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R&D and related Simulation Studies for the sPHENIX Time Projection Chamber

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The proposed sPHENIX detector design is focused mainly on a physics program of precise upsilon spectroscopy and jet measurements, which require a high tracking efficiency and excellent momentum resolution. A time projection chamber (TPC) is proposed as the outer tracking detector for sPHENIX, which has a rapidity coverage of $|\eta|$<1.1 and full azimuthal coverage. The sPHENIX TPC design has to be optimized for operation in the high rate, high charged particle multiplicity environment that is anticipated at RHIC in 2022. In the present article, we show the results of R&D, its related simulations and describe the ongoing efforts to optimize the design of the sPHENIX TPC.

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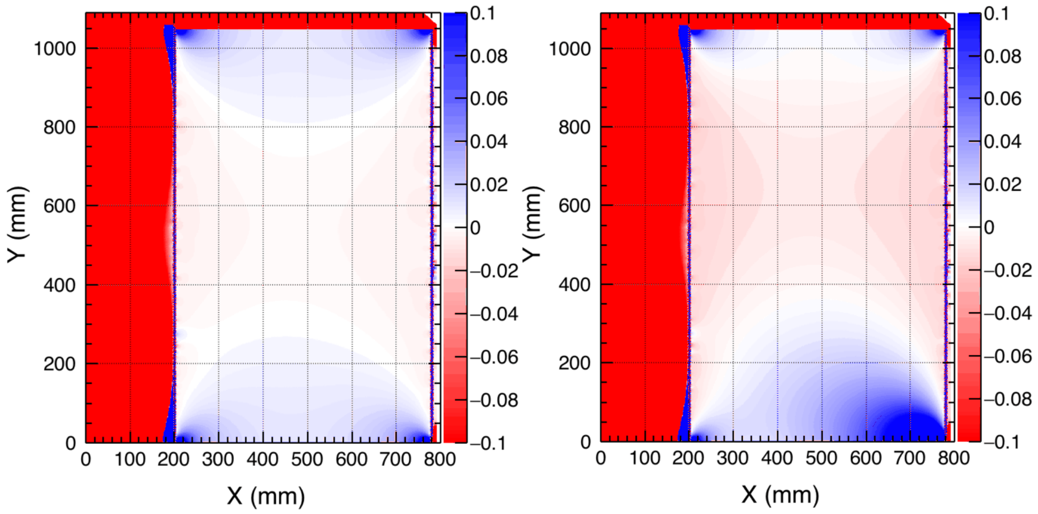
1. Introduction

The sPHENIX [1] Time Projection Chamber (TPC) is designed to extended in radii from 20 cm to 80 cm and ∼210 cm in length, which is mainly constrained by the size of BaBar solenoid magnet and other tracking detectors to be used in sPHENIX setup. The active volume of TPC will cover the pseodorapidity (η) of ± 1.1 and full phi ($\Delta\Phi = 2\pi$) acceptance. The BaBar solenoid will provide ∼1.5 Tesla of magnetic field along the z-direction of TPC volume. Hence, the compactness of sPHENIX TPC and high magnetic field present a careful design for the electric field and the choice of active gas volume. The TPC is dived into two symmetrical volumes by a membrane cathode; which provides the same electric field (∼ 400 V/cm) upto both readout planes. To achieve the uniform electric field , the printed circuit board (PCB) based copper strips will be used. These PCB's have cu-strips on both sides of a Kapton sheet arranged in a way to have complete overlap for electric field lines. The TPC readout planes will be segmented in r-ϕ as 3×12 on both ends. The readout will be based on micro pattern gaseous detectors like Gaseous Electron Multiplier (GEM) and/or Micro-MEsh Gaseous Structure (MicroMegas), coupled with the ZigZag pad readouts to achieve a good position resolution. These electron amplification based detectors also poses an issue of Ion-back flow which comes from the amplification stage and contributes to distort the detector resolution. In this presentation, the electric field uniformities and a method to cope with ion back flow are discussed.

2. Electric Field Uniformity in the TPC Volume

To study the electric field uniformity in the TPC volume, Finite Element Method based Simulation software ANSYS [2] is used. The field element is composed of cu-stripes of width 2.3 mm



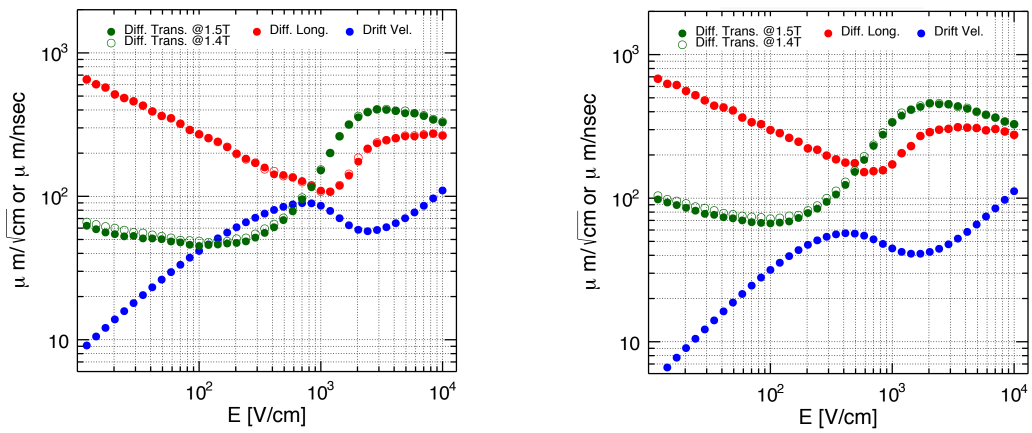
(a) Ideal TPC Geometry (b) With a tilt of 0.2 mm in central membrane

Figure 1: Electric Field Distortions from the nominal drift field in percentage.

and a pitch of 2.8 mm on both sides of a kapton sheet (thickness ∼100 micron). Cu-stripes are arranged on each side so that the center of the gap on one side is exactly aligned to the center of the back side cu-strip. Figure 1 shows the cross section in r-ϕ plane as X-Y plane where X = 200 mm shows the inner wall while X = 800 mm shows the outer wall of TPC. Further, Y = 0 corresponds the membrane plane while Y= 1050 mm shows the readout plane. As, both the TPC volumes are identical, only half of the total length is simulated. The potentials are applied across the membrane, cu-stripes and readout to have an effective drift field of 400V/cm. Figure 1(a) shows the percentage deviation in the electric field from the nominal drift field in the whole TPC volume assuming that all the mechanical construction is perfectly ideal. In reality it's not possible to have no tolerance on the physical detector, therefore these electric field maps are important to quantify the mechanical tolerances as well. As an example, Figure 1(b) shows the distortion map while the membrane is having a tolerance of 0.2mm. Similar studies are performed for other possibilities of mechanical tolerances and they are set to $\sim$100 microns to achieve the uniformity within 0.1%.

3. Errors in the Electron's Position

After the electric field calculations in ANSYS, these maps are imported in Garfield++ [3] Simulations to study the electron drift in gaseous volume with 1.5T of magnetic field. In order to quantify the errors in electron position, its important to study the electron movement as it strongly depends on the gas properties in magnetic field and the distortions in electric field. The current sPHENIX TPC design is exploring two gas combinations shown in Figure 2. Since the gas properties of these two combinations are not very different, the present studies should not have much effect of it, although Ne-CF_4-iC_4H_{10} (95:3:2) is used in the present studies.



(a) Ne-CF_4 (90:10)

(b) Ne-CF_4-iC_4H_{10} (95:3:2)

Figure 2: The drift velocity, longitudinal and transverse diffusion as a function of electric field are shown for Ne based mixtures in sPHENIX magnetic field.

To study the errors in the electrons position, three different drift fields (225, 525, 850 V/cm) are studied as a function of magnetic field as is shown in Figure 3. The electrons are drifted from a fixed position and collected after the full drift with suitable gas, electric field map and the magnetic field. The first row of Figure 3 shows the difference of initial and drifted position of the electrons while the initial position is r = 65, 70, 75 cm. To study the effect of E$\times$B, the errors in the perpendicular direction are shown in the second row of Figure3. The last row shows the quadrature sum of errors in position. It is found that the strong magnetic field helps to achieve the better performance.

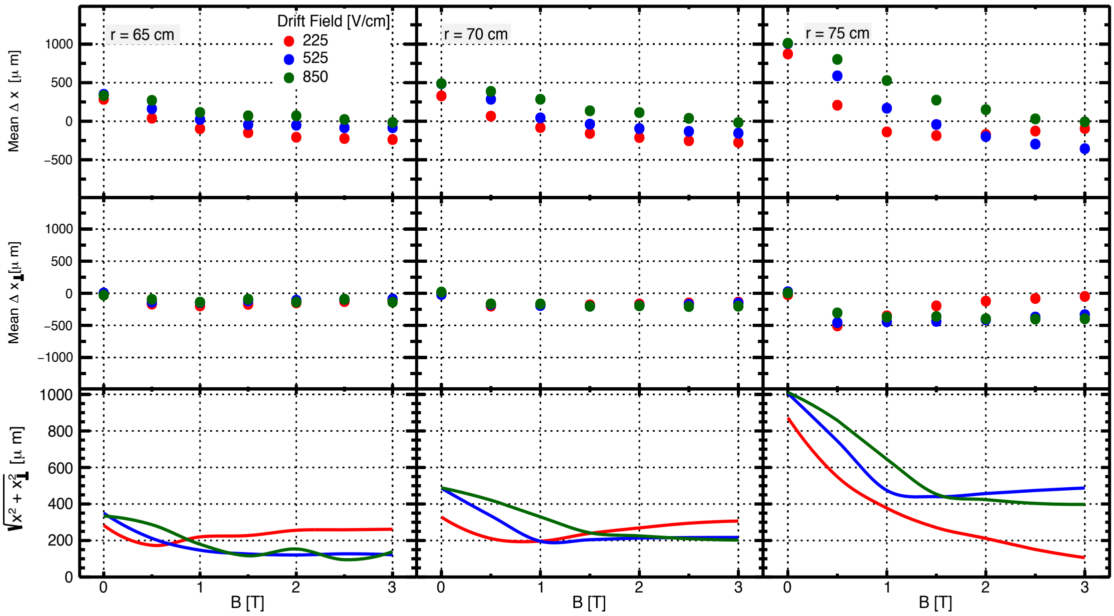


Figure 3: (Color online) Variation in errors of position as a function of magnetic field for three different drift field values.

Also, the combination of drift field, magnetic field and drift velocity for the sPHENIX TPC lies in a region that the errors are minimal.

4. EM Simulations for Ion-back Flow and Electron Transparency

As discussed Ref. [4], the ion back flow depends on the amplification stage and can distort the field maps due to space charge. In this presentation a proposal is made to block the ions coming from the amplification stage before they can go to the drift volume.

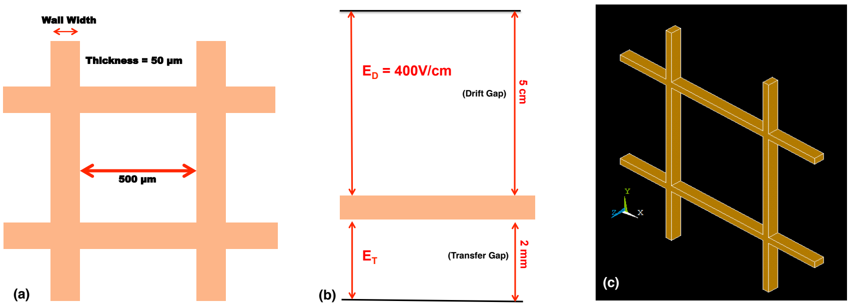


Figure 4: (a, b)The schematic view of the setup and (c) the ANSYS Model of an element.

It is presented that a suitable dimensions of a rectangular mesh coupled with a selective electric field settings can block a good fraction of ions while it's mostly transparent to the electrons passing through it. Figure 4 shows the schematic of one such mesh which is modeled in ANSYS to get the field maps. These maps are used in Garfield++ to study the ion blocking and electron transparencies for different transfer and drift field ratios and different dimensions of mesh as is shown in Figure 5

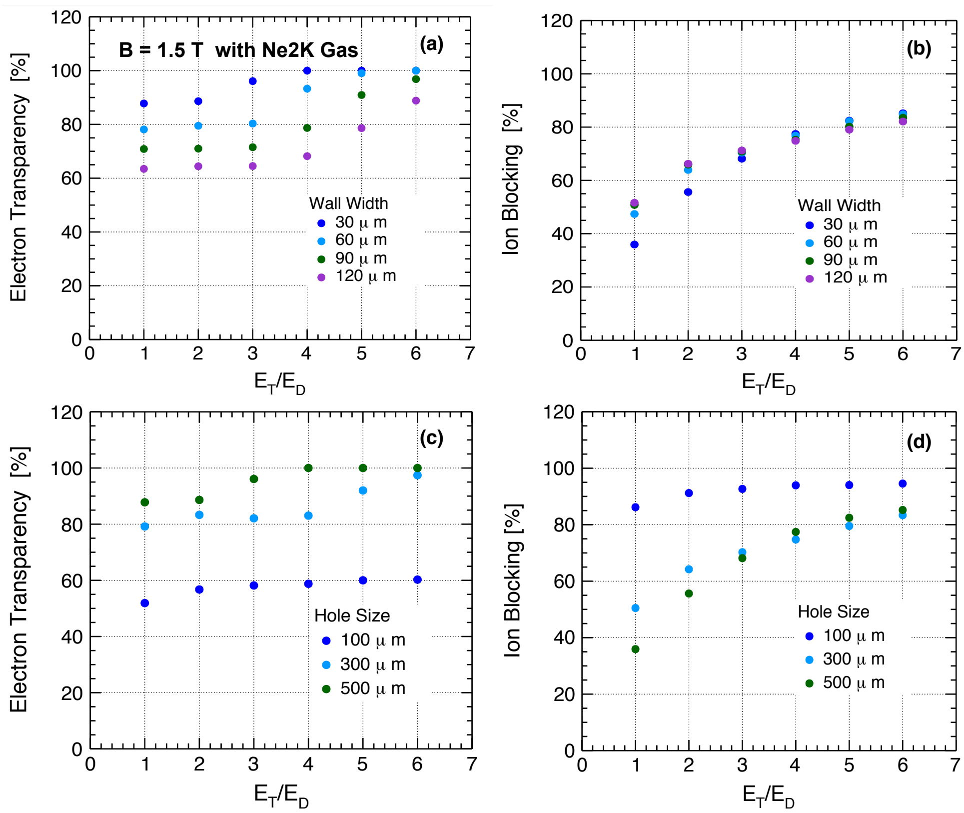


Figure 5: Electron transparency and ion blocking are shown as a function of E_T/E_D for different geometrical parameters of square mesh. Figure 3 (a) and (b) correspond to various wall thicknesses while Figure 3 (c) and (d) are shown for different square hole sizes.

It is found that for a particular settings it is possible to achieve almost full electron transparency and 80 to 90% of ion blocking, it might be an addition to sPHENIX TPC if the results are found consistent with the real setup.

References

[1] A. Adare et al., An Upgrade Proposal from the PHENIX Collaboration, 2014, arXiv:1501.06197.

[2] ANSYS, Inc.,Version 15, http://www.ansys.com/, 2015.

[3] CERN Garfield++, http://garfieldpp.web.cern.ch/garfieldpp/

[4] S. Rossegger, *Simulation and Calibration of the ALICE TPC Including Innovative Space Charge Calculations,* PhD thesis, University of Technology, Graz, 2009, CERN-THESIS-2009- 124.