General specifications for optical elements

Optical element	Distance from source (m)	Angle of operation	Optical area (mm×mm)	Notes
Pre-focusing toroidal mirror, **PFM**	15.1	2° (grazing), fixed	1000×60	p = 15.1 m, q = 15.1 m Si substrate Gold coating
Plane mirror, **PM**	25.2 (pivot point)	15°–2° (grazing), variable	500×20	SX700 mounting Angular rotation for selection of the working point. Si substrate. Gold coating.
VLS Plane grating 1, **PG1**	25.2	150°–176° (subtended), variable	110(130) ×20	G1: 1200 gr/mm, 50–1500 (2000) eV. Diffraction at first external order (β>α). Angular rotation for energy scanning. Si substrate. Gold coating.
VLS Plane grating 2, **PG2**	25.2	150°–176° (subtended), variable	130×20	G2: 400 gr/mm, 20–300 eV Diffraction at first external order (β>α). Angular rotation for energy scanning. Si substrate. Gold coating.
Re-focusing toroidal mirror, **RFM**	31.2	1.5° (grazing), fixed	100×10	p = 1 m, q = 2 m Gold coating

Detailed specifications for each of the optical elements

TOROIDAL MIRROR PFM	
Substrate	
Surface geometry	Toroidal
Material	Si<100>
Dimensions (L×H)	1100 mm×70 mm (±0.5 mm) Width to be defined by the vendor Note: substrate length considered 100 mm longer than optical length; substrate height considered 10 mm higher than optical height. Substrate with different sizes is acceptable, provided it is at least as large as the clear aperture.
Optical surface	
Clear aperture (L×H)	1000 mm × 60 mm
Geometrical parameters Tangential radius Sagittal radius	 432670 mm (±0.5 %) 527.0 mm (±0.25 %)
Surface quality Tangential slope errors Sagittal slope errors	 Guaranteed ≤ 8.0 μrad rms Target ≤ 6.0 μrad rms ≤ 20 μrad rms
Microroughness	< 0.5 nm rms
Coating	Au, no Cr interlayer 30–40 nm thickness
Thermal load	Heat load due to absorption up to 75 W. The designed system for power dissipation has to guarantee on the mirror surface a maximum thermal bump that does not modify the focusing properties more than 10% FWHM.

PLANE MIRROR PM	
Substrate	
Surface geometry	Plane
Material	Si<100>
Dimensions (L×W)	550 mm×30 mm (±0.3 mm) Height to be defined by the vendor Note: substrate length considered 50 mm longer than optical length; substrate width considered 10 mm wider than optical height. Substrate with different sizes is acceptable, provided it is at least as large as the clear aperture. Substrate with longer length has to be previously discussed.
Optical surface	
Clear aperture (L×W)	500 mm×20 mm
Geometrical parameters Tangential radius	>30 km
Surface quality Tangential slope errors Sagittal slope errors	≤0.6 µrad rms ≤2.0 µrad rms
Microroughness	≤0.5 nm rms
Coating	Au, no Cr interlayer 30–40 nm thickness
Thermal load	Heat load due to absorption up to 10 W. The designed system for power dissipation has to guarantee on the mirror surface a maximum thermal bump that does not modify the focusing properties more than 10% FWHM.

TOROIDAL MIRROR RFM	
Substrate	
Surface geometry	Toroidal
Material	Fused silica or equivalent
Dimensions (L×W)	110 mm×20 mm (±0.5 mm) Height to be defined by the vendor Note: substrate length considered 10 mm longer than optical length; substrate height considered 10 mm higher than optical height. Substrate with different sizes is acceptable, provided it is at least as large as the clear aperture.
Optical surface	
Clear aperture (L×W)	100 mm×10 mm
Geometrical parameters Tangential radius Sagittal radius	 50930 mm (±2.5 %) 34.9 mm (±1.5 %)
Surface quality Tangential slope errors Sagittal slope errors	 <10 μrad rms <20 μrad rms
Microroughness	<0.5 nm rms
Coating	Au, no Cr interlayer 30–40 nm thickness
Thermal load	Negligible heat load, but good thermal contact with the support has to be guaranteed.

VLS PLANE GRATING PG1	
Substrate	
Surface geometry	Plane
Material	Silicon
Dimensions (L×W)	120 (140*) mm×30 mm (±0.5 mm) Height to be defined by the vendor Note: substrate length considered 10 mm longer than optical length; substrate height considered 10 mm higher than optical height. Substrate with different size is acceptable, provided it is at least as large as the clear aperture.
Optical surface	
Clear aperture (L×W)	110 (130*) mm×20 mm
Geometrical parameters Tangential radius	>30 km
Surface quality Tangential slope errors Sagittal slope errors	 ≤0.5 μrad rms ≤2.0 μrad rms
Microroughness	<0.5 nm rms
Coating	Au, no Cr interlayer 30–40 nm thickness
Groove spacing	Variable groove spacing with 1200 gr/mm central density $d(y)$: groove density at coordinate y; y=0: grating center $d(y) = d_0 + d_1 y + d_2 y^2 + d_3 y^3$ $d_0 = 1200\ mm^{-1}$ $d_1 = 0.3990\ mm^{-2}$ (±0.0002) $d_2 = 1.0 \cdot 10^{-4}\ mm^{-3}$ ($\pm 0.1 \cdot 10^{-4}$) $d_3 = 0$
Groove geometry	Preferably lamellar, duty cycle 50% Groove depth 5 nm (Blazed gratings may be proposed if supported by optical calculations showing that higher order transmission is sufficiently low.)
Thermal load	Provision for cooling heat load due to absorption up to 3.5 W The designed system for power dissipation has to guarantee on the grating surface a maximum thermal bump that does not modify the focusing properties more than 10% FWHM.

*It might be convenient to make PG1 by 20 mm longer, i.e. of dimensions equal to PG2.

VLS PLANE GRATING PG2	
Substrate	
Surface geometry	Plane
Material	Silicon
Dimensions (L×W)	140 mm×30 mm (±0.5 mm) Height to be defined by the vendor Note: substrate length considered 10 mm longer than optical length; substrate height considered 10 mm higher than optical height. Substrate with different size is acceptable, provided it is at least as large as the clear aperture.
Optical surface	
Clear aperture (L×W)	130 mm×20 mm
Geometrical parameters Tangential radius	>30 km
Surface quality Tangential slope errors Sagittal slope errors	≤0.5 μrad rms ≤2.0 μrad rms
Microroughness	<0.5 nm rms
Coating	Au, no Cr interlayer 30–40 nm thickness
Groove spacing	Variable groove spacing with 400 gr/mm central density $d(y)$: groove density at coordinate y; y=0: grating center $d(y) = d_0 + d_1 y + d_2 y^2 + d_3 y^3$ $d_0 = 400\ mm^{-1}$ $d_1 = 0.1330\ mm^{-2}$ (±0.0002) $d_2 = 3.5 \cdot 10^{-5}\ mm^{-3}$ ($\pm 0.5 \cdot 10^{-5}$) $d_3 = 0$
Groove geometry	Preferably lamellar, duty cycle 50% Groove depth 20 nm (Blazed gratings may be proposed if supported by optical calculations showing that higher order transmission is sufficiently low.)
Thermal load	Provision for cooling heat load due to absorption up to 2 W The designed system for power dissipation has to guarantee on the grating surface a maximum thermal bump that does not modify the focusing properties more than 10% FWHM.

Estimated thermal loads on the different optical elements.

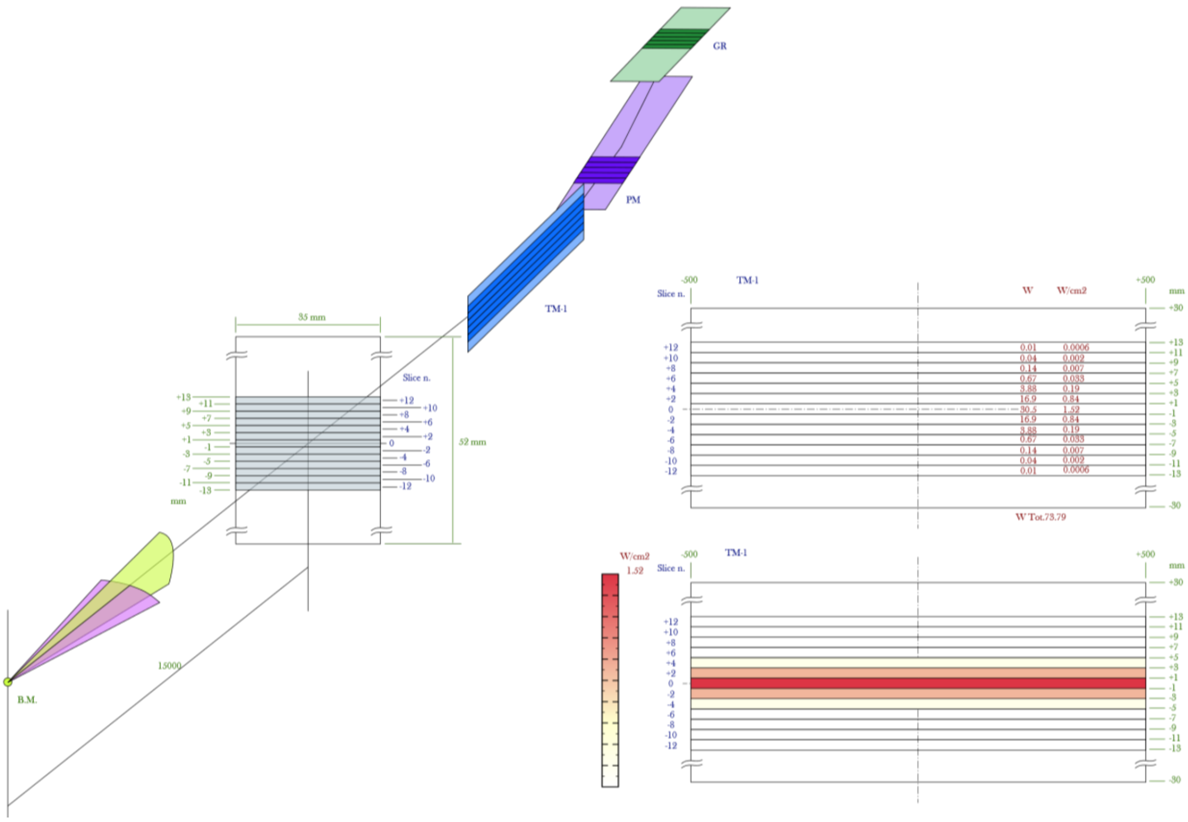
The table summarizes the incident and absorbed power on the PFM, PM, and gratings (PG = PG1 or PG2).

In red the worst cases (more absorbed power) for both the grating configurations are highlighted.

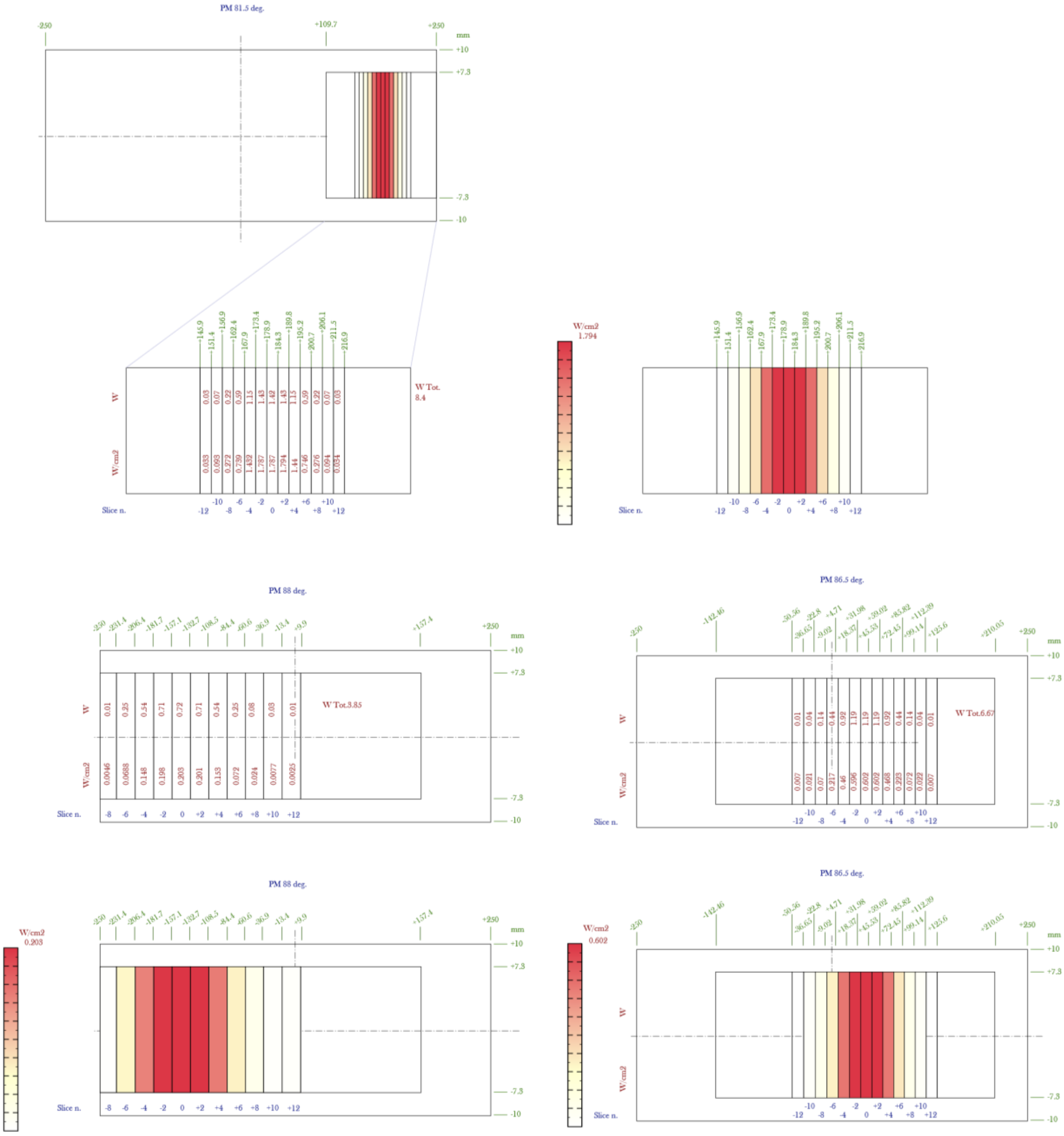
Incident angle PFM	Incident angle PM	Incident angle PG		Incident PFM (W)	Absorbed PFM (W)	Incident PM (W)	Absorbed PM (W)	Incident PG (W)	Absorbed PG (W)
88.0	88.0	87.2	PG1	82.89	73.79	9.10	3.85	5.25	3.05
88.0	81.5	79.8	PG1	82.89	73.79	9.10	8.40	0.70	0.29
88.0	75.0	71.0	PG1	82.89	73.79	9.10	8.71	0.39	0.16
88.0	86.5	85.6	PG2	82.89	73.79	9.10	6.67	2.43	1.54
88.0	80.0	78.7	PG2	82.89	73.79	9.10	8.51	0.59	0.24
88.0	75.0	72.3	PG2	82.89	73.79	9.10	8.71	0.39	0.16

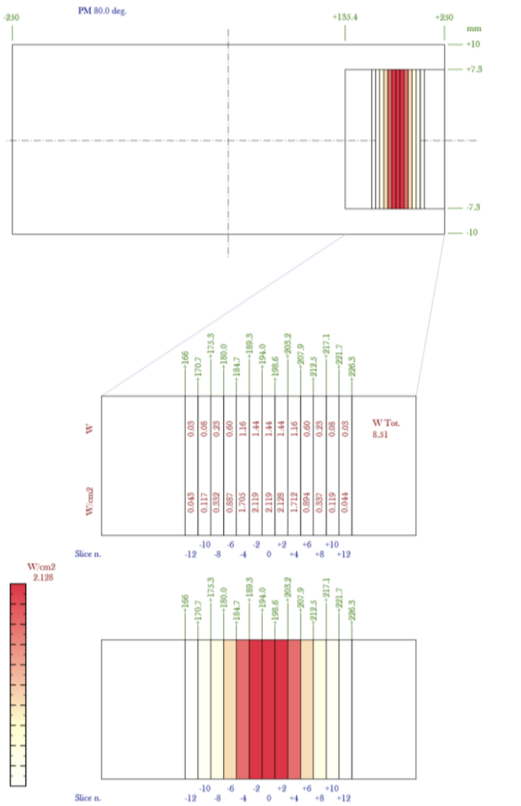
The expected spatial distribution of power and power density is indicated in the following images.

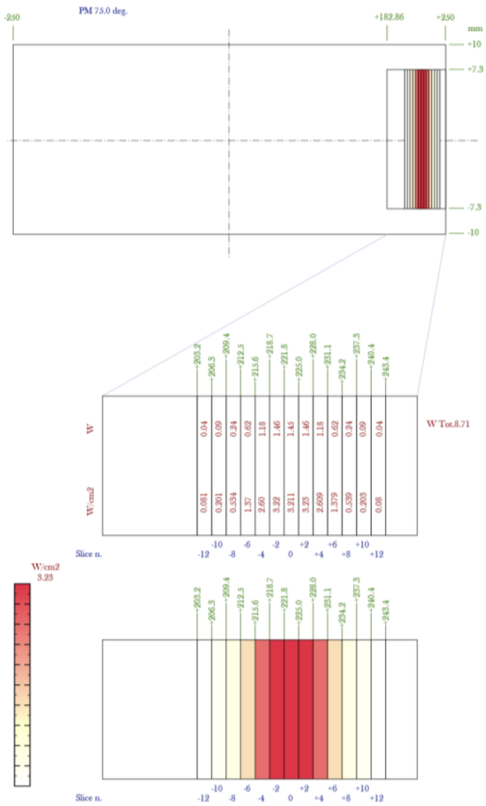
PFM



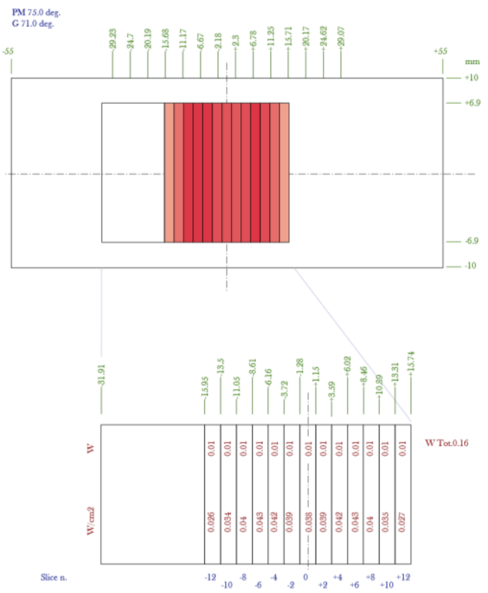
PM

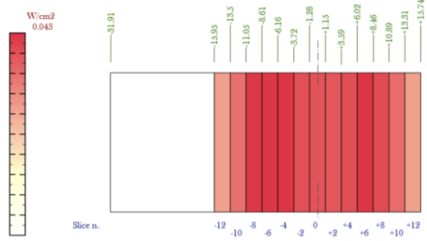

PM 81.5 deg.
W Tot.
8.4
W/cm2
1.794
Slice n.
PM 88 deg.
W Tot.3.85
PM 86.5 deg.
W Tot.6.67
W/cm2
0.203
W/cm2
0.602

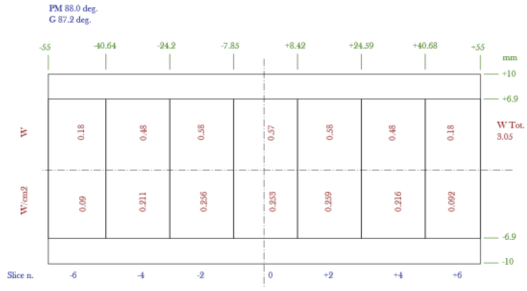

PM 80.0 deg.
W Tot. 8.51
W
W/cm2
Slice n.

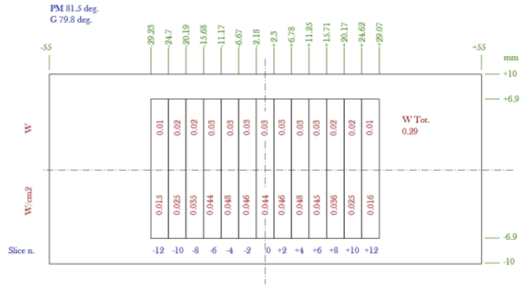

PM 75.0 deg.
W Tot.8.71
W
W/cm2
Slice n.

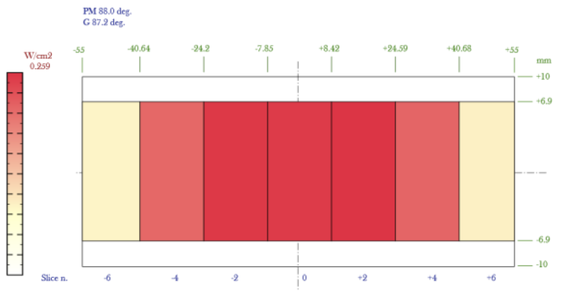
PG

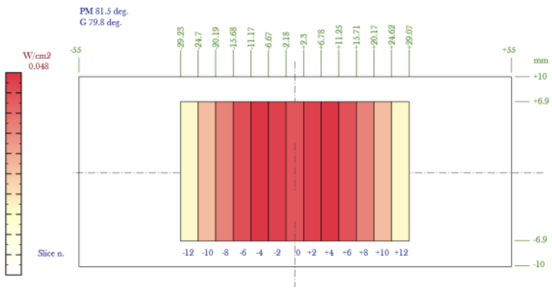

PM 75.0 deg.
G 71.0 deg.
W Tot.0.16
W
W/cm2
Slice n.

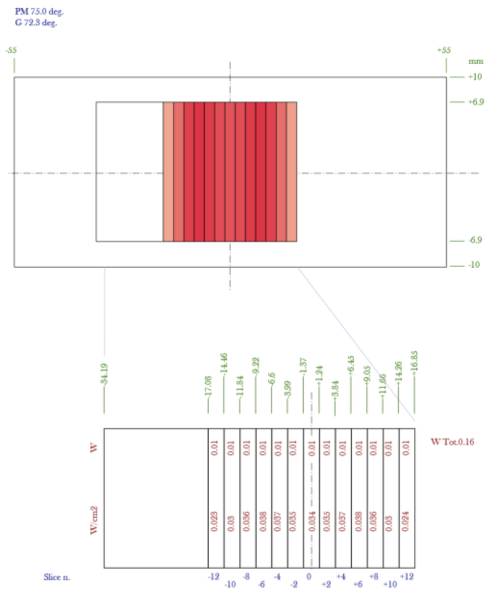

W/cm2
0.043
Slice n.

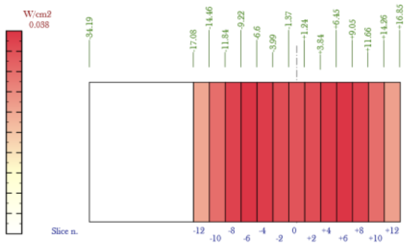

PM 88.0 deg.
G 87.2 deg.
W
W/cm2
W Tot.
3.05
Slice n.
mm

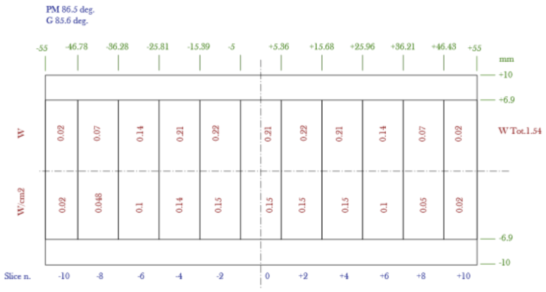

PM 81.5 deg.
G 79.8 deg.
W
W/cm2
W Tot.
0.29
Slice n.
mm

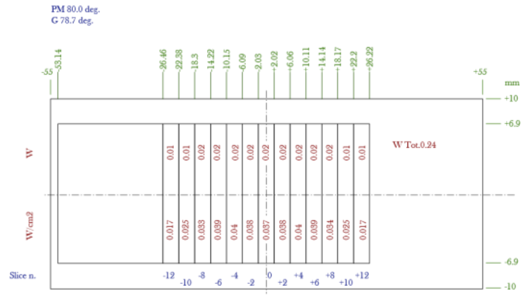

PM 88.0 deg.
G 87.2 deg.
W/cm2
0.259
Slice n.
mm

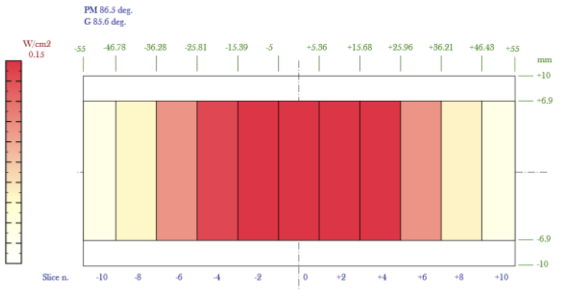

PM 81.5 deg.
G 79.8 deg.
W/cm2
0.048
Slice n.
mm

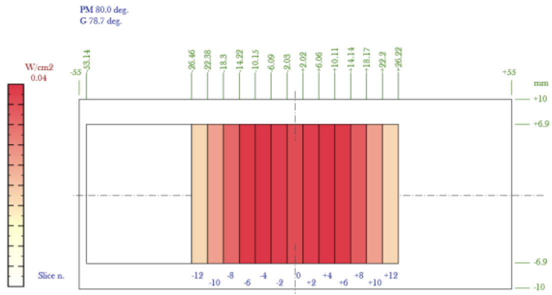

PM 75.0 deg.
G 72.3 deg.
mm
W
W/cm2
W Tot.0.16
Slice n.


W/cm2
0.038
Slice n.


PM 86.5 deg.
G 85.6 deg.
-55 -46.78 -36.28 -25.81 -15.39 -5 +5.36 +15.68 +25.96 +36.21 +46.43 +55
mm
+10
+6.9
-6.9
-10
W
W/cm2
0.02 0.07 0.14 0.21 0.22 0.21 0.22 0.21 0.14 0.07 0.02
0.02 0.048 0.1 0.14 0.15 0.15 0.15 0.15 0.1 0.05 0.02
W Tot.1.54
Slice n.
-10 -8 -6 -4 -2 0 +2 +4 +6 +8 +10


PM 80.0 deg.
G 78.7 deg.
-55 -53.14 -26.46 -22.38 -18.3 -14.22 -10.15 -6.09 -2.03 +2.02 +6.06 +10.11 +14.14 +18.17 +22.2 +26.22 +55
mm
+10
+6.9
-6.9
-10
W
W/cm2
0.01 0.01 0.02 0.02 0.02 0.02 0.02 0.02 0.02 0.02 0.02 0.01 0.01
0.017 0.025 0.033 0.039 0.04 0.038 0.037 0.038 0.04 0.039 0.034 0.025 0.017
W Tot.0.24
Slice n.
-12 -10 -8 -6 -4 -2 0 +2 +4 +6 +8 +10 +12


PM 86.5 deg.
G 85.6 deg.
W/cm2
0.15
-55 -46.78 -36.28 -25.81 -15.39 -5 +5.36 +15.68 +25.96 +36.21 +46.43 +55
mm
+10
+6.9
-6.9
-10
Slice n.
-10 -8 -6 -4 -2 0 +2 +4 +6 +8 +10


PM 80.0 deg.
G 78.7 deg.
W/cm2
0.04
-55 -53.14 -26.46 -22.38 -18.3 -14.22 -10.15 -6.09 -2.03 +2.02 +6.06 +10.11 +14.14 +18.17 +22.2 +26.22 +55
mm
+10
+6.9
-6.9
-10
Slice n.
-12 -10 -8 -6 -4 -2 0 +2 +4 +6 +8 +10 +12