# Parallel *hp*-Finite Element Simulations of 3D Resistivity Logging Instruments

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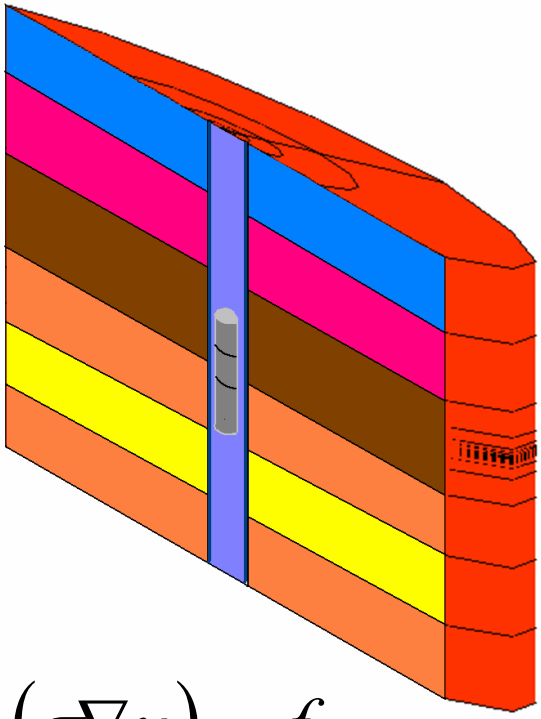
# Motivation

3D DC resistivity measurements simulations in deviated wells are of great interest to the oil industry.

There is a need to solve at least 40 positions of the receiver and transmitter antennas.

Each position requires fully 3D Finite Element Method computations of the Poisson equation.



The electric field is given by $E = -\nabla u$

where *u* is a scalar potential defined by $\nabla \cdot (\sigma \nabla u) = f$

**Main challenge:** 3D computations are **expensive**

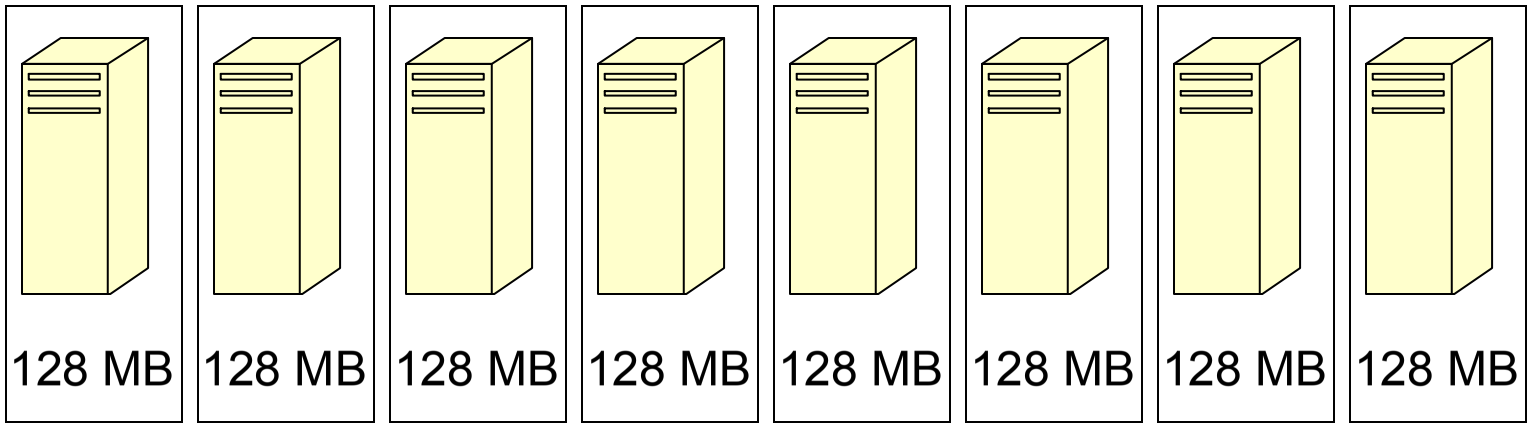
# Why distributed parallel computations?

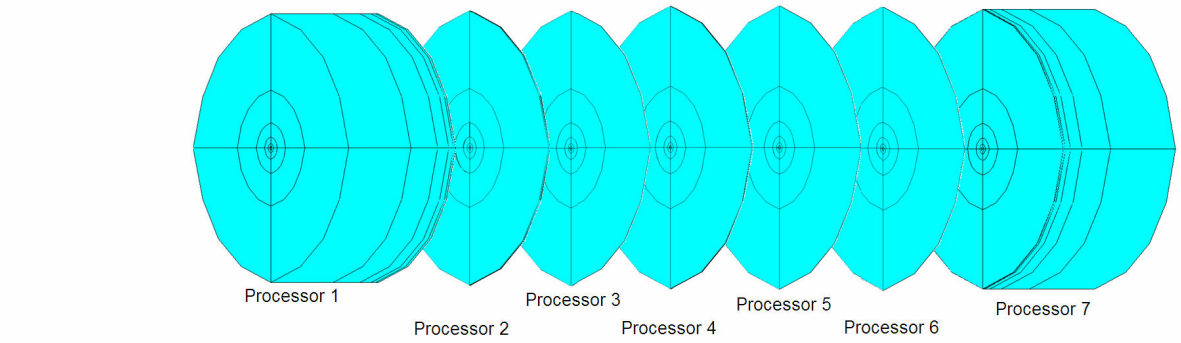
Parallel distributed software is better than execution of serial code for many logging positions simultaneously, because:

- It utilizes less memory.
- It can be utilized in large parallel machines (number of processors is NOT limited by number of logging positions).
- It re-utilizes information about results from previous logging positions.
- It is more suitable for inverse problems.
- It provides faster first results, which speeds up the developing and debugging process.
- It supports parallel *hp* adaptive computations

# Why distributed parallel computations?

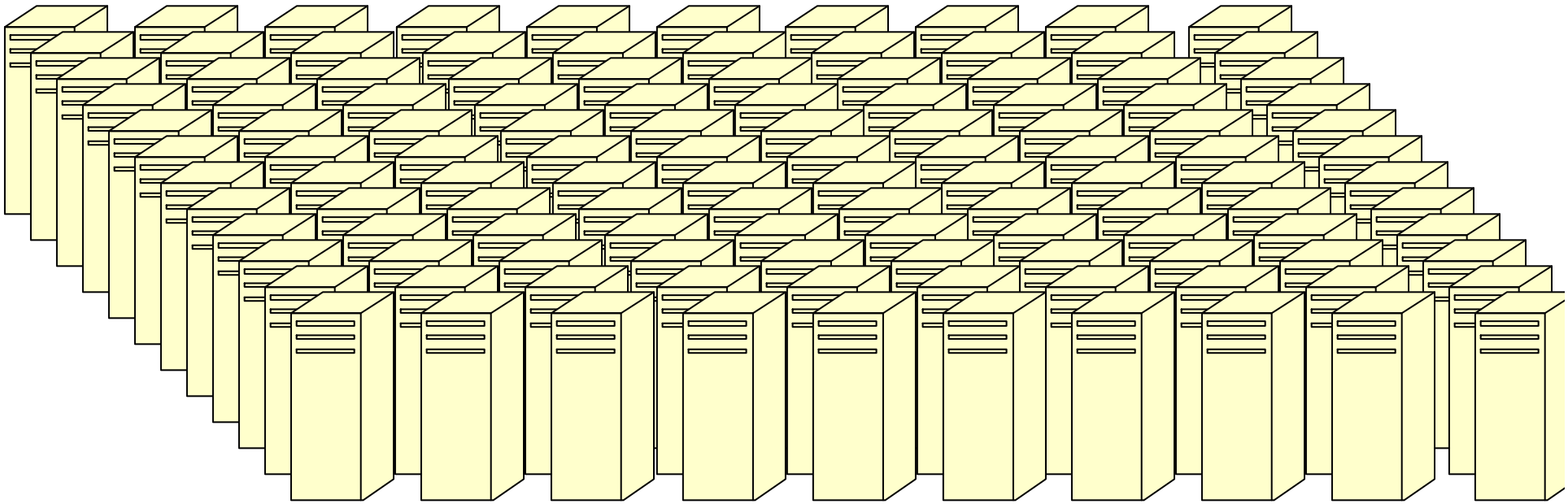
Distributed memory architecture




Less memory on each processor - **cheaper computations**

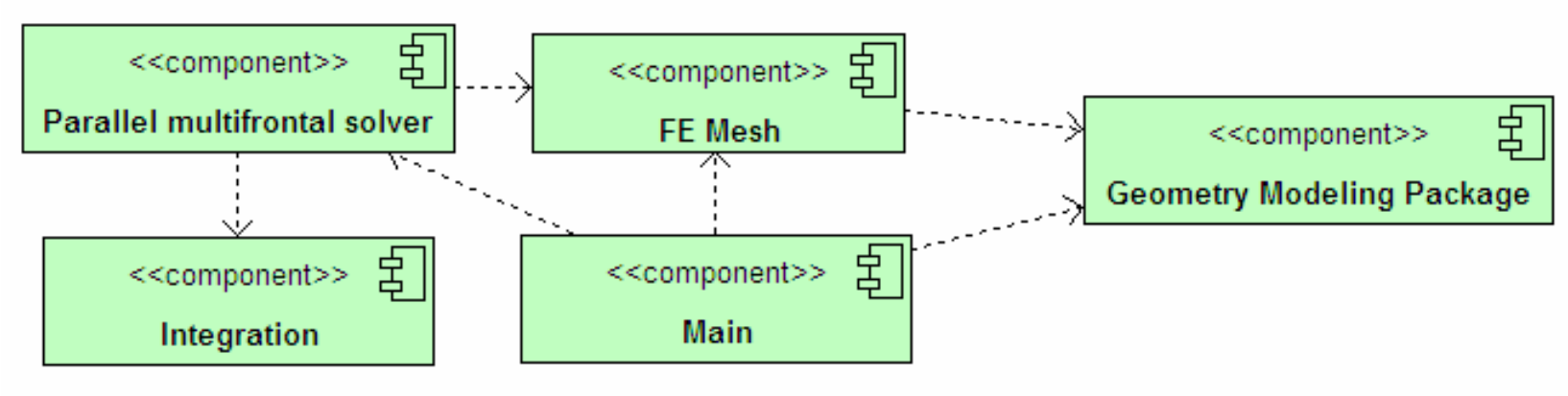
# Why distributed parallel computations?



We can utilize hundreds and thousands of processors

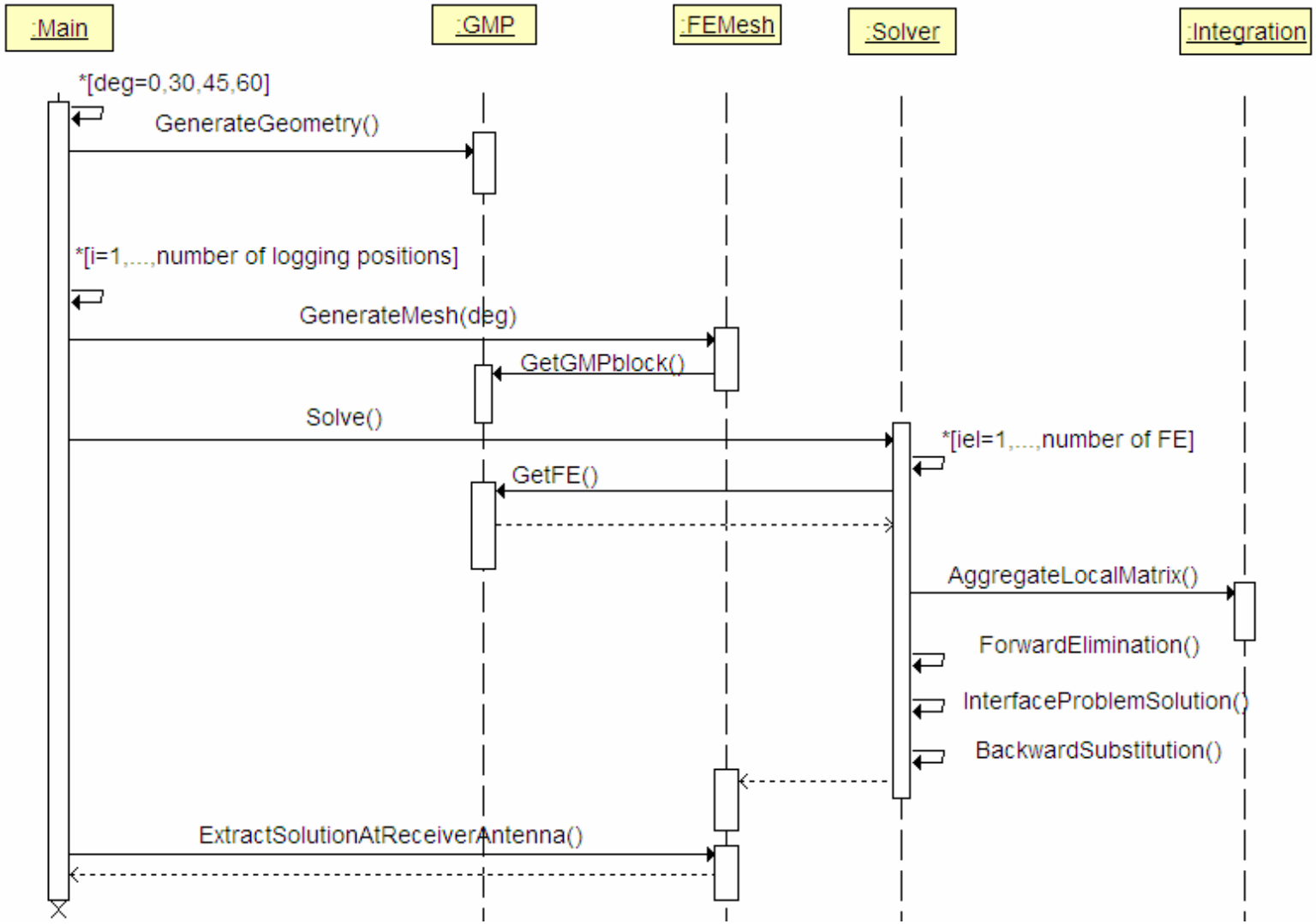
**Faster computations** wrt. parallel execution of serial code for each position of antenna

# CE infrastructure

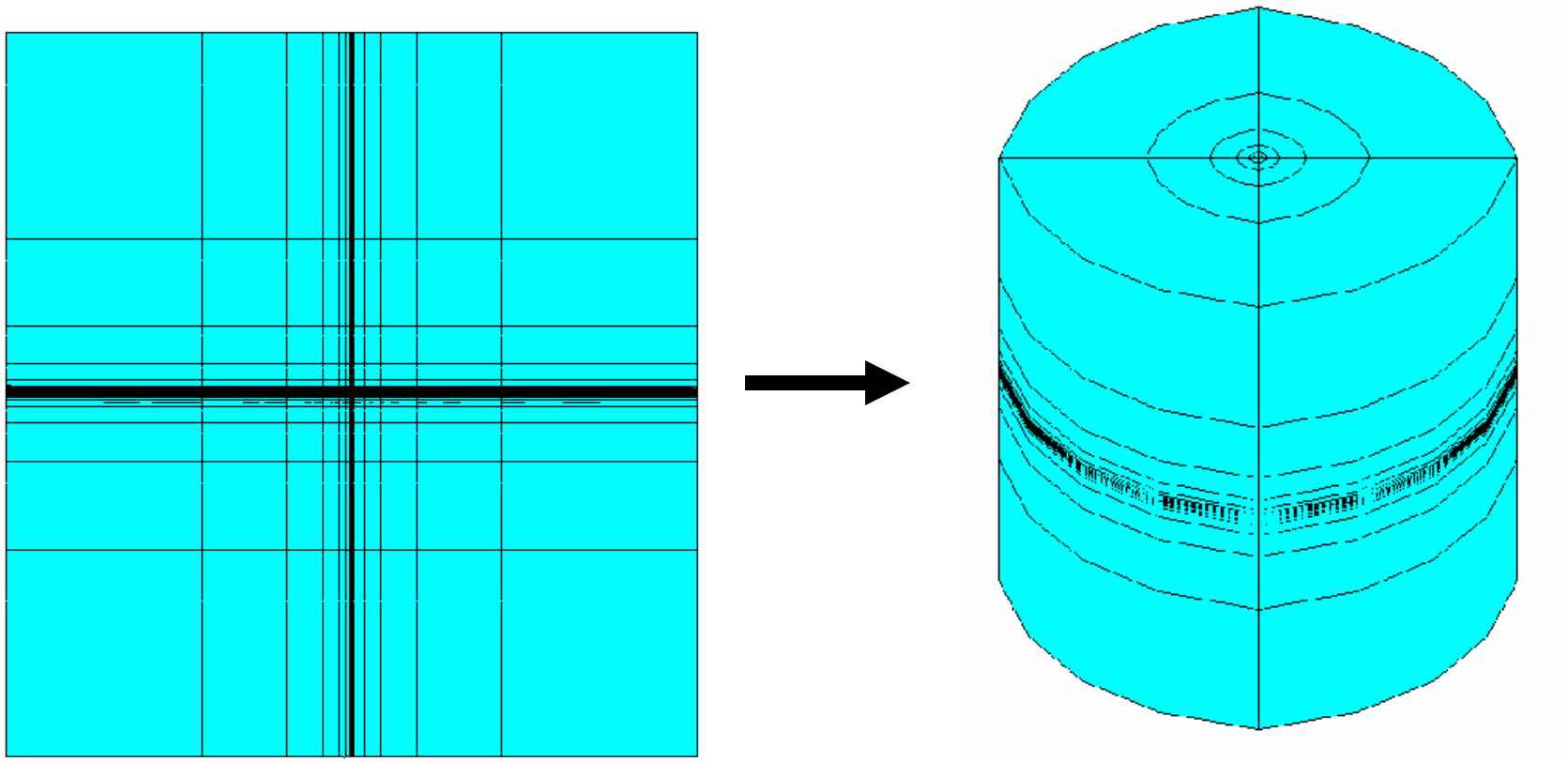



For each logging position, the **Main** component generates distributed **FE mesh** based on the geometry of the domain prescribed in the **Geometry Modeling Package**, and executes the **Parallel multifrontal solver** solving the Poisson equation prescribed in the **Integration** component.

# CE infrastructure

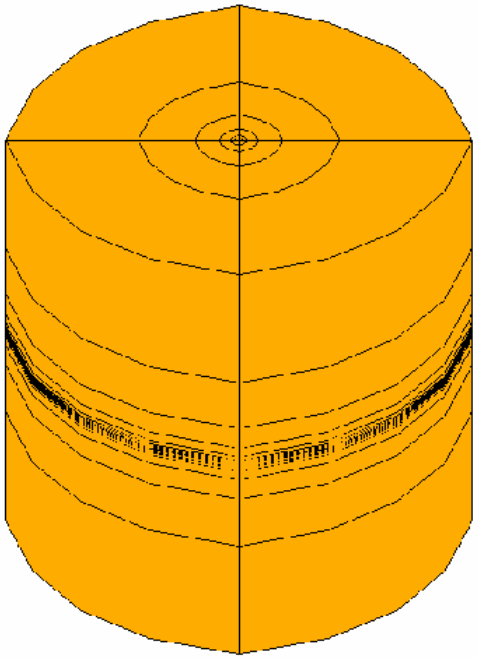


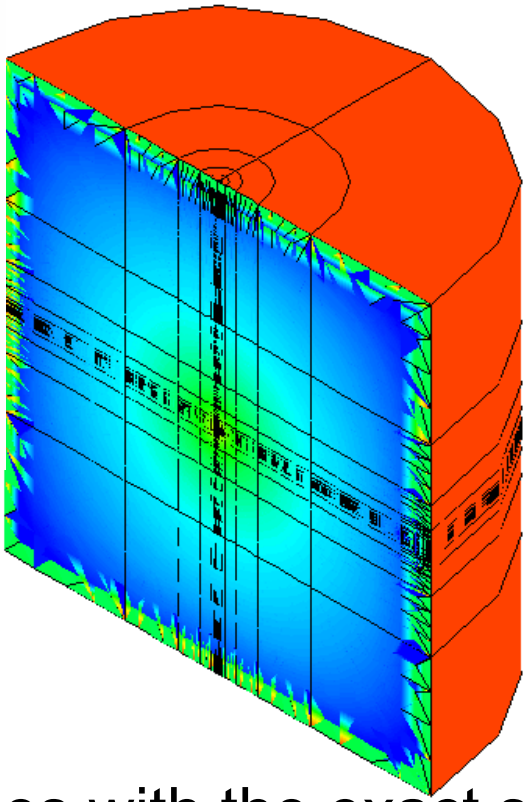
# Application of Parallel 3D Code to Resistivity Logging Simulations

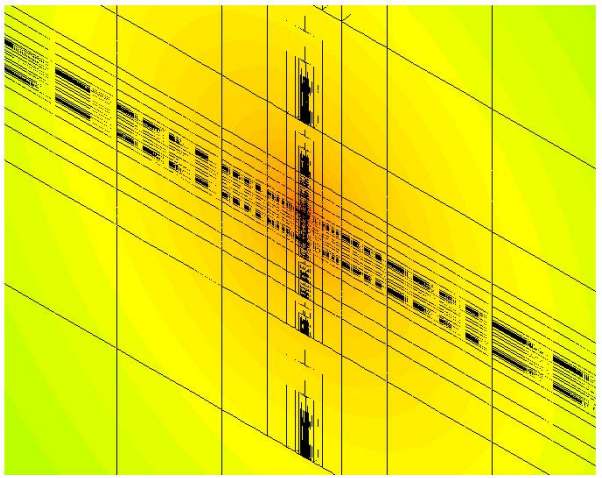


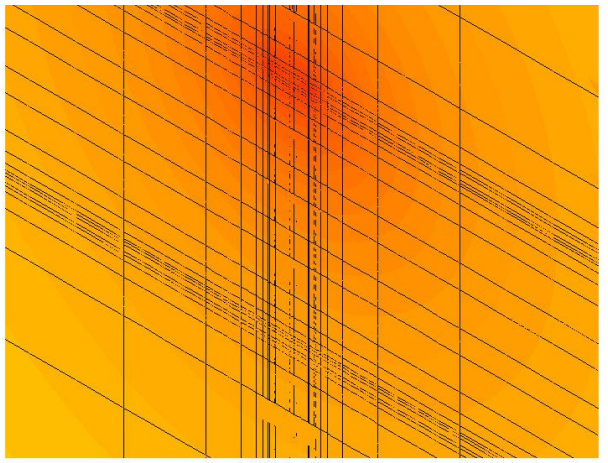
3D Mesh designed “by hand”

# Antenna radiating into a homogenous space. Mesh designed “by hand”.





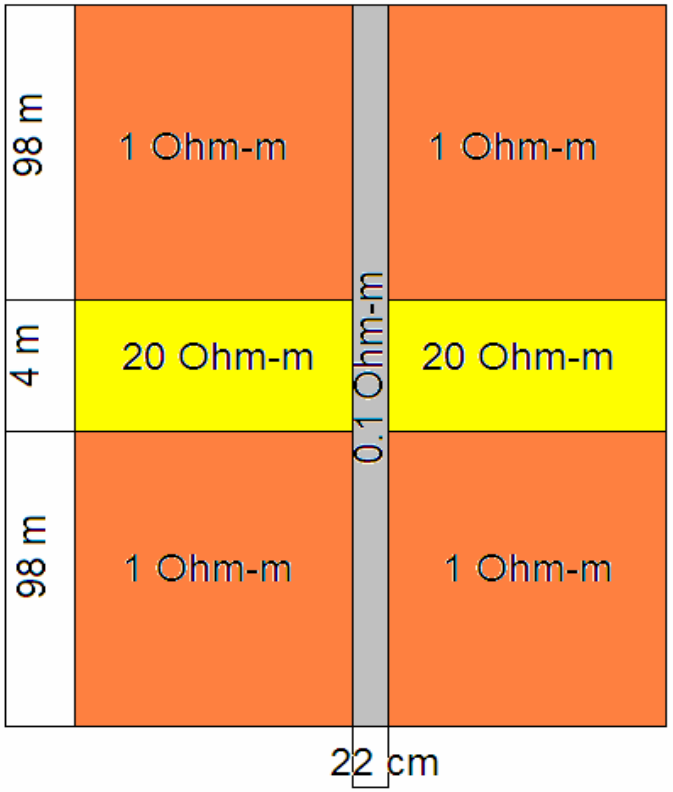


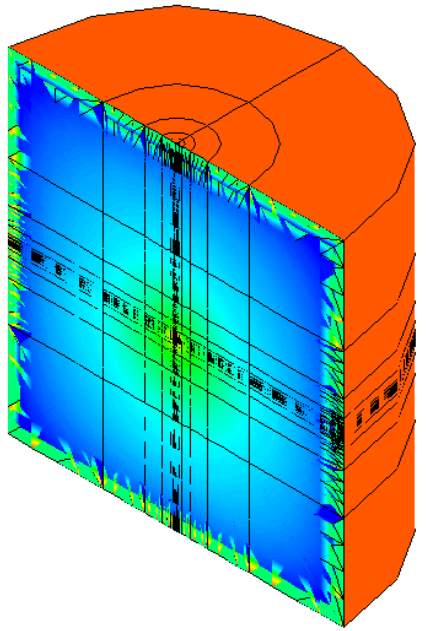


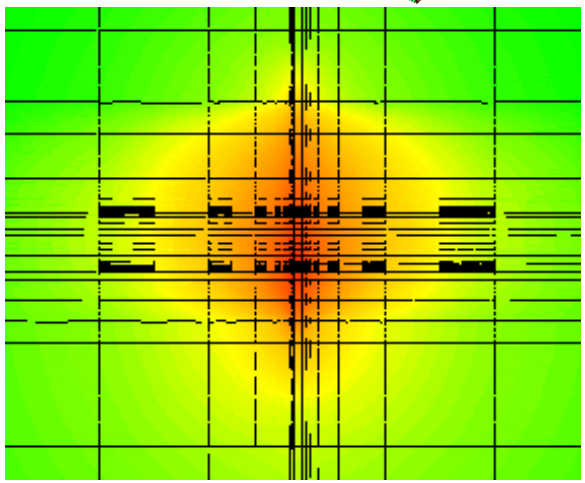
3D solution coincides with the exact solution and with result of 2D goal-oriented code

$$\frac{1}{4\Pi R\sigma}$$

# Axially symmetric layers, mesh designed “by hand”.



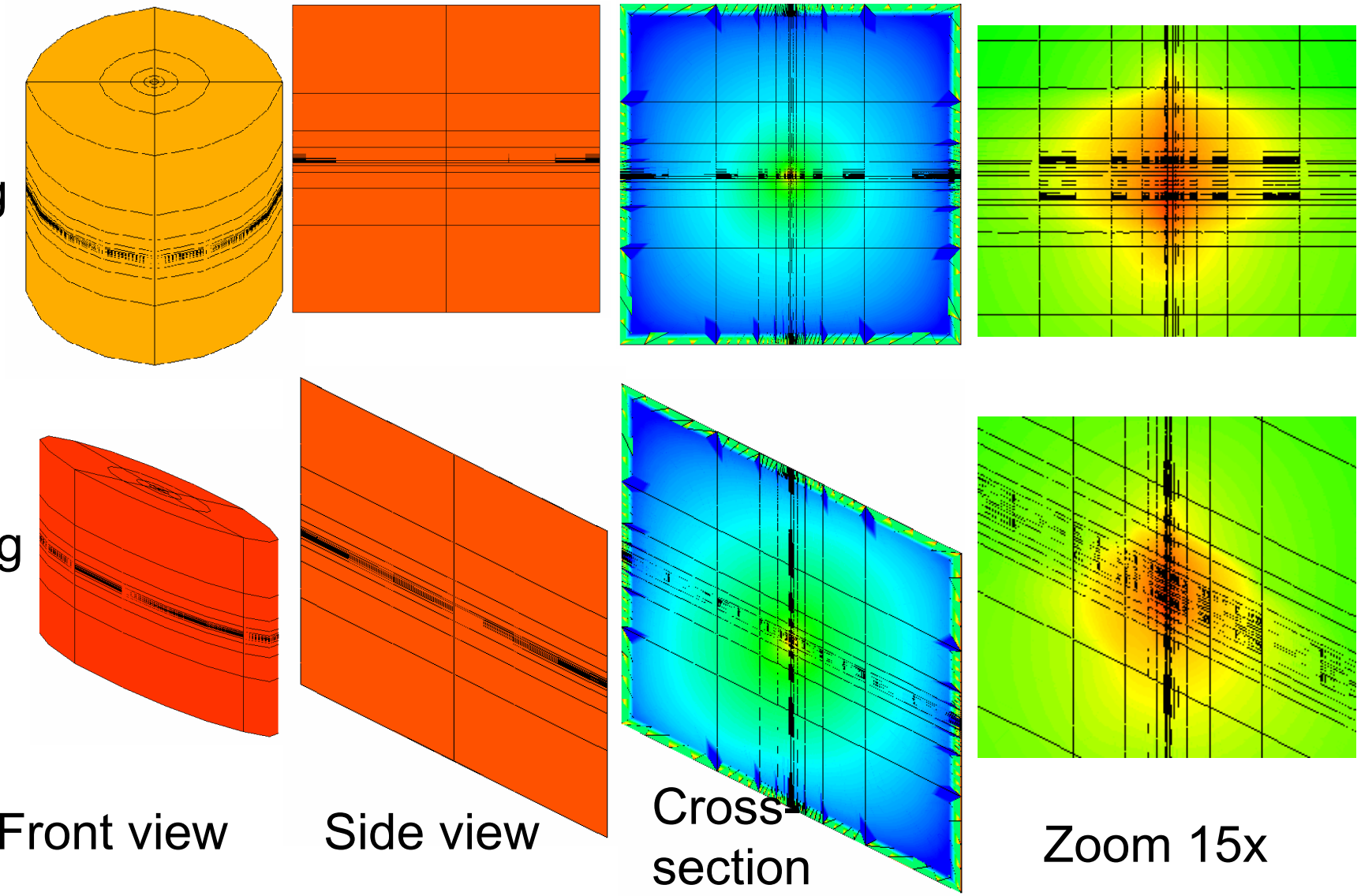


Fixed position of Tx and Rx.

3D Code Result: 1.059

2D Code Result: 1.04

# Full 3D problem for deviated wells.



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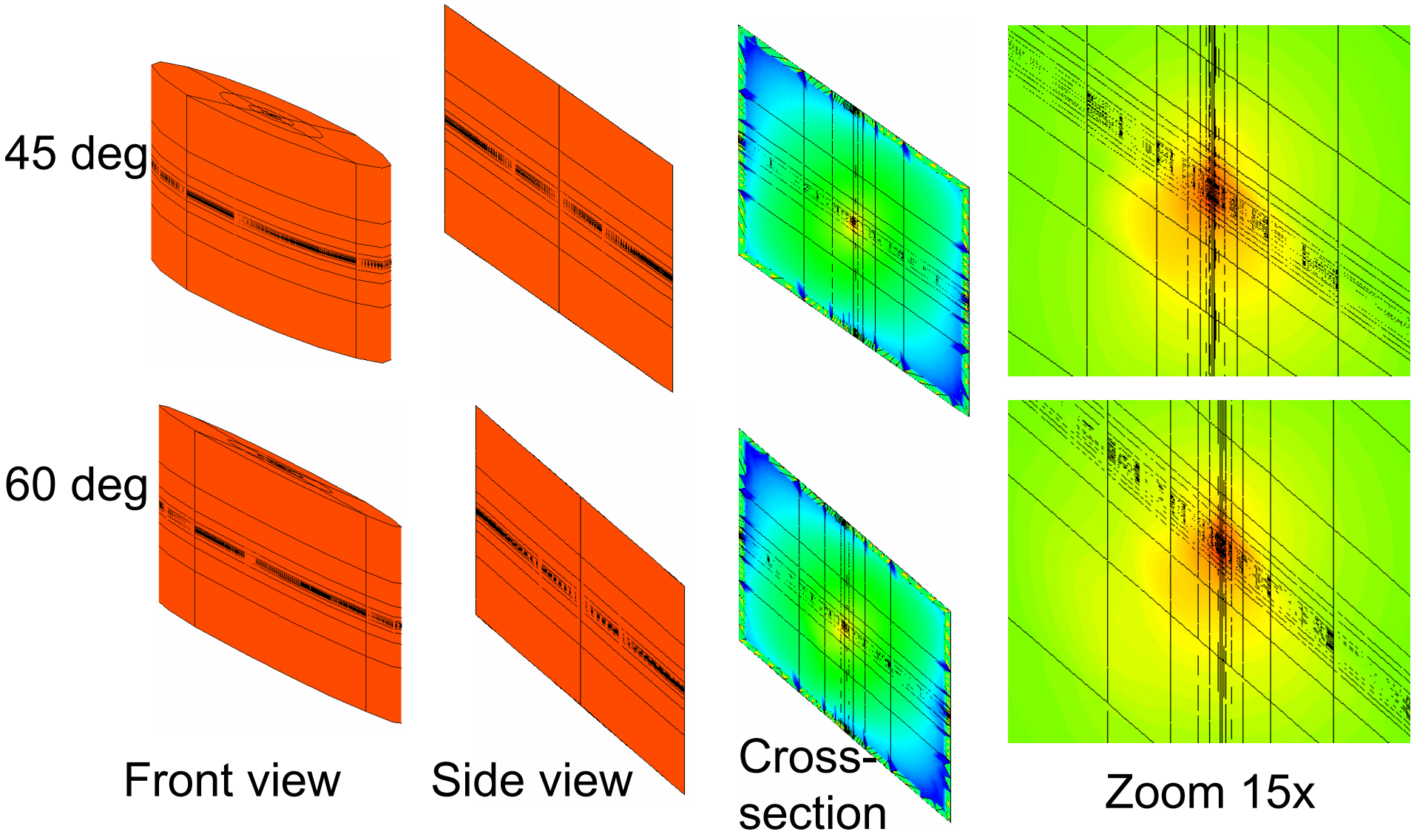

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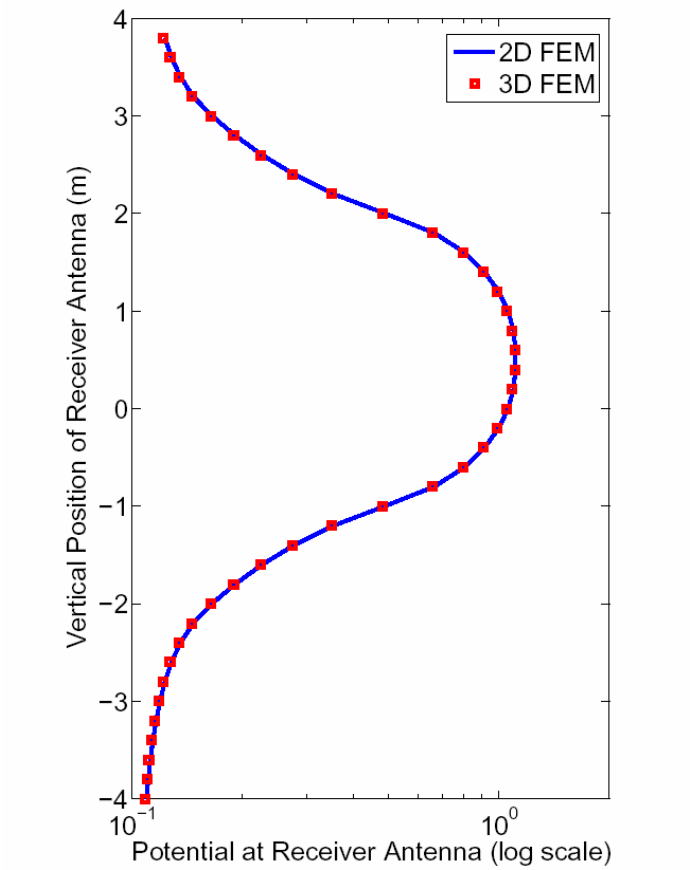
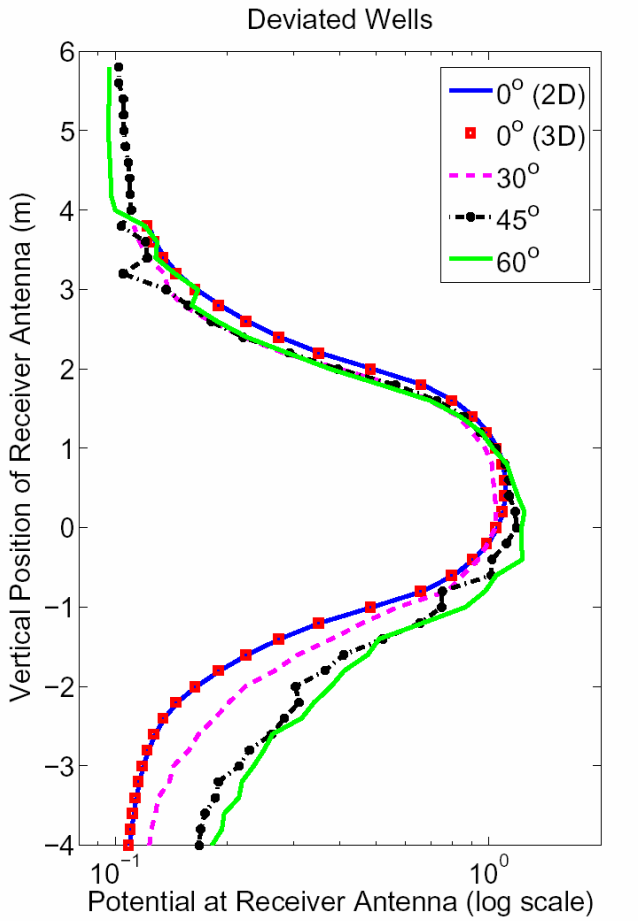



The problem with deviated wells requires introduction of the mesh refinement strategy to minimize the numerical error.

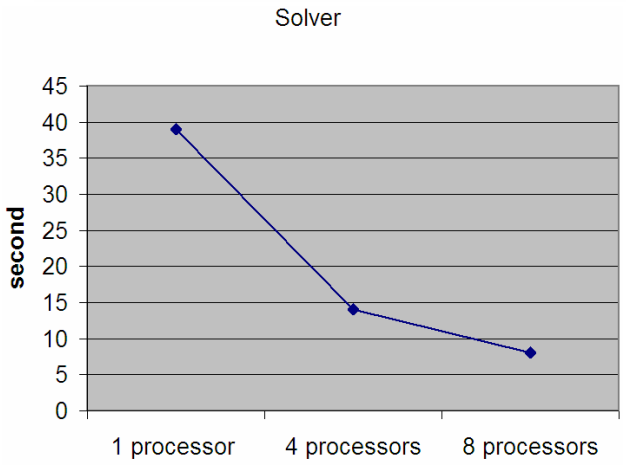
# Parallel performance – same for all above problems

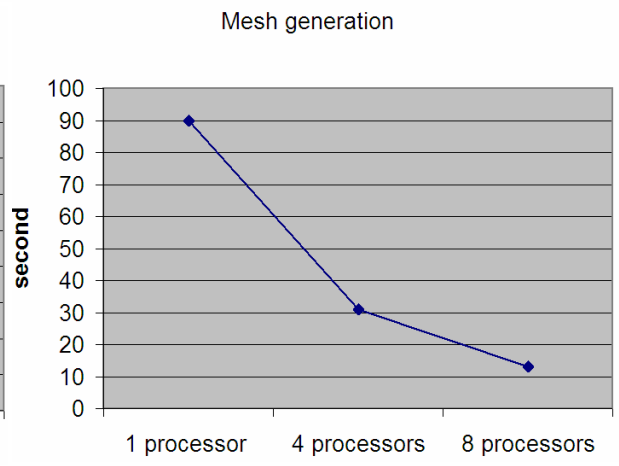
+ 1 master processor

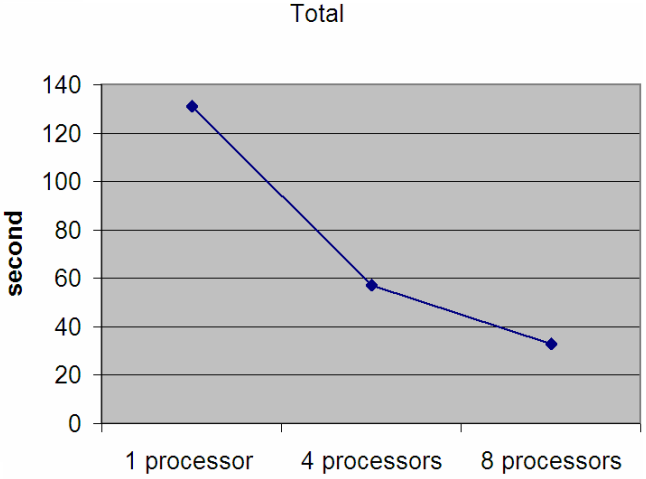
| | 1 processor | 3 processors | 7 processor |
|---|---|---|---|
| Initialization | 12 s | 12 s | 12 s |
| Mesh generation | 90 s | 31 s | 13 s |
| Solver | 39 s | 14 s | 6 s |
| Total | 141 s | 57 s | 31 s |

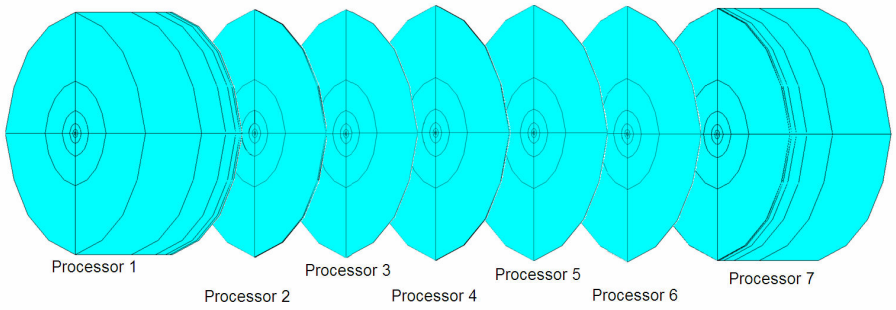
More then 90% relative efficiency

(6.7 times faster by utilizing 7 processors)

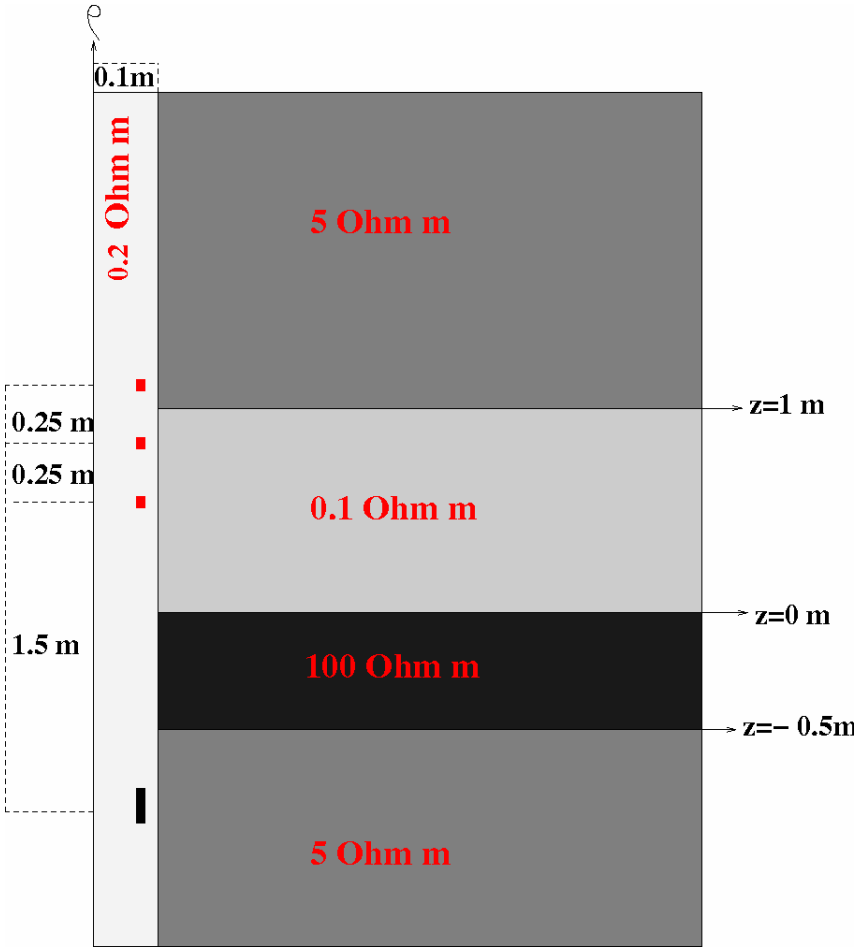


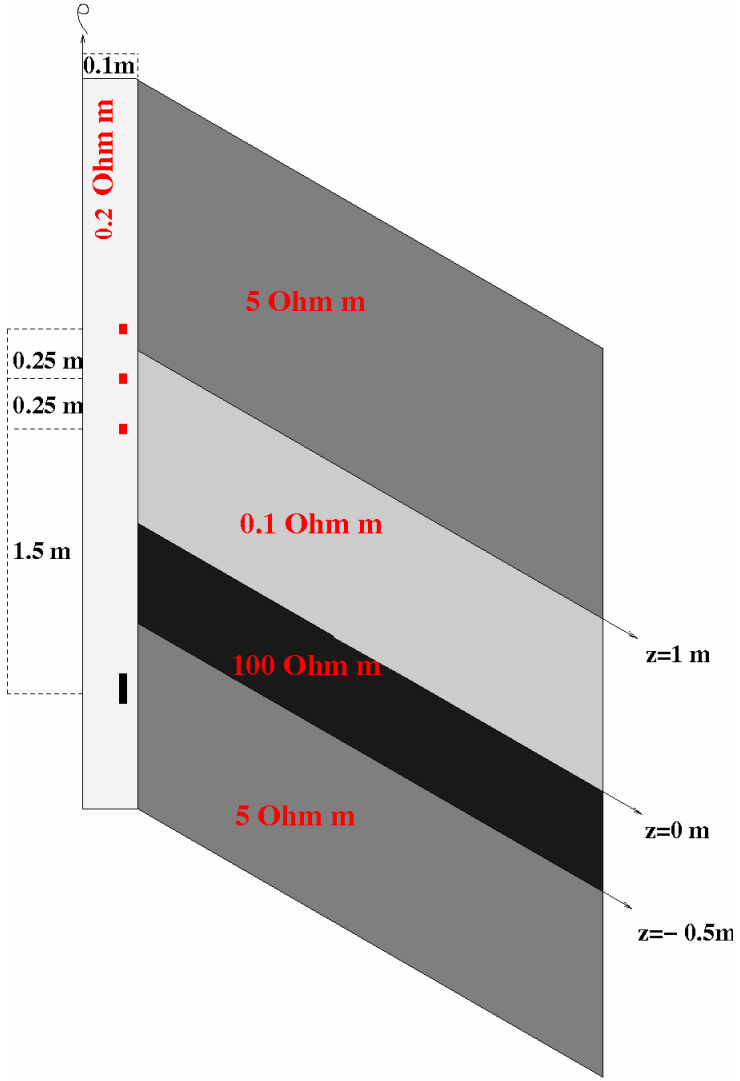



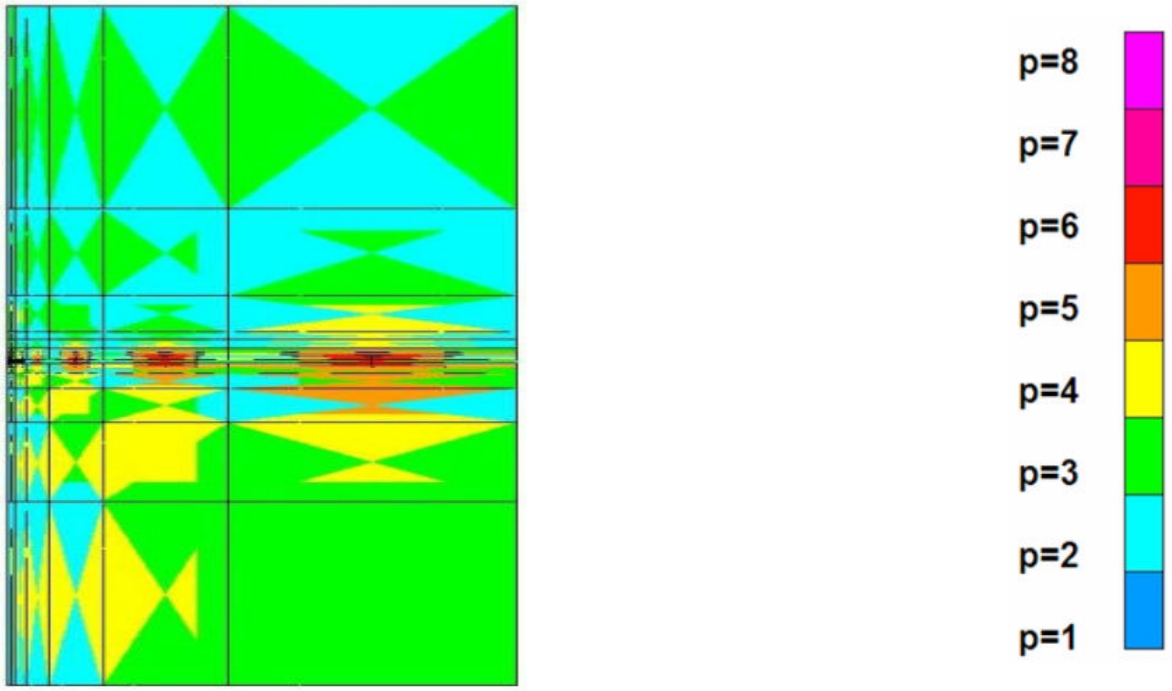



# One transmitter and three receiver antennas
# 2nd differenve of potentials in vertical direction



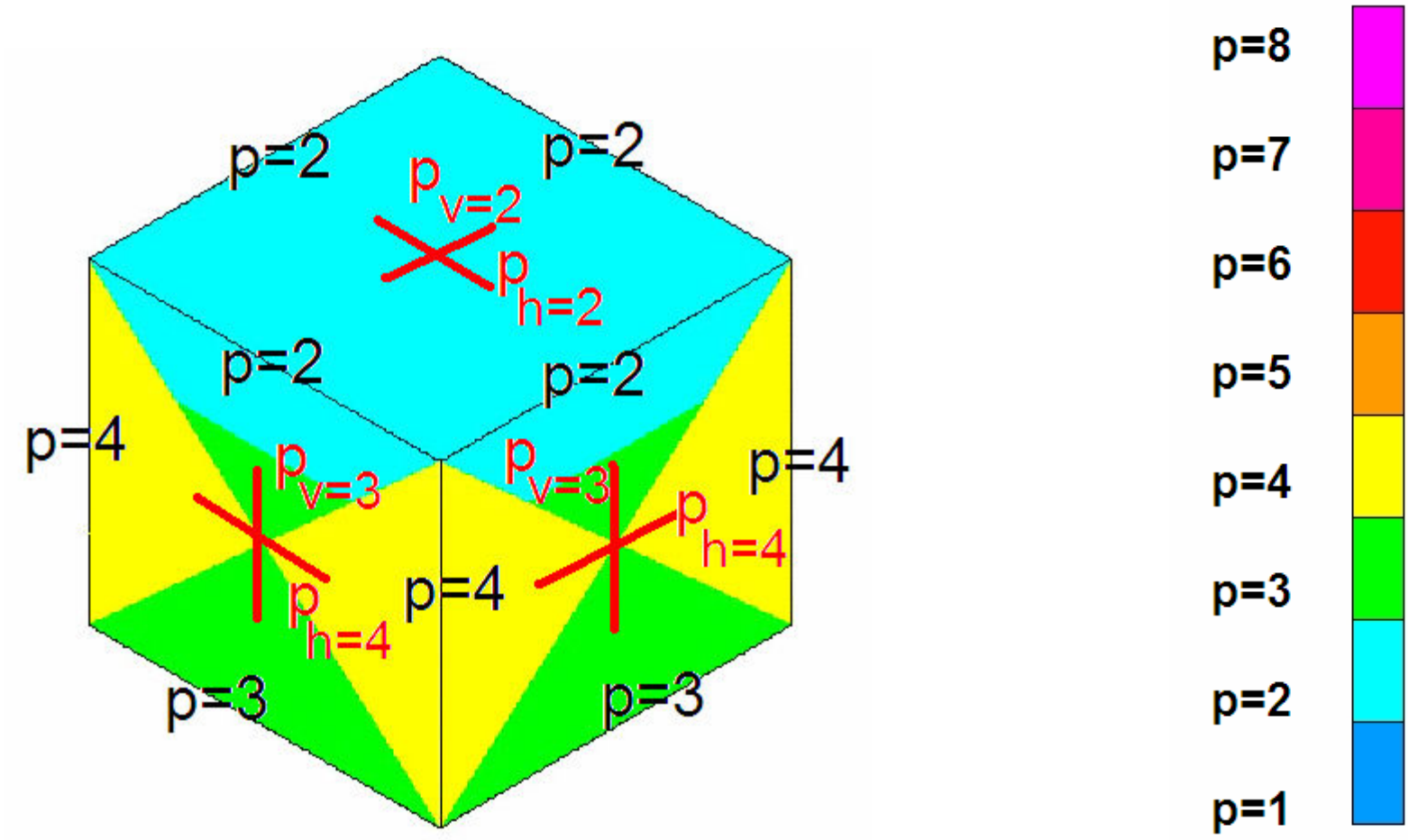
# Generation of the optimal 2D mesh




The optimal *hp* mesh for the axially symmetric problem generated by the 2D self-adaptive goal-oriented ***hp* Finite Element Method** code.

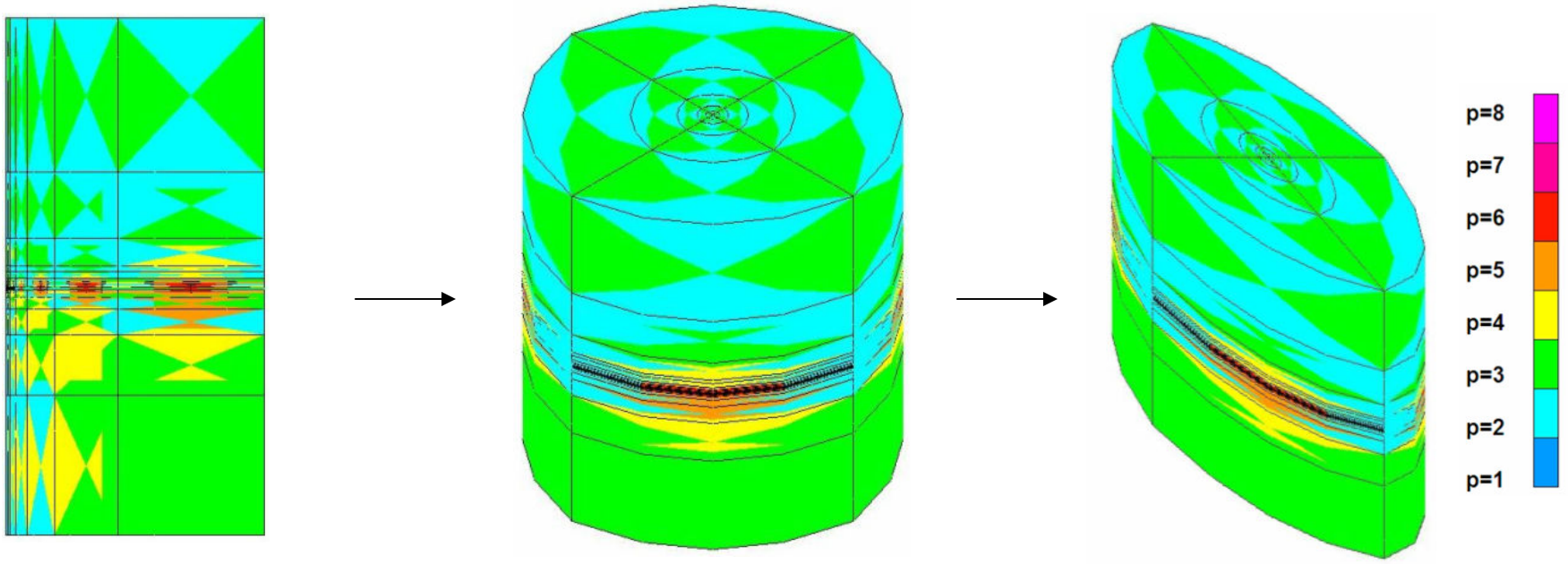
The mesh contains elements with various **size *h*,** and various **polynomial orders of approximation *p*** over finite element edges and interiors.

# *hp* Finite Element




Graphical notation for various polynomial orders of approximation on element edges and faces

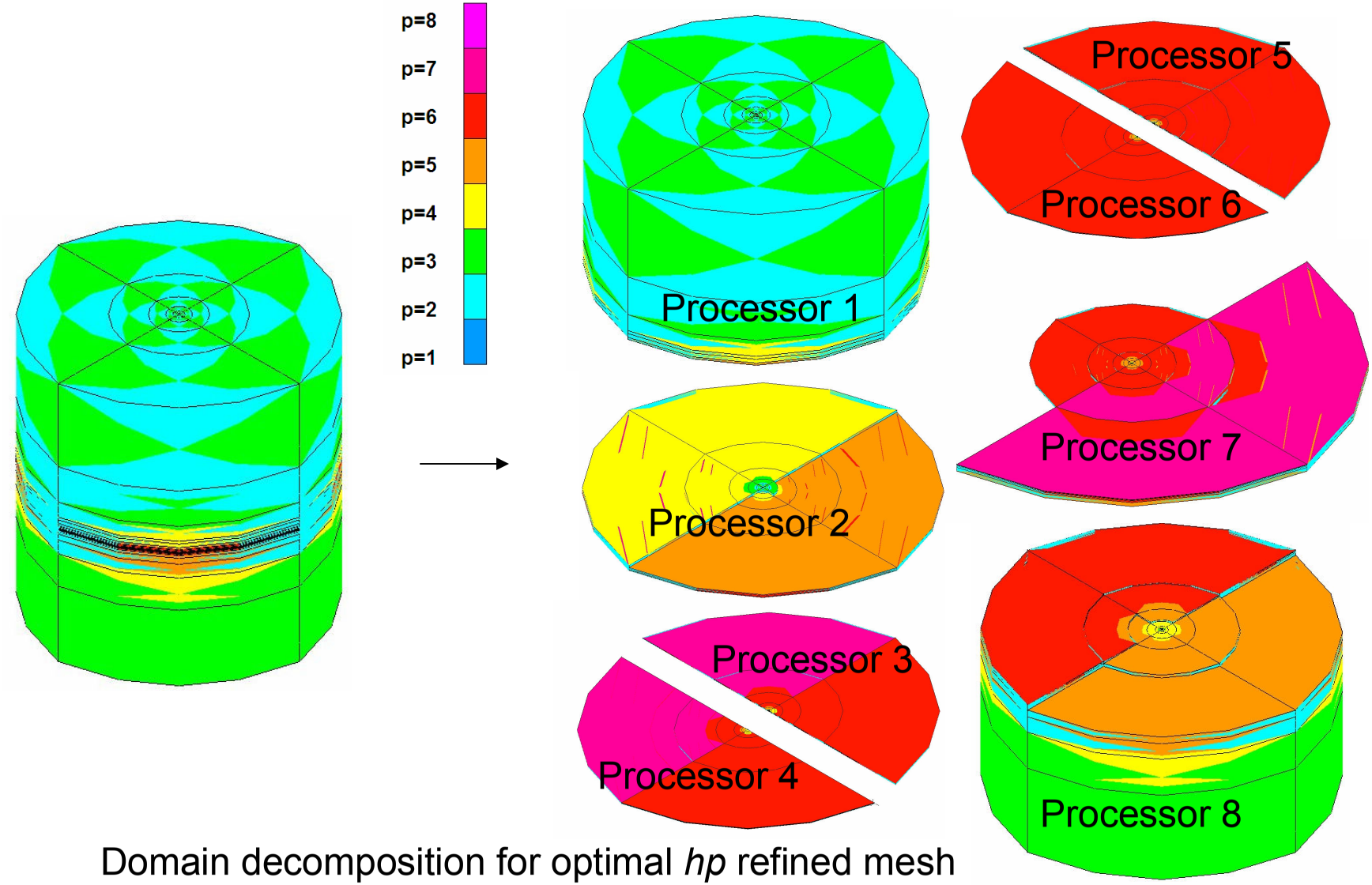
# Transfer of grids




The optimal 2D mesh generated by self-adaptive goal-oriented *hp* adaptive code was transferred into 3D mesh by full revolution of the 2D mesh.

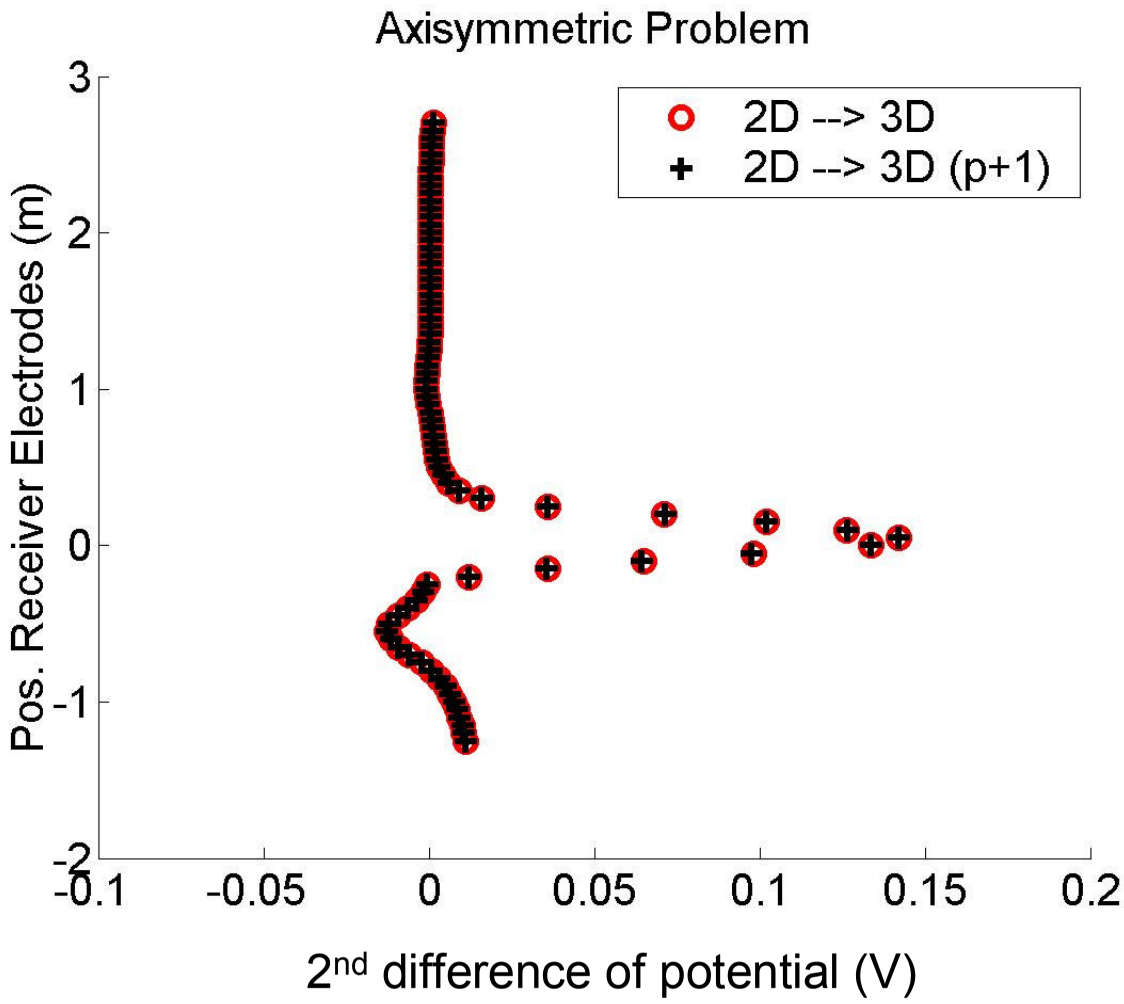
The obtained 3D mesh was tilted by 30, 45 and 60 degrees.

# Results - 2nd difference of potentials in vertical direction

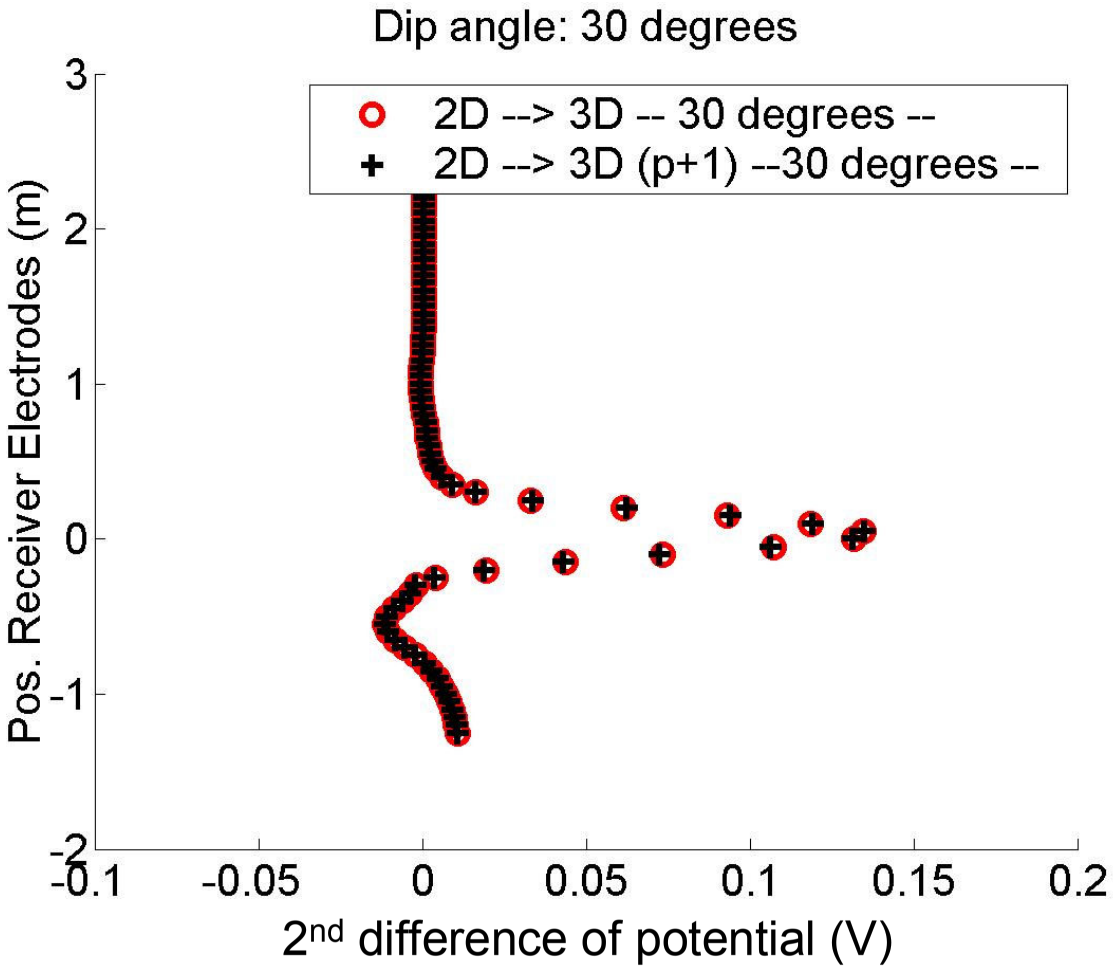



Domain decomposition for optimal *hp* refined mesh

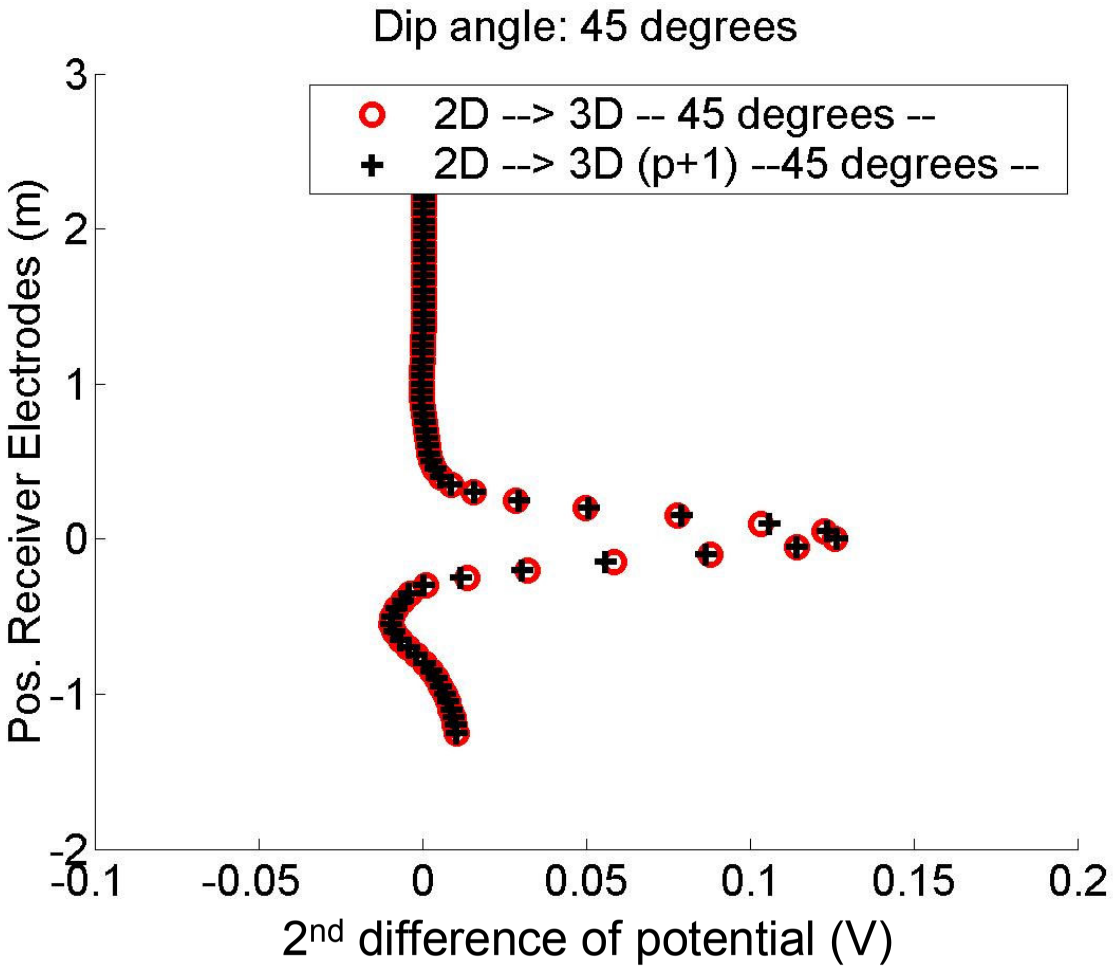
# Results for axisymmetric problem



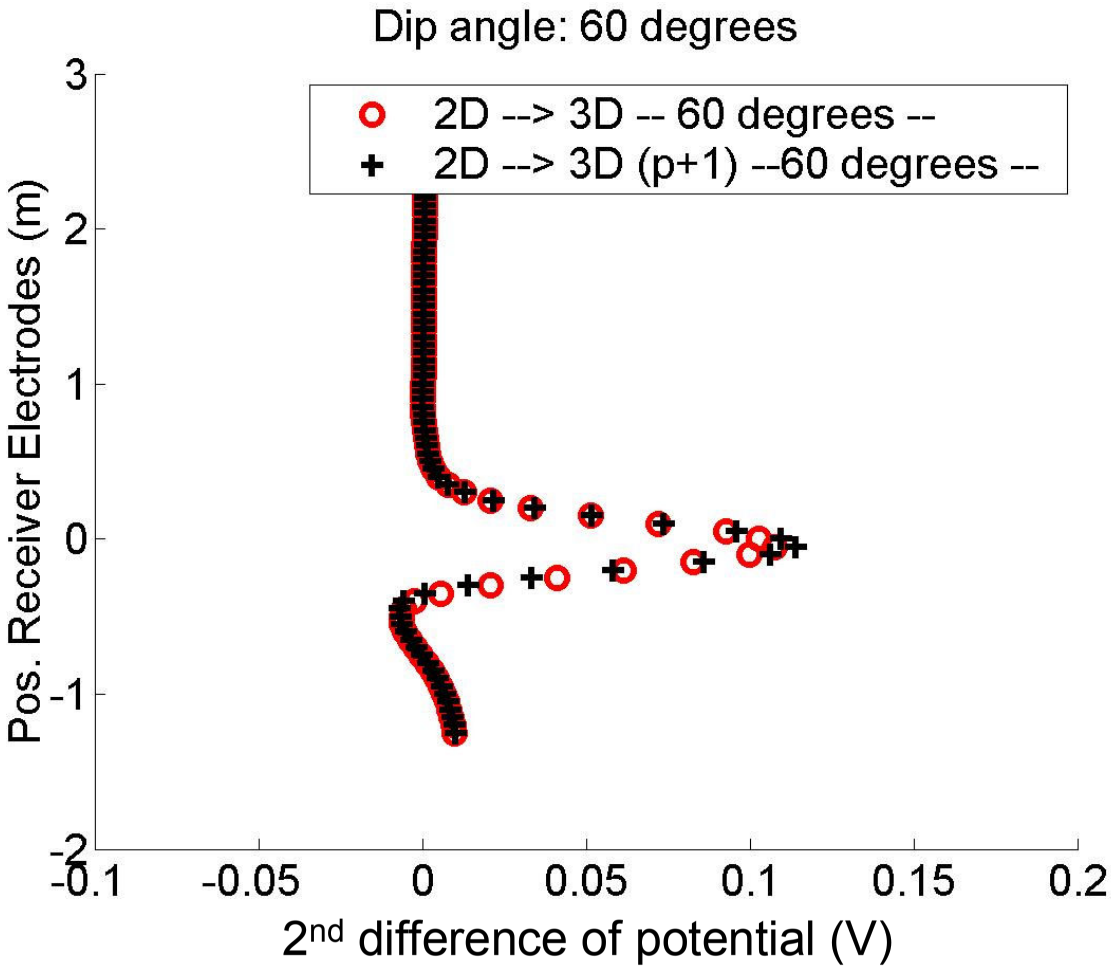
# Results for 30 degrees deviated wells



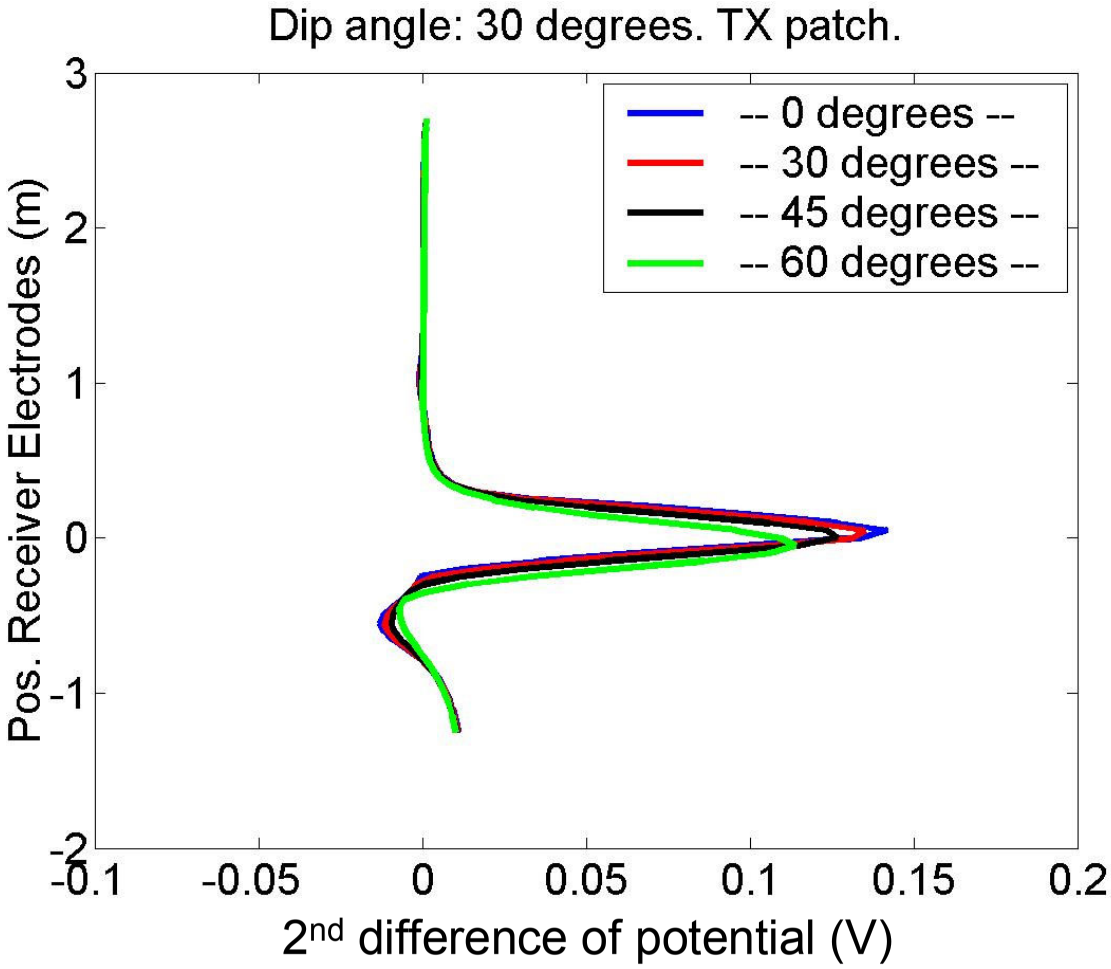
# Results for 45 degrees deviated wells



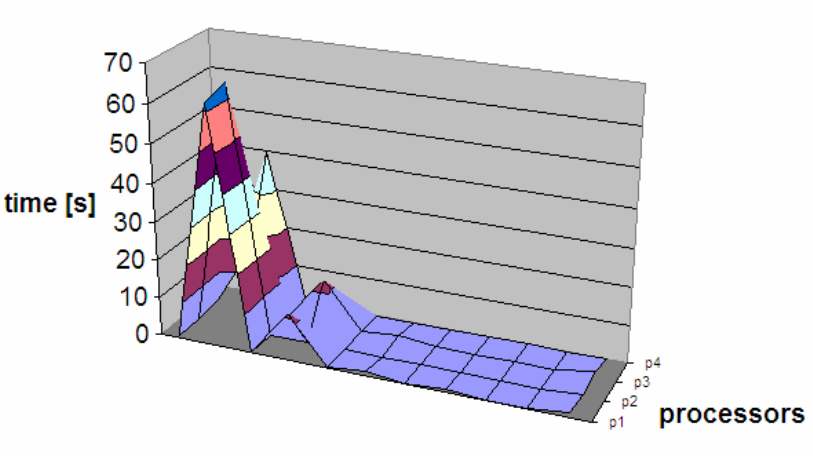
# Results for 60 degrees deviated wells

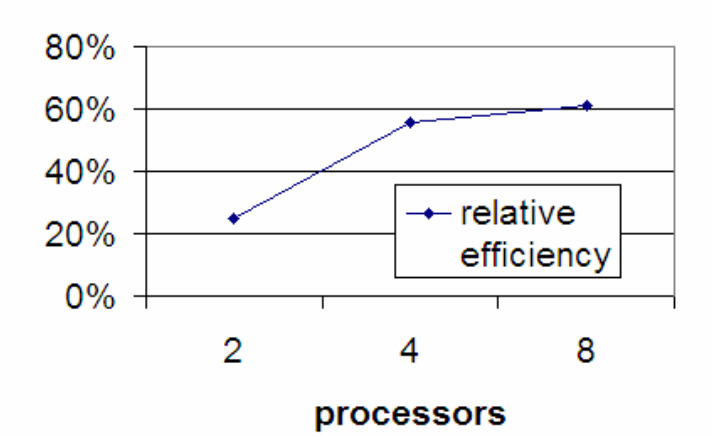


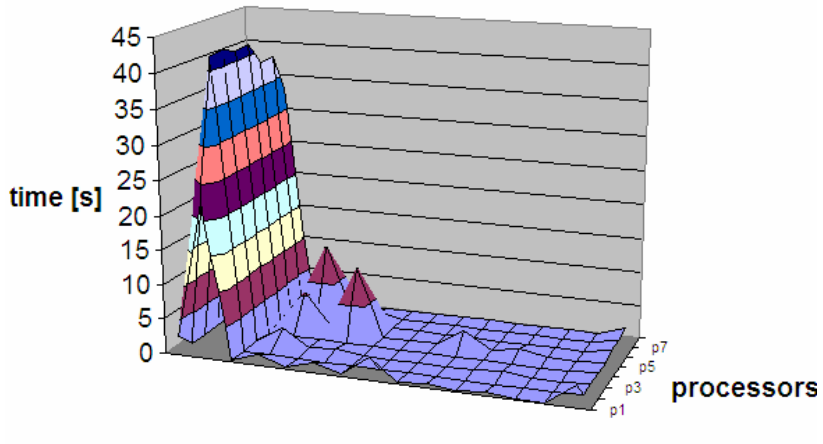
# Comparison of results

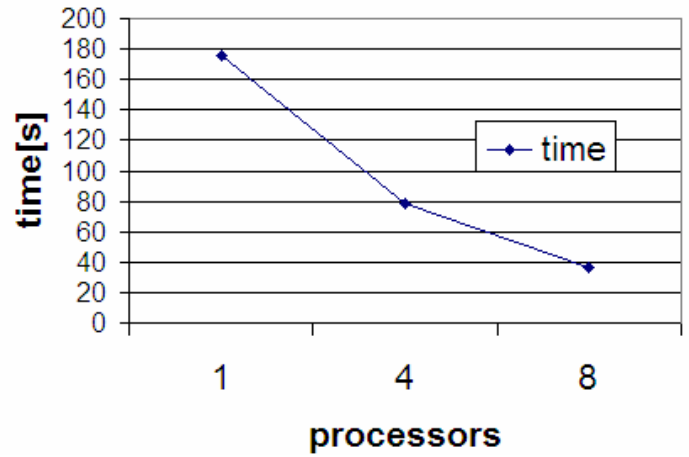


# Efficiency measurements




Problem size: 250 000 d.o.f.

Efficiency measurements of parallel solver executed on 2, 4 and 8 processors

# Conclusions

- CE infrastructure which automatically solves 3D ressistivity measurement problems in a sequence of logging positions in an efficient way has been developed.
- The 3D finite element mesh was obtained by revolution of the 2D optimal mesh produced by the 2D goal-oriented self-adaptive *hp* finite element code, minimizing the numerical error at the receiver antennas.
- The parallel 3D code supports automatic *hp* adaptivity driven by energy norm. The code will be extended to support 3D goal-oriented *hp* adaptivity.
- The future work will include goal-oriented *hp* adaptive computations of 3D problems in deviated wells, possibly with mandrel or casing, and with several layers in the formation. An anisotropy and invasion effects will be also studied.

# Acknowledgments

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