WLS & Dichroics for DUNE FD2

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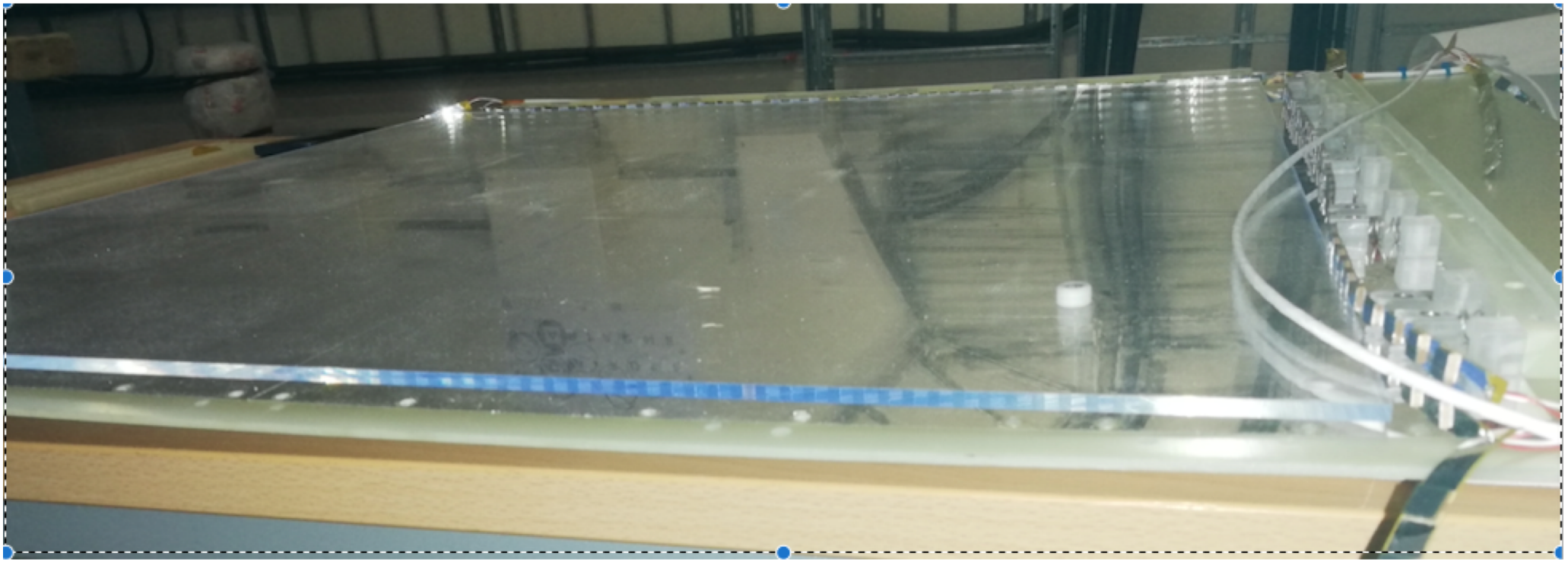
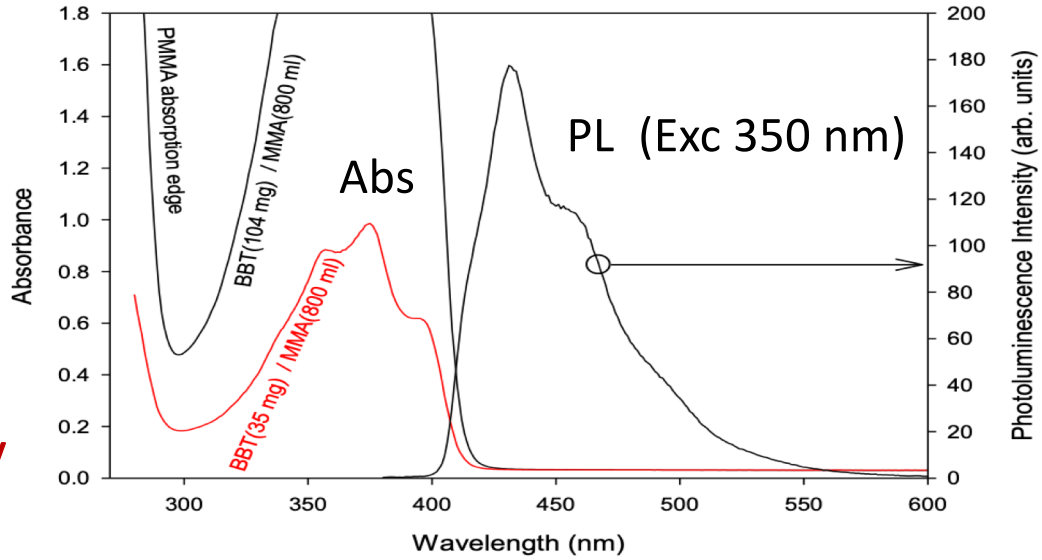
The WLS of FD2



The FD2 WLS during the assembly in the XA cell, together with SiPMs populated on flex circuits substrate.

WLS for FD2

- Requirements
  - Cryoresilience
  - Size 607 x 607 x 4 mm^3 with 0.2 mm tolerance for the thickness
  - Absorb: pTP emission (330-390 nm)
  - Emission: 420-500 nm to match the SiPM Q.E.
  - Abs. Length: $\lambda_{abs} \sim 1.0$ m (to preserve the PDE) of large size devices
- Geometry and SIPM coverage
  - Optical path: O(1 m)
  - (SiPM area/WLS area): 1.6%
- Number of WLS plate units:
  - 320 cathode
  - 352 membrane
  - Total 672 +10%
- Responsibility under INFN Italy



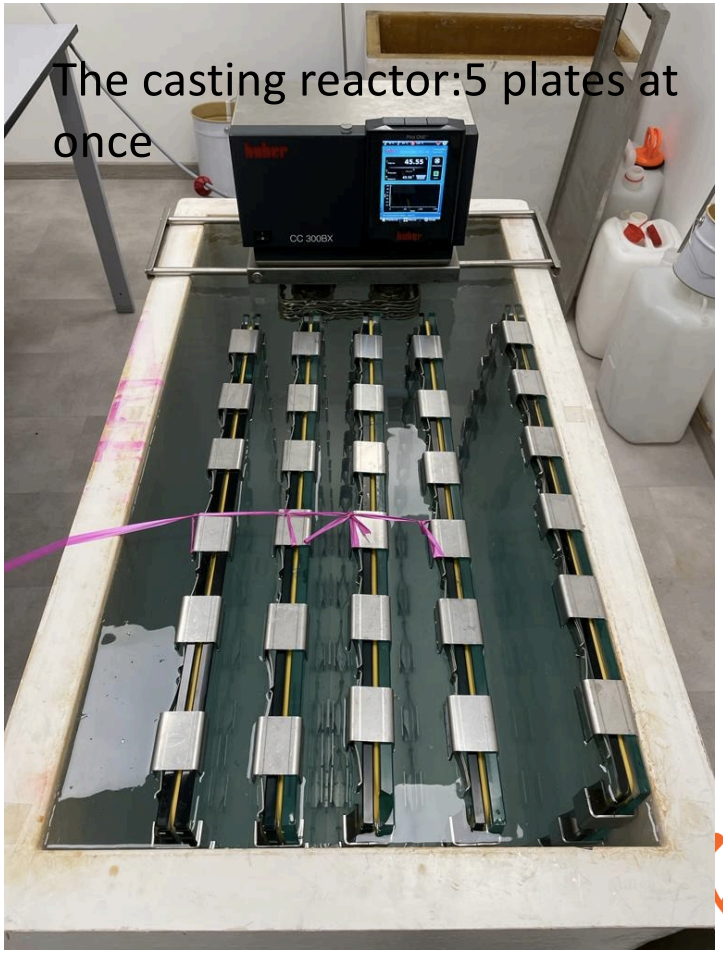
WLS manufacturing capabilities

- Manufacturer (Glass to Power Co.): Former start up of Uni MiB, now quoted at Eurostock: https://www.glasstopower.com/
- Core business: PV windows. PMMA embedding QD (Absorb white emits IR), R&D Department at UniMib,
- Skills and know-how on light down-shifters compounds. Collaboration ongoing since 2019.

- One reactor (will be duplicated for FD2 massive production) hosting 5 casting cells (620 x 620) mm^2

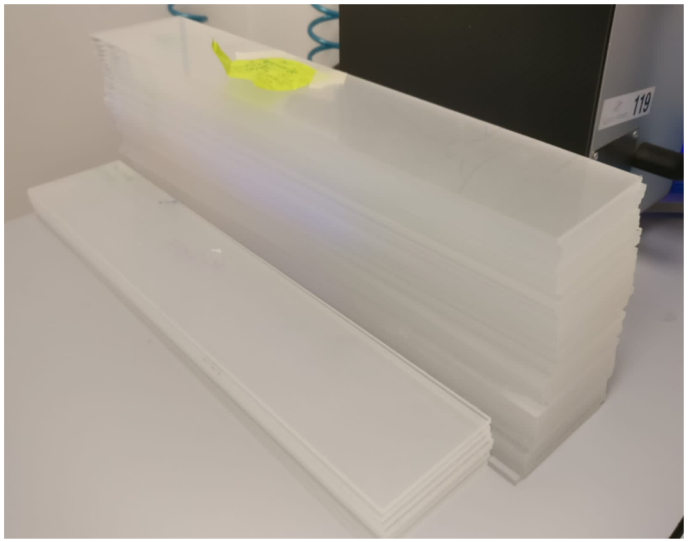
5 x 607 x 607 mm^2 plates/(day*reactor)

- external industrial partner ready to support the production



The casting reactor:5 plates at once

FD1 and FD2 productions



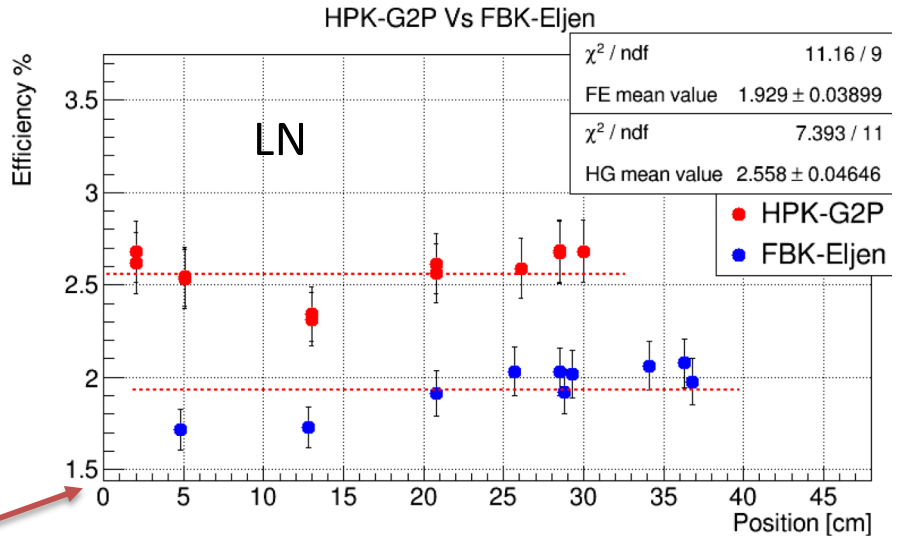
90 x WLS slabs for pDUNE HD-PDS: 480 x 93 mm^2 x 4mm thick

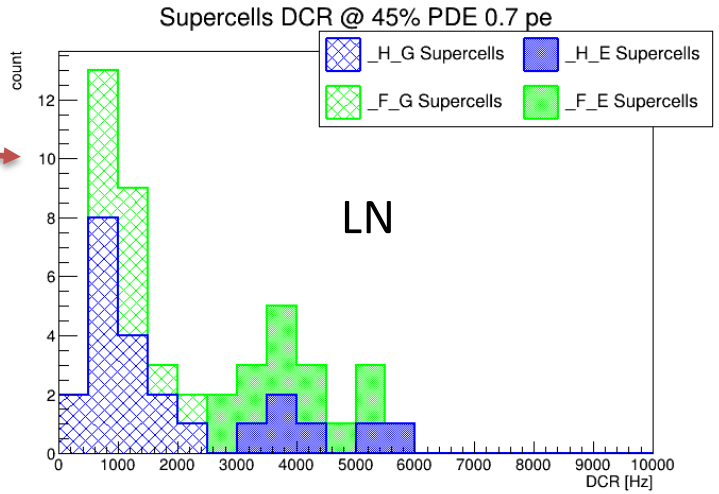
Laser cut and edge polishing procedures to cut out the casted plates in tiles defined and validated.

20 x WLS slabs for the pDUNE VD-PDS: 607 x 607 mm^2 x 4mm thick

WLS features & Performances

- **Superior Cryoresilience**: No cracks or failures in cooling/warming cycle at rate of 3-4 mm/sec of the 80 FD1 pDUNE and 16 FD2 Module-0 plates
- **Stress tests**: One prototype plates underwent 15-20 thermal cycles: no failures.
- **Superior light guiding surfaces as casted**
- **Superior DCR and LY**





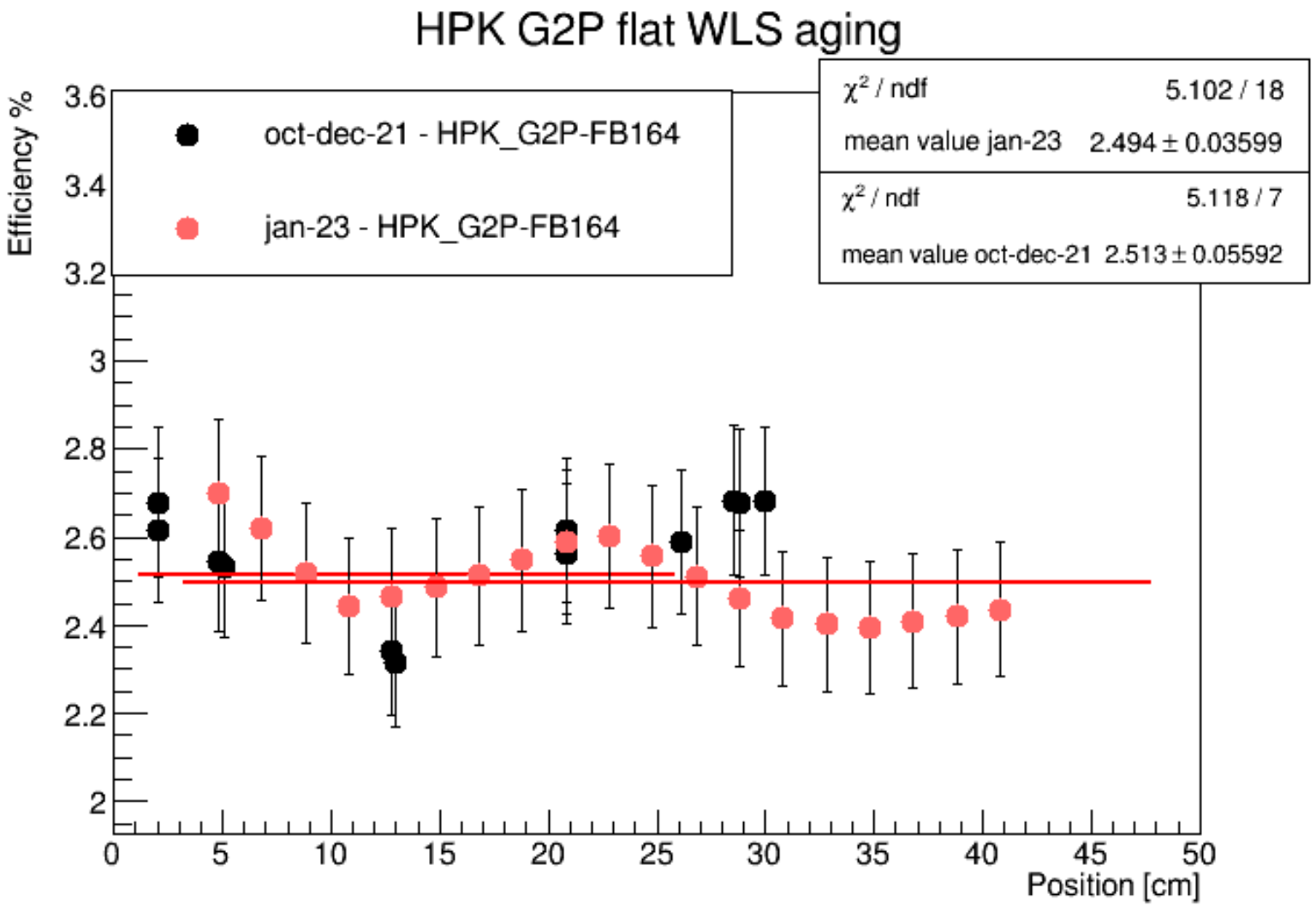
Assessment of radiocontaminants (γ-ray spectrometry of 800 g plate measured over 19 days) in a plate casted and exposed to air over several months:

- Ra-226 <160 μBq/kg (from Bi-214)
- K-40 < 1.7 mBq/kg
- Cs-137 < 44 mBq/kg
- U-238 and Th-232 concentration are <= 15 ppT (ICPMS)

To be compared with Ar-39 (1 Bq/kg) and FR4 (O(10mBq/kg))

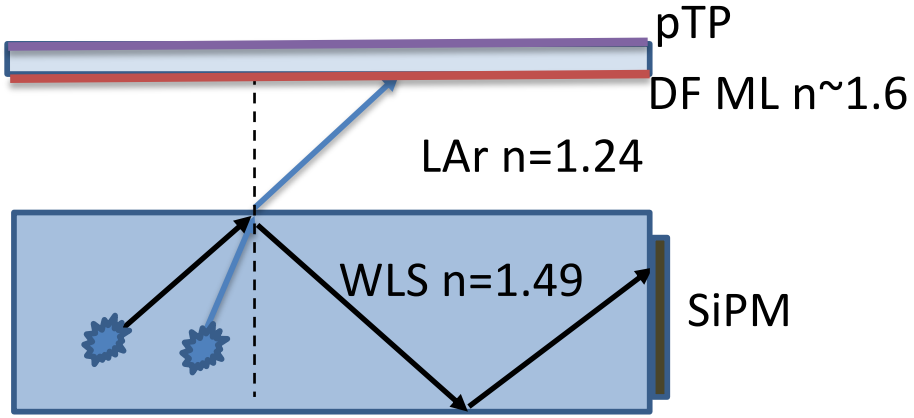
Assessment of Aging of FD1 WLS slab

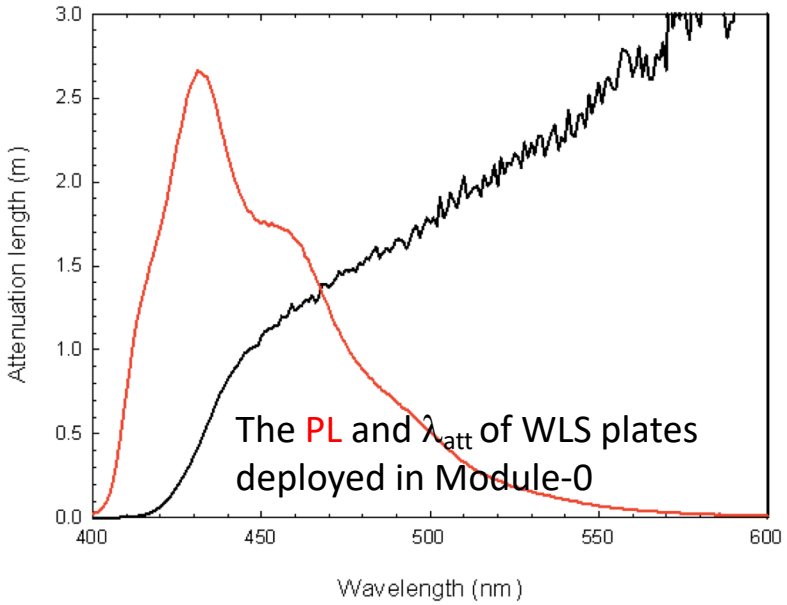
- ~15 thermal cycles in between with different configurations

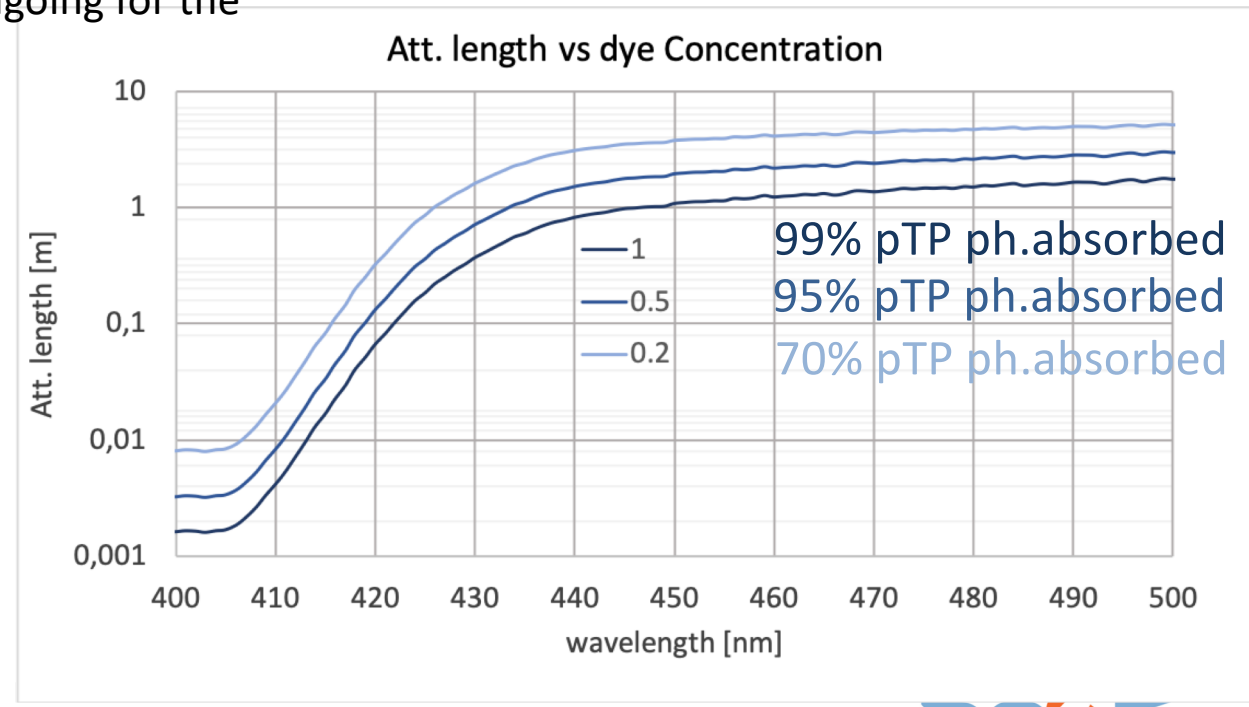


WLS: Attenuation length (λ_{att})

- Light impinging at the WLS surface with angle > 56° = θ_c is trapped and guided by TIR to SiPMs.
- Due to multiple reflections at the guiding surfaces and at the edges the optical path inside the WLS may reach a couple of meters.
- The dye concentration of the VD Module-0
  - optimized for the FD1 WLS size and optical path.
  - Optimization (driven by sims) ongoing for the FD2 shape

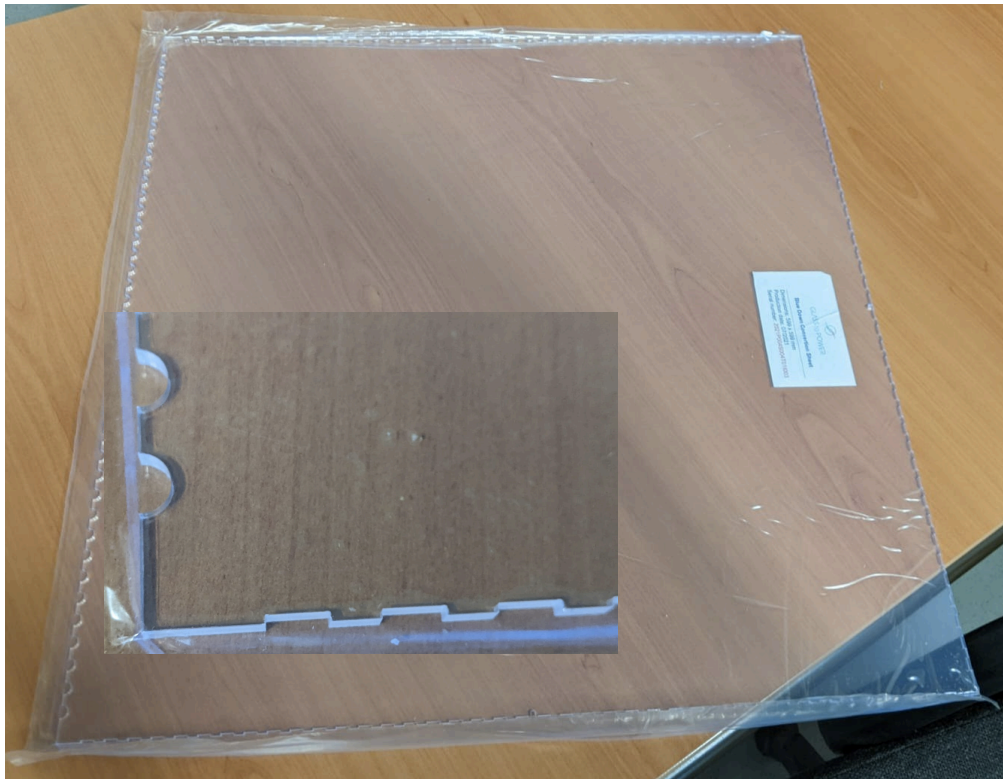


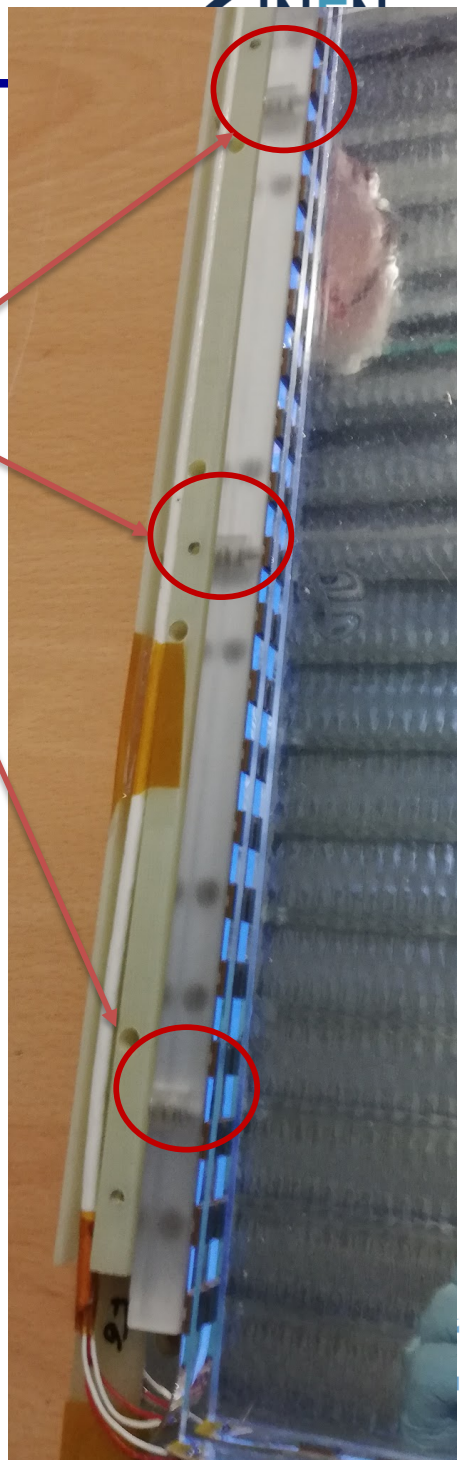




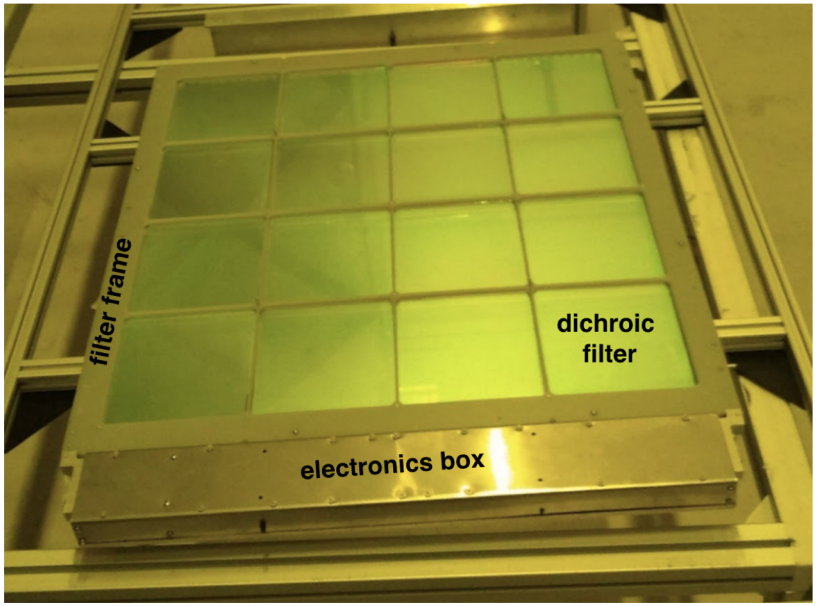
SiPM to WLS coupling

- BL design: WLS with flat edges
- Also tested SiPMs fitting in dimple-cuts (flat/cylindrical) at the edge of the WLS
- In LAr SiPMs are kept is in close contact to WLS thanks to flex circuits & spring loaded mechanism, to compensate the WLS shrinking (~1%. i.e. 6 mm)

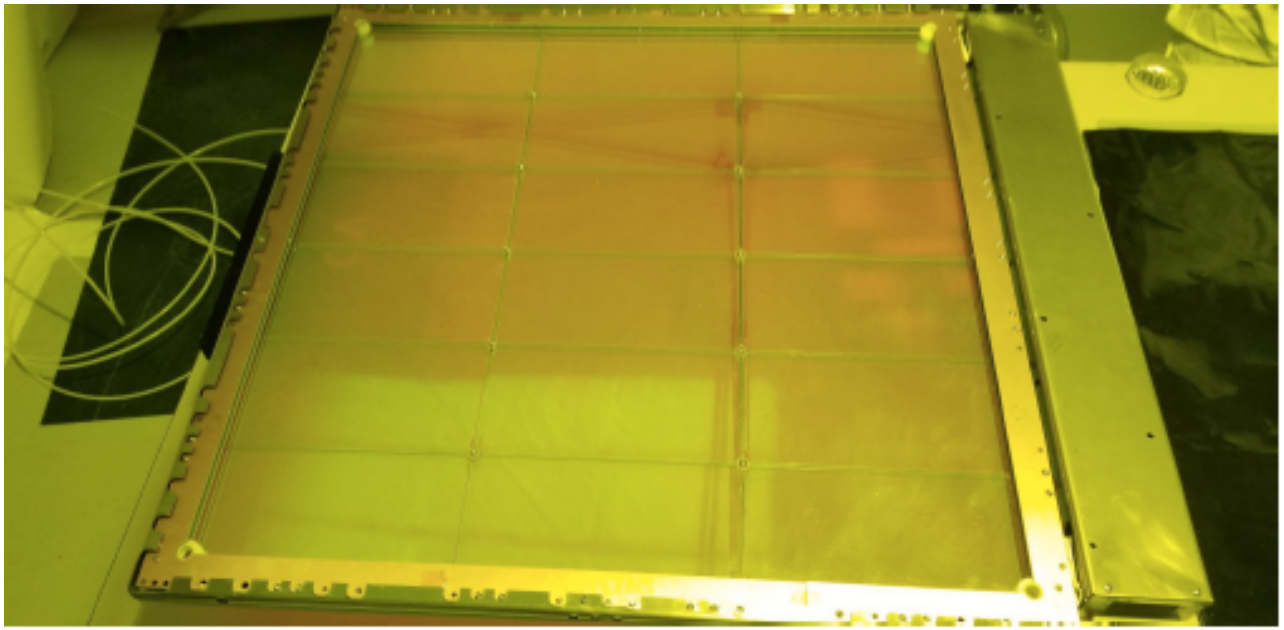




Two Module-0 XAs



	WLS dimples	DF size (mm^2)	DF	SiPM	PoF	SoF	shared elec. box
M1		100x200	ZAOT	HPK			x
M2		100x200	ZAOT	HPK			x
M3	x	100x200	ZAOT	HPK			x
M4	x	100x200	ZAOT	HPK			x
M5	x	150x150	PE	FBK		x	
M6	x	150x150	PE	HPK			
M7	x	150x150	PE	HPK			
M8	x	150x150	PE	FBK			
C1		100x200	ZAOT	HPK	x	x	
C2		100x200	ZAOT	HPK	x	x	
C3		150x150	PE	FBK	x	x	
C4	x	150x150	PE	HPK	x	x	
C5	x	150x150	ZAOT	HPK	x	x	
C6	x	150x150	ZAOT	HPK	x	x	
C7	x	150x150	ZAOT	FBK	x	x	
C8	x	150x150	ZAOT	HPK	x	x	



FD2 Dichroics

- Required n. of units (144 x 144 mm^2):
  - 320 x 16 x 2= 10240 for cathode
  - 352 x 16 x 1= 5632 for membrane

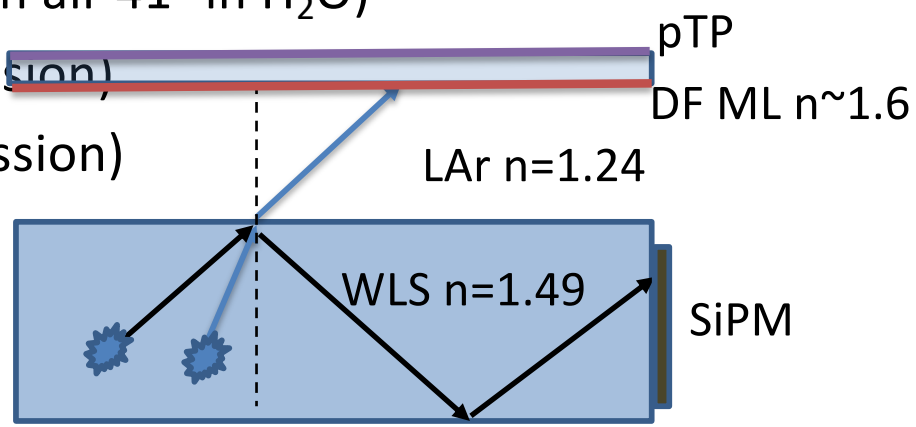
- Responsibility under Italy and Spain
- Two industrial partners in EU for the FD2 Dichroics
  - ZAOT (Italy)
  - Photon Export (Spain)

- Their design & technological & production capabilities of optical multilayer thin-film coating have been tested for the ColdBox and the Module-0 productions.

- OPTO Brazil (manufacturer of all the FD1 DF) may also support the production effort.

FD2 Dichroics requirements and features

- DF Size/shape for FD2: 144 x 144 x 1.1 mm^3 (larger shape to max active entrance window for the 128 nm light, reducing the frame ribs surface)
- In FD2 16 DF units/side instead of 36/side in FD1 → active surface increased x2.2 w.r.t. FD1 (97 x 97 mm^2) + reduced pTP coating & assembly time.
- Λ_{cutoff} = 400 nm at AOI = 45° in LAr (61° in air 41° in H_2O)
- T > 90% 320 nm < λ < 380 nm (pTP emission)
- T < 5% 420 nm < λ < 500 nm (WLS emission)
- Stability of the DF multilayer at cryogenic T (no flaking or cracking)



PhotonExport (PE) substrate

- Fused silica

ZAOT substrate

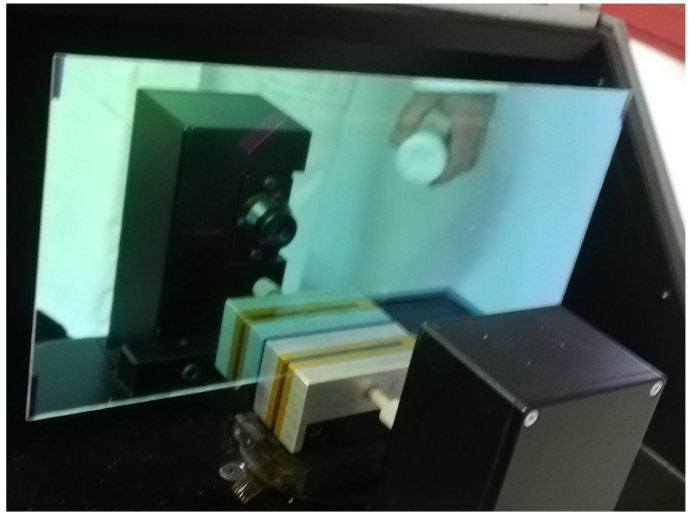
- Borofloat 33 Optical Glass

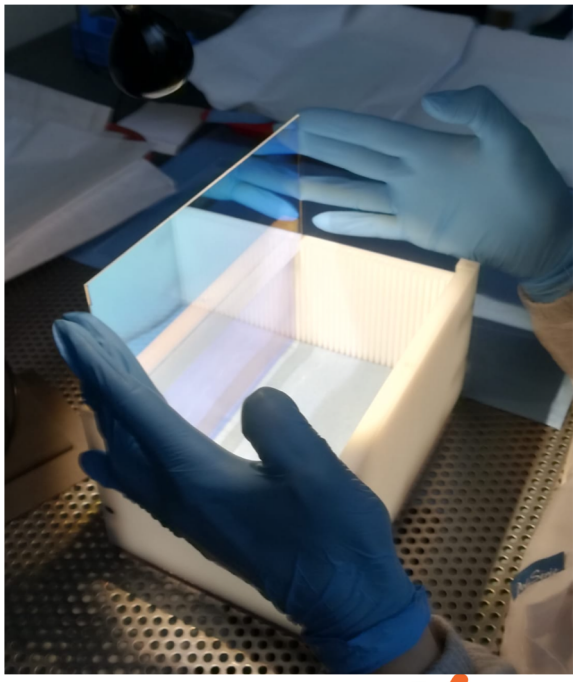
OPTO Substrate

- B270

DF: Module-0 experience

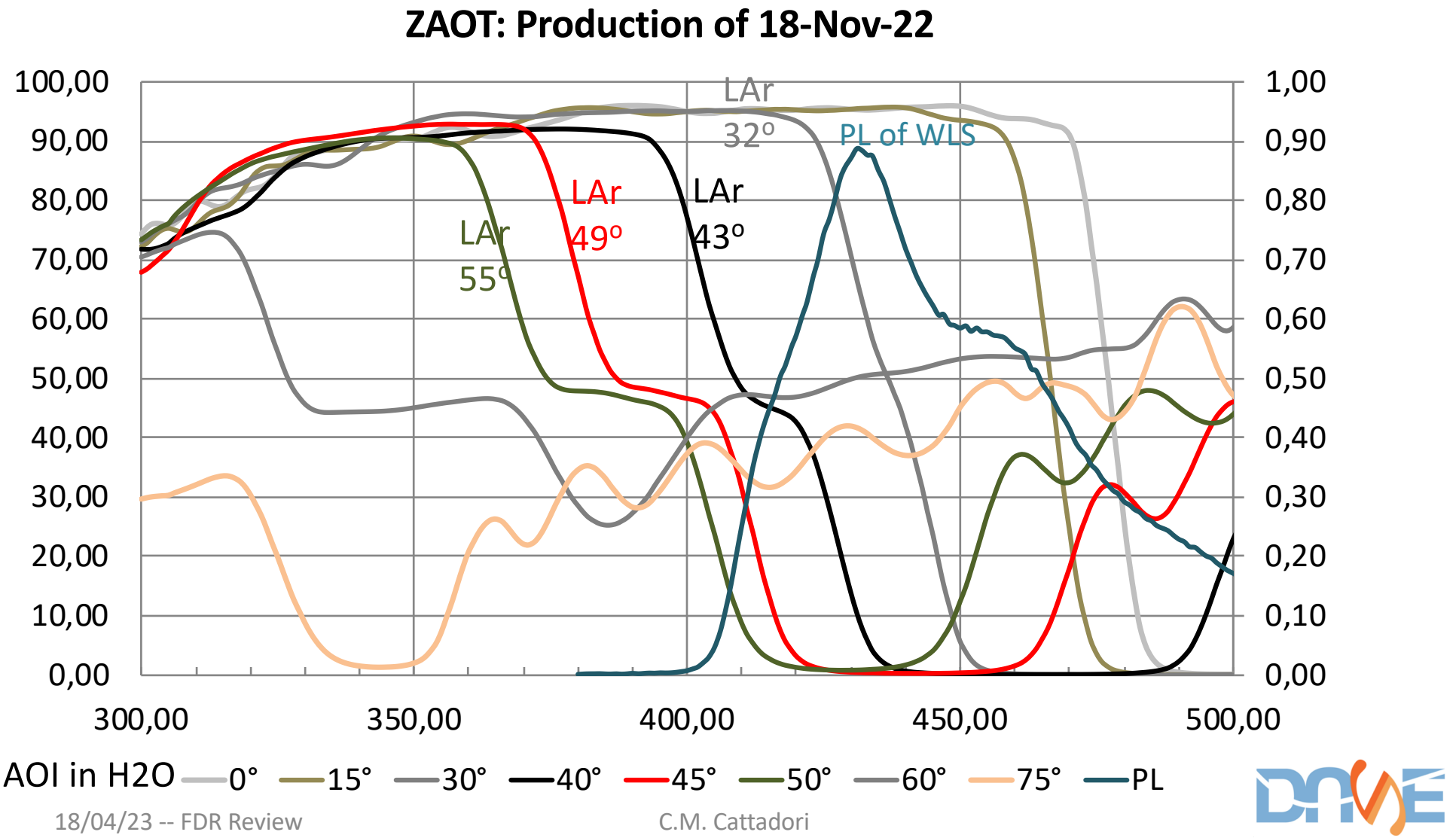
- ZAOT:
  - 265 DF for Module-0 + 54 for PDE→10 XA Megacells (4 membrane + 6 cathode)
- PE
  - 128 DF for Module-0 → 6 XA Megacell (4 membrane + 2 cathode)
- Production capabilities of both vendors: > 120 DF in 5 w.d.



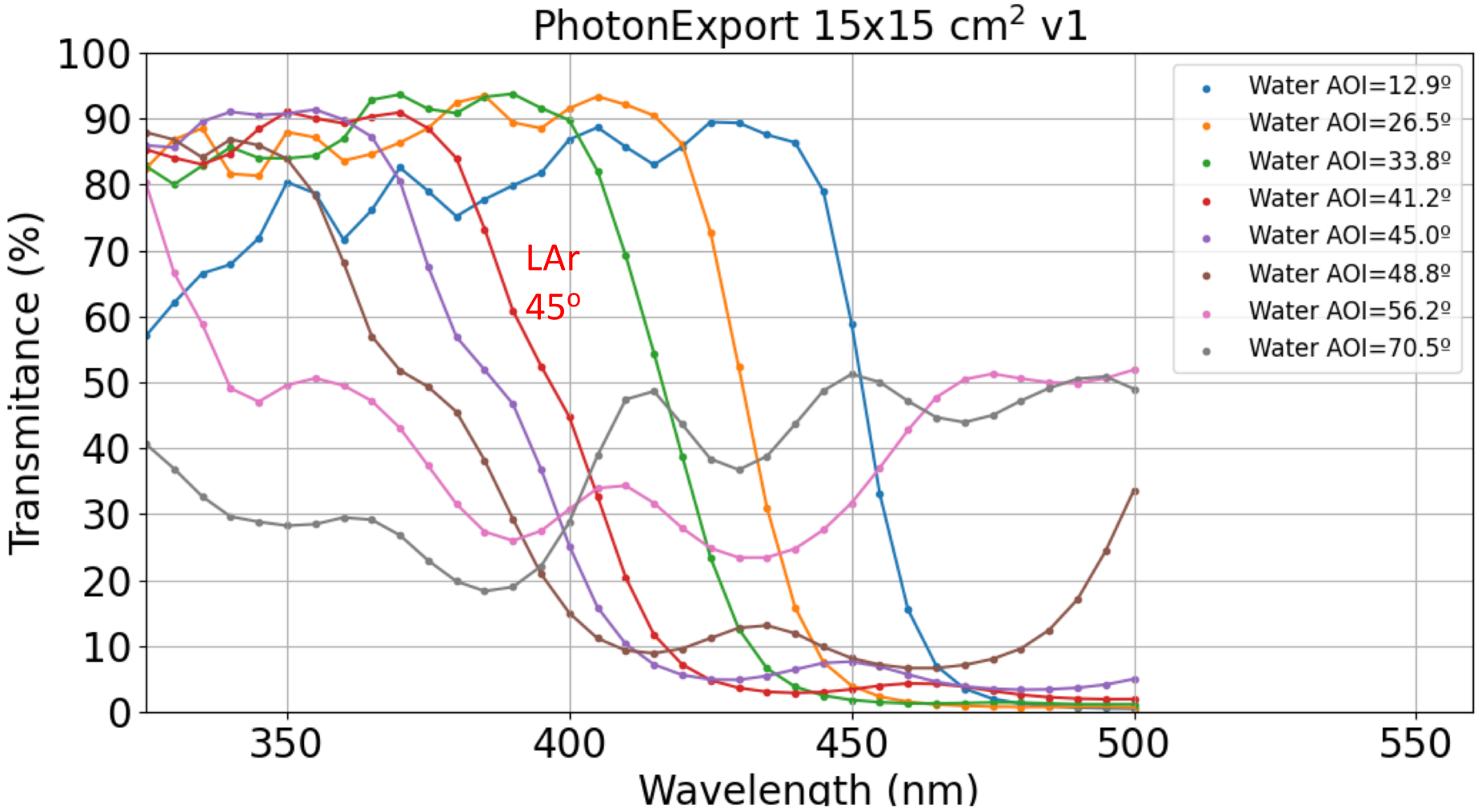


ZAOT - T curves

Cutoff change vs n→$\lambda = \lambda_0 \sqrt{1 - \frac{n_1^2}{n_2^2} \sin^2 \theta}$

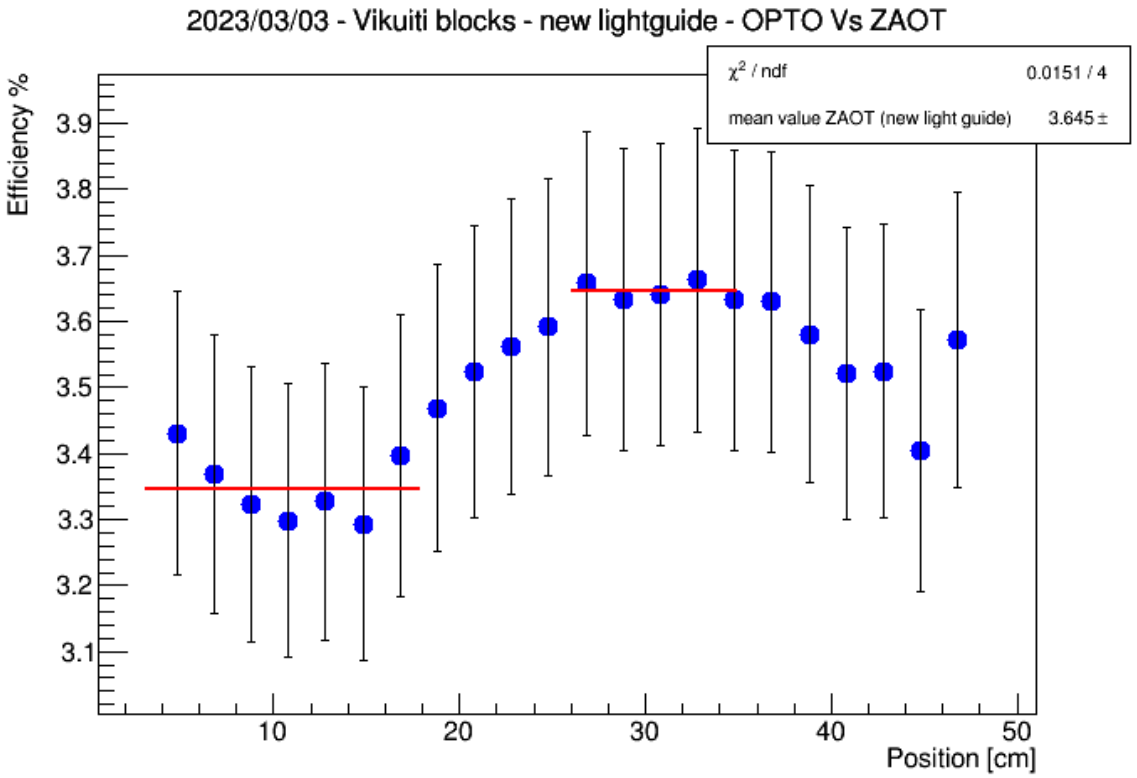


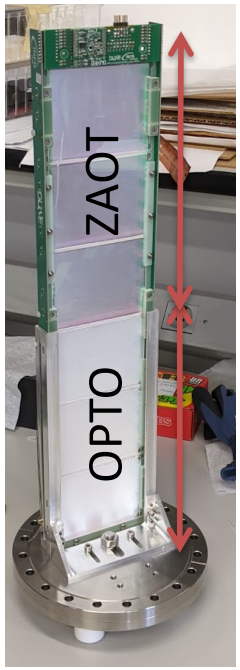
PhotonExpert: T Curves

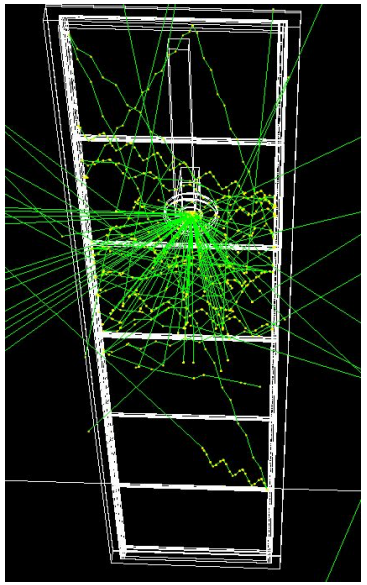


Assessment of ZAOT DFs performances in LAr

- Measurements of the PDE in Lar of one FD1-XA equipped with
  - three OPTO (0 < position< 24 cm)
  - three ZAOT (24 < position< 48 cm)



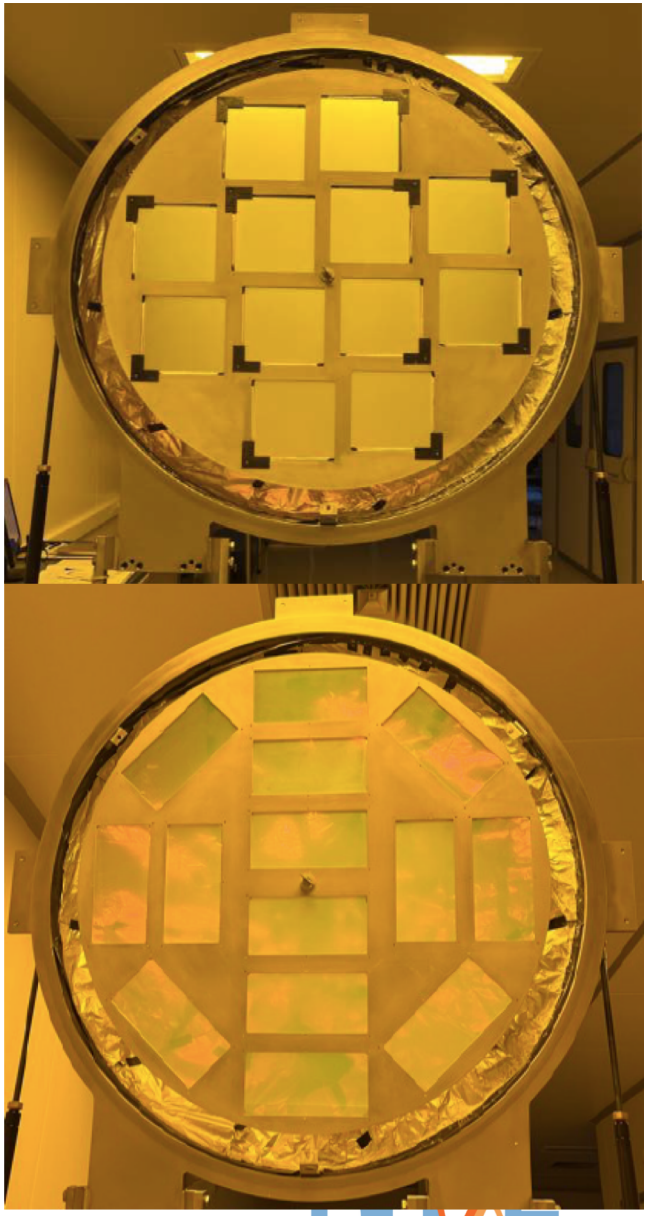




pTP coating

The coating report from UniCAMP

Date	Size	Disc position	Mass before	Mass after
26/01/23	143.75x143.75	Central (01)	66,62698 g	66,72385 g
26/01/23	143.75x143.75	External (07)	66,17028 g	66,22962 g
N. filters = 12		pTP = 4,000 g		Pc=2,2*10-5 mbar



Main pTP coating site: UNICAMP

Coating capabilities: 2 batches/day→ 24/day

- Evaporation of ~400 ug/cm2
- Thickness: 3.2 um

Twin facility will participate at the FD2 pTP coating efforts at INFN Napoli starting from spring 2024

QA/QC: WLS

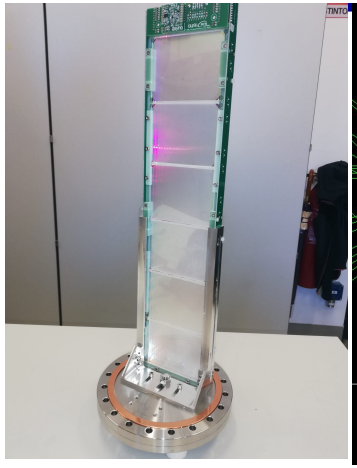
- Measure the «as casted» dye concentration uniformity
- Visual inspection
- Measurement of haze and gloss parameters
- Measurements of thickness tolerances along the perimeter and at the plate center
- Measure the edge polishness

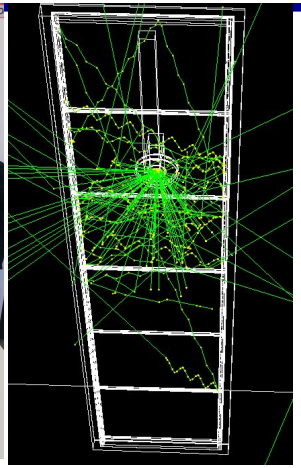
QA/QC: Dichroics

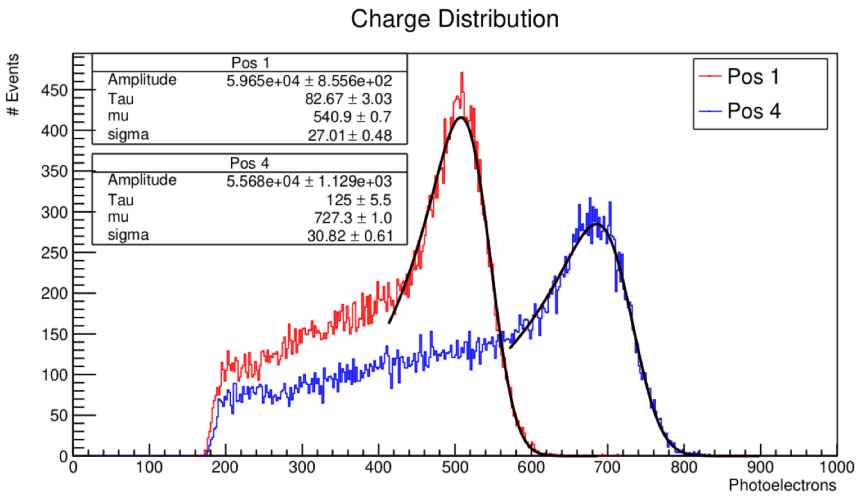
On a sample of the massive production

- Measure the T curves in water at 40-45-50 deg
- Measure the uniformity of the T curves at the different points of the surface (144 x 144 mm2)
- Cooling/warming: no cracking

FD1 XA-PDE measurements



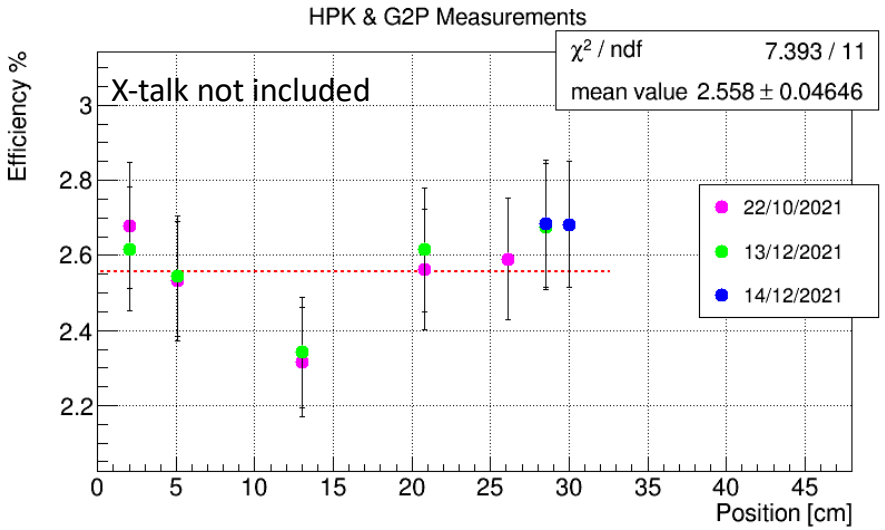




Method: z-scanning of the whole cell (~2 Sr) with an ^{241}Am exposed α source

(JINST 16 (2021)09027)

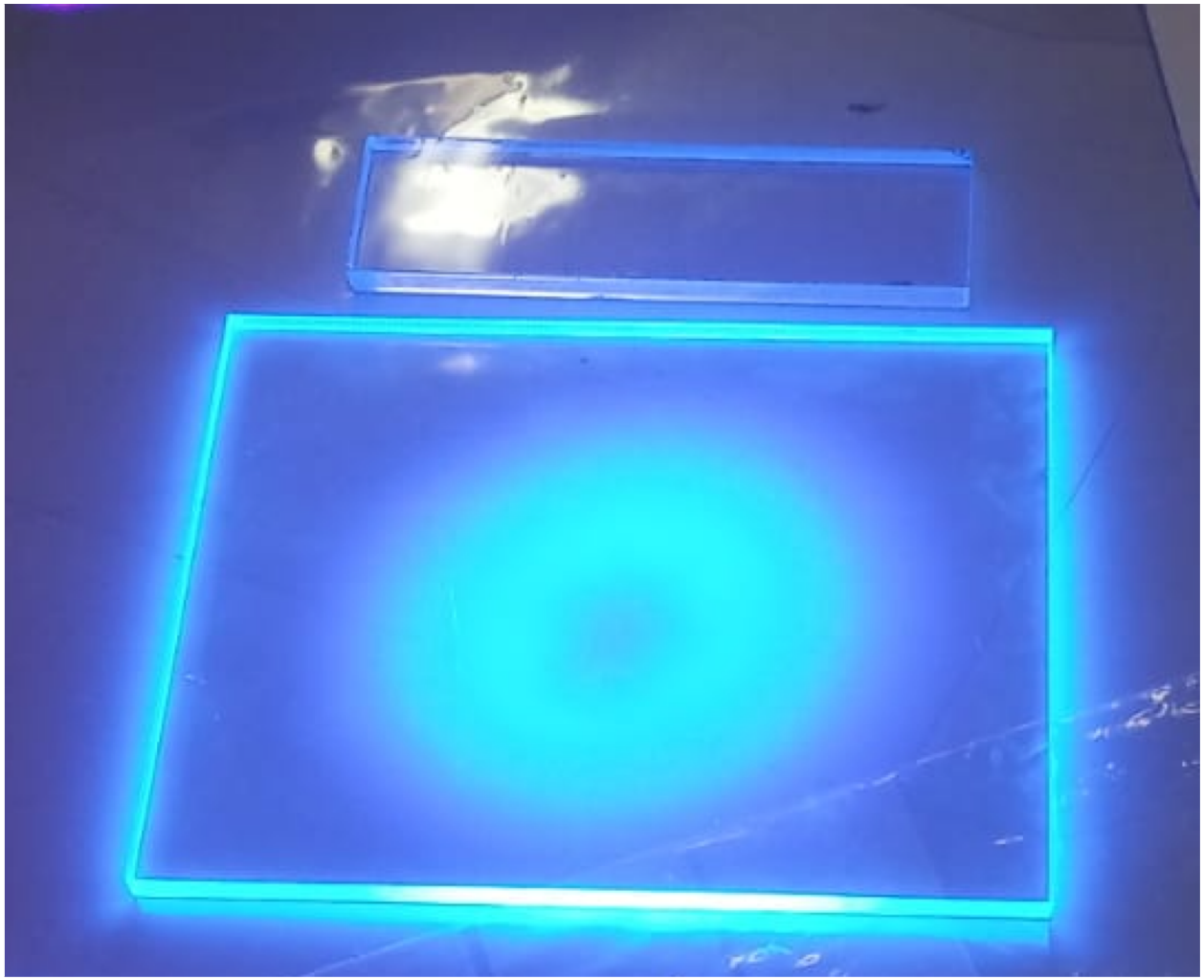
$$\epsilon = \frac{4\pi \cdot \alpha \text{ peak(ADC)}}{\text{s.ph.e.(ADC)} \cdot f_{int} \cdot \text{LY}_{\text{LAr}} \cdot \text{En}_{\alpha} \cdot \text{q}_{\alpha} \cdot \Omega}$$



No correction for LAr purity applied. Expected: +2% to +5%

	SiPM PDE	XA PDE MiB Xtalk corr.	XA PDE CIEMAT Xtalk corr.
HPK & G2P	50%	**2.2** (0.15)	**2.51** (0.21)
FBK & G2P	50%	**1.9** (0.14)	
FBK & Eljen	50%	**1.7** (0.14)	**1.56** (0.12)

WLS Lightguides



Absorption and Emission

The Abs and Emission (PL) spectra of the G2P WLS embedded in pDUNE-FD1 and Module-0 of FD2

PL spectra recorded for Exc.=350 nm