# Effects of space charge in GEM-based detectors

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on behalf of GDD team

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# Background

Unclear behaviour of GEM detector at extreme conditions

At very high fluxes:
- Behaviour of triple GEM gain (Everaerts)
- Decrease of ion back-flow (ALICE)
- Increase of mesh transparency

At very high gains
- Gain saturation effect (Majumdar)
- Transition to discharges

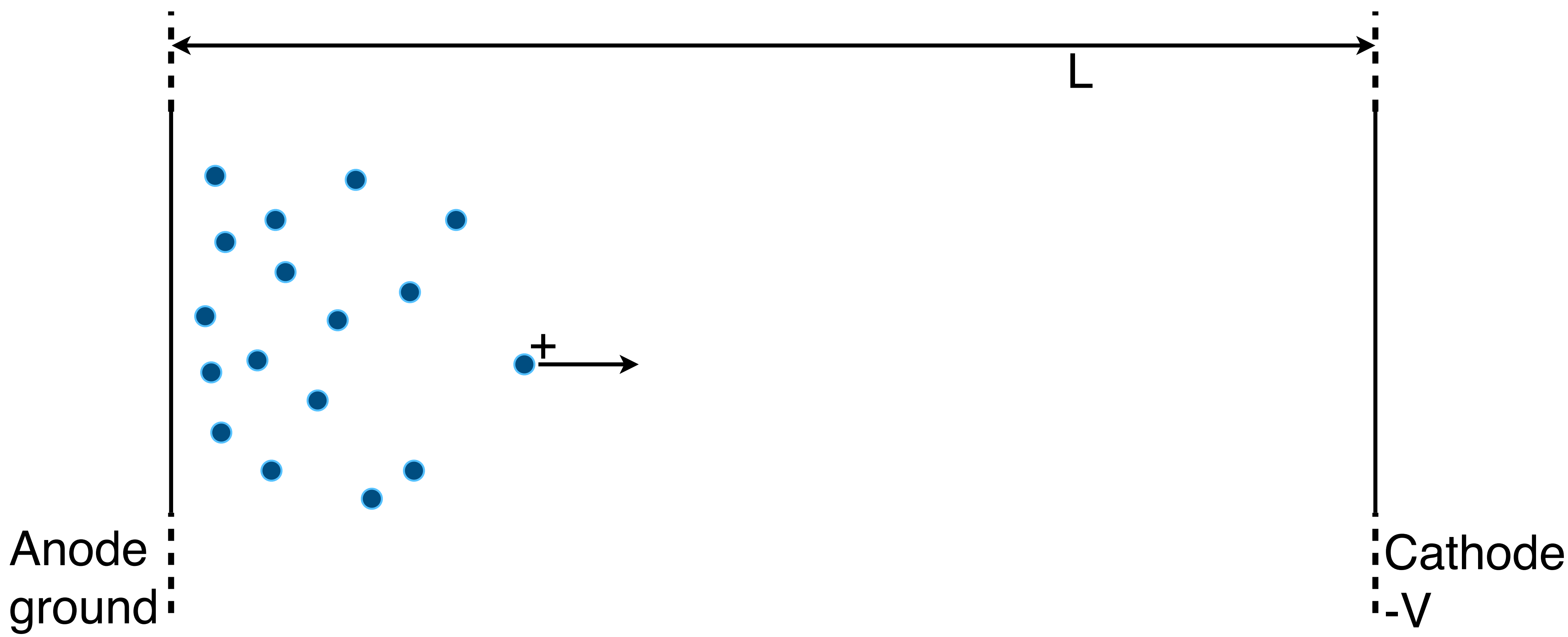
# Background

At very high fluxes:
- Related to space charges
- Collective effect

At very high gains:
- Related to charges in each avalanche
- Event by event

# High fluxes

# Problem




Infinite parallel plates at distance L with a potential difference $\Delta V$
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

# 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

# Steady state solution

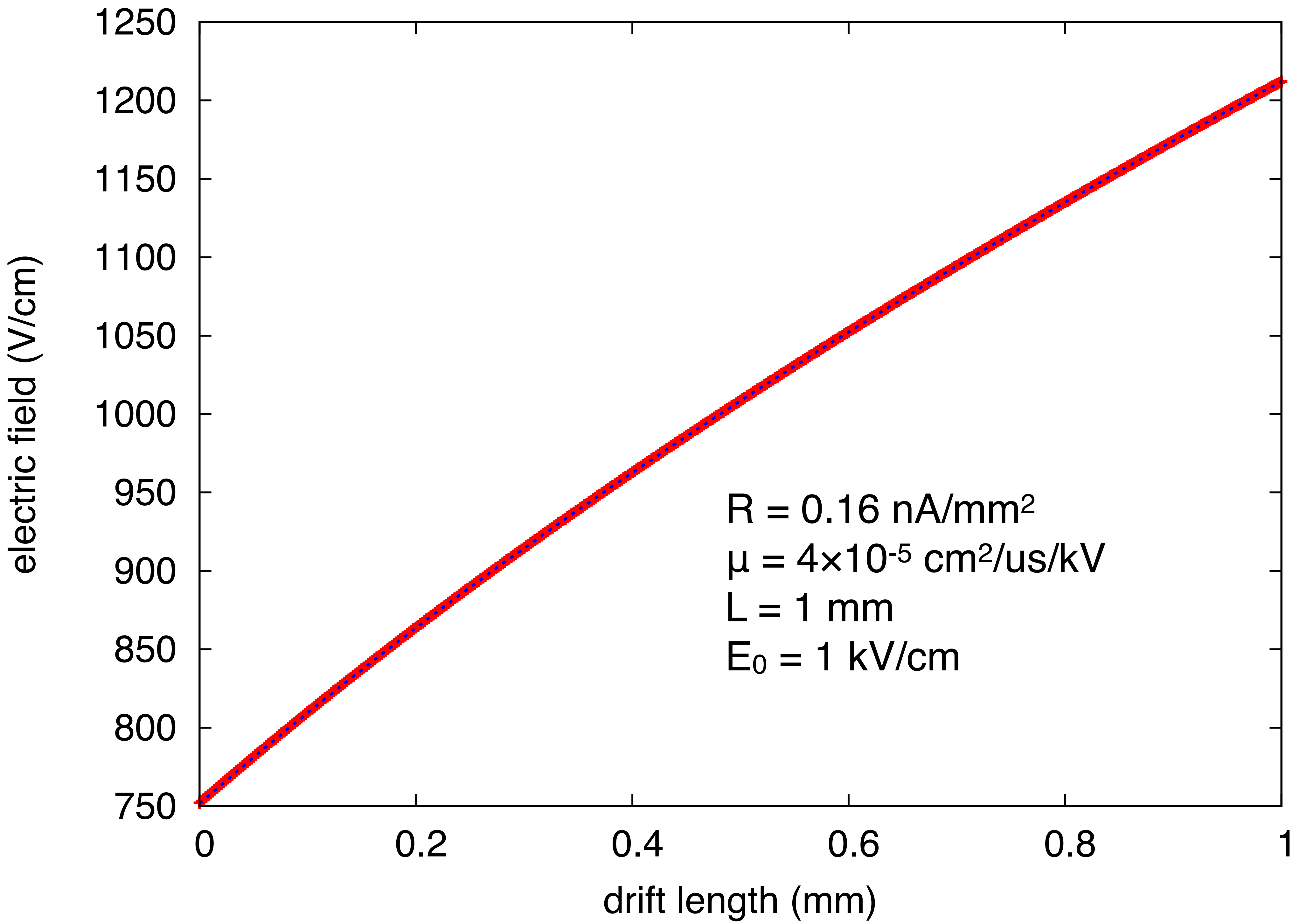
$$E_z = \sqrt{\frac{2R(z+z_0)}{\epsilon\mu}}$$

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

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

with $z_0$ such that the integral of the field equals ΔV

# Example



1250
1200
1150
1100
1050
1000
950
900
850
800
750
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

# In general

The electric field:
- decreases where the positive ions “enter”
- increases where the ions “exit”

In typical conditions, electrons can be neglected, because they are much faster than ions

# The model

Heavily inspired by P. Fonte work.
COMSOL: a FEA software which allows to dynamically compute the electric field in the presence of charges, as well as the amplification and transport of the charges themselves under the influence of the electric field.

$$\vec{\nabla} \cdot \epsilon \vec{\nabla} V = -q_e(\rho_i - \rho_n - \rho_e)$$

$$\frac{\partial \rho_e}{\partial t} = \alpha|\vec{W}_e|\rho_e - \eta|\vec{W}_e|\rho_e - K\rho_i\rho_e - \vec{\nabla} \cdot (\vec{W}_e\rho_e - D_e\vec{\nabla}\rho_e)$$

$$\frac{\partial \rho_i}{\partial t} = \alpha|\vec{W}_e|\rho_e - K\rho_i\rho_e - \vec{\nabla} \cdot (\vec{W}_i\rho_i - D_i\vec{\nabla}\rho_i)$$

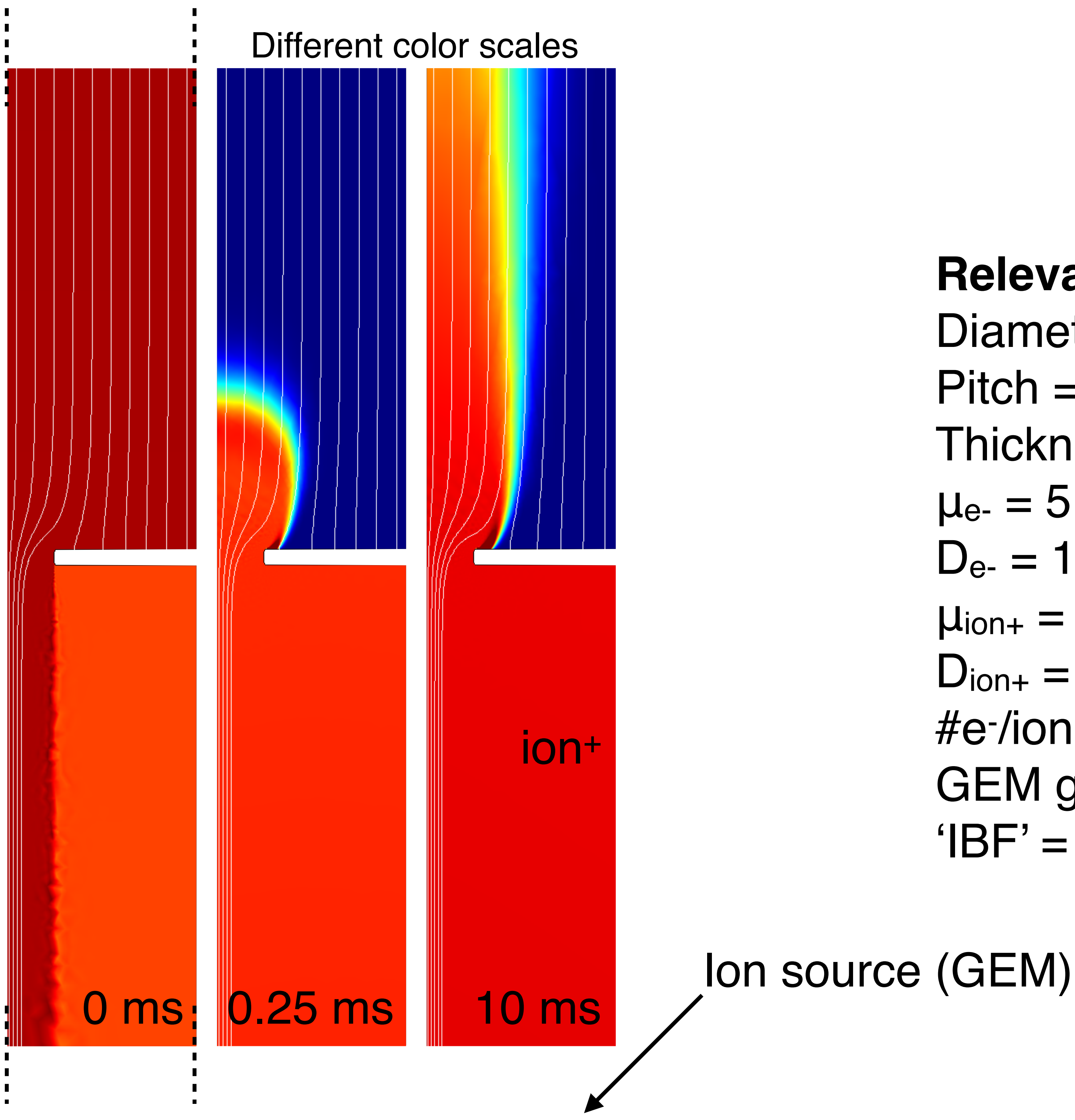
$$\frac{\partial \rho_n}{\partial t} = \eta|\vec{W}_e|\rho_e - \vec{\nabla} \cdot (\vec{W}_n\rho_n - D_n\vec{\nabla}\rho_n)$$

Coefficients dependent on the electric field computed with Magboltz

# Approximations of the model

- Electron and ion densities described macroscopically by their densities
- Stochastic nature of the avalanche not taken into account
- 3D geometry approximated with a 2D axisymmetric geometry
- Zero flux approximation at the edge of the volume
- Charged-up surfaces approximated by forcing the electric field to be parallel

# Mesh case




**Relevant parameters:**

Diameter = 30 um

Pitch = 120 um

Thickness = 5 um

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

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

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

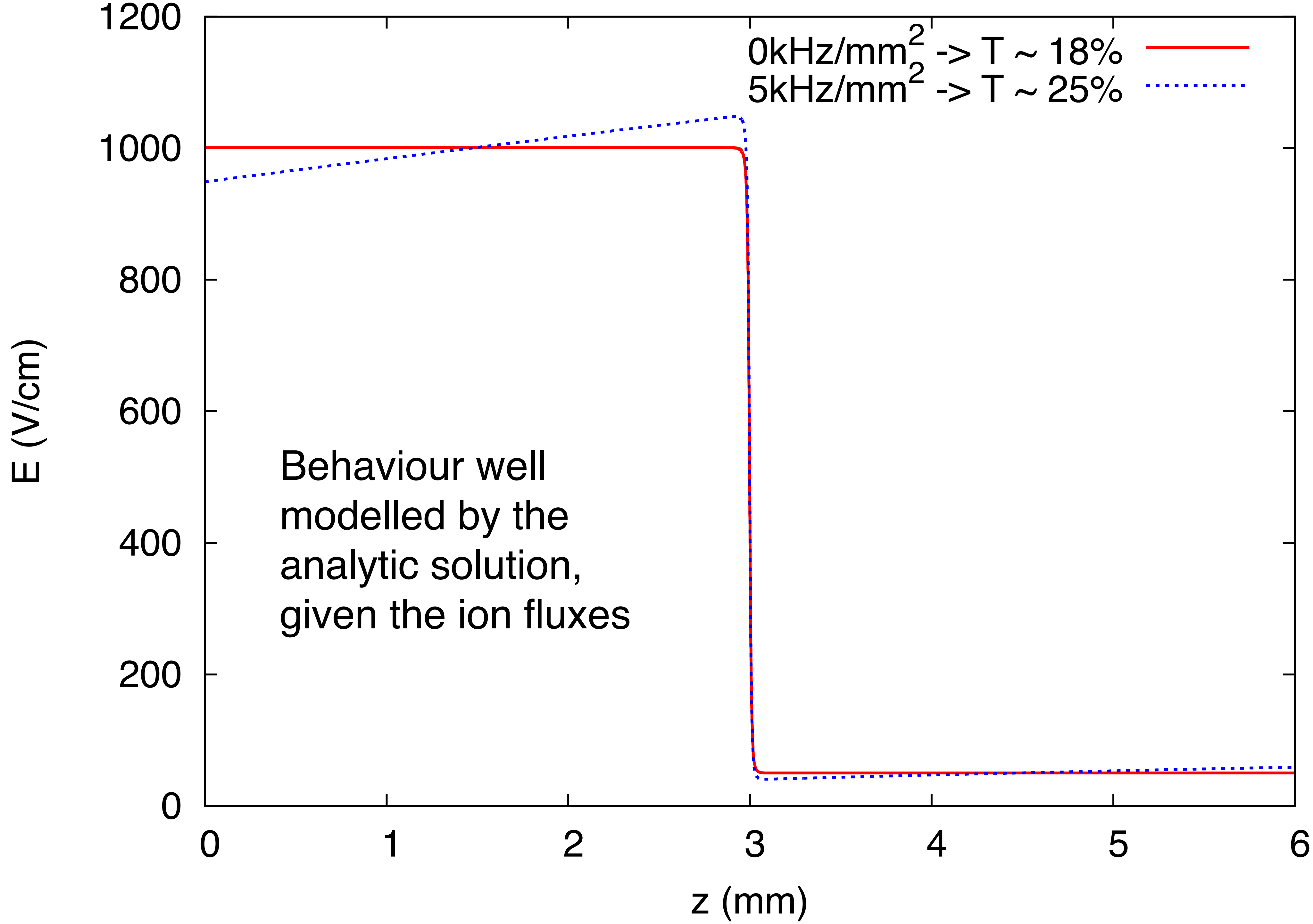
$D_{ion+}$ = 0 (approximately)

#$e^-$/$ion^+$ = 330 $e^-$/interaction

GEM gain = 1.5x$10^4$

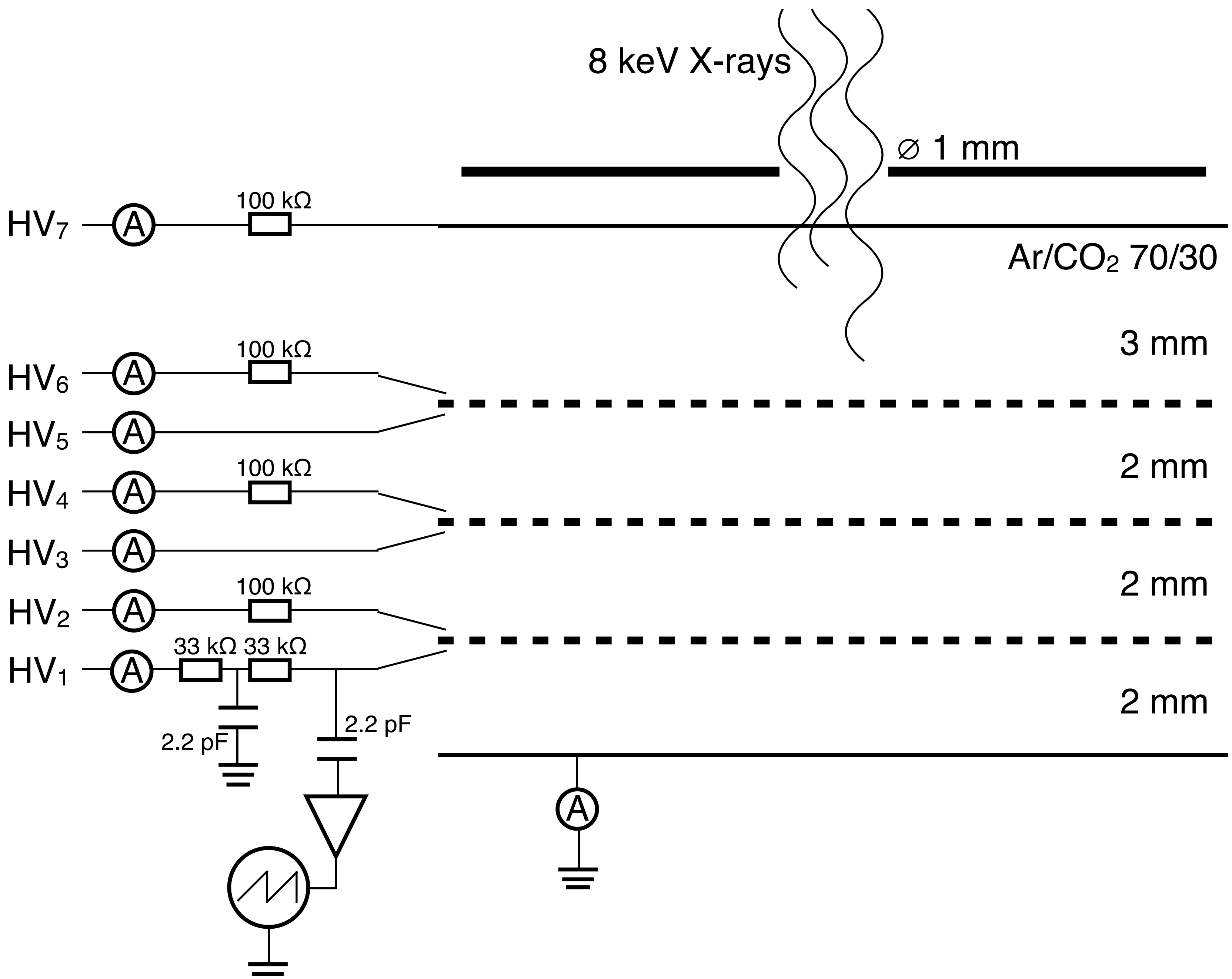
'IBF' = 20%

# Mesh case

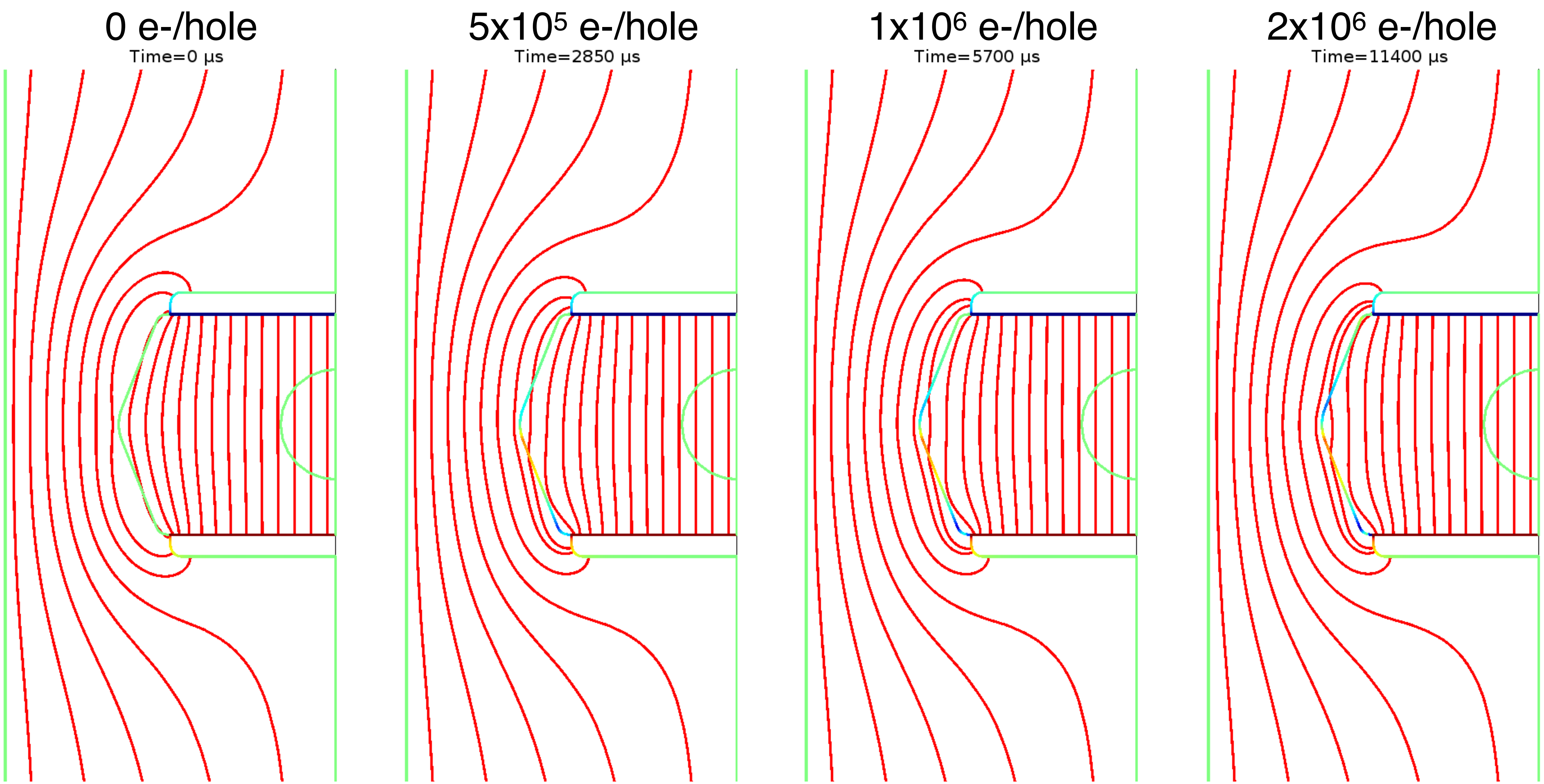


1200
1000
800
600
400
200
0
E (V/cm)
0
1
2
3
4
5
6
z (mm)
0kHz/mm$^2$ -> T ~ 18%
5kHz/mm$^2$ -> T ~ 25%
Behaviour well modelled by the analytic solution, given the ion fluxes

# Triple GEM setup

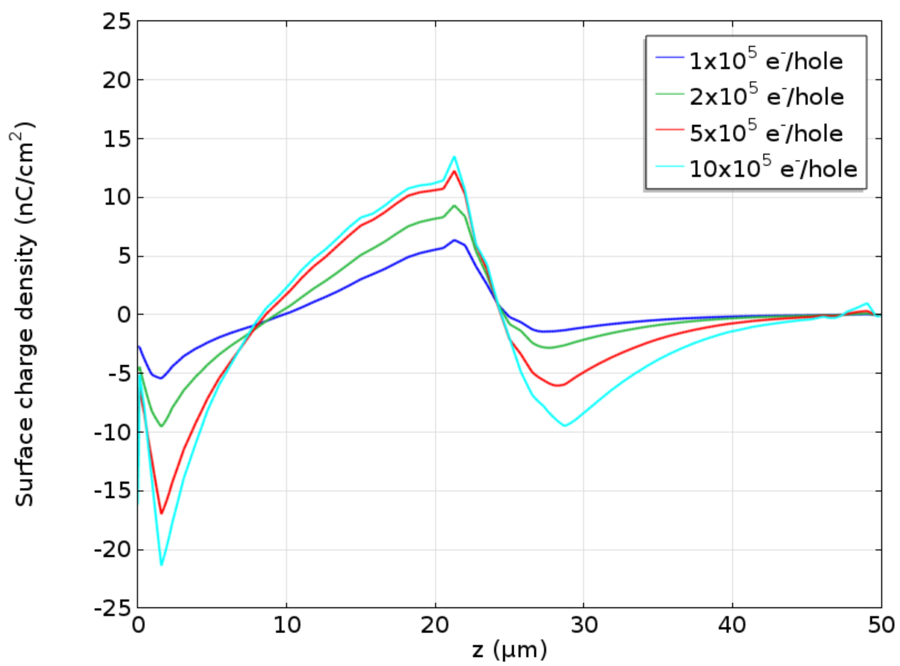


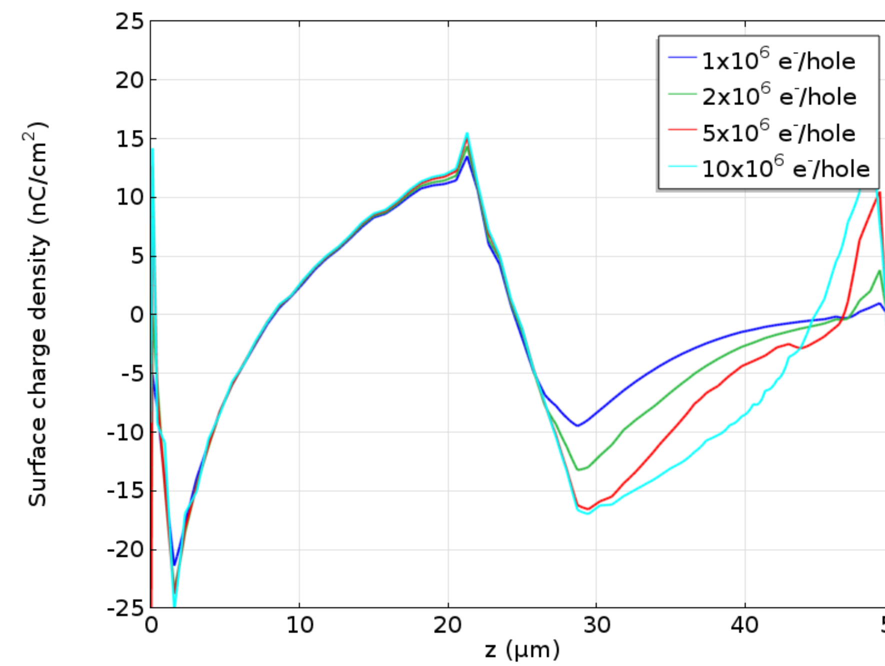
# Parenthesis: GEM charging up



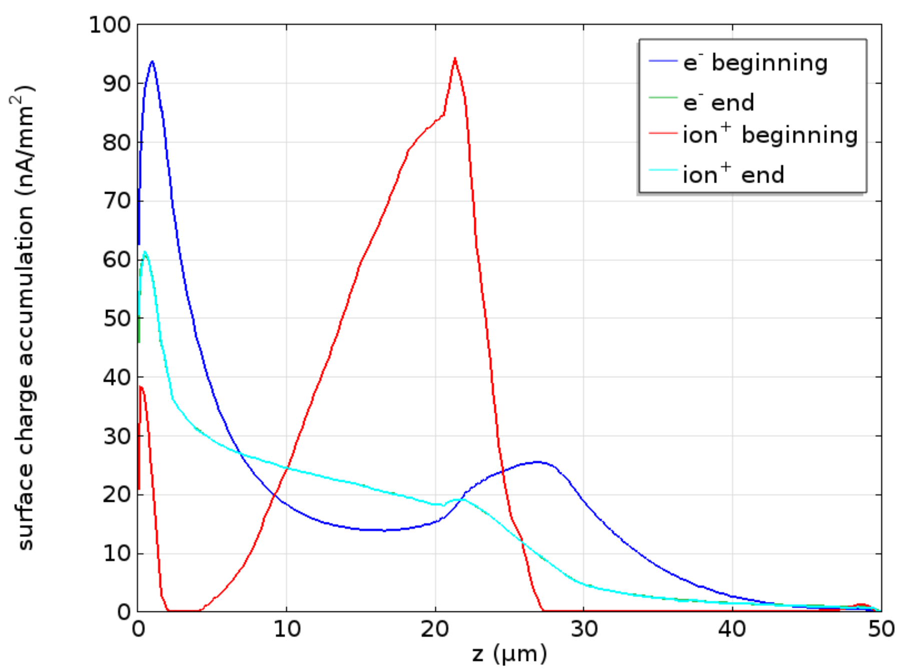

Single GEM, multiple stage GEM has ions from the bottom too. It is different…

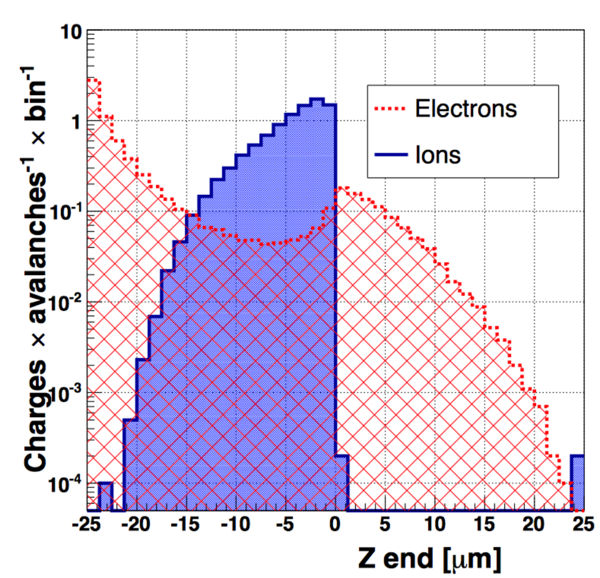
# Parenthesis: GEM charging up

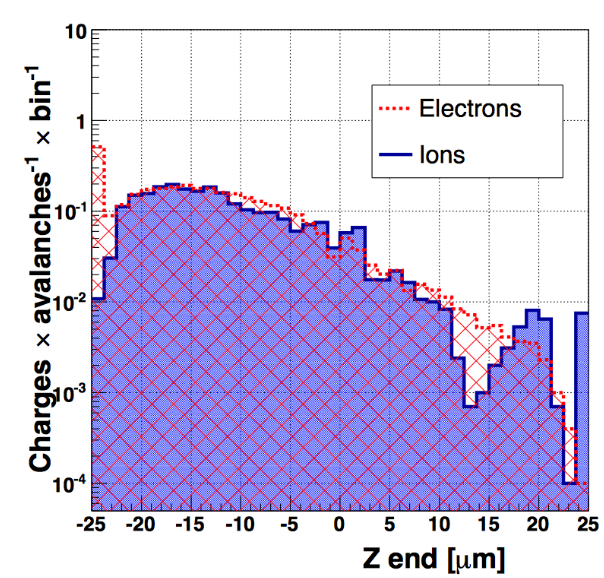


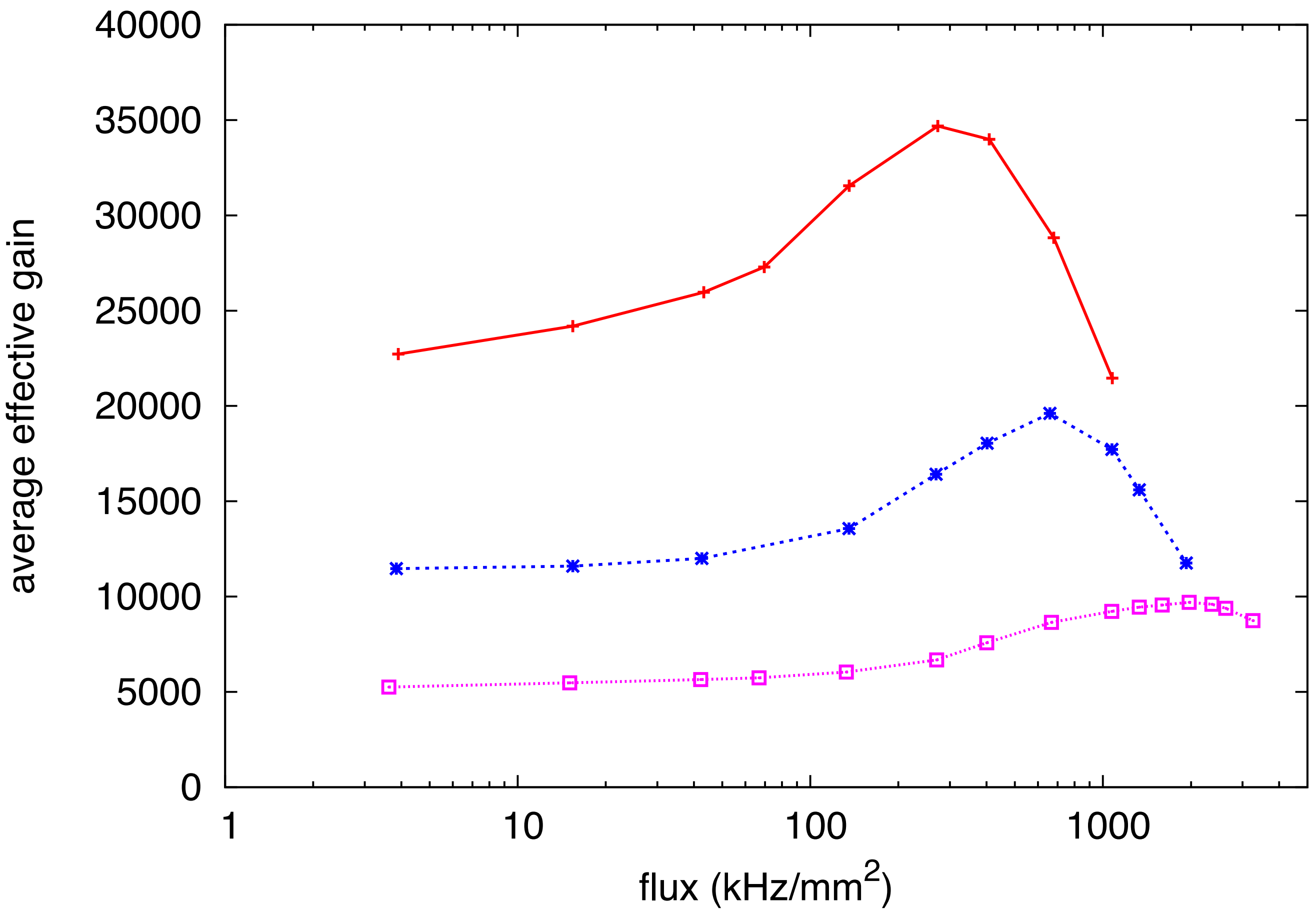

Correia *et al.*, JINST 9 (2014) P07025



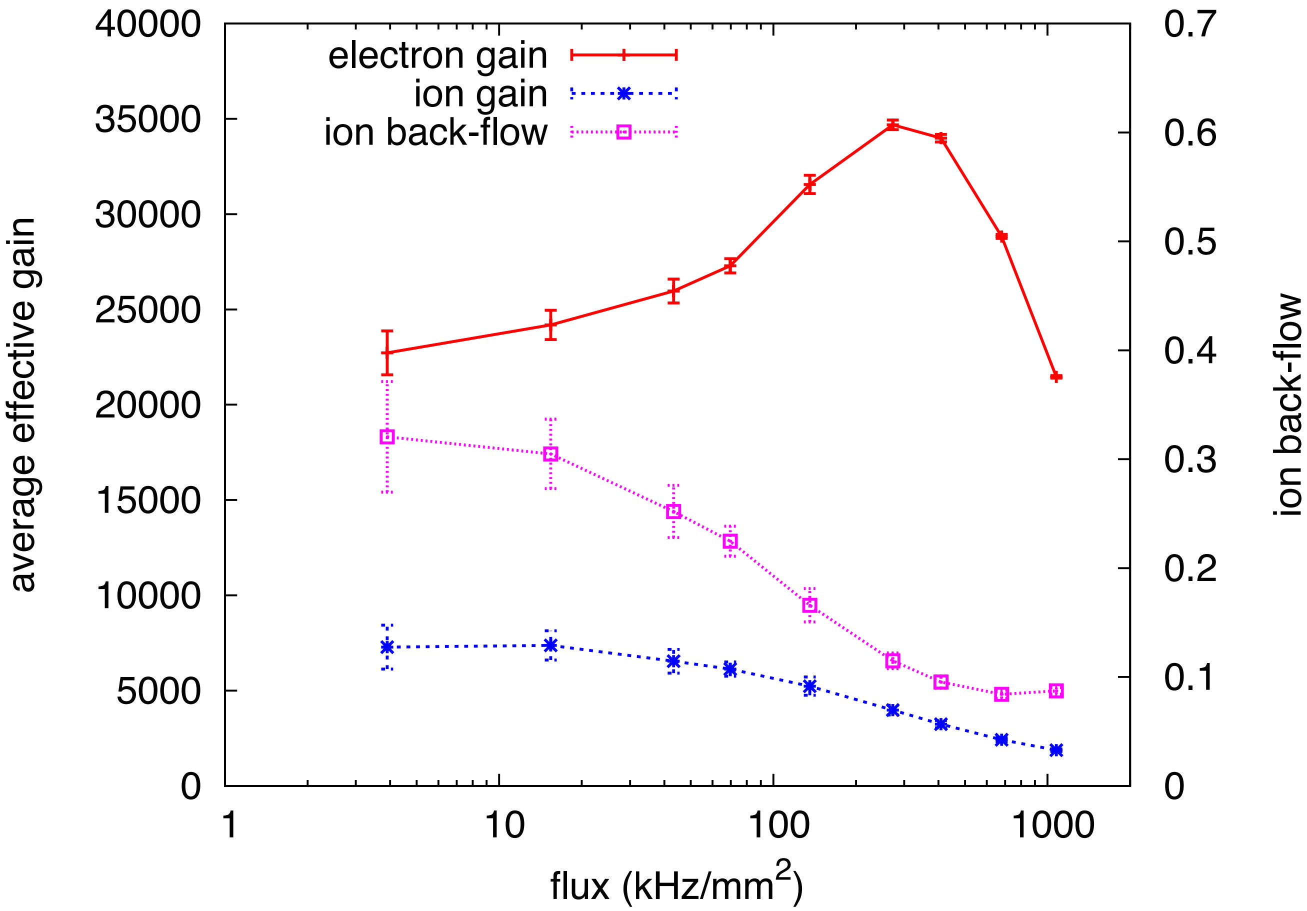



# Measurement results




Surprising behaviour

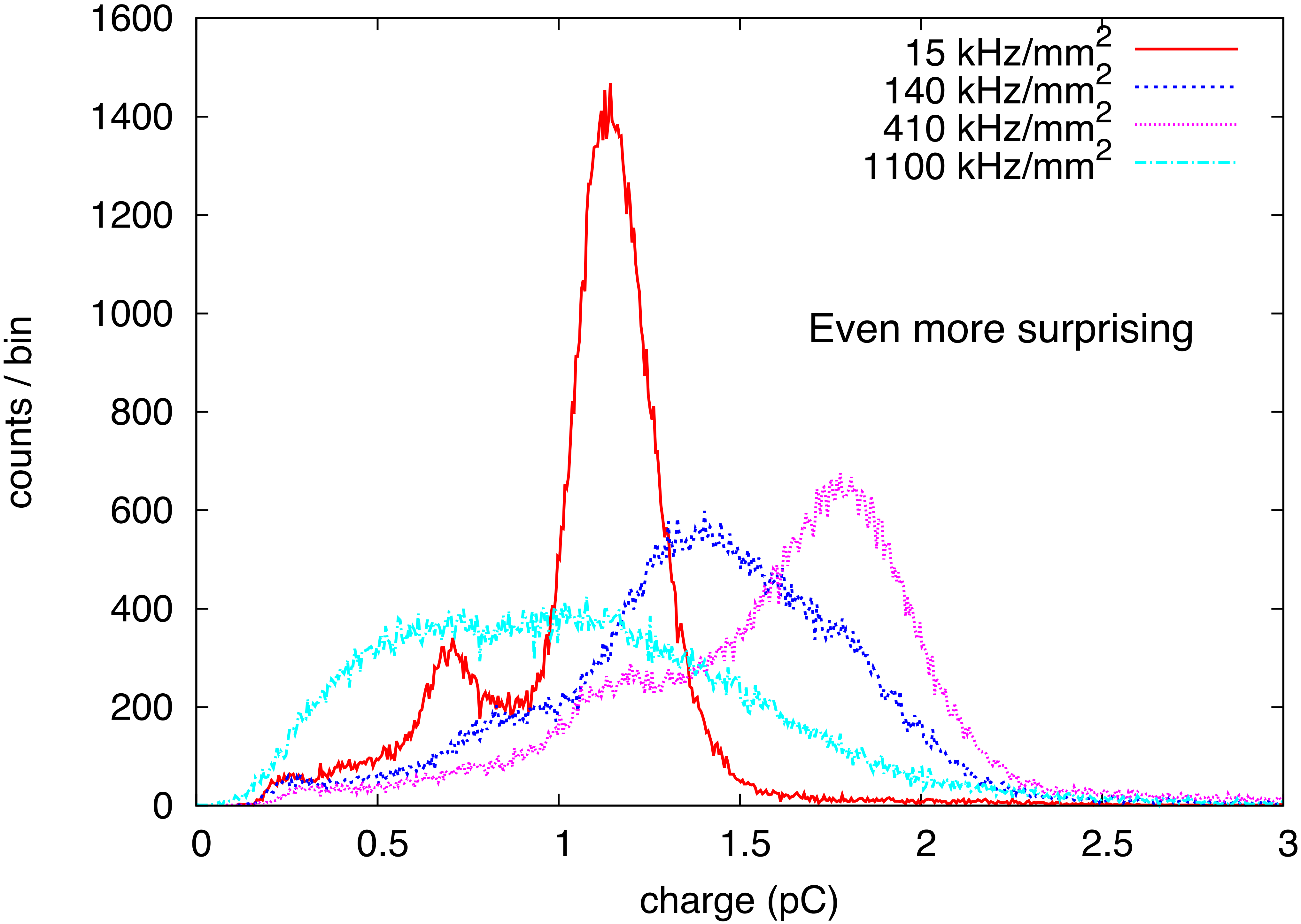


# Hints point to

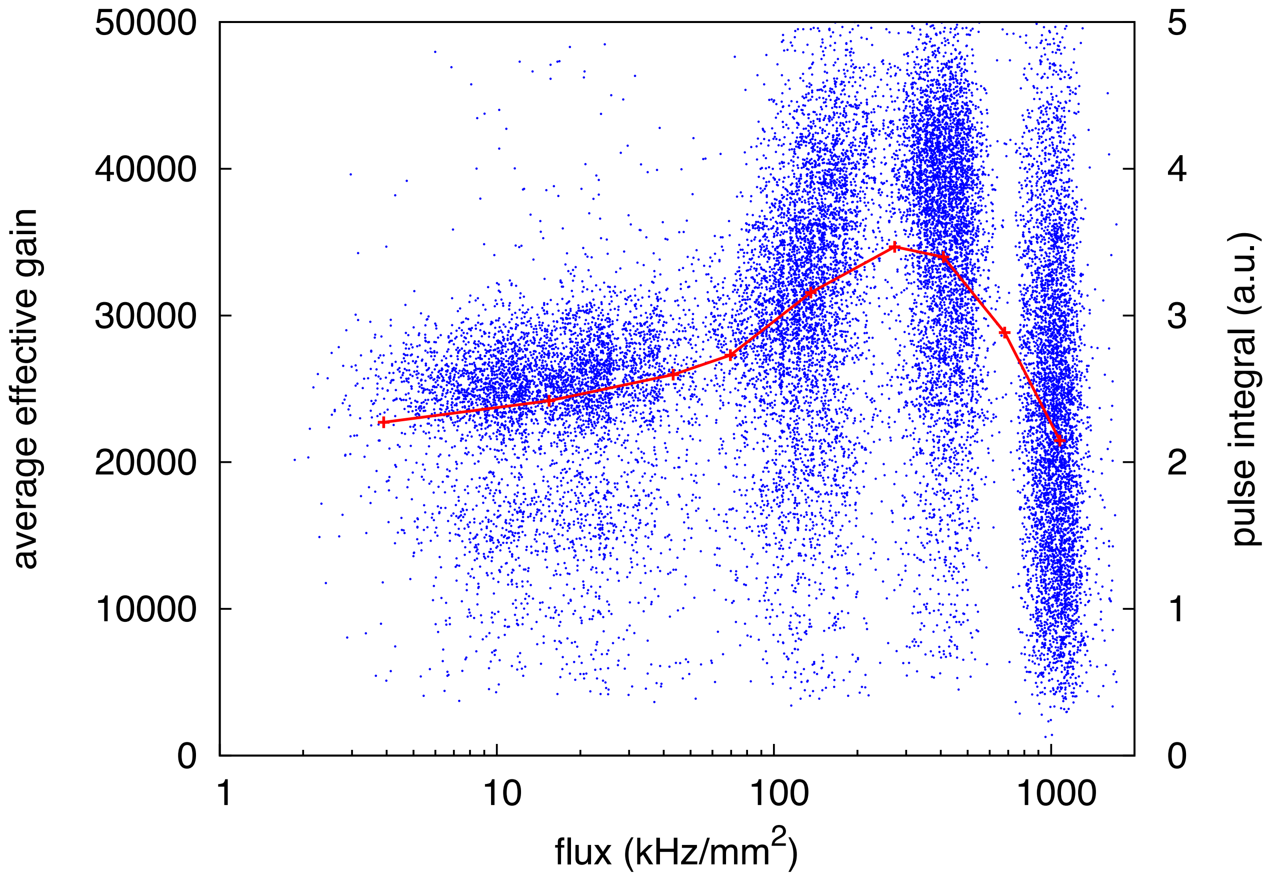
Gain increase:
- related to charge transfer

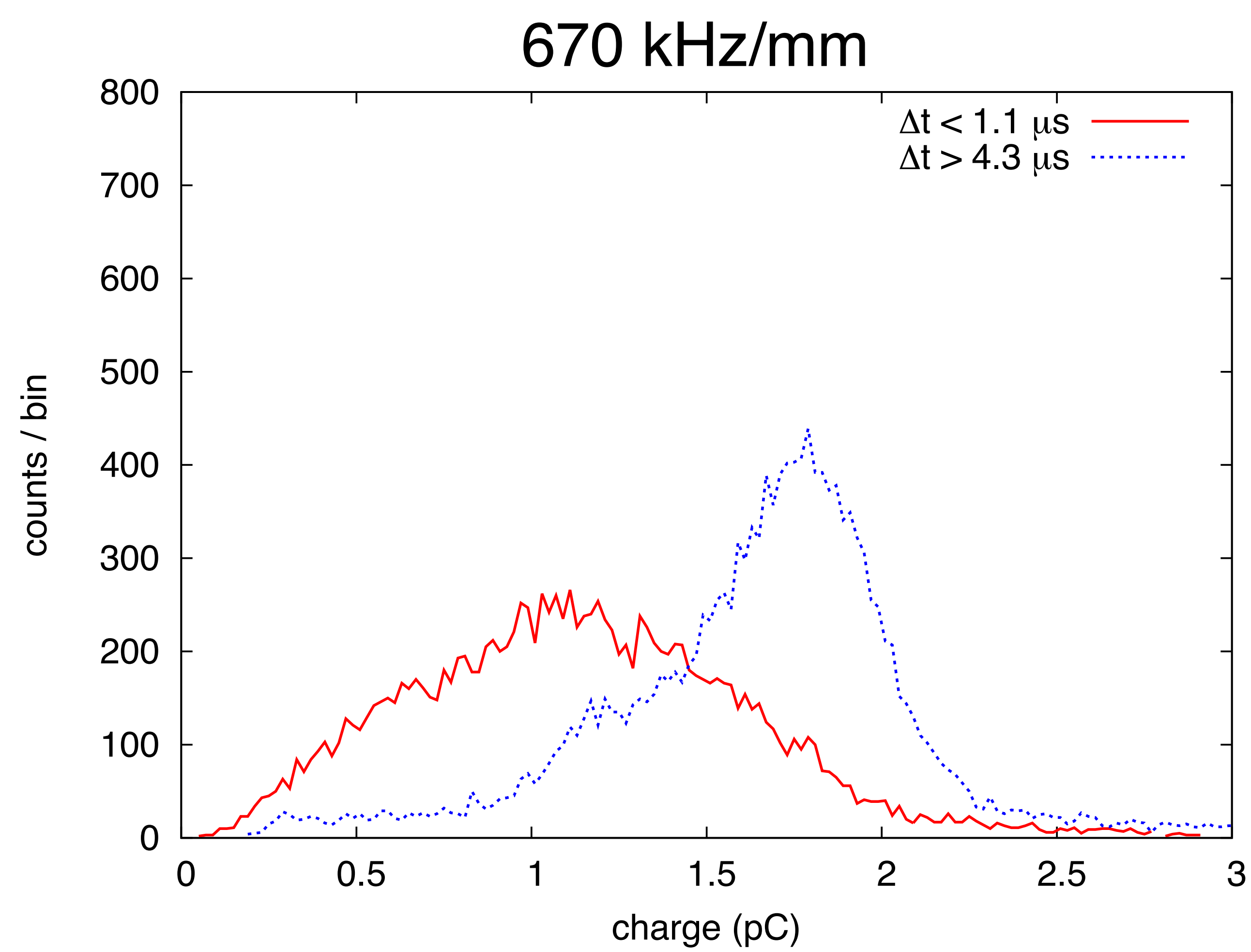
Gain decrease:
- related to the charge production

# Further results

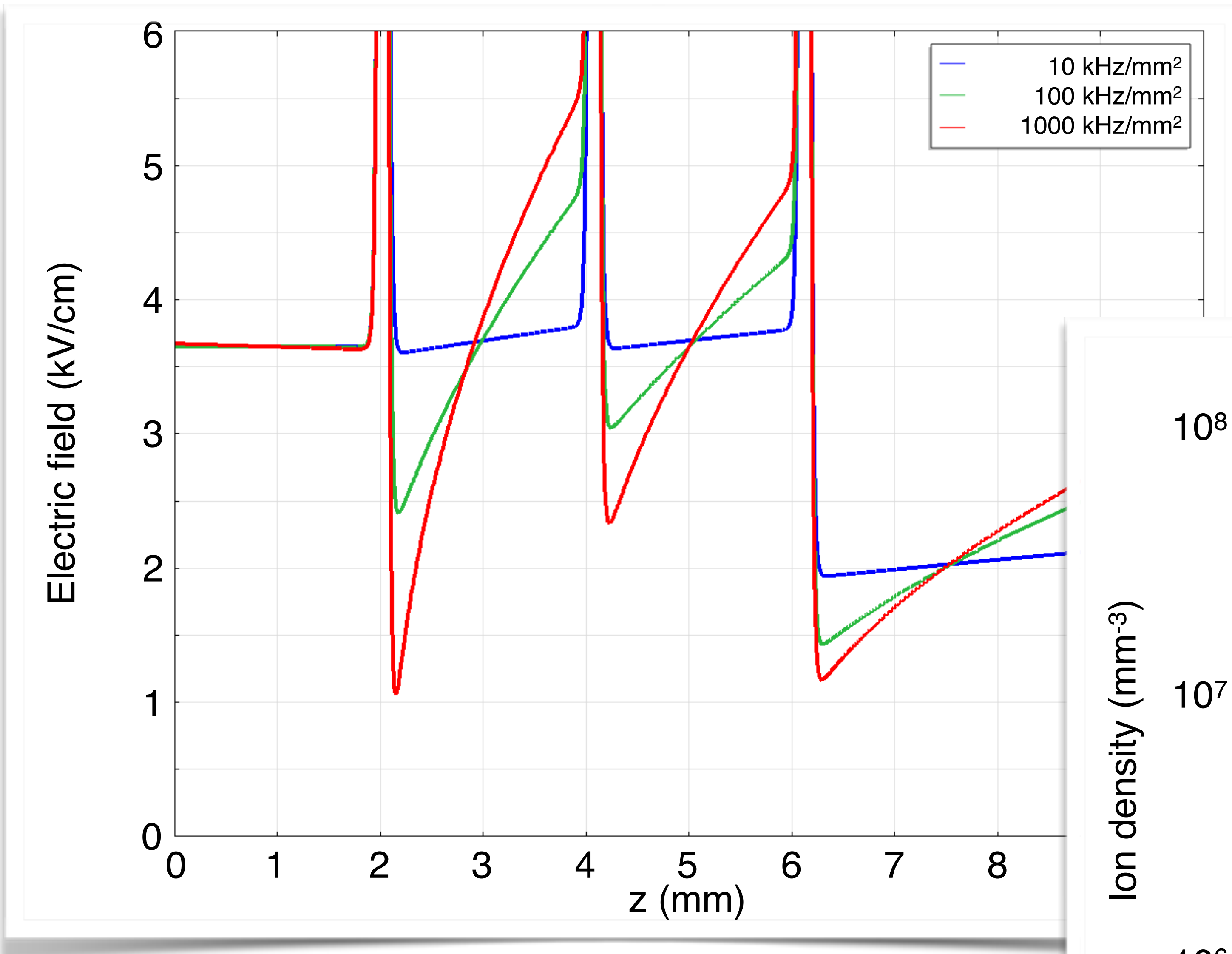


# Further results

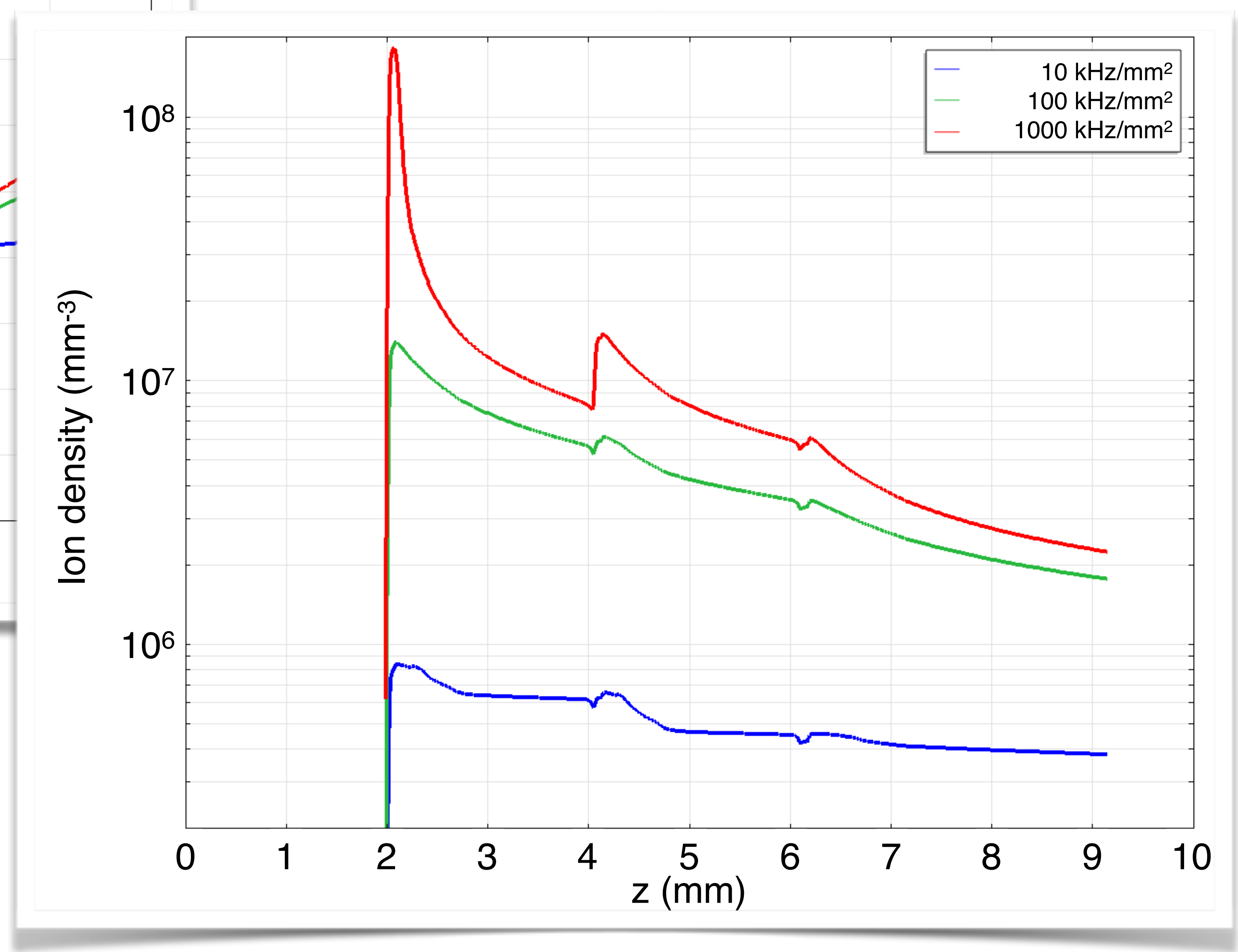


# Results from the model

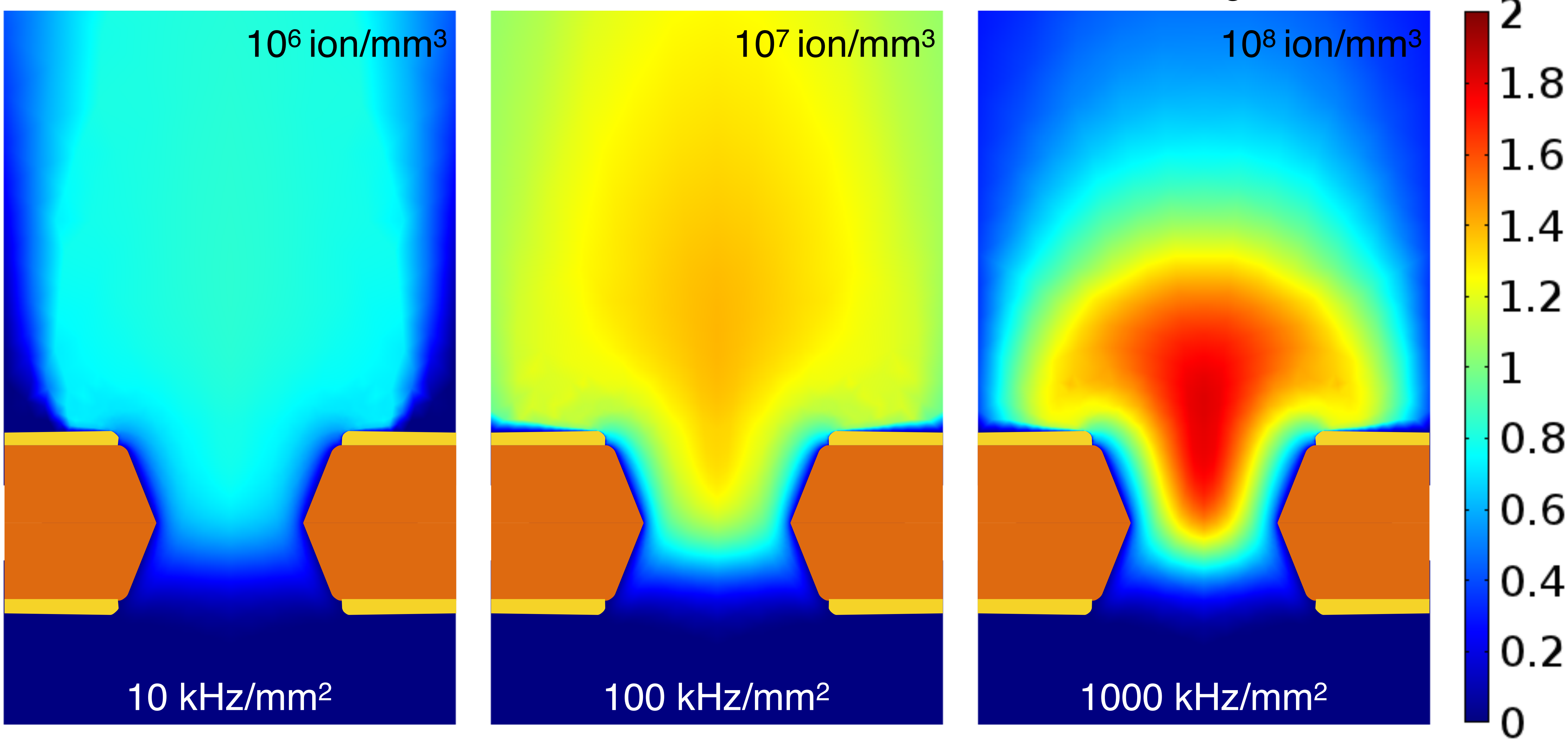



Reasons for the gain increase

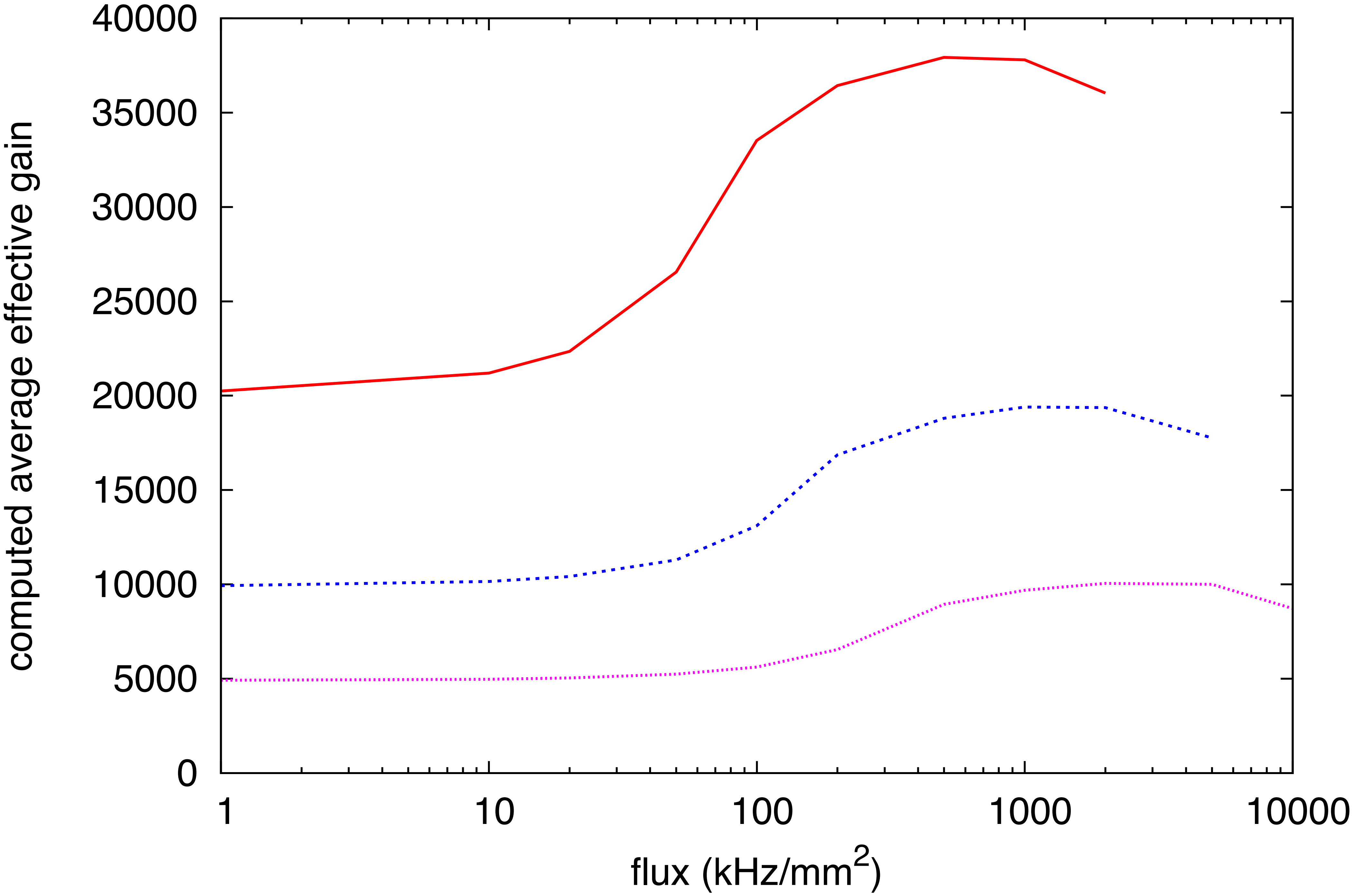


# Results from the model

Reasons for the gain decrease

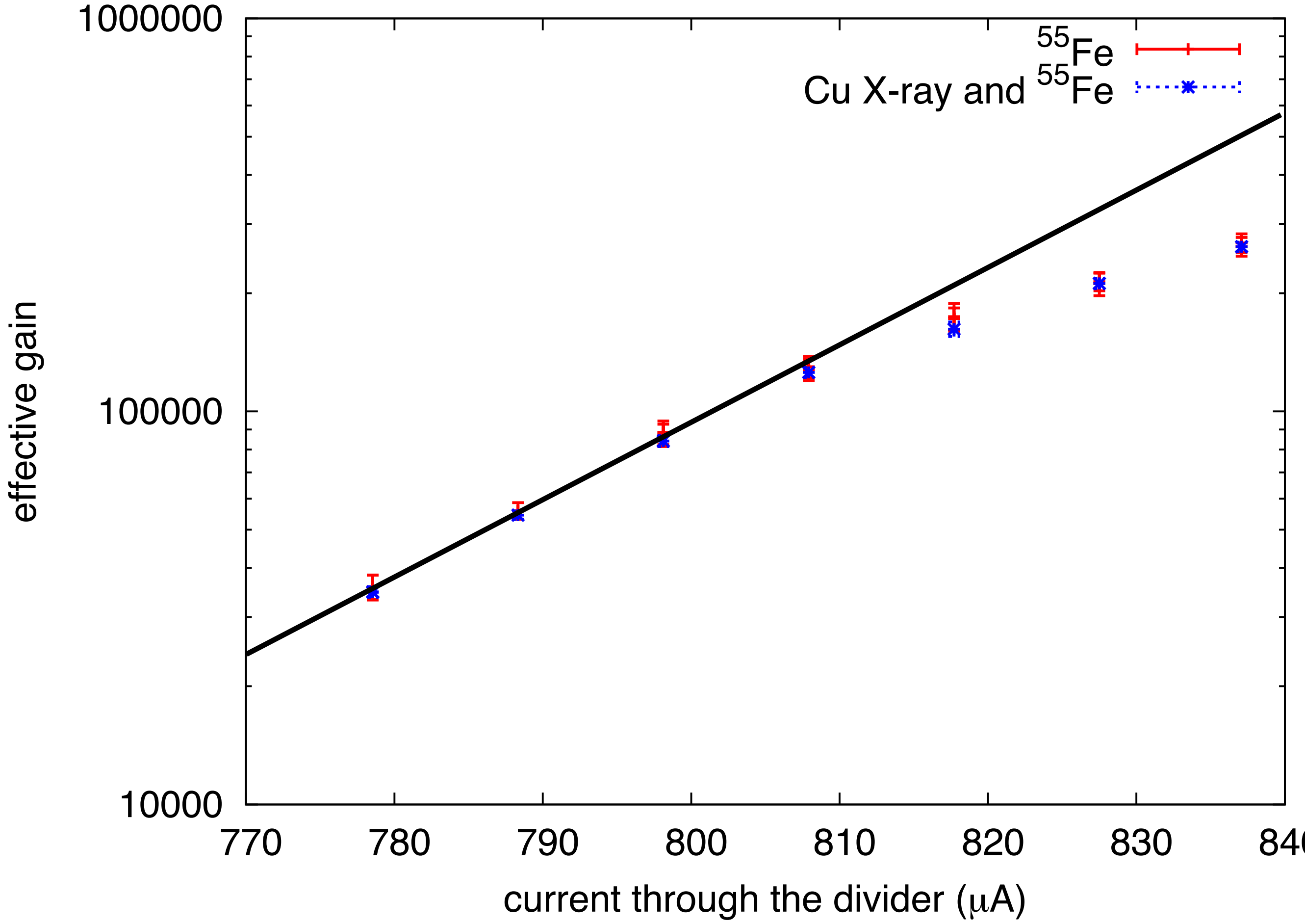


# Results from the model

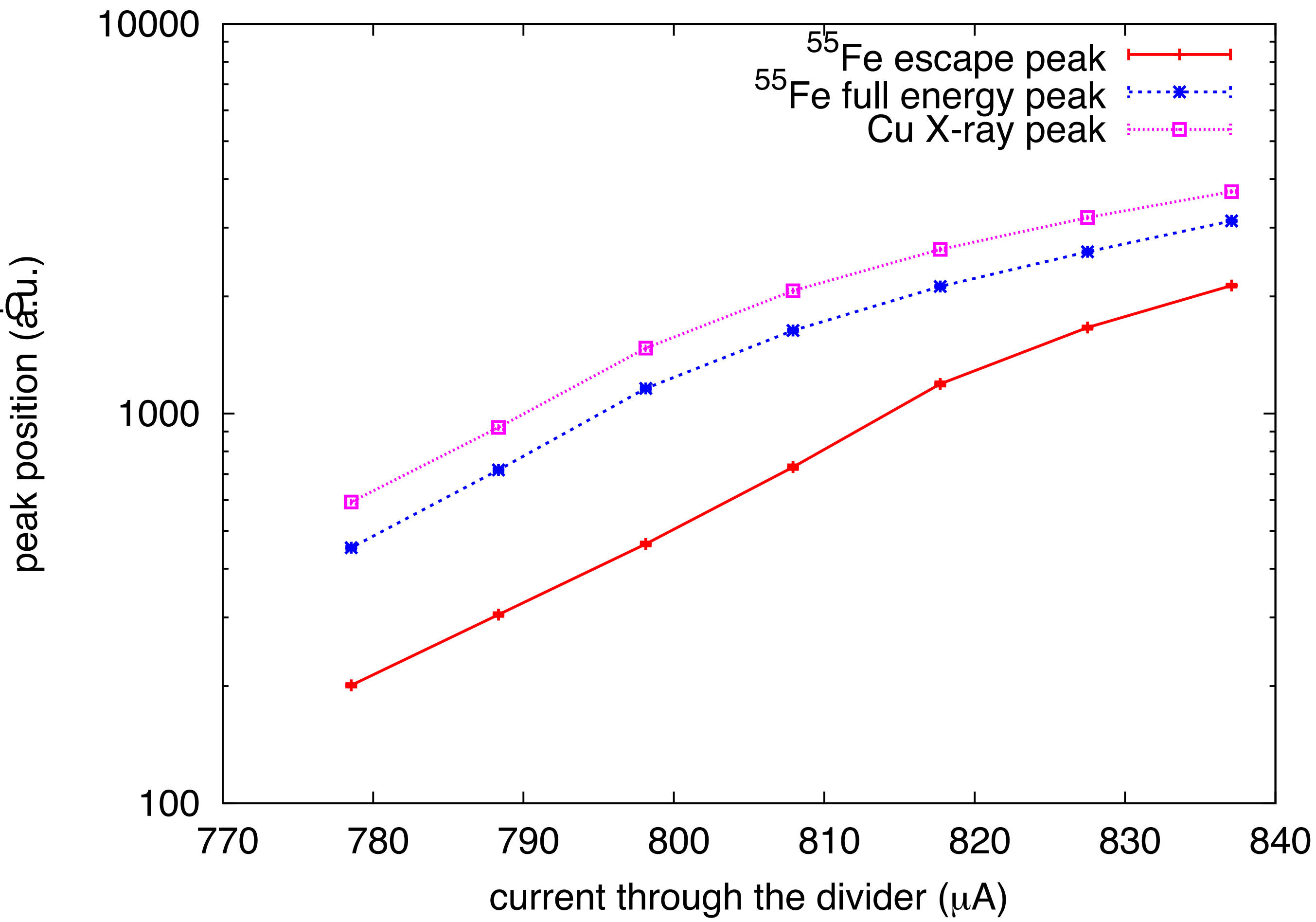


# High gains

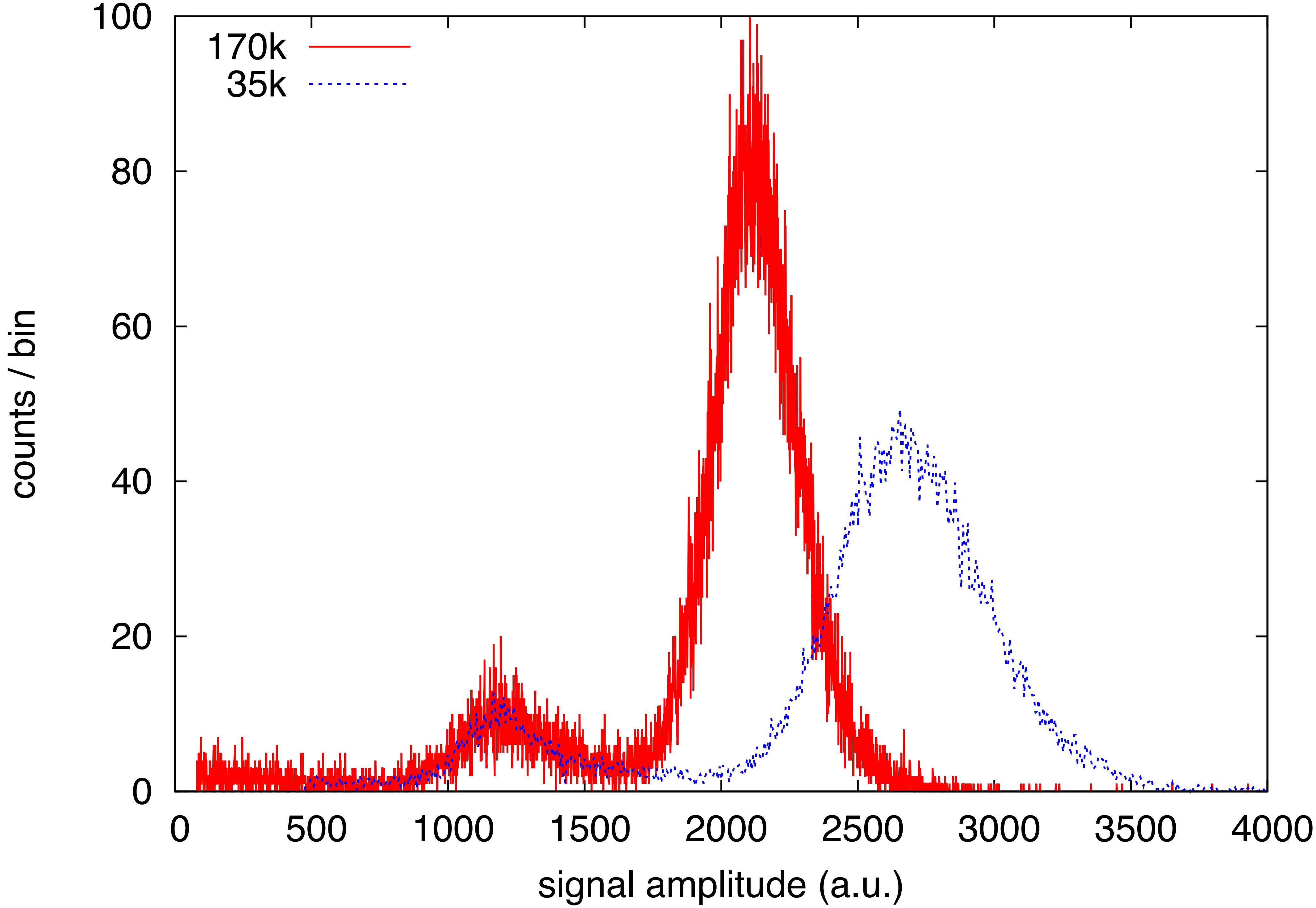
# Measurement



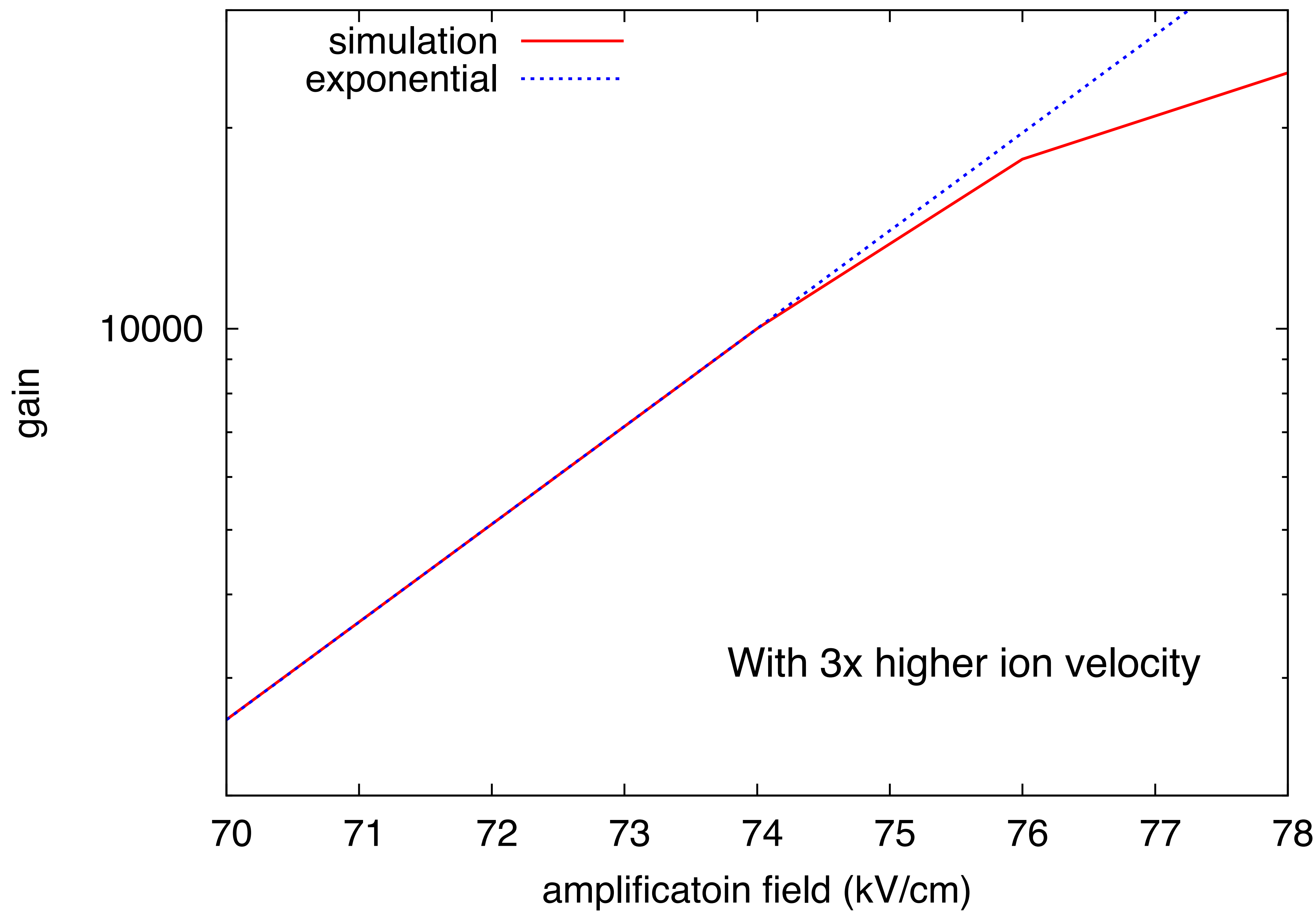

Clearly related to each single event



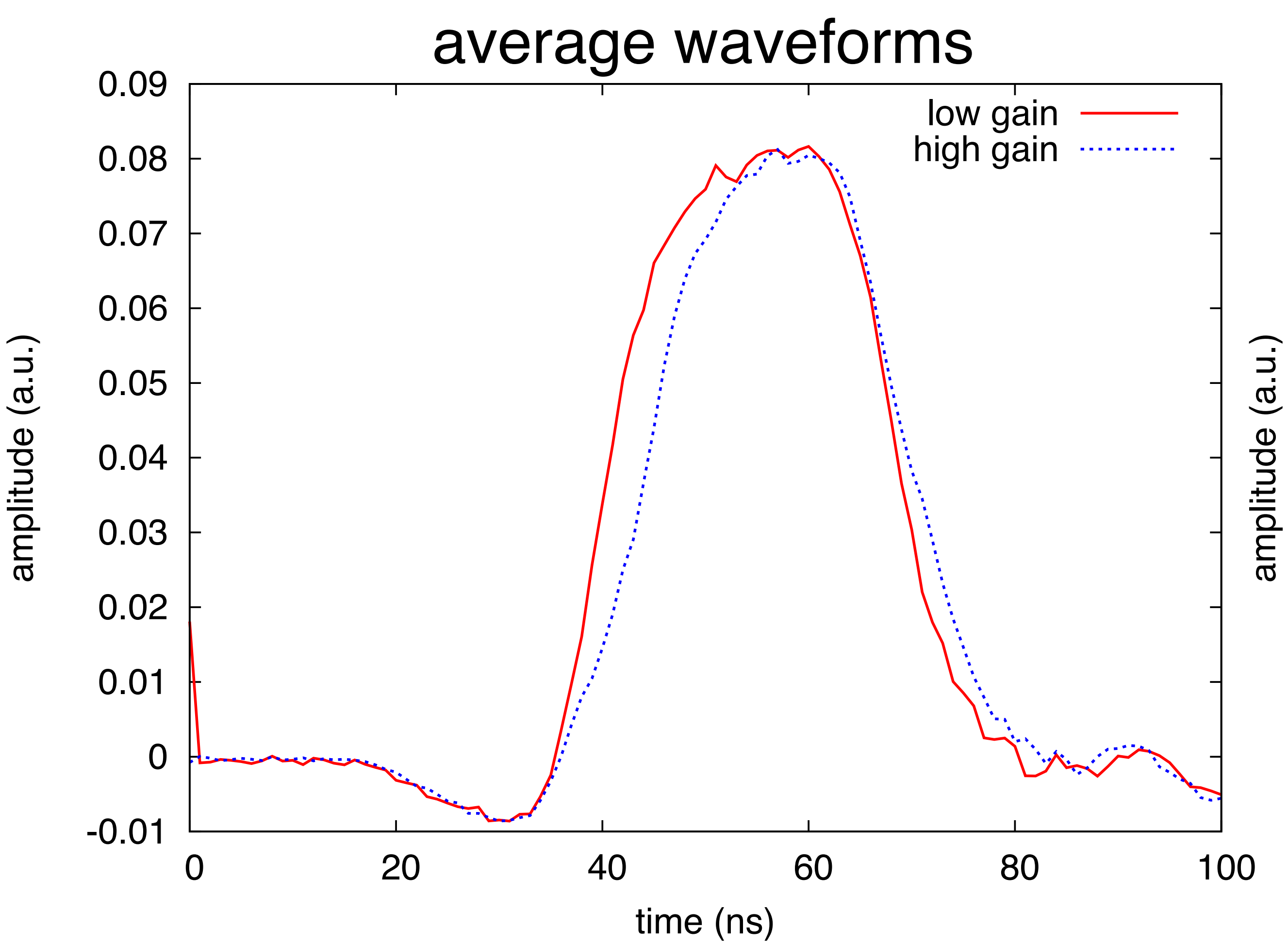
# Measurement

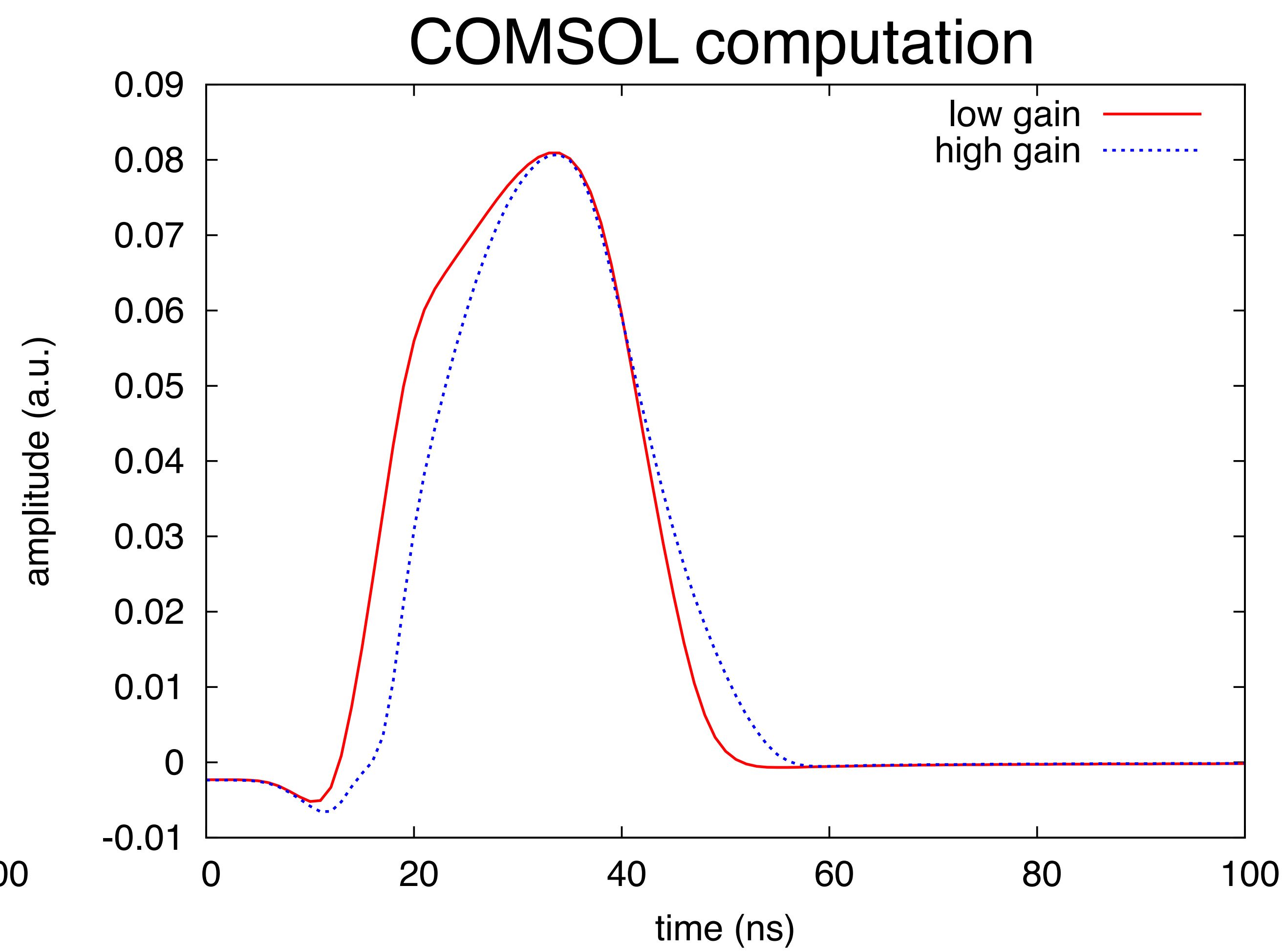


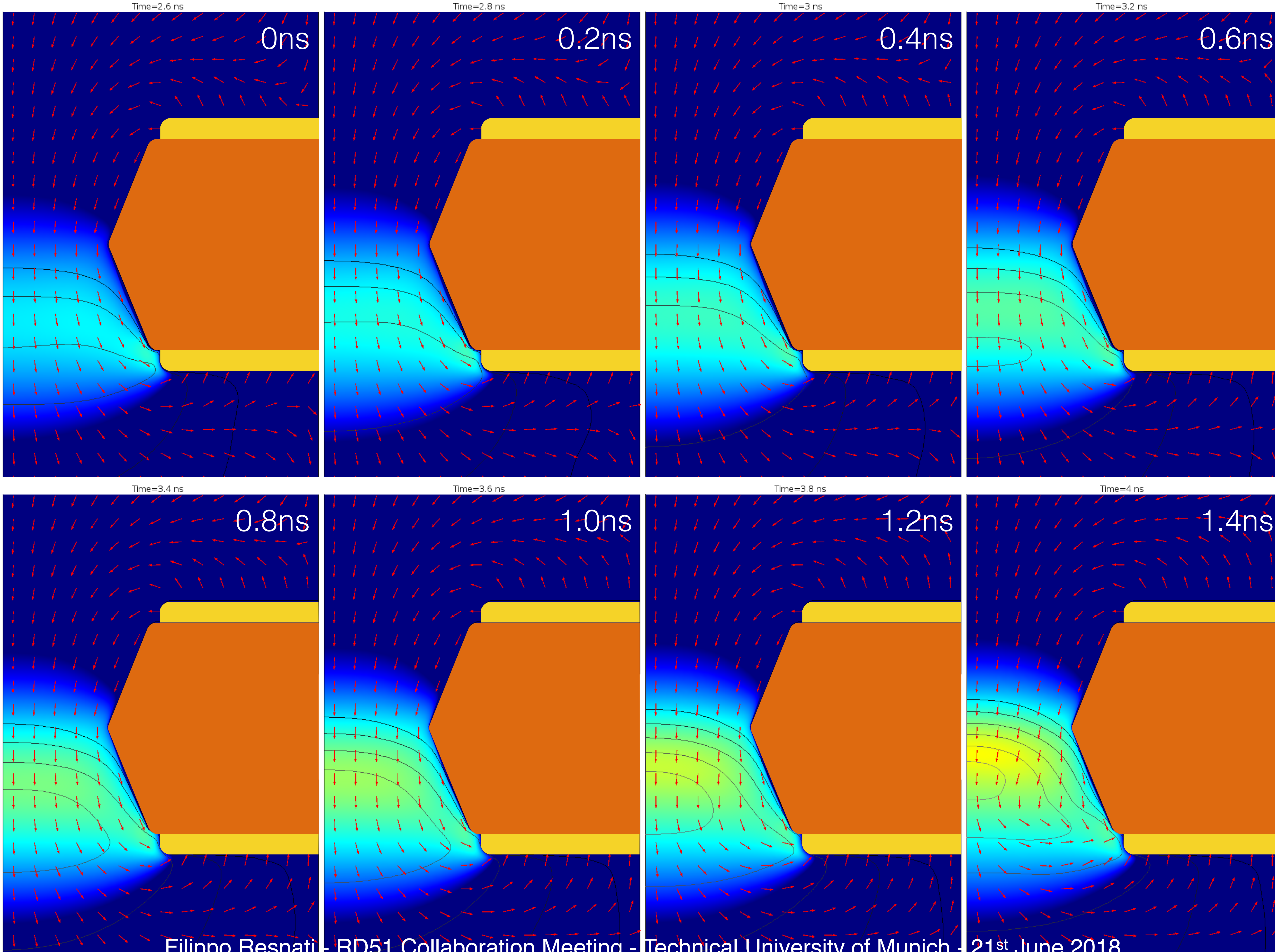
# Results from the model

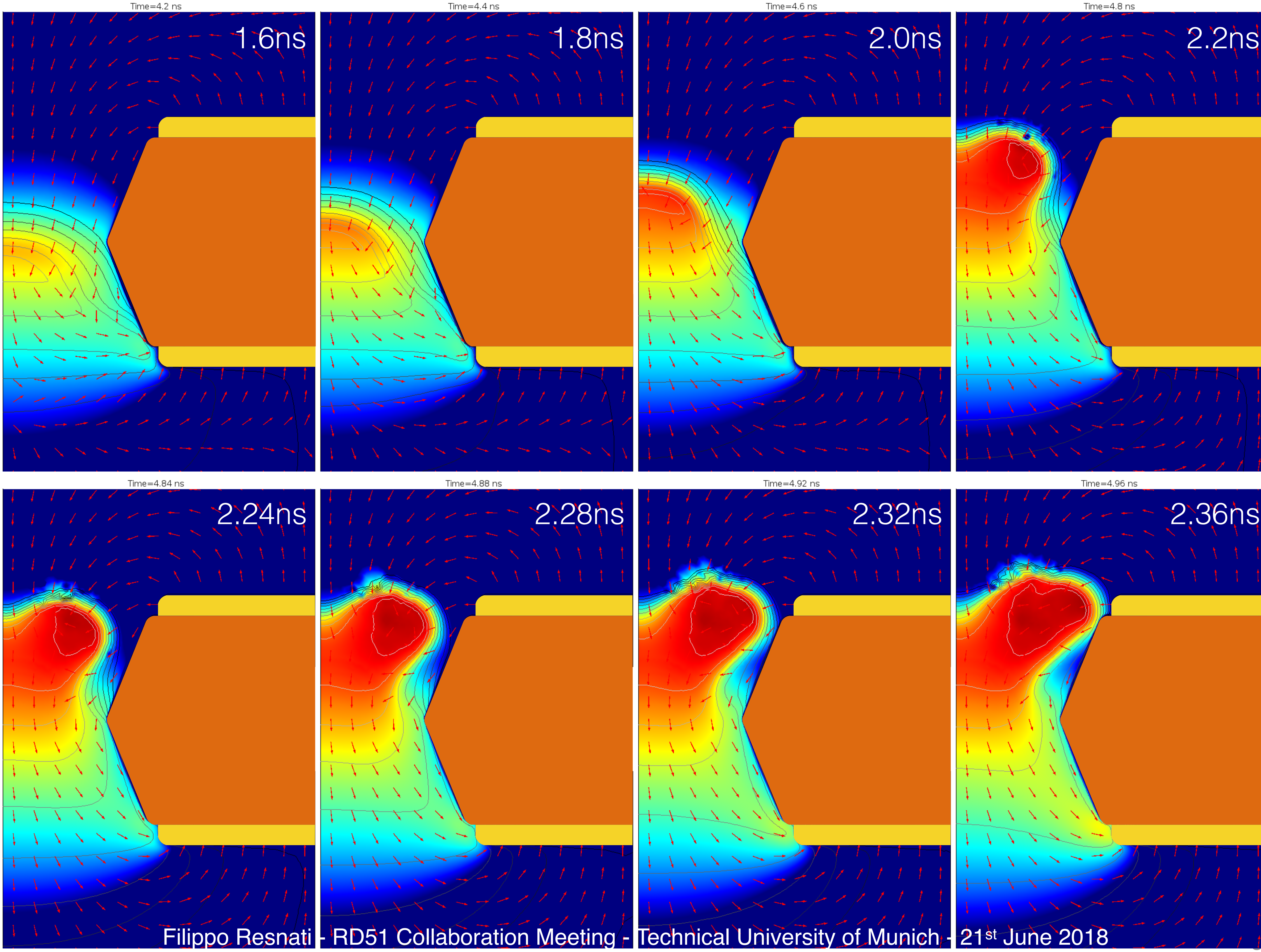


# Preliminary comparison




Time=2.6 ns
0ns
Time=2.8 ns
0.2ns
Time=3 ns
0.4ns
Time=3.2 ns
0.6ns
Time=3.4 ns
0.8ns
Time=3.6 ns
1.0ns
Time=3.8 ns
1.2ns
Time=4 ns
1.4ns



Time=4.2 ns
1.6ns
Time=4.4 ns
1.8ns
Time=4.6 ns
2.0ns
Time=4.8 ns
2.2ns
Time=4.84 ns
2.24ns
Time=4.88 ns
2.28ns
Time=4.92 ns
2.32ns
Time=4.96 ns
2.36ns

# Conclusions

High fluxes:
- Gain increases related to charge transport.

In common to all the devices that have less than 100% charge transport efficiency between one stage an the next.
- Gain decrease related to amplification.

Linked to ‘pile up’ of ions from the previous event at the entrance of the GEM hole with the avalanche of the next event.

High gains:
- In computation, saturation depends on ion speed and longitudinal dimension of the primary cloud.

‘Same effect’ as in high flux, but on event-by-event basis.