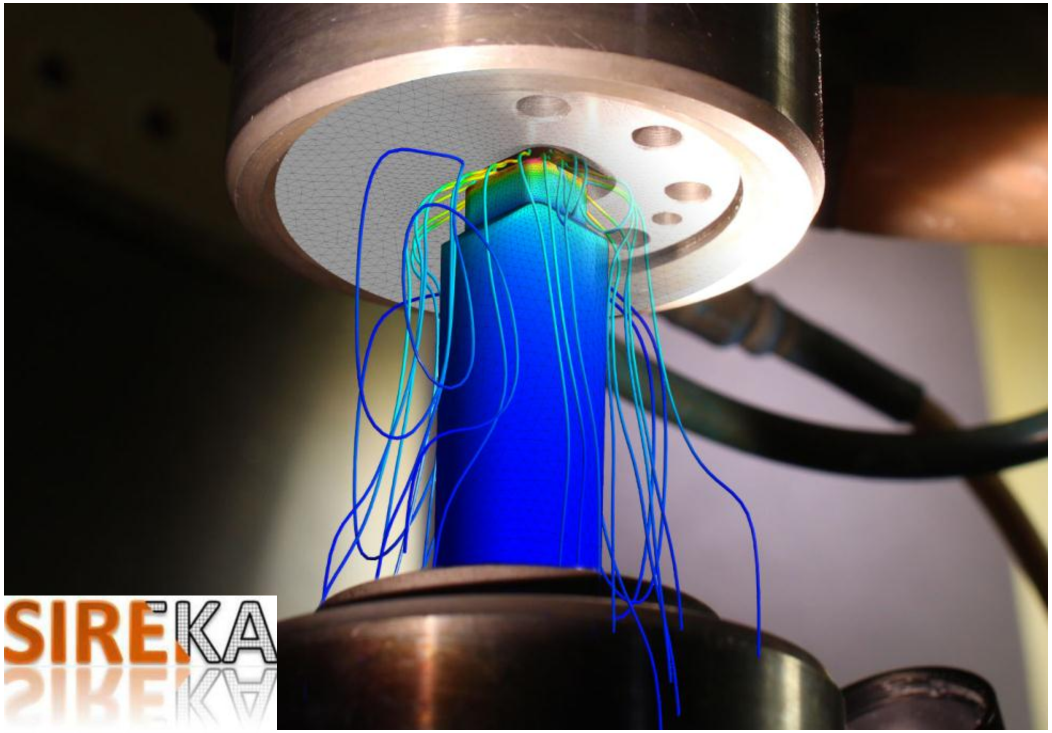


Optimized Design of Electrochemical Machining Processes by CFD Simulation

Dr. Andreas Spille-Kohoff
Benoit Bosc-Bierne

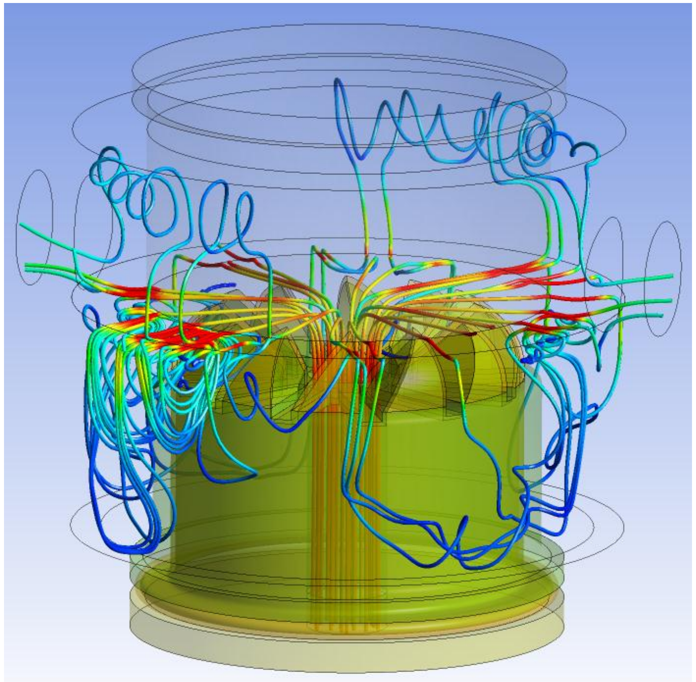
CFX Berlin Software GmbH

34. CADFEM ANSYS Simulation Conference
October 5 – 7, 2016, NCC Ost, Messe Nürnberg

Content

- What is Electrochemical Machining?
- Overview on research project SIREKA
- CFD simulation of ECM
- Summary and outlook

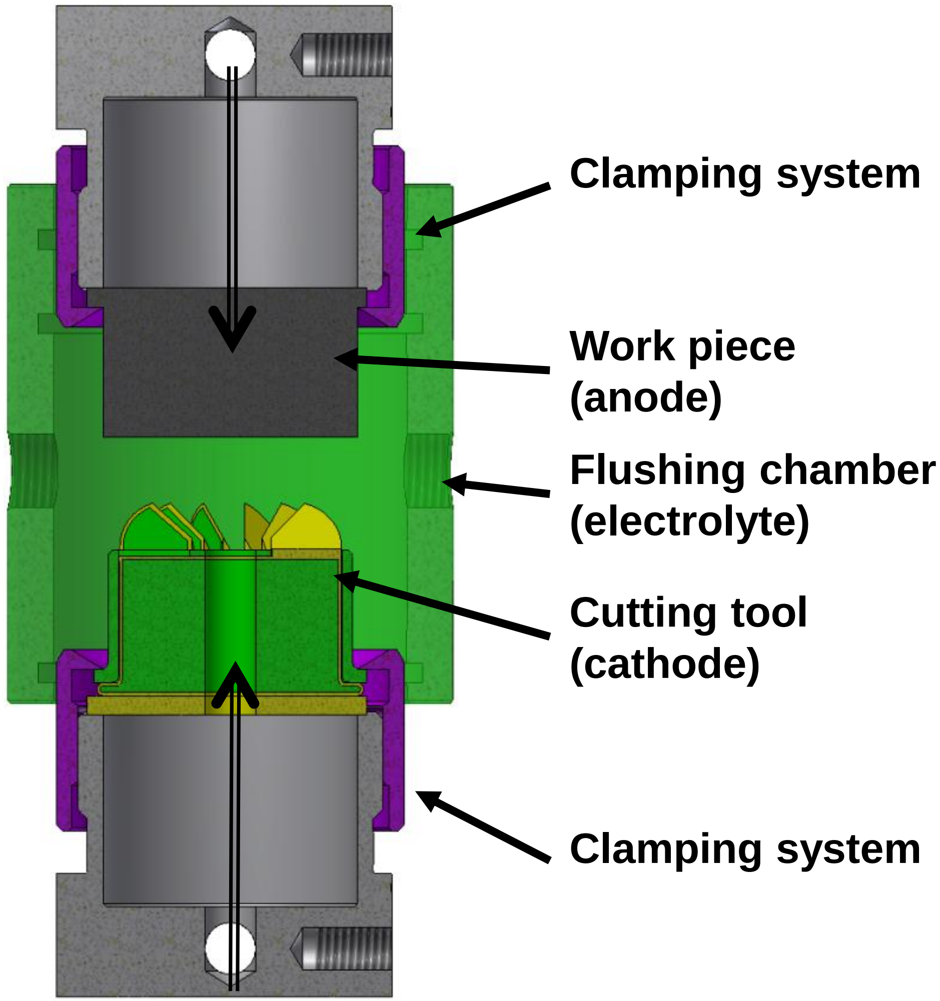
SIREKA



What is Electrochemical Machining?

What is Electrochemical Machining (ECM) ?

- Removal of metal by electrochemical process:
  - Electric potential between work piece (anode) and cutting tool (cathode) with electrolyte between
  - During metal removal, cutting tool is advanced into workpiece with small gap between (50 to 500 µm)
  - „reverse electroplating“
- Advantages:
  - no direct contact, no stress, no tool wear
  - hard materials can be machined
- Disadvantages:
  - high energy consumption, slow process
  - only electrically conductive materials



What is Electrochemical Machining?

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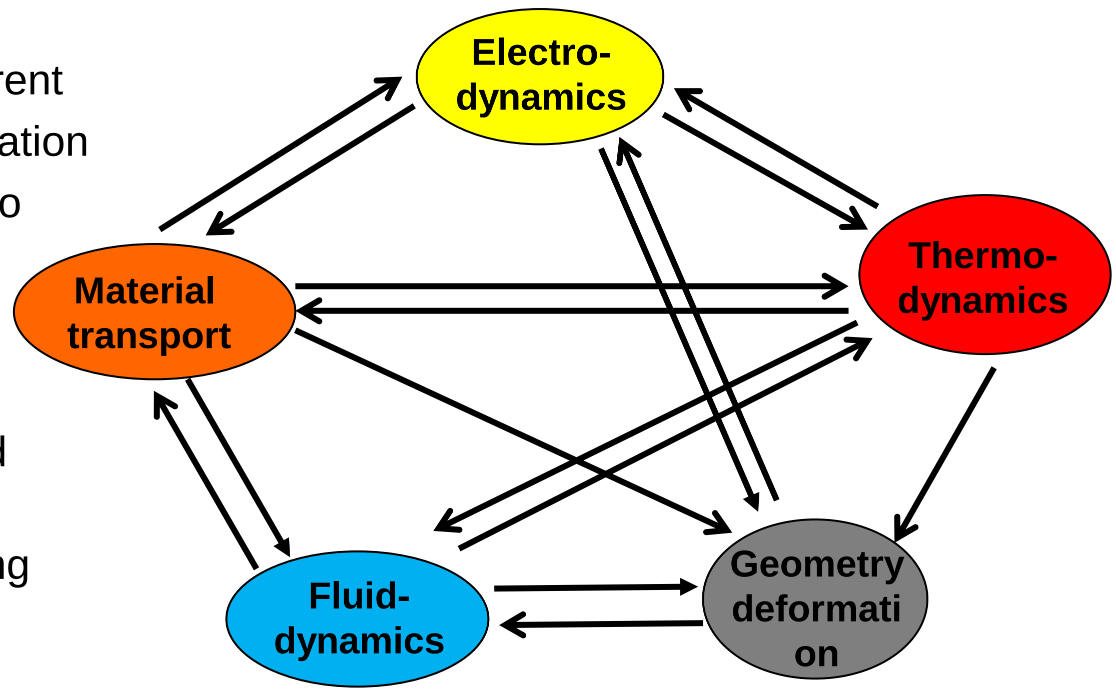
What is Electrochemical Machining (ECM) ?

- Complex physics
  - electric potential and electric current
  - metal dissolution and heat generation
  - material and heat transport due to electrolyte flow
  - geometry deformation
- Even more complex processes:
  - different processes for rough and fine machining
  - Pulsed Electrochemical Machining (PECM): pulsed current and/or oscillating working gap
- Main challenge:
  - **How should the tool look like to get desired removal shape in the workpiece?**



Research project SIREKA
Project partners

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Associated partners:

BOSCH Diesel Systems

P&G BRAUN

GEFÖRDERT VOM
Bundesministerium für Bildung und Forschung

Research project SIREKA
Overview

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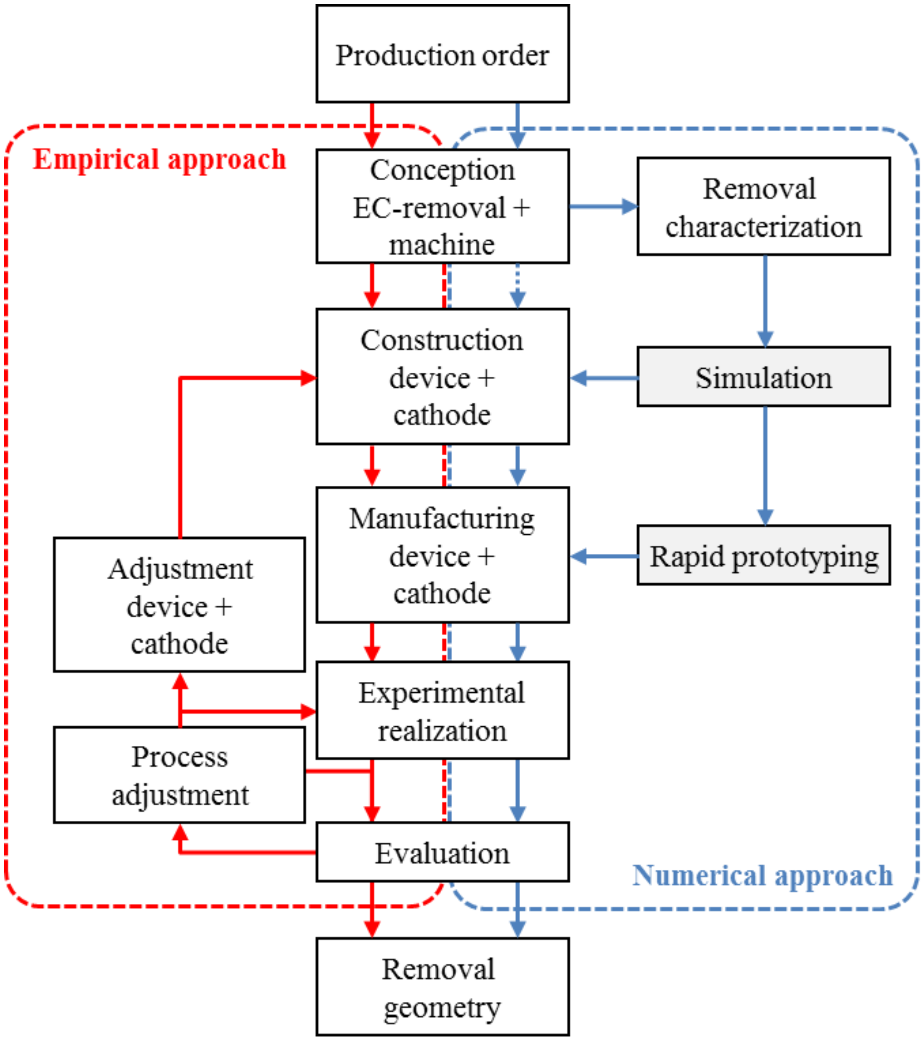
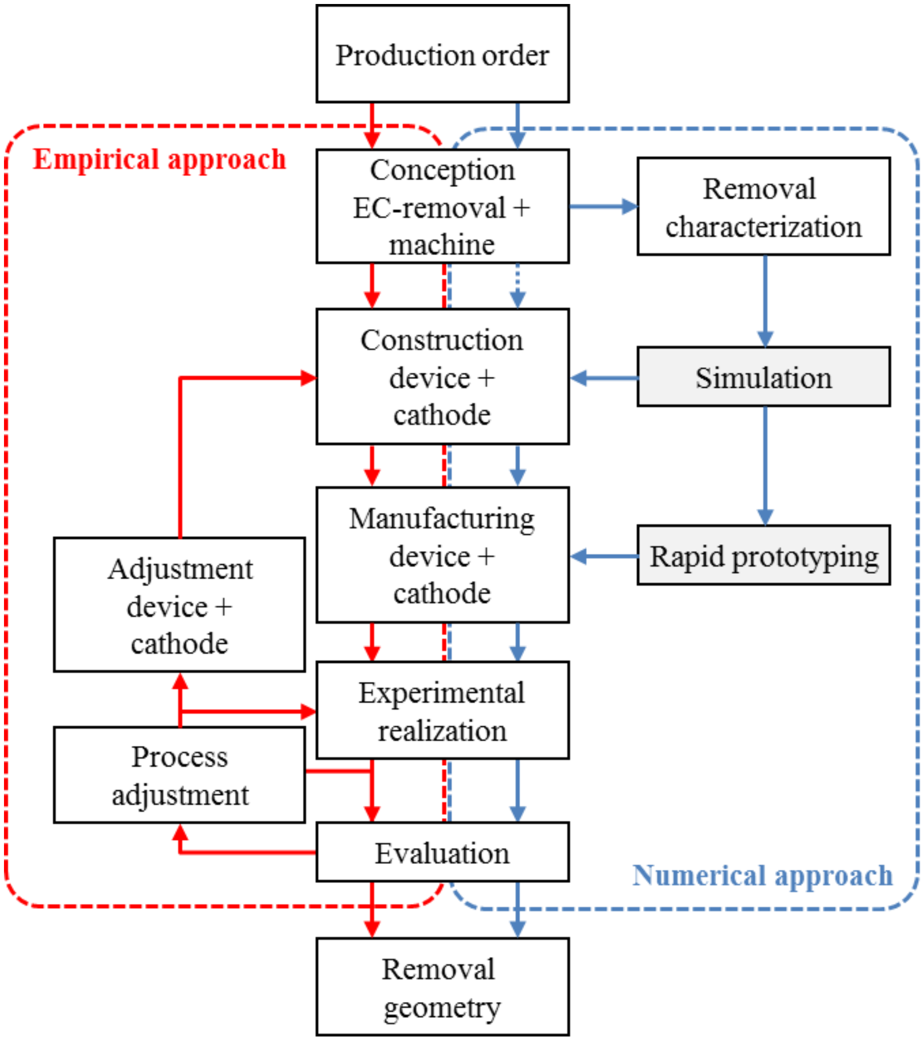
- **Name: SIREKA**
  Simulationsunterstützte ressourceneffiziente Auslegung und Realisierung des Elektrochemischen Abtragens
- **Duration:**
  1.4.2015-31.3.2017
- **Research program:**
  KMU-innovativ
- **Executing organization:**
  Projektträger Karlsruhe Produktion und Fertigungstechnologien
- **Funded by:**
  German Federal Ministry of Education and Research



Research project SIREKA
Aims

- **Optimized design process for electrochemical machining (ECM):**
  - Empirical approach of construction, manufacturing, experiment and adjustment too inefficient
  - Improvement of design process through 3D simulations of ECM
  - Simulations based on experimentally determined dissolving material characteristics
  - Optimization of process parameters and device shape
  - Speed-up of manufacturing through rapid prototyping of cathodes with Fused Deposition Modeling (FDM) or PolyJet technology, coated with metallic layer



Content

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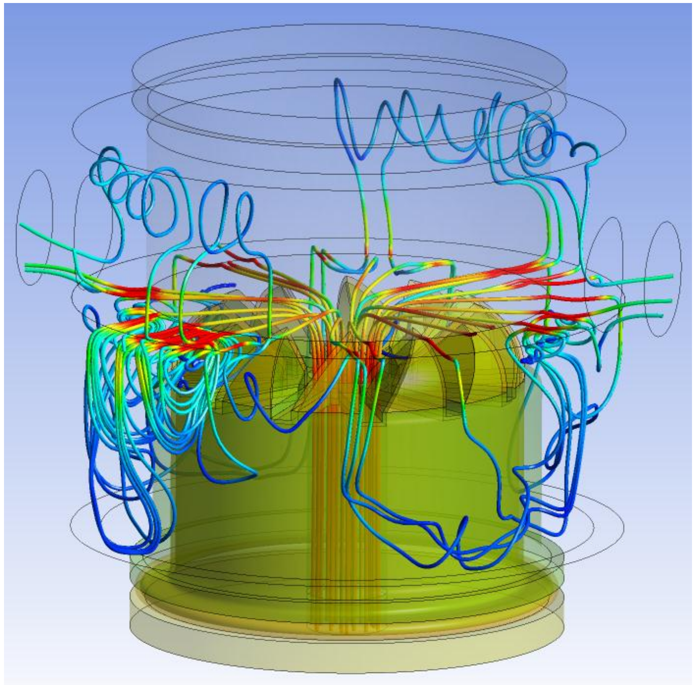
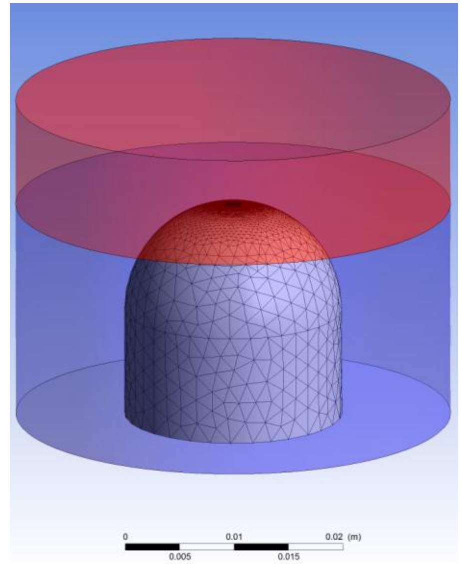
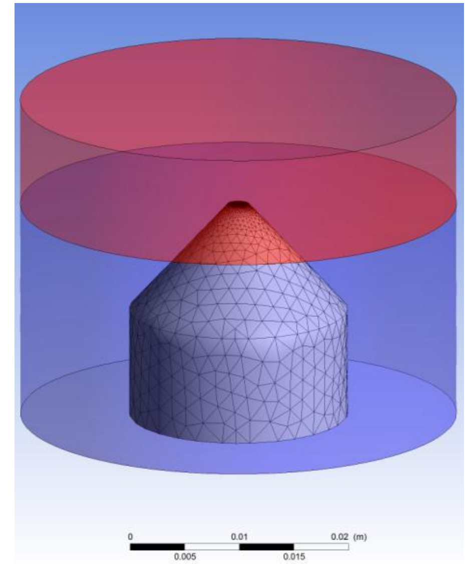
  - Setup and boundary conditions
  - Verification cases
  - Validation cases
- Summary and outlook

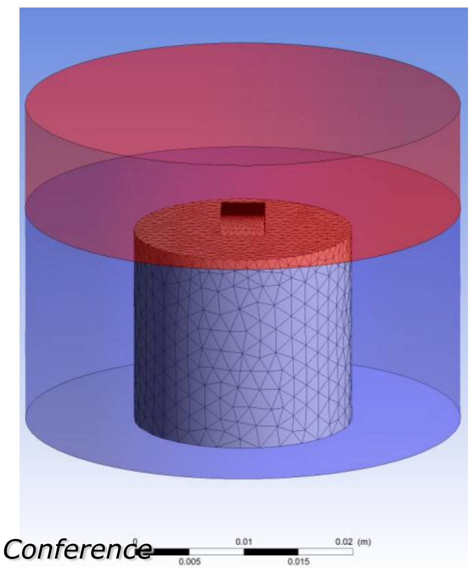


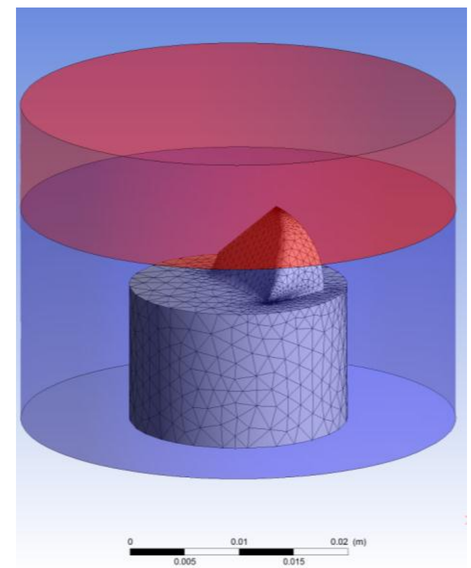
Typical geometry for an ECM process:

- workpiece
  - of steel, often initially flat
- flushing chamber
  - for electrolyte
- cathode
  - of steel, copper, galvanized plastic with complex geometry
  - verification shapes on cylinder:
    - half sphere
    - cone
    - cuboid
    - part of retarder geometry



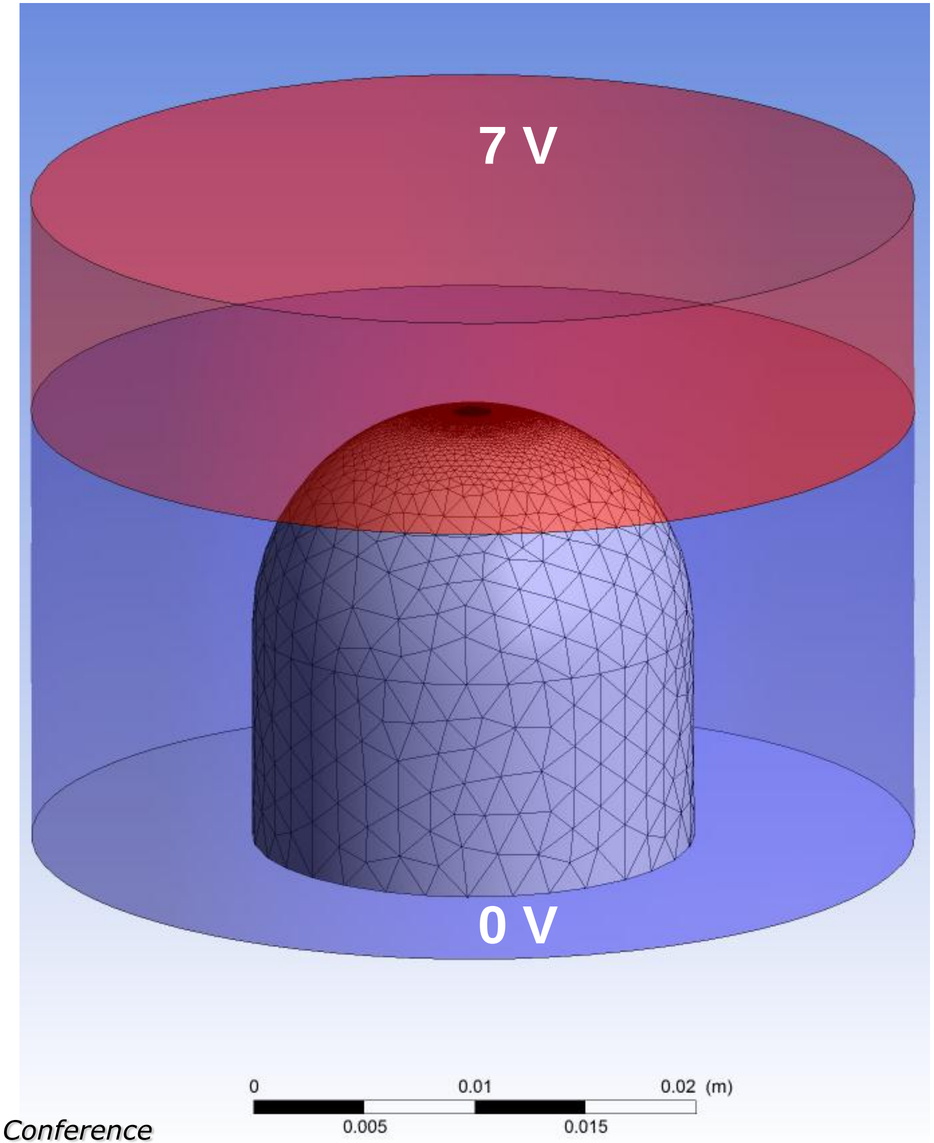






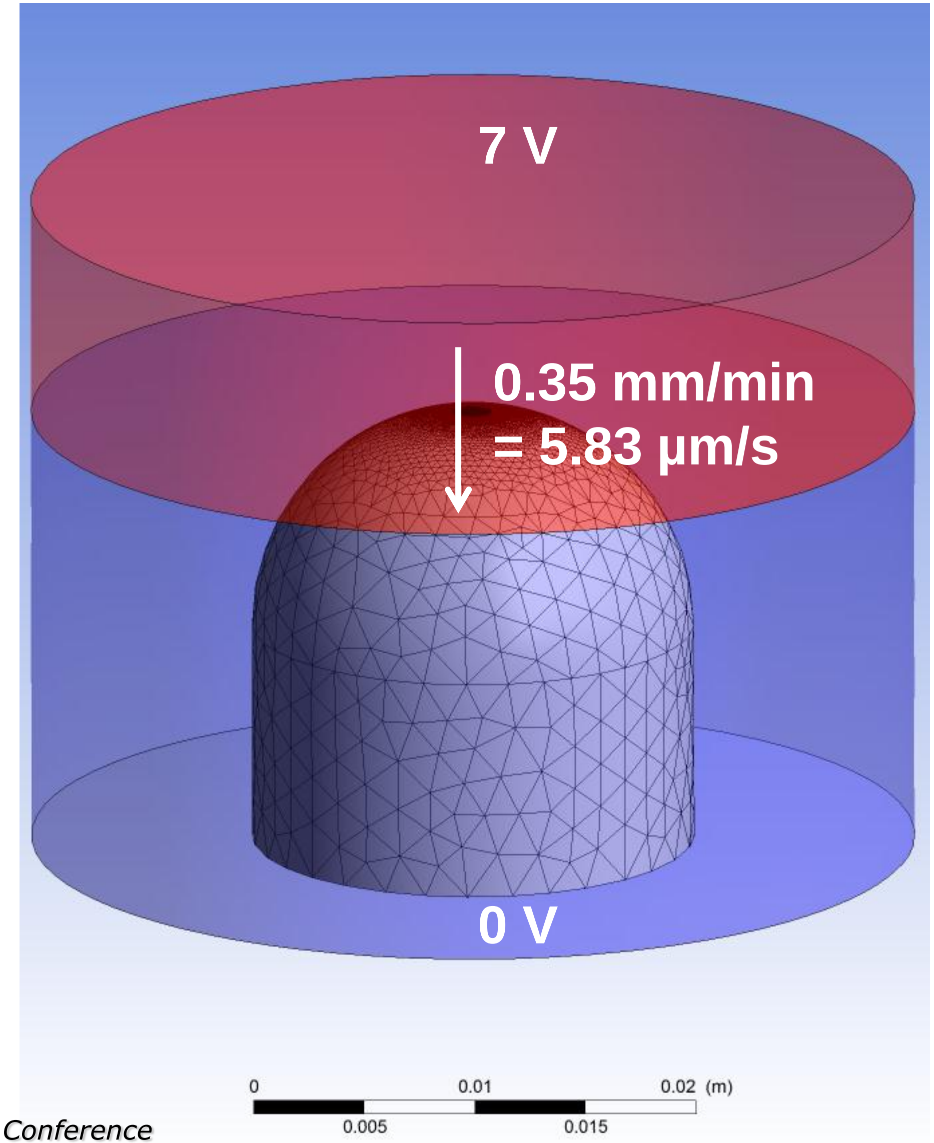
Boundary conditions for an ECM process:

- Anode at voltage
  - e.g. 7 V (already reduced by polarization voltage)
- Cathode grounded
  - 0 V



Boundary conditions for an ECM process:

- Anode at voltage
  - e.g. 7 V (already reduced by polarization voltage)
- Cathode grounded
  - 0 V
- Specified feed rate
  - e.g. 0.35 mm/min
- Process time or sinking depth
  - e.g. 10 min ➔ 3.5 mm



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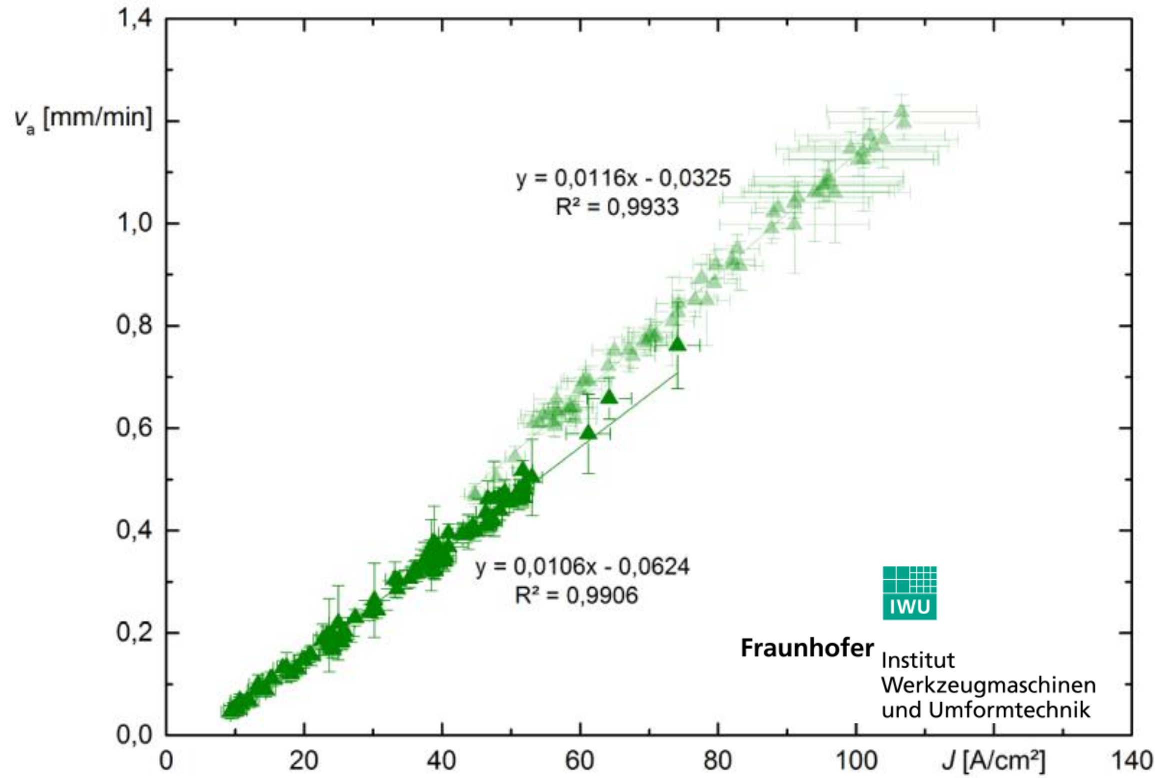
Boundary conditions for an ECM process:

- Anode at voltage
  - e.g. 7 V (already reduced by polarization voltage)
- Cathode grounded
  - 0 V
- Specified feed rate
  - e.g. 0.35 mm/min
- Process time or sinking depth
  - e.g. 10 min ➔ 3.5 mm
- Dissolution rate of metal at anode
  - experimentally determined: local removal velocity v_a as function of local current density J



Bereich	J in [A/cm²]	$\Delta v_a/\Delta J$ in [mm/min / A/cm²]	v_0 in [mm/min]
I	8 – 74	0,0106	-0,063
II	45 – 107	0,0116	-0,032

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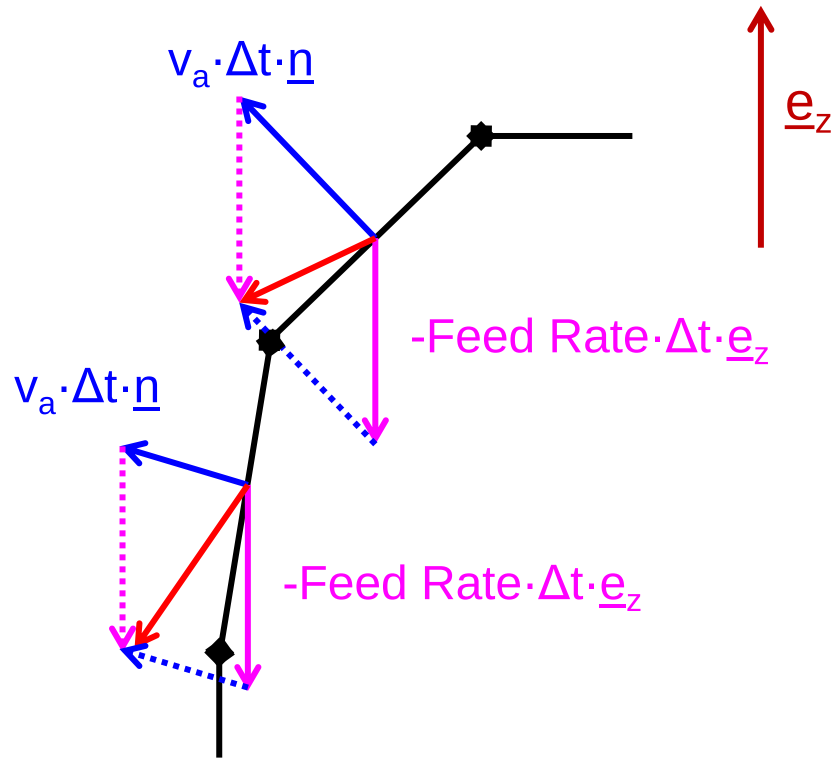
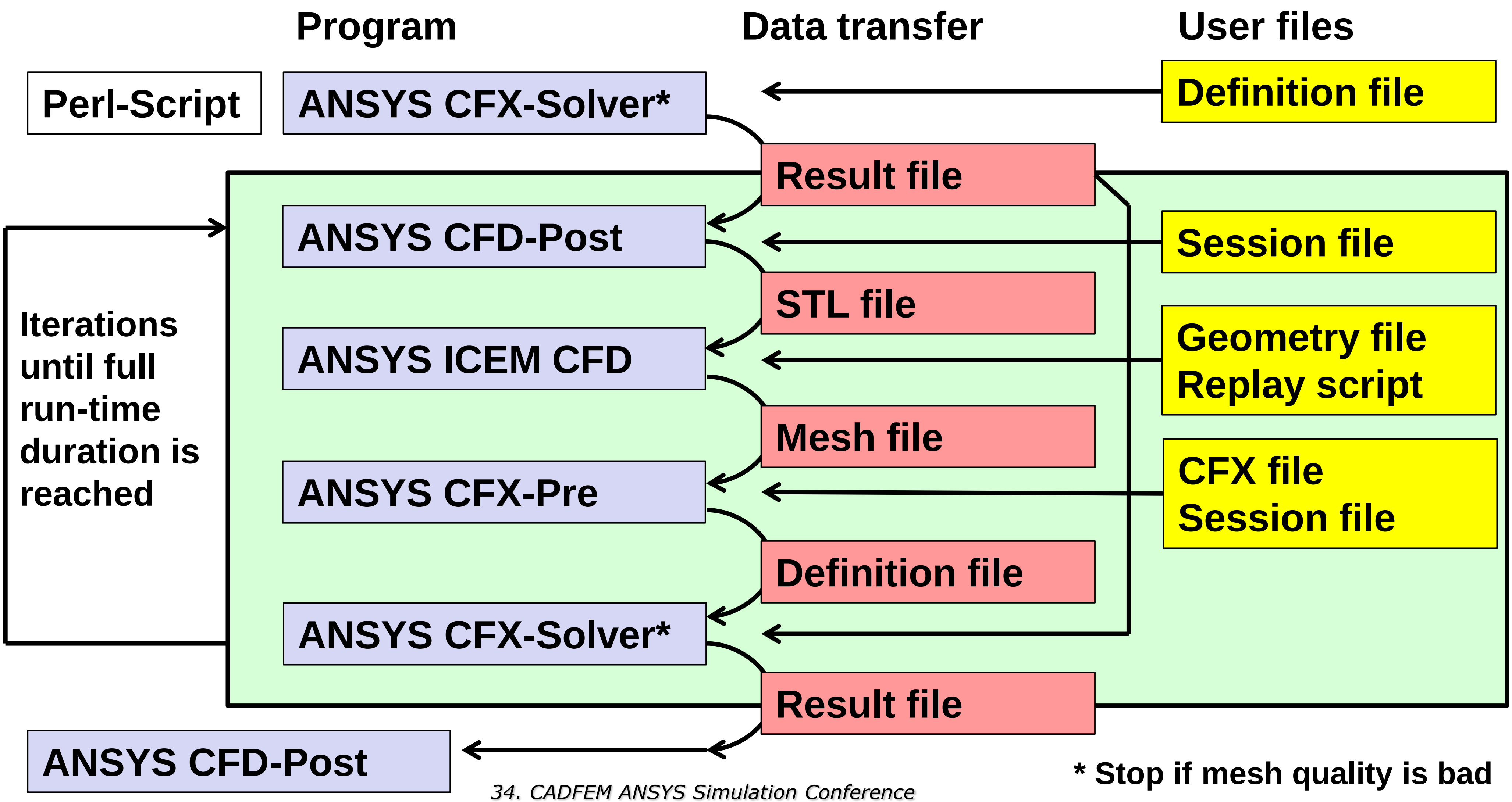
Setup for an ECM simulation:

- Simulation with ANSYS CFX
  - transient with time step size of e.g. 1 s
  - initialized with steady-state solution
  - duration of 10 min = 600 s
- Geometry deformation:
  - prescribed feed rate in fixed direction
  - metal dissolution $v_a(J)*\Delta t$ in normal direction at anode-fluid interface
  - net motion via User Fortran at boundaries
- Equations solved for:
  - boundary scale / wall distance
  - mesh deformation (for inner vertices)
  - electric potential
  - NO fluid flow, NO turbulence, NO heat transfer
- Problem: Deformed mesh becomes invalid!

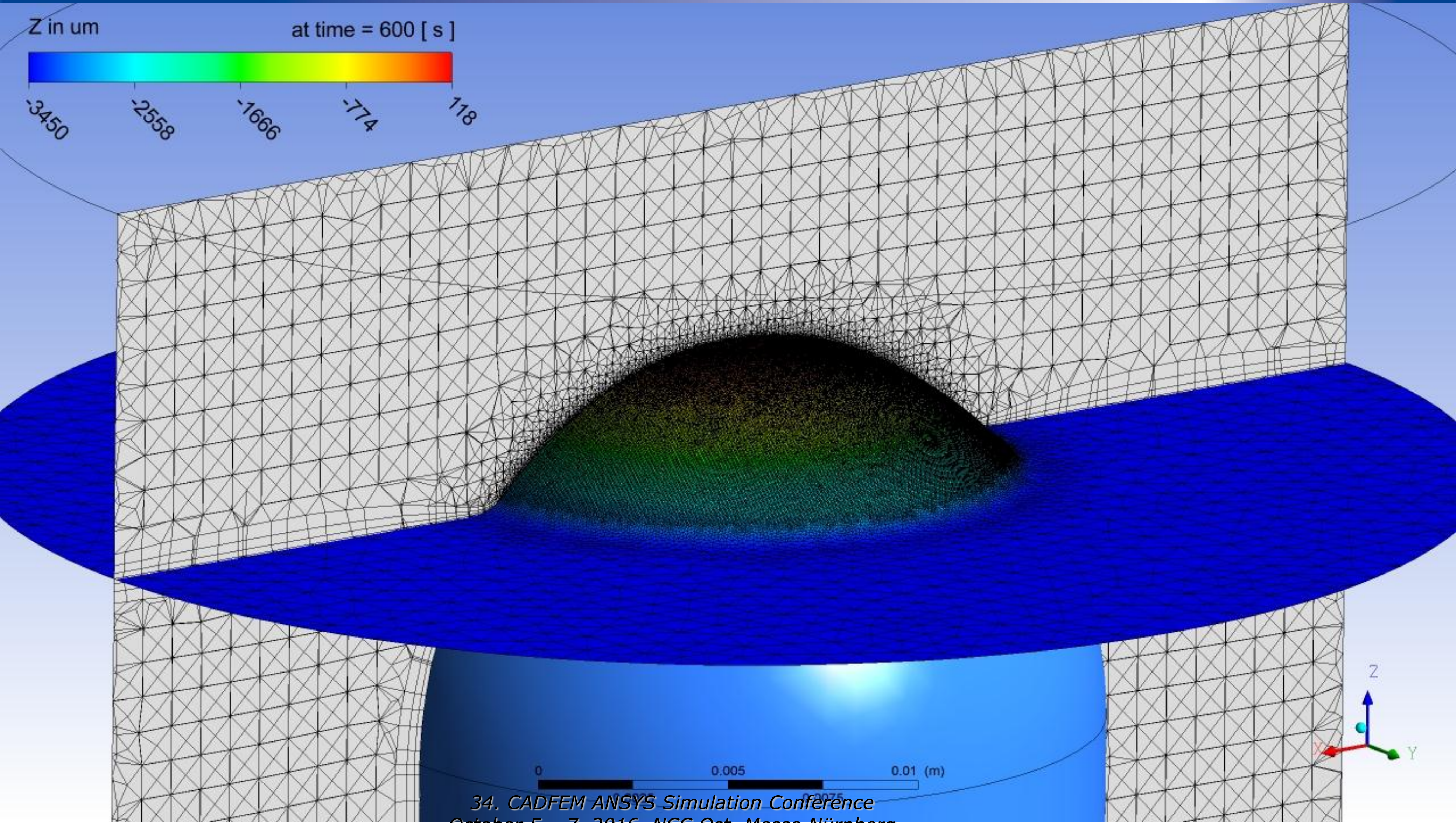


CFD simulation of ECM
Setup and boundary conditions



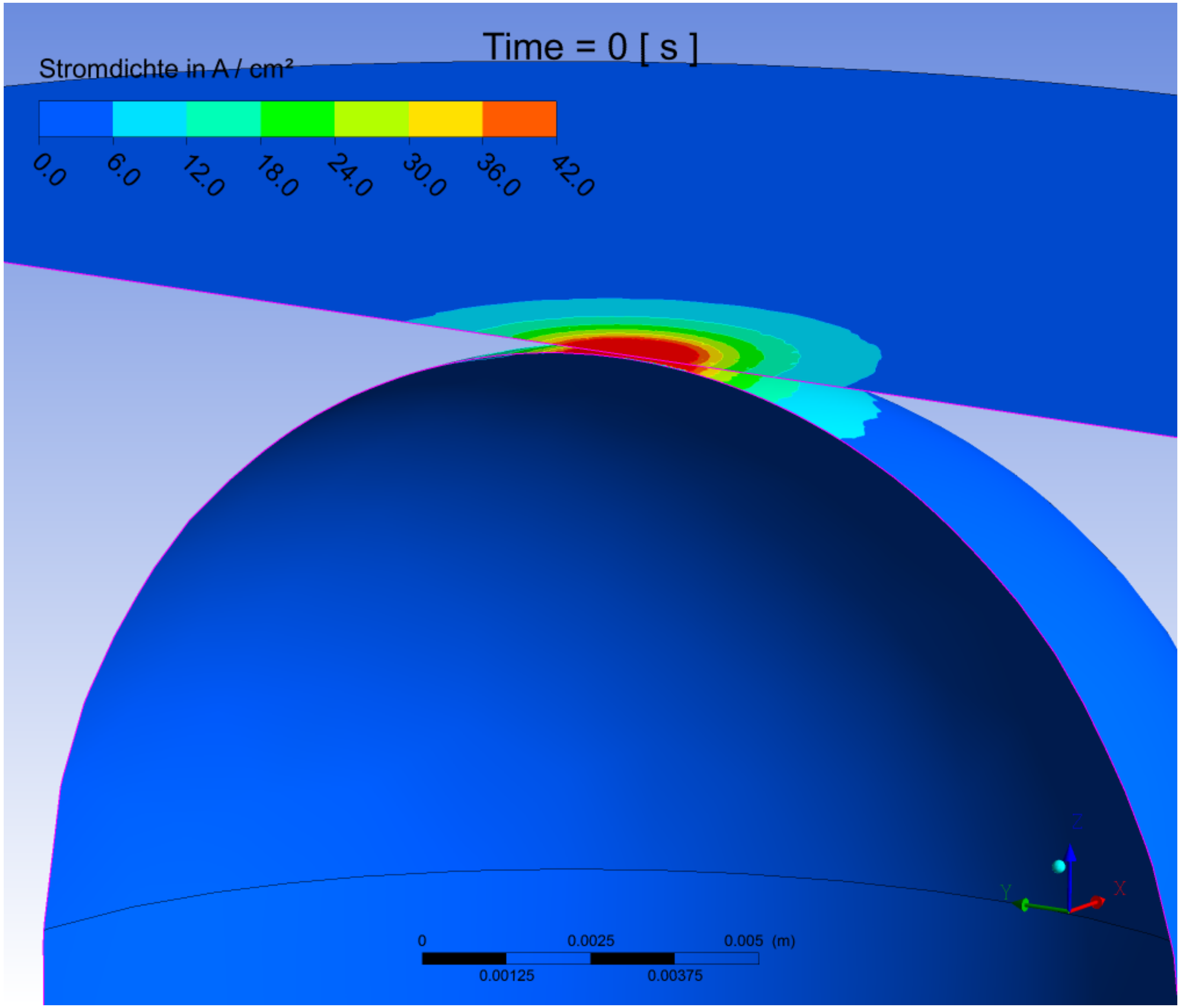
* Stop if mesh quality is bad

CFD simulation of ECM
Verification case: Half sphere

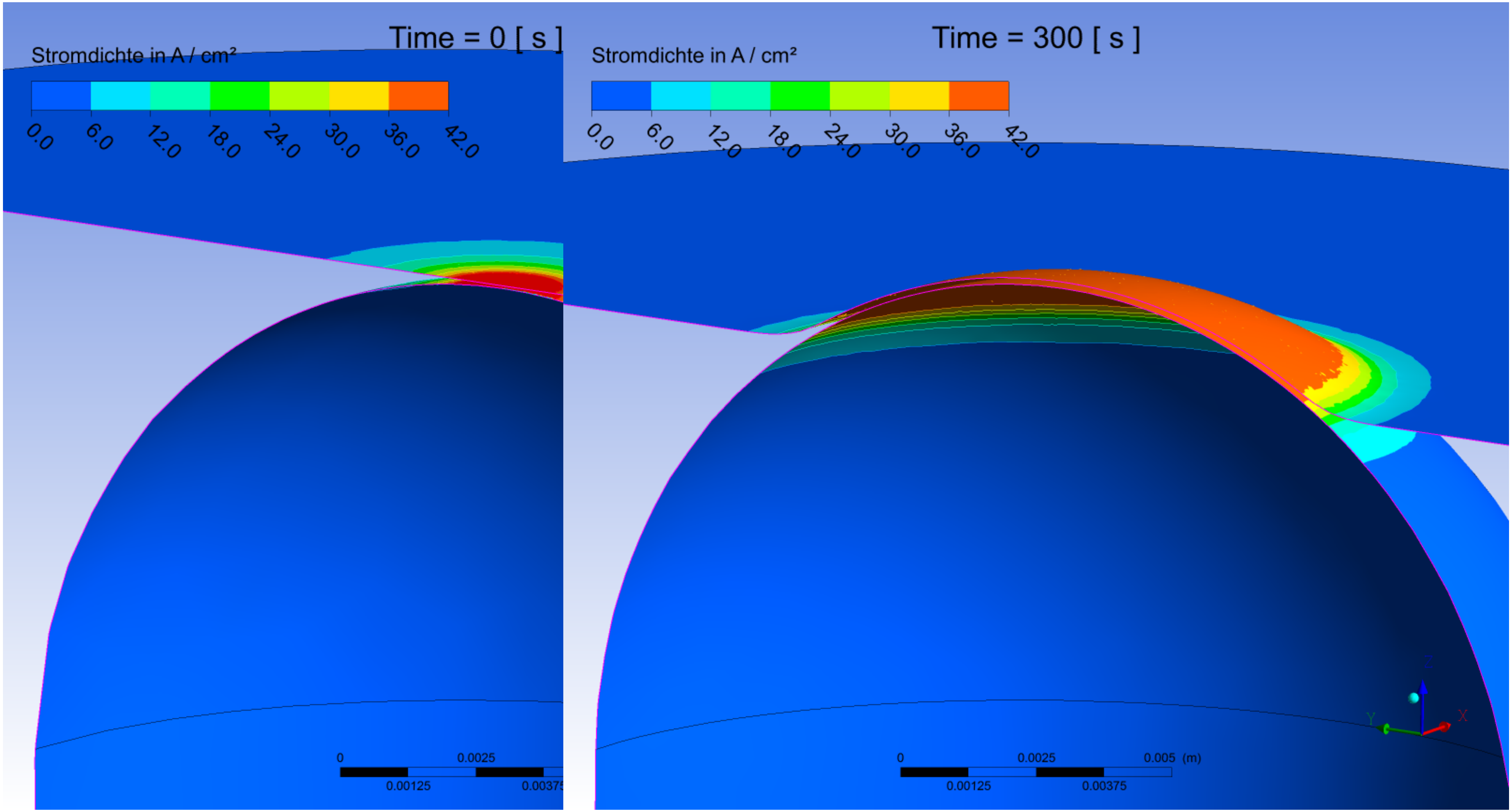


CFD simulation of ECM
Verification case: Half sphere

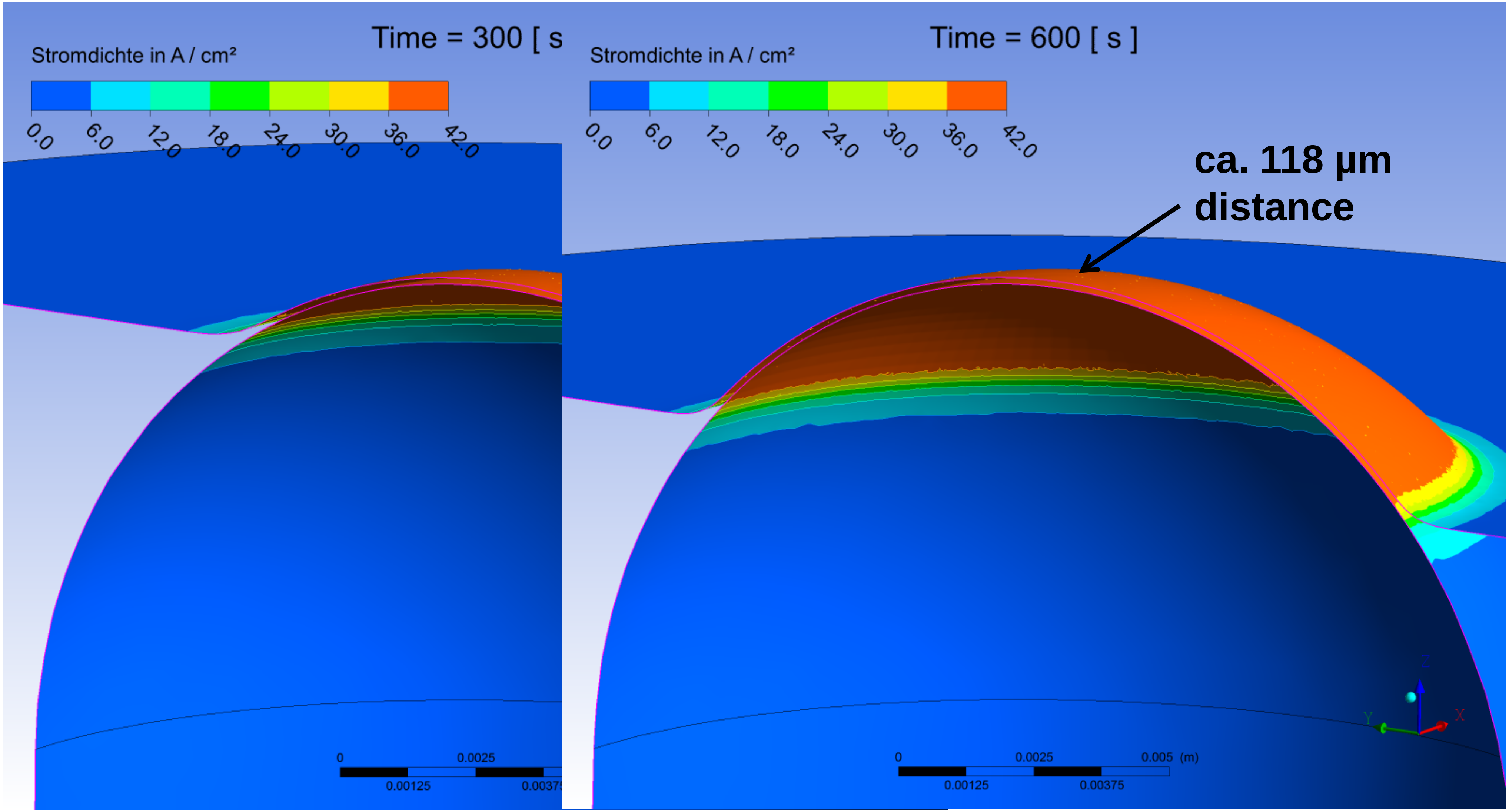
CFX Berlin



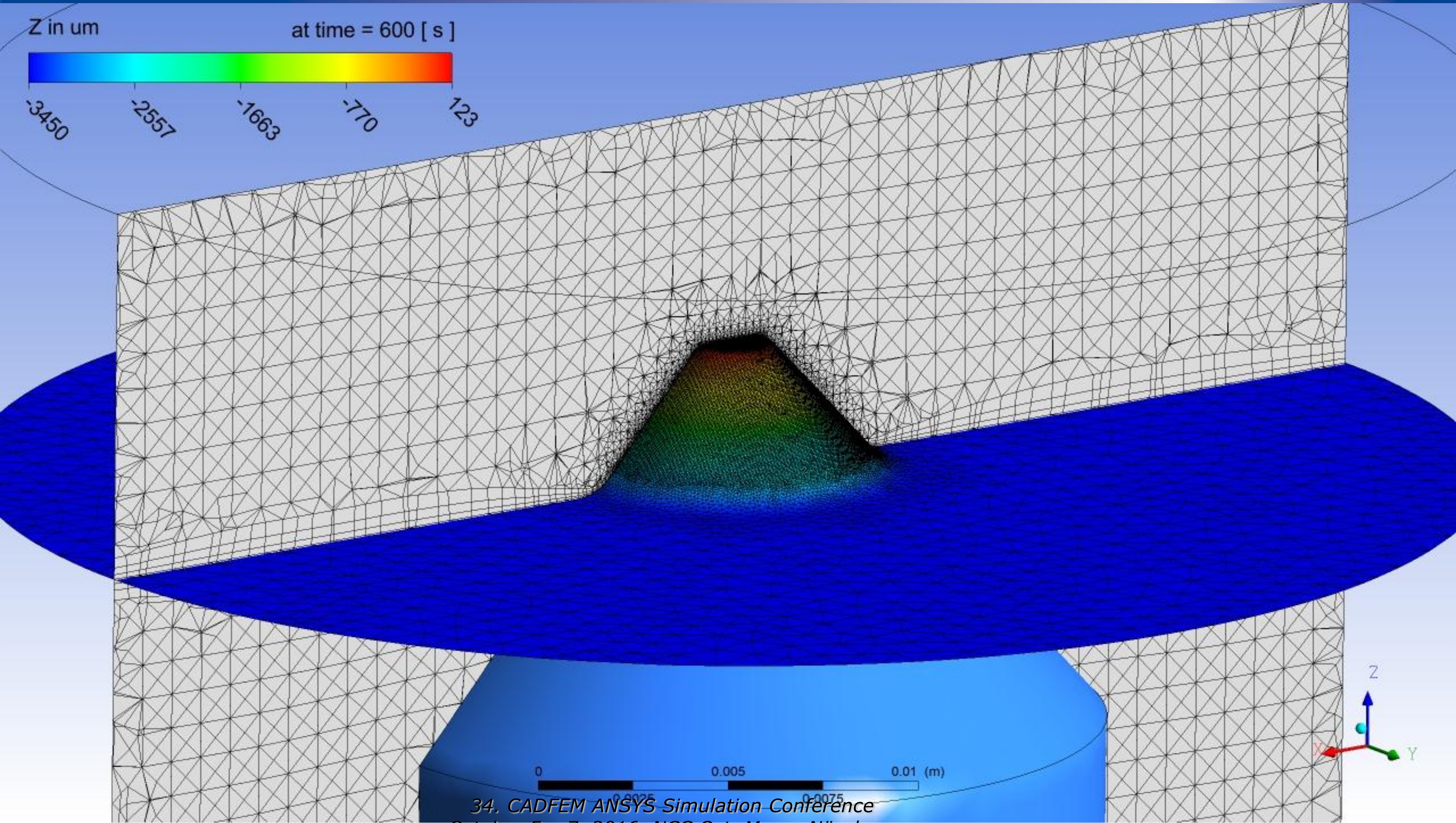
CFD simulation of ECM
Verification case: Half sphere



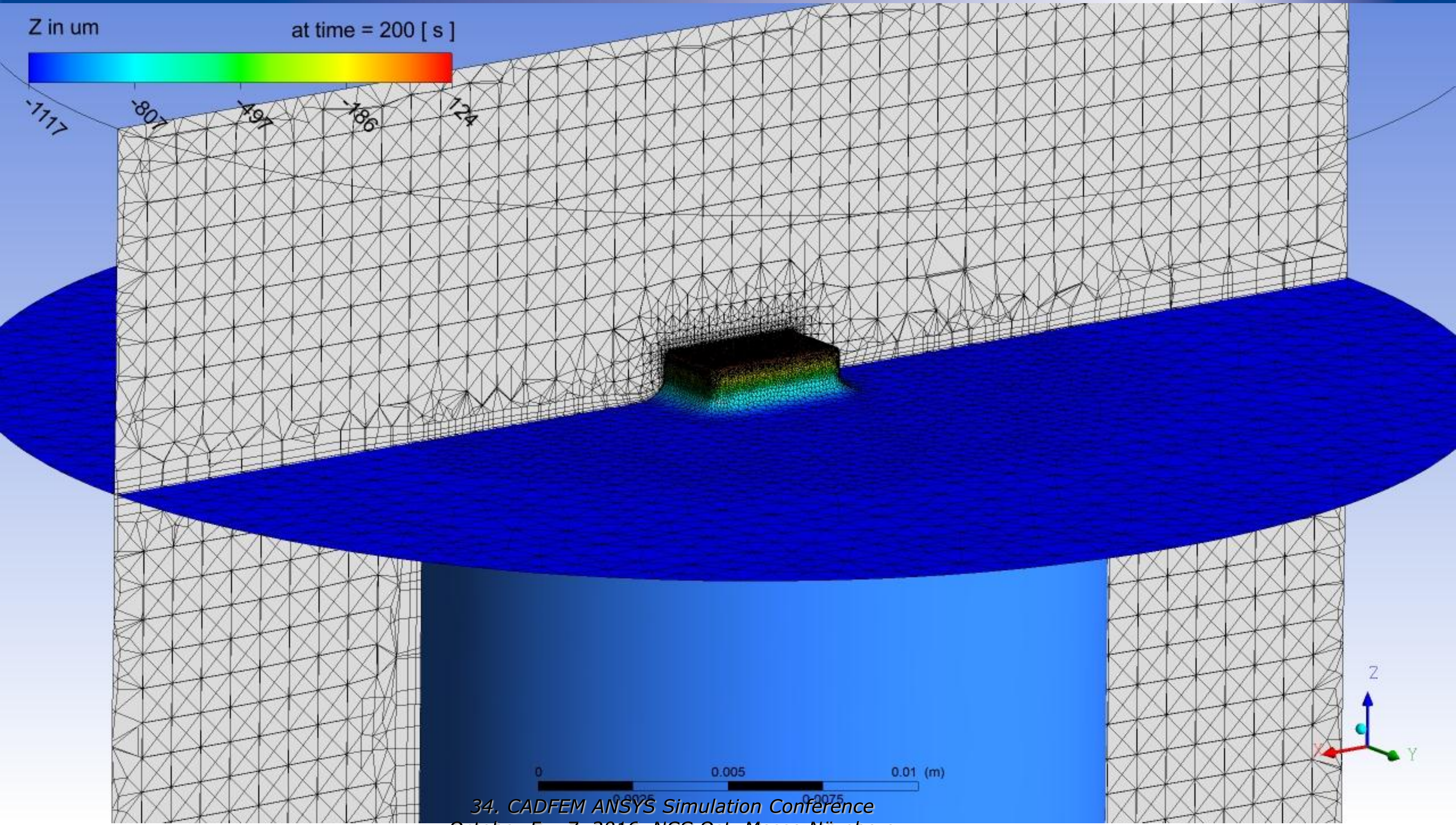
CFD simulation of ECM
Verification case: Half sphere



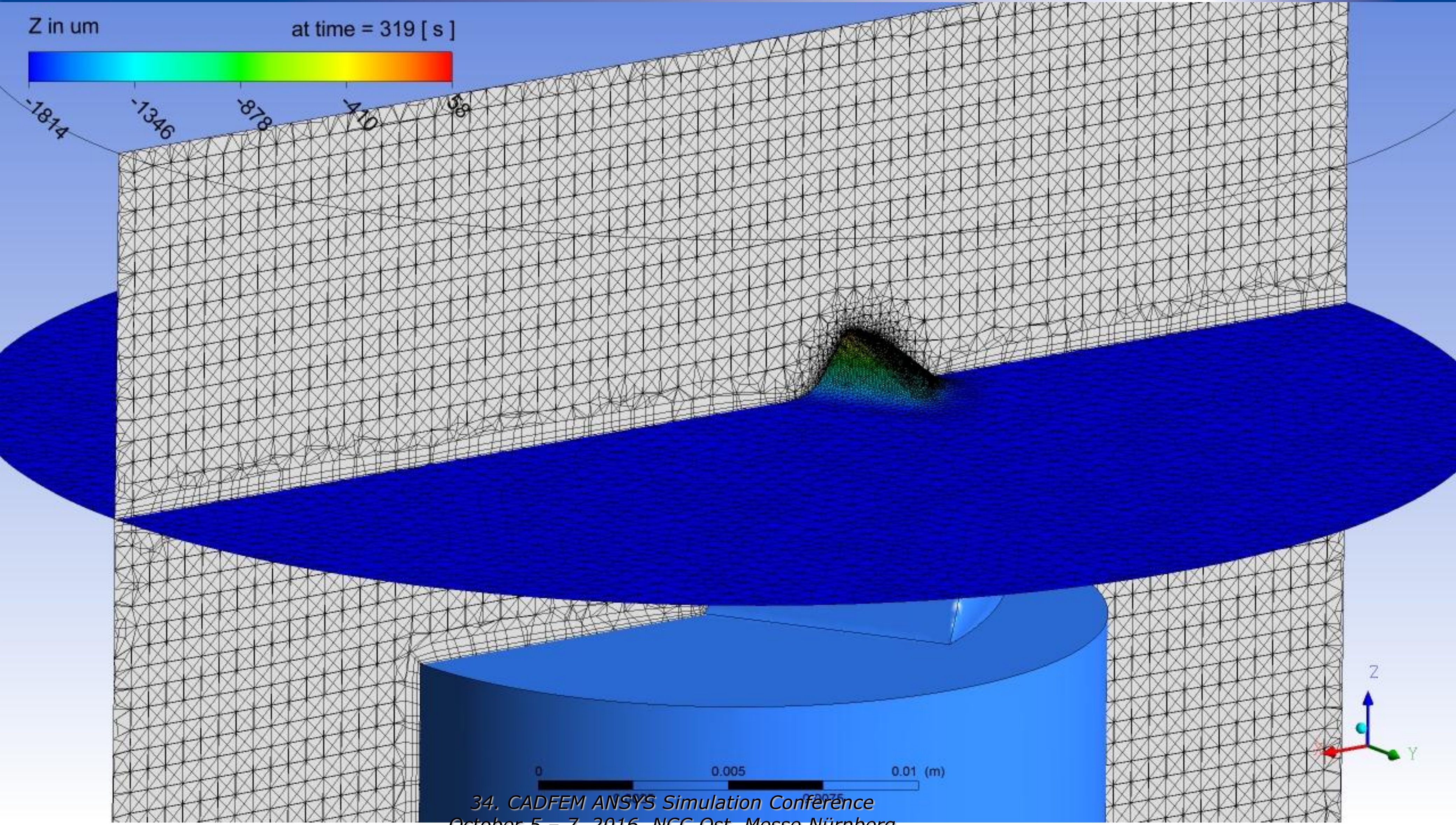
CFD simulation of ECM
Verification case: Truncated cone



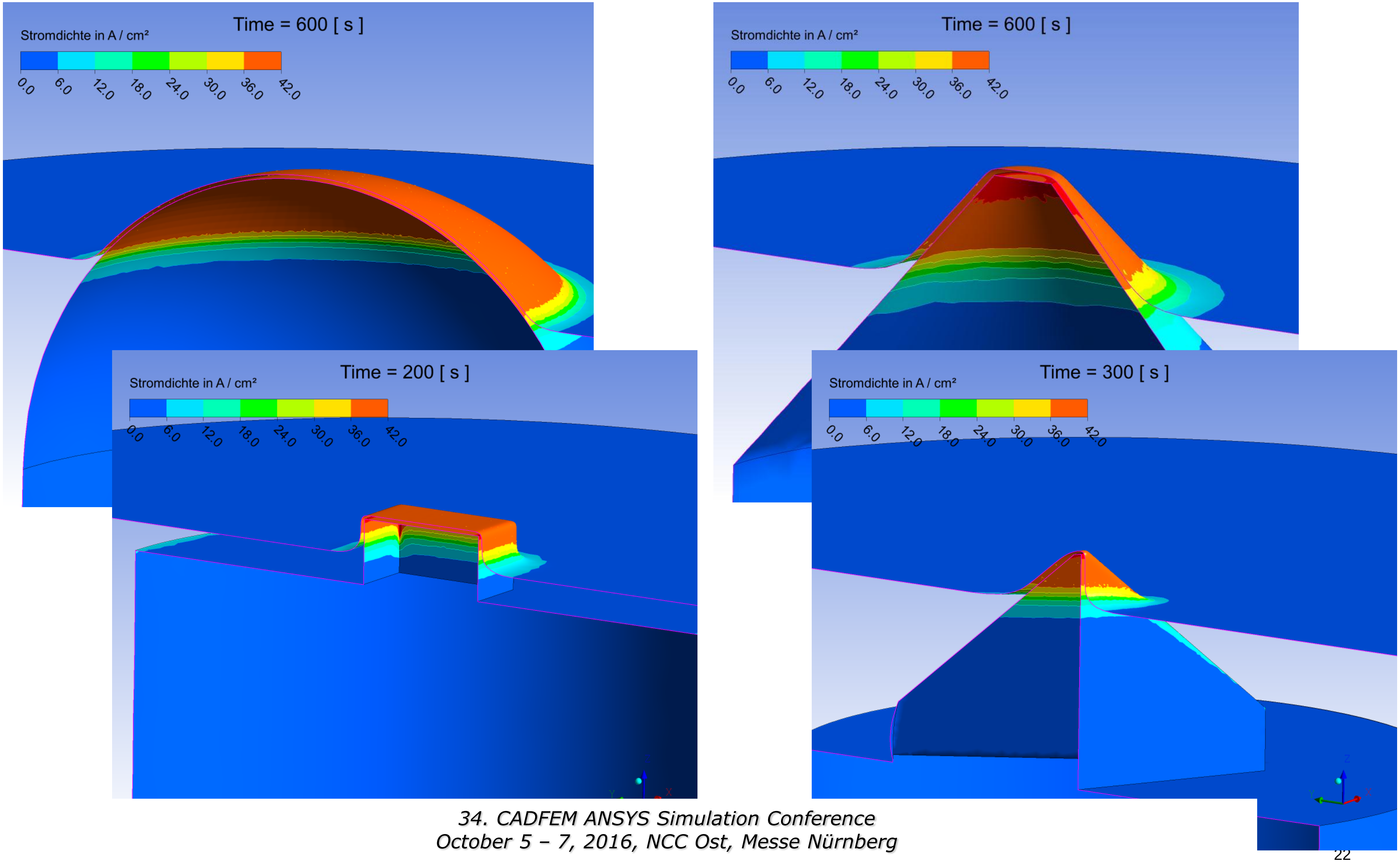
CFD simulation of ECM
Verification case: Cuboid



CFD simulation of ECM
Verification case: Part of Retarder geometry



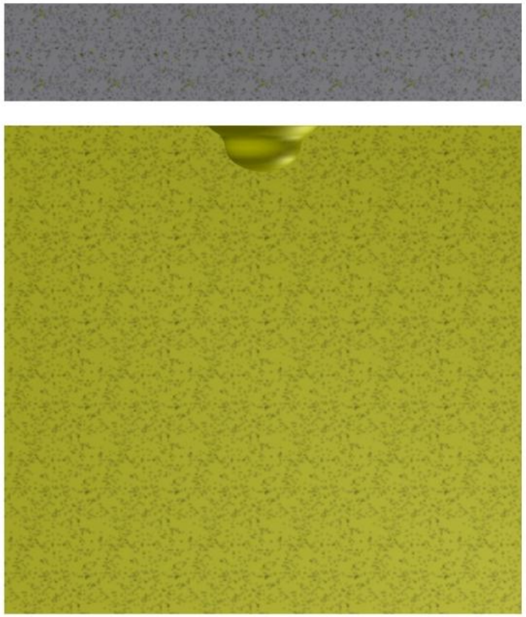
CFD simulation of ECM
Verification case: Final shapes



CFD simulation of ECM
Validation case: Micro-Calotte

Micro-Calotte validation case:

- Cathode with 97 identical cavities
- 6 different process parameter sets
  - voltage and feed rate values



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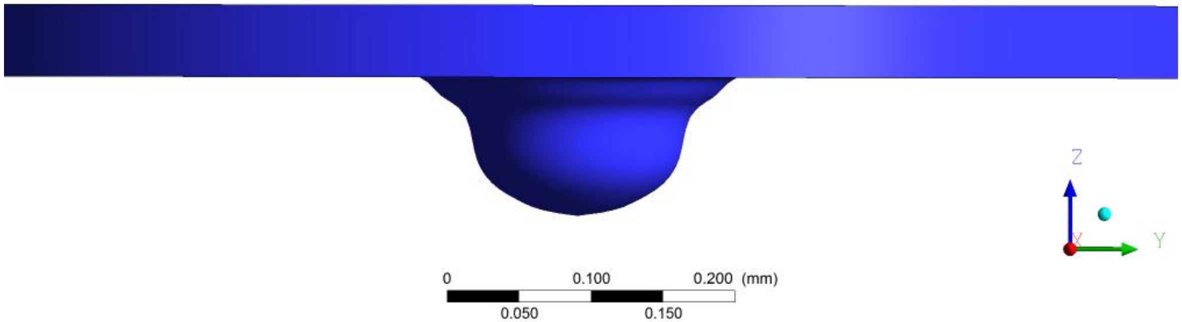
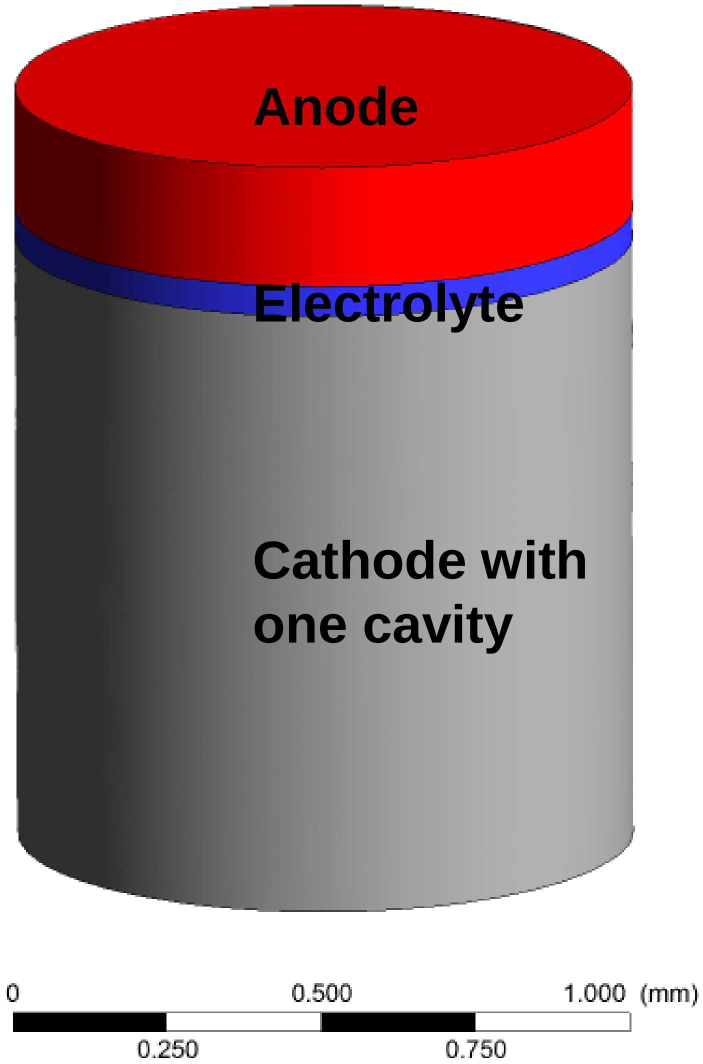
IWU

Micro-Calotte validation case:

- Cathode with 97 identical cavities
- 6 different process parameter sets
  - voltage and feed rate values
- Simulation of one cavity:
  - cylindrical part of anode, electrolyte and cathode with 1 mm diameter
  - initial distance of electrodes: 50 µm
  - cavity depth: 94 µm





CFD simulation of ECM
Validation case: Micro-Calotte

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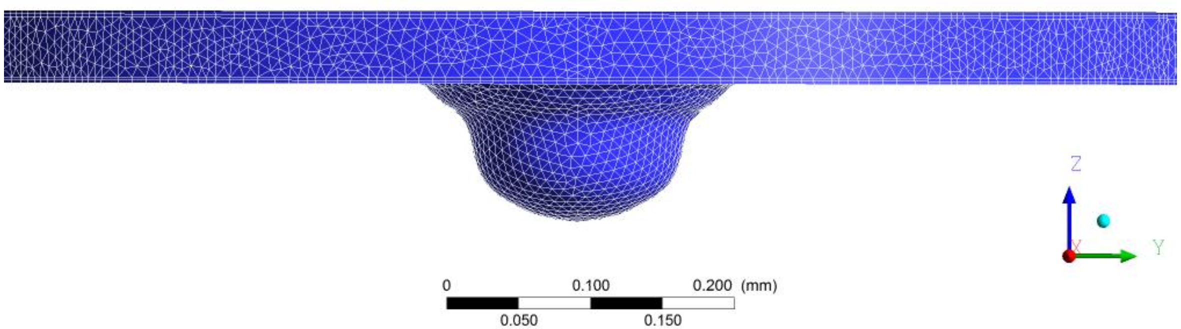
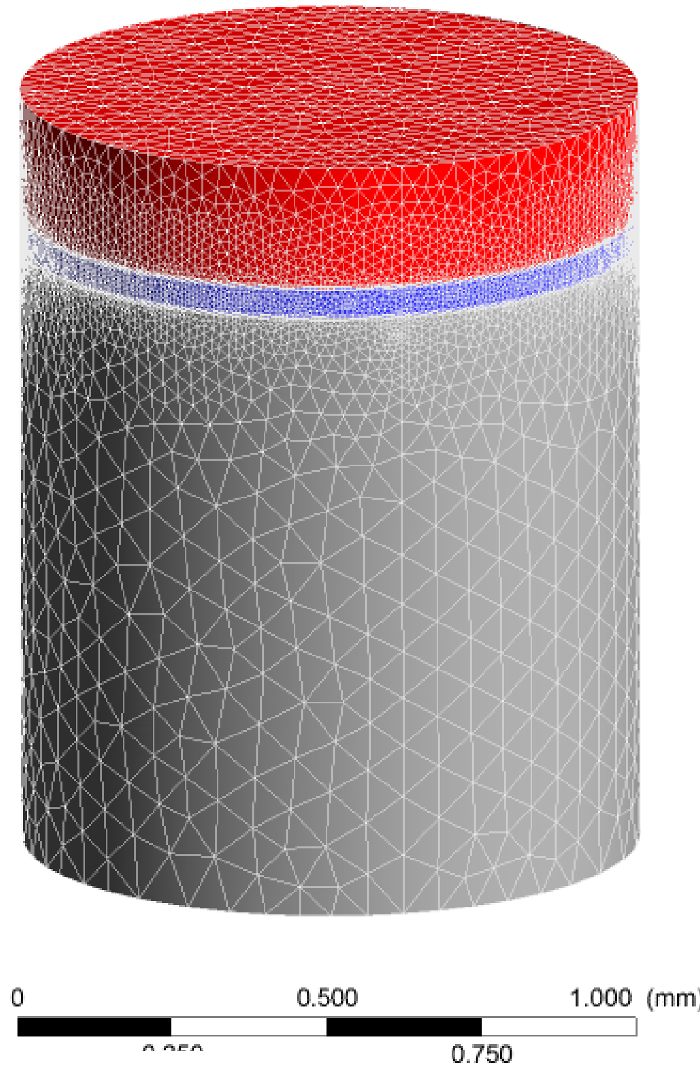
Micro-Calotte validation case:

- Cathode with 97 identical cavities
- 6 different process parameter sets
  - voltage and feed rate values
- Simulation of one cavity:
  - cylindrical part of anode, electrolyte and cathode with 1 mm diameter
  - initial distance of electrodes: 50 µm
  - cavity depth: 94 µm
  - meshed with tetras/prisms

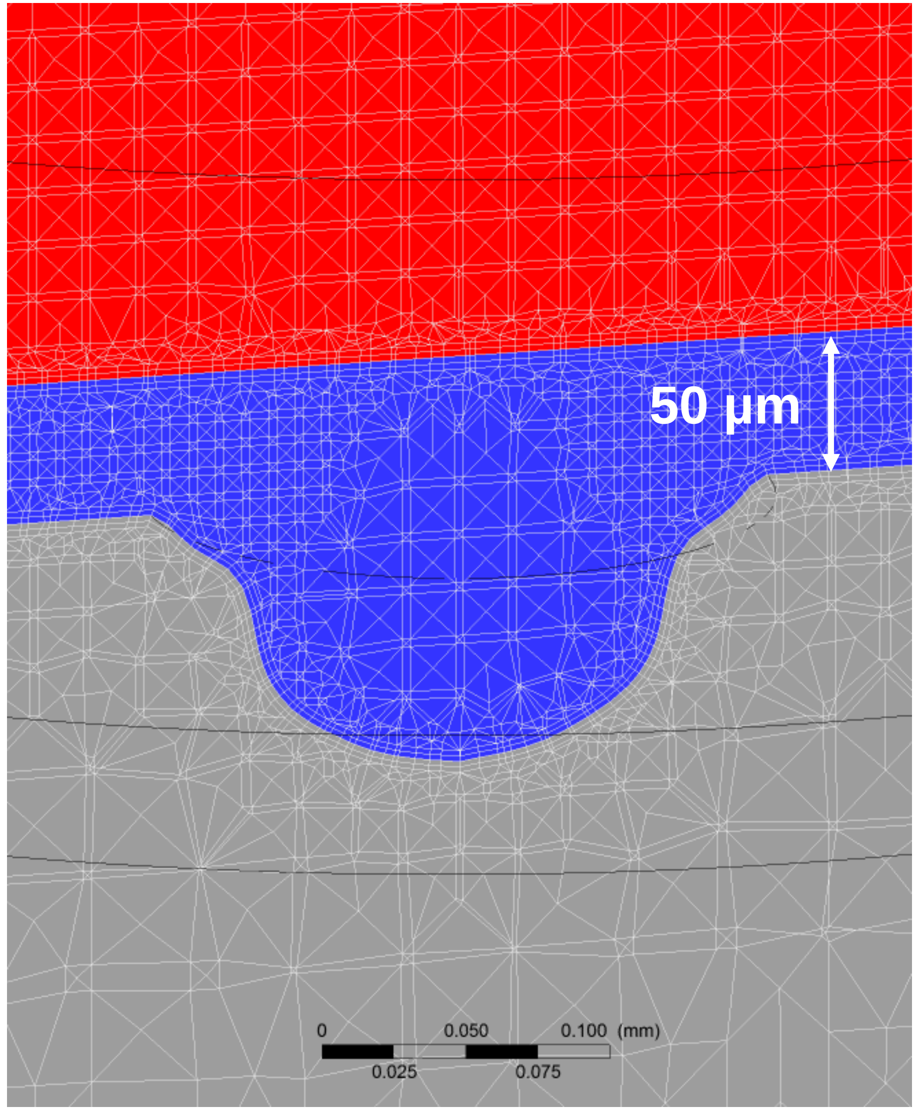




CFD simulation of ECM
Validation case: Micro-Calotte

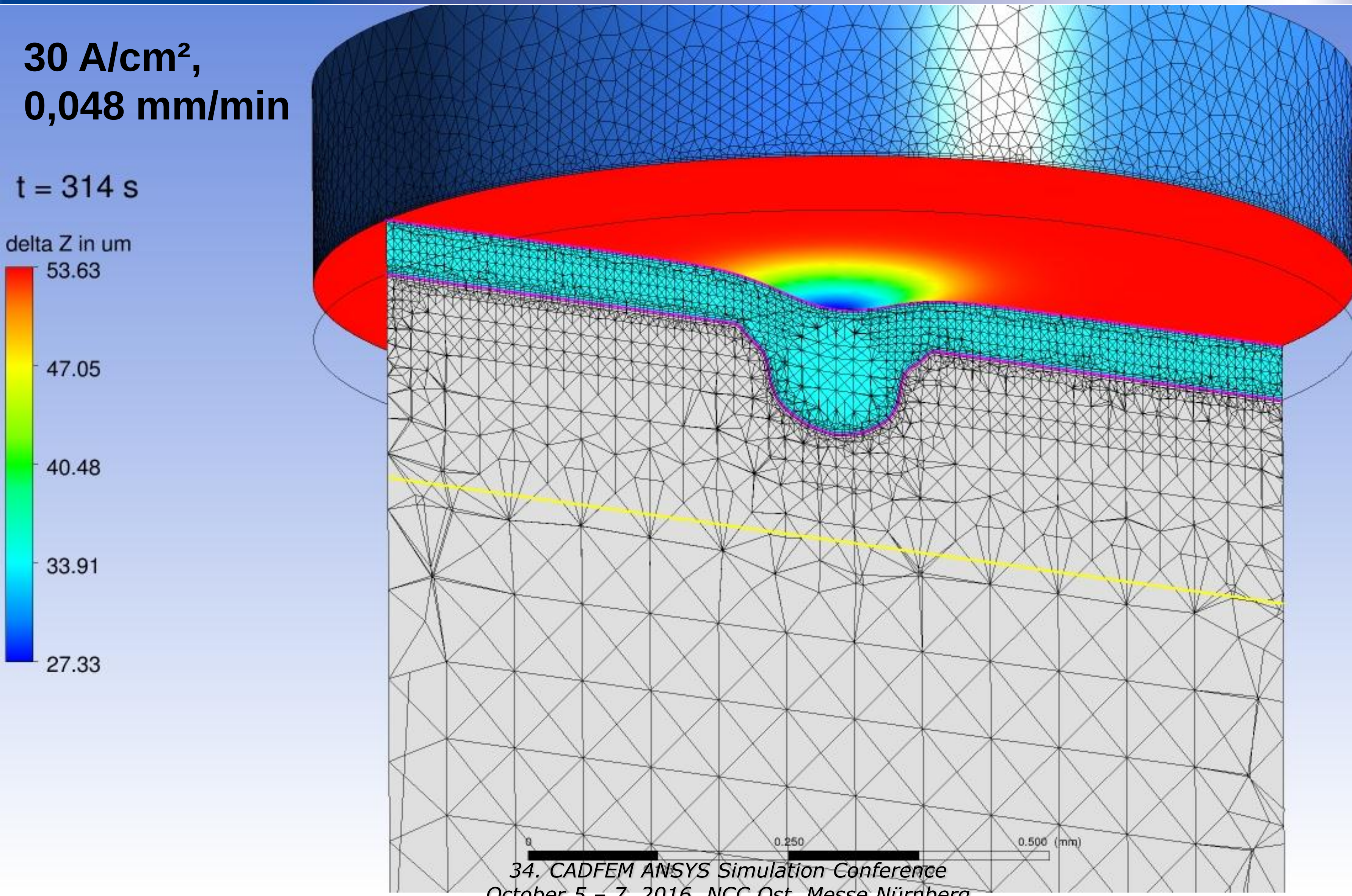
Micro-Calotte validation case:

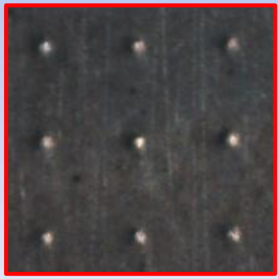
- Cathode with 97 identical cavities
- 6 different process parameter sets
  - voltage and feed rate values
- Simulation of one cavity:
  - cylindrical part of anode, electrolyte and cathode with 1 mm diameter
  - initial distance of electrodes: 50 µm
  - cavity depth: 94 µm
  - meshed with tetras/prisms
  - good resolution of 50 µm gap



CFD simulation of ECM
Validation case: Micro-Calotte

30 A/cm², 0,048 mm/min





CFD simulation of ECM
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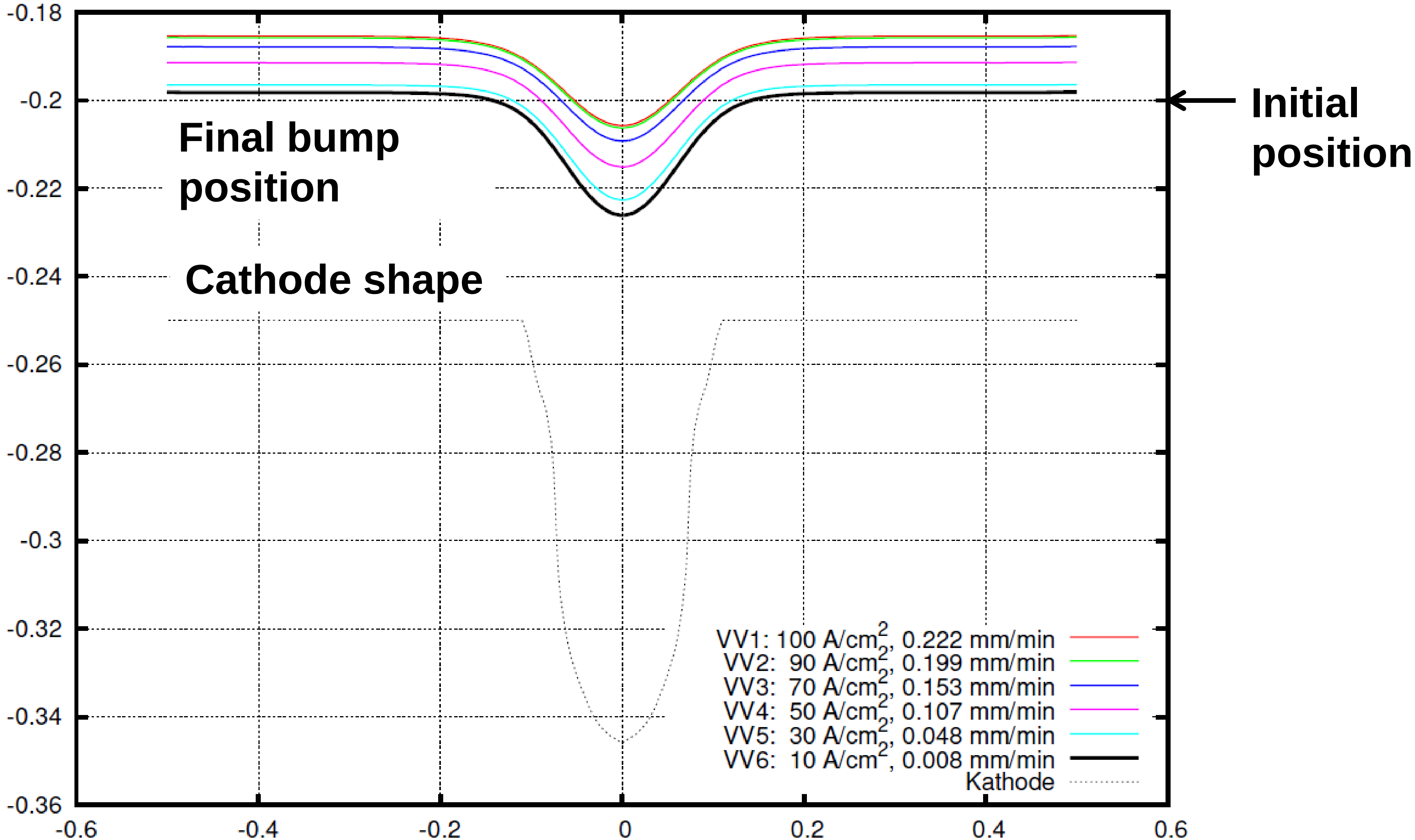

CFD simulation of ECM
Validation case: Micro-Calotte

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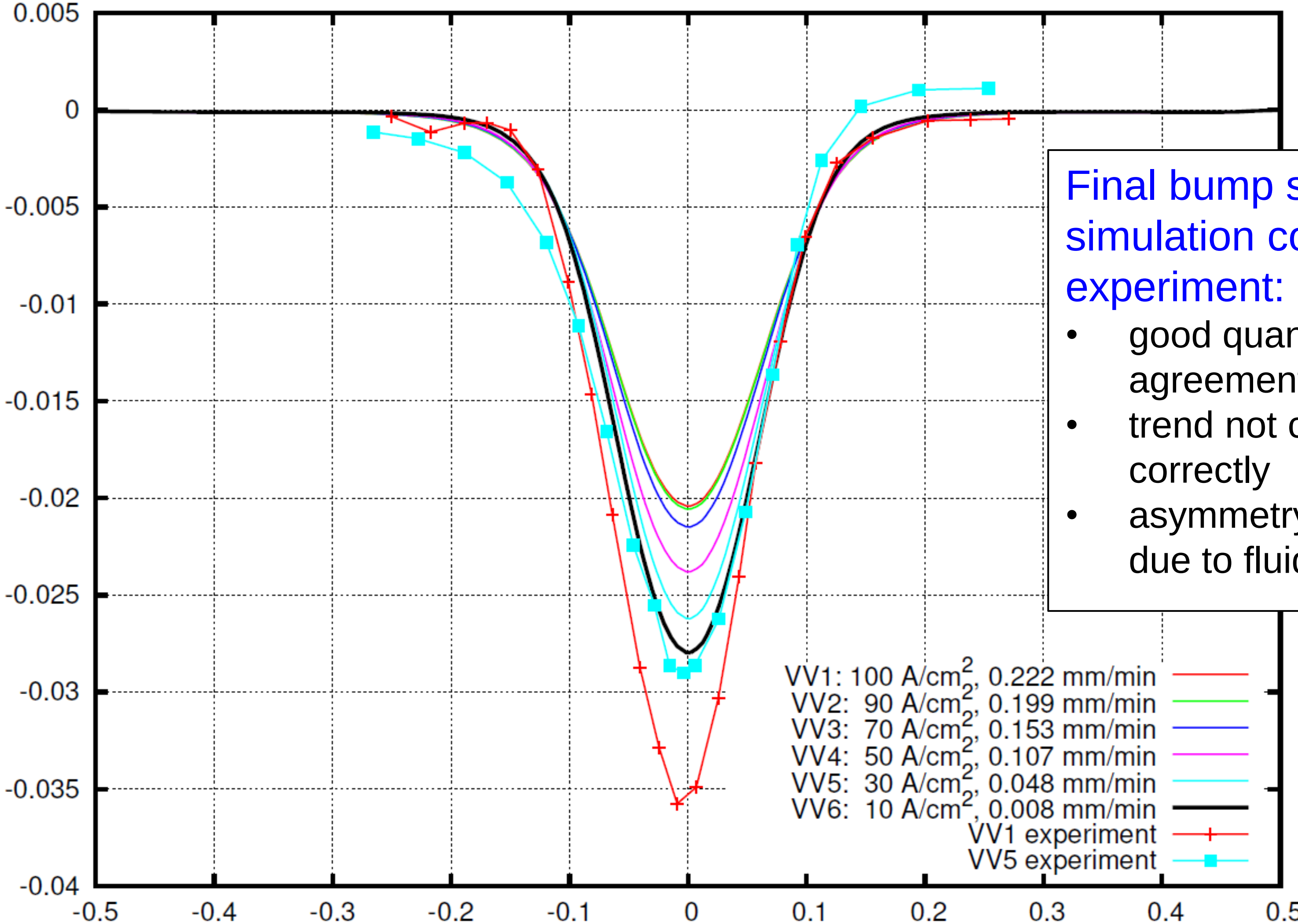


Final bump shape in simulation compared to experiment:

- good quantitative agreement
- trend not captured correctly
- asymmetry in experiment due to fluid flow

Macro-sphere validation case:

- Cathode as half-sphere
  - with radius 20 mm
  - and boring of radius 3 mm
- Anode:
  - initially flat with boring of radius 5 mm
- ECM process:
  - approx. 300 µm gap size
  - 6 mm sinking depth
  - two steps for rough and fine machining

Cathode

SITEC

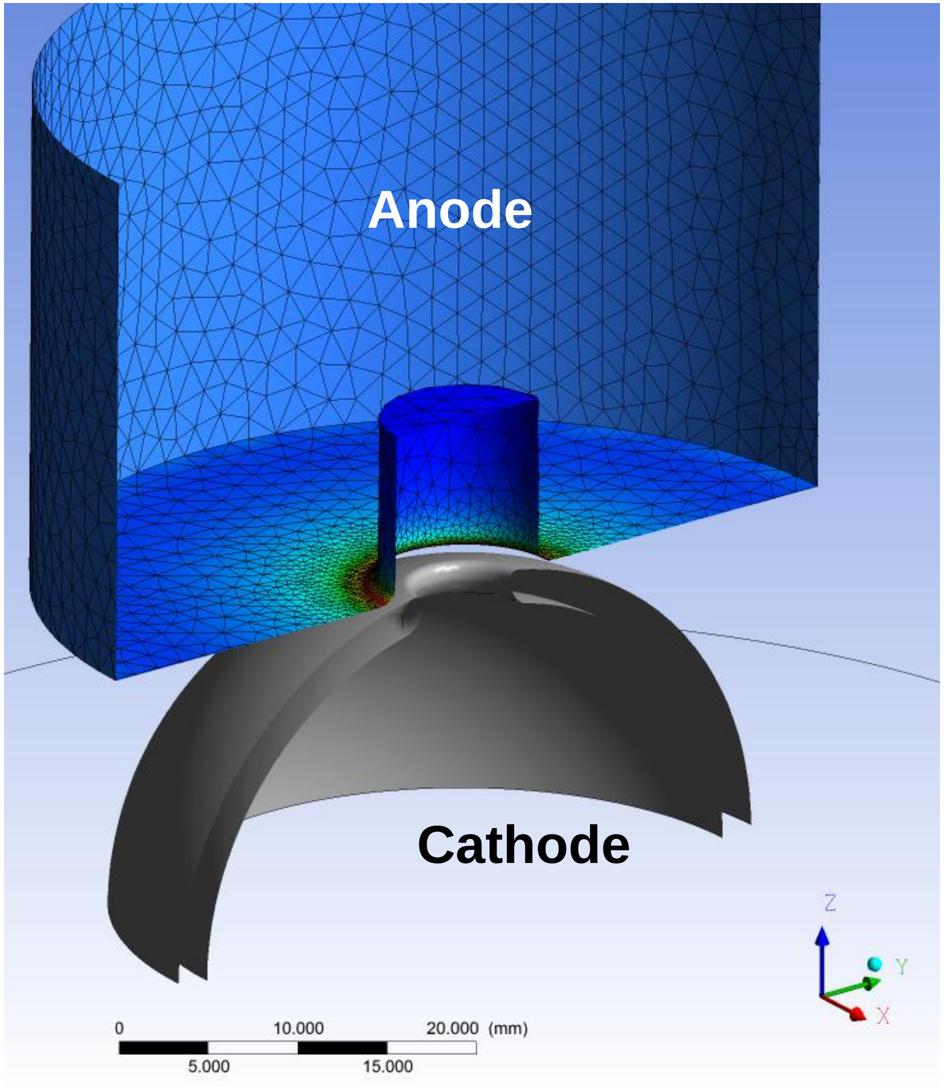
Final shape of anode

CFD simulation of ECM
Validation case: Macro-Sphere

CFX Berlin

Macro-sphere validation case:

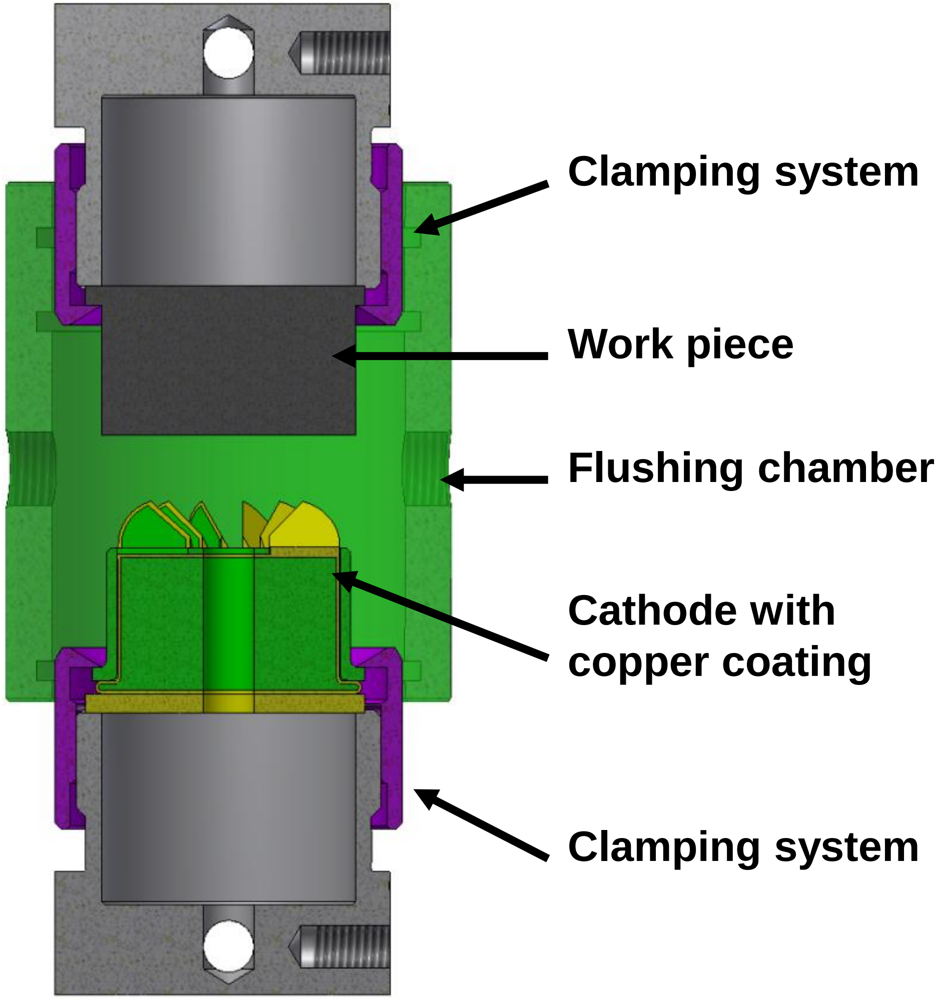
- Cathode as half-sphere
  - with radius 20 mm
  - and boring of radius 3 mm
- Anode:
  - initially flat with boring of radius 5 mm
- ECM process:
  - approx. 300 µm gap size
  - 6 mm sinking depth
  - two steps for rough and fine machining
- ECM simulation:
  - Simplified cathode shape



CFD simulation of ECM
Validation case: „Retarder“

Geometry for an ECM process:

- workpiece
  - of steel
- flushing chamber
  - for electrolyte with through-flushing and outlets at sides
- cathode
  - complex geometry with sharp edges and copper coating



CFD simulation of ECM
Validation case: „Retarder“

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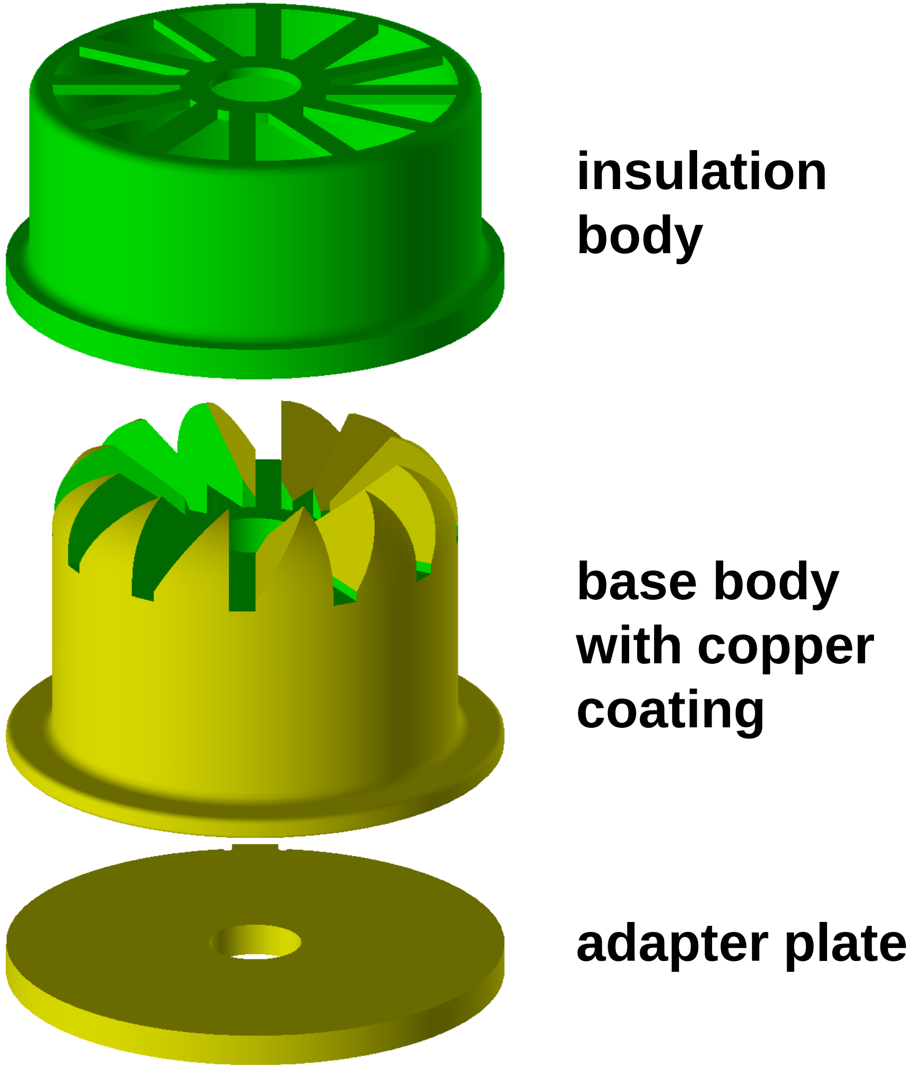
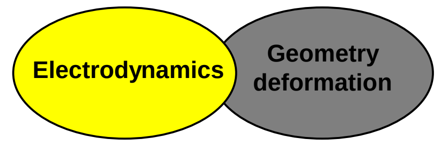
Geometry for an ECM process:

- workpiece
  - of steel
- flushing chamber
  - for electrolyte with through-flushing and outlets at sides
- cathode
  - complex geometry with sharp edges and copper coating
  - consists of three parts:
    - adapter plate (stainless steel)
    - base body from Fused Deposition Modeling (plastic) with copper coating
    - insulation body from FDM (plastic)



Summary and outlook

- Research project SIREKA to optimise the ECM design process:
  - Experimentally determined dissolving material characteristics
  - Numerical 3D simulation of ECM process with validation cases
  - Rapid prototyping with Fused Deposition Modeling and selective copper coating
- Simulations of ECM process with ANSYS CFX:
  - Solution for electric potential and mesh deformation only
  - Script-based solution workflow with remeshing
  - Applied on verification and validation cases



- Next steps:
  - Validation on micro and macro geometry and retarder
  - Optimisation of process parameters and/or cathode shapes
  - Export of optimised cathode shape towards rapid prototyping → validation

➢ Extension to fully coupled system for ECM processes including electrolyte flow and material and heat transport