Heavy quark correlation and the effective volume for J/ψ regeneration in rare heavy quark events

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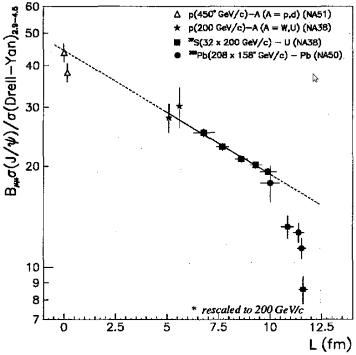
Outline

J/ψ in HIC



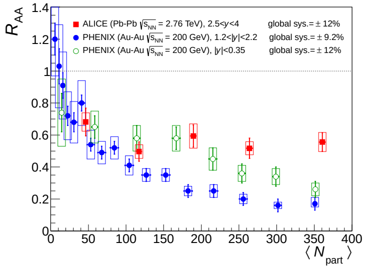
(SPS data, Nucl. Phys. A610, 404c (1996))

$J/\psi + g \to c + \bar{c}$

- Sequential dissociation (H. Satz, et al)
- Statistical model (P. Braun-Munzinger, et al)
- Transport model (R. Rapp, P. Zhuang, T. Song, et al)

J/ψ in HIC

$$R_{AA} = \frac{N_{J/\psi}^{AA}}{N_{J/\psi}^{pp} N_{coll}}$$



(Alice data, Phys. Rev. Lett. 109, 072301 (2014))

- Sequential dissociation
- Statistical model
- Transport model

Canonical effect of J/ψ production in the statistical model

Statistical model:

$$N_{c\bar{c}}^{dir} = \frac{1}{2} N_{open} + N_{hidden} \quad (1)$$

- Grand canonical ensemble:

$$N_{c\bar{c}}^{dir} = \frac{1}{2} \gamma n_{open}^{th} V + \gamma^2 n_{hidden}^{th} V \quad (2)$$

- Canonical ensemble:

$$N_{c\bar{c}}^{dir} = \frac{1}{2} \gamma n_{open}^{th} V \frac{I_1(\gamma n_{open}^{th} V)}{I_0(\gamma n_{open}^{th} V)} + \gamma^2 n_{hidden}^{th} V \quad (3)$$

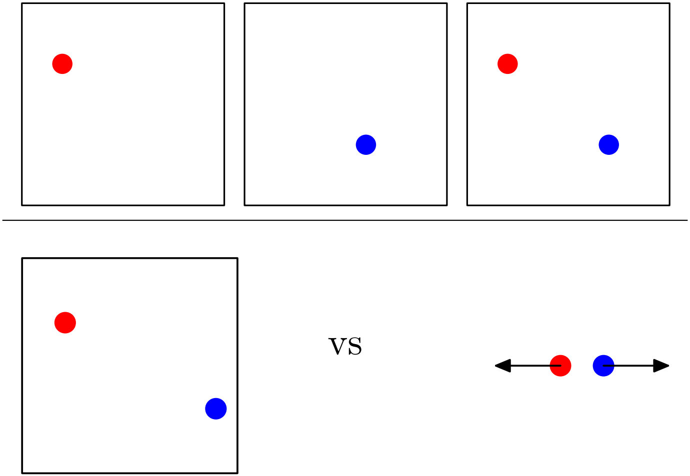
Canonical ensemble

$$N_{c\bar{c}}^{dir} = \frac{1}{2}\gamma n_{open}^{th} V \frac{I_1(\gamma n_{open}^{th} V)}{I_0(\gamma n_{open}^{th} V)} + \gamma^2 n_{hidden}^{th} V \quad (4)$$

$$\approx (\frac{1}{2}\gamma n_{open}^{th} V)^2 + \gamma^2 n_{hidden}^{th} V \quad (5)$$

- Canonical effect and the correlation
- Volume dependence of J/ψ production

Heavy quark correlation and the effective volume



Approach

Set up

- gluons: Boltzmann distribution
- charm quarks:

$$\partial_t f_c + \mathbf{v} \cdot \nabla f_c = C_{c+g \to c+g} \tag{6}$$

- parameters:
  - $\sigma_{cg} = 4$ mb, isotropic
  - $m_c = 1.25$ GeV
  - $m_g = 0$
  - constant temperature T
  - initial momentum of charm quarks p_0

Approach

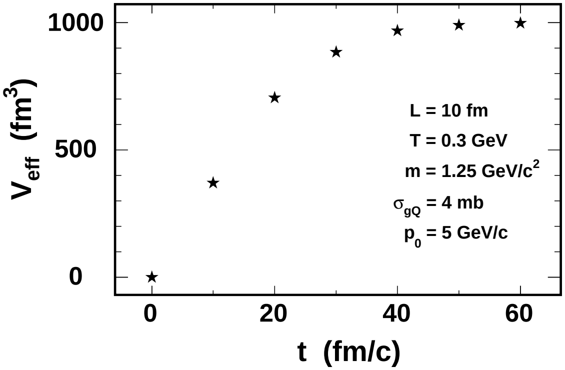
For thermalized charm quarks in volume V

$$\Delta N_{\rm coll}^{th} \quad = \quad \frac{N_1 N_2 \sigma \Delta t}{V} g(m_c/T), \tag{7}$$

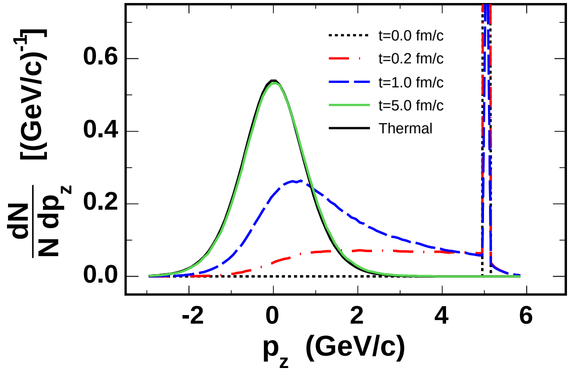
where $g(z) \equiv \frac{4K_3(2z)}{zK_2^2(z)}$.
We define the effective volume

$$V_{\rm eff} \quad = \quad \lim_{\substack{N_1,N_2\to\infty \\ \Delta t\to 0 \\ \sigma\to 0}} \frac{N_1 N_2 \sigma \Delta t}{\Delta N_{\rm coll}} g(m_c/T). \tag{8}$$

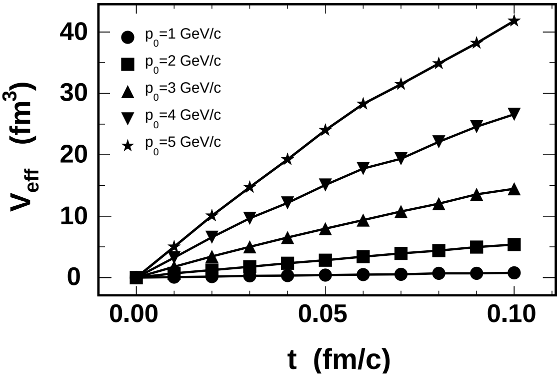
Box Test


1000
500
0
0
20
40
60
t (fm/c)
V_eff (fm^3)
L = 10 fm
T = 0.3 GeV
m = 1.25 GeV/c^2
σ_gQ = 4 mb
p_0 = 5 GeV/c

p_z distribution

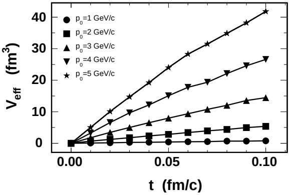


Short Time



p_0=1 GeV/c
p_0=2 GeV/c
p_0=3 GeV/c
p_0=4 GeV/c
p_0=5 GeV/c
0
10
20
30
40
V_{eff} (fm^3)
0.00
0.05
0.10
t (fm/c)

Short Time

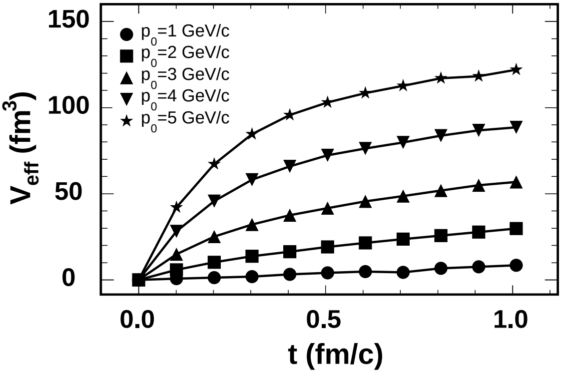


$$N_{J/\psi} \propto \int \frac{\Delta N_{Q\bar{Q}}}{\Delta t} dt$$

$$\propto \int \frac{1}{V_{\text{eff}}} dt$$

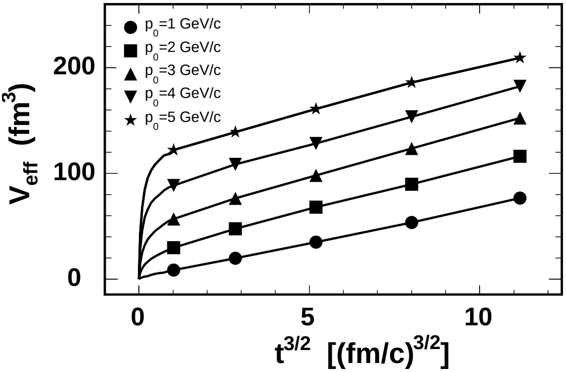
$$\propto \int \frac{1}{t} dt$$

Medium Time



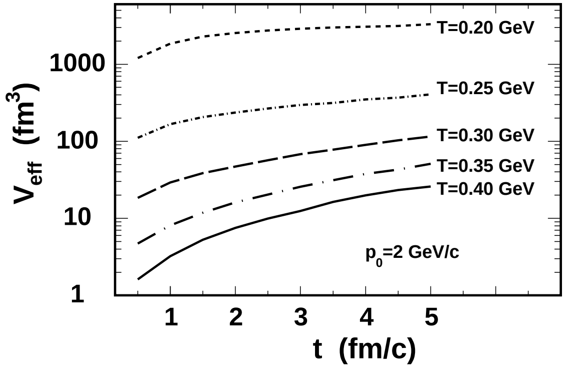
150
100
50
0
0.0
0.5
1.0
t (fm/c)
V_eff (fm^3)
p_0=1 GeV/c
p_0=2 GeV/c
p_0=3 GeV/c
p_0=4 GeV/c
p_0=5 GeV/c

Long Time

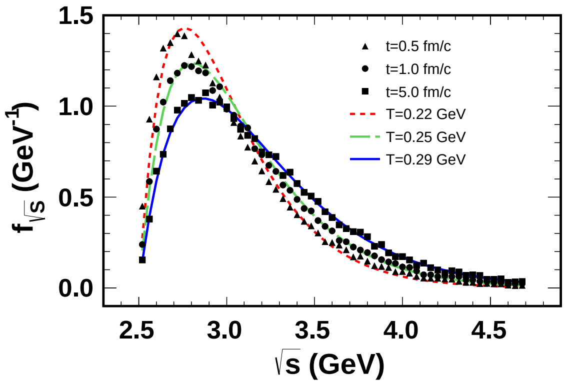


p0=1 GeV/c
p0=2 GeV/c
p0=3 GeV/c
p0=4 GeV/c
p0=5 GeV/c
200
100
0
Veff (fm3)
0
5
10
t3/2 [(fm/c)3/2]

T dependence



$\sqrt{s_{Q\bar{Q}}}$ distribution



Summary

1. $V_{\rm eff}$ is defined based on the collision rate.
2. Even in an infinite fireball, $V_{\rm eff}$ is finite, leading to finite yield of J/ψ.
3. $V_{\rm eff}$ depends on T and p_0 sensitively.
4. $V_{\rm eff}$ increases linearly at small t,
   and then increases more slowly,
   and increases with $t^{3/2}$ at large t.
5. $\sqrt{s_{Q\bar{Q}}}$ can roughly be described by thermal distribution even if the heavy quark is not thermalized.

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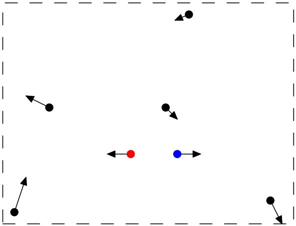
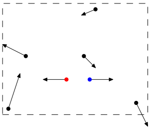
Proof of the linear behavior



$$x' = \lambda x$$
$$t' = \lambda t$$



$$
\begin{aligned}
& \Delta N_{Q\bar{Q}}(t, \Delta t, \sigma_{Q\bar{Q}}, \sigma_{gQ}, f_g) \\
= \; & \Delta N'_{Q\bar{Q}}(t', \Delta t', \sigma'_{Q\bar{Q}}, \sigma'_{gQ}, f'_g) \\
= \; & \frac{\Delta t' \sigma'_{Q\bar{Q}} (\sigma'_{gQ} f'_g)^2}{\Delta t \sigma_{Q\bar{Q}} (\sigma_{gQ} f_g)^2} \Delta N_{Q\bar{Q}}(t', \Delta t, \sigma_{Q\bar{Q}}, \sigma_{gQ}, f_g) \\
= \; & \lambda \Delta N_{Q\bar{Q}}(\lambda t, \Delta t, \sigma_{Q\bar{Q}}, \sigma_{gQ}, f_g)
\end{aligned}
$$