Effects of High Charge Densities in Multi-GEM Detectors

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Outline

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- Remarks pt. 1
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  - Effective gain
  - Space-charge effects in the transfer region
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- Observations pt. 3: Energy resolution
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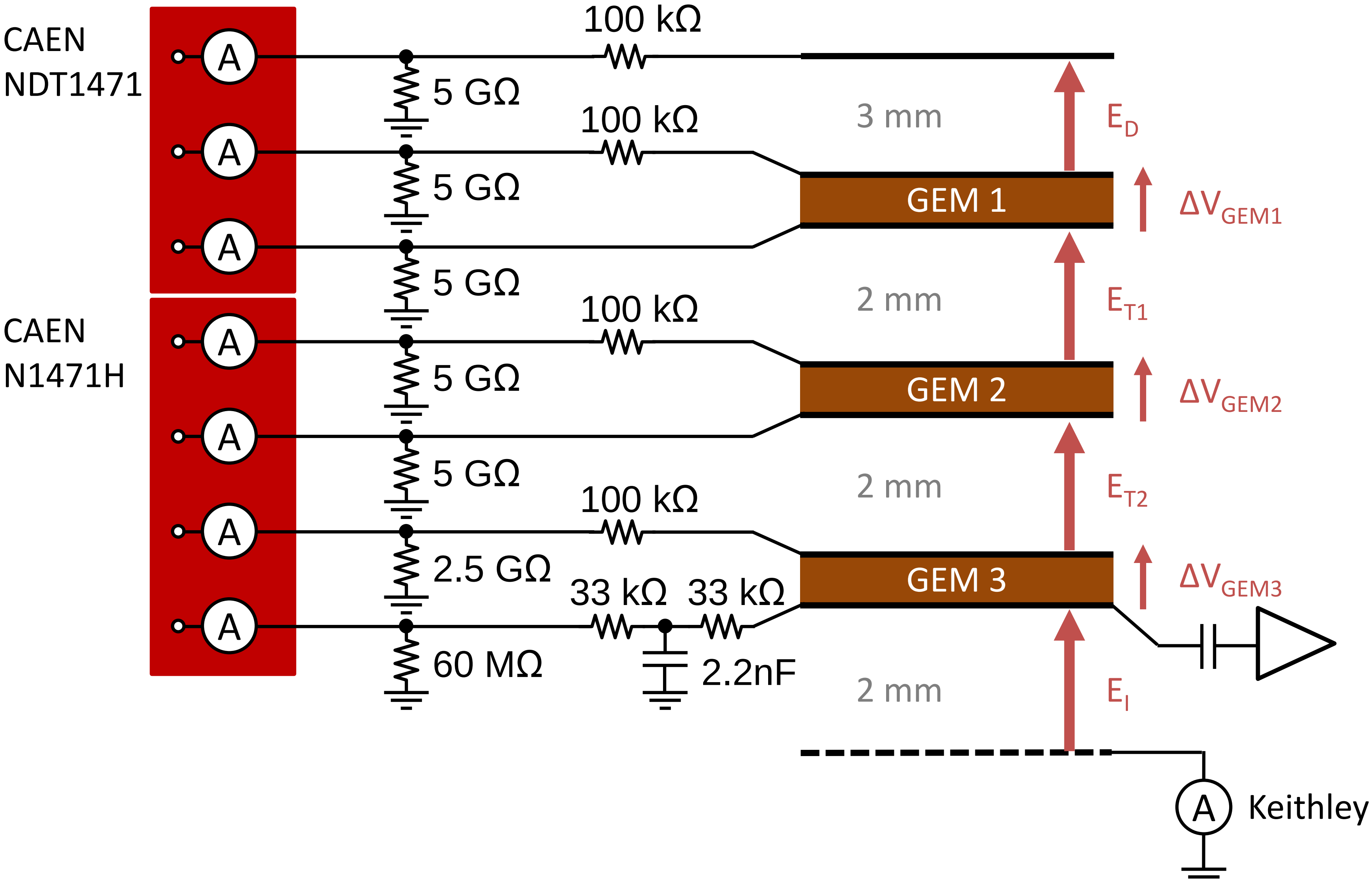
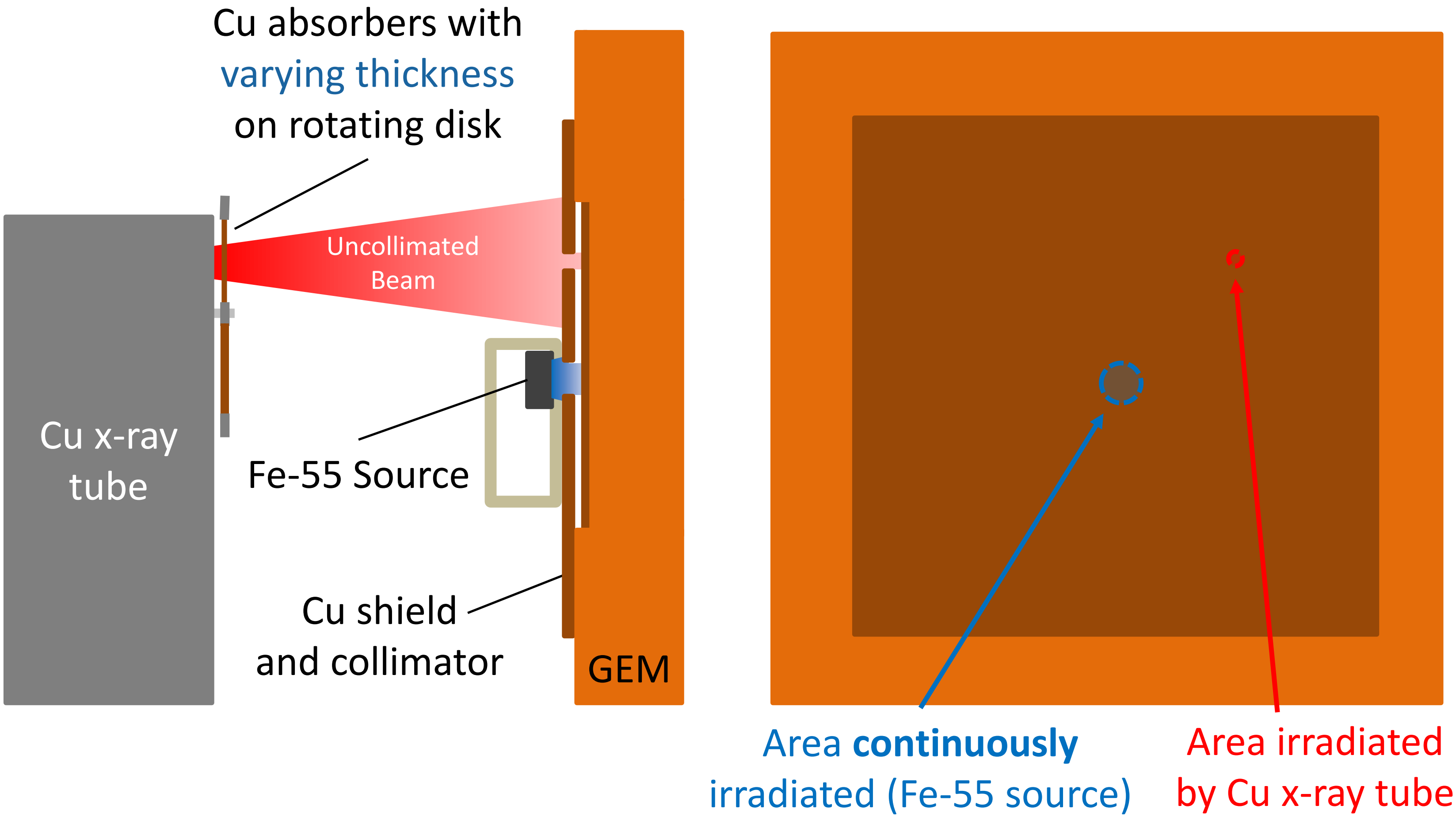
Motivation

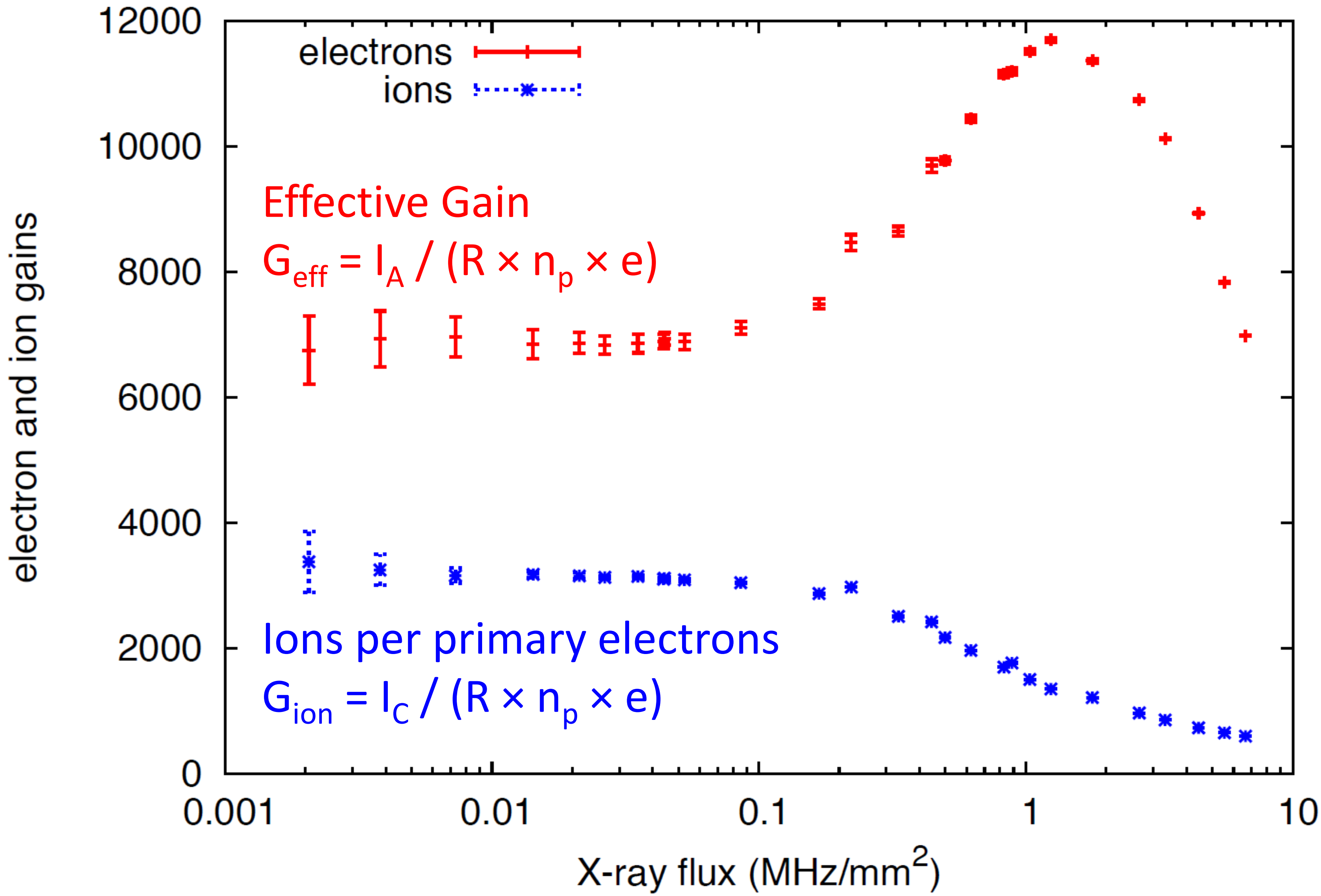
- Behaviour of triple GEM gain (Everaerts, 2006)
  - Increasing the flux first increases and for even higher flux decreases the effective gain
- Decrease of ion back-flow in GEMs (ALICE, 2013)
  - Increasing the flux reduces the ion back-flow
- Increase of mesh transparency (GDD lab, 2014)
  - Increasing the flux increases the electron transparency of a GEM-like mesh

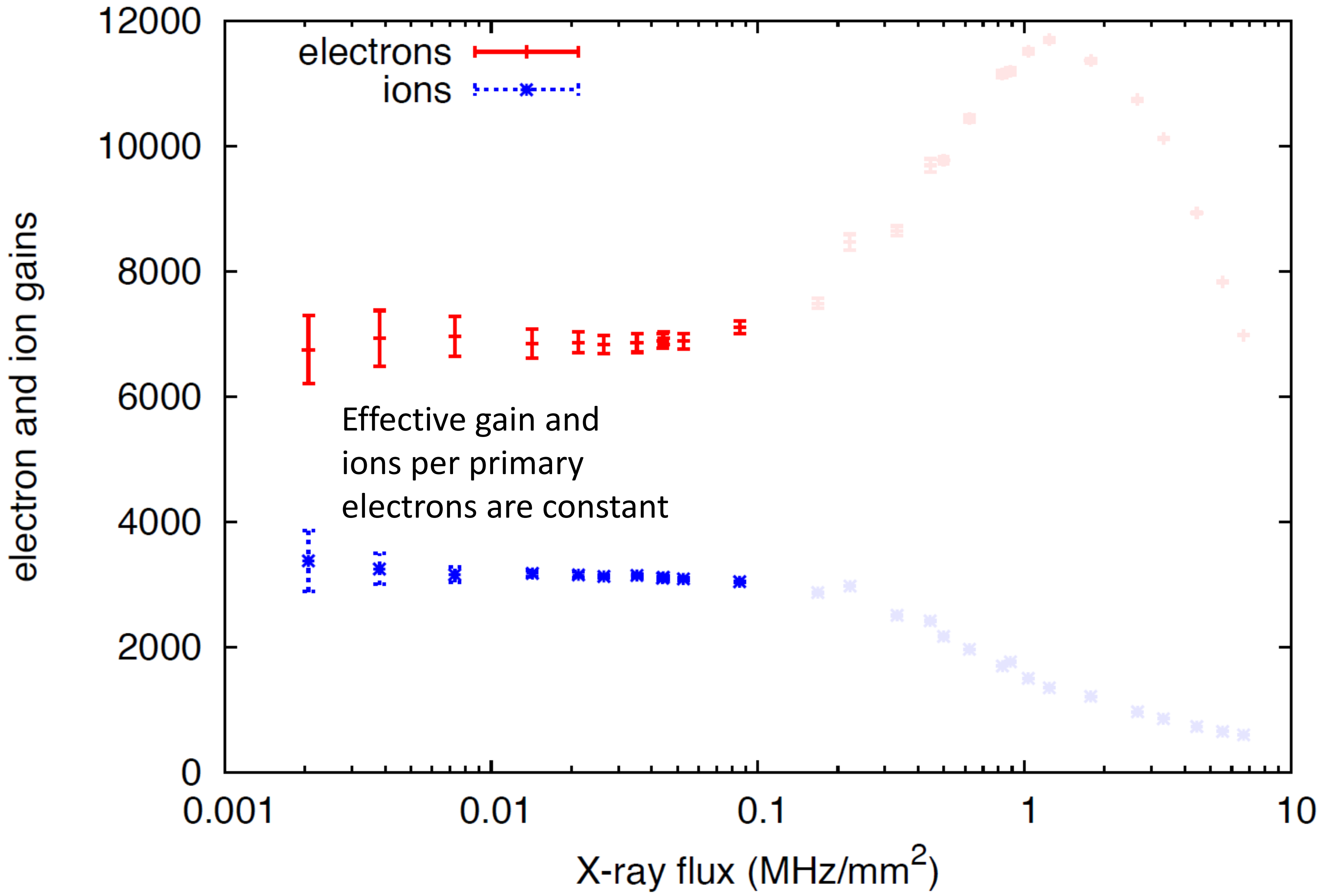

CAEN
NDT1471
CAEN
N1471H
A
100 kΩ
5 GΩ
2.5 GΩ
60 MΩ
33 kΩ
33 kΩ
2.2nF
3 mm
2 mm
2 mm
2 mm
GEM 1
GEM 2
GEM 3
E_D
E_{T1}
E_{T2}
E_I
ΔV_{GEM1}
ΔV_{GEM2}
ΔV_{GEM3}
Keithley

Ar/CO_2 70/30
Cu x-ray, $E_{x\text{-}ray}$ = 8 keV
d_{beam} = 1 mm
$n_p \approx 300$

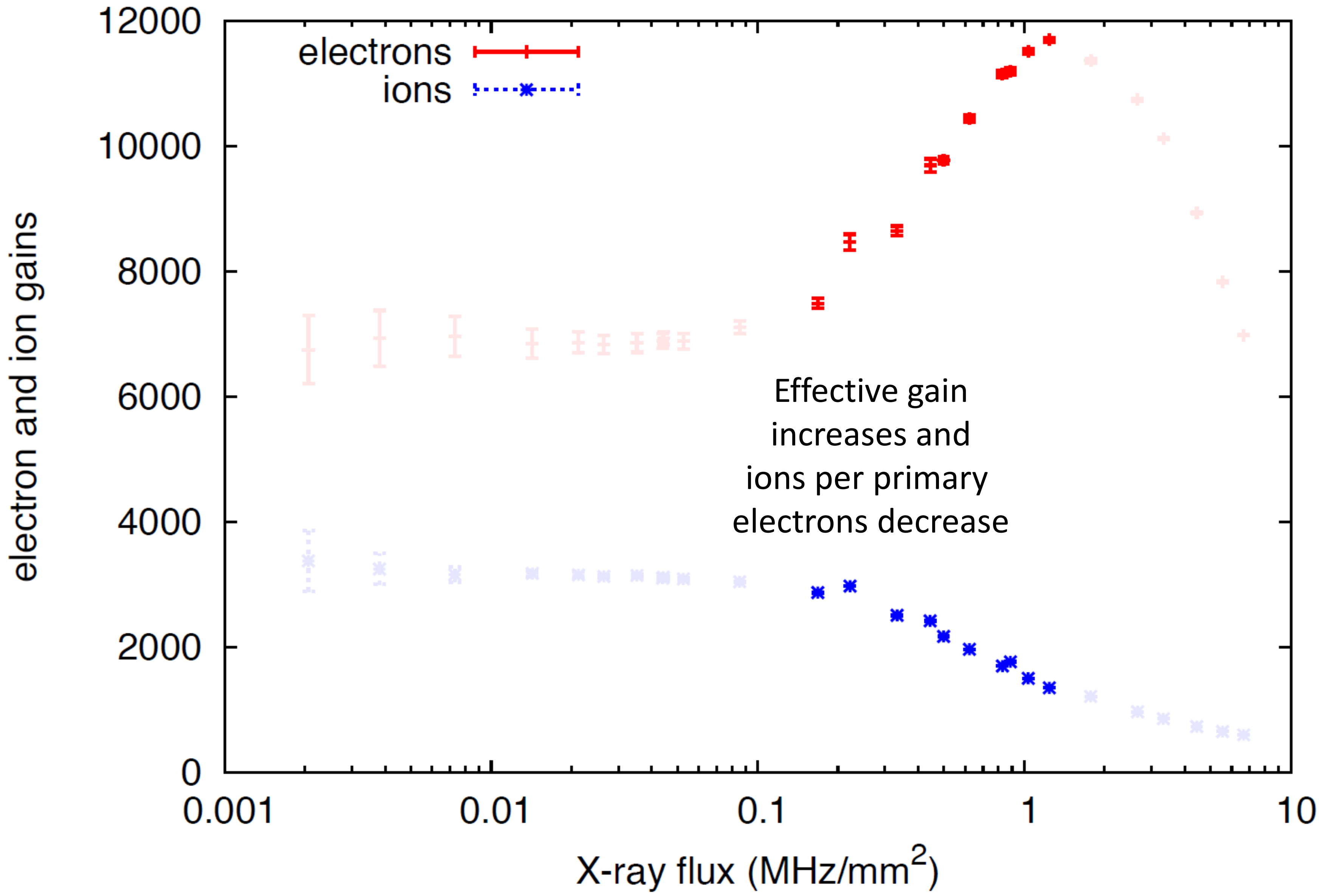


Observations pt. 1

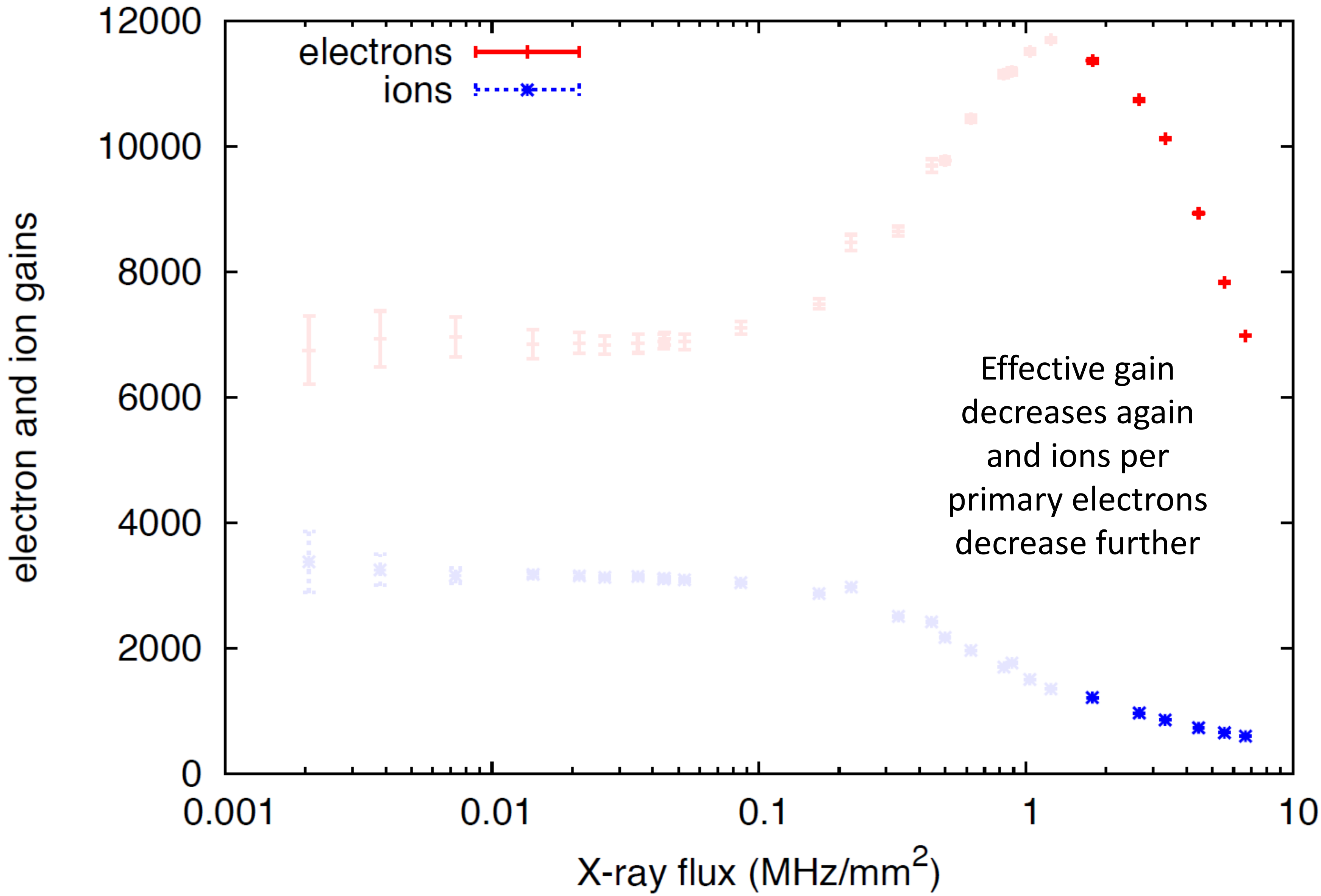



electrons
ions
Effective gain and
ions per primary
electrons are constant
electron and ion gains
X-ray flux (MHz/mm^2)
0
2000
4000
6000
8000
10000
12000
0.001
0.01
0.1
1
10

Observations pt. 1

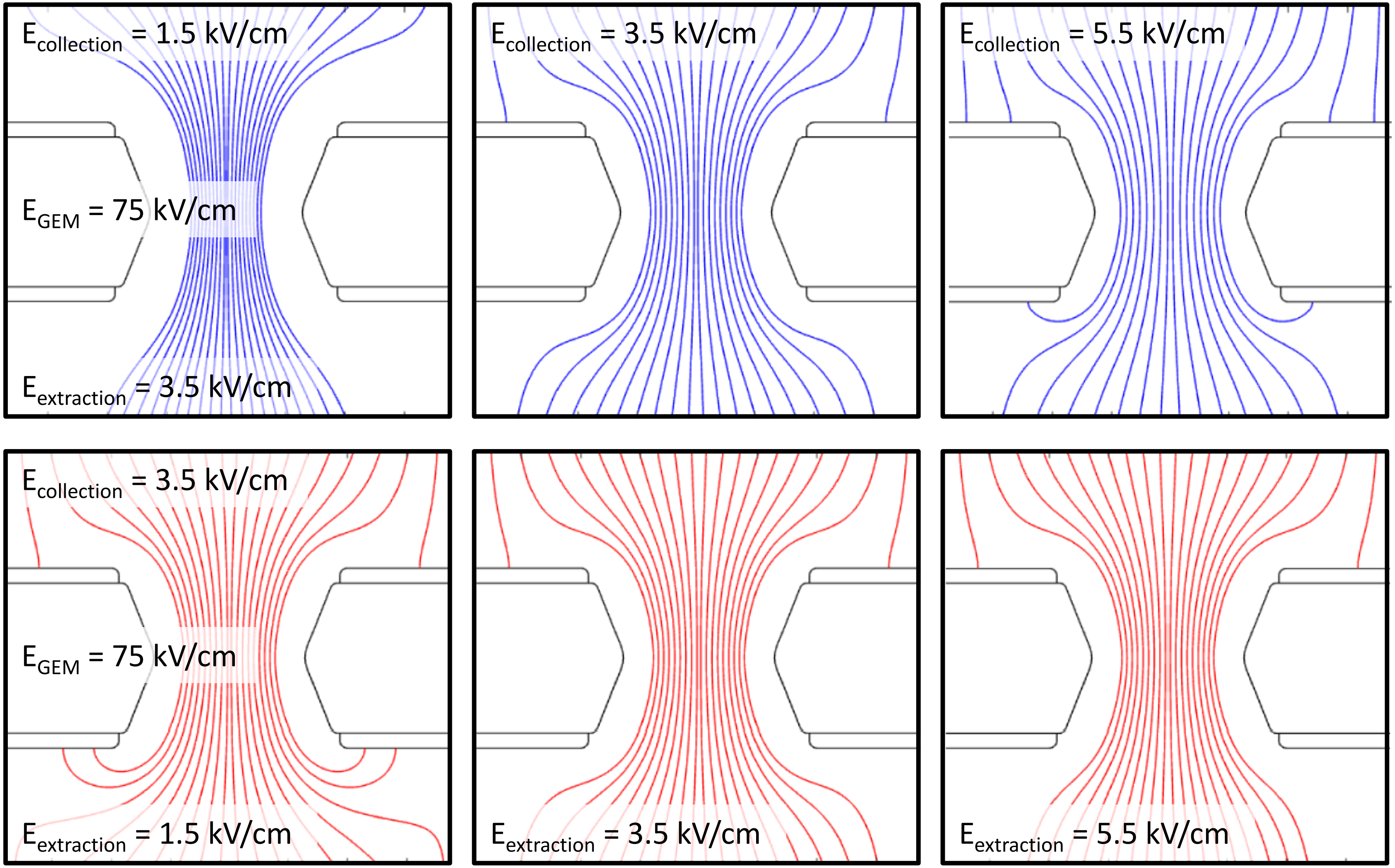


Effective gain increases and ions per primary electrons decrease

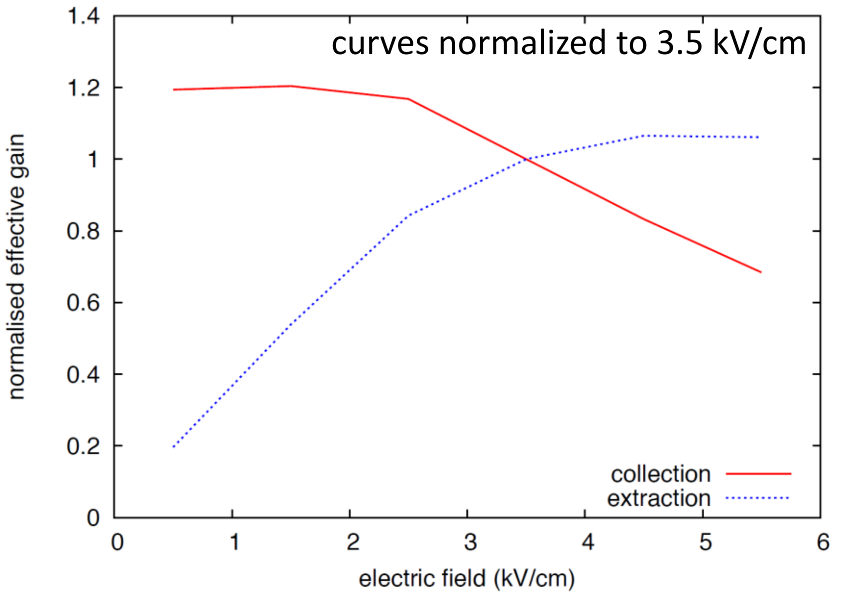


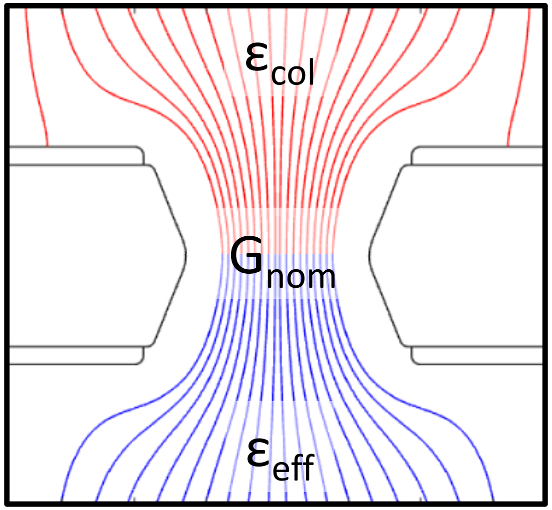
electrons
ions
12000
10000
8000
6000
4000
2000
0
0.001
0.01
0.1
1
10
electron and ion gains
X-ray flux (MHz/mm^2)
Effective gain decreases again and ions per primary electrons decrease further

Remarks pt. 1: Collection and extraction efficiency



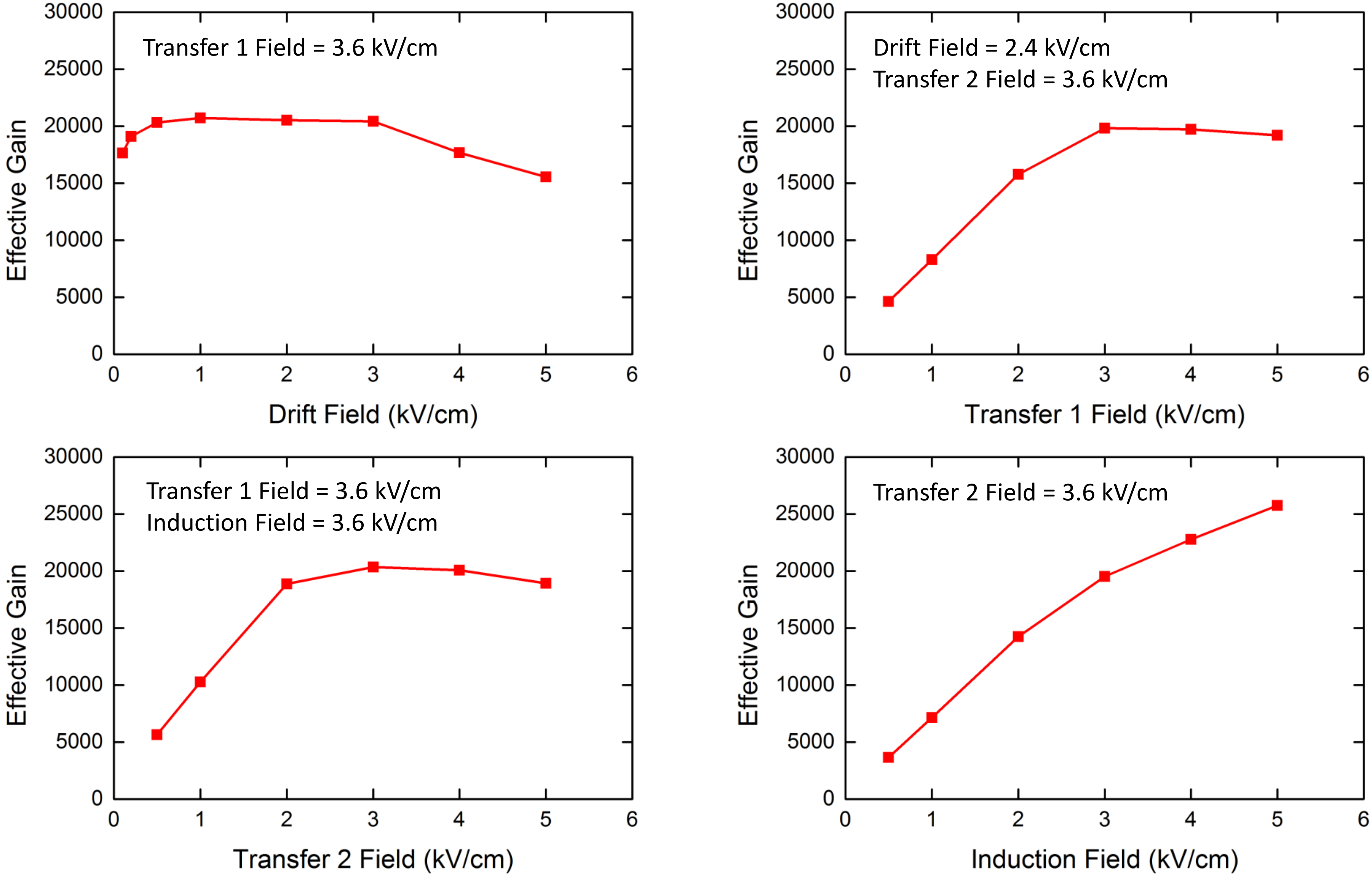
- Effective gain is nominal gain of the GEM, corrected for collection and extraction efficiency

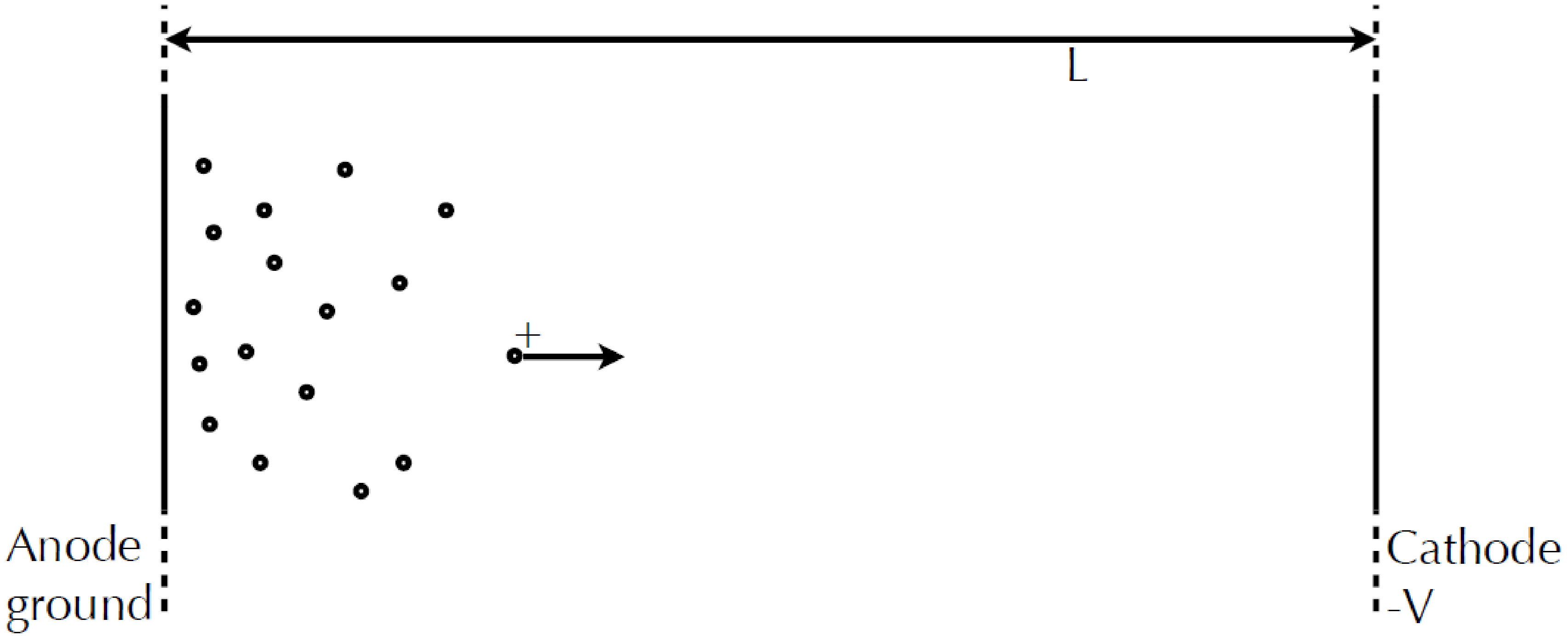




$$G_{eff} = \varepsilon_{col} \times \varepsilon_{extr} \times G_{nom}$$

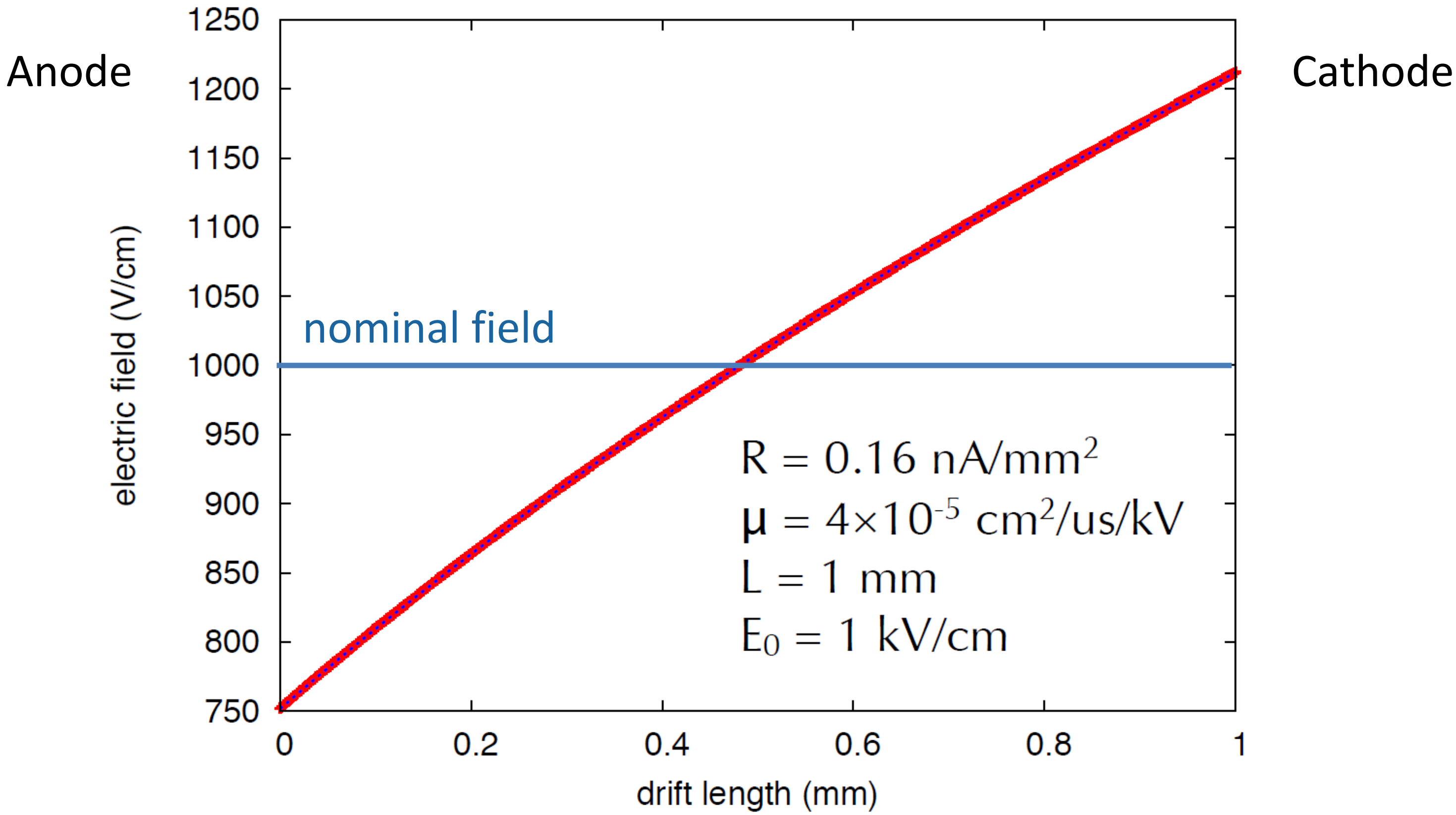
Remarks pt. 1: Measurements on triple GEM detectors





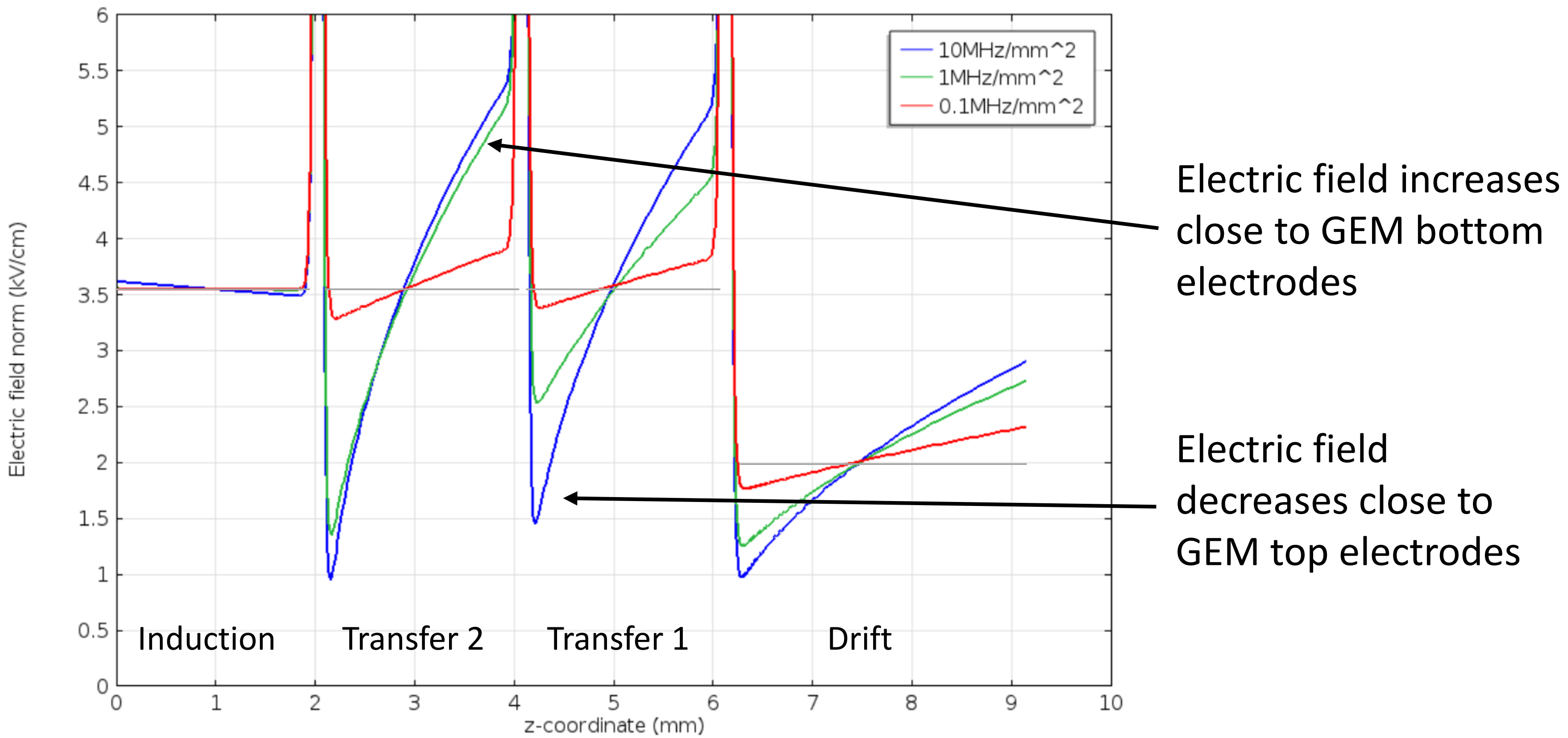
- Infinite parallel plates at distance L with a potential difference of ΔV
- At t = 0 uniform electric field of $E_0 = \Delta V/L$
- Positive ions generated at the anode at a constant and uniform flux R
- Ions moving towards the cathode at speed $v = \mu E$
- Actual electric field E modified by the charge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

- Stationary solution for problem solveable analytically and numerically



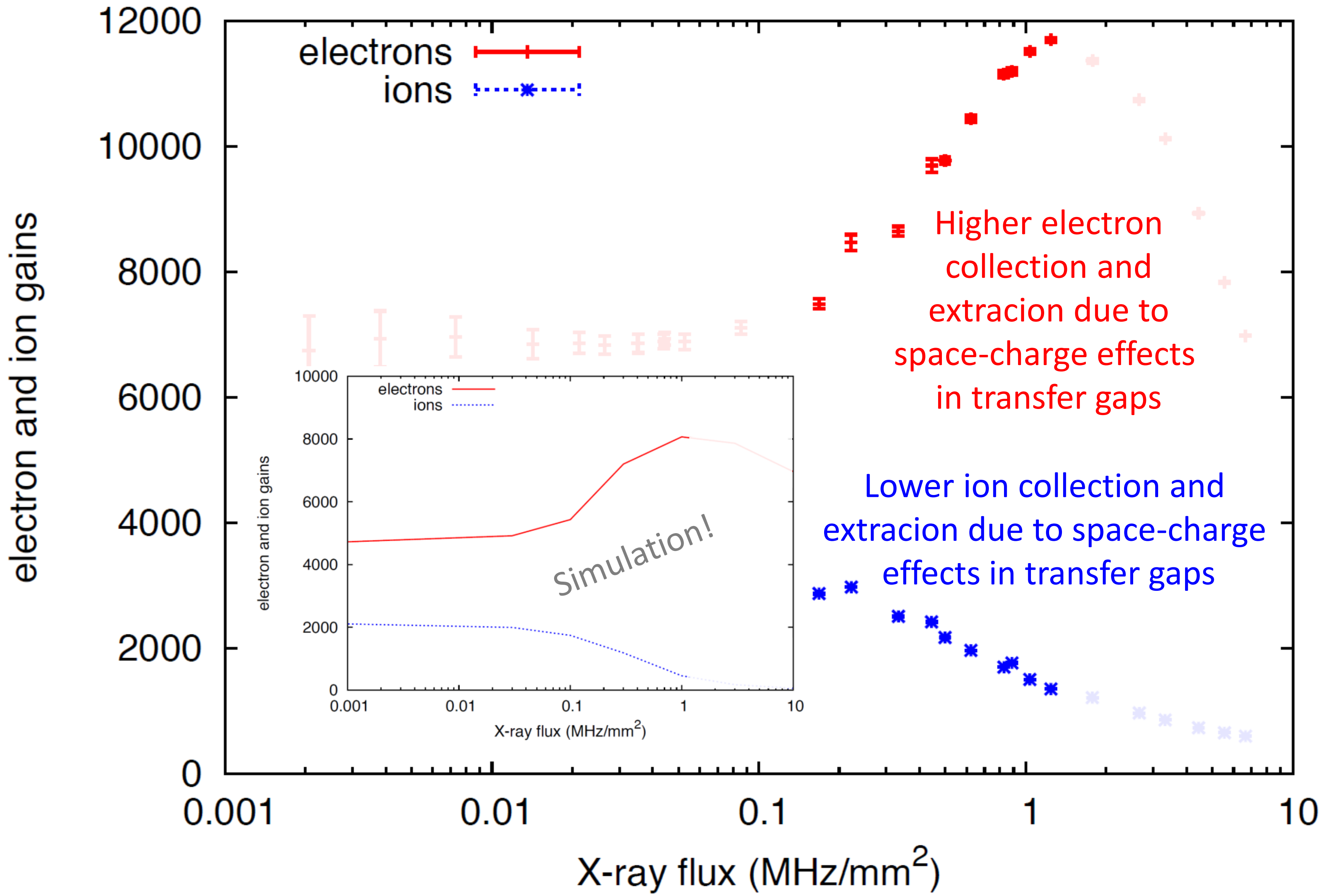
- Electric field decreases at anode and increases at cathode
- Average electric field over whole length equals nominal field
- Larger number of ions lead to a stronger effect
- Transfer fields and drift field behave similiarly

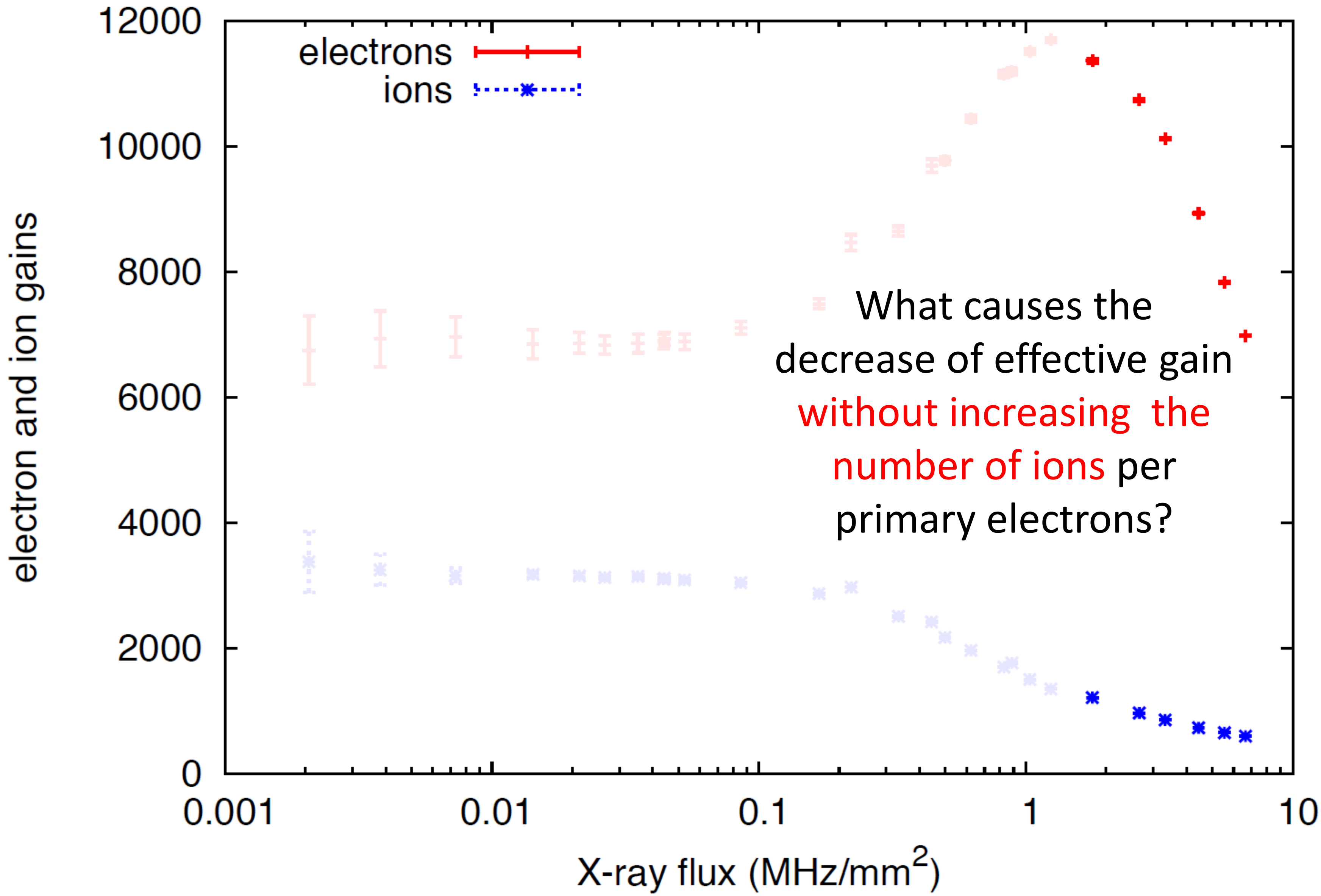
Remarks pt. 1: Space-charge effects in the transfer region



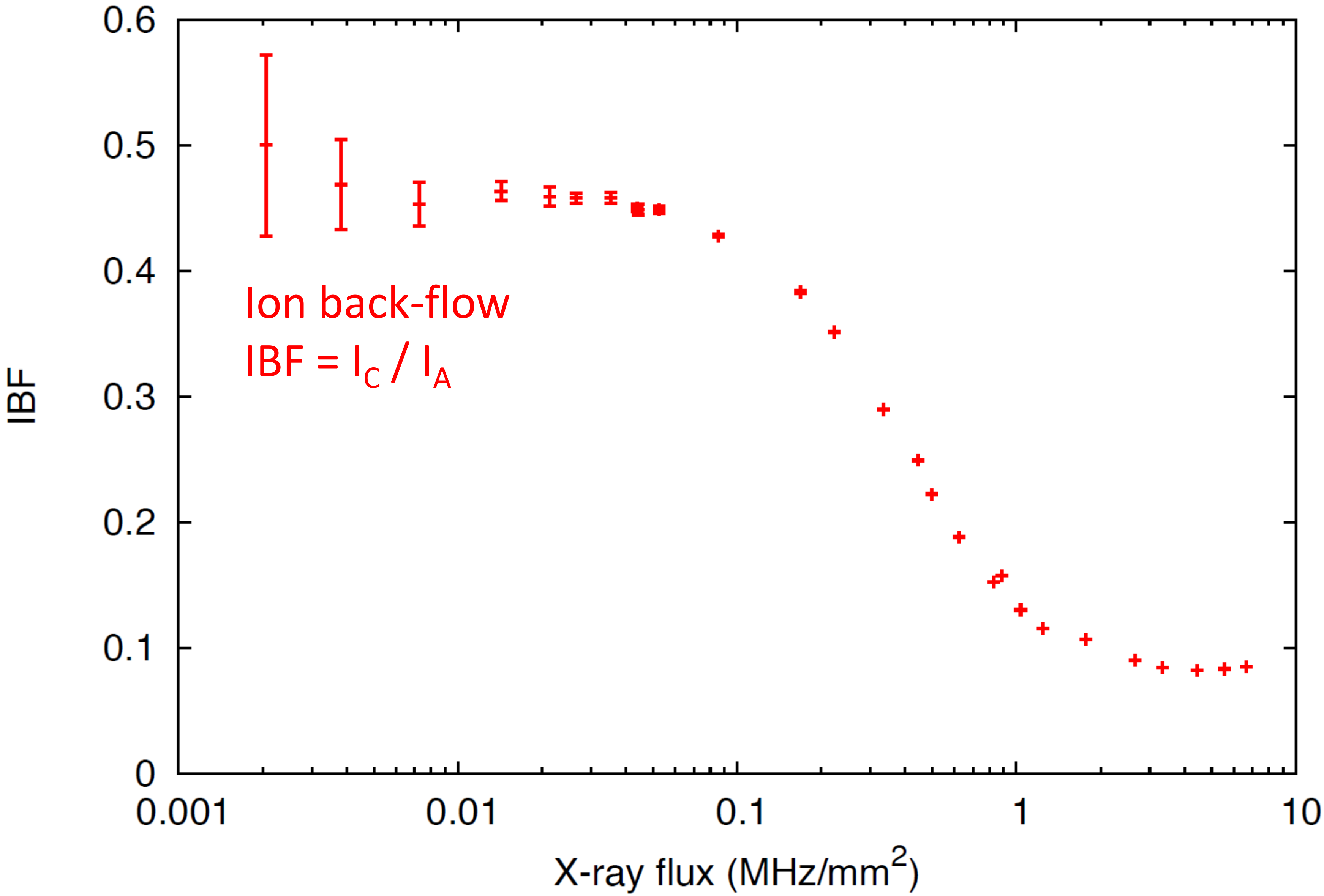
- Electron (ion) collection efficiency increasing (decreasing) with flux
- Electron (ion) extraction efficiency increasing (decreasing) with flux
- Effect more pronounced with every stage of the triple GEM

Conclusions pt. 1

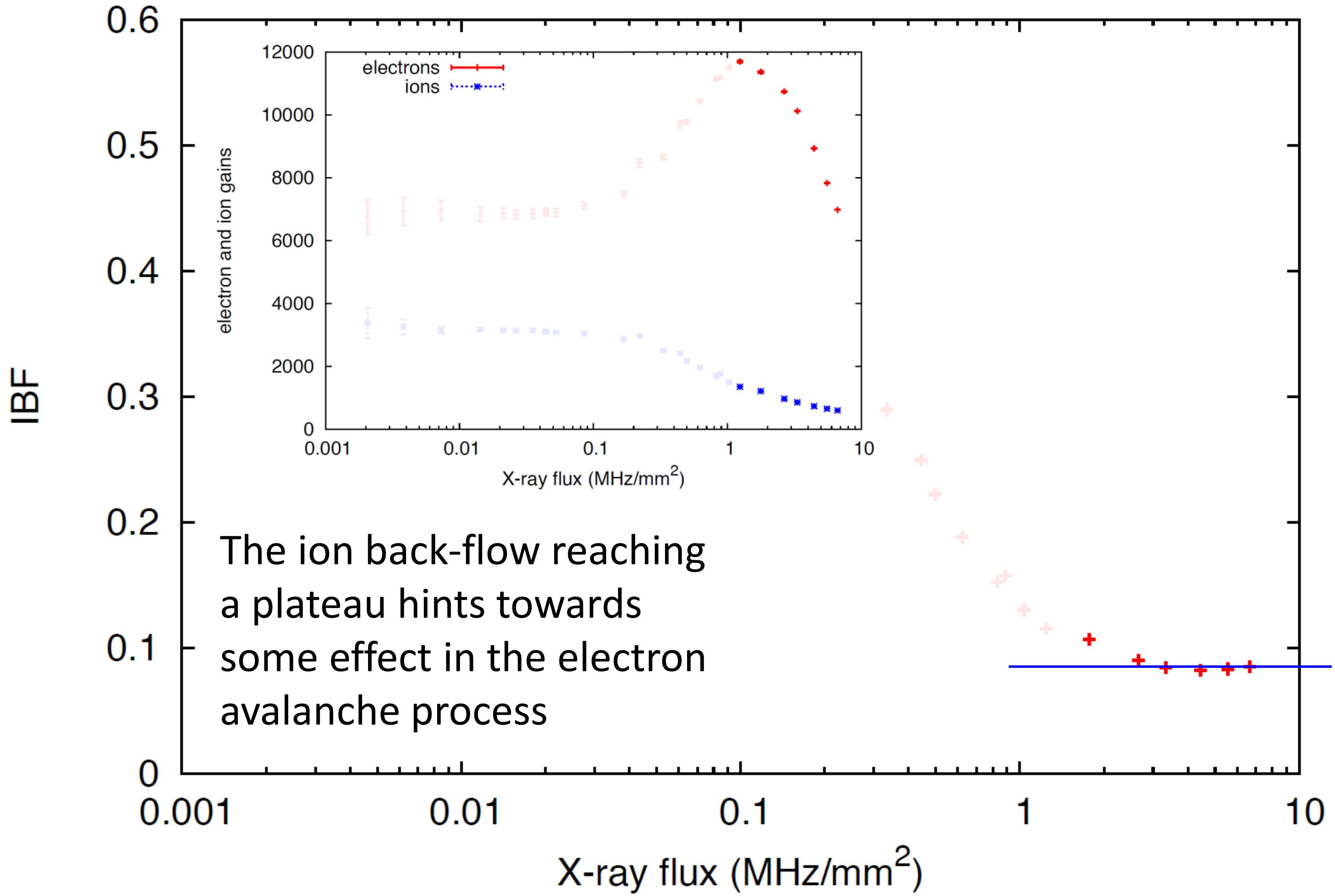




What causes the decrease of effective gain without increasing the number of ions per primary electrons?

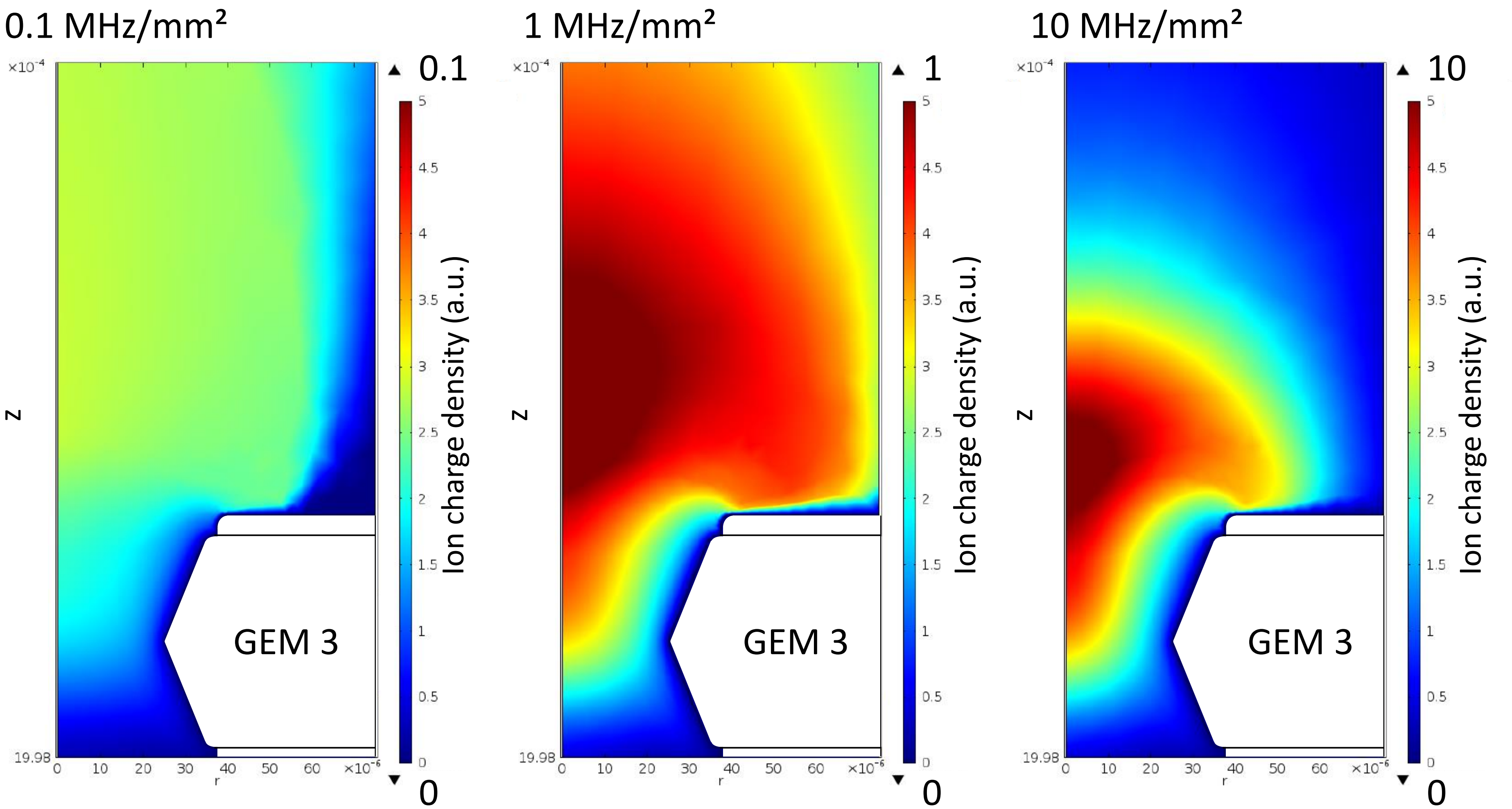

0.6
0.5
0.4
0.3
0.2
0.1
0
IBF
0.001
0.01
0.1
1
10
X-ray flux (MHz/mm^2)
Ion back-flow
IBF = I_C / I_A

Observations pt. 2



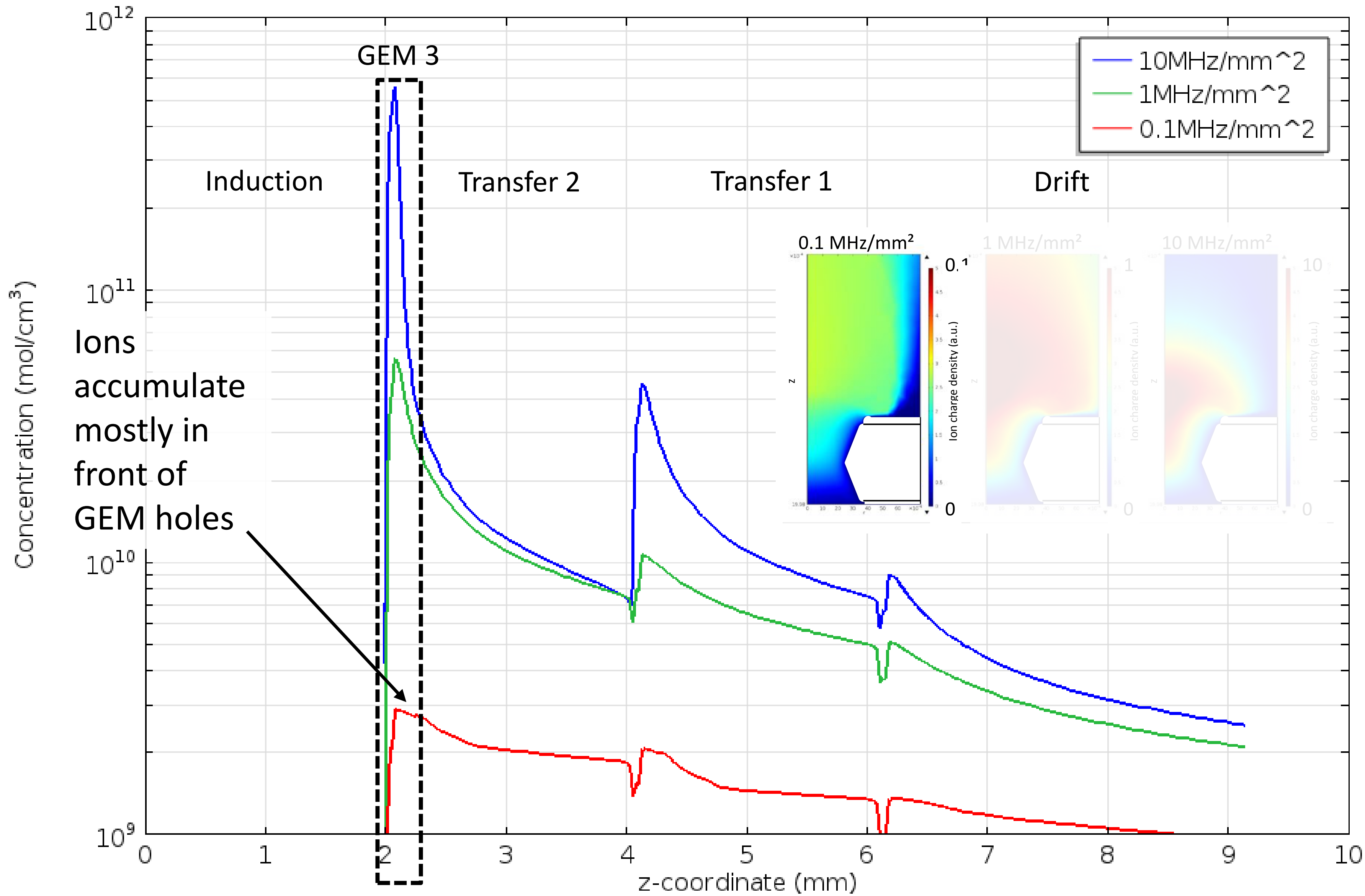
The ion back-flow reaching a plateau hints towards some effect in the electron avalanche process

Remarks pt. 2: Space-charge effects in the amplification region



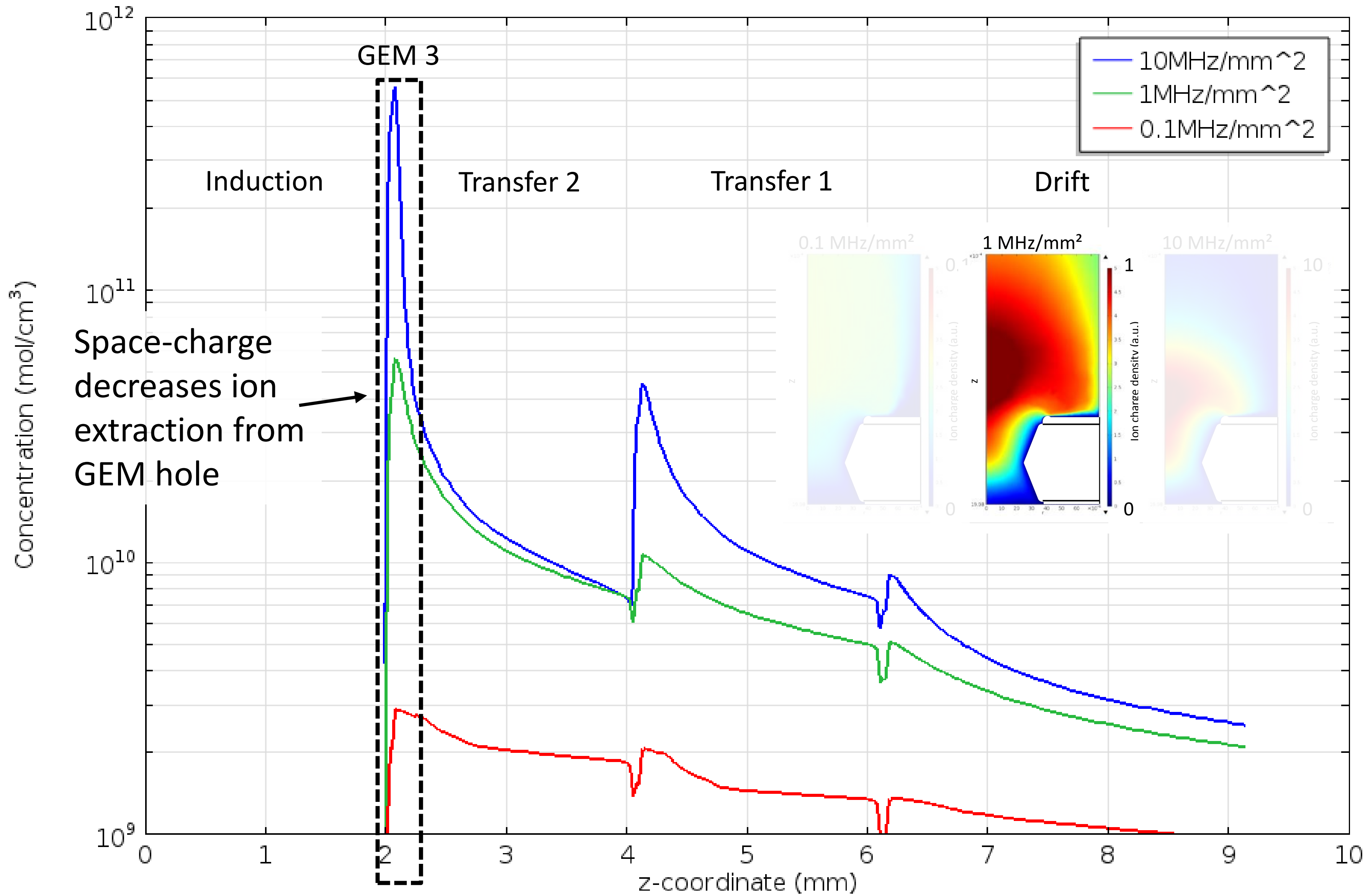
COMSOL simulation: single GEM hole, axial symmetric, stationary solution

Remarks pt. 2: Space-charge effects in the amplification region

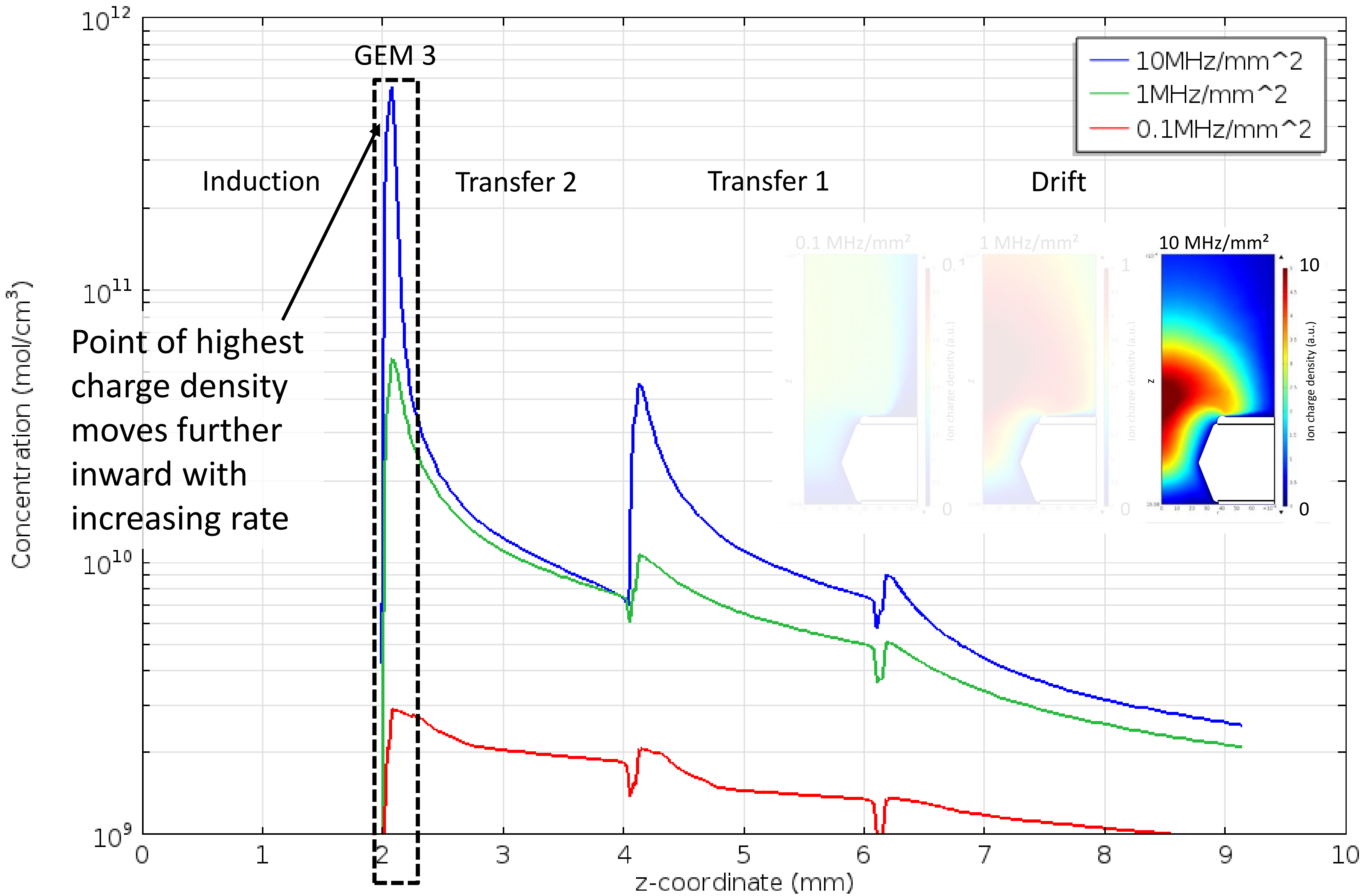


Ions accumulate mostly in front of GEM holes

Remarks pt. 2: Space-charge effects in the amplification region

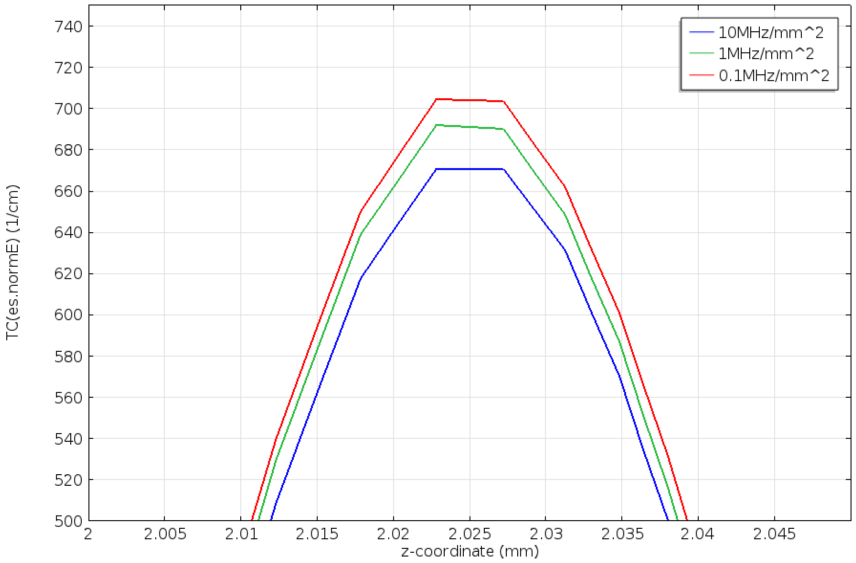


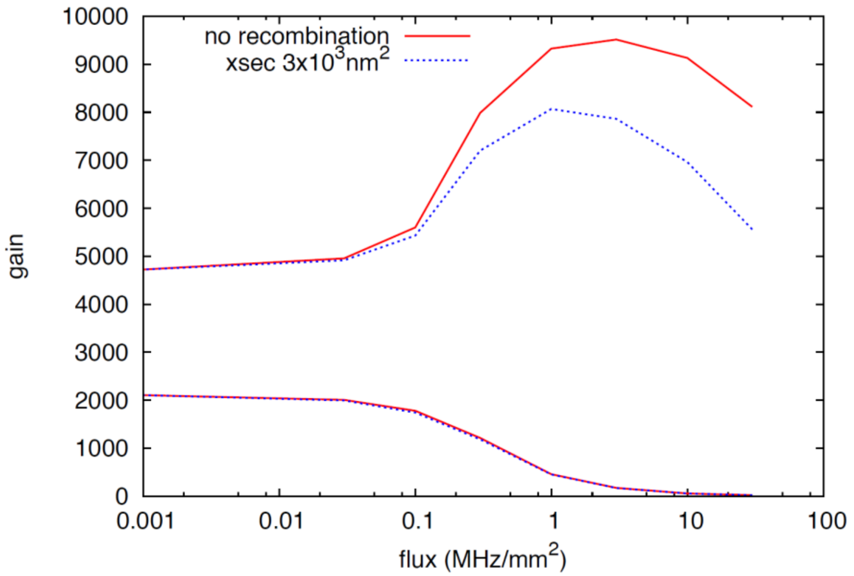
Remarks pt. 2: Space-charge effects in the amplification region

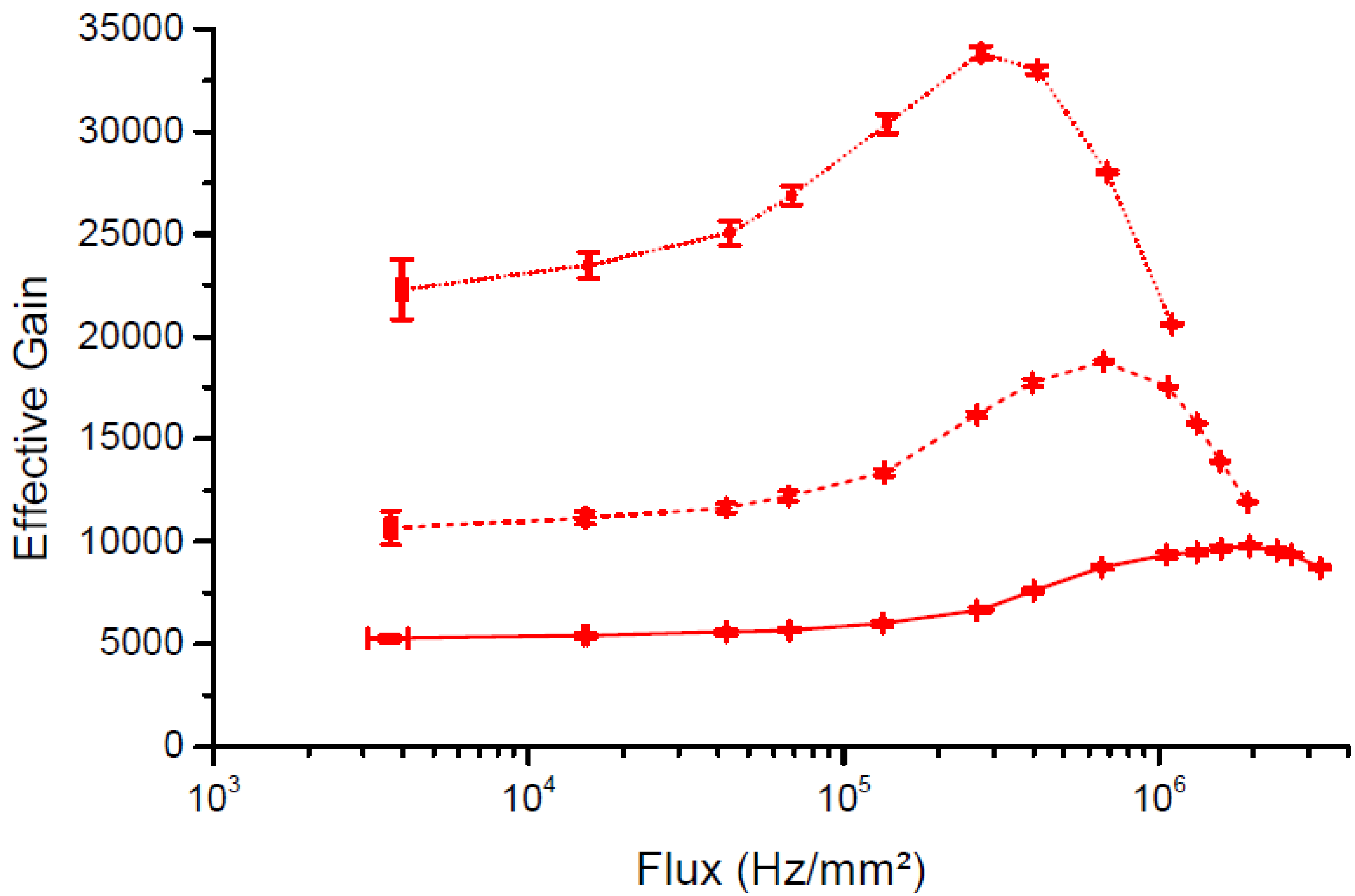


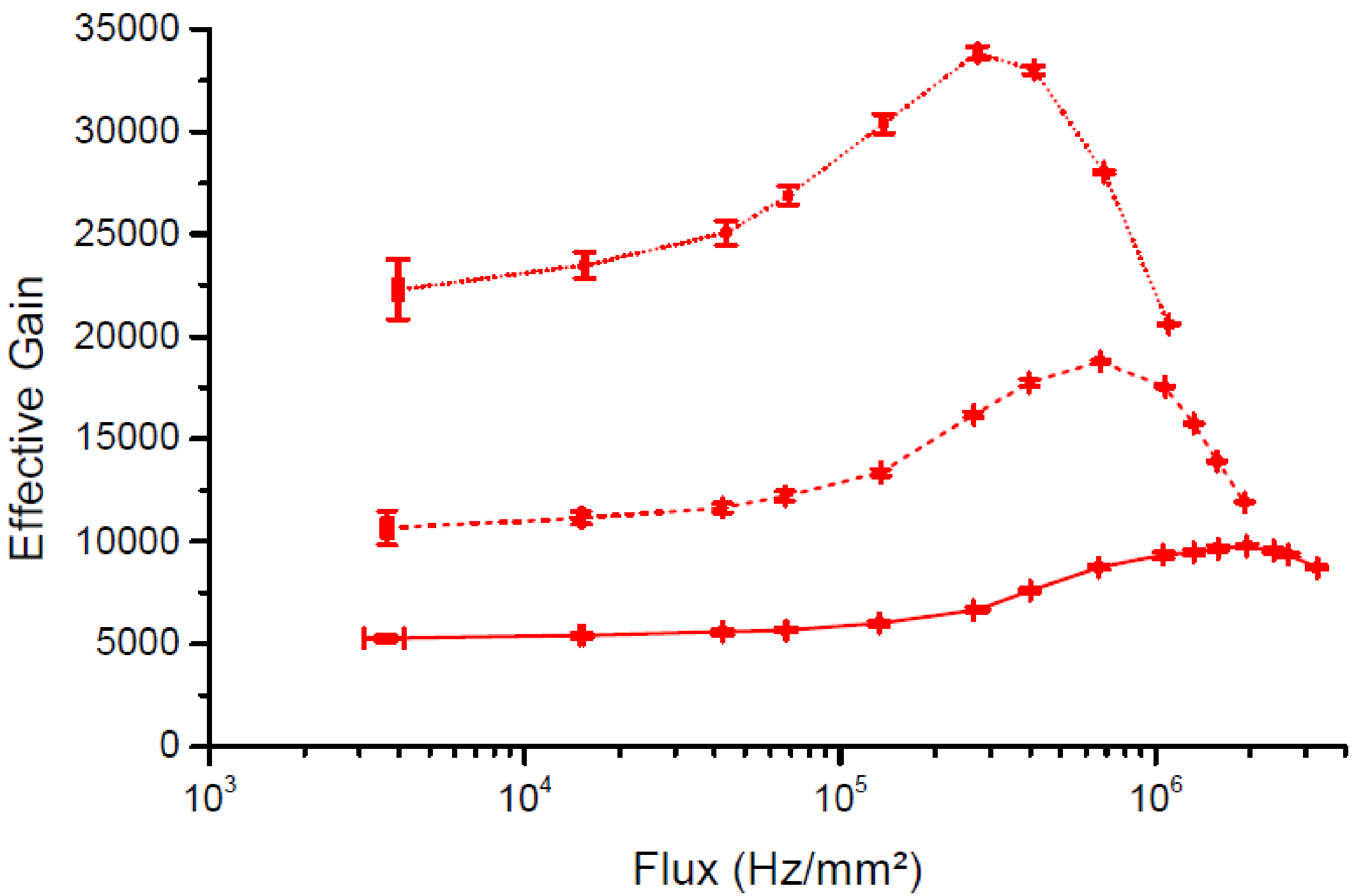
Conclusions pt. 2

- Ions accumulate in front of GEM holes
  - Extraction of ions drops to a few percent!
- Ions start accumulating in GEM holes!
  - Decrease of Townsend coefficient
  - Decrease of effective gain
- Increased ion-electron recombination



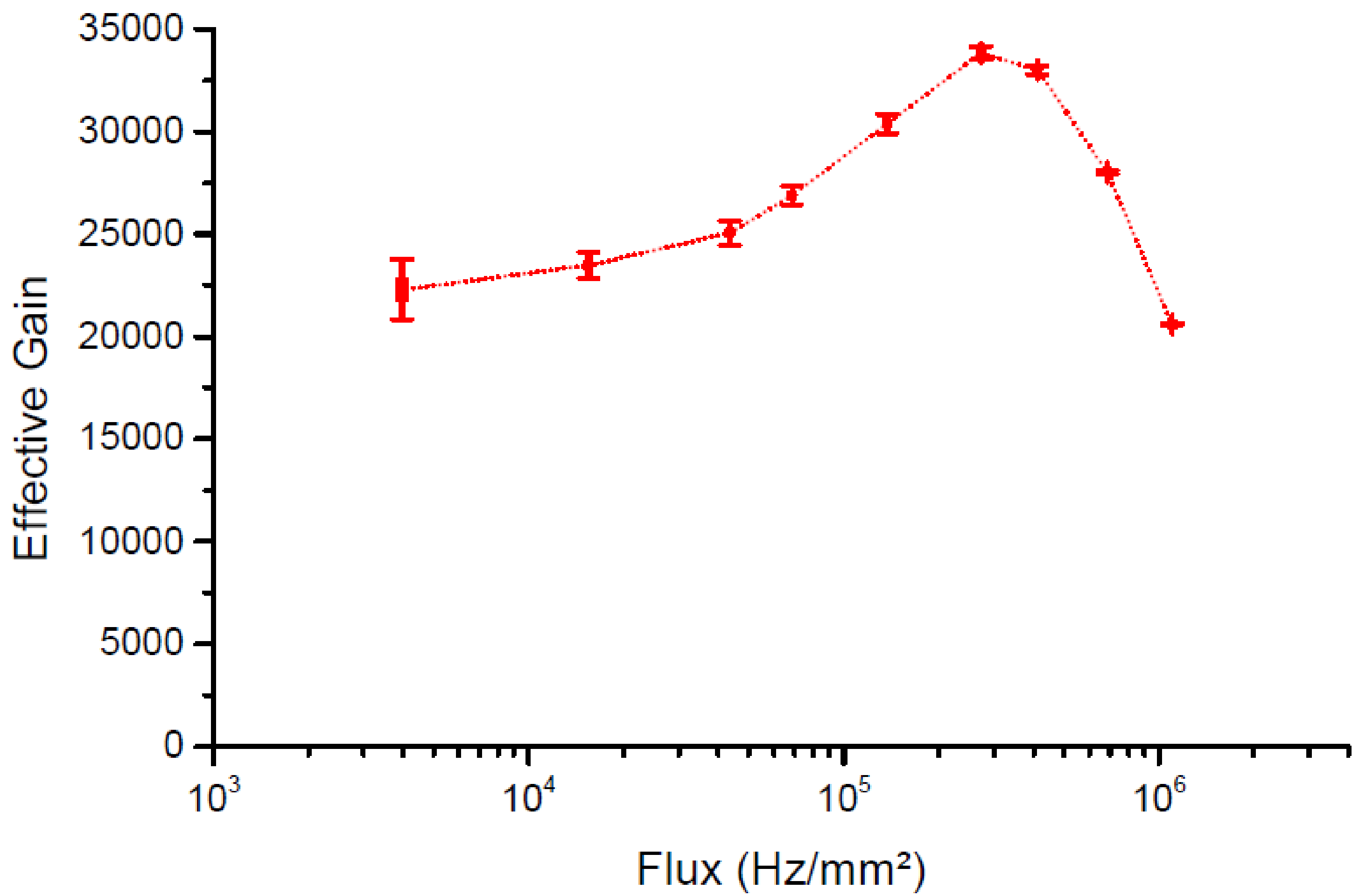



35000
30000
25000
20000
15000
10000
5000
0
Effective Gain
10^3
10^4
10^5
10^6
Flux (Hz/mm²)



What about the energy resolution?

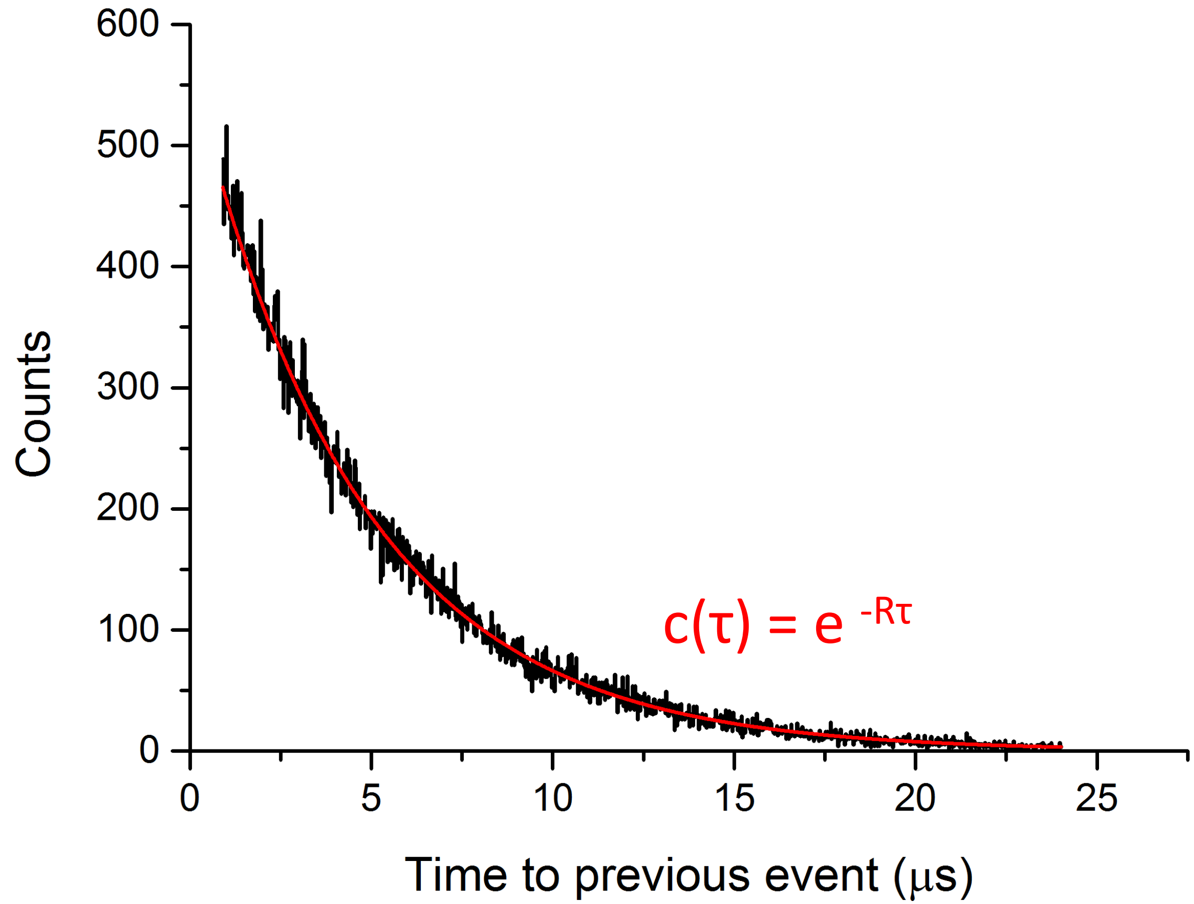
Effective gain



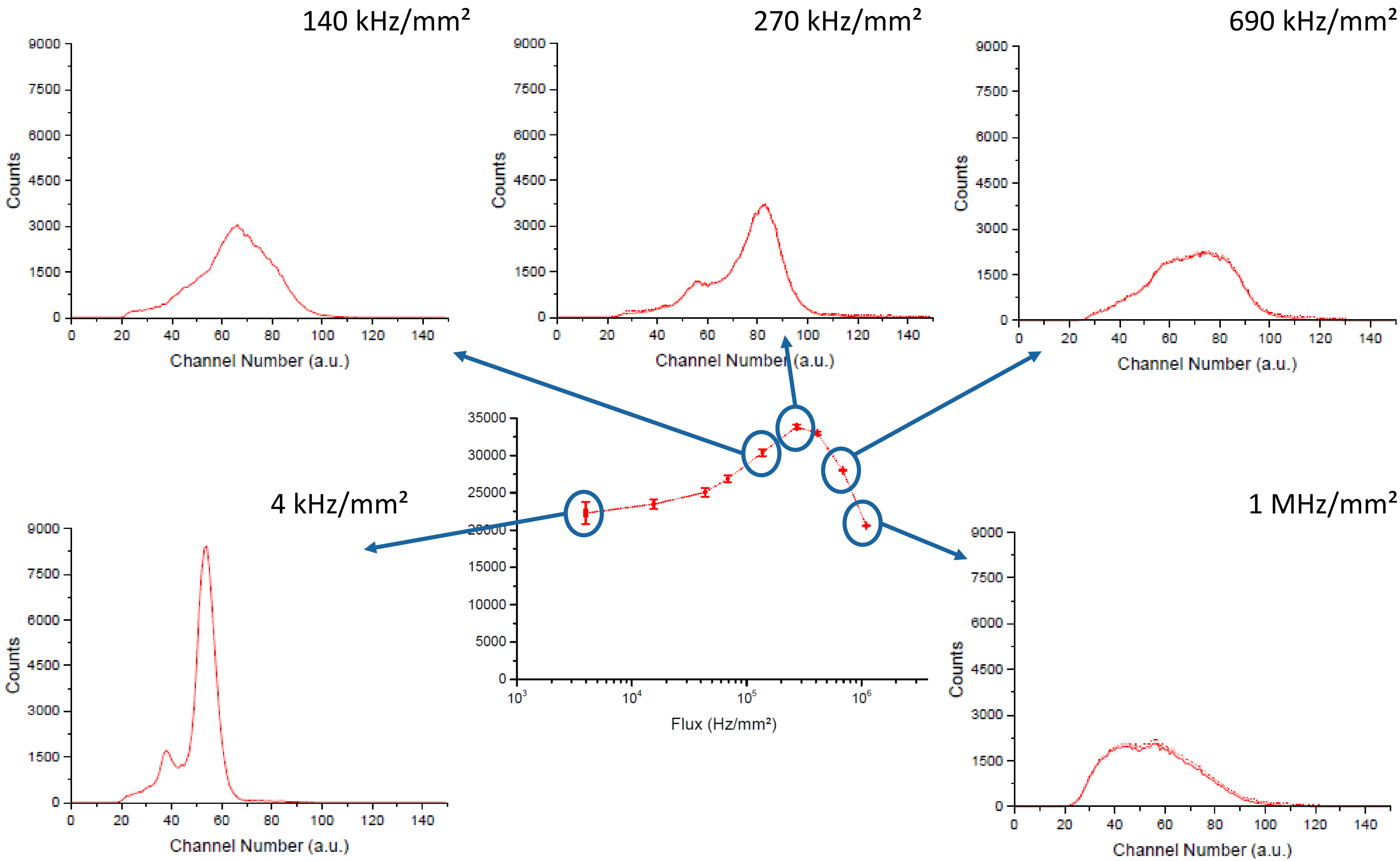
What about the energy resolution?

- Fast amplifier
  - No shaping
- Acquisition of pulses with fast oscilloscope
- Offline data analysis
  - Spectra: integral of each pulse
  - Rate: time to previous triggers

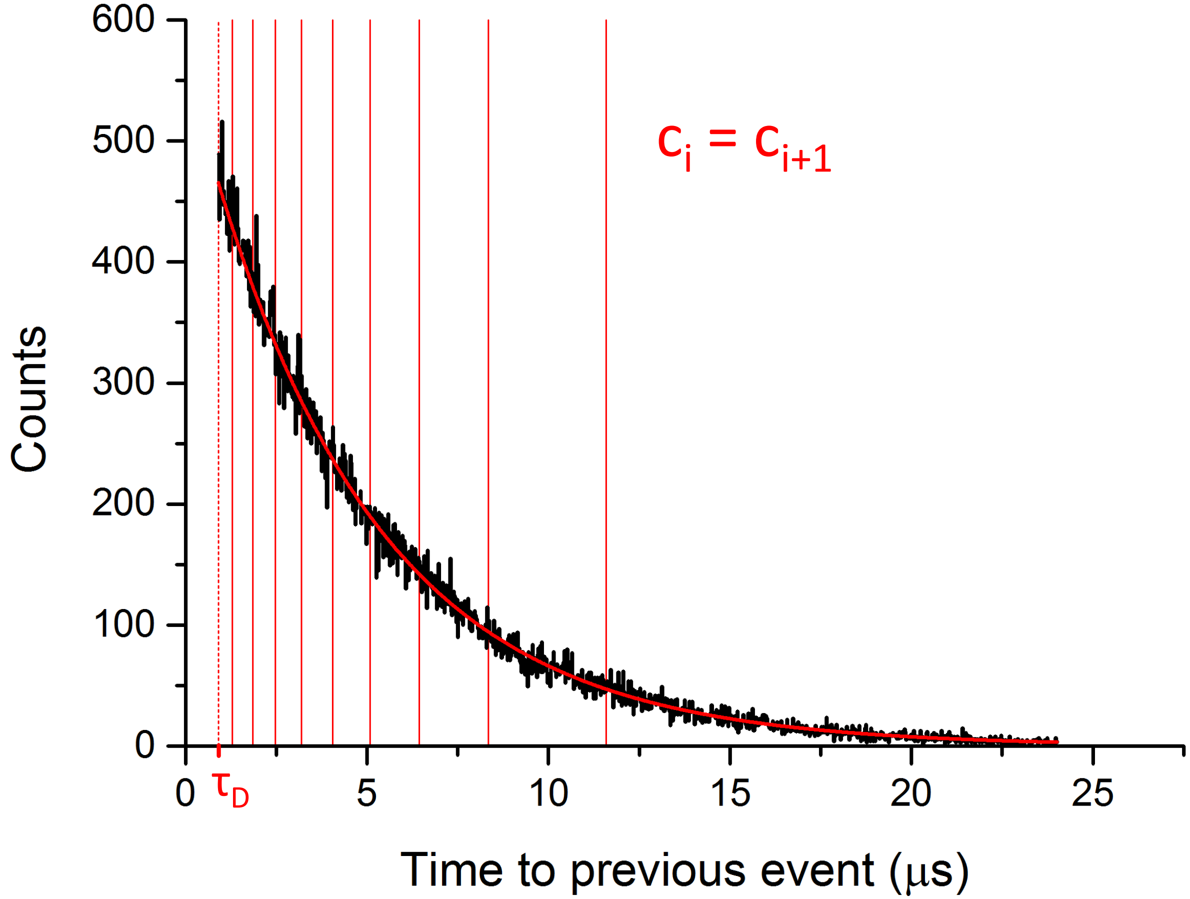
- Histogram of time to previous trigger
- Exponential fit



Energy resolution vs. particle flux



- Histogram of time to previous trigger
- Exponential fit
- Split into time intervalls with equal number of counts



- Histogram of time to previous trigger
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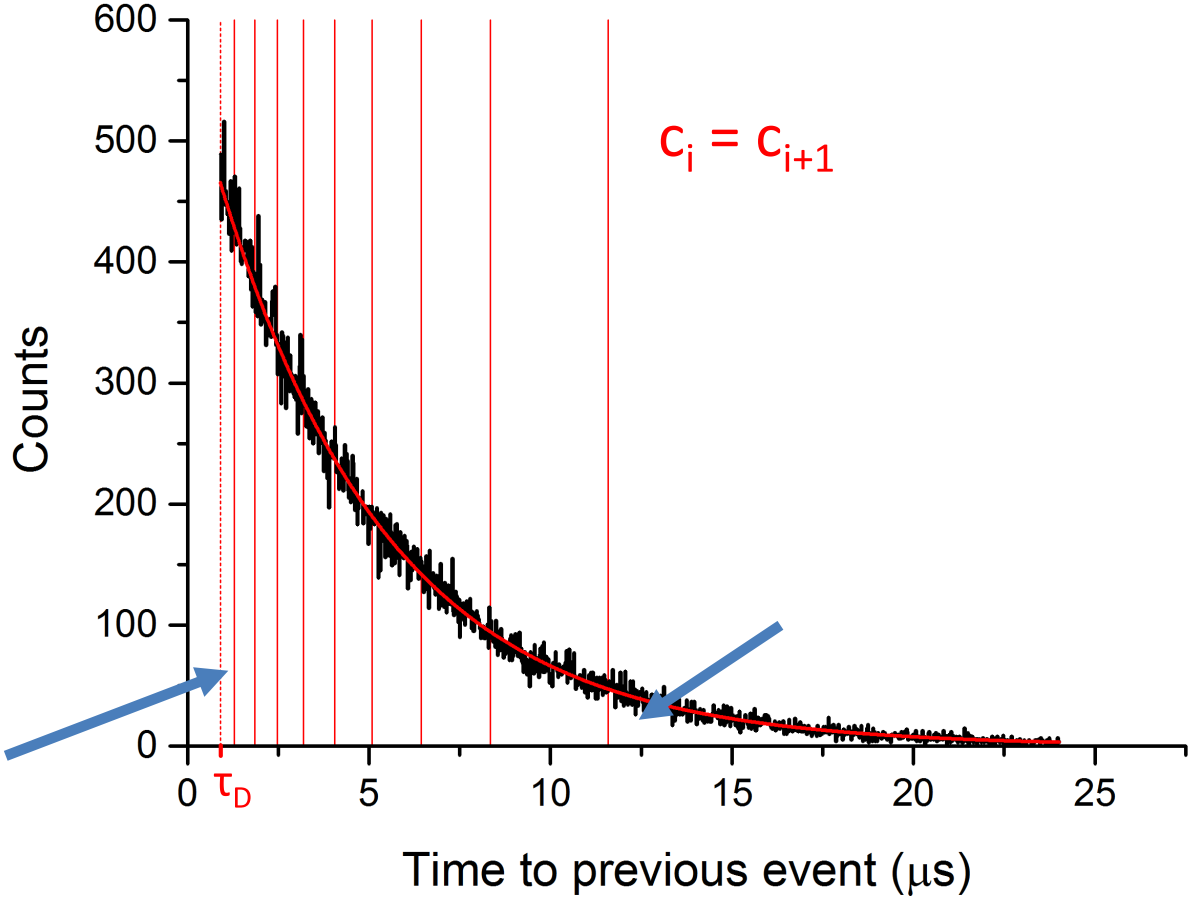
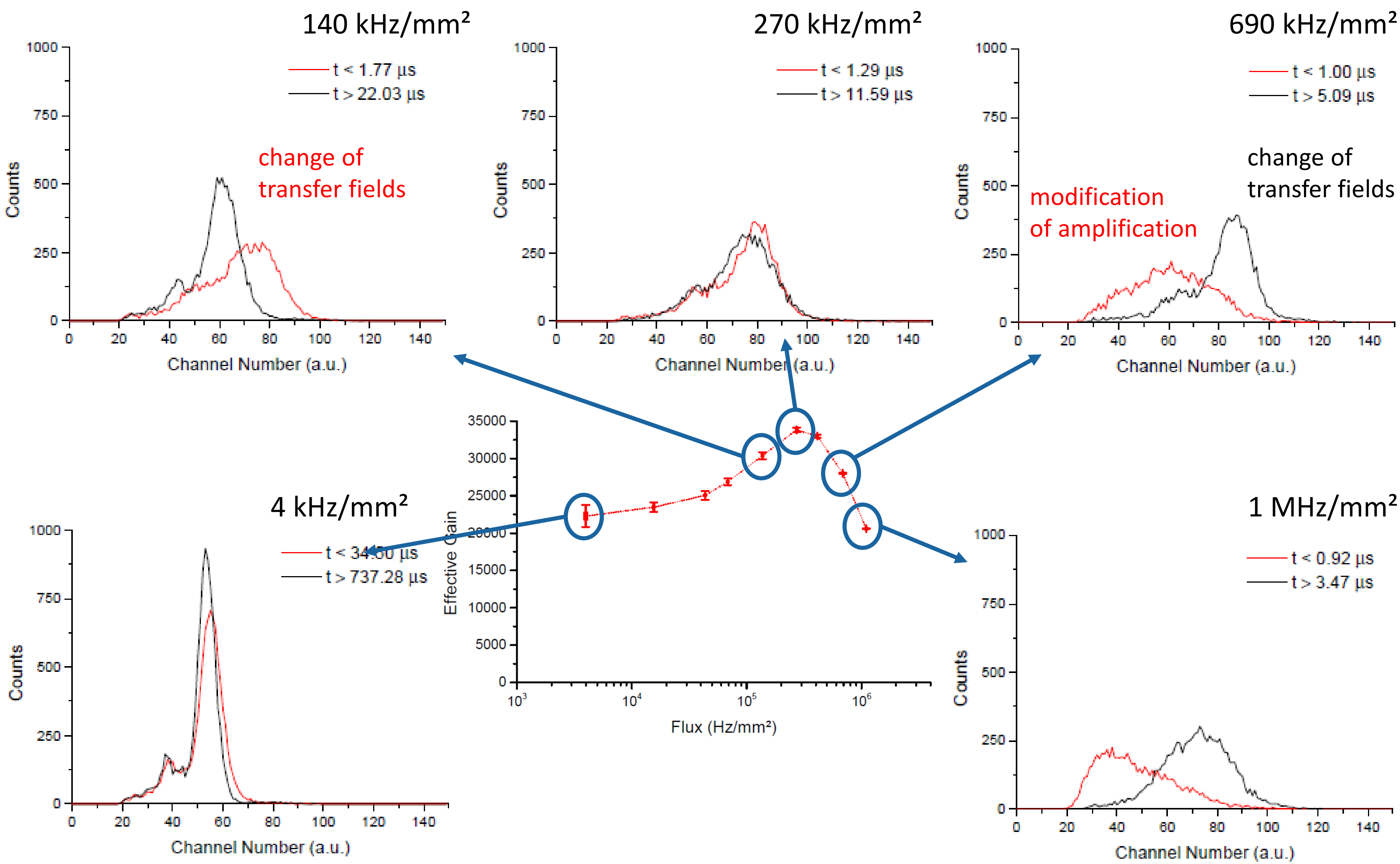
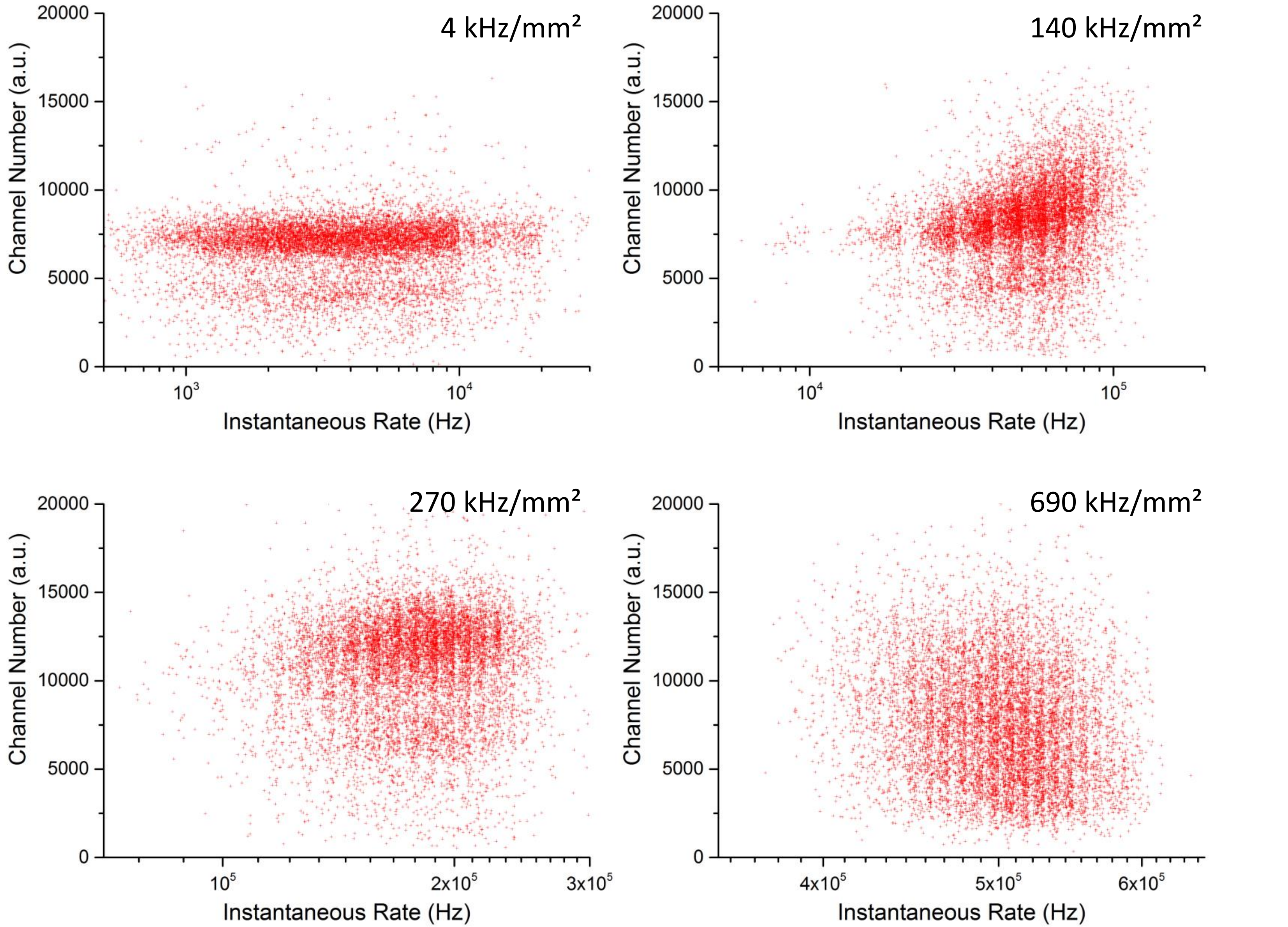


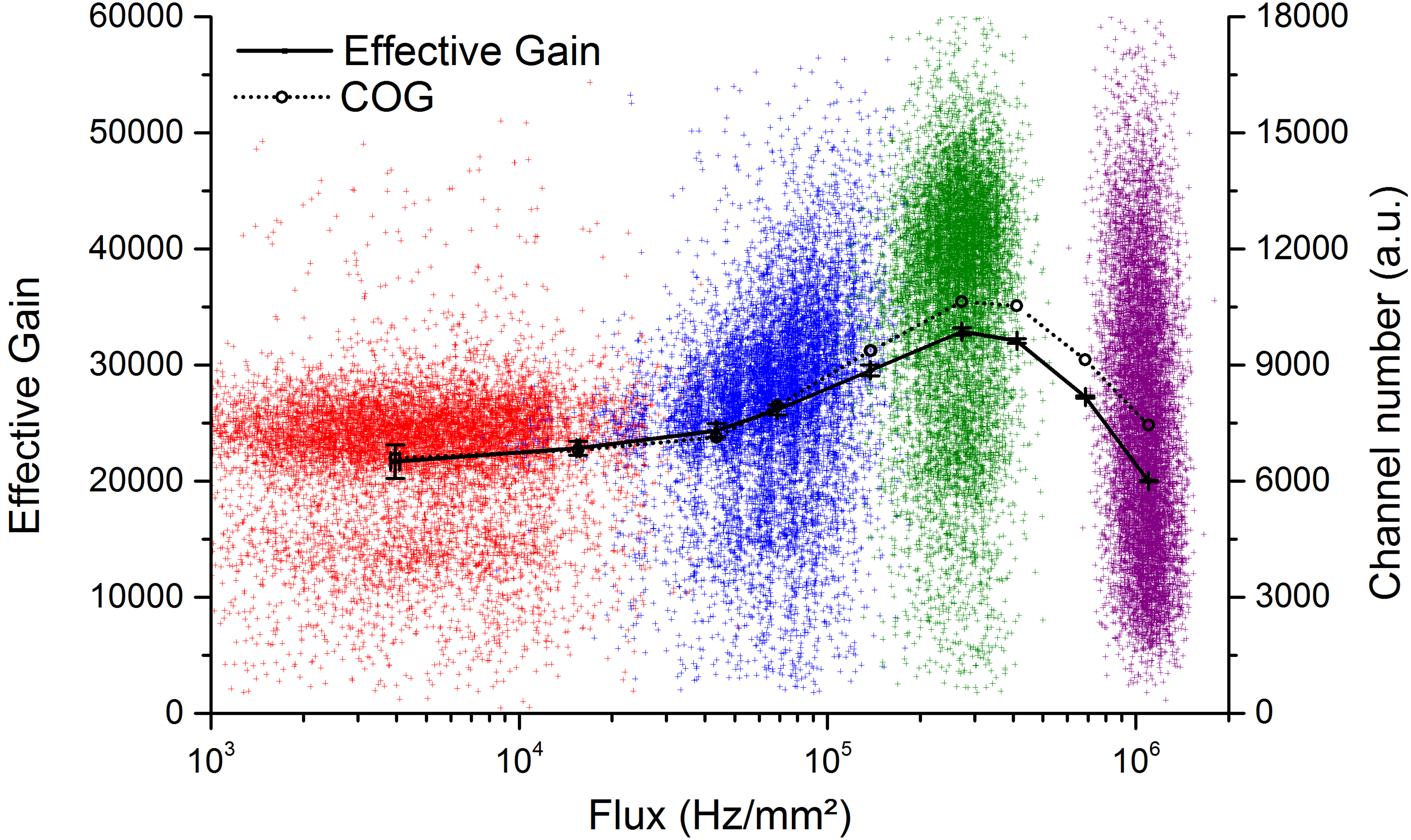
Energy resolution vs. particle flux



Energy resolution vs. particle flux



Energy resolution vs. particle flux



Conclusions

- Space-charge effects for high fluxes of 8 keV x-rays in Ar/CO_2 70/30 gas mixtures were observed
- The effects are modelled for standard triple GEMs and are quantitatively understood
- Similar behaviour is expected in any system where the transfer of charge is not 100%
- Ion space-charge modifies the transfer fields and amplification fields

- Study the effect of different transfer gaps to push the effect to higher fluxes
- Study the impact of different gasses
  - Changing ratio of Ar and CO_2 (diffusion)
  - Ne based gas mixtures (ion drift speed, diffusion)