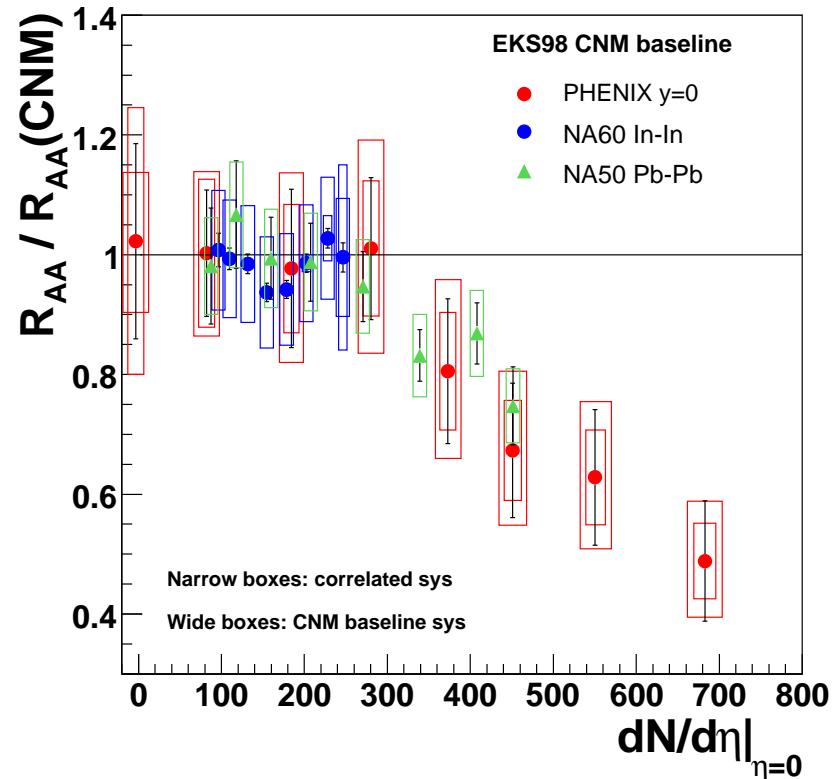


# HEAVY QUARKONIA DISSOCIATION RATES

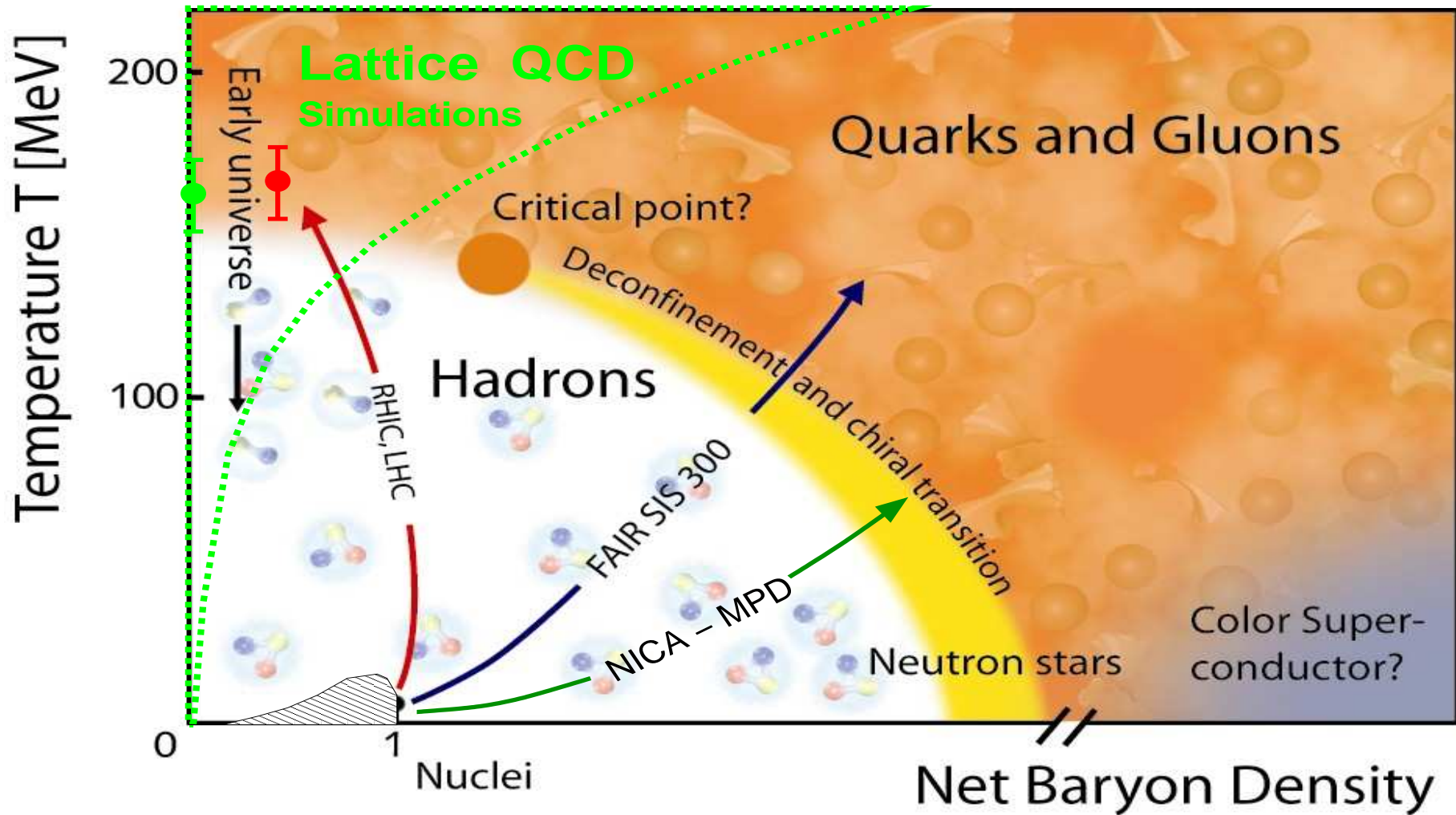
David Blaschke (Uni Wroclaw & JINR Dubna)



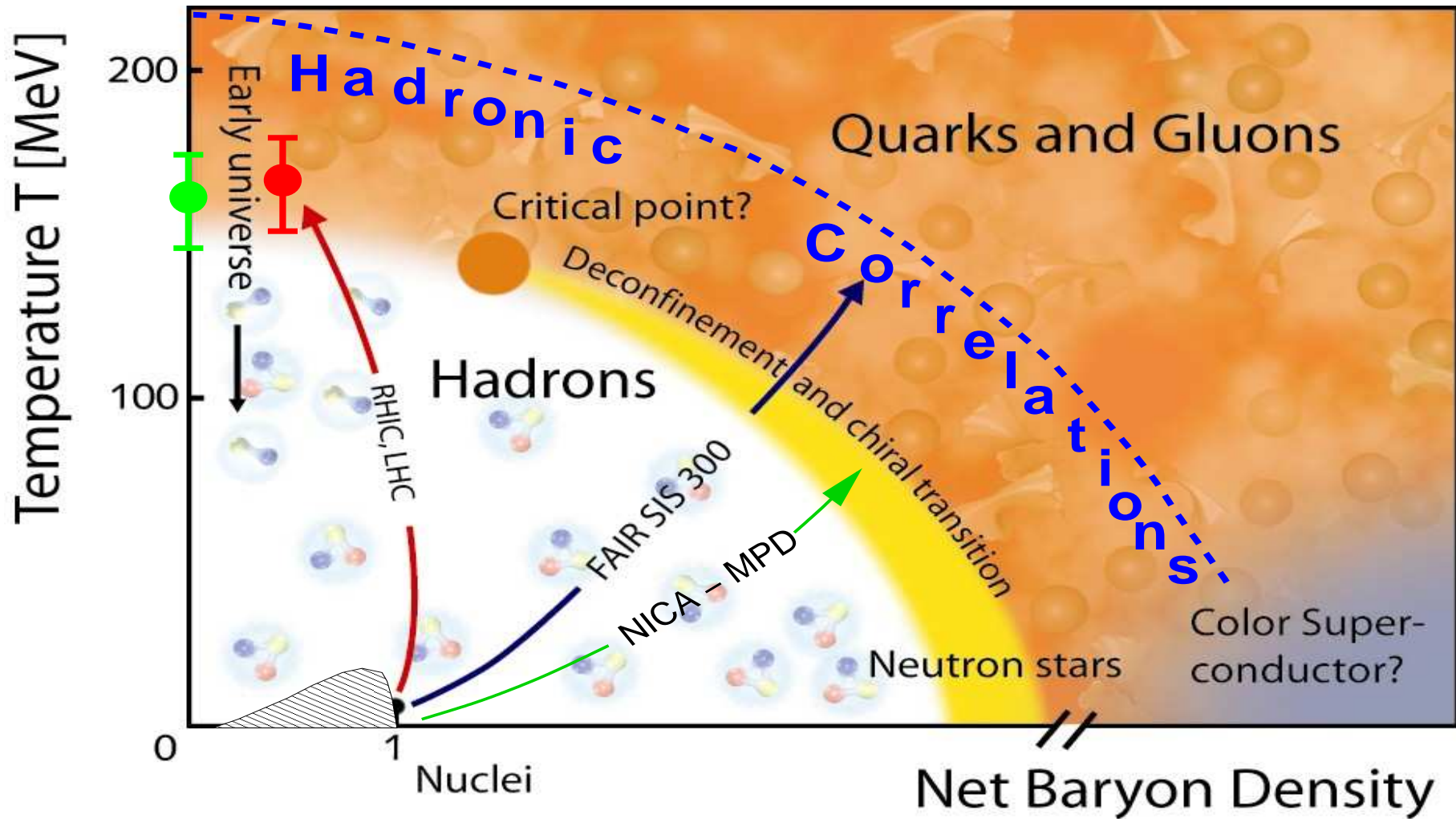
- Picture: strongly correlated matter
- Charmonium-hadron cross sections
- Lattice QCD: resonance interpretation
- Mott-Effect: potential & NJL model primer
- $J/\psi$  dissociation kinetics
  - Quantum kinetics in a resonance gas
  - In-medium cross section
  - Dissociation rate
- Summary / Outlook

Talk by R. Araldi, ECT\* Trento, 28.05.2009

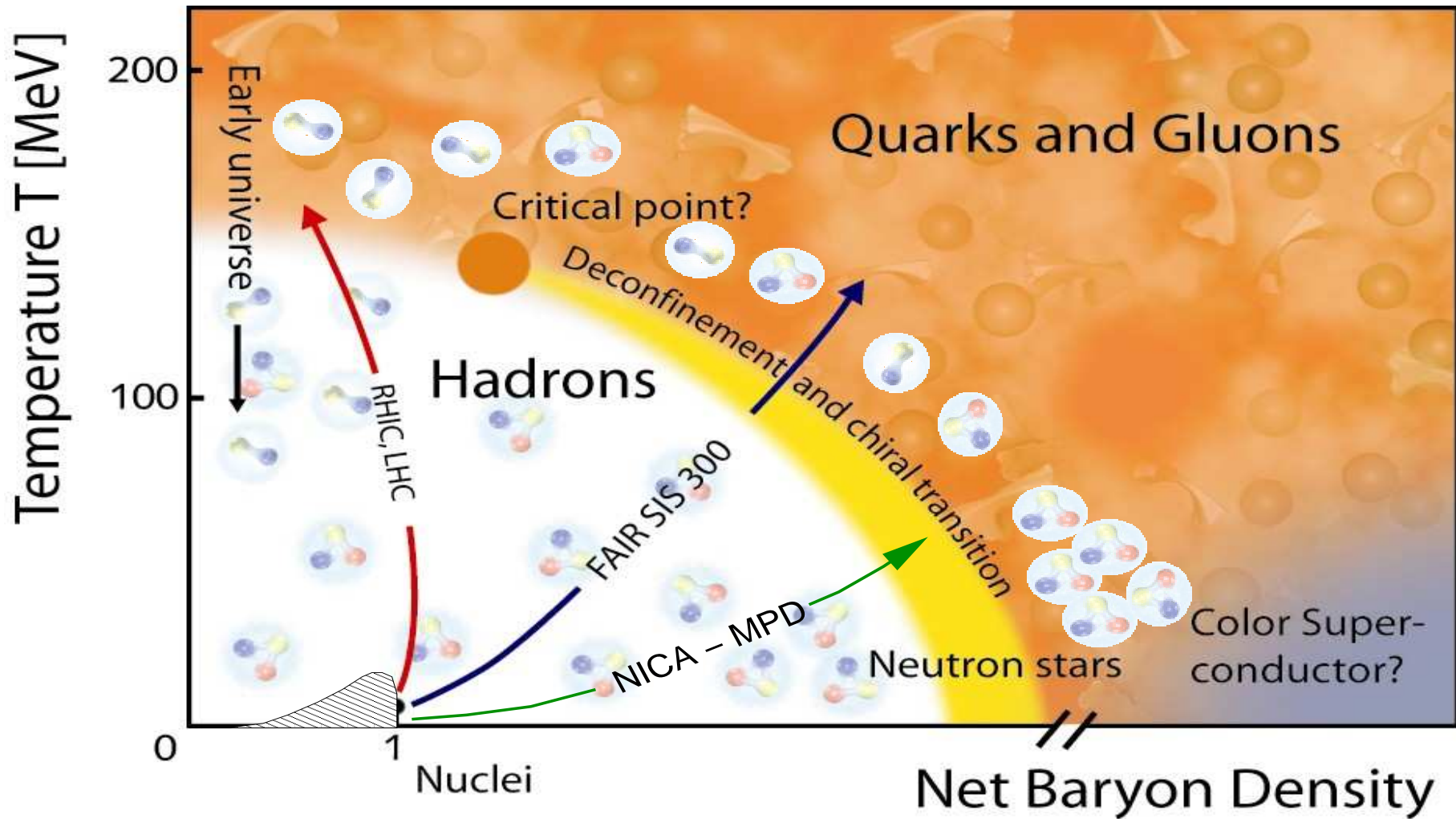
# PHASE DIAGRAM OF QCD: LATTICE SIMULATIONS



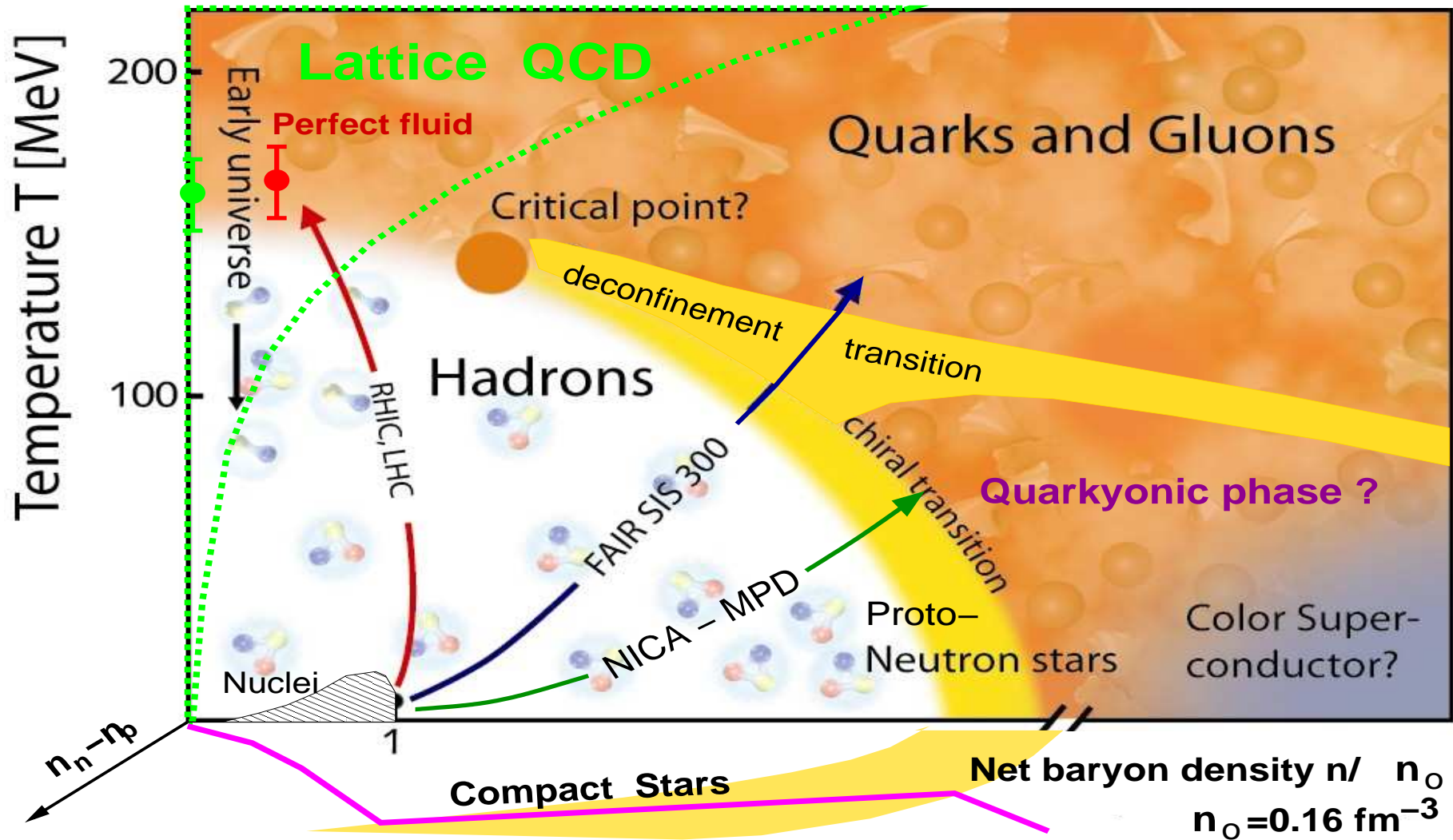
# HADRONIC CORRELATIONS IN THE PHASE DIAGRAM OF QCD



# HADRONIC CORRELATIONS IN THE PHASE DIAGRAM OF QCD



# MODERN QCD PHASE DIAGRAM: QUARKYONIC MATTER



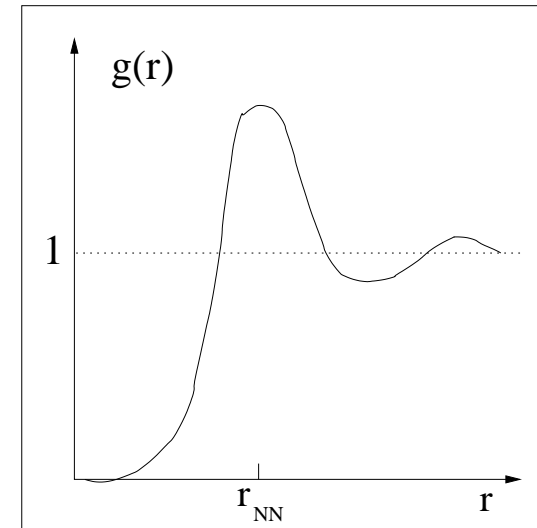
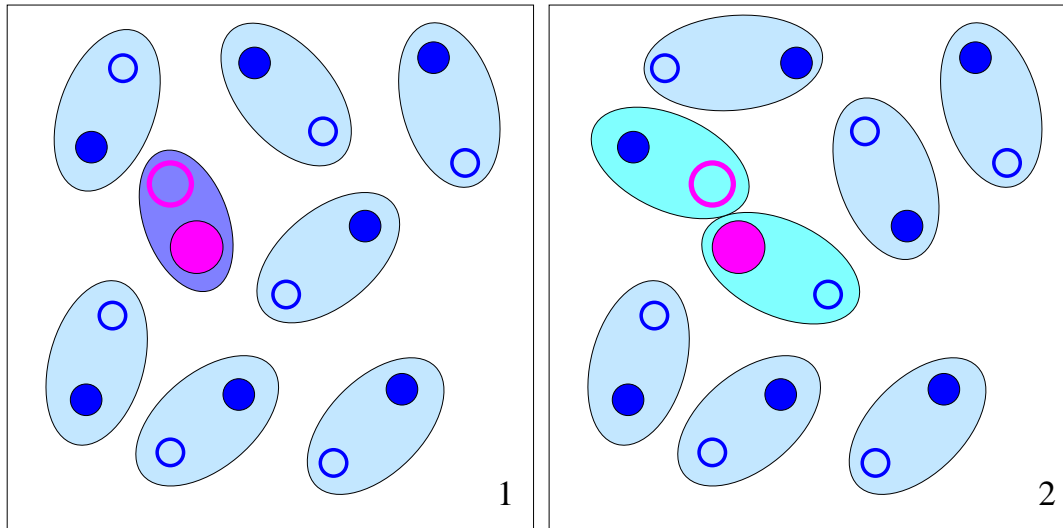
L. McLerran, arxiv:0906.2651; L. McLerran et al., in prep.

# A SNAPSHOT OF THE SQGP

**The Picture:** String-flip (Rearrangement)



Pair correlation

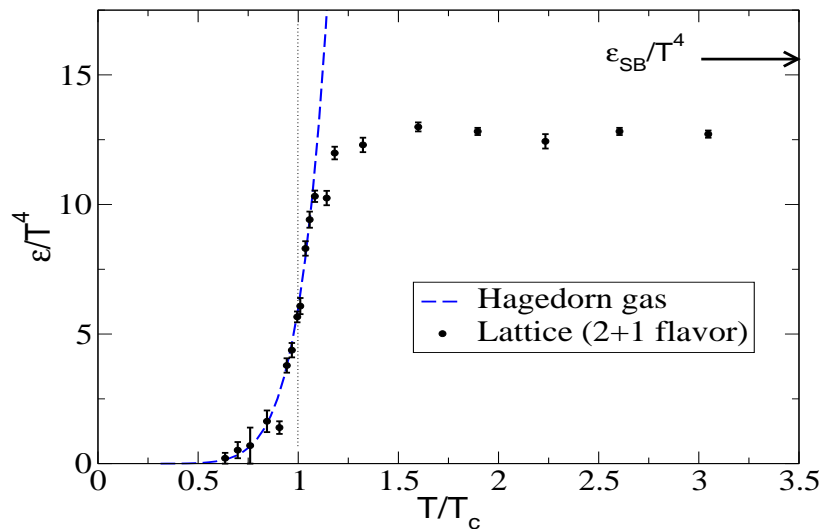
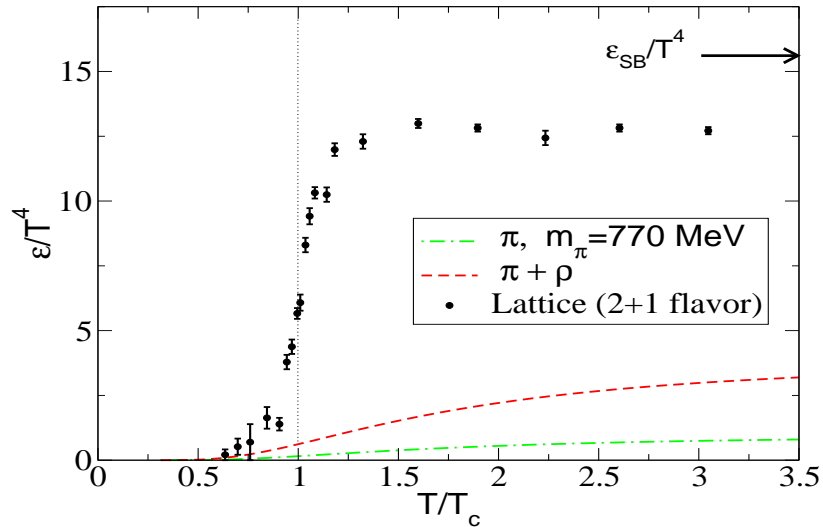


Horowitz et al. PRD (1985), D.B. et al. PLB (1985),  
Röpke, Blaschke, Schulz, PRD (1986)

Thoma, [hep-ph/0509154]  
Gelman et al., PRC 74 (2006)

- Strong correlations present: hadronic spectral functions above  $T_c$  (lattice QCD)
- Finite width due to rearrangement collisions (higher order correlations)
- Liquid-like pair correlation function (nearest neighbor peak)

# LATTICE QCD EoS VS. RESONANCE GAS



Ideal hadron gas mixture ...

$$\varepsilon(T) = \sum_{i=\pi,\rho,\dots} g_i \int \frac{d^3p}{(2\pi)^3} \frac{\sqrt{p^2 + m_i^2}}{\exp(\sqrt{p^2 + m_i^2}/T) + \delta_i}$$

missing degrees of freedom below and above  $T_c$

Resonance gas ...

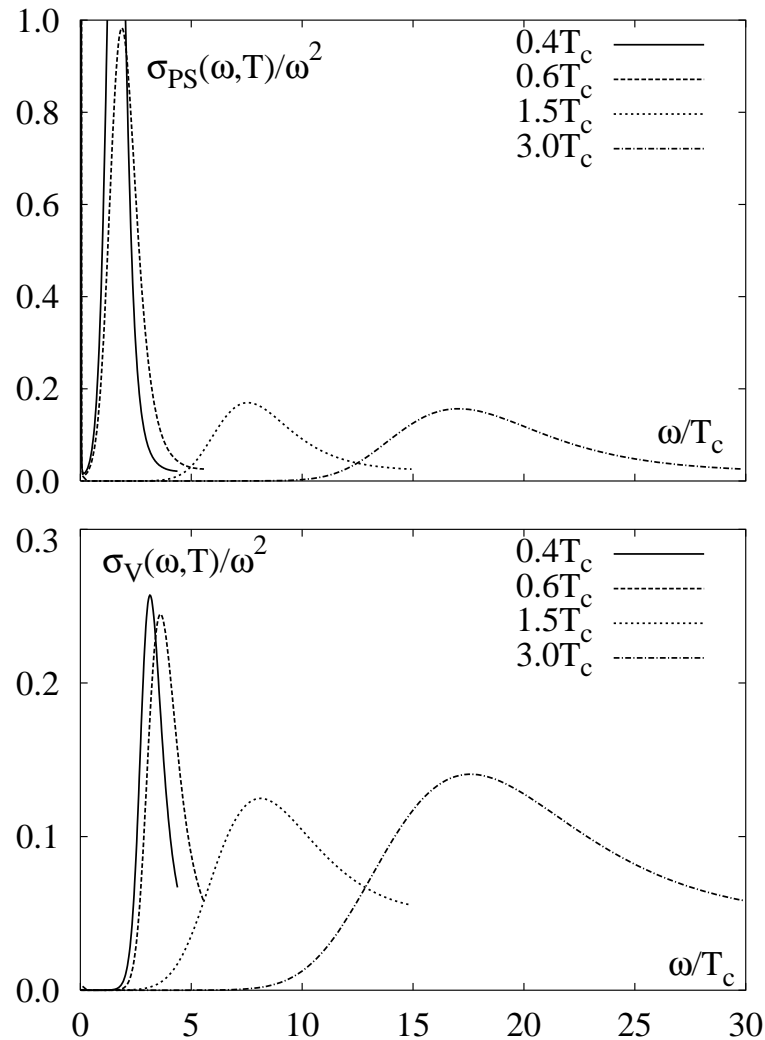
Karsch, Redlich, Tawfik, Eur.Phys.J. C29, 549 (2003)

$$\varepsilon(T) = \sum_{i=\pi,\rho,\dots} \varepsilon_i(T) + \sum_{r=M,B} g_r \int dm \rho(m) \int \frac{d^3p}{(2\pi)^3} \frac{\sqrt{p^2 + m^2}}{\exp(\sqrt{p^2 + m^2}/T) + \delta_r}$$

$\rho(m) \sim m^\beta \exp(m/T_H)$  ... Hagedorn mass spektrum

too many degrees of freedom above  $T_c$

# LATTICE QCD SPECTRAL DENSITIES



Hadron correlators  $G_H \implies$  spectral functions  $\sigma_H$

$$G_H(\tau, T) = \int_0^\infty d\omega \sigma_H(\omega, T) \frac{\cosh(\omega(\tau - T/2))}{\sinh(\omega/2T)}$$

Maximum entropy method

Karsch et al. PLB 530 (2002) 147

Result:

Correlations persist above  $T_c$  !

Karsch et al. NPA 715 (2003)

$J/\psi$  and  $\eta_c$  survive up to  $T \sim 1.6T_c$

Asakawa, Hatsuda; [hep-lat/0308034]

# LATTICE QCD EoS AND MOTT-HAGEDORN GAS

$$\varepsilon_R(T, \{\mu_j\}) = \sum_{i=\pi, K, \dots} \varepsilon_i(T, \{\mu_i\}) + \sum_{r=M, B} g_r \int_{m_r} dm \int ds \rho(m) A(s, m; T) \int \frac{d^3 p}{(2\pi)^3} \frac{\sqrt{p^2 + s}}{\exp\left(\frac{\sqrt{p^2 + s} - \mu_r}{T}\right) + \delta_r}$$

Hagedorn mass spectrum:  $\rho(m)$

Spectral function for heavy resonances:

$$A(s, m; T) = N_s \frac{m\Gamma(T)}{(s - m^2)^2 + m^2\Gamma^2(T)}$$

Ansatz with **Mott effect** at  $T = T_H = 180$  MeV:

$$\Gamma(T) = B\Theta(T - T_H) \left(\frac{m}{T_H}\right)^{2.5} \left(\frac{T}{T_H}\right)^6 \exp\left(\frac{m}{T_H}\right)$$

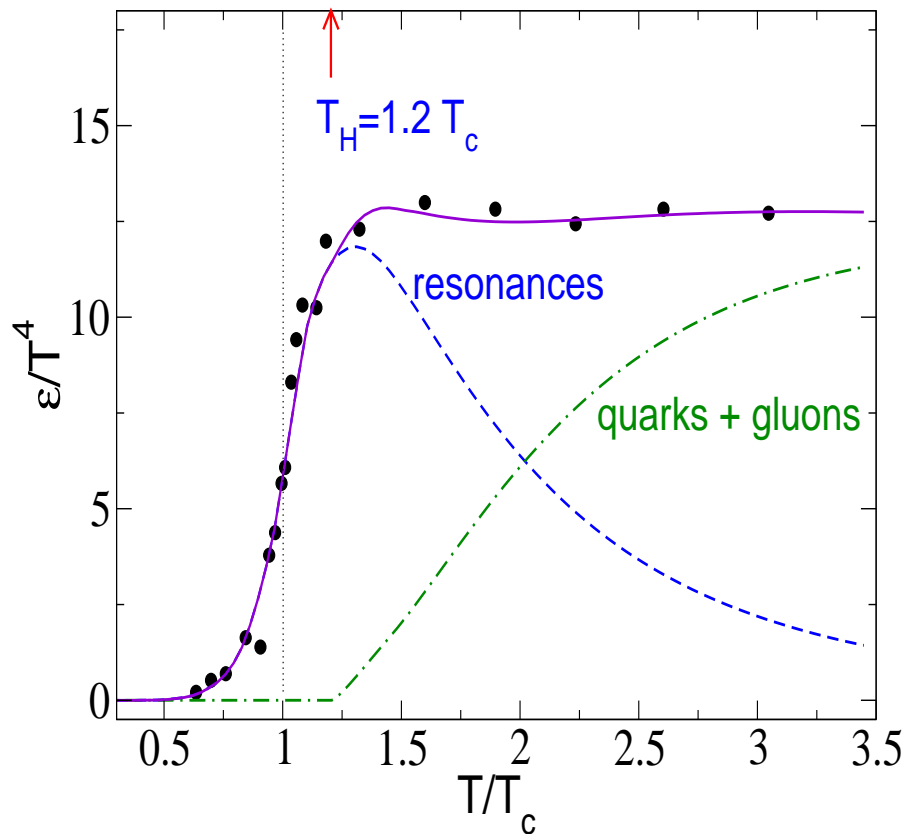
No width below  $T_H$ : Hagedorn resonance gas  
Apparent phase transition at  $T_c \sim 150$  MeV

**Blaschke & Bugaev, Fizika B13, 491 (2004)**

**Prog. Part. Nucl. Phys. 53, 197 (2004)**

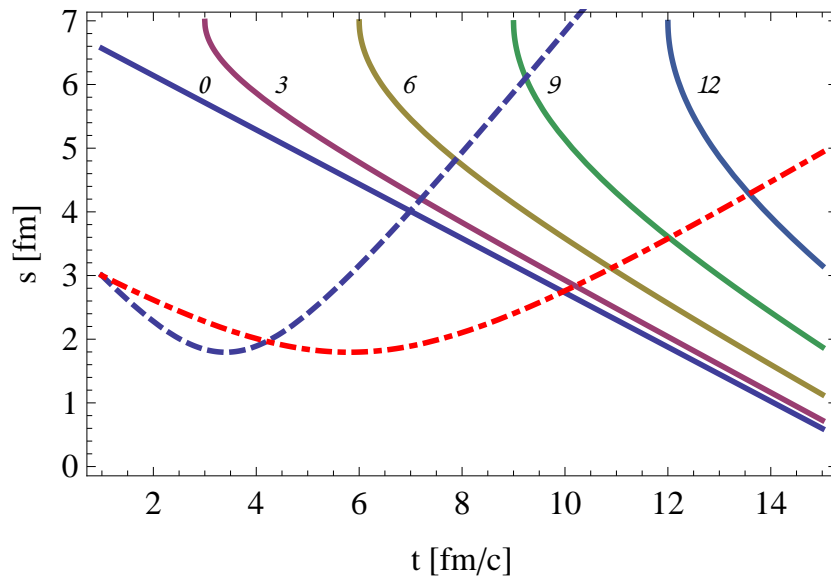
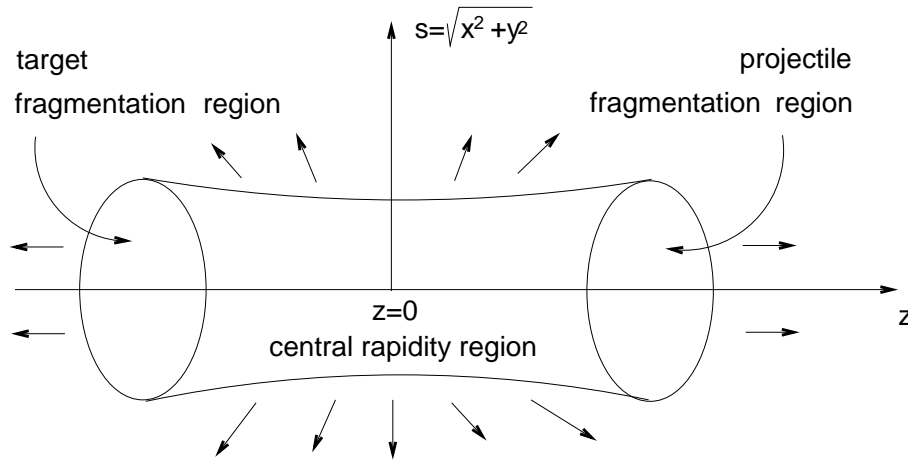
**Blaschke & Yudichev, in preparation**

**Bugaev, Petrov, Zinovjev, arXiv:0812.2189**



# J/ψ SUPPRESSION IN HADRONIC (QUARKYONIC) MATTER

Based on D. Prorok et al., arxiv/0901.0166; see also Prorok's talk at ECT\*, May 2009



## Rarefaction front (RF)

$$T(\vec{r}, t) = T(z, t) = T(0, \tau) = T_0 \cdot \tau^{-a}$$

with  $a = c_s^2(T_0)$ ;  $a = 0.148 - 0.156$

$T_0 = 222.6$  MeV for Au-Au

( $\epsilon_0 = 5.4$  GeV/fm<sup>3</sup>)

$T_0 = 201.8$  MeV for Cu-Cu

( $\epsilon_0 = 2.5$  GeV/fm<sup>3</sup>)

## Escape time: J/ψ trajectory

$$\vec{s} = \vec{d} + \vec{v}_T(t - t_0) \quad , \quad z = v_L(t - t_0) \quad ,$$

with  $\vec{v} = \vec{v}_T + \vec{v}_L = \vec{p}_T/E + \vec{p}_L/E$

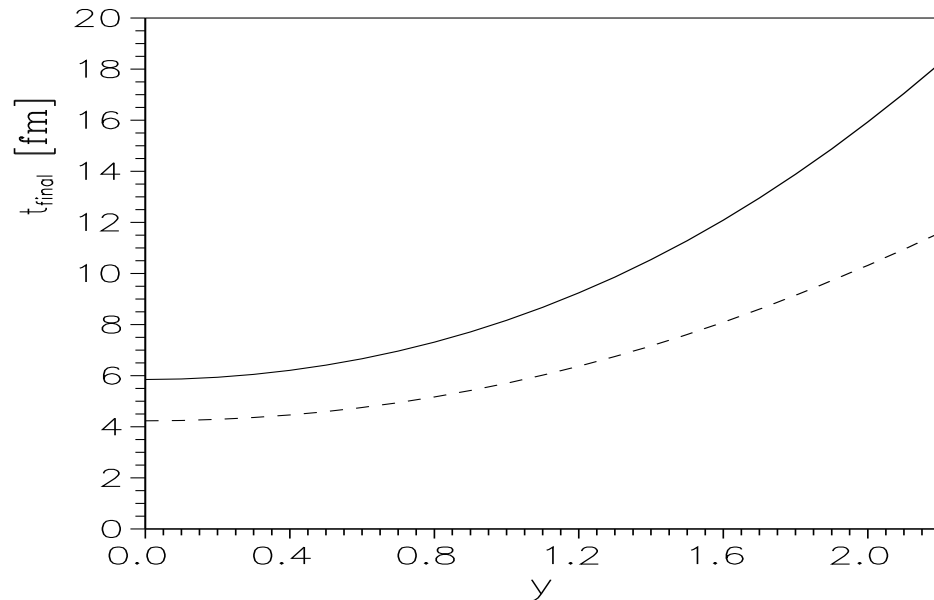
crossing the RF

$$(s - R_A)^2 + c_s^2 z^2 = c_s^2 t^2$$

## J/ψ SUPPRESSION IN HADRONIC (QUARKYONIC) MATTER (II)

RF crossing time from solution of

$$\sqrt{d^2 + 2\vec{d} \cdot \vec{v}_T(t - t_0) + v_T^2(t - t_0)^2} = R_A - c_s \sqrt{t^2 - v_L^2(t - t_0)^2}$$



Rapidity dependence of the “HRG absorption time”  $t_{\text{final}}$

$$S_{\text{HRG}}(y, b) = \frac{1}{\int dp_T M_T g_0(p_T)} \int dp_T M_T g_0(p_T) \exp \left\{ - \int_{t_0}^{t_{\text{final}}} dt \sum_{i=1}^l \int \frac{d^3q}{(2\pi)^3} f_i(\vec{q}, t) \sigma_i v_{\text{rel},i} \frac{p_\nu q_i^\nu}{EE'_i} \right\} ,$$

J/ψ suppression ratio

$$R_{AA}(y, b) = S_{\text{NA}}(y, b) \cdot S_{\text{HRG}}(y, b) ,$$

with nuclear absorption modeled by

$$S_{\text{NA}} \cong \exp \{ -\sigma_{\psi N} \rho_0 \langle L \rangle \} .$$

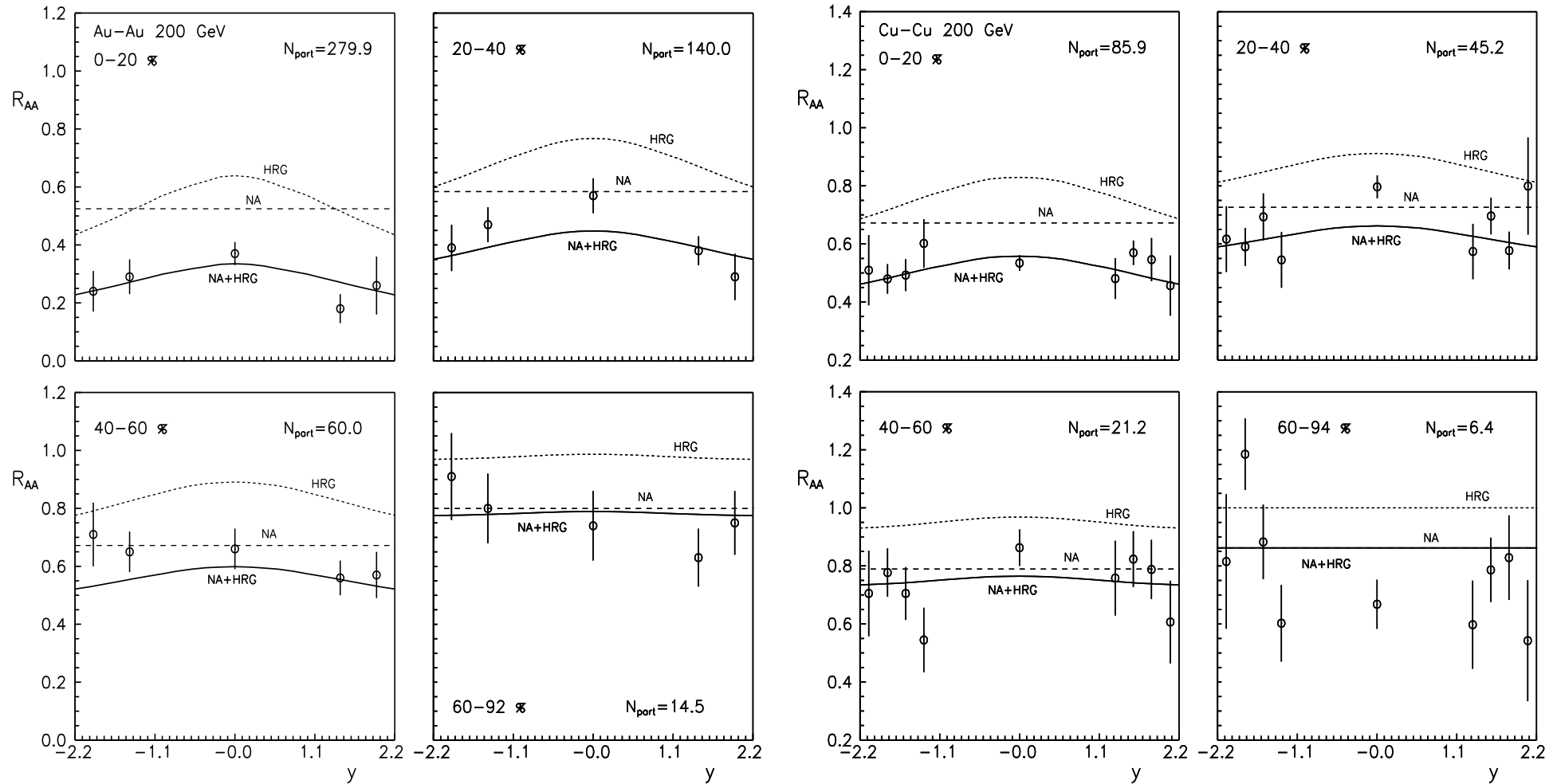
More cold nuclear matter (CNM) effects can be absorbed into this quantity:

$$S_{\text{NA}}(y, b) \rightarrow S_{\text{CNM}}(y, b)$$

Will be done later.

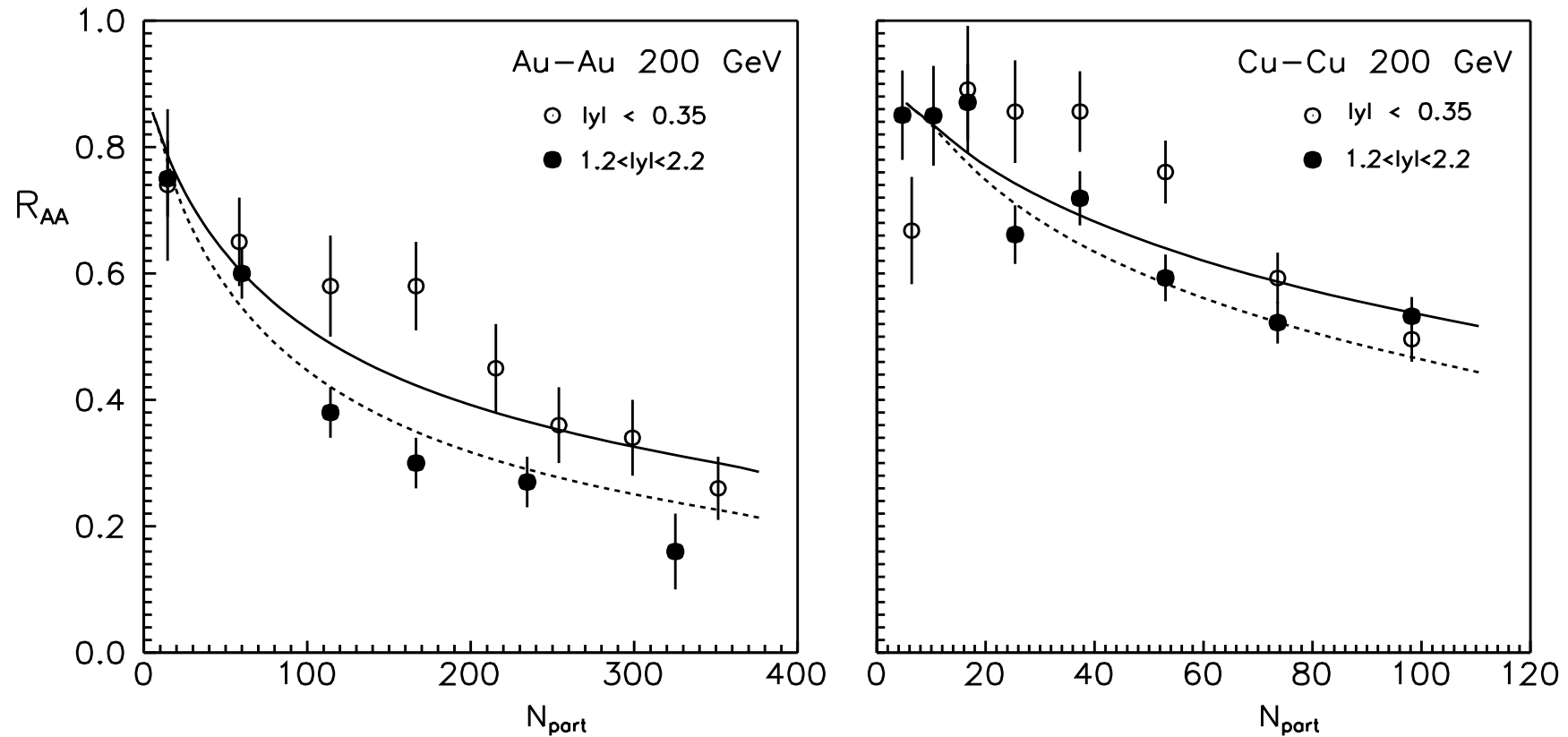
# J/ψ SUPPRESSION IN HADRONIC (QUARKYONIC) MATTER (III)

Rapidity dependence in Au-Au (left) and Cu-Cu (right) with  $\sigma_{J/\psi B} = 4 \text{ mb}$  ( $\sigma_{J/\psi M} = 2.7 \text{ mb}$ ).



## $J/\psi$ SUPPRESSION IN HADRONIC (QUARKYONIC) MATTER (IV)

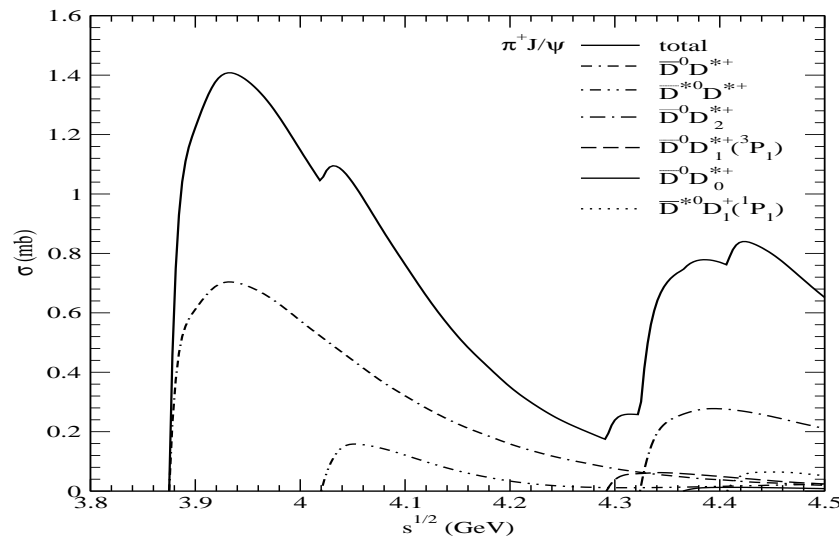
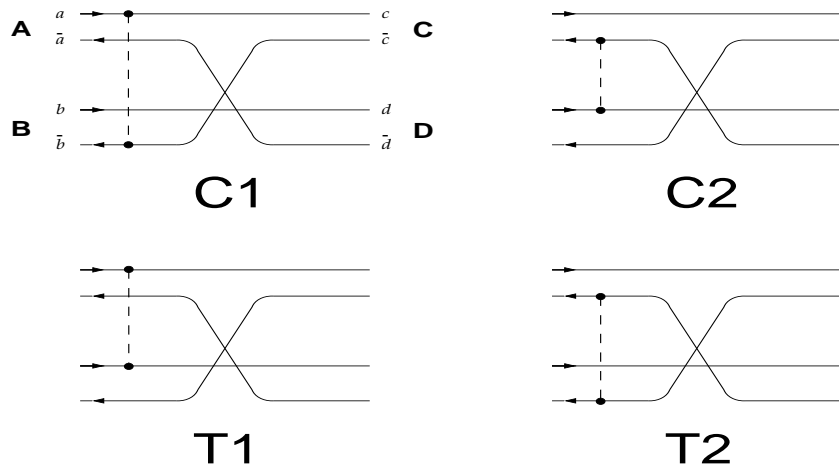
Centrality dependence in Au-Au (left) and Cu-Cu (right) with  $\sigma_{J/\psi B} = 4$  mb ( $\sigma_{J/\psi M} = 2.7$  mb).



Next steps:

Increase freeze-out  $T_{f.o.} \rightarrow T_c^+$ ; broadening of “pre” resonances; understand cross sections

# QUARK REARRANGEMENT I: NRQM BORN DIAGRAMS



Short history:

- Quark (+gluon) exchange model of short-range NN int.  
**Holinde, PLB 118 (1982) 266; ...**
- Born approx. to quark exchange in meson-meson scatt.  
**Barnes, Swanson: PRD 46 (1992) 131**
- Appl. to Charmonium dissociation:  $J/\psi + \pi \rightarrow D + \bar{D}, \dots$   
**Martins, D.B., Quack: PRC 51 (1995) 2723**
- Extension to other light mesons and excited charmonia  
**Barnes, Swanson, Wong, Xu: PRD 68 (2003) 014903**

(C)apture Diagrams:

→ interaction can be absorbed into the 'ladder' of a meson

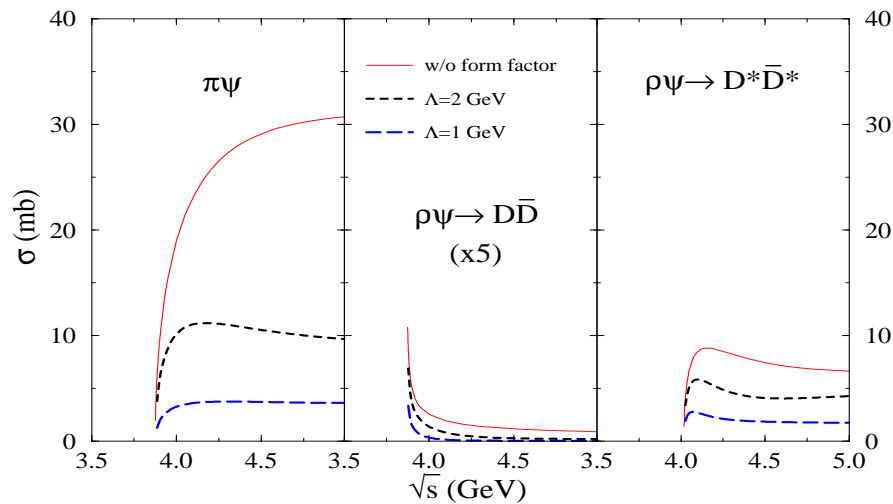
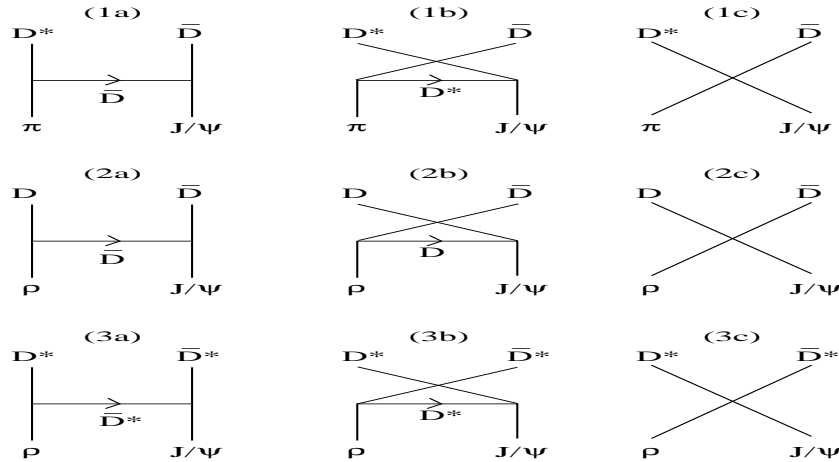
(T)ransfer Diagrams:

→ interaction between quarks from different mesons

Comments:

- Post-prior ambiguity for capture diagrams
- Interaction in capture and transfer diagrams different?
- Chiral symmetry restoration: problem in HFS term

# QUARK REARRANGEMENT II: CHIRAL LAGRANGIAN APPROACH



Short history:

- Meson exchange model for NN interaction  
**Yukawa(1935); Walecka, Ann. Phys. 83 (1974) 491; ...**
- Application to charmonium diss:  $J/\psi + \pi, \rho \rightarrow D + \bar{D}, \dots$   
**Matinyan, Müller, PRC 63 (1998) 2994**
- Inclusion of formfactors for the meson-hadron vertices  
**Haglin, PRC 61 (2000) 031902**  
**Lin, Ko, PRC 62 (2000) 034903**  
**Oh, Song, Lee, PRC 63 (2001) 034901**  
**Ivanov, Kalinovsky, D.B., Burau, hep-ph/0112354**

Meson exchange Diagrams:

→ Transfer diagrams: mesonic 'ladder' replaced by Born term

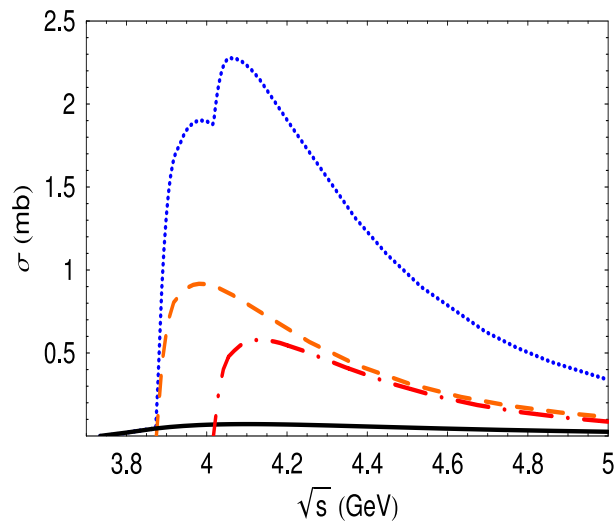
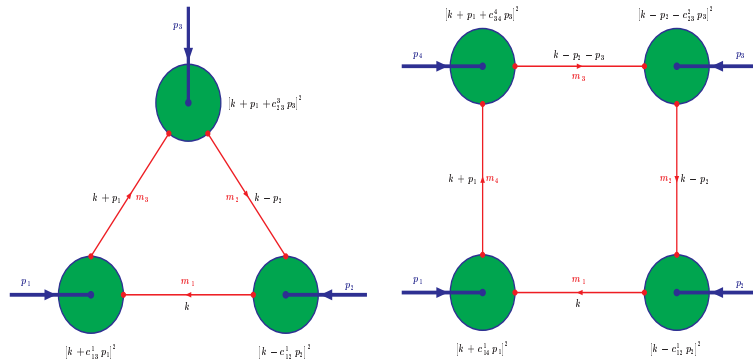
Contact Diagrams:

→ Capture diagrams: BS eq. at quark-meson vertex

Comments:

- Formfactors ad hoc, not part of the  $\chi L$  approach
- Quark substructure effects absent, or hidden in FF
- Finite  $T, \mu$  (and momentum-) behavior of vertices ?

# QUARK REARRANGEMENT III: RQM (DSE-BASED)



Short history:

- Dyson-Schwinger approach to hadronic processes  
**Roberts, Williams, PNP 33 (1994) 477**
- Application to D-mesons  
**Ivanov, Kalinovsky, Roberts, PRD 60 (1999) 034018**
- Calculation of  $J/\psi + \pi \rightarrow D + \bar{D}$   
**D.B., Burau, Ivanov, Kalinovsky, Tandy, hep-ph/0002047**  
**Ivanov, Körner, Santorelli, PRD 70 (2004) 014005**

(Double) Triangle Diagrams:

→ Meson exchange → Transfer diagrams

Box Diagrams:

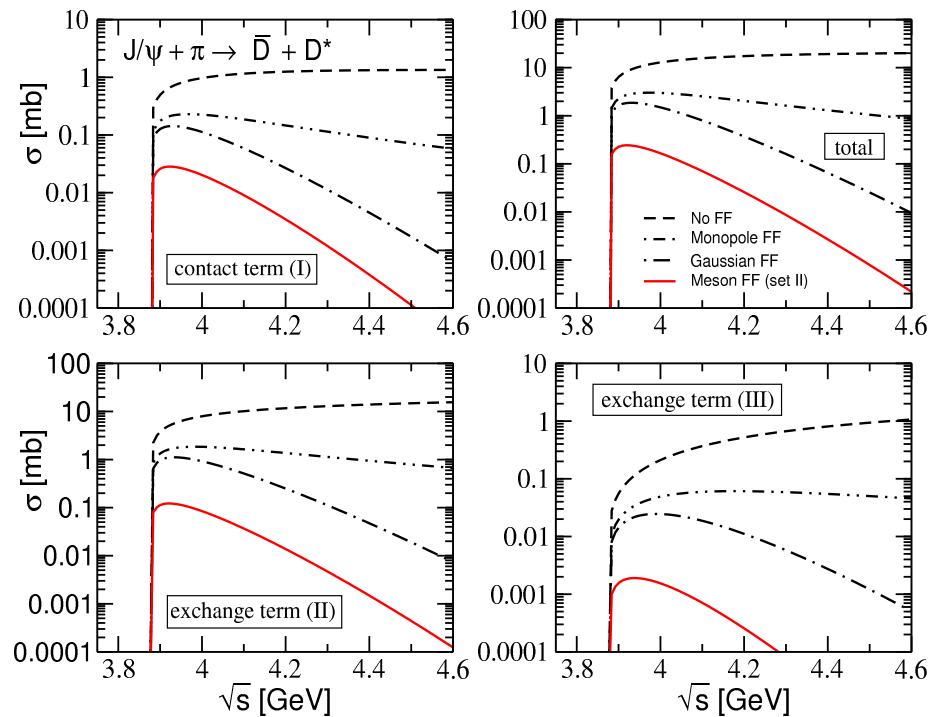
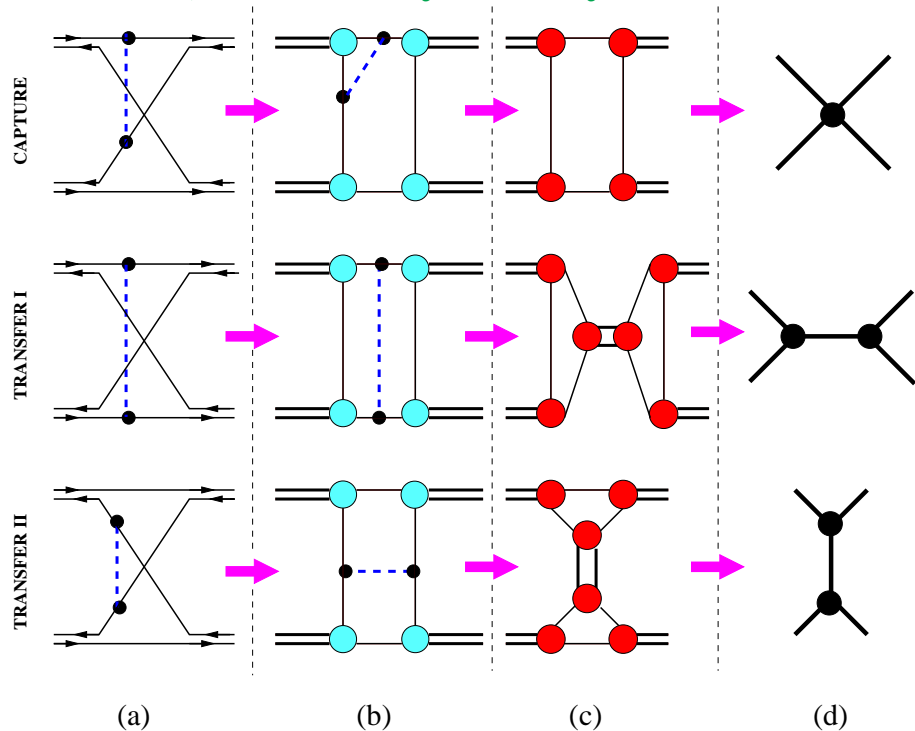
→ Contact Diagrams → Capture diagrams

Comments:

- Post-prior problem solved: covariant, chiral quark model
- Quark substructure effects in triangle and box diagrams
- BS amplitudes and quark propagators encode
  - Chiral restoration/ deconfinement
  - Mott effect: bound state dissociation

# QUARK REARRANGEMENT PROCESS $J/\psi + \pi, \rho \Leftrightarrow D^* + \bar{D}$

Blaschke, et al. Heavy Ion Phys. 18 (2003) 49



Ivanov, et al. PRD 70 (2004) 014005

