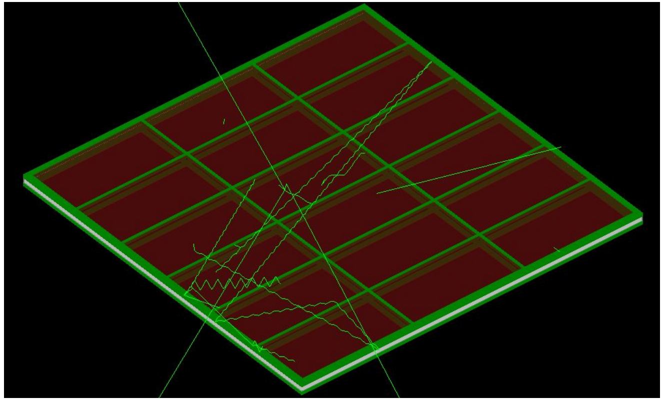
Megacell frame optimization via G4-based optical simulation

11 Oct. 2022

Julio Ureña, Justo Martín-Albo, Anselmo Cervera

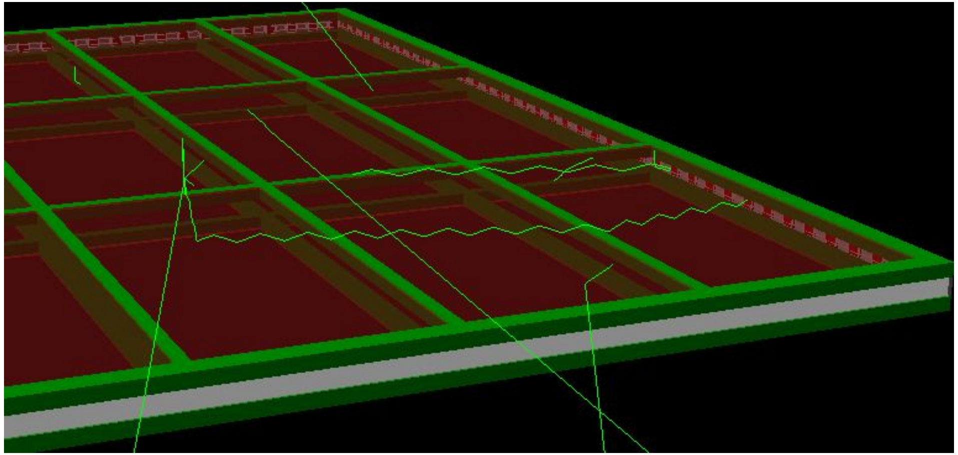
IFIC - Valencia



X-ARAPUCA simulation

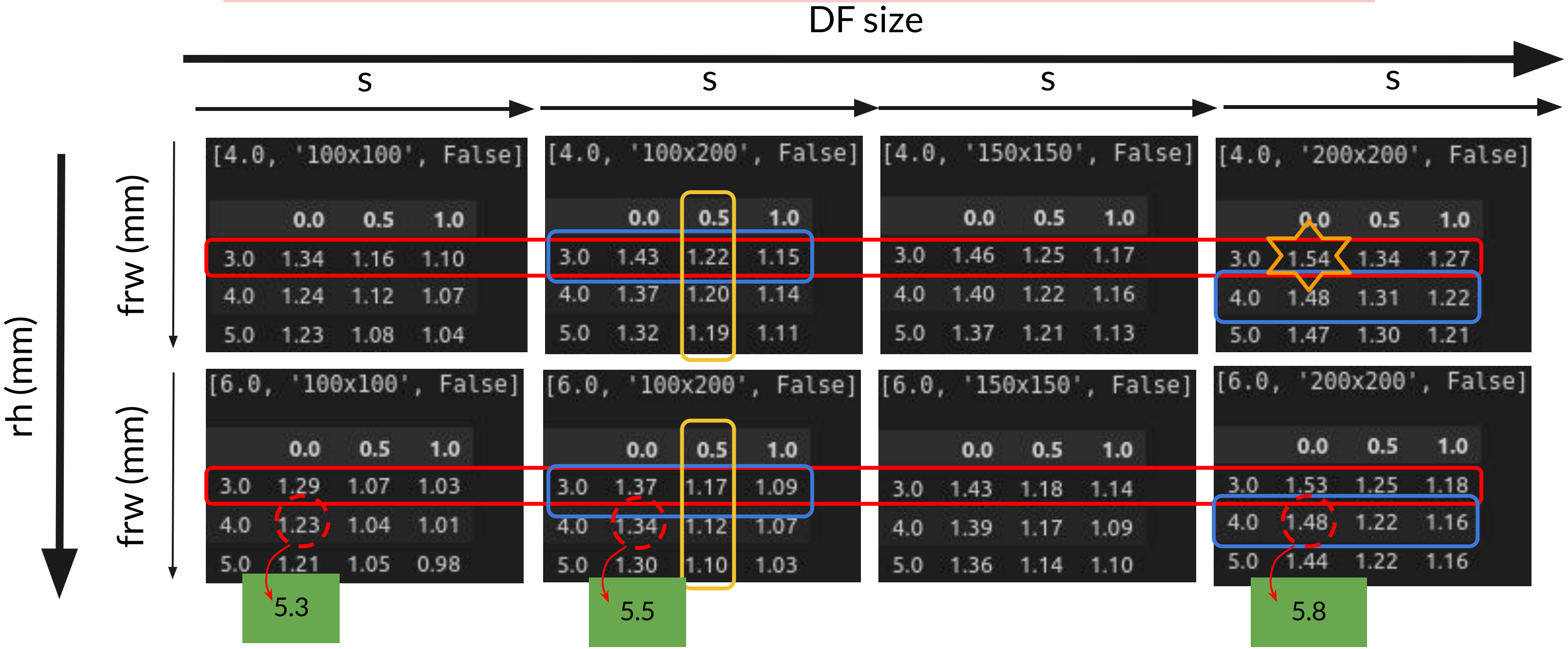
We have developed our own G4-based simulation to **optimize the photon collection efficiency (PCE)**. Among its features, such simulation takes into account:

- the emission spectrum of PTP coatings (wavelength and angle-wise),
- the transmission curve of the simulated DF (wavelength and angle-wise),
- the optical properties of the WLS plate, such as WLS-absorption and the emission spectra,
- the optical properties of other materials which the photons might interact with, such as FR4 or reflective coatings,
- attenuation length and wl-dependent refractive index of every media and
- detection efficiency of SiPMs.



Results from our 27/09 talk - *See indico.fnal.gov/event/56330/contributions/251478/attachments/160212/210973/27_09_2022_with_backup.pdf*

PCE with <u>non-reflective frame</u>



`[4.0, '100x100', False]`

	0.0	0.5	1.0
3.0	1.34	1.16	1.10
4.0	1.24	1.12	1.07
5.0	1.23	1.08	1.04

`[4.0, '100x200', False]`

	0.0	0.5	1.0
3.0	1.43	1.22	1.15
4.0	1.37	1.20	1.14
5.0	1.32	1.19	1.11

`[4.0, '150x150', False]`

	0.0	0.5	1.0
3.0	1.46	1.25	1.17
4.0	1.40	1.22	1.16
5.0	1.37	1.21	1.13

`[4.0, '200x200', False]`

	0.0	0.5	1.0
3.0	1.54	1.34	1.27
4.0	1.48	1.31	1.22
5.0	1.47	1.30	1.21

`[6.0, '100x100', False]`

	0.0	0.5	1.0
3.0	1.29	1.07	1.03
4.0	1.23	1.04	1.01
5.0	1.21	1.05	0.98

`[6.0, '100x200', False]`

	0.0	0.5	1.0
3.0	1.37	1.17	1.09
4.0	1.34	1.12	1.07
5.0	1.30	1.10	1.03

`[6.0, '150x150', False]`

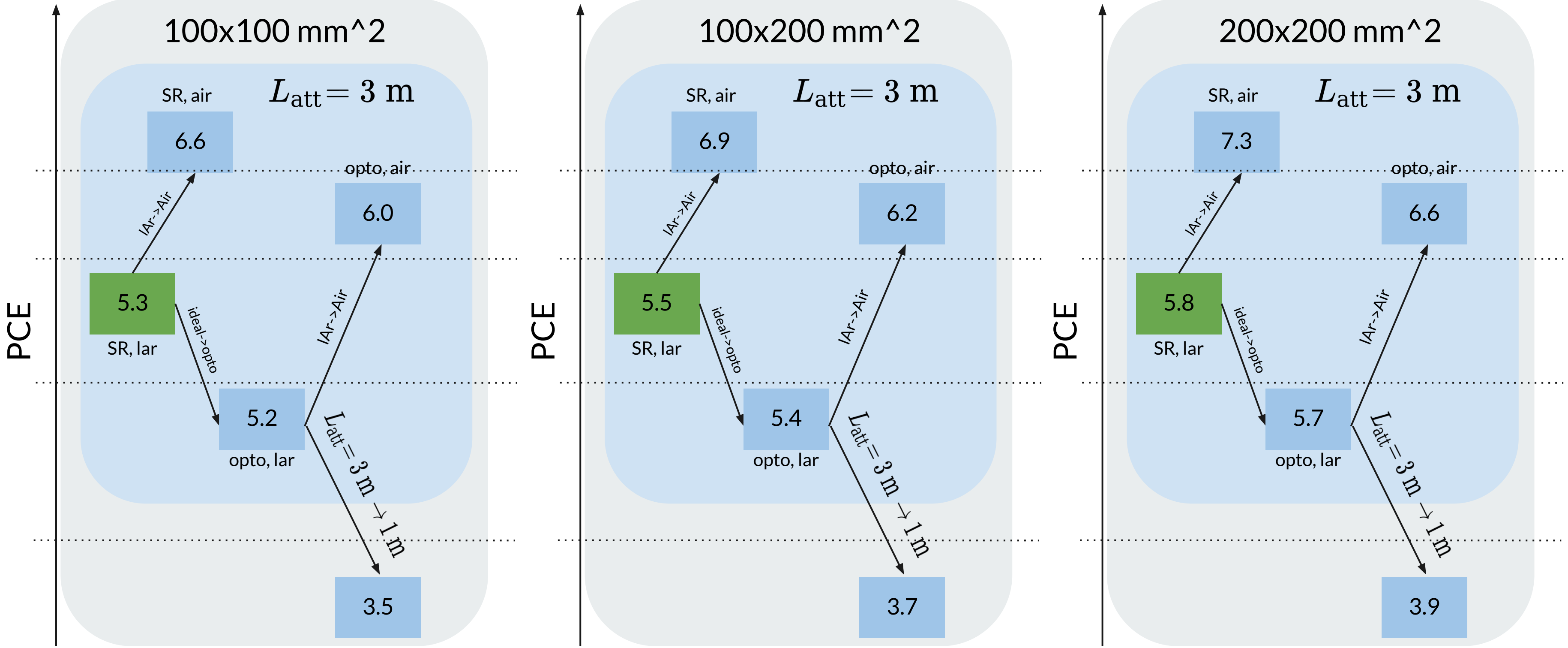
	0.0	0.5	1.0
3.0	1.43	1.18	1.14
4.0	1.39	1.17	1.09
5.0	1.36	1.14	1.10

`[6.0, '200x200', False]`

	0.0	0.5	1.0
3.0	1.53	1.25	1.18
4.0	1.48	1.22	1.16
5.0	1.44	1.22	1.16

There's a PCE improvement when tuning the G2P WLS absorption length according to *C. Brizzolari et al 2021 JINST 16 P09027*. There's still a need for attenuation length tuning and considering realistic DFs. These considerations should reduce this PCE to a realistic one. See next slide.

Transition towards more realistic conditions

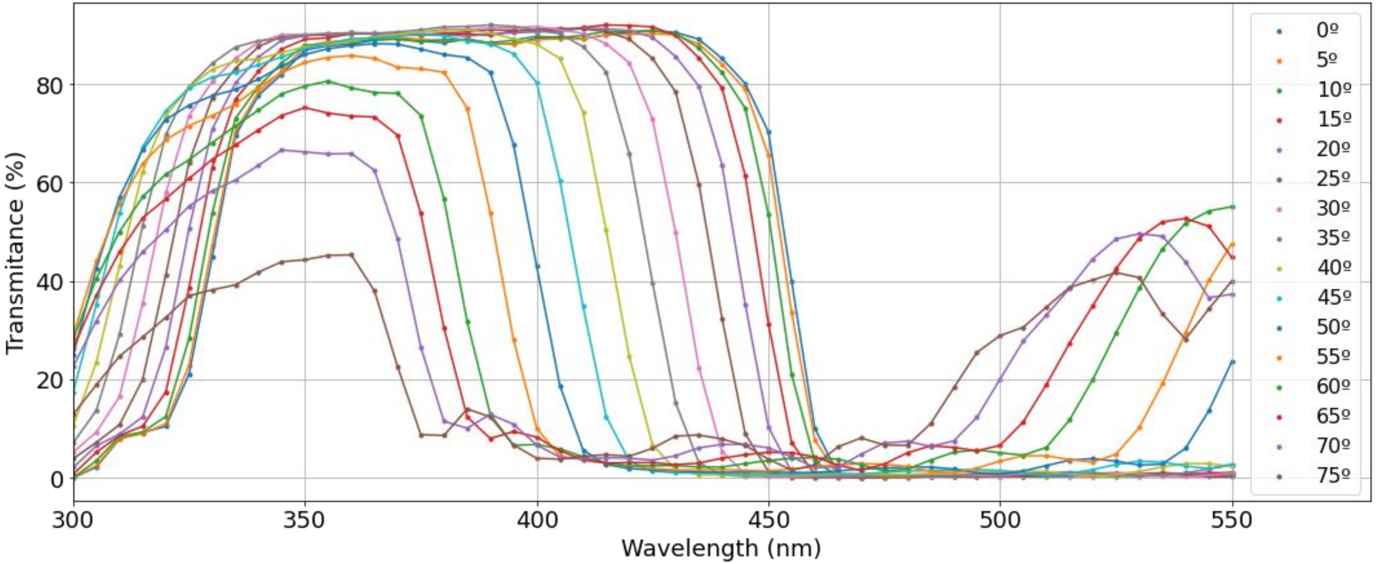


SR stands for Standard Requirements for a DF - In this case, we have considered $T_{bc} = 0.9, T_{ac} = 0.01, \lambda_c = 400$ nm and $\Delta\lambda_c = 10$ nm
See our 07/07 talk - *indico.fnal.gov/event/55302/contributions/245698/attachments/160453/211409/07_07_2022.pdf*

Simulation fixed parameters

- G2P WLS bar with 1m attenuation length *- See C. Brizzolari et al 2021 JINST 16 P09027*
- OPTO DF with transmitance curves measured at different angles in air, but shifted for LAr
- 6 mm rib height, 4 mm rib width and shallowness s=0
- Light is generated over the whole Dichroic Filters Assembly (DFA) (frame+DF)
- Flat dimples with dimensions as given in Carla's 07/07 talk - *See indico.fnal.gov/event/55302/contributions/245694/attachments/156811/204810/Preparation of VD-CBs WLS prototypes_220706.pdf*

OPTO DF measured @ IFIC



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Simulation fixed parameters

- G2P WLS bar with 1m attenuation length *- See C. Brizzolari et al 2021 JINST 16 P09027*
- OPTO DF with transmitance curves measured at different angles in air, but shifted for LAr
- 6 mm rib height, 4 mm rib width and shallowness s=0
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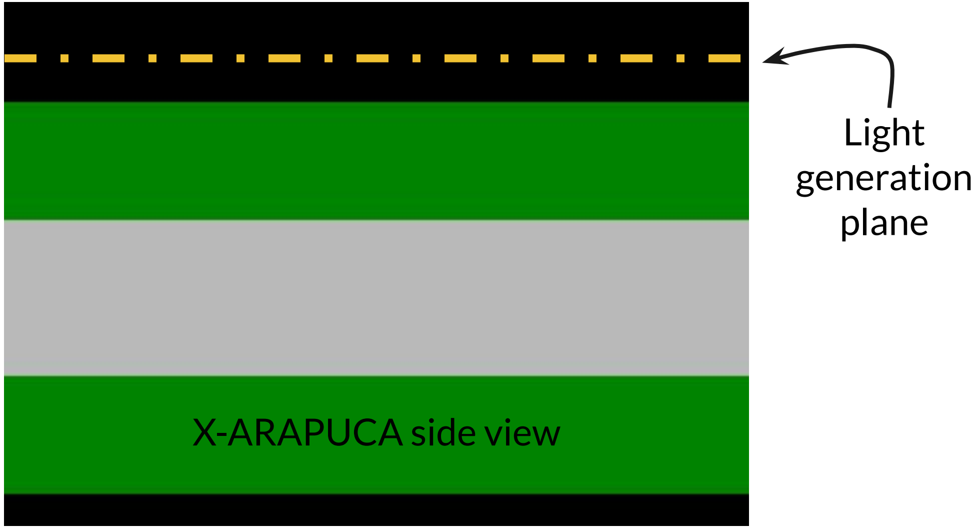


Frame reflectance

According to the results we presented in our 27/09 talk,

- *See indico.fnal.gov/event/56330/contributions/251478/attachments/160212/210973/27_09_2022_with_backup.pdf* -

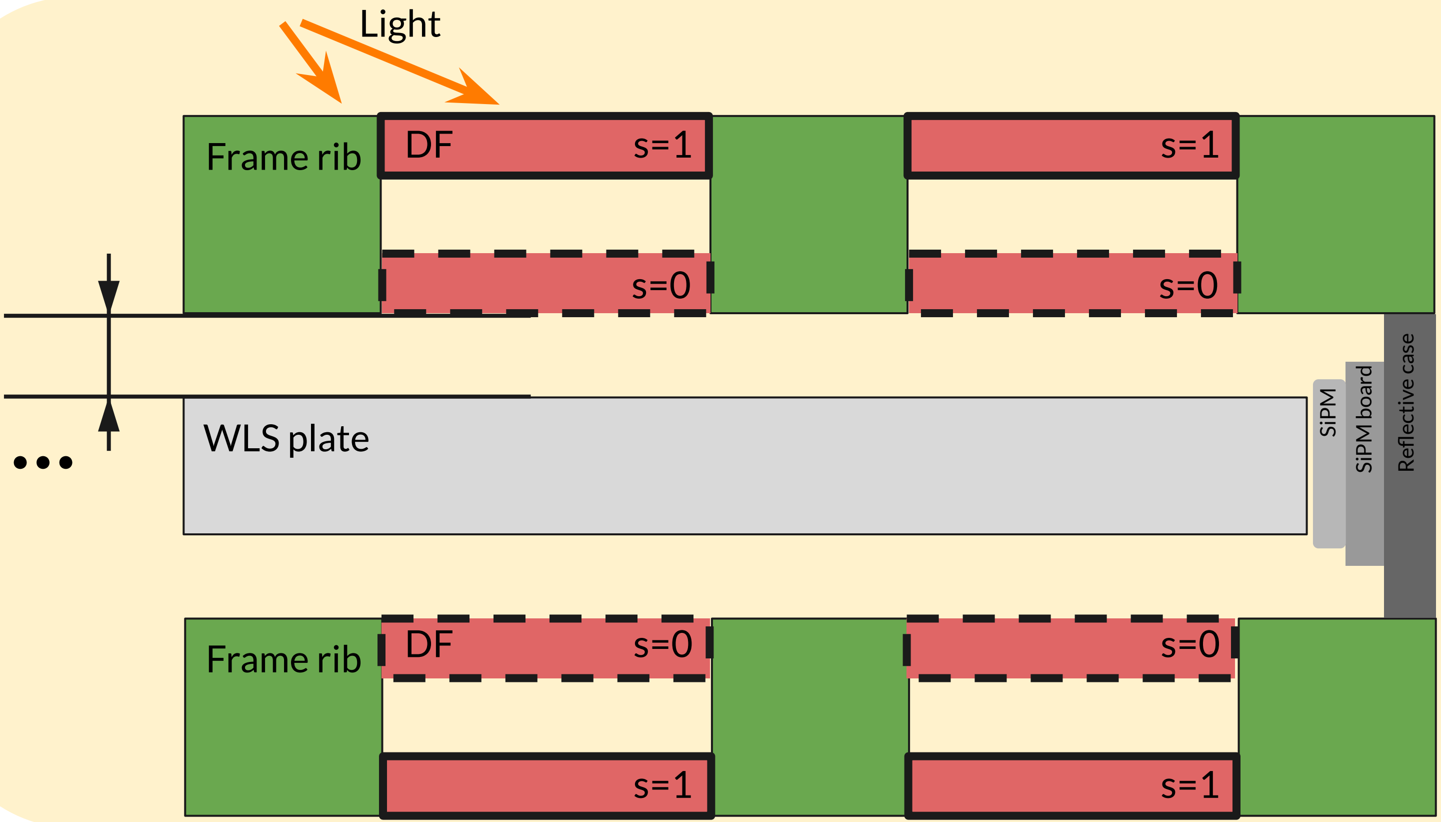
considering an specular-reflective frame caused a 1.3% absolute rise of the PCE. After implementing more realistic conditions, we have studied again the effects of considering a reflective frame, also considering the case of a diffusive-reflective coating.

reflectance type\DF size(mm^2)	100x100	100x200	200x200
Absorbent	3.5	3.7	3.9
Diffuse-reflective	4.2	4.4	4.6
Specular-reflective	4.3	4.5	4.7

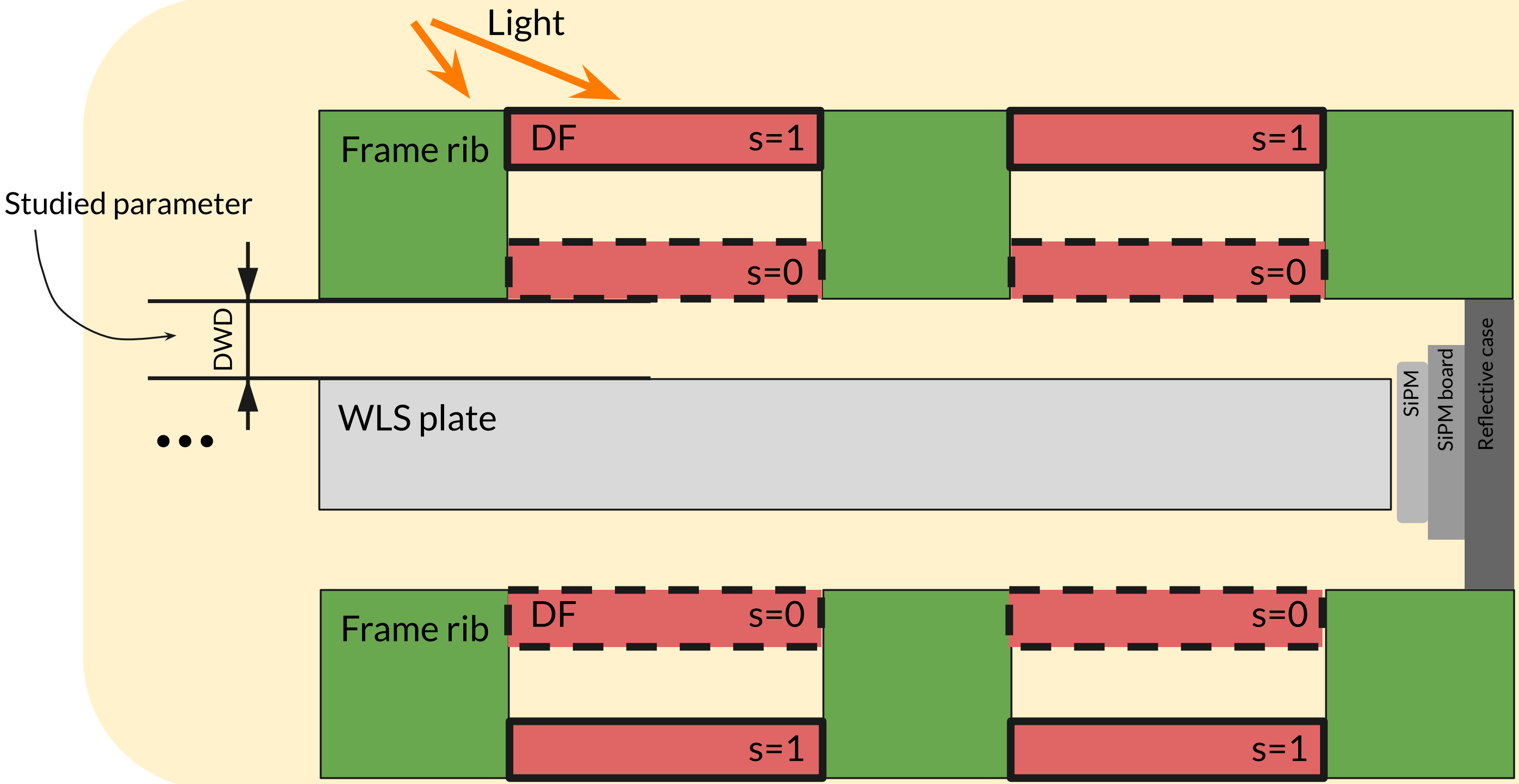
20% PCE improvement (on average) when considering a reflective frame (diffusive or specular) with respect to an absorbent frame

PCE vs. the DFA-WLSP distance

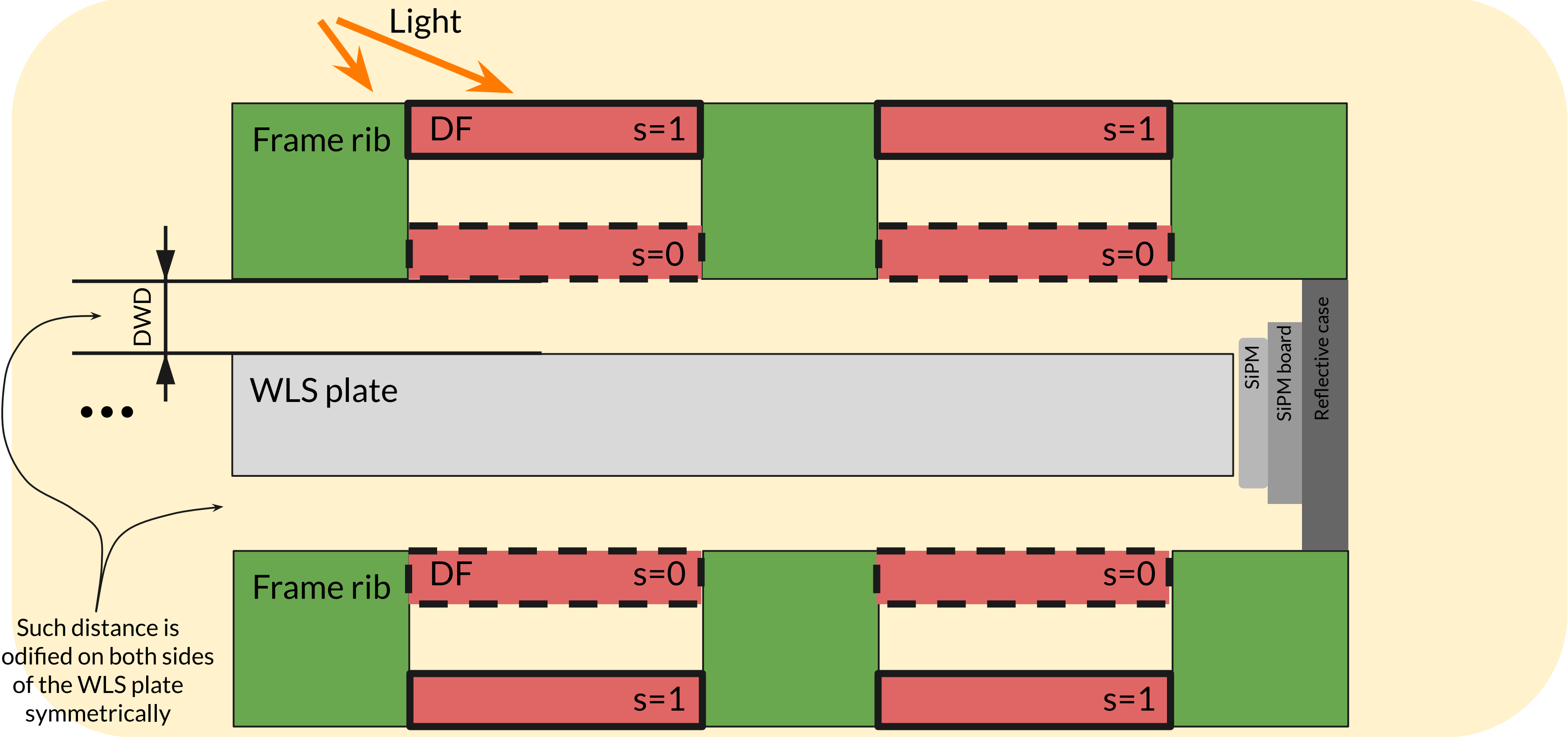
DFA = Dichroic Filters Assembly (DFs+frame)
WLSP = WaveLength Shifting Plate



PCE vs. the DFA-WLSP distance (= DWD)

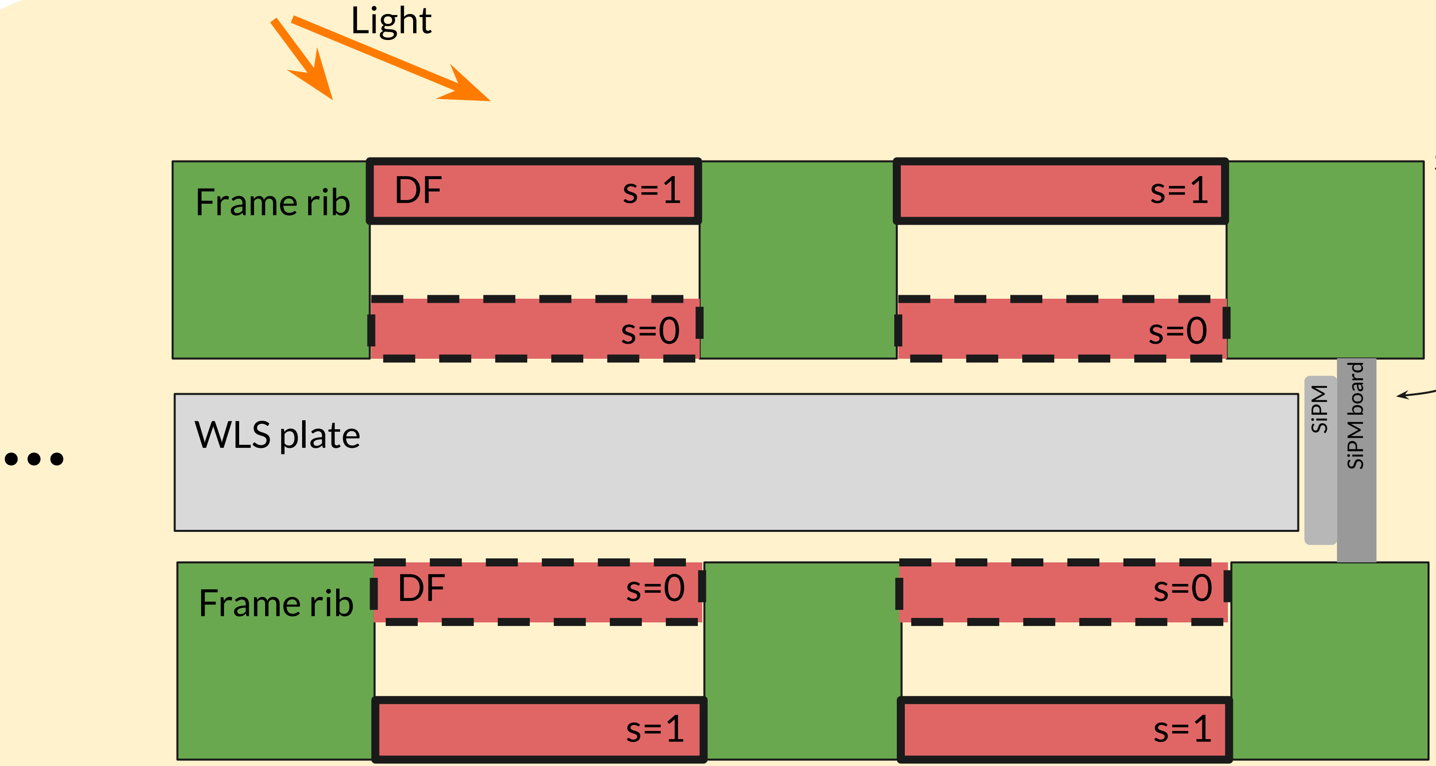


PCE vs. DWD



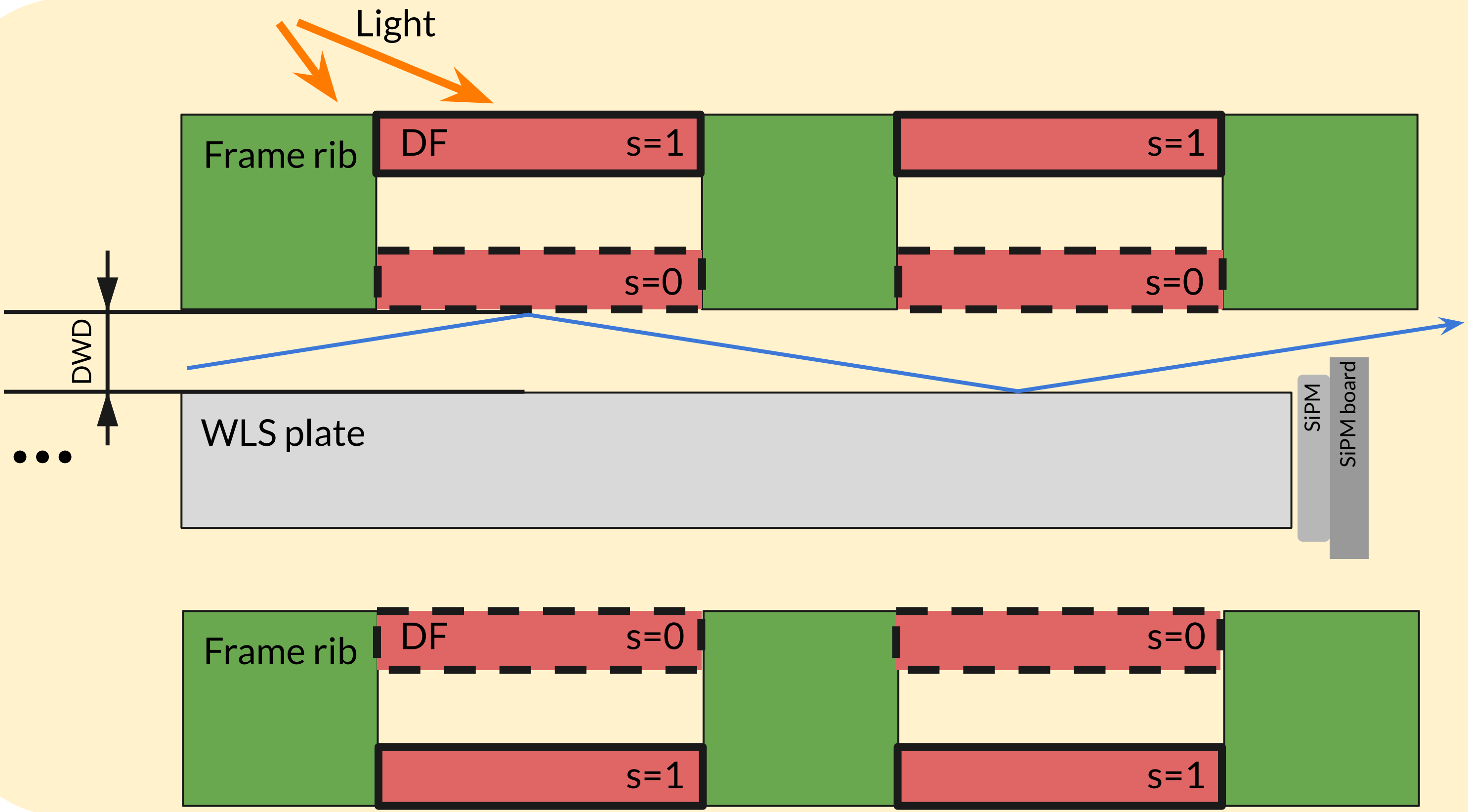
Such distance is modified on both sides of the WLS plate symmetrically

PCE vs. DWD



When the DWD is small enough, the SiPM-board height might be big enough so as to enclose the X-ARAPUCA cavity

PCE vs. DWD



However, when larger distances are considered, there's a gap through which photons could escape the X-ARAPUCA

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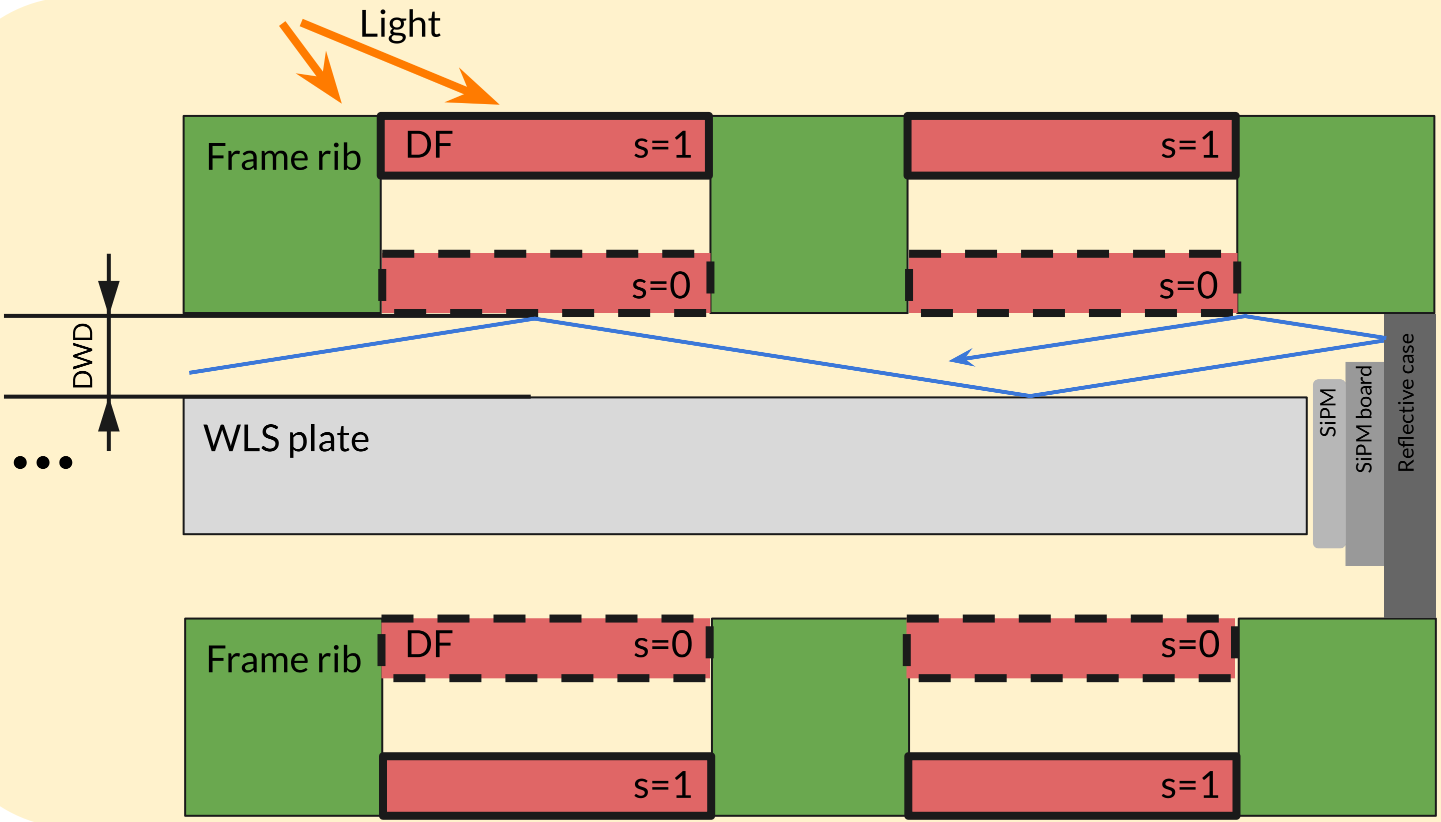
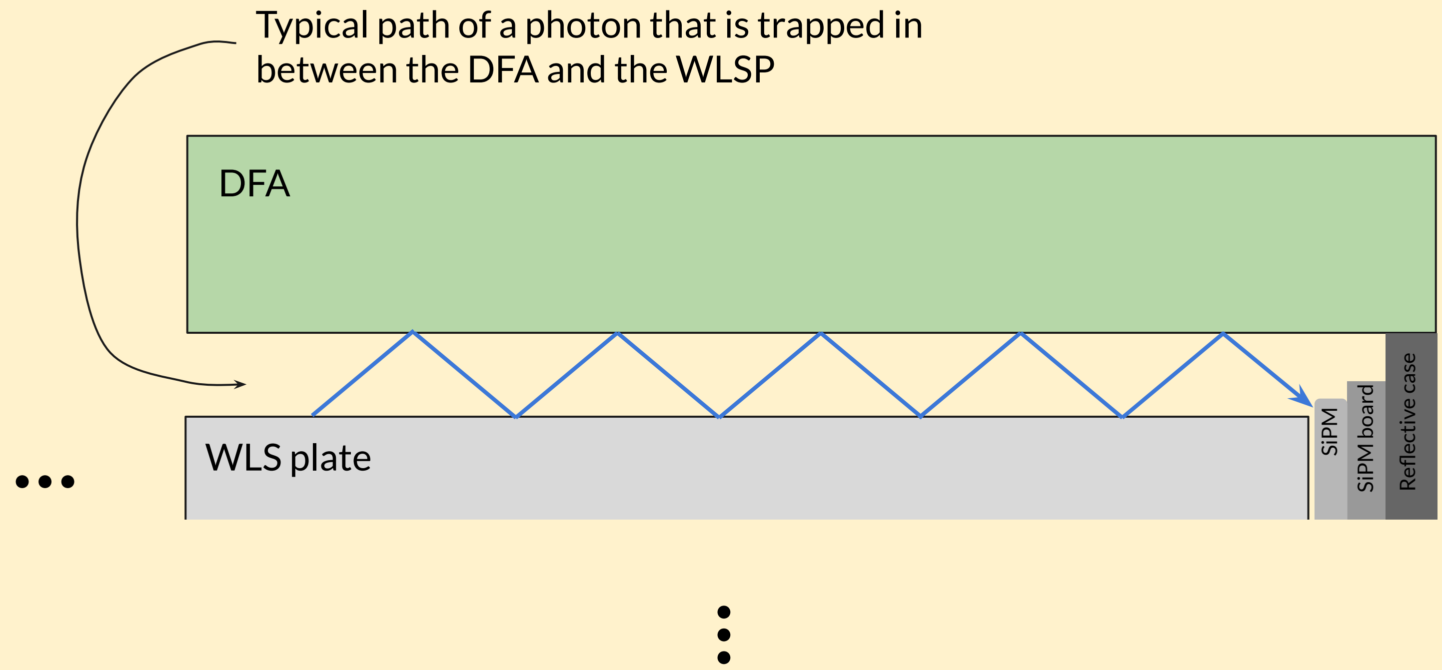
PCE vs. DWD

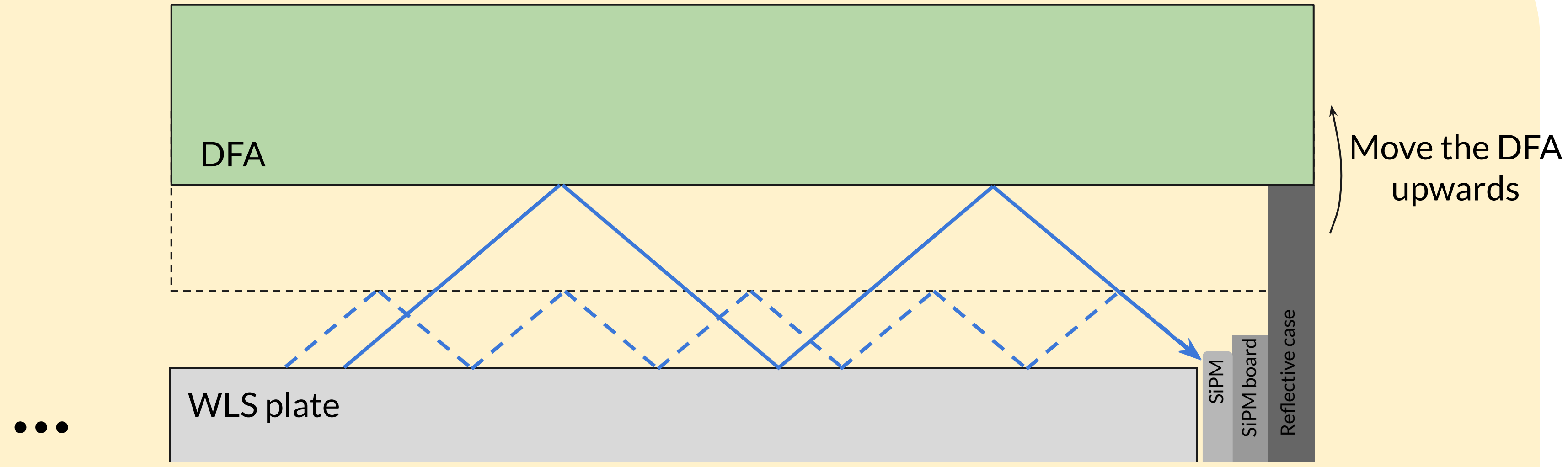


To prevent this from happening, we have considered an especular-reflective case. This case, together with both DFAs, fully enclose the X-ARAPUCA cavity

Why study the DWD?



Why study the DWD?



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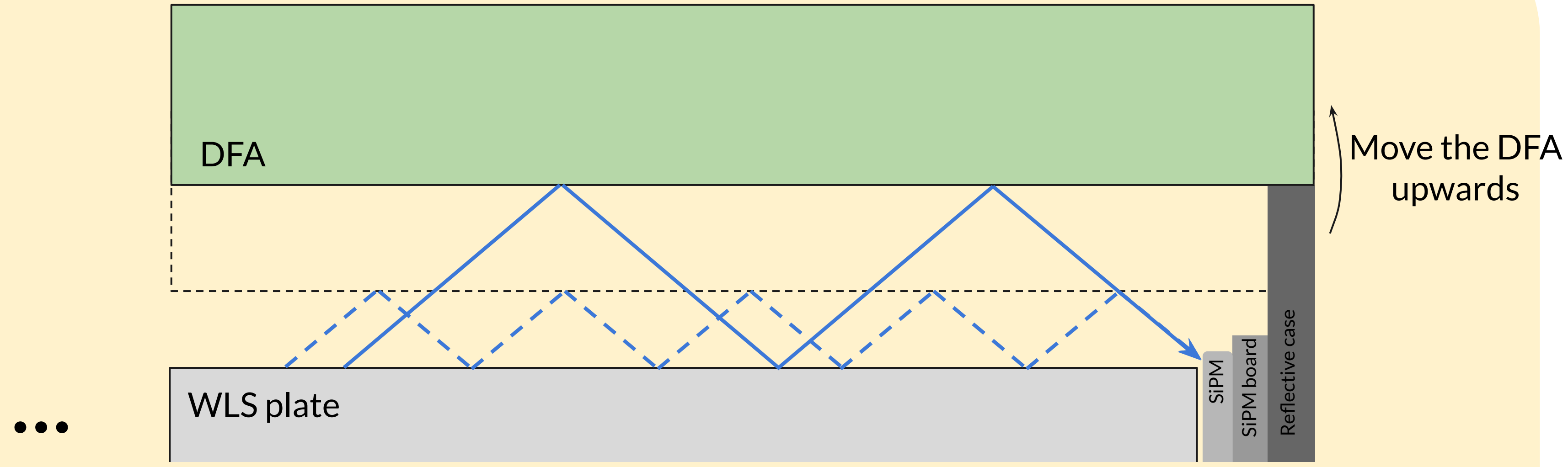
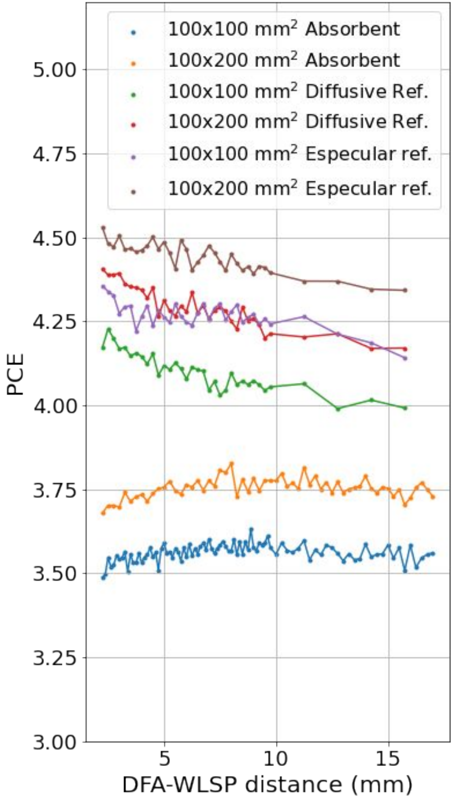
As a result, photons that are trapped in between the DFA and the WLSP, will take, on average, less interactions with the DFA to reach a SiPM

Why study the DWD?



I.e. there's **less reliance on the proper functioning of the DFA** for a photon to reach a SiPM, which is **specially convenient if** the DF are not properly optimized or **the frame is not reflective**

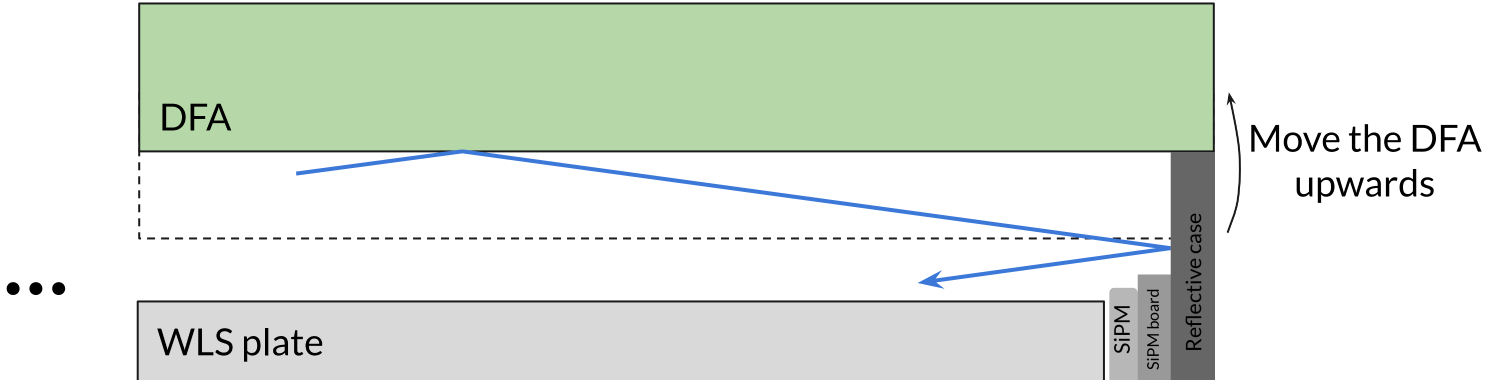
PCE vs. DWD results



- For non-reflective frame (less reliable DFA), the PCE roughly depends on the DWD.
- For a reflective frame, the PCE seems to slightly worsen with DWD. In this case, the DFA is more efficient than the non-reflective case, so increasing the DWD only introduces an improvement as far as the DFs are concerned, but still introduces the poor-focusing issue.

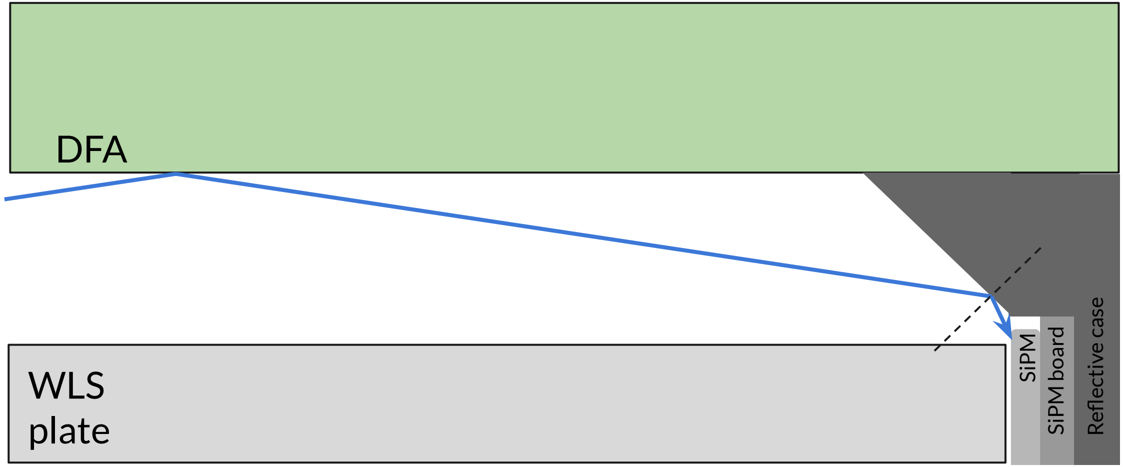
Conclusions

- Considering a reflective coating for the frame seems worthy (20% PCE improvement according to these results)
- PCE tendency with DWD depends on the quality of the DFA (p.e. the frame reflectivity) but has, in general, very little impact on the PCE.
- Our **guess**: In agreement with the reasoning depicted in slides 9 & 10, a bigger DWD might allow more photons to reach one megacell edge, where the SiPMs are placed. However, this might not translate into a considerable improvement of the PCE, since now, for photons that are trapped in between the DFA and the WLSP, they are less likely to actually hit a SiPM rather than the reflective case as the DWD increases. A focusing system might be convenient in this case.



Brainstorming on possible focusing systems

WARNING: This is just a **conceptual** sketch!



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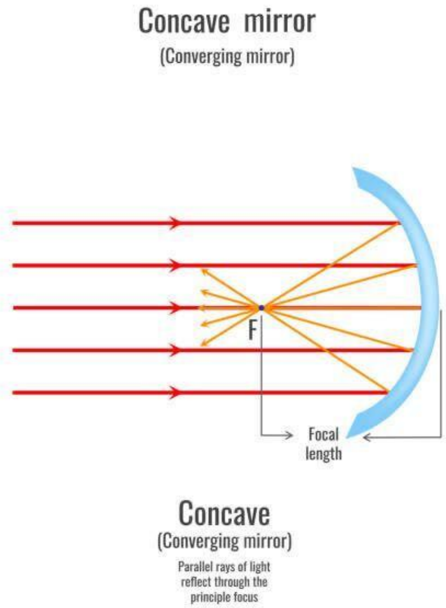
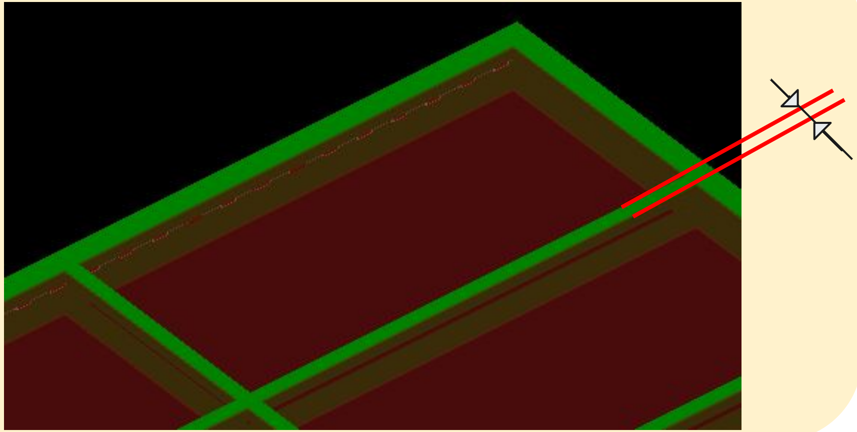


Since the PCE is not strongly affected by the DWD, even without considering any focusing system, **there might be room for improvement if we combine a big DWD with some focusing system,** which **might** make use of converging mirrors or other shape-optimized reflective surfaces.

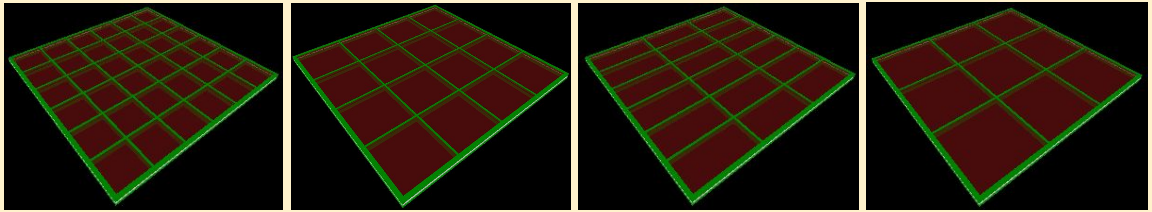
BACKUP

27/07 - Studied parameters

1. Frame rib width (frw)

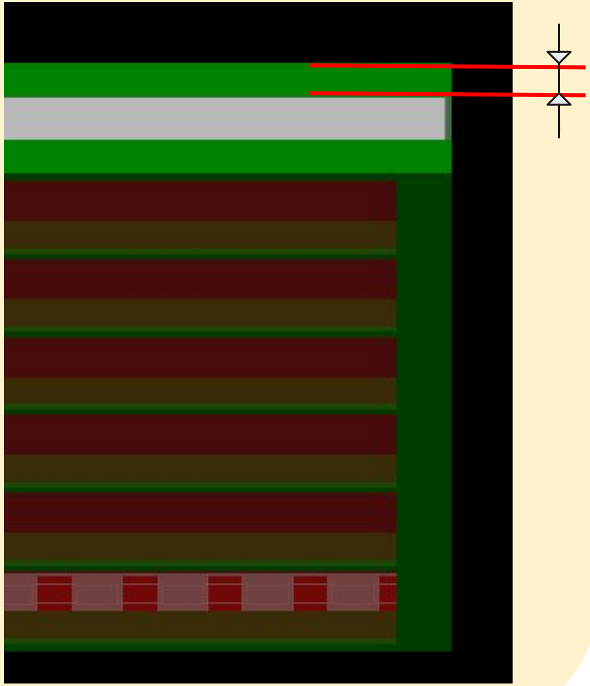


2. DF size (mm^2)



100x100 150x150 100x200 200x200

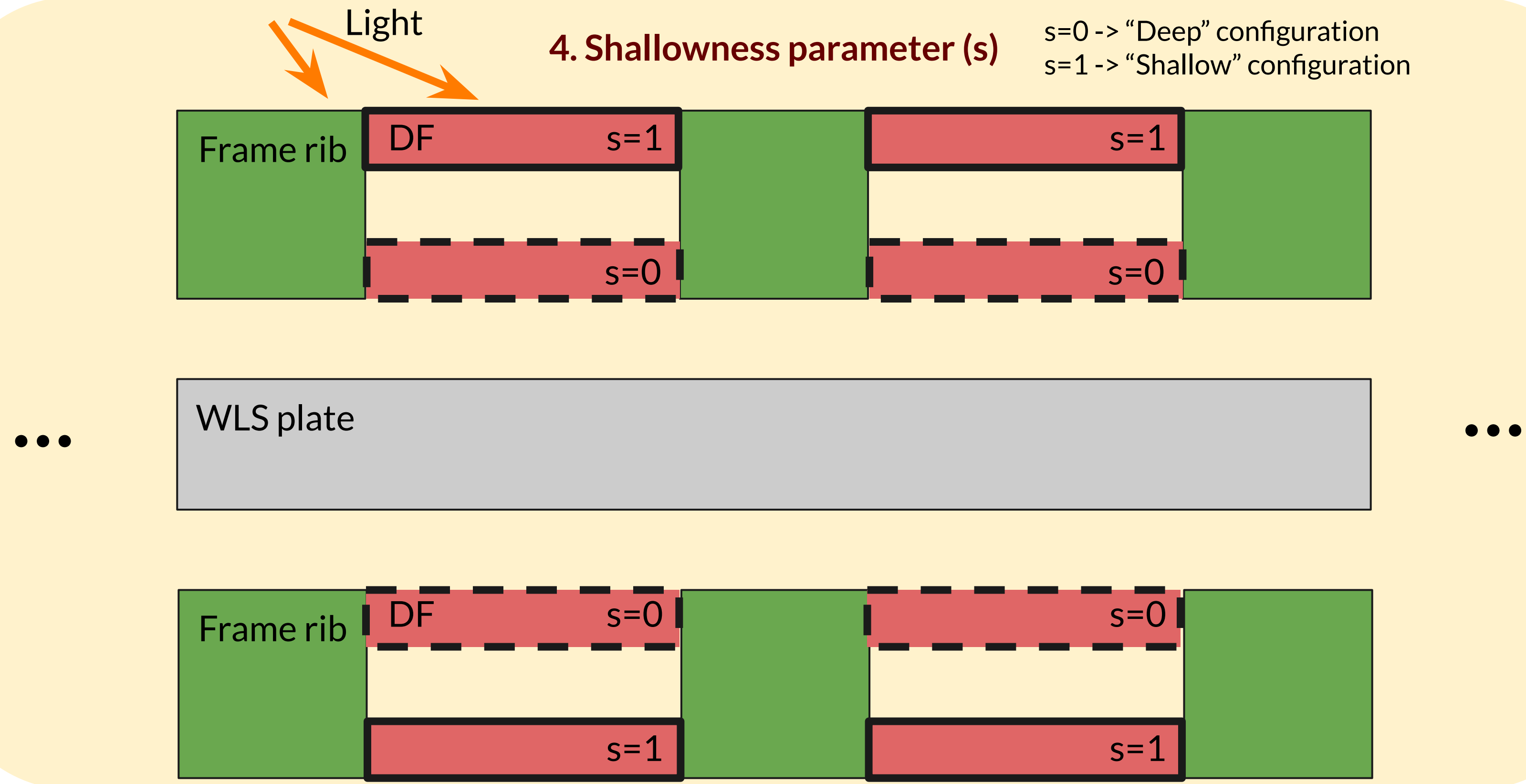
3. Frame height (rh)



27/07 - Studied parameters

4. Shallowness parameter (s)

s=0 -> “Deep” configuration
s=1 -> “Shallow” configuration



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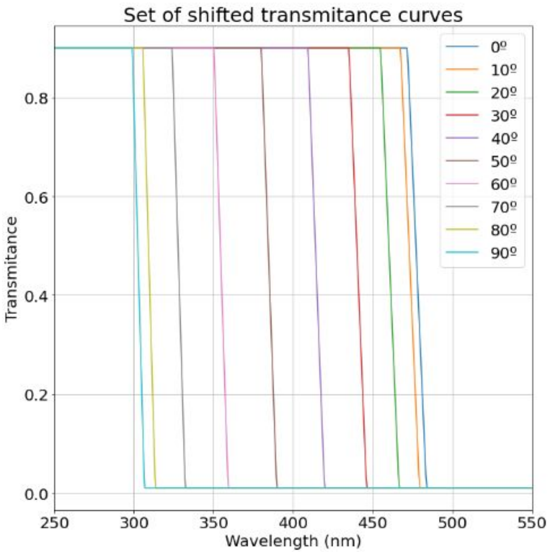
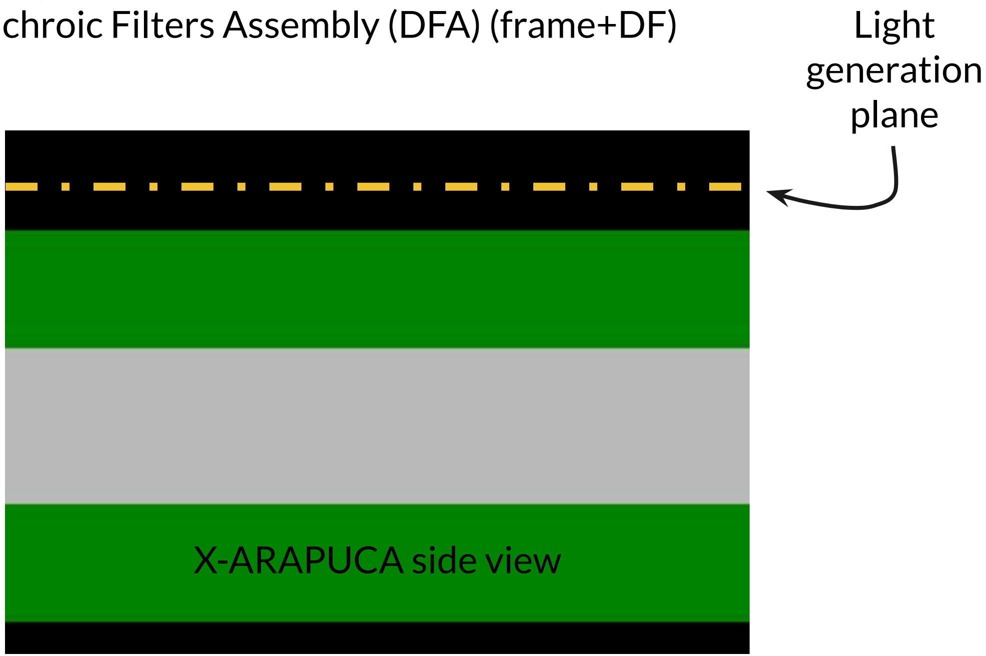
27/07 - Simulation fixed parameters

- G2P WLS bar with 3m attenuation length *- See C. Brizzolari et al 2021 JINST 16 P09027*
- Abstract DF with $T_{bc} = 0.9, T_{ac} = 0.01, \lambda_c = 400 \text{ nm and } \Delta\lambda_c = 10 \text{ nm}$
- Light is generated over the whole Dichroic Filters Assembly (DFA) (frame+DF)





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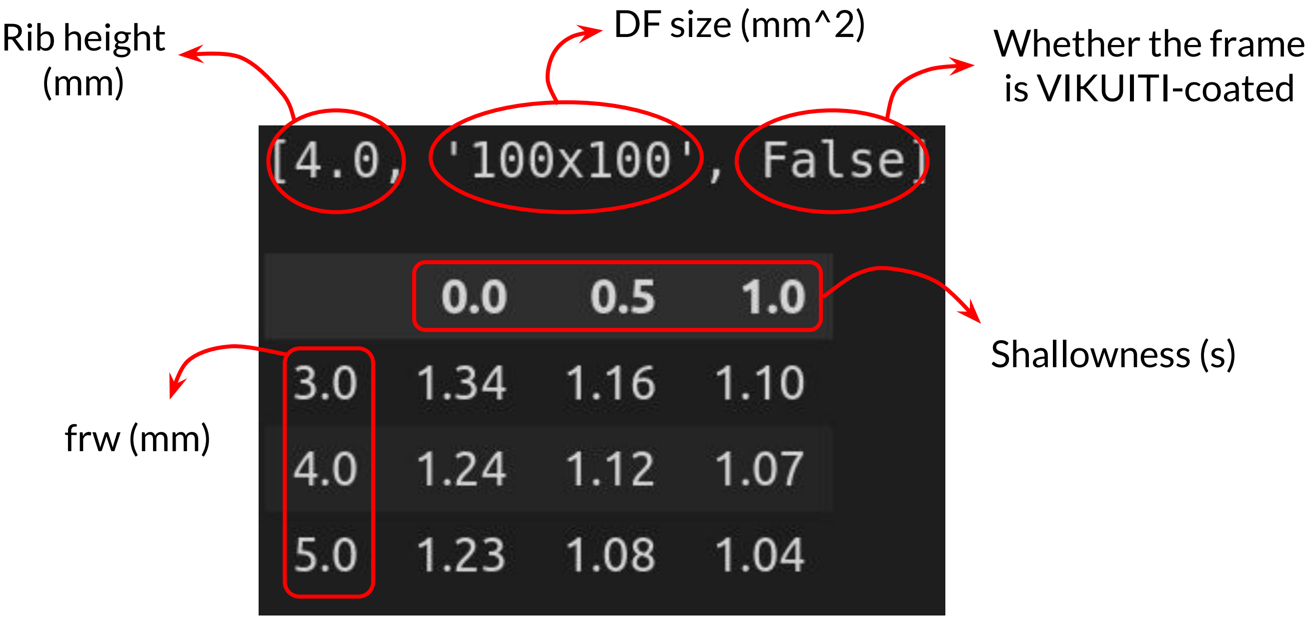
27/07 - Example result table



Rib height (mm)

DF size (mm^2)

Whether the frame is VIKUITI-coated

```
[4.0, '100x100', False]
```

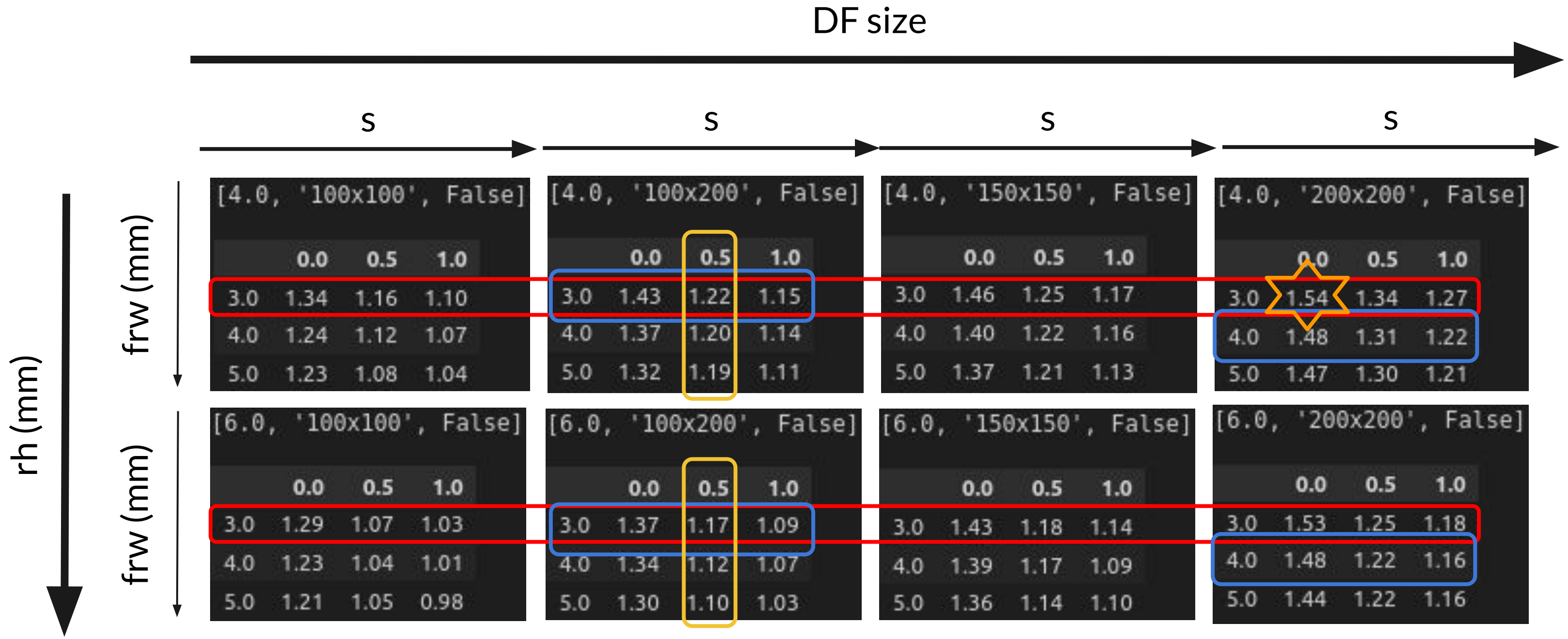
Shallowness (s)

frw (mm)

	0.0	0.5	1.0
3.0	1.34	1.16	1.10
4.0	1.24	1.12	1.07
5.0	1.23	1.08	1.04

27/07 - Results

PCE with non-reflective frame



[4.0, '100x100', False]

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3.0	1.34	1.16	1.10
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5.0	1.23	1.08	1.04

[4.0, '100x200', False]

	0.0	0.5	1.0
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5.0	1.32	1.19	1.11

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5.0	1.47	1.30	1.21

[6.0, '100x100', False]

	0.0	0.5	1.0
3.0	1.29	1.07	1.03
4.0	1.23	1.04	1.01
5.0	1.21	1.05	0.98

[6.0, '100x200', False]

	0.0	0.5	1.0
3.0	1.37	1.17	1.09
4.0	1.34	1.12	1.07
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[6.0, '150x150', False]

	0.0	0.5	1.0
3.0	1.43	1.18	1.14
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5.0	1.36	1.14	1.10

[6.0, '200x200', False]

	0.0	0.5	1.0
3.0	1.53	1.25	1.18
4.0	1.48	1.22	1.16
5.0	1.44	1.22	1.16

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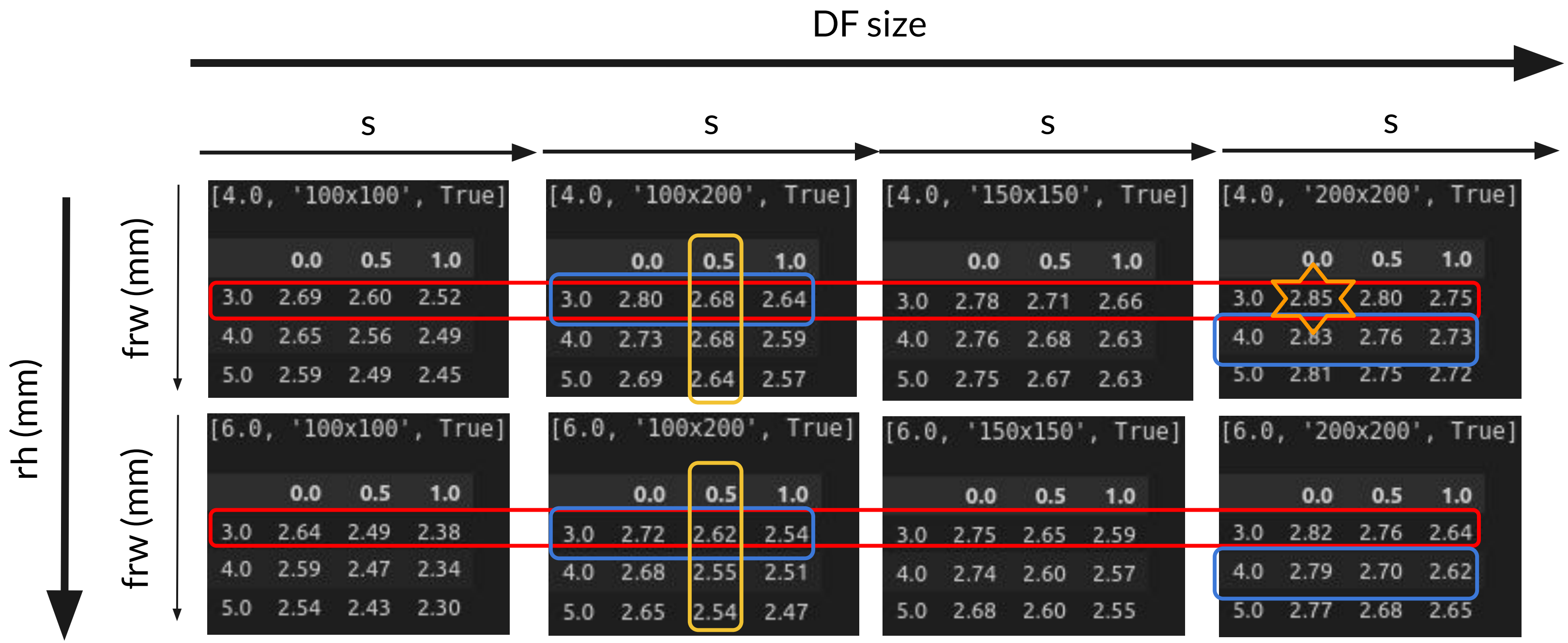
27/07 - Results

PCE with reflective frame



[4.0, '100x100', True]

	0.0	0.5	1.0
3.0	2.69	2.60	2.52
4.0	2.65	2.56	2.49
5.0	2.59	2.49	2.45

[4.0, '100x200', True]

	0.0	0.5	1.0
3.0	2.80	2.68	2.64
4.0	2.73	2.68	2.59
5.0	2.69	2.64	2.57

[4.0, '150x150', True]

	0.0	0.5	1.0
3.0	2.78	2.71	2.66
4.0	2.76	2.68	2.63
5.0	2.75	2.67	2.63

[4.0, '200x200', True]

	0.0	0.5	1.0
3.0	2.85	2.80	2.75
4.0	2.83	2.76	2.73
5.0	2.81	2.75	2.72

[6.0, '100x100', True]

	0.0	0.5	1.0
3.0	2.64	2.49	2.38
4.0	2.59	2.47	2.34
5.0	2.54	2.43	2.30

[6.0, '100x200', True]

	0.0	0.5	1.0
3.0	2.72	2.62	2.54
4.0	2.68	2.55	2.51
5.0	2.65	2.54	2.47

[6.0, '150x150', True]

	0.0	0.5	1.0
3.0	2.75	2.65	2.59
4.0	2.74	2.60	2.57
5.0	2.68	2.60	2.55

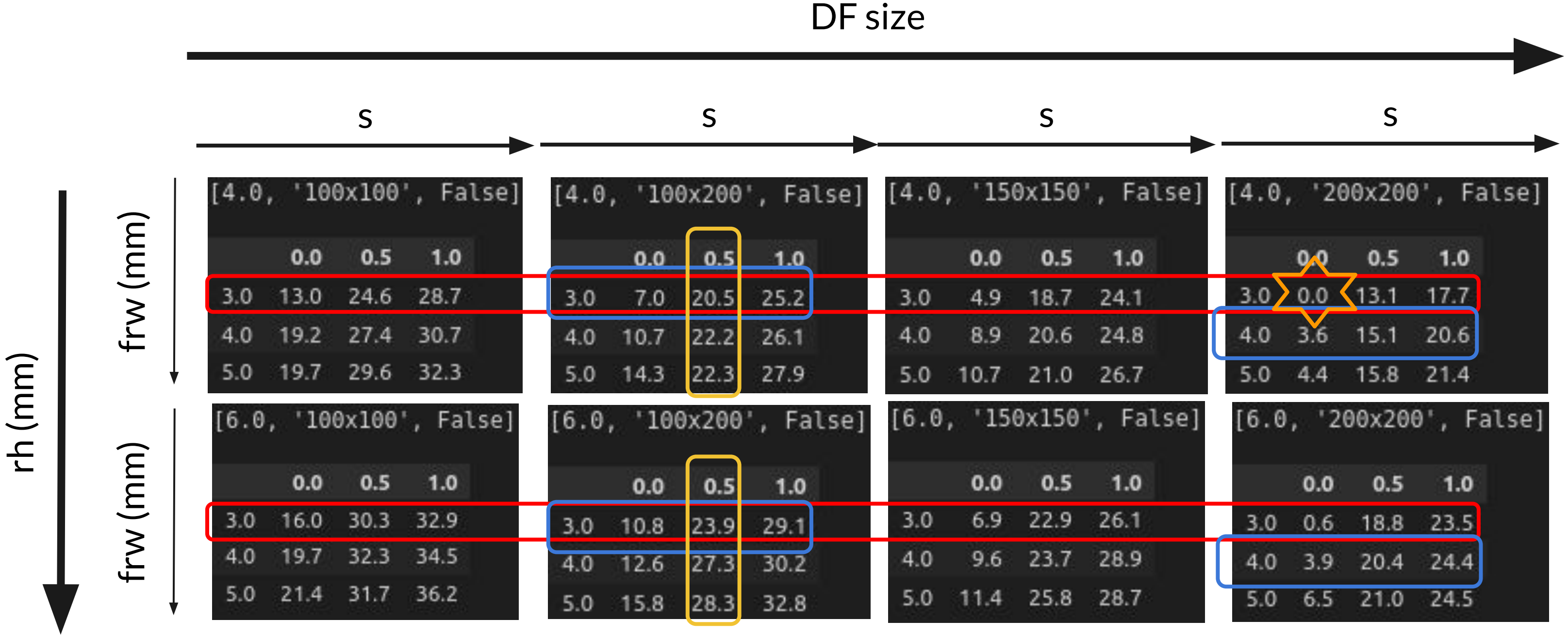
[6.0, '200x200', True]

	0.0	0.5	1.0
3.0	2.82	2.76	2.64
4.0	2.79	2.70	2.62
5.0	2.77	2.68	2.65

27/07 - Results

Percent PCE loss wrt best-case scenario with non-reflective frame

**best-case scenario within non-reflective configs.*



[4.0, '100x100', False]

	0.0	0.5	1.0
3.0	13.0	24.6	28.7
4.0	19.2	27.4	30.7
5.0	19.7	29.6	32.3

[4.0, '100x200', False]

	0.0	0.5	1.0
3.0	7.0	20.5	25.2
4.0	10.7	22.2	26.1
5.0	14.3	22.3	27.9

[4.0, '150x150', False]

	0.0	0.5	1.0
3.0	4.9	18.7	24.1
4.0	8.9	20.6	24.8
5.0	10.7	21.0	26.7

[4.0, '200x200', False]

	0.0	0.5	1.0
3.0	0.0	13.1	17.7
4.0	3.6	15.1	20.6
5.0	4.4	15.8	21.4

[6.0, '100x100', False]

	0.0	0.5	1.0
3.0	16.0	30.3	32.9
4.0	19.7	32.3	34.5
5.0	21.4	31.7	36.2

[6.0, '100x200', False]

	0.0	0.5	1.0
3.0	10.8	23.9	29.1
4.0	12.6	27.3	30.2
5.0	15.8	28.3	32.8

[6.0, '150x150', False]

	0.0	0.5	1.0
3.0	6.9	22.9	26.1
4.0	9.6	23.7	28.9
5.0	11.4	25.8	28.7

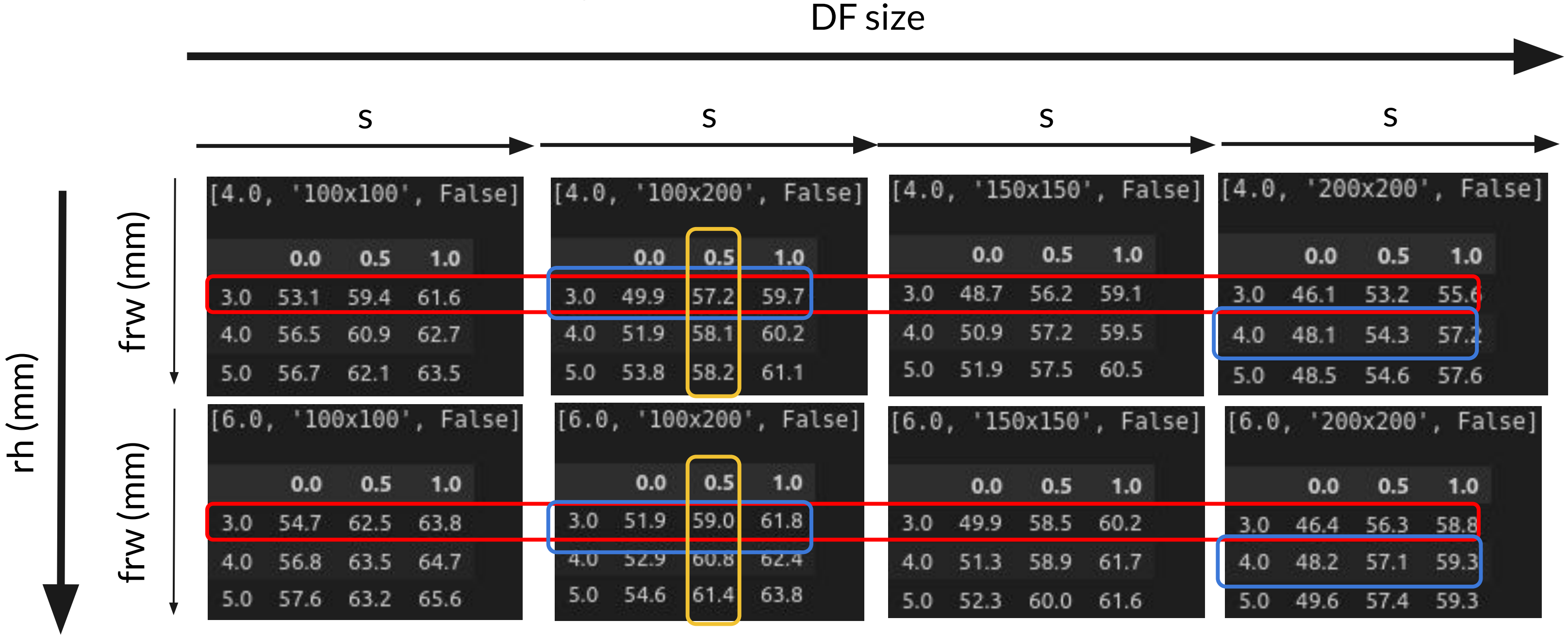
[6.0, '200x200', False]

	0.0	0.5	1.0
3.0	0.6	18.8	23.5
4.0	3.9	20.4	24.4
5.0	6.5	21.0	24.5

27/07 - Results

Percent PCE loss wrt best-case scenario with <u>non-reflective frame</u>

**overall best-case scenario (non-reflective and reflective configs.)*



[4.0, '100x100', False]

	0.0	0.5	1.0
3.0	53.1	59.4	61.6
4.0	56.5	60.9	62.7
5.0	56.7	62.1	63.5

[4.0, '100x200', False]

	0.0	0.5	1.0
3.0	49.9	57.2	59.7
4.0	51.9	58.1	60.2
5.0	53.8	58.2	61.1

[4.0, '150x150', False]

	0.0	0.5	1.0
3.0	48.7	56.2	59.1
4.0	50.9	57.2	59.5
5.0	51.9	57.5	60.5

[4.0, '200x200', False]

	0.0	0.5	1.0
3.0	46.1	53.2	55.6
4.0	48.1	54.3	57.2
5.0	48.5	54.6	57.6

[6.0, '100x100', False]

	0.0	0.5	1.0
3.0	54.7	62.5	63.8
4.0	56.8	63.5	64.7
5.0	57.6	63.2	65.6

[6.0, '100x200', False]

	0.0	0.5	1.0
3.0	51.9	59.0	61.8
4.0	52.9	60.8	62.4
5.0	54.6	61.4	63.8

[6.0, '150x150', False]

	0.0	0.5	1.0
3.0	49.9	58.5	60.2
4.0	51.3	58.9	61.7
5.0	52.3	60.0	61.6

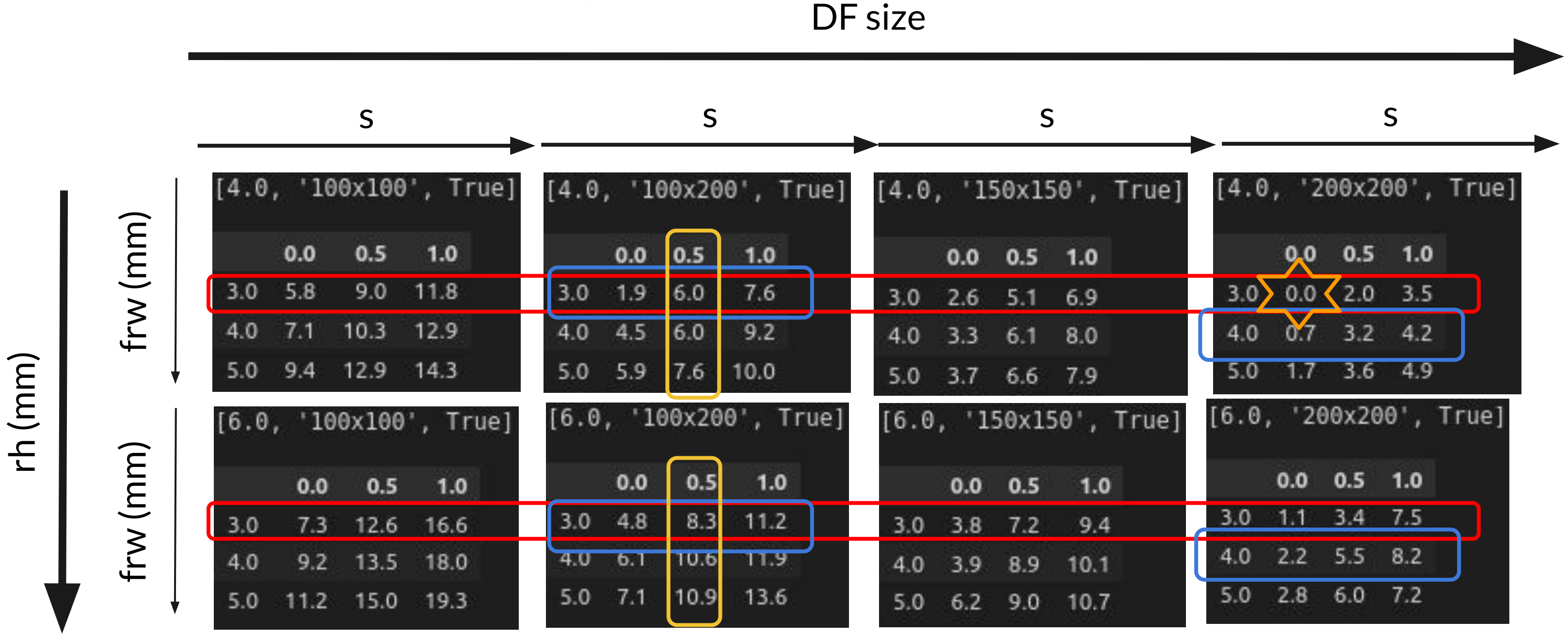
[6.0, '200x200', False]

	0.0	0.5	1.0
3.0	46.4	56.3	58.8
4.0	48.2	57.1	59.3
5.0	49.6	57.4	59.3

27/07 - Results

Percent PCE loss wrt best-case scenario with <u>reflective frame</u>

**overall best-case scenario (non-reflective and reflective configs.)*



[4.0, '100x100', True]

	0.0	0.5	1.0
3.0	5.8	9.0	11.8
4.0	7.1	10.3	12.9
5.0	9.4	12.9	14.3

[4.0, '100x200', True]

	0.0	0.5	1.0
3.0	1.9	6.0	7.6
4.0	4.5	6.0	9.2
5.0	5.9	7.6	10.0

[4.0, '150x150', True]

	0.0	0.5	1.0
3.0	2.6	5.1	6.9
4.0	3.3	6.1	8.0
5.0	3.7	6.6	7.9

[4.0, '200x200', True]

	0.0	0.5	1.0
3.0	0.0	2.0	3.5
4.0	0.7	3.2	4.2
5.0	1.7	3.6	4.9

[6.0, '100x100', True]

	0.0	0.5	1.0
3.0	7.3	12.6	16.6
4.0	9.2	13.5	18.0
5.0	11.2	15.0	19.3

[6.0, '100x200', True]

	0.0	0.5	1.0
3.0	4.8	8.3	11.2
4.0	6.1	10.6	11.9
5.0	7.1	10.9	13.6

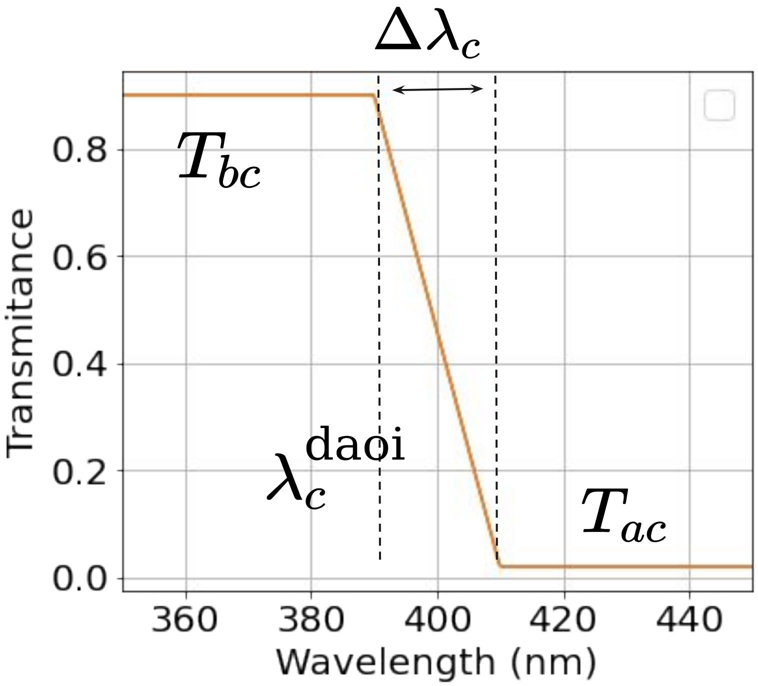
[6.0, '150x150', True]

	0.0	0.5	1.0
3.0	3.8	7.2	9.4
4.0	3.9	8.9	10.1
5.0	6.2	9.0	10.7

[6.0, '200x200', True]

	0.0	0.5	1.0
3.0	1.1	3.4	7.5
4.0	2.2	5.5	8.2
5.0	2.8	6.0	7.2

07/07 - Transmission curve model



$$T_{bc} = 0.9, T_{ac} = 0.01, \lambda_c = 400 \text{ nm and } \Delta\lambda_c = 10 \text{ nm}$$