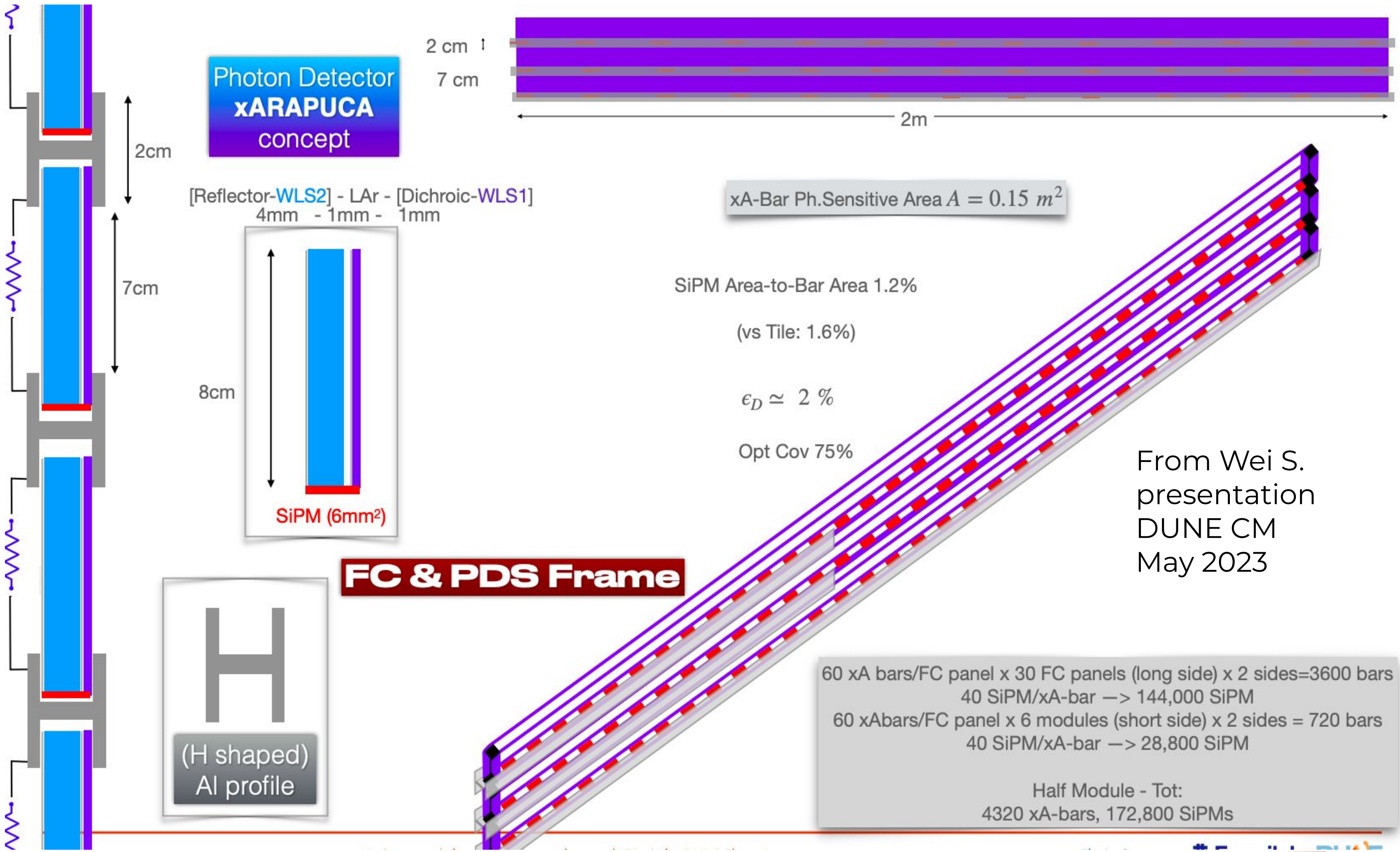
WLS for FD3

CM. Cattadori on behalf of the WG

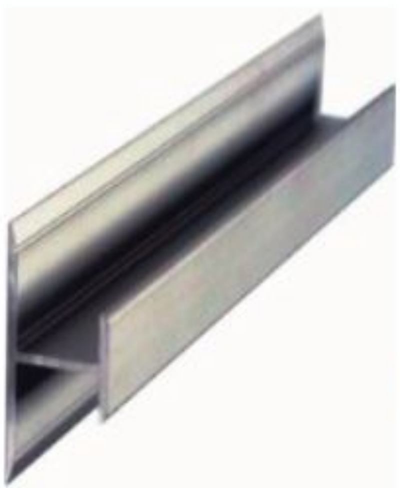
FD3 Mini- Workshop

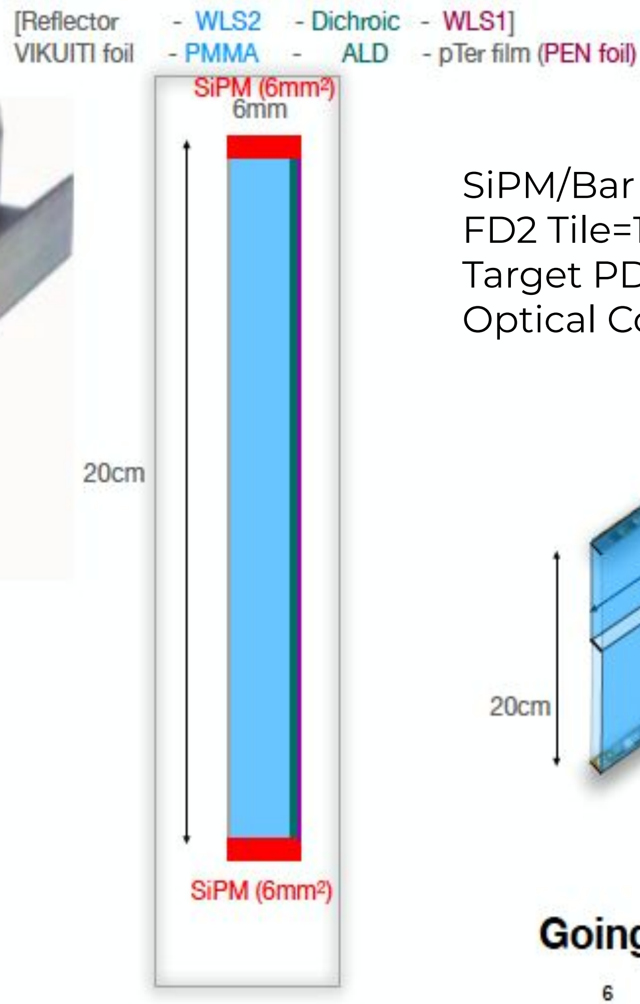
Stony Brook Univesrity 26/06/2023

Module APEX (Aluminium Profile Embedding XA)

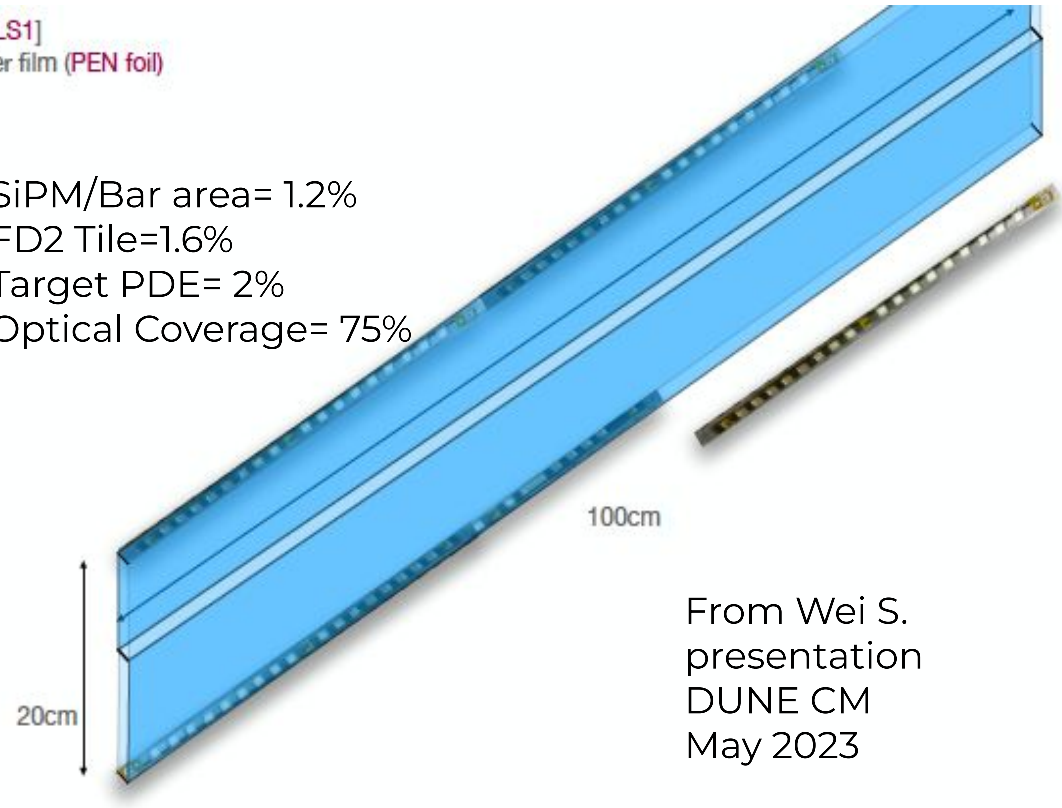


Simplified XA concept





SiPM/Bar area= 1.2%
FD2 Tile=1.6%
Target PDE= 2%
Optical Coverage= 75%



From Wei S. presentation DUNE CM May 2023

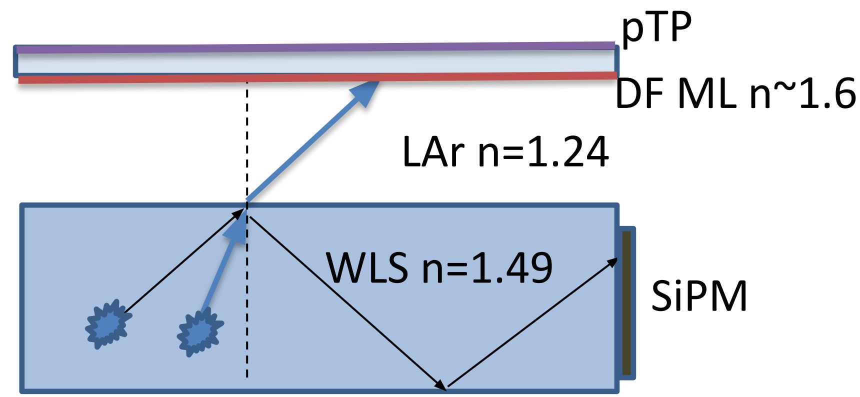
Going for larger WLS plates in y direction

6

The FD1&FD2 X-Arapuca concept

The XA light collection in LAr

- For $\theta > \theta_c$ (=56°) photons are trapped and guided to SiPMs. (Lightguide Collection-LGC)
- For $\theta < \theta_c$ photons leave the lightguide and imping onto the DF (DF Collection)



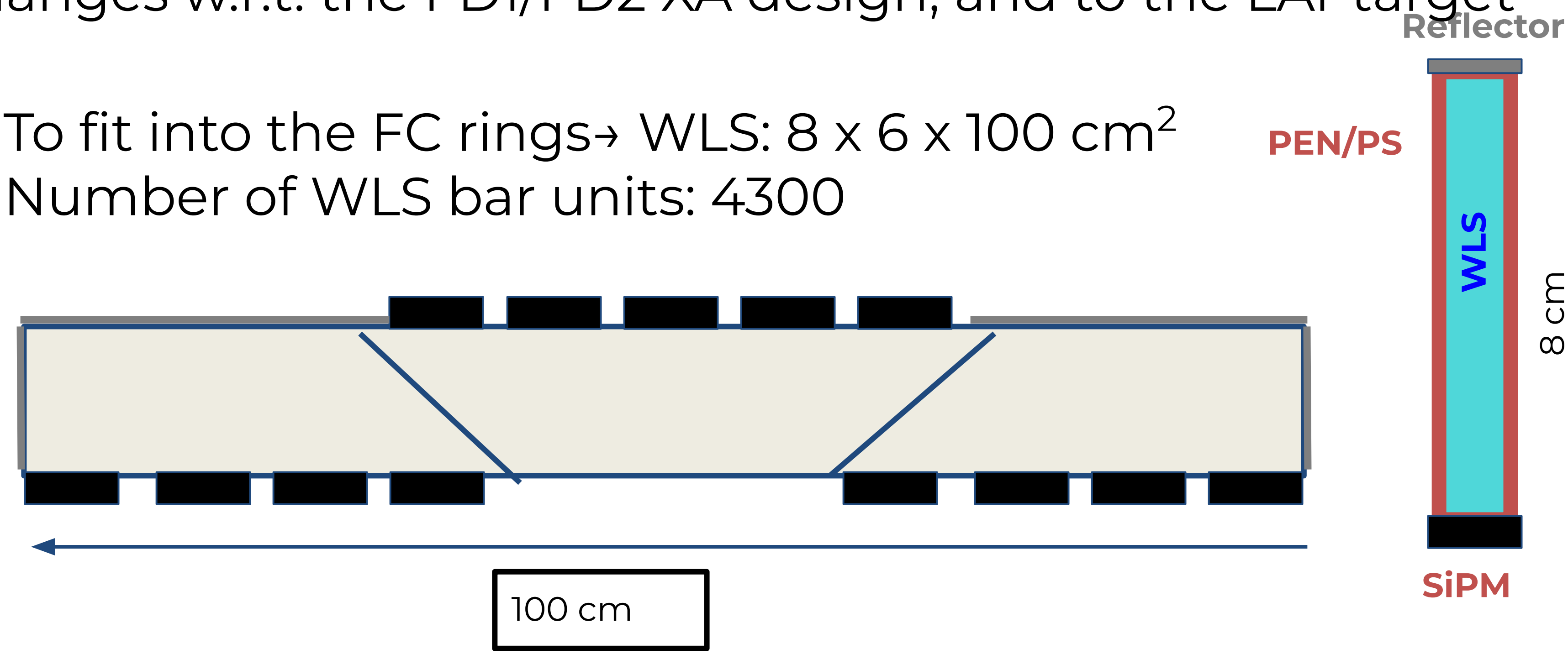
C.M.Cattadori

FD3-XA config. & WLS Requirements

One possible simplified XA configuration is based on the LGC mechanism is shown: it allows to save SiPMs thanks to the reduced OP inside the WLS lightguide

The WLS requirements & design are strictly related to the changes w.r.t. the FD1/FD2 XA design, and to the LAr target

- To fit into the FC rings→ WLS: 8 x 6 x 100 cm^2
- Number of WLS bar units: 4300



FD3 WLS design & manufacturing

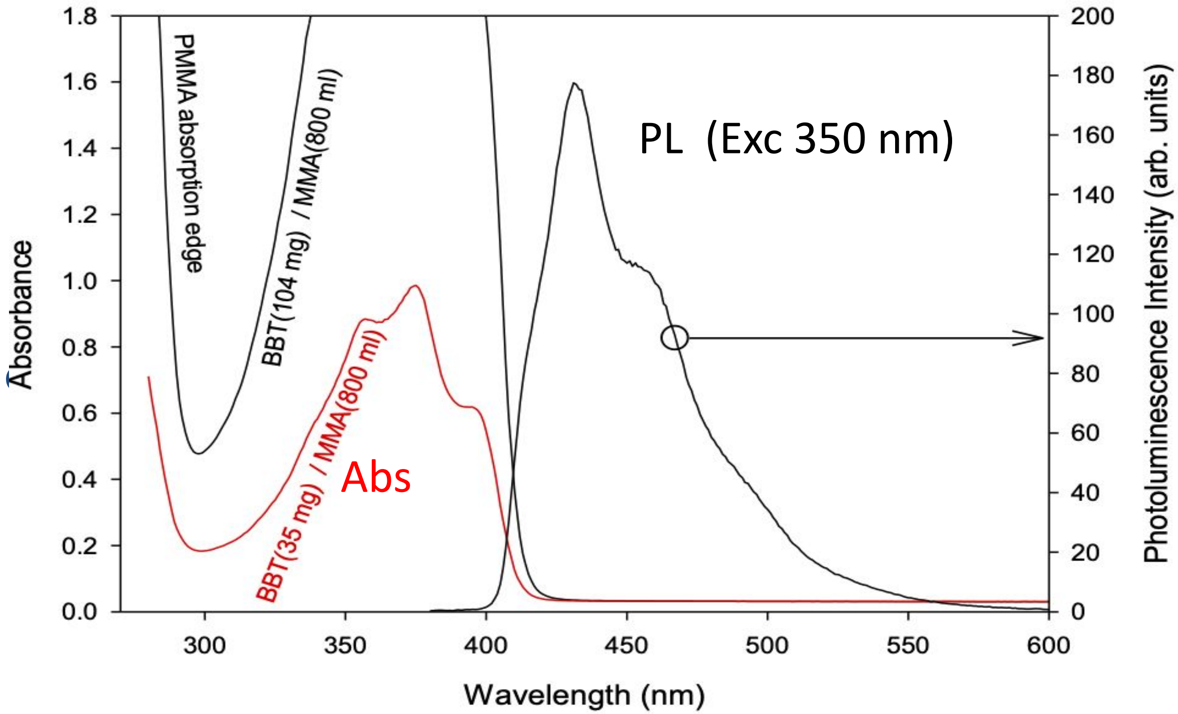
WLS

- Design:
  - choose bulk matrix (scintillator/Cerenkov only)
  - choose first shifter (from VUV to NUV/Vis))
  - choose the secondary cromophore (if needed) with proper Stoke shift and concentration to trade off PhotoLuminescense Yield and Abs. Length.
  - if bulk is scintillator, secondary chrom. may not be needed or in case will be properly selected
- Low Radioactivity casting process

- Mass production capabilities of Large Area WLS with optical grade surfaces
- Laser cut w./w.o. edge shapes to allocate SiPMs

Features of FD1 & FD2 WLS

- Cryoresilience
- Chromophore embedded in PMMA (no scintillator, only Cerenkov emission)
- High tolerances on the tiles both on
  - O(0.2 mm) x/y
  - O(0.3 mm) z
- Guiding surfaces: as casted
- Edges: polished
- Absorbption: 300-390 nm (tailored for pTP emission)
- Emission: 420-500 nm to match the SiPM Q.E.



FD1 BL: Optical Path O(20 cm) + trapping paths

FD2: Optical Path O (1 m)

WLS manufacturing capabilities

By the R&D dptm. of our industrial partner, an in house a casting facility is available

The syrup preparation (MMA + initiator + chromophore) is the preliminary step to the casting of plates.

The stirrer enclosed in a cabinet can operate in protected atmosphere.
It allows to reach low Rn contaminations in the WLS

The reactor to prepare the MMA syrup

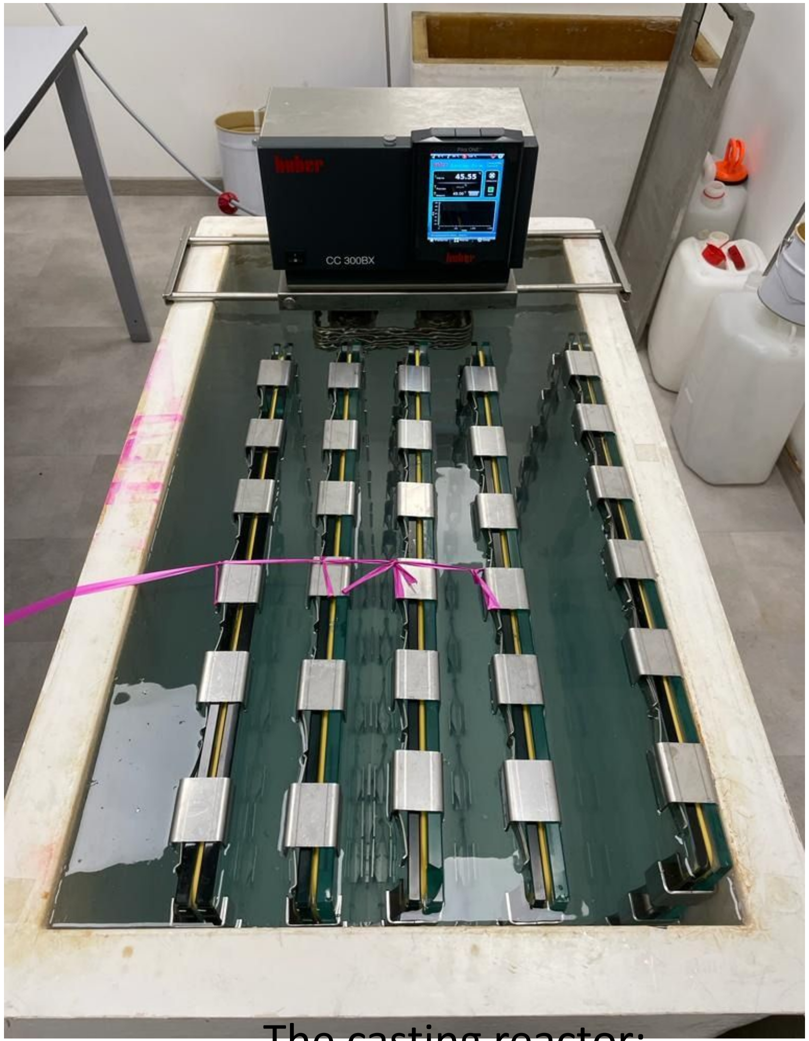
* Glass to Power Co.: Former start up of Uni MiB, now quoted at Eurostock: https://www.glasstopower.com/

WLS manufacturing capabilities

The joint R&D work triggered our industrial partner* to develop in house a casting reactor with casting capability of 5 large plates at time.

This reactor can be easily duplicated.
The syrup preparation (MMA + initiator + chromophore) is the preliminary step of the plates casting

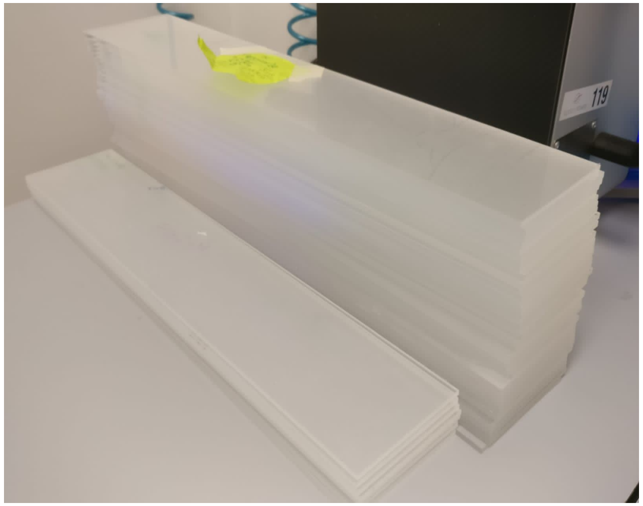
A second industrial partner is available for mass production and bars lengths >> 60 cm



The casting reactor:
5 plates at once

* Glass to Power Co.: Former start up of Uni MiB, now quoted at Eurostock: https://www.glasstopower.com/

WLS: Production of 90 FD1 and 20 FD2

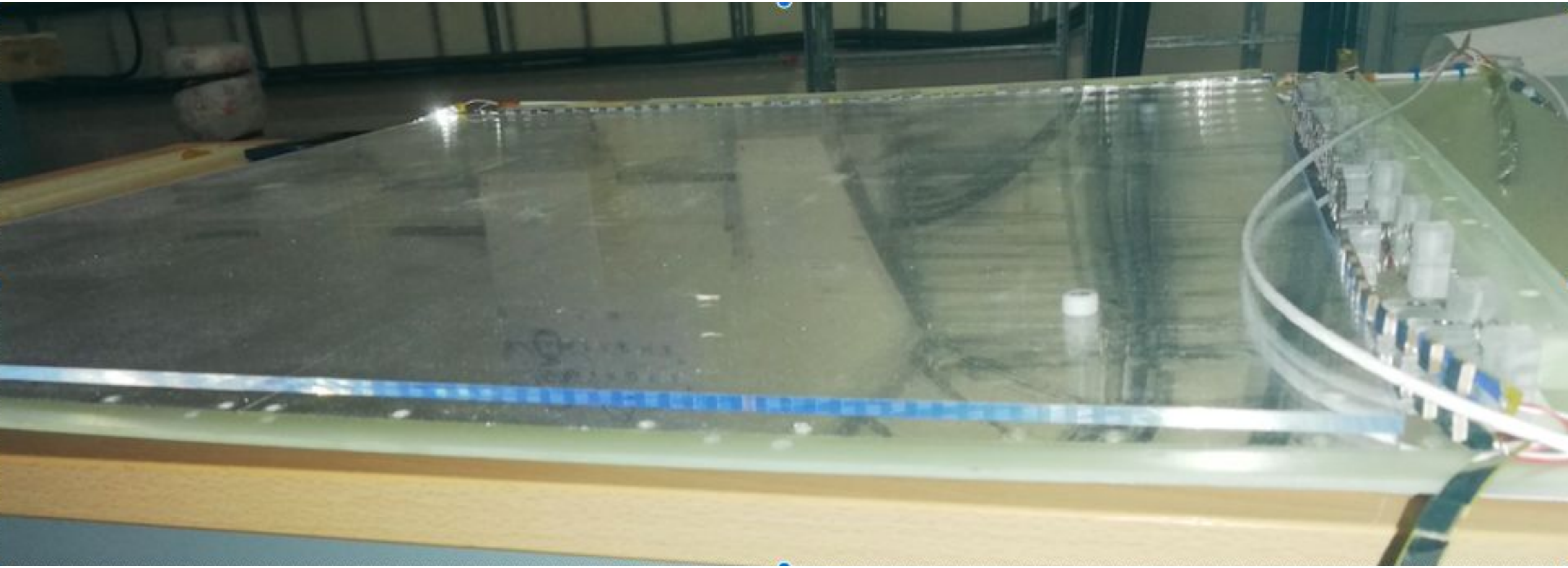


- 90 x WLS slabs for pDUNE
  FD1-PDS: 480 x 93 mm^2 x 4mm thick

Procedure to Laser cut (external industrial partner) and edge polishing procedures to cut out the casted plates in tiles is defined and validated.

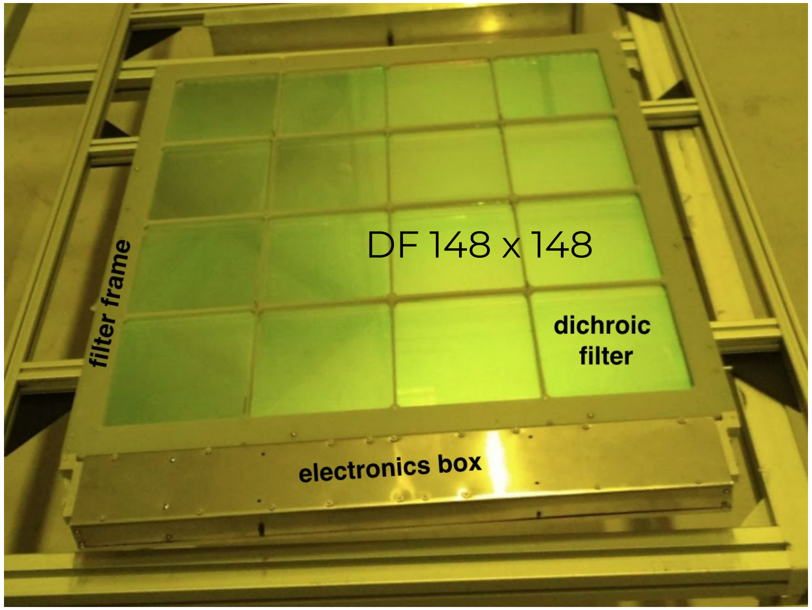
- **20** x WLS slabs for FD2 M0: 607 x 607 mm^2 x 4mm thick casted in one week
- **6 x WLS** slabs for M1: +1 mm thick & modified chromophore concentration (july/sept 2023).

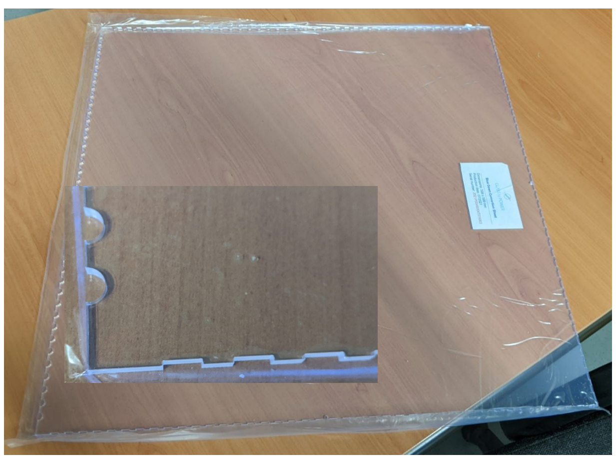
FD2: Large Area WLS



One 607 x 607 x 4 mm^3 slab is being assembled in one DUNE FD2 XA cell, together with SiPMs populated on flex circuits substrate.

Module-0 XA configurations



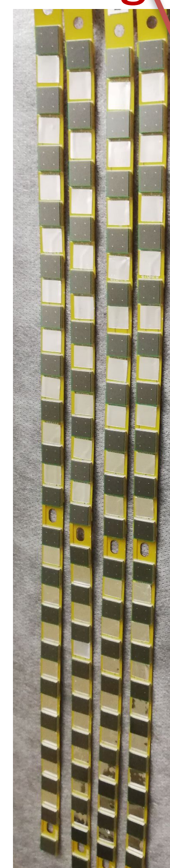


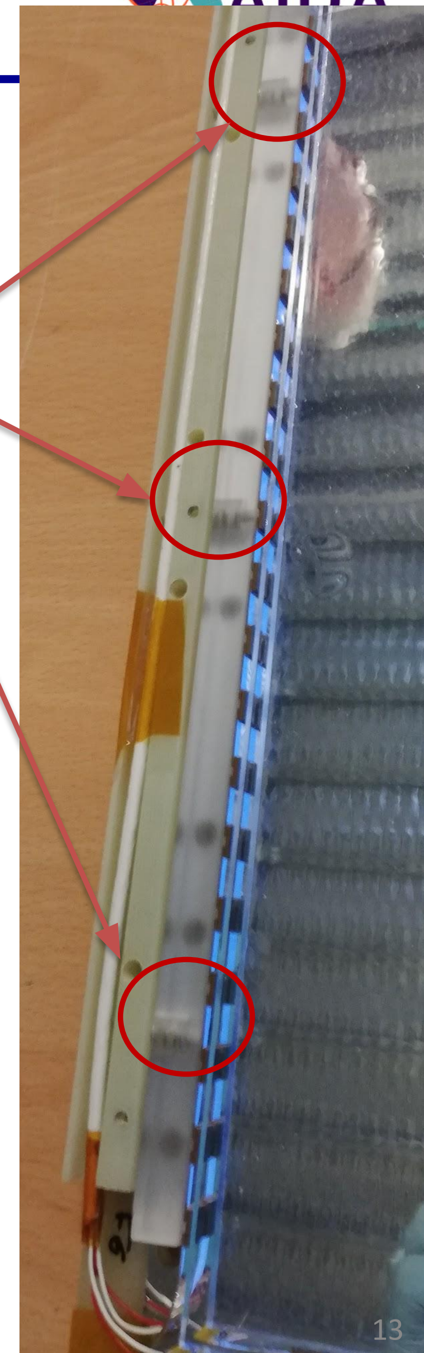
	WLS dimples	DF size (mm^2)	DF	SiPM	PoF	SoF	shared elec. box
M1		100x200	ZAOT	HPK			x
M2		100x200	ZAOT	HPK			x
M3	x	100x200	ZAOT	HPK			x
M4	x	100x200	ZAOT	HPK			x
M5	x	150x150	PE	FBK		x	
M6	x	150x150	PE	HPK			
M7	x	150x150	PE	HPK			
M8	x	150x150	PE	FBK			
C1		100x200	ZAOT	HPK	x	x	
C2		100x200	ZAOT	HPK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

- 11 WLS are Dimpled (SIPMS inside)
  - 2 sides square
  - 2 sides cylindrical
- 5 WLS are flat edges (SIPMS flushed with the WLS edges)
- Dichroics Filters
  - 10 ZAOT (3 rect. + 7 squared)
  - 6 are PE (all squared)

FD2-M0: SiPM to WLS coupling

- BL design: WLS with flat edges
- Also tested SiPMs fitting in dimple-cuts (flat/cylindrical) machined at the edges 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)

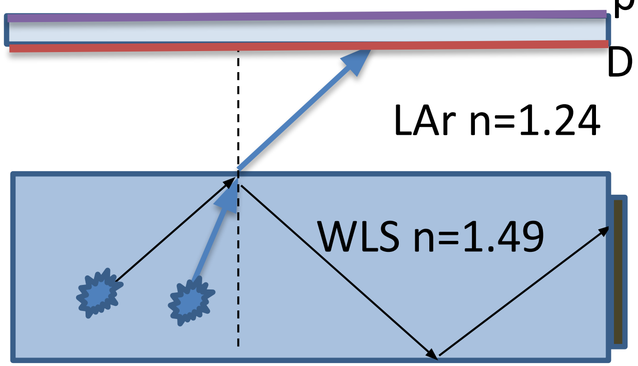




WLS: Attenuation length (l_{att})

The XA light collection in LAr

- For $\theta > \theta_c$ (=56°) photons are trapped and guided to SiPMs. (Lightguide Collection)
- For $\theta < \theta_c$ photons leave the lightguide and imping onto the DF (DF Collection)
- Due to multiple reflections the optical path inside large size WLS (as for FD2 of DUNE) may reach a couple of meters.

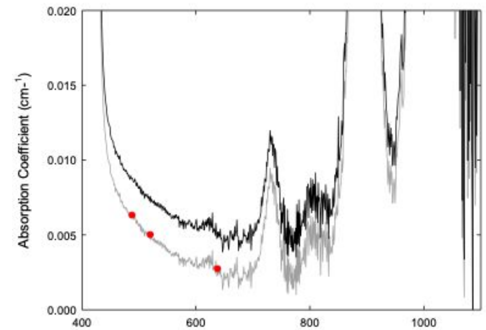


The WLS attenuation length l_{att} is the leading parameter to **maximize the Lightguide collection** at the edges of a large area WLS-lightguide.

FD1&FD2 WLS: Attenuation length (l_{att})

For the reference concentration (80 mg/Kg)

- The spectrophotometric T(λ) values at on a 4 mm sample are corrected (shifted) by the laser measurements
- The att.length (l_{att}) is derived
- The l_{att} for the other concentrations is scaled



$A = \log_{10}(1/T)$

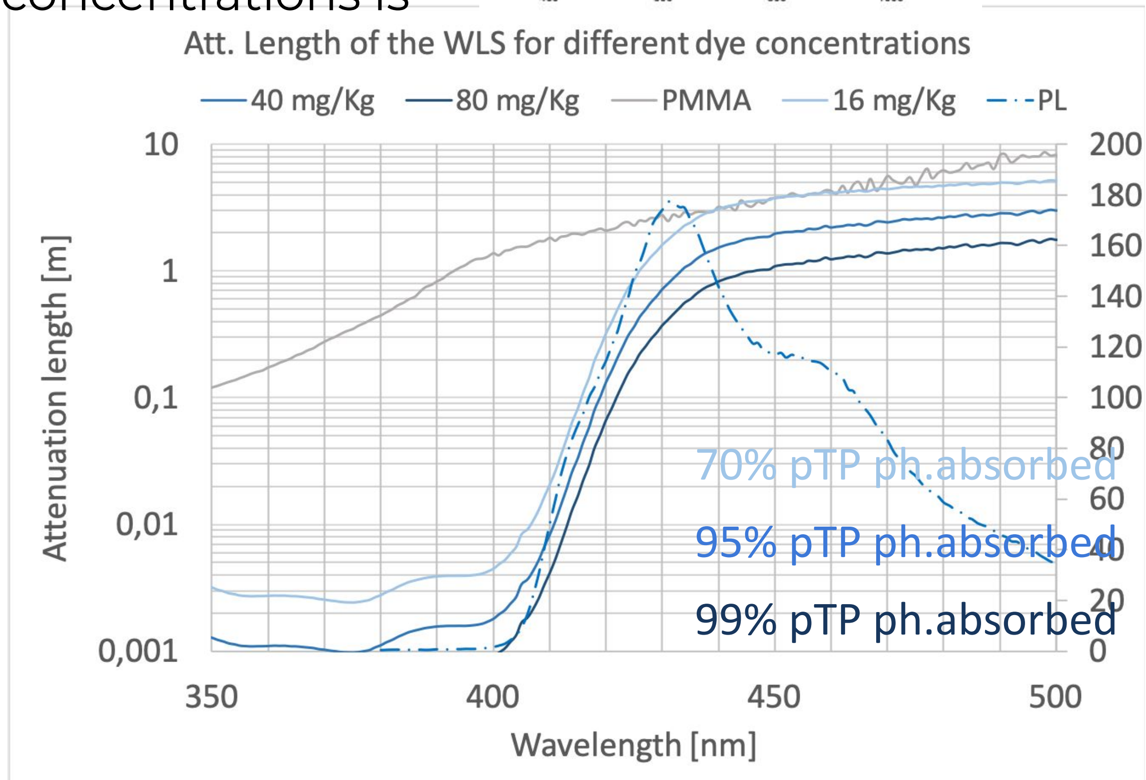
$T = I/I_o \exp(-d/l_{att})$

$A = \varepsilon \, c \, d$

ε = molar extintion coeff.

c = concentration

d = optical path



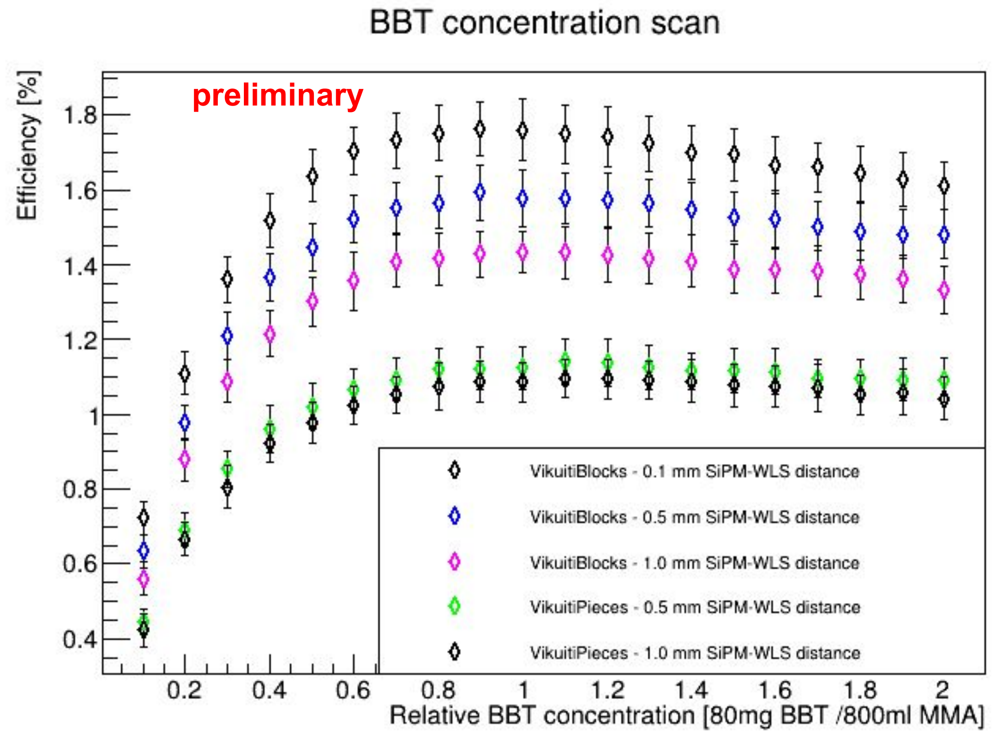
FD1 WLS: SimulatedAttenuation length (l_{att})

The l_{att} of the DUNE - FD1:

- is 37 cm at 430 nm (maximum of WLS PL spectrum)
- The dye concentration has been tailored on the FD1 WLS shape.
- an optical simulation is employed to evaluate the impact of different variables on the light collection efficiency:

  - chromophore concentration

  - lightguide shape and size

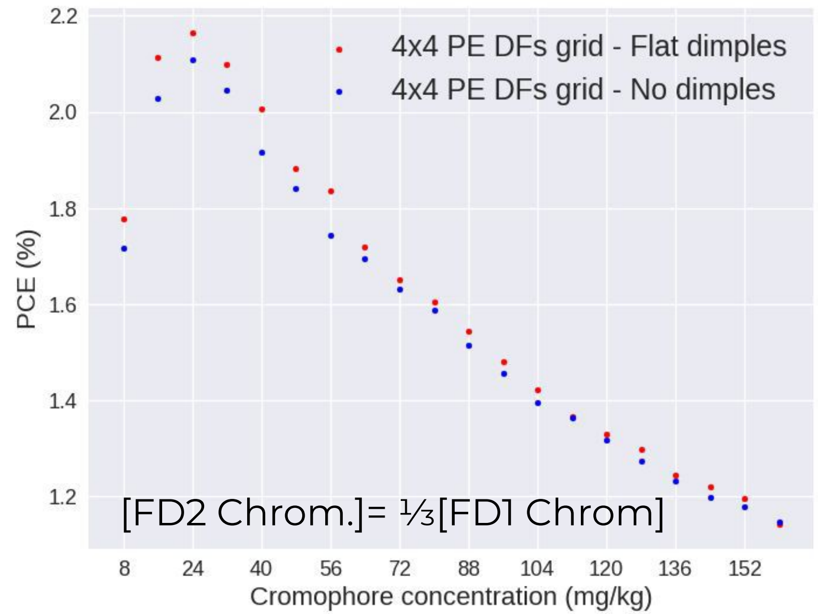


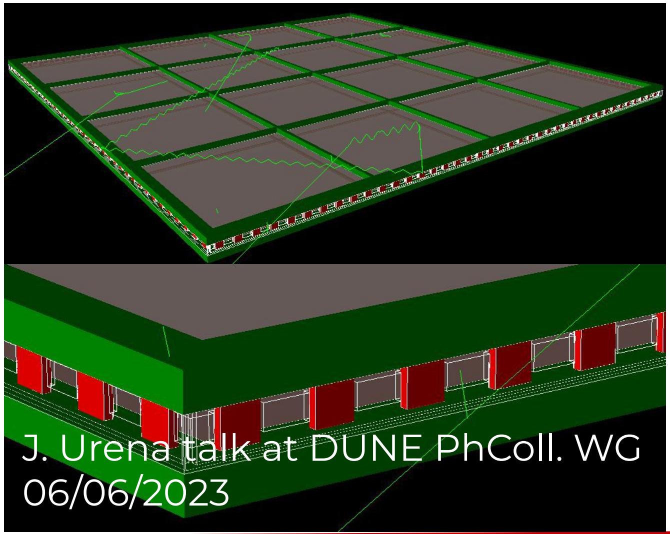
see L. Meazza Talk at PDS parallel Thursday 25th May

WLS optimization for Module-1 and FD2

The *cromophore concentration* of the DUNE - FD2:

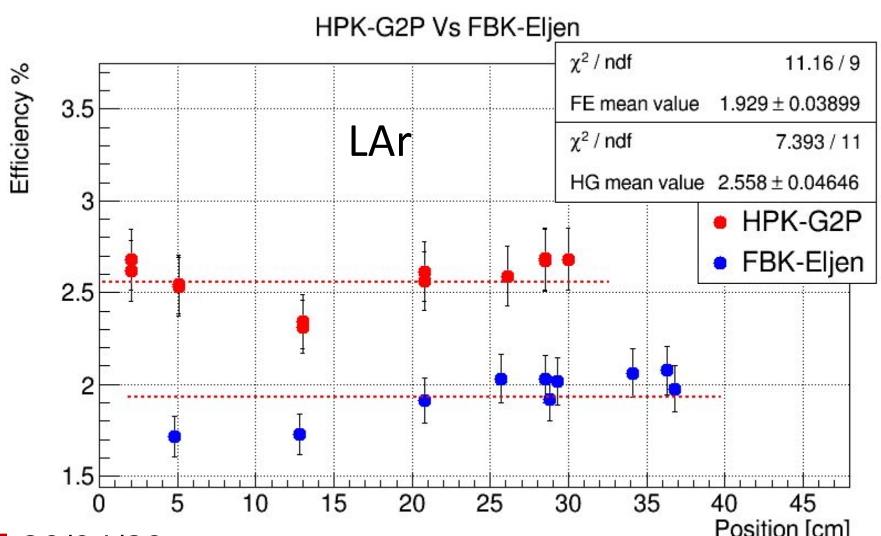
- must be tailored for the FD2 WLS size ⟶ optical path.
- Optimization (driven by sims and measurements)
- For the WLS plate thickness (4 mm) the cromophore concentration must be tuned by the trade off the l_{att} and the pTP ph. trapping efficiency
- Second option is to reduce the chromophore conc while increasing the WLS thickness to up 5-6 mm: mechanical constraints?

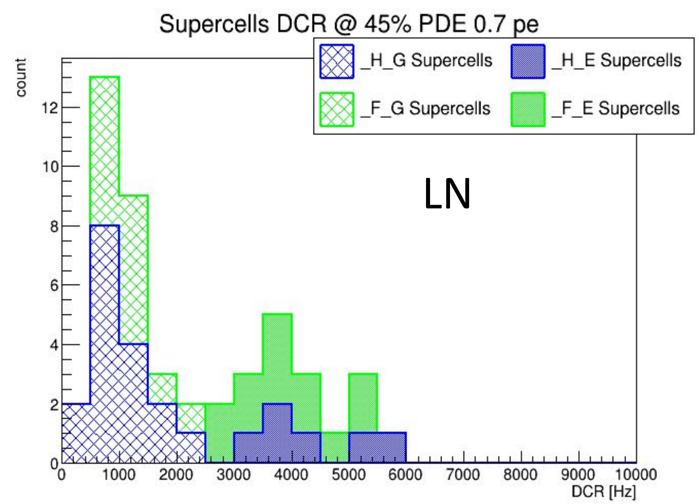




WLS features & Performances:PDE & DCR

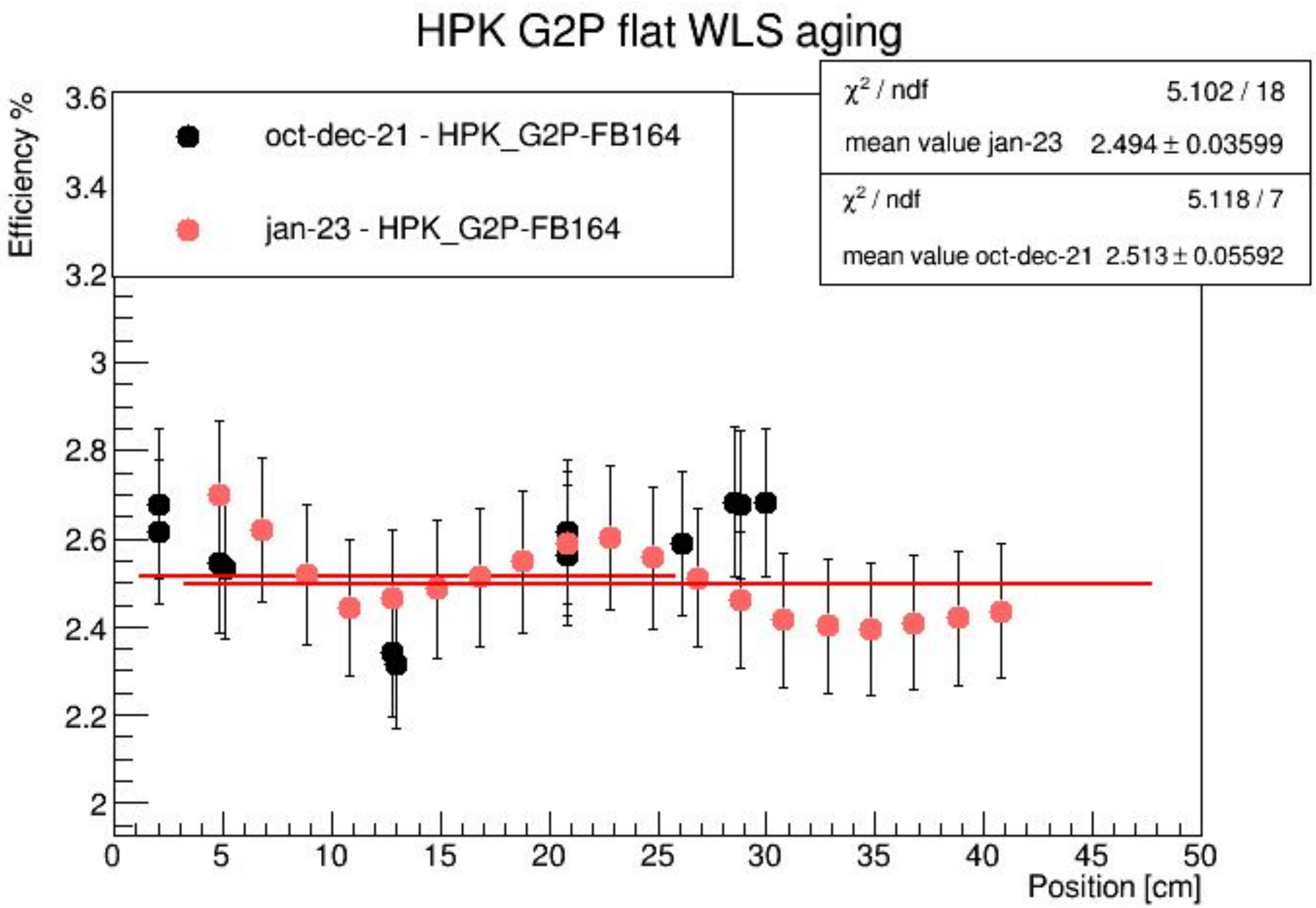
- **Superior Cryoresilience**: No cracks or failures in cooling/warming cycle at rate of 3-4 mm/sec of the 80 x FD1 pDUNE & 16 x FD2 Module-0 plates
- **Stress tests**: One prototype plate underwent 15-20 thermal cycles: no failures.
- **Superior light guiding surfaces as casted**
- **Superior LY and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



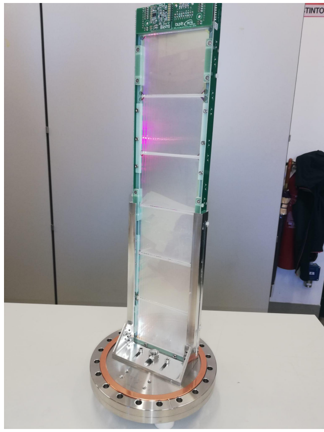


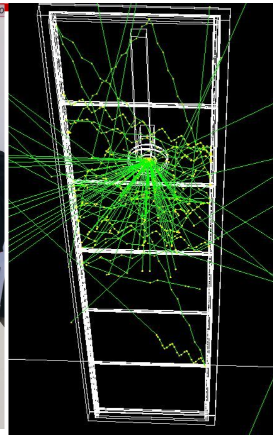
Aging assessment of WLS slabs

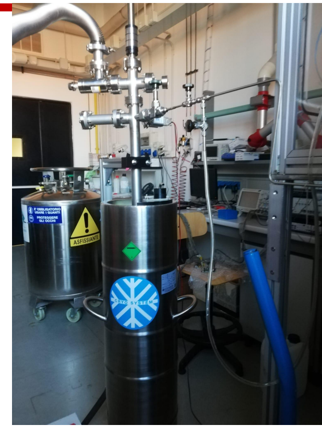
- ~15 thermal cycles in between oct-dec21 and jan-23.
- Tested different configurations of a 480 x 93 x 4 mm^3 plate

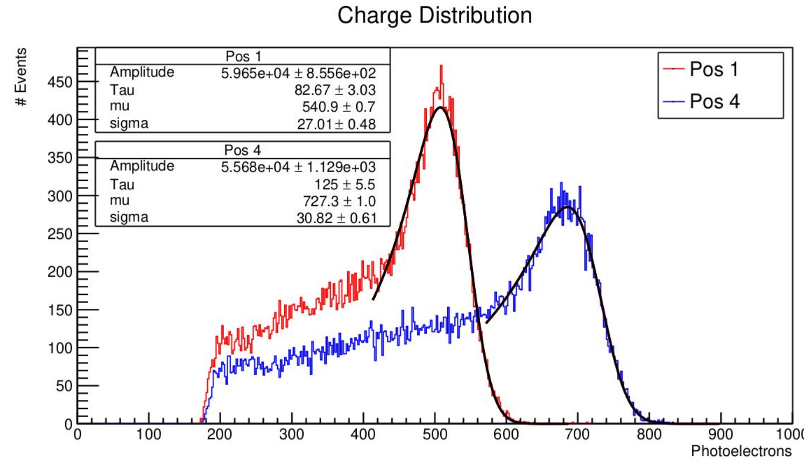


XA-PDE measurement method: old results





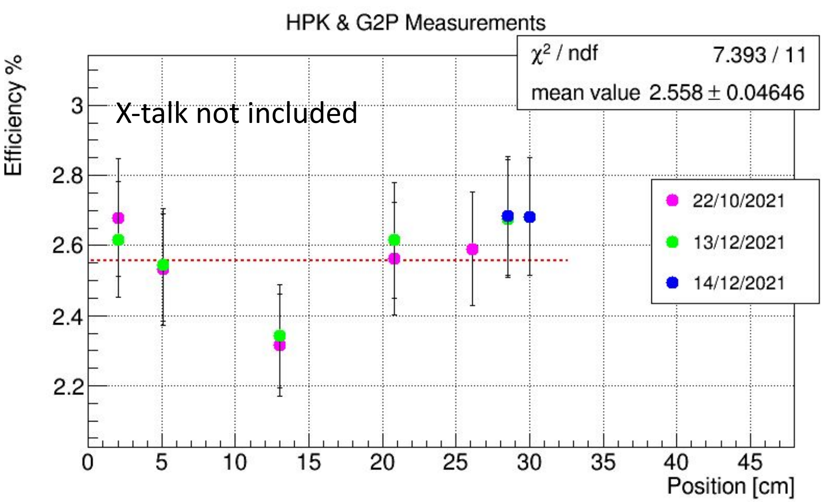




Method: z-scanning of the whole cell (~2 Sr) with an ^{241}Am exposed α source

(JINST 16 (2021)09027)

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



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)

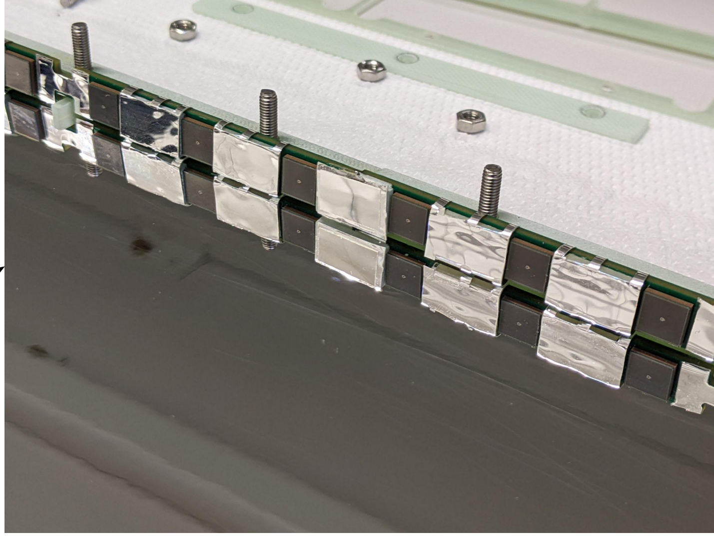
Enhancing the FD1-XA Supercell: PDE measurement list

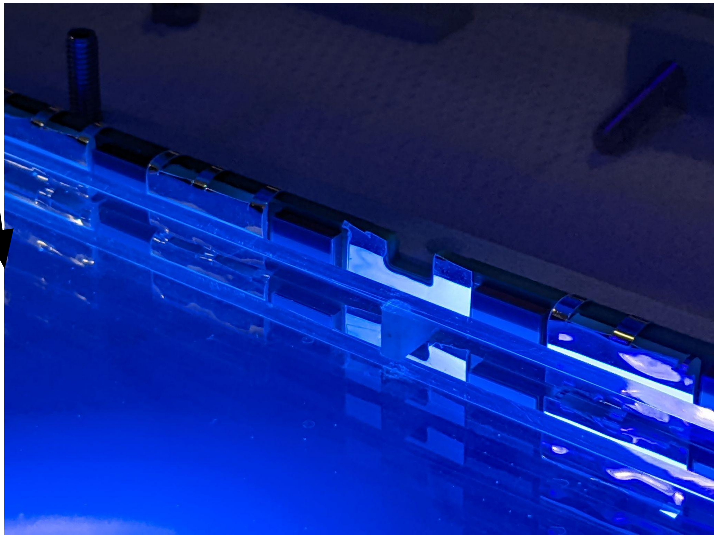
day [dd/mm/yyyy]	light guide	frame	filters
18-19 / 01 / 2023	G2P FB164	improved light sealing	OPTO
23-26 / 01 / 2023	G2P FB164 + vikuiti on long edge	improved light sealing	OPTO
01-03 / 03 / 2023	G2P protoDUNE run2 batch	improved light sealing	3 OPTO + 3 ZAOT
07-08 / 03 / 2023	G2P protoDUNE run2 batch	improved light sealing	OPTO
09-11 / 05 / 2023	G2P protoDUNE run2 batch	improved light sealing	ZAOT
16-17 / 05 / 2023	G2P protoDUNE run2 batch, 40° cut	improved light sealing	ZAOT
18-19 / 05 / 2023	G2P protoDUNE run2 batch	baseline	ZAOT

1. Improve light sealing Light sealing

- FD1-XA Supercell with Vikuiti-covered G10 spacer blocks between <u>all</u> the SiPMs; Vikuiti also covers the screw holes
  - placing Vikuiti closer to the light guide provides better light sealing
  - could be the cause of the better PDE of the SBND version

- Tested an "extreme" config.: Vikuiti on three sides (2 x short + 1 x long) edges of the WLS bar.
  - half the SiPMs are partially "blinded": to check effect of extreme sealing
  - increase dependence on the WLS-LG l_{att}



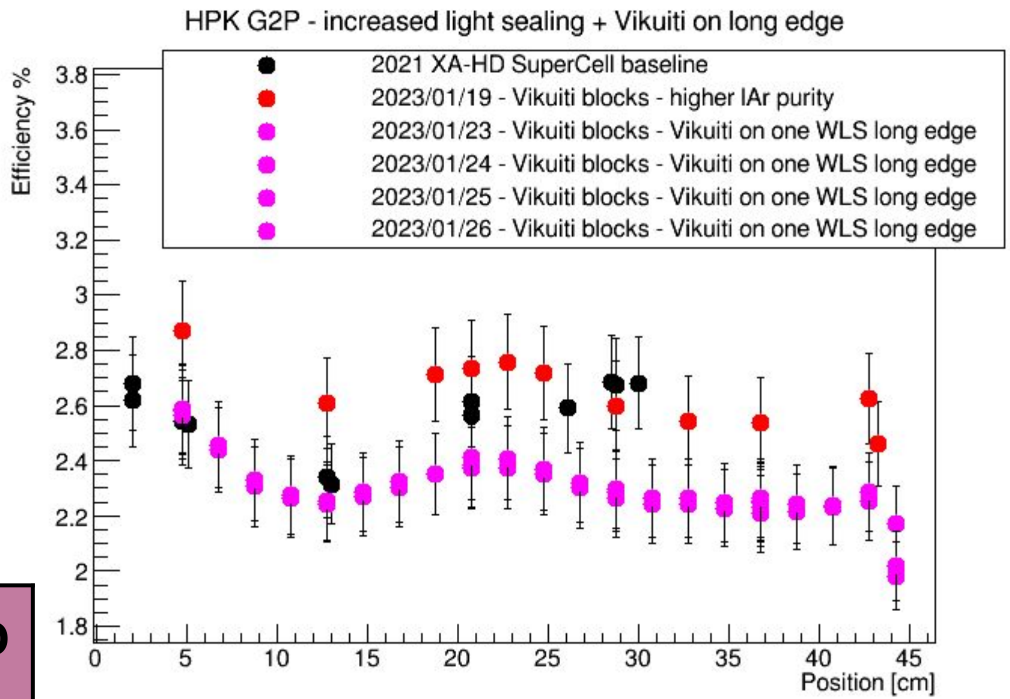


3. Observation IMPORTANT for FD3: SiPM readout only on one Long Edge, Vikuiti on opposite long edge

We lined with Vikuiti one of the two LG long edges

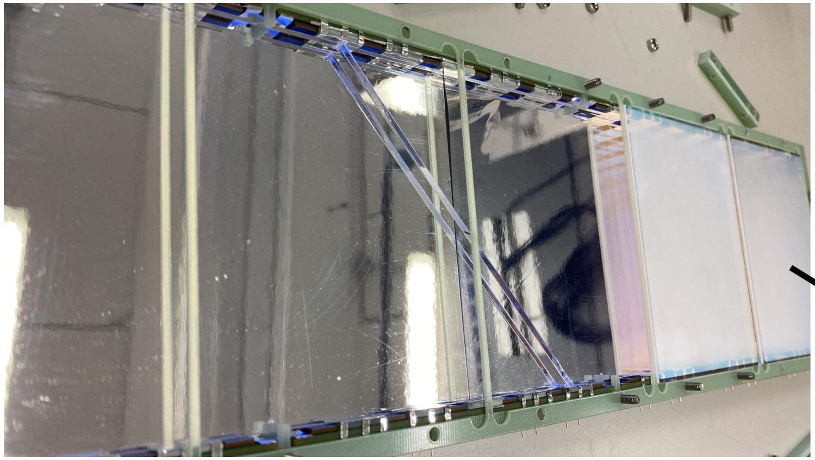
- **⅓ of the SiPM surface blinded (66% active)**

➢ **lower PDE, as expected, but still 87% of previous meas.**
  - the OP across the WLS width is O(10 cm)



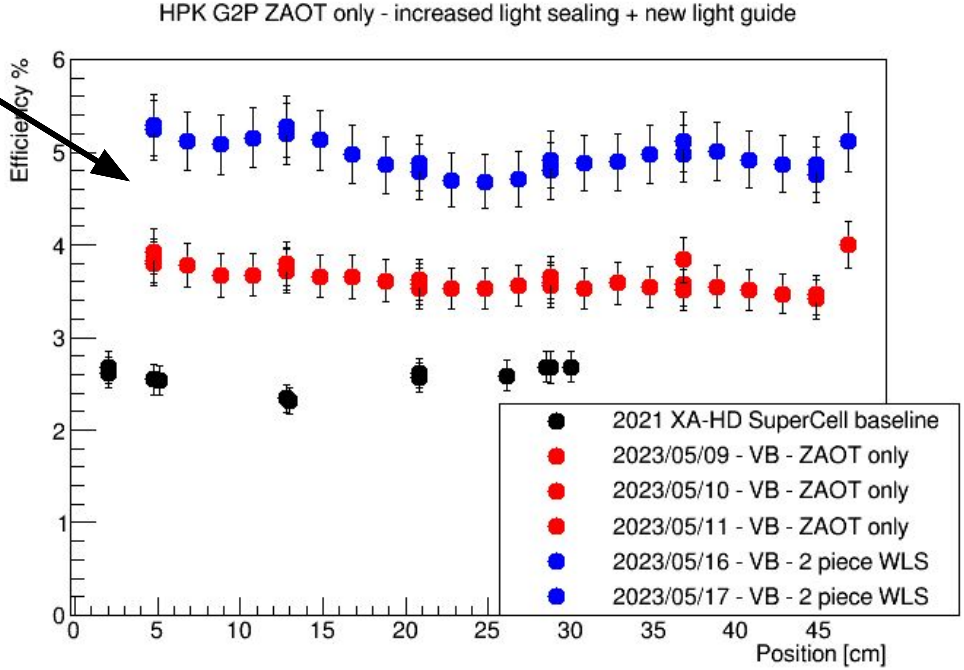
measure	baseline	19/01	23-26/01
avg PDE	2.51%	2.64%	2.29%
% wrt bl	-	+5%	-8%
% wrt 19/01	-	-	-13%

2. Break ineffective Optical Path +Optical sealing+ ZAOT DF



G2P p-DUNE LG with 40° cut

- PDE: + 37%



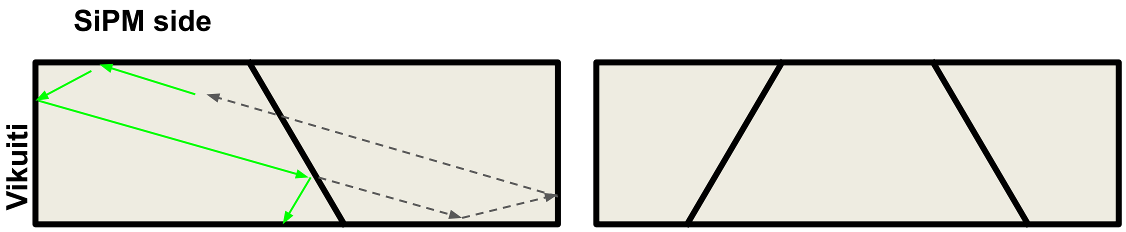
measure	baseline	10/05	16/05
avg PDE	2.51%	3.59%	4.93%
% wrt bl	-	+43%	+96%
% wrt 09/05	-	-	+37%

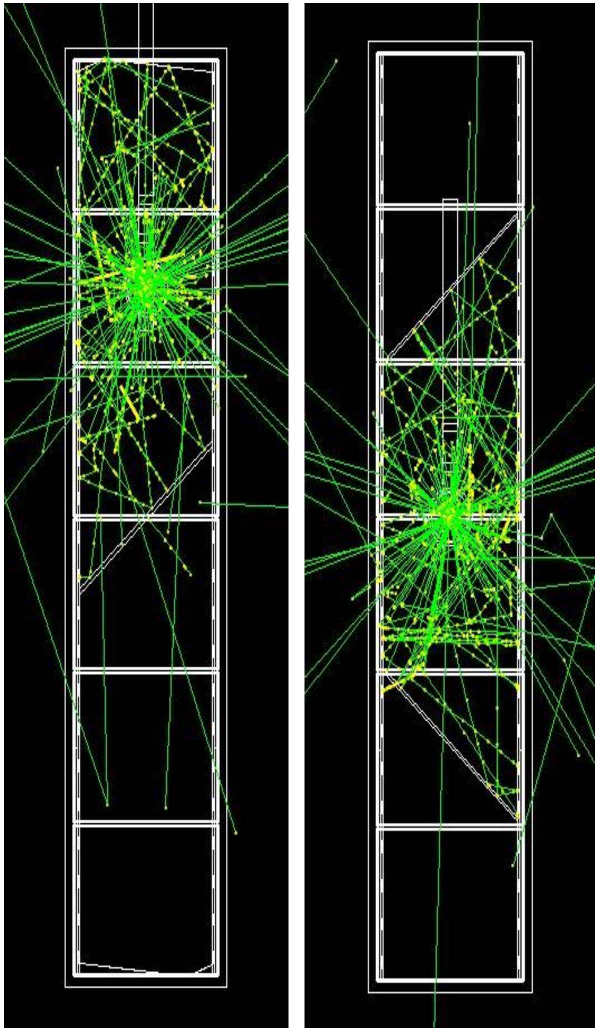
Simulation - light guide configurations

A different LG geometry should improve the PDE

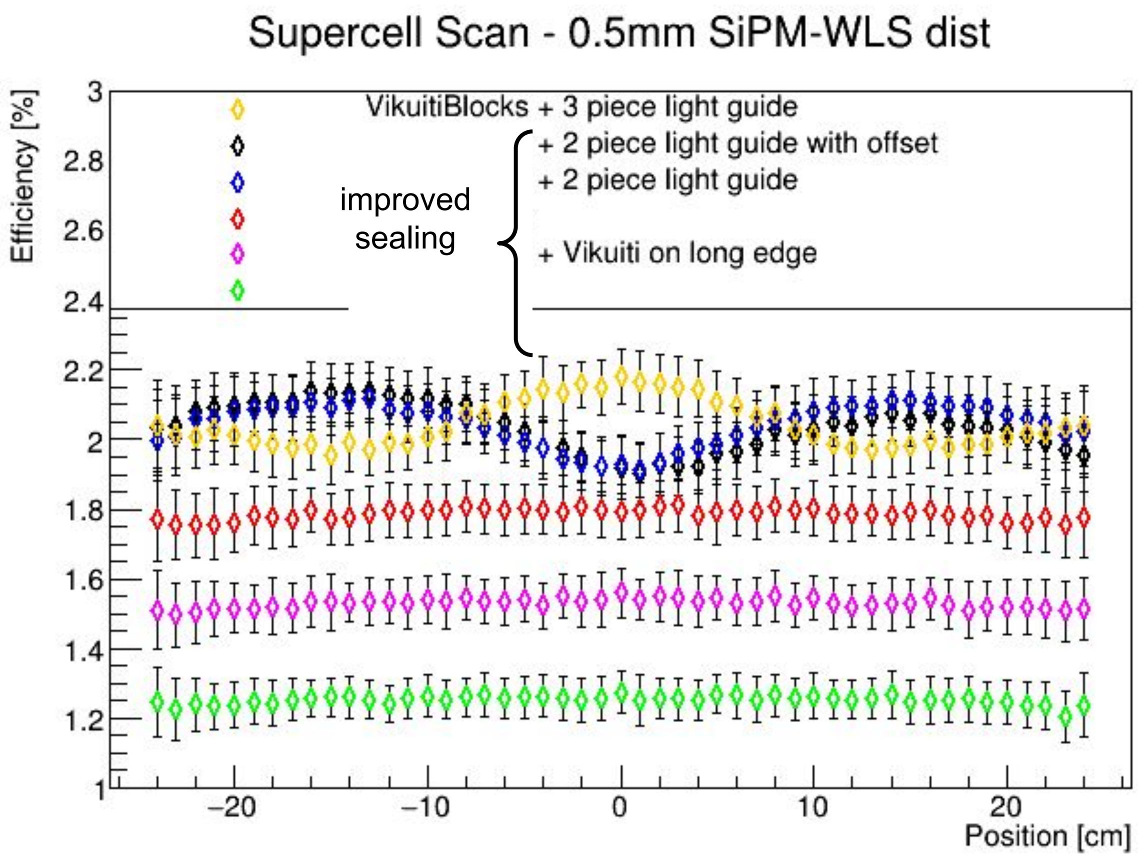
- **cutting the LG with an angle (about 40°)**
  - **breaks OP bouncing at the shorter edge**
  - **reflects light to the SiPMs**
  - decreases the distance light has to travel to reach a SiPM
  - mechanical constraints?

- simulated configurations:
  - **2 piece WLS, one 40° cut at the center**
  - **3 piece WLS, two cuts (+-40°)** (problem with existing light guide mechanical supports)





Simulation - light guide configurations



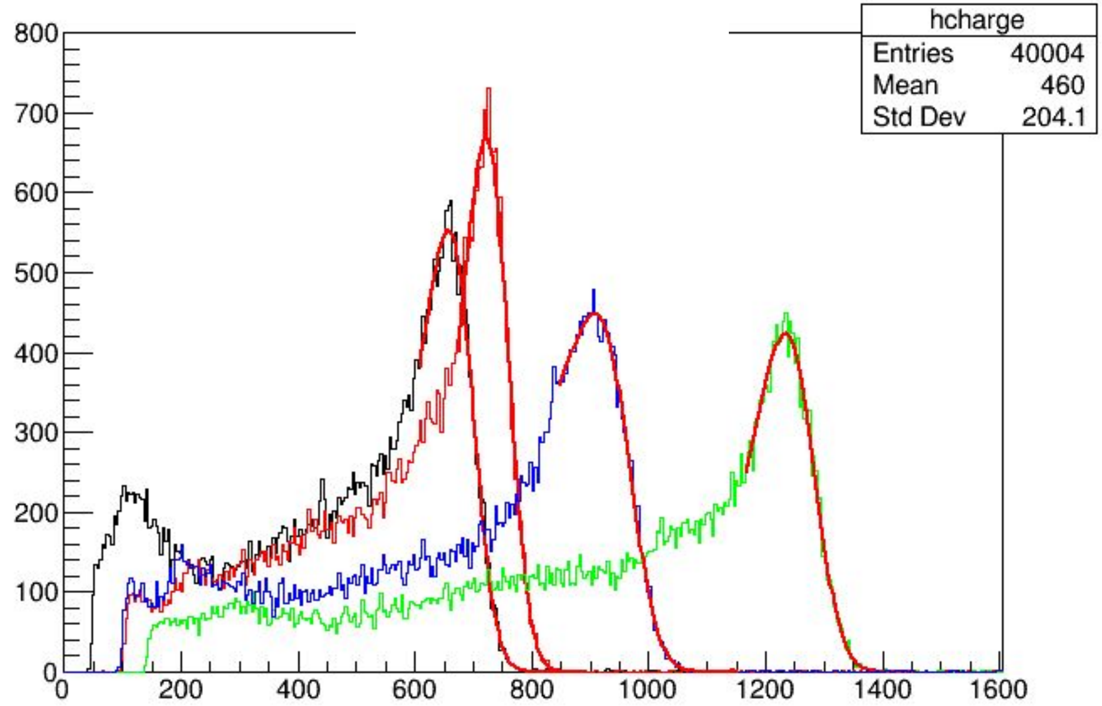
config	average PDE*	% wrt baseline
baseline	1.25	-
VB + VonLE	1.53	+22%
Vikuiti Blocks	1.79	+43%
VB + 2 piece WLS	2.04	+63%
VB + 2 piece offs	2.04	+63%
VB + 3 piece WLS	2.04	+63%

Alpha Spectra resolution, p.e. calibrated

— baseline
— p-DUNE WLS, NO G10 blocks, ZAOT
— p-DUNE WLS, G10 blocks, ZAOT
— WLS with cut, G10 blocks, ZAOT

All taken in the middle of the 3rd dichroic filter

mu = 692.704 **sigma = 31.4929**
mu = 749.976 **sigma = 30.3693**
mu = 962.185 **sigma = 38.2959**
mu = 1272.26 **sigma = 38.0256**

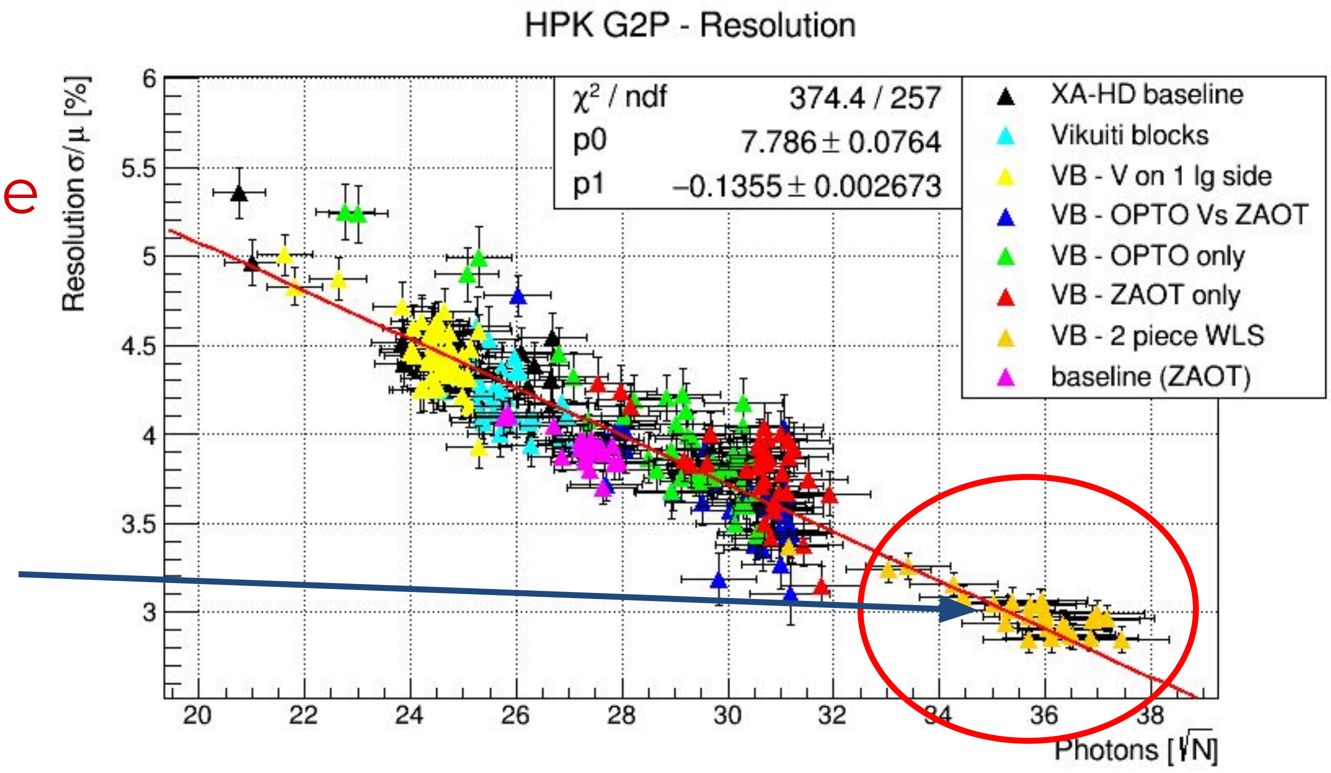


p.e.

Am-241 Alpha Spectra resolution: achieved results

Source is
- 5.4 MeV
- 5.5 cm distance

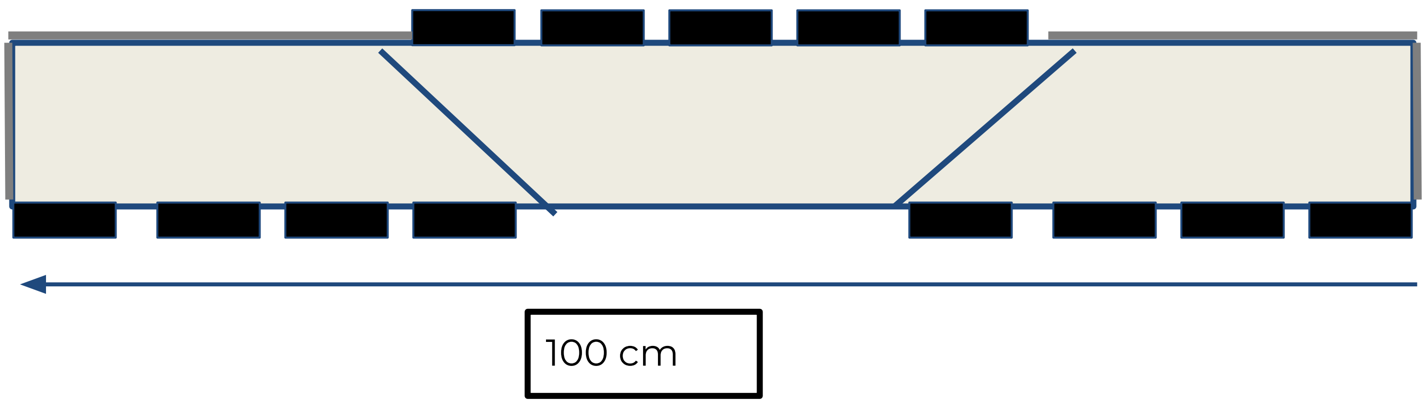
- The 2 pieces WLS lg enhances the PDE → energy resolution

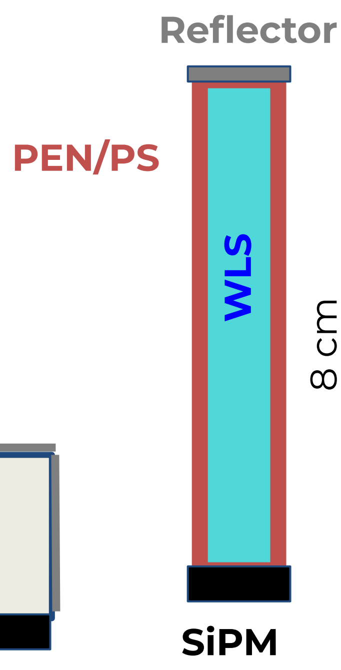


Conclusions: FD3-XA config.

The requirements and design of the WLS are strictly related to the modification of the FD1/FD2 XA design, and to the LAr target

- To fit in the FC rings→ WLS: 8 x 100 cm^2
- Number of WLS bar units: 4300





WLS: Assessment of the radioactivity budget

Results from ICPMS

U-238 ~ 15-20 ppt; Th-232 ~ 5 ppT

Results γ-ray spectrometry on a 800 g sample

Ra-226 <160 μBq/kg (from Bi-214)

K-40 < 1.7 mBq/kg

Cs-137 < 44 mBq/kg

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

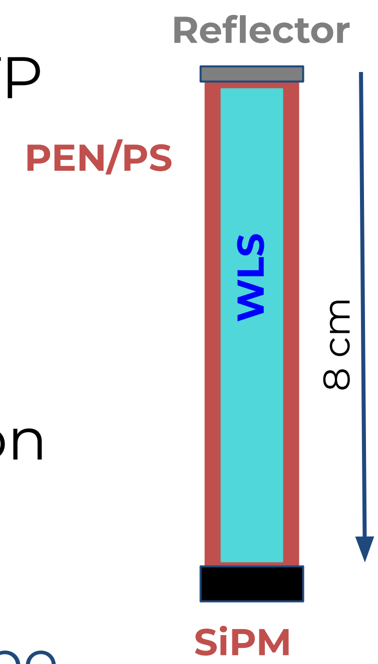
This material can be employed for low background applications

SoLAr, Legend,...

Backup

FD3-XA config. & WLS Specifications

- To define the WLS design the XA simplified config. & the LAr target must be defined:
  - FD3 Target: LAr or LAr/Xe mixture
  - WLS Bulk material : PMMA with PEN/PS/pTP lining?
  - Thermal coupling of PMMA/PS sandwich may be doable. Or PEN lining
  - SiPM readout only on one long edge?
  - WLS chromophore concentration/absorption length (relevant for PDE of large/long bars)
  - WLS thickness

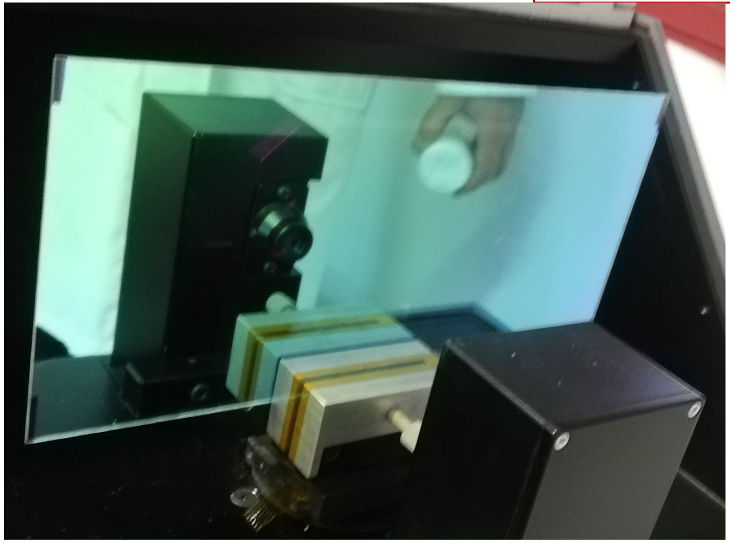


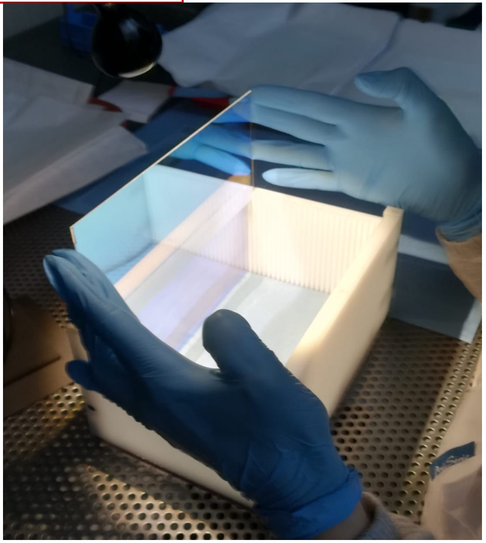
- Low radioactivity (O(10 ppt) U-238/Th-232) will be a plus, to push FD3 Phyiscs reach at low Energy (Solar/SN neutrino, 0nDBD). Mechanics should be low activity compliant→ NO G10-FR4

DF for FD2 M0

- Production, pTP coating and installation of 400 DF
  - Two manufacturers different dichroics design optimized for AOI=45° in LAr
    - ZAOT (Italy): 144 x (202 x 97.5 x 1.1) mm^3
      128 x (148 x 148 x 1.1) mm^3
    - PE (Spain): 128 x (148 x 148 x 1.5) mm^3

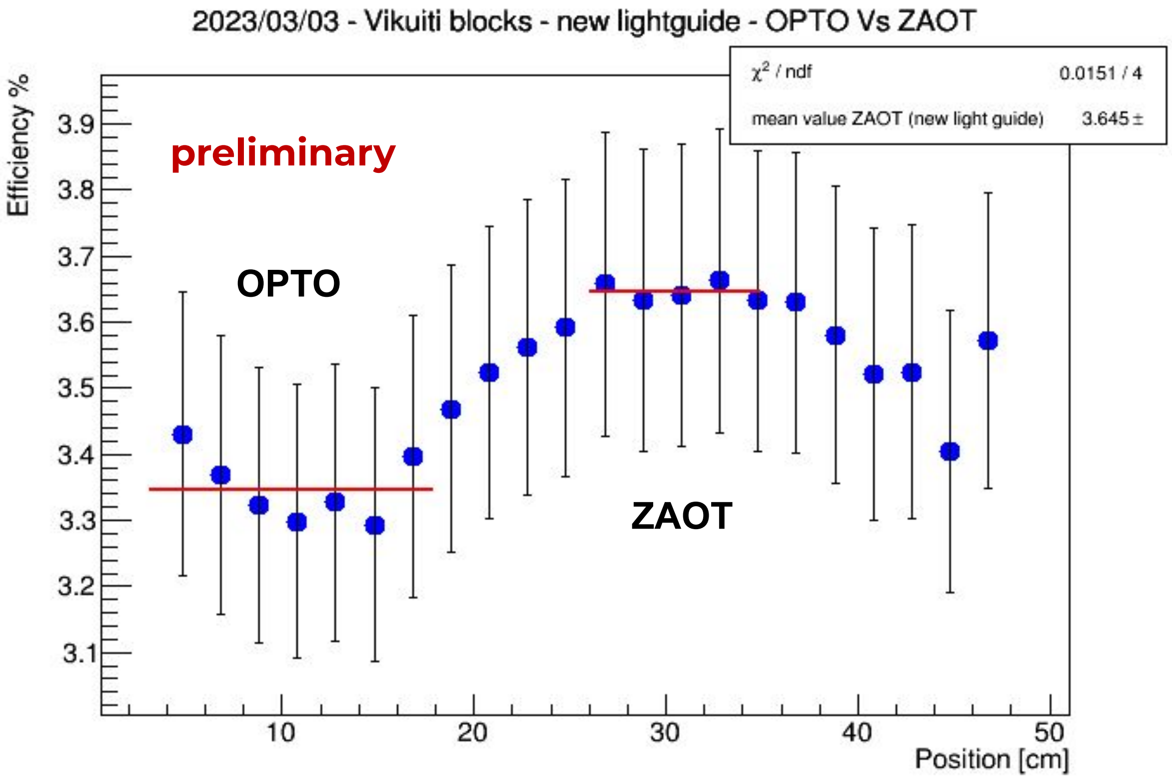
2.3 x FD1 surface

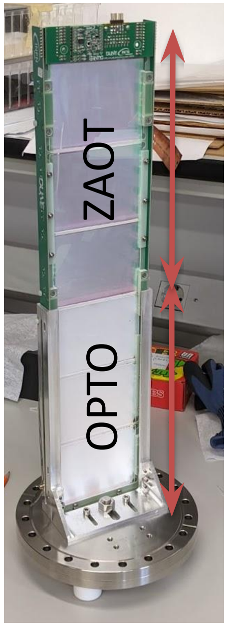




Assessment of ZAOT DFs performances in LAr: previous results

- Measurements of the PDE in LAr of one FD1-XA equipped with
  - three OPTO (0 < position< 24 cm)
  - three ZAOT (24 < position< 48 cm)
- Effect foreseen by GEANT based Simulations





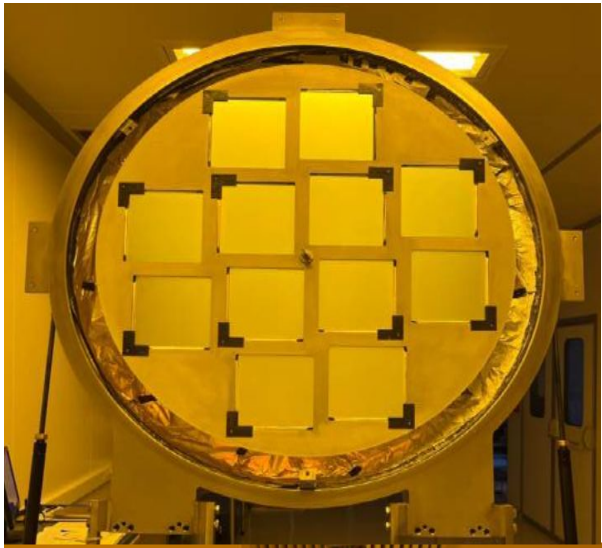
pTP coating

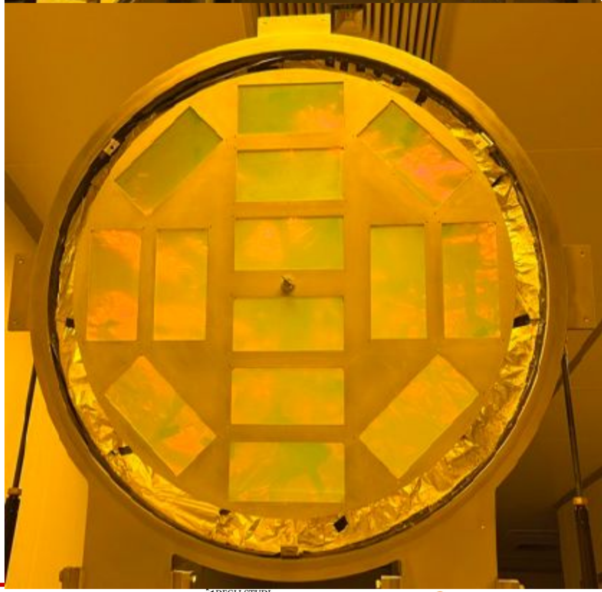
The coating report from UniCAMP

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
- Since January 2023 the UniCamp Facility evaporated
  - 128 PE filters and
  - 54 ZAOT DF for the VD XA PDE setups
- Twin facility will participate at the FD2 pTP coating efforts at INFN Napoli starting from spring 2024





Thank you!