A Geant4-based simulation of the X-ARAPUCA for the optimization of dichroic filters

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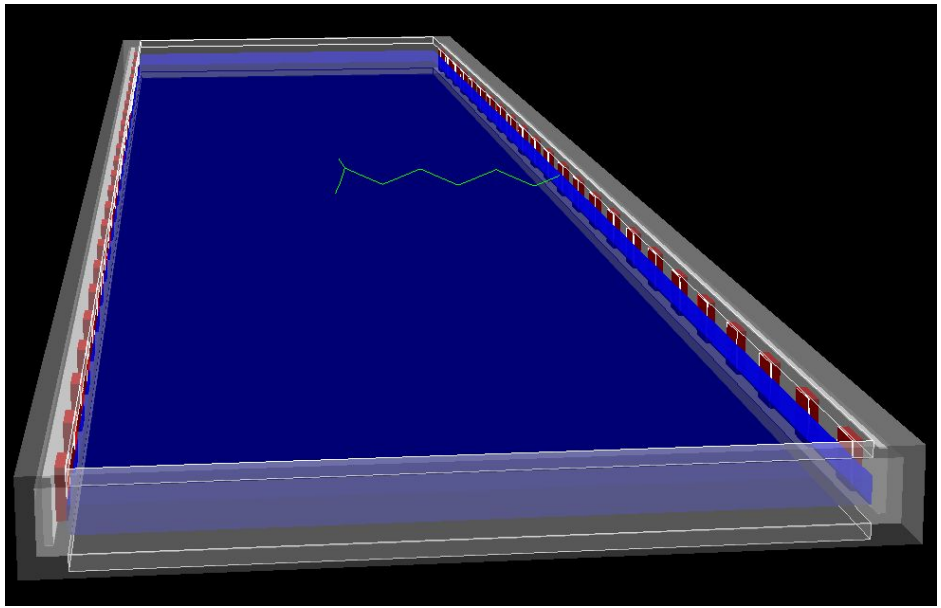
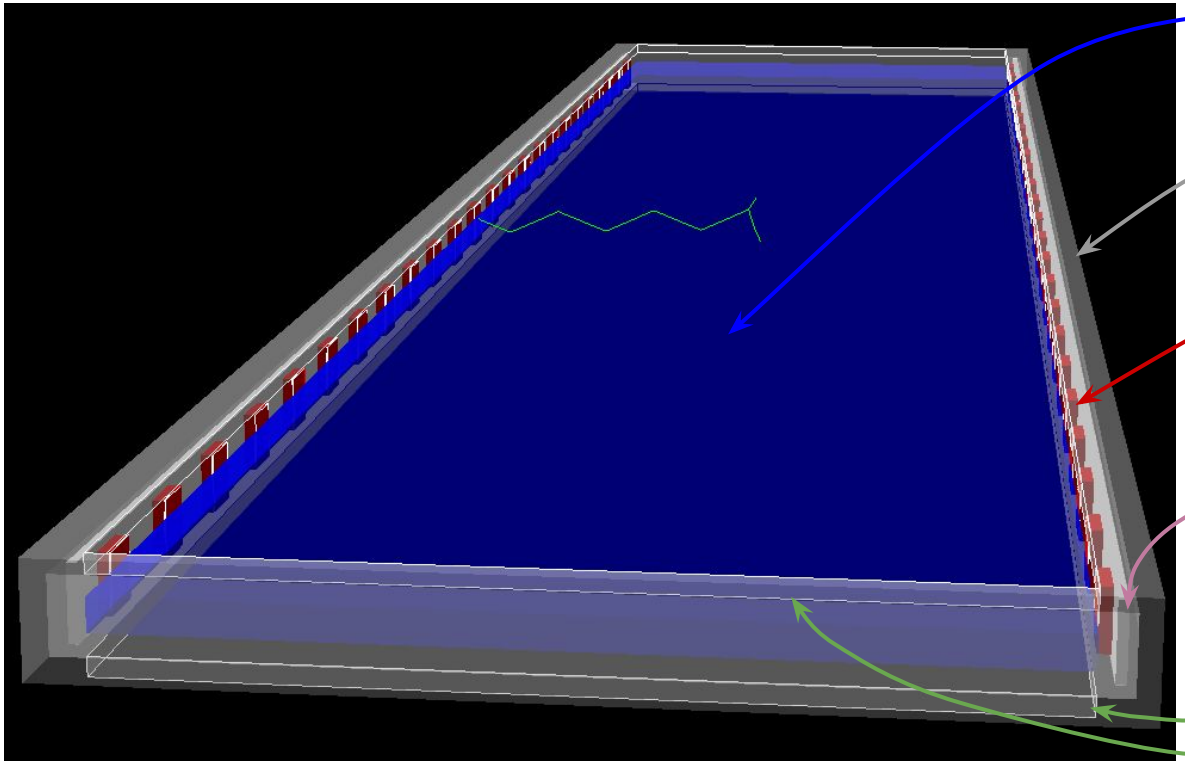


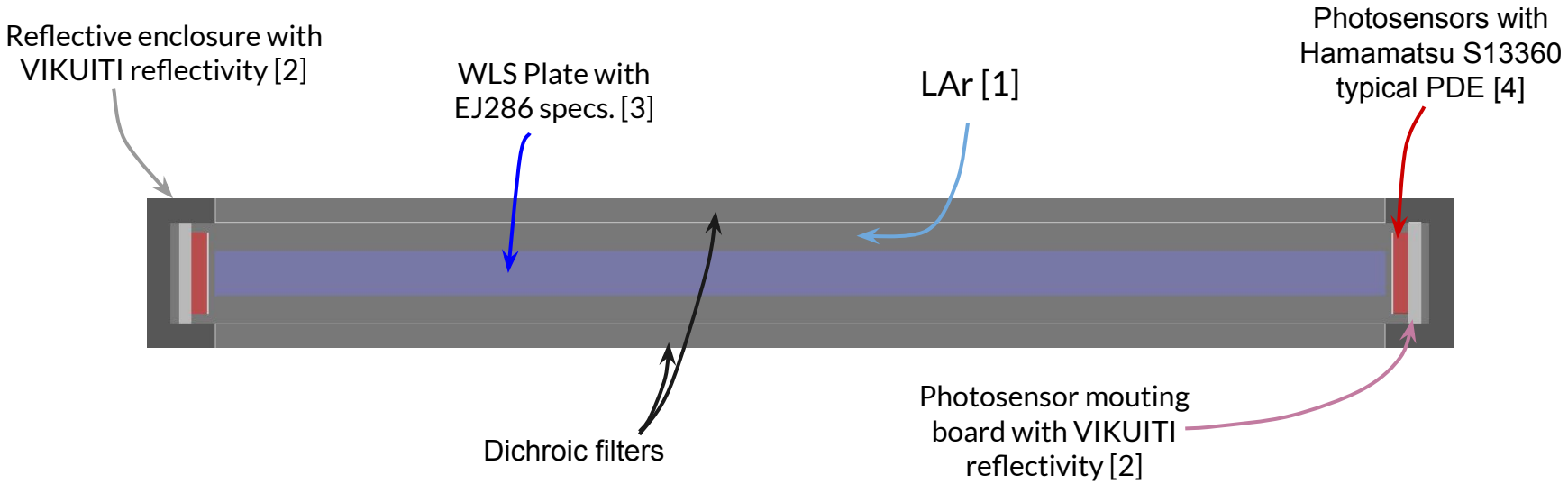
Introduction

- We have developed a Geant4 simulation of the X-ARAPUCA supercell to guide our R&D work on the dichroic filters.
- Our goal is to use this simulation to understand the optimal parameters for the prototype dichroic filters production in Spain.
- This simulation is complementary to the work done by Gustavo, Marcio and Franciole.
- This is still work in progress. Some of our assumptions need to be fine tuned.
- The software is parameterized so as to be easily adjusted to the simulation of related geometries, such as megacells, with adjustable optical properties for each component.
- Some preliminary photon collection efficiency (PCE) estimates have been computed.

Geometry


WLS Plate with
EJ286 specs. [3]
Reflective enclosure with
VIKUITI reflectivity [2]
Photosensors with
Hamamatsu S13360
typical PDE [4]
Photosensor mouting
board with VIKUITI
reflectivity [2]
Dichroic filters

Geometry

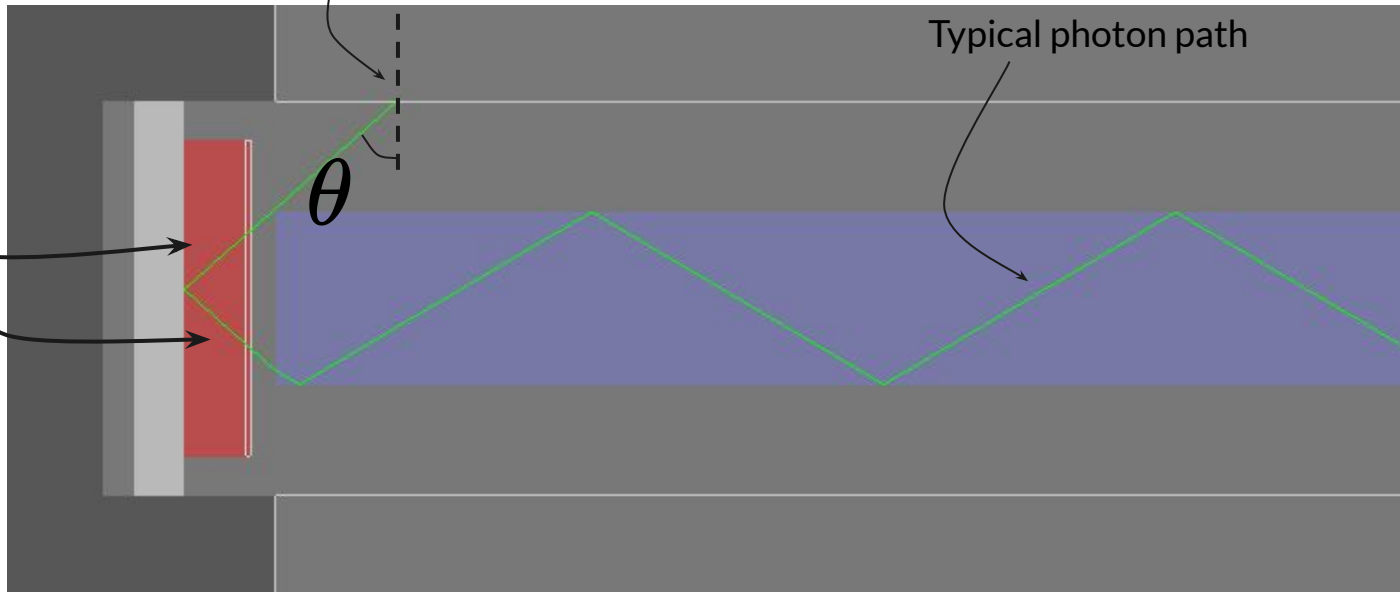


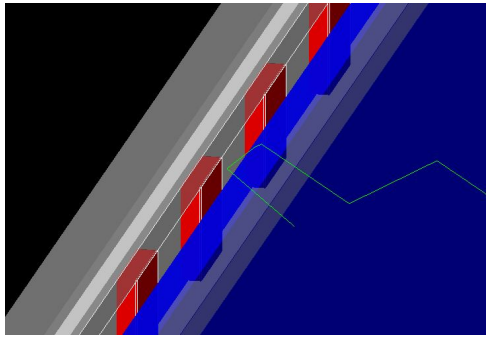
Dimensions were taken from [5] (TDR vol. IX)

Geometry

When reaching the dichroic filter, the photon is (artificially) absorbed and its angle is recorded

Passage of the photon in between photosensors



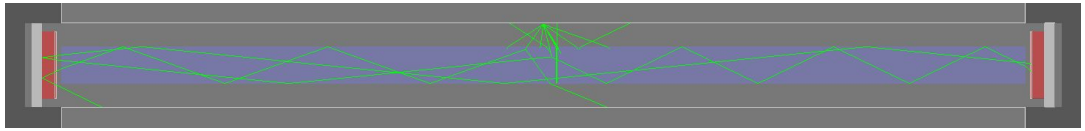


Building X-Arapuca step by step [6]

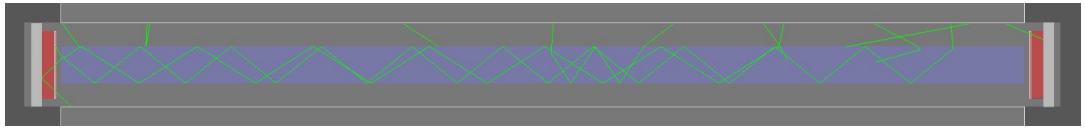
Double sided reflective box w/ WLSP, w/ photosensors and **lambertian generator** (L. D.)

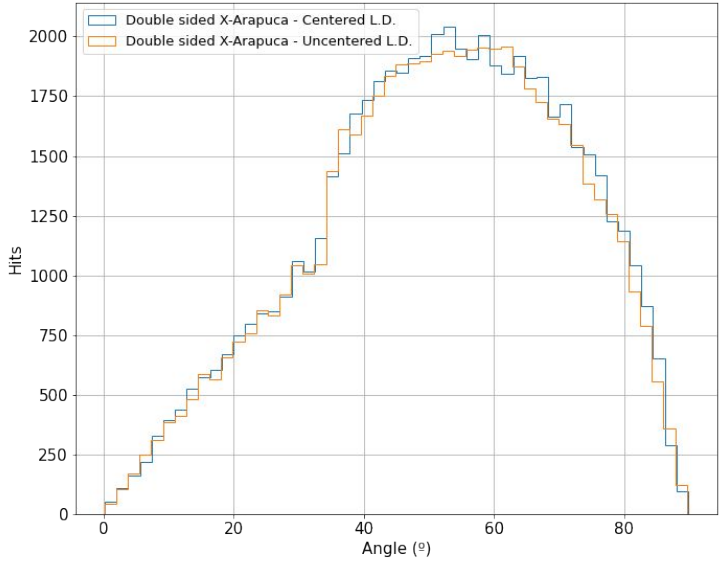
[6]

Centered L. D.



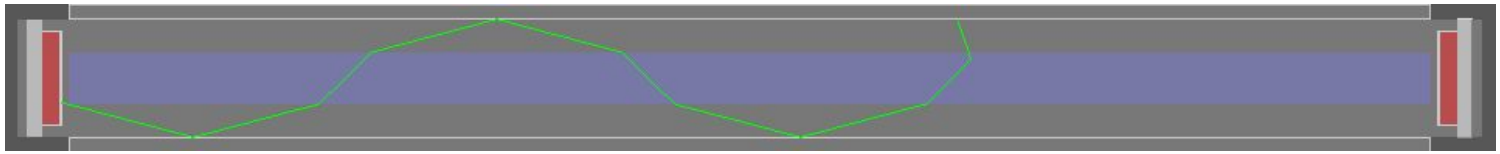
Uncentered L. D.



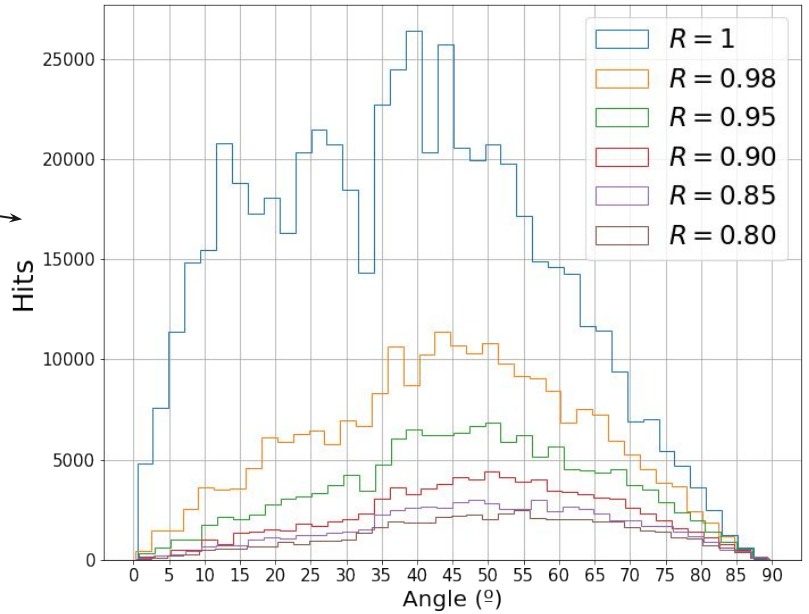


Building X-Arapuca step by step

Double sided reflective box w/ WLSP, w/ photosensors, lambertian generator and **reflective dichroic filters**

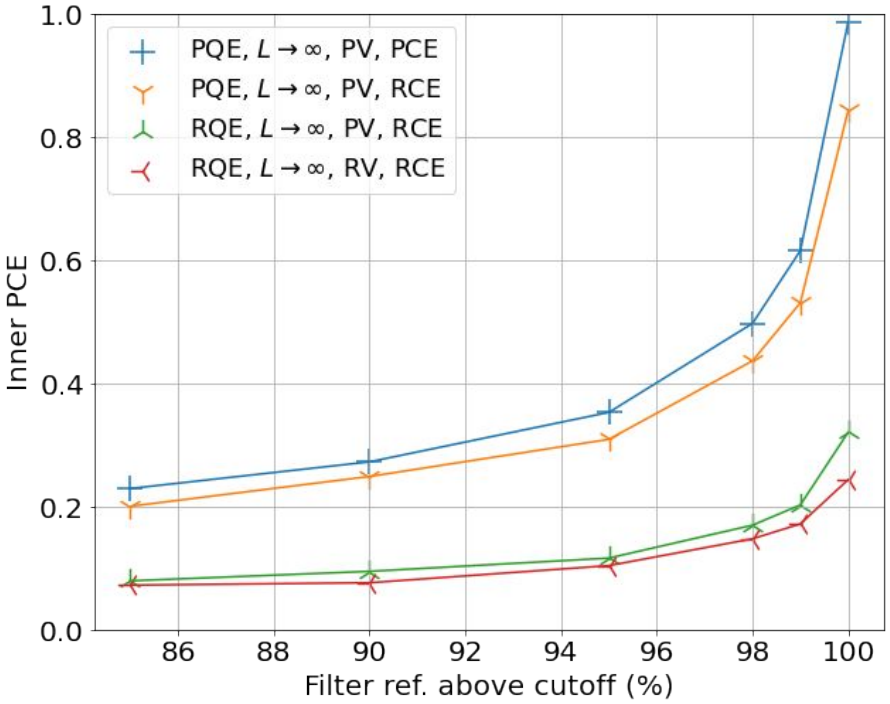


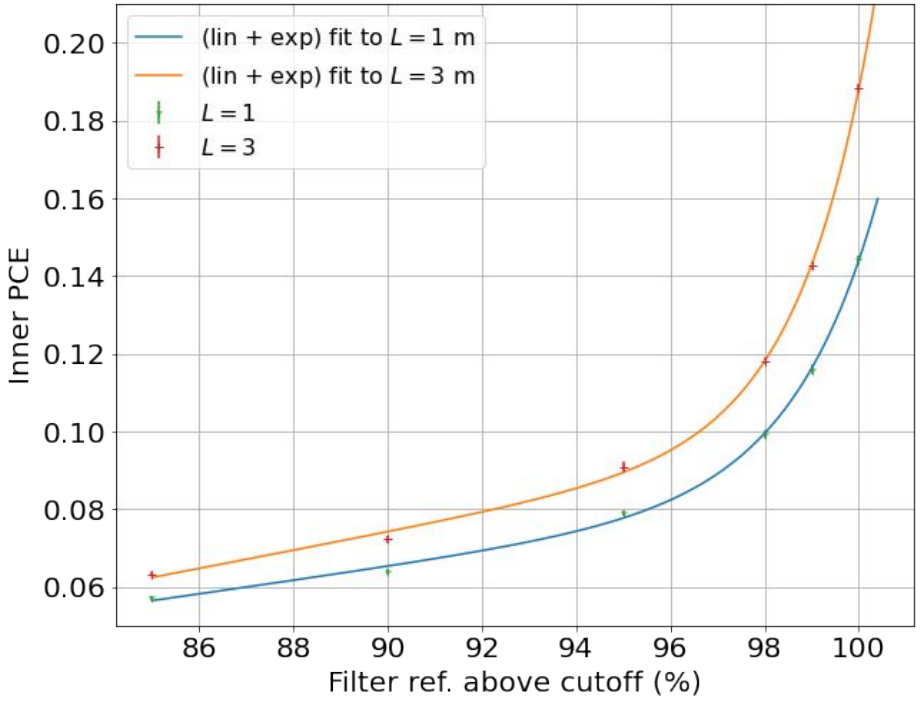
This result suggests that reflectance above the cutoff may be a crucial parameter



PCE estimates

Systematic approach to realistic conditions





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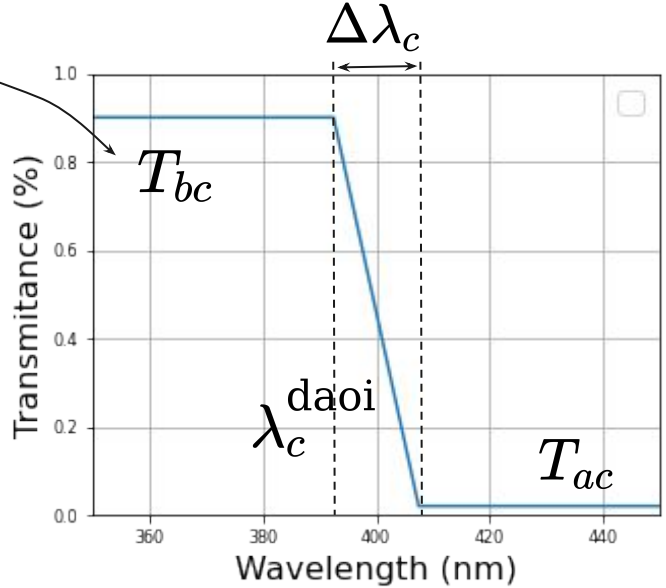
Next steps

- Introduce a more realistic dichroic filter model. To do so:
  - Simulate PTP emission spectrum and angular distribution ✓
  - Simulate substrate optical properties (i.e. refractive index and absorption length) *(ongoing)*
  - Simulate dichroic depositions via a simple parameterization of its transmission curve *(ongoing)*

A preliminary study could fix Tbc, since it should just scalate the amount of light that enters the X-ARAPUCA. This would leave three parameters to iterate over.



Next steps

- Compute overall PCE estimates by generating photons from outside the X-ARAPUCA and using the generated curves for the dichroic filters
- The goal is to understand which parameter should we particularly care for, and which ones (if any) affect in a way that its requirements can be relaxed (optimization cost)
- These results could guide dichroic filter optimization
- Geant4 interpolates across wavelength and angle. The input data must comprise transmission curves for different angles. To transform the generated curves according to its AOI, a shift is computed according to

$$\lambda_\theta = \lambda_0 \sqrt{1 - \left(\frac{n_0}{n_{\text{eff}}} \sin(\theta) \right)^2}$$ [7]

- Some transmission measurements at different AOIs revealed also scaling. **Any empirical data on transmission measurements at different AOIs are very welcomed** to infer a realistic transformation of the generated curves.

Conclusions

- Simulation of dichroic filters for their optimization is now usable.
- Preliminary results suggest that reflectance above the cutoff is a crucial parameter:
  - This was somehow expected since once inside the X-ARAPUCA, the photon may undergo multiple reflections on the filter before being collected.
  - For both simulated cases, we encountered a **>30% efficiency loss** when lowering filter reflectivity from 99% to 95%
- A numerical optimization iterating over the most important parameters will be performed.

Reference list

[1] Paulucci, L., Marinho, F., Machado A. A. & Segreto, E. (2019)
A complete simulation of the X-ARAPUCA device for detection of scintillation photon
arxiv.org/pdf/1912.09191.pdf

[2] Ana Machado's talk (06/18/2020)
Optical Components - WLS bars, filters and coatings
indico.fnal.gov/event/24273/contributions/188657/attachments/
130083/158244/DUNE_60Review1.pdf

[3] Eljen Technology website (Manufacturer's information)
eljentechnology.com/products/wavelength-shifting-plastics/ej-280-ej-282-ej-284-ej-286

[4] Hamamatsu website (Datasheet)
hamamatsu.com/eu/en/product/optical-sensors/mppc/mppc_mppc-array/S13360-6050VE.html

[5] Deep Underground Neutrino Experiment (DUNE), Far Detector Technical Design Report,
Volume IV: Far Detector Single-phase Technology
Section 5.4: Light collectors

[6] Julio Ureña's talk (17/05/2022)
A Geant4-based simulation of the
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filters
indico.fnal.gov/event/50217/contributions/241738/attachments/155327/202219/IFIC_x-arapuca_sim_17042022.pdf

[7] Angle of Incidence (AOI) and Polarization: Angle shift
https://www.alluxa.com/optical-filter-specs/angle-of-incidence-aoi-and-polarization/
Accesed (07/06/2022)