

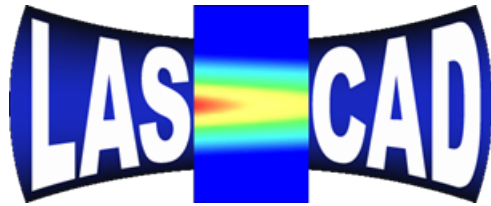


**LASer Cavity
Analysis & Design**

**Numerical Modeling of
Solid-State Lasers with
LASCAD™ 3.3**

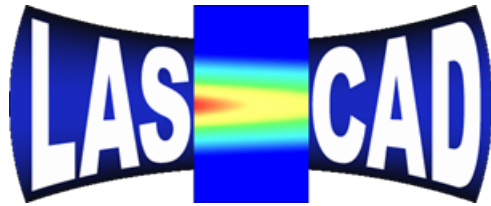
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LASer Cavity Analysis & Design

The 3-D nonlinear interaction of thermal and optical fields, commonly known as thermal lensing effect, is one of the key problems which need to be analyzed to optimize design of laser cavities for solid-state lasers (SSL, DPSSL etc.). Thermal lensing interferes with gain guiding and other effects that control beam quality and efficiency of a laser in a complicated manner.



LASer Cavity Analysis & Design

Numerical analysis of the 3-D nonlinear interaction of thermal and optical fields is of growing importance due to the tendency to miniaturize laser systems and simultaneously to increase their output power, causing the interaction of strong fields in very small volumes.

The industry-leading software package LASCAD combines all simulation tools necessary to model the 3-D nonlinear interaction of thermal and optical fields in DPSSL.

Based on a quantitative understanding of the multiphysics effects in laser cavities, LASCAD allows the laser engineer to control and compensate individual features of a resonator design prior to committing hardware.

LASCAD™ offers:

- **Thermal and Structural Finite Element Analysis (FEA)**
- **ABCD Gaussian Beam Propagation**
- **Physical Optics Propagation (BPM)**
- **Computation of Laser Power Output**

Design of LASCAD™ has been guided by three basic ideas:

• The Optical Workbench on the PC

• The Laser Engineering Tool

• The Educational Tool

LASCAD™ - The Optical Workbench on the PC

An easy-to-use and clearly organized user interface permits intuitive modeling and design of laser cavities. It helps the engineer to understand experimental results without wasting valuable time studying complicated manuals:

LASCAD™ - The Optical Workbench on the PC

- Optical elements like mirrors, lenses or crystals can be added, combined, positioned, adjusted or removed with a mouse click.
- Astigmatism of resonator and crystal is automatically analyzed.
- Finite Element Analysis, ABCD and Physical Optics Code can easily be started from a menu bar.

LASCAD™ - The Laser Engineering Tool

Finite Element Analysis (FEA)

FEA is used to compute temperature distribution, de-formation, and stress or fracture mechanics in laser crystals, or to analyze the effect of different cooling systems.

The FEA code of LASCAD has been specifically developed to meet the demands of laser simulation. Automatic mesh generation facilitates use of FEA for engineers not being familiar with this method.

LASCAD™ - The Laser Engineering Tool

Finite Element Analysis (FEA)

Predesigned FEA models with adjustable parameters, such as dimensions of crystal or material properties, are provided to assist the engineer with different configurations.

2D and 3D graphical tools based on OpenGL are available to visualize pump light distribution, boundary conditions, and results of FEA.

LASCAD™ - The Laser Engineering Tool

Configurations available with LASCAD:

- End pumped rods and slabs with the pump light distribution being modeled by the use of supergaussian functions, pumping from both ends can be available.
- Rods and blocks with top hat pump profile along crystal axis and supergaussian distribution perpendicular to the axis.

LASCAD™ - The Laser Engineering Tool

Configurations available with LASCAD:

- Side pumped rod with several diode arrays being grouped around and along the rod. Symmetrical as well as unsymmetrical arrangements are possible.
- Side pumped slab with oblique end faces.
- Rods and slabs with numerical input of pump light distribution generated by the ray tracing codes ZEMAX or TracePro

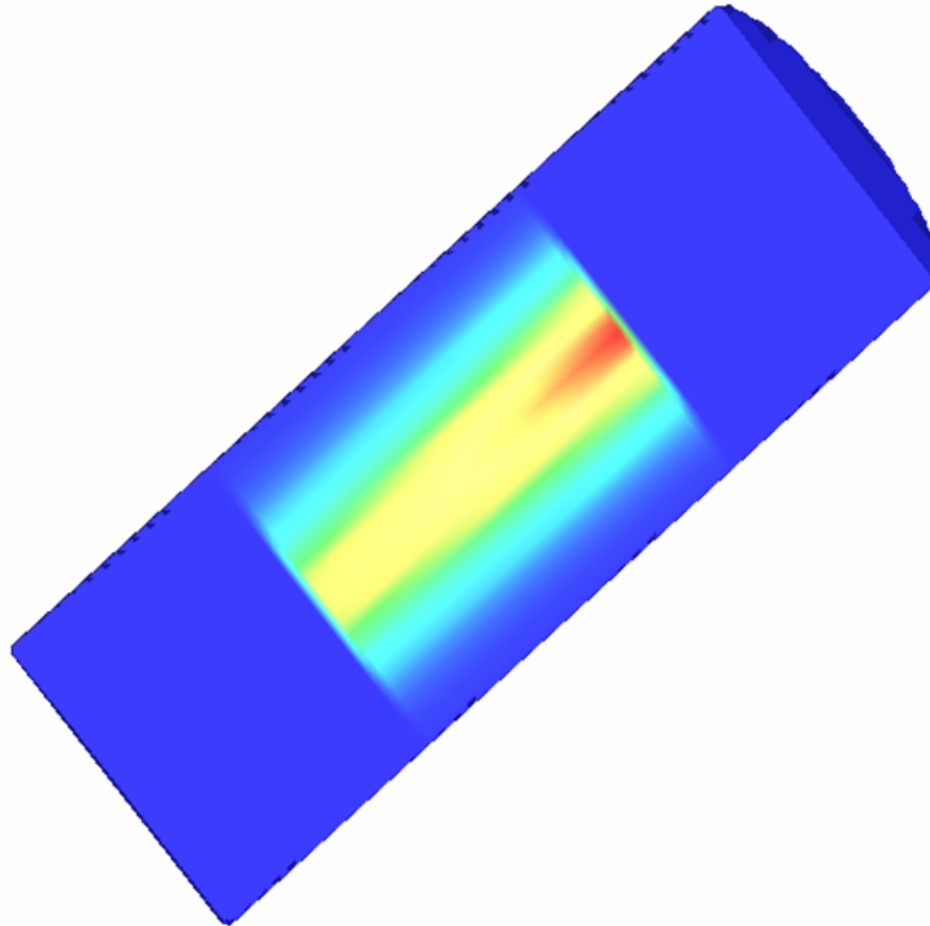
LASCAD™ - The Laser Engineering Tool

With all models composite crystals can be used. For instance, rods with undoped end caps, and sandwiched slabs with doped and undoped layers can be modeled.

Also heat sinks can be included into the FEA model. For example temperature distribution and deformation in a structure consisting of crystal slab between to copper plates can be computed.

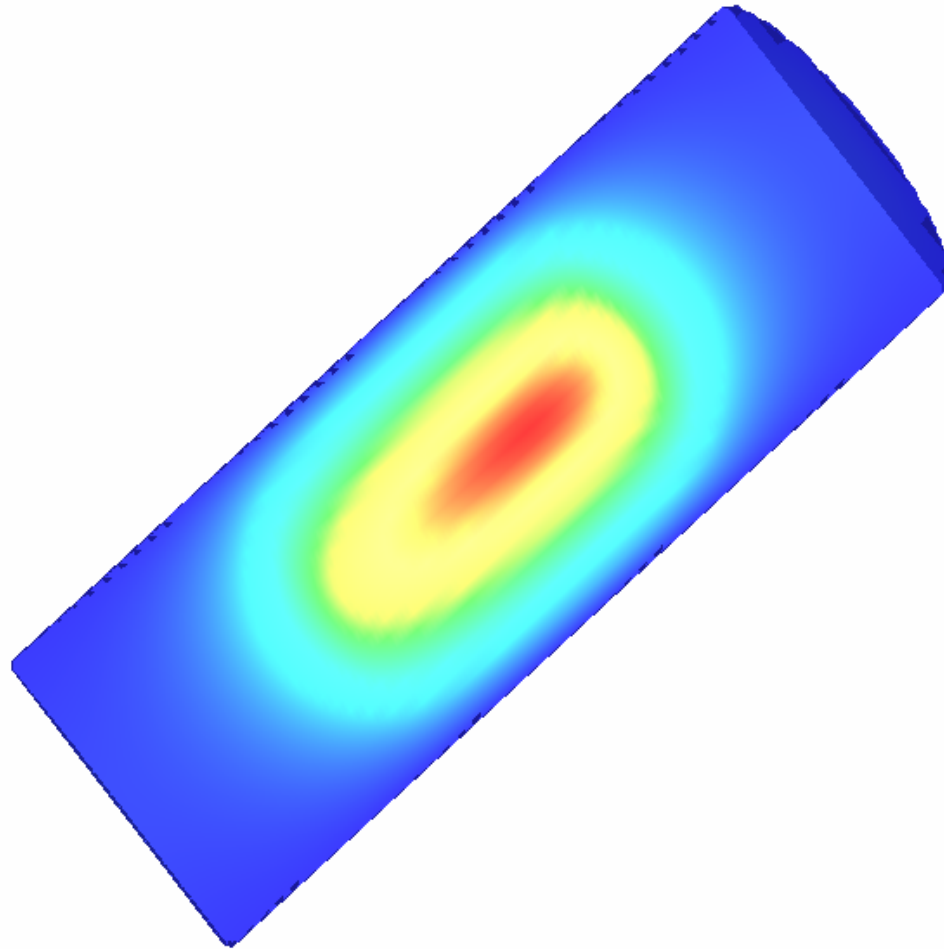
In the following several pictures visualizing FEA results are shown.

LASCAD™ - The Laser Engineering Tool



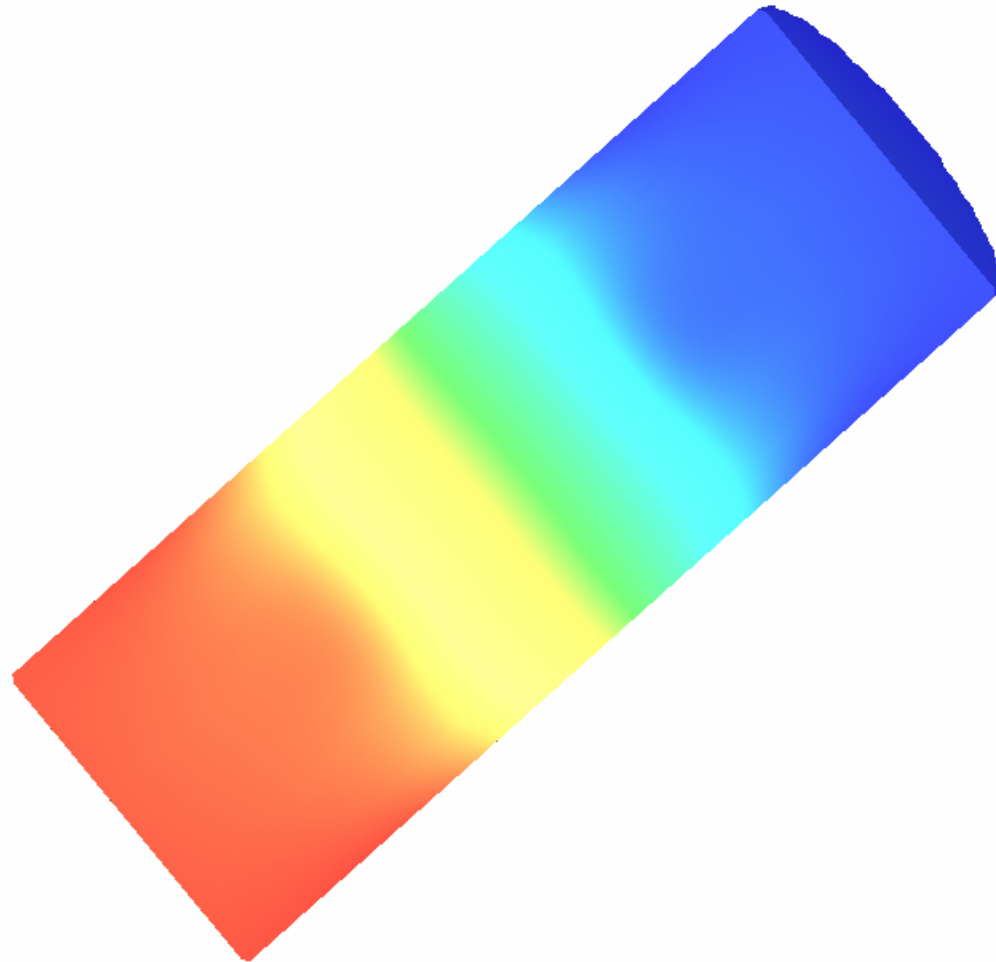
Example: Heat load distribution in a rod with undoped end-caps.

LASCAD™ - The Laser Engineering Tool



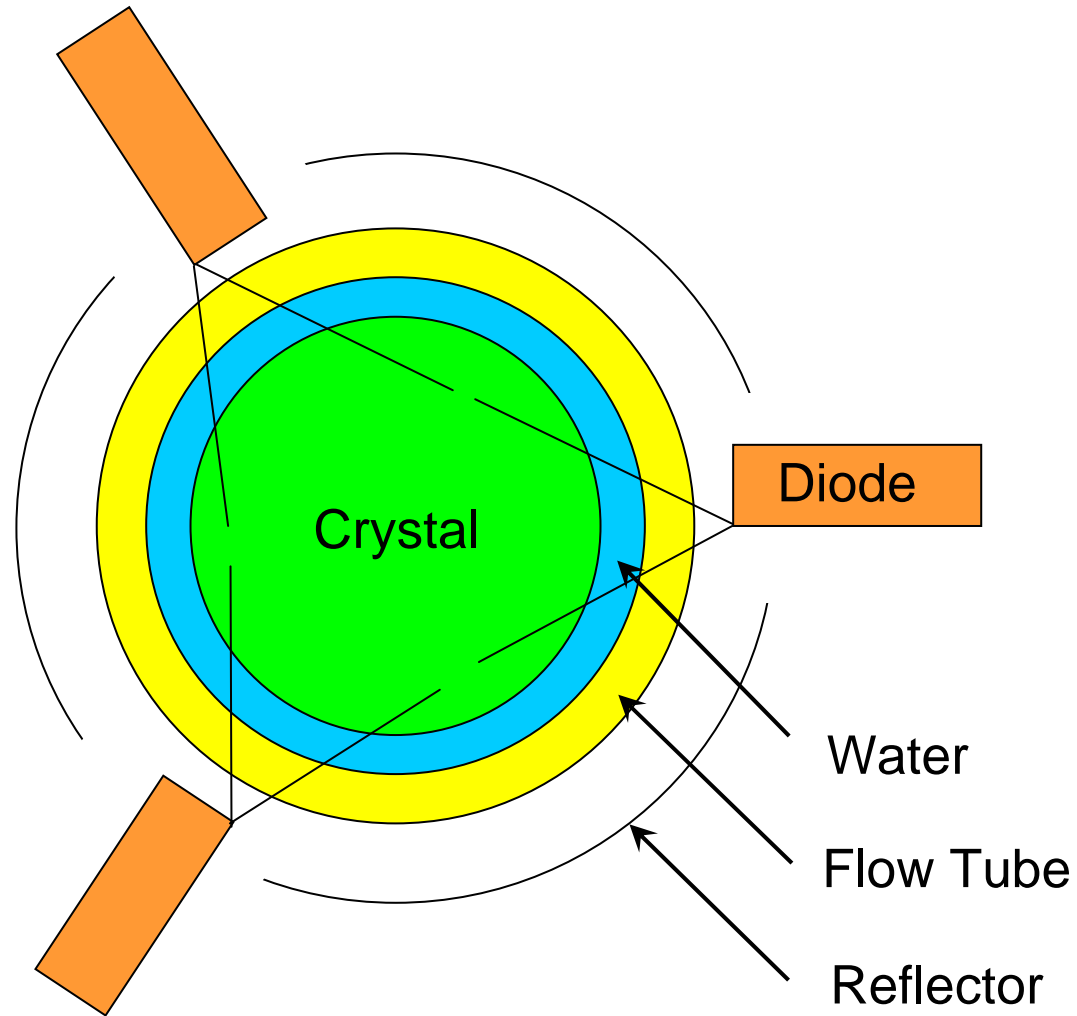
Example: Temperature distribution in a rod
with undoped end-caps

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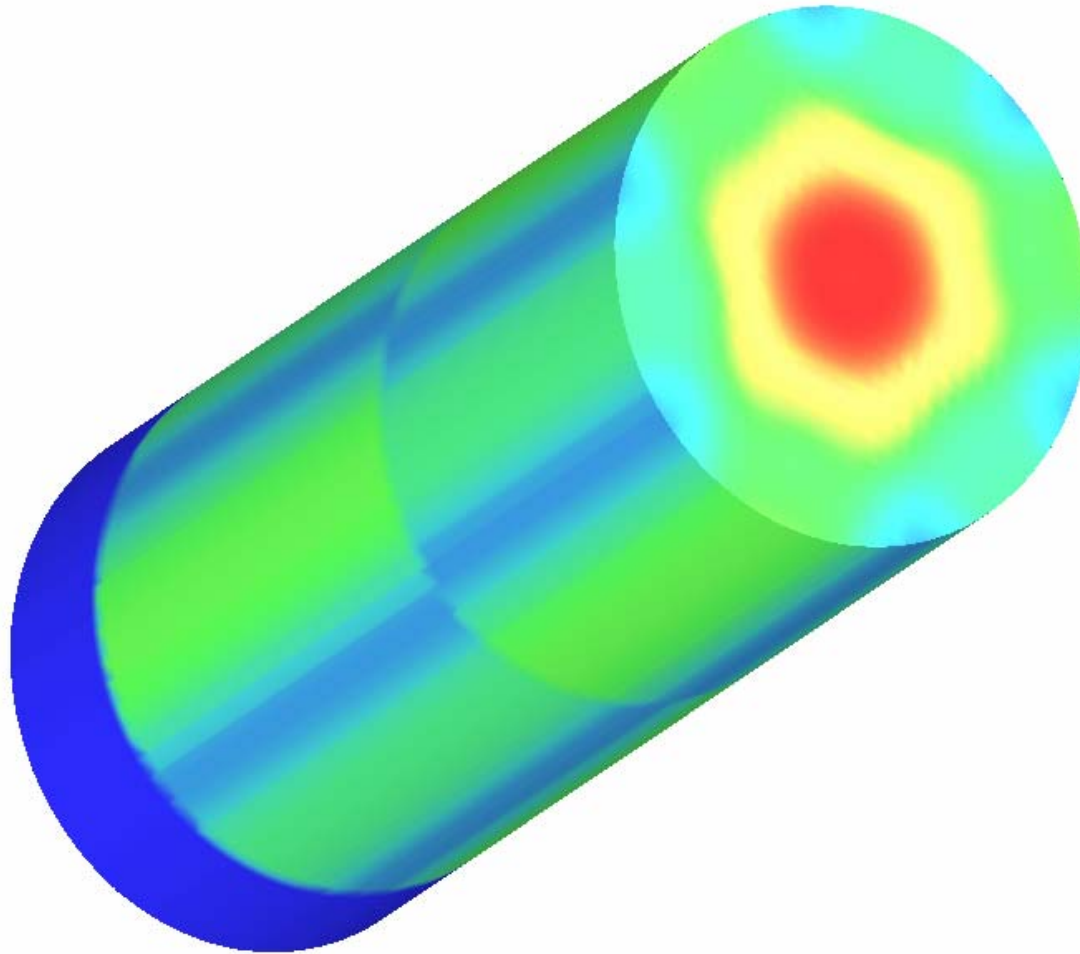
Example: z-component of displacement in a rod with undoped end-caps

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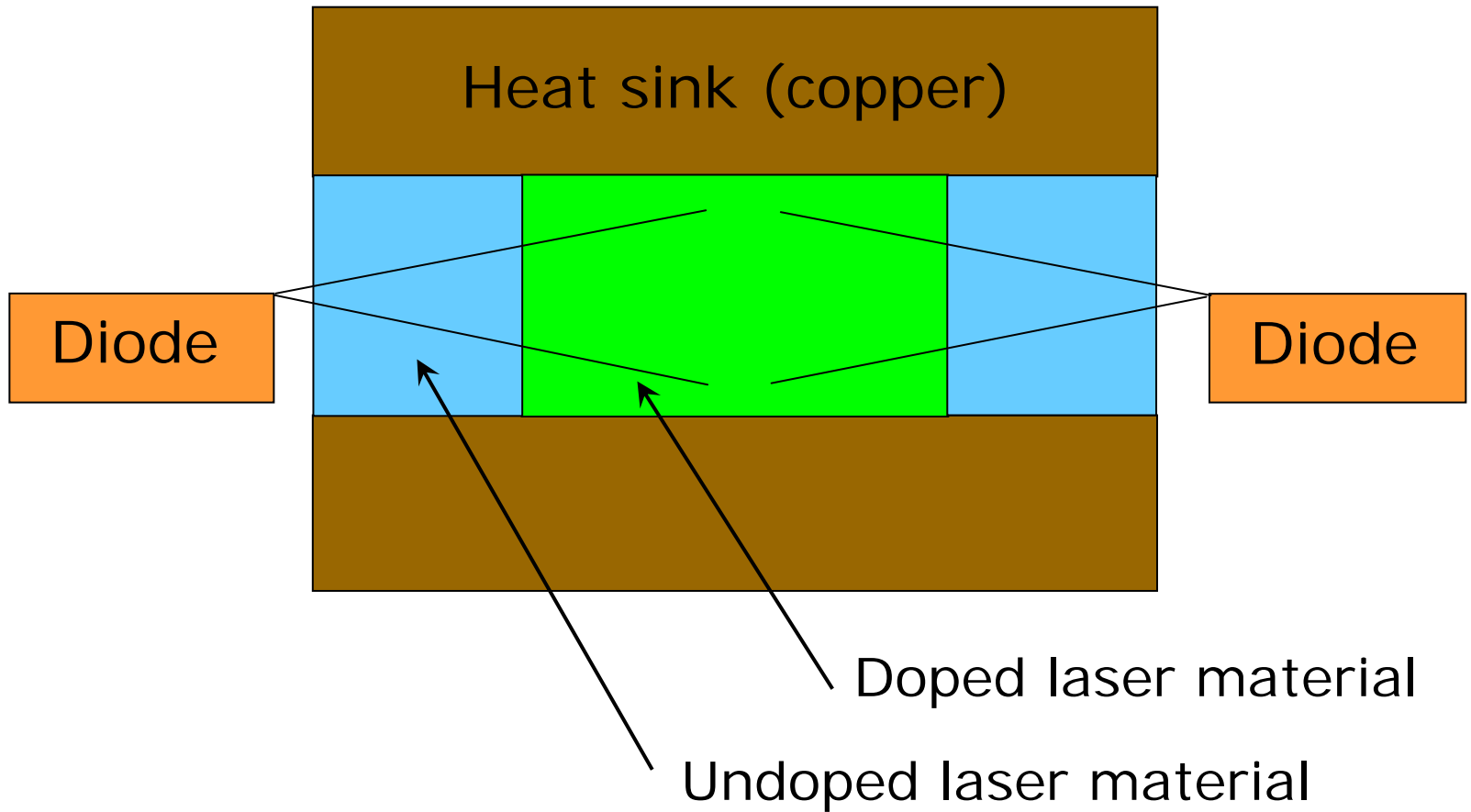
Side Pumped Rod

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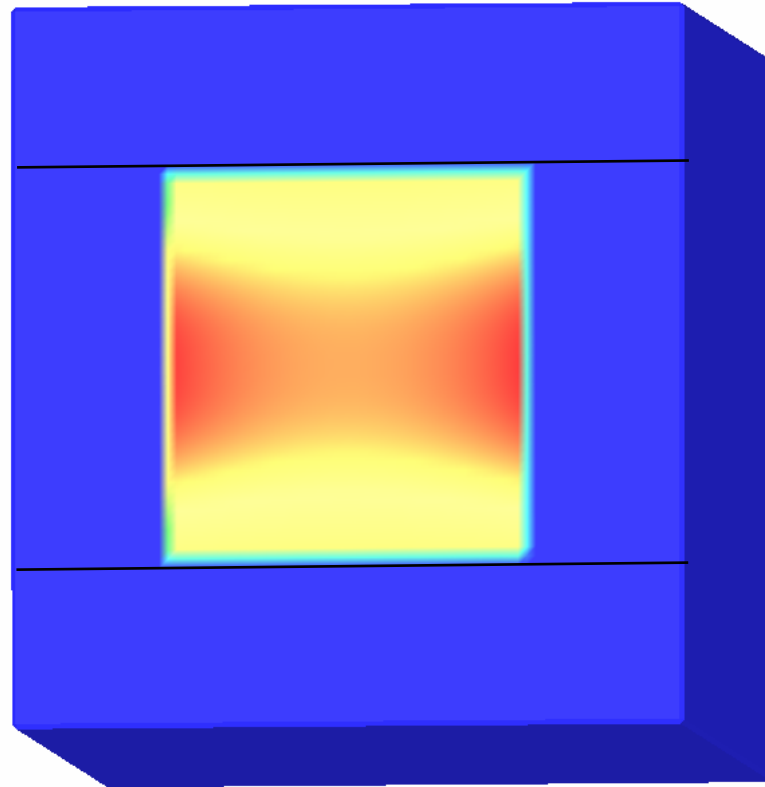
Example: Heat load distribution in a side pumped rod

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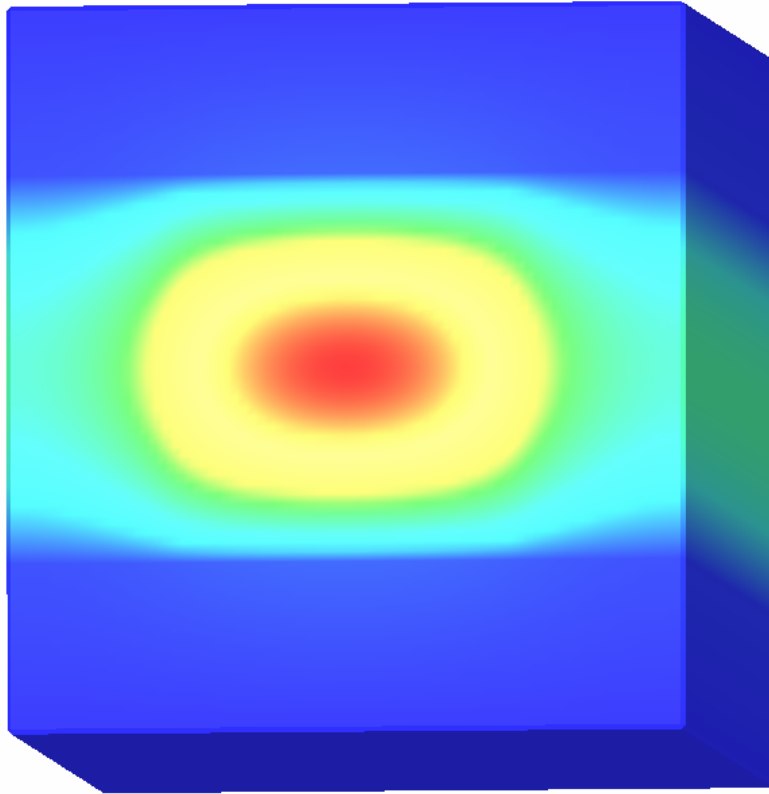
Side Pumped Slab with Copper at Top and Bottom

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Example: Heat load distribution in slab pumped from the left and the right hand side with two undoped layers at left and right and two copper plates at top and bottom.

LASCAD™ - The Laser Engineering Tool



Example: Temperature distribution in slab pumped from the left and the right hand side with two undoped layers at left and right and two copper plates at top and bottom.

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The results of FEA can be used with the ABCD gaussian propagation as well as with the BPM physical optics code.

FEA Results:

Temperature distribution
Deformation
Stress



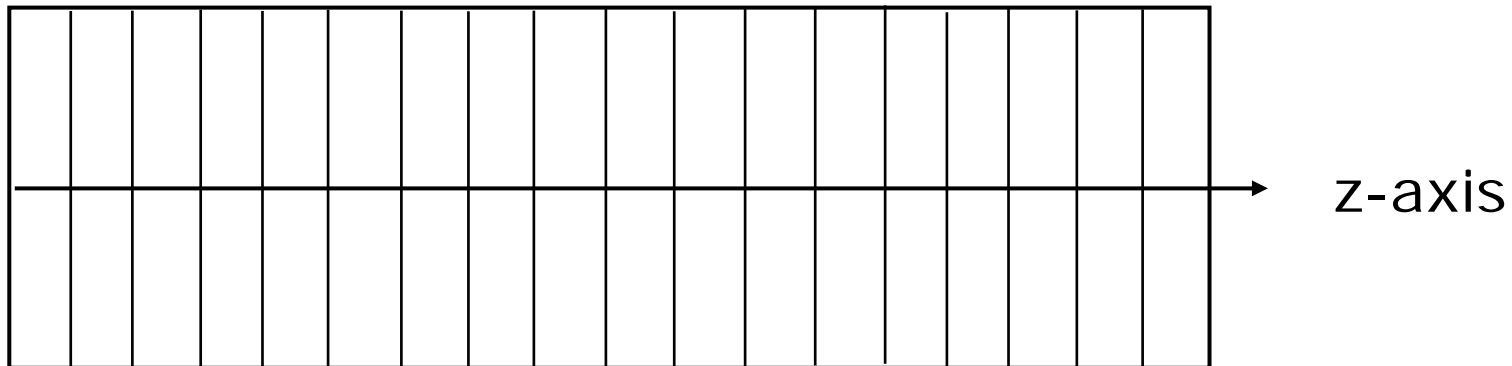
ABCD Gaussian
Propagation Code



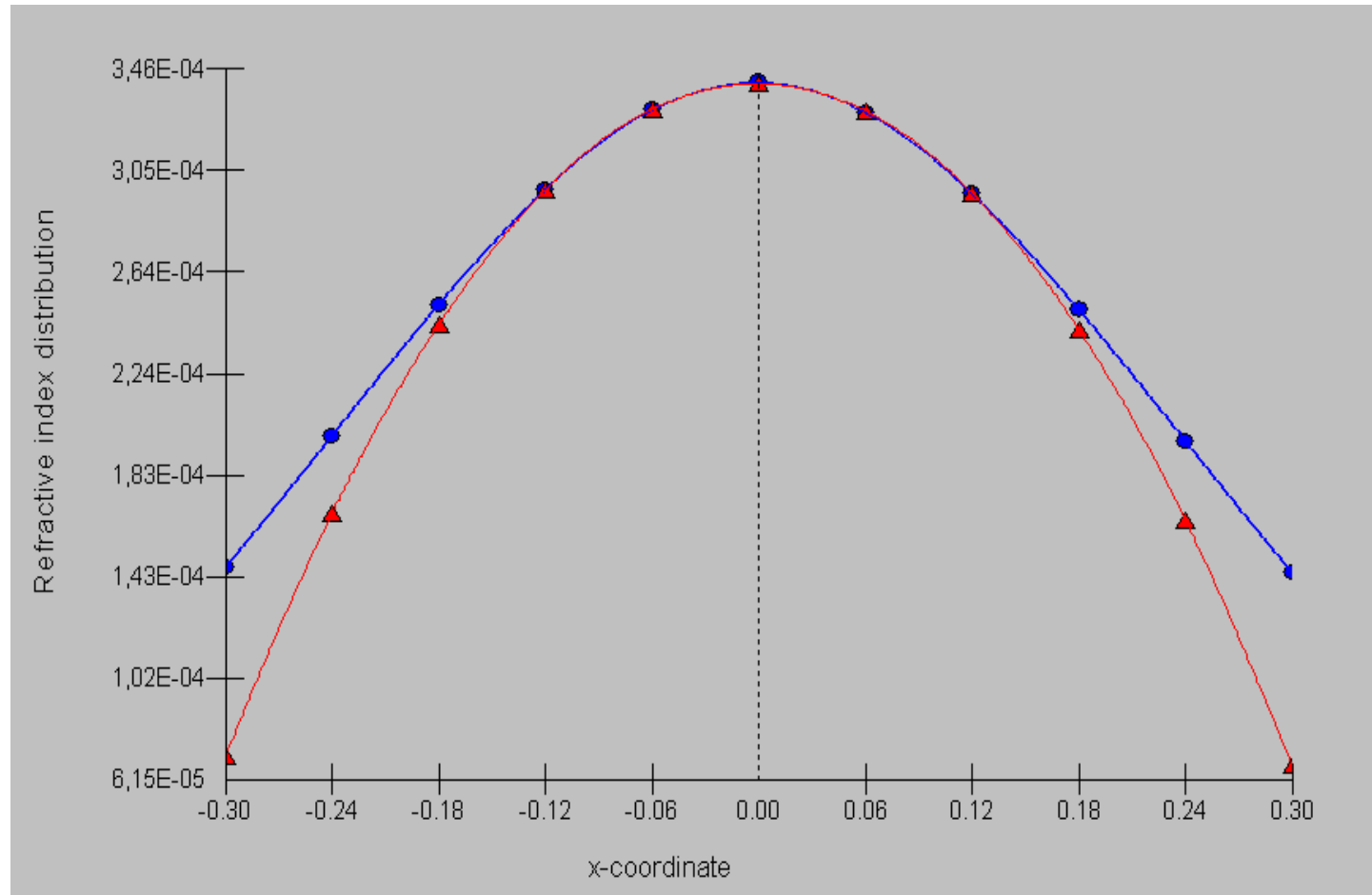
Physical Optics
Propagation Code

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When FEA results are used with the ABCD matrix code, the temperature distribution, multiplied by the derivative of refractive index versus temperature dn/dT , is fitted parabolically at right angles to the optical axis using the finite element mesh subdivisions.



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Example: Parabolic fit of the distribution of the refractive index

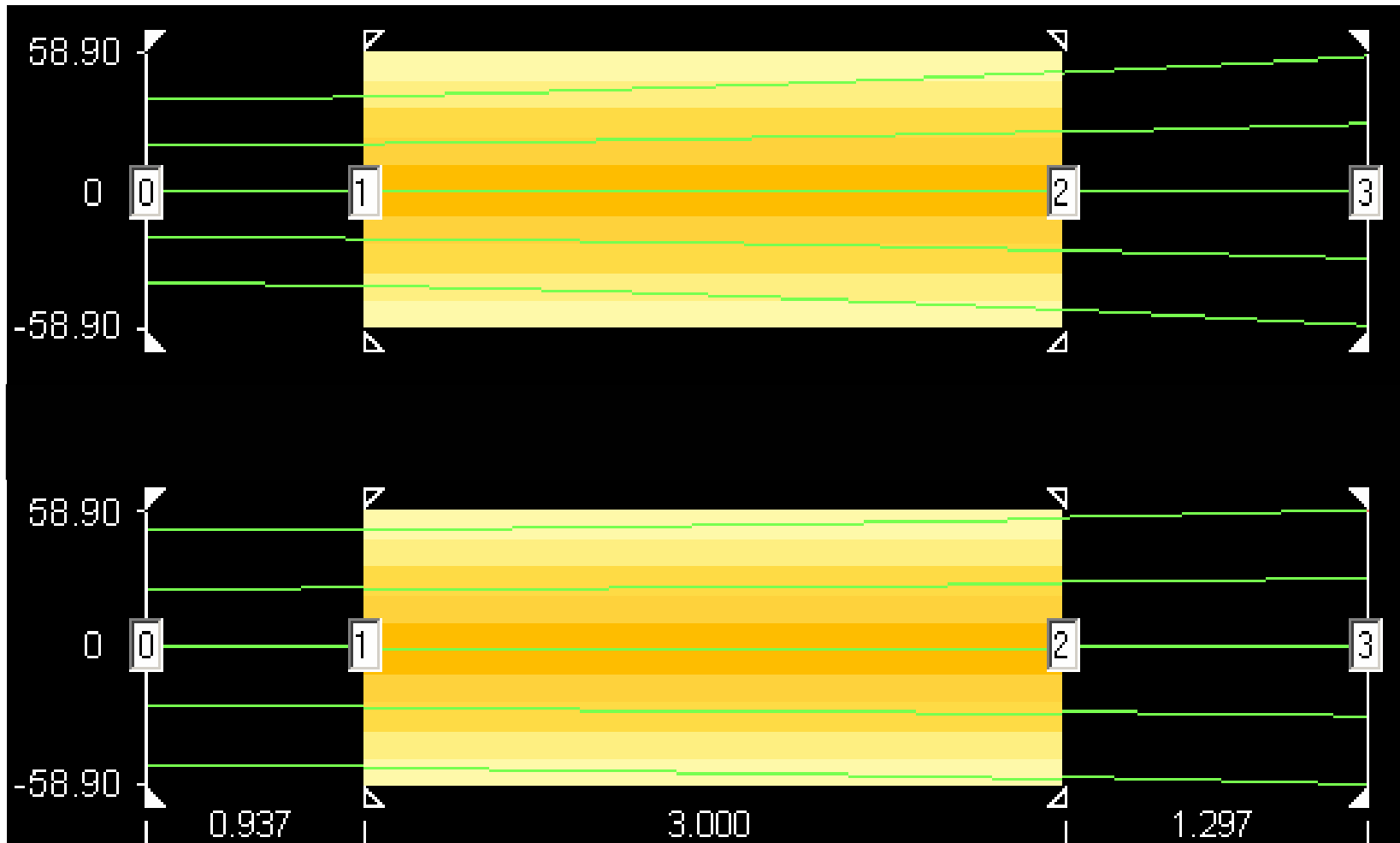
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In the same way, a fit of the deformed end facets of the crystal is carried through.

The obtained parabolic coefficients are then used with the ABCD gaussian propagation algorithm.

For many configurations, end pumped rods for example, this approximation delivers reliable results for the laser mode.

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Example: Mode plot for resonator with thermally lensing crystal between to external mirrors.

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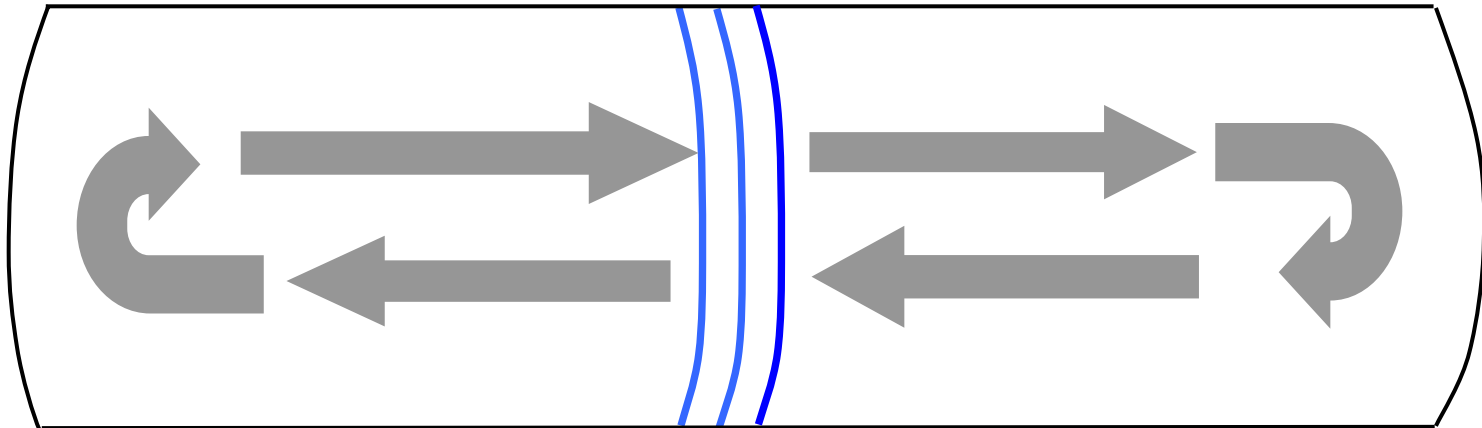
For cases where parabolic approximation and ABCD gaussian propagation code are not sufficient, FEA results alternatively can be used as input for a physical optics code that uses a FFT Split-Step Beam Propagation Method (BPM).

The physical optics code provides full 3-D simulation of the interaction of a propagating wavefront with the hot, thermally deformed crystal, without using parabolic approximation.

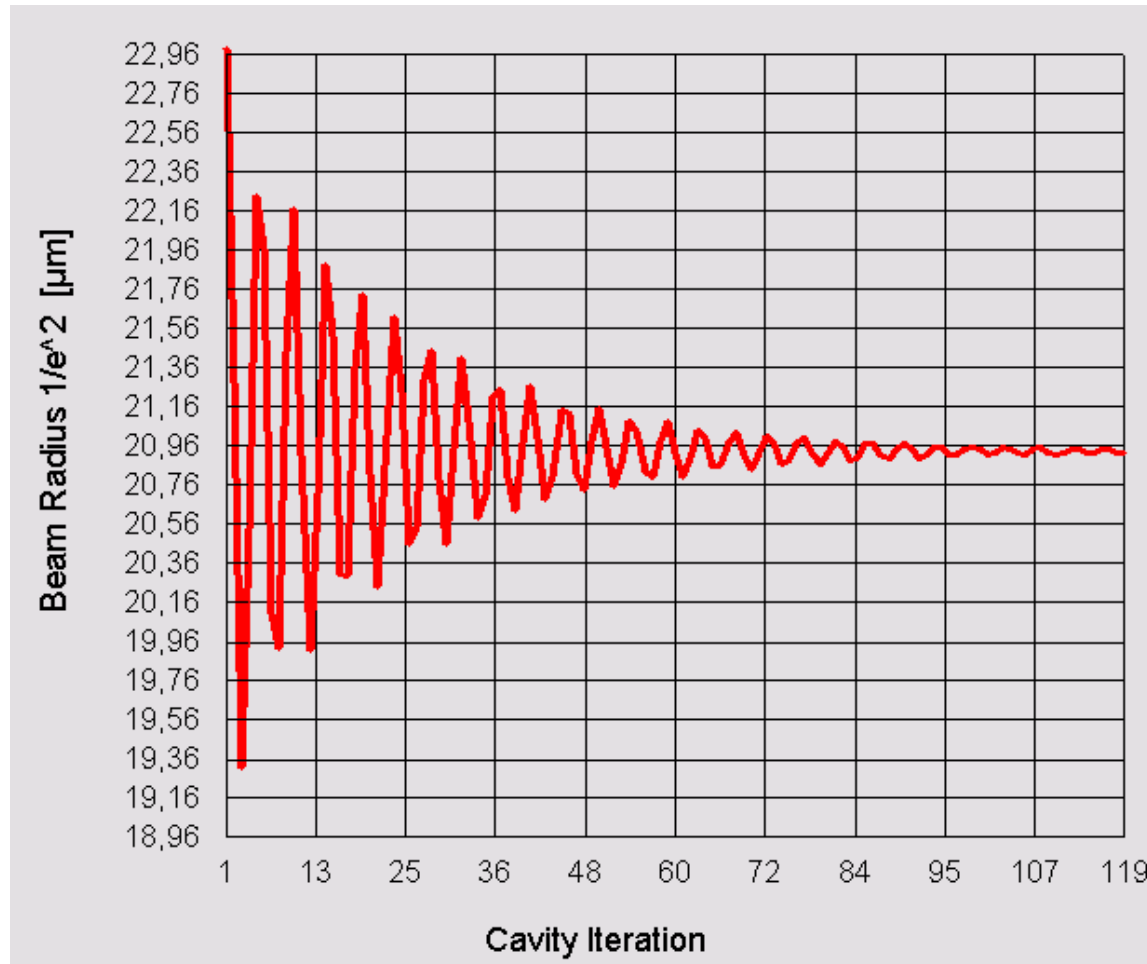
For this purpose the code propagates the wave front in small steps through crystal and resonator, taking into account the refractive index distribution, as well as the deformed end facets of the crystal, as obtained from FEA.

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Based on the principle of Fox and Li, a series of roundtrips through the resonator is computed, which finally converges to the fundamental or to a superposition of higher order transversal modes.



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Convergence of spot size with cavity iteration

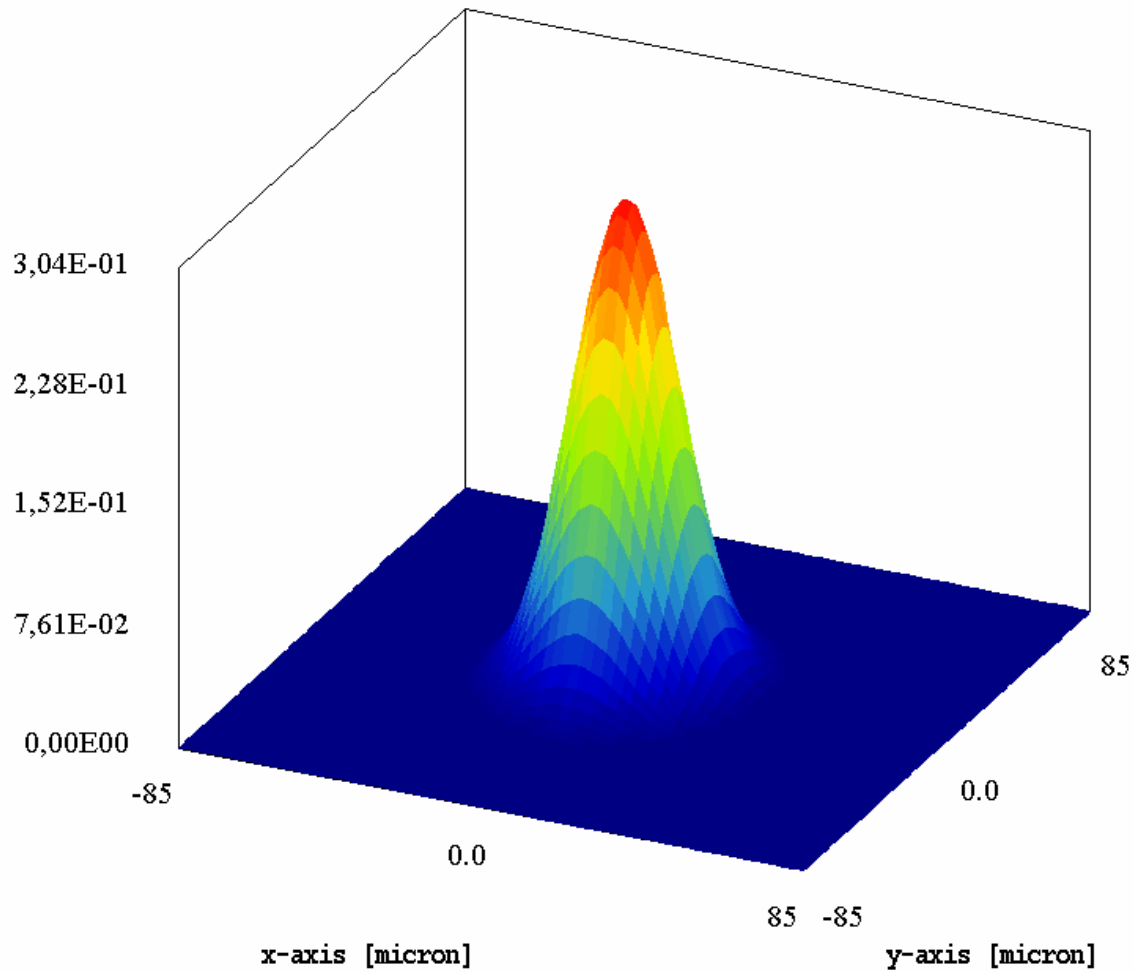
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Different from the ABCD algorithm the wave optics code also takes into account diffraction effects due to apertures. Computation of misalignment and gain guiding effects is under development.

The wave optics computation therefore delivers realistic results for important features of a laser like intensity and phase profile.

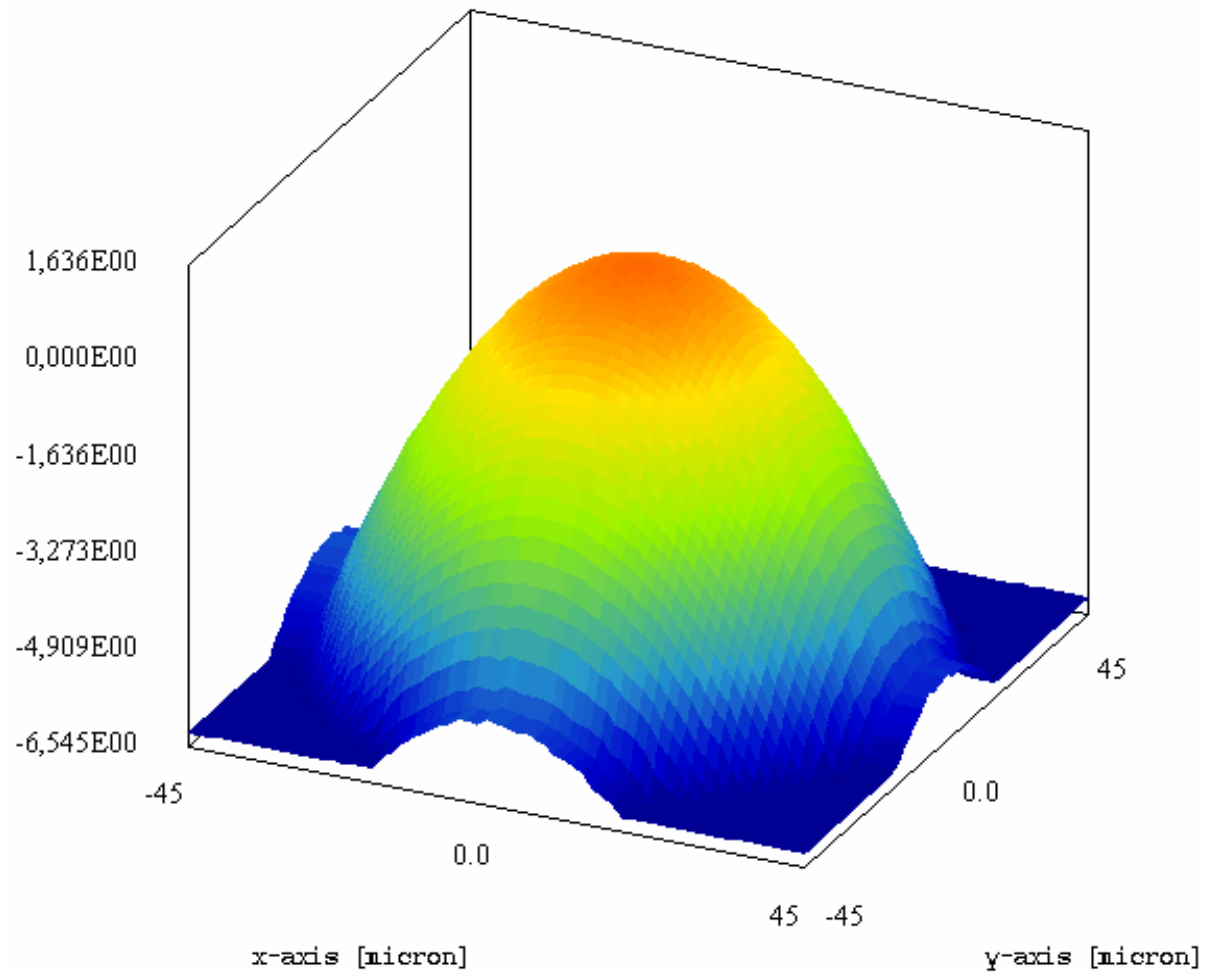
This information may then be compared directly with physical wavefront measurements after the resonator is constructed.

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Intensity distribution at output mirror

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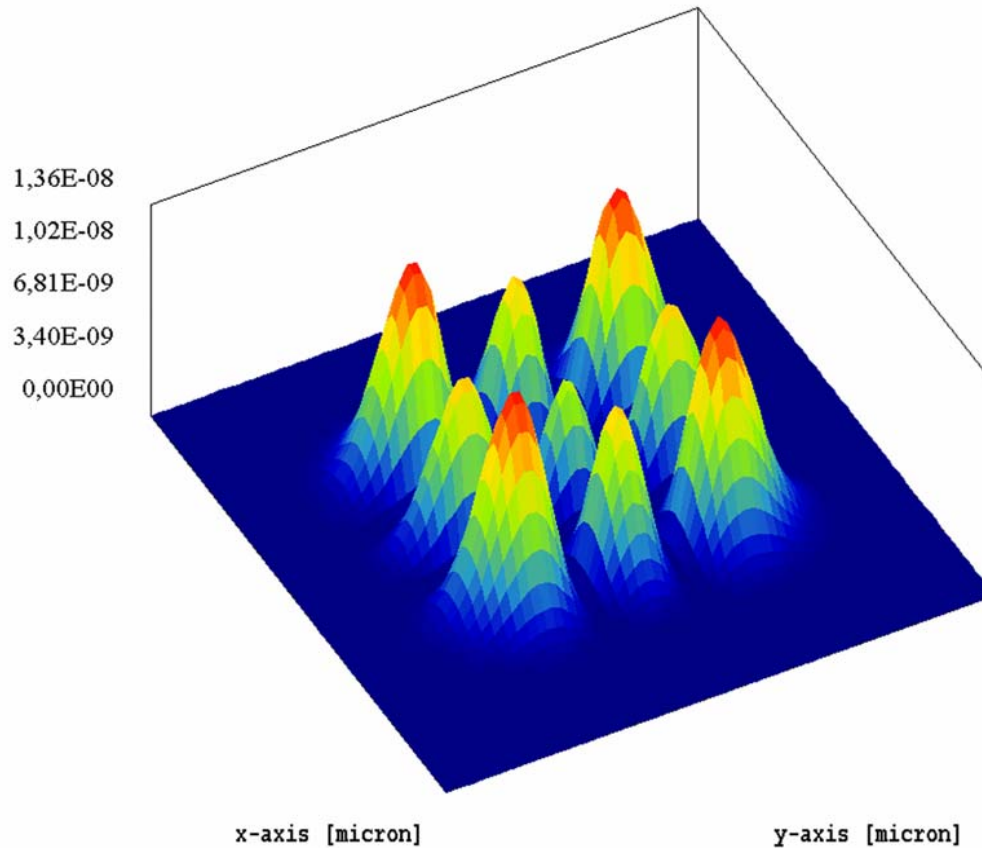
Phase distribution at output mirror

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In addition, the wave optics code is capable of numerically computing the spectrum of resonator eigenvalues and also the shape of the transverse eigenmodes. An example for a higher order Hermite-Gaussian mode is shown in the next slide.

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Mode TEM22



Mode TEM₂₂ obtained by numerical eigenmode analysis

LASCAD™ - The Educational Tool

Its easy-to-use and clearly organized user interface makes LASCAD ideally suited for educational purposes for students, and practicing scientists or engineers.

The principles of ABCD gaussian beam propagation can be studied interactively.

The behavior of complicated heterogeneous resonator design concepts or the combined influence of thermal lensing and gain guiding effects can be visualized interactively.

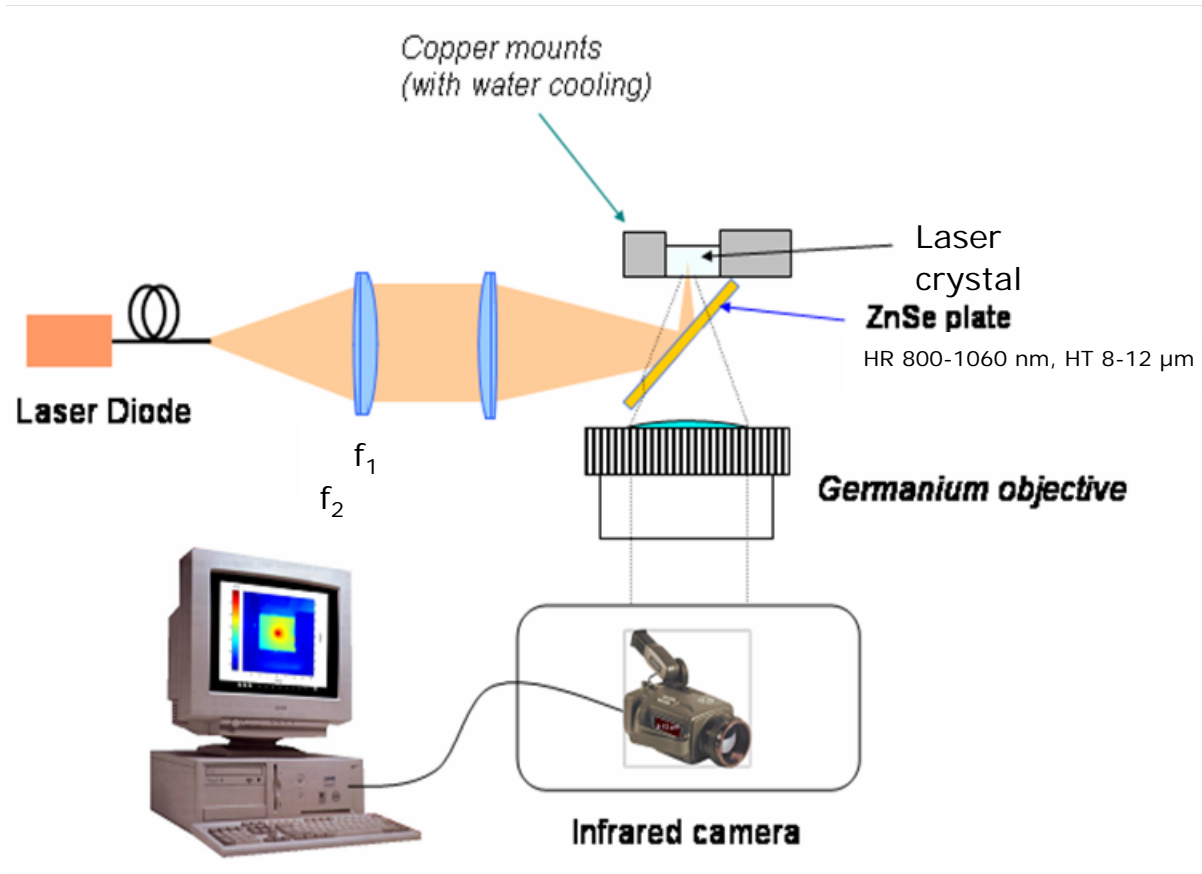
Verification of Results

Recently, simulation results obtained with LASCAD have been verified by the

Solid-State Lasers and Application Team (ELSA)
Centre Université d'Orsay, France

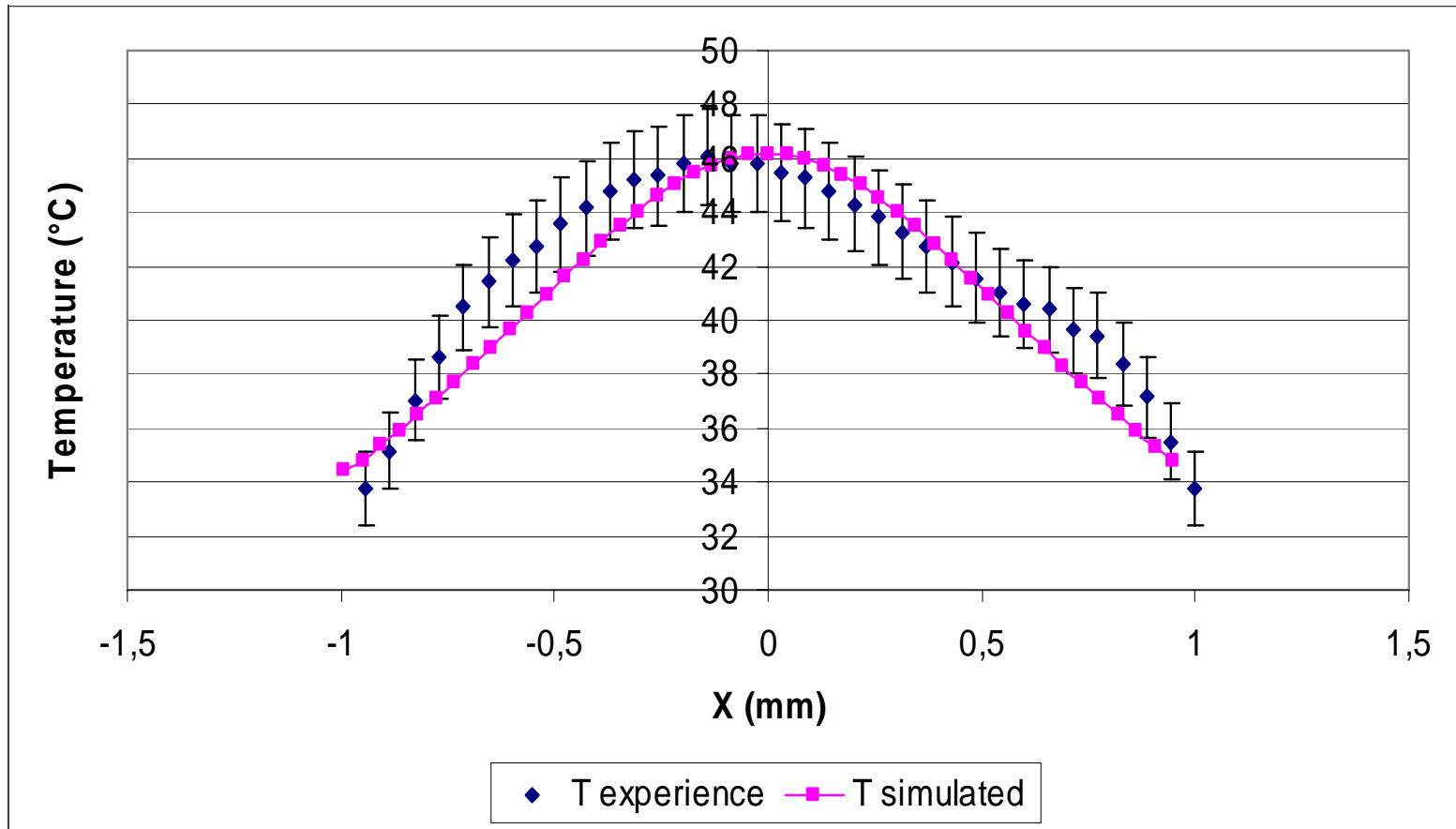
As already presented at this conference last year this group developed an experimental setup to carry through direct, absolute and spatially resolved temperature measurements in diode-end-pumped laser crystals, using an infrared camera.

Verification of Results



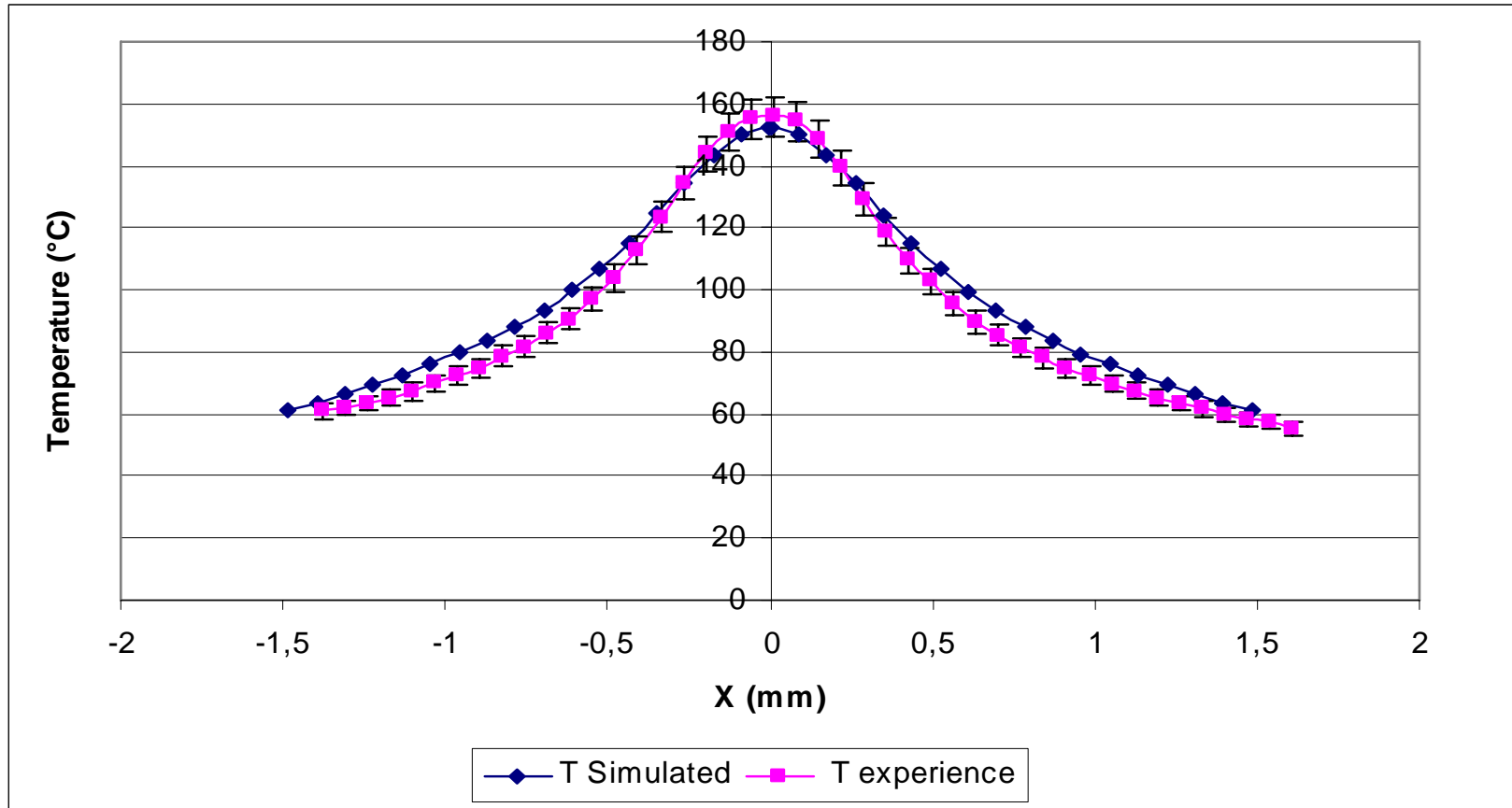
Experimental setup for direct temperature measurements

Verification of Results



Measured and computed distribution of temperature for Nd:YAG 1.0 at.% at the entrance plane of the pump beam

Verification of Results



Measured and computed distribution of temperature for Nd:YVO₄ 1.0 at. % at the entrance plane of the pump beam

Outlook

LASCAD is under continuous development.

Last year I presented at this conference a new method to compute the eigenmodes of a laser cavity by the use of a finite element approach. Please visit our website www.las-cad.com for our publications.

Currently, we are applying for grant at the Bavarian Research Foundation for a new research project. We are planning to develop a time dependent FEA code to analyze time dependence of the electromagnetic fields in the cavity.