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Charmonium production with Remler generalized coalescence model

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in collaboration with
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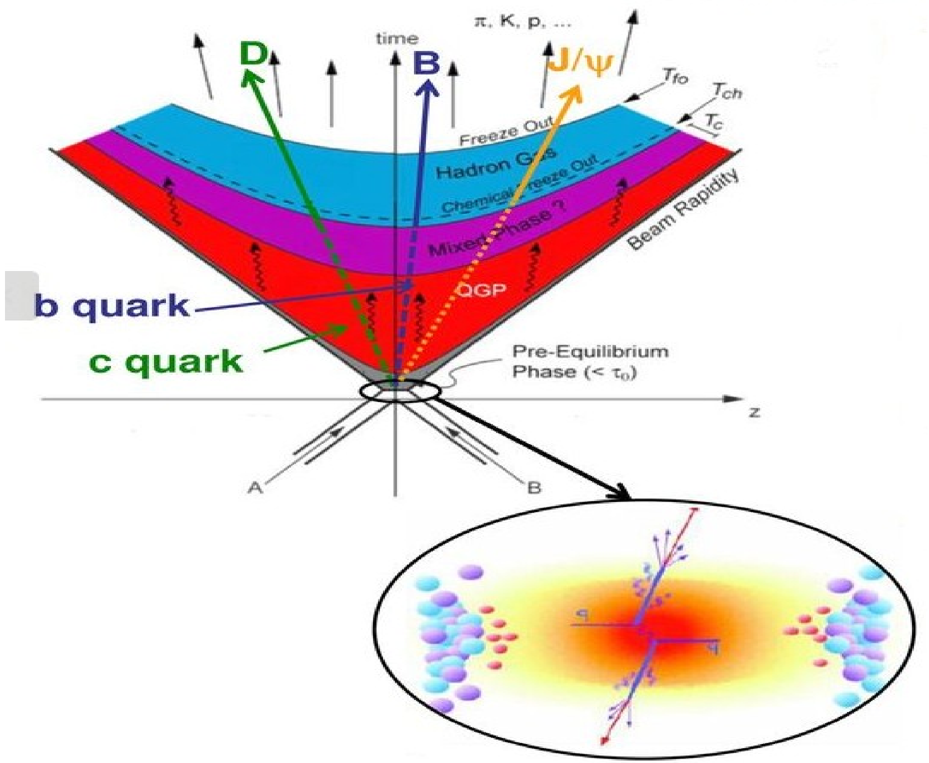
Background



For that the QGP is study by through different probes. Among the most promising probes are the heavy Quarkonium (bound state of a quark and its respective antimatter quark). Due to their heavy mass (m_c = 1.5 GeV and m_b=4.18 GeV) they are only created at early stage of QGP in hard processes and travels through the medium interacting and leave without reaching thermal equilibrium.

Need for theoretical and phenomenological models to understand the experimental data

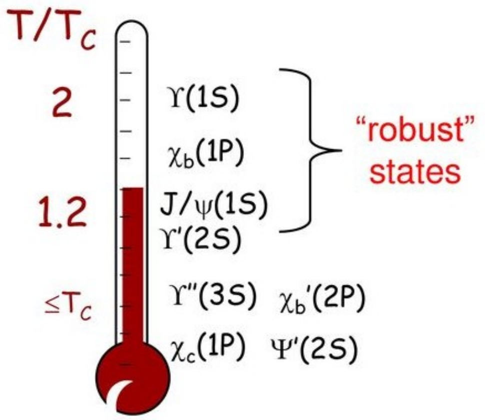
Background

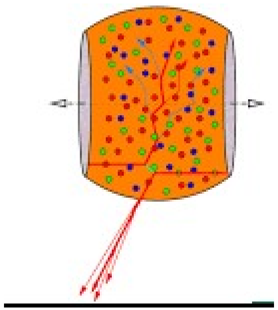
Quarkonium as Hard Probe

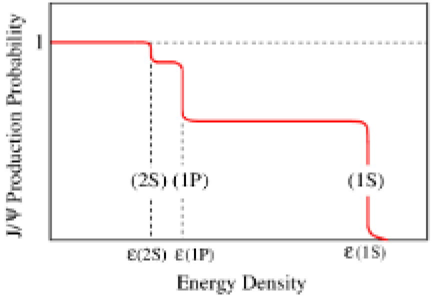
Thermometer

Transport properties

Medium density







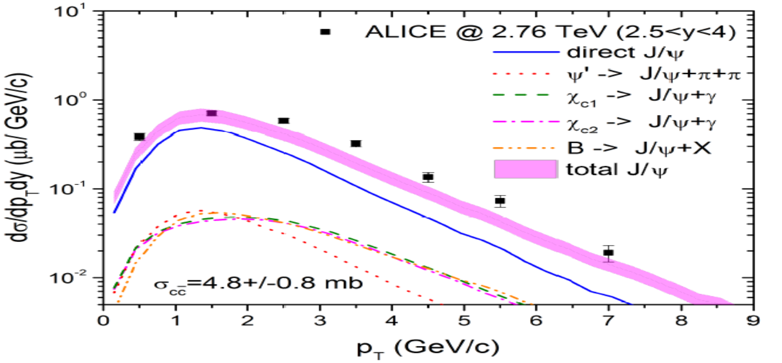
Model History

The idea of the formalism goes back to Remler's work in which a general formula connecting composite particle cross section with time-dependent density operators was presented. The formalism is able to deal with many particles (nucleons → deuterium)

E.A. Remler, ANNALS OF PHYSICS 136, 293-316 (1981)

Taesoo .S, J.Aichelin and E.Bratkovskaya , Physical Review C 96. 014907 (2017)

The model was also applied to Quarkonium production in pp and heavy ion collision(only primordial). And for the case of pp collision the model was able to reproduce the experimental data.



Motivation

However in the same contribution was pointed out that for heavy ion collision a considerable enhancement of primordial (in the initial state) J/Psi was found when QGP effects are ignored.

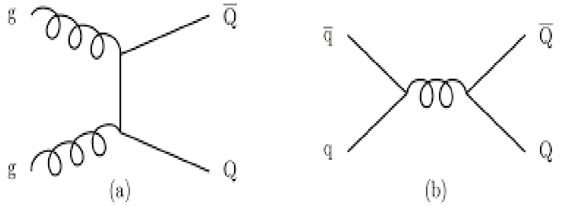
→

Apply the formalism to Quarkonium production in heavy ion collisions

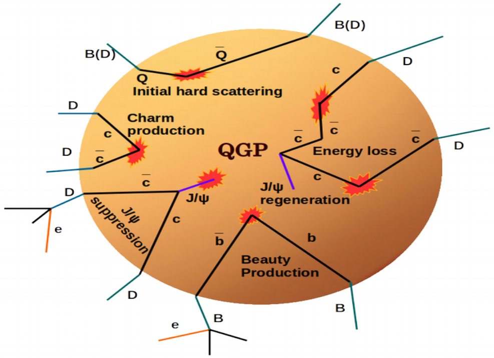
- Interaction of heavy quarks with the bulk particles
- Expansion of the medium
- Off-diagonal contributions

How does it work

HQ production



Quarkonium interaction with QGP



The probability of a Quarkonium state formation in the medium is given by

$$P^{\Psi}(t)=Tr[\rho^{\Psi}_{QQ}\rho_N(t)]$$

$$\rho^{\Psi}_{Q\bar{Q}}=\sum_i |\Psi^i_{Q\bar{Q}}\rangle\langle\Psi^i_{Q\bar{Q}}|$$

Two-body density matrix

$$\frac{\partial\rho_N(t)}{\partial t}=-i[H_N,\rho_N(t)]$$

N-body system density matrix

How does it work

The effective rate for Quarkonium state creation(dissociation) in the medium will be

$$\Gamma^{\Psi}(t)=\frac{\partial P^{\Psi}(t)}{\partial t}=Tr[\rho^{\Psi}_{Q\bar{Q}}\frac{\partial \rho_N(t)}{\partial t}]$$

Working in the phase space through Wigner function

$$W^{\Psi^i}=\int d^3y\, e^{ipy}\left\langle r-\frac{y}{2}\middle|\Psi^i\right\rangle\left\langle \Psi^i\middle|r+\frac{y}{2}\right\rangle$$

Semi-classical approach

$$W_N=\prod_i \hbar^3\delta(x_i-x_{i0}(t))\delta(p_i-p_{i0}(t))$$

Double Gaussian approximation (Harmonic oscillator)

$$W^{\Psi}_{Q\bar{Q}}(r_{rel},p_{rel})=C\,e^{-r^2_{rel}\sigma^2}e^{\frac{-p^2_{rel}}{\sigma^2}}$$

The Gaussian width σ

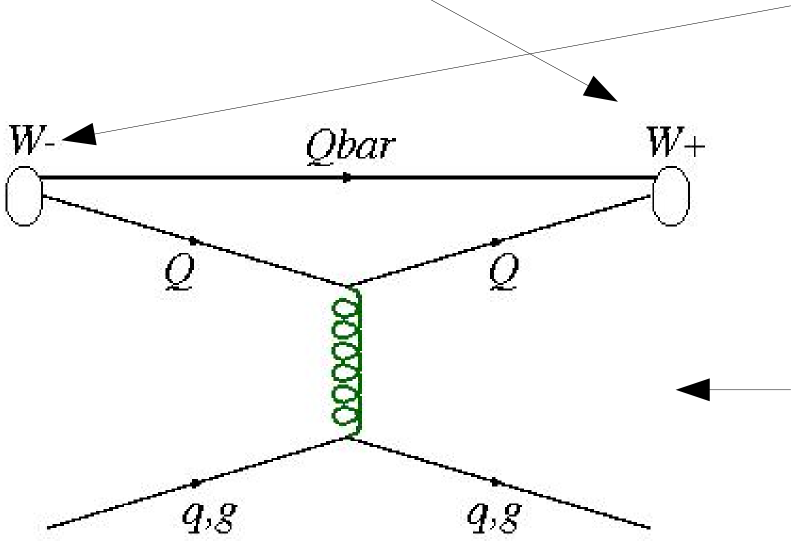
$$\begin{tikzcd}
\dfrac{\int e^{-\frac{r^2}{\sigma^2}}r^2d^3r}{\int e^{-\frac{r^2}{\sigma^2}}d^3r} & \langle r^2\rangle \arrow[l] & {[\frac{\hbar^2}{2\mu}\nabla^2+V(r)]\Psi_{Q\bar{Q}}(r)=E_{Q\bar{Q}}\Psi_{Q\bar{Q}}} \arrow[l]
\end{tikzcd}$$

How does it work

Substituting the expression for the Wigner functions associated to the density operator of Quarkonium state and the N-body system

$$\Gamma(t)=\sum_{i=1,2}\sum_{j\geq 3}\delta(t-t_{ij}(\epsilon))\int\frac{d^3p_i\,d^3x_i}{h^3}[W^{\Psi}_{Q\bar{Q}}(p_1,x_1;p_2,x_2)W_N(t+\epsilon)-W^{\Psi}_{Q\bar{Q}}(p_1,x_1;p_2,x_2)W_N(t-\epsilon)]$$

- The Quarkonium production in our model is a three body process, the HQ(anti-quark) interact only by collision !!
- Very good results for D (bound state of c-quark or anti-quark + light quarks) and B (b-quark or anti-quark + light quarks) mesons production



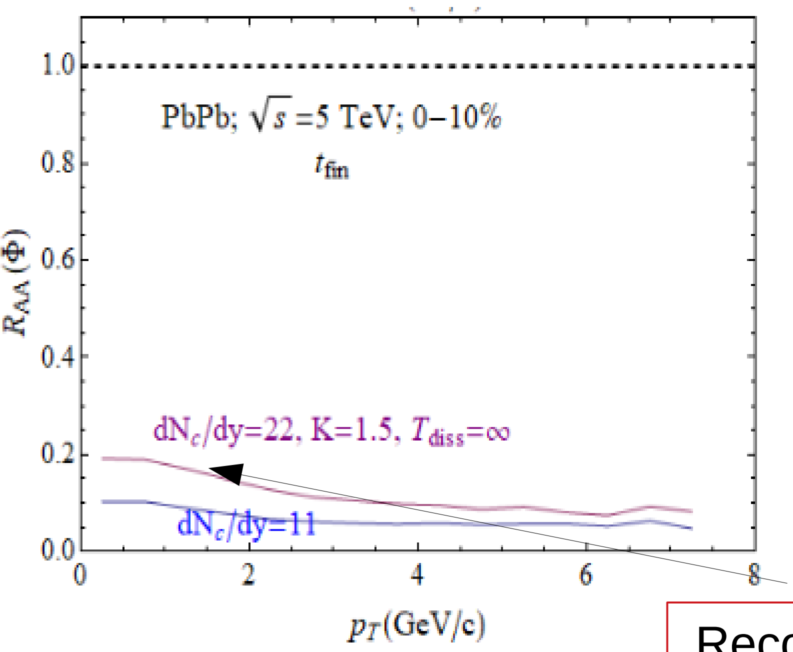
Interaction of HQ with the QGP were carried out by EPOSHQ

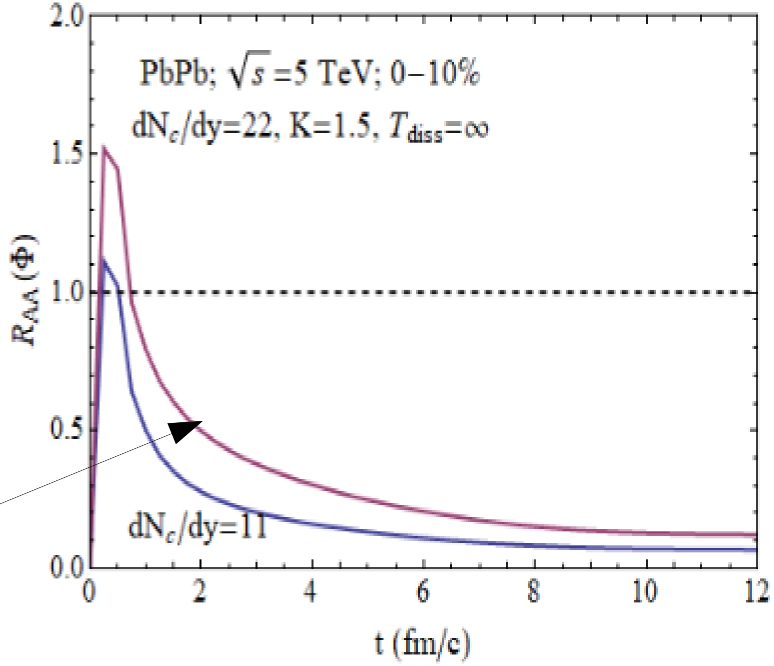
$$P^{\Psi}(t)=P^{\Psi}(t^{\Psi}_{init})+\int_{t^{\Psi}_{init}}^{t}\Gamma(t)\,dt$$

Preliminary Results J/Psi

Effect of primordial production (uncorrelated ccbar) $\frac{dN_c}{dy}$

$$R_{AA}(p_T,y)=\frac{\frac{dN^{AA}}{d^2p_T\,dy}}{\langle N_{coll}\rangle\frac{dN^{pp}}{d^2p_T\,dy}}$$

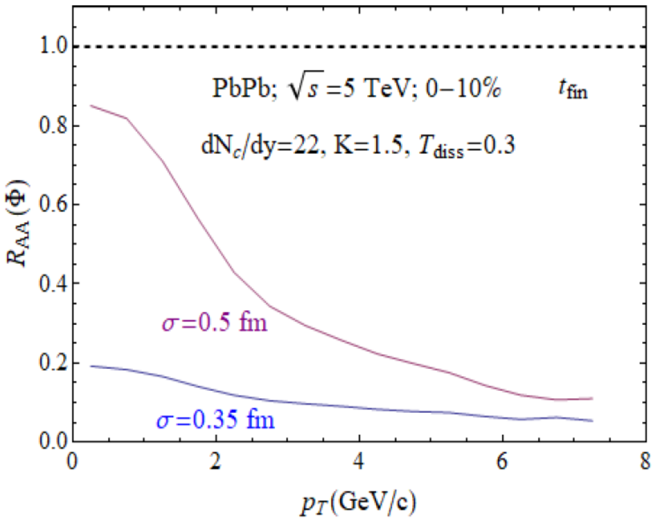




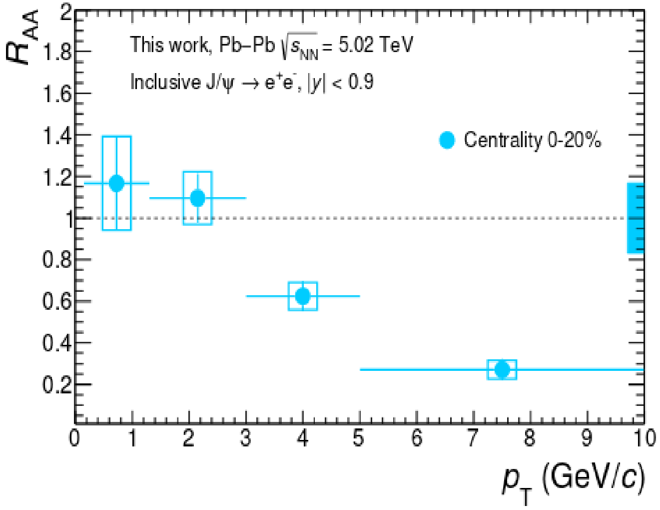
Recombination effects

Preliminary Results J/Psi

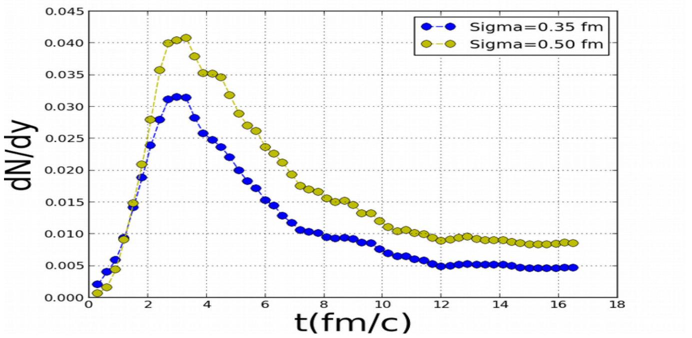
Temperature effects (uncorrelated c-cbar)



PhD Thesis : Raúl Tonaituh Jiménez
ALICE Collaboration

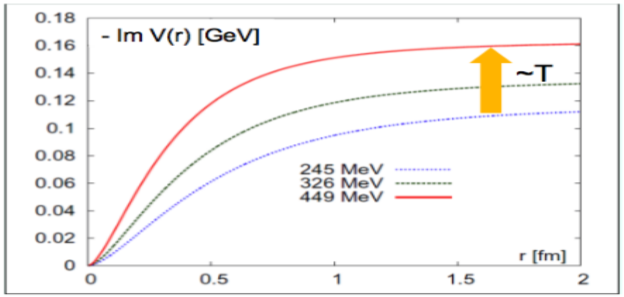


Mid-rapidity and $\sqrt{s}=2.76\,TeV$



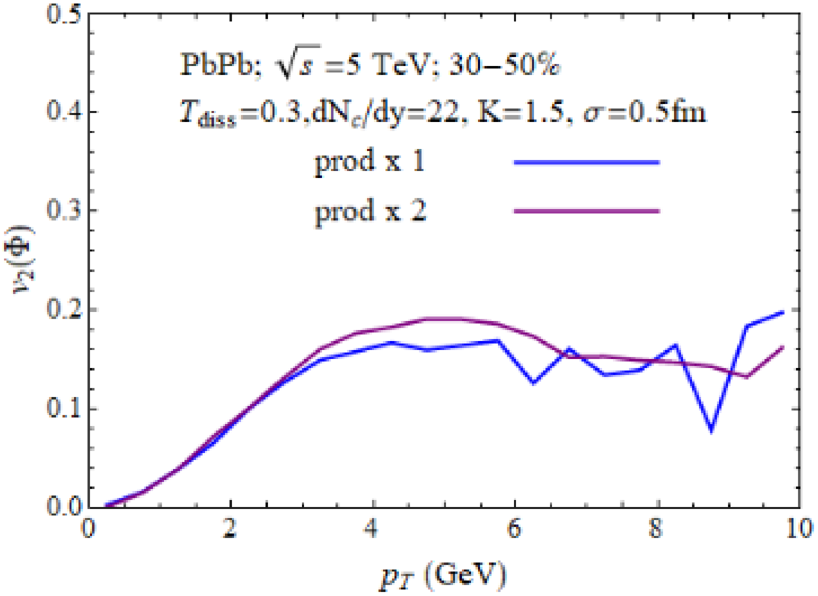
PhD Thesis : Nirupam Dutta

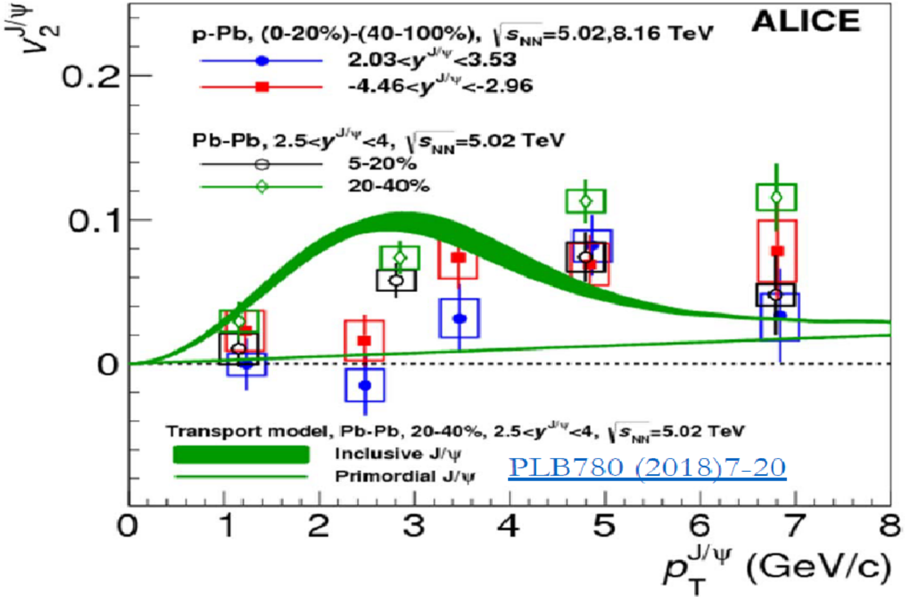
Need for temperature dependent Wigner function



Preliminary Results J/Psi

Elliptic flow (uncorrelated ccbar)



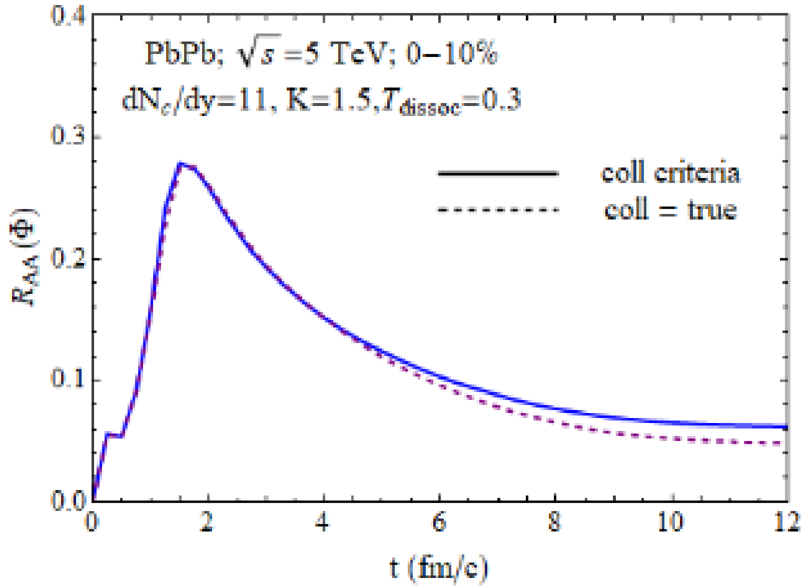


PLB780 (2018)7-20

v$_2$ that extend at rather large p$_T$

Preliminary Results J/Psi

Effects of collision criteria (uncorrelated ccbar)



- The effect of collision increase with time together with the thermalization degree
- As the fireball expand in time most of the collision leads to a dissociation process

$$J/\Psi + g \Leftrightarrow c + \bar{c} + X$$

Conclusions

We have presented a model based on the probability density operator that allows us to obtain the time evolution of the formation probability of Quarkonium through an effective rate in QGP.

According with the results, the temperature dependence of the Quarkonium radius needs to be taken into account via optical potential with a temperature dependence (currently on going)

While trying to go for higher p_T (higher energy Quarkonium formation) relativistic effects such retarded potential should also be implemented

Thanks!!!

Back up

The detail balance law

$$J/\Psi + g \Leftrightarrow c + \bar{c} + X$$

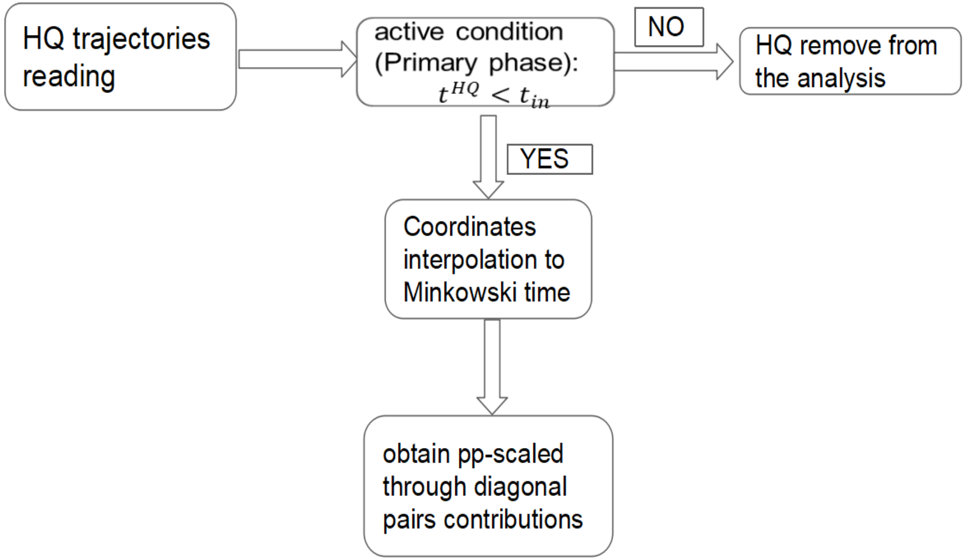
Rates Equation

$$\frac{dN_{\Psi}}{d\tau} = \Gamma_{recomb} N_c N_{\bar{c}} [V_{FB}(\tau)]^{-1} - \Gamma_{diss} N_{\Psi}$$

$$\frac{dN_{\Psi}}{d\tau} = -N_{\Psi} L \tau + G(\Psi) = \frac{-1}{\tau_{\Psi}} [N_{\Psi}(\tau) - N_{\Psi}^{eq}(\tau)]$$

Analysis implementation

Primary or static phase



HQ trajectories reading

active condition (Primary phase): $t^{HQ} < t_{in}$

NO

HQ remove from the analysis

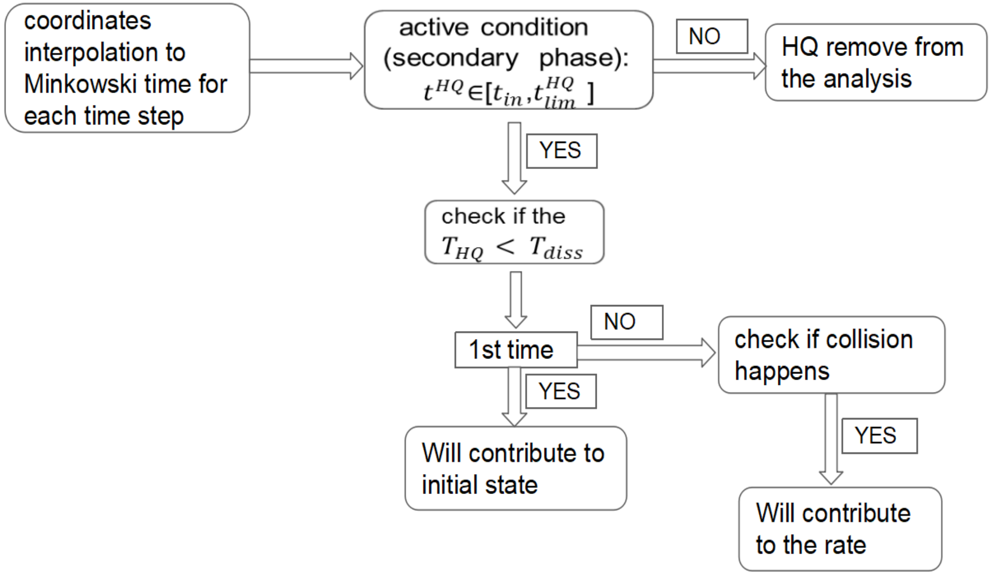
YES

Coordinates interpolation to Minkowski time

obtain pp-scaled through diagonal pairs contributions

Analysis implementation

Secondary or dynamical phase



coordinates interpolation to Minkowski time for each time step

active condition (secondary phase): $t^{HQ} \in [t_{in}, t_{lim}^{HQ}]$

NO

HQ remove from the analysis

YES

check if the $T_{HQ} < T_{diss}$

1st time

NO

check if collision happens

YES

Will contribute to initial state

YES

Will contribute to the rate