Evaluation of a baseline for the study of azimuthal correlations of charmed mesons in heavy-ion collisions at RHIC using PYTHIA and Herwig++

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Introduction

Measurements of azimuthal correlations of charmed mesons in high-energy heavy-ion collisions can shed light on the transport properties of the Qaurk-Gluon Plasma. The STAR experiment at the Relativistic Heavy Ion Collider (RHIC) collected in 2014 and 2016 a large sample of Au+Au reactions at $\sqrt{s_{NN}}$ = 200 GeV making such a study possible. The sPHENIX experiment will also offer a similar opportunity in the next few years. However, such a measurement in p+p collisions at the same energy has not been feasible so far.

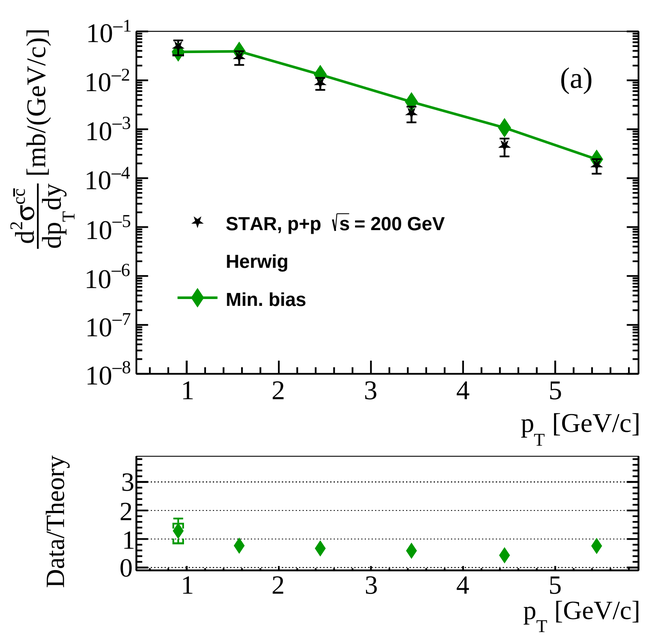
To provide a baseline for the heavy-ion measurements, we report studies of the azimuthal correlations between charmed mesons in p+p reactions using two Monte Carlo event generators, PYTHIA 8 and Herwig++. We validate the models against the available data from the STAR and CDF experiments, and compare their predictions to deliver a reliable p+p baseline for heavy-ion collision studies. Finally, we discuss prospects for performing such measurements in p+p collisions at RHIC.

Materials and Methods

We have used two Monte Carlo event generators: PYTHIA (version 8.244) [1] and Herwig++ (version 7.2.2) [2]. We simulated p+p collisions at the center-of-mass energy $\sqrt{s}$ = 200 GeV, 500 GeV and 1.96 TeV, and then studied correlations between charmed mesons ($D^0/\overline{D^0}$). For the PYTHIA simulations, we used parameters and configurations based on the *STAR-HF Tune*, which was developed to describe J/ψ and so-called non-photonic electrons (electrons from decays of D and B mesons) measurements at RHIC. We generated data for three classes of QCD processes: *hard QCD* and *soft QCD*, and for hard QCD heavy-flavor subset of charm production: *HardQCD:hardccbar*. For Herwig, we used the standard configuration for minimum bias p+p collisions, which is provided with the program.

Validation of the simulation

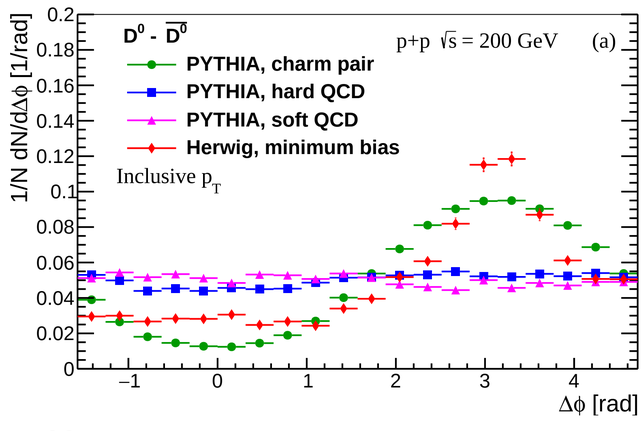
To validate the simulations, we compared the charm transverse momentum distributions from models to the data from the STAR experiment. The figure below shows differential charm production cross section at mid-rapidity ($|y| < 1$) reported by the STAR experiment [3], compared to results from the Herwig minimum bias simulations.

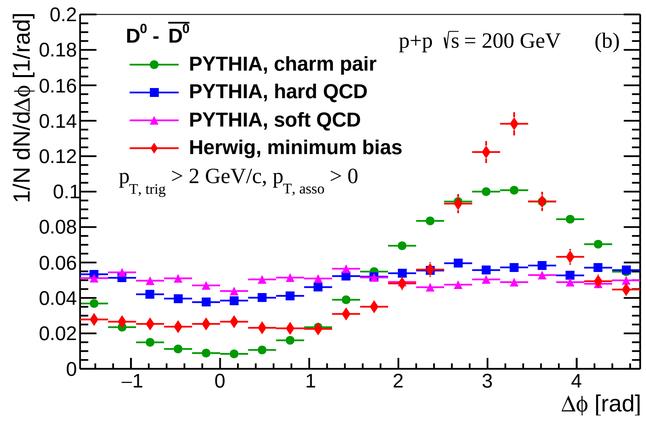


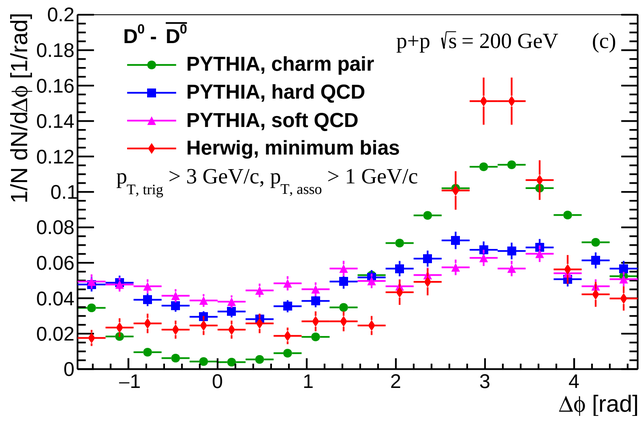
Azimuthal correlations from PYTHIA and Herwig

We have prepared the $D^0 - \overline{D^0}$ azimuthal correlations for Herwig minimum bias predictions and various PYTHIA 8 predictions, and for various transverse momenta conditions. We selected mesons at mid-rapidity ($|y|1$), and we defined two types of particles: trigger and associated ones. The trigger particle have higher transverse momentum ($p_{T,trig}$) than associated particles ($p_{T,asso}$).

The three figure belowe show the predictions obtained for p+p collisions at the energy $\sqrt{s}$= 200 GeV. From the left the figures show the azimuthal correlations: without p_T cuts, when the minimum p_T for $D^0/\overline{D^0}$ mesons is 2 GeV/c and when the minimum p_T for a triggered particle is 3 GeV/c, and for associated is 1 GeV/c.



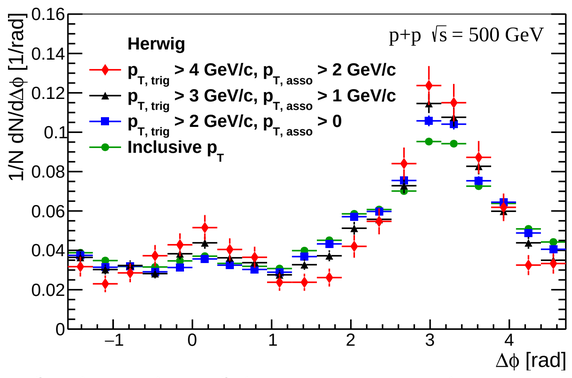


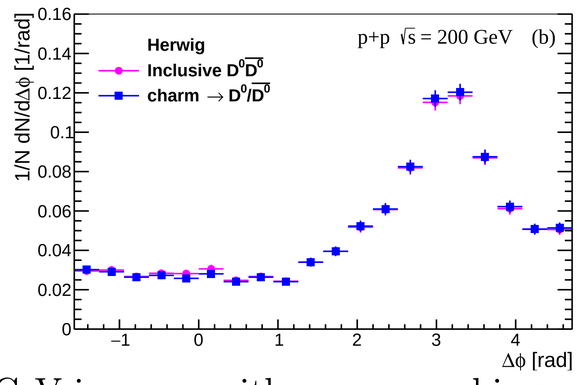


One can clearly see the back-to-back peak for PYTHIA charm pair production process. It is expected, as the charm quark production is dominated by $2 \rightarrow 2$ scatterings (leading order processes). For *hardQCD* and *softQCD* the correlation signal is smaller, it is most probably because of the increasing role of $c/\bar{c}$ production in partonic showers.

Correlations vs collision energy and the effect of feed-down

The charm production cross section increases with the energy of the collision, so the chance to measure the $D - \overline{D}$ correlation effect will be higher. The figures below present the azimuthal correlations for p+p collisions at two different energies: $\sqrt{s}$ = 200 GeV (on the left) and $\sqrt{s}$ = 500 GeV (on the right). We present them for various $p_{T,trig}$ and $p_{T,asso}$ conditions.





The correlation signal in p+p reactions at $\sqrt{s}$ = 500 GeV increase with $p_{T,trig}$ reaching around 10% at $\Delta\phi \approx \pi$, but also a significant near-side correlation shows up for the $p_{T,trig} > 4$ GeV/c.

We checked the impact of the B-hadron feed-down on the observed $D - \overline{D}$ correlations. The $\Delta\phi$ distribution for inclusive $D^0 - \overline{D^0}$ pairs and pairs originated $c/\bar{c}$ are similar, and we do not observe a significant effect of the feed-down on the measured correlations. The comparision between correlations is shown on the figure on the right in this section.

Conclusion

- The Herwig predictions successfully withstand validation against the experimental data, thus this model should provide a robust baseline for azimuthal correlations studies planned in heavy-ion collisions at RHIC.
- The feed-down does not change the observed azimuthal correlations. Thus, they charm correlations can be studied even with inclusive D- meson samples.
- An experimental studies of azimuthal correlations of charmed mesons in p+p collisions at STAR at $\sqrt{s}$ = 500 GeV should be possible, exploiting large data sets collected in 2017 and 2022.

References

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