Study of a passive gating grid for Ion Back Flow (IBF) suppression

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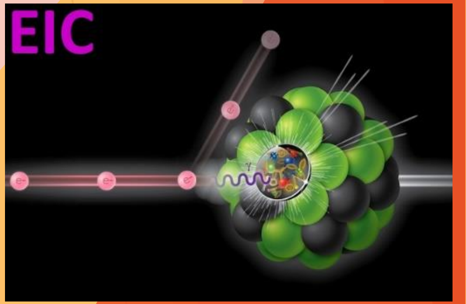
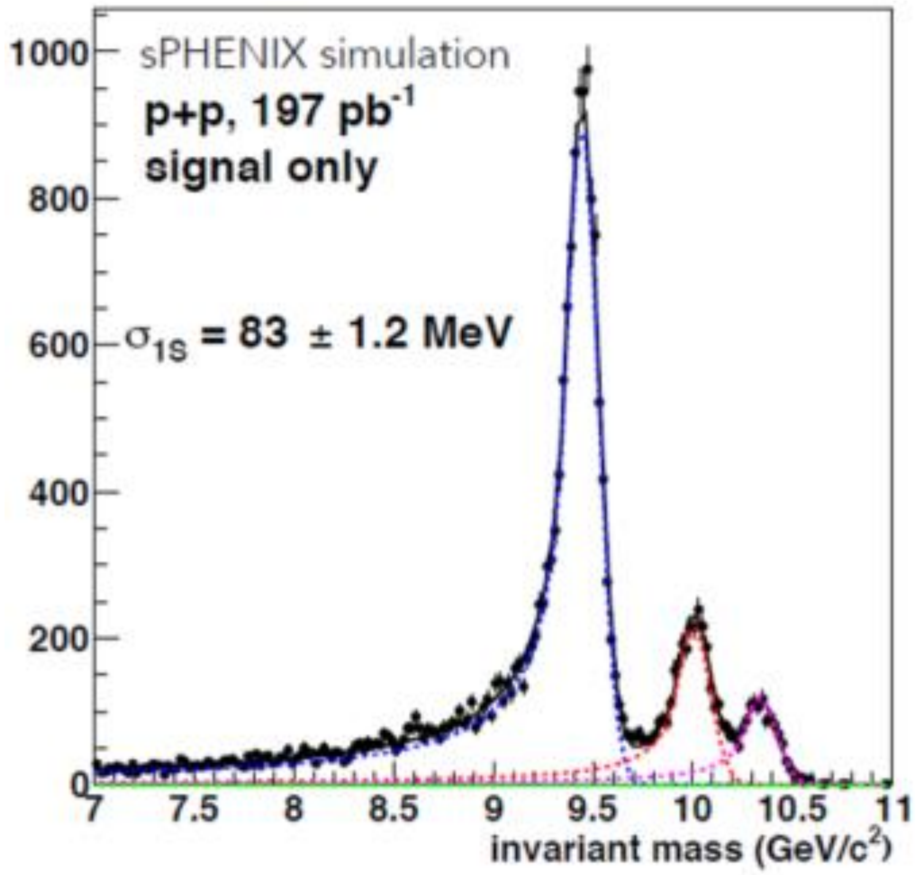
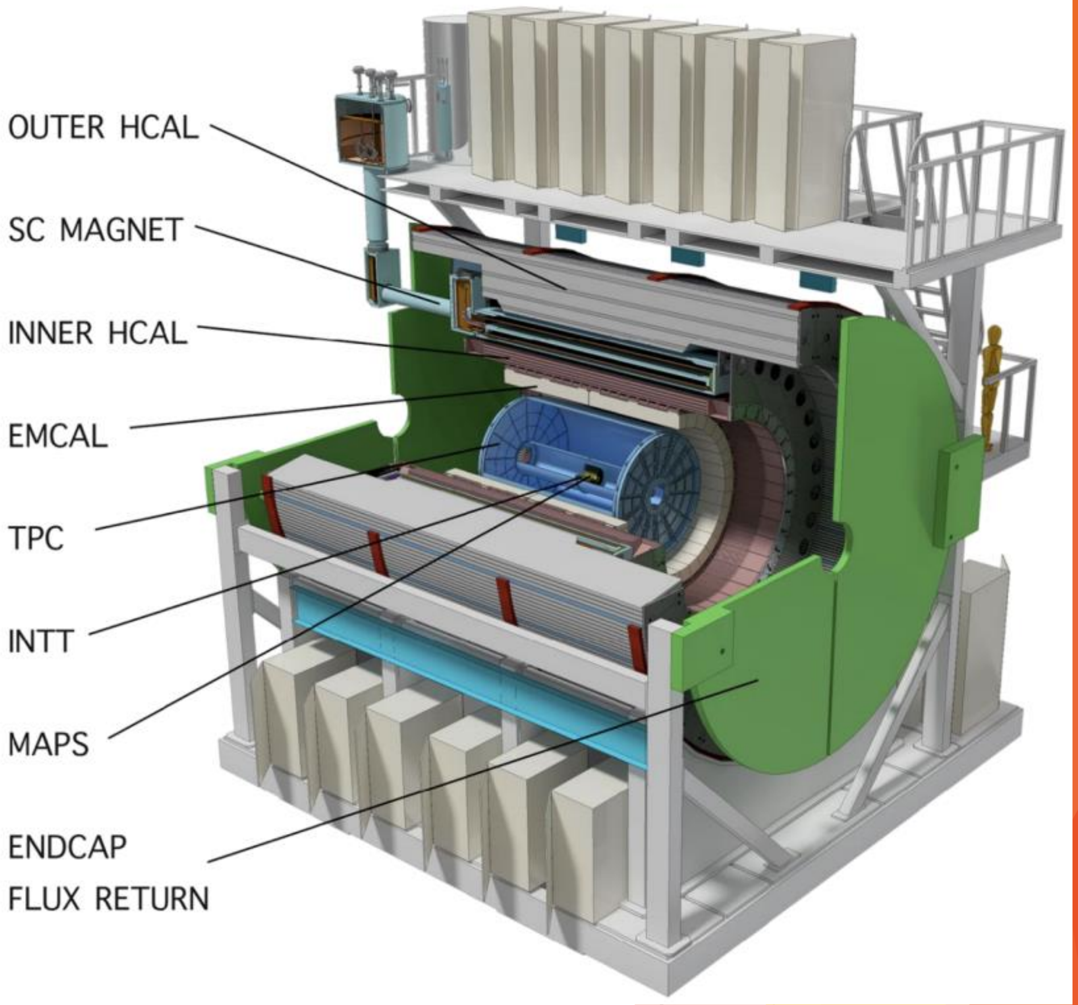


Stony Brook University

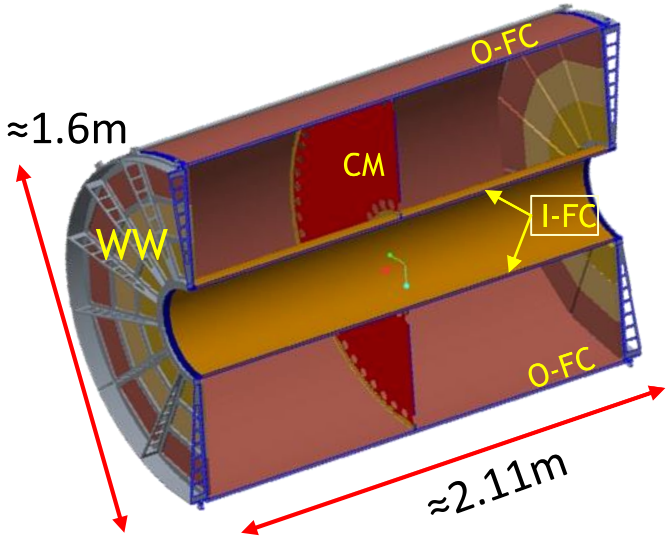
Overview of sPHENIX at RHIC

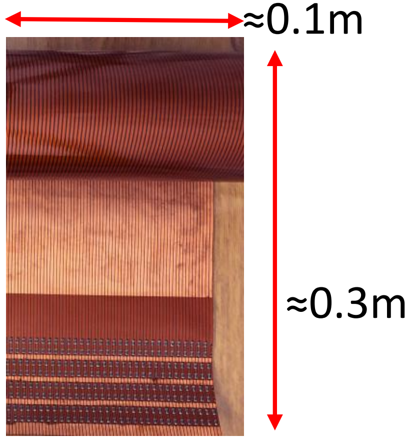




- Time Projection Chamber (TPC)
  - Clear Upsilon 1s, 2s, 3s energy states resolution [main tracking detector]
  - TPC is day-one ready for the Electron Ion Collider (EIC)

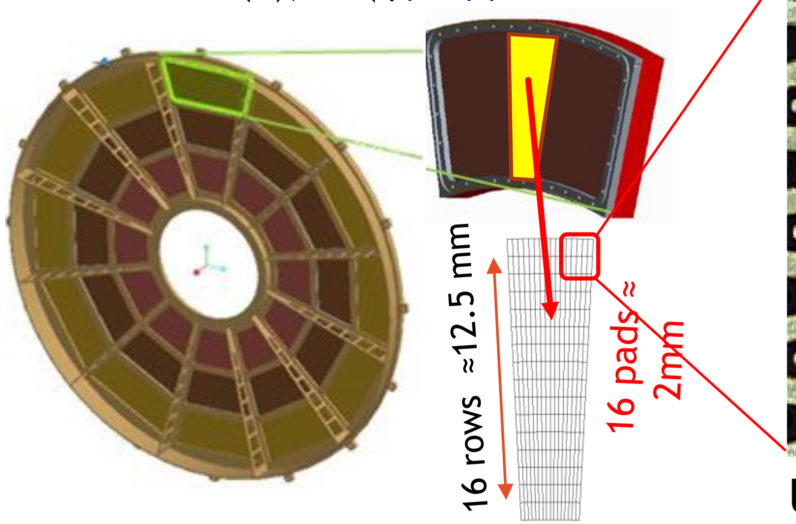
Time Projection Chamber (TPC)





Flexible Striped Circuit Cards

72 Modules: 2(z), 12(ϕ), 3(r)



Unique Zig-Zag shape

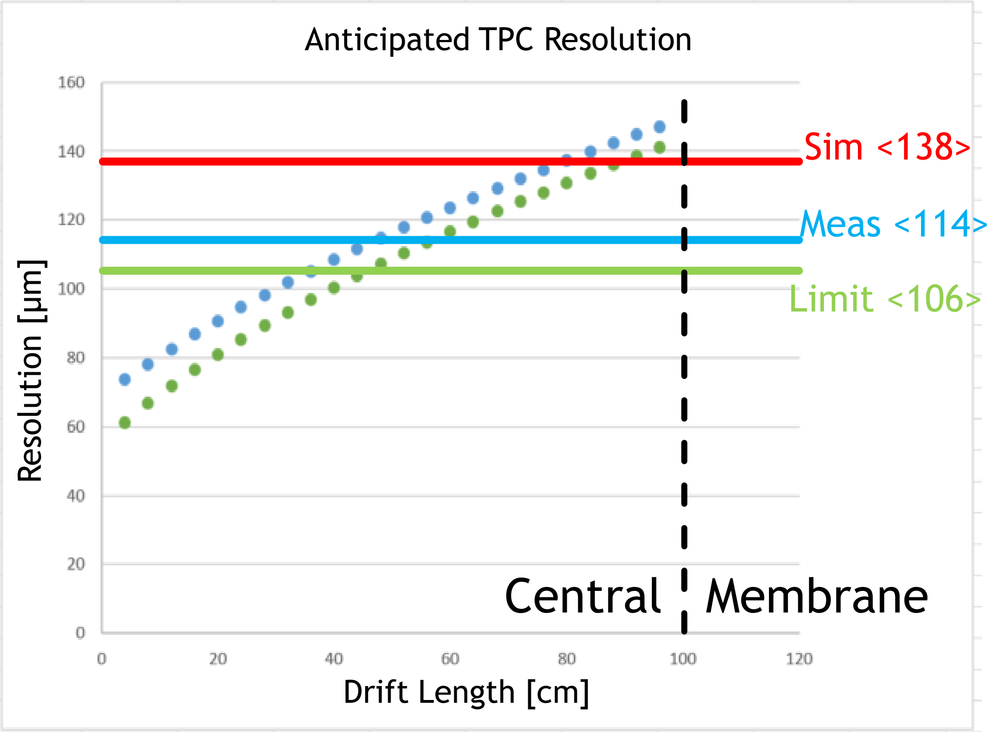
- Gas chamber, PCB flex cards with CM make 400V/cm $\vec{E}$-field
- Enclosed in solenoid magnet of 1.4T $\vec{B}$-field to decrease diffusion
- End Plates with amplification & detection modules
- Electronics contain SAMPA chips (similar to the ALICE design). Data is digitized and collected for storage.

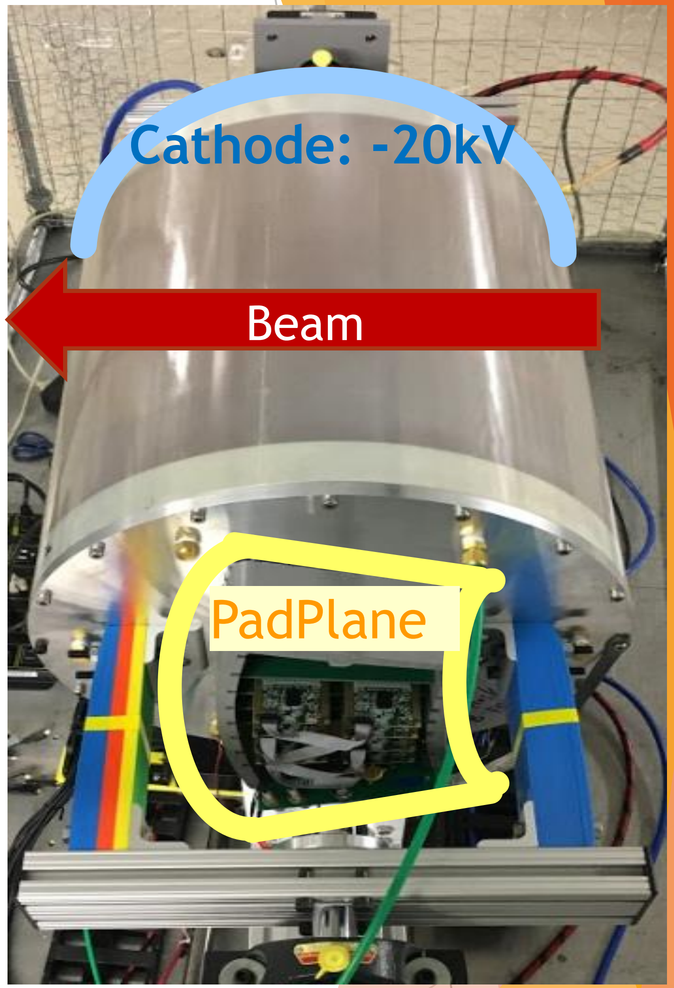
poster **50** by: **Steven Slote**

poster **49** by: **Henry Klest**

- Unique Zig-Zag pads [Talk by: **Bob Azmoun**]

Mini Prototype TPC





- Successfully tested in Fermilab Test Beam Facility (FTBF)
- TPC preforms better than required for sPHENIX specifications

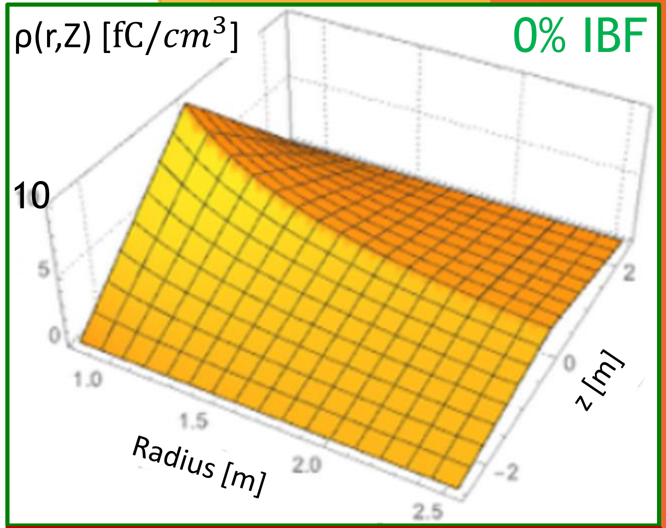
poster **40** by:
Niveditha Ramasubramanian

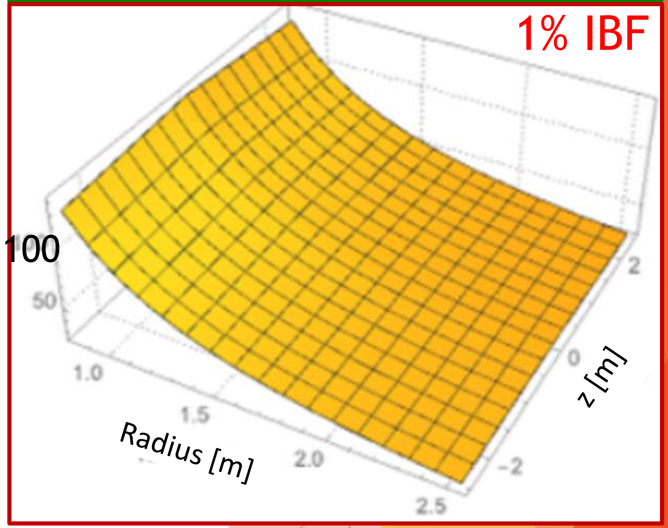
Vlad

IBF & Space Charge (SC)

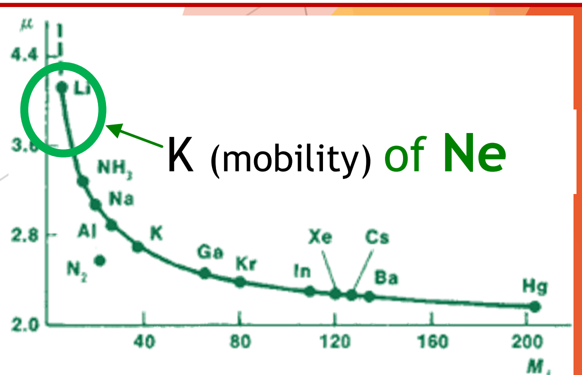
$$\rho(r,z) \propto \frac{Ionization * Multiplicity * Rate}{v_{ion}} \left[\frac{\overbrace{1-\frac{z}{Length}}^{\text{Primary}} + \overbrace{C}^{\text{IBF}}}{r^2}\right]$$

- SC is the enemy of resolution
- $\vec{v}_{ion\,drift} = K\vec{E}$ (large K {Ne}, large $\vec{E} = 400V/cm$)
- Detector performance limited by the fluctuations in deflections since SC is not continuous on average
- Minimize C: Bias Operating Point of MPGD for low IBF (ALICE), Passive IBF shielding (topic for today's talk)



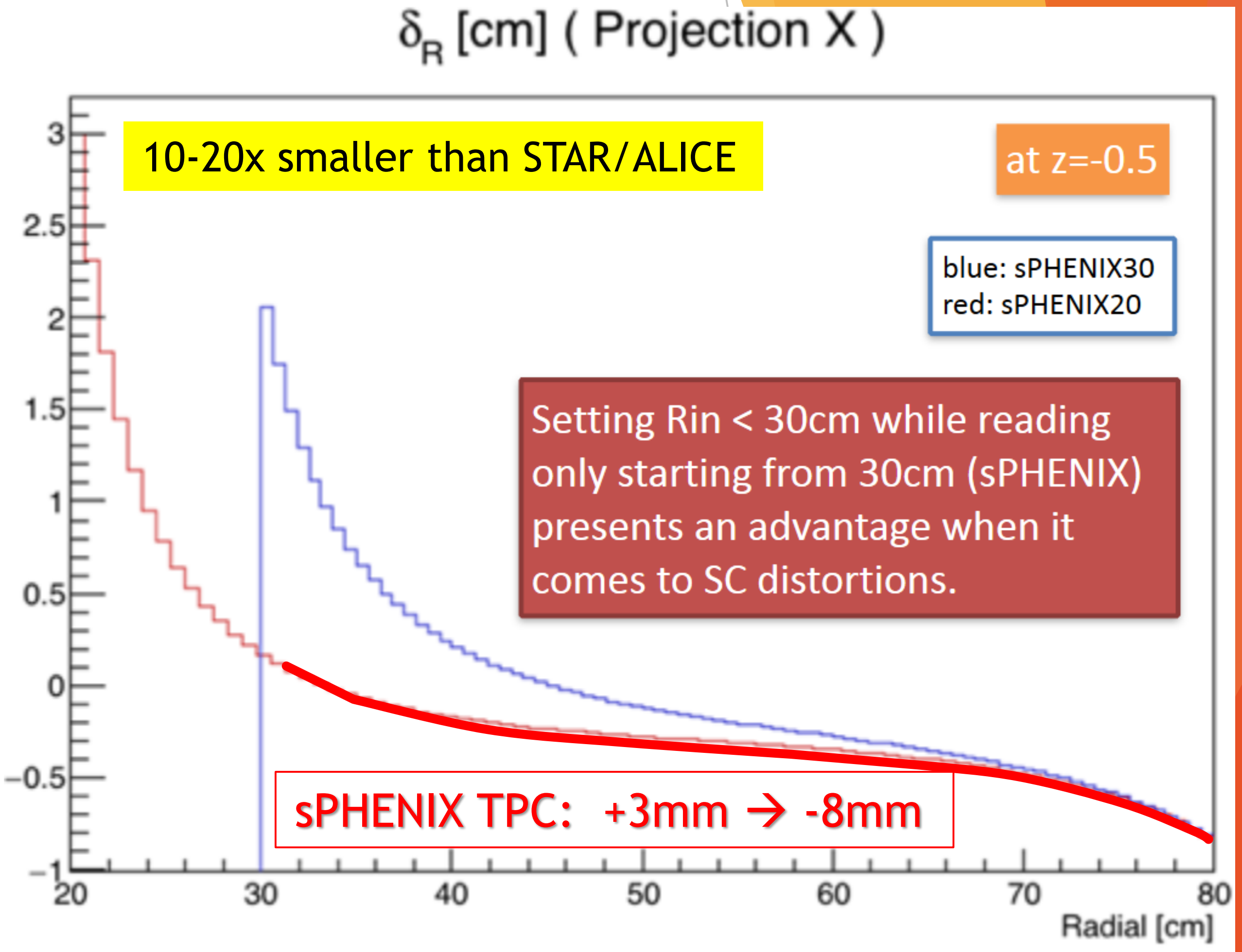


- At 2,000 gain & only 1% IBF, <u>20 ions</u> are drift and only 1 is primary.
  This is 95% of the Space Charge!



IBF & SC simulations for TPC

- Drift volume spans 20-78 cm
  - ALICE: 80-260 cm, STAR: 50-200 cm
- Instrument entire radii, but record only after 30cm
- Vertical axis is a shift
- This reduction in position/displacement (e^- recorded compared to where it should have landed) will improve our position/momentum resolution.
- One method to fight SC!



2016-05-11 - Carlos E. Perez Lara - Space Charge Distortions

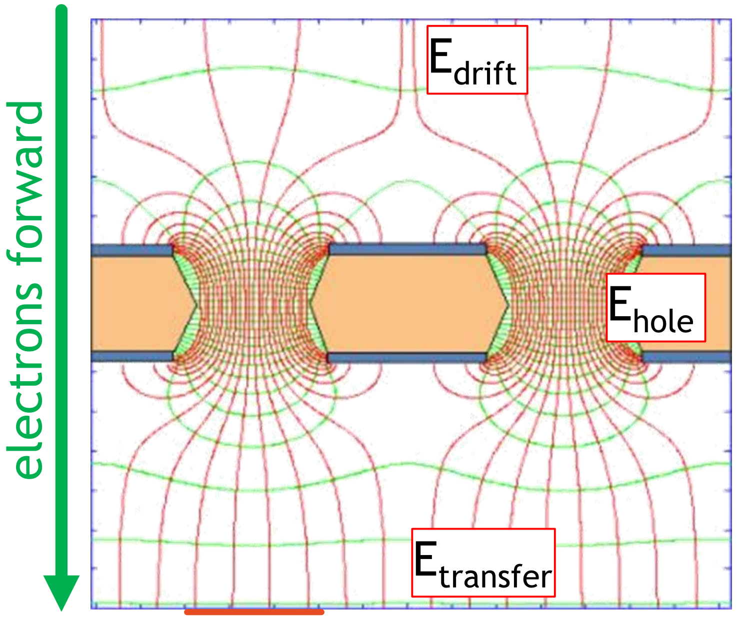
Electron vs. Ion Transport in a Gas

- Battling SC requires distinguishing between e⁻ and ion transport.
- Both obey the Langevin Equation for transport:

$$m\frac{d\vec{v}}{dt} = q\vec{E} + q\left(\vec{v} \times \vec{B}\right) - \kappa\vec{v}$$

- Complete characterization is VERY COMPLEX: Requires calculations & measurements.
- Nonetheless, we can direct our calculations using simplified considerations.
- The basic "Langevin Distinctions" between e⁻ and ions are:
  - Opposite q: Design Forward-Backward Asymmetry into electric field.
  - Different $\vec{v}$: Typically opposite in direction, different in magnitude…Use $\vec{B}$ to our advantage
  - Different κ : …maybe considered in a future discussion (?) …not today.
- It is possible to design structures that utilize all these differences to minimize ions from avalanche reaching the main drift volume while retaining electron transport to the avalanche zone.

Forward-Backward Asymmetry



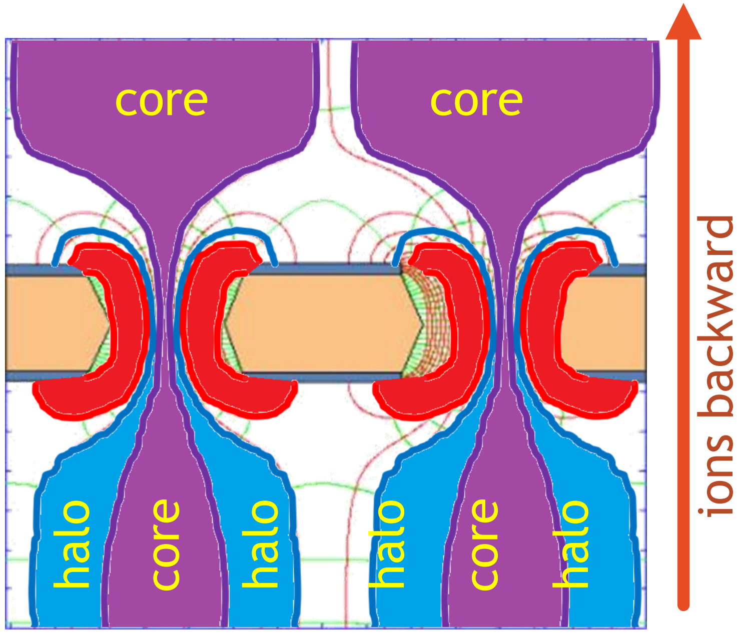
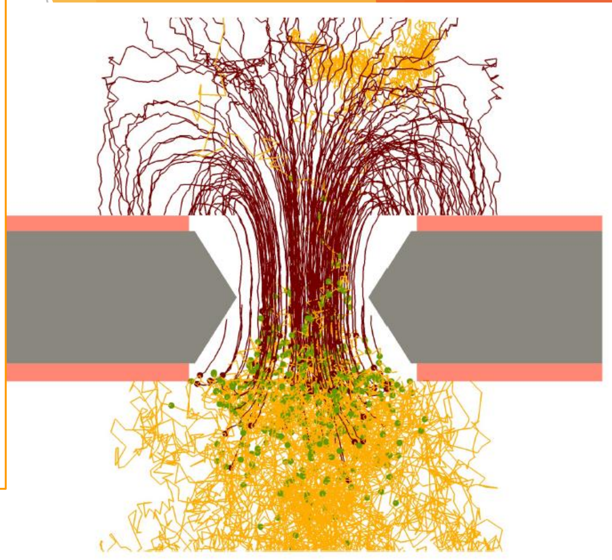


Figure 2: Garfield & Magboltz simulation of charge dynamics of 2 arriving e$^-$ in a GEM hole. e$^-$ paths are yellow, ion paths are red. Green spots at ionization locations. Paths projected on the cross section plane.

Bohmer et al.
SC Effects in an Ungated GEM-based TPC



- The classic GEM picture with $E_{transfer}$ > E_{drift}
- Only a fraction of the transfer field lines originate in the drift volume.
- Effective transparency difference for forward-backward:
  - Driving characteristic is the field ratio: $\frac{E_{transfer}}{E_{drift}}$
  - Most electrons get through (and avalanche), while many Ions are blocked.
  - REALISTIC calculations & measurements by ALICE for quad-GEM.

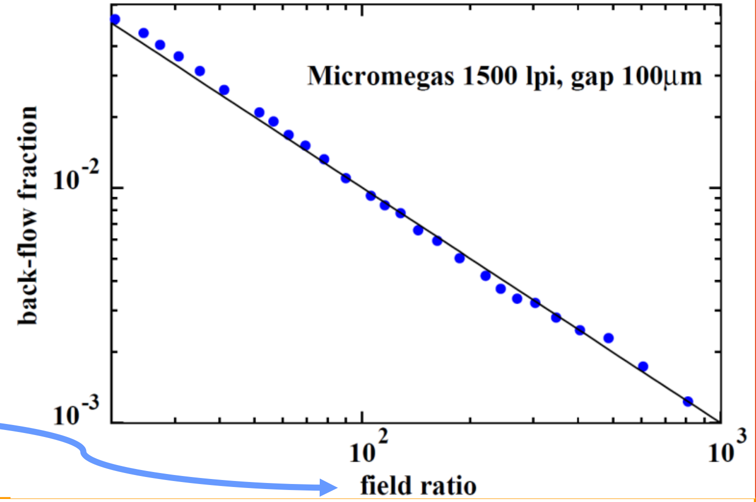
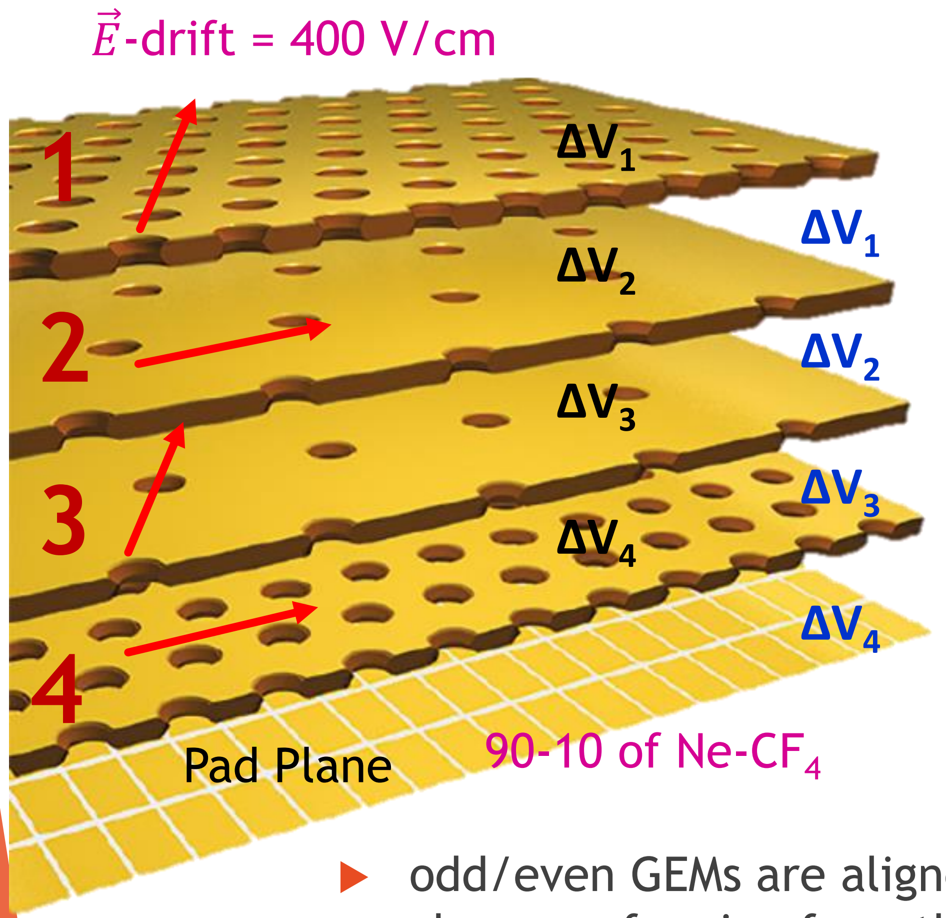


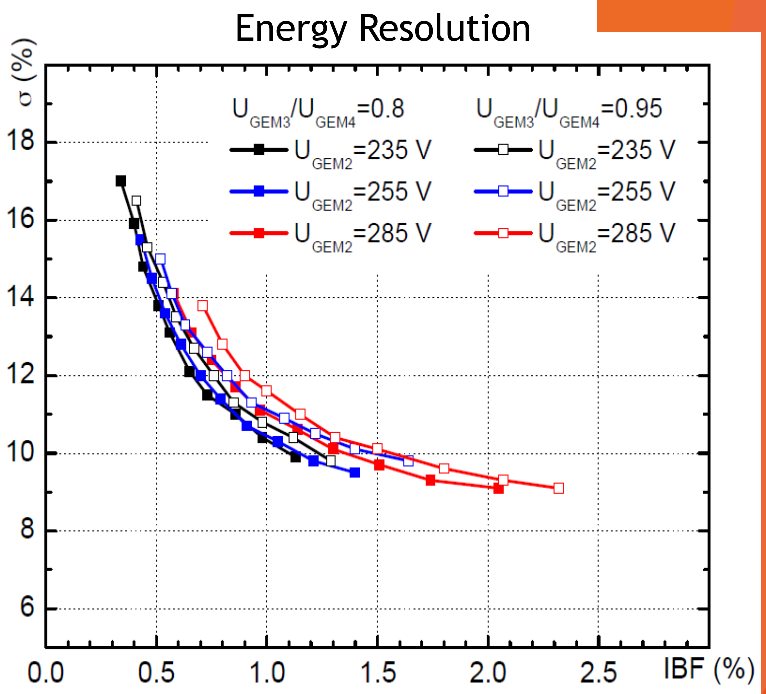
Fig. 7. Measurements of ion backflow vs. field ratio for a 1,500 lpi micromesh. It was performed using an intense (10mA-10keV) X-ray gun.

Colas P. et al - “Ion backflow in the Micromegas TPC for the future linear collider”
NIM A 535 (2004) 226-230

Gas Electron Multiplier (GEM) Quad-Stack



- Allows for ≈ 2,000 e^- gain & suppresses IBF
- ΔV = top to bottom of single foil
- ΔV = between two GEMs
- Pioneering results & now a mature technology
- Completely achieves ALICE goals (<1% IBF, <12%σ)

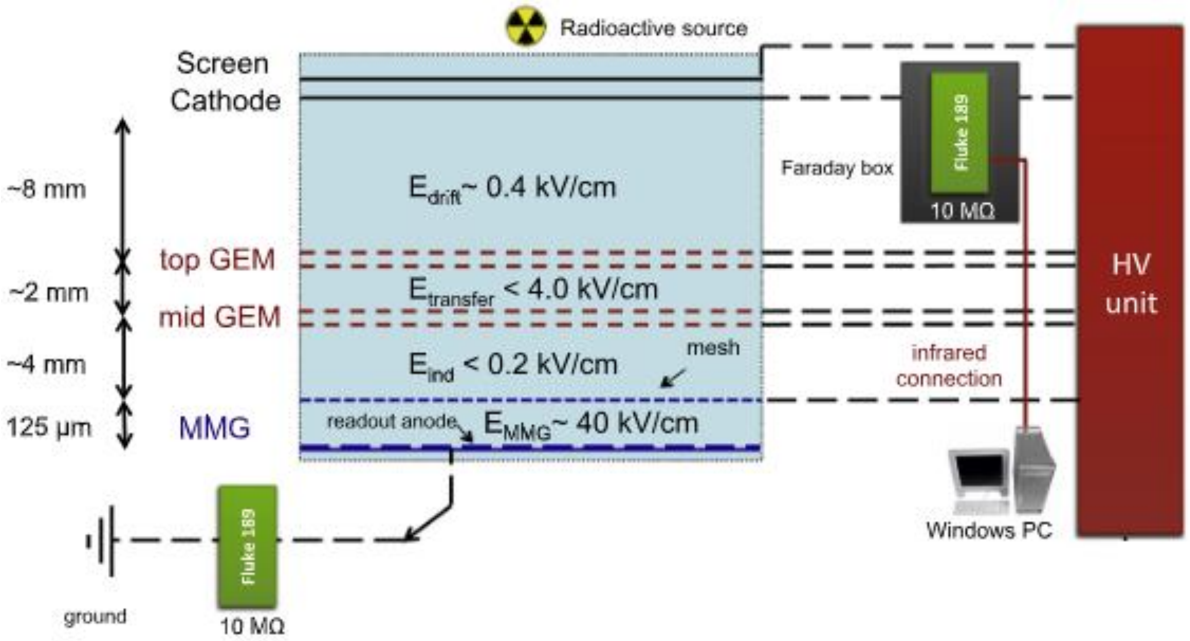


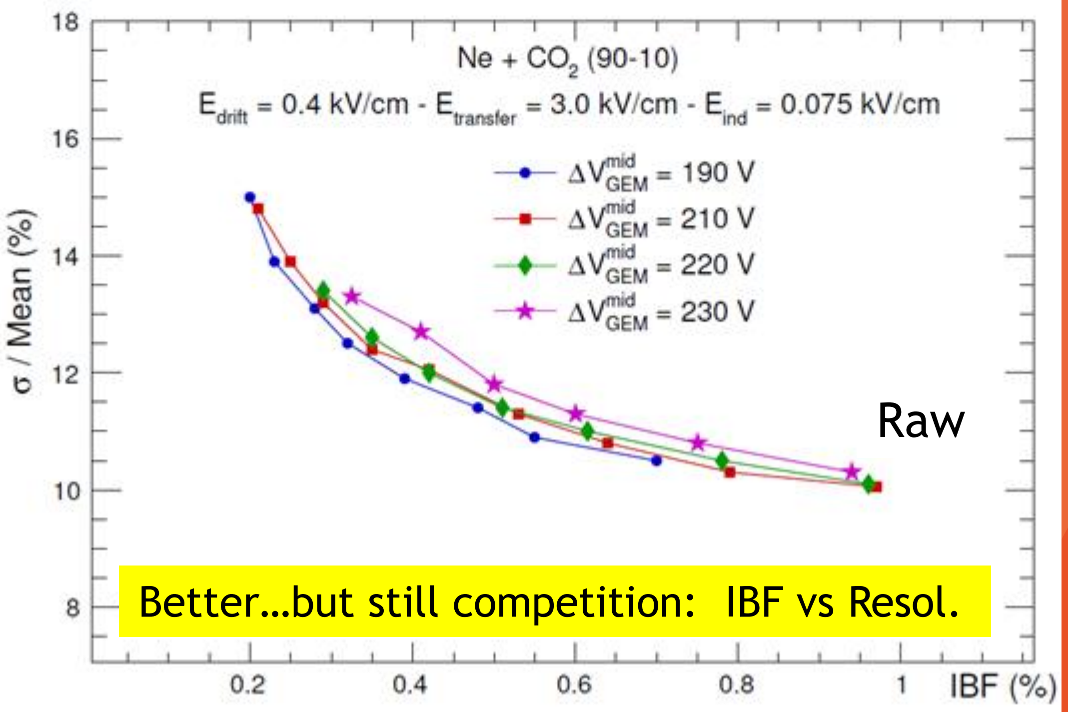
2014-03-03 TDR for the Upgrade of the ALICE TPC

- odd/even GEMs are aligned but vary in pitch and rotated with respect each other to reduce chances of an ion from the pad plane to float to the gas volume
- Fundamental tradeoff of IBF efficacy vs Energy Resolution:
  - Gain biased toward last GEM(s) [nearest pads] ➔ Low IBF
  - Gain biased away from first GEM(s) ➔ Gain fluctuations…decreased resolution

Hybrid: GEM-GEM-MicroMegas (µM)

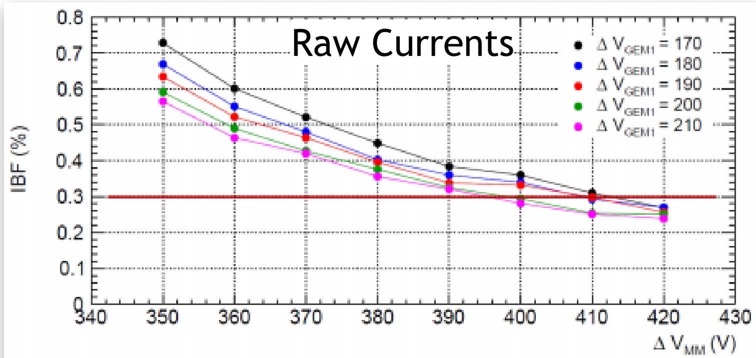
S. Aiola et al - Combination of dual-GEM and µM as gain elements for a TPC *NIM A 834 (2016) 149-157*

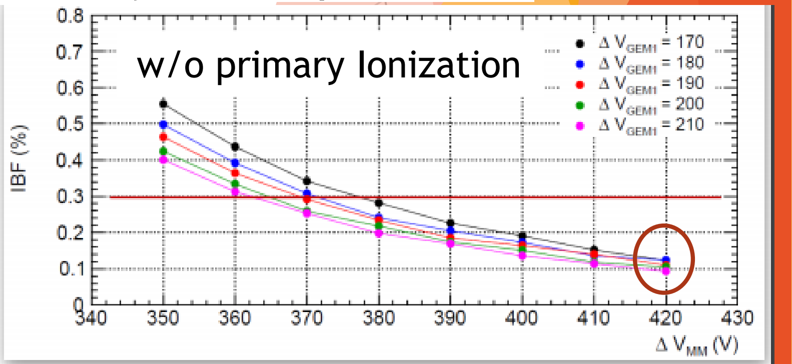




- Nothing beats µM for Field Ratio
- Most extreme by LOWERING $E_{induction}$
  - Mid GEM lowers $E_{induction}$, **but eats e$^-$**
  - Top GEM provides some gain to compensate for e$^-$ loss in Mid GEM

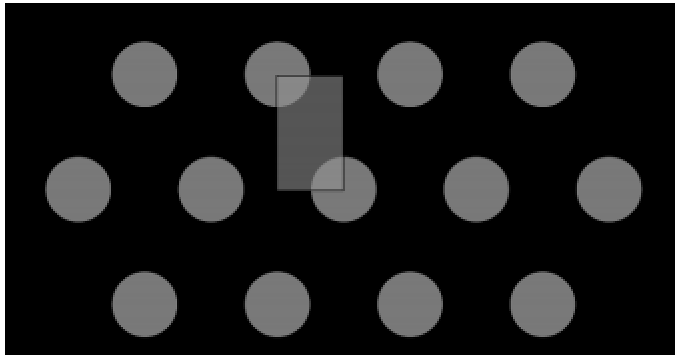
Recent Results from Saclay… 0.1% possible?



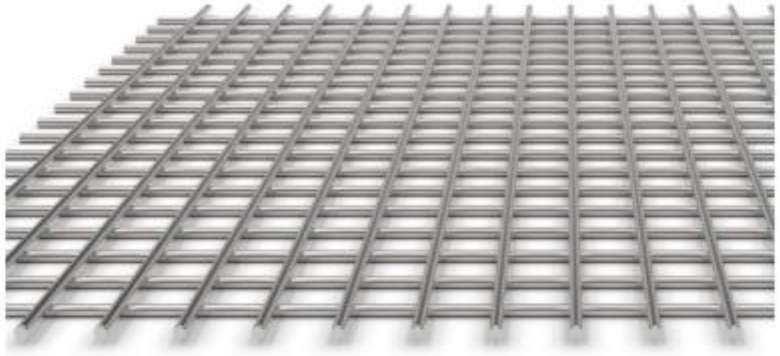


IBF reduction without e^- Resolution Loss?

Cylindrical Holes Gating



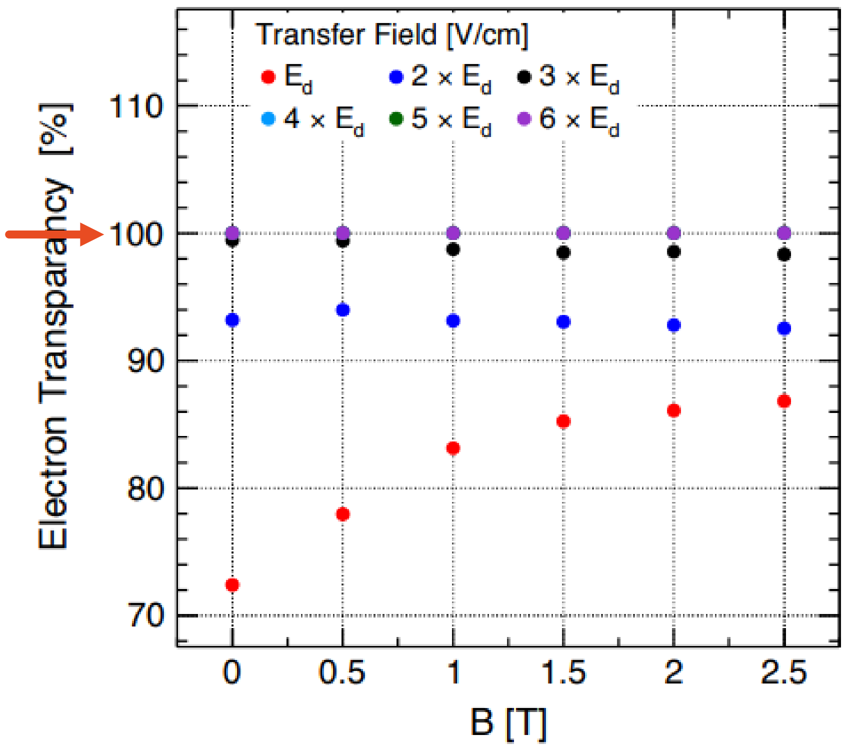
Wire Mesh Gating

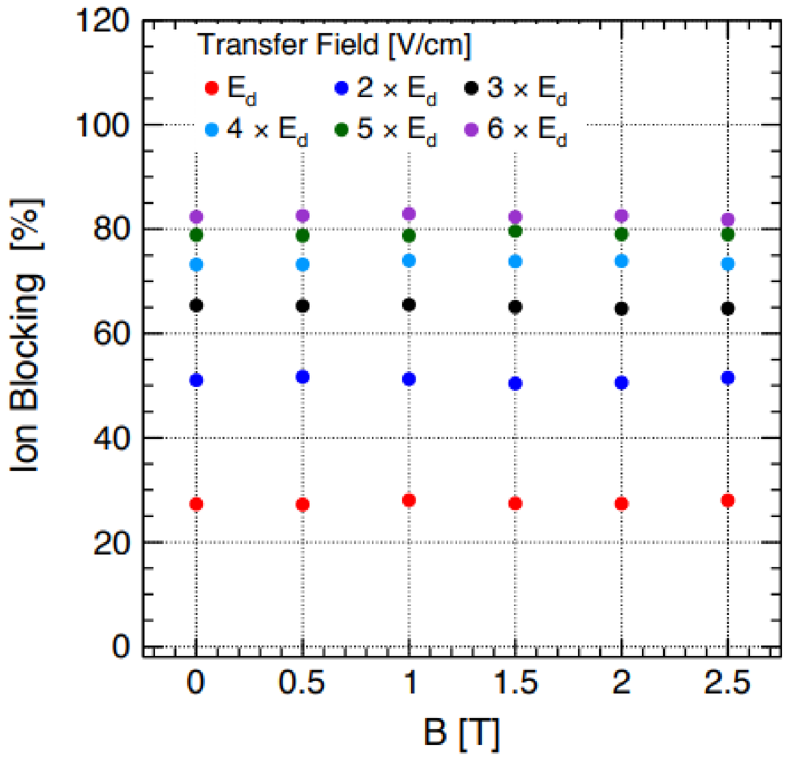


- In any multi-stage gain structure, a low gain stage makes irreducible contributions to gain fluctuations.
- The first (early) stage(s) of G-G-G-G and G-G-μM must have low gain since they are coupled strongly to the gas.
- Nonetheless, the field ratio principle (large $\frac{E_{transfer}}{E_{drift}}$ ➔ low IBF) applies even without gain.
- Therefore a passive structure generating a field ratio can lower IBF with little or no loss in energy resolution.
- (our gas has low transverse diffusion, which helps high e- transmission)

Passive Mesh Calculations/Simulations

Ideal





Ideal

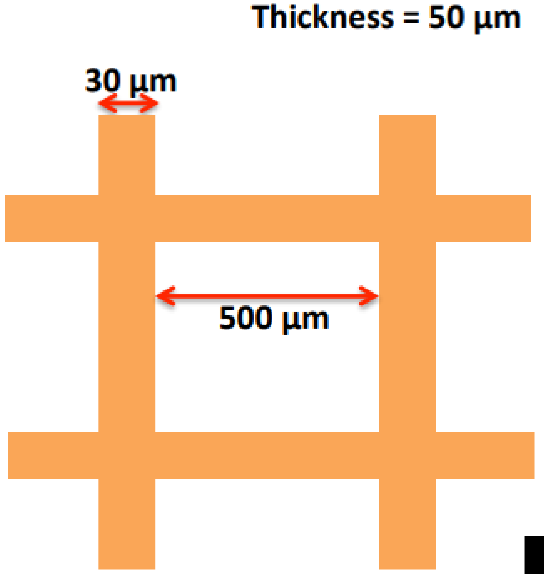
5X better

3X better

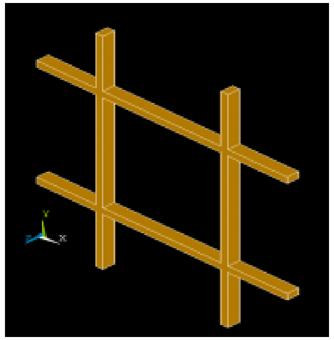
2X better

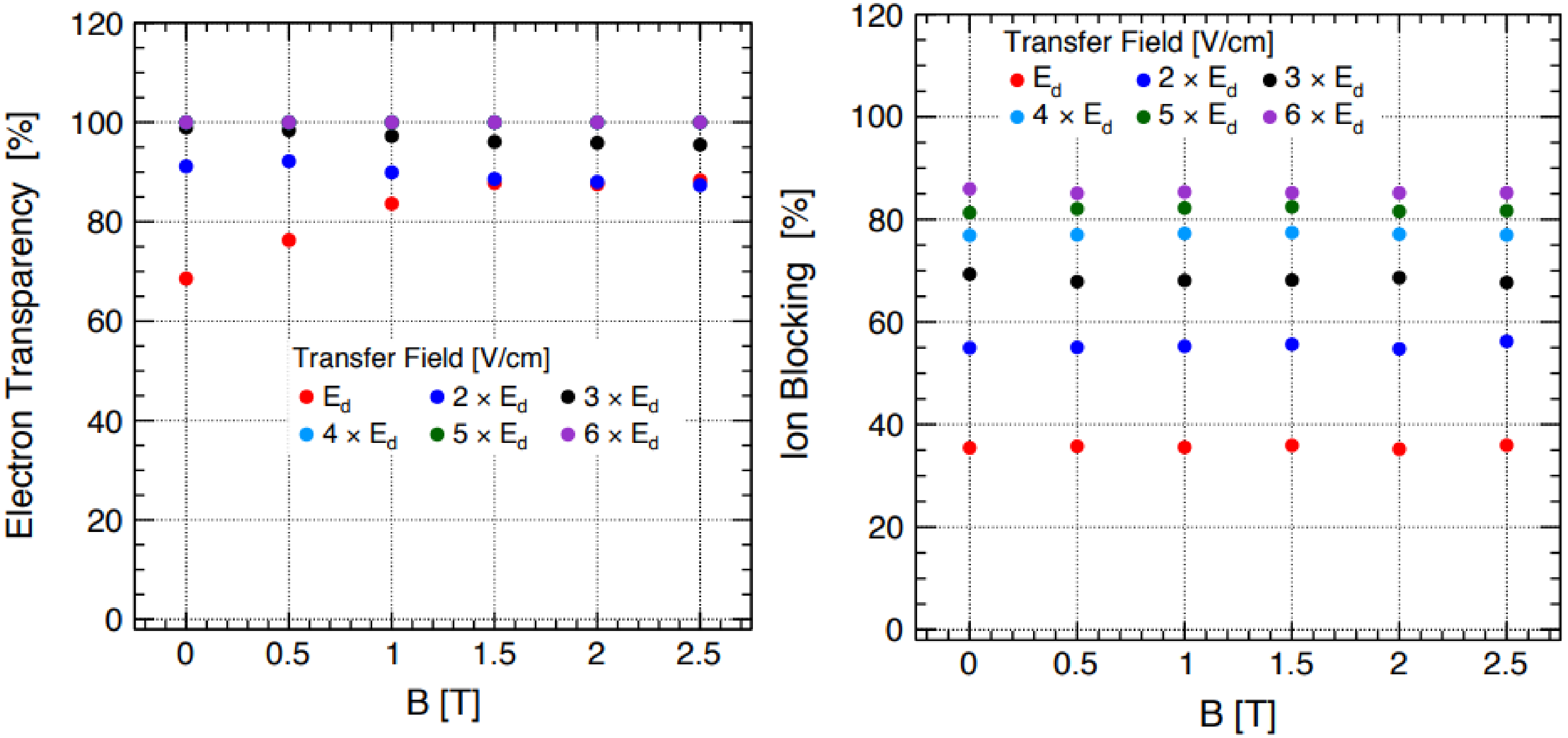
- Drift Field is fixed to sPHENIX (400 V/cm)
- Transfer Field is scanned: E_d, $2E_d$, $3E_d$, $4E_d$, $5E_d$, $6E_d$ (from sublime to ridiculous)
- Magnetic field is scanned (relevant for low E_T) 0T, 0.5T, 1.0T, 1.5T, 2.0T, 2.5T
- Full Garfield transport calculations.
- Ideal result would be 100% e^- Transparency and 100% Ion-blocking.

Among the Best were Passive Meshes Studied:



“Etched” Mesh





- Transfer field 2-3x E_{drift} (reasonable)
- IBF improvement factors 2-3x (excellent)
- e^- Transmission 90-98%

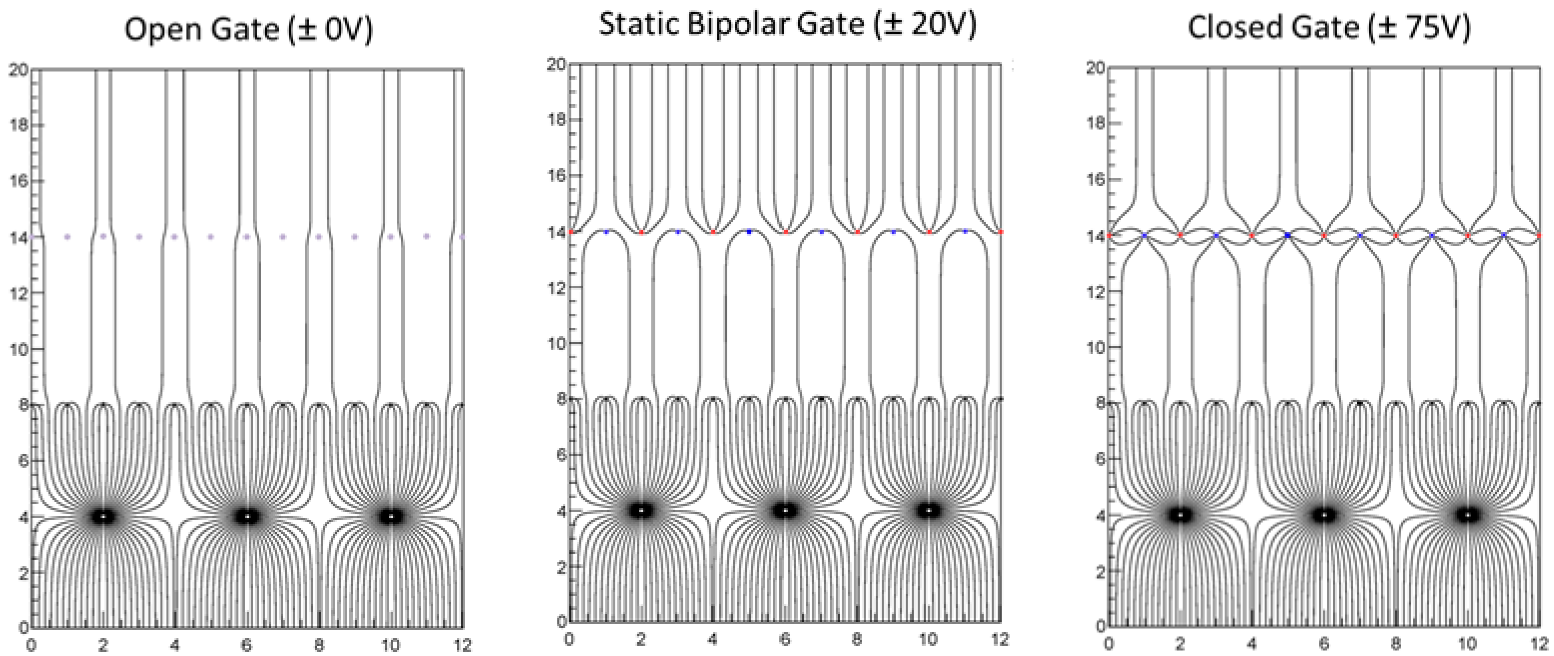
A simple mesh should lighten the burden and improve performance on any G-G-G-G or G-G-µMEGAS structure. However, an improvement of only 2-3x would mean that IBF is still the dominant source of SC

Vlad

What about the Magnetic Field Term?

$$m\frac{d\vec{v}}{dt} = q\vec{E} + q\left(\vec{v}\times\vec{B}\right) - \kappa\vec{v}$$

- Negligible for SLOW ions…not negligible for electrons in sPHENIX:
  - V_{drift} = 80 microns/nsec; B = 1.4 Tesla
- Traditionally one attempts to zero this term to avoid distortions $(\vec{v} \parallel \vec{B})$.
- Nonetheless, one can make a LOCALIZED $\vec{v}\times\vec{B}$ kick that only electrons feel.
- This concept is discussed in detail in Blum.



Question: Can the magnetic field aid electrons in passing through an otherwise closed gate?

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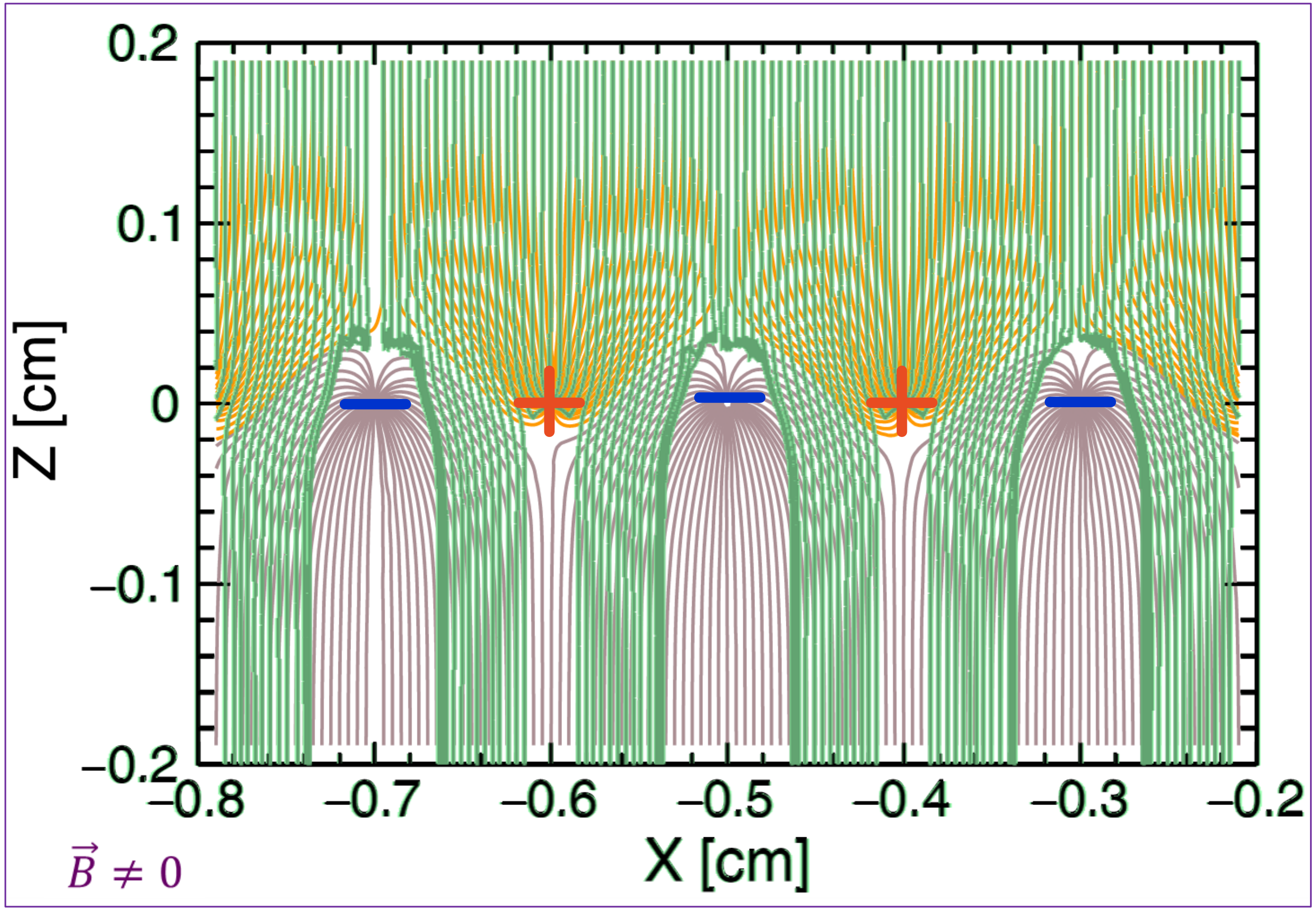
Introduction of Magnetic Field:



- Magnetic Field brings electrons through.
- Ions remain blocked.

Studies of the Bi-Polar Wires

Drift Field [V/cm]
300

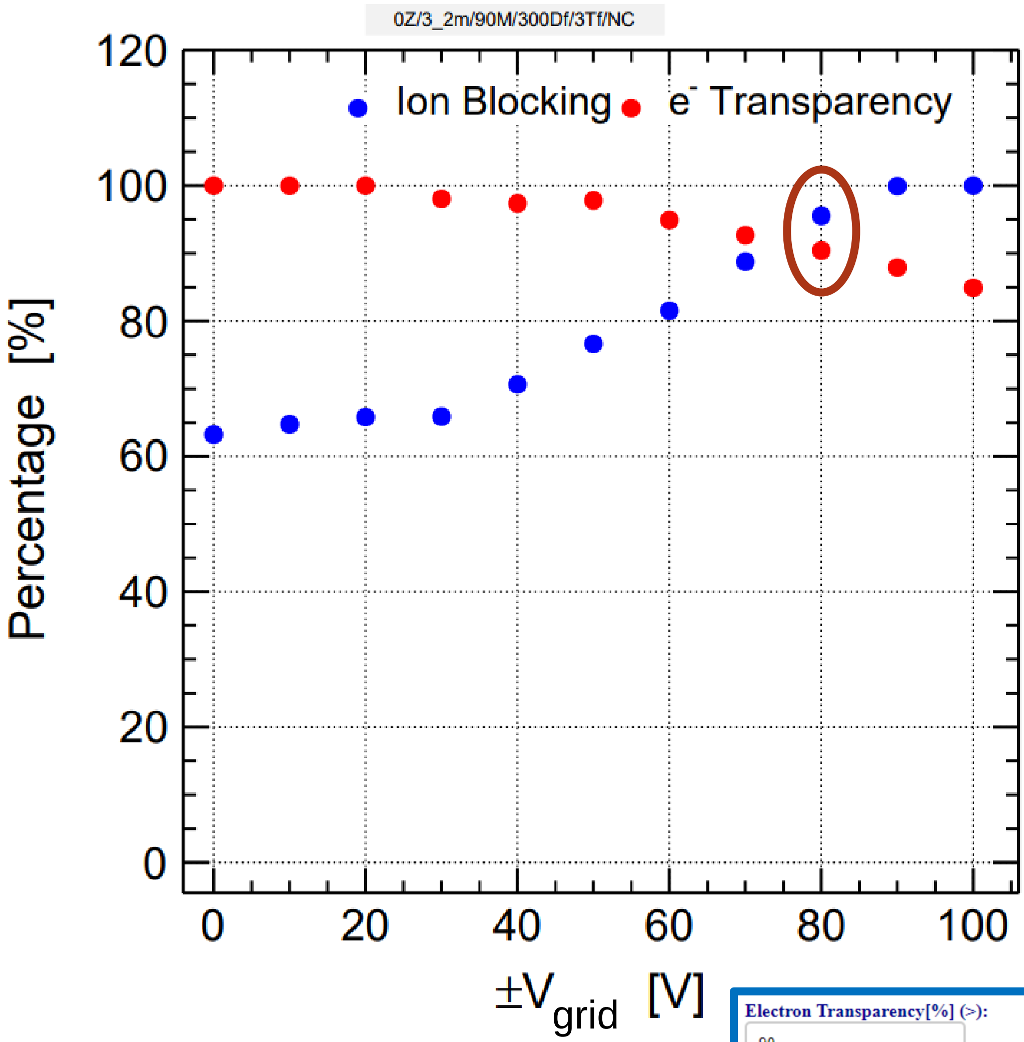
Transfer Field [V/cm]
3*DF

Wire Diameter [µm]
90

Pitch [mm]
3/2

Split Wire Planes [µm]
0.0

Gas Mixture
Ne+CF4 (90:10)



- e^- Transparency drops (100% ➔ 90%)
- Ion Blocking jumps (3x ➔ 20x)

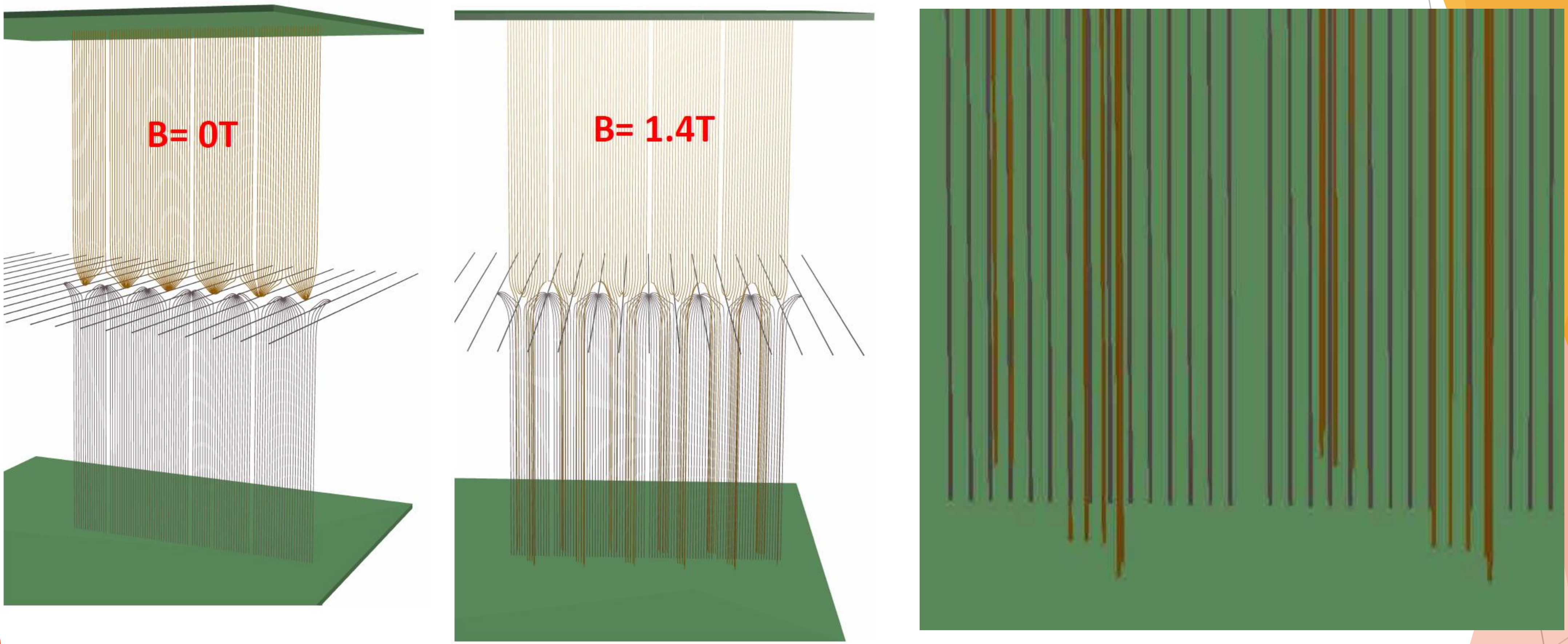
- Results tabulated over many Mesh properties.
- Web-searchable database over all parameters.

Electron Transparency[%] (>): 90
Ion Blocking[%] (>): 90
Drift Field [V/cm]: 300
Gas Mixture: Ne+CF4 (90:10)
Show List

Electron Transfer[%]	Ion Blocking[%]	Drift Field [V/cm]	Transfer Field[V/cm]	Pitch[mm]	Wire Diameter[micron]	Z_Split [micron]	Delta_V [Volt]	Gas Mixture
91.76	91.92	300	900	1.50	30	60	100	NeCF4
92.48	90.34	300	900	1.50	60	60	80	NeCF4
90.16	95.84	300	900	1.50	60	60	90	NeCF4
91.22	90.40	300	900	1.50	30	0	100	NeCF4
90.84	94.60	300	900	1.50	60	0	90	NeCF4
90.42	95.54	300	900	1.50	90	0	80	NeCF4

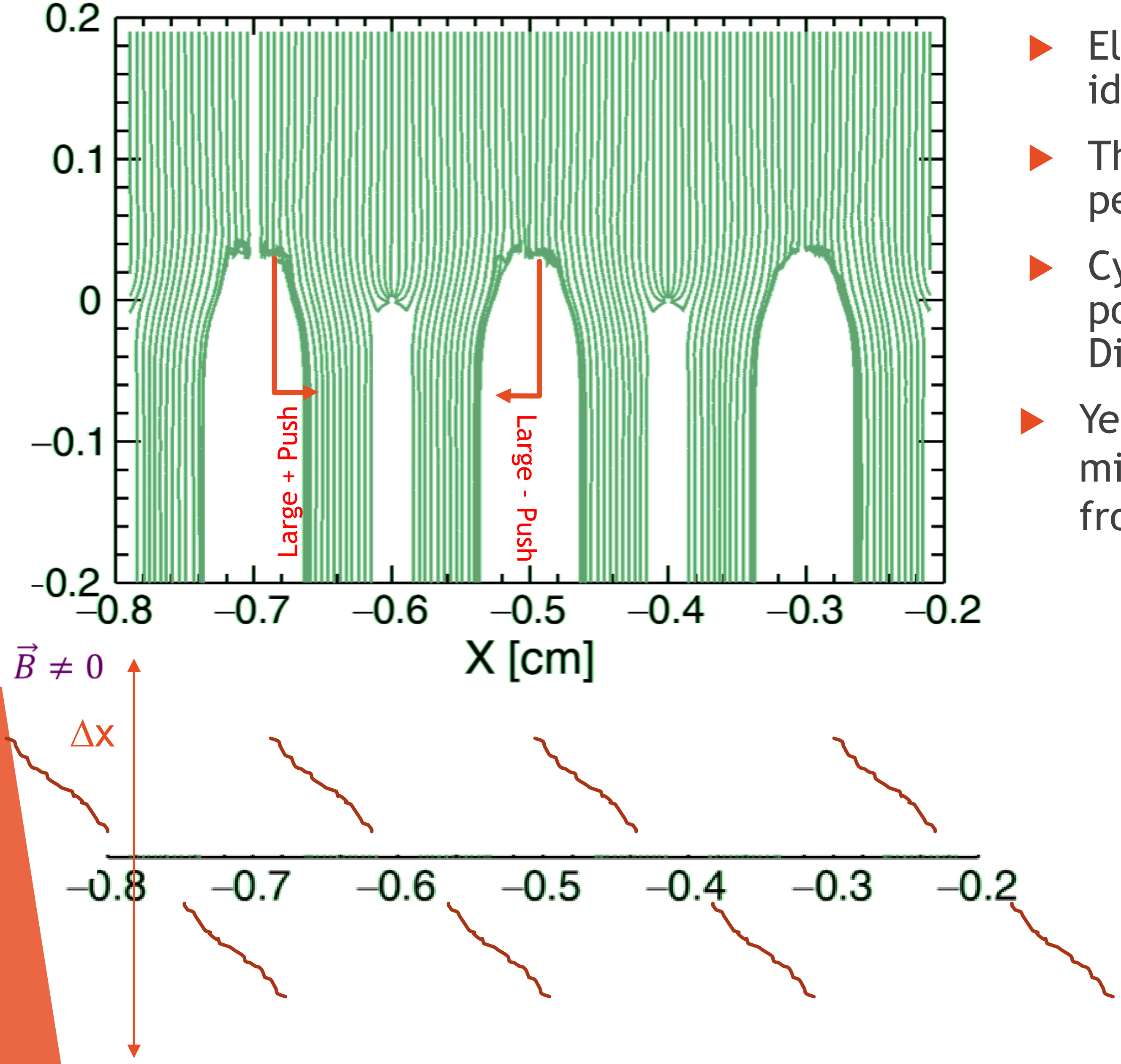
…But there must be a catch…right?

Primary Push is ALONG the wire!



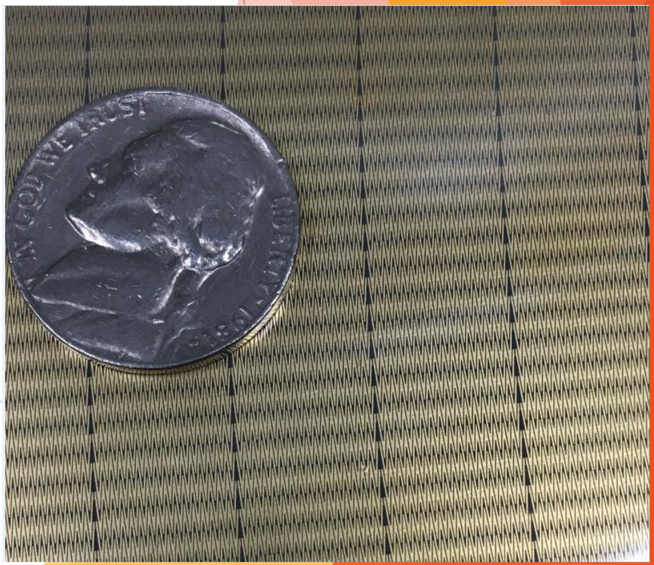
- $\hat{E} \times \hat{B}$ near the wire is along the wire.
- Once the electron picks up a velocity along the wire, only then does it move transverse to the wire…miss the wire…get transmitted…save the day.
- Can we tolerate or compensate the distortion along the wire?

Distortion as Differential Non-Linearity



- Electron Displacements from ideal trajectory are cyclic.
- The cycle repeats with the same period as the wires.
- Cyclical shifts from ideal positions are known as Differential Non-Linearity.
- Years of effort have gone into minimizing or eliminating DNL from zig-zag pad response.

QUESTION: Can we define a specially distorted pad shape to compensate the "DNL" in electron positions introduced by the Bi-Polar mesh?



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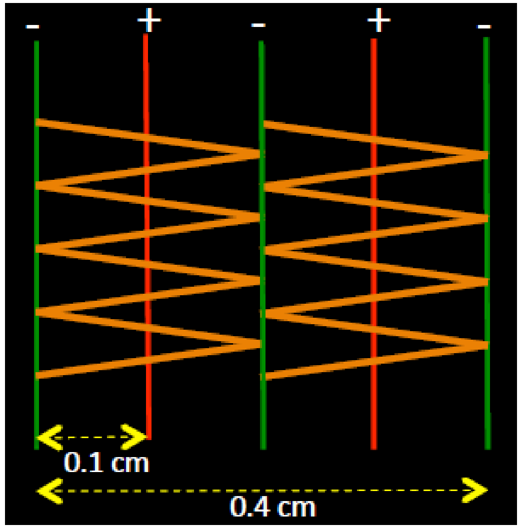
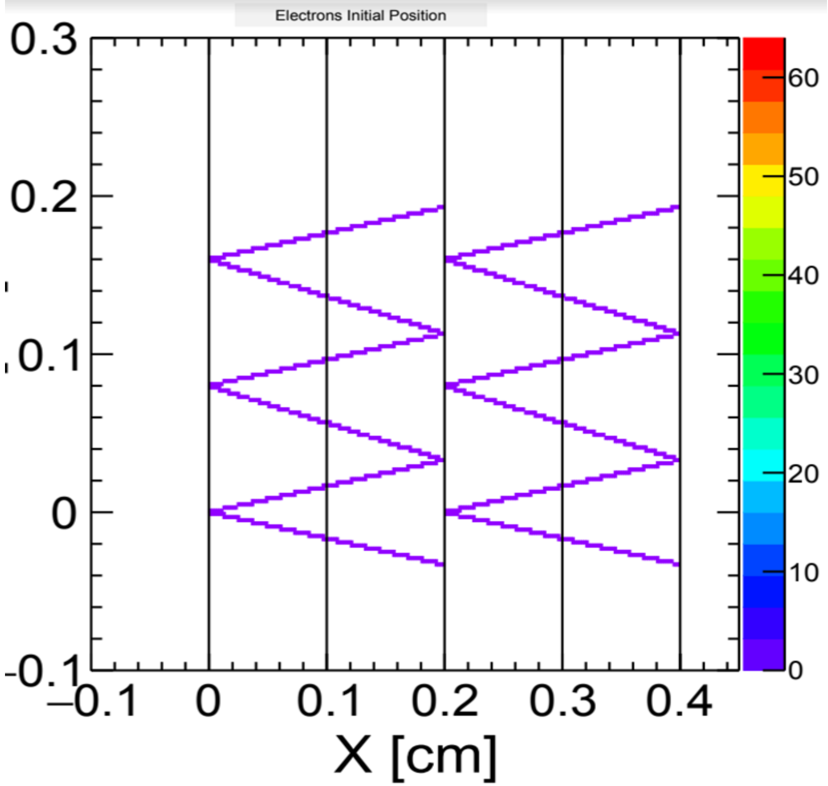
How to Anti-Distort the electrons?

- We know how to define a zig-zag shape with minimal DNL:
  - Maximum “incursion” of neighboring pads (>95%)
  - Minimal tip-to-tip spacing (< spot size of avalanche)
- The following procedure defines the anti-distortion zig-zag shape:
  1. Match the wire pitch to the pad pitch.
  2. Generate electrons at positions that SHOULD intercept the gaps between Zig-Zag.
  3. Propagate electrons through all distortions.
  4. Match the actual pad gaps to the determined electron landing spots.
- Shorthand: Design that each electron lands on the same pad number as without distortion!

Distortion Examples

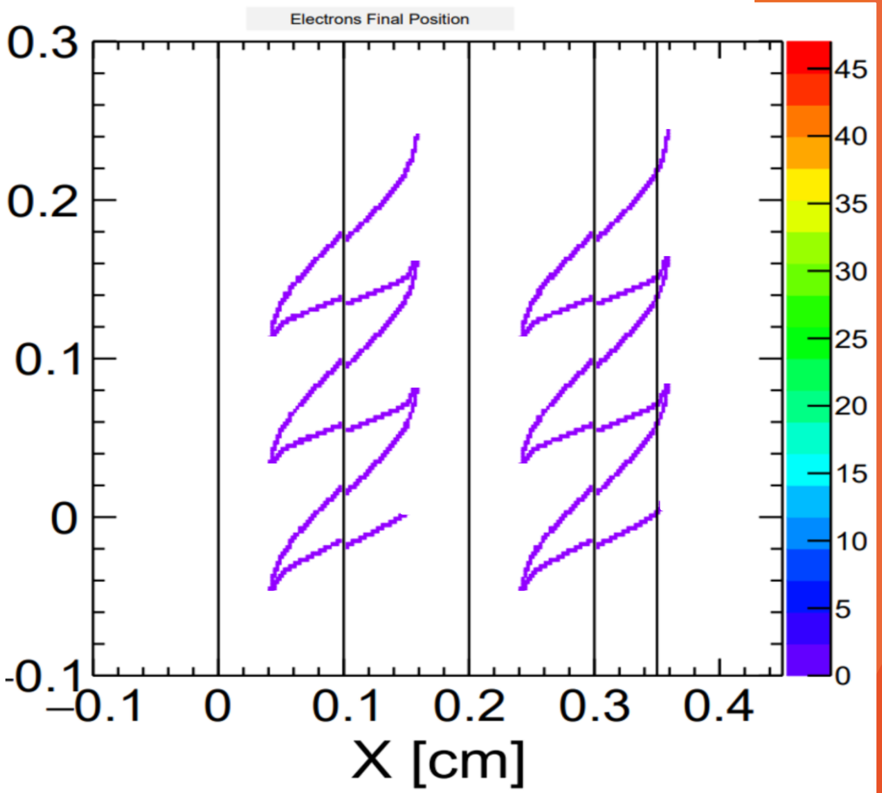


Original Pad Edges



Initial e^- positions

Distorted Pad Edges

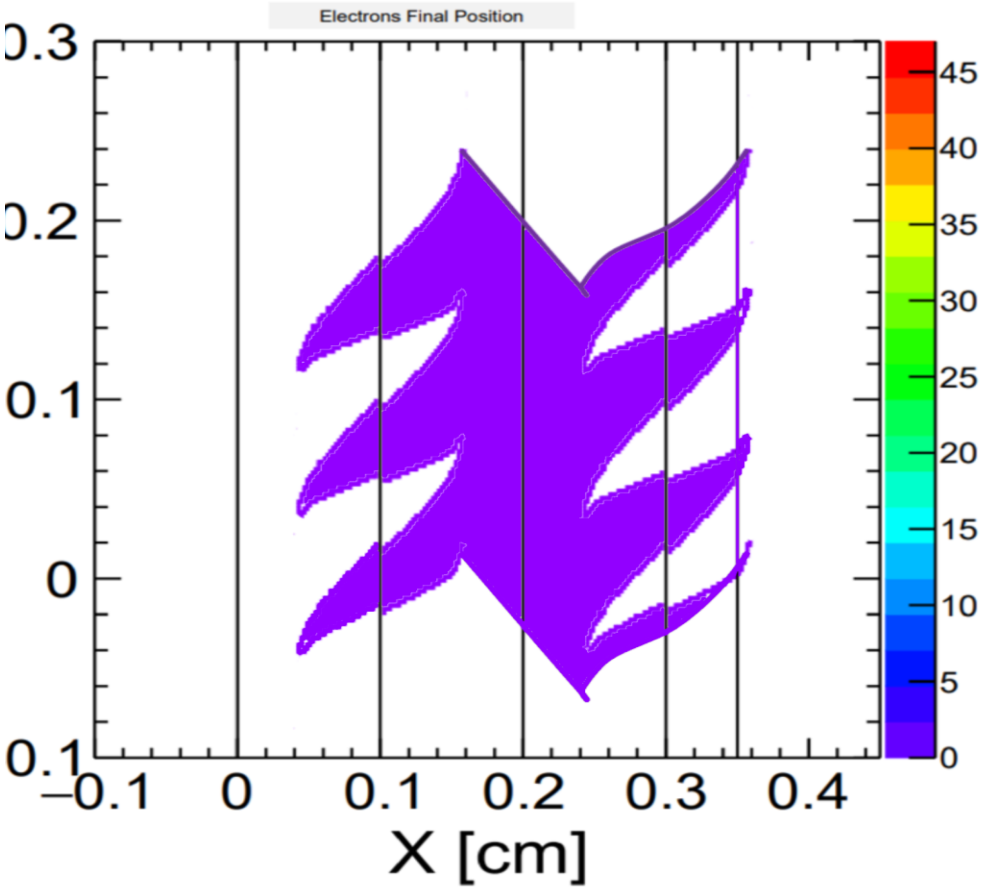


Final e^- positions

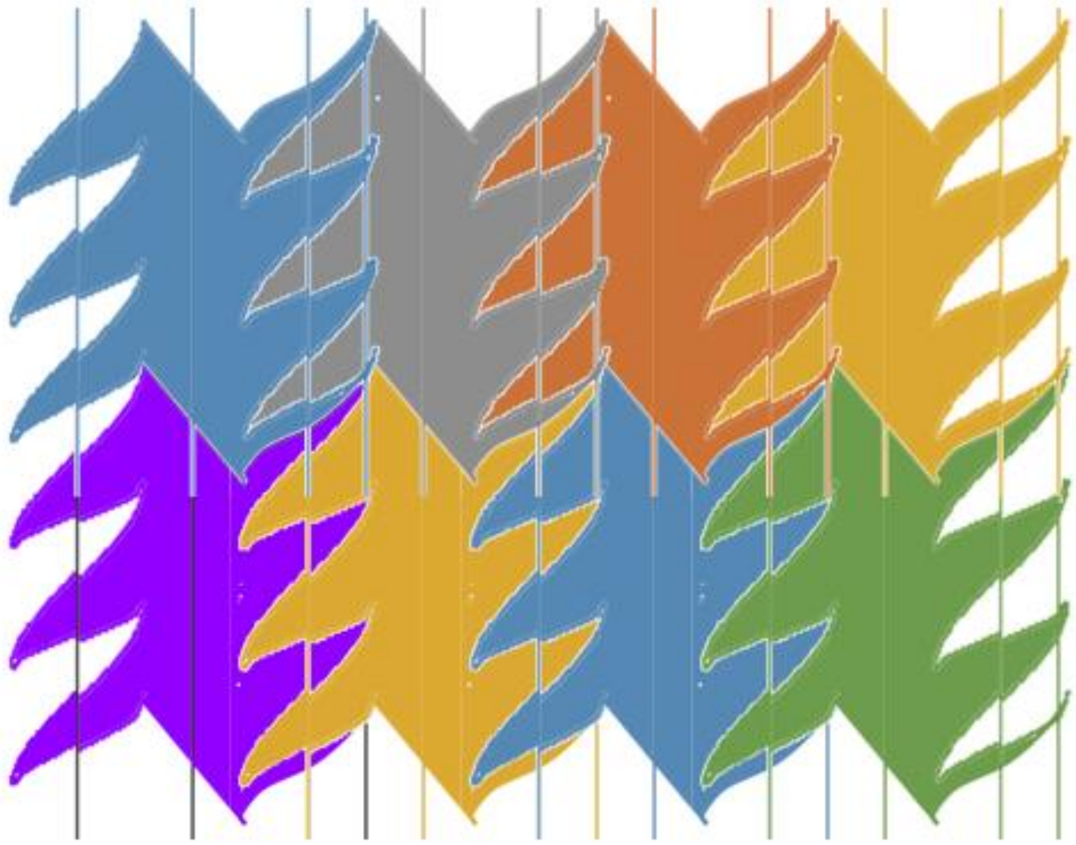
- Bipolar wires on top of pads (one example, multiple arrangements possible)

Colors to guide the eye

Distorted Pad Shape



Distorted Pad Array



Summary

- IBF is, by far, the main contribution to SC
- Quad-GEM & dual-GEM + μM are able to reduce IBF
- Passive wire mesh can reduce IBF
- Passive bi-polar wires can reduce IBF and we might be able to account for position resolution by creating pre DNL-distorted pads
- Further work needs to be done

- Current sPHENIX design meets all of our goals, but we will still study this as a possibility for improvement

- Thank you
  - Funded by U.S. DEPARTMENT OF ENERGY

BACKUP SLIDES

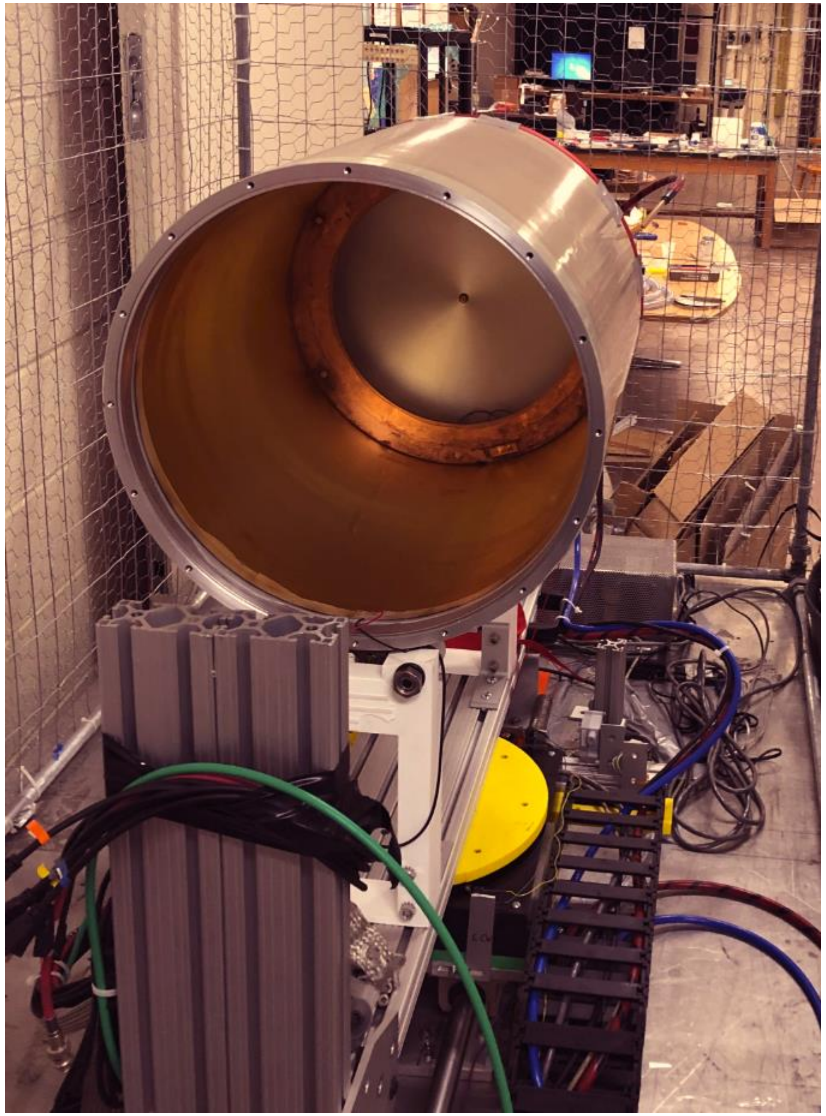
Construction & Primary sPHENIX Goals

- Tracking
  - Monolithic Active Pixel Sensor (MAPS)-based vertex detector (MVTX)
  - Intermediate silicon sTrip Tracker (INTT)
  - Time Projection Chamber (TPC) --Main tracking detector
- Calorimeter
  - Electromagnetic
  - Hadronic

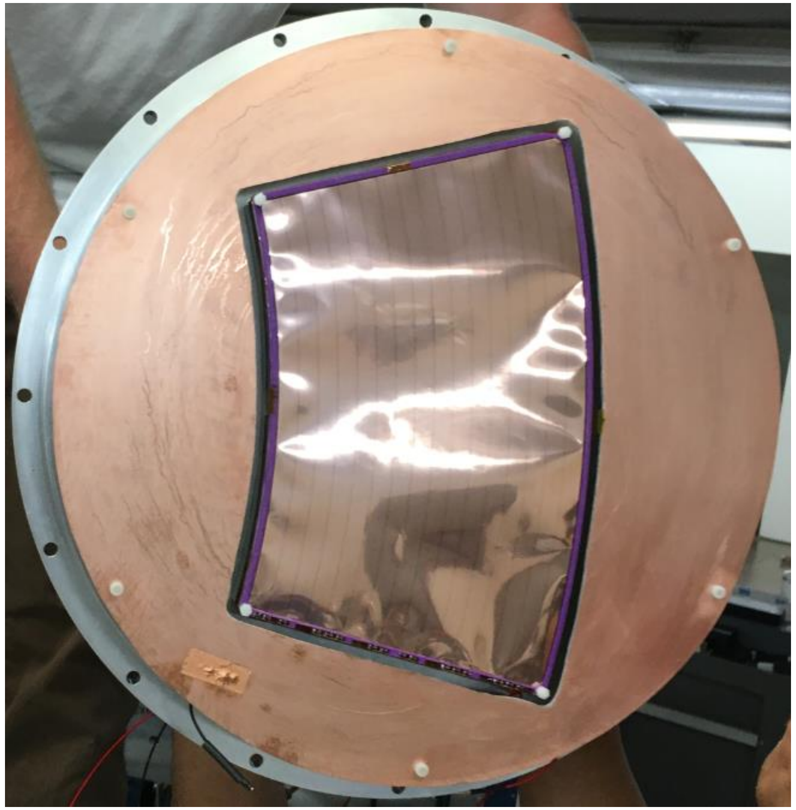
- Jet measurements
- b-quark tagging
- Clear Upsilon 1s, 2s, 3s energy states resolution
  - Achieved with TPC
  - Will allow probing of Quark Gluon Plasma (QGP) screening length
  - TPC is day-one ready for EIC

Backup 1

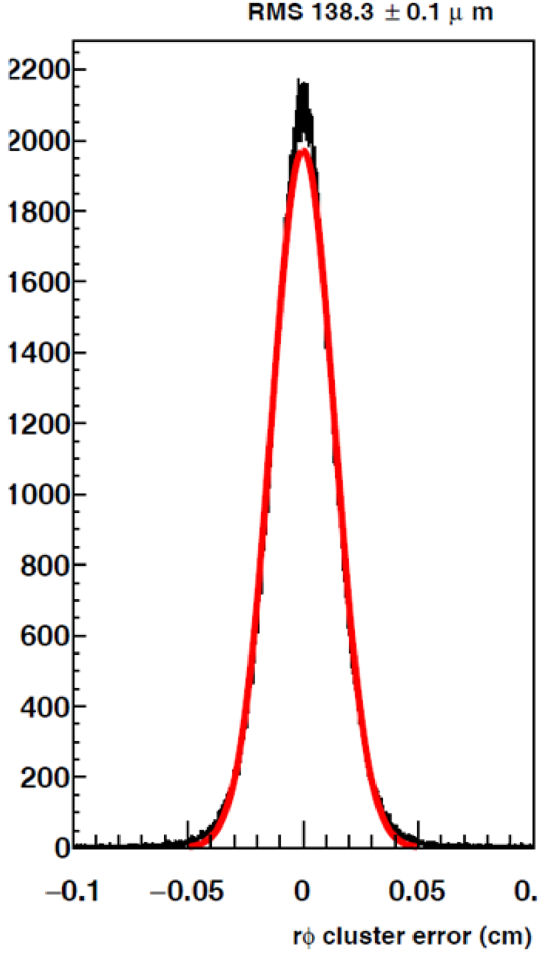
Mini Prototype TPC



Module with GEM Stack



TPC mid cluster [by Tony Frawley]



Backup 2

IBF & Space Charge (SC)

- Ionization $\propto Z^2$: Use Low-Z Primary Gas (Ne)
- Multiplicity: # of particles from collision (nature)
- Rate: beam-crossing interactions (we control, ≈100kHz)
- z = distance from CM
- ρ greater at smaller **r** since it's closest to beam collision, and particles spread $\propto \frac{1}{r^2}$
- ρ greater at smaller **z** since it sees more ions as they drift to the CM

Backup 3