Available online at www.sciencedirect.com

ScienceDirect

Nuclear Physics A 931 (2014) 135–144

NUCLEAR PHYSICS A

www.elsevier.com/locate/nuclphysa

Experimental results and phenomenology of quarkonium production in relativistic nuclear collisions

Anton Andronic

Reasearch Division and EMMI, GSI Helmholtzzentrum für Schwerionenforschung, D-64291 Darmstadt, Germany

Received 2 August 2014; received in revised form 1 October 2014; accepted 2 October 2014

Available online 13 October 2014

Abstract

An overview of recent measurements of quarkonium production in nucleus–nucleus collisions and their understanding in theoretical models is given.

Keywords: Deconfined matter; Quarkonium suppression; (Re)generation

1. Introduction

Among the various suggested probes of deconfinement, charmonium ($c\bar{c}$) states play a distinctive role. The J/ψ meson is the first hadron for which a clear mechanism of suppression in deconfined matter ("quark–gluon plasma", QGP) was proposed based on the color analogue of Debye screening [1]. Current terminology includes "dissociation" and "melting", which are somewhat harder terms compared to the initial proposal of screening as "hindered binding" of c and $\bar{c}$ quarks. Further refinements, including all quarkonium species, $c\bar{c}$ and $b\bar{b}$, led to the picture of "sequential suppression" [2–4]: a hierarchy of quarkonium dissociation dependent on the binding energy (size) of the quarkonium state, which could give information on the temperature of the medium, given that the Debye length in deconfined matter has a pronounced temperature dependence [3]. It was pointed out early on that the Debye screening phenomenon is a low-p_{T} effect [2,5], an issue highlighted in current research [6]. Lattice QCD calculations can give information on the screening [7–10], a subject of intense current research [11–17] (see a review in [18]). The theoretical challenge [19] is illustrated by the spread of results obtained with various

http://dx.doi.org/10.1016/j.nuclphysa.2014.10.009

approaches [20]. A review of charmonium data at the SPS and RHIC and its interpretation in the screening scenario is available in Ref. [21].

Novel quarkonium production mechanisms were proposed in the year 2000. In the statistical hadronization model [22], the charm (bottom) quarks and antiquarks, produced in initial hard collisions, thermalize in QGP and are "distributed" into hadrons at chemical freeze-out. It is assumed that no quarkonium state is produced in the deconfined state (full suppression). Quarkonia are produced, together with all other hadrons, at chemical freeze-out (hadronization) [22,23]. A variant with partial suppression of initial charmonium production has been also proposed [24]. An important aspect in this scenario is the canonical suppression of open charm or bottom hadrons [25,26], which determines the centrality dependence of production yields in this model. The overall magnitude is determined by the input charm (bottom) production cross section [27]. See a review in [28] and more recent predictions of this model in [29] and of a similar approach in [30].

Kinetic (re)combination of heavy quarks and antiquarks in QGP [31] is an alternative quarkonium production mechanism. In this transport model (see Refs. [32–35] for recent results) there is continuous dissociation and (re)generation of quarkonium over the entire lifetime of the deconfined stage. A hydrodynamical-like expansion of the fireball of deconfined matter, constrained by data, is part of the model, alongside an implementation of the screening mechanism with inputs from lattice QCD. Other important ingredients are parton-level cross sections and, as in the case of the statistical hadronization model, the production cross section of initial $c\bar{c}$ ($b\bar{b}$) pairs and quarkonium states.

A wealth of data on charmonium and bottomonium production in nucleus–nucleus collisions has become recently available at RHIC [20,36–41] and at the LHC [42–49], significantly extending our understanding of quarkonium production in deconfined matter. The new data in proton (deuteron) collisions with nuclei, both at RHIC [20,50] and at the LHC [51–56], are also significant. Initially intended to quantify the so-called "cold nuclear effects", effects of nuclear collisions not associated with hot (deconfined) matter, namely shadowing/saturation at collider energies, these data have revealed interesting aspects of quarkonium production.

2. Charmonium

The measurement of J/ψ production in Pb–Pb collisions at the LHC was expected to be decisive in clarifying the question of suppression via the Debye screening mechanism and answering what (re)generation scenarios are viable production mechanisms. The data measured at high p_T [43] showed a pronounced suppression of J/ψ in Pb–Pb compared to pp collisions and of the same magnitude as that of open-charm hadrons. This may indicate that the high-p_T charm quarks that form either D or J/ψ mesons had the same dynamics, determined by the energy loss process in deconfined matter.

The first LHC measurement of the overall (inclusive in p_T) production [42], showed at forward rapidities values of the nuclear modification factor R_{AA} significantly larger than those measured at RHIC energies. The full-statistics data of Run-1 confirmed this, see Fig. 1, where the LHC data [48] are compared to RHIC data [36,39,57] at midrapidity and forward rapidity. The comparison is performed as a function of the charged particle pseudorapidity density $dN_{ch}/d\eta$, measured around $\eta = 0$, which is a measure of the energy density of the system. In the Debye screening scenario, the larger energy density reached at the LHC is expected to lead to a reduced production of charmonium. In addition, the larger parton shadowing/saturation expected at the LHC implies lower R_{AA} values compared to the RHIC energy. The opposite is observed,