INP
FROM IDEA TO PROTOTYPE

DEHN

Simulation of the Arc Motion in Low-Voltage Surge Protection Devices

M. Baeva[1], M. Hanning[2], R.Methling[1], D. Uhrlandt[1], D. Gonzalez[1], A. Ehrhardt[2]
[1] Leibniz Institute for Plasma Science and Technology (INP), Greifswald, Germany
[2] DEHN SE , Neumarkt, Germany

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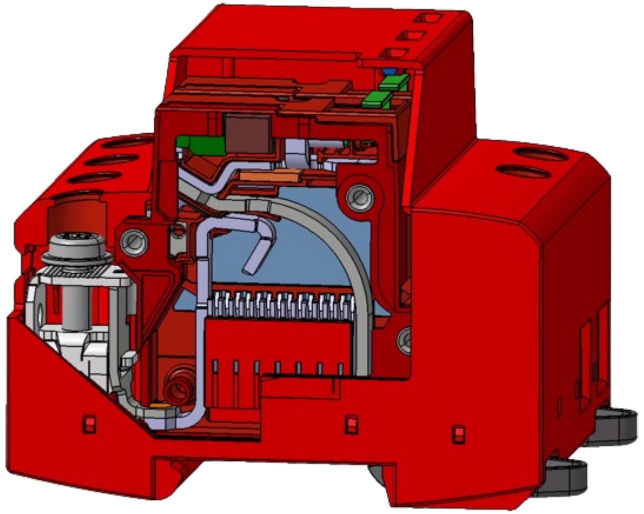
Introduction and motivation

- Spark gap based Surge Protection Devices (SPD) are used to reduce voltage surges preventing damages in electric industrial and housing grids
- Electric arc is generated after flashover
- Leaves a channel that can lead to a subsequent fault-current!
- The arc has to be extinguished, e.g., by elongation, cooling, splitting
- The arc development in SPD represents a multiphysics problem
  - electromagnetics
  - fluid flow
  - heat transfer
- In COMSOL Multiphysics we consider a 2D - planar and 3D geometry to describe the problem
- Validation by means of optical emission spectroscopy (OES)



Setup for a magnetohydrodynamic model

Arc motion
in air at atmospheric pressure

- Fluid flow
- Heat transfer
- Electromagnetics

Assumptions

- LTE plasma
- Laminar/Turbulent flow
- No transient electromagnetic effects

Material properties

$\rho(p,T)$ - mass density
$\sigma(p,T)$ - el. conductivity
$C_p(p,T)$ - heat capacity
$\kappa(p,T)$ - thermal conductivity
$\eta(p,T)$ - viscosity
$Q_r(p,T)$ - radiative losses

Mass continuity

$$\frac{\partial \rho}{\partial t} + \nabla\cdot(\rho\boldsymbol{u}) = 0$$

Momentum

$$\rho\frac{\partial \boldsymbol{u}}{\partial t} + \rho(\boldsymbol{u}\cdot\nabla)\boldsymbol{u} = \nabla\cdot[-p\boldsymbol{I}+\boldsymbol{K}]+\boldsymbol{F}$$

Current continuity

$$\nabla\cdot\boldsymbol{j} = 0$$

Ohm’s law

$$\boldsymbol{j} = \sigma\boldsymbol{E} + \boldsymbol{j}_e, \boldsymbol{E} = -\nabla V$$

Energy

3D

$$\rho c_p\frac{\partial T}{\partial t} + \rho c_p\boldsymbol{u}\cdot\nabla\mathrm{T} + \nabla\cdot\boldsymbol{q} = Q$$

2D

$$d_z\rho c_p\frac{\partial T}{\partial t} + d_z\rho c_p\boldsymbol{u}\cdot\nabla\mathrm{T} + \nabla\cdot\boldsymbol{q} = d_z Q$$

Maxwell equations

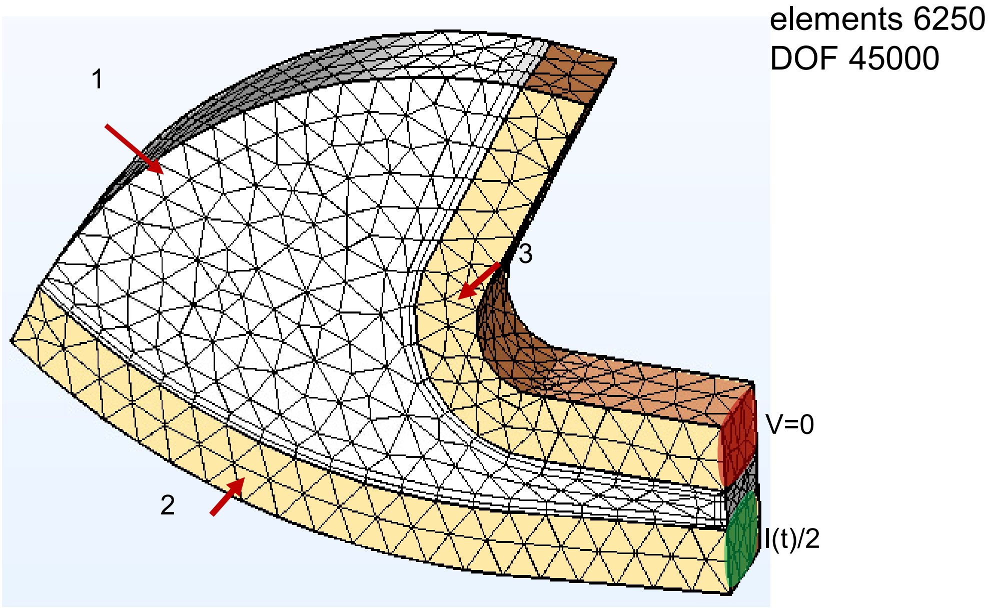
$$\nabla\times\frac{1}{\mu_0\mu_r}\boldsymbol{B} = \boldsymbol{j}$$

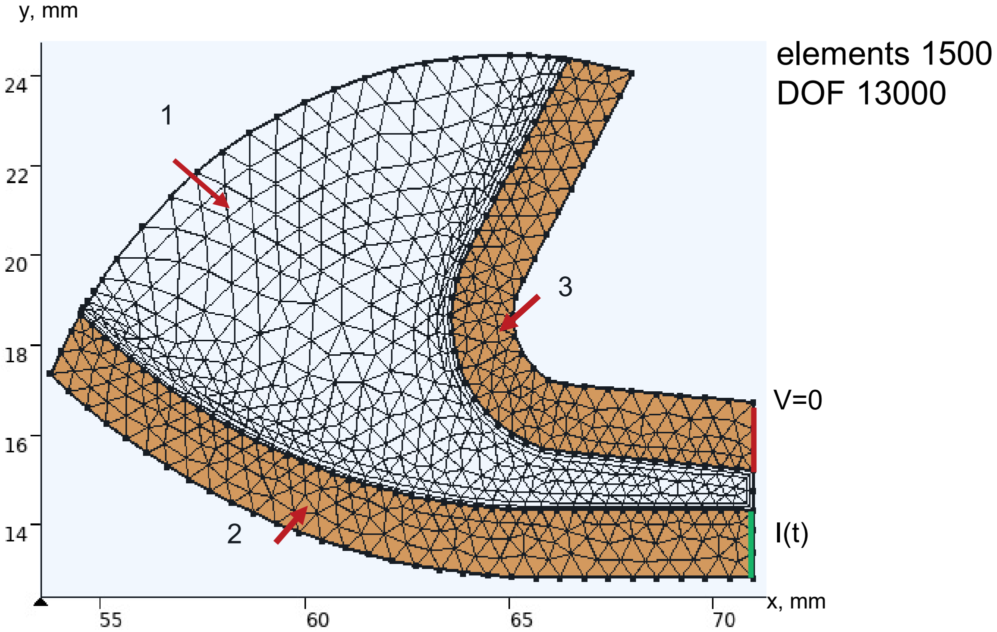
$$\mathbf{B} = \nabla\times\boldsymbol{A}$$

2D-planar and in 3D geometry

3D in a half geometry (symmetry plane)

2D-planar

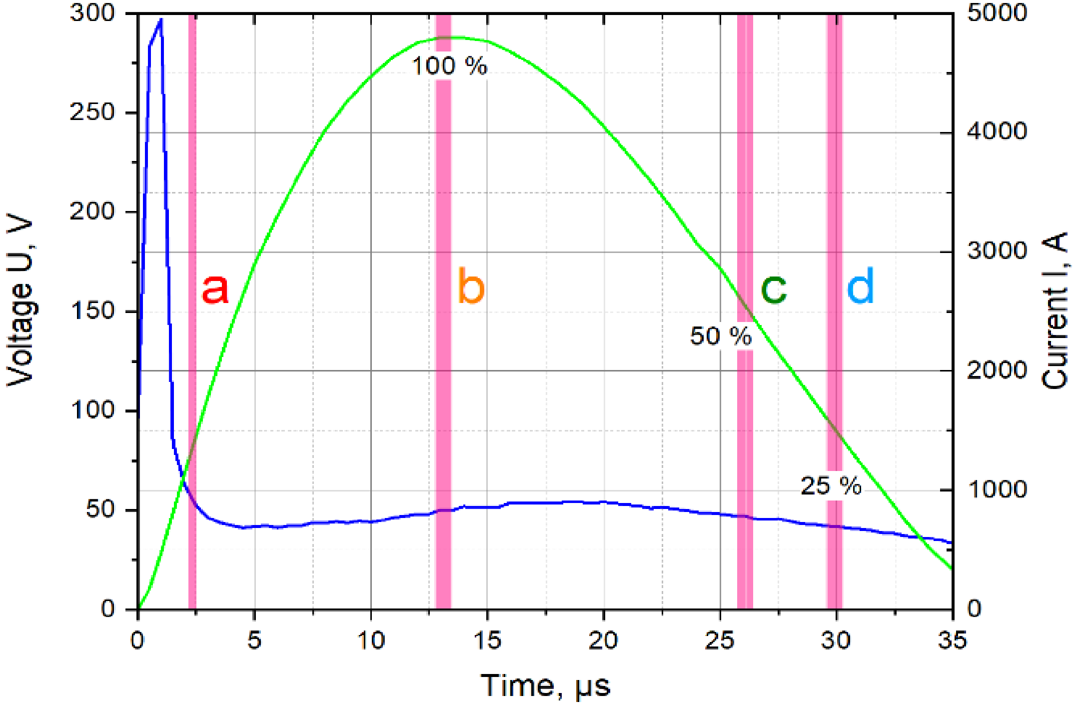


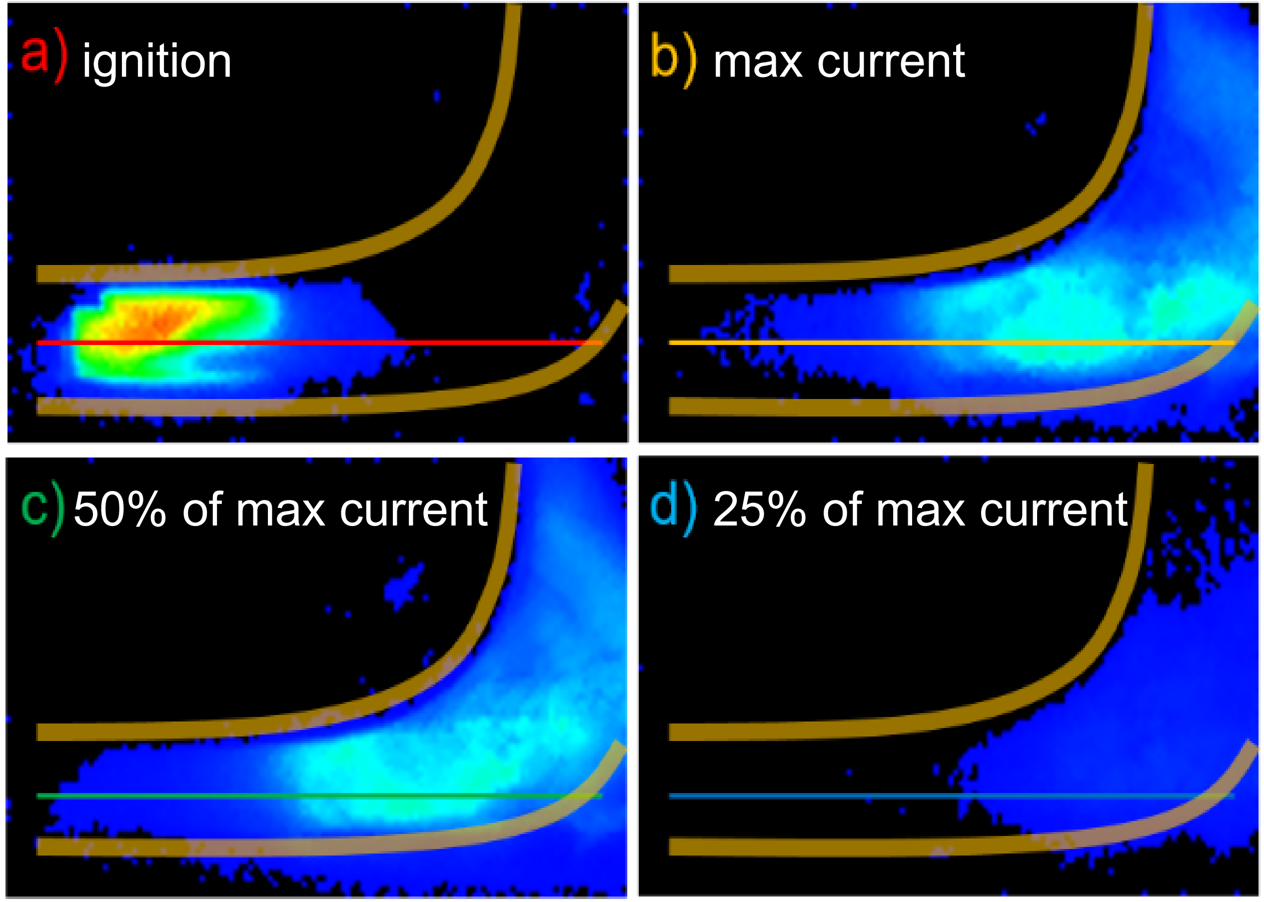


- region of fluid (1) filled with air
- arc runners (2, 3) made of copper
- grounded (*V*=0)
- terminal for the electric current I(t)

- repeating in the perpendicular direction
- considers the whole dickness of the device d_z
- the 3rd dimension is taken into account but not spatially resolved
- the results correspond to those in the symmetry plane of the 3D geomety

Electric current and arc-voltage/ High-speed imaging

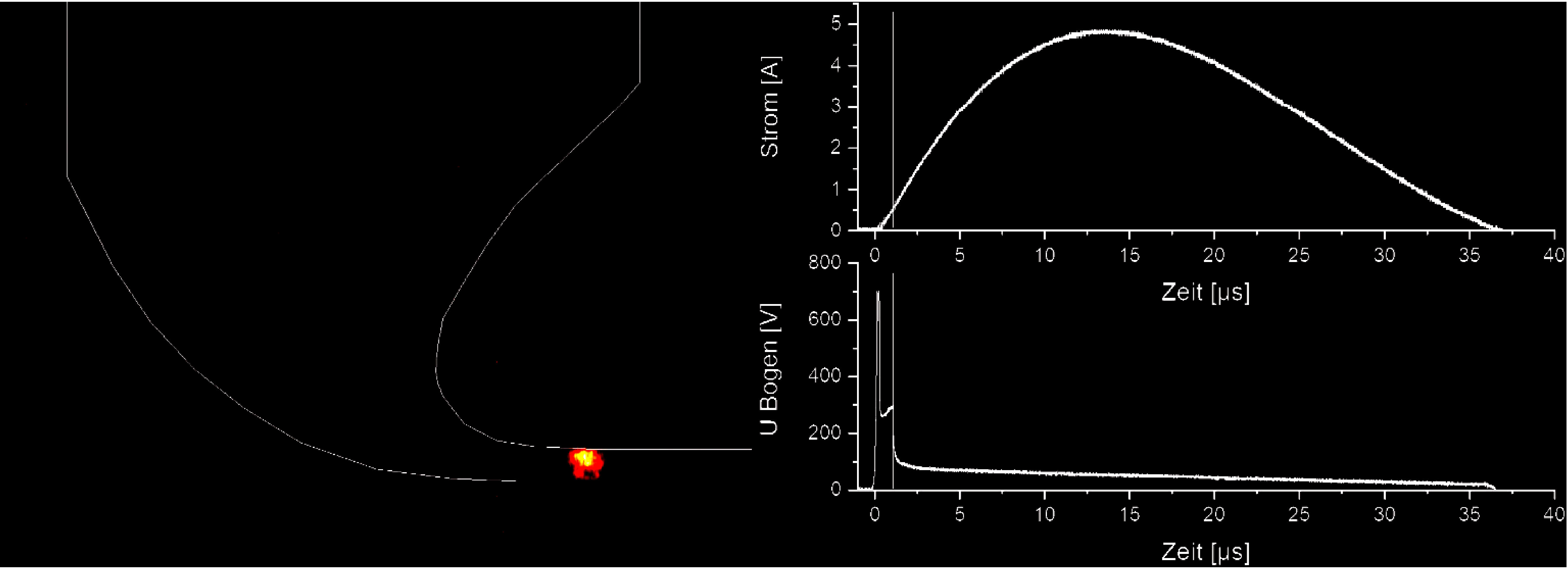




Time windows chosen for OES observations:

a – during ignition (2-3 µs);
b – around maximum current (13-14 µs);
c – decay to 50% of maximum current (25.5-26.5 µs);
d – decay to 25% of maximum current (29.5-30.5 µs).

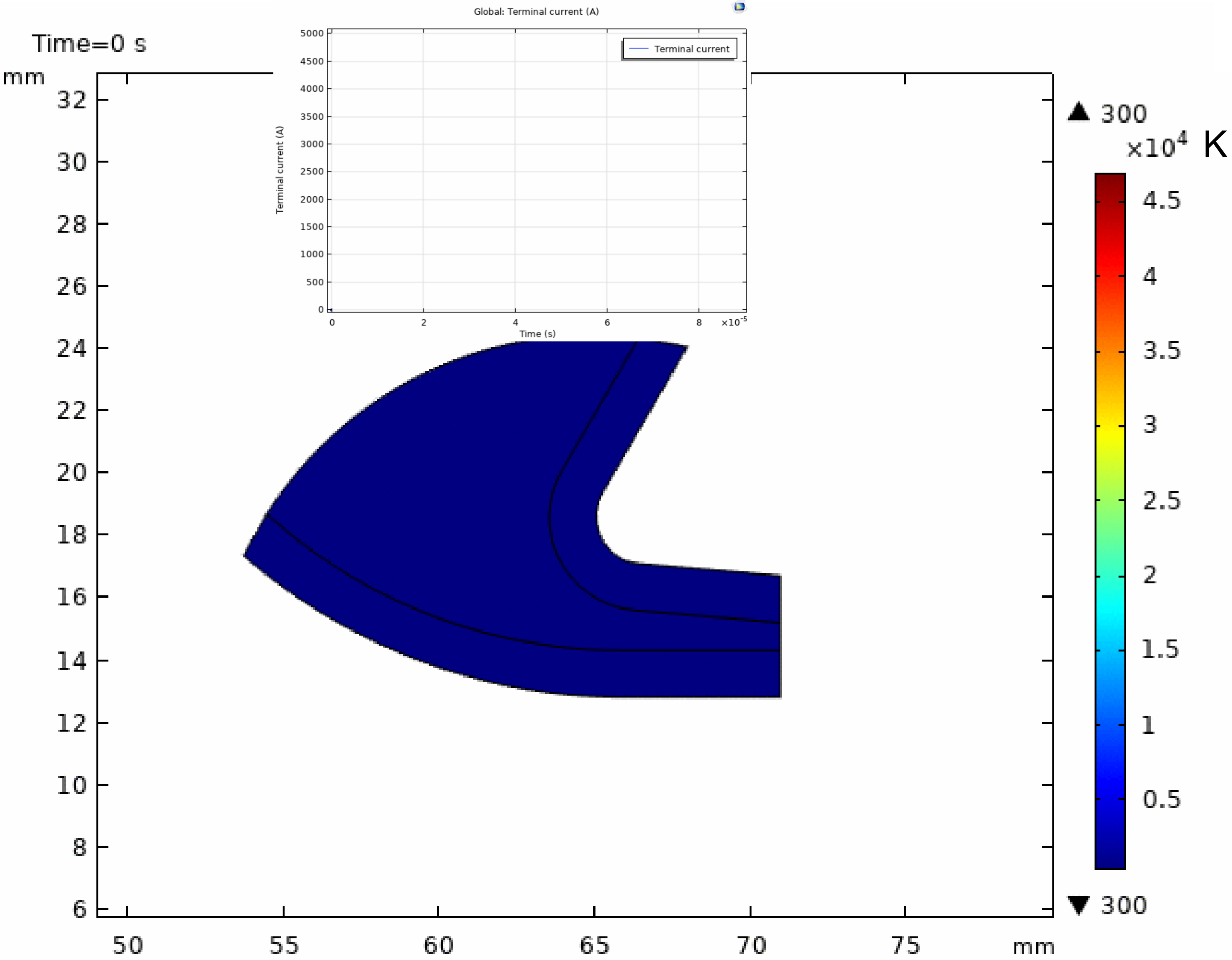
Arc appearance, current and voltage



Modelling results

Arc evolution from the 2D planar model

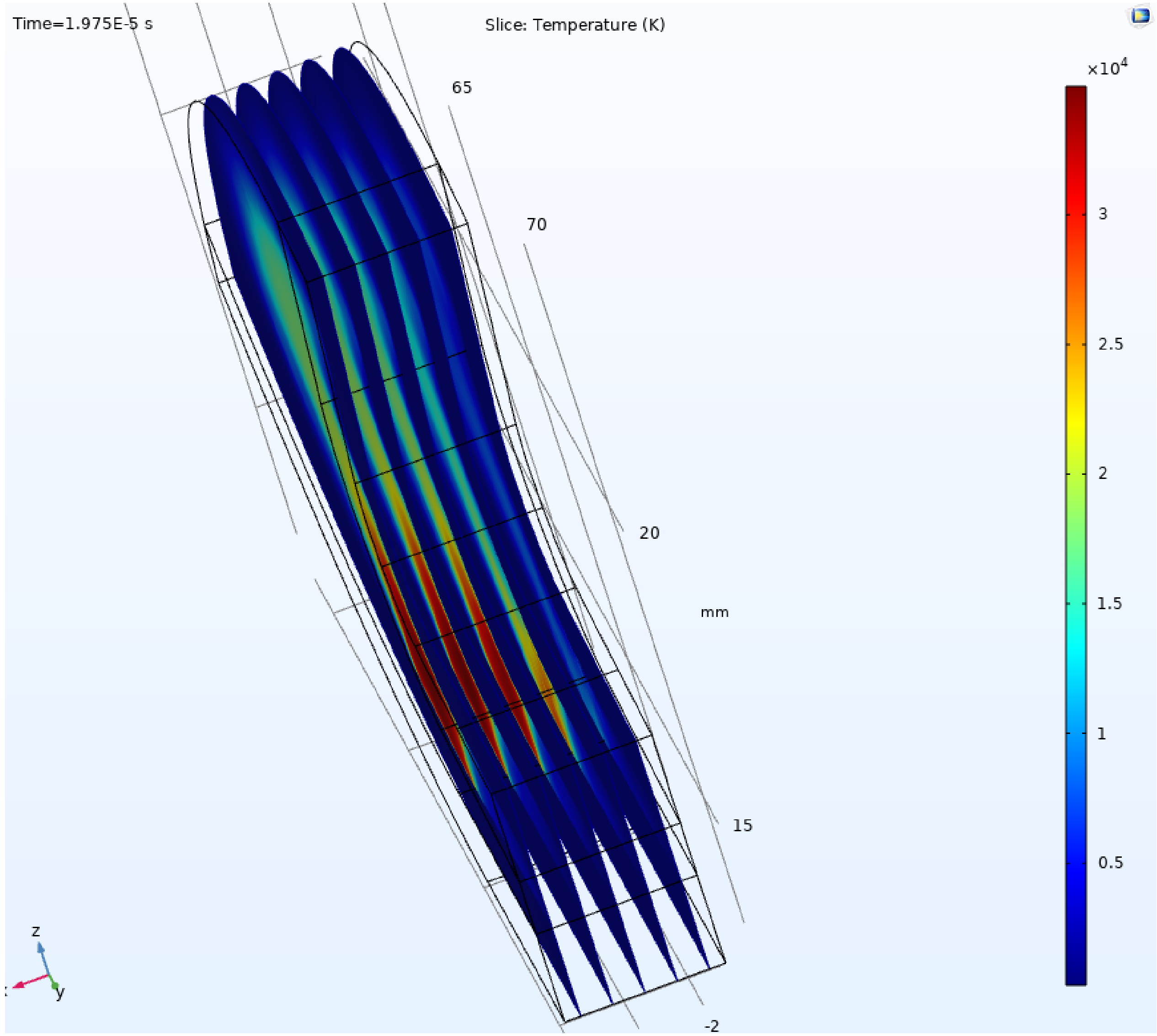
- Ignition in a conductive channel.
- Channel is switched off after T reaches 10^4 K (~3μs).
- Motion of the arc results from a 3D effect (the Lorenz force).



Modelling results

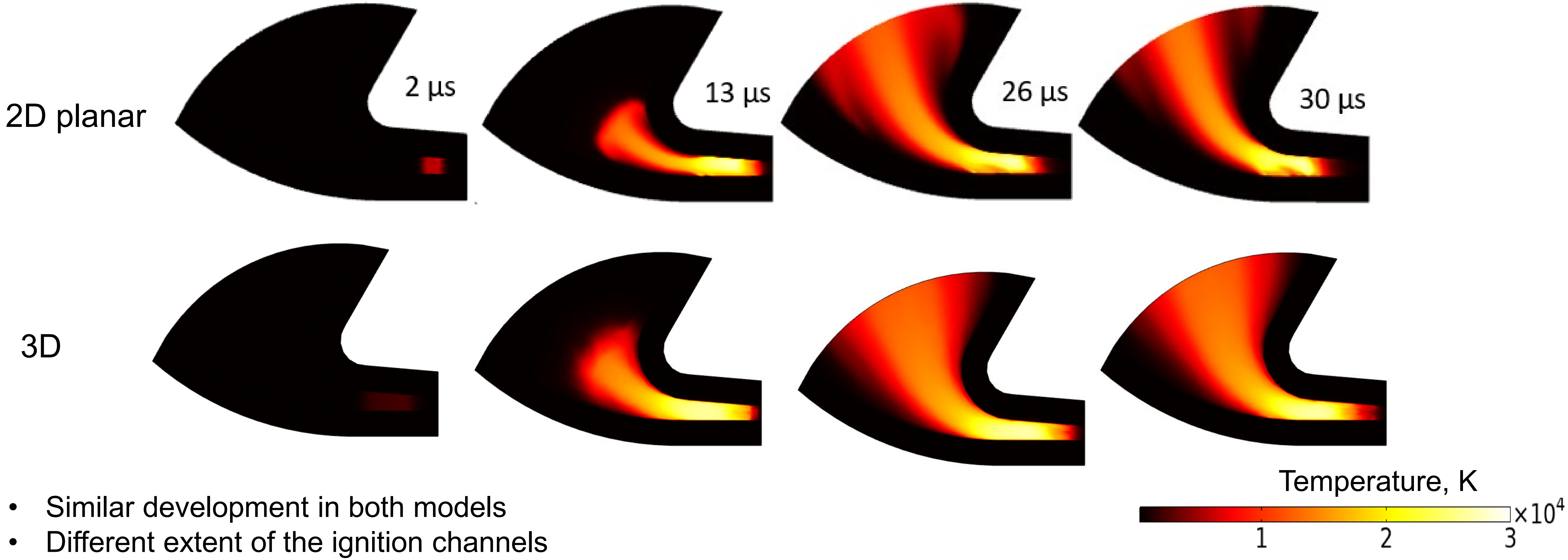
3D model

- Spatial distribution of the plasma temperature in several cut planes to the instant 19.75µs.
- Similar distribution for planes close to the plane of symmetry.
- Differences to the plane of symmetry become stronger pronounced towards the chamber wall.
- The plane of symmetry is repeated in the 2D planar model.



Modelling results

Snap-shots of the arc evolution



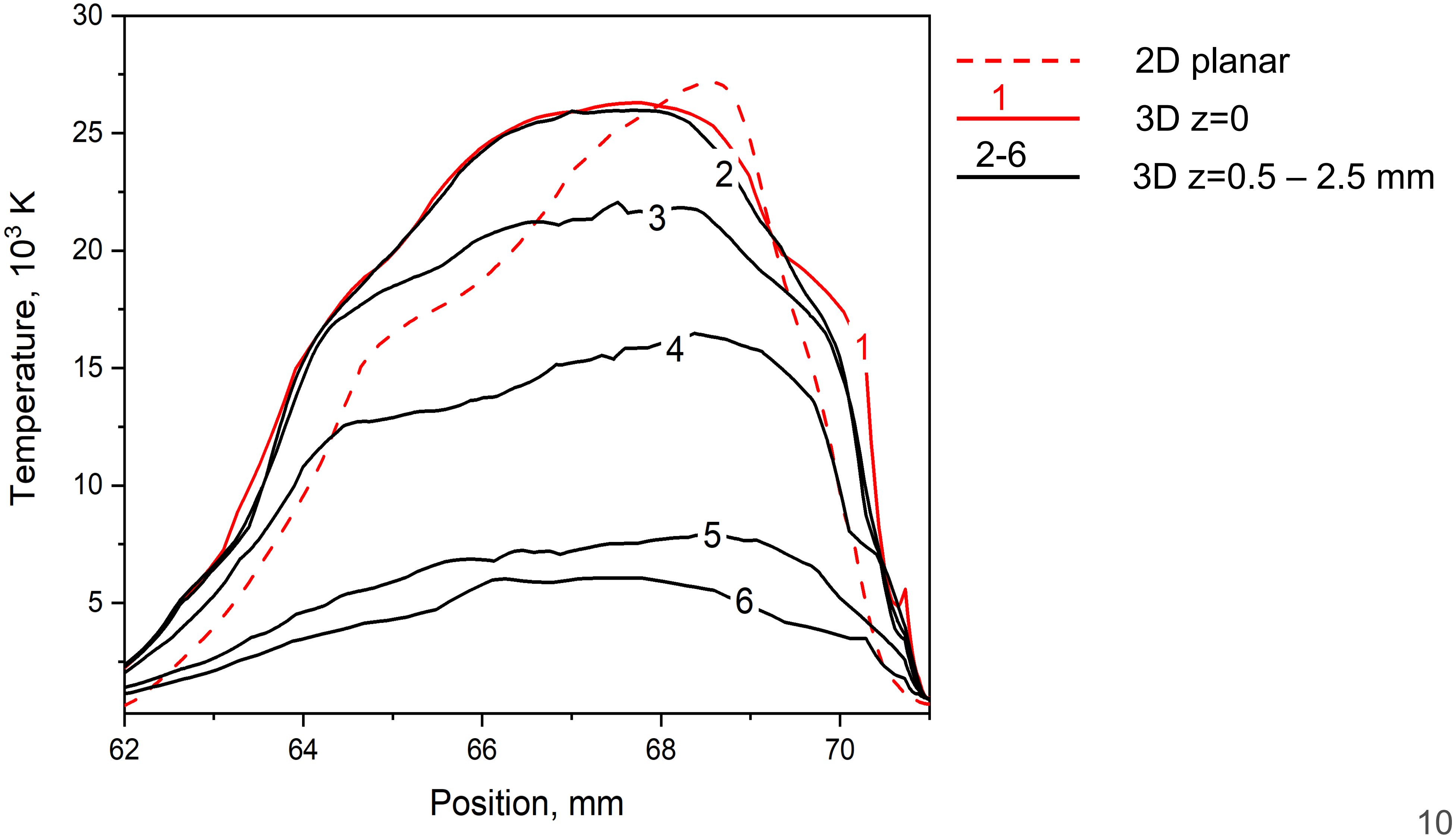
- Similar development in both models
- Different extent of the ignition channels
- More constricted channel in 2D provides a faster temperature increase
- Same arc motion after ignition
- Finer resolution in 2D – more details on the electrodes and towards the gas outflow

Modelling results

Spatial distribution of the plasma temperature along lines of sight

t=13 µs
(max current)

- Curves 1 and 2 almost overlap - there is no much difference in a thickness of 1 mm.
- Fair agreement with the 2D planar model.

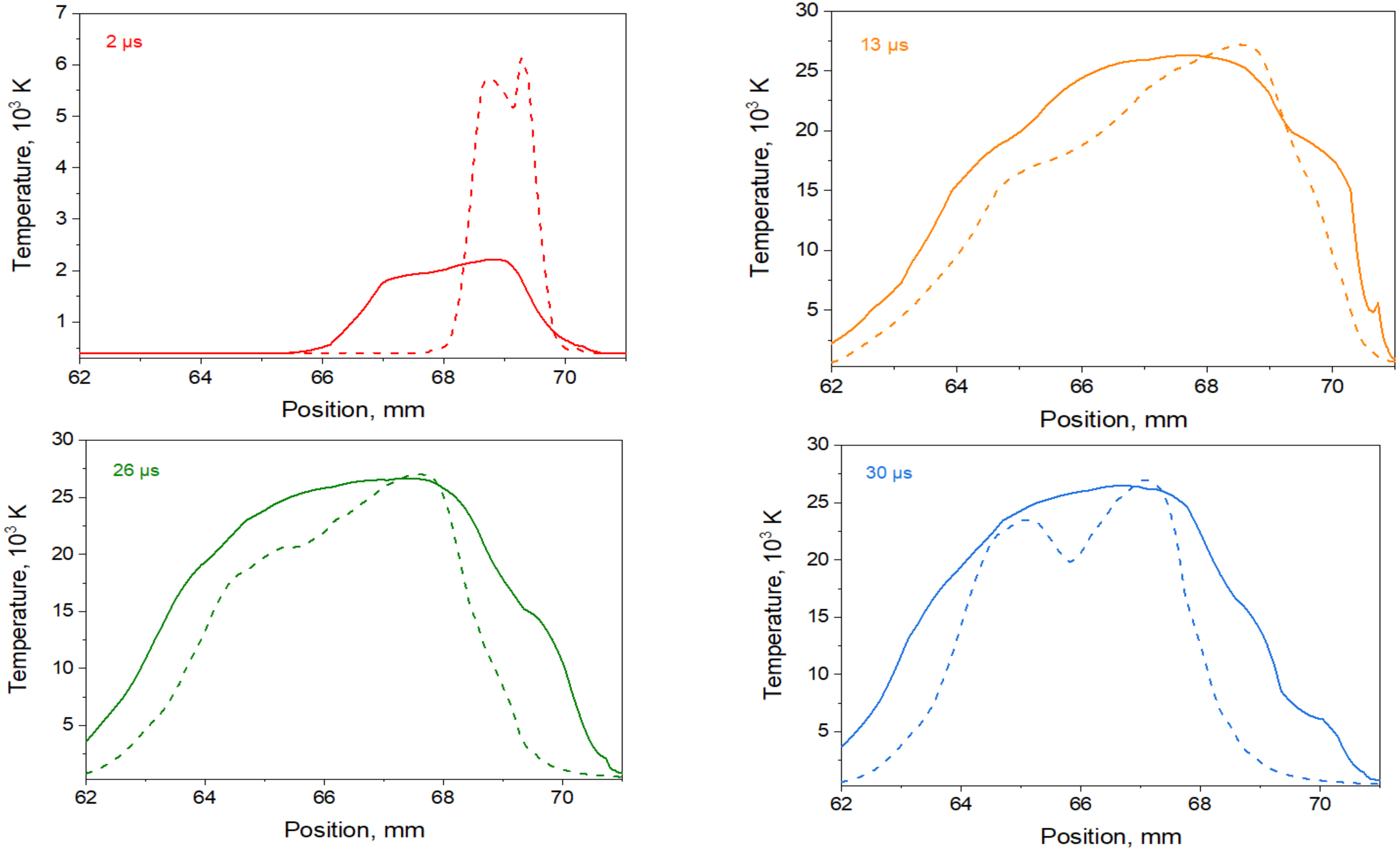


Modelling results

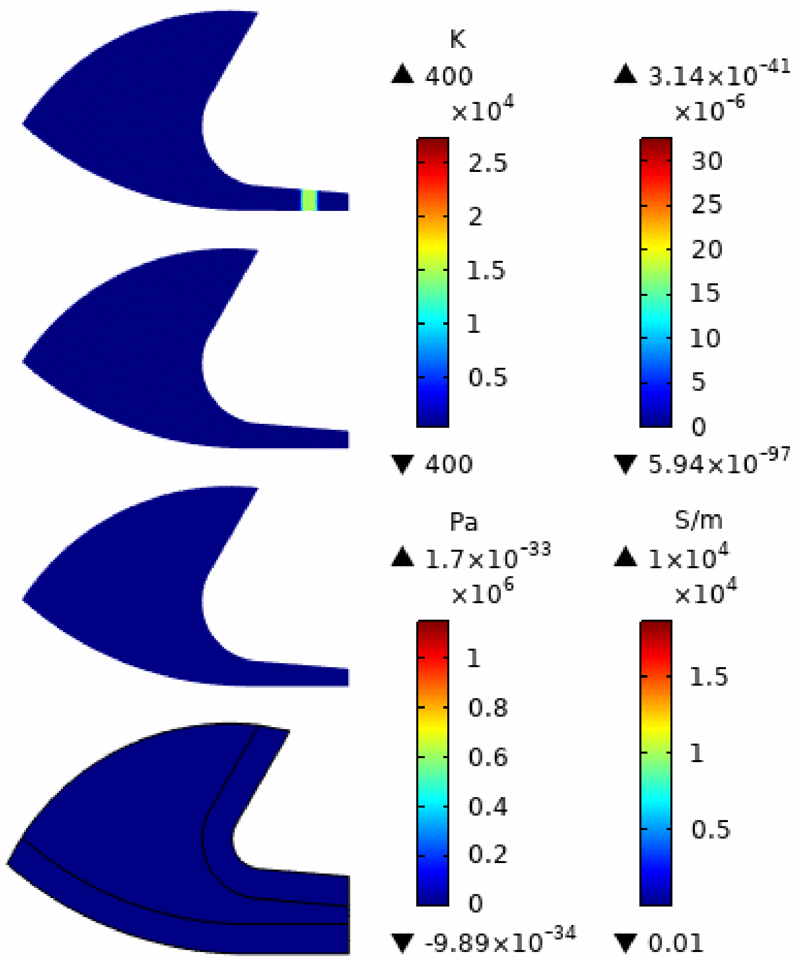
Spatial distribution of the plasma temperature along line of sight in the symmetry plane (3D) and in 2D

dashed – 2D planar model
solid – 3D model

- The results correlate with those from OES.
- Strongest emission within a distance of ca. 2 mm – the narrow ingnition channel in 2D agrees better with OES data.
- Similar max temperatues and a shift of the maximum due to the arc motion.



7. Summary



- Simulations of the arc motion in an interrupter with diverging metal runners by MHD models in 3D and 2D planar geometries.

- The 2D planar modelling approach can predict the arc properties and the arc motion in a good agreement with the results obtained in and close to the plane of symmetry in 3D modelling approach.

- Results from OES are presented to demonstrate the adequateness of the 2D planar modelling approach.

- 2D planar modelling can be used for preliminary developments to avoid long computational times.