Charmonium dynamics in the UrQMD transport model

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June 28th, 2012

TURIC 2012

Thanks to Marcus Bleicher, Elena Bratkovskaya, Olena Linnyk, Hendrik van Hees, Jan Steinheimer

Outline

Outline

Charmonium suppression

- Normal suppression
  - dissociation by nucleons
  - can explain suppression except for central collisions
- Comover sceanrio
  - dissociation by comoving mesons
  - can explain charmonium R_{AA} at SPS energies
- Recombination
  - principle of detailed balance requires recombination
  - formation rate proportional to the square of the number of unbound charm quarks
- Charmonium melting
  - spectral function of charmonia broadens in QGP
  - dissociation gets more likely
  - complete breakup only at very high temperatures

Implementation to UrQMD

- implementation of J/Ψ, χ_c, Ψ' and D-Mesons
- momenta fitted to experimental data
- charm production points determined using Glauber model
  $\Rightarrow$ UrQMD prerun to write down nucleon collision points
- we use a hadronic and a prehadronic phase

Hadronic phase

- elastic cross sections from effective Lagrangian calculations

  Ziwei Lin, C M Ko, J.Phys. G:Nucl.Part.Phys. 27 (2001) 617-623
- inelastic meson cross sections from two-body transition model fitted to data from Pb+Pb at SPS

  E. L. Bratkovskaya, W. Cassing, and H. Stoecker, Phys. Rev. C67, 054905 (2003)
- constant cross sections with baryons

  E. L. Bratkovskaya, W. Cassing, and H. Stoecker, Phys. Rev. C67, 054905 (2003)

Assumptions for a prehadronic phase

- implementation of a prehadronic phase to UrQMD to mime QGP ($\varepsilon > 0,6\,\mathrm{GeV}/\mathrm{fm}^3$)

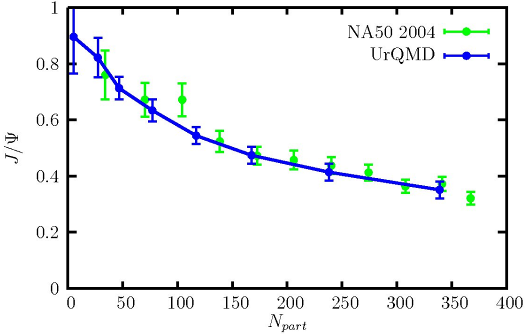
  S. Borsanyi *et al.*, JHEP **1009** (2010) 073

- no formation times $\Rightarrow$ prehadronic cross sections
- no recombination of D-Mesons above phase transition temperature
- at very high densities breakup of charmonium particles

  C.Miao, A.Mocsy, P.Petreczky, arXiv:1012.4433

  - breakup temperature 12 Gev for J/Ψ and 5 GeV for χ_c and Ψ'
  - charmonia have to stay in this hot medium for a proper time of $1\,\mathrm{fm}/c$

SPS



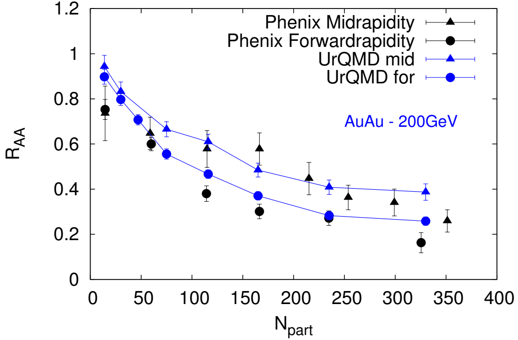
$Pb - Pb, p_{lab} = 158\ GeV$

B.Alessandro et al. (NA50 Collab.), Eur.Phys.J. C39 (2005) 335-345

- prehadronic cross sections are fitted to SPS data
- R_{AA} has not been measured at SPS $\Rightarrow$relative J/Ψ-yield
- shape fits well

RHIC

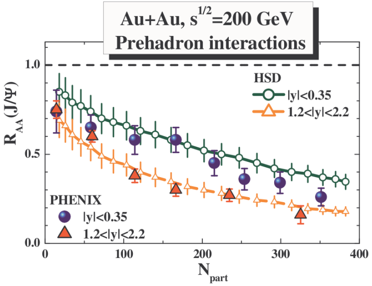
Our model can reproduce rapidity dependence at RHIC



$Au - Au, s^{1/2} = 200\ GeV$

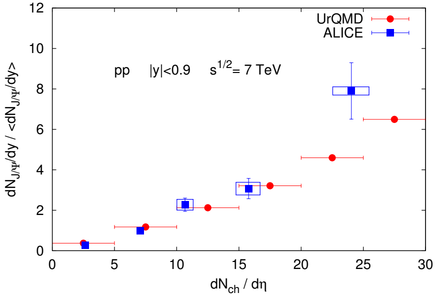
PHENIX, A. Adare et al., Phys. Rev. Lett. 98, 232301 (2007)

- same cross sections used as at SPS energies



E.Bratkovskaya et al., Int.J.Mod.Phys. E17 (2008) 1367-1439

Possible J/Ψ suppression in pp at LHC



- initial $dN_{ch}/d\eta$ taken from E. G. Ferreiro and C. Pajares, arXiv:1203.5936.

- J/Ψ yield in pp used as reference value for heavy ion collisions
- high energy density $\rightarrow$ comparable to energy densities in heavy ion collisions at SPS and RHIC energies
- possible suppression can be tested using different multiplicity bins

Similar study of medium modification of charm quarks in pp done by S.Vogel et al. (Phys.Rev.Lett 107 (2011) 032302)

Outline

1. Charmonium in UrQMD
2. Quark propagation in hydrodynamics
3. Summary and Outlook

Heavy quarks in UrQMD

- we want to improve the prehadronic phase, i.e. propagate quarks instead of mesons in the QGP
- have a look at quark propagation in UrQMD hydro (Phys. Rev. C 78 (2008) 044901)
- use of a Langevin model ⇒ i.e. propagating heavy quarks in a light quark medium

  R. Rapp, H. van Hees, Mar 2009, arXiv:0903.1096
- test of different drag and diffusion coefficients for heavy quark propagation (Resonance model and T-Matrix approach)

  R. Rapp, H. van Hees, Mar 2009, arXiv:0903.1096
- calculation for different decoupling temperatures in case of the Resonance model
- have a look at the influence of a k-factor on the results

Comparing our calculation to data

Two kinds of hadronization

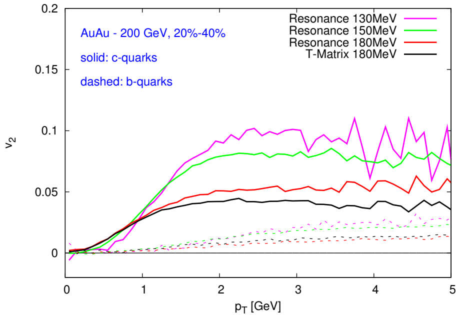
- using Peterson fragmentation

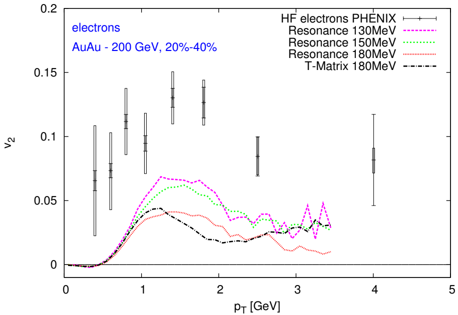
$$D_Q^H(z) = \frac{N}{z[1 - (1/z) - \epsilon_Q/(1-z)]^2}$$

- using a coalescence mechanism
  $\rightarrow$ adding momenta of heavy quarks and light quarks with the momentum of the surrounding medium

For the decay to electrons we use PYTHIA

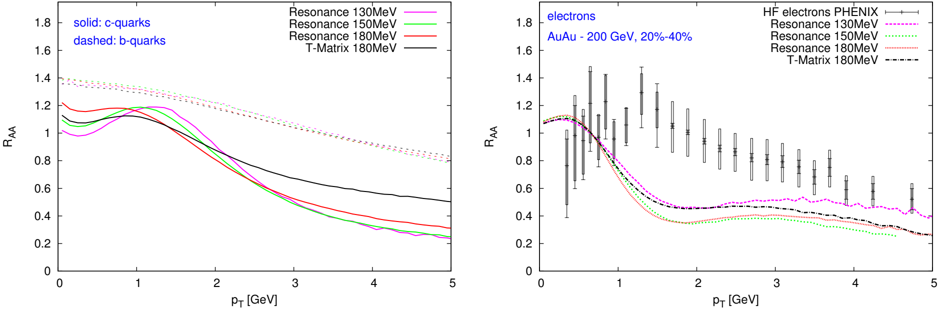
Elliptic flow in AuAu at RHIC energies





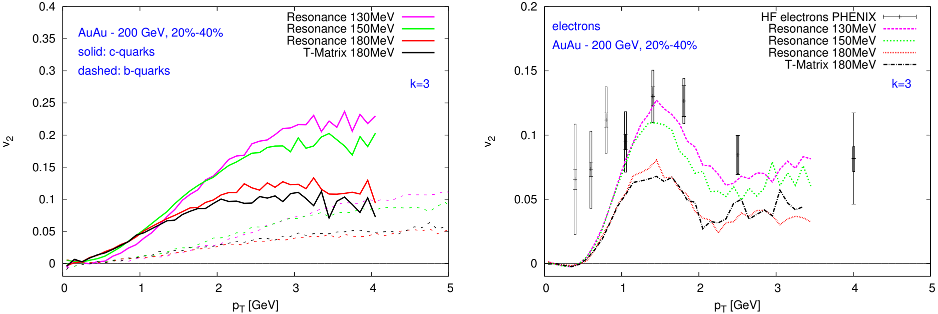
- medium modification of charm quarks much higher than for bottom quarks
- v_2 too small compared to data
- strong dependence of flow on decoupling temperature

Nuclear modification factor



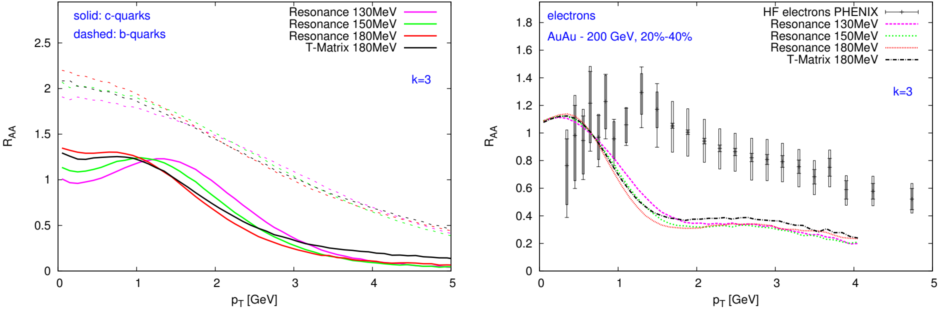
- for the T-Matrix approach we see a slightly smaller medium modification
- better results for small decoupling temperature

Elliptic flow using a k-factor of 3



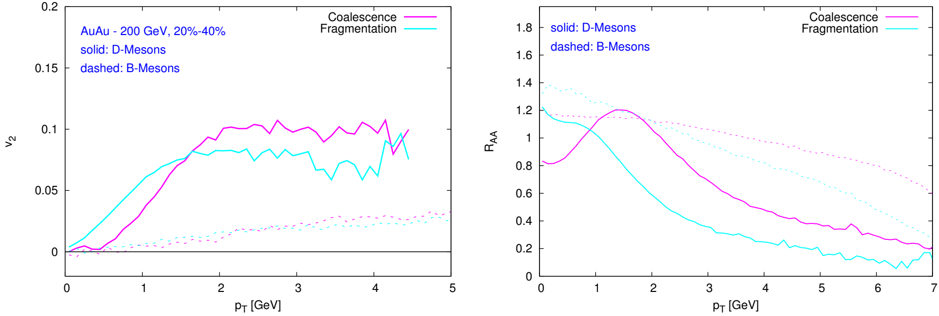
- a k-factor can correct our flow calculations so they fit to the experimental data

Nuclear modification factor using a k-factor of 3



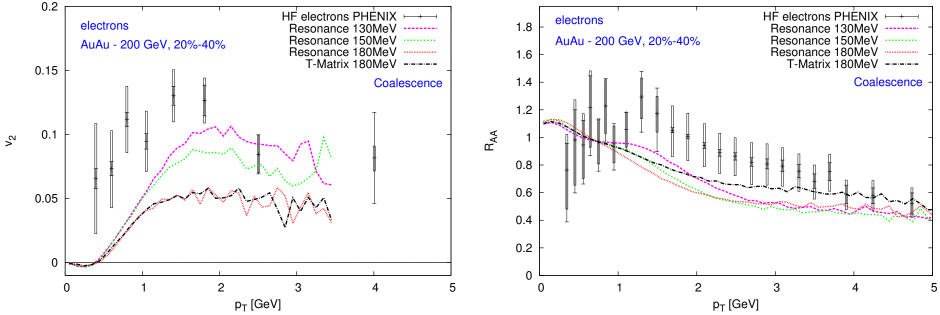
- using the k-factor suppresses the heavy quarks
- k-factor does not lead to a consistent description of v_2 and R_{AA} in our calculation

Coalescence versus fragmentation



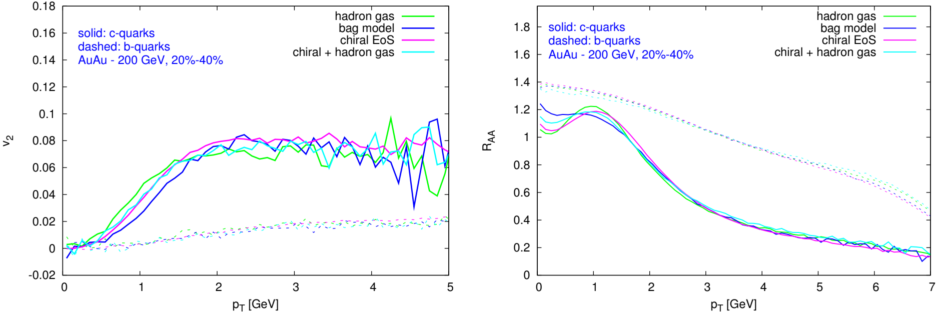
- the coalescence mechanism increases the input of the bulk medium on the heavy quarks

Results for the coalescence model



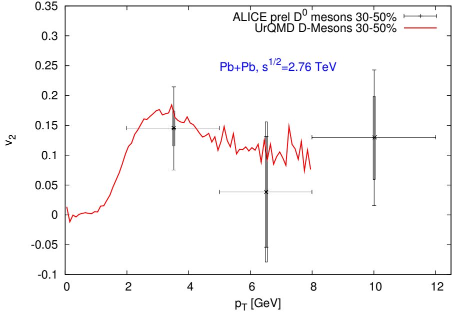
- the light quarks contribute a considerable fraction to the v_2 and R_{AA}
- rather nice agreement with data without using of a k-factor reached

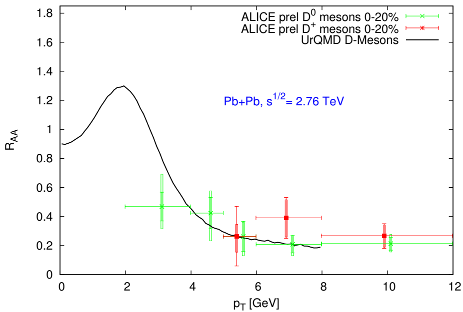
Different equations of state



- v_2 and R_{AA} barely depend on the EoS used

v_2 and R_{AA} at LHC





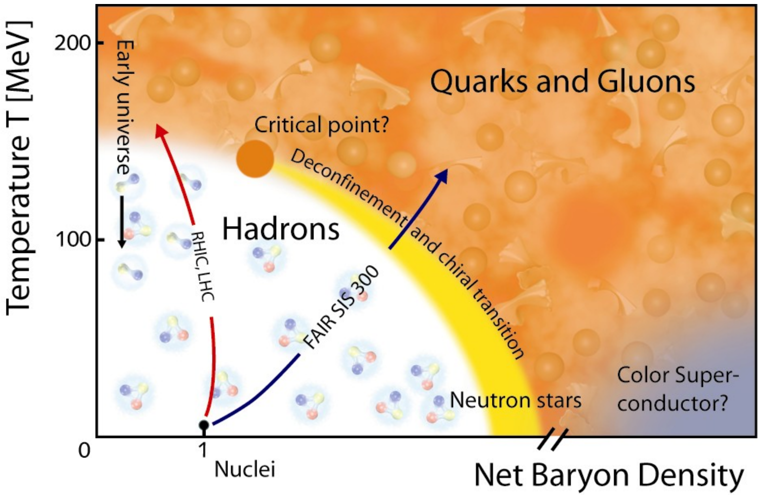
- for LHC energies we reach a nice agreement to measured date within the error bars

Outline

Summary and Outlook

- comparison of UrQMD approach to data for SPS and RHIC energies
- at RHIC we could reproduce the rapidity dependence of R_{AA}
- there might be a suppression in pp collisions at LHC also
- Langevin approach in UrQMD hydro for quark propagation in the prehadronic phase
- coalescence mechanism needed to describe experimental measurements
- results for the prehadronic phase and the Langevin approach
- comparison of Langevin approach for hadronic phase and a hadronic after burner

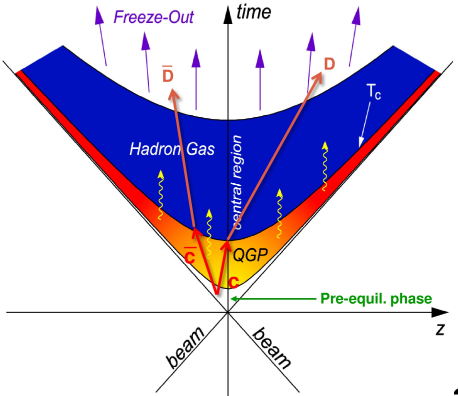
QCD phase diagram



Time evolution in HIC

- Charmonium: $c + \bar{c} \quad \rightarrow J/\Psi, \chi_c, \Psi'$
- Open Charm: $c +$ light quark $\quad \rightarrow$ D-Mesons

- Charm quark mass $\approx 1.5\ GeV$
- charm production at early stage of collision in hard processes
- hadronization when the system cools down
- ideal probe for the whole collision



Debye screening in QGP

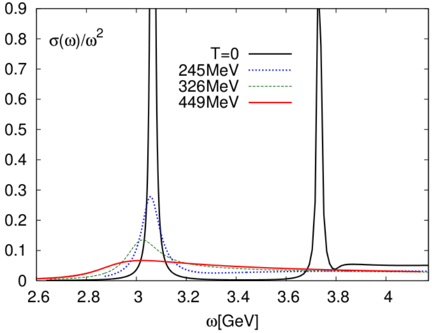
In 1986 T. Matsui and H. Satz proposed that charmonium will be suppressed in QGP.

- charmonium is produced in the initial phase of a heavy ion collision in hard processes
- interaction of c and $\bar{c}$ is weakened by color Debye screening
- charmonium gets dissociated and recombines after QGP phase transition to hadron gas

$\Rightarrow$ suppression of charmonium and enhancement of open charm mesons

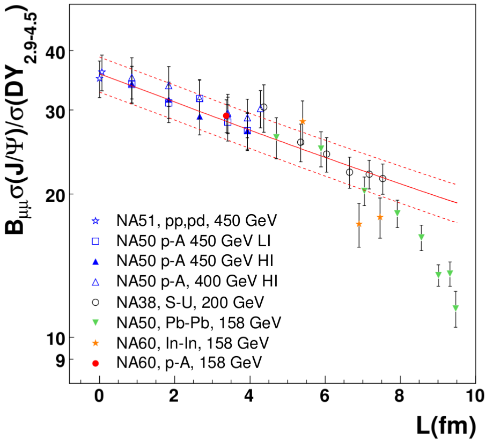
Charmonium melting

- spectral function of charmonium can be calculated using lattice QCD, it broadens in QGP
- dissociation is more likely
- width of the spectral function can be interpreted as life time
- complete breakup only at very high temperatures



C.Miao, A.Mocsy, P.Petreczky, arXiv:1012.4433

Normal suppression



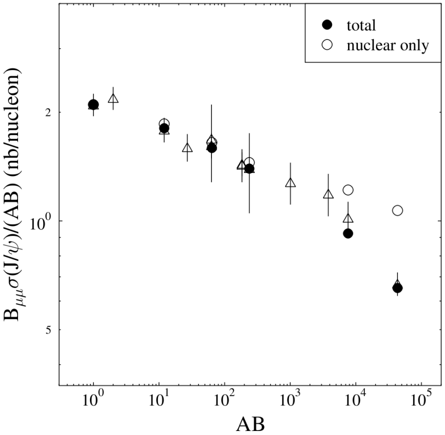
NA50, B. Alessandro et al., Eur. Phys. J. C39, 335 (2005)

- "Anomalous" suppression in central collisions?
- Can hadronic scatterings explain suppression?

Comover scenario

S. Gavin and R. Vogt
Nucl. Phys. B345 (1990) 104.

- charmonium can be dissociated by inelastic scatterings with comoving mesons
- cross sections are in the order of some mb
- gets important in a dense medium, that means central collisions and high collision energies
- improves description of data

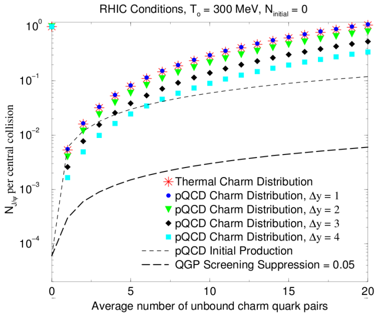


C.Spieles et al., arXiv:9902337v1

Regeneration

- R.L.Thews (R. L. Thews, J. Rafelski, Nucl.Phys. A698 (2002) 575-578) predicts recombination of heavy quarks and anti-quarks which originate from different space-time regions
- formation rate proportional to the square of the number of unbound charm quarks

$\Rightarrow$ J/Ψ-enhancement at RHIC and LHC



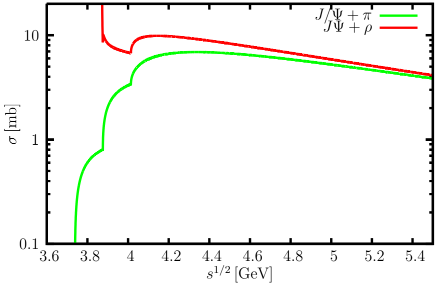
UrQMD

Ultra-Relativistic Quantum Molecular Dynamics Model

- non-equilibrium transport model
- classical trajectories in phase-space (relativistic kinematics): evolution of phase space distribution via Boltzmann equation
- includes all particle resonances and decays up to 2.1 GeV
- cross sections from measurements, additive quark model and detailed balance
- applicable to a huge range of collision energies
- can be coupled with different other models, for example hydro

Dissociation cross sections

$$\sigma_{1+2\to3+4}(s) = 2^4 \frac{E_1 E_2 E_3 E_4}{s} |M_i|^2 \left(\frac{m_3 + m_4}{\sqrt{s}} \right)^6 \frac{p_f}{p_i}$$

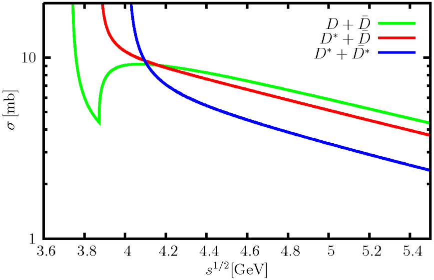


- cross sections with baryons independent on energy
  J/Ψ : $4,18\,\text{mb}$
  χ_c : $4.18\,\text{mb}$
  Ψ' : $7.6\,\text{mb}$
- meson dissociation from π-, ρ, K and K^*-mesons

E. L. Bratkovskaya, W. Cassing, and H. Stoecker, Phys. Rev. C67, 054905 (2003)

Regeneration cross sections

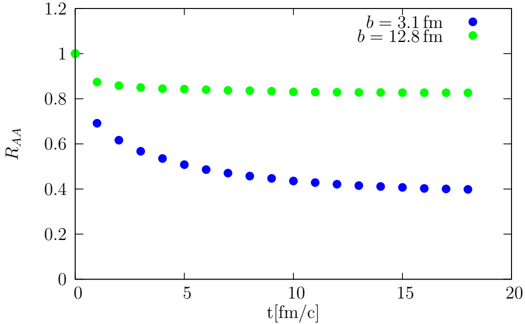
$$\sigma_{3+4\to1+2}(s) = \sigma_{1+2\to3+4}(s)\frac{(2S_1+1)(2S_2+1)}{(2S_3+1)(2S_4+1)}\frac{p_f^2}{p_i^2}$$



- $D\bar{D} \to J/\Psi$
- increased cross section for excited D-Mesons
- suppression for strange mesons

E. L. Bratkovskaya, W. Cassing, and H. Stoecker, Phys. Rev. C67, 054905 (2003)

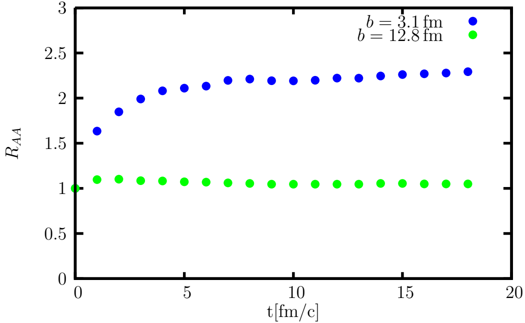
SPS - time evolution



$Pb - Pb, p_{lab} = 200\ GeV,\ 0 < y_{cm} < 1$

- $b = 12.8\ fm$
- $b = 3.1\ fm$

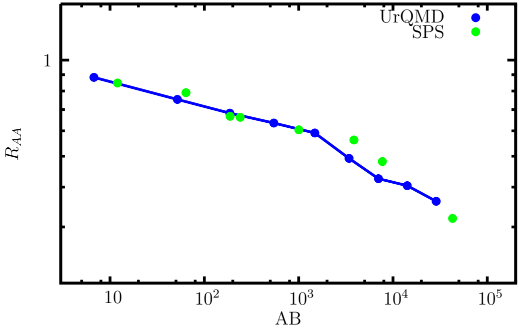
RHIC - Time evolution



$Au - Au, s^{1/2} = 200\ GeV,\ |y| < 0.35$

- $b = 3.1\ fm$
- $b = 12.8\ fm$

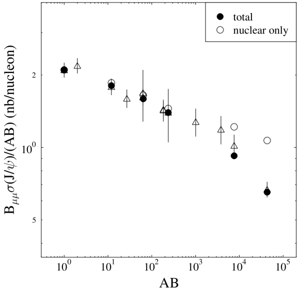
SPS



$Pb - Pb, p_{lab} = 200\ GeV$

M.C. Abreu et al. (NA50 Collab.), Phys. Lett. B410 (1997) 327, 337

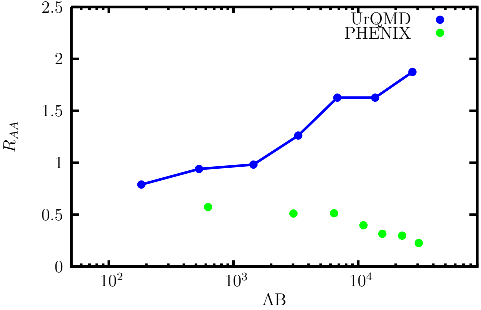
Implementation reproduces schematic calculation of C.Spieles et.al.



C.Spieles et al., arXiv:9902337v1

RHIC - centrality dependence

We can NOT describe charmonium suppression using a purely hadronic model

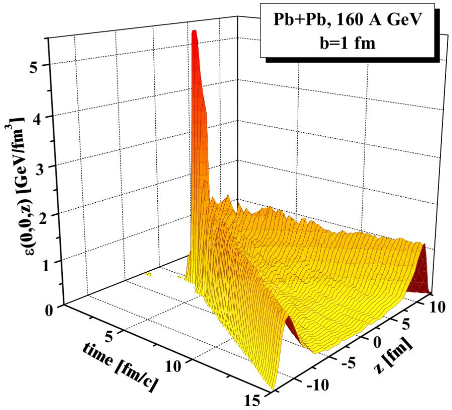


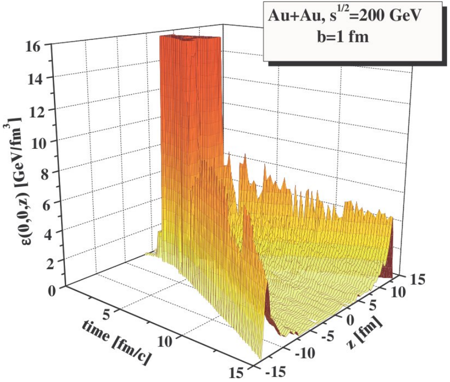
Apparently strong recombination

$Au - Au, s^{1/2} = 200\ GeV,\ |y| < 0.35$

PHENIX, A. Adare et al., Phys. Rev. Lett. 98, 232301 (2007)

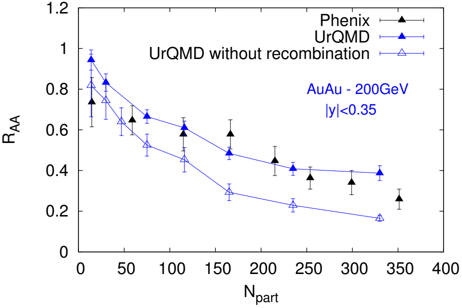
Energy density in heavy ion collisions



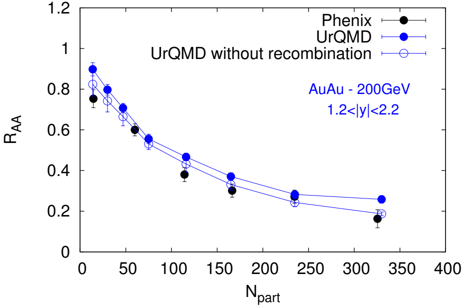


Contribution of recombination

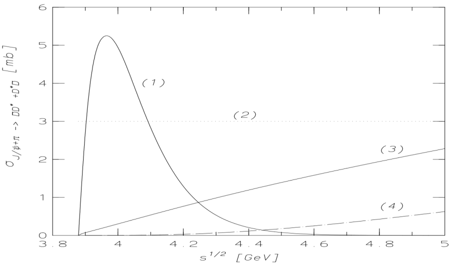
Mid-Rapidity



Forward-Rapidity



Different cross sections

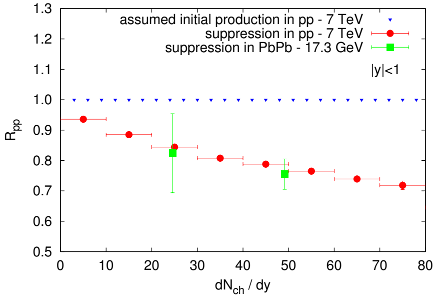


P.Braun-Munzinger, K.Redlich, Eur.Phys.J. C16 (2000) 519-525

- a lot of cross sections on the market
- possibility to test cross sections

1. non-perturbative quark-exchange model (K.Martins et al.)
2. constant cross section of 3 mb (R. Vogt et al.)
3. meson exchange model (S.G. Matinian et al.)
4. perturbative QCD (D. Kharzeev et al.)

Possible J/Ψ suppression in pp at LHC



- suppression reaches up to 30%
- J/Ψ suppression not dependent on collision energy but on particle multiplicity
- measurements at higher particle multiplicities would be helpful

$$R_{pp} = \frac{dN^{final}_{J/\Psi}/dy|_{|y|\leq 1}}{dN^{initial}_{J/\Psi}/dy|_{|y|\leq 1}}$$

Similar study of medium modification of charm quarks in pp done by S.Vogel et al. (Phys.Rev.Lett 107 (2011) 032302)