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J/ψ Suppression: Catching up with the Comovers

Ramona Vogt

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J/ψ Suppression: Catching up with the Comovers

Ramona Vogt*

Lawrence Livermore National Laboratory, Livermore, CA
and
Lawrence Berkeley Laboratory, Berkeley, CA, USA

and

Sean Gavin

Research Institute for Theoretical Physics, Helsinki, Finland

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ABSTRACT

The combined role of inelastic scattering with nucleons and comoving secondary particles in J/ψ suppression is explored. An analysis of the latest FNAL and CERN data suggests that the high–density comover contribution emerges with increasing incident energy and A.

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Measurements of J/ψ suppression by NA38 [1] strongly suggest the formation of high energy density matter in the central rapidity region of light-ion collisions with a uranium target. A unique quantitative interpretation of this data is currently prevented since nuclear effects that also contribute to this phenomena are not sufficiently understood. Significantly, a similar suppression is evident from the A-dependence of J/ψ hadroproduction [2,3]. The hadron-nucleus phenomena has previously been attributed to a single nuclear effect, J/ψ absorption by scattering with nucleons.

We study the combined role of inelastic final-state scattering with nucleons and comoving secondary hadrons on the suppression of J/ψ production in hadron-nucleus, hA, and nucleus-nucleus, AB, collisions. Our model is formulated from and applied to the FNAL E537 125 GeV $\pi^- A$ data [3] and the NA38 results in Ref. [5]. There, we found that nuclear scattering dominates the suppression in hA collisions while a comparable contribution from scattering in the dense comover gas appears in the AB case. Here, we confront the recent preliminary E772 pA data at 800 GeV discussed by J. Moss in these proceedings and find that the comover contribution can become substantial in hA interactions at these considerably higher energies.

We consider midrapidity J/ψ production since the majority of J/ψ's are produced there, comover effects are strongest, and the $c\bar{c}$ production mechanism — semihard gluon fusion — is best understood. At SPS energies, a $c\bar{c}$ pair is produced when the projectile nucleus crashes through the target. For the pair to form a J/ψ, it must first escape these nuclei without experiencing nucleon collisions. The pair is initially small, with a spatial extent on the order of its production time $\sim M_\psi^{-1}$. The color transparency of this small pair effectively reduces its absorption cross section. The cross section is assumed to reach its full hadronic value at the formation time τ_ψ, roughly the time needed for the pair to separate to the J/ψ binding radius.

In a hA collision at impact parameter b, the survival probability of a pair produced at longitudinal position z with velocity v is

$$S_{\rm nuc} = \exp\left\{-\int_z^\infty dz'\,\rho_A(b,z')\,\sigma_{\rm abs}(\{z'-z\}/\gamma v\tau_\psi)\right\}, \tag{1}$$

where ρ_A is the nuclear density and $\sigma_{\rm abs}$ is the $c\bar{c}$–N absorption cross section. (The product of two such factors arises in AB collisions.) To simulate color transparency, we allow $\sigma_{\rm abs}$ to grow with proper time as $\sigma_{\rm abs} = \sigma_0(\tau/\tau_\psi)^\kappa$ while $\tau < \tau_\psi$, saturating at the hadronic value $\sigma_{\rm tot} = \sigma_0$ afterwards. The γ of the pair accounts for the Lorentz dilation of the formation time in the target frame, and has the important effect of *reducing* nuclear absorption of midrapidity J/ψ's with increasing beam energy.

If the $c\bar{c}$ pair escapes the nucleus, it may yet scatter with comovers, which form at a time $\tau_0 \sim 1-2$ fm characteristic of soft processes. The comover contribution to the survival probability is roughly

$$S_{\rm co} \approx \exp\left\{-\frac{\langle\sigma_{\rm co} v\rangle}{\pi R^2}\ln\left(\frac{R}{\tau_0}\right)\frac{dN}{dy}\right\}. \tag{2}$$

where R is the transverse size of the system, σ_{co} is the $c\bar{c}$–comover absorption cross section, and v is the relative velocity of the J/ψ and comovers. We expect the contribution of the initial comover rapidity density to grow with the center-of-mass energy $\sqrt{s}$ as $dN/dy \sim a + b\ln^2 s$ in the central region where a and b are empirical constants [4], amounting to a 30% multiplicity increase at E772 compared to E537. We therefore expect comover scattering to *increase* with increasing beam energy while nuclear absorption is reduced. On the basis of (1) and (2), we expect comover scattering to become the dominant absorption mechanism in hA collisions for beam momenta exceeding ~ 1 TeV [5], somewhat above the E772 energy.

We determine a range of the parameters σ_0, σ_{co}, κ, and τ_ψ through examination of the 125 GeV E537 π^-A data and the NA38 O+U data. We find that $\sigma_0 = 20$ mb, $\sigma_{co} = 1.7$ mb, $\tau_\psi = 0.7$ fm, and $\kappa > 1 - 2$ best describe the data. Interestingly, the fit proceedure yields $\tau_\psi = 0.7 - 1$ fm in accord with the simple binding-radius estimate for all $\kappa > 1$. In fig. 1a, we compare this fit with a calculation neglecting formation time effects, *i.e.* $\kappa = 0$. When $\kappa = 0$, varying the comover component does not change the A dependence.

In fig. 1b, we compare our calculated p_T–integrated J/ψ–to–continuum yield $Y(E_T)$ to the NA38 O+U data. Both the data and calculations are normalized to $Y(E_T = 23\text{GeV})$ since absolute cross sections are not reported. To calculate the three curves in fig. 1b, we employ parameters that yield approximately equivalent agreement with E537. The solid curves in figs. 1a and 1b are calculated using the same values. The dashed curve neglecting comovers lies above the data, while the dot–dashed curve assuming a large comover contribution with $\sigma_{co} \sim 6$ mb lies below.

The E772 collaboration has recently reported the A dependence of J/ψ, ψ', and Υ production [6]. Preliminary results show that the J/ψ and ψ' appear to have similar A dependences while the Υ dependence is weaker. The measured A dependence is shown in fig. 1c, along with our model extrapolated to higher energy. To calculate the J/ψ's A dependence in 800 GeV pA collsions, we take the energy dependence of (1) and (2) into account and use the parameter values from the low energy fits *cf.* the solid curves in figs. 1a and 1b. To calculate the ψ' and Υ A dependence we scale σ_0 and σ_{co} according to the meson sizes [7], taking $\sigma_{hN} = \sigma_{J/\psi N}(R_h/R_{J/\psi})^2$, leading to the estimates $\sigma_{\psi' N} = 3.7\,\sigma_{J/\psi N}$ and $\sigma_{\Upsilon N} = 0.25\,\sigma_{J/\psi N}$. The formation times of the resonances are $\tau_{\psi'} = 1.5$ fm and $\tau_\Upsilon = 0.76$ fm [8]. Note that the 'fluctuations' seen in the calculation arise from the natural variation of the density profile from nucleus to nucleus [9]. Since ratios and not absolute cross sections are reported by E772, we normalize our calculations to the carbon point. (While not essential, we choose to normalize to carbon for simplicity because our formulation is not sufficiently refined to reliably calculate $p + d \to \psi$.) We stress that a direct comparison with cross sections would provide a much more rigorous test. Nevertheless, the unexpectedly remarkable agreement in fig. 1c with the high energy hA data encourages us to believe that benchmark estimates of hadronic effects may be possible at RHIC energies where quark–gluon plasma production is perhaps inescapable.

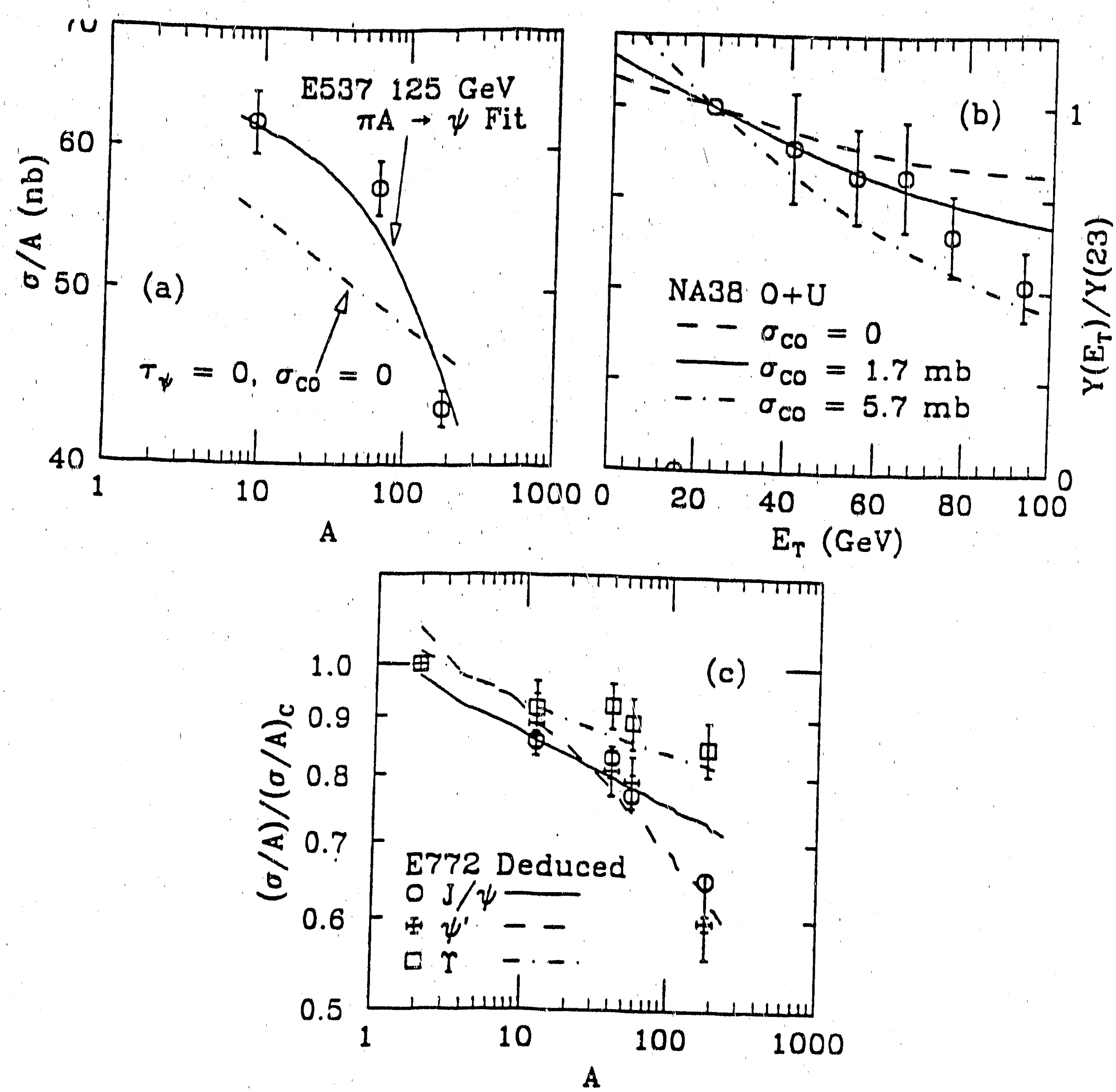

FIGURE 1.

(a) The model of [5] is compared to data from the 125 GeV E537 $\pi^- A$ experiment [3]. The solid line shows our calculation for $\sigma_0 = 20$ mb, $\sigma_{co} = 1.7$ mb, and $\kappa > 1 - 2$, while the dashed line shows a conventional $A^{0.94}$ dependence in the absence of formation time effects ($\sigma_0 = 4.5$ mb, $\sigma_{co} = 0$, and $\tau_\psi = 0$). (b) The calculated relative yield $\Upsilon(E_T)$ compared to the NA38 AB data [1] for parameters determined from E537 πA. The solid line corresponds to the same values as the solid line in 1a. The dashed line shows $\sigma_0 = 24$ mb and $\sigma_{co} = 0$ while the dot–dashed curve shows $\sigma_0 = 11$ mb and $\sigma_{co} = 5.7$ mb. (c) The A dependences of J/ψ, ψ', and Υ deduced from the lower energy data are shown with the preliminary E772 data [6]. The solid line, showing the J/ψ dependence uses the same parameters as in [5], *c.f.* 1a and 1b. The ψ' and Υ cross sections are scaled from the J/ψ values and are given by the dashed and dot–dashed curves respectively.

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