Strong parity violation at STAR: Quantifying background effects with Monte-Carlo event generators and detector effects study

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Abstract We present a systematic study of possible physics background effects in parity violation measurements with existing event generators, such as UrQMD, HIJING, and MEVSIM. We have found that none of these event generators are able to reproduce either quantitatively or qualitatively the signal observed in the analysis of experimental data collected with the STAR detector at RHIC. To exclude the possibility of generating a fake signal due to non-uniformities in the detector acceptance, we have performed a set of tests with available experimental data from the STAR experiment. We conclude that detector effects that we have studied are not able to mimic the signal for parity violation.

Charge separation as a probe for strong parity violation in heavy ion collisions

The effect of spontaneous parity ($\mathcal{P}$) violation in heavy ion collisions, predicted in [1], can be described by adding $\mathcal{P}$-odd sine term to the Fourier decomposition of the particle azimuthal distribution with respect to the collision reaction plane angle, Ψ_{RP}:

$$dN/d\phi_\alpha \propto 1 + 2a_\alpha \sin\Delta\phi_\alpha + 2v_{1,\alpha}\cos\Delta\phi_\alpha + 2v_{2,\alpha}\cos(2\Delta\phi_\alpha) + \dots, \quad (1)$$

where $\Delta\phi_\alpha = \phi_\alpha - \Psi_{RP}$ is the particle azimuth relative to the reaction plane (index α represents particle charge), $v_{1(2);\alpha}$ corresponds to particle directed (elliptic) flow. Parameters a_α describe (first harmonic) $\mathcal{P}$-violating effect, and can be probed via three-particle correlation measurements [2] of charge separation with respect to the Ψ_{RP}:

$$\langle\cos(\phi_\alpha + \phi_\beta - 2\Psi_{RP})\rangle = -\langle a_\alpha a_\beta\rangle + \langle v_{1,\alpha}v_{1,\beta}\rangle + [B^{in} - B^{out}]. \quad (2)$$

Here indices α and β denote particle charges. $B^{in} - B^{out}$ term represents the difference between in-plane and out-of-plane background correlations not related to the $\mathcal{P}$-violation. Experimental observation of the correlator (2) demands the reconstruction of the reaction plane angle. It is only possible to estimate this angle from azimuthal anisotropies of particle production in heavy ion collision, what introduces a *third* particle, c, in the analysis:

$$\langle\cos(\phi_\alpha + \phi_\beta - 2\Psi_{RP})\rangle \approx \langle\cos(\phi_\alpha + \phi_\beta - 2\phi_c)\rangle / v_{2,c}, \quad (3)$$

where $v_{2,c}$ represents the elliptic flow of particles used for the reaction plane determination. This procedure introduces additional systematic uncertainties in the measurement, which could be magnified by the non-uniformity of the detector acceptance and efficiency. Below we present our study of background correlations, $B^{in} - B^{out}$, with existing event generators of heavy ion collisions together with our systematic checks of possible detector effects specific to the STAR experiment.

Systematic study of possible physics background effects with existing event generators

The HIJING [3], uRQMD [4], and MEVSIM [5] event generators have been configured to reproduce single particle distributions and elliptic flow values specific for the RHIC environment. The MEVSIM generator, which tests the resonance contribution in the correlator (2), has been tuned to generate realistic number of resonances and their elliptic flow values. Included resonances in MEVSIM are: ϕ, Δ, ρ, ω, and K^*.

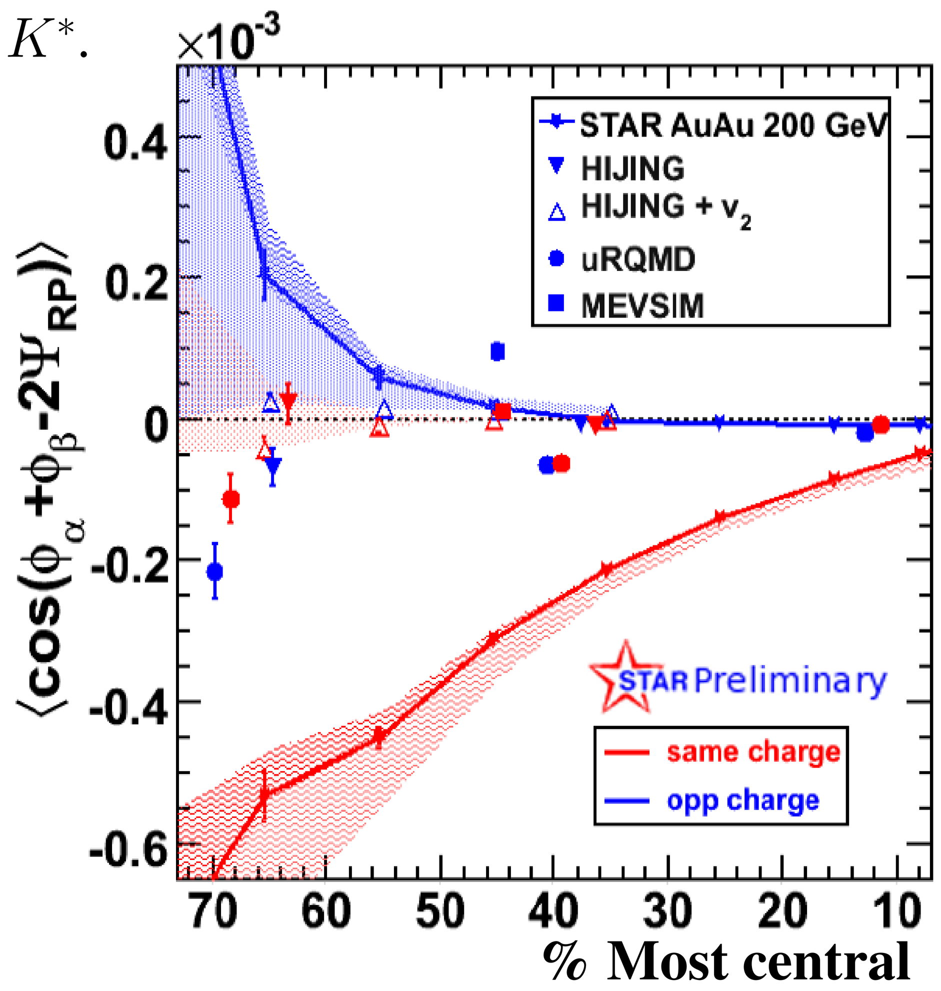

Fig. 1: Correlator (2) vs. collision centrality. Lines present STAR results for Au+Au collisions at $\sqrt{s_{NN}}$=200 GeV energy. Symbols indicate simulation results for the same colliding system with HIJING and its modification with added elliptic flow modulations, uRQMD, and MEVSIM event generators. Shaded bands represent systematic uncertainties of the measurement technique.

As it can be seen from Fig. 1, the simulated correlations are significantly smaller in magnitude than the signal from the data. The simulated data also tend to be very similar for the same sign and opposite sign correlations.

Detector effects in $\mathcal{P}$-violation measurements

We have performed the following checks to ensure that detector effects are not responsible for the signal observed by STAR for the correlator (2):

- *Distortions in the track momenta due to the charge buildup in the STAR Time Projection Chamber (TPC) at high accelerator luminosity.* Results obtained from RHIC Run II (a low luminosity run), and those from Run IV divided into high and low luminosity events, yield the same signal within statistical uncertainties.
- *Signal dependence on reconstructed position of the collision vertex along the beam line* has been checked, and no dependence has been found.
- *Displacement of track hits when it passes the TPC central membrane*. Correlator (2) has been calculated using only particles with the entire track in one of the different half-barrels of the TPC. Corrected for the signal dependence on the track separation in pseudorapidity, results are found to be consistent with those obtained before introducing the rapidity separation.
- *Feed-down effects from non-primary tracks (i.e. resonance decay daughters)* have been studied via cuts on track distance of closet approach (dca). Results for $dca < 1$ cm and $dca < 3$ cm are found to be consistent within statistical errors.
- *Electron contribution to the measured signal* has been checked via specific energy loss (dE/dx) in the volume of the TPC and found to be negligible. This check was done to test whether the signal was due to hadron production, or lepton production.
- *Studied a correlator similar to (2) but with the reaction plane angle rotated by* $\pi/4$. This new correlator should only deviate from zero due to detector effects. It was found to be consistent with zero within statistical errors.
- *Variation depending on the charge of the third particle used to reconstruct the reaction plane and changes of the STAR magnetic field polarity* are illustrated in Fig. 2. The variations does not change the observed signal.

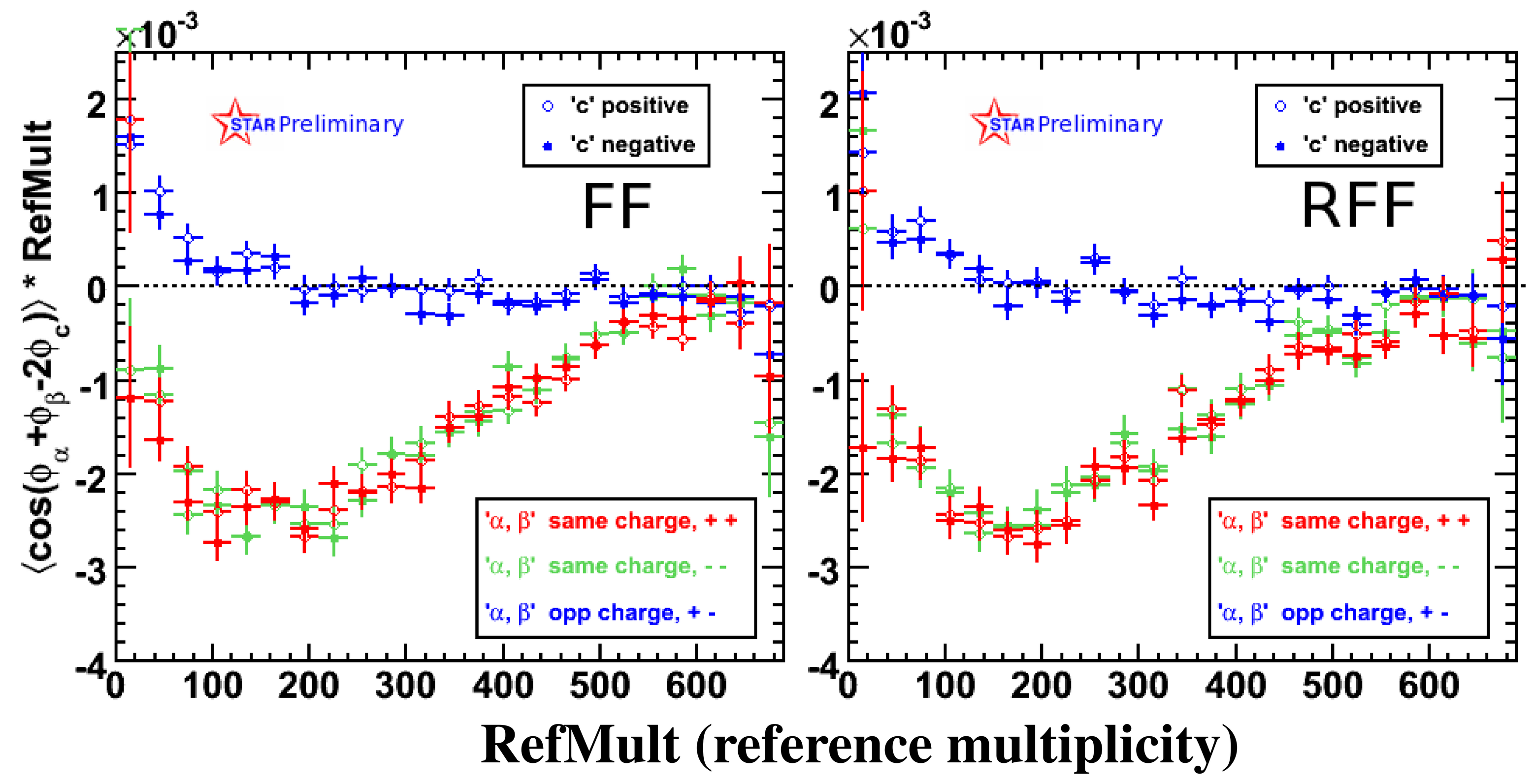

Fig. 2: Correlator (3) scaled with reference multiplicity for Au+Au collisions at $\sqrt{s_{NN}}$=200 GeV and two configuration of the STAR magnetic field polarities: left - Full Field (FF), right - Reversed Full Field (RFF). Results are shown after procedure to remove acceptance effects has been applied.

Conclusion

The systematic study of possible physics background effects in parity violation measurements has been done with UrQMD, HIJING, and MEVSIM event generators. We have found that none of these event generators is able to reproduce either quantitatively or qualitatively the signal observed in the analysis of experimental data collected with the STAR detector at RHIC. In addition, from various tests performed with the available data from the STAR experiment, plus Monte Carlo simulations of the detectors acceptance and inefficiency effects, we conclude that we are not able to mimic the signal for parity violation.

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