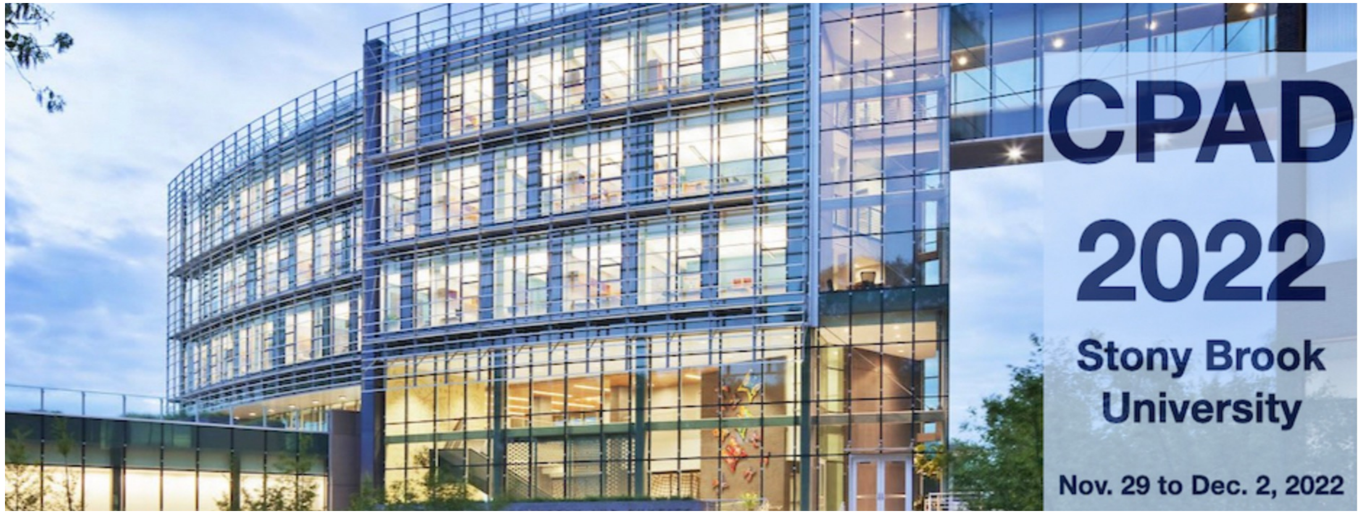


# Ion Back Flow and Energy Resolution study for Quadruple GEM detector

Sourav Tarafdar

Vanderbilt University

# Outline

Introduction

Ion Back Flow (IBF) and Energy Resolution

The Setup at Vanderbilt

IBF and Energy Resolution Results for Ar and Ne gas mixtures

Conclusions and Outlook

# Gas Electron Multipliers (GEM)

- Gaseous amplification device used heavily in Nuclear and Particle Physics experiments since it's discovery in 1990s.
- Fast , radiation hard, good energy resolution, reasonable spatial resolution.
- Recently used in Time Projection Chamber (TPC) in collider experiments (ALICE, sPHENIX, ILC [proposed] )

# Time Projection Chamber

- Proposed in 1978 [ref: D.R. Nygren et al., Phys. Today 31, 46 (1978)
- Advantages :
  - Large acceptance
  - Large active volume
  - Low material budget
  - 3D hits providing extremely good pattern recognition
  - High particle densities
  - Good momentum resolution
  - Particle identification

Limitations (based on Wire chambers):

- Drift distortions due to ion back flow
- Gating → Low trigger rates

Examples :

- STAR TPC
- ALICE TPC (prior to upgrade in 2020)

# Time Projection Chamber

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Limitations :

- Drift distortions due to ion back flow
- Gating → Low trigger rates

→ Eliminated by using exploiting **LOW** Ion Feed Back of micro pattern gas detectors , e.g. upgrade of ALICE TPC, sPHENIX TPC, proposed ILC TPC

# Ion Back Flow and Energy Resolution

- Ion Back Flow (IBF) $\frac{\text{Ions arriving at the cathode}}{\text{Electrons arriving at the anode}}$

In the presentation IBF $= \frac{I_{drift}}{I_{anode}}$

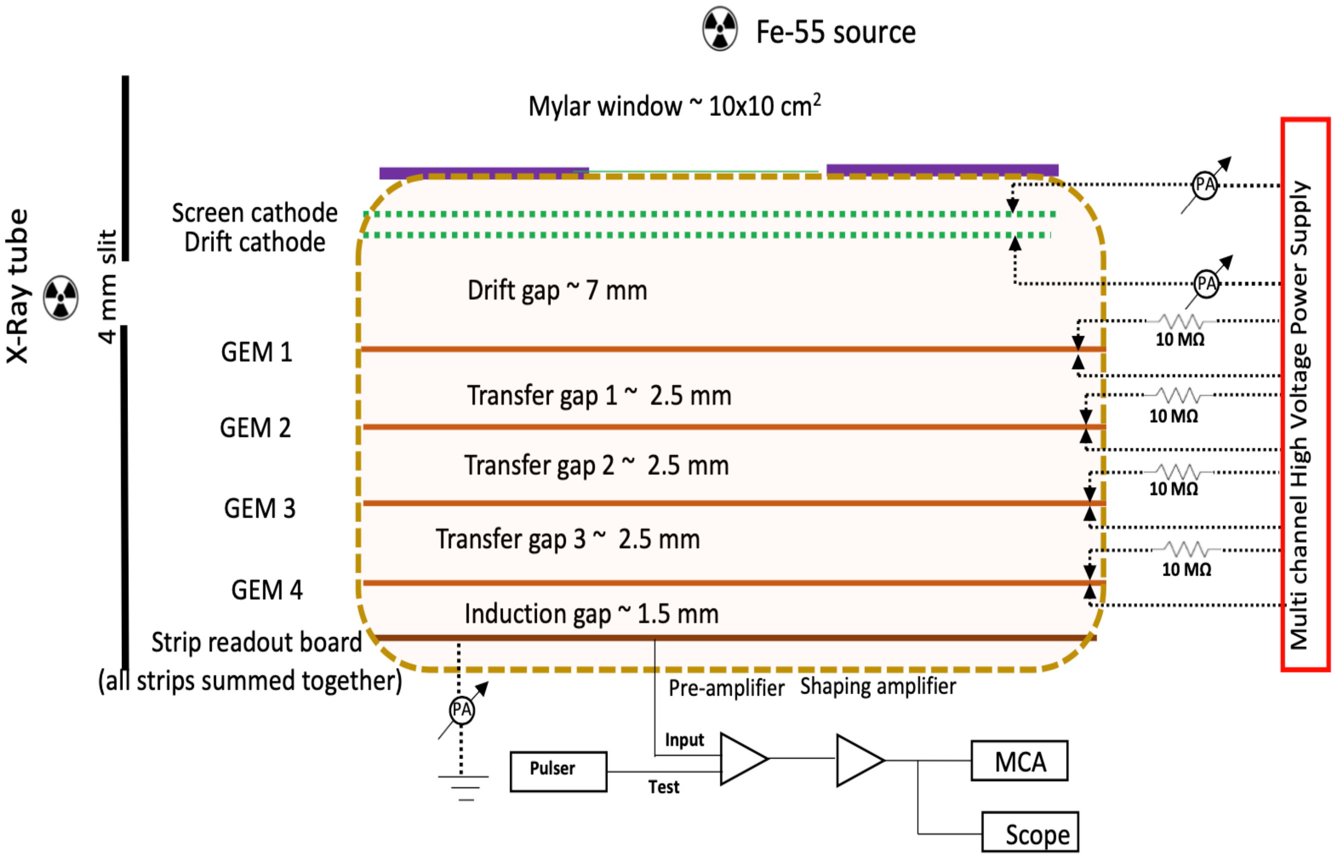
- Contributes to space charge density in drift volume.
- Lower IBF desirable for low space charge density for better tracking.

- Energy resolution

$$\frac{sigma\ of\ gaussian\ fit\ to\ energy\ spectra\ from\ monochromatic\ source}{Mean\ of\ gaussian\ fit}$$

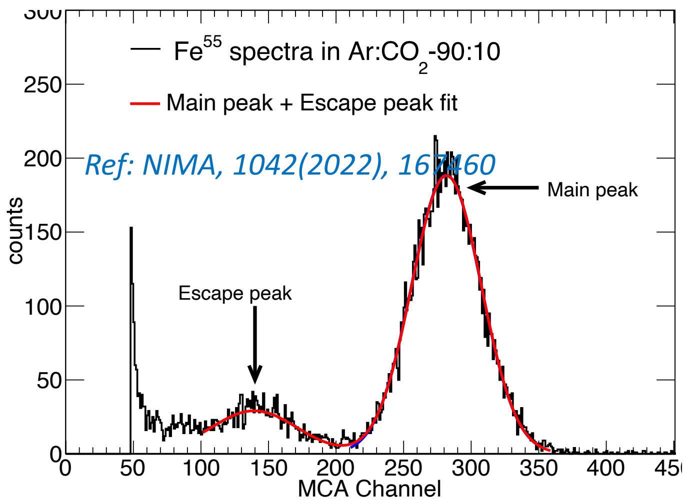
Good energy resolution for better Particle Identification

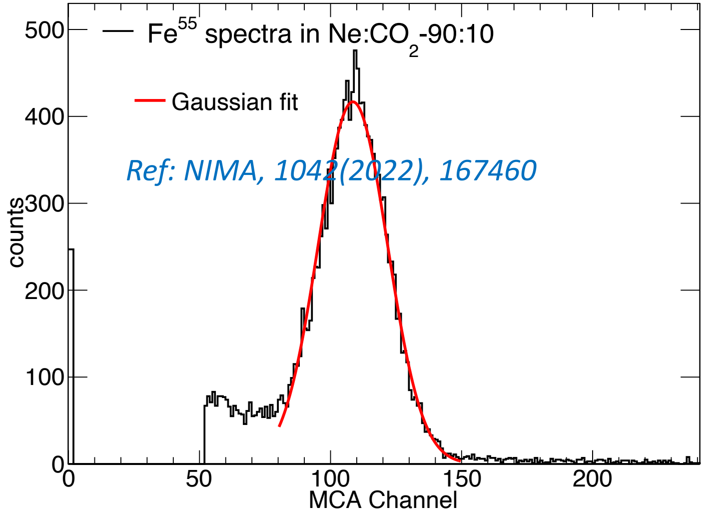
# Experimental setup

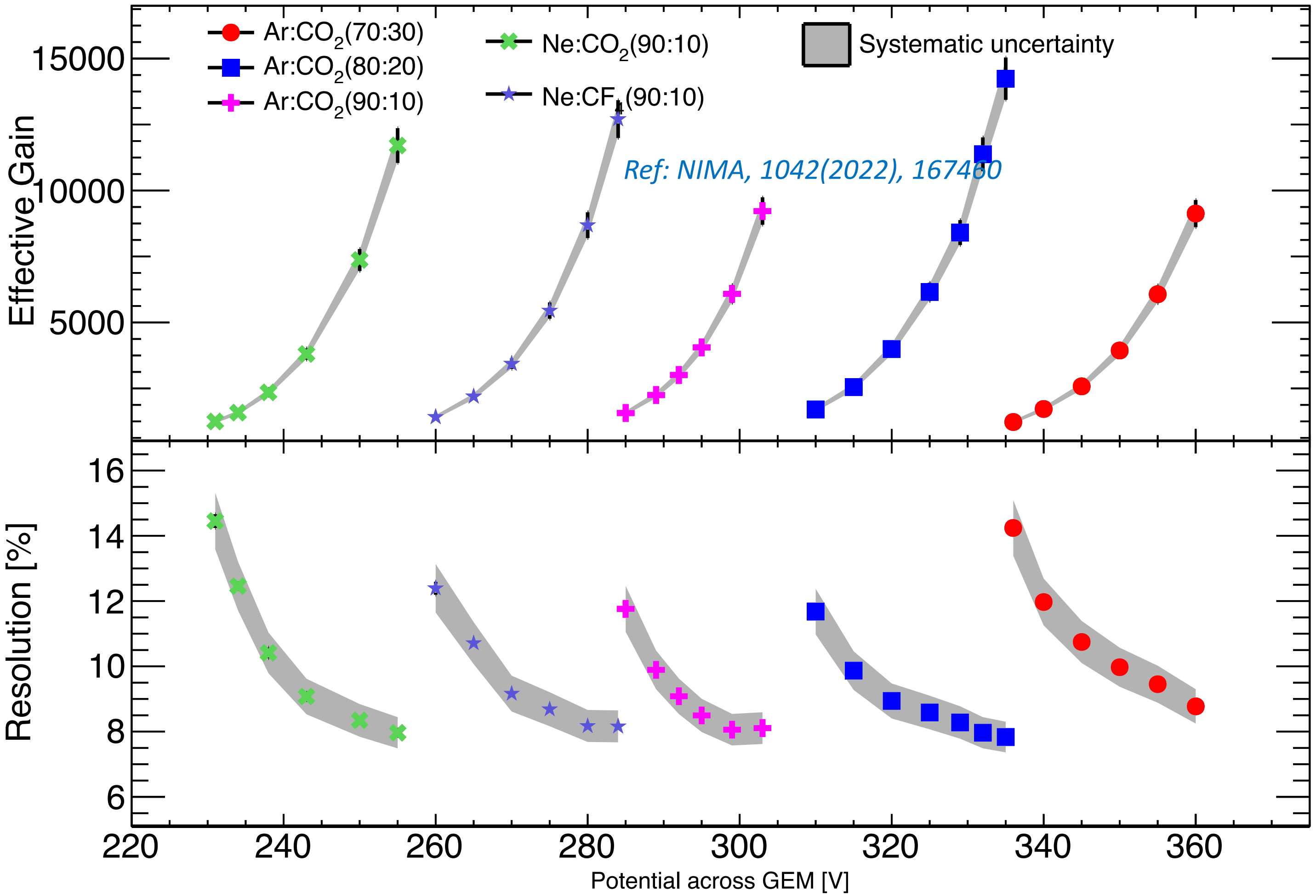



- Standard 10x10 GEMs with 140 microns pitch and 70 microns hole diameter.
- No "intentional" misalignment of hole patterns amongst different layers of GEM foils.
- Various Argon ,Neon, $CO_2$ and $CF_4$ based gas mixtures used for this study.
- Collimated $Fe^{55}$ source used for effective gain and energy resolution measurement while collimated for X-ray tube used for IBF study.
- $Fe^{55}$ spectra taken by summing few strips of readout board together while rest of the strips were at ground.
- Anode current for IBF was measured by summing all the strips of readout board.

# Energy Resolution



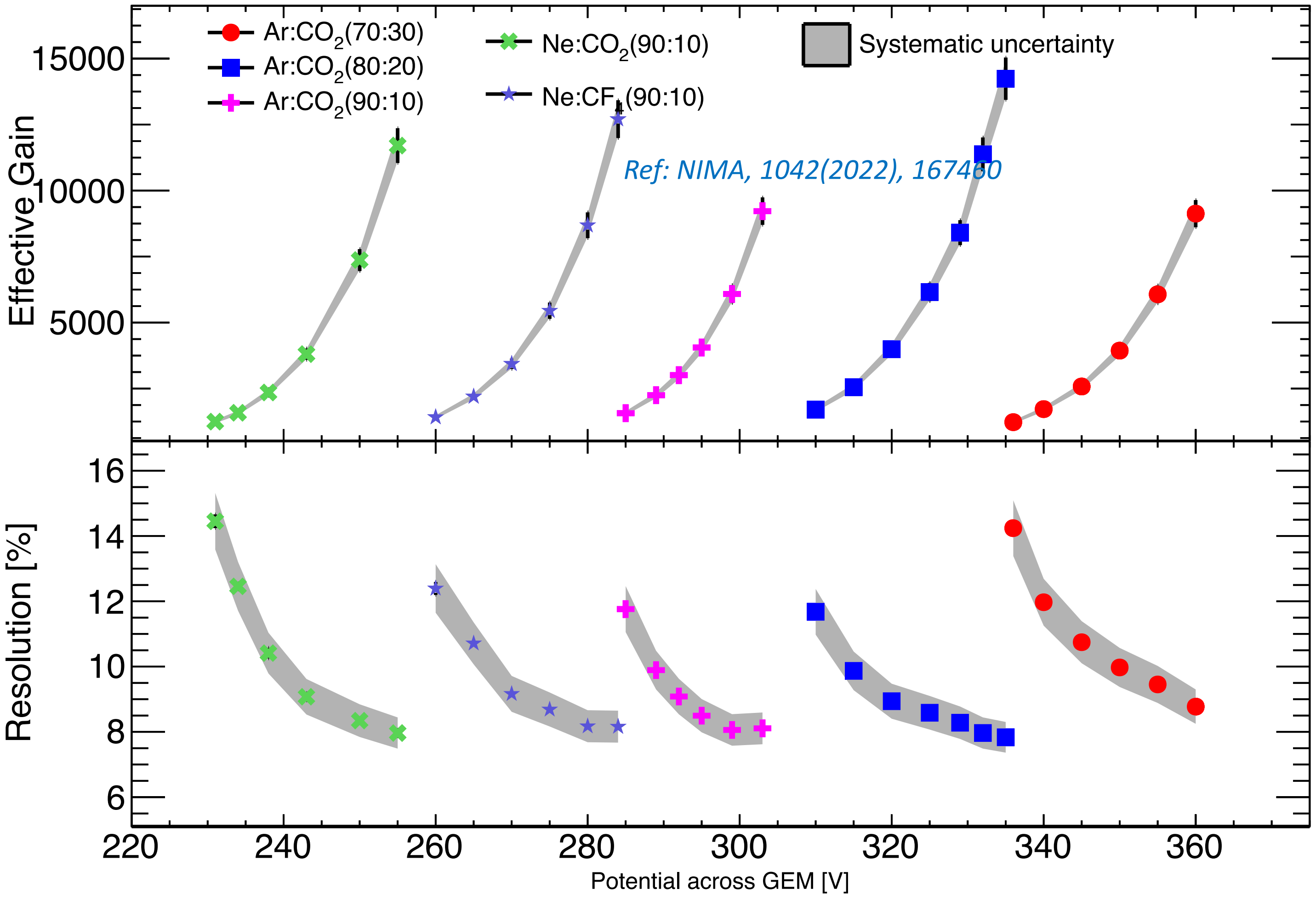



# Energy Resolution

- Charge collected by GEM stack : $Q = N_p e\, G_{eff1} G_{eff2} G_{eff3} G_{eff4}$
- Applying error propagation formula

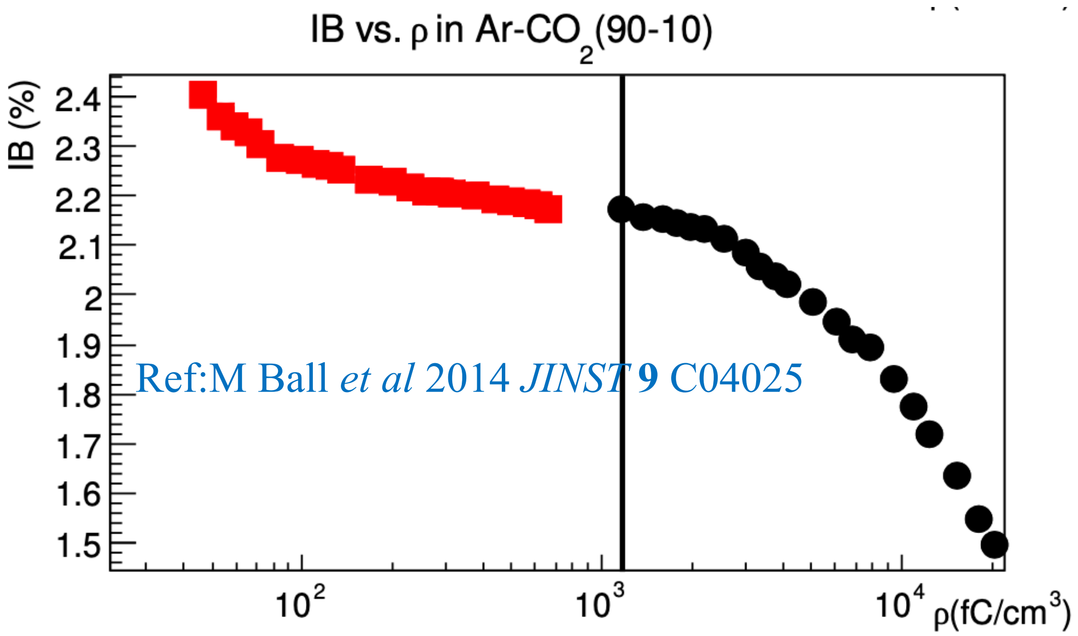
$$\left(\frac{\sigma_Q}{Q}\right)^2 = \left(\frac{\sigma Np}{Np}\right)^2 + \left(\frac{\sigma G1}{G1}\right)^2 + \left(\frac{\sigma G2}{G2}\right)^2 + \left(\frac{\sigma G3}{G3}\right)^2 + \left(\frac{\sigma G4}{G4}\right)^2$$

Energy resolution inversely proportional to gain of GEMs.



# Ion Back Flow Suppression

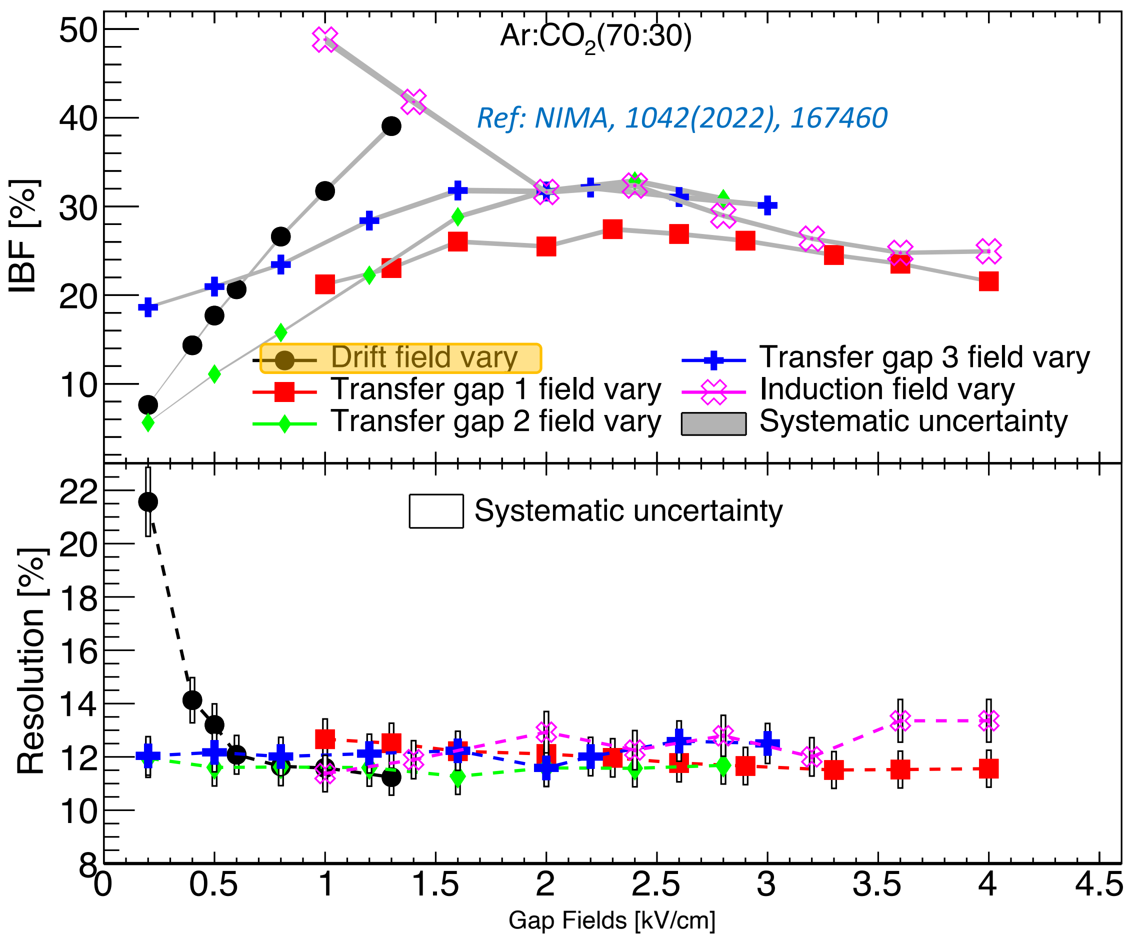
- $ArCO_2$ gas selected for optimization . IBF suppression depends on applied voltage to detector rather on gas parameters.
- Set the effective gain of Quad GEM detector at 2.0E+3 and keep it constant throughout.
- Note the effect of specific gap fields on IBF and also energy resolution while keeping other transfer and induction gap fields at 2 kV/cm.
- Special care need to be taken to set X-ray tube current as space charge density bias IBF measurement.




- Space charge $\rho = \frac{I_{drift}}{A.v_{ion}}$ , where A being the beam spot, $v_{drift}$ being ion drift velocity and $I_{drift}$ measured current at drift cathode. This study had space charge 600-$10^3$ $fC/cm^3$ for X-ray current of 12-15 uA .
- **No bias of space charge density on IBF measurement in this study.**

# Ion Back Flow Suppression :drift field

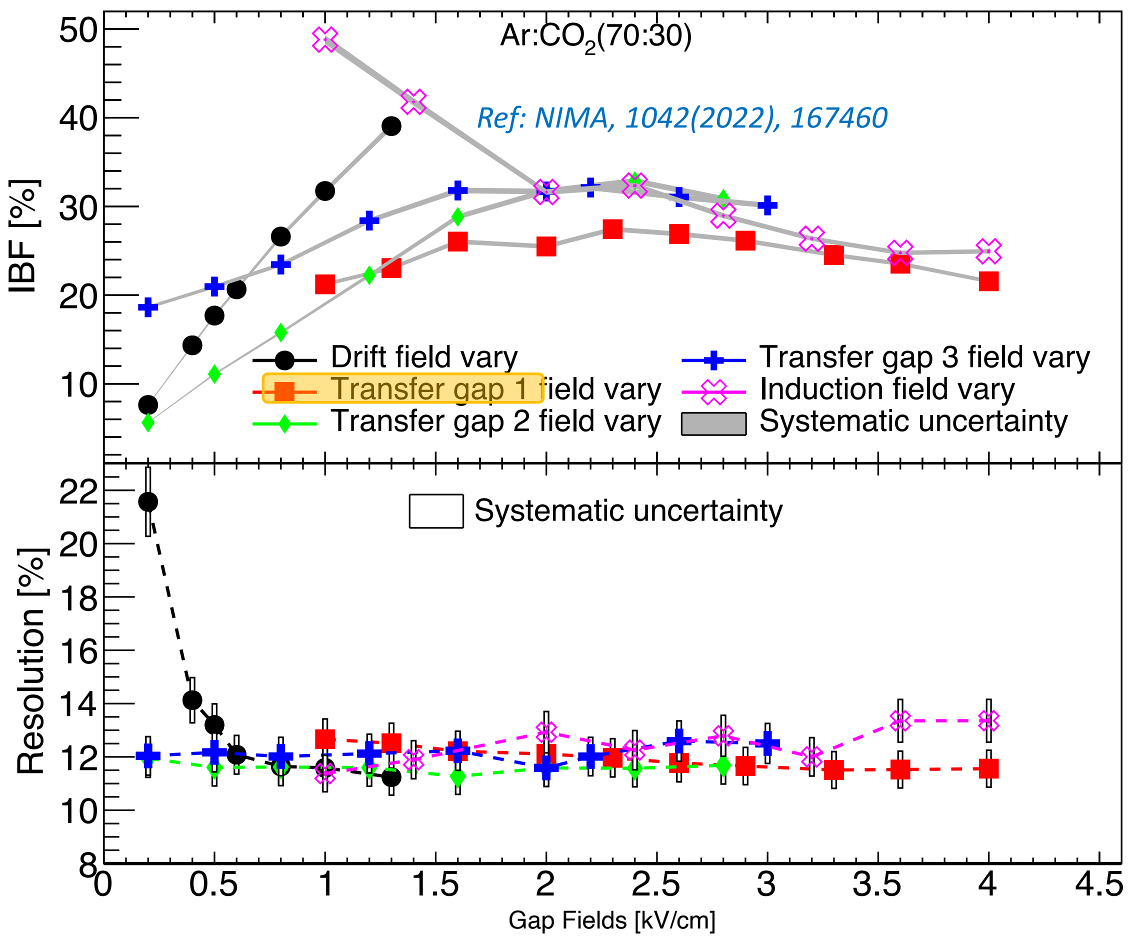
- Increase in drift field , more ions extraction from top GEM resulting in large IBF. Other gap fields were kept at 2 kV/cm.



# Ion Back Flow Suppression :Transfer Gap 1 [TG1] field

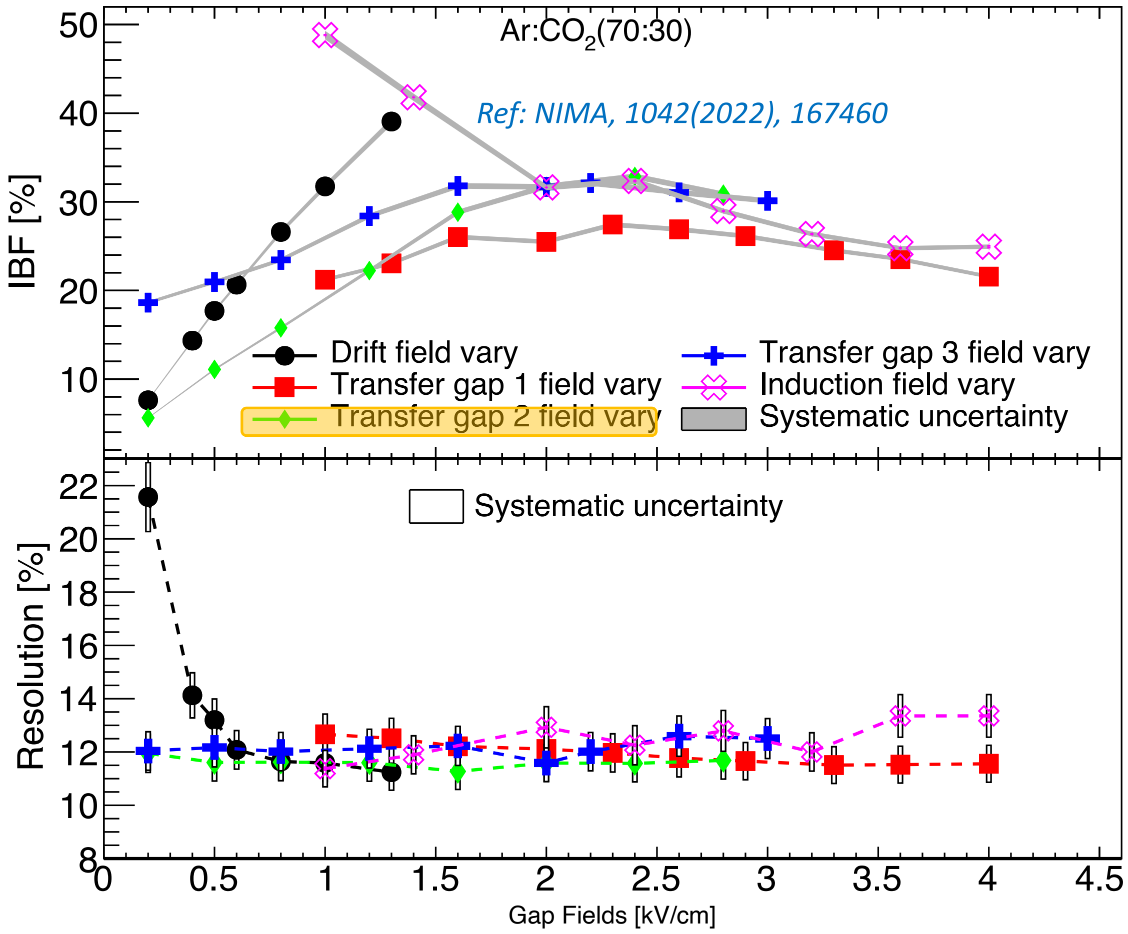
- Increase in drift field , more ions extraction from top GEM resulting in large IBF. Other gap fields were kept at 2 kV/cm.

- More suppression when transfer gap 1 field is larger than drift gap field set at 1 kV/cm.
  - ✓ Can be attributed to bending of fields lines away from GEM holes



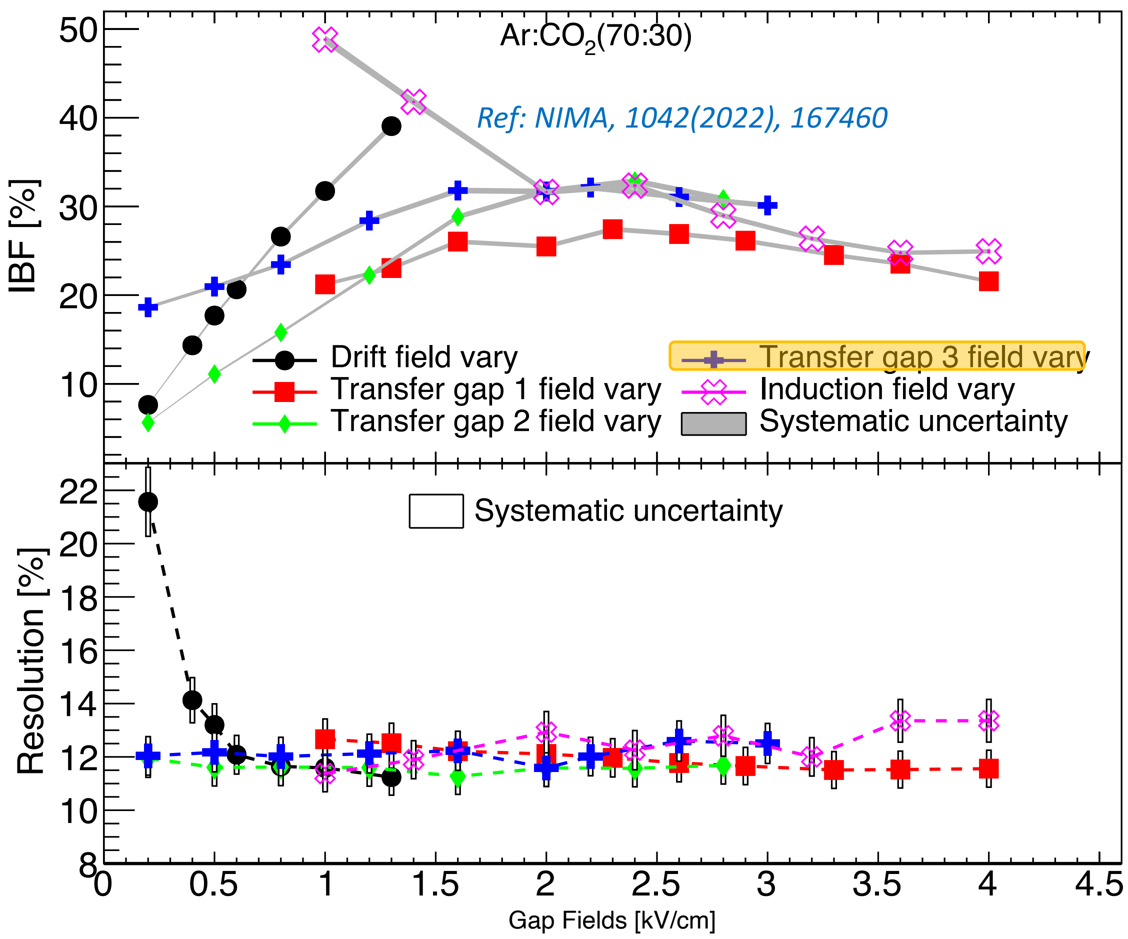
# Ion Back Flow Suppression : Transfer Gap 2 [TG2] field

- Increase in drift field , more ions extraction from top GEM resulting in large IBF. Other gap fields were kept at 2 kV/cm.
- More suppression when transfer gap 1 field is larger than drift gap field set at 1 kV/cm.
  - ✓ Can be attributed to bending of fields lines away from GEM holes
- Lower transfer gap 2 field than other gap fields set at 2 kV/cm causes more IBF suppression.
  - ✓ Can be attributed to less extraction of ions from bottom two GEM foils and gaps



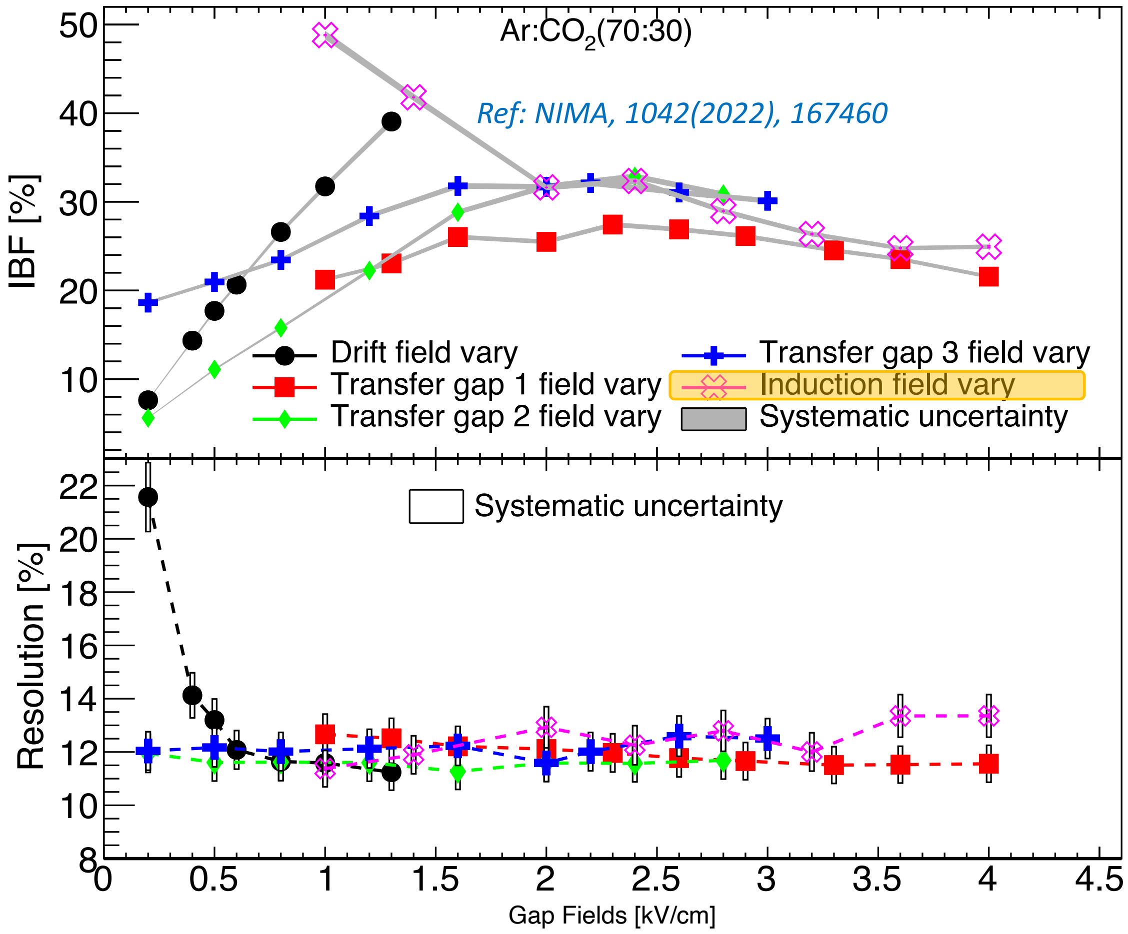
# Ion Back Flow Suppression : Transfer Gap 3 [TG3] field

- Increase in drift field , more ions extraction from top GEM resulting in large IBF. Other gap fields were kept at 2 kV/cm.
- More suppression when transfer gap 1 field is larger than drift gap field set at 1 kV/cm.
  - ✓ Can be attributed to bending of fields lines away from GEM holes
- Lower transfer gap 2 field than other gap fields set at 2 kV/cm causes more IBF suppression.
  - ✓ Can be attributed to less extraction of ions from bottom two GEM foils and gaps
- Low transfer gap 3 field compared to other gap fields also results in more IBF suppression.
  - ✓ Can be attributed to less extraction of ions from last GEM foil which contributes to maximum back flowing ions.



# Ion Back Flow Suppression : Induction field

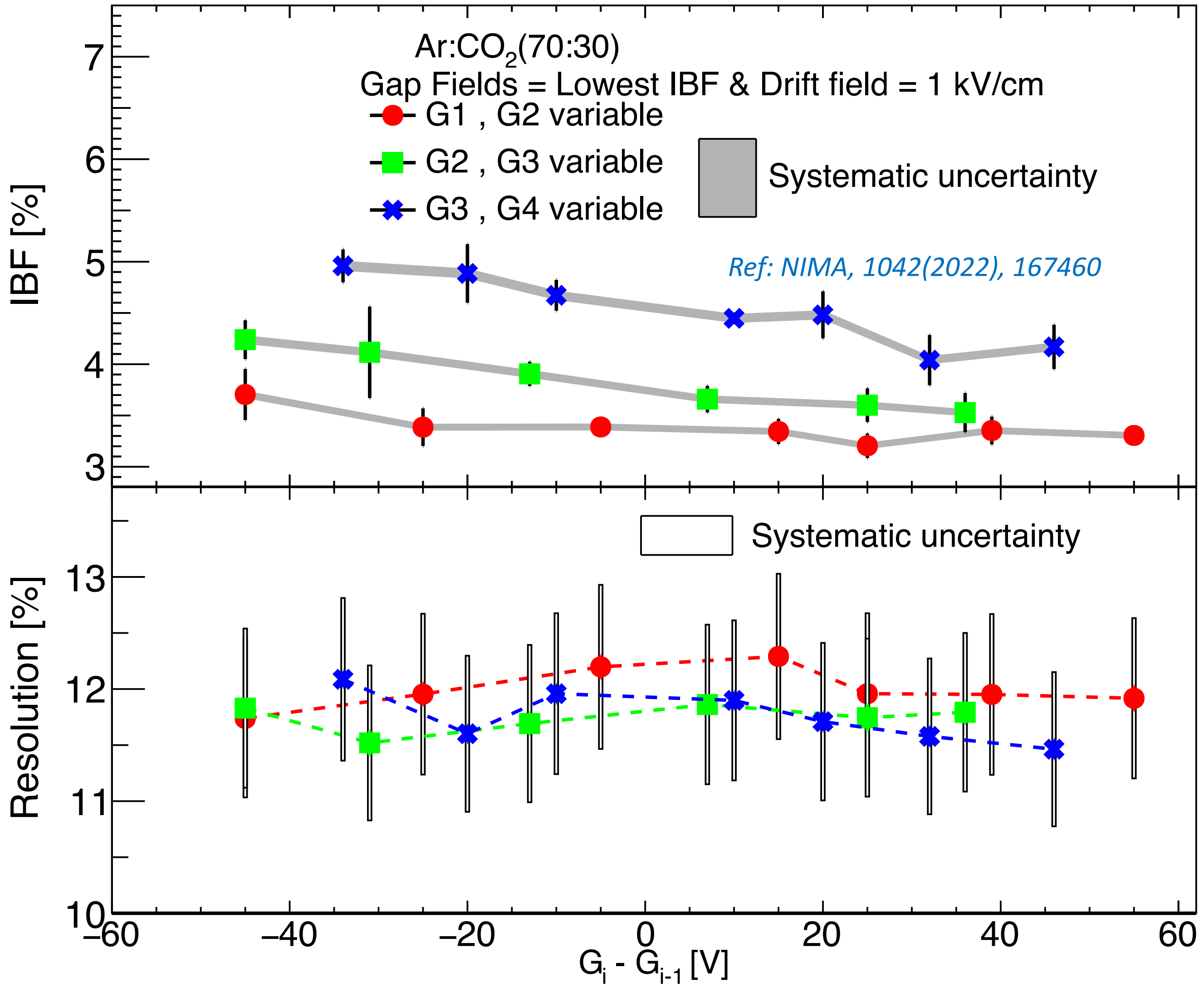
- Increase in drift field , more ions extraction from top GEM resulting in large IBF. Other gap fields were kept at 2 kV/cm.
- More suppression when transfer gap 1 field is larger than drift gap field set at 1 kV/cm.
  - ✓ Can be attributed to bending of fields lines away from GEM holes
- Lower transfer gap 2 field than other gap fields set at 2 kV/cm causes more IBF suppression.
  - ✓ Can be attributed to less extraction of ions from bottom two GEM foils and gaps
- Low transfer gap 3 field compared to other gap fields also results in more IBF suppression.
  - ✓ Can be attributed to less extraction of ions from last GEM foil which contributes to maximum back flowing ions.




- Larger induction gap field more IBF suppression due to bending to field lines at bottom of last GEM away from the holes

# Ion Back Flow Suppression : Asymmetric GEM voltages

- Asymmetric gain from each GEM causes suppression in
  IBF.
- Transfer gap and induction gap fields were set at lowest IBF configuration i.e.
  TG1 and induction gap field >> TG2 and TG3 fields
- Two of the GEM foils were kept at same potential while other two were varied keeping the effective gain at 2.0E+03.
- IBF is suppressed when a GEM layer is operated at higher gain compared to previous GEM layer. i.e.
  GEM1 < GEM 2 < GEM 3 < GEM 4
- Not optimal operating point in terms of stability !

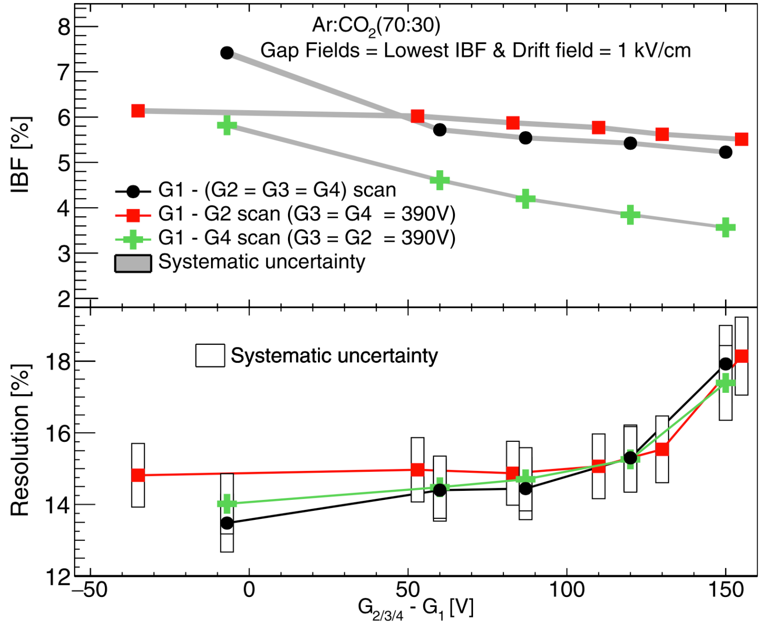


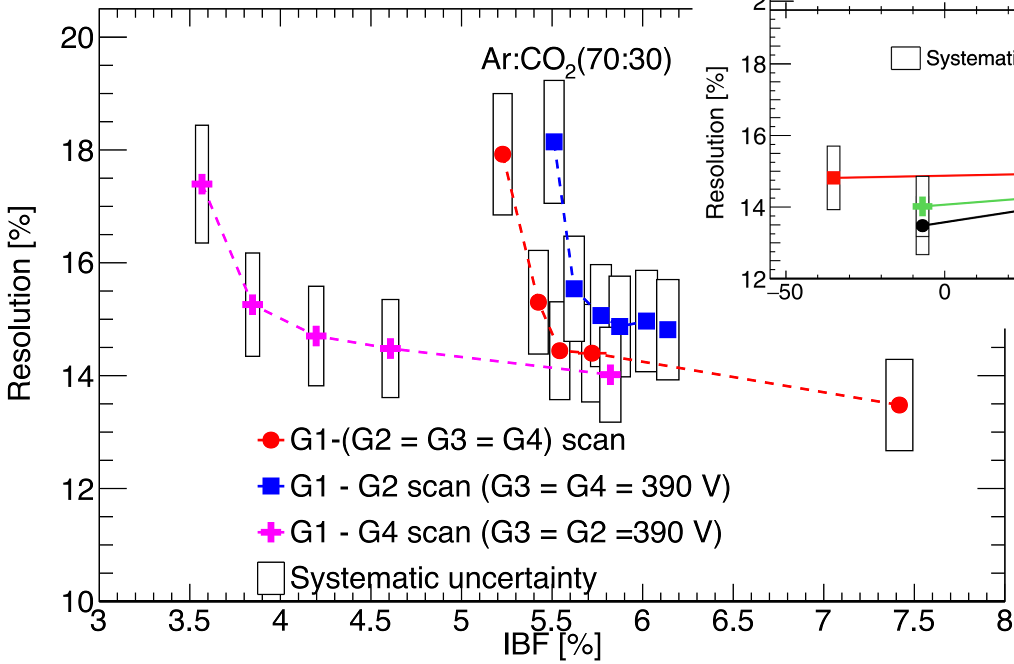
# Ion Back Flow and Energy resolution

$$\left(\frac{\sigma_Q}{Q}\right)^2 = \frac{F}{N_P} + \frac{1}{N_P}\left(\frac{\sigma_{A1}}{G_{eff,1}}\right)^2 + \frac{1}{N_P G_{eff,1}}\left(\frac{\sigma_{A2}}{G_{eff,2}}\right)^2 + \frac{1}{N_P G_{eff,1} G_{eff,2}}\left(\frac{\sigma_{A3}}{G_{eff,3}}\right)^2 + \frac{1}{N_P G_{eff,1} G_{eff,2} G_{eff,3}}\left(\frac{\sigma_{A4}}{G_{eff,4}}\right)^2$$

- $\boldsymbol{\sigma}_{Ai(i=1,2,3,4)}$ is standard deviation in gain from each GEM , F is Fano factor from fluctuation in primaries, $G_{eff,i(i=1,2,3,4)}$ is effective gain from each GEM foil .
- Energy resolution depends on gain from each GEM foil. Larger the gain better the energy resolution
- Mostly dependent on the gain from top GEM . Larger gain from top GEM corresponds to larger IBF !
- IBF and Energy resolution are anti-correlated.

*Ref: NIMA, 1042(2022), 167460*



# IBF and Energy resolution for various gas mixtures

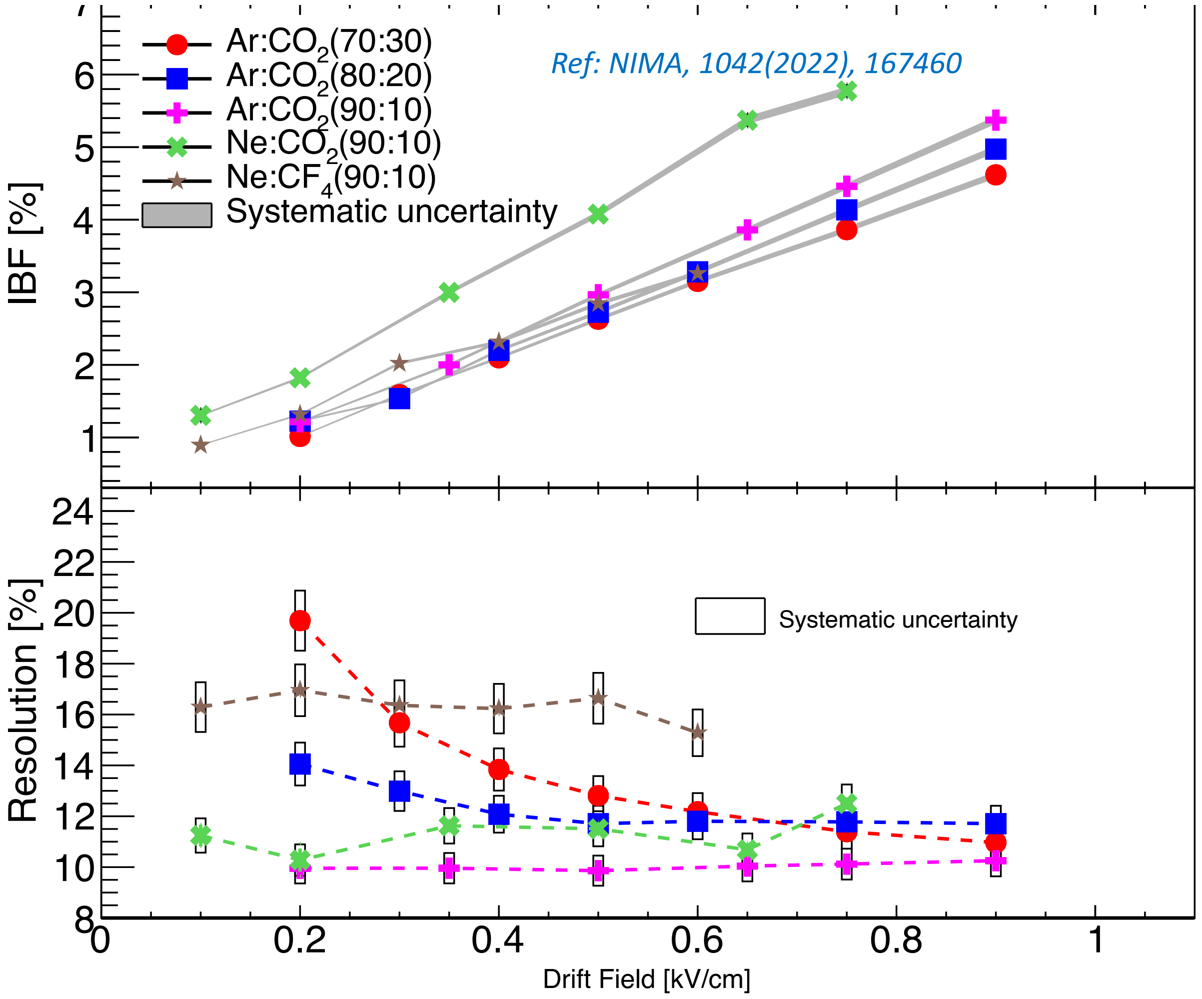
- Transfer gap and Induction gap fields along with GEM foil voltages were set at lowest IBF configuration i.e.

  TG1 and induction gap field >> TG2 and TG3 fields

  GEM 1 < GEM 2 < GEM 3 < GEM 4

while maintaining effective gain of 2.0E+03.

- Both IBF and energy resolution were measured by varying drift field.
- IBF suppression independent of gas mixture.
- Energy resolution is mostly affected in $ArCO_2$ gas with higher content in $CO_2$ .
- $NeCO_2$(90:10) shows slightly higher IBF than other gas mixtures . Reported by several other groups as well.



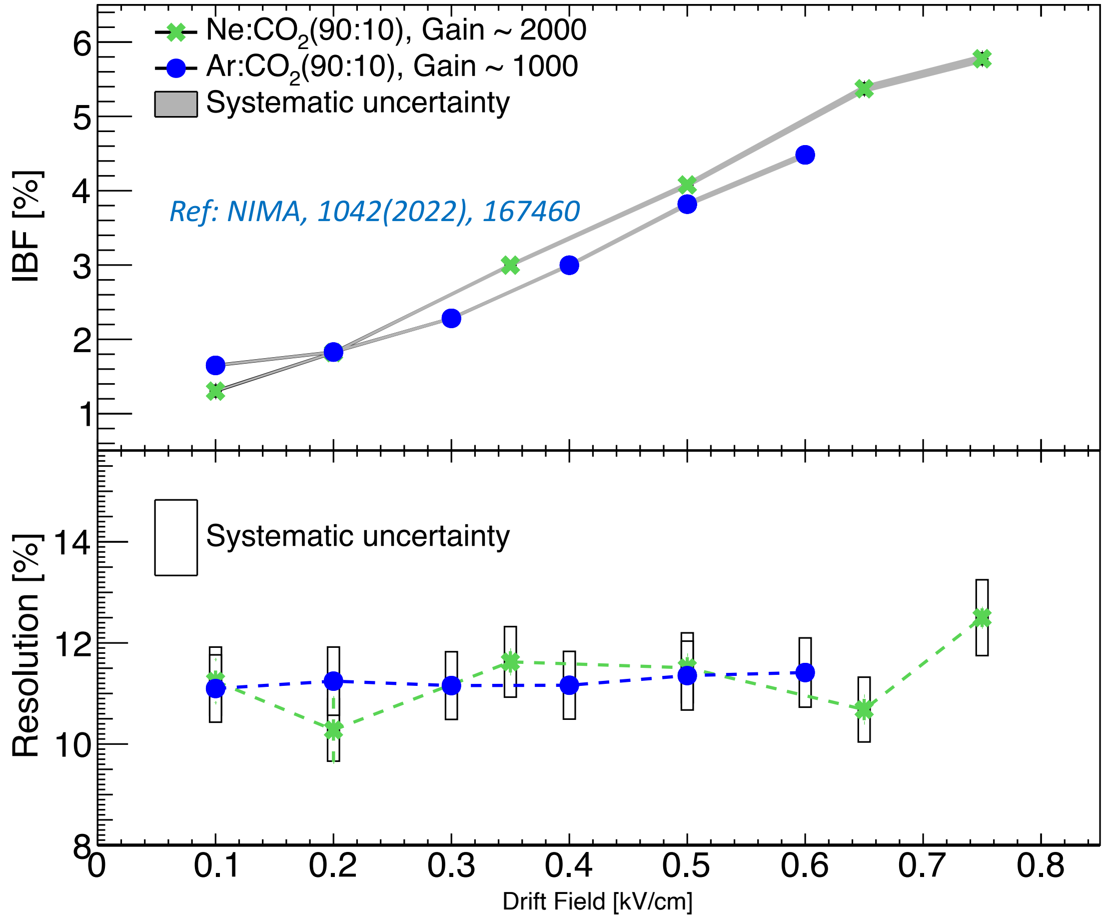
# IBF and space charge density

- Same level of IBF suppression in various gas mixture but what about space charge ?
- Operate under same S/N for different gas mixtures.
- Primary ionization in Ar almost twice as Ne for MIP.
- Operate detector at half the effective gain with $ArCO_2$(90:10) compared to $NeCO_2$(90:10)
- Space charge density as a function of gas parameters

$$\rho = \frac{(\varepsilon + 1)\times n_{prim}}{v_{ion}}$$

**ε** = IBF x Gain and corresponds to number of backflowing ions per incoming electrons

$n_{prim}$ being number of primaries and $v_{ion}$ being ion velocity



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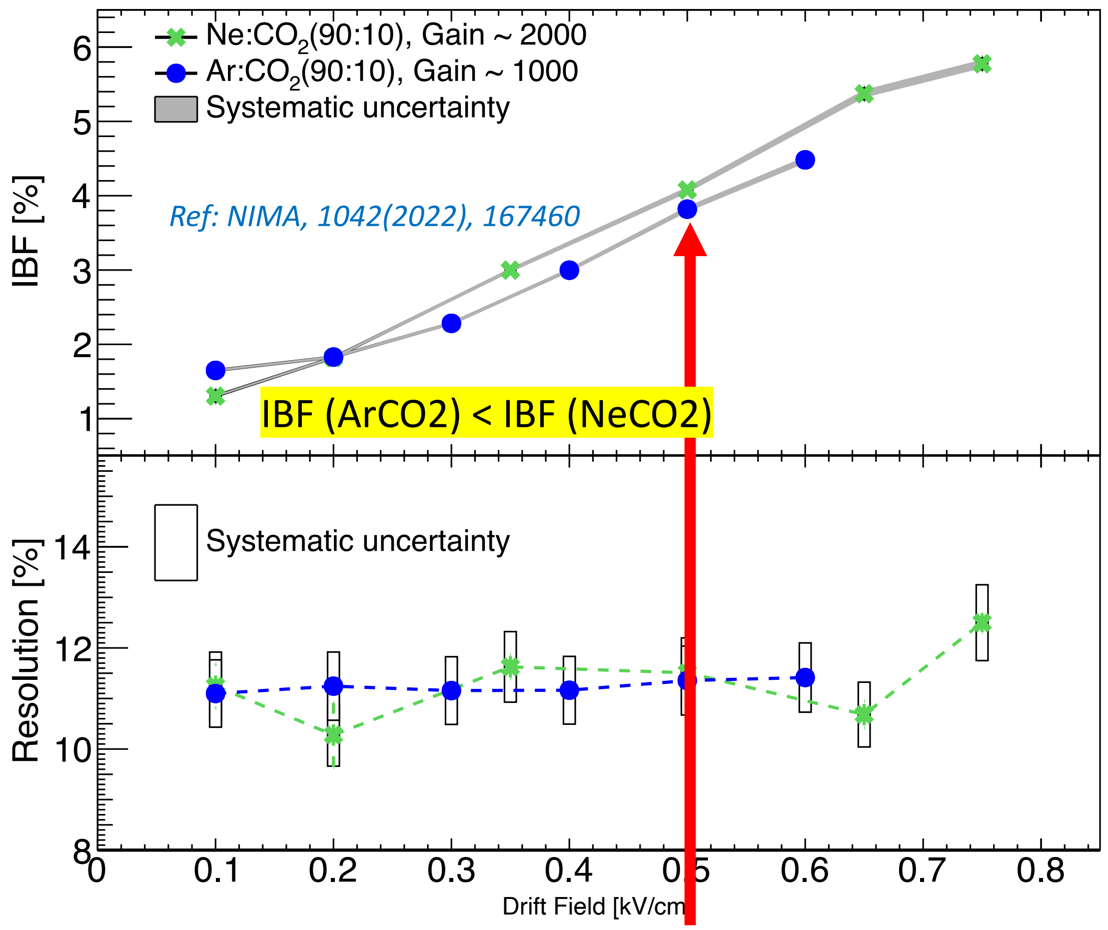



$v_{ion}$ for Ne ~ 3 x $v_{ion}$ for Ar

**ρ**($Ar:CO_2$-90:10) = 2 X **ρ**($Ne:CO_2$-90:10)

Neon based gas mixtures preferred for TPC

# Conclusion

- IBF suppression and corresponding energy resolutions in quadruple GEM detector using GEM foils of 140 um pitch and 70 um hole diameter are shown .

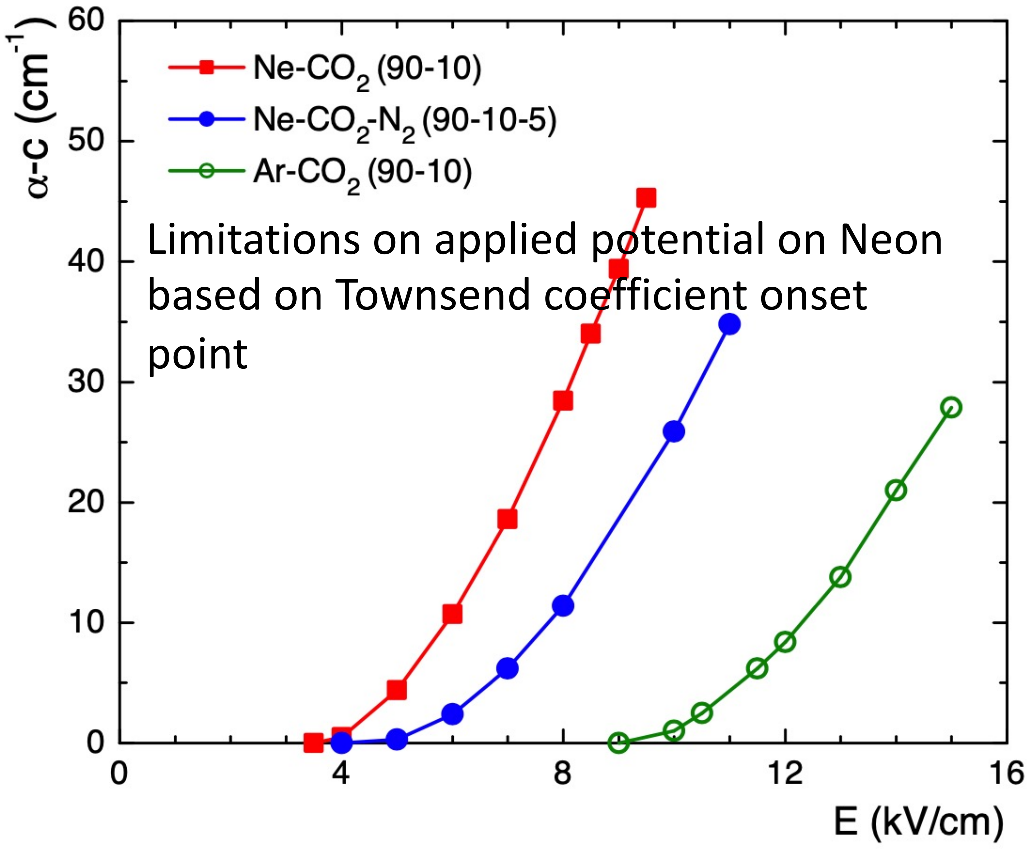
- IBF and energy resolutions are anti-correlated.

- Lowest IBF mode operation, where last GEM foil has largest gain is not optimal in terms of operational stability.

- Even though IBF suppression in $NeCO_2$(90:10) is slightly lower than $ArCO_2$ (90:10) under same S/N ratio but the space charge density is a factor of 2 lower.

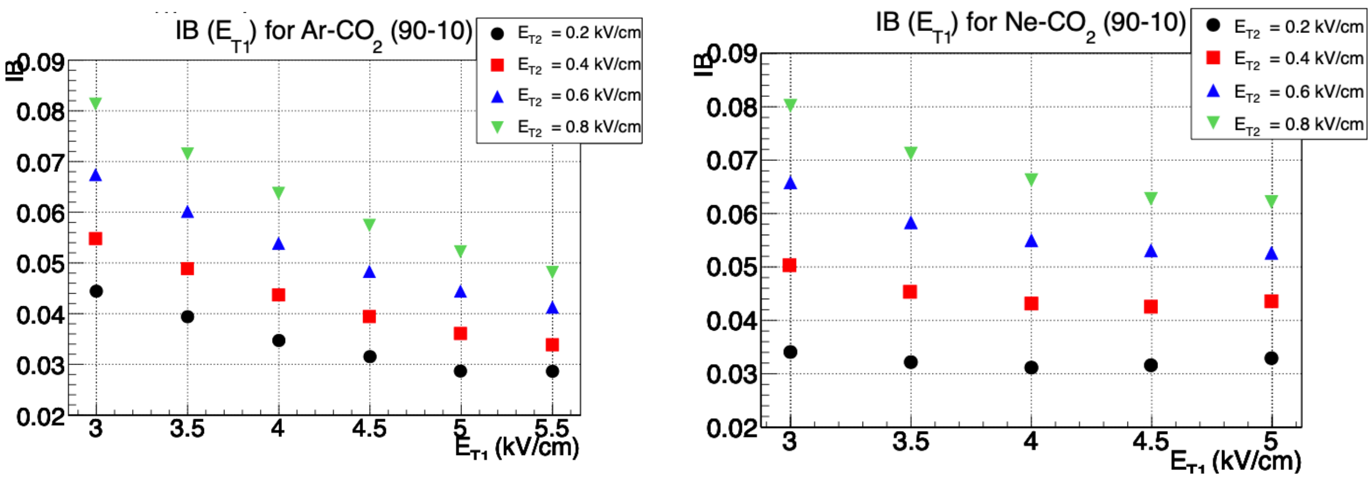
# Backup

# Backup



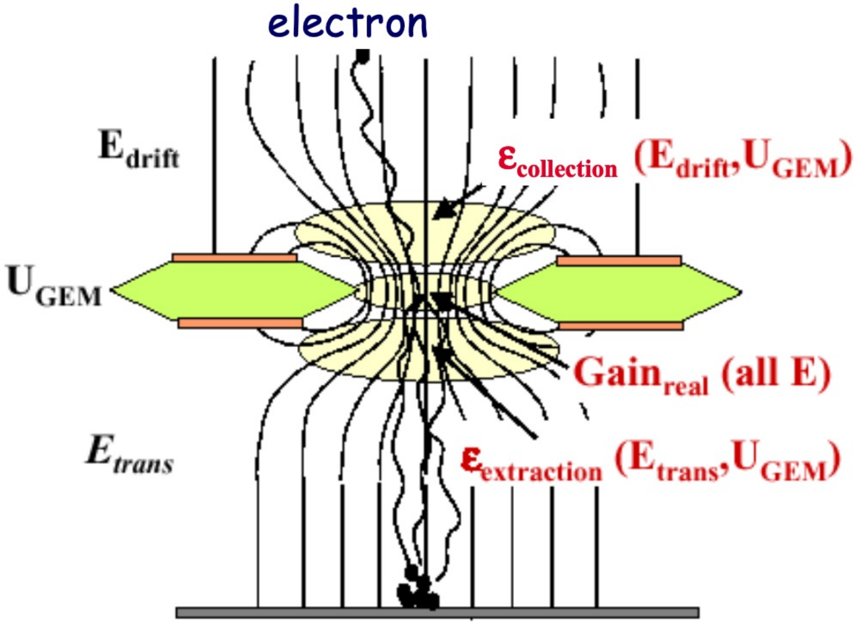

Limitations on applied potential on Neon based on Townsend coefficient onset point

Ref:M Ball *et al* 2014 *JINST* **9** C04025

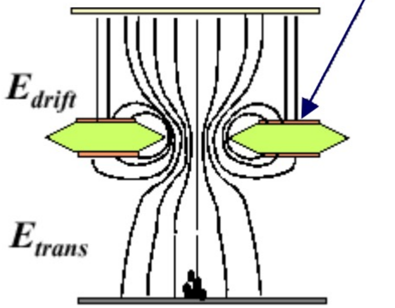



Ne-CO2 (90:10) IBF > ArCO2 (90:10) from triple GEM detector at lowest IBF configuration

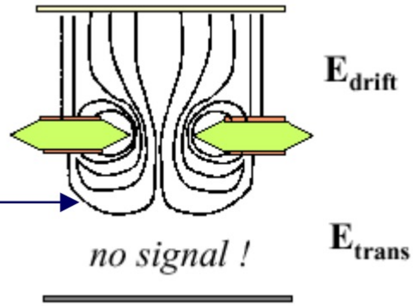
# Backup




Collection efficiency
decrease at high drift field
values due to defocusing of field
lines above the GEM




Extraction efficiency
decrease at low transfer fields values
due to a worst electron extraction
capability from the lower side of the
GEM




F. Murtas LNF/INFN

Frascati 28 November 2002

Same scenarios with back flowing ions