Distortions in the sPHENIX TPC using Digital Current with Machine Learning

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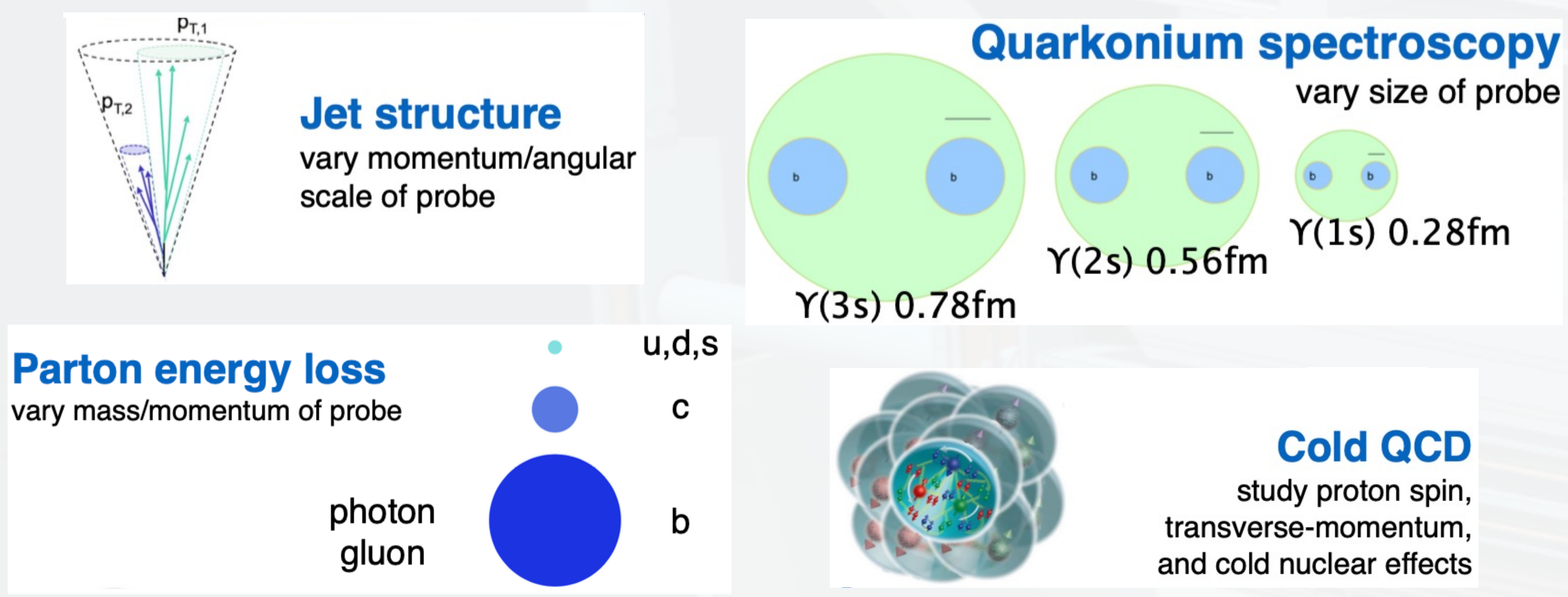
Abstract

The Time Projection Chamber (TPC) to be used for tracking and particle identification in the sPHENIX [1] experiment at the Relativistic Heavy Ion Collider (RHIC) is expected to experience significant distortions from build-up of backflowing ions created by the combination of high collision rates and amplification from Gas Electron Multiplier (GEM). By integrating the digitized readout from the detector, one produces a 'digital current' which serves as a proxy for the ion backflow current. The digital current can then be used to reconstruct the ion space charge density to calculate the electric field distortions in the chamber, but at significant computational cost. Machine learning methods provide a mechanism to reduce this computational cost while also reducing errors by training and validating with experimental data. We will present methods and results using machine learning techniques to predict and correct for space-charge induced distortions in the sPHENIX TPC.

sPHENIX Physics Program

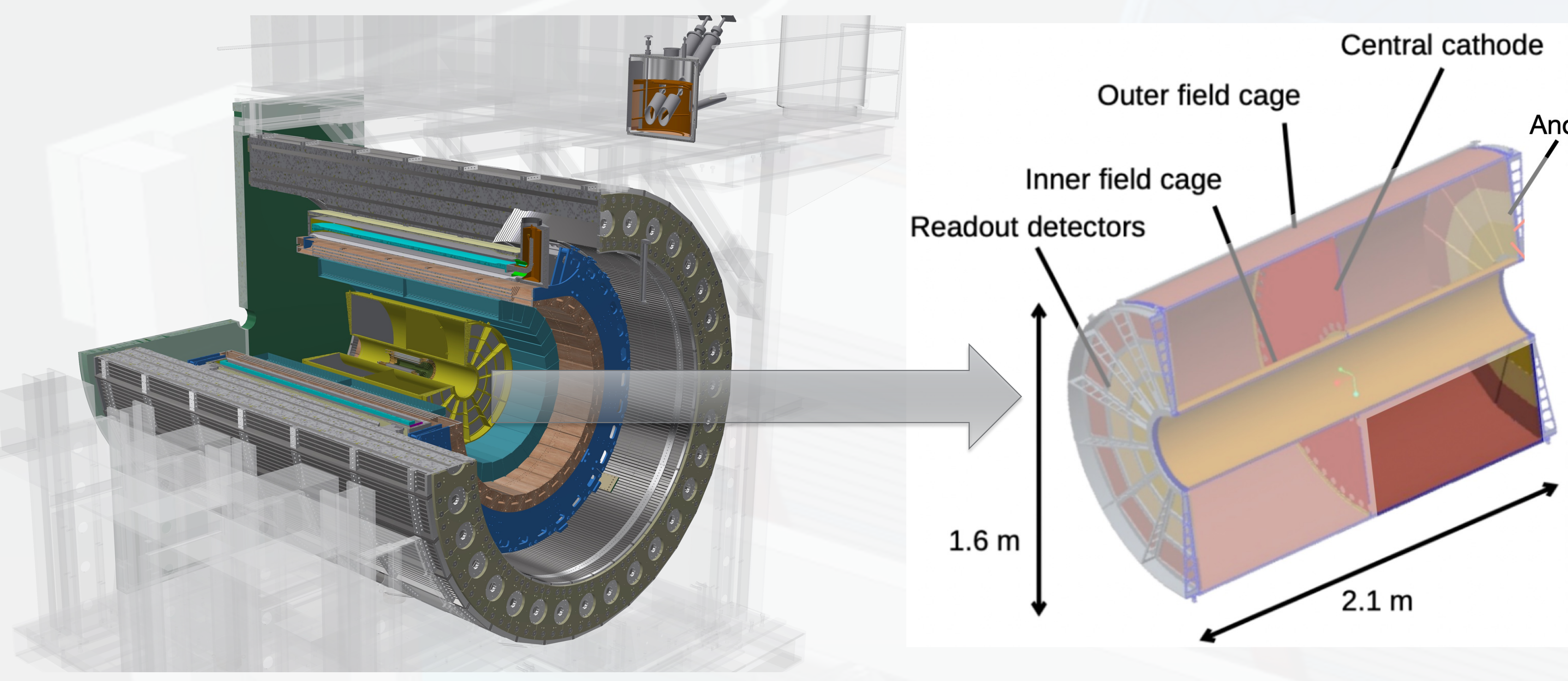
Use pp, p-Au and Au-Au collisions at 200 GeV to access and understand exciting physics!



*from A. Francisco, QM22

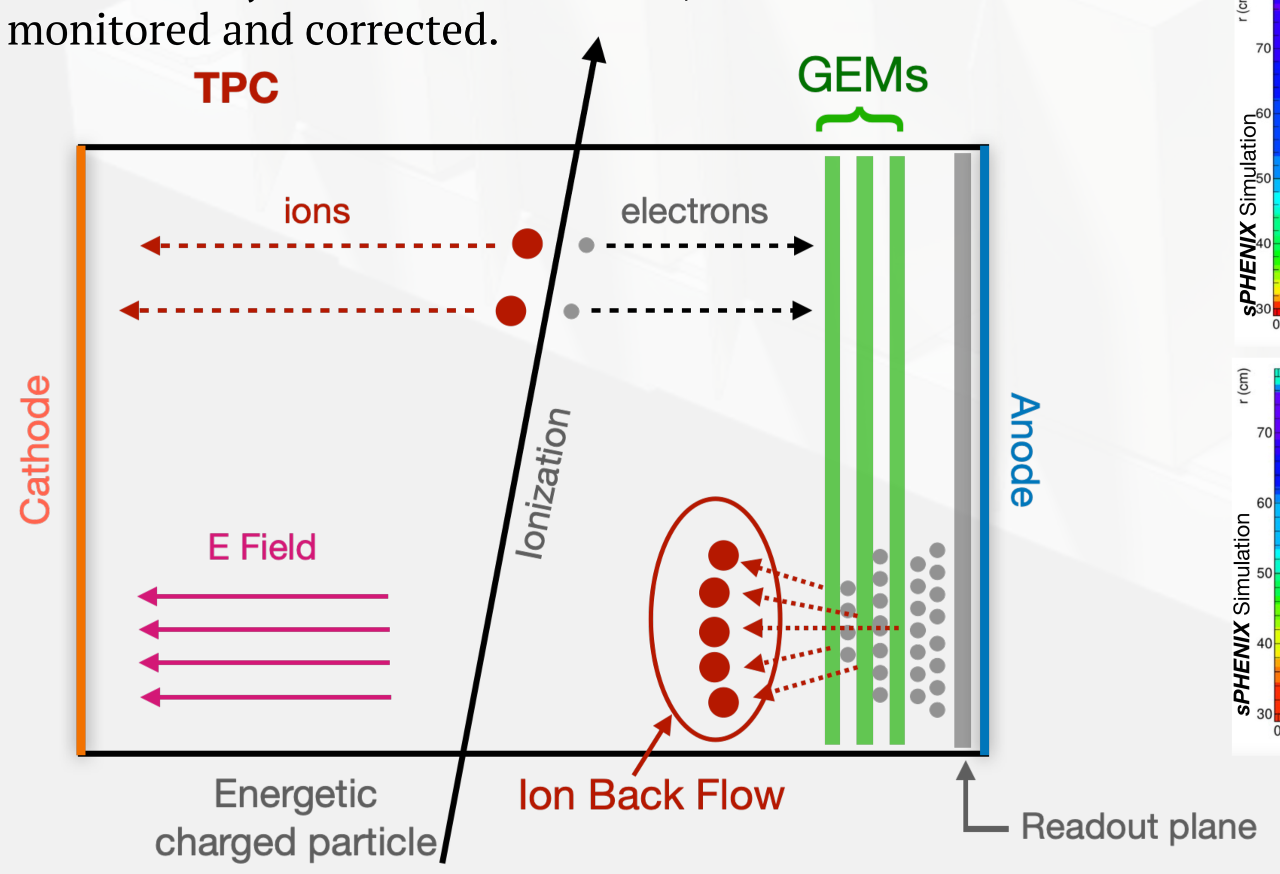
The Time Projection Chamber (TPC) in sPHENIX

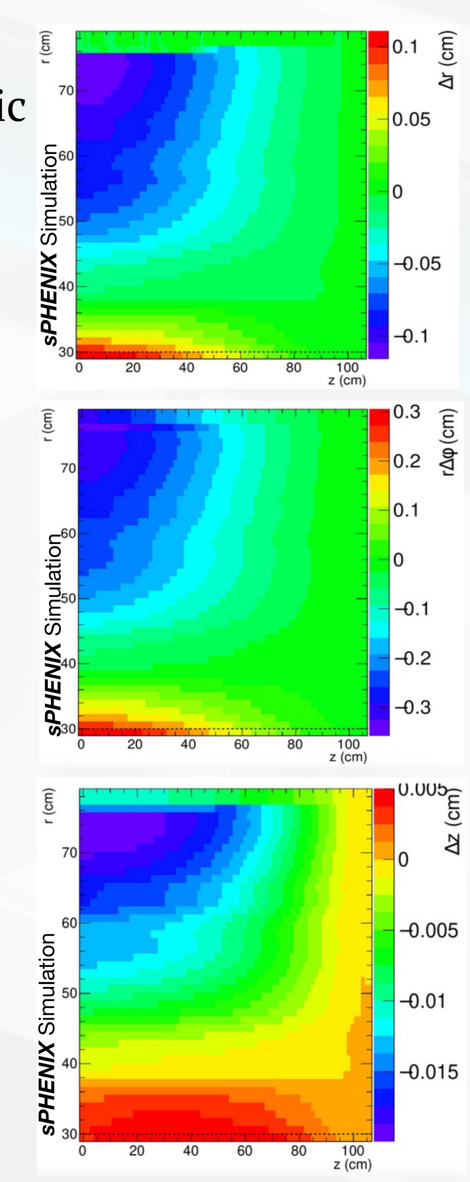
TPC [2] is the main tracking detector and is critical for achieving the physics goals



Distortions in the TPC

- Electrons released from ionization by a charged particle traversing the TPC are drifted towards the anode by an electric field.
- Ion Backflow (IBF): Ions produced in the electron amplification stage drift slowly in the opposite direction and distort the electric field.
- To accurately reconstruct the track, these distortions must be monitored and corrected.



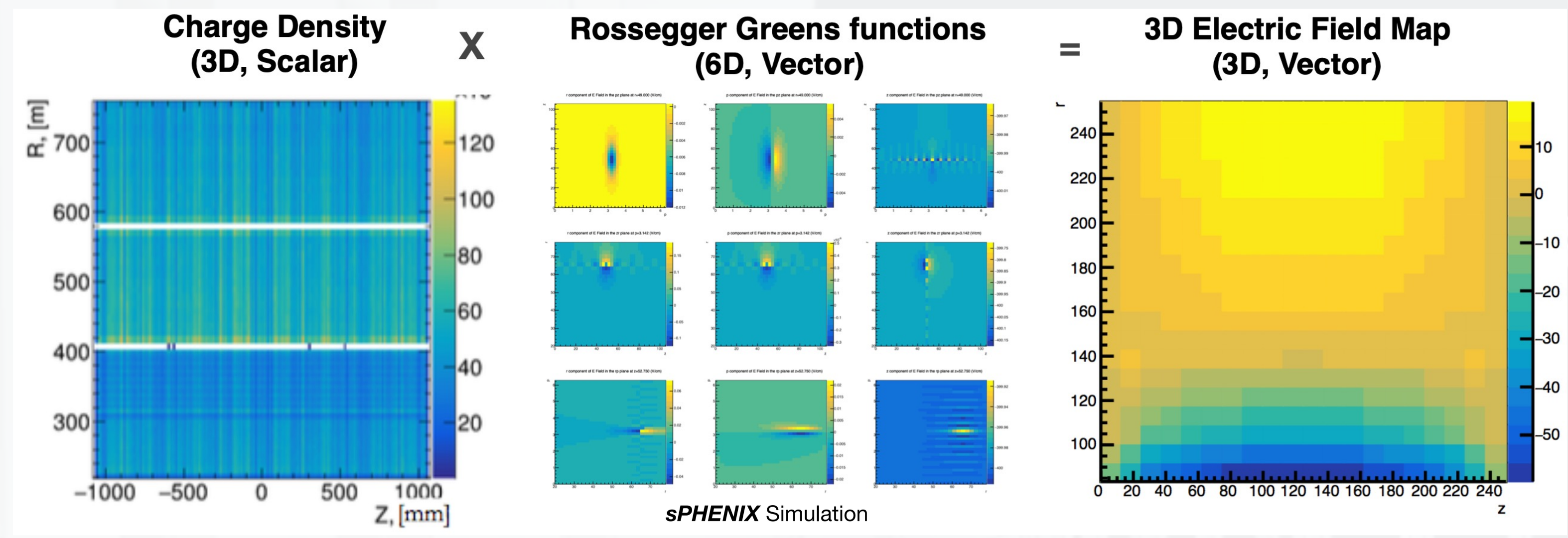


*from H. Pereira Da Costa, PAC 2021

Need to correct for the distortions in the TPC for precise track reconstruction

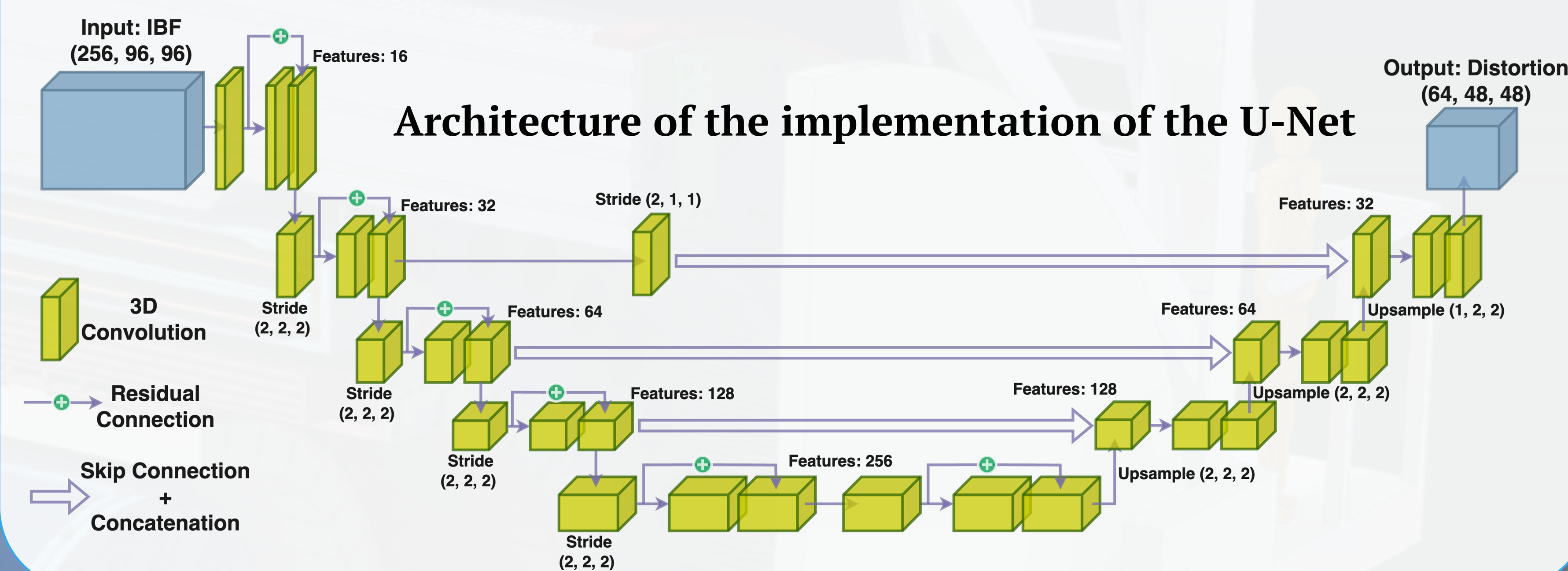
Monitor distortions with Digital Currents and Machine Learning

- Integrating e- arriving at logical blocks of readout pads over O(10ms) and scaling it by IBF gain gets us the "digital current" density
- The digital current is then used to reconstruct the distortions due to this modified electric field in the chamber, but at significant computational cost.

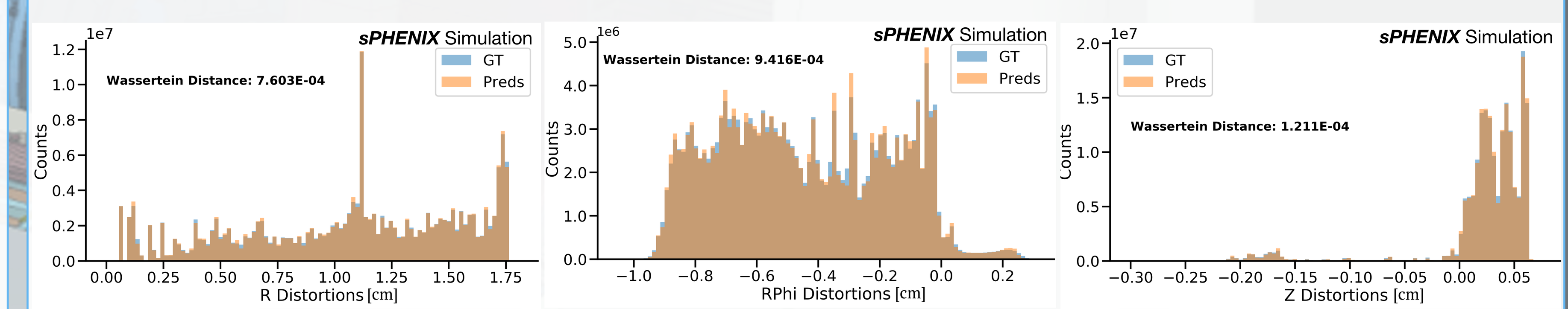


*from R. Corliss, QM22

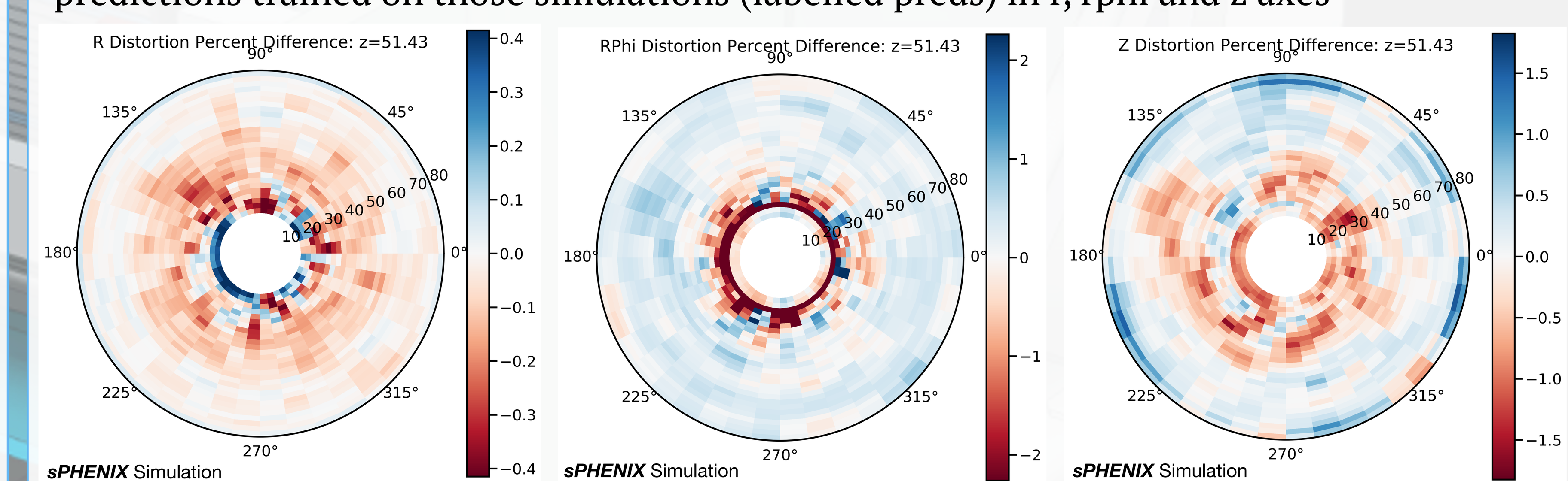
- Distortions in the electron drift paths are represented as a set of three 3D images corresponding to the distortions in the R, Phi, and Z dimensions from the nominal drift.
- A 3D U-Net [3] convolutional neural network is ideal for mapping the 3D image of the digital currents to 3D image of the distortions.
- The model uses both global and local information from the digital currents to make distortion predictions.



TPC Distortion Prediction Results from Machine Learning



Simulated distortions in the TPC (cm) shown in blue for brute-force calculations on simulated space charge distributions (labelled GT) and in orange for ML-based predictions trained on those simulations (labelled preds) in r, rphi and z axes



Difference in the TPC distortions (%) between calculated values in simulations and ML-based predictions in r, rphi and z axes shown for a specific value of z (=51.43 cm)

Summary

The use of ML methods in deriving TPC distortion corrections provides a mechanism to

1. significantly reduce computing costs (anticipated savings of ~$1M over the operation of sPHENIX),
2. reduce distortion errors by training and validating with experimental data.

Work is is ongoing to use data from the TPOT detector, which provides partial phi coverage, and use limited dataset to train the models by enforcing phi symmetries.

First real data for this system is expected to be available in 2024!

References

[1] A. Adare et al., sPHENIX: An Upgrade Concept from the PHENIX Collaboration, arXiv:1207.6378
[2] H. Klest, Overview and Design of the sPHENIX TPC, J. Phys.: Conf. Ser. 1498 012025 (2020)
[3] O. Ronneberger, P. Fischer and T. Brox, MICCAI 2015 3, 234-241 (2015)

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