Enhancing the LAr VUV Light Collectors of the DUNE Photon Detection System and of low background LAr based experiments

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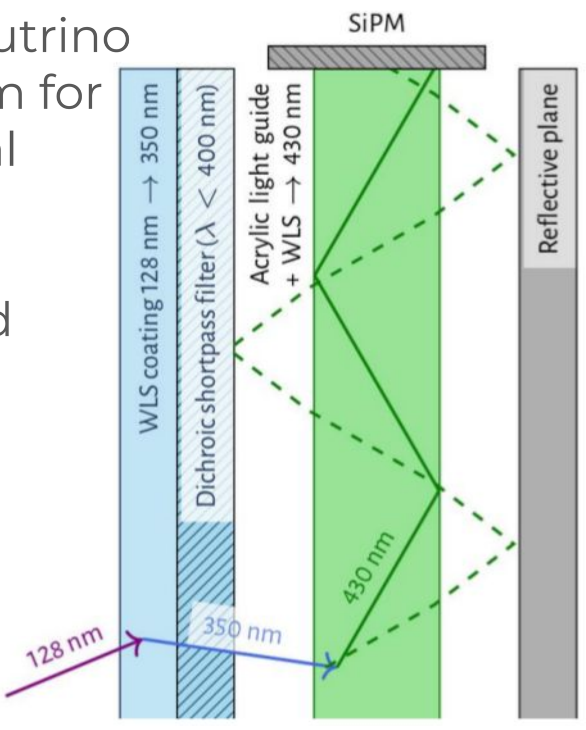
X-ARAPUCA (XA): from VUV to visible light

Building block of the Deep Underground Neutrino Experiment (DUNE) Photon Detection System for Far Detector 1 (Horizontal Drift) and 2 (Vertical Drift).

LAr VUV scintillation light is abundant (25k photons/MeV @ 500 V/cm)→light downshifted from 128 to 430 nm in two stages to allow for photon trapping with dichroic filter.



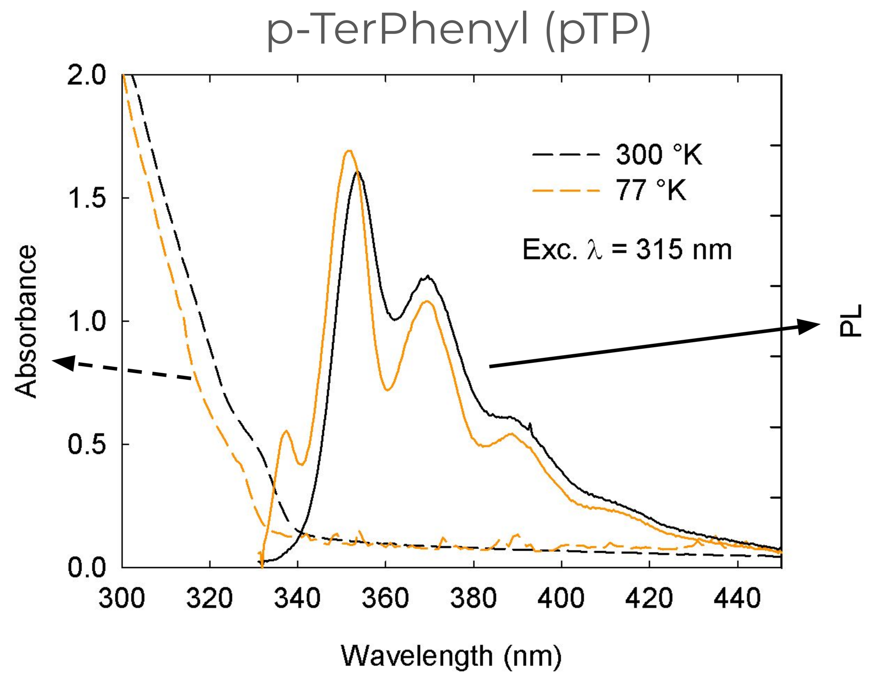
Photon Detection Efficiency ε depends on:

$$\varepsilon = T_w \times (g_{LG} + g_{DF})$$

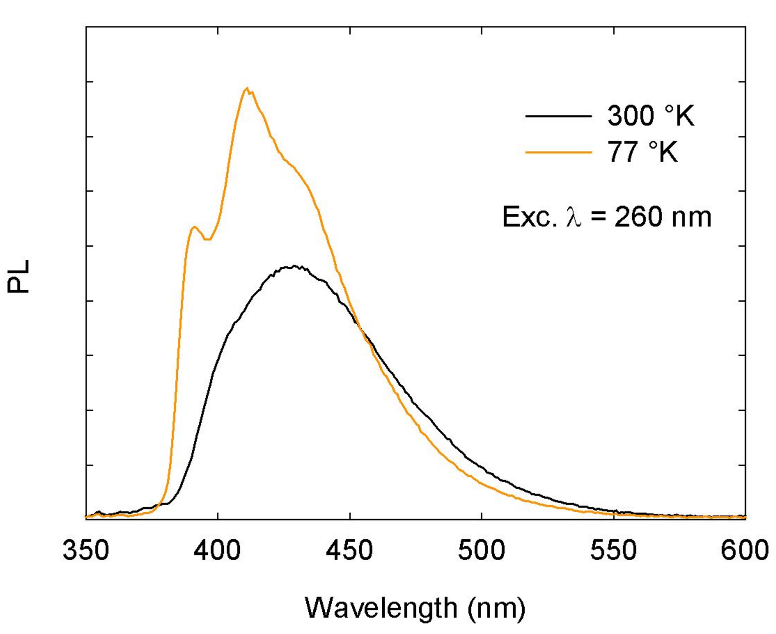
T_w: transmissivity of the entrance window, influenced at large angle of incidence by dichroic filter (-30%)
g_{LG}: collection efficiency by WLS Light Guide, driven by attenuation length, grade of the driving surfaces, and light sealing of the light guide, SiPM to LG coupling
g_{DF}: collection efficiency by dichroic filter

Absorbance and PhotoLuminescence (PL) of pTP & PEN and of the WLS-LG dye: study of the temperature dependance

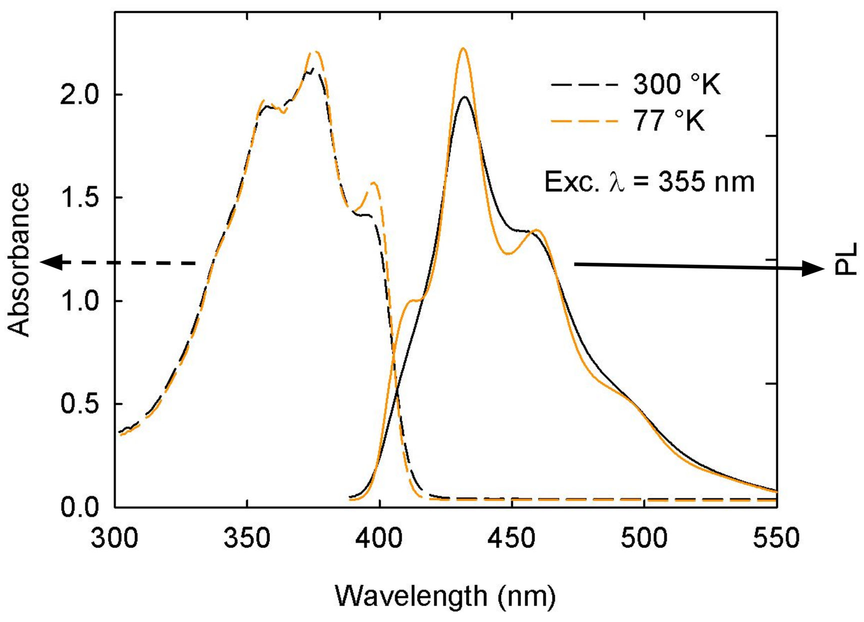
p-TerPhenyl (pTP)

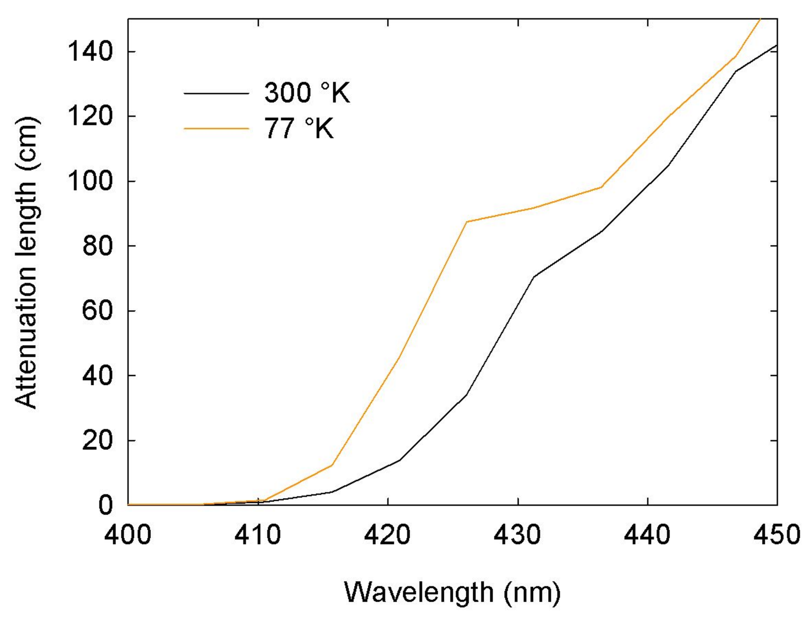


Teonex Q51 foil: PolyEthilenNaphatalate (PEN)



The WLS-LG dye optimized to absorb and re-emit pTP light





The spectra collected at 77K show a more prominent vibronic structuring with respect to the spectra collected at room temperature. The **Teonex Q51 PEN foil** (primary shifter proposed for DUNE FD3 and LEGEND1000) **PL yield increases by 40% at 77K** while **no modification is observed for pTP and for the WLS-LG dye**. Our findings on PEN are in agreement with [3]. The increase of the 0-0 vibronic replica in th PL spectra at 77K is due to the reduced self absorption caused by the steepening of the absorption edge. **For the WLS-LG dye, this results in a doubling of the attenuation length at 425 nm.**

Radiopurity assessment of the WLS-LG & pure PMMA

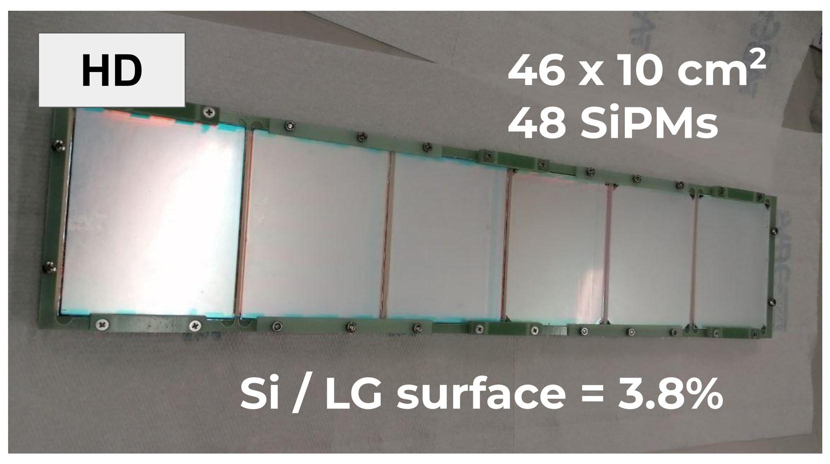
	^{238}U† [ppt]	^{232}Th† [ppt]	^{226}Ra‡ [mBq/kg]	^{40}K‡ [mBq/kg]
WLS-LG	15 - 25	3 - 6	< 0.16	< 1.7
PMMA	23 ± 7	5 ± 2	(16 ± 6) 10^{-3}	< 0.16

† ICPMS and ‡ γ spectrometry.

The WLS-LG after casting, laser-cut and polishing has ^{238}U and ^{232}Th concentration compatible with the bare PMMA. It is qualified for the use in low energy neutrino projects such as LEGEND, DUNE FD3, SoLAr/SOLAIRE.

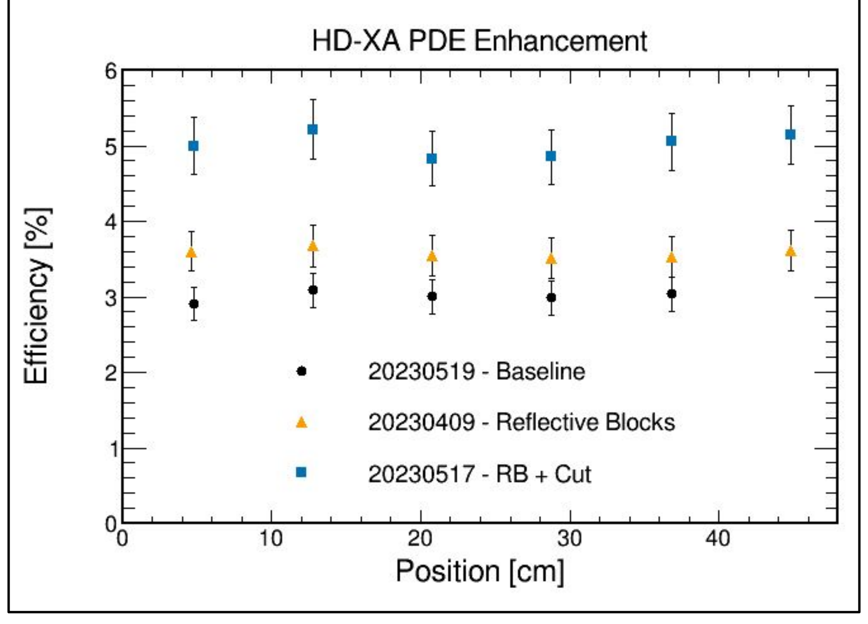
[1] arXiv:2405.12014 [physics.ins-det]
[2] C.M. Cattadori on behalf of the DUNE collaboration 2024 JINST 19 C06007
[3] L. Leonhardt et al. JINST 19 (2024) C05020

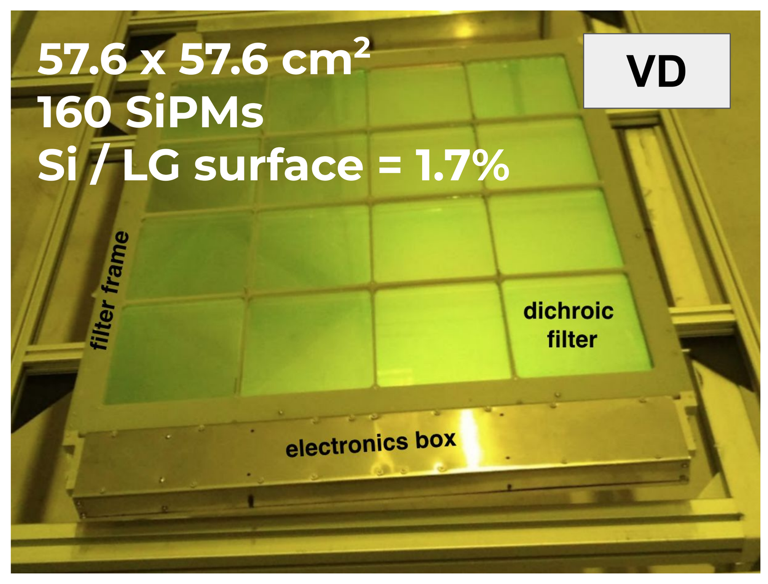
Horizontal HD and Vertical Drift VD XA efficiencies



ε = 1.34-2.50% depending on SiPM-light guide combination used (see also poster **#625**)[1].

Simulation-driven measurements in Milano-Bicocca with increased Light Guide sealing and different Light Guide geometry (40° cut in the middle) → **ε = 4.4-5.0%** (+45-67% w.r.t. baseline) [2].





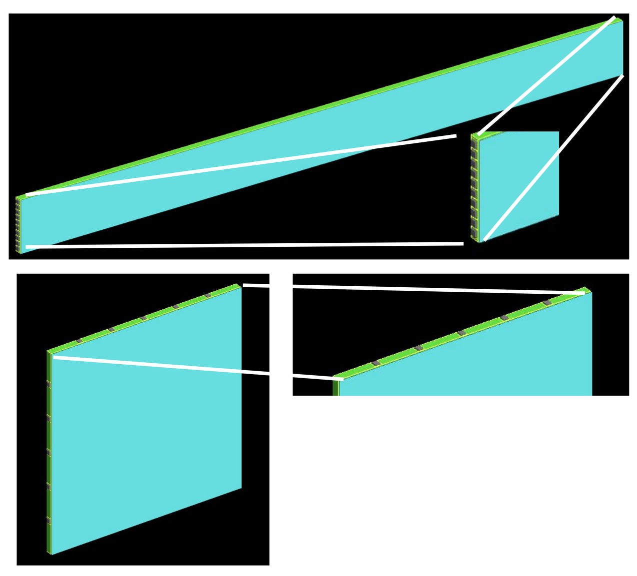
ε > 2.50% (analysis ongoing)

The ratio between SiPMs area and detector sensitive area is 2.2 times higher in HD-XA w.r.t. VD-XA → better performance of VD-XA attributed to better SiPM-light guide coupling (spring loaded circuits, absent in HD), different geometry and all sides covered with SiPMs (in HD only longer ones).

Impact of dichroic filters on HD-XA Photon Detection Efficiency (ε)

Baseline HD-XA: **+10-15%** w.r.t. substrate + pTP only
Modified HD-XA (improved light guide sealing and light collection upon SiPMs): **NO IMPACT** on ε w.r.t. substrate + pTP only

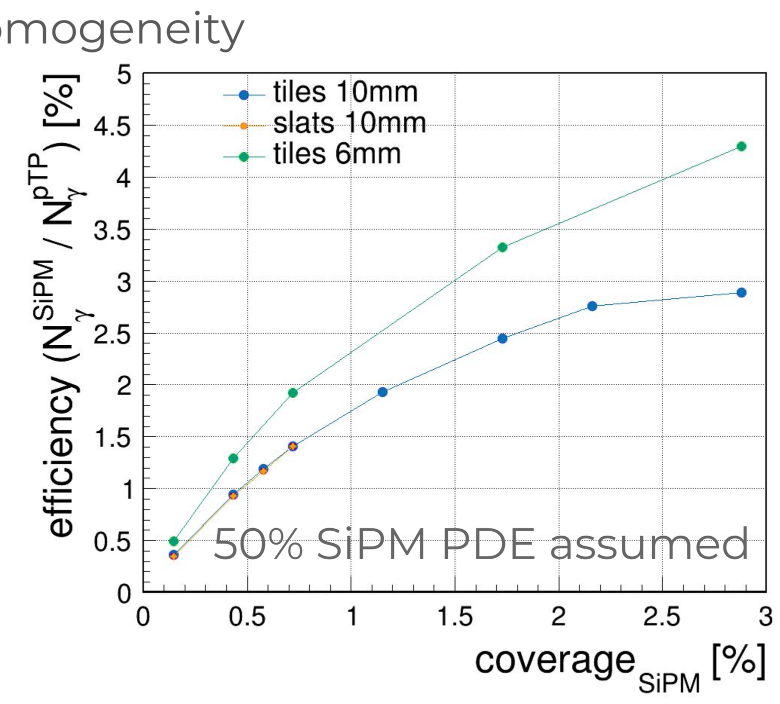
Large area WLS-LG for double down-shift LAr photon detection

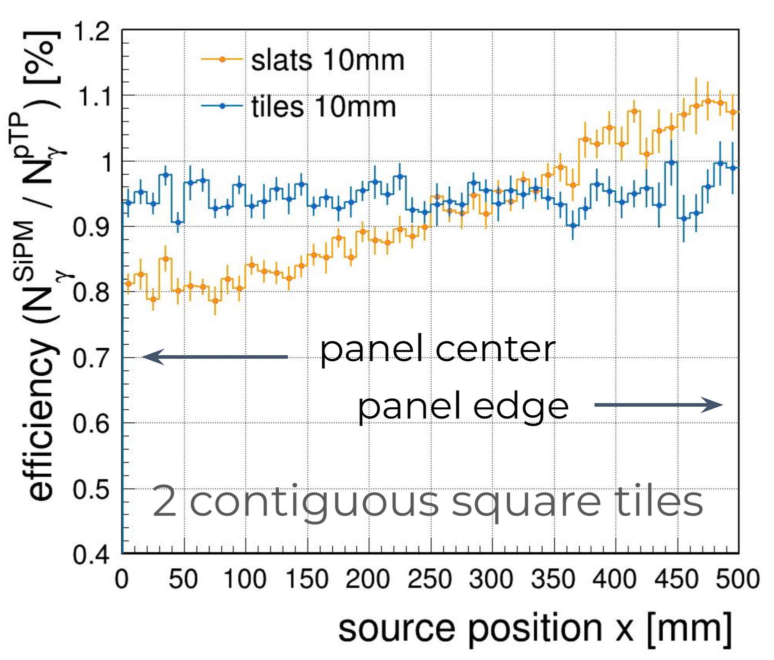


Geant4 simulations for two geometry layouts:
- "slats": 100×10×1 cm^3 elongated light guides. SiPM readout at the ends
- "tiles": 31×31×1 cm^3 square light guides. SiPM equally distributed on the tile 4 sides

Both read with 6x6 mm^2 SiPMs.
- Nominal design has 12 SiPM/light guide → **Si / LG surface = 0.43%**
- Primary WLS (pTP) deposited onto a PMMA substrate 1 mm away from the light guide

Study of the light guide photon collection efficiency (photons hitting the SiPM / photons hitting the pTP). **Left:** the drivers of the efficiency are the optical path inside the LG and the SiPM coverage. **Right:** square tiles display higher homogeneity





Left:The syrup preparation reactor. **Right**: the casting reactor and some blue WLS-LG laser cut out from the casted plates. The casting reactor can host up to 5 casting cells, 60 cm side. For larger sizes an industrial partner has been selected and tested.