Some features of the GEM -TPC prototype operation in Ne+CF4

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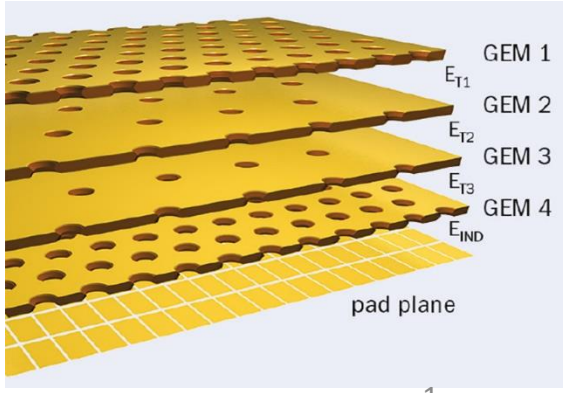
Behalf of the ALICE TPC upgrade team

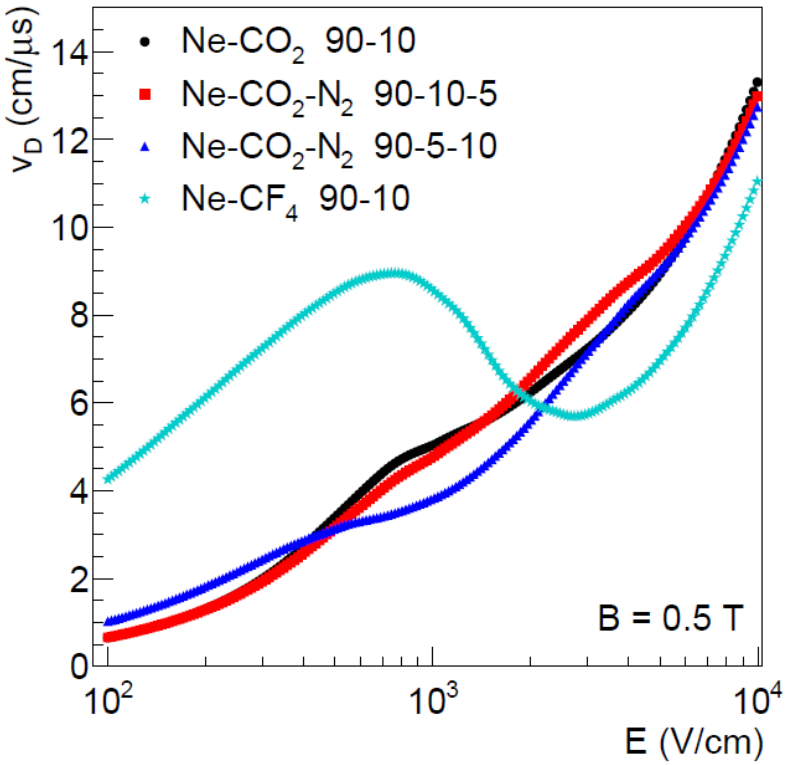


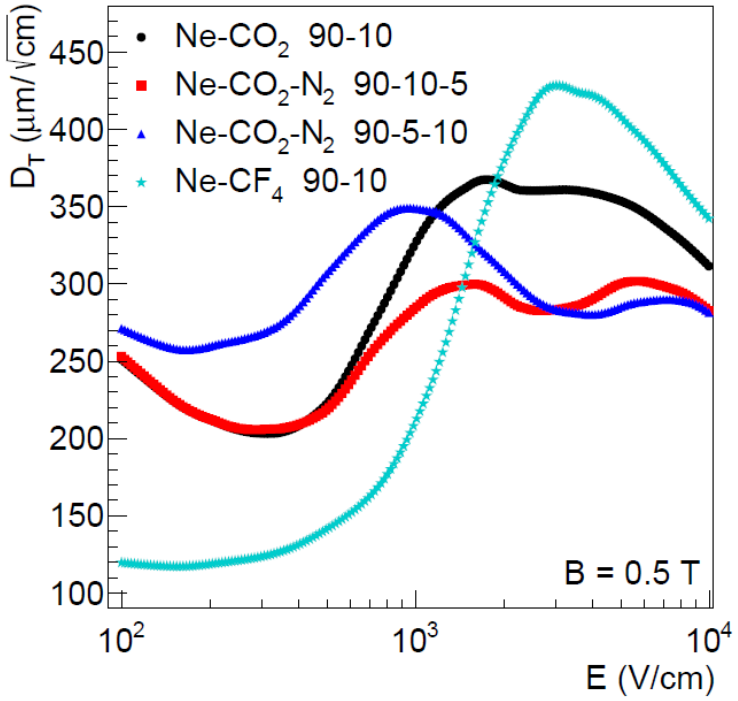
This message, we received among others from one of our s-PHENIX colleagues, stimulated our presentation:

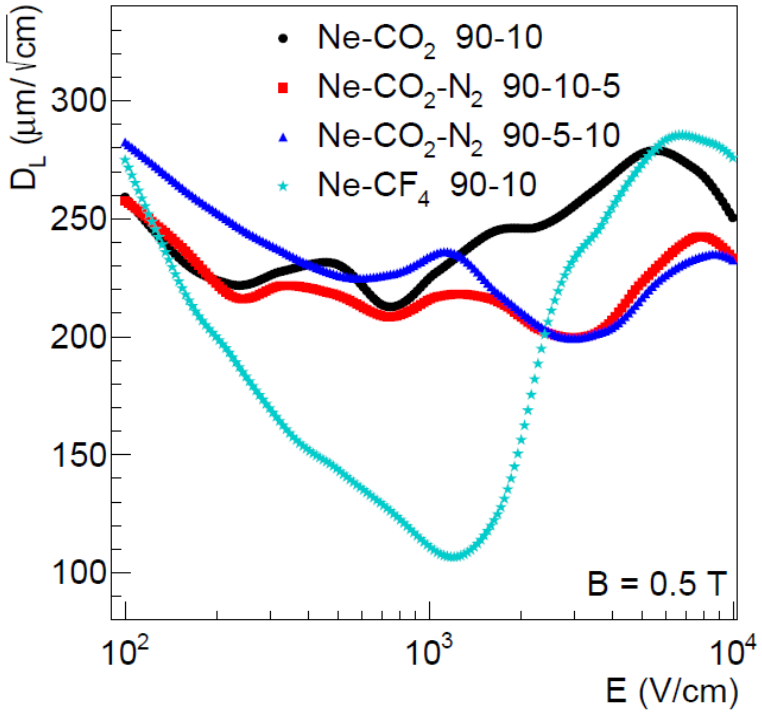
"…I attach a plot we generated during the ALICE R&D. We tested 90% Ne + 10% CF4.
We found that there is something like resonant capture of electrons on CF4.
The plot was generated for a 2-GEM MMG chamber, varying the field between the two GEMs.
Our colleagues in Europe verified that the same happens with a 4-GEM chamber.
If you run a 4-GEM setup with the high transfer fields that are needed for best IBF suppression (4kV/cm) the chamber gain is lower by at least a factor of ~10 from that at a transfer field of ~1 - 1.5 kV/cm.
Anyhow I'd like to raise this as a point for discussion of which gas really is the best for the sphenix tpc.."

We, thus, think that it will be useful to give more details from these ALICE studies

Reminder: why some people think that CF4 could be an interesting alternative to Ne+CO2+N2?



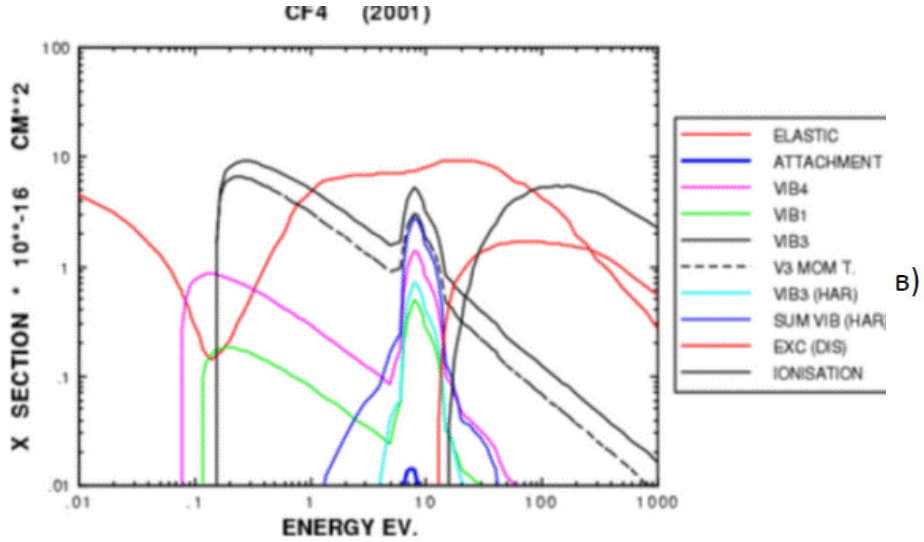




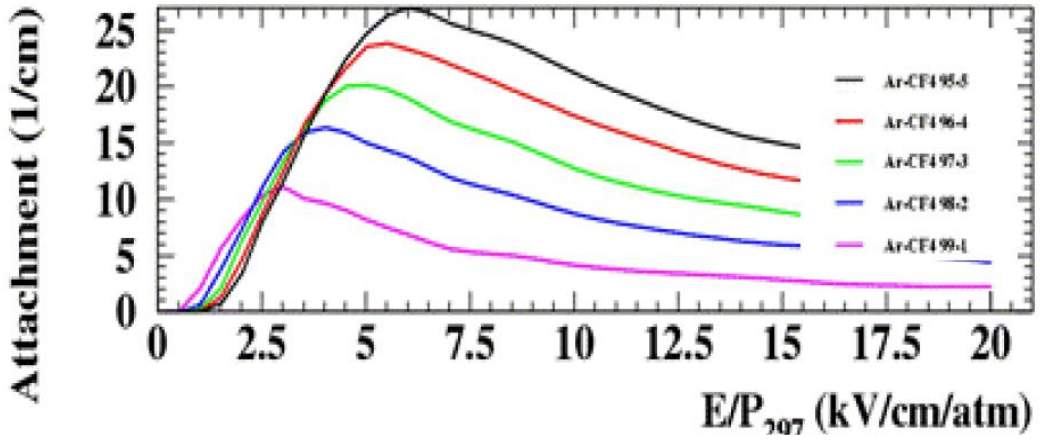
...because in this gas in some voltage interval electrons have faster drift velocity and lower diffusion

The challenge, however is the CF4 electronegativity

a)



b)

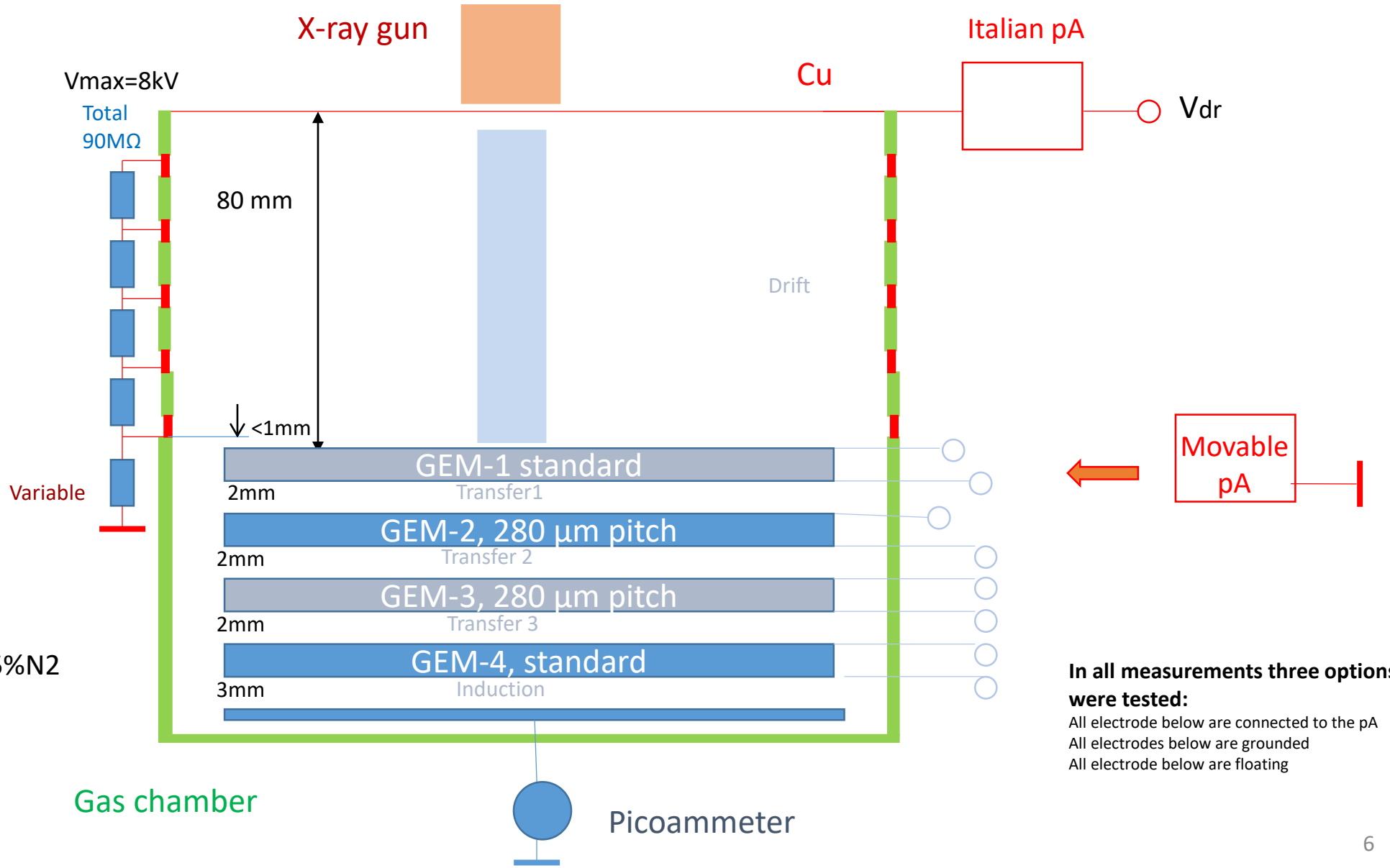


ALICE TPC upgrade group made some pilot studies of a quadruple GEM operation in CF4 mixtures focused mainly on the IBF issue

We will present some of them: comparison of quadruple GEM operation in Ne+CO2+N2 and Ne +CF4 (10 and 20%)

(note: these ALICE results were never presented outside ALICE community)

Experimental setup



Gases:

Ne+10%CO2+ 5%N2

Ne+10%CF4

Ne+20%CF4

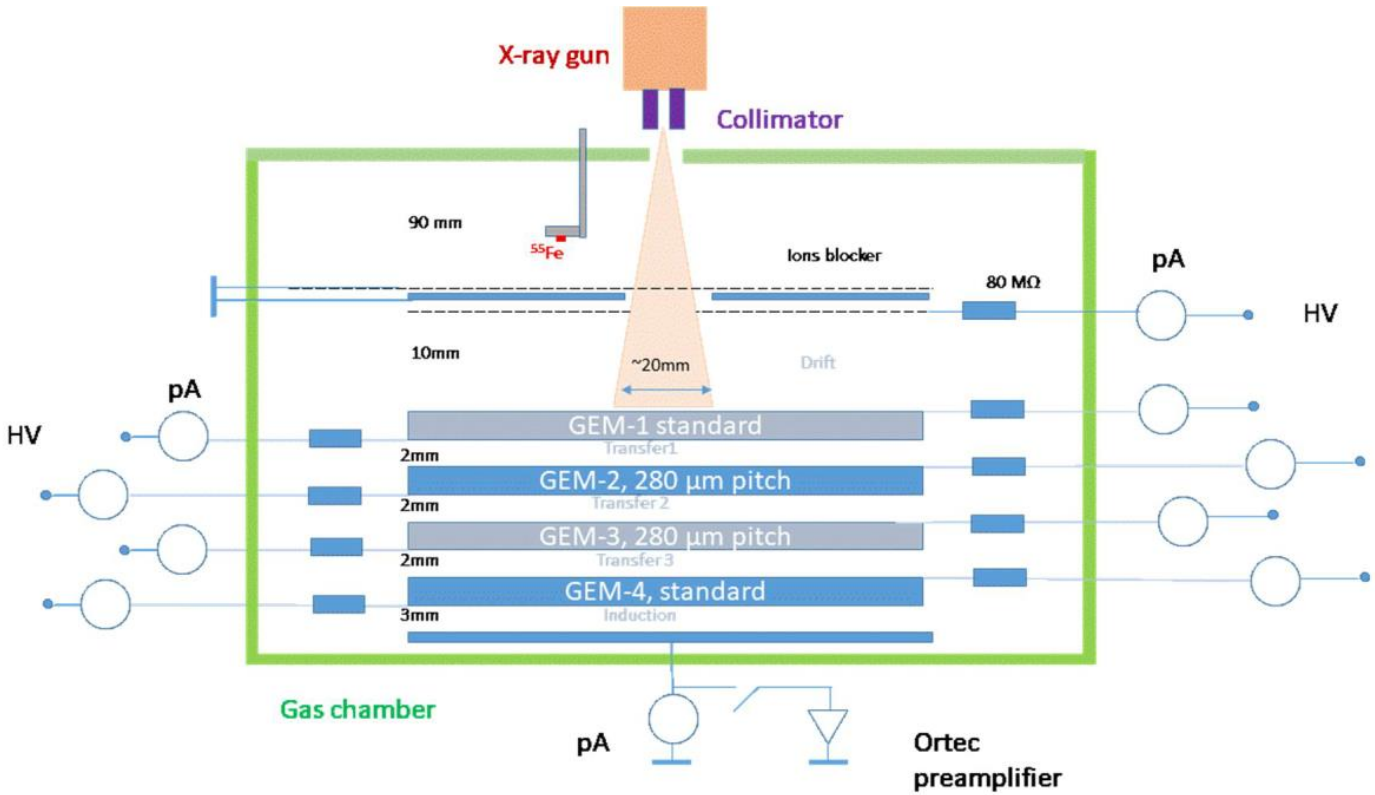
In all measurements three options were tested:

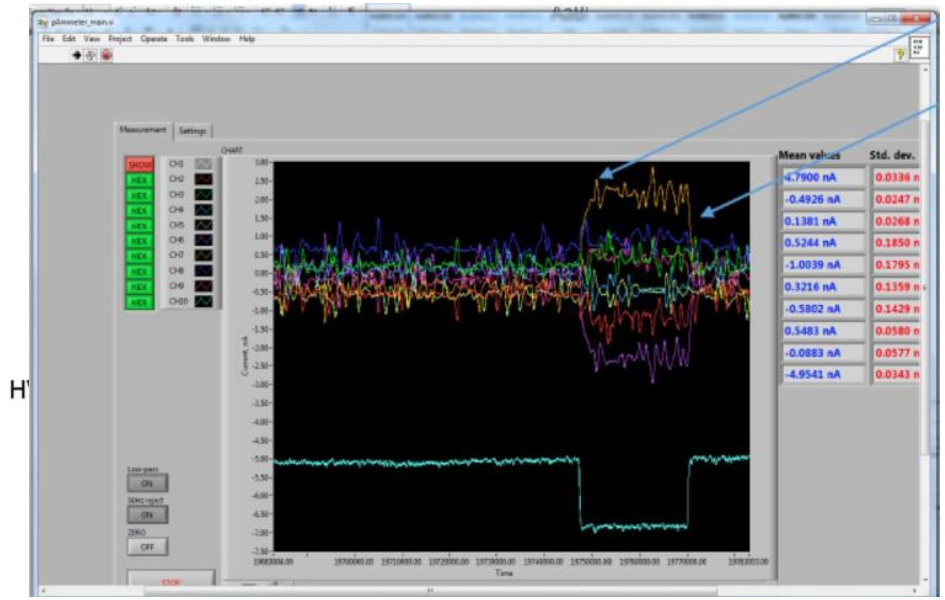
All electrode below are connected to the pA

All electrodes below are grounded

All electrode below are floating

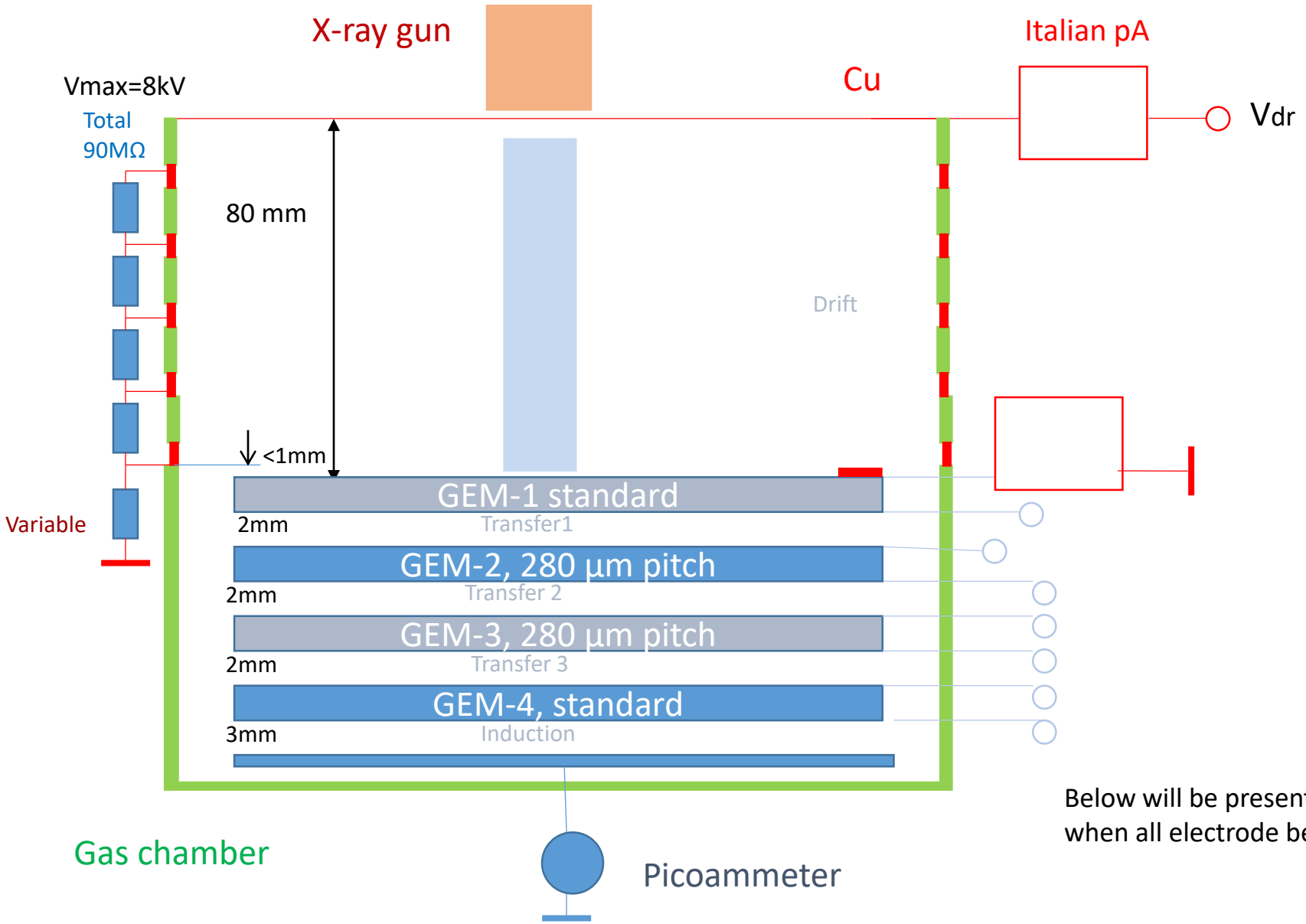
Some measurements were repeated at WIS , using a more sophisticated set-up, when one could control all GEM currents simultaneously





… but today we will show only CERN results

Measurements of the primary ionization current

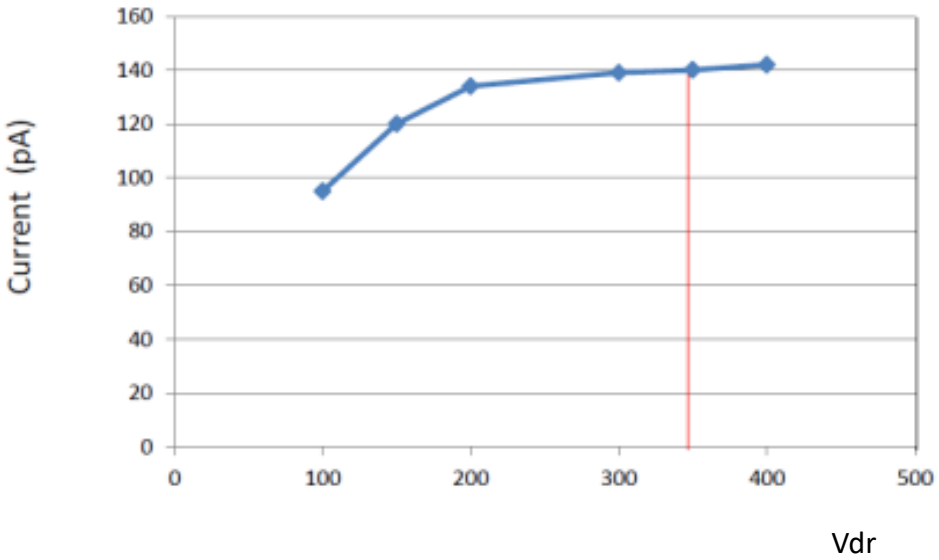


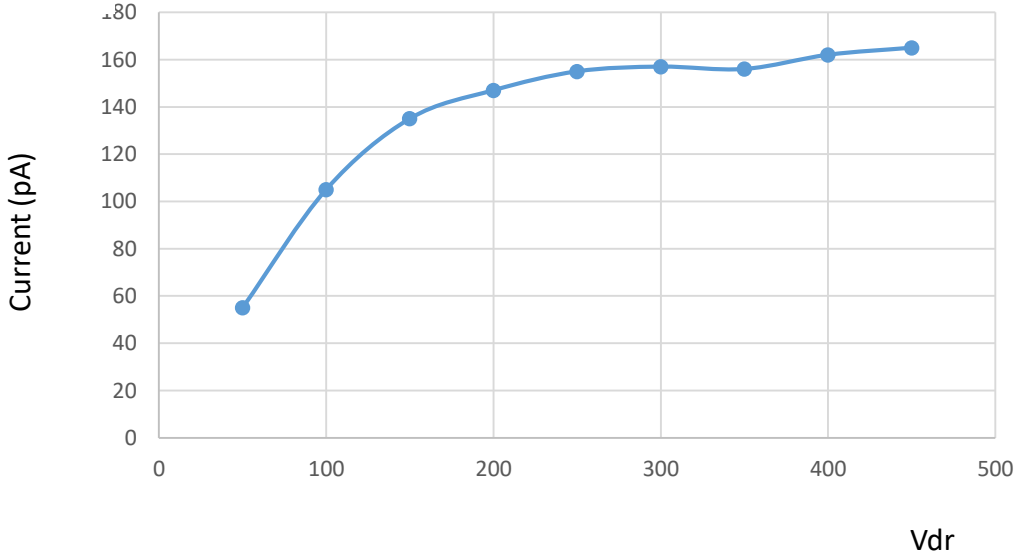
Below will be presented results
when all electrode below were floated

Ne+10%CO2+5%N2

Ne+20%CF4

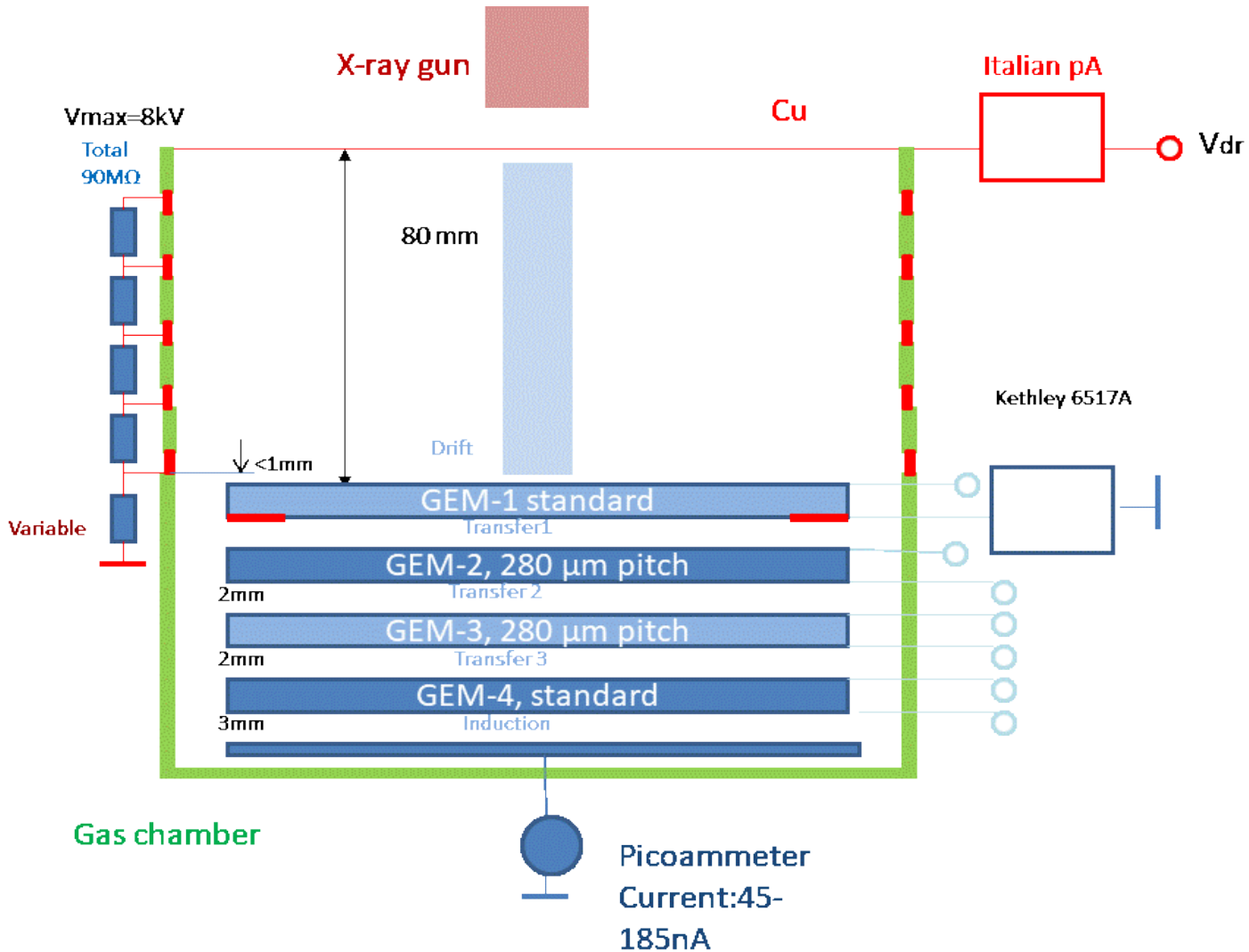
X-rays:
40kV, 100mkA

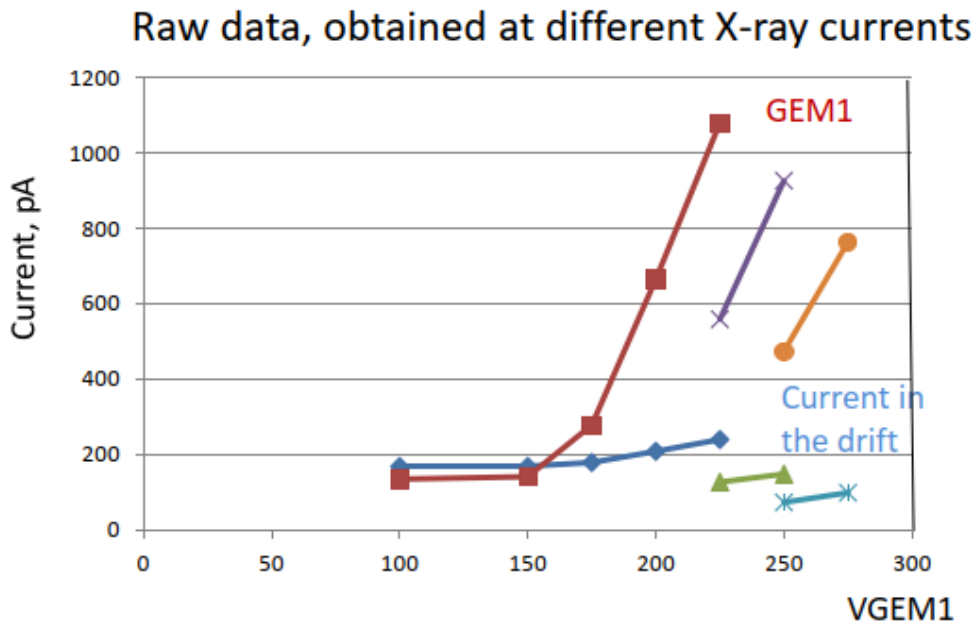




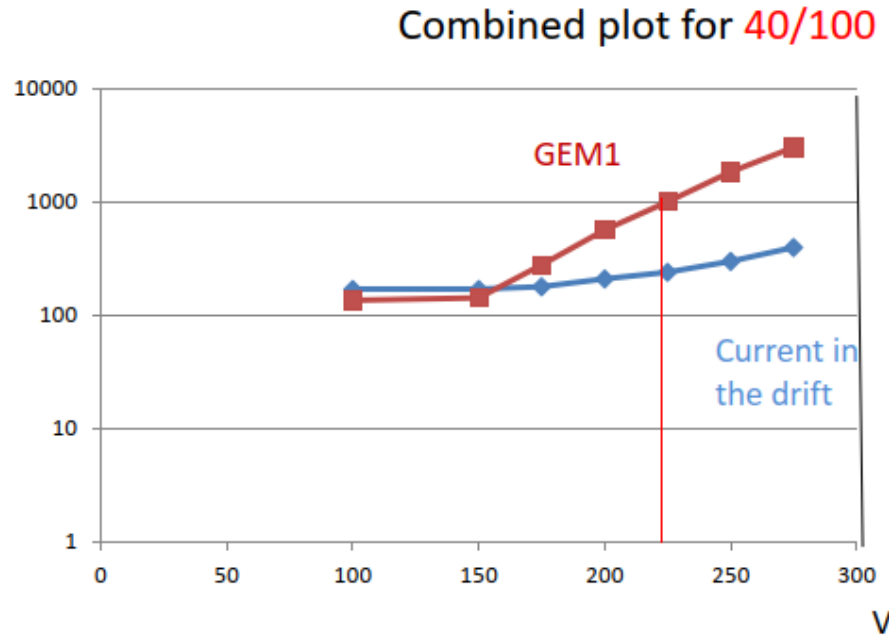
At a drift voltage of 200V/cm electron capture by CF4 is small, so it is not astonishing that the results in both gases were similar

Measurements of multiplication in first GEM





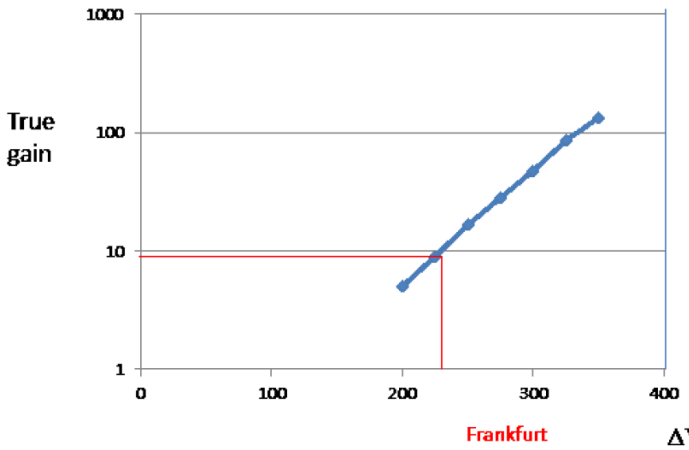
Ne+10%CO2+5%N2



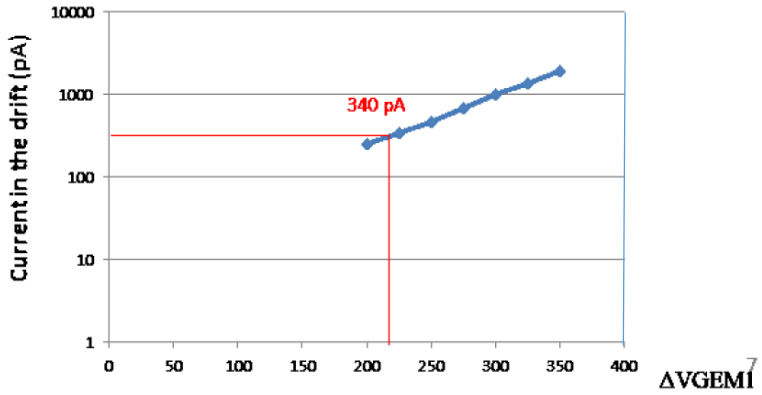
At VGEM1=225
Gain = 7.2,
IBF≈24%

We used the max setting to measure the primary current in the drift and then, when operating with a gain the x-ray current was reduced to avoid the space charge effect (we always kept the current on the readout plate below 10nA, which is expected current at the ALICE experiment). However, presenting the data, obtaining with the gain, we often, for convenience, recalculate then to the setting 40/100 in order to see immediately the IBF.

Ne+10%CO2+5%N2



Frankfurt

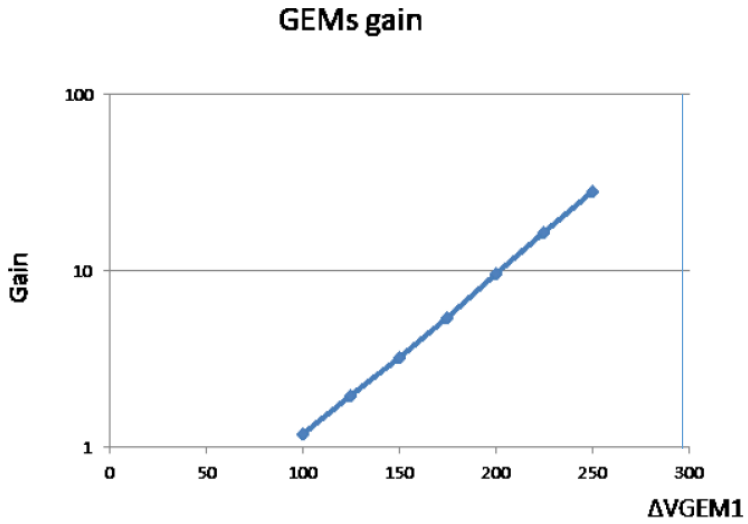


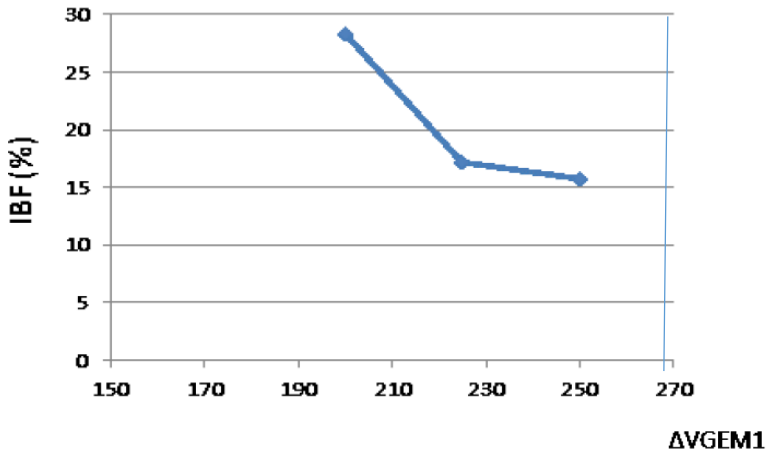
$A_1=I_{GEM1}/I_{inj}$,

$ABF= (I_{dr}-I_{ioniz})/I_{GEM1}$

X-ray setting
40/100

Ne+20%CF4



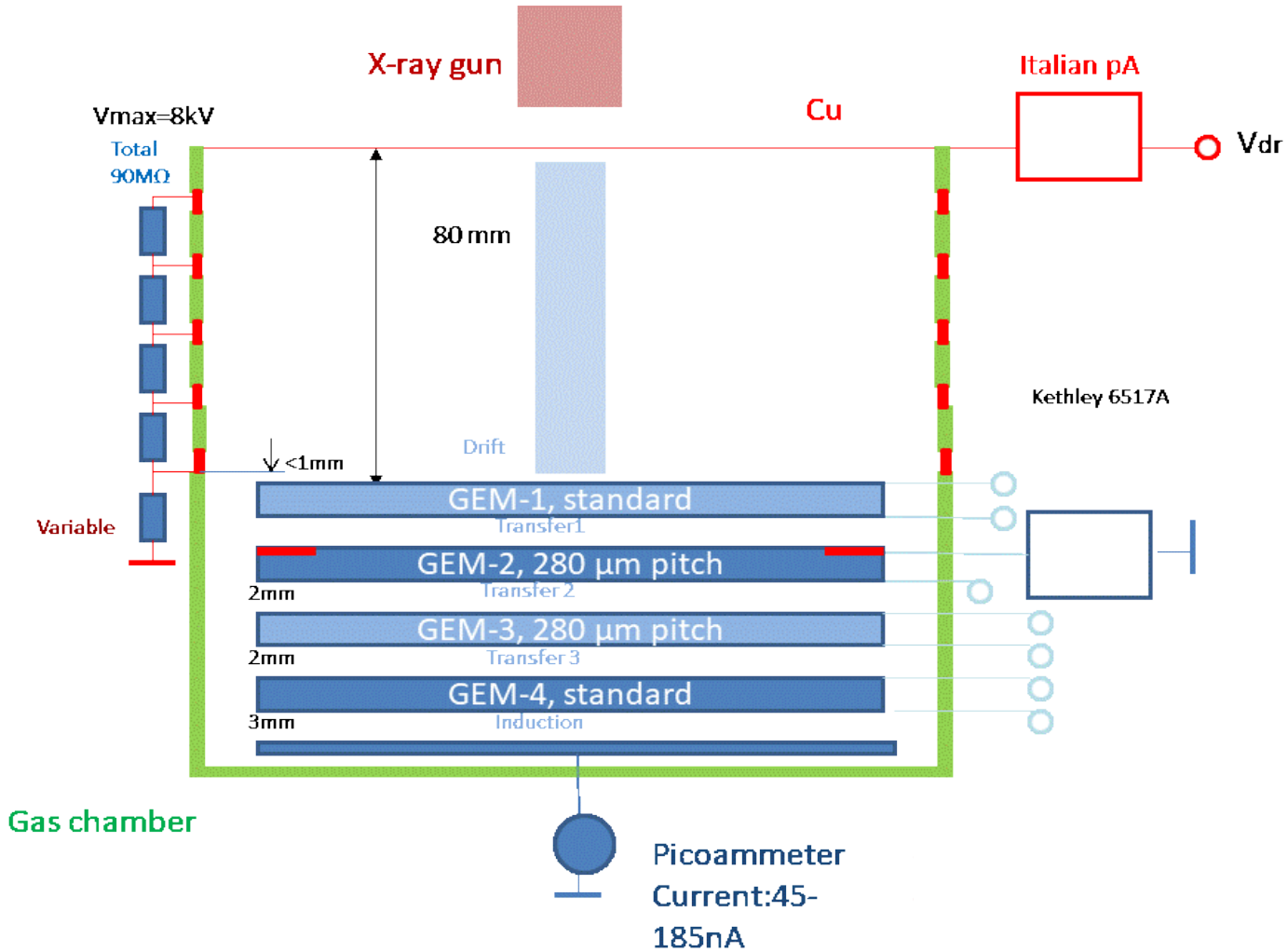


In a uniform field $A= \exp(\alpha)x$

$A= \exp(\alpha-\eta)x$

In both cases the dependence should be exponential and this was observed experimentally

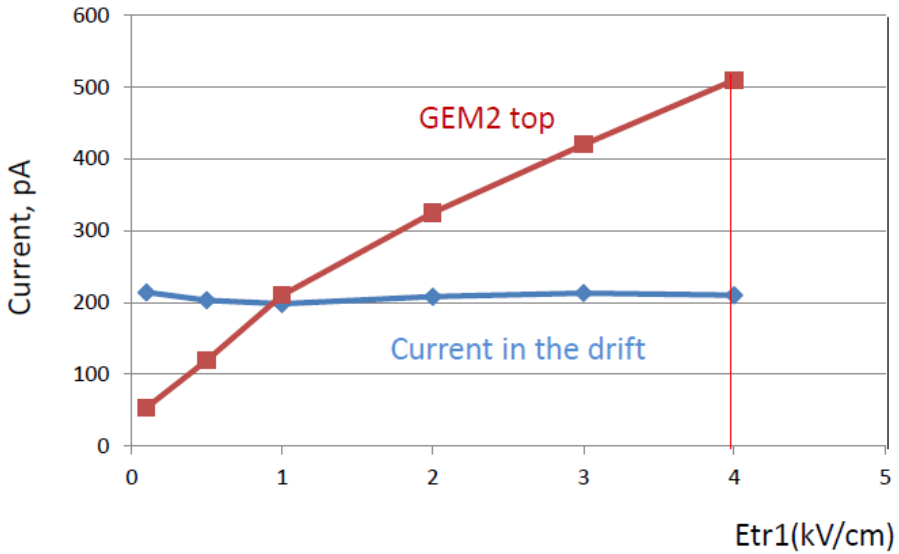
Measurements of extraction from first GEM



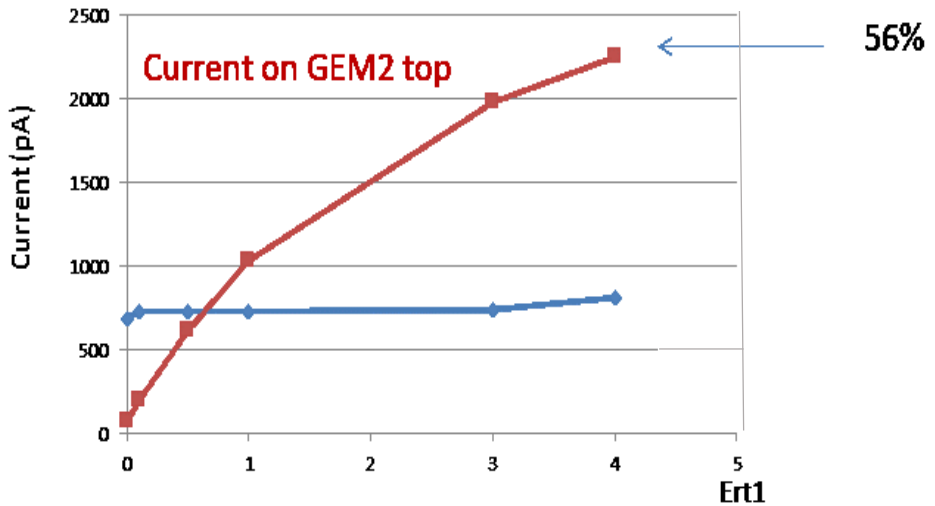
Ne+CO2+N2

Ne+CF4

VGEM1=225
40/100



40/100

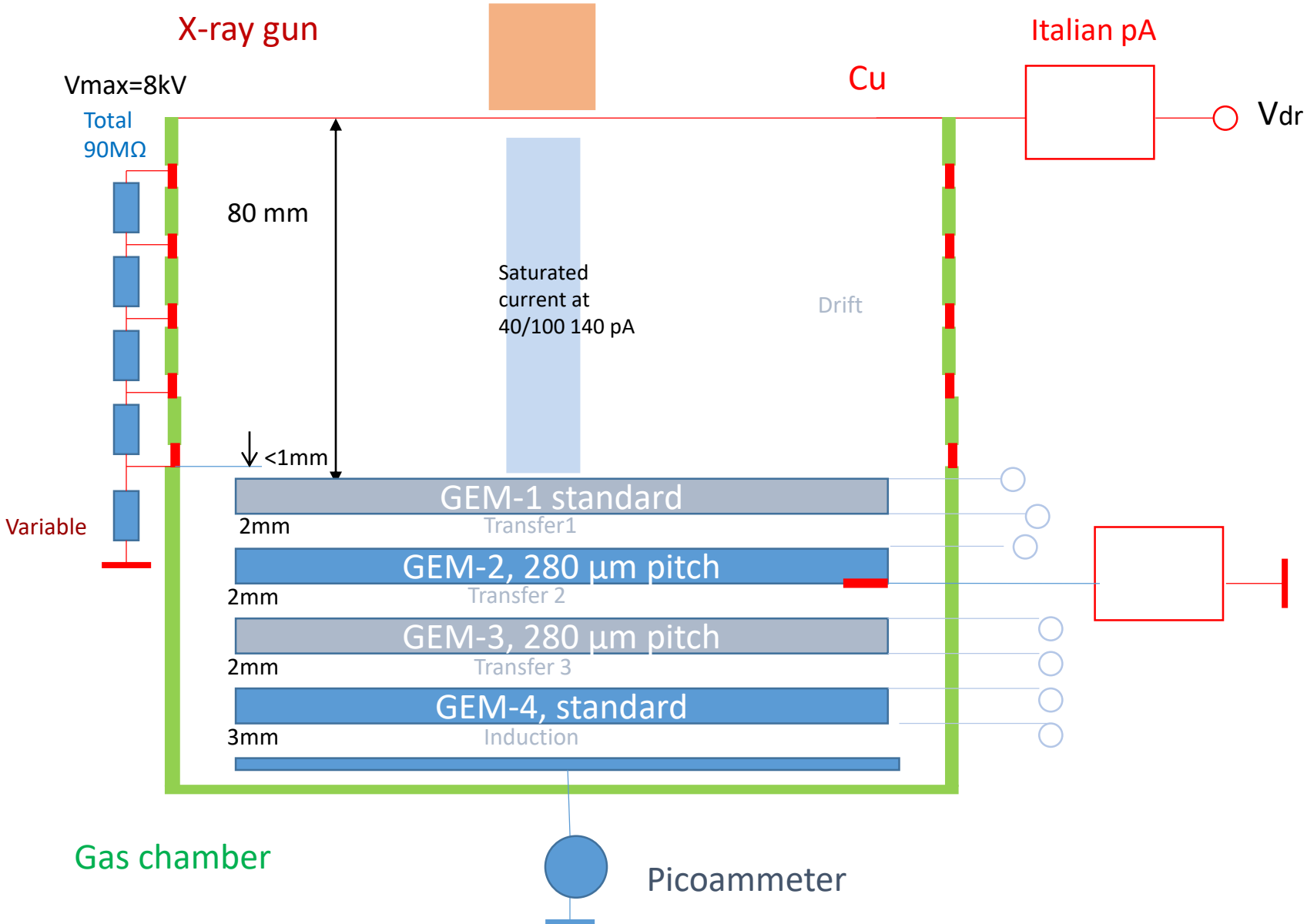


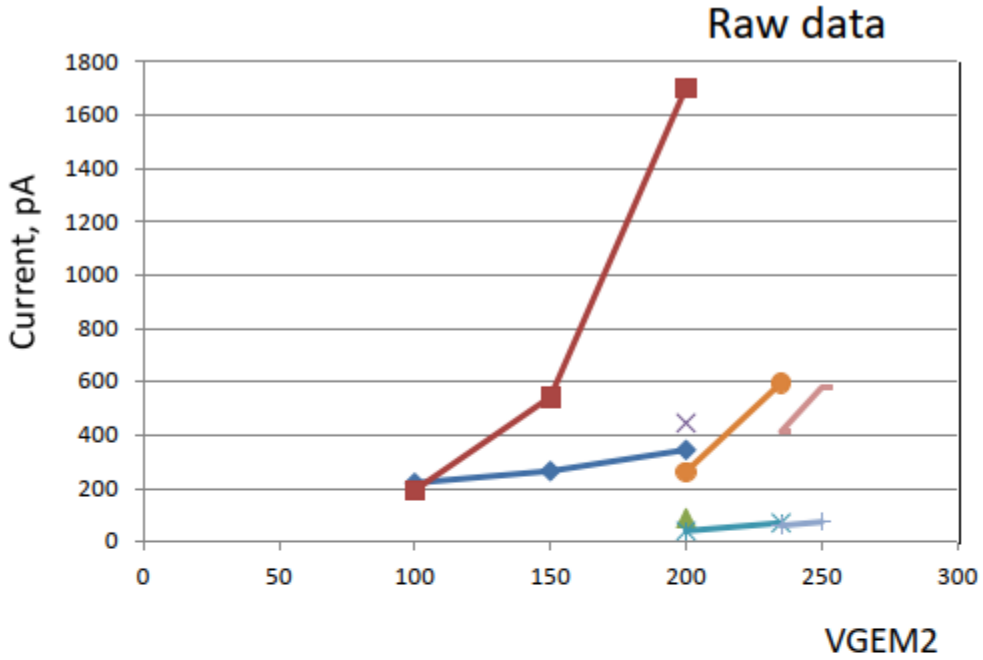
ΔVGEM1=const=245V

At VGEM1 =225 and Etr1=4 kV/cm extraction 0.47

In this case there is a strong effect of electron capture, but in ionization chamber mode negative ions are “invisible”, so results for both gas mixtures were qualitatively similar

Measurements of multiplication in second GEM

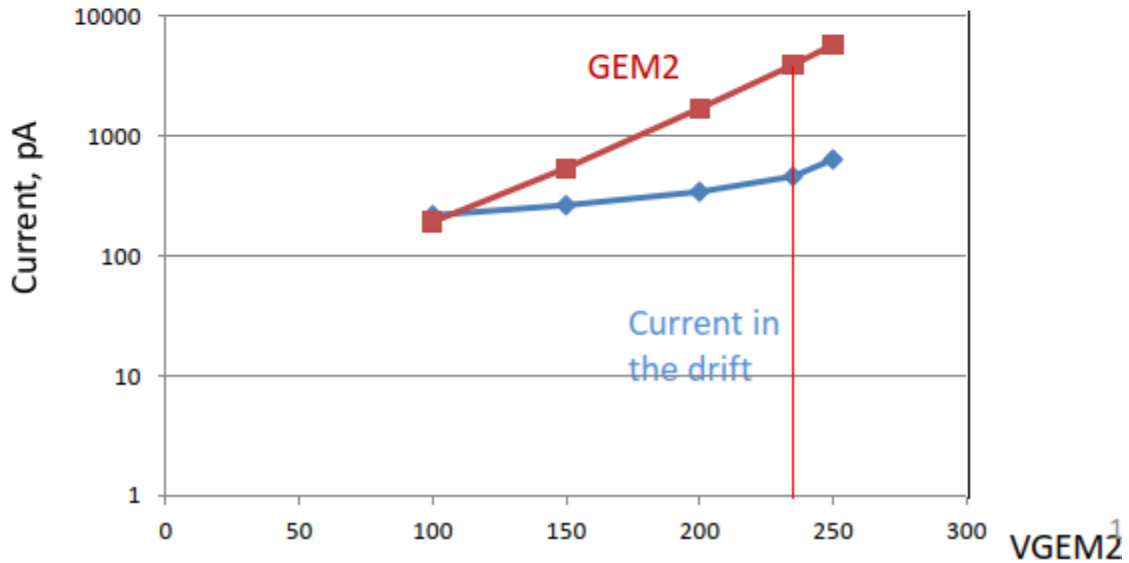




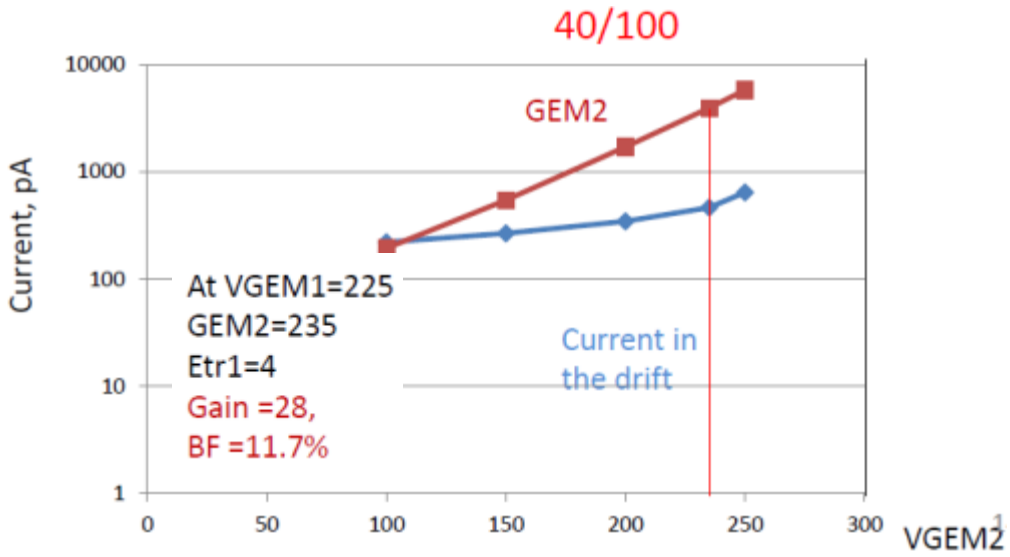
Setting:
GEM1=225,
Ert=4

At VGEM1=225
GEM2=235
Etr1=4
Gain =28,
BF =11.7%

Combined plot,
40/100

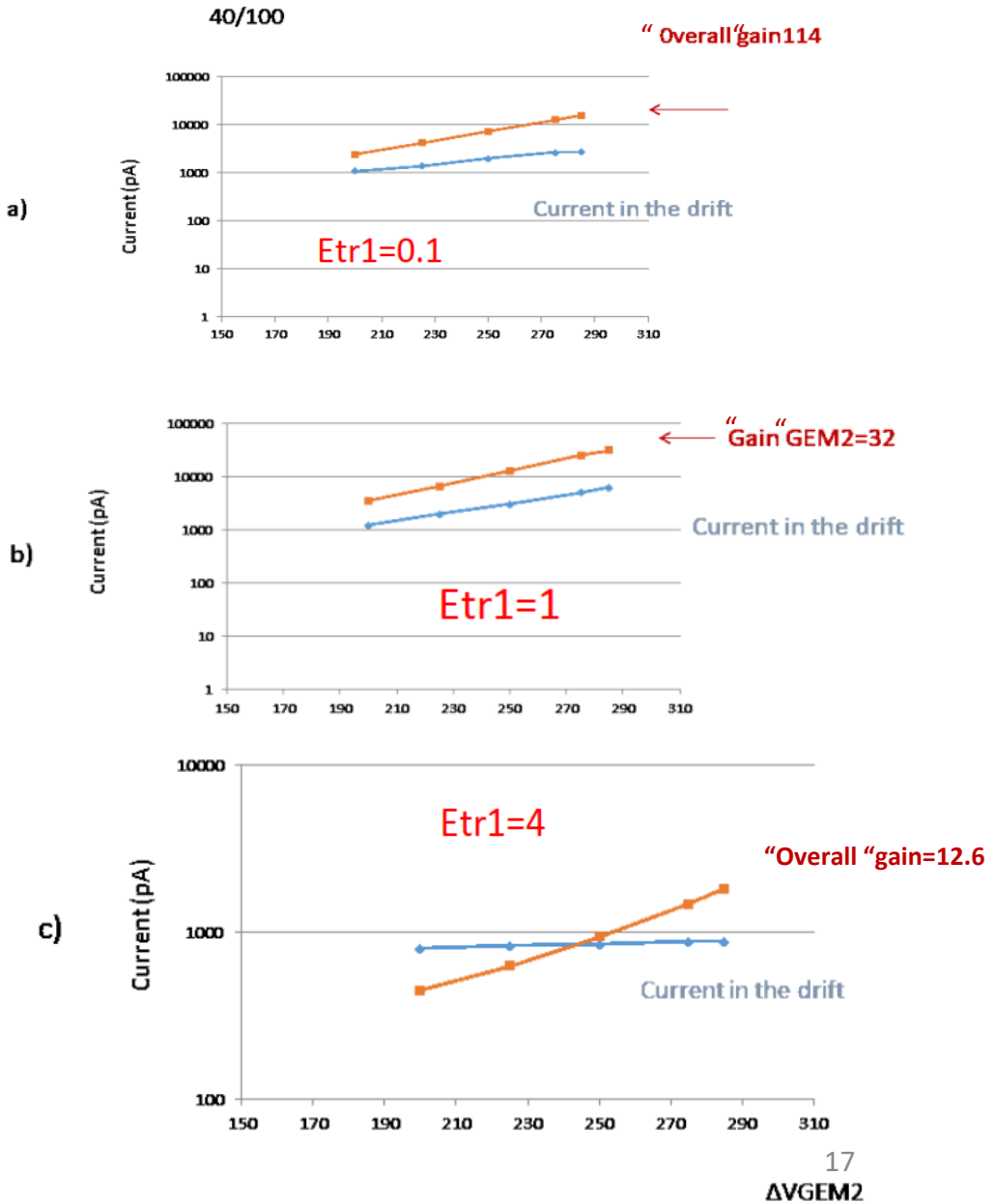


Ne+CO2+N2



Ne+CF4

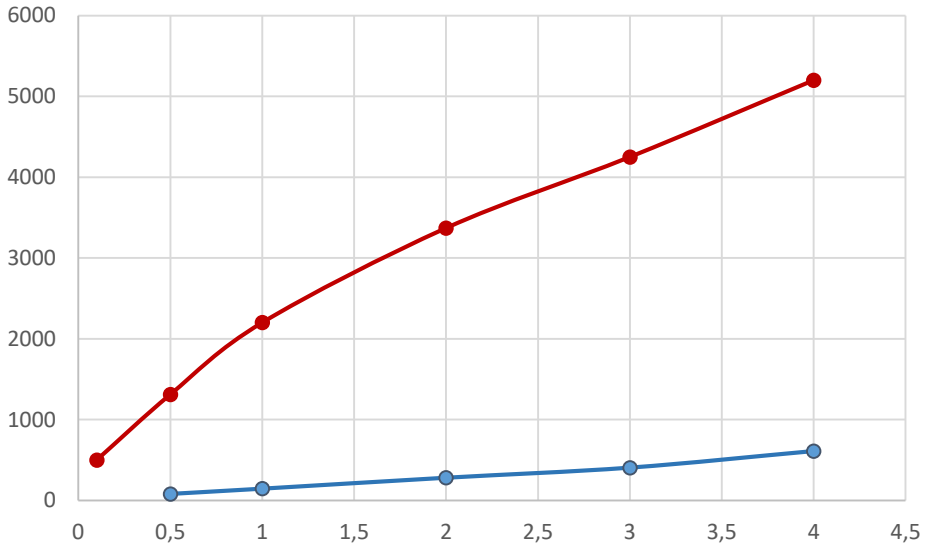
"Overall" gain =I_2/I_0



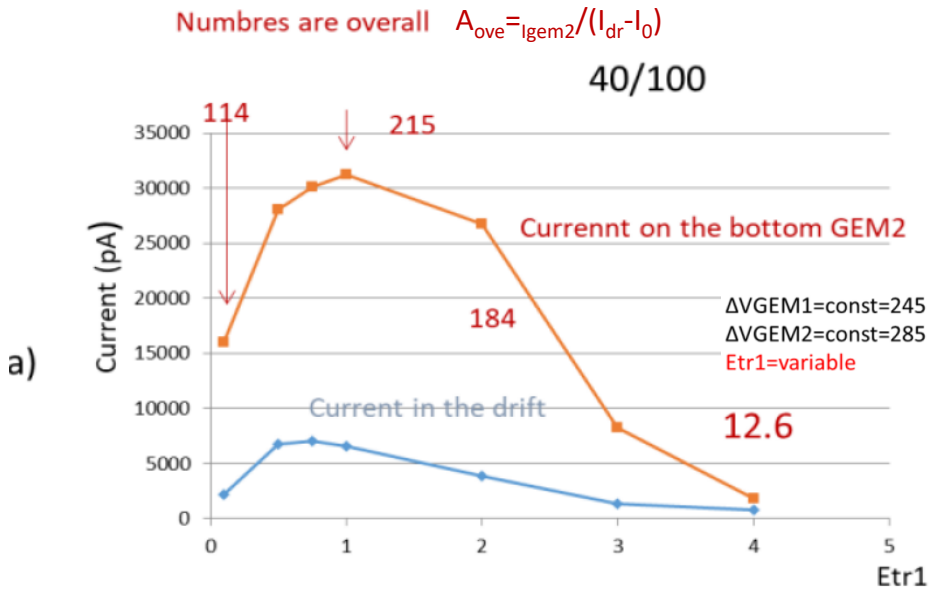
Suddenly one can see a big difference: in Ne+CF4 there is no monotonic dependence of GEMbot current as a function of the transfer field applied to its top

The same data, but presented in another variable: Etr1

Ne+CO2+N2



Ne+CF4



In the case of electronegative gases, the current generated in GEM2:

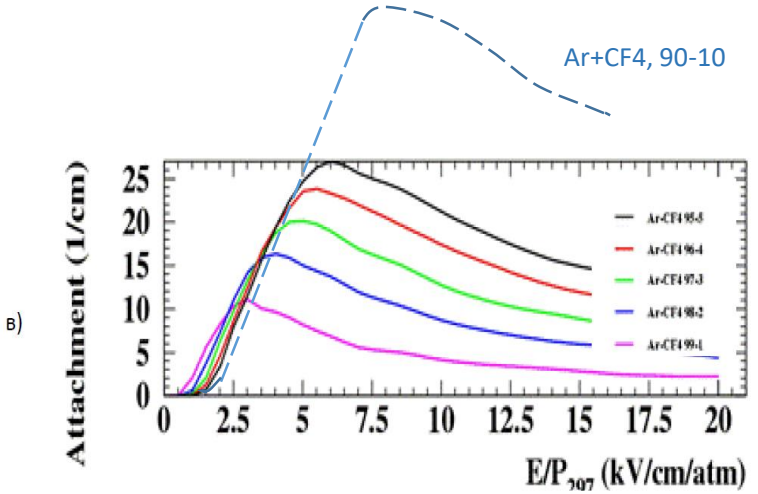
$$I_{gem2} = A_{gem2} n_e$$

$$I_{gem2} = A_{gem2} \{I_e + I_{ni} B_{coll} (Etr_1, A) K_{da} (A)\},$$

where B_{coll} is “collection efficiency” - what proportion of negative ions falls into the holes of the lower GEM, and K_{da} (A) is the coefficient indicating how much electronegative ions decay in the holes of the GEM (the so-called “disattachment process,” supposedly due to impact ionization) , freeing free electrons, then initiating avalanches.

Therefore the possible qualitative explanations are

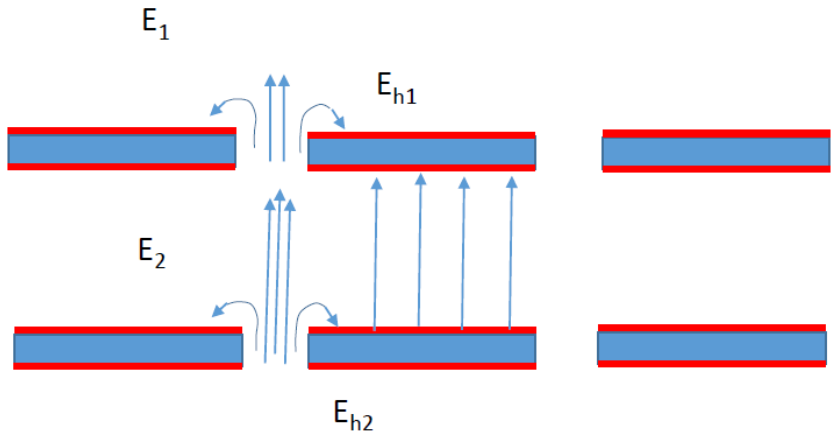
Capture of electron
(space charge can change current flows)



$n_e=N_{eo}\exp(-kx)$

(linear dependence from CF4 concentration)

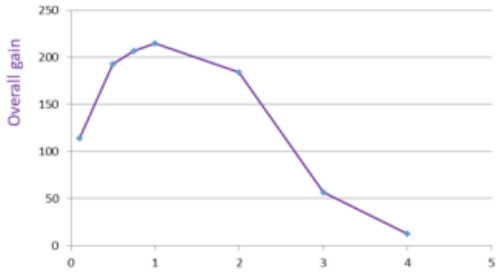
Collection between hole
(effect well known for positive ions)



All dependence become then exotics

"Visible" overall gain

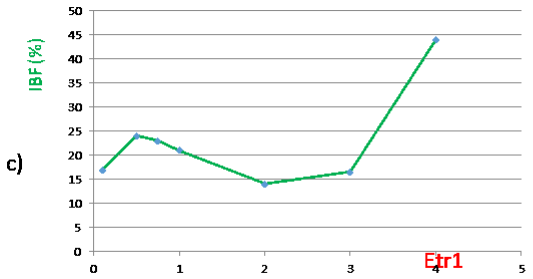
b)



Etr1

Note: gain in GEM2 =const!

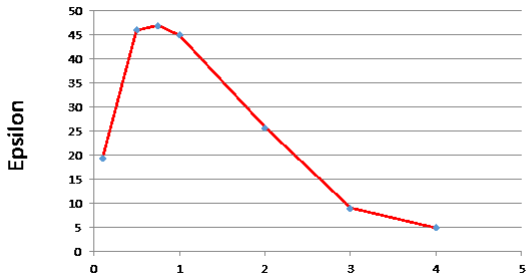
Current:



c)

Etr1

ΔVGEM1=const=245
ΔVGEM2=const=285
Etr1=variable



d)

$\varepsilon_{IBF} = A\eta_{IBF} - 1$

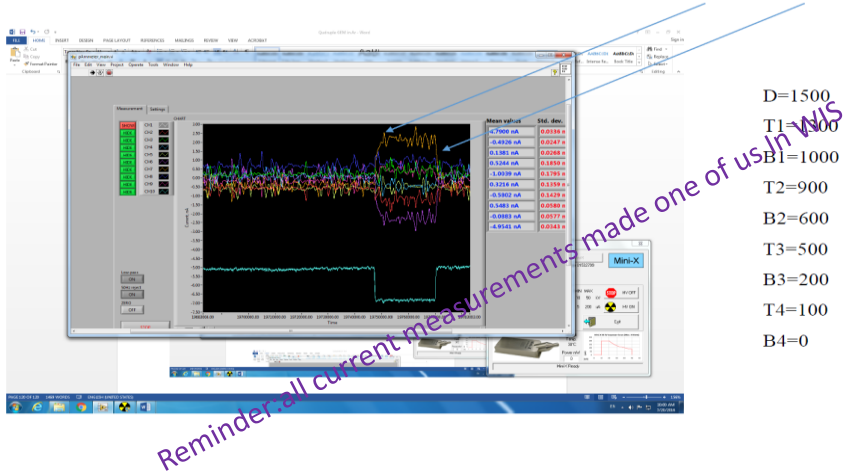
2

Possible reasons:

I_{ni} changes due to the space charge
(but in our case one can neglect this effect),
B_{coll} changes due to the low ion diffusion
(I_e is negligible at high E)

The first was checked experimentally

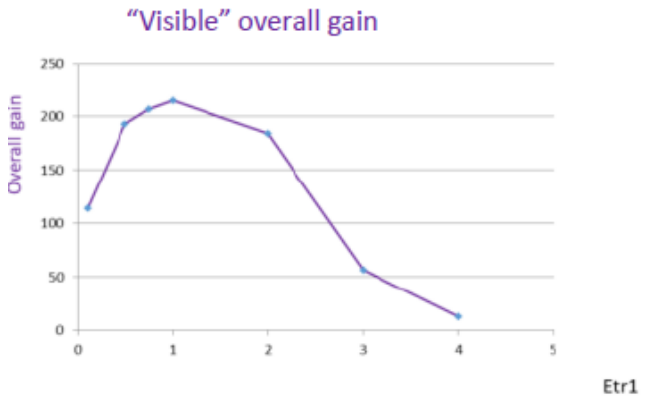
Example of histograms of current from GEM electrodes, when the X-ray gun was on and off



The second effect is well known

In any case, simulations are needed to clarify the reasons

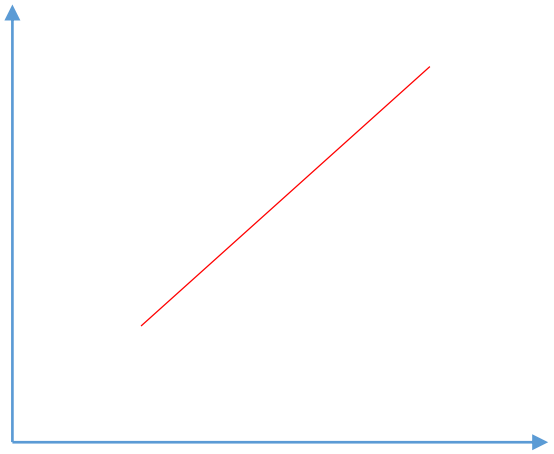
Ions generated in holes



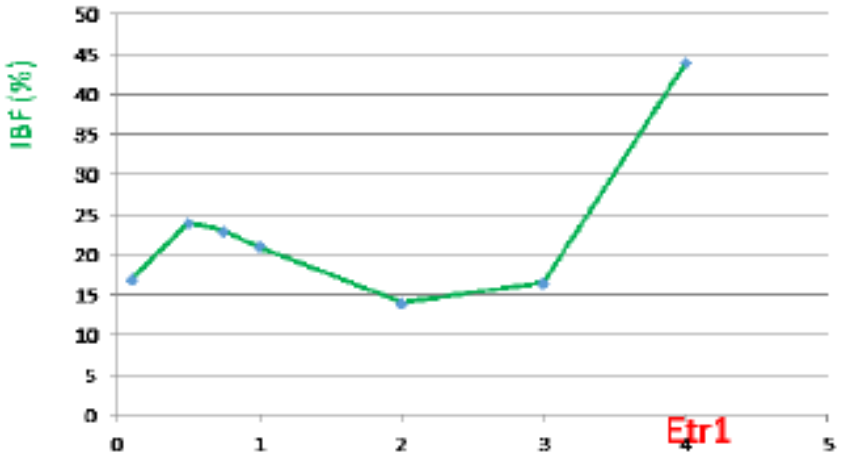
Positive ions backflow:

$$\sim A_{Vis.overall} X_{extr}$$

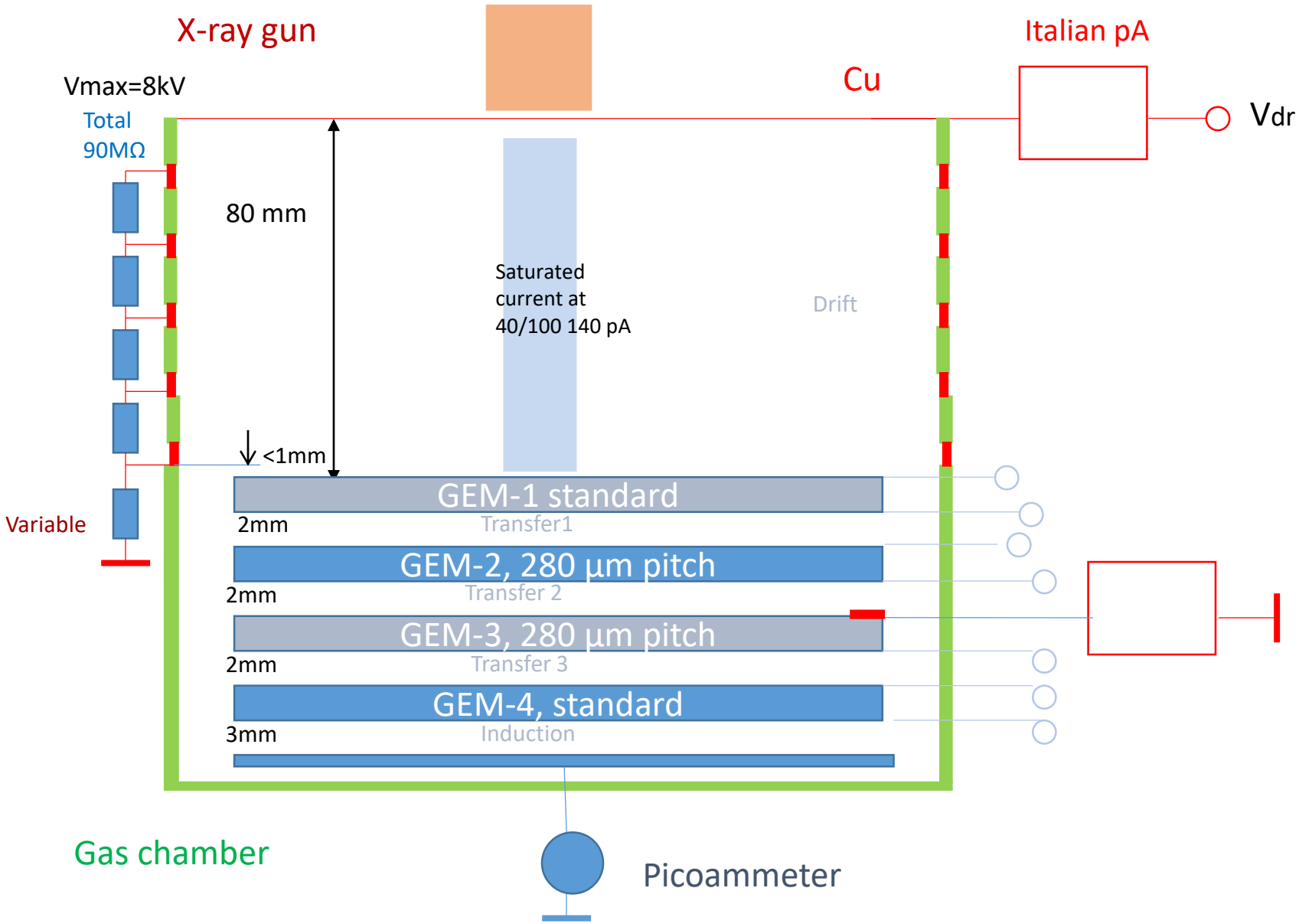
Extracted positive ions



Experimental data for IBF



Measurements of extraction from second GEM

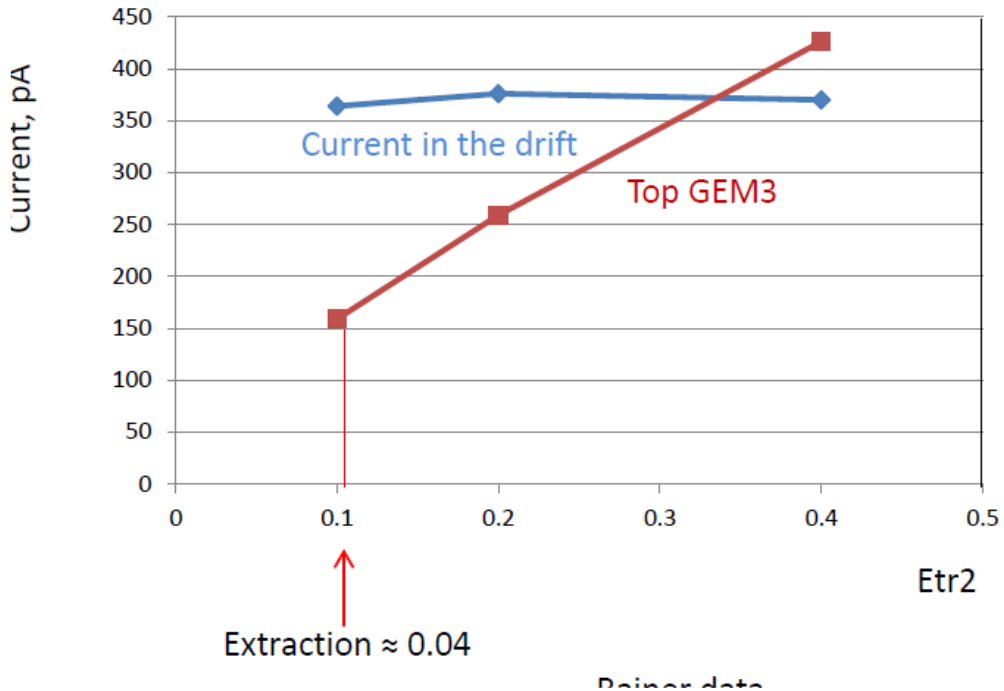


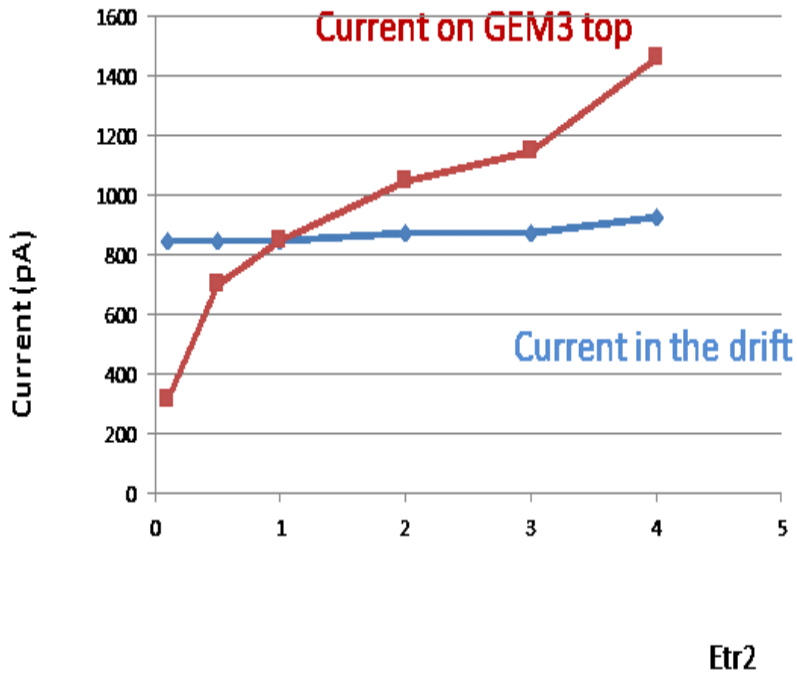
Ne+CO2+N2

Ne+CF4

ΔVGEM1=245
ΔVGEM2=285
Etr1=4
Etr2=variable

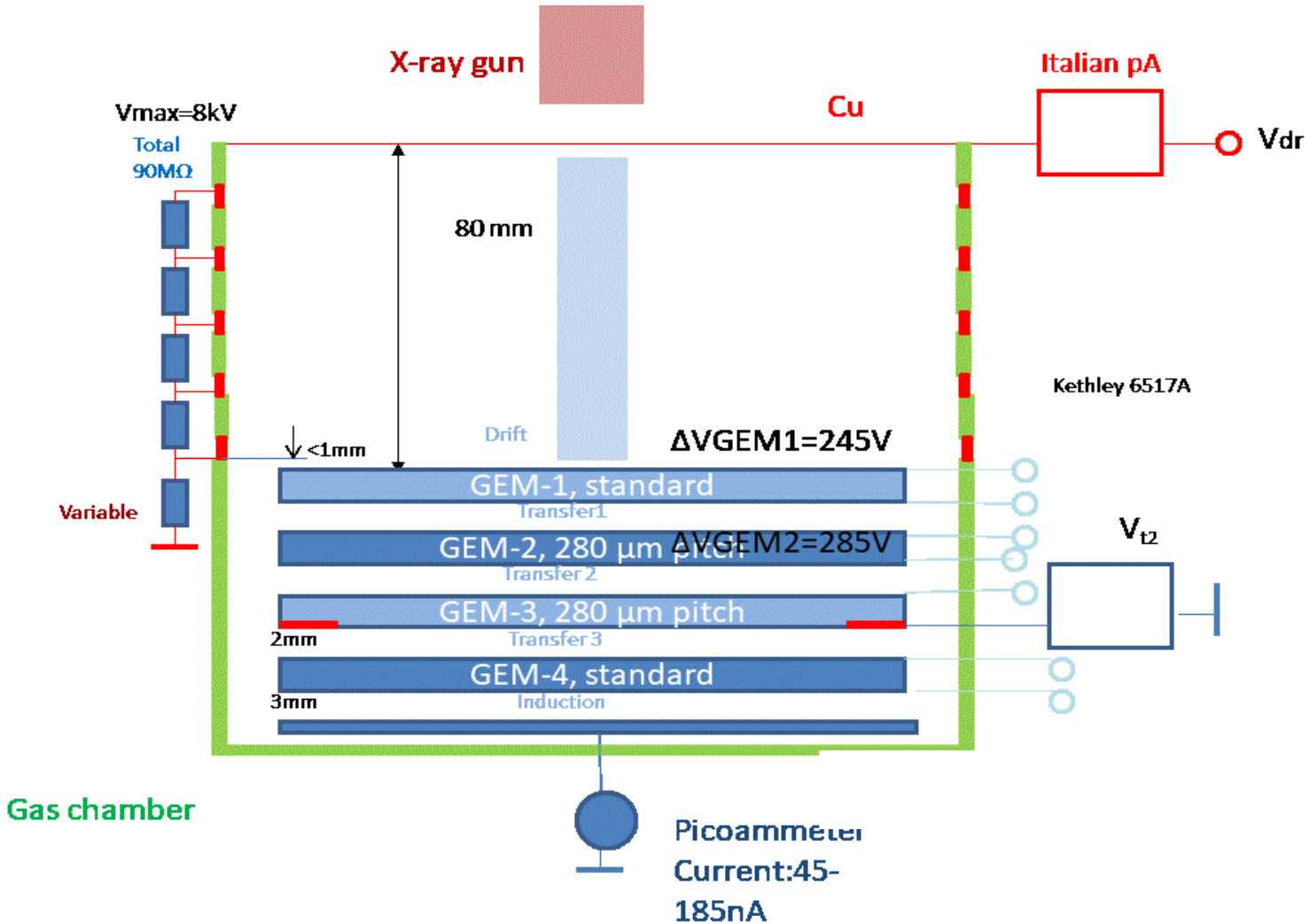
40/100



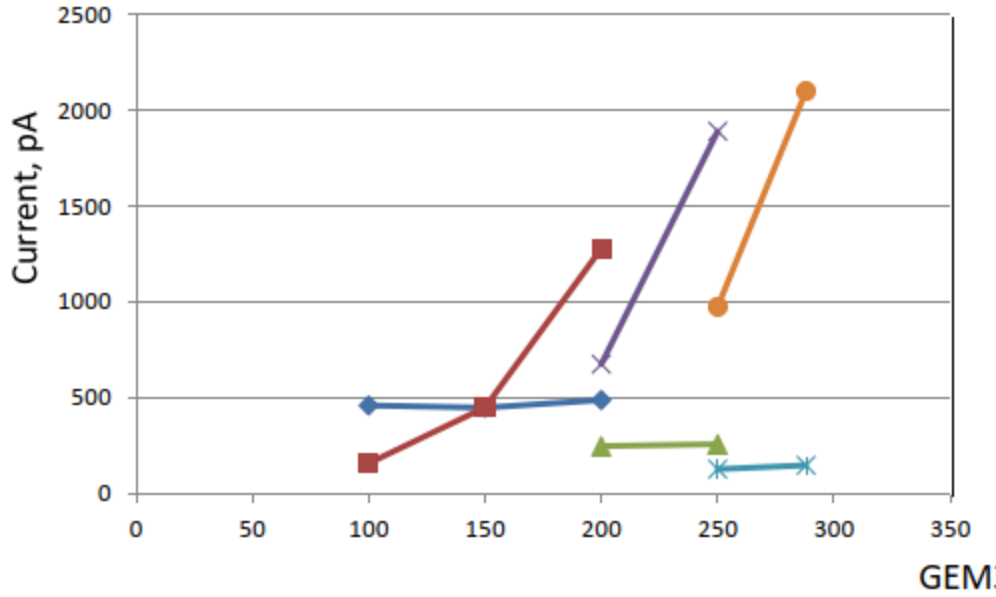


…again, in ionization chamber mode negative ions are “invisible”, so results are qualitatively similar

Measurements of multiplication in third GEM

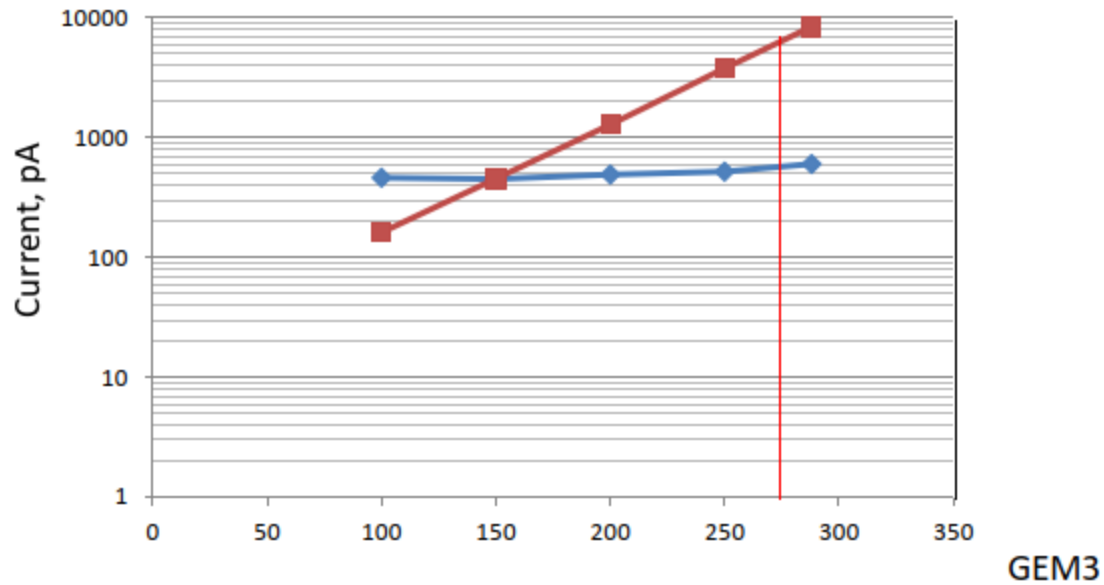


Raw data (various X-ray currents)

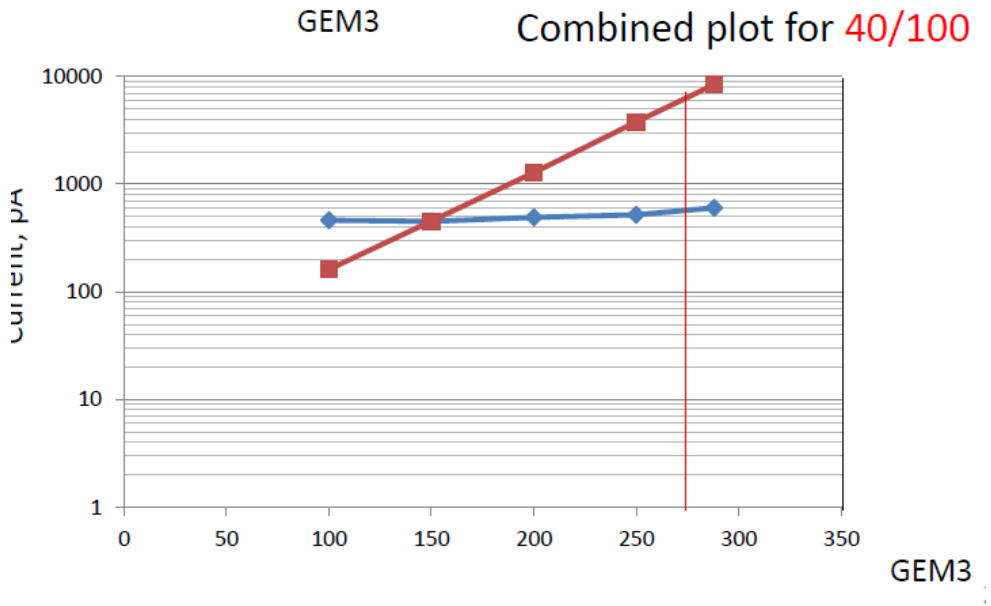


Combined plot for 40/100

At VGEM1=225
GEM2=235
GEM3=272
Etr1=4
Et2=0.1
Gain =42,
BF =1.2%

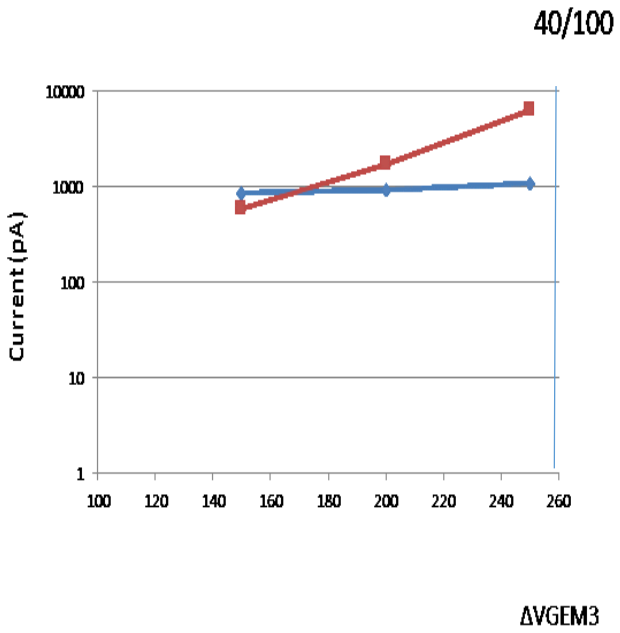


Ne+CO2+N2



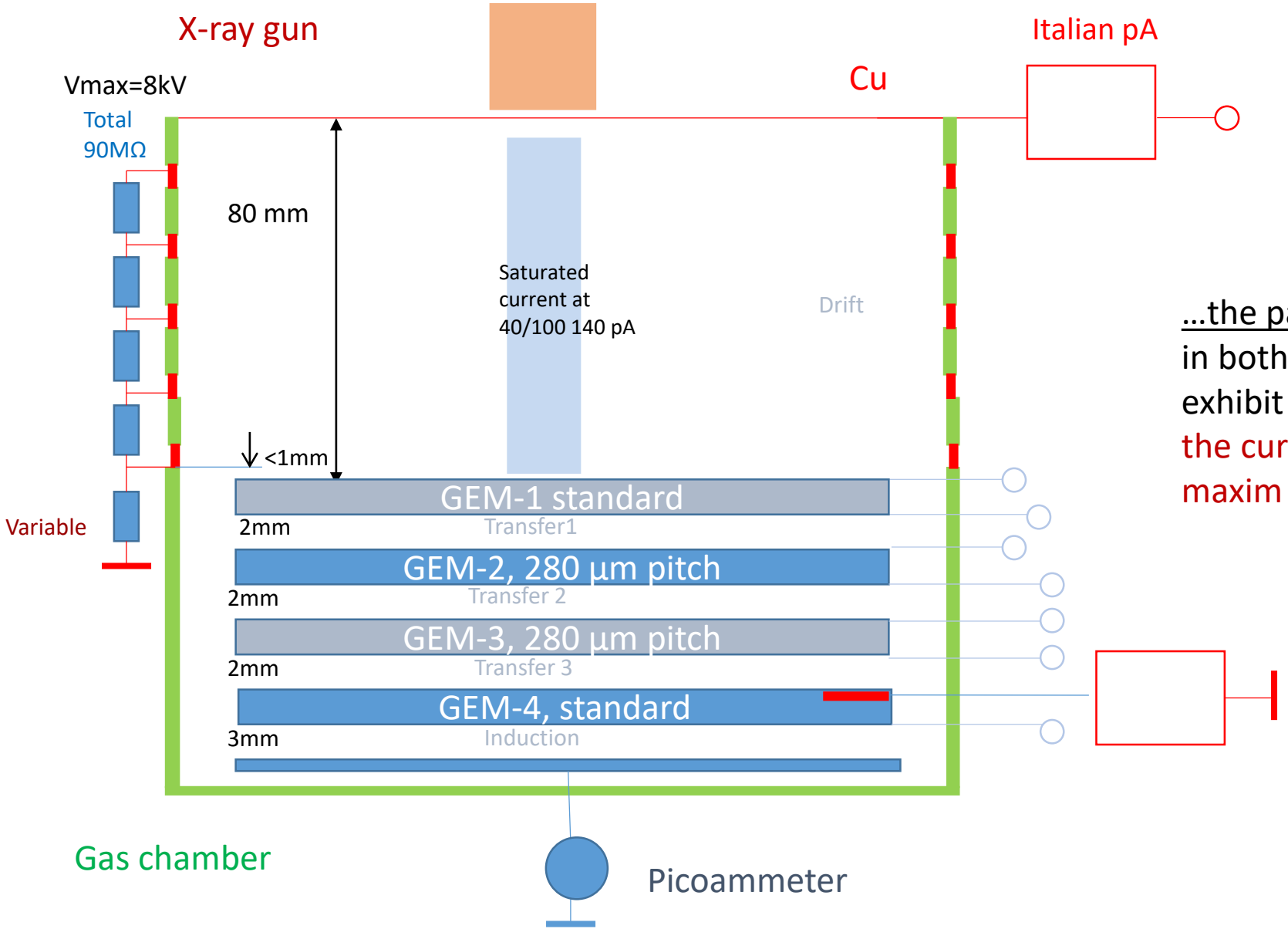
Ne+CF4

ΔVGEM1=245
ΔVGEM2=285
ΔVGEM3=variable
Etr1=4
Etr2=0.75



…as expected-exponential multiplication, so no surprises

Measurements of extraction from third GEM and from fourth GEM

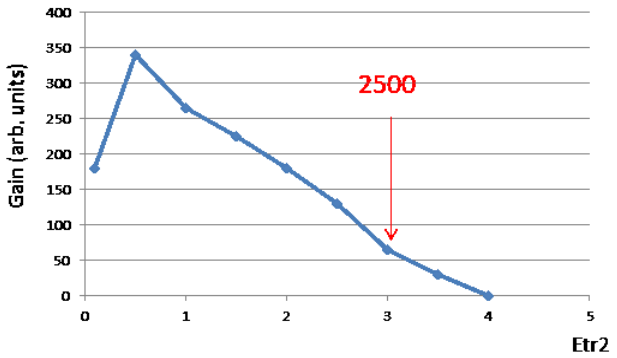


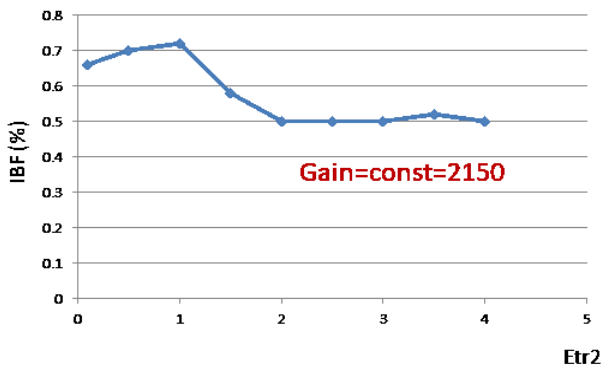
…the pattern remain the same:
in both cases the extraction current exhibit monotonically growth, whereas the current measured on GEMbot has a maxim (as was shown before)

Were there any radical changes when all voltages were applied to the quadrupole GEM ?

Ftr2 scan

ΔVGEM1=245
ΔVGEM2=285
ΔVGEM3=320
ΔVGEM4=360
Etr1=4
Etr2=0.1-4
Etr3=0.1
Eind=4

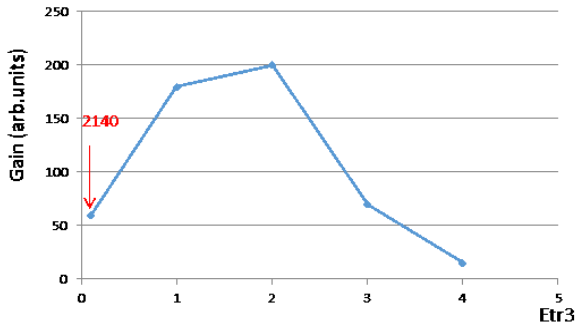


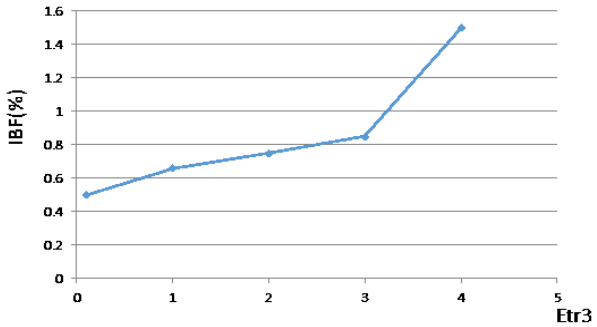


GEM3bot

ΔVGEM1=245
ΔVGEM2=285
ΔVGEM3=320
ΔVGEM4=360
Etr1=4
Etr2=3
Etr3=0.1-4
Eind=4

… The same behaviour…

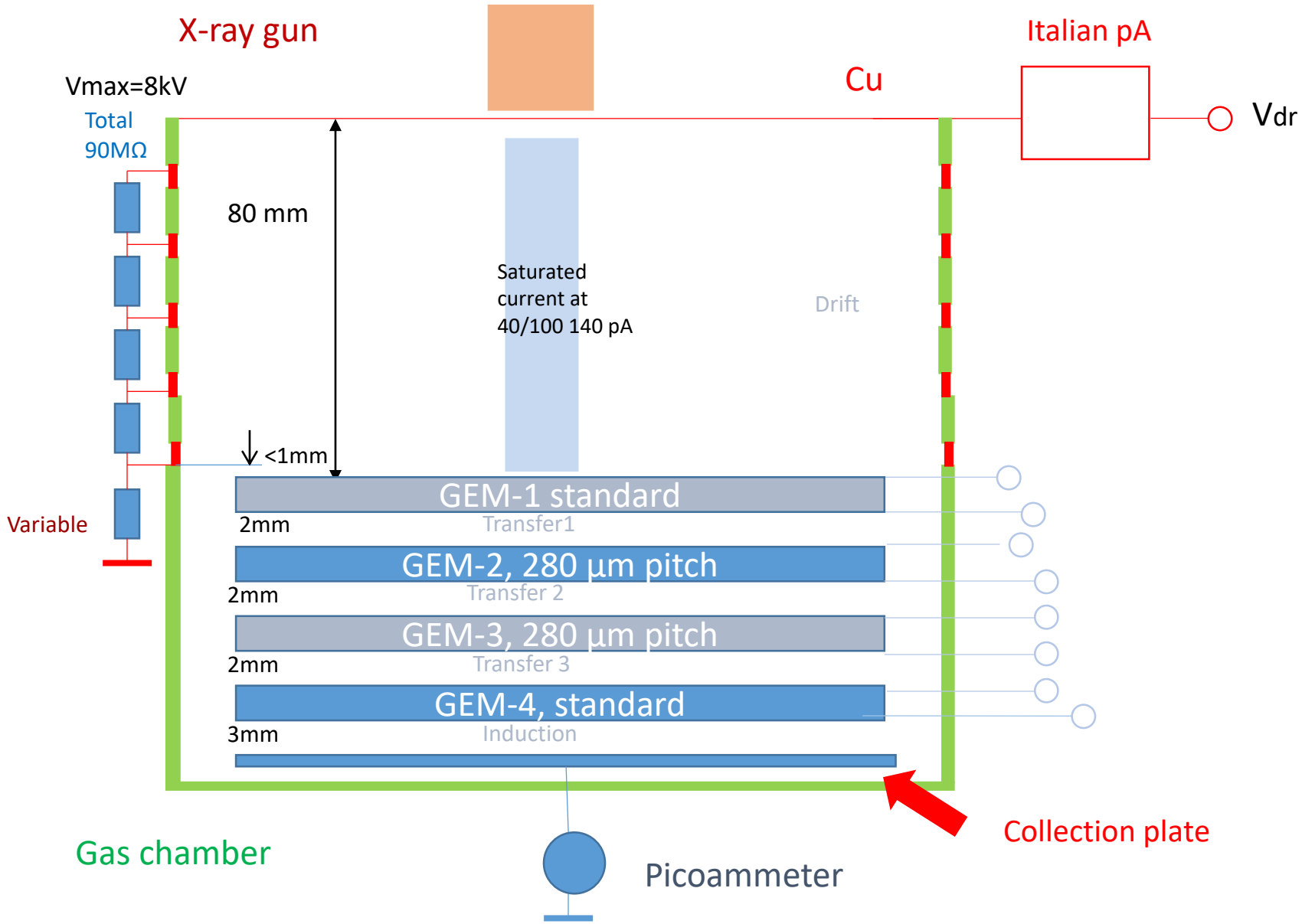


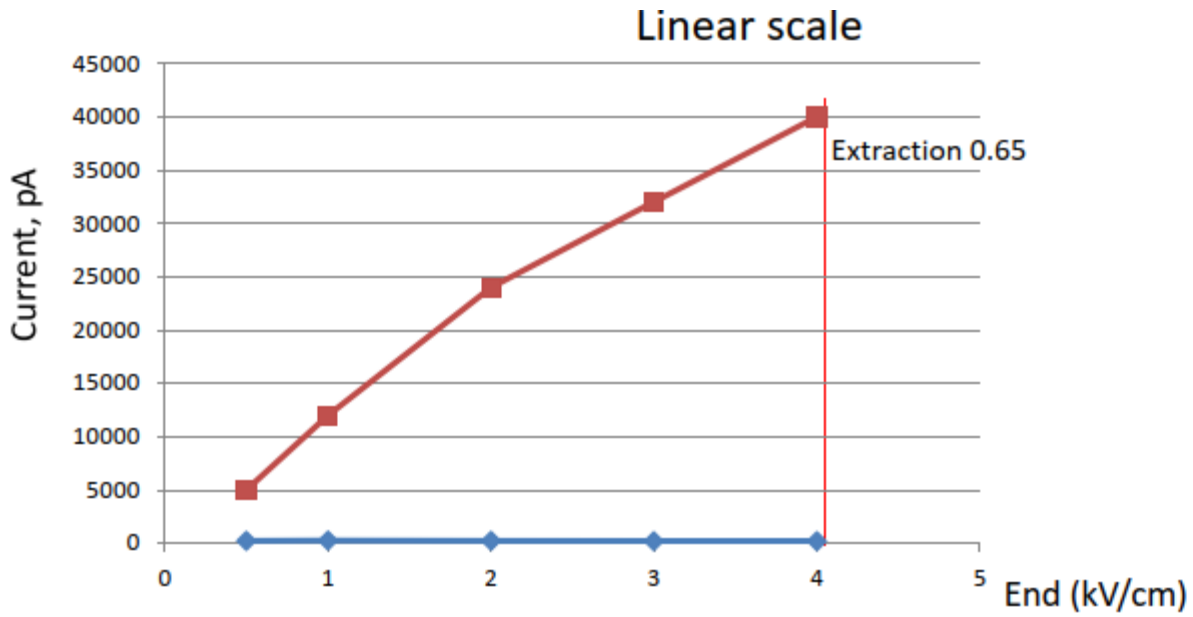


GEM4bot

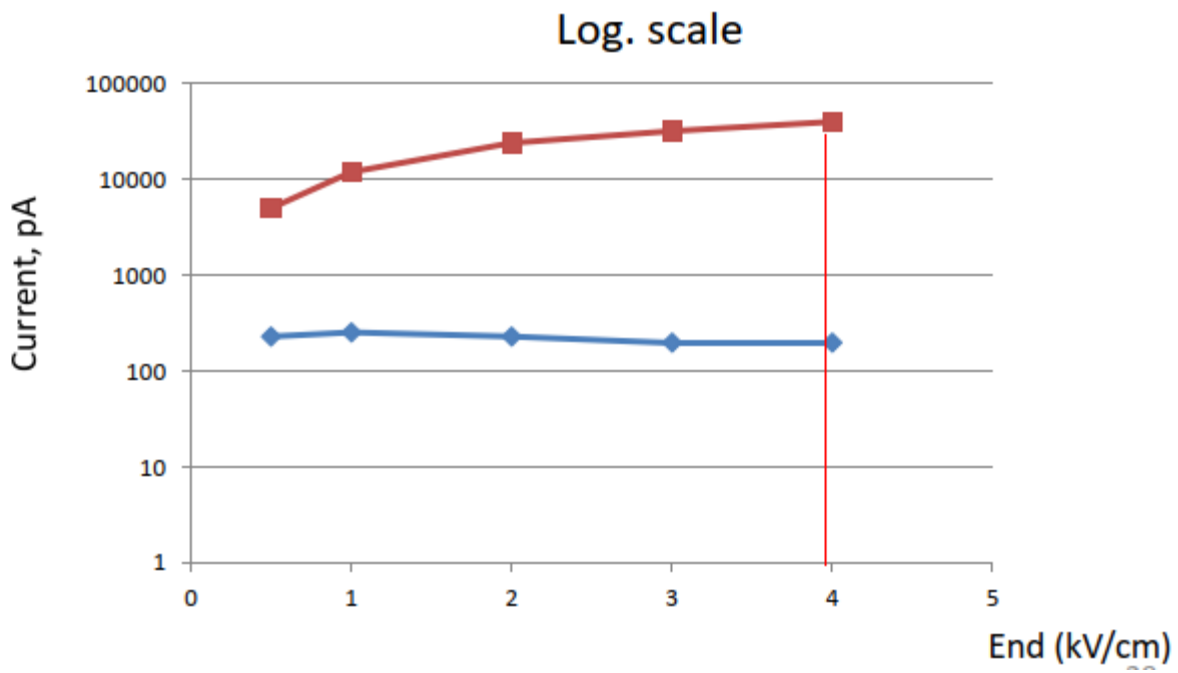
…actually no..

Measurements at the collection plate

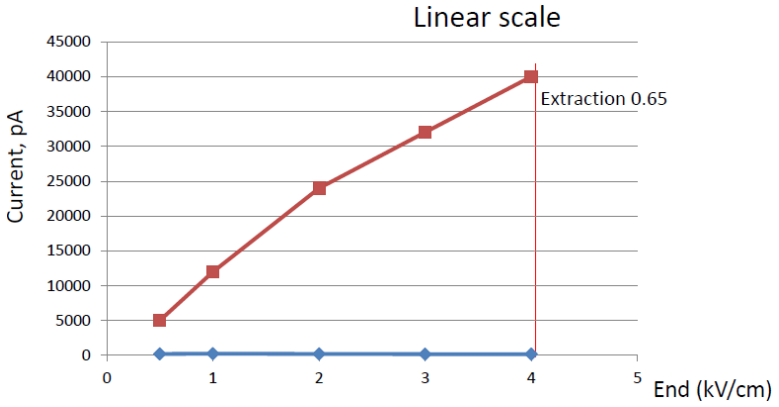



Linear scale
Current, pA
45000
40000
35000
30000
25000
20000
15000
10000
5000
0
0
1
2
3
4
5
Extraction 0.65
End (kV/cm)

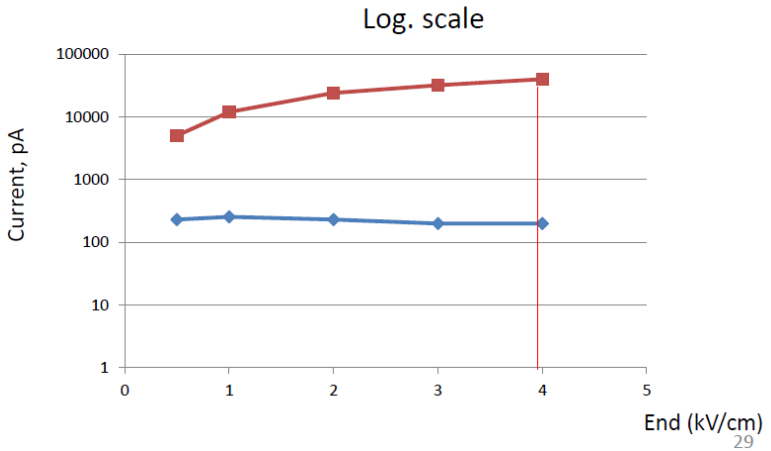
40/20


Log. scale
Current, pA
100000
10000
1000
100
10
1
0
1
2
3
4
5
End (kV/cm)

Ne+CO2+N2



40/20



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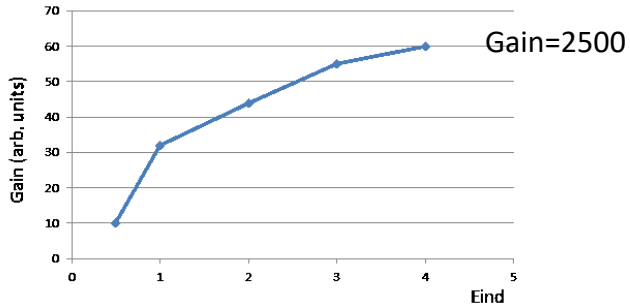
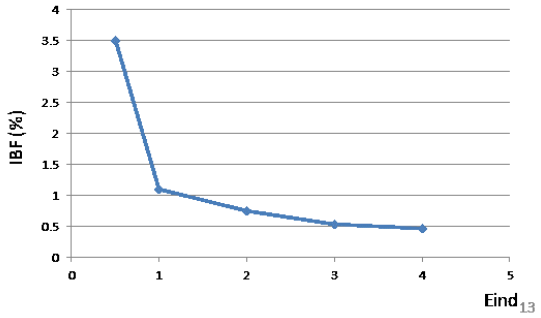
Ne+CF4

Ein scan

ΔVGEM1=245
ΔVGEM2=285
ΔVGEM3=320
ΔVGEM4=360
Etr1=4
Etr2=3
Etr3=0.1
Eind=0.5-4





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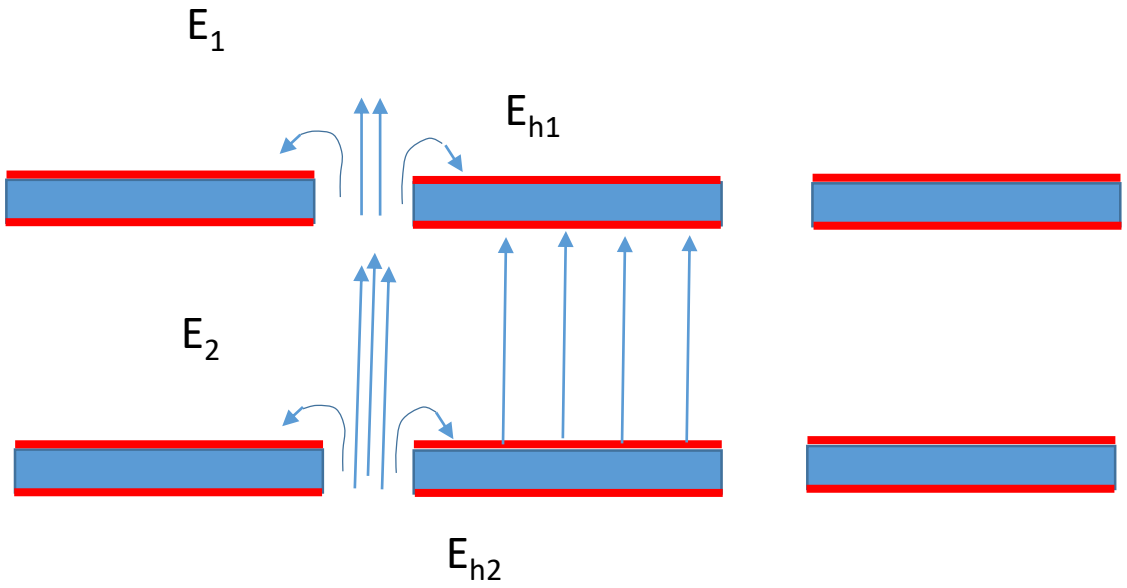
Qualitatively results are similar. In both cases the current was generated by negative carries: electrons and negative ions

Voltage setting optimization

Positive ions motion

$\sim E_1/E_{h1}$



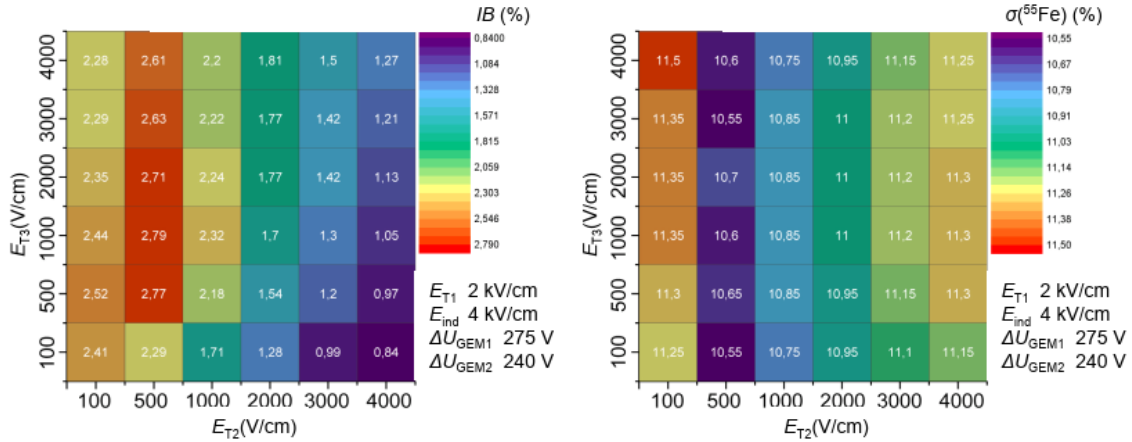
If one ignore a space charge effect
(which is valid at ALICE condition)
negative ions do not affect positive
Ion movement

Therefore, roughly speaking,
one can search for the optimum
voltage settings around one found
For Ne+CO2+N2

One of the best setting tested so far

ΔVGEM1=245
ΔVGEM2=285
ΔVGEM3=320
ΔVGEM4=360
Etr1=4
Etr2=3
Etr3=0.1
Eind=4

IBF=0.5 %
At a gain "2500"-
old calibration



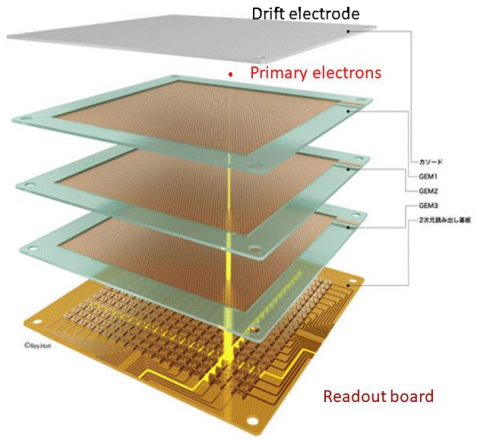
Example of systematic scans performed by the ALICE TPC upgrade team

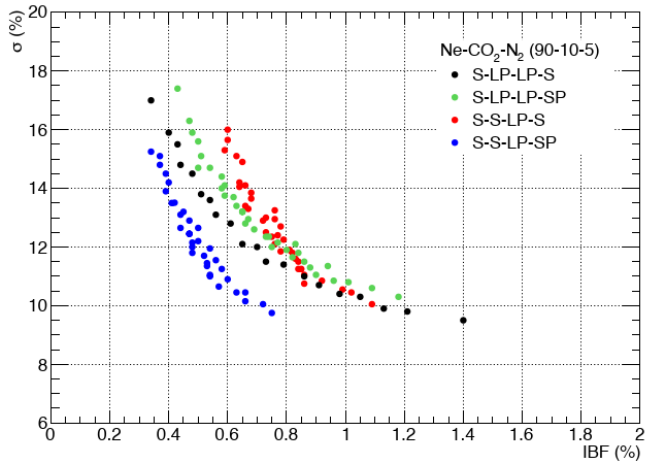
…so, in principle, the IBF achieved in Ne+CF4 gas mixture could as low as in Ne+CO2+N2.
Of course, careful scans should be done for the true voltages optimization

The aim of the talk was not to present any systematic studies or careful voltage optimization, but rather focus on a not monotonic dependence of the gain vs. transfer field in Ne+CF4 gas mixture

Conclusions

- "Visible "gain of GEM in the tested Ne+CF4 gas mixtures has a maximum as a function of the transfer field applied to its top
- This should be taken into account in a quadrupole GEM voltages optimization
- At some particular voltage setting the IBF achieved in Ne+CF4 gas mixture was as low in the "standard" mixture Ne+CO2+N2 (≈ 0.5%)
- However, careful scans of various parameters vs. applied voltages is missing, so the results are very preliminary and more studies should be done to prove that Ne+CF4 gas mixture could be an alternative to Ne+CO2+N2



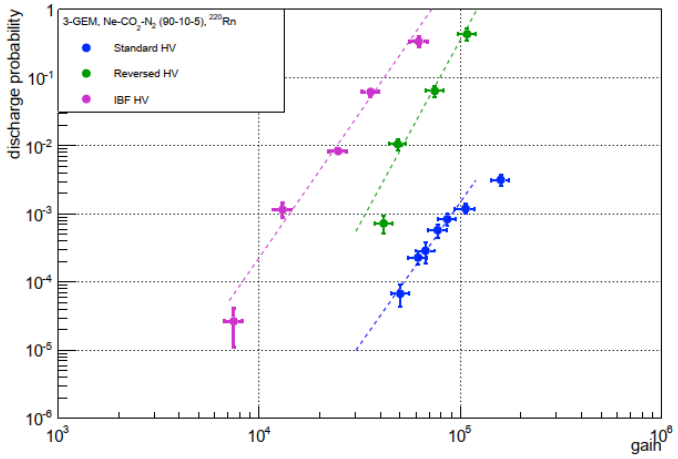


What is missing in particular?

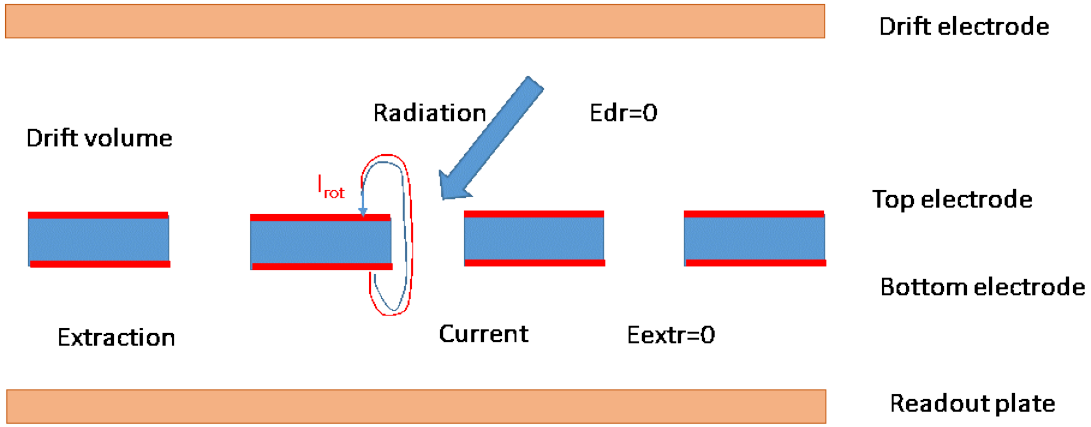
(if one wants to go ahead with this mixture)

- Energy resolution vs. IBF measurements
- Spark probability measurements and voltage setting optimising ensuring acceptable trade between energy resolution and spark probability
- Long-term stability studies
- Aging (RPC experience with water vapours))
- Beam tests

and, probably, much more…



Back up slides



Some basic of electrons and ions flow in GEM:

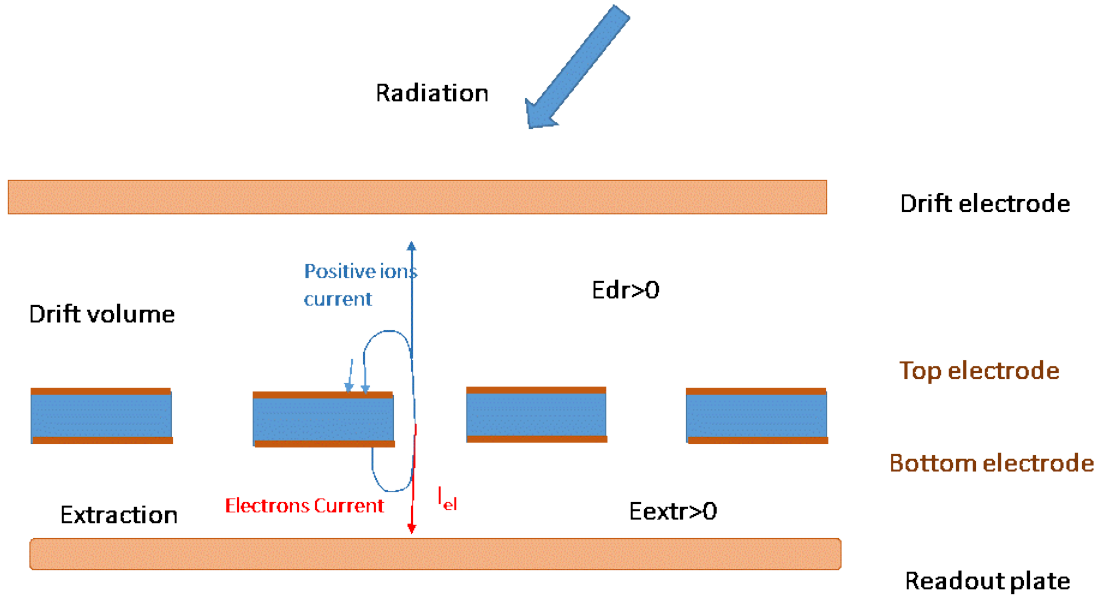
qualitative picture is quite clear, but an analytical model is quite complicated as well as simulations

In the case of Edr and Eextr=0 the current I_{rot} circulate between the top and the bottom GEM electrodes

$$I_{ion}=I_{rot}f_{ion}(E_{dr})$$

$$I_{el}=I_{rot}f_{el}(E_{extr})$$

$$I_{bot1}=I_{top1}+I_{dr},$$



Similarly, if Eextr>0, the extracted current (electrons) $I_{el}=I_{rot}\cdot f_{el}(E_{extr})$ where $(f_{el}(E_{extr})<1)$

Ne+CO2+N2

GEM1=225
GEM2=235
GEM3=272
GEM4=340
Etr1=4
Etr2=0.1
Etr3=4
Eind=4
Gain= 1800
IBF=0.5

GEM1=270
GEM2=250
GEM3=270
GEM4=340
Etr1=4
Etr2=2
Etr3=0.1
Eind=4
Gain= 2000
IBF=0.7