DEEP UNDERGROUND NEUTRINO EXPERIMENT

Photon collector meeting
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Dichroic filters in Spain

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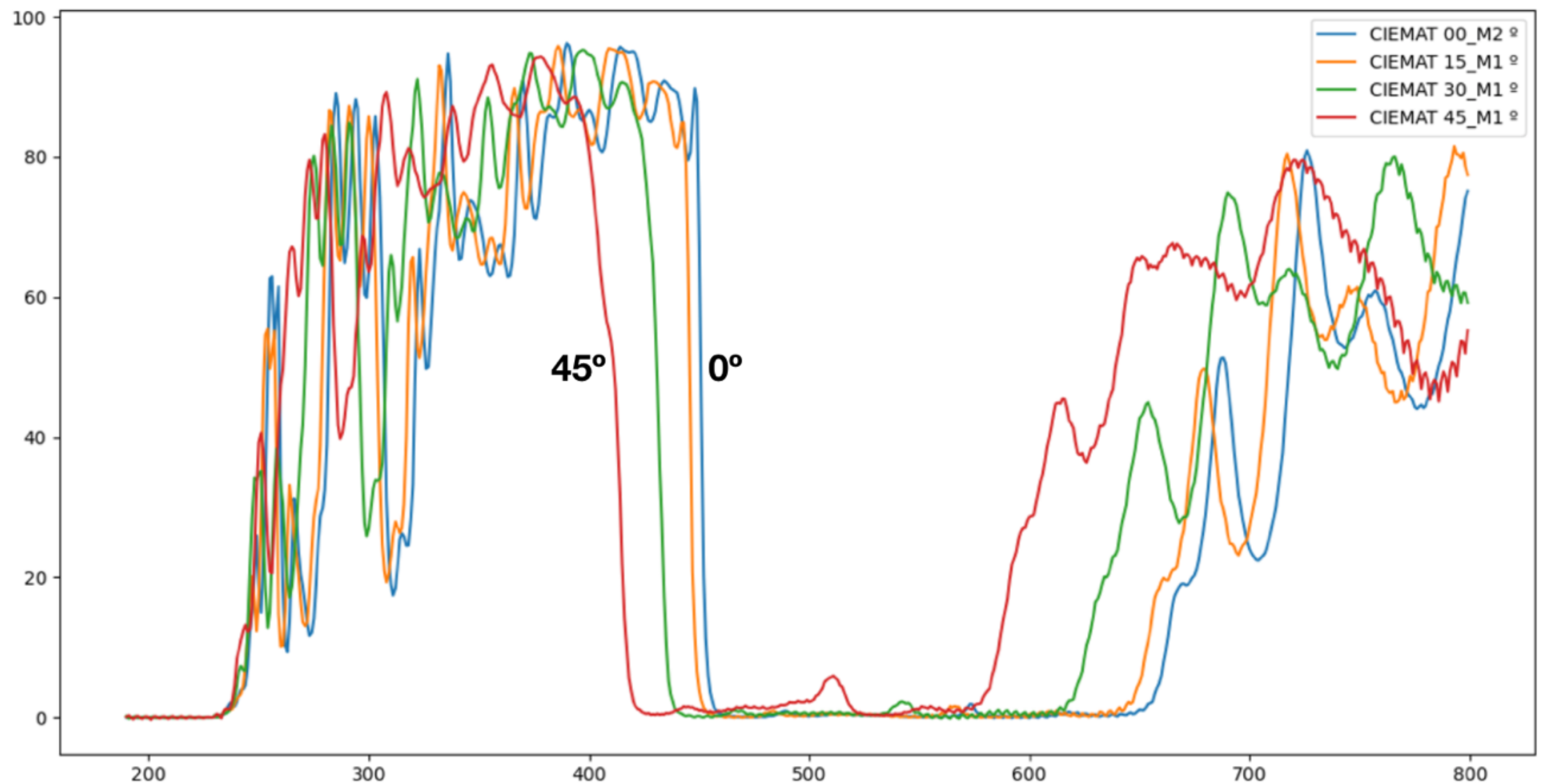
2nd iteration: Air optimization

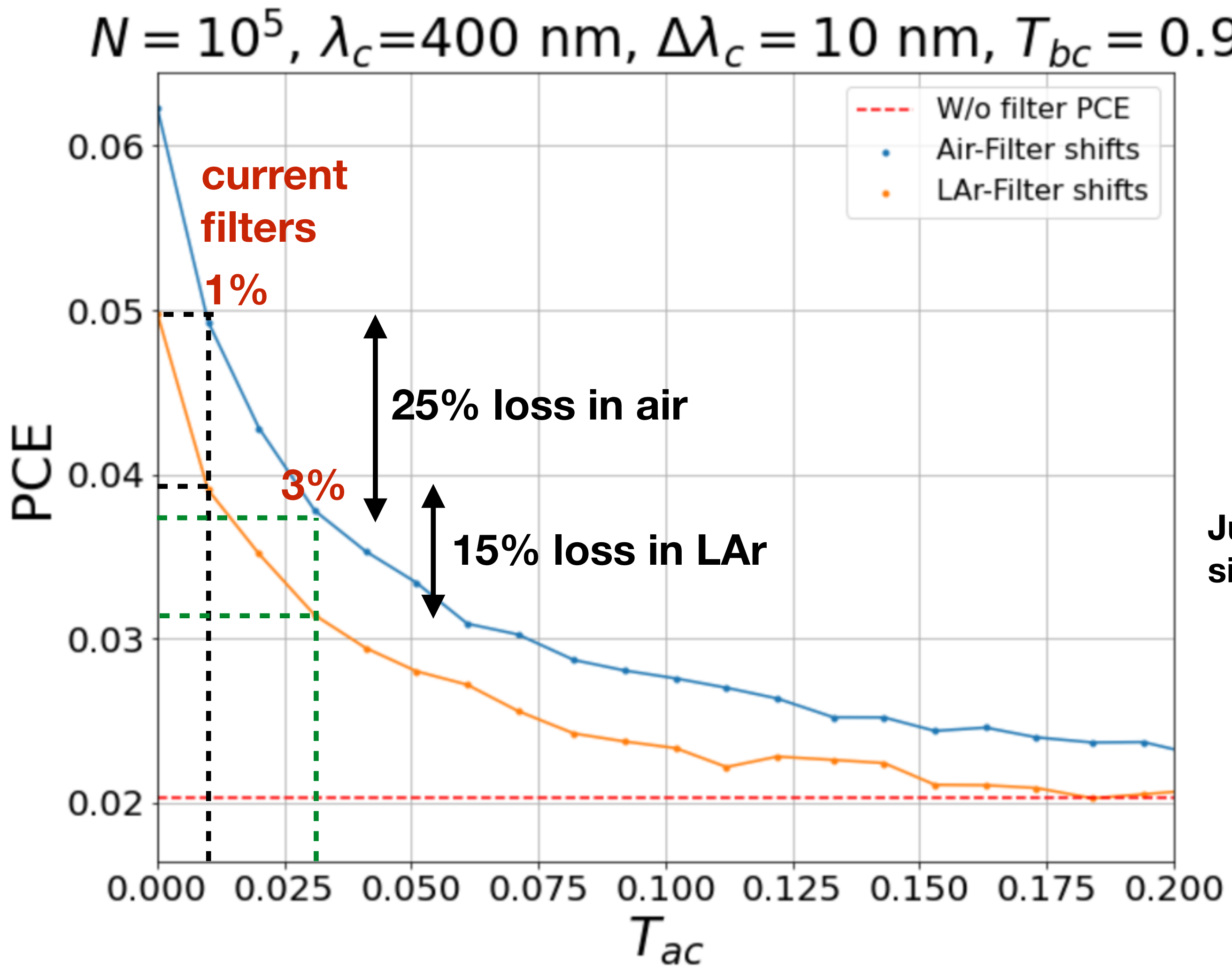
- Completed, resulting in filters in the cold box, optimized for air with < 1.5% reflectance above cut-off at 45º AOI
- Those filters were not optimal but there was no time for another iteration for the cold box prototype

CIEMAT's measurements



Transmission above cutoff

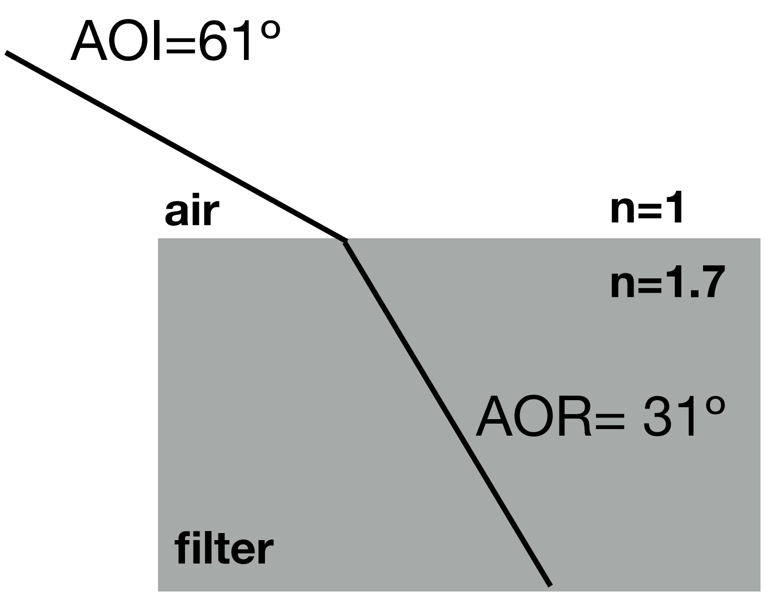
- 25% efficiency loss in air when going from 1% to 3% transmission
- 15% in LAr (for simplified trans. curves)

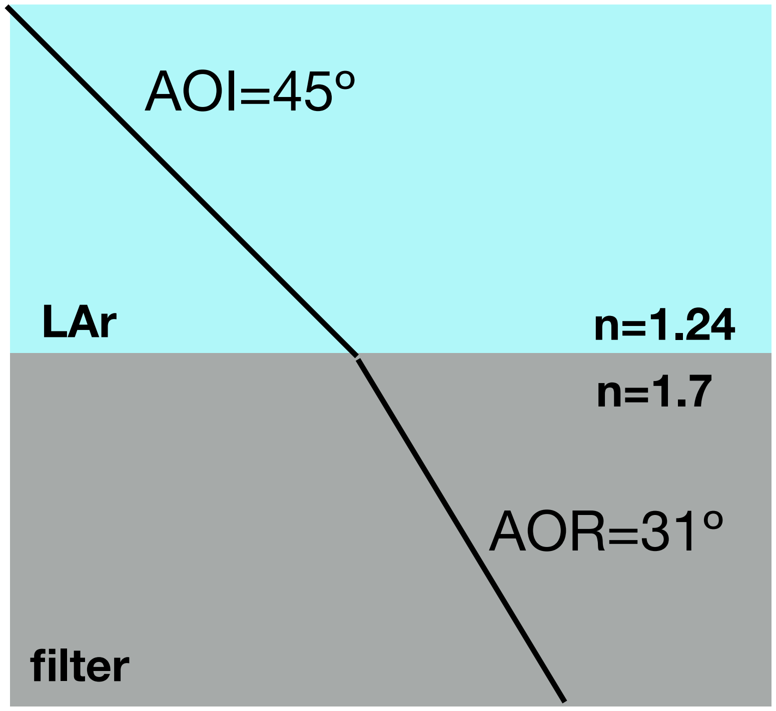


Julio/Justo's simulation

AOI vs AOR

- Filters should be optimized for AOI=45° in LAr with cutoff at 400 nm
- At first order the filter cares about the AOR (angle of refraction) and not about the AOI (angle of incidence)
- The two setups below are expected to give similar results because the AOR is the same





3rd iteration: LAr Optimization

1. **Different AOI:**
   - From Snell's law 45° in LAr corresponds to 61° in air. Cut-off moves left
   - ML structure needs to be changed to recover cutoff at 400 nm. Easy
2. **Reflection loss at equivalent AOR:**
   - because n_1 =1.24 is closer to n_2~1.7~(effective n)
   - small effect (next slides)

$$R = \left| \frac{n_1 - n_2}{n_1 + n_2} \right|^2$$

3. **Larger dependence of cutoff position with AOI (θ_1)**
   - because n_1 =1.24 is closer to n_2~1.7

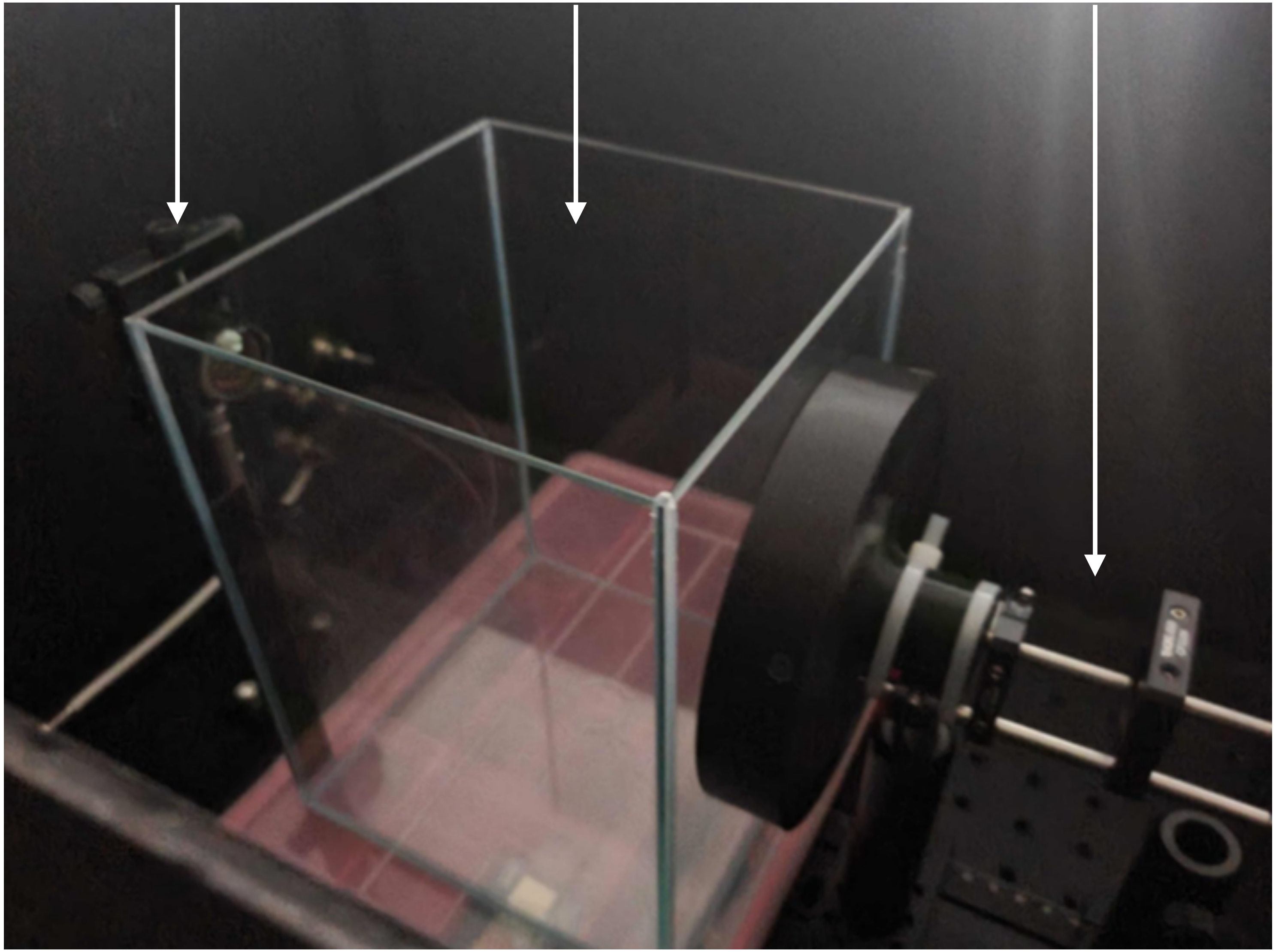
$$\lambda = \lambda_0 \sqrt{1 - \frac{n_1^2}{n_2^2} \sin^2 \theta_1}$$

4. **Reflexion loss at same AOI:**
   - Same AOI corresponds to larger AOR in LAr

- **Effects 3 & 4 could be solved using filter with larger refractive index (n_2)**

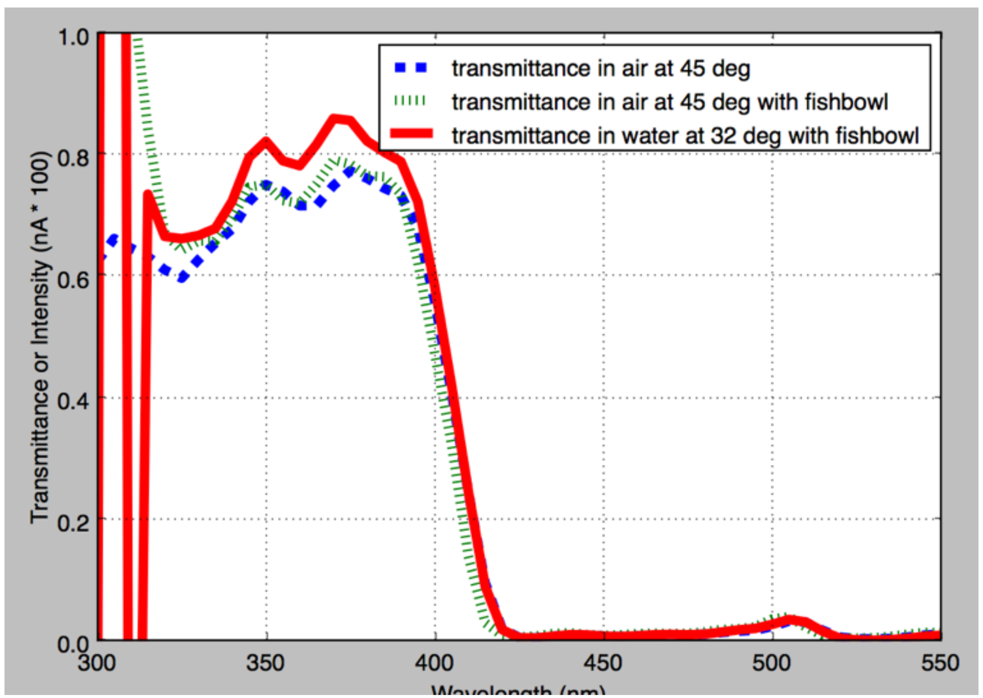
Measurements in water

PMT fishbowl collimator

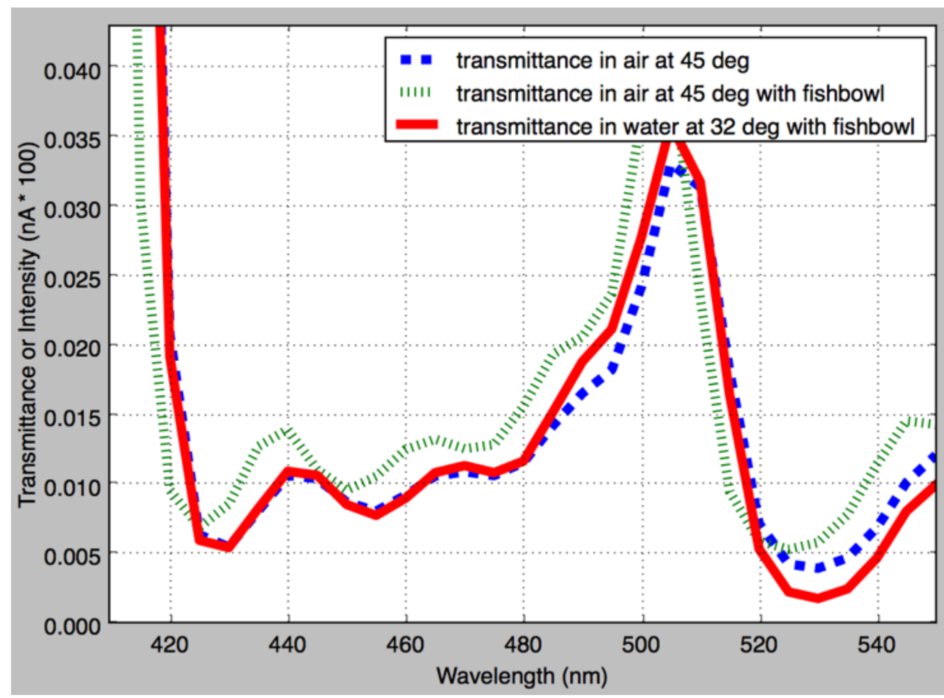


2.Reflexion loss at equivalent AOR

- We have done tests in water
- From Snell's law 45° in air corresponds to 32° water
- Similar behaviour above cutoff



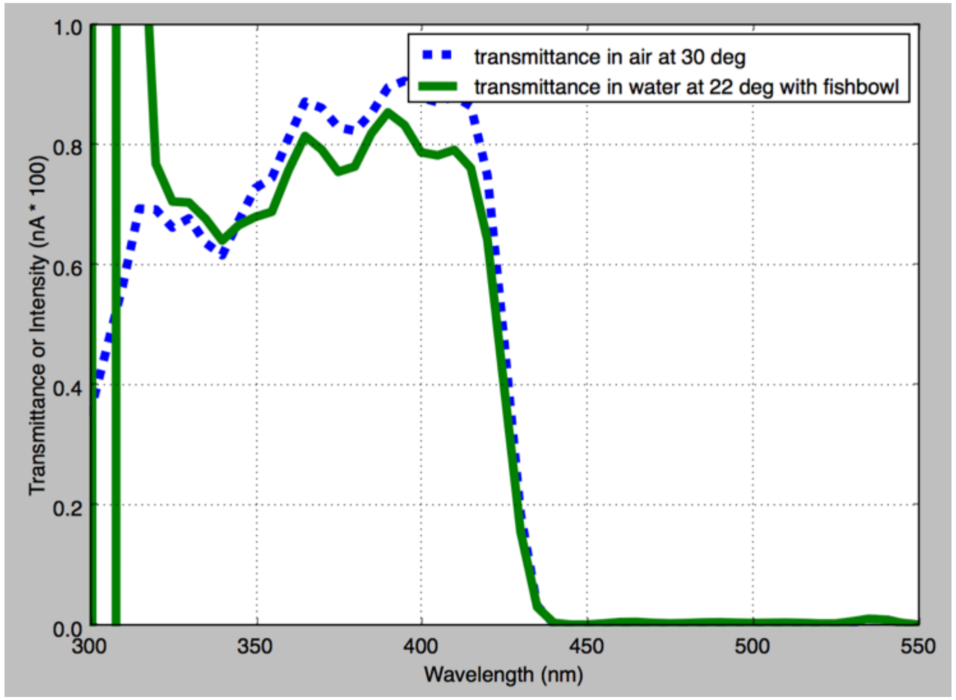
ZOOM

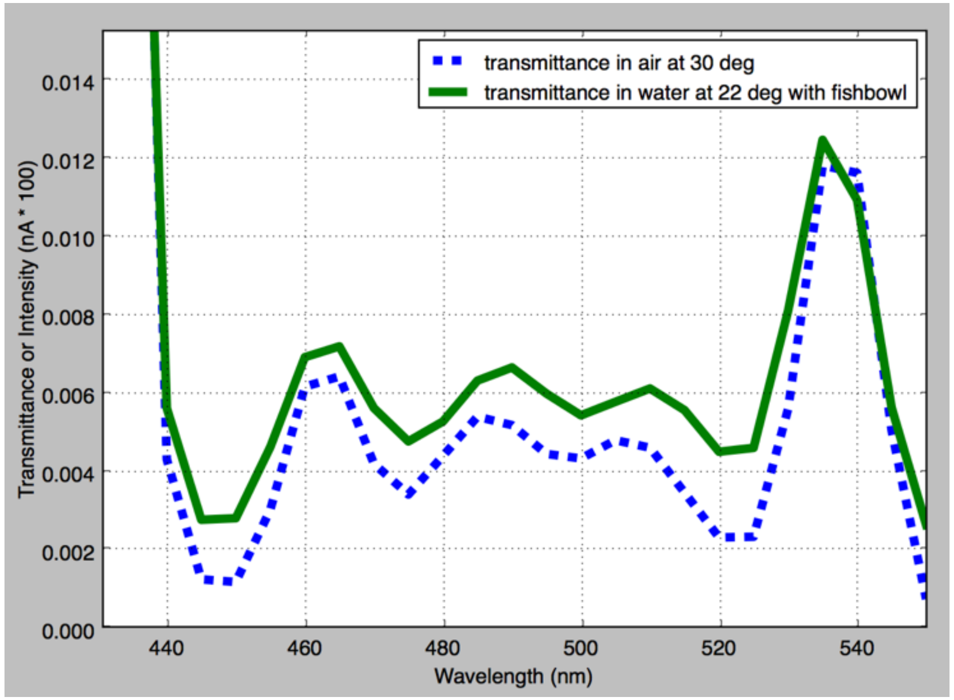


2.Reflexion loss at equivalent AOR

- We have done tests in water
- From Snell's law 30° in air corresponds to 22° water
- Similar behaviour above cutoff

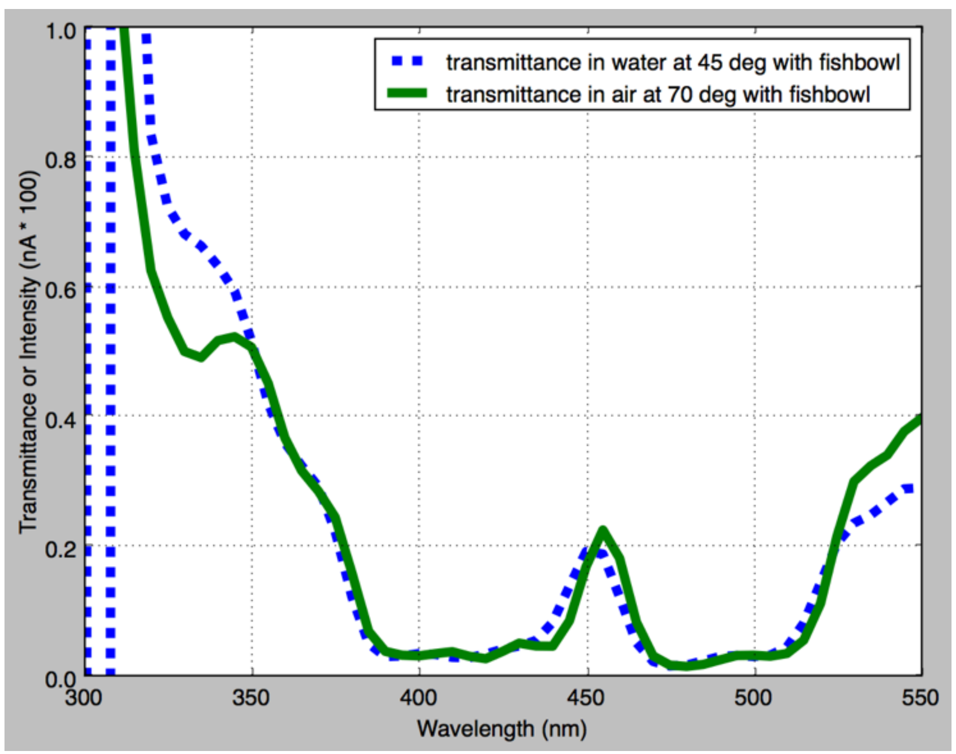
ZOOM





2.Reflexion loss at equivalent AOR

- We have done tests in water
- From Snell's law 70º in air corresponds to 45º water
- Similar behaviour above cutoff



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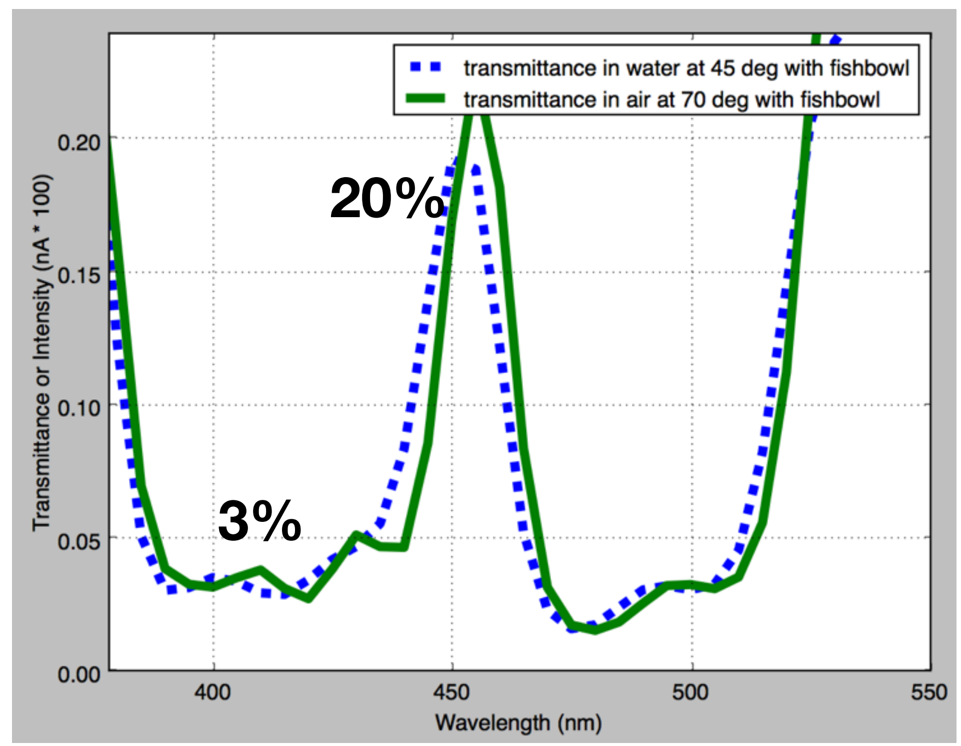
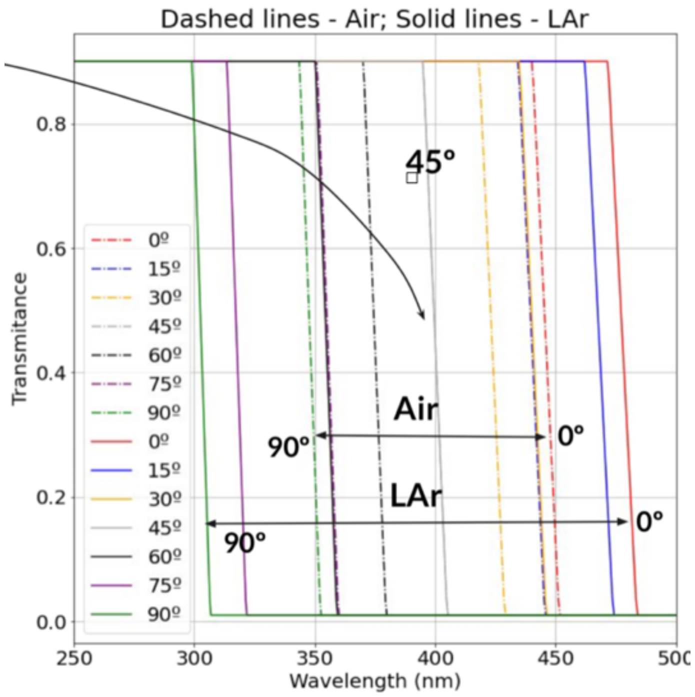


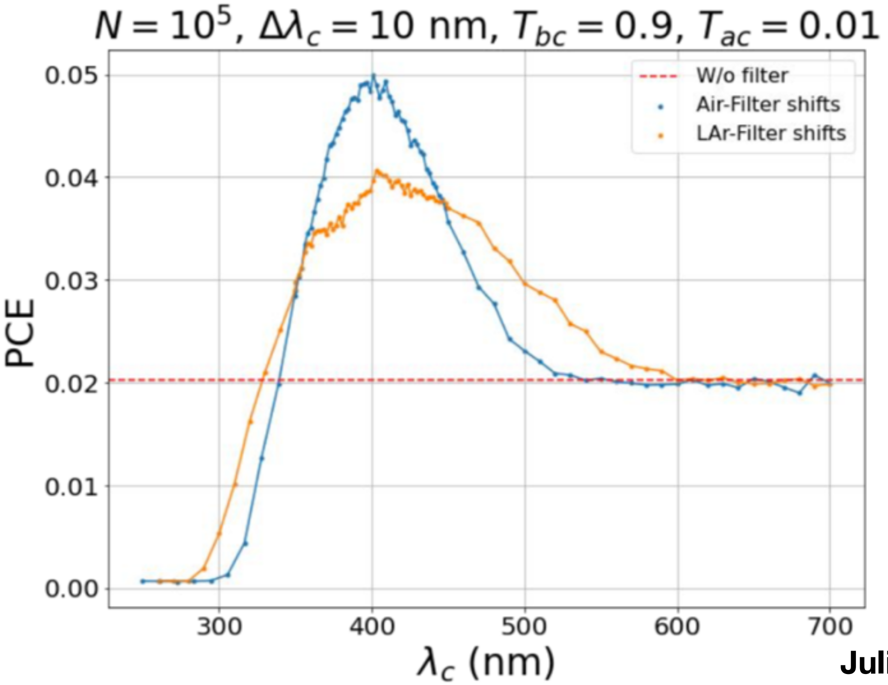
3. Larger AOI cutoff dependence

The larger n_1 the larger the shift

$$\lambda = \lambda_0 \sqrt{1 - \frac{n_1^2}{n_2^2} \sin^2 \theta_1}$$



5% —> 4% drop in efficiency for ideal transmission curves



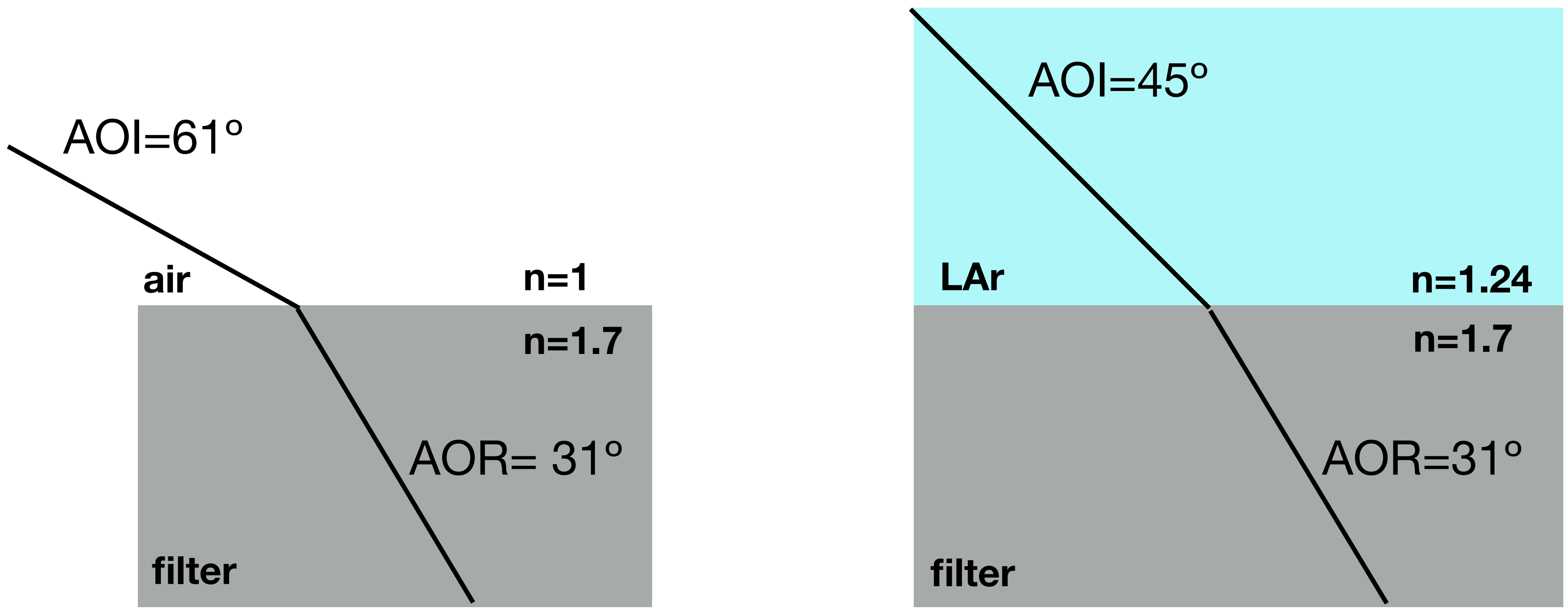
Cut-off position at 45º (DAOI)

Julio/Justo's simulation

Could be solved increasing the effective refractive index of the filter

4. Reflexion loss at same AOI

- Average AOI from PTP is 45º. We want good performance at 45º
- 45º in LAr corresponds to 61º in air, which is worse than 45º



Could be solved either with more layers or increasing the effective refractive index of the filter

Other materials

- **v1 & v2:** ZrO_2 (2.2) and SiO_2 (1.46) used in previous two iterations
- Plan is to use materials with higher n
- Standard materials used by PE (see table below) do not have good transmission below 350 nm
- PE is investigating other materials

Material properties (Cf PhotonExport coating material catalog)

Material	Density g/cc	Melting Point ºC	Refractive Index @ 550 nm	Transparency Range (µm)	e-beam performance
ZnS	4.1	1850	2.39	0.35 - 14.5	Good
SiO2	2.2	1700	1.46 V2	0.2 - 9	Excellent
MgF2	3.18	1266	1.38	0.1 - 10	Excellent
ZnSe	5.27	1520	2.66	0.5 - 22	Good
TiO2 (rutile)	4.23	1830	2.65	0.36 - 9	Fair
ZrO2	5.89	2715	2.2 V2	0.25 - 9	Good
Ta2O5	8.2	1872	2.16	0.35 - 9	Good

Conclusions about optimization

- Current filters are expected to give a poor efficiency in LAr
- PhotonExport is currently doing simulations for LAr
  - Studying materials with larger refractive index
  - Adding more layers
  - Expected results this week

Filter size and offers

LINE	ITEM	QUANTITY	PRICE €	TOTAL €
1	**PRO376** Optical Filter *Material FUSED SILICA JGS2* *Surface* *size 100 mm x 100 mm x 1 mm* *incidence angle 45 °* *300-370nm T Average>80%* *370-400 nm: Transmission band* *400 - 500 nm: Reflection >97%* *Values are indicative and can vary +/- 1.5% the objective being to have a cutoff wavelength at 400 nm and the sharpest slope on the wavelength cut.* *Coating based on ZrO2/SiO2*	300	50,00€	15.000,00€
2	**PRO376** Optical Filter *Material FUSED SILICA JGS2* *Surface* *size 150 mm x 150 mm x 1 mm* *incidence angle 45 °* *300-370nm T Average>80%* *370-400 nm: Transmission band* *400 - 500 nm: Reflection >97%* *Values are indicative and can vary +/- 1.5% the objective being to have a cutoff wavelength at 400 nm and the sharpest slope on the wavelength cut.* *Coating based on ZrO2/SiO2*	150	130,00€	19.500,00€
3	**PRO376** Optical Filter *Material FUSED SILICA JGS2* *Surface* *size 200 mm x 200 mm x 1,5 mm* *incidence angle 45 °* *300-370nm T Average>80%* *370-400 nm: Transmission band* *400 - 500 nm: Reflection >97%* *Values are indicative and can vary +/- 1.5% the objective being to have a cutoff wavelength at 400 nm and the sharpest slope on the wavelength cut.* *Coating based on ZrO2/SiO2*	75	285,00€	21.375,00€

Delivered

1.5 mm thickness

- Today they told me that the offer would include 98.5% minimum reflexion above cutoff, with 99% achievable

Proposed schedule

- 1st batch for installation in December (**air optimization**)
  - Option 1: reuse existing filters
  - Option 2: new small production of current filters
    - 5 weeks production
    - Ship to Campinas the first week of November
    - Coating in Campinas by end November
    - Ready to install in December
- 2nd batch for installation in February (**LAr optimization**)
  - Finalize simulations next week
  - Test production ready in early November
  - Characterisation done by mid November
  - 5 weeks production. Filters ready at the end of the year
  - Coating in Campinas in January
  - Ready to install in February