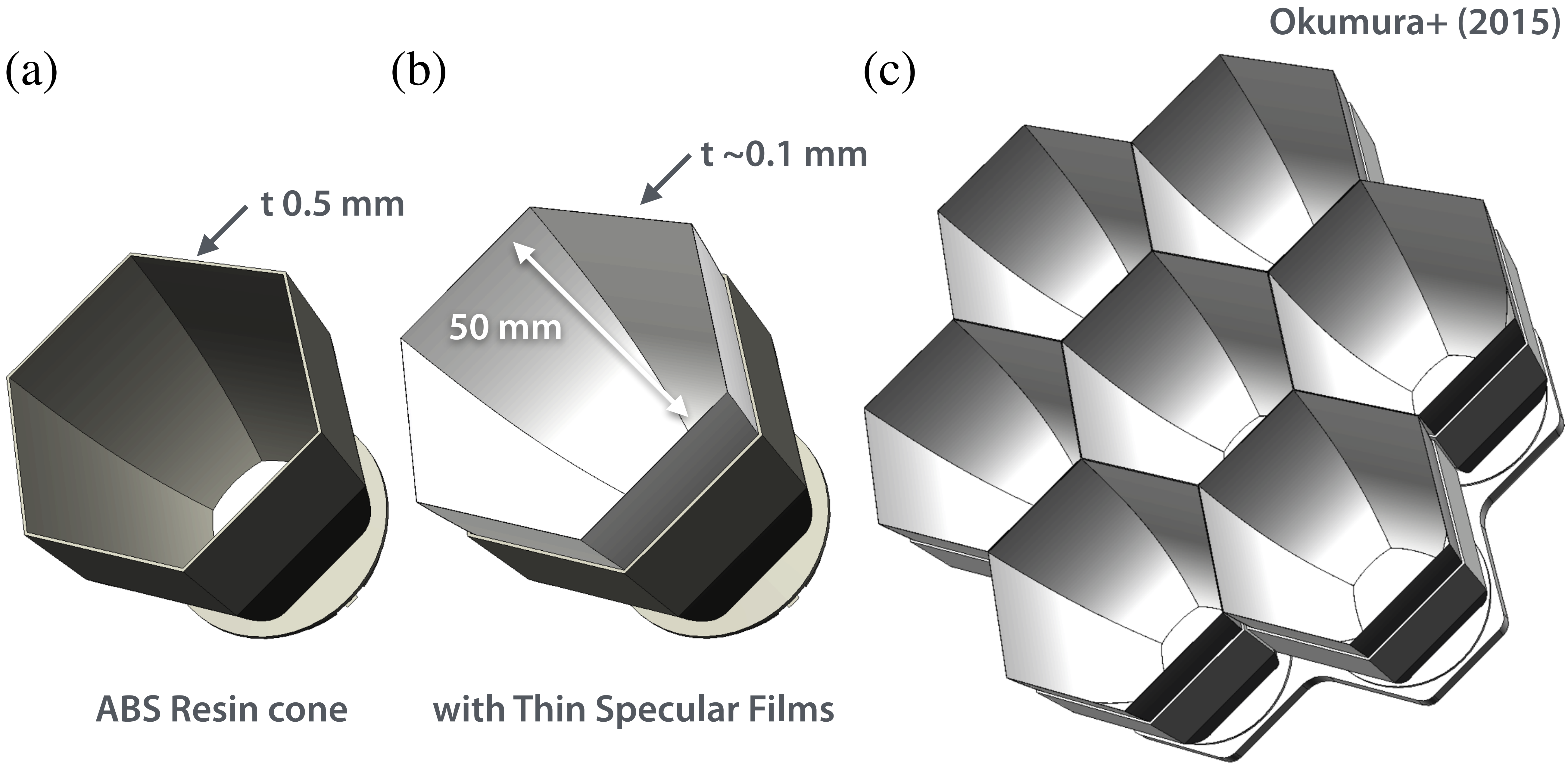
Hexagonal Case



Okumura 2012

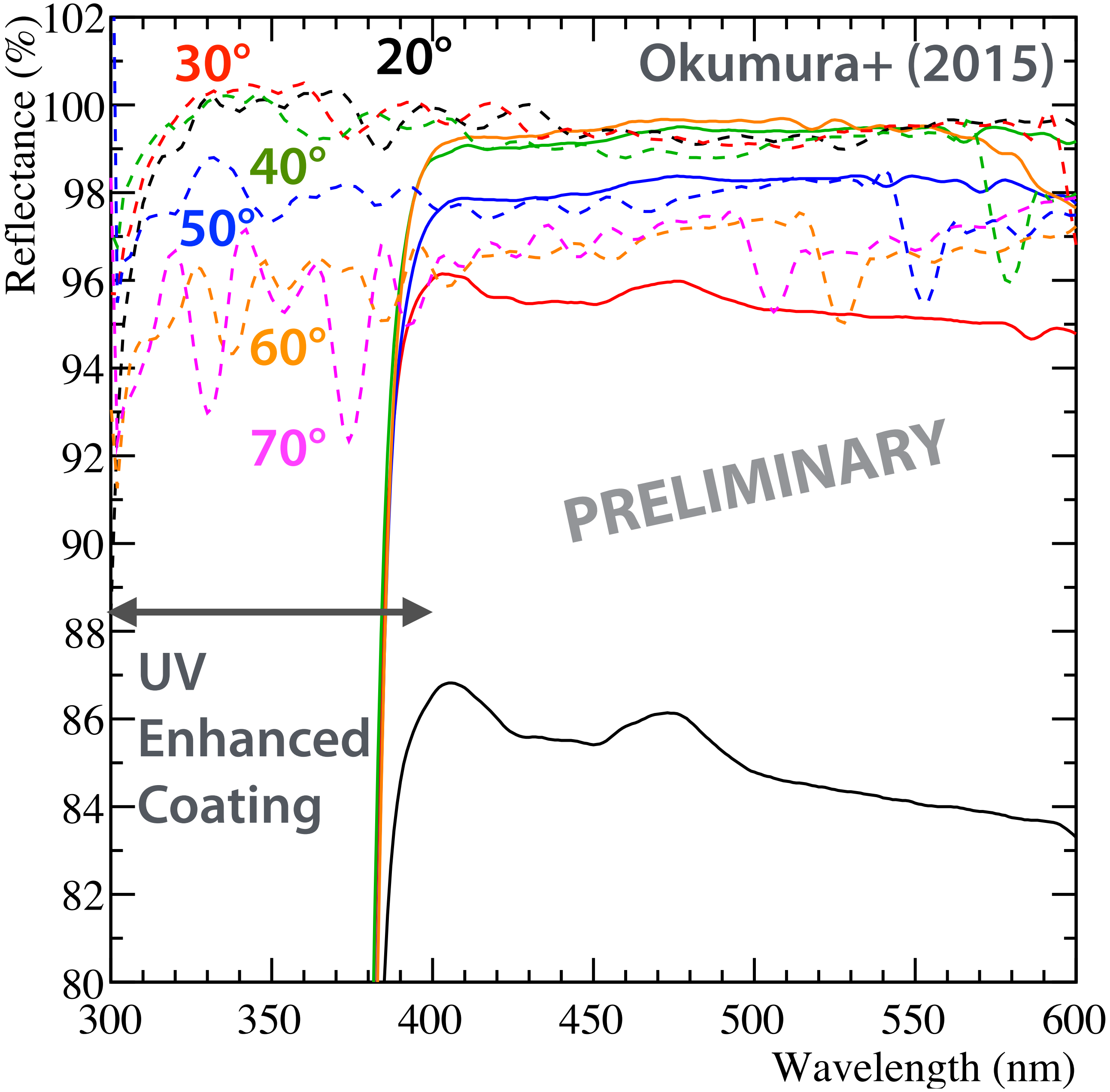
- So-called a Winston cone accepts only photons with angle of incidence within a cutoff angle (in 2D space)
- For a 3-dimensional hexagonal cone, use of a Bézier curve profile outperforms a parabolic profile

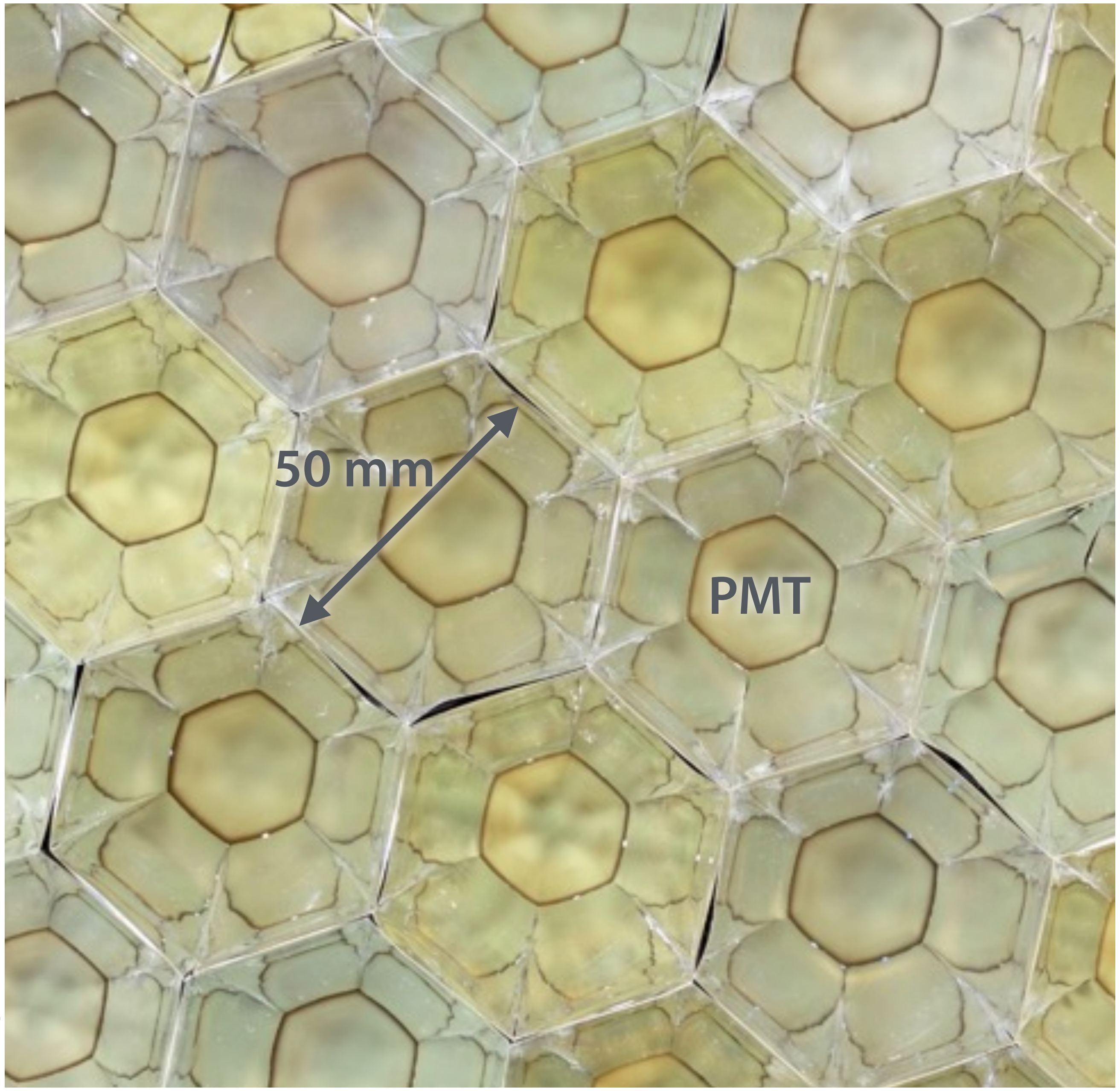
Ideas (2) – ABS Cone + Thin Specular Films



- Light weight
- Very high reflectance (~95–99%) in a wide wavelength (300–800 nm) and angle (20–70 deg) ranges that cannot be achieved by aluminum coating
- Minimum dead area (~0.1 mm) thanks to the film thickness

Ideas (3) – ESR Films + Multilayer Coating



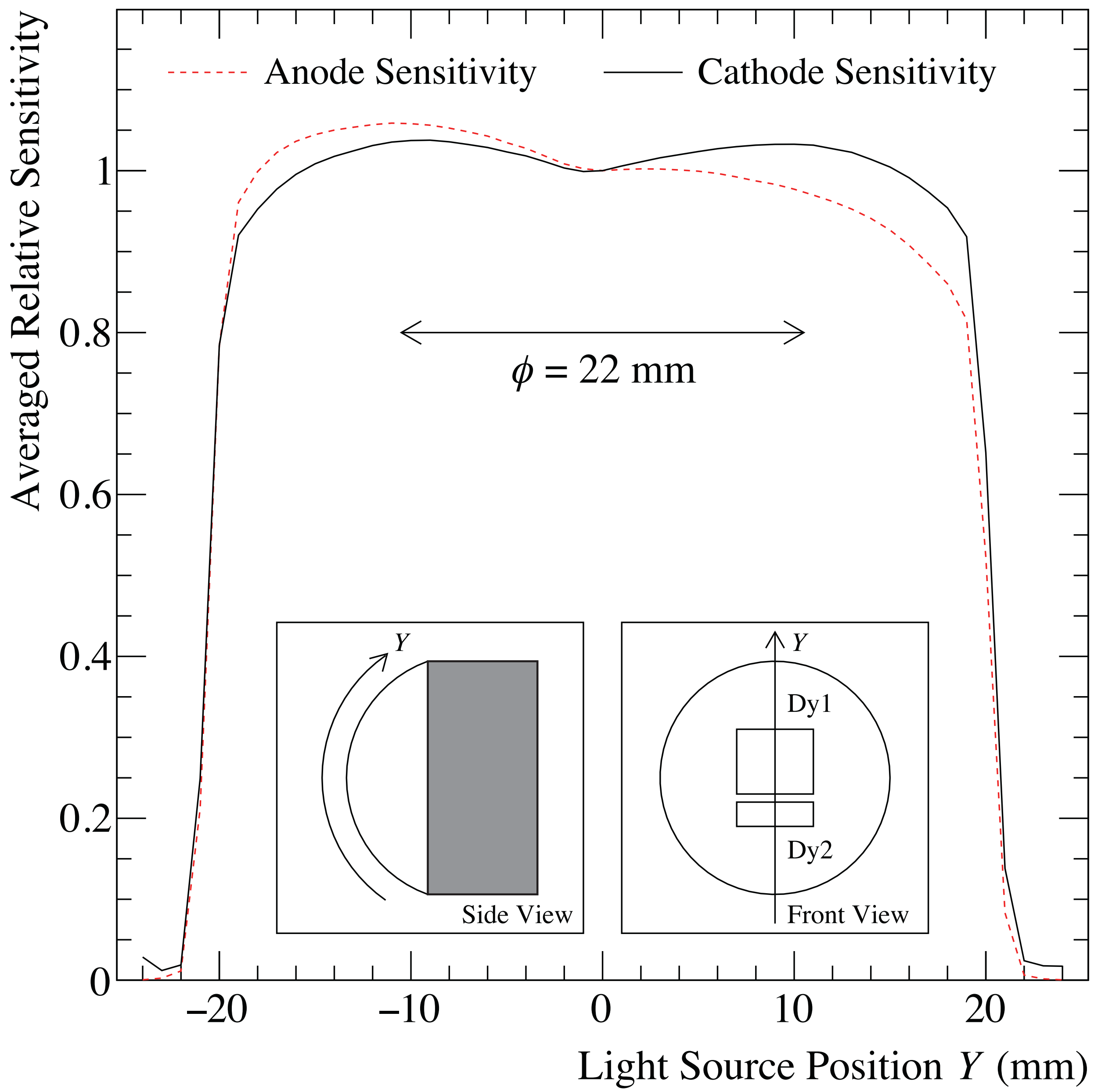


- Base film: 3M Vikuiti™ Enhanced Specular Reflector (ESR) (insulating, *R* >95%, >400 nm)
- Multilayer coating: 54 layers (Ta_2O_5 and SiO_2) to enhance UV reflectance
- ≳95% reflectance in wide ranges of angle and wavelength

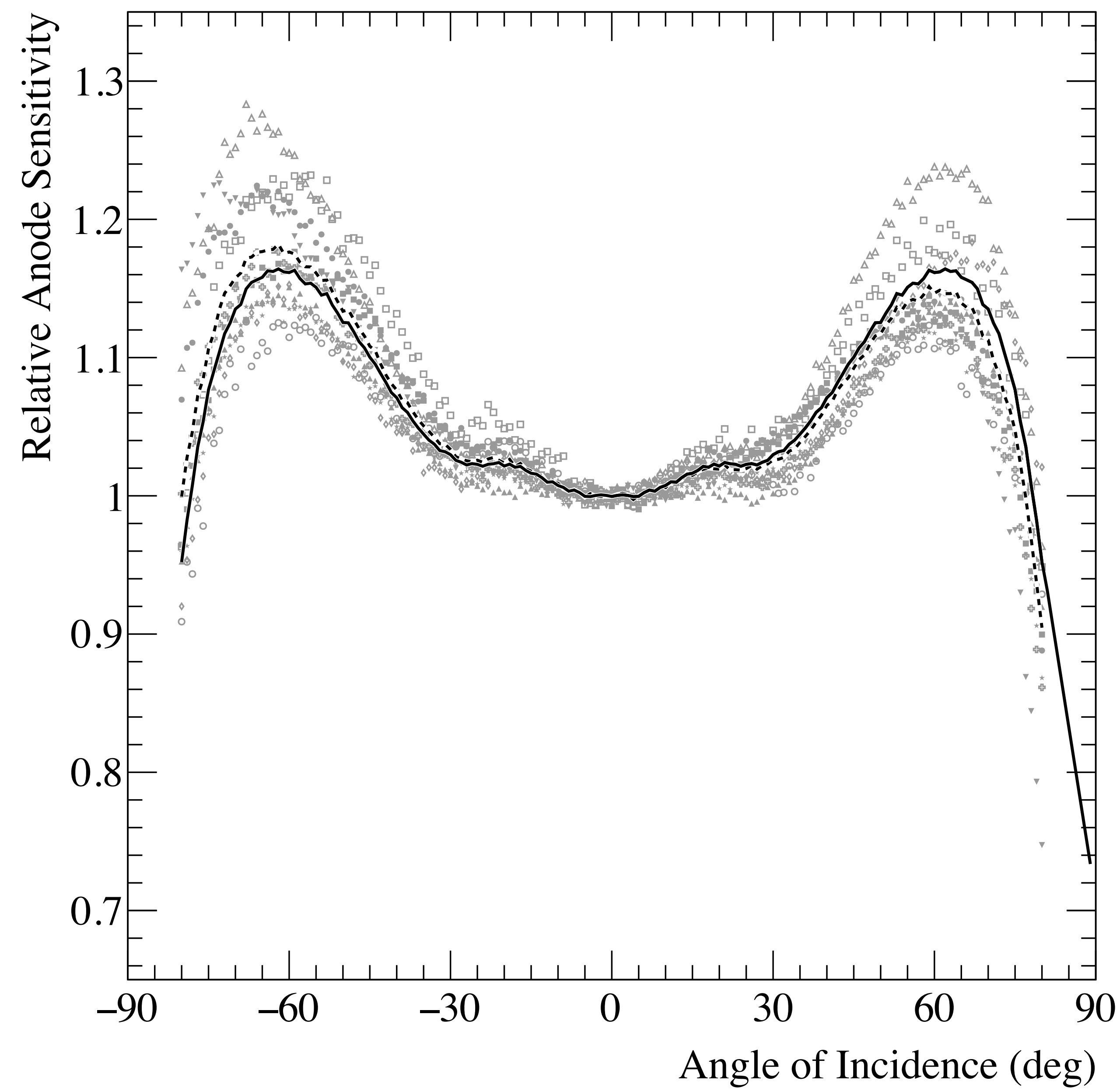
PMT Anode Sensitivity

Okumura+ (2015)

Positional Dependence



Angular Dependence

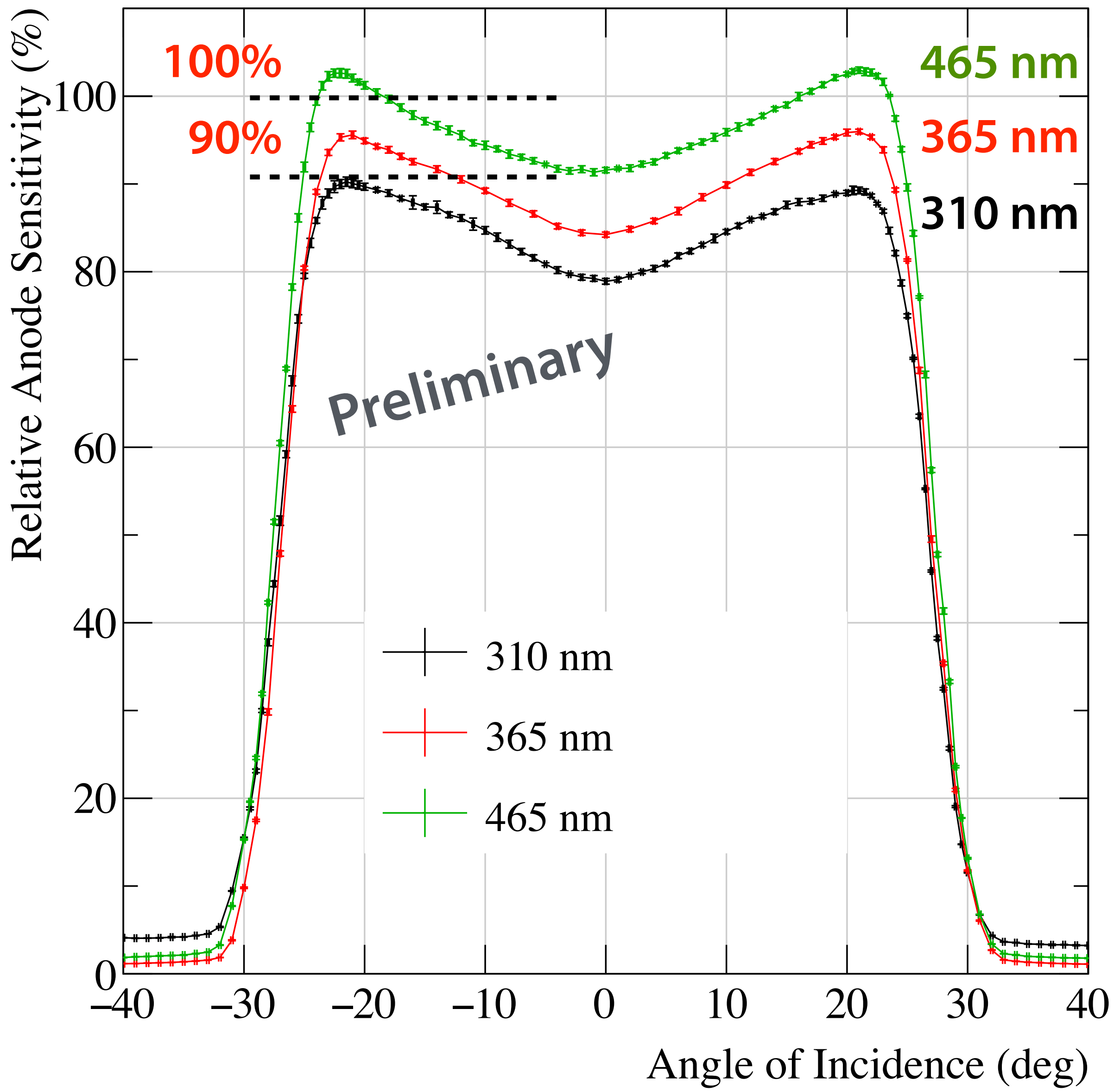


- CTA PMT (R11920-100-20) has positional and angular dependence of anode sensitivity
- The cone profile was optimized considering these dependence and film reflectance
- Note: Collection efficiency of a light concentrator cannot be defined

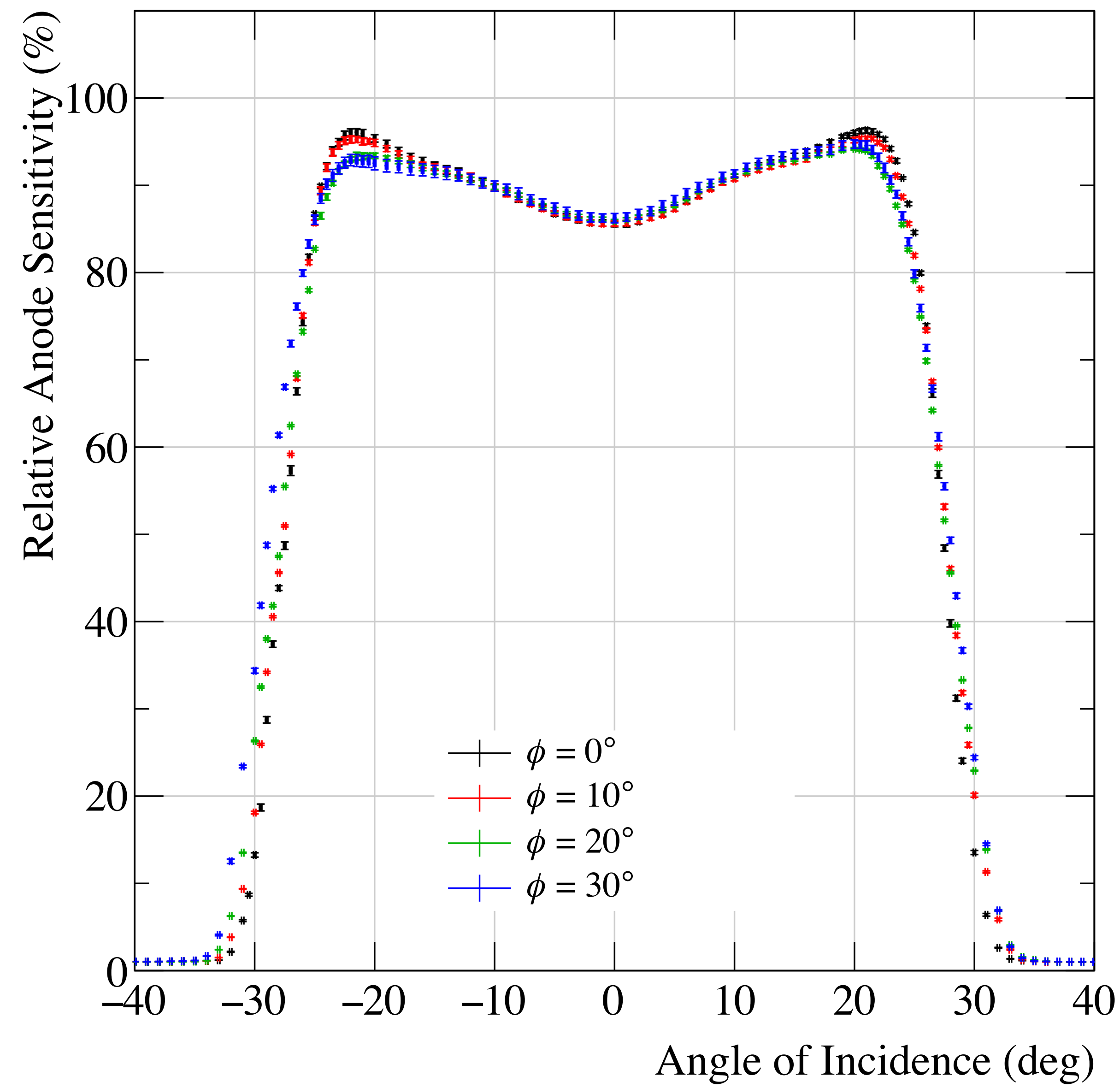
Performance

Measurements by Dang Viet Tan (Ibaraki)

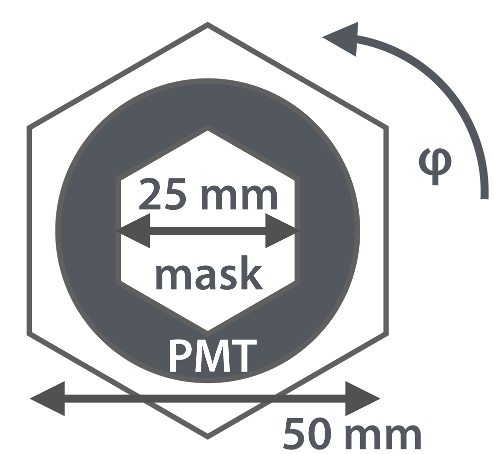
Color Dependence



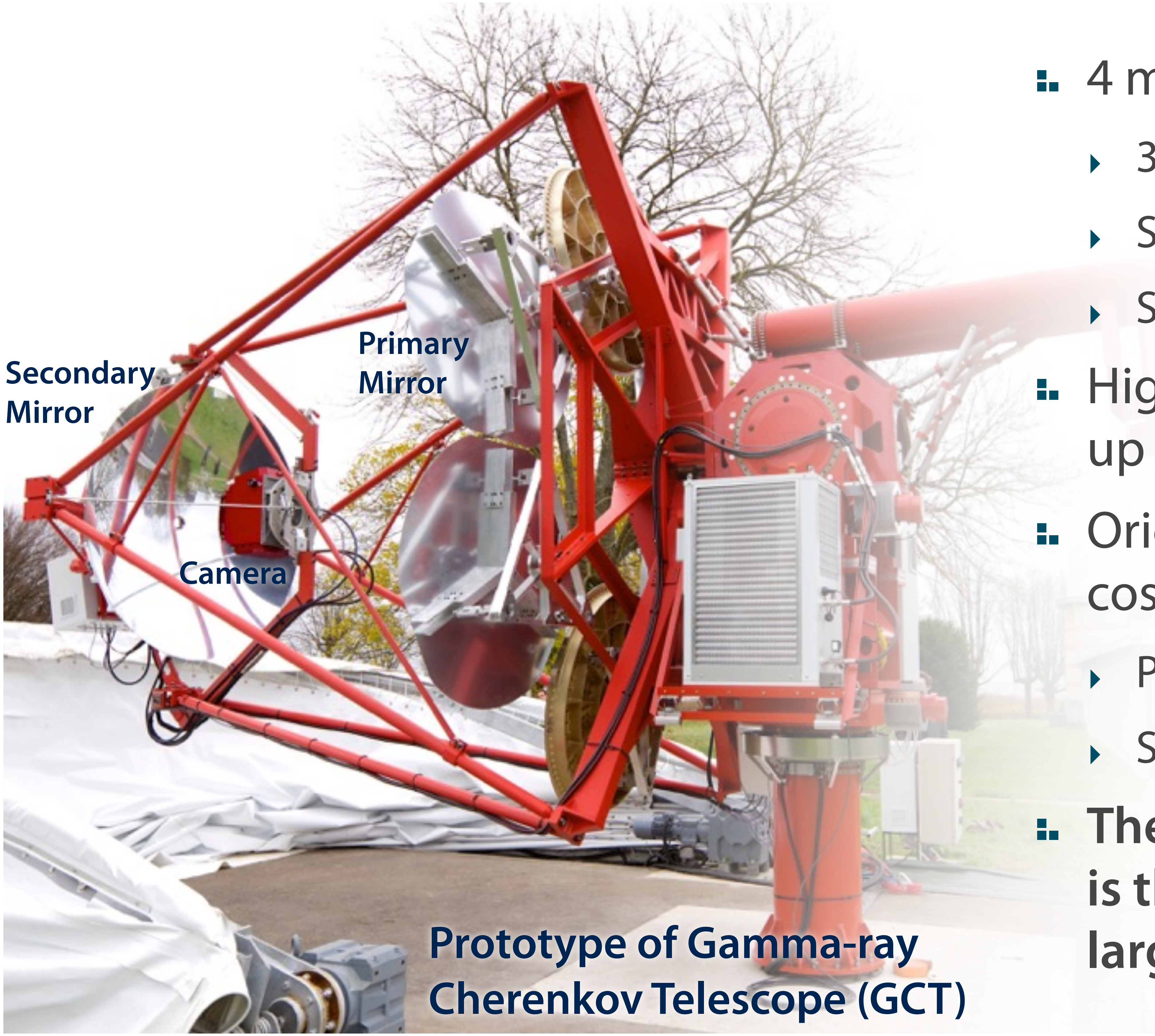
Rotational Dependence (365nm)



- The anode sensitivity normalized to a 25-mm mask shows 90 to >100% at the most important angles
- 5–10% better than Al + multilayer coating on plastic
- Trade-off between detection efficiency and cost/labor/uniformity

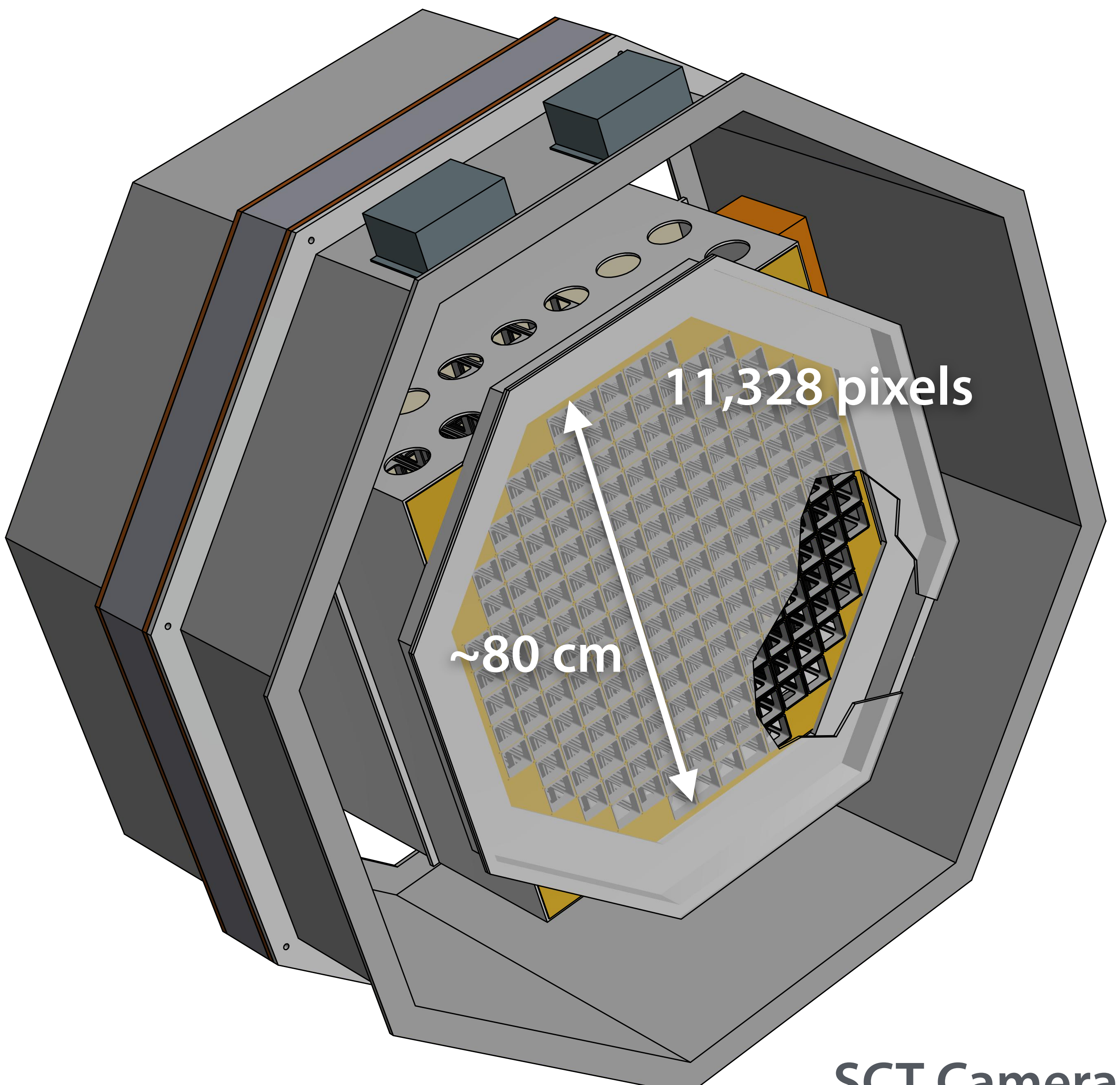


Small-Sized Telescope (SST)

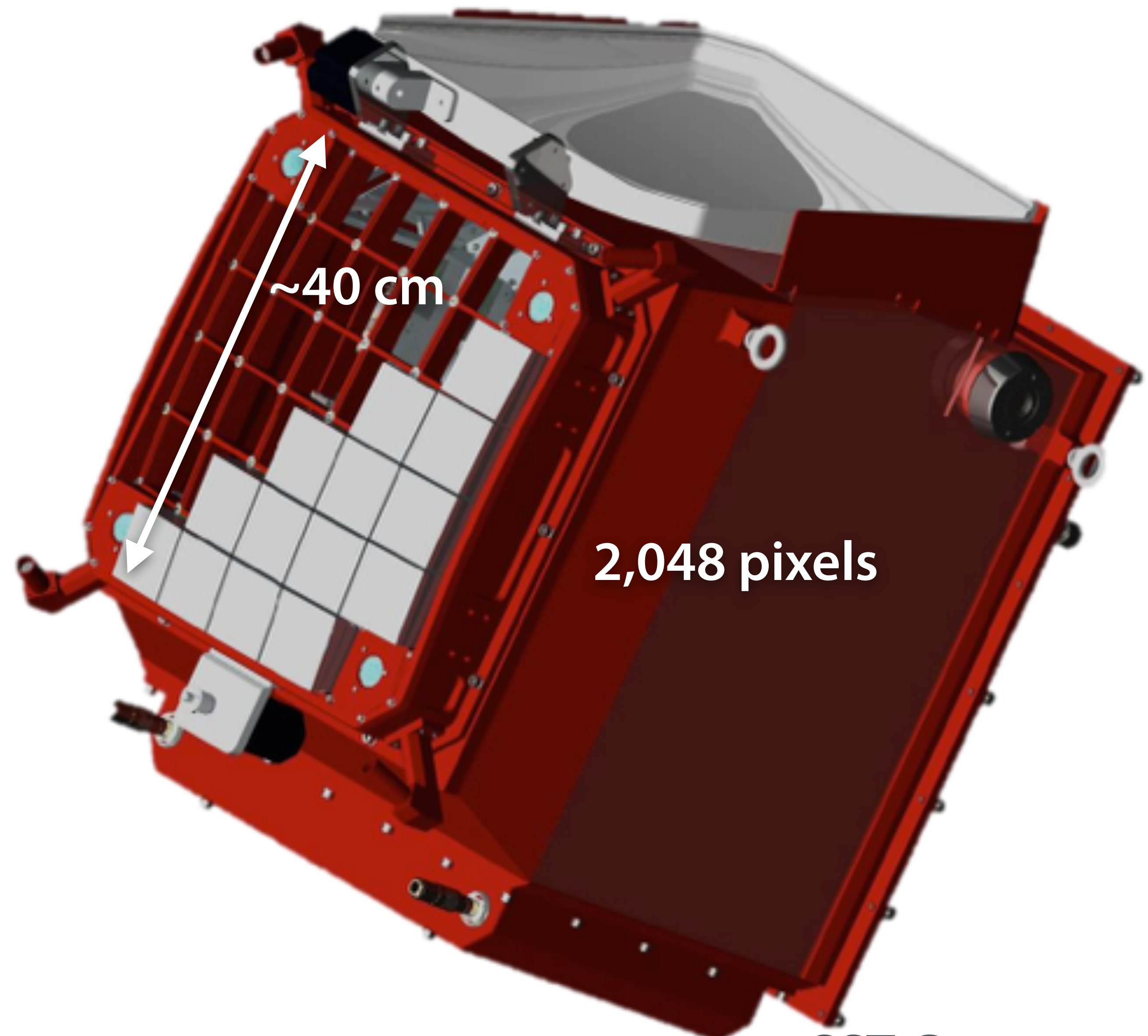


- 4 m diameter × 70
  - 3 designs proposed
  - SiPM based cameras
  - Spread over a few km^2
- High-energy frontier up to 300 TeV
- Origins of Galactic cosmic rays
  - PeVatron(s) search
  - Supernova remnants
- **The cheaper unit price is the better for a large effective area**

SiPM Cameras (SCT and SSTs)



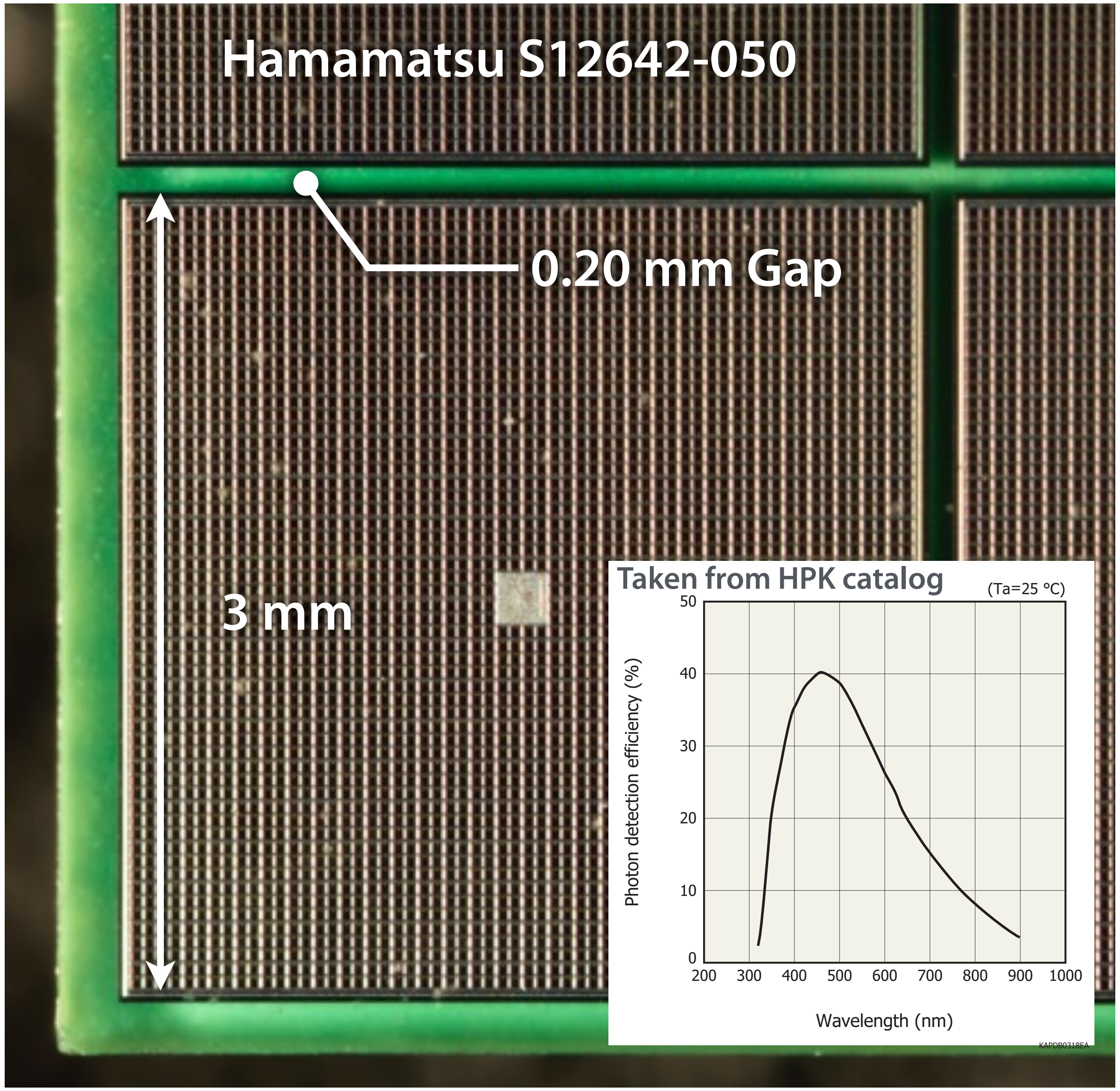
SCT Camera

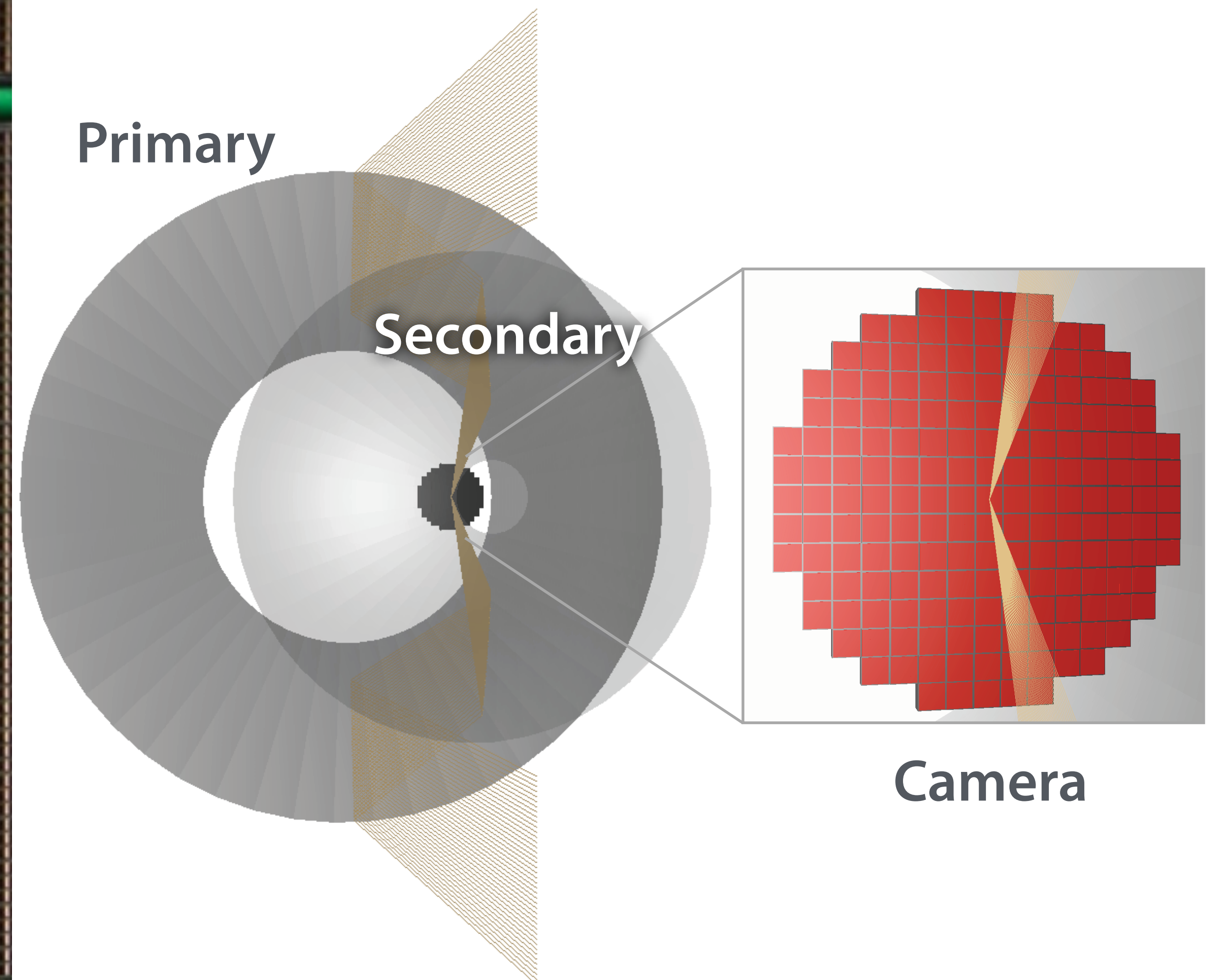


SST Camera

- First use of Schwarzschild-Couder optics (aspherical primary and secondary)
- Small plate-scale, small angular resolution (~4–6 arcmin), and large FOV (8–9°) require a fine pixel size of ~6 mm and multi-channel photodetectors

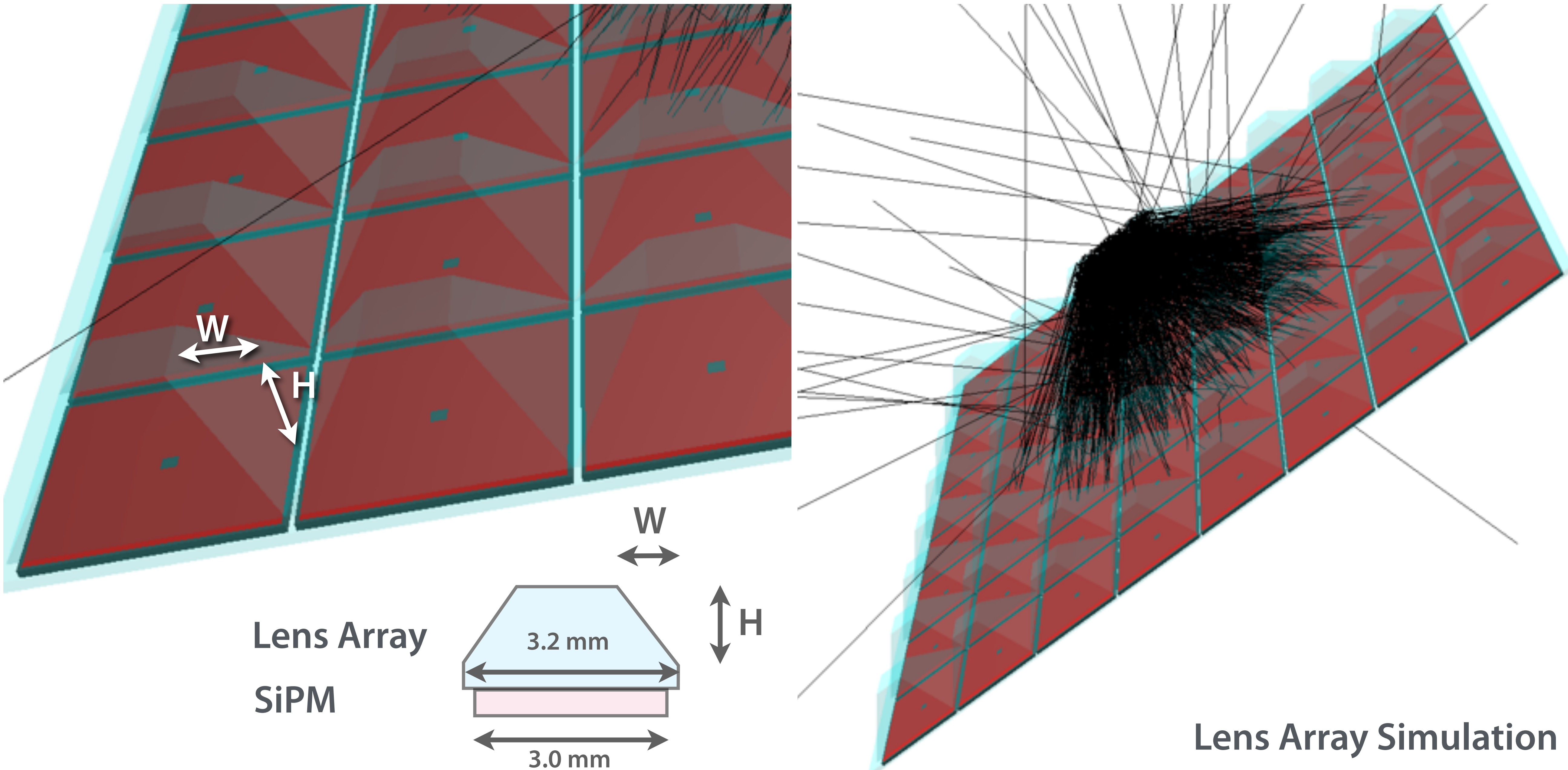
SiPM Dead Space and Fresnel Reflection





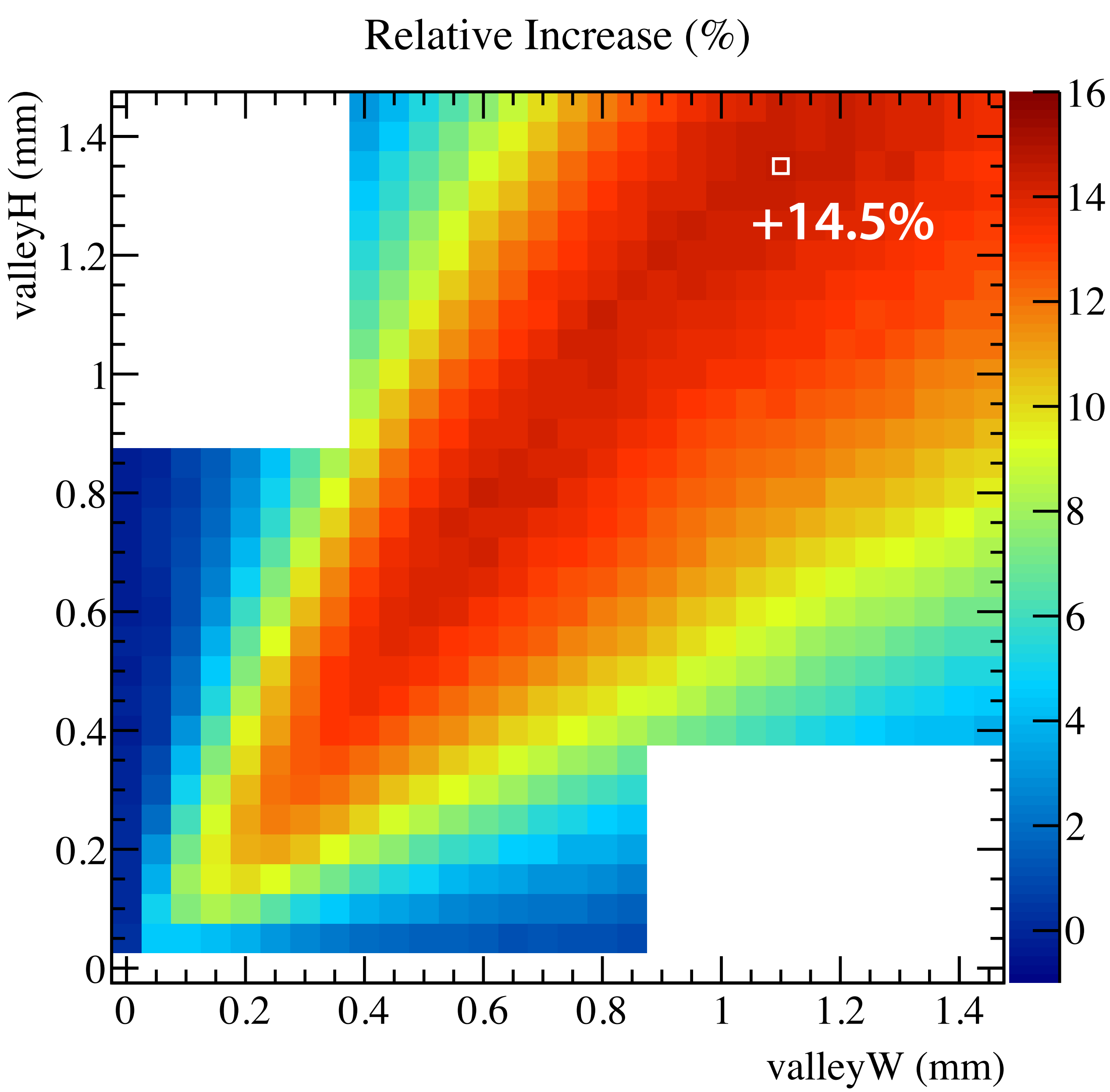
- ~15% photons are lost due to the pixel gaps (typically 0.2 mm)
- Angle of incidence ranges from 30 to 60 degrees in SC optics, resulting in higher Fresnel reflection than parabola or Davies–Cotton

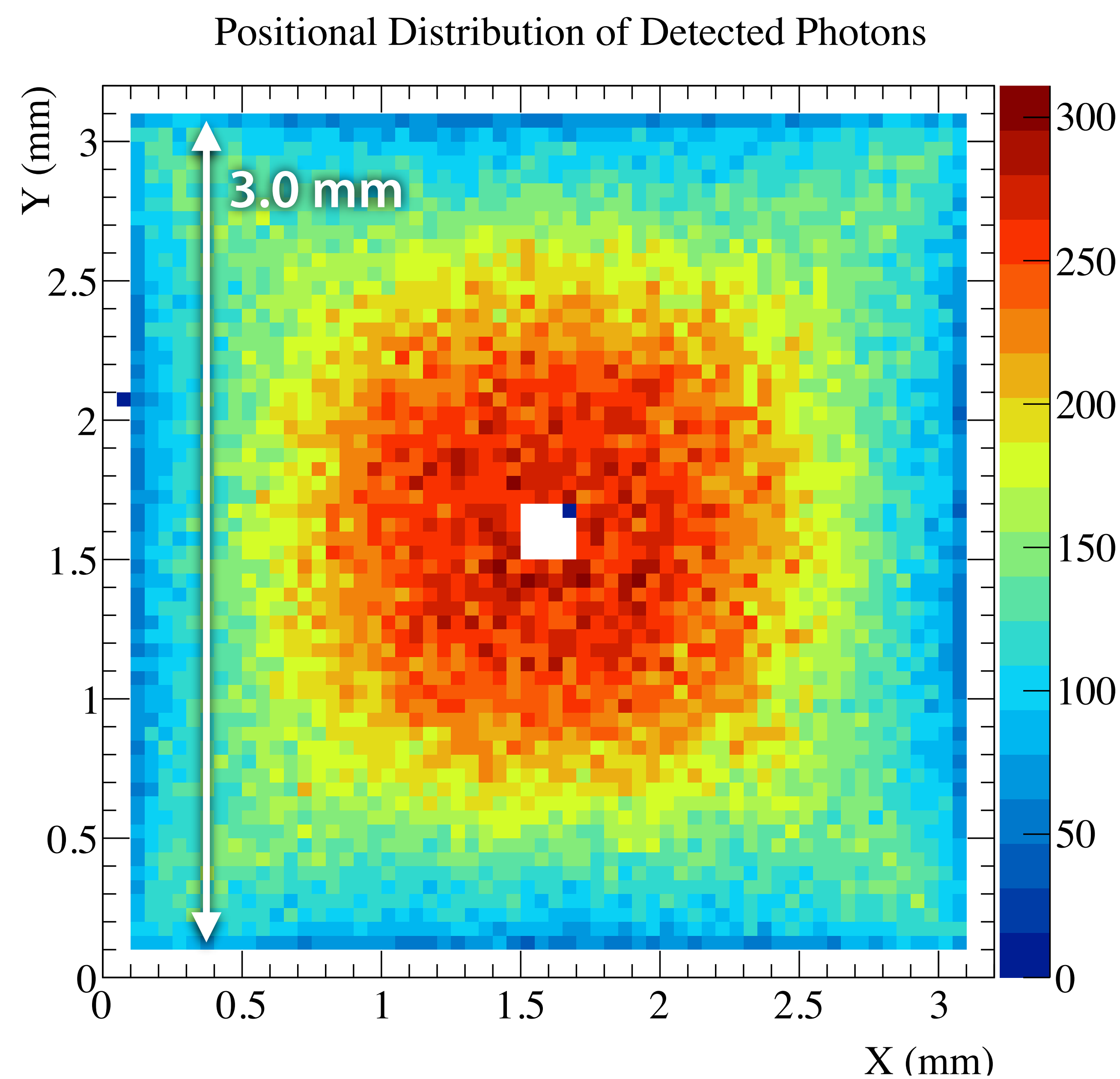
Lens Array for SiPM



- Silicone is highly UV transparent and can be molded
- Simulated a silicone lens array with various lens shape parameters by ROBAST (Okumura+ 2016, see http://robast.github.io/)

Simulation Results





- PDE can be improved by 14.5% (e.g., PDE 40% → 46%)
- Photons are concentrated on the inner region of individual SiPM pixels
- Currently prototyping a lens array made of UV-transparent glass

Summary

- Developed a hexagonal light concentrator for CTA Large-Sized Telescopes using highly reflective specular films
- Achieved 80–100% collection efficiency for various colors
- The film can be used for other detectors such as scintillators

- An idea of a light concentrator (lens array) for an SiPM array has been also studied and proposed
- Prototyping a lens array made of UV-transparent glass