CTA報告 171：小口径望遠鏡用 SiPMの光検出効率の入射角度依存性

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2020 年 9 月 15 日 @ 日本物理学会 2020 年秋季大会

名古屋大学 NAGOYA UNIVERSITY

ISEE Institute for Space-Earth Environmental Research

KMI Kobayashi-Maskawa Institute for the Origin of Particles and the Universe

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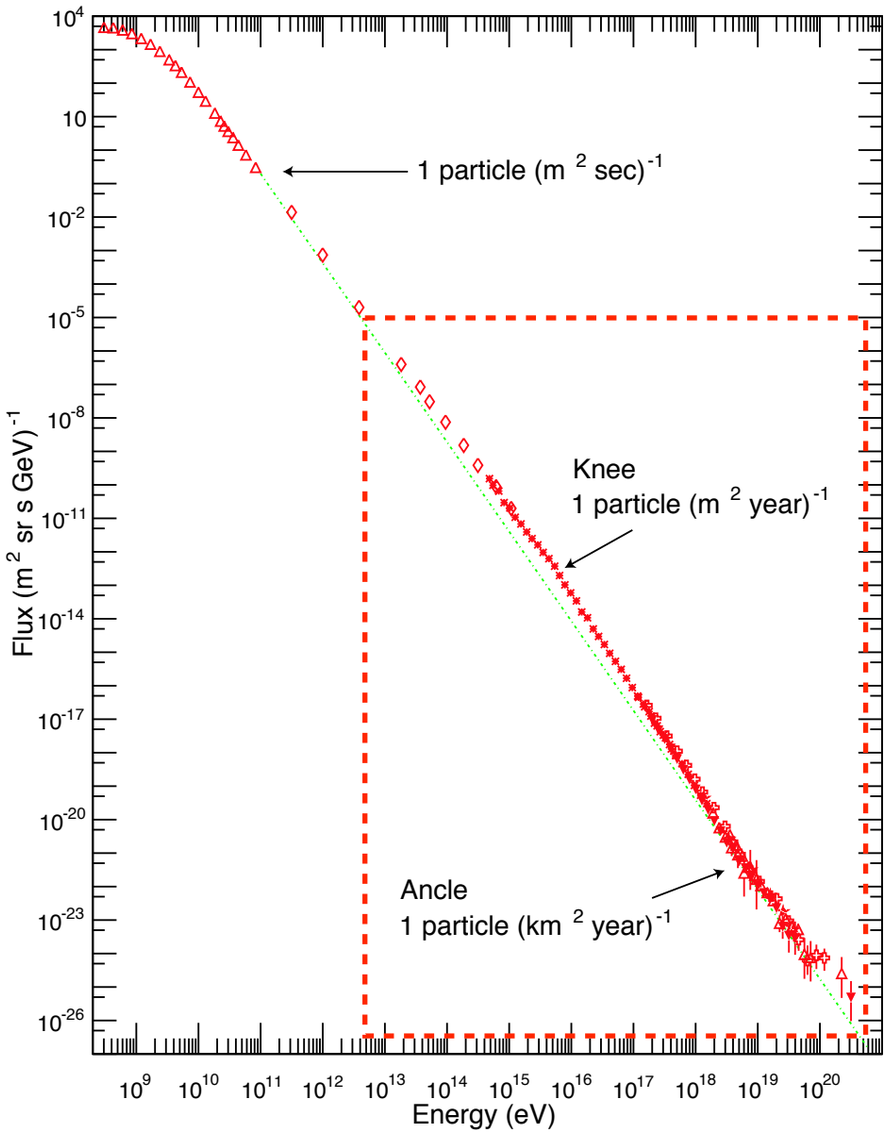
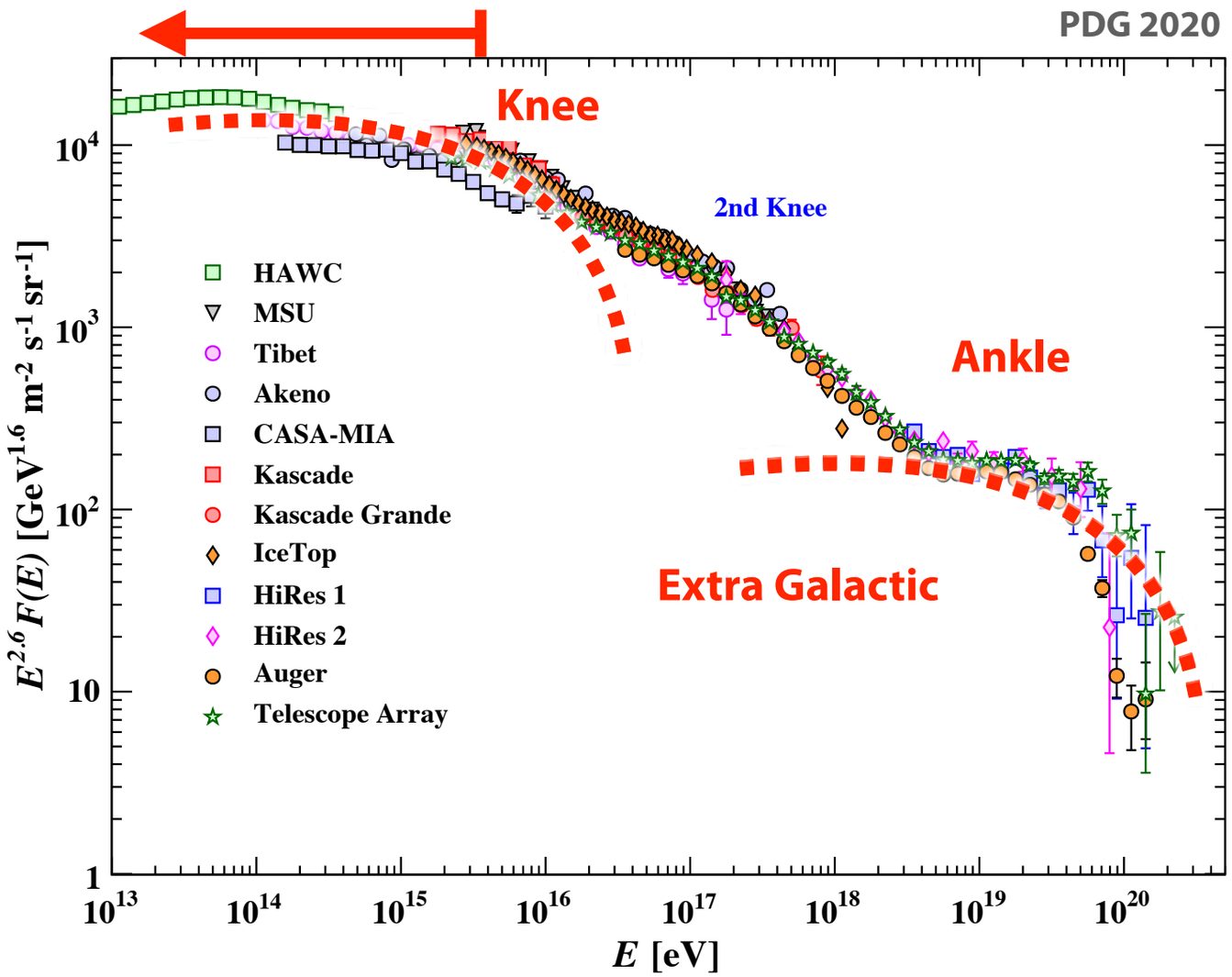
Cosmic-ray Hadron Spectrum

Modified Cronin+ (1997)



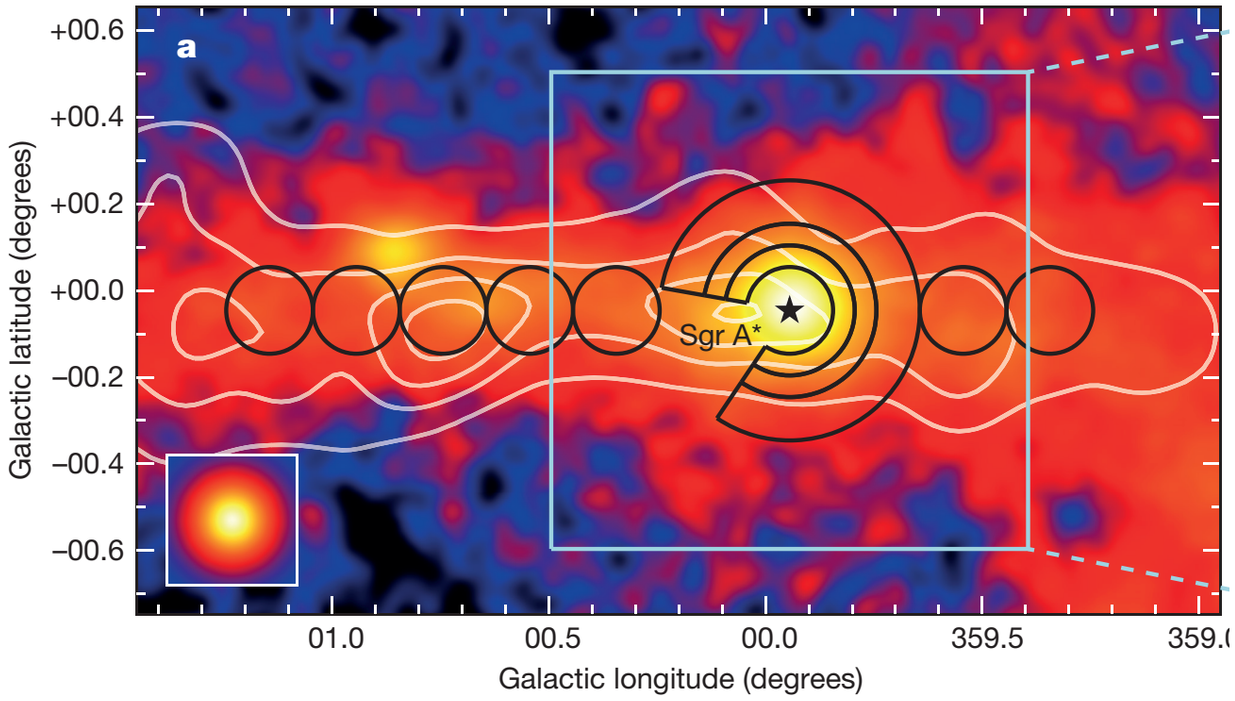
Galactic CRs ~3 × 10¹⁵ eV (3 PeV)

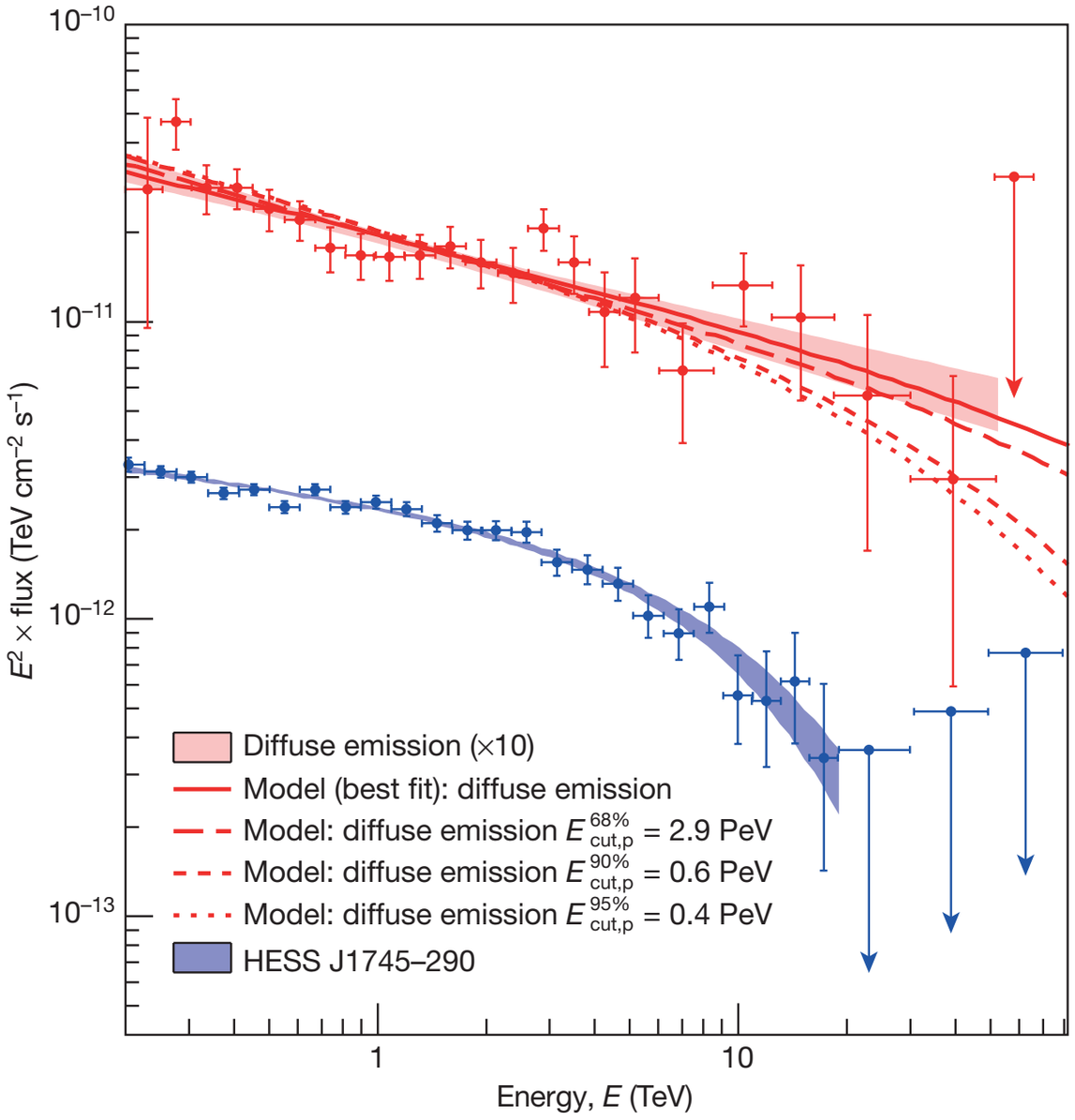


- ~10^8 eV (~100 MeV) to > 10^{20} eV, with a power law of $dN/dE = E^{-2.7}$ to $E^{-3.0}$
- What is the origin (PeVatron) of Galactic CRs (< ~3 PeV)? Supernova remnants? Galactic center?

Galactic Center Region

H.E.S.S. (2016)





- Massive black hole ($4 \times 10^6\ M_\odot$) at Sgr A* (bright radio source)
- Point source HESS J1745–290 at Str A* and diffuse gamma-ray emission
- Diffuse component has a cutoff energy of 2.9 PeV (68% conf.) → PeVatron?

Cherenkov Telescope Array (CTA)

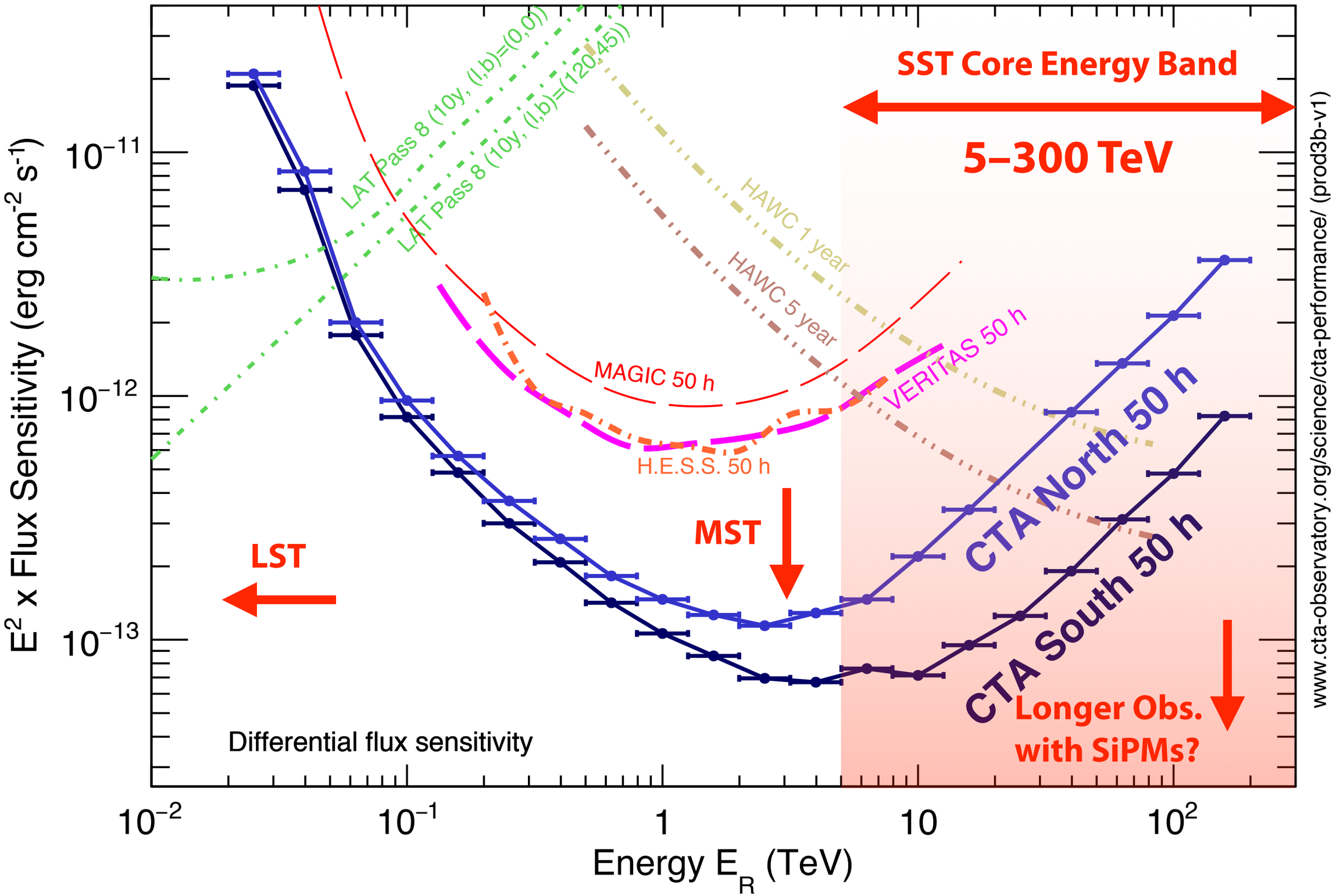
cherenkov
telescope
array

Small-Sized Telescope (SST)
Dia. : 4 m
Energy : 5–300 TeV
N_{Tel} : 0 @ North, 70 @ South

Image Credit: G. Pérez, IAC, SMM

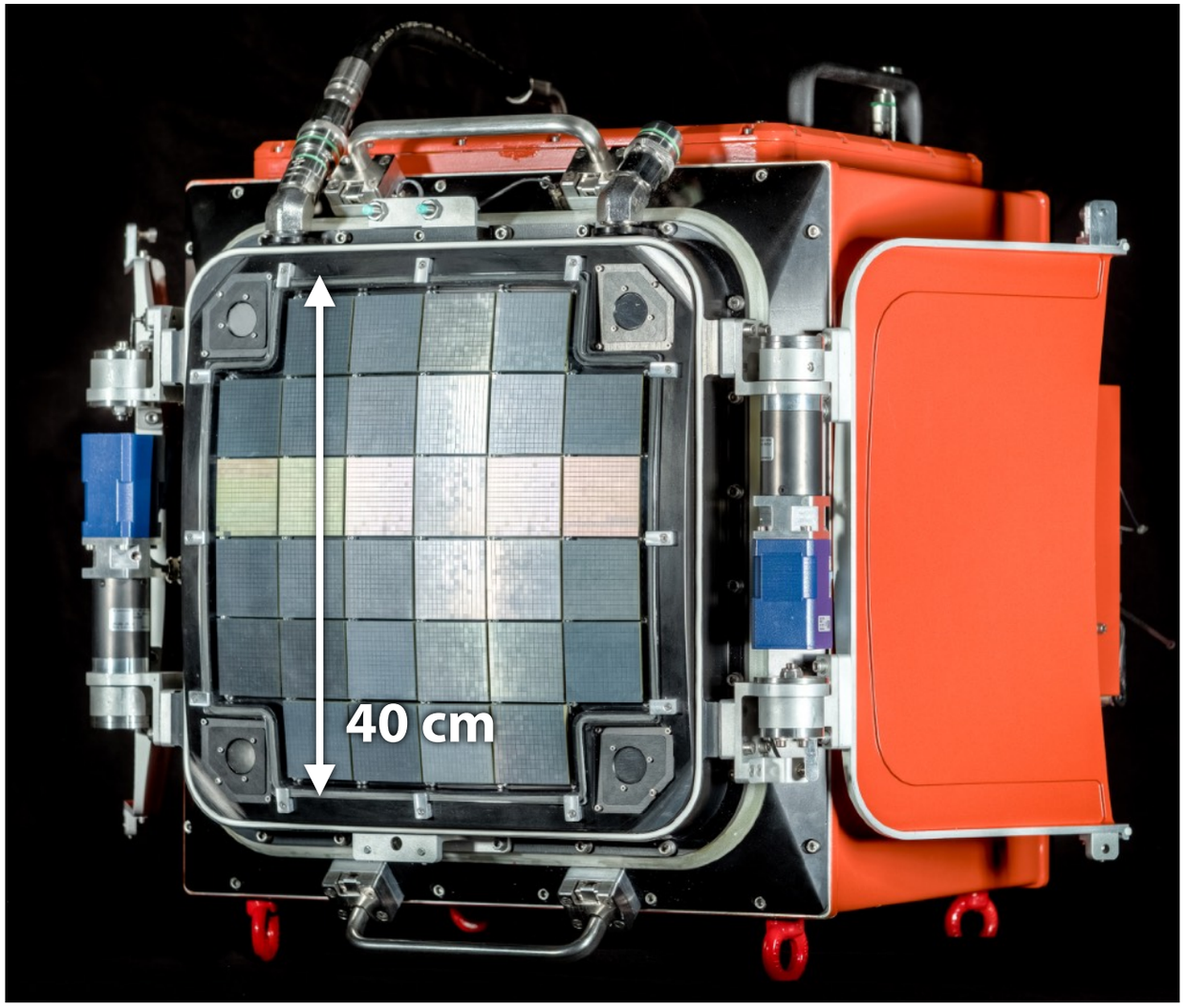
High-energy Frontier by CTA SSTs

CTA Consortium arXiV:1709.07997



Three SST Designs → SST Harmonization

Compact High-Energy Camera (CHEC)

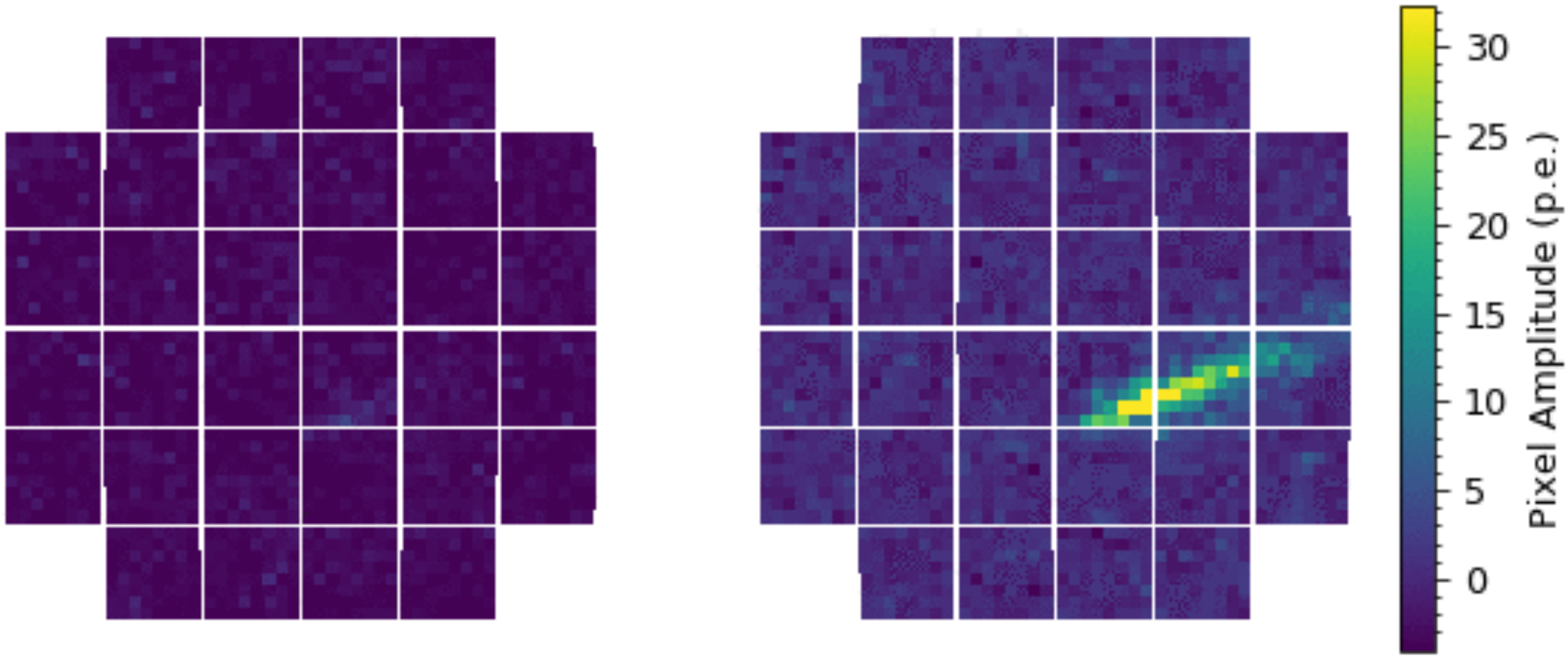


ASTRI

Credit: Christian Föhr (MPIK)

- CTA had a design review process to "harmonize" the different SST designs (3 cameras and 3 telescopes) since May 2018
- CHEC and ASTRI designs were finally chosen in June 2019 (to be further improved)
- CTA Nagoya group will continue working on electronics, SiPM, software, and optics simulation

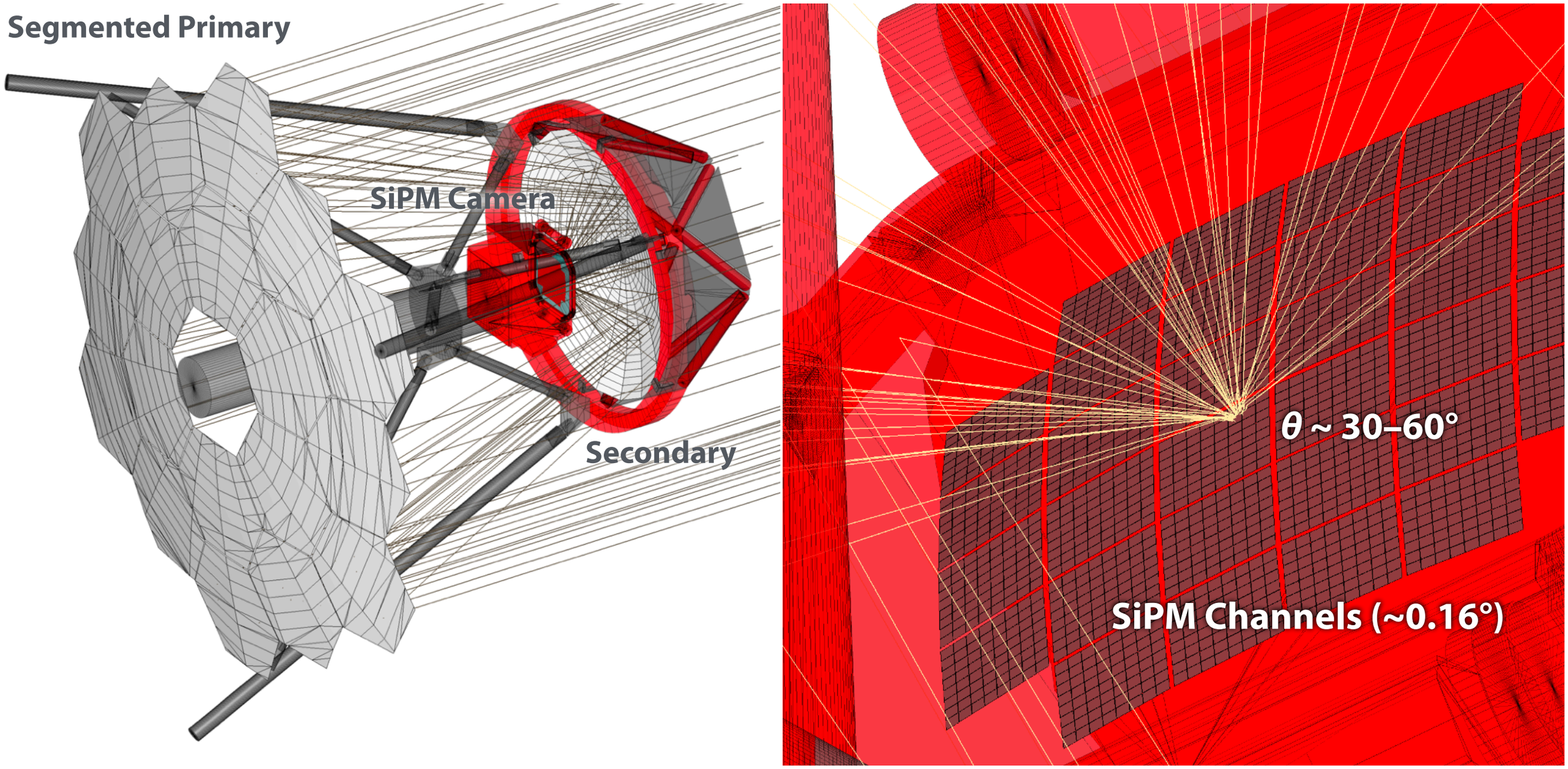
Crab Observations by an SST Prototype (CHEC–ASTRI)



https://www.cta-observatory.org/chec-achieves-first-light-on-astri/

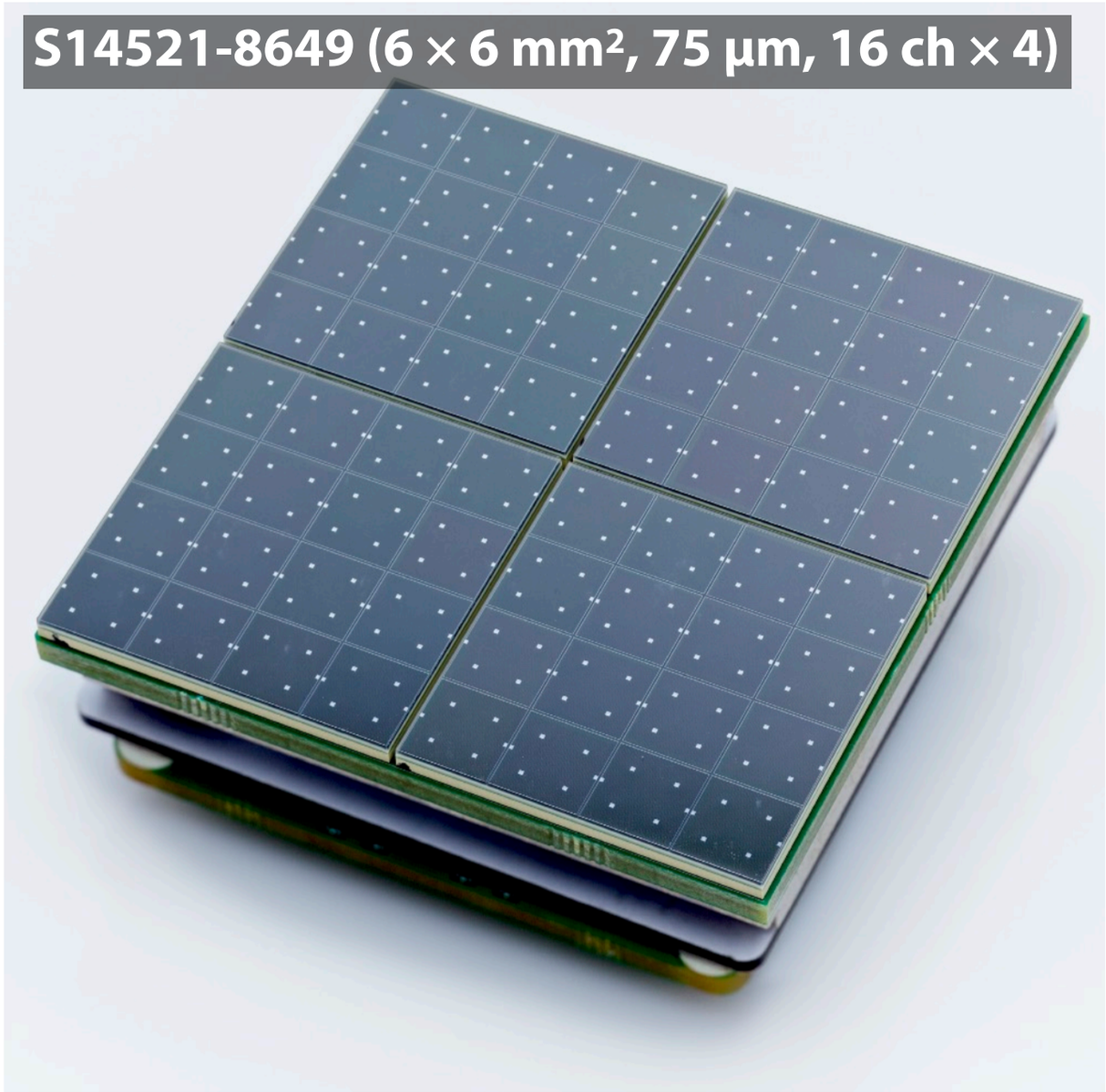
- Two observation campaigns were held on Mt. Etna, Italy in 2019 (but with very early SiPM product)
- Additional test observations canceled due to mirror re-coating and COVID-19

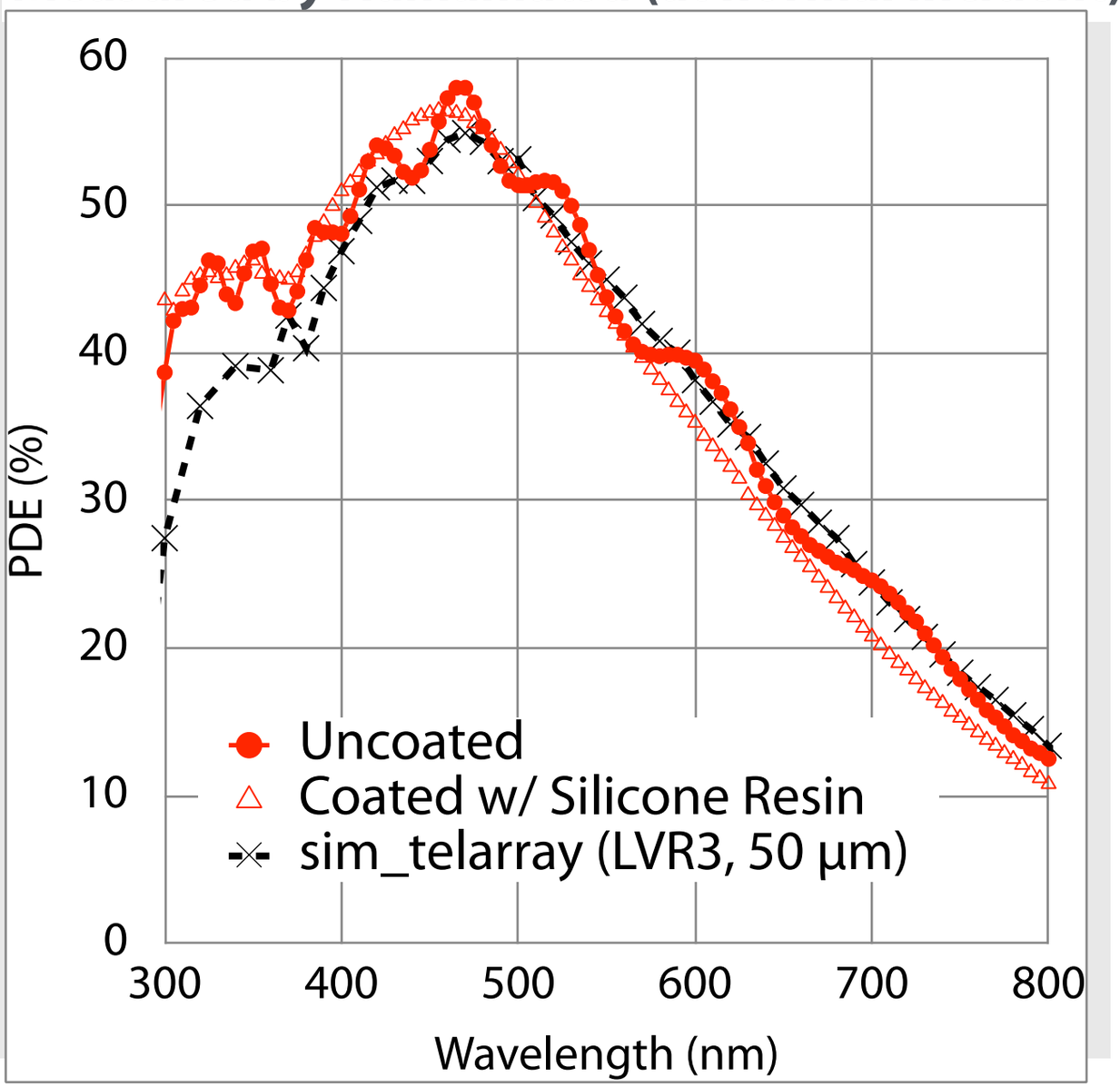
Schwarzschild–Couder Configuration with SiPM Camera



- **Aspherical** primary/secondary mirrors for wide FOV (< 10°) with good angular resolution
- Wider FOV brings fast survey and wider effective area for higher-energy photons
- Large angular distribution (30–60°) of angles of incidence on SiPMs

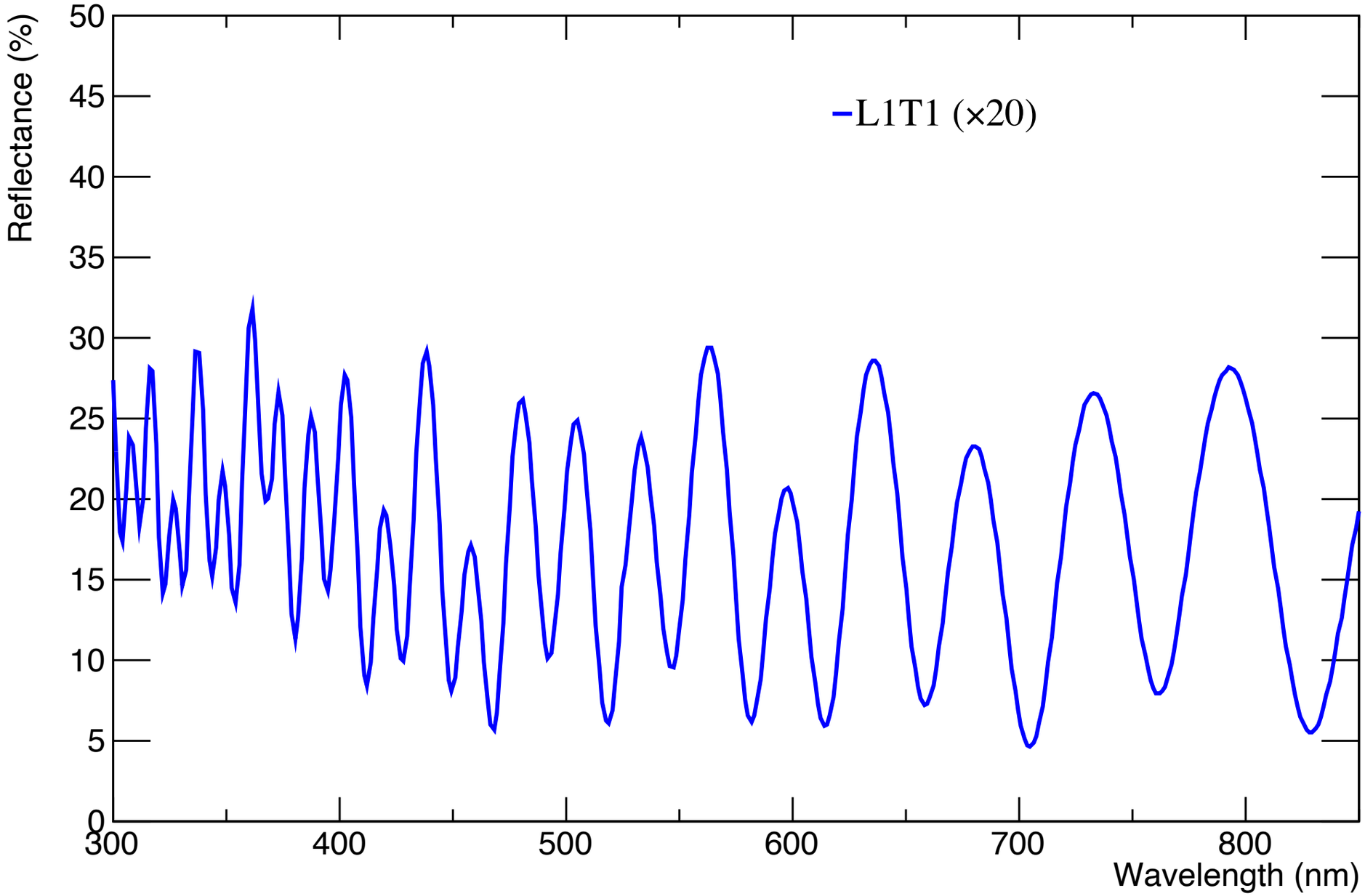
S14521-8649 (Coated) and S14521-8648 (Uncoated)





- Uncoated SiPMs (thin SiO_2 and SiN layers only) is preferred for CTA to reduce the optical crosstalk rate (See Nakamura et al. 2018)
- But thin protection layers behave as multilayer coating, thus wavelength- and angular-dependent photodetector efficiency (PDE) will appear (30–60° for SST)

Measurement of Single APD-Cell Reflectance (50 µm, Normal Incidence)



- Bumpy reflectance was observed, explaining the bumpy PDE
- Eight different APD cells in the same channel show different peak positions
  → Can be explained if the SiO2 thickness is not uniform (typ. ±30 nm)

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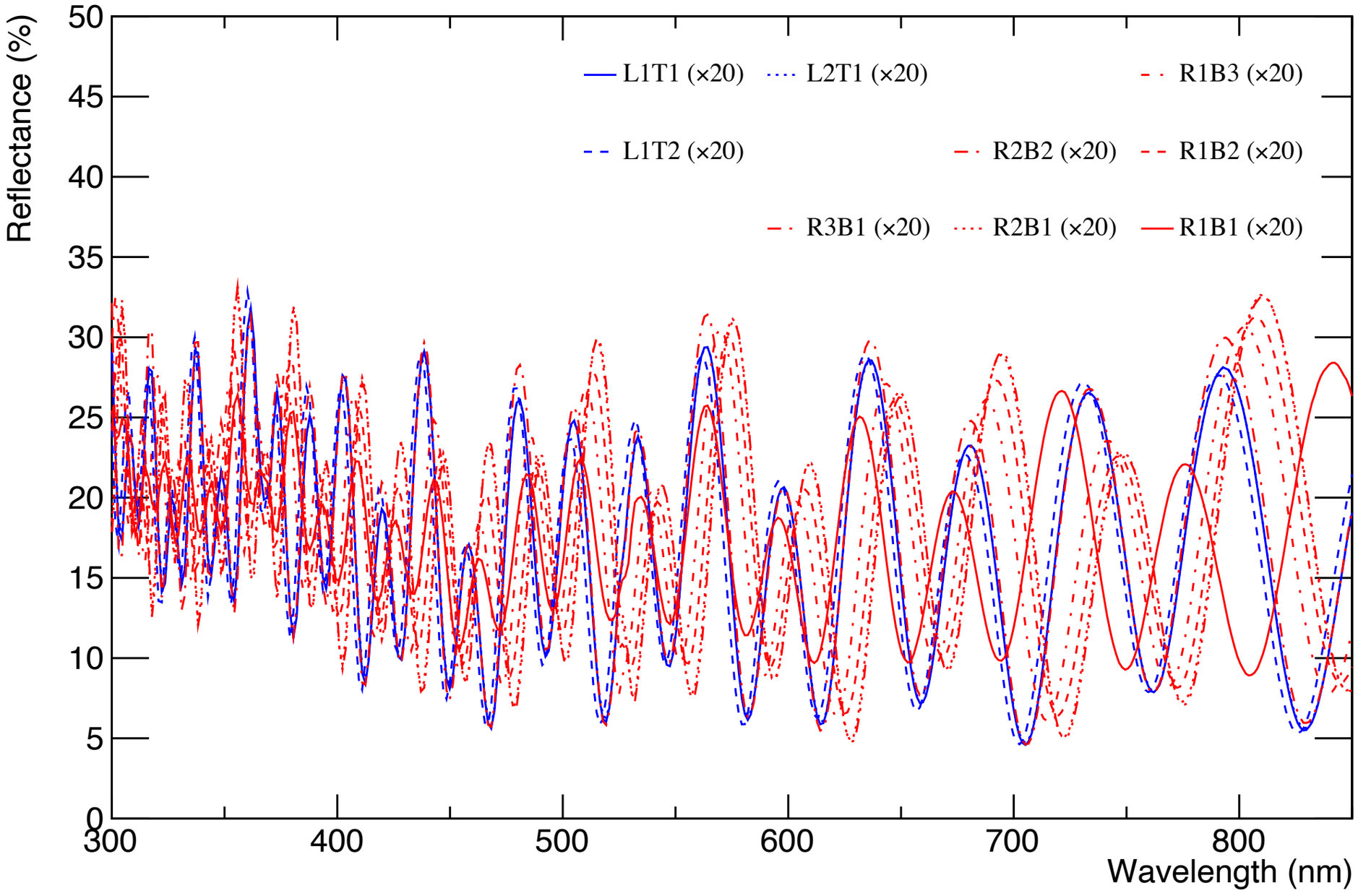

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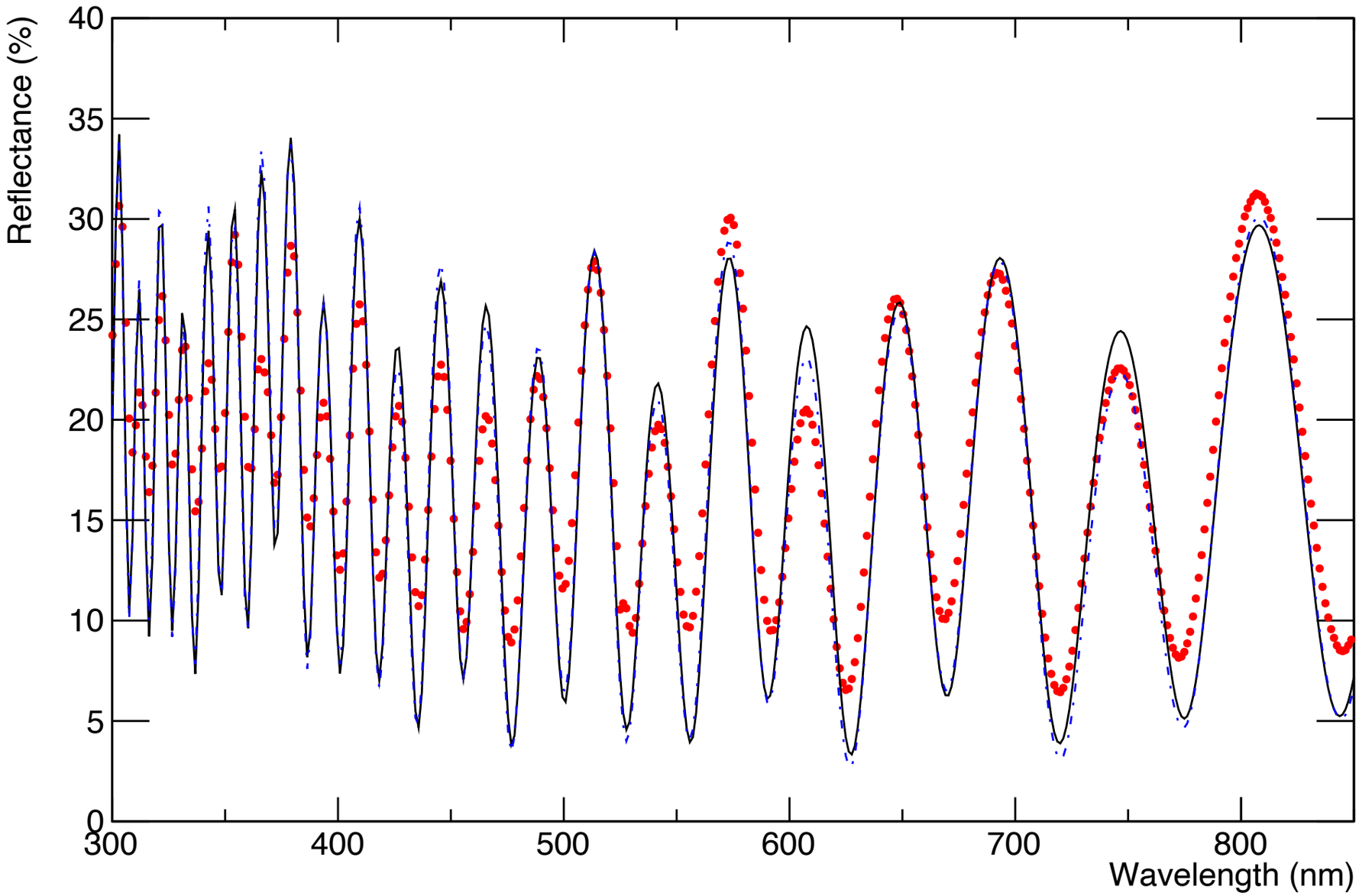
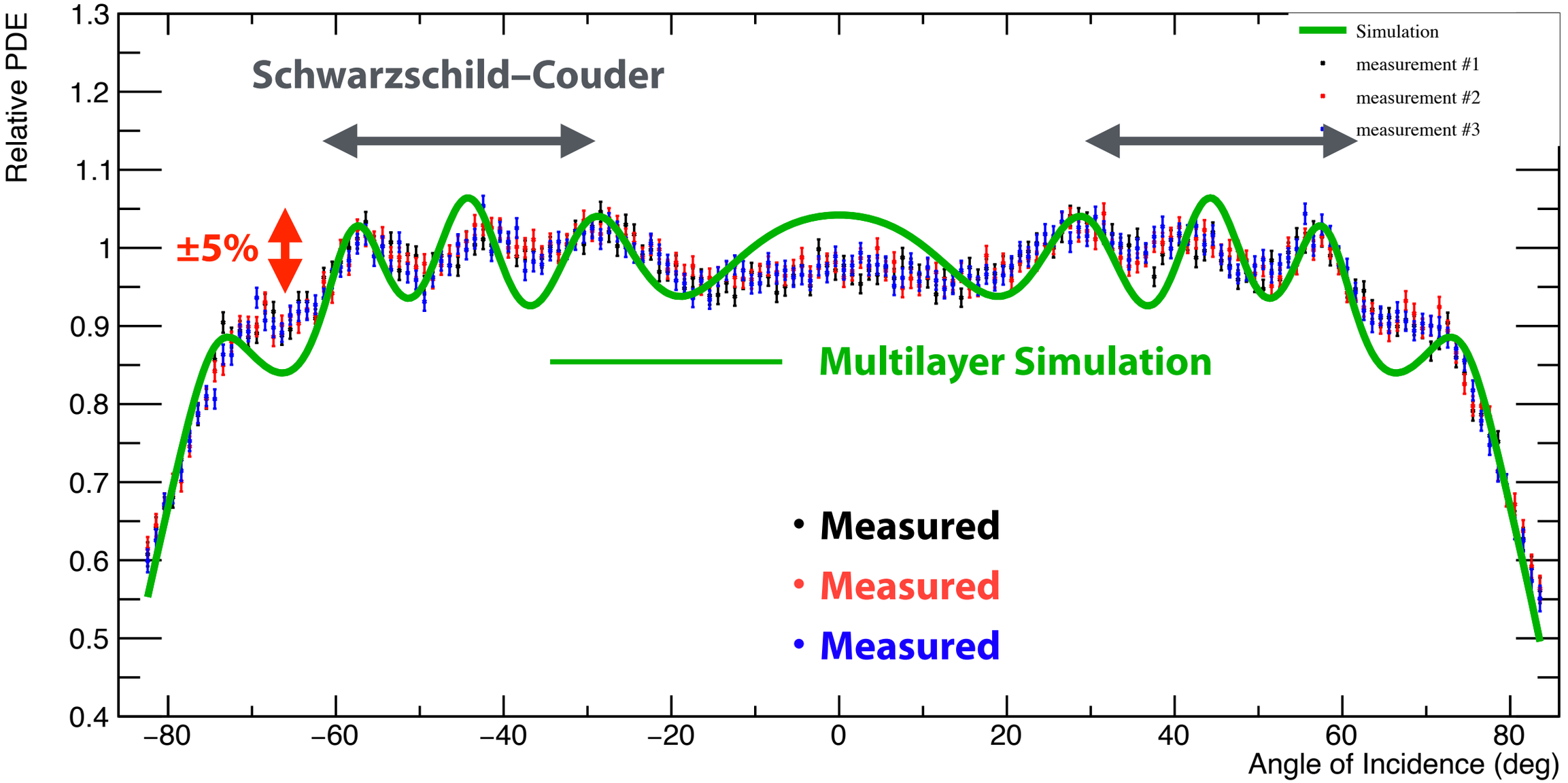
Multilayer Simulation



- Measured the thickness of the layers and identified the materials (not allowed to make it public)
- Multilayer simulation by **ROBAST** (first talk after break) roughly reproduces the measurement
- Thickness non-uniformity is not taken into account

PDE Measurement Rel. to Normal Incidence (635 nm)



- Bumpy PDE vs angle was obtained as expected
- Single multilayer simulation only roughly reproduce the measured PDE vs angle
- Need to measure how uniform the SiO_2 thickness is to reproduce the measurements
- LED spectrum ($\Delta\lambda \sim 15$ nm) is convoluted in simulation

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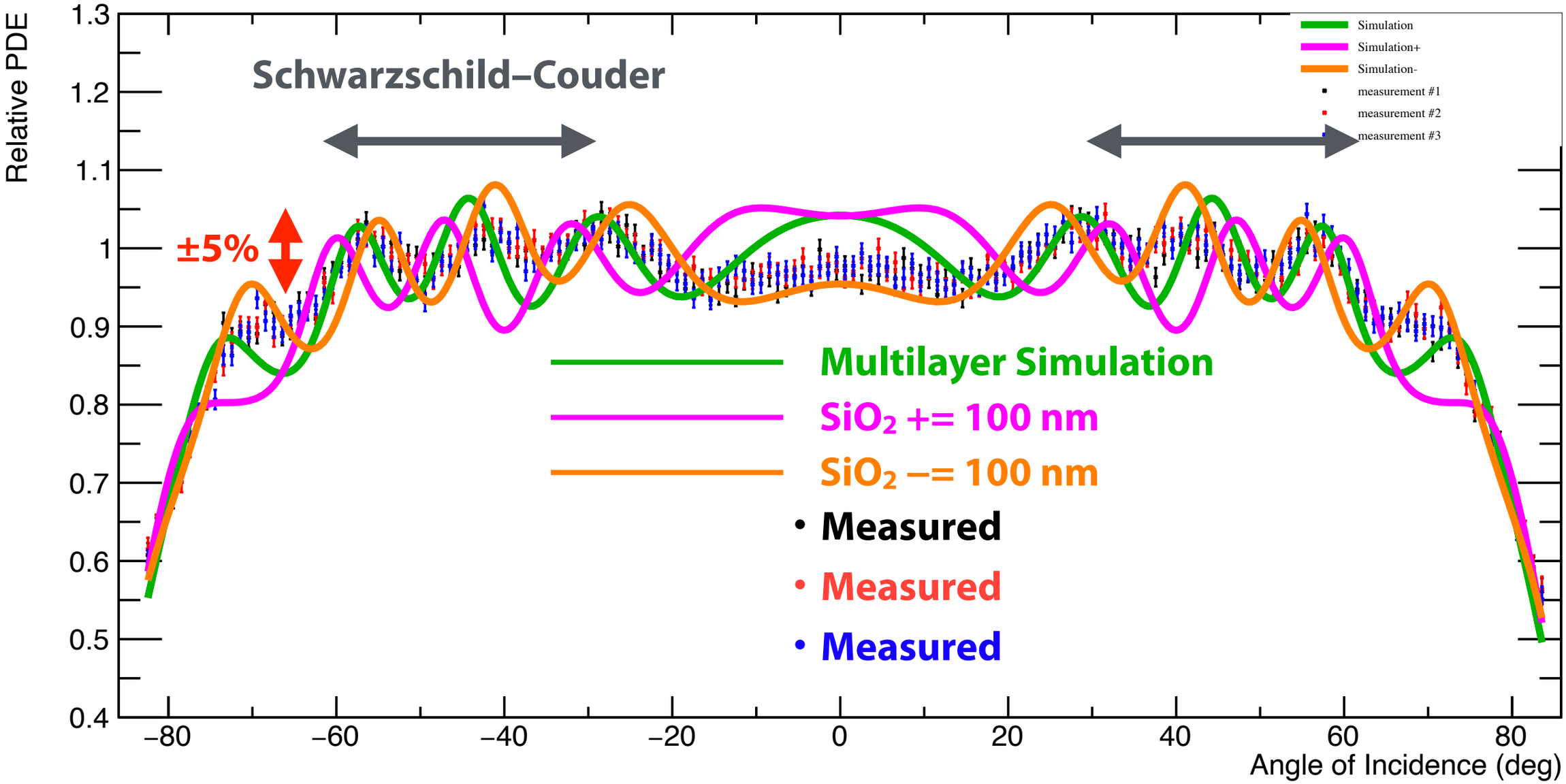

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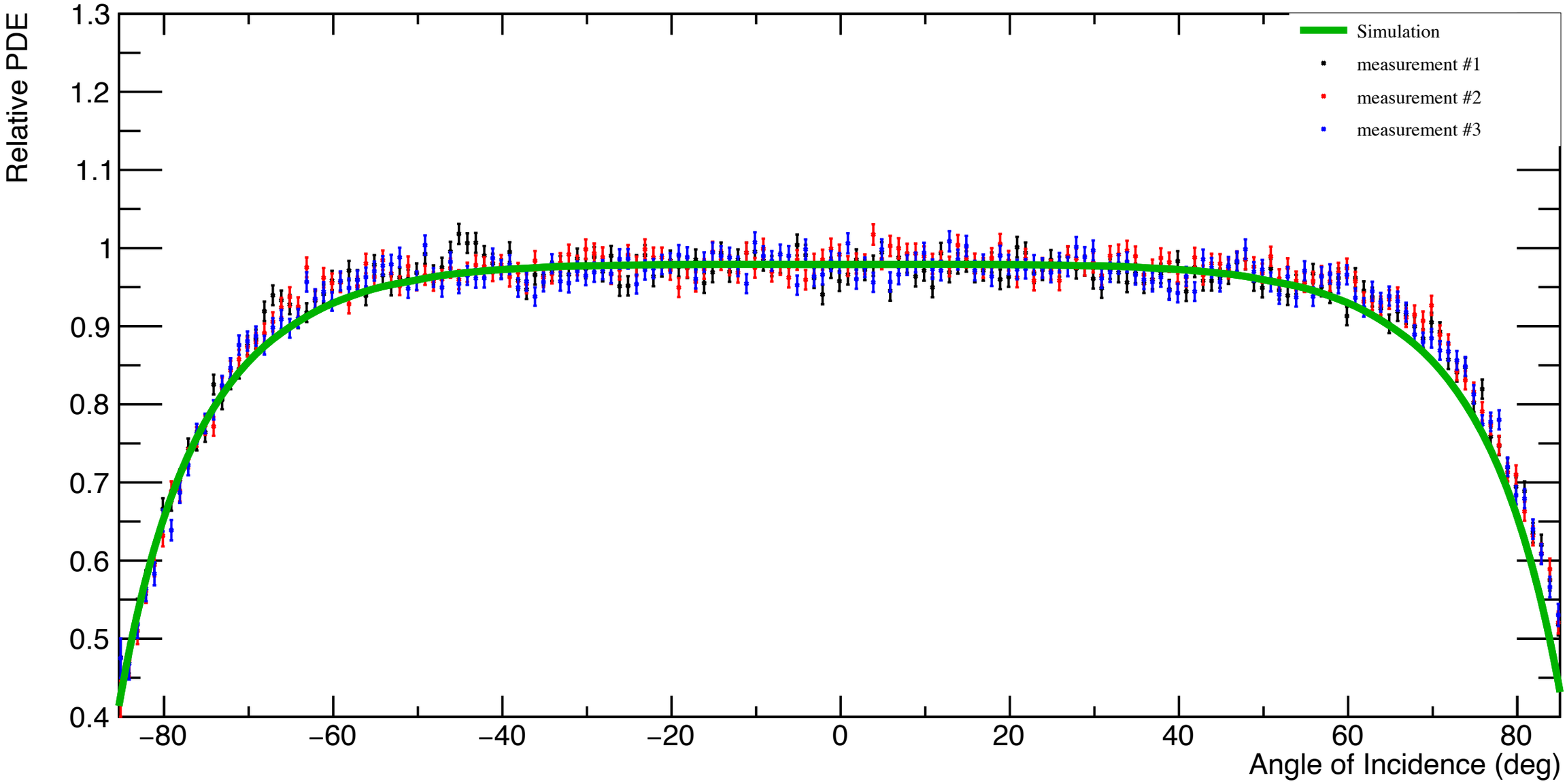
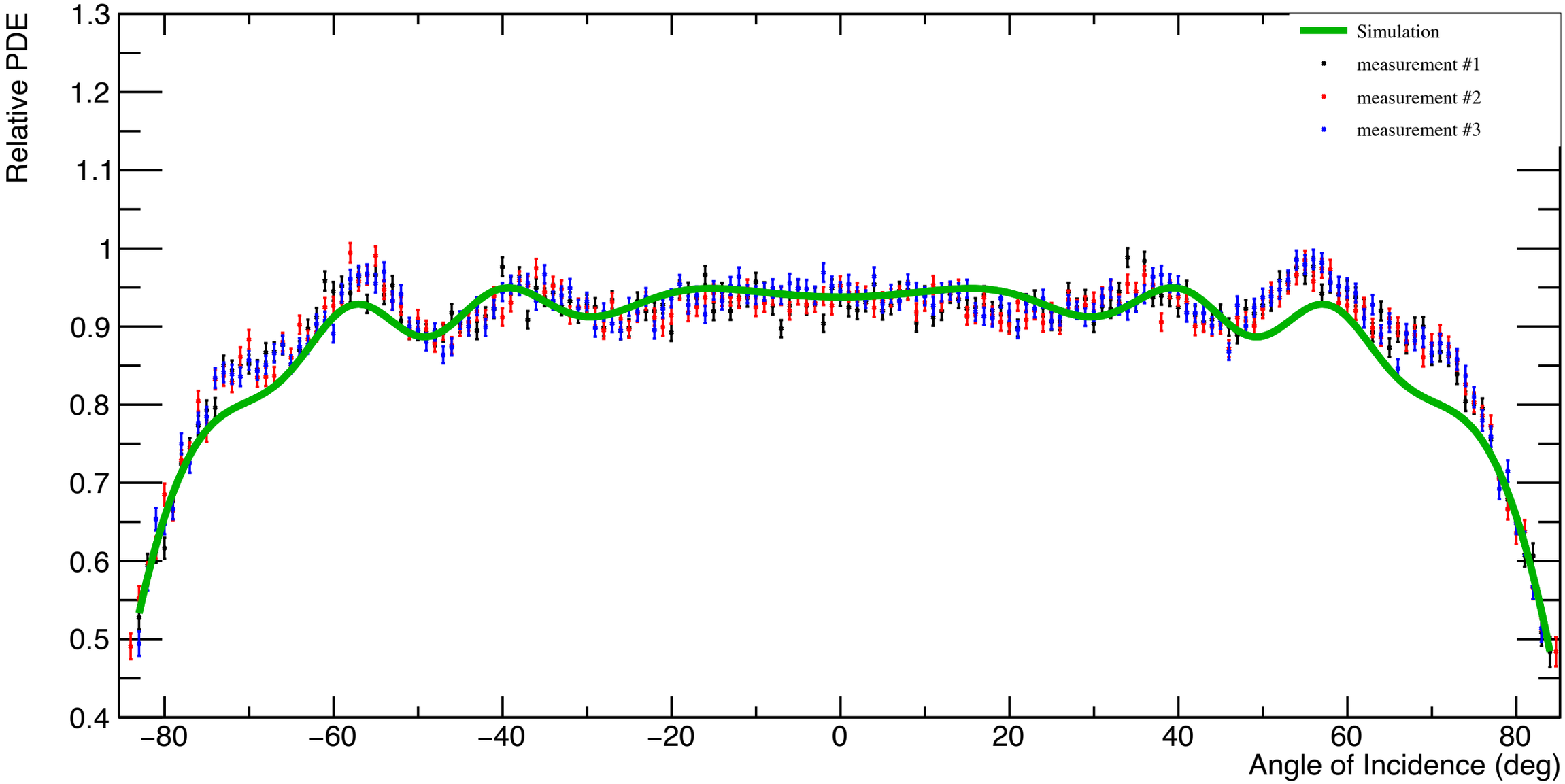
PDE Measurement Rel. to Normal Incidence (310 nm)



- Peaks and valleys are smoothed out because the LED spectrum is wider than the wavelength dependency

PDE Measurement Rel. to Normal Incidence (830 nm)



Summary and Plans

- “The” SST design has been chosen from 3 camera and 3 optics designs after the “SST Harmonization” process in CTA
- Prototype Schwarzschild–Couder (SC)telescopes for the CTA Medium- and Small-sized Telescopes constructed (see backup)
  - First realization of the SC configuration ever
- SiPM PDE has non-negligible angular dependence when resin coating is removed for CTA
- Characterized by both measurement and ROBAST simulation
- Angular-dependent PDE will be taken into account in future CTA simulations and calibration