Charmonium Suppression at RHIC and SPS - Hadronic Baseline

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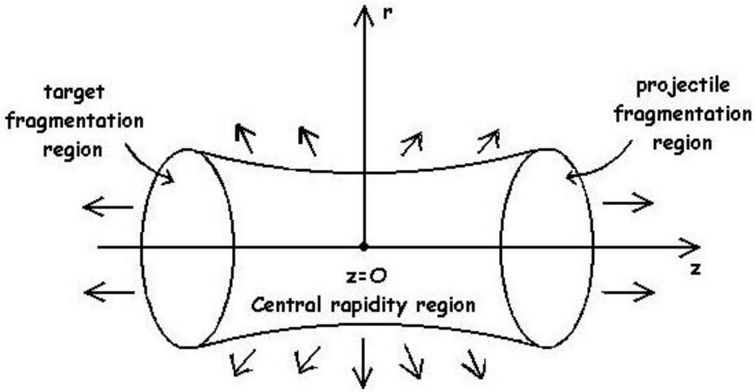
based on a preprint:

DP, L. Turko and D. Blaschke, arXiv:0901.0166

Basic ingredients of the model

- Hadron resonance gas exists from the beginning (i.e. from t_0), the gas consists of all particles from PDG up to 2 GeV.
- The gas expands longitudinally and transversally.
- J/Ψ disintegration is due to inelastic scattering with constituents of the gas.

Sketch of a central collision



Solution of hydro equations for $n_B^0 = 0$ and $b = 0$

G. Baym, B. L. Friman, J. P. Blaizot, M. Soyeur and W. Czyż, Nucl. Phys. **A407**, 541 (1983)

- In the $z = 0$ plane the transverse expansion proceeds in the form of the rarefaction wave which moves inward with the sound velocity c_s.
- Inside the temperature/density is constant (radial velocity $v_r = 0$), in the narrow stripe of the rarefaction wave it decreases rapidly (radial velocity increases).
- In the $z \neq 0$ plane and the moment t the transverse expansion looks the same as in $z = 0$ but at the moment $\tau = \sqrt{t^2 - z^2}$. Longitudinal velocity $v_z = z/t$.

$z = 0$ plane

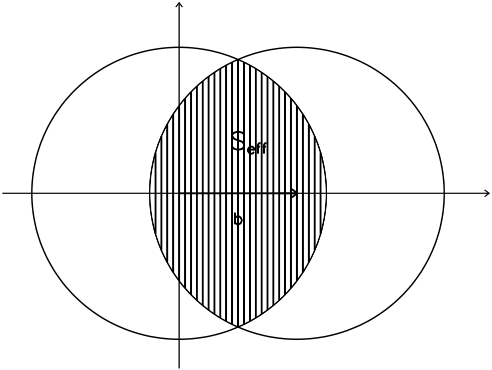


Figure: View of an AA collision at impact parameter b. The region where the nuclei overlap has been hatched and its area equals S_{eff}.

J/Ψ inelastic scattering in a hadron gas

Inspired by J. P. Blaizot and J. Y. Ollitrault, PRD**39**, 232 (1989), generalized in:
DP and L. Turko, PRC **64**, 044903 (2001)

$$J/\Psi + h_i \longrightarrow D + \bar{D} + X$$

$$\frac{\partial f}{\partial t} + \vec{v} \cdot \vec{\nabla} f = -f \sum_{i=1}^{l} \int \frac{d^3 q}{(2\pi)^3} f_i(\vec{r}, \vec{q}, t) \sigma_i v_{rel}^i \frac{p_\nu q^\nu}{E E'}$$

$$E = \sqrt{M^2 + \vec{p}^{\,2}} \,, \quad E' = \sqrt{m_i^2 + \vec{q}^{\,2}}$$

Formal solution of the kinetic equation

$$f(\vec{r},\vec{p},t) = f_0(\vec{r}-\vec{v}(t-t_0),\vec{p})$$

$$\times \exp\left\{ -\int_{t_0}^{t} dt' \sum_{i=1}^{l} \int \frac{d^3q}{(2\pi)^3} f_i(\vec{r}-\vec{v}(t-t'),\vec{q},t')\sigma_i v^i_{rel} \frac{p_\nu q^\nu}{EE'} \right\}$$

$\vec{p}$ - momentum of J/Ψ

$\vec{v} = \frac{\vec{p}}{E}$ - velocity of J/Ψ

$f_0(\vec{r},\vec{p})$ - initial distribution of J/Ψ at $t_0 = 1$ fm

Distribution of hadron species in the presence of a flow

$$f_i(\vec{r},\vec{q},t) = \frac{(2s_i+1)}{(2\pi\hbar c)^3} \frac{1}{\exp\left\{\frac{q_\nu u^\nu(\vec{r},t)-\mu_i(\vec{r},t)}{T(\vec{r},t)}\right\} \pm 1}$$

$$\mu_i(\vec{r},t) = B_i\mu_B(\vec{r},t) + S_i\mu_S(\vec{r},t)$$

$$u^\nu(\vec{r},t) = \frac{1}{\tau}(t,0,0,z)\ , \quad T(\vec{r},t) = T(z,t) = T(0,\tau)\ ,$$

$$\mu_{B(S)}(\vec{r},t) = \mu_{B(S)}(z,t) = \mu_{B(S)}(0,\tau)$$

J/Ψ survival factor in the expanding hadron gas

$$\mathcal{N}_{\mathrm{HRG}}(y,b) = \frac{\int d^2p_T \int d^3r \; \mathcal{F}(\vec{r},y,\vec{p}_T,t)|_{t=\infty}}{\int d^2p_T \int d^3r \; \mathcal{F}(\vec{r},y,\vec{p}_T,t)|_{t=t_0}}$$

$$\mathcal{F}(\vec{r},y,\vec{p}_T,t) = M_T \cosh(y) \cdot f(\vec{r},\vec{p}_T,p_L = M_T \sinh(y),t)$$

$$f_0(\vec{r},\vec{p}) = f_0(\vec{s}) \cdot g_0(p_T) \cdot h_0(y) \; , \qquad \vec{s} \in S_{eff}$$

$$f_0(\vec{s}) = \frac{T_A(\vec{s})T_B(\vec{s}-\vec{b})}{T_{AB}(b)}$$

J/Ψ survival factor in the hadron gas, *cont.*

$$\mathcal{N}_{\mathrm{HRG}}(y,b) = \frac{1}{\int dp_T\ M_T\ g_0(p_T)} \int dp_T\ M_T\ g_0(p_T) \times \exp\left\{ -\int_{t_0}^{t_{\mathrm{final}}} dt \sum_{i=1}^{l} \int \frac{d^3q}{(2\pi)^3} f_i(\vec{q},t)\sigma_i v_{\mathrm{rel},i} \frac{p_\nu q_i^\nu}{EE_i'} \right\}$$

t_{final} - average time of leaving the hadron medium by J/Ψ with the velocity $\vec{v}$ and produced in a collision at impact parameter b

$$\sigma_i = \sigma_b \quad \text{for} \quad i = \text{baryon}, \qquad \sigma_i = \frac{2}{3}\sigma_b \quad \text{for} \quad i = \text{meson}$$

Full survival factor of J/Ψ

Possible J/Ψ disintegration in the nuclear matter (pA data):

$$\mathcal{N}_{\mathrm{NA}} \cong \exp\left\{-\sigma_b \rho_0 \langle L \rangle\right\}$$

$$\boxed{\mathcal{N}^{th}_{J/\Psi} = \mathcal{N}_{\mathrm{NA}} \cdot \mathcal{N}_{\mathrm{HRG}}}$$

J/Ψ suppression at SPS

J/Ψ experimental survival factor only for midrapidity, $y \approx 0$

$$\boxed{\mathcal{N}^{exp}_{J/\Psi} = \frac{\left(\frac{B_{\mu\mu}\sigma^{AB}_{J/\psi}}{\sigma^{AB}_{DY}}\right)}{\left(\frac{B_{\mu\mu}\sigma^{pp}_{J/\psi}}{\sigma^{pp}_{DY}}\right)}}$$

J/Ψ survival factor at SPS: Pb-Pb @ 17.2 GeV

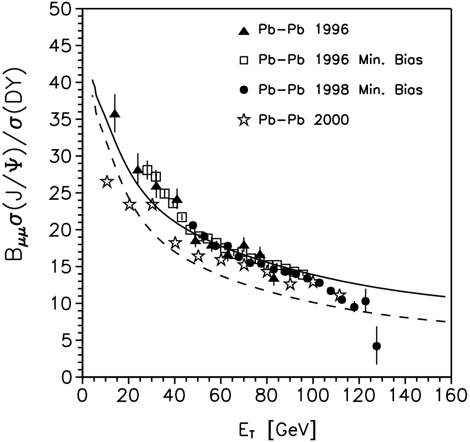


Figure: J/Ψ survival factor times $B_{\mu\mu}\sigma^{pp}_{J/\psi}/\sigma^{pp}_{DY}$ as a function of centrality for $n^0_B = (<)\ 0.25$ fm^{-3} and $T_{f.o.} = 140$ MeV. The curves correspond to $\sigma_b = 4$ mb (solid) and $\sigma_b = 5$ mb (dashed).

J/Ψ suppression at RHIC

J/Ψ experimental survival factor = J/Ψ nuclear modification factor

$$\mathcal{N}^{exp}_{J/\Psi} \equiv R_{AA} = \frac{\frac{dN^{AA}_{J/\Psi}}{dy}}{N_{coll} \cdot \frac{dN^{pp}_{J/\Psi}}{dy}}$$

J/Ψ survival factor at RHIC: Cu-Cu @ 200 GeV

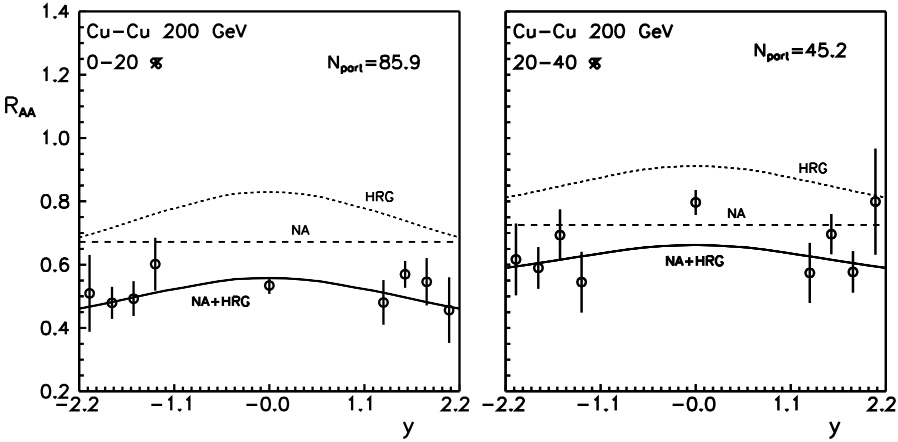
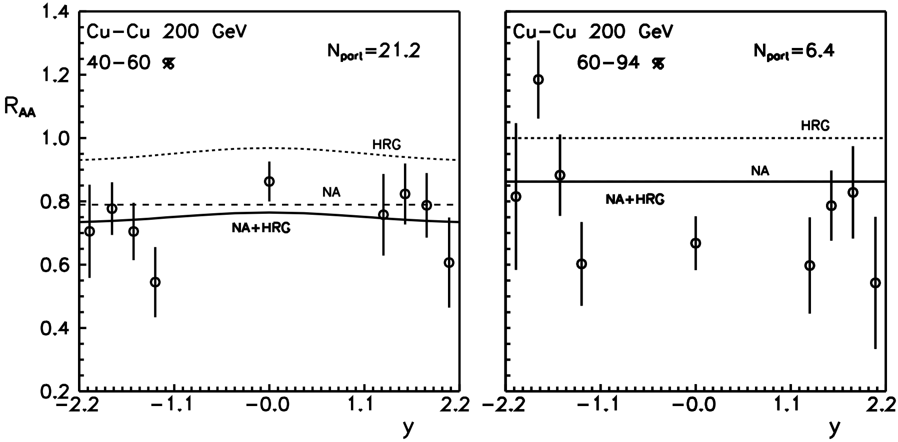


Figure: J/Ψ survival factor as a function of rapidity for a given centrality. Curves correspond to $n_B^0 = 0$, $\sigma_b = 4$ mb and $T_{f.o.} = 150$ MeV, circles are the PHENIX data.



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J/Ψ survival factor at RHIC: Au-Au @ 200 GeV

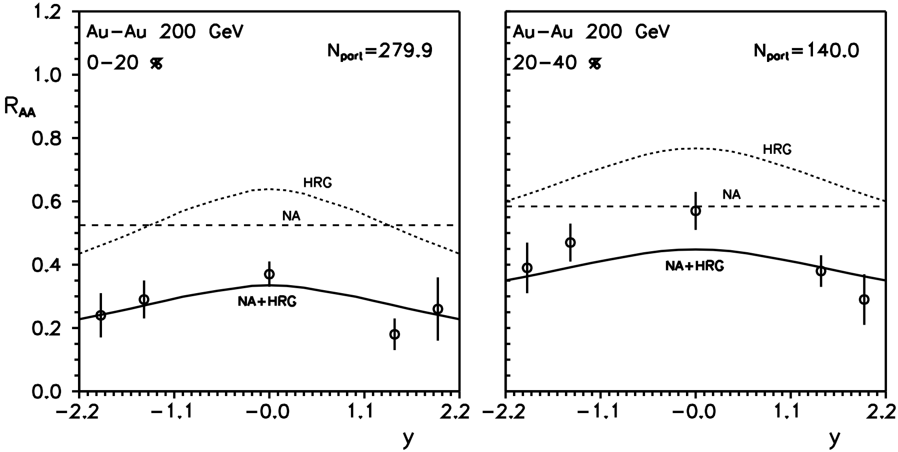


Figure: J/Ψ survival factor as a function of rapidity for a given centrality. Curves correspond to $n_B^0 = 0$, $\sigma_b = 4$ mb and $T_{f.o.} = 150$ MeV, circles are the PHENIX data.

J/Ψ survival factor at RHIC: Au-Au @ 200 GeV

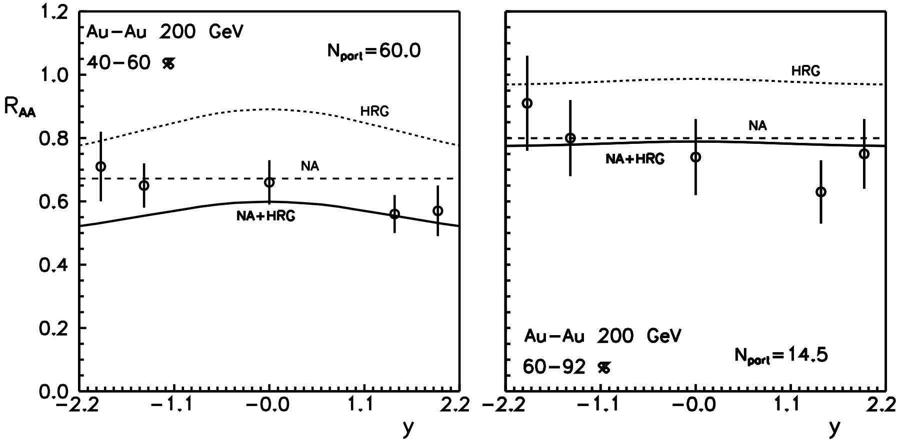


Figure: J/Ψ survival factor as a function of rapidity for a given centrality. Curves correspond to $n_B^0 = 0$, $\sigma_b = 4$ mb and $T_{f.o.} = 150$ MeV, circles are the PHENIX data.

J/Ψ survival factor at RHIC: Cu-Cu, Au-Au @ 200 GeV

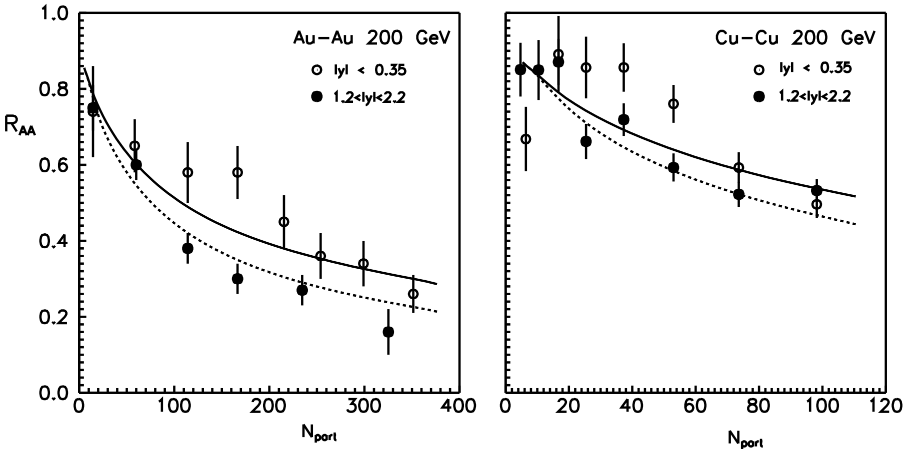


Figure: J/Ψ survival factor as a function of centrality for mid (solid) and forward (dashed) rapidity. Curves correspond to $n_B^0 = 0$, $\sigma_b = 4$ mb and $T_{f.o.} = 150$ MeV, symbols are the PHENIX data.

Taking into account the shadowing (in a rough way)

E. G. Ferreiro *et al.*, arXiv:0903.4908 with
http://phenix-france.in2p3.fr/software/jin/index.html

- Fits to PHENIX d-Au data chose the extrinsic scheme with the EPS08 model and $\sigma_{abs} = 3.6$ mb.
- $\mathcal{N}_{\rm NS}^{AuAu}(y) \equiv R_{dAu}^{Ferreiro}(\mid y \mid, \sigma_{abs} = 0)$
- $\mathcal{N}_{J/\Psi-AuAu}^{th} = \mathcal{N}_{\rm NA} \cdot \mathcal{N}_{\rm NS}^{AuAu} \cdot \mathcal{N}_{\rm HRG}$

J/Ψ suppression in Au-Au @ 200 GeV: shadowing included

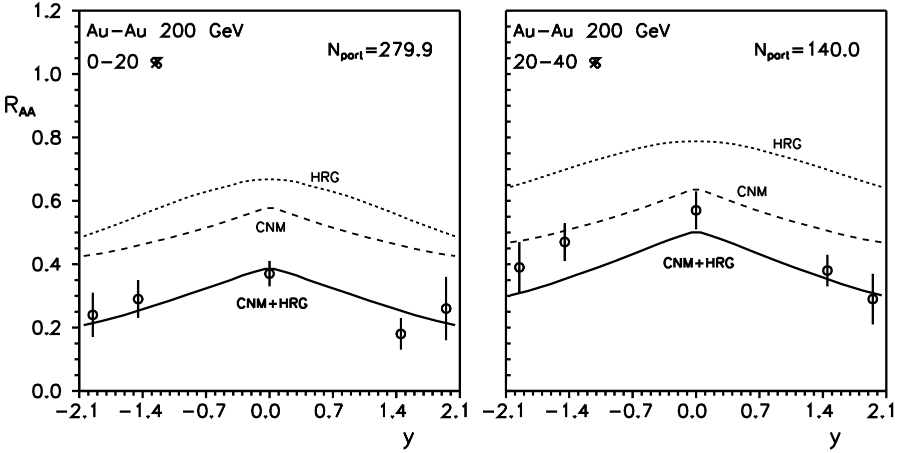


Figure: J/Ψ survival factor as a function of rapidity. Curves correspond to $n_B^0 = 0$, $\sigma_b = 3.6$ mb and $T_{f.o.} = 150$ MeV, circles are the PHENIX data.

Conclusions

1. Up to RHIC energies the observed J/Ψ suppression might be explained without QGP.
2. In this model suppression at $y \neq 0$ is stronger than for $y = 0$, as it is observed at RHIC.
3. It seems that geometry of the collision is responsible in great part for the pattern of J/Ψ suppression observed at SPS and RHIC.

How to obtain $T(t)$, $\mu_B(t)$ and $\mu_S(t)$?

Inside the rarefaction wave only the Bjorken longitudinal expansion:

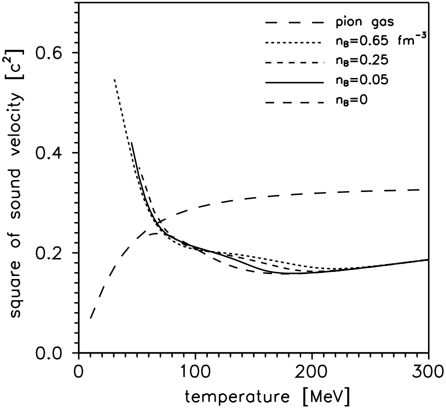
$$s(t) = \frac{s_0 t_0}{t} , \qquad n_B(t) = \frac{n_B^0 t_0}{t} , \qquad n_S = 0 .$$

Expressing left sides as corresponding densities in the Grand Canonical Ensemble:

$$s = s(T, \mu_B, \mu_S) , \quad n_B = n_B(T, \mu_B, \mu_S) , \quad n_S = n_S(T, \mu_B, \mu_S)$$

and solving at each moment t the above equations, one obtains $T(t)$, $\mu_B(t)$ and $\mu_S(t)$.

Sound velocity in the hadron gas



$$T(t) \cong T_0 \cdot \left(\frac{t_0}{t}\right)^{c_s^2(T_0)}$$

$\Longrightarrow$ putting $T_{f.o.}$ one obtains $t_{f.o.}$

Initial state scattering of gluons prior $c\bar{c}$ creation

J. Hufner, Y. Kurihara and H. J. Pirner, PL **B215**, 218 (1988)
S. Gavin and M. Gyulassy, PL **B214**, 241 (1988)
J. P. Blaizot and J. Y. Ollitrault, PL **B217**, 392 (1989)

The form proposed by S. Gupta and H. Satz, PL **B283**, 439 (1992):

$$g(p_T) = \frac{2p_T}{\langle p_T^2 \rangle_{J/\Psi}^{AB}} \cdot \exp\left\{ -\frac{p_T^2}{\langle p_T^2 \rangle_{J/\Psi}^{AB}} \right\}$$

$\langle p_T^2 \rangle_{J/\Psi}^{AB}$ - the mean squared transverse momentum of J/Ψ gained in an A-B collision

J/Ψ suppression in Au-Au @ 200 GeV: shadowing included

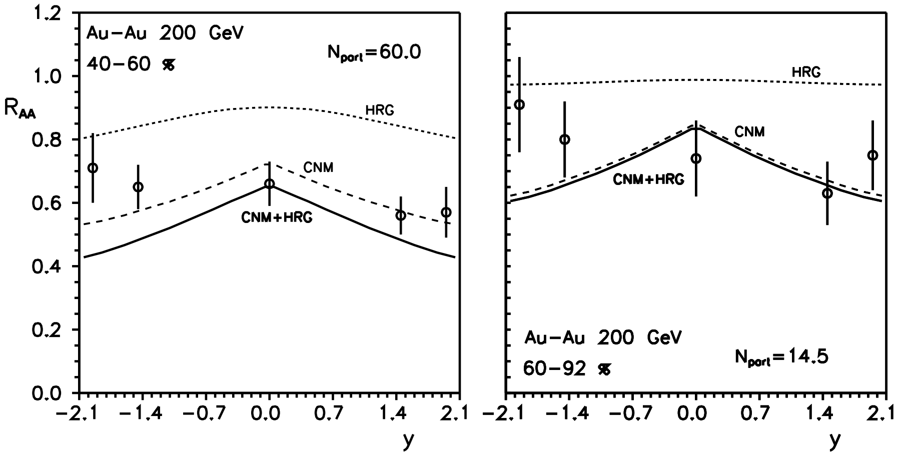


Figure: J/Ψ survival factor as a function of rapidity. Curves correspond to $n_B^0 = 0$, $\sigma_b = 3.6$ mb and $T_{f.o.} = 150$ MeV, circles are the PHENIX data.

J/Ψ dissolution in QGP

J/Ψ suppression as a signal for the QGP appearance in a heavy-ion collision

T. Matsui and H. Satz, Phys. Lett. **B178**, 416 (1986)

$$V(r) = \sigma \cdot r - \frac{\alpha}{r} \, , \qquad\qquad T = 0$$

In the QGP ($T \geq T_c$):

$$V(r) = \sigma \cdot r_D \left[1 - \exp\left\{ -\frac{r}{r_D} \right\} \right] - \frac{\alpha}{r} \exp\left\{ -\frac{r}{r_D} \right\}$$

$r_D = r_D(T)$ - screening radius

NA50 announced: Evidence for deconfinement of quarks and gluons from the J/Ψ suppression pattern measured in Pb-Pb collisions at the CERN-SPS

Phys. Lett. **477**, 28 (2000)

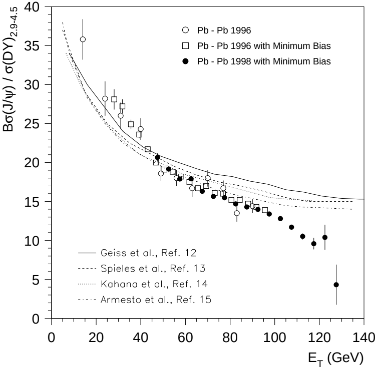


Figure 6: Comparison between our data and several conventional calculations of J/ψ suppression.

Definitions

Rapidity $\quad y = \frac{1}{2}\ln\frac{E+p_L}{E-p_L} = \frac{1}{2}\ln\frac{1+v_L}{1-v_L}$

Pseudorapidity $\quad \eta = -\ln\left(\tan\frac{\theta}{2}\right) = \frac{1}{2}\ln\frac{p+p_L}{p-p_L}$

$$N = \int d^3\vec{p}\, f(\vec{p}) = \int dy \int d^2p_T\; Ef = \int dy \int d^2p_T\; \frac{d^2N}{2\pi p_T dp_T dy}$$

$$\frac{d^2N}{2\pi p_T dp_T dy} = E\cdot f = A\, m_T \cosh(y) \exp\left\{-\frac{m_T\cosh(y)-\mu}{T}\right\}$$

$$m_T = \sqrt{m^2+p_T^2}, \quad E = m_T\cosh(y), \quad p_L = m_T\sinh(y)$$