B_c Meson enhancement at LHC

Yunpeng Liu
in collaboration with Prof. Carsten Greiner and Dr. Andriy Kostyuk

Transport Group Meeting

10-05-2012

GOETHE UNIVERSITÄT FRANKFURT AM MAIN

Outline

Motivation

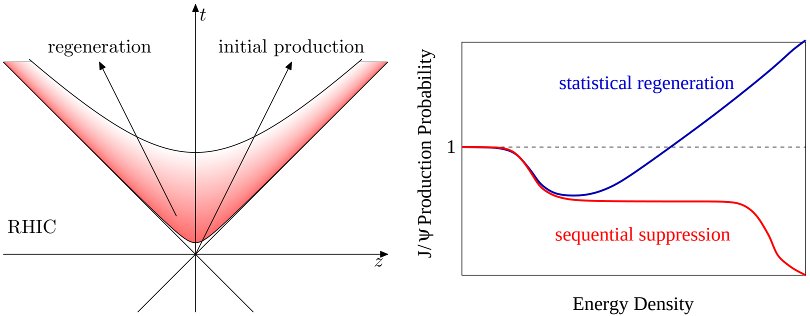
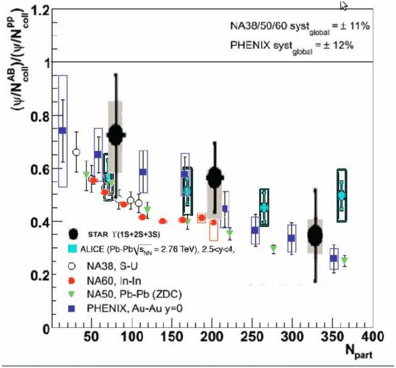


Figure: Satz: arXiv:1101.3937

Motivation



$$R_{AA} = \frac{N_{AA}}{N_{coll}N_{pp}} \propto \frac{\sigma^{Q}\sigma^{\bar{Q}}}{\sigma(Q\bar{Q})}$$

$$\frac{d\sigma^{c\bar{c}}}{dy} \sim 10^{-1}\ \text{mb}$$

$$\frac{d\sigma^{b\bar{b}}}{dy} \sim 10^{-2}\ \text{mb}$$

$$\frac{d\sigma^{J/\psi}}{dy} \sim 10^{-3}\ \text{mb}$$

$$\frac{d\sigma^{\Upsilon}}{dy} \sim 10^{-5}\ \text{mb}$$

$$\frac{d\sigma^{B_c}}{dy} \sim 10^{-5}\ \text{mb}$$

GOETHE UNIVERSITÄT FRANKFURT AM MAIN

B_c in Vacuum

$$V(r) = -\frac{\alpha}{r} + \sigma r \tag{1}$$

with

$$\alpha = \pi/12 \tag{2}$$
$$\sigma = 0.2\ \mathrm{GeV}^2 \tag{3}$$

$$m_{B_c(1S)} = 6.36\ \mathrm{GeV} \tag{4}$$
$$m_{B_c(1P)} = 6.72\ \mathrm{GeV} \tag{5}$$
$$m_{B_c(2S)} = 6.90\ \mathrm{GeV} \tag{6}$$

B_c cross section

Particle	M/GeV	Γ/keV	$d\sigma_{pp}/dy$
J/ψ	3.096	93	3.4 μb$(1.96\ \mathrm{TeV})$[?]
B_c^+	6.277	0.00000145	15.5 nb $(1.96\ \mathrm{TeV}, p_t > 6\ \mathrm{GeV})$[?]
$\Upsilon(1S)$	9.460	54	30.36 nb$(1.8\ \mathrm{TeV}, p_t < 16\ \mathrm{GeV})$[?]

Pythia simulation(4×10^8 events):

- $d\sigma_{B_c^+}(1.96\mathrm{TeV}, p_t > 0)/dy \sim 2.7\mathrm{nb}(\ll Experiments)$
- $$\frac{\sigma_{B_c^+}(p_t > 6GeV)}{\sigma_{B_c^+}(p_t > 0)} \sim \frac{2}{7}$$

.

Estimation for LHC energy:

$$\frac{d\sigma_{B_c^+}}{dy}(2.76\text{TeV}) \quad \approx \quad 4 \times \frac{d\sigma_{B_c^+}}{dy}(p_t > 6\text{GeV}, 1.96\text{TeV}) = 62\text{nb}$$

which gives the ratio

$$\frac{d\sigma/dy(B_c)}{d\sigma/dy(b)} = \frac{62nb}{20\mu b} = 3.1 \times 10^{-3} \tag{7}$$

consistent with estimation based on CDF measurement[**?**, **?**]

$$\frac{\sigma(B_c^+)}{\sigma(\bar{b})} = 2.08^{+1.06}_{-0.95} \times 10^{-3}$$

GOETHE UNIVERSITÄT FRANKFURT AM MAIN

Suppose the distribution is in the form of

$$\frac{d\sigma_{B_c^+}}{dy}(p_t) \propto p_t \left(1 + \frac{p_t^2}{(n-2)\langle p_t^2 \rangle}\right)^{-n} \tag{8}$$

From Pythia simulation, we can also estimate:

$$\langle p_t^2 \rangle = 25.1\mathrm{GeV}^2 \qquad n \approx 4.165 \tag{9}$$

The heavy quark production cross section is estimated from experiments as

$$\frac{d\sigma_{c\bar{c}}}{dy} = 620\mu b, \tag{10}$$

$$\frac{d\sigma_{b\bar{b}}}{dy} = 20\mu b, \tag{11}$$

GOETHE UNIVERSITÄT FRANKFURT AM MAIN

Statistical Hadronization Model (SHM)

The original Formula of SHM (balance equation)[?]

$$N_{c\bar{c}}^{dir} = \frac{1}{2} g_c N_{oc}^{th} + g_c^2 N_{c\bar{c}}^{th} \tag{12}$$

where

$$N_{c\bar{c}}^{dir} : \text{\# of directly produced charm pair.} \tag{13}$$

$$g_c : \text{fugacity of charm and anti-charm.} \tag{14}$$

$$N_{oc}^{th} : \text{\# of thermal charmed mesons due to g.c.e.} \tag{15}$$

$$N_{c\bar{c}}^{th} : \text{\# of thermal hidden charms.} \tag{16}$$

Main Parameters: T, g.

GOETHE UNIVERSITÄT FRANKFURT AM MAIN

Event by event effect

$$N_{c\bar{c}}^{dir} = \frac{1}{2} g_c N_{oc}^{th} + g_c^2 N_{c\bar{c}}^{th} \tag{17}$$

$$X \sim P(\lambda) \tag{18}$$

$$\langle X \rangle = \lambda \tag{19}$$

$$\langle X^2 \rangle = \lambda(\lambda + 1) = \lambda^2 (1 + \frac{1}{\lambda}) \tag{20}$$

An updated version of the balance equation [**?**]

$$N_{c\bar{c}}^{dir} = \frac{1}{2} g_c N_{oc}^{th} + g_c^2 (1 + \frac{1}{N_{c\bar{c}}}) N_{c\bar{c}}^{th} \tag{21}$$

Main Parameters: T, g, V.

GOETHE UNIVERSITÄT FRANKFURT AM MAIN

Parameters of SHM

The parameters were fit in the following form[?]

$$T = T_{lim} \frac{1}{1 + e^{2.6 - \frac{1}{0.45} \ln \frac{\sqrt{s_{NN}}}{\mathrm{GeV}}}}, \tag{22}$$

with

$$T_{lim} = 164\mathrm{MeV}, \tag{23}$$

at LHC energy, we take $T = T_{lim}$.
The volume is fit at LHC energy as $V_{\Delta y=1} \approx 4160\mathrm{fm}^3$.

GOETHE UNIVERSITÄT FRANKFURT AM MAIN

SHM with B_c meson

The balance equation

$$
\begin{aligned}
N_{c\bar{c}}^{dir} &= \frac{1}{2} g_c (N_{oc}^{th} + g_b N_{B_c}^{th}) + g_c^2 (1 + \frac{1}{N_{c\bar{c}}}) N_{c\bar{c}}^{th} \\
N_{b\bar{b}}^{dir} &= \frac{1}{2} g_b (N_{ob}^{th} + g_c N_{B_c}^{th}) + g_b^2 (1 + \frac{1}{N_{b\bar{b}}}) N_{b\bar{b}}^{th}
\end{aligned}
$$

Rough estimation

$$
N_{c\bar{c}}^{dir} = \frac{1}{2} g_c N_{oc}^{th} \quad \rightarrow \quad g_c = 32
$$

$$
\frac{N_{B_c}}{N_{c\bar{c}}^{dir}} = \frac{g_c N_{B_c}^{th}}{N_{ob}^{th}} \quad \approx \quad g_c e^{-(M_{Bc} - M_{B^+})/T} = \frac{g_c}{445} \approx 8.1\%
$$

Solution (only $B_c^+(J^P = 0^-)$ considered)

$$
\begin{aligned}
g_c &= 31.1 \\
g_b &= 2.39 \times 10^8 \\
N_{o\bar{b}} &= 0.59617 = 98.3\% \cdot N_{b\bar{b}}^{dir} \\
N_{B_c^+} &= 0.00669 = 1.08\% \cdot N_{b\bar{b}}^{dir} \\
N_{\Upsilon s} &= 0.00569 = 0.60\% \cdot N_{b\bar{b}}^{dir} \\
N_{b\bar{b}}^{dir} &= 0.60854
\end{aligned}
$$

$$\frac{N_{B_c}}{N_{b\bar{b}}^{dir}} = 1.1\% \tag{24}$$

$$\frac{N_{B_c}^{dir}}{N_{b\bar{b}}^{dir}} = \frac{\sigma_{B_c}^{dir}}{\sigma_{b\bar{b}}^{dir}} = \frac{62 \text{ nb}}{20 \ \mu\text{b}} = 0.3\% \tag{25}$$

which leads to $R_{AA} = 1.1/0.3 = 3.5$.

The Transport Model

For B_c meson:

$$(\partial_t + \vec{v} \cdot \nabla) f_{B_c} = -\alpha f_{B_c} + \beta \tag{26}$$

For the fireball:

$$\partial_\mu T^{\mu\nu} = 0 \tag{27}$$

with EoS of ideal gas of partons and hadrons in Bag model.

GOETHE UNIVERSITÄT FRANKFURT AM MAIN

Dissociation rate

$$\alpha = \frac{1}{E}\int \frac{d\vec{k}}{(2\pi)^3 E_k} k^\mu p_\mu \sigma_{g+B_c\to b+\bar{c}}(s) f_g(k^\mu, u_\mu, T)$$

$$\beta = \frac{1}{2E}\int \frac{d^3\vec{k}}{(2\pi)^3 2E_g}\frac{d^3\vec{q}_b}{(2\pi)^3 2E_b}\frac{d^3\vec{q}_{\bar{c}}}{(2\pi)^3 2E_{\bar{c}}} W_{b+\bar{c}\to B_c+g}(s)$$
$$f_b(\vec{q}_b,\vec{x},t) f_{\bar{c}}(\vec{q}_{\bar{c}},\vec{x},t)(2\pi)^4\delta^{(4)}(p+k-q_b-q_{\bar{c}})(1+f_g)$$

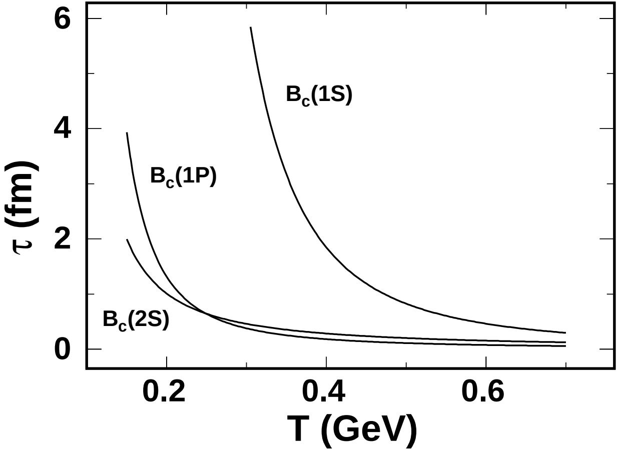
where

$$\sigma_{g+Bc(1S)\to b+\bar{c}} = A_0 \cdot \frac{(\omega/\epsilon_\psi - 1)^{3/2}}{(\omega/\epsilon_\psi)^5} \quad (28)$$

$$A_0 = (2^{11}\pi)/(27\sqrt{\mu^3\epsilon}) \quad (29)$$

GOETHE UNIVERSITÄT FRANKFURT AM MAIN

Lifetime of B_c due to gluon dissociation



GOETHE UNIVERSITÄT FRANKFURT AM MAIN

Cornell Potential at Finite Temperature

$$\left[\frac{1}{2\mu}\nabla^2 + V(r,T)\right]\psi(\vec{r},T) = E\psi(\vec{r},T)$$

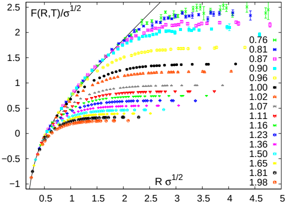
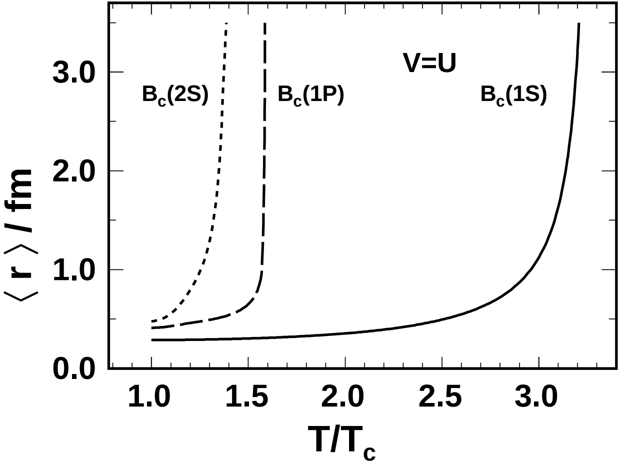


Figure: Free energy of heavy quarks by LQCD.

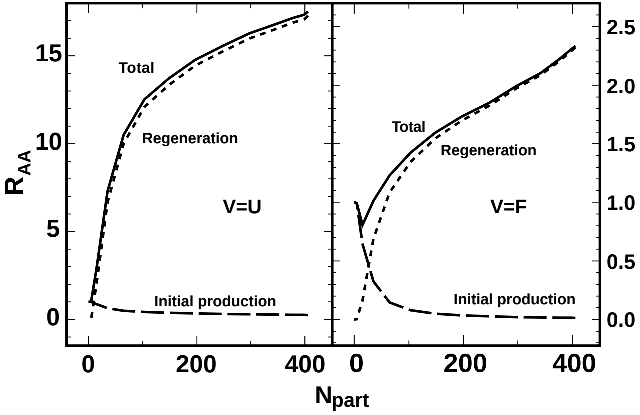
- $V = F$ Free energy;
- $V = U$ Internal energy.

$$U = F + TS$$

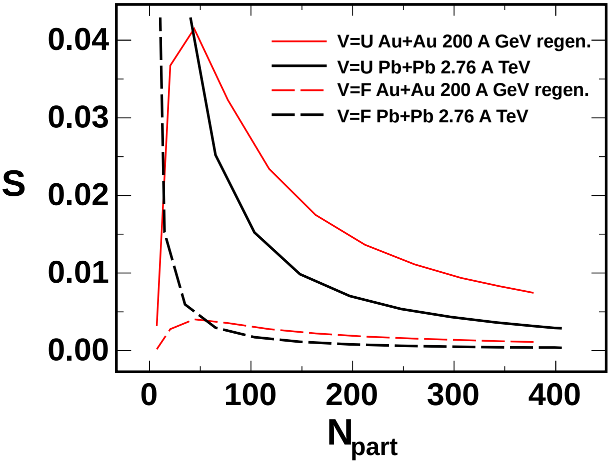
Radius of B_c at finite temperature



Centrality dependence of R_{AA}



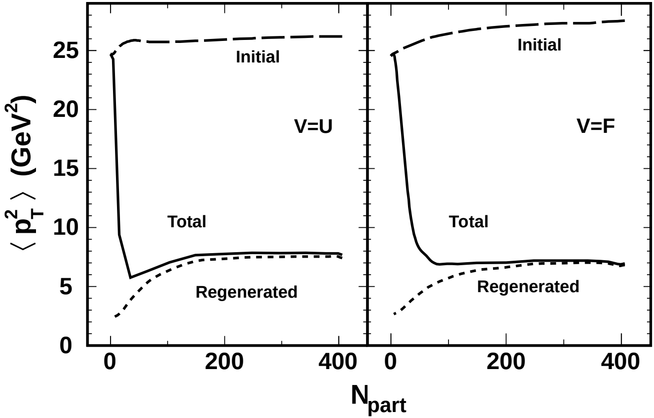
$$R_{AA} = \frac{N_{AA}}{N_{coll} N_{pp}} \propto \frac{\sigma^Q \sigma^{\bar{Q}}}{\sigma^{(Q\bar{Q})}}$$



$$S \equiv \frac{dN^{B_c}/dy}{dN^b/dy \cdot dN^c/dy}$$

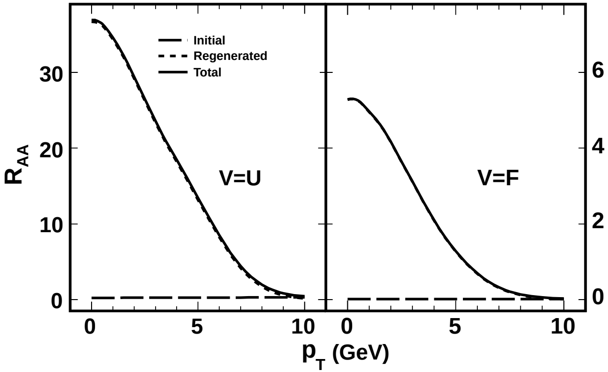
GOETHE UNIVERSITÄT FRANKFURT AM MAIN

Mean p_T^2

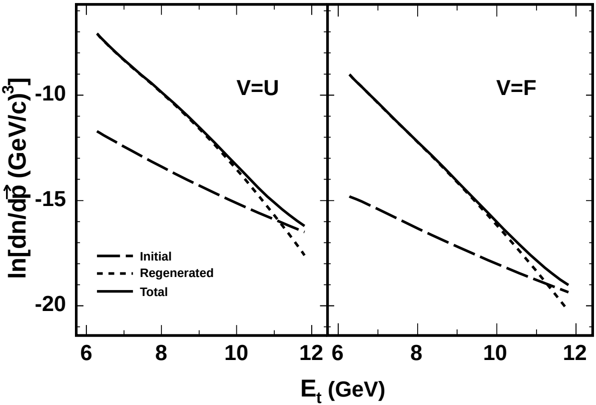


Initial
V=U
Total
Regenerated
Initial
V=F
Total
Regenerated
⟨p_T^2⟩ (GeV^2)
0
5
10
15
20
25
0
200
400
0
200
400
N_part

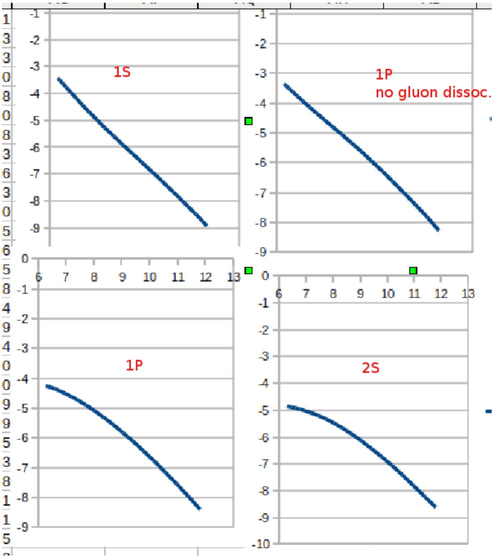
Momentum dependence of R_{AA}



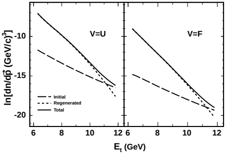
Momentum spectrum



Spectra of different states $b = 0$ fm



Effective temperature



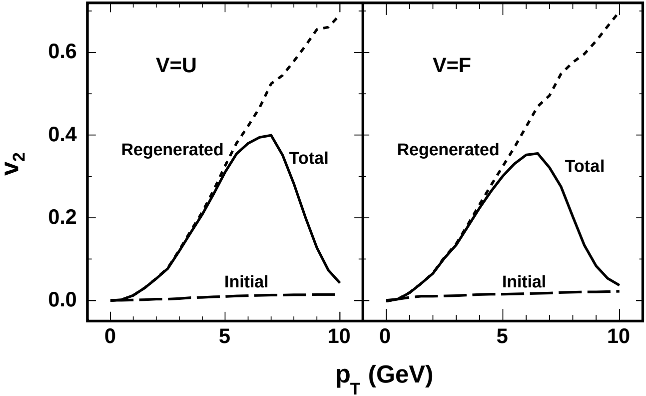
$$\frac{dn}{d\vec{p}} = Ae^{-E/T_{\rm eff}} \tag{30}$$

	V=U	V=F
Regeneration	567	533
Total	569	534

Table: Effective temperature $T_{\rm eff}/\mathrm{MeV}$ of B_c.

GOETHE UNIVERSITÄT FRANKFURT AM MAIN

Elliptic flow at $b = 8.4$ fm



GOETHE UNIVERSITÄT FRANKFURT AM MAIN

Conclusion

- Enhancement of B_c production is expected at LHC energy, which can verify the regeneration mechanism directly.
- Contribution from the excited states are sensitive to the heavy quark potential.
- Less regeneration at low p_T relative to thermal production may suggest dissociation of the regenerated quarkonia.
- B_c meson carries the information from the fireball like temperature and flow.

GOETHE UNIVERSITÄT FRANKFURT AM MAIN