Fiber-to-SiPM Coupling Studies

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on behalf of Volker Büscher, Karl-Heinz Geib, Asma Hadef, Lukas Koch, Antoine Laudrain, Lucia Masetti, Marisol Robles Manzano, Paula Nehm, Steffen Schönfelder, Liam O'Sullivan, Anna Rosmanitz, Christian Schmitt, Patricia Theobald, Alfons Weber, Quirin Weitzel

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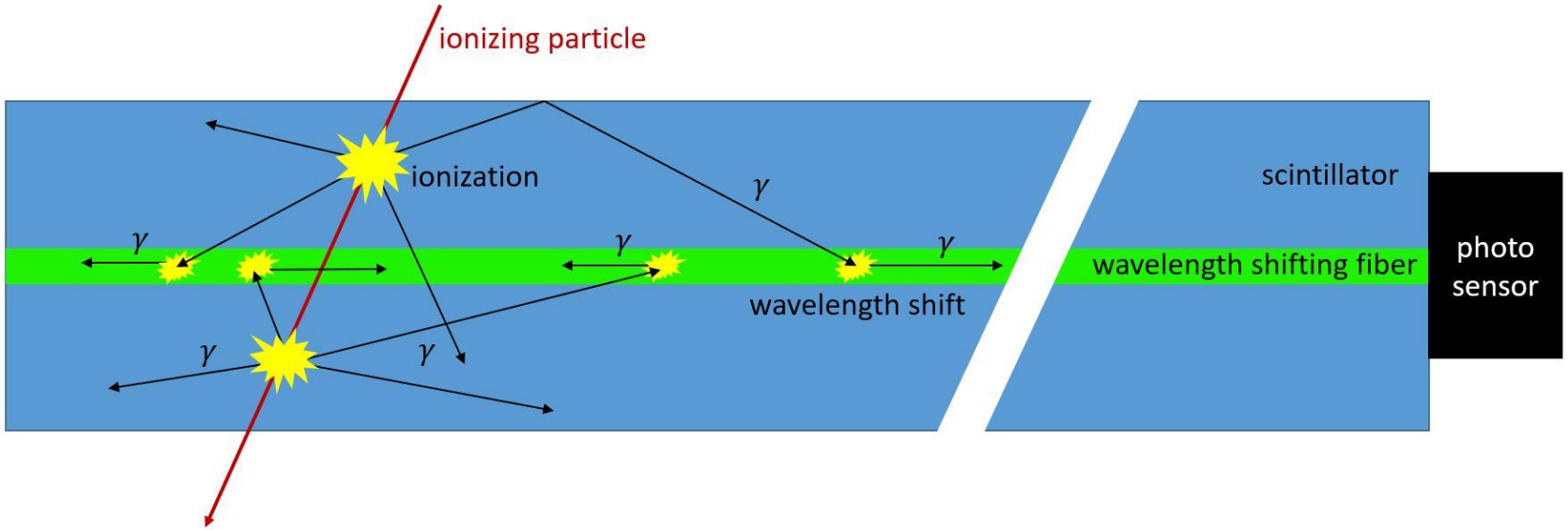
OUTLINE

- Motivation
- Concept
- Prototype
- Measurements
- Results

SCINTILLATOR STRIP READOUT



- Scintillator strips with wavelength shifting fiber for better signal propagation
- Readout of fiber with photo sensor at the end of the strip (usually SiPM)

TWO MAIN CHALLENGES

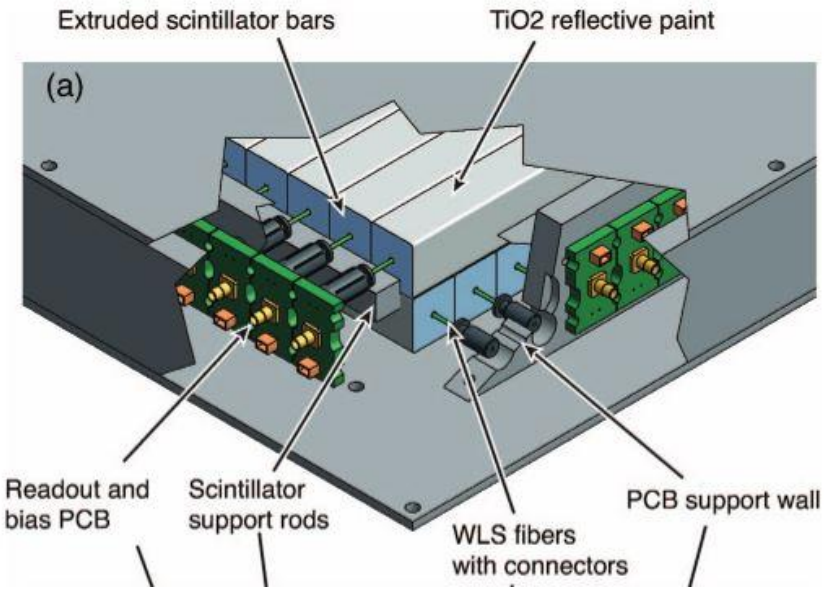
- Usually, fiber directly attached to SiPM
  - Glue/gel
  - Mechanical structures

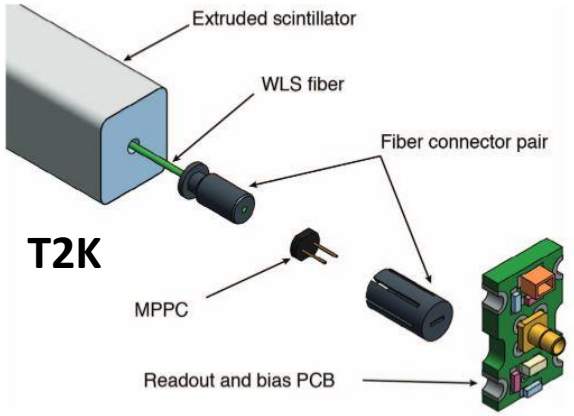
➢ Precise **attachment** and **alignment** structures necessary

➢ Fiber and SiPM **geometries don’t match**

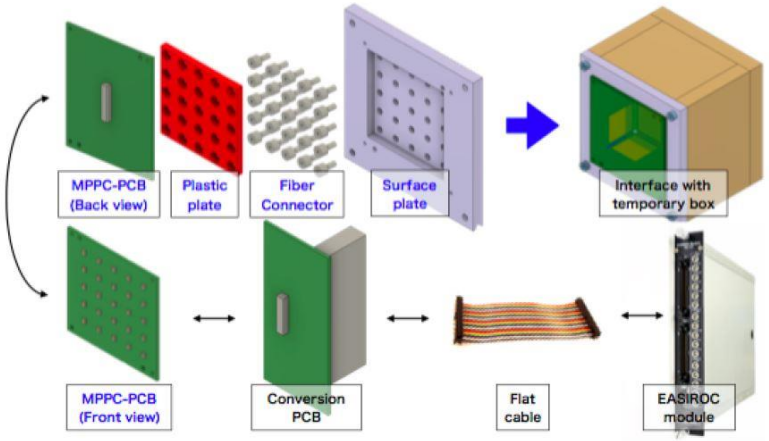
STATE OF THE ART FIBER READOUT

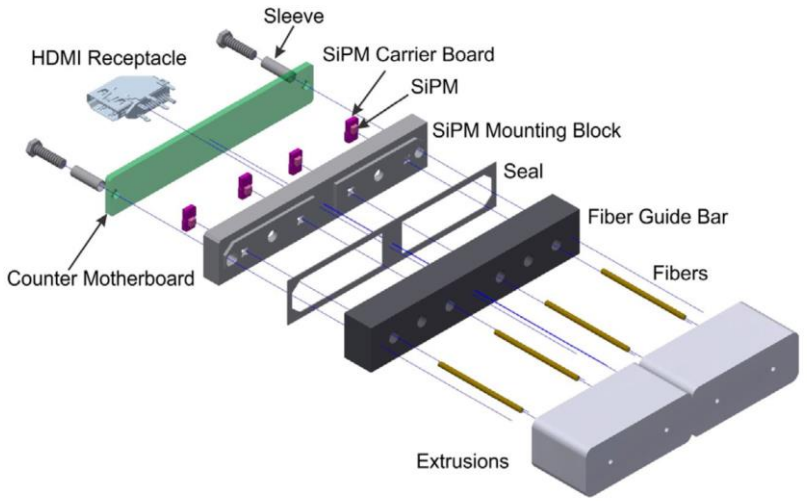
Lots of individual parts to ensure direct contact and alignment of fiber and SiPM



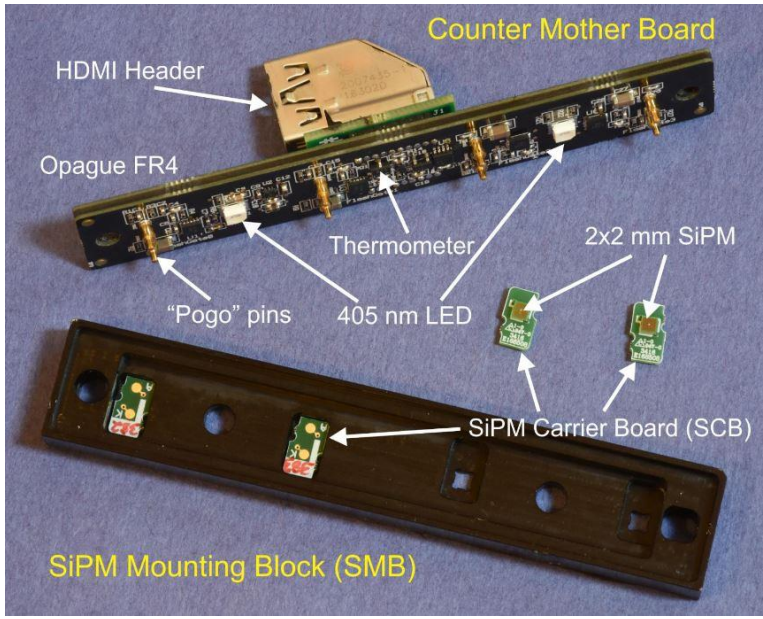


T2K



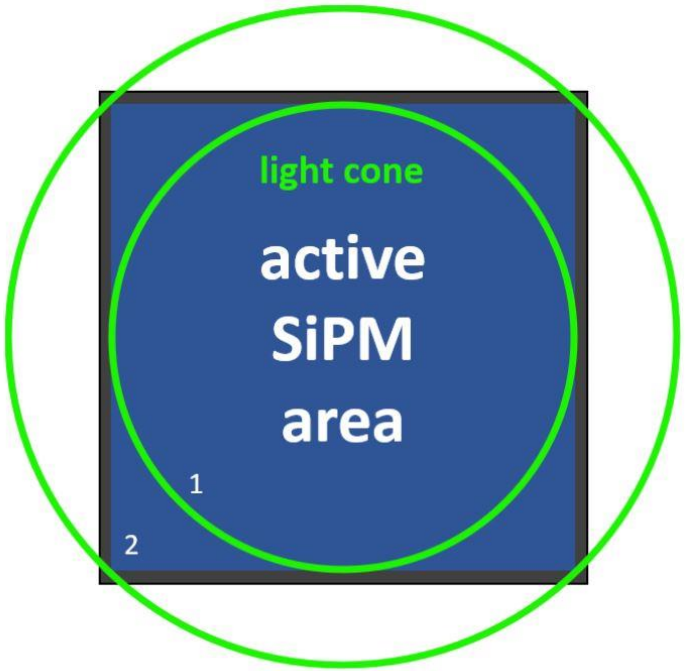


Mu2e



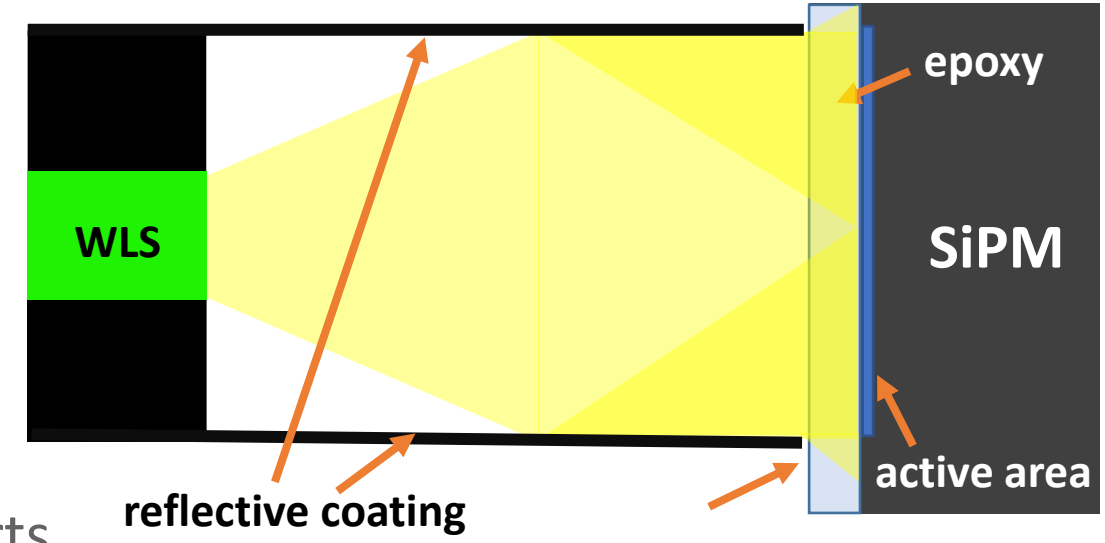
GEOMETRY MISMATCH

- Fiber-to-SiPM distance is key parameter
  - **Too close: (case 1)**
    quicker saturation, loss in dynamic range
  - **Too far: (case 2)**
    light not hitting active area is lost
  - Relative **alignment in sub-mm range necessary**



- Examples:
  - T2K: 1 mm fiber + 1.3x1.3 mm² SiPM - only 46% coverage
  - Mu2e: 1.4 mm fiber + 2x2 mm² SiPM - only 38% coverage

CONCEPT

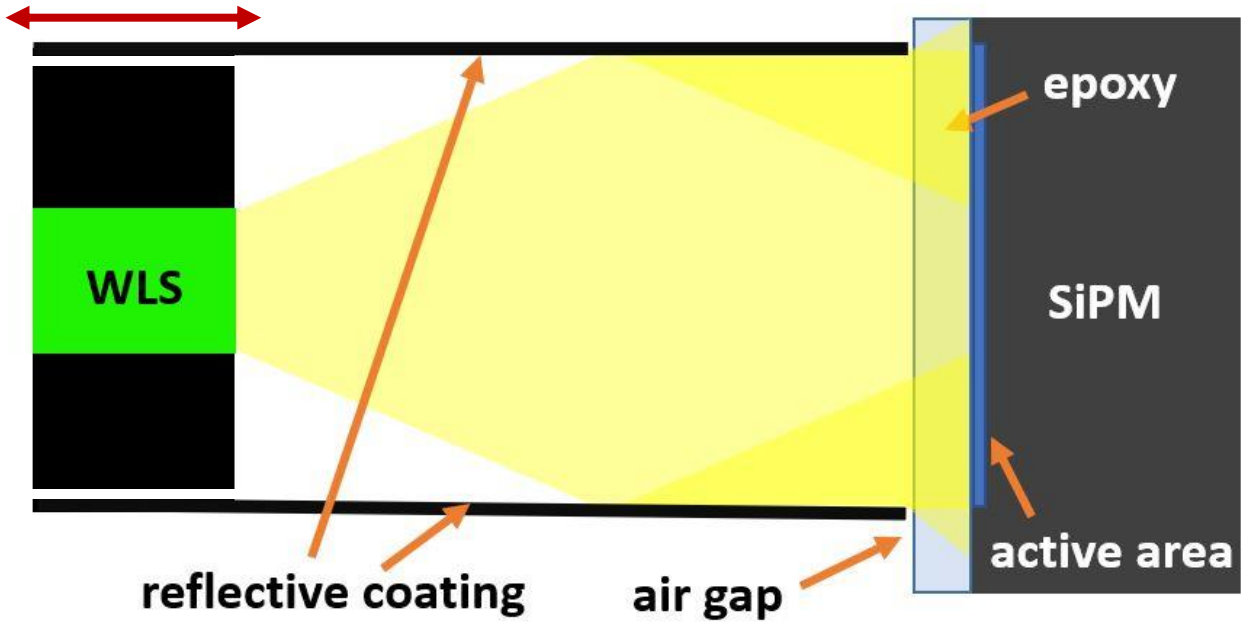


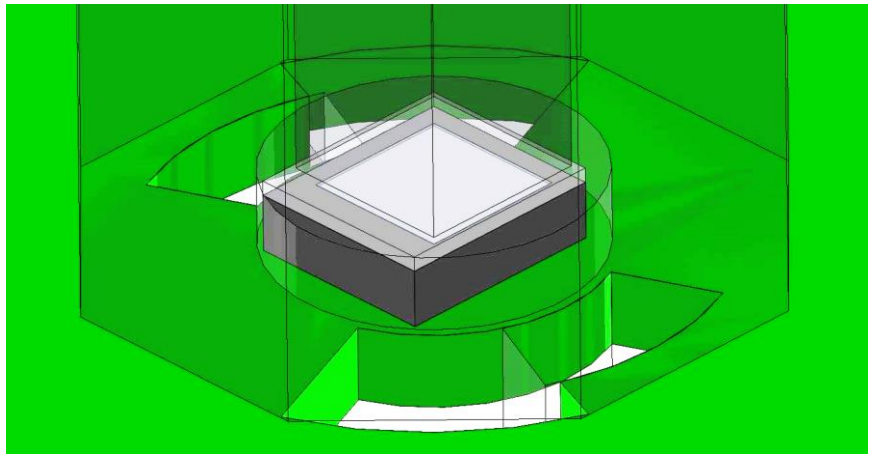
- **Wanted:**
  - Low space consumption
  - Plug-and-play design / minimal number of parts
  - Maximum coverage of SiPM

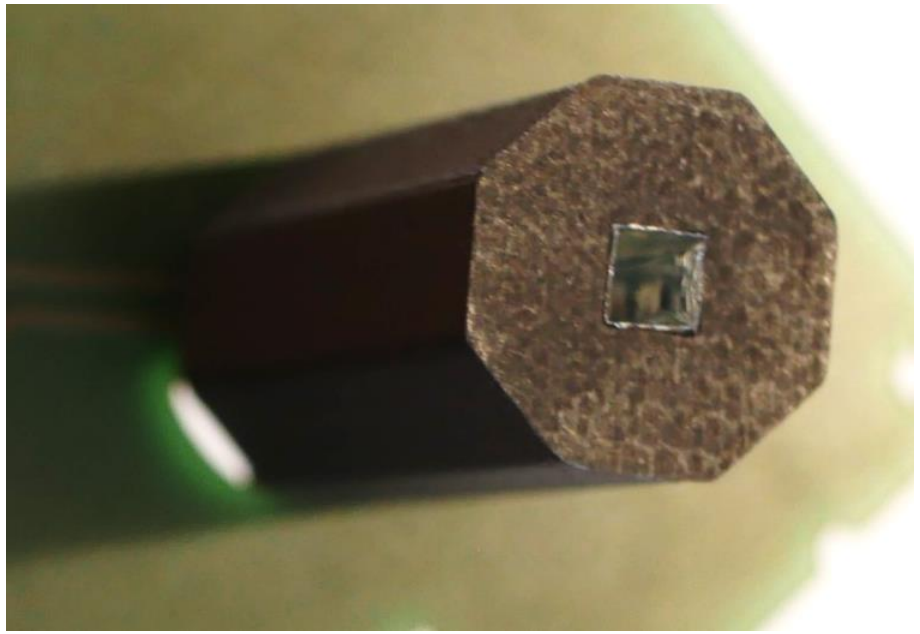
- **Concept:**
  - Insert **reflective cavity** between fiber and SiPM
  - Illuminate SiPM **homogenously**
  - **Optimized distance** for different fiber and SiPM pairs
  - **Minimize light loss** in coupling
  - ➢ **Utilization of full dynamic range**

PROTOTYPE

- 3D-printed piece with bayonet mount
- Inside coated with highly reflective film (3M DF2000MA)
- Fiber-to-SiPM distance variable to determine optimum
- Air gap between cavity and SiPM minimized
- Cavity footprint matching active SiPM area

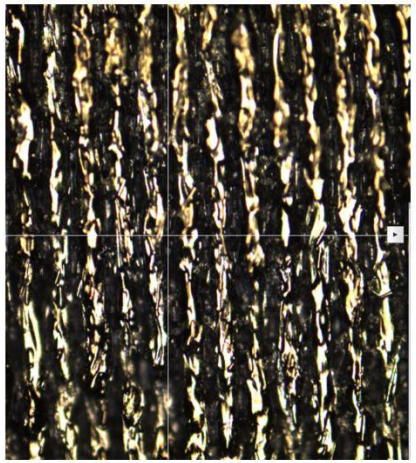


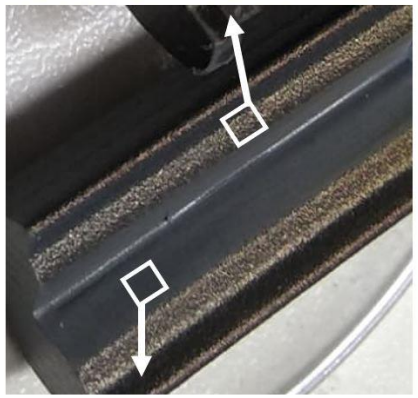


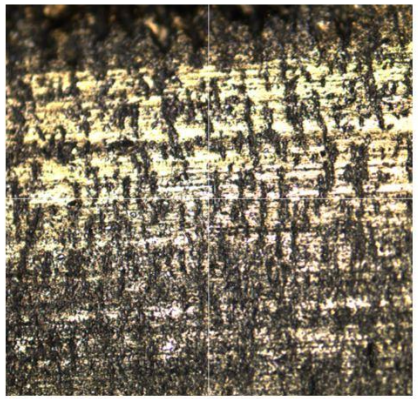


MANUFACTURING STUDIES

- Manual insertion of foil only suitable for prototyping
- Exploring aluminum sputtering as coating technique
  - Application of single atoms on surface with plasma
  - Resulting reflectivity very sensitive to surface finish
- Poor surface quality of 3D print resulted in dull coating
  - Different manufacturing techniques might yield better, faster and cheaper results (injection molding/different 3D printing technique)
  - Other coating methods to be explored
- **Easier manufacturing crucial for success**

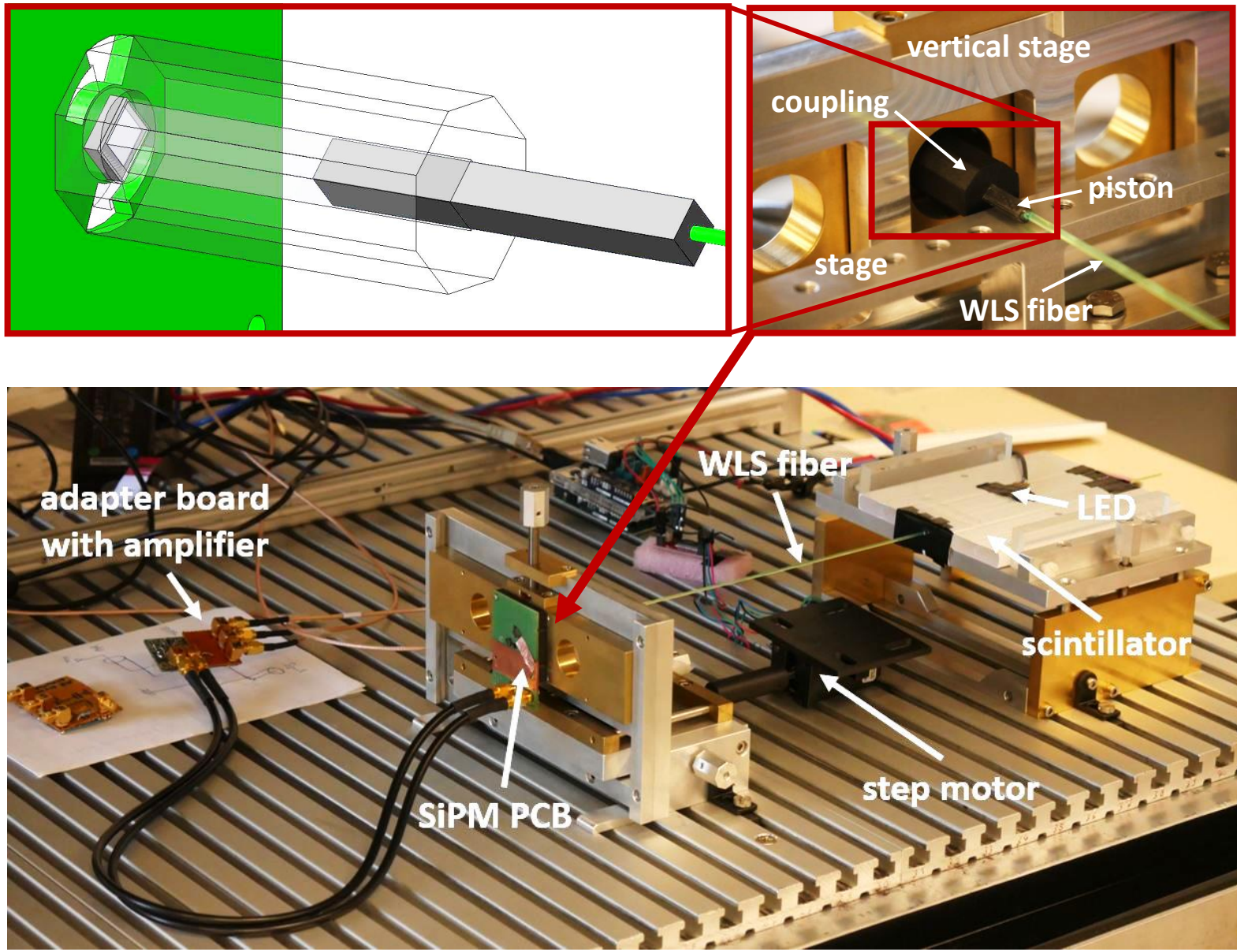




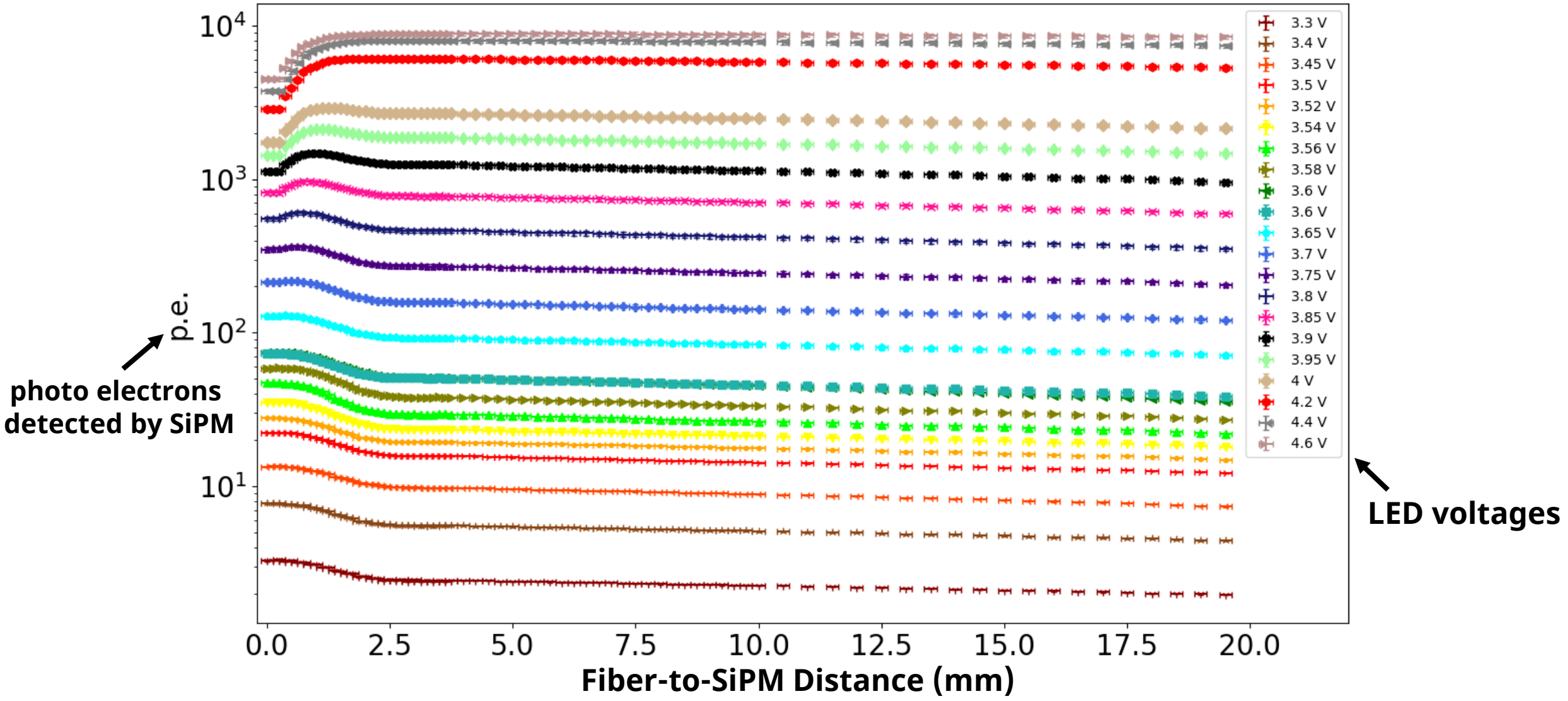


SETUP

- Scintillator illuminated by pulsed UV-LED
- 1.0/1.5 mm Y-11 WLS
- Hamamatsu S13660 SiPM
  - 3x3mm active area
  - 25/50 µm pixels
- Precisely adjustable (<0.25 mm) distance (z) between fiber and SiPM



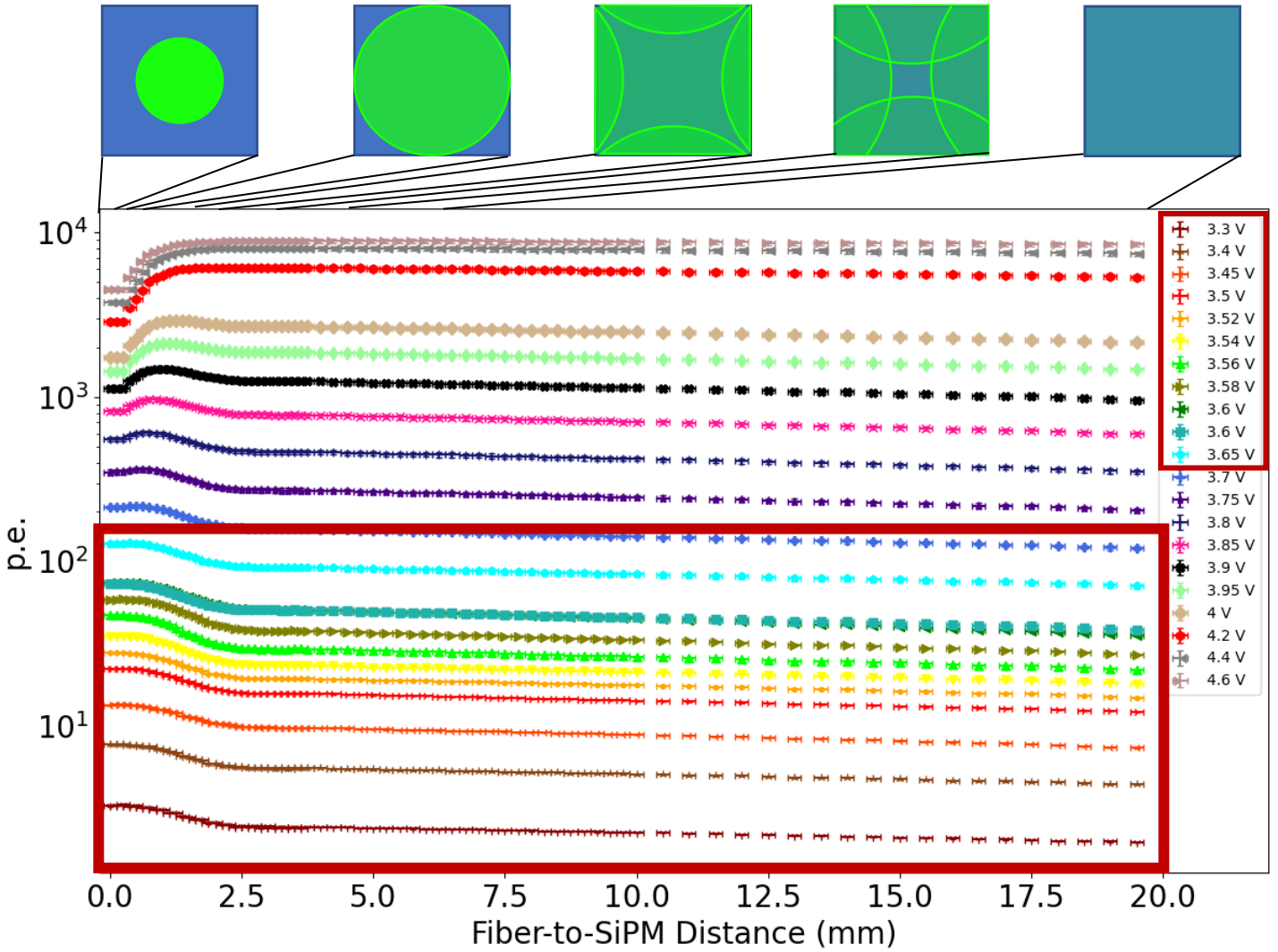
RESULTS FOR S13660-3025 SIPM + 1 MM FIBER



RESULTS FOR S13660-3025 SIPM + 1 MM FIBER

Low LY curves:

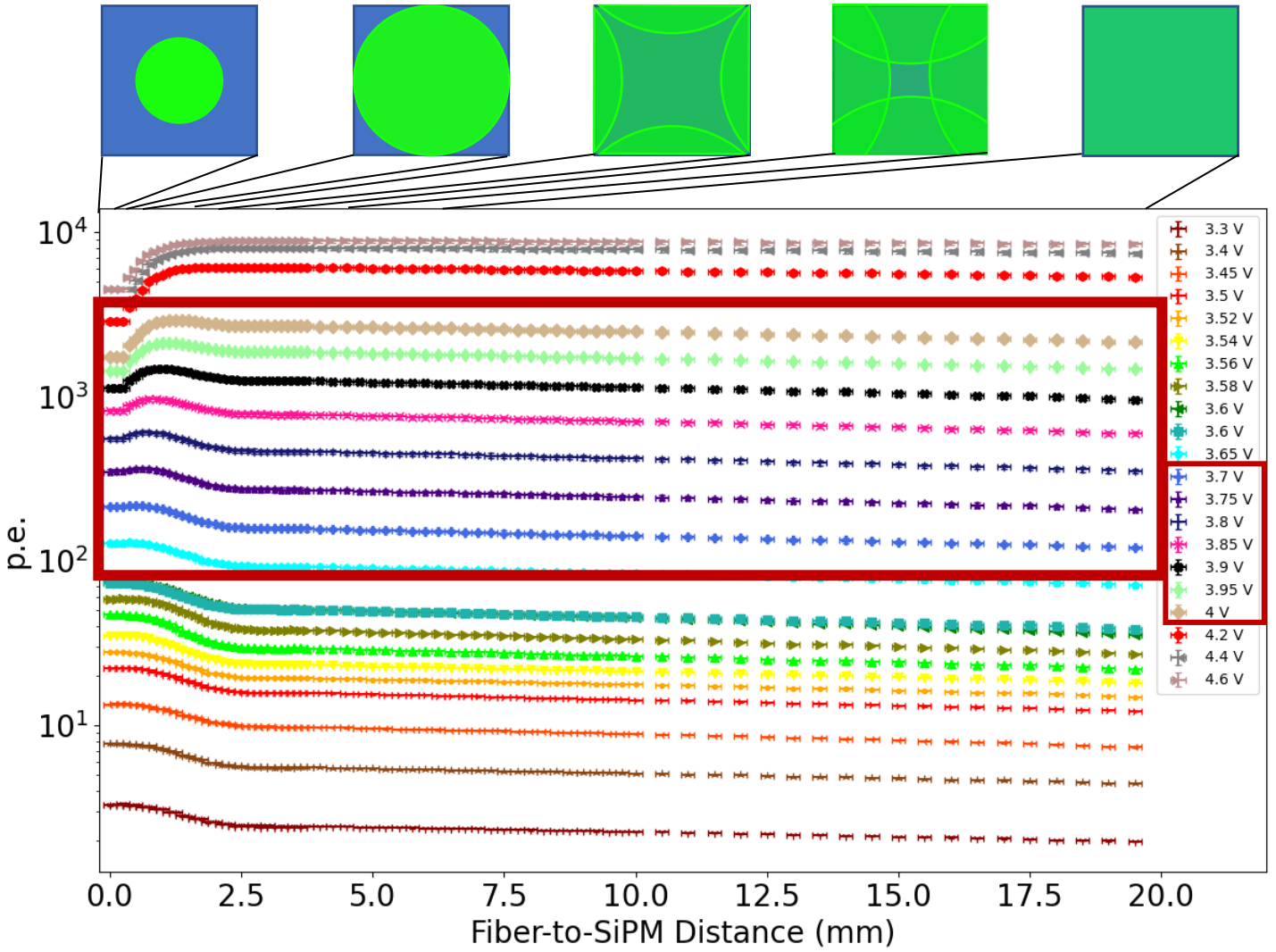
- Up to about 150 p.e.
- First data point has the highest signal (***not saturated***)
- Plateau at the start
- Initial drop between 0.75- and 2-mm distance
- Steady decline at higher distances



RESULTS FOR S13660-3025 SIPM + 1 MM FIBER

Medium LY curves:

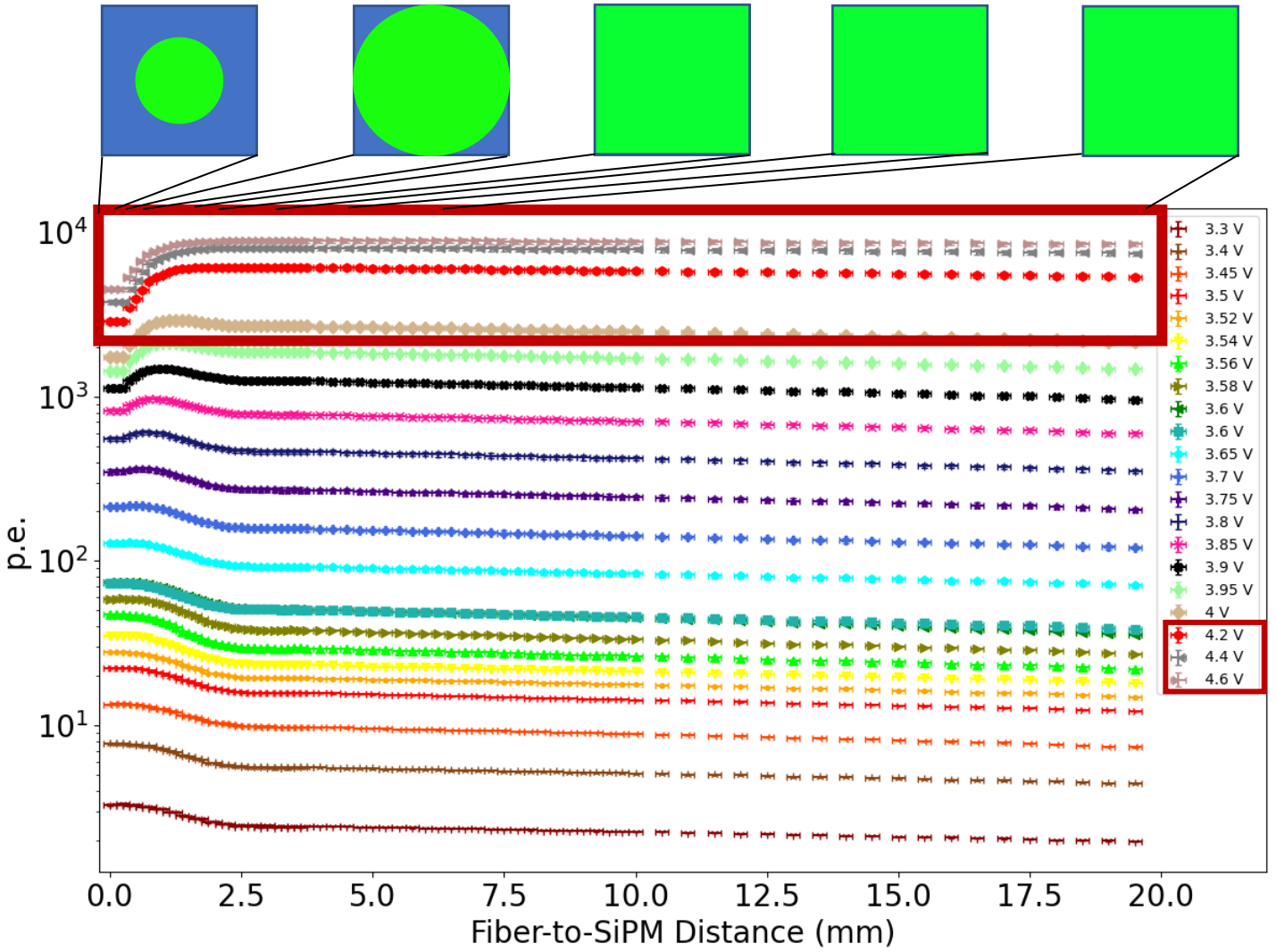
- Around 150 to 3000 p.e.
- First data point not the highest anymore (***saturation***)
- Plateau at the start
- Initial rise to the maximum between 0.75- and 1.5-mm distance (***illumination of larger SiPM area + desaturation***)
- Drop from maximum to around 2-mm distance
- Steady decline at higher distances



RESULTS FOR S13660-3025 SIPM + 1 MM FIBER

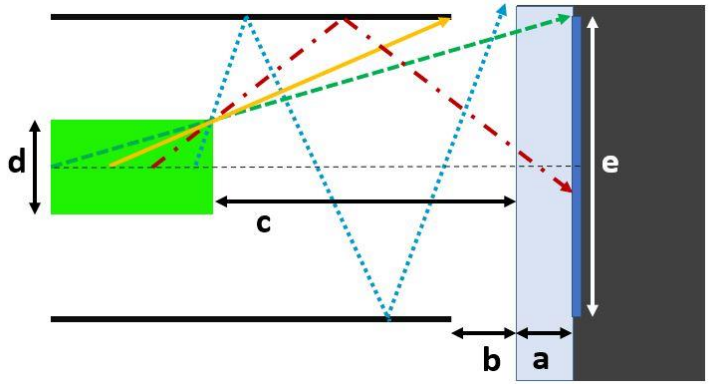
High LY curves:

- Starting at 3000 p.e.
- First data point is lowest data point (***saturation***)
- Plateau at the start
- Rise between 0.75 and 2 mm (***illumination of larger SiPM area***)
- Plateau, because light level to high for SiPM to desaturate

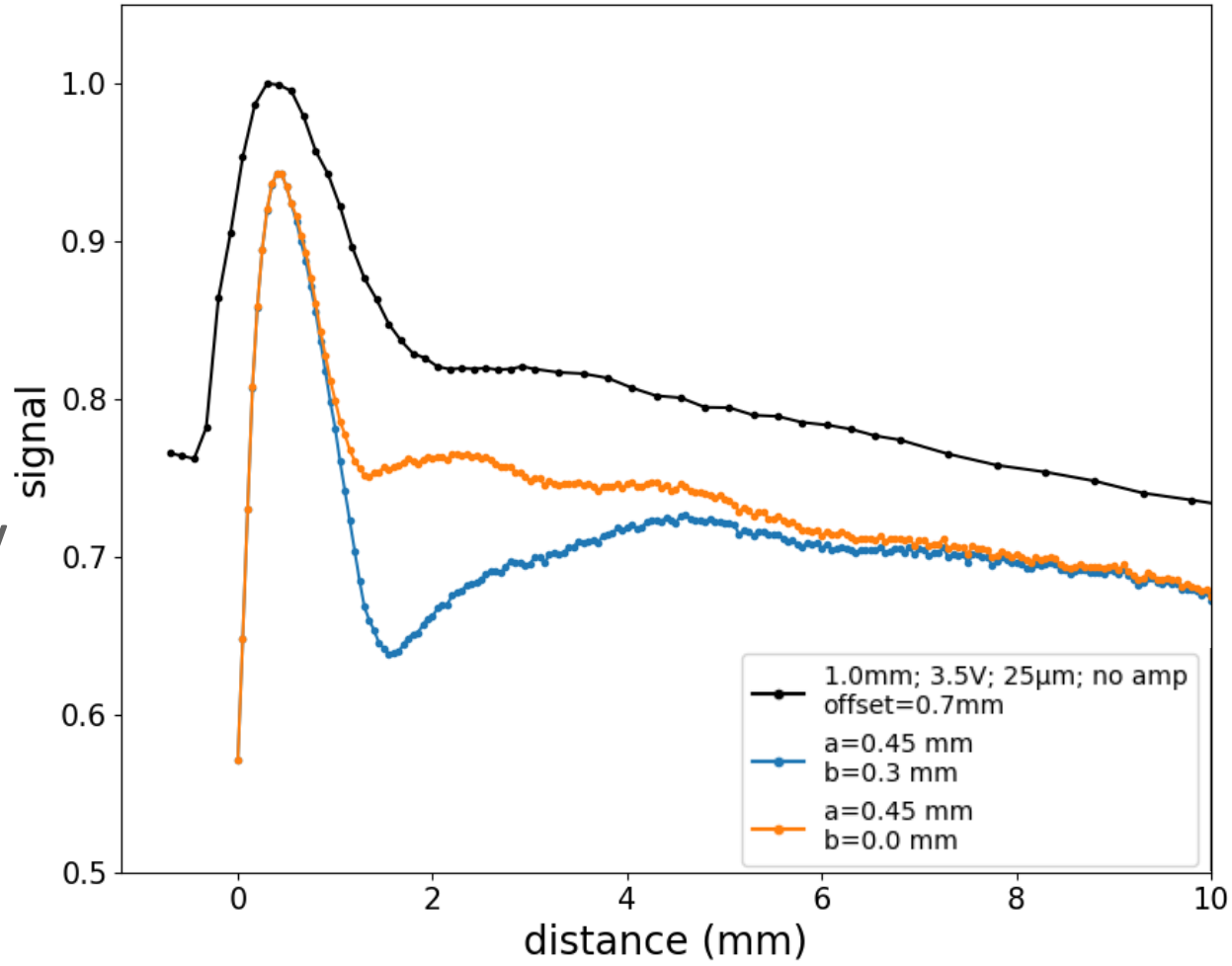


SIMULATION VS. REALITY

- Simplified geometrical simulation
- Simulated signal shape very similar to real data
- Results suggest signal loss caused by loss in protective epoxy layer
- Slope of tail determined by reflectivity of coating



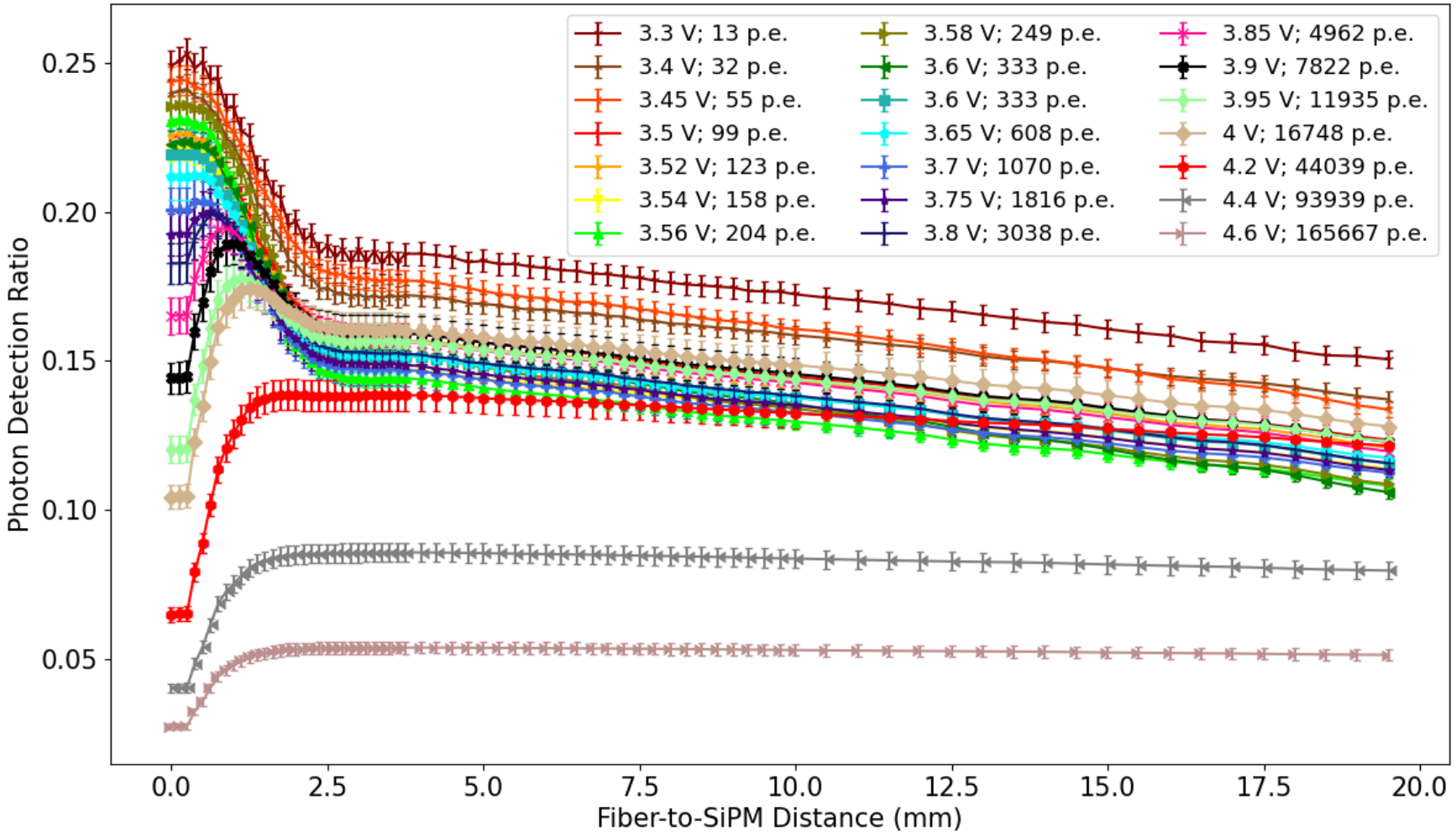
Comparison measurement vs. simulation



PHOTON DETECTION RATIO

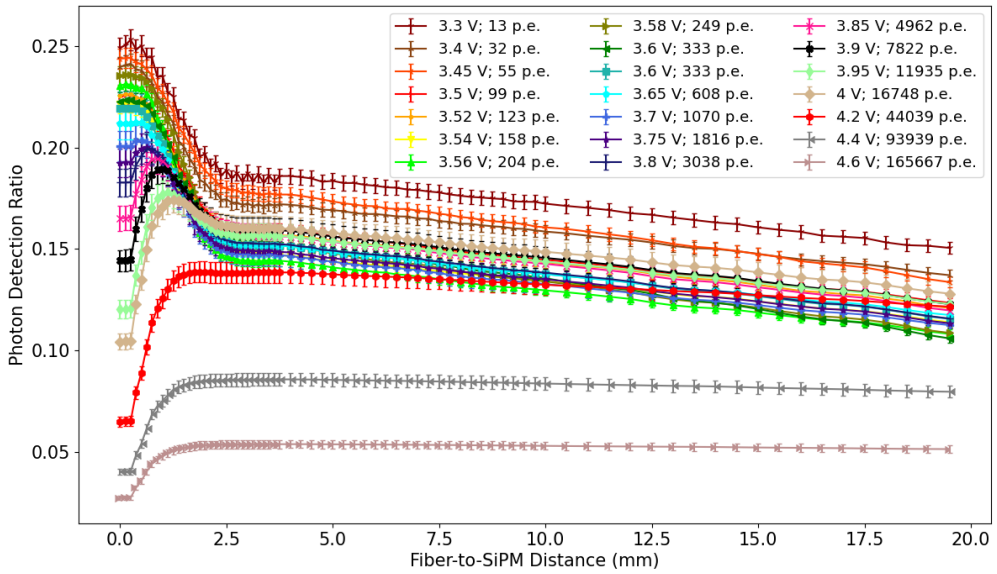
- Ratio of detected photo electrons vs. normalized number of photons leaving the fiber
- Maximum is limited by the PDE (0.25) of the SiPM
- The detection ratio gets smaller at higher photon numbers (***saturation***)

Fiber-to-SiPM distance of zero only the best at low intensities



COMPARISON OF RESULTS

S13660-**3025** + **1.0 mm** fiber

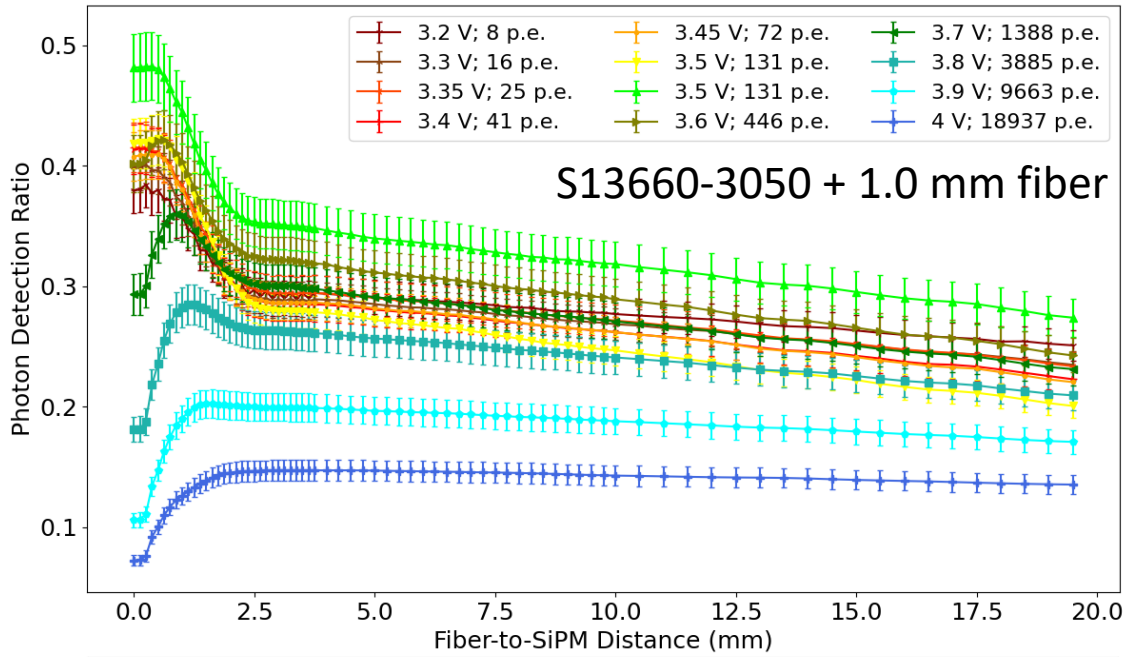


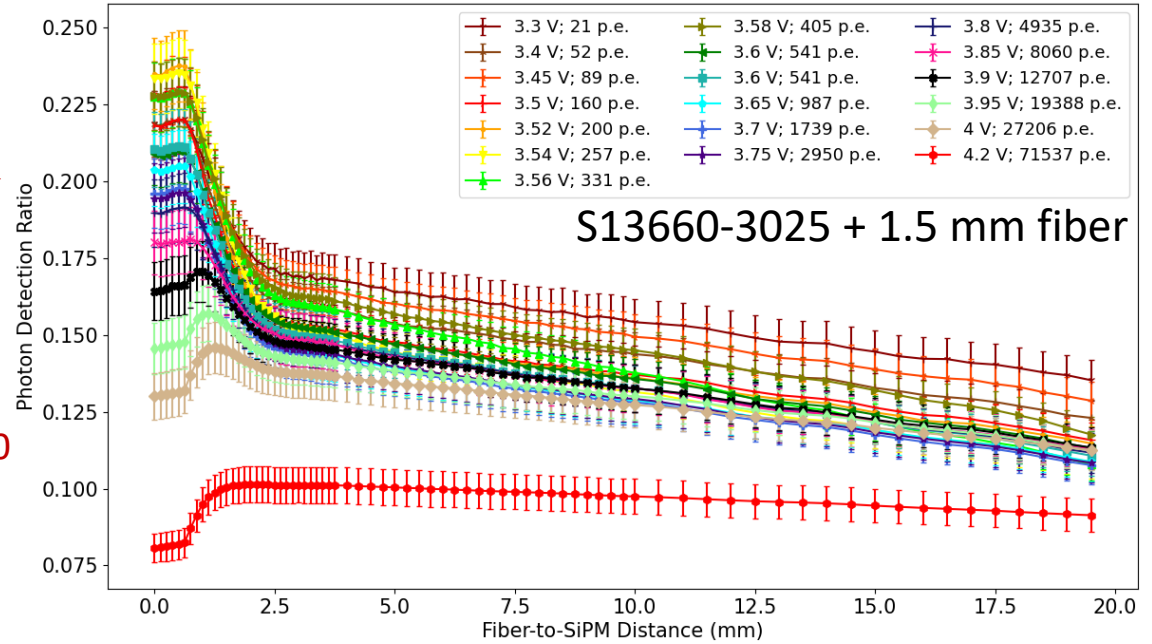
Less pixels

- saturates faster
- better at low LY

Bigger fiber

- higher LY (40-50%)
- less desaturation
- bigger plateau at x=0

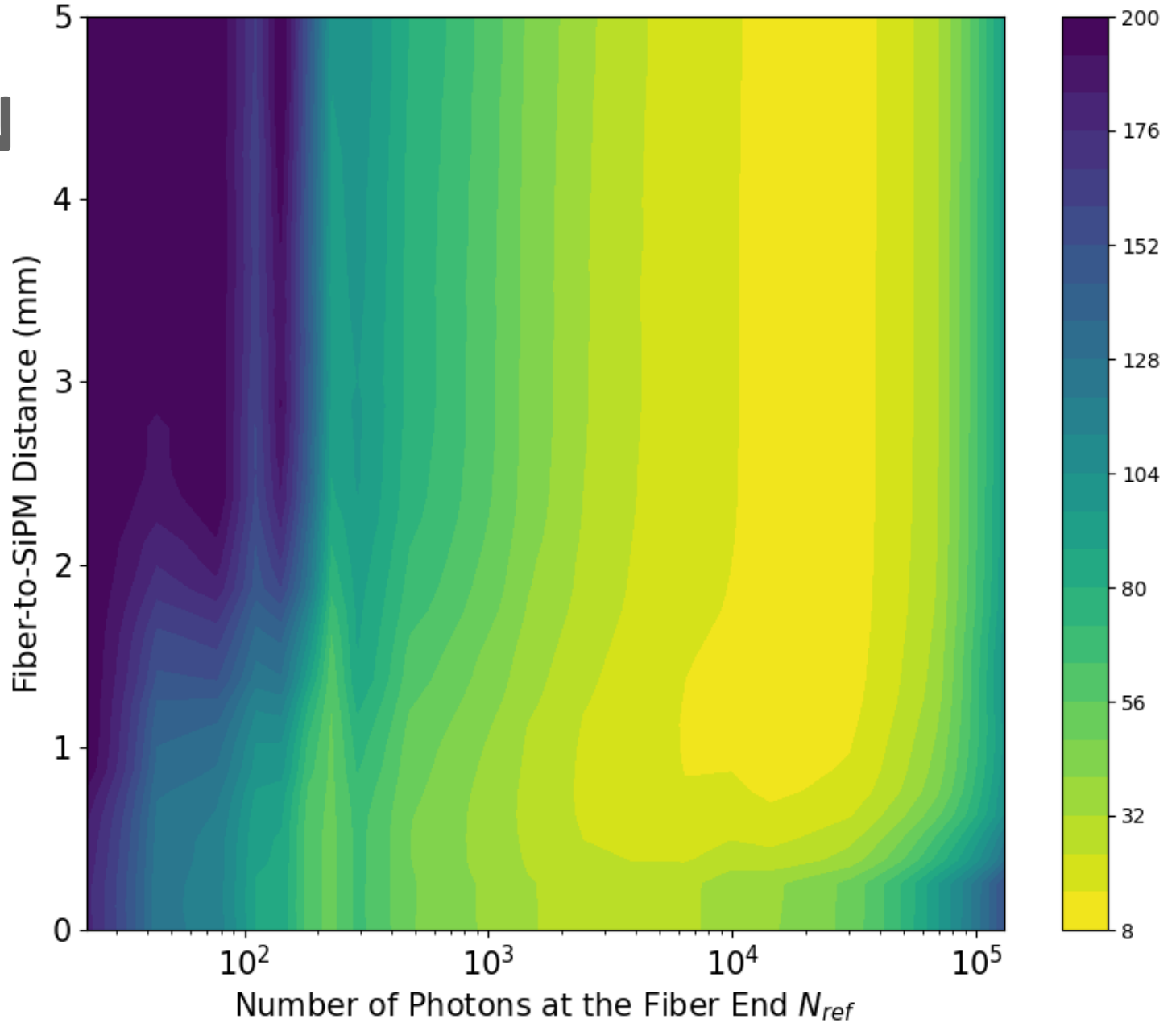




RELATIVE RESOLUTION

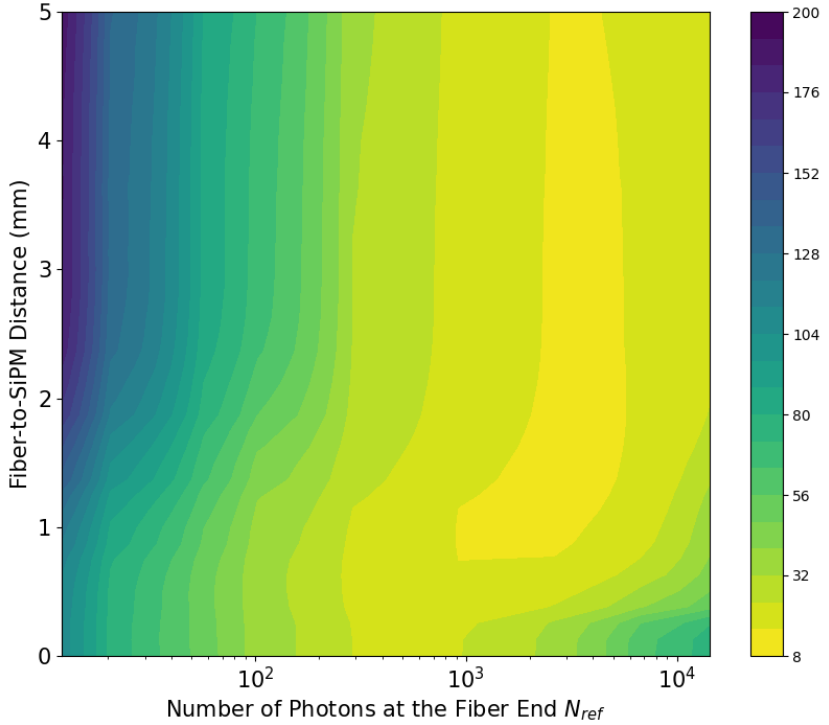
- Relative resolution $\frac{\Delta N_{ref}}{N_{ref}}$ based on the shot noise of a single hit (z-scale in %)

- Distance for optimal resolution highly dependent on light level (N_{ref})
- Resolution gets better for z>0 starting from 1000 p.e.



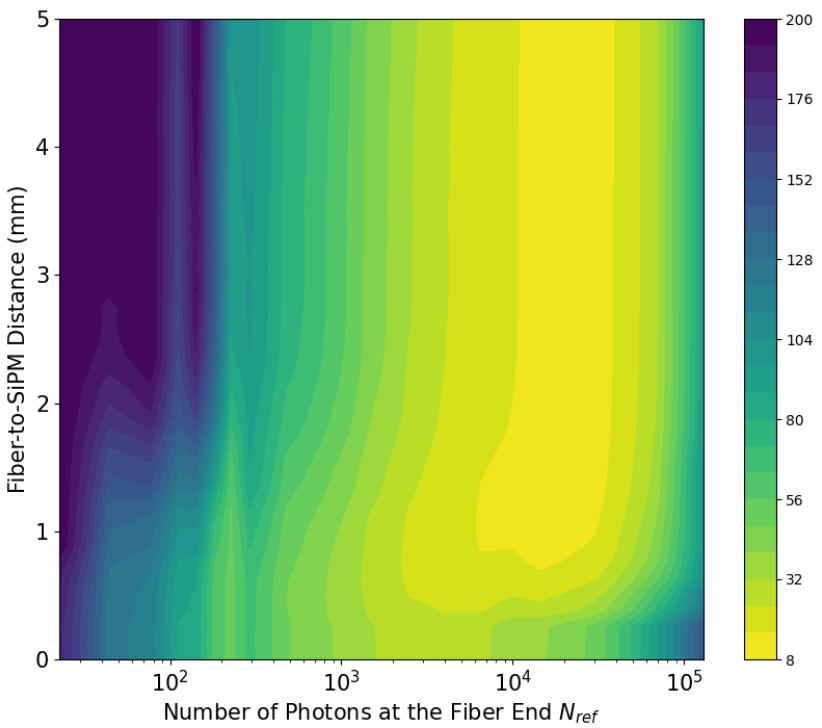
COMPARISON OF RESULTS

S13660-30**50** + **1.0** mm fiber



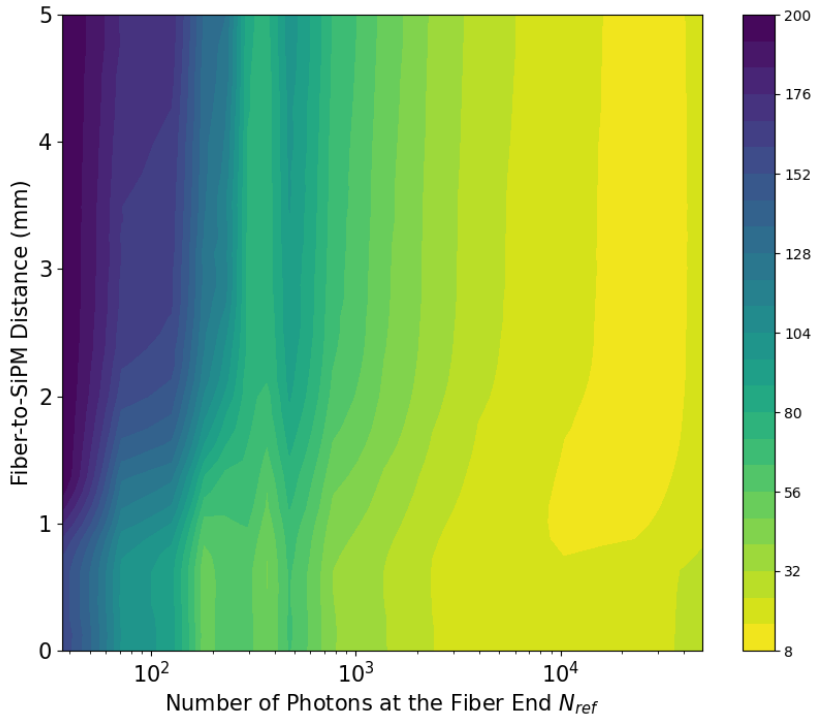
- Lower pixel number
- Saturation/improvement start at lower LY
- Optimal resolution at around 2k p.e.

S13660-**3025** + **1.0** mm fiber



- Saturation starting at 6-8k p.e.
- Optimal resolution at around 10k p.e.
- Improvement from coupling from about 1000 p.e.

S13660-30**25** + **1.5** mm fiber



- Similar to 1.0 mm fiber
- Better coverage with bigger fiber
  - Better resolution
  - Improvement only at higher LY

DISCUSSION

- Proof of concept and advanced studies completed for prototype
- Further R&D in manufacturing necessary
- Possibility of extensive cost saving by using SiPMs more efficiently instead of using more expensive models

- Resolution increase at high LY
- **Easy handling and mounting for any application**

Questions?

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