Rate equation approach to J/ψ equilibration

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Outline

1. J/ψ in the statistical hadronization model
2. Production and dissociation processes
3. Rate equation approach
4. Results

Statistical hadronization

Multiplicity given by T, μ, V:

$$N_i^{th} = \frac{d_i V T}{2\pi^2} m_i \sum_{n=1}^{\infty} (\mp 1)^{n+1} \frac{\lambda_i^n}{n} K_2\left(\frac{n m_i}{T}\right)$$

T, μ: ratio fits

V: charged hadron multiplicity

Exact charm conservation
(hadron picture)

Balance equation:

$$N_{c\bar{c}}^{dir} = \frac{1}{2} g_c N_{oc}^{th} \frac{I_1\left(g_c N_{oc}^{th}\right)}{I_0\left(g_c N_{oc}^{th}\right)} + g_c^2 N_{\psi}^{th}$$

g_c: charm fugacity (hadronic picture)

$$N_{J/\psi} = g_c^2 \frac{d_{J/\psi} V T}{2\pi^2} m_{J/\psi} \sum_{n=1}^{\infty} \frac{\lambda_{J/\psi}^n}{n} K_2\left(\frac{n m_{J/\psi}}{T}\right)$$

Exact charm conservation
(QGP picture)

Balance equation:

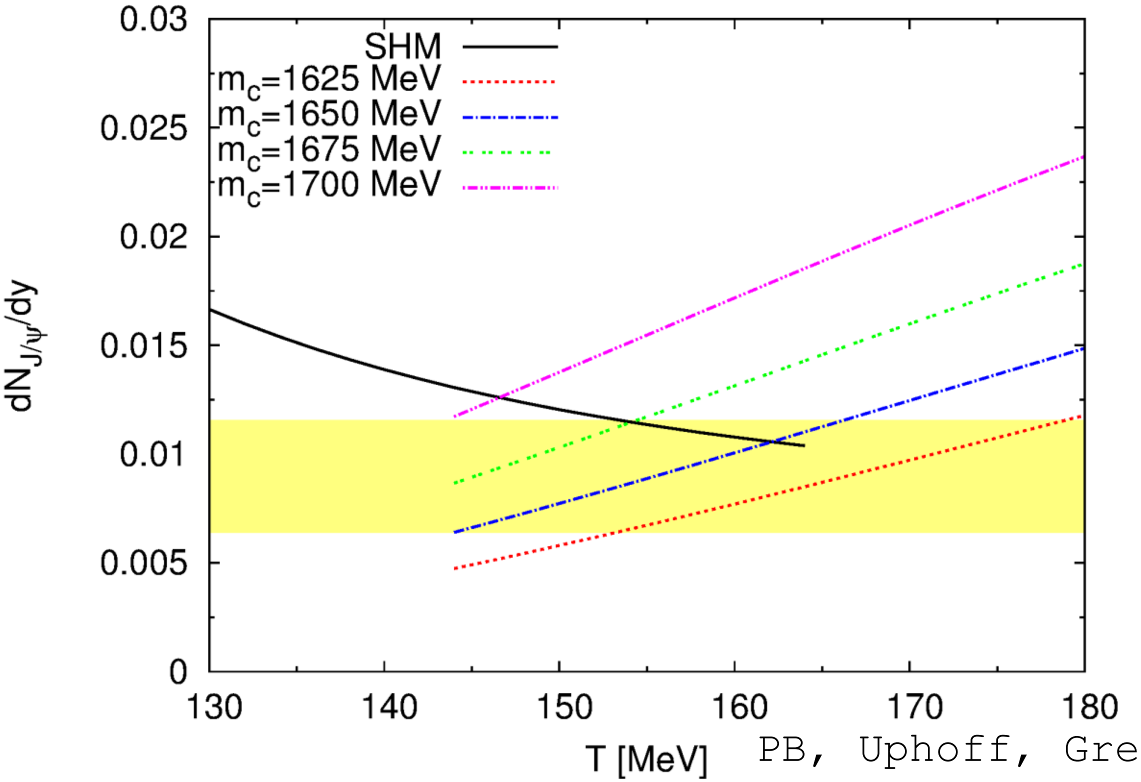
$$N_{c\bar{c}}^{dir} = \lambda_{c\bar{c}} N_c^{th} = \lambda_{c\bar{c}} \frac{d_c V T}{2\pi^2} m_c \sum_{n=1}^{\infty} (-1)^{n+1} \frac{\lambda_c^n}{n} K_2\left(\frac{n m_c}{T}\right)$$

$\lambda_{c\bar{c}}$: charm fugacity (QGP picture)

$$N_{J/\psi} = \lambda_{c\bar{c}}^2 \frac{d_{J/\psi} V T}{2\pi^2} m_{J/\psi} \sum_{n=1}^{\infty} \frac{\lambda_{J/\psi}^n}{n} K_2\left(\frac{n m_{J/\psi}}{T}\right)$$

Production equivalency

g_c and $\lambda_{c\bar{c}}$ are connected measures of chemical equilibrium



Strong dependence on m_c!

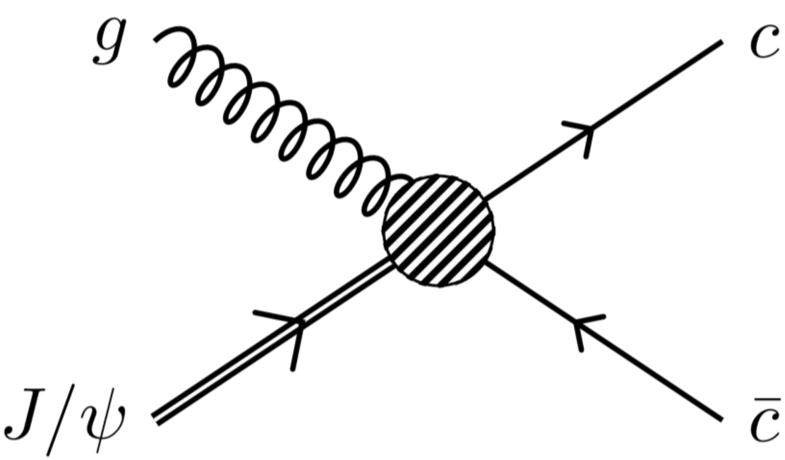
PB, Uphoff, Greiner: PRC 90 (2014) 6, 061901

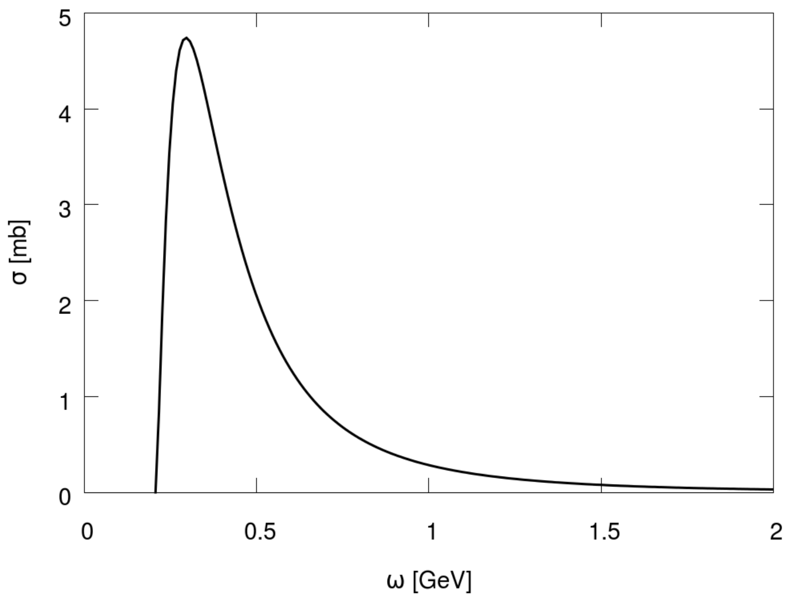
Motivation

- Simultaneous production of hadrons fits J/ψ
- $T_{dis} > T_{FO}$: QGP picture should hold

Can QGP scatterings produce statistical J/ψ multiplicities?

Processes



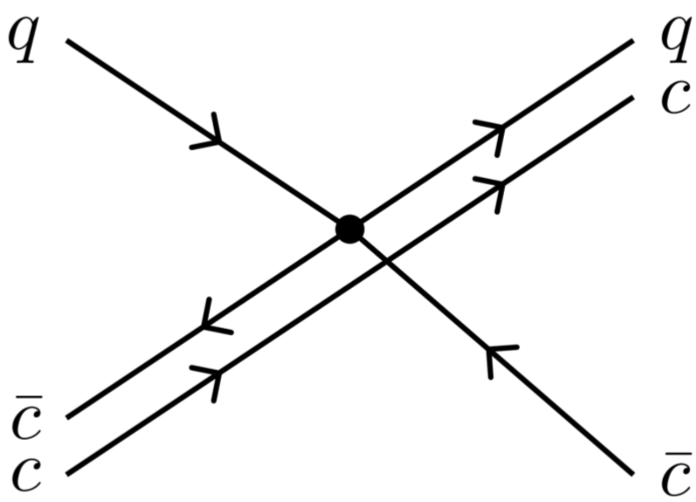


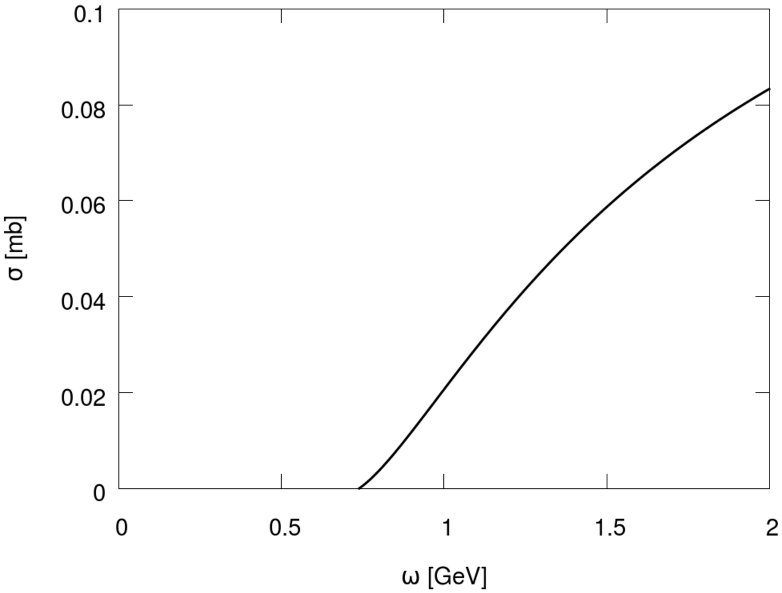
Bhanot-Peskin gluon dissociation

$$\frac{2^{11}}{27}\frac{1}{\sqrt{m_c^3\epsilon}}\frac{\left({}^{\omega}/_{\omega_0}-1\right)^{3/2}}{\left({}^{\omega}/_{\omega_0}\right)^{5}}$$

Bhanot, Peskin: Nucl. Phys. B 156 (1979) 391

Processes



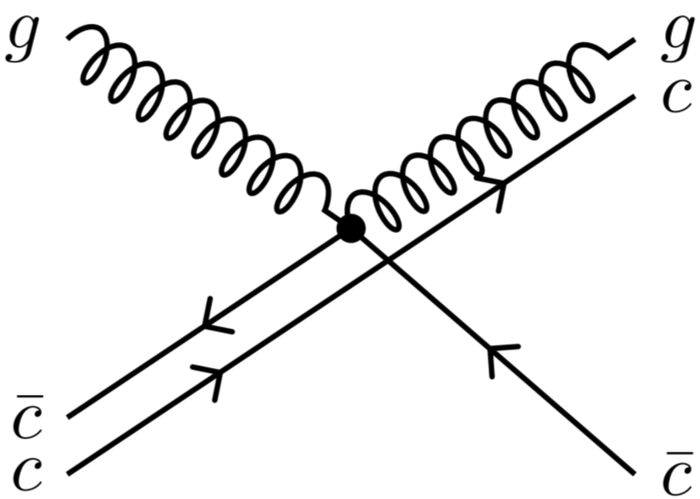


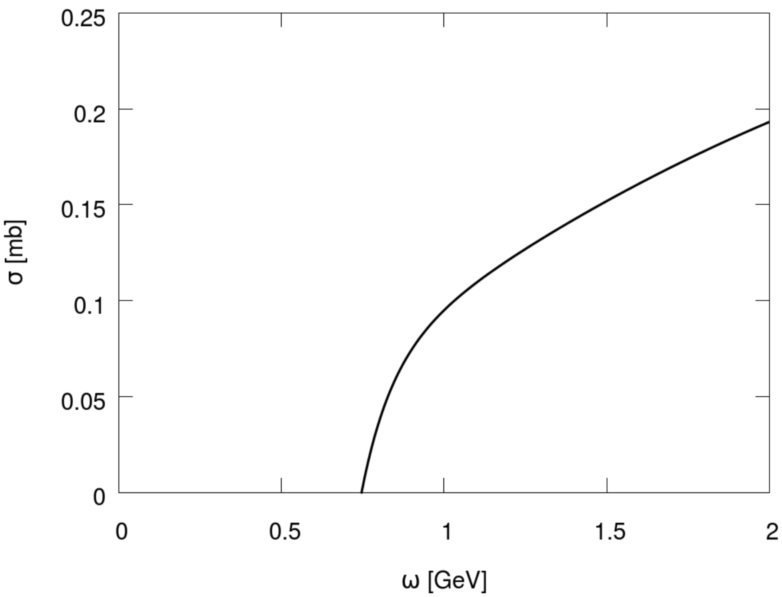
Quasi-free quark dissociation

$$\frac{4\pi\alpha^2}{9(2m_c\omega)^2}\left[\left(1+\frac{2(2m_c\omega+m_c^2)}{Q_0^2}\right)\left(\frac{(2m_c\omega)^2}{2m_c\omega+m_c^2}-Q_0^2\right) -2(2m_c\omega+m_c^2)\log\frac{(2m_c\omega)^2}{(2m_c\omega+m_c^2)Q_0^2}\right]$$

Combridge: Nucl. Phys. B 151 (1979) 429

Processes





Quasi-free gluon dissociation

$$\frac{2\pi\alpha^2}{(2m_c\omega)^2}\left[\left(1+\frac{4}{9}\left(\frac{m_c+\omega}{\omega}\right)^2\right)(L-Q_0^2)+\frac{Q_0^4-L^2}{9m_c\omega}+4m_c(m_c+\omega)\log\frac{Q_0^2}{L}\right.$$
$$\left.+\frac{2}{9}\frac{m_c^3-5m_c^2\omega}{\omega}\log\frac{2m_c\omega-Q_0^2}{2m_c\omega-L}+8m_c^2\omega^2\left(\frac{1}{Q_0^2}-\frac{1}{L}\right)+\frac{16m_c^4}{9}\left(\frac{1}{2m_c\omega-L}-\frac{1}{2m_c\omega-Q_0^2}\right)\right]$$

Combridge: Nucl. Phys. B 151 (1979) 429

Potential model

Binding radius from screened potential:

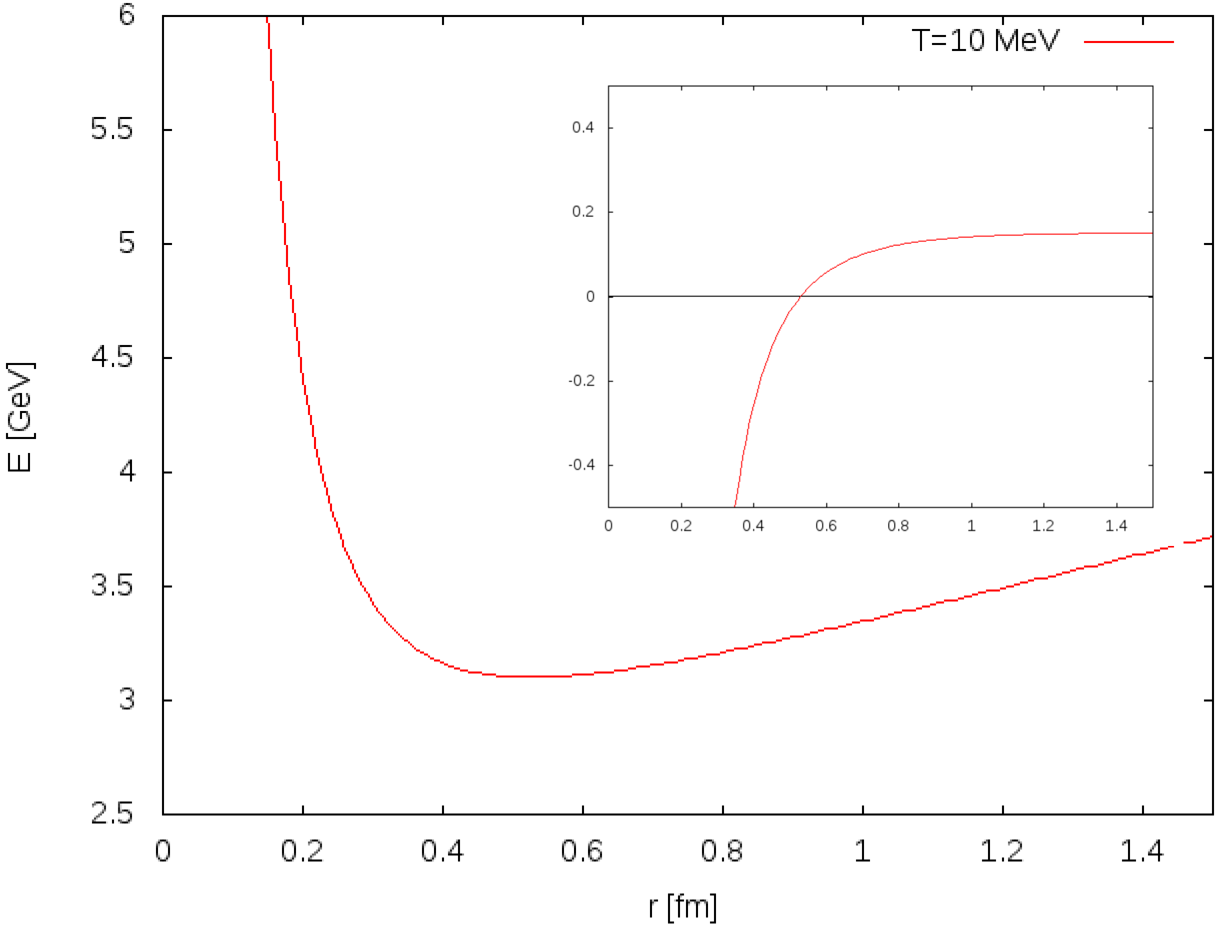
$$V = -\frac{4}{3}\frac{\alpha}{r}e^{-m_D r} + \frac{\sigma}{m_D}\left(1 - e^{-m_D r}\right)$$

$$E = 2m_c + \frac{b}{m_c r^2} - \frac{4}{3}\frac{\alpha}{r}e^{-m_D r} + \frac{\sigma}{m_D}\left(1 - e^{-m_D r}\right)$$

$$-\frac{2b}{m_c r^3} + \left(\sigma + \frac{4}{3}\frac{\alpha}{r}\left(\frac{1}{r} + m_D\right)\right)e^{-m_D r} = 0$$

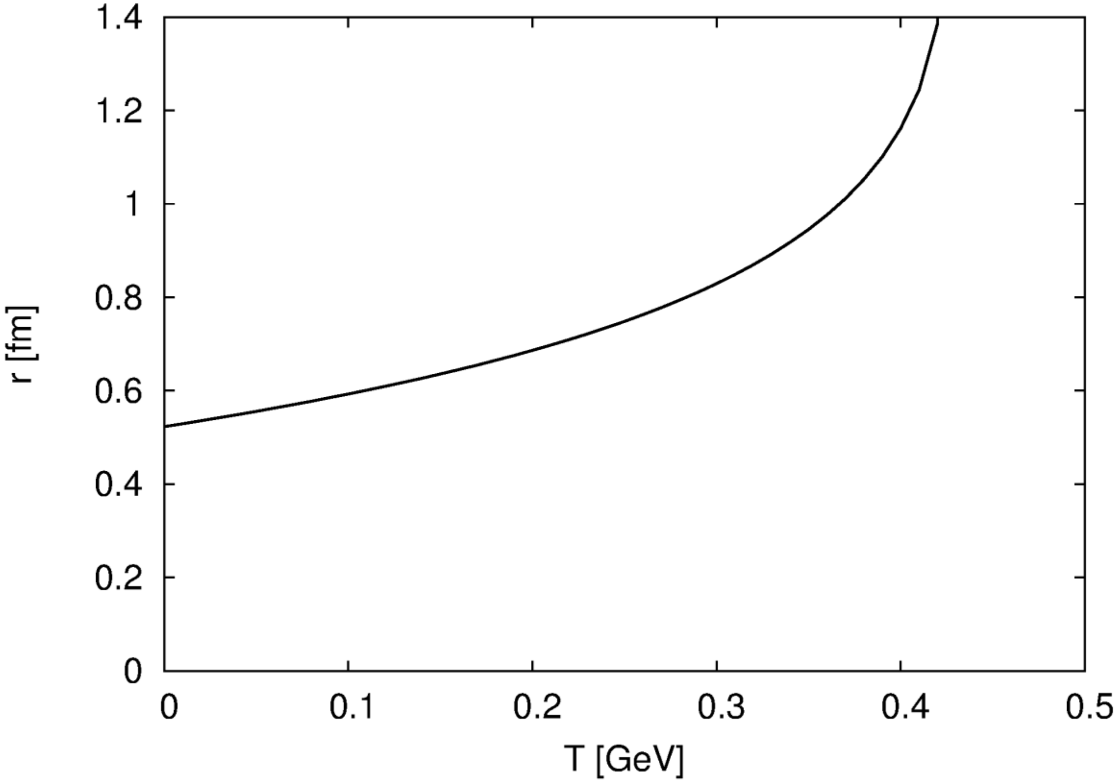
Karsch, Mehr, Satz: Z. Phys. C 37, 617 (1988)

Melting



Modifications

Cross sections increase with radius



$$\sigma(T) = \sigma(0)\,\frac{\langle r^2\rangle(T)}{\langle r^2\rangle(0)}$$

Dissociation rate

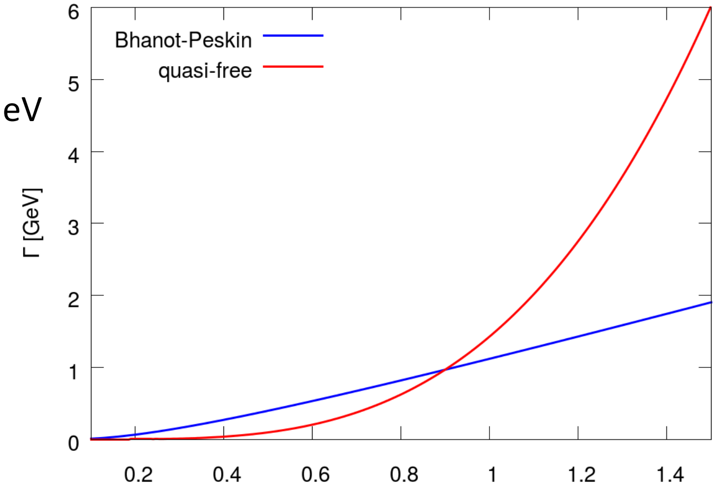
$$\Gamma = \int \frac{\mathrm{d}^3\boldsymbol{p}}{(2\pi)^3} d_g f_g \sigma_{gJ/\psi}\, v_{rel}$$

$$\Gamma(u_r, T) = \frac{d_g T}{(2\pi)^2 |\boldsymbol{u_r}|} \int_{\omega_0}^{\infty} \mathrm{d}\omega\, \omega_{gJ/\psi} \log \frac{1 - e^{-\left(\sqrt{|\boldsymbol{u}_r|^2+1}+|\boldsymbol{u}_r|\right)\omega/T}}{1 - e^{-\left(\sqrt{|\boldsymbol{u}_r|^2+1}-|\boldsymbol{u}_r|\right)\omega/T}}$$

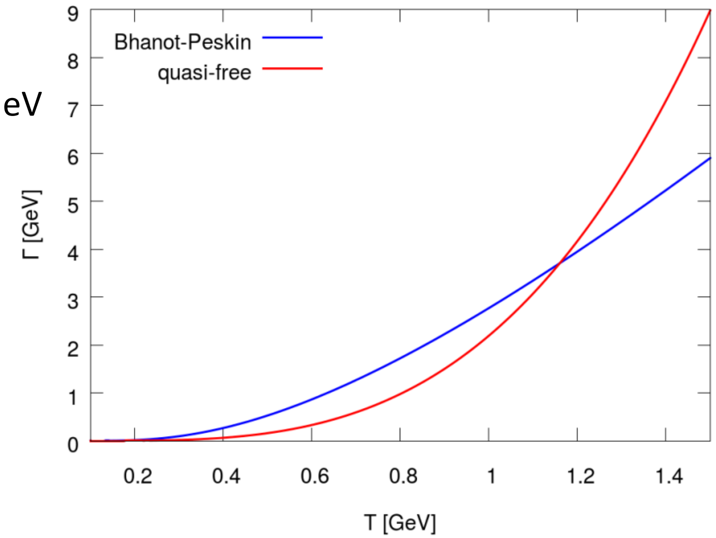
$$\Gamma(\mathrm{T}) = \frac{d_g}{2\pi^2} \int_{\omega_0}^{\infty} \mathrm{d}\omega\, \frac{\omega^2 \sigma_{gJ/\psi}}{e^{\omega/T} - 1} \text{ for } |\boldsymbol{u_r}| = 0$$

Rates

$m_c = 1.65$ GeV



$m_c = 1.87$ GeV



Rates

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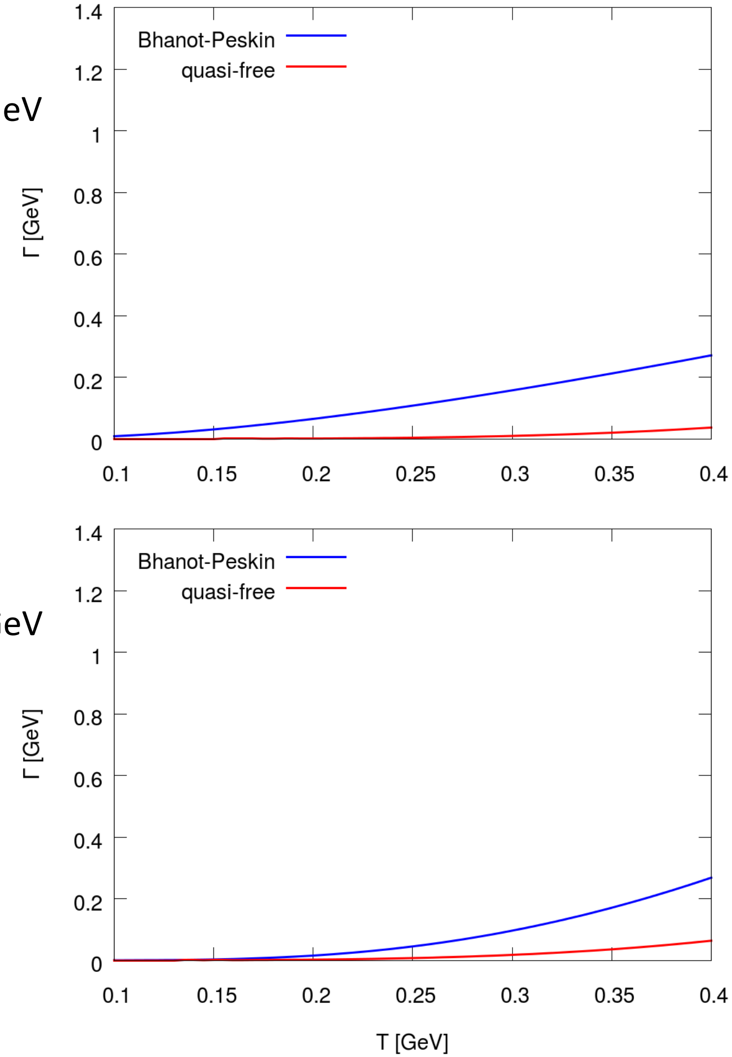
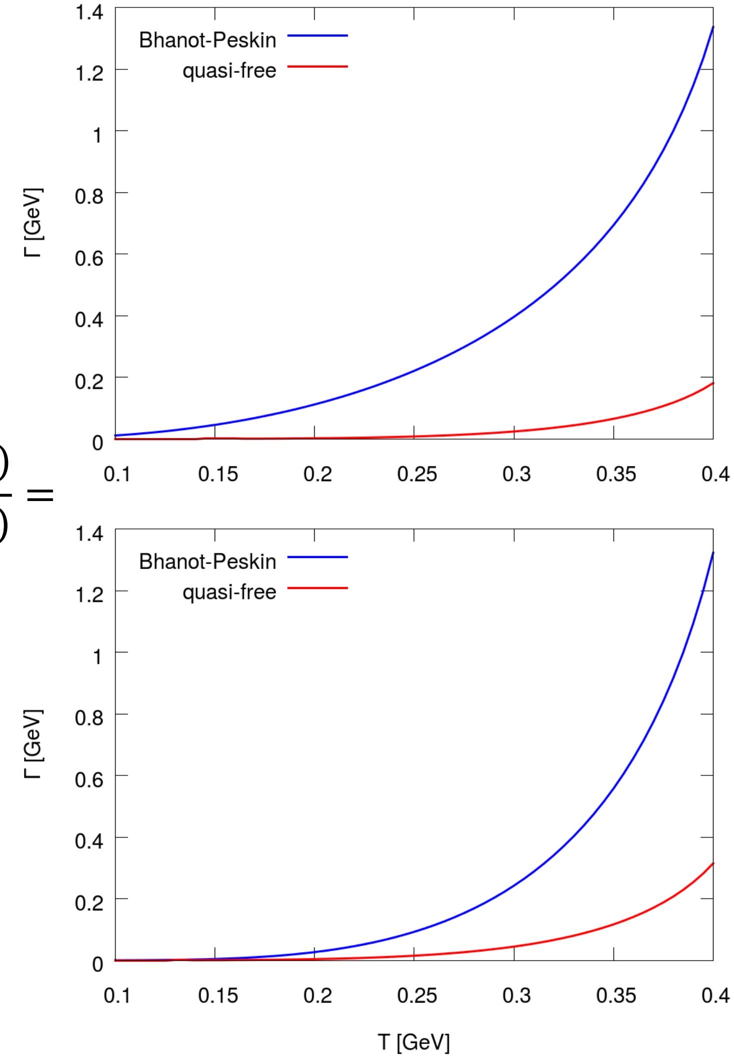


$$\times \frac{\langle r^2\rangle(T)}{\langle r^2\rangle(0)} =$$



Rate equation

$$\mathrm{d}N = \text{gain rate} - \text{loss rate}$$

$$\text{loss} \leftrightarrow \Gamma N(t)$$

$$N = N_{eq} \leftrightarrow dN = 0 \leftrightarrow \text{gain} = \Gamma N_{eq}$$

$$\frac{dN}{dt} = -\Gamma \left(N(t) - N_{eq}\right)$$

Explicit form

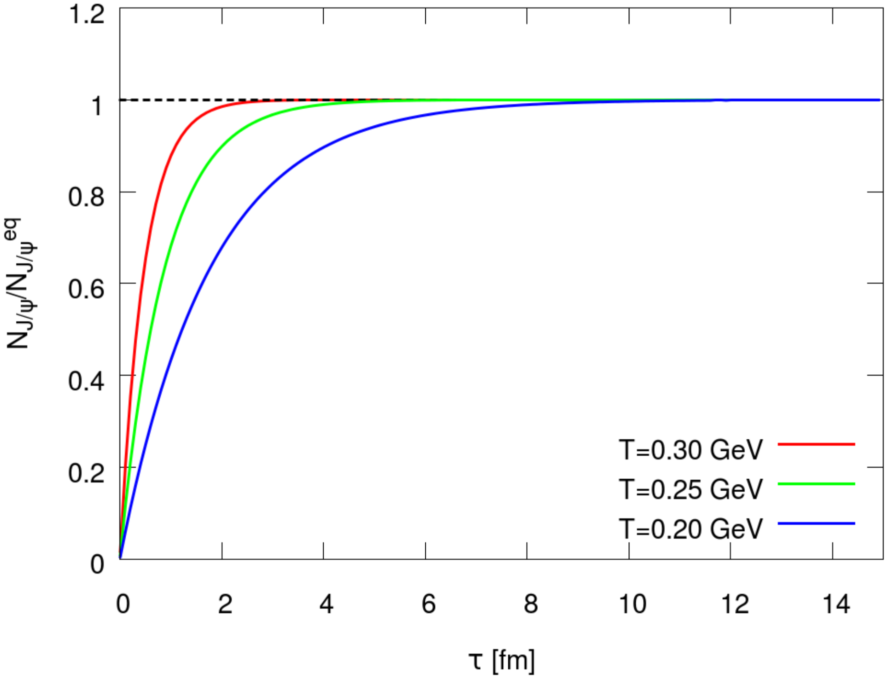
$$N_c = \lambda_{c\bar{c}}(T)\, V(T)\, n_c^{th}(T) = const.$$

$$N_{eq} = \lambda_{c\bar{c}}^2 N_{J/\psi}^{th} = \frac{1}{V n_c^2} N_c^2\, n_\psi^{th}$$

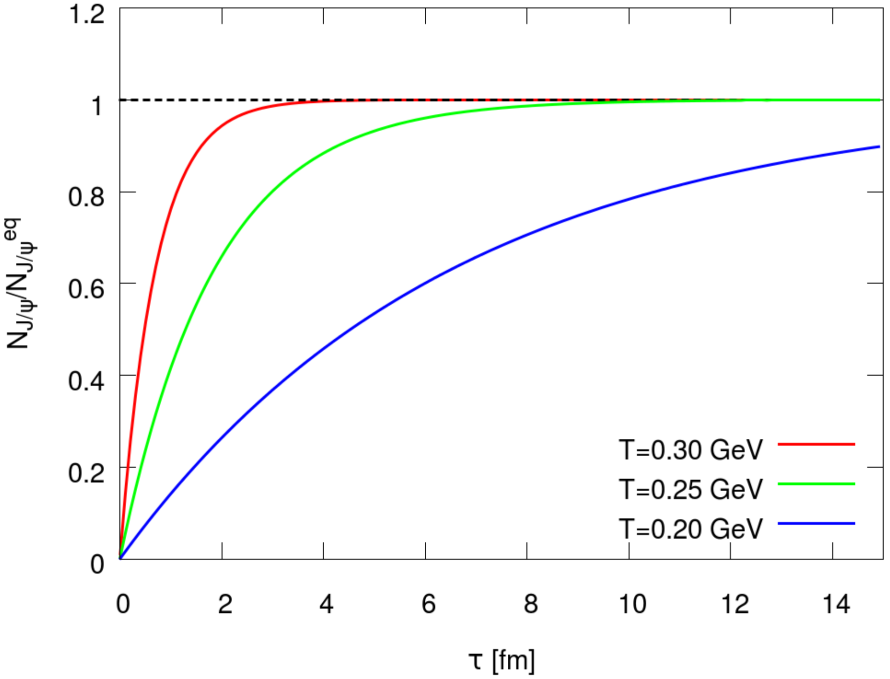
$$\frac{dN}{dt} = -\Gamma(T)\left(N - \frac{N_c^2}{V(T) n_c^2(T)} n_\psi^{th}(T)\right)$$

Static box

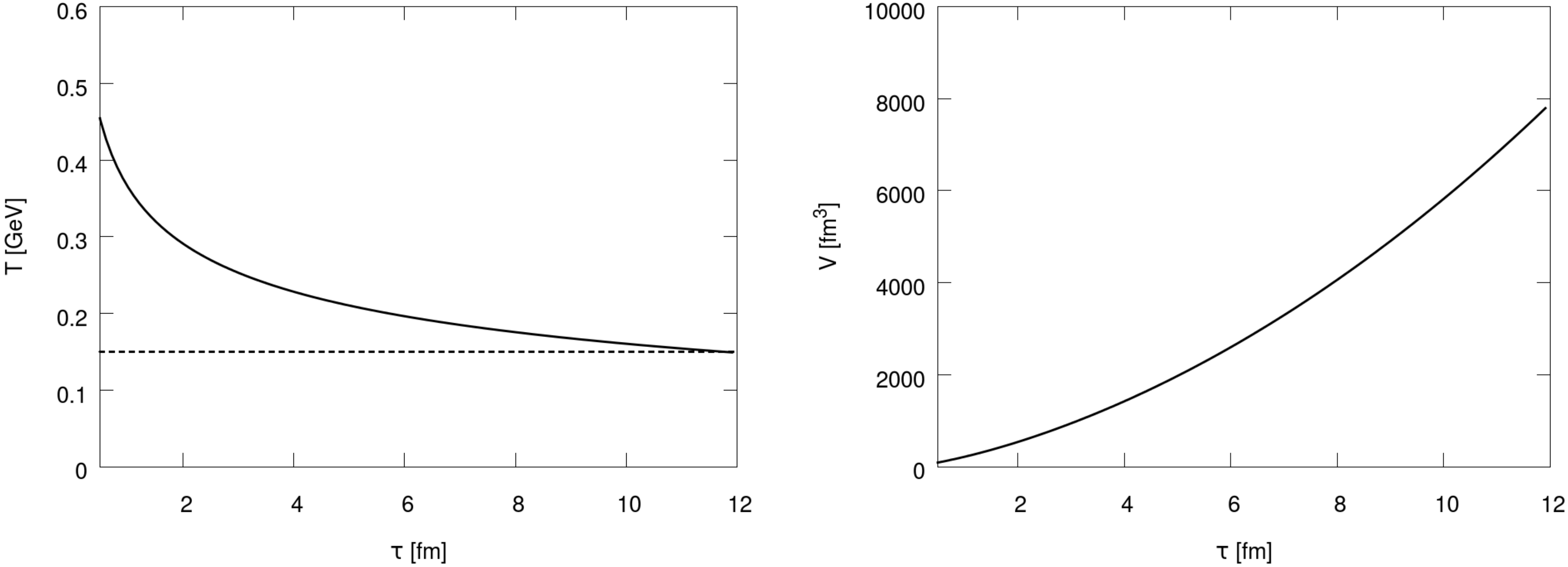
$m_c = 1.65$ GeV



$m_c = 1.87$ GeV



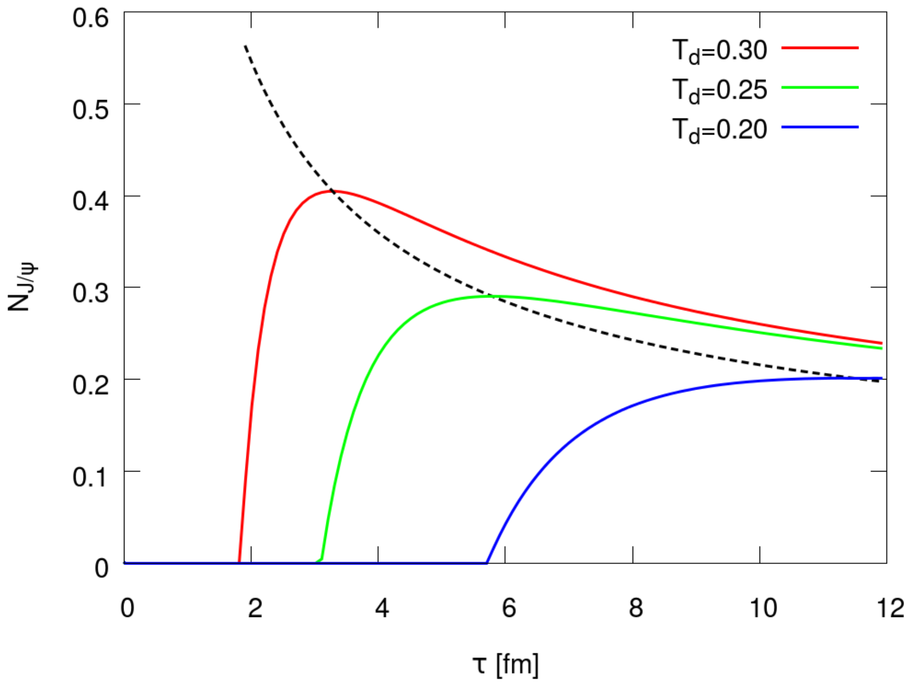
Cooling and expanding



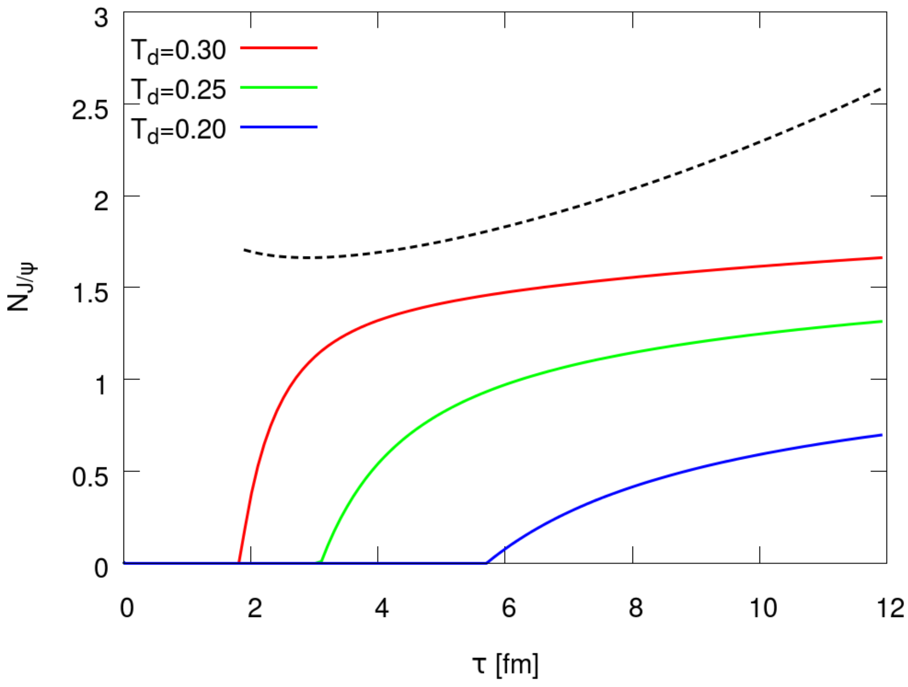
Schenke, Jeon, Gale: Phys. Lett. B 702 (2011) 59

Dynamic equilibration

$m_c = 1.65$ GeV



$m_c = 1.87$ GeV



Summary

- Systematic approach cross sections → equilibration times
- External temperature profiles
- Equilibration possible for $m_c = 1.65$ GeV
- To do: external flow profiles