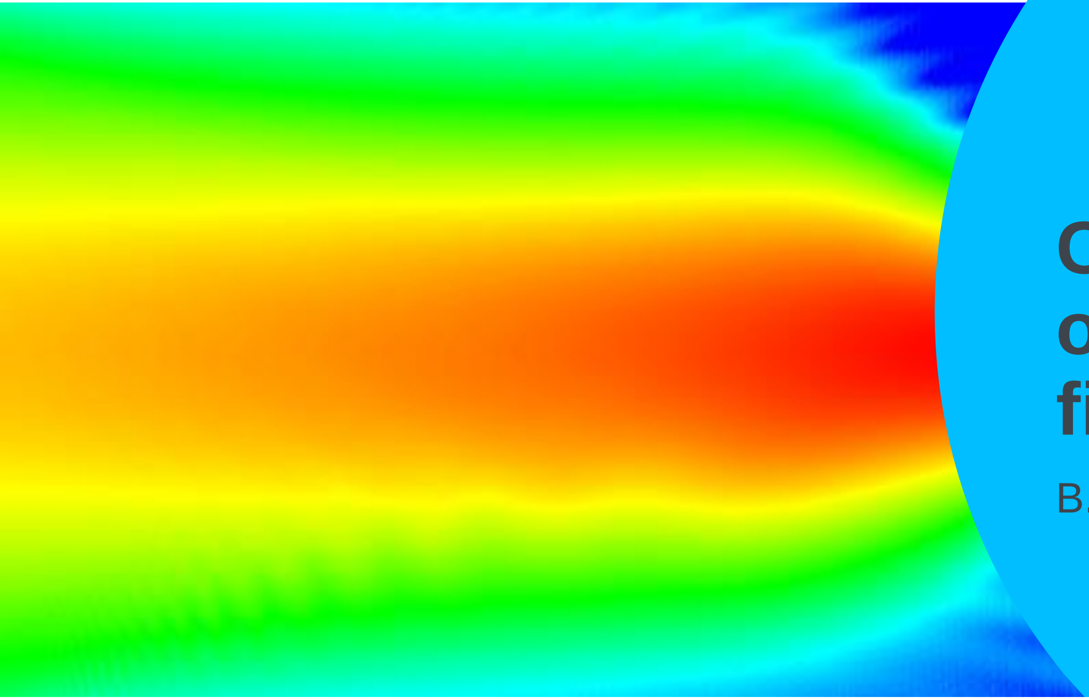
University of Stuttgart
Institute of Interfacial Process Engineering and Plasma Technology



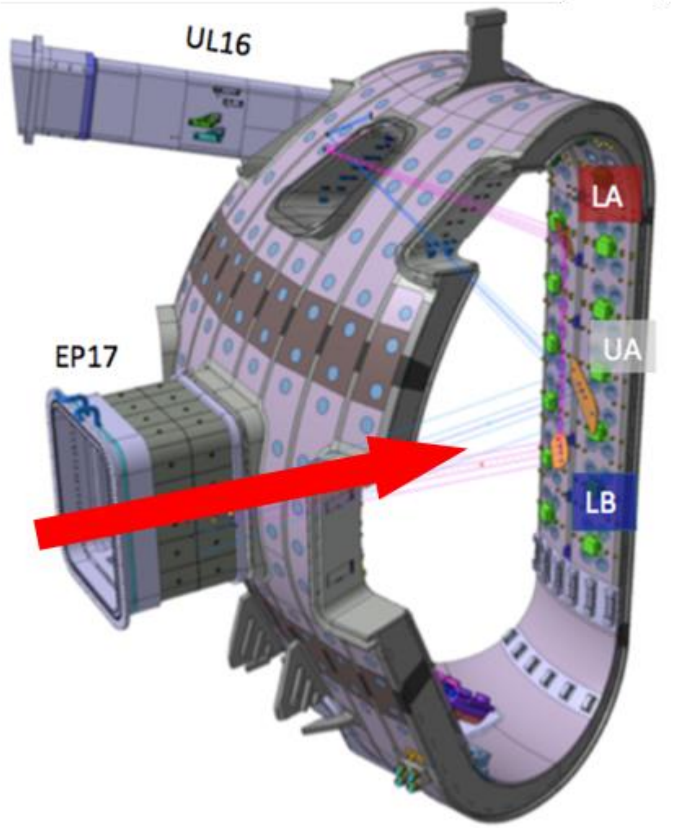
Calculations for the optical system for the first ITER plasma

B. Plaum, M. Preynas, M. Choe

Introduction

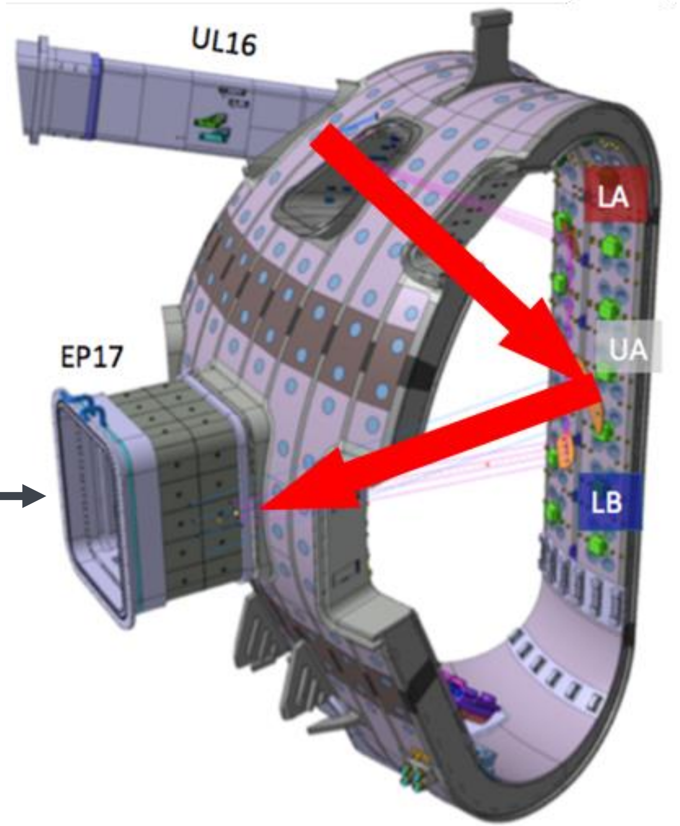
- For the breakdown of the first ITER plasma, the equatorial launcher will not be installed yet.
- Therefore, the MW-beams from the upper launcher will be redirected towards the resonance with a dedicated optics using in-vessel mirrors.
- The design was analysed using the PROFUSION tools

Introduction

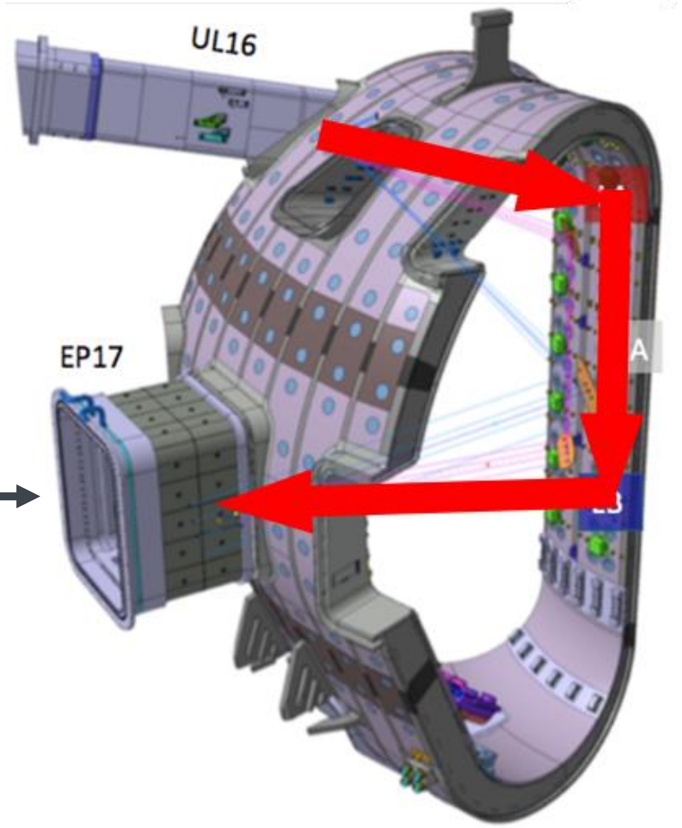


Introduction

Beam dump



Introduction

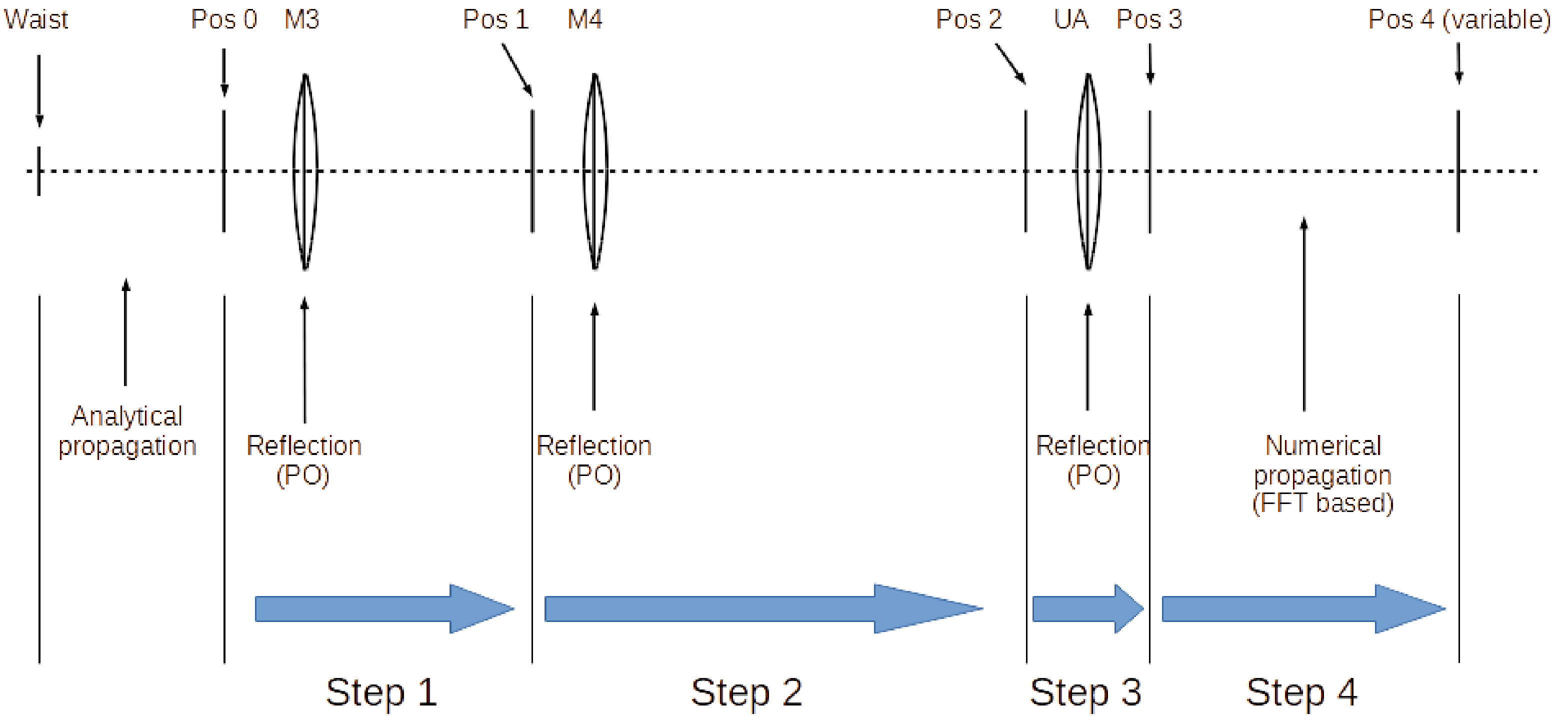


Beam dump

Calculation methods

- Propagation from the start position to the first mirror: **Gaussian Optics** with analytical formulas
- Reflection at the mirrors: **Physical Optics** solver (parallelized to run on 40 CPU cores)
- Propagation after the last mirror: **FFT-Propagation** (plane wave decomposition)
- All calculations were done in vacuum

Calculation scheme (U-Beams)



Physical optics solver

- Calculate the currents in the mirror surface from the incident magnetic field:

$$\vec{J} = 2\vec{n} \times \vec{H}_i$$

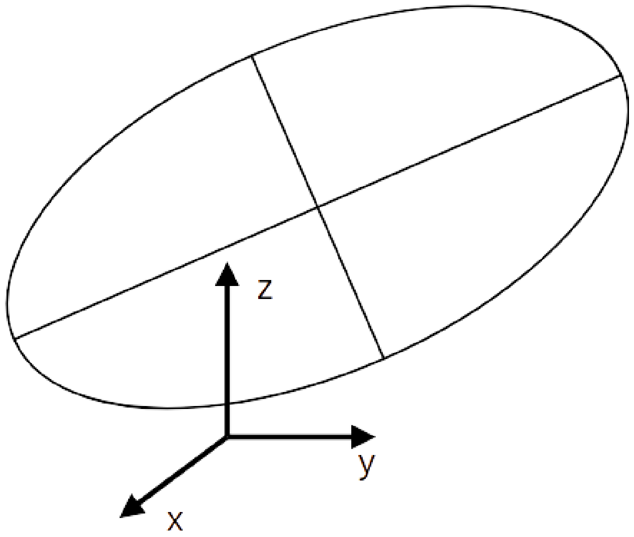
- Calculate the radiated magnetic field from the currents in the mirror:

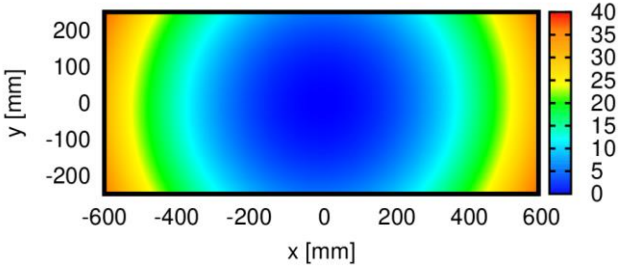
$$\vec{H}_r = \iint \left(-jk - \frac{1}{R}\right) \cdot \vec{J} \times \frac{\vec{R}}{R} \frac{e^{-jkR}}{4\pi R} \, dy \, dx$$

- Very accurate method, which considers:
  - **Mode conversion** due to non perpendicular incidence
  - **Cross polarization** effects due to the reflection of straight field lines on a curved surface
  - **Beam truncation** effects due to the limited mirror size, even for irregular (numerically given) shapes

Discretization of the mirror surfaces

- The mirrors are given in terms of **ellipsoid-, cylinder-, or hyperboloid-parameters**
- For the PO solver we need xyz-Coordinates in a **mirror local coordinate system**
- Finding the z-coordinate is equivalent to finding the intersection of a line with the surface → no analytical solution
- An iterative method was developed, which starts with 2 points (one above and one below the mirror surface)
- Just a few iterations needed for subatomic precision

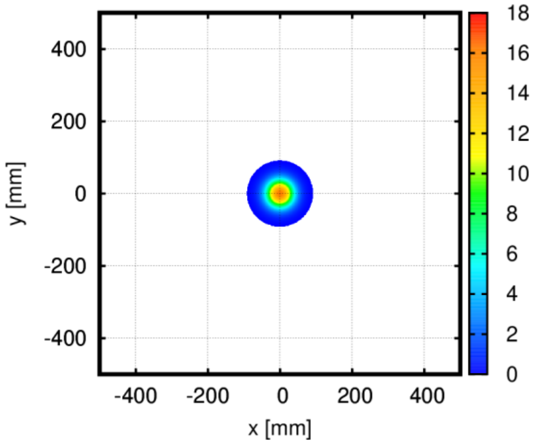




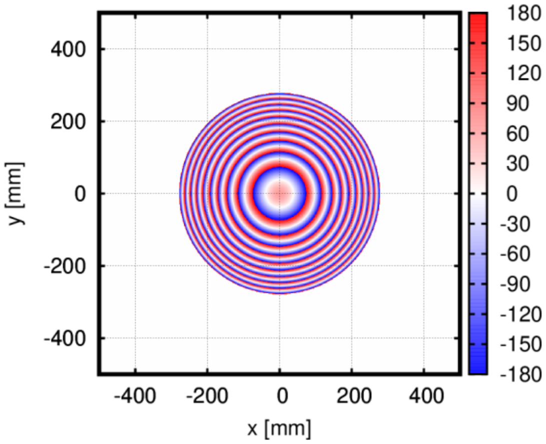
Choice of the coordinate systems

- For **beam-local** coordinate systems:
  - **Z-axis** is always parallel to the beam axis and points in the **propagation direction**
  - **Y-axis** is parallel to the desired polarization direction of the **E-field**
  - For a **perfect linear** polarization, the x-component is **zero**
  - Advantage: The cross-polarization (≈ 300W) can be distinguished from the co-polarization (1 MW)
- Mirror local systems:
  - **Z-axis** is always the mirror normal at the incident point of the beam axis
  - **X- and Y-axes** are arbitrary
- All coordinates were provided in **TGCS @ OT** (Torus Global Coordinates @ Operating Temperature)

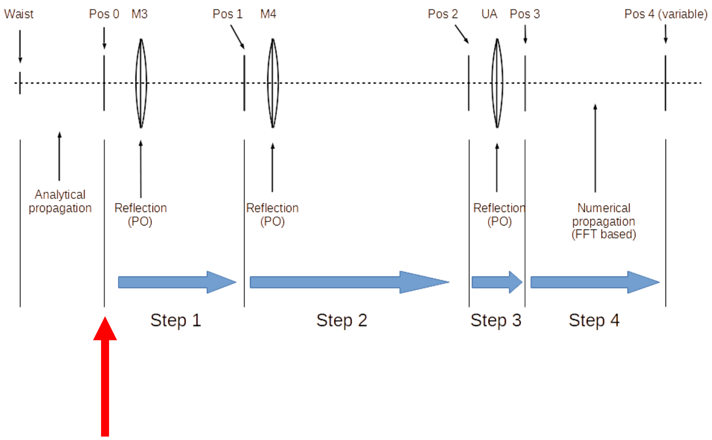
Results



18
16
14
12
10
8
6
4
2
0
400
200
0
-200
-400
y [mm]
-400
-200
0
200
400
x [mm]

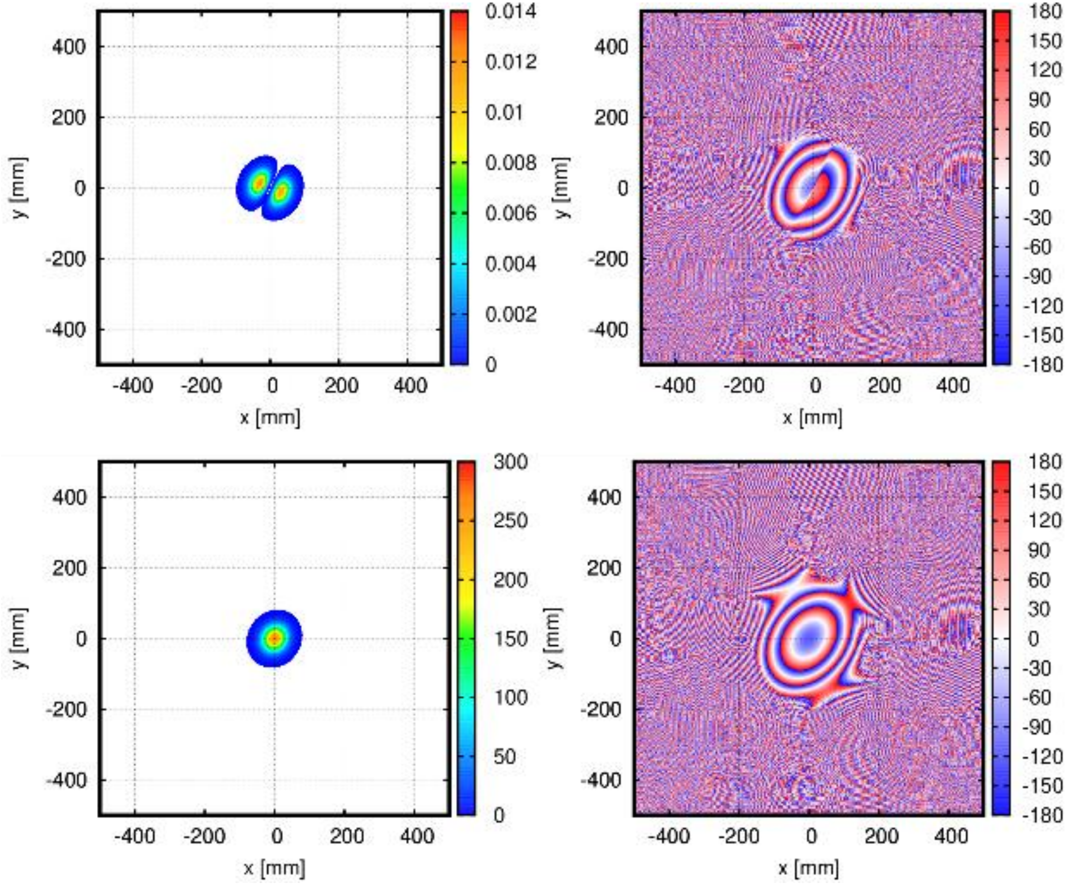


180
150
120
90
60
30
0
-30
-60
-90
-120
-150
-180
400
200
0
-200
-400
y [mm]
-400
-200
0
200
400
x [mm]

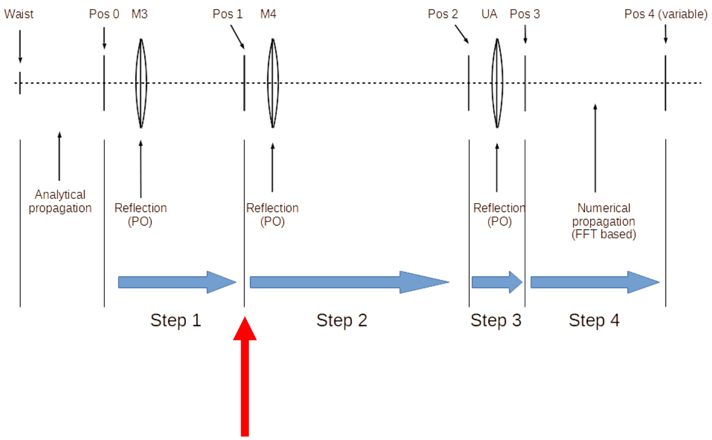


Waist
Pos 0
M3
Pos 1
M4
Pos 2
UA
Pos 3
Pos 4 (variable)
Analytical propagation
Reflection (PO)
Reflection (PO)
Reflection (PO)
Numerical propagation (FFT based)
Step 1
Step 2
Step 3
Step 4

Results



0.014
0.012
0.01
0.008
0.006
0.004
0.002
0
y [mm]
x [mm]
180
150
120
90
60
30
0
-30
-60
-90
-120
-150
-180
300
250
200
150
100
50



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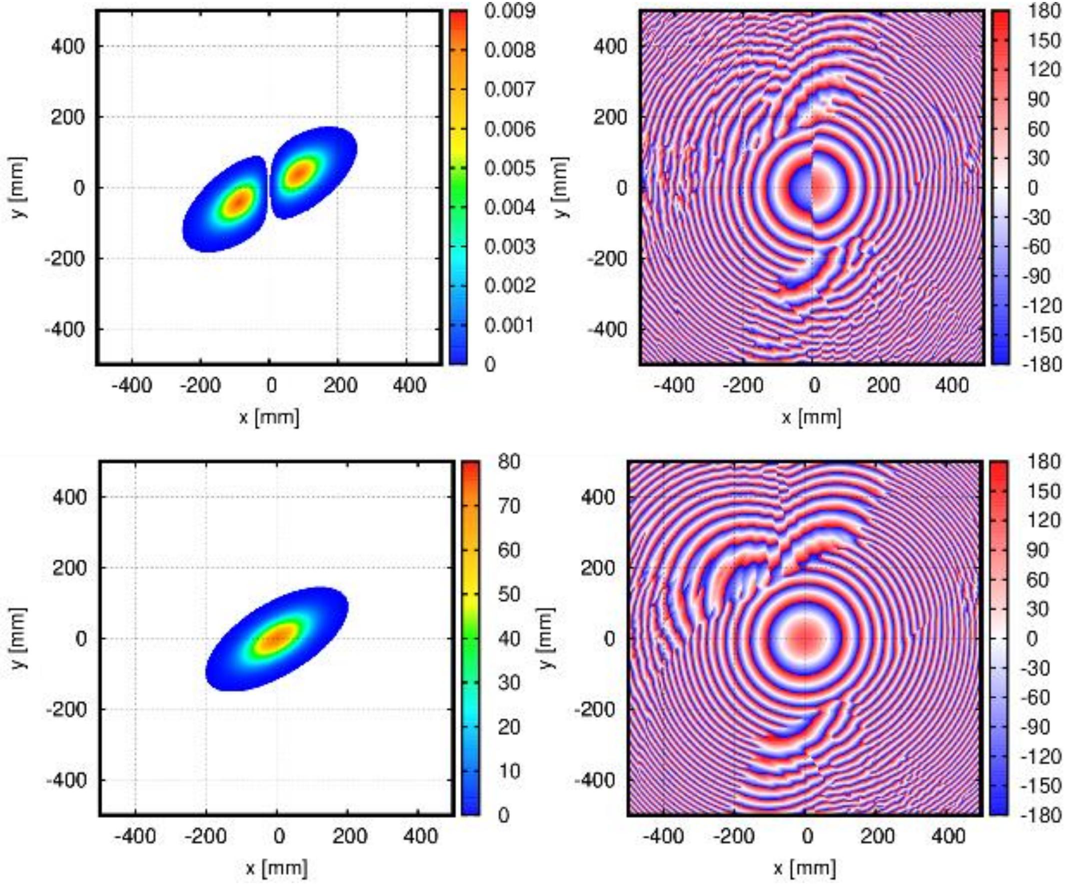
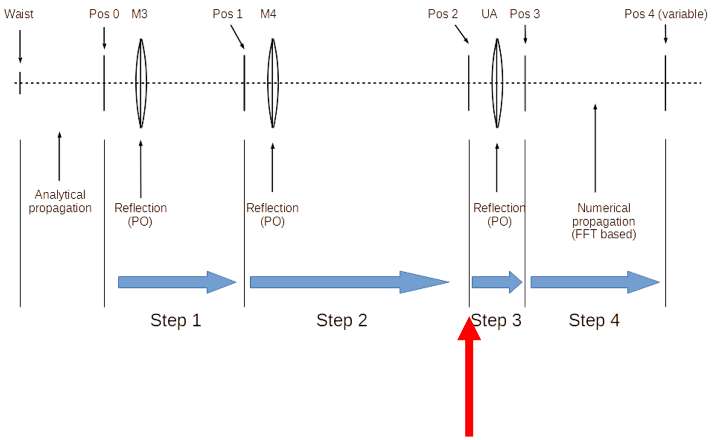

y [mm]
x [mm]
0.009
0.008
0.007
0.006
0.005
0.004
0.003
0.002
0.001
0
180
150
120
90
60
30
0
-30
-60
-90
-120
-150
-180
80
70
60
50
40
30
20
10
0
400
200
0
-200
-400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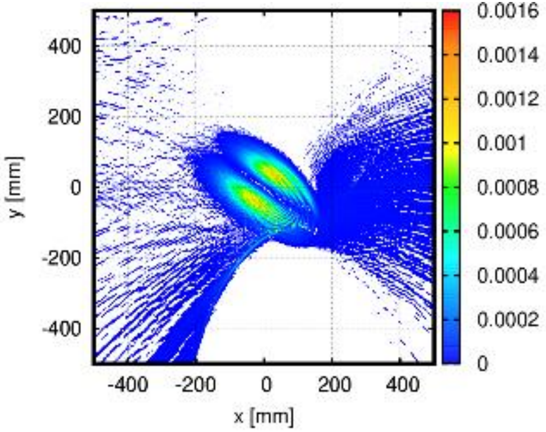
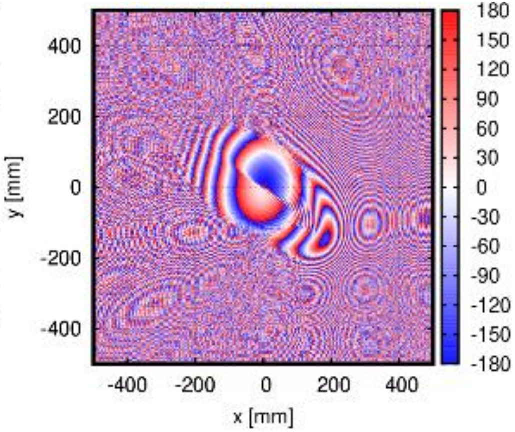
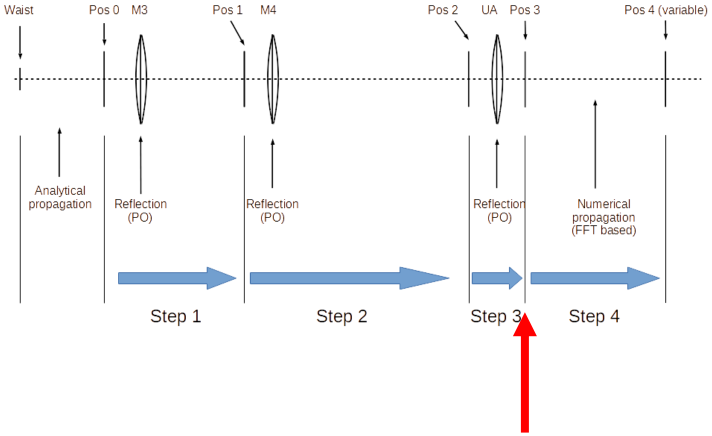


0.0016
0.0014
0.0012
0.001
0.0008
0.0006
0.0004
0.0002
0
y [mm]
x [mm]



180
150
120
90
60
30
0
-30
-60
-90
-120
-150
-180
y [mm]
x [mm]



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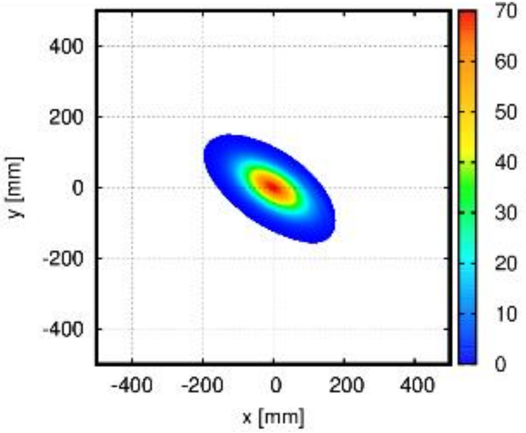
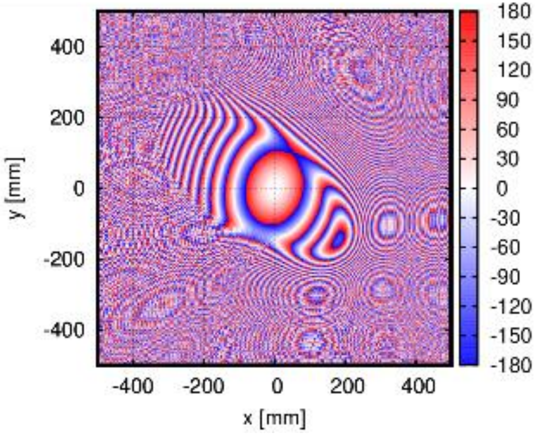


70
60
50
40
30
20
10
0
y [mm]
x [mm]



180
150
120
90
60
30
0
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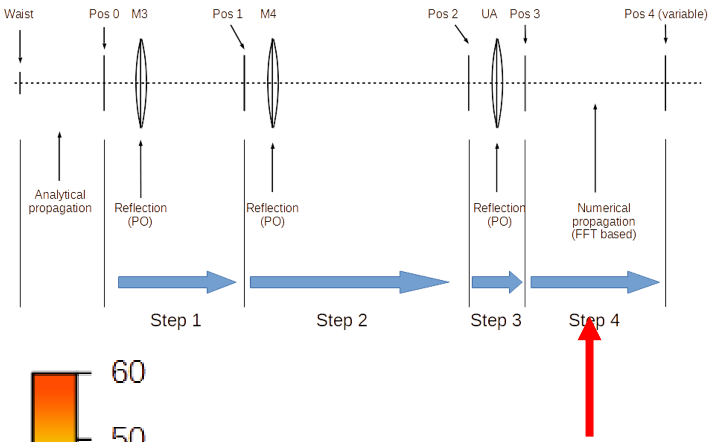
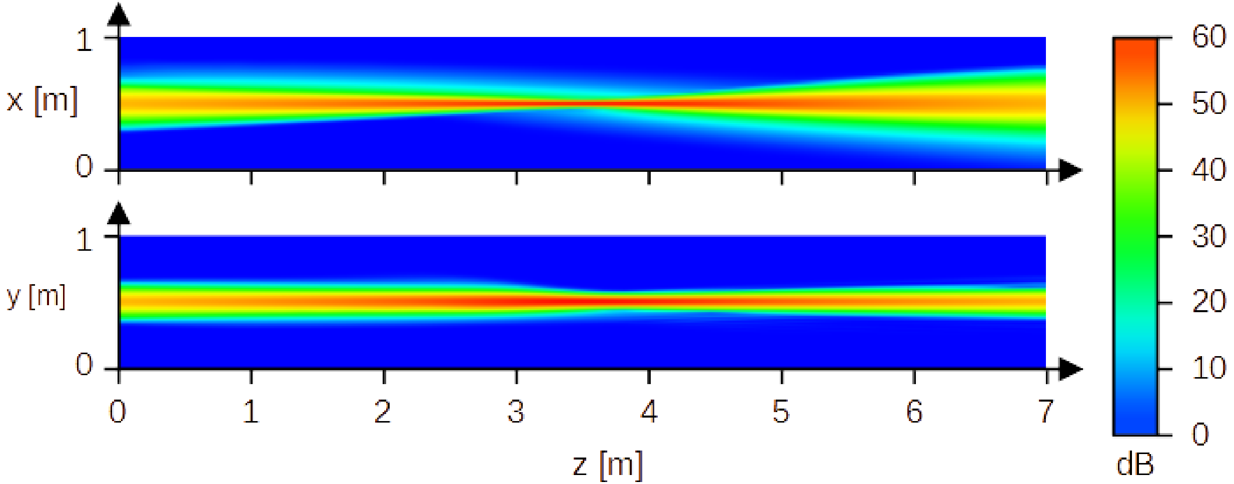
-60
-90
-120
-150
-180
y [mm]
x [mm]

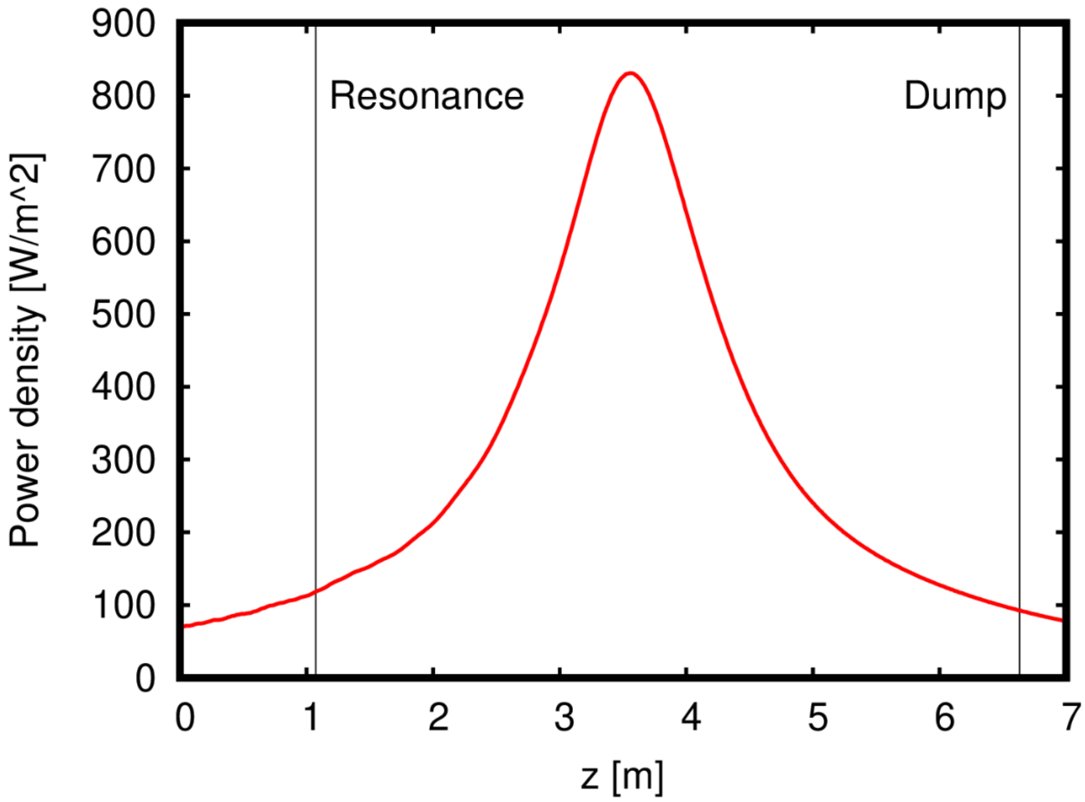
Results



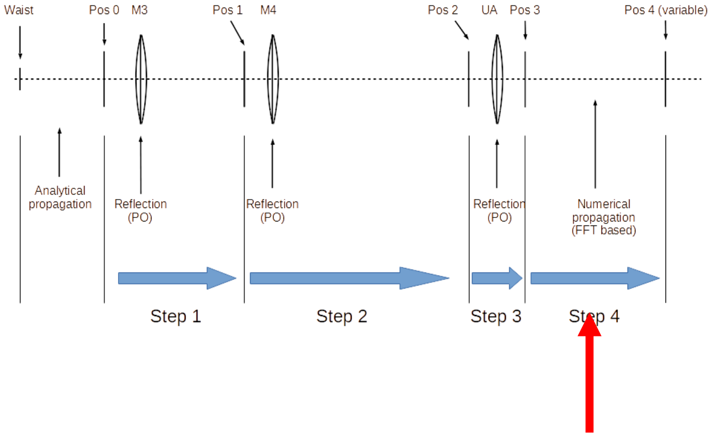
Beam profiles after UA



Results



Power density [W/m^2]
900
800
700
600
500
400
300
200
100
0
Resonance
Dump
0
1
2
3
4
5
6
7
z [m]



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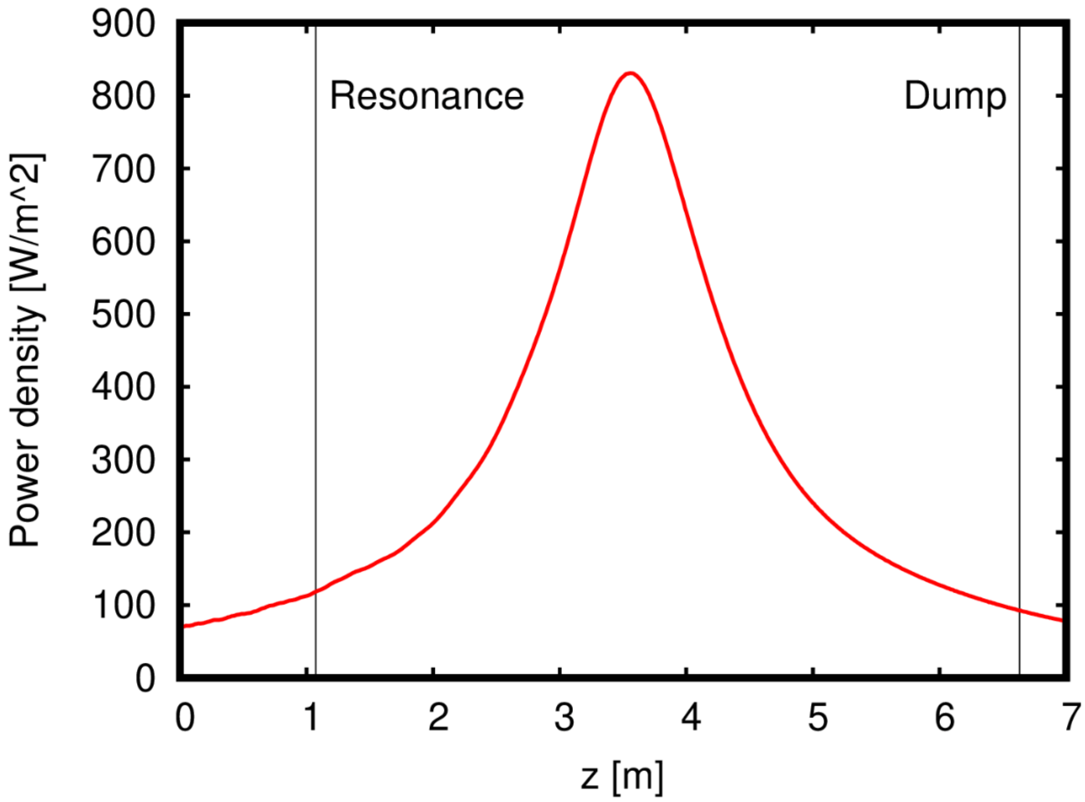
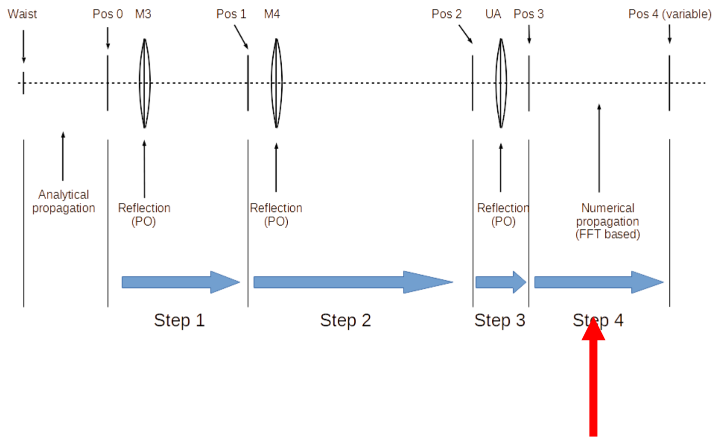
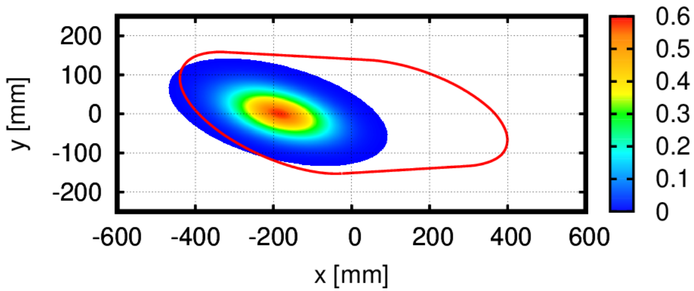




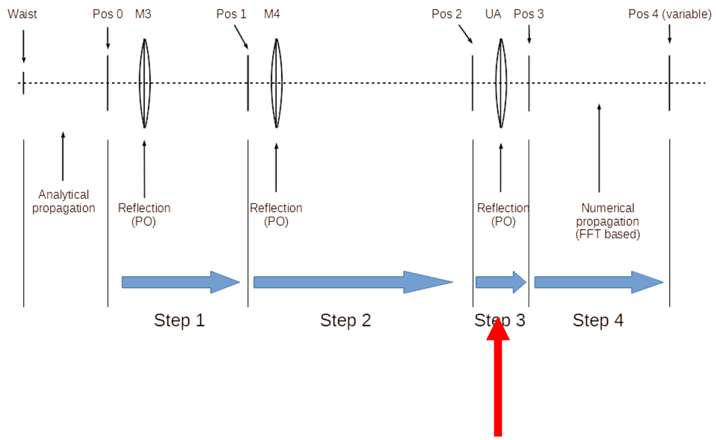
Maximum offset in the beam dump (after 3 mirrors and > 13 m propagation):

1.702 mm

Results



y [mm]
x [mm]



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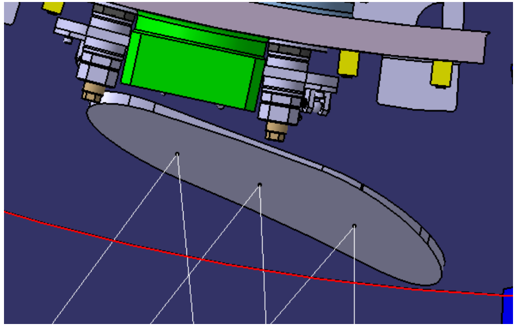
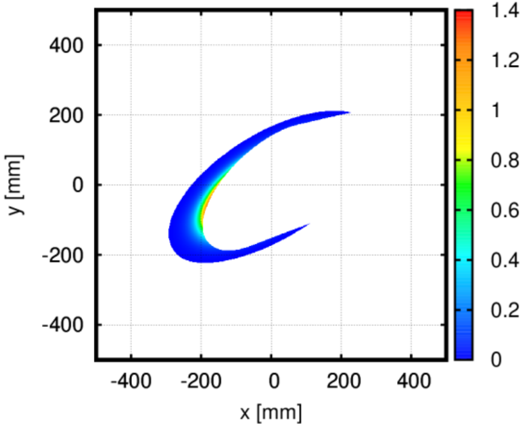
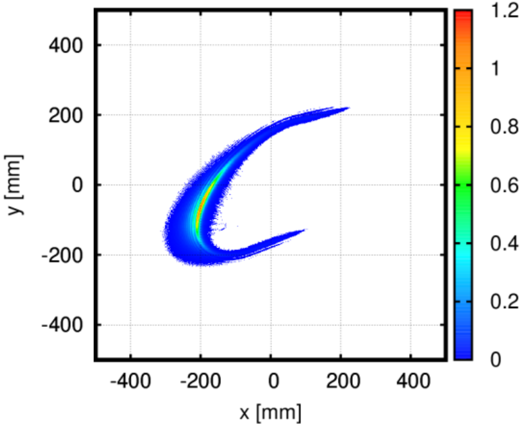


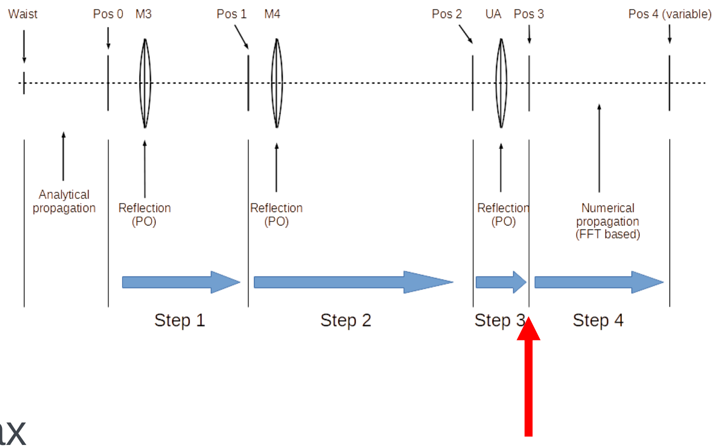


y [mm]
x [mm]

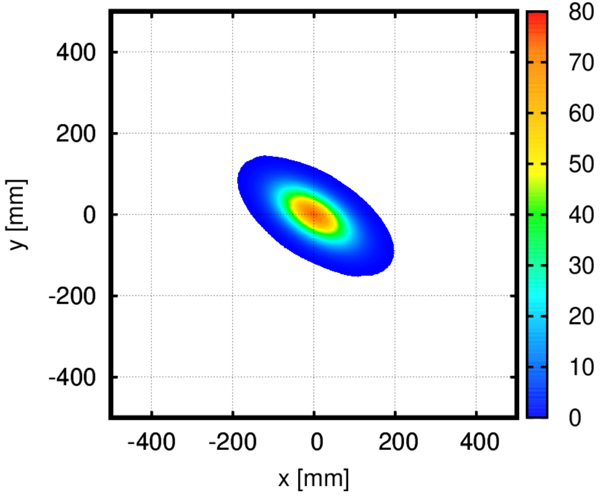


y [mm]
x [mm]

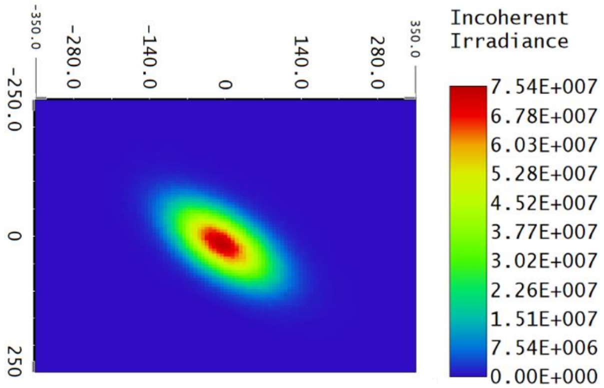
Results



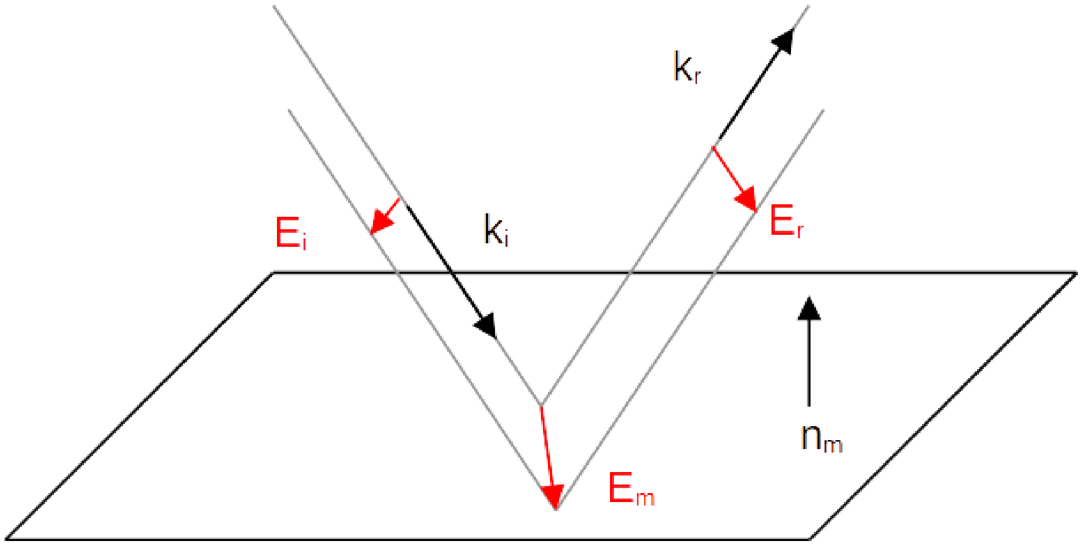
PROFUSION



Zemax



Tracking the polarisation



- The polarization plane of a beam is defined by the **E-vector** and the **k-vector** in the beam axis
- The projected E-field E_m on the mirror is obtained by intersecting the polarization plane with the mirror (assumed locally flat)
- Simple rule: E_m is the same for the incident and reflected beam

Tracking the polarisation

Normal vector n_i of the incident polarisation plane: $\vec{n}_i = \vec{E}_i \times \vec{k}_i$

Projected E-field E_m on the mirror: $\vec{E}_m = \vec{n}_i \times \vec{n}_m = (\vec{E}_i \times \vec{k}_i) \times \vec{n}_m$

Normal vector n_r of the reflected polarisation plane: $\vec{n}_r = \vec{E}_m \times \vec{k}_r = ((\vec{E}_i \times \vec{k}_i) \times \vec{n}_m) \times \vec{k}_r$

Electric field of the reflected beam: $\vec{E}_r = \vec{n}_r \times \vec{k}_r$

$$\vec{E}_r = (((\vec{E}_i \times \vec{k}_i) \times \vec{n}_m) \times \vec{k}_r) \times \vec{k}_r$$

Conclusions

- The optics system for the ITER plasma was modelled with the PROFUSION tools
- The code was extended to support irregular mirror contours and polarization tracking
- The design was confirmed, no major disagreements or other obstacles were identified
- Final analysis and comparison with Zemax to be done for the current version of the optical design

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Thank you!

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