Presented at the COMSOL Conference 2008 Hannover

Ferdinand-Braun-Institut
für Höchstfrequenztechnik

Ignition Process of Microplasmas

H. E. Porteanu, R. Gesche

...translating ideas into innovation

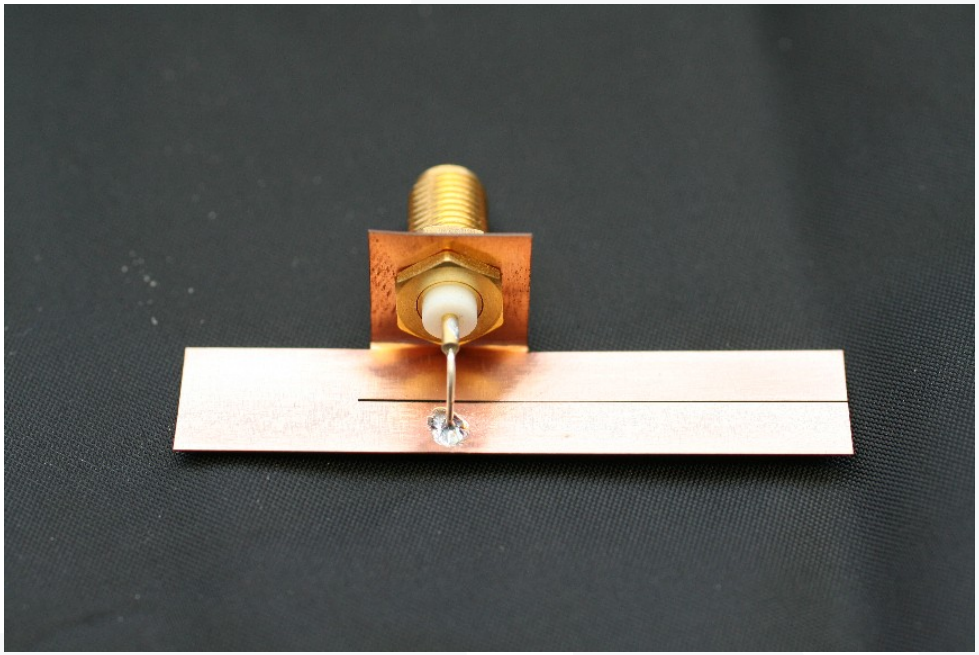
Outline

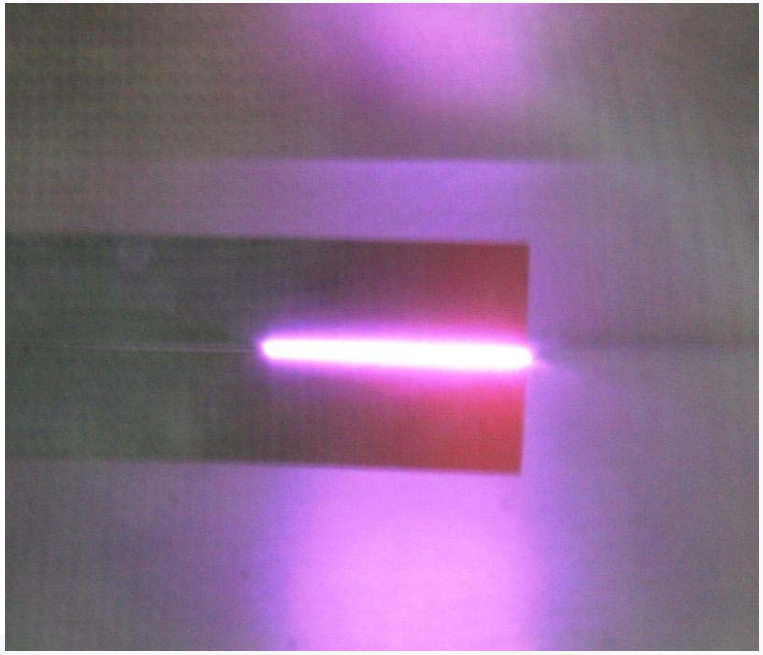
- Microplasma sources: motivation and solutions
- Choice of the simplified 2D model
- Implementation of the plasma equations
- Time dependencies (ignition process)
- Summary

Ferdinand-Braun-Institut
für Höchstfrequenztechnik

Microplasma sources: motivation

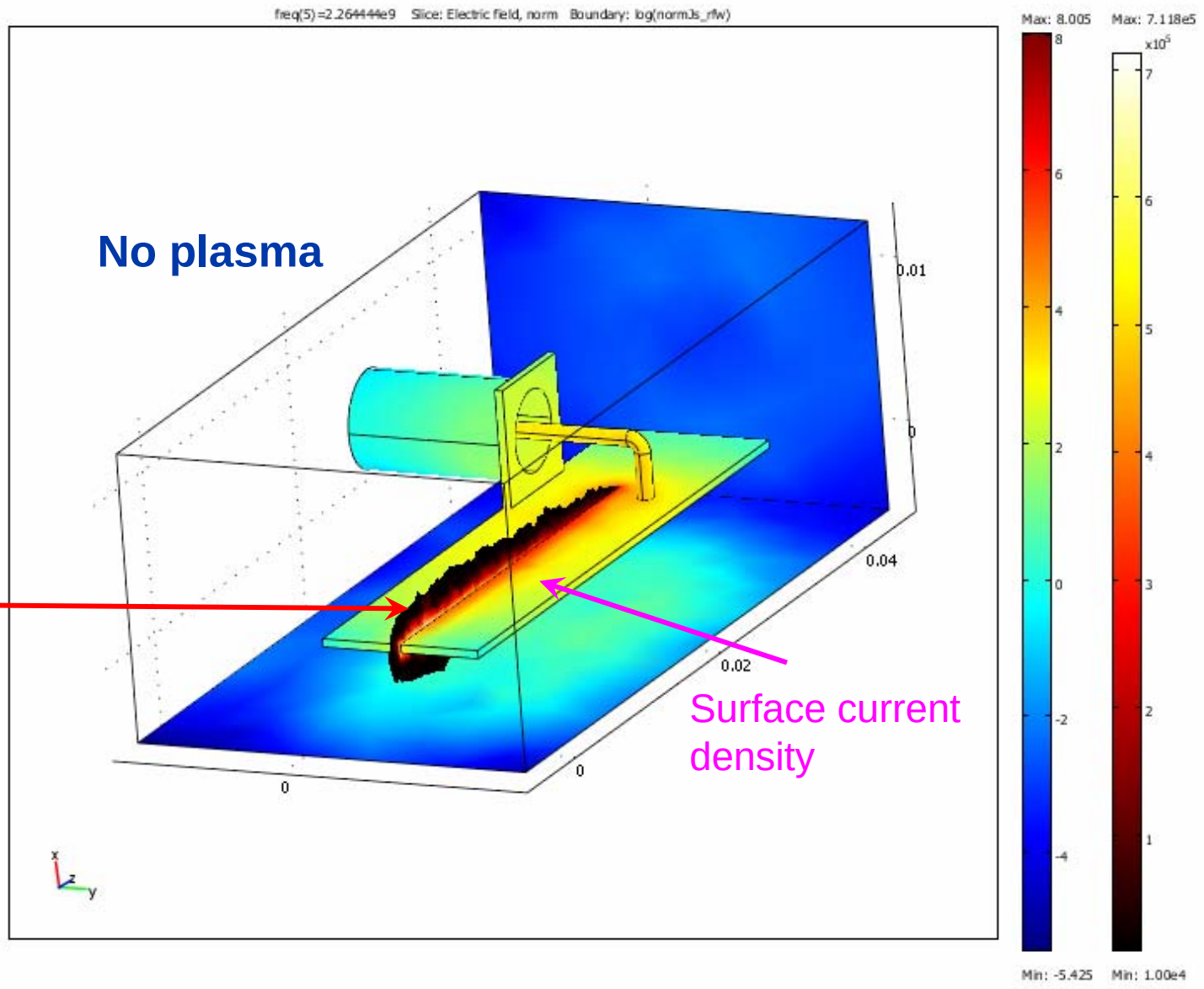
Technical applications require *microplasma* sources at *atmospheric* pressure. Example: the slot resonator





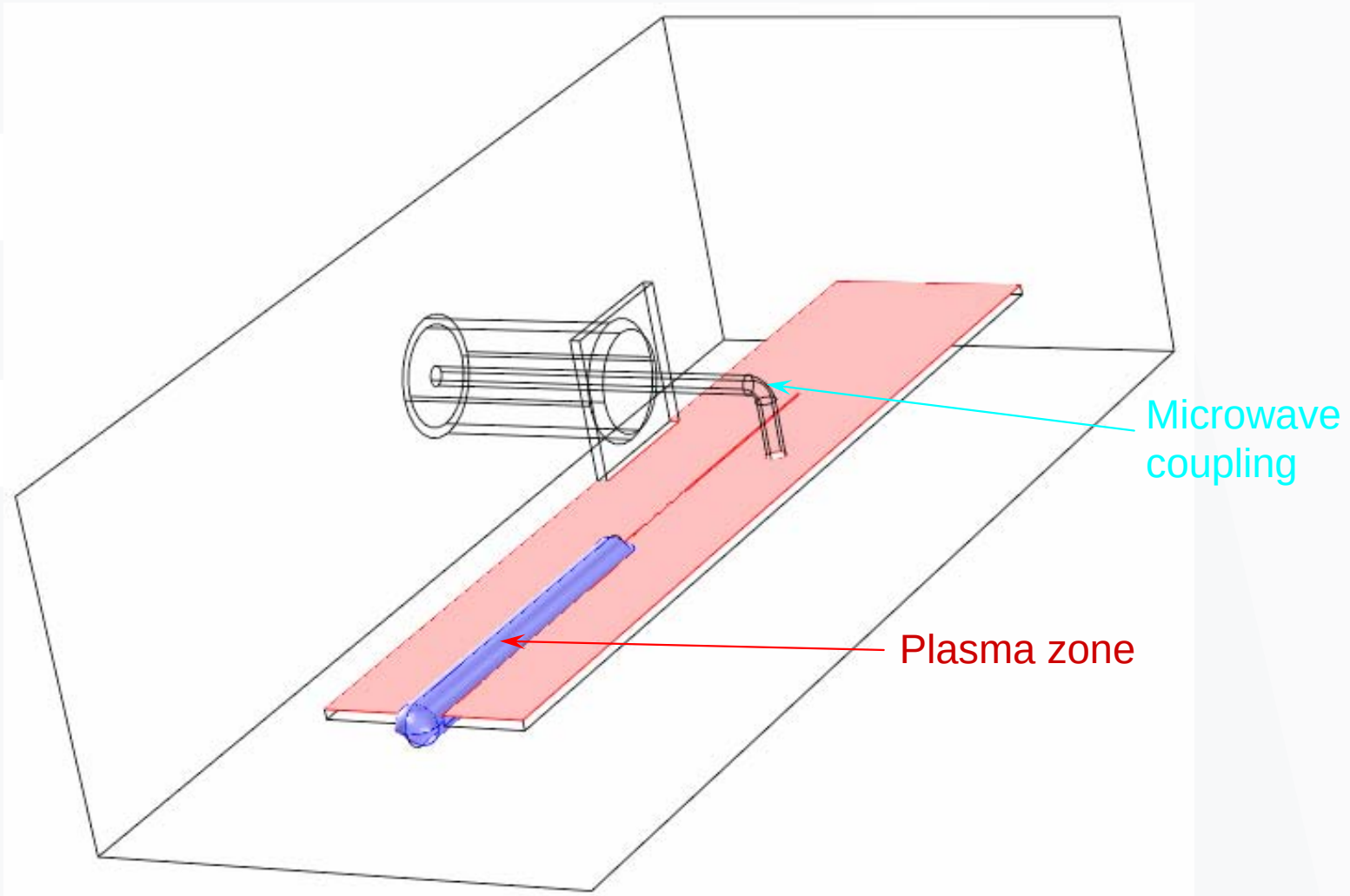
Circuit design is based on knowledge about plasma impedance (stationary) and ignition behavior (time dependent)

Microplasma sources: Comsol field simulations



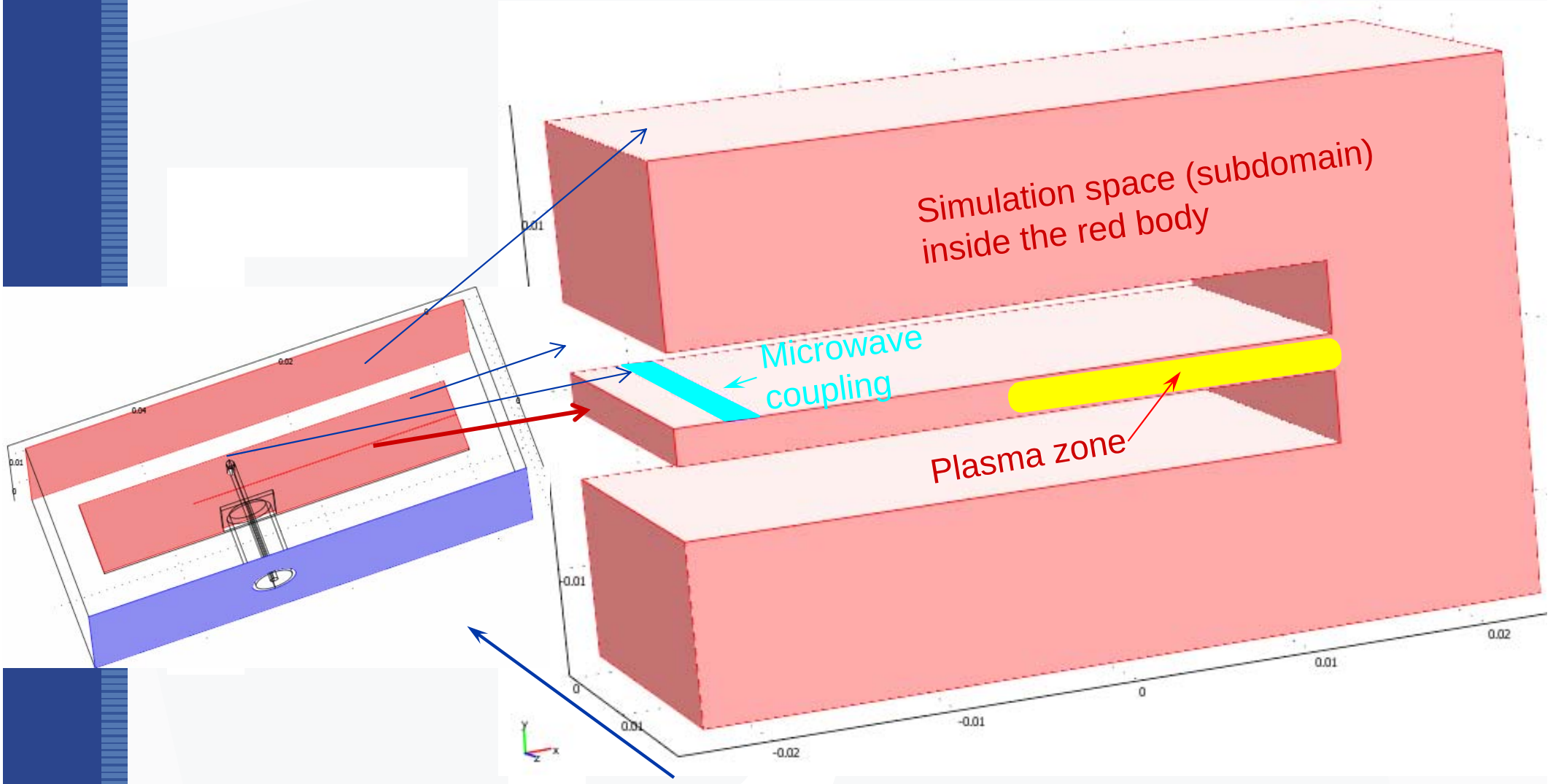
Ferdinand-Braun-Institut
für Höchstfrequenztechnik

Realistic 3D model with a complex geometry



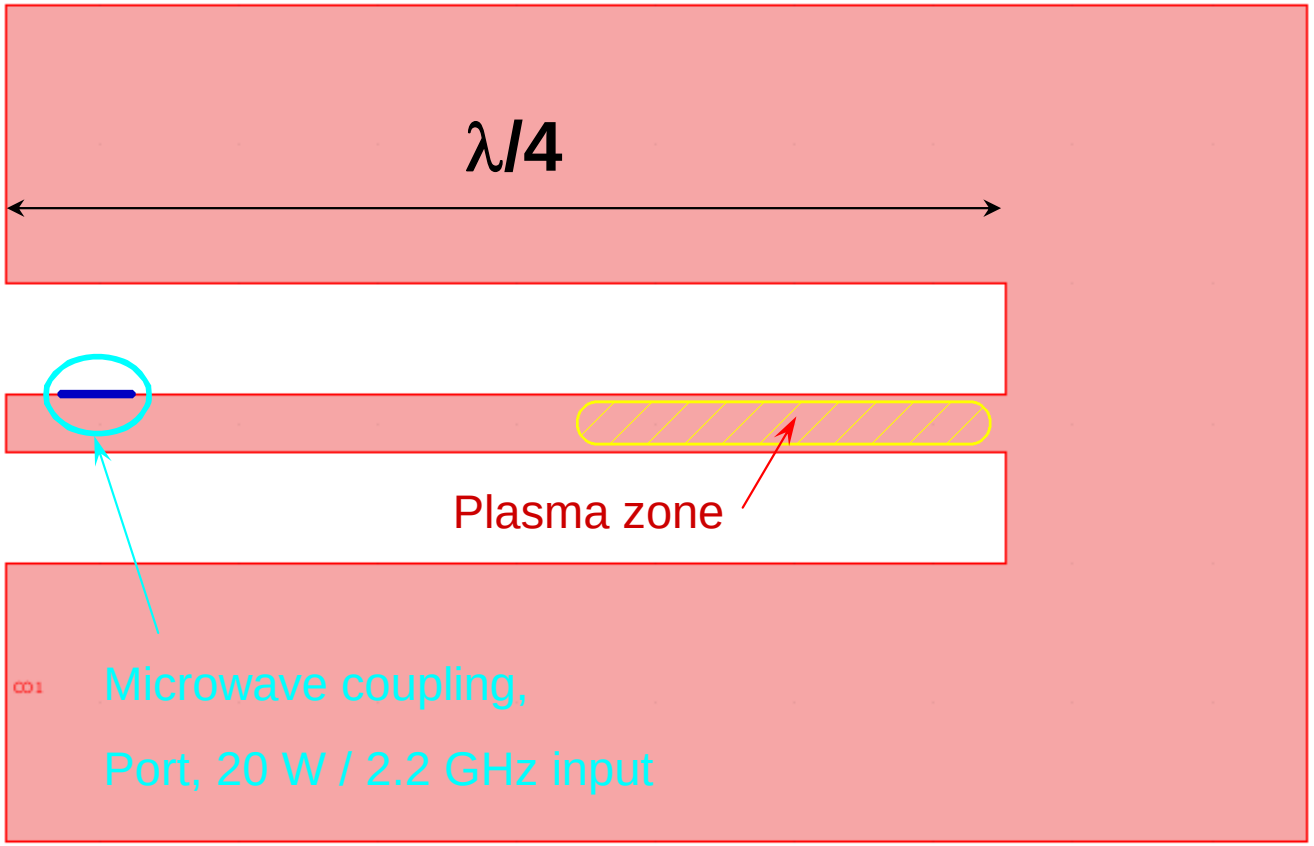
Ferdinand-Braun-Institut
für Höchstfrequenztechnik

Simplified 3D model



Infinitely large
structure in z direction

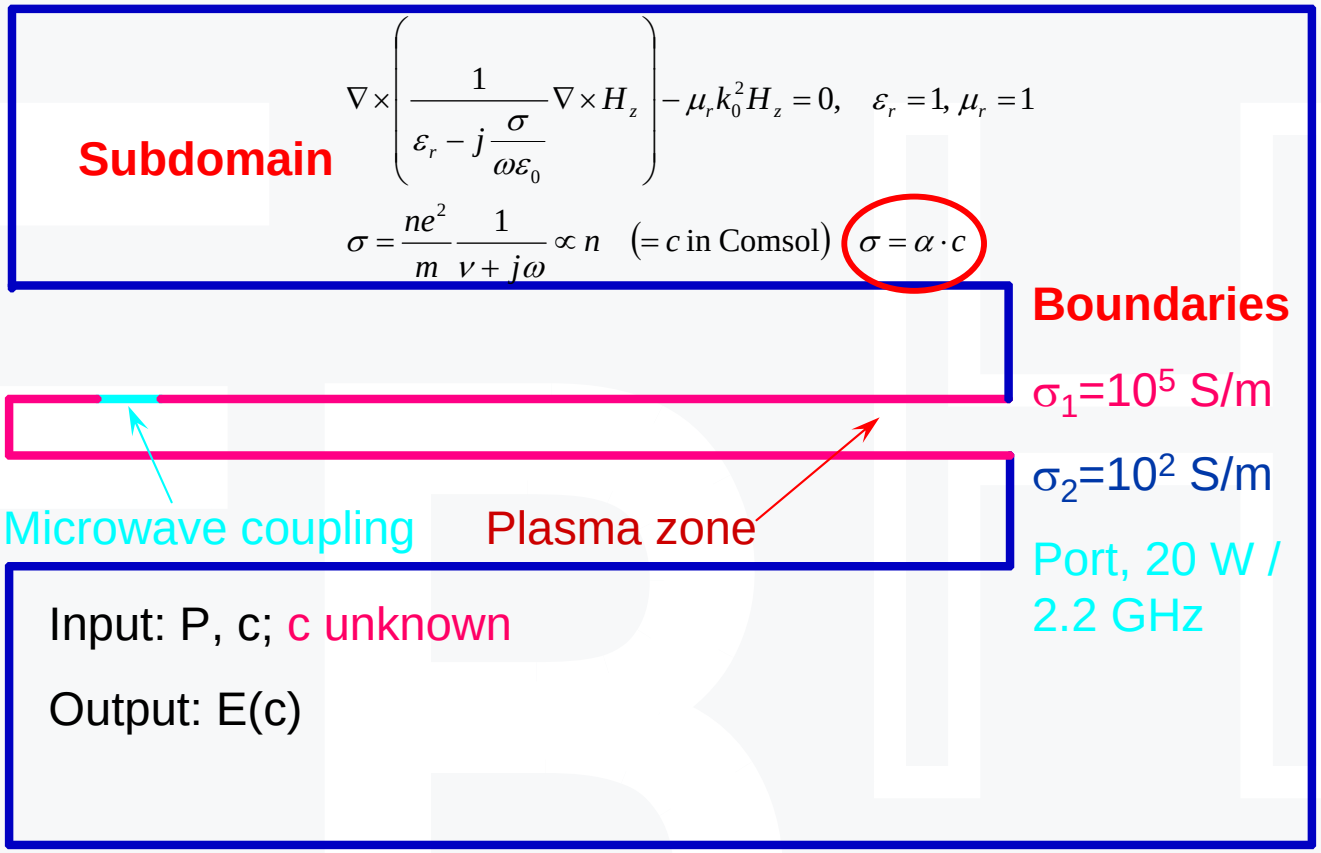
Reduced 2D geometry



Ferdinand-Braun-Institut
für Höchstfrequenztechnik

Implementation of the Plasma Equations

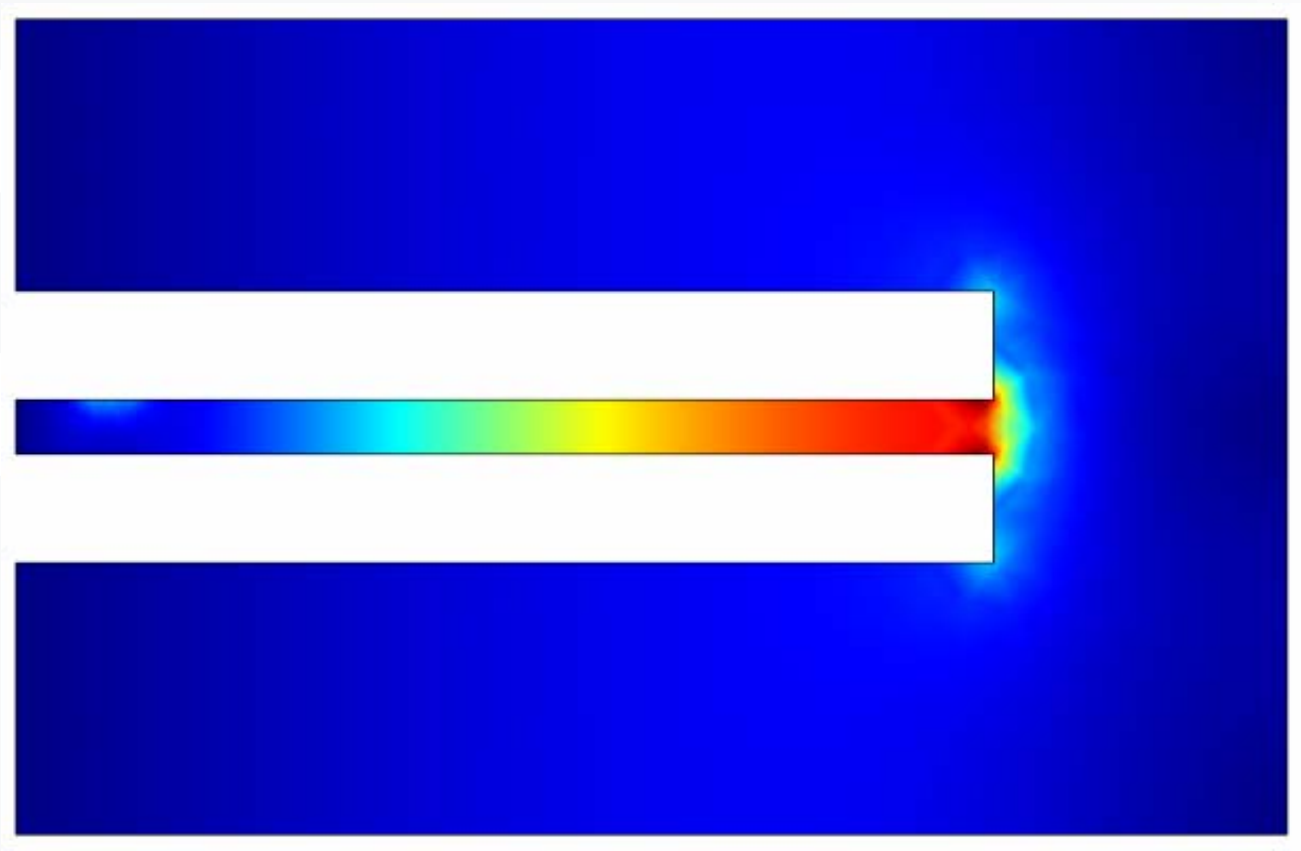
1. RF Module: In-Plane TM Propagation, *Harmonic Propagation*



Ferdinand-Braun-Institut
für Höchstfrequenztechnik

Microwave Field as Energy Source

Initial Distribution of the Electric Field: $E_{norm} = \sqrt{E_x^2 + E_y^2}$



Ferdinand-Braun-Institut
für Höchstfrequenztechnik

Implementation of the Plasma Equations

2. Heat Transfer (of the Ionic Gas), *Time Dependent*

$$\rho C_p \frac{\partial T}{\partial t} + \nabla\left(-k\nabla T\right) = Q$$

Subdomain

$$Q = \mathrm{Re}(\sigma)\left|E\right|^2$$

Boundaries

Heat flux to outside

300 K

Input: E, σ(c); c unknown

Output: T(c)

T_{ini}=300 K

Implementation of the Plasma Equations

3. Diffusion (of Electrons), *Time Dependent*

Subdomain

$$\frac{\partial c}{\partial t} + \nabla\left(-D\nabla c\right) = R$$

$$R = Gen(c,T) - Rec(c,T)$$

Boundaries

Insulation / Symmetry

Input: T

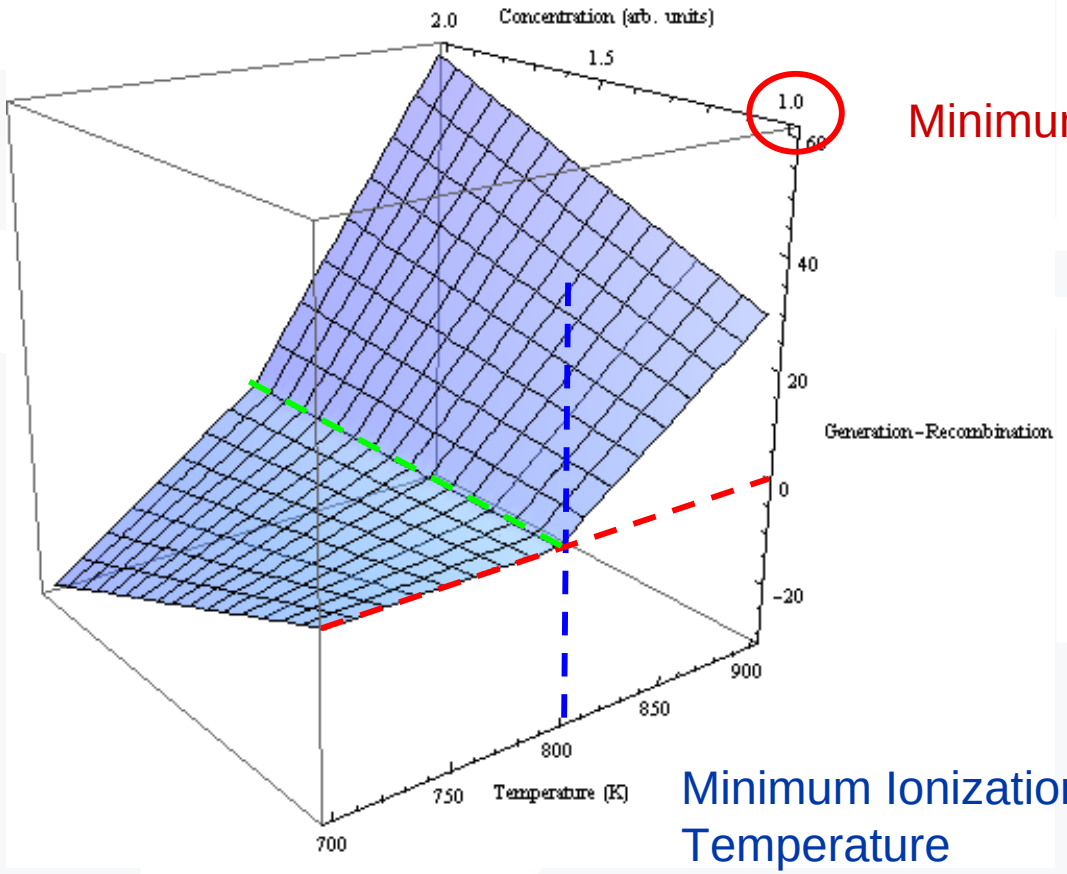
Output: c

c ->RF Module -> E(c)

$c_{ini}=c_{min}=1$ (rel. units)

Reaction Term *R*, Simplified: Linear Dependence

1. No recombination for $T<T_{ref}$ and $c=c_{min}$, $R=0$
2. Generation for $T>T_{ref}$, $R=\alpha_1 c (T-T_{ref})>0$
3. Recombination for $T<T_{ref}$ *and* $c>c_{min}$, $R=\alpha_2 c (T-T_{ref})<0$

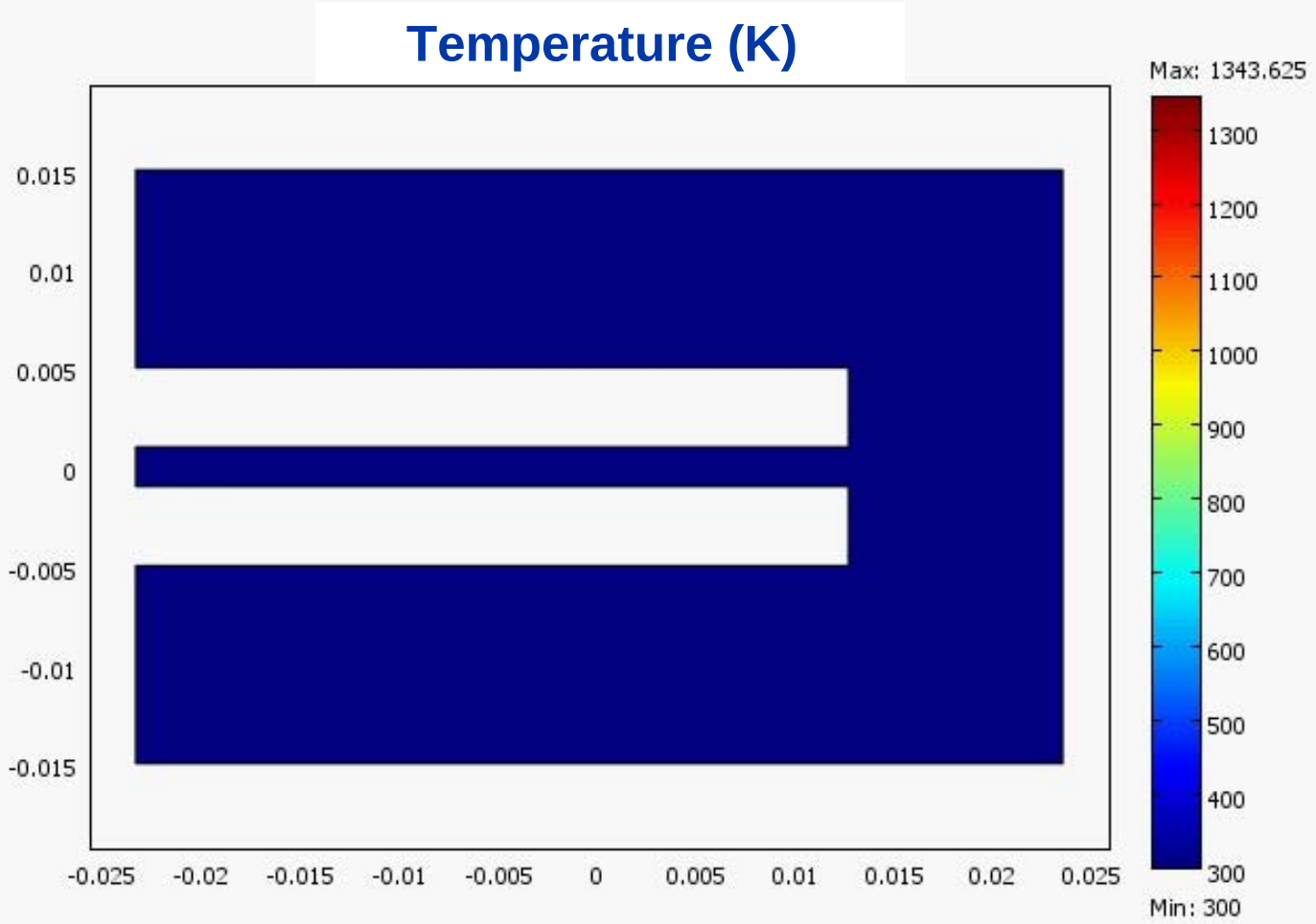


Minimum concentration

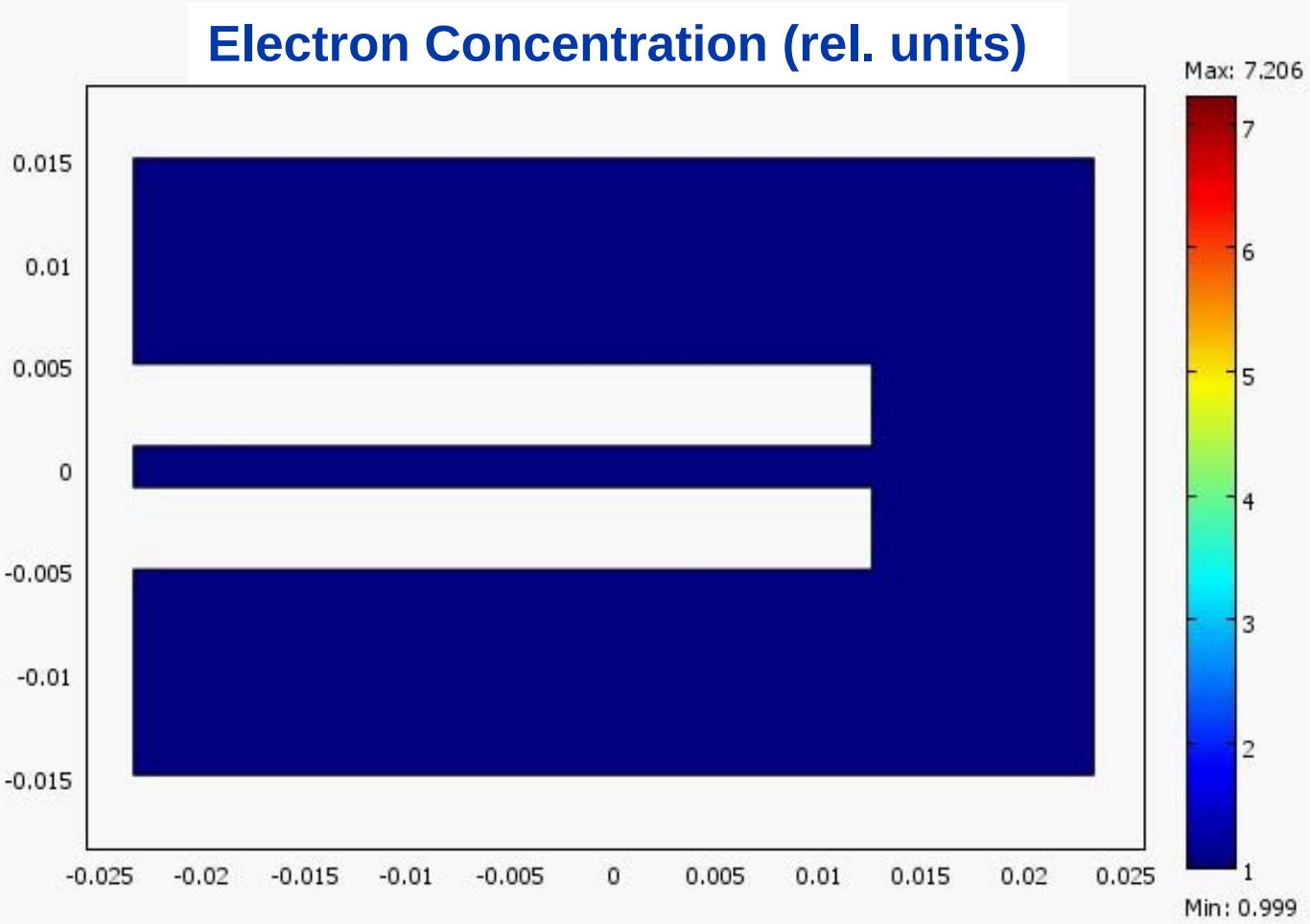
Minimum Ionization Temperature

Ferdinand-Braun-Institut
für Höchstfrequenztechnik

Time Dependence of the Temperature

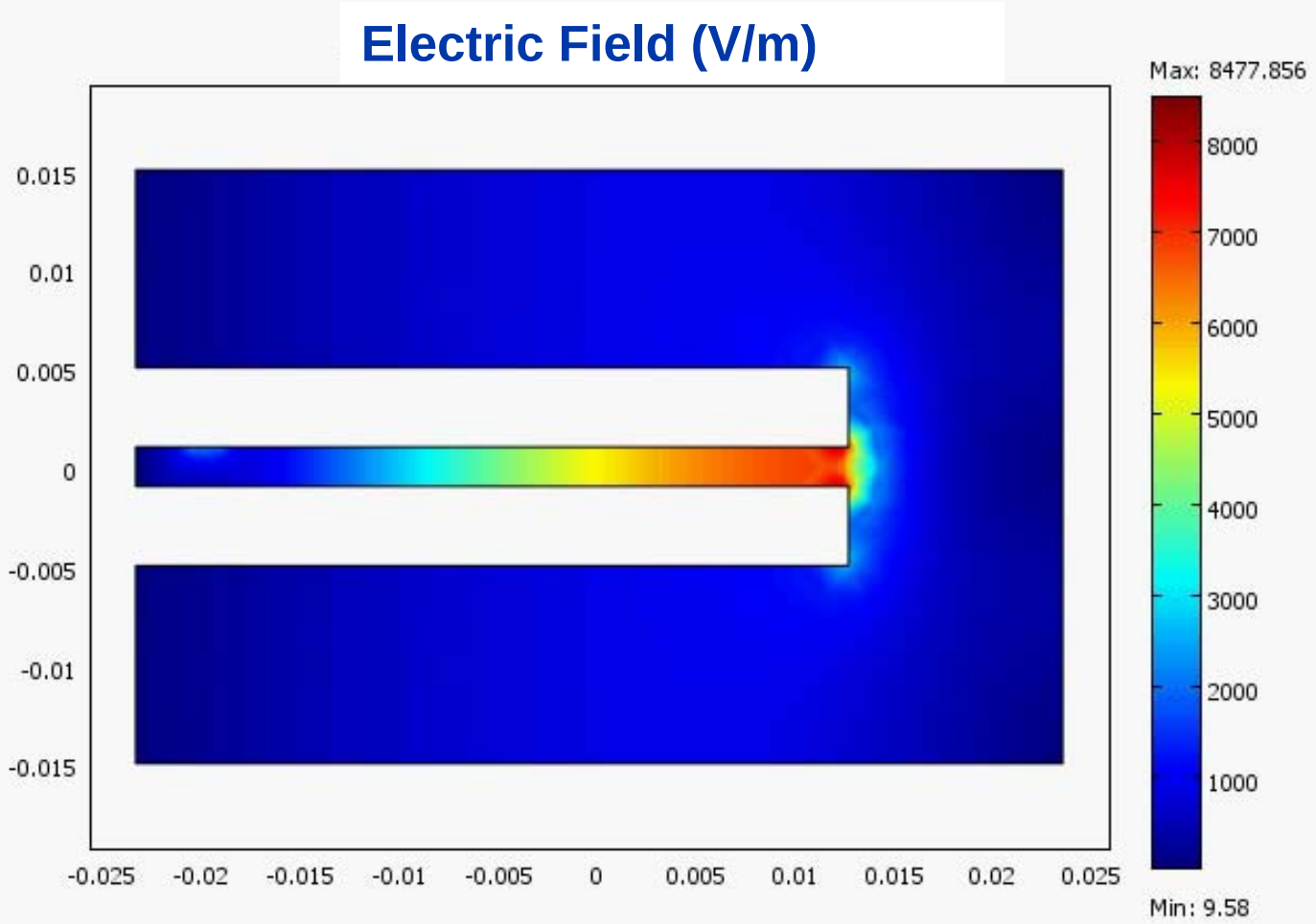


Time Dependence of the Electron Concentration

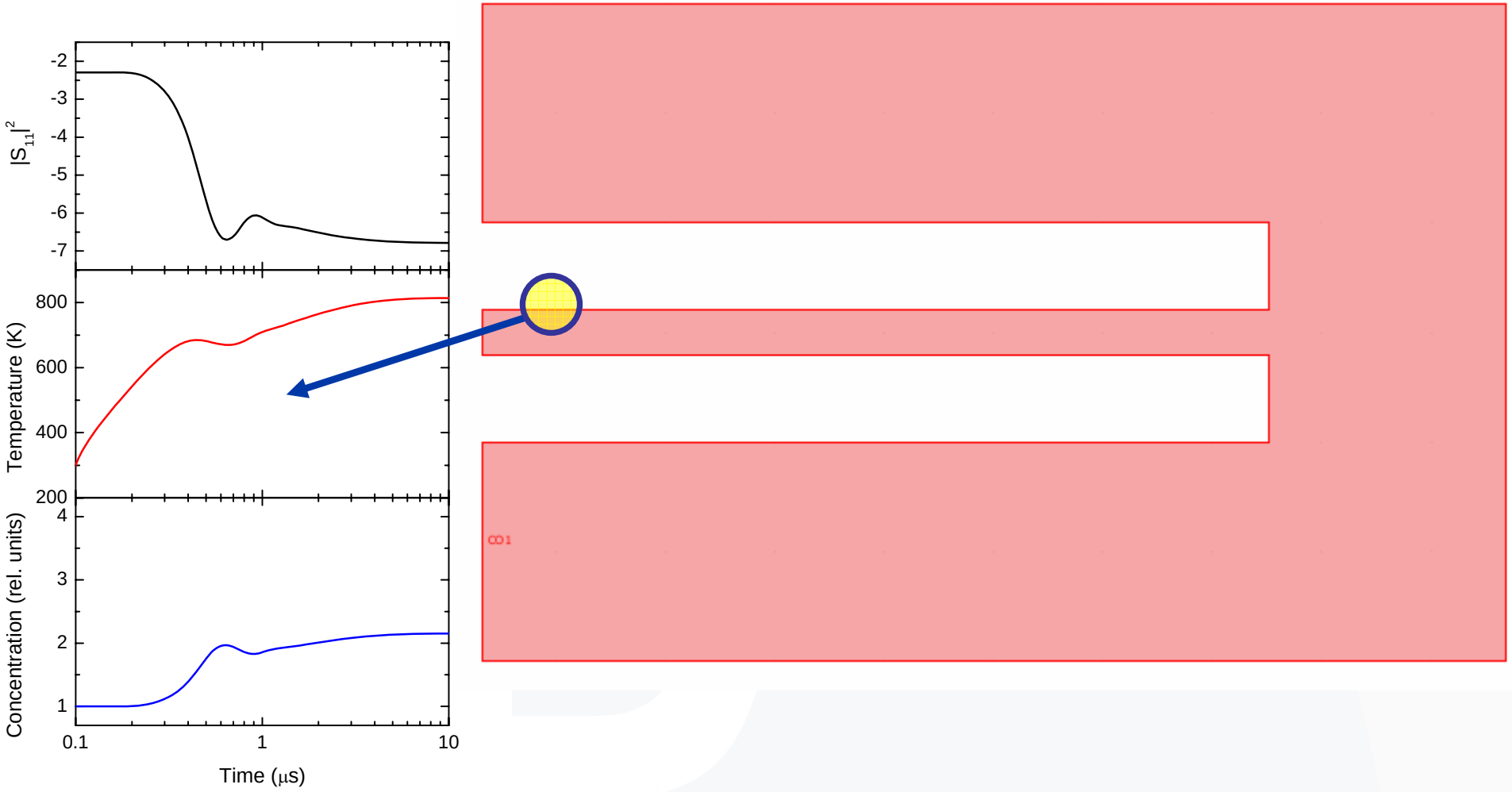


Ferdinand-Braun-Institut
für Höchstfrequenztechnik

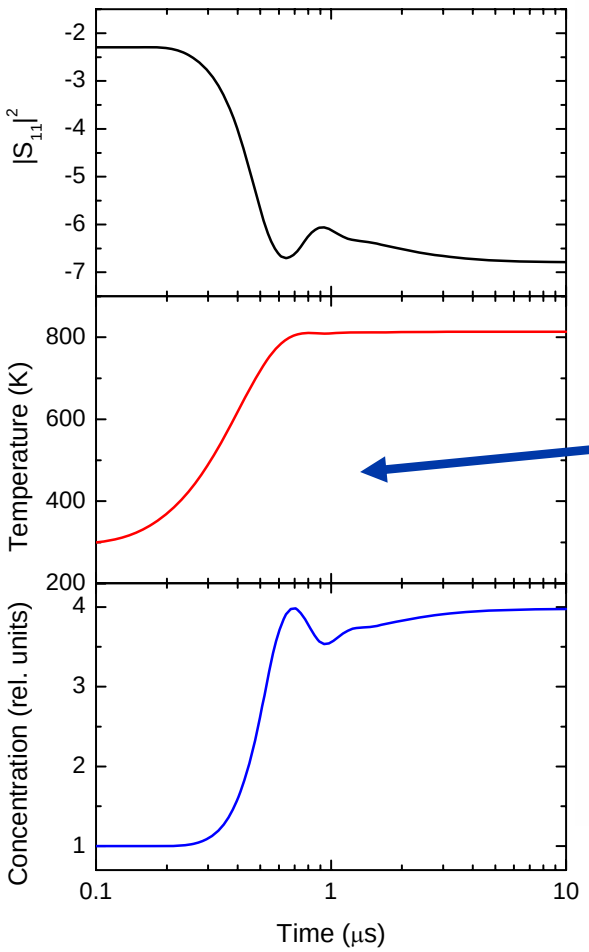
Time Dependence of the Electric Filed

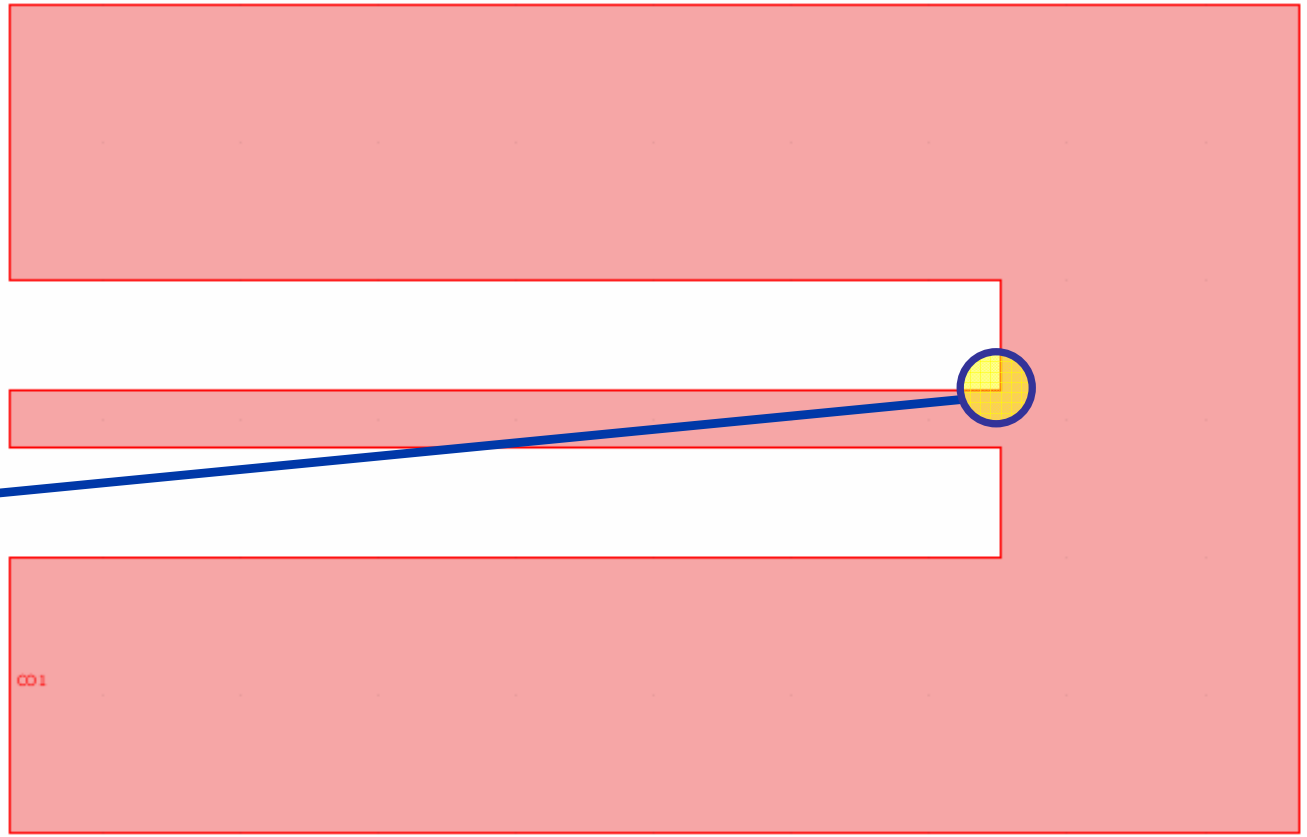


Time Dependences at Different Points

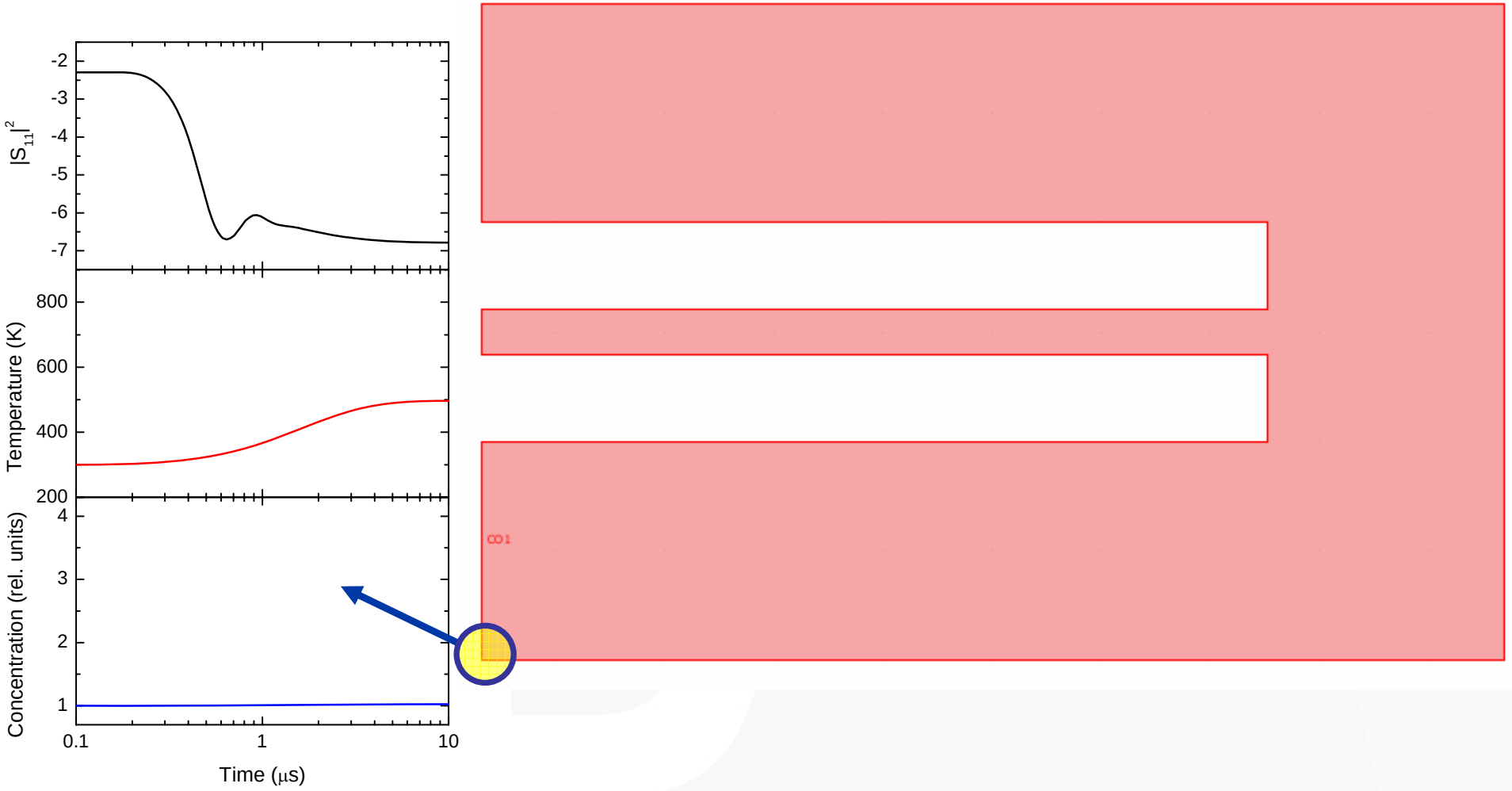


Time Dependences at Different Points





Time Dependences at Different Points



Ferdinand-Braun-Institut
für Höchstfrequenztechnik

Summary

- Choice of the appropriate 2D model reduces considerably the computation time (DOF=3615, 100 time points, PC Core Duo, 2.66 GHz, 4 GB RAM, 35 Min.)
- The plasma physics is essentially contained in the Reaction term (Generation - Recombination)
- Scattering rate and diffusion coefficients are constants for illustration purposes. Adequate temperature dependence to be implemented
- Good qualitative agreement of the simulated ignition process with the measured data (S-Parameter)

Acknowledgments

- The authors would like to thank to their colleagues S. Kühn, Dr. M. Herms, and Dr. P. Heymann for useful discussions and hints and to C. Hunyar and M. Graf (Fraunhofer ICT, Pfinztal) for giving details concerning plasma simulation.