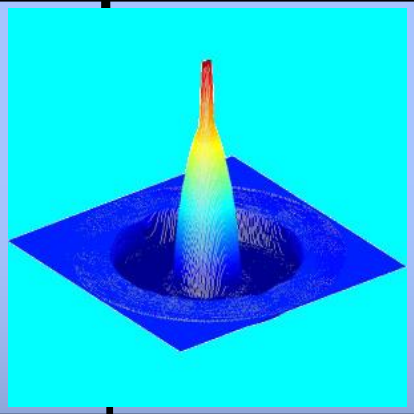

Software for tomographic reconstruction of refractive index profile of special optical fibre preforms

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2009 – 2010

Project leader: **Ing. Jaroslav Pavel (FNSPE)** Project consultant: **Ing. Pavel Peterka, Ph.D. (IPE ASCR)**

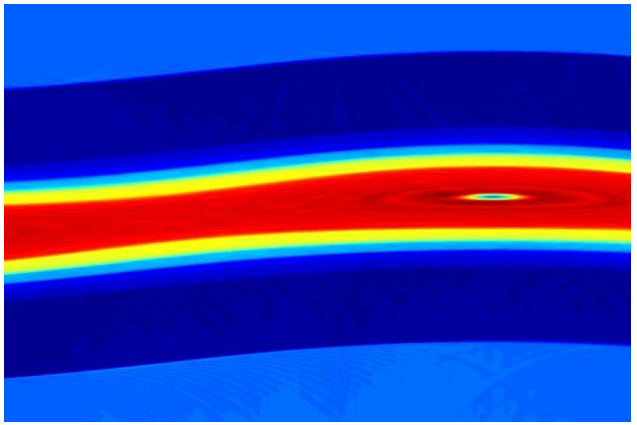
Presentation Structure

- Motivation & Submitter
- Goals
- Laboratory in Suchdol
- Special optical fiber preform
- Preform analyzer PK2600
- Analysis deflection functions
- My solution
- Program TRORIP
- Testing
- Examples of preforms
- Conclusion
- Future

Motivation & Submitter

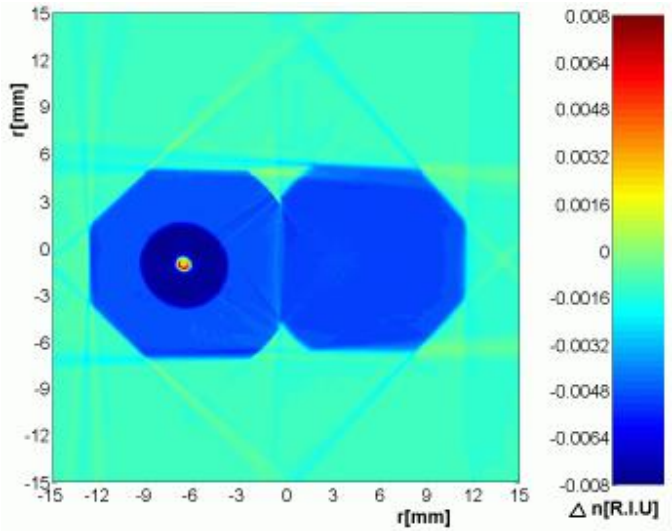
Ústav fotoniky a elektroniky

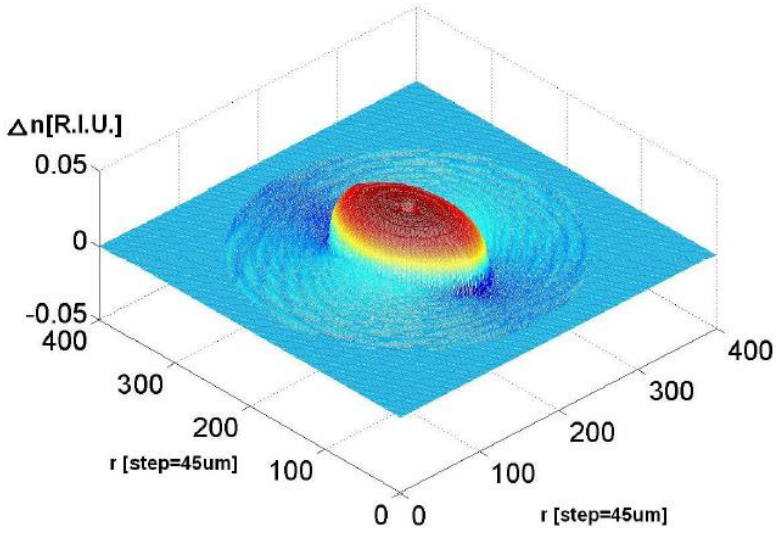
- Solving the real technical tasks
- Routine use my developed application in scientific work
- IPE - The Institute of Photonics and Electronics
  - non-profit research institution belonging to the Academy of Sciences of the Czech Republic
- Supported by the Ministry of Education, Youth and Sports of the Czech Republic (Institutional research plan AV0Z20670512)



Goals

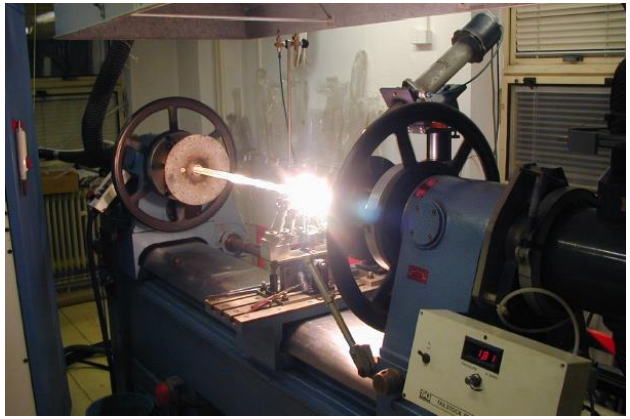
- Get acquainted with fiber amplifiers and lasers
- Learn how to work with PHOTON Kinetics' 2600 Preform Analyzer
- Devise and debug a program for visualization refractive index profile

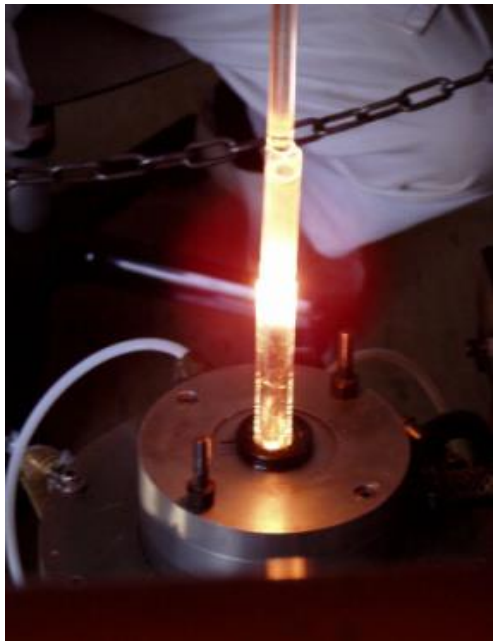




Laboratory in Suchdol

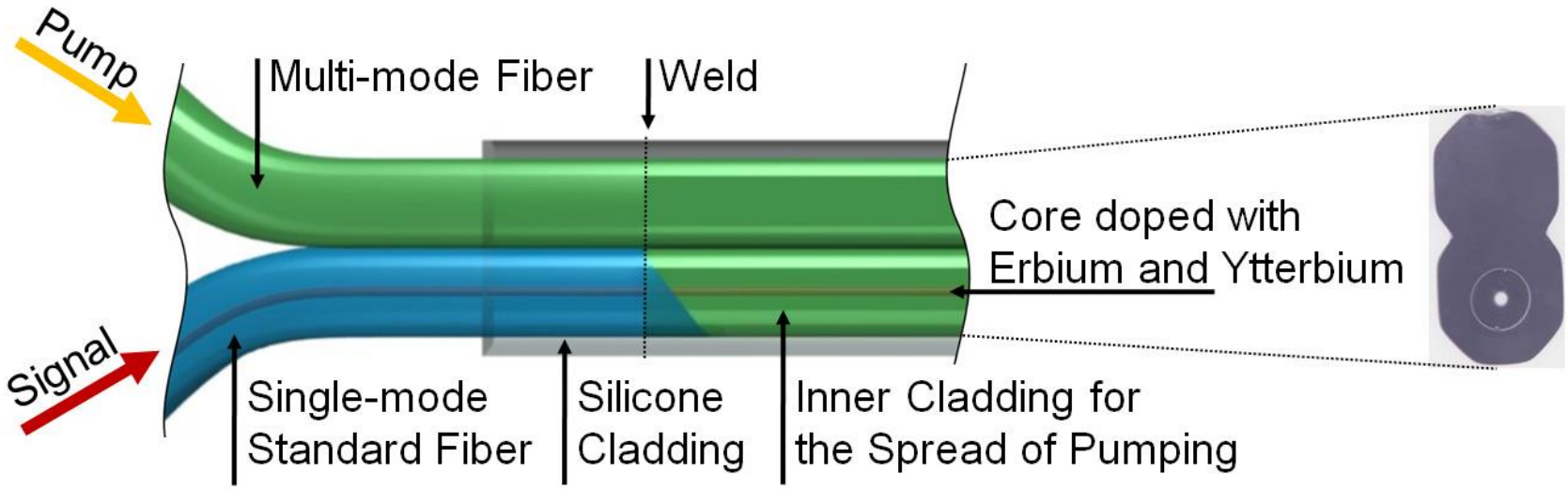
- The preparation of special optical fibers for basic research (lasers, amplifiers, and sensors)
- Preform – the stake with:
  - Diameter: 1-10 cm
  - Length: decimeters to 1.5 m
- MCVD - Modified Chemical Vapour Deposition
- PHOTON Kinetics' 2600 Preform Analyzer





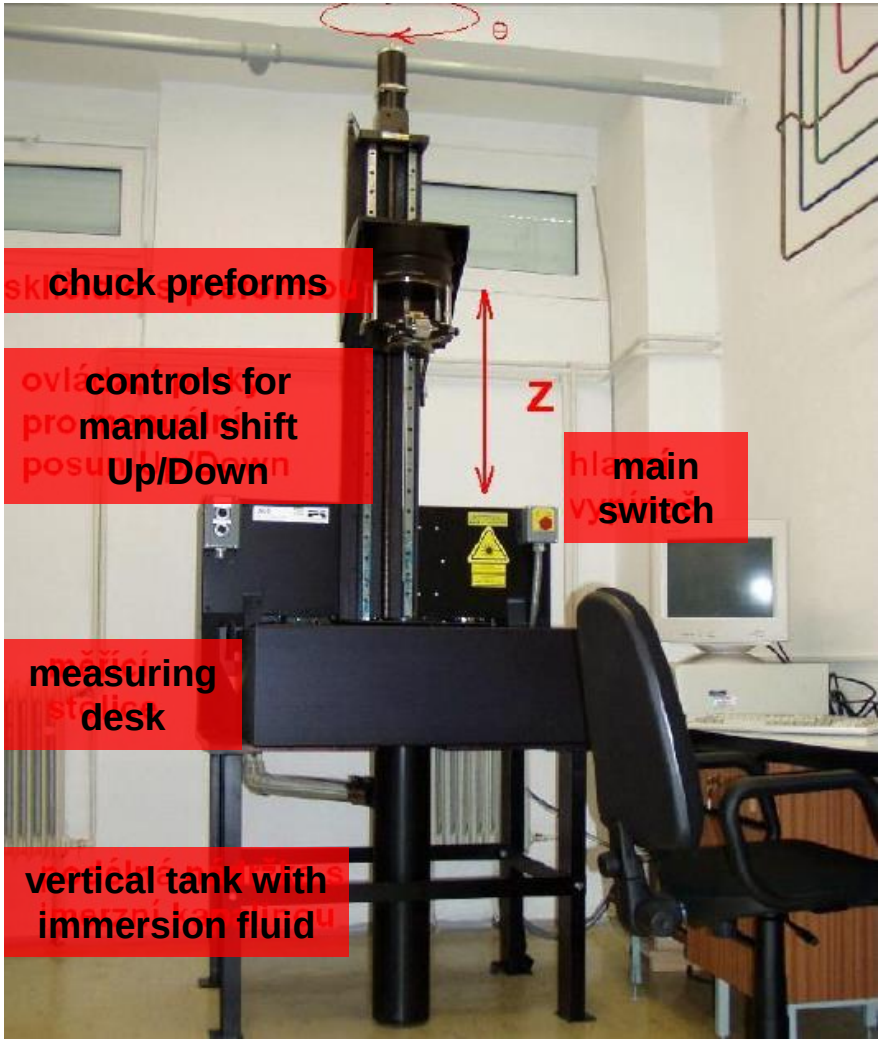
Special optical fiber preform

- Multimode preform with the jump profile
- Gradient fiber with a single mode core
- Gradient preform with highly elliptical core
- Double-clad (DC) optical fiber



Preform analyzer PK2600

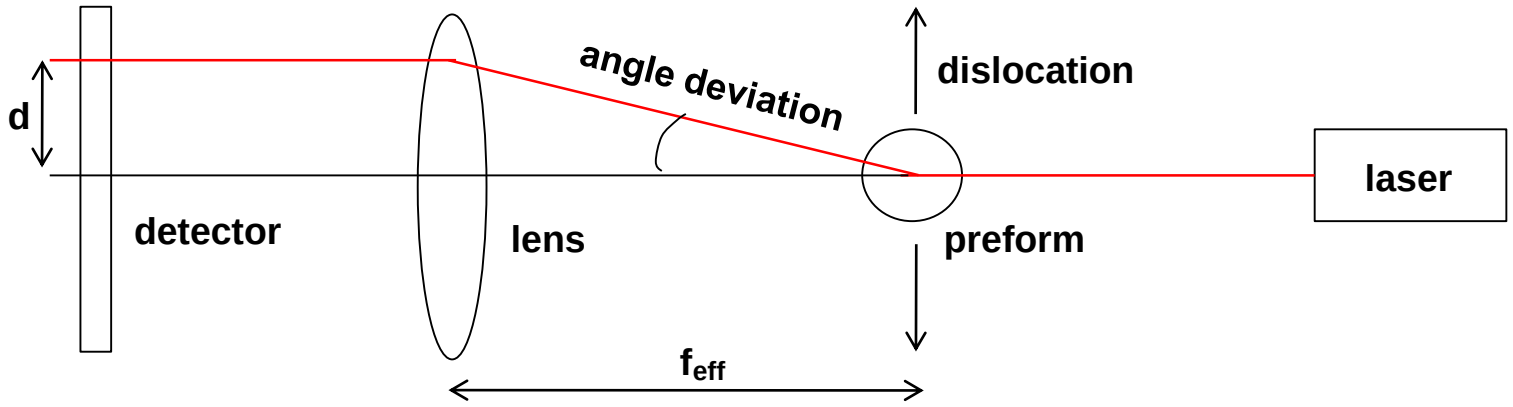
- Advantages
  - automatic measurement deflection function step by step
  - easy data export
- Disadvantages
  - measurement is slow
  - Often focus error
  - archaic software



Analysis deflection functions

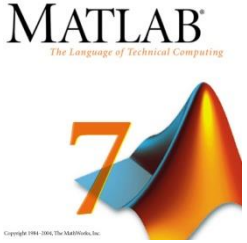
- The laser beam passes through the measured Preforms submerged in the immersion fluid
- The beam is curving due to index of refraction
- The lens bring it to semiconducting detector
- Scanned in multiple projections

$$\Phi = a\sin\left(\frac{1}{const \cdot f_{eff}} \cdot \frac{V_b - V_a}{V_b + V_a}\right)$$



My solution

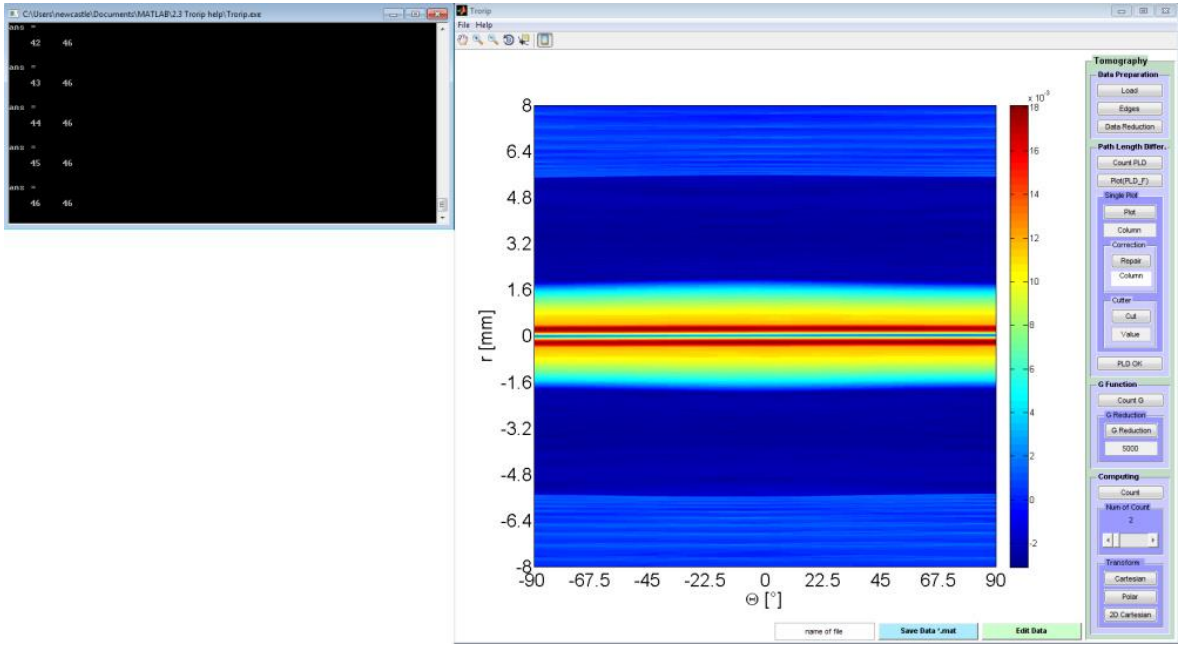
- The scripts for counting deflection functions were written in MatLab software
  - from Ing. Jiří Slanička (former employee IPE)
- Optimized them and completed them into a compacted program for visualization RIP
- Friendly GUI was programmed for routine using
- Measuring macros on the A2600 have been rewritten for acceleration
- The scripts was transferred to the standalone application independent of MatLab



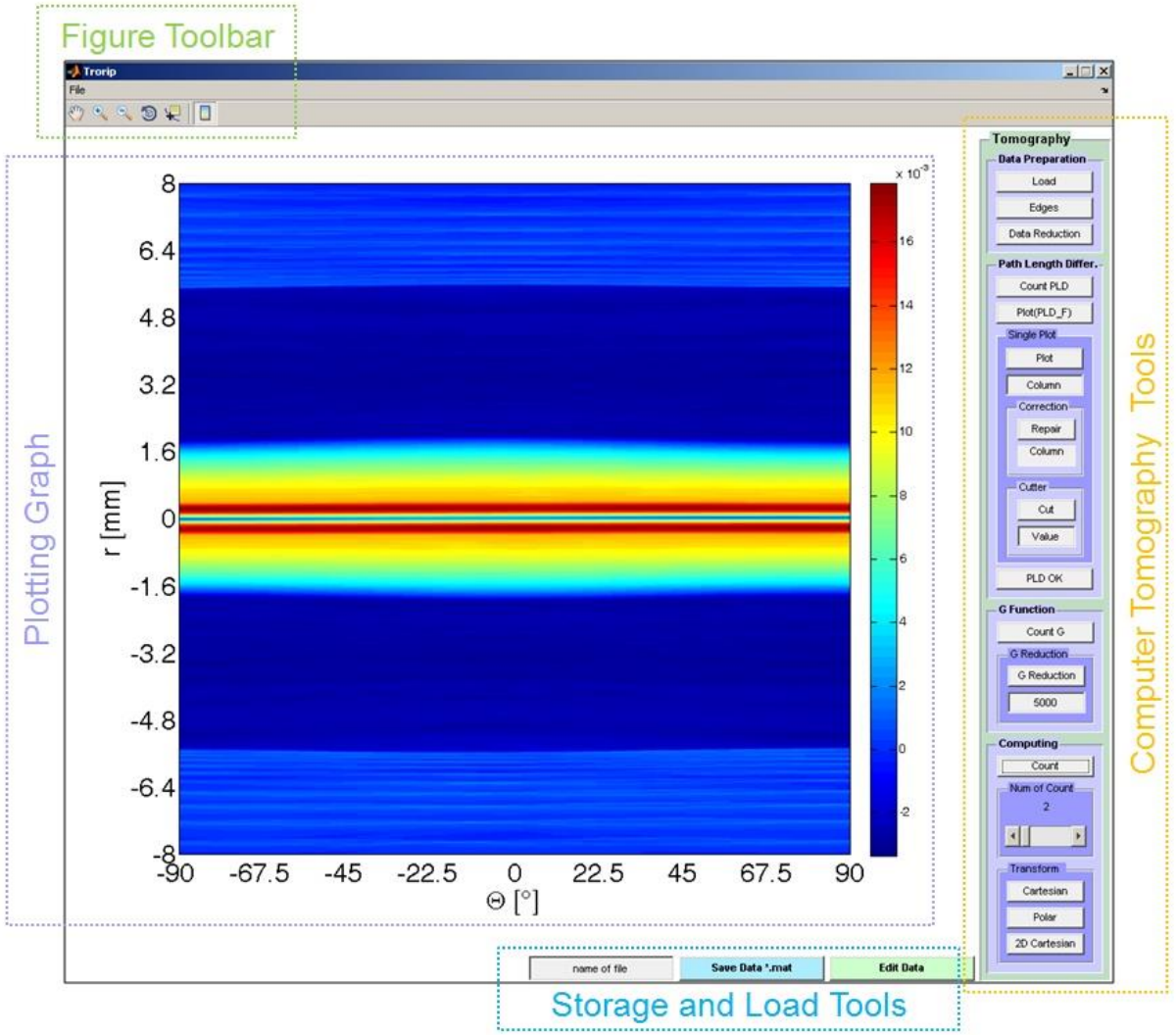
TRORIP

- the acronym of Tomographic Reconstruction of Refractive Index Profile

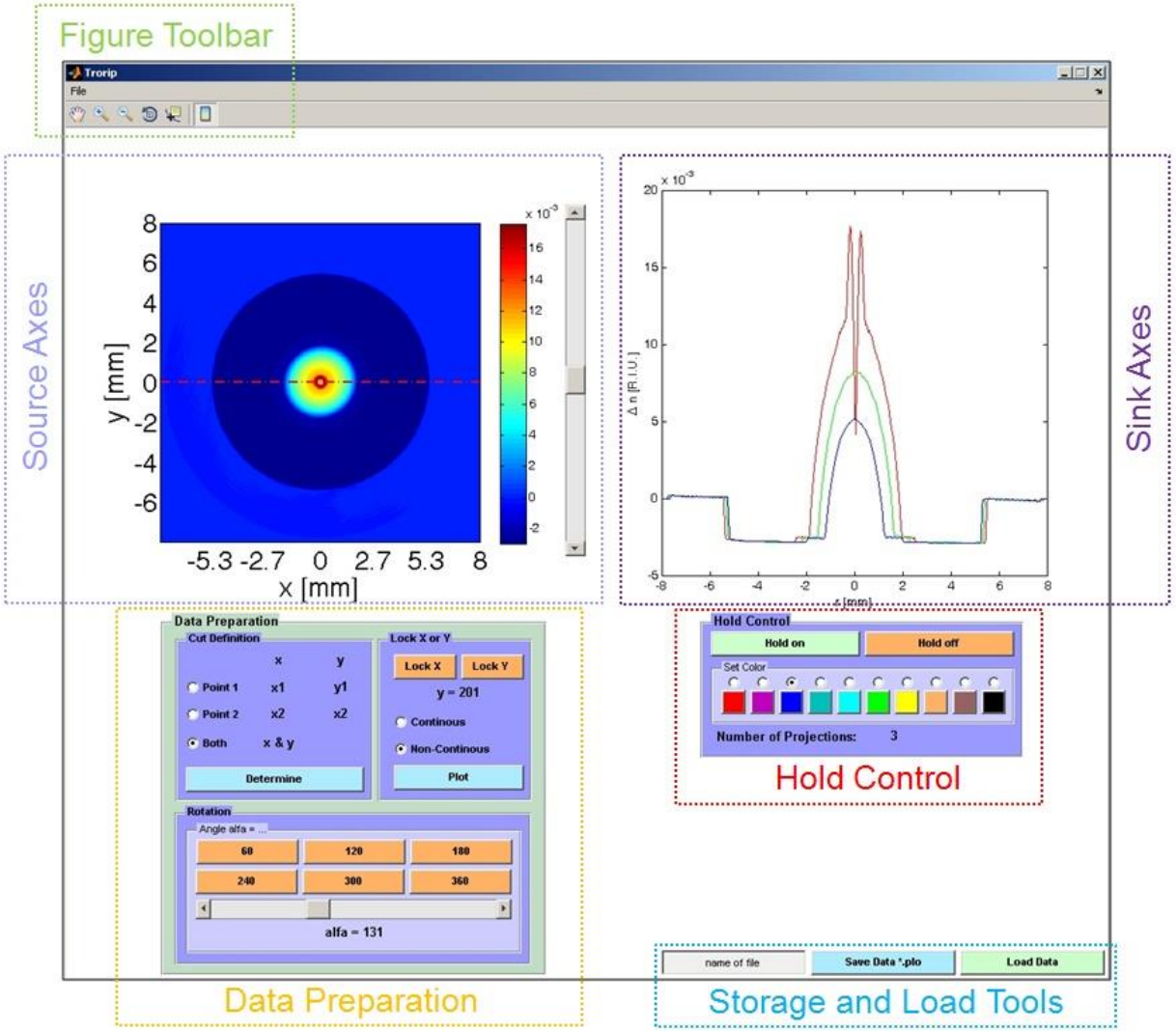
- Divided into two parts
  - Dump Window with error and operations
  - GUI with three modes – Tomography Reconstruction , Viewing the Refractive Index Profile, Examination of the Calculated Data



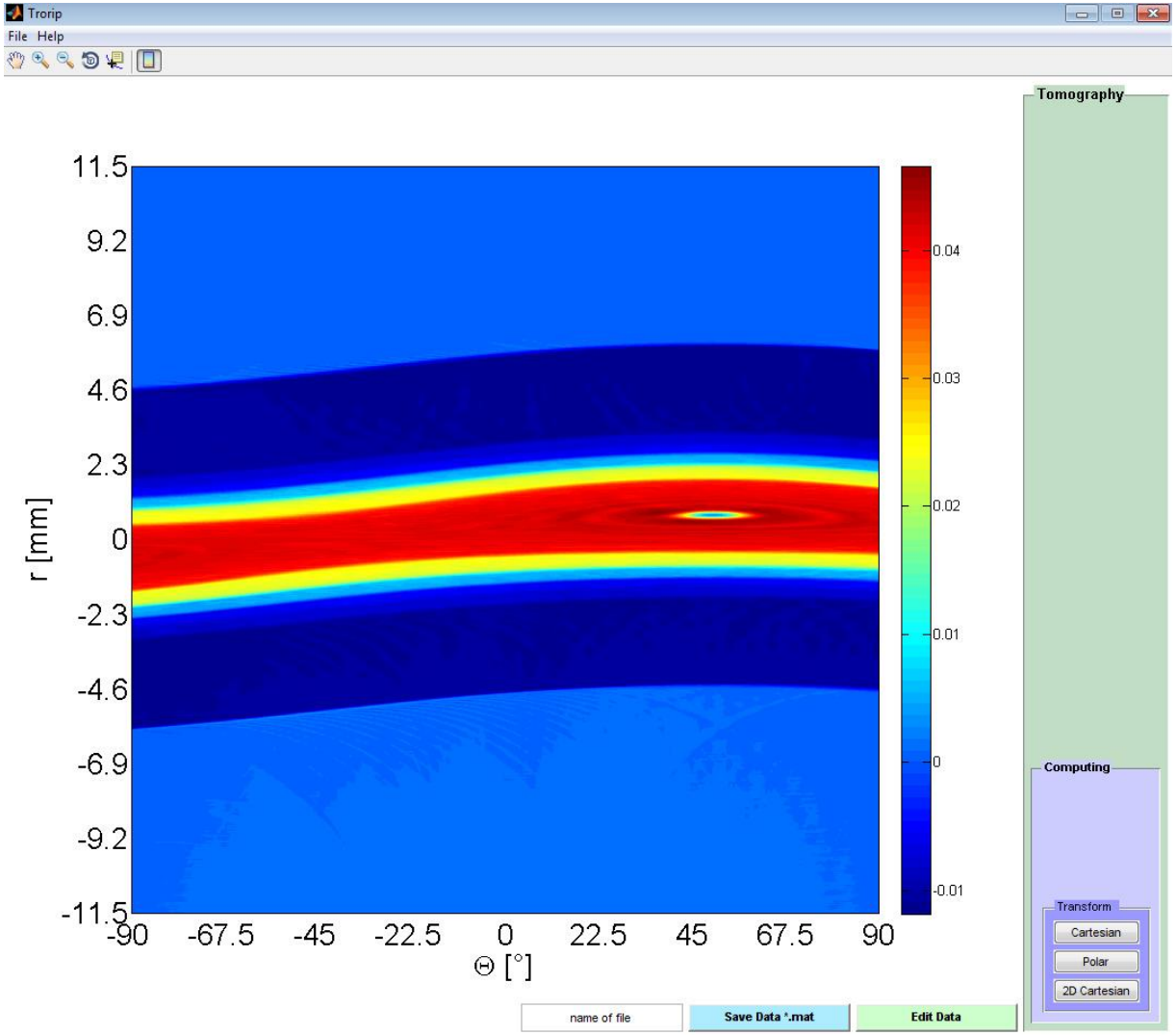
Tomography Reconstruction



Viewing the Refractive Index Profile



Examination of the Calculated Data



TRORIP – Instalation

- Compiled with MATLAB Compiler
- Files Necessary for Deployment
  - Our compiled exe file
  - MATLAB Compiler Runtime Installer
  - The text file <name>.exe.manifest

Example

- Path Length Difference function:

$$\Psi(\rho,\theta) = n_c \int_0^{\rho} \phi(\xi,\theta)d\xi + \frac{n_c\rho}{12}\phi^3(\rho,\theta) + \Delta E + \Delta G$$

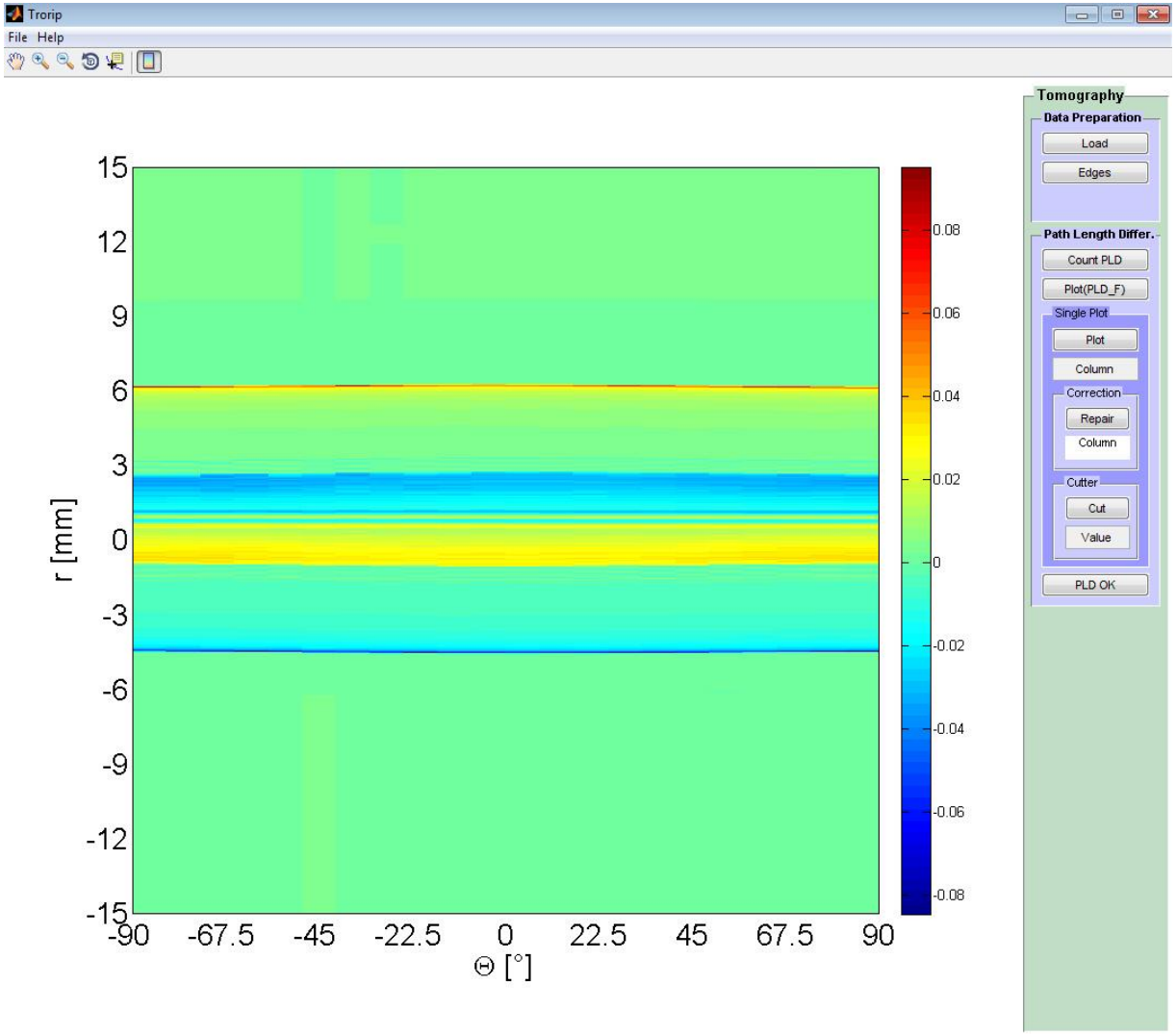
- G-function:

$$g(\rho,\theta) = \mathcal{F}^{-}\{|k|\mathcal{F}\{\Psi(\rho,\theta)\}\} = \int_{-\infty}^{+\infty}\left[\int_{-\infty}^{+\infty}\Psi(\rho,\theta)e^{-j2\pi k\rho}\,d\rho\right]|k|e^{j2\pi k\rho}dk$$

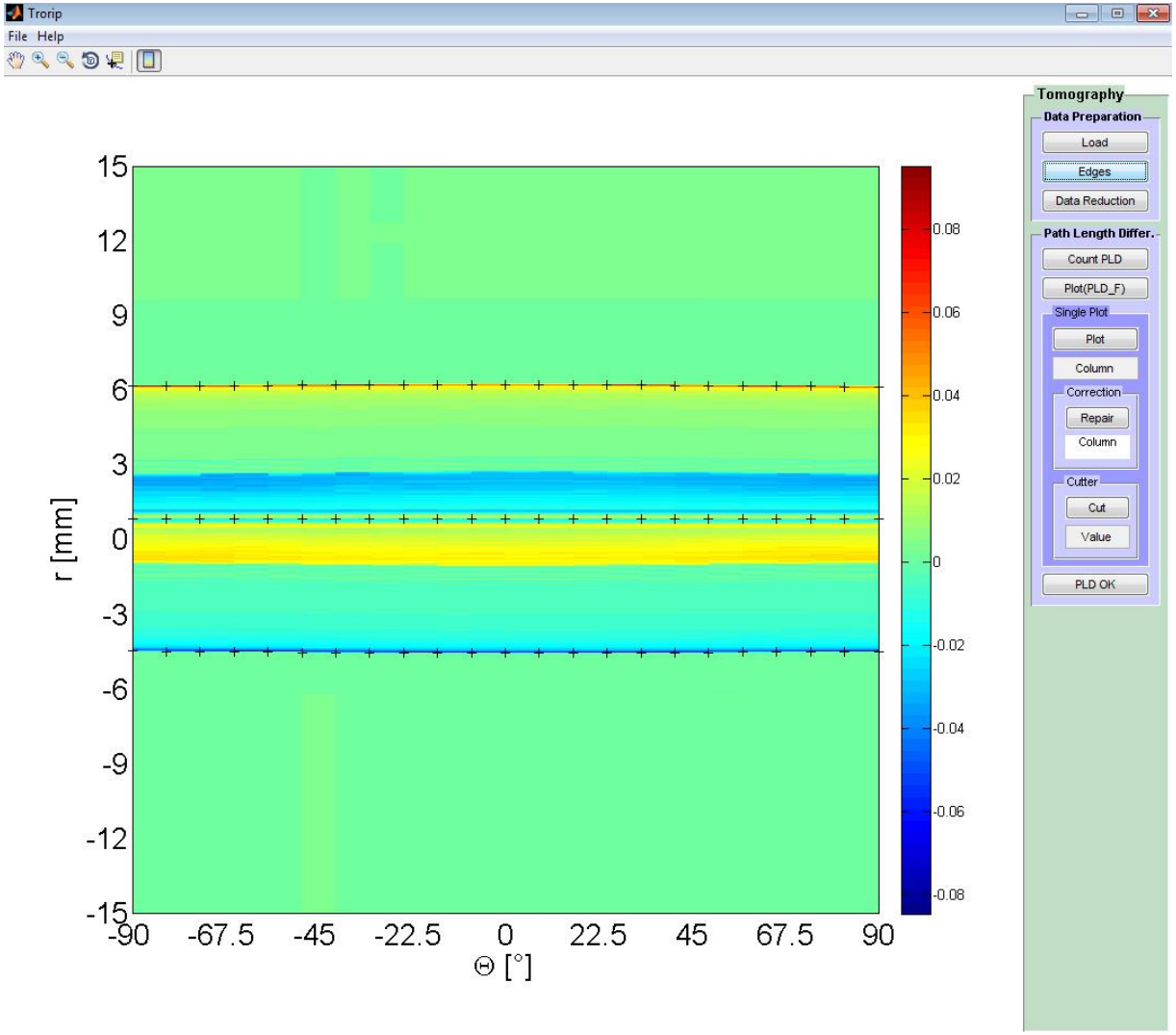
- RIP:

$$n(r,\psi) - n_c = \int_0^{\pi} g(\rho,\theta)d\theta$$

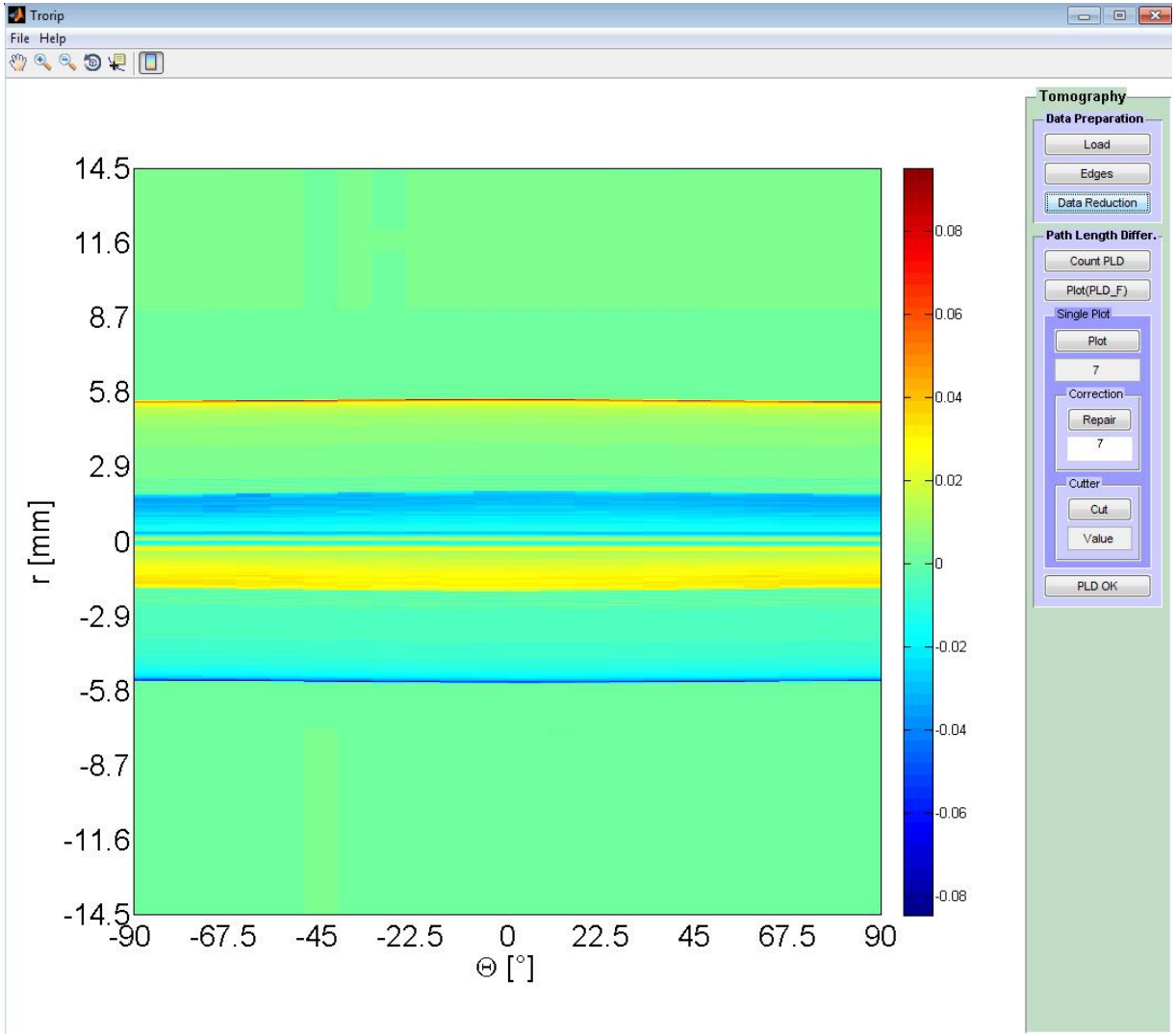
Loading the deflection functions



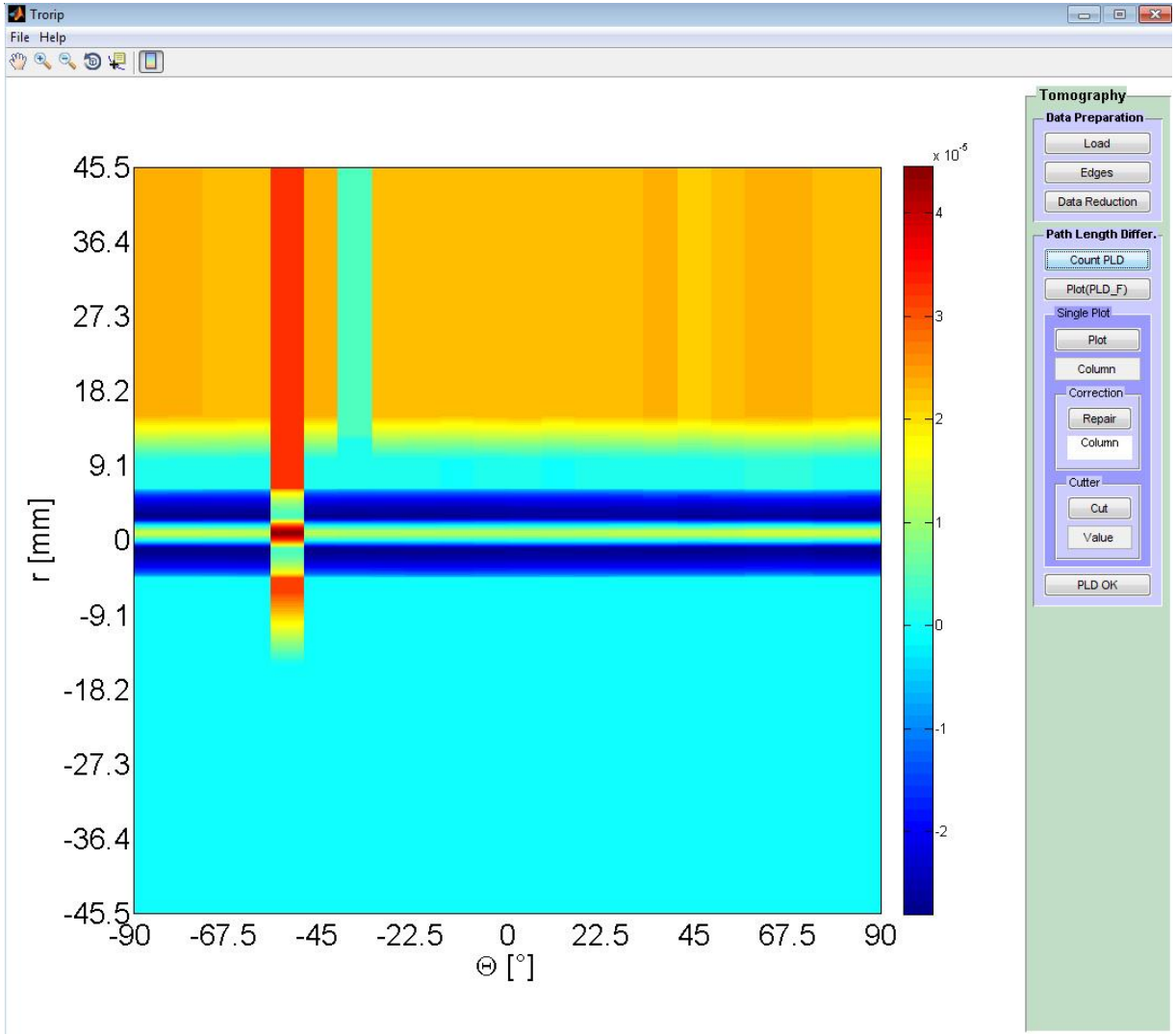
Finding edges of preform



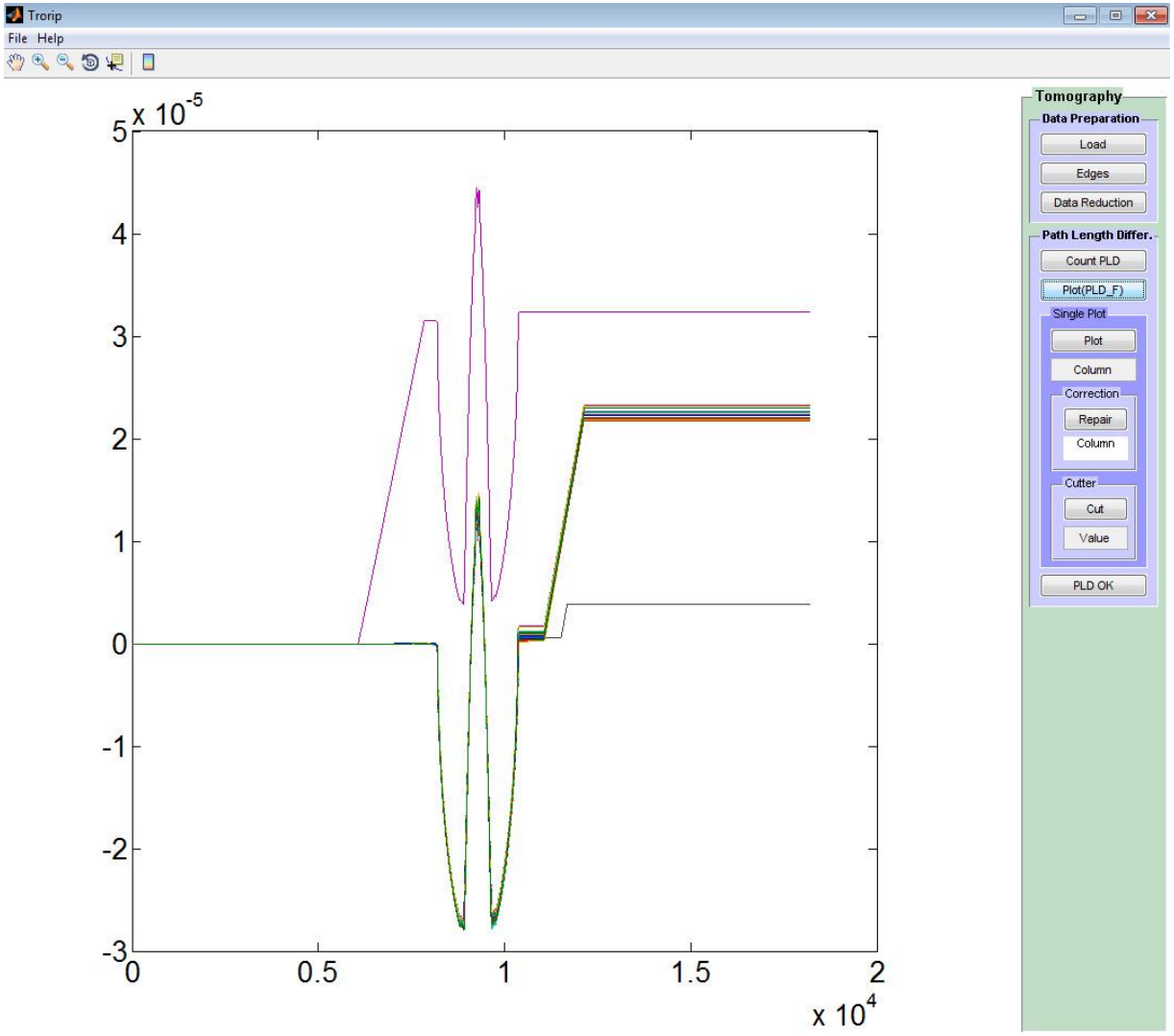
Centering


Trorip
File Help
Tomography
Data Preparation
Load
Edges
Data Reduction
Path Length Differ.
Count PLD
Plot(PLD_F)
Single Plot
Plot
7
Correction
Repair
7
Cutter
Cut
Value
PLD OK
14.5
11.6
8.7
5.8
2.9
0
-2.9
-5.8
-8.7
-11.6
-14.5
r [mm]
-90
-67.5
-45
-22.5
0
22.5
45
67.5
90
Θ [°]
0.08
0.06
0.04
0.02
0
-0.02
-0.04
-0.06
-0.08

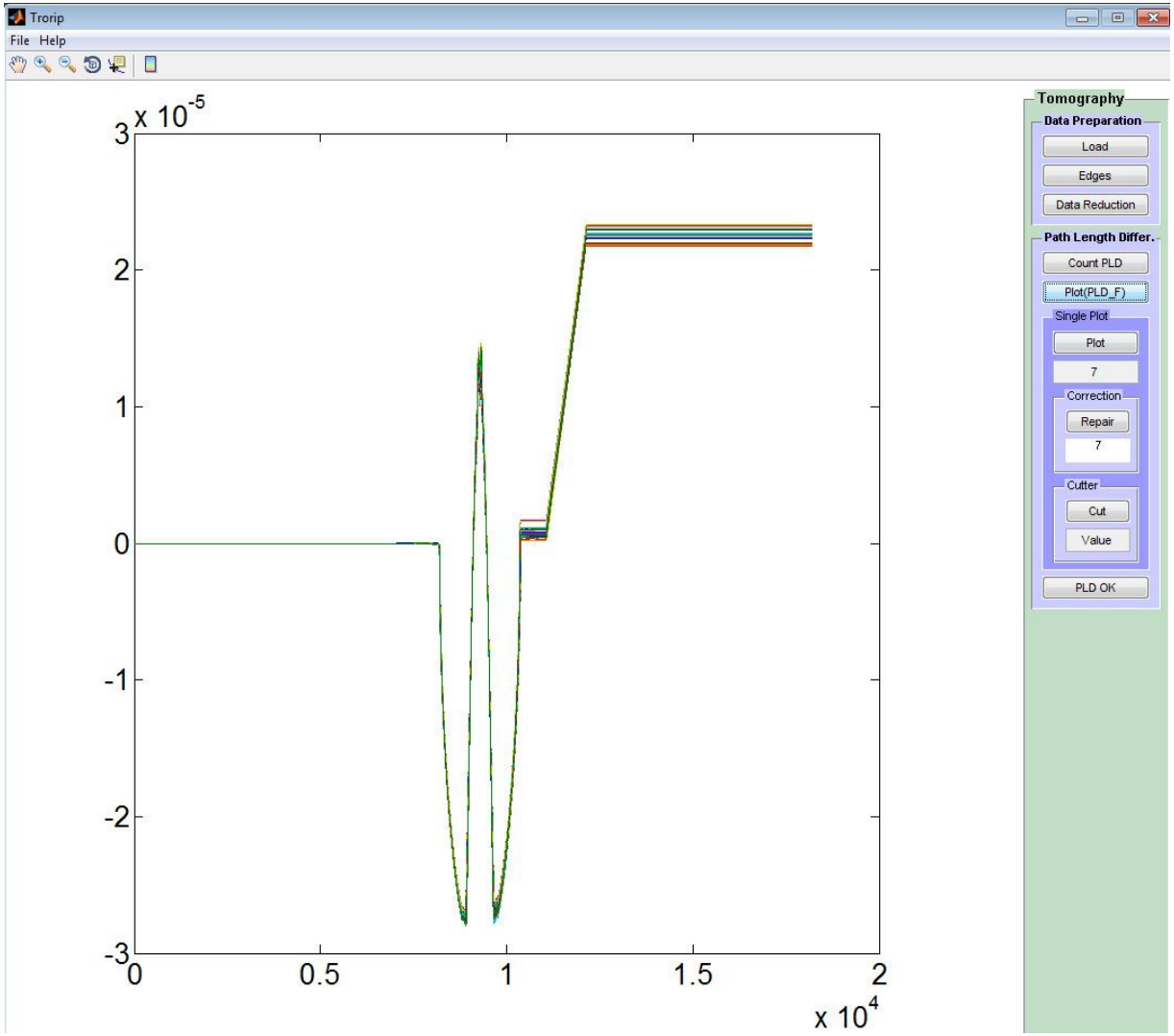
Calculating the Path Length Difference functions



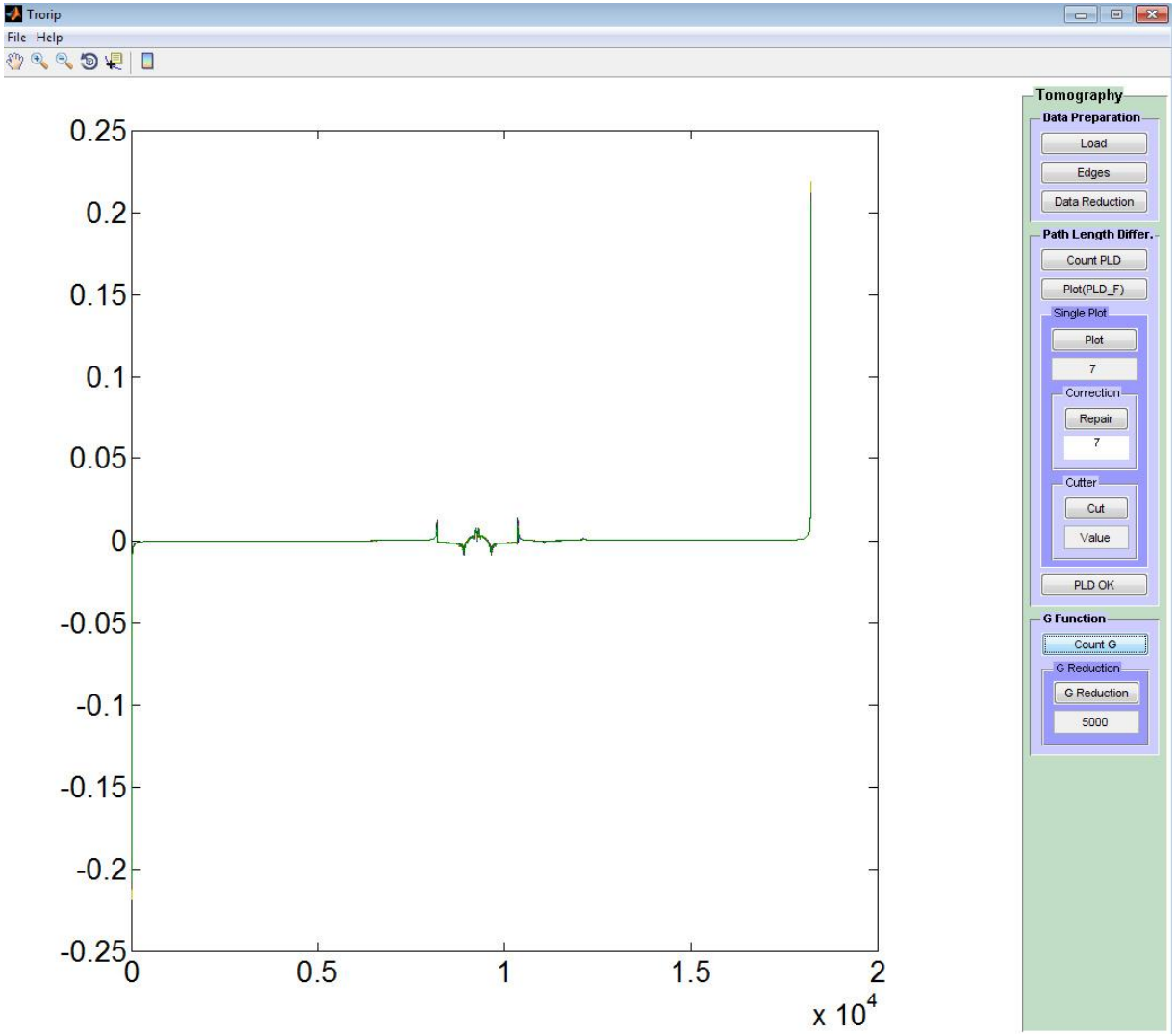
PLD functions in 2D



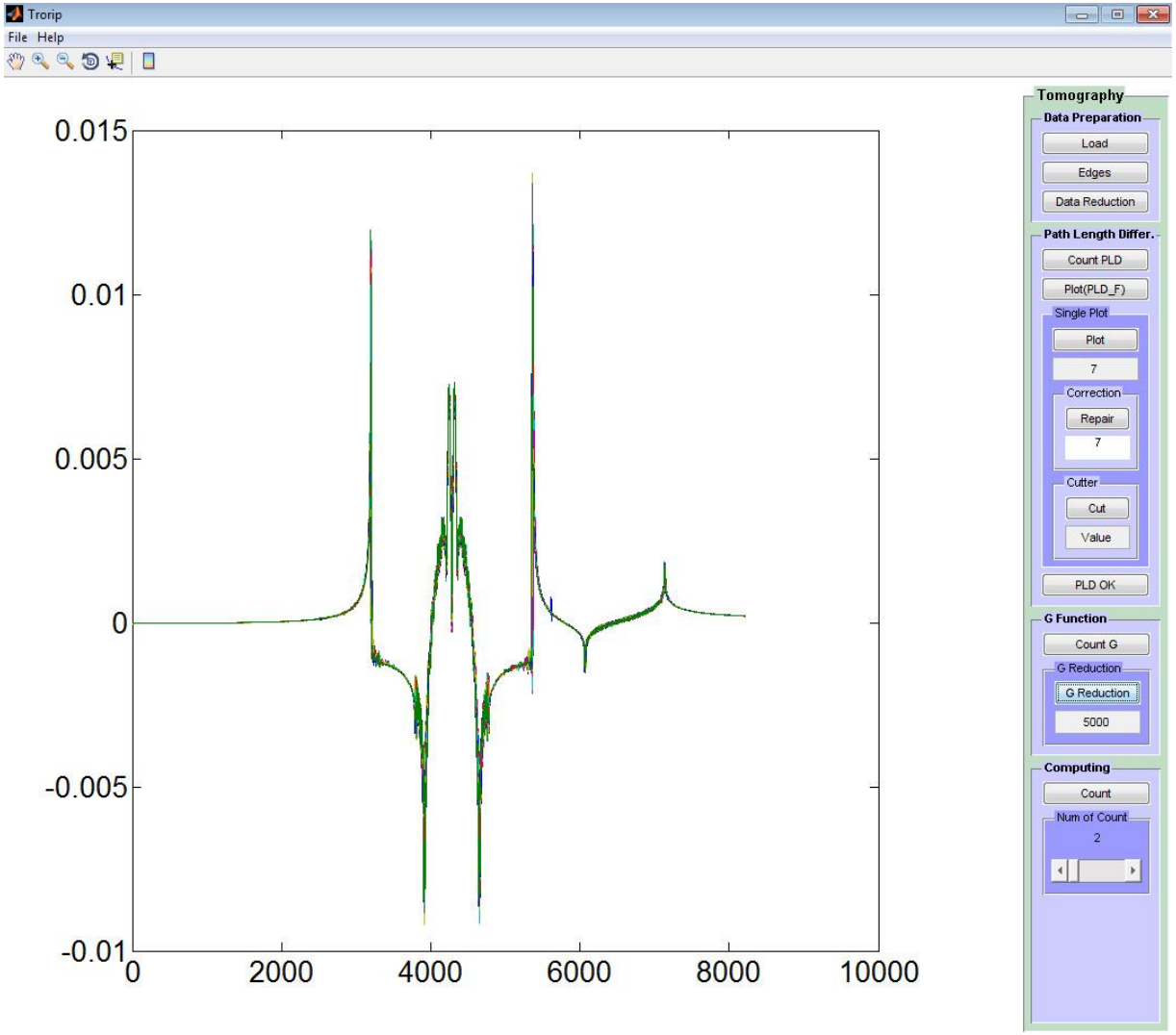
Corrected PLD functions



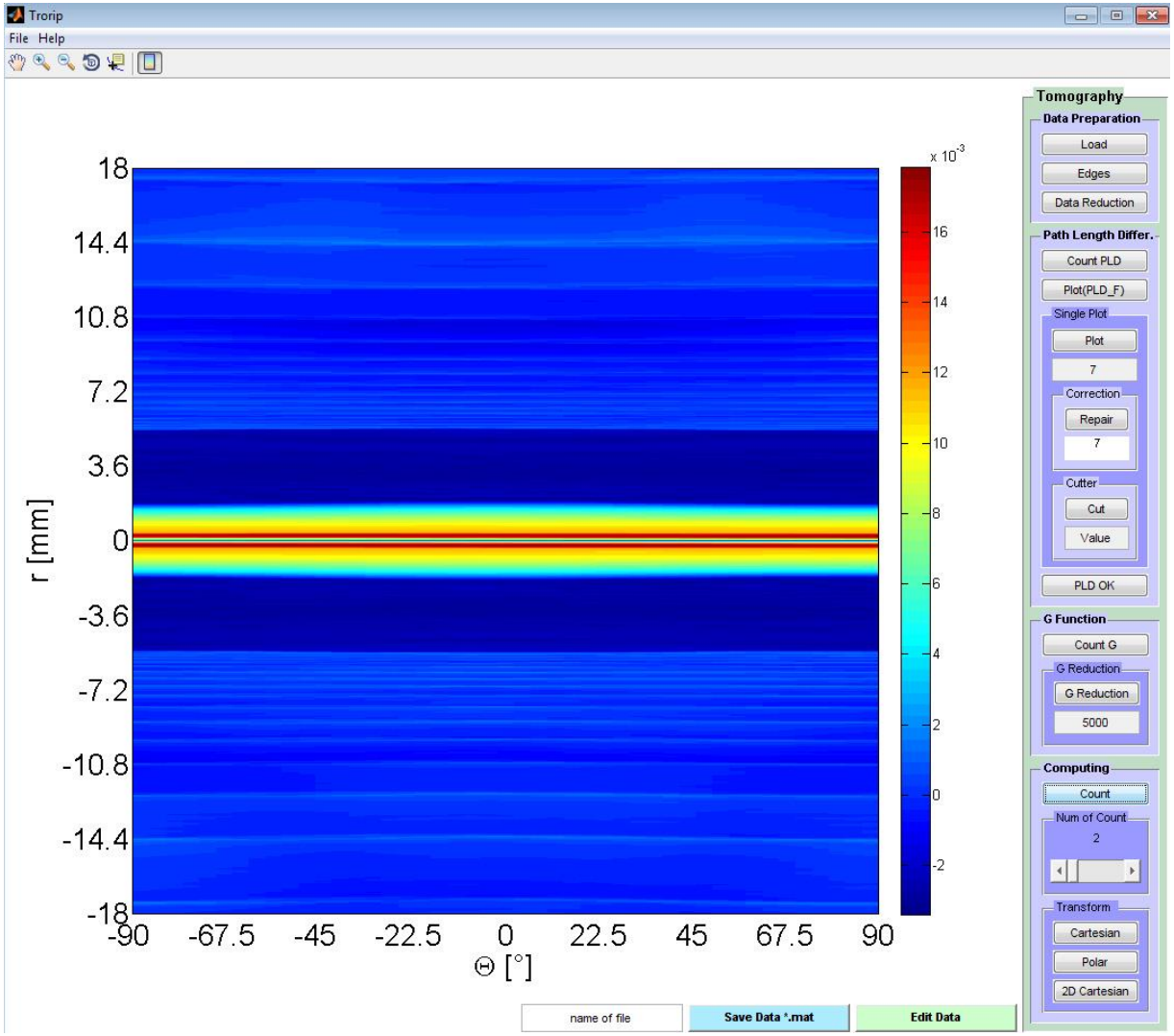
Calculating the g-functions



Reduction of g-functions



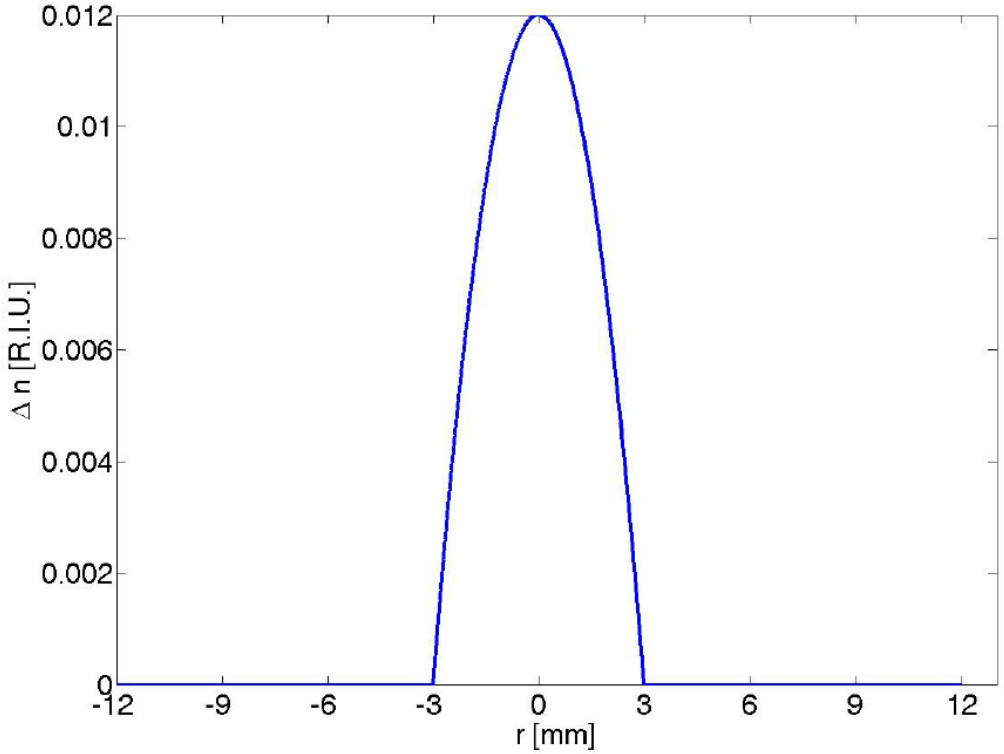
Calculating the RIP from g-functions



Testing the Theoretical Deflection Function

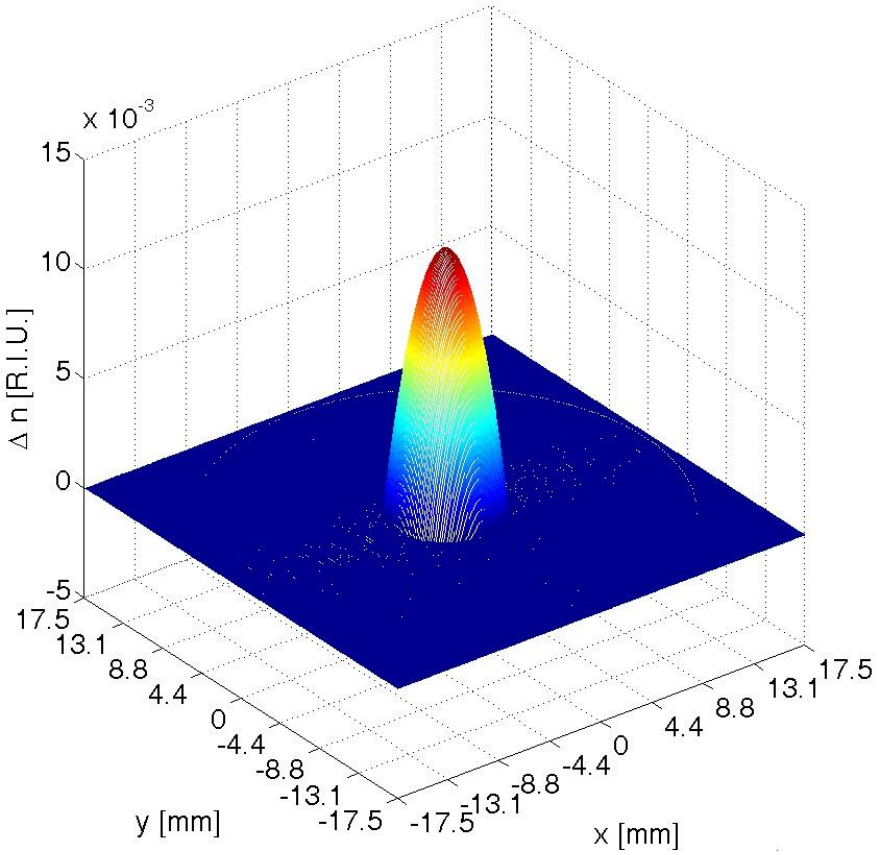
$$n(r) = \left(1 - \frac{r^2}{R^2}\right) n_{max} \Leftrightarrow r < R$$

$$n(r) = 0 \Leftrightarrow r \geq R$$

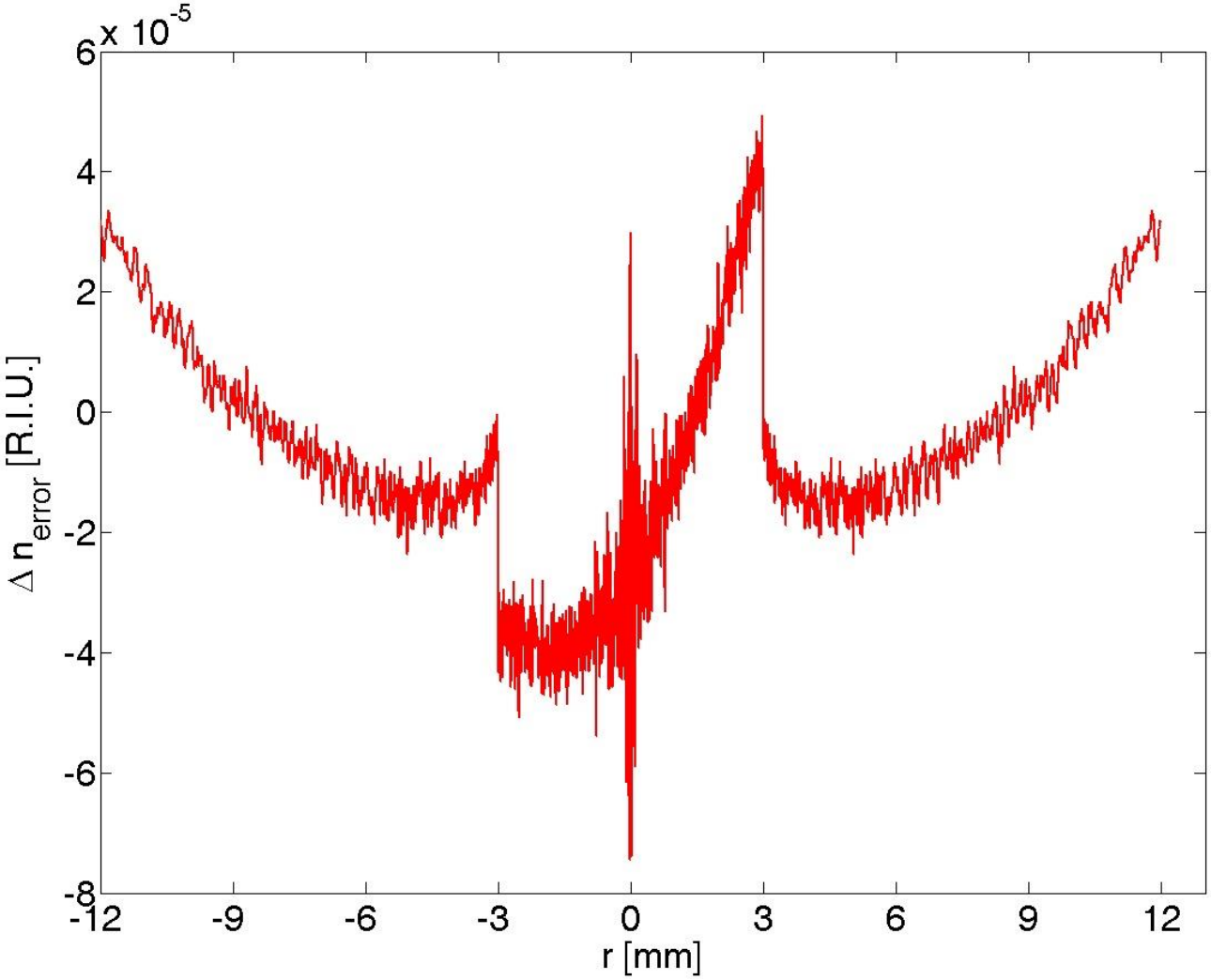


Testing the Theoretical Deflection Function

$$PLD = \int_a^b n(s)ds = \frac{4n_{max}}{3R^2}(R^2 - \rho^2)^{\frac{3}{2}}$$

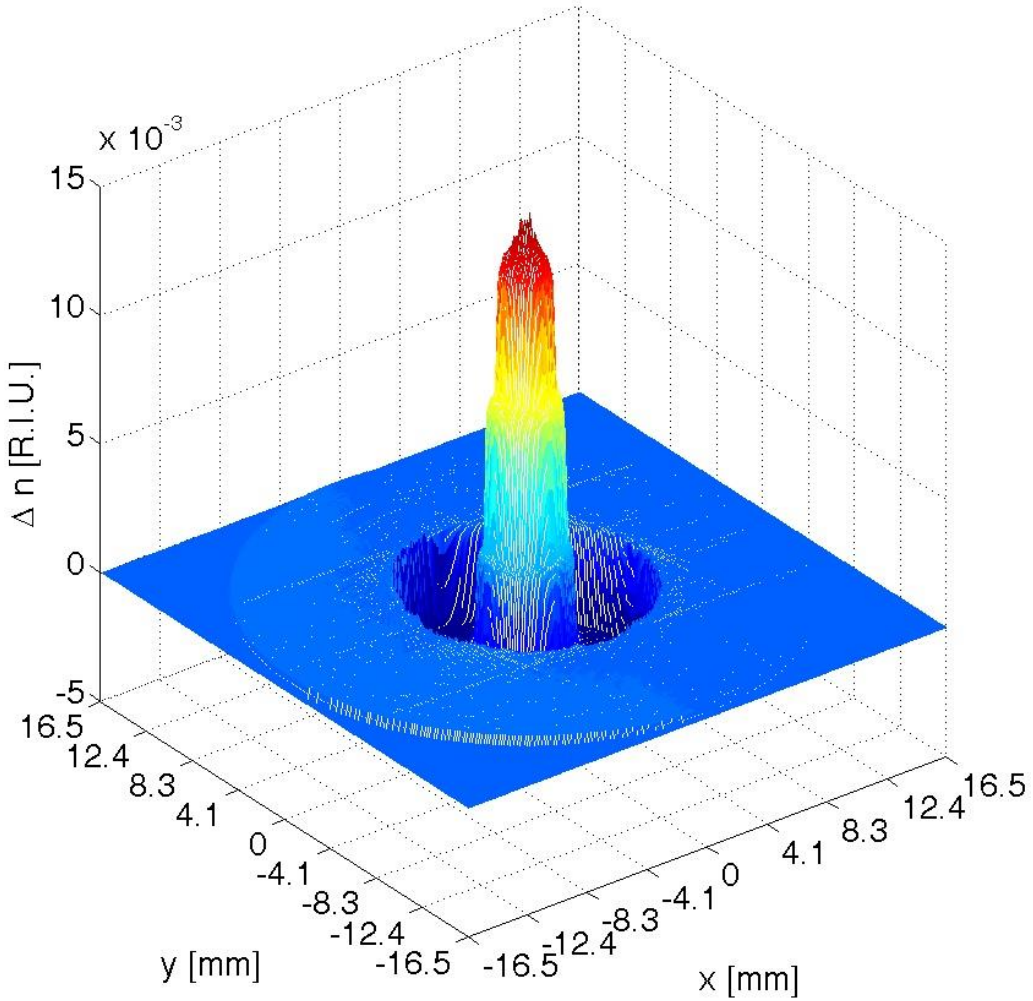


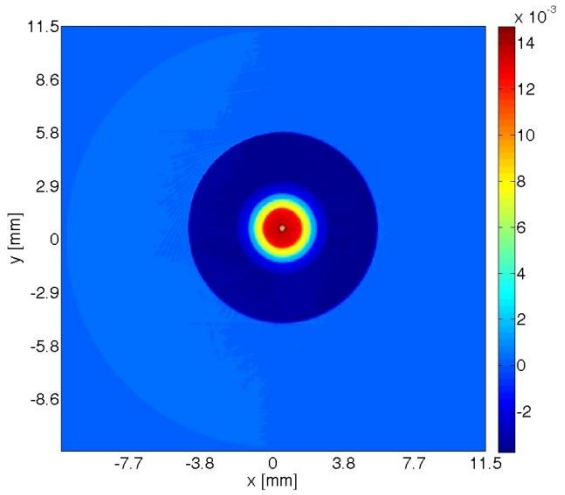
Testing the Theoretical Deflection Function

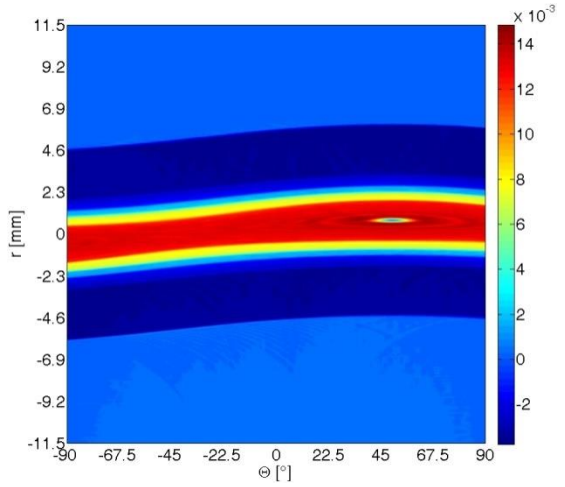


Example of preform - SG105

Multimode preform with the jump profile (in 45 projections with four degrees step)

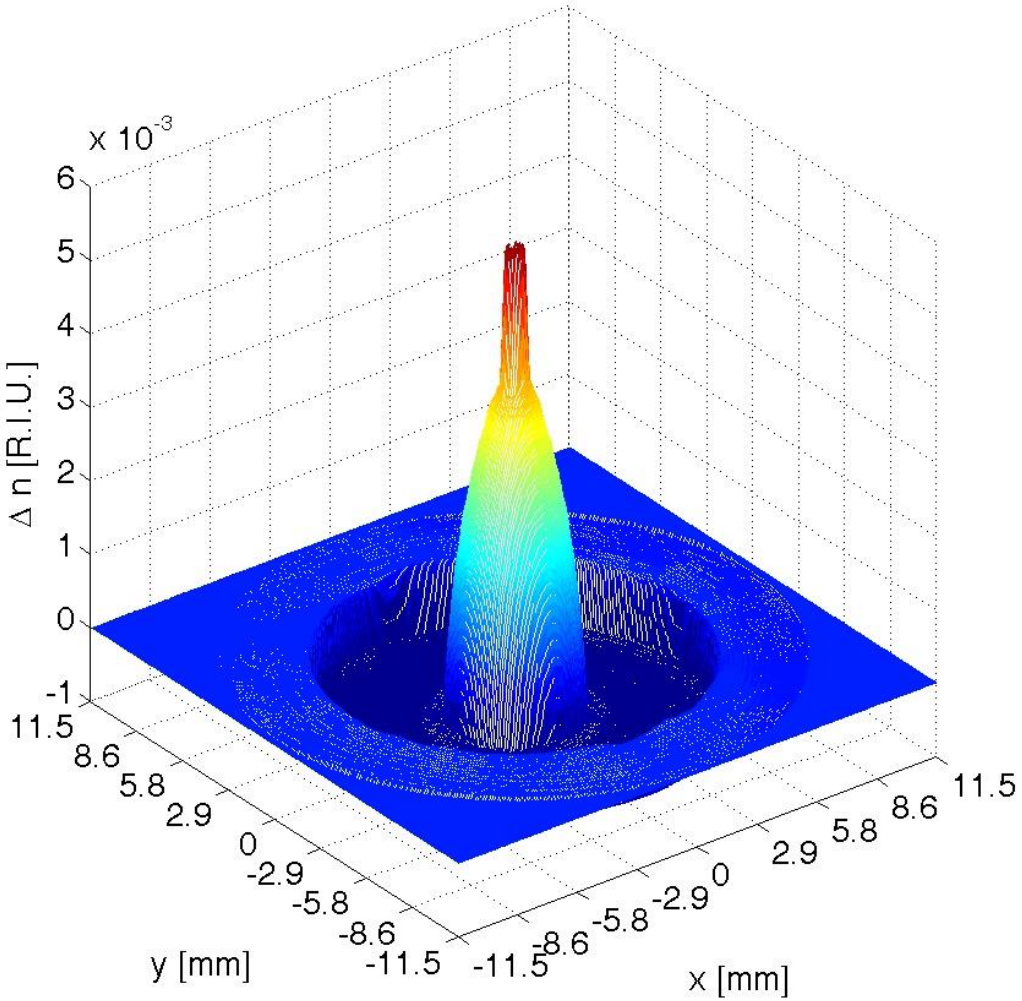


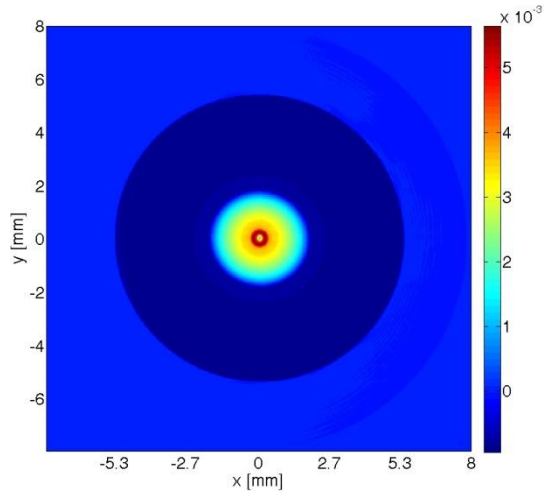


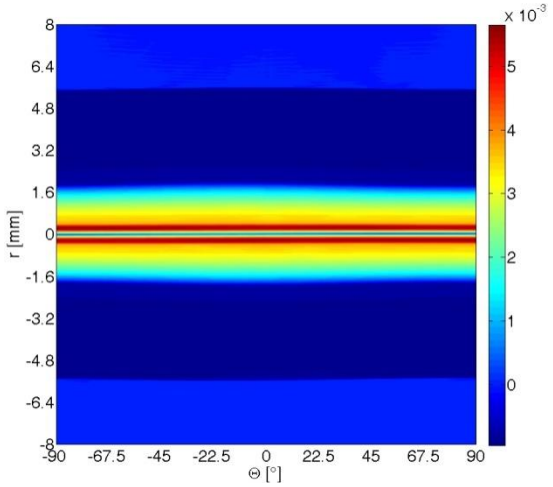


Example of preform – SG939

Gradient fiber with a single mode core (in 45 projections with four degrees step)

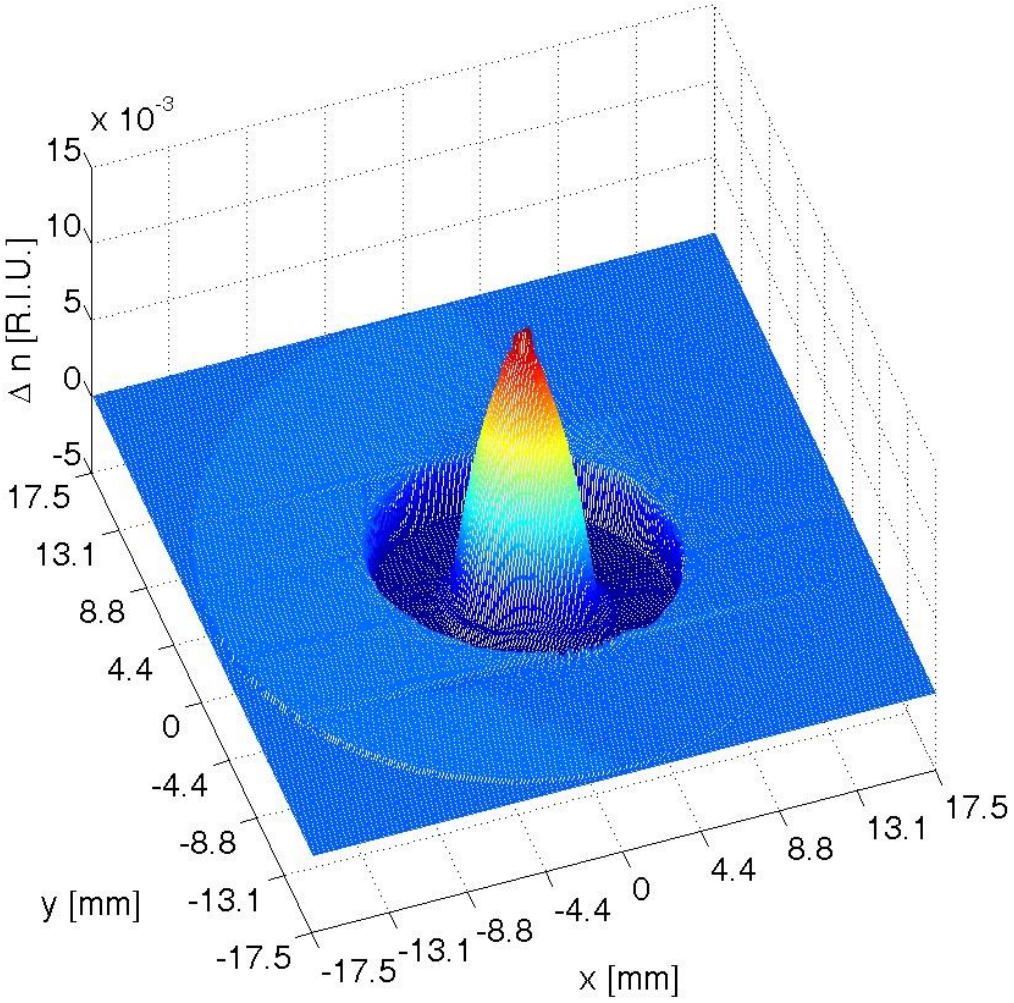


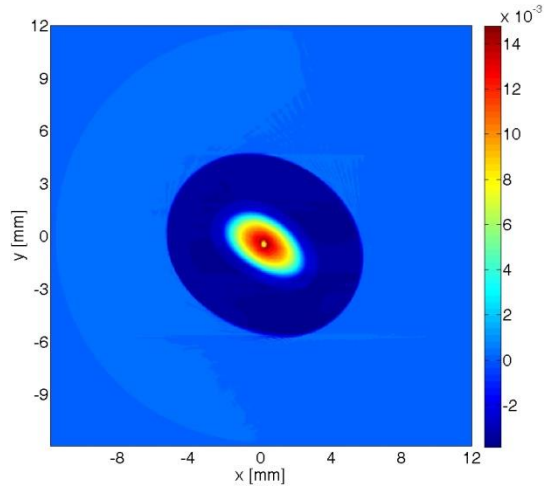


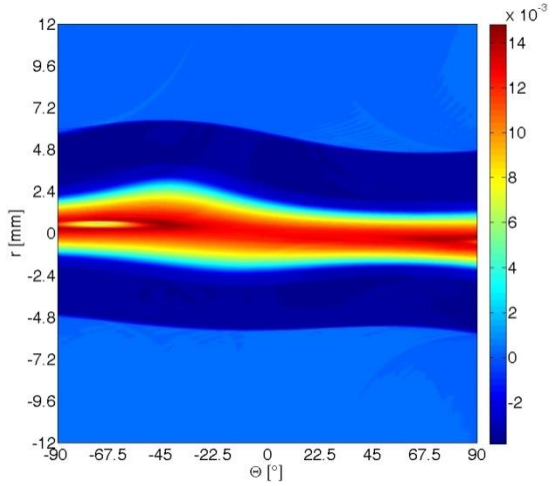


Example of preform – SG44

Gradient preform with highly elliptical core (in 45 projections with four degrees step)

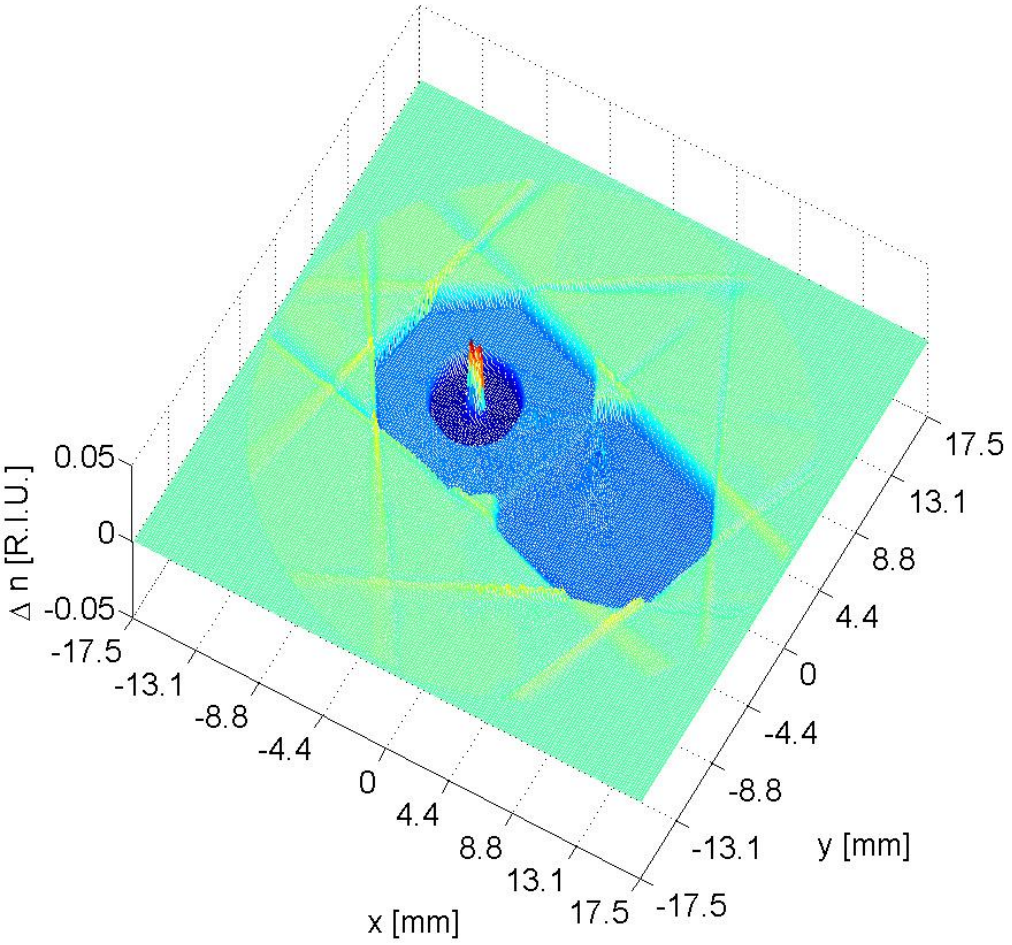


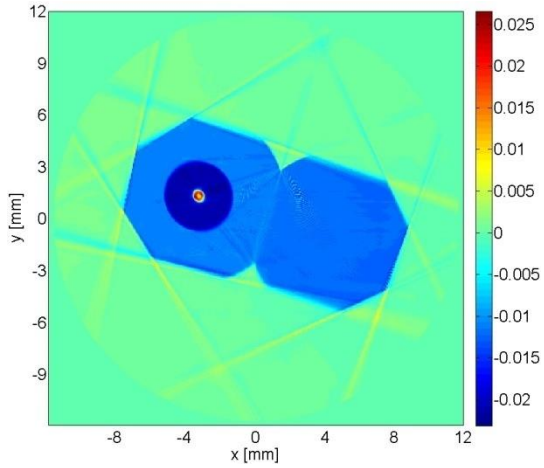


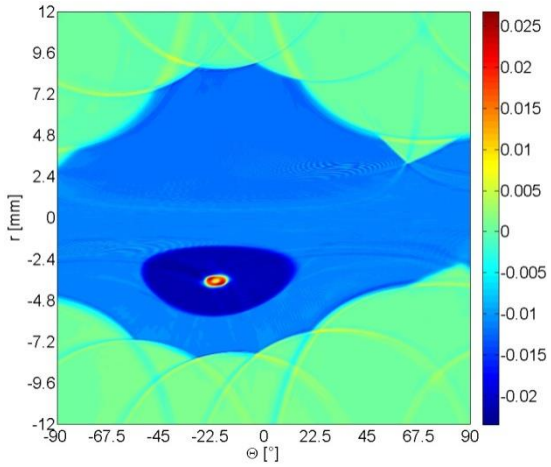


Example of preform – SG827

Composite preform of “stadium” – like cross section for cladding pumped lasers (in 180 projections in one degree step)





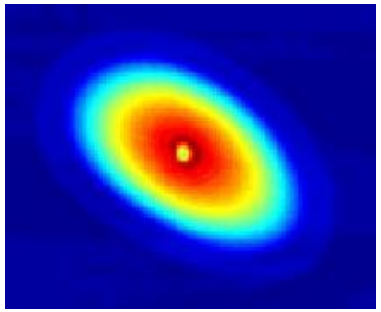


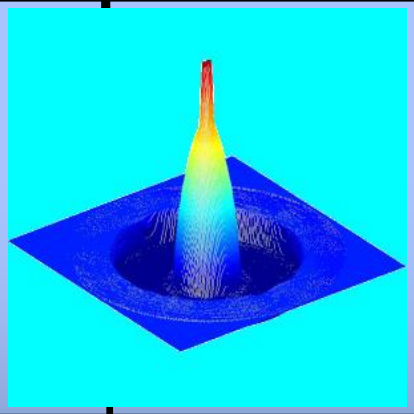
Conclusion

- Get acquainted with fiber amplifiers
- Able to measure with PK2600
- Graphical user interface was programmed

Future

- Testing and debugging
- Consultation the output data format
- Preparing a poster at the conference





Software for tomographic reconstruction of refractive index profile of special optical fibre preforms

Thank you for your attention.