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Plasma Edge Simulations by Finite Elements using COMSOL

Ch.Hollenstein and A. Howling

EPFL/CRPP

Lausanne

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Introduction

Large area PECVD depositions (>1m^2)

Application

Silicon deposition

Thin film solar cells

Flat displays

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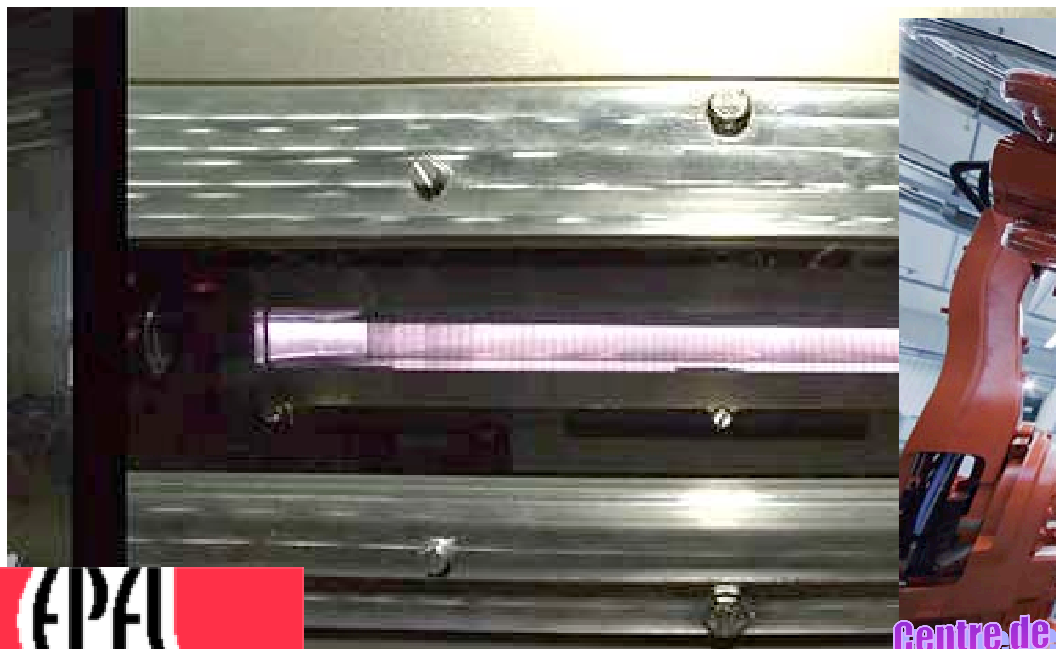
Problems of large area plasma depositions

Homogeneity (… of layer thickness, structure)

Gas flow
Electrical parameters
Edge effects
……



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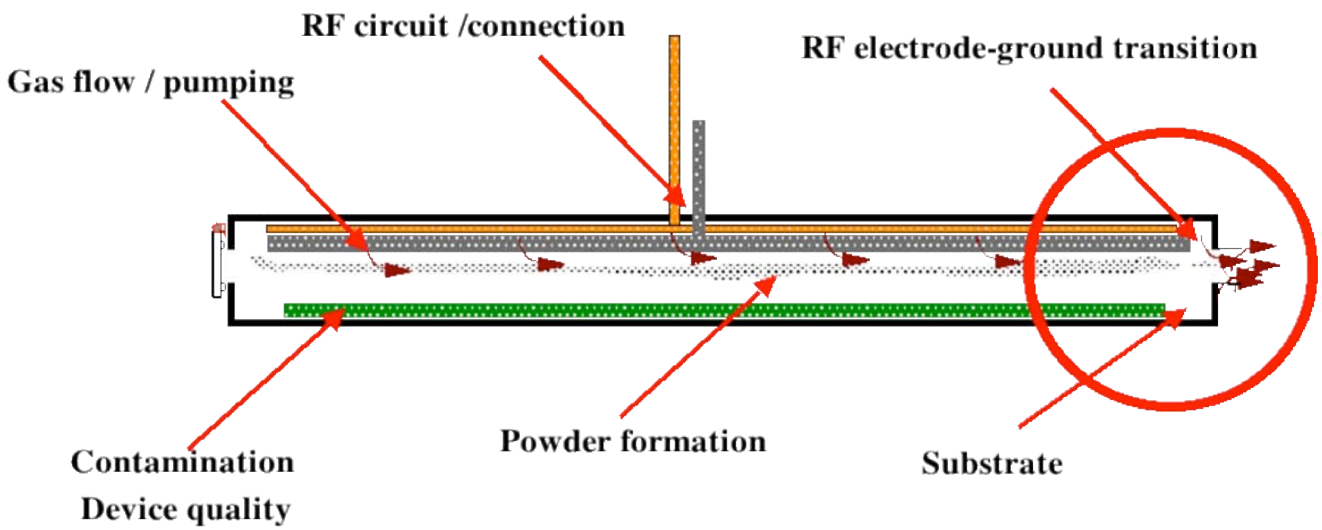
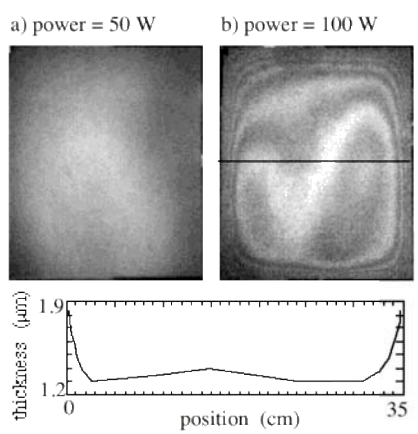
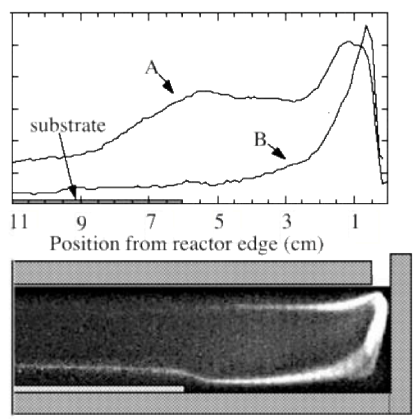
Problems of large area plasma reactors



Inhomogeneity





Powder formation

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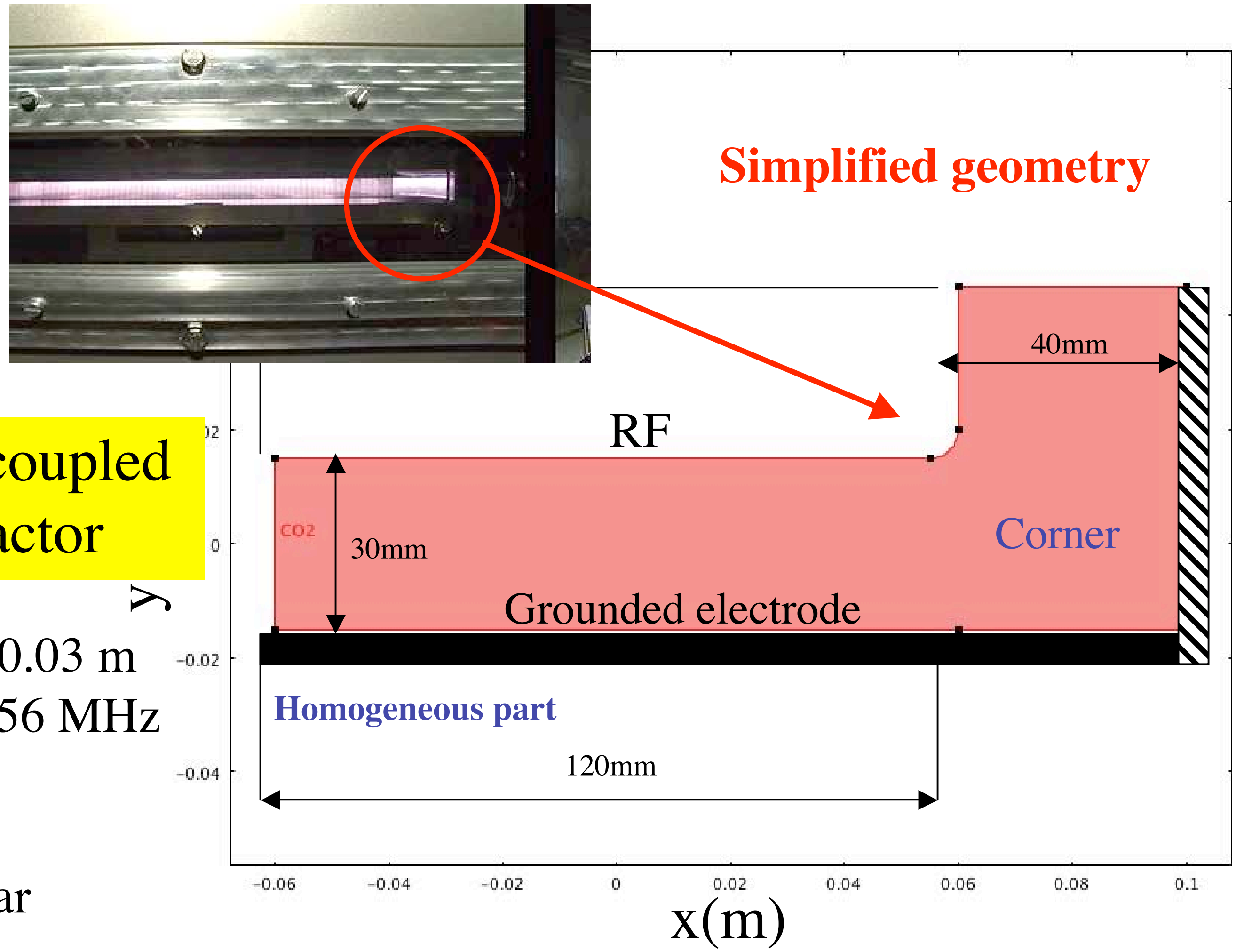
Plasma reactor parameters and geometry



Capacitively coupled RF plasma reactor

Electrode gap 0.03 m
Frequency 13.56 MHz
RF 200V_{pp}
Gas Argon
Pressure 1 mbar

Basic equations and boundary conditions

2D Fluid equation

electron continuity: $\frac{\partial n_e}{\partial t} + \nabla \cdot \underline{\Gamma}_e = k_{ion} n_e N; \quad \underline{\Gamma}_e = -\mu_e n_e \underline{E} - D_e \nabla n_e$

ion continuity: $\frac{\partial n_i}{\partial t} + \nabla \cdot \underline{\Gamma}_i = k_{ion} n_e N; \quad \underline{\Gamma}_i = \mu_i n_i \underline{E} - D_i \nabla n_i$

electron energy continuity; $(n_e \varepsilon)$ is the energy density in $\mathrm{eV} \cdot \mathrm{m}^{-3}$:

$$\frac{\partial (n_e \varepsilon)}{\partial t} + \nabla \cdot \underline{\Gamma}_w = -\underline{\Gamma}_e \cdot \underline{E} - K_{loss} n_e N; \quad \underline{\Gamma}_w = -\frac{5}{3} \mu_e (n_e \varepsilon) \underline{E} - \frac{5}{3} D_e \nabla (n_e \varepsilon);$$

$$-\underline{\Gamma}_e \cdot \underline{E} = \mu_e n_e \left(E_x^2 + E_y^2\right) + D_e \left(\frac{\partial n_e}{\partial x} E_x + \frac{\partial n_e}{\partial y} E_y \right).$$

Poisson's equation: $\nabla^2 V = -\frac{e}{\varepsilon_0}(n_i - n_e); \quad \underline{E} = -\nabla V$

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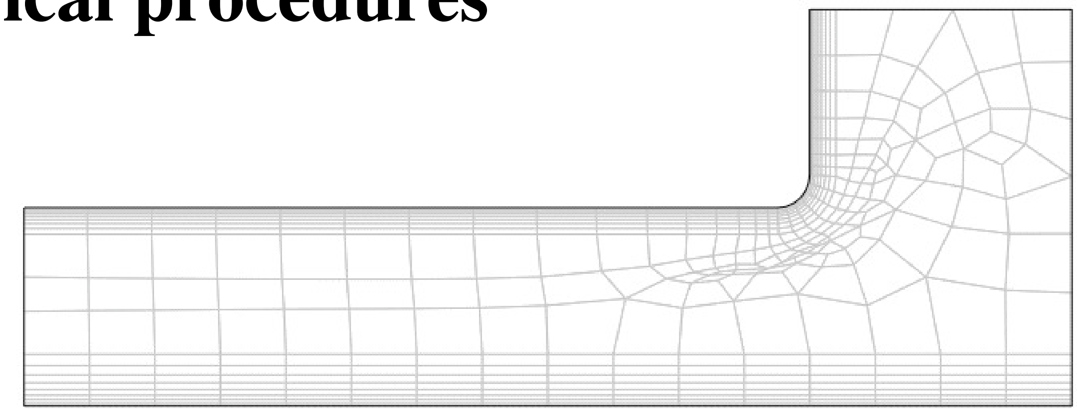
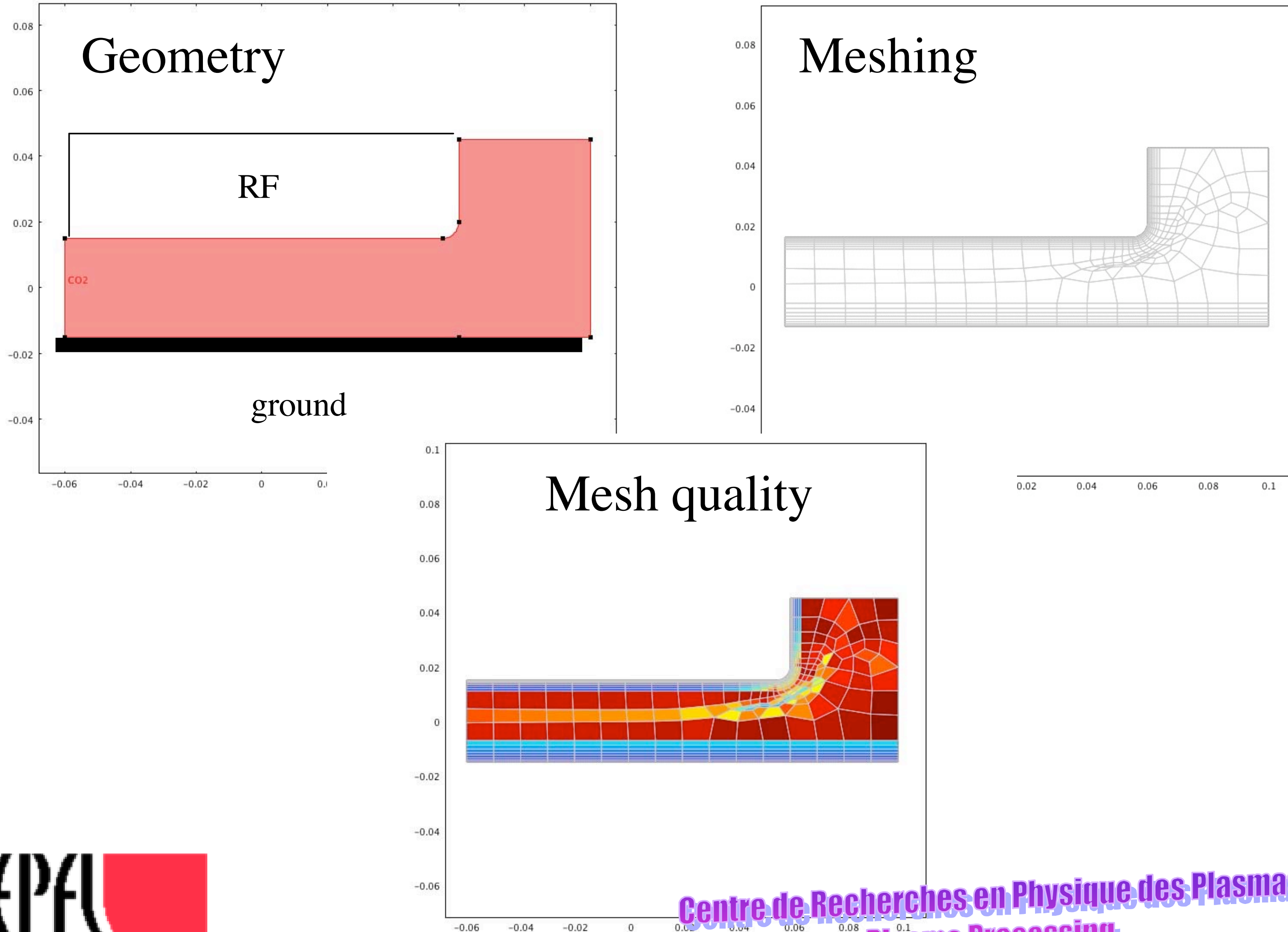
Numerical procedures



Meshing: Quadrilateral mesh
Boundary mesh option
Optimizing (calculation time, memory…)

Solver: Spoole (time dependent)

A simple case



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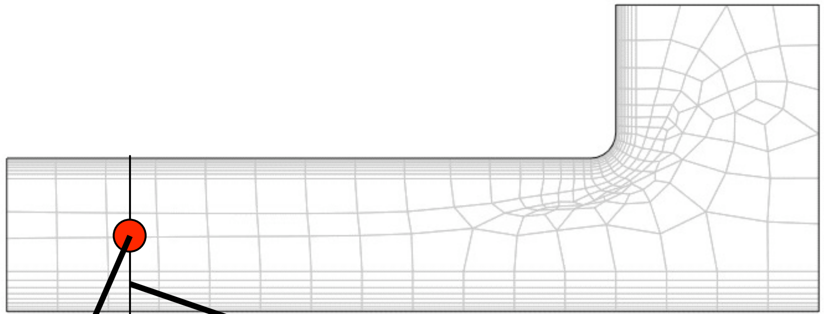
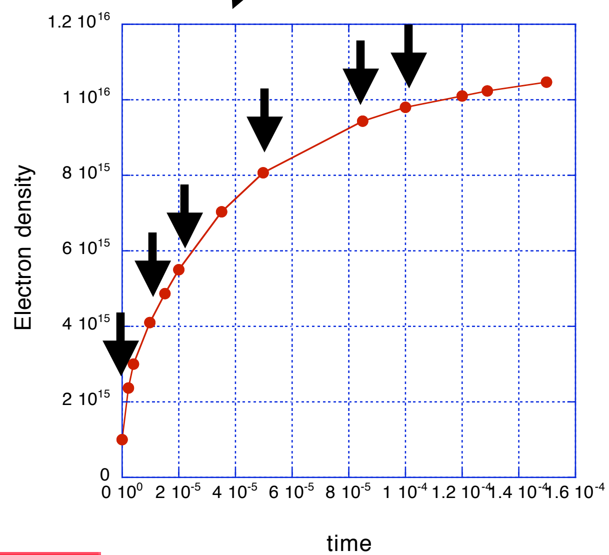
Meshing and convergence

Important !

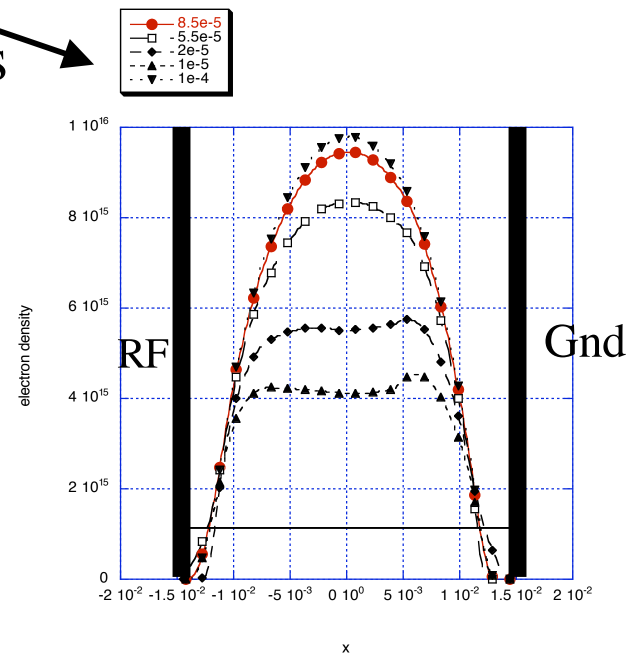
Mesh



Convergence



Profils



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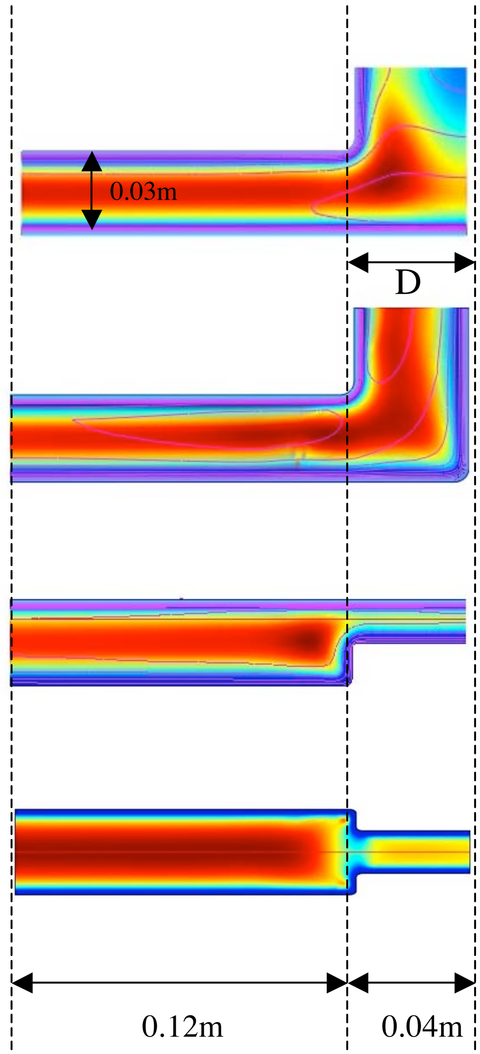
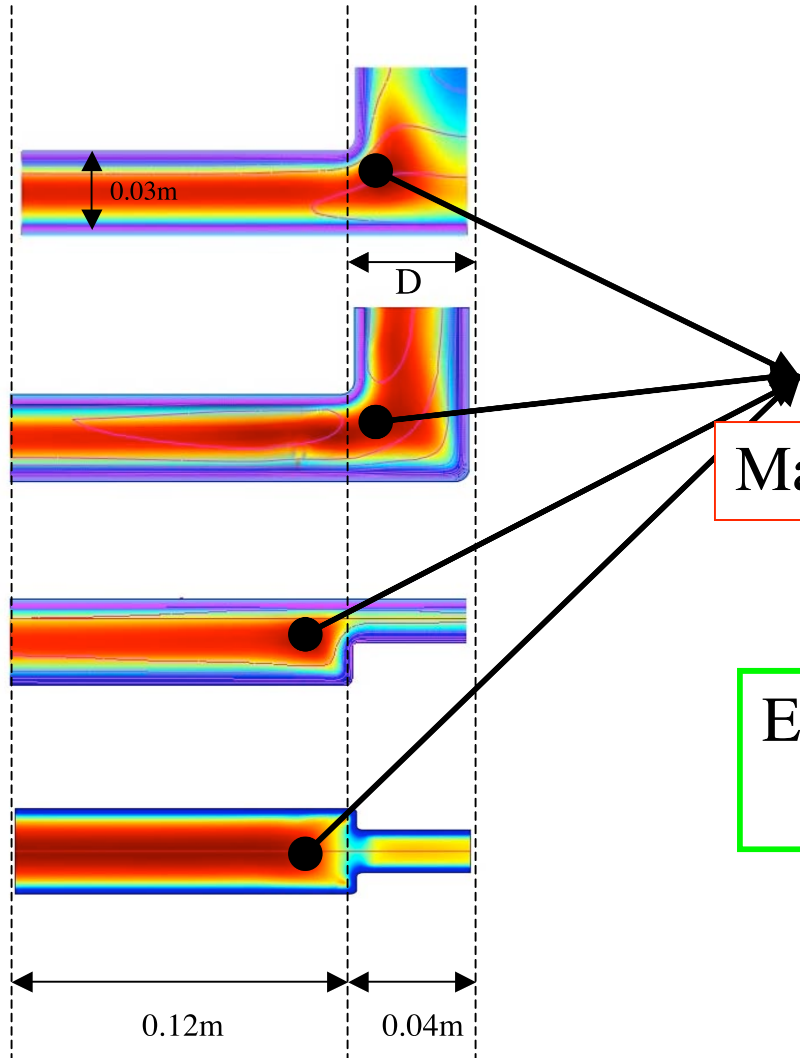
Investigated simplified geometries



Open geometry
Closed geometry D=40mm D=20mm D=10mm
Asymmetric D=15mm
Symmetric D=15mm

Benchmark with 1D

First result



Maximum of the electron density

+

Maximum of ionisation rate

Experimental evidence
Powder formation

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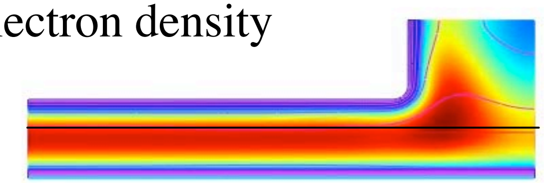
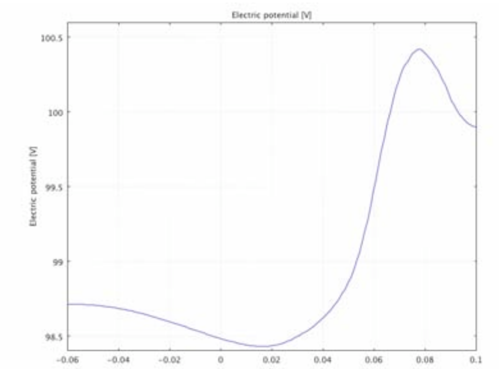
Presence of a Double Layer?

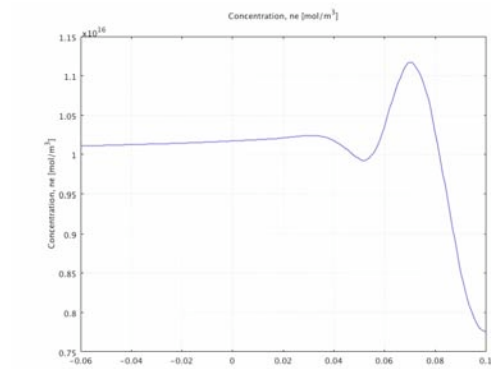
Contour plot electron density



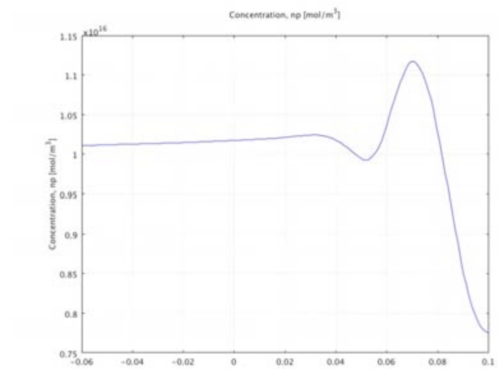
Line plots



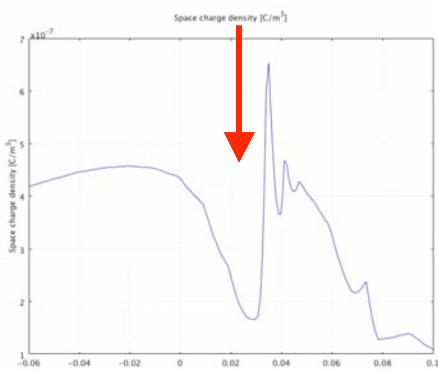
Potential



n_e



n_p



Presence of a Double Layer

Space charge density

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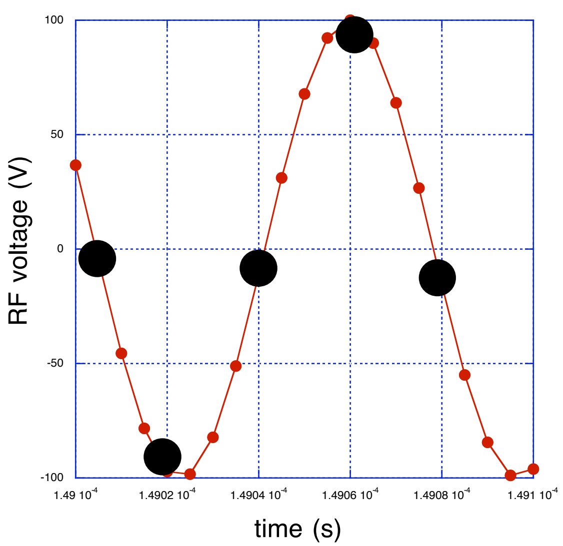
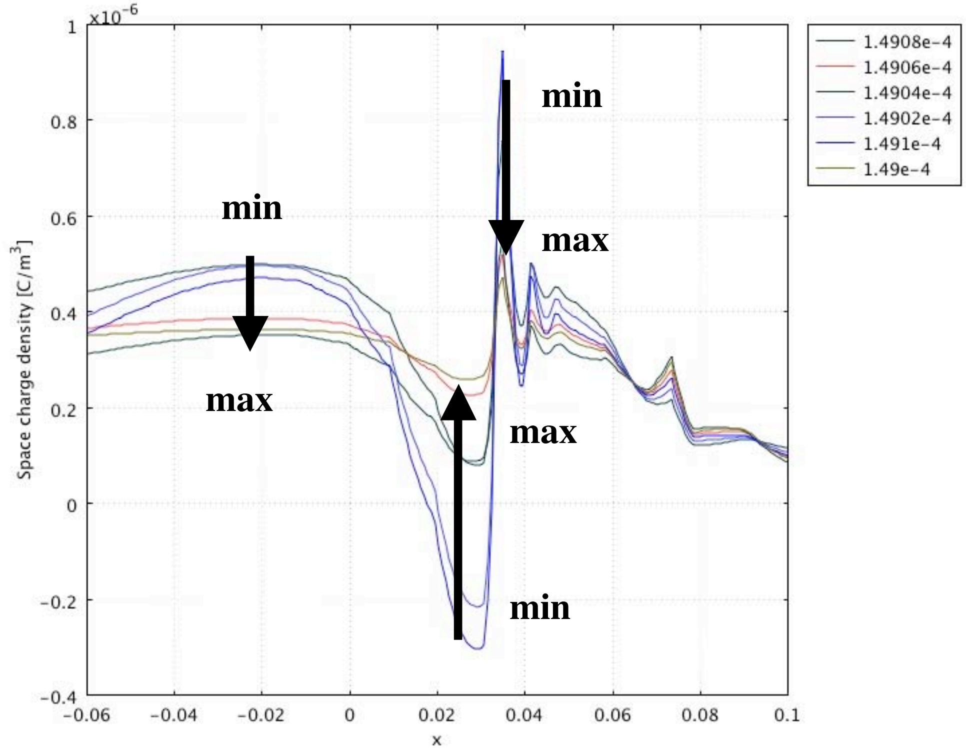
Time dependent space charge density

RF voltage



Space charge density



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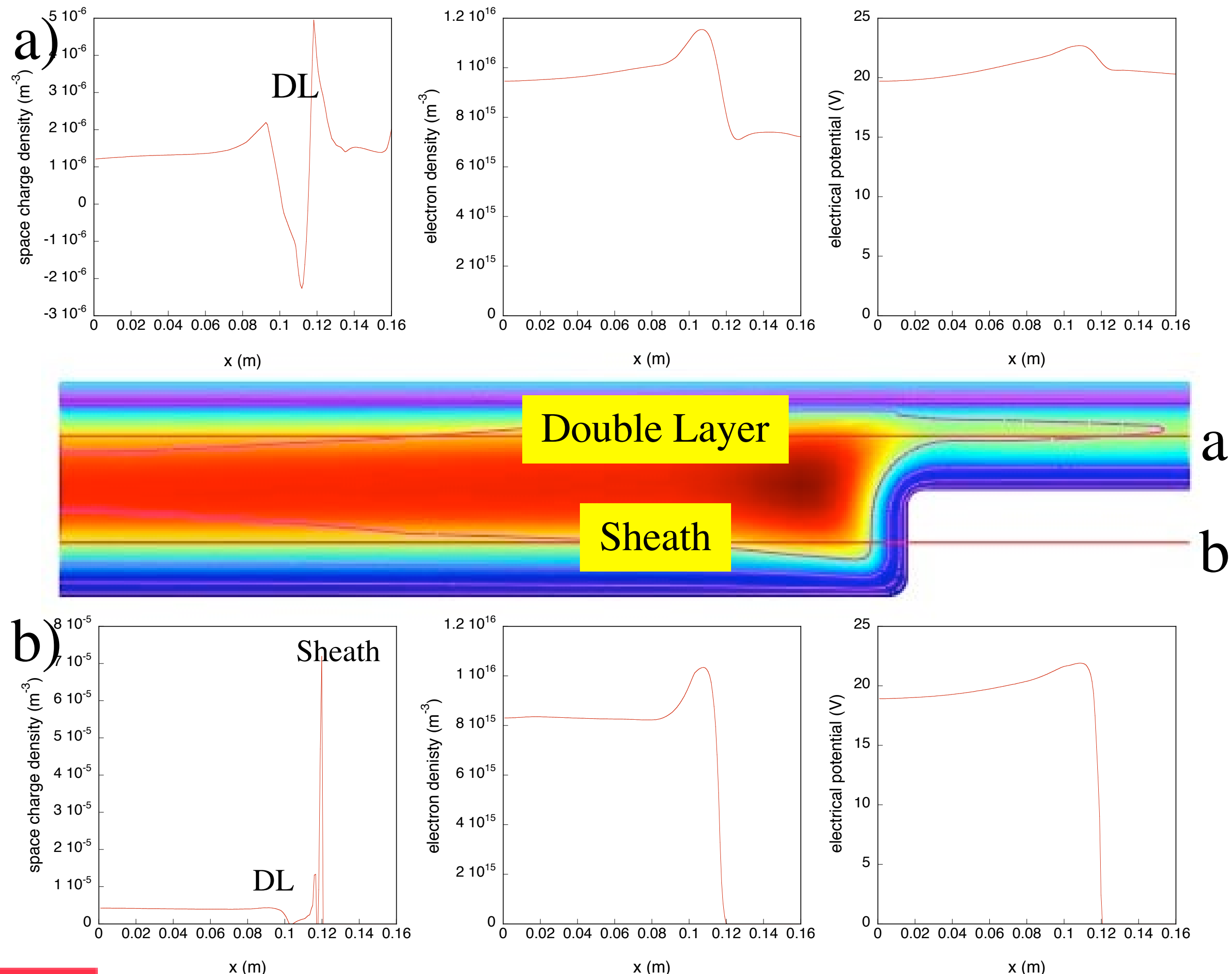
Double Layer and Sheath



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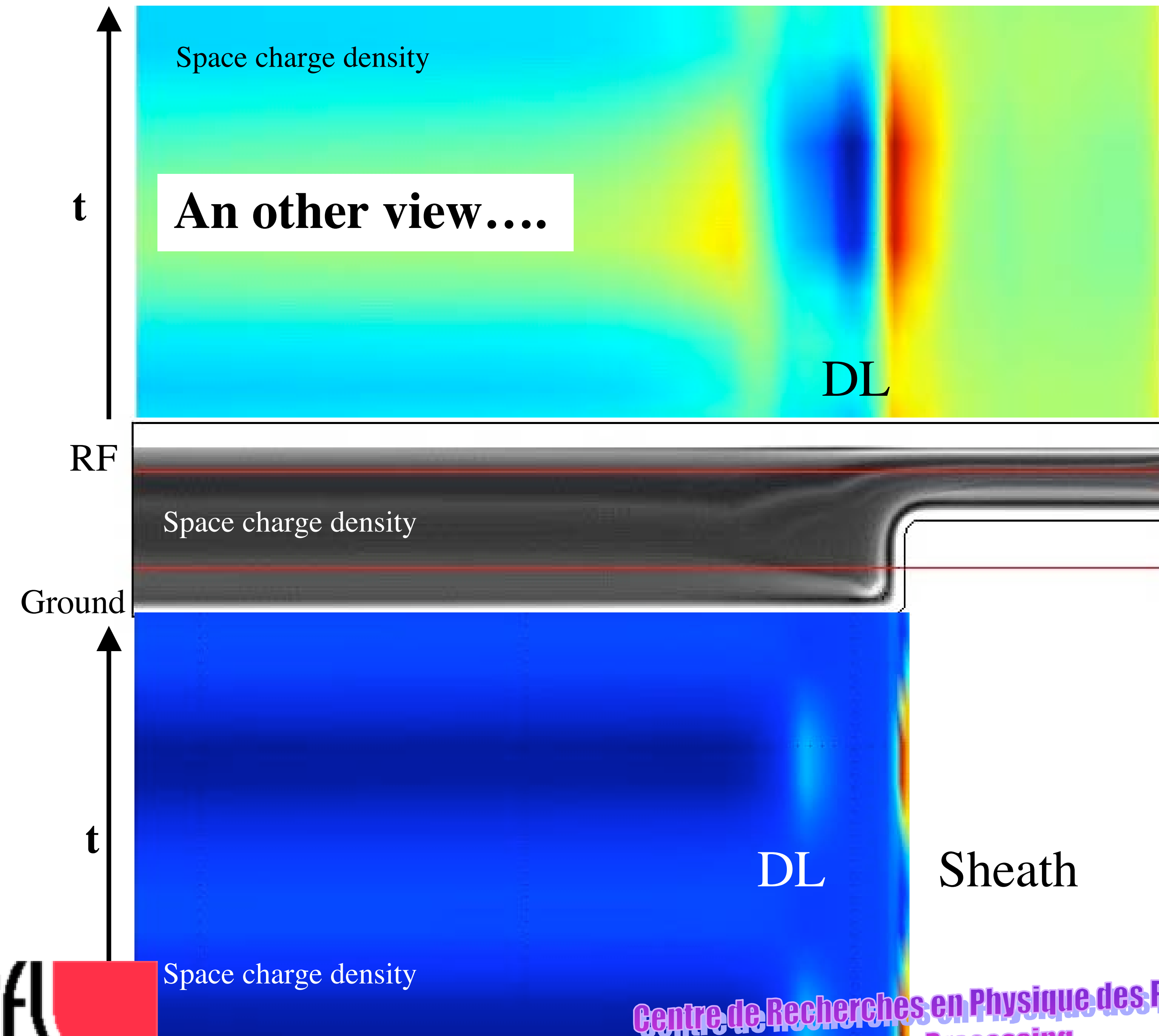
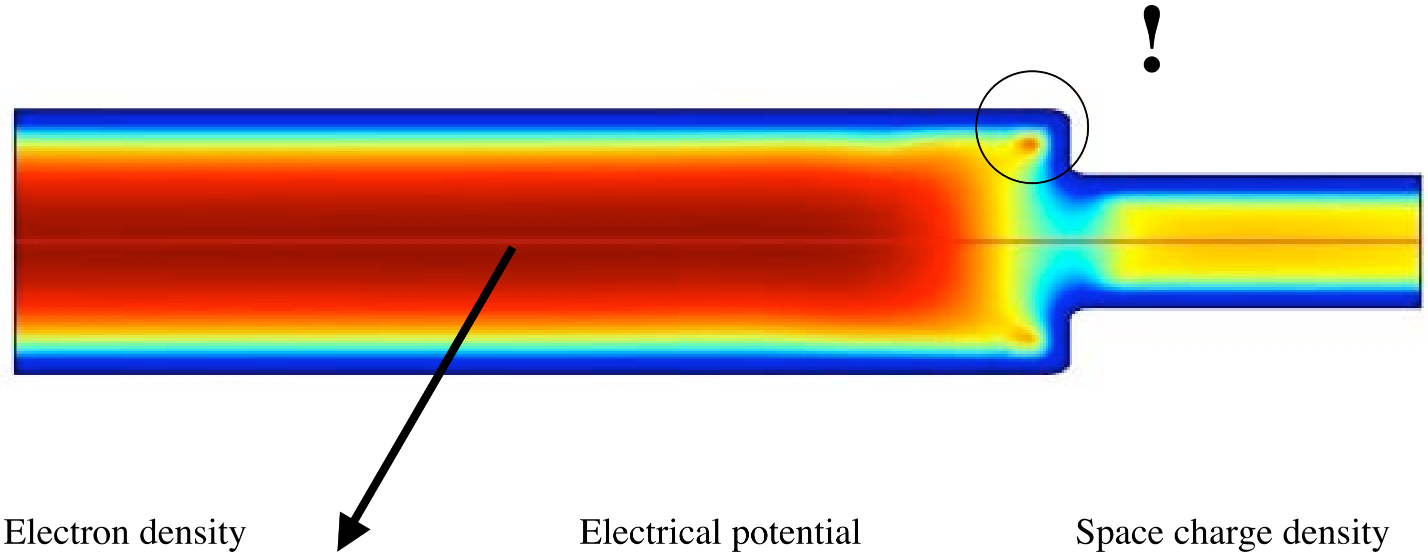
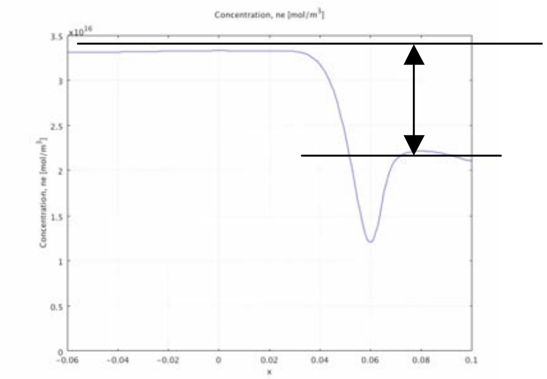
An other view….



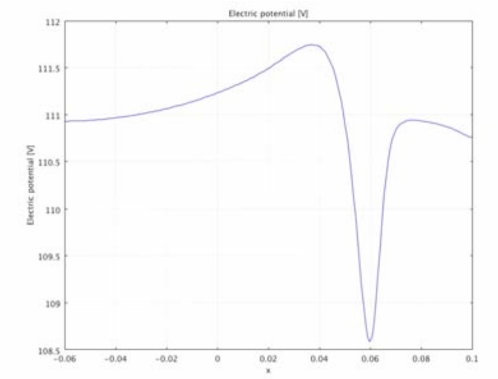
The symmetric case



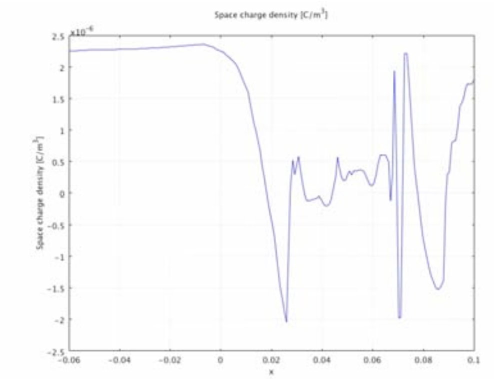
Electron density



Electrical potential

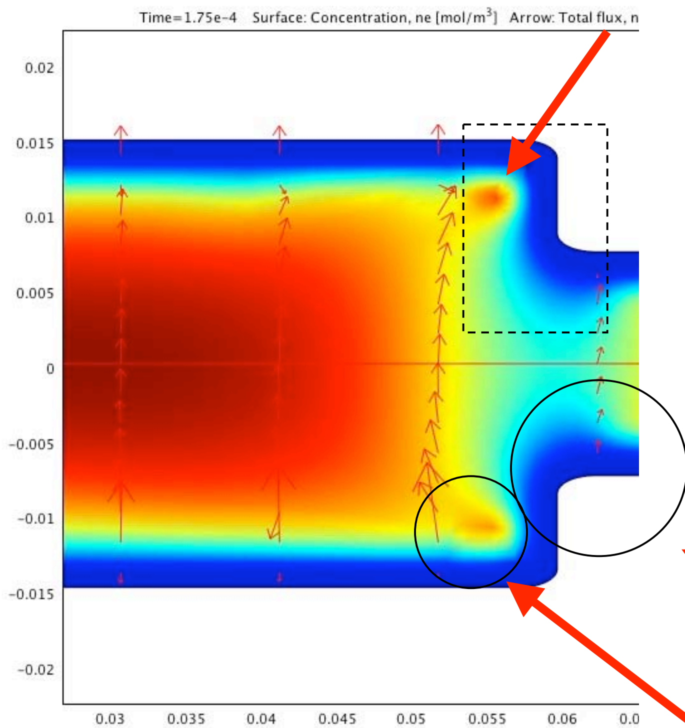


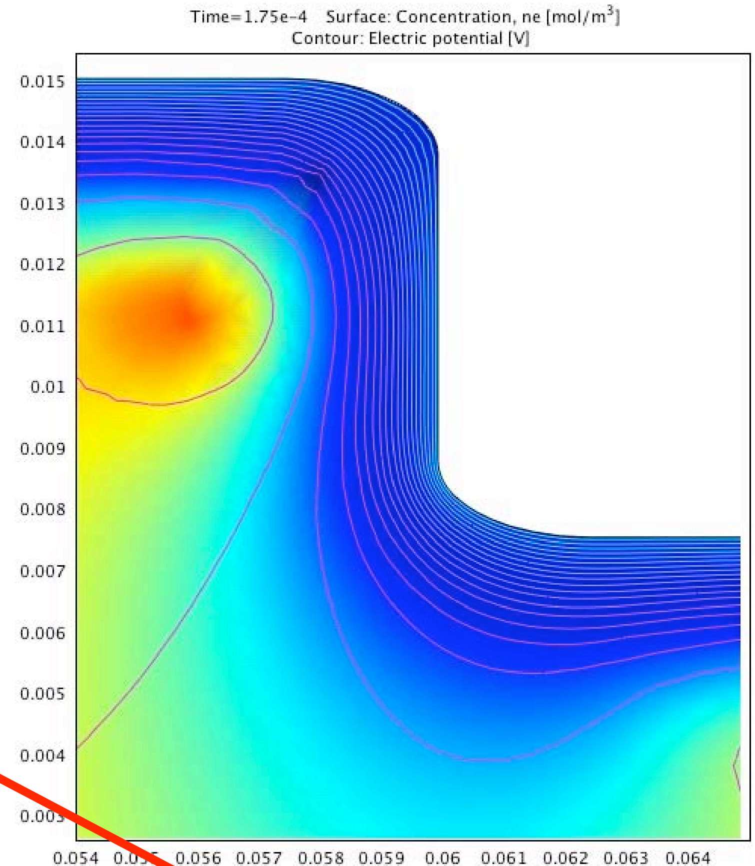
Space charge density



Fundamental role of corners

High ionisation rate

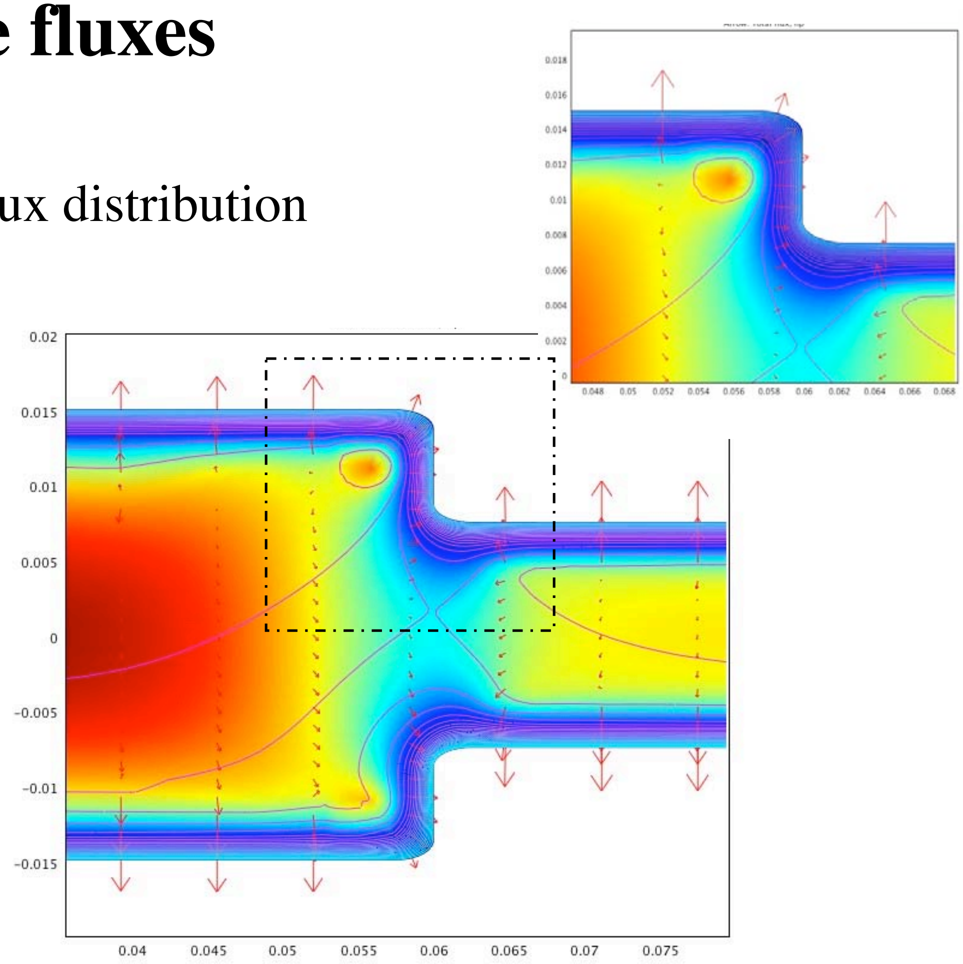




Different role of concave and convex corners

Role of the particle fluxes

Electron and ion flux distribution



Role of corners

Known problem from ion implantation

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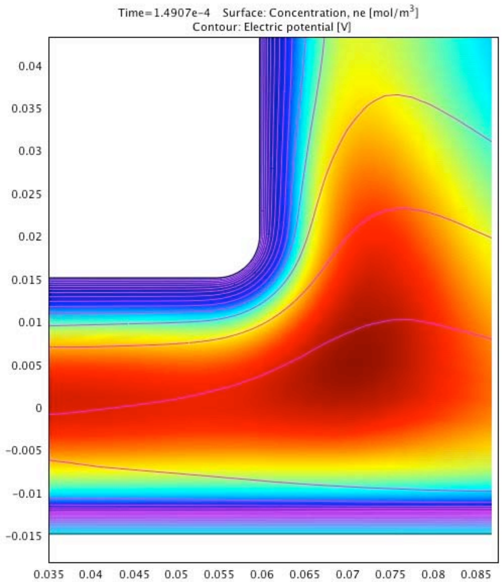
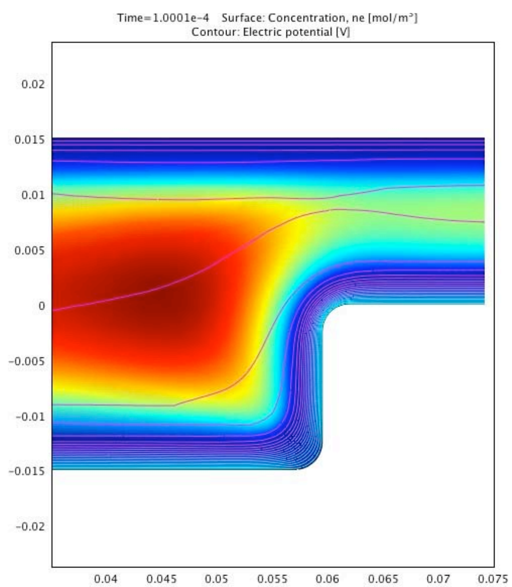
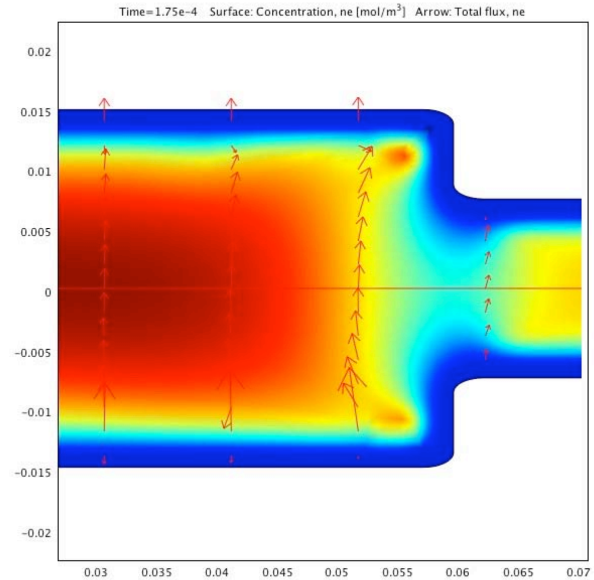
Influence of the reactor edge







Corners are an important design element

Important parameter:

Sheath thickness

Geometrical dimensions of the corner

Other design parameters which influence the plasma

Rounding of the corners

Material (Insulator…)

Spacing (dimensions)

Conclusion

Simulations are a very useful method for plasma physics and plasma edge design

COMSOL software is well adapted

Simplified geometries

Meshing

Convergence

Insight in the physics of corners

Insight into the physics of RF reactors

Design of plasma edge