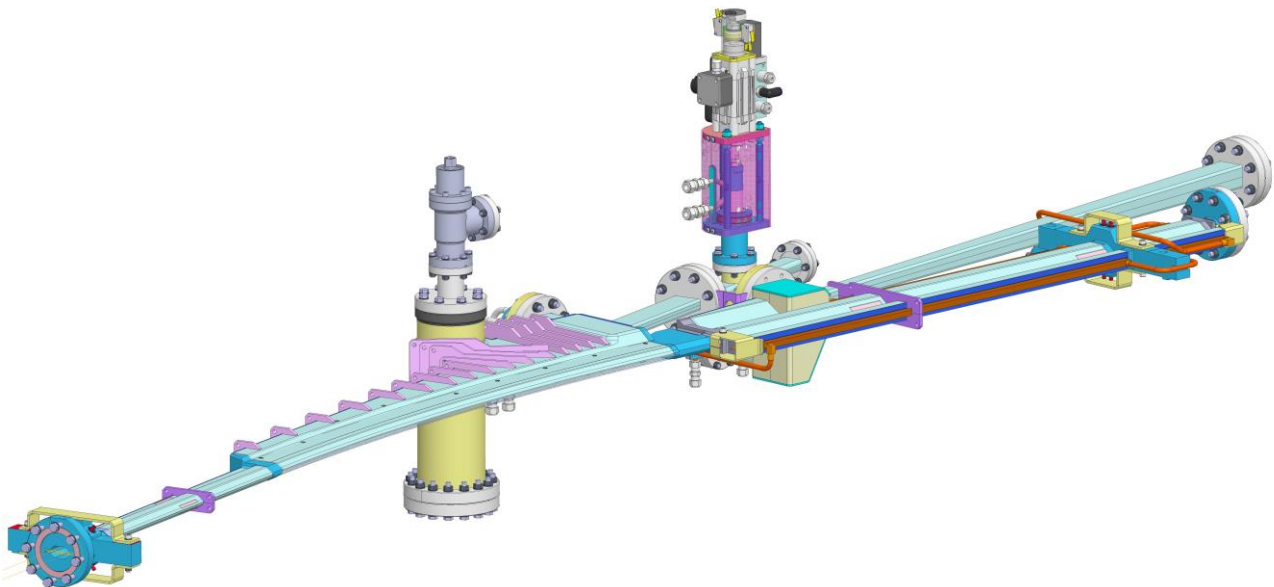


Design Considerations

3-Pole-Wiggler - Raytracing and Heat Absorbers



Version 0.1

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3-Pole Wiggler Frontend @ SOLARIS

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3-Pole Wiggler Frontend @ SOLARIS

1 INTRODUCTION

The goal of this design study is to investigate the heat dissipation caused by the new 3-pole-wiggler in the downstream components VK1-Chamber (drawing number 725-10-00), VK5-Chamber (drawing number 725-14-00), absorber HAA (725-42-00), and crotch absorber (drawing number 725-61-00). Two positions for the 3-pole-wiggler are considered: in the middle of the straight section or shifted by 638 mm downstream. These preliminary results showed, that the photon beam causes a not negligible heat dissipation on the inboard wall at the beginning of VK1 chamber. We proposed a modification of the VK1 design, that adds a water-cooled channel at this position. Due to space constraints of the surrounding infrastructure (e.g. steering magnets), this modification is not feasible. Therefore, SOLARIS proposed a third position, where the 3-pole-wiggler is shifted 867 mm from the centre of the straight section (downstream). This third position is added in the raytracing section.

We obtain the following results:

- Raytracing shows fairly low power densities, low total power, but a large horizontal opening angle.
- FEA shows that heat dissipation at the crotch absorber and absorber HAA is low. No change is needed for these components as well as VK5 chamber.
- Using the third considered position, no heat is dissipated by the photon beam in its nominal position.
- During beam missteer, small amounts of power might still be dissipated (for a short time) on the inboard wall of VK1 at the beginning of the bending section. We advise to monitor the temperature of this section with thermocouples.
- Additional cooling of this region with a small flow of room temperature air is advised.

3-Pole Wiggler Frontend @ SOLARIS

2 RAYTRACING

2.1 INPUT PARAMETER

The following parameters were used for the machine (SOLARIS) and the insertion device (3-pole-wiggler):

Legend:

Symbol:	✓	/	✗	1e-1
Meaning:	Given/specified	Not specified	Doubtful	1×10^{-1}

2.1.1 MACHINE: SOLARIS – STRAIGHT SECTION

Source: Appendix 2 Proposal BINP of SCMW for SOLARIS June 2020.pdf – page 4f

Parameter	Unit	Data	Customer spec.
Accelerator Type		Storage Ring	✓
Electron energy	GeV	1.5	✓
Average current	mA	500	✓
Circumference	m	96	✓
Bunches		32	✓
σ_z (bunch length, rms)	mm	60	✓
Peak current	A	9.97355	/
Natural emittance	m • rad	5.982e-9	✓
Coupling constant (ϵ_y/ϵ_x)		0.01	✓
Horizontal emittance ϵ_x	m • rad	5.923e-9	/
Vertical emittance ϵ_y	m • rad	5.923e-11	/
Energy spread (rms)		0.000745	✓
Betatron func. β_x	m	5.697	✓
Betatron func. β_y	m	2.82	✓
Lattice func. α_x		0.0038	✓
Lattice func. α_y		0.0058	✓
Dispersion func. η_x	m	0	✓
Dispersion func. η_y	m	0	✓
Dispersion func. η_x'		0	✓
Dispersion func. η_y'		0	✓

3-Pole Wiggler Frontend @ SOLARIS

e- beam size σ_x	mm	0.1837	/
e- beam size σ_y	mm	0.01292	/
e- beam divergence $\sigma_{x'}$	mrاد	0.03224	/
e- beam divergence $\sigma_{y'}$	mrاد	4.583e-3	/

Table 1: Machine parameters – straight section

2.1.2 LIGHT SOURCE: 3-POLE-WIGGLER

Source: 6_A3_23_K06-MADE_2023-05-15.pdf;

Parameter	Unit	Data	Customer spec.
Light source		3-pole-wiggler	✓
Max. gap value	mm	11	/
Magnetic field B	T	2.936	✓
Total power	kW	0.37	/

Table 2: Light source parameters

3-Pole Wiggler Frontend @ SOLARIS

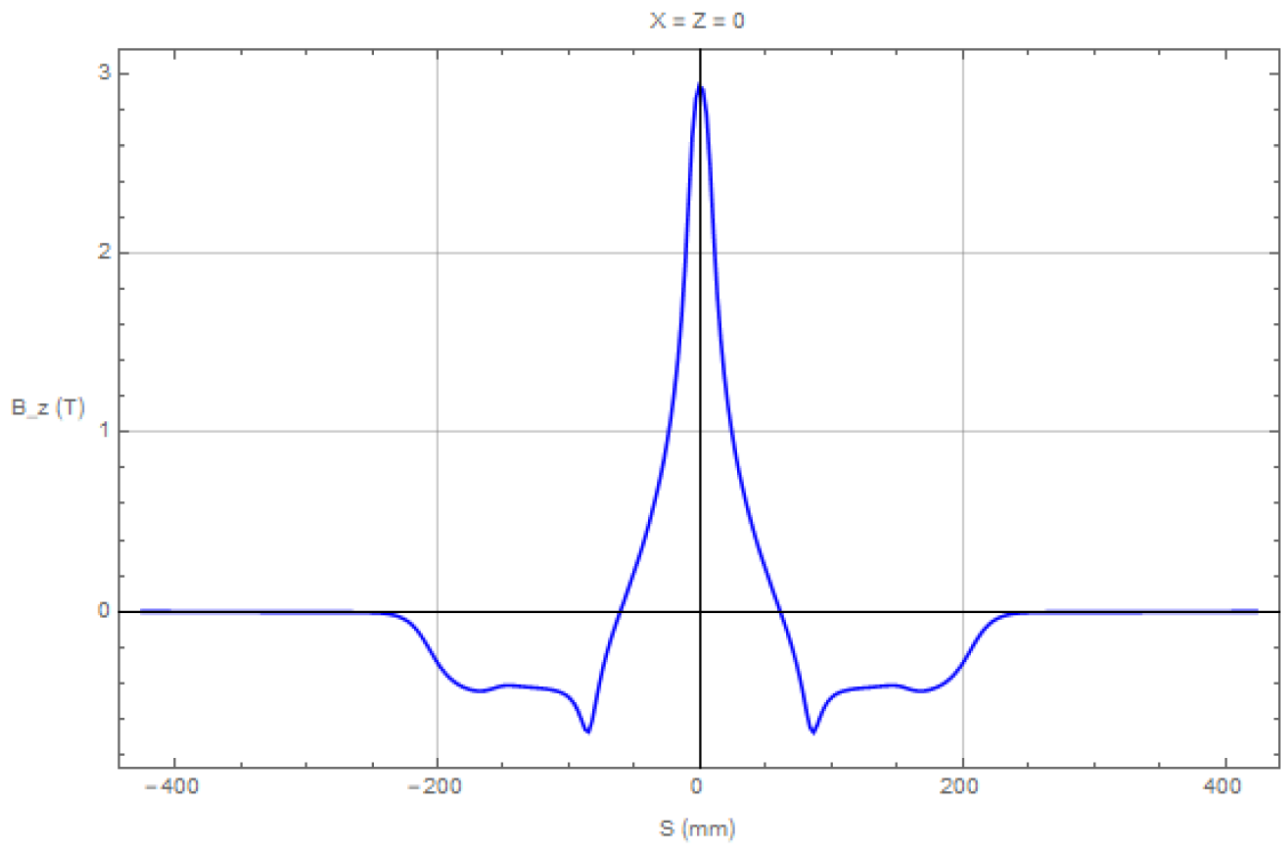


Figure 1 Magnetic field profile of 3-pole-wiggler

3-Pole Wiggler Frontend @ SOLARIS

2.1.3 DISTANCES

Raytracing was performed at the following positions (CSS = center of straight section):

Parameter	Unit	Data	Customer spec.
Beam foot print 1: Start VK1 chamber			
Distance from CSS	mm	1667.5	✓
Beam foot print 2: Start of bending section			
Distance from CSS	mm	2320.1	✓
Beam foot print 3: Crotch absorber			
Distance from CSS	mm	3260.0	✓
Beam foot print 4: Absorber HAA			
Distance from CSS	mm	3730.0	✓
Beam foot print 5: End VK1 chamber / Start VK5 chamber			
Distance from CSS	mm	3636.0	✓
Beam foot print 6: End VK5 chamber			
Distance from CSS	mm	3937.0	✓
Beam foot print 7: Beam position monitor SPM			
Distance from CSS	mm	5000.0	approx.

Table 3 Distances from CSS for beam foot print calculations

2.1.4 BEAM OFFSETS

The beam position changes during injection, ramping, etc. The following table shows the relevant deviations from the nominal position. Also, during (future) top-up mode a horizontal oscillation with larger amplitude between -17mm and +15mm takes place, until the beam reaches the kicker magnet.

Source: Wiggler Straight Section v2.pdf – page 17f

Parameter	Unit	Data	Customer spec.
Injection, ramping, stored beam process			
Delta y	mm	1.5	✓
Delta x	mm	0.3	✓
Beam oscillation in 1st straight section during top-up mode			
Delta x	mm	-17 ... +15	✓
Delta x after kicker	mm	+/-8 (+/-5)	✓

Table 4 Deviations from nominal beam position

3-Pole Wiggler Frontend @ SOLARIS

2.2 CALCULATION (WIGGLER SHIFTET 867 MM DOWNSTREAM)

The power dissipation inboard of VK1 is a potential danger and might heat the vacuum chamber significantly. To mitigate this effect, the 3-pole-wiggler is shifted by 867 mm downstream with respect to the center of the straight section. Again, the nominal photon beam without missteer or offset is shown.

2.2.1 START VK1

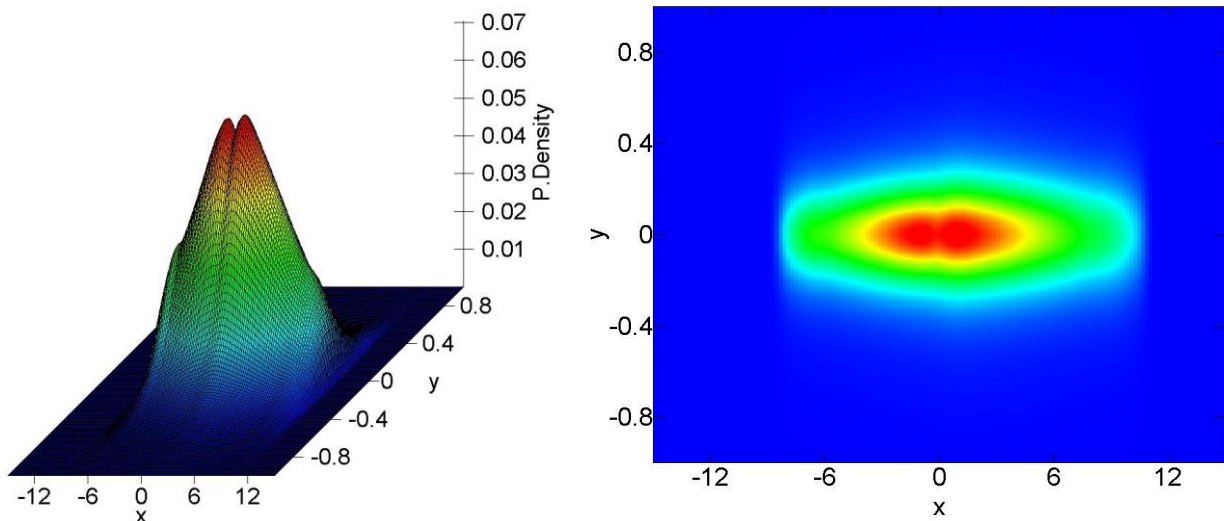


Figure 2 Raytracing at start of VK1 chamber

Parameter	Value
Maximum power density	70.4 W/mm ²
Total power	370 W
Maximum power density of block beam	0 W/mm ²
Total power of blocked beam	0 W

The start of VK1 does not get hit. Outer ellipsoid shows, where the beam power density drops to 1% of the maximum power density (=edge of beam). Red arrows mark the distance of the beam edge to the nearest chamber wall. Inner ellipsoids show 25%, 50%, and 75% of maximum power density.

3-Pole Wiggler Frontend @ SOLARIS

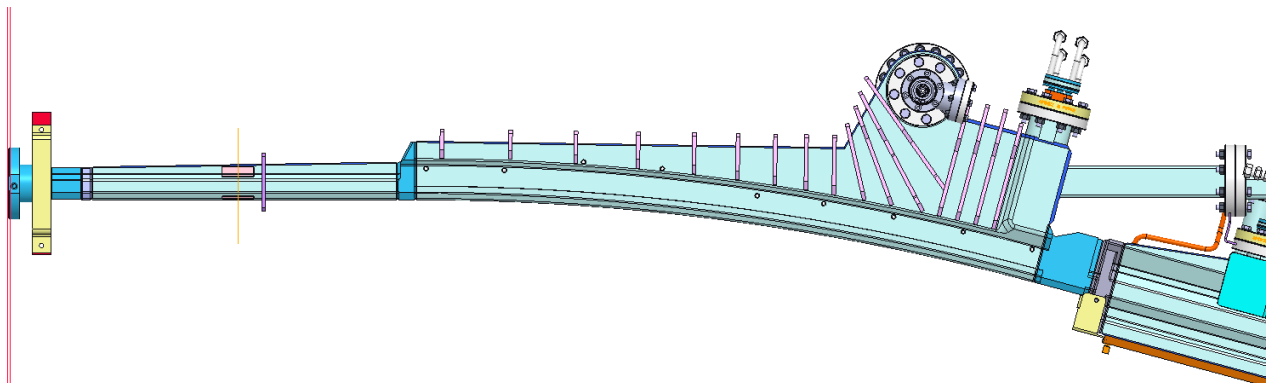
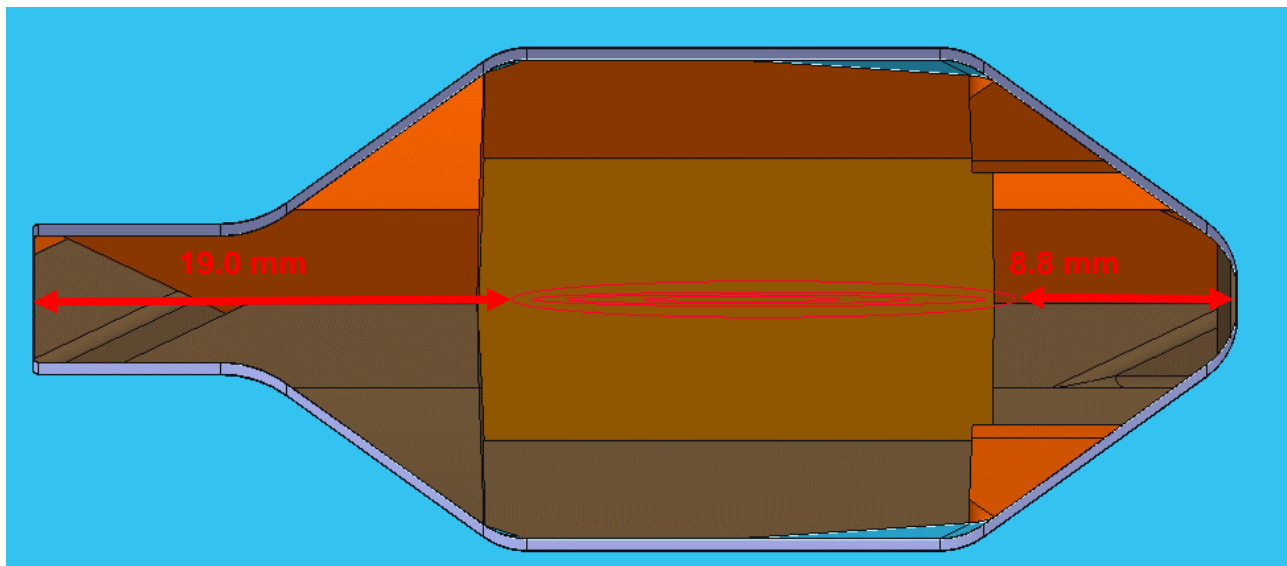
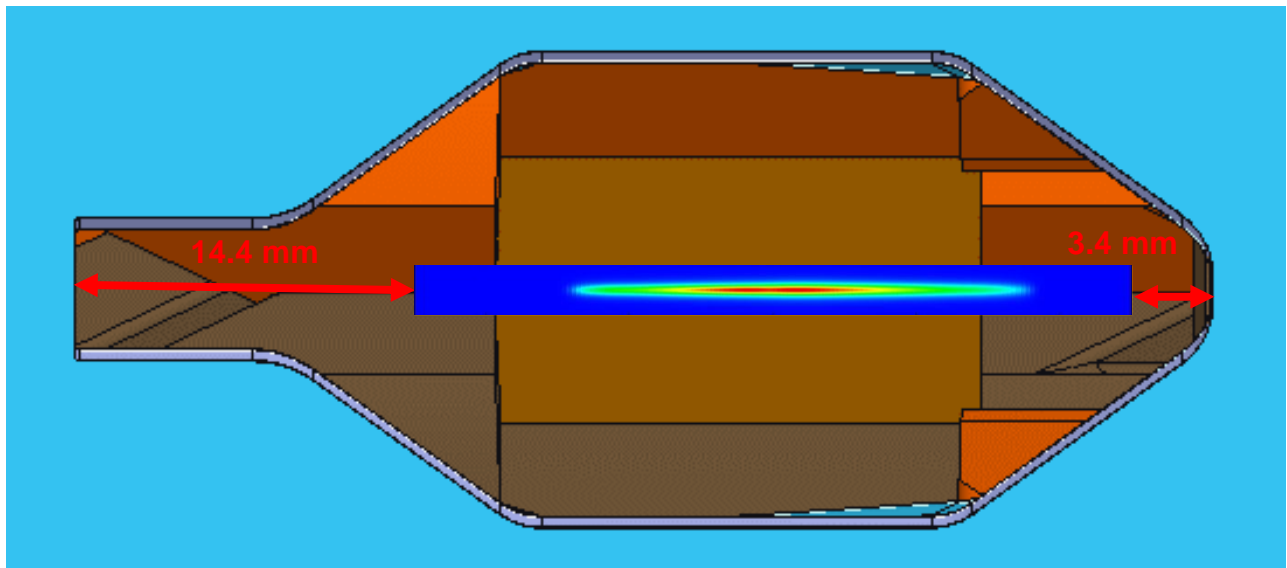


Figure 3 Beam at start of VK1 chamber

3-Pole Wiggler Frontend @ SOLARIS

2.2.2 START BENDING

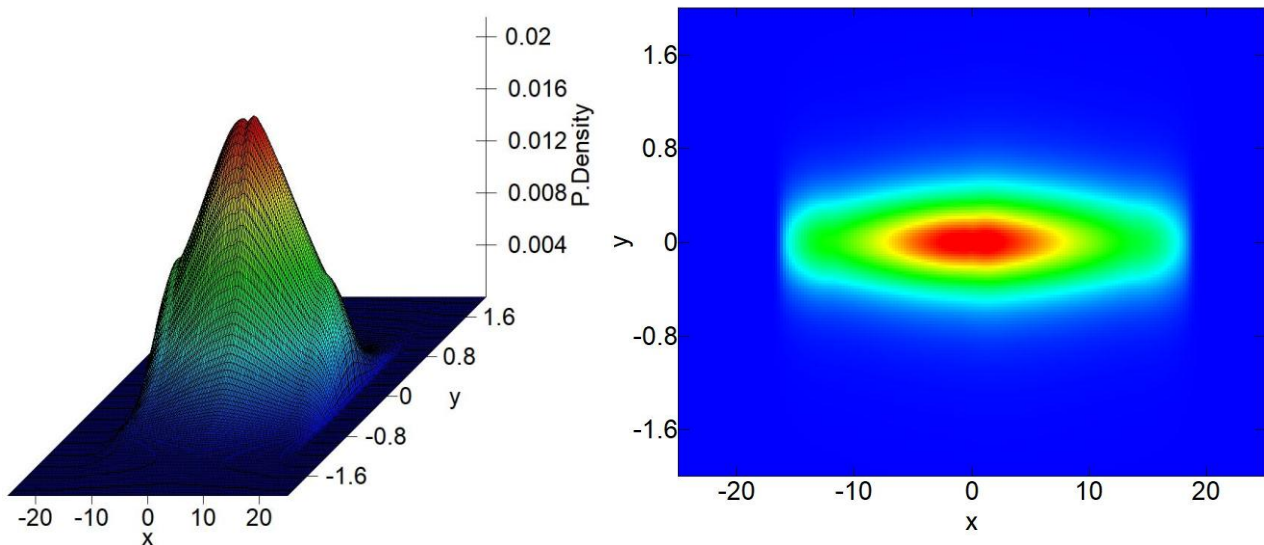


Figure 4 Raytracing at start of bending section

Parameter	Value
Maximum power density	21.5 W/mm ²
Total power	370 W
Maximum power density of block beam	0 W/mm ²
Total power of blocked beam	0 W

VK1 does not get hit by 1 mm. Outer ellipsoid shows, where the beam power density drops to 1% of the maximum power density (=edge of beam). Red arrows mark the distance of the beam edge to the nearest chamber wall. Inner ellipsoids show 25%, 50%, and 75% of maximum power density.

The following table shows the approx. power dissipated on the wall of VK1 chamber during horizontal beam missteer.

Horizontal missteer in mm	Power in W	Power density in W/mm ²
0	0	0
1	0.15	0.34
2	2.33	4.12
3	6.63	6.02
4	12.24	7.69
5	18.80	8.79

3-Pole Wiggler Frontend @ SOLARIS

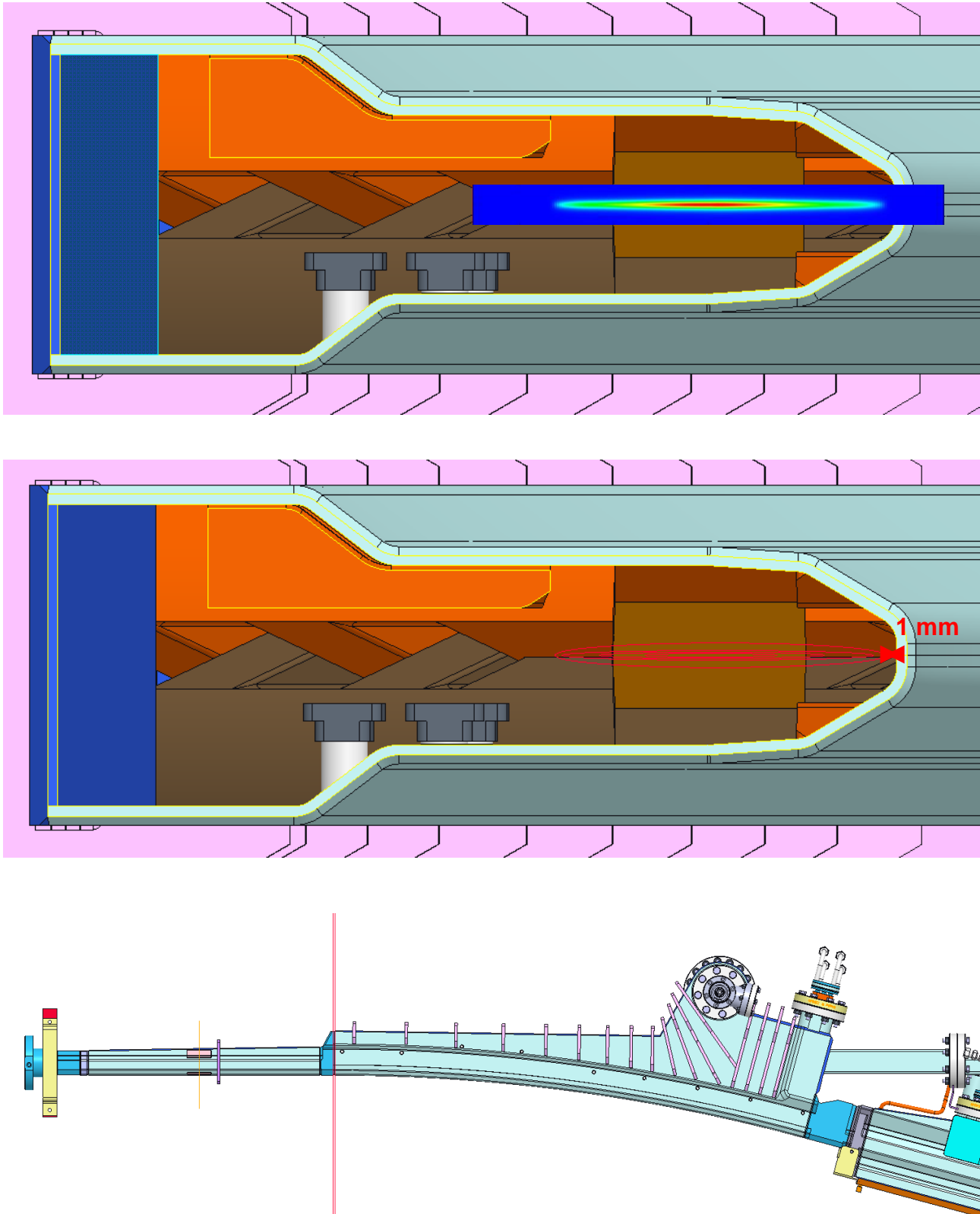


Figure 5 Beam at start of bending section

3-Pole Wiggler Frontend @ SOLARIS

2.2.3 CROTCH ABSORBER

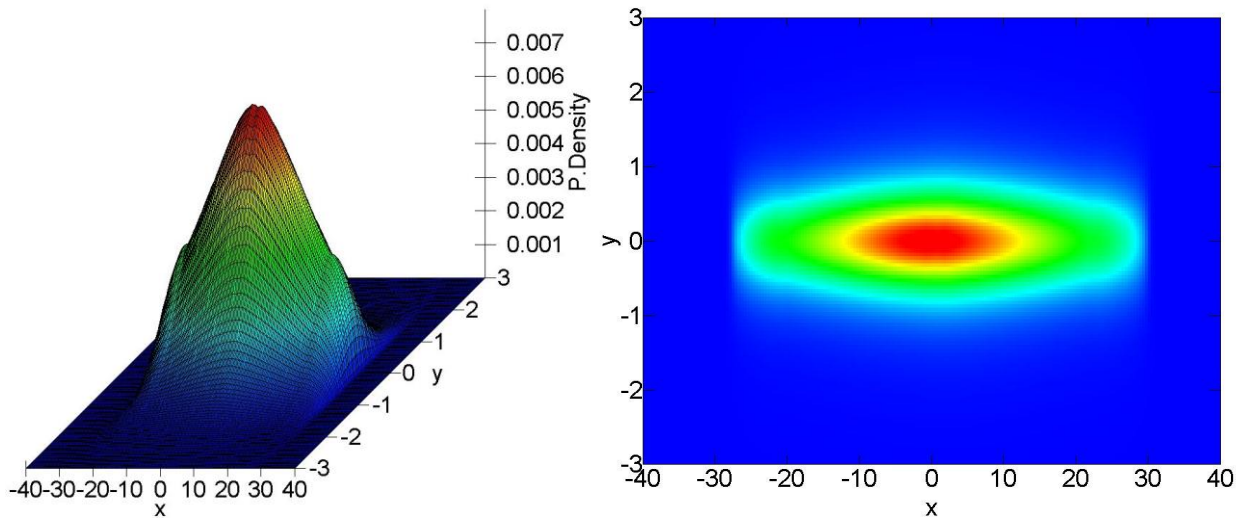


Figure 6 Raytracing at crotch absorber

Parameter	Value
Maximum power density	8.0 W/mm ²
Total power	370 W
Maximum power density of block beam	6.2 W/mm ²
Total power of blocked beam	185 W
Total power of transmitted beam	185 W

The shift of the 3-pole-wiggler increases the maximum power density of the crotch absorber, while also increasing the transmitted power. The values are still moderate. Outer ellipsoid shows, where the beam power density drops to 1% of the maximum power density (=edge of beam). Inner ellipsoids show 25%, 50%, and 75% of maximum power density.

3-Pole Wiggler Frontend @ SOLARIS

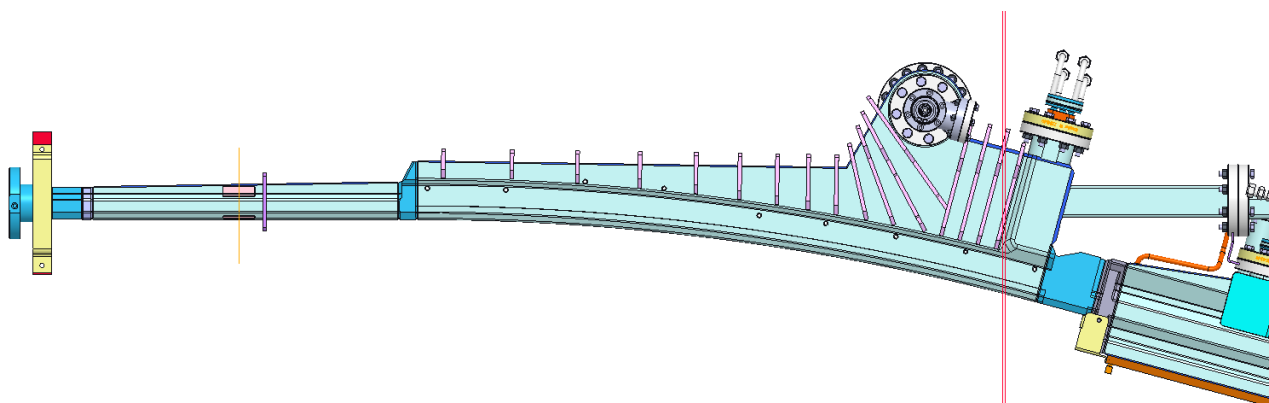
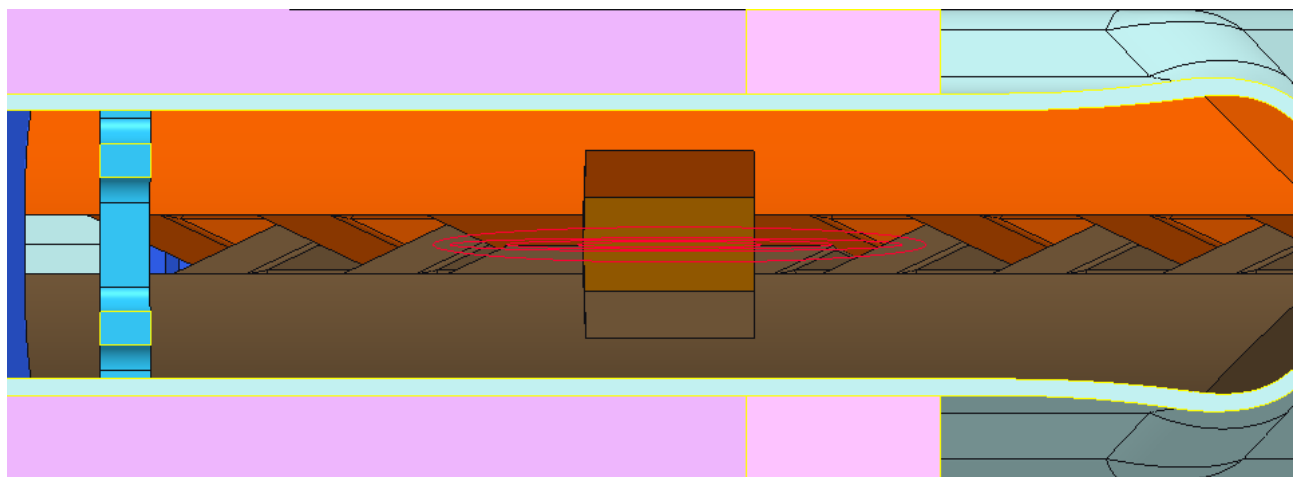
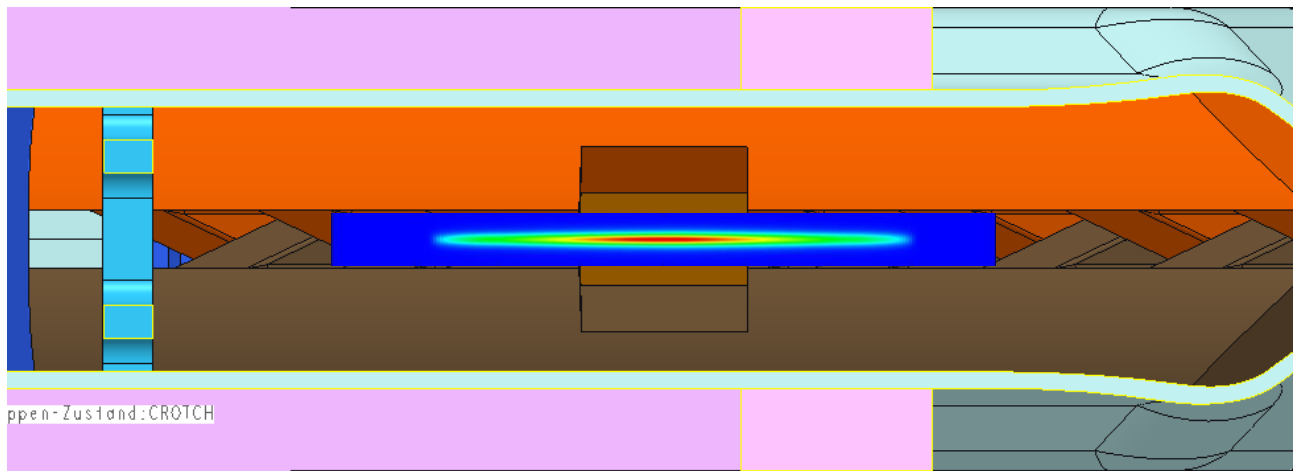


Figure 7 Beam at crotch absorber

3-Pole Wiggler Frontend @ SOLARIS

2.2.4 ABSORBER HAA

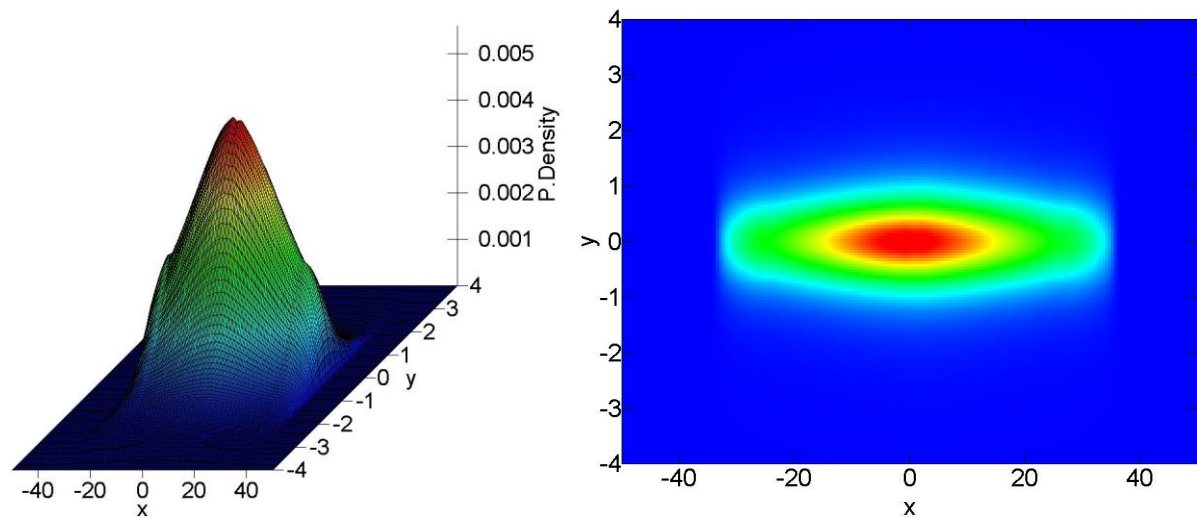


Figure 8 Raytracing at absorber

Parameter	Value
Maximum power density	5.6 W/mm ²
Total power	185 W
Maximum power density of block beam	5.6 W/mm ²
Total power of blocked beam	185 W

3-Pole Wiggler Frontend @ SOLARIS

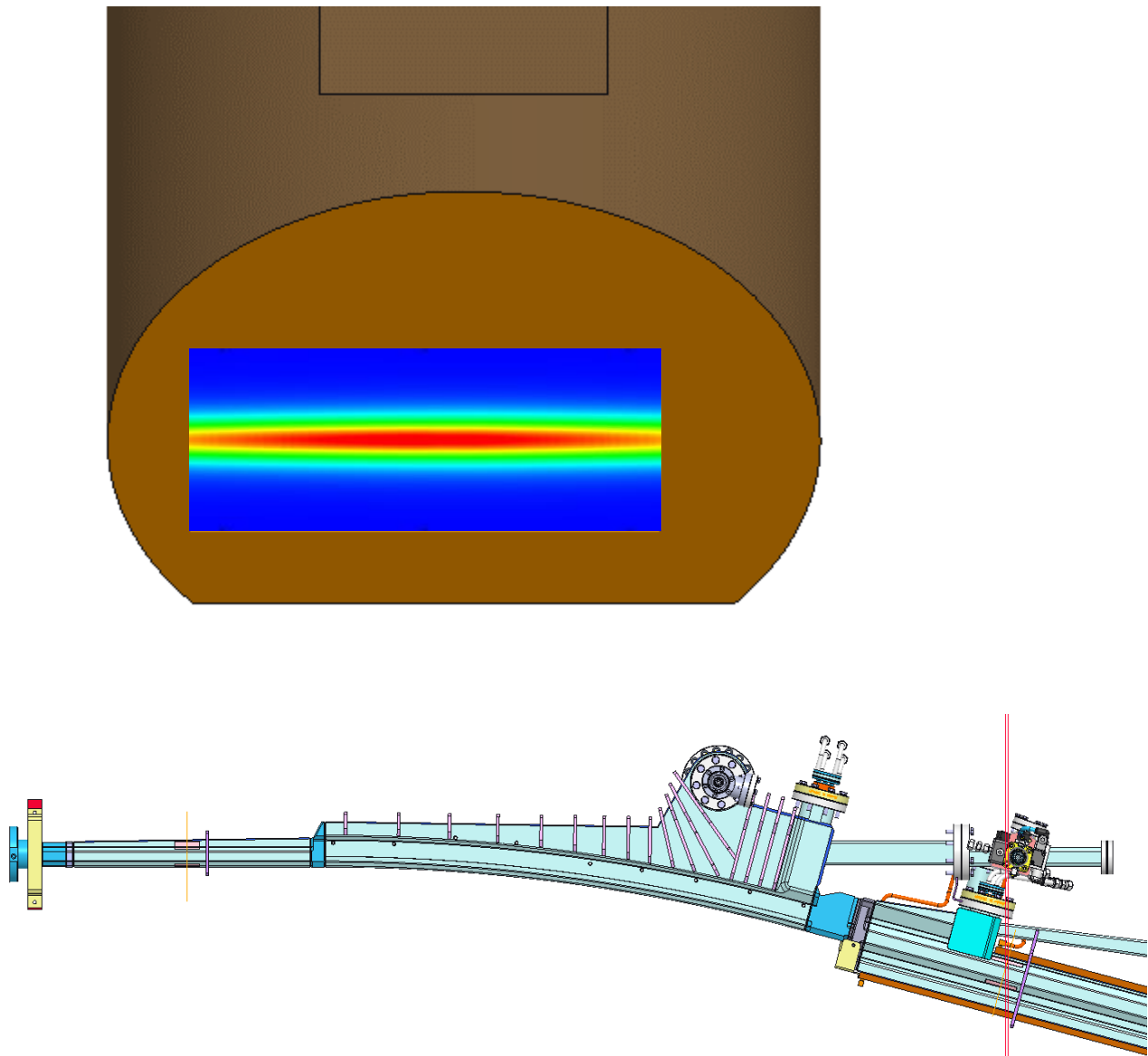


Figure 9 Beam at absorber

3-Pole Wiggler Frontend @ SOLARIS

2.2.5 END VK1/START VK5

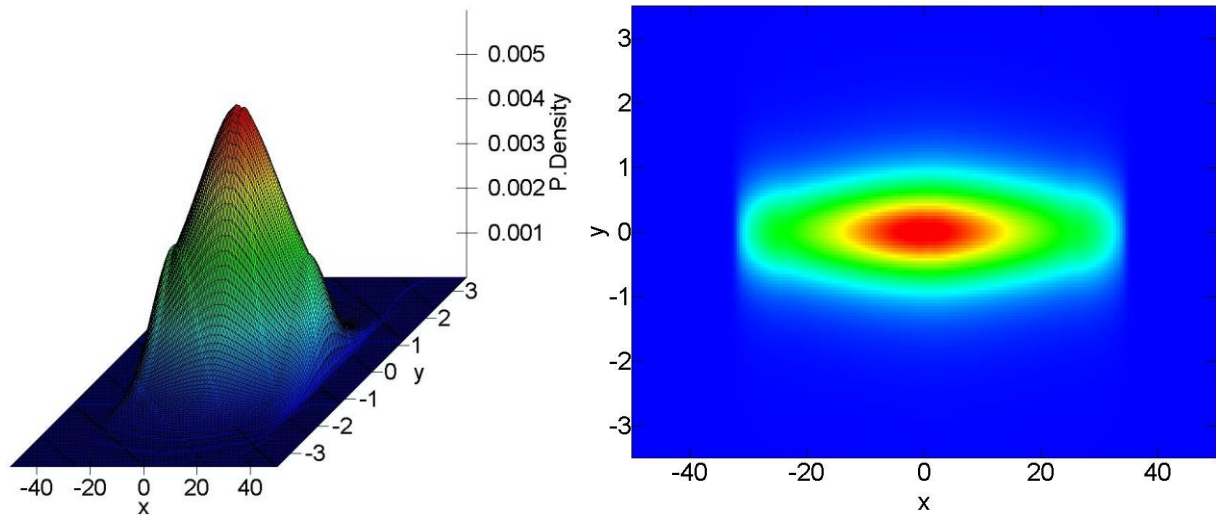


Figure 10 Raytracing at end of VK1 chamber

Parameter	Value
Maximum power density	6.0 W/mm ²
Total power	185 W

The photon beam is collimated by the crotch absorber. We show the distance of this collimated beam to the nearest chamber wall (red arrows in picture above).

3-Pole Wiggler Frontend @ SOLARIS

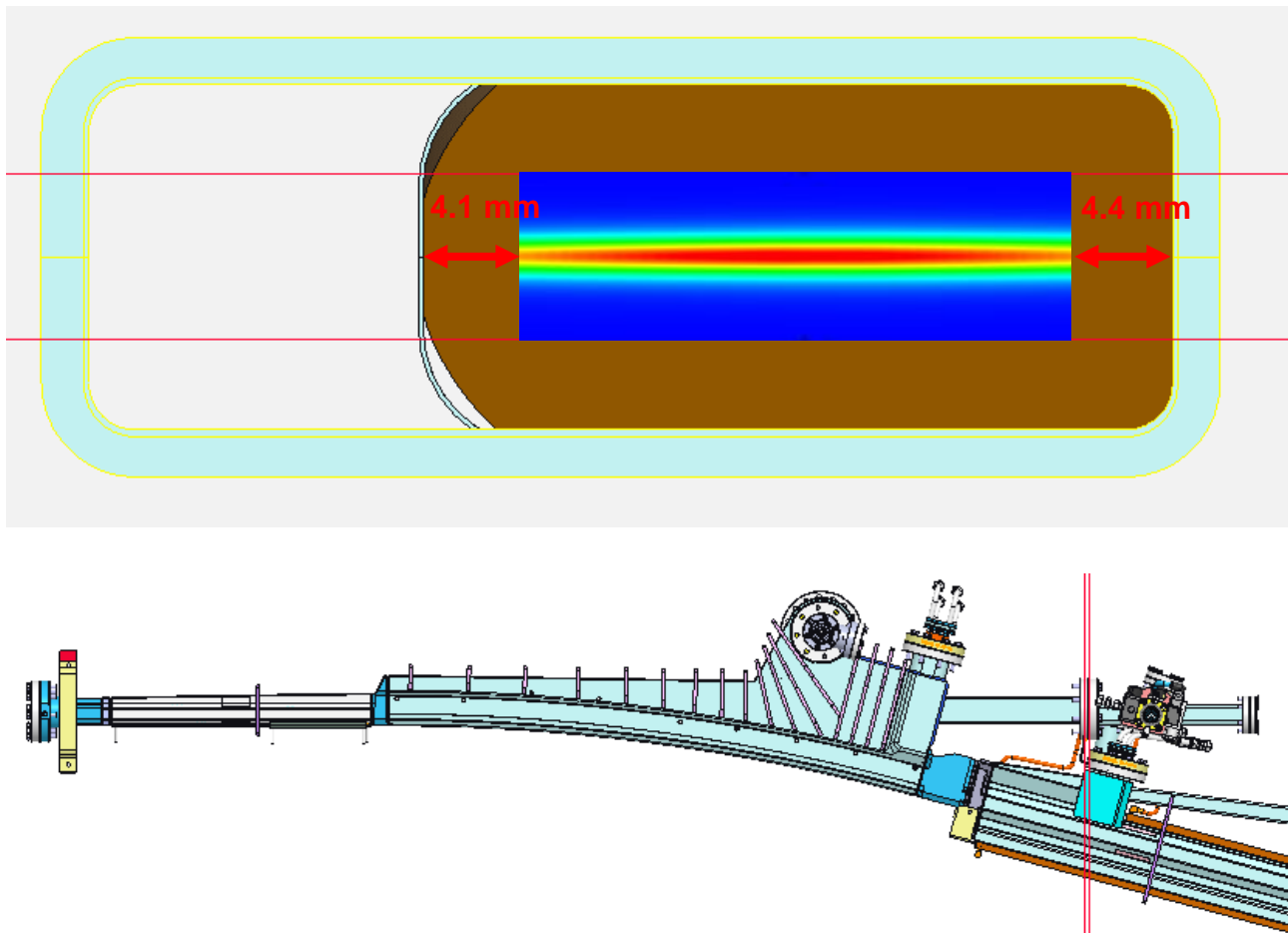


Figure 11 Beam at end of VK1 chamber (looking downstream)

3-Pole Wiggler Frontend @ SOLARIS

2.2.6 END VK5

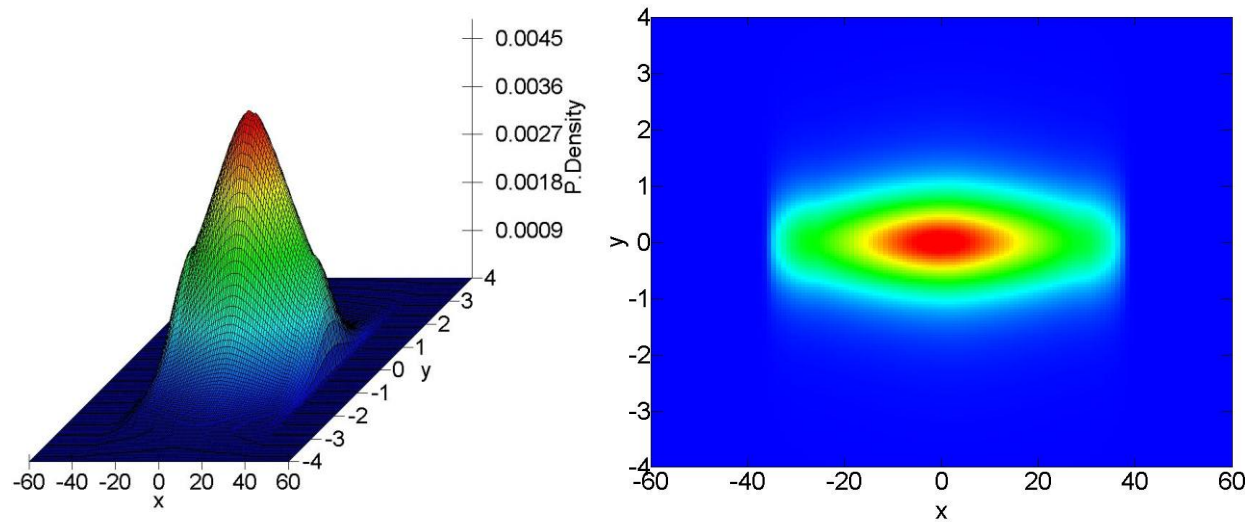


Figure 12 Raytracing at end of VK5 chamber

Parameter	Value
Maximum power density	4.9 W/mm ²
Total power	185 W

The photon beam is collimated by the crotch absorber. We show the distance of this collimated beam to the nearest chamber wall (red arrows in picture above).

3-Pole Wiggler Frontend @ SOLARIS

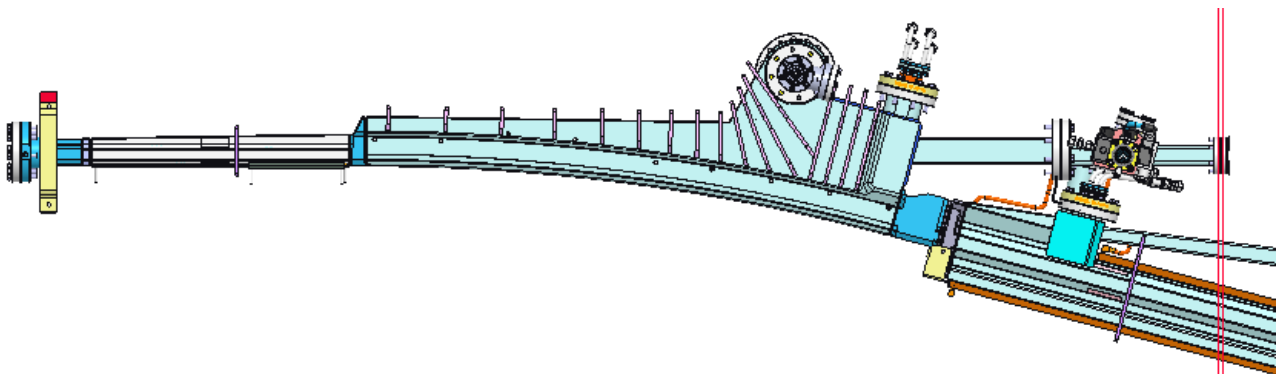
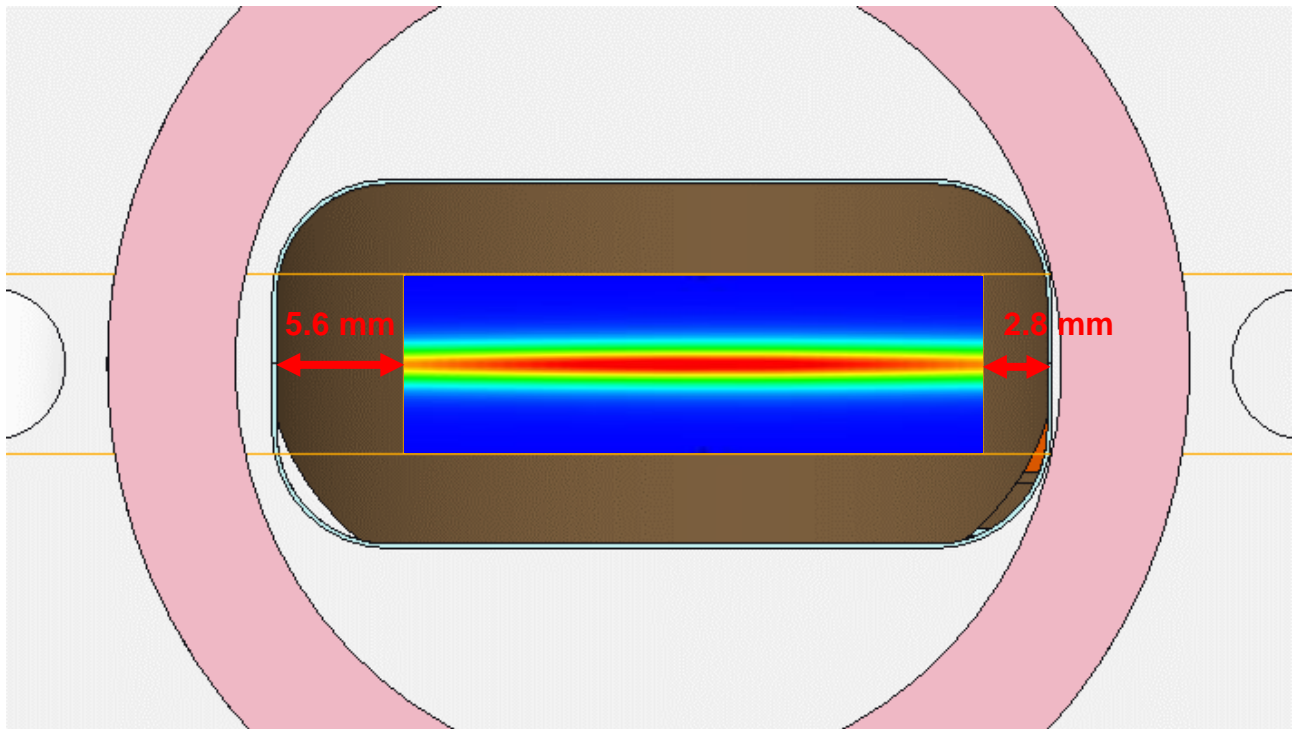


Figure 13 Beam at end of VK5 chamber (looking towards the source)

3-Pole Wiggler Frontend @ SOLARIS

2.2.7 BEAM POSITION MONITOR

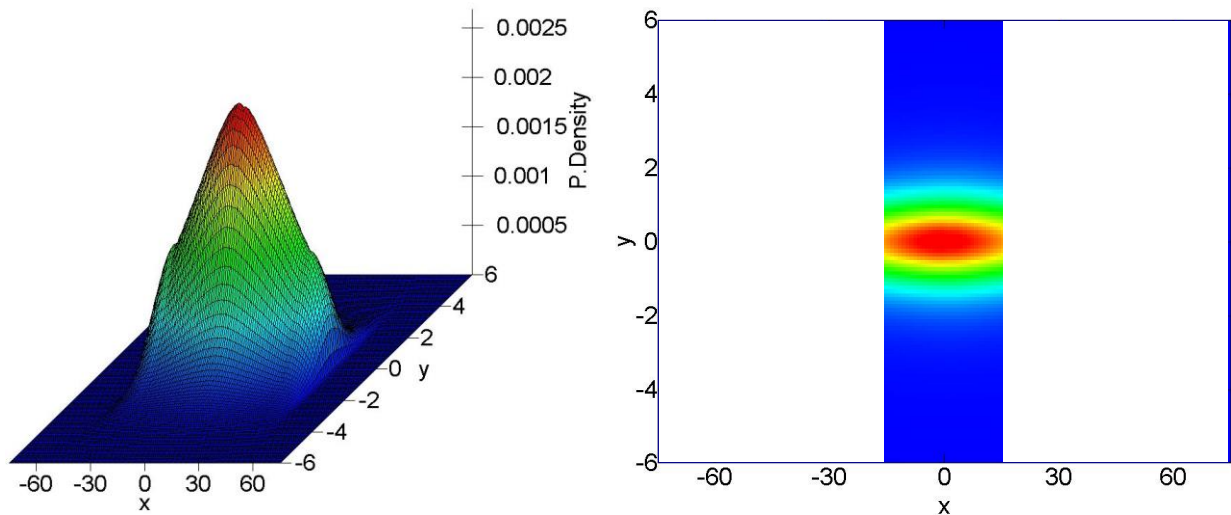


Figure 14 Raytracing at beam position monitor

Parameter	Value
Maximum power density	2.7 W/mm ²
Total power (transmitted through crotch)	185 W

3-Pole Wiggler Frontend @ SOLARIS

2.2.8 SUMMARY OF RAYTRACING

The following table shows a summary of the raytracing for the given position of the insertion device. We show the vertical and horizontal size of the photon beam, when power density reaches 75% of the maximum power density (50%, 25%, 1%). For these values, no collimation is assumed.

Position	Direction	75% mm	50% mm	25% mm	1% mm
Start VK1 $p_{\max}=70.4 \text{ W/mm}^2$	x	-3.6/+4.2	-6.6/+7	-8/+10	-8.8/+11.2
	y	± 0.11	± 0.18	± 0.27	± 0.72
Start Bending $p_{\max}=21.5 \text{ W/mm}^2$	x	-6.75/+7.25	-11.5/+12.25	-15.5/+17.5	-16.75/+19.25
	y	± 0.2	± 0.325	± 0.5	± 1.3
Crotch Absorber $p_{\max}=8 \text{ W/mm}^2$	x	-10.8/+11.2	-19.2/+19.6	-26/+28	-28/+30.8
	y	± 0.35	± 0.55	± 0.8	± 2.1
Absorber HAA $p_{\max}=5.6 \text{ W/mm}^2$	x	-13/+13.5	-23/+23.5	-31.5/+33.5	-34/+36.5
	y	± 0.4	± 0.65	± 0.95	± 2.6
End VK1 $p_{\max}=6.0 \text{ W/mm}^2$	x	± 12.5	± 22	± 30.5	± 33
	y	± 0.4	± 0.6	± 0.9	± 2.5
End VK5 $p_{\max}=4.9 \text{ W/mm}^2$	x	± 14	± 24	± 34	± 38
	y	± 0.4	± 0.65	± 1	± 2.7
XBPM $p_{\max}=2.7 \text{ W/mm}^2$	x	± 19	± 33	± 47	± 51
	y	± 0.6	± 0.9	± 1.4	± 3.8

The photon beam is collimated by the crotch absorber. The table below shows the horizontal size of the collimated beam. The opening angle is 8.4 mrad

Position	Δx in mm
Crotch Absorber	20.1
Absorber HAA	24.0
End VK1	23.3
End VK5	25.8
XBPM	34.7

3-Pole Wiggler Frontend @ SOLARIS

2.3 FEA FOR ABSORBER HAA

FEA geometry:

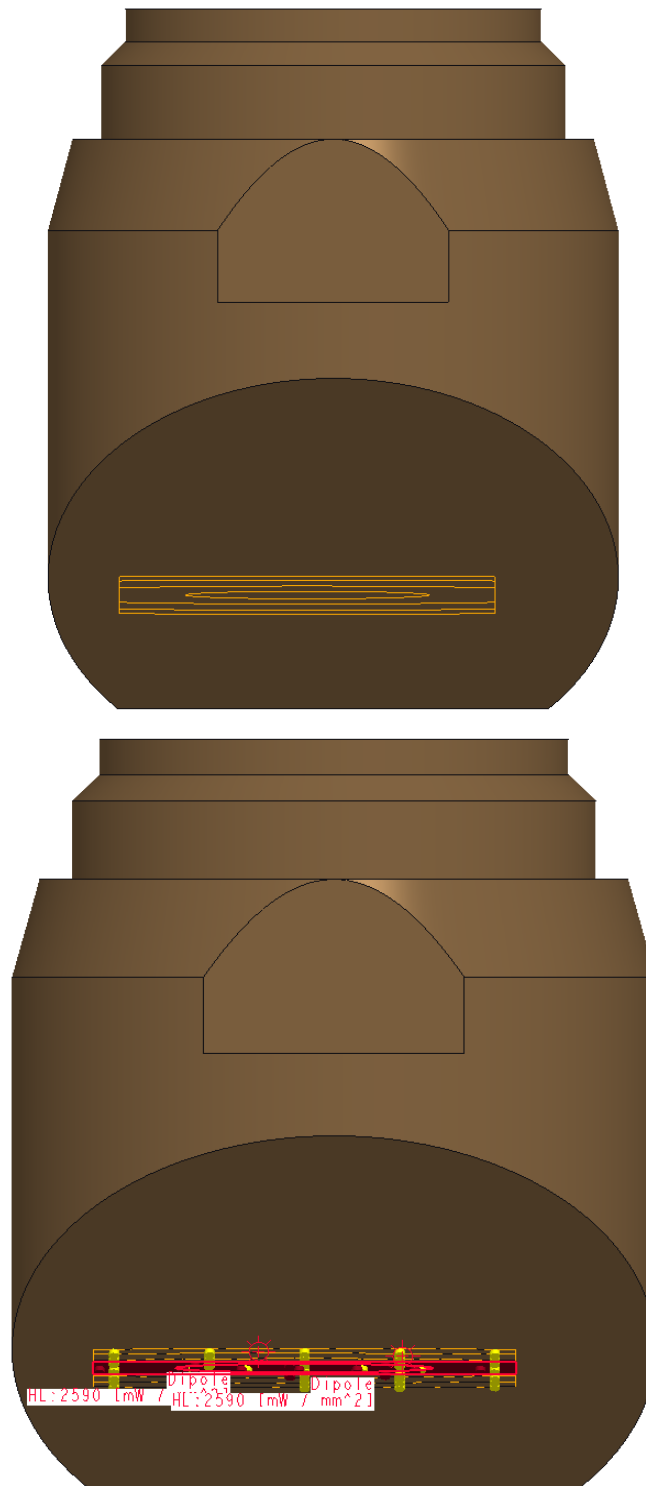


Figure 15 FEA geometry and simplified beam foot print, dipole beam load

3-Pole Wiggler Frontend @ SOLARIS

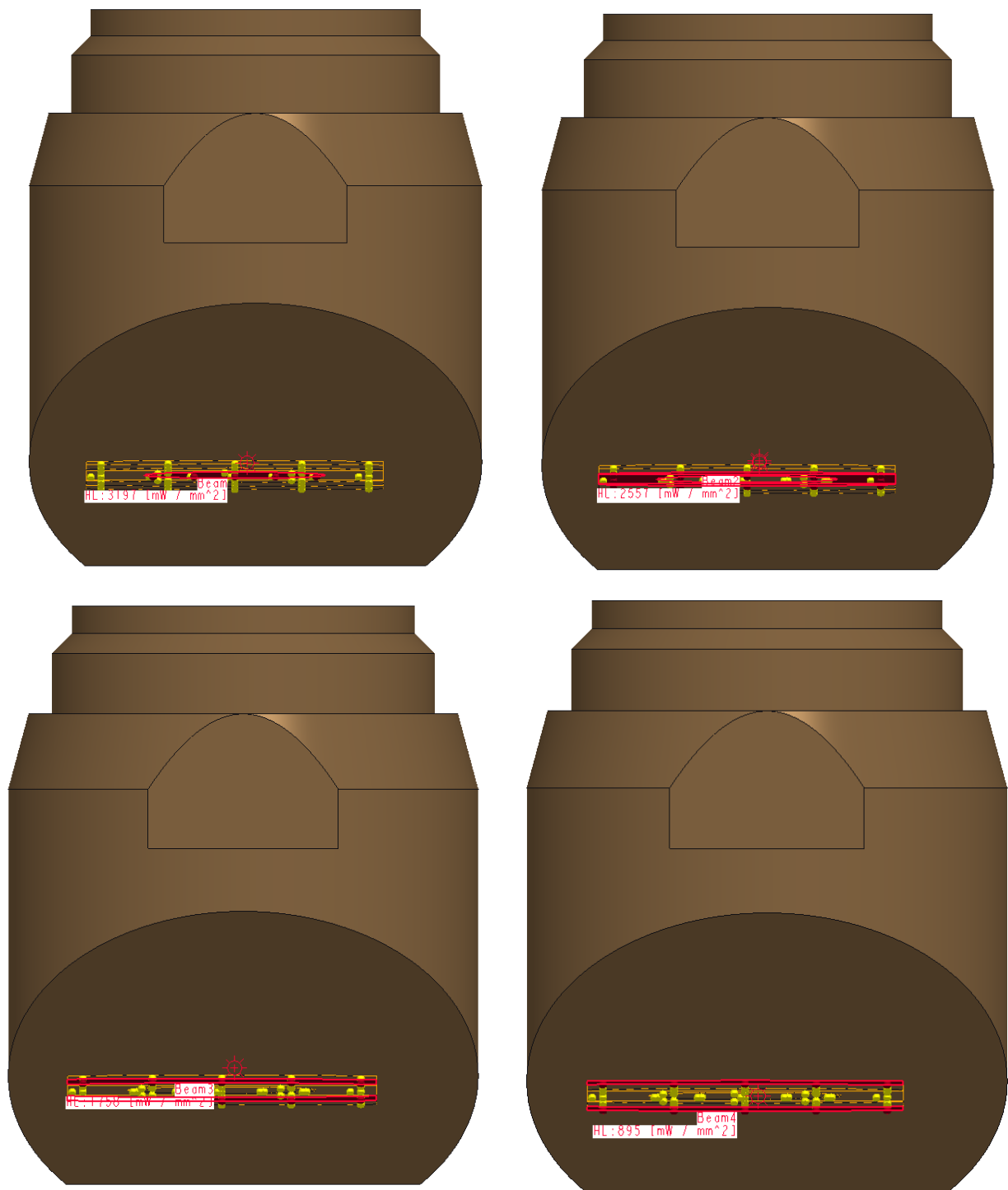


Figure 16 Wiggler beam loads

3-Pole Wiggler Frontend @ SOLARIS

The absorber body is made of copper with the material properties defined below:

Property	OFHC Copper
Mass density ρ	8.9 g/cm ³
Younge's Modulus	115 GPa
Poisson's ratio ν	0.323
Thermal expansion coeff. α	1.7e-5 1/K
Thermal conductivity k	391 W/mK

Table 5 Material properties used in the FEA calculation

Loads:

Loads	Value
Absorbed power wiggler	185 W
Max. power density on absorber (wiggler)	3.197 W/mm ² (beam under 35°)
Absorbed power bending magnet	78 W
Max. power density on absorber (bending)	2.59 W/mm ²
Cooling water temperature	298.0 K
Convection coefficient	10000 W/m ² K

Table 6 Loads of FEA calculation case

Results:

The maximum temperature of the absorber HAA is 105.8°C, the maximum temperature of the cooling channel is 79°C, which is acceptable. A maximum von Mises stress of 41.9 MPa occurs (limit 60 MPa), which is also acceptable.

Please note: To achieve a convection coefficient of 10000 W/m²K, a water flow of at least 3.4 l/min is necessary. This leads to a water flow velocity of 2 m/s.

3-Pole Wiggler Frontend @ SOLARIS

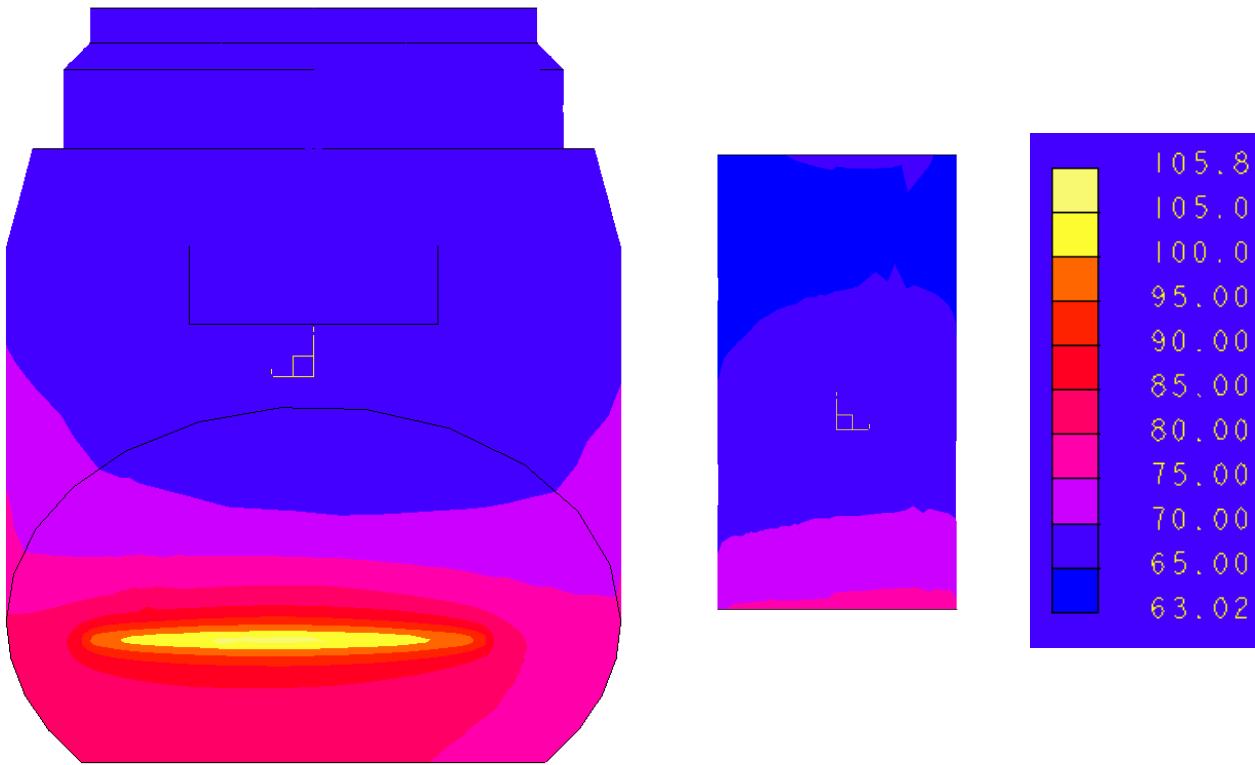


Figure 17 Results of thermal FEA. Temperature in degree Celsius is colour coded. Surface of cooling channel is on the right side.

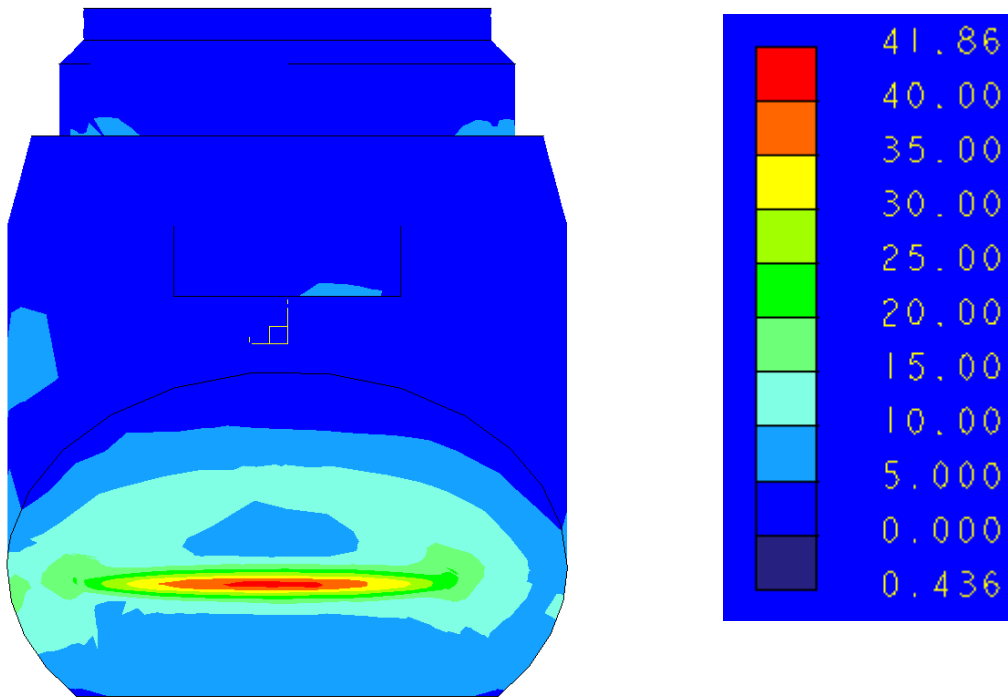


Figure 18 Results of structural FEA. Von Mises stress in MPa is colour coded.

3-Pole Wiggler Frontend @ SOLARIS

3 BPM

The 3-pole-wiggler requires the use of an SPM, due to the very broad photon beam. We plot the power density map filtered by the absorption curve of tungsten (the photon beam as “seen” by the tungsten blades). The vertical lines indicate the opening fan, which is defined by the crotch absorber. We can see, that the signal has only little variation in the horizontal direction, which makes the use of an XBPM unfeasible.

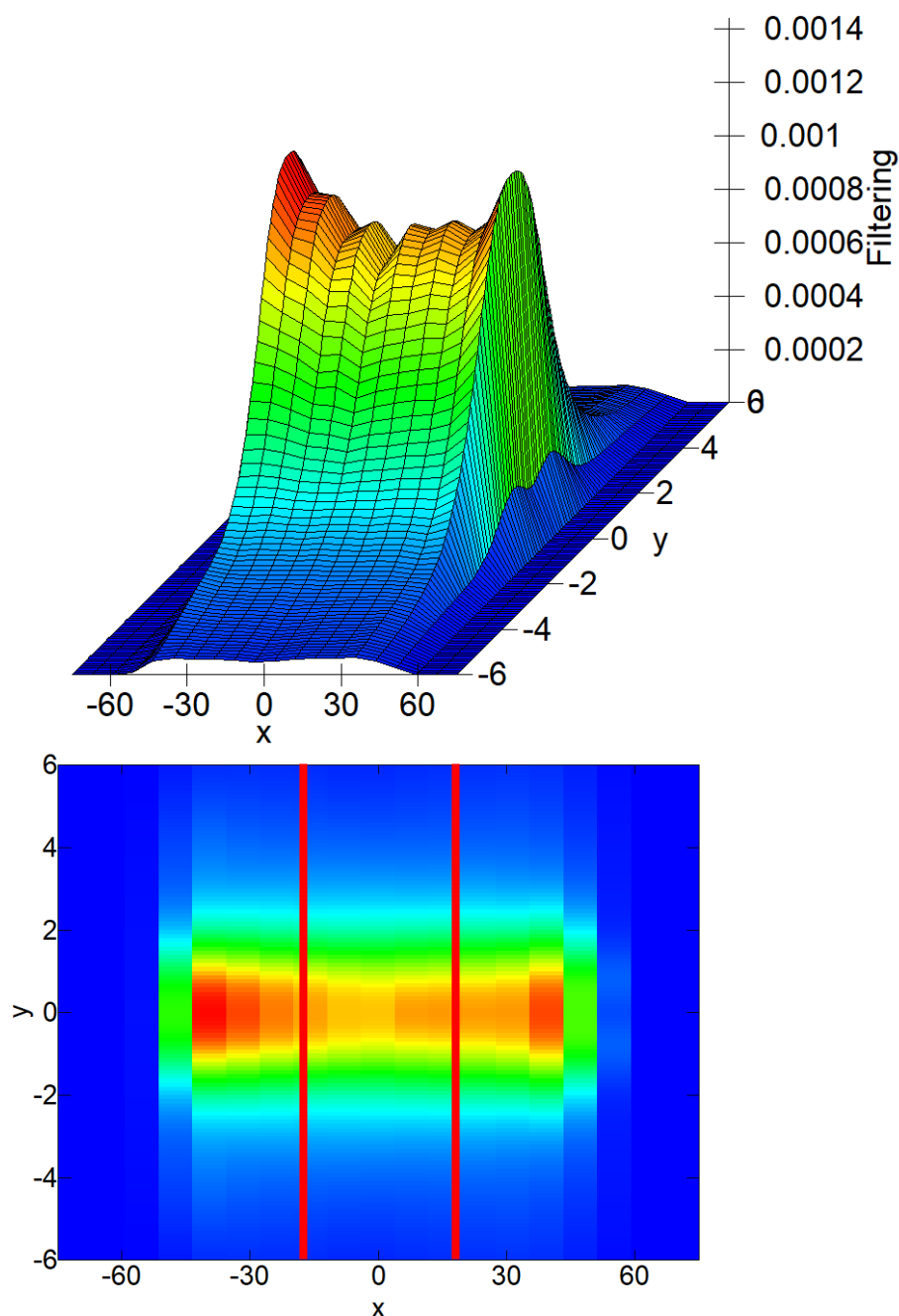


Figure 19 Tungsten filtered power density at the position of a beam positioner.

3-Pole Wiggler Frontend @ SOLARIS

For the front-end section, a fixed mask is foreseen, which collimates the beam to a size of 1.5 mrad x 1 mrad (hor. x vert.). At the potential SPM position, this corresponds to a beam size of 6.2 mm x 4.1 mm. The situation is visualized in the picture below. The usable beam is inside the blue rectangle. Possible blade positions are sketched as well (black vertical lines). Red vertical lines are once more the beam size defined by the crotch absorber. The blades can be placed inside the radiation defined by the crotch absorber, but outside the useable beam.

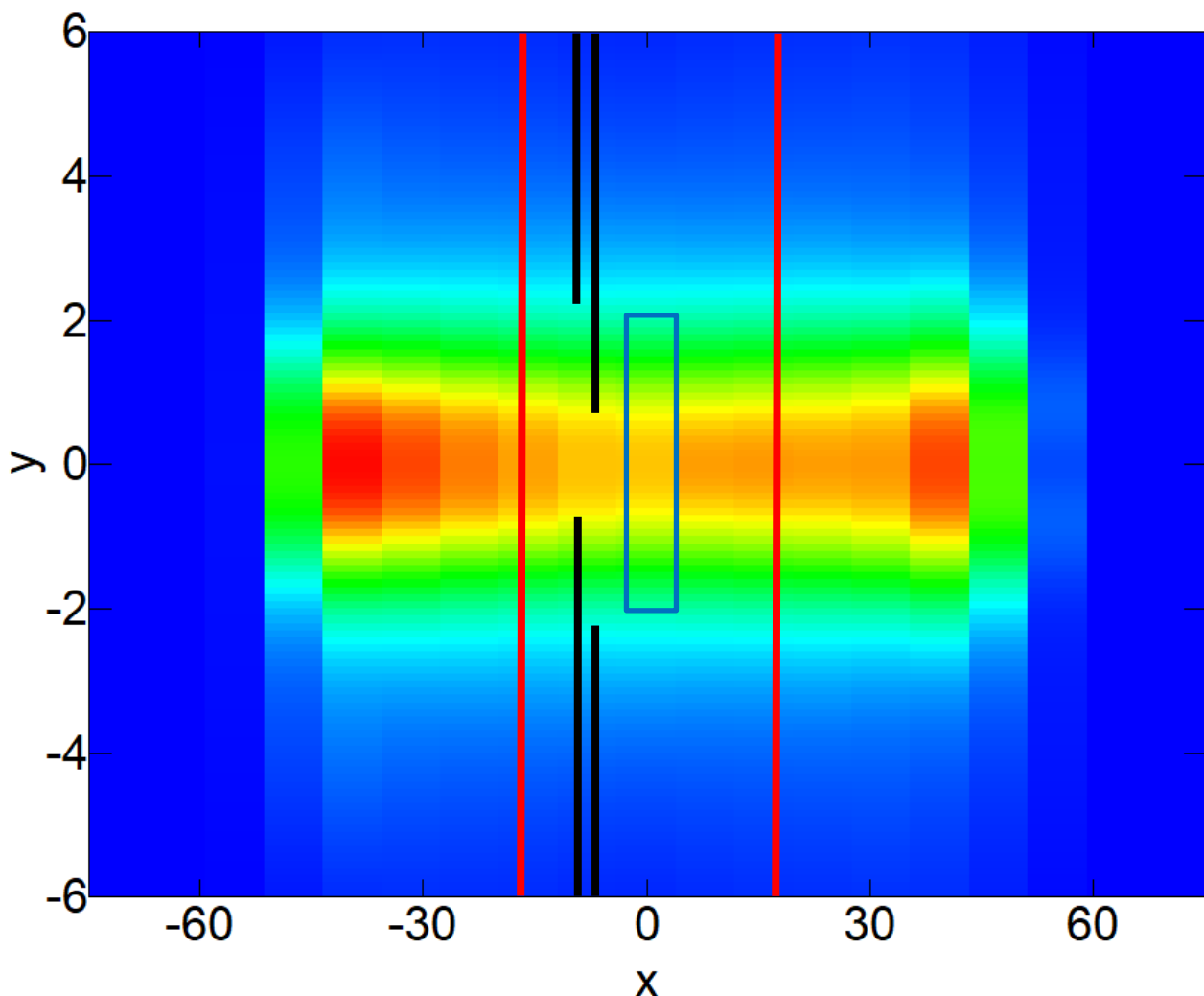


Figure 53b Possible SPM blade position and useable beam of 1.5mrad x 1mrad.