Introduction

In this work we investigate the phenomenological approaches of diffractive exclusive production of quarkonium in collisions proton-nucleus for the LHC\(^3\) energies. These bound states are called quarkonium in analogy with positronium states in electromagnetic interactions. Such bound states of charm-anticharm states, called exclusive, possess an experimental signal more “clean” than inclusive production because it is characterized by low multiplicity of particles between final produced states and the incident protons of the collider beam [11]. This is an open topic in literature and theoretical predictions in energies window available data at LHC are crucial.

Theoretical Basis

In particular, we make use of theoretical models based in Regge’s Theory and perturbative models of Quantum Chromodynamics (QCD). Furthermore, we consider the exchange Pomeron model, understood as virtual object that makes possible the exclusive (diffractive) production process; thus this is the focus of this field. The inclusive production process occurs in the following way: two hadrons (protons and/or charmonia) interact in collision, and this results in two quarks, a charm and an anti-charm. Then, we use a color evaporation model (CEM) in order to hadronize the two quarks to result in a quarkonium bound state. This model provides us a cross section for a process in which the partons (quarks and gluons) of two hadrons (protons and/or nucleons), namely h1 and h2, interact for producing a heavy state called quarkonium H

\[ h_1 + h_2 \rightarrow H (n_{JPC}) + X \]

given by the cross section of pair production of heavy quarks summed over all color states and spin. All information on the non-perturbative transition of the pair (Q \& \bar{Q}) for the heavy H quarkonium with quantum numbers \( n_{JPC} \). It is contained in the factor \( F_{h,\bar{h}} \) that a priori depends of all quantum numbers \([2,3]\)

\[ \alpha(\bar{q}Q \rightarrow h) = F_{\bar{h},h} \cdot \alpha(\bar{q}Q \rightarrow hQ) \quad (1) \]

where \( \alpha(\bar{q}Q \rightarrow h) \) is the total cross section of open production of heavy quarks calculated by integration over the invariant mass of massive pair \( \bar{Q}Q \) on \( 2m_\bar{Q} \) to \( 2m_h \), being \( 2m_h \) the associated mass of D meson. This can be written as

\[ \alpha_{\bar{q}Q}(\bar{q}Q \rightarrow h) = \int_{x_1}^{x_2} \frac{d\sigma}{dxf_{\bar{h},h}}(x_1, x_2, \mu^2) \times f_{\bar{h},h}(x_1, x_2, \mu^2) \quad (2) \]

where \( x_1 \) and \( x_2 \) are the momentum fraction due to partonic collision, \( f_{\bar{h},h} \) is the parton distribution of quarks (Parton Distribution Function); we assume also that the factorization and renormalization scale are identical, \( \alpha(\bar{q}Q \rightarrow h) \).

Now, we analyze the diffractive exclusive production, modeled by a single exchange of pomeron. For this, we will consider the approach given by Ingelman-Schlein (IS) [8], where the pomeron structure (quark and gluon content) is explored. In the case of single diffraction, a pomeron is emitted by one of the hadrons. This hadron is detected in principle, in the gluon content) is explored. In the case of single diffraction, a pomeron is emitted by one of the hadrons. This hadron is detected in principle, in the experimental data [9, 10, 11] for PDF’s.

The diffractive cross section of one hadron-hadron collision is factorized as product of pomeron-hadron cross section and Pomeron flux factor [8]. The single diffraction event is represented by

\[ h_1 + h_2 \rightarrow h_1 + h_2 + H (n_{JPC}) + X \]

Diffractive Production of Quarkonium in Proton-Nucleus Collisions at Large Hadron Collider

\[ f_{\mu^2}(x_1, x_2) = A f_{\mu^2}(x_1, x_2) \exp[(-A \mu^2 F_{\mu^2}(x_1, x_2))] \quad (5) \]

where the pomeron’s trajectory is assumed linear, \( \alpha_{\bar{q}Q}(\bar{q}Q \rightarrow h) \), and the parameters \( A_{\bar{q}Q} \) and \( \alpha_{\bar{q}Q} \) are obtained from the fit of the H1 FPS Data [9]. In addition, in (4) the partonic distribution function \( f_{\bar{h},h}(x_1, x_2, \mu^2) \) that is used in the numerical calculations was obtained using the DIFDPS (Diffractive Partonic Distribution Function) from the collaboration H1 FPS [9, 10 e 11] for PDF’s.

Results and Final Considerations

Our analyses were calculated numerically using algorithms in FORTRAN both for inclusive case and for the diffractive process, providing us the differential cross section \( \alpha(\bar{q}Q \rightarrow h) \) and \( \alpha(\bar{q}Q \rightarrow h) \) of the pomeron, and in function of centre of mass energy of process.

The analyses concluded that, with enough reliability, the theoretical predictions produced by numerical analysis agrees with the accelerators data including the LHC data for the inclusive process. Figure 1 displays a summary of the analysis. The experimental data on the inclusive production in the high energy regime are presented in their proper errors (up 200GeV regarding the RHIC accelerator). The blue line represents the theoretical prediction of the color evaporation model in function of the center of mass energy. The behavior and the order of magnitude are consistent with the data. In short, these promising results led us to develop predictions now for exclusive diffractive production processes of charmonium in p-Pb collisions.

Figure 1. Total cross section versus centre of mass energy for inclusive hadronic production (blue line). The green curve represents the total cross section for diffractive production.

The flux factor gives the emission rate of pomeron by the hadron, here we use the experimental analysis of the diffractive structure function [9], where the dependency on \( x_1 \) is parameterized using flux factor motivated by the theory of Regge.

References


\(^3\) LHC: The Large Hadron Collider is a hadron collider in operation at CERN (European Organization for Nuclear Research) located on the frontier between France and Switzerland. It has about 27km in circumference and is close to 100 meters deep in the ground, and until then the largest experiment carried out by humans. Furthermore, this magnificent instrument was made possible through the collaboration of 100 countries, involving more than 10,000 scientists. This only reinforces the power that mutual collaboration has to do science.