CTA report 145:
Feasibility study on a future upgrade of PMT camera pixels with silicon photomultipliers

Anatolii Zenin, Hiroyasu Tajima, Akira Okumura,
Yuki Nakamura

ISEE, Nagoya University

Outline

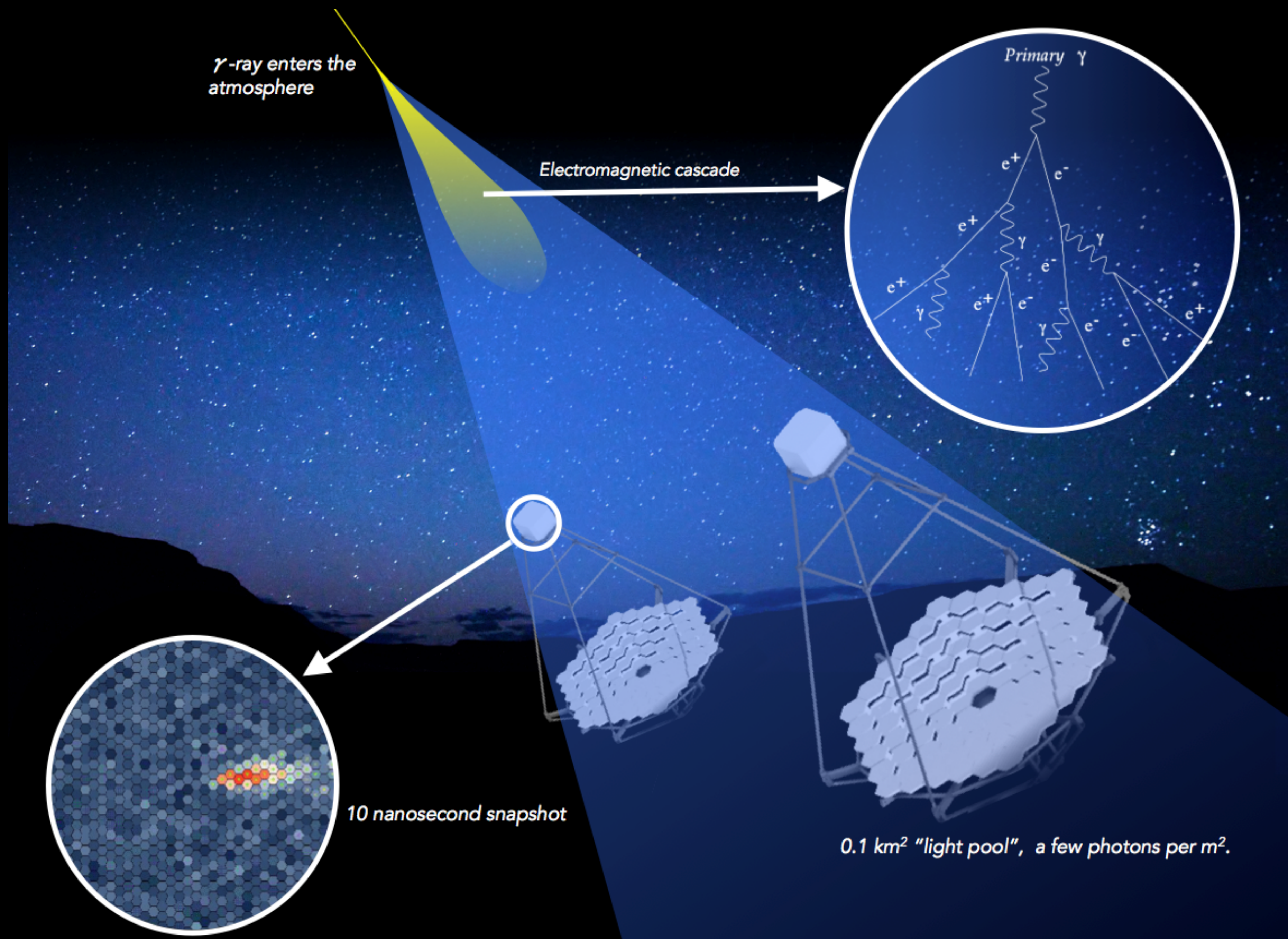
Introduction

- CTA and atmospheric imaging
- Motivation
- PMT and SiPM
- MST and light concentrators

Main Part

- Simulated setup
- Simulation and measurement results
- Discussion

CTA and atmospheric imaging



Credit: CTA

Air Cherenkov technique

Motivation

Why upgrade:

- The duty cycle of telescopes with photomultiplier tube (PMT) cameras is ~10%, strongly limited by moonlight.

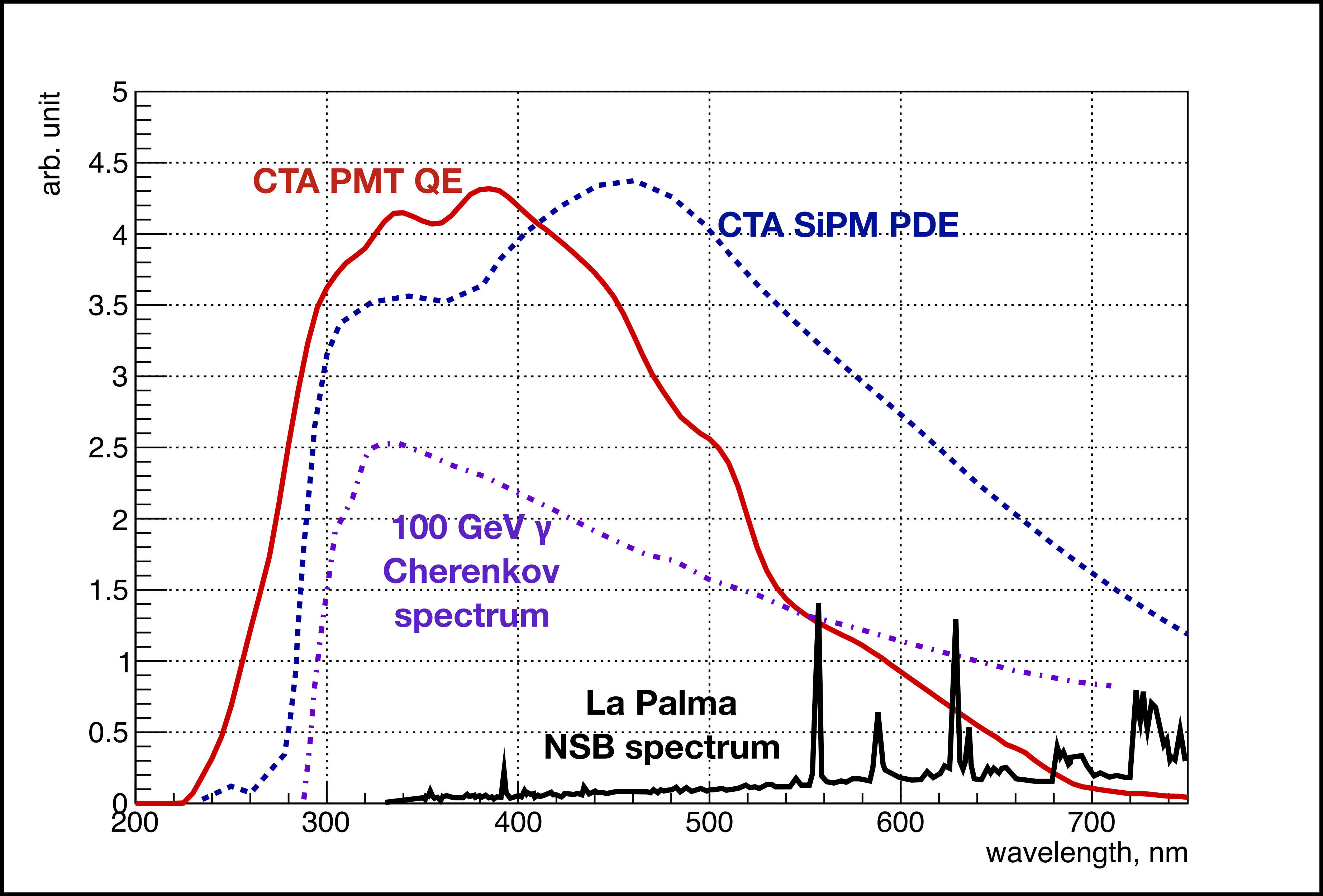
  Photocathodes of PMTs degrade over time, especially when the operating current is high, such as under high night sky background conditions. It is necessary to change PMTs every 10 years

- Silicon photomultipliers (SiPMs) are background-tolerant, meaning we can extend observation time by using them instead of PMTs. SiPMs do not degrade, so there will be no decrease in telescopes' performance over time

PMT and SiPM

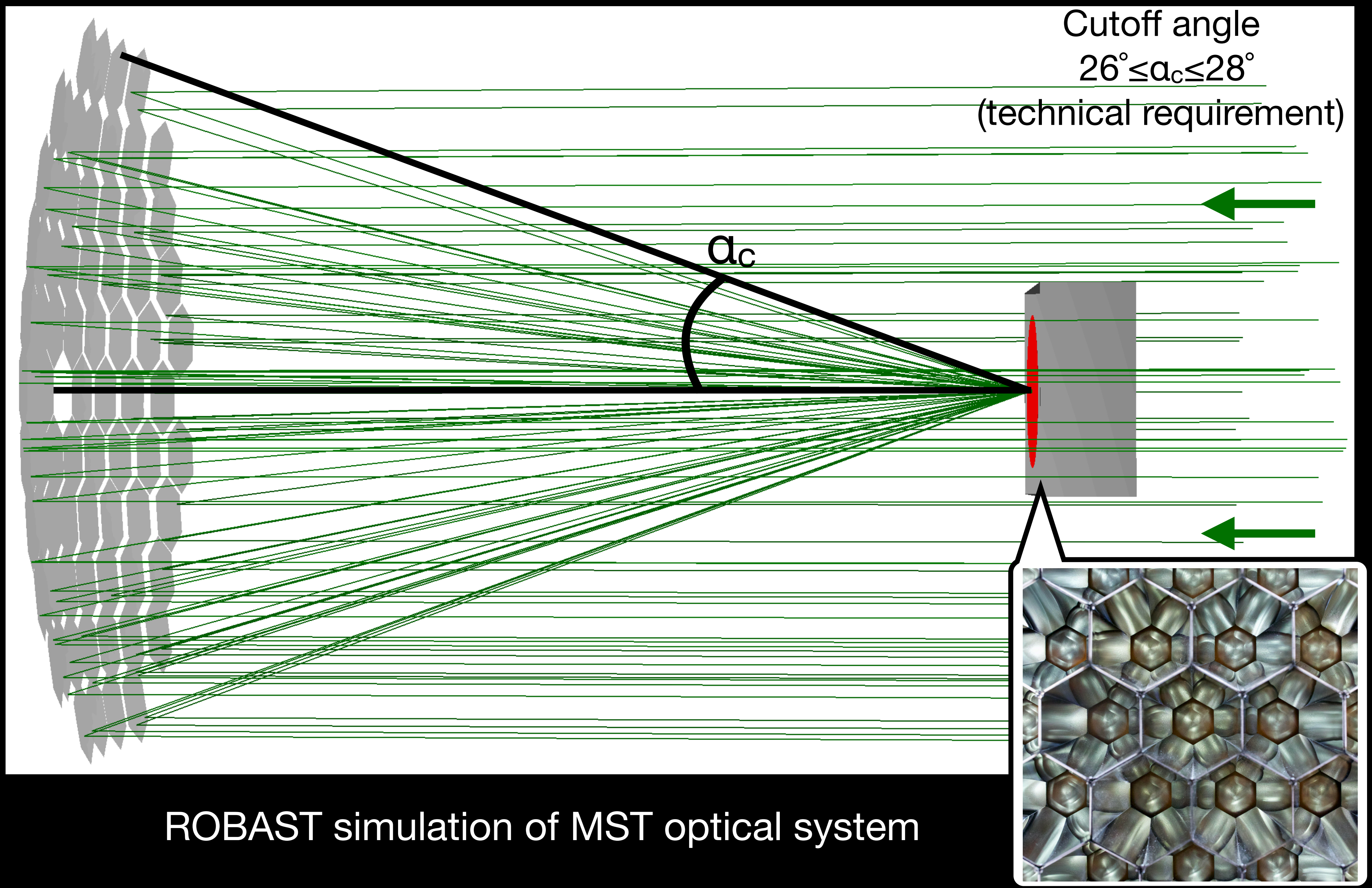
To ensure that the performance of SiPM cameras will not be inferior to the current PMT cameras, we have to compare:

- QE / PDE
- Sensitivity to signal
- Sensitivity to noise
- High NSB (moonlight) tolerance and performance under high NSB conditions
- Overall telescope performance (the end goal of this work)



PMT and SiPM sensitivity comparison
(not to scale)

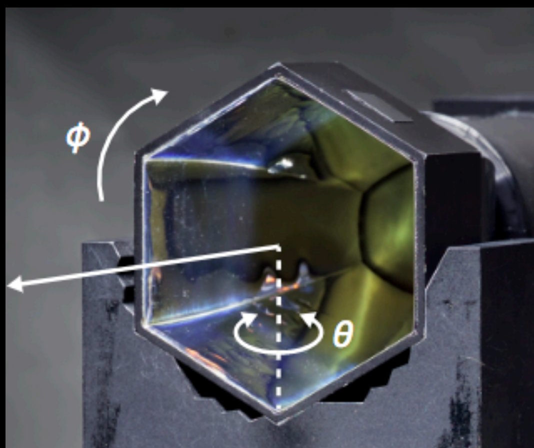
Medium-sized telescope

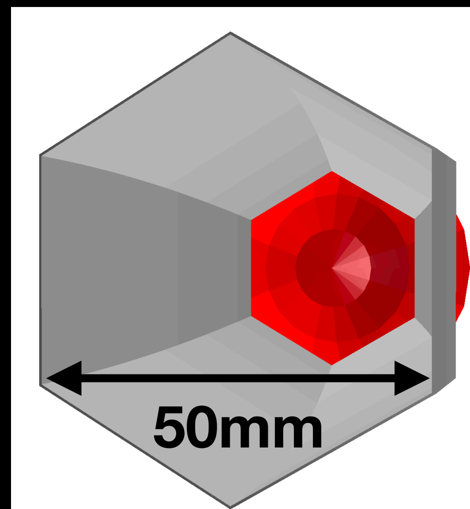


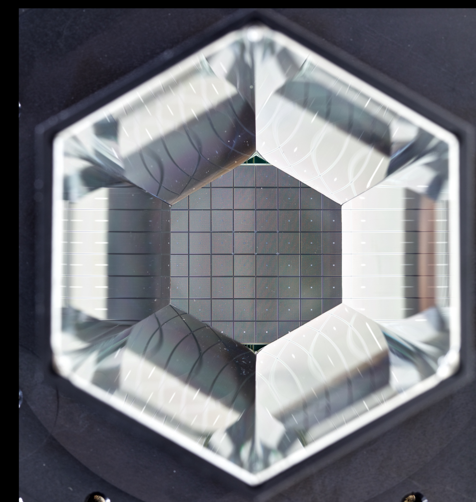
ROBAST simulation of MST optical system

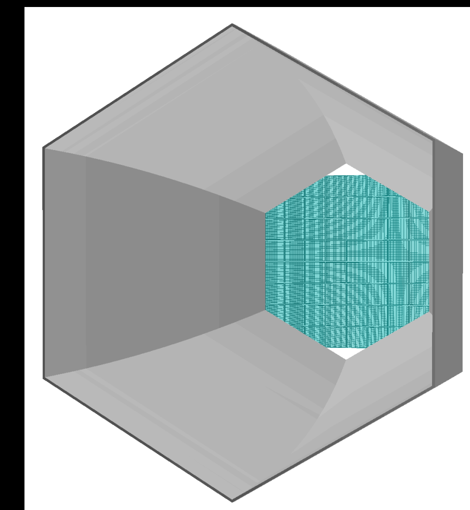
Simulated setup

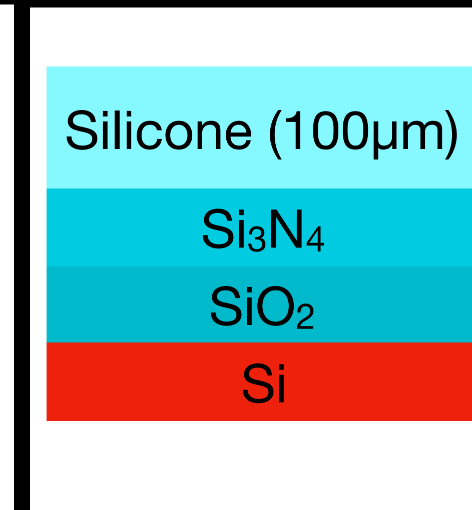
ROBAST tool was used for the simulation











PMT

+ QE data
+ Angular dependence
+ Positional dependence

? Anode collection efficiency (95% assumed)

Light concentrator

? Reflectance assumed

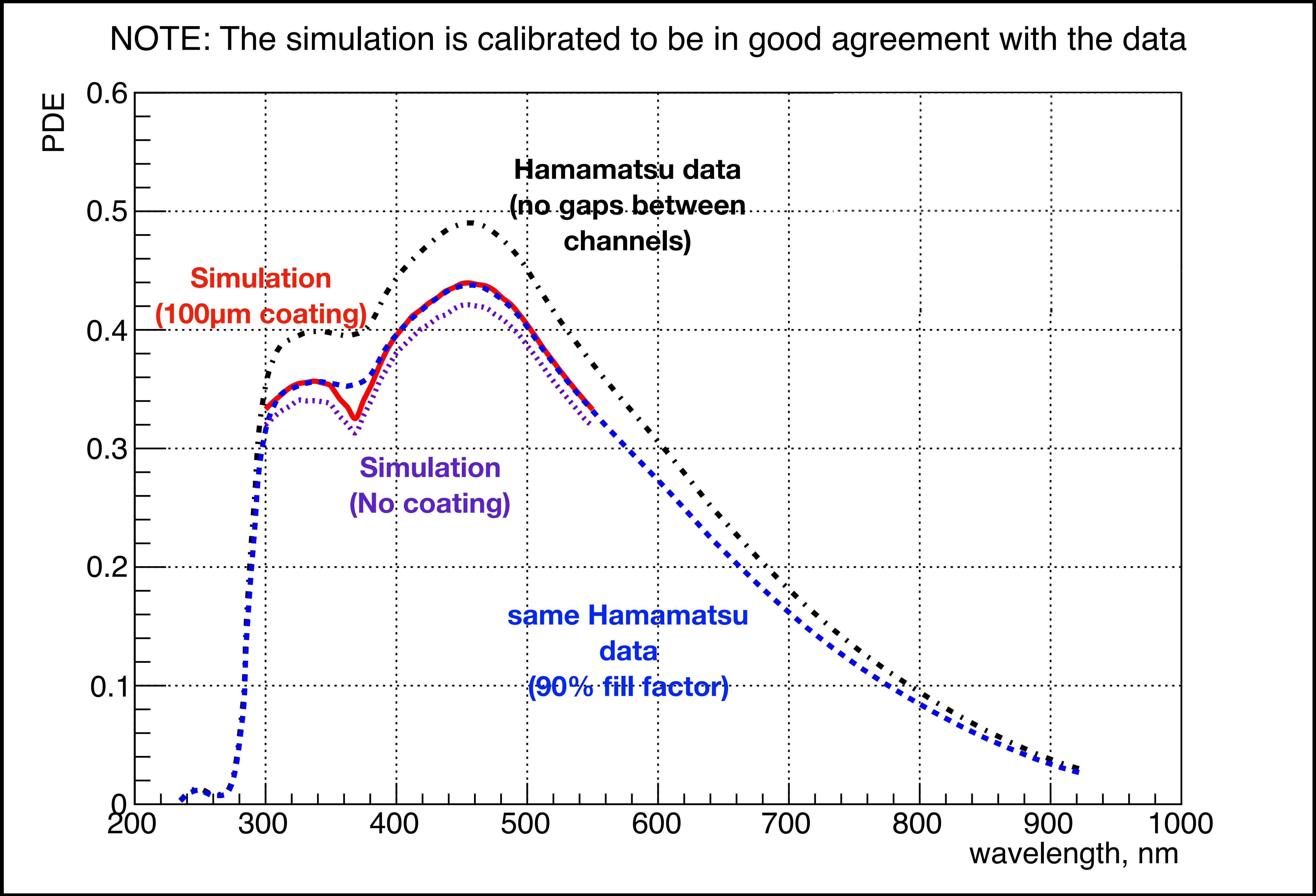
SiPM

Based on the latest Hamamatsu S14520-3050VS model

+ Geometry, incl. separate 50μm cells
+ 64 ch. 3x3mm, 0.2mm gap
+ Refractive indices of the materials
+ Resin absorption length
+ Si absorption in UV region

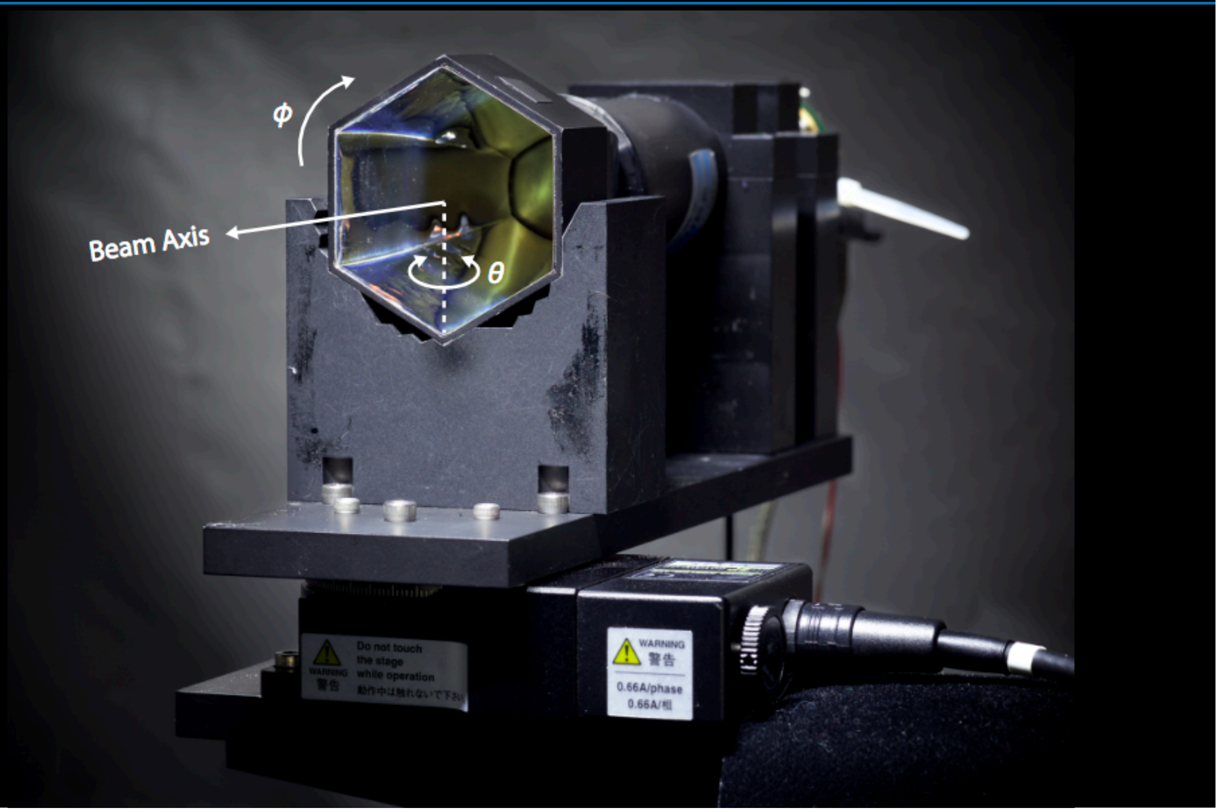
? QE: 98.5% assumed up to 450nm, Hamamatsu measurement data used for longer wavelengths

Simulated setup

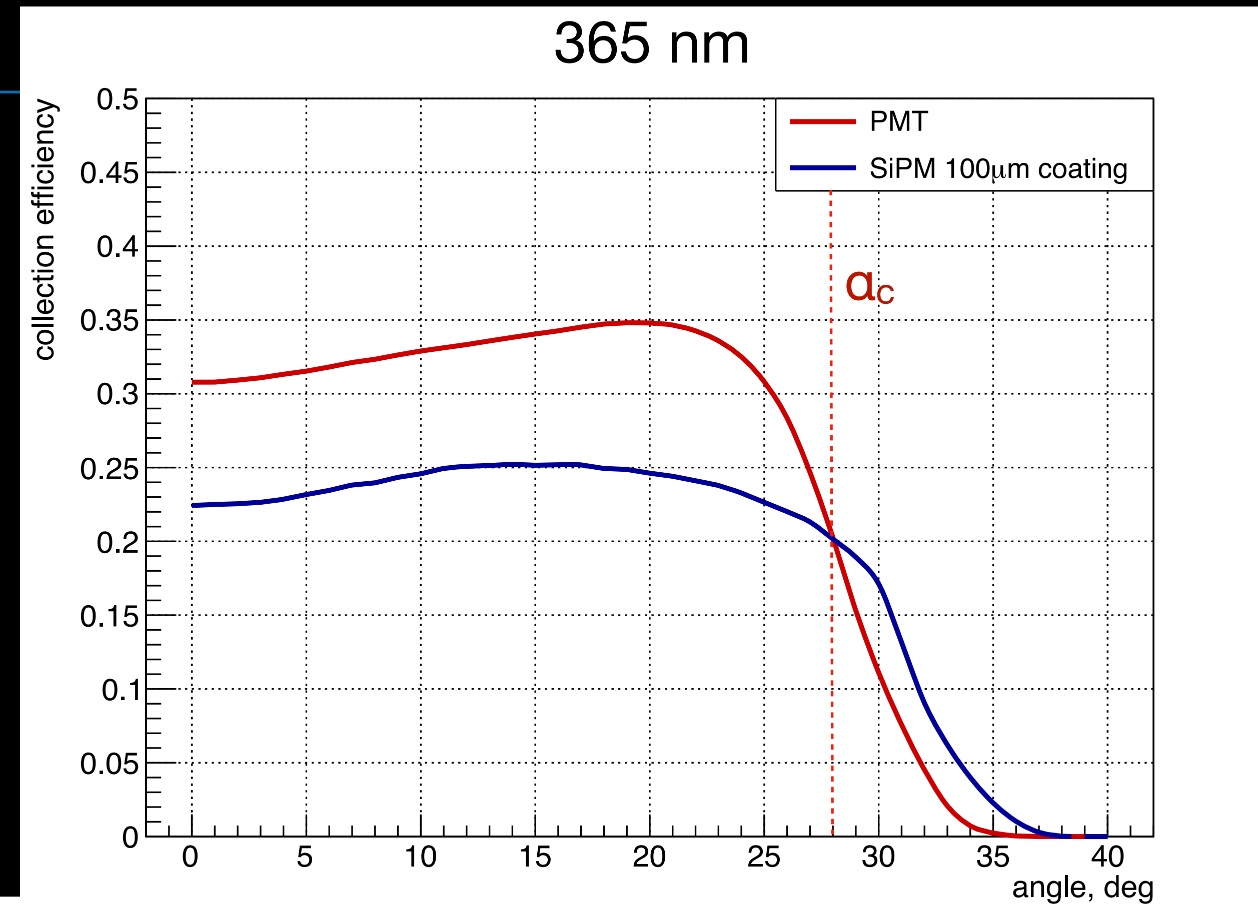


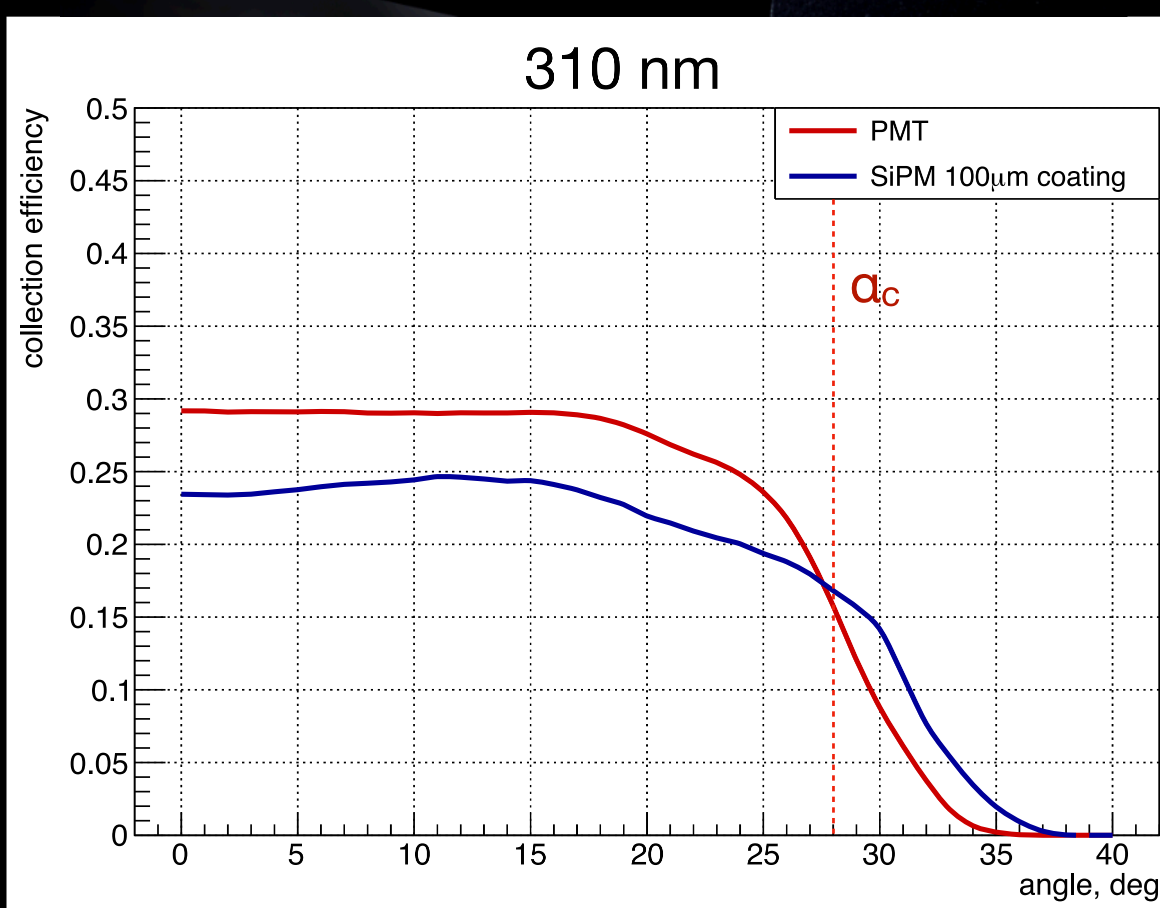
SiPM PDE

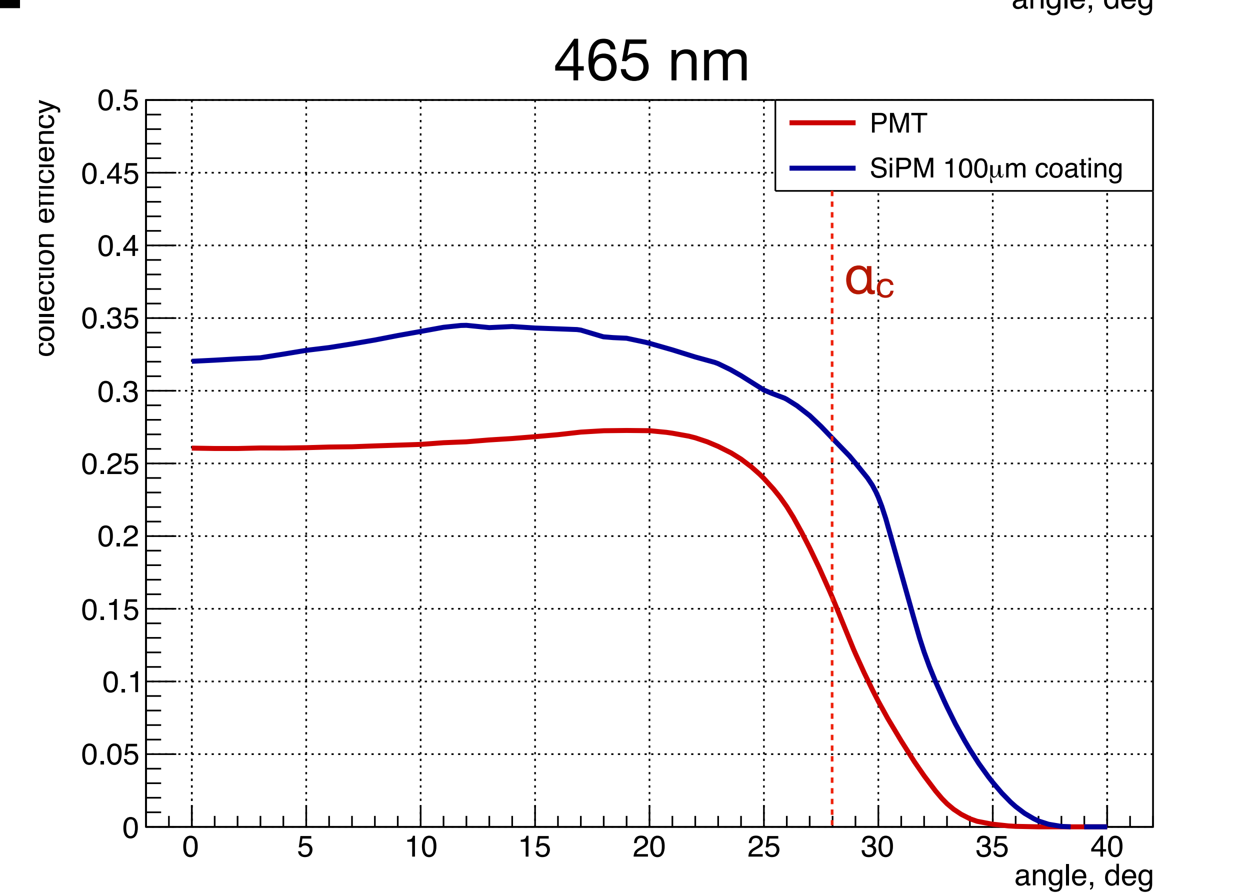
Simulation results



Results integrated over the whole range of azimuthal angle ϕ

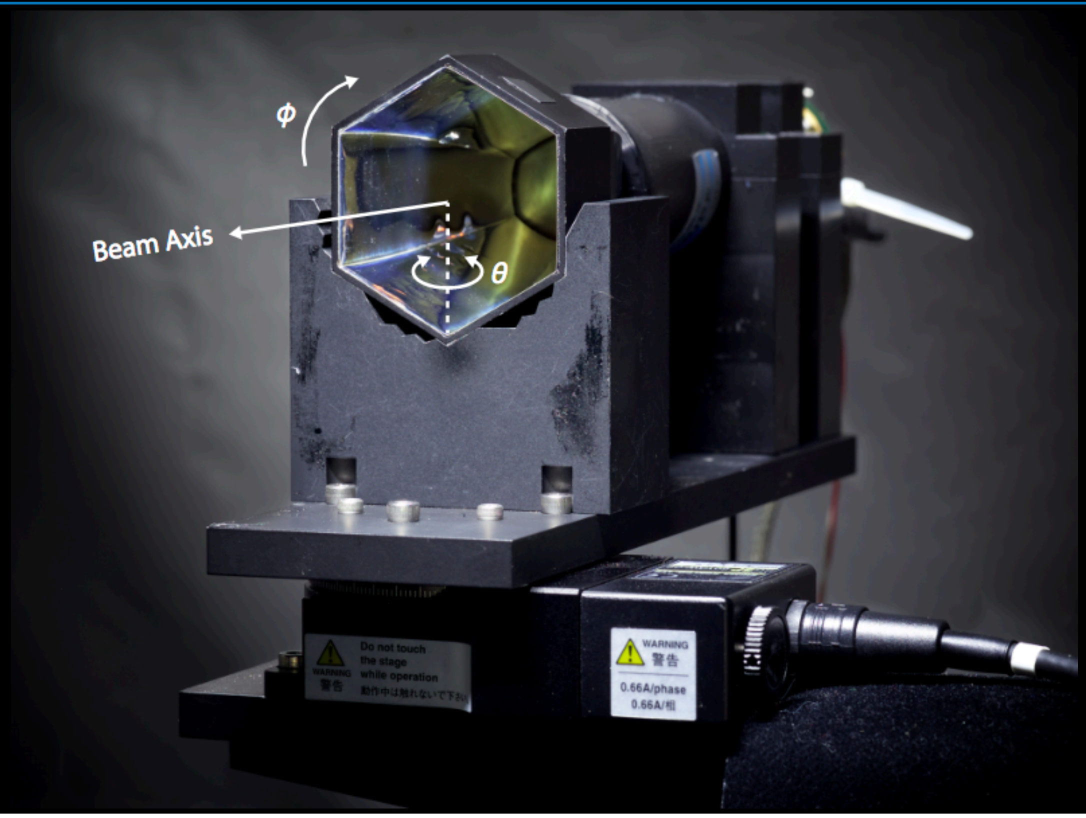


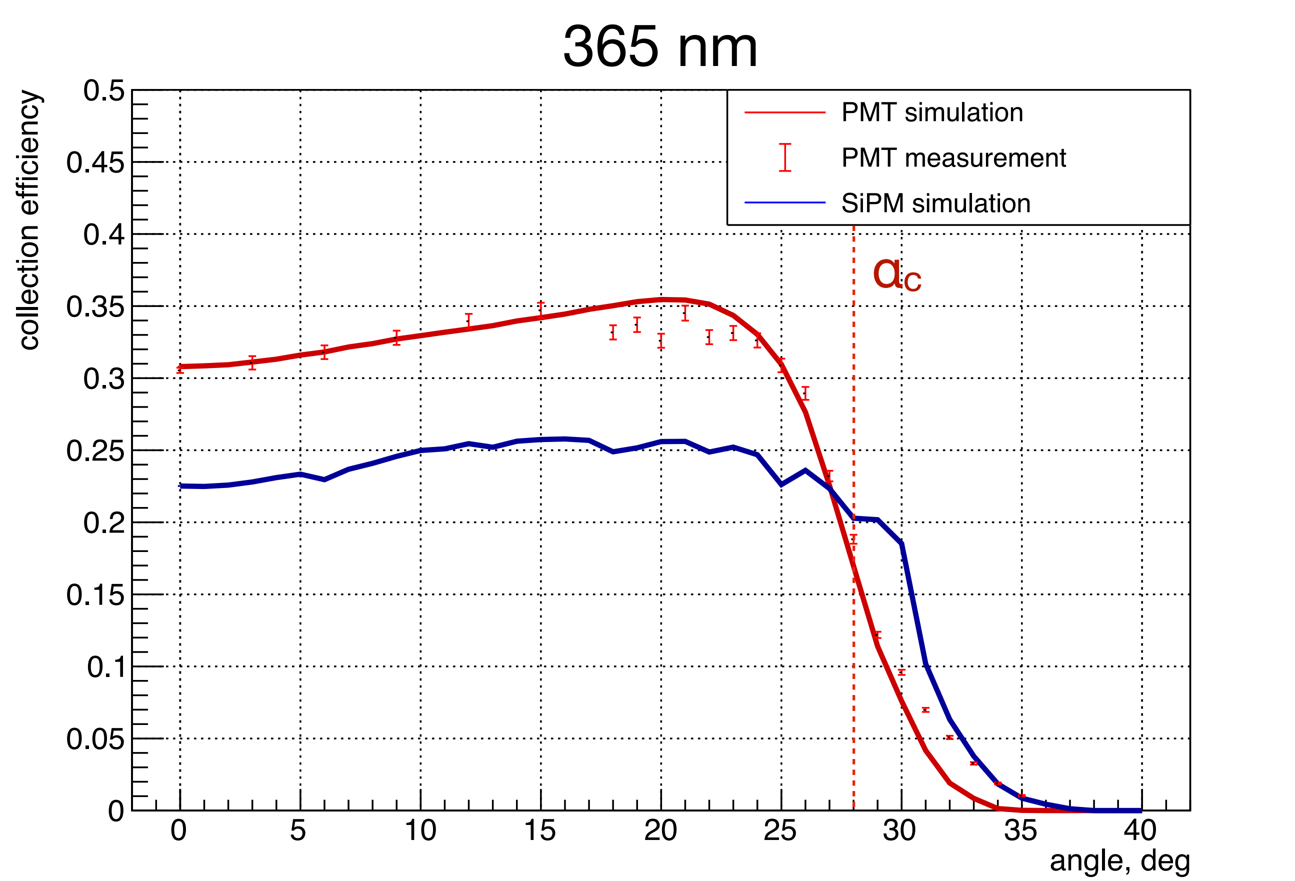


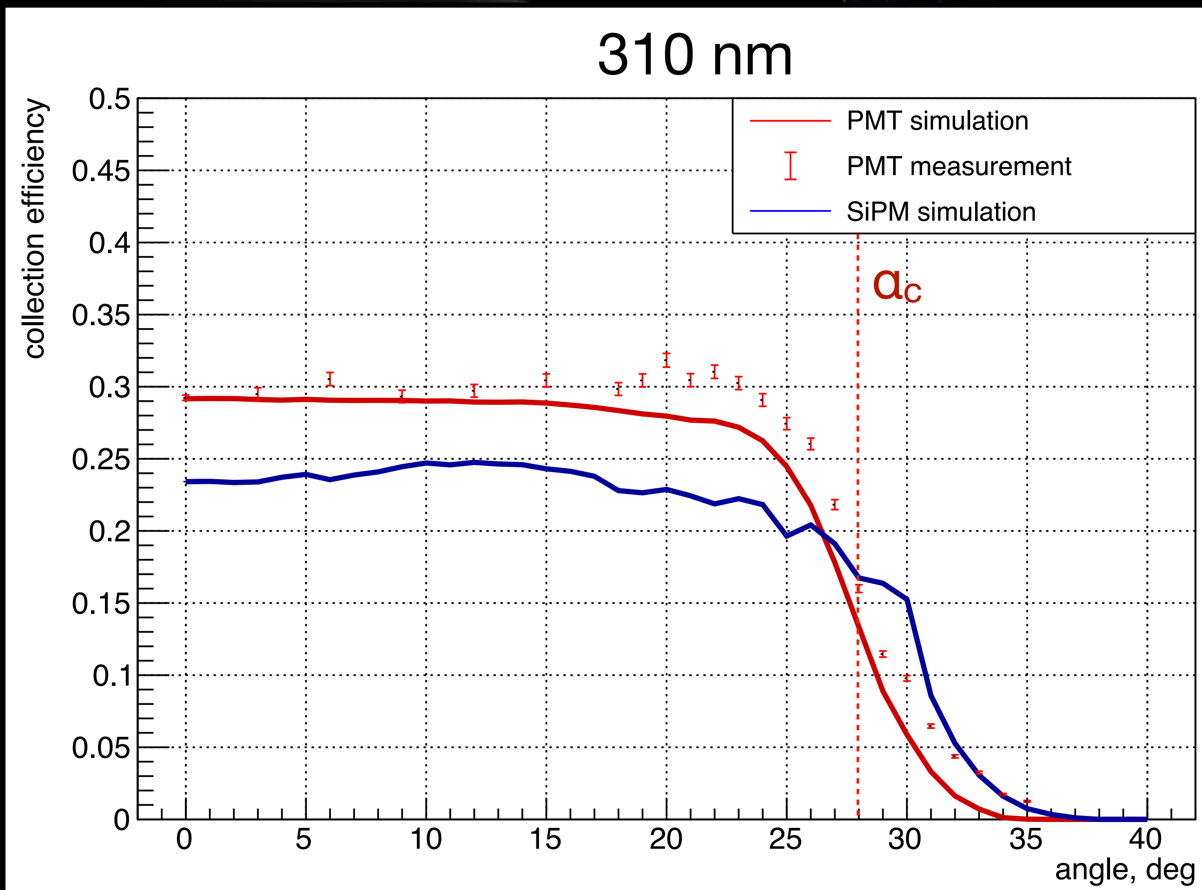


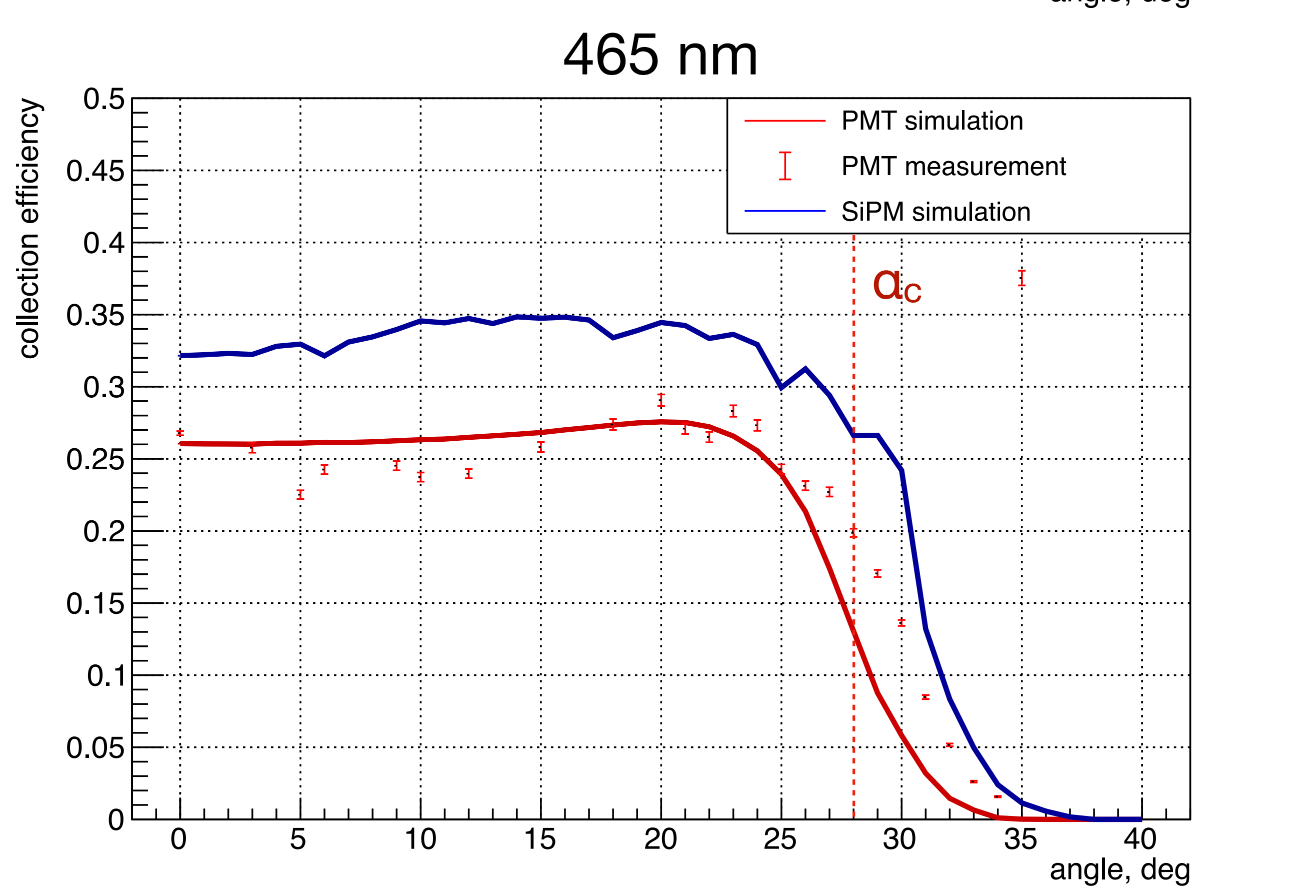
Measurement results

Results for azimuthal angle ϕ = 0
(see the figure on the left)



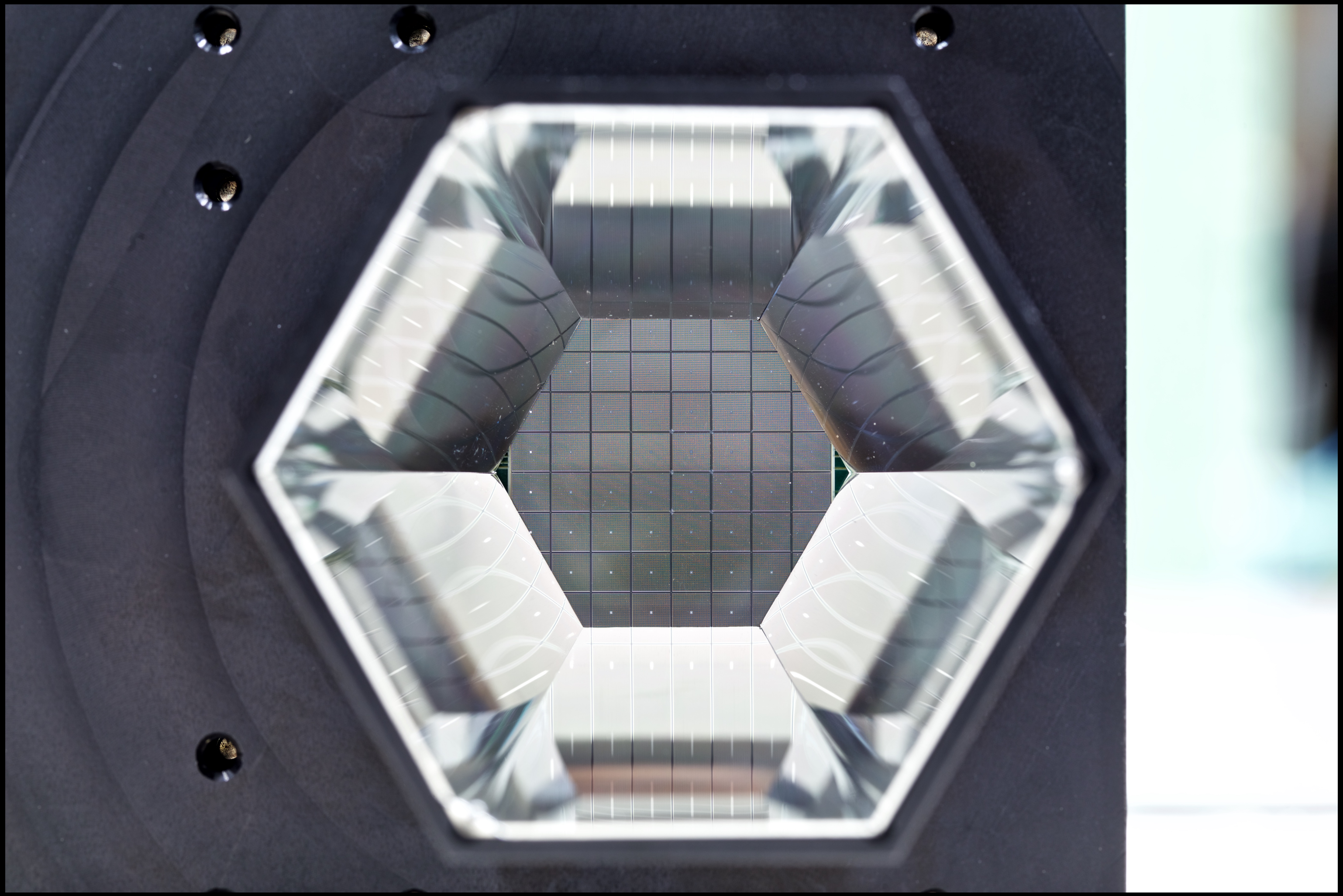




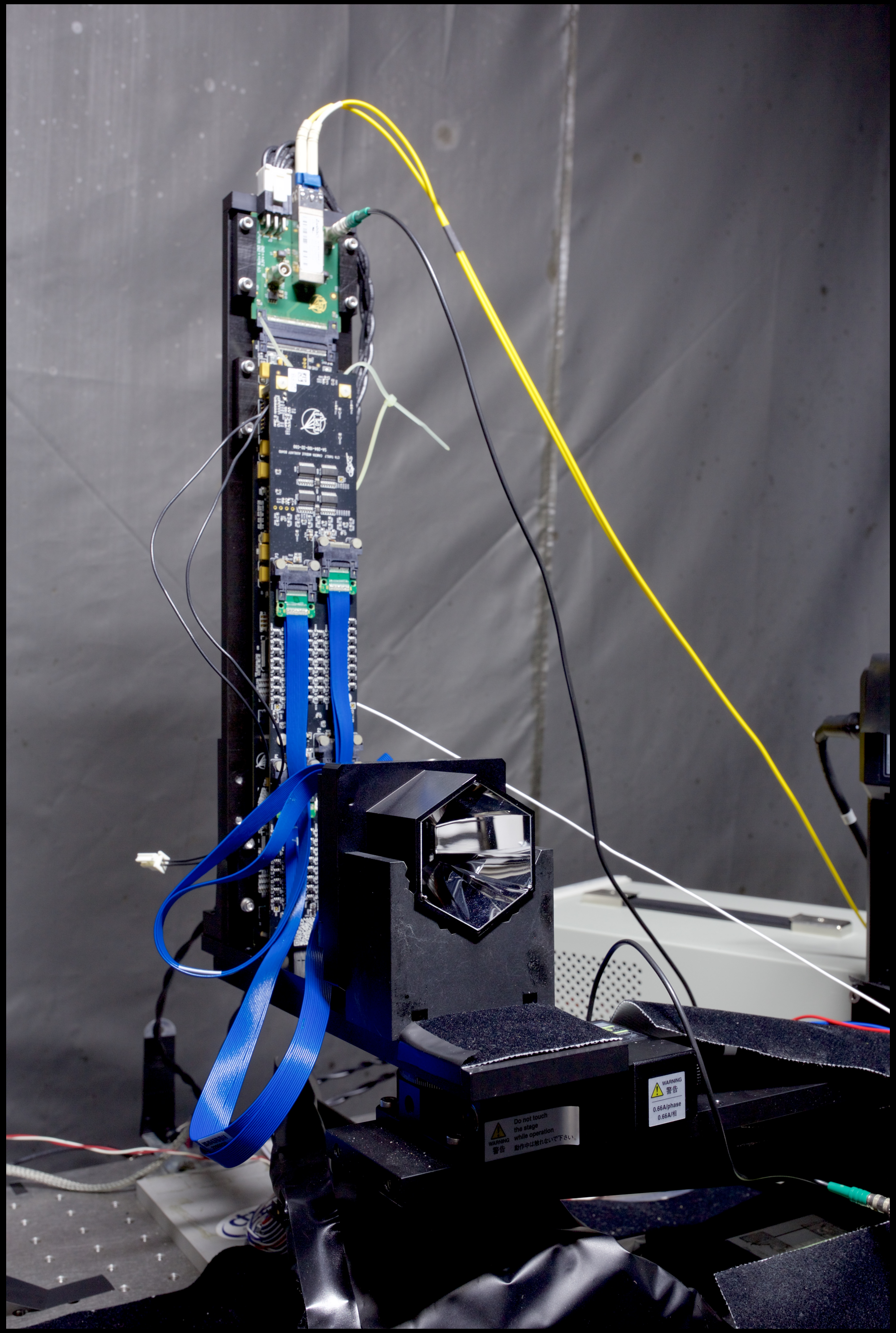


Measurement results

We have created a functioning setup for SiPM measurements, so the data necessary for the comparison will be obtained in the nearest future.

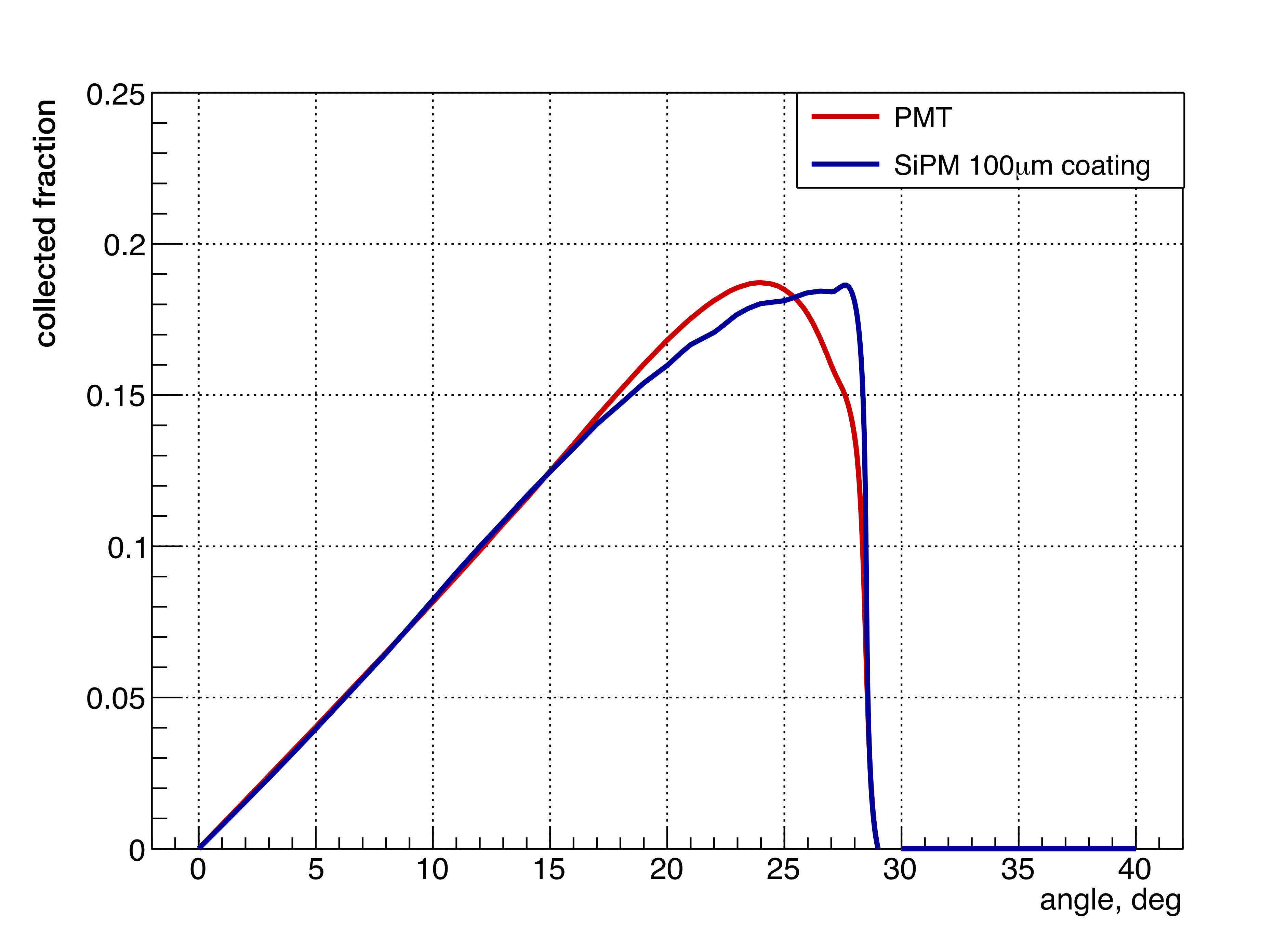


SiPM under a light concentrator



Readout module (TARGET)
on a rotating stage

Simulation results



Signal collection efficiency convolved with Cherenkov spectrum (300~550 nm) and angular photon distribution at the camera module

Integration over the angle from 0 to α_c results in:

$$\frac{Y(MPPC)}{Y(PMT)} = 1.00$$

Discussion

From the simulation we can see that:

- SiPM offers roughly the same signal collection efficiency when compared to PMT even with the light concentrator designed for PMT
- SiPM is very sensitive to stray light when used with current light concentrator
- A new light concentrator designed specifically for SiPM might improve its performance

To do

Several things have to be done before making any solid conclusions:

- Comparing the simulation results to experimental data and revising the simulation if necessary
  (in progress)

- Designing a new light concentrator
  (in progress)

  Comparing the performance of PMT and SiPM by a simple ray-tracing simulation
  (after designing a new light concentrator)

- Full telescope simulation with CORSIKA and sim_telarray
  (the final step)