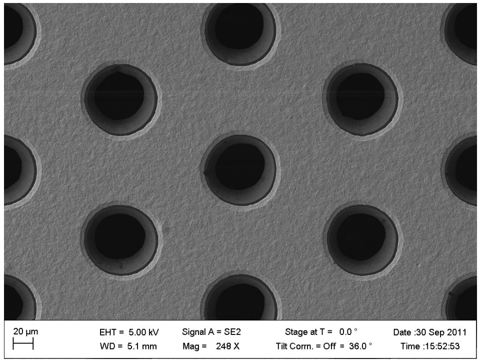
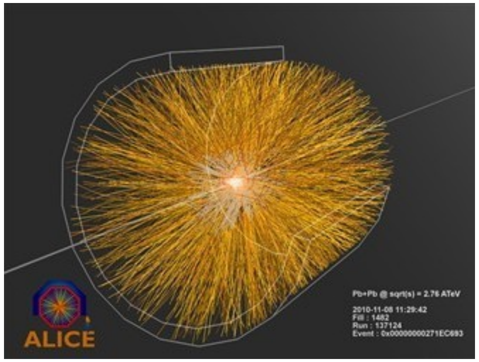
GEM upgrade of the ALICE TPC

Markus Ball
Physics Department E18
Technische Universität München
On Behalf of the ALICE TPC upgrade

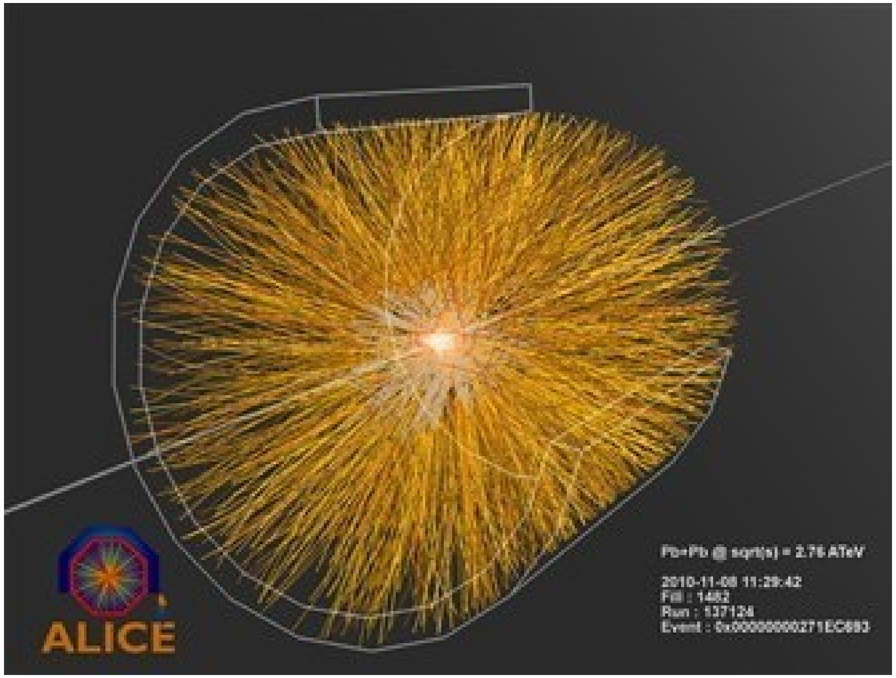




Outline

- Motivation for the GEM upgrade
- Ion Backflow Suppression with GEMs
- Construction of a GEM IROC prototype
- Performance Measurements
- Conclusions and Outlook

Advantages and Limitations of a TPC



An (almost) ideal tracking detector:

- Large acceptance
- Large active volume
- Low material budget
- 3D hits ⇨ simple pattern recognition
- Extremely high particle densities
- Good momentum resolution
- Particle identification

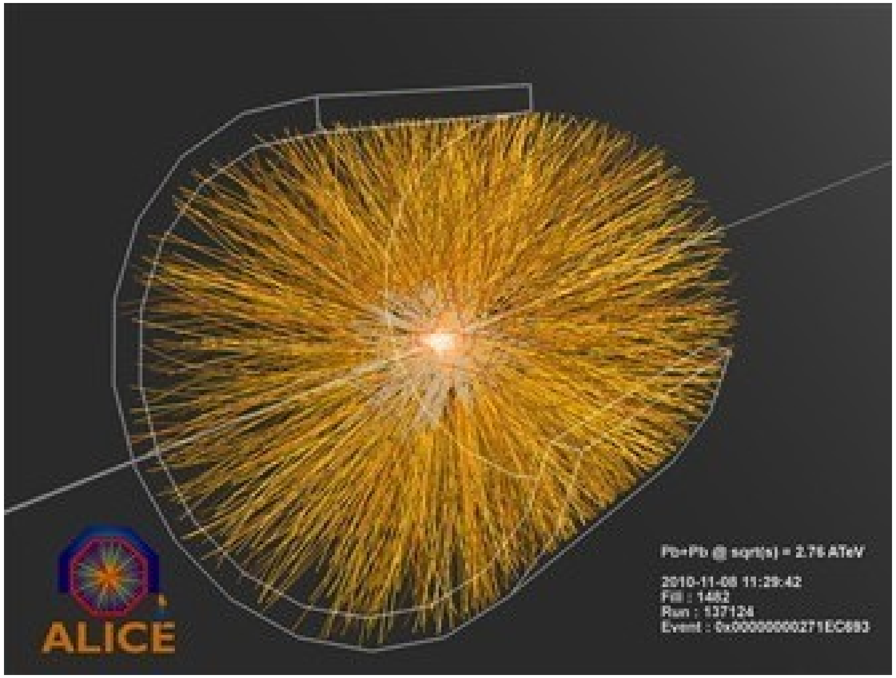
Limitations:

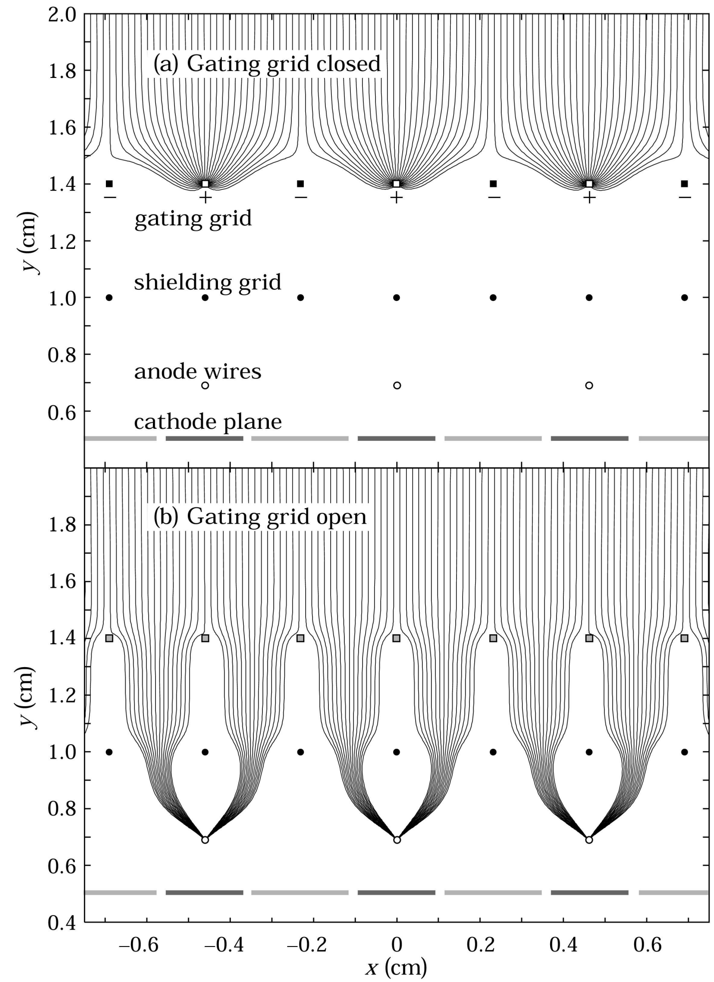
- Calibration very demanding
- Drift distortions due to ion backflow
- Gating ⇨ low trigger rates

Examples:

- STAR (420 cm × 400 cm)
- ALICE (500 cm × 500 cm)
- ILC (360 cm x 460 cm)

Advantages and Limitations of a TPC



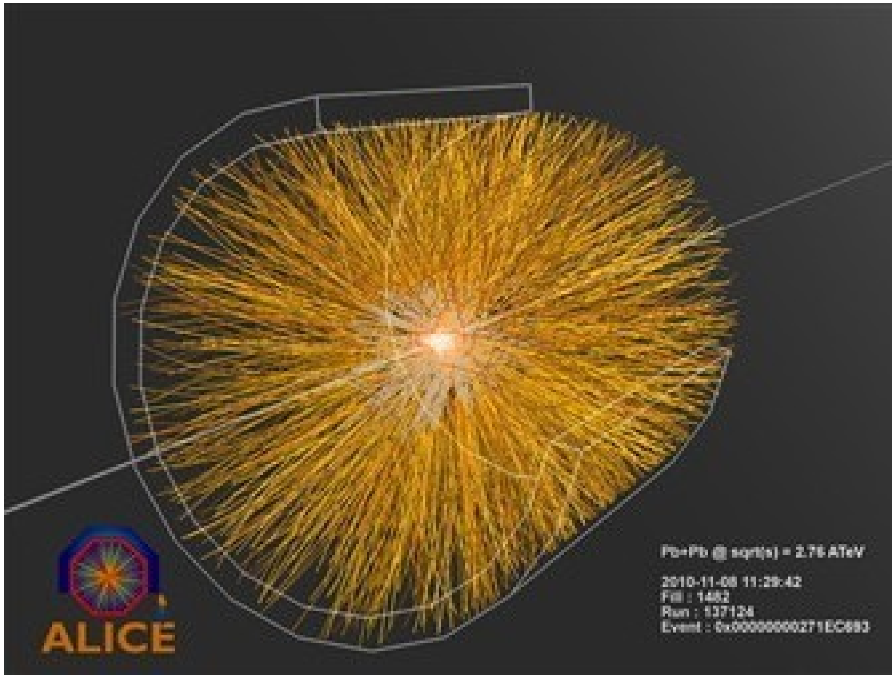


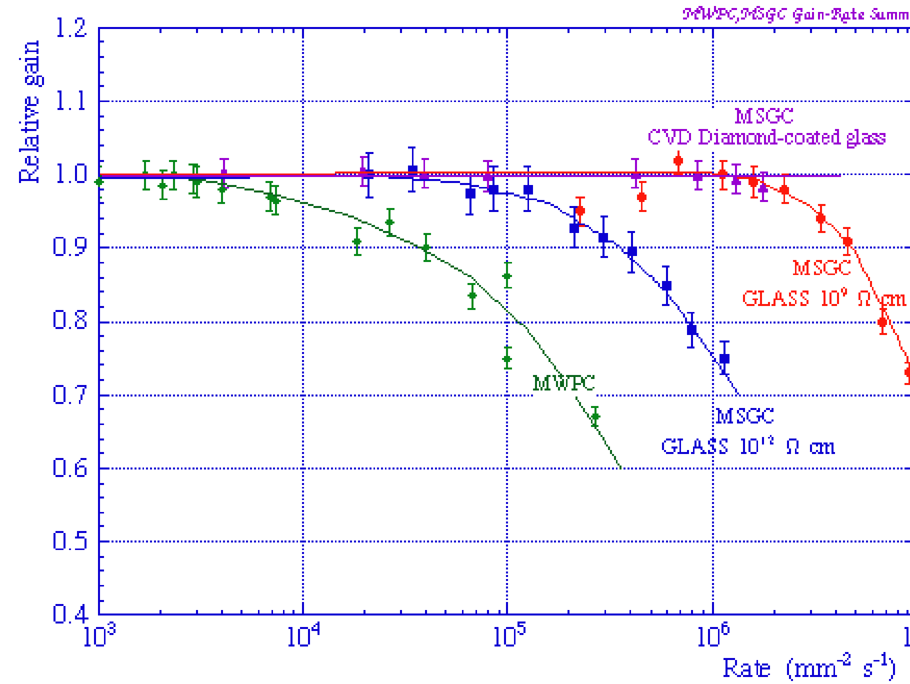
Limitations:

- Calibration very demanding
- Drift distortions due to ion backflow
- Gating ⇨ low trigger rates ~ 1 kHz

Ion Backflow suppression of a MWPC with a Gating grid ~ 10^{-5} !

Advantages and Limitations of a TPC



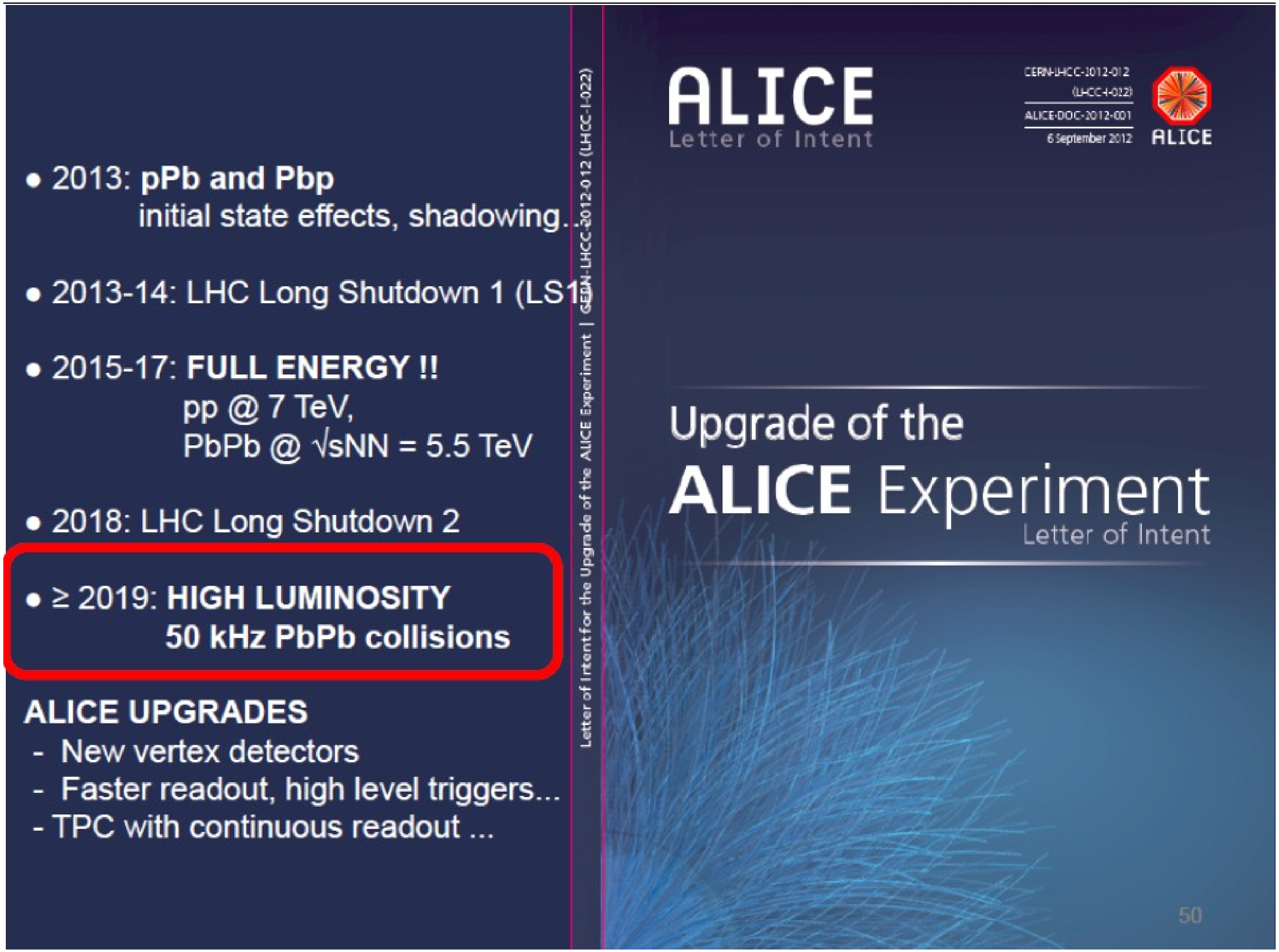


Limitations:

- Calibration very demanding
- Drift distortions due to ion backflow
- Gating ⇨ low trigger rates ~ 1 kHz

Rate capability for Micro Pattern Gas Detectors (MPGD) 10^2 higher than MWPC, ...
… but Ion supression for GEMs is in the order of % !

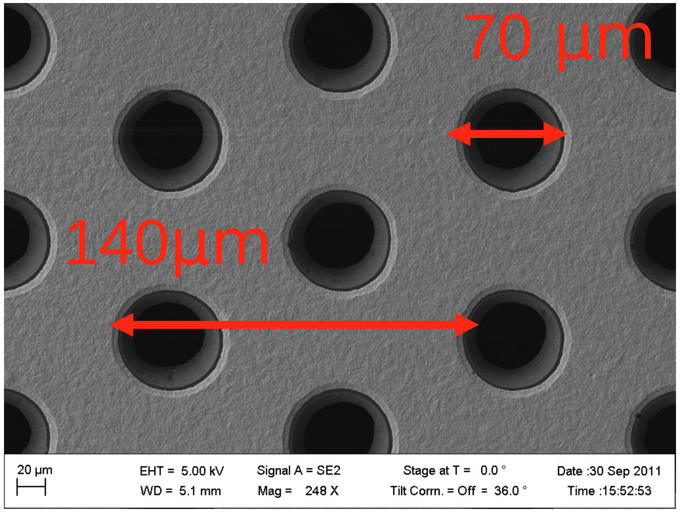
Operation at High Rates

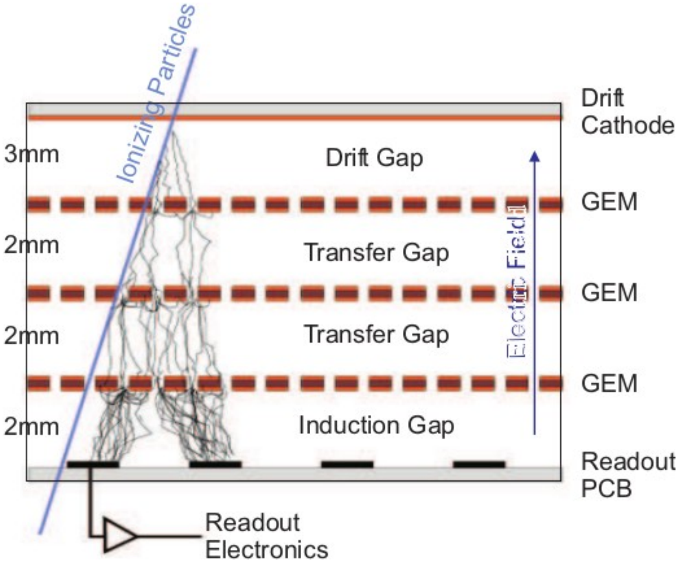


Gas Electron Multiplier (GEM)

- Introduced by Fabio Sauli (1996)
- 50 µm thick kapton
- 5 µm layers of copper on both sides
- Voltage of several hundred volts produce an electric field of several 10^4 V/cm
- Amplification within the holes
- Gain up to 10^3 for a single GEM feasible

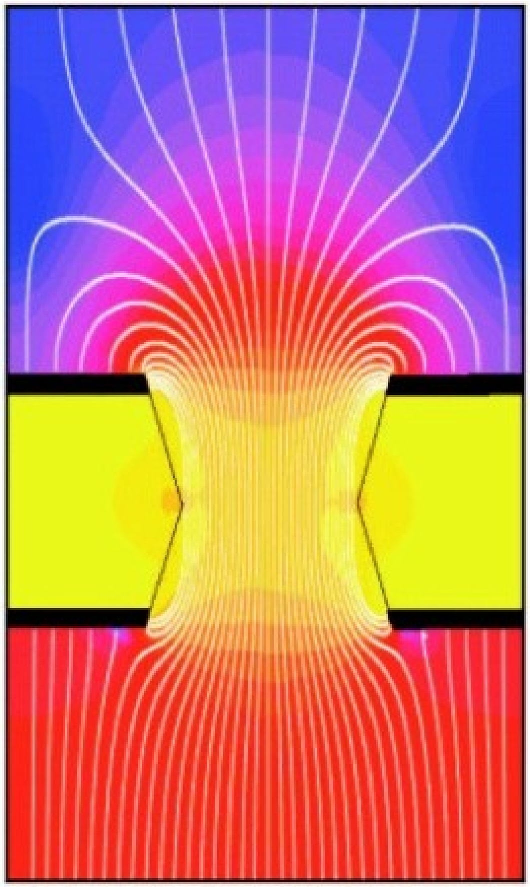
- A multi-GEM structure reduces significantly the discharge rate
- Excellent spatial resolution (ILC, CLIC)
- Intrinsic Reduction of the ion backflow (High Rate TPCs)

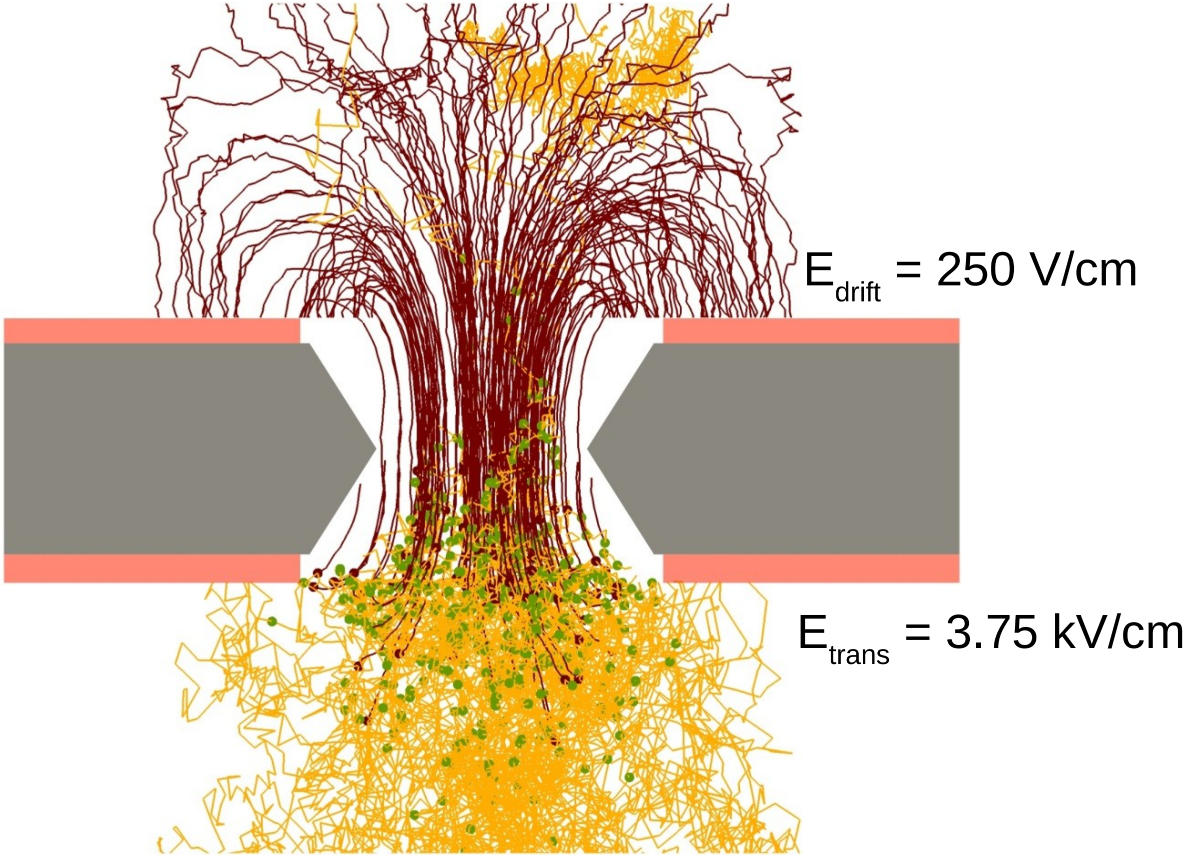




- Motivation for the GEM upgrade
- Ion Backflow Suppression with GEMs
- Construction of a GEM IROC prototype
- Performance Measurements
- Conclusions and Outlook

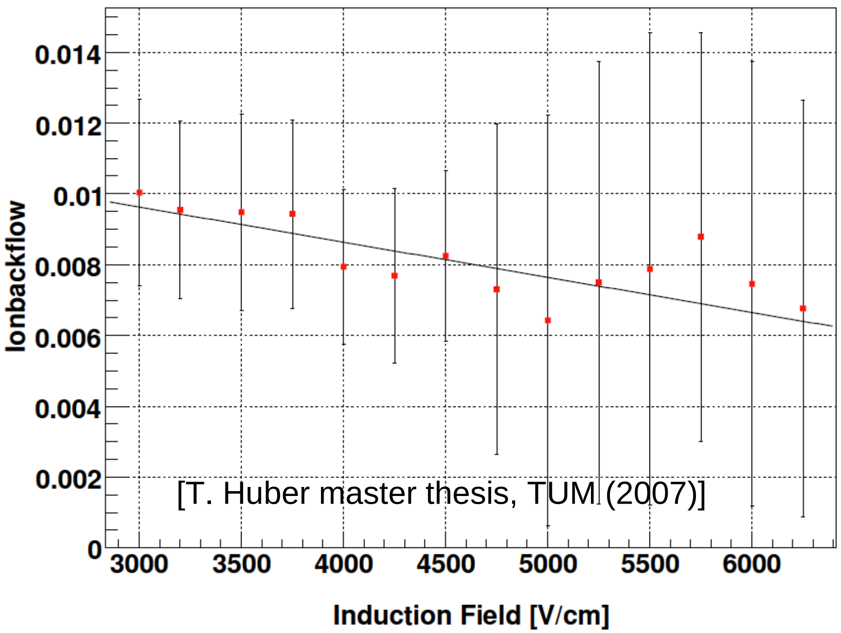
Principle of Ion Backflow Suppression in a GEM





Current Limits on Ion Backflow

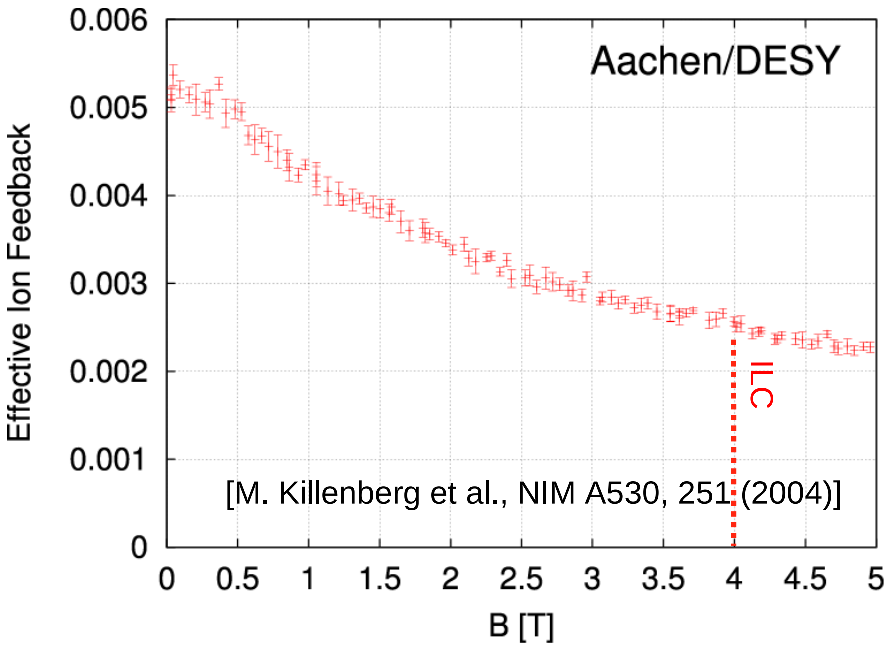
Ar/CO_2(70/30)



GEM voltage settings		Detector field settings	
GEM1	330 V	E_{Drift}	0.25 kV cm^{-1}
GEM2	375 V	E_{T1}	6.00 kV cm^{-1}
GEM3	450 V	E_{T2}	0.16 kV cm^{-1}
		E_{Ind}	5.00 kV cm^{-1}

$Ar/CO_2/CH_4$(93/2/5)

$V_{drift} \sim E + \omega\tau\,(E\times B) + (\omega\tau)^2 (EB)B$

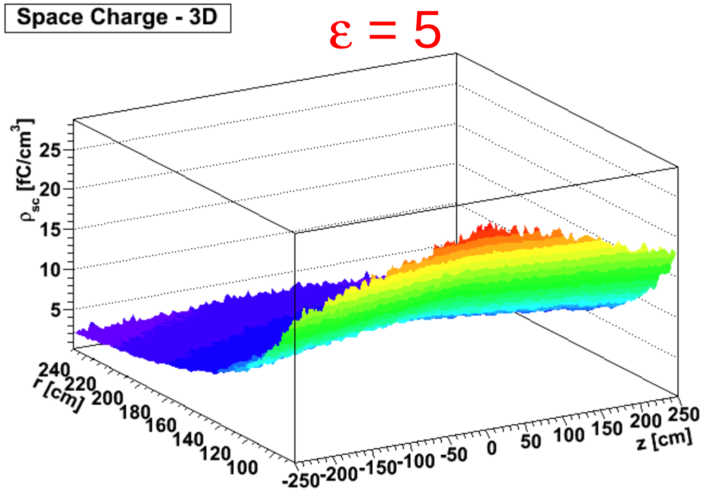


GEM voltage settings		Detector field settings	
GEM1	310 V	E_{Drift}	0.2 kV cm^{-1}
GEM2	310 V	E_{T1}	6.00 kV cm^{-1}
GEM3	350 V	E_{T2}	0.06 kV cm^{-1}
		E_{Ind}	8.00 kV cm^{-1}

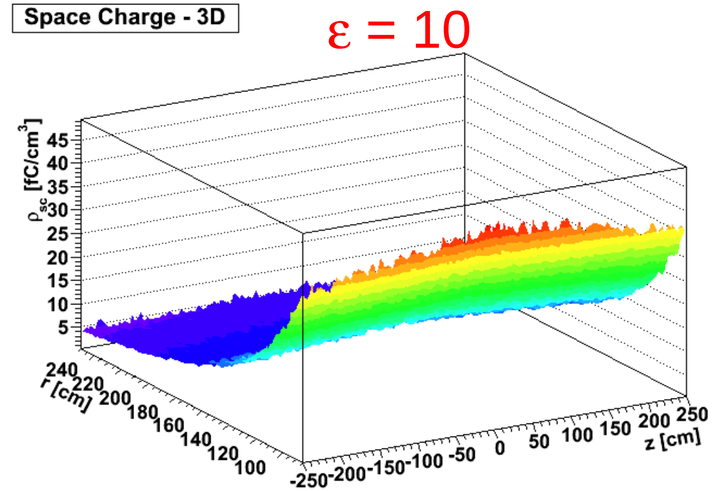
Triple GEM with an IB=0.25 % realistic: ε= 4 at G=2000

Space Charge Effects at ALICE

[CERN-LHCC-2012-012 / LHCC-1-022]

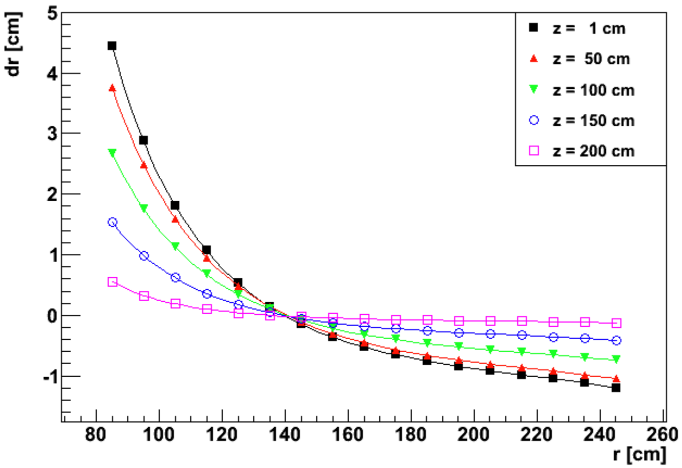


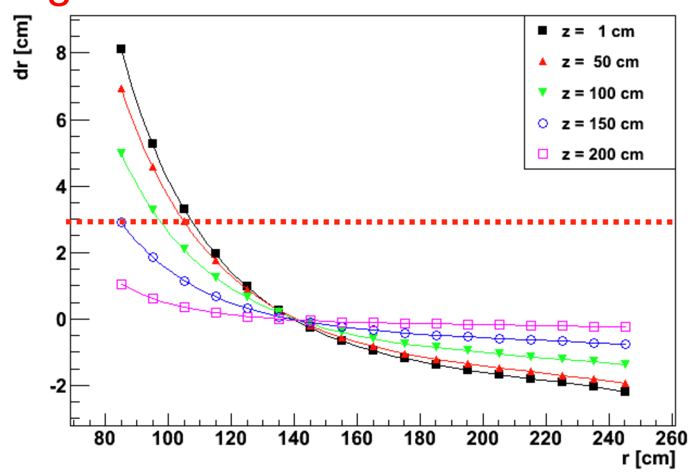
[CERN-LHCC-2012-012 / LHCC-1-022]



Resulting distortions ~ 5 cm can be corrected

IB-Goal ~ 0.5 % (ε = 10) at a gain of 2000





Definitions

- Define limits for a standard triple GEM setup for different gases
- Gas candidates so far Ar/CO_2 (90/10) Ne/CO_2(N_2) 90/10(5)
- Find the most promising gas candidate before trying different GEM geometries or alternative GEM structures
- Characterize the bias coming from rate dependent effect on the IBF

Ion Back-Flow (IBF) and ϵ

Ion Back-Flow is the ratio

$$\frac{\text{Ions arriving at the cathode}}{\text{Electrons arriving at the anode}}.$$

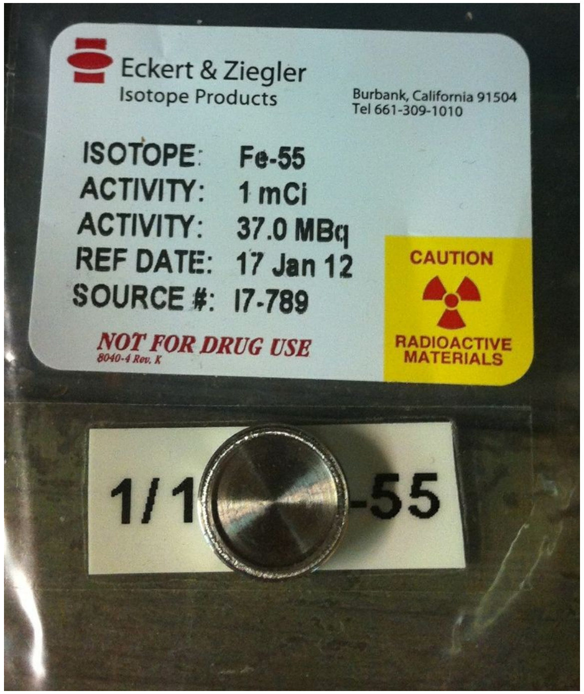
In the following presentation the ratio of currents defines the IBF

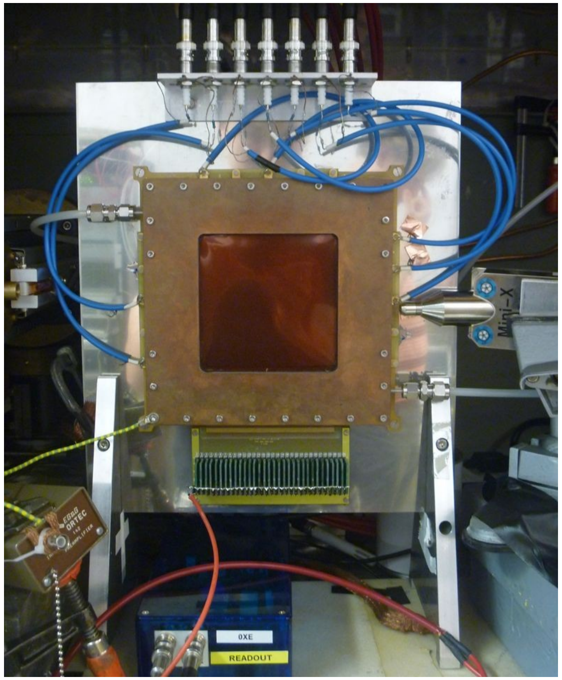
$$\text{IBF} = \frac{I_{\text{drift}}}{I_{\text{readout}}}$$

The number of backdrifting ion per incoming electrons is then defined as

$$\text{epsilon} = \text{IBF*gain-1}$$

TUM Setup - Detector





^{55}Fe with an activity of 37 MBq

- Well defined energy

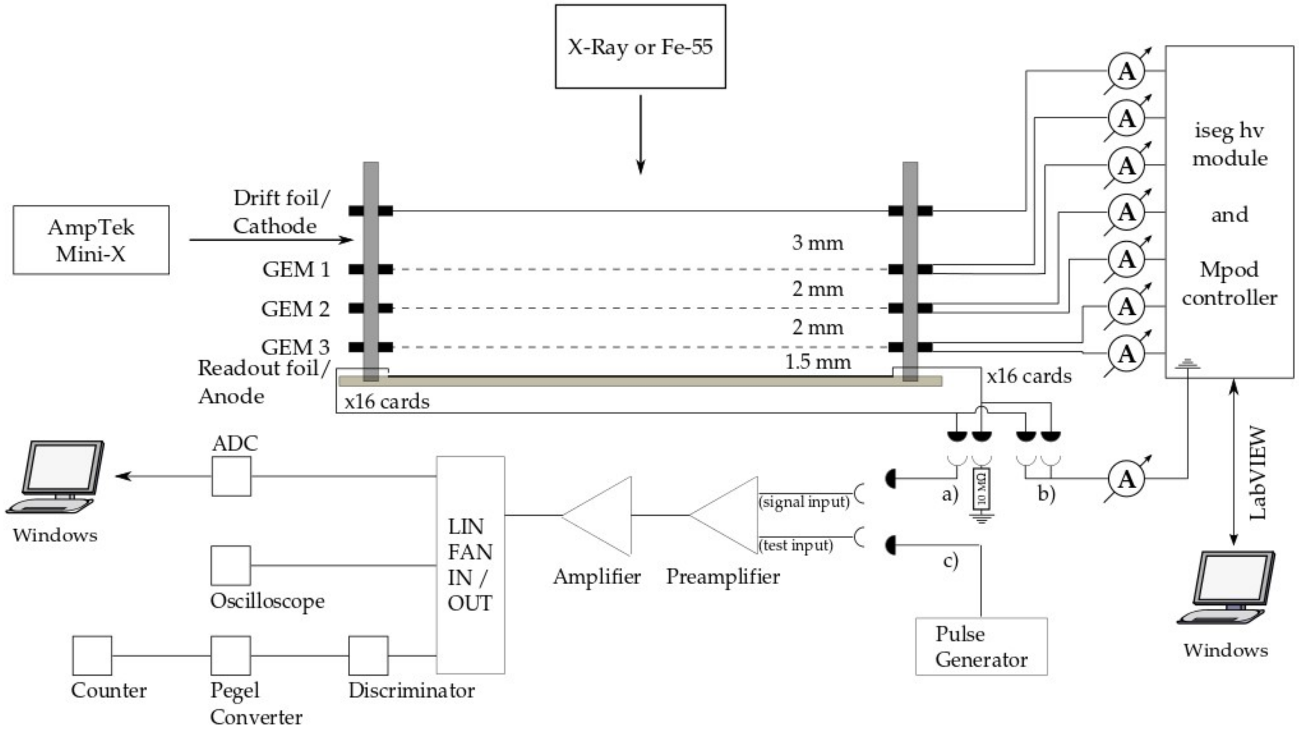
  ⇨ excellent for measurements of energy resolution and gain

Amptek Mini-X Au (4 W)

- High rates

  ⇨ high currents at the GEMs (µA), but energy spectrum is deteriorated by Bremsstrahlung

TUM Setup - Detector



- Small drift volume of 3 mm
- Standard Triple GEM structure
- Gas gain around 1000 for Ar/CO_2 resp. 2000 for Ne/CO_2(N_2) ⇨ same S/N
- Strip readout (512 strips)
- X-Rays enter from top ⇨ measure also the beam profile (resp. charge density)

Settings for IBF modes

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

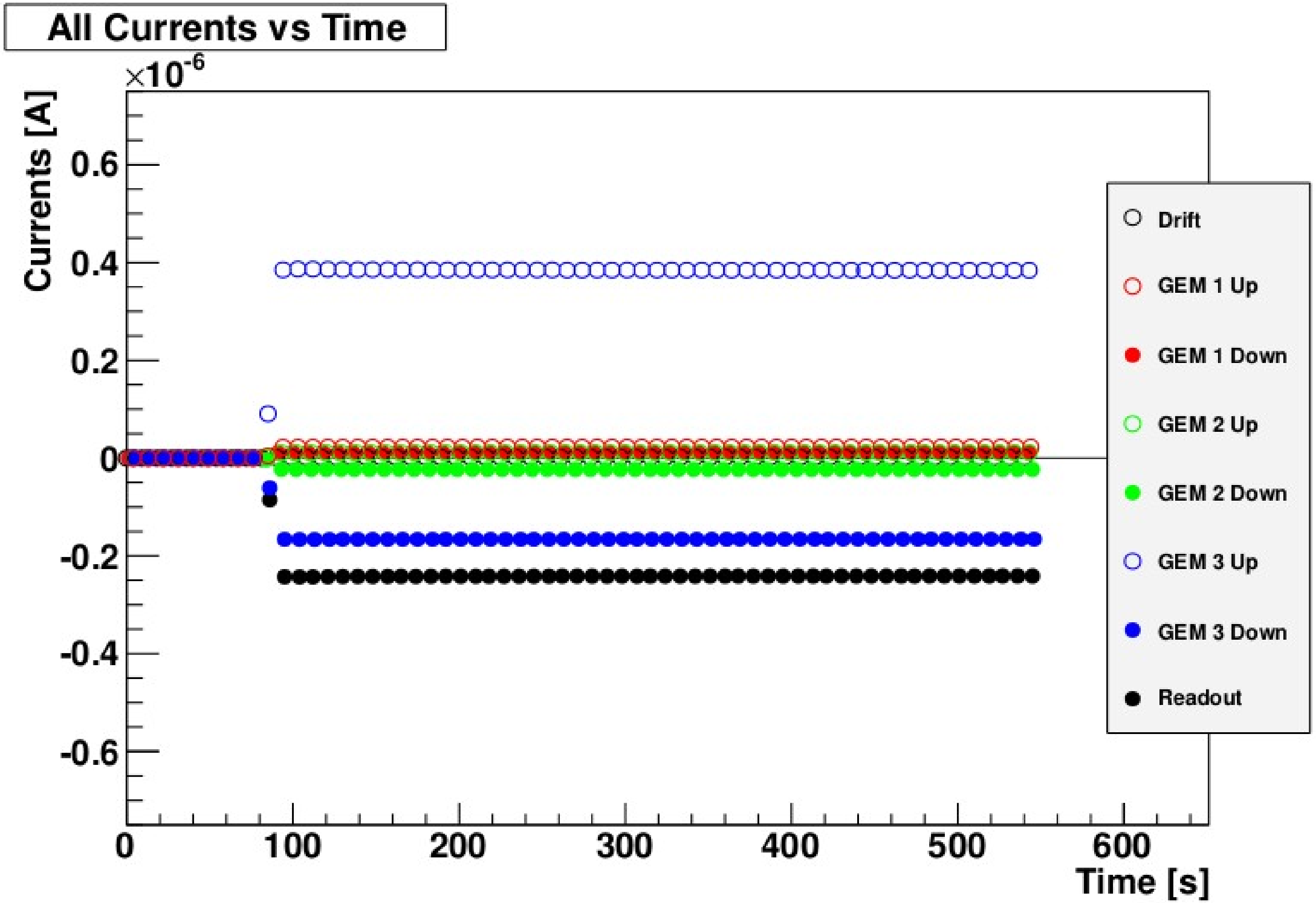
GEM voltage settings		*Detector field settings*	
GEM1	235 V	E_{Drift}	$0.4\,kV\,cm^{-1}$
GEM2	245 V	E_{T1}	$5.0\,kV\,cm^{-1}$
GEM3	steerable	E_{T2}	$0.2\,kV\,cm^{-1}$
		E_{Ind}	$3.8\,kV\,cm^{-1}$

For Ne/CO_2/N_2 90/10/5

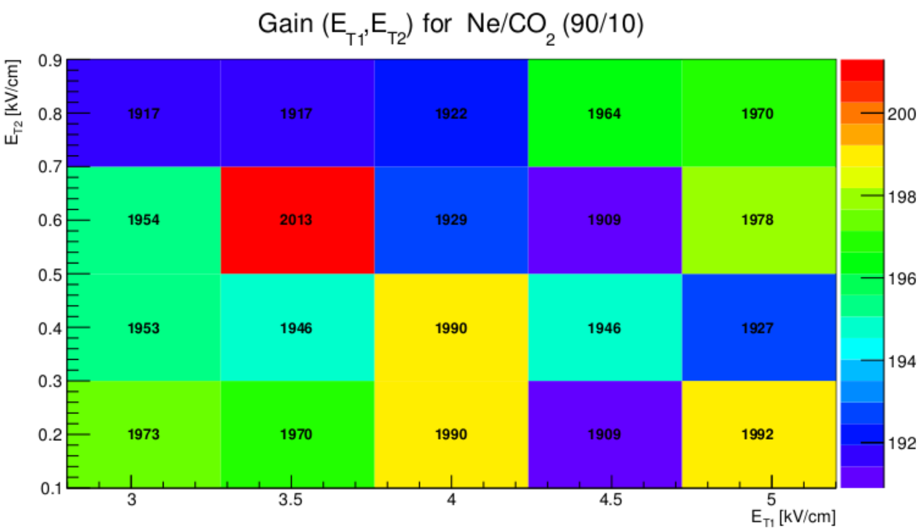
GEM voltage settings		*Detector field settings*	
GEM1	263 V	E_{Drift}	$0.4\,kV\,cm^{-1}$
GEM2	305 V	E_{T1}	$5.5\,kV\,cm^{-1}$
GEM3	steerable	E_{T2}	$0.2\,kV\,cm^{-1}$
		E_{Ind}	$4.0\,kV\,cm^{-1}$

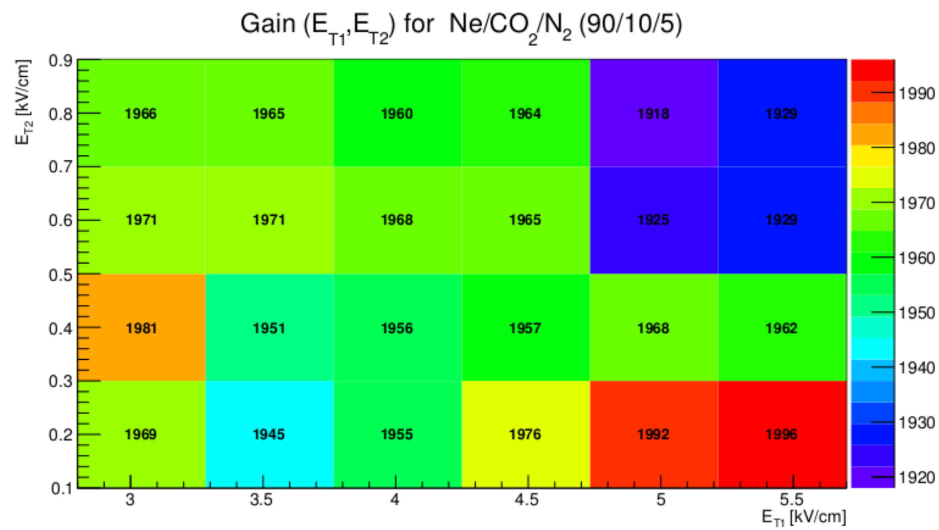
- $\Delta U_{GEM\,1} < \Delta U_{GEM\,2} \ll \Delta U_{GEM\,3}$
- E_{T1} and E_{Ind} are high
- E_{T2} as low as possible
- Scan of E_{T1} from:
  3.0 kV/cm, …, 5.5 kV/cm
- Scan of E_{T2} from:
  0.2 kV/cm, …, 0.8 kV/cm
- Use GEM_3 to keep gain const.

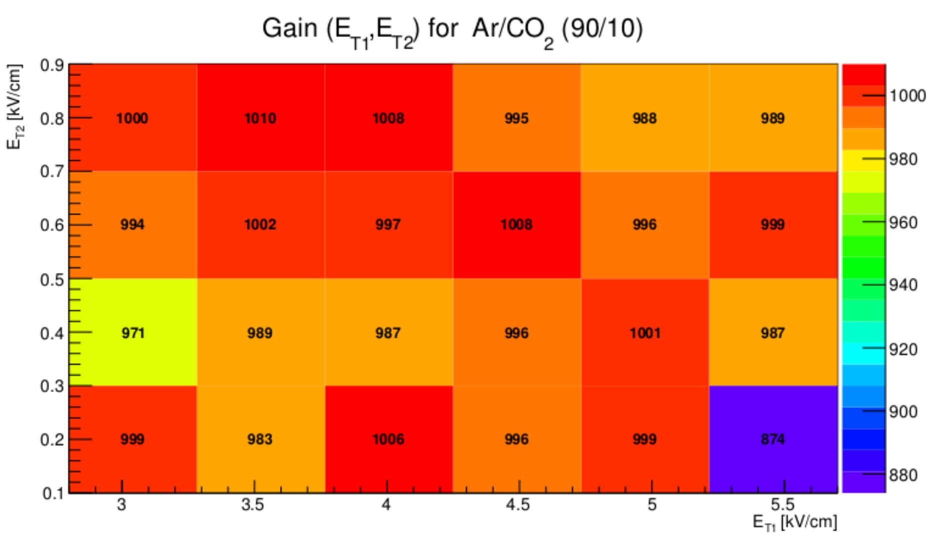
$I_{CM}(t)$ for IBF Settings



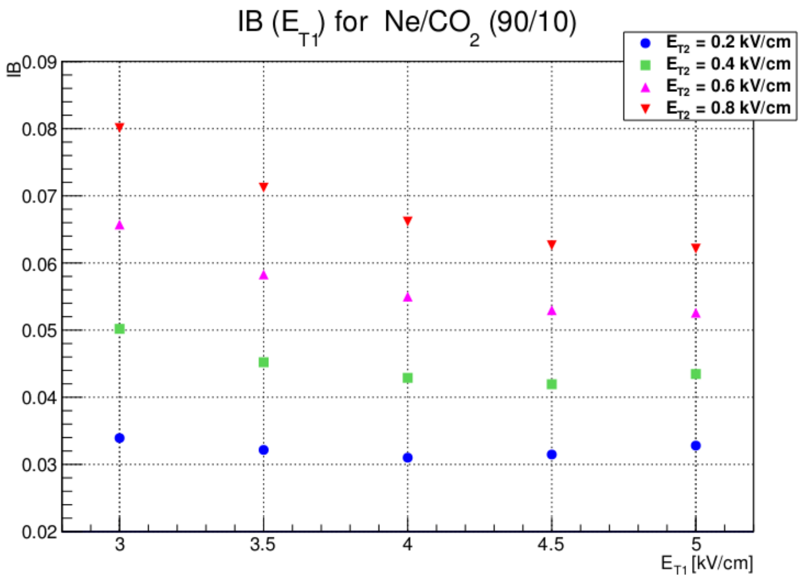
Gain for Different Gases

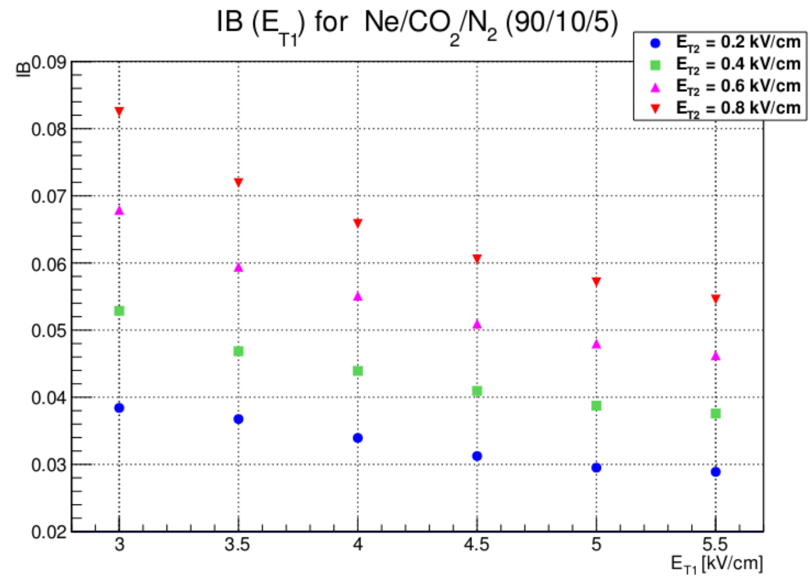


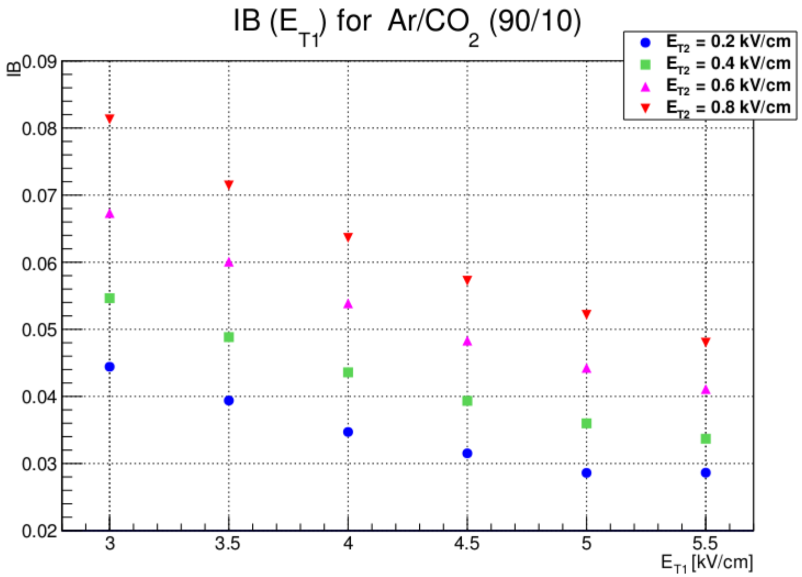




IBF for Different Gases

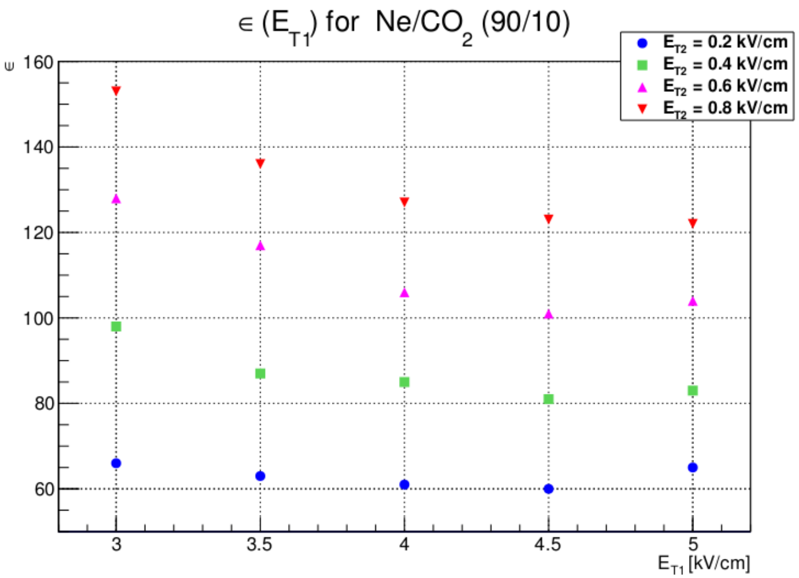


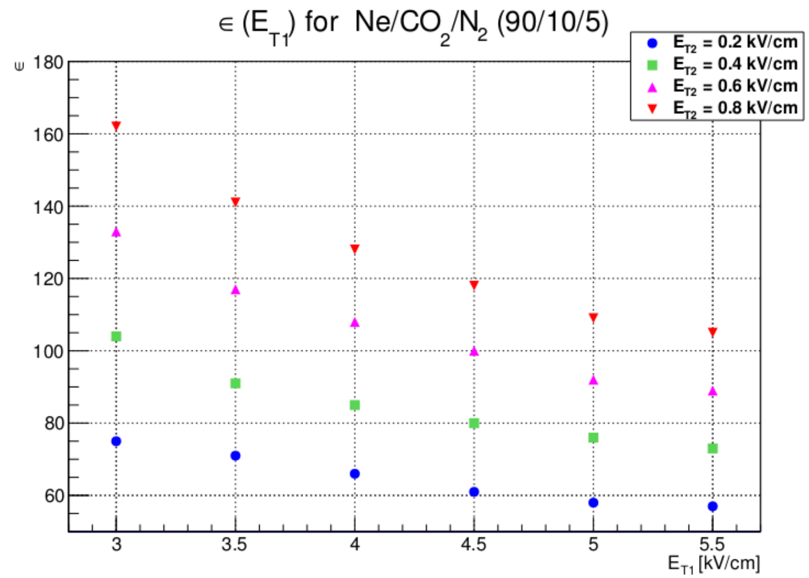


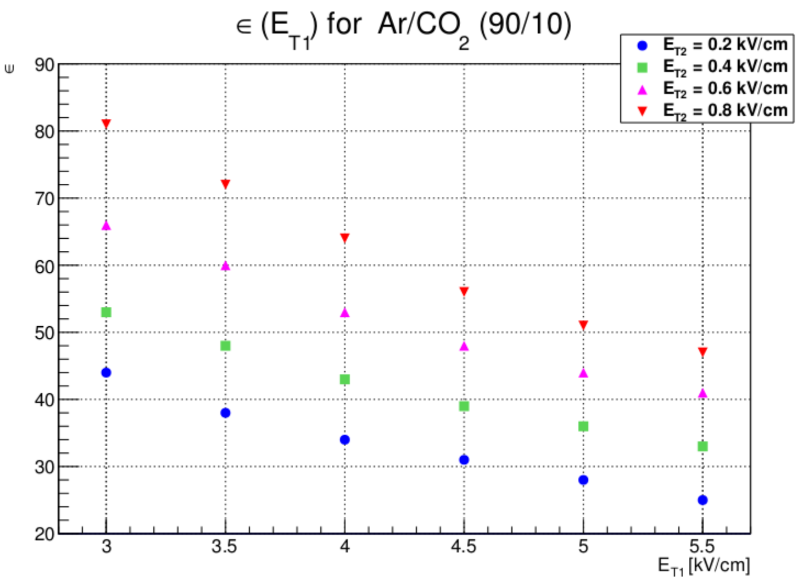


- Best values for lowest E_{T2} and highest E_{T1}
- Except Ne/CO_2 (amplification at 4 kV/cm) for E_{T1} > 4 kV/cm IBF increases again
- Ions from Transfer gap 1 escape in drift volume

ε for Different Gases



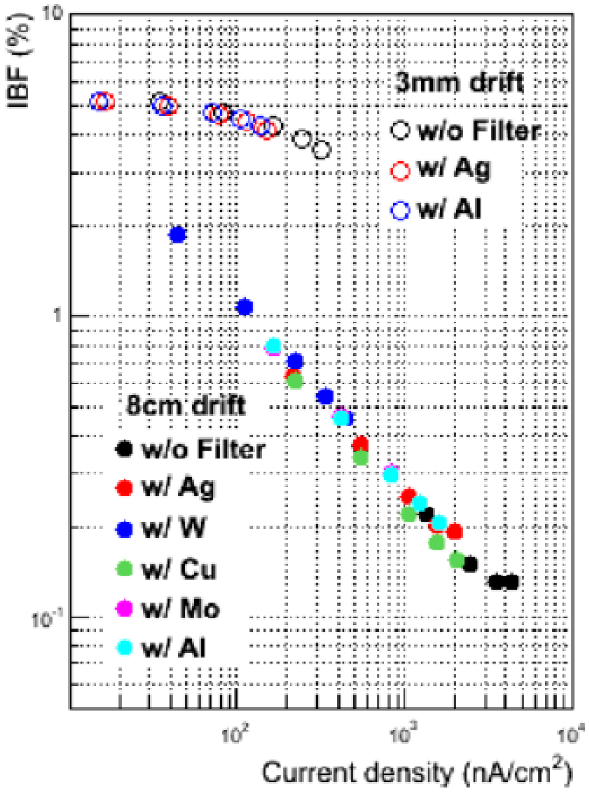




- $\rho = I/u_{ion}$ with $I \sim \varepsilon * n_{prim}$
- $\rho(Ne/CO_2):\rho(Ne/CO_2/N_2):\rho(Ar/CO_2)$ = 1,65 : 1,57 : 3,75
- Ion mobility of argon about a factor 2,5 slower than neon !

IBF – Rate Dependency

$Ar/CO_2(70/30)$

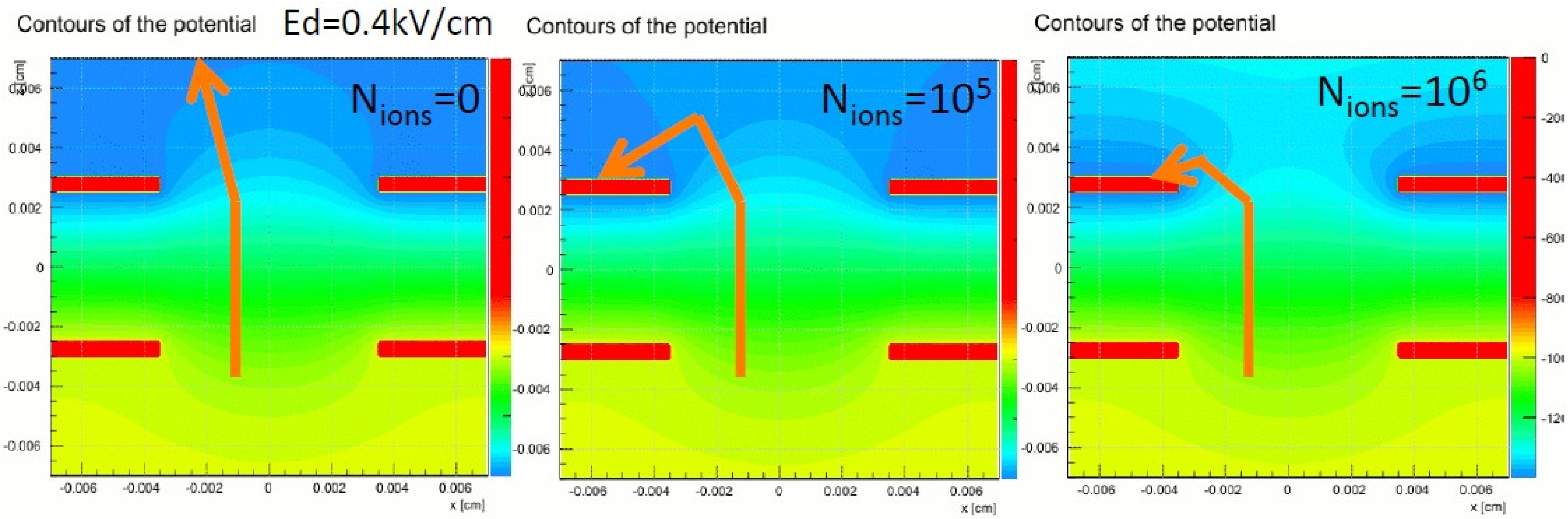


[C. Garabatos, Y. Yamaguchi, CERN (2012)]

- Drop of IBF measured for high X-ray rates resp. high charge densities ρ in the detector
- Fundamental difference for different drift length of the detector (3-80 mm)
- Could this be affected by space charge ?

IBF – Space Charge Simulations

- Space charge possible candidate to explain the effect
- First preliminary studies in 2012
  - Ion disks in very limited space
- Electric field with N_{ions} in [0 – 100 μm] above GEM hole
  - Ion disk in front of the GEM hole block

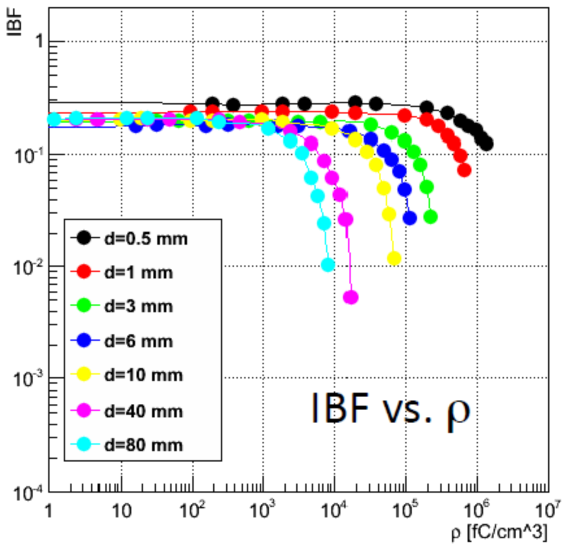


[T. Gunji, University of Tokio(2012)]

IBF performance (Space Charge)

IBF - Simulation for a single GEM as a function of charge density ρ

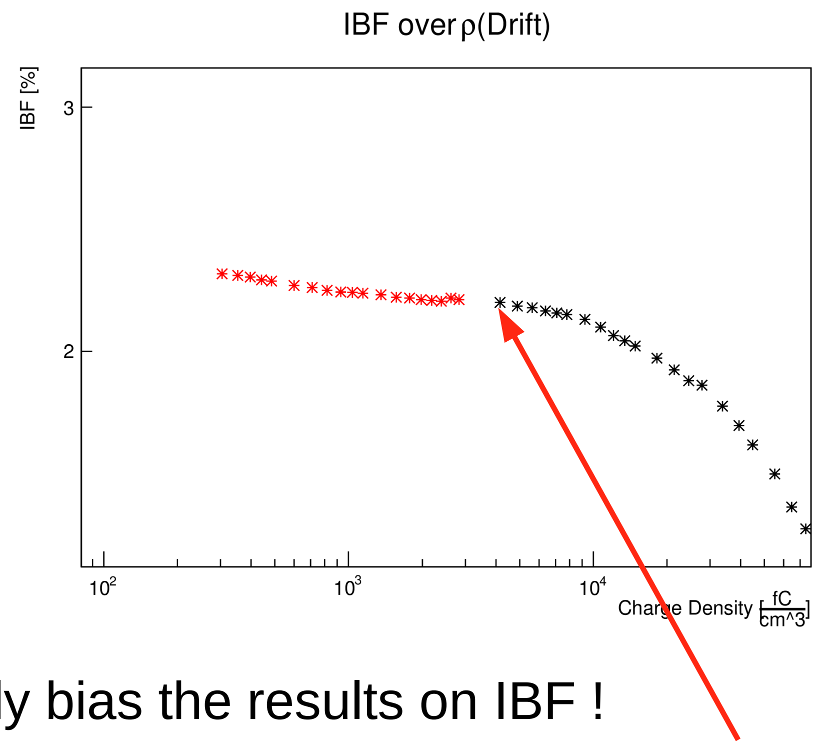
IBF - Measurement of a 3 GEM setup as a function of charge density ρ



[T. Gunji, University of Tokio(2013)]

Ar/CO_2 (90/10)

E_{drift} = 0.4 kV/cm



- Space charge effects can severely bias the results on IBF !
- Fortunately our measurements were performed in the plateau region
- Increase of IBF at low ρ values comes from systematic effects of the pA-meters

Conclusions and Outlook IBF

Conclusions on IBF:

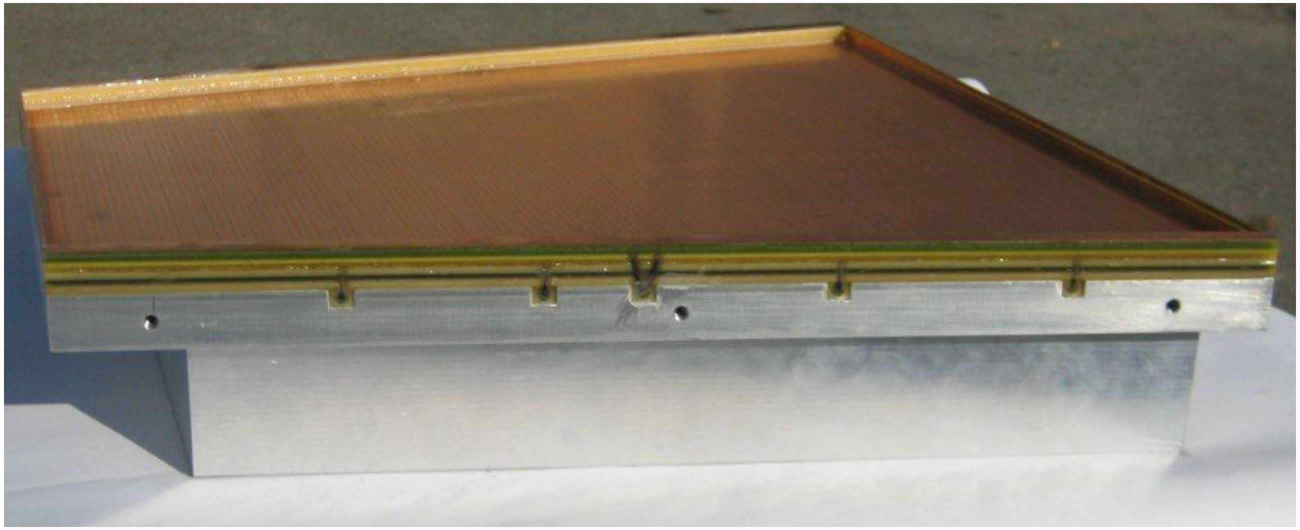
- Preliminary measurements show that all tested gases do not match the requirements
- For the best case $Ne/CO_2/N_2$ so far still a factor 6 to high (if $\varepsilon = 10$)
- $\rho = I/u_{ion}$ with $I \sim \varepsilon * n_{prim}$
- $\rho(Ne/CO_2):\rho(Ne/CO_2/N_2):\rho(Ar/CO_2) = 1{,}65 : 1{,}57 : 3{,}75$
- Most promising gas candidate so far $Ne/CO_2/N_2$ (no amplification in E_{T1})
- IBF can be biased for high rate resp. high charge densities
- Had to skip more simulations on IBF as well as measurements for COBRAs

Outlook on IBF

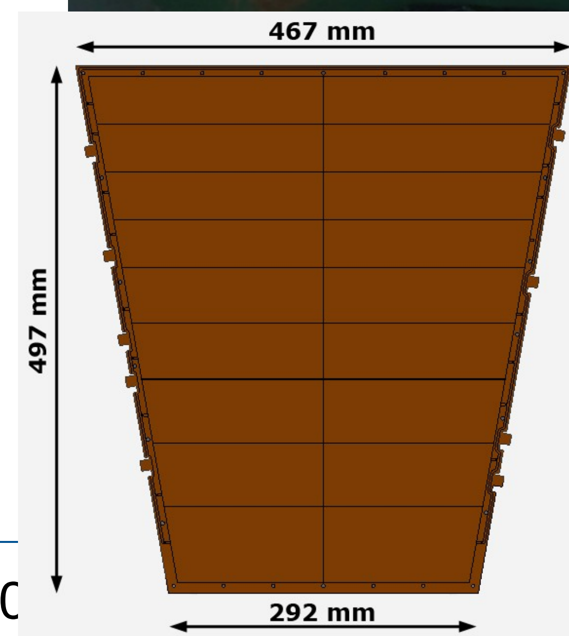
- Scan of gases almost complete (Ne/CF_4 still missing)
- Test GEMs with different aspect ratio (smaller resp. conical holes)
- Investigate fourth GEM setup

- Motivation for the GEM upgrade
- Ion Backflow Suppression with GEMs
- Construction of a GEM IROC prototype
- Performance Measurements
- Conclusions and Outlook

ALICE IROC Prototype

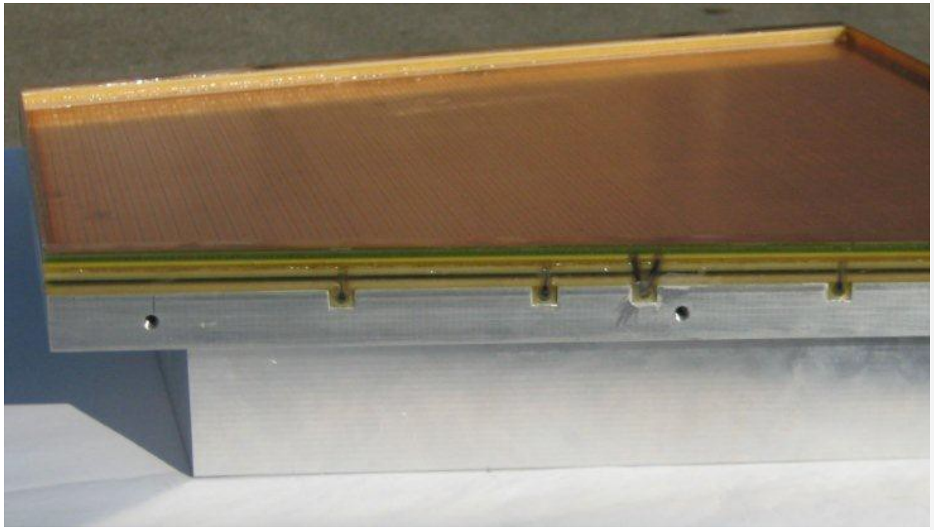


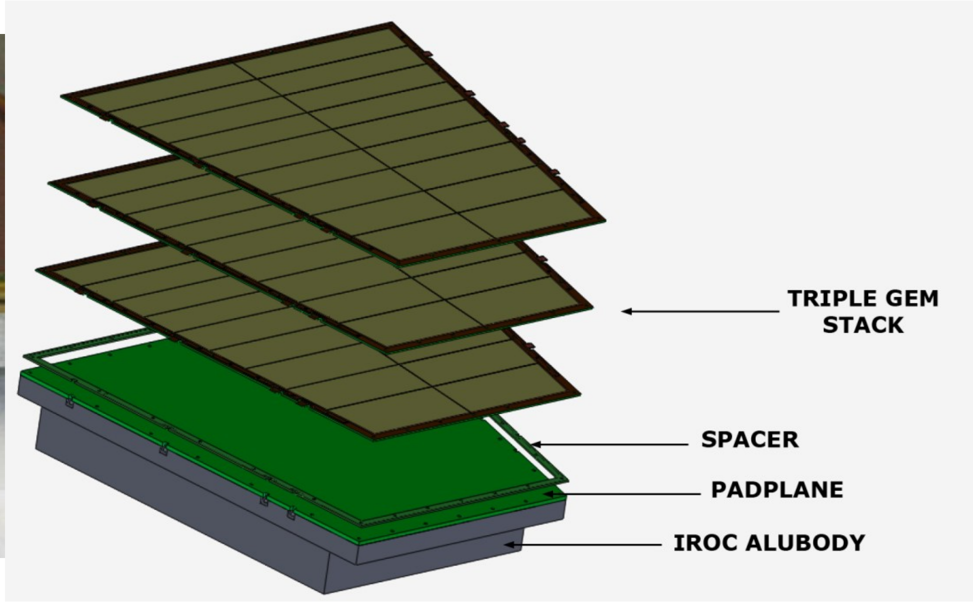
- 3 large-size GEM foils: single-mask
- 18 sectors (top side), ~ 100 cm^2 each
- bias resistors 10 resp. 1MO
- 2mm frames glued on bottom side
- spacer grid: 400 µm thickness
- additional frame for induction gap: 4mm



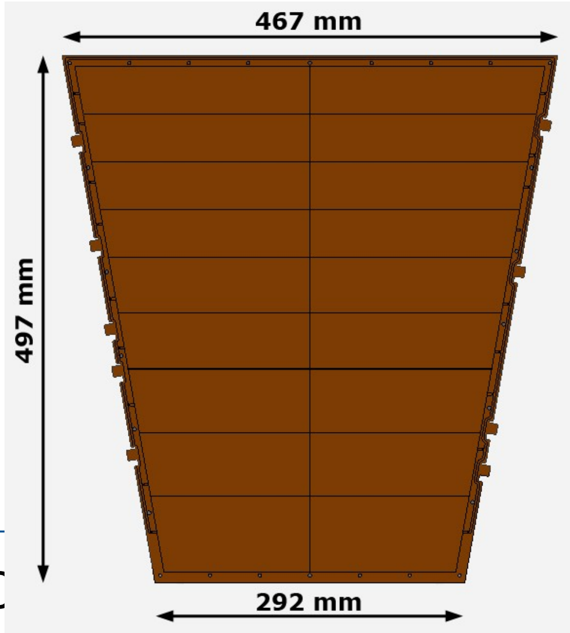
[M. Berger]

ALICE IROC Prototype



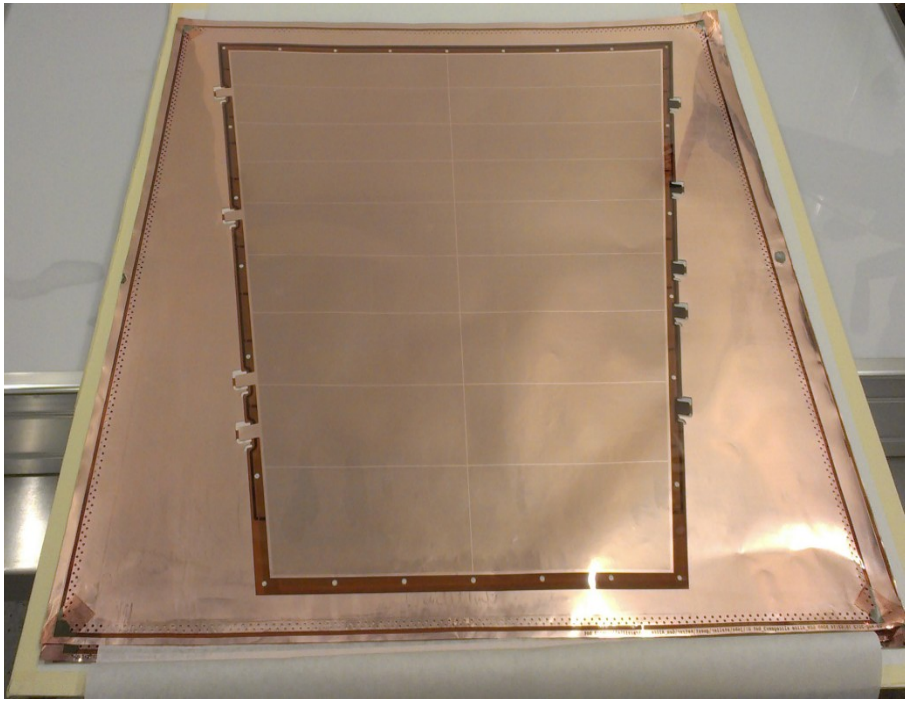


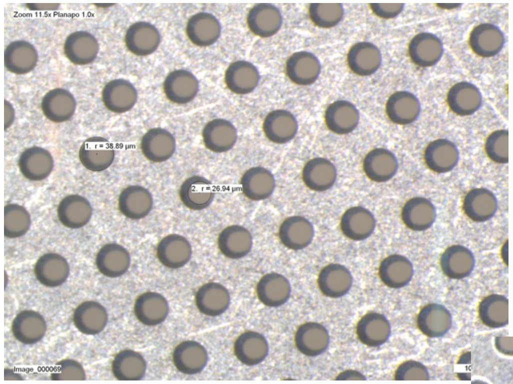
- 3 large-size GEM foils: single-mask
- 18 sectors (top side), ~ 100 cm^2 each
- bias resistors 10 resp. 1MO
- 2mm frames glued on bottom side
- spacer grid: 400µm thickness
- additional frame for induction gap: 4mm

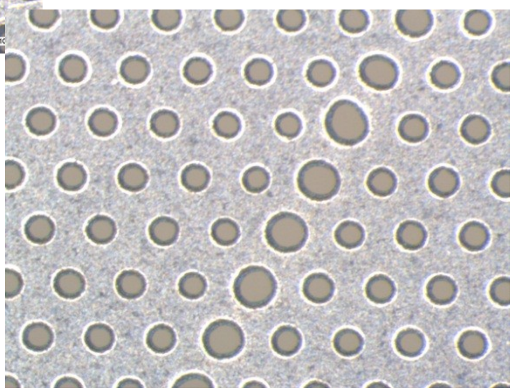


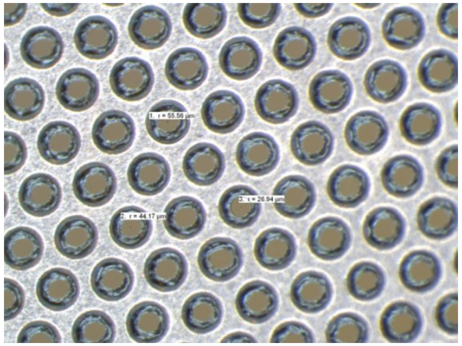
[M. Berger]

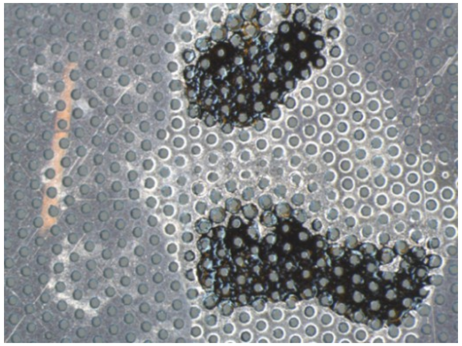
Single-mask GEM Foils

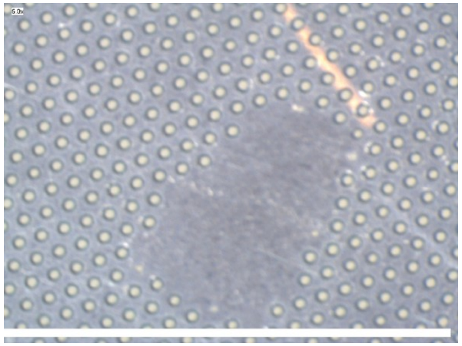


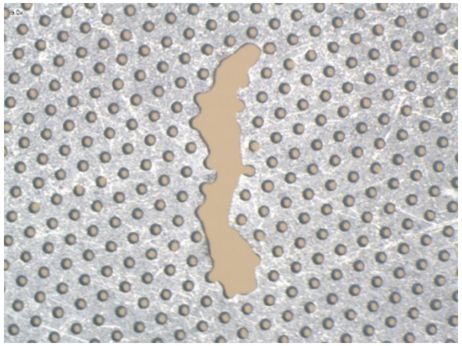




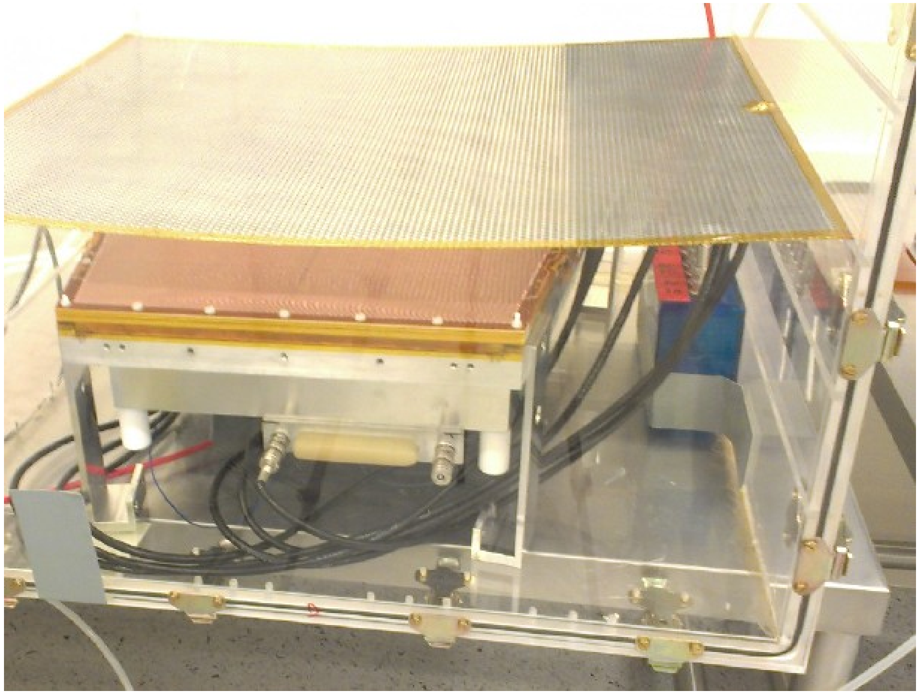




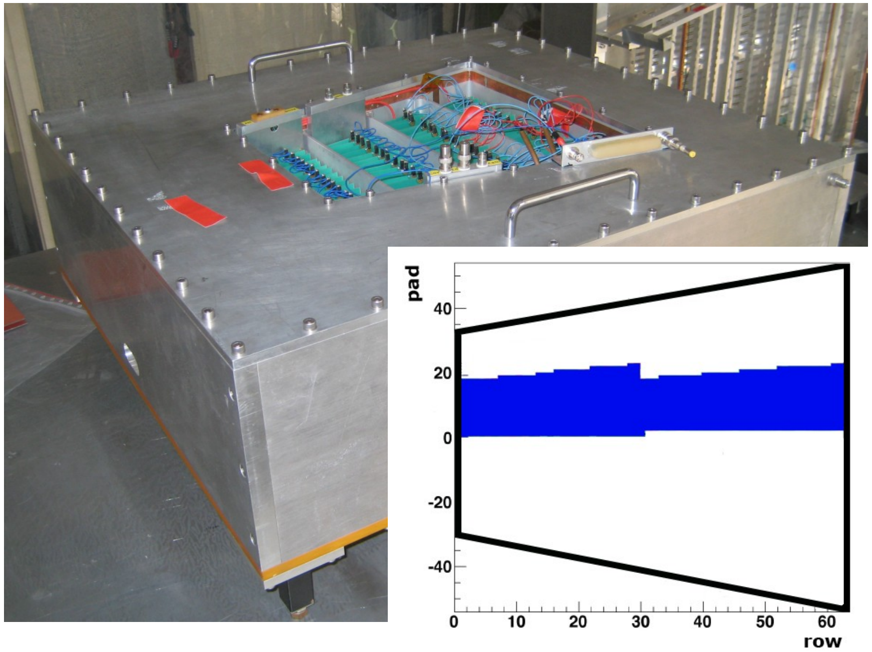




ALICE IROC with GEMs



Test in flush box with “cathode”

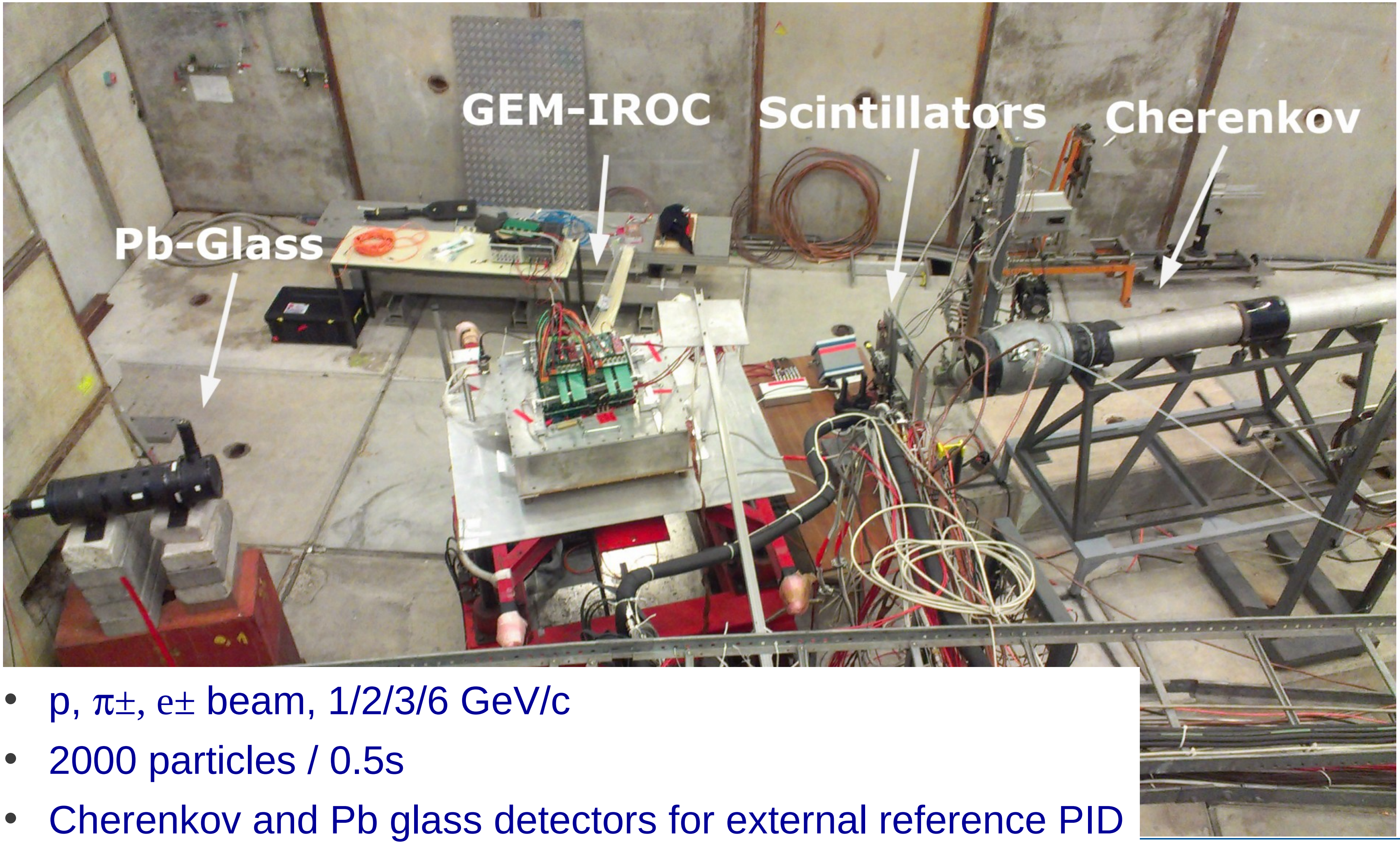


IROC mounted inside field cage

- Drift length 11.5 cm, 400 V/cm
- Gas Ne/CO2 (90/10)
- 64 rows with pads
- **FEE: PCA16 / ALTRO (LCTPC)**
- ENC: 500 – 600 e-

- Motivation for the GEM upgrade
- Ion Backflow Suppression with GEMs
- Construction of a GEM IROC prototype
- Performance Measurements
- Conclusions and Outlook

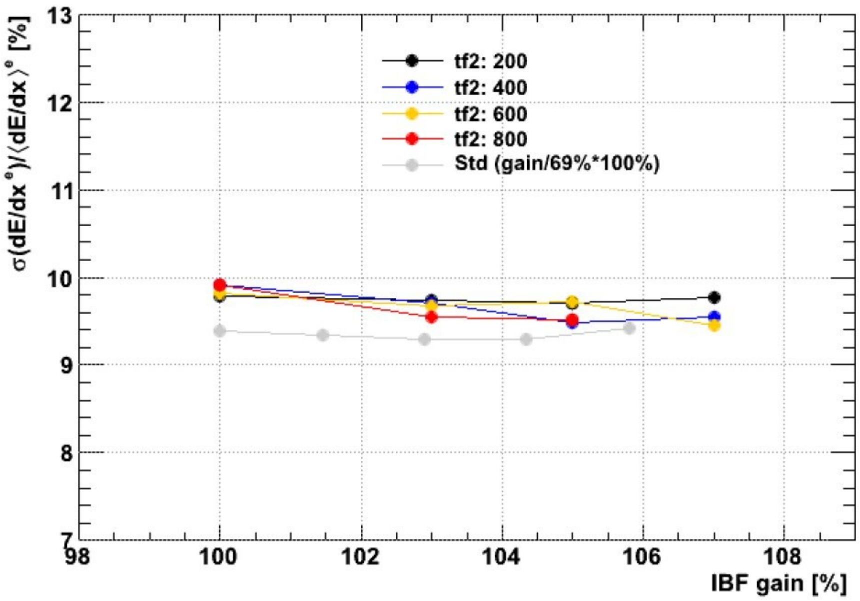
IROC Beam Test at CERN PS

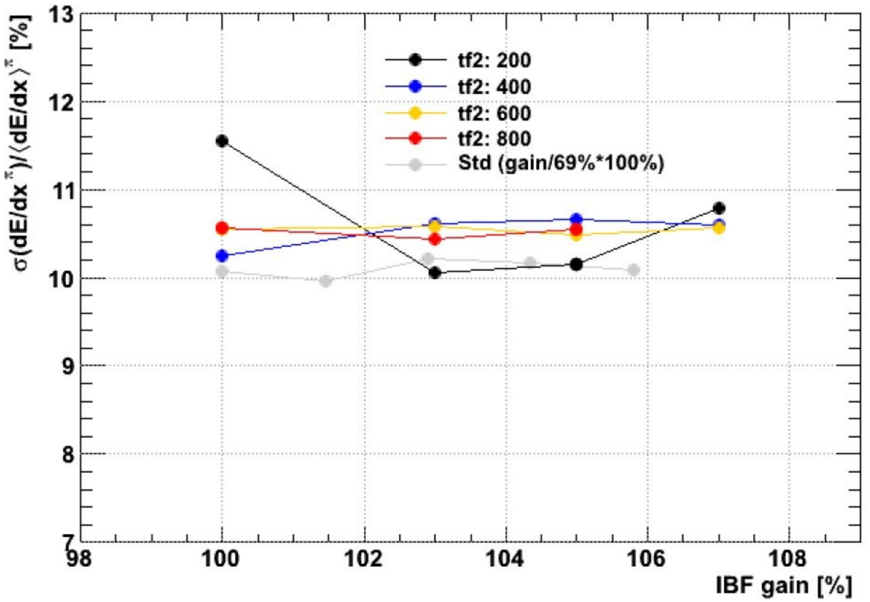


- p, $\pi^{\pm}$, $e^{\pm}$ beam, 1/2/3/6 GeV/c
- 2000 particles / 0.5s
- Cherenkov and Pb glass detectors for external reference PID
- Goal: measure separation power for different GEM settings

dE/dx Results

dE/dx resolution of 1 GeV electrons and pions
for different IBF settings and as a function of gain



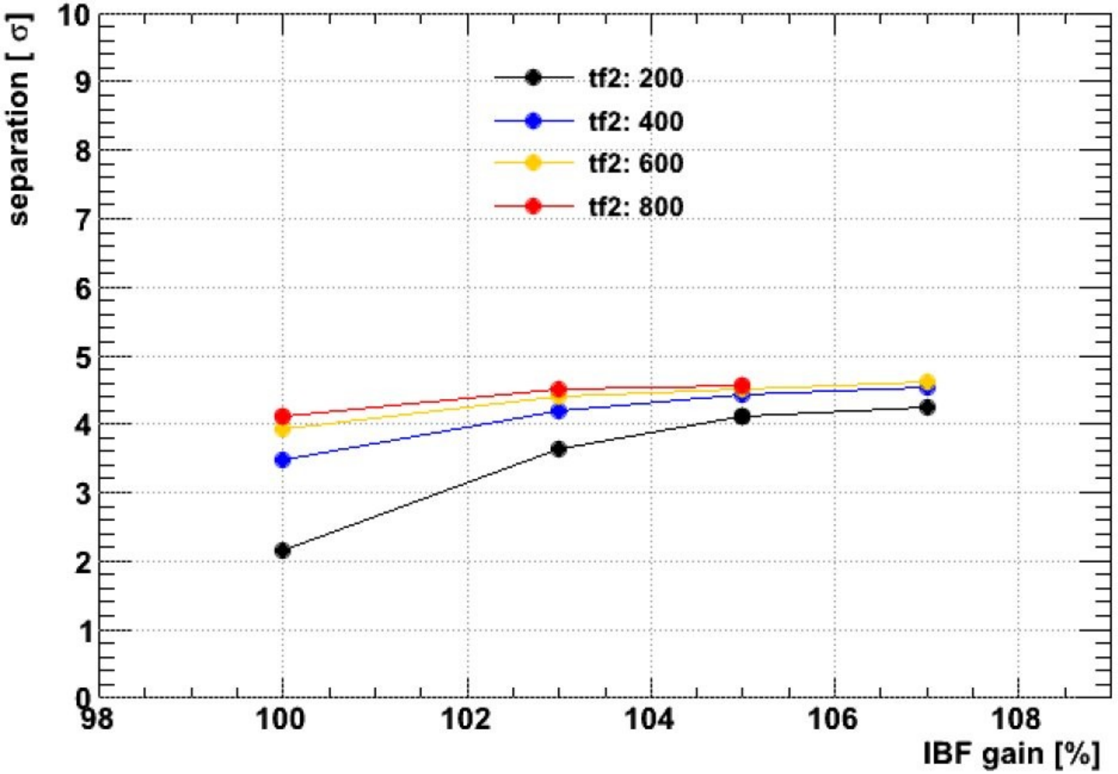


dE/dx resolution for e^- ~ 9.5 % for π^- ~ 10 %

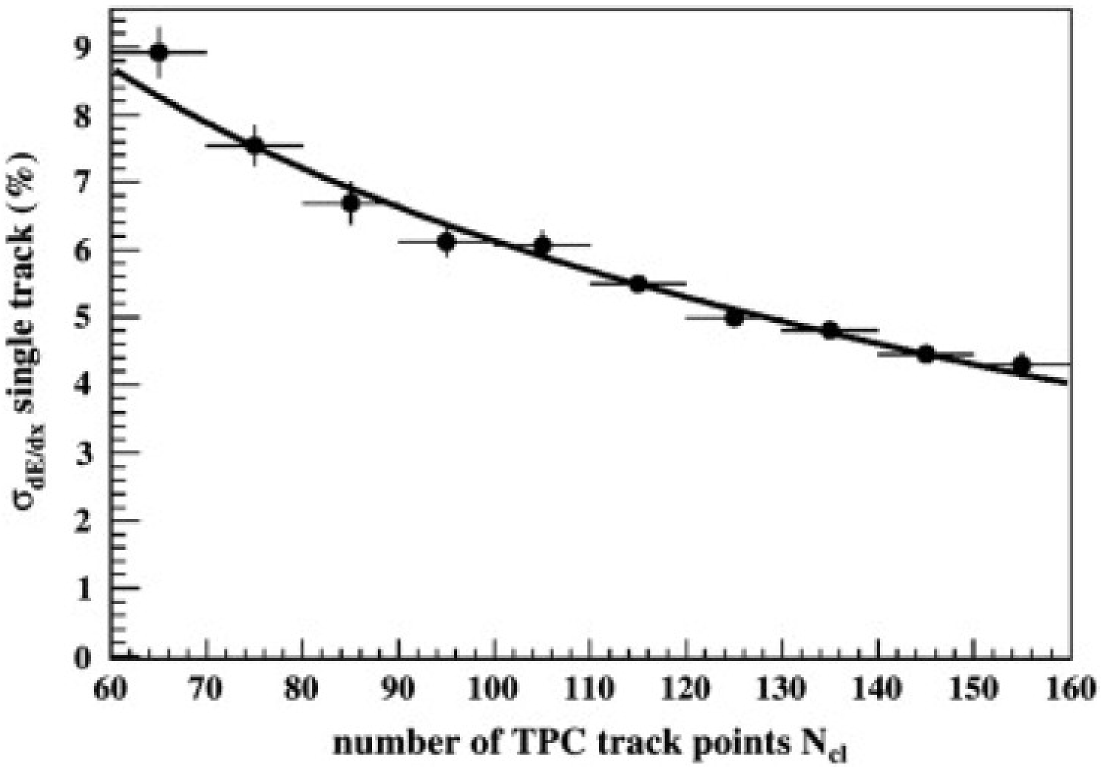
dE/dx Results

dE/dx separation of 1 GeV electrons and pions

for different IBF settings and as a function of gain



dE/dx Results



W. Yu, Nuclear Instruments & Methods In Physics Research A (2012), http://dx.doi.org/10.1016/j.nima.2012.05.022

dE/dx-resolution achieved with the GEM IROC with 64 rows looks promising to satisfy the performance for the full TPC

Conclusions and Outlook GEM IROC

Conclusions on GEM IROC:

- Plan to upgrade TPC with GEM approved by LHCC
- GEM IROC prototype equipped with GEMs at TUM
- Successful beam test at CERN PS
- Stability test in ALICE cavern during p+Pb run in January 2013

Outlook on GEM IROC

- New GEM IROCs prepared for additional tests on stability
- Take into account the lessons learned at first beamtimes
  (Improve GEM production, HV powering scheme, mounting structure, etc ...)
- How to equip an OROC (splicing of GEMs)
- Many things more, e.g. electronics for continuous readout, etc. ...

Thank you for your attention!

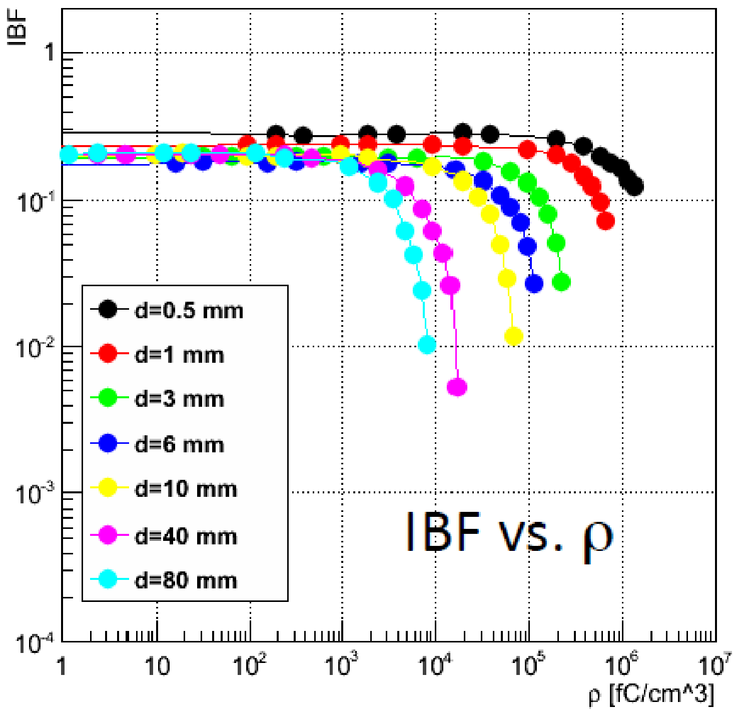
Backup Slides

IBF performance (Space Charge)

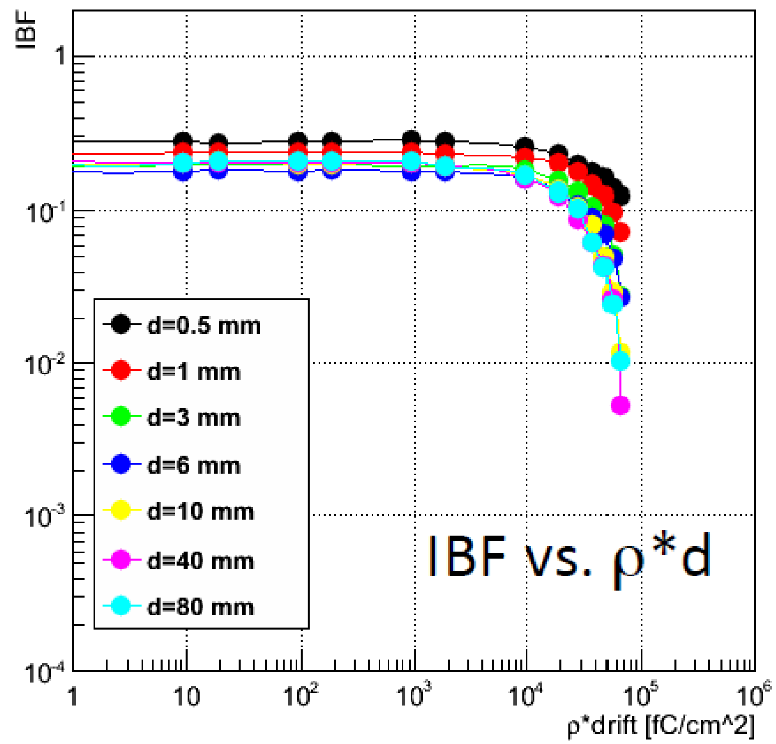
IBF - Simulation for a single GEM as a function of charge density ρ

IBF - Simulation for a single GEM as a function of charge density ρ*d

Ar/CO_2 (90/10) E_{drift} = 0.4 kV/cm



[T. Gunji, University of Tokio(2013)]

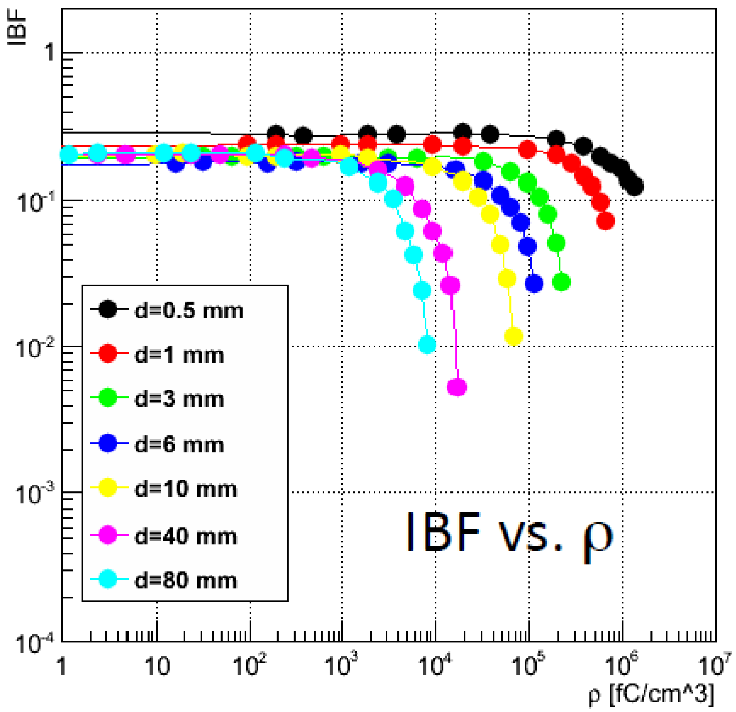


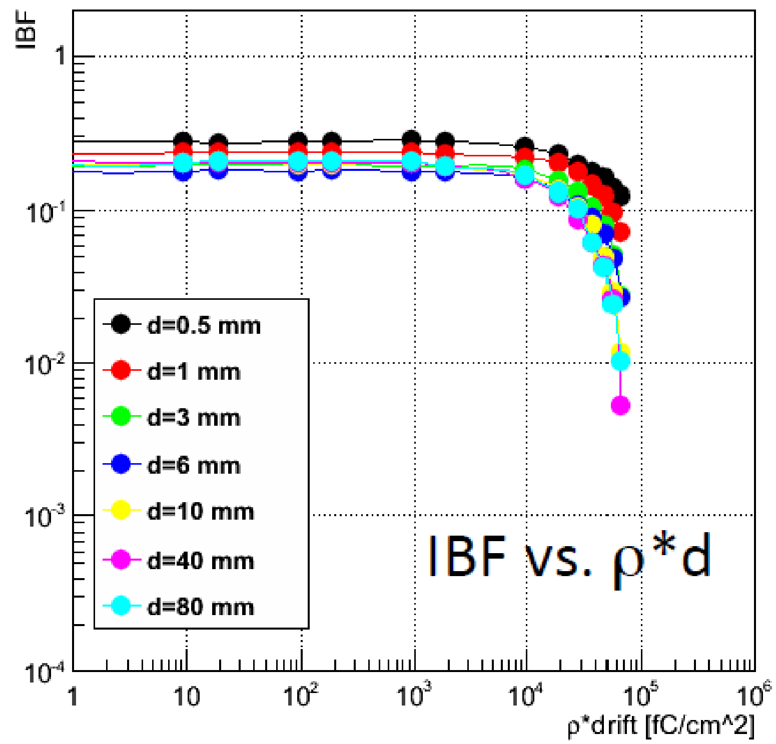
IBF performance (Space Charge)

IBF - Simulation for a single GEM as a function of charge density ρ

IBF - Simulation for a single GEM as a function of charge density ρ*d

Ar/CO_2 (90/10) E_{drift} = 0.4 kV/cm

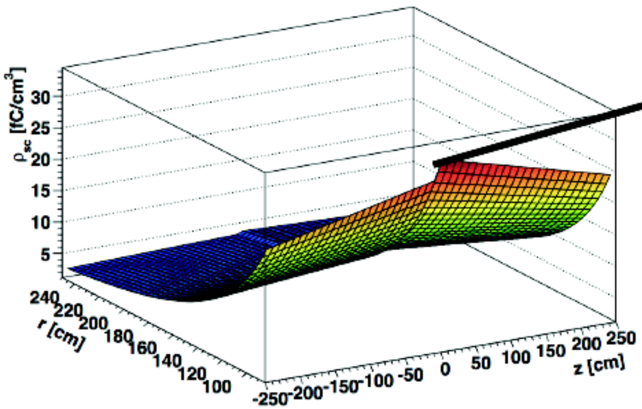


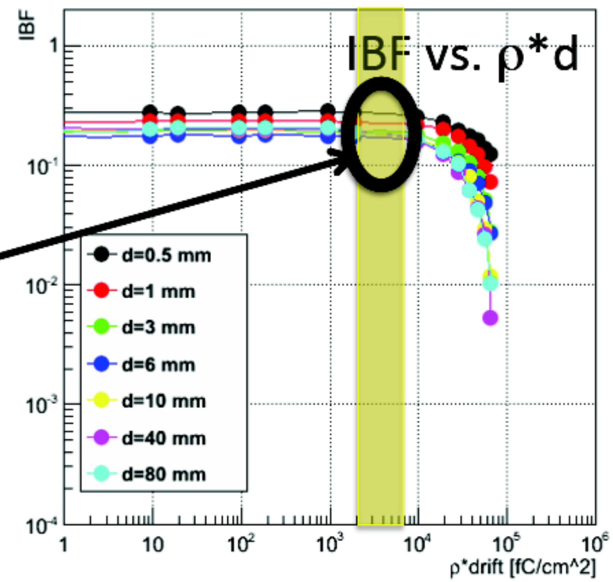


[T. Gunji, University of Tokio(2013)]

Space-charge effects at 50kHz Pb-Pb

- Ion density in the drift
  - ρ_{ion} < 20fC/cm^2 in drift space (in Ne/CO_2, ε=5)
  - ρ_{ion}*d < 5x10^3 [fC/cm^2] < $(\rho^*d)_{onset}$ ~10^4 fC/cm^2
- Ion density in Tr2 (low E_{t2} , 2-3mm)
  - $I_{GEM2\text{-}GEM3}$ ~ 0.46 nA/cm^2
  - ρ_{ion}*d < 10^3 [fC/cm^2]
- No space charge is expected.



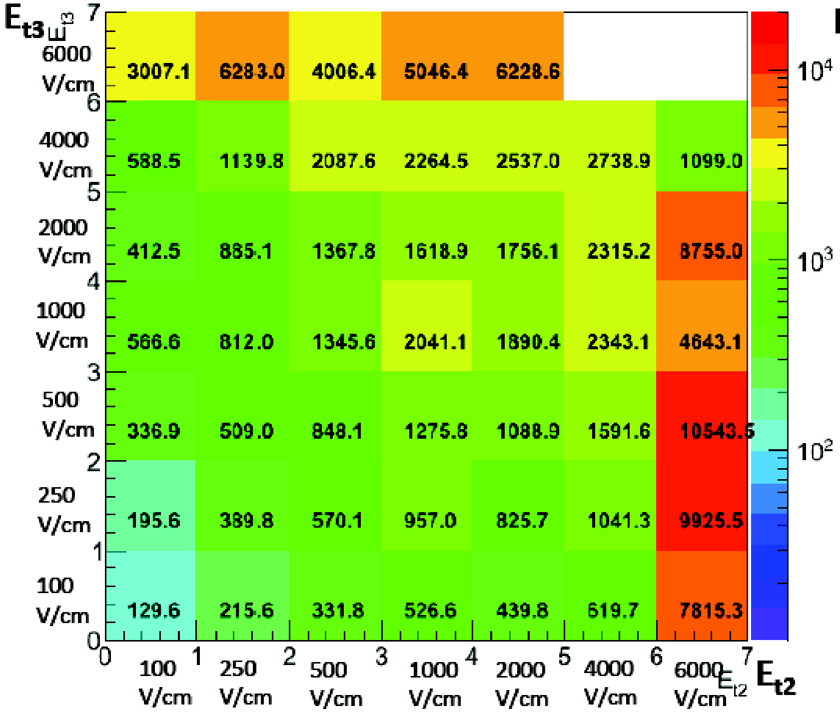


[T. Gunji, University of Tokio(2013)]

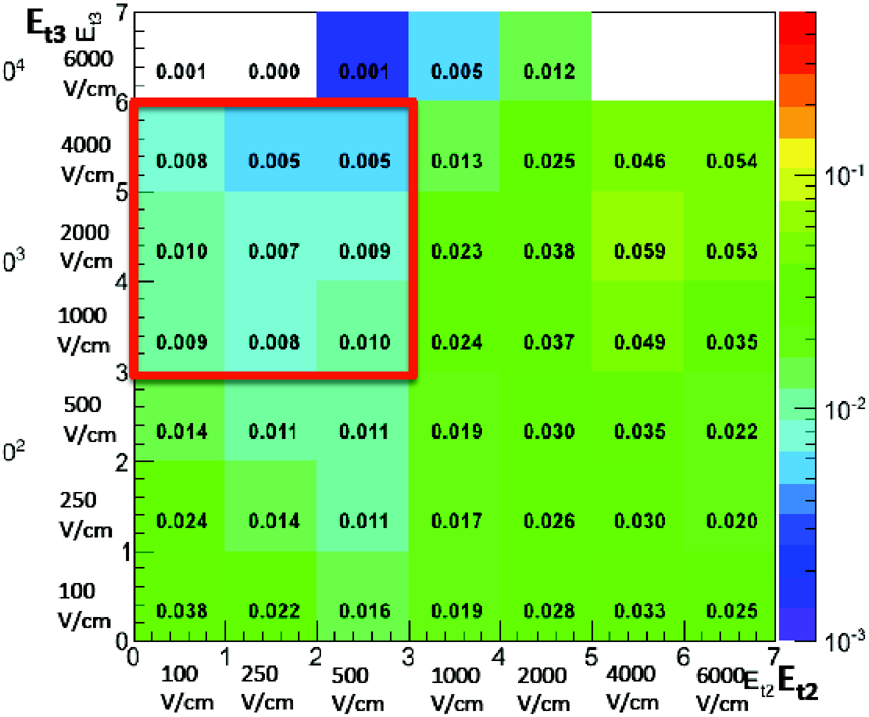
IBF with a 4th GEM

[T. Gunji, University of Tokio(2013)]

Eff. gain in Ne(90)/CO2(10)



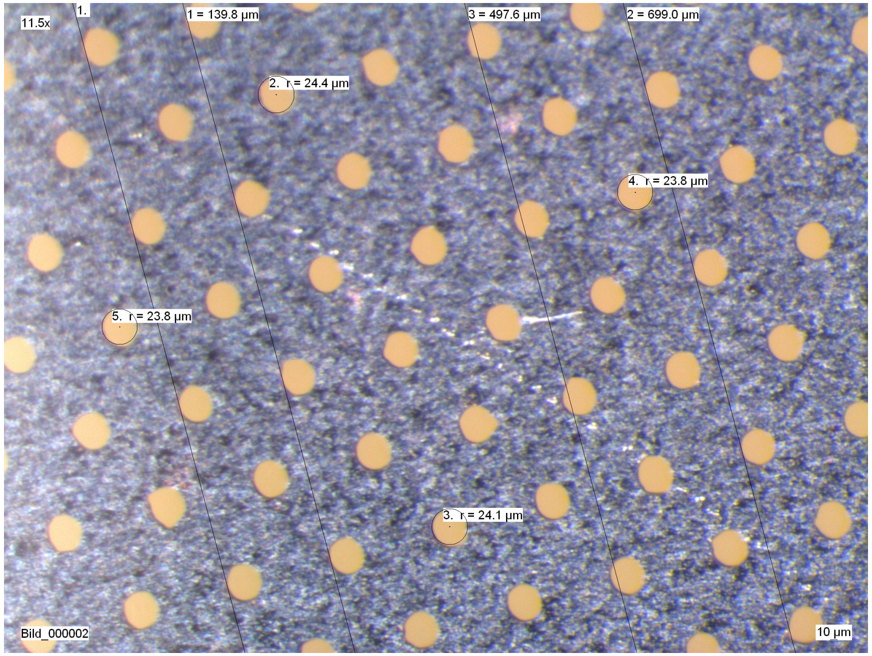
ibf in Ne(90)/CO2(10)



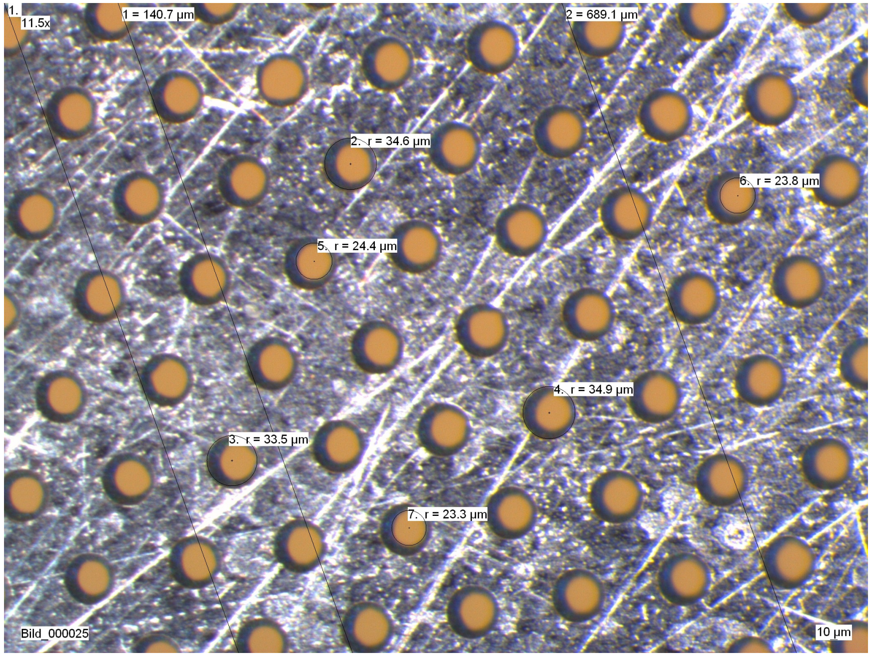
- Scan of the fields (E_{T2},E_{T3}) with 4 GEMs (E_{T1} = 4 kV/cm)
- GEM2 is misaligned w.r.t. To GEM1
- 0.5 % IBF with 4 GEMs

Conical GEMs

Top Side

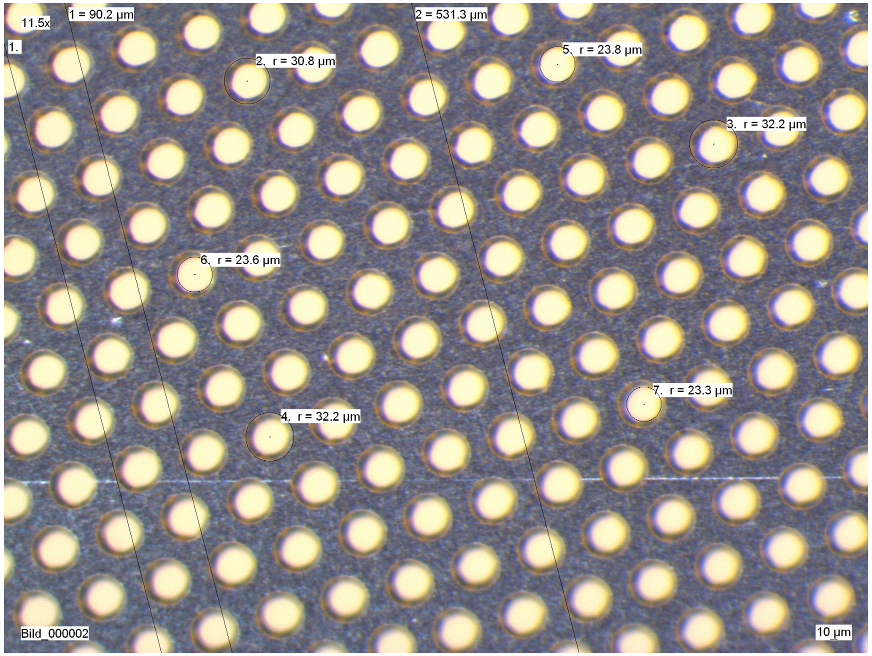


Bottom Side

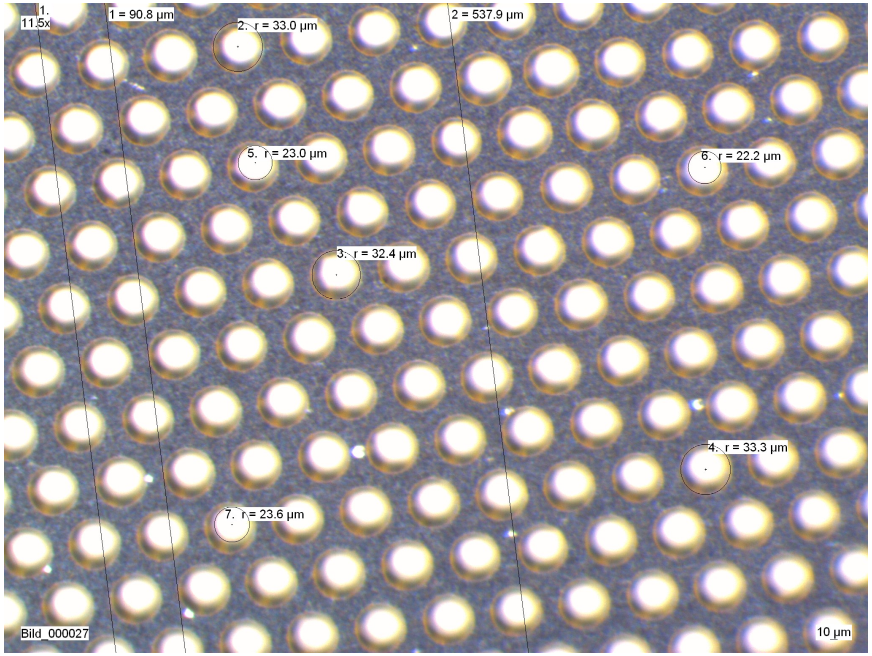


GEMs with different optical transparancy

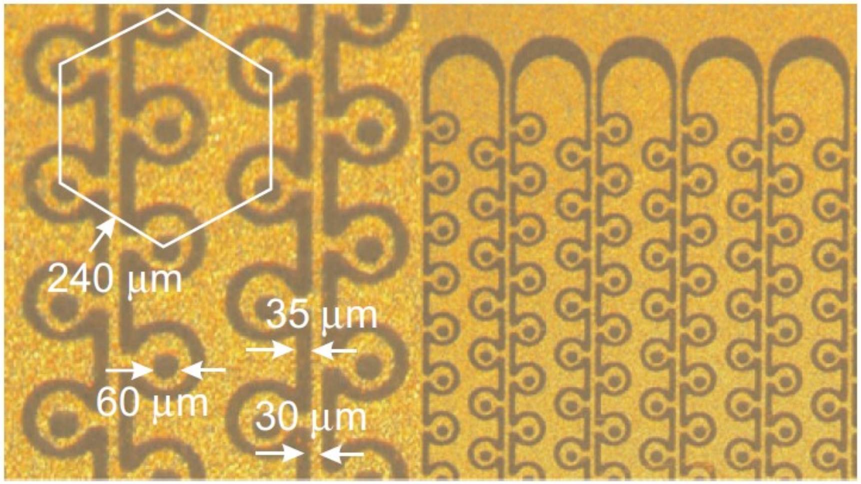
Top Side

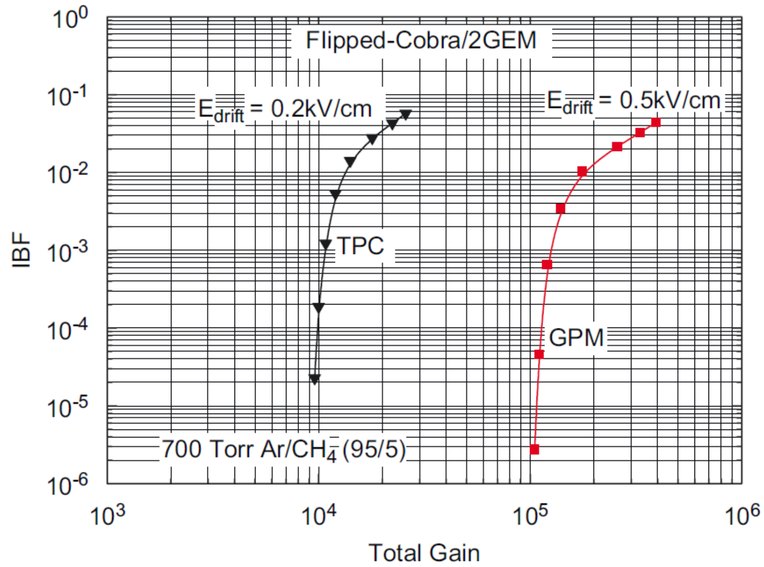


Bottom Side

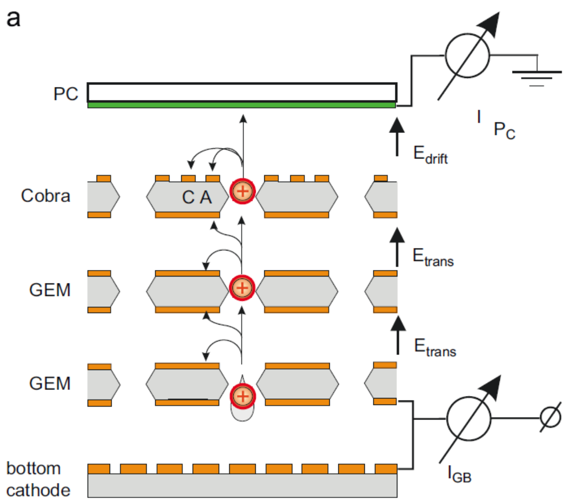


Outlook on further ideas for IB suppression





[A. Lyashenko et al., NIM A 598 (2009) 116–120]



IB = $2.7 \cdot 10^{-5}$!!!

problem of IB completely eliminated !

to be studied: e- transparency !!