Observations of High Rate Capabilities in Standard Triple-GEMs

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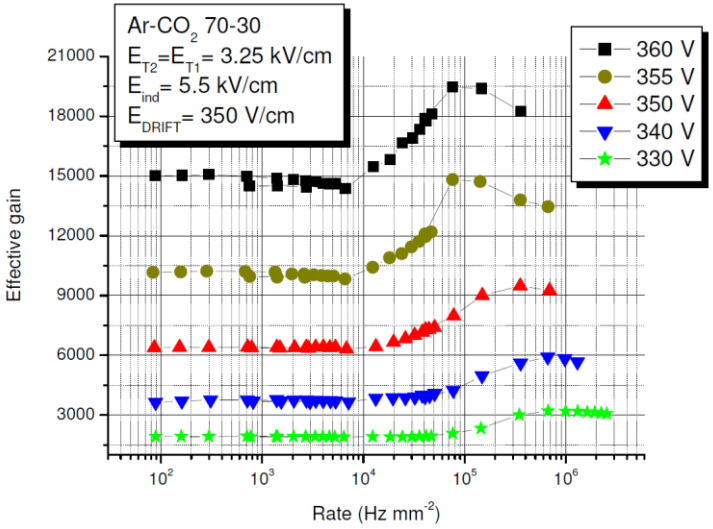
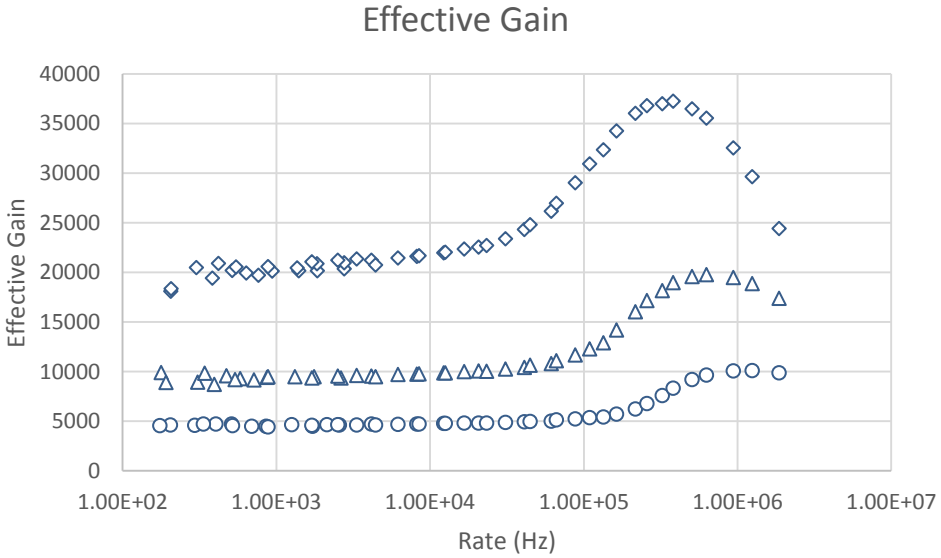
[1]CERN, [2]Technische Universität Wien,
[3]ESS, [4]Uludağ University

Motivation

Pieter Everaerts' thesis (2006)

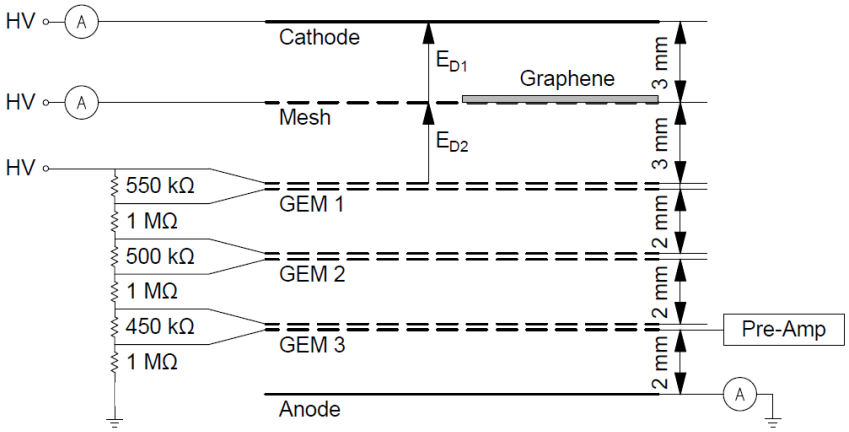


Ella Warras' summer student project (2014)



"Charge Transfer Properties Through Graphene Layers in Gas Detectors" (ongoing)

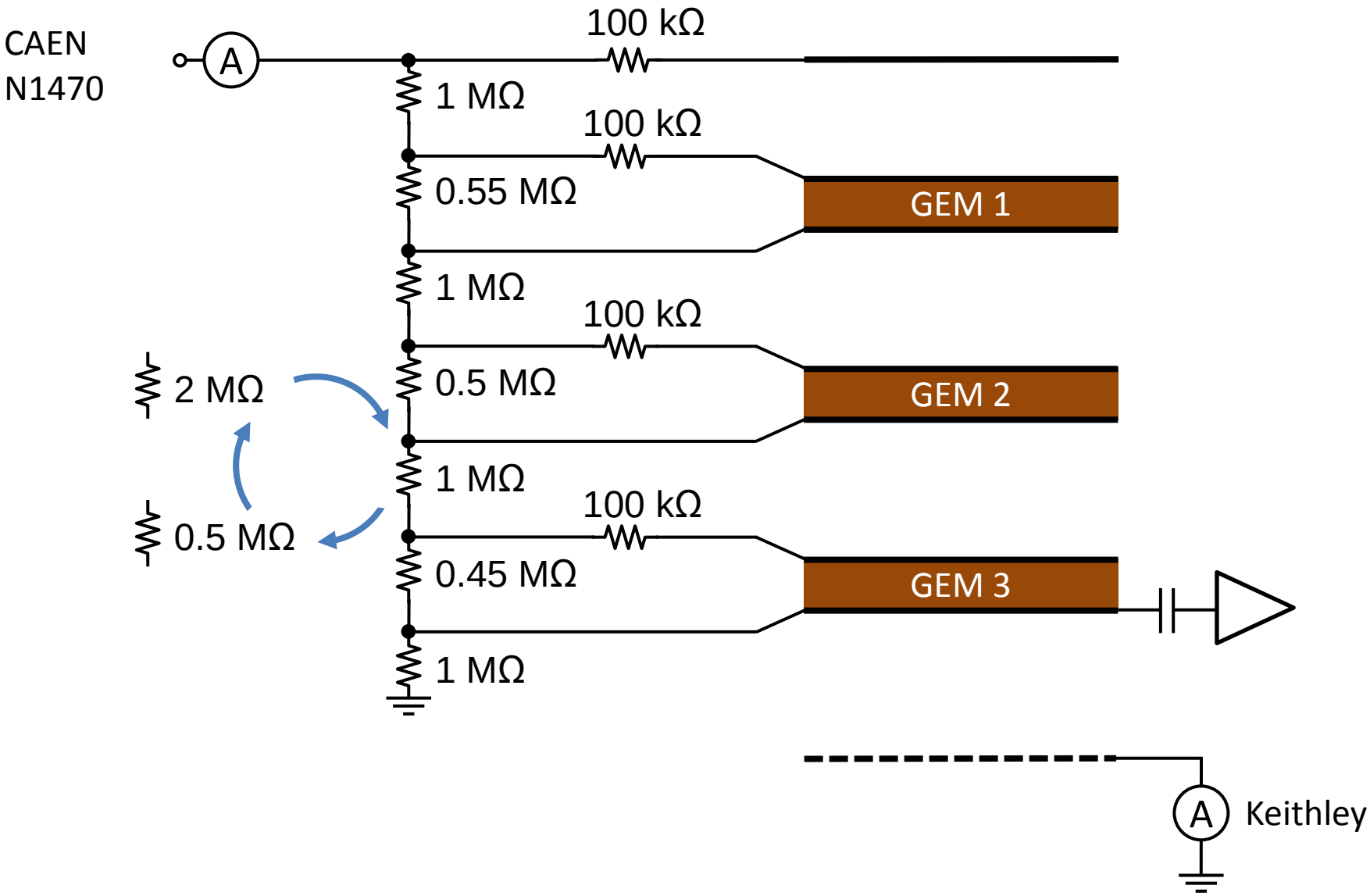
- Increasing x-ray rate is reducing transparency of a mesh



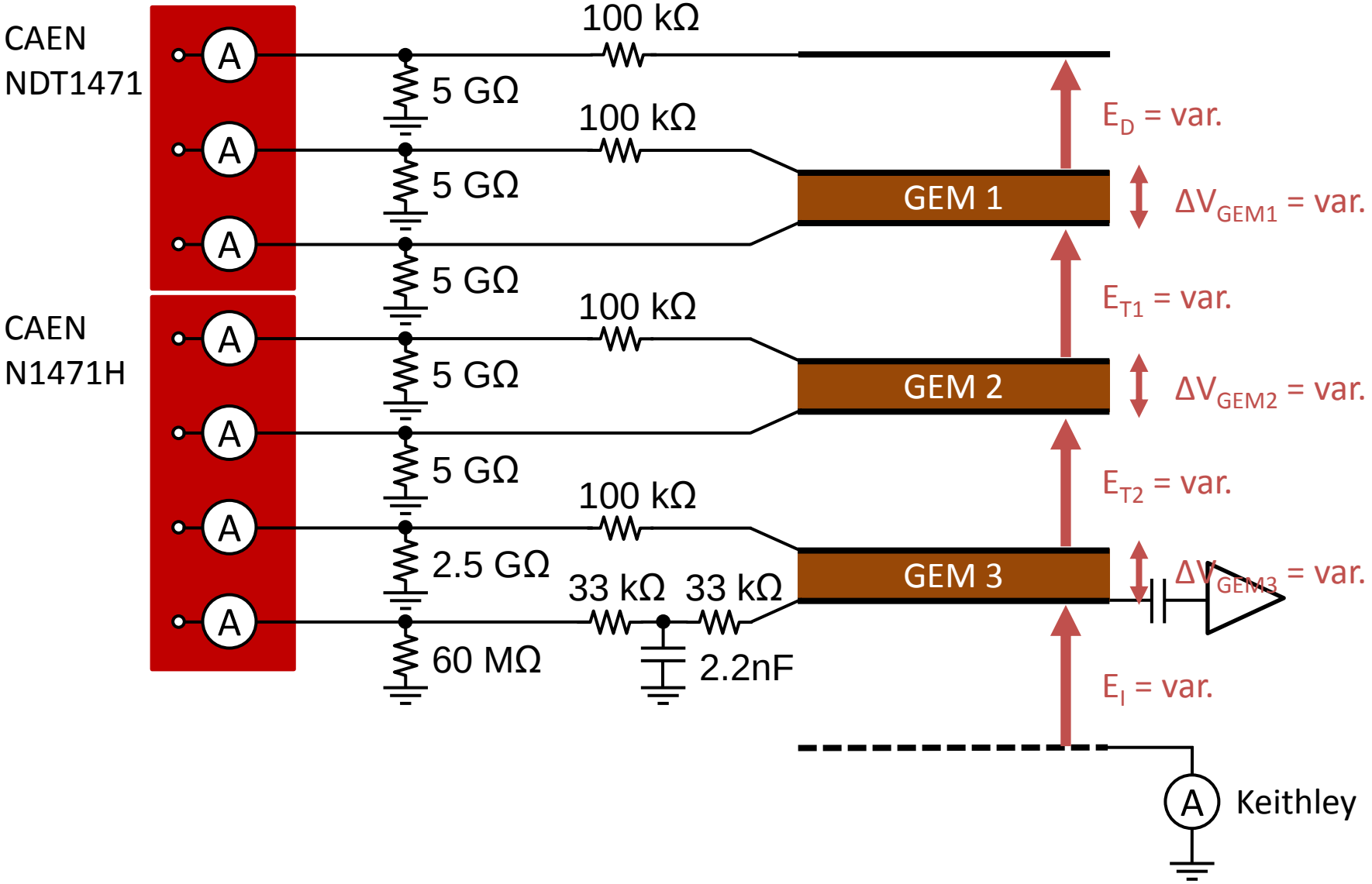
Setup

- Standard Triple-GEM
  - Drift gap: 3 mm
  - Transfer 1, Transfer 2, Induction gap: 2 mm
- Two 4 channel power supplies
  - Drift & each GEM electrode powered indivudually
  - 50 pA current resolution (1 nA for GEM 3 bottom)
- Spectrum from GEM 3 bottom
- Anode current read by Keithley pico-ammeter
  - 50 pA current resolution

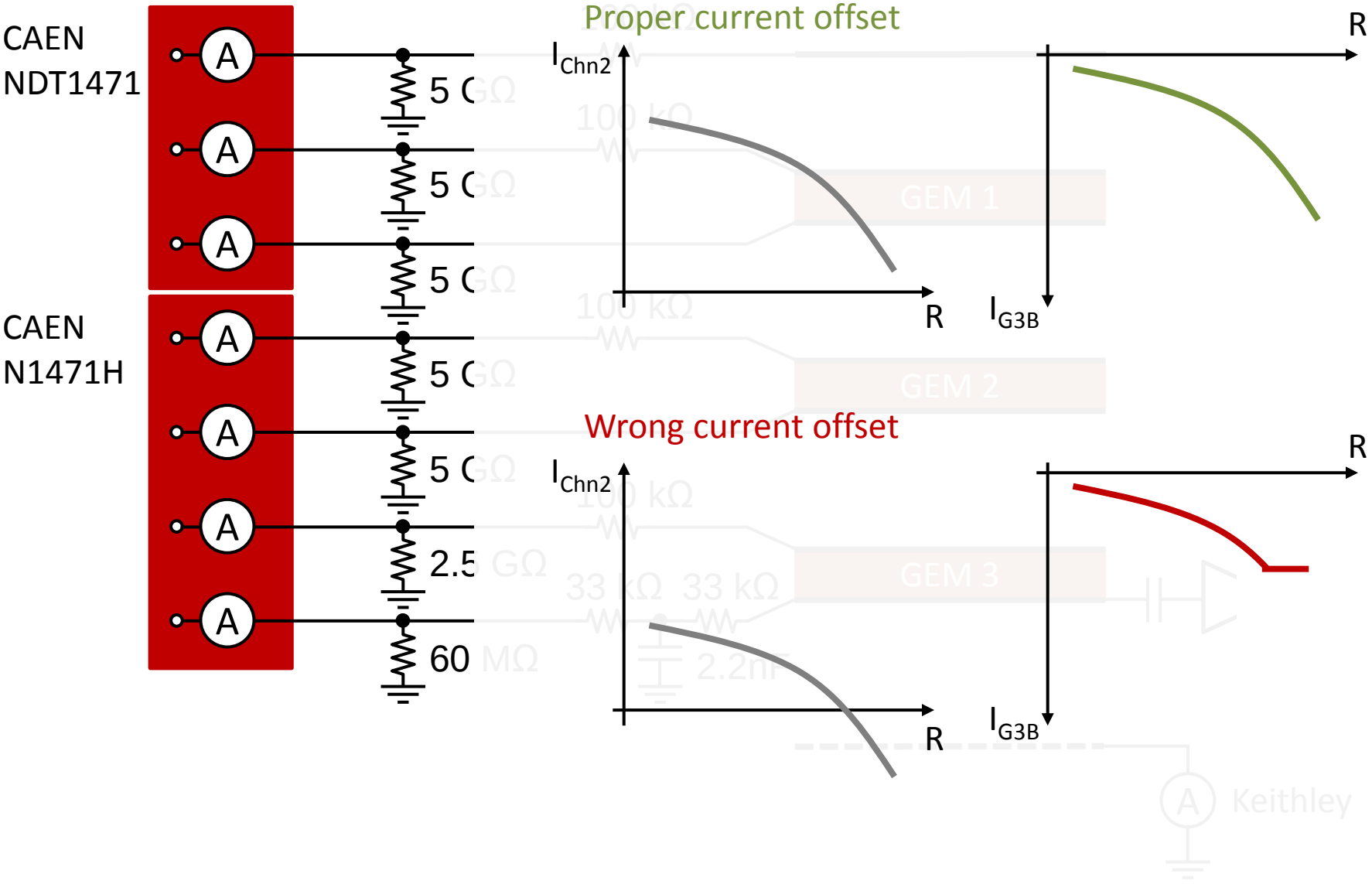
Setup


CAEN
N1470
A
100 kΩ
1 MΩ
100 kΩ
0.55 MΩ
GEM 1
1 MΩ
100 kΩ
0.5 MΩ
GEM 2
2 MΩ
0.5 MΩ
1 MΩ
100 kΩ
0.45 MΩ
GEM 3
1 MΩ
A
Keithley

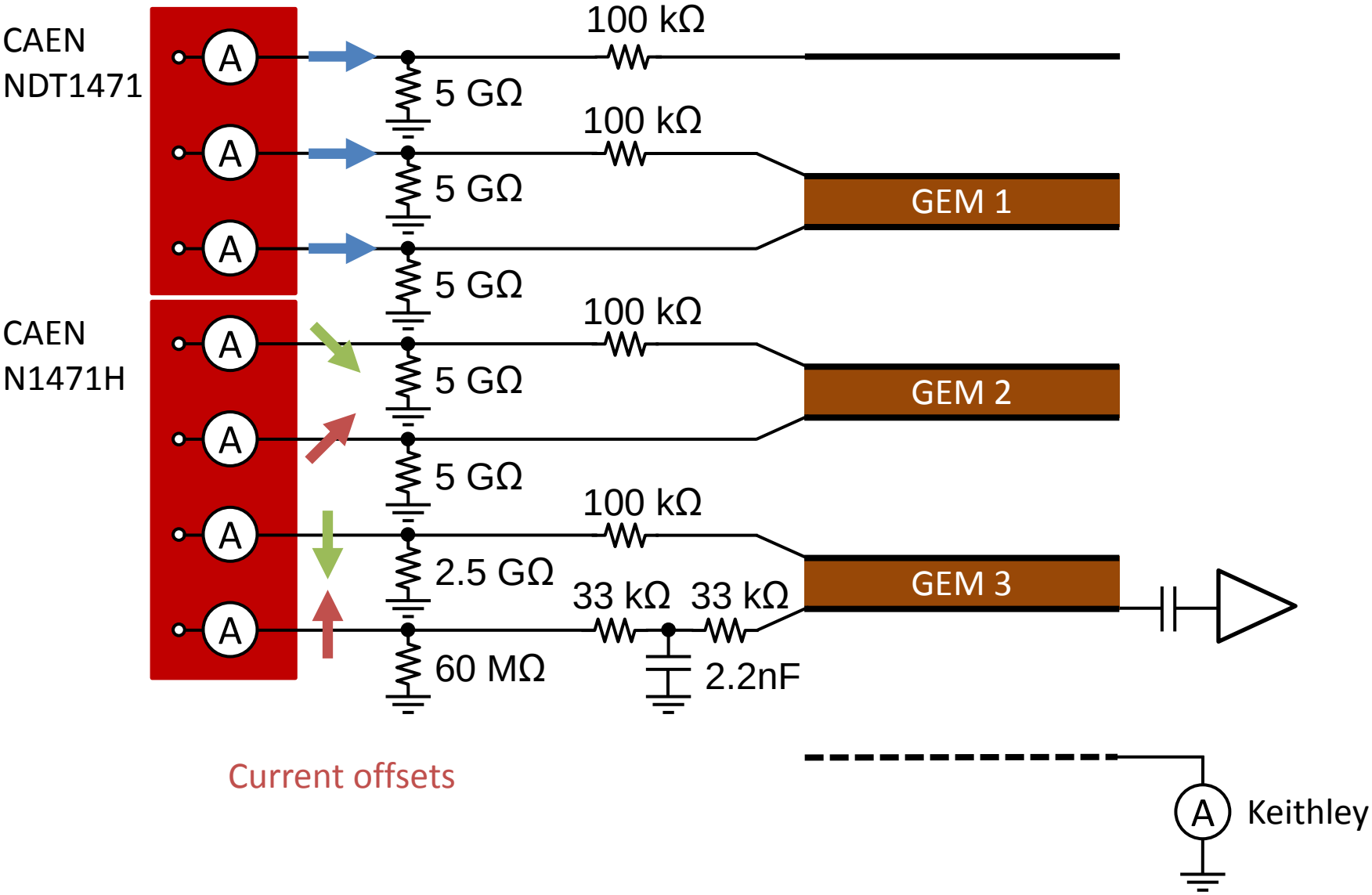
Setup


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

Setup

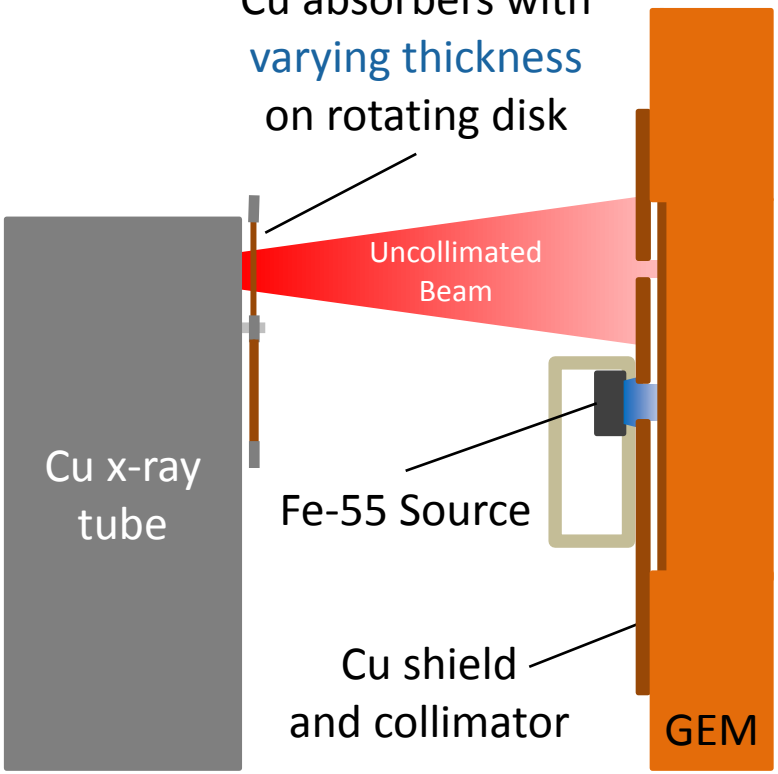

CAEN
NDT1471
CAEN
N1471H
A
A
A
A
A
A
A
5 G
5 G
5 G
5 G
5 G
2.5
60
Proper current offset
I_{Chn2}
R
R
I_{G3B}
Wrong current offset
I_{Chn2}
R
R
I_{G3B}
GEM 1
GEM 2
GEM 3
100 kΩ
100 kΩ
33 kΩ
33 kΩ
2.2nF
A
Keithley

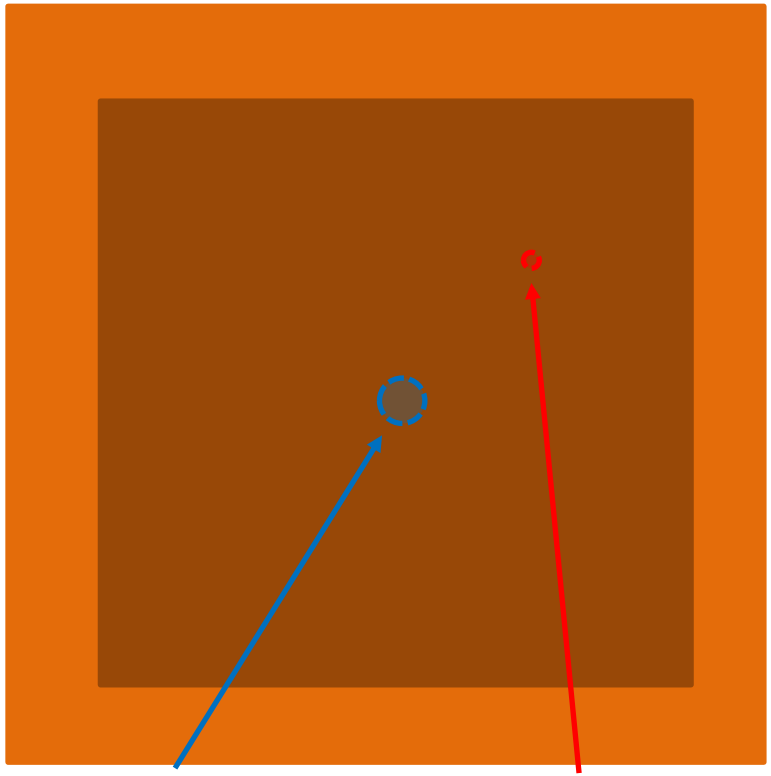
Setup


CAEN
NDT1471
CAEN
N1471H
A
A
A
A
A
A
100 kΩ
5 GΩ
100 kΩ
5 GΩ
5 GΩ
100 kΩ
5 GΩ
5 GΩ
100 kΩ
2.5 GΩ
60 MΩ
33 kΩ
33 kΩ
2.2nF
GEM 1
GEM 2
GEM 3
Current offsets
A
Keithley

Setup

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





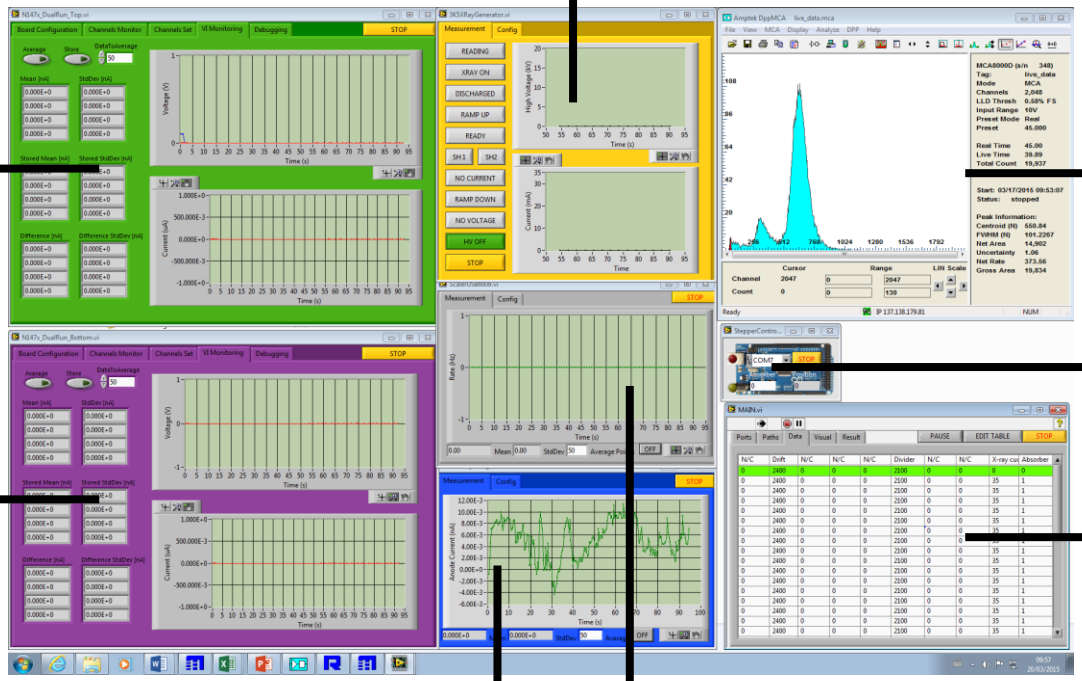
Area **continuously** irradiated (Fe-55 source)

Area irradiated by Cu x-ray tube

Setup

X-ray control

Current and voltage monitoring



Spectrum acquisition

Absorber control

Current and voltage monitoring

DAQ & measurement control

Anode current monitoring

Rate monitoring

Measurements

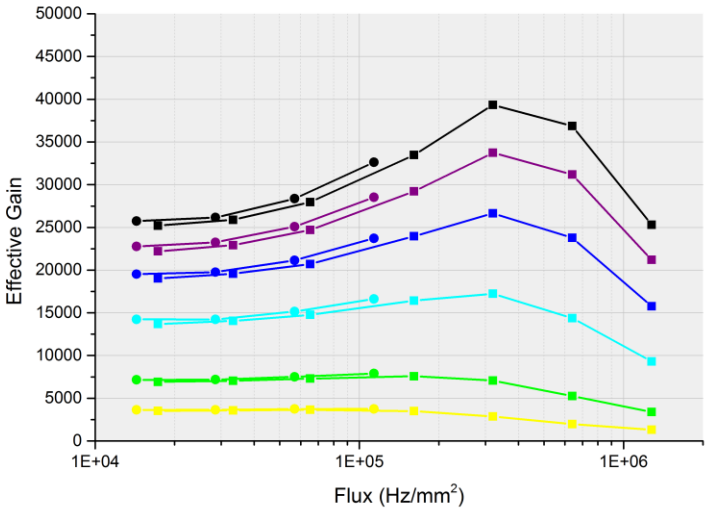
- Fixed gain, variation of
  - Induction field: 0.5 kV/cm to 5 kV/cm
  - Drift field: 0.1 kV/cm to 5 kV/cm
  - Transfer 1 field: 0.5 kV/cm to 5 kV/cm
  - Transfer 2 field: 0.5 kV/cm to 5 kV/cm

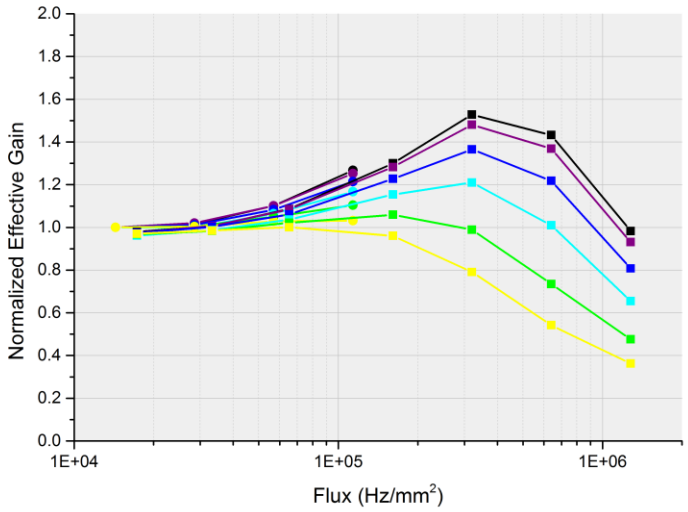
  with other fields and GEM voltages constant
- Changing gain by variation of
  - GEM1 voltage: 370 V to 410 V
  - GEM2 voltage: 330 V to 370 V
  - GEM3 voltage: 290 V to 330 V

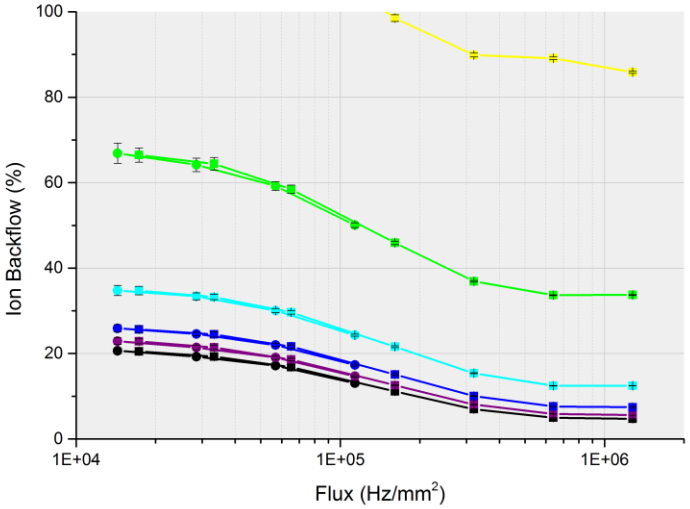
  with other GEM voltages and fields constant

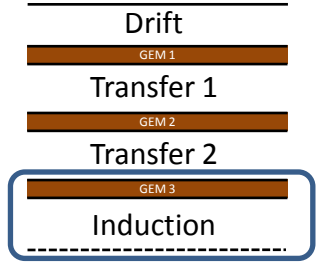
Induction Field Variation

Induction Field Variation



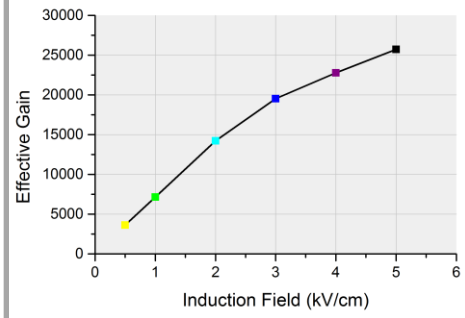




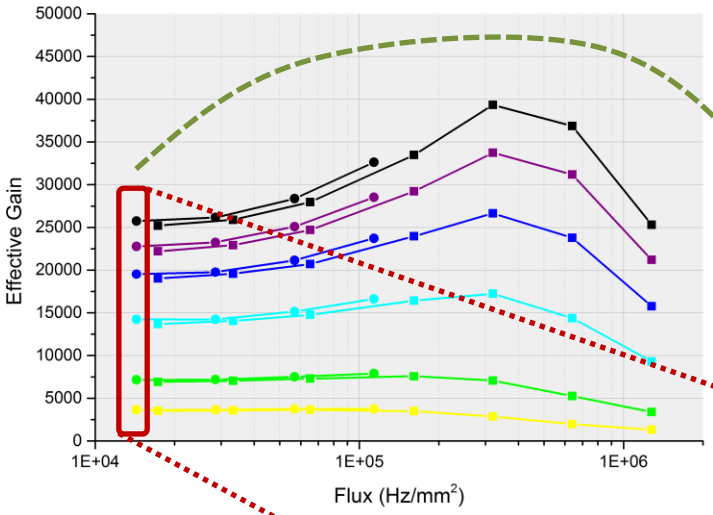


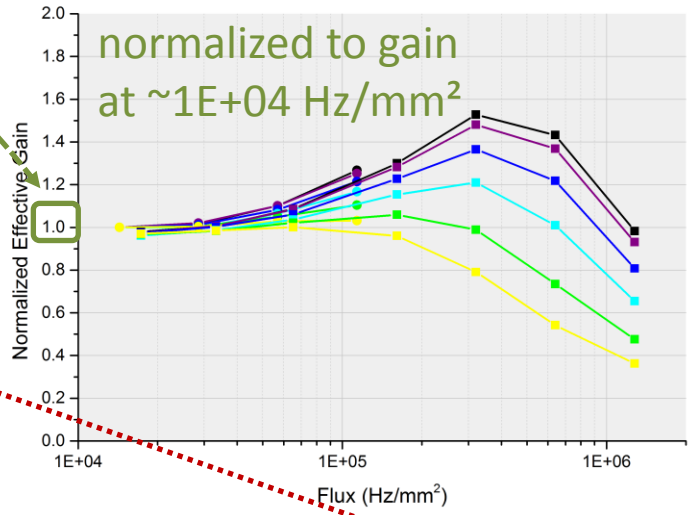
Ar/CO_2 70/30
I_D = 3 mm
$I_{T1} = I_{T2} = I_I$ = 2 mm
$E_{X\text{-}Ray}$ = 8 keV

ΔV_{GEM1} = 410 V
ΔV_{GEM2} = 370 V
ΔV_{GEM3} = 330 V
E_D = 1.5 kV/cm
$E_{T1} = E_{T2}$ = 3.6 kV/cm
E_I = 5 kV/cm
E_I = 4 kV/cm
E_I = 3 kV/cm
E_I = 2 kV/cm
E_I = 1 kV/cm
E_I = 0.5 kV/cm

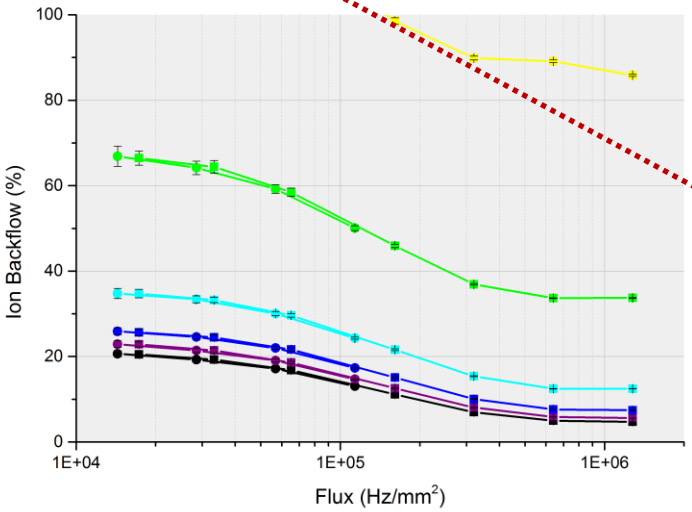


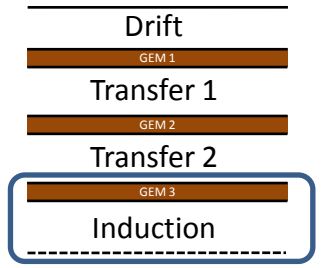
Induction Field Variation





normalized to gain
at ~1E+04 Hz/mm²





where are we?

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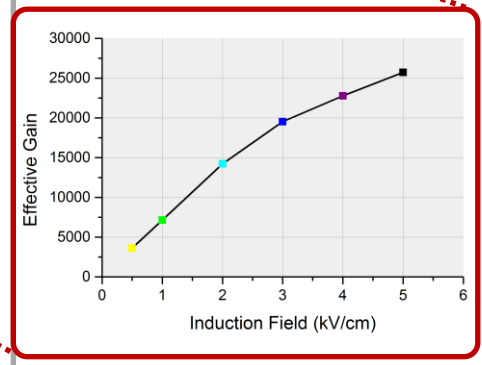
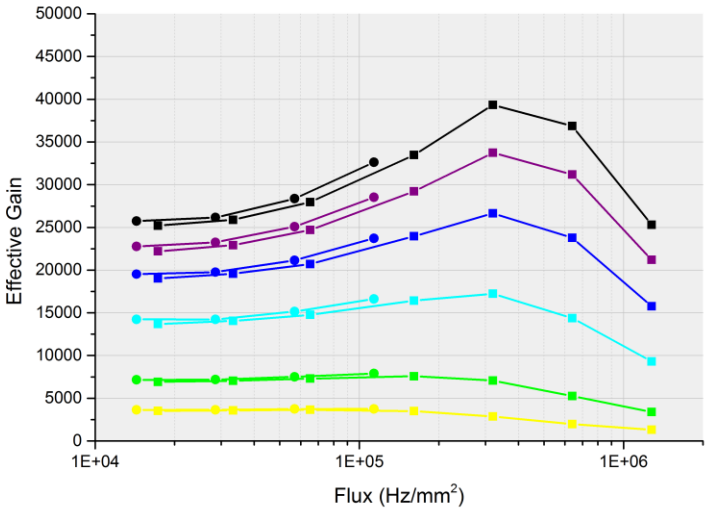
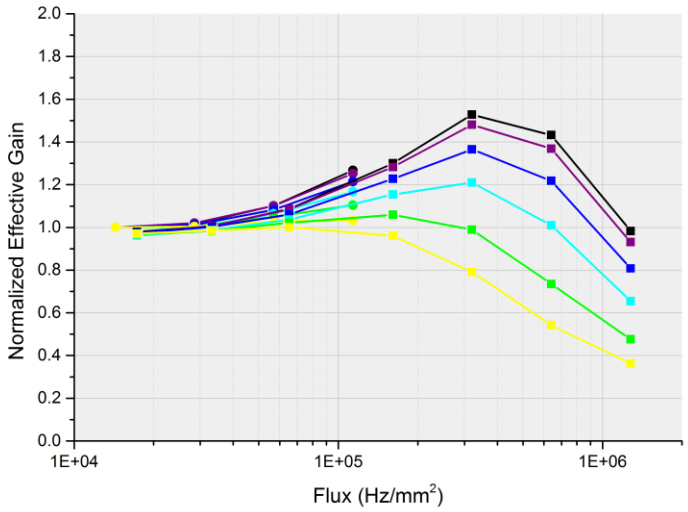
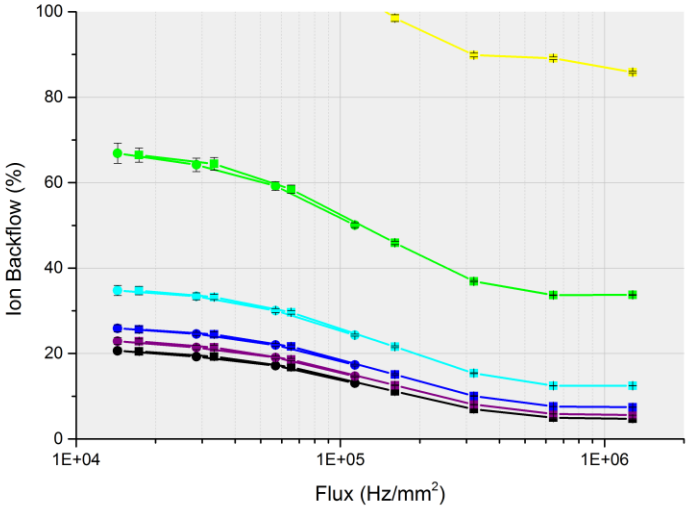
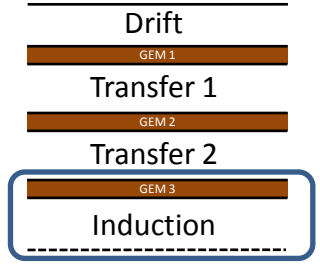


Induction Field Variation









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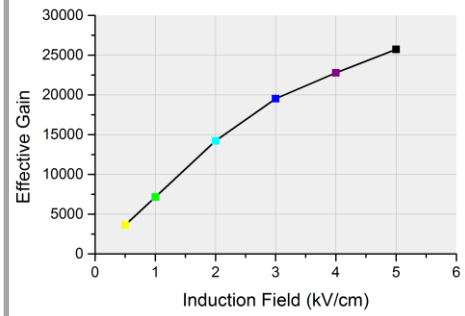
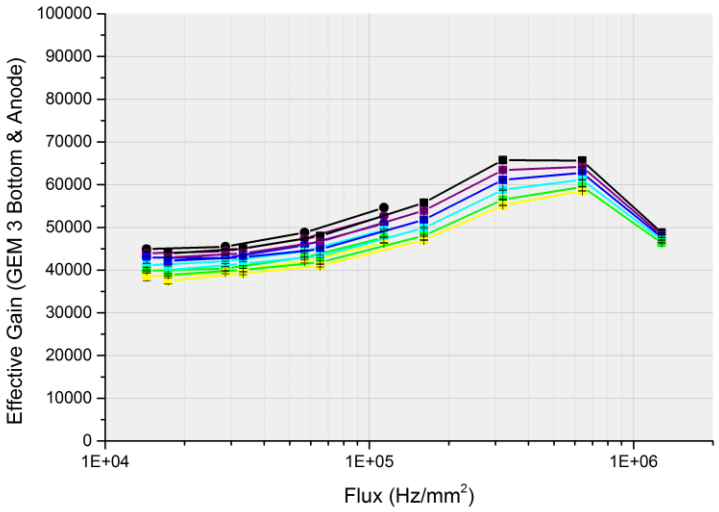
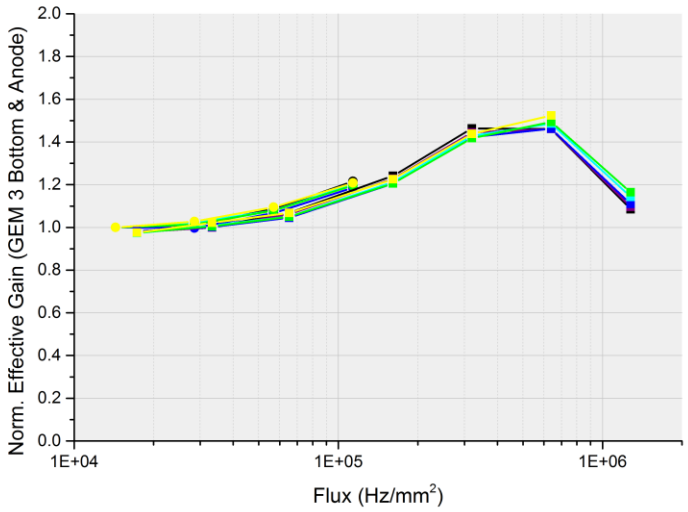
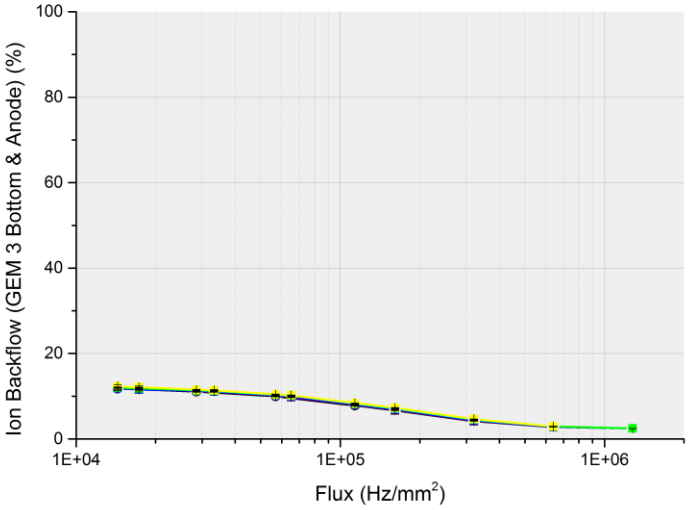


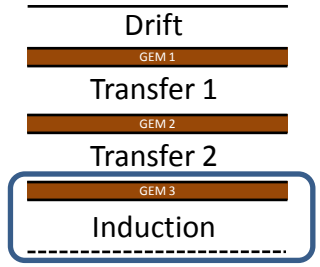
Induction Field Variation







1) Rise of gain still observable
2) Different slopes due to charge sharing between GEM 3 bottom electrode and anode



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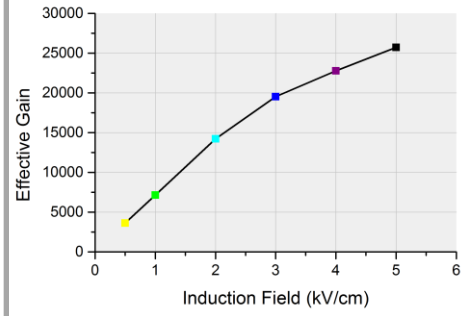
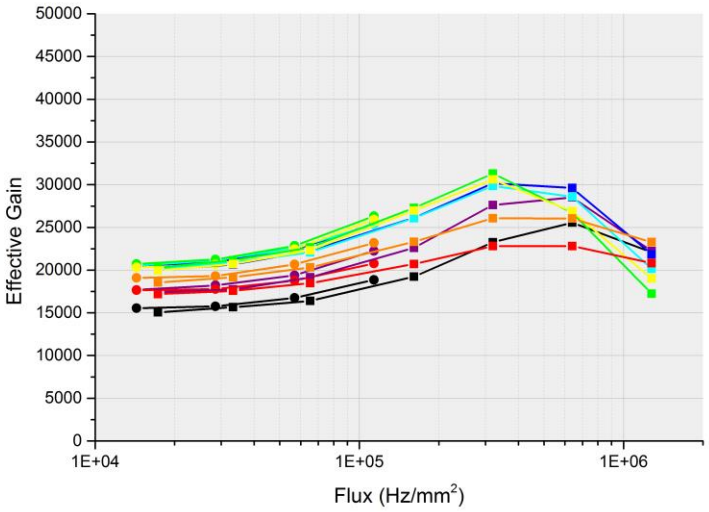
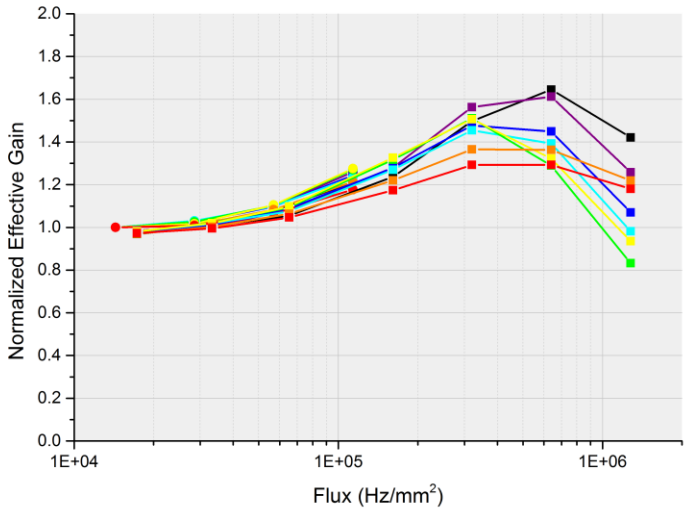
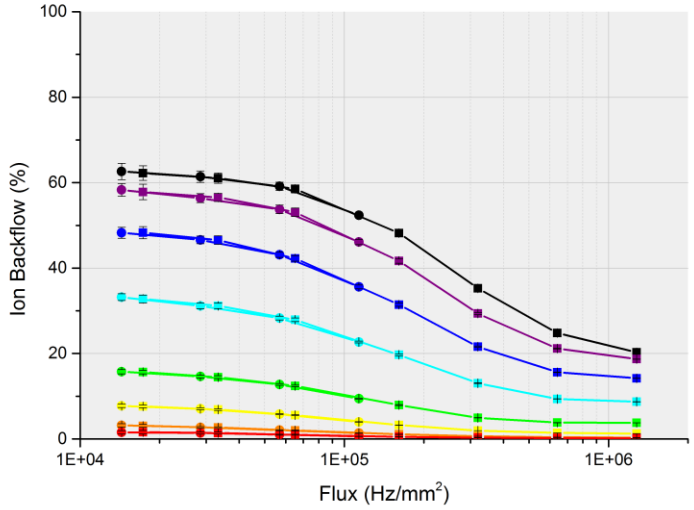


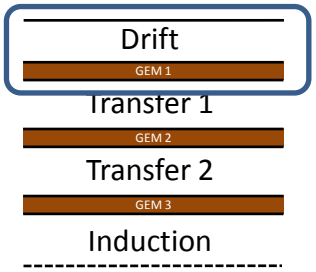
Drift Field Variation

Drift Field Variation









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l_D = 3 mm
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ΔV_{GEM1} = 410 V
ΔV_{GEM2} = 370 V
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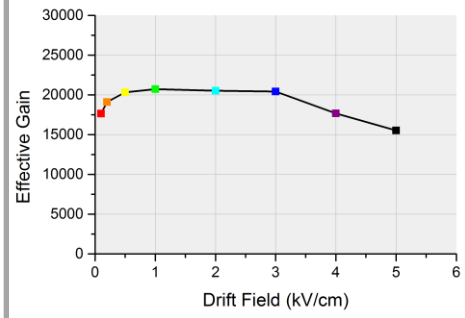
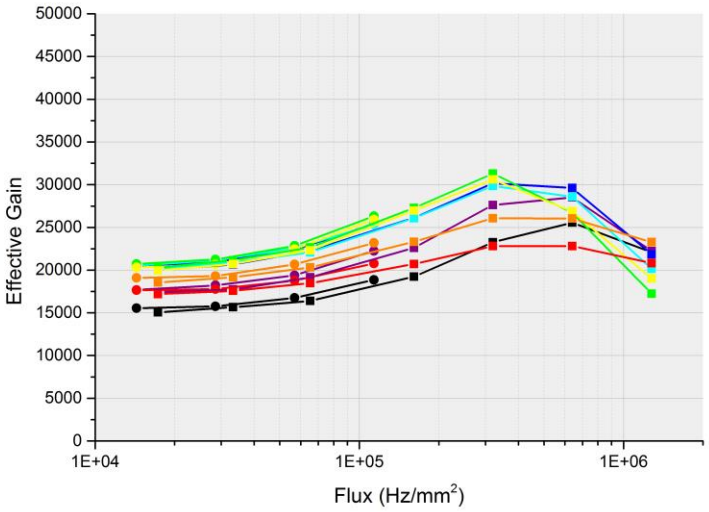
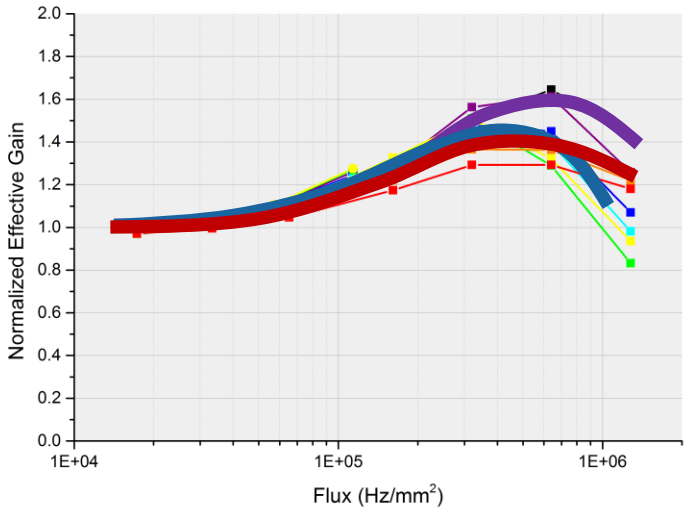
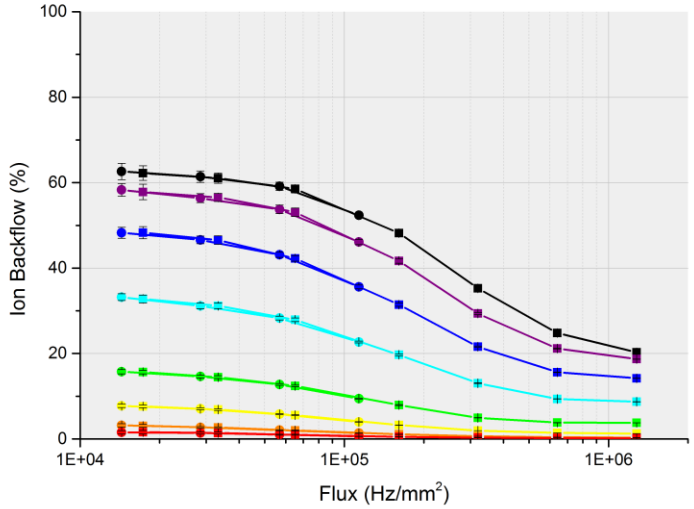
$E_{T1} = E_{T2} = E_I$ = 3.6 kV/cm
E_D = 5 kV/cm
E_D = 4 kV/cm
E_D = 3 kV/cm
E_D = 2 kV/cm
E_D = 1 kV/cm
E_D = 0.5 kV/cm
E_D = 0.2 kV/cm
E_D = 0.1 kV/cm



Drift Field Variation

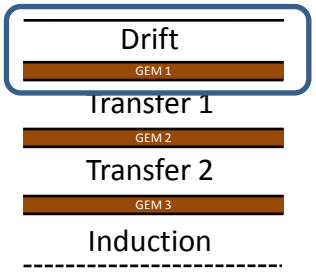






Three different regions observable

1) Loss of primaries for $E_D \leq 0.2$ kV/cm
2) Plateau
3) Loss of primaries for $E_D \geq 4$ kV/cm



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ΔV_{GEM1} = 410 V
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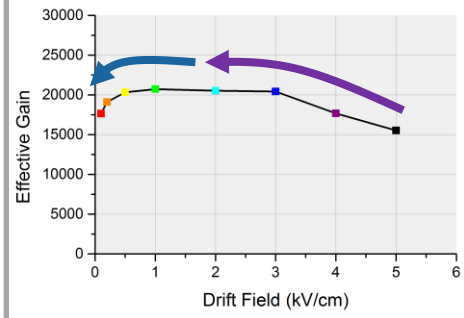
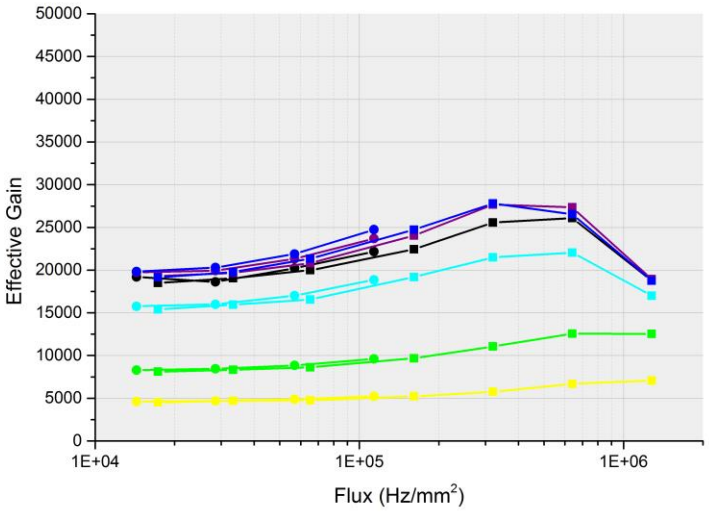
ΔV_{GEM3} = 330 V
$E_{T1} = E_{T2} = E_I$ = 3.6 kV/cm

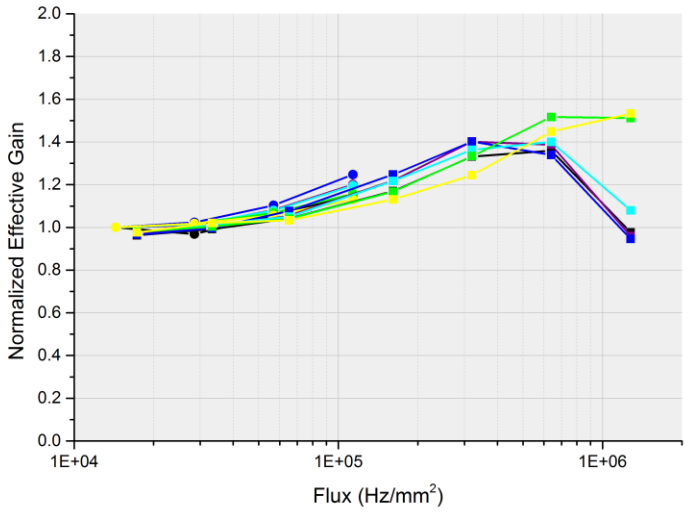
E_D = 5 kV/cm
E_D = 4 kV/cm
E_D = 3 kV/cm
E_D = 2 kV/cm
E_D = 1 kV/cm
E_D = 0.5 kV/cm
E_D = 0.2 kV/cm
E_D = 0.1 kV/cm

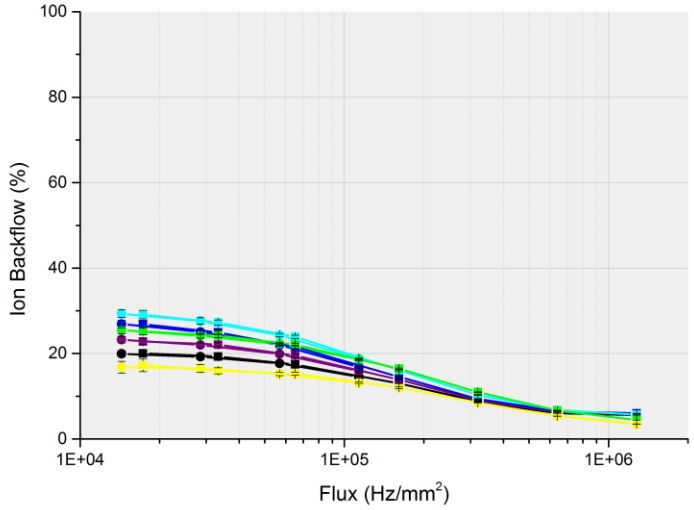


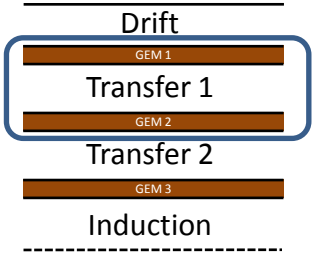
Transfer 1 Field Variation

Transfer 1 Field Variation



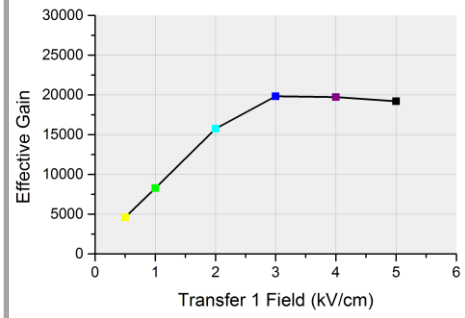




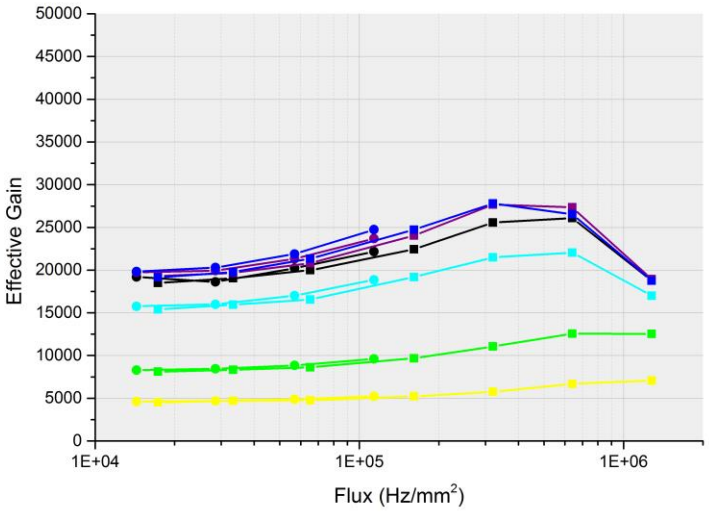


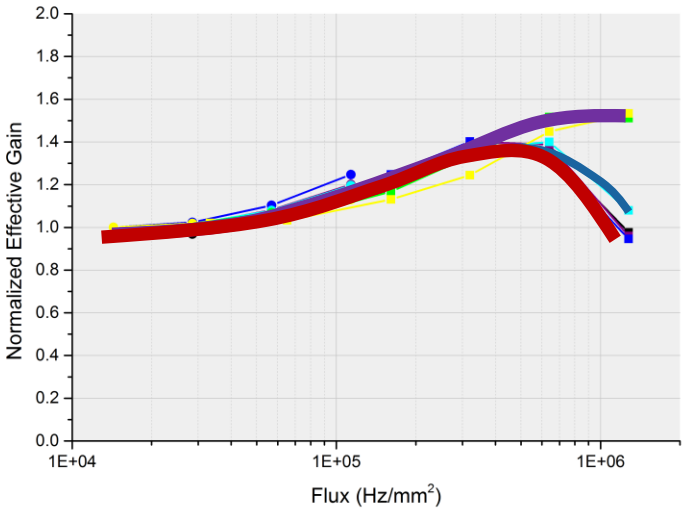
Ar/CO_2 70/30
I_D = 3 mm
$I_{T1} = I_{T2} = I_I$ = 2 mm
$E_{X\text{-}Ray}$ = 8 keV

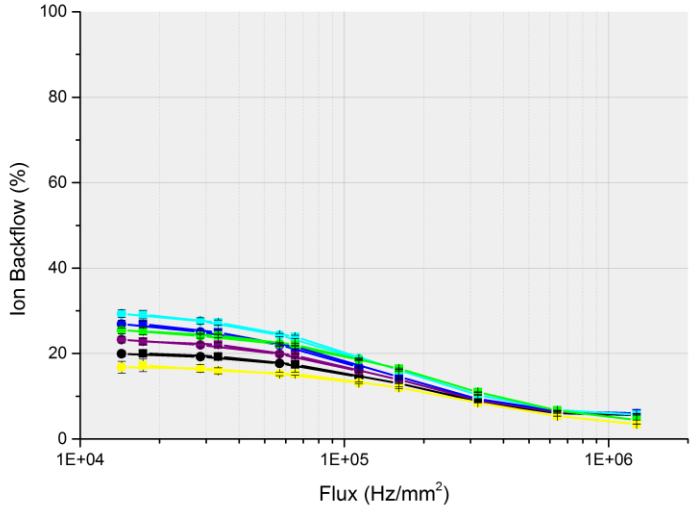
ΔV_{GEM1} = 410 V
ΔV_{GEM2} = 370 V
ΔV_{GEM3} = 330 V
E_D = 1.5 kV/cm
$E_{T2} = E_{TI}$ = 3.6 kV/cm
E_{T1} = 5 kV/cm
E_{T1} = 4 kV/cm
E_{T1} = 3 kV/cm
E_{T1} = 2 kV/cm
E_{T1} = 1 kV/cm
E_{T1} = 0.5 kV/cm



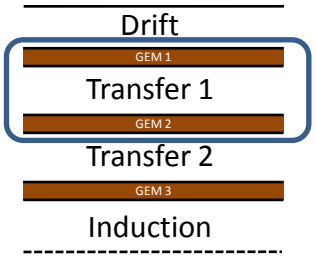
Transfer 1 Field Variation







1) Plateau for $E_{T1} \geq 3$ kV/cm
2) No plateau for $E_{T1} \leq 1$ kV/cm



Ar/CO_2 70/30
I_D = 3 mm
$I_{T1} = I_{T2} = I_I$ = 2 mm
$E_{X\text{-}Ray}$ = 8 keV

ΔV_{GEM1} = 410 V
ΔV_{GEM2} = 370 V
ΔV_{GEM3} = 330 V
E_D = 1.5 kV/cm
$E_{T2} = E_{TI}$ = 3.6 kV/cm
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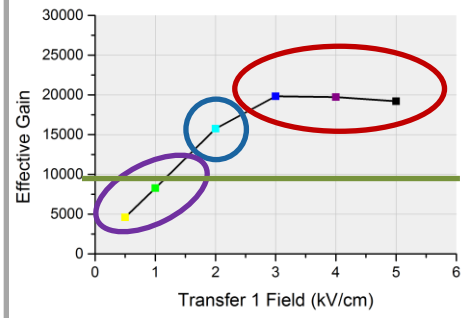
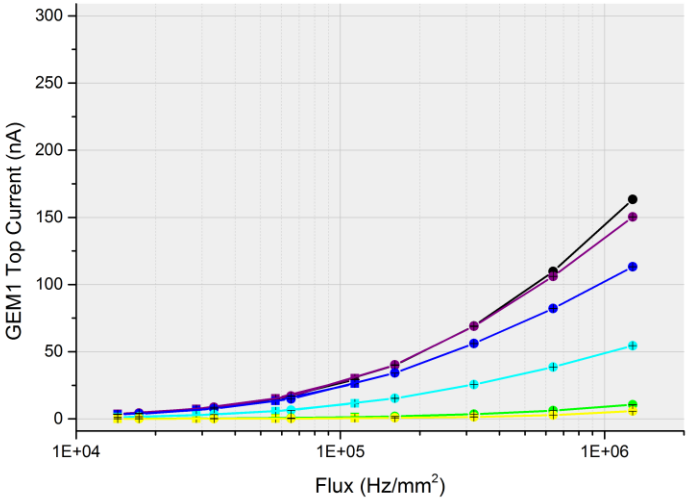
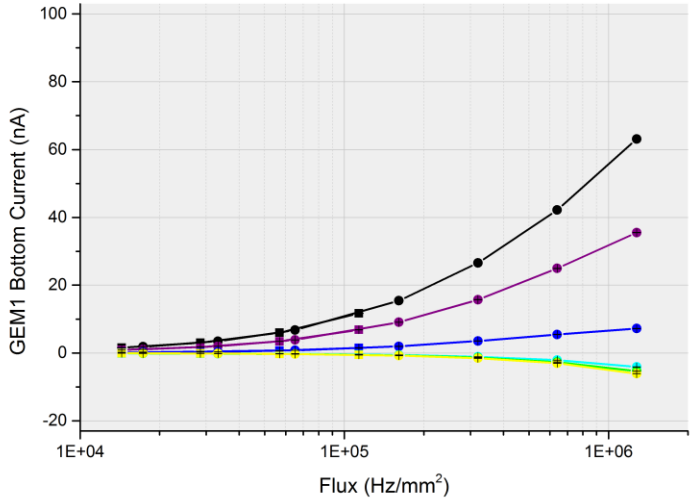
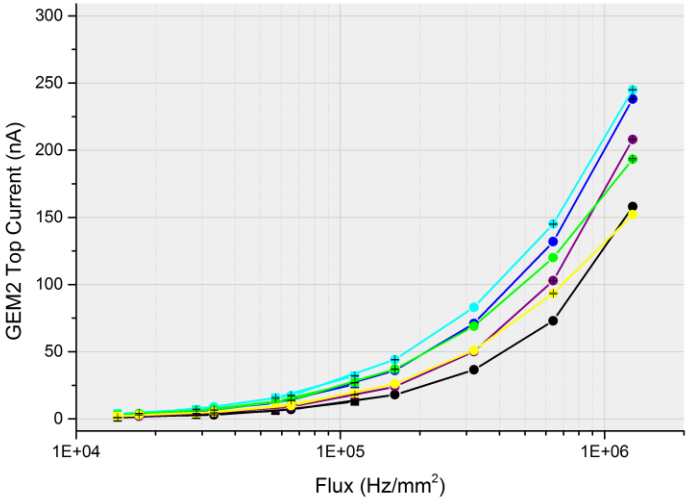
E_{T1} = 4 kV/cm
E_{T1} = 3 kV/cm
E_{T1} = 2 kV/cm
E_{T1} = 1 kV/cm
E_{T1} = 0.5 kV/cm

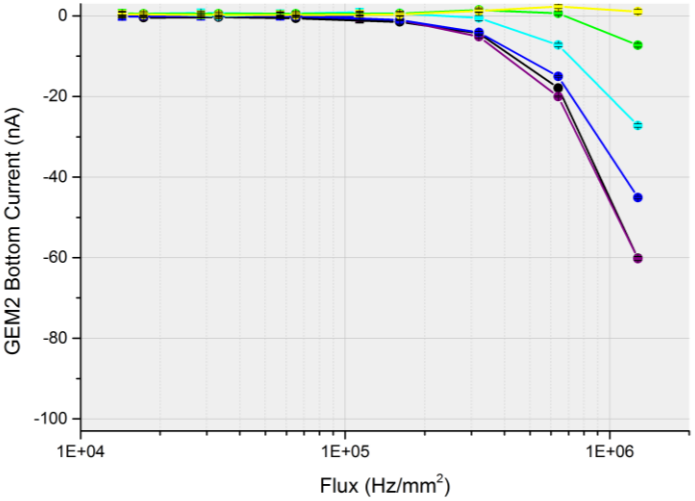


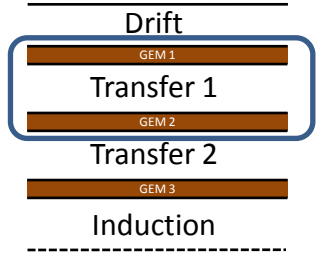
Transfer 1 Field Variation





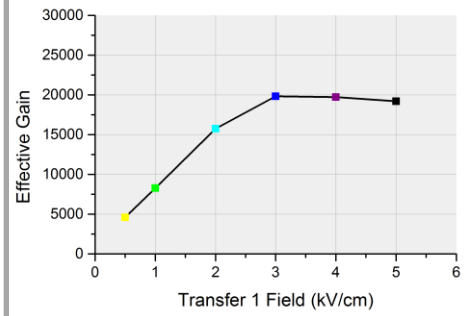






Ar/CO_2 70/30
I_D = 3 mm
$I_{T1} = I_{T2} = I_I$ = 2 mm
$E_{X\text{-}Ray}$ = 8 keV

ΔV_{GEM1} = 410 V
ΔV_{GEM2} = 370 V
ΔV_{GEM3} = 330 V
E_D = 1.5 kV/cm
$E_{T2} = E_{TI}$ = 3.6 kV/cm
E_{T1} = 5 kV/cm
E_{T1} = 4 kV/cm
E_{T1} = 3 kV/cm
E_{T1} = 2 kV/cm
E_{T1} = 1 kV/cm
E_{T1} = 0.5 kV/cm

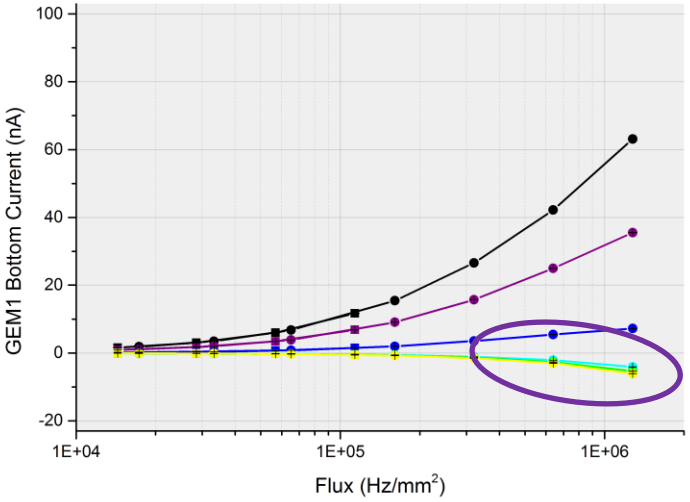


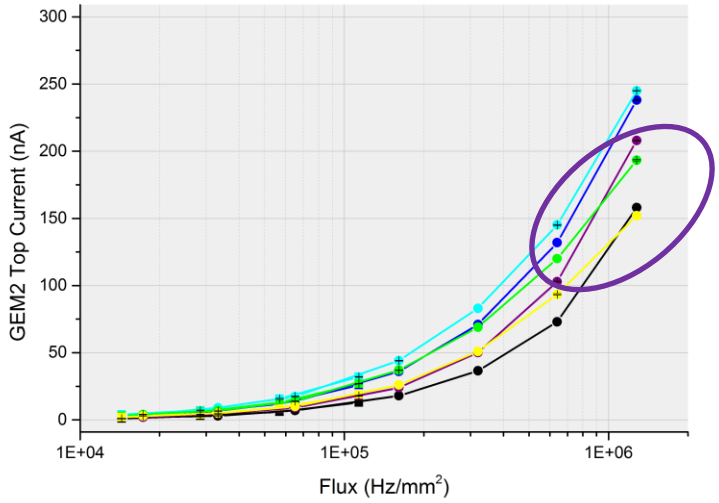
Transfer 1 Field Variation

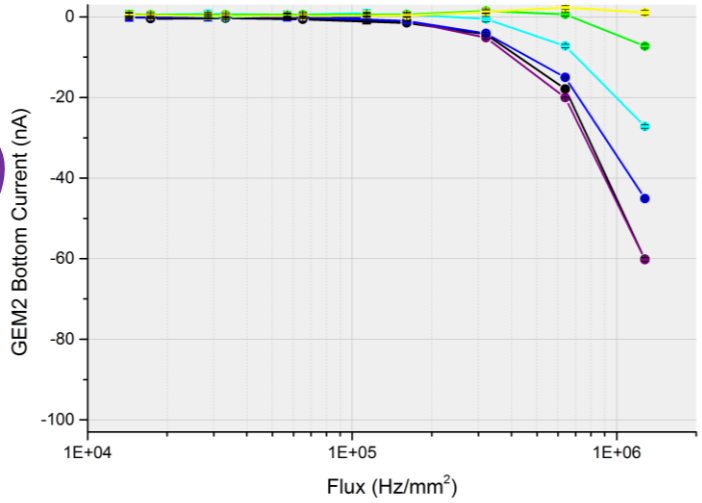
Problem:

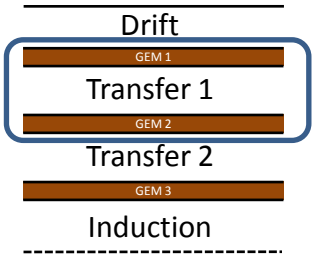
not possible to discriminate ion from electron current

- Electrons attached to bottom of GEM 1 for $E_{T1} \leq 1$ kV/cm
- No ions extracted from GEM2
- Probably both!



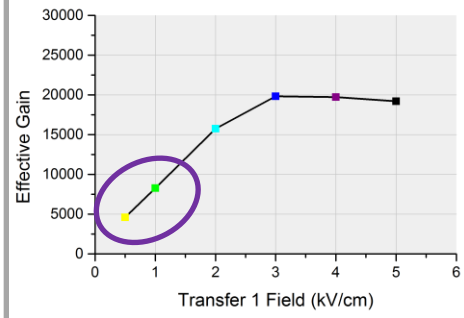






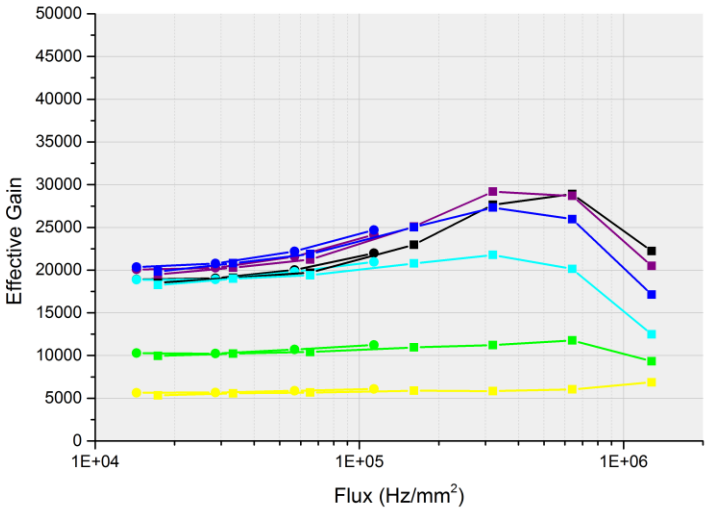
Ar/CO_2 70/30
I_D = 3 mm
$I_{T1} = I_{T2} = I_I$ = 2 mm
$E_{X\text{-}Ray}$ = 8 keV

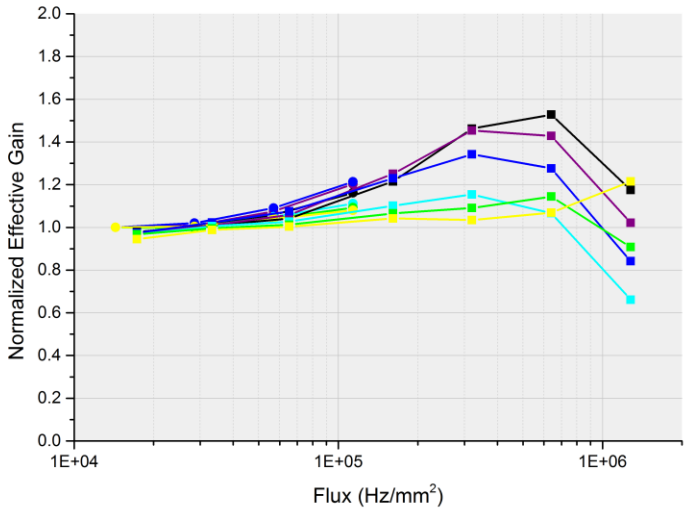
ΔV_{GEM1} = 410 V
ΔV_{GEM2} = 370 V
ΔV_{GEM3} = 330 V
E_D = 1.5 kV/cm
$E_{T2} = E_{TI}$ = 3.6 kV/cm
E_{T1} = 5 kV/cm
E_{T1} = 4 kV/cm
E_{T1} = 3 kV/cm
E_{T1} = 2 kV/cm
E_{T1} = 1 kV/cm
E_{T1} = 0.5 kV/cm

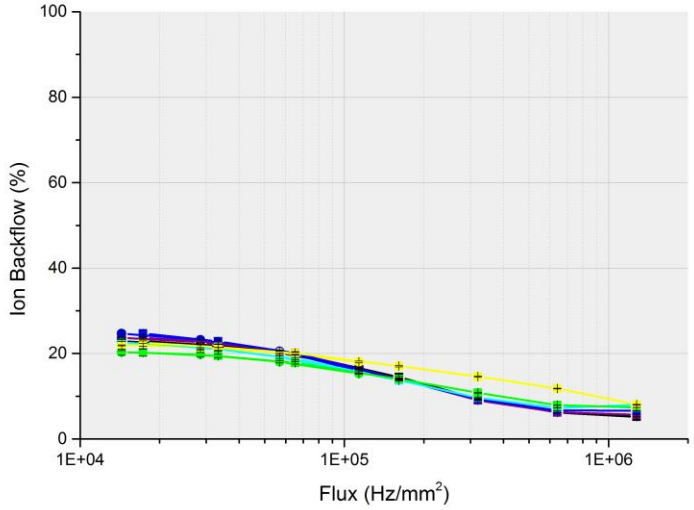


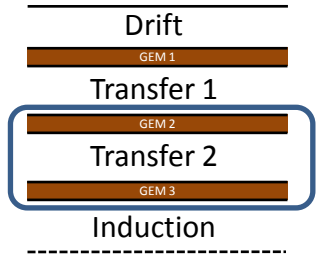
Transfer 2 Field Variation

Transfer 2 Field Variation



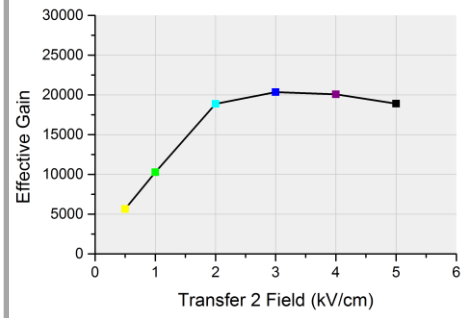




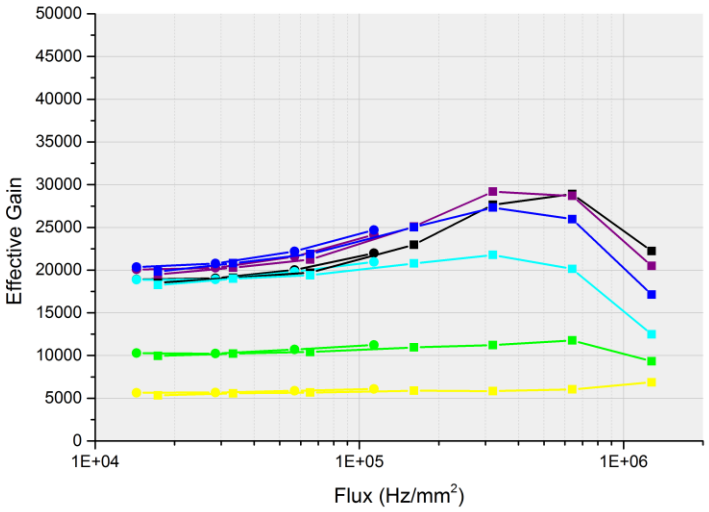


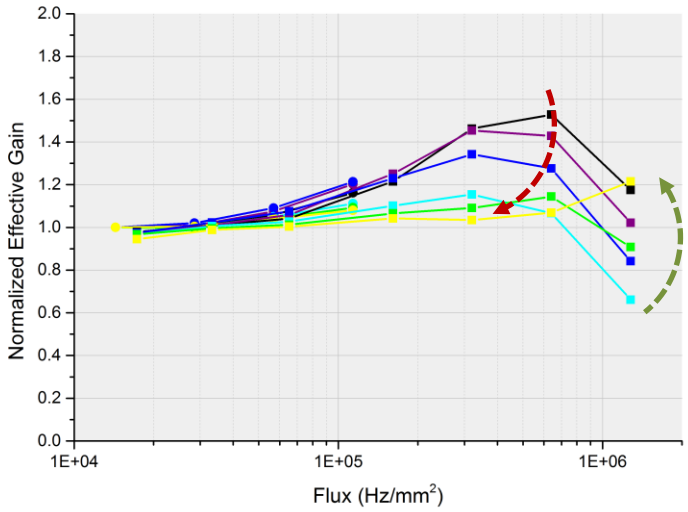
Ar/CO_2 70/30
I_D = 3 mm
$I_{T1} = I_{T2} = I_I$ = 2 mm
$E_{X\text{-}Ray}$ = 8 keV

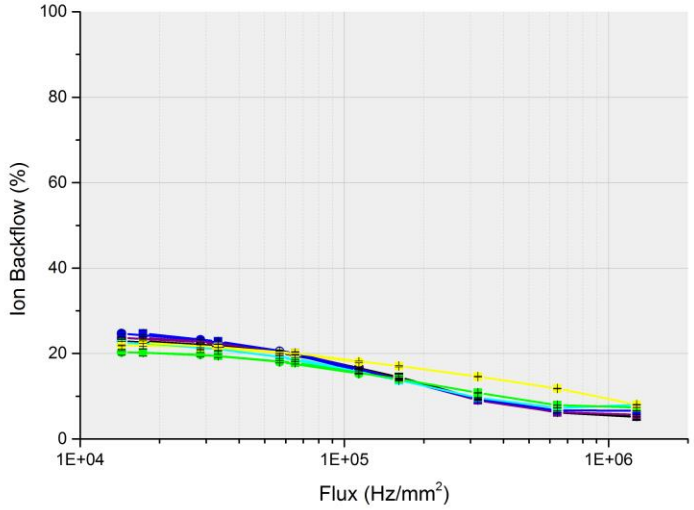
ΔV_{GEM1} = 410 V
ΔV_{GEM2} = 370 V
ΔV_{GEM3} = 330 V
E_D = 1.5 kV/cm
$E_{T1} = E_I$ = 3.6 kV/cm
E_{T2} = 5 kV/cm
E_{T2} = 4 kV/cm
E_{T2} = 3 kV/cm
E_{T2} = 2 kV/cm
E_{T2} = 1 kV/cm
E_{T2} = 0.5 kV/cm

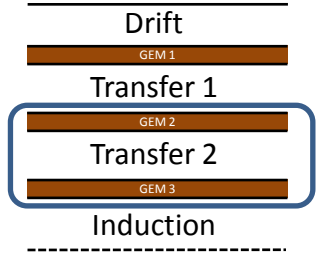


Transfer 2 Field Variation



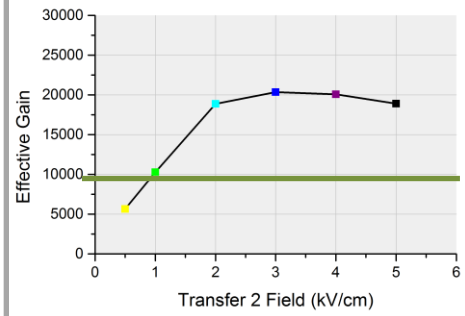






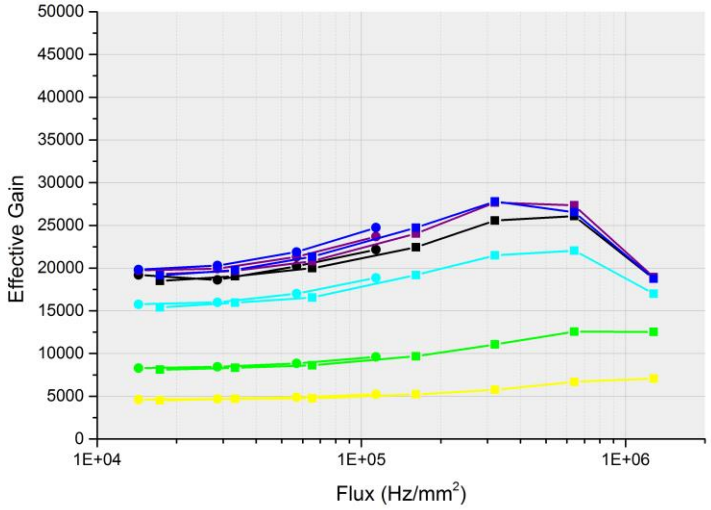
Ar/CO_2 70/30
I_D = 3 mm
$I_{T1} = I_{T2} = I_I$ = 2 mm
$E_{X\text{-}Ray}$ = 8 keV

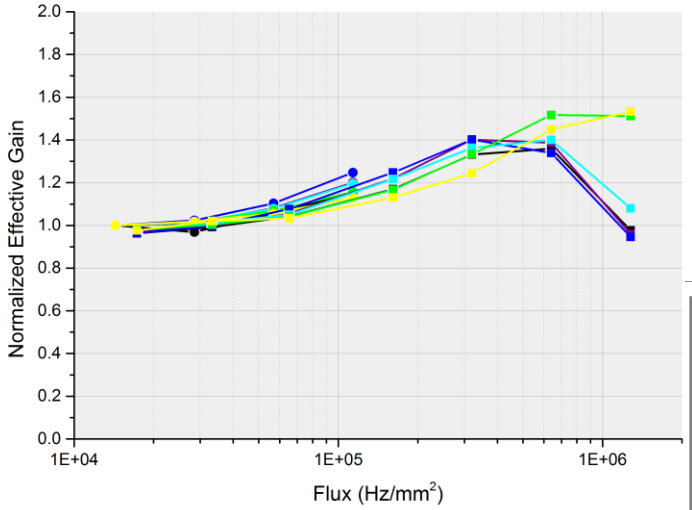
ΔV_{GEM1} = 410 V
ΔV_{GEM2} = 370 V
ΔV_{GEM3} = 330 V
E_D = 1.5 kV/cm
$E_{T1} = E_I$ = 3.6 kV/cm
E_{T2} = 5 kV/cm
E_{T2} = 4 kV/cm
E_{T2} = 3 kV/cm
E_{T2} = 2 kV/cm
E_{T2} = 1 kV/cm
E_{T2} = 0.5 kV/cm

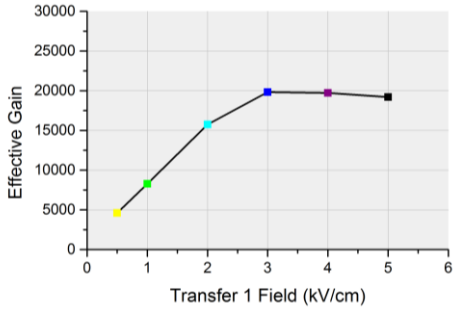


Comparison Transfer 1 & 2 Field Variation

Transfer 1 field variation





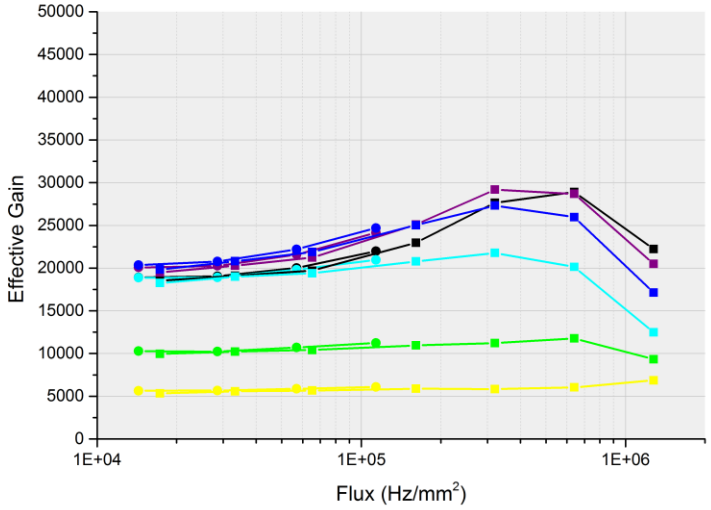


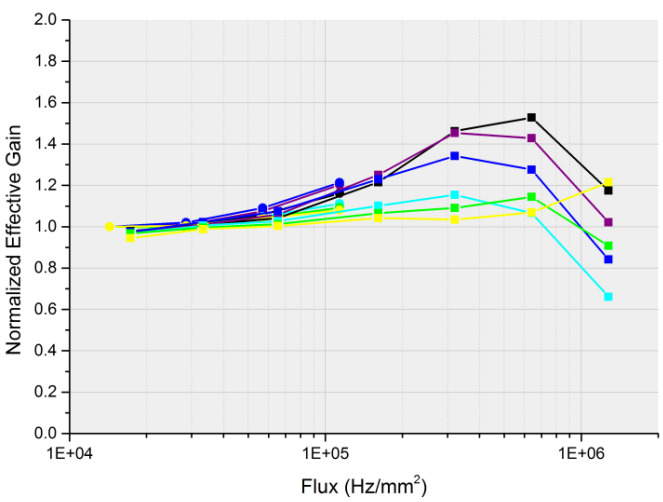
Ar/CO_2 70/30
I_D = 3 mm
$I_{T1} = I_{T2} = I_I$ = 2 mm
$E_{X\text{-}Ray}$ = 8 keV

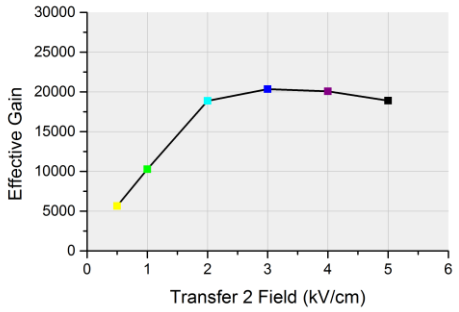
ΔV_{GEM1} = 410 V
ΔV_{GEM2} = 370 V
ΔV_{GEM3} = 330 V
E_D = 1.5 kV/cm
$E_{T1} = E_I$ = 3.6 kV/cm
E_{T2} = 5 kV/cm
E_{T2} = 4 kV/cm
E_{T2} = 3 kV/cm
E_{T2} = 2 kV/cm
E_{T2} = 1 kV/cm
E_{T2} = 0.5 kV/cm

Ar/CO_2 70/30
I_D = 3 mm
$I_{T1} = I_{T2} = I_I$ = 2 mm
$E_{X\text{-}Ray}$ = 8 keV

ΔV_{GEM1} = 410 V
ΔV_{GEM2} = 370 V
ΔV_{GEM3} = 330 V
E_D = 1.5 kV/cm
$E_{T2} = E_{TI}$ = 3.6 kV/cm
E_{T1} = 5 kV/cm
E_{T1} = 4 kV/cm
E_{T1} = 3 kV/cm
E_{T1} = 2 kV/cm
E_{T1} = 1 kV/cm
E_{T1} = 0.5 kV/cm



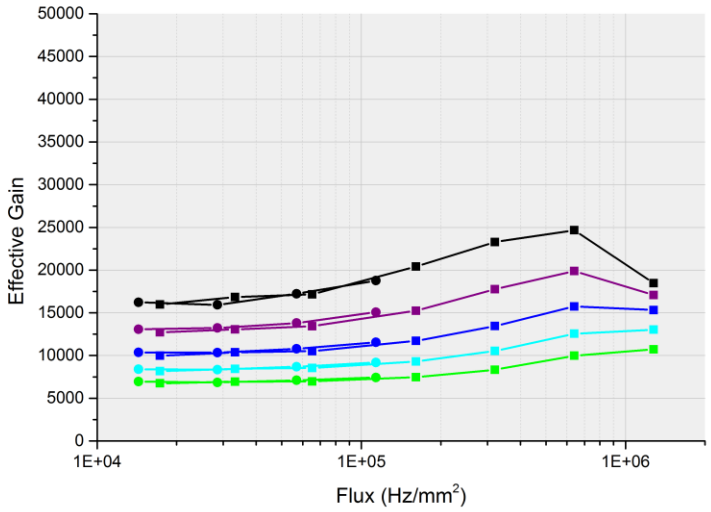


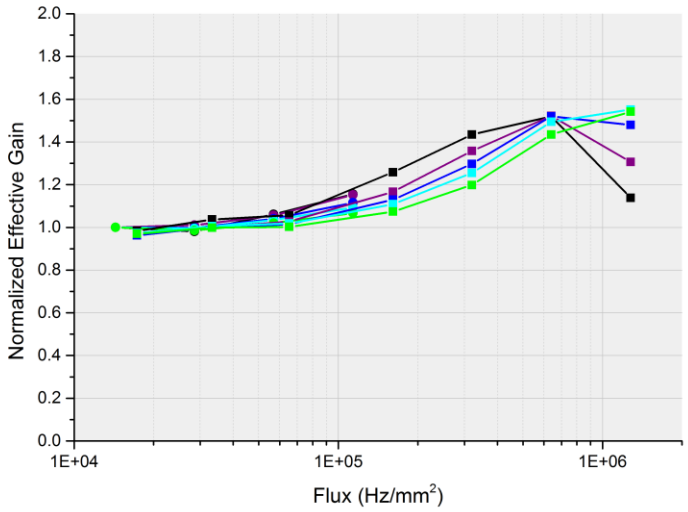


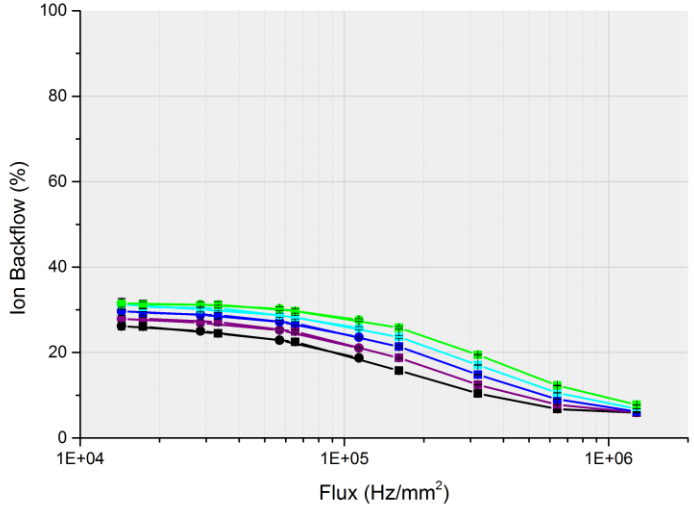
Transfer 2 field variation

GEM 1 Voltage Variation

GEM 1 Voltage Variation

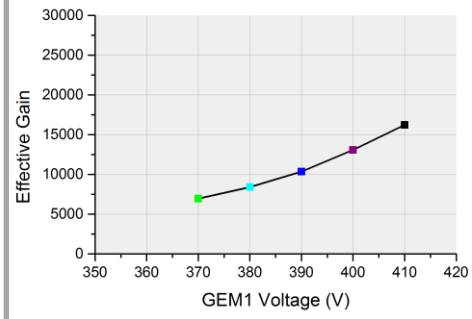




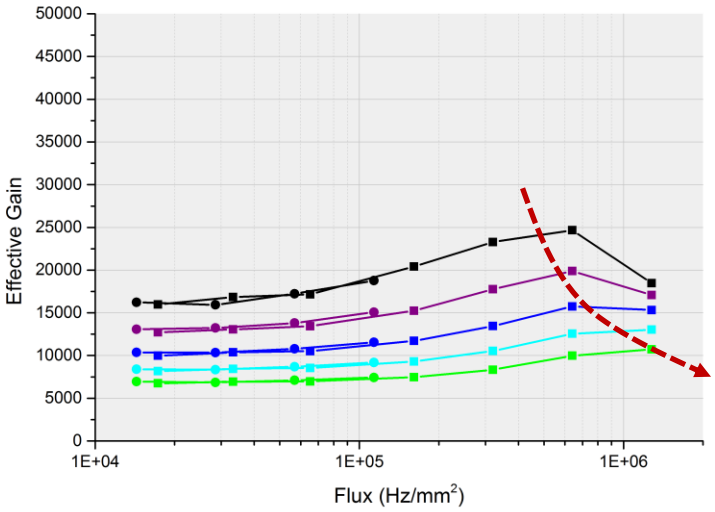


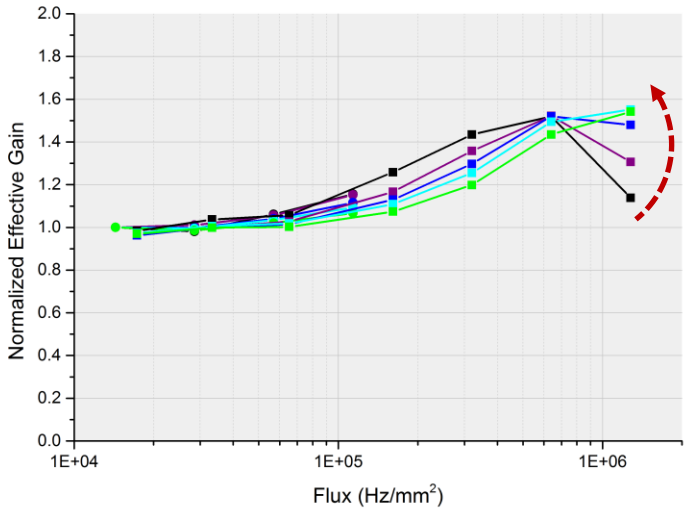
Ar/CO_2 70/30
I_D = 3 mm
$I_{T1} = I_{T2} = I_I$ = 2 mm
$E_{X\text{-}Ray}$ = 8 keV

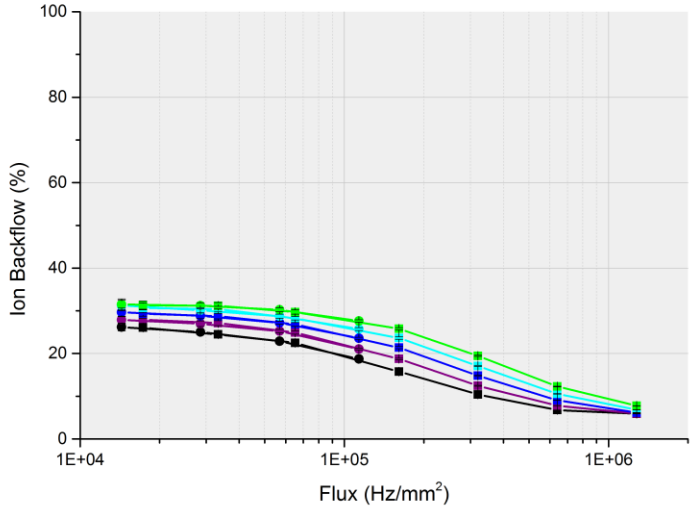
ΔV_{GEM2} = 370 V
ΔV_{GEM3} = 330 V
E_D = 1.5 kV/cm
$E_{T1} = E_{T2} = E_I$ = 3.6 kV/cm
ΔV_{GEM1} = 410 V
ΔV_{GEM1} = 400 V
ΔV_{GEM1} = 390 V
ΔV_{GEM1} = 380 V
ΔV_{GEM1} = 370 V



GEM 1 Voltage Variation





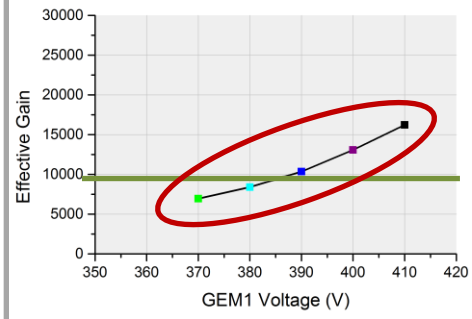


1) No plateau!
2) Still difference in slopes of gain increase & decrease

Space charge effect!

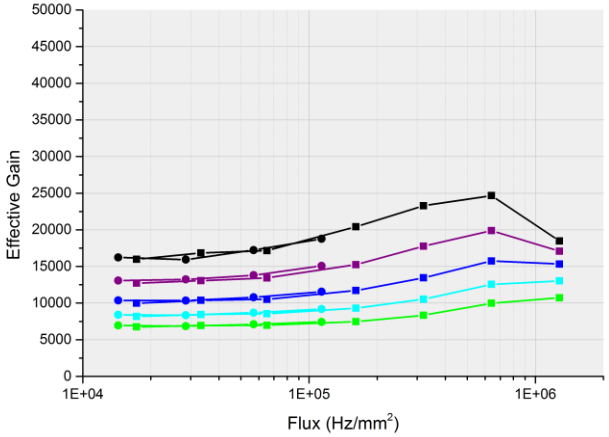
Ar/CO_2 70/30
I_D = 3 mm
$I_{T1} = I_{T2} = I_I$ = 2 mm
$E_{X\text{-}Ray}$ = 8 keV

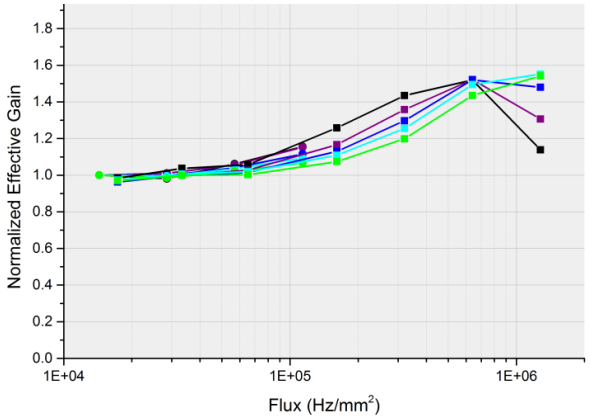
ΔV_{GEM2} = 370 V
ΔV_{GEM3} = 330 V
E_D = 1.5 kV/cm
$E_{T1} = E_{T2} = E_I$ = 3.6 kV/cm
ΔV_{GEM1} = 410 V
ΔV_{GEM1} = 400 V
ΔV_{GEM1} = 390 V
ΔV_{GEM1} = 380 V
ΔV_{GEM1} = 370 V

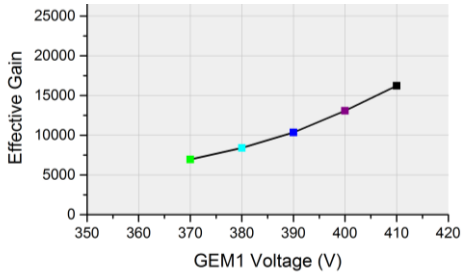


Comparison of GEM 1, 2 & 3 voltage variation

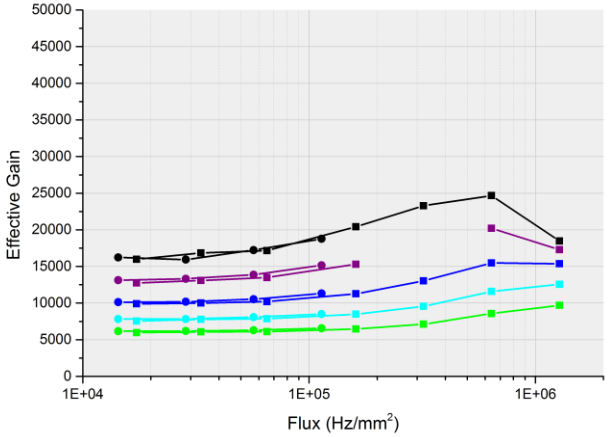
GEM 1 voltage variation

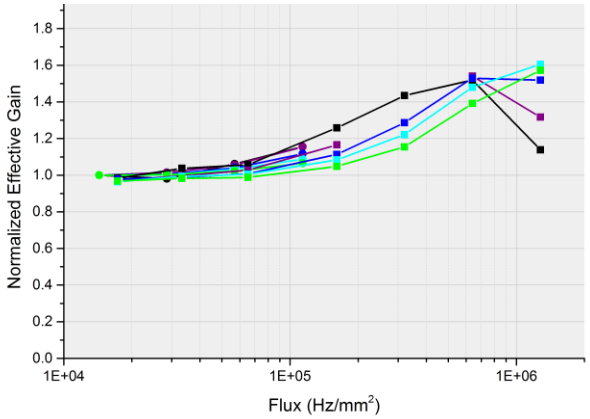


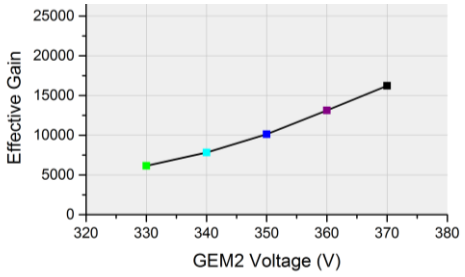




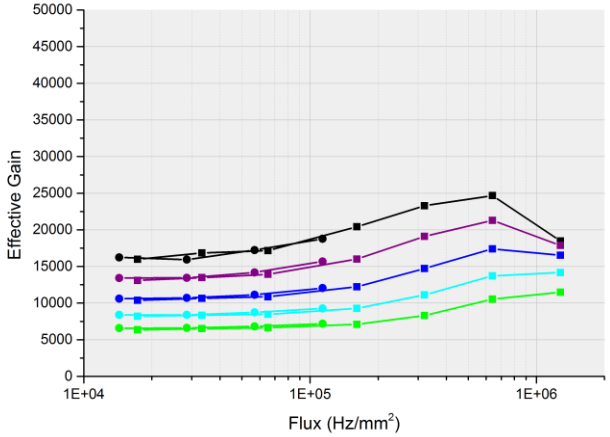
GEM 2 voltage variation

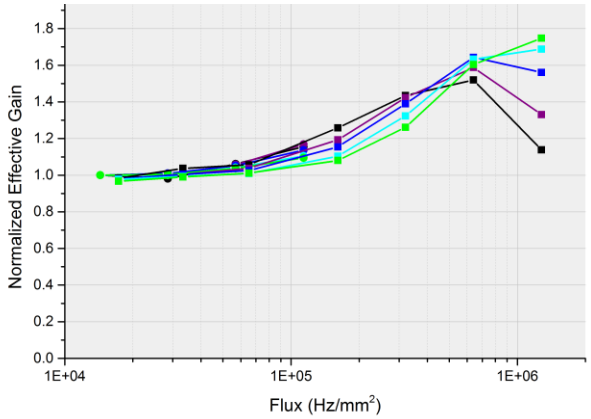


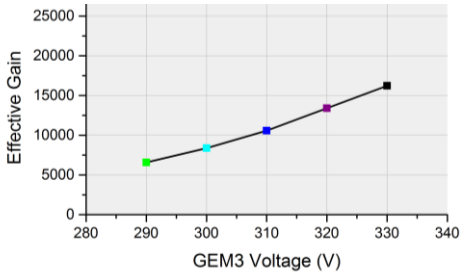




GEM 3 voltage variation



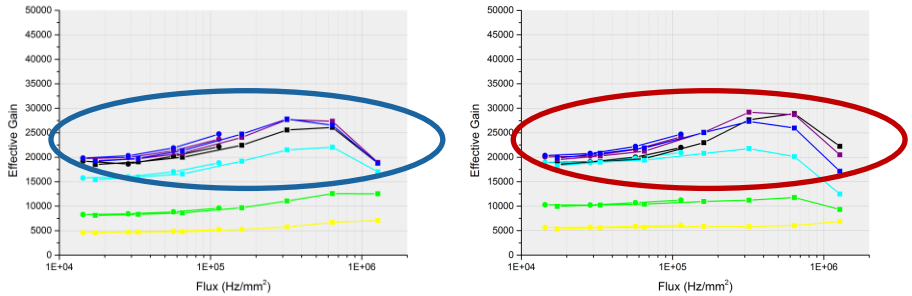


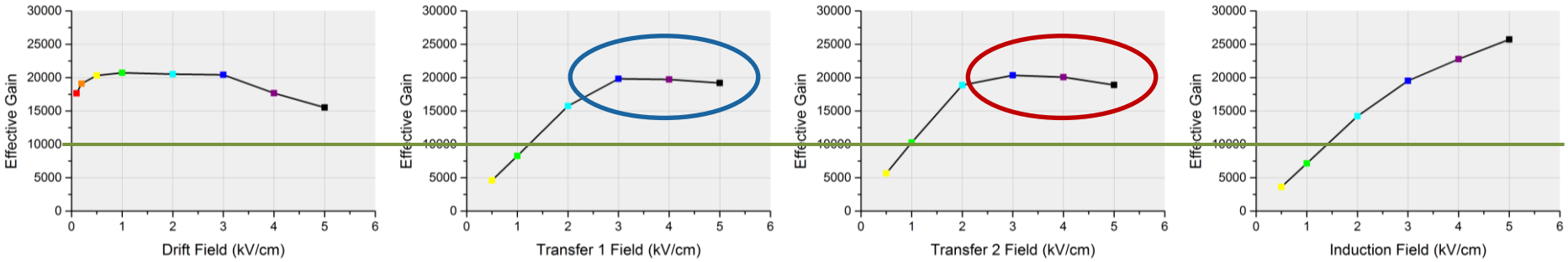


Conclusions and Outlook

Conclusions

- Clearly effect related to transparency of GEMs
  - Small variations in plateau regions (measured at low rates!)





- Some threshold effect for slopes
- Two effects
  - Increase of gain due to space charge
  - Change of transparency due to electron and ion collection/extraction efficiency of each GEM

Conclusions

- Very important to know the setup
  - Expected rates (absorbers!)
  - Expected currents (saturation, trips)
- Look at all the data
  - Best example: „change of slope“ for induction field variation
- Do some estimations
  - e.g. charge in volume → order of field change?
- Don‘t put the cart in front of the horse!
  - Why start with a triple stage device?

Outlook

- Repetition of measurement with
  - Single GEM
  - Double GEM (?)
  - Triple GEM with more points outside plateaus
- Measurements with different gains

- And now for something completely different...
  - Setup currently used to study high rate behaviour of (single!) Glass GEM and crystalized Glass GEM