The sPHENIX TPC Project

KLAUS DEHMELT
FOR THE sPHENIX COLLABORATION

MPGD2017

TEMPLE UNIVERSITY
MAY 23, 2017

Stony Brook University | The State University of New York

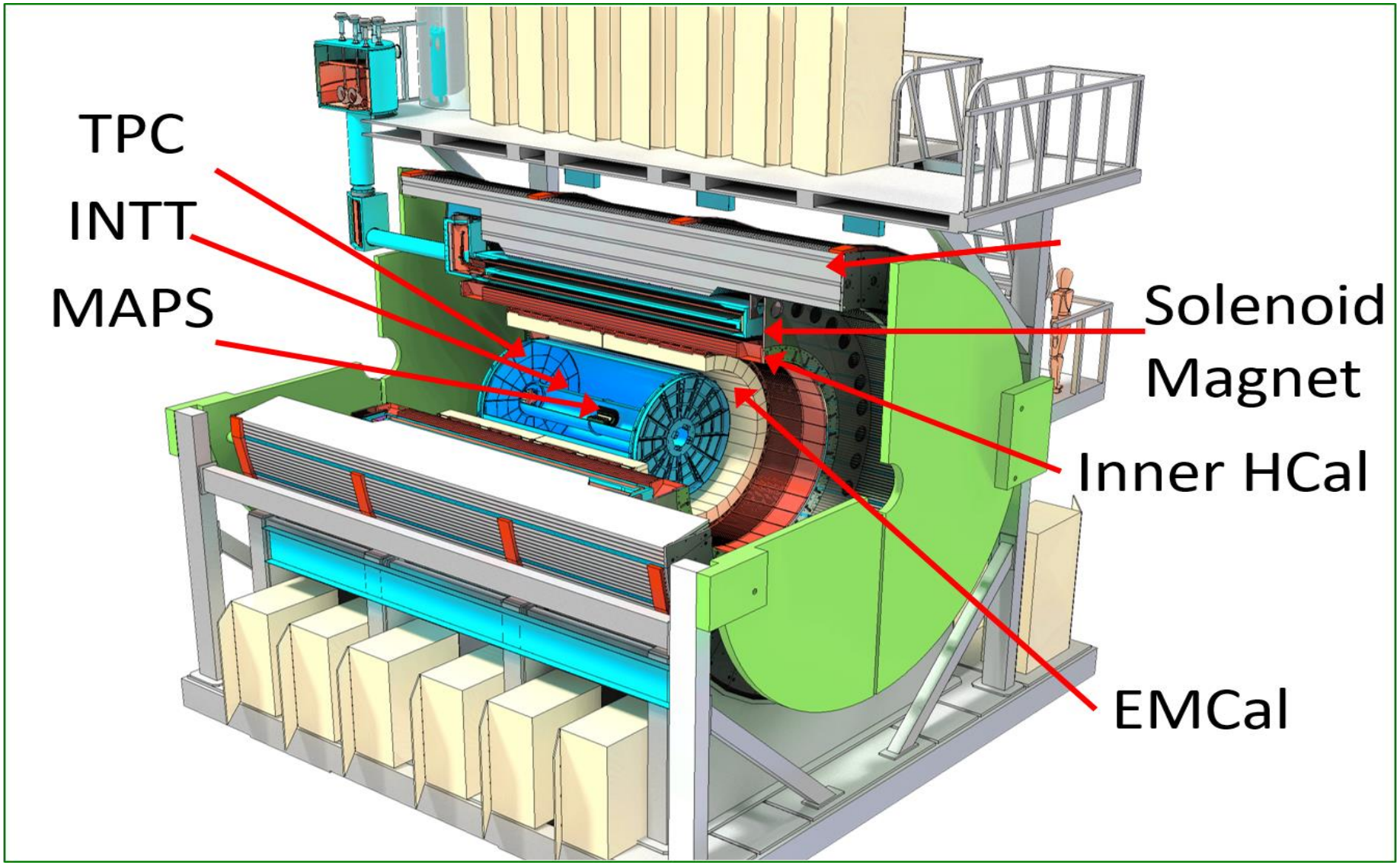
PHENIX

The sPHENIX Experiment

- sPHENIX is a new proposed experiment at RHIC, plans to begin taking data in 2022
- Goal
  - Determine temperature dependence of Quark-Gluon Plasma
  - Measuring
    - Jets
    - Jet correlations
    - Upsilon states
- Required ingredients for these measurements
  - Electromagnetic/Hadronic calorimetry
  - High resolution, low mass tracking system
  - High data acquisition system to handle an estimated peak collision rate of 200 kHz and ~15 kHz "trigger" rate

The sPHENIX Experiment

M. Connors



The sPHENIX Experiment

M. Connors

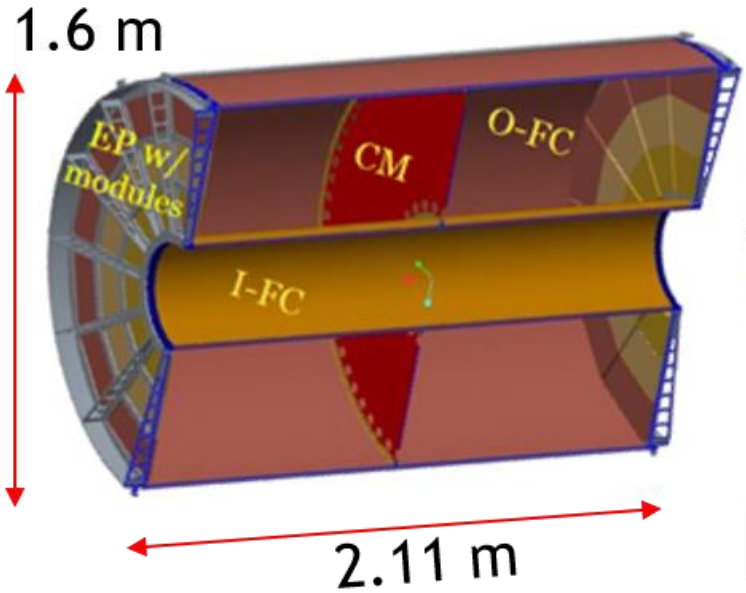
Physics Goal	Detector Requirement
Fragmentation Functions	Excellent Momentum Resolution: $dp/p \sim 0.2\%$ for p to > 40 GeV/c
Jet Substructure	Excellent track pattern recognition
Distinguish Upsilon States	Mass resolution: $\sigma_M < 100$ MeV/c^2
Heavy Flavor jet tagging	Precise DCA resolution $\sigma_{DCA} < 100$ μm
High Statistics Au+Au 200 GeV	Handle multiplicity and full RHIC luminosity

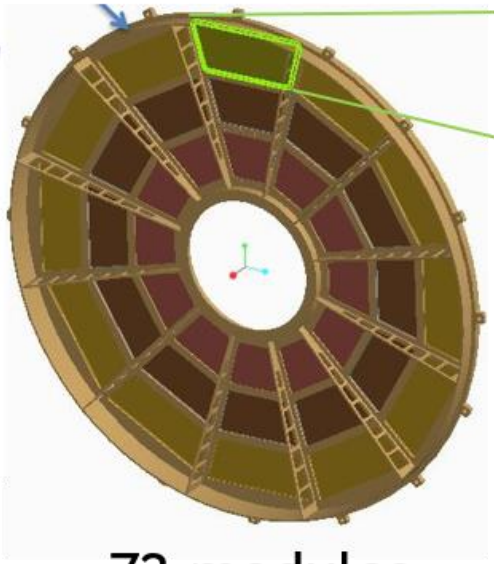
- Accomplished by
  - 3-layer Si-pixel detector (MAPS)
  - 4-layer Si-strip detector (Intermediate tracker)
  - Compact Time-Projection Chamber (TPC)
- TPC → continuous readout, small space charge distortion
- Barrel solenoid magnet (Babar) dictates dimension of TPC
  - 20 cm < radius < 75 cm, 2π azimuthal coverage
  - Total length = 211 cm → $|\eta| < 1.1$ polar coverage

Poster: sPHENIX TPC simulation studies by S. Tarafdar

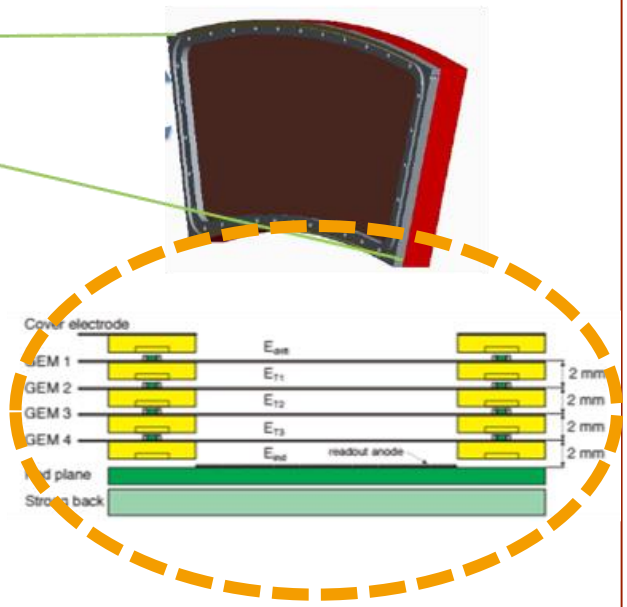
The sPHENIX TPC

- Novel TPC concept developed by ALICE
  - No-gate option due to continuous, high rate readout requirement
  - Can only be achieved with MPGD readout → combat Ion Back Flow



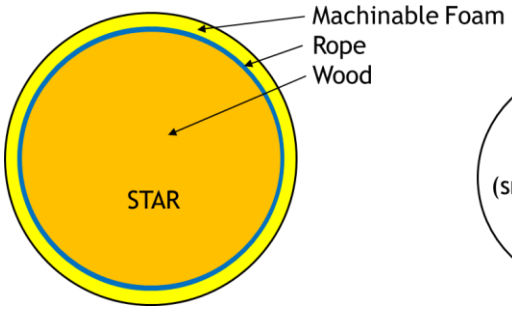


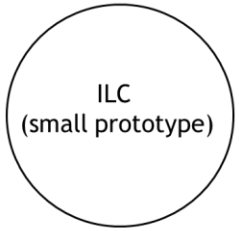
72 modules
2(z), 12(ϕ), 3(r)

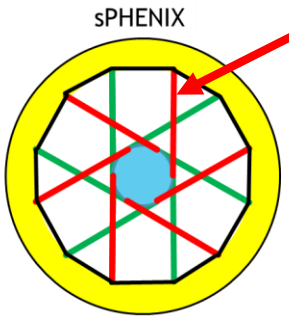


Field Cage

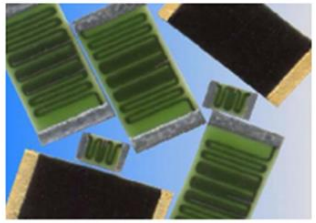
- Hybrid between STAR and ILD

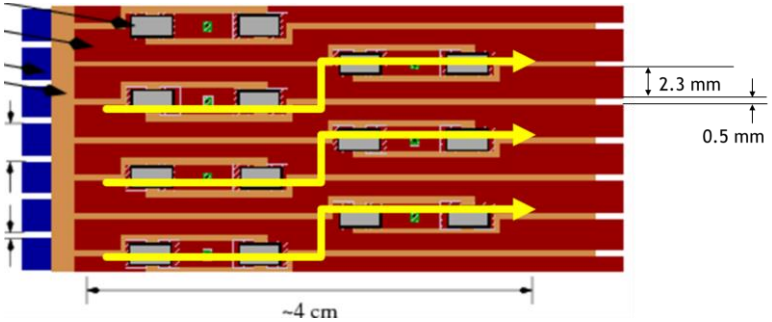


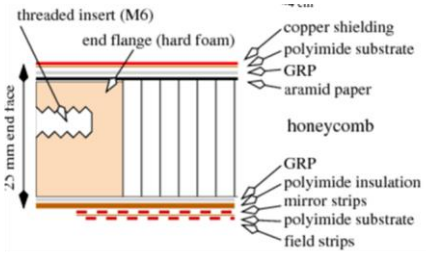


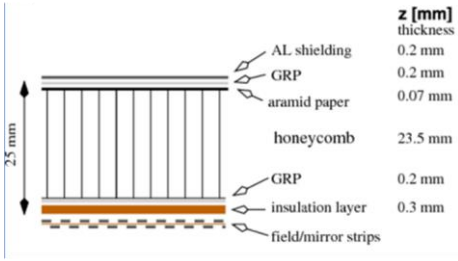


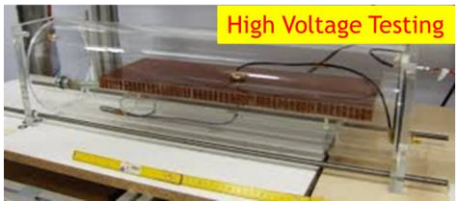
Disassemble spokes to release field cage.

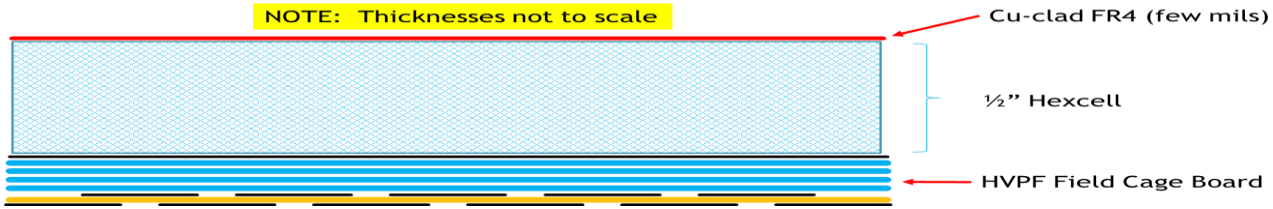










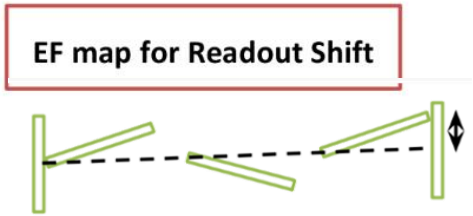


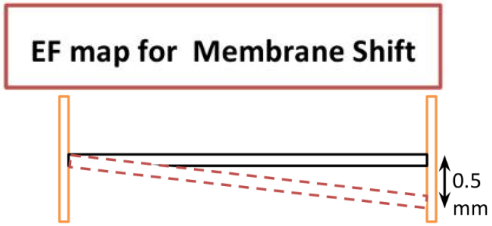
Poster: Mechanical Construction of the field cage of sPHENIX TPC by N. Ram

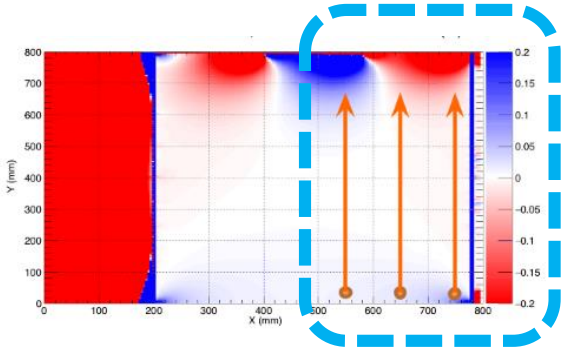
Field Cage

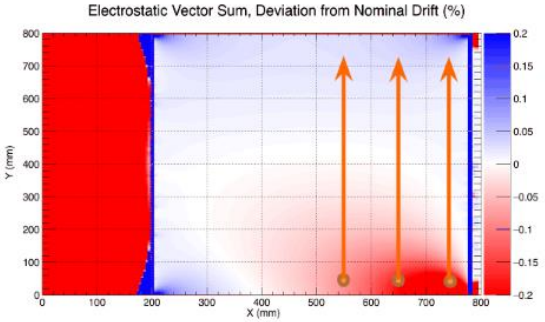
P. Garg (SBU) using ANSYS & GARFIELD

- Mechanical/electrostatic tolerance studies
  - Module tilt
  - Membrane tilt
  - Shifted field cage
  - Rotated field cage
  - Resistor tolerance







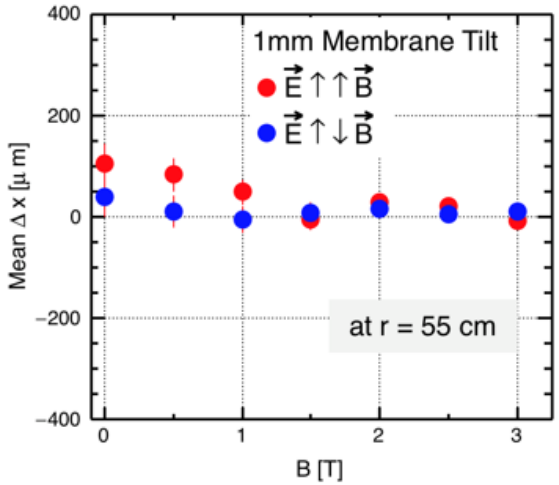


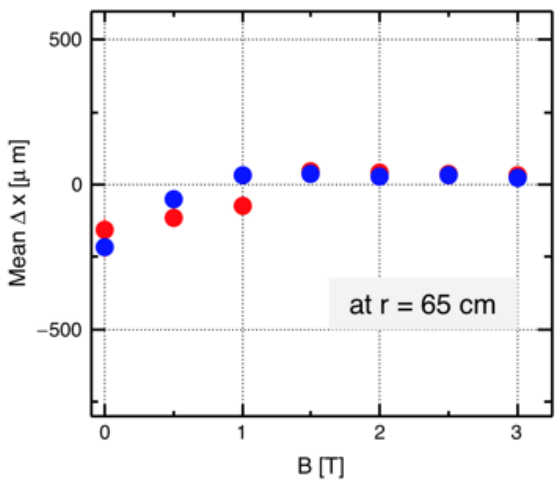
Poster: R&D and related Simulation Studies for the sPHENIX Time Projection Chamber by P. Garg

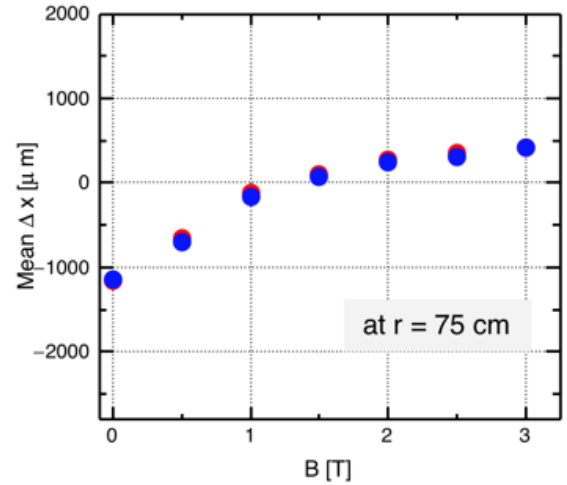
Field Cage

P. Garg (SBU) using ANSYS & GARFIELD

- Mechanical/electrostatic tolerance studies
  - Module tilt
  - Membrane tilt







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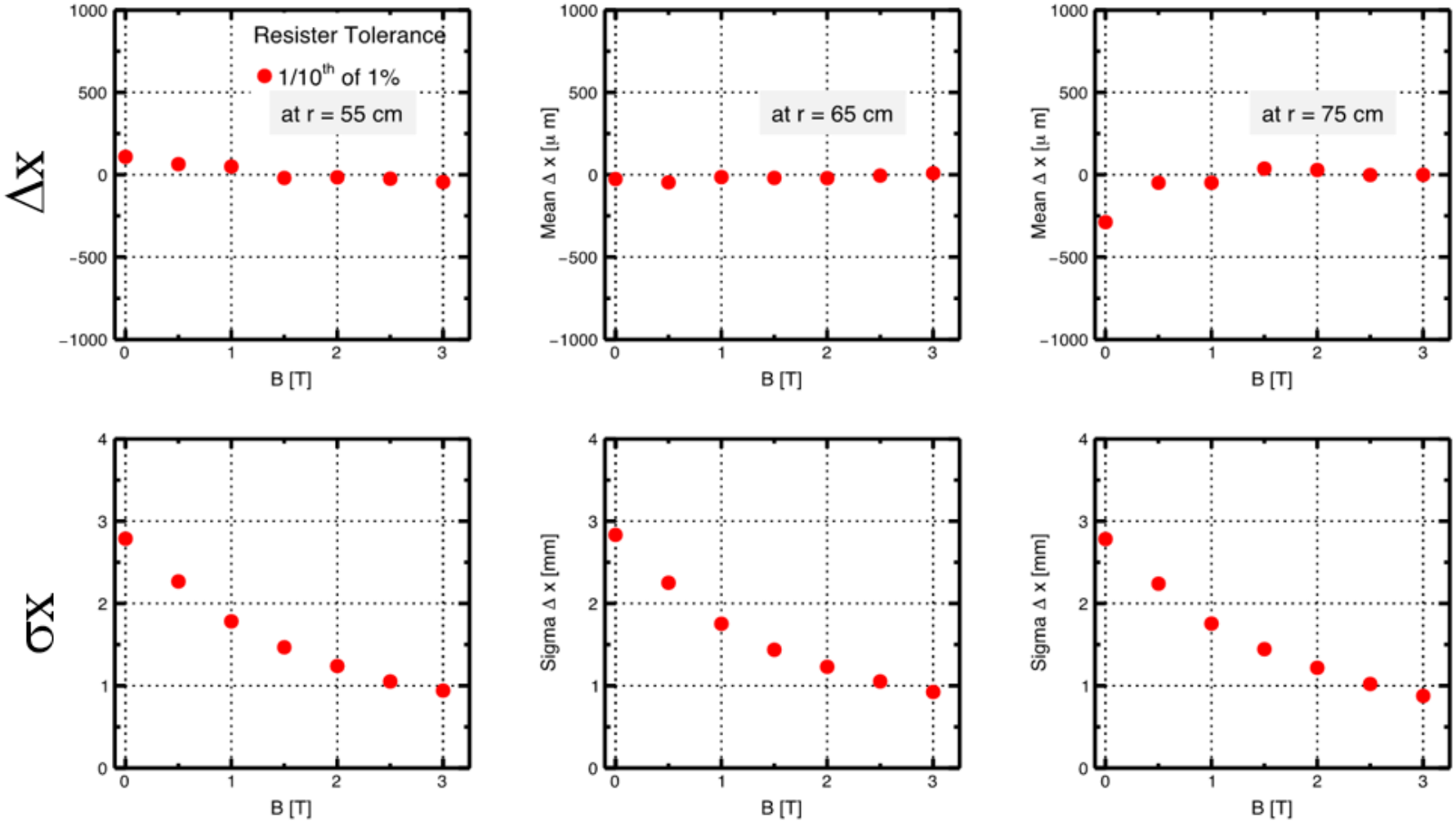
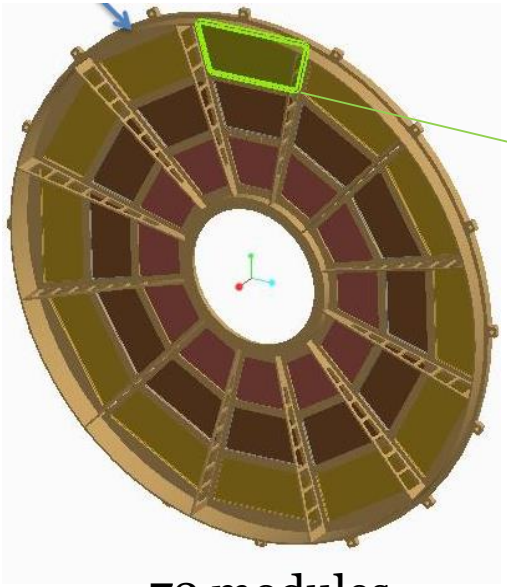
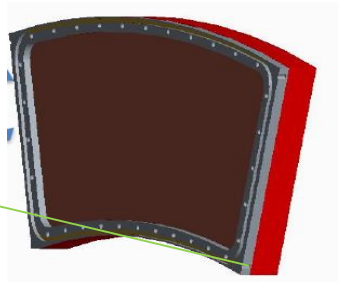


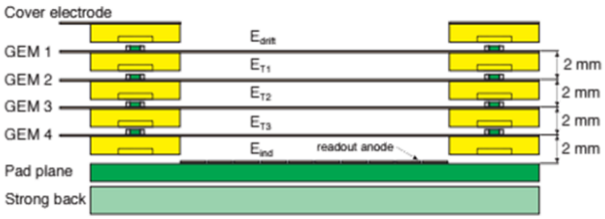
Poster: R&D and related Simulation Studies for the sPHENIX Time Projection Chamber by P. Garg

Readout Modules

- Module design





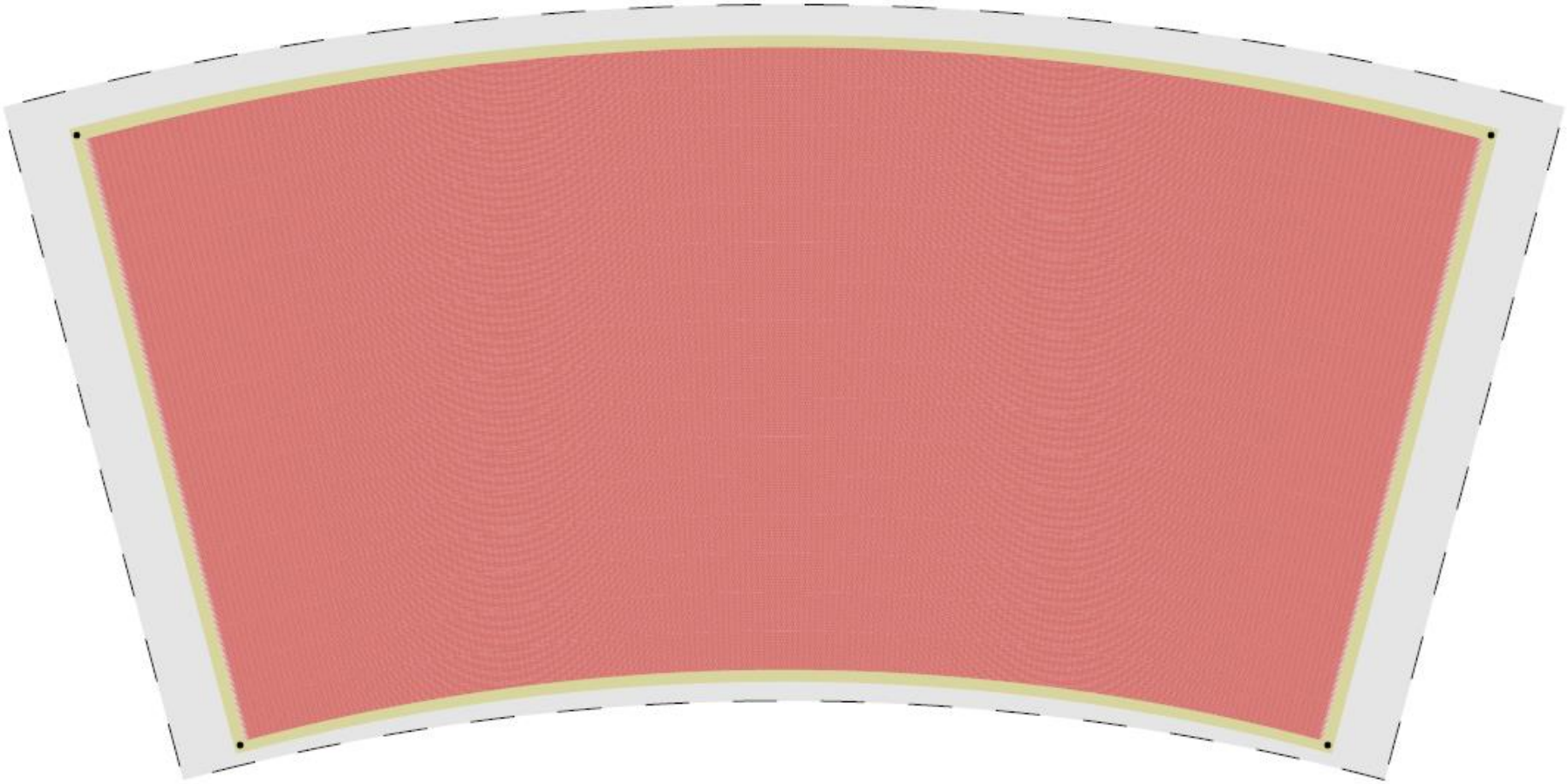


72 modules
2(z), 12(ϕ), 3(r)

Quad-GEM Gain Stage
Operated @ low IBF

Readout Modules

B. Azmoun



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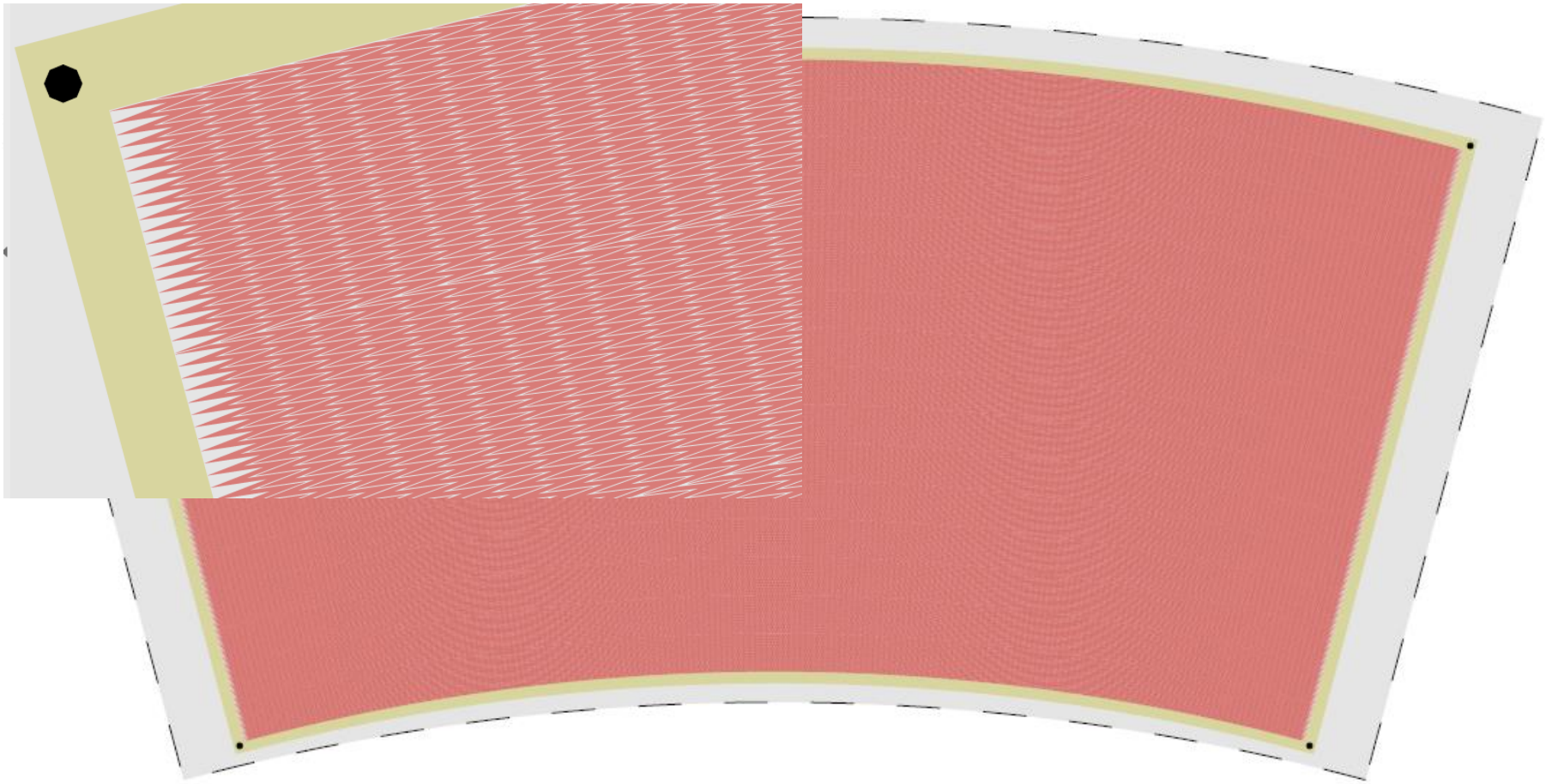
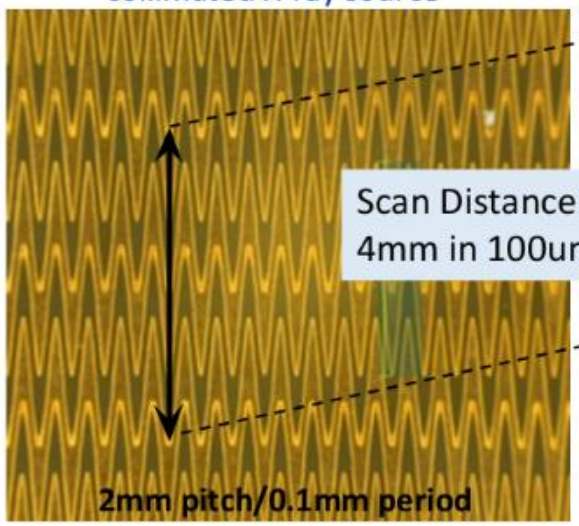


Readout Modules

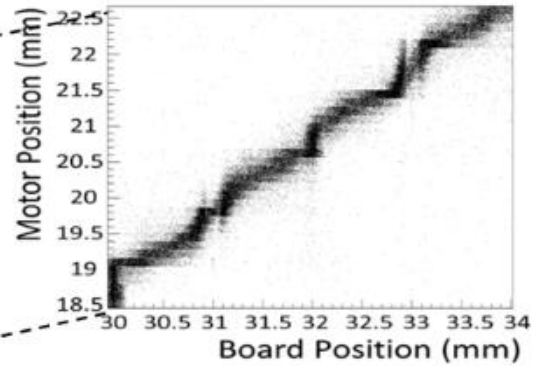
B. Azmoun

- Module design

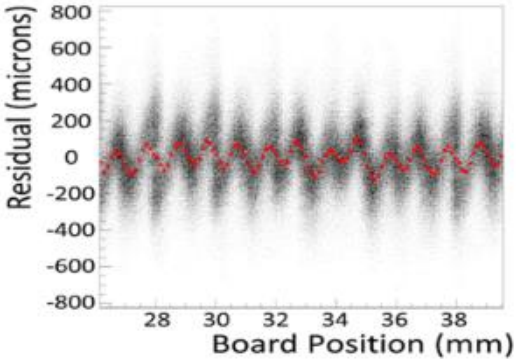
Scan across chevron pads with collimated X-ray source



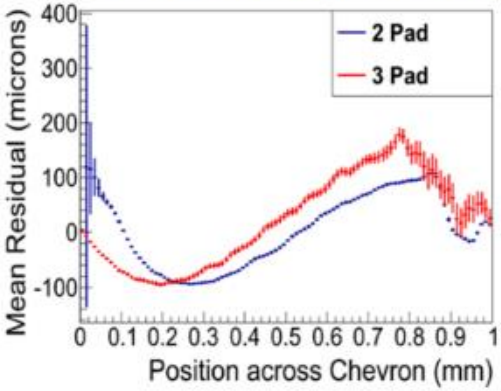
True Hit Pos. Vs Derived Pos.



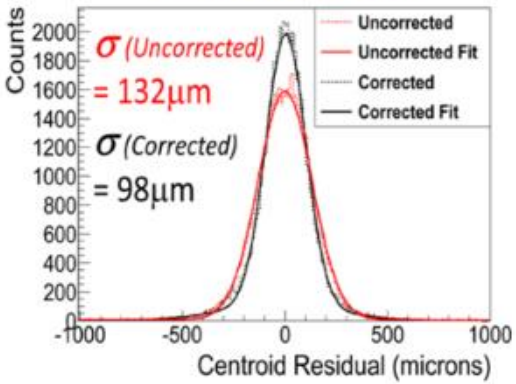
Differential Nonlinearity



Universal Correction for DNL



Position Resolution



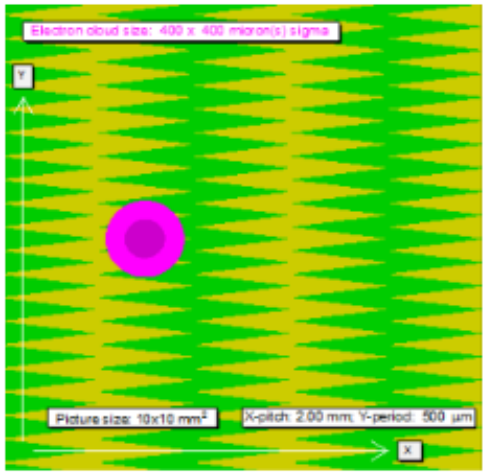
- Ideally, looking for flat correction fcn, so that no correction is required
- Interleaving pads can obtain better than 100um resolution with 2mm pitch

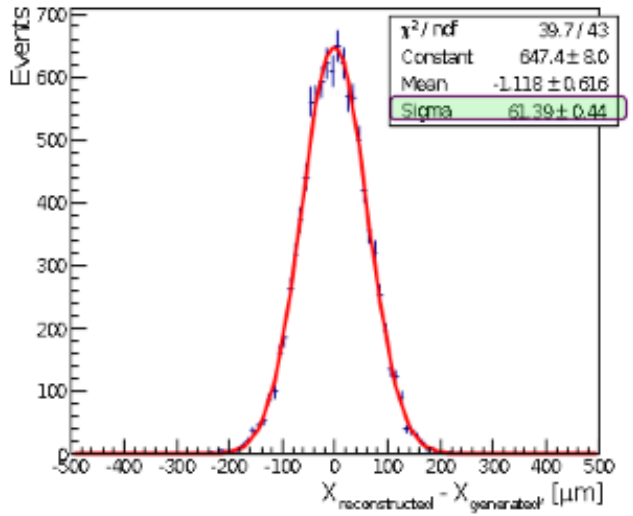
Readout Modules

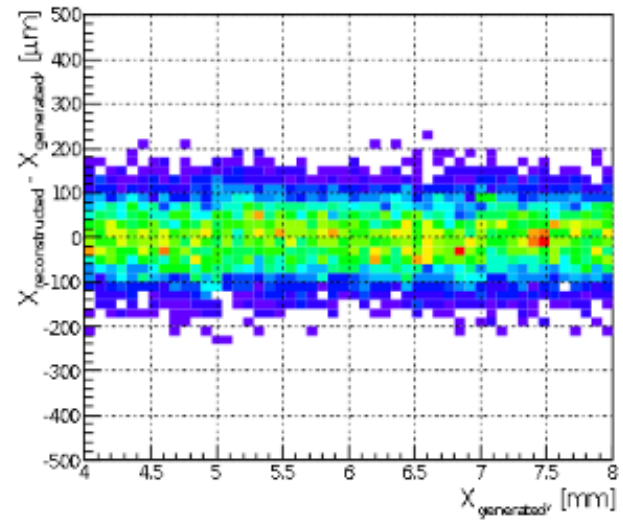
B. Azmoun

- Electron cloud: 2D Gaussian profile
- Generate N electrons according to gain
- Constant 2% N/S per pad

- Collect electrons onto pads assuming uniform field
- (field distortion will be added soon)
- Cross talk at level of 5% added, but unfolded

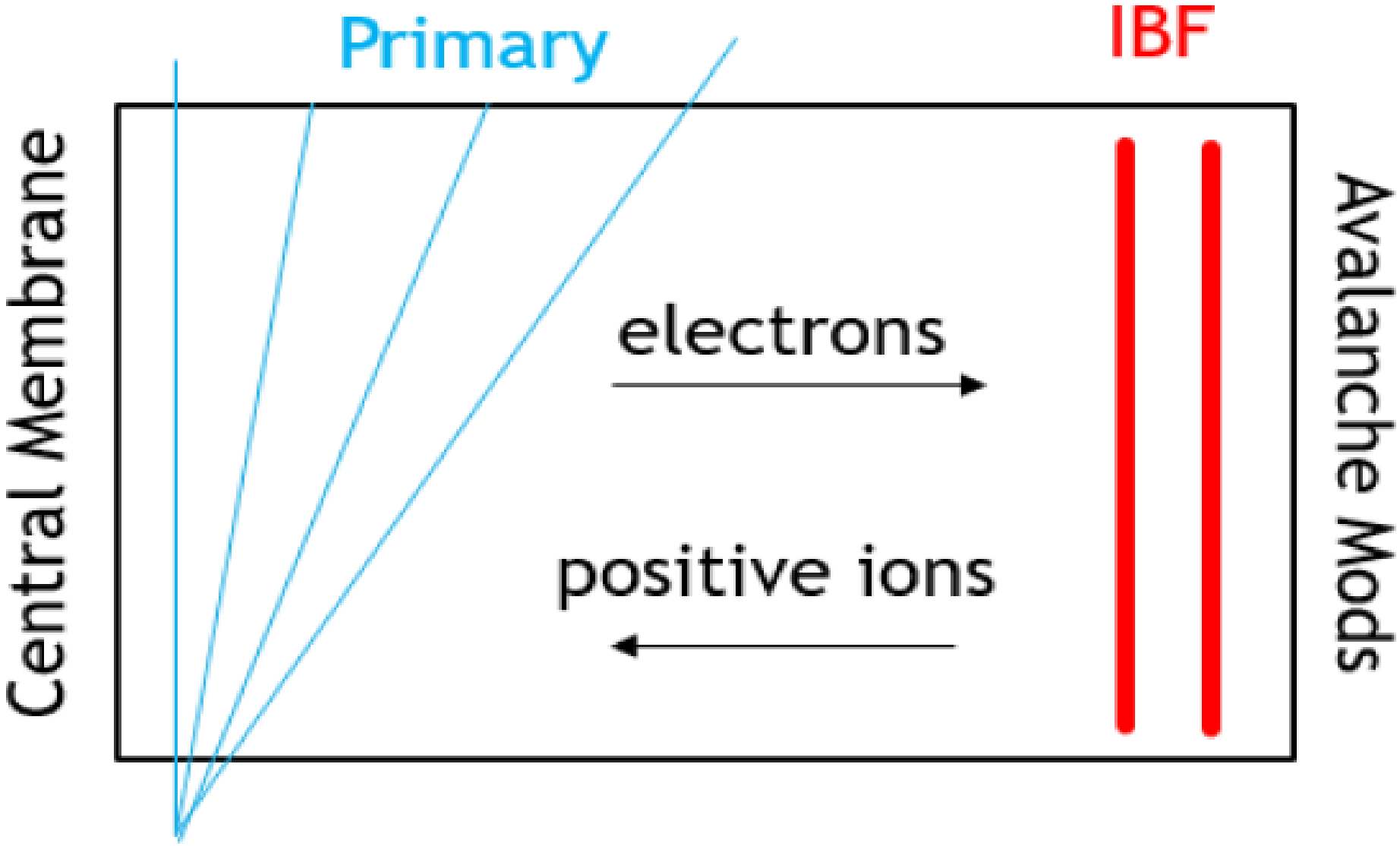






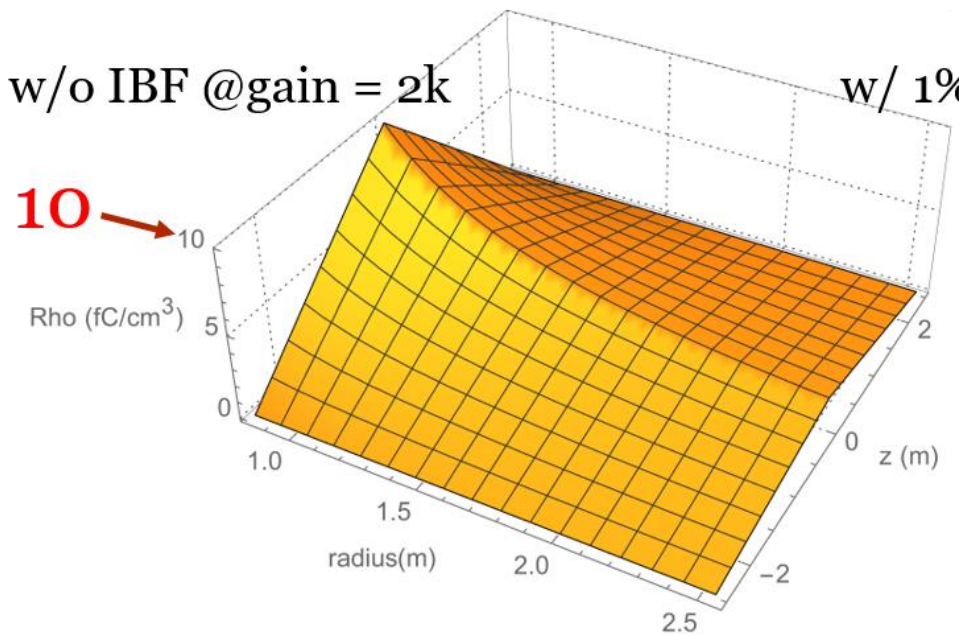
- **Guiding principle**: develop design with as close to linear response as possible (ie minimize need for correction functions, like DNL)
- The zigzag design above ensures that the charge sharing is directly proportional to hit position
- No DNL; constant resolution as a function of hit position
- Pad pitch and zigzag period are nicely matched to size of charge cloud (400-600um)
  - →No single pad hits (ie, avoid low position sensitive regions)
  - No beating artifacts as a function of Y (since Y-zigzag period is small compared to cloud size)
  - No strip collects more than 85% of charge
- This design is almost independent of charge cloud size (from 200-600um)
- More exotic designs needed to address real life constraints like gap width and trace thickness limitations, and field distortions

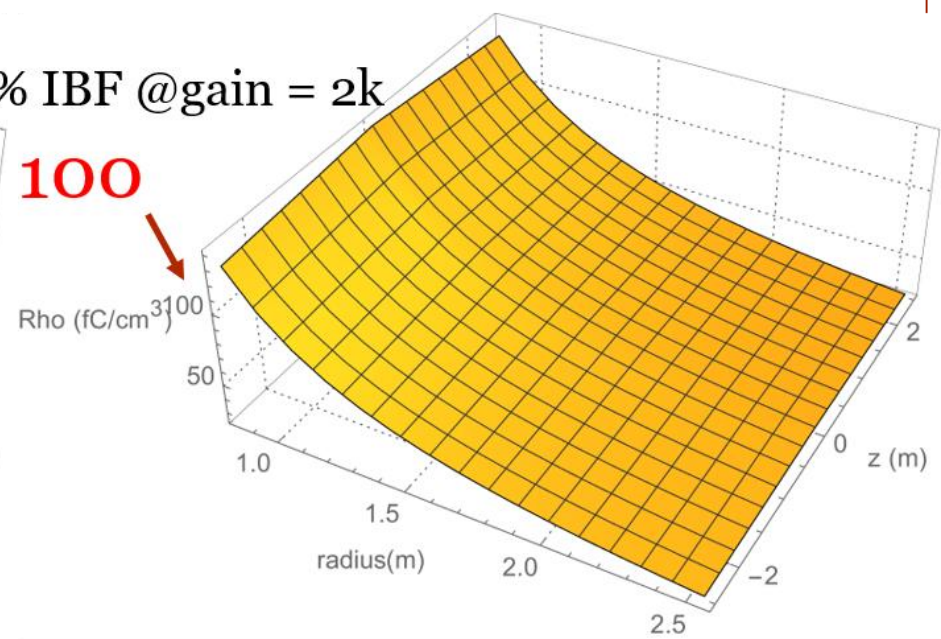
TPC & Space Charge



TPC & Space Charge

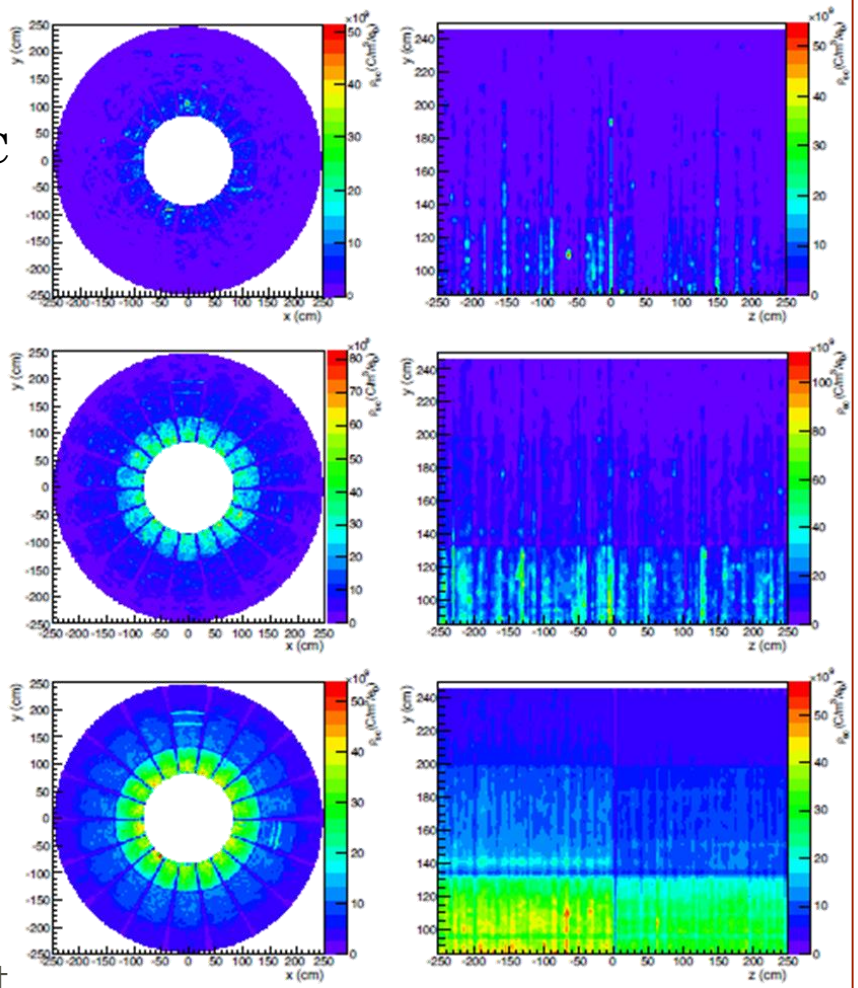
ALICE w/50 kHz PbPb: charge density in fC/cm³ vs radius and z (in m)





TPC & Space Charge

- Distortions can be ENORMOUS
  - STAR: 10 cm peak distortion corrected to 400 μm (0.4 %)
    - Corrects for primary charge only (gated TPC ~no IBF from gain stage)
    - Analytical phi-symmetric correction driven by current luminosity
  - ALICE: 20 cm distortion corrected to 200 μm (0.1%)
    - IBF = 20*x* larger than primary charge
    - Continuous readout determines INSTANTANEOUS space charge (every 5 ms)
    - 3D correction since IBF determined by GAIN
- Advantages in sPHENIX
  - Only the physics of the effect is given
  - Appropriate design can minimize the impact



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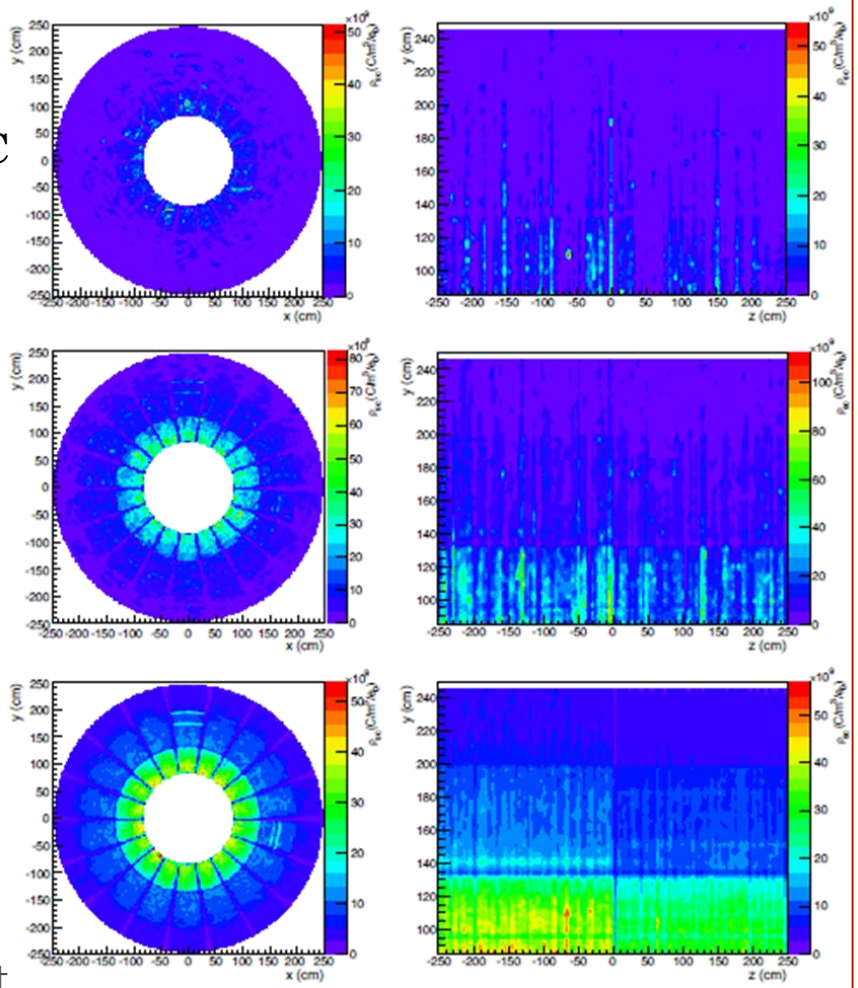


Poster: sPHENIX Compact TPC for Tracking and Particle Identification by C.E.P. Perez Lara

Focusing on computation of the space charge using as initial density a simulation of hijing+geant4 and bunch crossings for the sPHENIX case

Combat Space Charge

- Several ways to combat Space Charge
  1. Make the ions fast through mass
  2. Choose the largest drift field possible
  3. Optimize amplification device's operating point
  4. Update design of field cage informed by current experience
  5. Improve amplification device
     i. Remove "gain fluctuation" before amplification
     ii. Increase number of amplification stages
  6. Multi-layer gating grid
  7. Accelerator parameters
  8. Don't let ions be created

Combat Space Charge

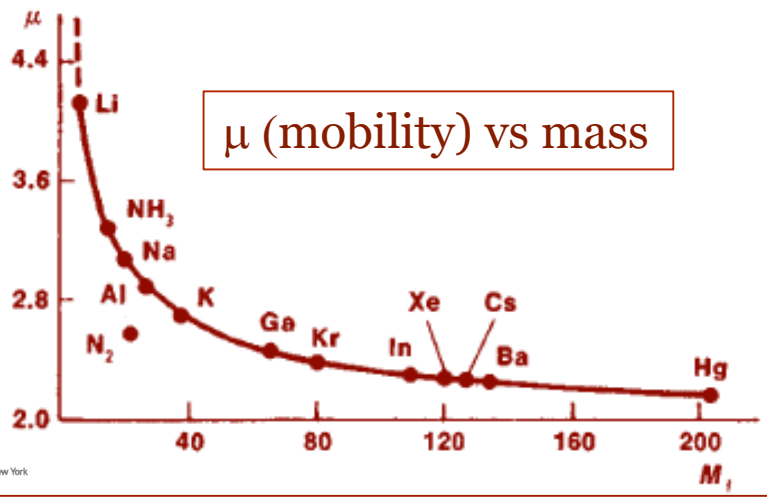
- Several ways to combat Space Charge
  1. Make the ions fast through mass

$$v_{ion} = K \cdot E$$

with K: ion mobility
E: Electric field

$$\frac{1}{K_{tot}} = \frac{f_1}{K_1} + \frac{f_2}{K_2} + \frac{f_3}{K_3} + \cdots$$

→ Choose primary gas component with low mass: Ne-based (Ne-CF_4 90-10)



μ (mobility) vs mass

Combat Space Charge

- Several ways to combat Space Charge
  2. Choose the largest drift field possible

Gas	K ($\frac{cm^2}{Volt \cdot sec}$)	v_D ($E = 130\frac{V}{cm}$)	v_D ($E = 400\frac{V}{cm}$)
Ar	1.51	196	604
Ar-CH_4 90:10	1.56	203(STAR)	624
Ar-CO_2 90:10	1.45	189	582
Ne	4.2	546	1680
Ne-CH_4 90:10	3.87	503	1547
Ne-CO_2 90:10	3.27	425	1307(ALICE)
He	10.2	1326	4080
He-CH_4 90:10	7.55	981	3019
He-CO_2 90:10	5.56	722	2222
T2K	1.46	190(ILC)	584

Combat Space Charge

- Several ways to combat Space Charge
  3. Optimize amplification device's operating point

Gain on first GEM determines desired properties → compromise between energy resolution and IBF

Quad-GEM Solution for ALICE

R. Majka

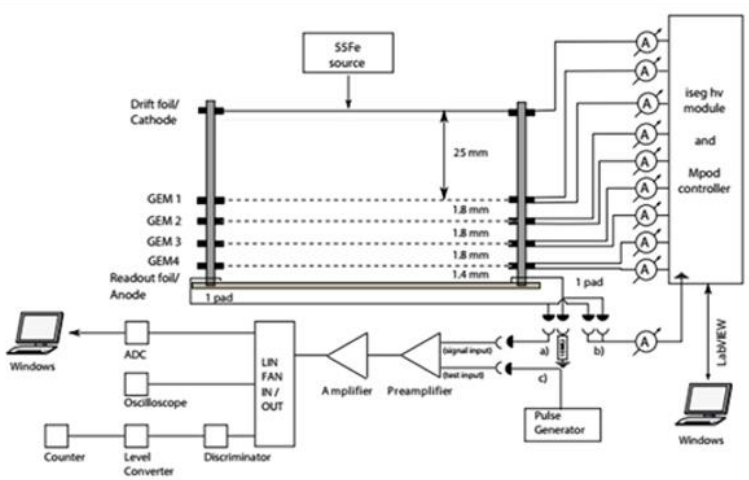
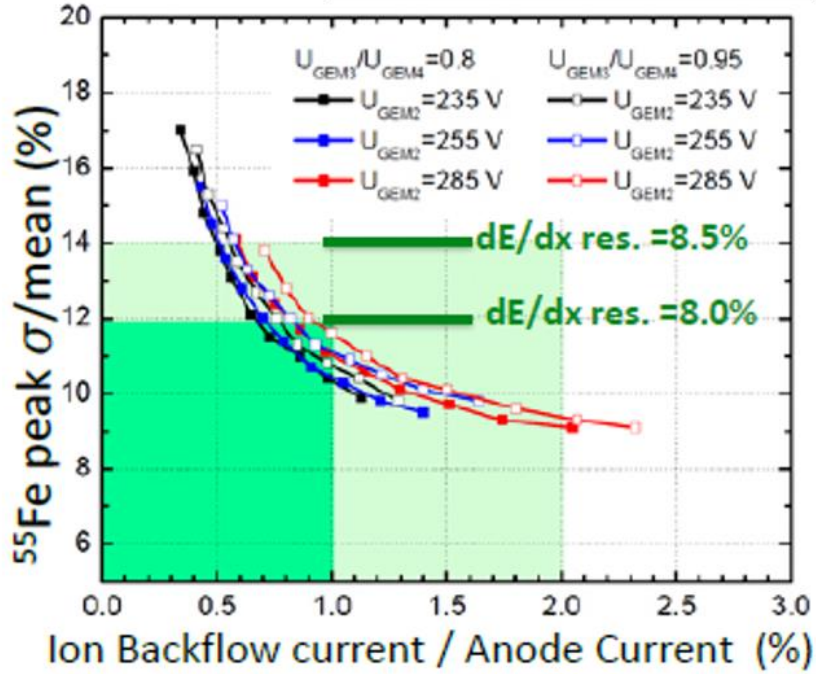


Figure 5.1: Sketch of the Munich quadruple GEM setup.



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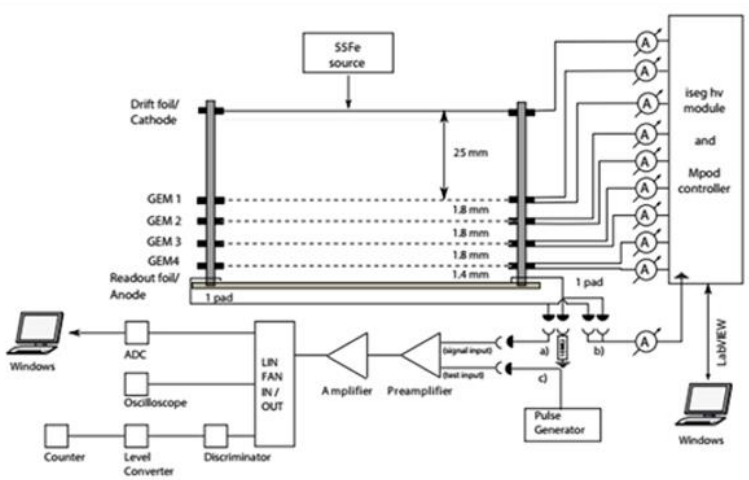

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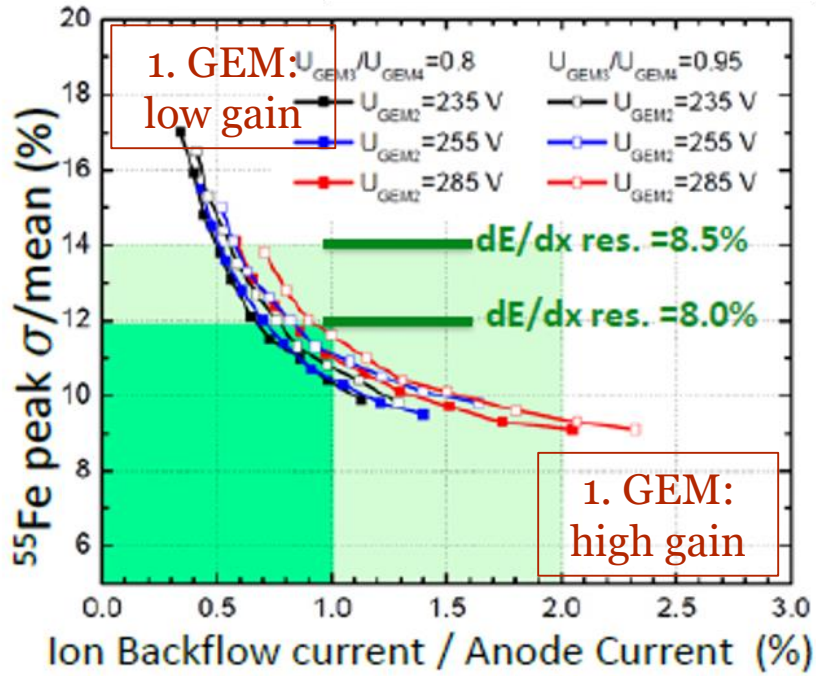

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Quad-GEM Solution for sPHENIX

R. Majka

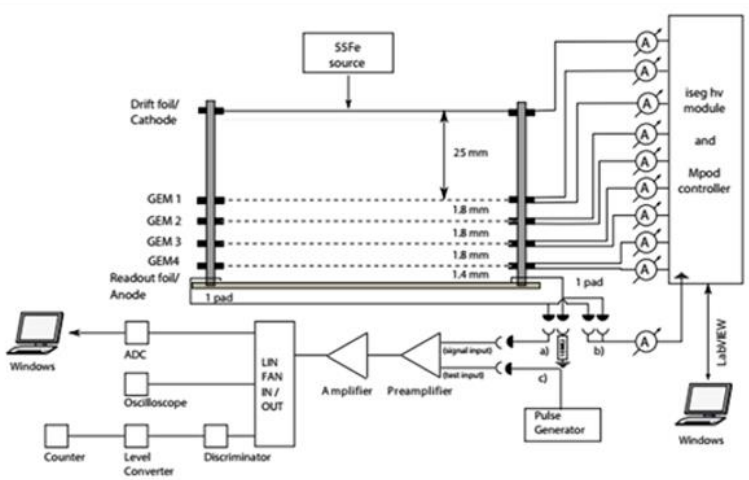
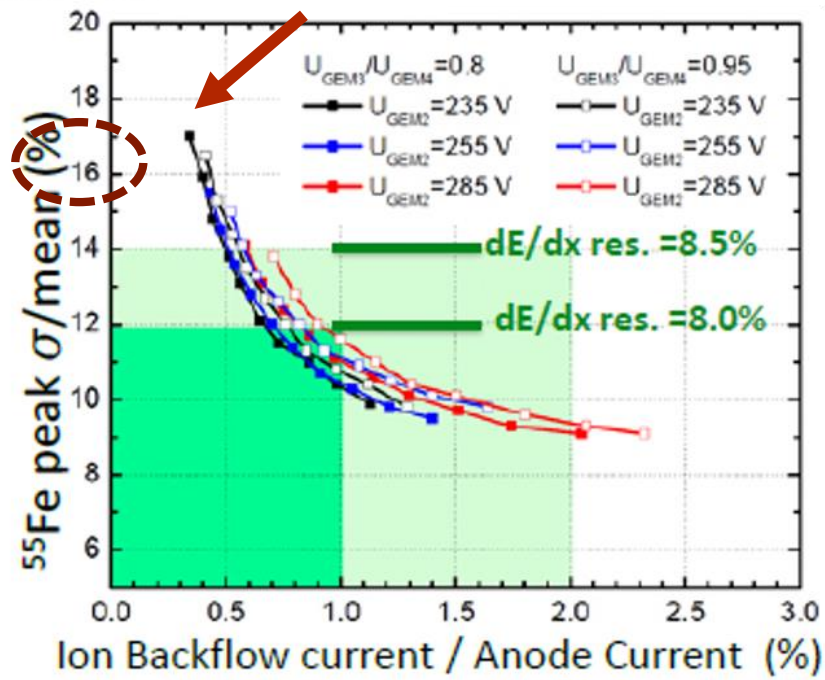


Figure 5.1: Sketch of the Munich quadruple GEM setup.



Combat Space Charge

- Several ways to combat Space Charge
  3. Optimize amplification device's operating point

Gain on first GEM determines desired properties → compromise between energy resolution and IBF

Quad-GEM Solution for ePHENIX

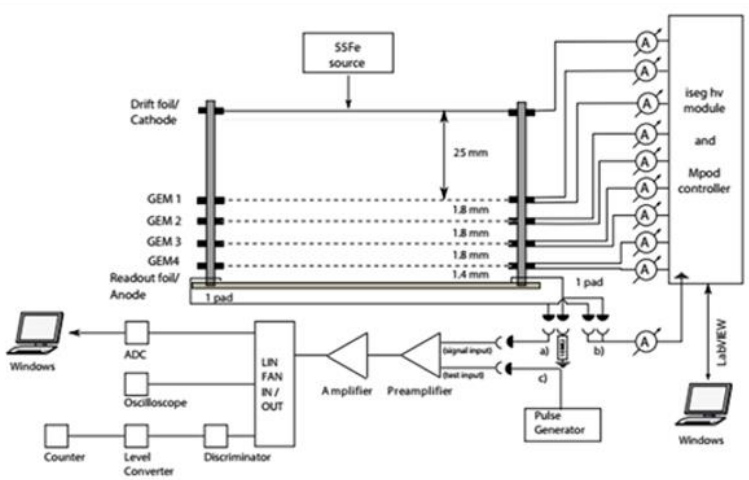


Figure 5.1: Sketch of the Munich quadruple GEM setup.

Recover dE/dx when environment allows

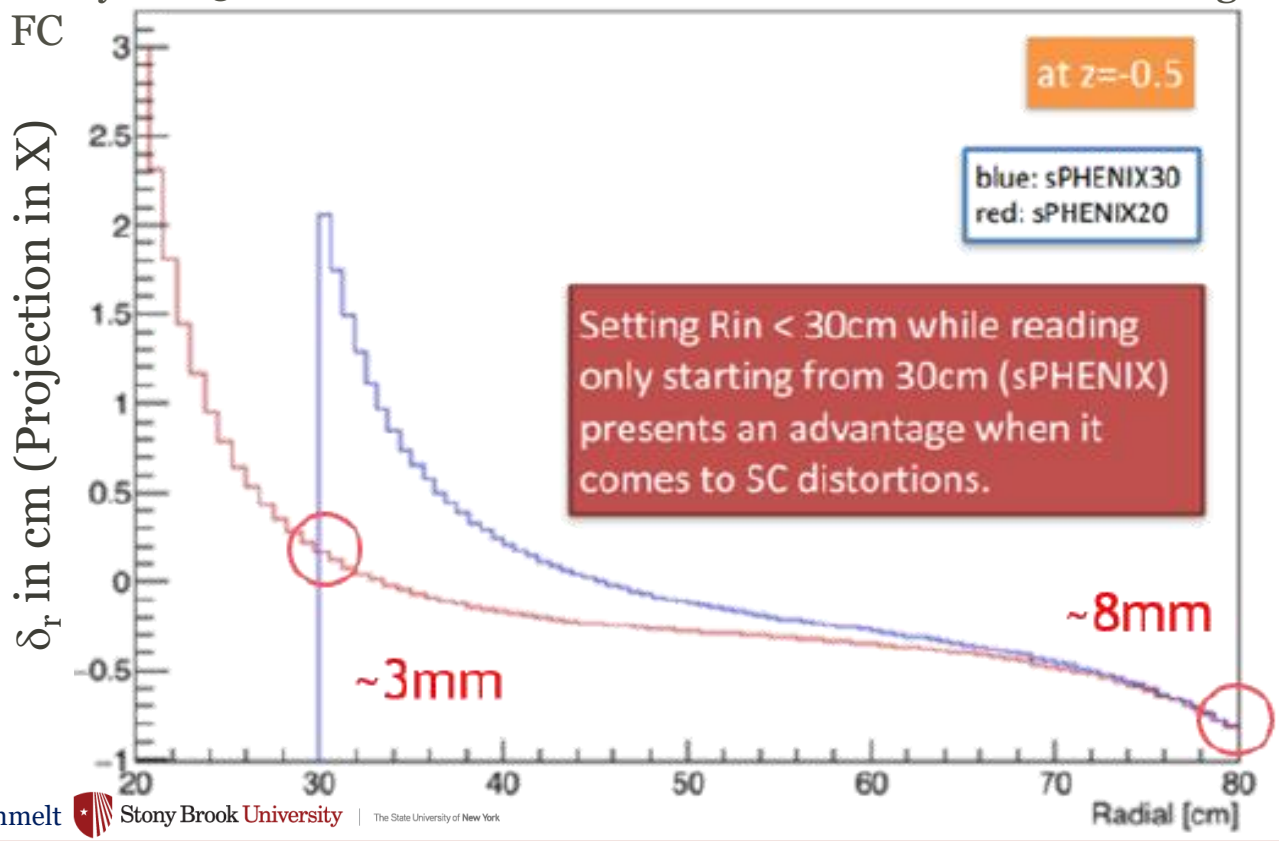
Combat Space Charge

- Several ways to combat Space Charge

4. Update design of field cage informed by current experience

Space charge distortions at maximum where space charge density has discontinuity → FC entrance windows

Analytical 3-D model based on work for ALICE TPC revealed large distortions close to inner FC



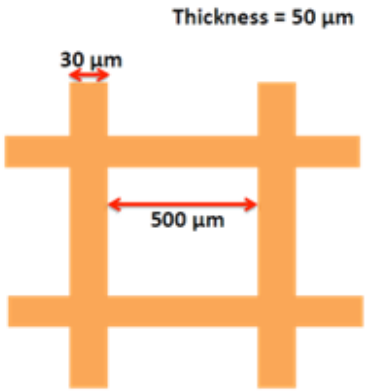
Set r = 20 cm
but make volume at
r> 30 cm active

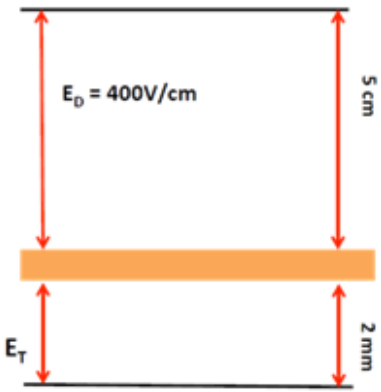
Combat Space Charge

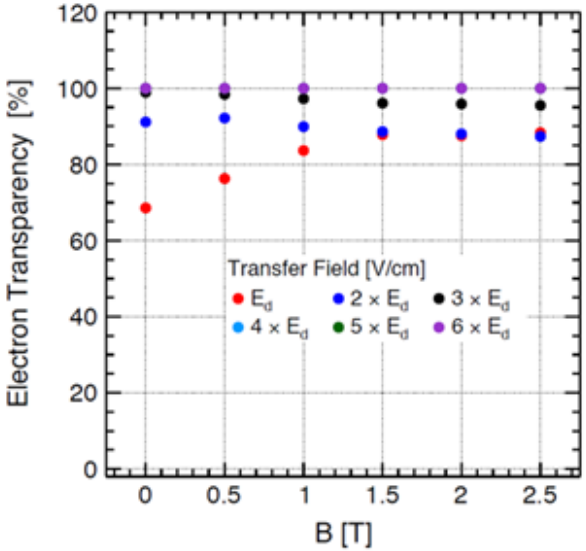
- Several ways to combat Space Charge
  5. Improve amplification device
     i. Remove “gain fluctuation” before amplification

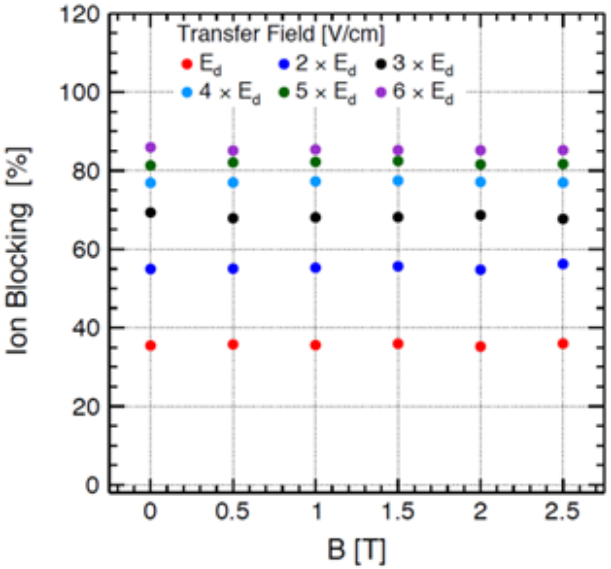
Combat Space Charge

- FC design includes a "termination grid" to ensure uniformity of the field in the drift volume
- Multiple simulations:
  - Wire mesh,
  - Photo-etched
  - Square/Round Hole
- Single conclusion:
  - Tune the field ratio surrounding the mesh to block many positive ions









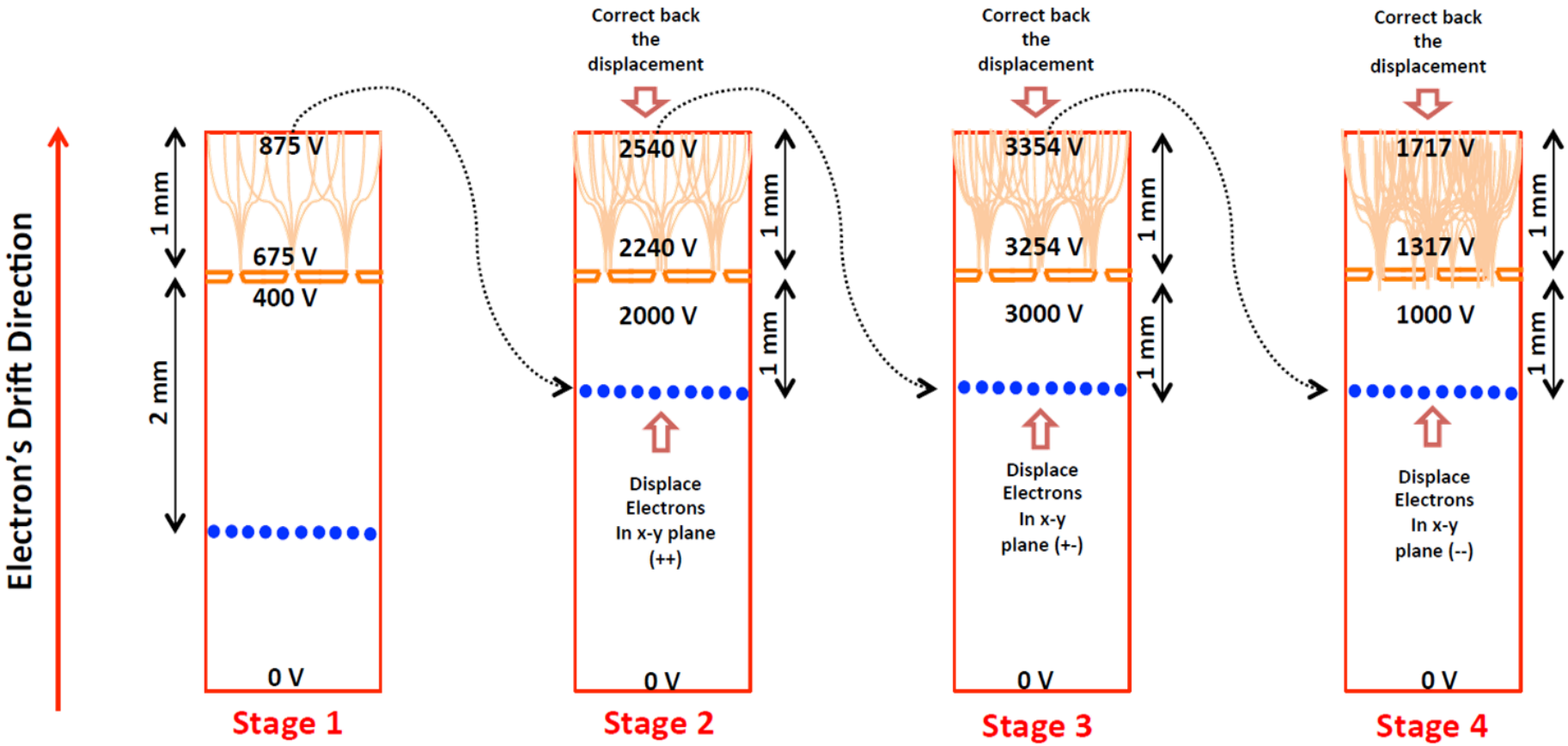
Combat Space Charge

- Several ways to combat Space Charge
  5. Improve amplification device
     i. Remove "gain fluctuation" before amplification
     ii. Increase number of amplification stages → Quintuple GEM?
  6. Multi-layer gating grid
  7. Accelerator parameters → Crossing angle?
  8. Don't let ions be created → Electroluminescence

5. – 8. require (significant) R&D

GEM Amplification and IBF Studies

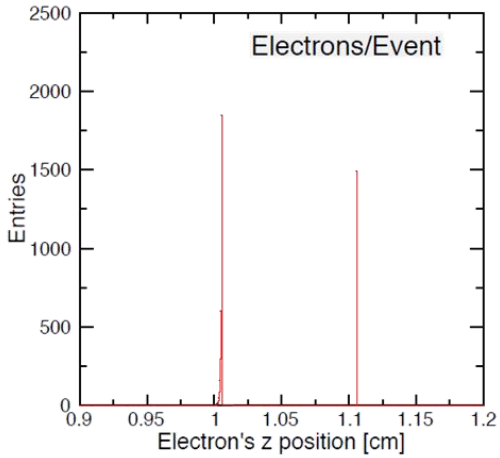
P. Garg (SBU) using ANSYS & GARFIELD

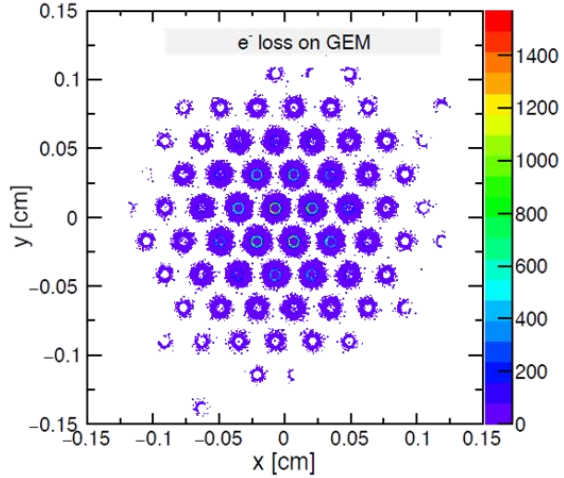


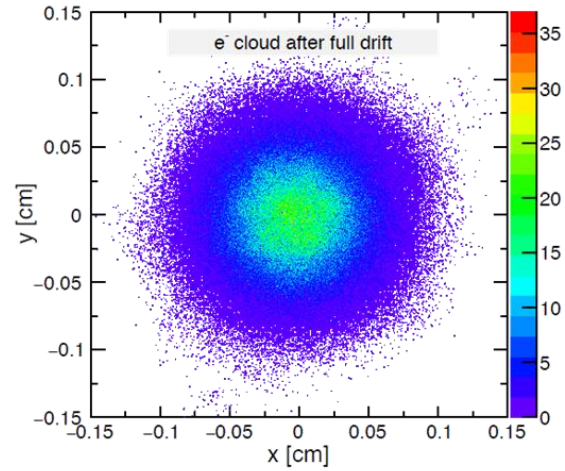
Stage 1	Stage 2	Stage 3	Stage 4
pitch = 140 µm	pitch = 280 µm	pitch = 280 µm	pitch = 140 µm
kapton = 50 µm	Kapton = 50 µm	kapton = 50 µm	Kapton = 50 µm
Copper = 5 µm	Copper = 5 µm	Copper = 5 µm	Copper = 5 µm
Dia. up = 70 µm	Dia. up = 70 µm	Dia. up = 70 µm	Dia. up = 70 µm
Dia. down = 80 µm	Dia. down = 80 µm	Dia. down = 80 µm	Dia. down = 80 µm

GEM Amplification and IBF Studies

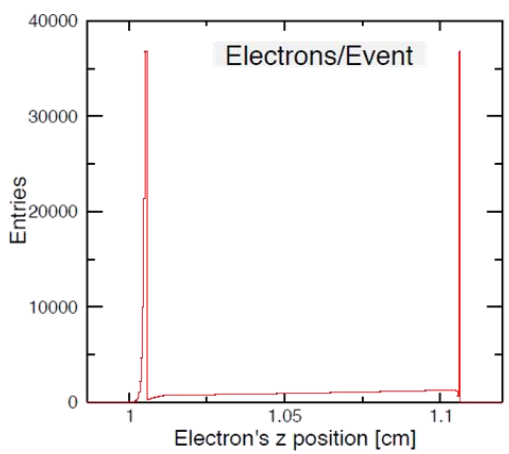
Stage 3

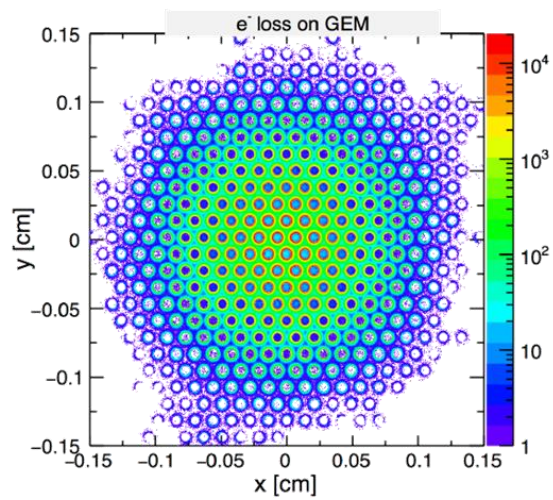


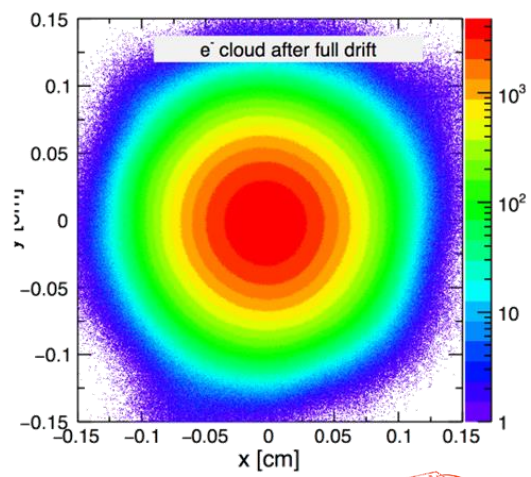




Stage 4

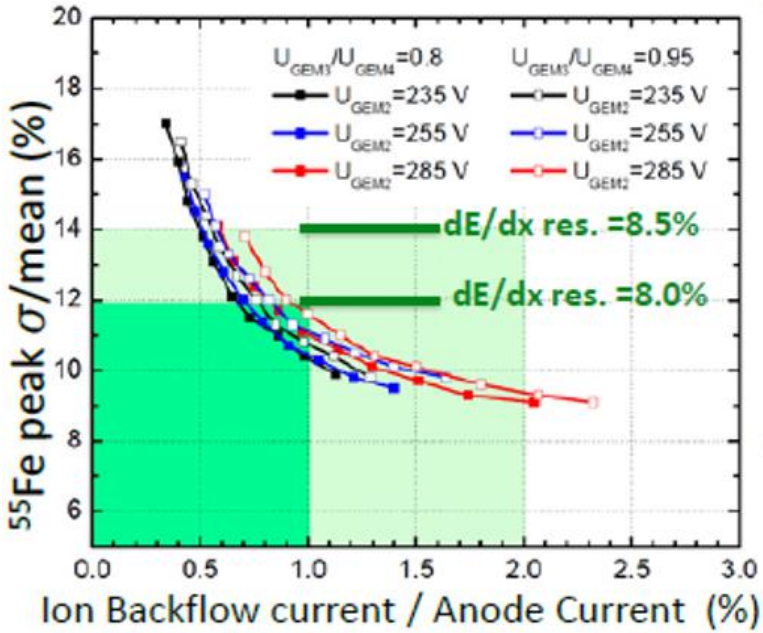


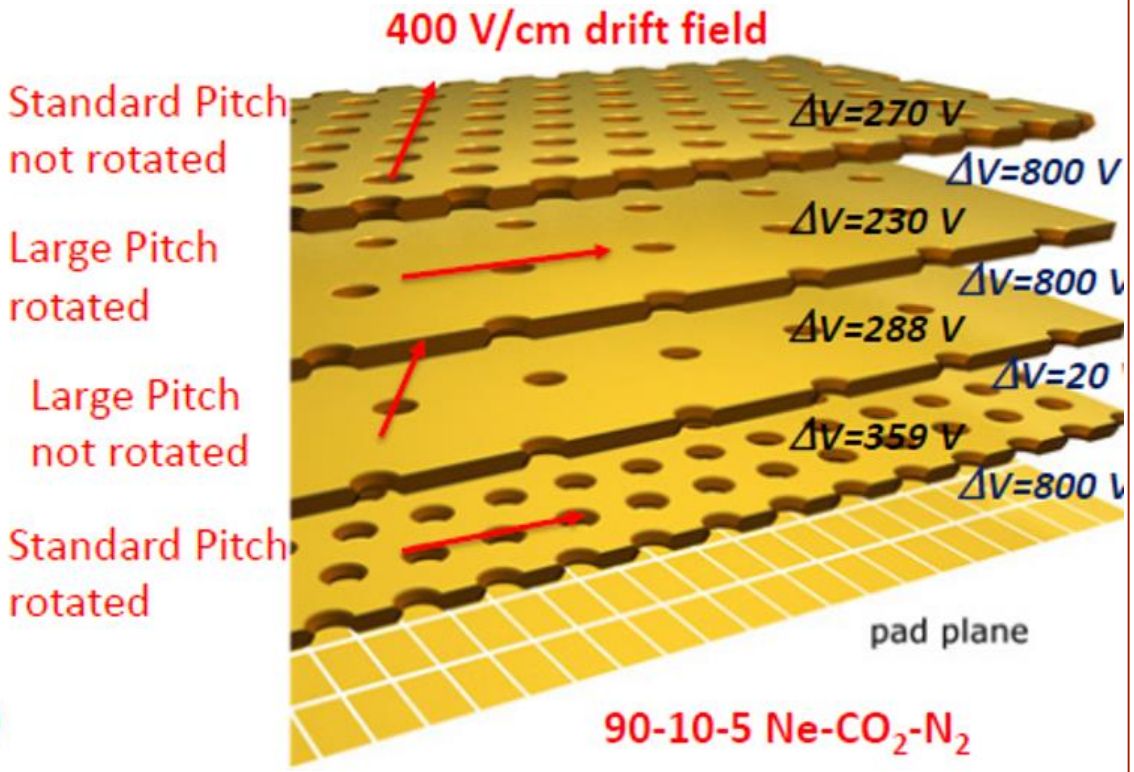




Alternative IBF Stopper

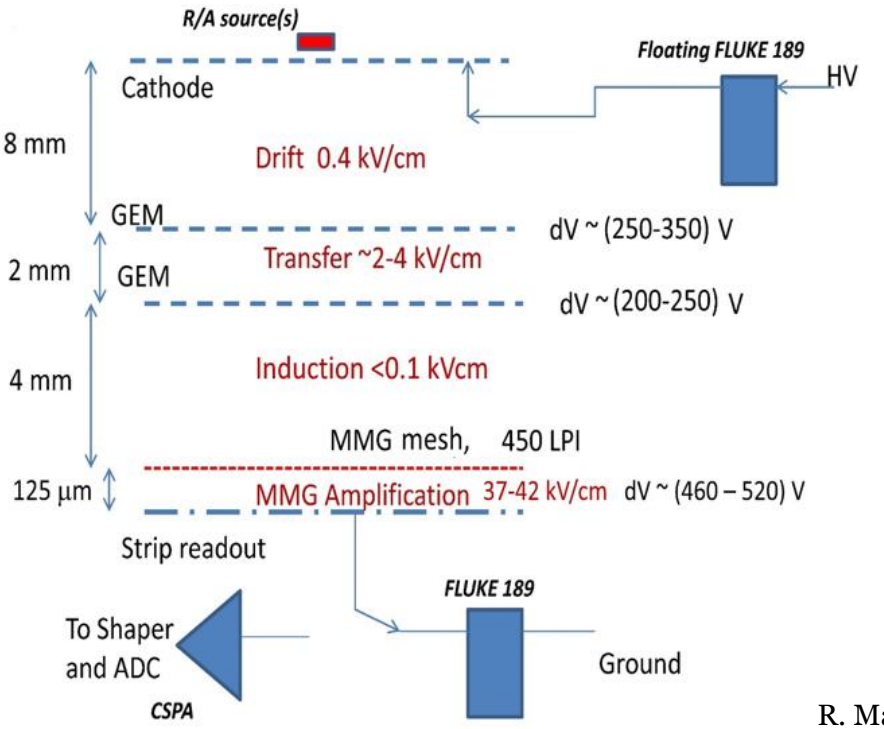
R. Majka

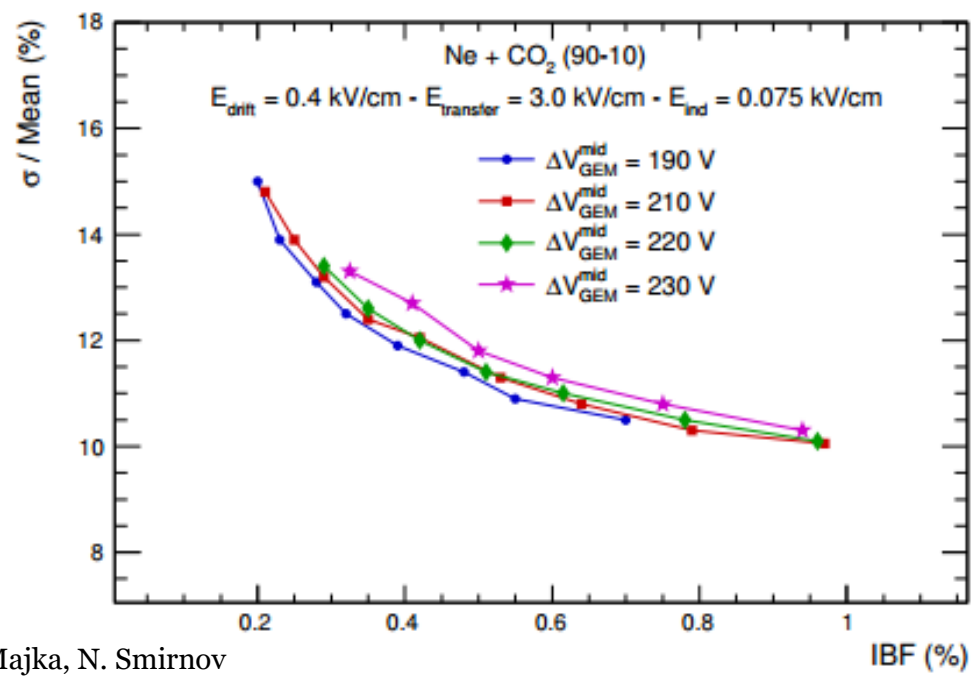




Alternative IBF Stopper

- Dual-GEM + MicroMeGas Solution from Yale





R. Majka, N. Smirnov

See talk by N. Smirnov: 25 May 2017, 16:10

Electronics/DAQ

- SAMPA = CSA + Shaper + ADC + DSP
  - 32 channels input
- Prototype chip is available now (Aug 2016)
  - Final version SAMPA will be available in late 2018

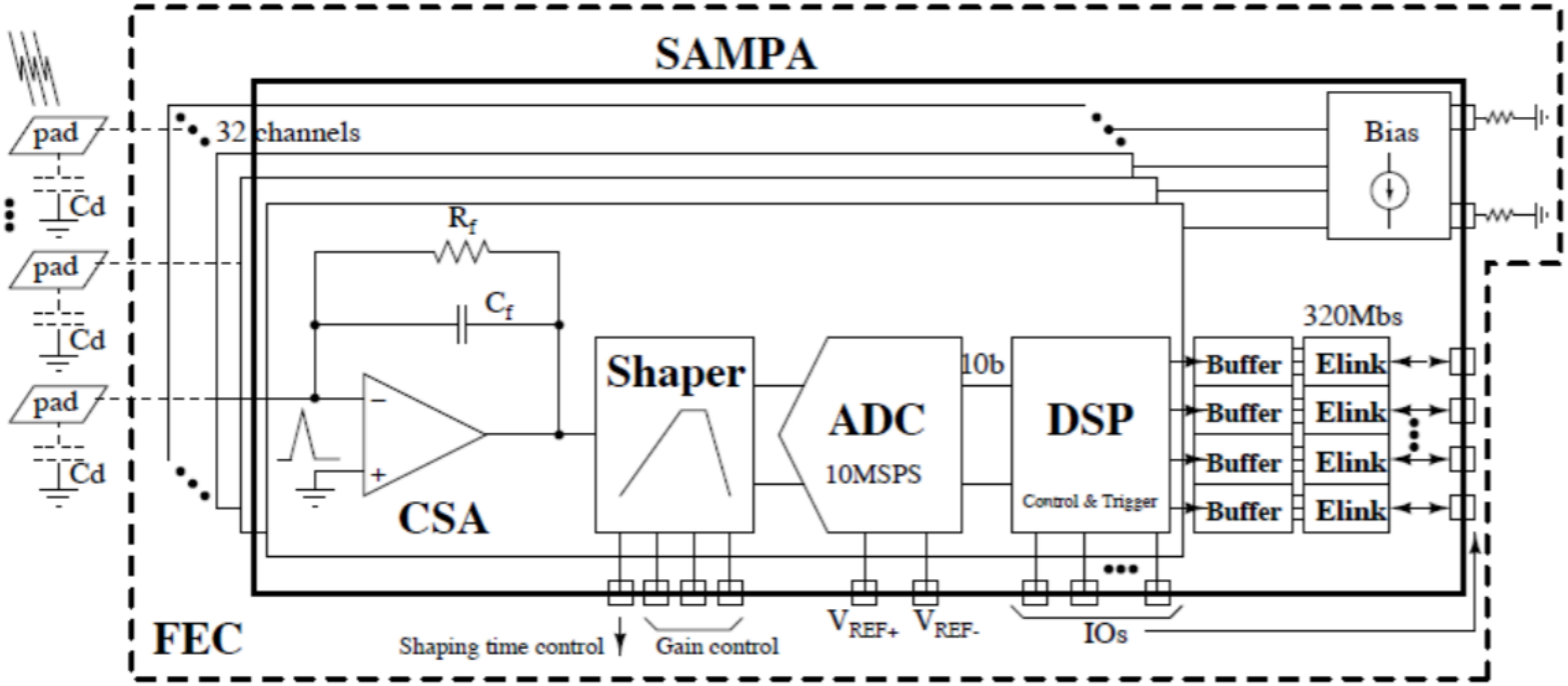


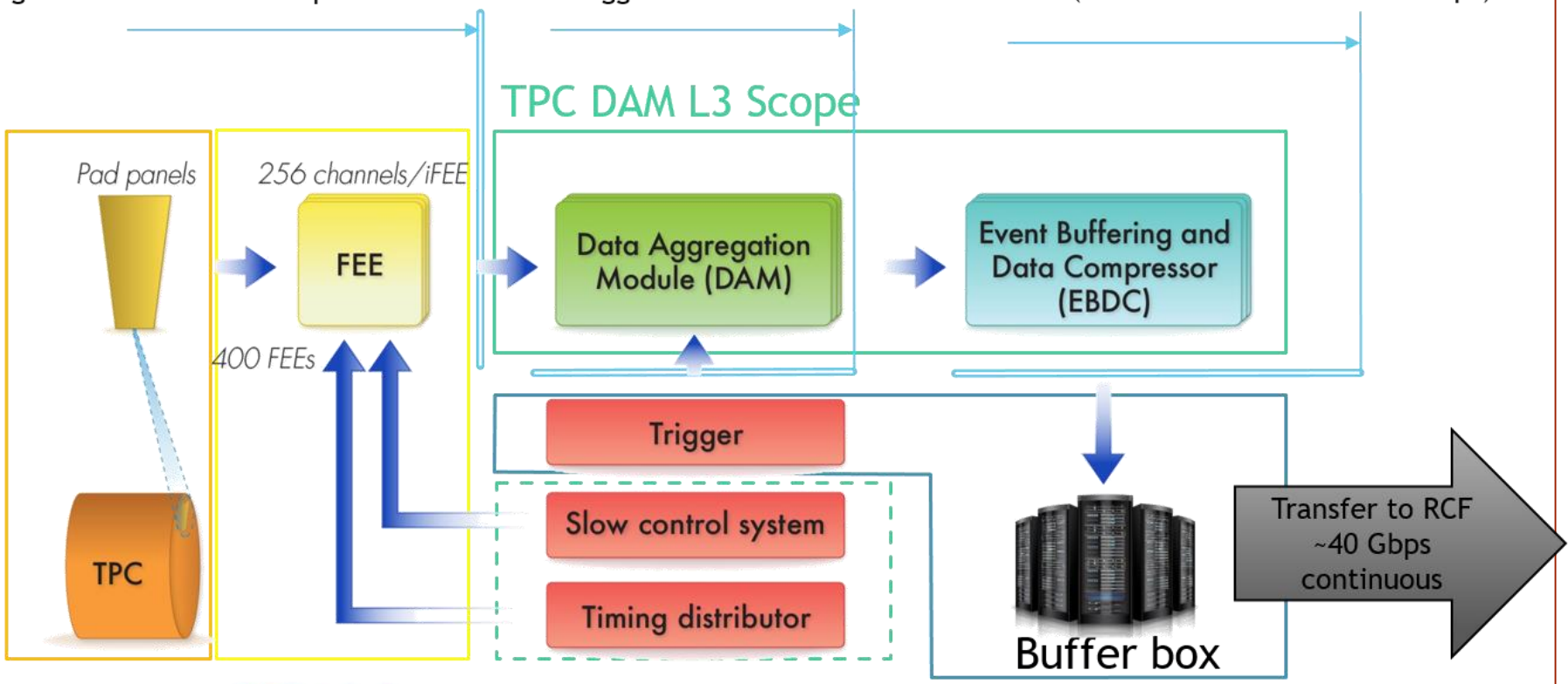
Figure 6.4: Schematic of the SAMPA ASIC for the GEM TPC readout, showing the main building blocks.

Electronics/DAQ

Input data stream:
600 4-Gbps fibers total
Max continuous: 2.87 Gbps / fiber
Average continuous: 1.43 Gbps x 600 fibers

Clock/Trigger input:
Fiber, protocol TBD
Clock = 9.4 MHz
Trigger Rate = 15 kHz

Output data stream to buffer box:
N x 10 Gbps Ethernet via fiber (N=10-50)
Total continuous limit: <120 Gbps (?)
i.e. 3x (Transfer rate to RCF ~ 40 Gbps)



Structure/ GEM L3 Scopes

FEE L3 Scope

Possible TPC DAM L3 Scope

DAQ L2 Scope

Summary & Conclusion

- Aggressive schedule for TPC completion
  - Mechanical design well defined
  - Prototype v1 will contain full size Field Cage
  - Operating parameters to be determined, following existing applications
  - Simulations promising, will be followed by experimental verification
  - IBF as main issue to be solved
- sTPC well on track
- Possible compromises to be made
- Alternative IBF solutions being looked into