Effects of High Charge Densities in Multi-GEM Detectors

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- Remarks pt. 1
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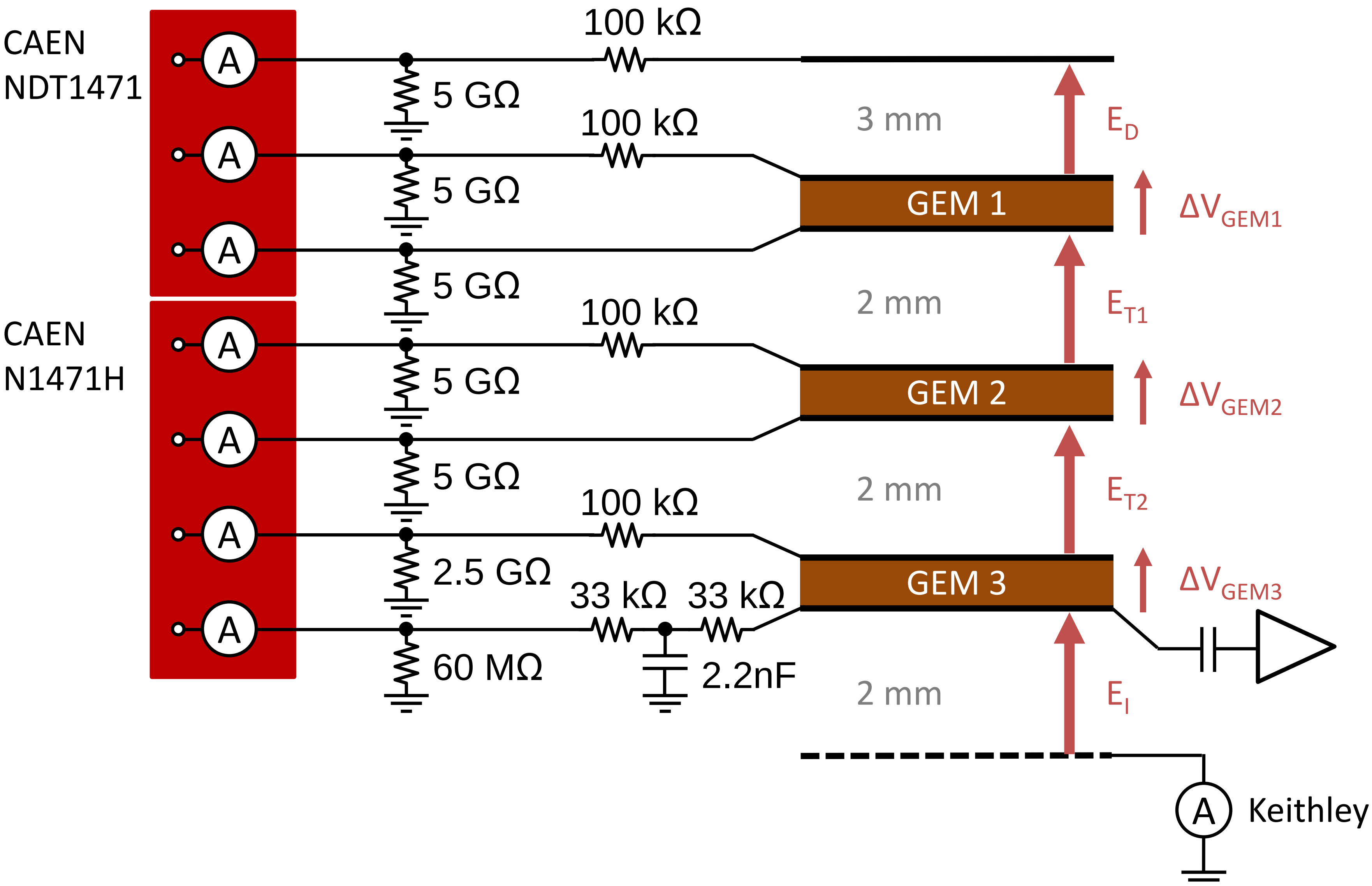
Motivation

- 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

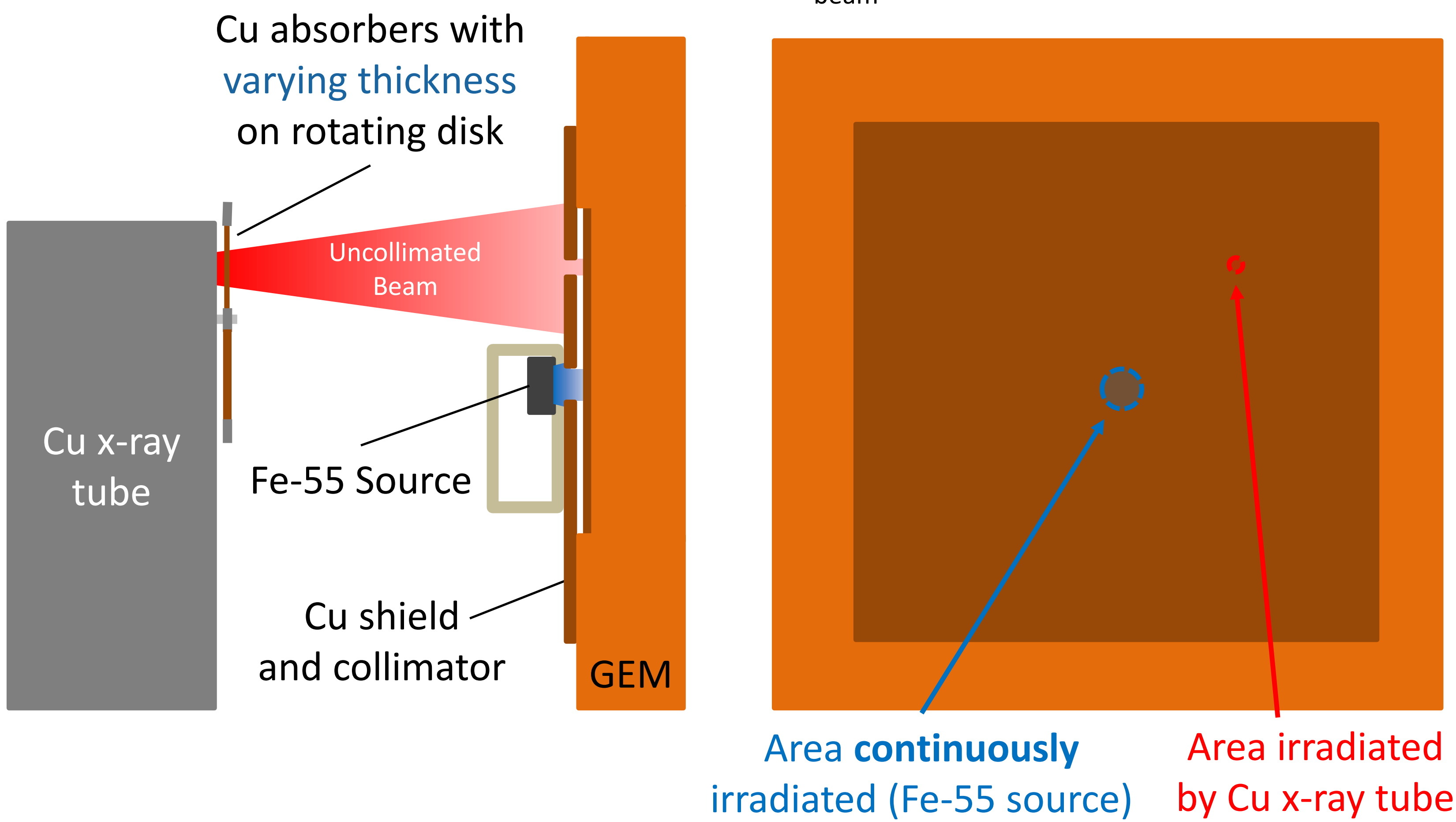
Setup


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

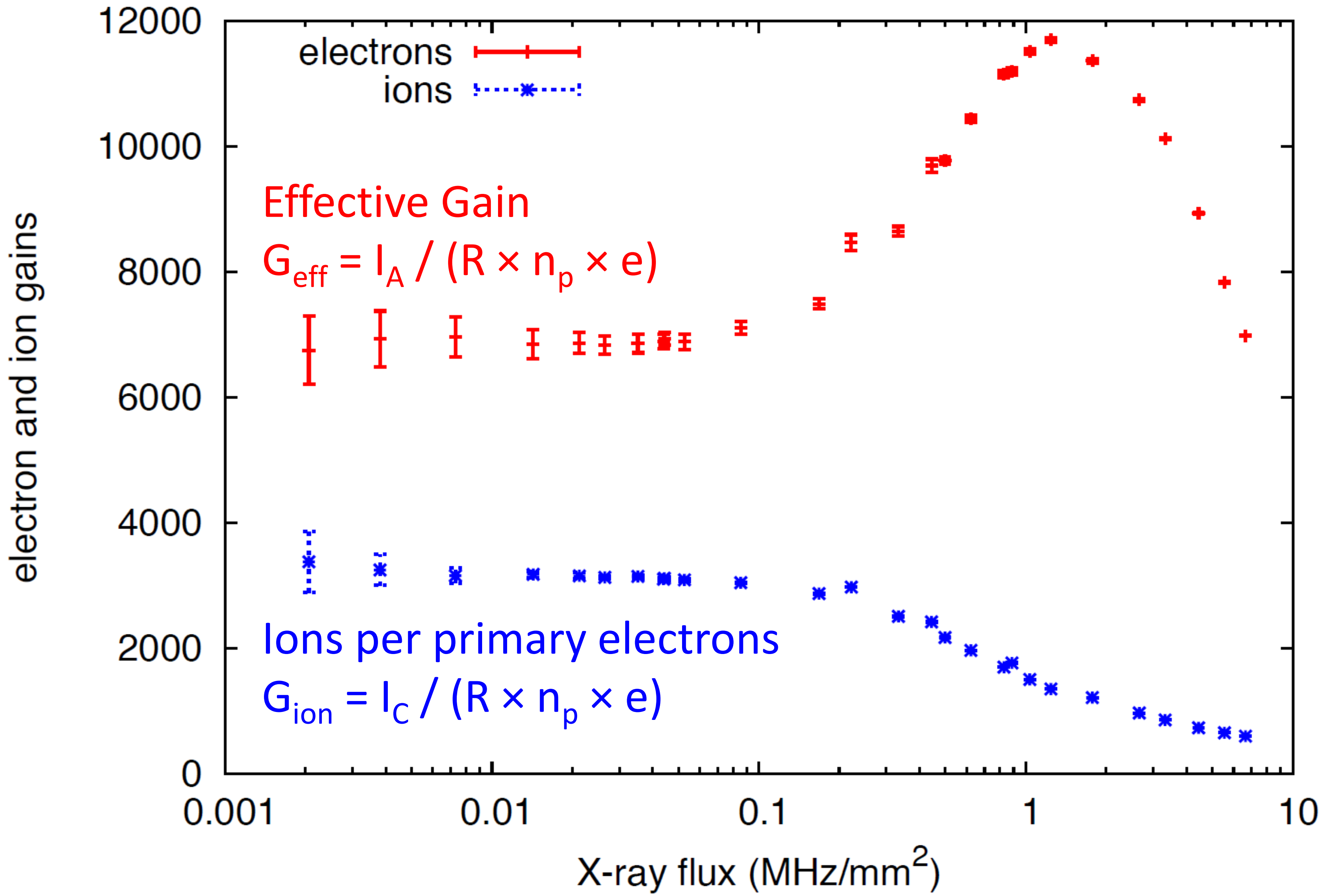
Setup

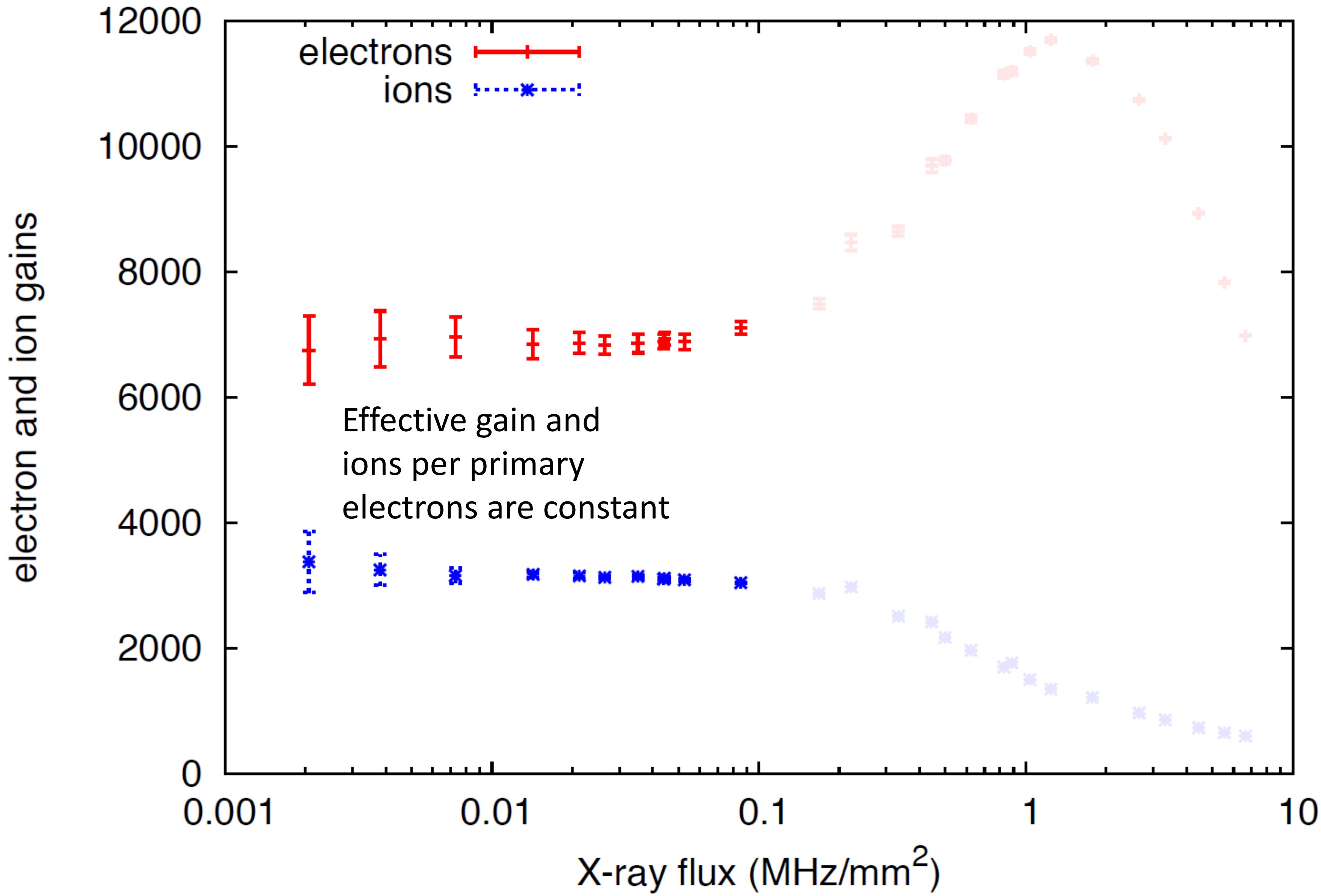
Ar/CO_2 70/30
Cu x-ray, $E_{x\text{-}ray}$ = 8 keV
d_{beam} = 1 mm

$n_p \approx 300$



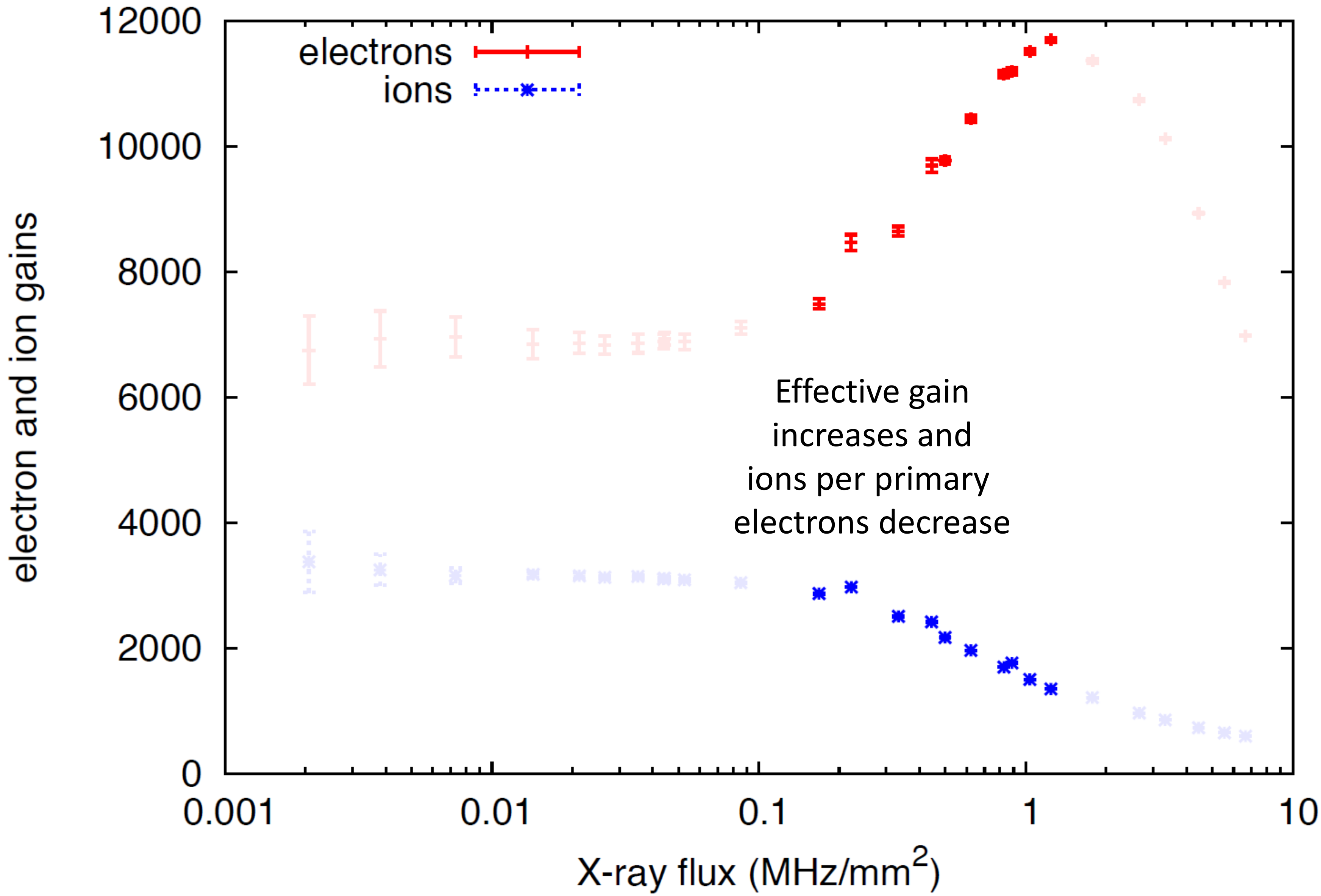
Observations pt. 1

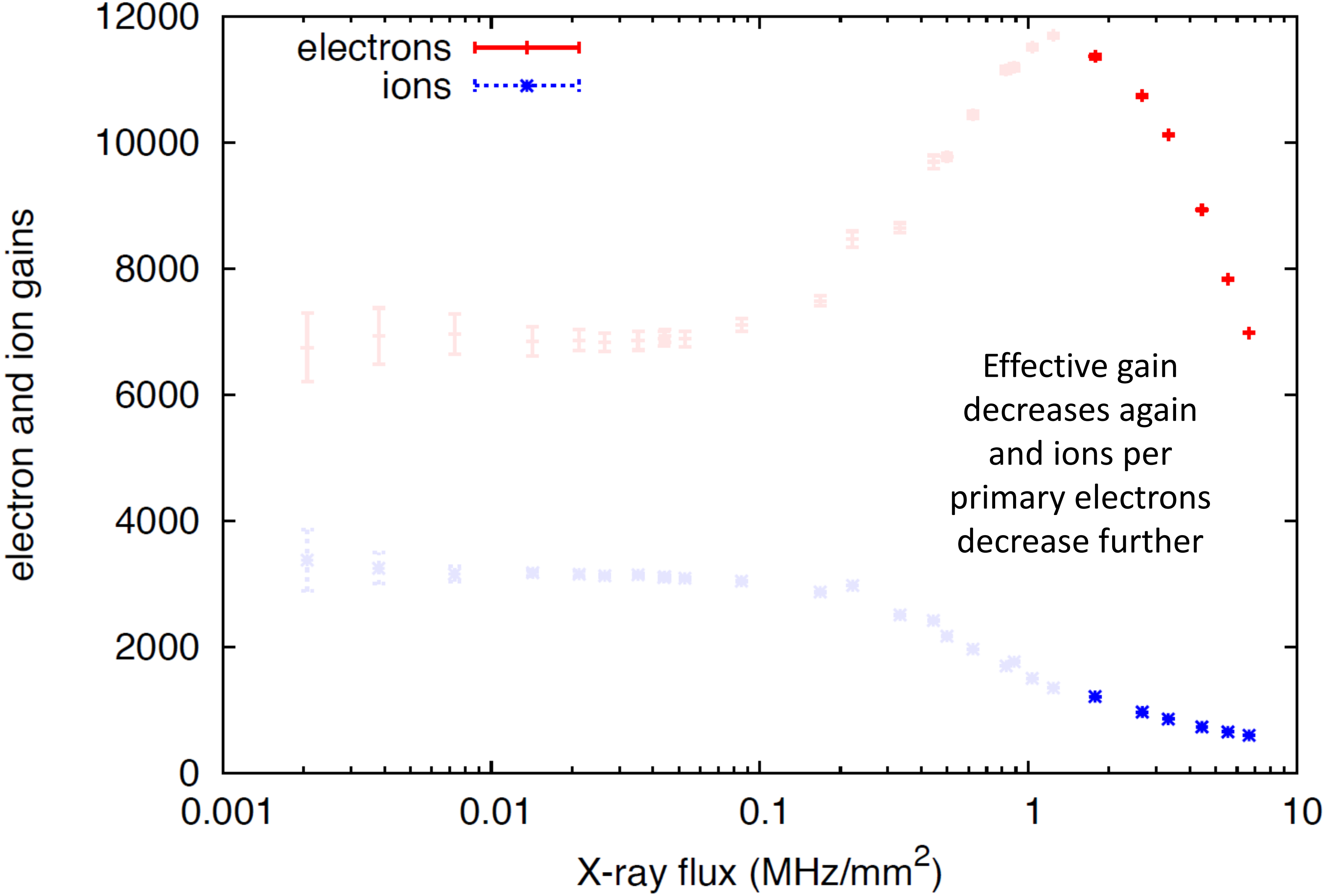




Effective gain and ions per primary electrons are constant

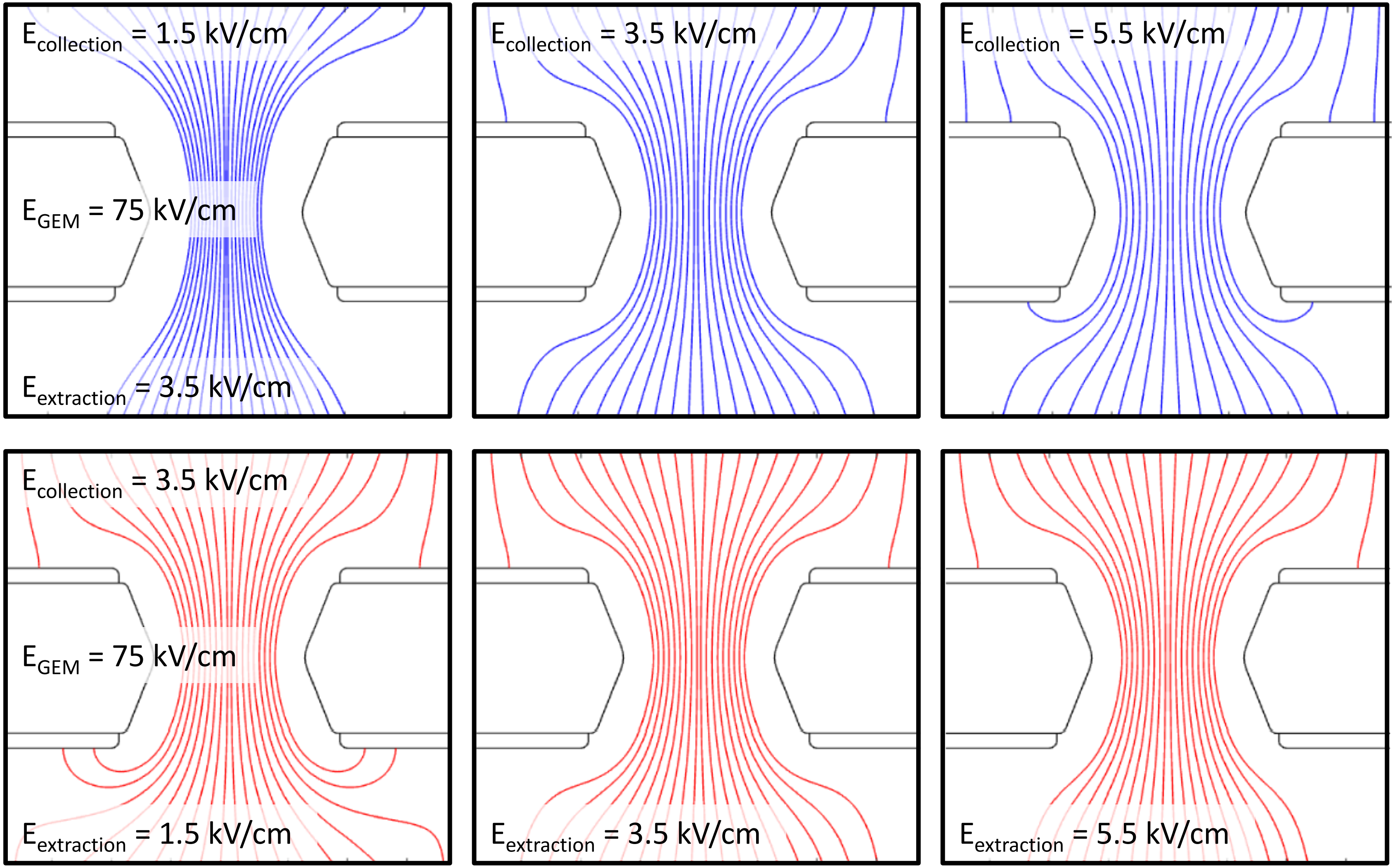
Observations pt. 1



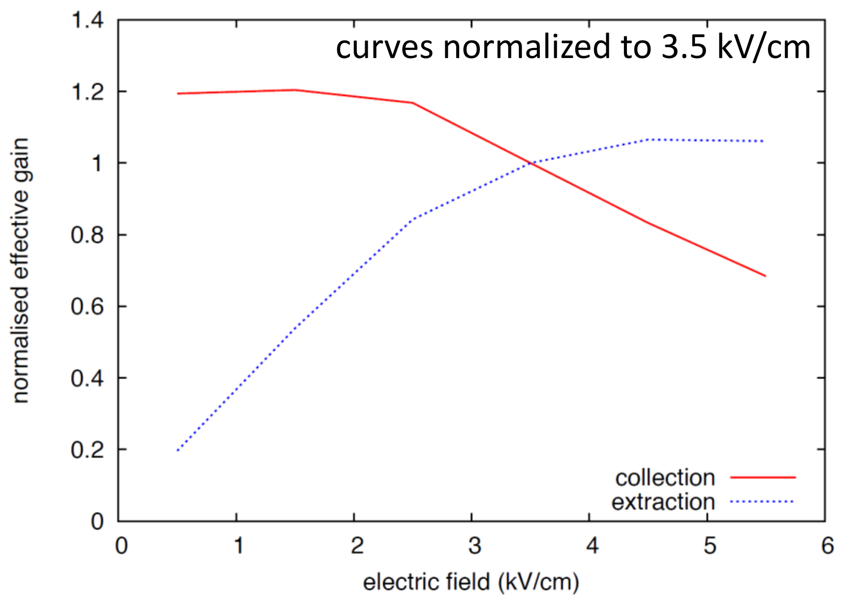


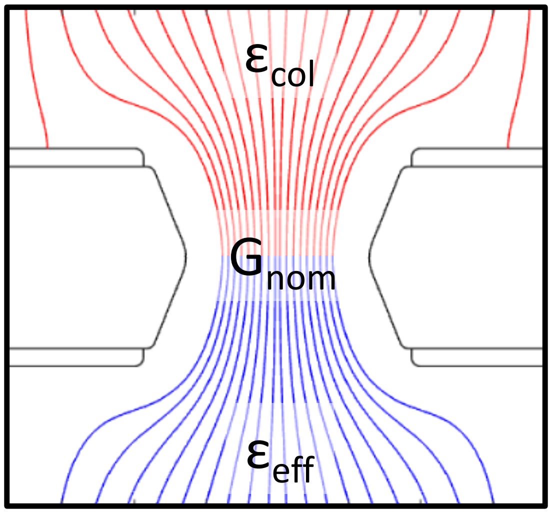
Effective gain decreases again and ions per primary electrons decrease further

Remarks pt. 1: Collection and extraction efficiency



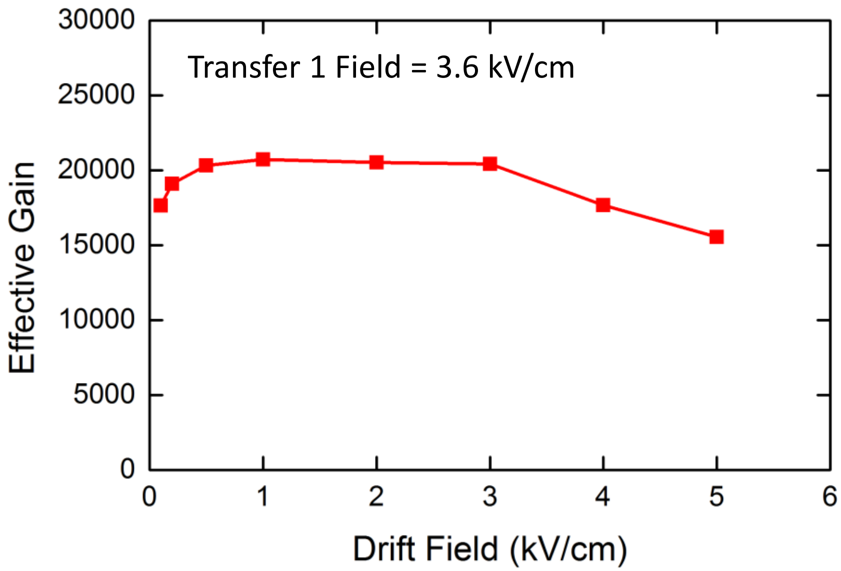
- Effective gain is nominal gain of the GEM, corrected for collection and extraction efficiency

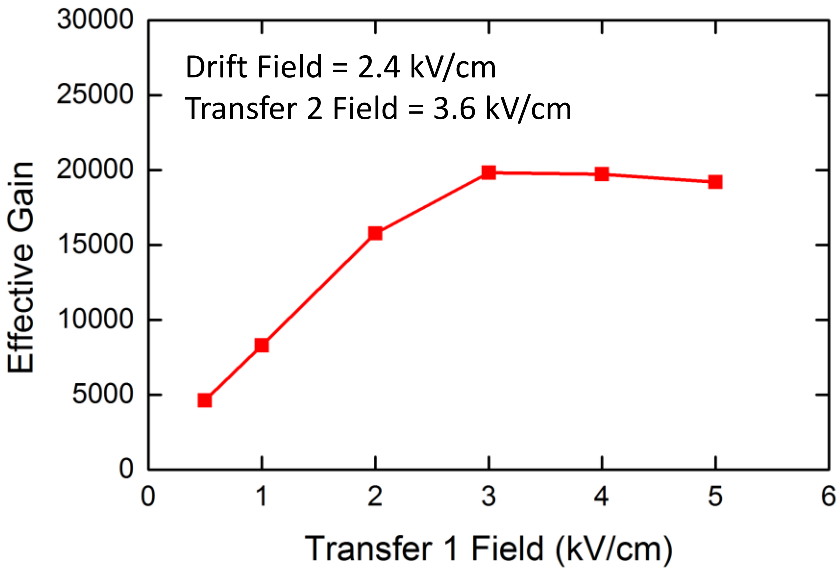


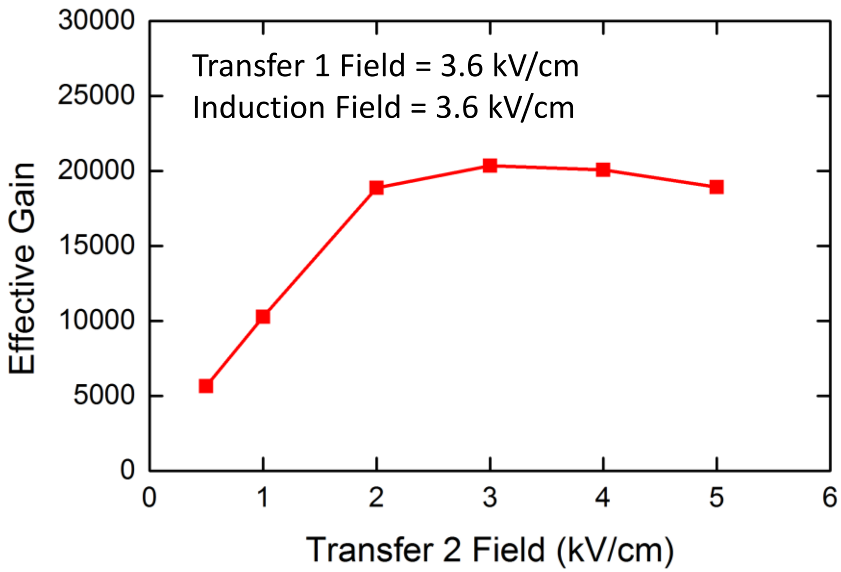


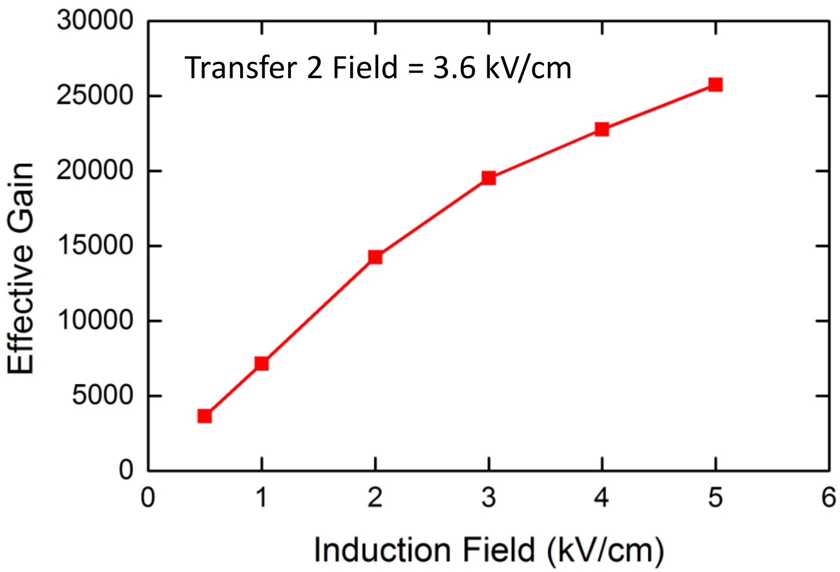
$$G_{eff} = \varepsilon_{col} \times \varepsilon_{extr} \times G_{nom}$$

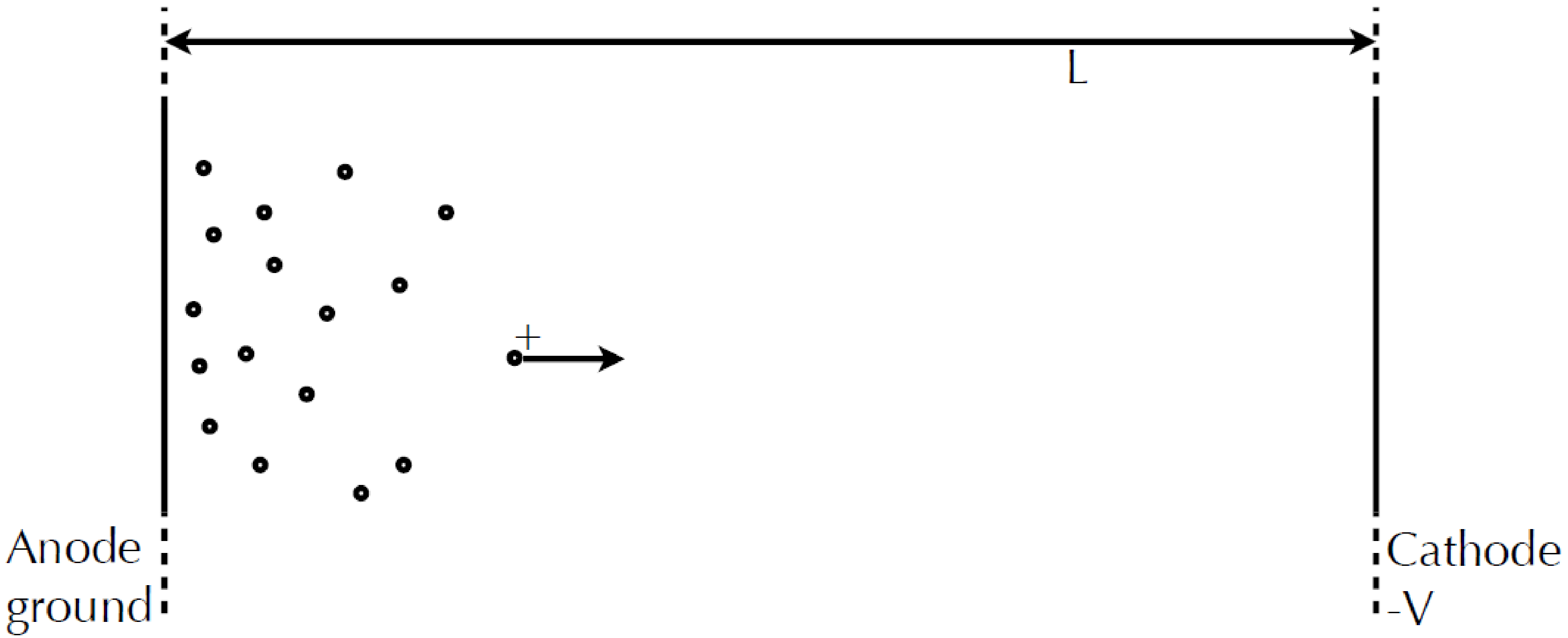
Remarks pt. 1: Measurements on triple GEM detectors







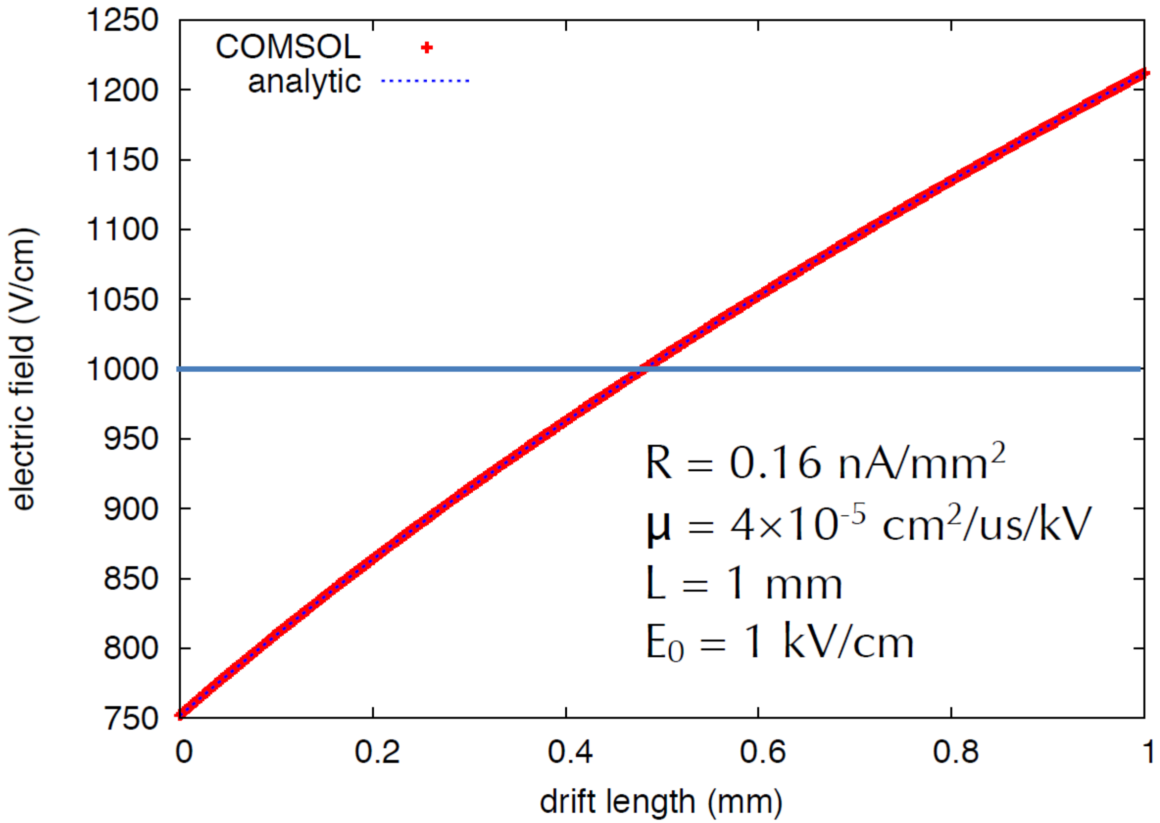




- Infinite parallel plates at distance L with a potential difference of ΔV
- At t = 0 uniform electric field of $E_0 = \Delta V/L$
- Positive ions generated at the anode at a constant and uniform flux R
- Ions moving towards the cathode at speed $v = \mu E$
- Actual electric field E modified by the charge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

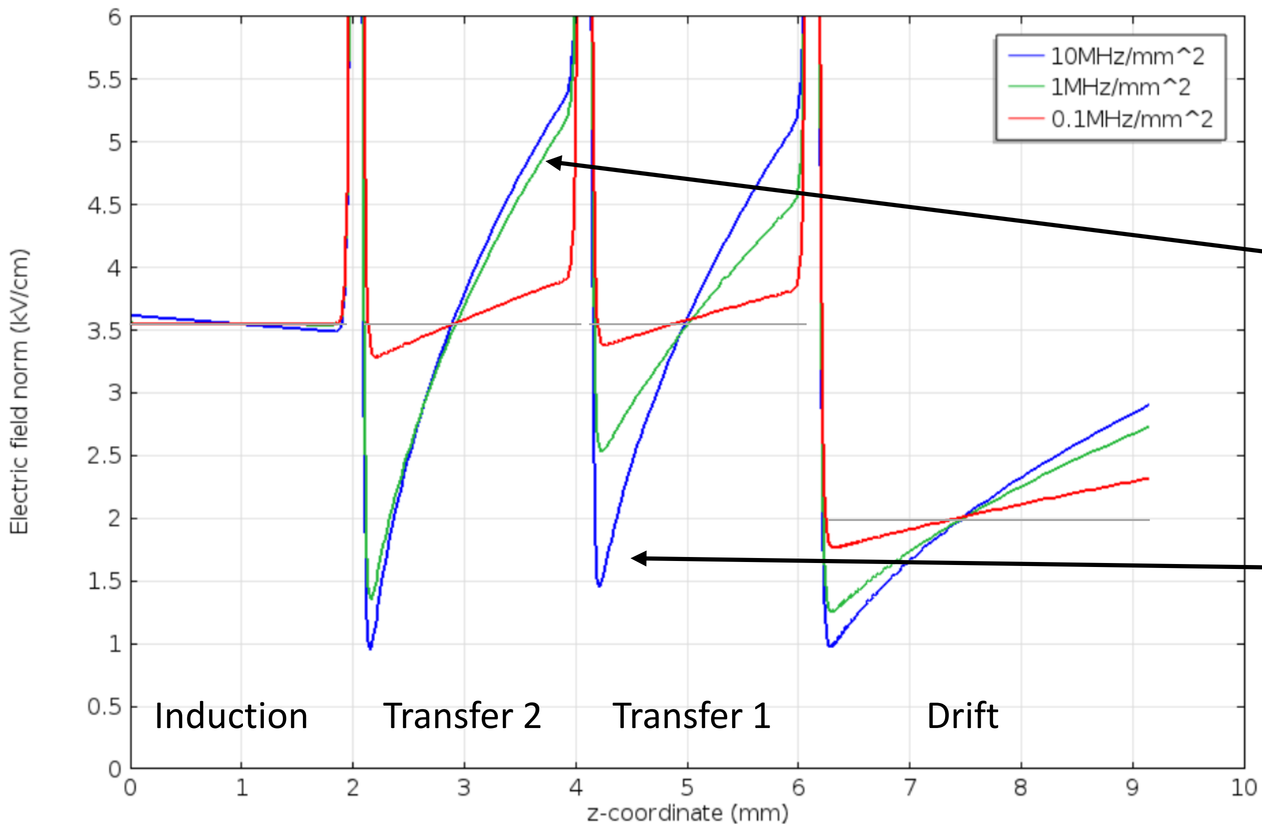
Remarks pt. 1: Space-charge effects in the transfer region

- 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

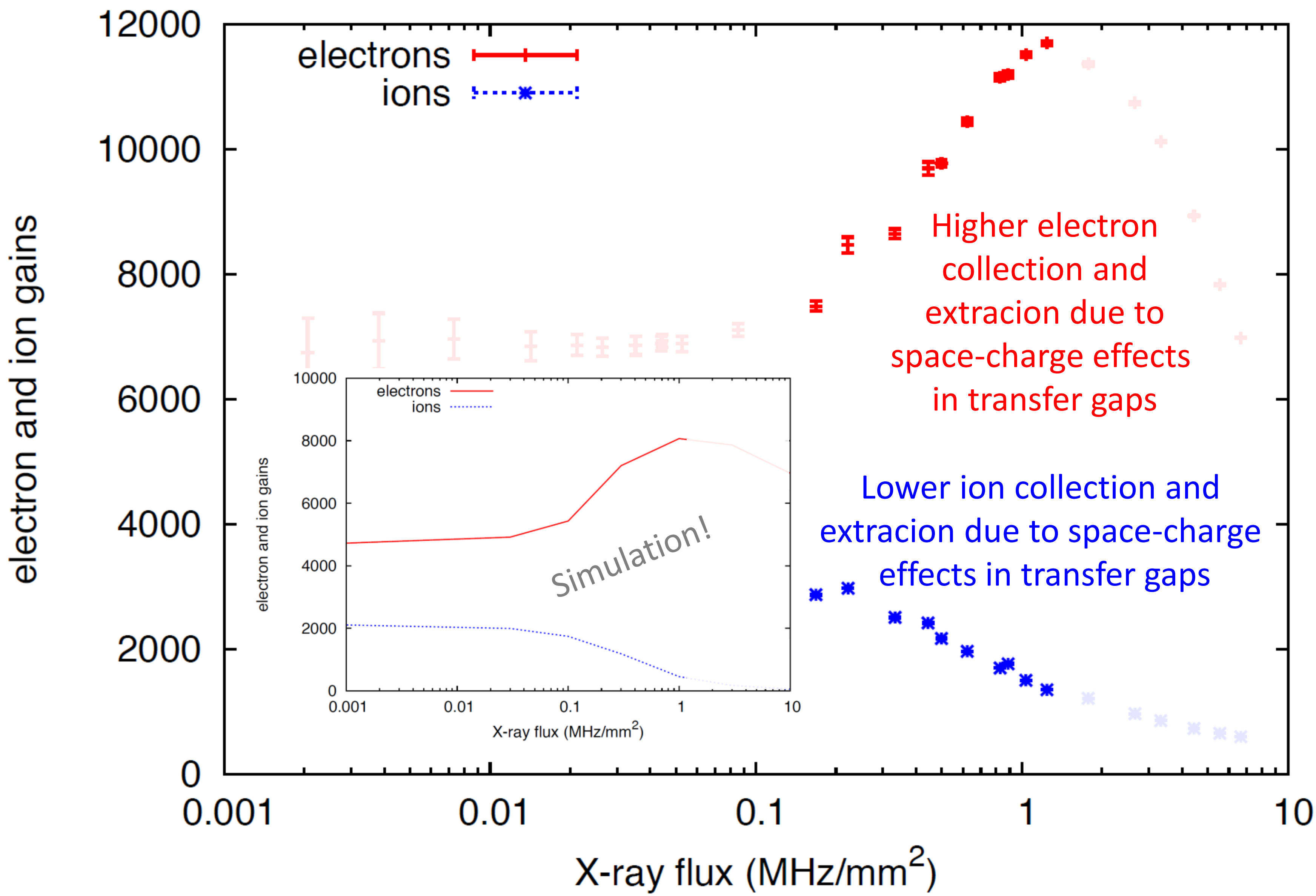


Electric field increases close to GEM bottom electrodes

Electric field decreases close to GEM top electrodes

- 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

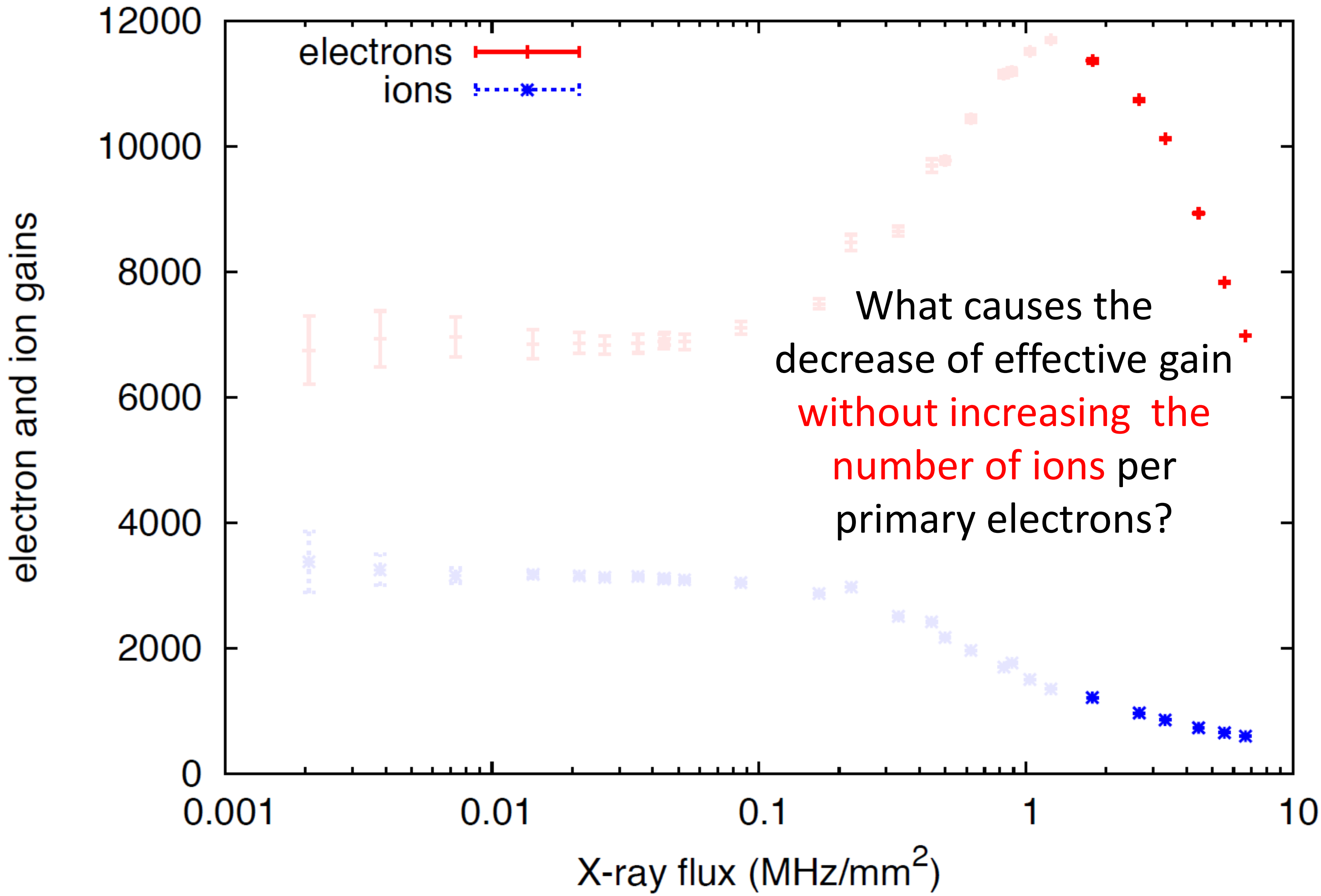
Conclusions pt. 1



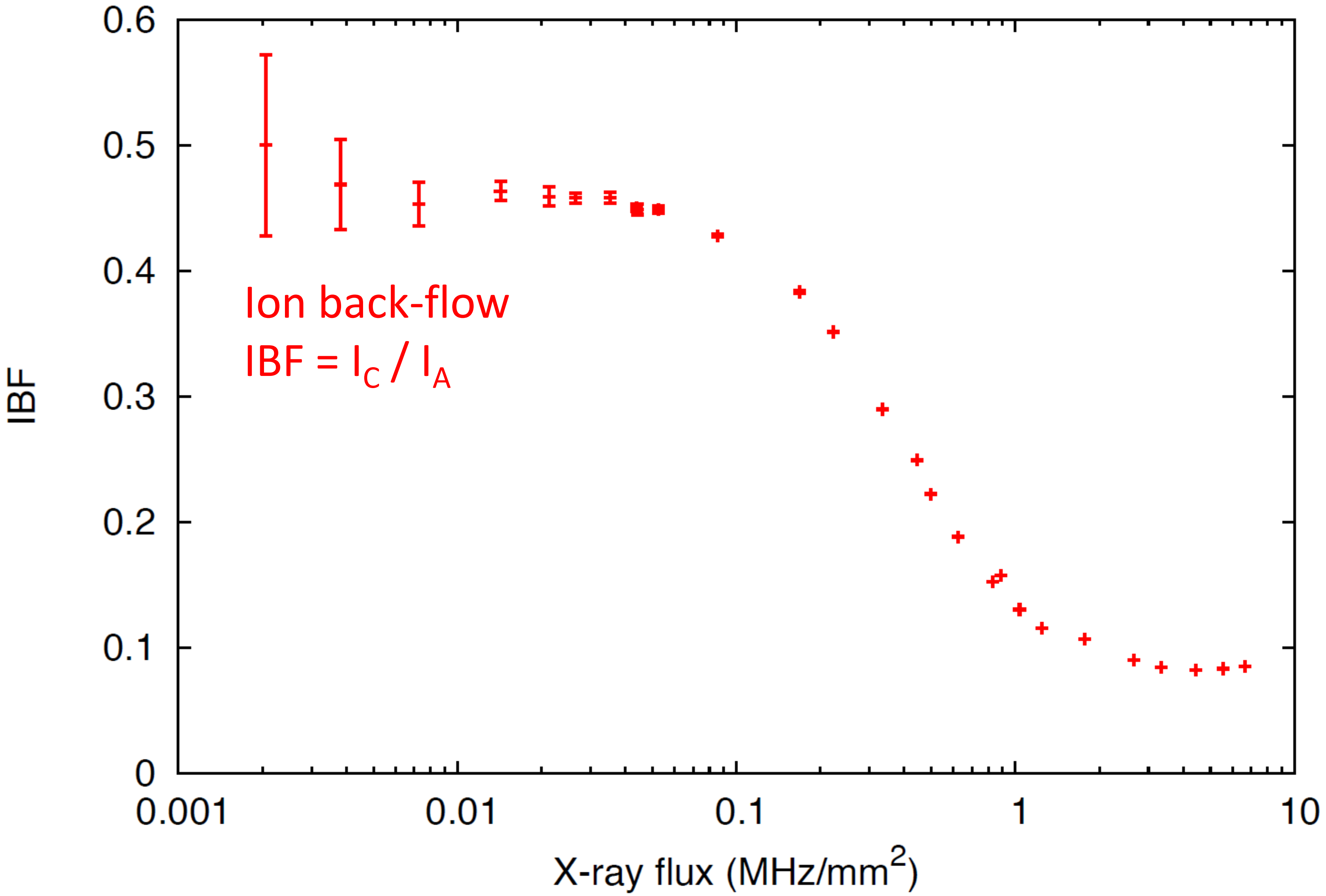
Conclusions pt. 1

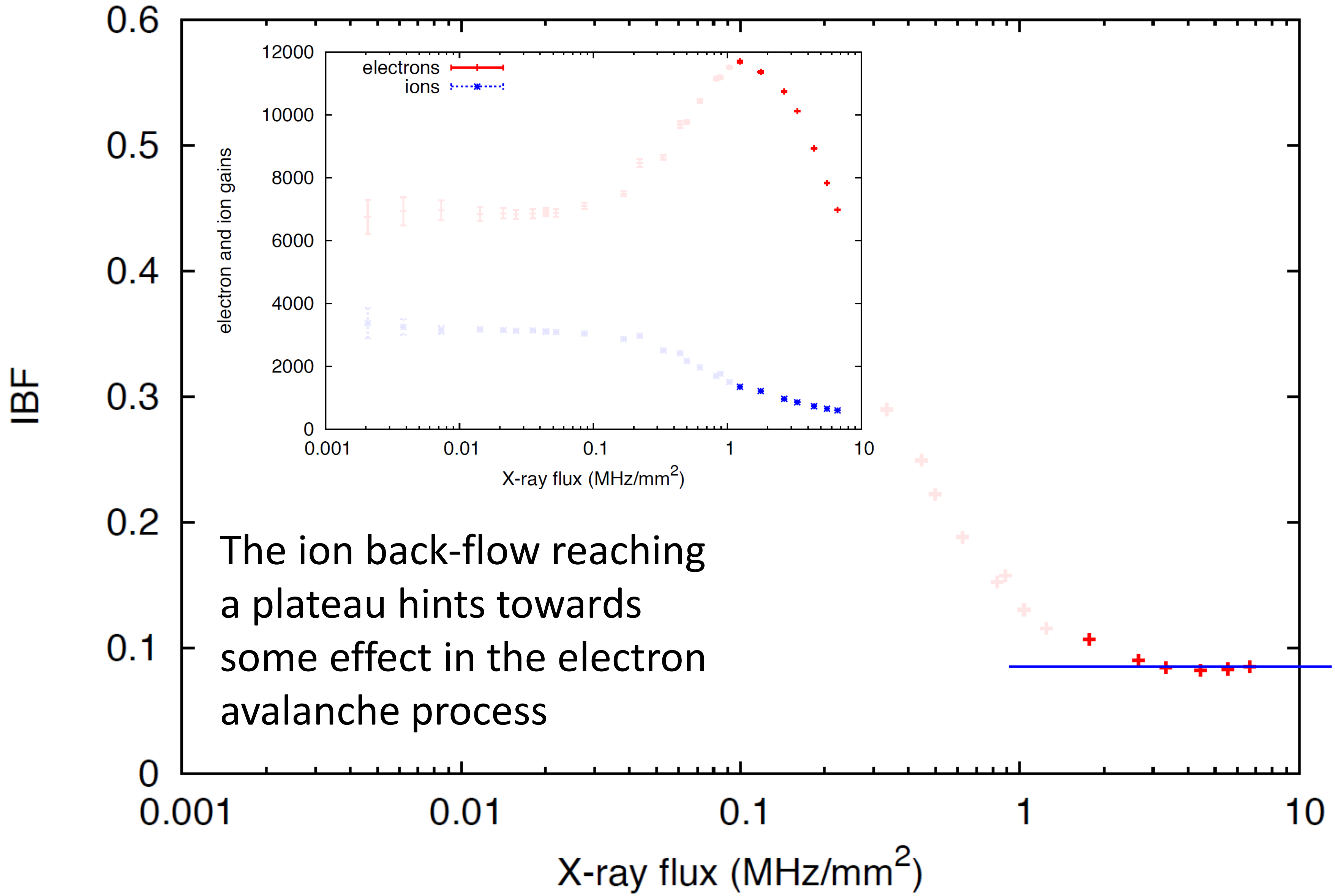
- Evacuation of ions from transfer regions is slower by $O(10^6)$ compared to rate of incoming x-rays
  - Accumulation of ions in drift and transfer gaps
- Ion space-charge distorts fields such that
  - Electron collection and extraction increases
  - Ion collection and extraction decreases
- Resulting in
  - Increased electron gain
  - Reduced ion back-flow

Observations pt. 2

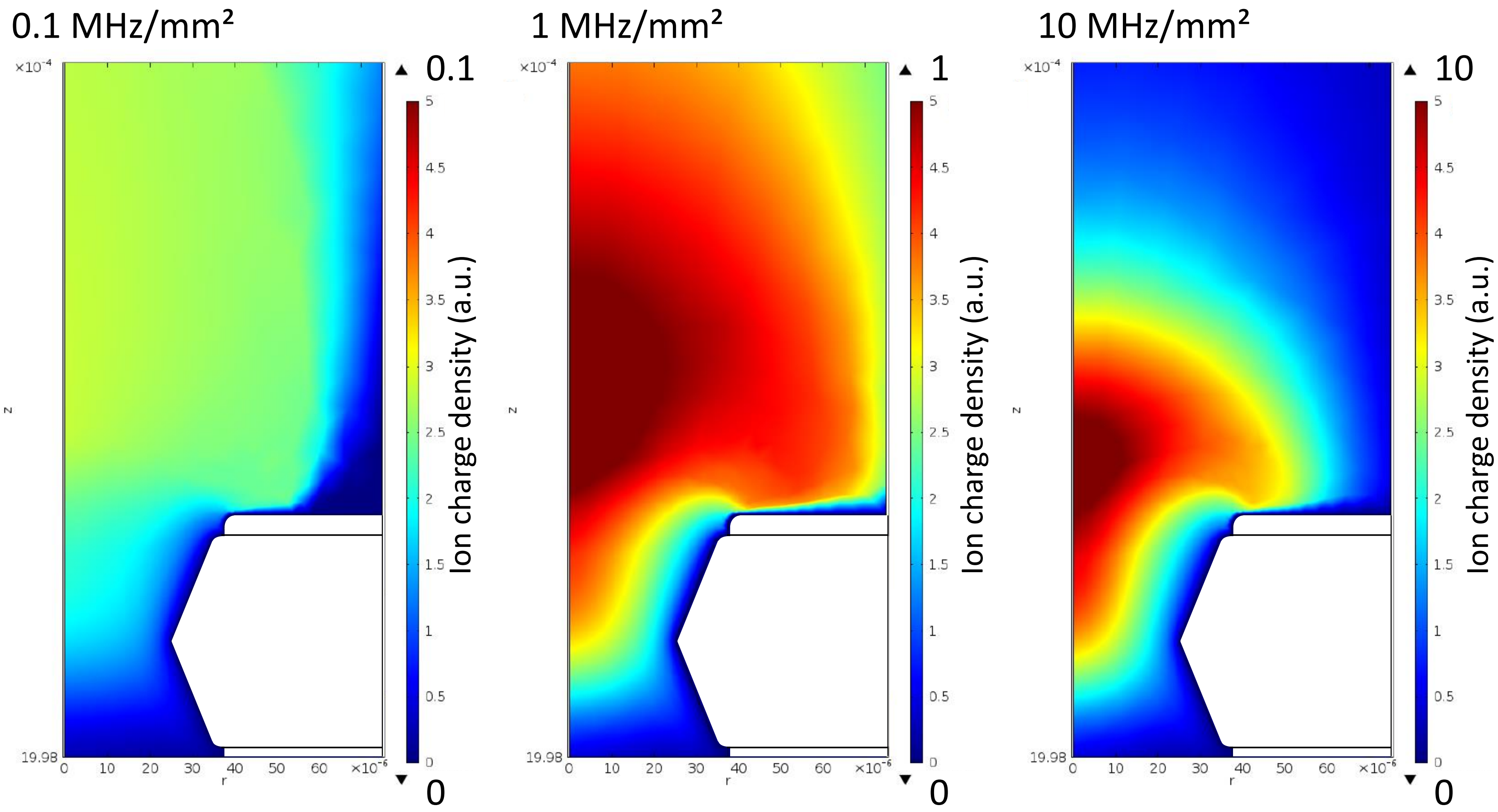


Observations pt. 2



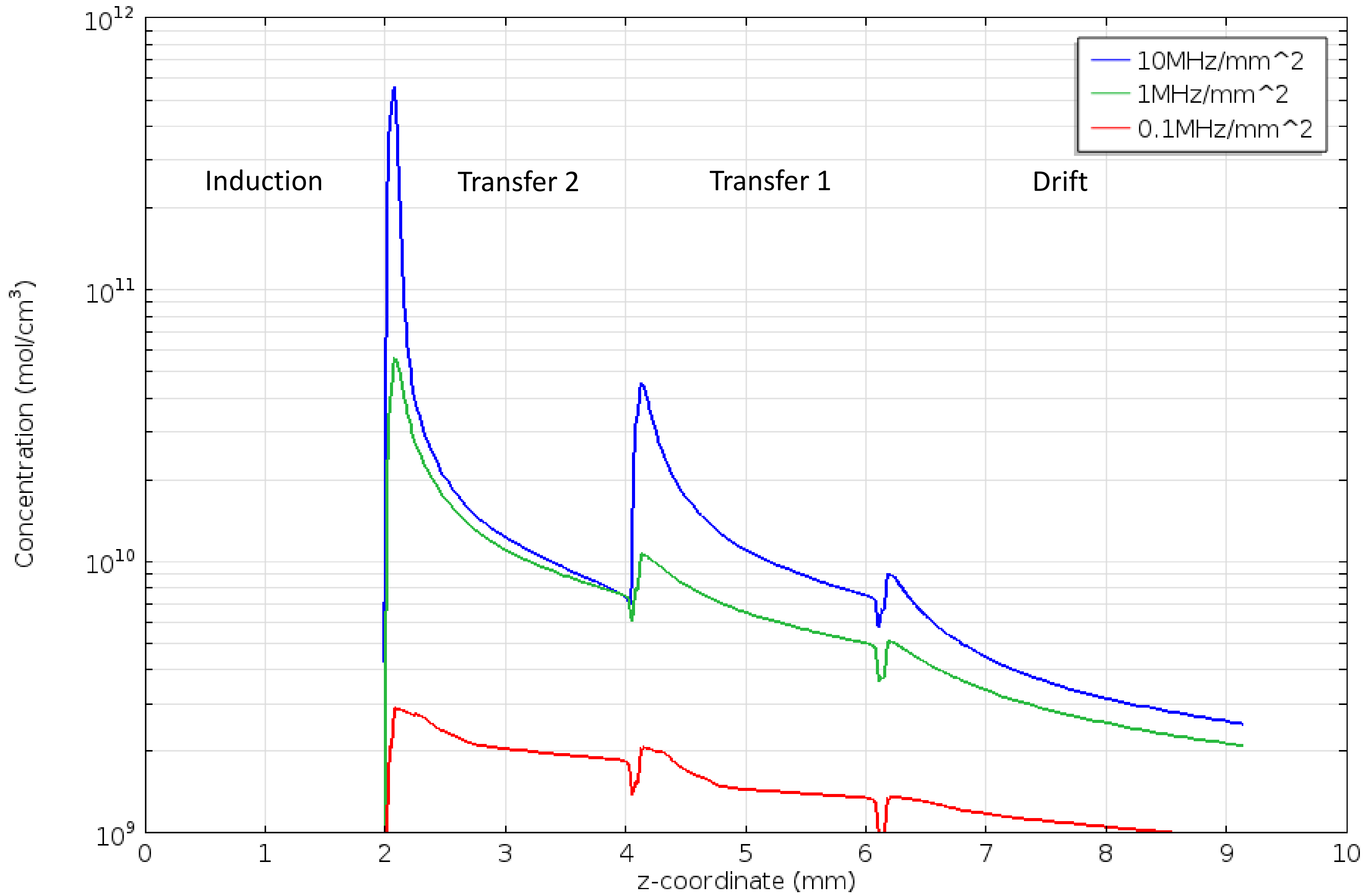


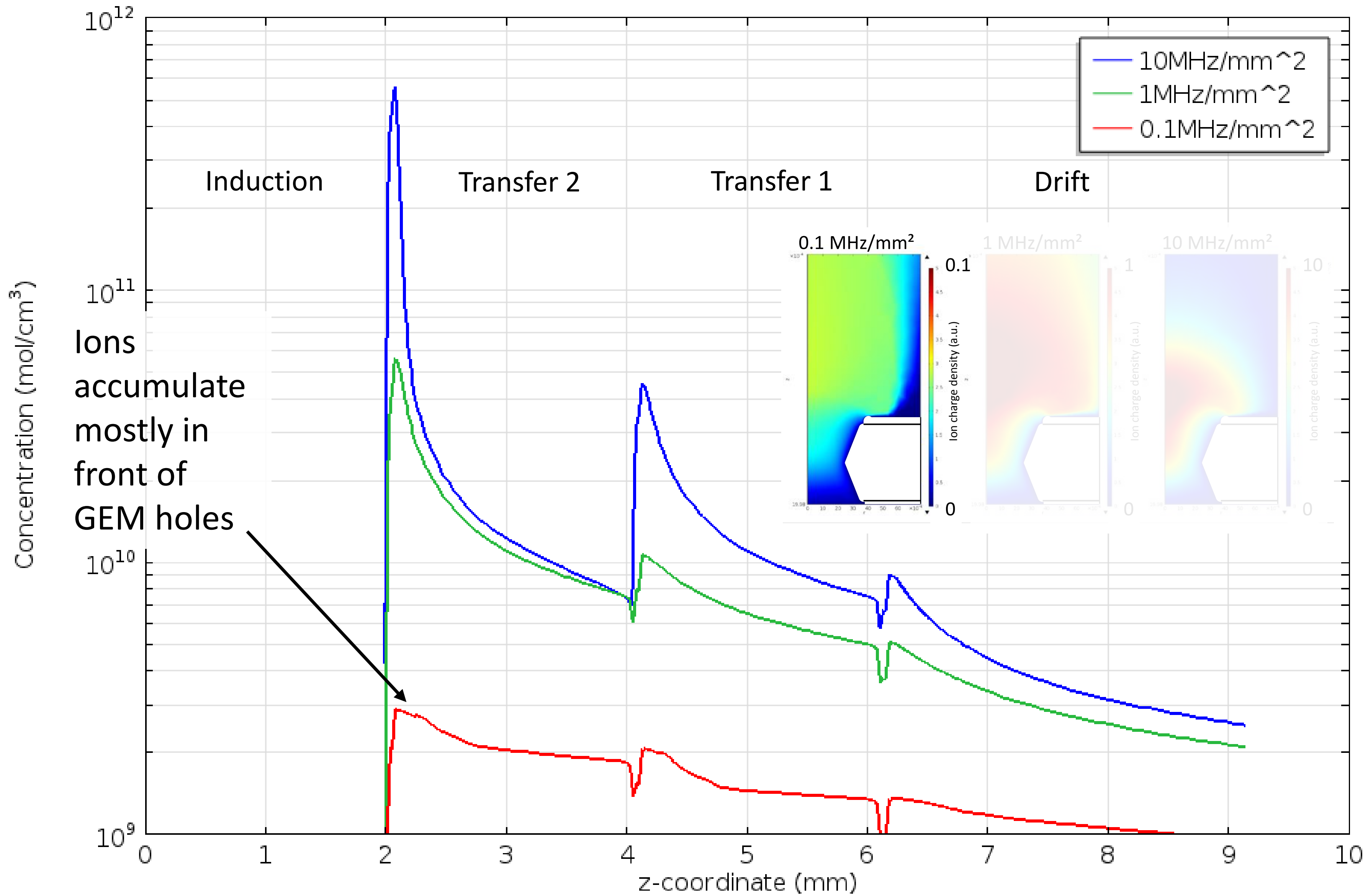
The ion back-flow reaching a plateau hints towards some effect in the electron avalanche process



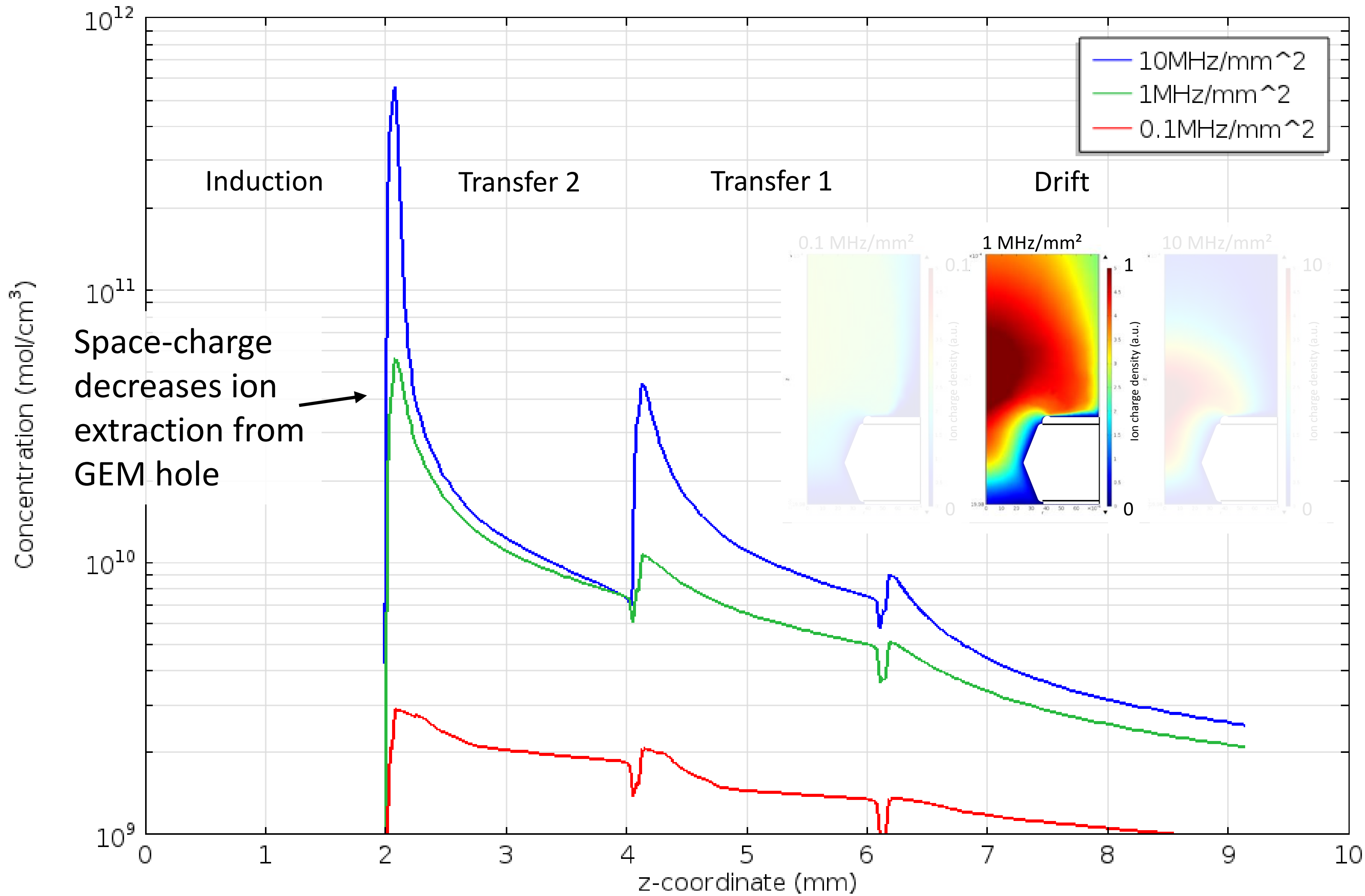
COMSOL simulation: single GEM hole, axial symmetric, stationary solution

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

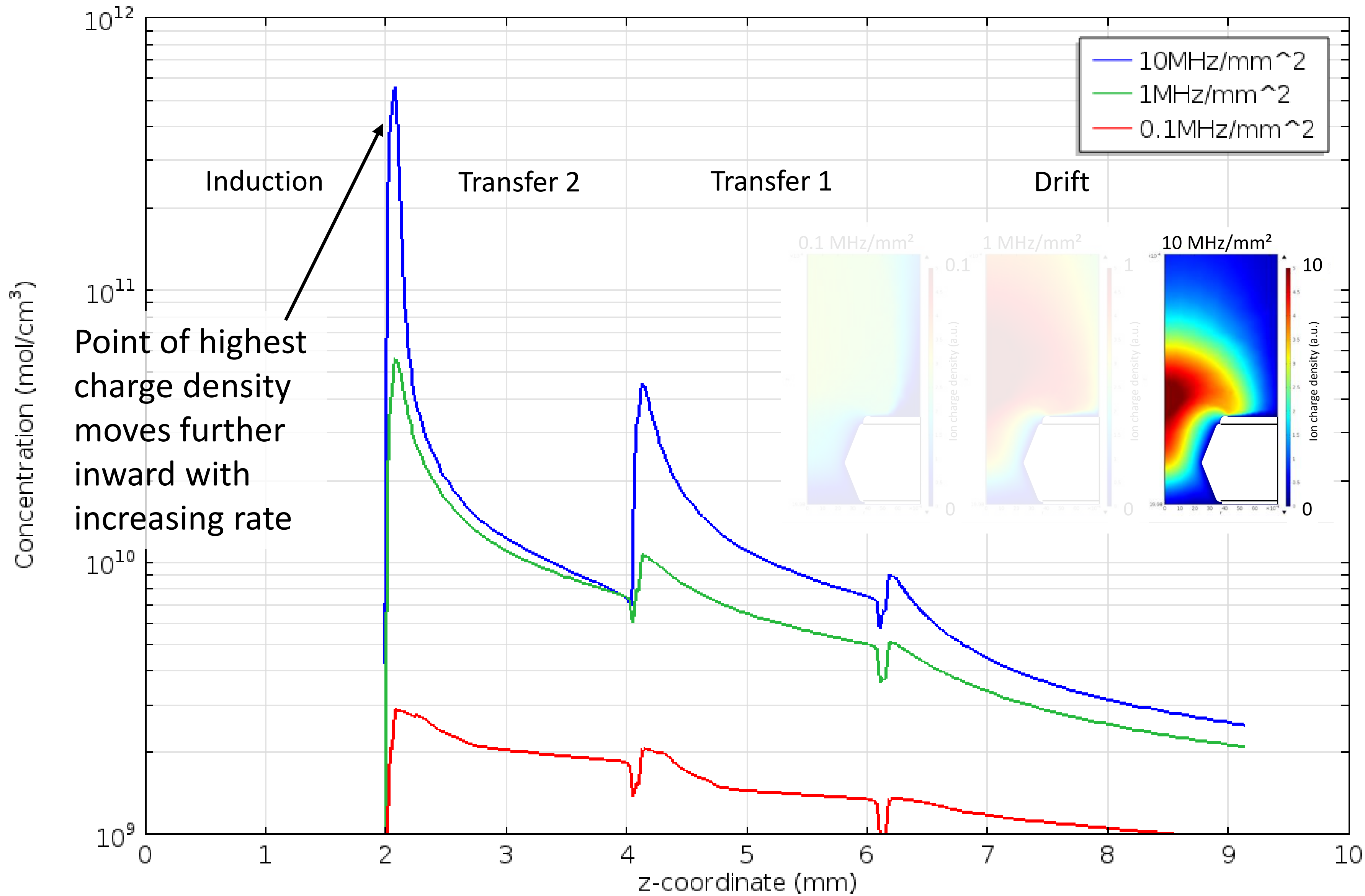



10MHz/mm^2
1MHz/mm^2
0.1MHz/mm^2
Induction
Transfer 2
Transfer 1
Drift
0.1 MHz/mm²
1 MHz/mm²
10 MHz/mm²
0.1
0
1
0
10
0
Ion charge density (a.u.)
Ions accumulate mostly in front of GEM holes
Concentration (mol/cm³)
z-coordinate (mm)
10^{12}
10^{11}
10^{10}
10^{9}
0
1
2
3
4
5
6
7
8
9
10

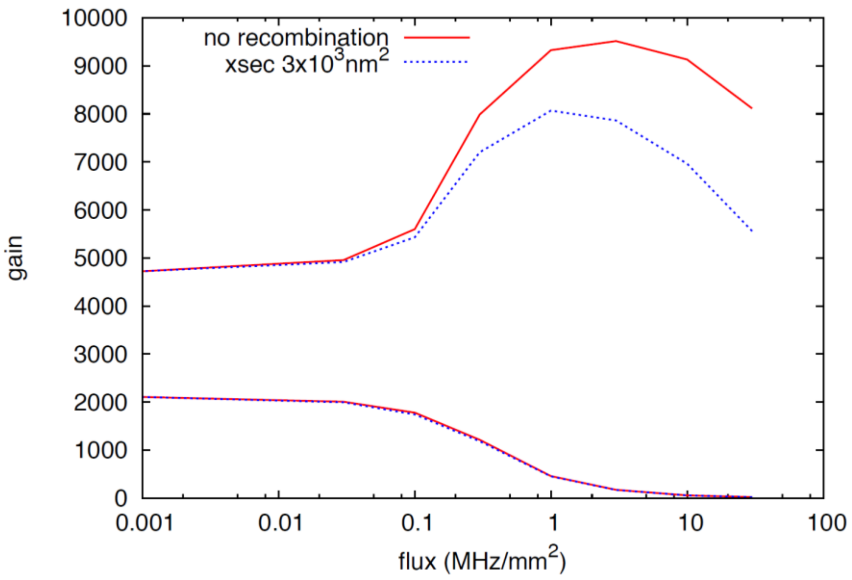
Remarks pt. 2: Space-charge effects in the amplification region

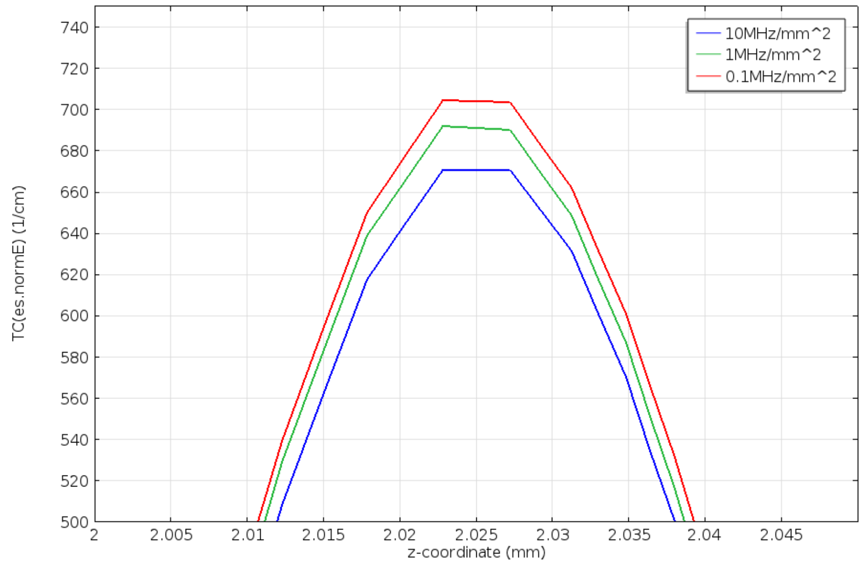


Remarks pt. 2: Space-charge effects in the amplification region



- Ions accumulate in front of GEM holes
  - Extraction of ions drops to a few percent!
- Ions start accumulating in GEM holes!
- Increased ion-electron recombination
  - Probability increasing with flux
- Less electrons per avalanche





Conclusions pt. 2

- Space-charge effects in amplification stages
- Accumulation of ions close to GEM holes
  - Fields on top of GEM holes dropping to $O(10^2)$ V/cm
  - Ion extraction reduced significantly
- Accumulation of ions in GEM holes
  - Decrease of Townsend coefficient
  - Decrease of effective gain
  - Reduced ion back-flow
- Effect will become stronger for even higher fluxes!

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%
- The impact of recombination on the space-charge effects was simulated

Countermeasures

- Change number of ions
  - Reduce number of primaries (MIPs vs x-rays)
  - Lower gain
- Evacuate ions faster
  - Gas mixture with higher ion drift velocity
  - Reduced gap size
- Increase transparency
  - Higher optical transparency of the GEM
  - Gas mixture with lower diffusion

Outlook

- Repeating of measurements for selected field settings to validate simulations
- Changing ratio of Ar and CO_2 to study impact of recombination
- Wrap it up and write the paper on "Effects of High Charge Densities in Multi-GEM Detectors“