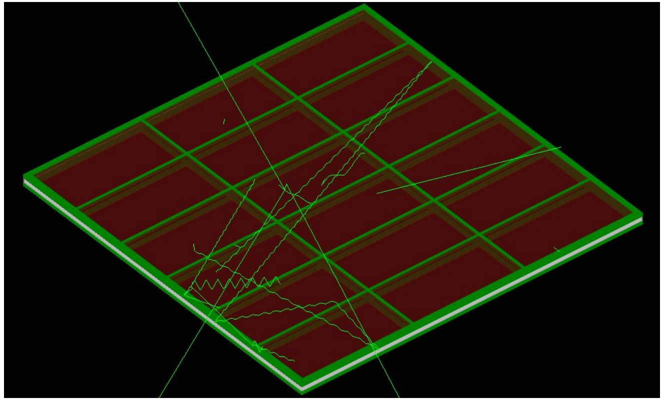
Megacell frame optimization via G4-based optical simulation

Julio Ureña, Justo Martín-Albo, Anselmo Cervera

IFIC - Valencia



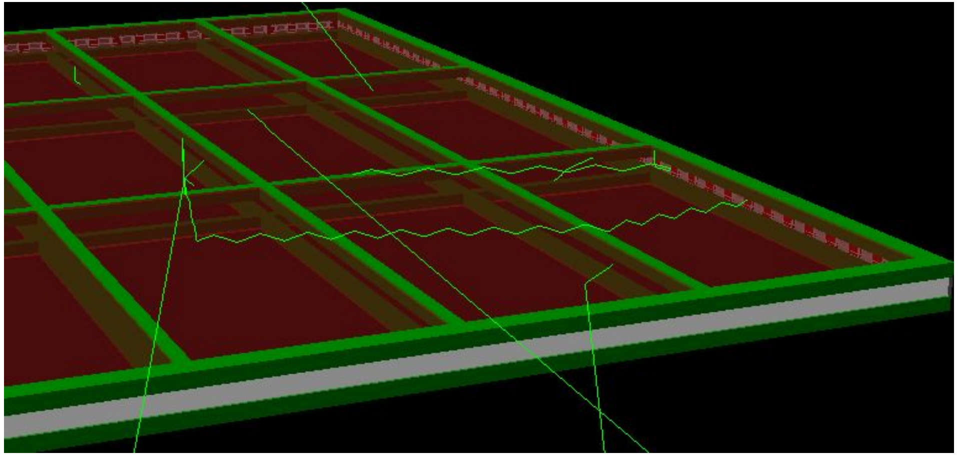
DEEP UNDERGROUND NEUTRINO EXPERIMENT

INSTITUT DE FÍSICA CORPUSCULAR

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:

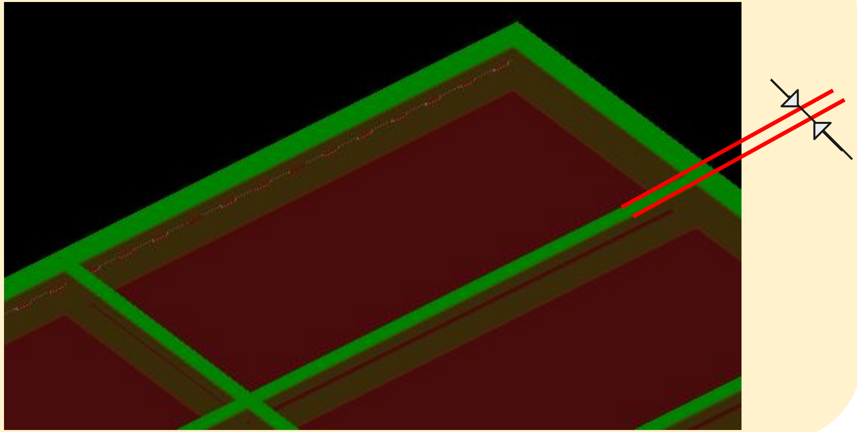
- the emission spectrum of PTP coatings (wavelength and angle-wise),
- the transmission curve of the simulated DF (wavelength and angle-wise),
- the optical properties of the WLS plate, such as WLS-absorption and the emission spectra,
- the optical properties of other materials which the photons might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



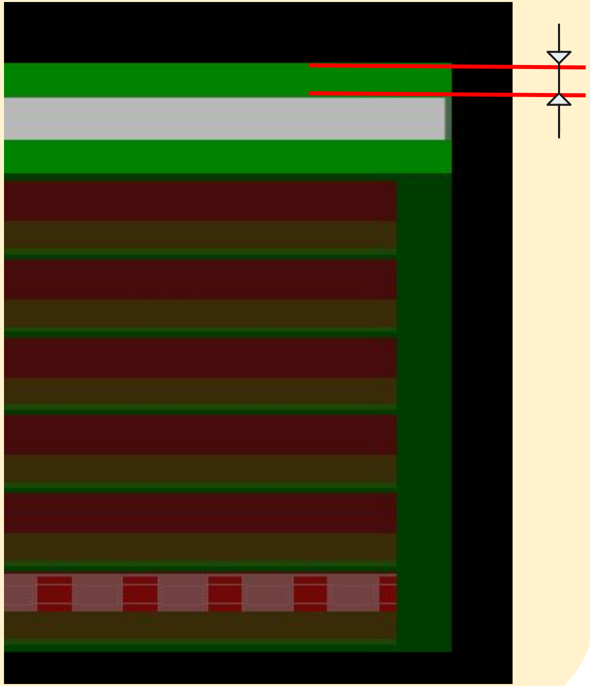
Inspired by John Harton's (CSU) recent study on megacell frame parameters, we have used this simulation to study the impact of such parameters on PCE.

Studied parameters

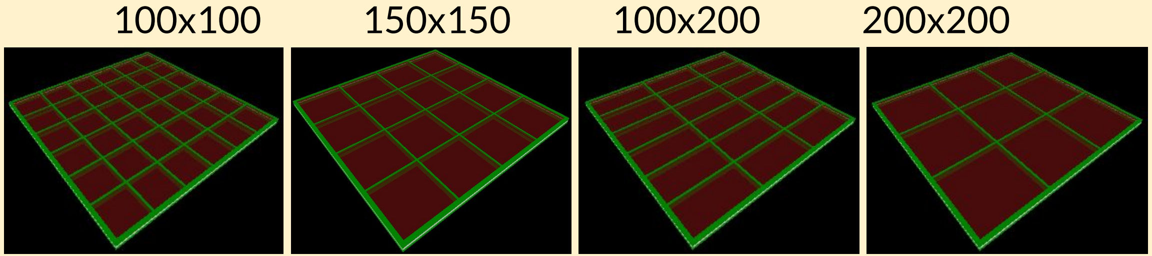
1. Frame rib width (frw)



3. Frame height (rh)



2. DF size (mm^2)

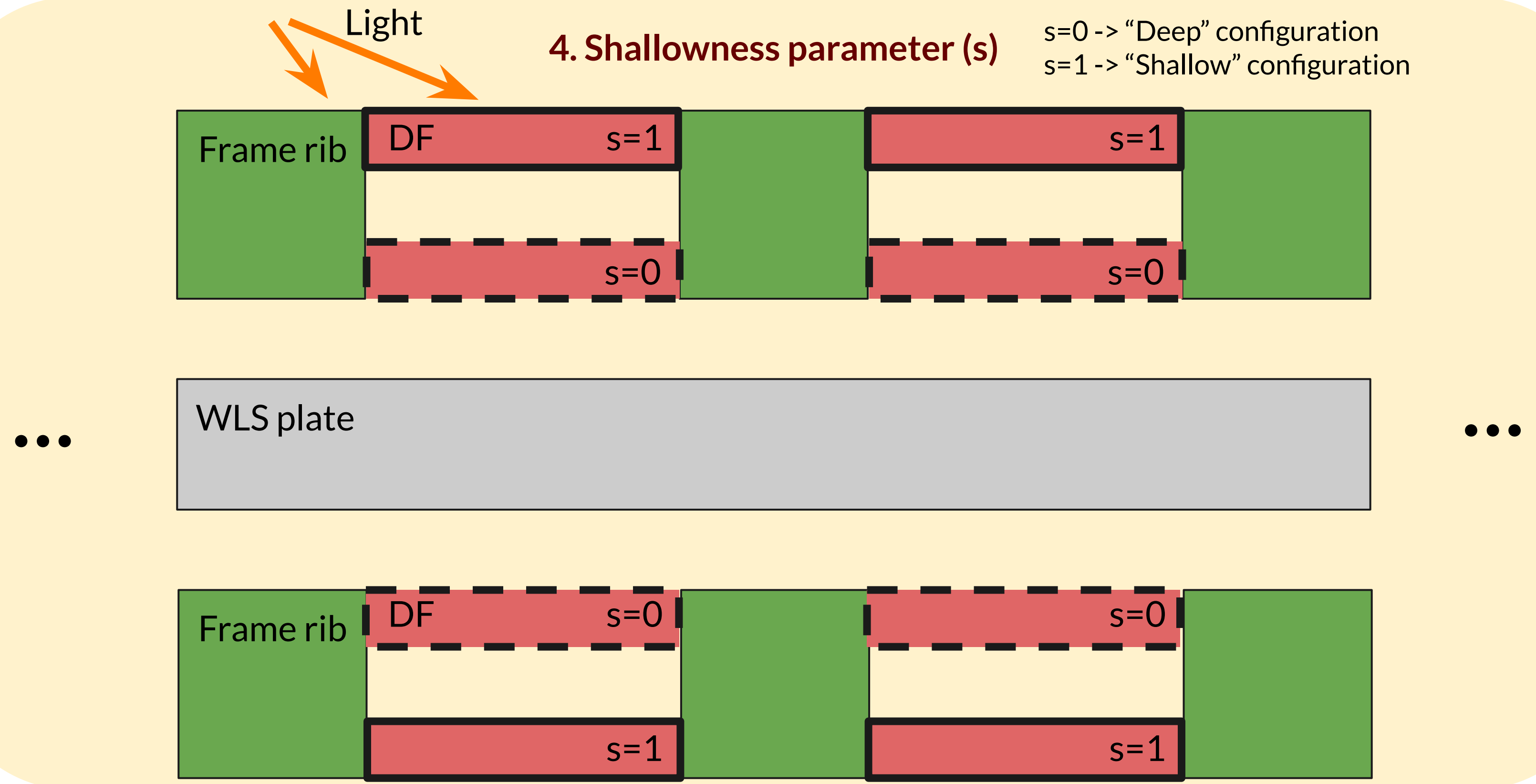


Julio Ureña, Justo Martín-Albo, Anselmo Cervera

Studied parameters

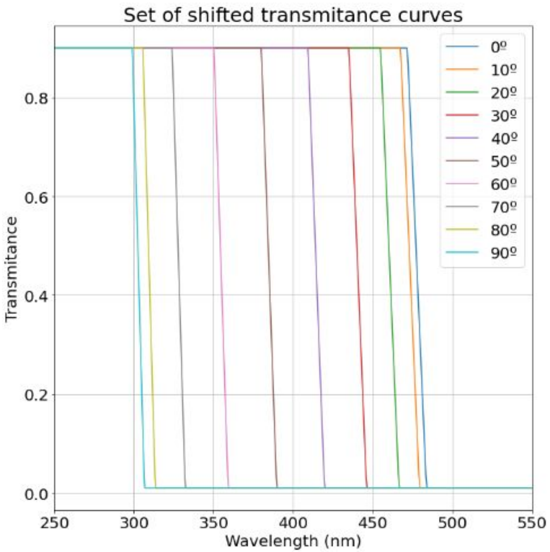
4. Shallowness parameter (s)

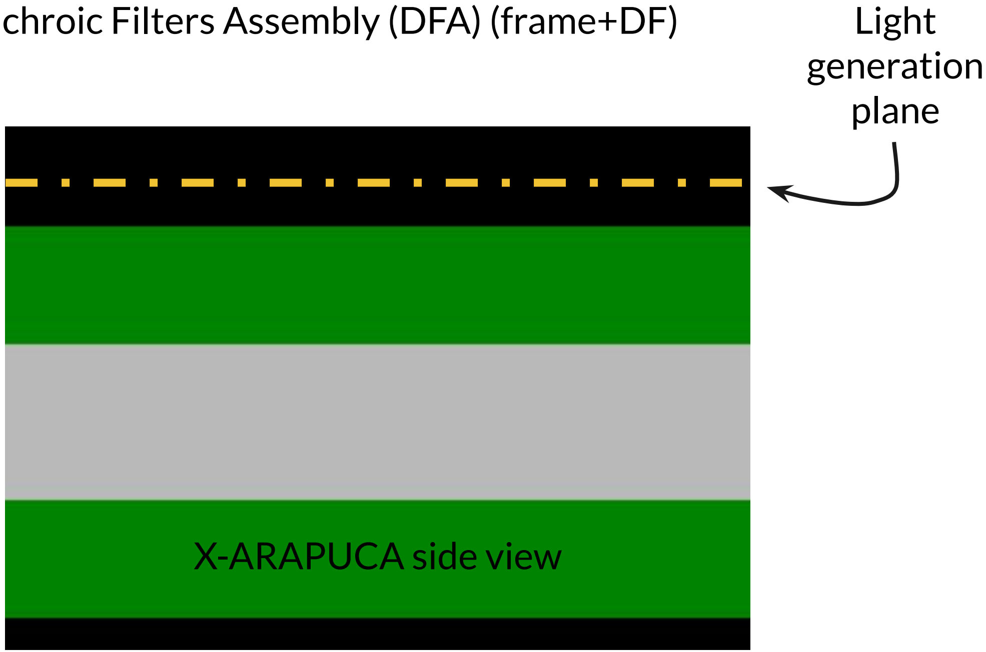
s=0 -> “Deep” configuration
s=1 -> “Shallow” configuration



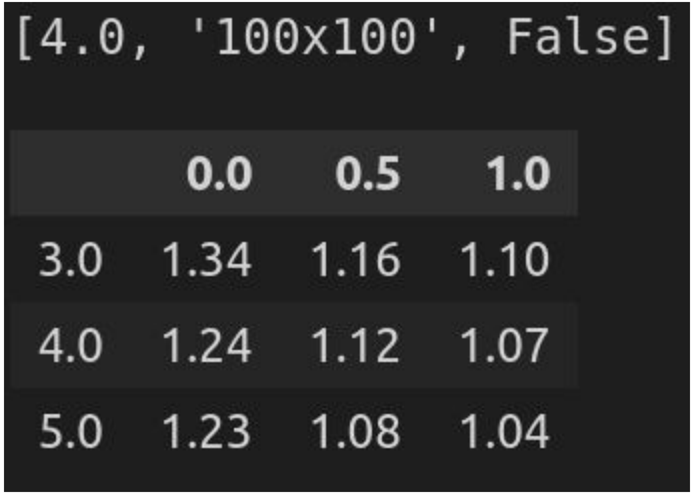
Simulation fixed parameters

- 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)





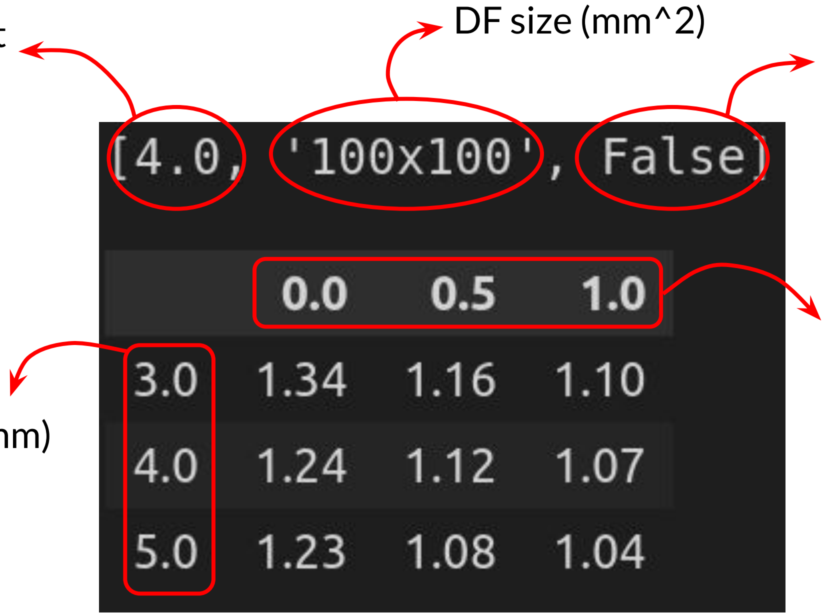
Example result table



```
[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

Example result table



```
[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

Rib height (mm)

DF size (mm^2)

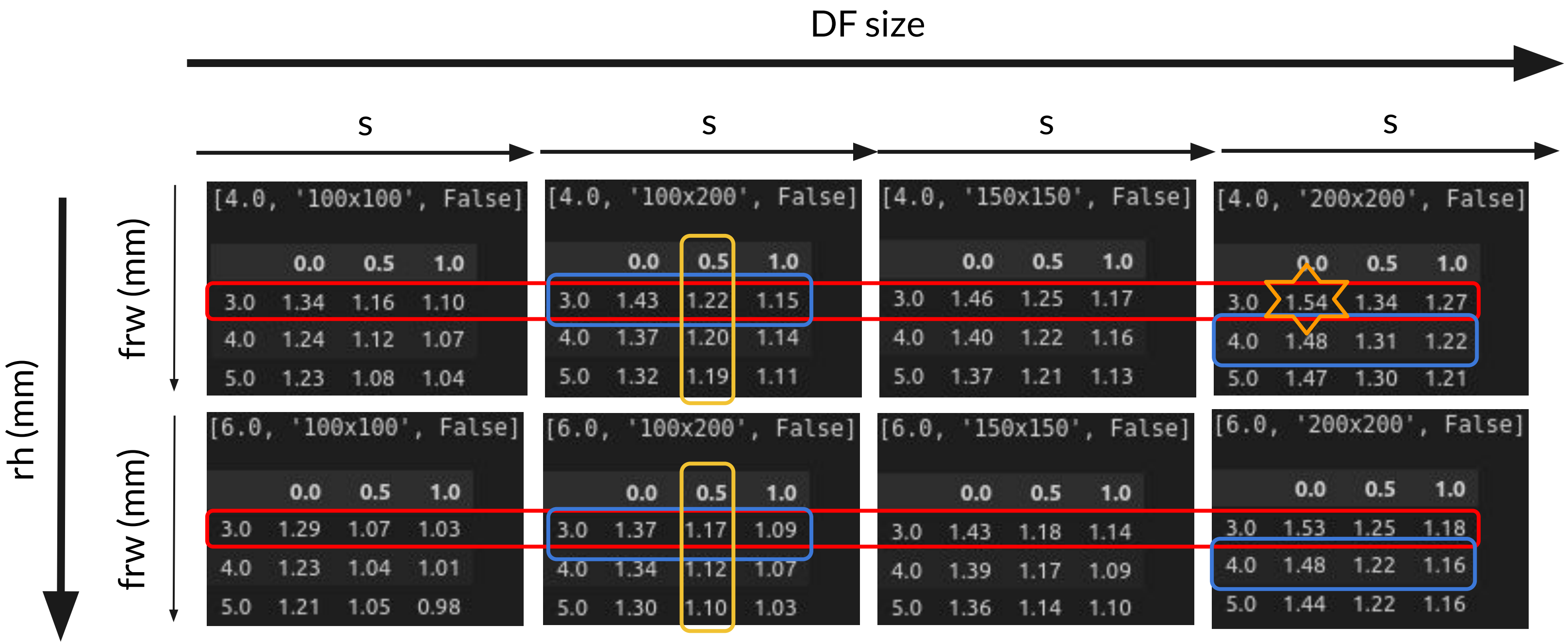
Whether the frame is VIKUITI-coated

Shallowness (s)

frw (mm)

Results

PCE with non-reflective frame



```
[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
```

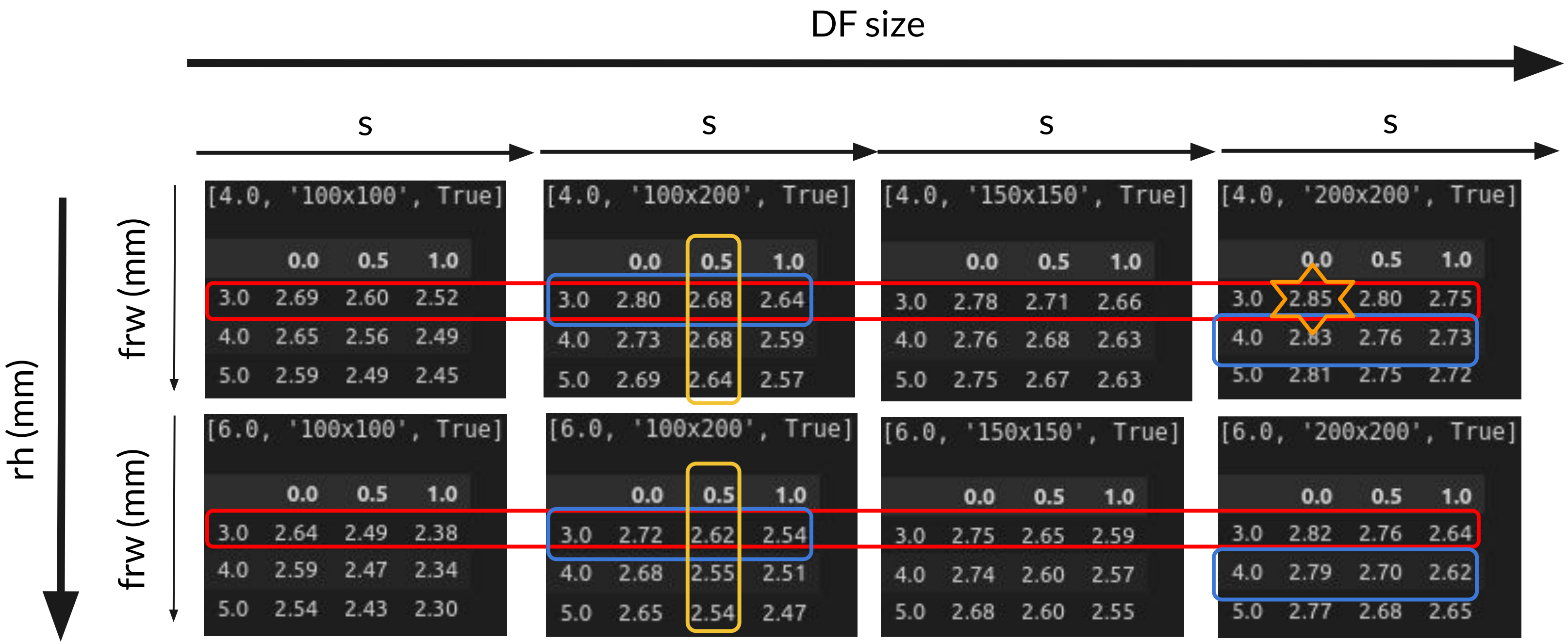
```
[6.0, '100x200', False]
      0.0   0.5   1.0
3.0  1.37  1.17  1.09
4.0  1.34  1.12  1.07
5.0  1.30  1.10  1.03
```

```
[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
```

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

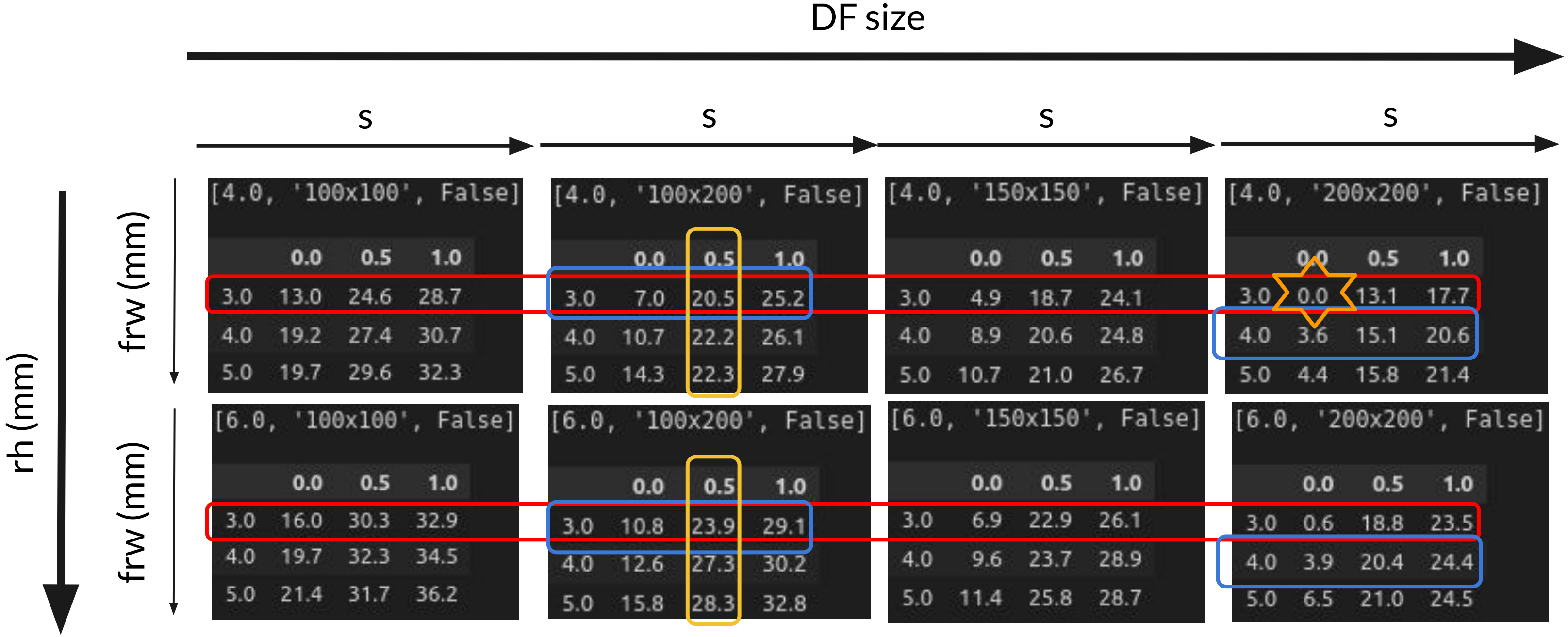
[6.0, '200x200', True]

	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

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

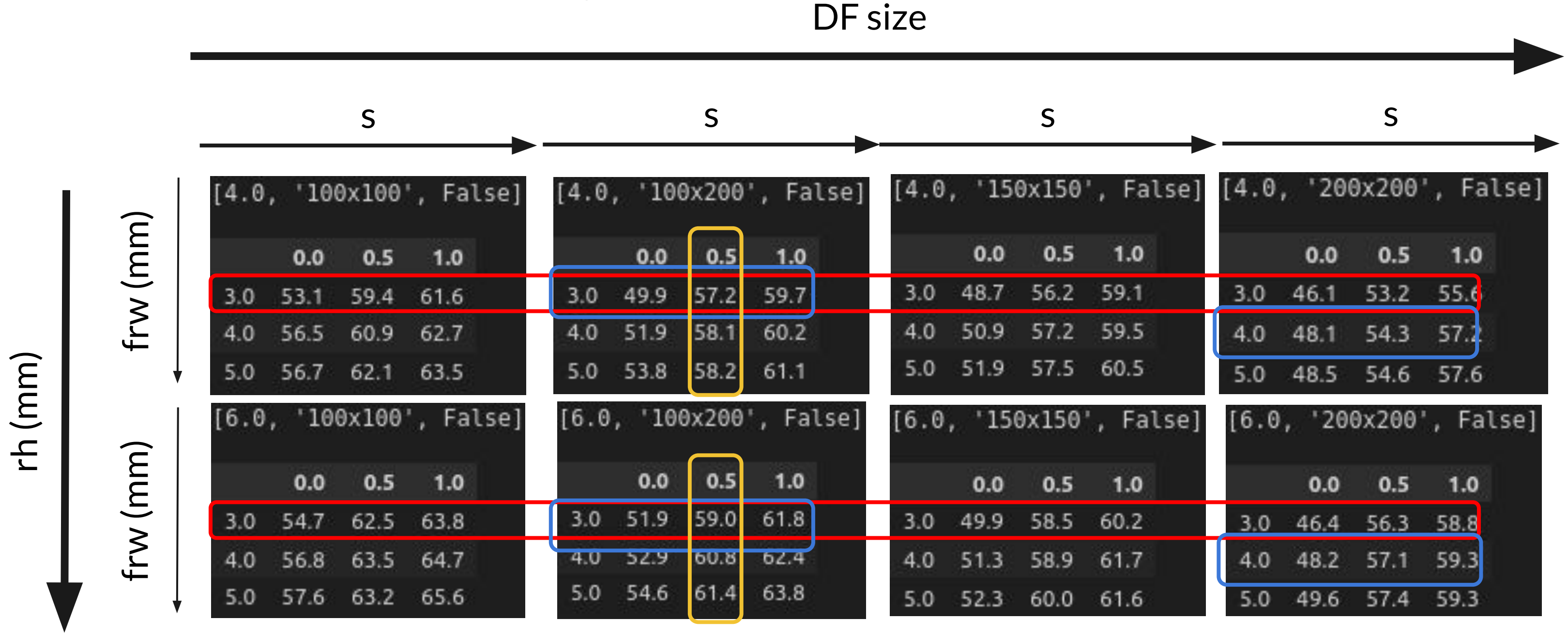
[6.0, '200x200', False]

	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

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

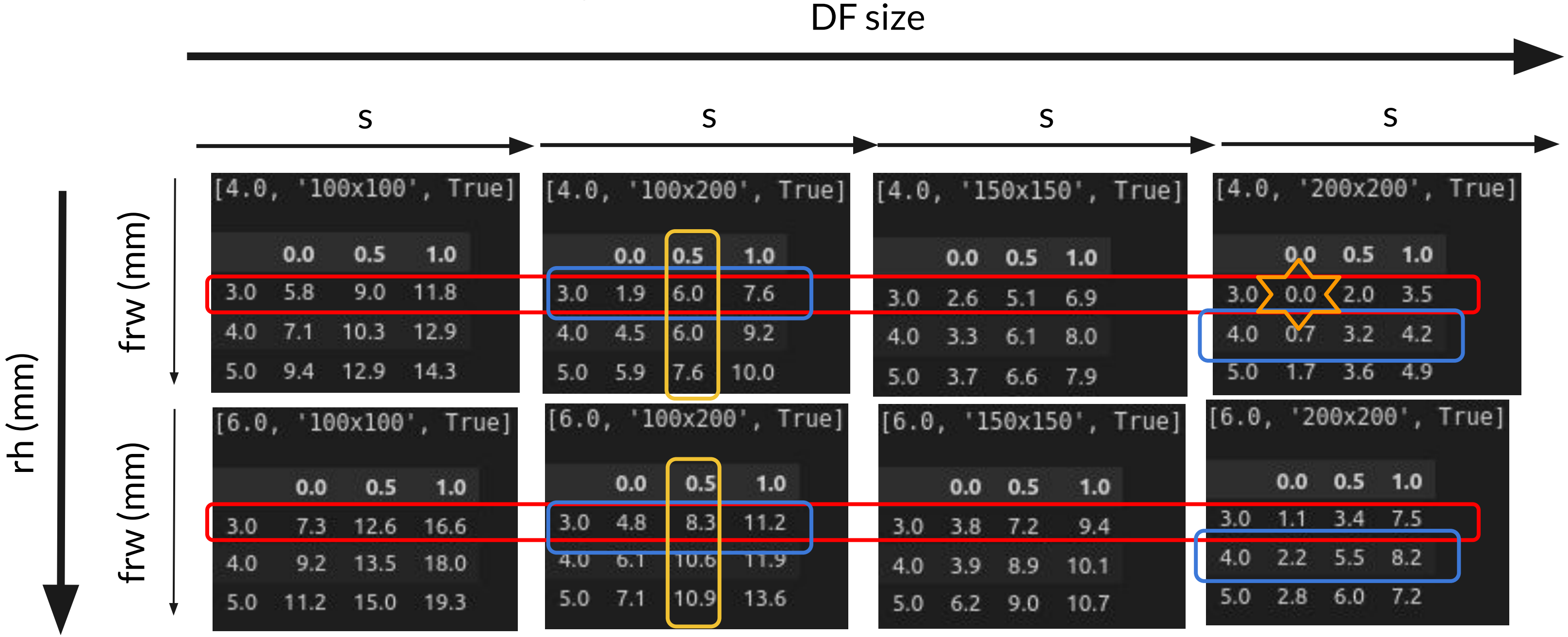
[6.0, '200x200', False]

	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

Results

Percent PCE loss wrt best-case scenario with reflective frame

**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]

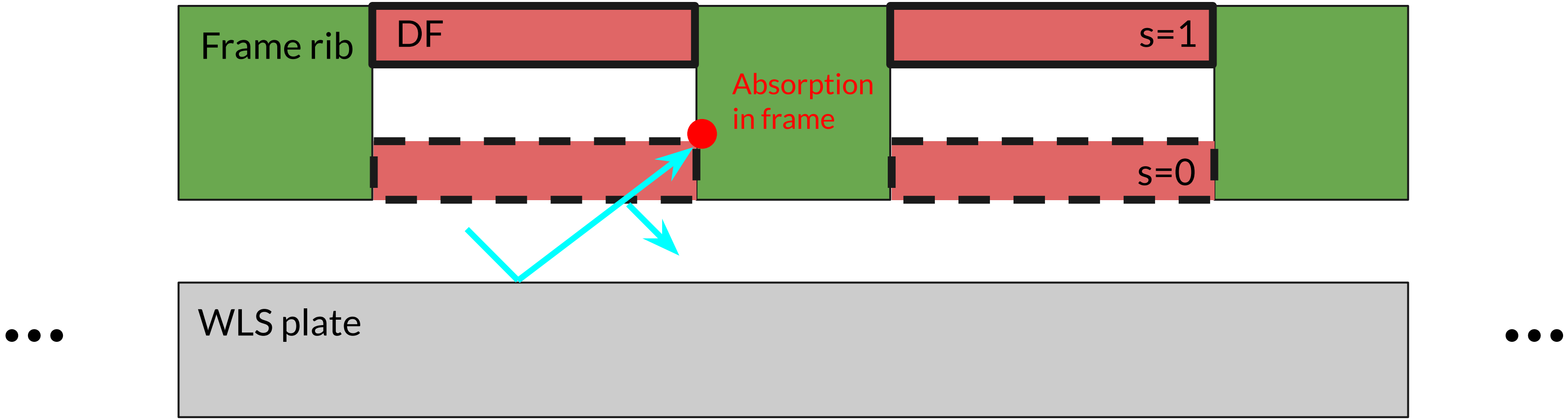
	0.0	0.5	1.0
3.0	3.8	7.2	9.4
4.0	3.9	8.9	10.1
5.0	6.2	9.0	10.7

[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

Conclusions

- The tendencies that we found for PCE vs. frw, rh and DF size were the expected ones
- Considering a reflective frame has the biggest impact on PCE (**doubles it**)
- **Deep configuration seems preferred to the shallow one**



- (frw = 4 mm, 200x200 mm^2) configuration seems **slightly preferred** to (3 mm, 100x200mm^2)
- For non-reflective-frame configurations, **switching from s=1 to s=0 has**, on average, **≃4.4 times more impact** on the PCE **than switching from frw=5mm to frw=3mm**.
- For reflective-frame configurations, it has ≃2.5 times more impact.

Conclusions

- Some parameters may not be realistic, such as:
  - WLS plate attenuation length (Simulated one is 3m. The worst-case scenario for G2P bars is 1m. *- See C. Brizzolari et al 2021 JINST 16 P09027*)
  - DF transmission profile
- Such elections were made so as to have a "good signal" for the PCE. A priori, one would expect such parameters-tuning to **scale the PDE**, but **may not spoil the displayed PCE monotonicity**, which is mainly due to the geometrical features.
- Some other parameters might need further investigation/fine tuning, such as:
  - p.e. scaling of the wl-dependent WLS absorption length of the G2P WLS plate and
  - Light generation angular distribution *- Input from FD standalone simulation?*

Near future prospects

- Study the PCE dependence with the rib-WLS bar distance
- We should simulate the ribless frame. One would expect:
    - ribless frame should be similar, provided the distance between filters is kept small (≃1mm)
    - ribless frame with slightly overlapping filters would be ideal

BACKUP

Preliminary results

Preliminary results assumed a **G2P WLS plate** with the worst-case scenario **attenuation length (1 m) -** ***See C. Brizzolari et al 2021 JINST 16 P09027*** - and **OPTO DF -** ***See indico.fnal.gov/event/54110/contributions/239131/attachments/154076/200083/Filter_tests.April12_22.pdf Brizzolari et al 2021 JINST 16 P09027***

Porcentual PCE loss wrt to best-case scenario

s=0

frw (mm) \DF size (mm^2)	100x100	100x200	200x200
4	15.4	7.7	**0.**
5	18.2	11.7	1.6
6	19.5	11.7	2.5

s=1

frw (mm) \DF size (mm^2)	100x100	100x200	200x200
4	25.3	20	14.3
5	26.9	21.3	15.4
6	28.1	22.7	15.7

PCE values given by this simulation ranged from 1% to 1.4%