LLNL-CONF-413585

Cold nuclear matter effects in J/(psi) production

H. K. Wohri, P. Faccioli, C. Lourenco, R. Vogt

June 4, 2009

XLVII International Winter Meeting on Nuclear Physics
Bormio, Italy
January 26, 2009 through January 30, 2009

Disclaimer

Cold nuclear matter effects in J/ψ production

H.K. Wöhri[1)], P. Faccioli[1)], C. Lourenço[2)] and R. Vogt[3)]

[1)] LIP, Lisbon, Portugal; [2)] CERN, Geneva, Switzerland;
[3)] LLNL, Livermore, and University of California, Davis, CA, USA

Lattice QCD predicts that, above a certain critical energy density or temperature, strongly interacting matter undergoes a phase transition from the hadronic world to a quark-gluon plasma state, where the coloured quarks and gluons are no longer bound to colourless hadrons. The suppression of quarkonium production in high-energy nuclear collisions is one of the most interesting signatures of QGP formation, for two reasons: due to their large masses, charm and beauty quarks are created only in the initial hard scattering processes, before the QGP is formed; and the $\mathrm{Q\overline{Q}}$ binding potential should be screened in the deconfined colour medium. Until the LHC starts colliding Pb nuclei, charm is the heaviest quark that can check the validity of the finite temperature QCD predictions, given the much smaller beauty production cross sections. However, the interpretation of the presently available results on charmonium suppression in heavy-ion collisions, obtained at the SPS and RHIC, is hampered by a multitude of other "nuclear effects", which exist even in the absence of QGP formation, such as the badly understood nuclear modifications of the gluon distribution functions, the level of energy lost by the partons traversing the nuclei before producing the $\mathrm{Q\overline{Q}}$ pair, the rate at which the nascent quarkonium state is broken up by the surrounding nuclear matter, etc. Fortunately, most of these "cold nuclear matter" effects can be studied on the basis of proton-nucleus measurements. However, care must be taken when converting the p-A observations into a reference baseline that can be used in the analysis of the heavy-ion data. In particular, it has recently been shown [1] that it is wrong to assume that the rate of final-state Glauber-like J/ψ absorption, usually called the "J/ψ absorption cross section", $\sigma_{\rm abs}^{{\rm J}/\psi}$, is independent of the collision energy and of the charmonium kinematics, as was previously assumed in the analysis of the SPS heavy-ion data.

The J/ψ production cross section was measured in p-A collisions with several nuclear targets and with proton beams of energies up to 920 GeV. Figure 1-left shows, for illustration, the NA50 measurements [2], performed with 400 GeV protons incident on six different targets. The nuclear dependence of J/ψ production is often parameterized as $\sigma_{\rm pA} = \sigma_0 \cdot A^\alpha$. Figure 1-right shows that the α values determined by E866 [3] and HERA-B [4] depend very significantly on $x_{\rm F}$, clearly indicating that the mid-rapidity and forward regions are affected by different mechanisms. In the analysis presented here, we assume that the mid-rapidity window is mostly affected by final-state charmonium absorption while the forward region reflects the effects of initial-state parton energy loss. Our calculations are made with the Colour Evaporation Model [5] and take into account the initial-state modifications of the parton densities, according to the EKS98 model [6].

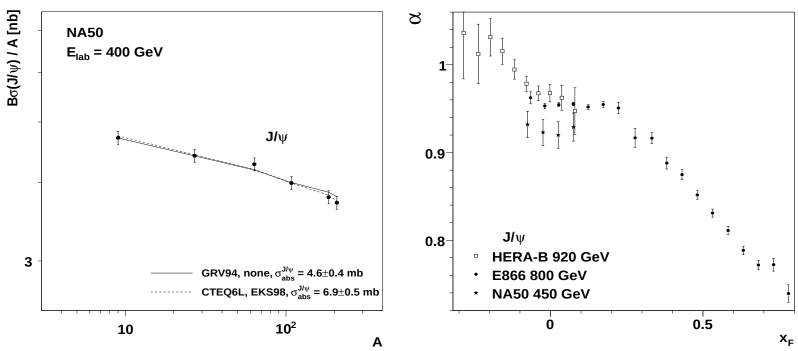

Figure 1: Left: Decrease of the per-nucleon J/ψ production cross section as a function of the target nucleus, as measured by NA50. Right: $x_{\rm F}$ dependence of α, as measured by three fixed-target experiments.

The Glauber formalism allows us to describe the "smaller than linear" increase of the charmonium production cross section with the number of nucleons in the target nuclei in terms of break-up of the newly formed charmonium state while traversing the nuclear medium. This "normal nuclear absorption" happens with a rate given by the $\sigma_{\rm abs}^{{\rm J}/\psi}$ cross section, which can be derived from the measured data. The obtained numerical values depend on whether or not we take into account the nuclear modifications on the parton densities, as shown in Fig. 1-left. Many more details are presented in

Ref. [1]. It is worth noting that, as in most previous studies of charmonium absorption in nuclear matter, we treat the J/ψ as a single meson passing through the nuclear medium, without trying to disentangle the feed-down contributions due to ψ' and χ_c decays [7].

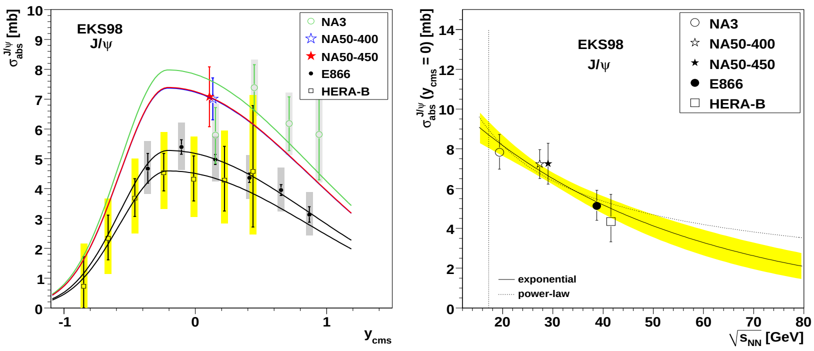

Figure 2: Left: $\sigma_{\rm abs}^{{\rm J}/\psi}$ as a function of $y_{\rm cms}$, at mid-rapidity. Right: Dependence of $\sigma_{\rm abs}^{{\rm J}/\psi}(y_{\rm cms}{=}0)$ on the nucleon-nucleon centre-of-mass energy.

Figure 2-left shows the resulting $\sigma_{\rm abs}^{{\rm J}/\psi}$ as a function of $y_{\rm cms}$, as obtained from the p-A data of NA3 [8], NA50 [2, 9], E866 [3] and HERA-B [4]. The E866 and HERA-B patterns are well described by an asymmetric Gaussian function. The low energy data clearly require higher $\sigma_{\rm abs}$ values than the high energy data. The change of $\sigma_{\rm abs}^{{\rm J}/\psi}(y_{\rm cms}{=}0)$ with collision energy, $\sqrt{s_{NN}}$, is given in Fig. 2-right, which also shows extrapolations to the SPS heavy-ion collision energy, leading to $\sigma_{\rm abs}^{{\rm J}/\psi}(158\ {\rm GeV}, y_{\rm cms}{=}0) = 8.9 \pm 0.9$ mb (power-law) or 8.7 ± 0.6 mb (exponential), with EKS98 nPDFs.

The observation that $\sigma_{\rm abs}^{{\rm J}/\psi}$ depends on the rapidity of the J/ψ and on the collision energy shows that the simple absorption model commonly used in J/ψ suppression studies is insufficient to properly reproduce the available measurements. The much stronger "nuclear absorption" seen at forward $x_{\rm F}$ (see Fig. 1-left) can be reproduced assuming that the beam partons lose energy when traversing the target nucleus, before interacting and producing the charmonium state. This parton energy loss leads to a decrease of the production cross section at large $x_{\rm F}$, in heavy targets, as shown in Fig. 3, where we compare the E866 W/Be and Fe/Be measurements to the results of calculations assuming a constant fractional loss, ϵ, per nucleon-nucleon collision, $E = E_0(1-\epsilon)^{(\langle N_{\rm coll}\rangle -1)}$, with $\langle N_{\rm coll}\rangle$ calculated by the Glauber model for each p-A system. Since these calculations do not include the nuclear absorption discussed above (or, equivalently, assume $\sigma_{\rm abs}^{{\rm J}/\psi} = 0$) the

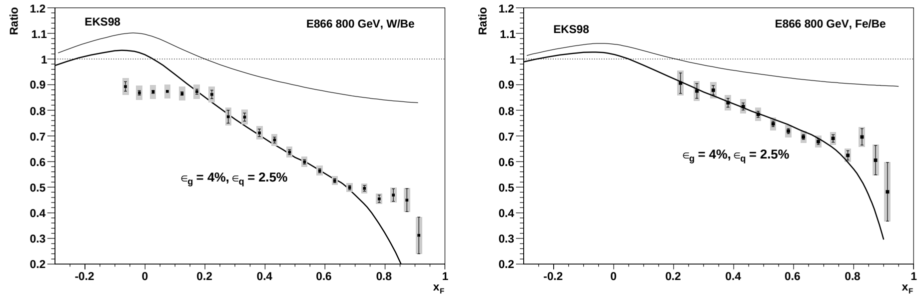

Figure 3: $x_{\rm F}$ dependence of the W/Be (left) and Fe/Be (right) J/ψ cross section ratios, as measured by E866. The top curves reflect the EKS98 nuclear PDFs and the lower ones also include our simple model of initial-state parton energy loss, with the gluons (quarks) losing 4 % (2.5 %) of their energy per NN collision.

comparison of the curves to the data should only be made for $x_{\rm F} \gtrsim +0.2$.

Further progress in understanding quarkonium production and absorption, in the absence of high-density QCD effects, requires accounting for feed-down contributions and formation time effects, besides the three effects addressed in this paper (nuclear modifications of the parton distribution functions, final state Glauber-like absorption, and initial-state parton energy loss), and will significantly benefit from detailed analyses of other data samples, including Drell-Yan and D meson measurements.

P.F. and H.W. were funded by the Fundação para a Ciência e a Tecnologia, Portugal, under contracts SFRH/BPD/42343/2007 and 42138/2007. R.V. was funded by the US Dep. of Energy under contract DE-AC52-07NA27344 and by the National Science Foundation Grant PHY-0555660.

References

[1] C. Lourenço, R. Vogt and H.K. Wöhri, JHEP **02** (2009) 014.
[2] B. Alessandro *et al.* (NA50 Coll.), Eur. Phys. J. **C48** (2006) 329.
[3] M.J. Leitch *et al.* (E866 Coll.), Phys. Rev. Lett. **84** (2000) 3256.
[4] I. Abt *et al.* (HERA-B Coll.), Eur. Phys. J. **C60** (2009) 525.
[5] R.V. Gavai *et al.*, Int. J. Mod. Phys. **A 10** (1995) 3043.
[6] K.J. Eskola, V.J. Kolhinen, C. Salgado, Eur. Phys. J. **C9** (1999) 61.
[7] P. Faccioli, C. Lourenço, J. Seixas, H.K. Wöhri, JHEP **10** (2008) 004.
[8] J. Badier *et al.* (NA3 Coll.), Z. Phys. **C20** (1983) 101.
[9] B. Alessandro *et al.* (NA50 Coll.), Eur. Phys. J. **C33** (2004) 31.

This work performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344.