Effects of high X-ray fluxes and high gains on GEM detectors

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Coarse outline

High flux section
High gain section
Relation between the two

Background

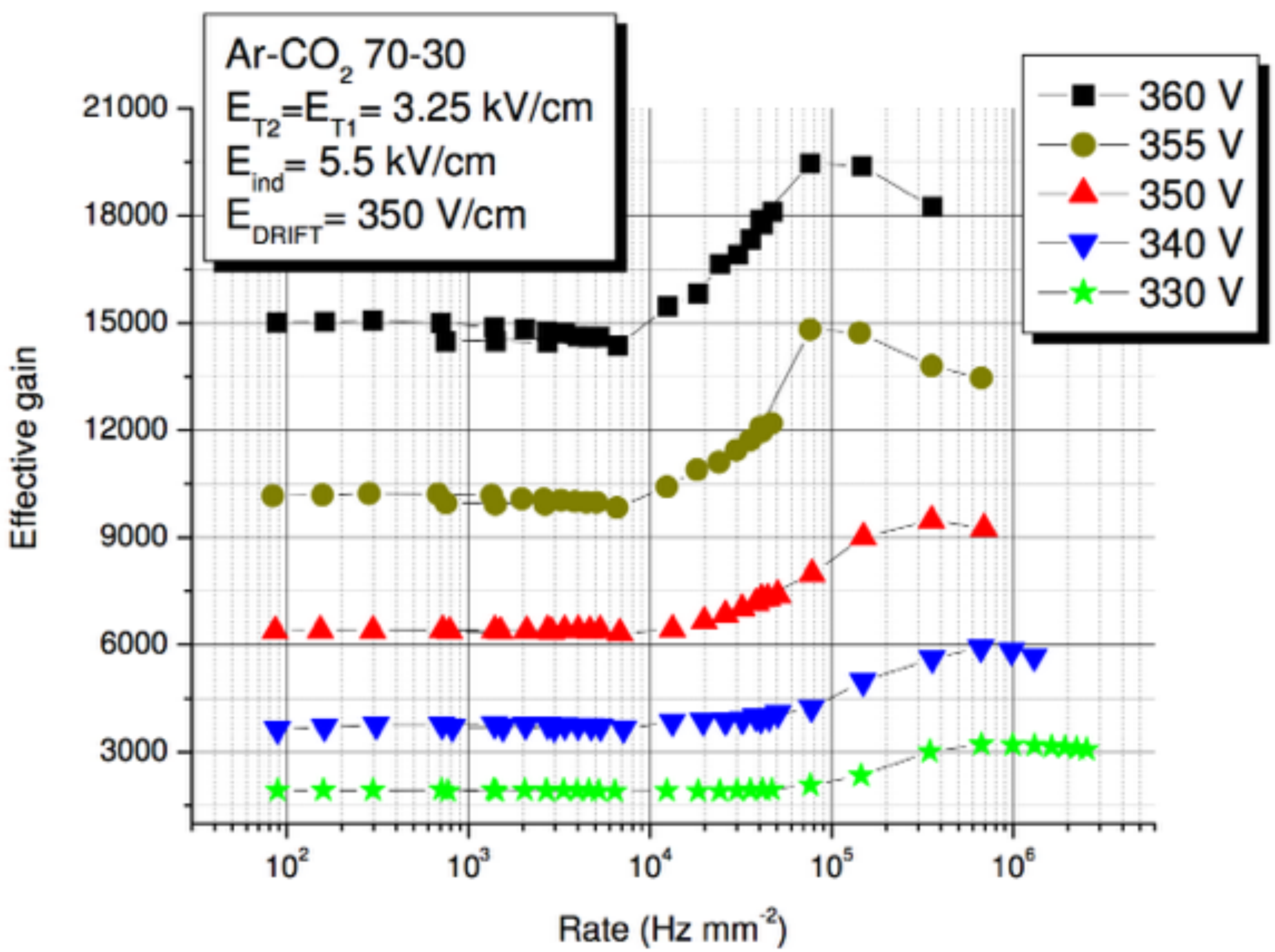
Triple GEMs are detectors known to
- reach huge gains
- sustain very high interaction fluxes

Where are the intrinsic limits*?
What are they due to?

*Limits are well beyond any reasonable application

Background

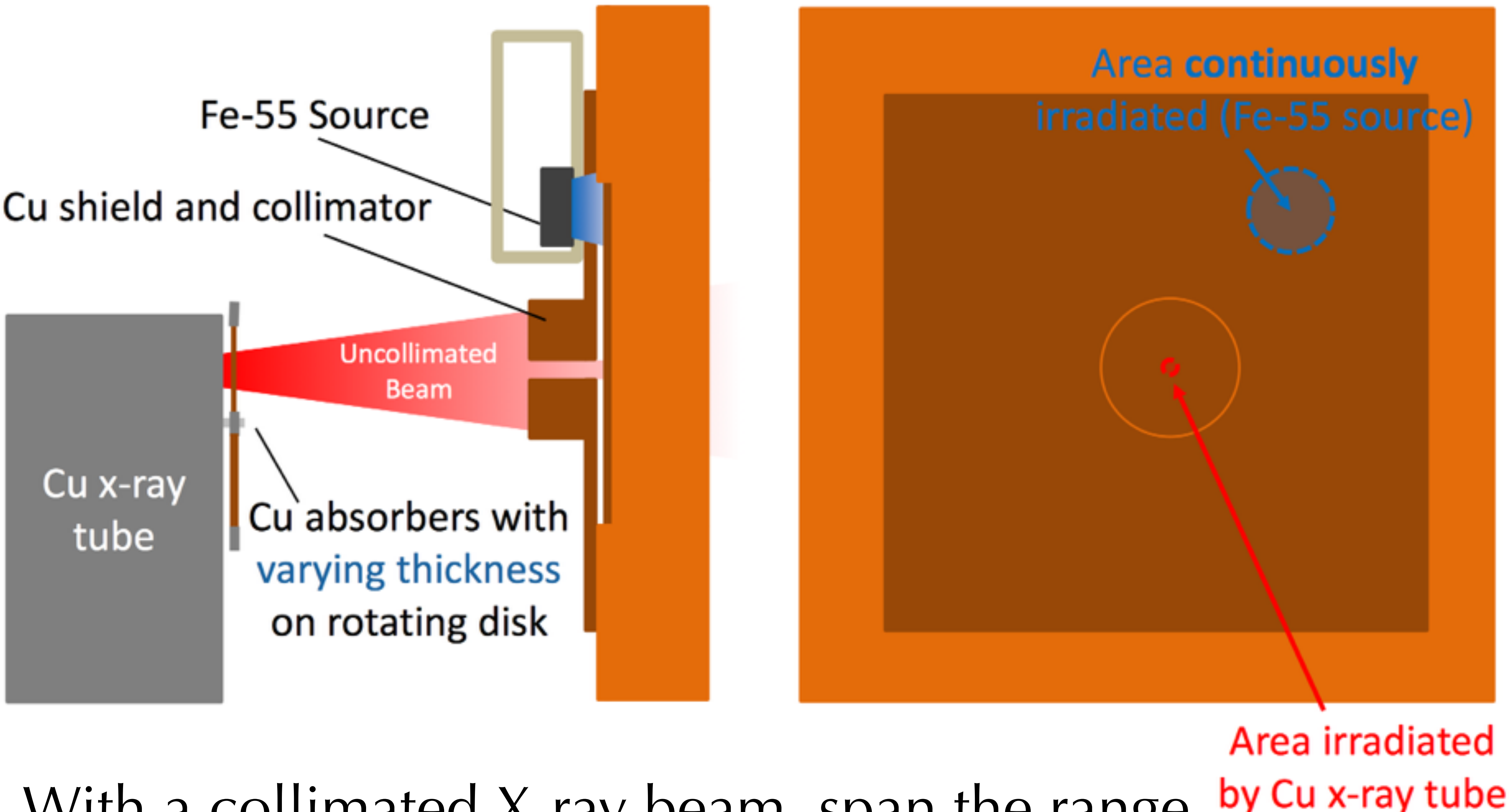
In 2006, Pieter Everaerts in his thesis showed an interesting behaviour of triple GEM detectors



In certain conditions, the gain is not constant when changing the X-ray flux!

Tests pointed to a space charge effect

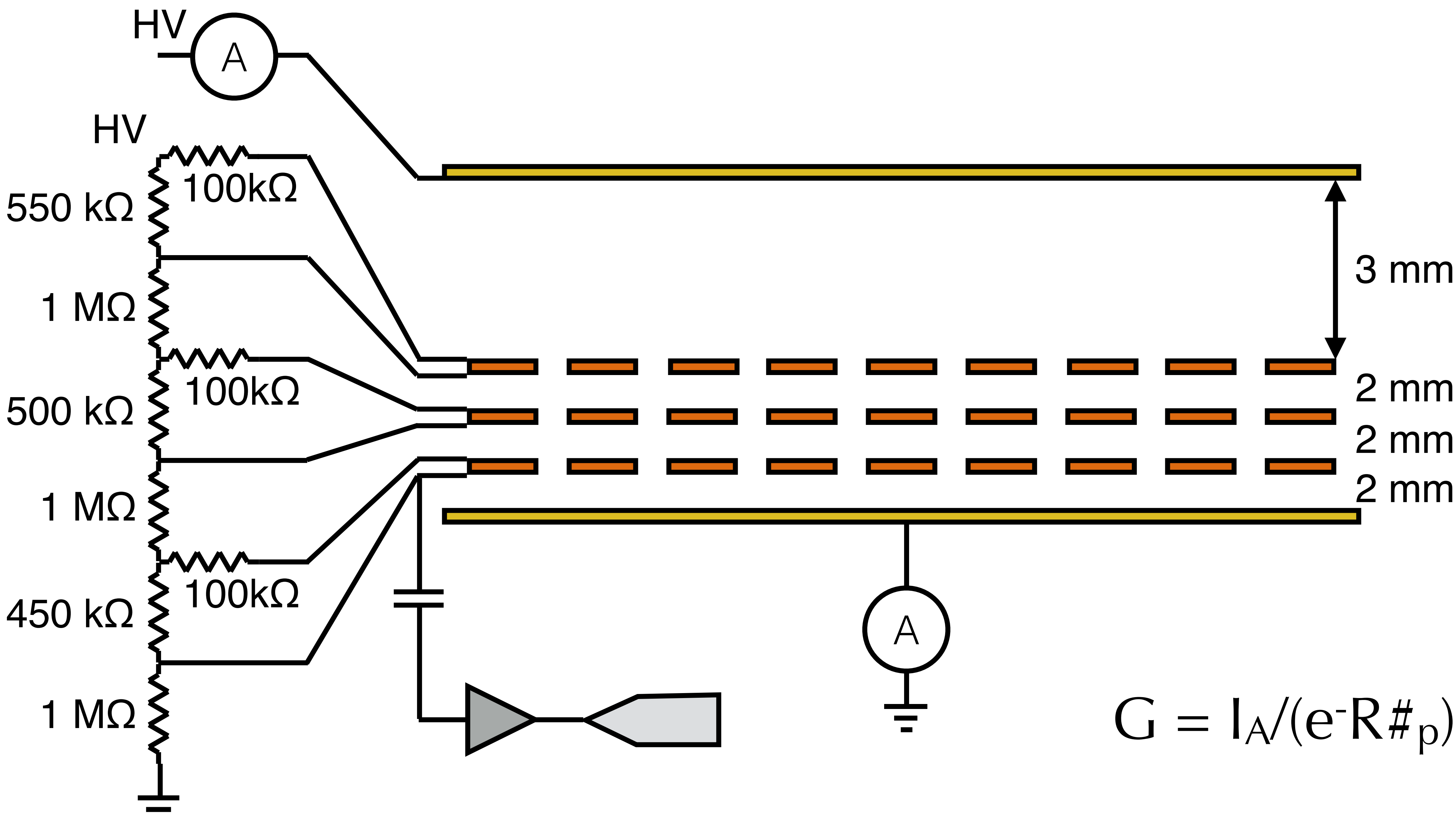
The actual setup



With a collimated X-ray beam, span the range from 1kHz/mm^2 to 10MHz/mm^2 measuring the gain varying… possibly every variable

Schematic

Ar/CO_2 70/30

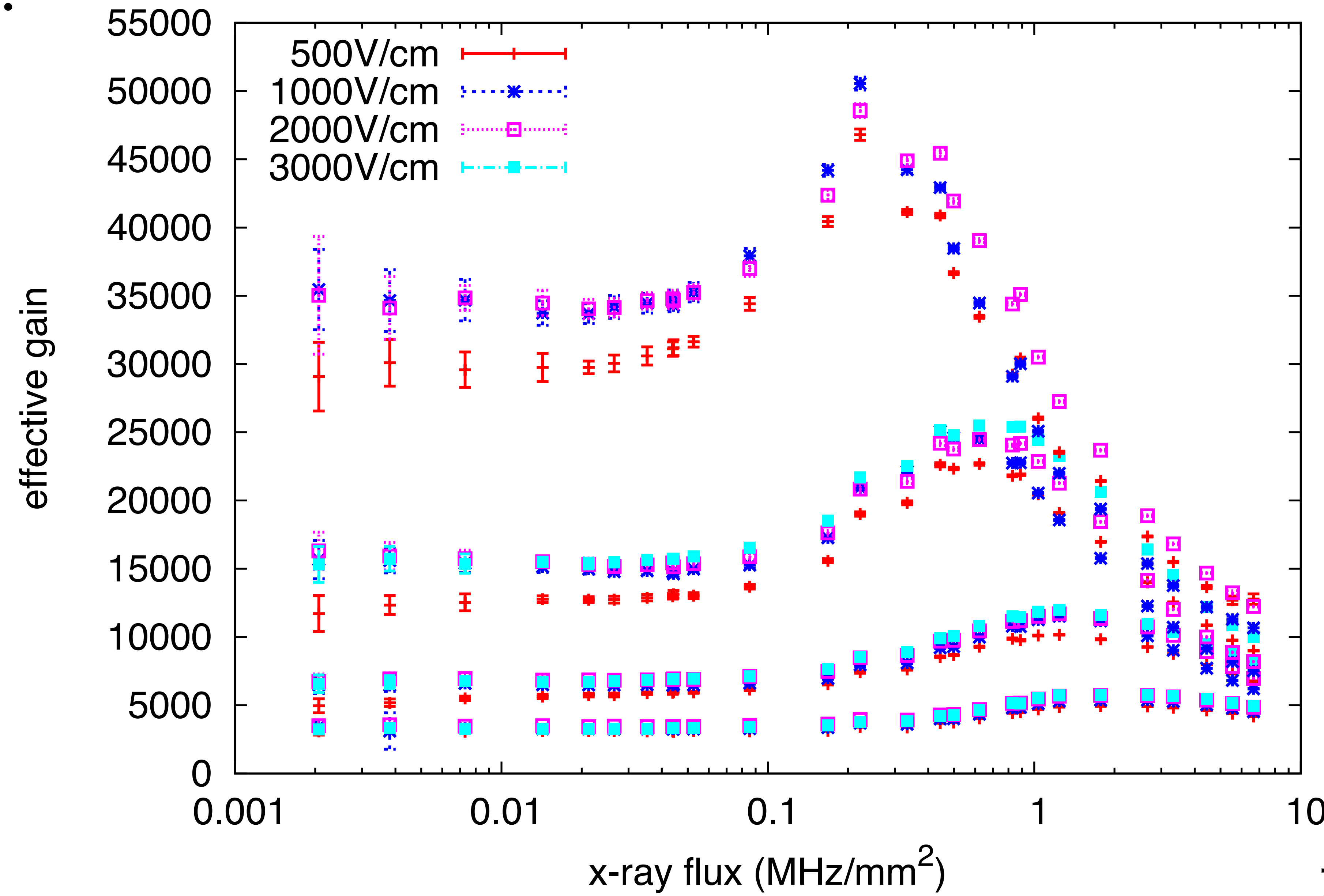


$G = I_A/(e^{-}R\#_p)$

Gain vs flux

Compatible with existing measurements
No effect at same interaction rate over larger areas
Drift field has small impact
Initial gain matters!

When X-rays off, the stability of the detector was checked with the ^{55}Fe source

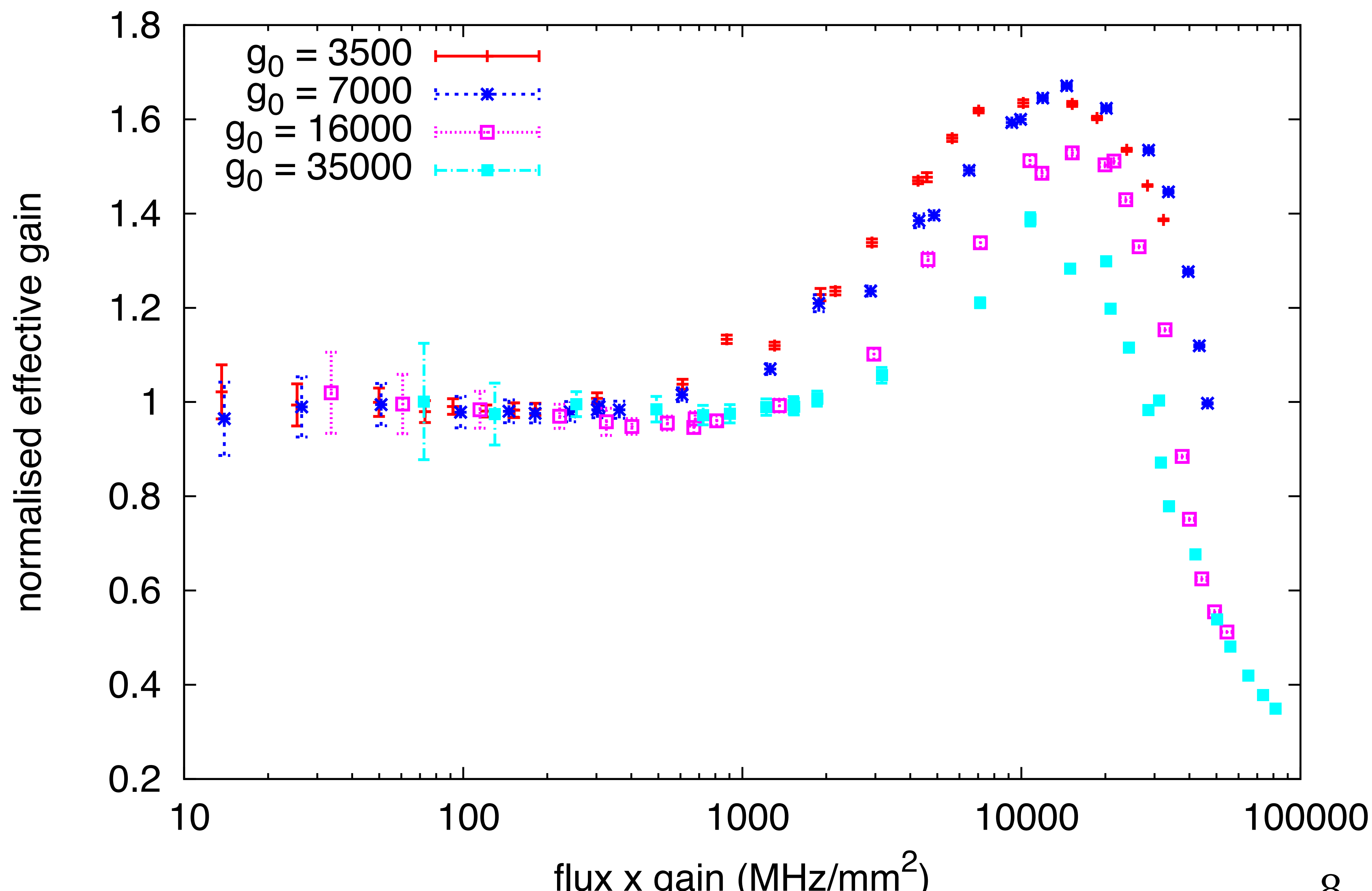


Gain normalised

The normalised gain is a*lmost* a function only of flux x gain
Total charge is the important parameter
Effect smaller for larger gains (change the transfer fields too)

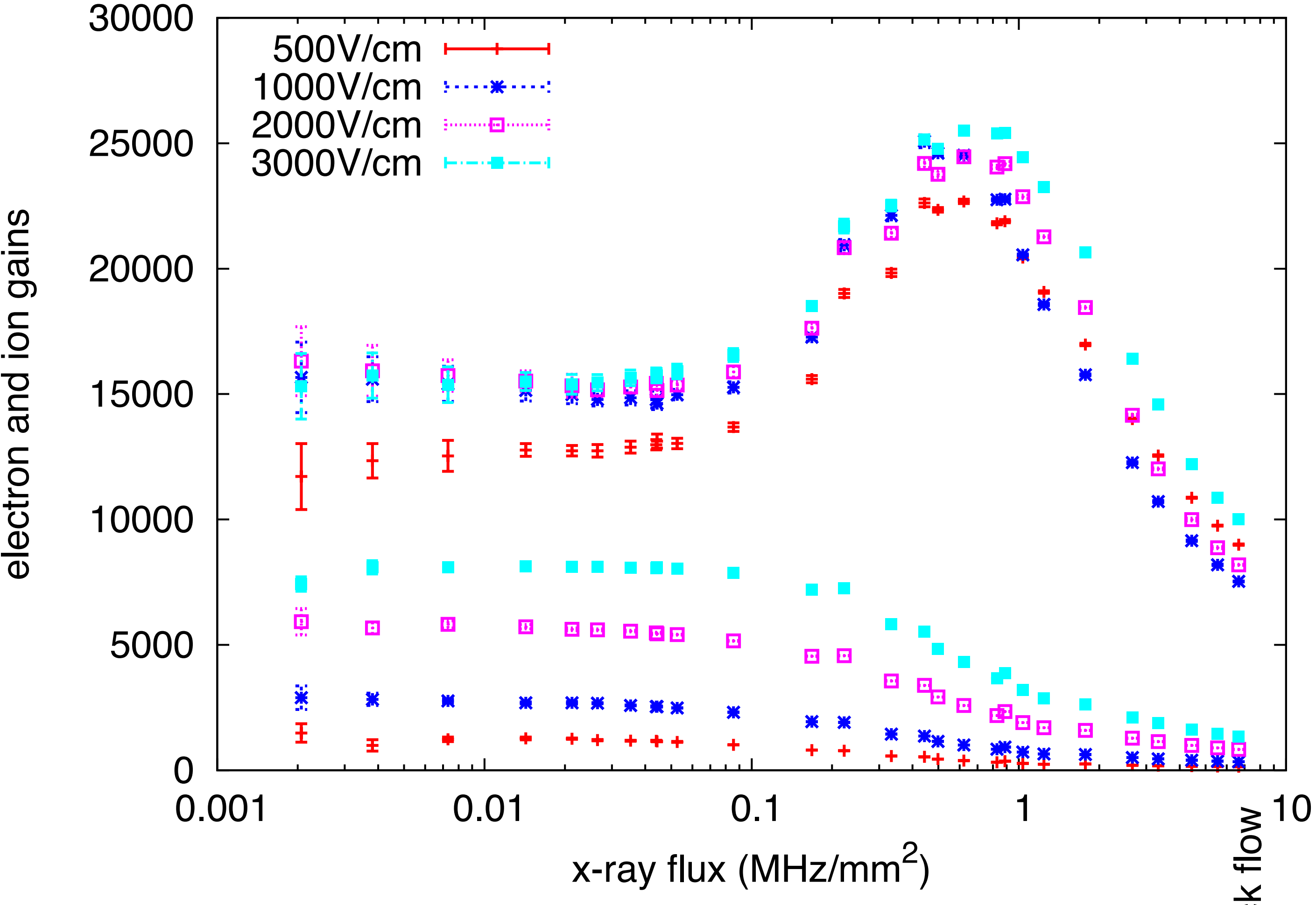
- Drift not relevant
- Gain matters

Therefore, it is an effect involving the charge after the first GEM



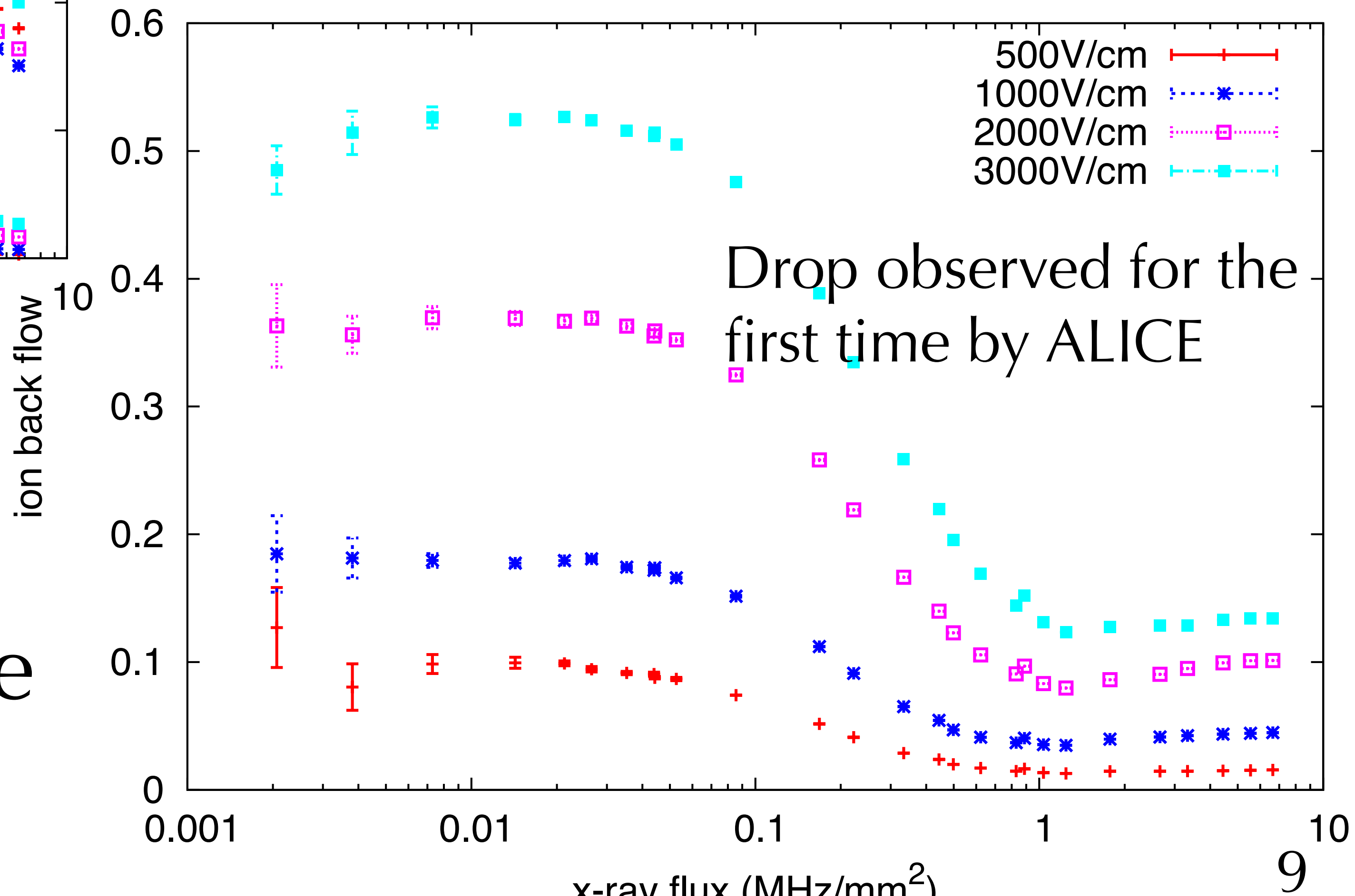
Ion back flow

While the e$^-$ at the anode increase, the ions at the cathode decrease!



Increase can be due to
- More e$^-$/ion created
- More charge collected

Therefore, the rise may involve the amplification. It involves the transport

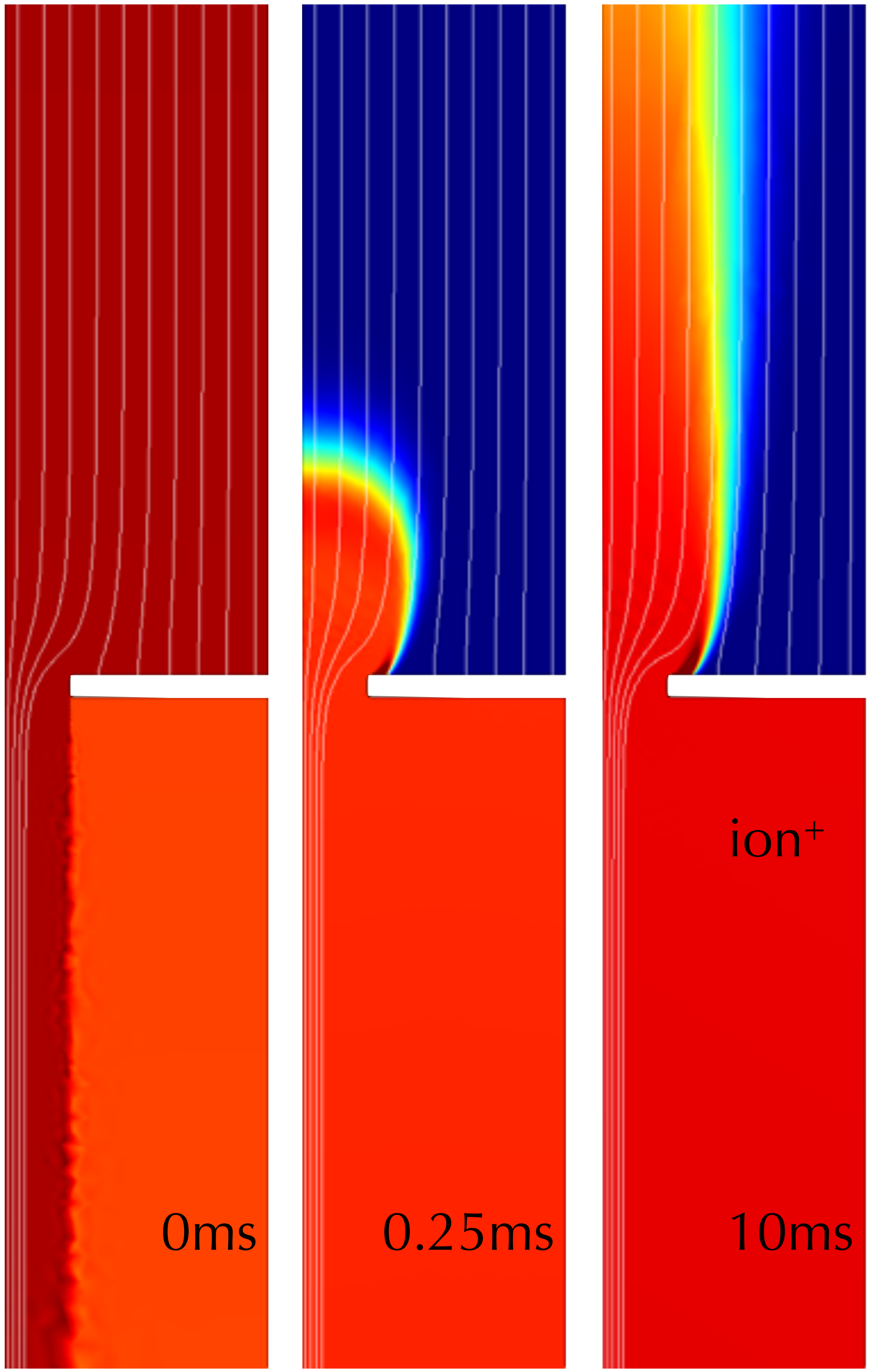


IBF drops and then stabilises
Therefore, the fall may involve the amplification only.

Ion space charge

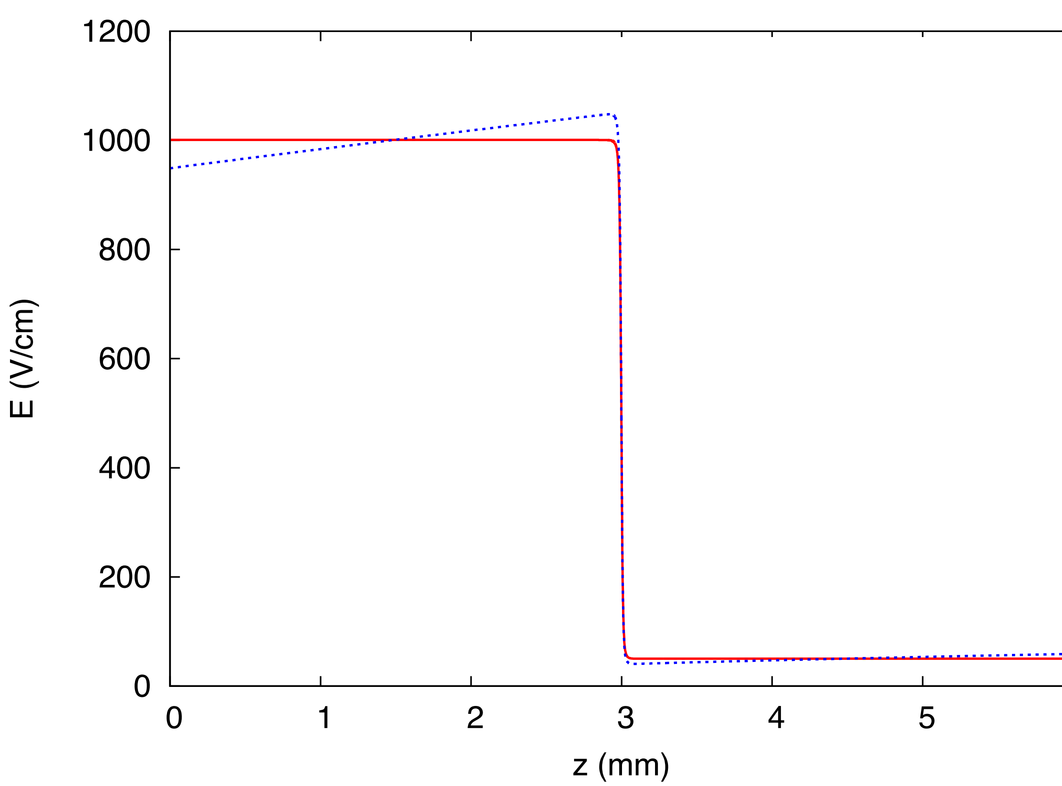
Simpler problem: a metal mesh and two "drift gaps"

Field lines change!



Electron are more focused
Ions are more de-focussed
Electron transparency increases
Ion transparency decreases

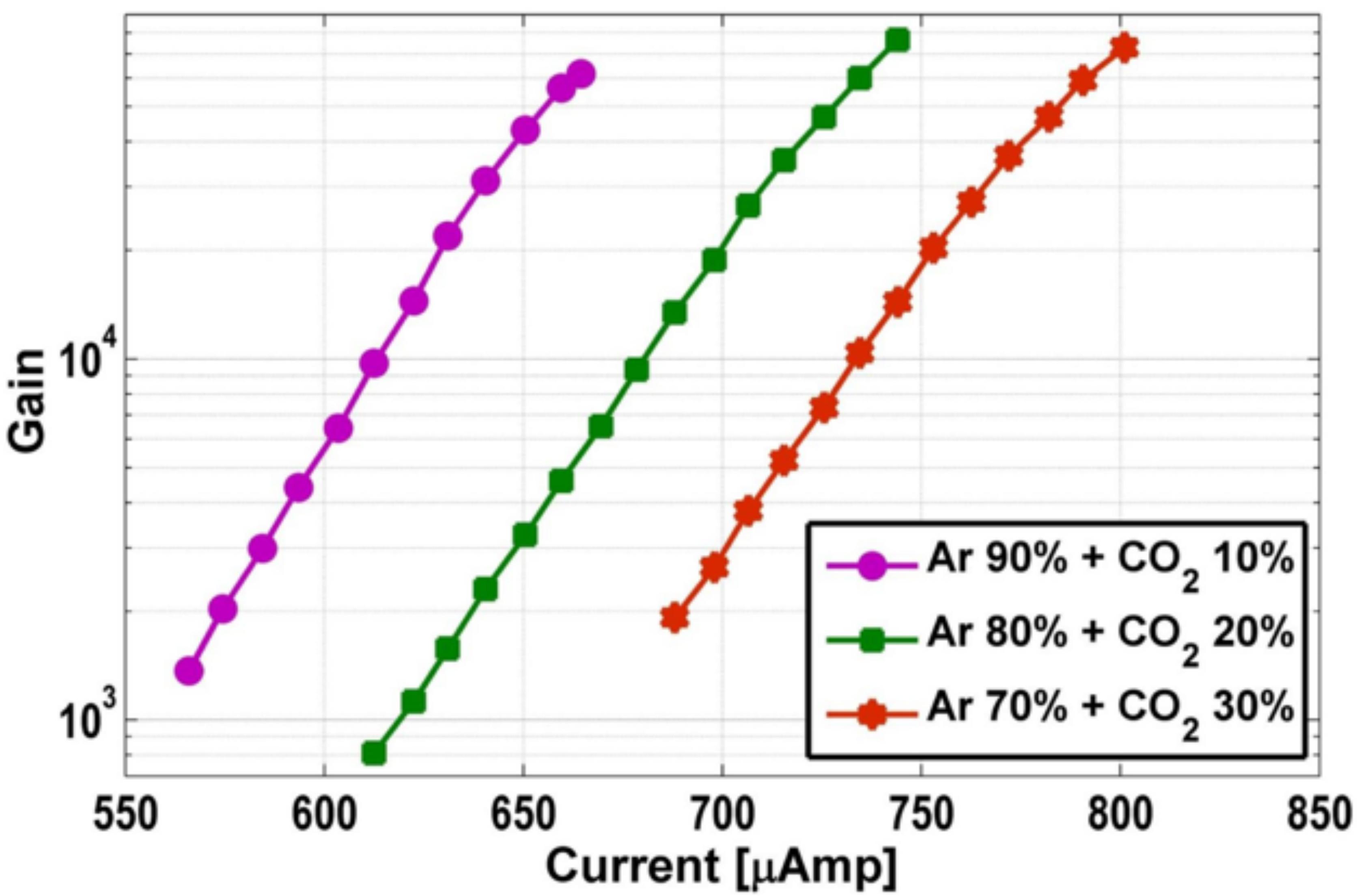
Can be a starting point to understand the gain increase
What about the decrease?



Changing topic

High gain characterisation triggered by the talk of Nayana Majumdar et al. at RD51 MiniWeek of June 2014

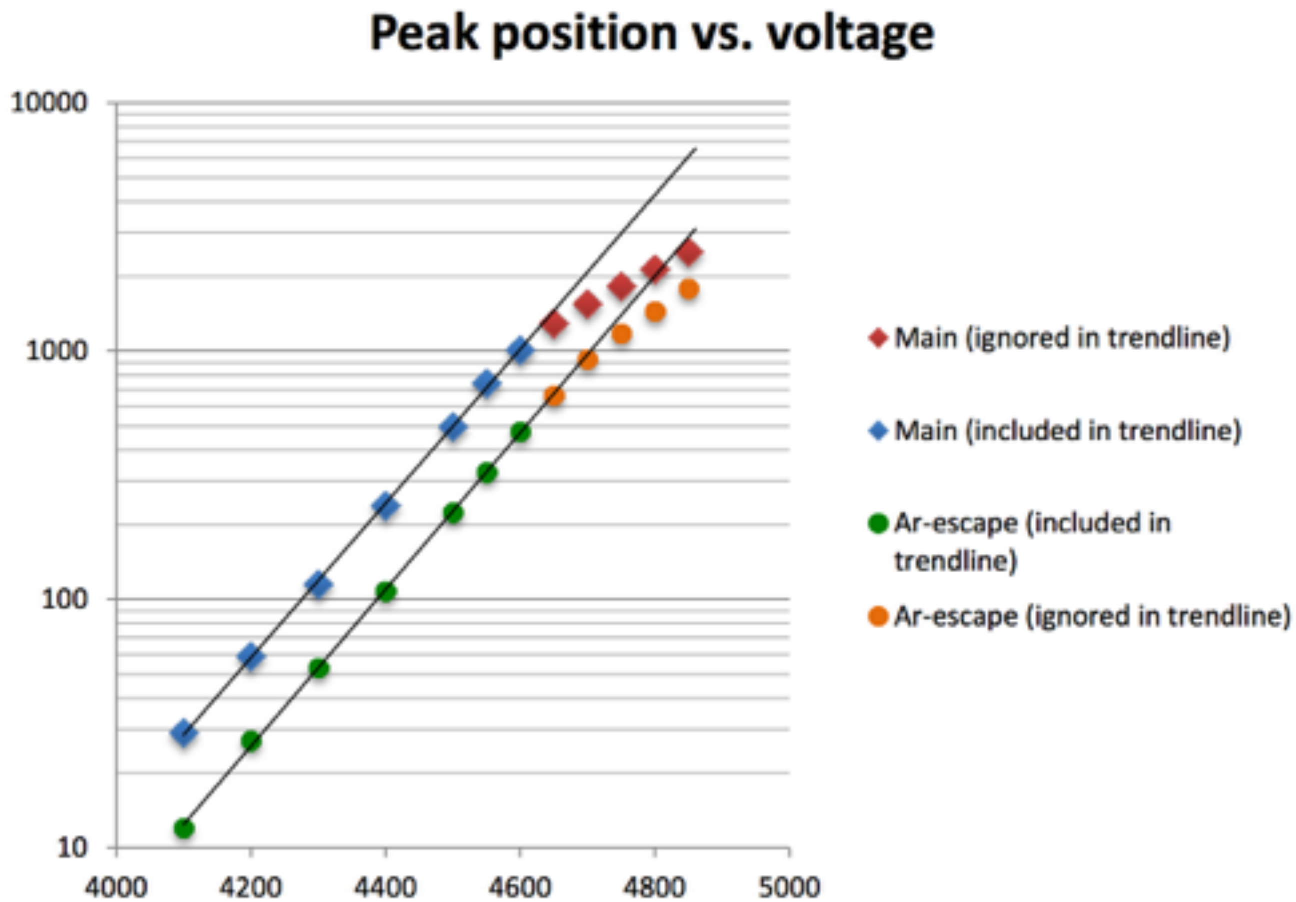
Their measurement



^{55}Fe source
Gain evaluated from the spectrum

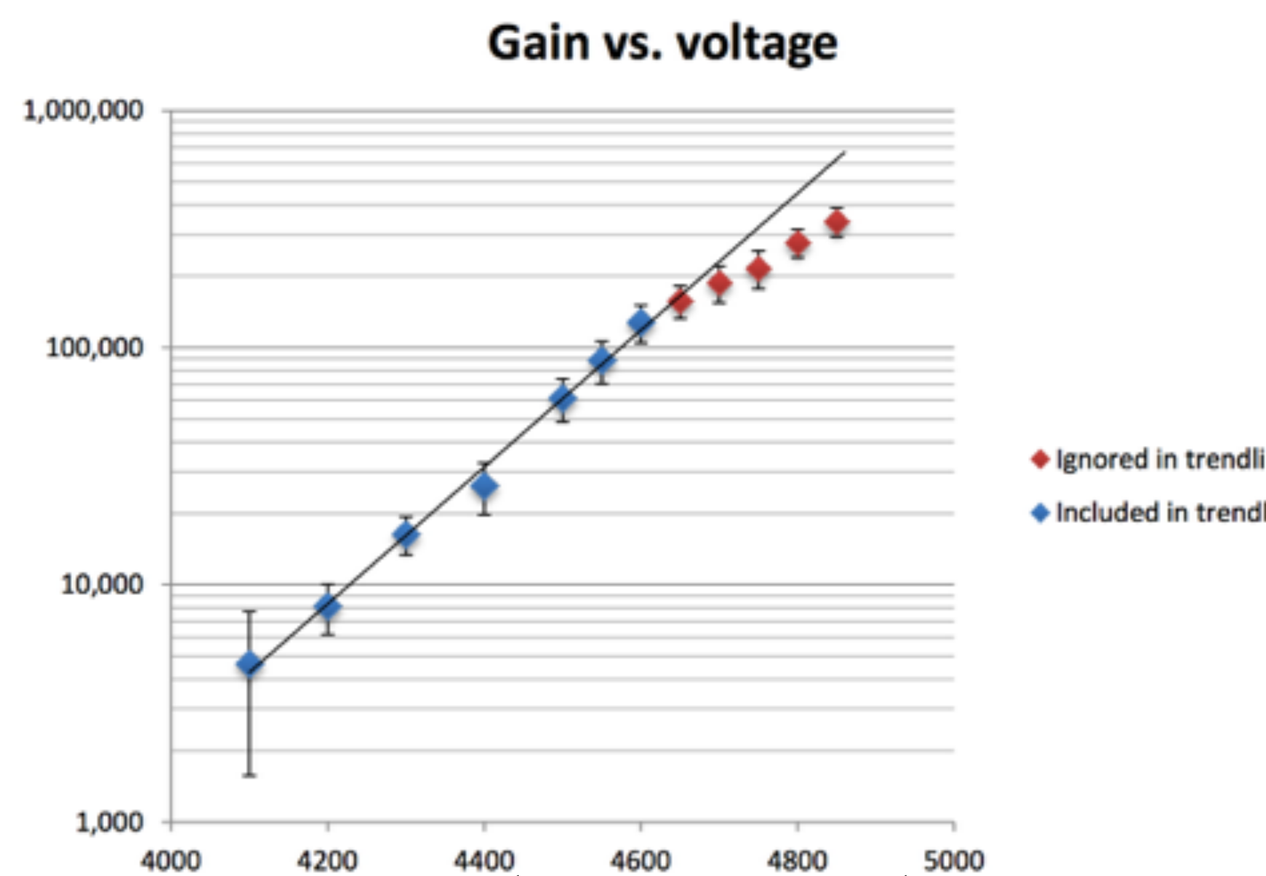
Gain of triple GEM

^{55}Fe source
Ar/CO_2 70/30



spectrum measurement

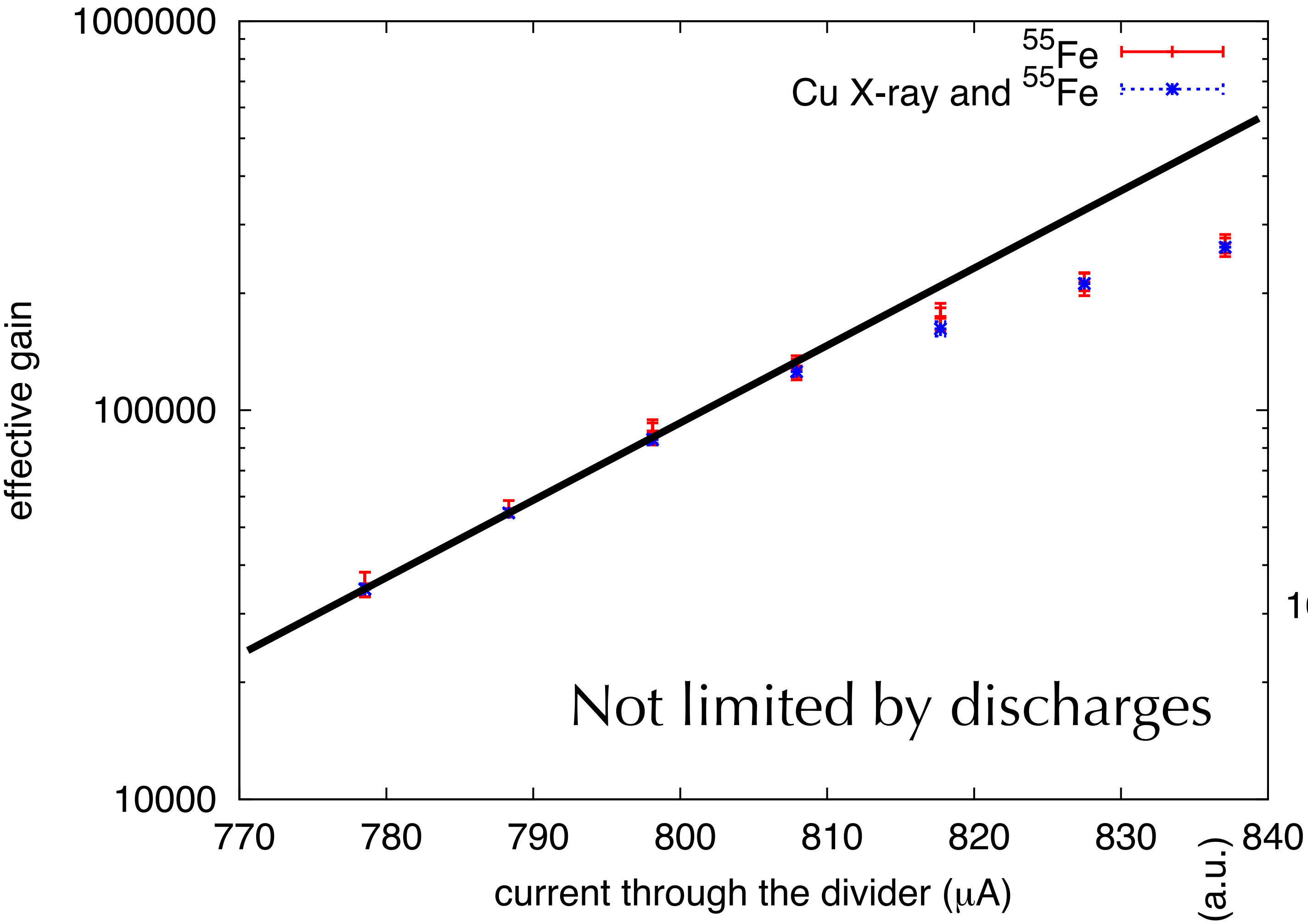
Measurement done by Ella Warras last summer



current measurement

Deviation from the exponential behaviour after 10^5 gain
Saturation involves the full energy peak first

Gain of triple GEM



^{55}Fe source

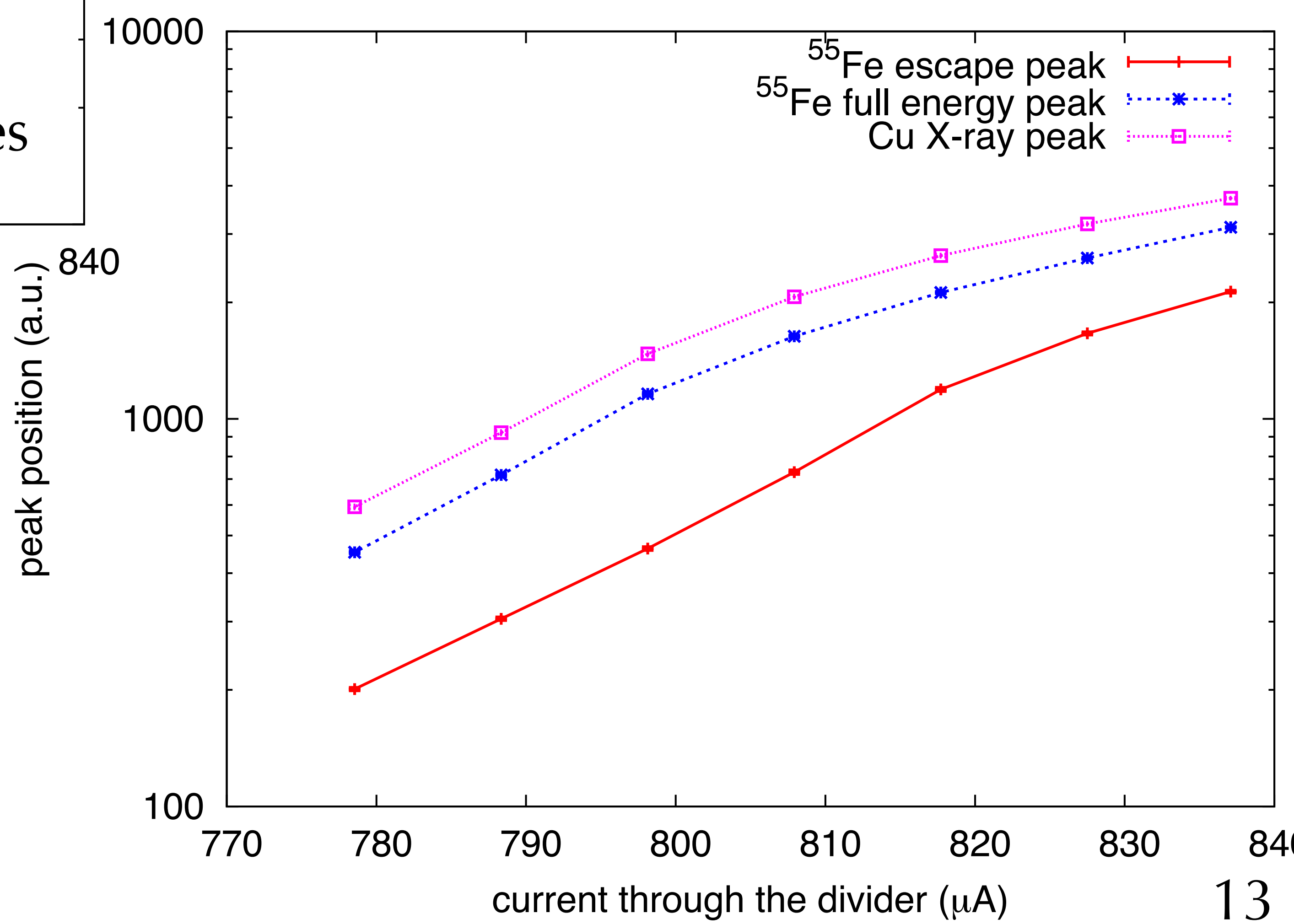
Cu X-rays

Ar/CO_2 70/30

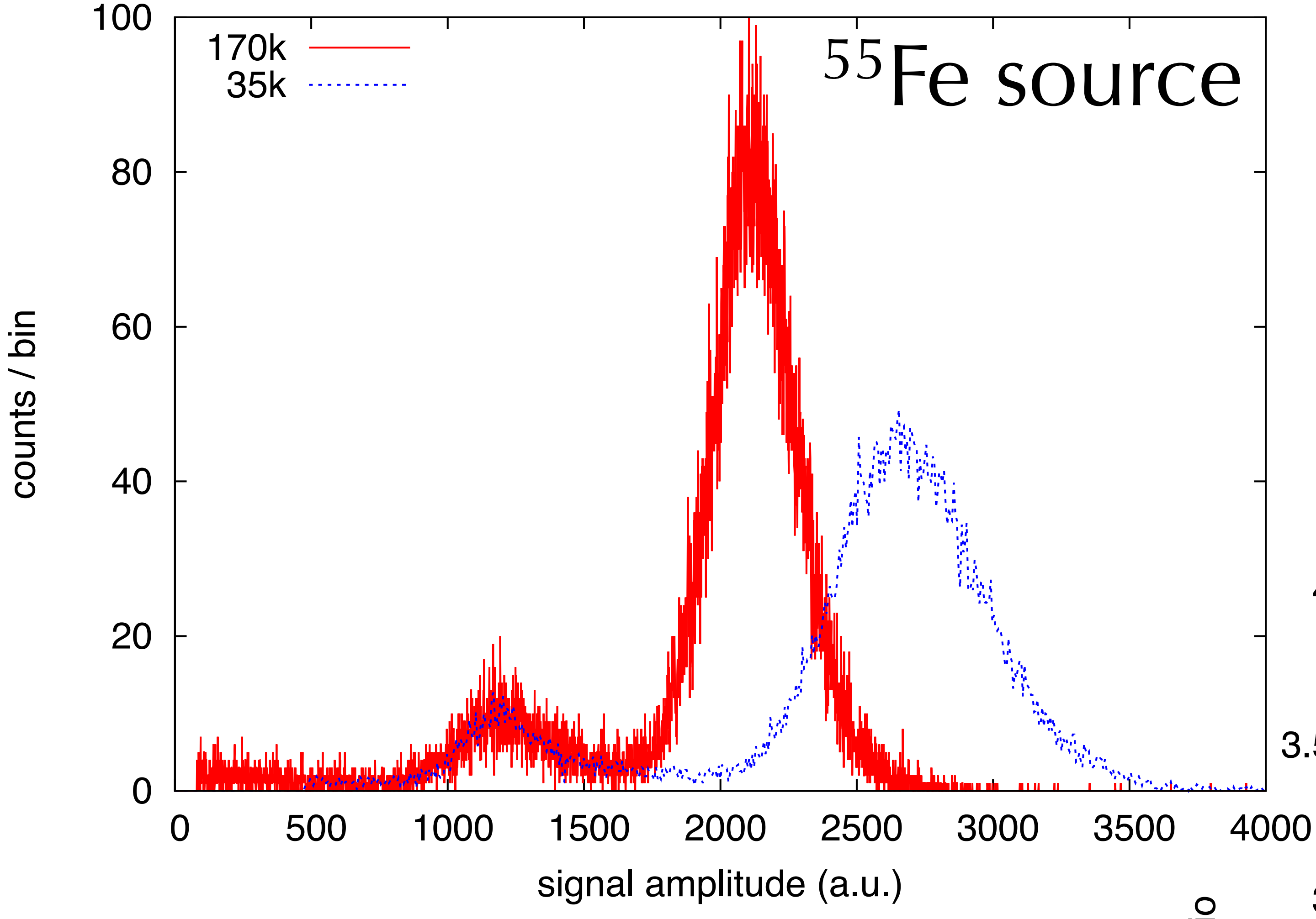
Measurement confirmed

Depends on the amount of charge

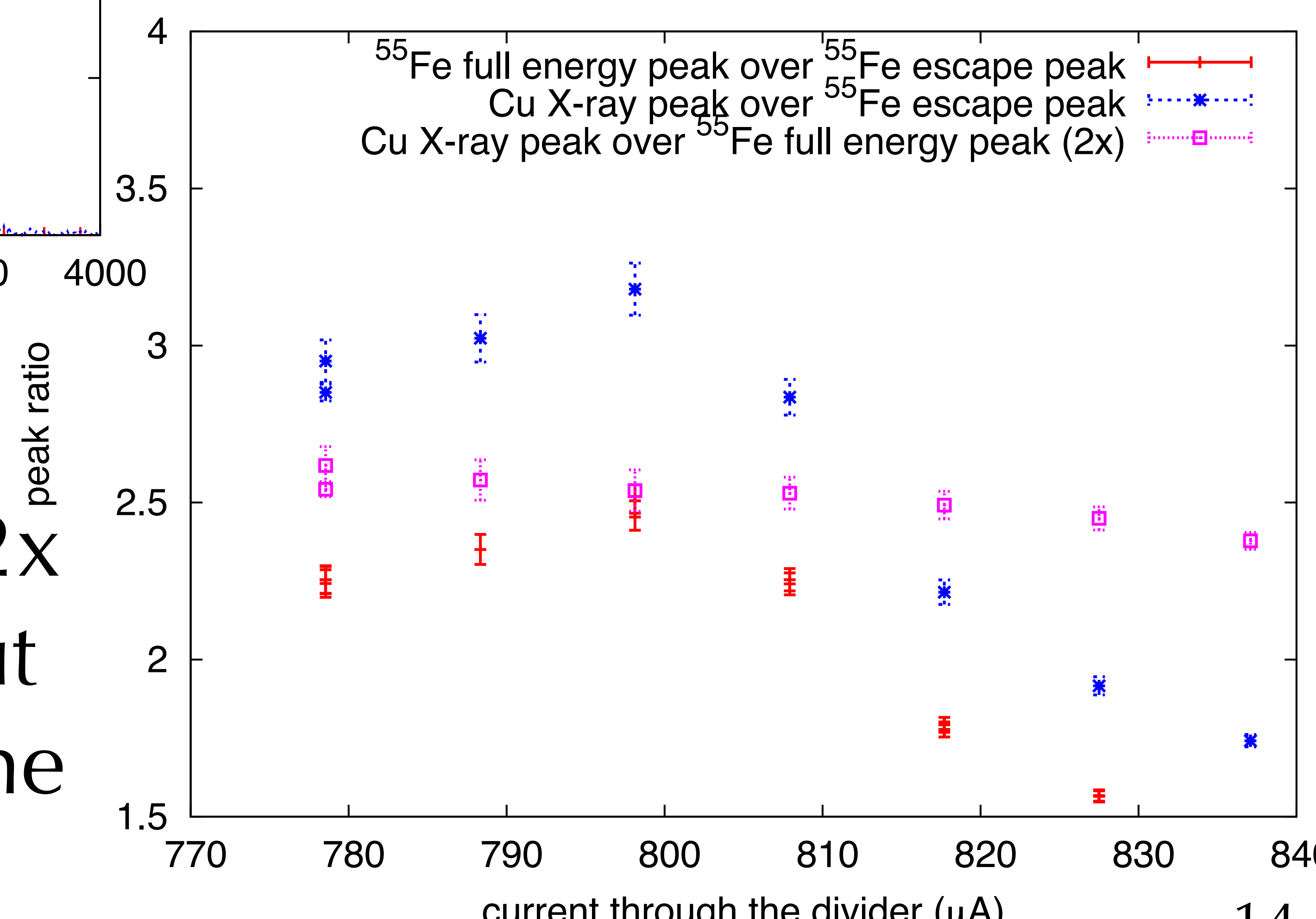
At very low flux i.e. very low space charge Each avalanche must quench its growth



Spectrum deformation

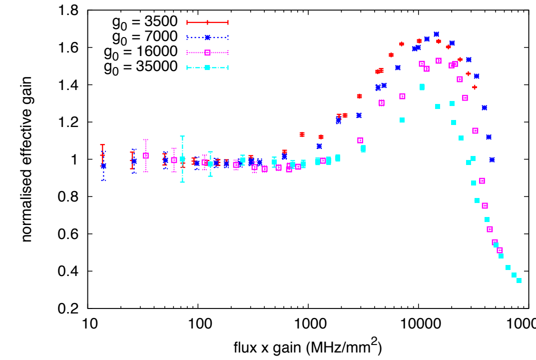


Resolution improves, i.e. large avalanche cannot grow, small avalanche can still grow



Measurement repeated with 2x attenuator at the preamp input
It is not due to saturation of the electronics

The two effects together



High flux

G x f ~ 20000MHz/mm^2 Hole density ~ 50mm^{-2}

$$\#_{ion}/hole = \#_p \times G \times f \times t / v_d / \rho = 120000$$

Primaries ~ 300 GEM thickness ~ 50µm

Ion drift velocity ~ 0.05mm/µm

High gain

Gain ~ 100000 Hole density ~ 50mm^{-2}

$$\#_{ion}/hole = \#_p \times G / \sigma / \rho = 800000$$

Primaries ~ 200 avalanche size ~ 0.5mm^2

Not too different…

Not a computation, just an idea

Summary

High flux

Gain increase due to transparency changes due to the space charge in the GEM region

Gain decrease may be due to saturation similar to the high gain behaviour, but due to space charge in the holes

For MIPs across 3mm @ G = 2000 limit > 3MHz/mm^2

High gain

Avalanche self-quench due to its own charge

For MIPs across 3mm limit > 750k

Outlook

For the moment no conclusions
Ideas how to interprete the results
Continue the measurements of both effects
Several parameters not yet investigated
(Gas, X-ray energy, transfer fields, …)
Find measures to prove or disprove ideas