CENTRAL EXCLUSIVE PARTICLE PRODUCTION IN DPE PROCESS: SEARCH FOR GLUEBALLS ETC.*

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(Received November 23, 2015)

We shall discuss resonance production in the process of Central Exclusive Production (CEP) at hadron colliders. The corresponding program of glueball search in Double Pomeron Exchange (DPE) process shall also be discussed. As an exercise, we shall "construct" an experiment to measure CEP using the STAR experiment at the Relativistic Heavy Ion Collider (RHIC), where this program is currently under way. Preliminary $\pi^+\pi^-$ mass spectra (dN/dM_X) from the Central Exclusive Production (CEP) measured in the STAR detector shall be presented. For this measurement, one proton on each side of STAR was detected in the Roman Pots and the charged particle recoil system was measured in the Time Projection Chamber (TPC) of STAR.

DOI:10.5506/APhysPolB.47.53

1. Introduction

Diffractive processes at high energies occur mostly via the exchange of a color singlet object (the "Pomeron") with internal quantum numbers of the vacuum [1]. Even though properties of diffractive scattering at high energies are described by the phenomenology of Pomeron ($\mathbb{P}$) exchange in the context of Regge theory, the exact nature of the Pomeron still remains elusive. The main theoretical difficulties in applying QCD to diffraction are due to the intrinsically non-perturbative nature of the process in the kinematic and energy ranges of the data currently available. In terms of QCD, Pomeron exchange consists of the exchange of a color singlet combination of gluons.

One of the diffractive processes of interest is shown in Fig. 1, a process with tagged forward protons $pp \to pM_Xp$, in which two protons emerge intact after the scattering and a recoil system M_X is produced mostly around

* Presented at the LV Cracow School of Theoretical Physics "Particles and Resonances of the Standard Model and Beyond", Zakopane, Poland, June 20–28, 2015.

pseudorapidity $\eta \approx 0$ (midrapidity). Such process belongs to a class of Double Pomeron Exchange (DPE) processes and is commonly called a Central Production process. In the case when all the products of the interaction are measured and the balance of momentum for all the products of the reaction is satisfied in the reaction, including forward protons, it is called Central Exclusive Production (CEP) process.

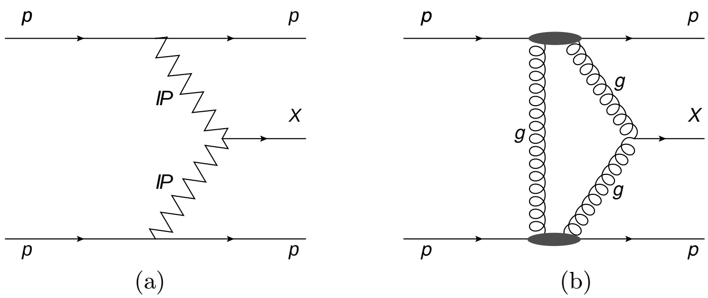


Fig. 1. (a) Central Production diagram in DPE; and (b) pQCDPicture.

Many other processes are of interest in DPE and CEP: resonance production, jet production and also diffractive Higgs production at the LHC are examples. For a most recent review of CEP, see [2] and references therein.

For the CEP process at high energy, the DPE constraint selects processes mediated by the gluonic matter, see Fig. 1. In the DPE mechanism $pp \to pM_Xp$, as shown in Fig. 1, the two protons stay intact after the interaction, but they lose momentum to the Pomeron and the Pomeron–Pomeron interaction produces a system M_X at midrapidity of the colliding protons. Hence, triggering on forward protons at high energies in this central production process allows selection of interactions for which gluonic exchanges are dominant.

One of the important motivations for the inelastic diffraction program at the high energy colliders, to which DPE belongs, is searching for a gluonic bound state (glueball) whose existence is allowed in pure gauge QCD. An idea that glueballs might be preferentially produced in the DPE process due to high gluon density in such process can be traced back to [3]. Two of the gluons in the DPE process could merge into a mesonic bound state without a constituent quark, forming a glueball in the central production process $pp \to pXp$.

QCD predicts the existence of mesons which contain only gluons, the glueballs. These states are a consequence of the non-Abelian nature of the gauge fields which allows that gluons couple to themselves and hence may bind. Despite the theoretical predictions of glueballs, no glueball state has been unambiguously established to date [4–6]. Lattice QCD calculations have predicted the lowest-lying scalar glueball state in the mass range of 1500–1700 MeV/c^2, and tensor and pseudo-scalar glueballs in 2000–2500 MeV/c^2 [7]. Experimentally measured glueball candidates for the scalar glueball states are the $f_0(1500)$ and the $f_J(1710)$ [8] in central production, $pp \to pM_Xp$, as well as other gluon-rich reactions such as $\bar{p}p$ annihilation, and radiative J/ψ decay [5].

Because of the nature of the Pomeron, the central DPE process has been regarded as one of the potential channels of glueball production [7]. The energy regime where glueball candidates from central production have been identified so far is estimated to be not DPE dominated [6]. Because of the constraints provided by the double Pomeron interaction, the glueballs, and other states coupling preferentially to gluons, are expected to be produced with much reduced backgrounds compared to standard hadronic production processes [7]. It is imperative to cover a wide kinematic range to extract information of the production of glueball candidates at an energy regime where DPE is expected to be a dominant process in Central Production.

However, the energy regime where centrally produced glueball candidates have been identified so far is estimated to be not DPE dominated [6]. The experiments at CERN ISR Collider [9–11] and CERN SPS [12, 13] have provided measurements of many CEP-type processes, however their interpretation in terms of Pomeron–Pomeron interactions is not fully justified [14] at these rather low center-of-mass energy (62 GeV for ISR and 30 GeV for SPS).

2. Experimental setup

Since the CEP process requires tagging forward protons, those diffraction processes are triggered using Roman Pots as shown in Fig. 2, while the recoil system X is measured in the Central Detector. We shall use an example from the RHIC program to describe how to construct an experiment to search for resonances in the CEP process, including the glueballs. First, one needs an accelerator with colliding protons at a high enough energy so that DPE process is dominant. This could be, for example, RHIC where collisions of polarized protons are realized in the $\sqrt{s}$ range up to 510 GeV. We also need a suitable detector, with good charged particle ID to measure the central recoil system, which at RHIC is the STAR detector [15], with its Time Projection Chamber (TPC) which measures charged particle momenta and ionization energy loss dE/dx of particles in azimuth range of $0 < \phi < 2\pi$ in pseudorapidity range of $-1 < \eta < 1$. In addition, the Time-of-Flight (ToF) system extends the momentum range of π/K separation in momentum range up to 1.6 GeV/c.

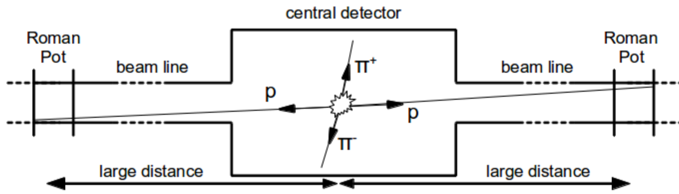


Fig. 2. The layout of the general experimental setup. Main detector in the center and forward proton taggers (Roman Pots).

Finally, to detect forward protons,the Roman Pot (RP) system of the *pp*2*pp* experiment [16] was installed downstream of the STAR detector at RHIC, see Fig. 3, where the location of the Roman Pots, top view, and schematically Si detectors and scintillation counters in the Roman Pots are shown. The location is such that no special accelerator conditions, like large β^* are needed to operate Roman Pots together with the rest of the physics program allowing acquiring of large data samples needed for glueball searches.

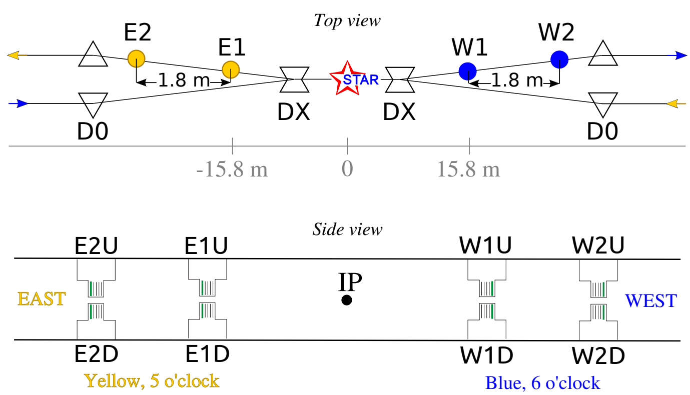
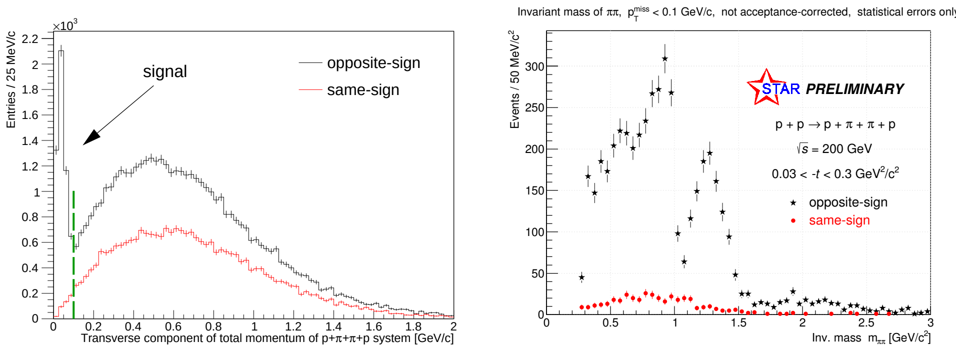


Fig. 3. The layout of the RPs with the STAR detector (not to scale). The Roman Pot setup at STAR for measuring forward protons with high-t. Two sets of RPs will be positioned between DX and D0 magnets, at 15.8 m and 17.6 m from the IP. Top and side view are shown.

3. Data taking and preliminary results from Run 15 at RHIC

With the setup described in the previous section, the Central Production data were collected during Run 15. Roman Pots operated very efficiently through the whole data taking period. The events were required to have two outgoing protons in the RPs, and the inclusive charged tracks in the central region were reconstructed with STAR Time Projection Chamber (TPC).

Selecting exclusive central reactions requires energy-momentum conservation constraint between the central system and the forward protons. As an example, the balance of the transverse momentum Δp_{T} between the central system and the forward protons was required, as shown in Fig. 4. The exclusivity cut required $\Delta p_{\mathrm{T}} \leq 0.1$ GeV$/c$. A small background from like sign pions is shown in grey/red.



(a) (b)

Fig. 4. (a) Transverse momentum (Δp_{T}) balance between centrally produced $\pi\pi$ system and the outgoing protons detected in the Roman Pots; (b) Reconstructed, uncorrected mass distributions, dN/dt, for two charged pions in the inclusive central diffraction at $\sqrt{s} = 200$ GeV. Asterix points are for neutral states and solid circles (grey/red) represent charged states. Errors are statistical only.

Consequently, STAR experiment's preliminary effective mass distributions of two charged pion states from RHIC Run 15 at $\sqrt{s} = 200$ GeV with the RP setup (see Fig. 3) is shown in Fig. 4. Extrapolating from the above preliminary data set, we expect about 100k $\pi^+\pi^-$ meson pairs in the mass range above 1 GeV$/c^2$. The features of this mass distribution are very similar to those obtained by other collider experiments [9, 17]. Namely, a sharp drop around 1 GeV$/c^2$ mass, attributed to the negative interference with $f_0(980)$ wave, and a peak structure around 1.270 GeV$/c^2$.

This work was supported in part by the Office of Nuclear Physics within the U.S. DOE Office of Science and by the Polish National Science Centre under contract UMO-2011/01/M/ST2/04126.

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