The improved FD1 XA assembly: summary of the results and discussion on the proposed changes

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HD-XA Supercell PDE: simulations & measurements

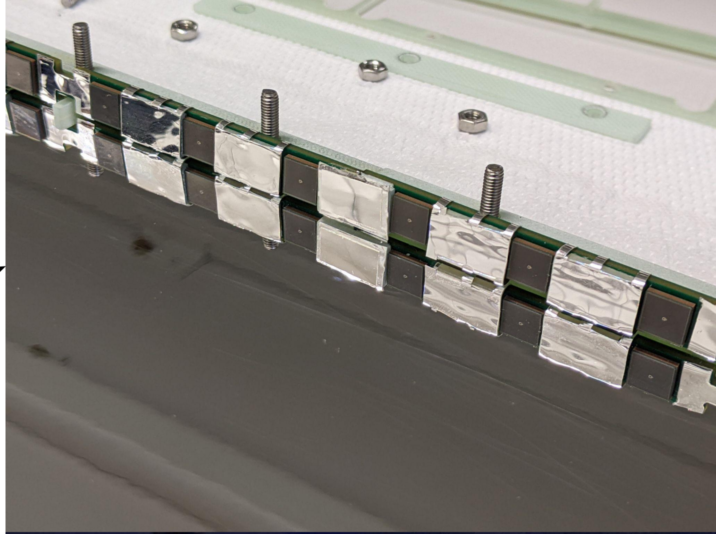
- optical simulation to study ***PDE dependence*** on:
  - light guide edge - SiPM (Vikuiti) **distance**
  - different **light guide configurations**
  - WLS dye concentration (**attenuation length**)

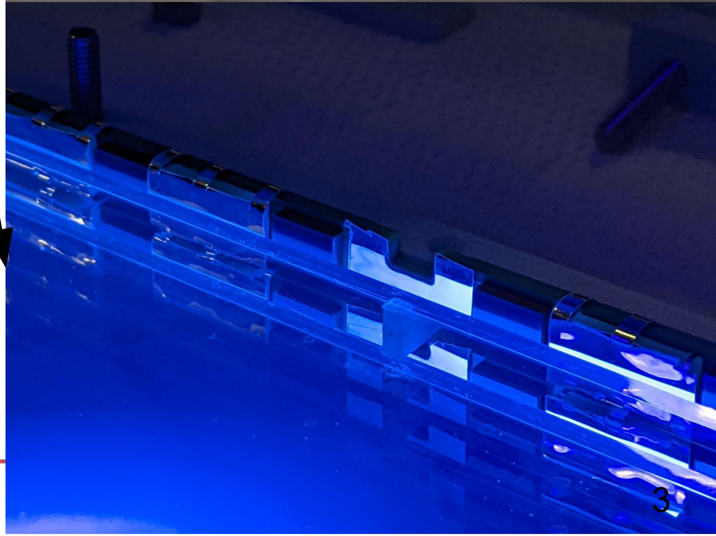
- **measurements** from January to May with **increased light sealing**:
  - tested different configurations varying:
    - **light sealing**
    - **light guide width**
    - **light guide geometry**
  - one last “control” measurement with the baseline configuration

Light sealing

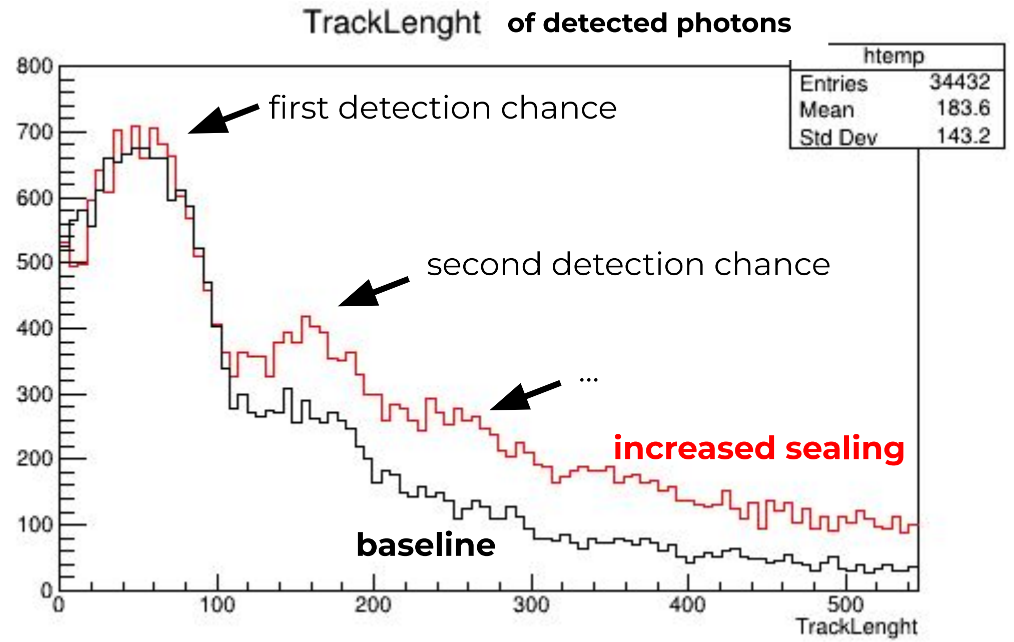
- FD1-XA Supercell with Vikuiti-covered G10 spacer blocks between all the SiPMs; Vikuiti also covers the screw holes
  - placing Vikuiti closer to the light guide provides better light sealing
  - could be the cause of the better PDE of the SBND version

- 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 the effect of extreme sealing
  - increase dependence on the WLS-LG l_{att}

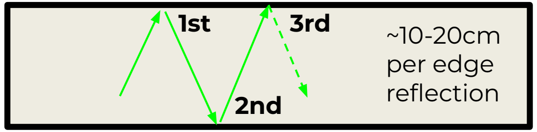




Photon optical path in the module - increased light sealing



- plot of the optical path of **detected photons**
  - “track length” between photon generation (lg WLS process 350->450nm) and detection in a SiPM
- **peaks correspond to photons reaching an edge** instrumented with SiPM and being detected



- **each time a photon hits a long edge has a chance of being detected**

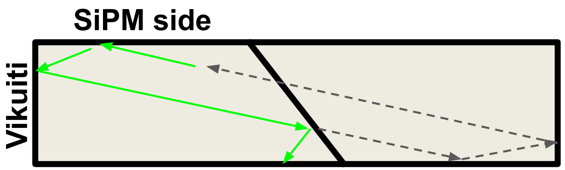
- at the **first chance the two configurations are equal** since the SiPM surface is the same
- from the second chance increasing light sealing provides an improvement since:
  - with **Vikuiti close** to the light guide, the **photons are reflected to the other edge**
  - with **distant Vikuiti** photons **can escape the light guide**

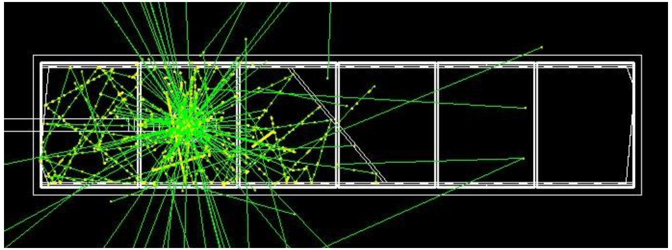
light guide configurations

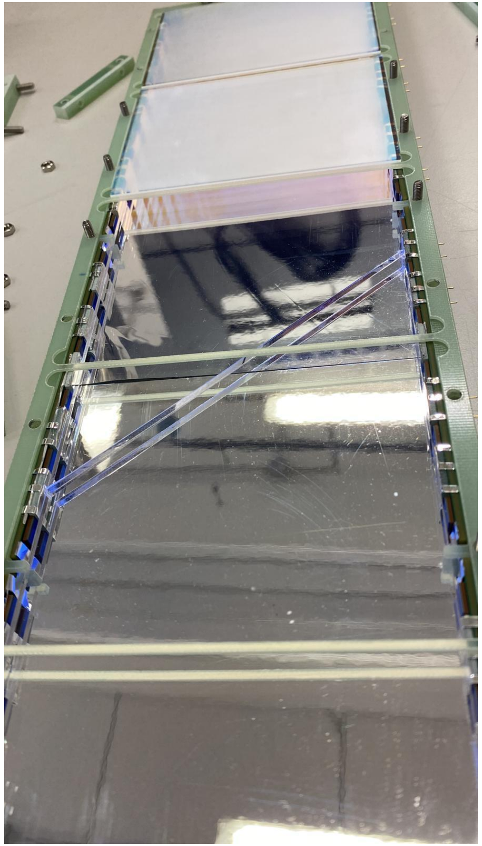
A different LG geometry should improve the PDE

- **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

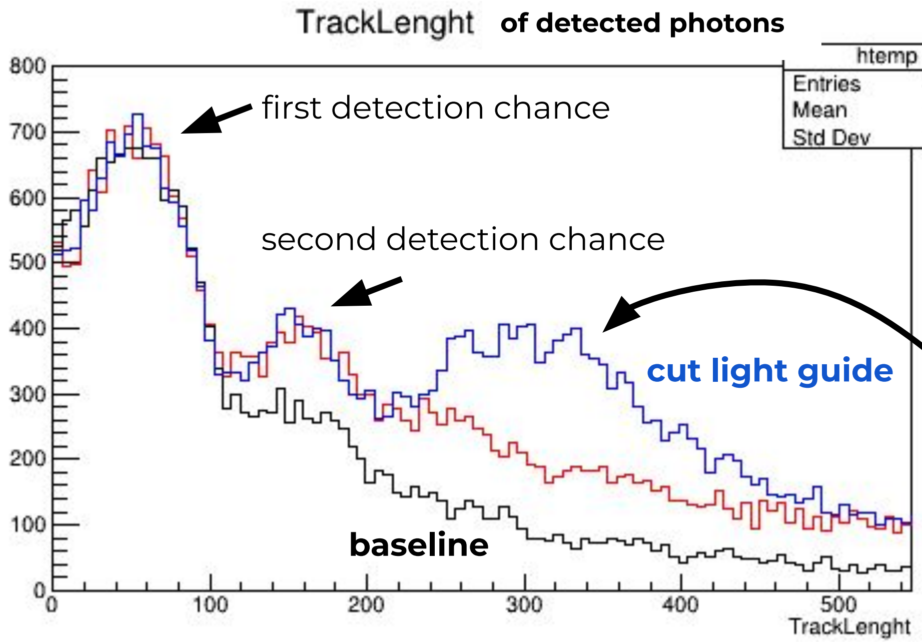
- simulated configurations:
  - **2 piece WLS, one 40° cut at the center**





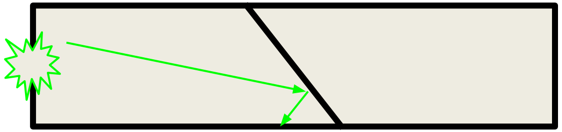


Photon optical path in the module - new geometry



- plot of the optical path of **detected photons**
  - “track length” between photon generation (lg WLS process 350->450nm) and detection in a SiPM
- **the new peak is given by photons emitted towards the short sides reflected at the center**

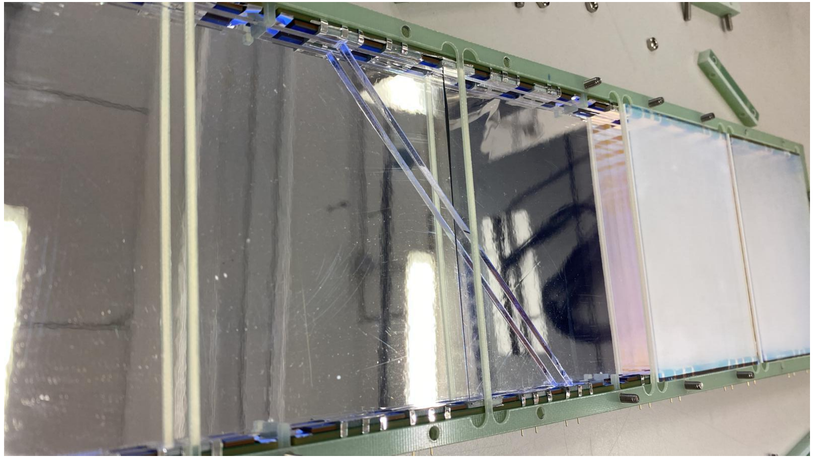
source placed at the edge of the SC in this test



~20cm from the short side + ~5cm from the reflection => peak around 30cm TL

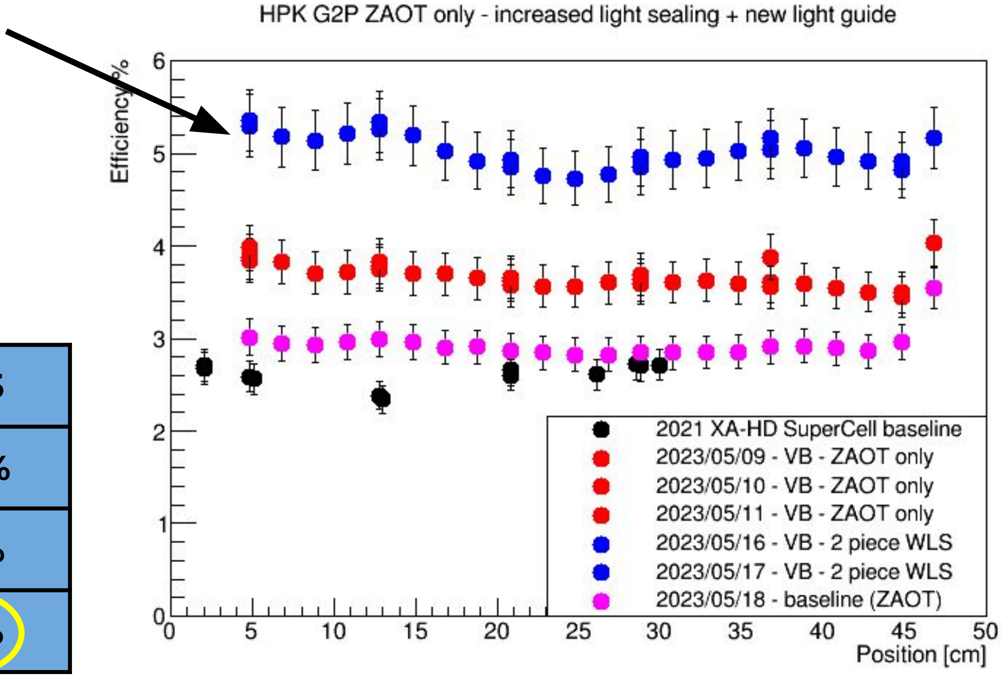
- the **reflective surface placed at 40°** in the middle of the light guide allows to **detect photons emitted towards the module short sides**

16-17/05/23 - 40° cut light guide, ZAOT only, G10 blocks



G2P p-DUNE LG with 40° cut

➢ PDE: + 37%

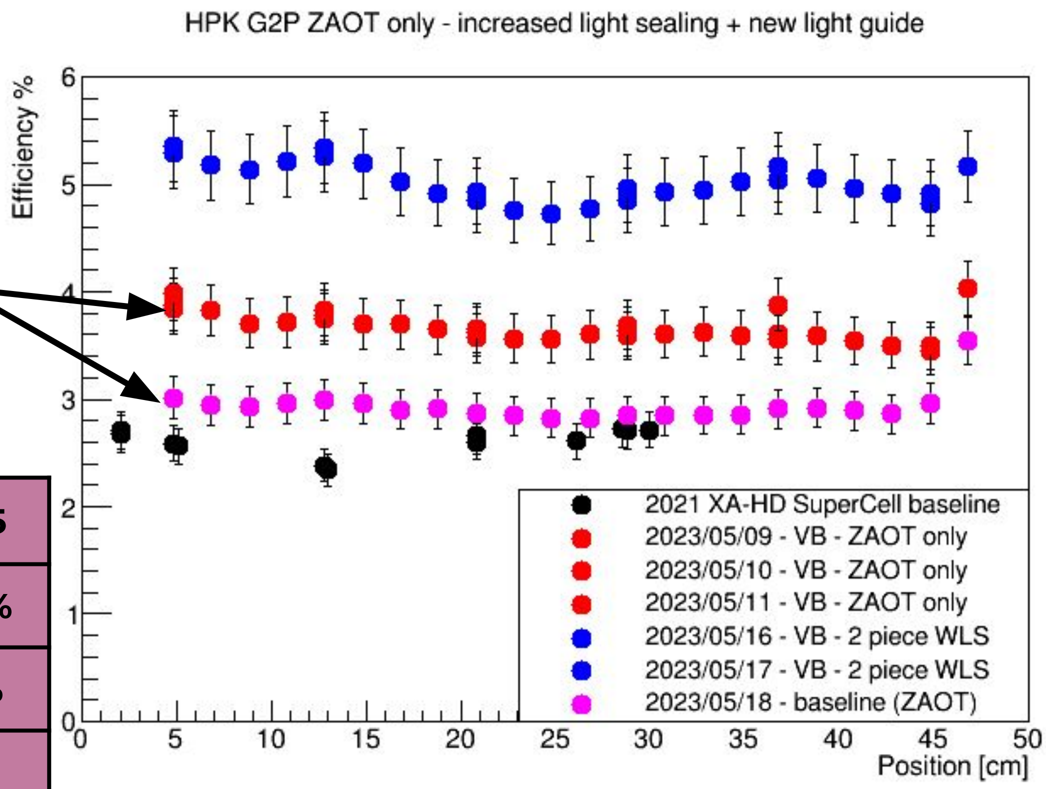


measure	baseline	10/05	16/05
avg PDE	2.51%	3.59%	4.93%
% wrt bl	-	+43%	+96%
% wrt 09/05	-	-	+37%

18-19/05/23 - Control measurement for G10 blocks

p-DUNE WLS-LG no cut: used the same bar as in previous meas.

- **All ZAOT DF**
- **Removed G10 blocks to check their effect**
  - confirmed their relevant effect (PDE: ~ -25%)



measure	bl	10/05	16/05	18/05
avg PDE	2.51%	3.59%	4.93%	2.86%
%wrt bl	-	+43%	+96%	+14%
%wrt ctrl	-	+26%	+72%	-

Conclusions

- We observed a **PDE increase when minimizing**
  - **SiPM-WLS distance**
  - **WLS-Vikuiti distance**: → **insert Viquiti lined blocks between SiPMs**.

  This improves the WLS light-sealing and prevent photons to impinge onto the inactive SiPMs sides (see also Marcio's sim work)

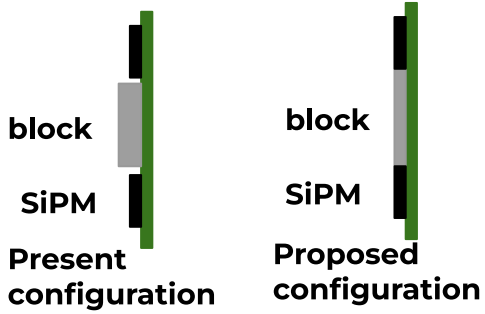
- A **diagonal cut of the WLS-LG also improves the PDE**
  - **breaks the OP** bouncing back and forth from the short edges **reflecting the light onto the SiPMs**
  - **reduces the OP**

- The ZAOT DF perform slightly better than the OPTO when deployed in a FD1-XA, provided the pTP coating has the same performances → dedicated measurements in Pavia with monochromator

- The detailed simulations are an important tool and drove our work

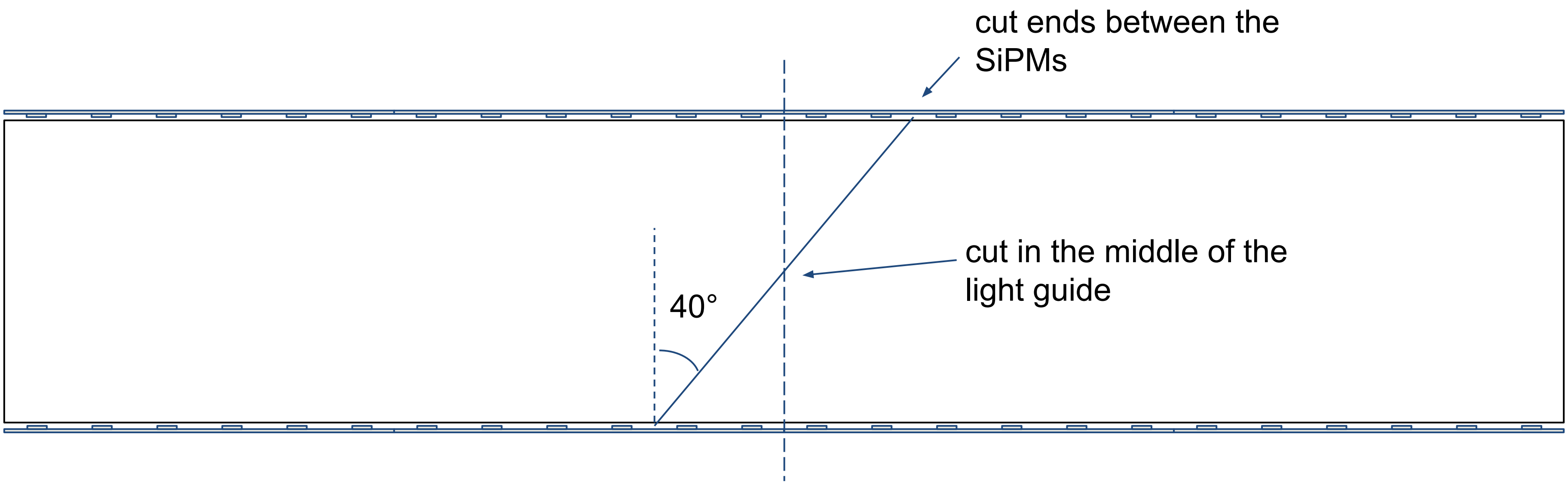
Recommendations for the FD1 XA configuration

- Use the **widest possible WLS** within the SiPM-WLS tolerances.
- **Differentiate the WLS bars width for HPK and FBK** photosensors: Width difference 1.3 mm
- Use thinner (than BL design) spacer blocks
- **Fill the gaps between SiPMs** with G10 blocks
  - lined **with Vikuiti**,
  - **possibly flush with the SiPM surface**
- Adopt **WLS with one cut to break looping optical paths**
- Adjust the chromophore concentration in the WLS (minor)



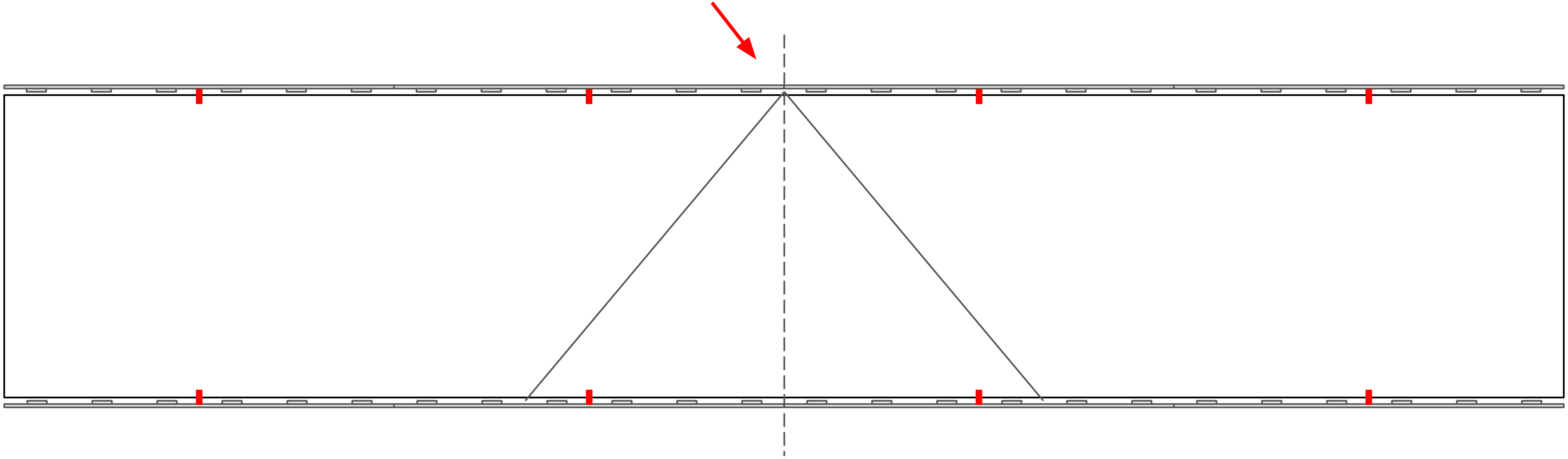
	HPK		FBK	
	ave	tol	ave	tol
Encapsulated SiPM thickn.	1.35	0.2	1.8	0.2
Die attach	-	-	0.3	0.2
SiPM height on top of the PCB	1.34	0.1	2.1	0.3
PCB thickness	1.6	0.15	1.6	0.16
Pin Protrusion	<0.5		<0.15	
SIPM-SIPM side gap	14	-	12.3	0.3
FBK WLS width w.r.t. HPK			-1.3	

light guide sketch



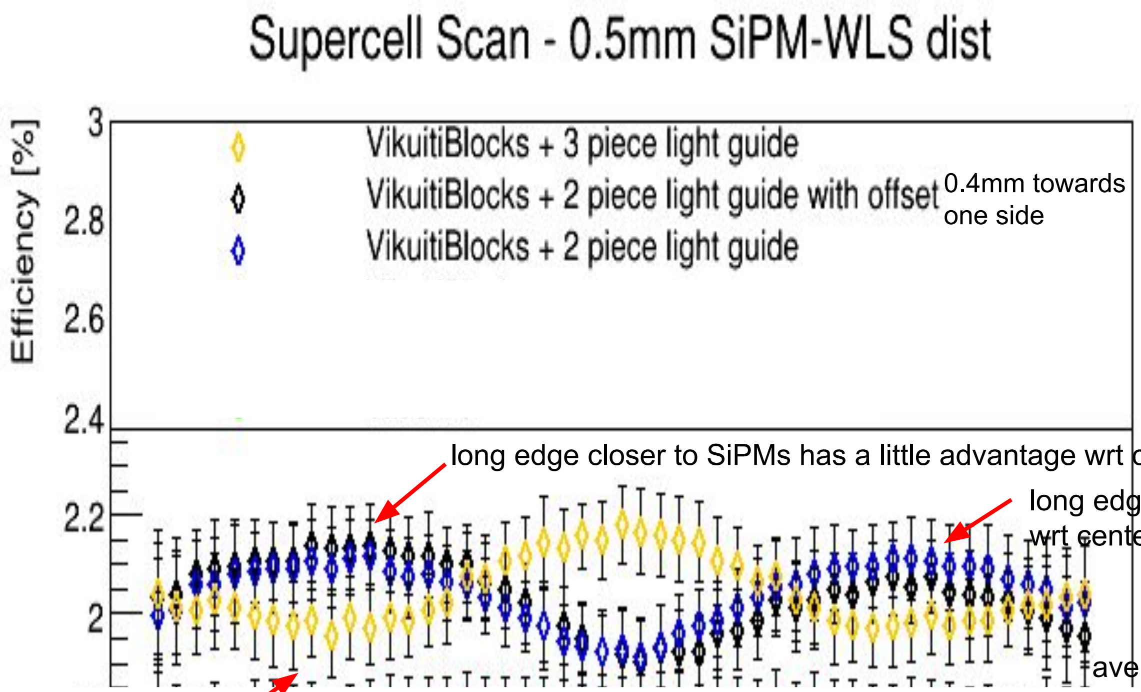
Backup

middle piece has no supports (in red) on one side



if we want at least 3 supports per piece, with 3 pieces we would need 9 supports

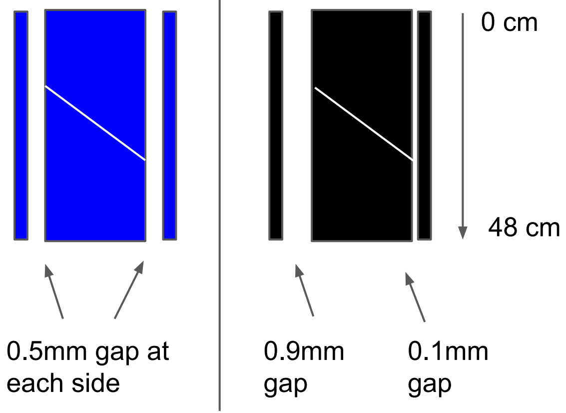
buoyancy



0.4mm towards one side

centered bar - blue curve

buoyancy - black curve



total gap is 1mm for both sim runs

long edge closer to SiPMs has a little advantage wrt centered bar

long edge more distant to SiPMs has a little disadvantage wrt centered bar

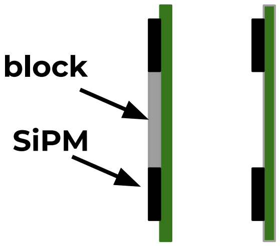
averaging, the two effects cancel, given the 2 piece geometry symmetry

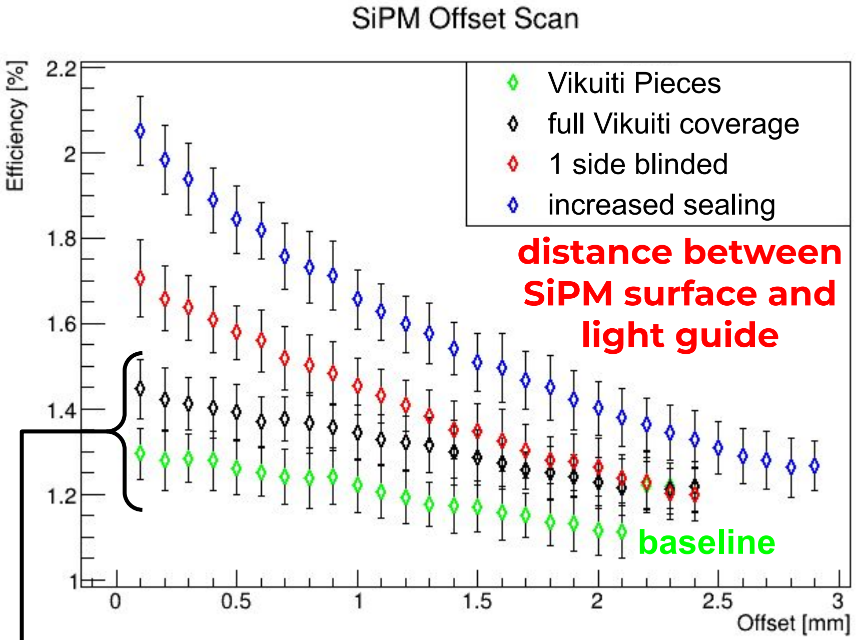
the effect is small, even maximizing the edges close to the SiPM (3 piece geometry) the total gain would be O(1%)

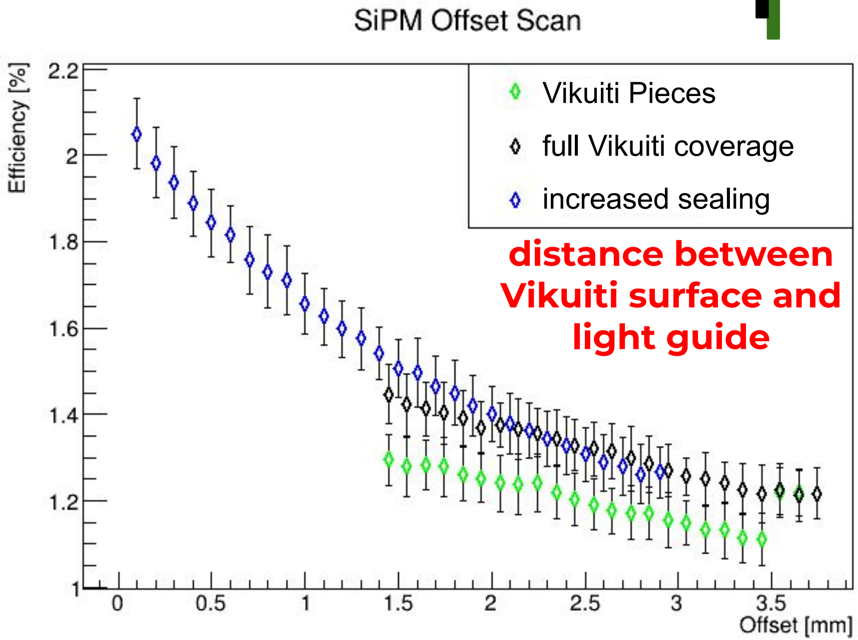
without taking into account the offset (buoyancy) from the center, the 3 piece bar performs the same as the 2 piece one (about +63% wrt baseline according to the sim)

Simulation - distance between SiPMs and light guide

- **PDE is strongly dependent on the SiPM-lg distance**
  - **distance of the Vikuiti reflector** seems to be the main factor
- simulated PDE offsetting the SMB wrt the light guide
  - SiPM and Vikuiti are integral with the PCB







Vikuiti on the board is 1.35mm away from SiPM surface

Legend items of the previous plots

For all the simulations: Vikuiti on the mechanical frame.

- Vikuiti Pieces = Vikuiti on SiPM PCBs as it currently is (holes for screws and inner side of the SiPM pins);
- Full Vikuiti coverage = Vikuiti on SiPM PCBs but without any hole;
- Increased sealing = G10 blocks placed between each SiPM and covered with Vikuiti → Vikuiti closer to the WLS bar without covering the SiPMs;
- 1 side blinded = Increased sealing + Vikuiti on one of the long edges of the WLS bar (SiPMs are hence partially covered).

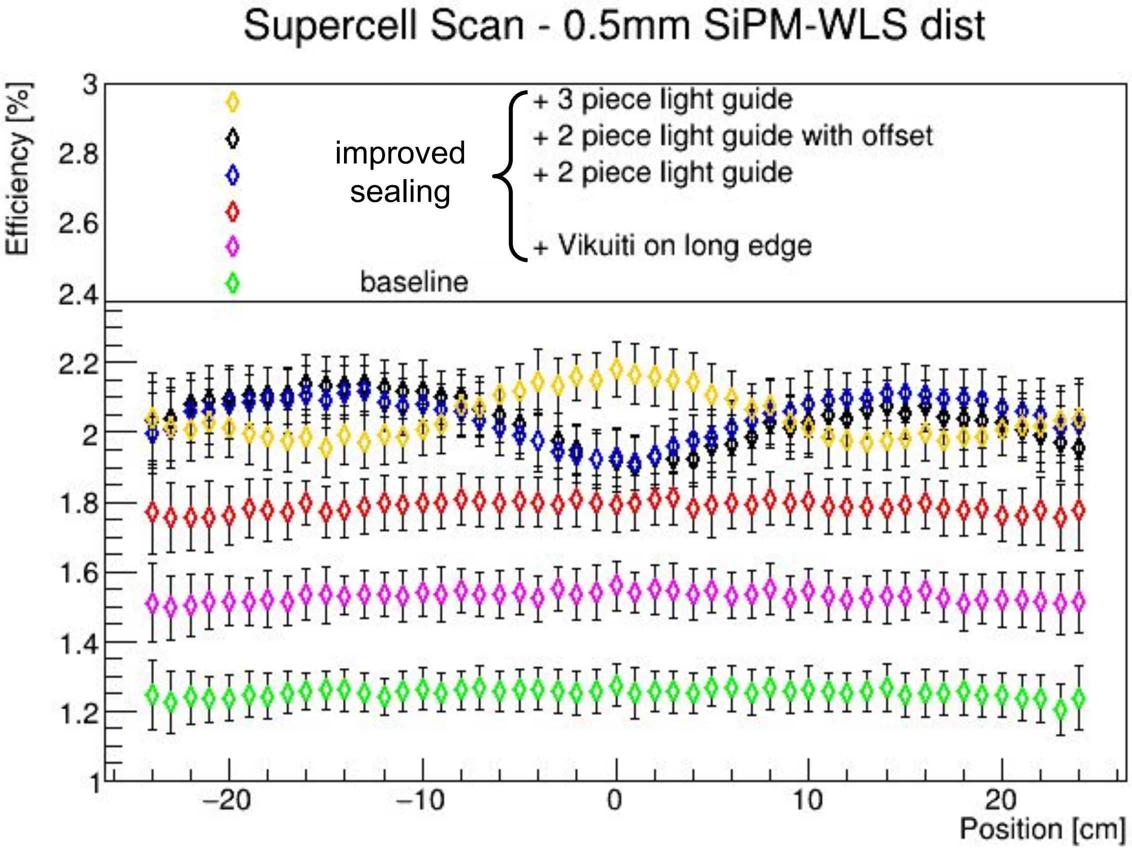
Simulation - light guide configurations

- Cons: the cut causes a (minor) **disuniformity in the light collection** along Z
  - less increase in PDE near the cut

- **simulated different SC configs Z scans with the SiPM distance fixed at 0.5 mm**
  - then averaged all the Z-positions

- **this plot can vary a lot depending on the fixed variables**
  - SiPM distance
  - light guide attenuation length
  - ...

Simulation - light guide configurations

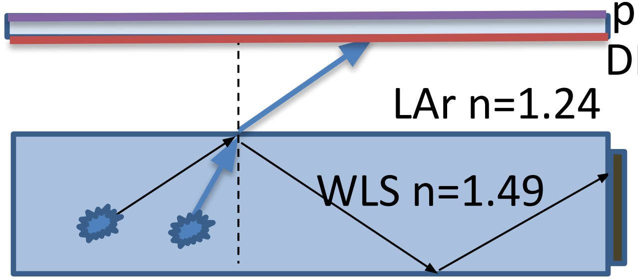


config	average PDE*	% wrt baseline
baseline	1.25	-
VB + VonLE	1.53	+22%
Vikuiti Blocks	1.79	+43%
VB + 2 piece WLS	2.04	+63%
VB + 2 piece offs	2.04	+63%
VB + 3 piece WLS	2.04	+63%

PDE enhancing

The two XA photon collection mechanisms:

- Lightguiding (LG): For θ > θc (=56°) pTP downshifted photons are trapped into the LG and guided to SiPM.
- Dichroic Filters (DF): For θ < θc photons leave the lightguide and may reach the SiPM by multiple bounces onto the DF & reflectors



The work presented in the following

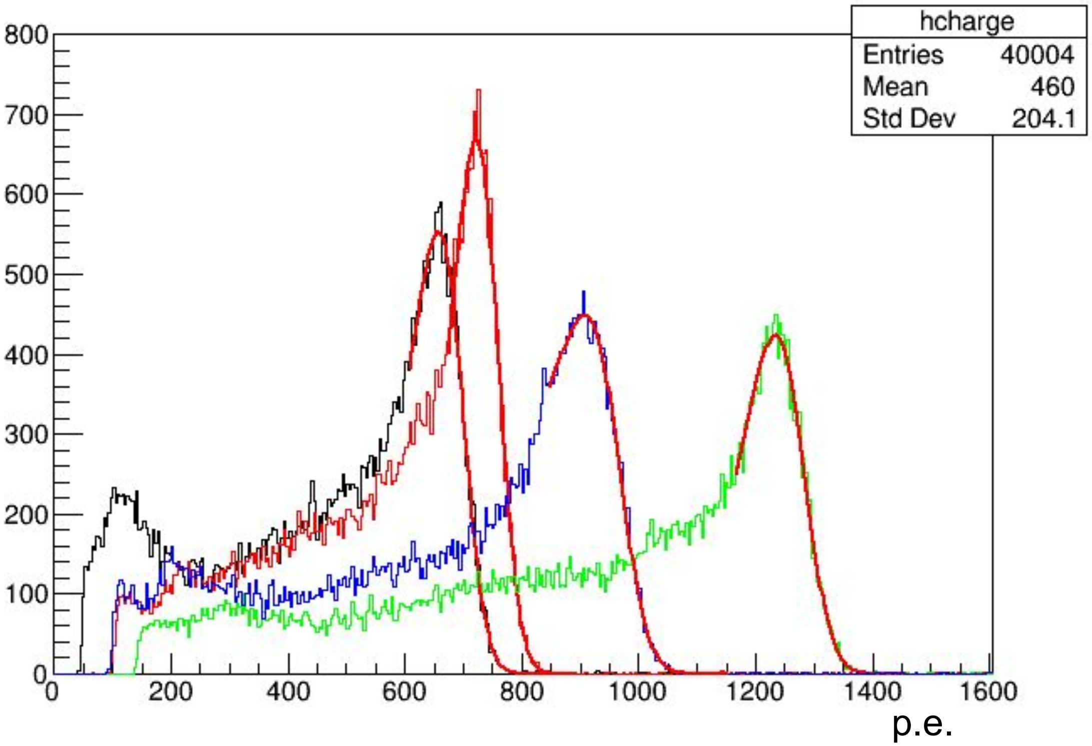
- **enhances the LG mechanism, within the FD1 mechanical & electrical constraints.**
- **assesses the FD2 Module-0 DF performances w.r.t to the FD1-BL**

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

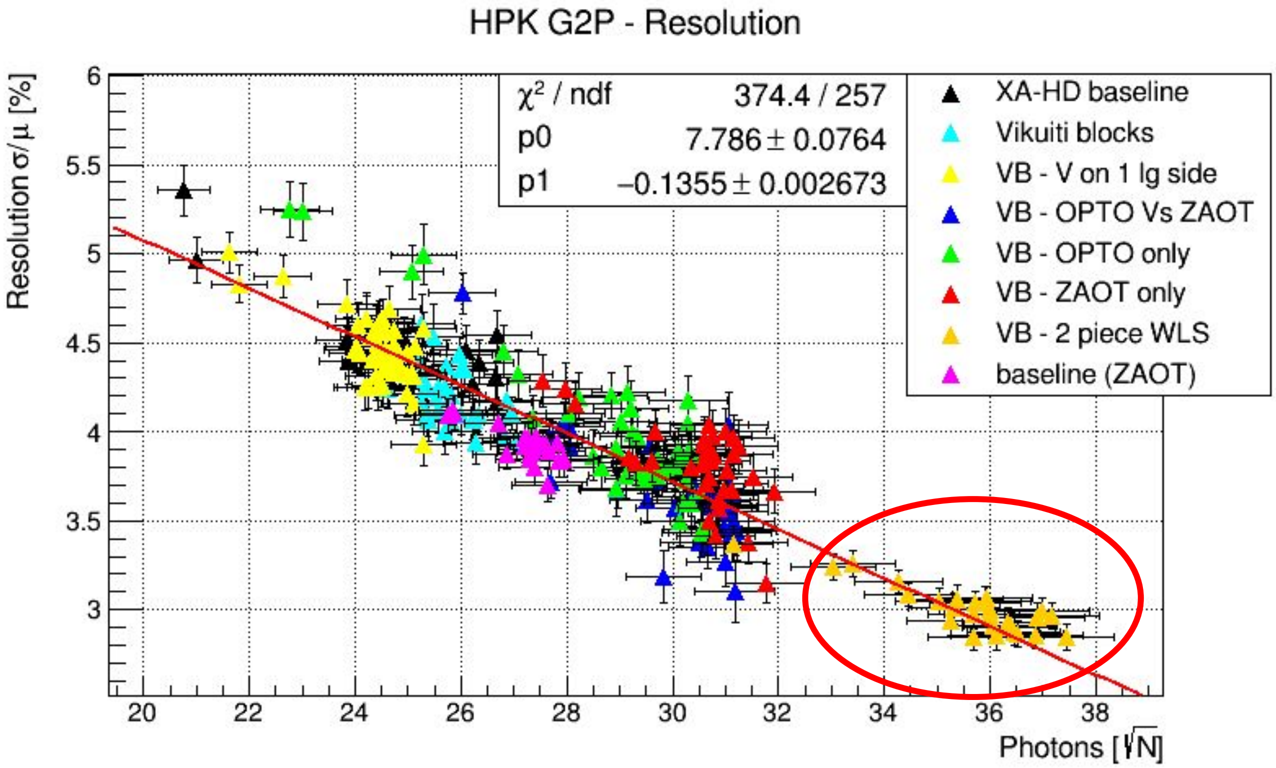
All taken in the middle of the 3rd dichroic filter

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



Alpha Spectra resolution

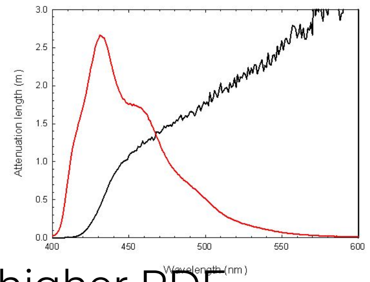
- The 2 pieces WLS lg improves the energy resolution w.r.t. all the other configurations

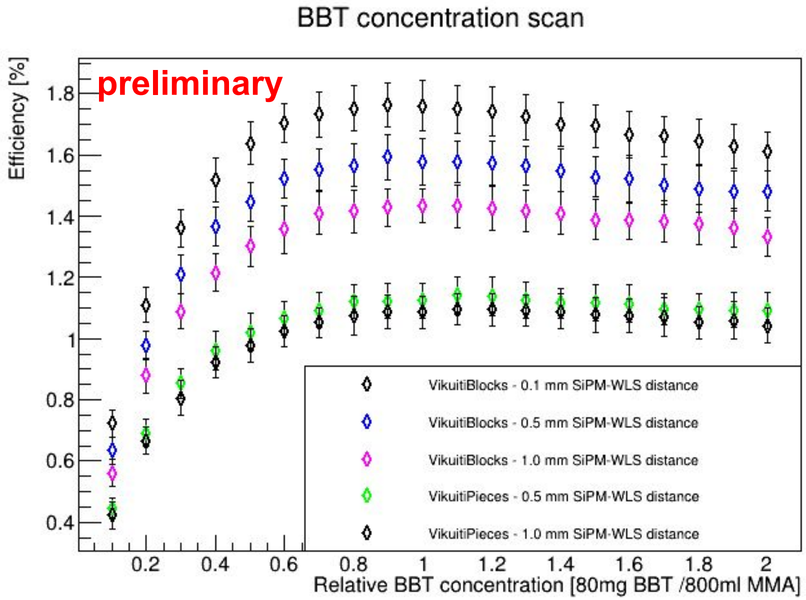


Simulation - WLS dye concentration (Attenuation length)

G2P UniMiB provided the **attenuation curve** of the **WLS**

- l_{att} depends on the chromophore concentration (Lambert-Beer law)
- **through simulation, different attenuation curves can be tested to obtain the optimal concentration for a given geometry**



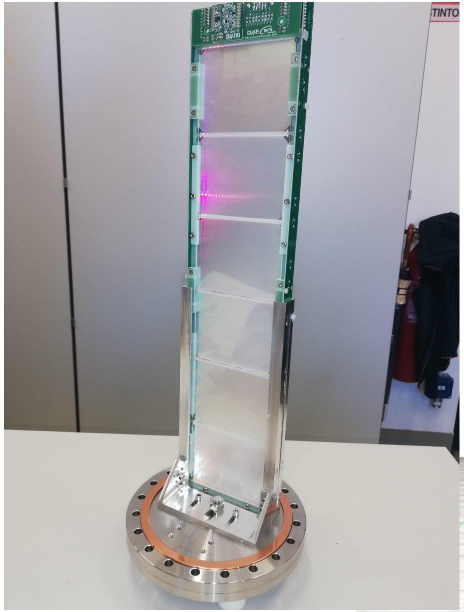


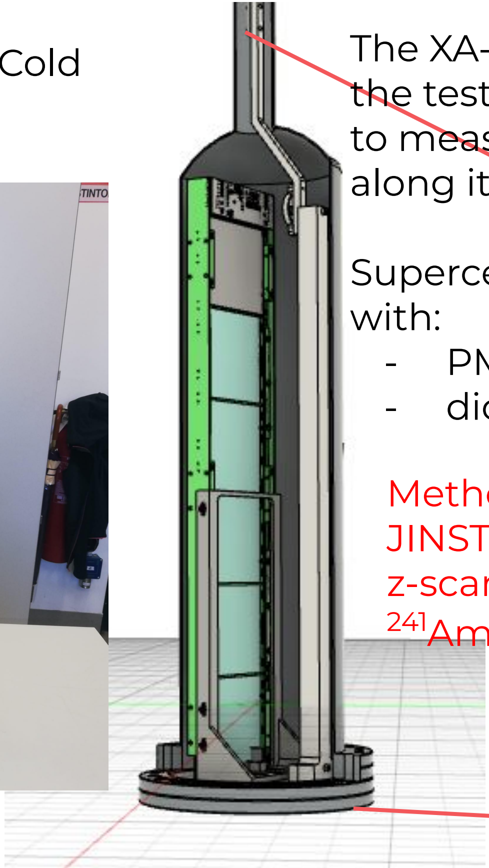
- higher light sealing leads to higher PDE
- light sealing increases the optical path
  - light can bounce back and forth
- a lower dye concentration corresponds to longer l_{att}
- the actual WLS is properly designed to optimize the FD1 PDE (maybe possible a 20% decrease of the chromophore)

→ **an optimum is found at lower dye concentration when the optical path is higher**

Setup to measure the XA-HD-SC PDE in LAr

The XA-HD-SC w. Cold FE circuit (top)





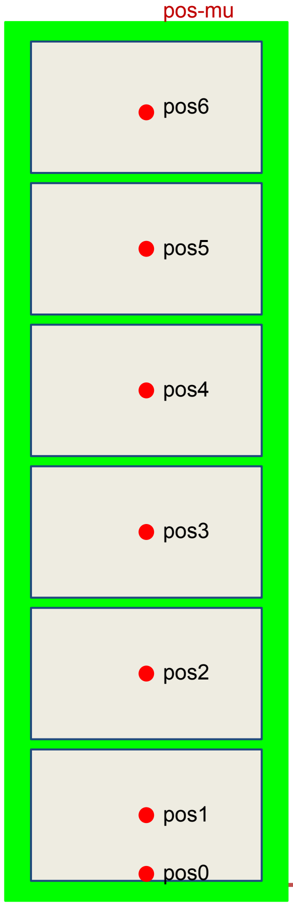
The XA-SC installed in the test chamber (~10 l) to measure the PDE along its z-axis.

Supercell equipped with:

- PMMA WLS (G2P)
- dichroic filters

Method as published in JINST 16 (2021) 09027: z-scanning with an ^{241}Am exposed α source

Method & Data taking



z-scanning of the SC with the ^{241}Am α (5.480 MeV) source at the following positions:

1. **pos0**: (the lowest possible): ~2 cm above the flange.
2. **pos1, 2, 3, 4, 5, 6**: the center of each dichroic filter.
   Acquired: 10^4 x 4 wfms; 20 μs length; ~5 μs pretrigger.

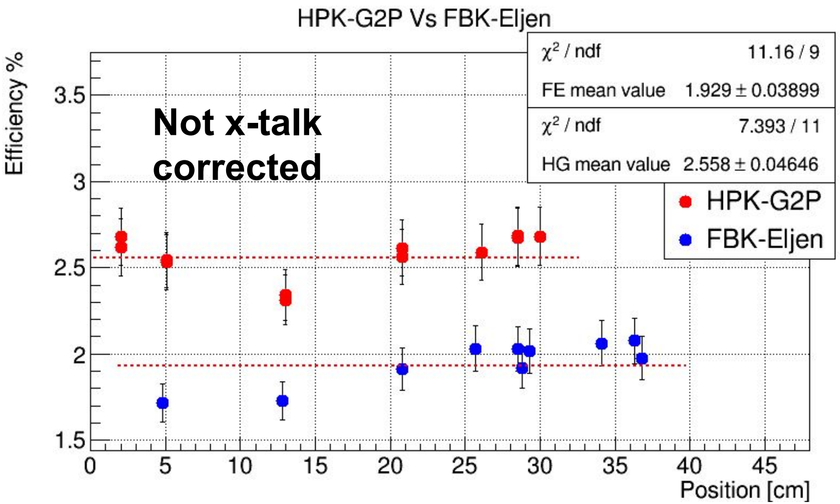
3. Source at the topmost position (~49 cm from the flange) and ~ out of LAr:
   - one **μ run** (10^4 x 4 events; 20 μs, 5 μs pretrigger)
   - one **s.ph.e. run** (10^4 x 8 events; 20 μs length; 1.6 μs pretrigger)

Source-to-dichroic filter distance: (55 +/- 1) mm.

Noise Run: V_{bias} = V_{bd}-1V for FFT and filter shape&cutoff definition

Results for the FD1 XA baseline configuration

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



	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)
SBND (HPK & G2P)	50%	**2.9** (0.1)	

SBND: the SiPM distribution allowed the max. optical seal with Viquiti the LG (>50% of perimeter) *C. Brizzolari et al 2021 JINST 16 P09027*

→ efforts to improve the PDE for the FD1-XA (preserving the current mechanics)

MC computed geometric acceptance

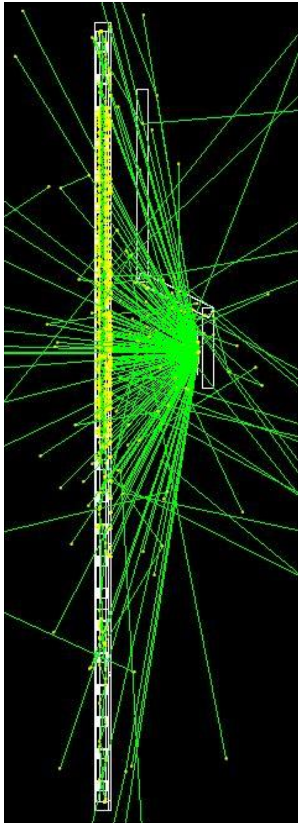
The knowledge of the solid angle is crucial for the PDE determination.

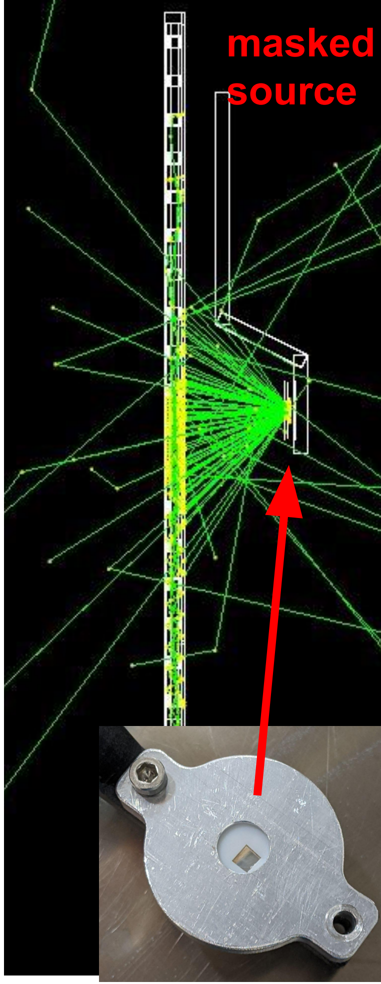
Solid angle computed via a geant4 simulation

- geometry takes into account also the source holder, the source arm and the teflon mask (in the first analytical simulation only the source holder arm was modeled)

- solid angle obtained from the ratio of photons hitting the pTP deposit over the scintillation photons
  - $\Omega = (\gamma_{pTP}/\gamma_{scint})*4\pi$

unmasked source





ZAOT vs OPTO: T measurements @ MiB