Magnet Simulation at DESY

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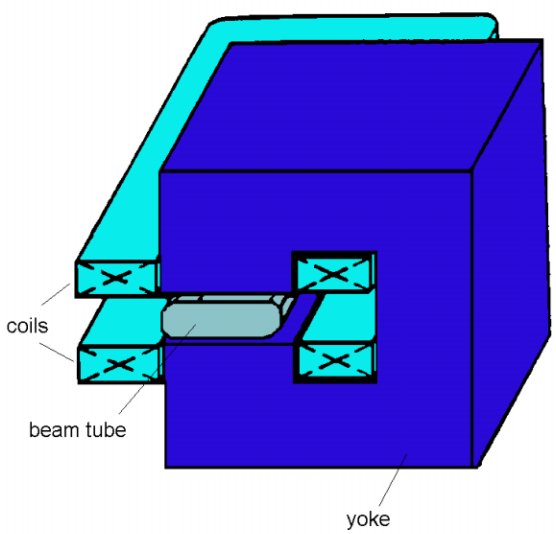
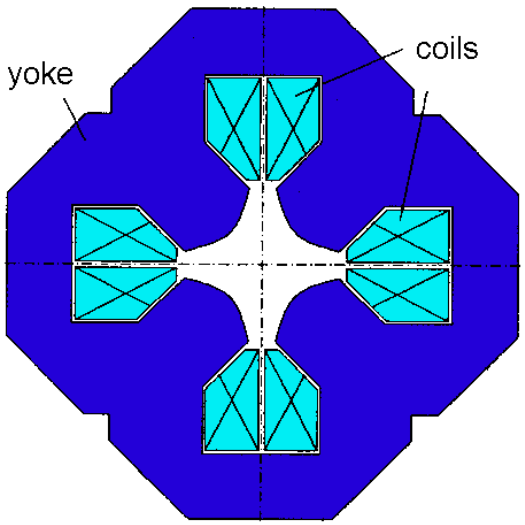




Magnet Simulation Workshop
May 18 – 19, 2005
Knoxville, Tennessee, USA

Magnet Simulation at DESY
- Overview -

- Main codes used at DESY: MAFIA4 and OPERA-3d
- General introduction to MAFIA / Features of MAFIA 4
- General introduction to OPERA-3d / Features of OPERA-3d
- Example: A steering dipole for TTF (Tesla Test Facility)
- Generation of the model with MAFIA and OPERA-3d
- Calculations and results
- Comparison of MAFIA and OPERA-3d results with measurement
- Future plans

Main codes used at DESY
MAFIA and OPERA-3d

General information

- Commercial products, for 2- and 3-d problems

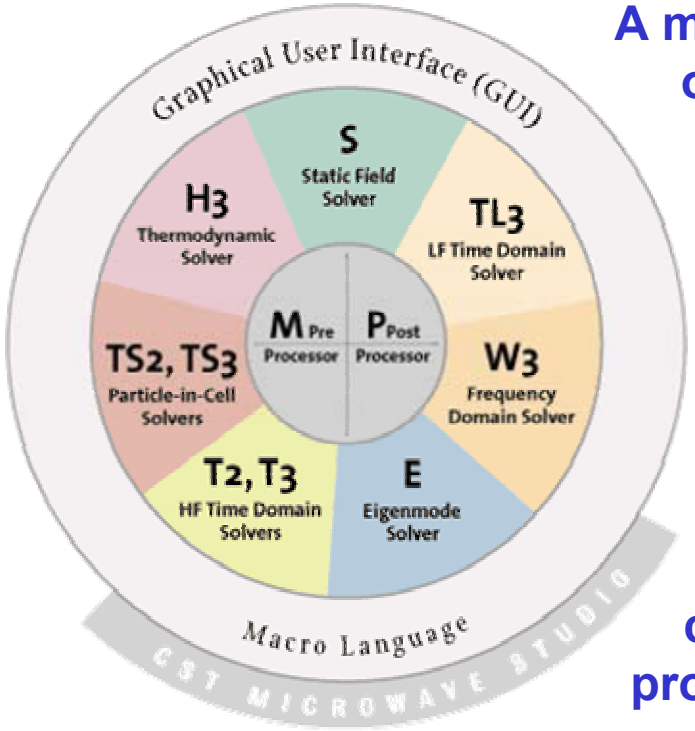
- Both software packages run on various hardware platforms.
  At DESY: UNIX Workstations and Windows PCs are used.

- MAFIA has also been installed and successfully tested
  on a 64-bit machine with 2 Opteron processors

  disk space: 1 TB
  memory: 8 GB (will be upgraded to 16 GB)

General Introduction to MAFIA* (1)

MAFIA is an acronym for the solution of MAxwell´s equations using the Finite Integration Algorithm.



A multi-purpose ECAD system consisting of a pre-processor (M), a post-processor (P) and several solver modules.

MAFIA-S is the static field solver.

Graphical User Interface (GUI) or direct command input possible.
(→ faster for advanced users)

The modules T2/T3, E and W3 are also covered by the more specialized HF ECAD program CST MICROWAVE STUDIO®.

*Distributed by the CST Company, Darmstadt, Germany
http:// www.cst.com

General Introduction to MAFIA (2)

MAFIA 4 is based on the Finite Integration method.

MAFIA uses a rectangular grid with a dual grid so that both electric and magnetic components are continuous at material surfaces. The cells can be diagonally filled.

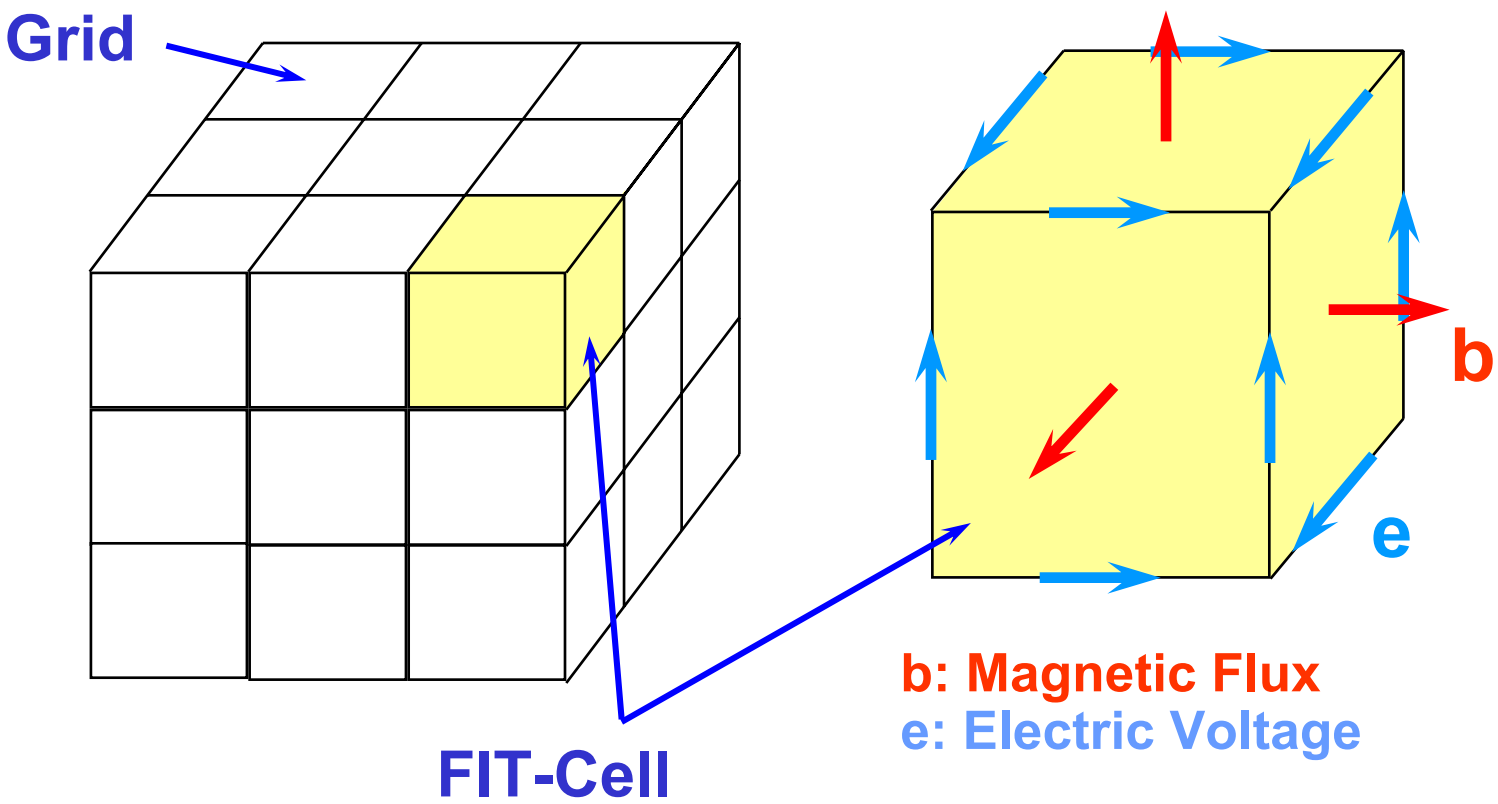
Although this can occasionally lead to a stair step discretisation. With sufficient mesh cells the error is very small.

The FI method translates the analytical Maxwell's equations into discrete matrix equations.

This theoretical foundation enables MAFIA 4 to achieve an unsurpassed accuracy and reliablity.

General Introduction to MAFIA (3)

Finite Integration Technique: divide the volume into grid cells:



b: Magnetic Flux
e: Electric Voltage

MAFIA Features

- Primitives for geometric definition:

  → bricks, spheres, ellipsoids, circular cylinders, elliptic cylinders, cylinders with arbitrary cross section, figures of rotation, washers, torus, filaments

  → boolean operations

- Import and export of data from the most popular CAD systems (ProEngineer, I-DEAS, AutoCad).

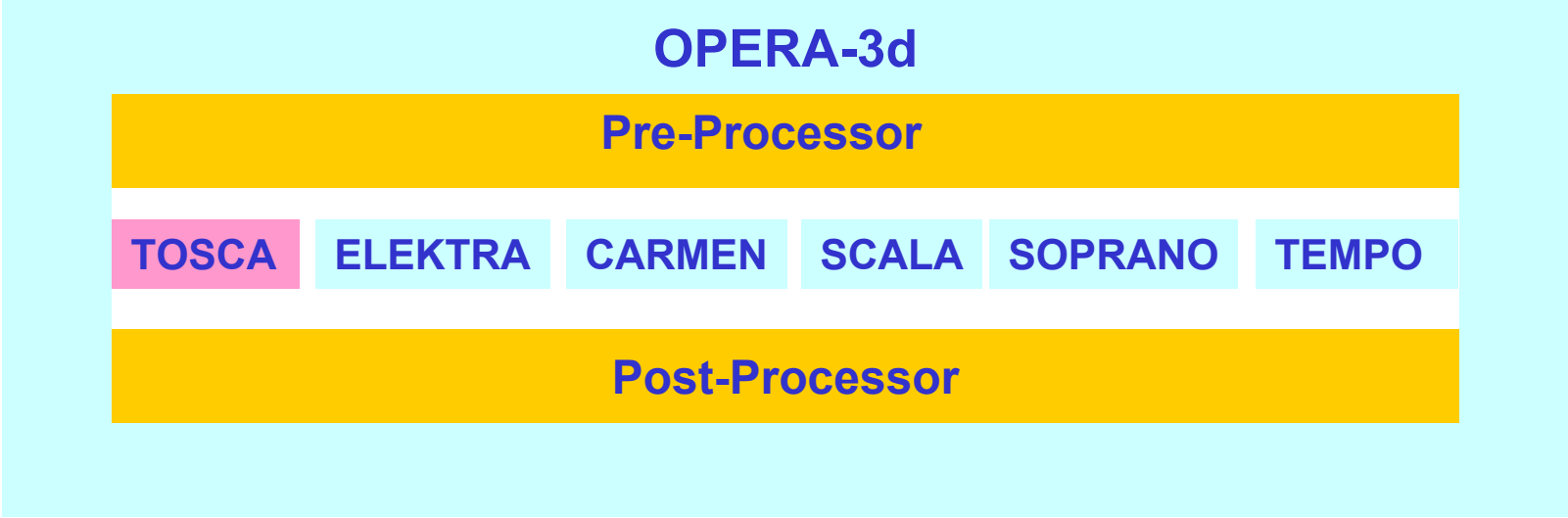
- Automatic mesh generation

- Fully parametric modeling for optimization

- Easy to use command files + command language

General Introduction to OPERA-3d (1)

OPERA-3d* is a powerful analysis package which includes a pre and a post processor:



TOSCA : 3d static analysis
ELEKTRA: 3d dynamic analysis
CARMEN : 3d rotating machines
SCALA : 3d space charge analysis
SOPRANO: 3d modal analysis
TEMPO : 3d thermal analysis

*distributed by the Vector Fields company in Oxford/GB
http://www.vectorfields.co.uk

General Introduction to OPERA-3d (2)

- Two possible ways to generate data files and models for the electromagnetic analysis programs

Modeller : uses geometric primitive volumes and Boolean operations to construct the model

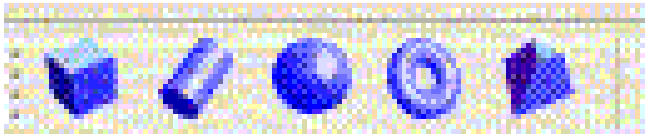
Pre-Processor: uses extrusion from a 2D cross-section

- Finite element mesh

- A scripting language is included for automation of both pre and post-processors

OPERA-3d Features

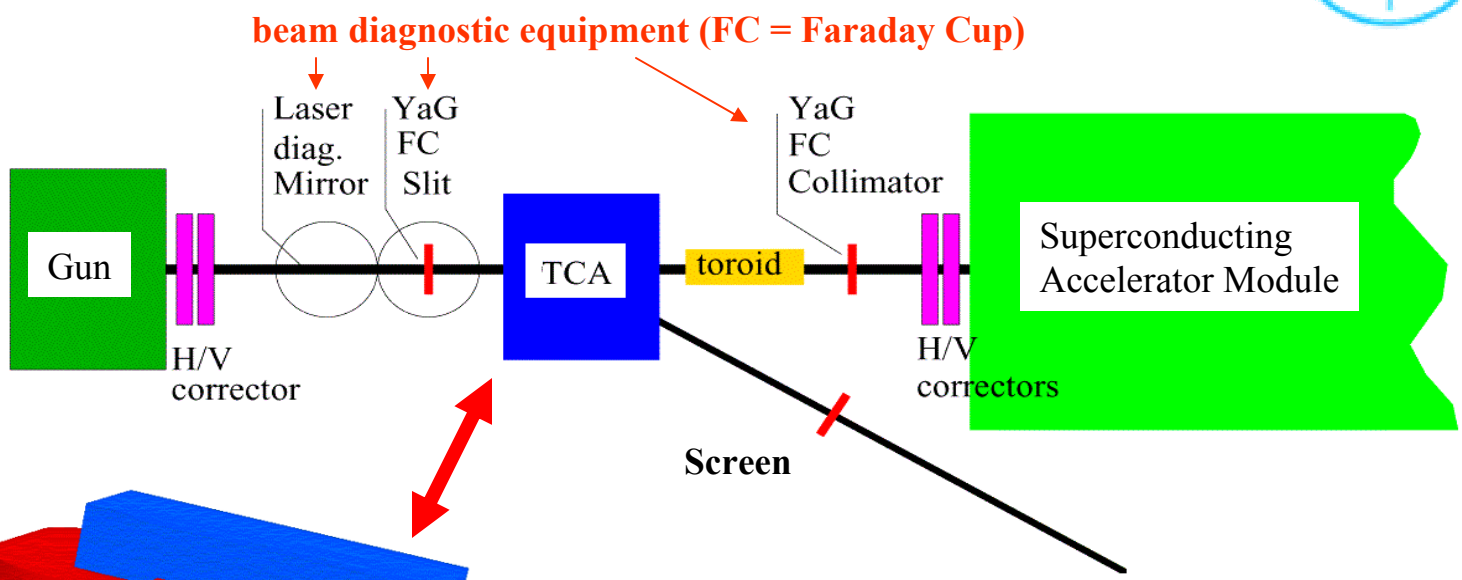
- Menu driven user interface
- Geometric primitives (tetrahedron, prism, brick)

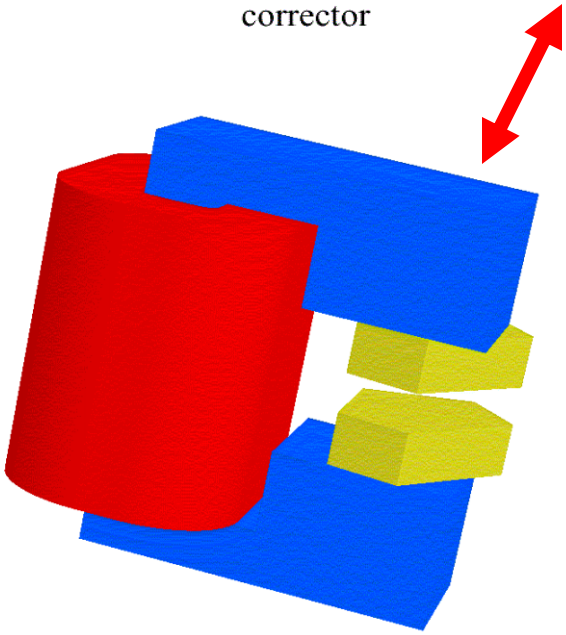


- 3D curved surfaces
- Wire frame and hidden surface displays
- Calculation of fields, forces and energies
- Graphs, histograms and contour maps of solutions
- Contours of components of the results on any plane surface
- Plotting of particle trajectories

Example: A steering dipole for TTF*

* TTF = TESLA TEST FACILITY @ DESY Hamburg



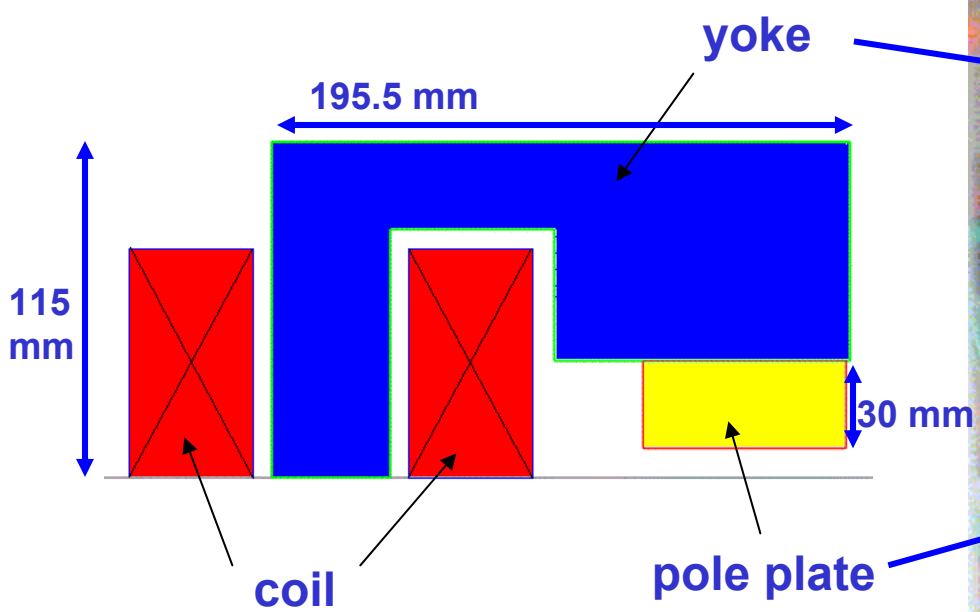


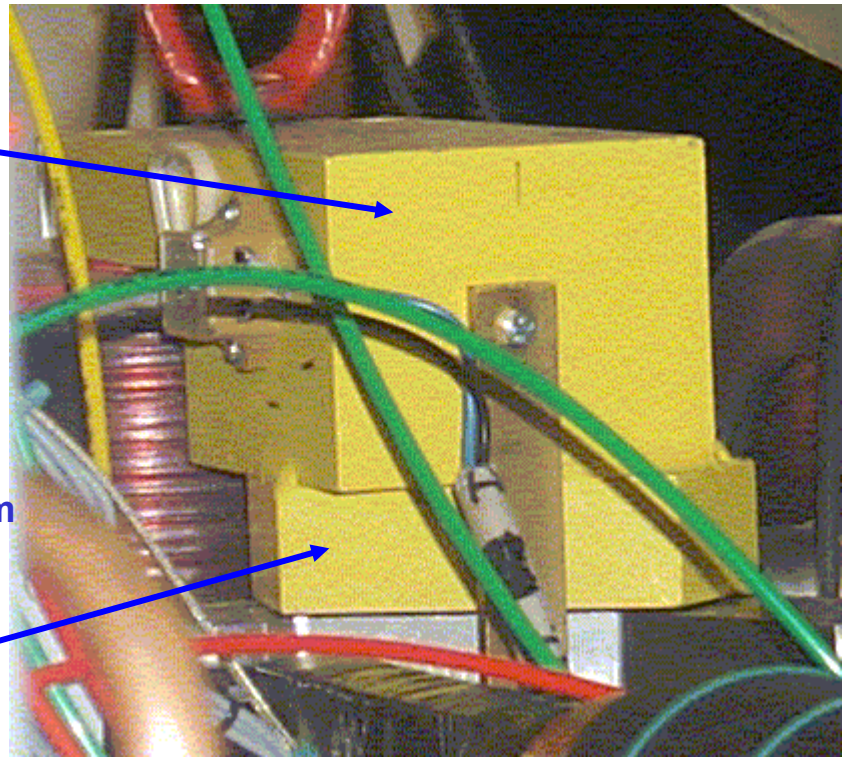
The function of this magnet is to deflect the beam for a beam momentum measurement and also to focus the beam onto a downstream screen for divergence and emittance measurements.

Example: A steering dipole for TTF*

* TTF = TESLA TEST FACILITY @ DESY Hamburg

2d view of the dipole (upper half):



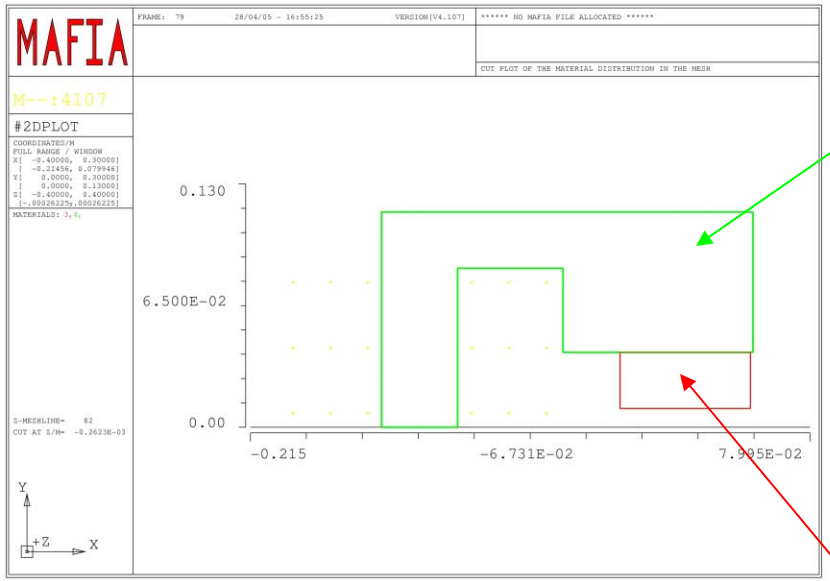


I = 1.427 A, 1820 windings

gap: 20 mm
iron: stabocor (bh curve from B. Krause, DESY)
nonlinear field calculation

Generating a 3D model with MAFIA-M

M Pre Processor



MAFIA input data

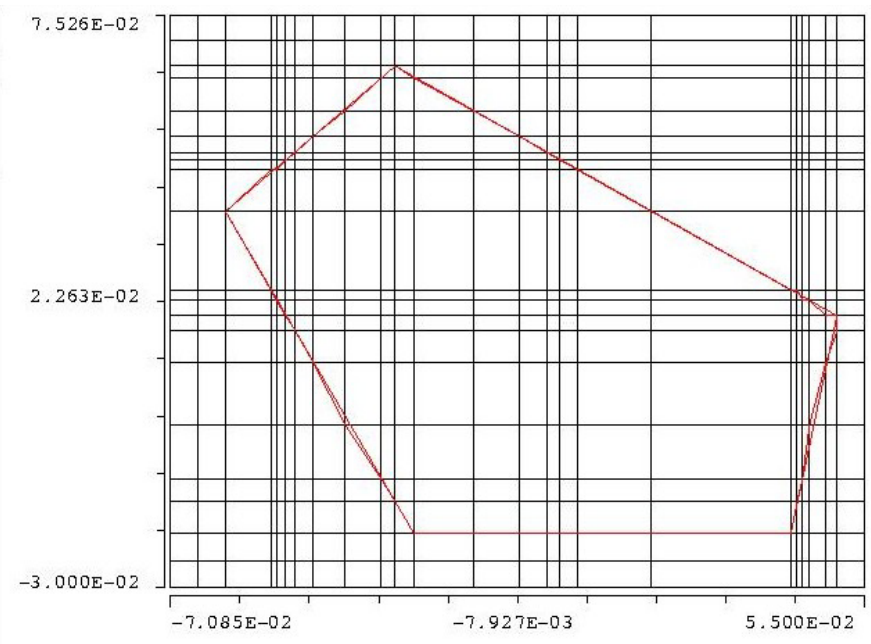
```
$ ---- the yoke:
#cylin material=4
      orientation=z range=zz2n zz2
$-- points in x---y plane:
    p xx4n  yymin
    p xx4n  yy4
    p xx1   yy4
    p xx1   yy2
    p xx1n  yy2
    p xx1n  yy3
    p xx3n  yy3
    p xx3n  yymin
    p xx4n  yymin
    execute

$ ---- the pole plate:
#cylin material=3 ori=y range=yy1 yy2
$-- points in z---x plane:
    p zpp1 xpp3
    p zpp2 xpp4
    p zpp5 xpp2
    p zpp4 xpp1
    p zpp3 xpp1
    p zpp1 xpp3
    execute
```

Strategy:

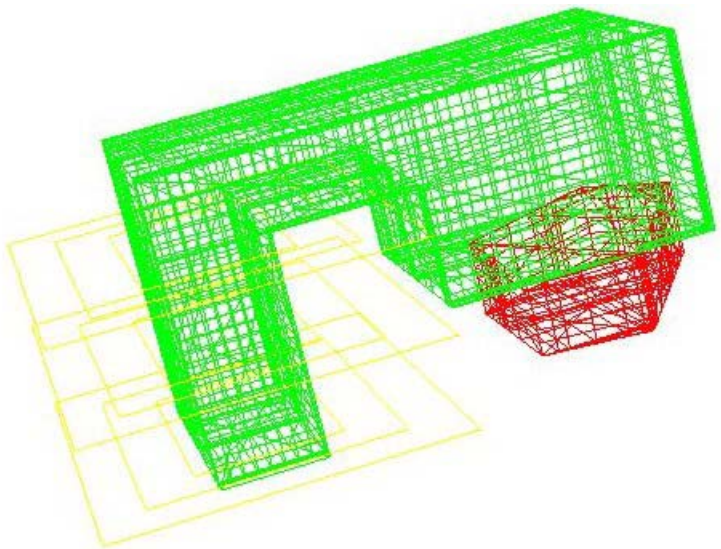
- Think about model dimensions (symmetries) and generate the mesh
- Enter the structure: each model can be made up of simple geometric shapes like bricks, cylinders, cones etc.
  2d cross-sections can be rotated or extruded into the 3rd dimension.
- Enter the filaments (to simulate the coil)
- Save geometry on MAFIA file (= direct access file)

Generating a 3D model with MAFIA-M

The Mesh



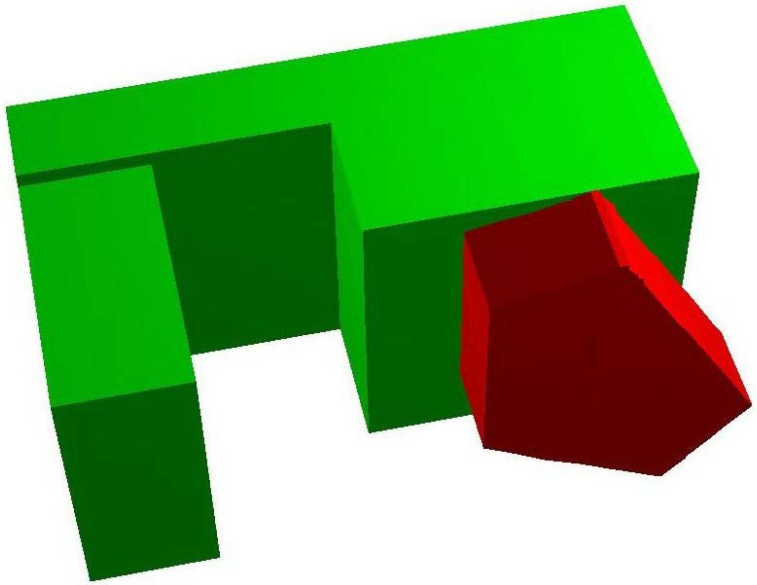
2d cut of the pole plate with mesh cells

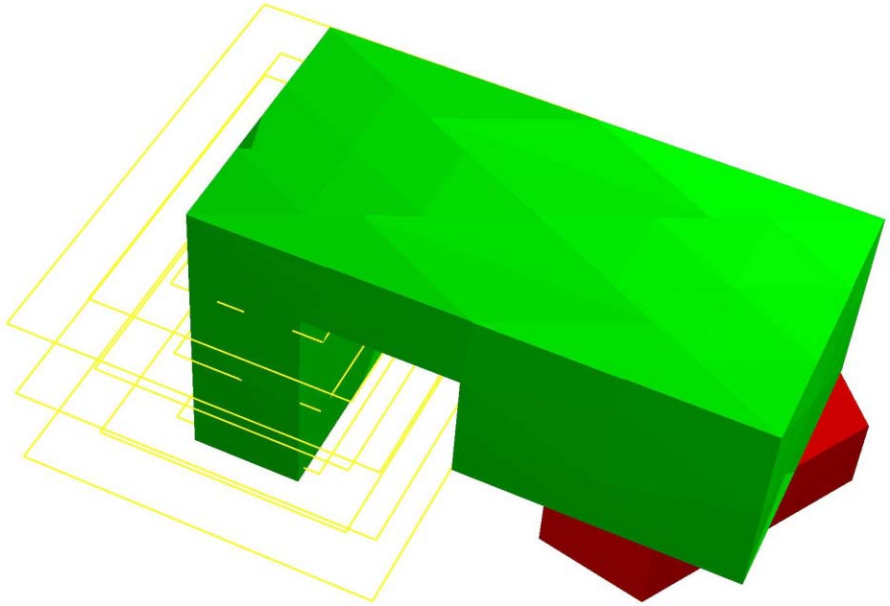


3d wire frame with filaments

Generating a 3D model with MAFIA-M

3d views





MAFIA 4: Running the Static Field Solver S

S Static Field Solver

- Electrostatic and electroquasistatic fields
- Magnetostatic fields
- Electric Currents
- Temperature distributions
- Coupled calculations
- Standard and open boundary conditions
- Non-linear, anisotropic material properties
- Basic grids: xyz, rfz, xy,rz

Calculation Procedure:

- ⇨ Open the MAFIA file
- ⇨ Set the calculation problem (magneto- or electrostatic)
- ⇨ Define the boundary conditions
- ⇨ Enter the bh-data (in case of a nonlinear calculation)
- ⇨ Set the material properties
- ⇨ Assign currents to the filaments
- ⇨ Solve the problem
  (several modern algorithms are available for the solution of different types of problem).

Features of the Post Processor MAFIA-P

P Post Processor

- Graphical representations of 1D, 2D and 3D fields
  - arrow (vector) plot, contour plot, line plot

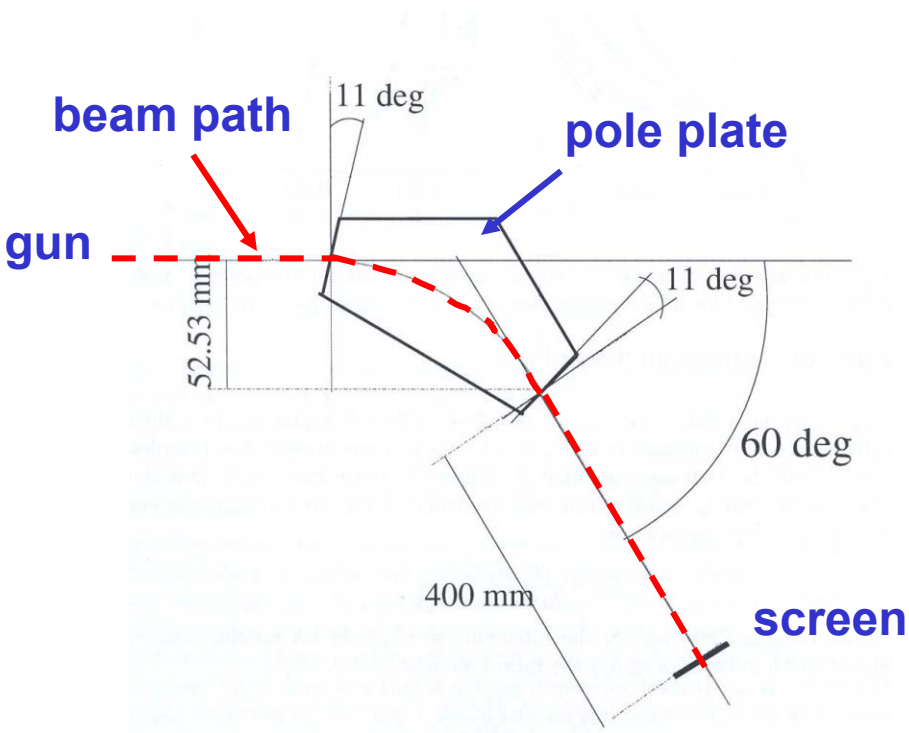
- Computation of physical quantities
  - multipole analysis
  - forces, energies, losses, voltages
  - 1D integral, 2D integral

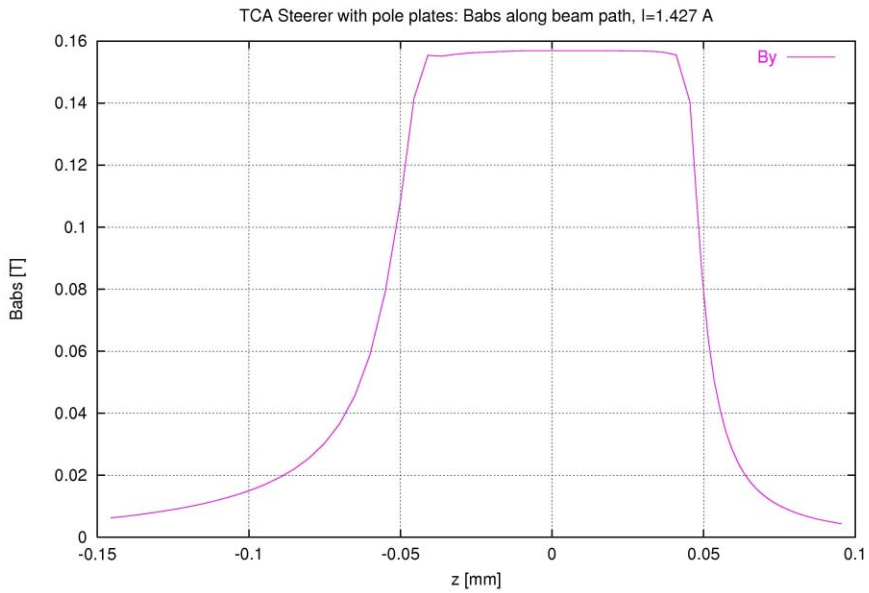
- Mathematical operations on computed fields such as curl, div, grad, cross product, surface currents, addition, subtraction, multiplication, division, etc.

- Fields from other calculations with the same geometry (mesh) can be imported and compared (#load-section)

Running the Post Processor MAFIA-P

For the TCA magnet we are interested in the B-Field along the e-beam path. Calculation has been done for I = 1.427 A ==> B = 0.1568 T.

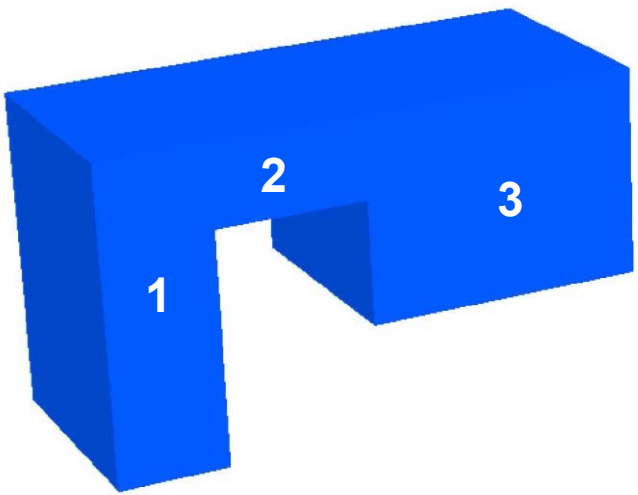




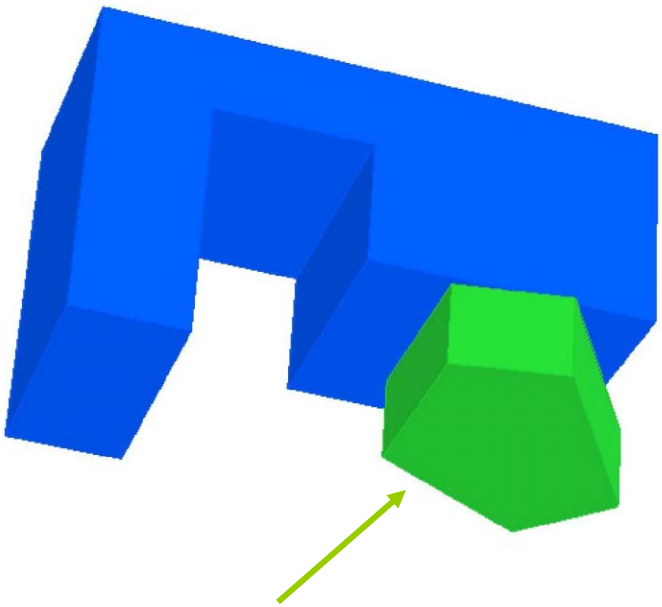
B_{abs} along beam path calculated with MAFIA

Generating a 3D model with OPERA-3d

Generate the model by selecting and combining simple geometric shapes.



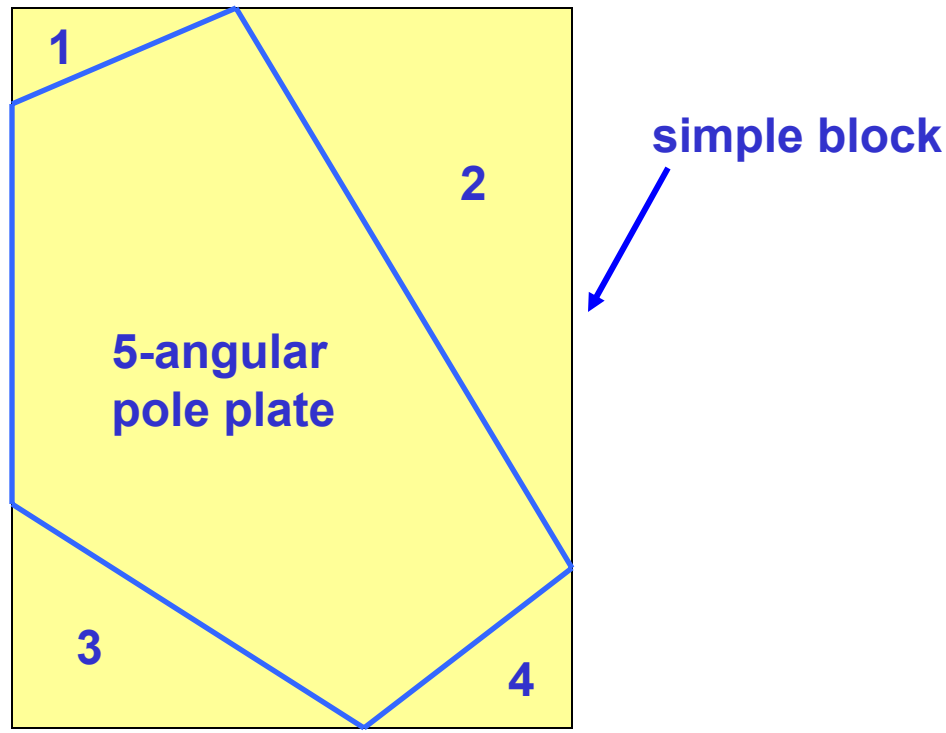
yoke: 3 simple bricks



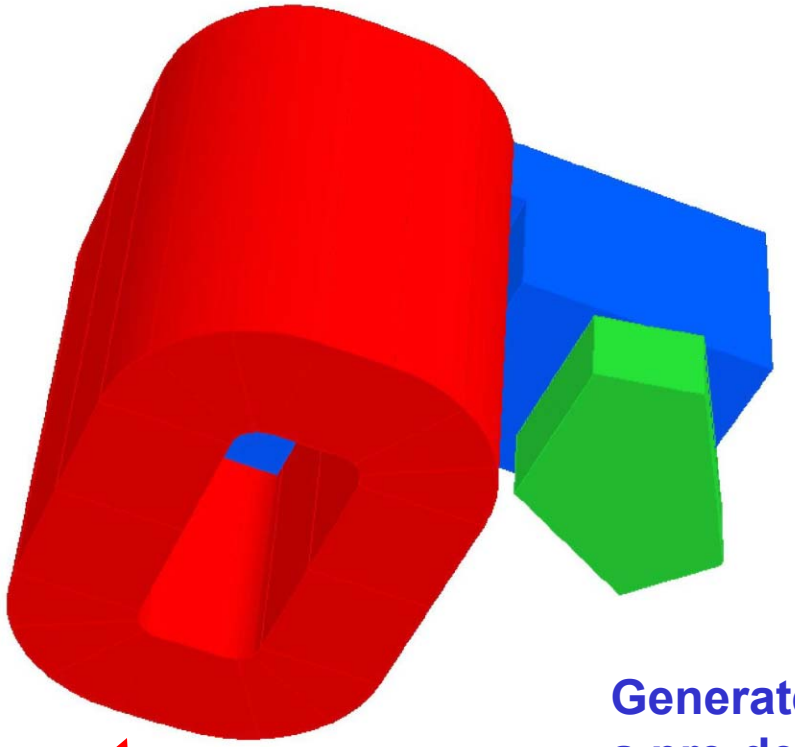
Create the pentagonal pole plate by combining simple blocks (… a little more sophisticated).

Generating a 3D model with OPERA-3d

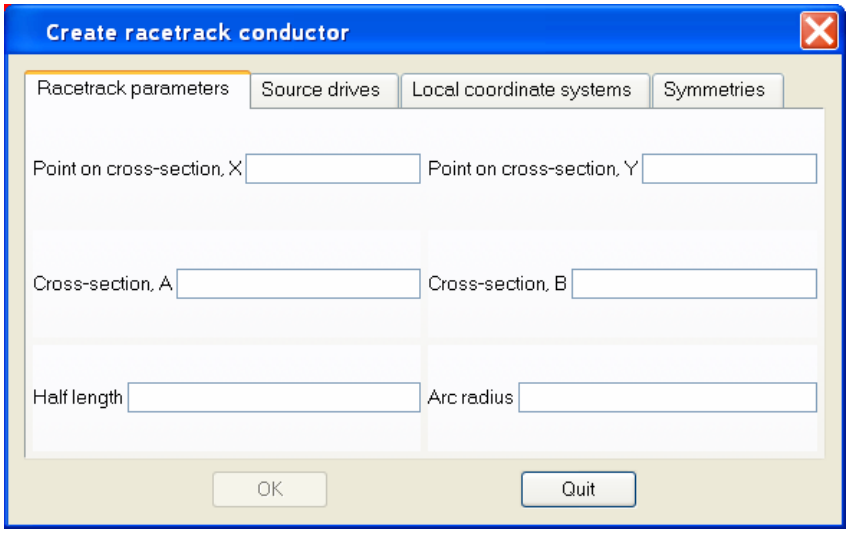
Generate a simple block and cut off the 4 unwanted triangles by transform operations.



Generating a 3D model with OPERA-3d



racetrack conductor



Generate the racetrack conductor by selecting a pre-defined shape from a list of conductor geometries.
Also available: primitive conductor elements to build up conductor circuits.

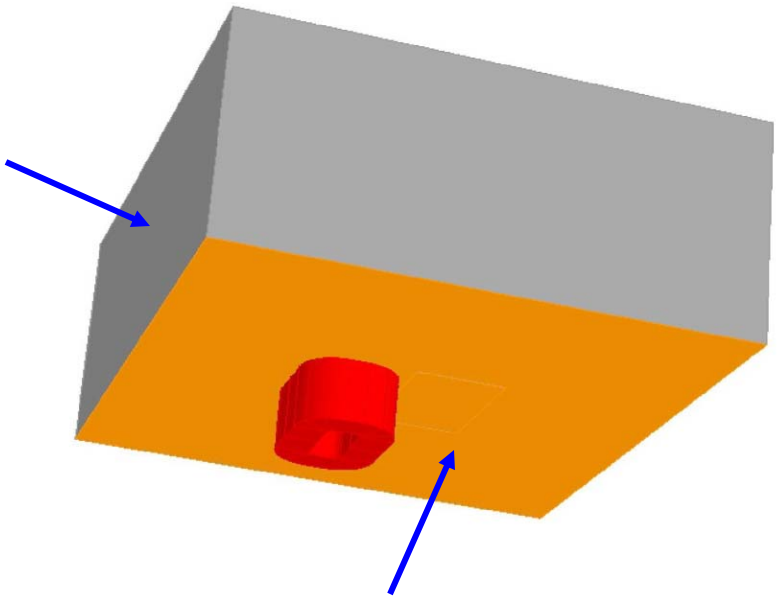
Generating a 3D model with OPERA-3d

Last pre-processing steps:

- Surround the model with a brick of air
- Define boundary conditions
- Define material properties
- Assign bh curve to the according materials
- Generate surface and volume mesh

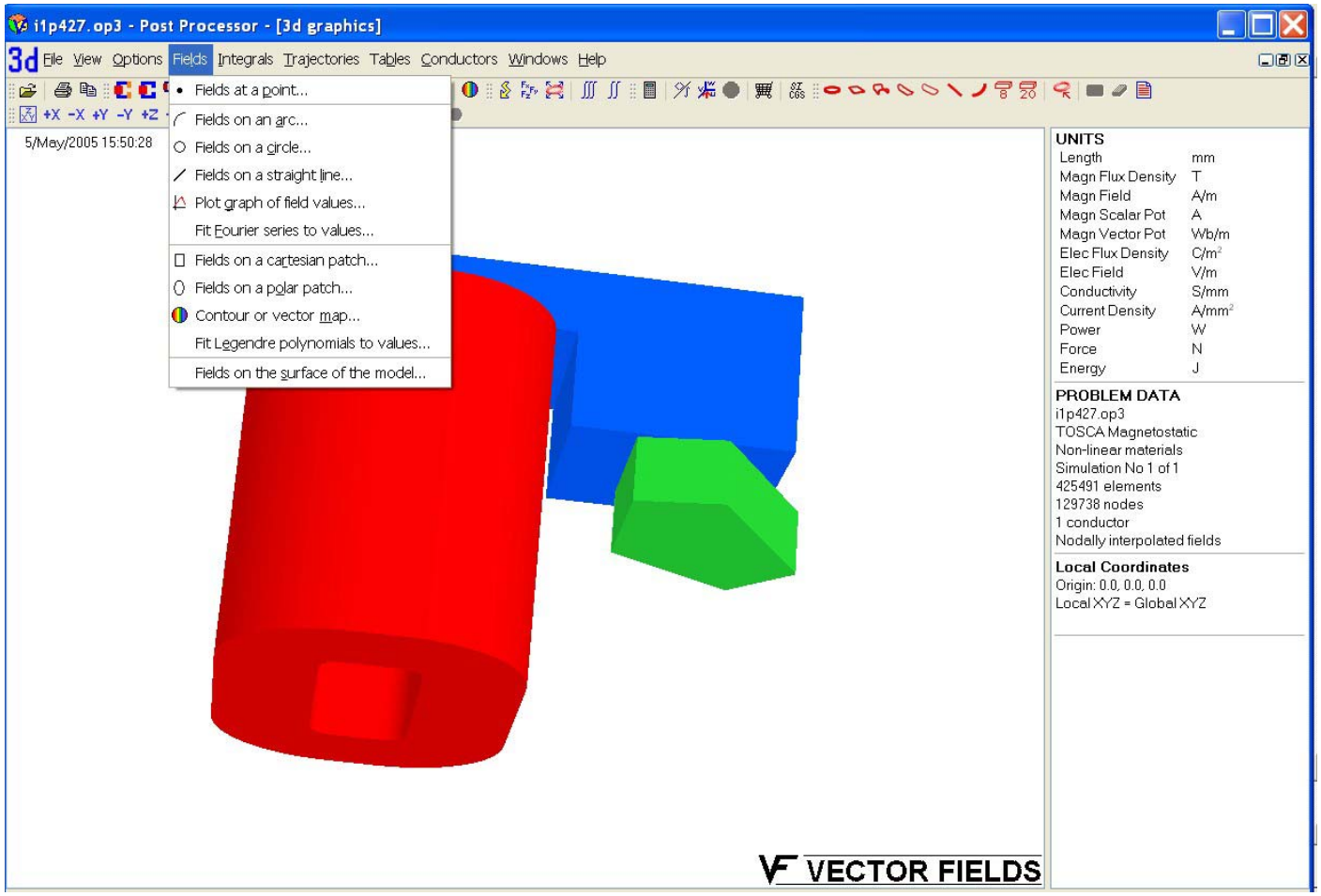
The magneto-static analysis will be performed directly from the pre-processor.

Select the magneto-static solver, save the model and start the analysis.



Selected symmetry plane highlighted in orange. Pick each plane to assign a boundary condition.

Running the OPERA-3d Post-Processor

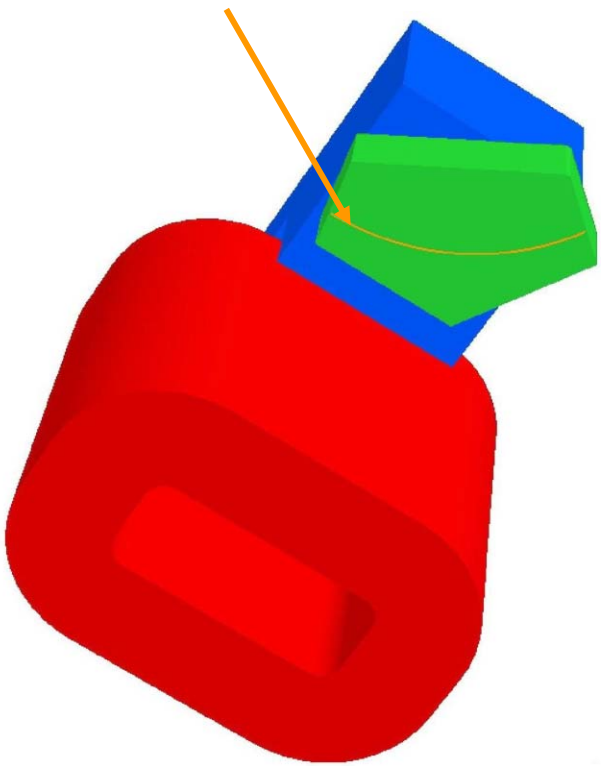


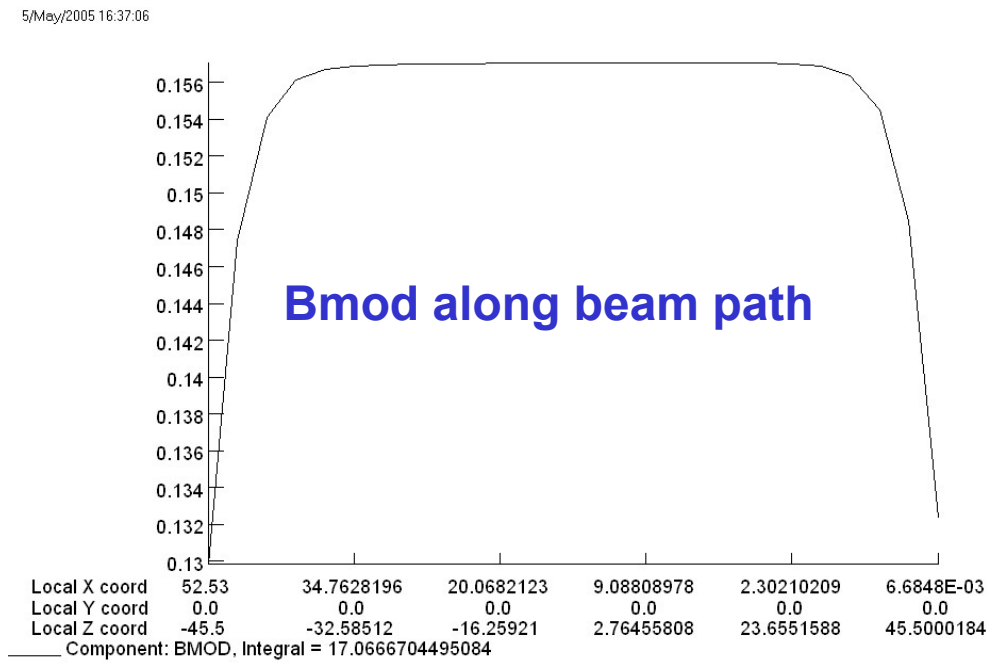
Screen shot of the OPERA-3d Post-Processor

Running the OPERA-3d Post-Processor

TOSCA solution: I = 1.427 A ==> B = 0.1570 T

Geometric model showing the beam path

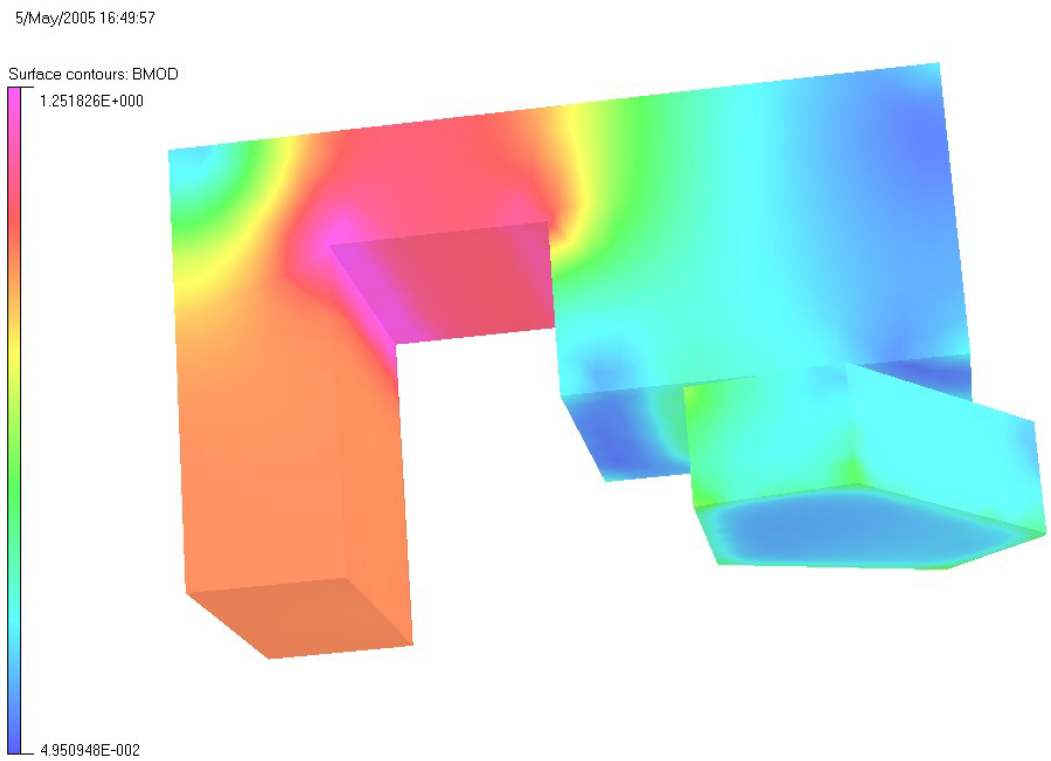




VECTOR FIELDS

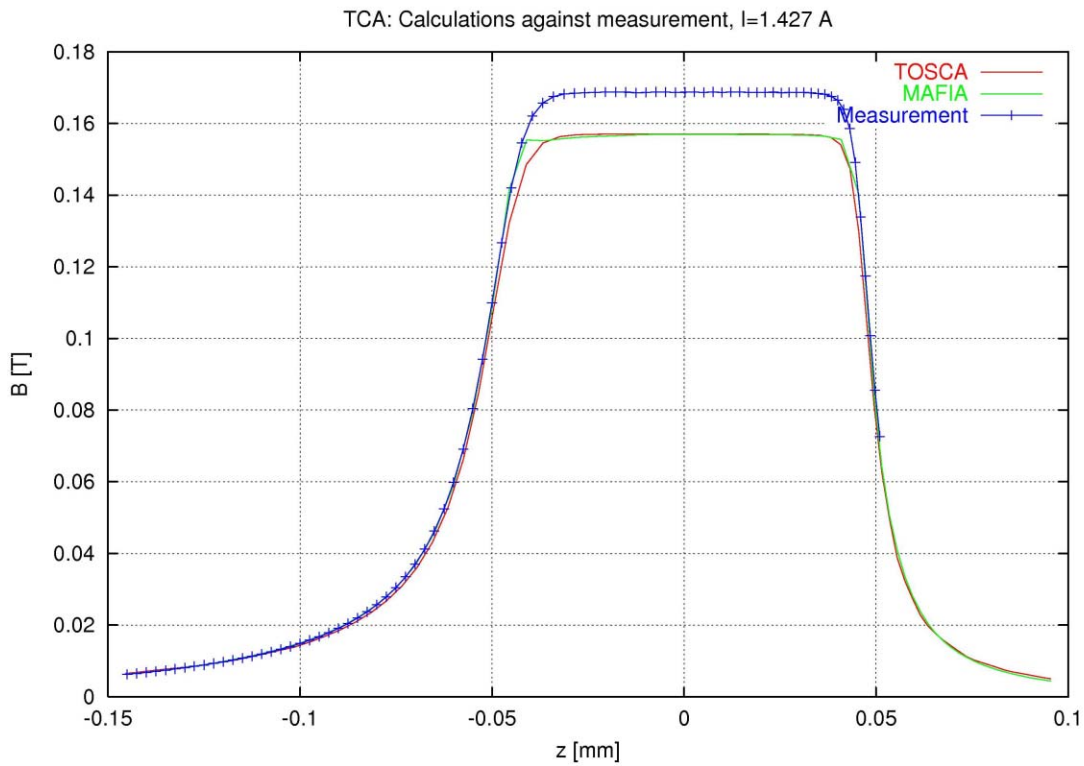
Running the OPERA-3d Post-Processor

TOSCA result: 3D contour plot of Bmod



VECTOR FIELDS

Comparison of MAFIA and OPERA-3d results with measurement



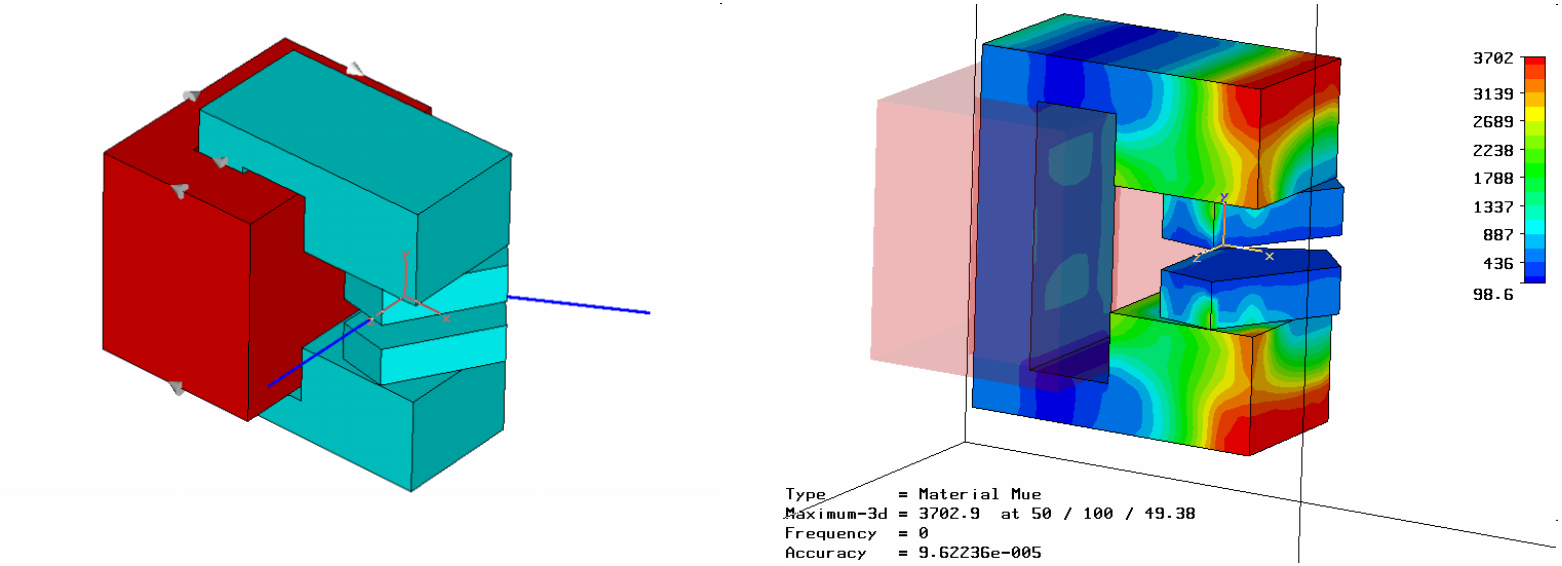
Good agreement between MAFIA and TOSCA.

Discrepancy between simulation and measurement is
dB = 0.011 T,
= 6.5%

MAFIA: 1.395.680 mesh points, calculation time: 5 Minutes on 64-bit Opteron Processor
TOSCA: 425491 elements, 129738 nodes, calc. time: 3 Minutes on P4, 2.8 GHz

Future plans: New Software Package

CST EM STUDIO™ is a brand new, easy-to-use tool for the analysis and design of static and low frequency structures.
EM-Studio is the follower of MAFIA-S using the improved mesh with "perfect boundary approximation".



Thanks to Ulrich Becker from the CST company for running the TCA dipole with EM-Studio.