J/Psi absorption in a multicomponent hadron gas

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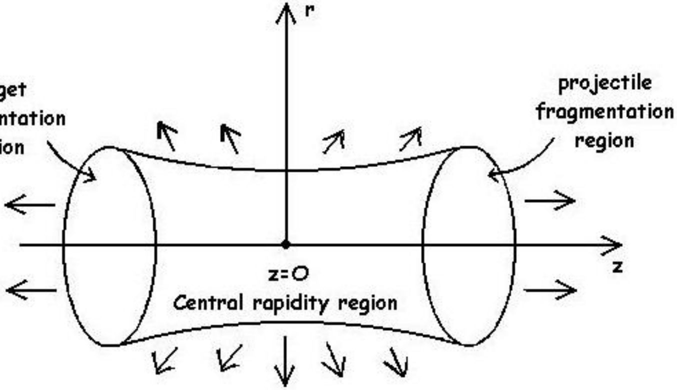
Sketch of a central collision



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 $v_z = z/t$.

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)

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

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)

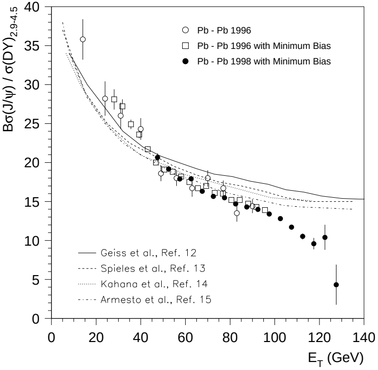


Figure 6: Comparison between our data and several conventional calculations of J/ψ suppression.

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)

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

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

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

Formal solution of the kinetic equation

Restriction to the $z = 0$ plane and assumption that $p_L = 0$.

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

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

$\vec{p}_T$ - transverse momentum of J/Ψ

$f_0(\vec{r}, \vec{p}_T)$ - initial distribution of J/Ψ

Distribution of the i-th hadron species

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

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

Assuming that the solution of hydro equations from G. Baym *et al.* is valid also for $n_B^0 \neq 0$ (small), in the $z=0$ plane one has:

$$f_i(\vec{r},\vec{q},t) = f_i(\vec{q},t) = \frac{(2s_i+1)}{(2\pi\hbar c)^3}\,\frac{1}{\exp\left\{\frac{E'-\mu_i(t)}{T(t)}\right\}\pm 1}$$

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

Inside the rarefaction wave only the Bjorken longitudinal expansion:

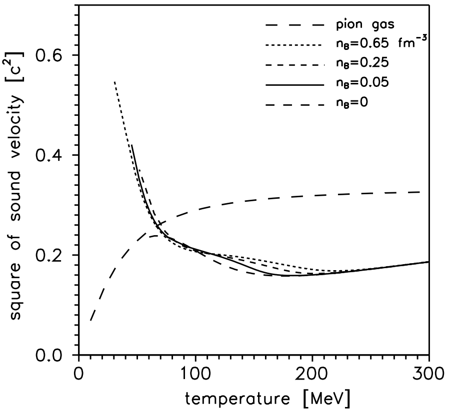
$$s(t) = \frac{s_0 t_0}{t} \,, \qquad n_B(t) = \frac{n_B^0 t_0}{t} \,, \qquad n_S = 0 \,.$$

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



$$T(t) \cong T_0 \cdot \left(\frac{t_0}{t}\right)^{c_s^2(T_0)} \quad \Longrightarrow \quad \text{putting } T_{f.o.} \text{ one obtains } t_{f.o.}$$

J/Ψ survival factor in the hadron gas

$$\mathcal{N}_{h.g.}(\epsilon_0) = \frac{\int d^2p_T \int d^2r \; f(\vec{r}, \vec{p}_T, t = +\infty)}{\int d^2p_T \int d^2r \; f_0(\vec{r}, \vec{p}_T)}$$

and $\epsilon_0 = \epsilon_0(E_T) = \epsilon_0(E_T(b))$ obtained from NA50 data, Phys. Lett. **B450**, 456 (1999); *ibid.* **477**, 28 (2000)

If one assumes that $f_0(\vec{r}, \vec{p}_T) = f_0(r) \cdot g(p_T)$, $f_0(r)$ and $g(p_T)$ are normalized to 1, then ...

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

$$\mathcal{N}_{h.g.}(\epsilon_0) = \int dp_T \; g(p_T) \times \exp\left\{ - \int_{t_0}^{t_{final}} dt' \sum_{i=1}^{l} \int \frac{d^3q}{(2\pi)^3} f_i(\vec{q}, t') \sigma_i v_{rel}^i \frac{p_\nu q^\nu}{EE'} \right\}$$

$t_{final} = min\{\langle t_{esc} \rangle, t_{f.o.}\}$

$\langle t_{esc} \rangle (b, v)$ - average time of leaving the hadron medium by J/Ψ with the velocity $v = p_T/E$ and produced in a collision at impact parameter b

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):

$$g(p_T, \epsilon_0) = \frac{2p_T}{\langle p_T^2 \rangle_{J/\Psi}^{AB}(\epsilon_0)} \cdot \exp\left\{ -\frac{p_T^2}{\langle p_T^2 \rangle_{J/\Psi}^{AB}(\epsilon_0)} \right\}$$

$\langle p_T^2 \rangle_{J/\Psi}^{AB}(\epsilon_0)$ - the mean squared transverse momentum of J/Ψ gained in an A-B collision

$$\langle p_T^2 \rangle_{J/\Psi}^{AB}(\epsilon) = \langle p_T^2 \rangle_{J/\Psi}^{pp} + K \cdot \epsilon$$

$z = 0$ plane

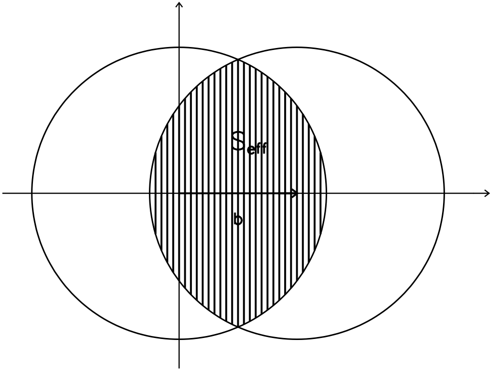


Figure: View of a Pb-Pb collision at impact parameter b. The region where the nuclei overlap has been hatched and its area equals S_{eff}.

Full survival factor of J/Ψ

Possible J/Ψ disintegration in the nuclear matter:

$$\mathcal{N}_{n.m.}(\epsilon_0(b)) \cong \exp\left\{-\sigma_{\psi N}\rho_0 L(b)\right\}$$

$$\boxed{\mathcal{N}_{c\bar{c}}(\epsilon_0) = \mathcal{N}_{n.m.}(\epsilon_0) \cdot \mathcal{N}_{h.g.}(\epsilon_0)}$$

Only $\sim 60\%$ of J/Ψ measured are directly produced during collision, so the realistic J/Ψ survival factor should read

$$\mathcal{N}(\epsilon_0) = 0.6 \cdot \mathcal{N}_{J/\psi}(\epsilon_0) + 0.3 \cdot \mathcal{N}_{\chi}(\epsilon_0) + 0.1 \cdot \mathcal{N}_{\psi'}(\epsilon_0) \ .$$

J/Ψ survival factor as a function of E_T

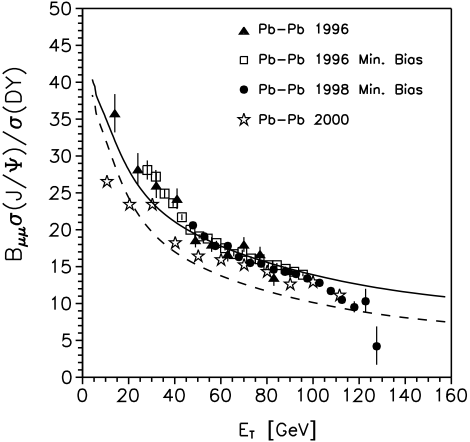


Figure: J/Ψ survival factor times $B_{\mu\mu}\sigma^{pp}_{J/\psi}/\sigma^{pp}_{DY}$ for $n^0_B = 0.25$ fm^{-3}, $T_{f.o.} = 140$ MeV and $c_s = 0.45$. The curves correspond to $\sigma_b = 4$ mb (solid) and $\sigma_b = 5$ mb (dashed).

Conclusion and outlook

1. J/Ψ suppression is not a good signal for the quark-gluon plasma appearance during a heavy-ion collision.
2. Generalization of this model to $y \neq 0$ is in progress, preliminary calculations show that suppression is much deeper in this case than for $y = 0$ (as observed in RHIC).