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STAR TPC Space Charge Calibration: Methods and Strategy for Run 22

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STAR 2022 pp 508 GeV

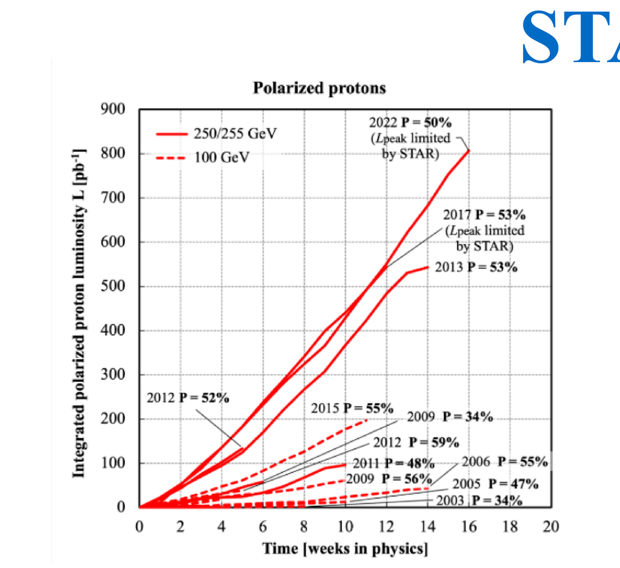


Figure 1: Integrated polarized luminosity over time.

- During STAR Run 2022, polarized proton beams were collided at a center-of-mass energy, $\sqrt{s} = \mathbf{508}\,\boldsymbol{GeV}$.
- The size of the data sample collected during this period is $\sim\mathbf{400}\,\boldsymbol{pb^{-1}}$, larger than Run 2017, which will greatly improve the statistics of precision measurements at STAR, such as the $\boldsymbol{W/Z}$ cross section and IFF analyses.
- Figure 1 on the left shows the integrated luminosity of Run 22 over time in comparison with previous pp runs.

Time Projection Chamber (TPC)

- The Time Projection Chamber (TPC) shown in figure 2 records event tracks, particle momenta, and provides particle identification (PID) for charged particles via measurement of ionization energy loss *dE/dx.*
- The TPC covers ±1.5 units of pseudorapidity and the full azimuthal range.
- Particles collide very close to the TPC center. Paths of primary ionizing particles are reconstructed by tracking secondary electrons released by ionization of the surrounding gas.
- Electrons drift to the readout caps at either end of the chamber driven by a uniform electric field of ~135V/cm generated by a thin conductive central membrane.
- Precise calibration of the TPC is necessary to ensure accurate data and analysis.

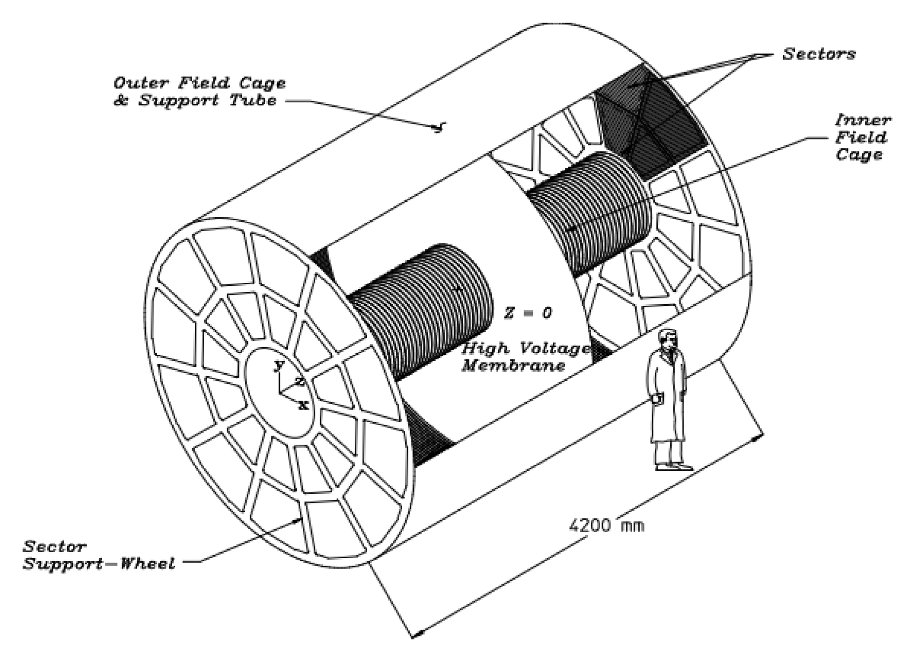
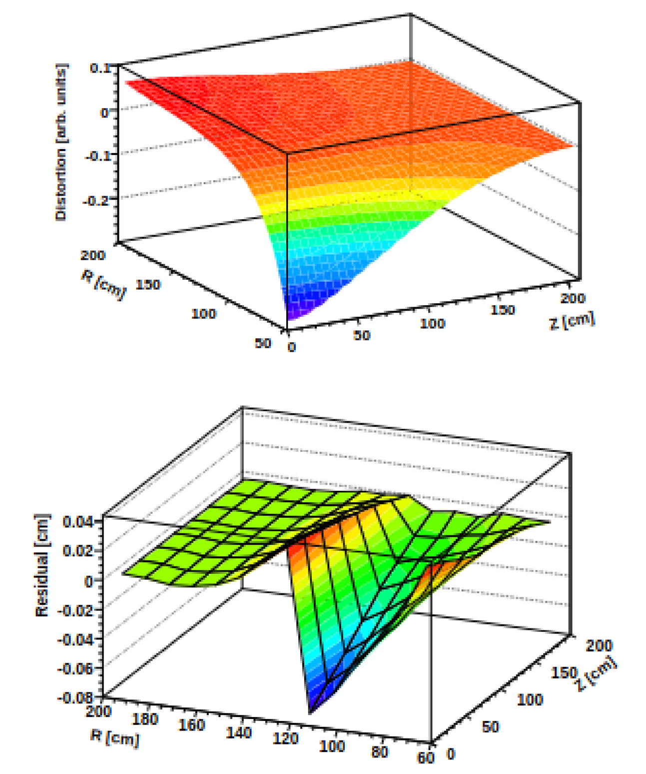


Figure 2: Time Projection Chamber Diagram

TPC Space Charge and Grid Leak Calibration

Distortions to TPC Hit Points:

- Gas ions in the chamber created a positive charge density called the Space Charge (SC).
- Ions from around the anode wires leak through gaps in the gating grid. This leakage is called Grid Leak (GL).
- Distortions of tracking from SC and GL are reduced by subtracting calculated charge contributions from measured electron positions to estimate the undistorted track.
- Figures 3 and 4 on the right show the azimuthal distortions of the position of electron clusters and the residual tracks over R and Z for high luminosity events before correcting for SC and GL distortions.


Figures 3 & 4: Nucl.Instrum.Meth. A566 (2006), 22-25

Calibration Methodology:

- Initial calibration for Run 22 was done following well established calibration procedures.
- Corrections are linearly proportional to SC and GL. Scaler coefficients and offsets will be found according to the equation:

$$SC = SC_{obs} \cdot (\text{scaler} + SC_{offset})$$

- If SC_{obs} is directly linearly proportional to SC as seen in the graph on the left from the Run 17 TPC Calibration, then that scaler can be used to subtract out distortions from the tracks.
- A fit was produced for each scaler or pair of scalers available, and the fit closest to a direct linear relationship was then used in the next iteration.

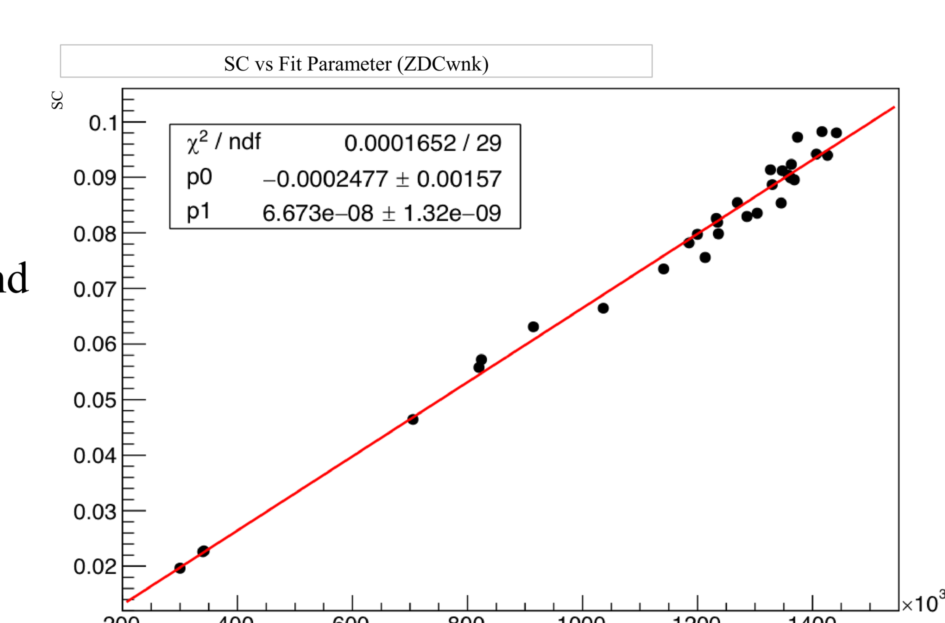


Figure 5: Run 17 Official TPC Calibration

- This iteration processes was repeated until the fit produced a direct linear relationship with a low chi square value, proportional to two scalers.
- The process was iterated a total of eight times over the initial seed data range.

Seed Data & Calibration Status:

- A total of 69 runs from a wide range of luminosities across 5 different fills will be used as the initial seed for TPC calibration.
  - Fills: 33049, 33052, 33054, 33055, 33056
  - Run Range: [23034051 - 23037015]
- Runs with around 1000 events and no reported issues in the Shift Log were picked at random from this range.
- The general Run 22 calibration is complete after eight passes total.
- The Space Charge value is proportional to the trigger rates from the Zero Degree Calorimeter (West) and the Beam-Beam Counter (Coincidence) (Nucl.Instrum.Meth. A902 (2018), 228-237).
- This general calibration result was used as an initial SC value for individual fill calibrations, and that effort is still ongoing.

SC Calibration Technical Details

- During the calibration, the BEMC pedestals were updated to alleviate the large number of pile up tracks.
- As a result, the statistics from a single DAQ file were no longer sufficient to meet the 1500 track minimum required to calibrate the Space Charge.
- To remedy this, the number of DAQ files from each run was increased from one to four.
- Installation of the iTPC has significantly reduced the impact of Grid Leak on the detector. only a nominal value set in the parameters of the Space Charge calibration, reducing our computing time by two thirds.
- The signed Distance of Closest Approach as seen in figure 6 is the closest that the track comes to the primary vertex, with the sign denoting the spiral direction. We use this as a means of determining the convergence of the calibration.
- Figure 7 shows a comparison of the Pass08 distribution to previous pp500 runs, as well as the earlier preview production for Run 22.

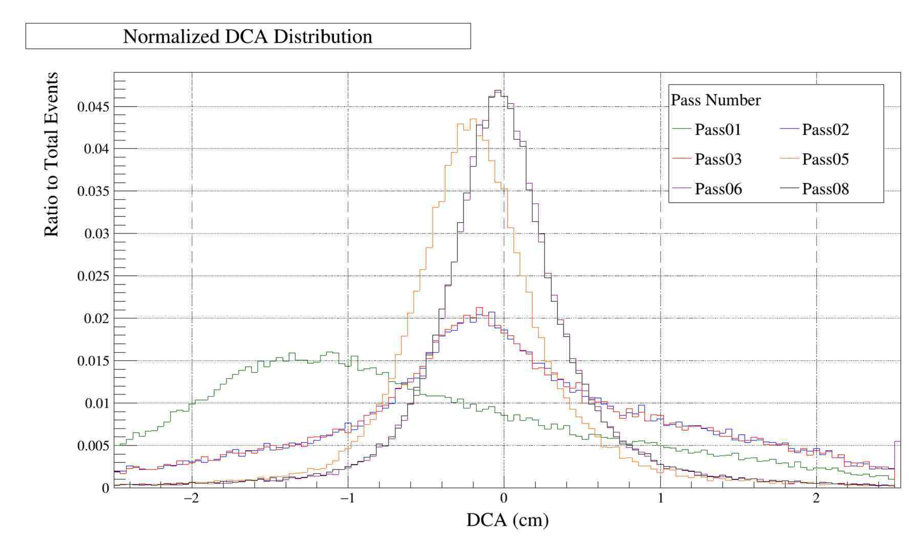


Figure 6: Normalized DCA Distributions from SC calibration iterations

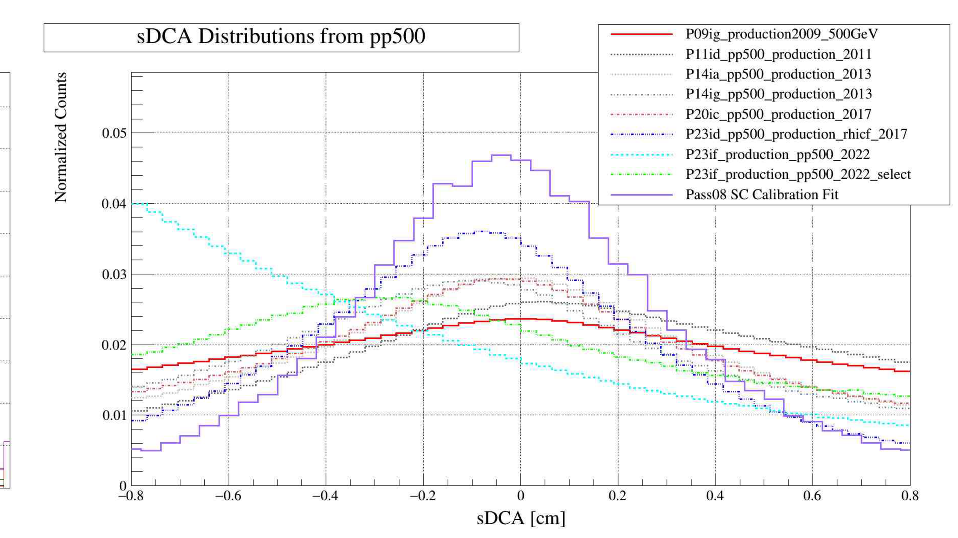


Figure 7: DCA Distributions from pp500 Runs

Fill Dependent Space Charge

- During the Run 17 TPC and BEMC calibration efforts, fill-dependent variations in the Space Charge were observed, as seen in figure 8.
- To account for this, the Space Charge was fit with an exponential function of N+/N- to normalize to an average that was assumed to be correct.
- Similar anomalies have been observed in Run 22, illustrated by figures 9 and 10. We have decided to develop machinery to calibrate each fill individually, using a general calibration over the entire run as an initial Space Charge value.
- This strategy was not used in Run 17 because of time constraints. Developing this strategy now, however, will allow quicker and easier calibration in the future.
- Each fill from Run 22 can be calibrated separately using the same method as a general calibration.
- Each fill is separated in the database with its own Space Charge Correction file, with an appropriate timestamp corresponding to that fill.
- The process will be iterated as needed, until the SC converges for each fill.
- The general calibration effort reduces the number of iterations needed significantly.
- We expect the full calibration to be completed soon.

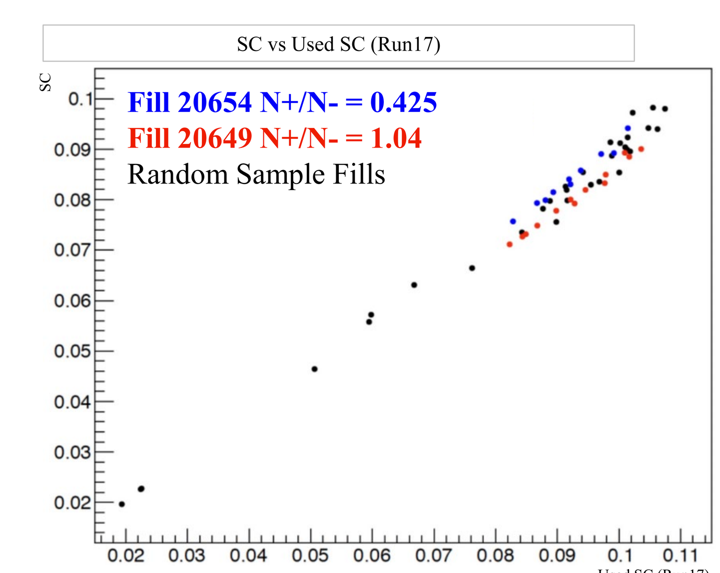


Figure 8: SC vs Used SC (Run17)

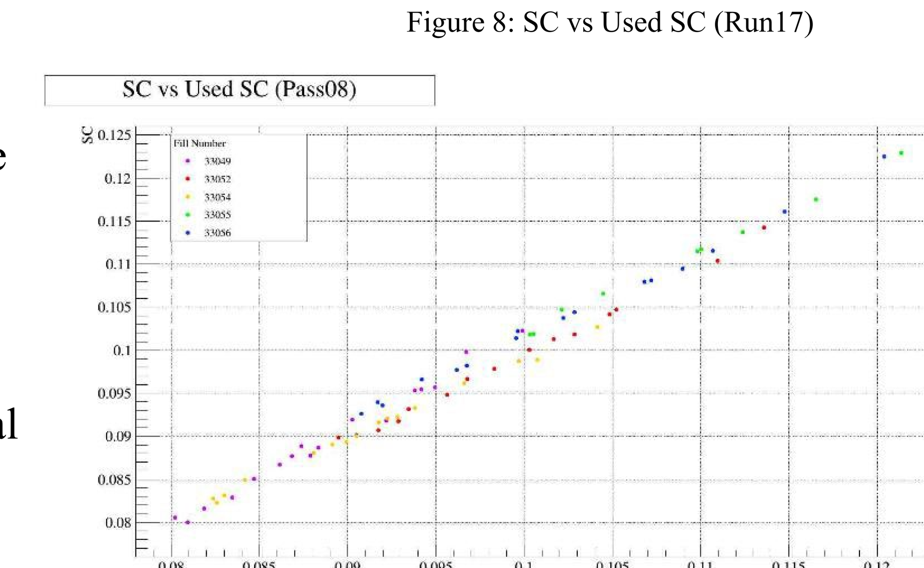


Figure 9: SC vs Used SC (Pass08) for Seed Fills

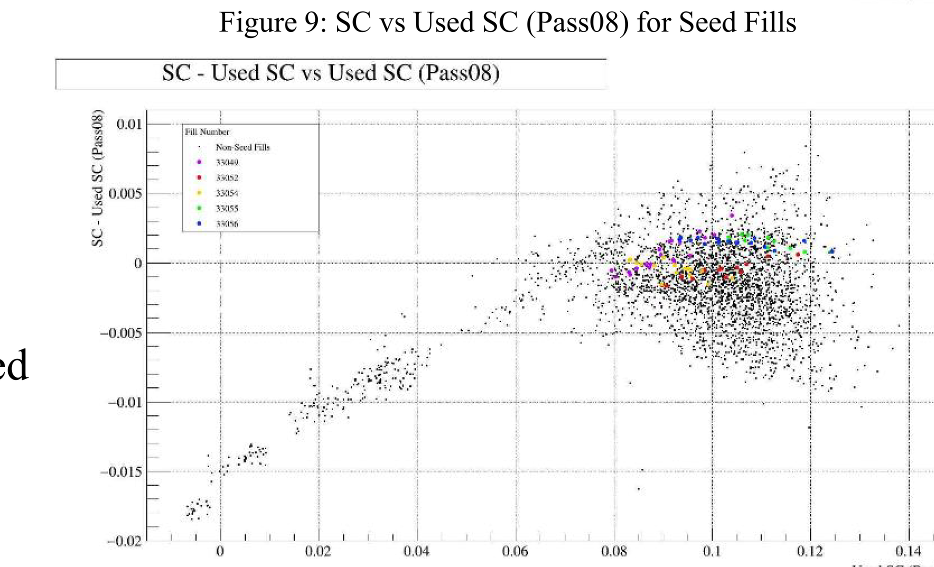


Figure 10: SC – Used SC vs Used SC (Pass08)

Summary, Outlook, & Acknowledgements

- Space Charge distortions require an iterative process to be calibrated for use in analyses.
- A general calibration for Run 22 is complete, using a sampling of 5 fills with a wide range of luminosities.
- Fill dependent SC variations were observed in Run 22, like those in Run 17. We develop a formal approach to address this with long-term benefits.
- The Space Charge calibration methodology has been updated to reflect additions to the TPC subsystem.
- The fill dependent calibration effort is ongoing and will be complete in the next few months.
- Larger statistics allow us to further investigate other relevant questions of SC.
- One such goal is to evaluate which RICH scalers best reflect the luminosity dependence of SC and study their correlation to one another.
- In addition, it may also be possible to determine sets of scalers that are more accurately correlated to SC in phi space, since each detector occupies a different region in phi space.

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