COMSOL Multiphysics: potentially a profitable tool?

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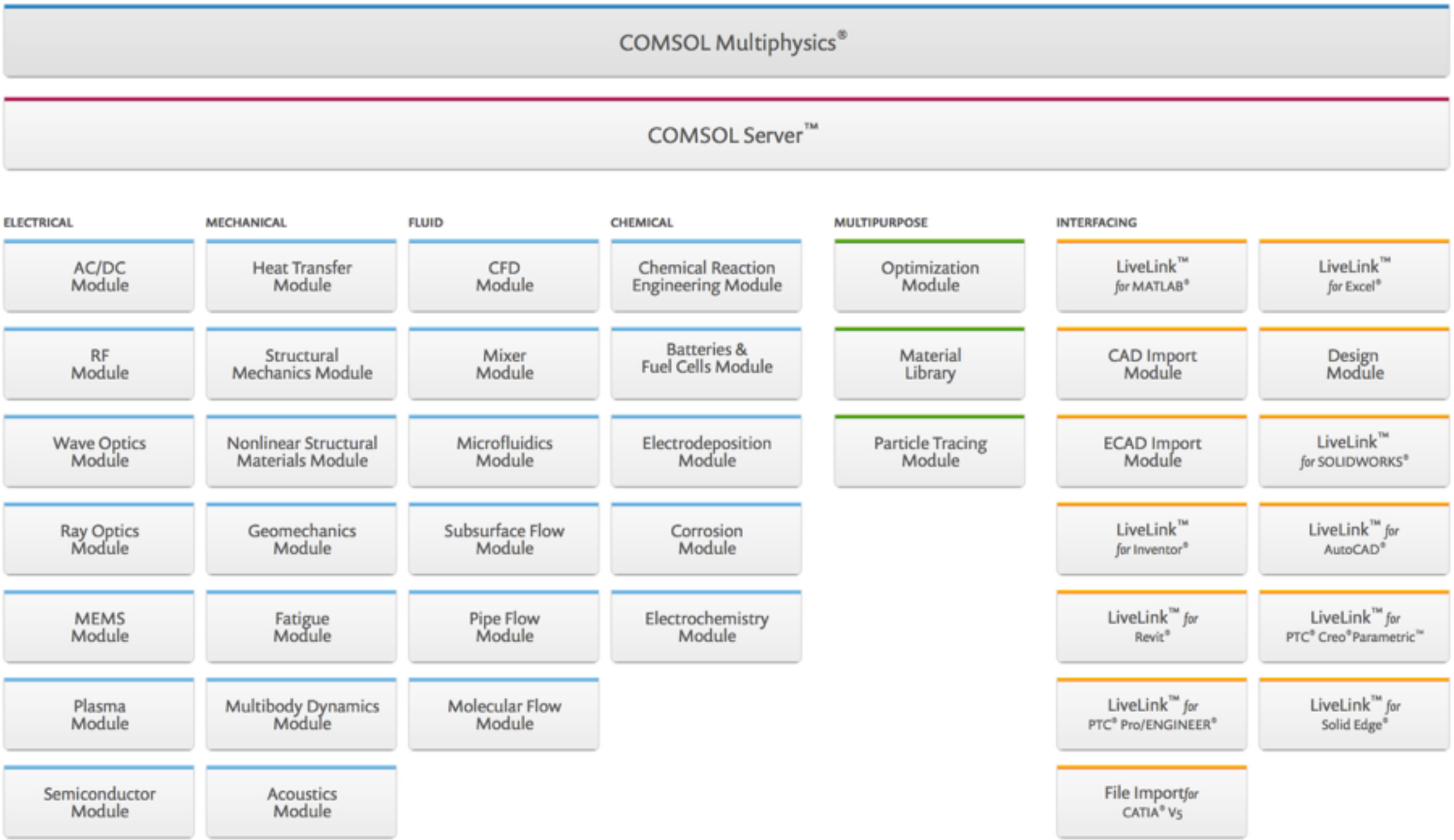
What COMSOL is

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!

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

mass: e_a
damping: d_a
diffusion: c
conservative convection: α
flux source: γ
convection: β
absorption: a
source: f

It's called Multiphysics



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:

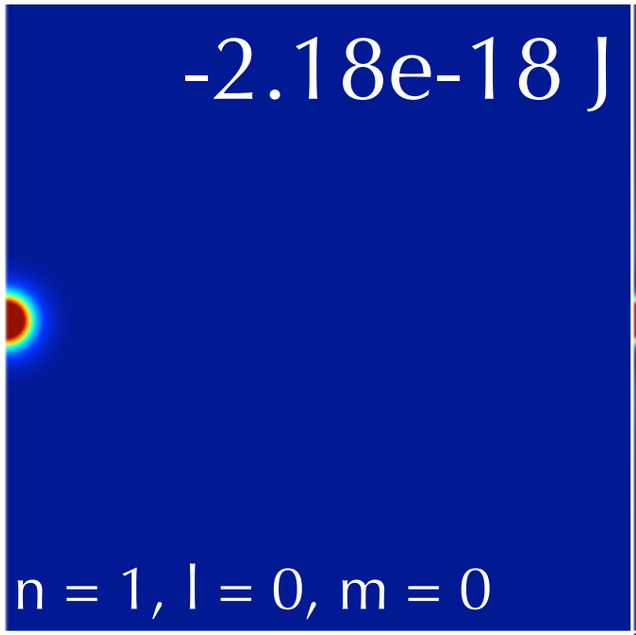
CFD Module

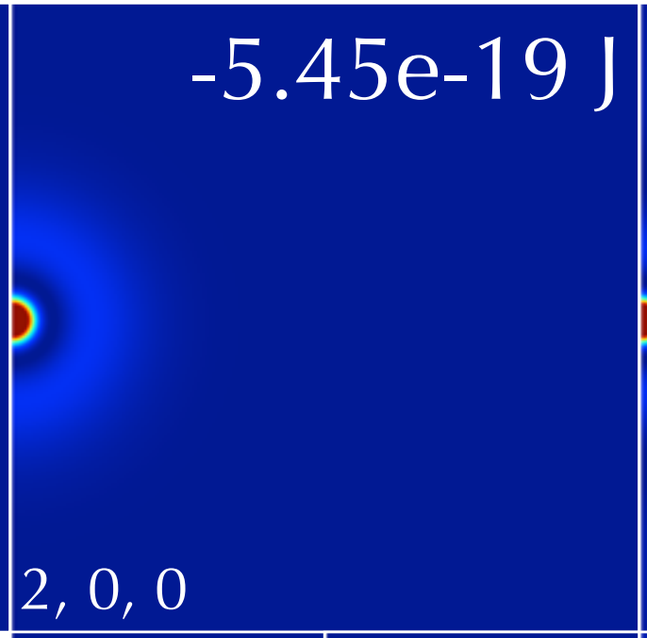
$$\frac{\partial u}{\partial t} = \nabla \cdot D \nabla u - \nabla \cdot \vec{v} u + R$$

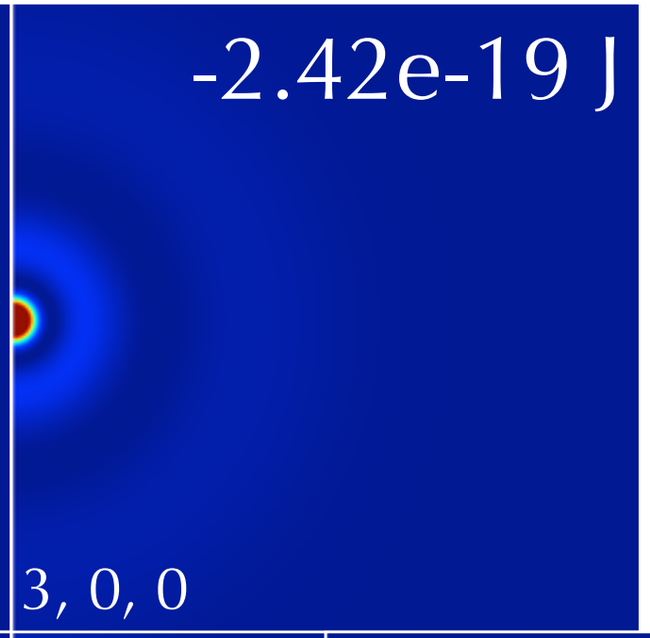
Schrödinger:

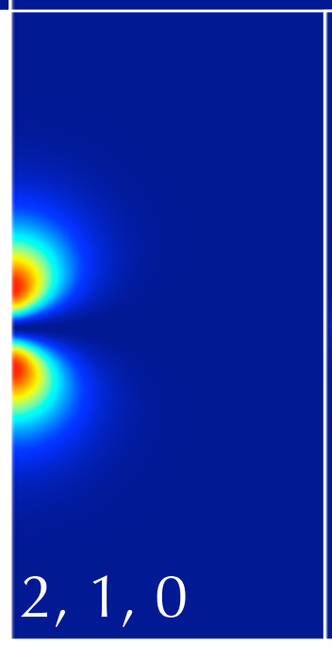
$$Eu = \frac{-\hbar^2}{2m} \nabla^2 u + V u$$

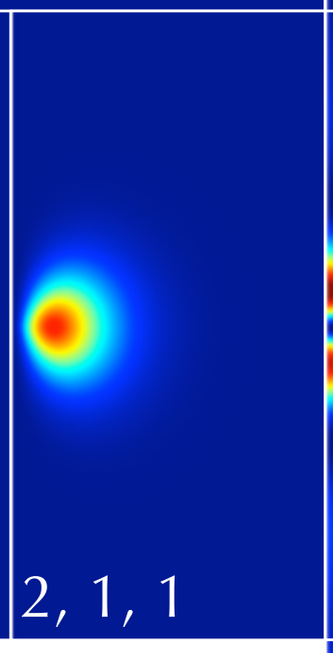
Quantum Mechanic Module is not there, and Gaseous Detector Module neither, but

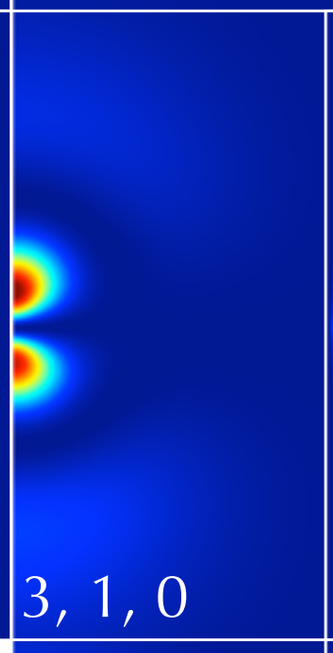


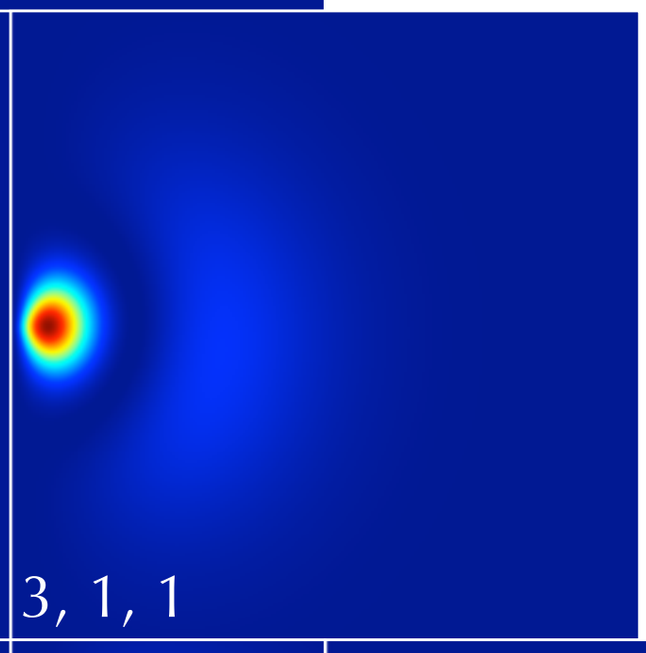






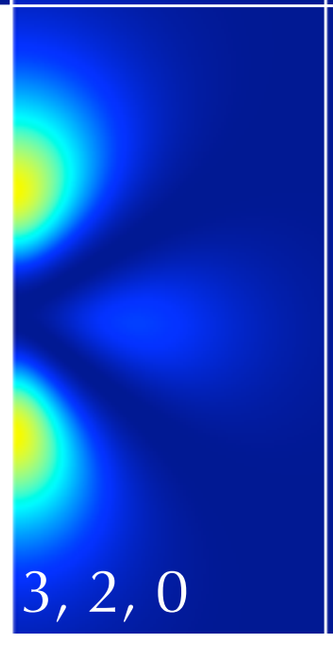


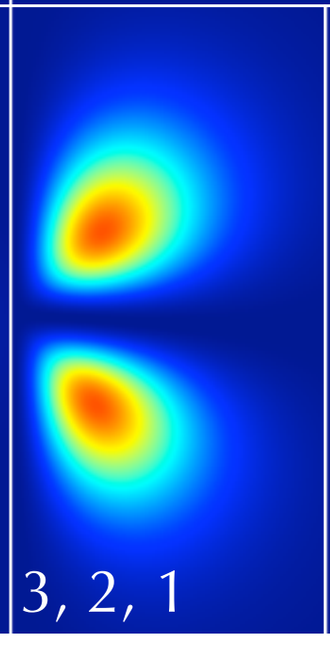


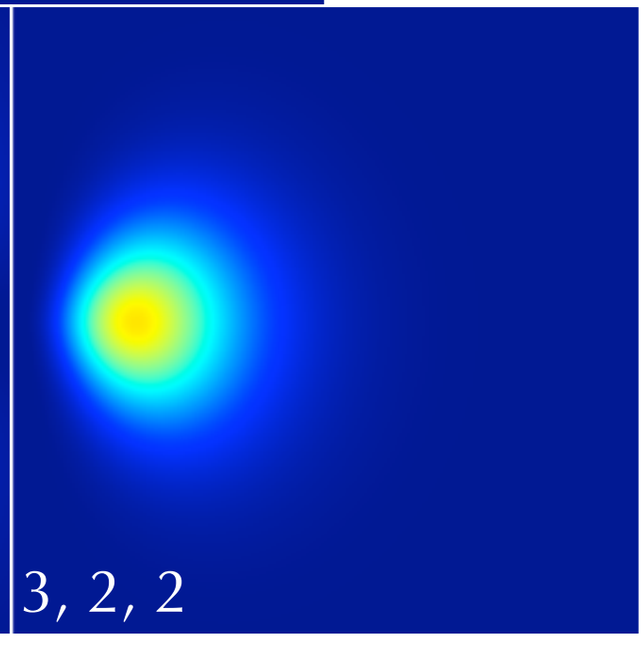


Non built-in problem:
the hydrogen atom

Eigenvalue study of the
Schrödinger equation







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

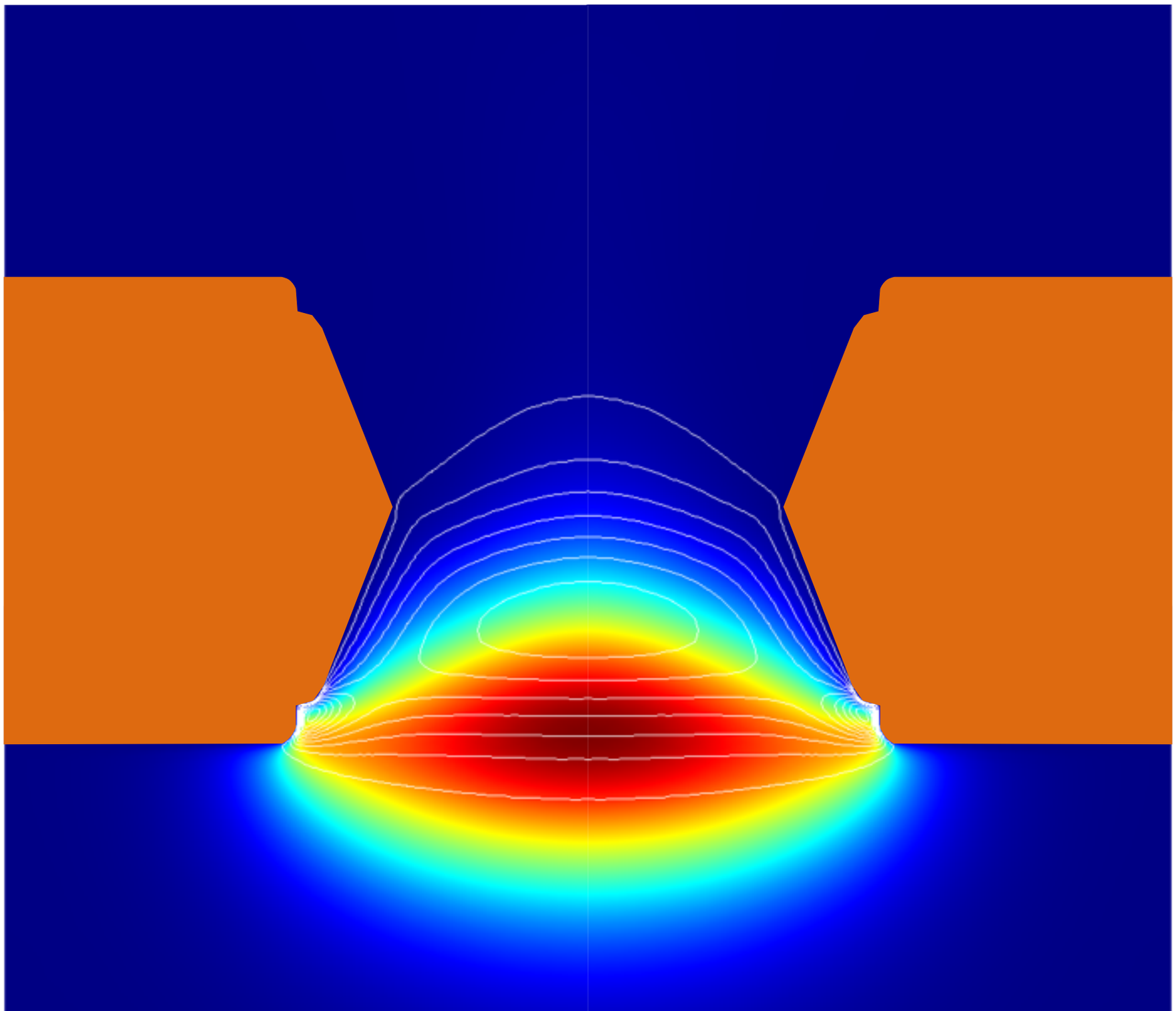
Hydrodynamic approximation

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

Axis-symmetric approximation
(a necessity in some cases)

Avalanche

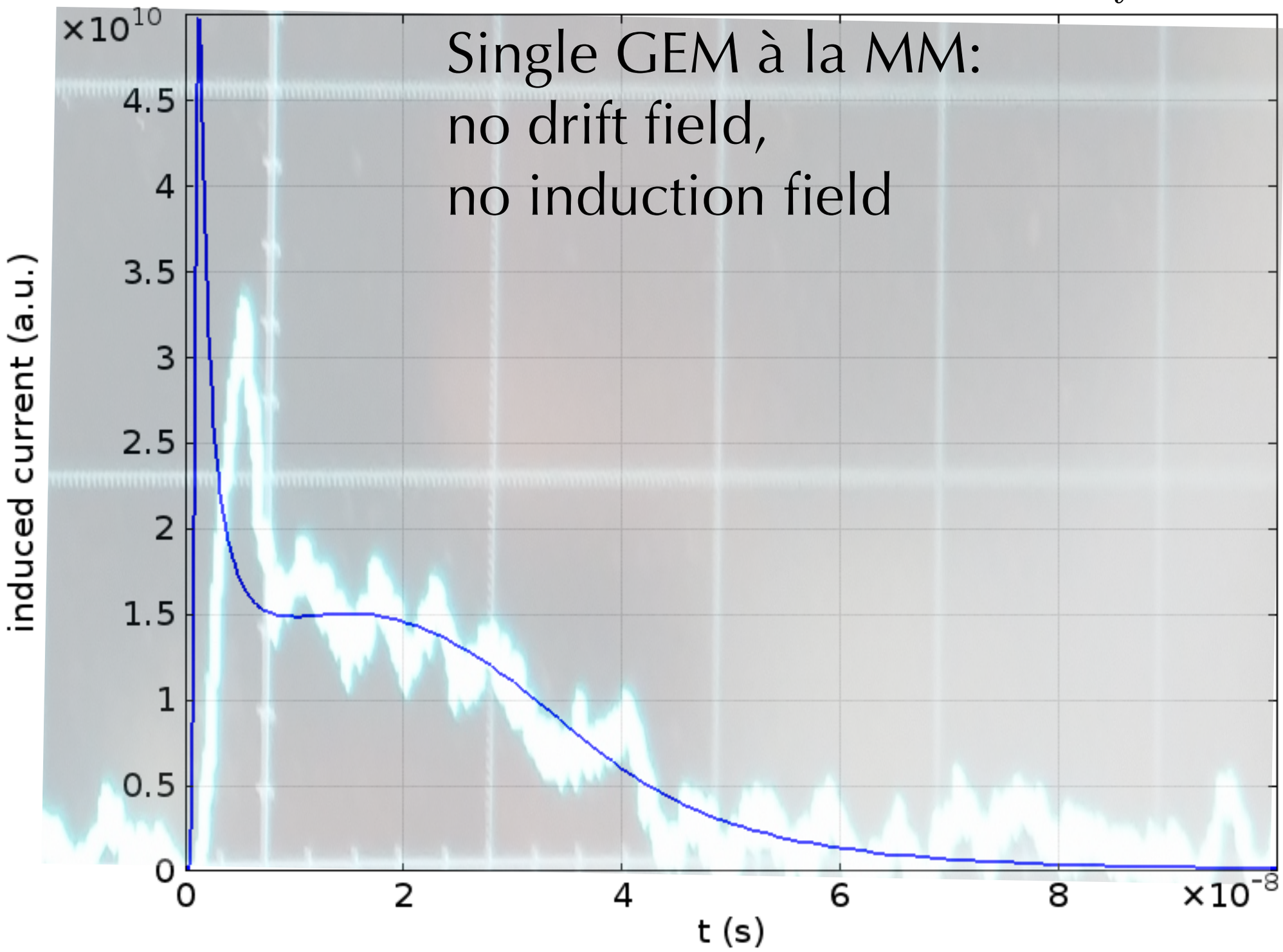
$$R = (\alpha - \eta) v_e n_e$$



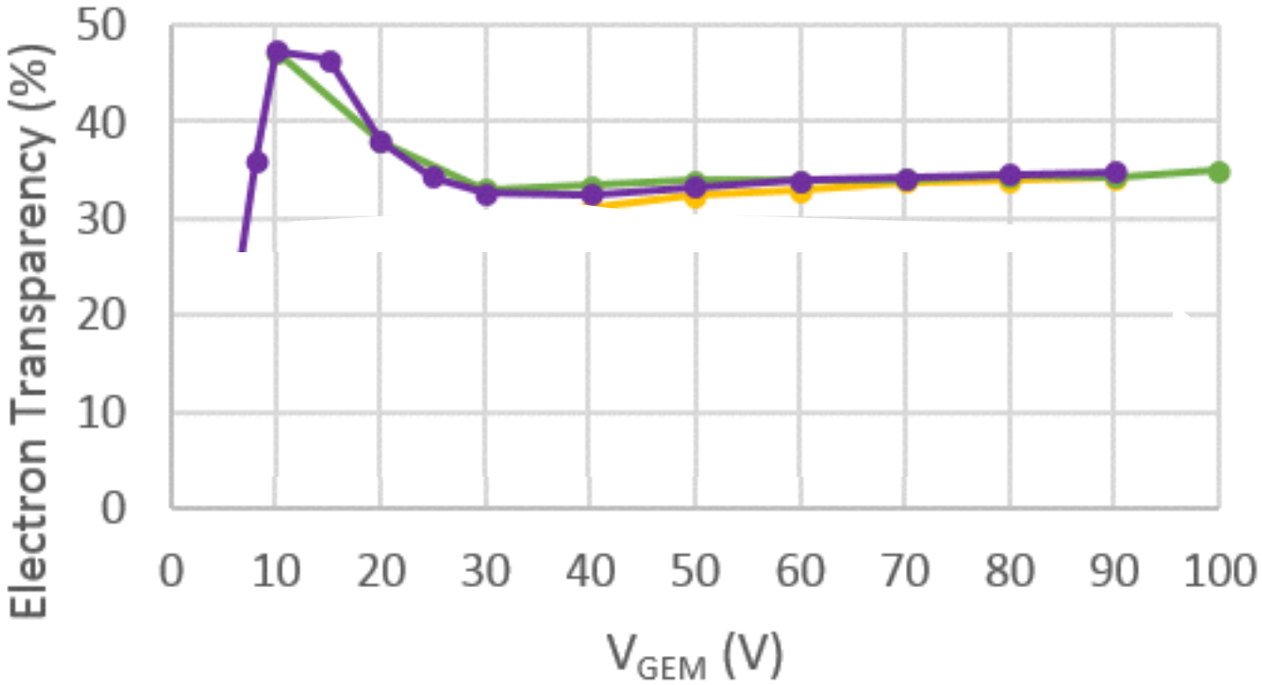
Electrons and ions treated like a gas

Signal induction

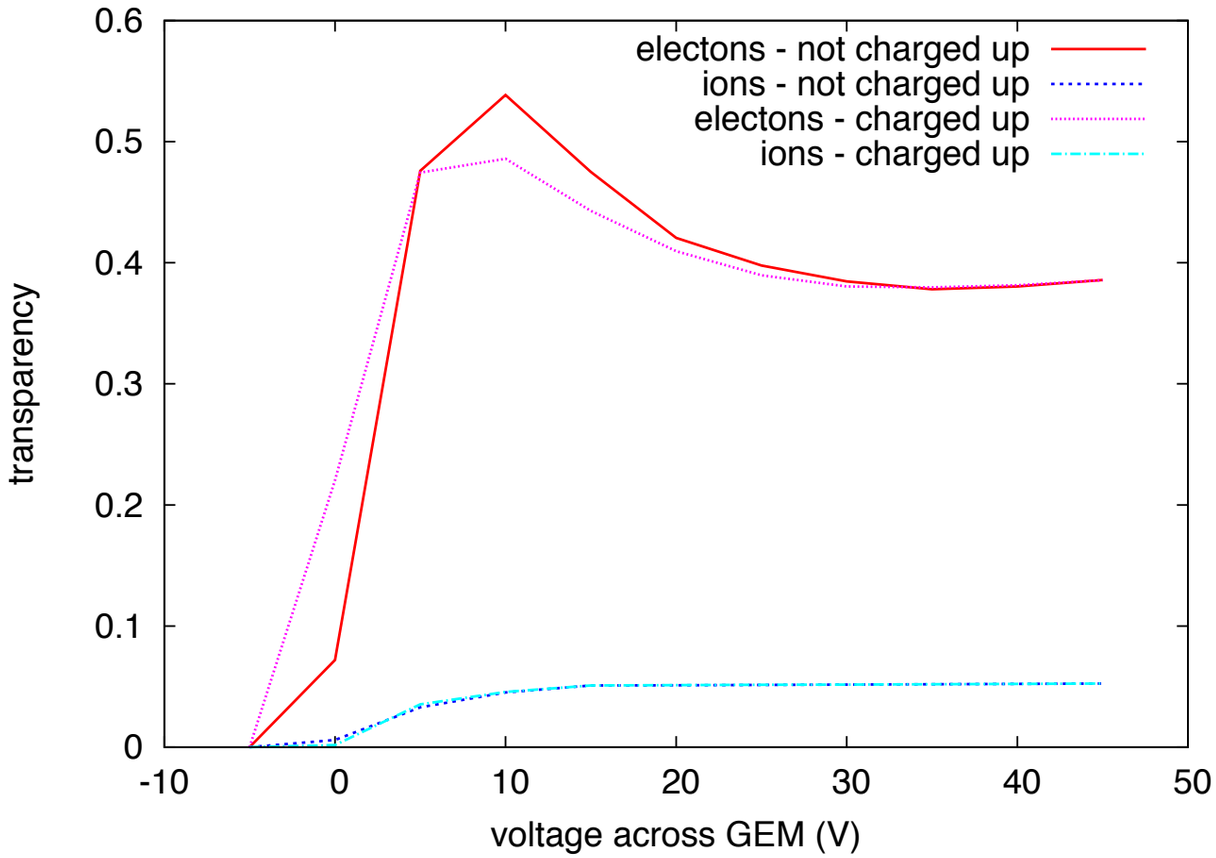
$$I = \sum_i \int \rho_i \vec{v_i} \cdot \vec{W}$$



Single GEM transparency

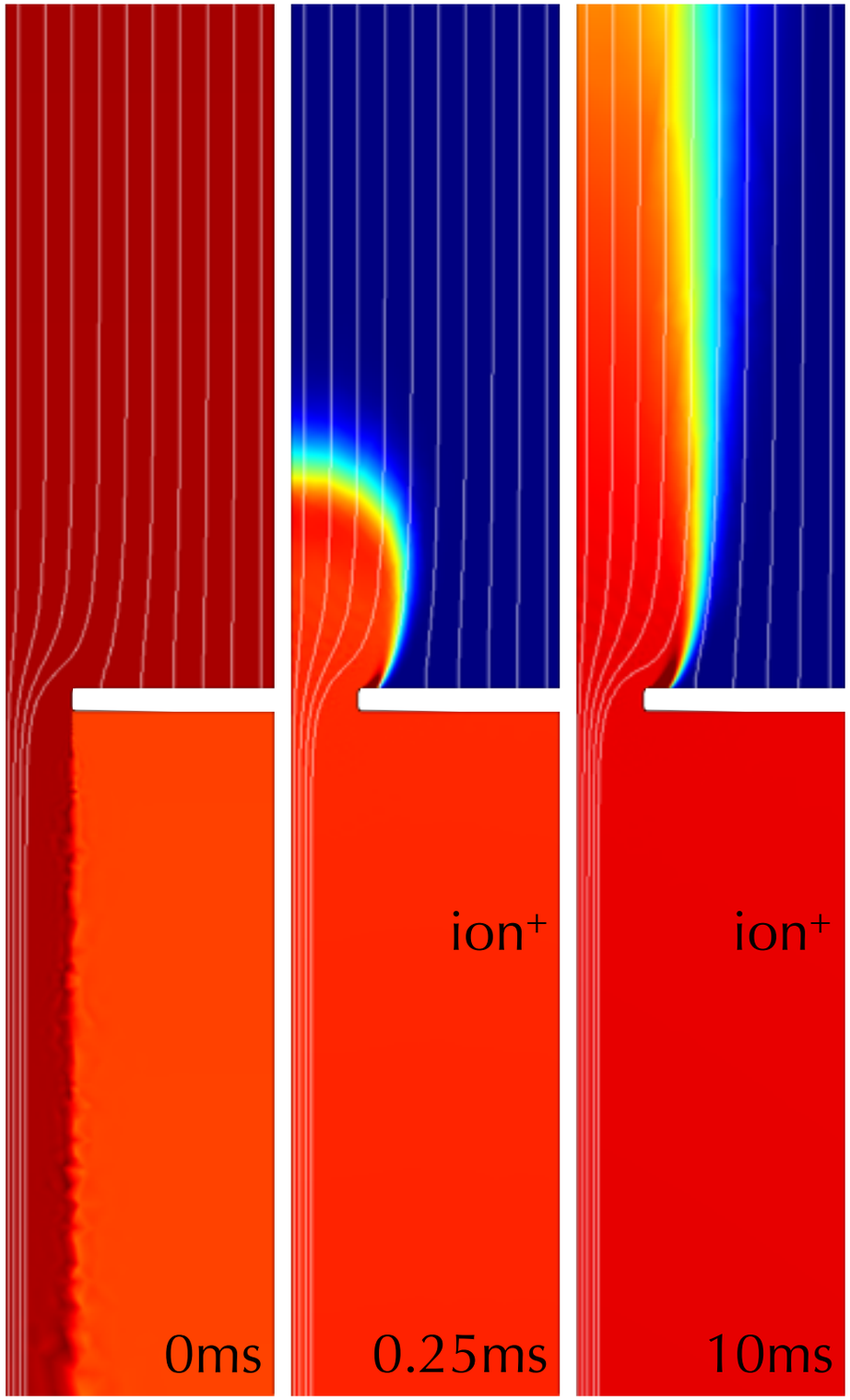


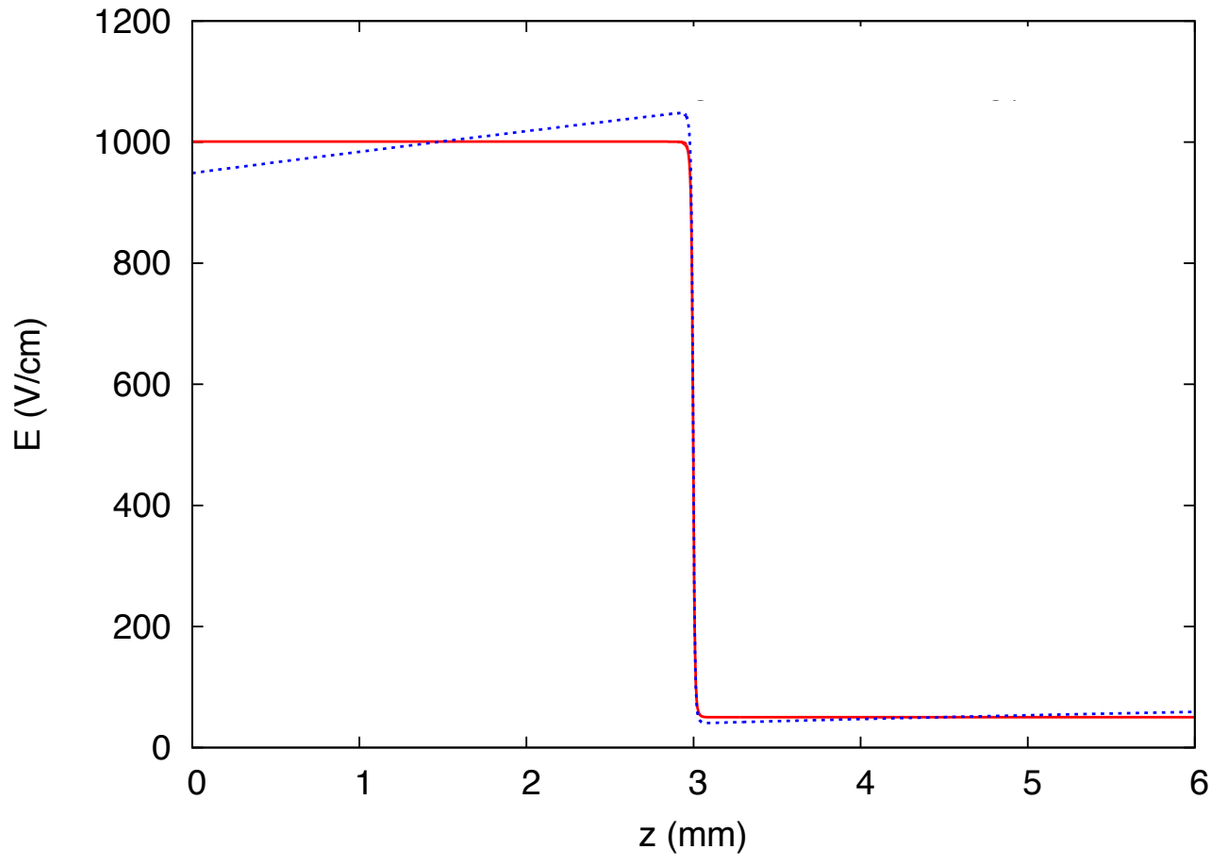
E_{D1} = 50V/cm
E_{D2} = 1kV/cm



E_{D1} = 100V/cm
E_{D2} = 2kV/cm

Space charge

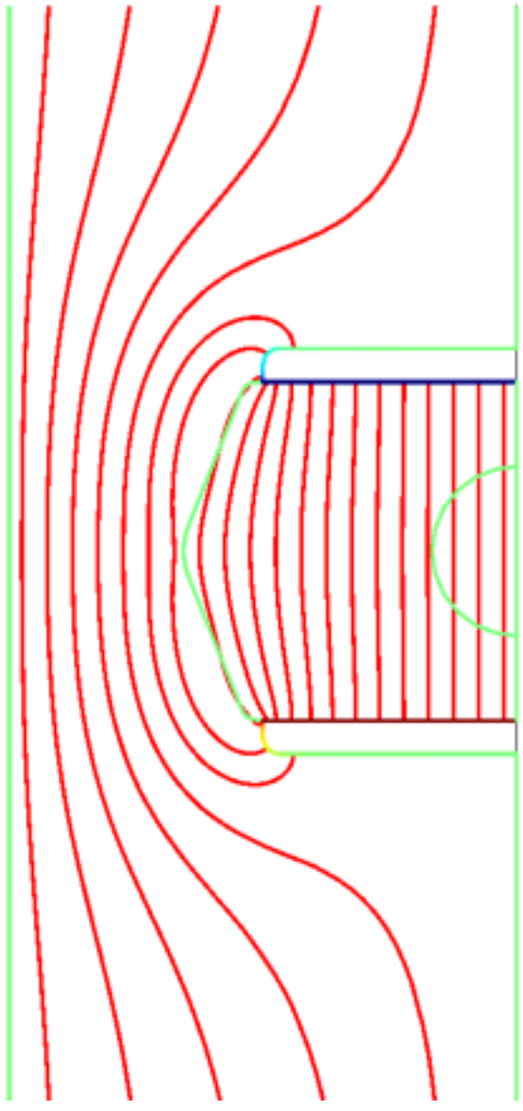




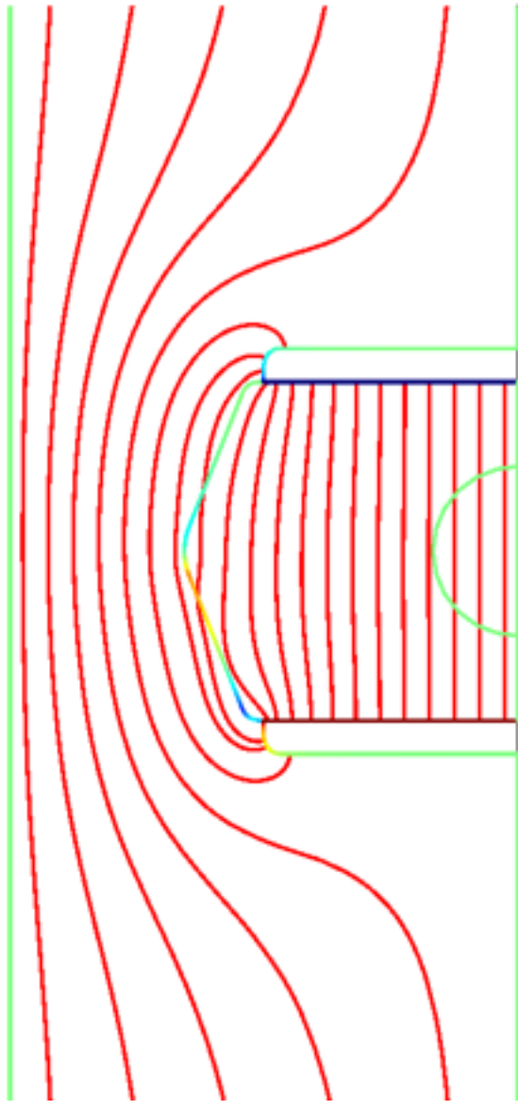
$$\nabla^2 V = q_e(n_i - n_e)/\epsilon$$

GEM charging up

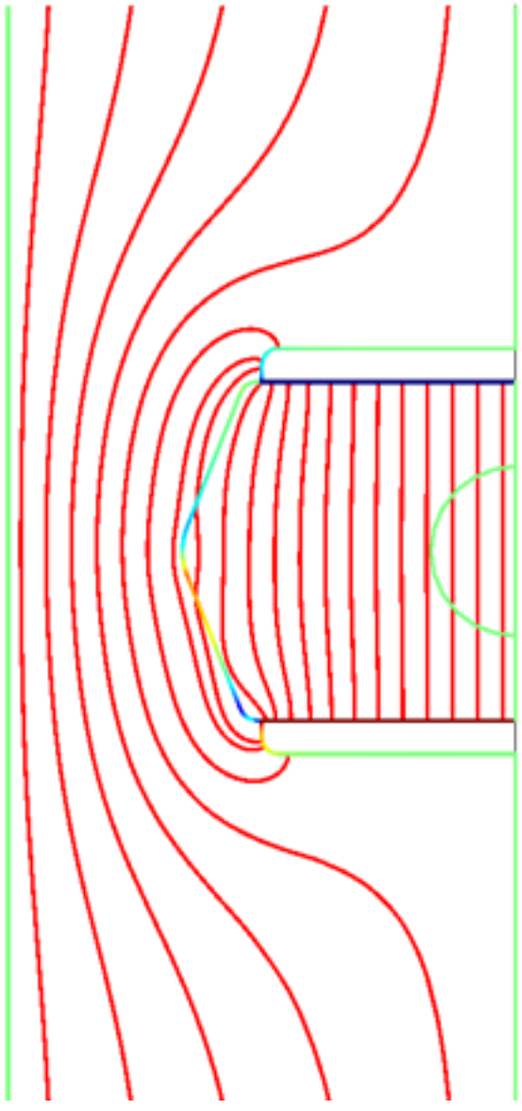
0 e^-/hole



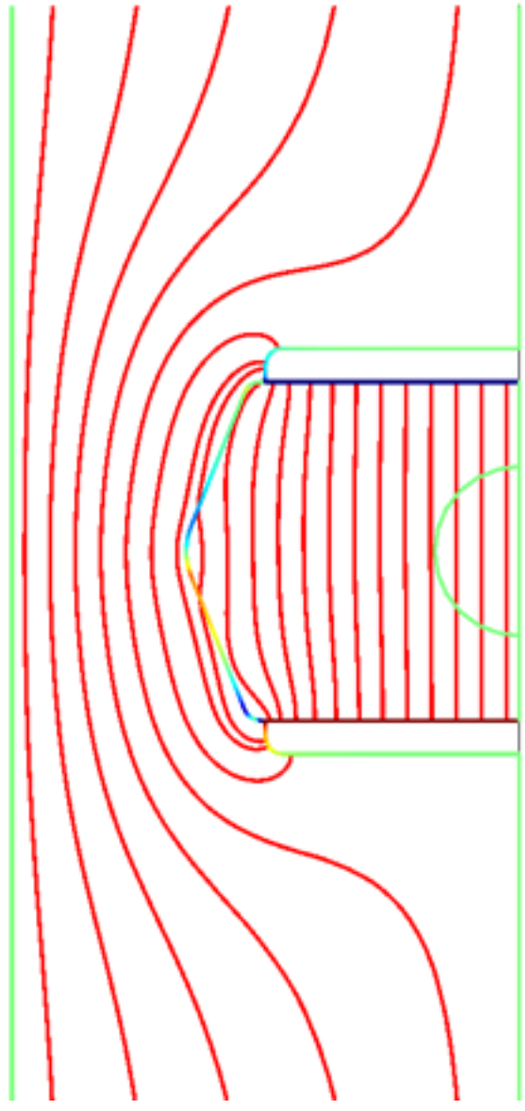
$5x10^5$ e^-/hole



$1x10^6$ e^-/hole

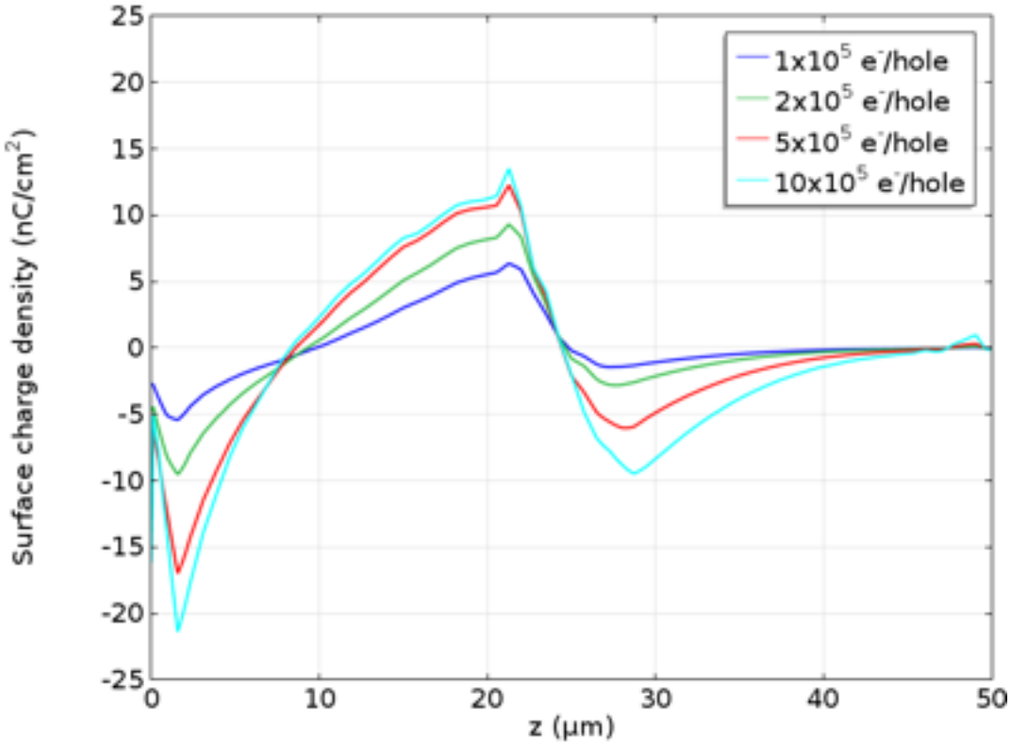


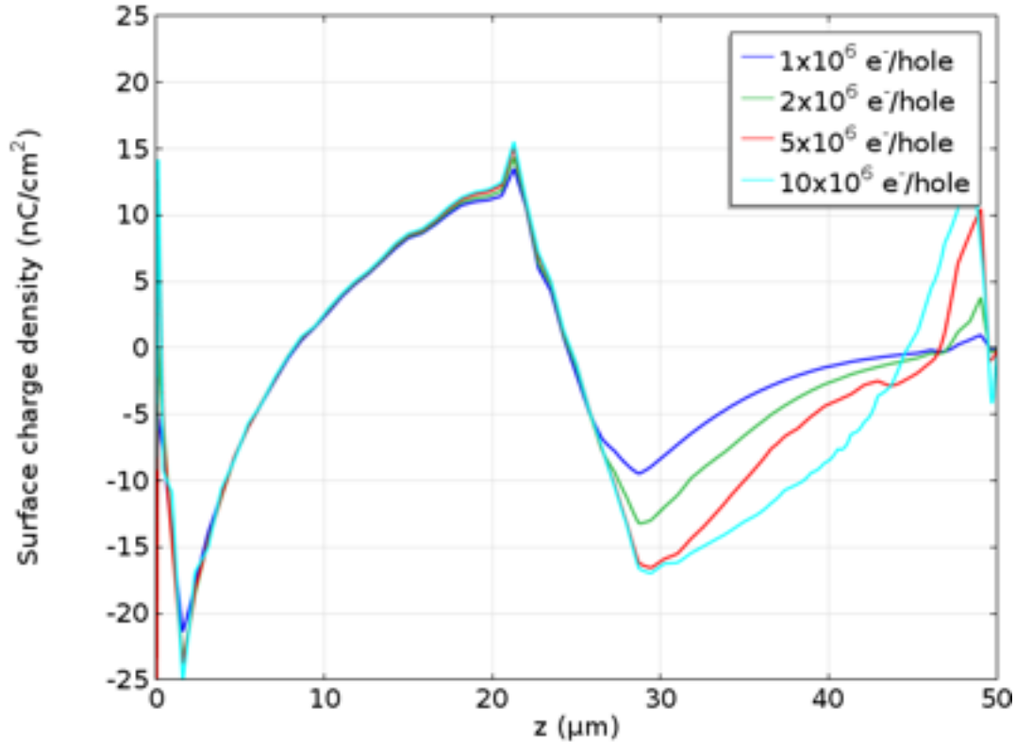
$2x10^6$ e^-/hole

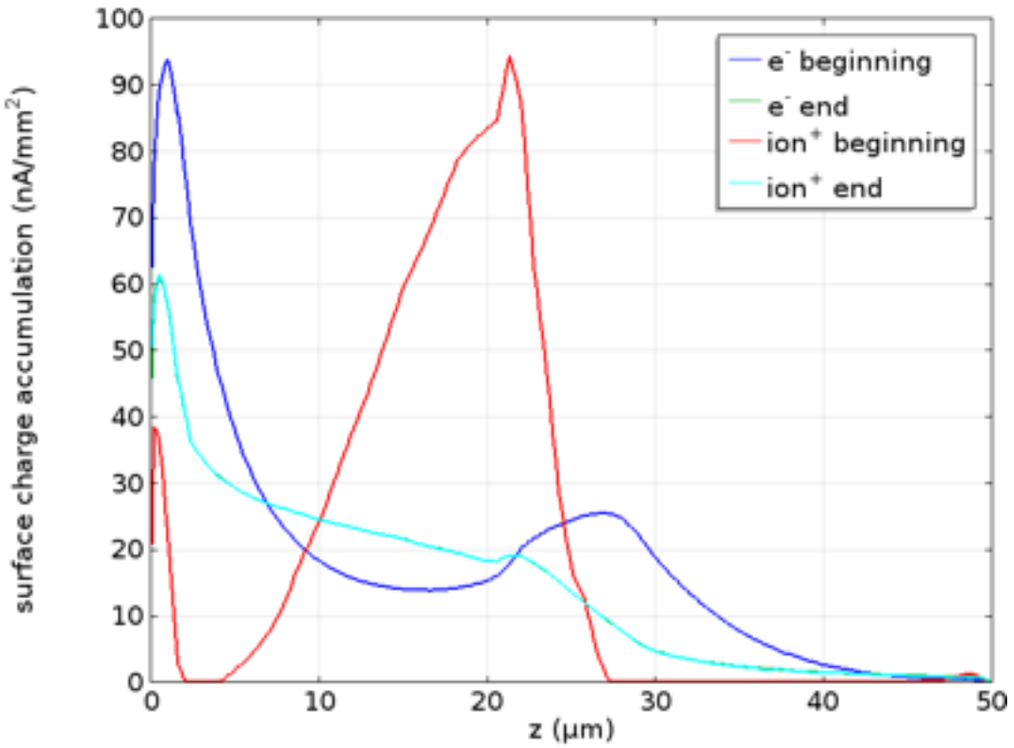


Multiple stage is different…

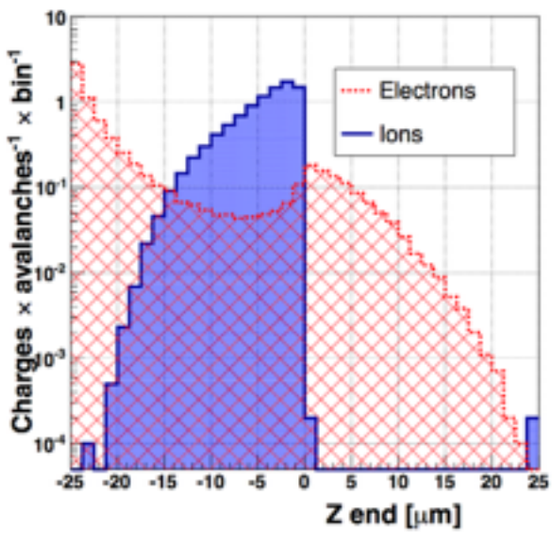
GEM charging up

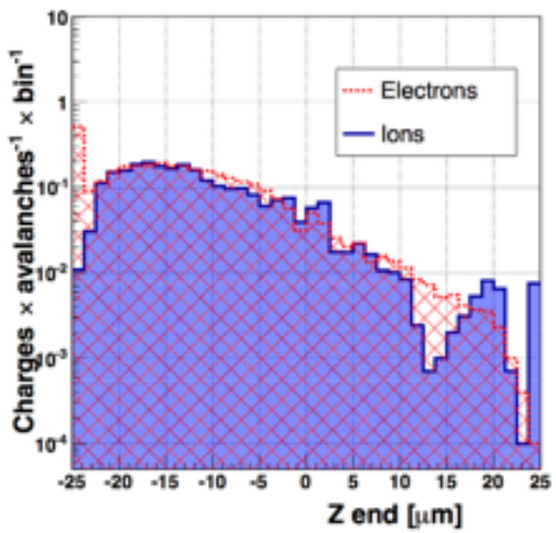






Correia *et al.*, JINST 9 (2014) P07025





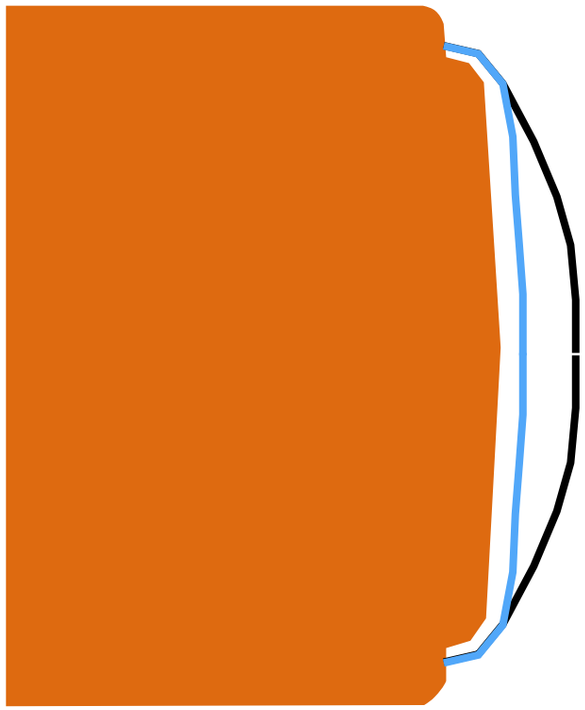
Charging up

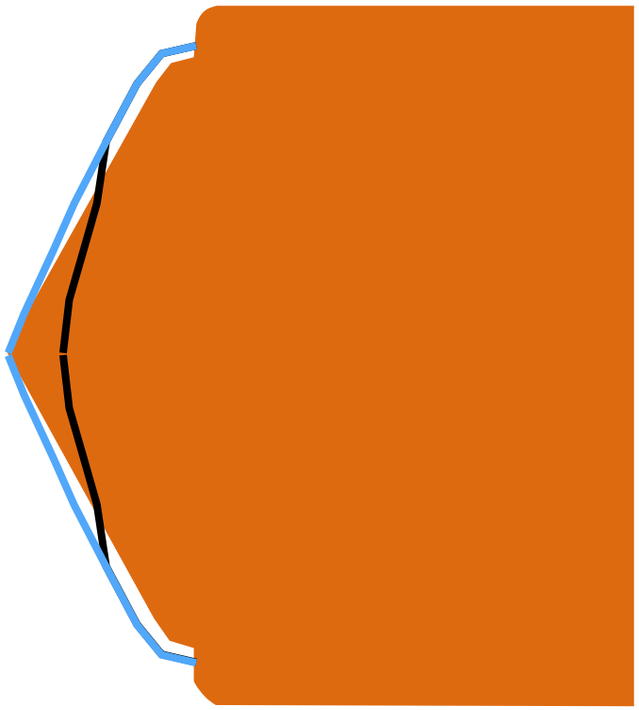
not charged

charged up

THGEM

GEM

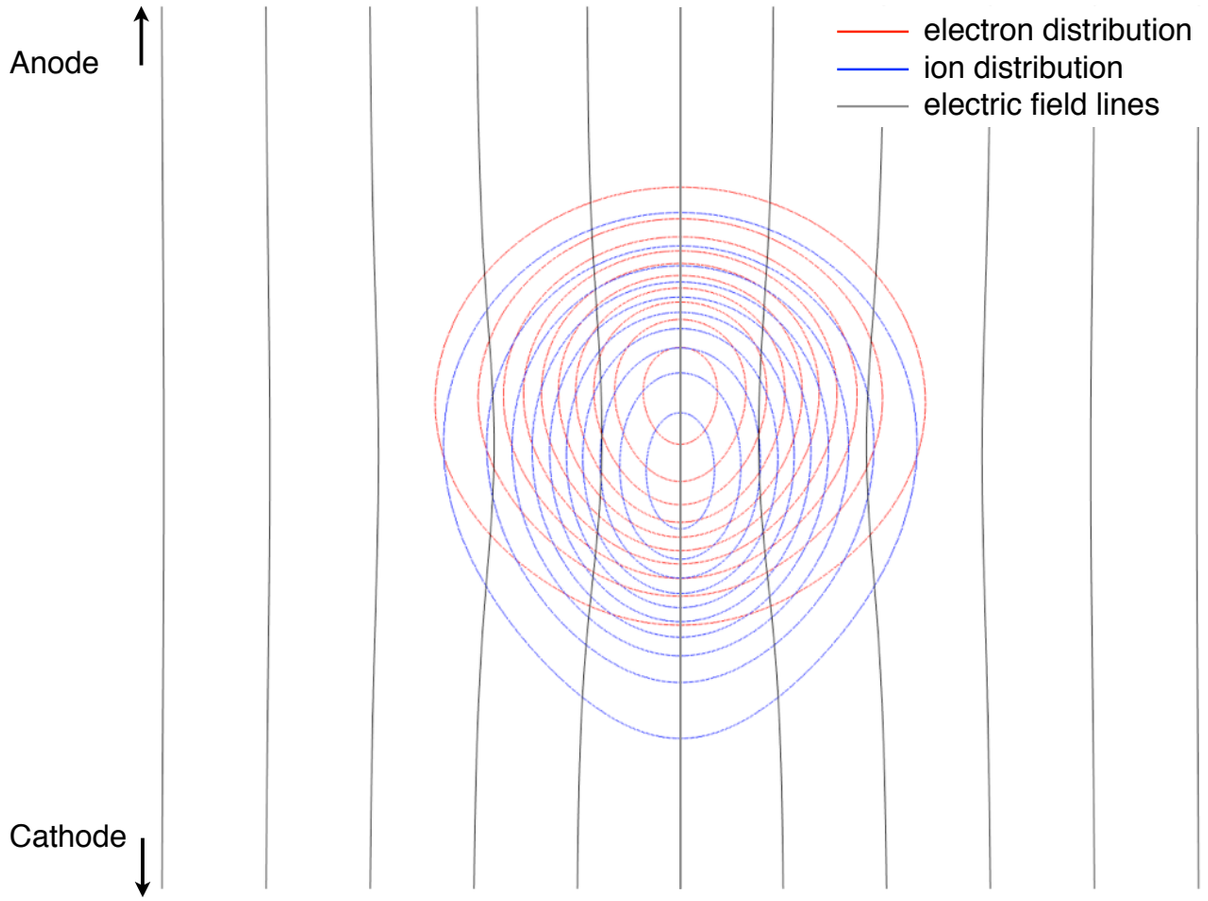


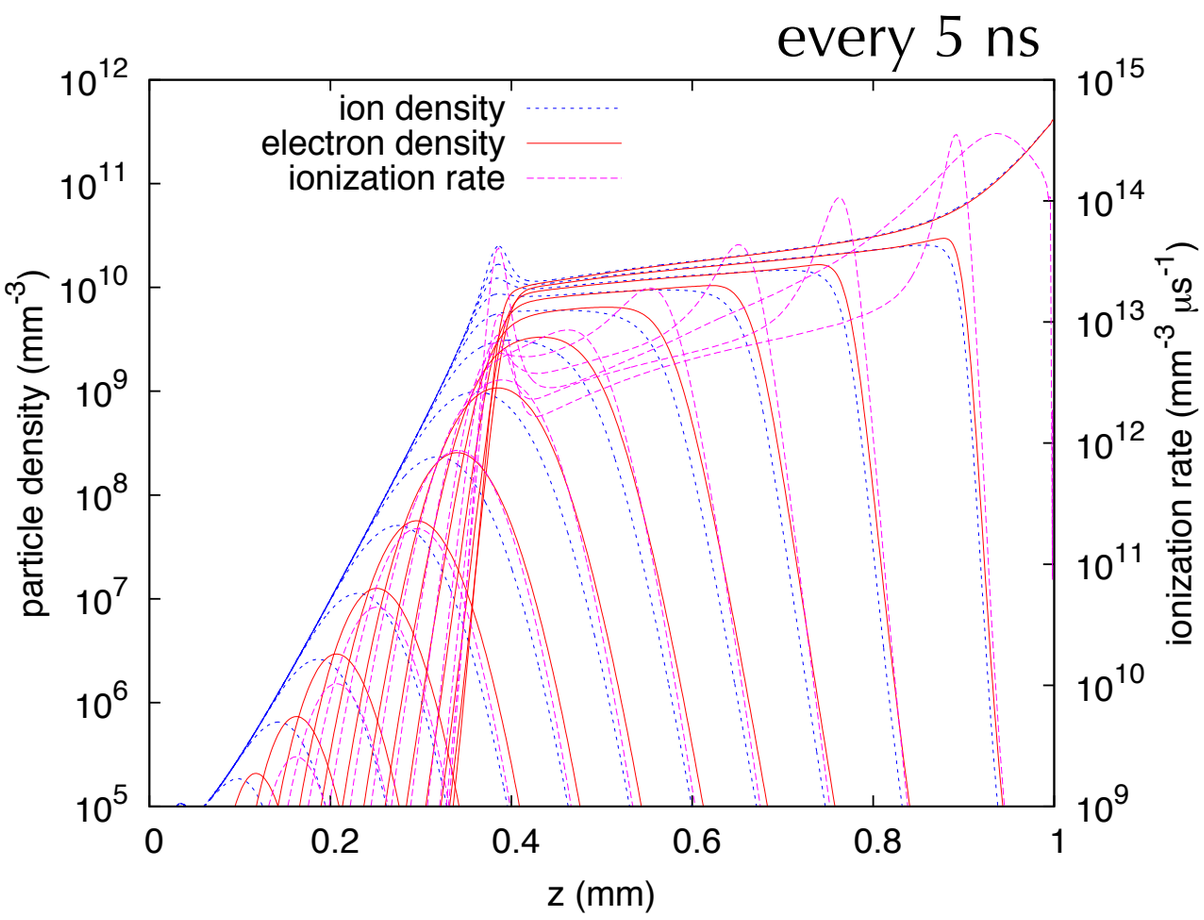


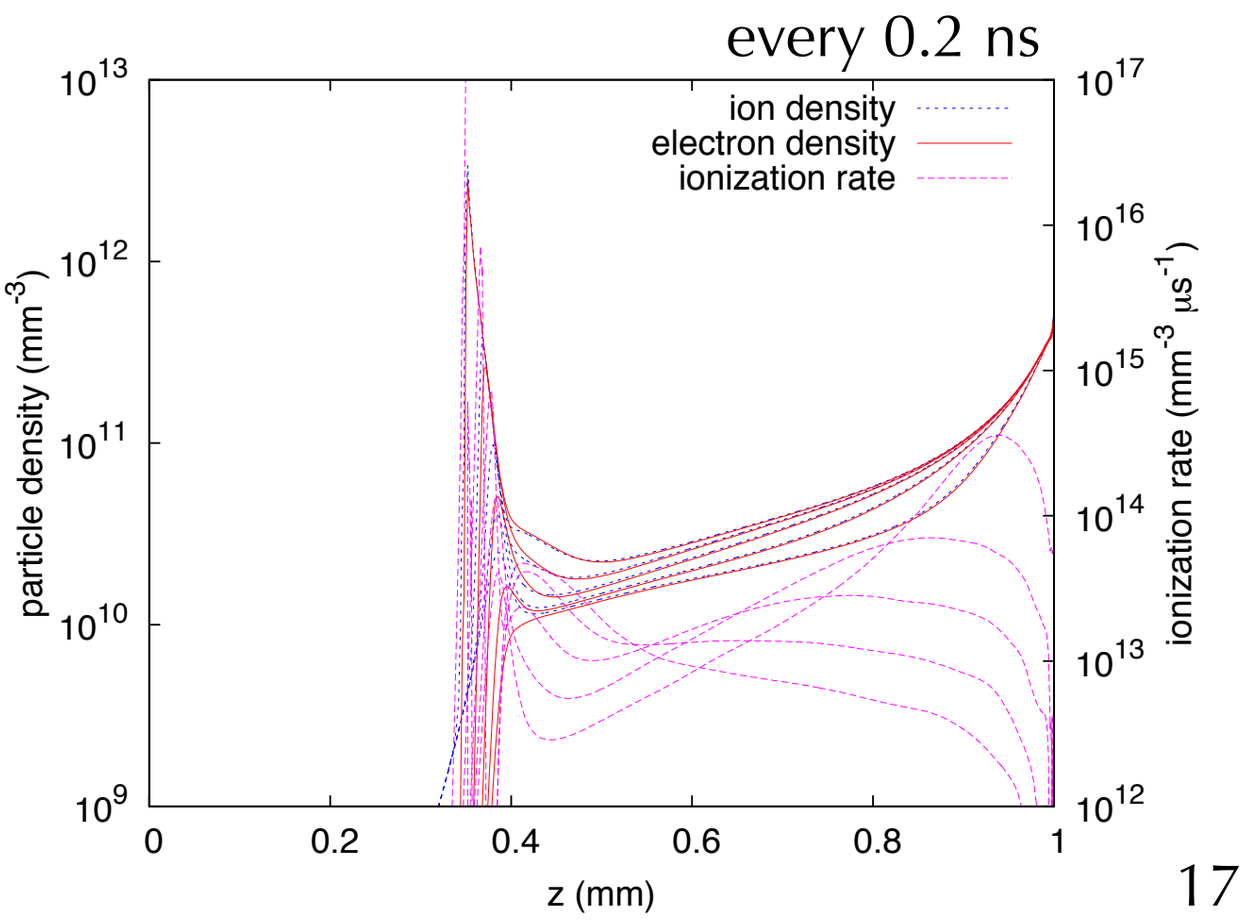
Gain decreases

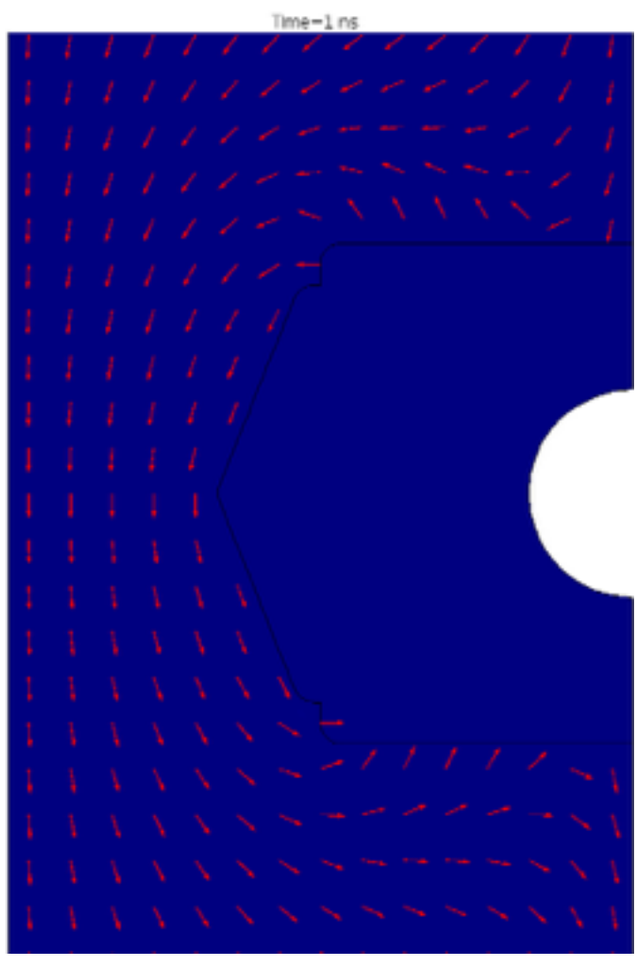
Gain increases

The streamer





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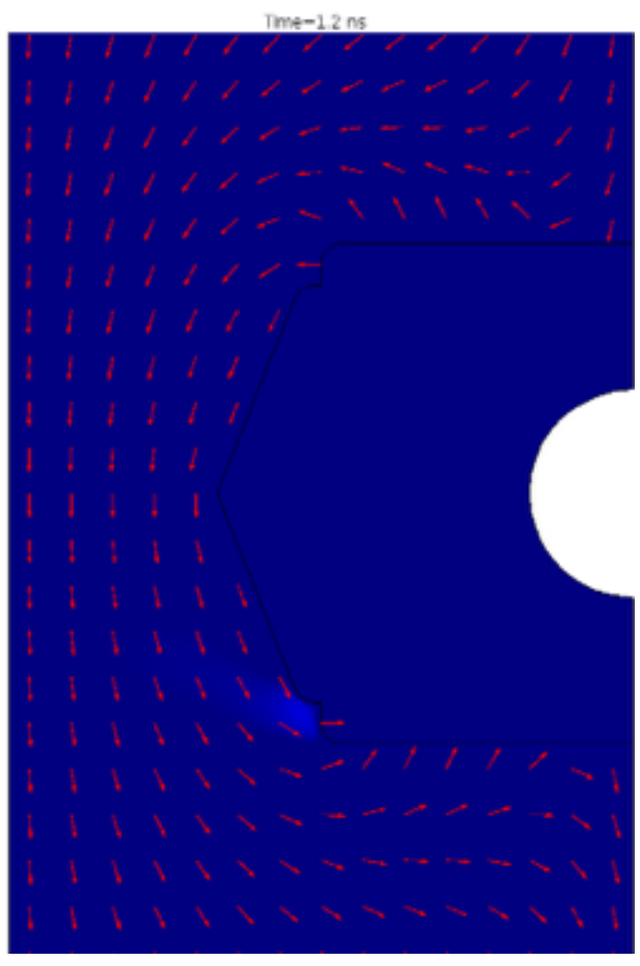
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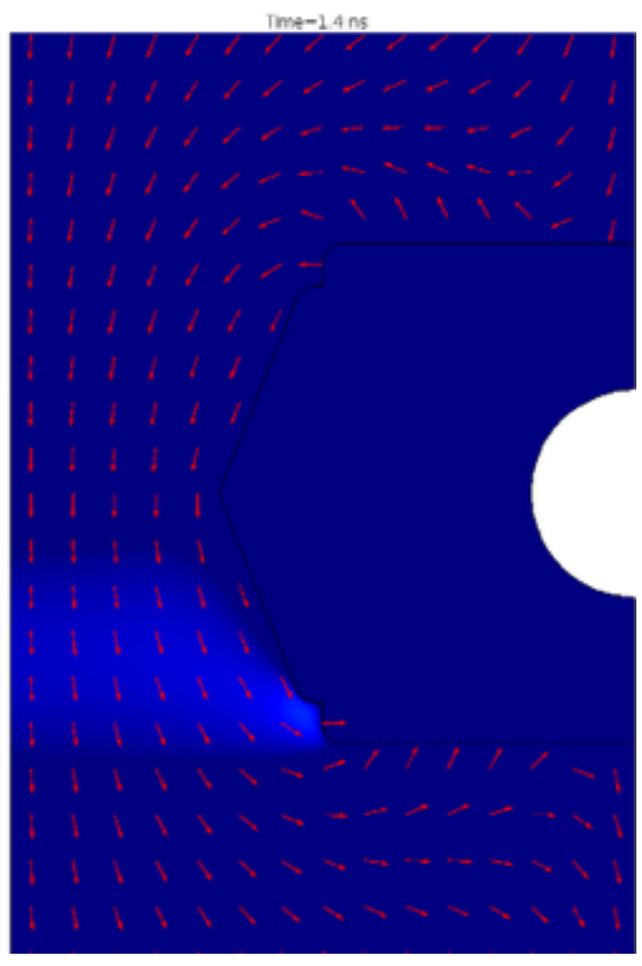
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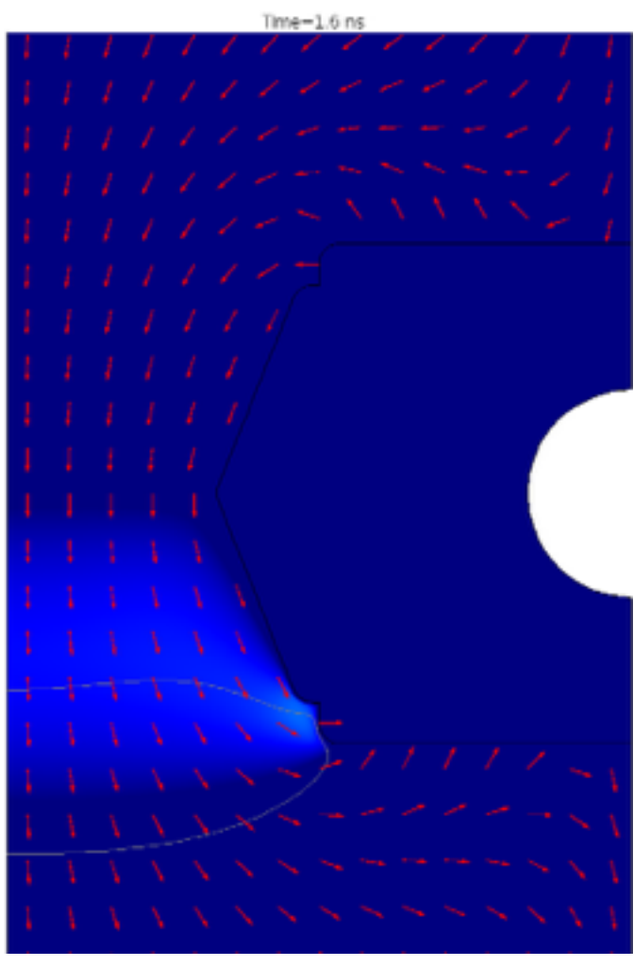
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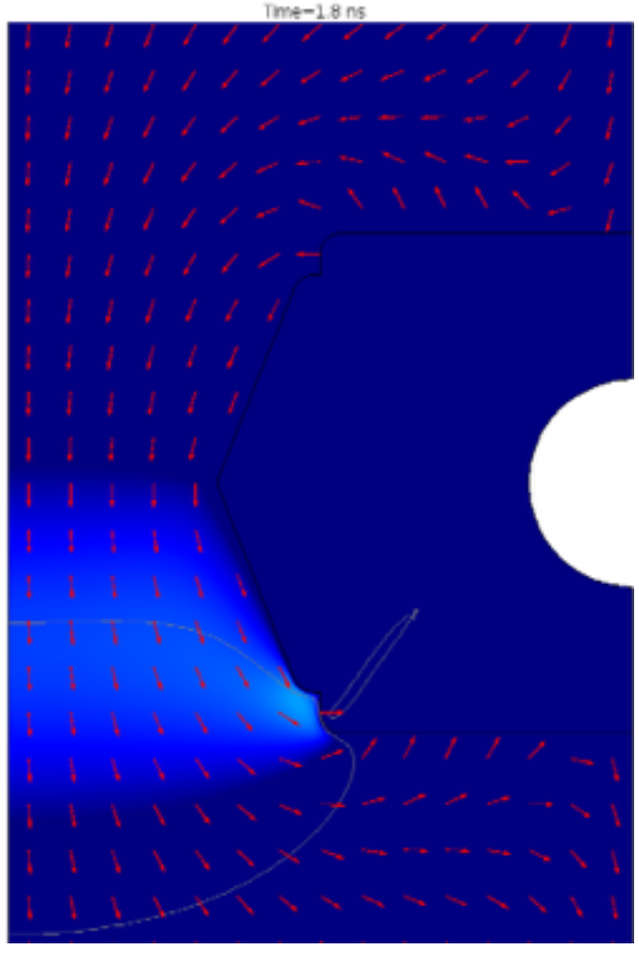
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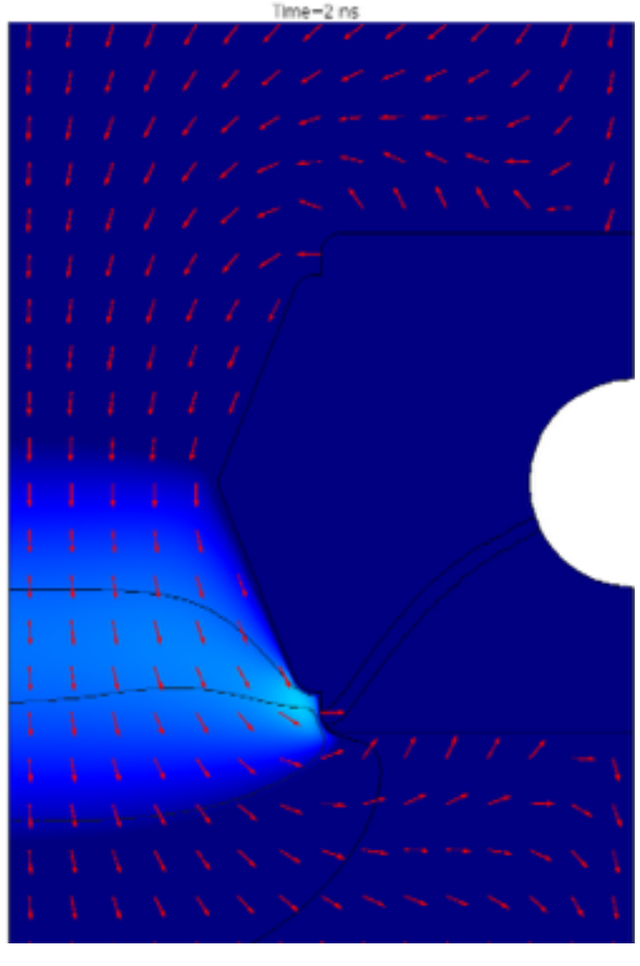
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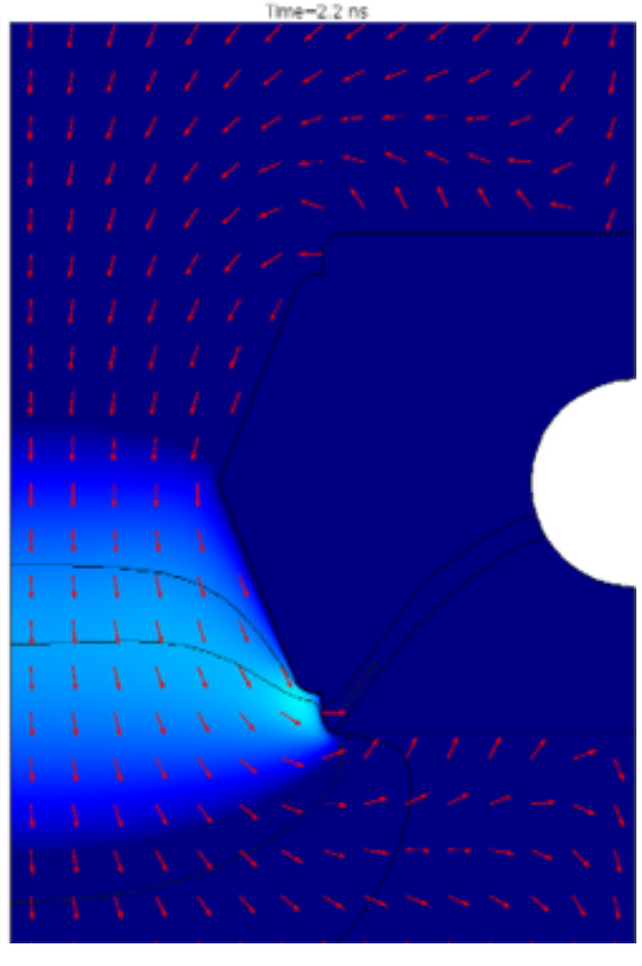
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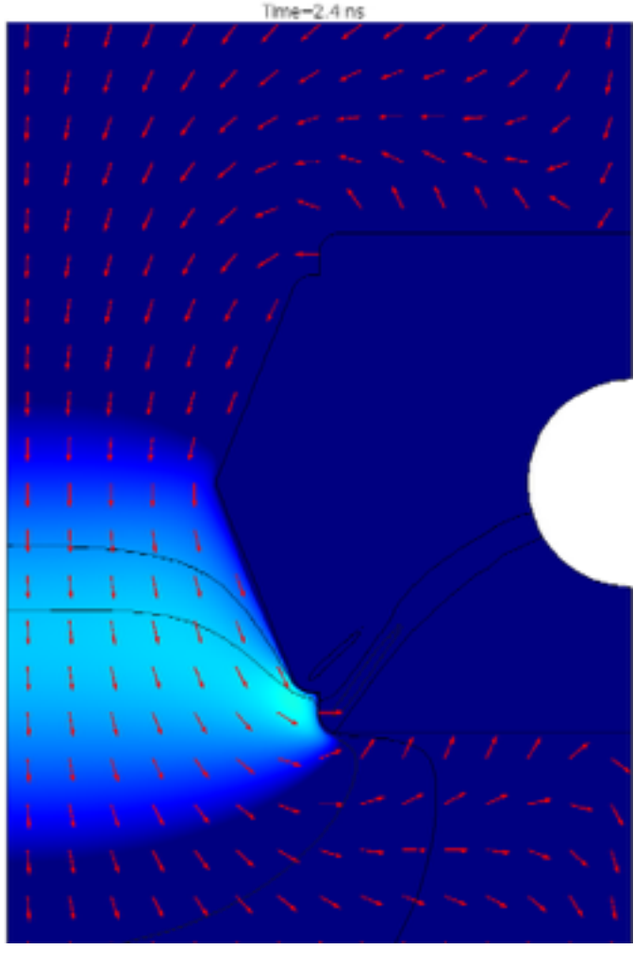
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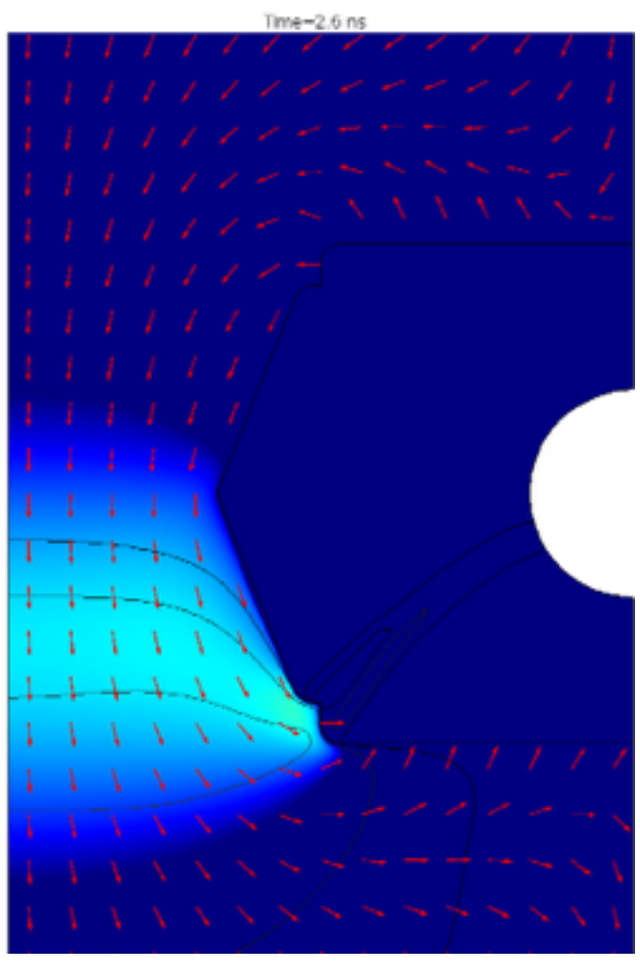
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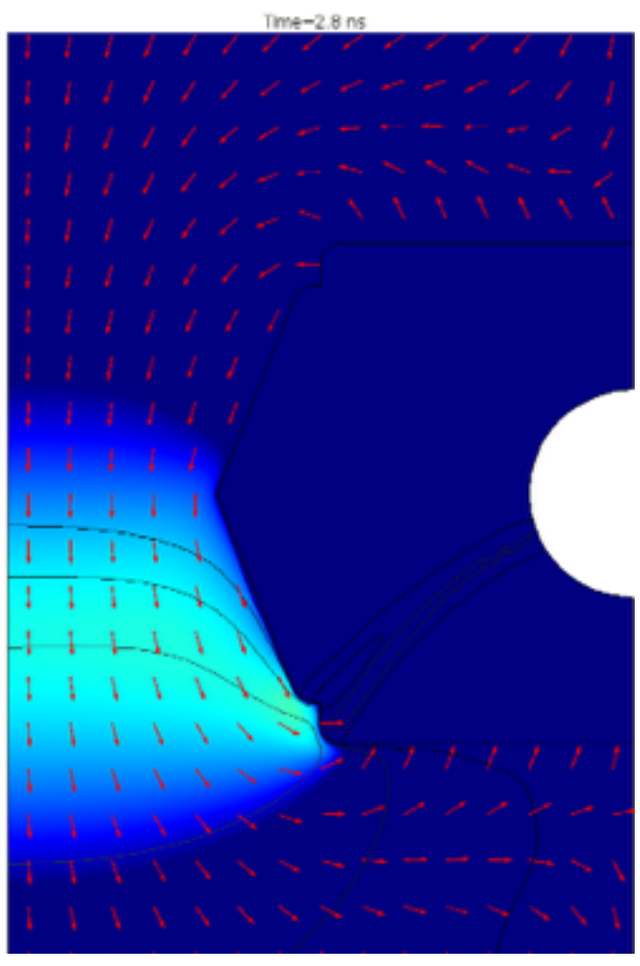
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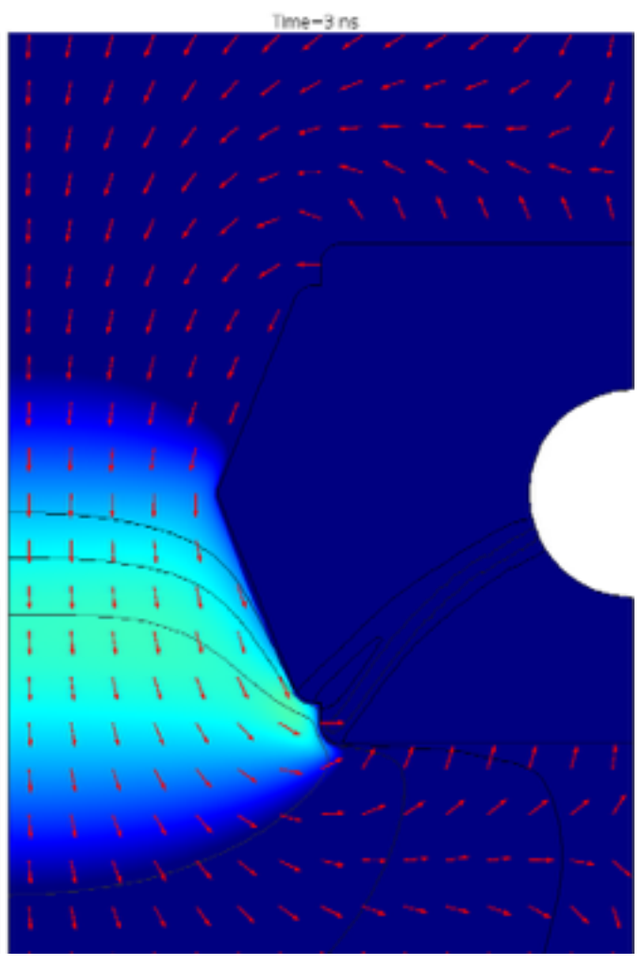
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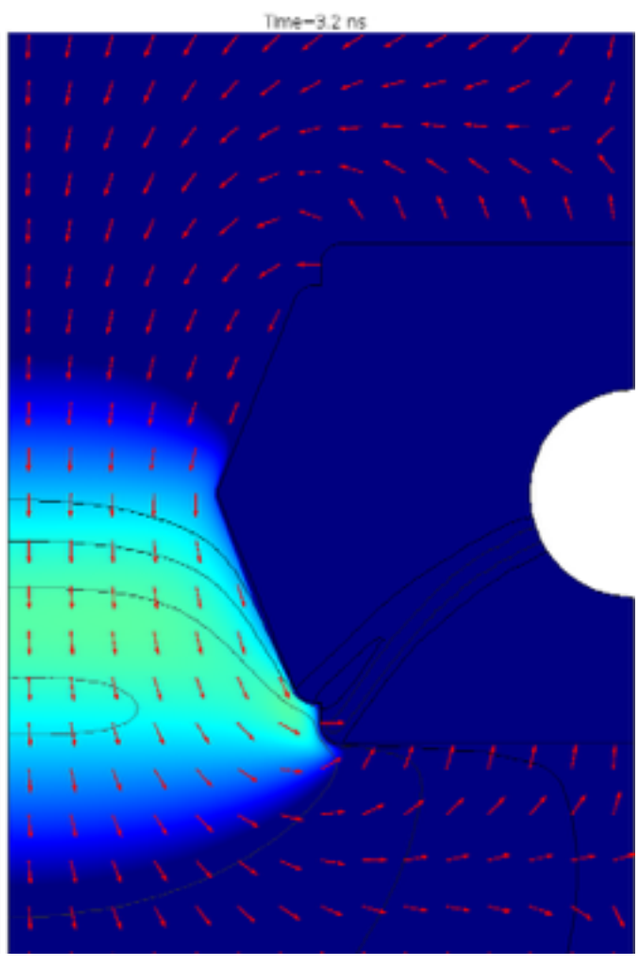
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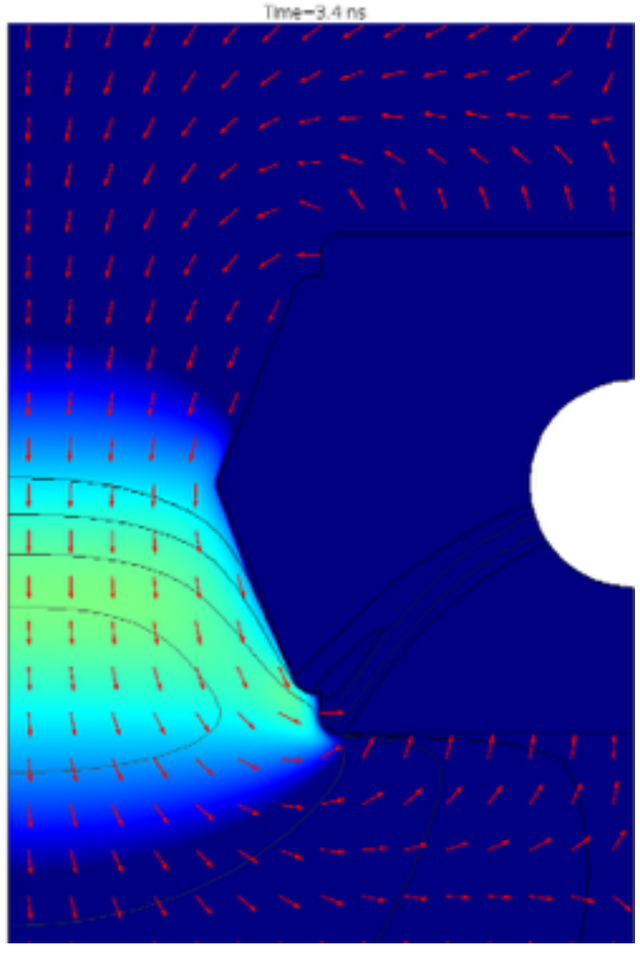
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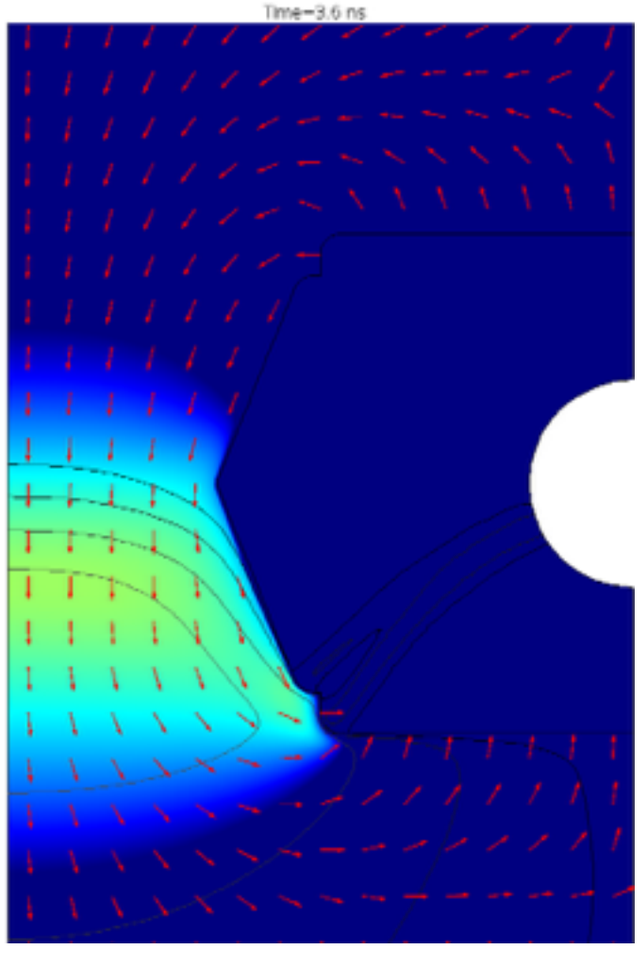
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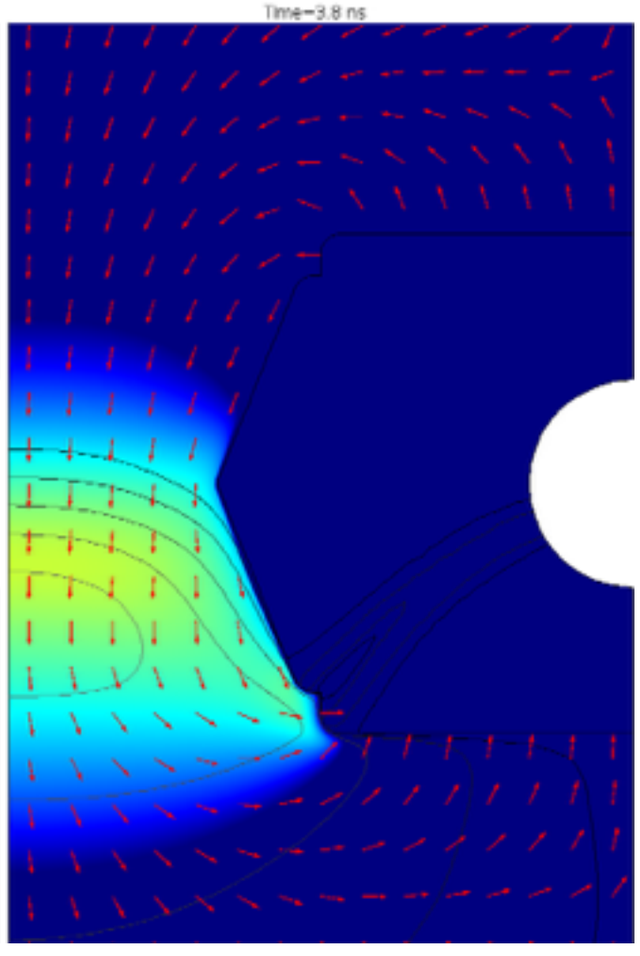
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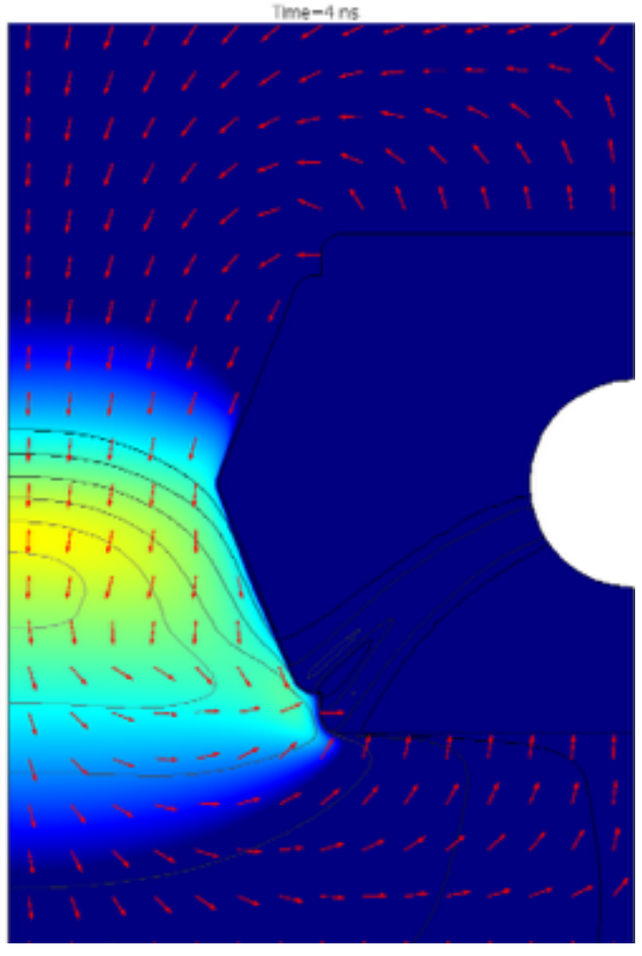
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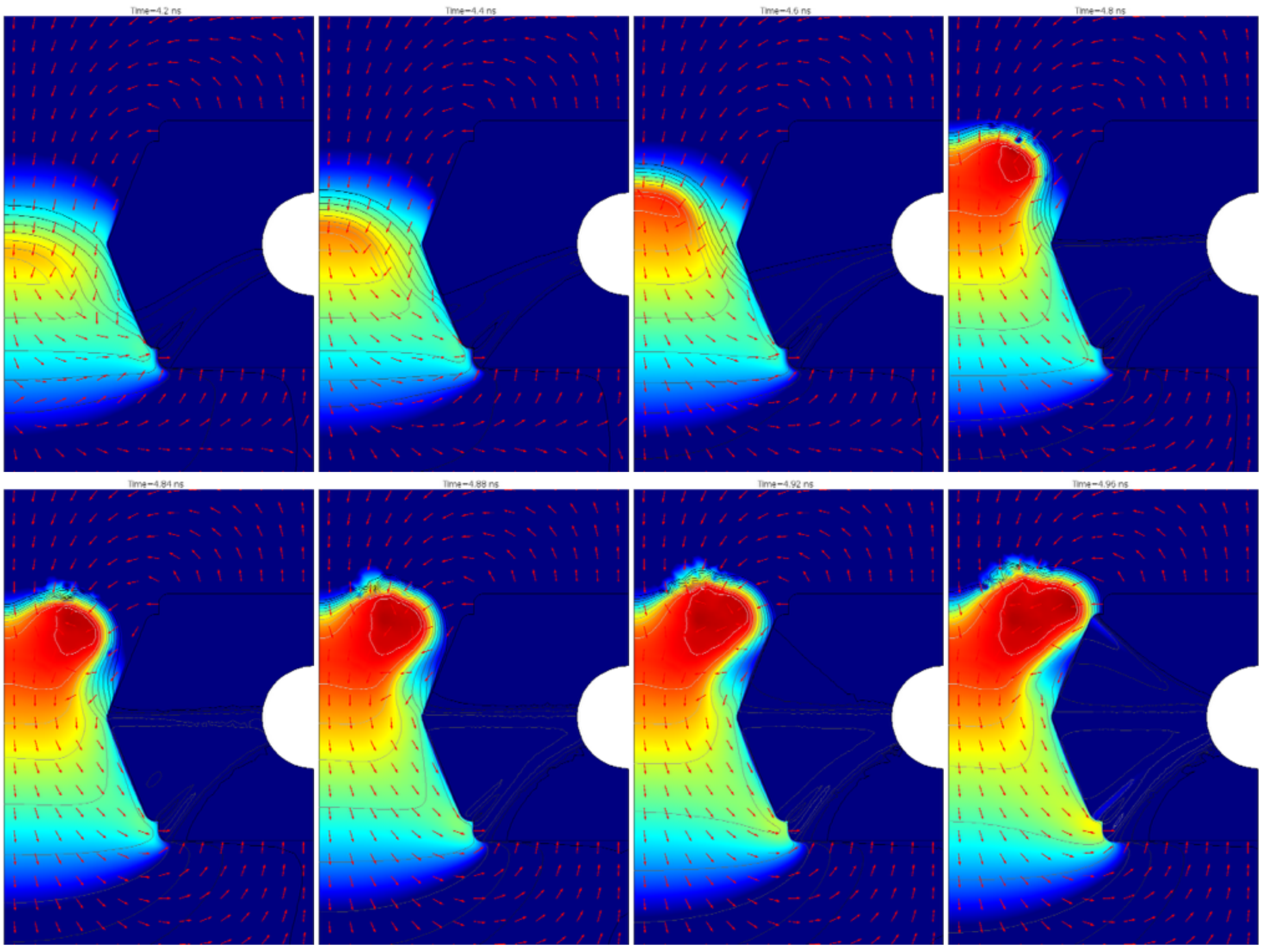
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Conclusion

Yes