EPJ Web of Conferences will be set by the publisher
DOI: will be set by the publisher

Central Exclusive Production in Proton-Proton Collisions with the STAR Experiment at RHIC

Włodek Guryn[a]

[1] *Brookhaven National Laboratory*
Upton, NY 11973 USA

Abstract. We shall describe the physics program with tagged forward protons, focusing on Central Exclusive Production in polarized proton-proton collisions at the Relativistic Heavy Ion Collider (RHIC), with the STAR detector at $\sqrt{s} = 200$ GeV. Preliminary results in CEP of two oppositely charged pions and kaons produced in the processes $pp \rightarrow pp\pi^+\pi^-$ and $pp \rightarrow ppK^+K^-$ shall be presented. Those Double Pomeron Exchange (DPE) processes, allow the final states to be dominated by gluonic exchanges. Silicon strip detectors placed in Roman Pots were used for measuring forward protons. The preliminary results are based on the measurement of the recoil system of charged particles in the STAR experiment's Time Projection Chamber (TPC). Ionization energy loss, dE/dx, of charged particles was used for particle identification (PID).

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 ($\boldsymbol{P}$) 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 $pp \rightarrow pM_Xp$, in which two protons emerge intact after the scattering and a recoil system M_X is produced mostly around pseudorapidity $\eta \approx 0$ (midrapidity). This process belongs to a class of Double Pomeron Exchange (DPE) processes and is commonly called a Central Production process. 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, is called Central Exclusive Production (CEP) process.

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.

[a] e-mail: guryn@bnl.gov

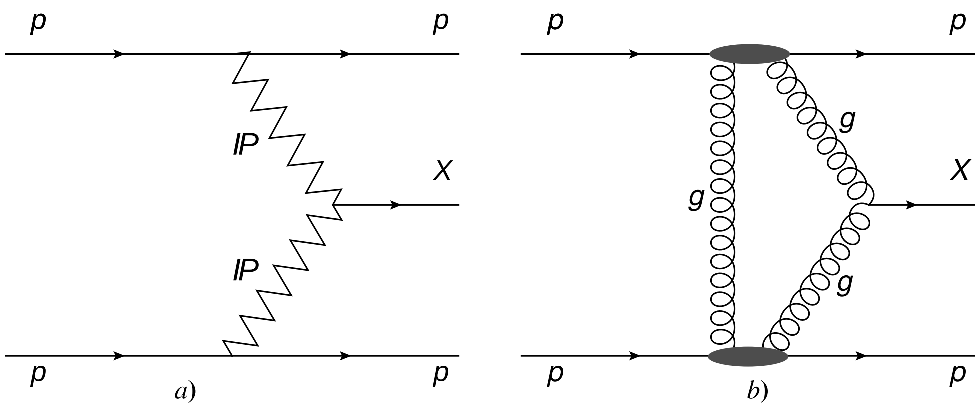

Figure 1. a) Central Production diagram in DPE; and b) pQCDPicture.

For the CEP process at high energy the DPE constraint selects processes mediated by the gluonic matter, see Fig. 1. In the DPE mechanism $pp \to pM_X p$, 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 mid-rapidity 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. The 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 $f_0(1710)$ [8] in central production, $pp \to pM_X p$, 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]. 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 energies (62 GeV for ISR and 30 GeV for SPS).

2 Experimental Setup

Since the CEP process requires tagging froward 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 a 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 $0 < \phi < 2\pi$ in pseudorapidity range $-1 < \eta < 1$. In addition the Time-of-Flight (ToF) system extends the momentum range of π/K separation in momentum range up to 1.6 GeV$/c$.

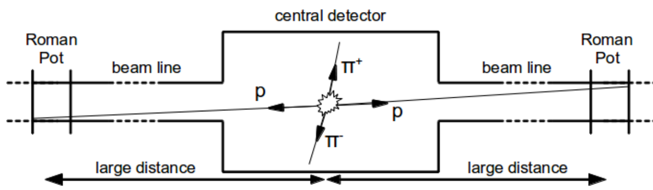

Figure 2. The layout of the general experimental setup. Main detector in the center and forward proton taggers (Roman Pots).

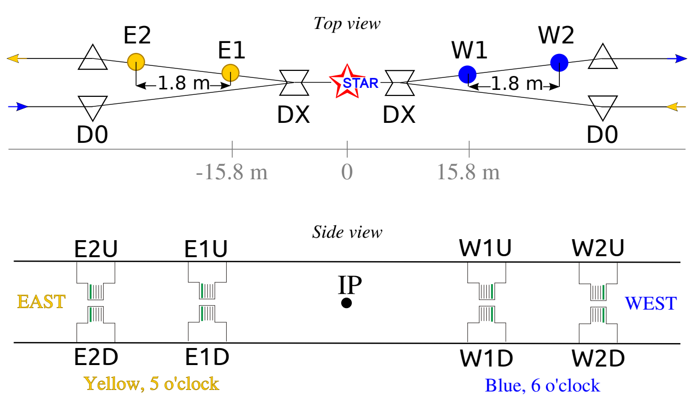

Figure 3. The layout of the RPs with the STAR detector (not to scale). The Roman Pot setup at STAR for measuring forward protons with high-t. Two sets of RPs will be positioned between DX and D0 magnets, at 15.8 m and 17.6 m from the IP. Top and side views are shown.

Finally, to detect forward protons the Roman Pot (RP) system of the pp2pp 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.

3 Data Taking and Preliminary Results from Run 15 at RHIC

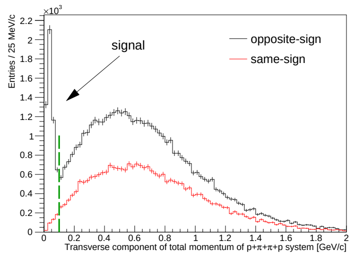

Figure 4. Transverse momentum balance (Δp_T) between centrally produced $\pi\pi$ system and the outgoing protons detected in the Roman Pots

With the setup described in the previous section the Central Production data were collected during Run 15 at RHIC. 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). In addition hits in the Time of Flight (ToF) system were required. The pions and kaons were identified by the ionization energy loss dE/dx and the particle momentum measured in the 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 $\Delta p_T \leq 0.1$ GeV/c. A small background from lsame-sign pions is shown in red. As one can see the background level is very small, which to large extent is due to the momentum conservation constraint in the CEP process.

Consequently, STAR experiment's preliminary effective mass distributions of two charged pion and kaon states from RHIC-Run 15 at $\sqrt{s} = 200$ GeV with the RP set-up (See Fig. 3) is shown in Fig. 5. Extrapolating from the above preliminary data set we expect about 100k $\pi^+\pi^-$ meson pairs in the mass range above 1 GeV/c^2 and about 10k K^+K^- meson pairs. The features of the $\pi^+\pi^-$ 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 f0(980) wave, and a peak structure around 1.270 GeV/c^2.

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

References

[1] For a review, see S. Donnachie *et al.*, “Pomeron Physics and QCD”, Cambridge University Press.

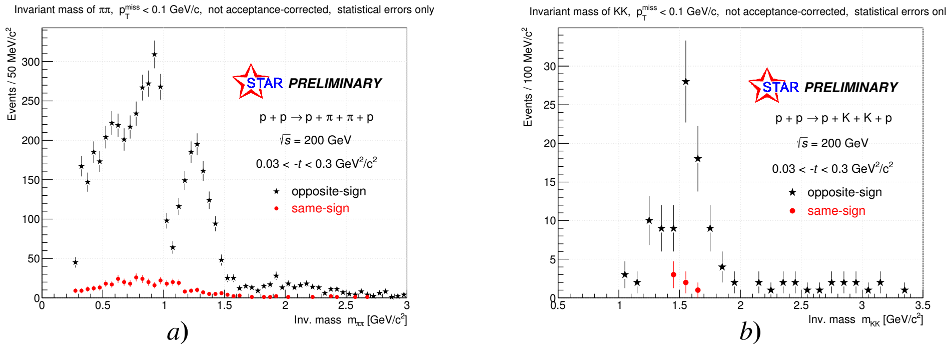

Figure 5. a) Reconstructed, uncorrected mass distributions, dN/dt, for two charged pions in the CEP process at $\sqrt{s}$ = 200 GeV. Asterix points are for neutral states and solid circles represents charged states ; b)Reconstructed, uncorrected mass distributions, dN/dt, for two charged kaons in the CEP process at $\sqrt{s}$ = 200 GeV. Asterix points are for neutral states and solid circles represents charged states. Errors are statistical only.

[2] M. Albrow, V. Khoze and C. Royon, Int J Mod Phys A, **Vol. 29**, No 28 (2014).

[3] D.Robson, Nucl.Phys. **B130**, 328 (1977).

[4] W. Ochs, “The Status of Glueballs", J. Phys. **G 40**, 043001 (2013).

[5] V. Crede and C.A. Meyer, Prog. Part. Nucl. Phys.**63**, 74 (2009).

[6] E. Klempt and A. Zaitsev, Phys. Rept. **454**, 1 (2007).

[7] For a review, see F.E. Close, Rep. Prog. Phys. **51**, 833 (1988), and C. Amsler and N.A. Tornqvist, Phys. Rept.**389**, 61 (2004).

[8] S. Abatziz *et al.*, Phys. Lett. **B324**, 509 (1994).

[9] T.Akesson *e*t al. AFS Collaboration, Nucl.Phys. **B264**, 154 (1986).

[10] A.Breakstone *e*t al. ABCDHW Collaboration, Z.Phys. **C48**, 569 (1990).

[11] A.Breakstone *e*t al. ABCDHW Collaboration, Z.Phys. **C58**, 251 (1993).

[12] F. Antinori *e*t al. WA91 Collaboration, Phys.Lett. **B353**, 589 (1995).

[13] D.Barberis *e*t al. WA102 Collaboration, Phys.Lett. **B474**, 423 (2000).

[14] P.Lebiedowicz, A.Szczurek, Phys.Rev. **D81**, 036003 (2010).

[15] K.H. Ackermann *et al.*, Nucl. Instr. and Meth. **A499**, 624 (2003).

[16] S. Bueltman *et al.*, Nucl. Instrum. and Meth. in Phys. Research **A535**, 415 (2004).

[17] CDF Collaboration: T. Aaltonen *et al.*, Phys.Rev. **D91**, 091101 (2015).