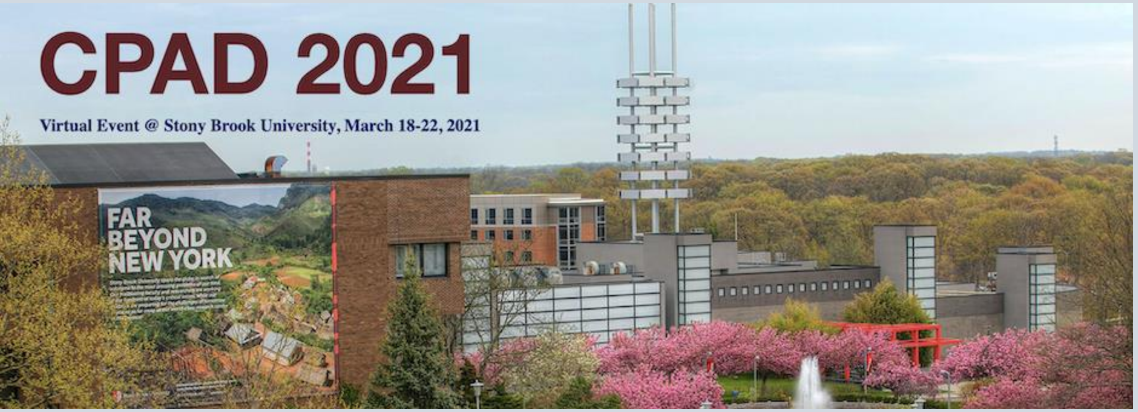
Options for gain elements and gas mixtures in a high rate EIC Time Projection Chamber



BOB AZMOUN[1], CAITLIN BEATTIE[2], JOHN W. HARRIS[2], ALEXANDER KISELEV[1], RICHARD MAJKA[3], NIKOLAI SMIRNOV[2], CRAIG WOODY[1]

[1]PHYSICS DEPARTMENT, BNL

[2]PHYSICS DEPARTMENT, YALE UNIV.

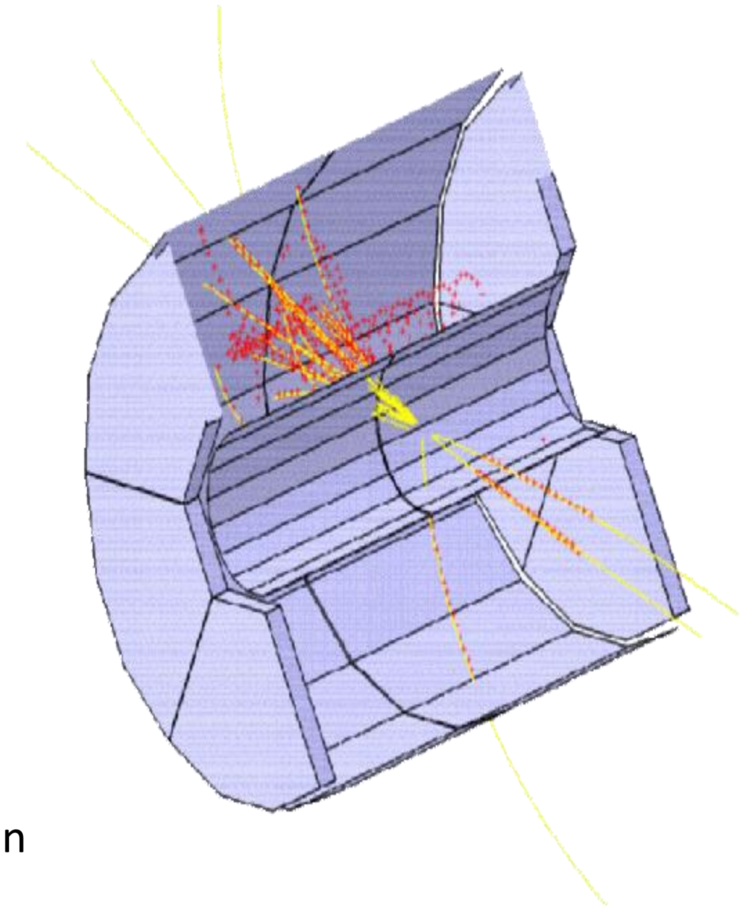
[3]PHYSICS DEPARTMENT, YALE UNIV., DECEASED

Yale University

BROOKHAVEN NATIONAL LABORATORY

Motivation

- ➢ A Time Projection Chamber (TPC) is a good choice for central tracking at EIC
  - Low mass, large-continuous active volume
  - Precision tracking
  - Pattern recognition
  - Momentum reconstruction
  - Particle identification
- **Requirements:**
  - Operate at and acquire data for collision rates as high as 500 kHz
  - Continuous readout option should be considered (active gating grid is not possible, but perhaps a passive (bi-polar) one is)
  - Operate in magnetic field in the range 1.5 - 3 T
  - Limited space: r ~ 80 cm, z ~ +/-100cm inside a SC solenoidal magnet.
- **Main challenge**: Space Charge Distortions of the E-field will be the main degradation factor for tracking and dE/dx performance (due to high interaction rate at ultimate EIC luminosity, possibly high backgrounds, and high demands on precision)
- **Crucial EIC TPC parameters** : ion back flow (IBF), energy resolution (dE/dX), electron and ion drift speed, electron diffusion (in E- and B- fields), gain structure, and stability



EIC TPC Gas Mixture Options

- One TPC gas option that satisfies most criteria is a mixture of Ne + CF_4
  - sPHENIX TPC selected this mixture: low diffusion (for high spatial resolution) and high ion mobility
    (Ar provides greater primary ionization and may be preferable in terms of energy resolution)

Three issues:

- Strong CF_4 electron absorption resonance
- Possible transfer of ion charge: $Ne^+ + CF_4 \rightarrow Ne + CF_3^+ + F$ [1]
- Both components are transparent to UV, and can be a source of scintillation causing photon feedback

Solution:

- Add a “cool” gas component with an energy of ionization less than that for CF_4 [2]
- Add methane (CH_4) component
  - permits transfers of positive charge from the Ne^+ ions to CH_4^+
  - does not degrade diffusion, or the electron and ion drift velocities
  - known to be an effective quencher to stabilize gain process
  - for safety reasons the level of CH_4 is generally kept at or below 10%

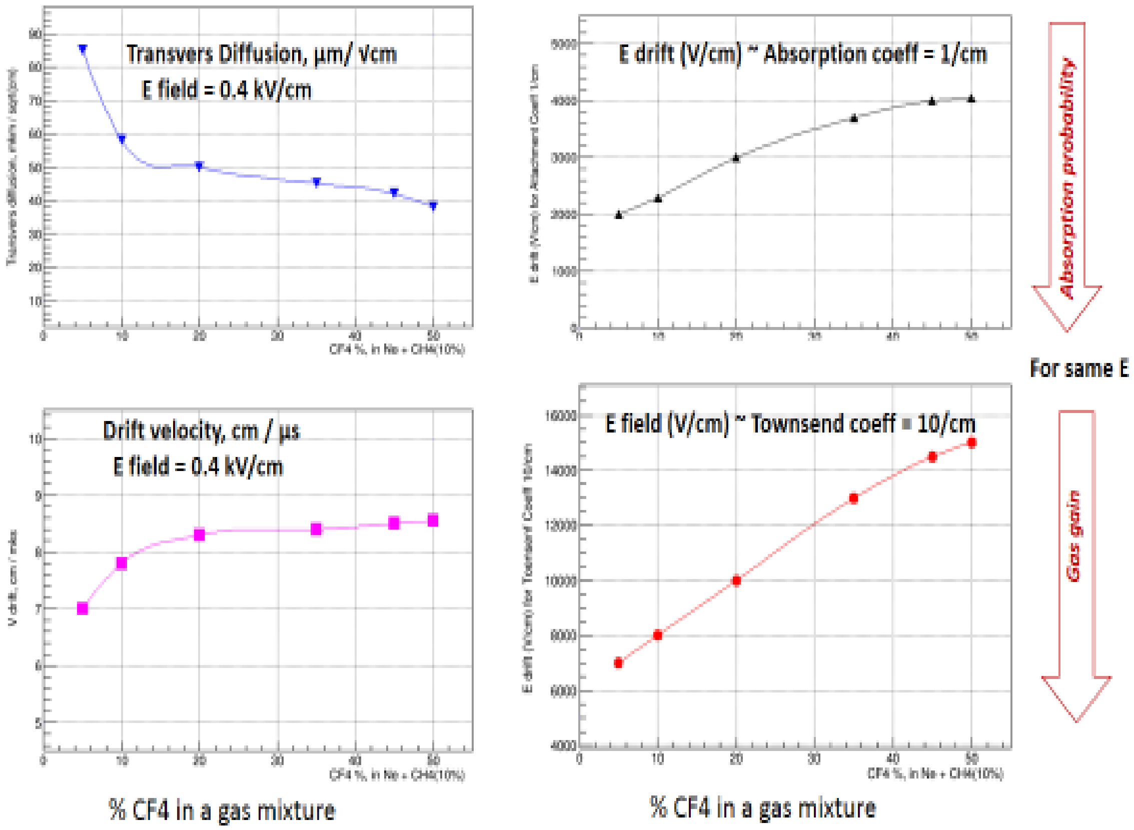
[1] D.J.G. Marque et al, “Experimental ion mobility measurements in Ne-CF4,” 2019 JINST 14 P04015.
[2] J. Va’vra, “Wire Chamber Gases,” SLAC-PUB-5793.

Percentage of CF_4

- Initial R&D question: what percentage of CF_4 used in a Ne + CH_4 (10%) gas mixture?

- GARFIELD simulation results to consider [3]:
  - CF_4 percentages have a small impact on transverse diffusion and electron drift speed
  - Though, ion mobility increases by a factor 2 for gas mixtures with 10% CF_4 compared to 50%
  - Electron absorption probability decreases with increasing CF_4 percentage (ie, better energy resolution at higher %)
  - The magnitude of the electric field should be increased to maintain the same gas gain with increasing CF_4 percentages (ie, lower gain at higher %)
  - Thus, the gas gain (Townsend coefficient) and energy resolution (electron attachment probability) are the main trade-off

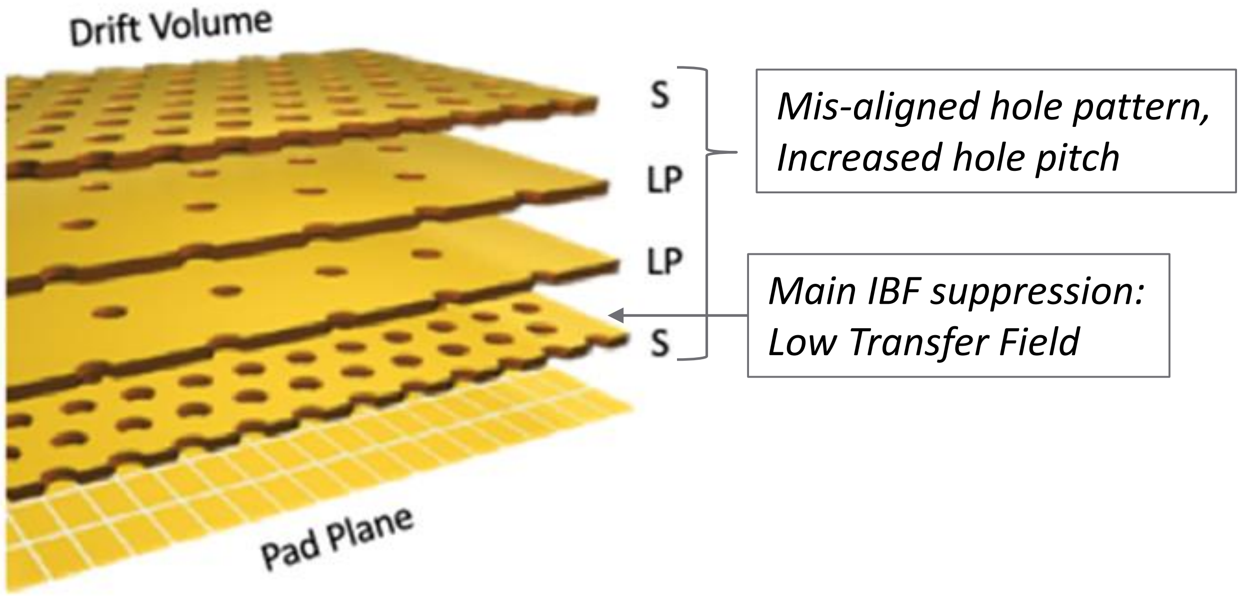
GARFIRLD: Ne + CF4(5 – 50%) + CH4(10%), B field = 1.5T ***)

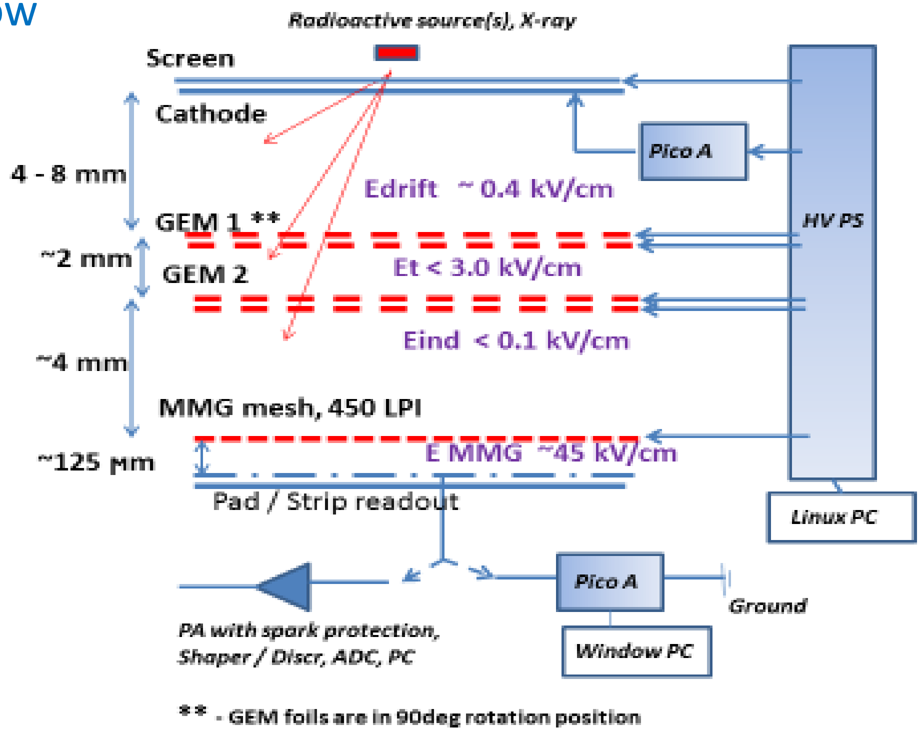


[3] Prakhar Garg, private communication, http://skipper.physics.sunysb.edu/~prakhar/tpc/HTML_Gases/split.html

Gain Structure Options to Minimize IBF

➢ Layered MPGD amplification stages provide a means to control the flow of charge by tuning the electric field in several drift gaps





- A 4GEM ion blocking scheme was realized by the ALICE TPC upgrade project using 4 unique GEM foils
- The sPHENIX TPC will utilize a similar concept with some essential modifications
  - Top GEM Gain =1 (~Zero fluctuations, $\Delta E/E$ undamaged)
  - Sacrifice some electron transparency at lower gain stages to improve IBF

- A novel hybrid MMG + 2GEM scheme was proposed by the Yale University team as an alternative to the ALICE concept
  - Fully exploits large $E_{drift}/E_{induction}$ field ratio of MMG to strongly suppress IBF
  - Small GEM gain (low IBF): GEMs effectively transfer primary charge and simultaneously act as effective IBF shield

IBF Comparison w/ ALICE Gas Mixture

- MMG is the primary gas gain element with a maximum field ratio between the amplification and induction gaps, resulting in a MMG IBF value of ~1% or lower

- The voltage on the top GEM assures a continuous drift field in the TPC volume and provides small effective gain to preserve electron statistics for good energy resolution

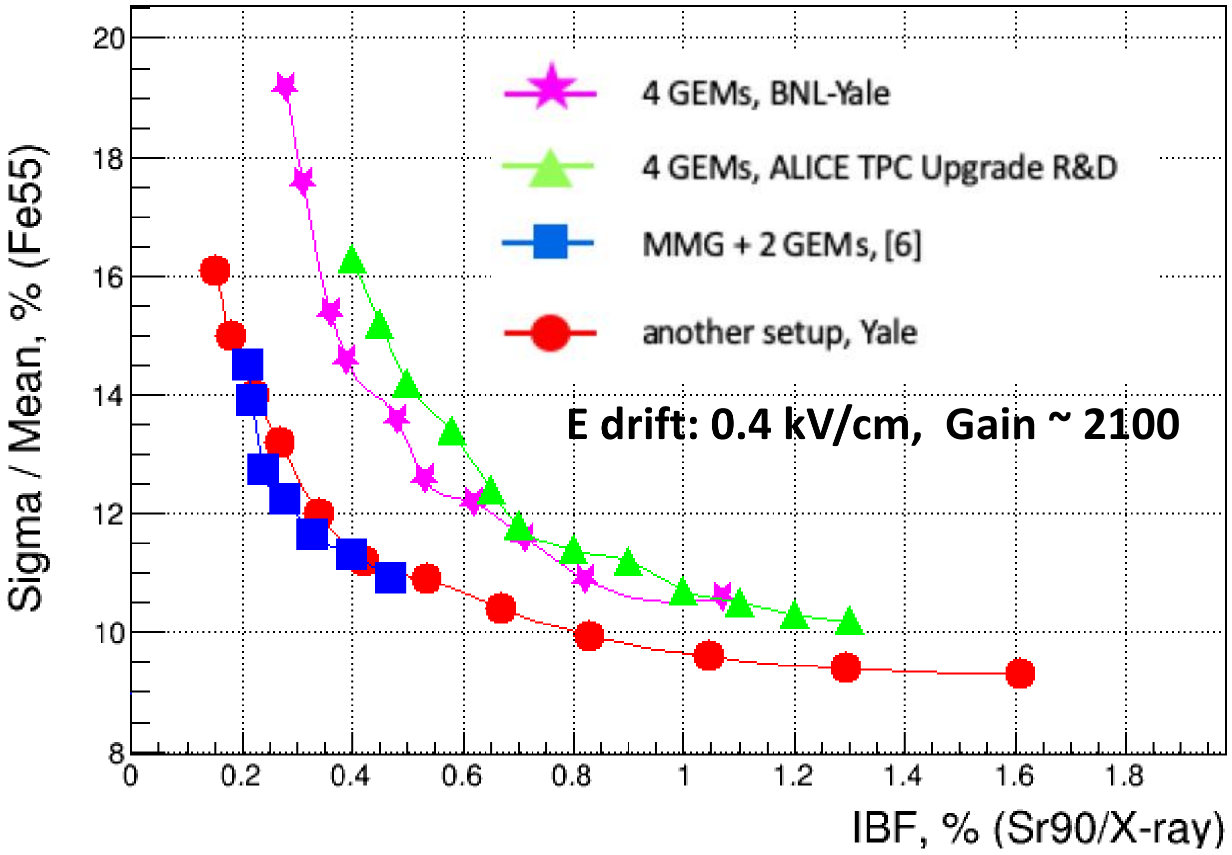
- The extraction field (between GEMs) can be varied without destroying other parameters (easy tuning)

  - The second GEM transfers electron clusters from the first gain step (a high E-field) to the MMG induction gap (a very low E-field), with effective gain for GEM2 is less than one

- Other possible parameters are different pitches and/or patterns of the GEM holes.

- All critical TPC parameters of the 4GEM setup can be obtained for the MMG + 2 GEMs option, with even lower IBF by a factor 2 – 2.5 and smaller max voltage

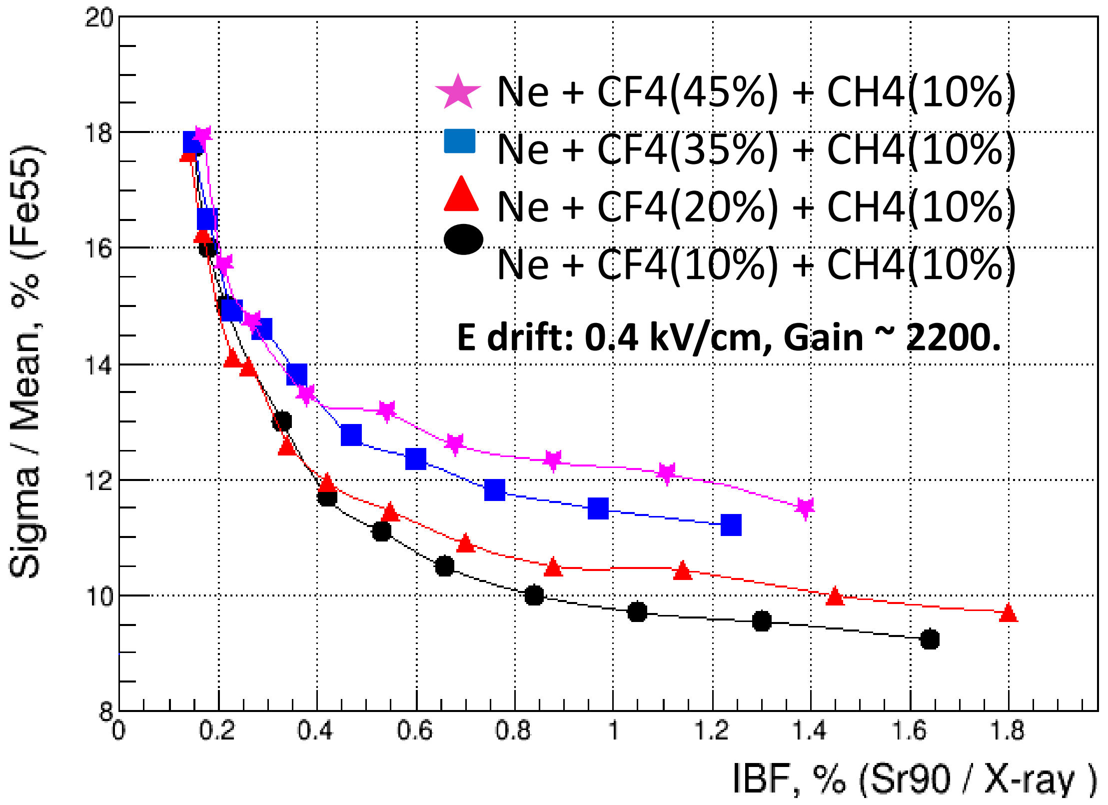
ALICE TPC Gas mixture: Ne (90) + CO2(10) + N2(5)



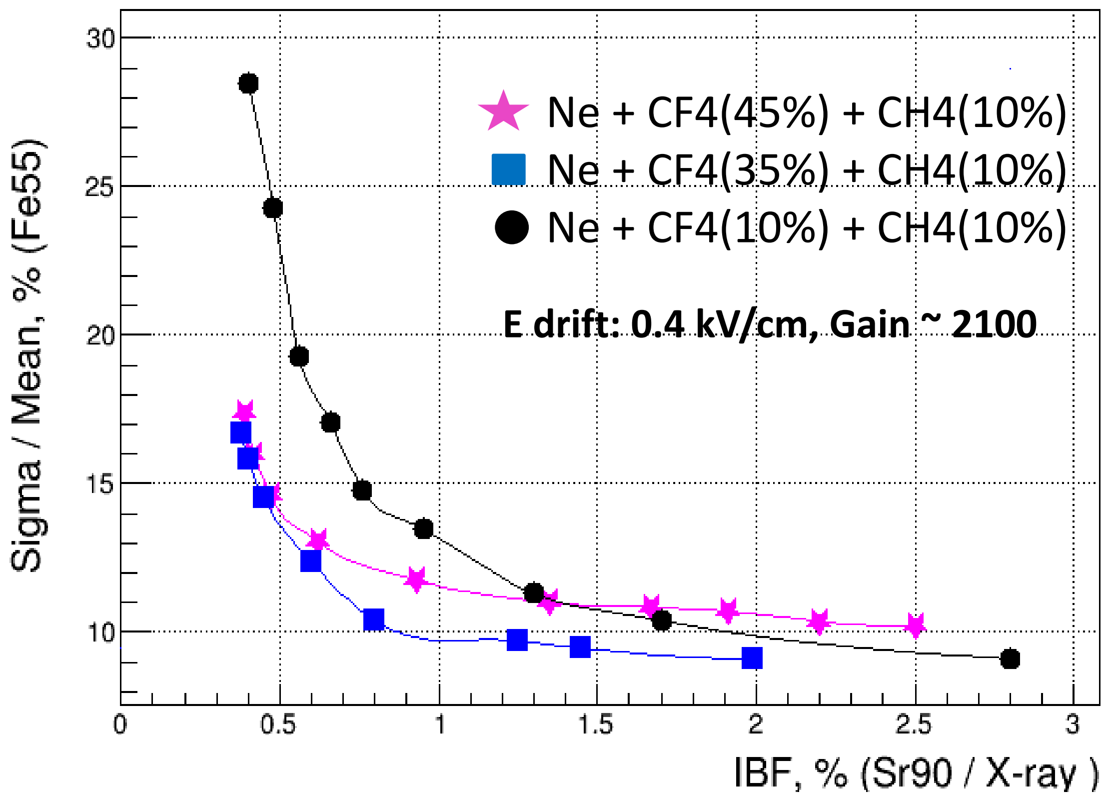
[6] S. Aiola et al, NIM 834 (2016) 149

Two Gain Options for EIC TPC

MMG + 2 GEMs: Ne + CF4 + CH4 gas mixtures



ALICE TPC 4GEM upgrade: Ne + CF4 + CH4 mixtures



- For the MMG + 2GEM option **10 percent of CF_4** provides the best performance in terms of energy resolution and IBF, while for the 4GEM option **~35 - 40%** performs best.
- Best IBF results for 12% E. Res: 0.40% (MMG + 2 GEMs) and 0.60% (4 GEMs)
- Best IBF results for 16% E. Res: 0.18% (MMG + 2 GEMs) and 0.40% (4 GEMs)

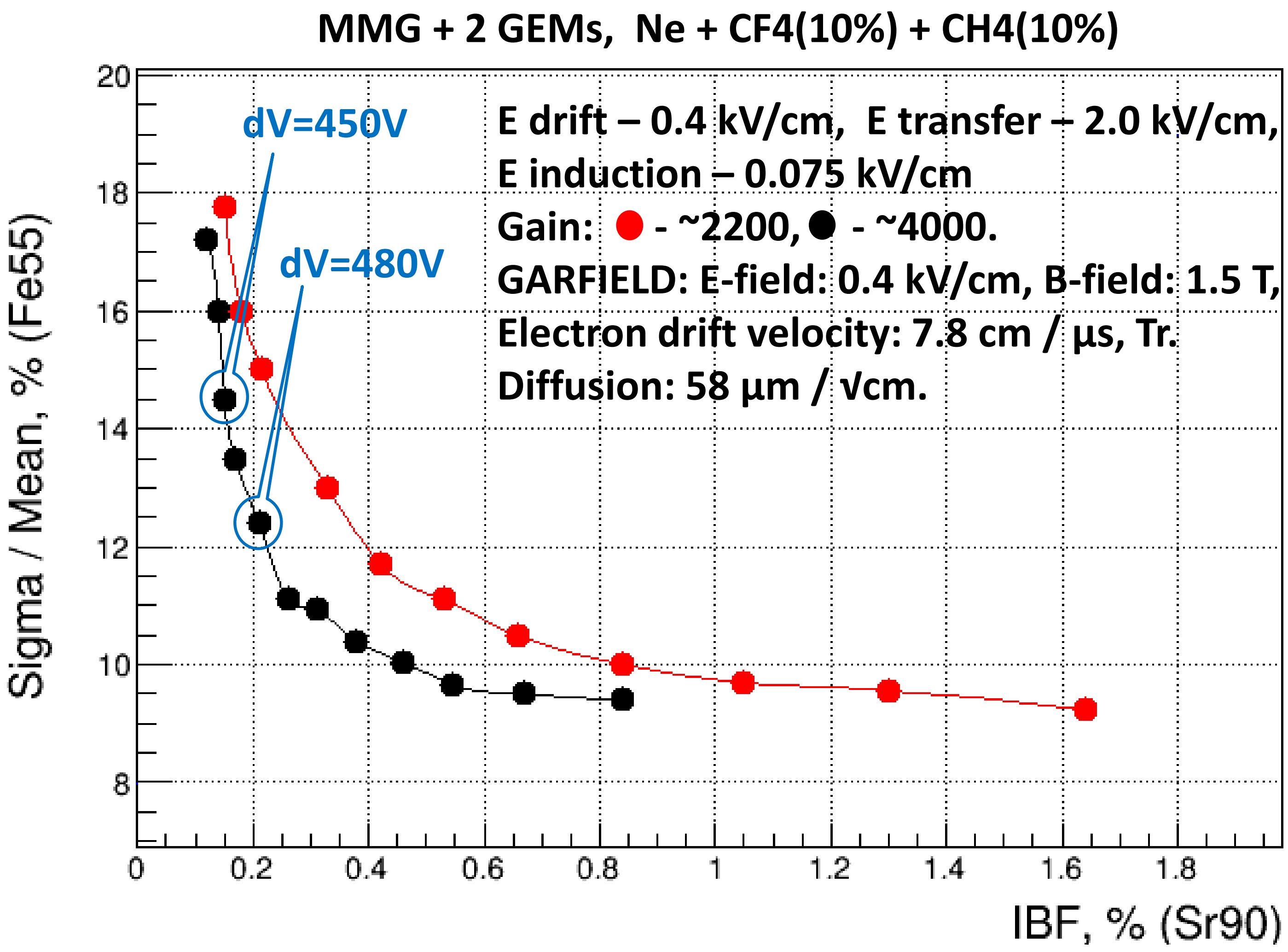
Stability Tests with x-ray Source

- ➢ MMG + 2GEM exposed to high rate of x-rays with anode current reaching 10nA/cm^2

- Similar probability of MMG sparking that could occur when high momentum particles interact in the mesh material

- Stability test performed at 2 different MMG potentials: 450V and 480V

- Stable operation: 7 hrs of running with no spark!



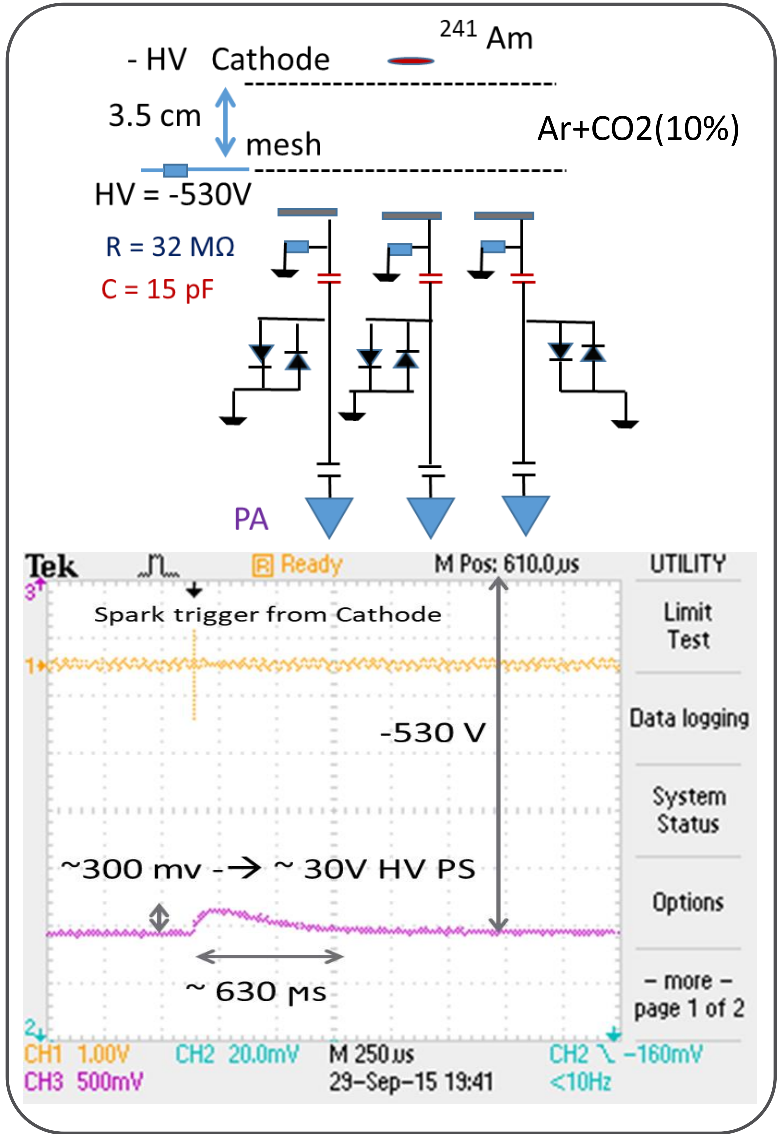
Resistive Layer Protection

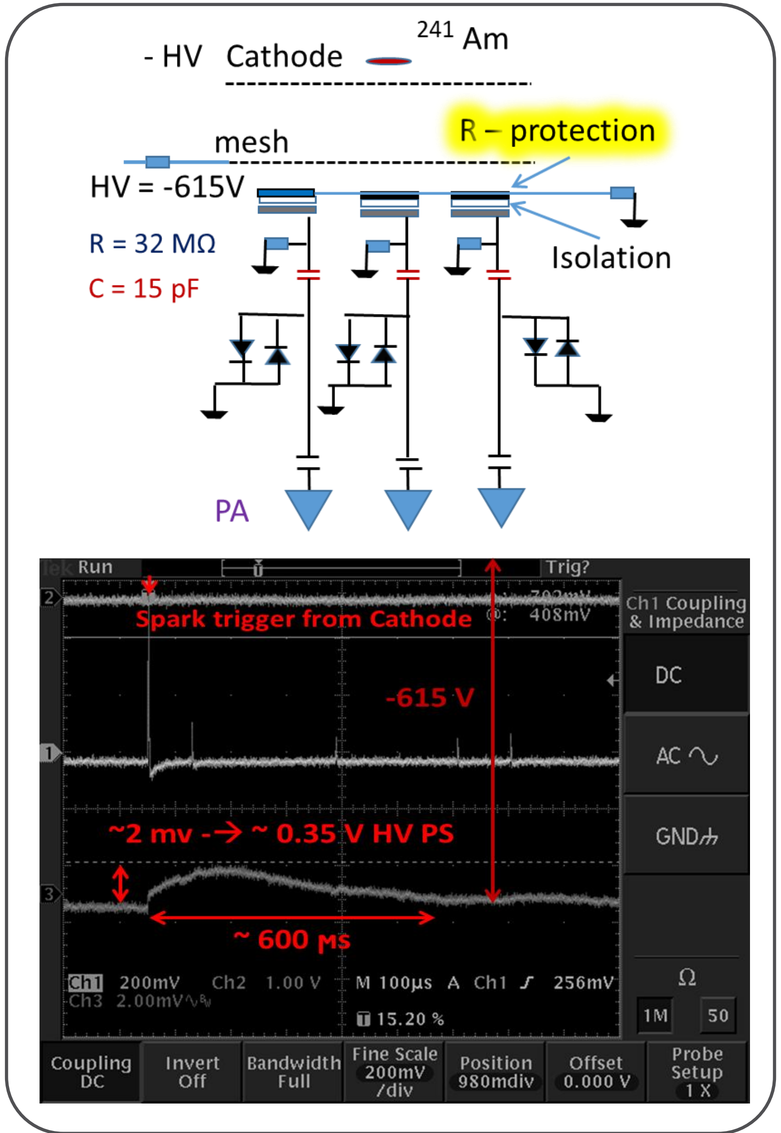
➤ In the event of a spark, a resistive protection layer on the r/o reduces the induced voltage drop and dead time

- $10x10cm^2$ MMG + $4x7.5mm^2$ pad r/o
- Spark trigger rate ~ 1/20 s
- Signal from divider connected to MMG mesh
- Signals recorded on oscilloscope

Results:

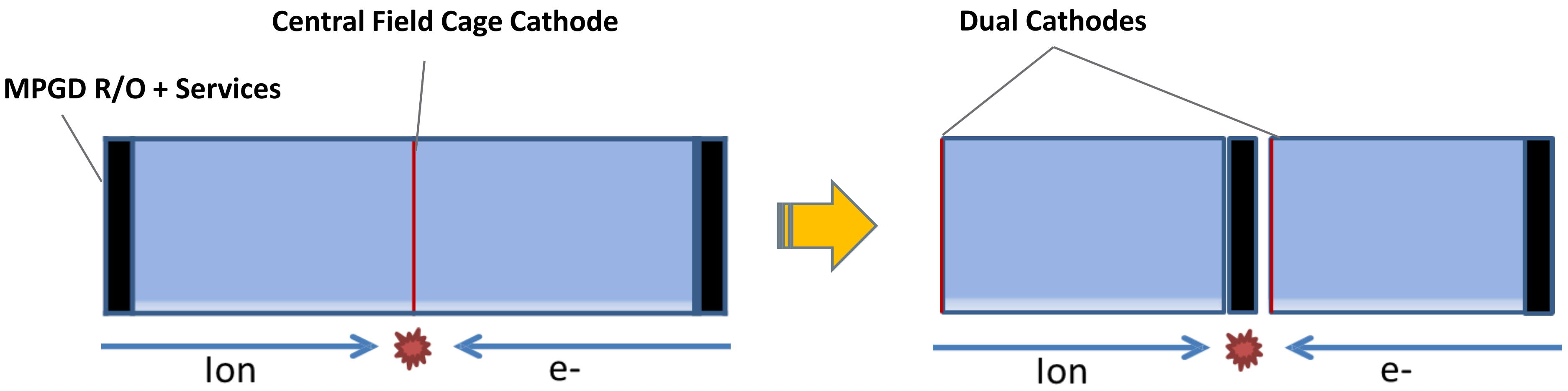
- <u>No Protection Layer</u>
  - HV drop = 30V (significant gain drop)
  - 630μs recovery time
- <u>With Resistive Layer: 1MΩ/cm²</u>
  - HV drop ~0.4V (negligible effect)
  - ~600μs recovery time





Low Mass Readout Options for TPC

- In order to measure the outgoing electron in EIC collisions with high precision momentum and tracking, a dense readout at the TPC endcap (for $|\eta|>1$) must be avoided
- Possible solutions
  A. Si-based readout: TimePix with 55x55μm^2 pixel (demonstrated with 3GEM or Ingrid gain options by ILC team)
     - Large sampling of primary ionization electrons with excellent dE/dx performance
     - Data flow/volume can potentially be challenging, but for EIC events with relatively few tracks per event, this may not be an issue
  B. Couple charge from large (~1x10mm^2) anode pads of TPC r/o plane to input of high density channels of Si readout
     - Additional CCD element may be needed to facilitate the transfer of charge
  C. Reposition TPC endcap readout in the electron-going direction to dramatically minimize material thickness for $|\eta|>1$
     - Split TPC into two halves: one half with cathode near IP, one standard



- Challenges
  - This concept needs to be tested with simulation
  - Rapidity hole near η=0
  - Impact on Physics seems small (Jets, Abs. X-section measurements?)
  - Acceptance of vertex det. obscured
  - Routing of services, cabling

Summary

- Investigated crucial parameters for a future high rate TPC at the EIC: ion back flow, energy resolution (dE/dx), electron and ion drift speed, electron diffusion, and stability
- Concentrated on two MPGD gain structures: 4GEM and MMG+2GEM
  - For the hybrid option, we achieved an IBF below 0.3% and an $\Delta E/E < 12\%$ for Fe^{55} x-rays at a gain of ~2000 for several gas mixtures
  - Optimal gas mixture ratios were identified for both the 4GEM and hybrid option
  - We have demonstrated the stability of operation for the hybrid gain element with the optimal working gas
  - We have also showed that for relatively rare spark events, the impact on the performance of the hybrid gain element is negligible

Conclusion: The hybrid amplification stage allows for a TPC design that can operate in a continuous mode, serves as a viable option to limit space charge distortions in high-rate TPCs, and guarantees that dE/dx, ionization cluster space reconstruction resolution, drift parameters and detector stability will not be compromised