sPHENIX Compact TPC for Tracking and Particle Identification

Carlos E. Perez Lara, *for the sPHENIX Collaboration*

Stony Brook University, Physics and Astronomy. New York, USA.

Stony Brook University

Abstract

Heavy ion collisions provide a direct experimental framework to study the properties of the Quark Gluon Plasma. The sPHENIX detector will be the next state-of-the-art system to measure hard processes observables with high accuracy in a broad pT range. The sPHENIX tracking system will feature a compact Time Projection Chamber working in continuous read-out mode as the main tracking detector. The compact TPC combines both good momentum resolution, below 2% at 5 GeV/c, together with high rate withstand, as high as 100 kHz. It spans geometrically in a volume covering 2.2 units of pseudo-rapidity and 20 < R < 78 cm. One of the technologies considered is a quad-GEM configuration connected to 200k readout channels using SAMPA chips able to read ~4Gbit/s. For such configuration one of the key aspects of the design will be the ability to mitigate spacecharge distortion due to ion back flow. Several studies on this regard were done and will be shown here.

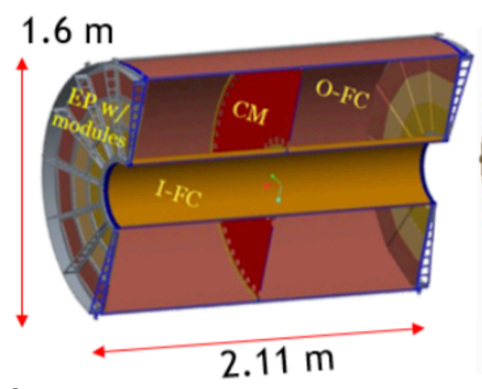
sPHENIX Compact Time Projection Chamber

Physical Coverage:

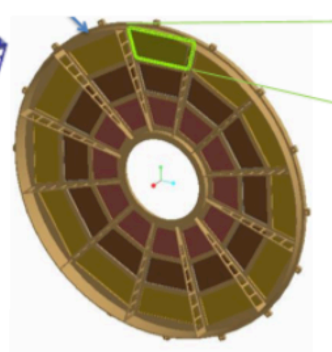
- R [20-78] cm
- Z [-105.5 , +105.5] cm

Operating Fields:

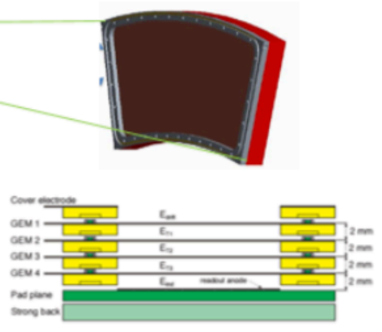
- E = 400 V/cm
- B = 1.4 T



for more on construction, see Niveditha's poster



72 modules
2(z), 12(ϕ), 3(r)



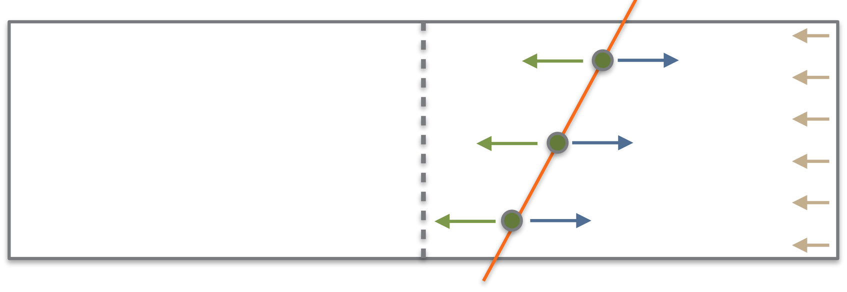
Quad-GEM Gain Stage
Operated @ low IBF

Gases under consideration:

Gas Mixture	Drift Velocity (cm / us)	Ion Mobility (cm2 / V / s)	Nt electrons per cm for MIP
Ne-CF4 (90-10)	8 @ 400 V/cm	4 (Ne+ in Ne)	~49
Ne-CF4-iC4H10 (95-3-2)	6 @ 400 V/cm	4 (Ne+ in Ne)	~48

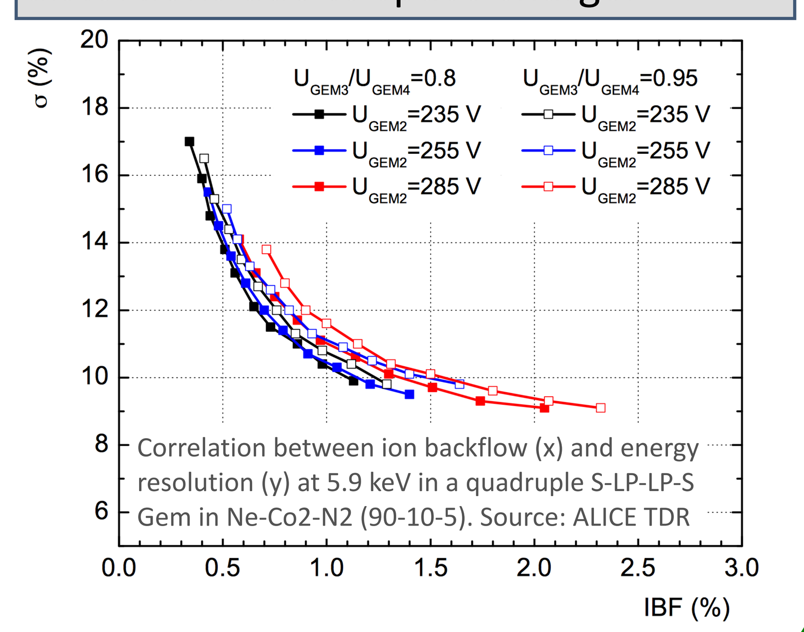
Sources of SpaceCharge PileUp

Primary ionization: As particles ionize the gas volume, electrons drift quickly towards the readout plane, while ions move slowly towards the central membrane. These ions create space charge density and modify the electric field lines.



Ion BackFlow (IBF) from the GEM stage is also a source of SpaceCharge. For high rate data acquisition, IBF is the main source of SpaceCharge buildup.

The more molecules ionized, the better energy resolution, but also the worse distortions due to space charge.



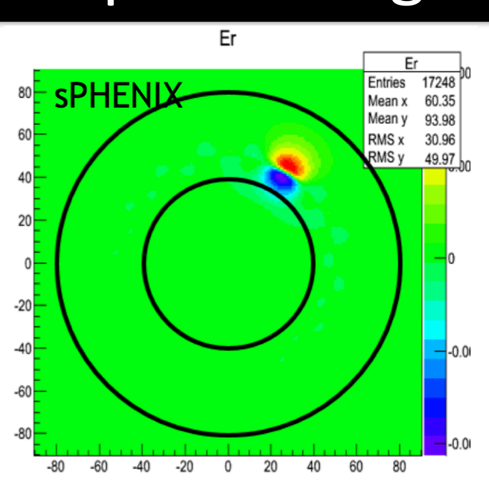
E Field Distortions due to SpaceCharge

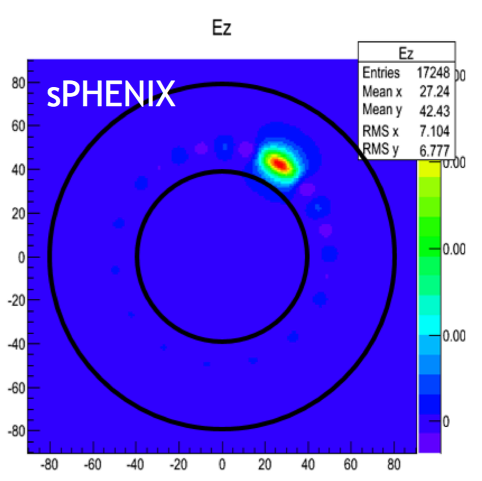
Electric Field inside volume

1. Grounded Shell and Space Charge (this work), plus
2. Graded Potential and no charge (for more on this topic, see Prakhar's poster)

E for Ground shell and SpaceCharge
Analytic solution from Laplace equation under proper boundary conditions.

- Greene's theorem: point charge solution
- Convolution with Initial SpaceCharge





Flow Diagram

Simulation of SpaceCharge PileUp

Space Charge Distribution

↓ Laplace formalism for superposition of charges

E (and B) Field Distortions

↓ Langevin formalism up to 2nd order

Drift Distortions

Propagation in Distorted Electric Field

Single electron moving in electric and magnetic field under frictional force: **Langevin Equation**

$$m\frac{d\vec{u}}{dt} = \underbrace{qe\vec{E} + qe\left[\vec{u}\times\vec{B}\right]}_{\text{EB force}} - \underbrace{K\vec{u}}_{\text{Friction }(K>0)}$$

(charge of the drifting particle: qe; drift velocity: $\vec{u}$)

Solution $t \gg m/K$ Adiabatic approx. $\frac{d\vec{u}}{dt} = 0$ Steady state

$$\vec{u} = \frac{\mu\left|\vec{E}\right|}{1+\omega^2\tau^2}\left[\hat{E} + \omega\tau\left(\hat{E}\times\hat{B}\right) + \omega^2\tau^2\left(\hat{E}\cdot\hat{B}\right)\hat{B}\right]$$

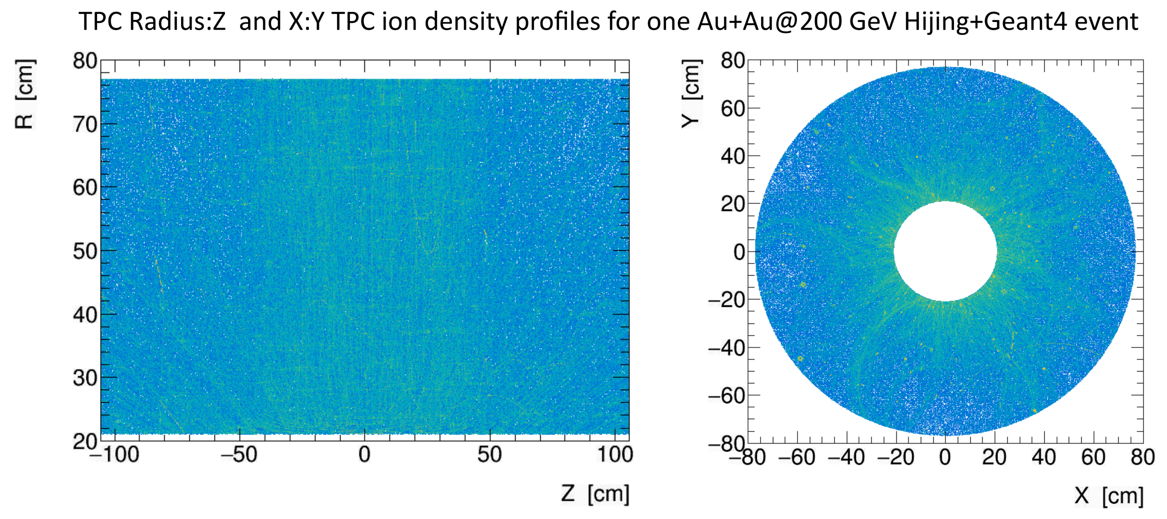
scalar mobility of the electric field $\mu = \frac{qe}{K}$; mean interaction time between drifting electrons and atoms from the gas τ; cyclotron frequency for electron ω

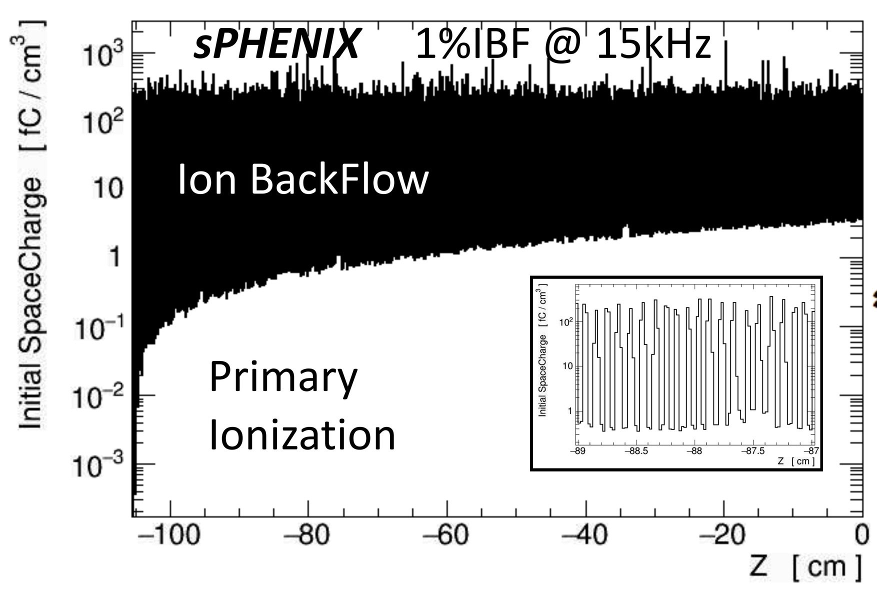
Predicted Effects Under Several Running Conditions of the sPHENIX Experiment at the RHIC

Initial Charge Density Simulation

- Evaluate primary ionization left in volume by central Au+Au collision at 200 GeV
- Drift electrons and Inject IBF from GEMs
- Propagate Ions in between collisions
- Repeat until readout rate saturates full volume

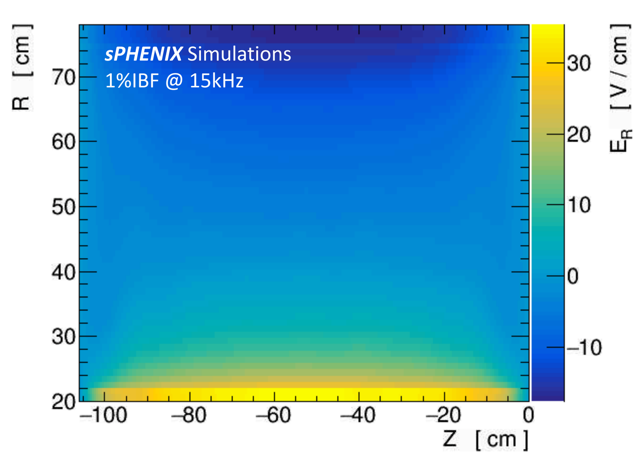
TPC Radius:Z and X:Y TPC ion density profiles for one Au+Au@200 GeV Hijing+Geant4 event



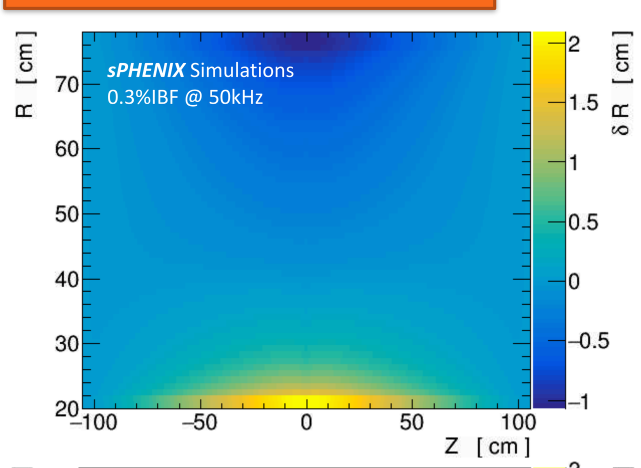


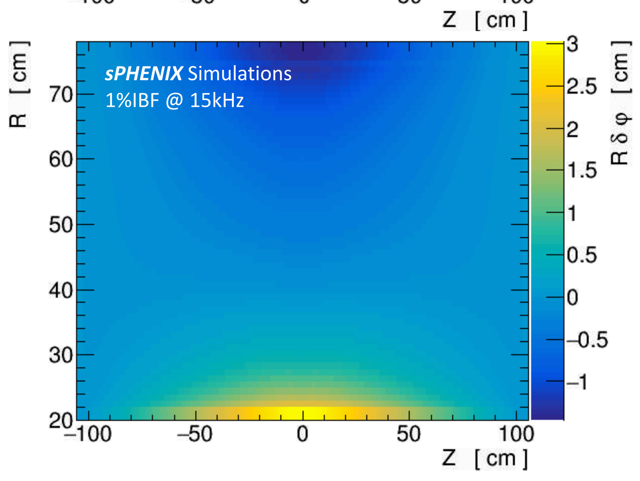
$$\approx a\left(\frac{1 - bz + ce}{f_d r^d}\right)$$

Electric Field Distortions

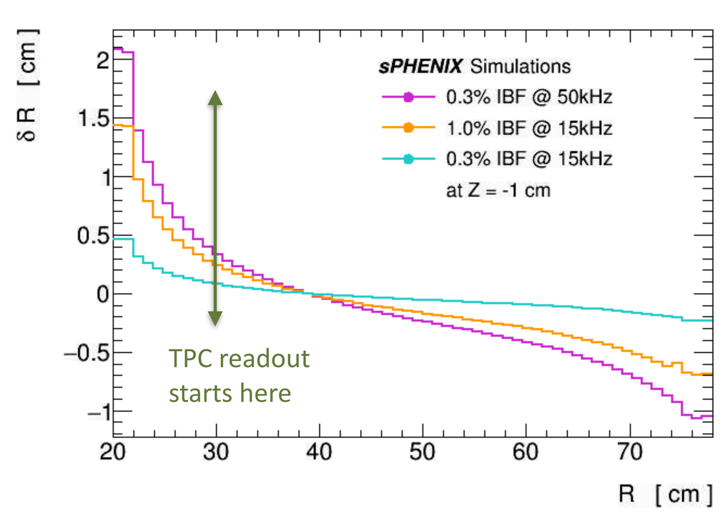


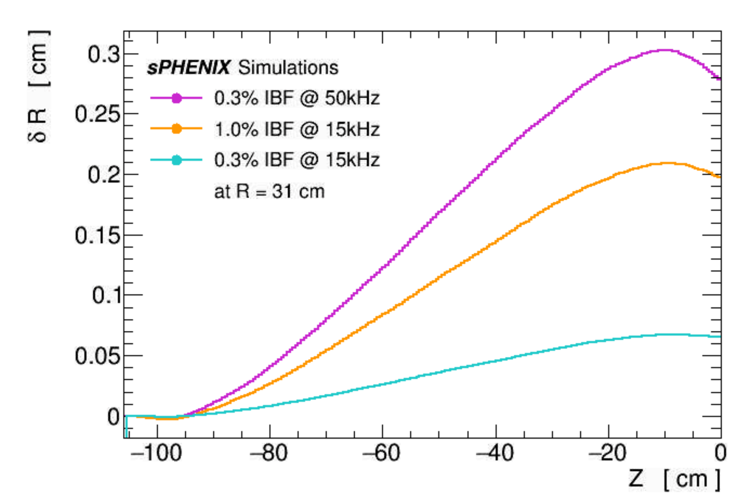
Drift Distortions Map





Comparison of different running conditions





The top (bottom) plots show the distortion in the radial (phi) direction in the regions where the distortion is maximal. For the Ne-based gases and setup under consideration, the expected distortions are below 2 cm at 15kHZ and 3 cm at 50 kHz.
(for the effect of distortions on tracking, see Sourav's poster)