

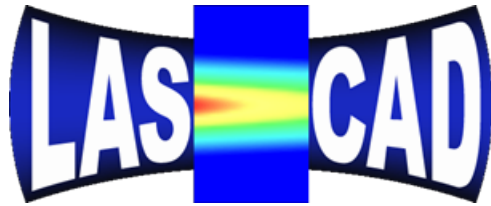


**LASer Cavity  
Analysis & Design**

# **How to Use LASCAD™ Software for LASer Cavity Analysis and Design**

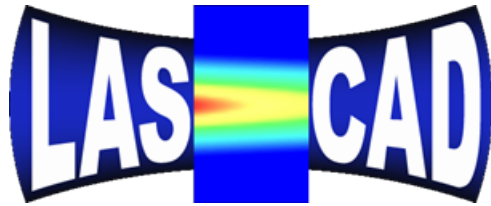
*Konrad Altmann*

**LAS-CAD GmbH, Munich, Germany**



## **LASer Cavity Analysis & Design**

Numerical analysis of the 3D nonlinear interaction of the optical fields in a cavity with thermal effects, such as the temperature-dependent refractive index distribution, absorbed pump power distribution, doping distribution, population inversion etc. is of growing importance to optimize SSL systems



## **LASer Cavity Analysis & Design**

Intuitive approach based on personal experience is still important, but is not sufficient due to the tendency to miniaturize laser systems and simultaneously to increase their power output, causing interaction of strong fields in very small volumes.

To model the complex interactions in a laser cavity, LASCAD software combines the necessary simulation tools into one package.

Based on a quantitative understanding of the multiphysics effects in laser cavities, LASCAD allows the laser engineer to optimize important features of a laser like beam quality and laser power output.

## **LASCAD™ offers:**

- **Thermal and Structural Finite Element Analysis (FEA)**
- **ABCD Gaussian Beam Propagation**
- **Physical Optics Beam Propagation (BPM)**
- **Computation of Laser Power Output and Beam Quality**
- **Dynamic Analysis of Multimode and Q-Switch Operation (DMA)**

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 understand experimental results without wasting valuable time studying complicated manuals:

## LASCAD™ - The Optical Workbench on the PC

- Optical elements like mirrors, lenses and 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, DMA 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, deformation, 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.

## Finite Element Analysis (FEA)

Pre-designed 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 are available to visualize pump light distribution, boundary conditions, and results of FEA.

# LASCAD™ - The Laser Engineering Tool

## **Configurations available with LASCAD:**

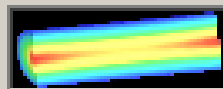
- End pumped rods and slabs with the pump light distribution being modeled by the use of supergaussian functions or pumping from both ends.
- Rods and slabs, with top hat pump profile along crystal axis and supergaussian distribution perpendicular to the axis.

# LASCAD™ - The Laser Engineering Tool

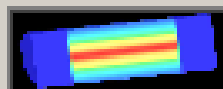
## **Configurations available with LASCAD:**

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

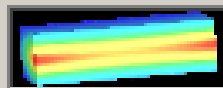
## Crystal and pumping configurations



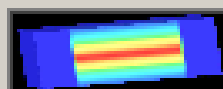
- Single or dual end pumped cylindrical rod



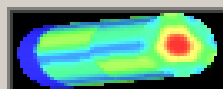
- Cylindrical rod with top hat profile of pump light along z-axis and supergaussian shape perpendicular to z-axis



- Single or dual end pumped slab



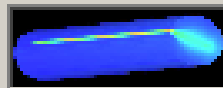
- Slab with top hat profile of pump light along z-axis and supergaussian shape perpendicular to z-axis



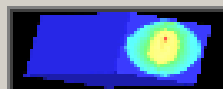
- Side pumped cylindrical rod



- Side pumped slab including sandwich configurations



- Cylindrical rod with numerical input of pump light distribution



- Slab with numerical input of pump light distribution

Click into the pictures to zoom in or out.

Examples are found in the subdir. `EXAMPLES` of the LASCAD application dir.

Tutorials are found in the subdir. `TUTORIALS` of the LASCAD application dir.

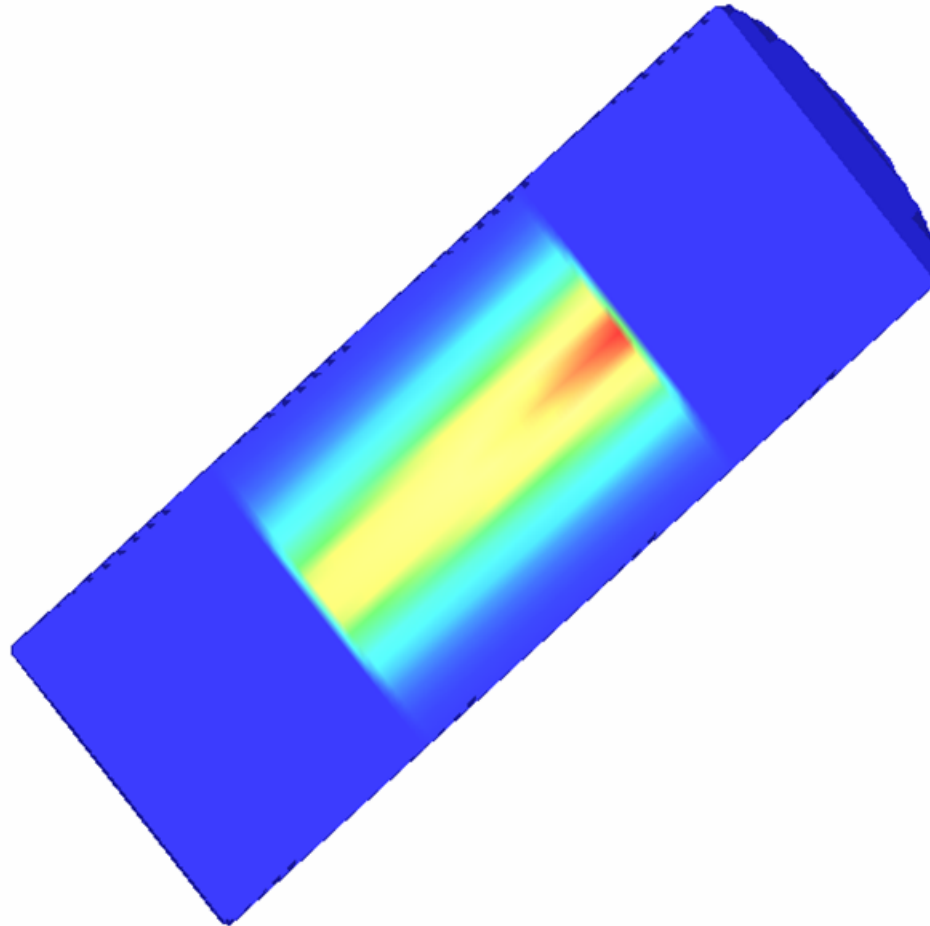
## **LASCAD™ - The Laser Engineering Tool**

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

Heat sinks can also be included into the FEA model. For example, temperature distribution and deformation in a structure consisting of crystal slab between two copper plates can be computed.

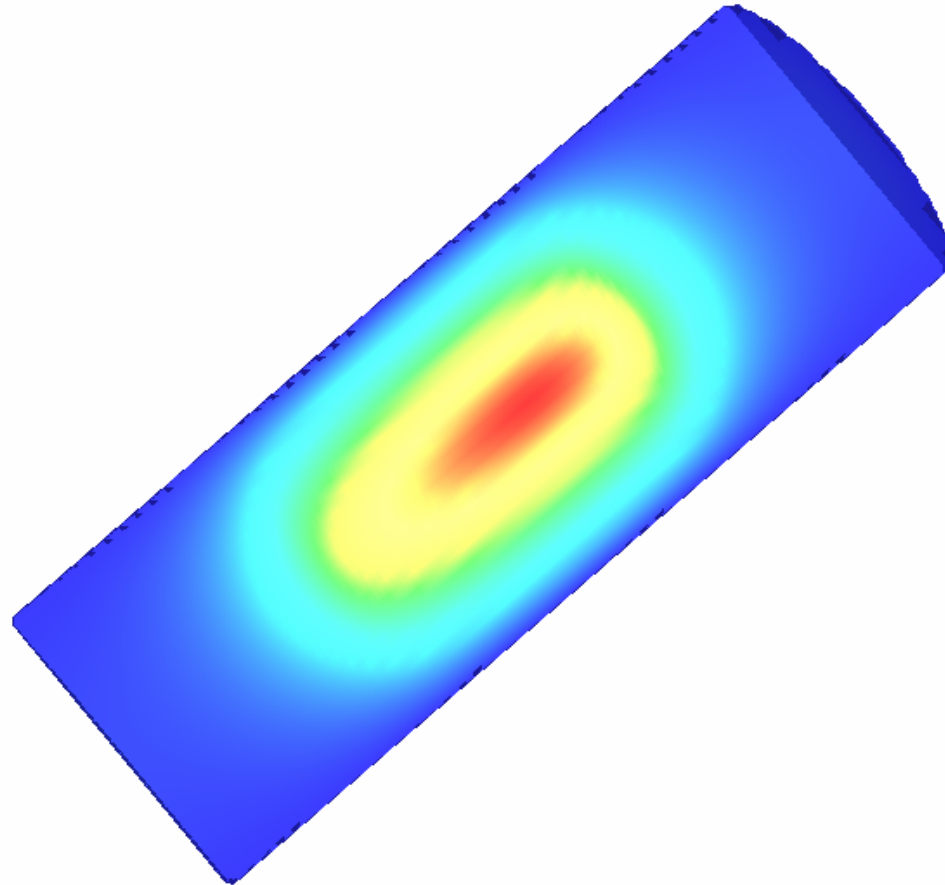
In the following, several pictures visualizing FEA results are shown.

# LASCAD™ - The Laser Engineering Tool



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

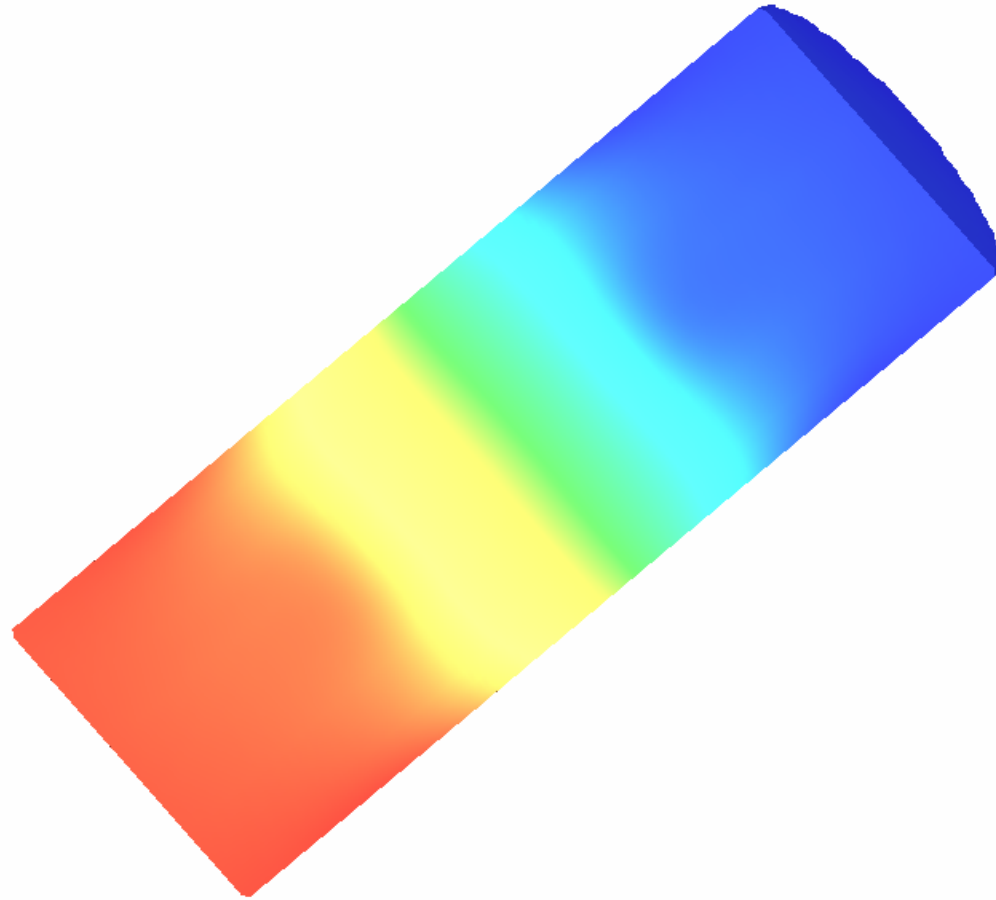
# LASCAD™ - The Laser Engineering Tool



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

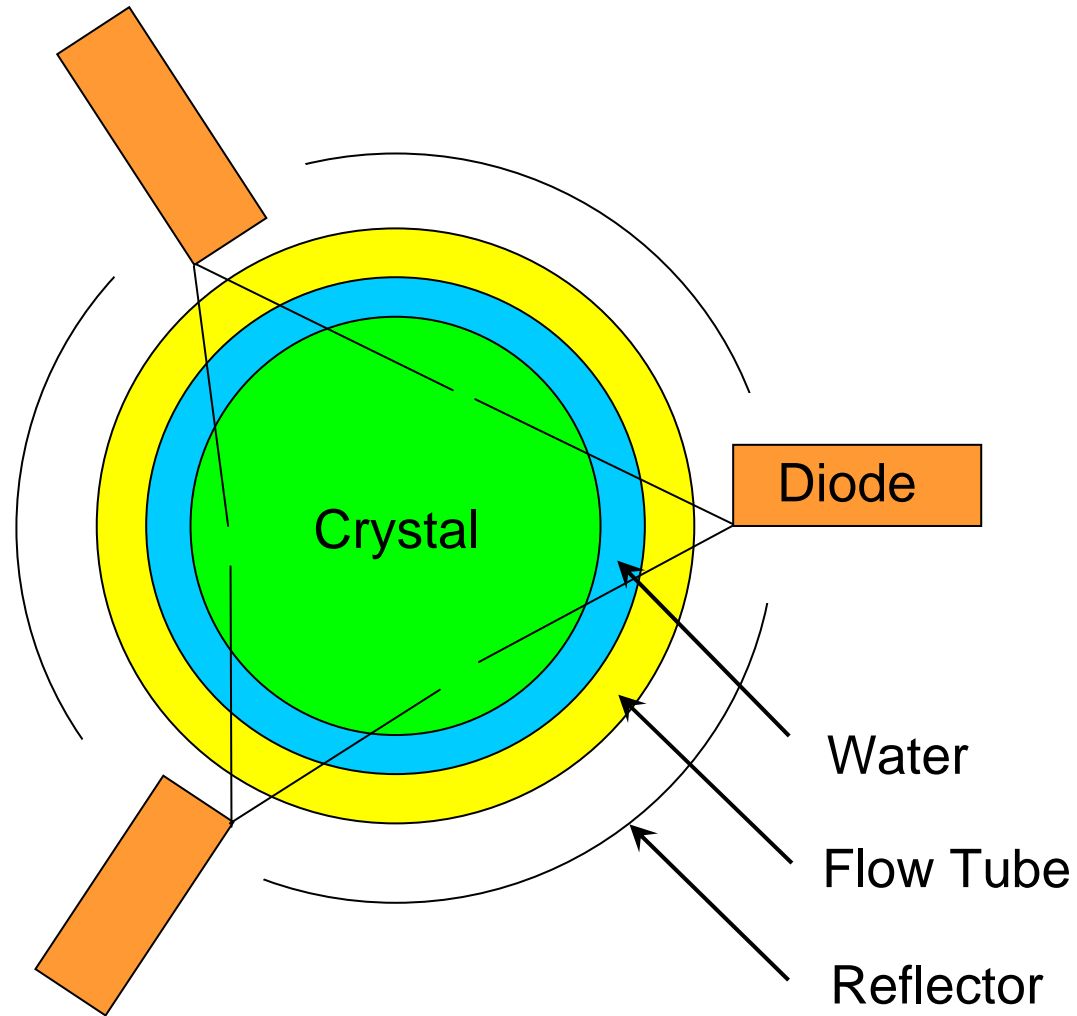


# LASCAD™ - The Laser Engineering Tool



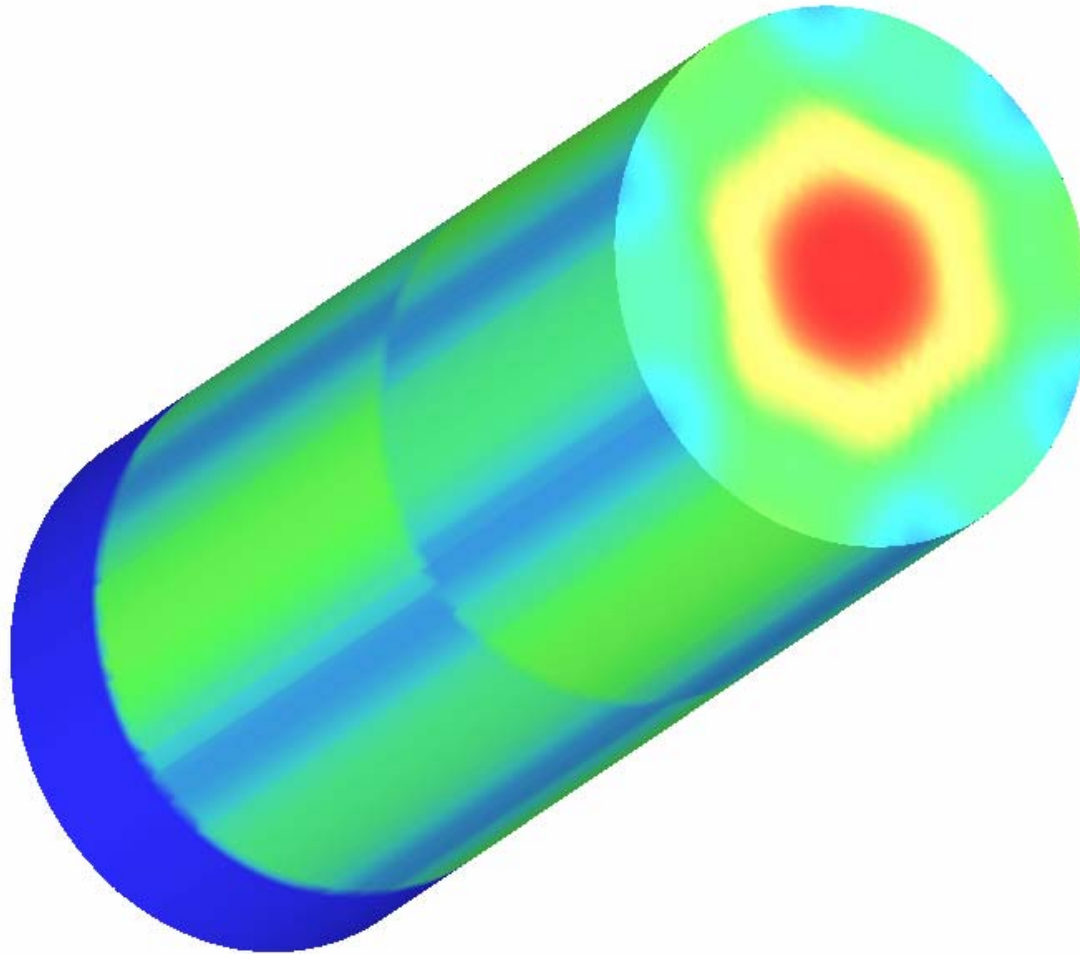
Example: z-component of displacement in a rod with undoped end-caps

# LASCAD™ - The Laser Engineering Tool



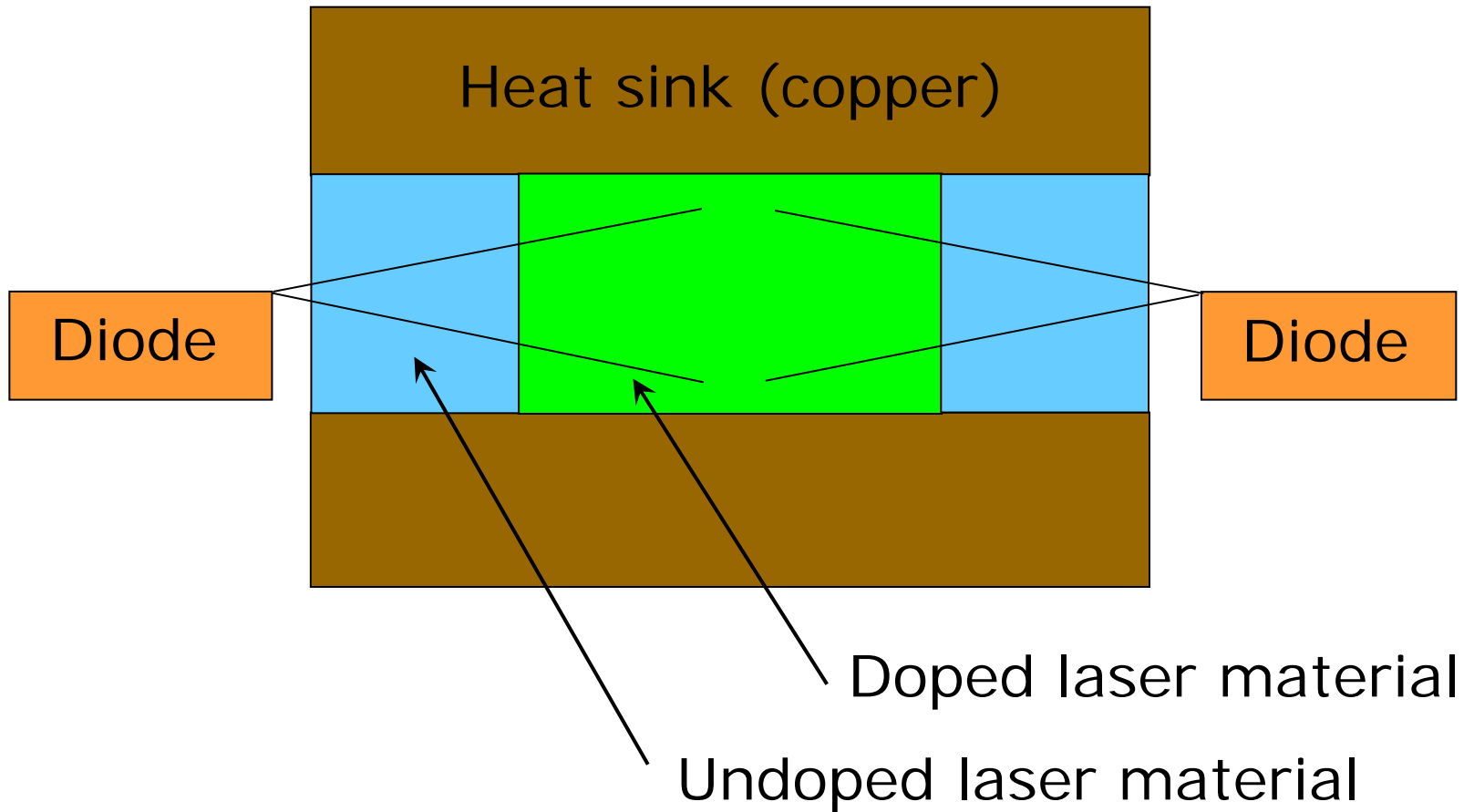
Side Pumped Rod

# LASCAD™ - The Laser Engineering Tool



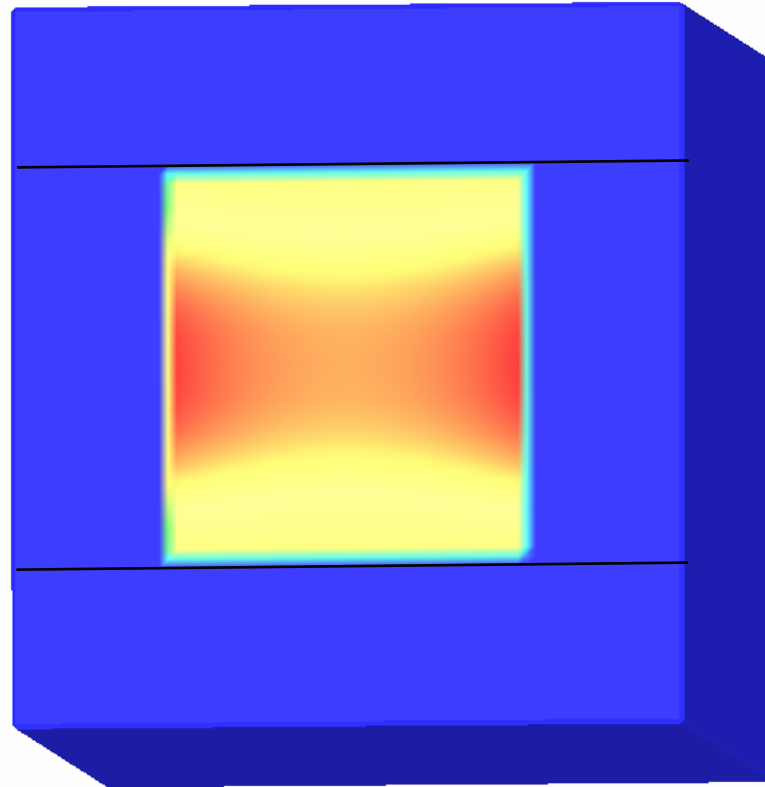
Example: Heat load distribution in a side pumped rod

# LASCAD™ - The Laser Engineering Tool



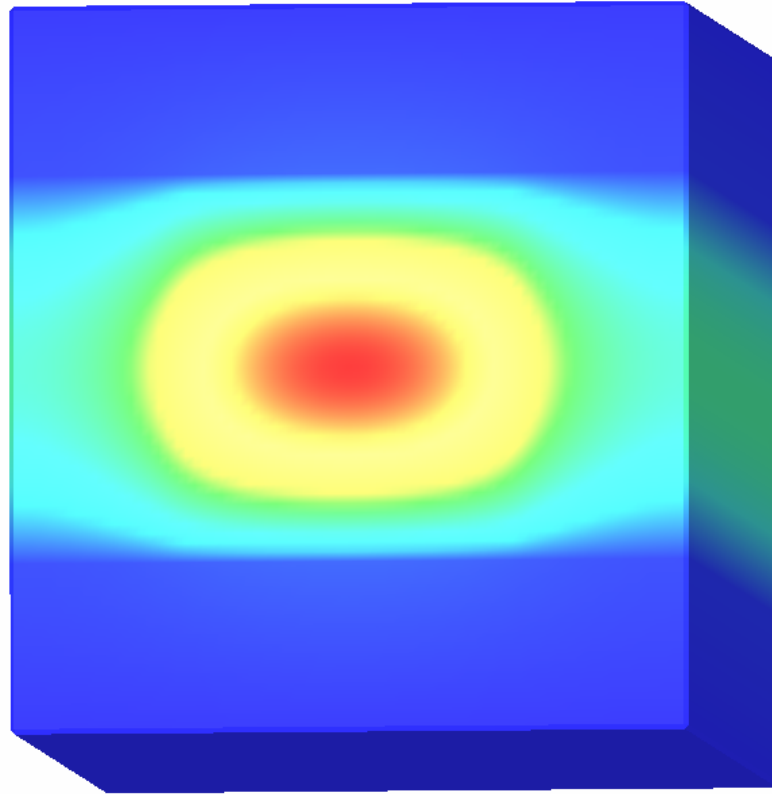
Side Pumped Slab with Copper at Top and Bottom

# LASCAD™ - The Laser Engineering Tool



Example: Heat load distribution in a 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 a 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

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

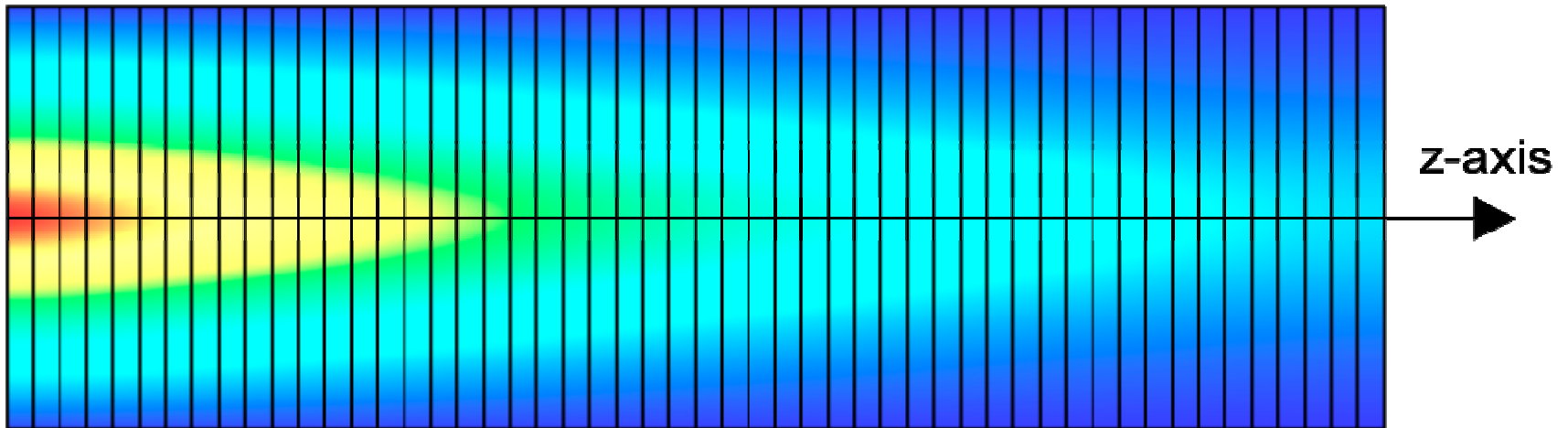
```
graph LR; A[FEA Results: Temperature distribution, Deformation, Stress] --> B[ABCD Gaussian Propagation Code]; A --> C[Physical Optics Propagation Code];
```

ABCD Gaussian Propagation Code

Physical Optics Propagation Code

# LASCAD™ - The Laser Engineering Tool

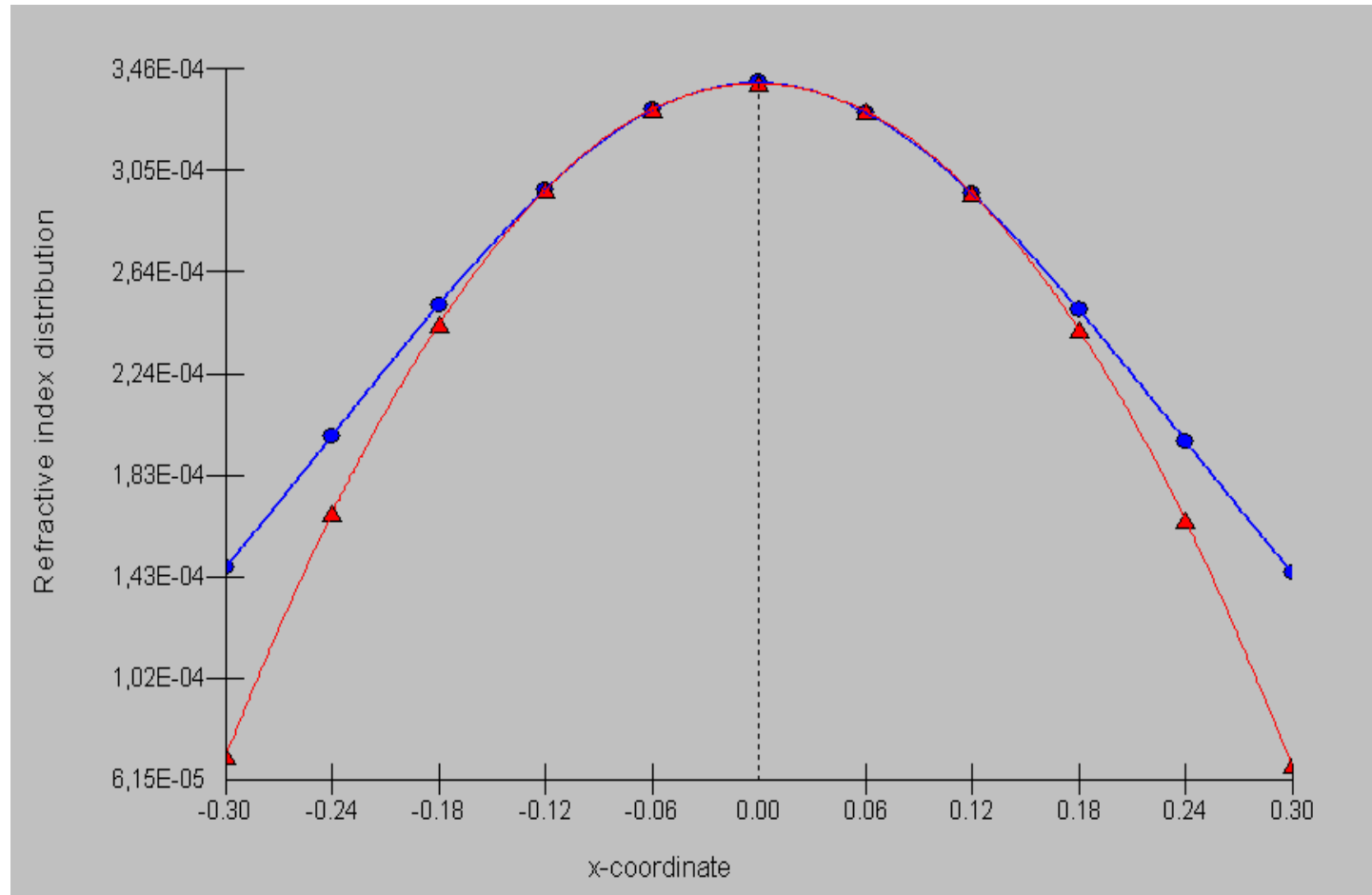
When FEA results are used with the ABCD matrix code, the temperature distribution, multiplied by the derivative of refractive index versus temperature  $dn/dT$ , is fitted parabolically at right angles to the optical axis. The fit is carried through for each slide by using the FEA mesh.



This plot demonstrates this for an end pump rod



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Example: Parabolic fit of the distribution of the refractive index

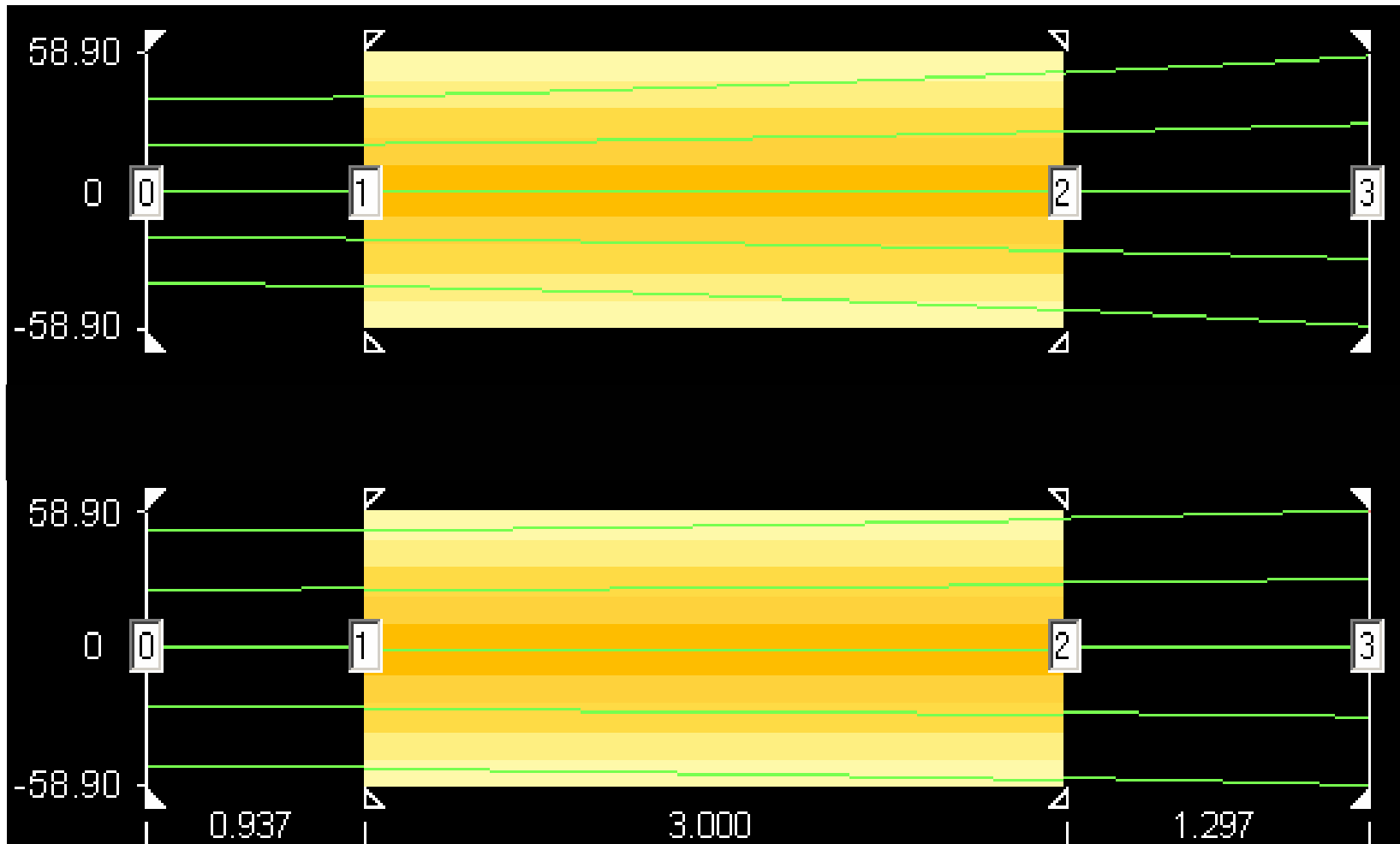
## LASCAD™ - The Laser Engineering Tool

In the same way, a fit of the deformed end faces 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: Resonator with thermally lensing crystal between to external mirrors.

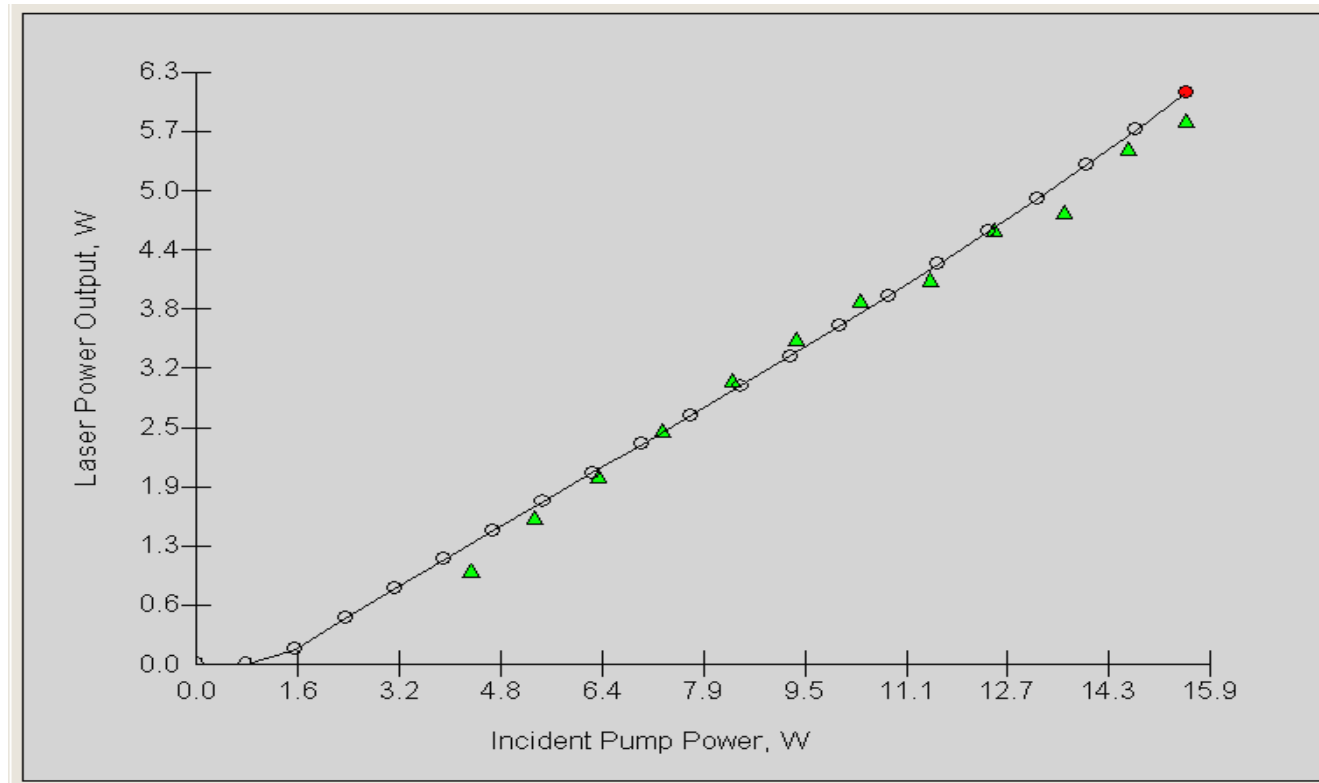
# LASCAD™ - The Laser Engineering Tool

The modes obtained by the gaussian ABCD matrix approach can be used to compute the laser power output for cw operation, as well as for Q-switch operation.

In the first case, the steady-state rate equations are solved by the use of an iteration procedure.

An example showing lasing threshold and slope efficiency for a 0.27 at.% Nd:YVO4 is displayed on the next slide.

# LASCAD™ - The Laser Engineering Tool



Example: Output power vs. pump power for 0.27 at.% Nd:YVO<sub>4</sub>

▲ Measurement

o—o Computation

# LASCAD™ - The Laser Engineering Tool

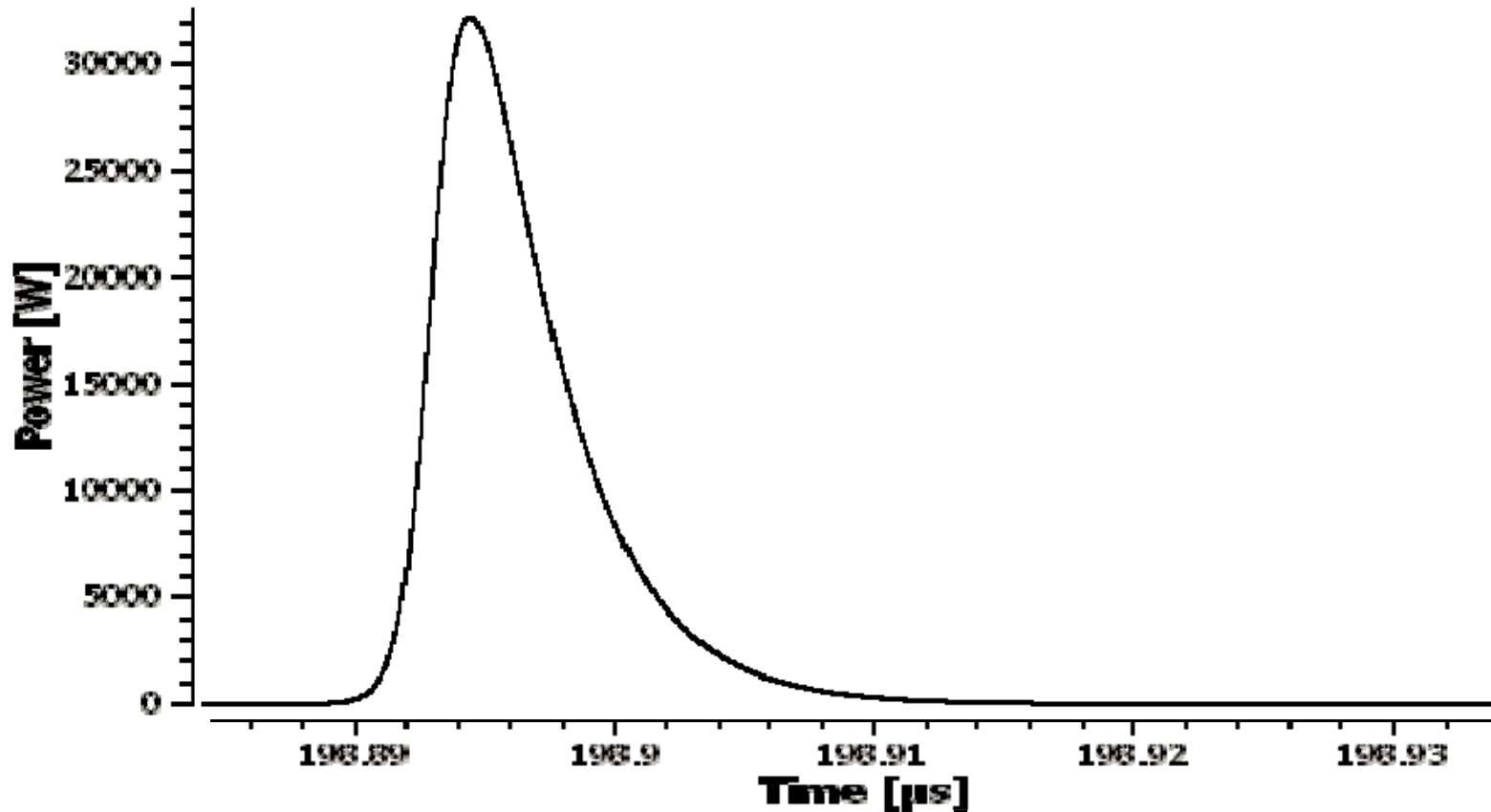
In addition to solving the steady state rate equations, LASCAD offers a new tool for the dynamic analysis of multimode competition and Q-switch operation.

For this purpose, the time dependent rate equations are solved for a predefined set of transverse eigenmodes, by the use of a finite element solver.

The next slide is showing an example for a typical pulse shape computed by this tool.

# LASCAD™ - The Laser Engineering Tool

**Power output over time**



Pulse shape computed by the new DMA tool

## LASCAD™ - The Laser Engineering Tool

For cases where parabolic approximation and ABCD gaussian propagation code are not sufficient, FEA results alternatively can be used as input for physical optics code using 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.

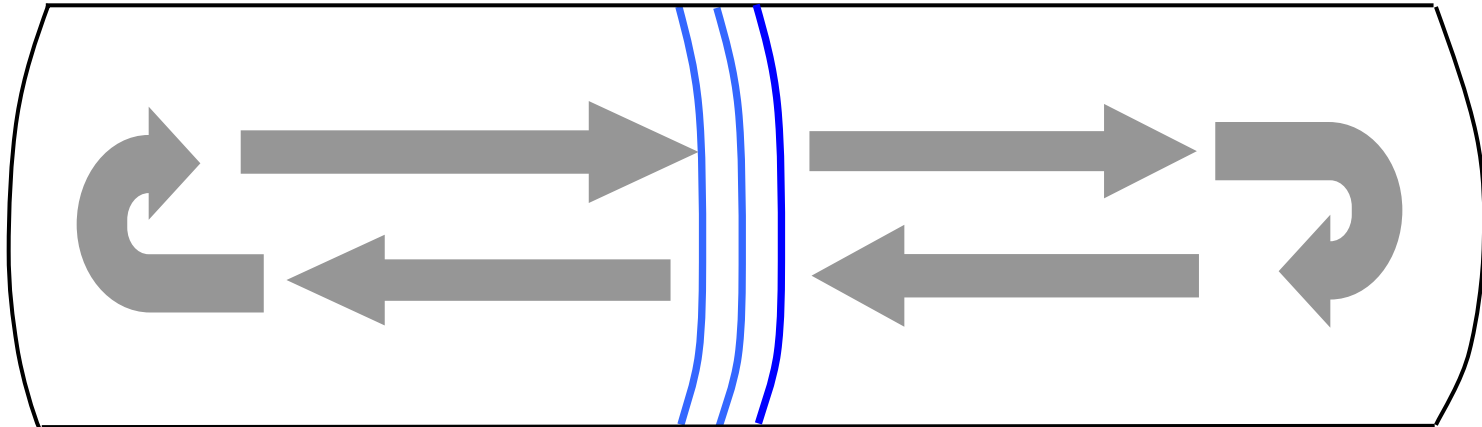


## LASCAD™ - The Laser Engineering Tool

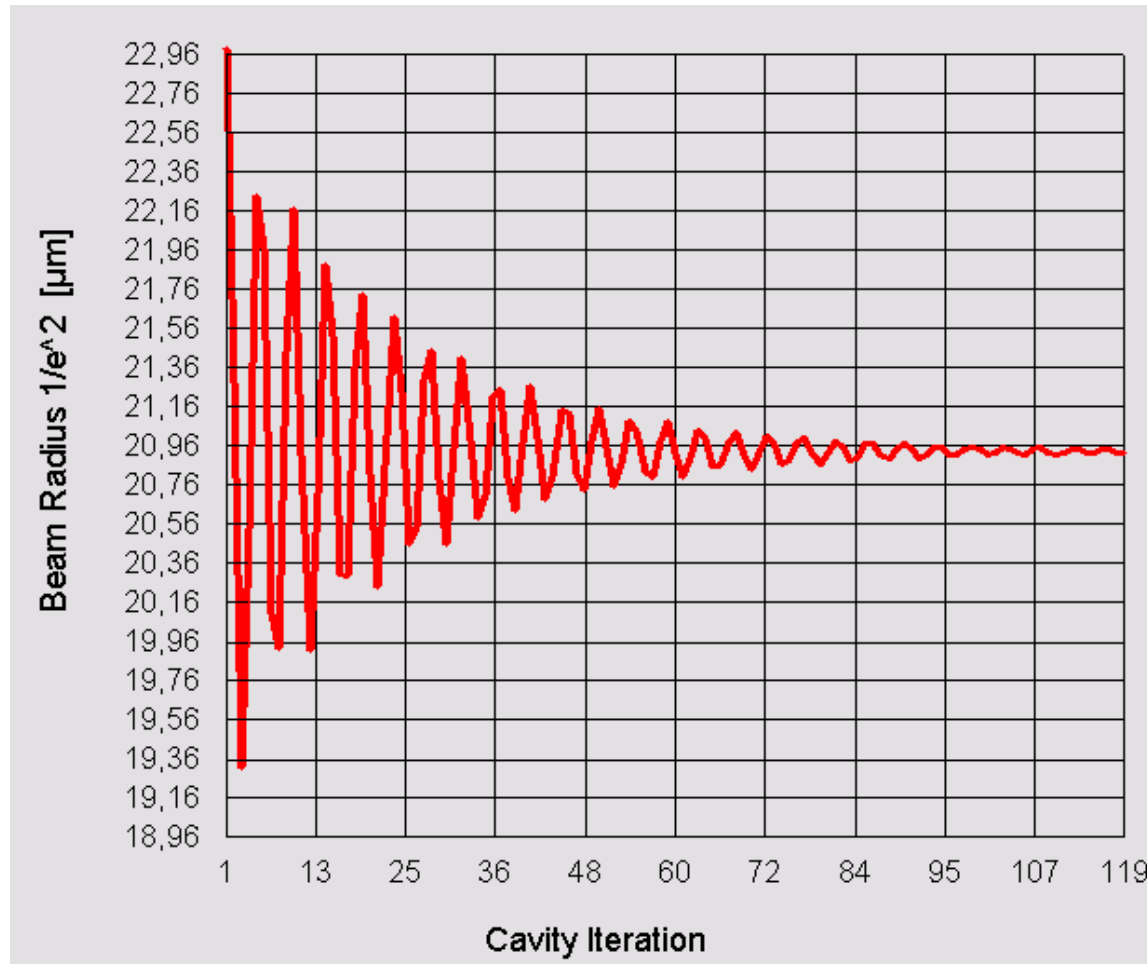
For this purpose the code propagates the wave front in small steps through crystal and resonator, taking into account the refractive index distribution, the gain distribution, and the deformed end faces of the crystal, as obtained from FEA.

# LASCAD™ - The Laser Engineering Tool

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 transverse modes.



# LASCAD™ - The Laser Engineering Tool



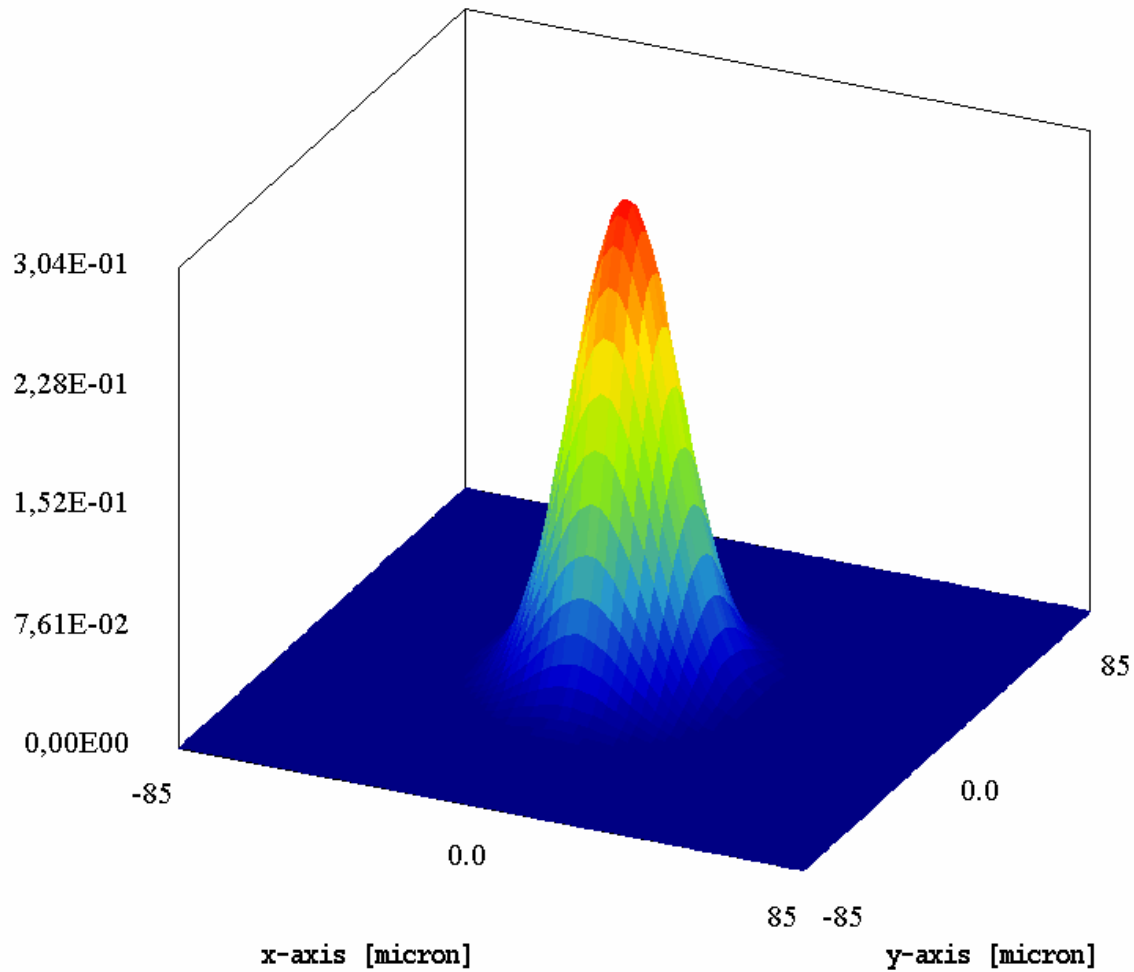
Convergence of spot size with cavity iteration

# LASCAD™ - The Laser Engineering Tool

The wave optics code takes into account diffraction effects due to apertures, misalignment effects, absorbed pump power distribution and gain saturation.

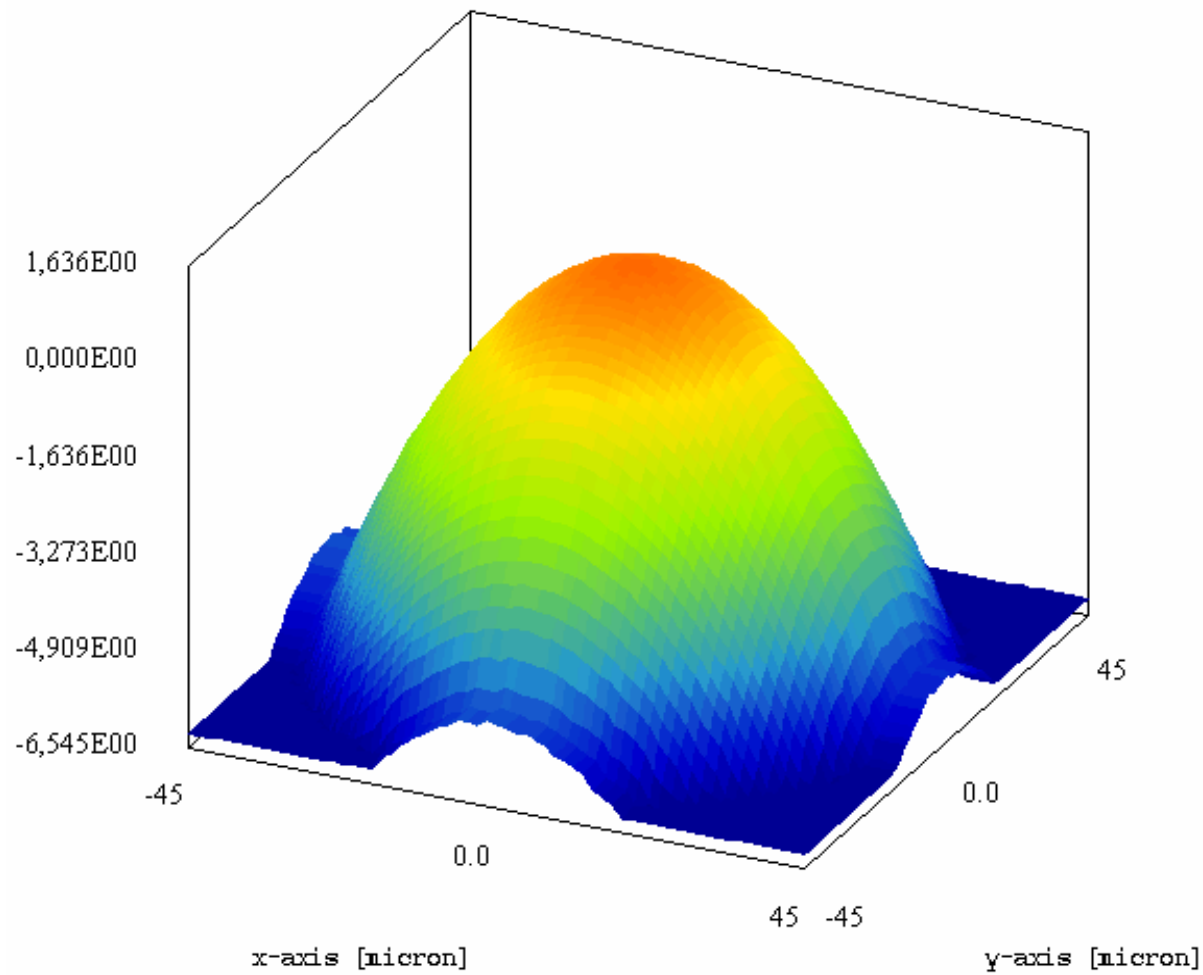
In this way the wave optics code delivers realistic results for important features of a laser, like intensity and phase profile as shown in the next two slides.

# LASCAD™ - The Laser Engineering Tool



Intensity distribution at output mirror

# LASCAD™ - The Laser Engineering Tool



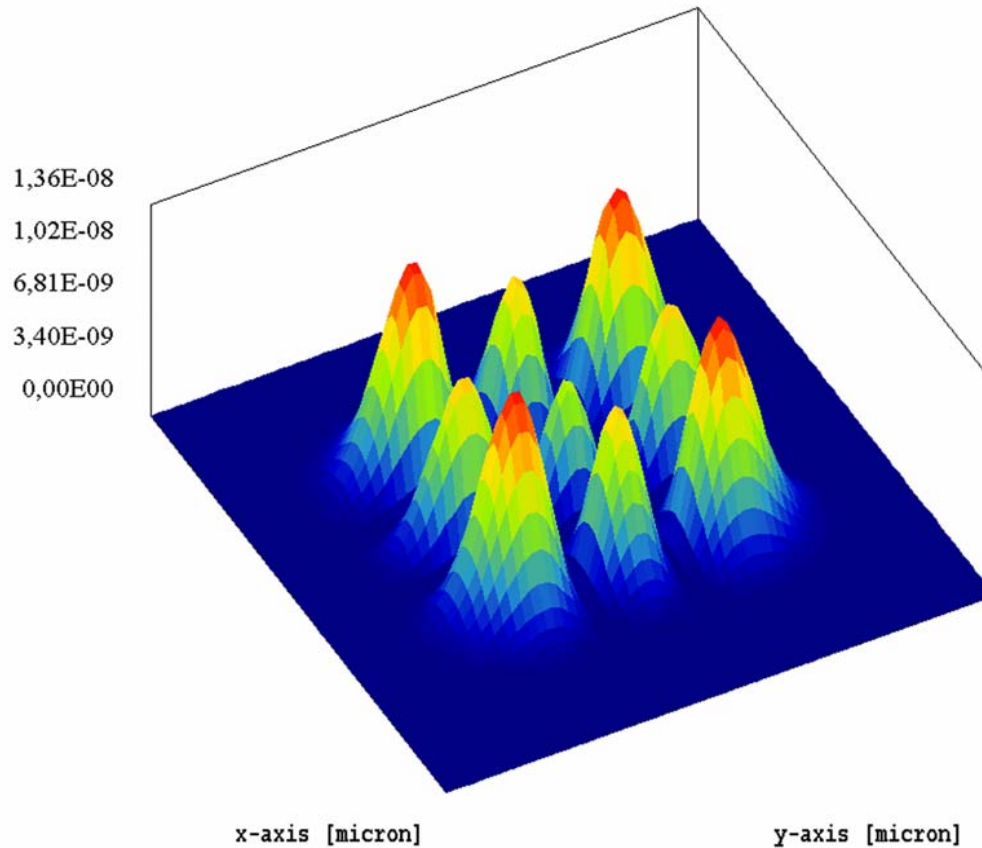
Phase distribution at output mirror

## LASCAD™ - The Laser Engineering Tool

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.

# LASCAD™ - The Laser Engineering Tool

Mode TEM22



Mode TEM<sub>22</sub> obtained by numerical eigenmode analysis



# LASCAD™ - The Educational Tool

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

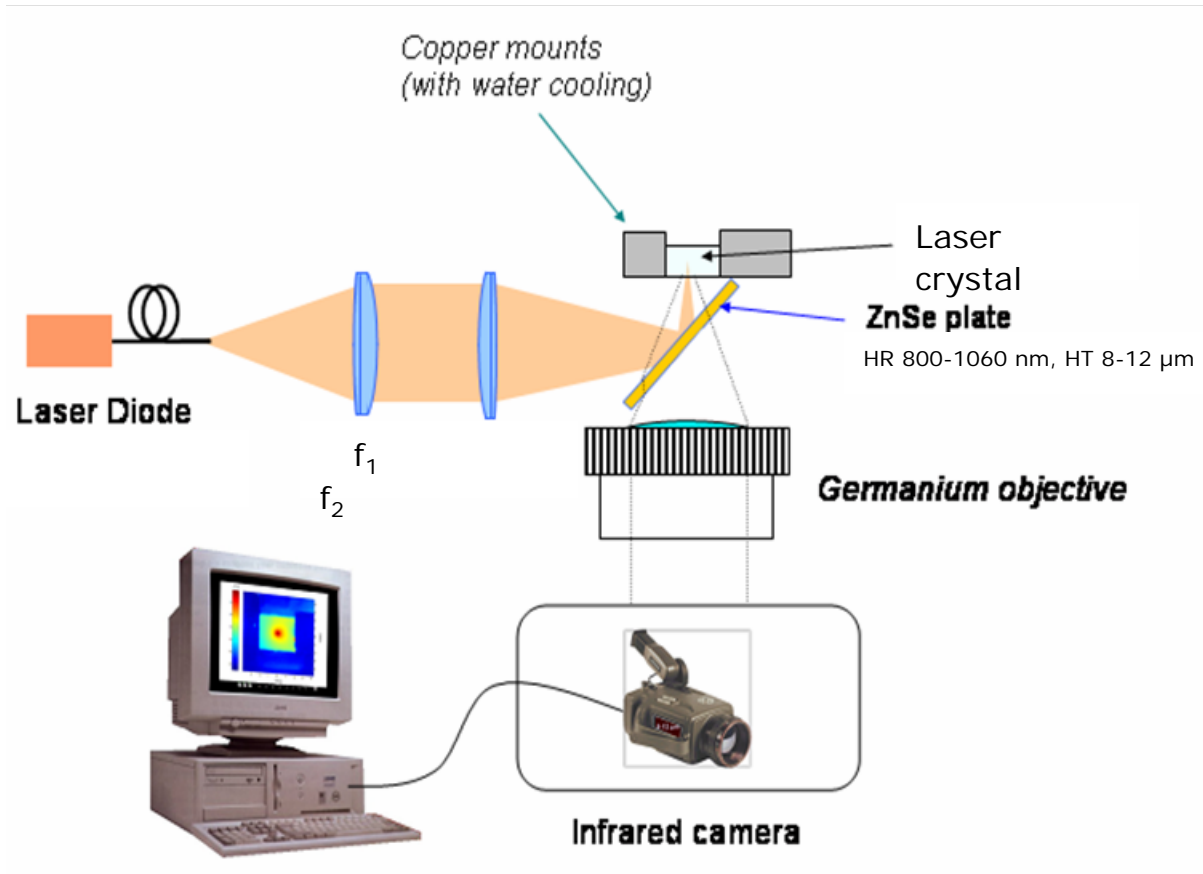
The principles of ABCD gaussian beam propagation including thermal lensing effects can be studied interactively.

Laser power output and beam quality can be computed for cw and Q-switch operation

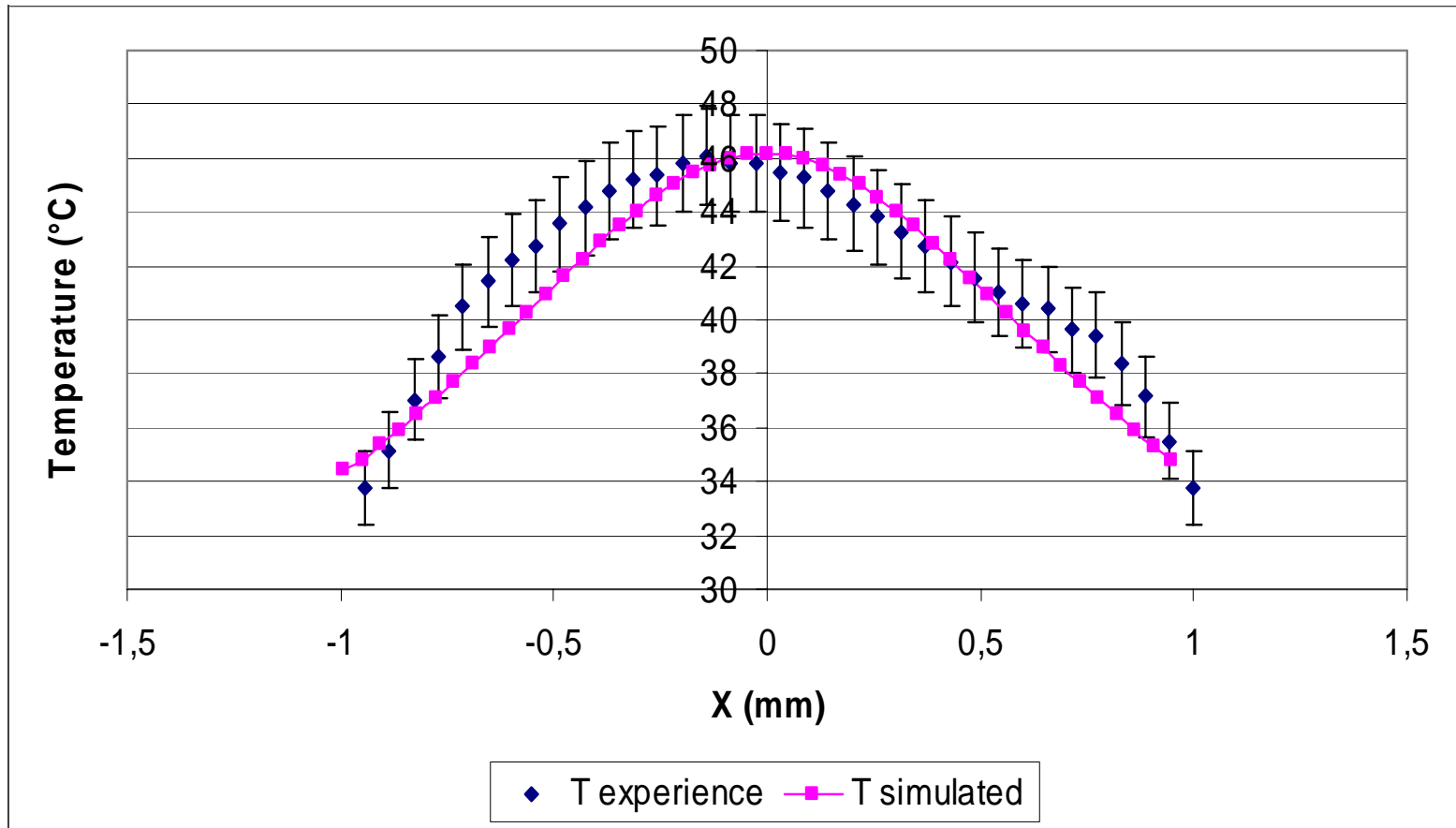
Simulation results obtained with LASCAD have been verified by the

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

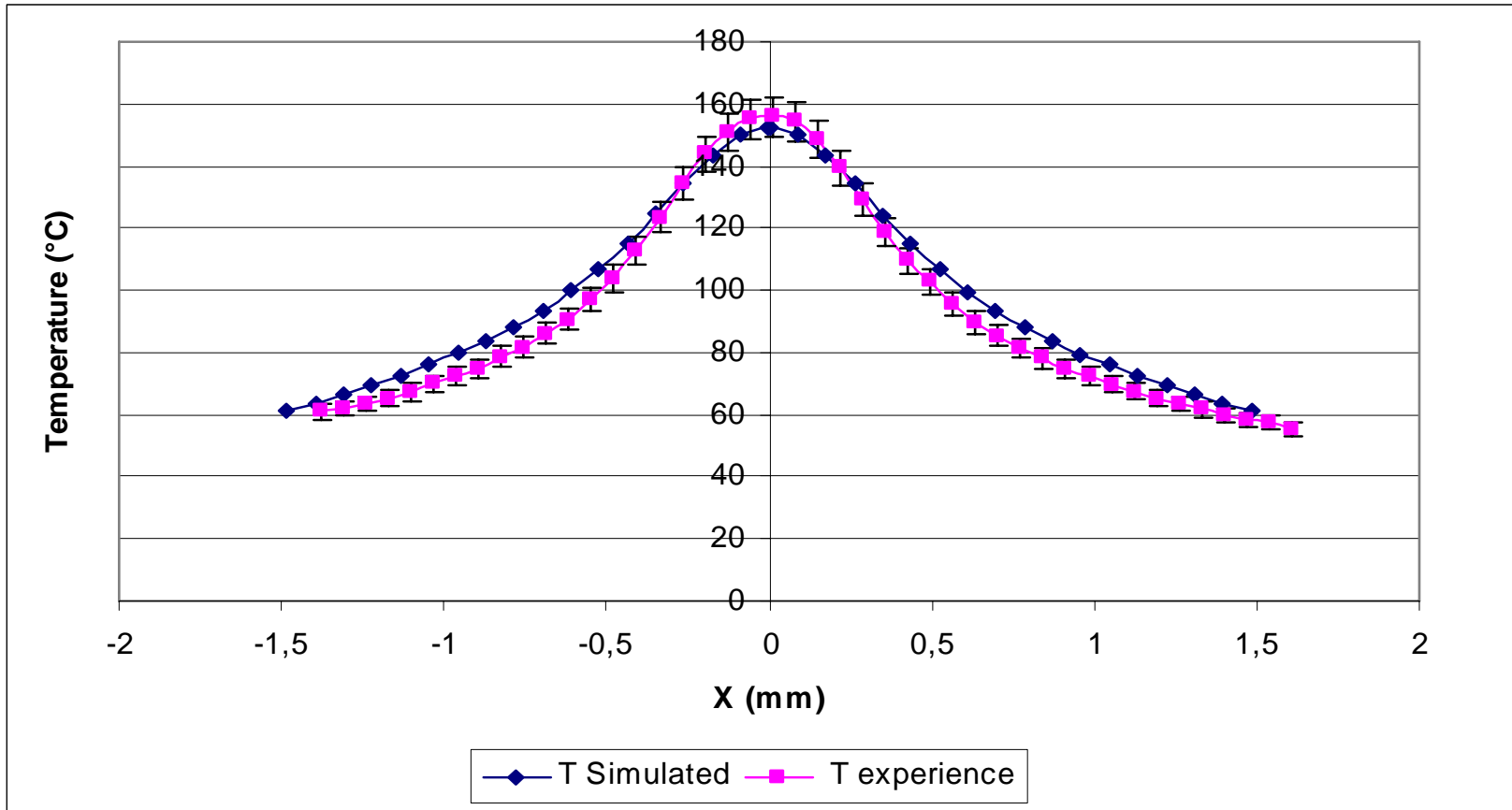
This group developed an experimental setup to carry through direct, absolute and spatially resolved temperature measurements in diode-end-pumped laser crystals, using an infrared camera.



Experimental setup for direct temperature measurements



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



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

A new approach using a **dynamic 3D FEA model for the electrical field** has been presented at:

**Advanced Solid Photonics 2009**

Denver, February 1-4, 2009

OSA Conference Proceedings TuB20:

**New Approaches for the Dynamic 3D Simulation of Solid-State Lasers**, *Matthias Wohlmuth\**, *Konrad Altmann\*\**, *Christoph Pflaum\**;

*\*Univ.Erlangen-Nürnberg, Germany; \*\*LAS-CAD GmbH*

New simulation methods for solid state lasers are presented: We describe a dynamic multimode analysis to model mode competition and Q - switching.

Furthermore, we propose a **3D FEA model for the electrical field** without mode decomposition.