Matching GeoPET data with COMSOL Multiphysics simulation results

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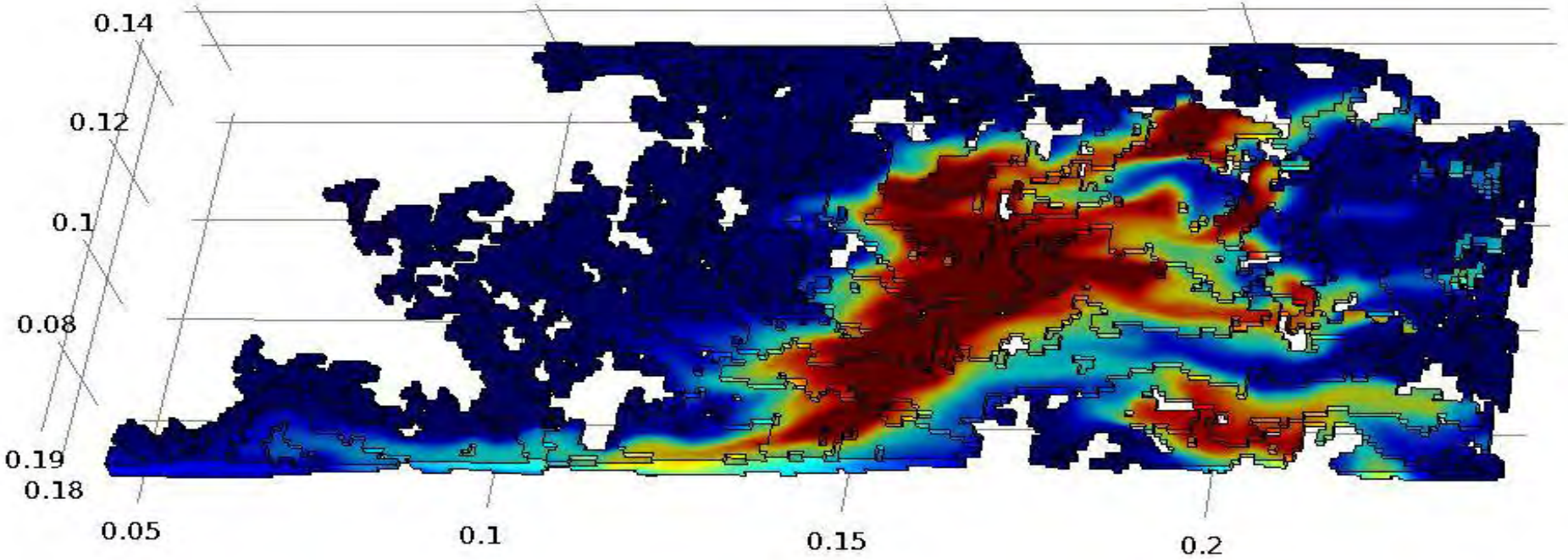
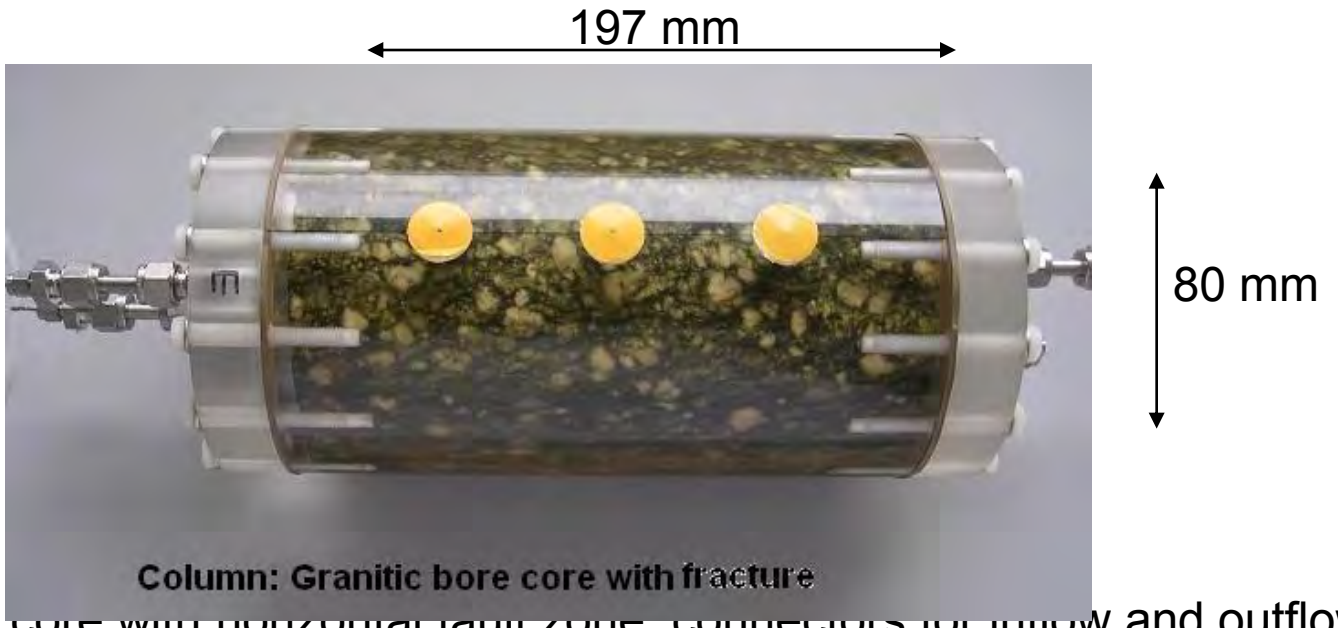


Excerpt from the Proceedings of the 2011 COMSOL Conference in Stuttgart

HZDR

HELMHOLTZ ZENTRUM DRESDEN ROSSENDORF

Materials and Methods



Granitic drill core with horizontal fault zone, connectors for inflow and outflow, plexiglass casing, flow through experiment (0.1ml/min)

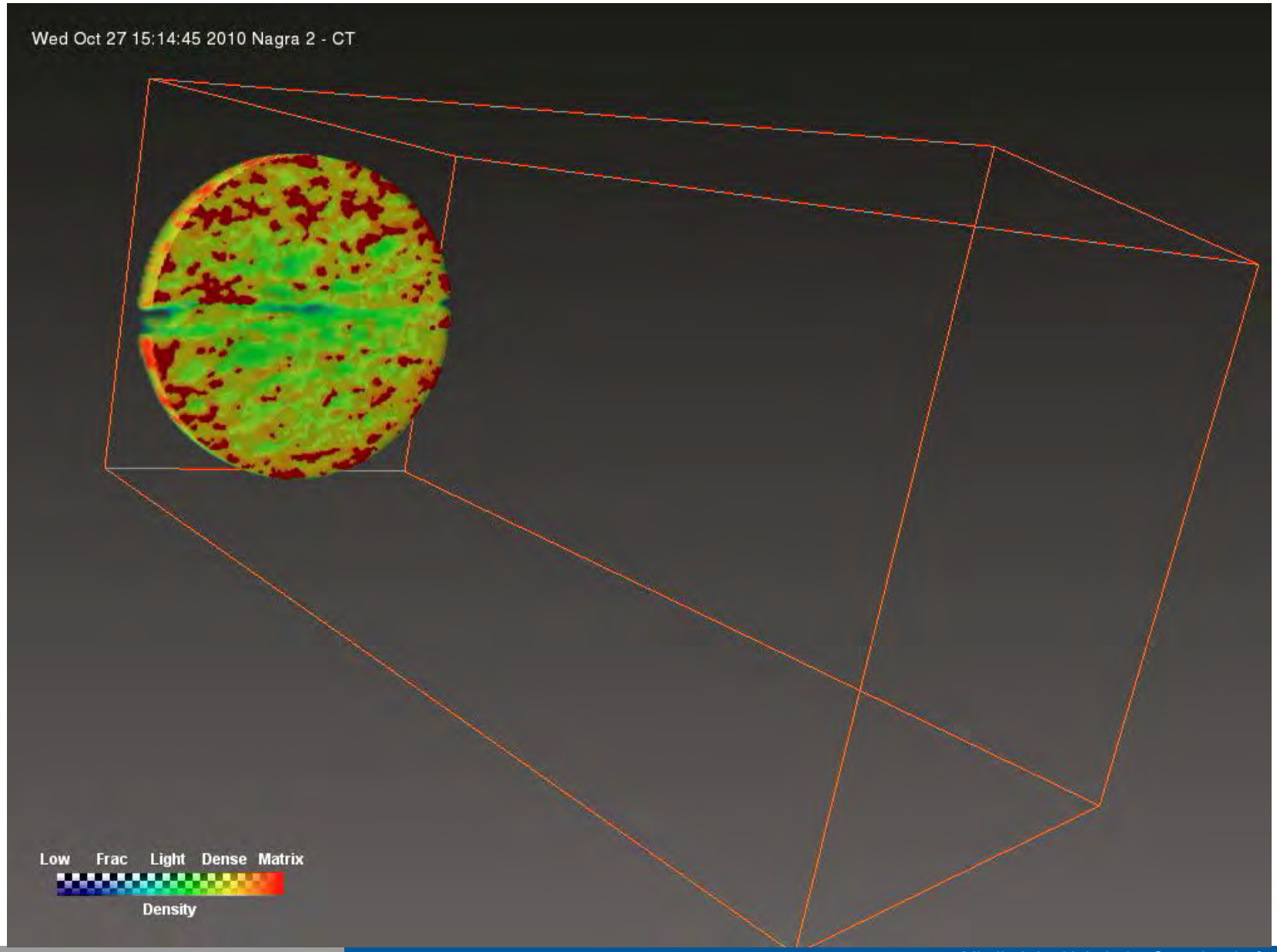
Characterisation of void geometry by means of CT (x-ray tomography)

Process monitoring of fluid flow in dense rock material by means of GeoPET

Simulation of fluid flow in void geometry by means of COMSOL Multiphysics

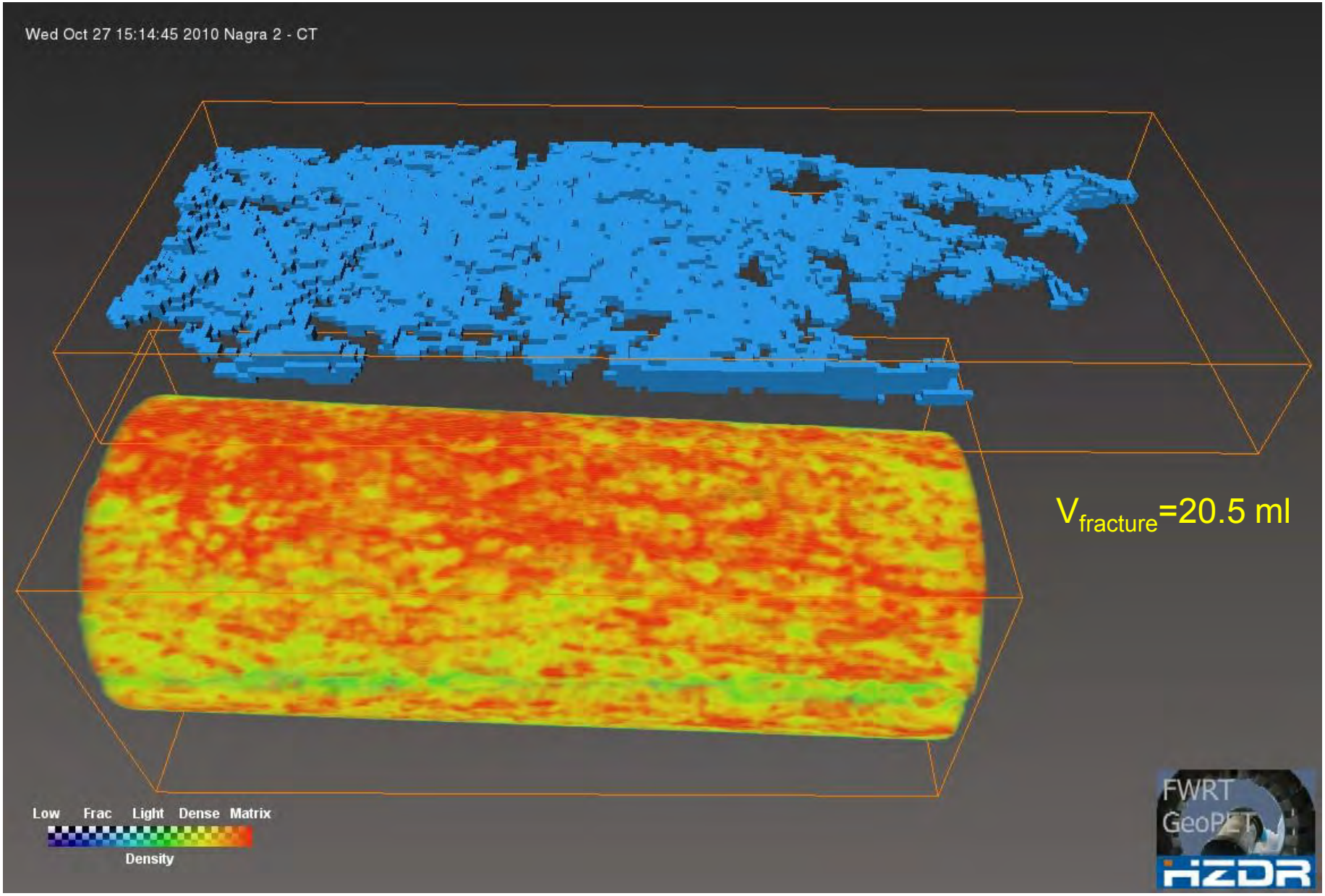
Matching GeoPET data with COMSOL Multiphysics simulation results….

Structural information from CT (beam hardening correction)



PET-CT SIEMENS Biograph16,
Clinic for Nuclear Medicine, Leipzig University, Germany

Building of structure with CT-like resolution (stl-file)

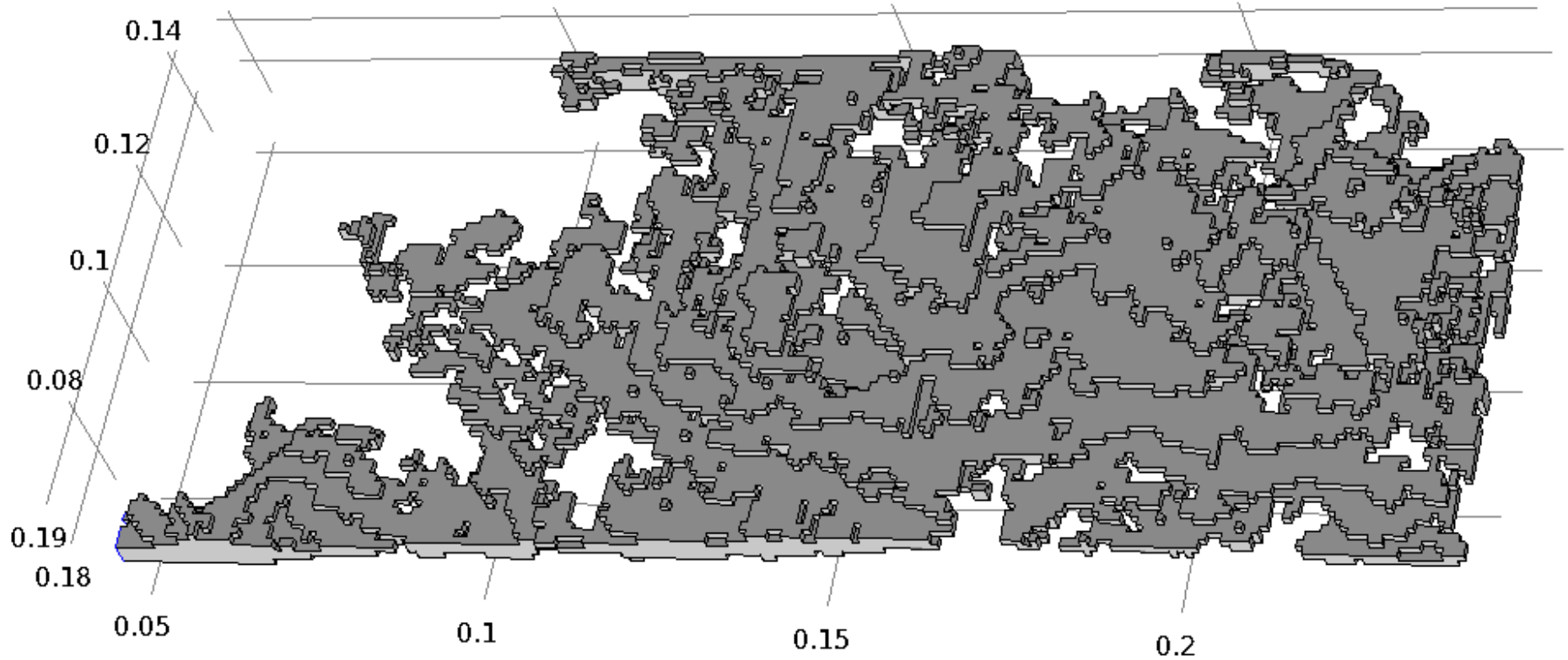


Structure as imported into COMSOL Multiphysics

„lego-structure“ imported to COMSOL:

11 MB *.stl file
converted to solid
scaled (1/1000) m to mm

1 Domain
6.248 Faces
17.629 Edges
11.174 Points

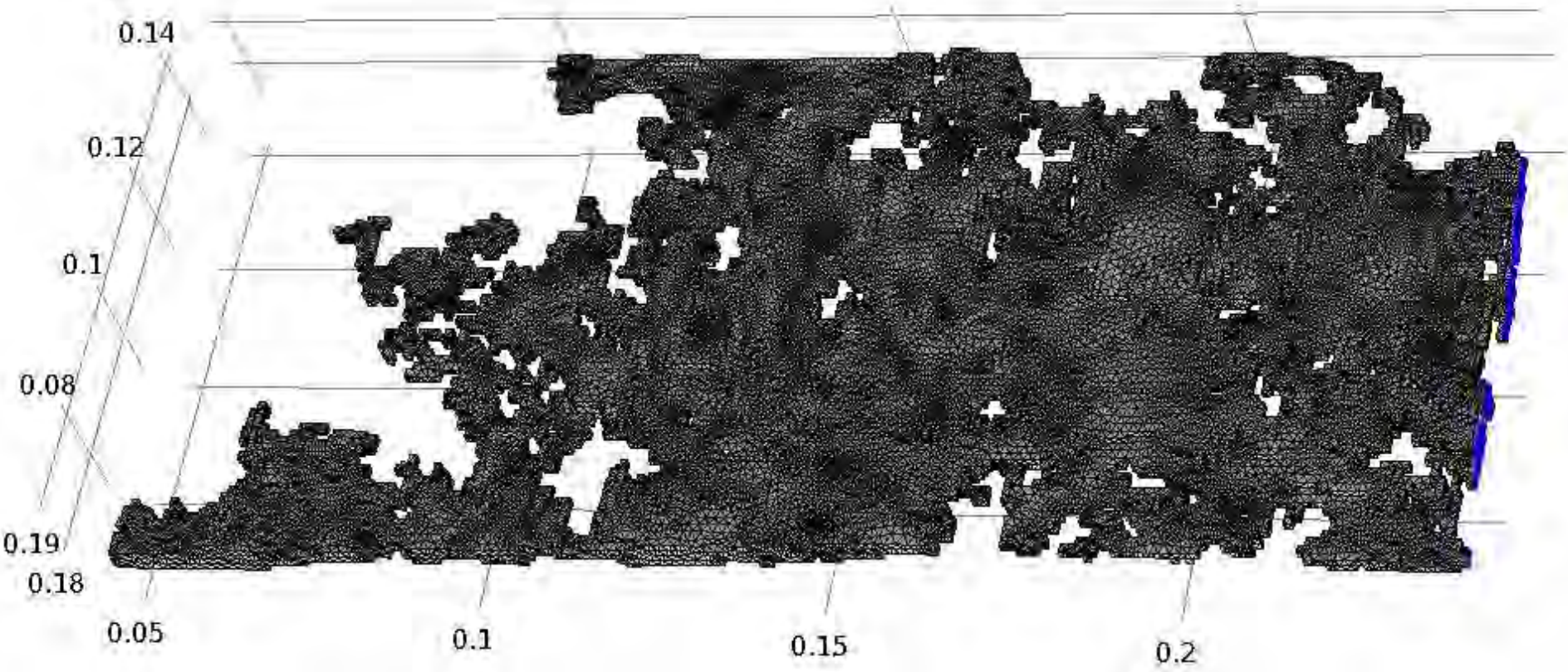


Adding Materials and Physics (Laminar Flow)

- We assign *Water* as material to the domain (volume of about 20 ml)
- First we assign *Laminar flow* (Navier-Stokes, Compressible flow, Ma<0.3) to the domain and solve it stationary.
- We attribute *No slip* walls and initial conditions ($\boldsymbol{u} = 0$, $p_0 = 0$).
- We identify 5 inflow faces ($6.6 \cdot 10^{-5}$ m²) and assign a normal inflow velocity to it ($v_{inflow} = 2.0 \cdot 10^{-4}$ m/s).
- We identify 2 outflow faces (area = $8{,}2 \cdot 10^{-6}$m²) and assign a pressure ($p = 0$) to it.
- Therewith the experimental conditions are well represented by the model.

Meshing: user-controlled sequence, element size calibrated for fluid dynamics, *normal* size, free tetrahedral

➔ ~370,000 elements

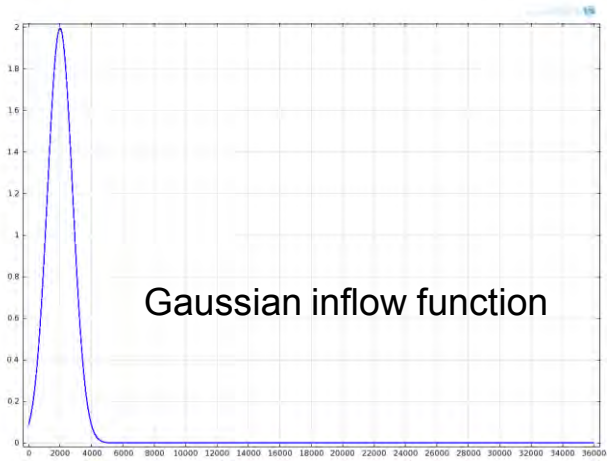


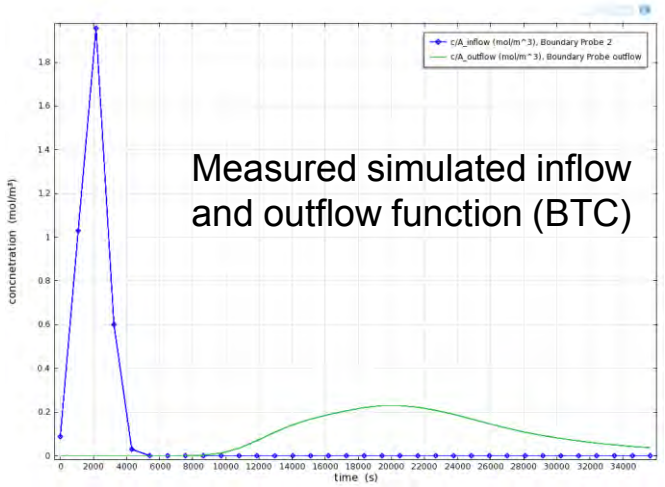
GMRES solver for stationary problem

- The stationary flow and pressure field is solved by the GMRES solver in less than four minutes.

Adding Physics (Transport of diluted species) and solving again

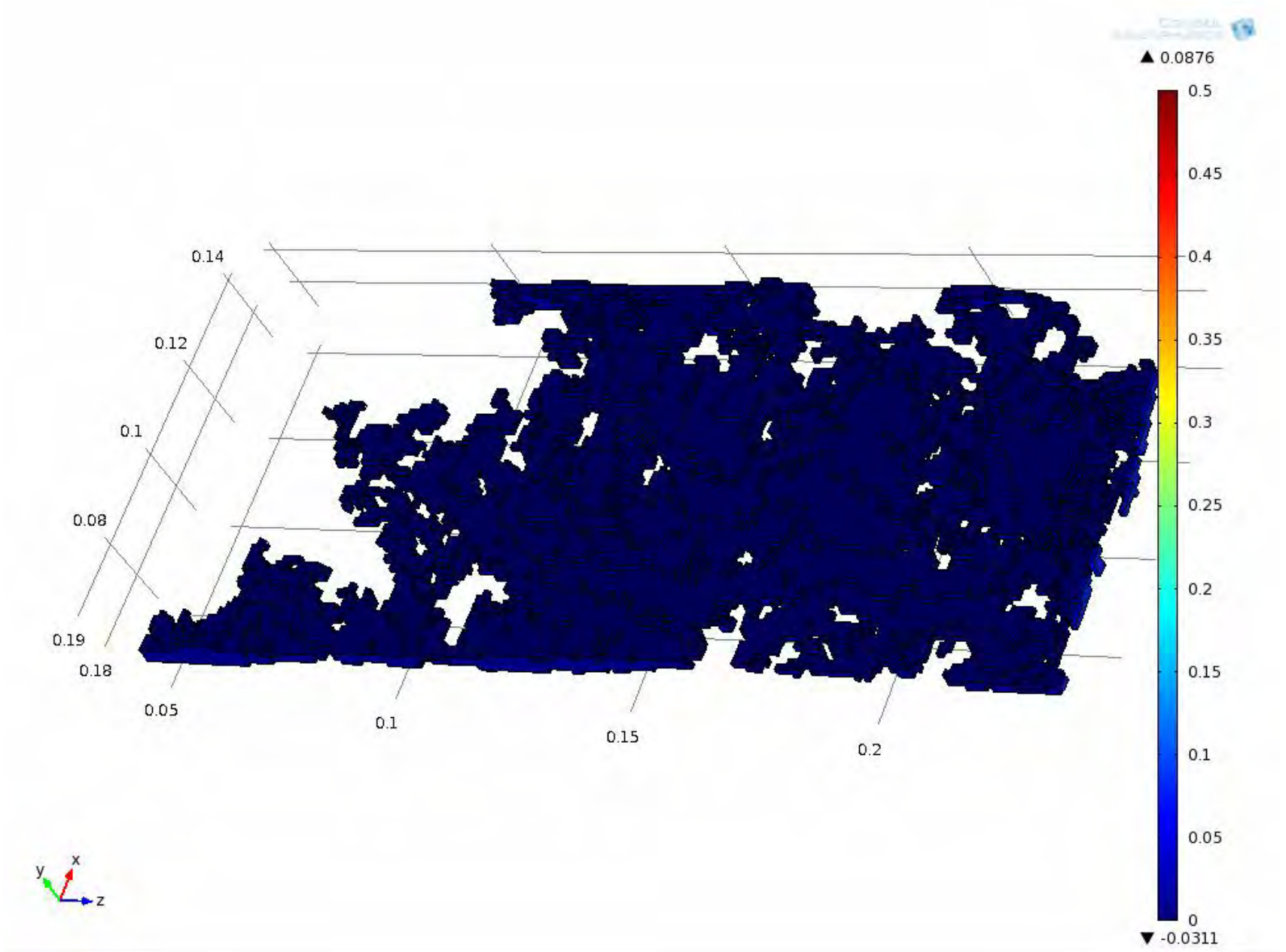
- We add *Transport of a diluted species* (Convection and Diffusion, no reaction) with a Gaussian concentration-input function (standard deviation ~14 min at t = 30 min) for simulating our time dependent experiment. This computing time amounts to additional 23 minutes.



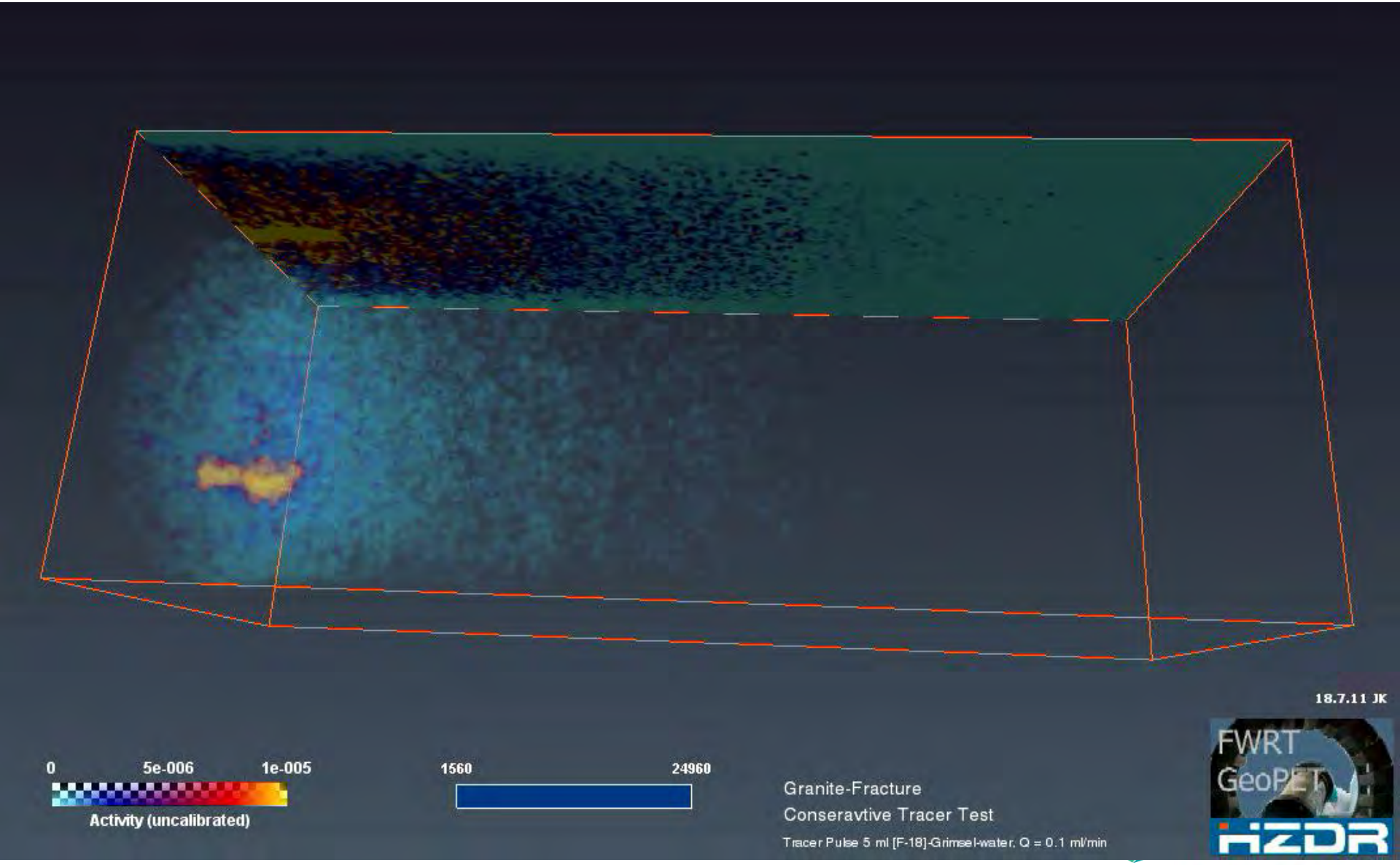


- We obtain 4D simulation results covering 10 hours with 10 min resolution

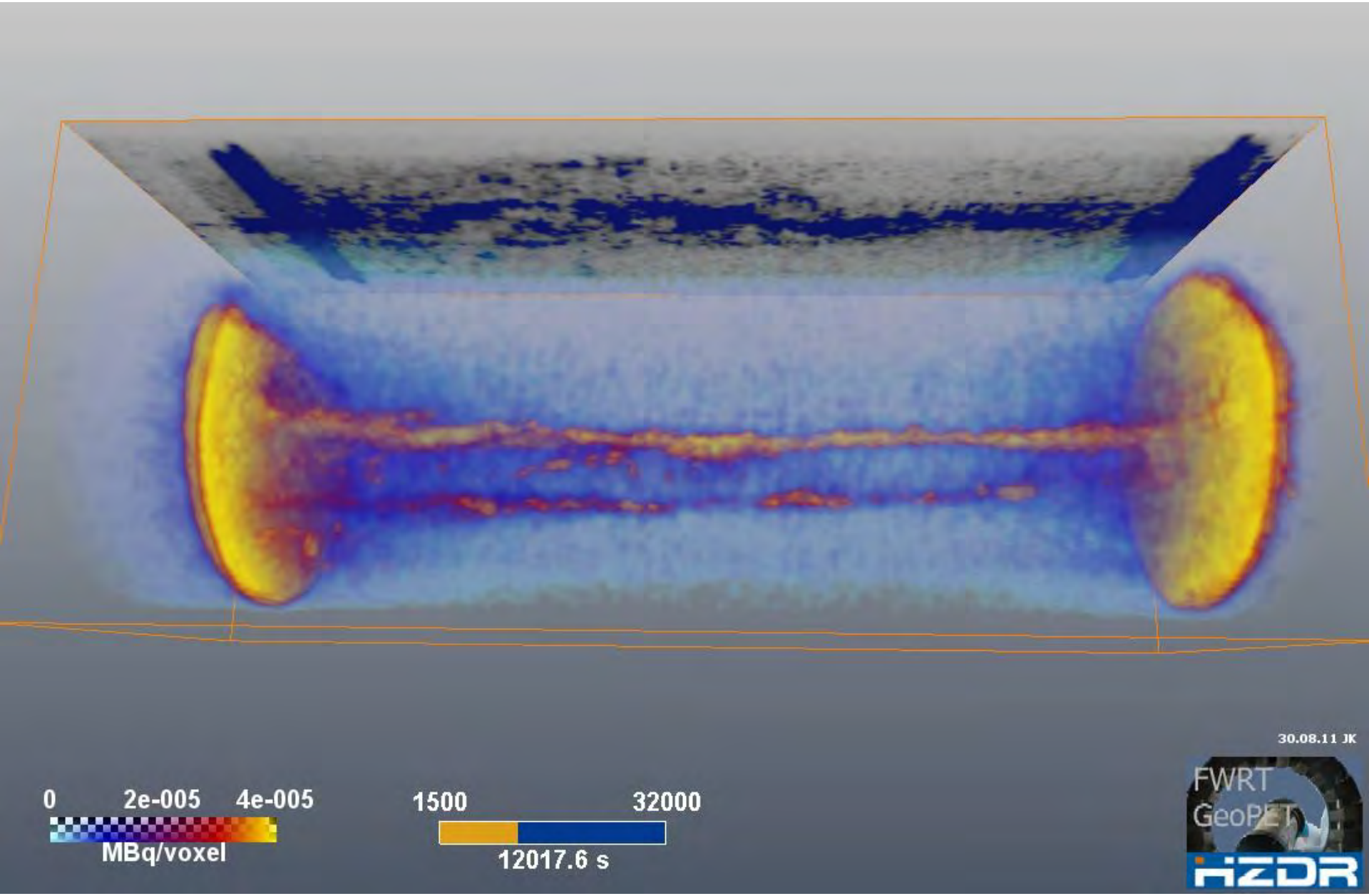
Results of the simulation: 10 hours with 10 min resolution



Real GeoPET flow monitoring:
Radiotracer solution passes through granitic core

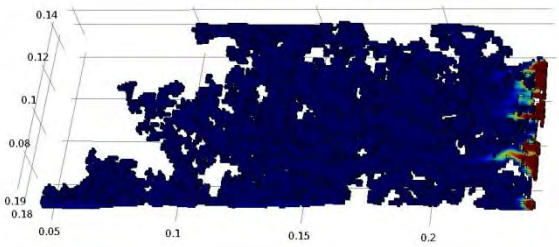


Still: 3 h or 15 ml (Tracerpuls 5 ml)

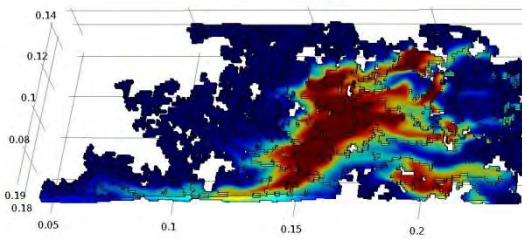


Matching BTC from COMSOL and GeoPET-Monitoring

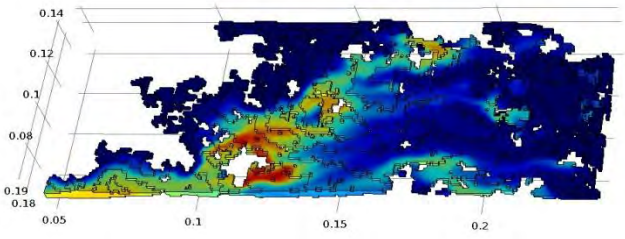
20 min

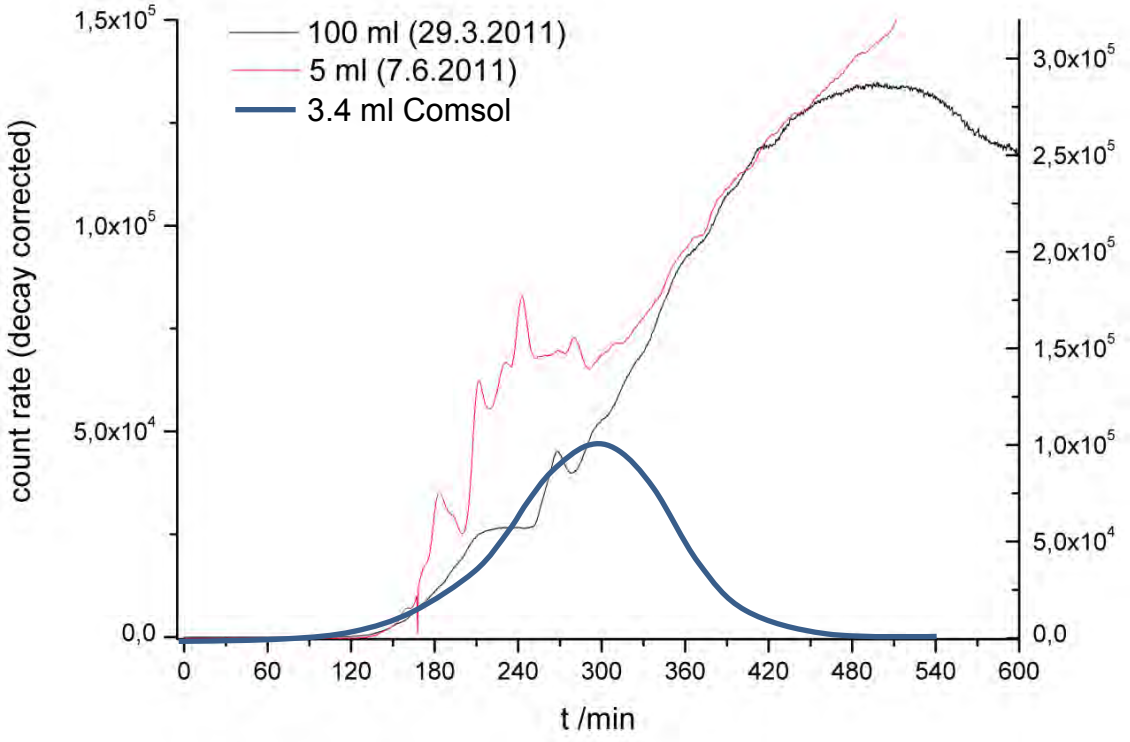


180 min



310 min





- GeoPET experiments with different volumes of tracer solution
- After 450 min uncertainties are very large (decay)
- flow rates: 0.1 ml/min
- A first comparison of the experimental (thin lines) and simulated BTC (thick line) returns a reasonable match.

Conclusion:

- All necessary methods and techniques for matching GeoPET data with CT-flow&transport simulation data are available/ skills are acquired.
- BTC-matching is good, but does not profit from available 4D information!
- Matching by eye: The simulated results do not realistically reflect the observed flow and transport process in the fractured granitic rock.
  ➔ This is due to “unrealistic” geometry of fracture.
- Refining the geometry on the basis of **higher resolution CT** measurements will help approaching better matches between simulated and measured 4D data sets of flow and transport in heterogeneous geological media. *But smart CT-data reduction then poses a* new *challenge to us.*

Outlook:

- Acquiring higher and higher resolutions is NOT generally the way to go.
- We aim at developing algorithms for **flow pattern identification**, parameterisation of **pattern evolution** and **pattern tracking**. This might allow for quantitative **similarity studies** of 4D flow and transport processes.
- Once smart-simplified geometries produce realistic flow patterns, coupled reactive processes might be added – capturing the relevant processes ruling on the field scale.

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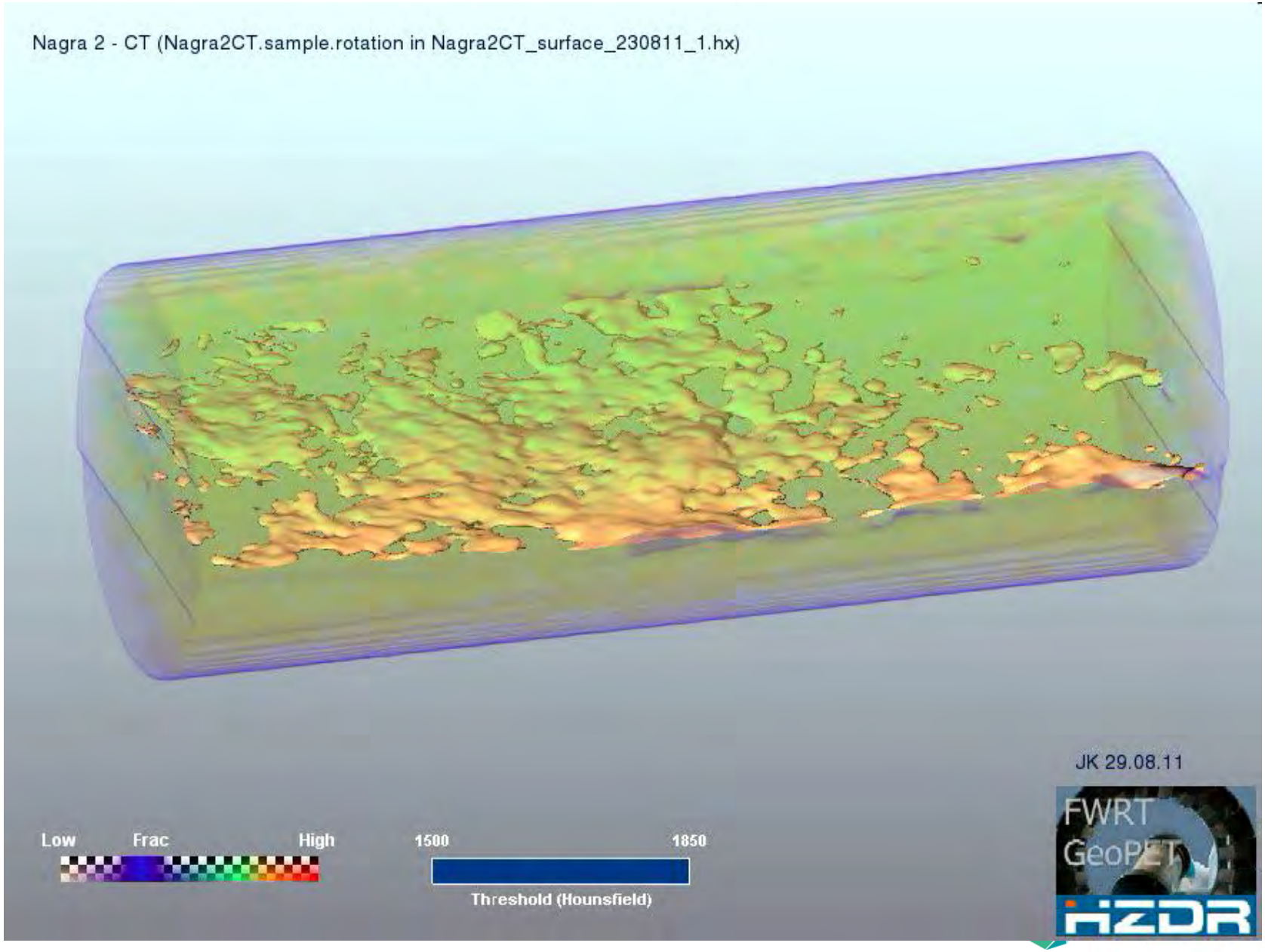
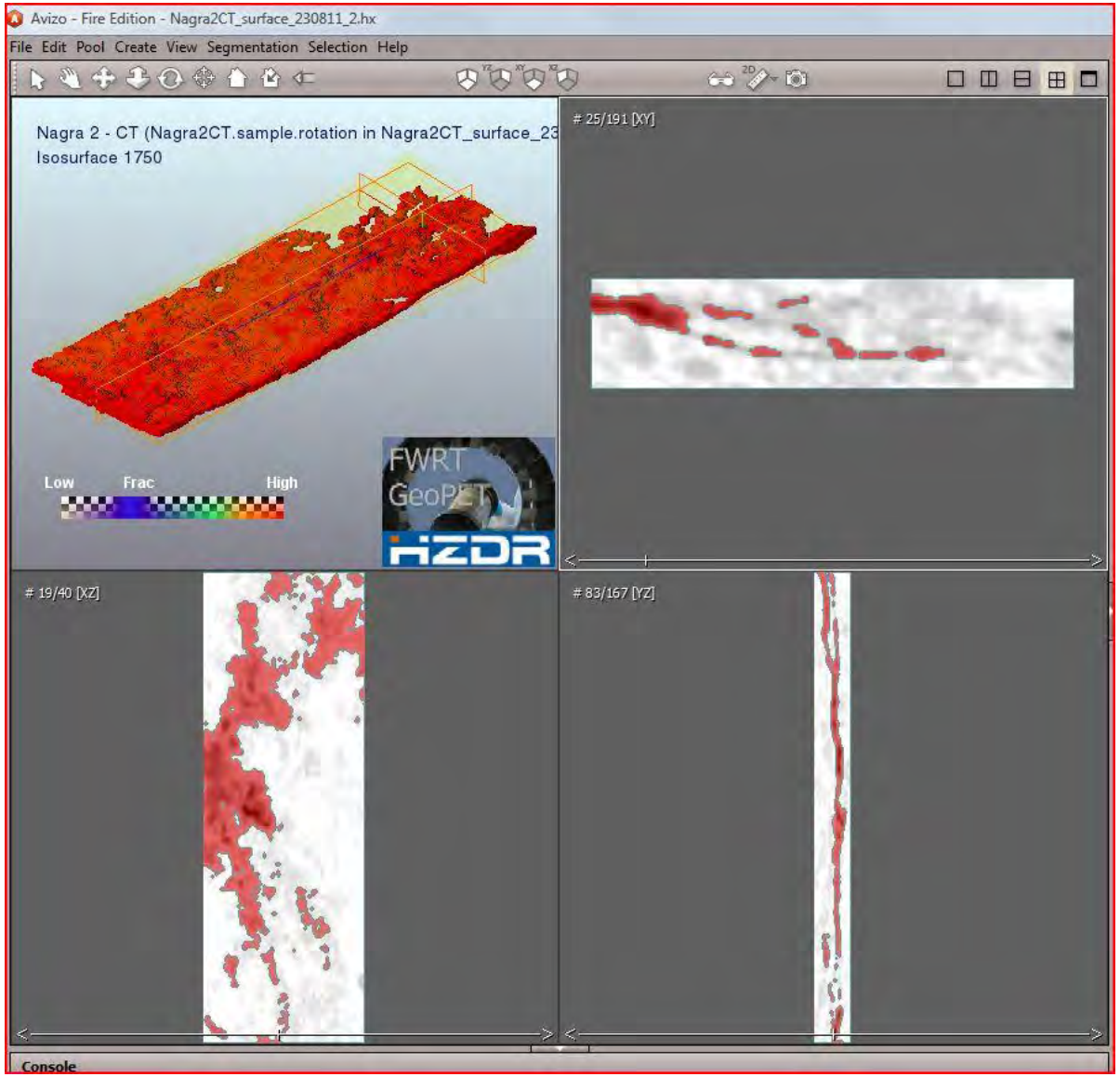
nagra. aus verantwortung

Problem with Segmentation: „partial-volume-effect“



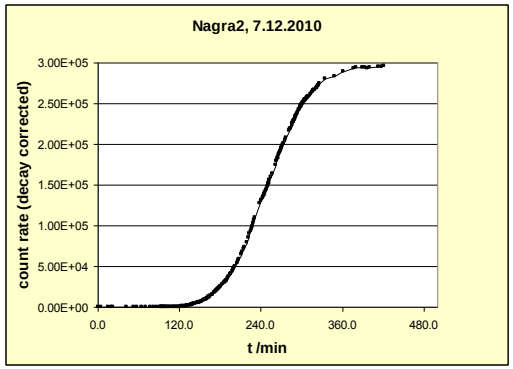
Segmentation of CT data in void and rock with AVIZO®



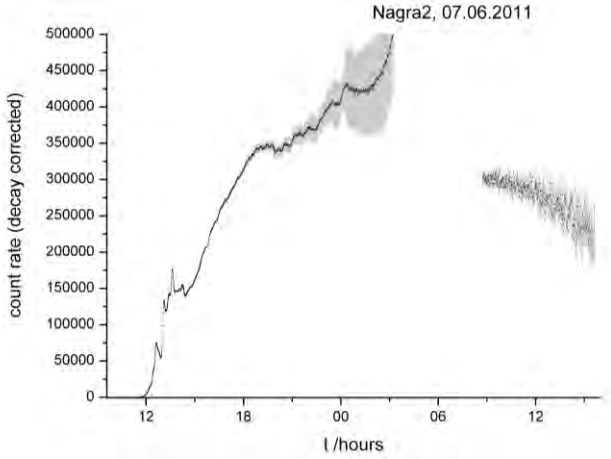
CT data is a „grey scale“

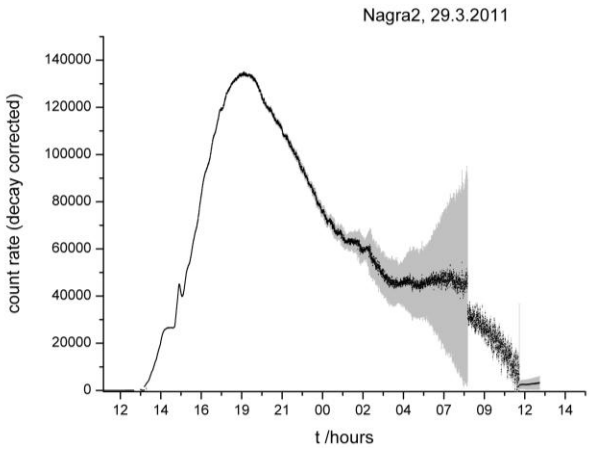
Depending on treshold values, „void“ has different shape

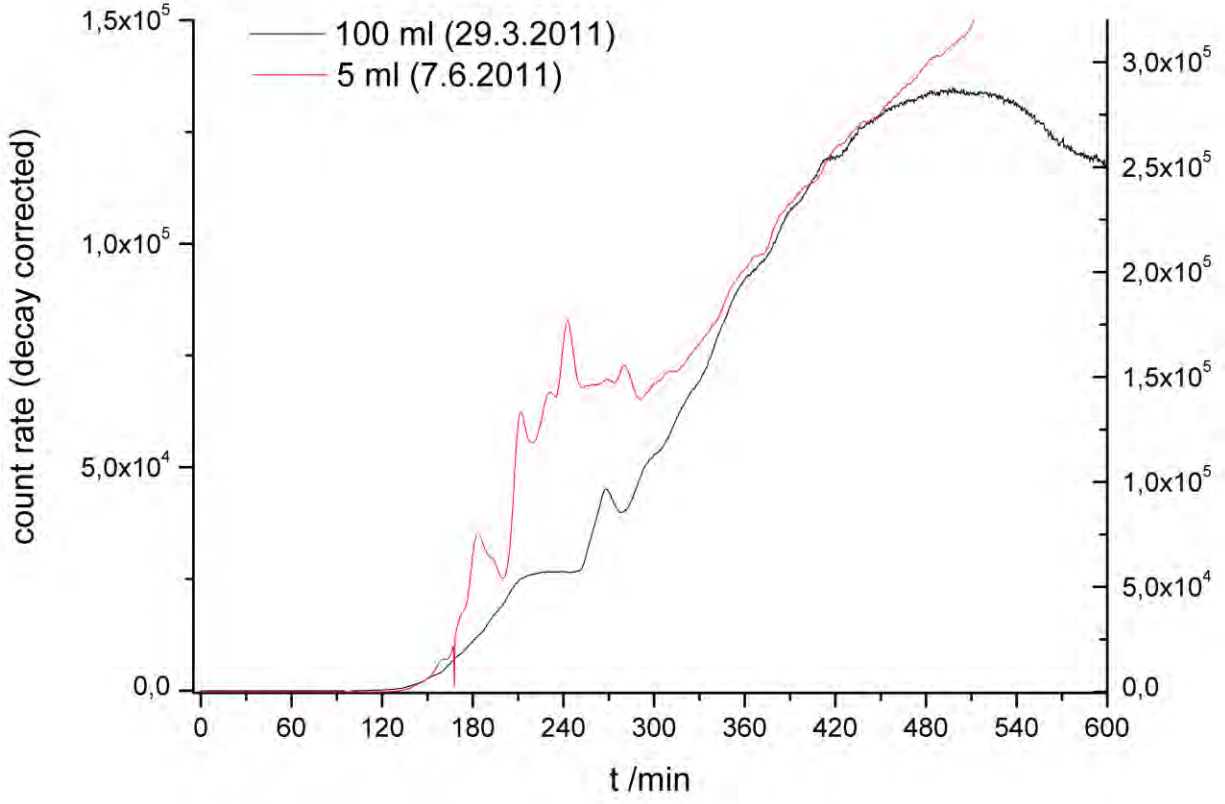
BTC mit γ-Durchfluss-Zähler



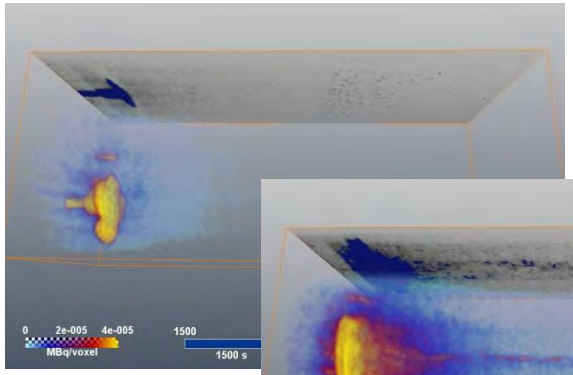
- nach ca 8 h (4 HWZ) fehlerhaft (Hintergrund)
- erste Ankunft nach 120 min bzw. 9 ml
- Maximum nach > 6 h (> 30 ml)
- merkliche Fluktuationen der Zählrate



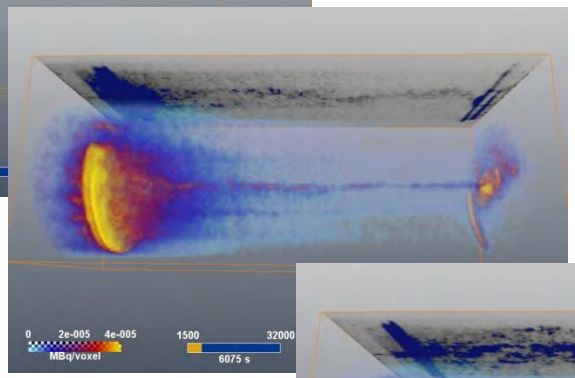




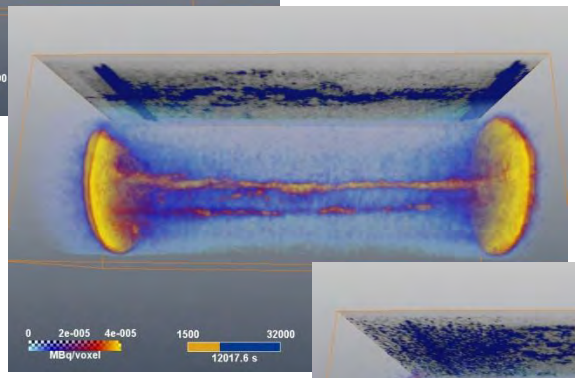
Durchflussexperiment, Tracerpuls 5 ml



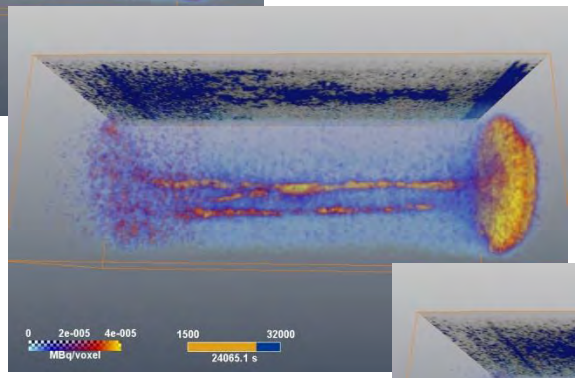
25 min (1.5 ml)



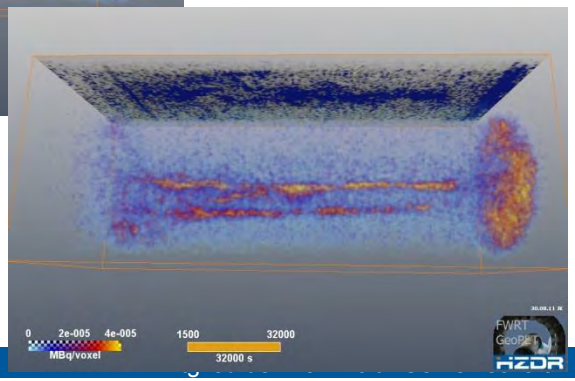
100 min, 9 ml



200 min, 17 ml



400 min, 34 ml



550 min, 50 ml