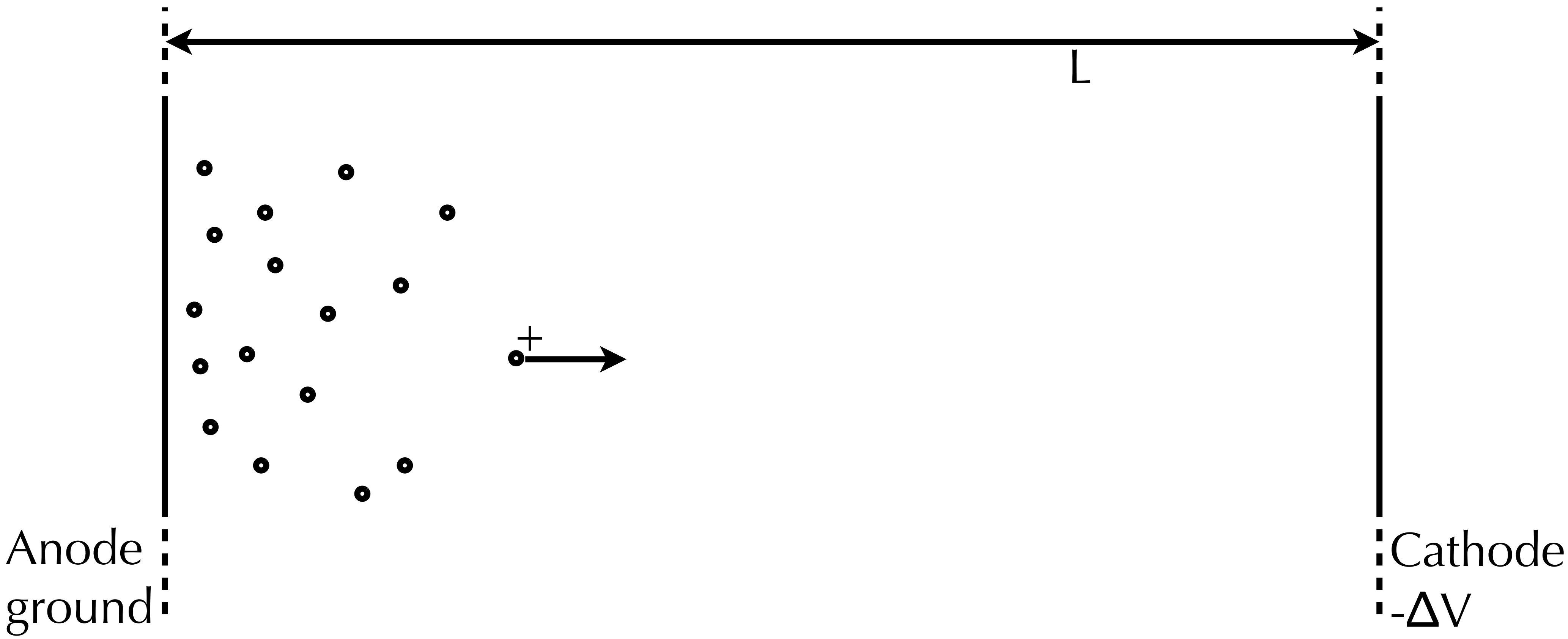
Simplified problem



Infinite parallel plates at distance L with a potential difference of ΔV
At t = 0 uniform electric field of $E_0 = \Delta V/L$
Positive ions generated at the anode at a constant and uniform flux R
Ions moving towards the cathode at speed $v = \mu E$
Actual electric field E modified by the charge distribution

Steady state solution

$$E_z = \sqrt{\frac{2R(z+z_0)}{\epsilon\mu}}$$

$$\rho = \epsilon\frac{dE_z}{dz} = \sqrt{\frac{\epsilon R}{2\mu(z+z_0)}}$$

$$\Delta V = \int_0^L E_z dz = \sqrt{\frac{8R}{9\epsilon\mu}}((L+z_0)^{3/2} - z_0^{3/2})$$

with z_0 such that the integral of the field equals ΔV

In general

- The electric field module decreases where the ions “enter” and increases where the ions “exit”
- For more complex (realistic) problem one needs a numerical calculation: FEA with COMSOL

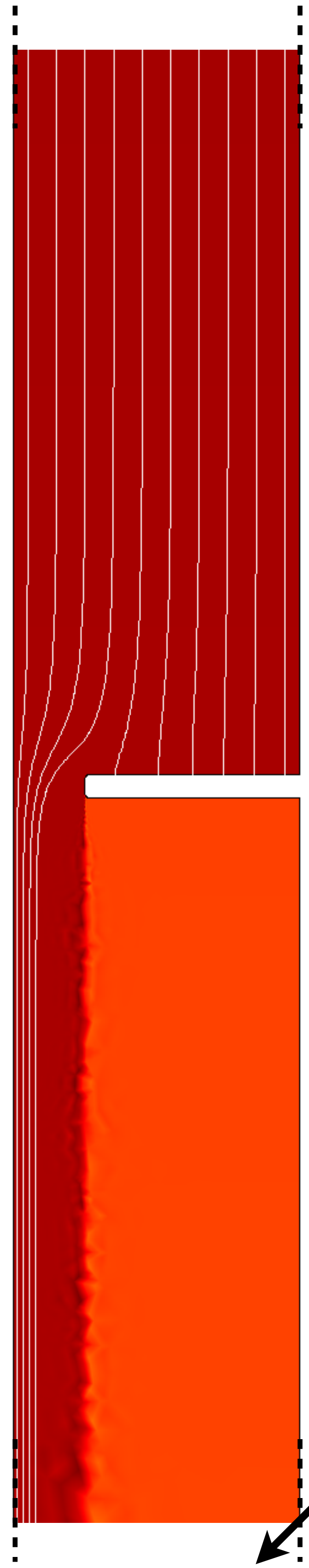
Approach

Start with a simple problem (no charge amplification) sensitive to space charge distribution:
the electron transparency of a GEM-like metal mesh changes with the X-ray flux

Mesh transparency studies are related to yesterday Patrik's talk

GEM-like mesh

2D axial symmetry



Relevant parameters:

Drift regions and fields

Interaction flux

$\mu_{e-} = 5cm^2/us/kV$

$D_{e-} = 100cm^2/s$

$\mu_{ion+} = 1.5cm^2/s/V$

$D_{ion+} = 0$ (approximately)

$\#_{e-/ion+} = 330e^-$/interaction

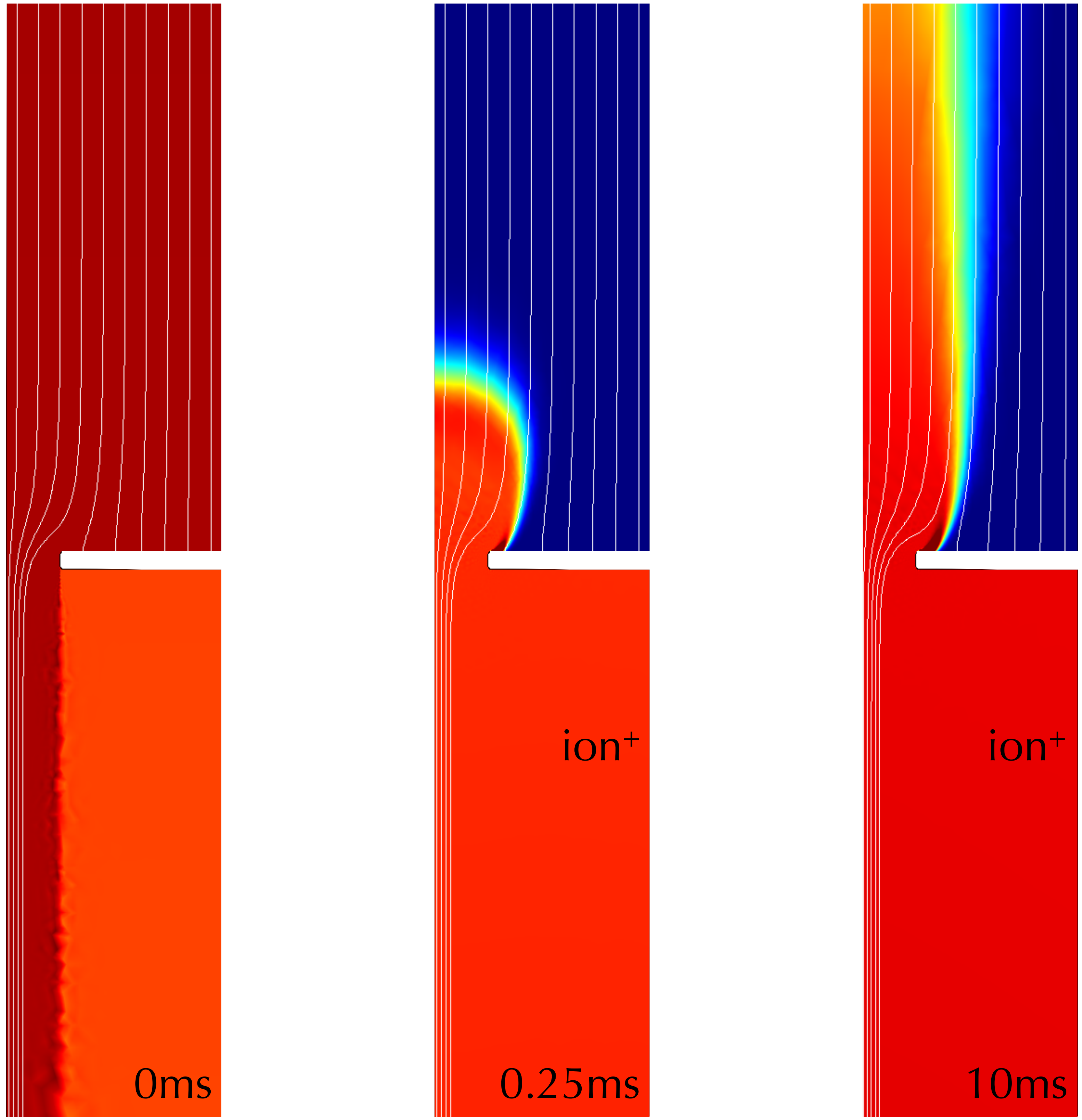
GEM gain = $1.5x10^4$

'IBF' = 20%

Ion space charge

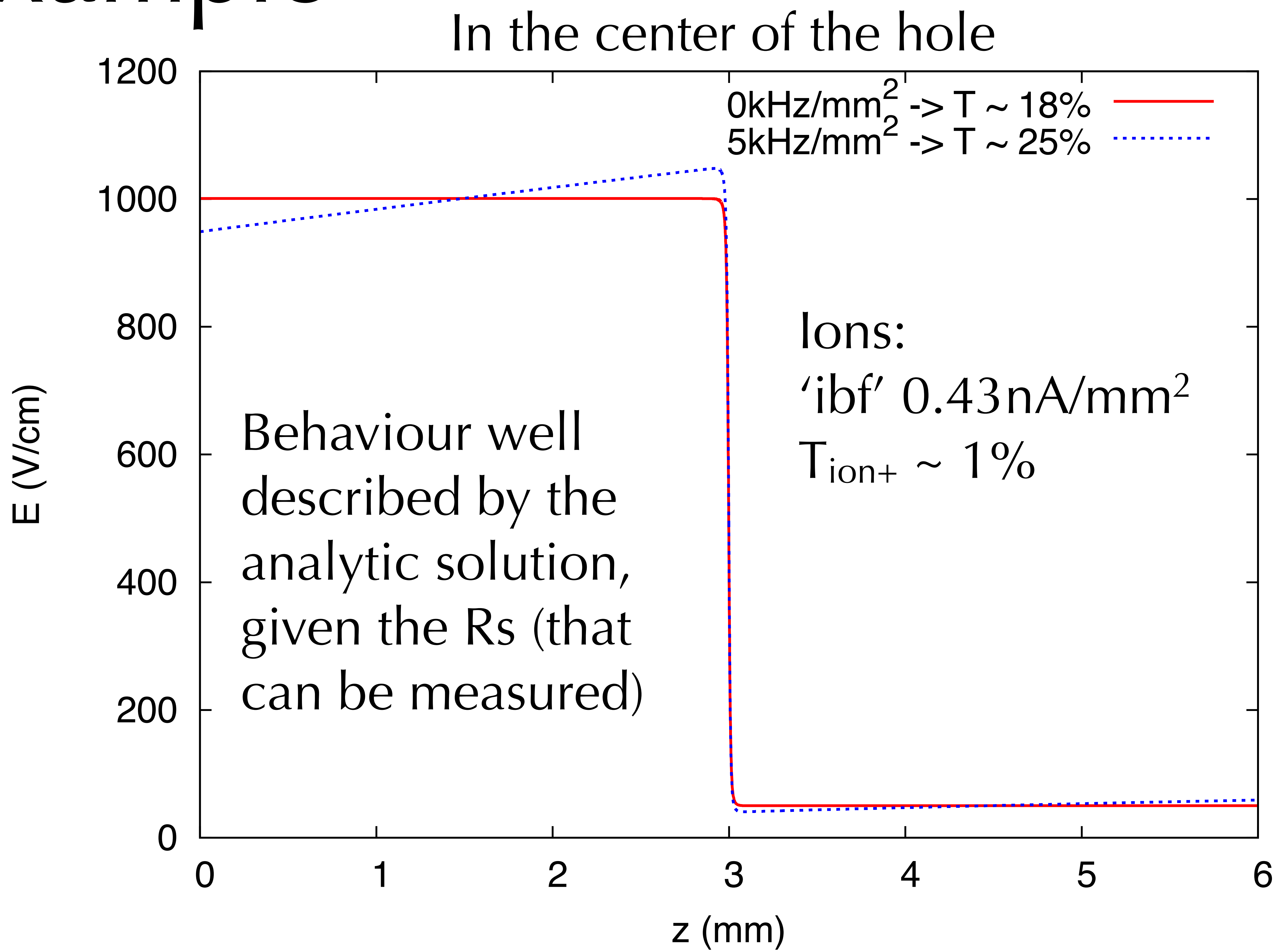
Different colour scales

e^-/ion$^+$ primaries distribution (Cu mesh stops some X rays)



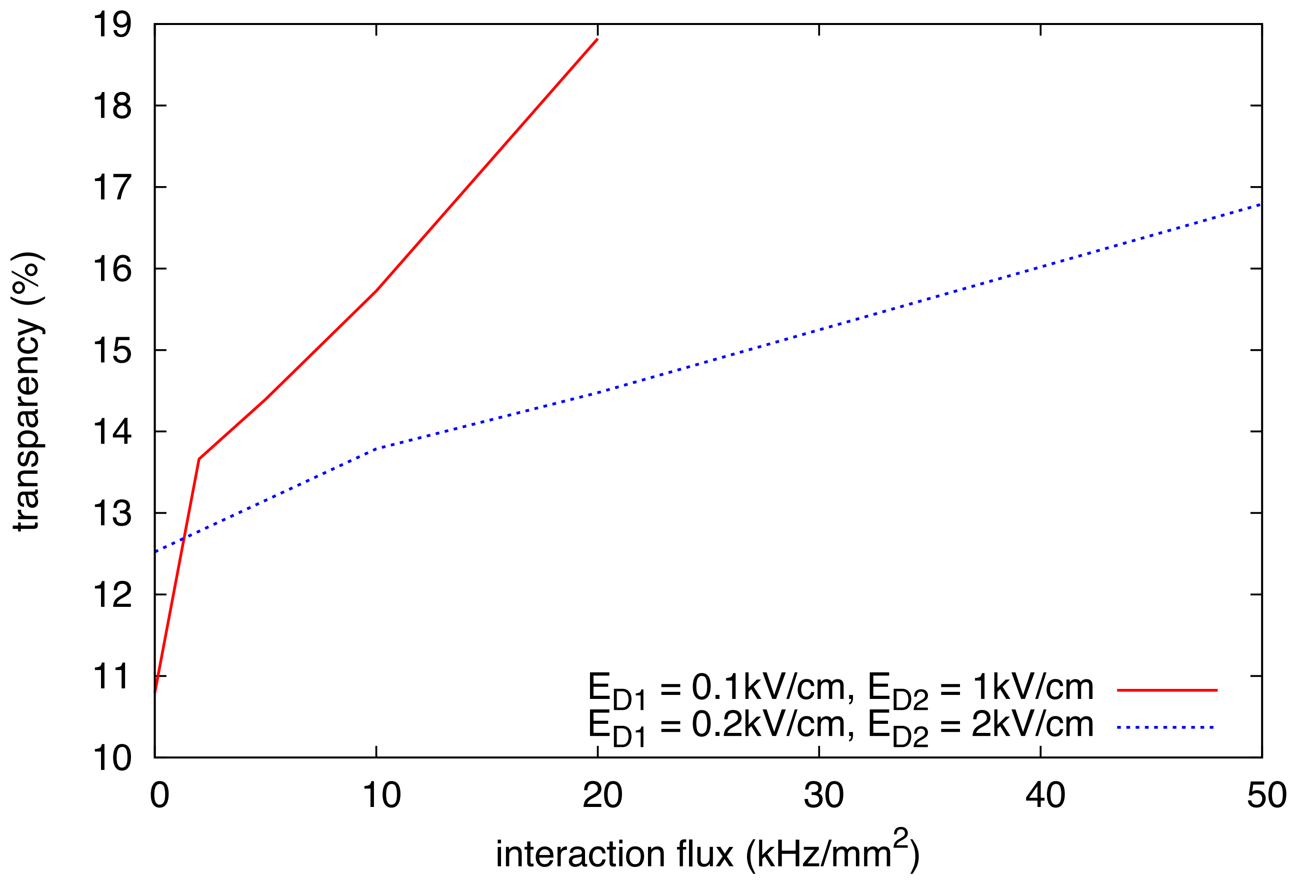
Field lines change: T increases

Example

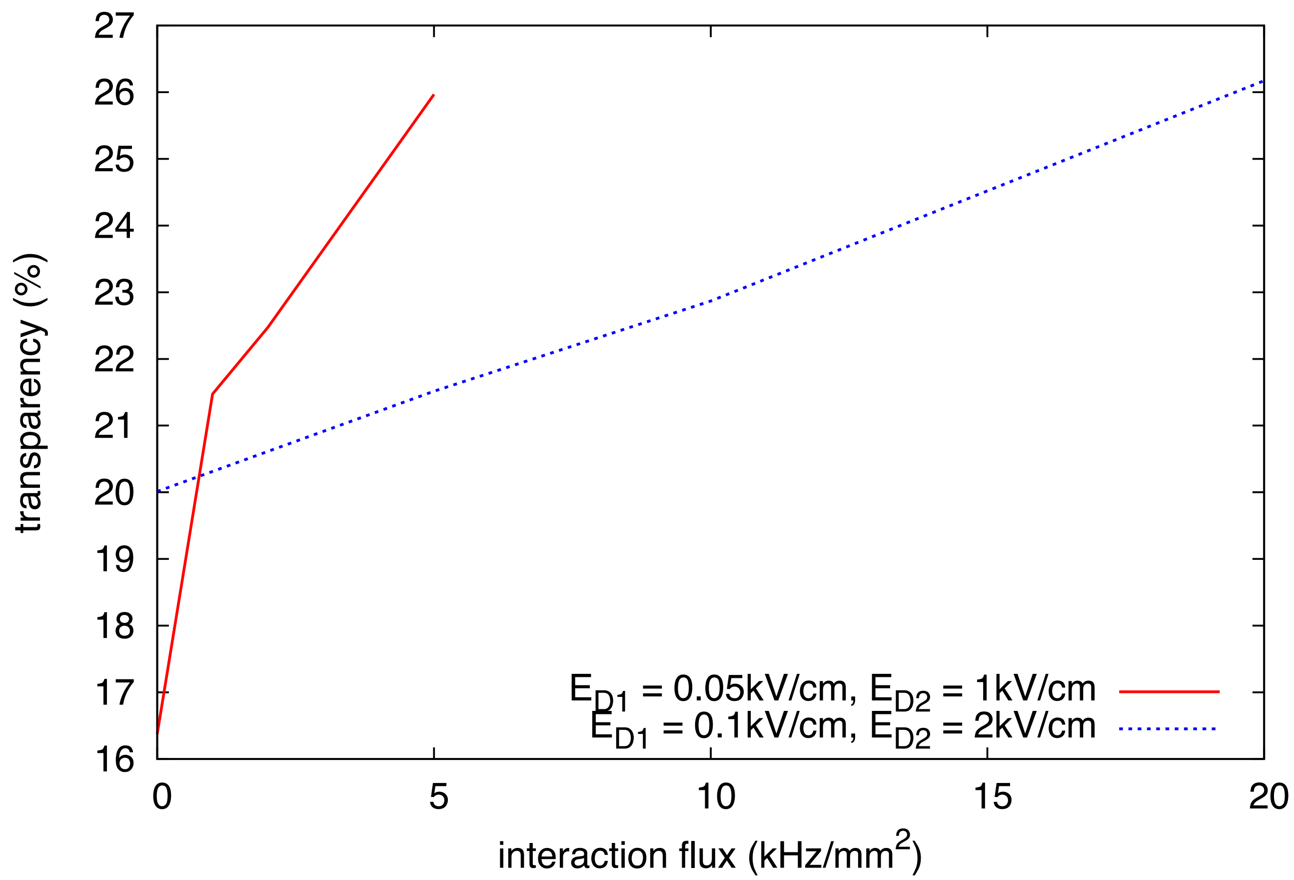


In the center of the hole
0kHz/mm^2 -> T ~ 18%
5kHz/mm^2 -> T ~ 25%
E (V/cm)
z (mm)
0
200
400
600
800
1000
1200
0
1
2
3
4
5
6
Behaviour well described by the analytic solution, given the Rs (that can be measured)
Ions:
'ibf' 0.43nA/mm^2
T_{ion+} ~ 1%

Electron transparency



Preliminary: quantitative comparison with data not yet done, but trends are reproduced and numbers involved are correct



Larger fields, larger velocities, less ions in the volume and smaller space charge effect

Summary

This effect can alone explain the transparency variation of the meshes

It is linked to the gain and IBF variations of the GEM and it may help explaining the gain increase and the IBF decrease (increase of the GEM transparency and transfer efficiency)

Further

Implement the proper electron and ion transport properties and compute the transparency behaviour of different gas mixtures

Simulate a single GEM hole including the avalanche process

Further

Changing the interaction rates, fields and gas mixtures, systematic measurements of:
- mesh transparencies to e^- and ion^+
- single GEM behaviour, i.e. transparency, gain and IBF

Quantitative comparison with the numerical calculations

Analytically

$$|\vec{v}| = \mu|\vec{E}| = \mu E_z$$

For symmetry reasons E_z is the only component

$$R = \rho v_{\perp} = \rho|\vec{v}|$$

Ion flux conservation

$$\rho/\epsilon = \vec{\nabla} \cdot \vec{E} = \frac{dE_z}{dz}$$

Maxwell first equation

$$R = \epsilon\mu \frac{dE_z}{dz} E_z$$

$$dz = \frac{\epsilon\mu}{R} E_z dE_z$$

$$z = \frac{\epsilon\mu}{R} E_z^2/2 - z_0$$

z_0 is the integration constant

Moreover

E = 0 at the anode (for $z_0 = 0$). Therefore, it exists a **maximum ion flux** or, equivalently, a **minimum nominal field** for which the ions still drift

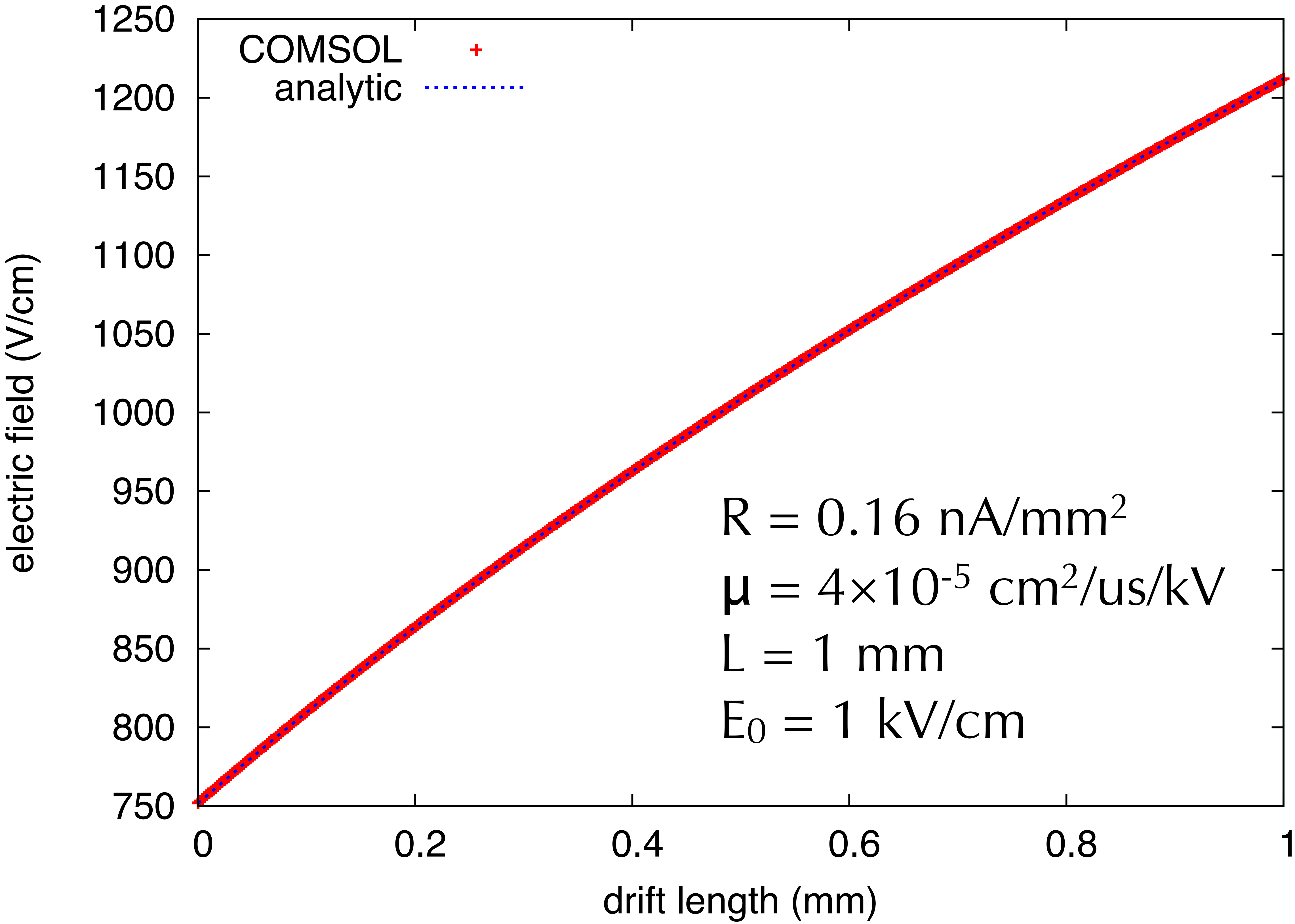
$$R_{max} = \frac{9\epsilon\mu E_0^2}{8L}$$

$E_0 = \Delta V/L$ is the electric field at t = 0 (nominal field)

$$E_{min} = \sqrt{\frac{8RL}{9\epsilon\mu}}$$

E_{min} is the nominal field at which E = 0 at the anode

Validation


1250
1200
1150
1100
1050
1000
950
900
850
800
750
COMSOL
analytic
electric field (V/cm)
0
0.2
0.4
0.6
0.8
1
drift length (mm)
R = 0.16 nA/mm²
μ = 4×10⁻⁵ cm²/us/kV
L = 1 mm
E0 = 1 kV/cm