Analysis Note
of the STAR Experiment

Measurement of Central Exclusive Production with Roman Pot detectors in diffractive proton-proton interactions at $\sqrt{s} = 200$ GeV

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Abstract

In this note we present analysis of the Central Exclusive Production process using data from proton-proton collisions collected in 2015. This data was collected using the Roman Pot detectors which ensured efficient triggering and measuring diffractively scattered protons. We describe all intermediate stages of analysis involving extraction of the acceptance and effciency corrections, comparison of data with Monte Carlo simulations of detector response, and study of systematic uncertainties. Finally, we show the physics outcome of the analysis.

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1. Introduction

1.1 Central Exclusive Production

The Central Exclusive Production (CEP) takes place when interacting particles form in the mid-rapidity region a state ("central production") whose all constituents/decay products are measured in the detector ("exclusive"). The initial state particles can either dissociate, excite or stay intact. The latter case of CEP in proton-proton collisions can be written as

$$p \;+\; p \quad\rightarrow\quad p \;+\; X \;+\; p \tag{1.1}$$

and depicted as in Fig. 1.1. Mass and rapidity of state X is given by

$$M_X = \sqrt{s\Big(\xi_1\xi_2\sin^2(\alpha/2) - (1-\xi_1-\xi_2)\cos^2(\alpha/2)\Big)} \overset{\alpha\equiv\pi}{=} \sqrt{s\xi_1\xi_2}, \tag{1.2}$$

$$y_X = \frac{1}{2}\ln\frac{\xi_1}{\xi_2}, \tag{1.3}$$

where α is angle between scattered protons and $\xi = (p_0 - p)/p_0$ is the fractional momentum loss of proton.

1.2 Double IPomeron Exchange

Reaction from Eq. 1.1 can exhibit purely electromagnetic (γ-γ), mixed (γ-$\mathcal{O}$) or purely strong nature ($\mathcal{O}$-$\mathcal{O}$). The last type is dominant at RHIC energies. It is characterized by the lack of hard scale (if protons are scattered at small angles), therefore perturbative QCD cannot be applied and Regge theory [1] is used instead. An object $\mathcal{O}$ does not have direct QCD representation - in Regge formalism it is the so-called "trajectory" (IReggeon, IR). IReggeon with quantum numbers of vacuum is called "IPomeron" (IP) and IP-IP reaction (Fig. 1.2) is called "Double IPomeron Exchange".

Processes involing IPomeron exchange are referred as diffraction due to cross-section in scattering angle resembling similar shape to instesity pattern of diffracted light. For low values of Mandelstam t (small scattering angles) cross-section takes exponential form

$$\frac{d\sigma_a}{d|t|} \propto e^{-B|t|}, \tag{1.4}$$

where the slope parameter B reflects the size of target at which IPomerons scatter.

Diffractive events have specific property of the "rapidity gap" which is an angular region free of hadrons. In DIPE two such gaps are present, marked in Fig. 1.1 as $\Delta\eta_1$ and $\Delta\eta_2$.

DIPE is a spin-parity filter - from the fact that scattered particles have all quantum numbers unchanged after the interaction, central states must satisfy

$$I^G J^{PC} = 0^{+}\mathrm{even}^{++}. \tag{1.5}$$

The lowest order QCD picture of the IPomeron is a pair of oppositely colored gluons (colour singlet). This fact makes the DIPE recognized as the gluon-rich environment process which should enhance production of the bound states of gluons ("glueballs") or hybrid mesons.

For detailed introduction to the topic of diffraction see [2,3].

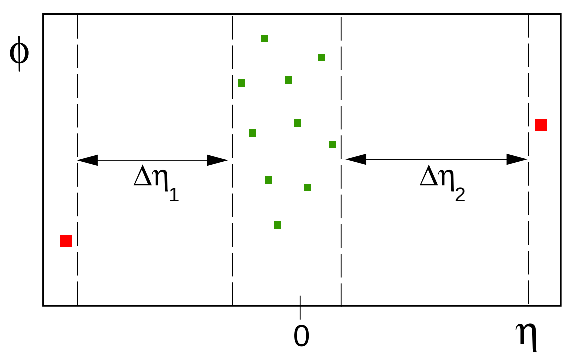


Figure 1.1: Central Exclusive Production in η-ϕ space.

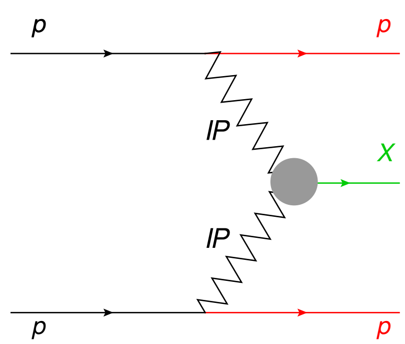


Figure 1.2: Diagram of DIPE process.

1.3 Physics motivation for the measurement

STAR collected in 2015 large dataset dedicated for the measurement of DIPE. It has great advantage of detection of the forward protons - properties of the central state can be studied with respect to observables related to exchanged IPomerons. No such measurement was performed at that high $\sqrt{s}$ (200 GeV, contamination from IReggeon exchanges is small) which makes it particularly attractive. A list of physics issues that can be covered with the study described in this note is briefly introduced below.

1.3.1 DIPE differential cross-sections, mass spectrum

As stated in Sec. 1.2 DIPE is a soft process whose theoretical description is done mainly using phenomenological tools, thus measurement of differential cross-sections is needed to verify various production models.

The main focus is put on the simplest state (and most numerously) produced in DIPE, namely a pair of oppositely charged pions, $\pi^+\pi^-$. It can be formed either in a non-resonant or resonant mechanism. In the first case the $\pi^+\pi^-$ continuum is formed by the exchange of the off-shell pion between IPomerons. Currently there are two models of this reaction on the market [4, 5], [6]. In the second case the IPomerons directly couple into resonance (e.g. $f_2(1270)$), which then decays to $\pi^+\pi^-$. Attempts to calculate cross-section for this production mechanism are presented in [5] and [7].

Understanding of the mass spectrum in $\pi^+\pi^-$ channel is important to learn about relative contribution from continuum and resonant production, as well as relative production of resonances. Recognition of resonant states may indicate candidates for low-mass glueballs of $J^{PC} = 0^{++}$, however presence of underlaying scalar $q\bar{q}$ states makes this task challenging.

Other channels, like K^+K^-, are also of great interest. Comparison of the cross-sections for production of $\pi^+\pi^-$ and K^+K^- gives information about strength of the IPomeron coupling to different quark flavors. Also, structures in $d\sigma/dm$ spectra can be easier attributed to resonances by measuring more than one channel and known branching ratios thereof.

Detection of intact protons scattered at very small angle with respect to the beamline enables determination of the reaction plane which makes the Partial Wave Analysis (PWA) possible. It also allows to look at the the cross-sections more differentially, especially with respect to properties of exchanged IPomerons, like carried squared four-momentum t, azimuthal separation of the IPomerons in the transverse plane $\Delta\varphi$ or relative momentum of IPomerons Δp_T. The last quantity was proposed to distinguish pure $q\bar{q}$ states from these with gluonic content [8].

1.3.2 Absorption effects

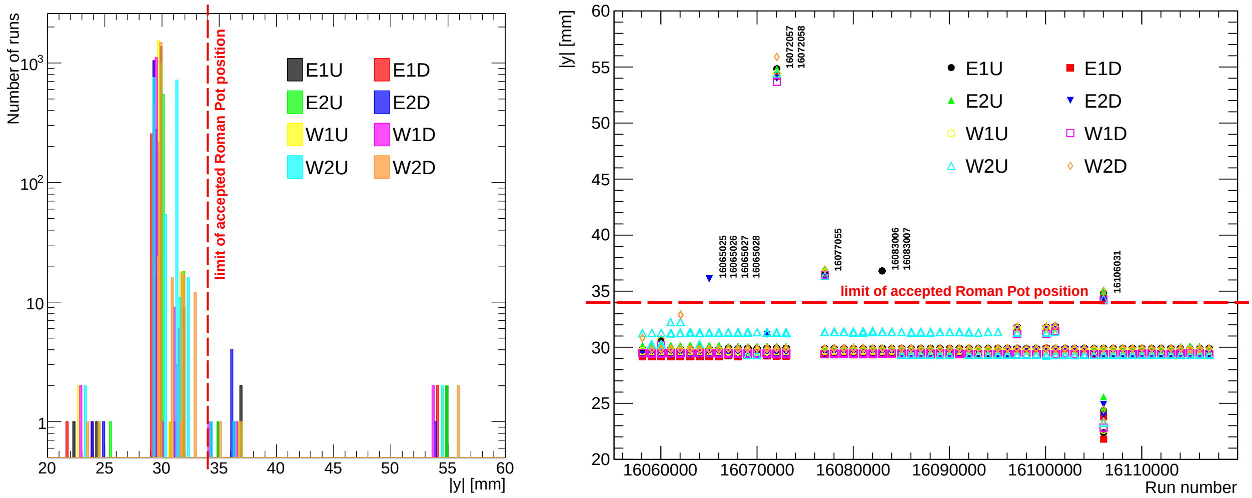
One can imagine in diagram in Fig. 1.2 additional soft lines e.g. between protons in the initial state or one of IPomerons and final state proton. These so-called rescattering effects (or absorption effects) lead to production of hadrons other than these belonging to central state X and the diffractive signature of an event in form of rapidity gap is no longer present. Measurement of the probability that the state X will remain exclusive and forward protons will remain intact, in other words the rapidity gap survival probability S^2, would be valuable ingredient for development of absorption models.

1.3.3 Size of interaction region

From the measurement of protons in Roman Pots one is able to reconstruct squared four-momenta transferred in proton-IPomeron vertices and determine the differential cross-section $d\sigma/d|t|$. Fit of exponent allows to extract the slope parameter B, which may depend on the IPomeron-IPomeron c.m.s. energy, in other words on the mass of diffractive system X. Knowledge on the slope parameter gives insight to the volume and distribution of IPomerons inside proton.

2. Data set

2.1 Bad runs



(a) (b)

Figure 2.1: map of elastic proton hits in .

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