

COMSOL

Multiphysics:

potentially a

profitable tool?

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# What COMSOL is

Finite Element Analysis software able to find an approximate solution for a *coupled system* of PDEs on an (almost) arbitrary (3D, 2D, and 1D) mesh.

Coefficients are arbitrary!

$$e_a \frac{\partial^2 u}{\partial t^2} + d_a \frac{\partial u}{\partial t} + \nabla \cdot (-c \nabla u - \alpha u + \gamma) + \beta \cdot \nabla u + a u = f$$

mass      damping      diffusion      conservative convection      flux source      convection      absorption      source

# It's called Multiphysics

COMSOL Multiphysics®

COMSOL Server™

ELECTRICAL

MECHANICAL

FLUID

CHEMICAL

MULTIPURPOSE

INTERFACING

AC/DC  
Module

Heat Transfer  
Module

CFD  
Module

Chemical Reaction  
Engineering Module

Optimization  
Module

LiveLink™  
for MATLAB®

LiveLink™  
for Excel®

RF  
Module

Structural  
Mechanics Module

Mixer  
Module

Batteries &  
Fuel Cells Module

Material  
Library

CAD Import  
Module

Design  
Module

Wave Optics  
Module

Nonlinear Structural  
Materials Module

Microfluidics  
Module

Electrodeposition  
Module

Particle Tracing  
Module

ECAD Import  
Module

LiveLink™  
for SOLIDWORKS®

Ray Optics  
Module

Geomechanics  
Module

Subsurface Flow  
Module

Corrosion  
Module

LiveLink™  
for Inventor®

LiveLink™ for  
AutoCAD®

MEMS  
Module

Fatigue  
Module

Pipe Flow  
Module

Electrochemistry  
Module

LiveLink™ for  
Revit®

LiveLink™ for  
PTC® Creo® Parametric™

Plasma  
Module

Multibody Dynamics  
Module

Molecular Flow  
Module

LiveLink™ for  
PTC® Pro/ENGINEER®

LiveLink™ for  
Solid Edge®

Semiconductor  
Module

Acoustics  
Module

File Import for  
CATIA® V5

# COMSOL strength

Link different physics problems (via the proper choice of the coefficients)

Example:

Compute the thermal deformation of a resistor (Joule effect, heat transfer, mechanical deformation, ...)

# Some well known equations

Heat equation:

Heat Transfer  
Module

$$\frac{\partial u}{\partial t} = \alpha \nabla^2 u$$

Convection and diffusion:

CFD  
Module

$$\frac{\partial u}{\partial t} = \nabla \cdot D \nabla u - \nabla \cdot \vec{v} u + R$$

Schrödinger:

$$E u = \frac{-\hbar^2}{2m} \nabla^2 u + V u$$

Quantum Mechanic  
Module

is not there, and  
Gaseous Detector  
Module neither, but

$-2.18e-18 \text{ J}$

$-5.45e-19 \text{ J}$

$-2.42e-19 \text{ J}$

$n = 1, l = 0, m = 0$

$2, 0, 0$

$3, 0, 0$

$2, 1, 0$

$2, 1, 1$

$3, 1, 0$

$3, 1, 1$

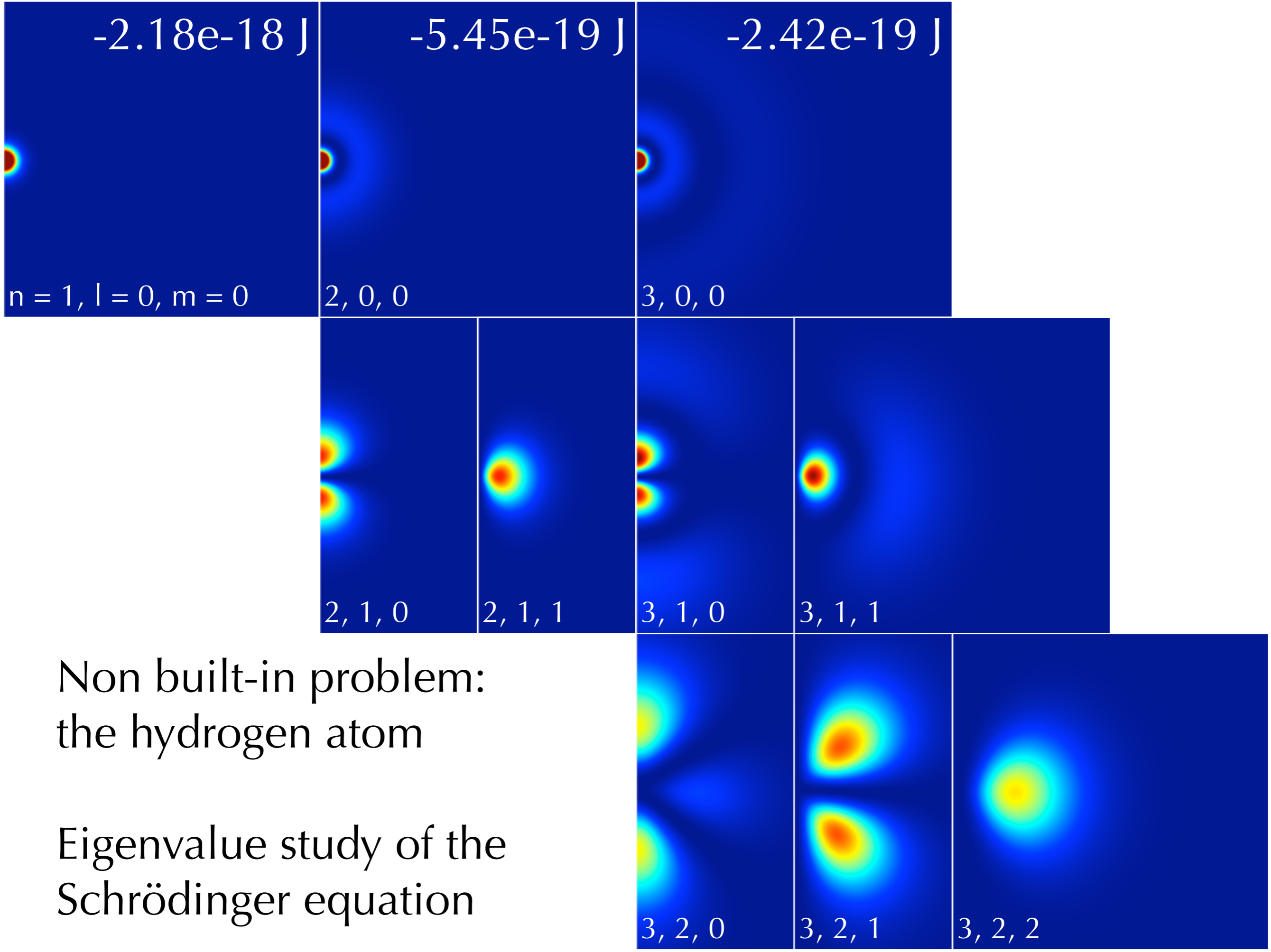
Non built-in problem:  
the hydrogen atom

Eigenvalue study of the  
Schrödinger equation

$3, 2, 0$

$3, 2, 1$

$3, 2, 2$



# How this relates to MPGDs

Possibly in several engineering ways

Profitable where needed *dynamical* or *adaptive* approaches, e.g.

Paulo Fonte computed the streamer formation and propagation in gas

# Few examples

Electron avalanche  
Signal induction  
GEM transparency  
Space charges  
GEM charging up  
Streamer



# General approximations

Electrons velocity, diffusion, Townsend, and attachment coefficients from Magboltz

Hydrodynamic approximation

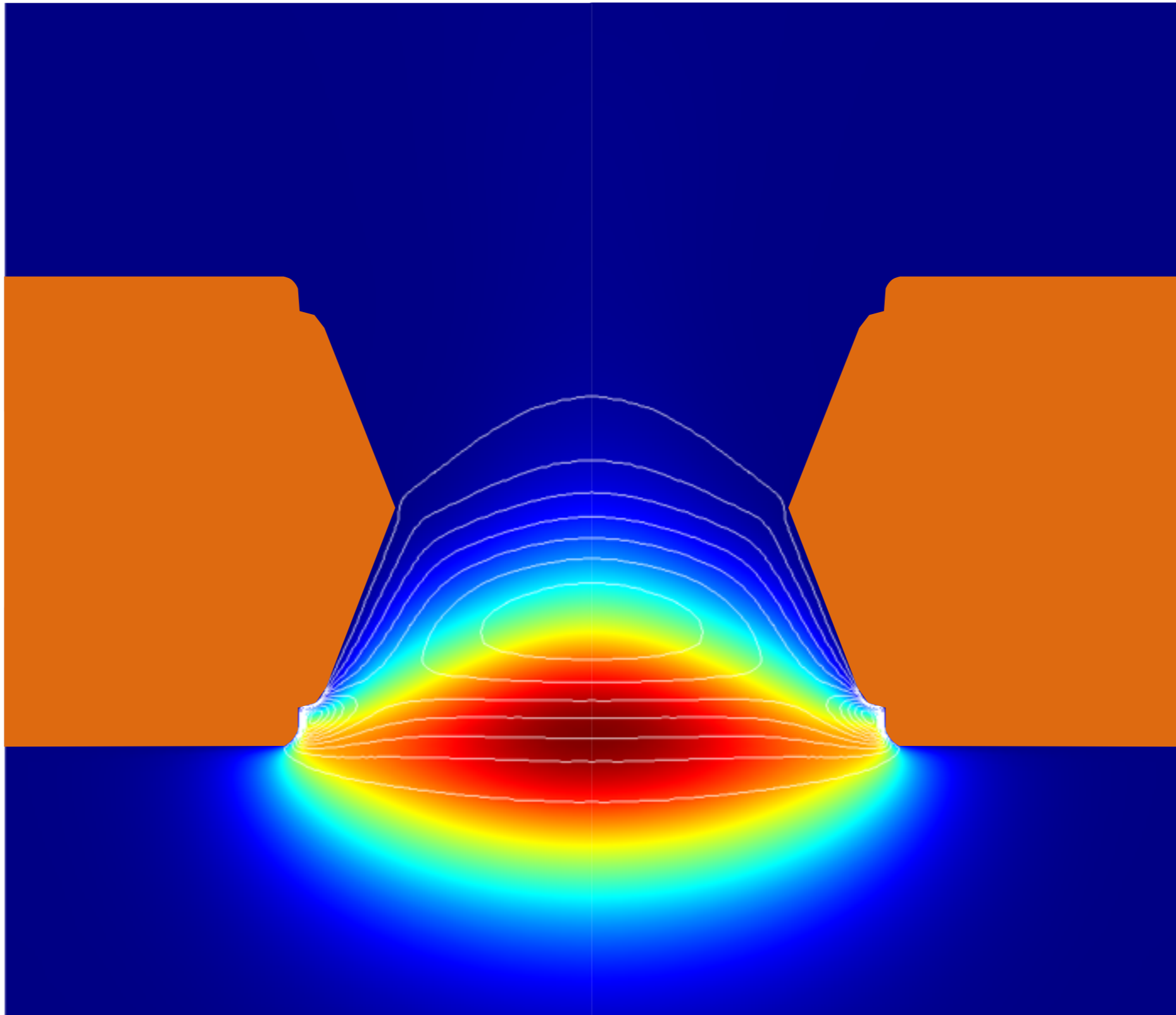
$$\frac{\partial u}{\partial t} = \nabla \cdot D \nabla u - \nabla \cdot \vec{v} u + R$$

Axis-symmetric approximation

(a necessity in some cases)

# Avalanche

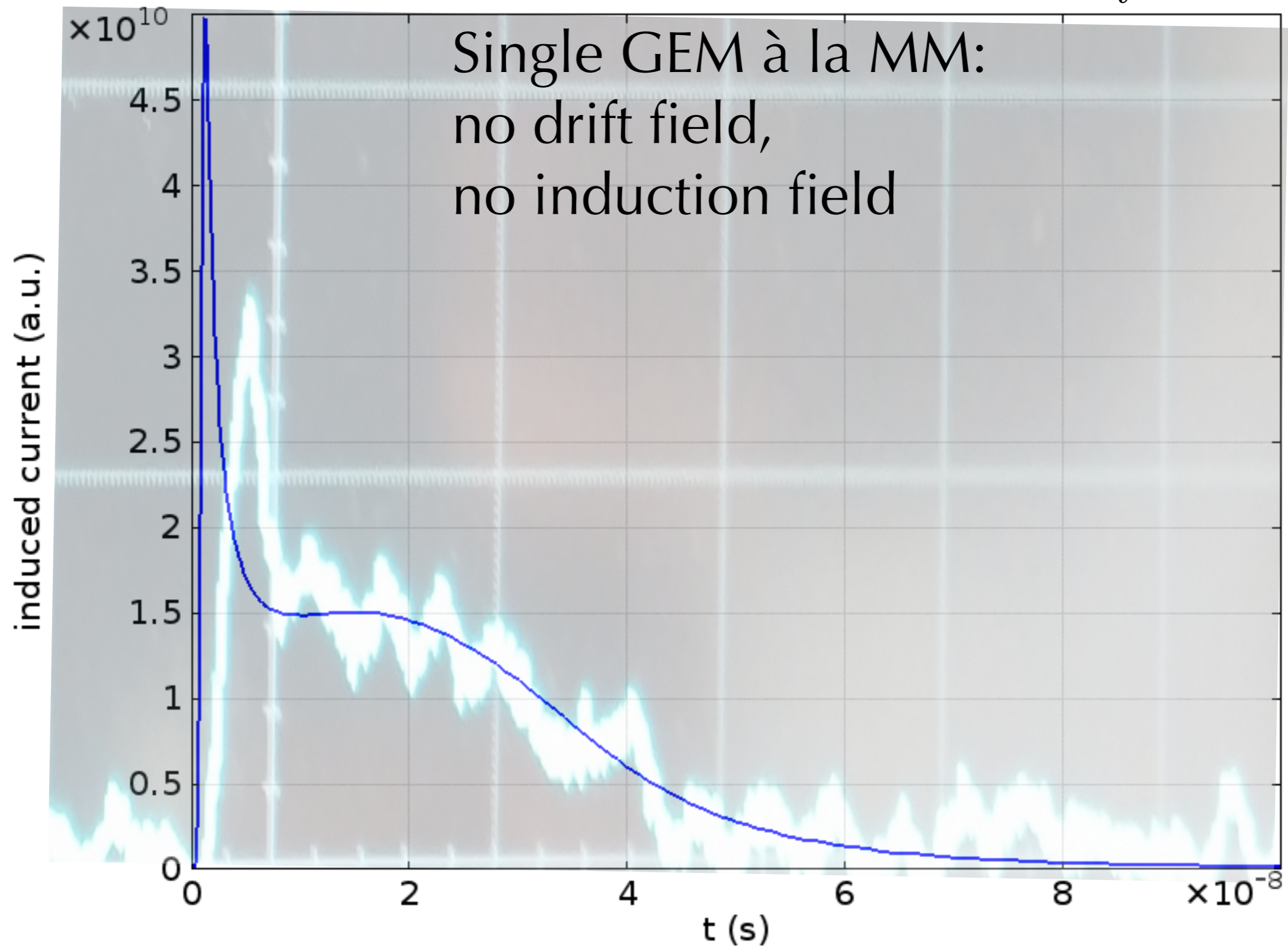
$$R = (\alpha - \eta)v_e n_e$$



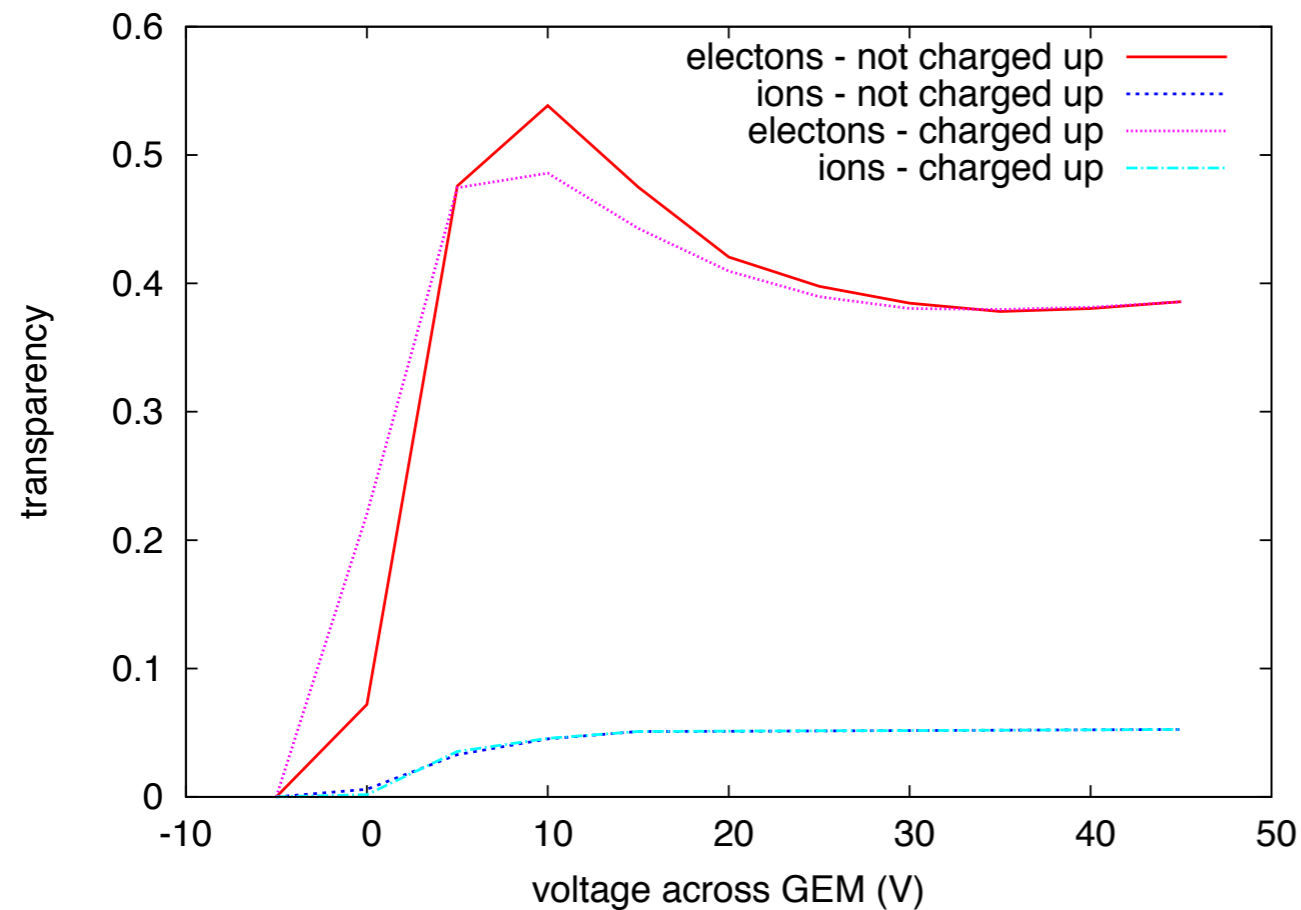
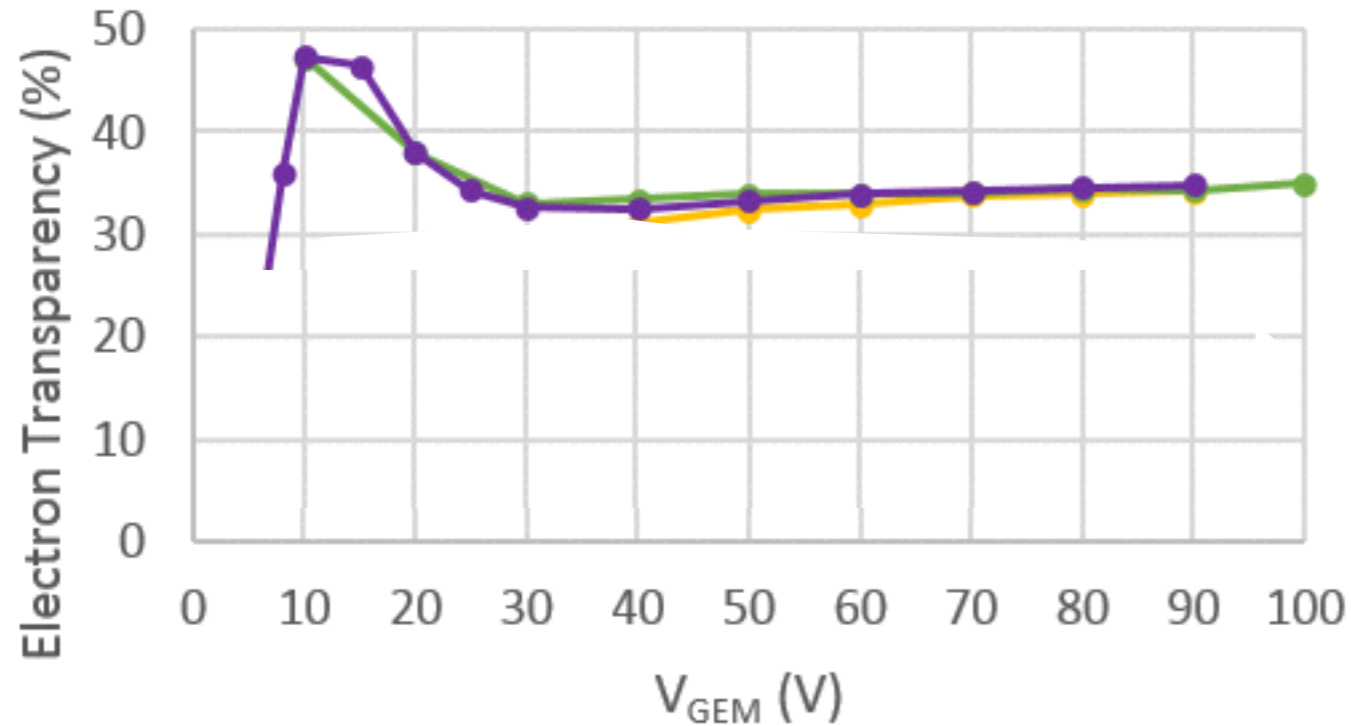
Electrons and ions treated like a gas

# Signal induction

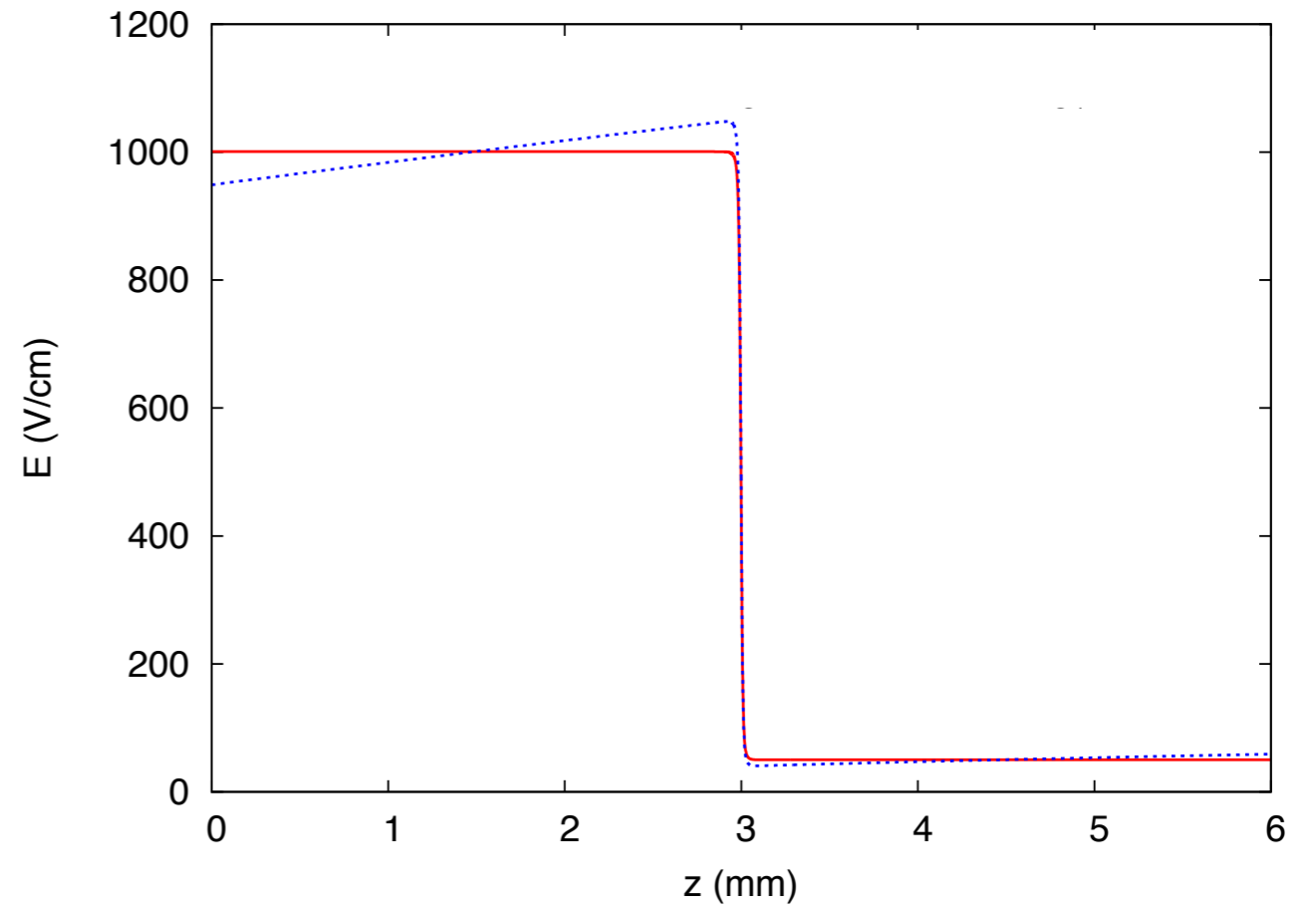
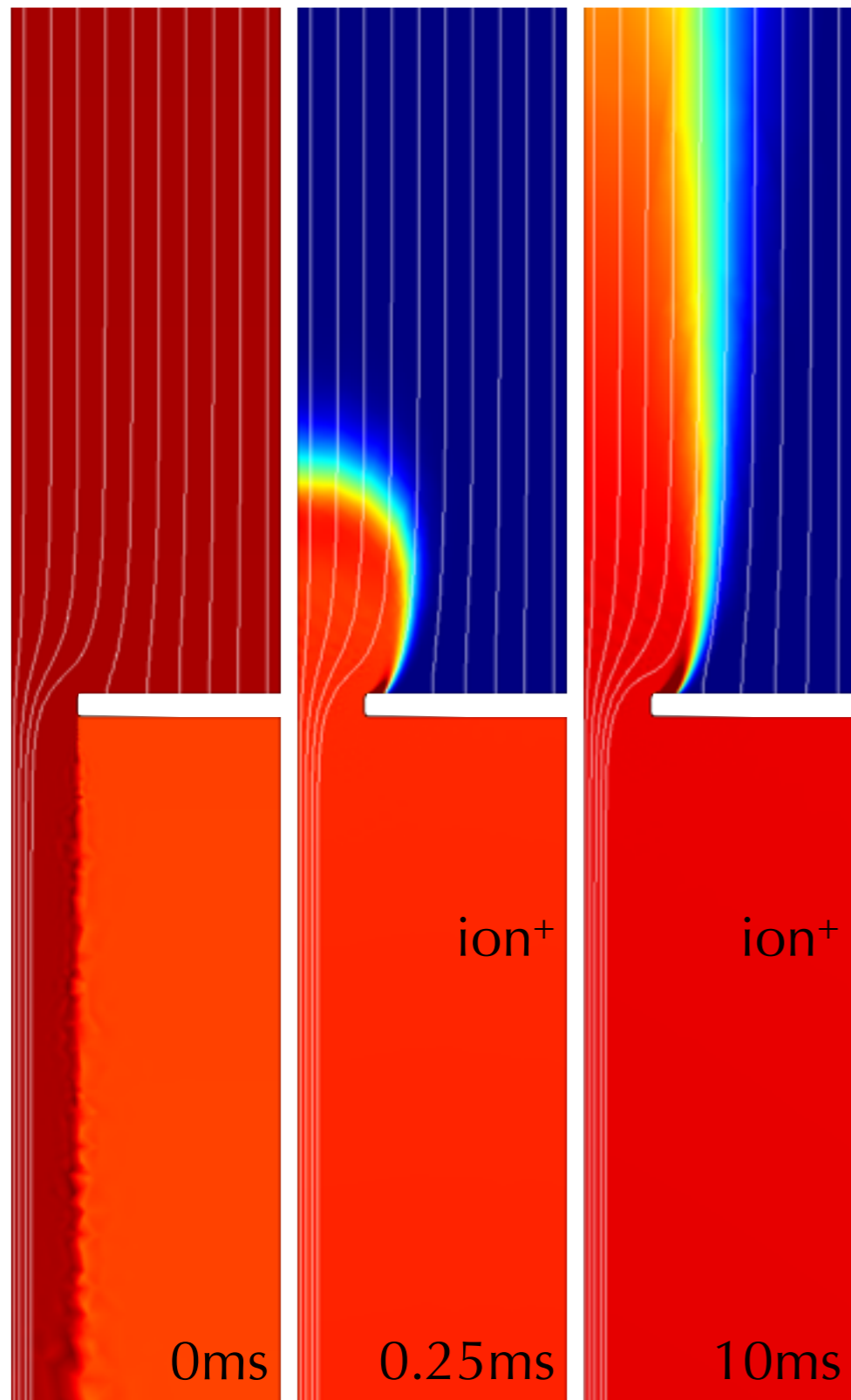
$$I = \sum_i \int \rho_i \vec{v}_i \cdot \vec{W}$$



# Single GEM transparency



# Space charge



$$\nabla^2 V = q_e(n_i - n_e)/\epsilon$$

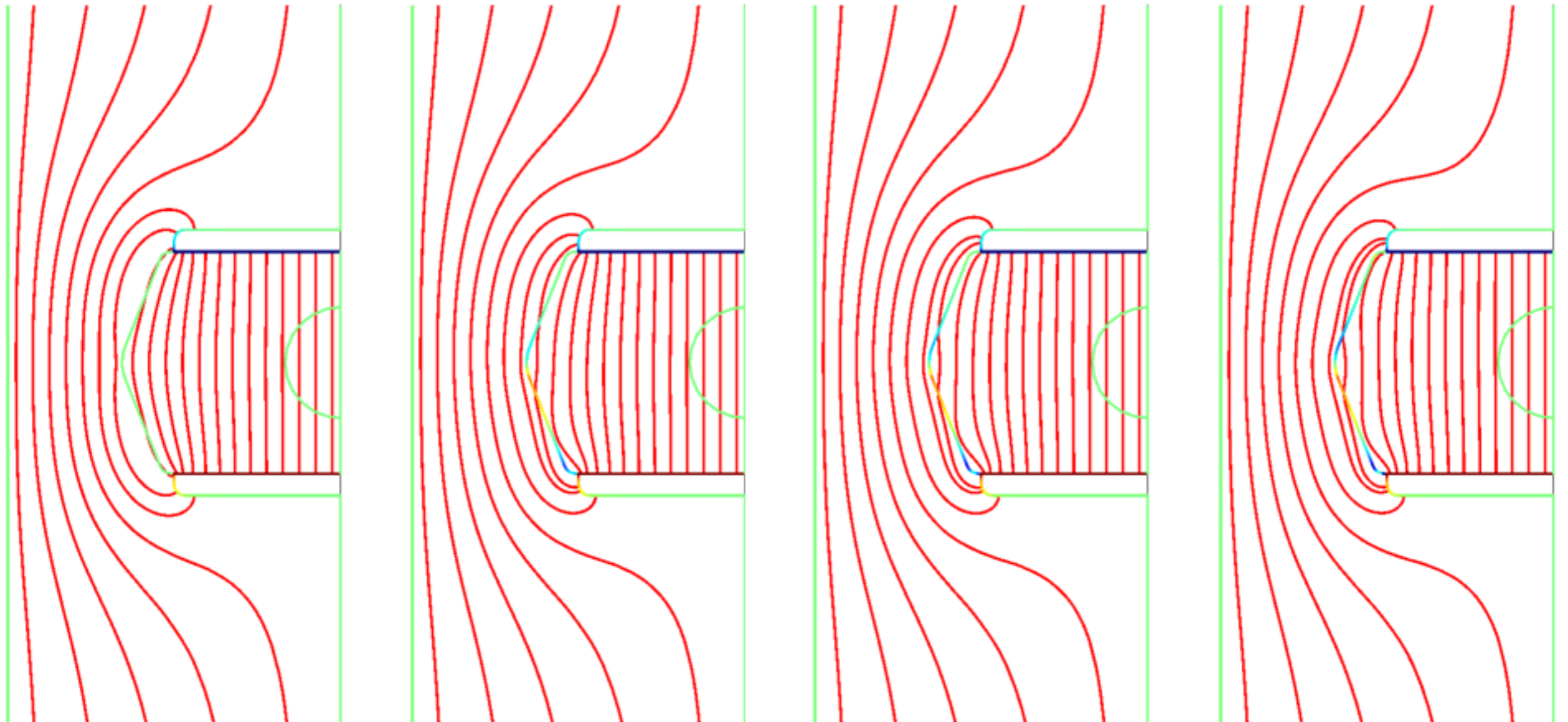
# GEM charging up

0 e-/hole

$5 \times 10^5$  e-/hole

$1 \times 10^6$  e-/hole

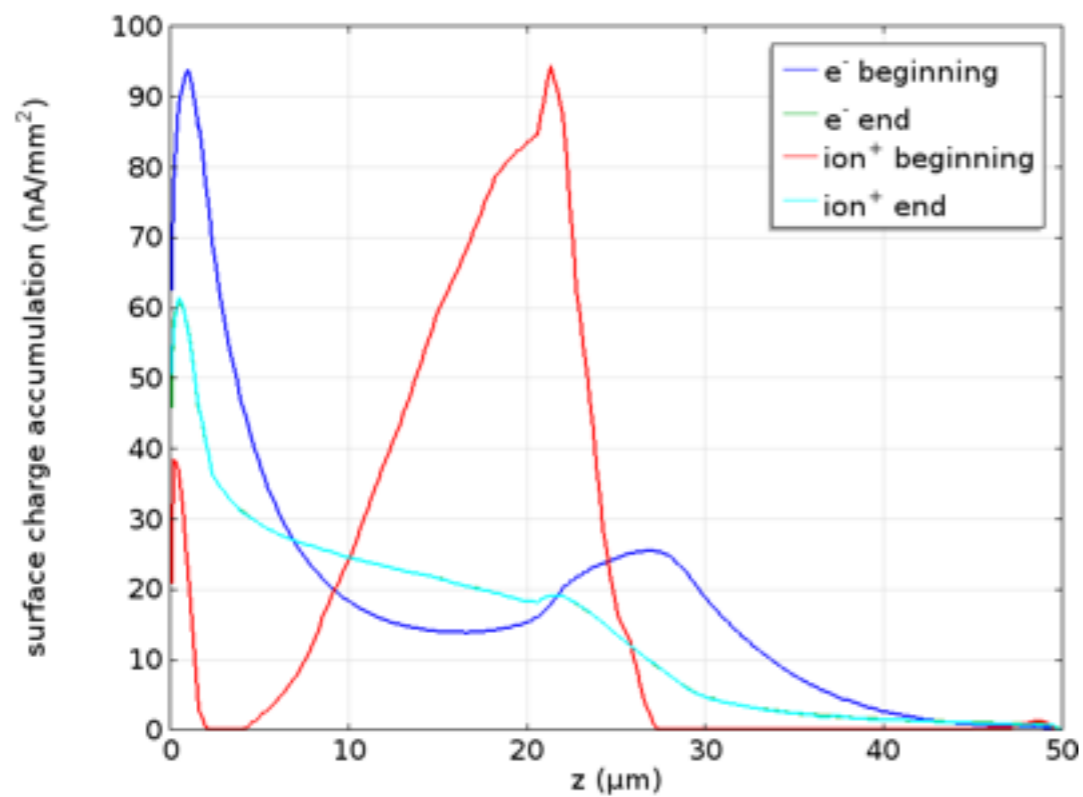
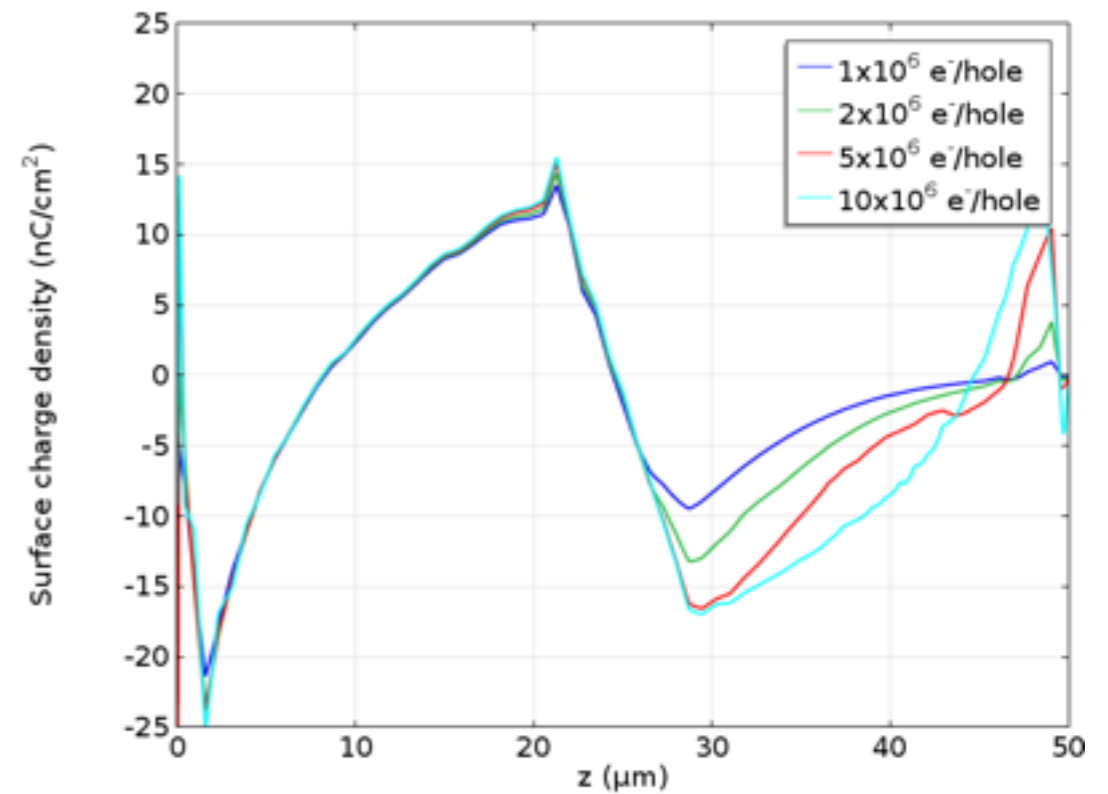
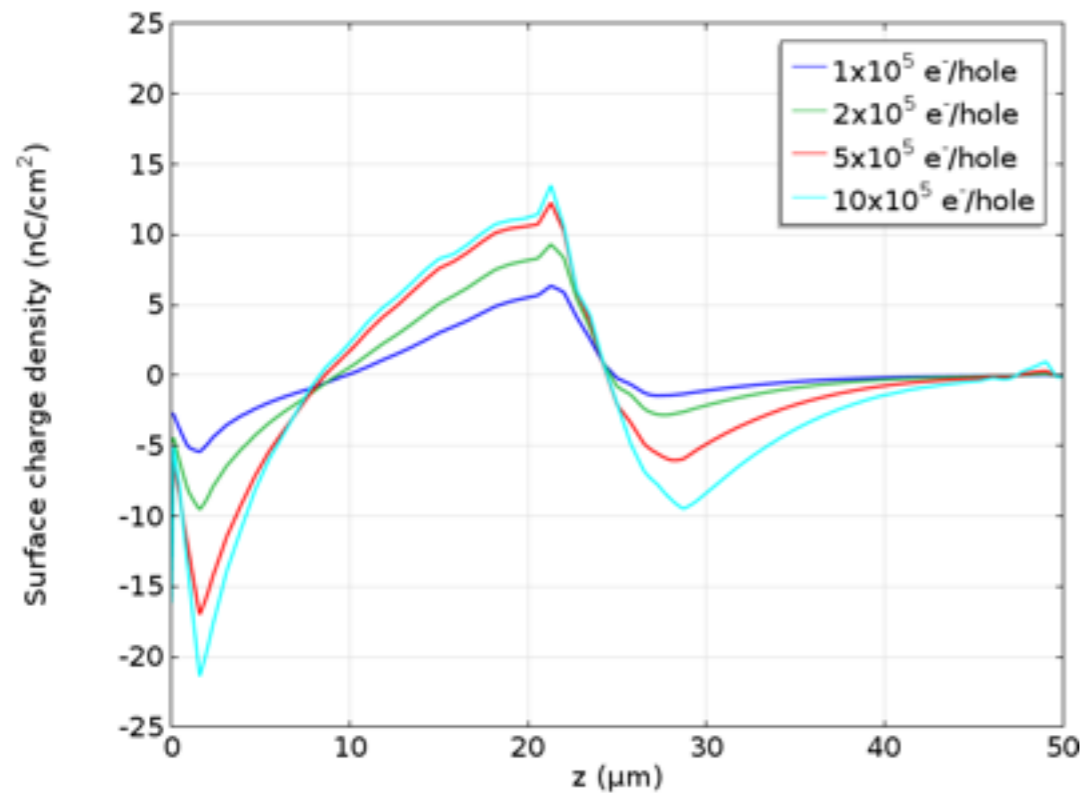
$2 \times 10^6$  e-/hole



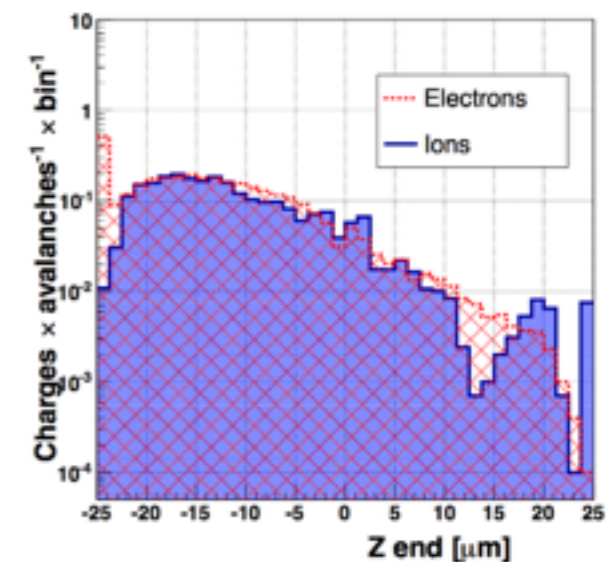
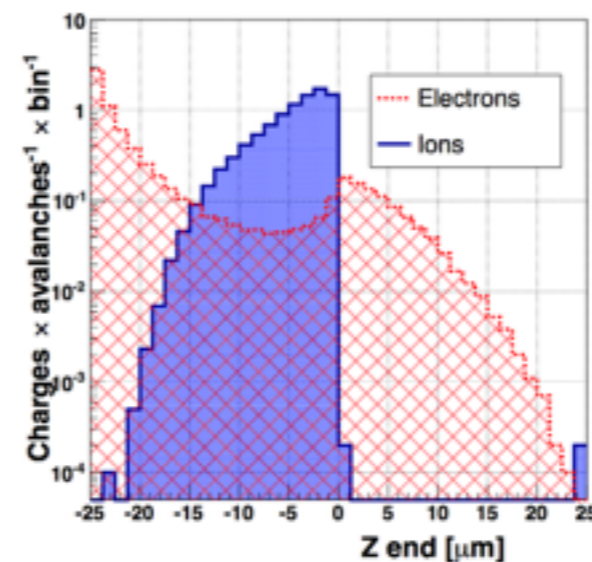
Multiple stage is different...



# GEM charging up



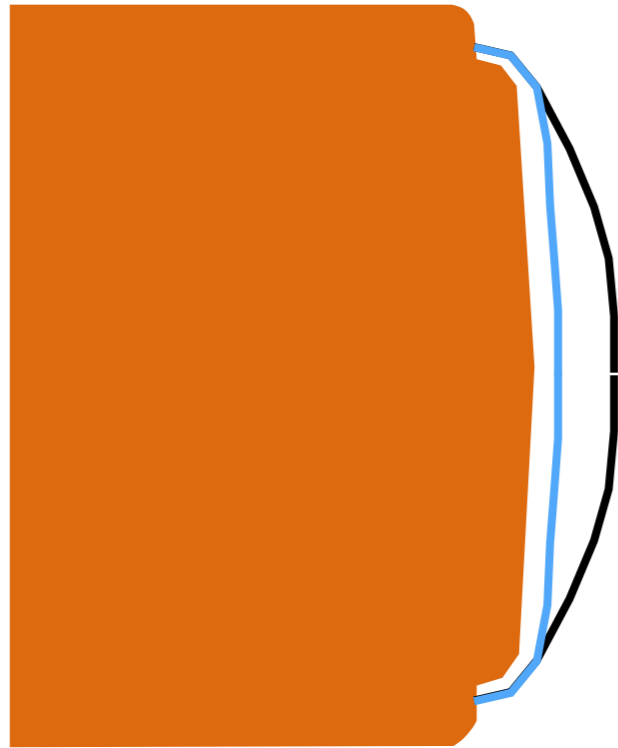
Correia *et al.*, JINST 9 (2014) P07025



# Charging up

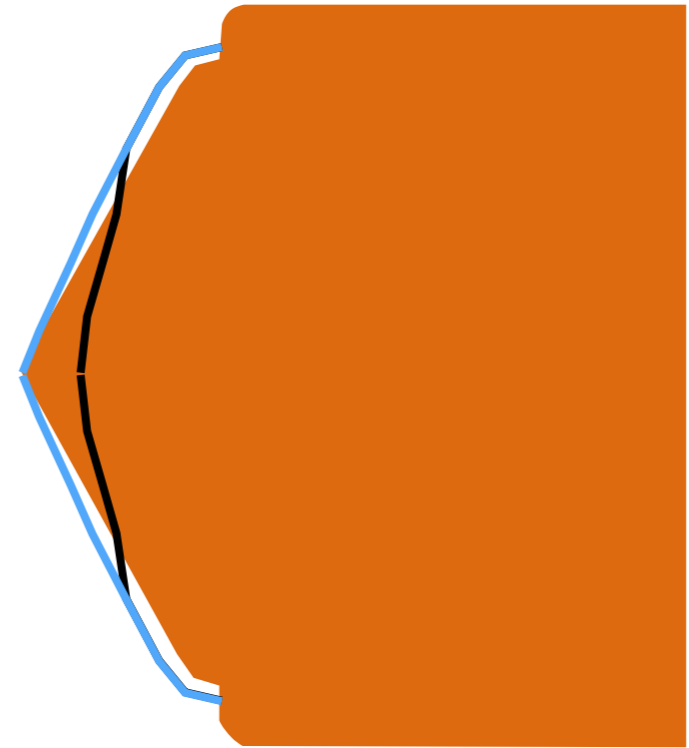
not charged  
charged up

THGEM



Gain decreases

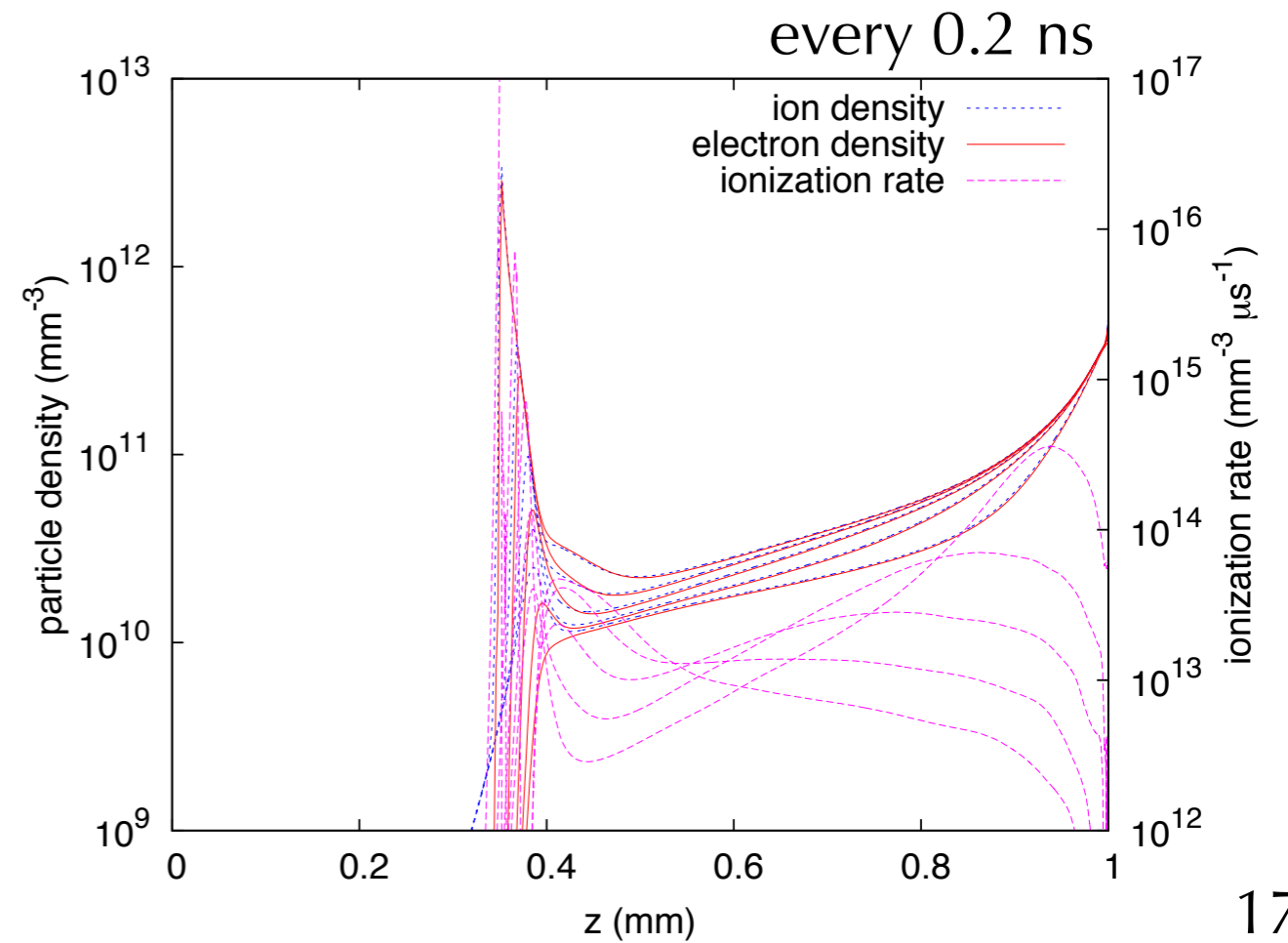
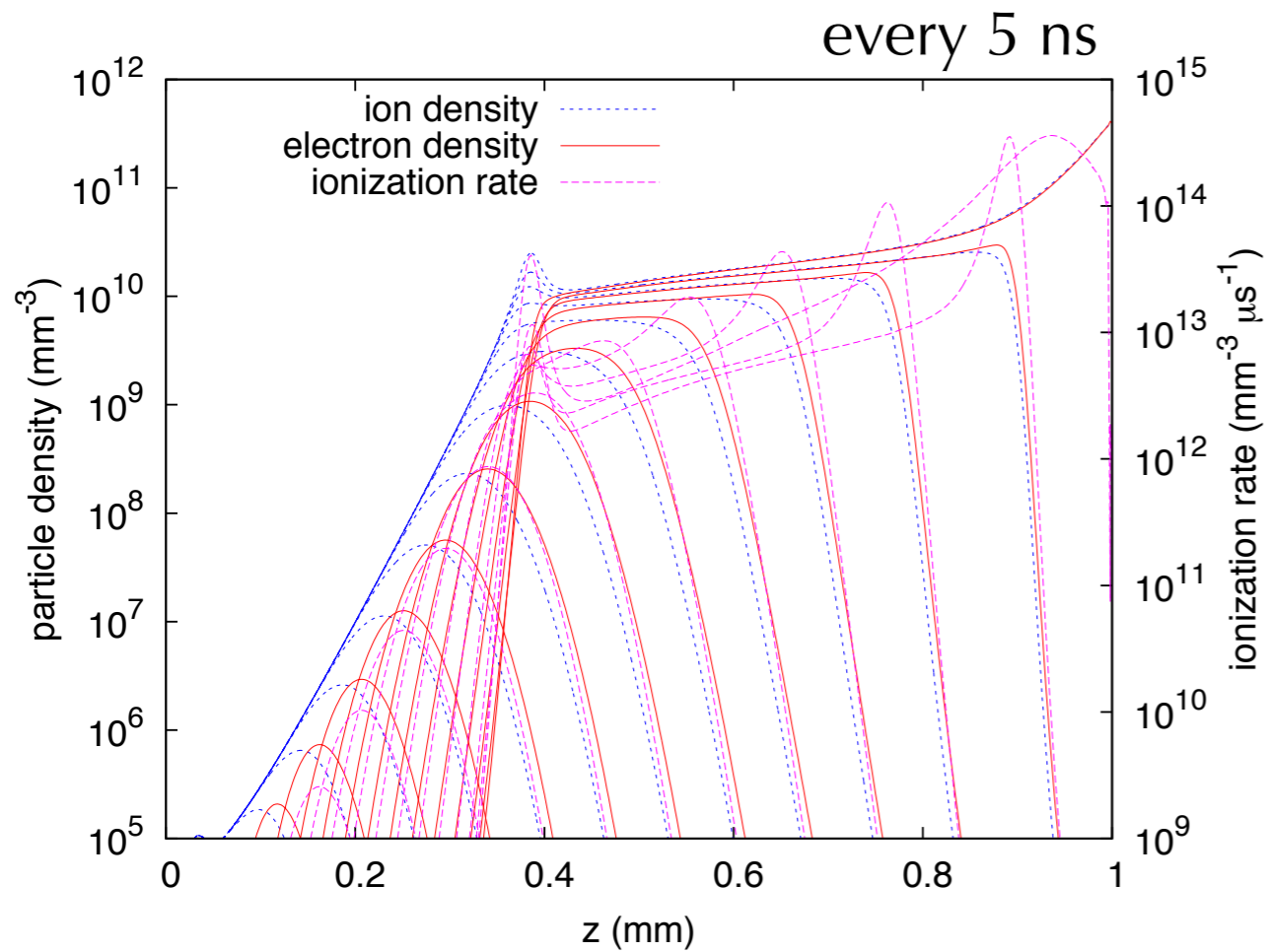
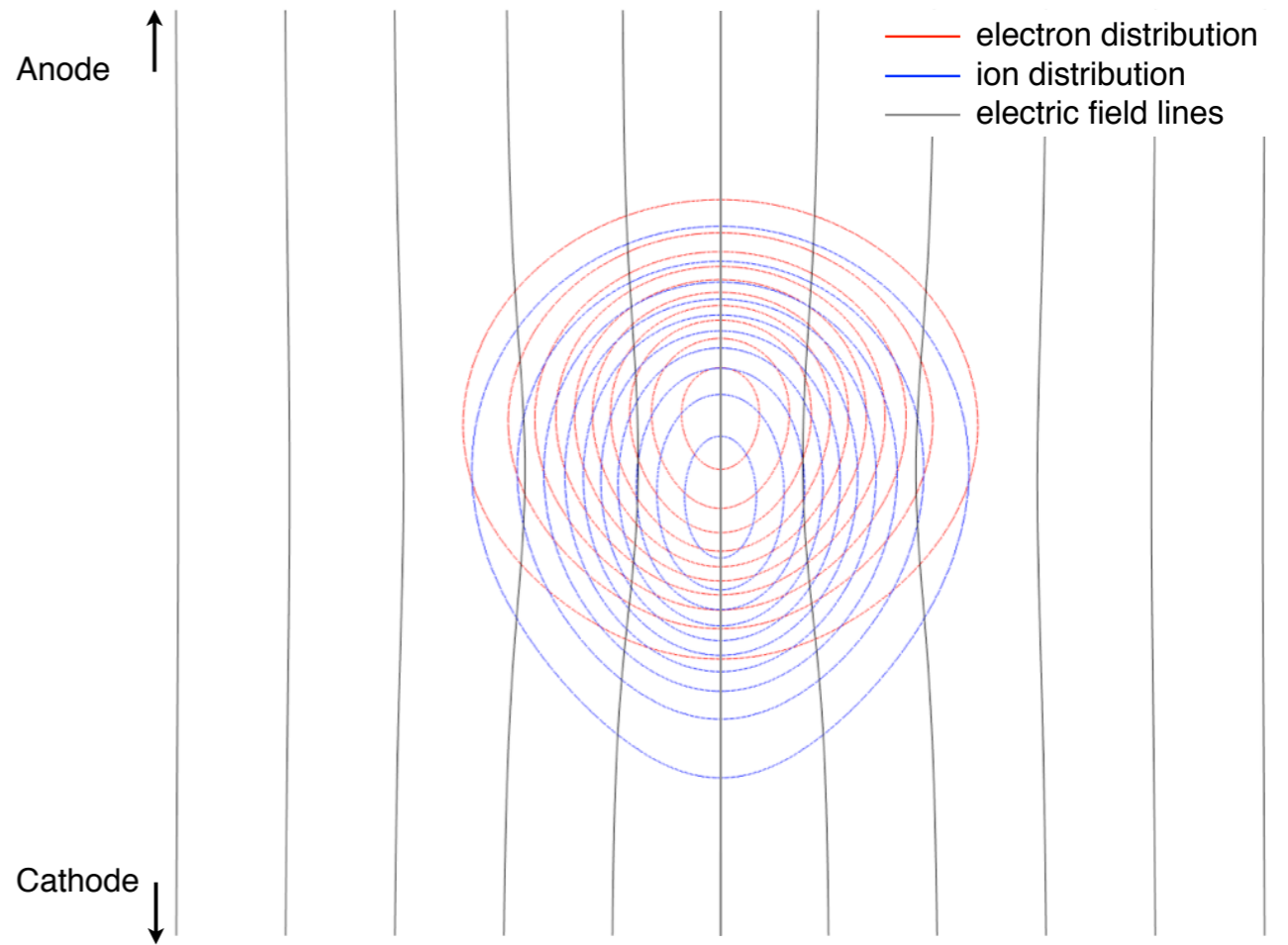
GEM



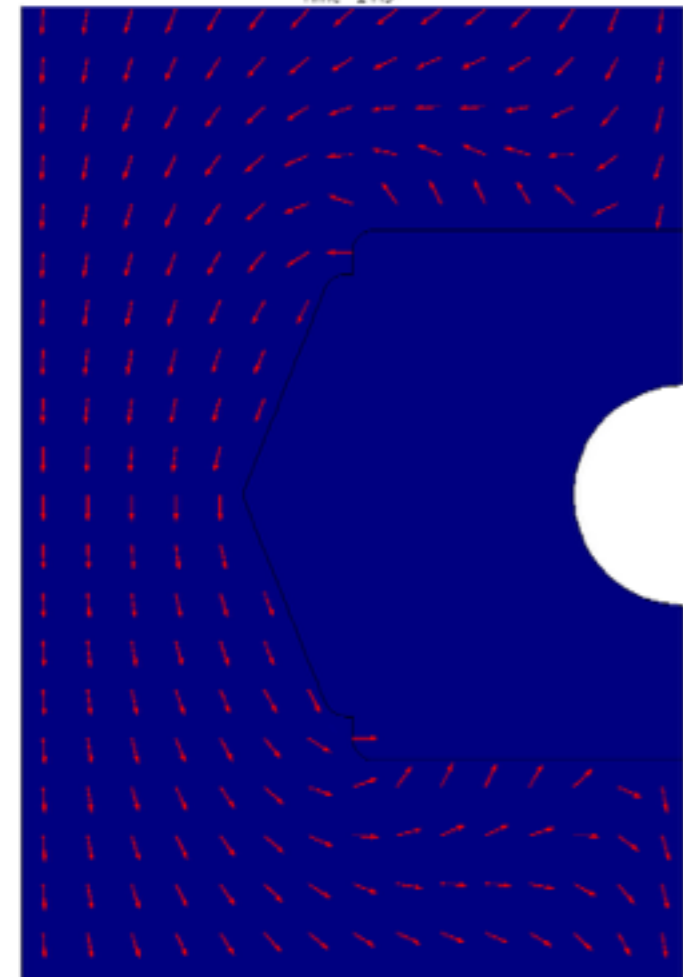
Gain increases



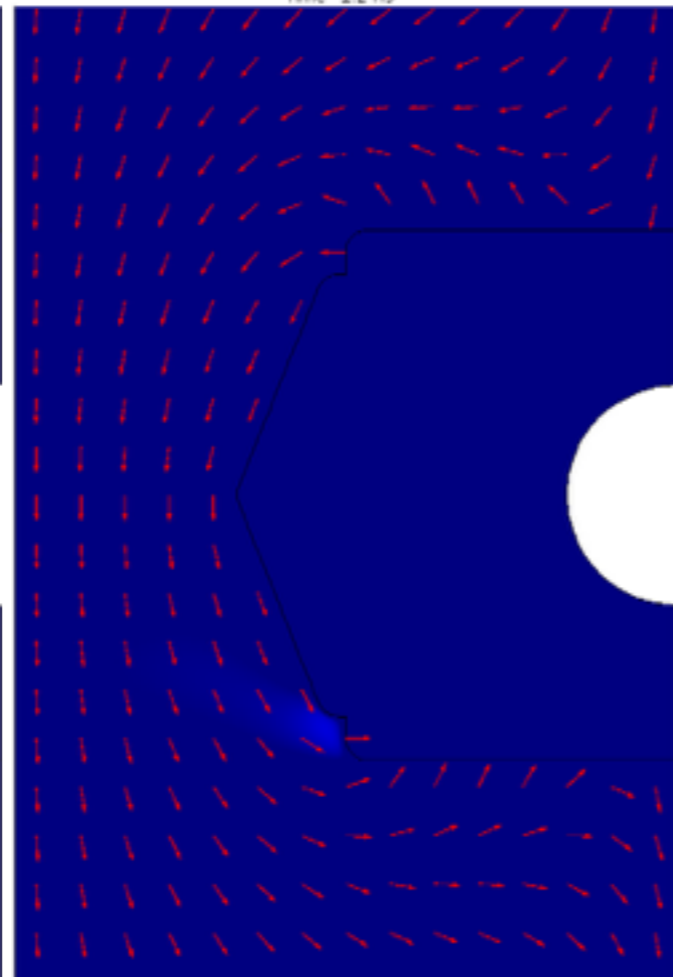
# The streamer



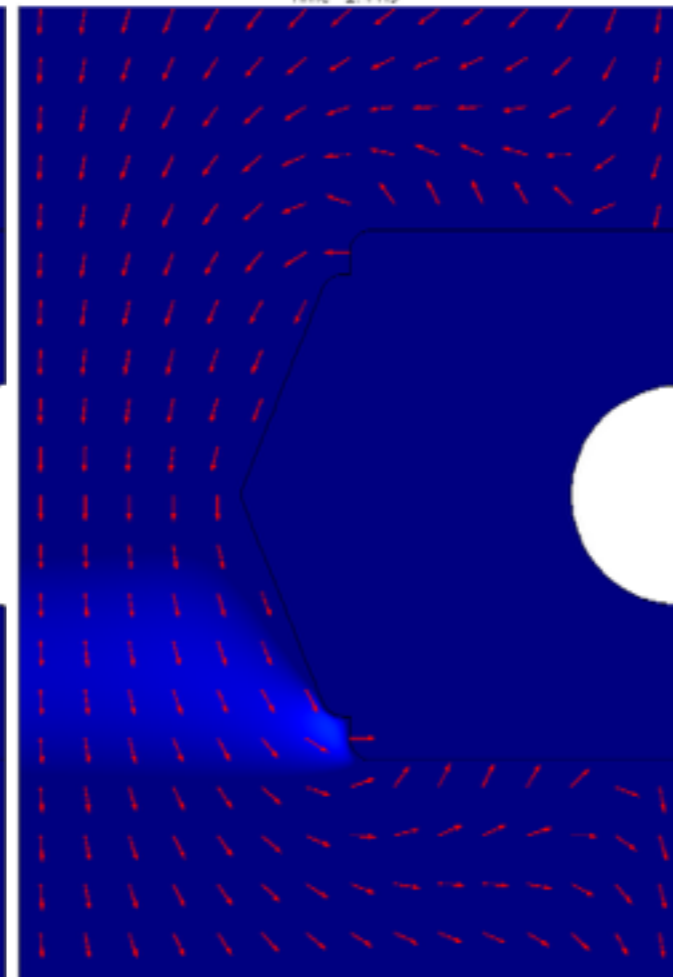
Time=1 ns



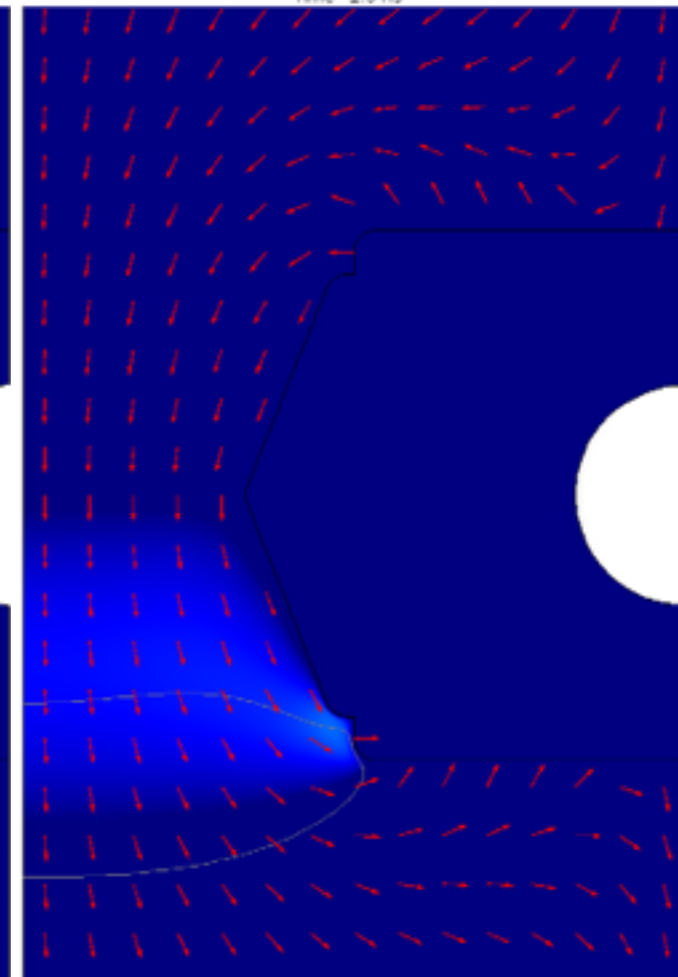
Time=1.2 ns



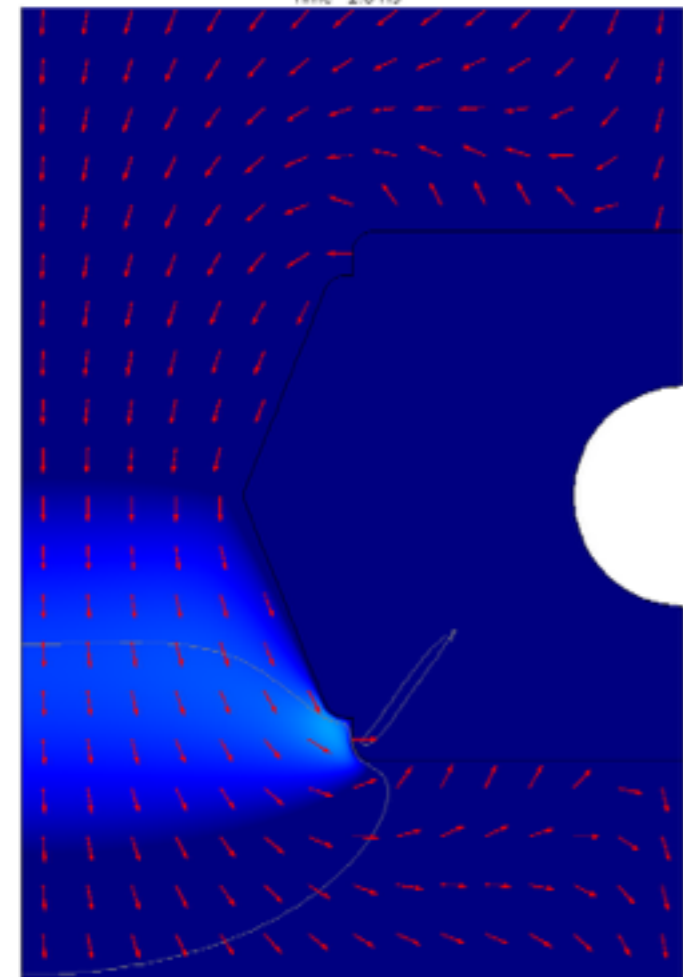
Time=1.4 ns



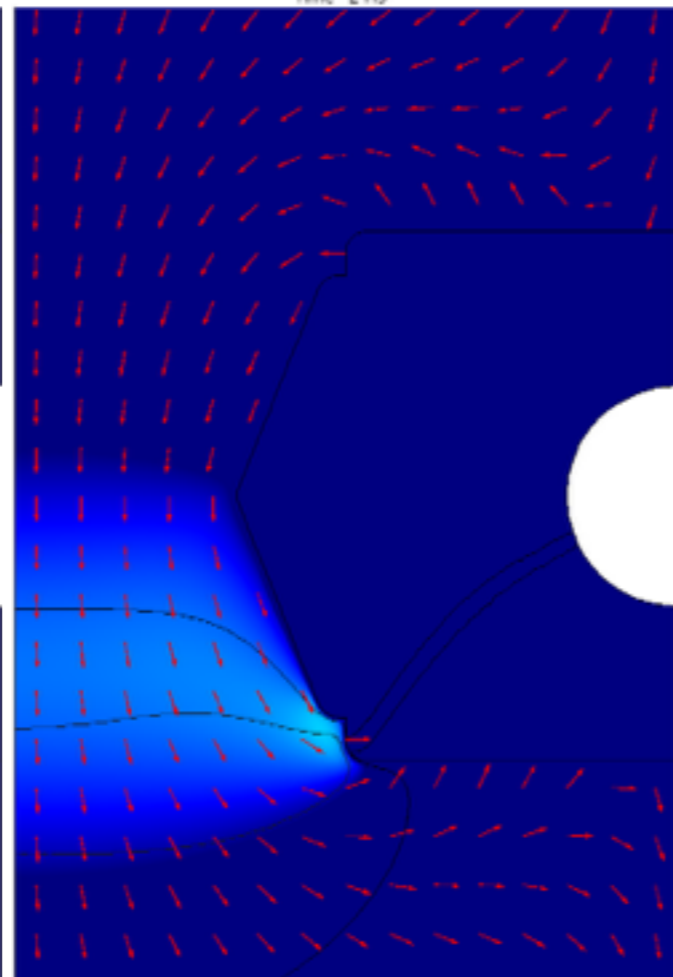
Time=1.6 ns



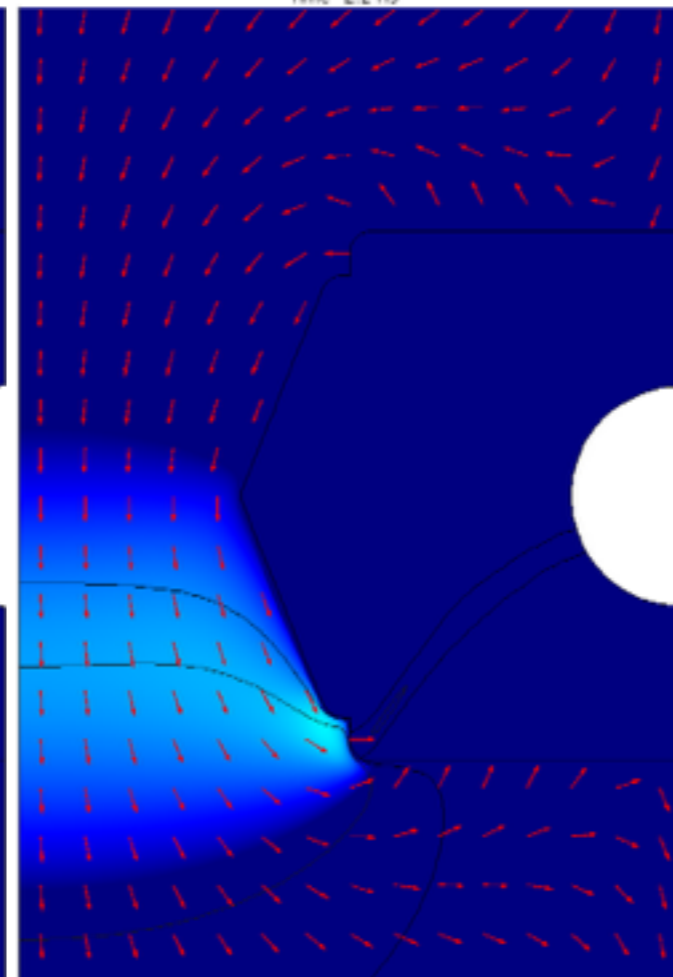
Time=1.8 ns



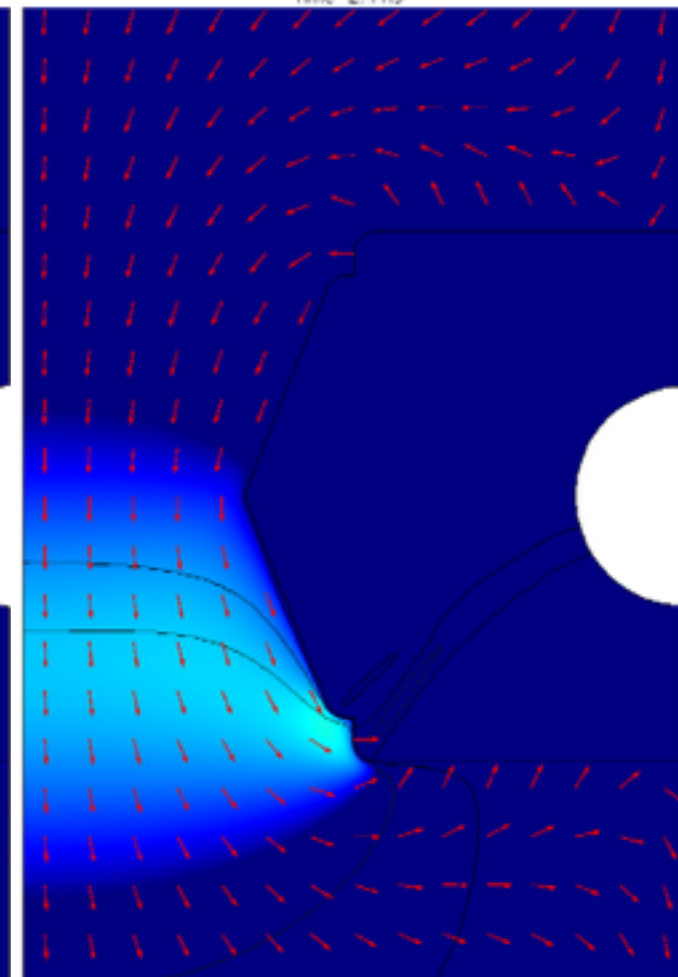
Time=2 ns



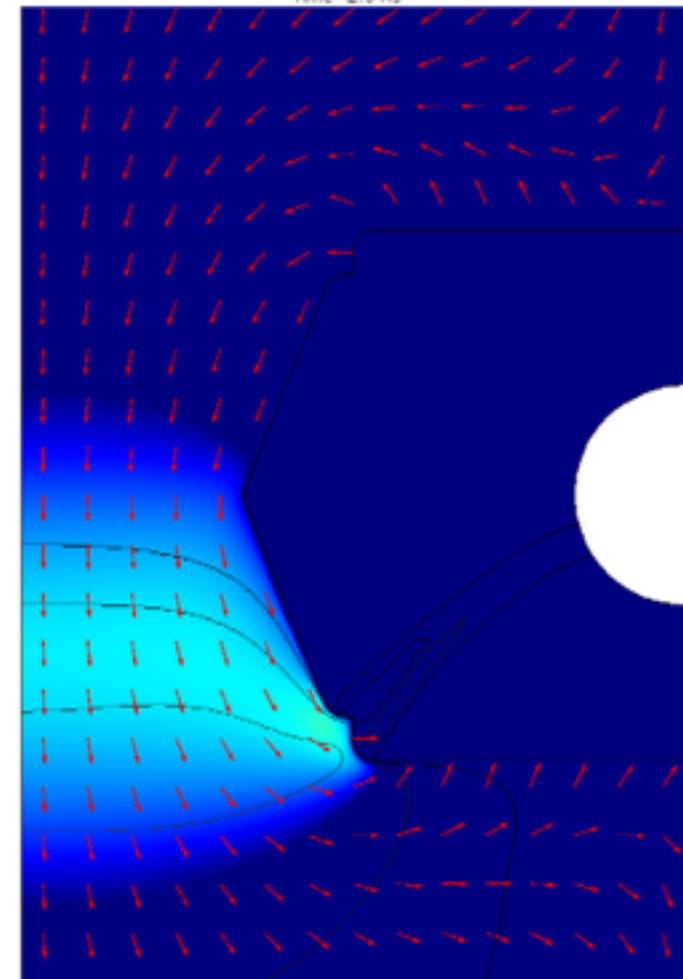
Time=2.2 ns



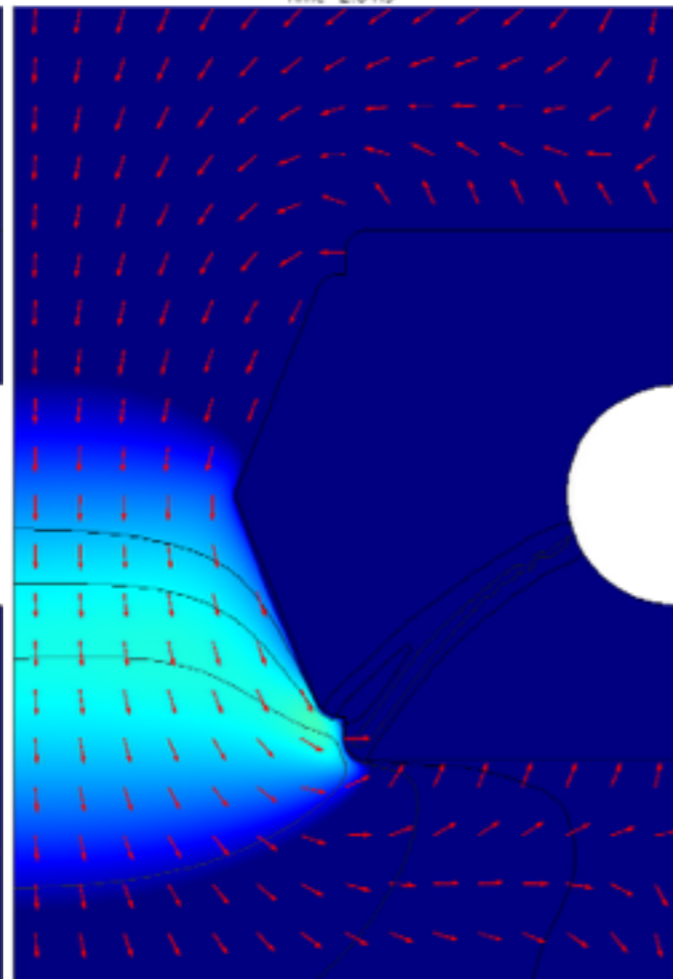
Time=2.4 ns



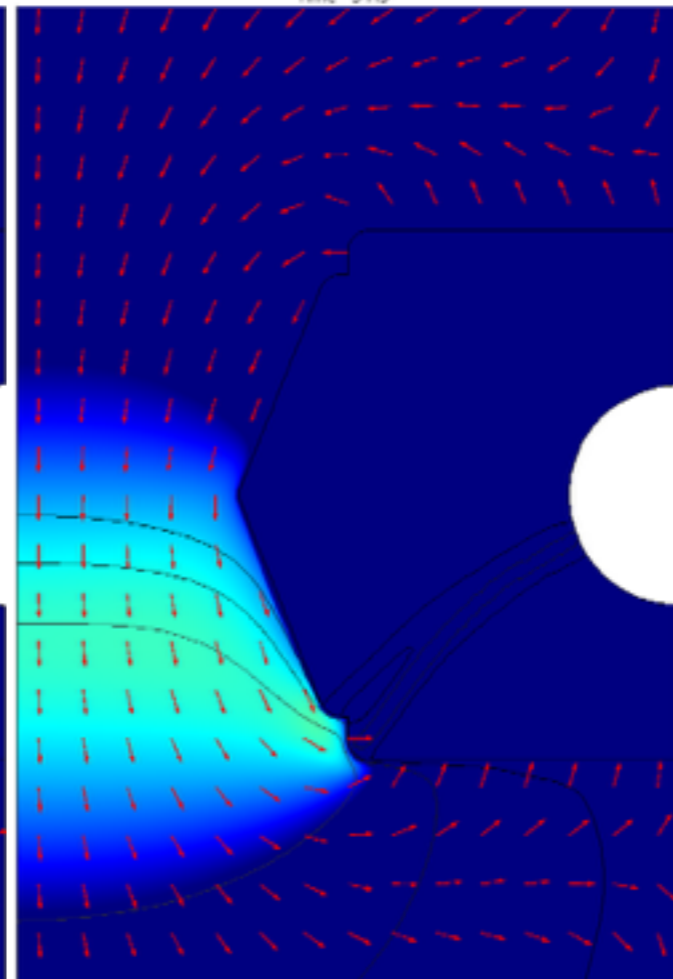
Time=2.6 ns



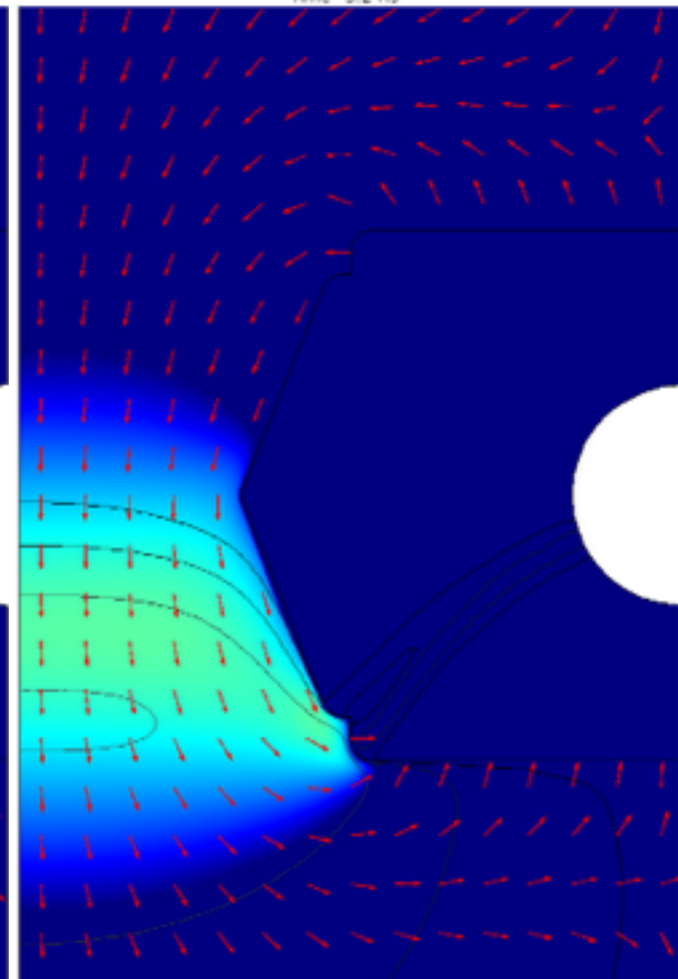
Time=2.8 ns



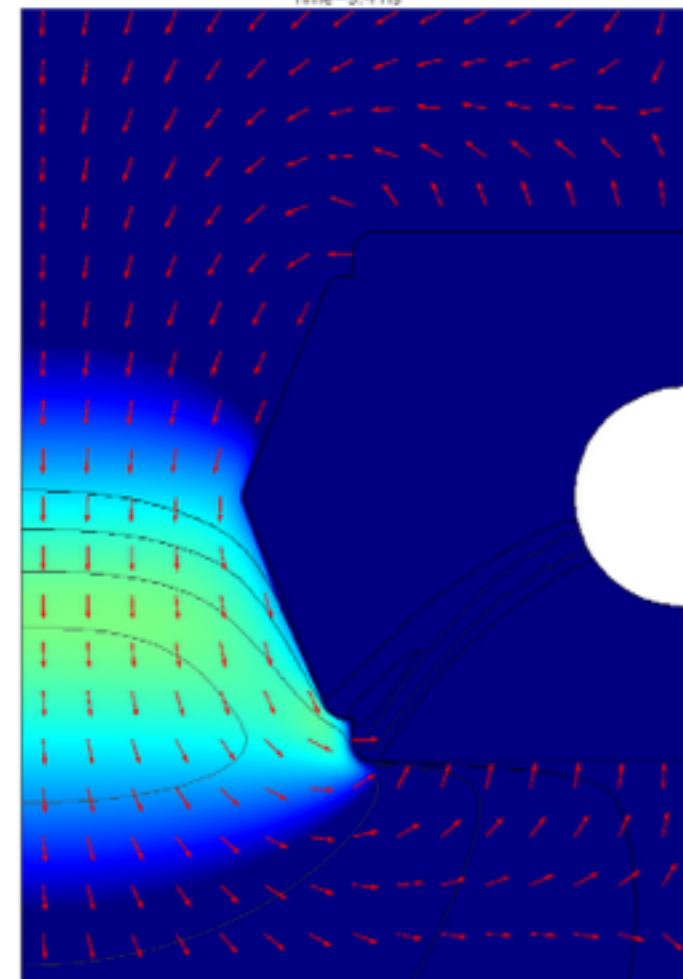
Time=3 ns



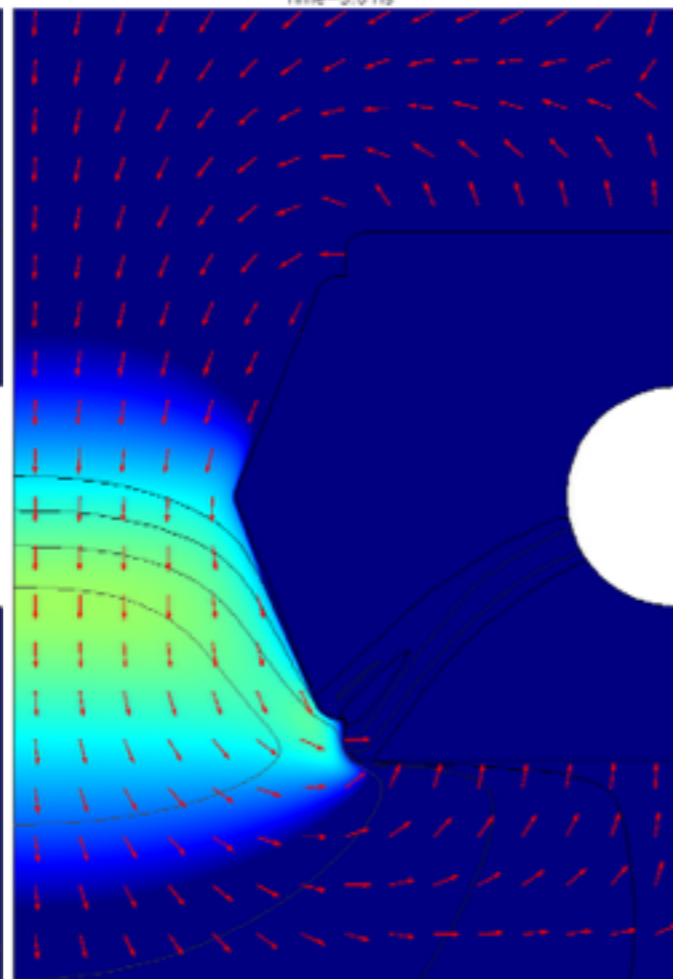
Time=3.2 ns



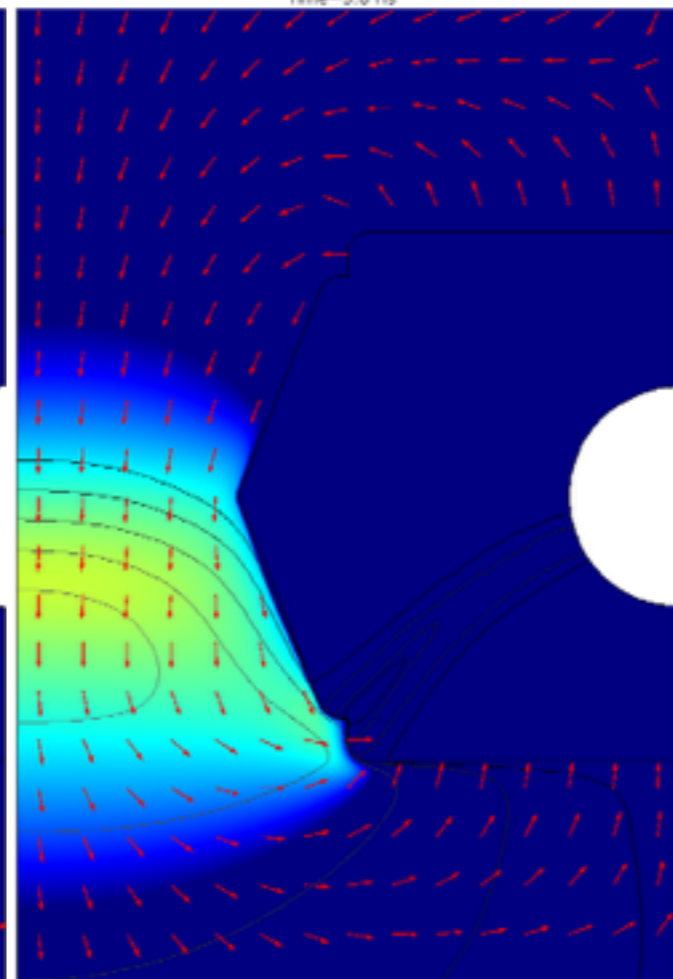
Time=3.4 ns



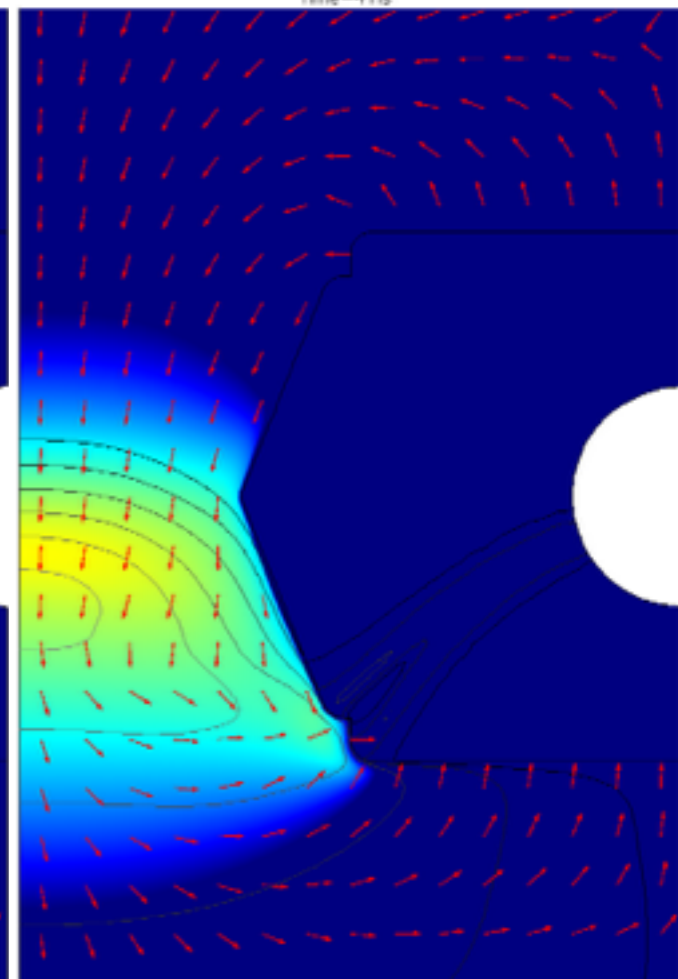
Time=3.6 ns



Time=3.8 ns



Time=4 ns





Time=4.2 ns

Time=4.4 ns

Time=4.6 ns

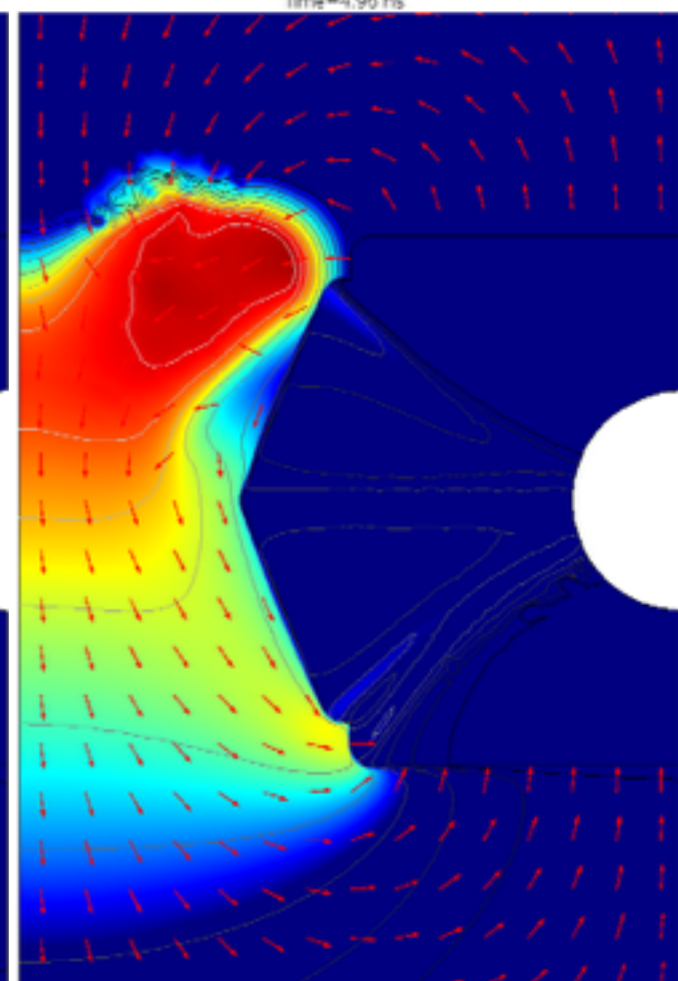
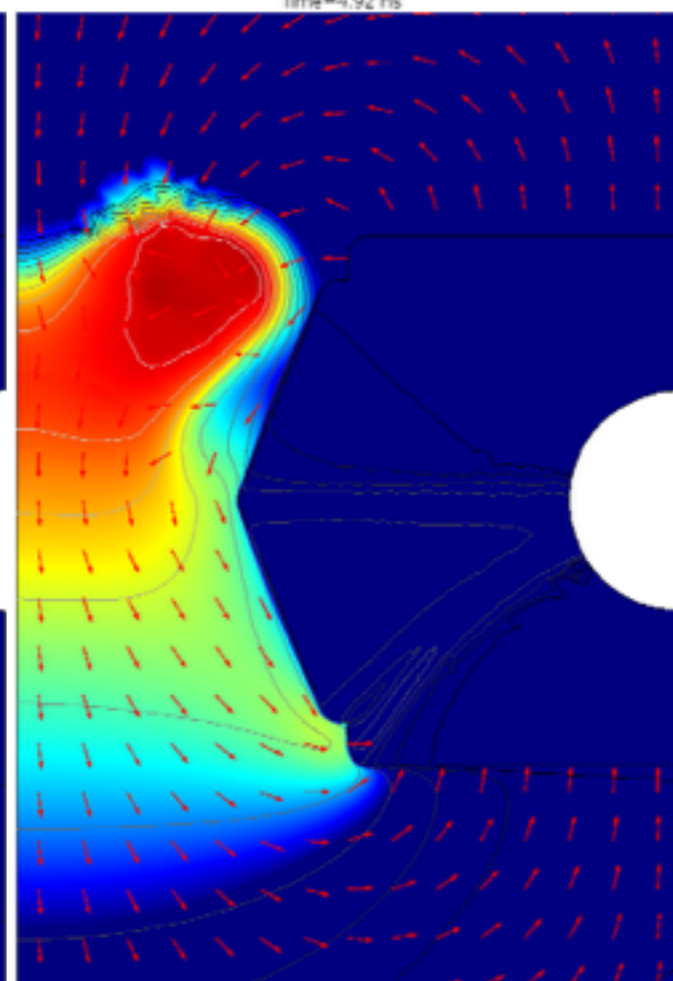
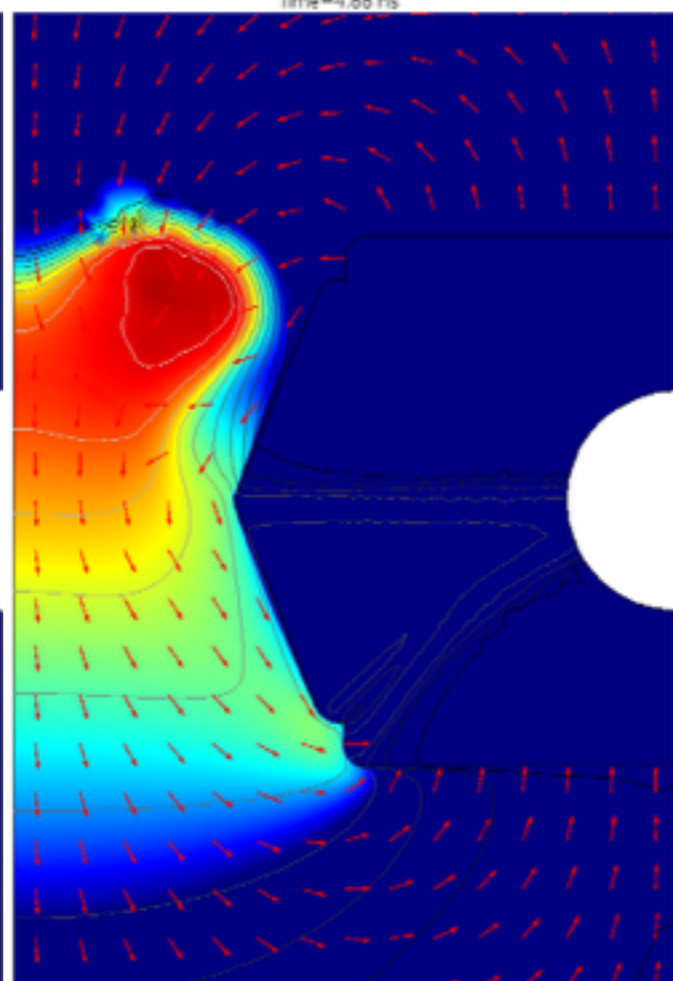
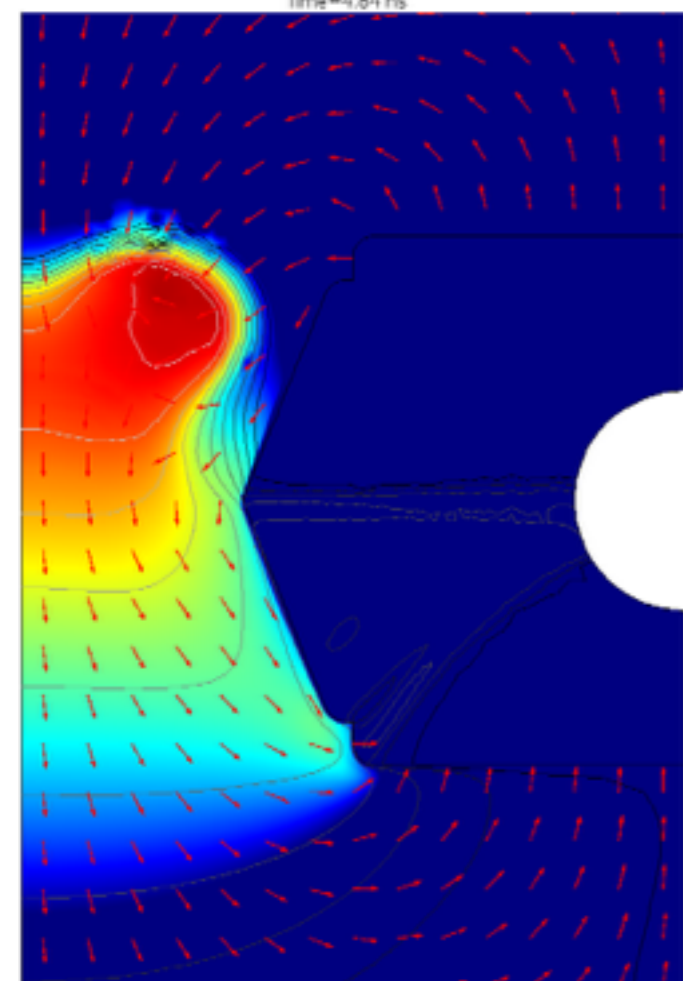
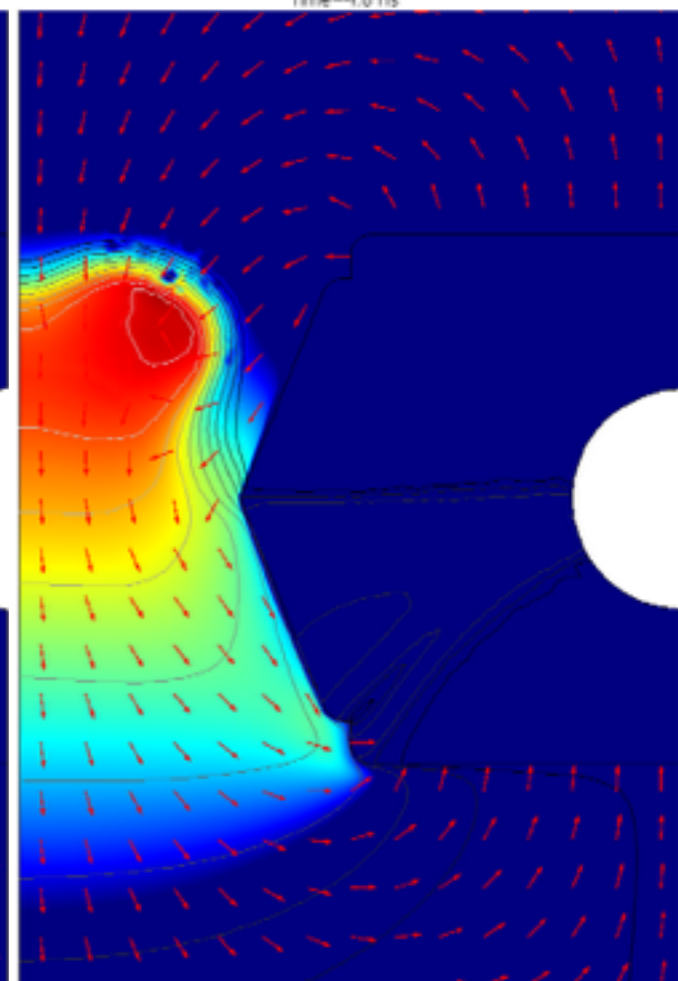
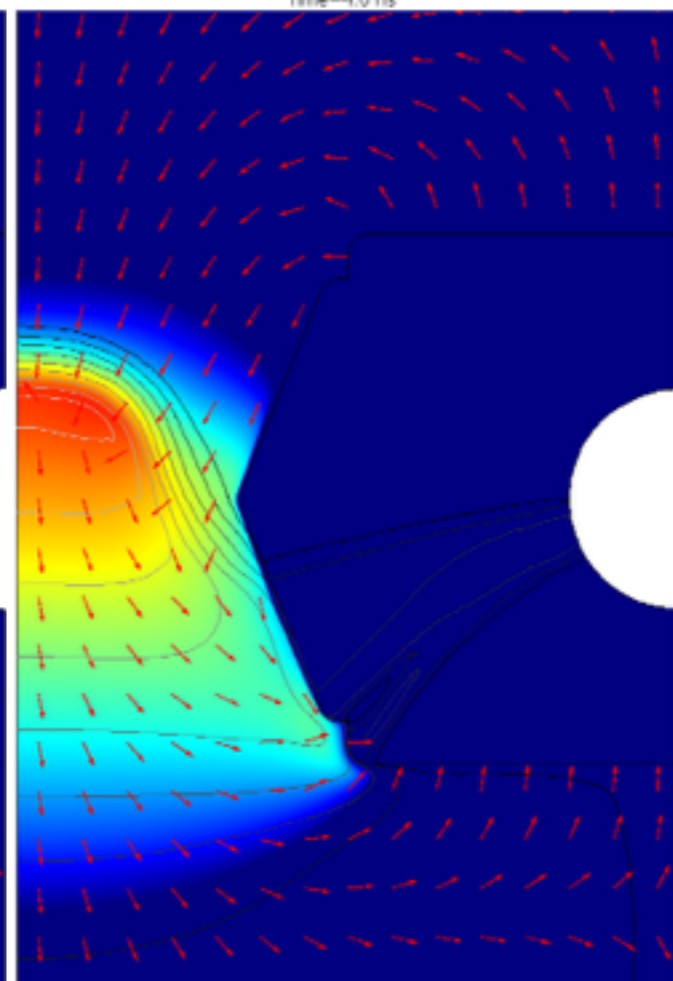
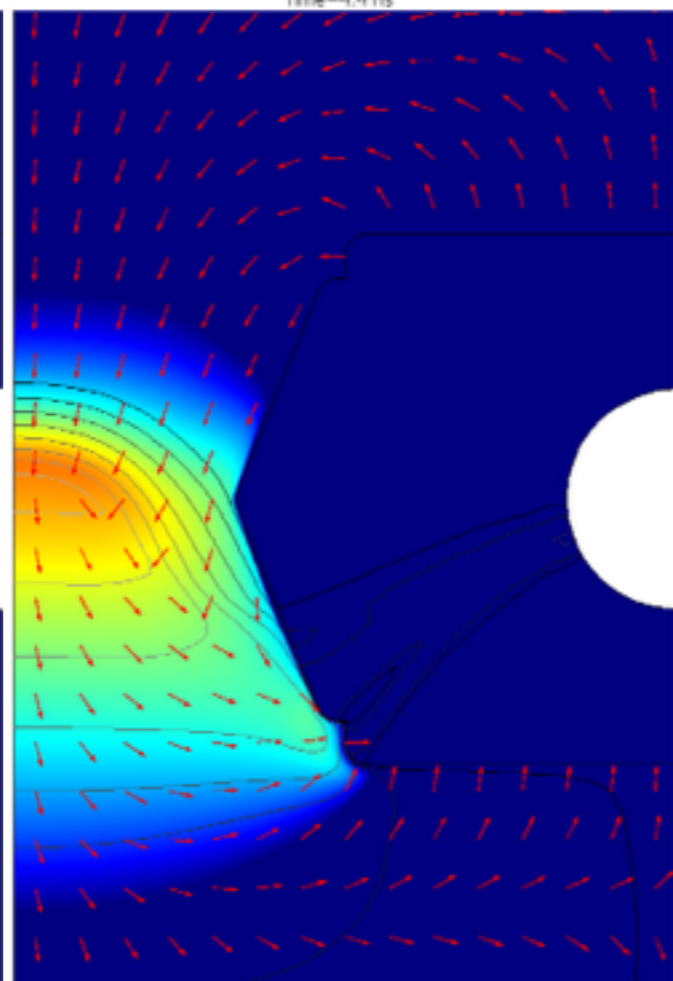
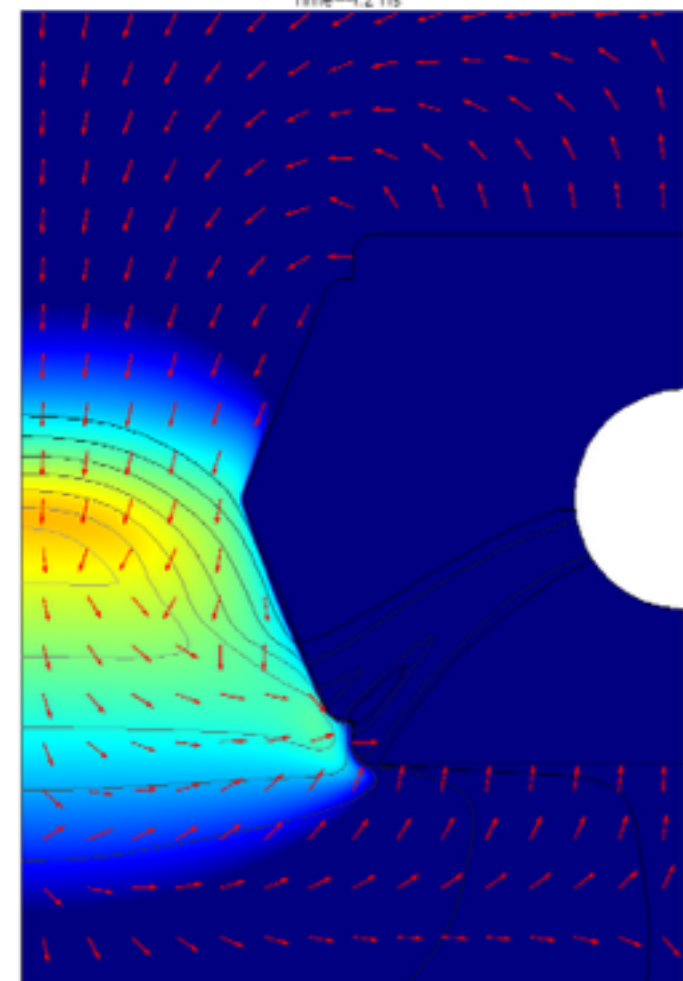
Time=4.8 ns

Time=4.84 ns

Time=4.89 ns

Time=4.92 ns

Time=4.96 ns



# Conclusion

Yes