Charmonium dynamics in the UrQMD transport model

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TORIC Workshop Heraklio

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Outline

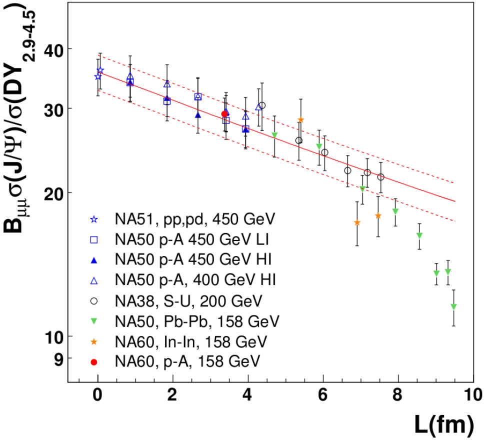
Debye screening in QGP

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 chamonium and enhancement of open charm mesons

Normal suppression



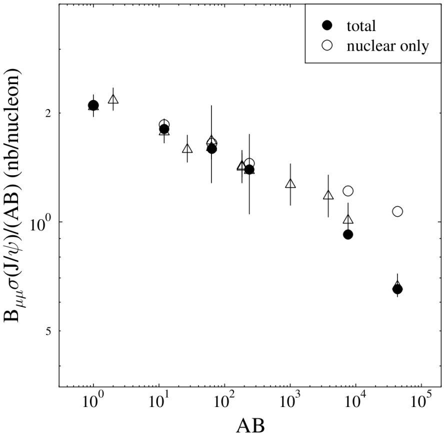
- "Anomalous" suppression in central collisions?
- Can hadronic scatterings explain suppression?

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

Comover scenario

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

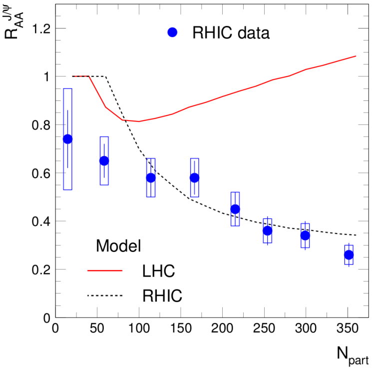
- charmonium can be dissociated by inelastic scatterings with comoving mesons
- cross sections are in the order of some mb
- gets important in a dense medium, that means central collisions and high collision energies
- improves description of data



C.Spieles et al., arXiv:9902337v1

Regeneration

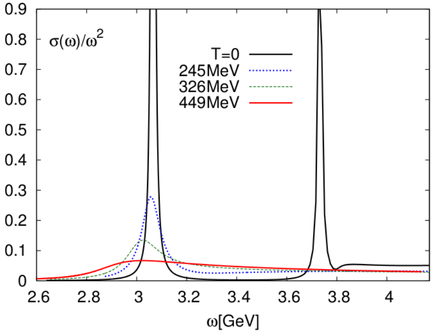
- R.L.Thews predicts recombination of heavy quarks and antiquarks which originate from different space-time regions
- formation rate proportional to the square of the number of unbound charm quarks
- $\Rightarrow$ possible J/Ψ enhancement at LHC



P.Braun-Munzinger, arXiv:0901.2500

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 possibly be interpreted as life time
- complete breakup only at very high temperatures



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

Outline

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

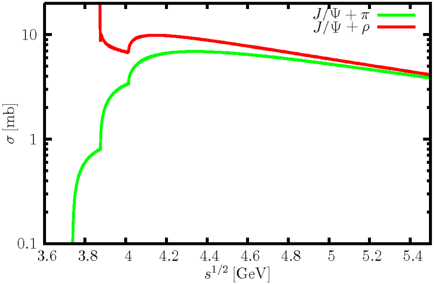
Implementation to UrQMD

- charm production points determined using Glauber model
  $\Rightarrow$ UrQMD prerun to write down nucleon collision points
- momenta and yields of J/Ψs and D-Mesons are fitted to experimental data
- purely hadronic interactions with baryons and mesons
- elastic cross sections from effective Lagrangian calculations

  Ziwei Lin, C M Ko, J.Phys. G:Nucl.Part.Phys. 27 (2001) 617-623
- inelastic cross sections taken from SPS-fits and 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)

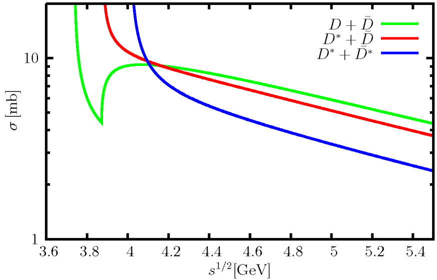
Dissociation cross sections



- cross sections with baryons independent on energy
  J/Ψ : 4, 18 mb
  χ_c : 4.18 mb
  Ψ' : 7.6 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

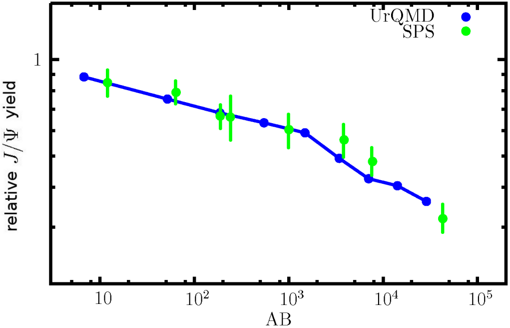


- $D\bar{D} \rightarrow J/\Psi$
- increased cross section for excited D-Mesons
- suppression for strange mesons

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

Outline

SPS

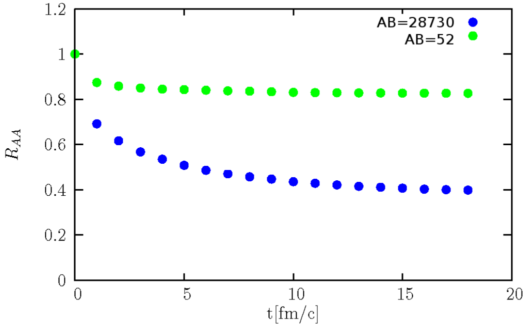


$Pb - Pb, p_{lab} = 200\ GeV$

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

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

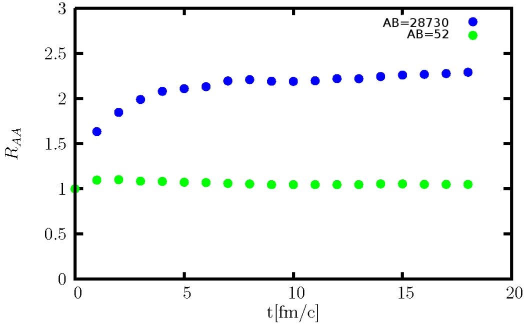
SPS - time evolution



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

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

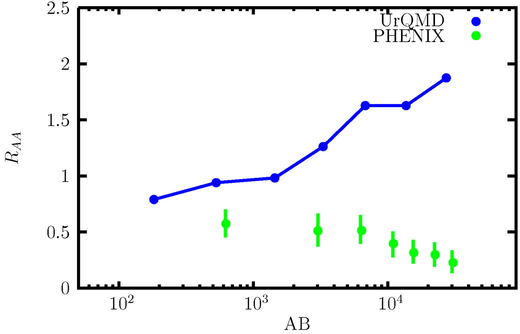
RHIC - Time evolution



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

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

RHIC - centrality dependence



Apparently strong recombination

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

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

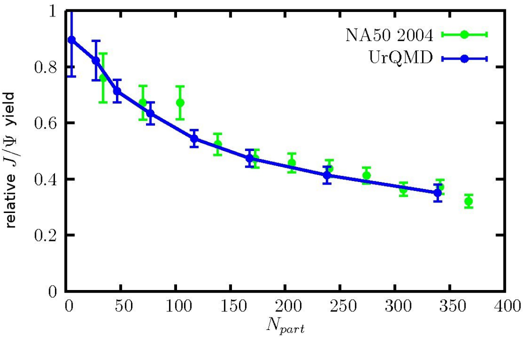
Outline

1. Charmonium suppression
2. Charmonium in UrQMD
3. Results of a purely hadronic approach
4. Results of a prehadronic approach
5. Summary/Outlook

Is a prehadronic phase the solution?

- implementation of a prehadroic phase to UrQMD
- below transition temperature normal hadronic model
- no recombination of D-Mesons above phase transition temperature
- no formation times $\Rightarrow$ prehadronic cross sections
- at very high densities breakup of charmonium particles

SPS

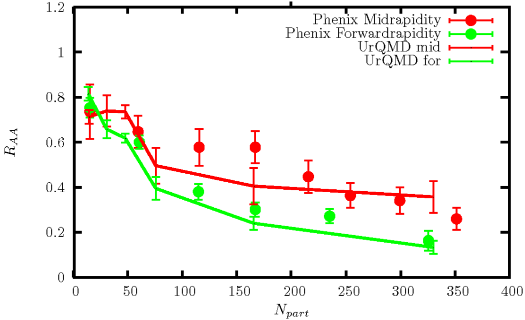


$Pb - Pb, p_{lab} = 158\ GeV$

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

- variables of new model are fitted to SPS data
- detailed balance model used
- shape fits well

RHIC

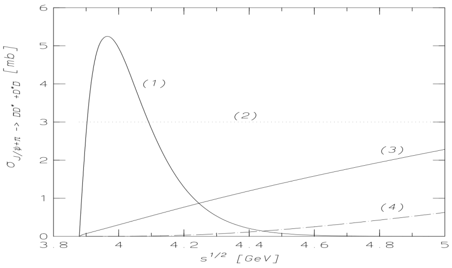


$Au - Au, s^{1/2} = 200\ GeV$

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

- same variables used as at SPS energies
- stronger recombination at midrapidity ⇒ less suppression at midrapidity

Different cross sections

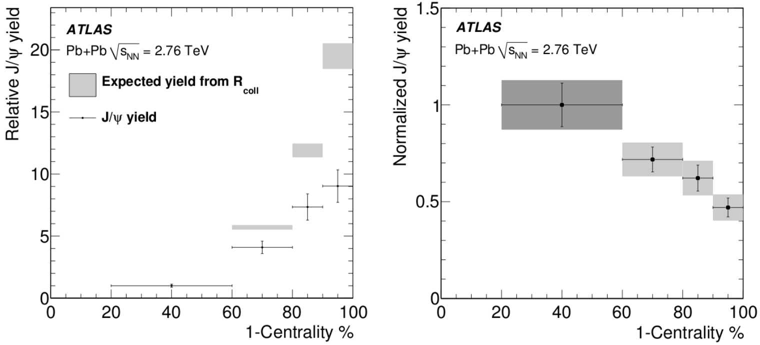


P.Braun-Munzinger, K.Redlich, Eur.Phys.J. C16 (2000) 519-525

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

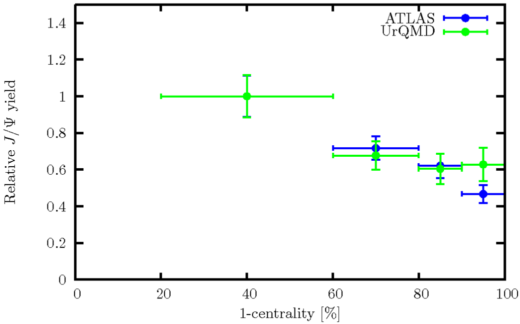
1. non-perturbative quark-exchange model (K.Martins et al.)
2. constant cross section of 3 *mb* (R. Vogt et al.)
3. meson exchange model (S.G. Matinian et al.)
4. perturbative QCD (D. Kharzeev et al.)

J/Ψ suppression at LHC



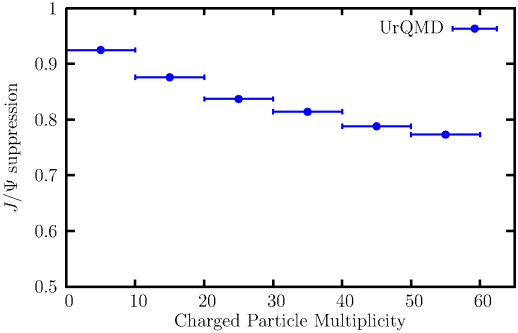
ATLAS, Georges Aad et al., Phys.Lett. B697 (2011) 294-312

J/Ψ suppression at LHC



- first measurements show that charmonium is suppressed at LHC
- R_{AA} still missing
- higher D-Meson number has no effect due to energy density and phase space reasons

J/Ψ suppression in pp at LHC



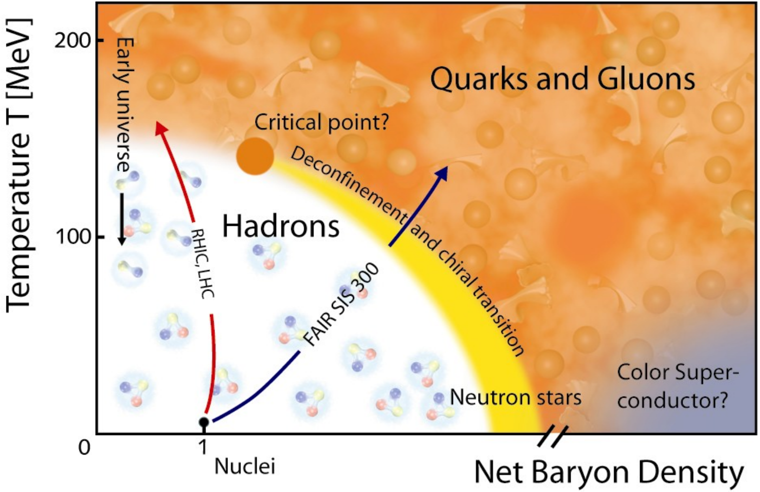
- J/Ψ yield in pp used as reference value for heavy ion collisions
- high energy density
- possible suppression can be tested using different multiplicity bins
- this calculation is not comparable to experiments directly!

Outline

Summary/Outlook

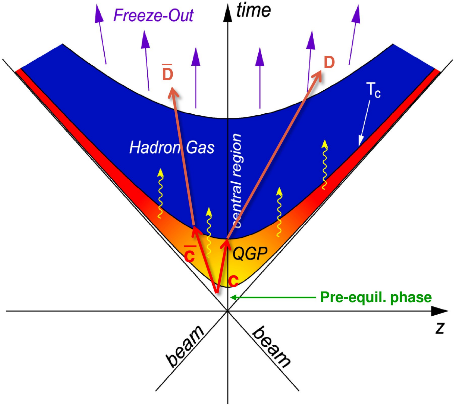
- charmonium suppression
- realization of charmonium dynamics in UrQMD
- comparison to data for SPS and RHIC energies
- prehadronic phase needed for proper description
- suppression in pp collisions also
- have a look at more observables
- need for improvement of the prehadronic phase

QCD phase diagram

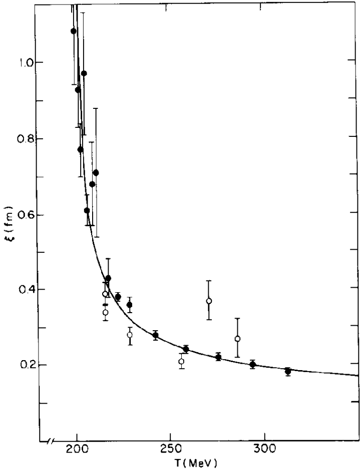


Time evolution in HIC

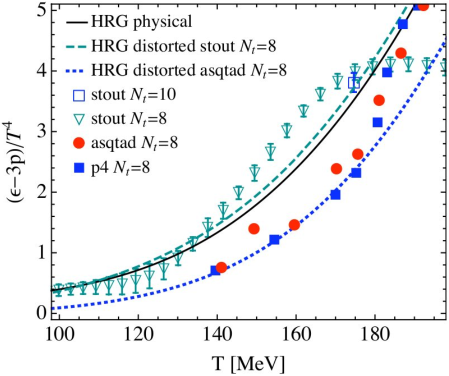
- Charm quark mass $\approx 1.5\ GeV$
- charm production at early stage of collision in hard processes
- hadronization when the system cools down
- ideal probe for the whole collision



QGP phase transition



T.Matsui and H.Satz, Phys.Lett. B178 (1986) 416

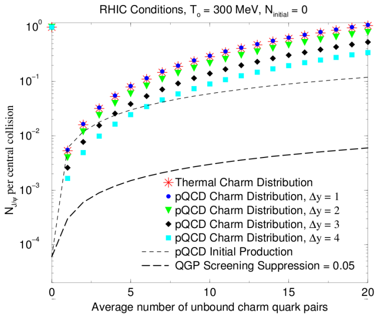


Szabolcs Borsanyi et al., arXiv:1005.3508

Regeneration

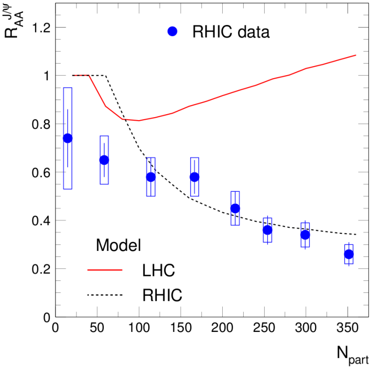
- R.L.Thews (R. L. Thews, J. Rafelski, Nucl.Phys. A698 (2002) 575-578) predicts recombination of heavy quarks and antiquarks which originate from different space-time regions
- formation rate proportional to the square of the number of unbound charm quarks

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



Regeneration

- P. Braun-Munzinger (arXiv:0901.2500v1) uses thermal model
- J/Ψ-production at phase boundary, proportional to the square of charm quarks



$\Rightarrow$ possible J/Ψ enhancement at LHC

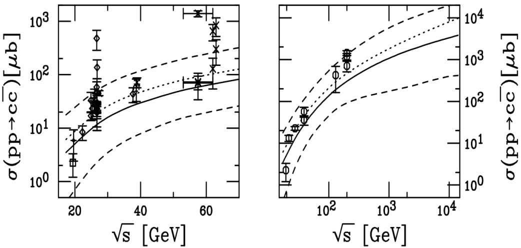
Charmonium yield

- charmonium yield → about 0.1 in a central collision
  D-Meson yield → approximately 30 in a central collision

  R.Vogt, arXiv:0709.2531v1 (2007)

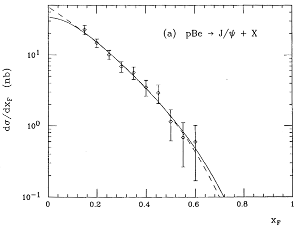
- fraction of charmonium states

  E 705: L. Antonizzi et al., PRL 70 (1993) 383



Initial conditions

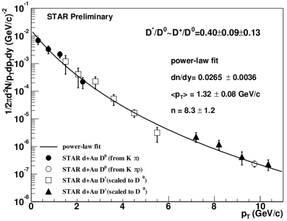
x_f-distribution



E672/E706, V. Abramov et al., FERMILAB-Pub-91/62-E,

IFVE-91-9, Mar. 1991

p_T-distribution



STAR, A. Tai et al., J. Phys. G30, S809 (2004)

Transport models

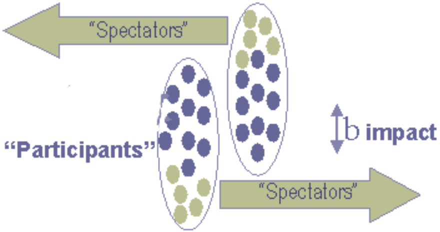
- HSD: Hadron String Dynamics
  $\Rightarrow$ coupled set of relativistic transport equations for particles with in-medium selfenergies

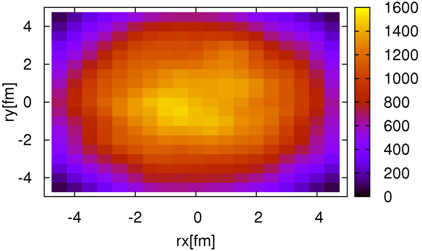
  W. Cassing and E.L. Bratkovskaya, Phys. Reports 308 (1999) 65-233
- AMPT: A multiphase transport model
  $\Rightarrow$ uses different approaches for partonic and hadronic interactions

  B. Zhang, C. M. Ko, B. A. Li, and Z. W. Lin, Phys. Rev. C 61, 067901 (2000)
- EPOS: Energy conserving, Partons, Off-shell remnants, Splitting of parton ladders
  $\Rightarrow$ multiple scattering approach based on partons and Pomerons

  K. Werner Nucl. Phys. B (Proc. Suppl.) 175-176 (2008) 81-87
- BAMPS: Boltzmann Approach of Multi-Parton Scatterings
  $\Rightarrow$ describes parton interactions in HIC on pQCD basis

Glauber model





- participant-spectator model
- elementary baryon-baryon cross section
- thickness function gives propability for baryon-baryon collision

$$T(b)\sigma_{NN} = \int \rho_A^z(b_A)db_A\rho_B^z(b_B)db_B t(b - b_A + b_B)\sigma_{NN}$$

Nuclear modification factor

$$R_{AA} = \frac{dN^{AA}_{J/\Psi}/dy}{\langle N_{coll} \rangle \cdot dN^{pp}_{J/\Psi}/dy}$$

- J/Ψ suppression in AA collisons compared to J/Ψ yield in pp scaled by binary collisons

Assumption

J/Ψ particles are not suppressed in pp collisions

Principle of detailed balance

Relation between reaction rates

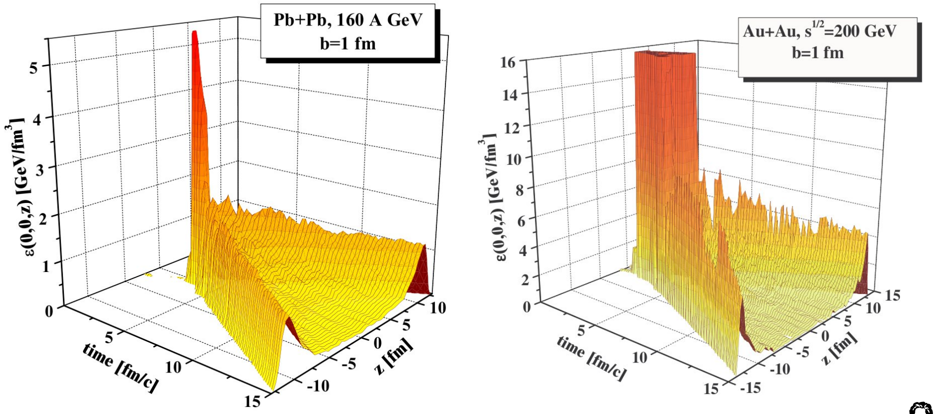
$$a(p_a, m_a) + b(p_b, m_b) \rightarrow c(p_c, m_c) + d(p_d, m_d)$$

$\Rightarrow$ after parity and time transformation the reaction is

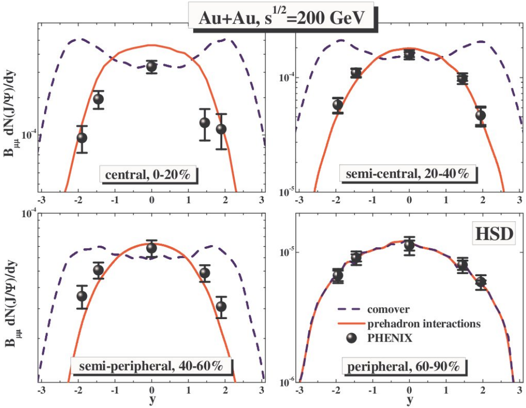
$$c(p_c, -m_c) + d(p_d, -m_d) \Rightarrow a(p_a, -m_a) + b(p_b, -m_b)$$

- if one averages over all spin projections, the reaction rates are the same
- valid for strong and electromagnetic reactions
- confirmed experimentally

Energy density in heavy ion collisions

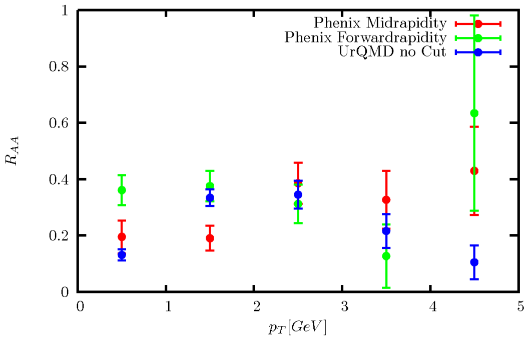


Charmonium in HSD



O. Linnyk, E.L. Bratkovskaya, W. Cassing, Int.J.Mod.Phys. E17 (2008) 1367-1439

Transverse momentum at RHIC

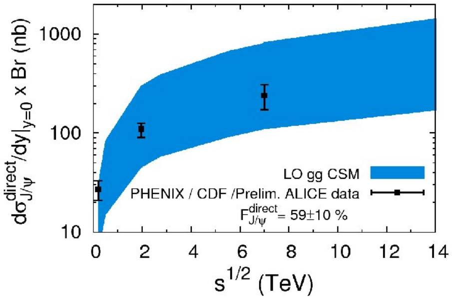


$Au - Au, s^{1/2} = 200\ GeV$

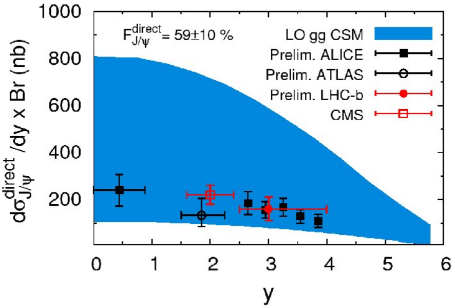
PHENIX, A. Adare et al., Phys. Rev. Lett. 98, 232301 (2007)

- we have to wait for better data
- at very high p_T increasing R_{AA}

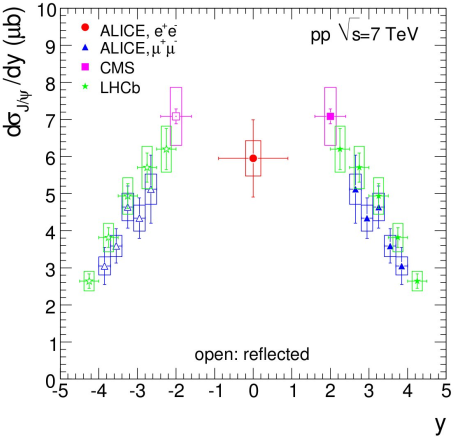
Charmonium yield at LHC energies



J.P.Lansberg (2010), arXiv:1012.2815

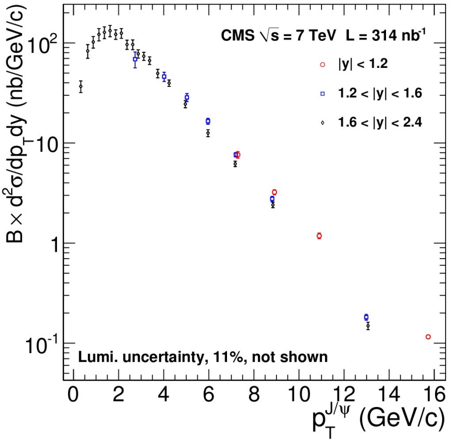


Rapidity at LHC energies

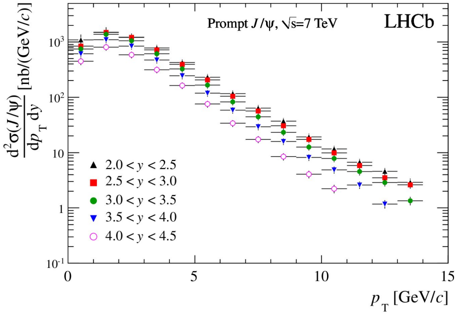


ALICE, K.Aamodt et al., arXiv:1105.0380v1

Transverse momentum at LHC energies



CMS, V.Khachatryan et al., Eur.Phys.J. C71 (2011) 1575



LHCb, R.Aaij et al., arXiv:1103.0423