PROCEEDINGS OF SCIENCE

Measurement of the Central Exclusive Production of pion pairs using tagged forward protons at the STAR detector at RHIC

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Preliminary measurement of the Central Exclusive Production of the two oppositely charged pions produced in the process $pp \to p\pi^+\pi^- p$, obtained with the STAR detector at RHIC at $\sqrt{s}$ = 200 GeV is presented. The Roman Pots were used to tag forward protons while pion pair tracks were reconstructed in the STAR Time Projection Chamber (TPC). Predictions of models based on Regge phenomenology are compared to the spectra of the kinematic variables corrected for detector acceptance and efficiency.

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1. Introduction

In this paper Central Exclusive Production (CEP) of the $\pi^+\pi^-$ meson pairs in the process $pp \to p\pi^+\pi^-p$ is investigated (see [1] for recent review of CEP). In general in a CEP-type process, $pp \to pXp$, scattered protons are tagged in the forward detectors while neutral system X of hadrons is fully measured in the central detector (see Fig. 1). The physics motivation of the measurement

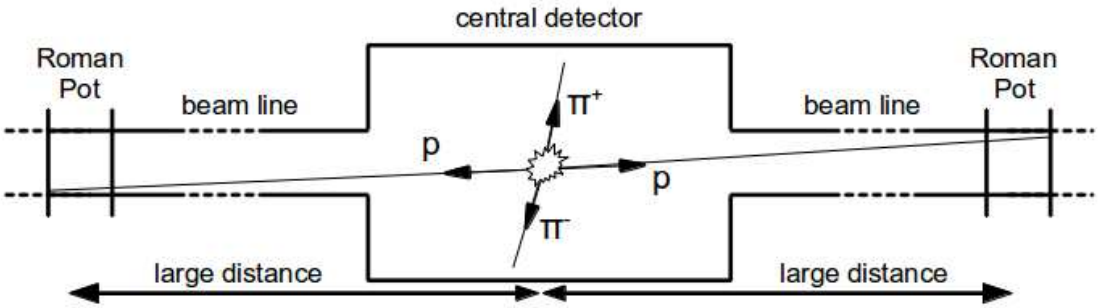

Figure 1: Setup of the detector for measurements of Central Exclusive Production processes (CEP). In measurement described in this paper central detector is STAR TPC with TOF capability while forward scattered protons are measured in silicon strip detectors placed in Roman Pots.

presented in this paper can be traced back to heuristic hypothesis [2] that glueballs might be preferentially produced in Pomeron-Pomeron-Meson vertices due to high gluon density in such processes.

The experiments at CERN ISR Collider [3, 4] and CERN SPS [5] have provided measurements of many CEP-type processes, however their interpretation in terms of Pomeron-Pomeron collisions is not fully justified [6] at these rather low center-of-mass energy (62 GeV for ISR and 30 GeV for SPS). The interpretation of the invariant $\pi^+\pi^-$ mass spectrum and glueball search has to be based on consistent theories of the resonance production and non-resonant background. In the present study with very limited statistics (380 events) we test recently published models of the non-resonant background [6, 8]. The model of the non-resonant production of meson pairs in non-perturbative regime has been originally proposed in [6] and is implemented in the GenEx event generator described in [12]. This model can be viewed as an elastic scattering of protons on virtual pair of pions (see Fig. 2). The event generator described in [8] employs a modified amplitude defined in [6] as a Born term for the full amplitude of process which includes screening corrections.

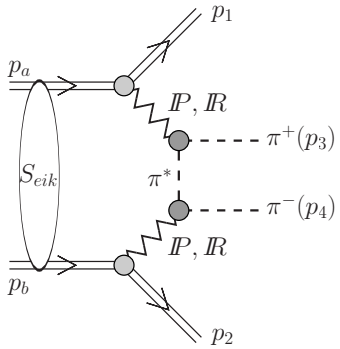

Figure 2: Exclusive production of meson pairs by double Regge exchanges ($\mathbb{P}, \mathbb{R}$). The absorptive corrections due to proton-proton interactions are also indicated.

2. Event selection, corrections for detector efficiency and acceptance

The paper presents study of the events collected in runs of STAR experiment with special

beam optics dedicated to the elastic pp scattering measurements at small angle in t range $0.003 \leqslant |t| \leqslant 0.035$ GeV^2. Components of the STAR detector relevant for this analysis are Time Projection Chamber (TPC) [9], used to measure the meson tracks and to determine the interaction vertex, and silicon micro-strip arrays in Roman Pots (RP) on both sides of the interaction point [10]. The event selection is based on Central Production (CP) trigger, tracks in TPC and RP and transverse momentum balance:

- trigger for CP requires signal in RP on both east and west sides of the Interaction Point (IP) and low multiplicity Time of Flight (TOF) signal,
- two oppositely charged tracks from the primary vertex with transverse momentum $p_T >$ 150 MeV and at least 15 hits/track are required,
- exactly one track on each RP,
- transverse momentum balance p_T^{miss} between all four particles in the final state : $p_T^{miss} = |\mathbf{p}_T^E + \mathbf{p}_T^W + \boldsymbol{\pi}^+ + \boldsymbol{\pi}^-| < 0.02$ GeV.

The transverse momenta of final protons are estimated assuming $|\mathbf{p}_E| = |\mathbf{p}_W| = 100$ GeV. It was verified that in the range of the invariant $\pi^+\pi^-$ mass $M_{\pi\pi} <$ 1.5 GeV the effect of proton momentum loss is negligible for the $p_T^{miss} < 0.02$ GeV condition. In Fig. 3 number of selected unlike sign (black points) and like sign (red points) meson pairs as a function of the p_T^{miss} is shown. It can be seen that the non-exclusive background, the source of like sign events, quickly decreases with decreased transverse momentum imbalance and the above mentioned cut leaves practically clean sample of 380 CEP events. As the majority of events is below KK threshold dE/dx particle identification was not applied.

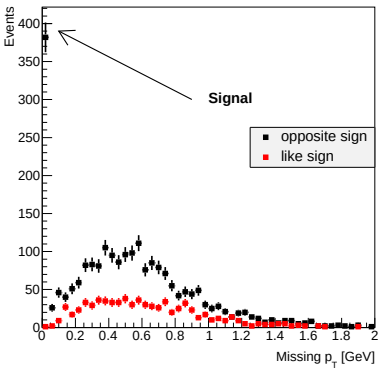

Figure 3: Transverse momentum balance distribution for events selected by trigger, TPC and RP track requirements described in text. Unlike (like) charge sign events are indicated by black (red) data points.

The acceptance has been calculated using a simple event generator with uncorrelated four momentum transfers to scattered protons t_1, t_2 distributed as $e^{-6.5|t|}$ and the invariant mass $M_{\pi\pi}$ of the central isotropically decaying system distributed as $1/M_{\pi\pi}^2$. The generated events, passed through detailed STAR simulation of the central detector and Geant4 simulation of the STAR beam line, RP trigger and RP geometry, describe the data at the detector level well. The acceptance and detector efficiency bin-to-bin corrections have been made to visible kinematic range:

- $0.005 < t_1, t_2 < 0.03$ GeV^2 (four-momentum transfer to protons)
- $|\eta_\pi| < 1.0$ (pseudorapidity of pions)
- $|\eta_{\pi\pi}| < 2.0$ (pseudorapidity of $\pi\pi$ system)

in which acceptance for all measured variables exceeds 10%.

The data are normalized using elastic scattering events, measured in parallel, and assuming the value and shape of the differential elastic scattering pp cross section as in [11] (fit to pp and $p\bar{p}$ world data). As the RP trigger and detector are common for elastic scattering and CEP, many systematic uncertainties cancel out in cross section calculation. Included systematic uncertainties are:

- sensitivity to variation of TPC track selection cuts - 6%
- uncertainty of the normalization using elastic sample - 5%
- uncertainty of TOF trigger efficiency (estimated using TOF-independent trigger) - 5%

Total systematic uncertainty was obtained by adding these uncertainties in quadrature. A possible loss of the elastic events which does not affect CEP events, estimated to be less than 20%, has not been taken into account in the cross section calculation.

3. Results

STAR preliminary cross section for Central Exclusive Production of $\pi^+\pi^-$ at $\sqrt{s} = 200$ GeV in the visible kinematic range defined above is $133 \pm 8(\text{stat.}) \pm 12(\text{syst.})$nb. In Fig. 4 the differential cross section for $pp \to p\pi^+\pi^- p$ process is presented as a function of $M_{\pi\pi}$. The $\pi\pi$ invariant mass spectrum shows characteristic features observed in CEP experiments at lower energies quoted in the Introduction: wide $f_0(600)$ resonance, sharp drop around 1 GeV due to interference of $f_0(980)$ with non-resonant background and some structure in the region 1.2 - 1.5 GeV. Present low statistics does not allow for any meaningful interpretation of the resonance structure. Instead, we test consistency of the non-resonant background models [6] and [8] with measured differential cross sections. By far the largest uncertainties in tested models are: the unknown off-shell form-factor of the Born term amplitude and soft survival factor (SF) due to screening corrections. The off-shell form-factor can be parametrized e.g. as $e^{(t-m_\pi^2/\Lambda_{off}^2)}$ where Λ_{off}^2 is the parameter which controls peripherality of the process and can be

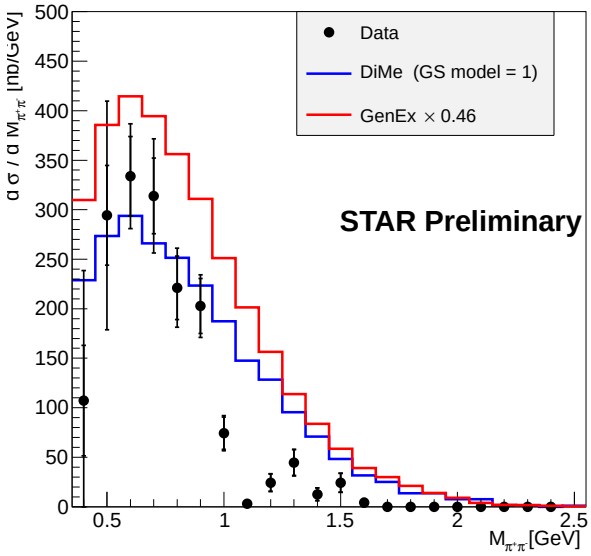

Figure 4: Differential cross section for exclusive production of $\pi^+\pi^-$ pairs as a function of their invariant mass $M_{\pi\pi}$. Error bars represent statistical and systematic uncertainties added in quadrature. Prediction of GenEx with off-shell form-factor parameter $\Lambda_{off}^2 = 1.6$ GeV^2 and survival factor calculated in [7] SF $= 0.46$ is shown as red curve. Prediction of DIME Model 1 is represented as blue curve.

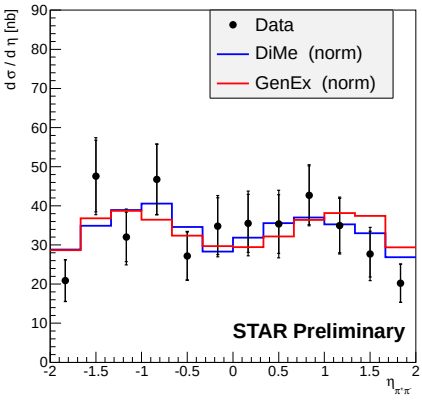

Figure 5: Differential cross section for the exclusive production of $\pi^+\pi^-$ system as a function of its pseudorapidity. Red and blue lines represent results of GenEx and DIME respectively.

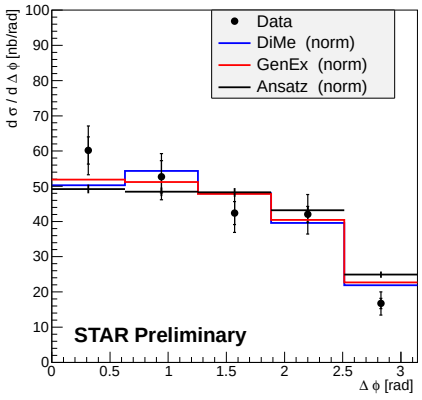

Figure 6: Differential cross section for the exclusive production of $\pi^+\pi^-$ system as a function of azimuthal angle between scattered protons. Red and blue and black lines represent results of GenEx, DIME and Ansatz respectively.

tuned to the data. In [8] and [12] off-shell form-factor was adjusted in such a way that the non-resonant background in the mass spectrum presented in [3] is nowhere above the data points. In GenEx $\Lambda^2_{off} = 1.6$ GeV^2 while for DIME, in which the SF is much smaller, $\Lambda^2_{off} = 2.2$ GeV^2. The SF calculated for kinematic range of this experiment in [7] and Born term defined in [6] is 0.46. DIME prediction for SF is 0.26. In Fig. 4 predictions of GenEx with SF $= 0.46$ and DIME are shown. It can be seen that the parameter Λ^2_{off} affects strongly not only the normalization but also the shape of the invariant mass spectrum. As models do not describe the invariant mass distribution above 1 GeV/c^2 all the other distributions are calculated in the range $M_{\pi\pi} < 1$ GeV/c^2 and predictions are normalized to the cross section measured in this range. Both models describe the data well, however it should be noted that the agreement of similar quality has been obtained with much simpler generator based on ansatz described in the section 2. We conclude that the shape of distributions of kinematic variables (except for $M_{\pi\pi}$), including azimuthal correlation between the scattered protons shown in Fig. 6, is completely determined by kinematic constraints and assumption of S-wave dominance in the decay of the centrally produced system. Both tested models are good candidates for non-resonant background in the exclusive production of meson pairs.

4. Conclusions and outlook

The measurement of the central exclusive production of $\pi^+\pi^-$ pairs in proton-proton collisions at $\sqrt{s} = 200$ GeV at RHIC demonstrates exceptional efficiency of the Roman Pot tagging of scattered protons for reduction of the non-exclusive background. Cross section for this process measured in the visible kinematic range with 15% uncertainty is broadly consistent with predictions of DIME [8] and GenEx [12] generators, based on Regge phenomenology and tuned to the ISR collider CEP data at $\sqrt{s} = 62$ GeV. Except for the $M_{\pi\pi}$ invariant mass spectrum, shape of the measured distributions is well described by models, however it should be noted that effect of

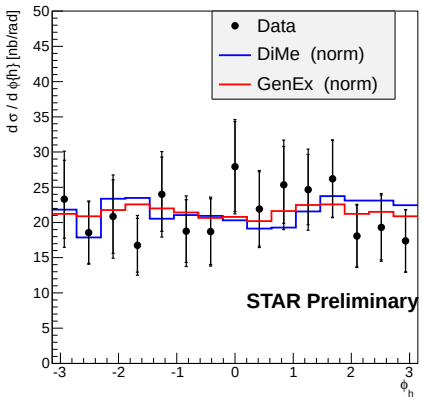

Figure 7: Differential cross section for the exclusive production of $\pi^+\pi^-$ system as a function of the azimuthal angle in helicity frame. Red and blue lines represent results of GenEx and DIME respectively.

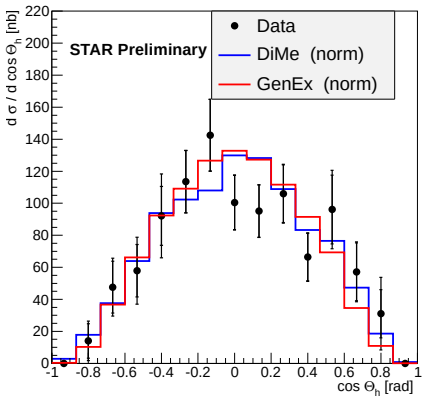

Figure 8: Differential cross section for the exclusive production of $\pi^+\pi^-$ system as a function of the polar angle in helicity frame.Red and blue lines represent results of GenEx and DIME respectively.

kinematic constraints is dominant. In particular substantial azimuthal angle correlation between scattered protons has purely kinematic origin.

Preparations for CEP measurements in STAR 2015 runs are in progress. Present RP setup will be moved to new position in which RP proton tagging will be possible with the standard beam optics i.e. during normal STAR running. In effect we expect data with 30 - 40 times of present statistics in the higher and wider range of four-momentum transfers to scattered protons.

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