IBF studies of triple and quadruple GEM for the ALICE TPC upgrade

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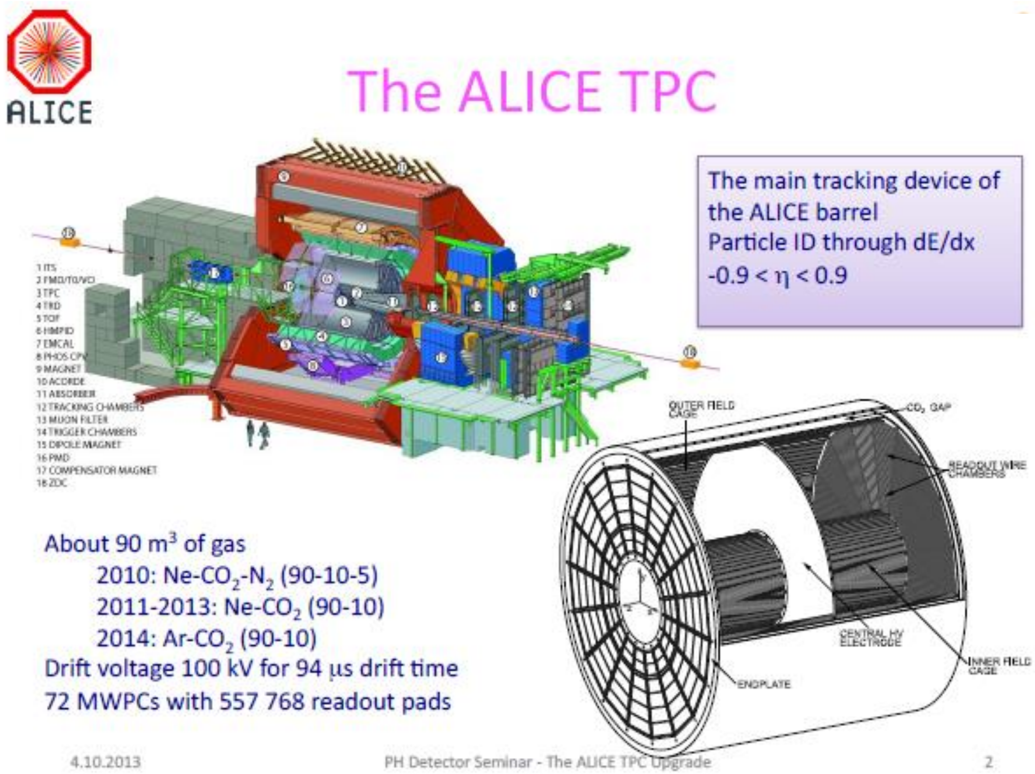
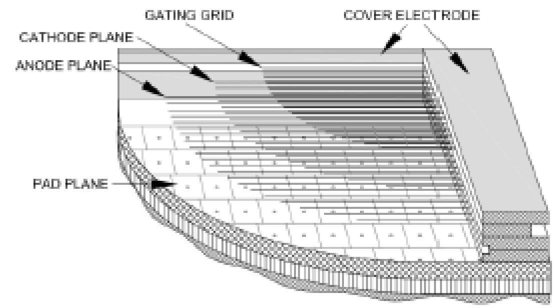
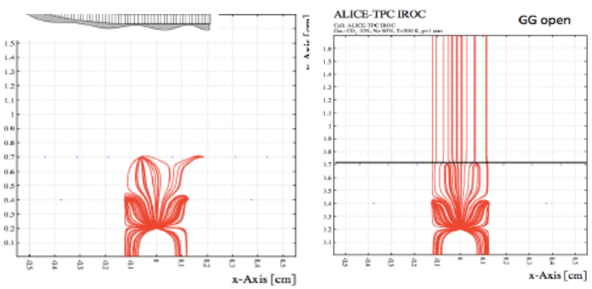
Behalf of the ALICE TPC upgrade team

I. Motivation

Current ALICE TPC





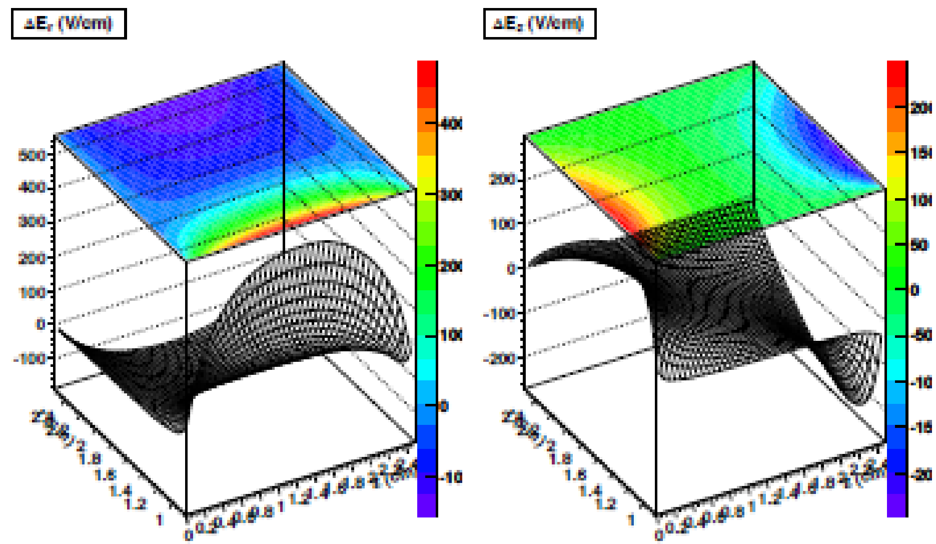


IBF suppression 10^{-4},
Gate opening time 100μs

Challenge:

Run3: 50 kHz Pb-Pb

- From <1 kHz to 50 kHz (10 nb^{-1})
  - Heavy quarks, quarkonia (low p_T), dileptons, exotica
- Continuous readout: no trigger, no gating → space charge distortions of order of 1 m → not an option
- Current TPC doesn't do the job



Radial and z distortions as a function of r and z for 50 kHz Pb-Pb collisions with non-gated MWPC. Note that drift field is 400 V/cm

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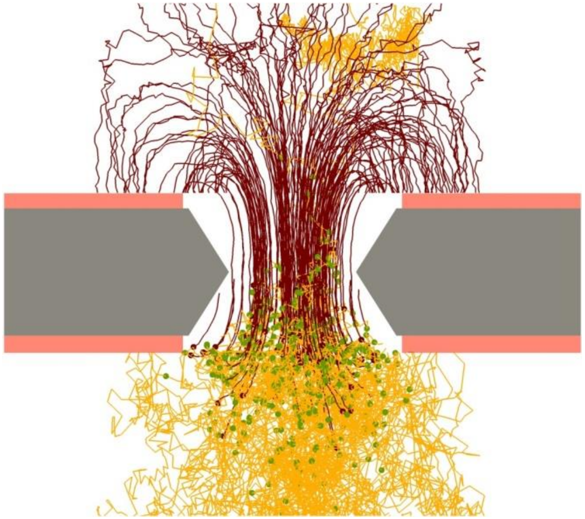
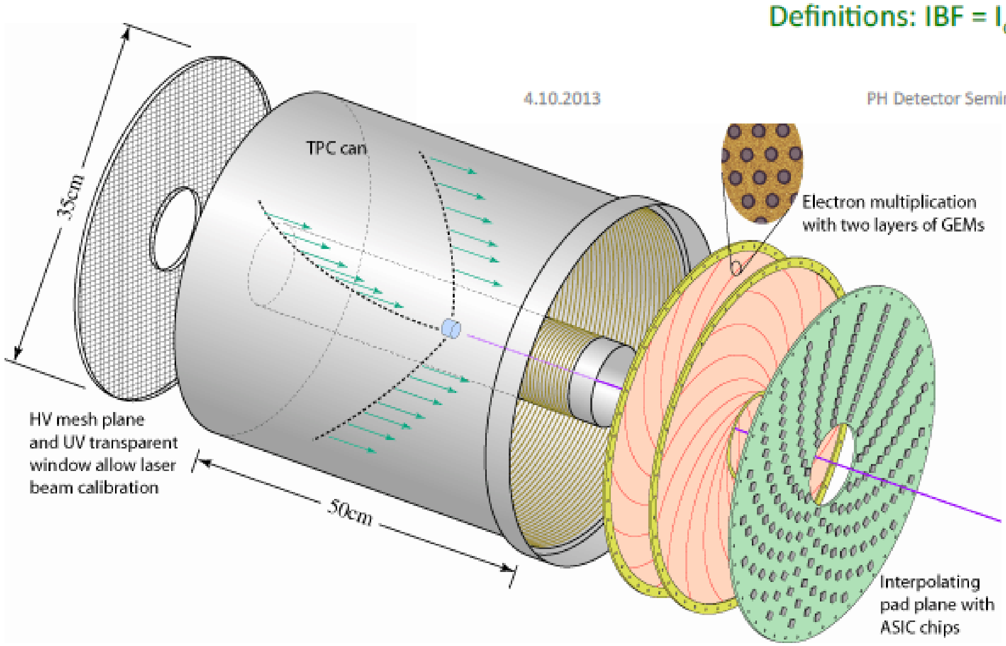
ALICE

R&D issues with GEMs



- Most GEM detectors are triple stacks operated with a standard HV configuration with a standard gas
  - IBF is several %, OK for position resolution
- A different configuration is necessary for minimizing IBF
  - Study IBF: goal is below 1%, ε below 20, for which distortions are ~10 cm
- Therefore stability of operation has to be re-demonstrated
- dE/dx resolution has to be proven
  - maintain the current performance

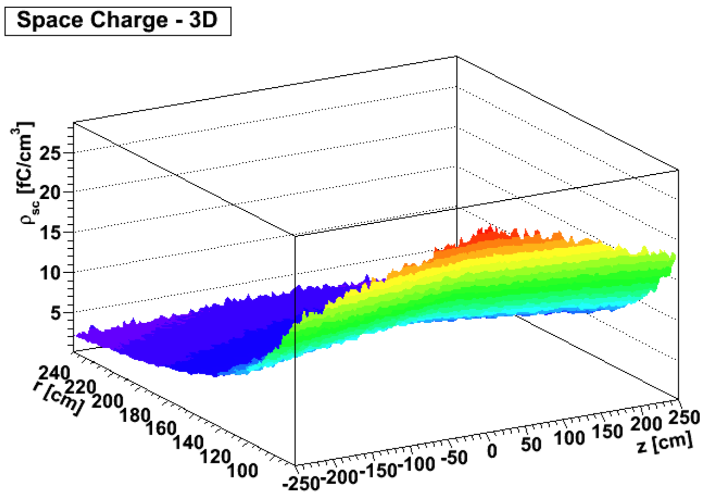
Definitions: IBF = $I_{drift}/I_{anode} = (1+\varepsilon)/\text{gain}$



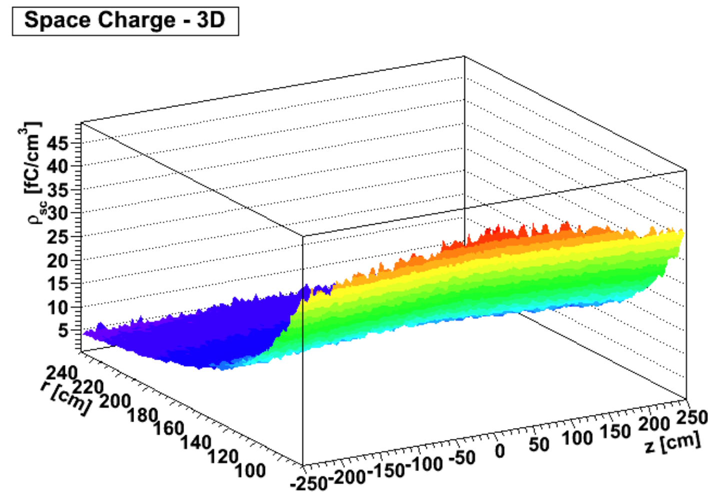
The idea of the GEM-based TPC
(it is not ALICE TPC!)

Space Charge Effects

ε = 5



ε = 10



Current goal: IBF~1%, at a gain of 2000, ε ~10

Resulting field distortion can be corrected

II. Earlier measurements of IBF by different groups

Modified by us Breskin review/table on IBF measuremenst

	TPC (E_{drift}=0.1-0.2kV/cm, Gain=10^4)		GPM (E_{drift}=0.5kV/cm, Gain=10^5)	
Detector type	IBF	Collection efficiency	IBF	Collection efficiency
2GEM	4%@0.4kVcm	100%	5% (20%)*	100%
3GEM	0.5%	100%	5% (20%)*	100%
4GEM		100%	2% (0.01%)**	100%
R-MHSP/ GEM/MHSP	0.08%	100%	0.1%	100%
F-R-MHSP/ GEM/MHSP	0.015%	100%	0.03%	100%
"Cobra"/ 2GEM	0.0027%	20%	0.0003%	20%

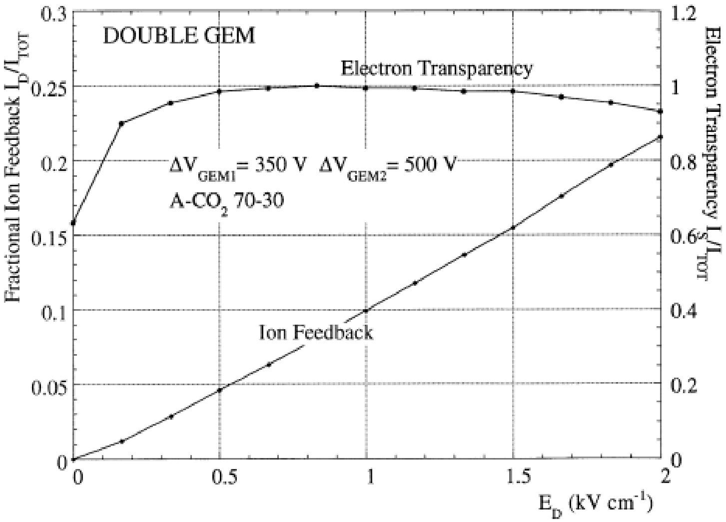
* Reflective PC   **Gated mode

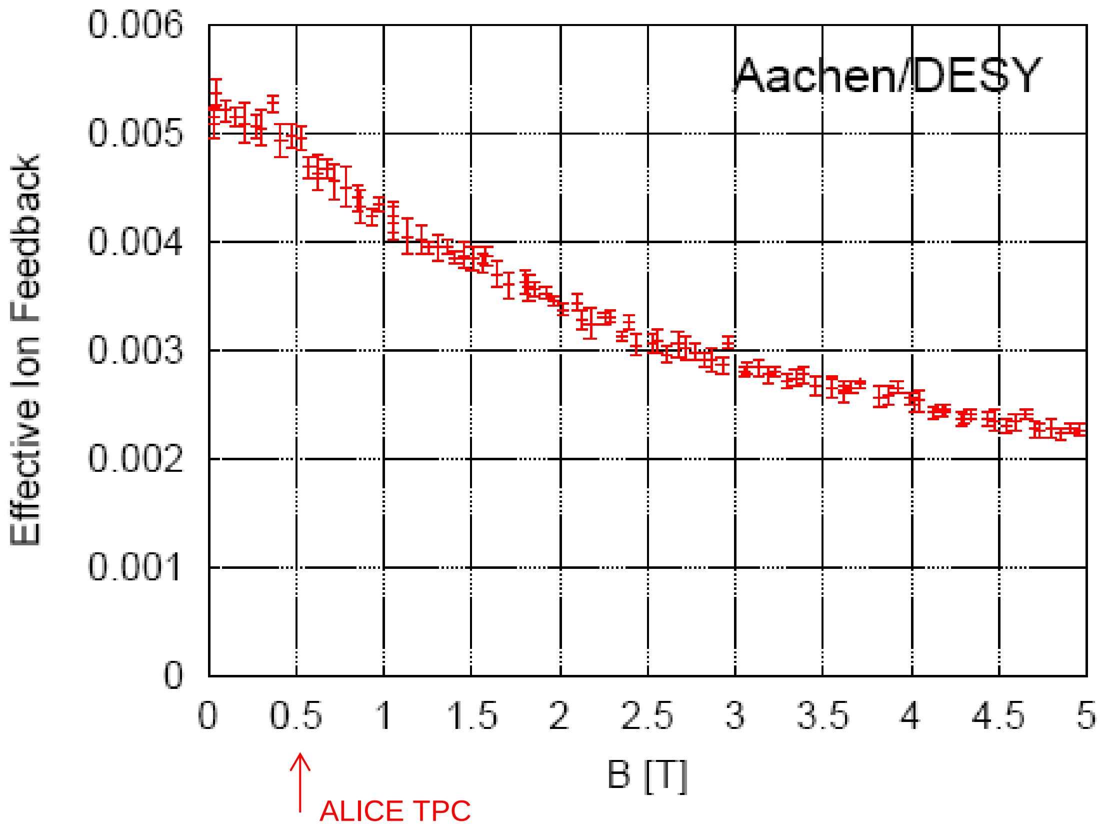
At what current measuremenst were done!?

Two examples of exper. data:

Bachman, NIM A438 (1999) 376

Gain 10^5





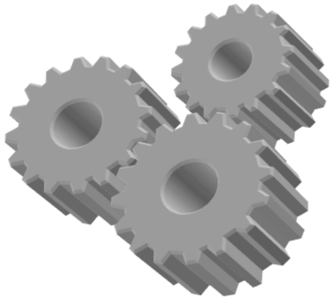
- E_{drift}=200V/cm
- $U_{GEM1,2}$=310V
- U_{GEM3}=350V
- E_{trans1}=6kV/cm
- E_{trans2}=60V/cm
- E_{ind}=8kV/cm

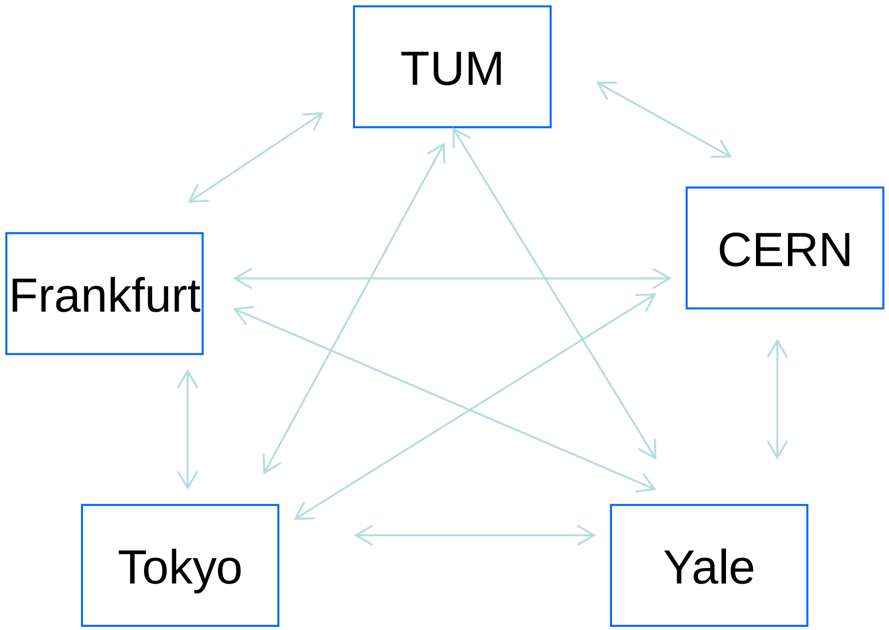
At effective gains of 10^4

Killengebrg et al

III. Earlier measurements of IBF by our TPC upgrade groups

TPC upgrade experimental sub-groups, involved in IBF studies, and their interactions





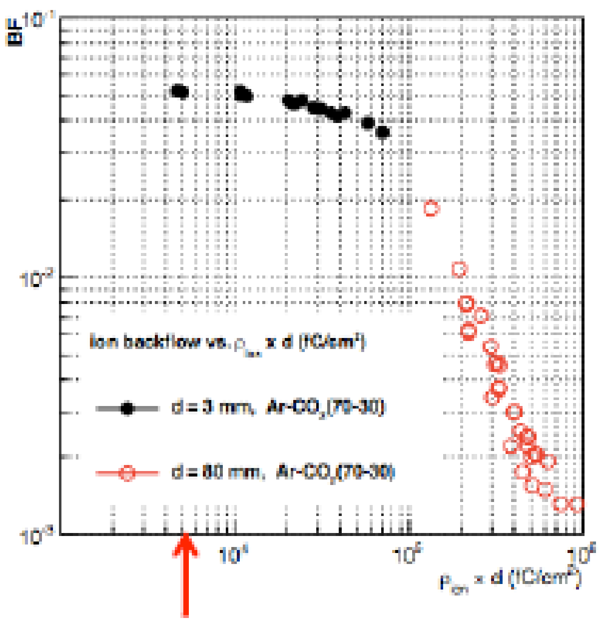
New important results!

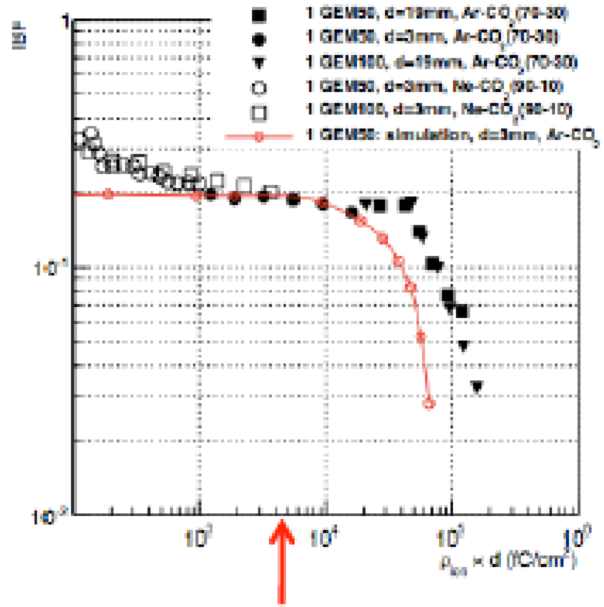
Two important observations was made by a CERN and TUM teams:

1) IBF depends on Rate
2) IBF depends on gas gain

IBF dependence on rate

- Ion accumulation on top of a GEM foil produces enough space-charge to shield the electric field above from incoming ions from below, thus fakely improving IBF
- This has obviously no effect on the rate capability





•Effect found to scale with the product of the charge density and the drift length

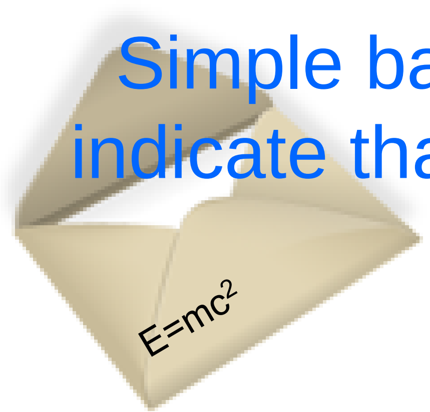
•Reasonable agreement with Garfield++ simulations

Expected in the upgrade scenario: ~ 5000 fC/cm²

Note:

the difference in absolute values of IBF is due to the different voltage settings used in our earlier measurements:

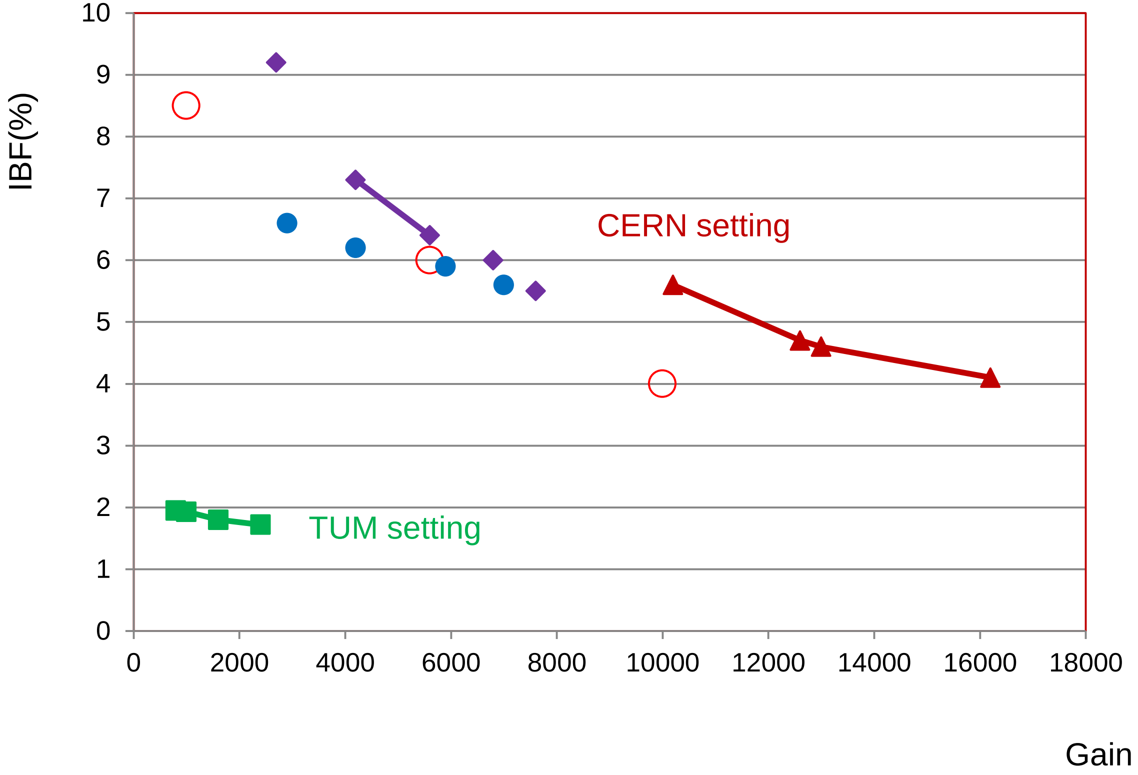
TUM used “Aachen/DESY” setting (shown earlier)
CERN –used a setting close to the “Bachman et al” (also shown earlier)



Simple back on the envelope calculations indicate that IBF drop with rate is due to the space charge effect

Detailed simulations made by Tokyo group fully confirmed the role of the space charge in the IBF suppression at high rates

Example: effect of gain in the case of triple GEM (low rate)



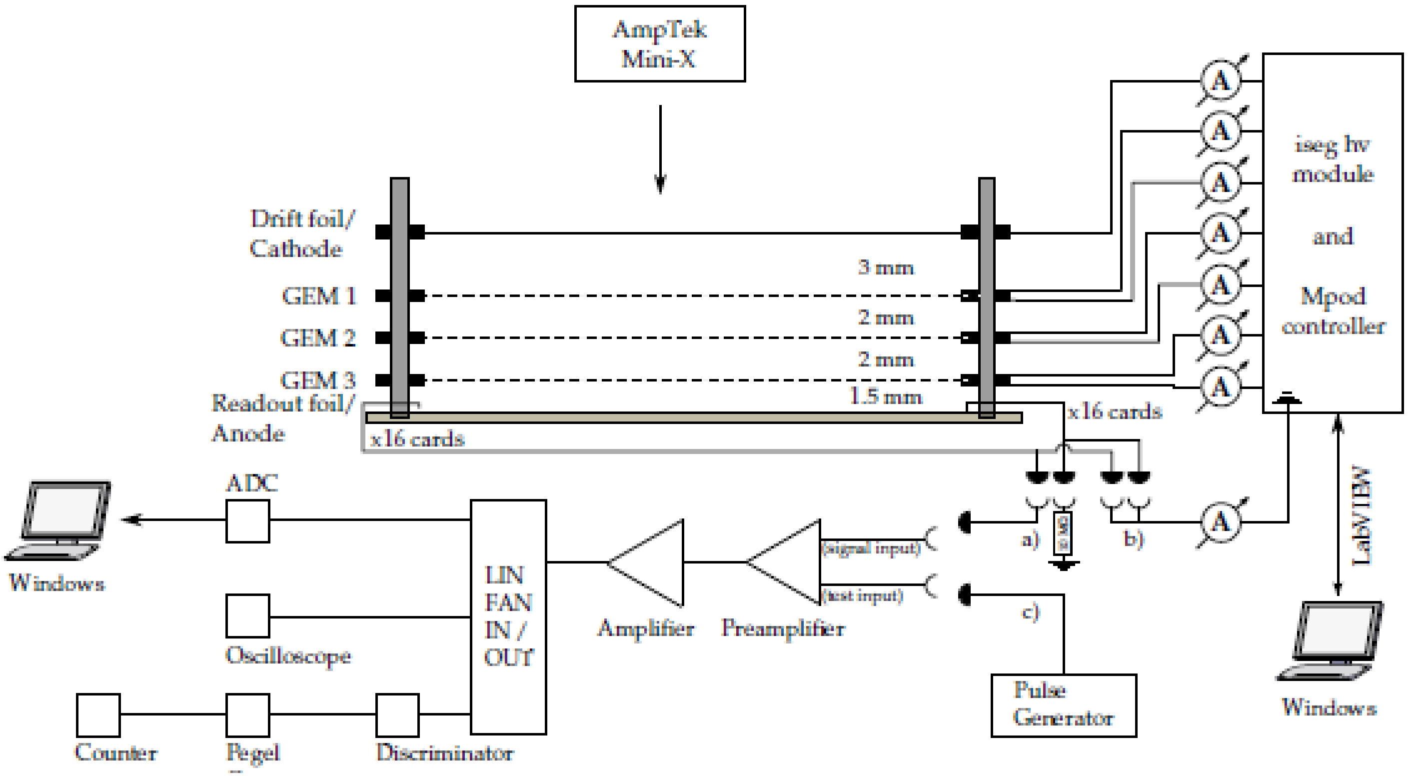
The observed effects forced us to critically evaluate earlier works and <u>triggers scrupulous studies</u>

IV. Latest measurements performed by ALICE TPC upgrade sub-groups

IV.1.Triple GEM

IV.1.1 TUM results

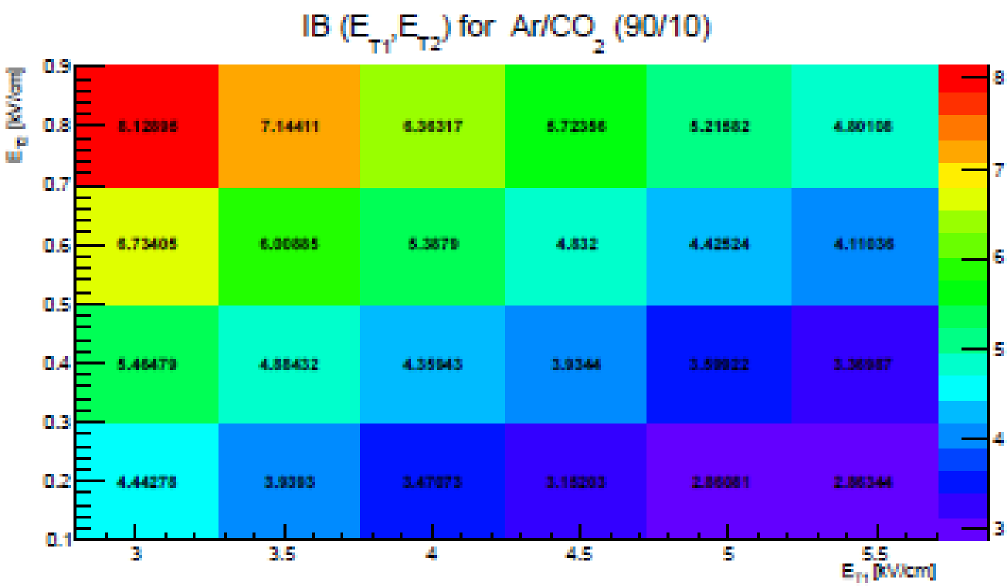
TUM setup

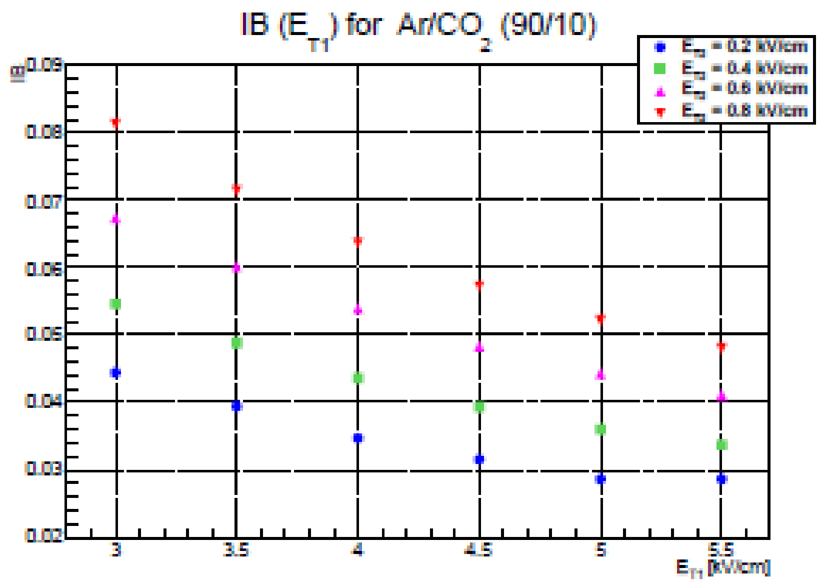


AmpTek
Mini-X
Drift foil/
Cathode
GEM 1
GEM 2
GEM 3
Readout foil/
Anode
3 mm
2 mm
2 mm
1.5 mm
x16 cards
x16 cards
iseg hv
module
and
Mpod
controller
LabVIEW
Windows
ADC
Windows
LIN
FAN
IN /
OUT
Amplifier
Preamplifier
(signal input)
(test input)
a)
b)
c)
Oscilloscope
Counter
Pegel
Discriminator
Pulse
Generator

For Ar/CO_2 90/10

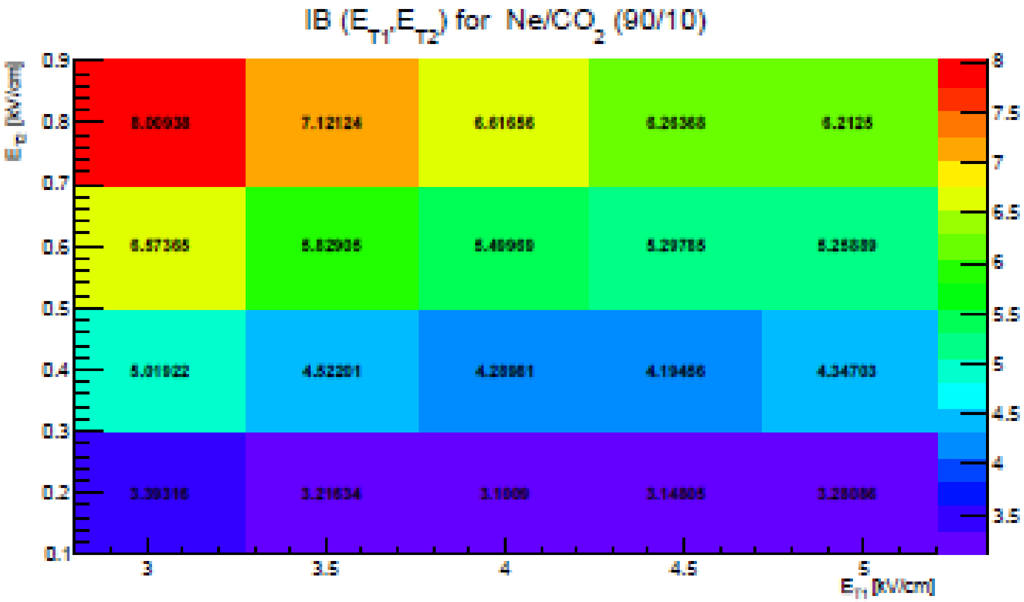
GEM voltage settings		*Detector field settings*	
GEM1	280 V	E_{Drift}	$0.4\,kV\,cm^{-1}$
GEM2	315 V	E_{T1}	$5.5\,kV\,cm^{-1}$
GEM3	steerable	E_{T2}	$0.2\,kV\,cm^{-1}$
		E_{Ind}	$4.5\,kV\,cm^{-1}$

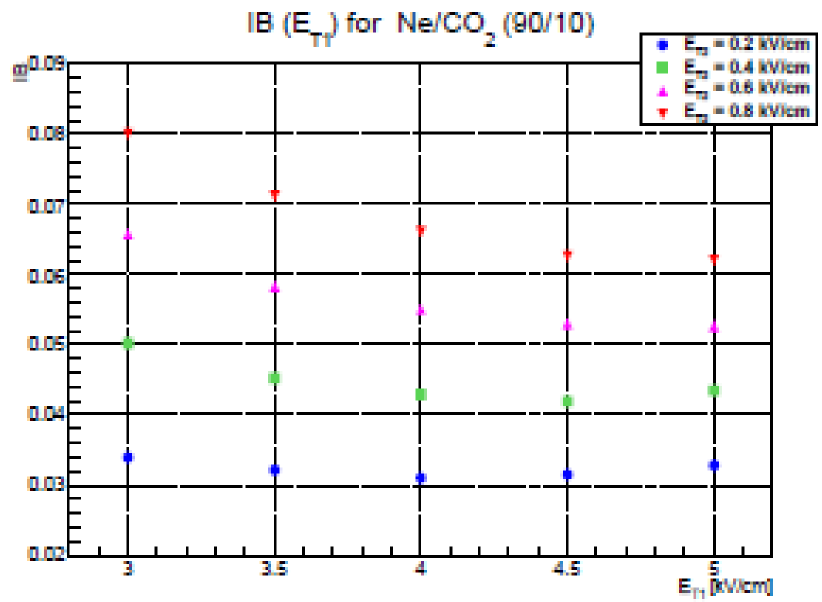




For Ne/CO_2 90/10

GEM voltage settings		*Detector field settings*	
GEM1	235 V	E_{Drift}	$0.4\,kV\,cm^{-1}$
GEM2	245 V	E_{T1}	$5.0\,kV\,cm^{-1}$
GEM3	steerable	E_{T2}	$0.2\,kV\,cm^{-1}$
		E_{Ind}	$3.8\,kV\,cm^{-1}$



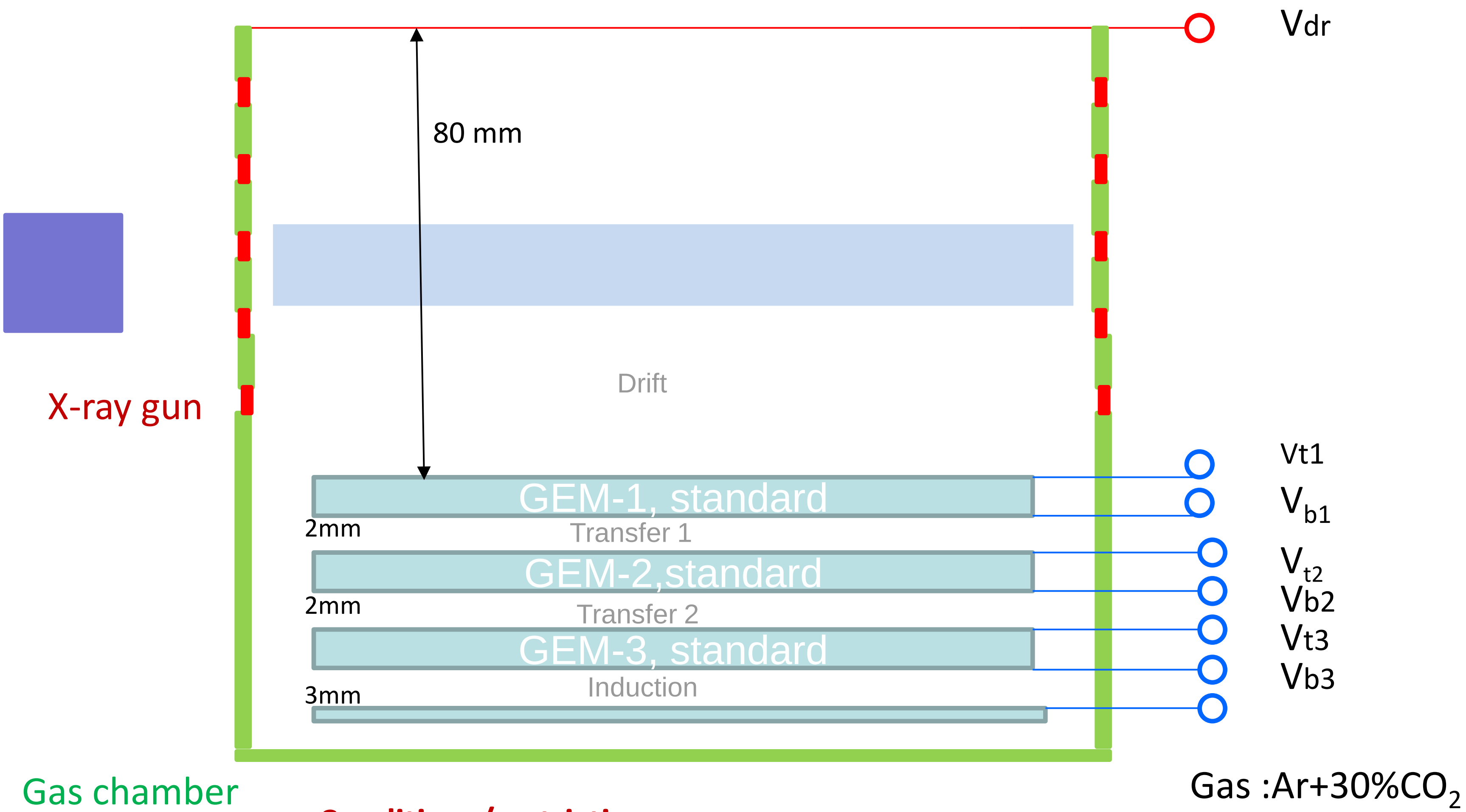


IBF close to 3 % was achieved with triple GEMin Ar- and Ne-based mixtures

IV.1.2. CERN results

IV.1.2a. Triple GEM

Experimental setup:



Conditions/restrictions:

40kV/10mA, to minimize the space charge effect, Gain ~ 2000, Vdr=400V/cm, current on readout plate 20-50nA

LabView

- Use programmable CAEN N1471A HV PS for GEMs
- Use N471 HV PS for manual setting of drift voltage and current measurement (the fun part)
- Measure pad-plane current with Ohm-meter (1 MΩ)
- GSI GEMs 2-2-3 mm

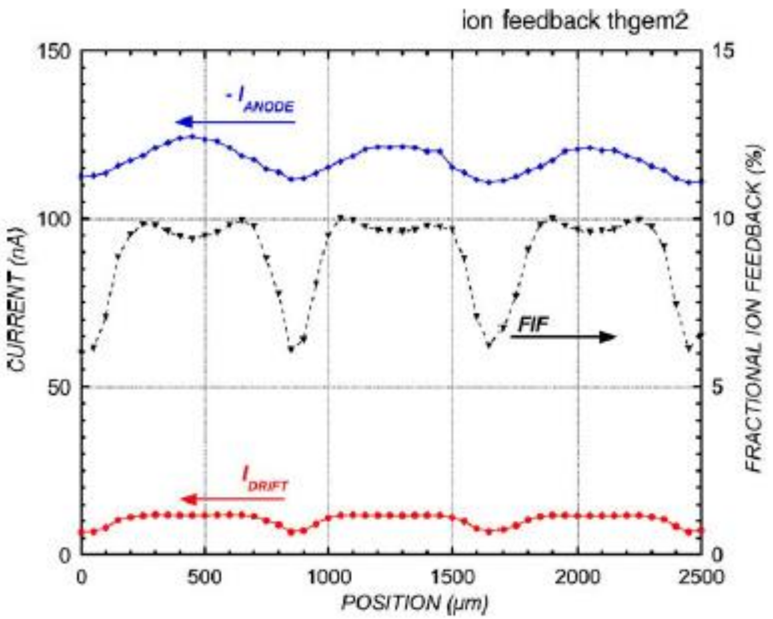
Results of CERN measurements with triple GEM at CERN

ΔGEM1=250 V
ΔGEM2= 380 V
ΔGEM3 =400 V
Etr1=4.5 kV/cm
Etr2=variable
Eind= variable

E2 \ Eind	3	3. 5	4	4.5
0.4	4.3	3.8	3.6	3.45
0.3	4.15	3.7	3.5	3.4
0.2	4.1	3.65	3.4	3.3
0.1	4.2	3.7	3.5	3.3

Although our detector is different (much larger drift region) TUM results were well reproduced: I BF close to 3% was achieved , however ε~60-too much

A new approach: use one large pitch GEM

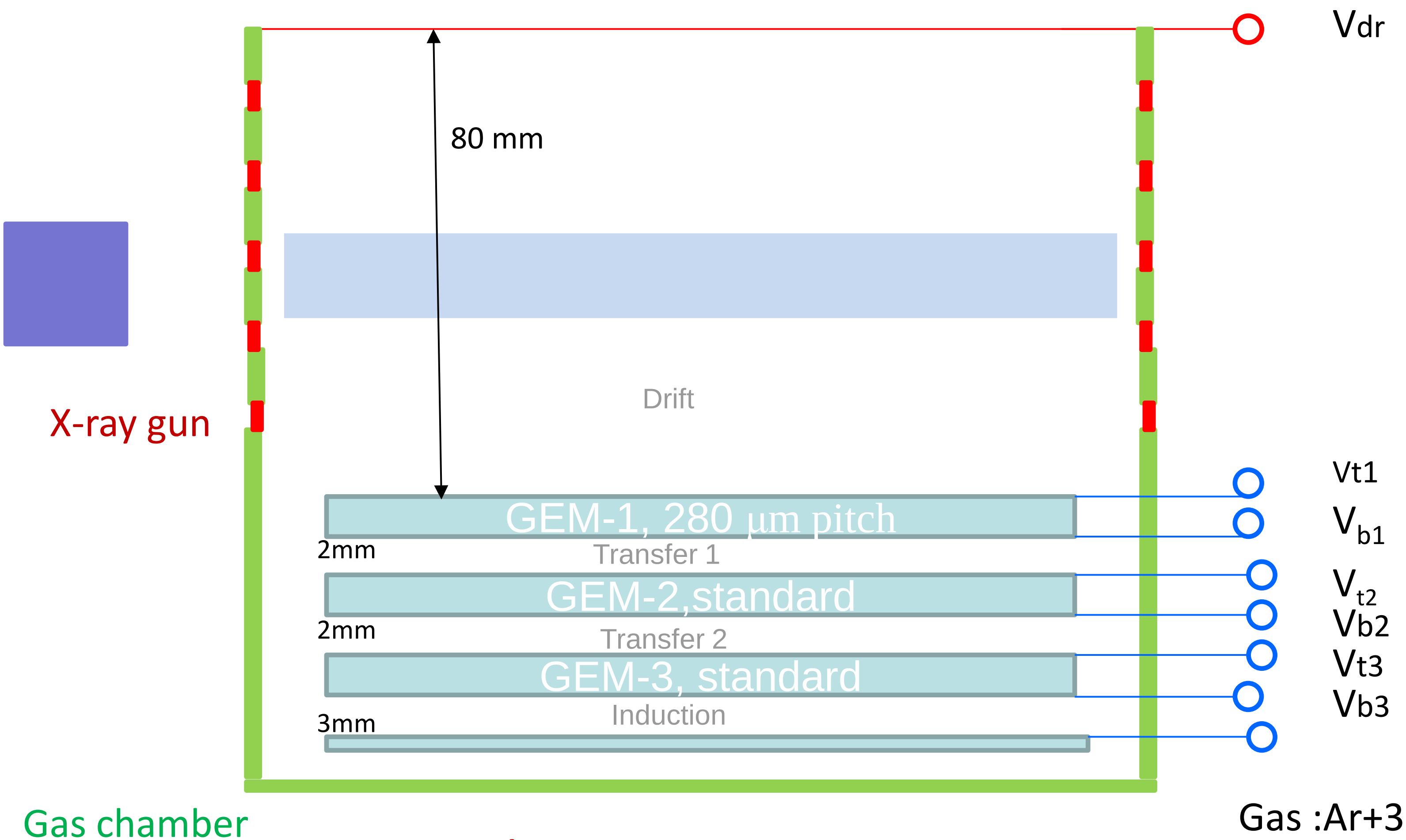


As follows from earlier measurements of Sauli and Ropelewski and as well as from the recent simulations, misalignment is a very important factor in achieving low IBF

After several discussions with Leszek we decided to use **one large pitch GEM** to create strong misalignment

IV.1.2b. Triple GEM with one large pitch GEM

Experimental setup

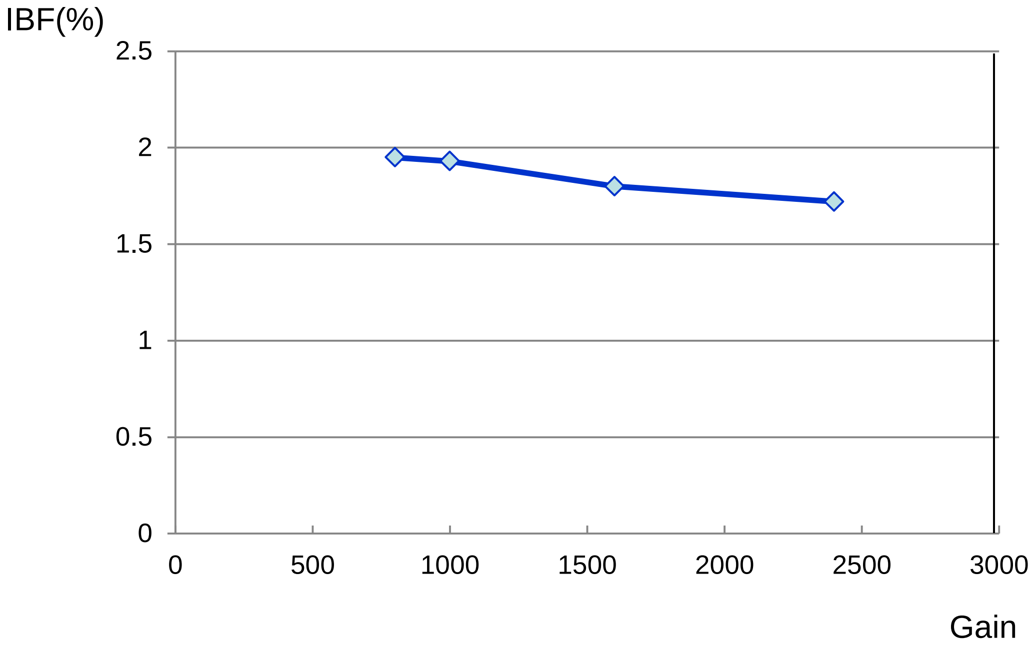


Gas :Ar+30%CO_2

Conditions/restrictions:

40kV/10mA, to minimize the space charge effect,
Gain ~2000Vdr=400V/cm, current on readout plate
20-50nA

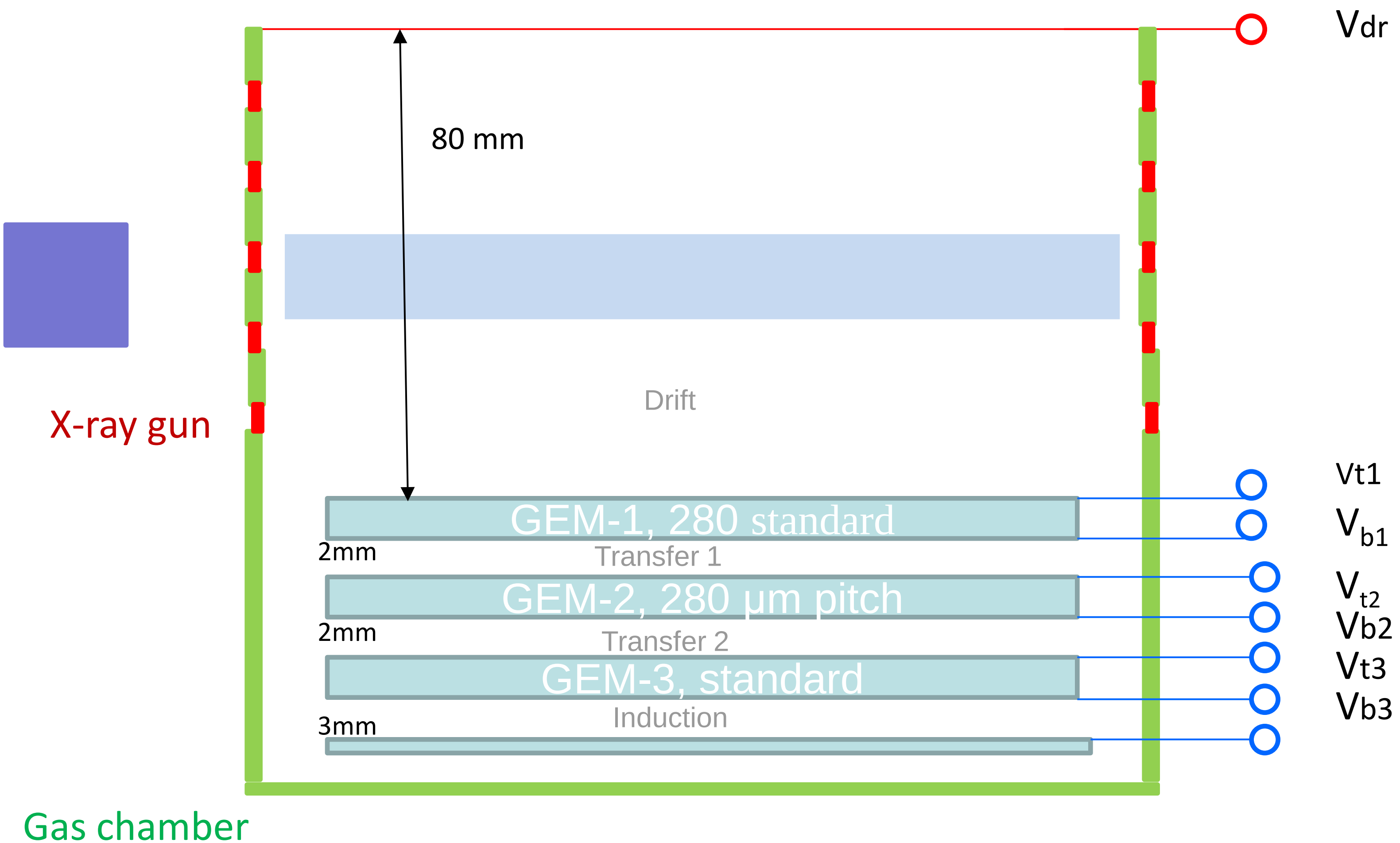
Gain scan at Vdr=400V/cm



So the improvement due to the large pitch GEM was an a factor of <u>1,65</u>

Gain is another parameter to reduce IBF however, the price is an <u>increase of ε</u>

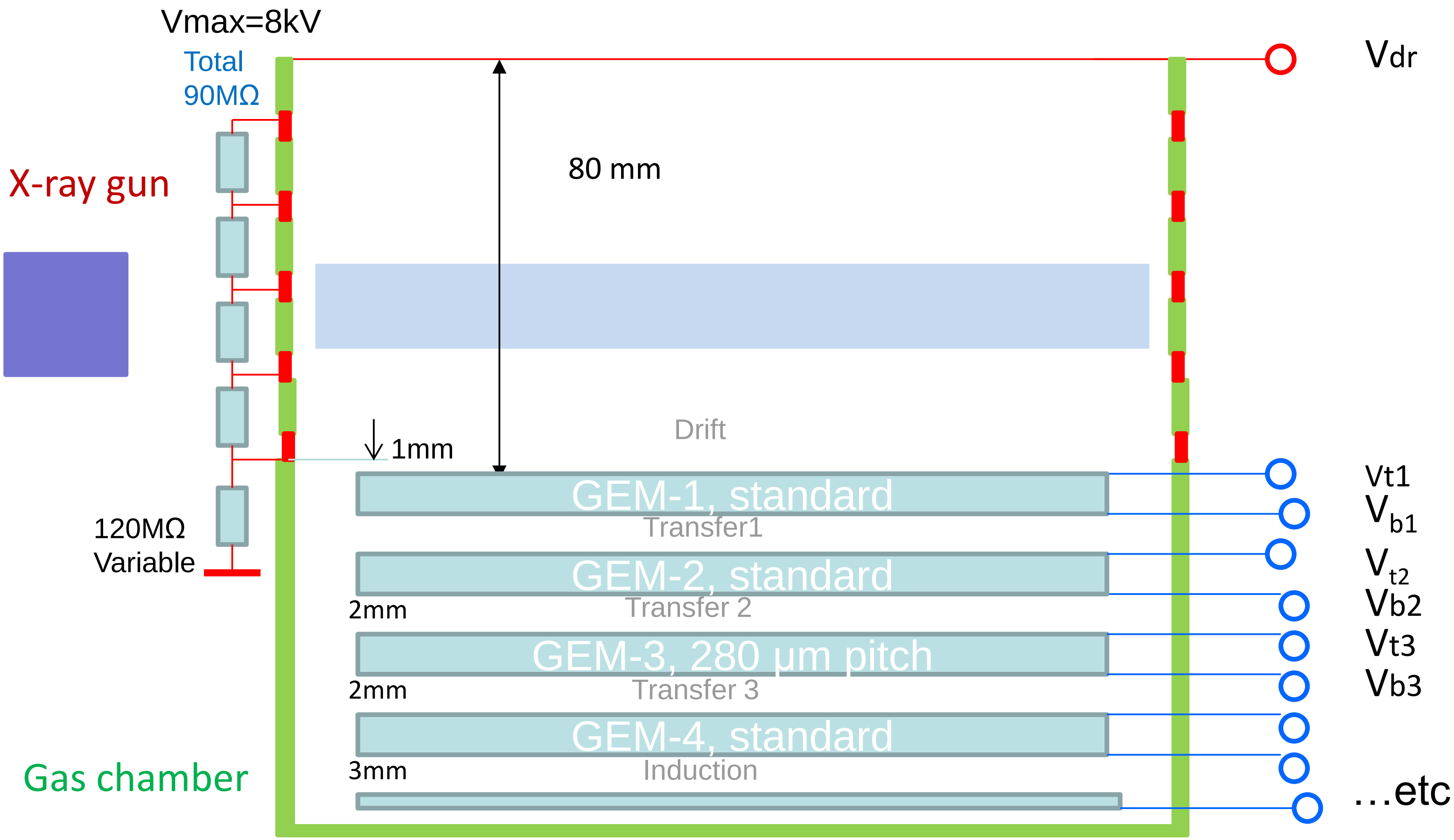
We also tested the arrangement when the large pitch was in the middle



Results were similar…

IV.1.2c. Quadruple GEM with one large pitch GEM

Experimental setup and a resistive divider



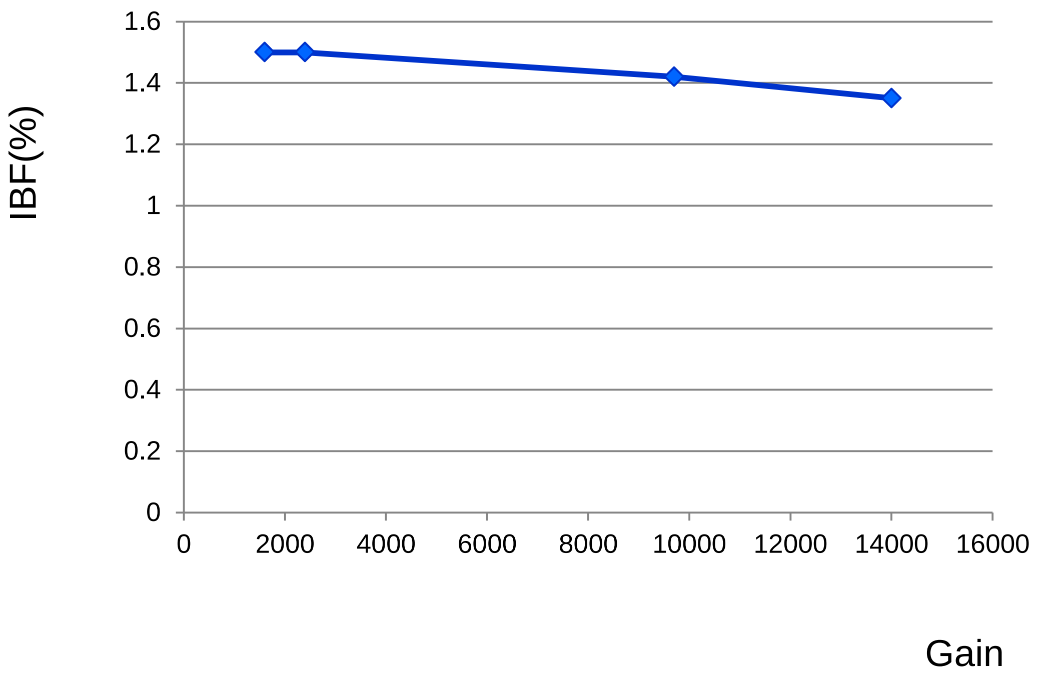
Conditions/restrictions:

40kV/10mA ,to minimize the space charge effect,
Gain ~2000, Vdr=400V/cm ;current on readot t plate 20-50nA

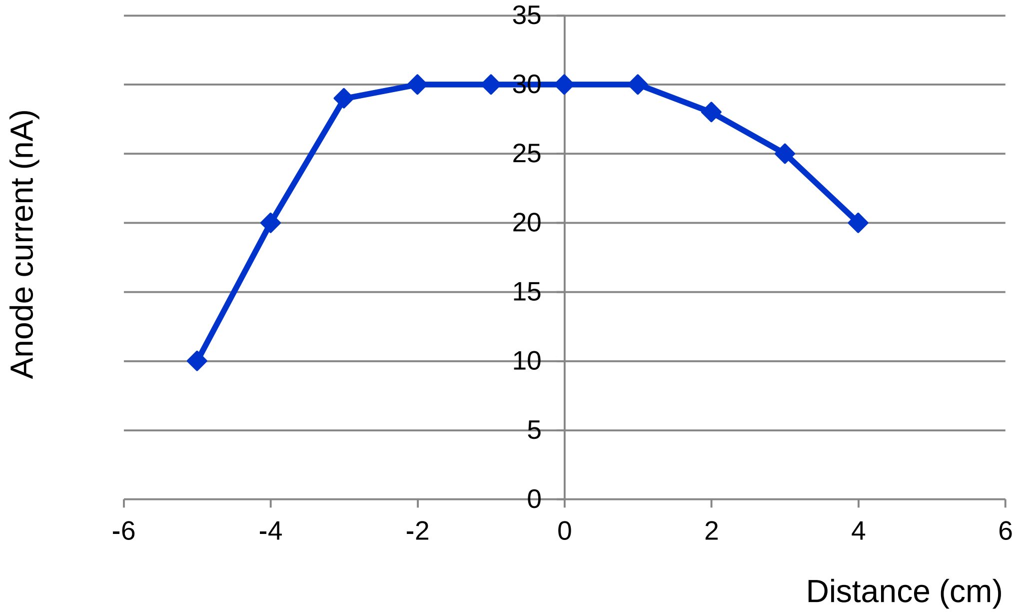
Gas :Ne+10%CO_2 +5%N2

Measurements without a vertical beam in the center

(data obtained after N2 replacement, when both gain and IBF for unknown reason increased. Before IBF was 25% lower-changes in gas mixture?)

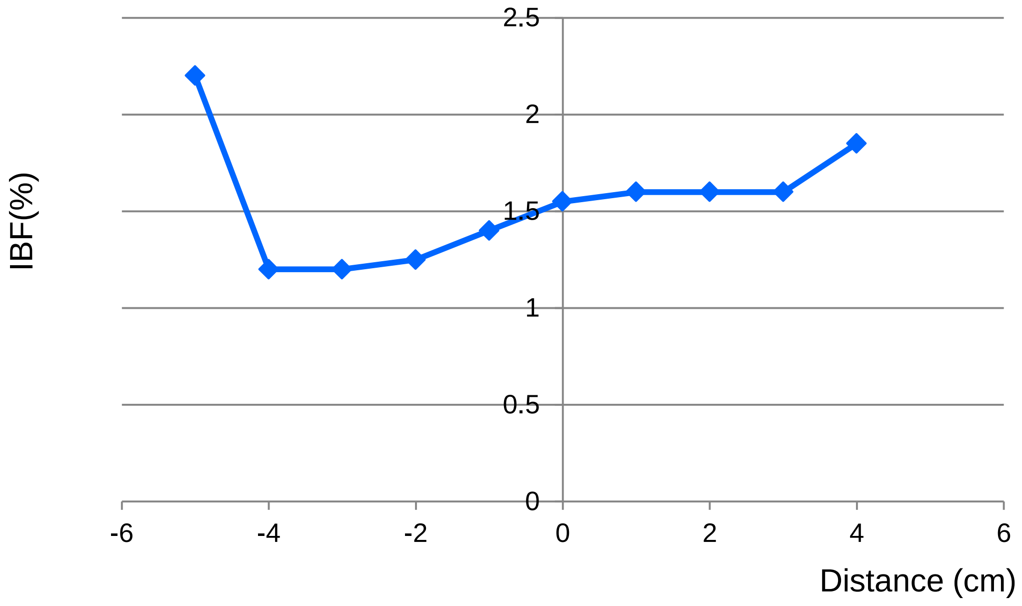


Scans with vertical X-ray beam



Anode current (nA)
35
30
25
20
15
10
5
0
-6
-4
-2
0
2
4
6
Distance (cm)

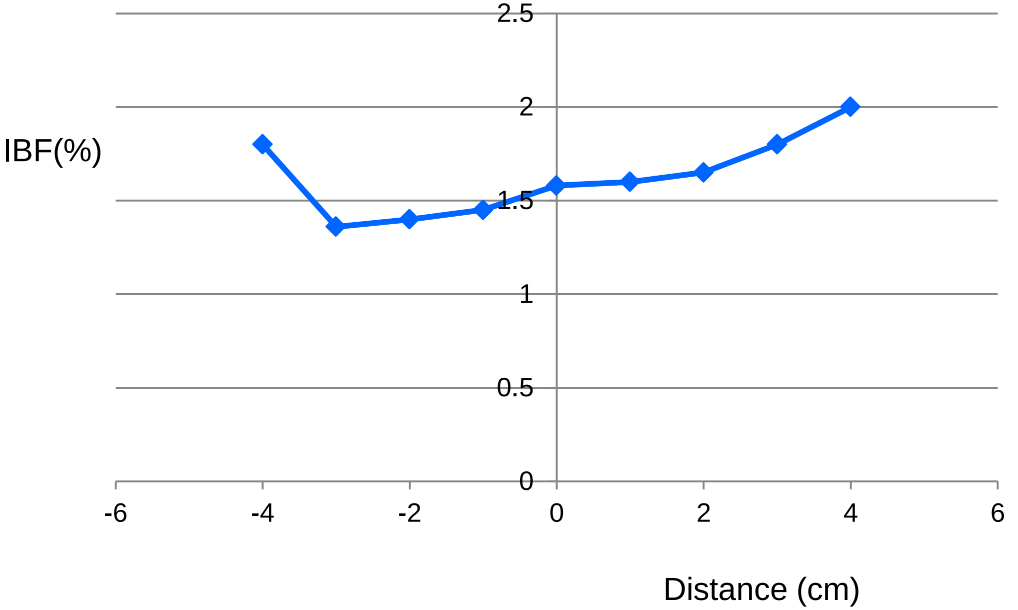
Gain 2310



IBF(%)
2.5
2
1.5
1
0.5
0
-6
-4
-2
0
2
4
6
Distance (cm)

Scan in a perpendicular direction

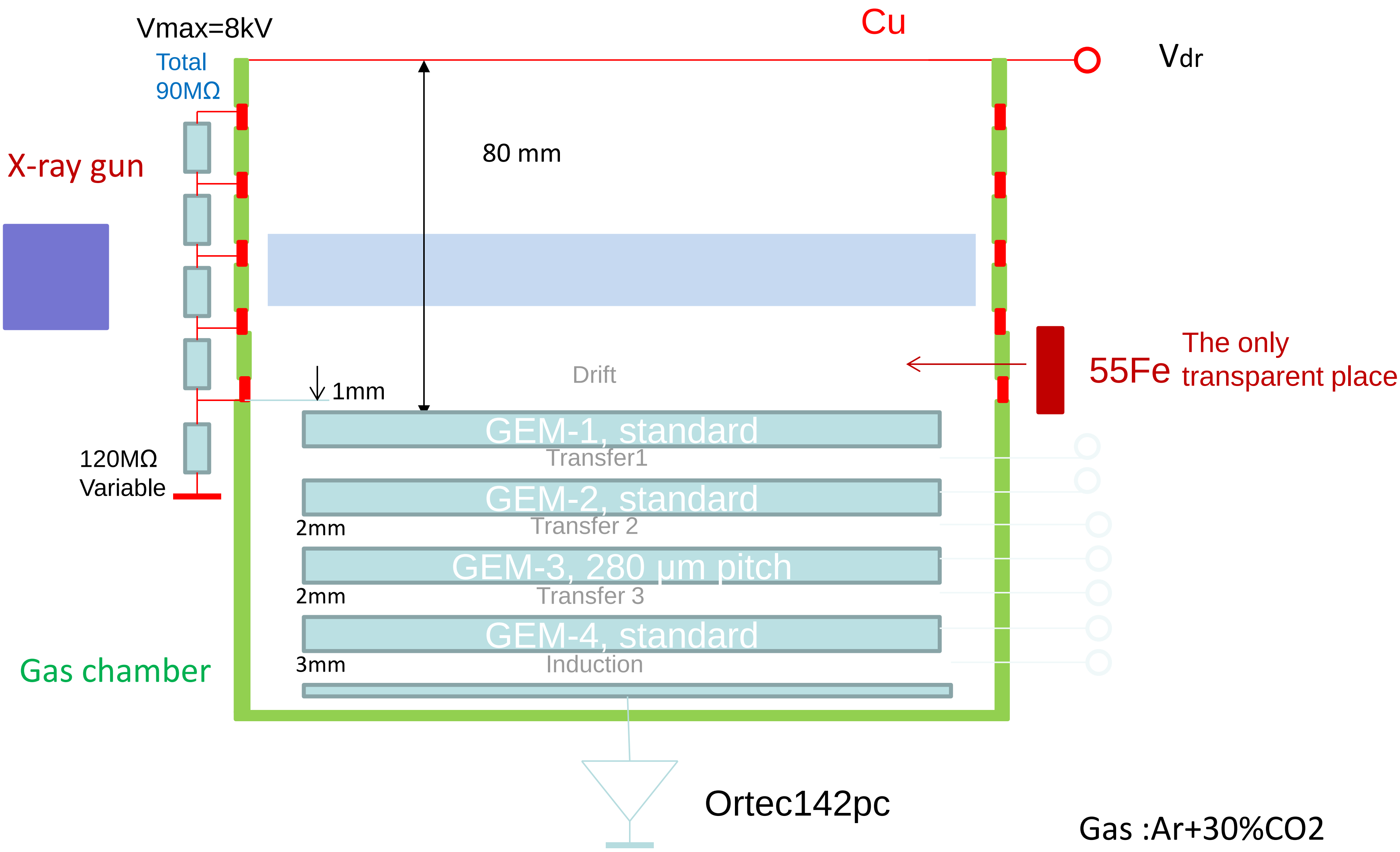
ΔV1=210V
ΔV2=250V
ΔV3=285V
ΔV4=340V
Etr1=4.3kV/cm
Etr2=4.3kV/cm
Etr3=0.12kV/cm
Eind=4.7kv/cm



Due to the nonuniformity IBF measured with a parallel beam were always 30-50% better

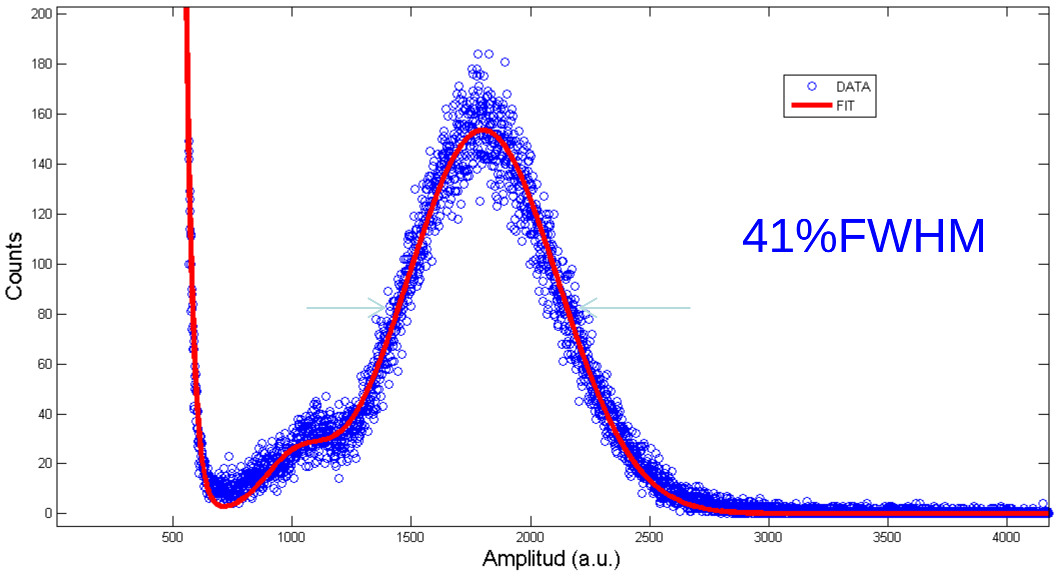
Preliminary energy resolution measurement

Experimental setup and a resistive divider



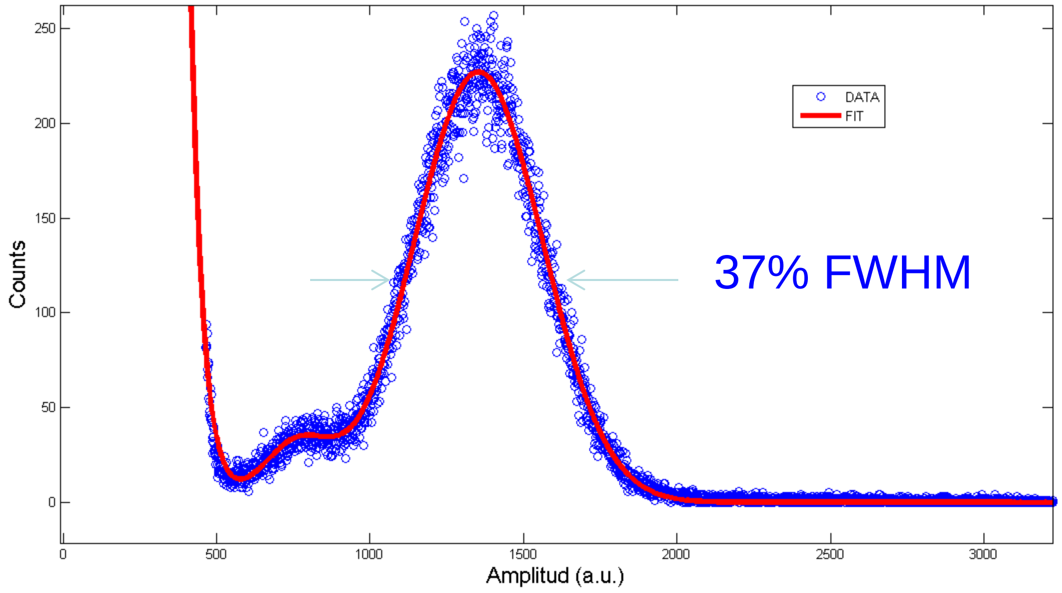
Gas :Ar+30%CO2

Rodrigo treatment

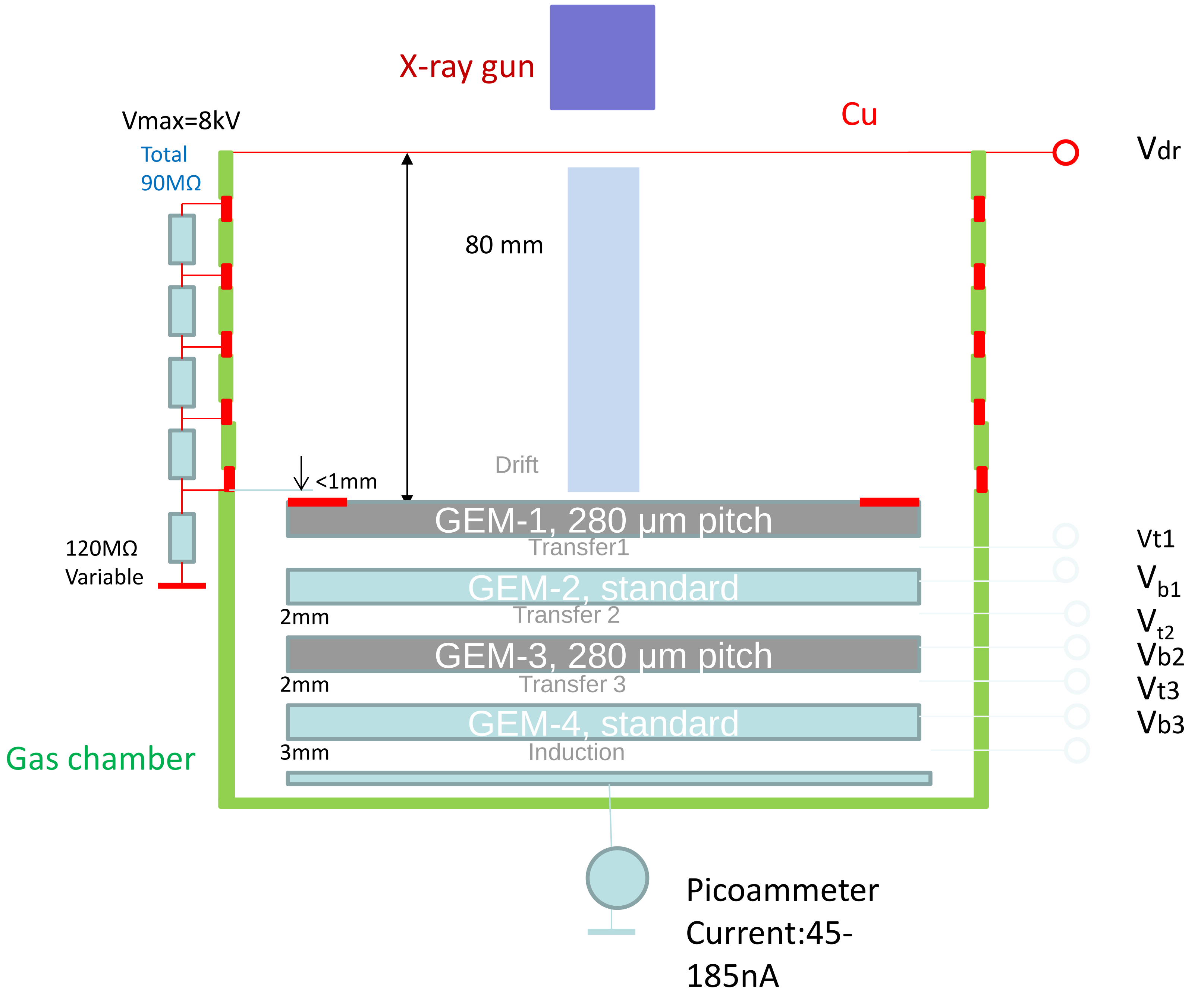


ΔV1=325
ΔV2=340V
ΔV3=380V
ΔV4=420V
Etr1=4.5kV/cm
Etr2=3.5 kV/cm
Etr3=0.3kV/cm
Eind=4.5kV/cm

ΔV1=365
ΔV2=365V
ΔV3=365V
ΔV4=365V
Etr1=4.5kV/cm
Etr2=3.5 kV/cm
Etr3=0.3kV/cm
Eind=4.5kV/cm

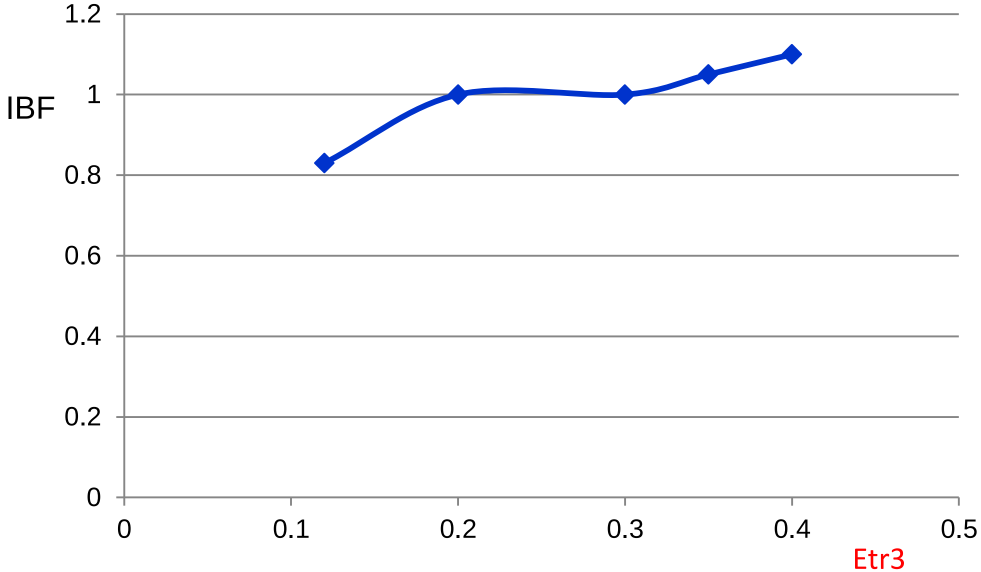


IV.1.2d. Quadruple GEM with two large pitch GEMs

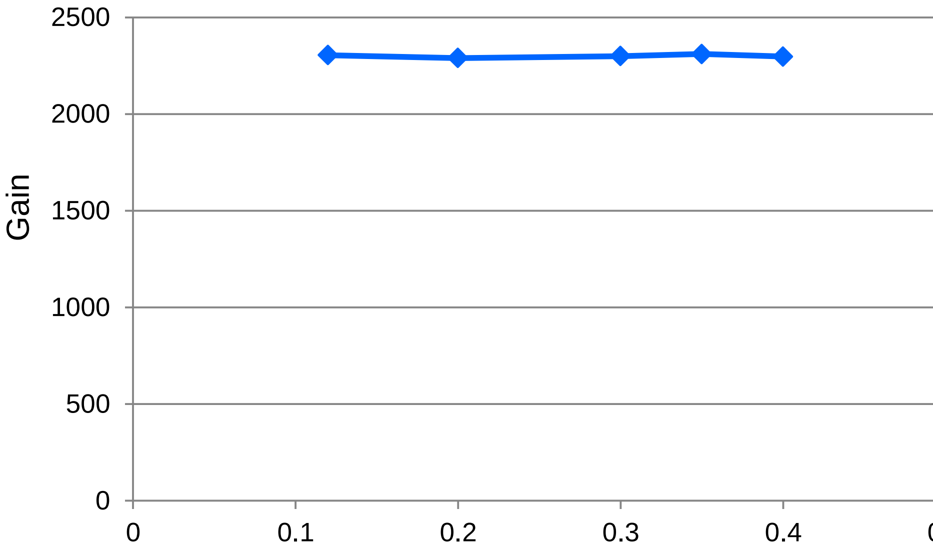

X-ray gun
Cu
Vmax=8kV
Total
90MΩ
Vdr
80 mm
Drift
<1mm
GEM-1, 280 µm pitch
Transfer1
120MΩ
Variable
Vt1
GEM-2, standard
Vb1
2mm
Transfer 2
Vt2
GEM-3, 280 µm pitch
Vb2
2mm
Transfer 3
Vt3
GEM-4, standard
Vb3
Gas chamber
3mm
Induction
Picoammeter
Current:45-185nA

Example of a scan

(for the first time with the vertical beam we observed IBF around 0.8%)

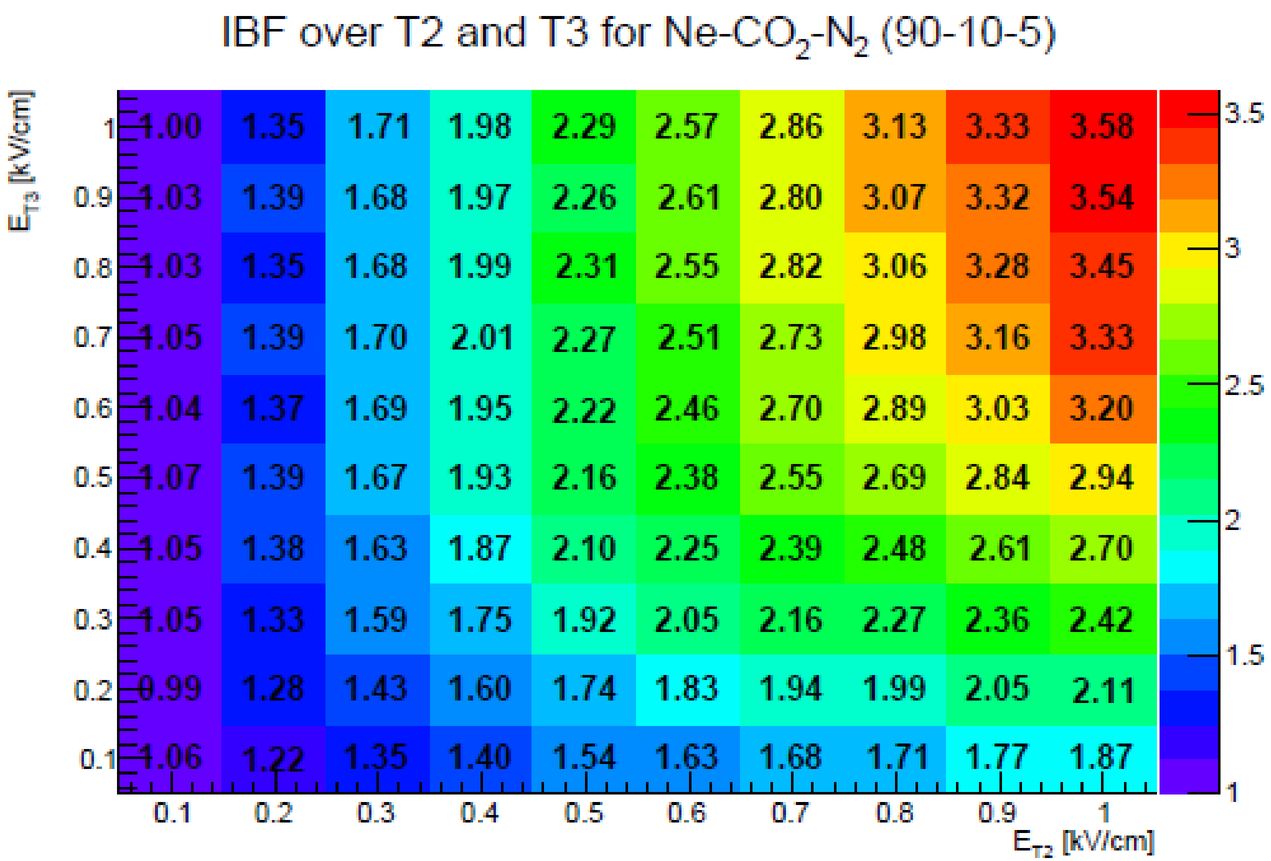


ΔV1=210V
ΔV2=250V
ΔV3=285V
ΔV4=340V
Etr1=4.3kV/cm
Etr2=4.3kV/cm
Etr3=0.1-0.3kV/cm
Eind=4.7kv/cm



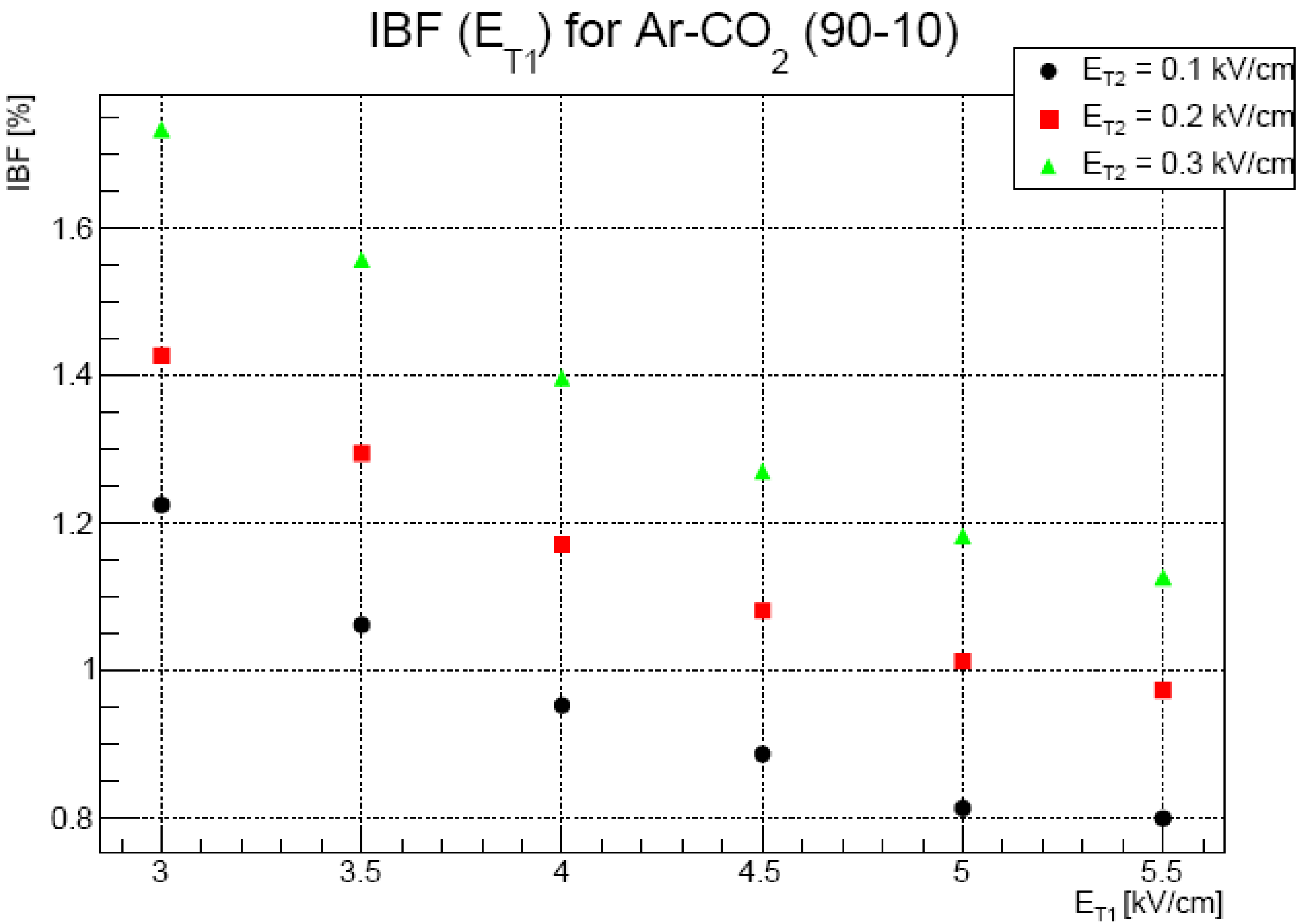
V. Important works performed in parallel by TUM and Frankfurt groups

V.1.TUM results with quadruple GEM (all ordinary)

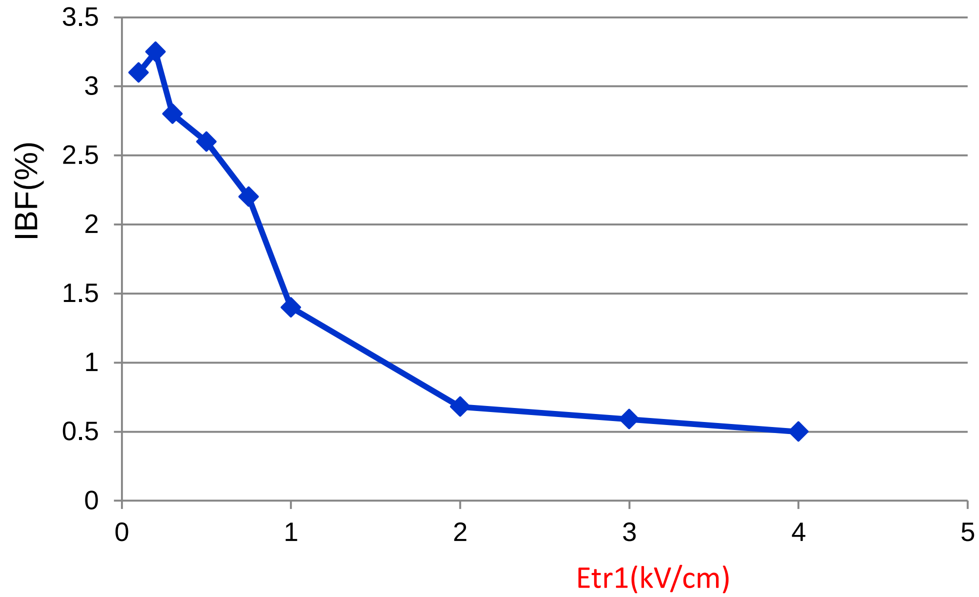


IBF of ~1% was reached

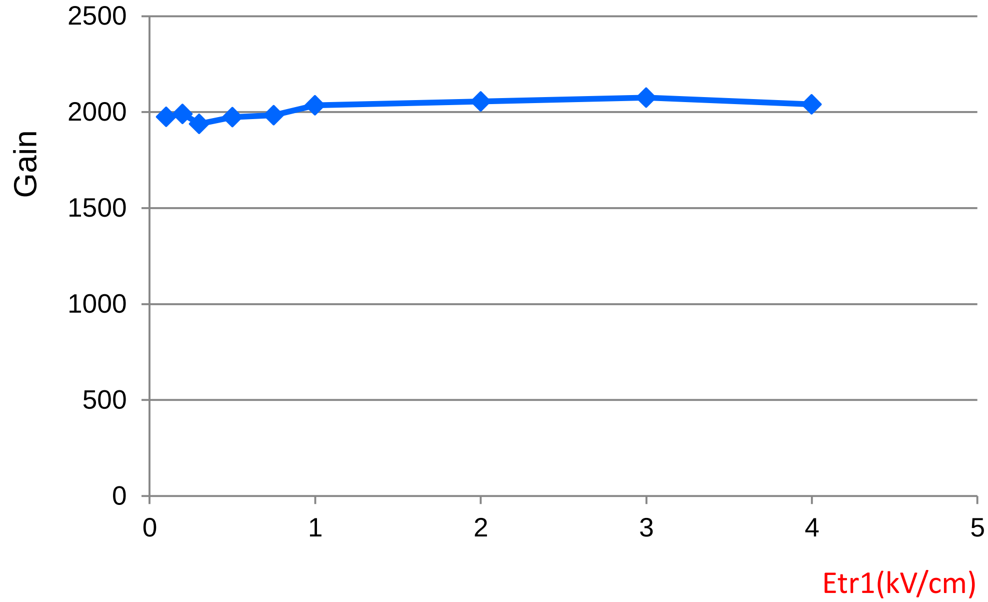
One of TUM scans with usual quadruple GEM



Cross –check: similar scans in the case of our/CERN quadruple GEM containing two large pitch GEMs

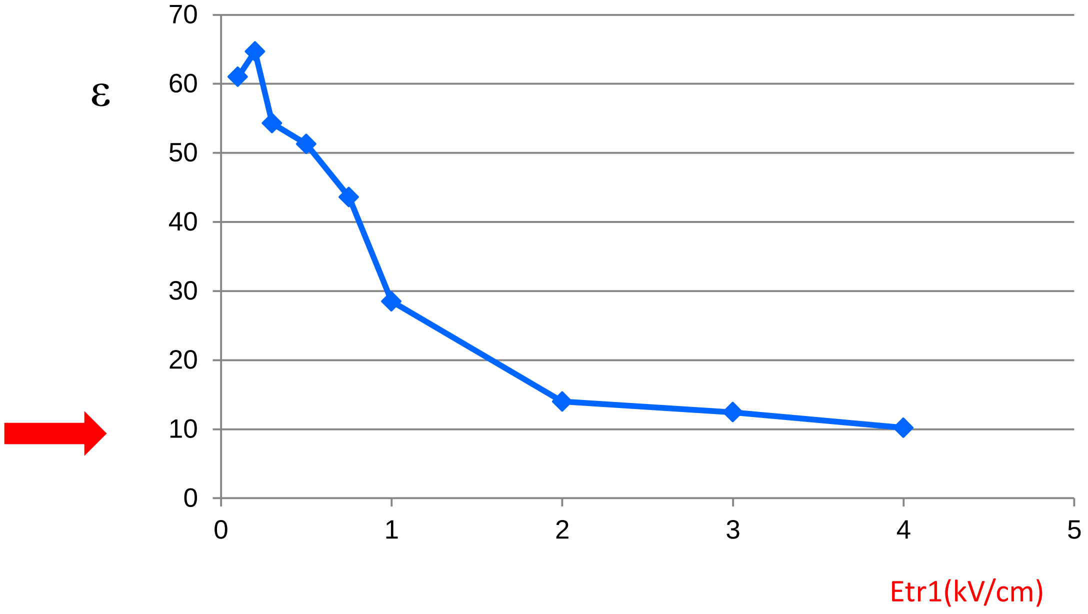


Our results at similar conditions

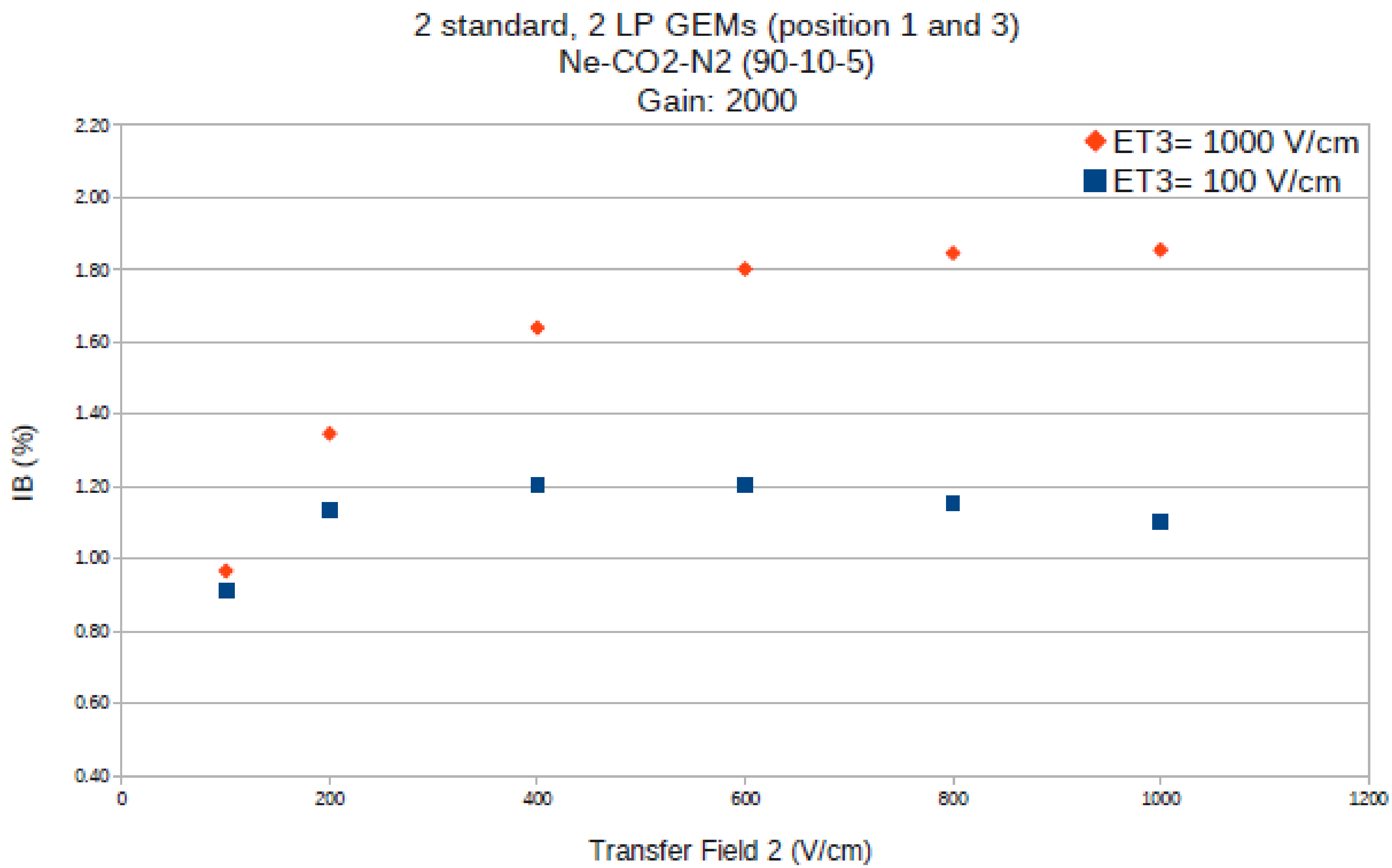


ΔV1=225V
ΔV2=250V
ΔV3=variable
ΔV4=variable
Etr1=0.1-4 kV/cm
Etr2=0.1kV/cm
Etr3=4kV/cm
Eind=4kV/cm

Epsilon

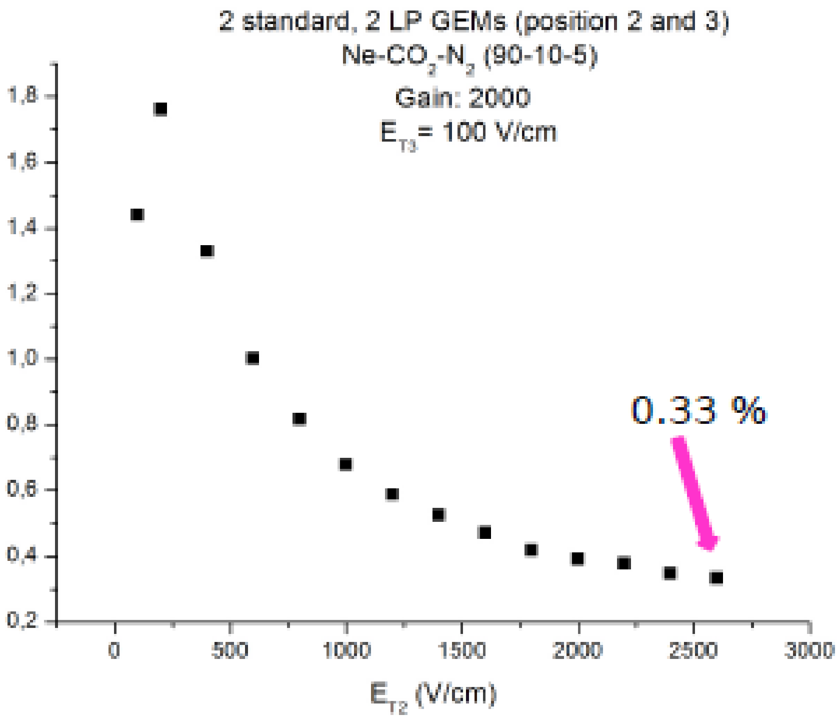


V.2.Frankfurt results with quadruple GEM with two large pitch GEM

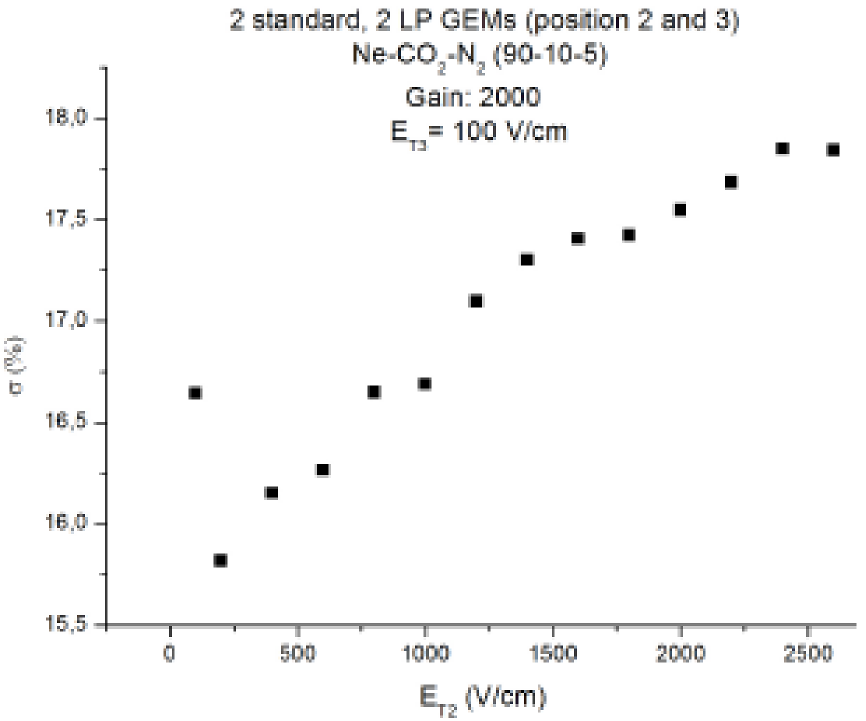

2 standard, 2 LP GEMs (position 1 and 3)
Ne-CO2-N2 (90-10-5)
Gain: 2000
ET3= 1000 V/cm
ET3= 100 V/cm
IB (%)
2.20
2.00
1.80
1.60
1.40
1.20
1.00
0.80
0.60
0.40
0
200
400
600
800
1000
1200
Transfer Field 2 (V/cm)

E_{T2} on x-axis - E_{T3}= 100V/cm

Ion backflow



Energy resolution



CERN, TUM and Frankfurt results have a tendency to merge!

Conclusions:

- We are approaching IBF ~0.5 and ε ~ 10 which is even better than our goal
- This can be achieved by various voltage settings which gives us flexibility in optimization
- We are focused now on finding optimum operational points offering at the same time low IBF (ε), sufficient energy resolution, stability with time and low sparking probability

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