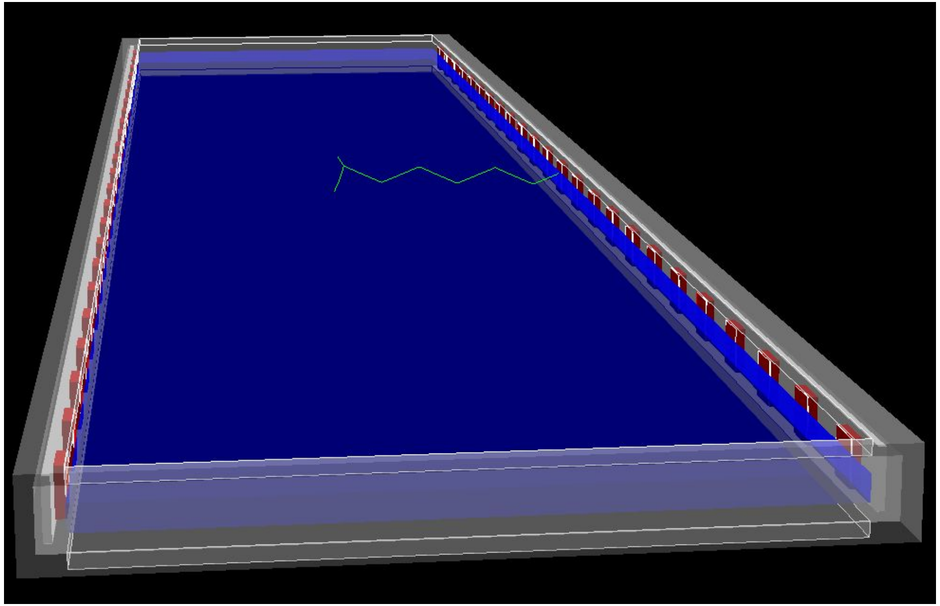
A Geant4-based simulation of the X-ARAPUCA for the optimization of dichroic filters



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IFIC - Valencia

7 July 2022

DEEP UNDERGROUND NEUTRINO EXPERIMENT

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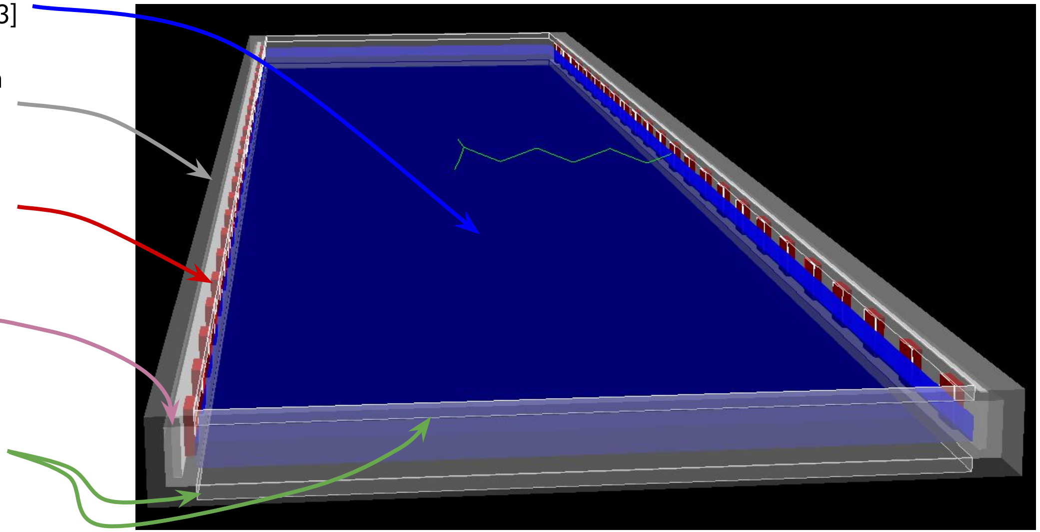
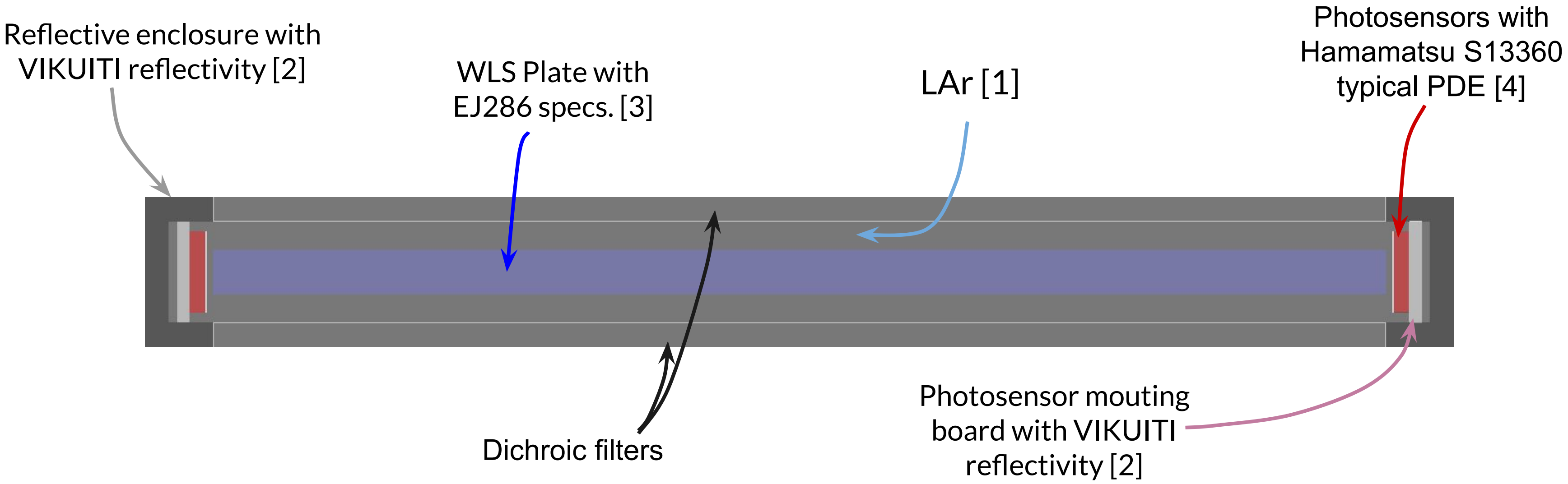
Introduction



The used X-ARAPUCA geometry was introduced in previous talks. See:

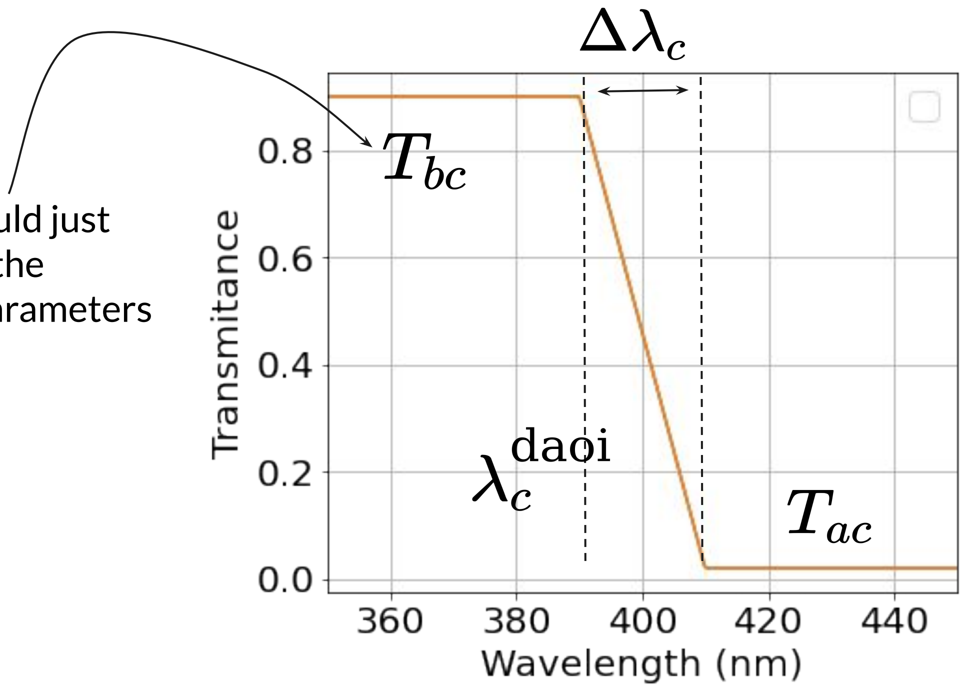
- indico.fnal.gov/event/50217/contributions/241738/attachments/155327/202219/IFIC_x-arapuca_sim_17042022.pdf
- indico.fnal.gov/event/54798/contributions/242876/attachments/155944/203305/df_simulation_07_06_2022.pdf



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

Transmission curve model

Our first study fixes T_{bc} , since it should just scalate the amount of light that enters the X-ARAPUCA. This would leave three parameters to iterate over.



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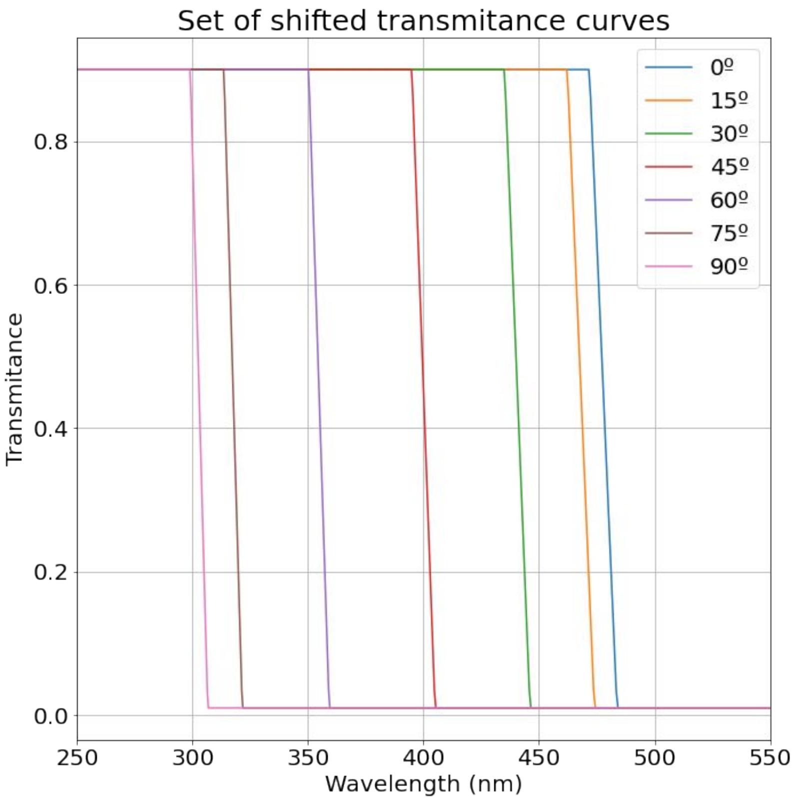
Transmission curve model

The curve that is generated for the design AOI (DAOI), is transformed for every AOI using

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



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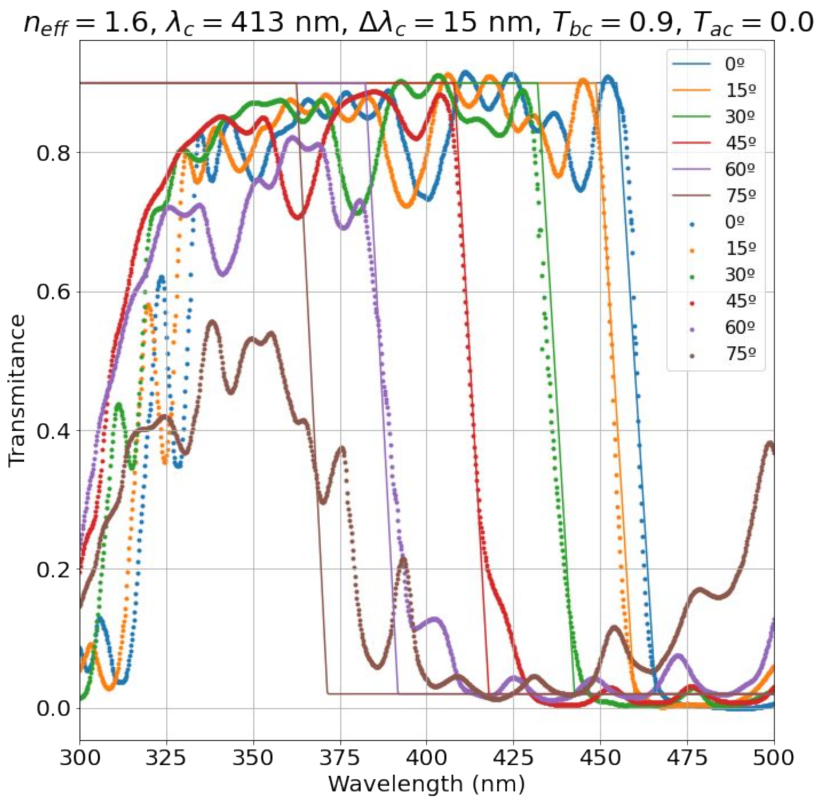
Transmission curve model

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

In order to make a reasonable estimate of the effective refractive index, we fitted a particular case of our model to the **OPTO** data measured at UNICAMP [8]
This fit gave **n_{eff}=1.6**, which is a plausible value given the refractive index (1.52) of the OPTO filters substrate (SCHOTT B270).



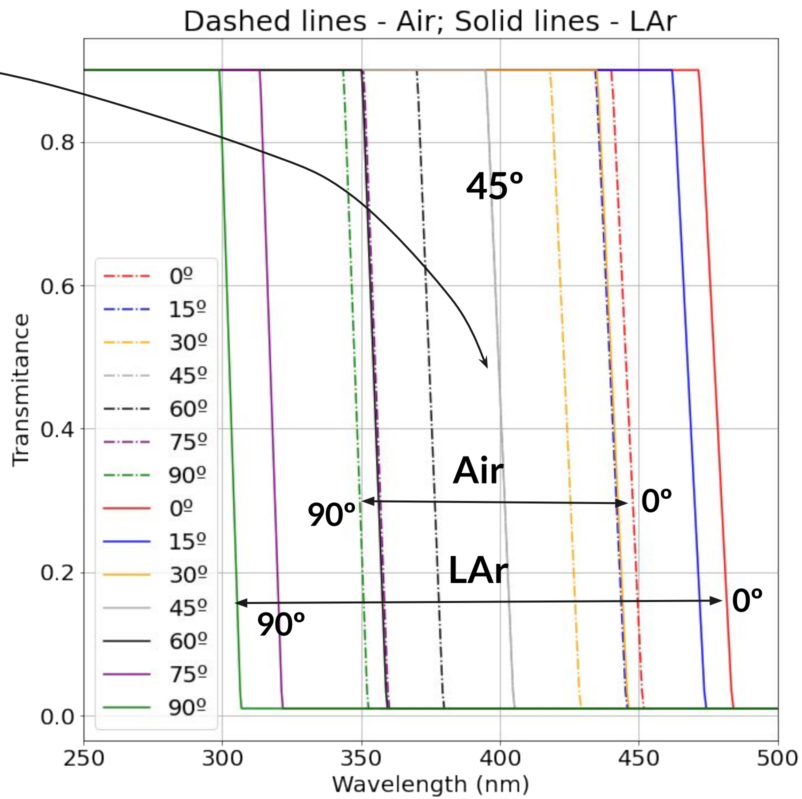
Transmission curve model

Given certain parameters, a curve is generated for DAOI=45º. The shift is applied afterwards.

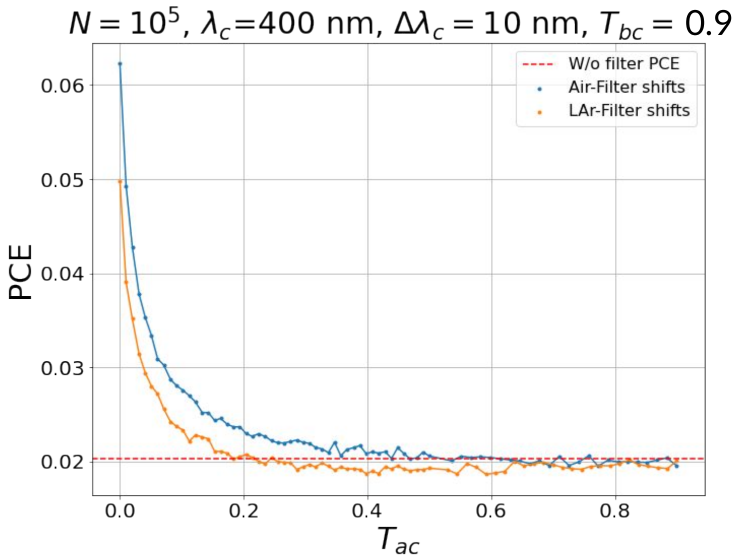
$$\lambda_\theta = \lambda_0 \sqrt{1 - \left(\frac{n_0}{n_{\mathrm{eff}}}\sin(\theta)\right)^2}$$ [7]

The bigger n_0, the greater the shift. For this range of wavelengths, we considered constant refractive indices of n_{air}=1.0003 and n_{LAr}=1.2375 .

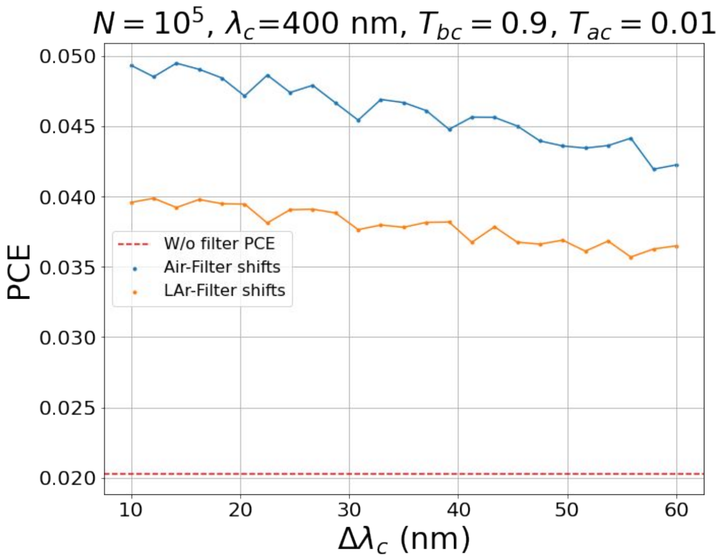
n_0 is fixed by LAr, but n_{eff} depends on the filter



1D scans



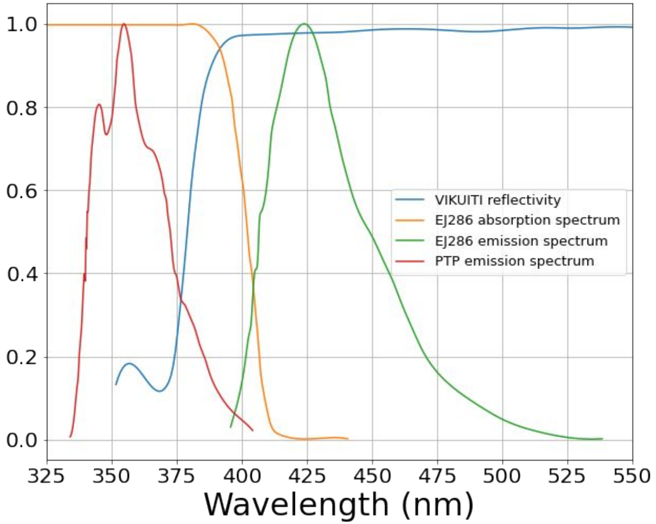
Transmission above cut-off

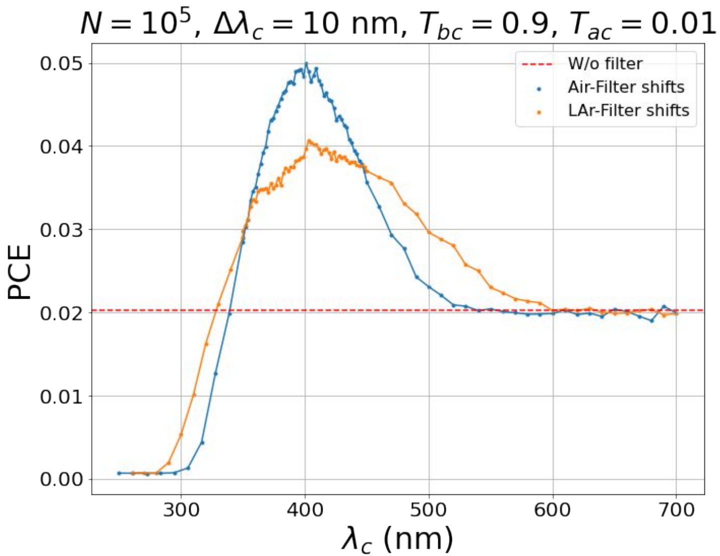


Cut-off width

The reflectance above the cut-off has a greater impact on photon collection than other parameters such as the cut-off width.

1D scans

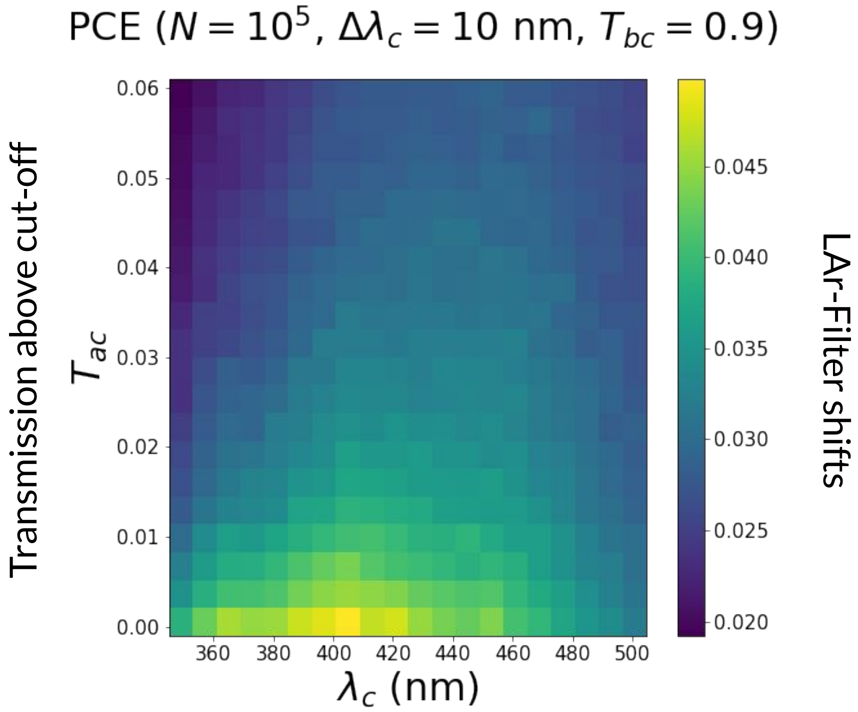




Cut-off position at 45° (DAOI)

As expected, the optimal position for the cut-off at DAOI=45° seems to be 400 nm. For peak efficiency, switching from Air shifts to LAr shifts entails a 20% decrease in PCE. This is only due to larger shifts as a function of the angle.

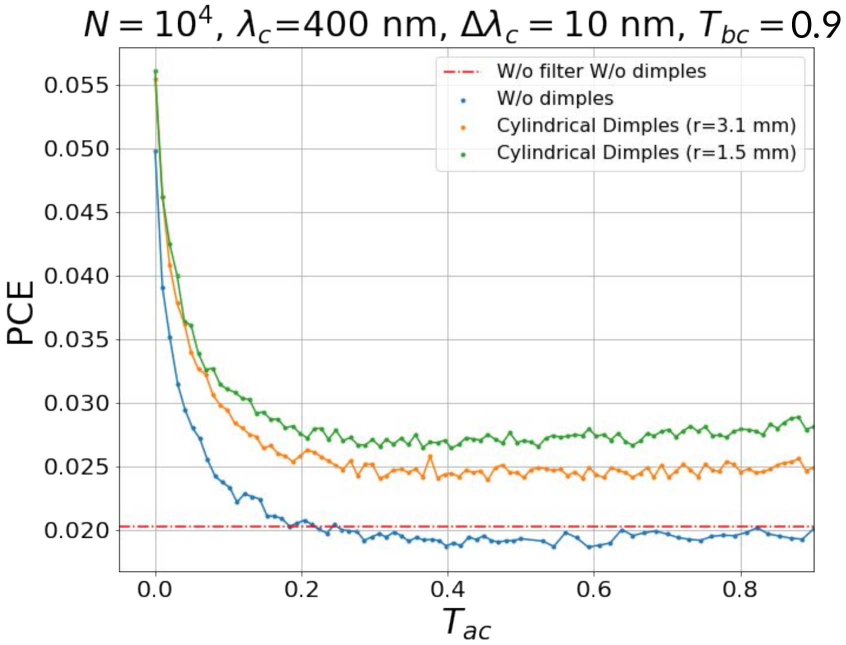
2D scan



Cut-off position at 45° (DAOI)

Optimal cut-off position seems to get slightly bigger as T_{ac} increases.

LAr-Filter shifts



Transmission above cutoff

We have also investigated the PCE vs. T_{ac} dependence for some dimple geometries. [9]

Conclusions

- A simulation study iterating over the model-curve parameters has been performed.
- Both in air and LAr, the filtro is optimal when its cut-off is positioned at 400 nm (at DAOI=45º).
  The peak efficiency loss when switching from air-shifts to LAr-shifts is roughly 20%.
  A way to recover this 20% would involve increasing the effective refractive index of the filter, most likely using a different substrate. This is currently under investigation with PhotonExport.
- The most critical parameter is the transmission above cut-off. **Rising it from 1% to 5% entails a 50% loss in PCE.**
- The parameter with the lowest impact on PCE is the cut-off width. Increasing it from 10 nm to 50 nm entails a 9% loss in PCE. As a matter of fact, **narrower cut-offs can be sacrificed in favour of a larger reflectance above cutoff.**

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
X-ARAPUCA for the optimization of dichroic
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)

[8] Ana Machado's talk (07/06/2022)
Measurements of optical properties of dichroic filters @ UNICAMP
indico.fnal.gov/event/54798/contributions/243631/attachments/155945/203306/PhCollMett_220607.pdf

[9] Marcio Adames's talk (12/04/2022)
X-ARAPUCA efficiency comparison for different Dichroic filters and WLS with dimples
indico.fnal.gov/event/54110/contributions/239132/attachments/154018/200006/Status_update.pdf