Grid leak simulation for STAR TPC using GARFIELD
Presented work is done in close collaboration with TPC/iTPC working groups

Irakli Chakaberia[1,2,3]

[1]Brookhaven National Laboratory, Upton, NY, USA

[2]Kent State University, Kent, OH, USA

[3]Shandong University, Shandong, China

ABSTRACT

This document presents the simulation study of the STAR time projection chamber (TPC) ion feedback from the anode wires back into the main volume of the TPC, referred in this document as a grid leak. The study is performed using GARFIELD (Gar) simulation software to understand and quantify the grid leak and design the ways of minimizing it.

1 INTRODUCTION

Positive ion re-injection into the drift volume of the TPC introduces problems for particle tracking, such as complicated space charge distribution and electric field distortion. This positive ion feedback at the ends of the wire grids (outside the first and last wires) is referred to as a grid leak in this document; it is uncontrolled and can be especially large. The region between the inner and outer sectors is referred as IO region, the gap between inner sector and inner field cage as II region and between outer sector and outer field cage as OO region. In light of the upcoming upgrade of the inner TPC (iTPC) sectors, we have a unique opportunity to make an effort in order to suppress the grid leak for II and IO regions.

GARFIELD simulation software was used to simulate the grid leak in the current TPC setup and understand its dependence on different aspects of the MWPC as well as to optimize the position of the new iTPC wires and the design of additional structures required to minimize or eliminate the leak.

2 GARFIELD SETUP

In order to do simulation the following aspects need to be defined for the STAR TPC: gas, geometry of the gas container, active electronics, proper setup of the avalanche mode for the electrons.

2.1 Gas

GARFIELD uses the MAGBOLTZ program to invoke proper Boltzmann and Lorentz transfer functions in calculating electron drift velocities, and longitudinal and transverse diffusion coefficients. It also computes the excitation and ionization rates for various gas mixtures.

Temperature (K)	Pressure (Torr)	Max. electron energy	Penning r	Penning λ
297.839 (273.15 + 24.7)	795.5	300	0.57	0

TABLE 1. Gas parameters, where Penning r and λ are value of transfer efficiency and a distance characterizing the spatial extent of Penning transfers respectively

The gas composition is set to 90% Ar and 10% CH_4 for the STAR TPC P10 mixture. Main parameters for the gas are given in table 1.

Table 2 shows the ion mobility parameters.

2.2 Geometry

Geometry in this case is a simple box which contains the gas as described above.

2.3 Electronic Components

Table 3 show the parameters of the various TPC wires.

The potential on the gating grid (GG) is either at a constant base potential of -115 V, when the GG is in its open state, or alternating with ± 75 V to the base potential from wire-to-wire, when the GG is in its closed state. In case of closed GG the selected polarity of the GG may affect some of the results of the simulation. Therefore the simulations are done with two polarities, referred to as nominal and shifted polarities.

$\frac{E}{N}$ (Td)	Mobility ($cm^2V^{-1}s^{-1}$)
0	1.53
8	1.53
10	1.53
12	1.53
15	1.52
20	1.51
25	1.49
30	1.47
40	1.44
50	1.41
60	1.38
80	1.32
100	1.27
120	1.22
150	1.16
200	1.06
250	0.99
300	0.95
400	0.85
500	0.78
600	0.72
800	0.63
1000	0.56
1200	0.51
1500	0.46
2000	0.40

TABLE 2. Ion mobility parameters for TPC P10

Wire Type	Diameter (μm)	Potential (V)	Pitch (mm)	Y Position (mm)
Anode	20	1100 / 1390 (I/O)	4	8
Cathode	75	0	1	6
Gating Grid	75	-115(±75)	1	0
Field Wire	125	2		8

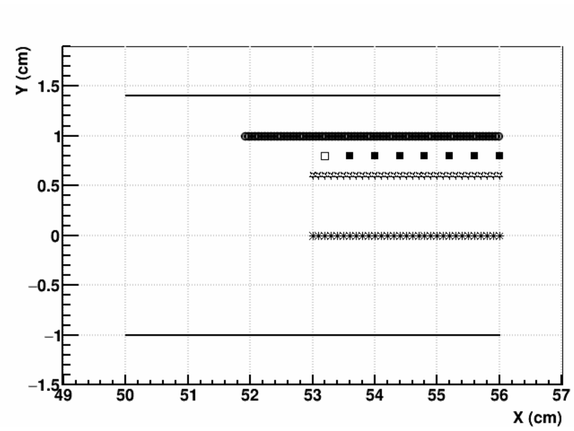
TABLE 3. Parameters of the TPC wires. I/O for anode wires indicate that we have different potentials for anode wires in inner and outer sectors

In case of nominal polarity the innermost GG wire is of the outer sector (one closest to the inner sector) has potential -40 V, thus making the outermost wire of the inner sector (one closest to the outer sector) to be biased to -190 V. The GG wires with -190 V potential are the ones that focus the feedback ions.

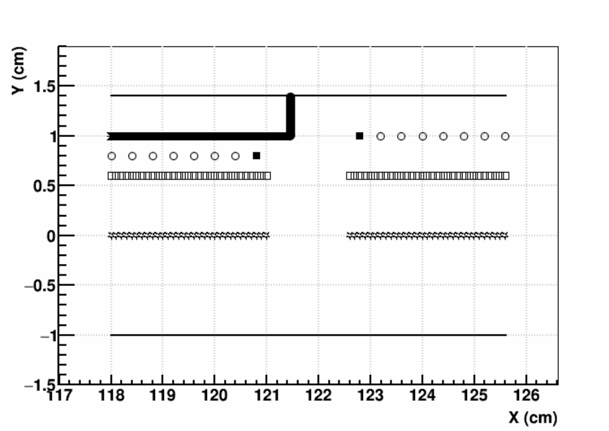
The shifted polarity, as name suggests has the polarity shifted by one wire, therefore making the outermost wire of the inner sector to have -40 V potential and innermost wire of the outer sector -190 V. Hence in this case the innermost wire of the outer sector is the focusing one and tends to create larger leak as seen in section 3.3.

The electric field in the main volume of the TPC is set to the same potential gradient as given by the -27950 V potential at the TPC central membrane in the realistic position (208.707 cm from the gating grid wire plane).

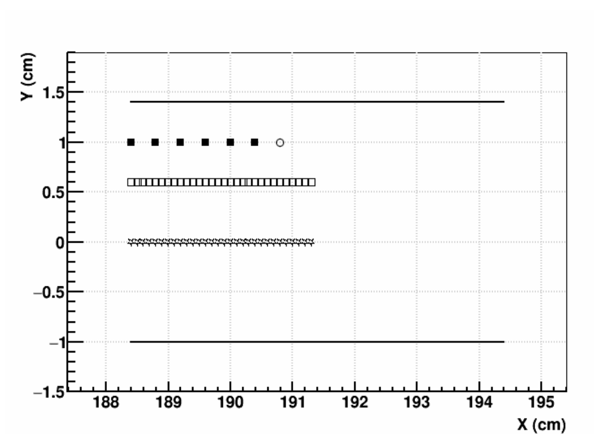
The geometry of the current TPC setup as set in GARFIELD is shown on Fig. 1



(a) OO region



(b) IO region



(c) OO region

Fig. 1. Current TPC design geometry for GARFIELD simulations

Different sets of wires are shown with different markers. The inner pad plane is not on the same level as the outer one. In order to accommodate inner pad plane it is composed of wires with 10 μm diameter and 5 μm pitch, which act as a solid plane. A similar approach is taken for additional wall structures: they too are composed of wires with 10 μm diameter, but in this case the pitch is just 1 μm, to approximate a solid wall as closely as possible.

The resultant field produced by the wires is shown in Fig. 2

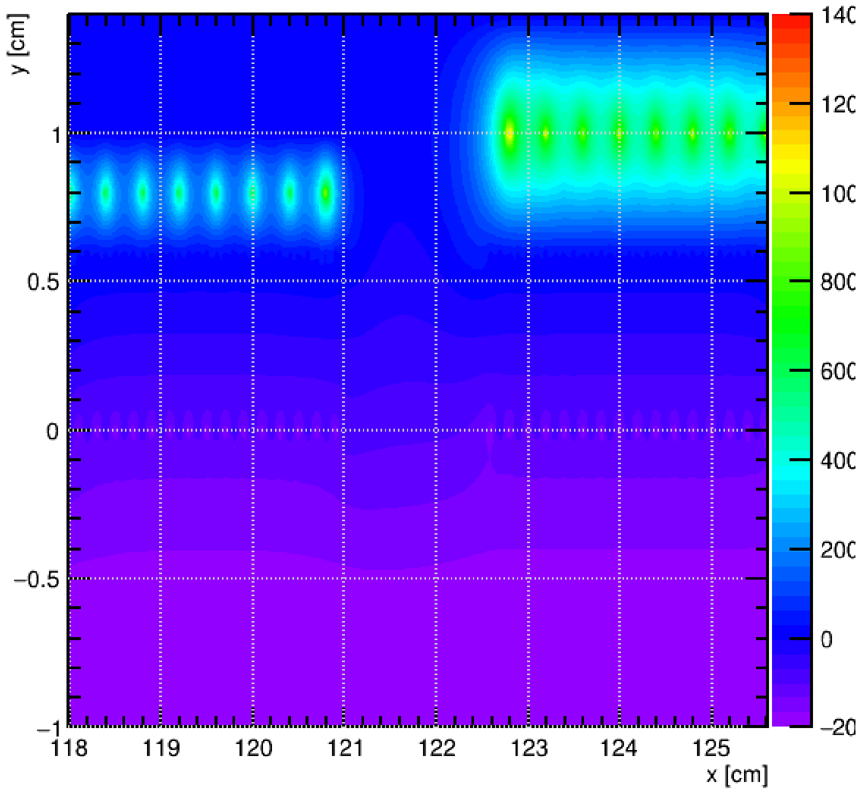


Fig. 2. Electric field near IO region of the current TPC setup as simulated by GARFIELD

3 RESULTS

Results of the simulations with above-described specifications of the TPC are given in the sections below. Two main ideas have been considered for eliminating the grid leak.

The first idea is related to reducing the grid leak by extending the GG coverage over the anode wires, which is effectively achieved by removing the outermost anode wires.

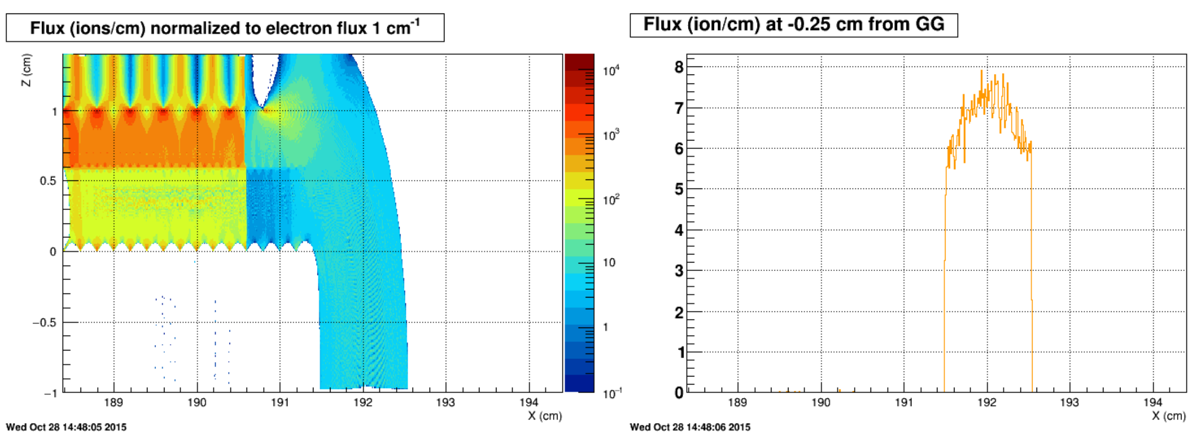
The second idea is to install additional shielding on the inner sectors, which are being upgraded, therefore we have a unique opportunity to alter their design based on the experience we gained thus fur and supporting simulation studies.

The measurements of the grid leak are quantified in number of ions per initial electron which manage to escape beyond the GG into the main volume of the TPC.

3.1 OO Region

The OO region has been simulated to better understand the grid leak and incorporate the results in the space charge calibrations. With only inner sectors upgraded for TPC upgrade there is no opportunity to reduce the grid leak in OO region.

Figure 3 shows the flux of the grid leak across the TPC chamber wires.



(a) Total grid leak flux **(b)** Grid leak at 2.5 mm after GG

Fig. 3. TPC grid leak in OO region

3.2 II Region

The leak between the inner sector and inner field cage (II region) is reduced by receding the field wire under the gating grid by two anode wire pitch steps. The field wire is the outermost wire on both sides of the sector. The idea of having the field wive, which is an anode wire with a higher diameter, is to have the anode field uniform for all anode wires participating in avalanche creation. The larger diameter is intended to ensures negligible avalanche, and most importantly it increases the rigidity of wire which experiences higher tension due to the non-uniform field (asymmetric situation for last wire).

This effect of receding anode wires under the GG by two pitch steps showed to reduce the leak by a factor of 25 on both sides of the iTPC, each step corresponding to about a factor of 5 reduction as shown on Fig. 4. In each of these three cases the last regular anode wire is at the same place, but the number of field wires varies (3, 2, 1). So even though a gain from the field wires is very small in combination with the leak from regular anode wires their number still makes a big difference.

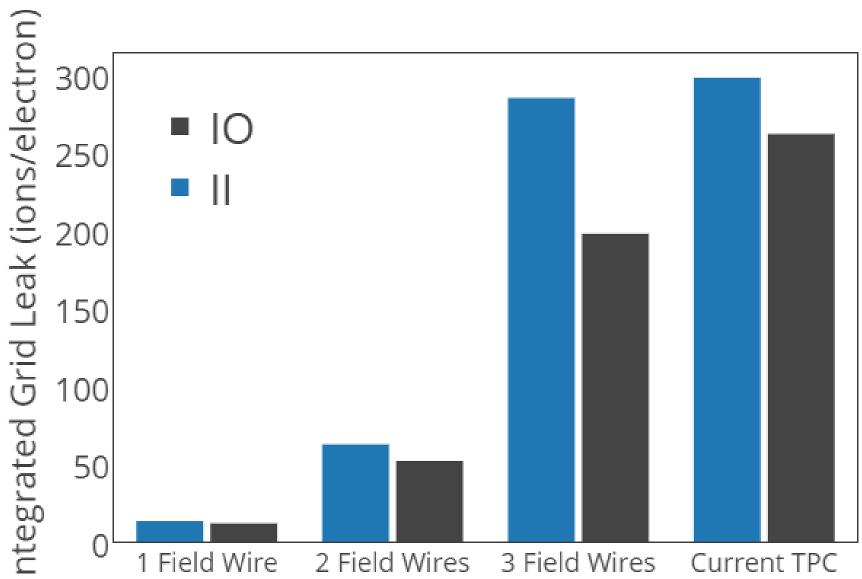
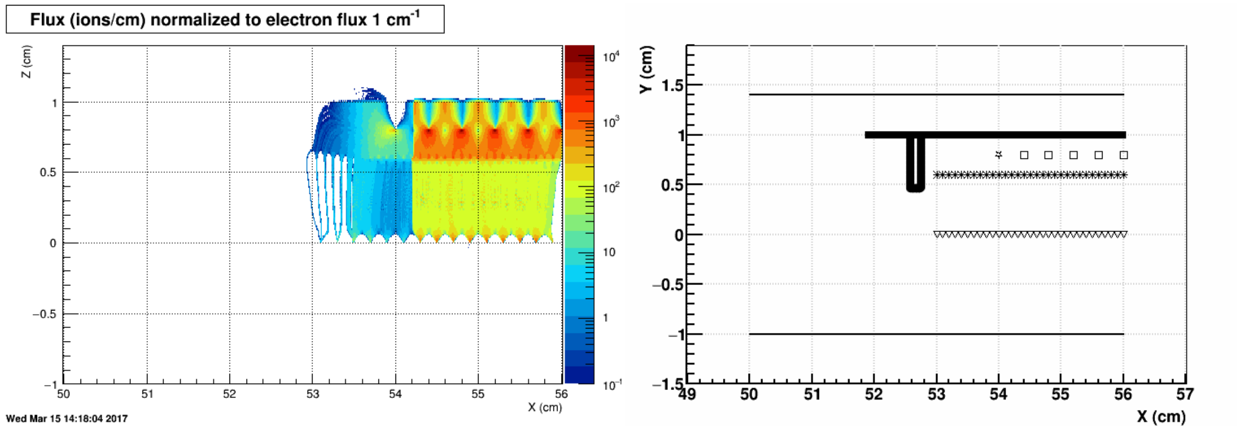


Fig. 4. TPC grid leak for different configurations of field wires

This argument supports having just one field wire which is receded under the gating grid. Nevertheless, there is still a non-zero leak on both sides. To further suppress the residual leak additional structures are employed.

For the II region the simple grounded wall was chosen and shown to be sufficient to entirely eliminate the leak (Fig. 5).

The wall for the simulation extends 1.25 mm beyond the cathode wire plane (towards the GG) and is 0.18 mm thick with the distance of 2.5 mm to the nearest anode wire.

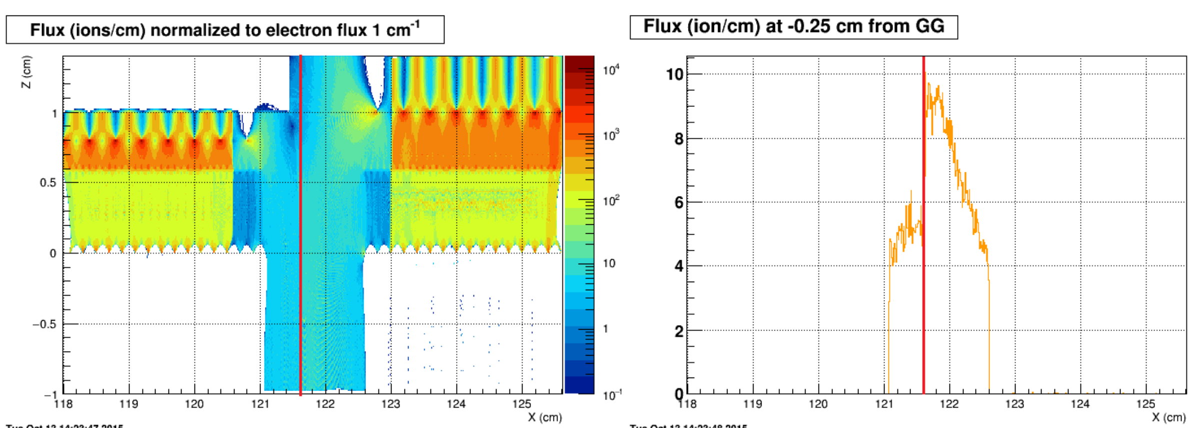


(a) Total grid leak flux **(b)** Geometry with added wall

Fig. 5. TPC grid leak in II region with additional wall

3.3 IO Region

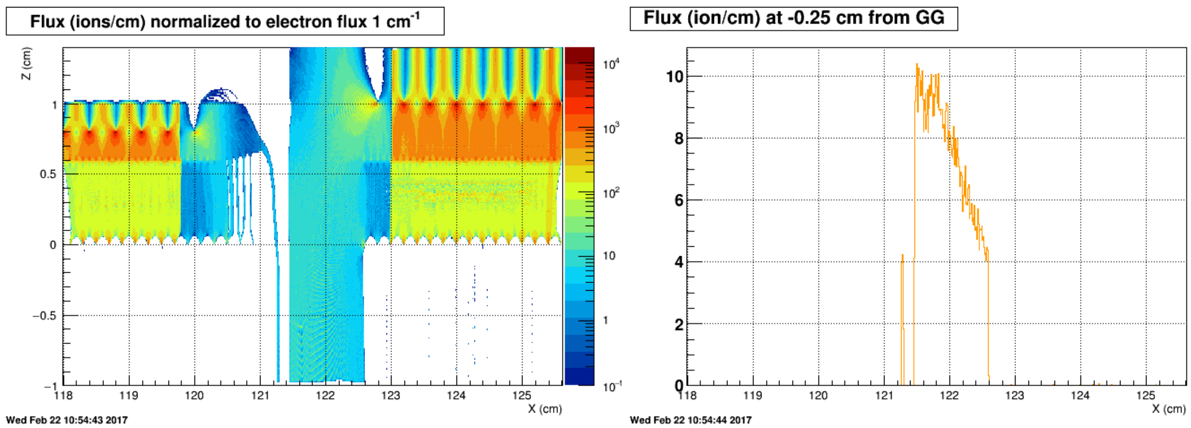
The IO region leak is split into two parts: the side corresponding to the leak from the iTPC and the side corresponding to the leak from the outer sector. Figure 6 shows the grid leak for the existing TPC design. The red line on the figure is added to separate the contribution by the inner and outer sectors to the leak in the IO region.



(a) Total grid leak flux **(b)** Grid leak at 2.5 mm after GG

Fig. 6. TPC grid leak in IO region with red line indicating the visible border between the leak from the inner and outer sides of the IO region

Once again the first approach is to reduce the leak with minimal change to the design, which in our case means receding the anode wires discussed in section 3.2. The effect for the IO region's inner side leak was shown in Fig. 4. However, while the inner side contribution to the leak in the IO region is substantially reduced by receding the anode wires, the contribution from the outer side is still substantial (see Fig. 7)



(a) Total grid leak flux

(b) Grid leak at 2.5 mm after GG

Fig. 7. TPC grid leak in IO region with anode wires receded under the the GG by two pitch steps

Even though the iTPC upgrade envisions only replacing the inner sectors without any interference with outer sectors, a clever approach can have an effect to the contribution of the outer sector side to the total leak in the IO region: have a wall which is electrically biased in such a way that creates the field to attract feedback ions before they reach the GG. To do so, in contrast to the wall on the II side, which didn't have to extend all the way to the GG wires, in the IO region the wall needs to be taller. Therefore distortion of the field along the GG needs to be considered. To minimize this distortion the tip of the wall (Fig. 8) is held at the nominal GG potential of -115 V. The inner side of the wall (facing iTPC) is grounded and the outer side of the wall is biased. The outer side contribution to the IO leak depends on the value of the bias potential.

Figure 9 shows how the grid leak decreases as we crank up the bias potential of the outer side (facing the outer sector) of the wall, causing more ions to be collected on it. The simulation is performed for both nominal and shifted polarity of the the gating grid. The result shows that for that having the outermost wire as the focusing one requires higher potential on the wall to divert the ions towards it.

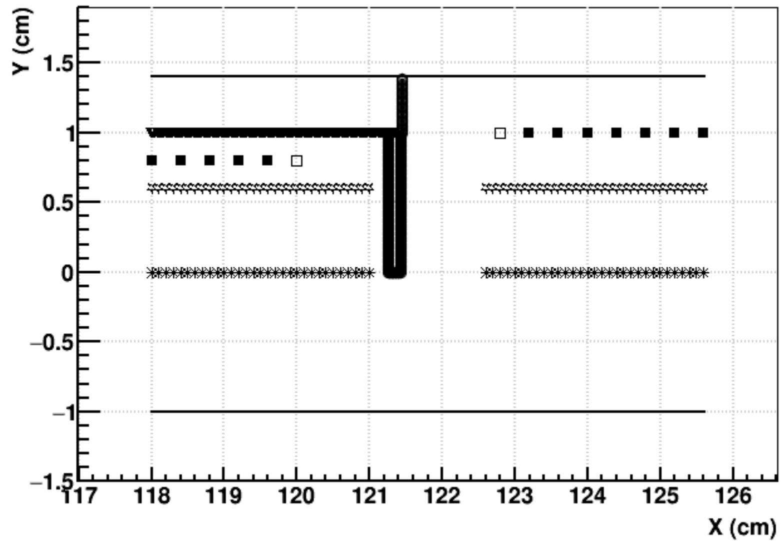


Fig. 8. iTPC geometry for IO region with added wall

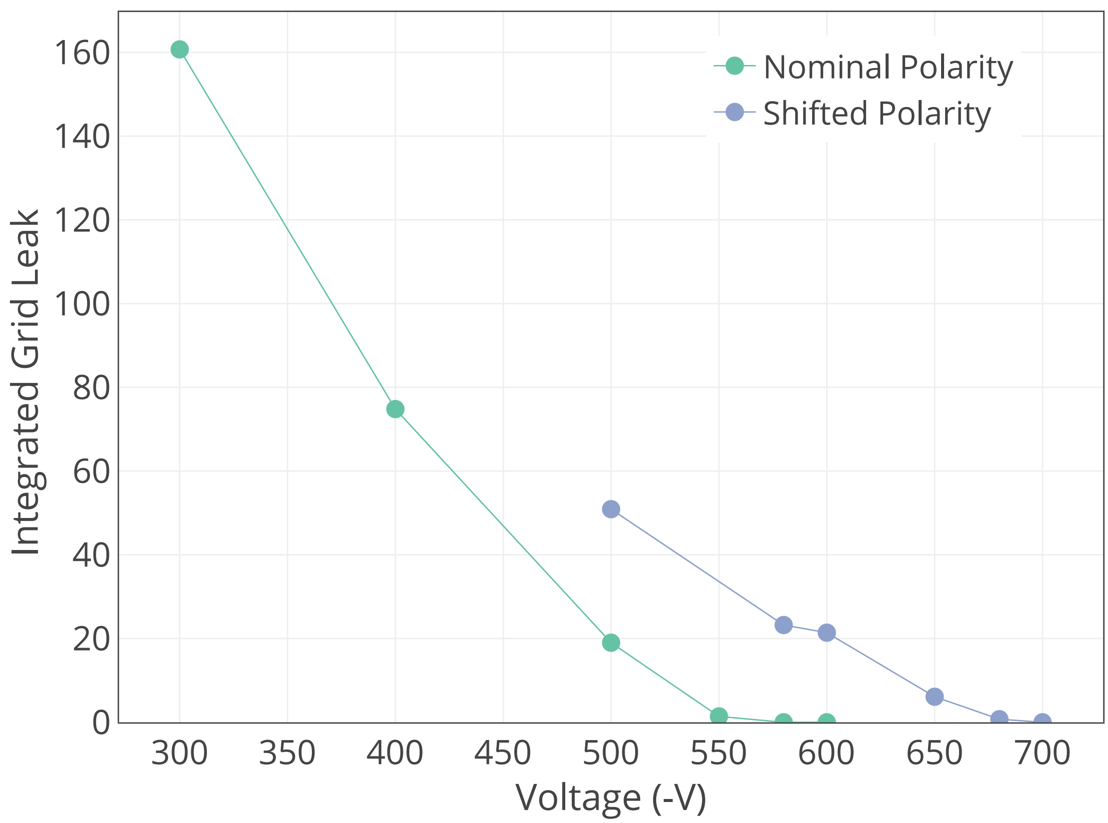


Fig. 9. Grid leak as a function of the potential of the outside part of the wall

Based on the simulation we learn that adding the wall, in the IO region, with about -600 V potential on the side facing the outer sector can eliminate the leak in the IO region completely. The final design of the wall in the IO region with dimensions and potentials used in the simulation of the final result is shown on Fig. 10.

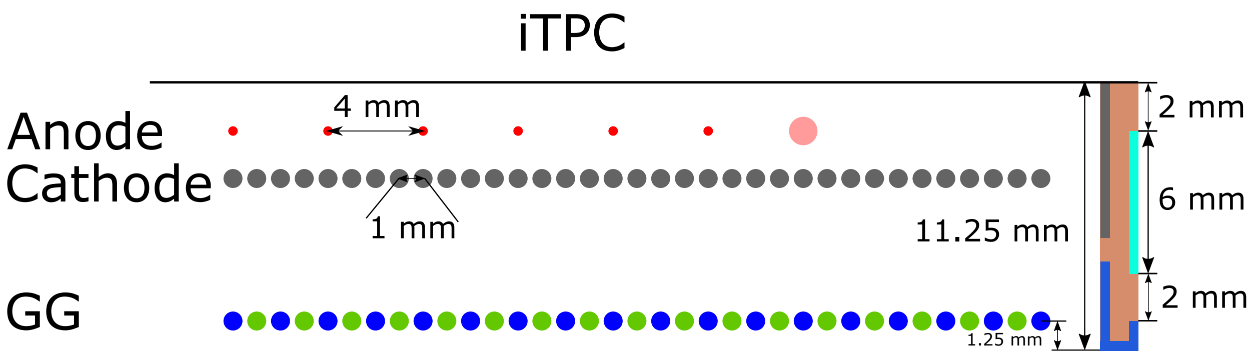


Fig. 10. Final wall design for IO region

4 CONCLUSION

In summary, it is important to reiterate that the main cause of the grid leak is that in spite of the larger diameter of the field wires, which is intended to ensure a very low gain, they still produce feedback ions, hence the grid leak. This culprit was identified in Nikolai earlier study at STAR as well (Smirnov and Lebedev). In this analysis the effect is quantified and means of grid leak elimination through upcoming iTPC upgrade suggested. Due to the above mentioned main reason of the leak, the focus of the study was primarily on the field wire manipulation and only then on additional structures to completely eliminate the residual leak.

The simulation study presented in this technical note can be used for the final design of the iTPC. The conclusion from the simulation is twofold.

Firstly, the suggested number of field wires is one. The field wire should be receded under the gating grid plane by two anode wire pitch steps from its position in the current TPC design.

Lastly, addition shielding is necessary to completely remove the residual grid leak. To do so in the II region, a simple grounded wall is sufficient. The IO region requires a longer wall with bias potential of at least -600 V on the side facing the outer sector to prevent the ion feedback produced by the ions from the outer sector.

Such design, according to the detailed simulation using GARFIELD, ensures elimination of the leak in II and IO regions, leaving only the OO region where iTPC related intervention is not sufficient.

5 RUNNING GARFIELD AT RCF

The code that has been developed and used for the simulations for this analysis can be accessed at GitHub.

https://github.com/iraklic/STAR-Garfield

It can be checked out using:

```
git clone https://github.com/iraklic/STAR-Garfield
```

The checked out package will include generated P10 gas file, so the user doesn't have to lose time on regenerating it, the `setup.csh` file to help setup the environment, `tpcGL.xml` file to run the batch jobs, and the `tpcGL.C` file itself, which contains the code and some geometry definitions used in the study.

The `setup.csh` file is based on the libraries and their structure available at RCF (RHIC Computing Facility) as they are during at the moment of writing this manuscript. The `README` file provides step-by-step instruction for running the code and acquiring the results.

REFERENCES

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Smirnov, N. and Lebedev, A. “Gridleak simulations.” *https://drupal.star.bnl.gov/STAR/subsys/tpc/GridLeakSimulation*.