RECENT RESULTS ON CENTRAL EXCLUSIVE PRODUCTION WITH THE STAR DETECTOR AT RHIC

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We report on the measurement of the central exclusive production process $pp \rightarrow ph^+h^-p$ in proton-proton collisions at $\sqrt{s} = 200$ and 510 GeV with the STAR detector at RHIC. At these energies, the process is dominated by a double Pomeron exchange mechanism. The charged particle pairs were reconstructed from the tracks in the central detector of STAR, the Time Projection Chamber and the Time of Flight systems. The pairs were identified using the ionization energy loss and the time of flight method. Furthermore, the diffractively scattered protons, moving intact inside the RHIC beam pipe after the collision, were measured in the Roman Pots system allowing full control of the interaction's kinematics and verification of its exclusivity. Differential cross sections for centrally produced $\pi^+\pi^-$, K^+K^-, and $p\bar{p}$ pairs measured within the STAR acceptance at $\sqrt{s} = 200$ GeV are presented together with the preliminary results on the measurement of the same physics process at higher $\sqrt{s} = 510$ GeV.

1 Introduction

Measurement of Central Exclusive Production (CEP) [1] through the Double Pomeron Exchange (DIPE) allows us to study strong interaction described by the quantum chromodynamics and to look for hadronic production of glueballs, bound states consisting of only gluons. CEP through DIPE is a process, where each colliding proton "emits" a Pomeron. The Pomerons fuse and produce a neutral central system with quantum numbers of vacuum. Furthermore, the central system is well separated from outgoing intact protons by rapidity gaps.

Despite the fact that CEP is topologically very simple, it is theoretically very complex and rich in phenomena. The cross section of CEP is a combination of resonance and continuum production adding in quadrature. Hence, significant interference effects between resonance and continuum production are presence. Furthermore, there may be significant rescattering (absorption) effects via additional interaction between the protons and/or hadron and proton. A generic diagram of CEP with resonance and continuum production is shown in Fig. 1.

The data from the STAR experiment at the Relativistic Heavy Ion Collider (RHIC), gives an unique opportunity to perform such studies since the DIPE is expected to be dominant CEP mechanism at RHIC energies [2]. This was confirmed by the most recent results of the CEP in proton-proton collisions at $\sqrt{s} = 200$ GeV [2], the highest center-of-mass energies at which DIPE has been measured with the detection of the outgoing protons. The detection of the forward-scattered protons with the measurement of the central system allows full control of the interaction's kinematics and verification of its exclusivity. At STAR experiment [3], all particles in the final state are fully measured. The central system is measured in the Time Projection Chamber (TPC) and in the Time of Flight (TOF) systems and the forward-scattered protons are measured in the Roman Pot detectors [4].

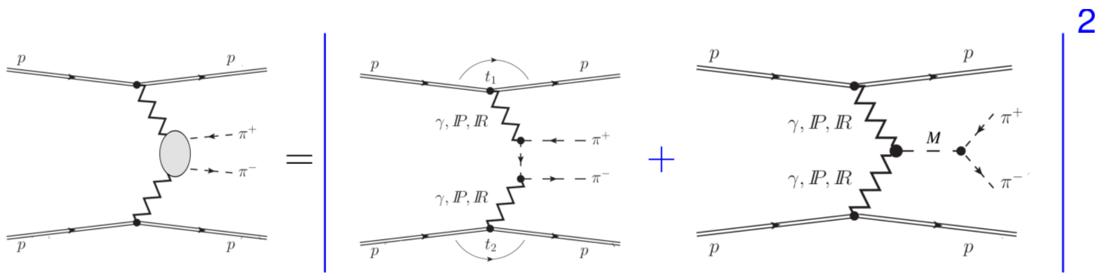

Figure 1 – A generic diagram of central exclusive production of two hadron as a combination of continuum and resonance production.

2 Data sample and event selection

In 2015 and 2017, the STAR experiment collected proton-proton collision data at $\sqrt{s} = 200$ and 510 GeV, respectively. About 622 (560) million CEP event candidates were triggered in 2017 (2015). The next paragraphs describe the selection criteria used to select a sample of CEP events at $\sqrt{s} = 510$ GeV. Although the selection criteria used at $\sqrt{s} = 200$ GeV are similar, their detailed description can be found here [2].

The CEP events were triggered by requiring signals in at least one Roman Pot station in lower or upper branch on each side of the interaction point and requiring lack of signals in the other branches to reduce pile-up events, or events involving proton dissociation. In the TOF, $2 - 10$ hits were required to ensure at least two in-time tracks in the TPC. Moreover, a veto on signals in both the Beam-Beam Counter and the Zero Degree Calorimeter detectors was imposed to ensure the pseudorapidity gaps characteristic to CEP events.

In the offline analysis, only events with exactly one forward-scattered proton on each side of the interaction point were selected. The protons were further required to have all eight silicon planes used in the proton reconstruction and to have transverse momenta inside a fiducial region, as listed in the legend of Fig. 2 (right), to ensure high geometrical acceptance and good track quality.

Next, the information of the central system was checked. Only events with exactly two opposite-charged TPC tracks matched with two TOF hits, originating from the same vertex, were selected. To ensure high geometrical acceptance for the central tracks in the entire fiducial phase space, further criteria were applied: a cut on the $z-$position of the vertex ($|z$-position of vertex$| < 80$ cm) and a cut on pseudorapidity of central tracks ($|\eta| < 0.7$). In addition, tracks reconstructed in the TPC had to satisfy track quality cuts – number of hits used in track reconstruction (> 25) and number of hits used for determining the ionization energy loss (> 15).

Then, the exclusivity criterion ($p_{\mathrm{T}}^{\mathrm{miss}} < 100$ MeV) was used to ensure exclusivity of the event. The $p_{\mathrm{T}}^{\mathrm{miss}}$ is defined as the absolute value of sum of the transverse momenta of all measured particles. Due to the conservation of the momentum, the $p_{\mathrm{T}}^{\mathrm{miss}}$ should be equal to zero for CEP processes.

Finally, the particle identification was done based on combined information from the TPC, the ionization energy loss of the particle, and from TOF (m^2_{TOF}), where the m^2_{TOF} is the squared invariant mass of a particle type (π, K, and p). After applying all the selection criteria mentioned above, 62077 $\pi^+\pi^-$, 1697 K^+K^-, and 125 $p\bar{p}$ CEP event candidates were selected.

3 Results

In Fig. 2 (left), the differential cross-section for CEP of $\pi^+\pi^-$ as a functions of the invariant mass of the pair is presented with Monte Carlo model predictions available at that time. Since these models can generate only continuum production, they cannot fully describe the data. Figure 2 (right) shows the invariant mass distribution of selected $\pi^+\pi^-$ pairs at $\sqrt{s} = 510$

GeV with GRANIITTI [5] prediction. GRANIITTI is a Monte Carlo event generator for high energy diffraction based on recent phenomenological models [6,7,8]. It calculates invariant mass spectra assuming both continuum and resonance contributions. Hence, it takes into account significant interference effects. In addition, significant rescattering (absorption) effects via additional interaction between the protons and/or hadron-proton are also embedded. The new tune GRANIITTI v. 1.080 includes CEP resonance couplings also tuned to the STAR CEP results at $\sqrt{s} = 200$ GeV. The following resonances were included in GRANIITTI calculation: $f_0(500)$, $\rho(770)$, $f_0(980)$, $\phi(1020)$, $f_2(1270)$, $f_0(1500)$, $f_2(1525)$, and $f_0(1710)$. To be able to compare the results with GRANIITTI predictions, the results at $\sqrt{s} = 510$ GeV were corrected using acceptance corrections obtained from pure single particle STAR simulation and were normalized such that area under the distribution is equal to one. The invariant mass distribution of $\pi^+\pi^-$ pairs shows expected features: a drop at about 1 GeV, possibly due to the quantum mechanical negative interference of $f_0(980)$ with the continuum contribution, and a peak consistent with the $f_2(1270)$. Shown error bars represent the statistical uncertainties only and natural units are used.

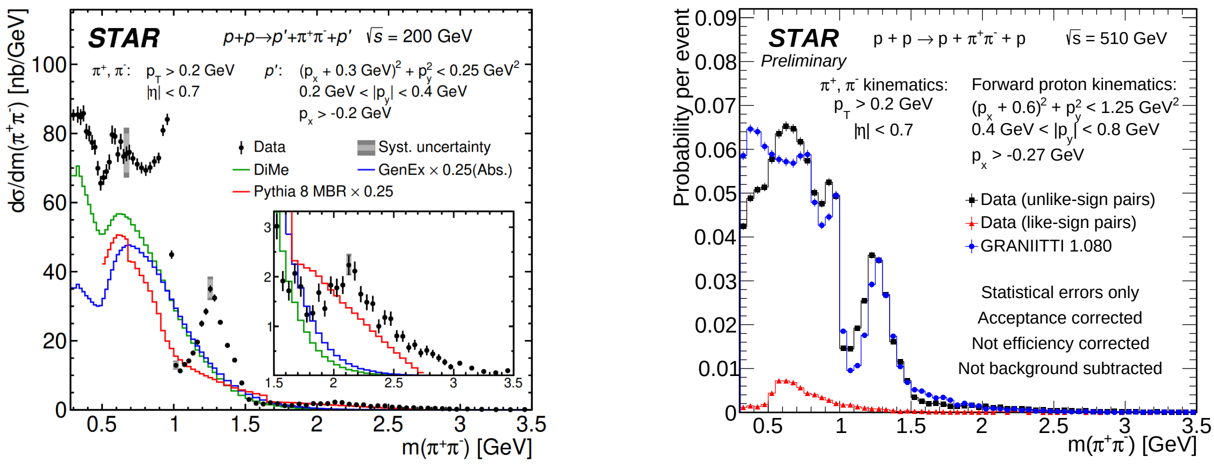

Figure 2 – Left: Differential cross-section as a function of invariant mass of $\pi^+\pi^-$ pairs at $\sqrt{s} = 200$ GeV. Right: The acceptance corrected invariant mass spectrum of exclusively produced $\pi^+\pi^-$ pairs at $\sqrt{s} = 510$ GeV.

Figure 3 depicts the invariant mass distribution of $\pi^+\pi^-$ pairs differentiated in two regions of $\Delta\varphi$, where different Pomeron dynamics is expected. The $\Delta\varphi$ is the difference of azimuthal angles between the forward protons. A suppression of $f_2(1270)$ and an enhancement at low invariant mass in $\Delta\varphi < 90°$ are seen. Figure 4 illustrates invariant mass distributions of selected K^+K^- and $p\bar{p}$ pairs measured within the STAR acceptance. The invariant mass of K^+K^- pairs shows a peak at about 1.5 GeV, possible $f_2(1525)$, and a strong enhancement at low invariant mass, possible $f_0(980)$ or $\phi(1020)$. The invariant mass distribution of $p\bar{p}$ pairs does not show any resonances. In general, GRANIITTI can describe shapes of all presented distributions.

4 Summary

Recent results on the CEP $\pi^+\pi^-$, K^+K^-, and $p\bar{p}$ pairs measured within the STAR acceptance at $\sqrt{s} = 200$ and 510 GeV have been presented. These are currently the highest center-of-mass energies at which the DIPE has been measured with the detection of the forward-scattered protons that allows full control of the interaction's kinematics and verification of its exclusivity.

The results confirm features seen in previous experiments even though new features are seen, like the peak at about 1 GeV in the distribution of K^+K^- pairs at $\sqrt{s} = 510$ GeV, where there are still ongoing studies. The new Monte Carlo event generator, GRANIITTI, is able to describe the shape of the presented data suggesting significant role of resonance production.

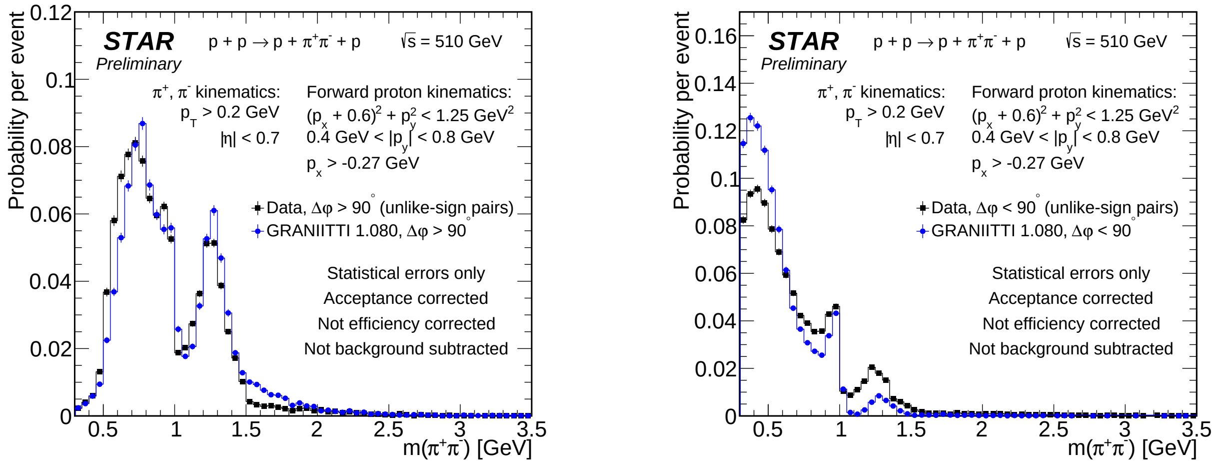

Figure 3 – Acceptance corrected invariant mass spectra of exclusively produced $\pi^+\pi^-$ pairs in two regions of the difference of azimuthal angles of the forward-scattered protons: $\Delta\varphi > 90°$ (left) and $\Delta\varphi < 90°$ (right). Error bars represent the statistical uncertainties.

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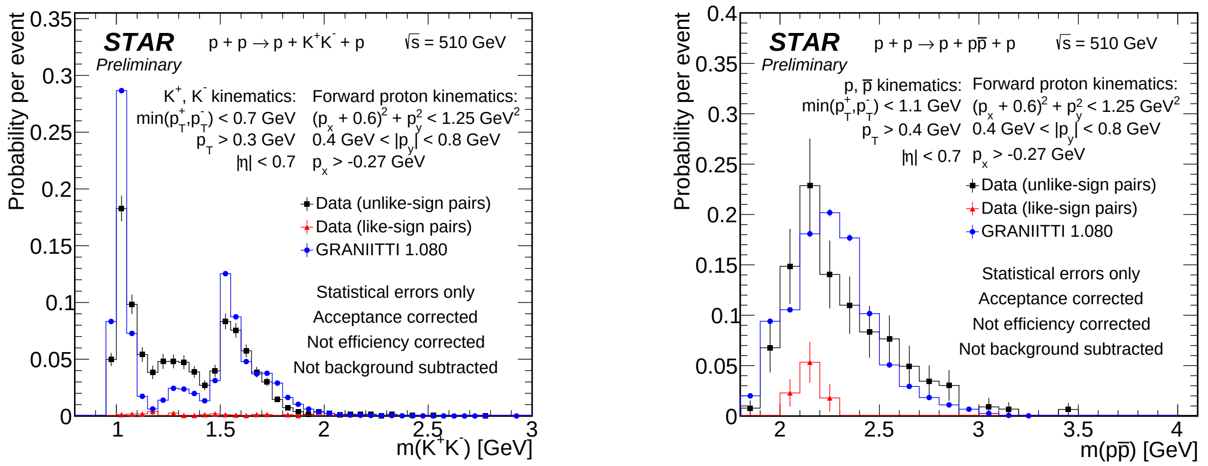

Figure 4 – Acceptance corrected invariant mass spectra of exclusively produced $K+K-$ (left) and $p\bar{p}$ (right) pairs at $\sqrt{s} = 510$ GeV. Error bars represent the statistical uncertainties.

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