Quarkonium physics in nuclear collisions @ LHC

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Outline

I. Introduction

II. Melting model and kinetic model

III. Statistical Hadronization Model

IV. RHIC data and predictions for LHC

V. Experiments @ LHC
Introduction

• Formation of QGP at nucleon-nucleon collisions
• “Fingerprint” for QGP $J/\Psi$ suppression / enhancement
• Different Models describing $J/\Psi$ production
• Satz – Matsui approach, Statistical Hadronization model, kinetic model …
Review

- Quarkonia = bound state of quark antiquark pair of heavy quarks e.g. J/Ψ

- No strong decay if mass of Quarkonia is less than combination of open charm mesons
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Review Melting Model

- Time Scales for QGP Formation and J/Ψ formation of same order
- Debye screening of color charge $\rightarrow$ deconfinement
- Deconfining radius smaller than hadron radius $\rightarrow$ diffusion during lifetime of QGP
- Melting before $T < T_D$ with $T_D > 1.15 T_C$
- Resent studies indicate $T_D = 2 T_C$
Widths of Charmonia in QGP

- Estimated from mean free path length in QGP $\lambda = 1 / n_p \sigma$
- Parton density $n_p = 4.25 \ T^3$
- $J/\Psi$ Parton cross section $\sigma = 2\text{mb}$
- $v_{rel}$ of $J/\Psi$ vs. Partons
  \[ \rightarrow \text{in medium width} \Gamma = \frac{v_{rel}}{\lambda} \]
- with numerical values:
  \[ \Gamma(T=300 \text{ MeV}) = 320 \text{ MeV} \]
  \[ \Gamma(T=400 \text{ MeV}) = 760 \text{ MeV} \]
Kinetic Model – Basic ideas

• Production of $J / \Psi$ in the QGP through binding of independent quark antiquark pairs
• Centrality dependence due to impact parameter $b$
• Enhancement in $J / \Psi$ production for central collisions at RHIC energies
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Statistical Hadronization Model

• All Charm quarks produced in initial hard collisions
• Early produced Charmonia destroyed in QGP
• Number of charm quarks = const.
• Input parameters
  i. Charm production cross section
  ii. Temperature $T$, Baryochemical Potential $\mu_B$, and Volume $V_{\Delta y=1}$
Input Parameters

- Up to $\sqrt{s} = 200$ GeV $T \sim 160$ MeV
- $\mu_B$ decreases from 434 to 22 MeV
- Volume at midrapidity rises continuously
- For LHC:
  
  $T = 161 \pm 4$ MeV
  
  $\mu_b = 0.8^{+1.2}_{-0.6}$ MeV
  
  $V = 6200 \text{ fm}^3$


### Input parameters

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$$
\mu_B = \frac{1270 \text{ [MeV]}}{1 + \frac{\sqrt{s_{NN}} \text{ [GeV]}}{4.3}}
$$
Charm production cross section

- $\sigma_{c\bar{c}}$ depends on $m_c \approx 1.3$ GeV
- Depends on rapidity as well
- extrapolated to small energies

$\sigma_{c\bar{c}}^{pp} / y = 0.64^{+0.64}_{-0.32}$ mb.


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Charm Production Cross Section

• Calculation for extrapolation

\[ \sigma_{c\bar{c}} = k \left( 1 - \frac{\sqrt{S_{thr}}}{\sqrt{S}} \right)^a \left( \frac{\sqrt{S_{thr}}}{\sqrt{S}} \right)^b \]

with \( k = 1.85 \mu b \), \( \sqrt{S_{thr}} = 4.5 GeV \)

\( a = 4.3 \) and \( b = -1.44 \)
Charm Balance Equation

- Balance equation

\[
N_{cc}^{dir} = \frac{1}{2} g_c N_{oc}^{th} \frac{I_1(g_c N_{oc}^{th})}{I_0(g_c N_{oc}^{th})} + g_c^2 N_{cc}^{th}
\]

with \( N_{oc}^{th} = n_{oc}^{th} V \) and \( N_{cc}^{th} = n_{cc}^{th} V \)

from grand-canonical densities
Canonical Suppression

- Energy dependent
- $I_1/I_0 > 0.9$ for LHC Energies
- Dependent on centrality class


Source: A. Andronic et al. nucl-th/0611023v2
Initially produced charm quark pairs

- Strong rise with rising Energy

- For RHIC Energy \(\sim 1.6 - 1.7\)

- Extrapolation for LHC \(\rightarrow\) 1 order of magnitude

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Nuclear Modification Factor

- Ratio relating yield in nucleus-nucleus collisions to yield of $N$ independent nucleon-nucleon collisions

$$R_{AA}^{J/\Psi} = \frac{dN_{J/\Psi}^{AA} / dy}{N_{Coll} \cdot dN_{J/\Psi}^{pp} / dy}$$

with rapidity density $dN_{J/\Psi}/dy$ integrated over transverse momentum $p_t$
Rapidity dependence of $R$

Source: P. Braun-Munzinger, nucl-th/0701093v1

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Centrality dependence of $R$

- Reversed trends for RHIC data and LHC predictions

Source: P. Braun-Munzinger, nucl-th/0701093v1
Different Production cross sections

- If observed in Experiment; striking fingerprint for deconfined quarks in QGP

Source: P. Braun-Munzinger, nucl-th/0701093v1
Charmed Hadron Production

- Open charm production in Mesons and Baryons
- Yield normalized to yield of initial charm anticharm
- Increase in $J/\Psi$ yield
- For LHC ~ 1%

Mass dependence

- Two models for mass change
- Open charm vary linearly with $g_C$
- Charmonia vary quadratic with $g_C$

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ALICE @ LHC

- A large ion collider experiment
- \( \frac{dN}{dy} = 8000 \)
- Only heavy ion experiment at LHC
ALICE @ LHC

- Decay of Charmonia in hadrons, dimuons, di-electrons …
- Many particles to be detected
- Sub-detectors TPC, TRD, ITS, etc.
- Charged particle tracks
• P. Braun-Munzinger, nucl-th/0701093v1
• A. Andronic, P. Braun-Munzinger, K. Redlich, J. Stachel, nucl-th/0701079v2
• A. Andronic, P. Braun-Munzinger, K. Redlich, J. Stachel, nucl-th/0209035v2
• A. Andronic, P. Braun-Munzinger, K. Redlich, J. Stachel, nucl-th/0303036v2
• A. Andronic, P. Braun-Munzinger, K. Redlich, J. Stachel, nucl-th/0611023v2
Thank you for your attention