Hard Probes '04 Ericeira, Nov. 4-10, 2004

Charmonium suppression by thermal dissociation and percolation

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general remarks

J/ψ suppression…

…in high energy heavy ion collisions:

test of deconfinement#

- hot deconfined medium dissolves the binding of the c-cbar pair
- hadronic medium is transparent to the J/ψ

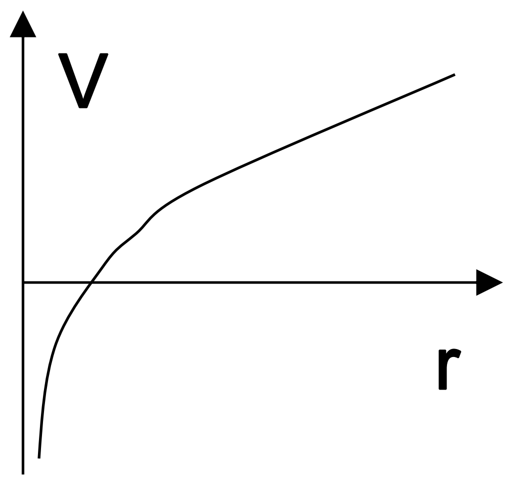
Experimental investigation by NA38/50 Coll.

#Matsui, Satz, Phys.Lett. B178 (1986) 416

general remarks

Charmonium (bottomonium) spettroscopy is well reproduced by simple NR model §

by solving the Schroedinger equation with the Cornell potential : $V(r) = -\frac{a}{r} + \sigma r$



- **$r_{J/\psi} \sim 0.2$ fm**

(hadron : r ~ 1 fm)

- **$E = 2M_D - 2M_{J/\psi}$**

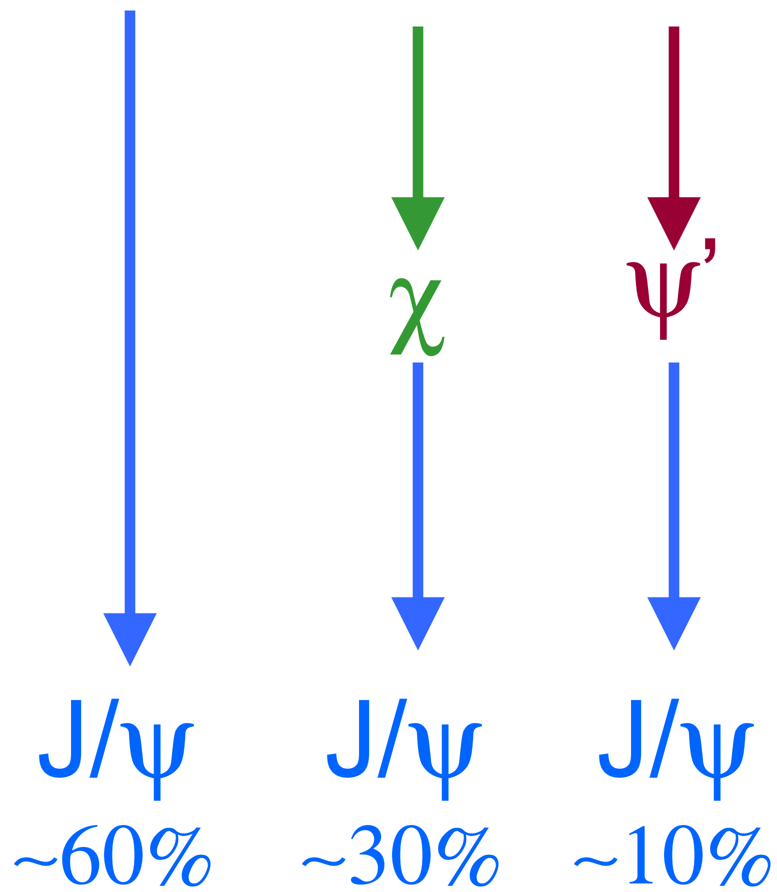
§ Jacobs et al. Phys. Rev. D 33 (1986) 3338; Eichten et al. Phys. Rev. D 52 (1995) 1726.

general remarks

Only a fraction of the observed J/ψ's are directly produced.

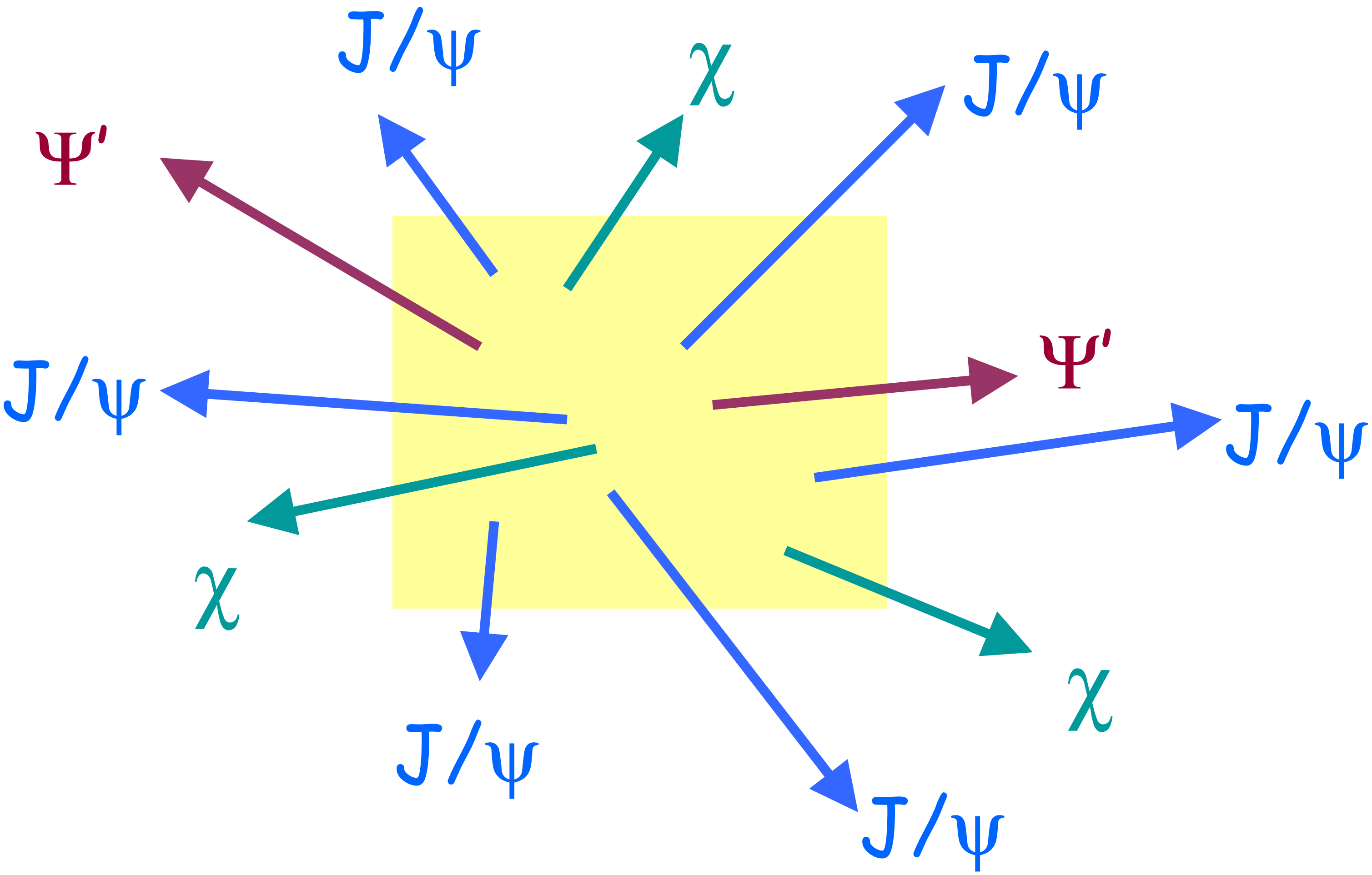
The rest come from the decay of higher excited states.

The feed-down has been studied in p-N and π-N interactions.

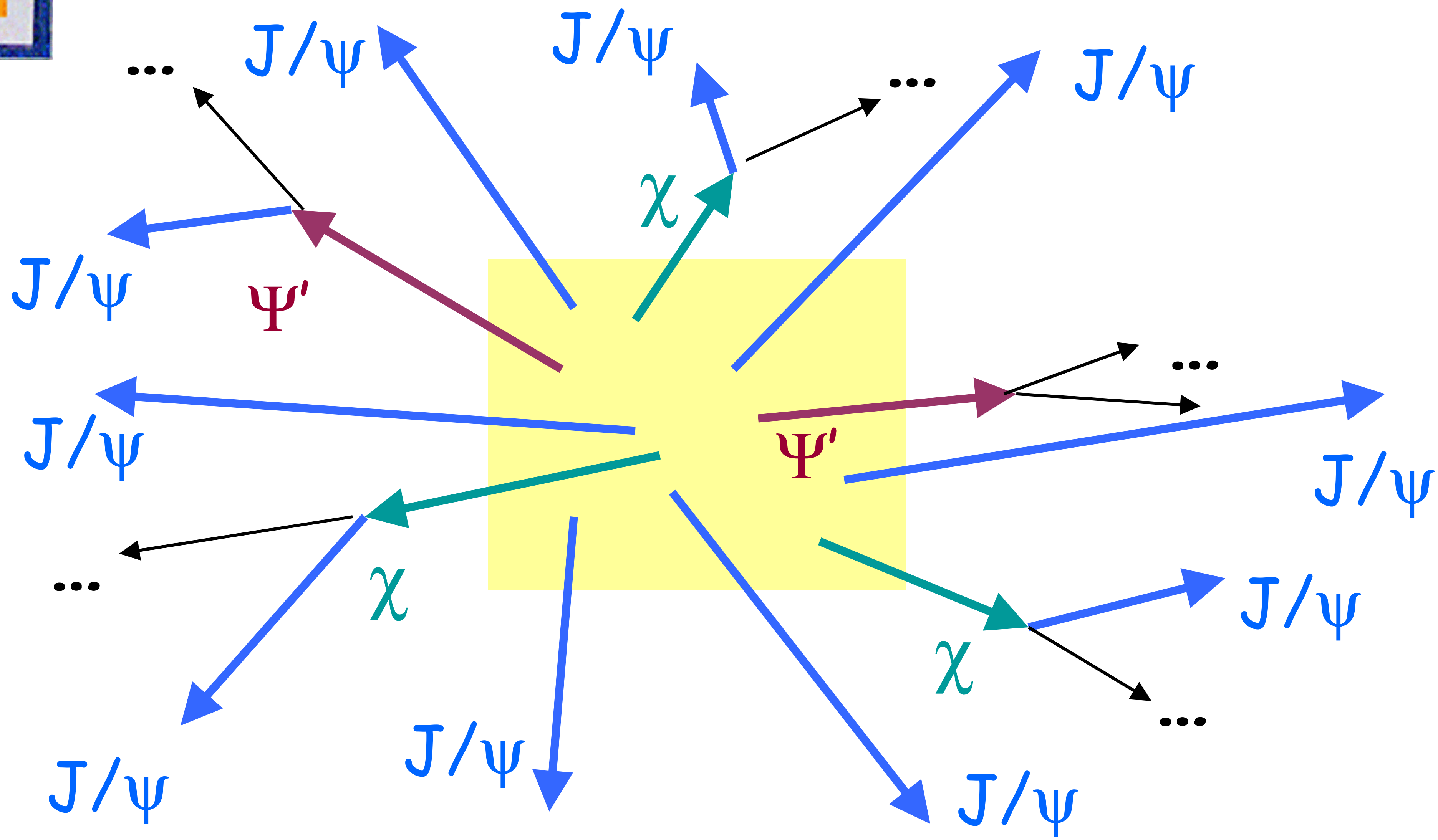


general remarks

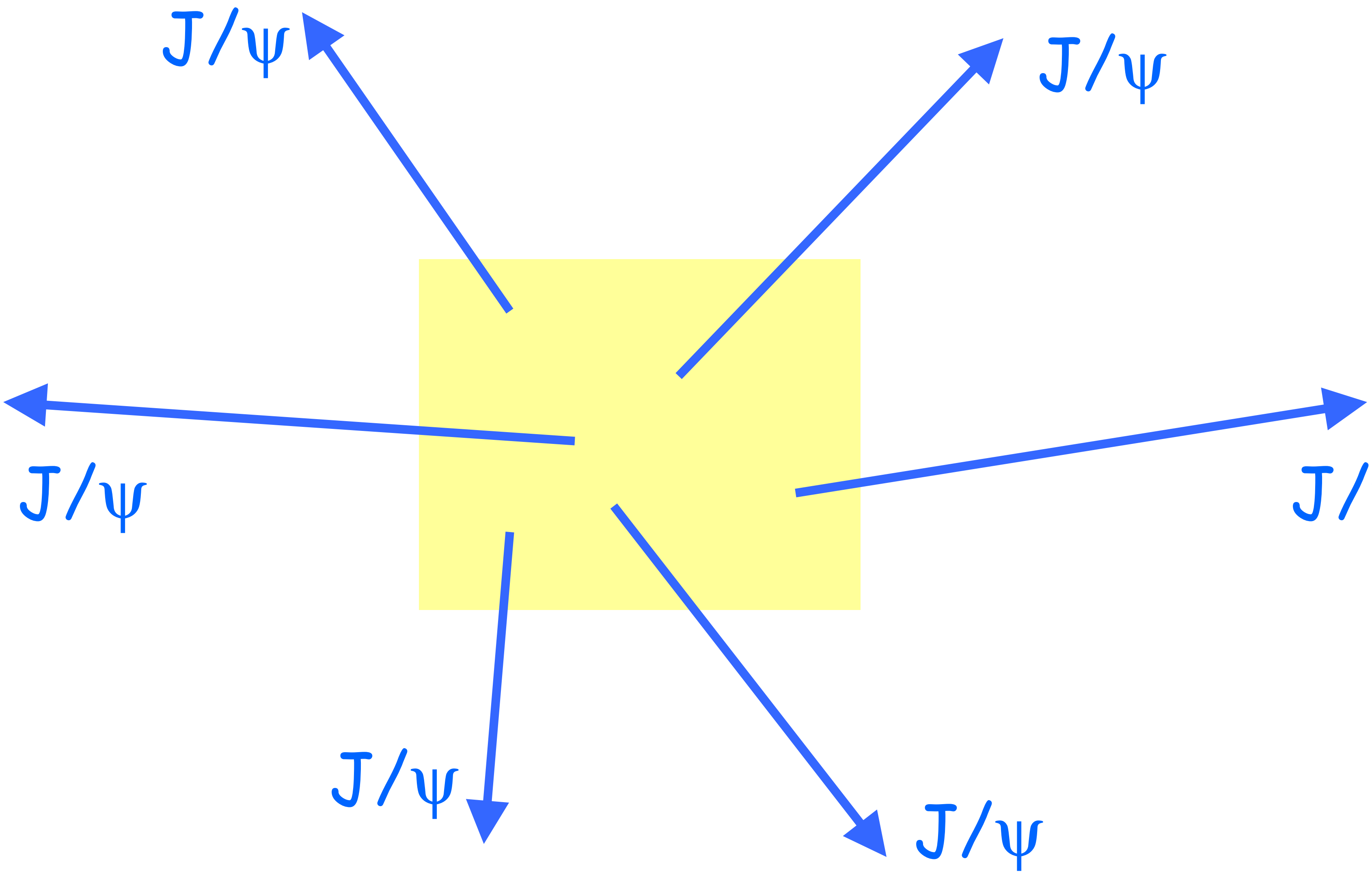
general remarks



general remarks



general remarks



general remarks

The medium (confined / deconfined) affects differently the different charmonium states.

Different properties (binding energy, size,…) implies different dissociation temperatures or different cross-sections for interactions with hadrons.

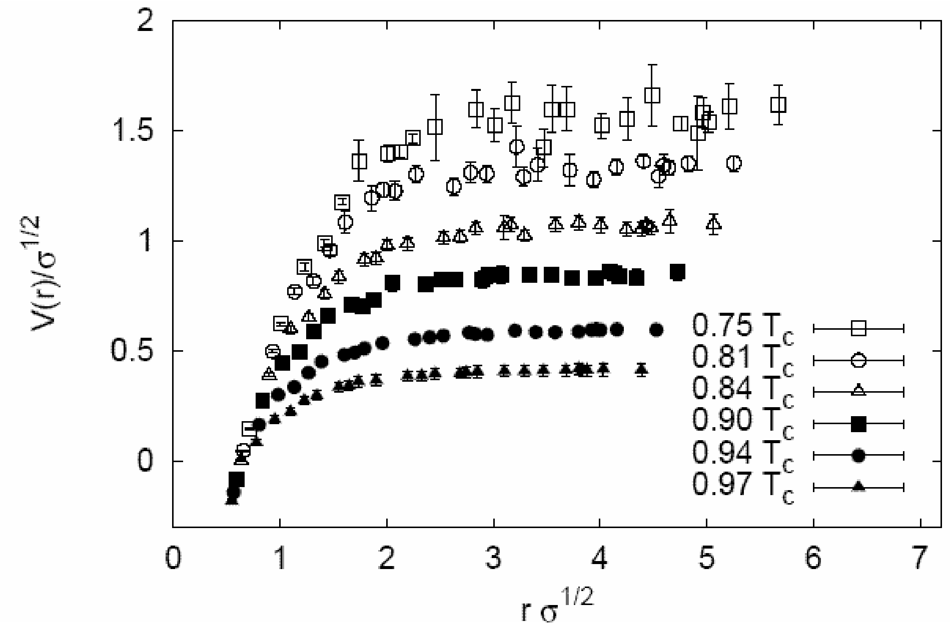
$$S_{J/\psi} = 0.6 S_{J/\psi}^{dir} + 0.3 S_{\chi}^{dir} + 0.1 S_{\psi'}^{dir}$$

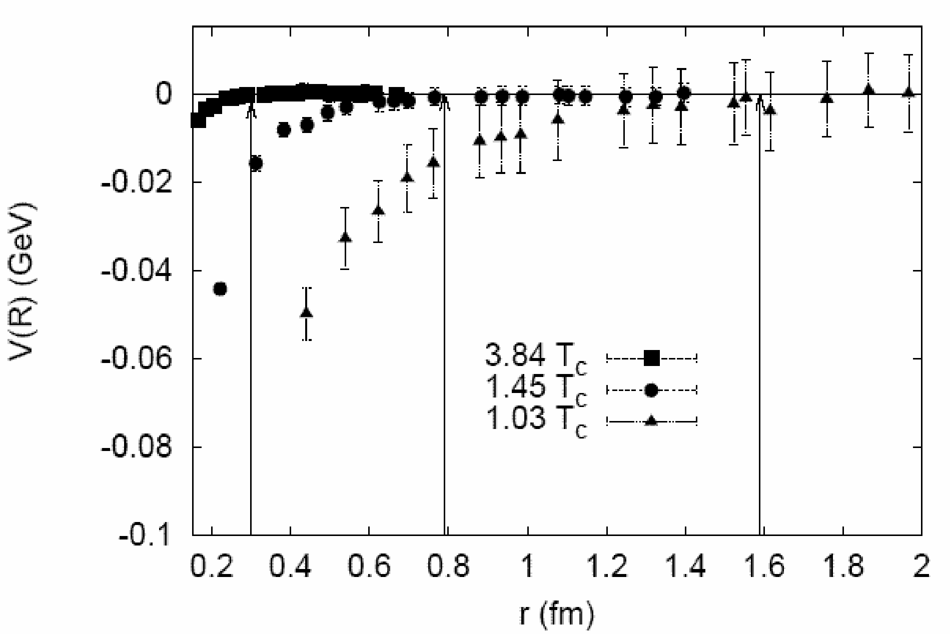
thermal dissociation

thermal dissociation

The heavy quark potential at high T can be obtained with lattice QCD calculation:

$$-T \ln \langle L(0)L^{+}(r)\rangle = V(T,r) - TS + C$$

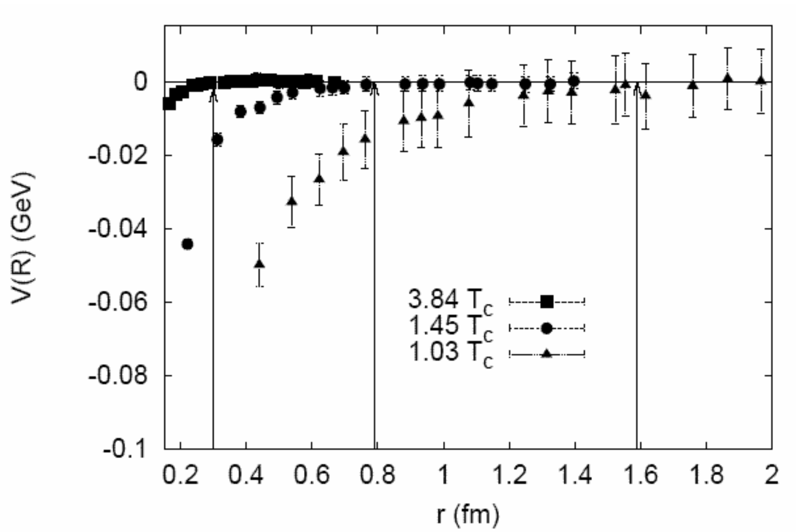


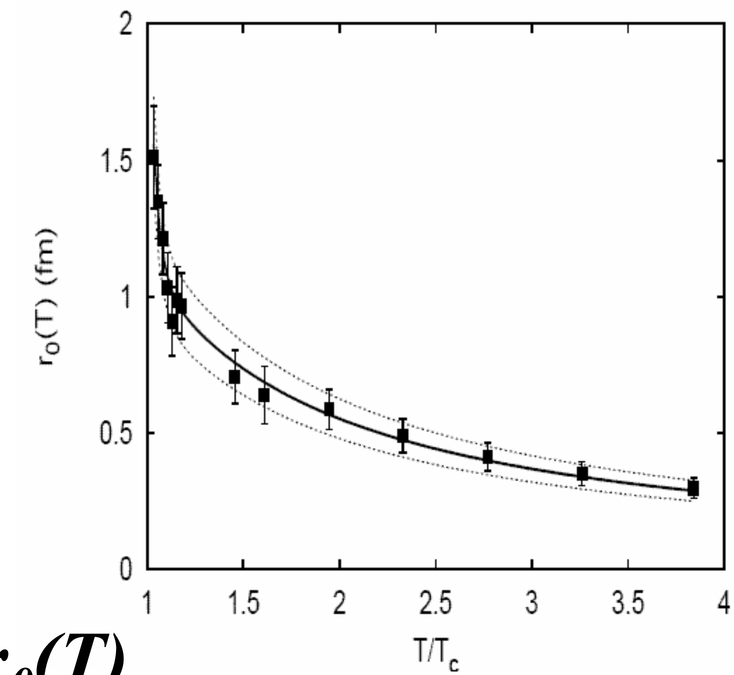


De Tar et al., Phys.Rev.D59('99) 03150; Karsch et al.,Nucl.Phys.B605 ('01) 579

thermal dissociation

Above T_c (170 MeV for 2+1 flavor QCD) :





The interaction vanishes for $r > r_0(T)$

[Digal et al., hep-ph/0110406; Phys.Rev.D64 (2001) 094015]

thermal dissociation

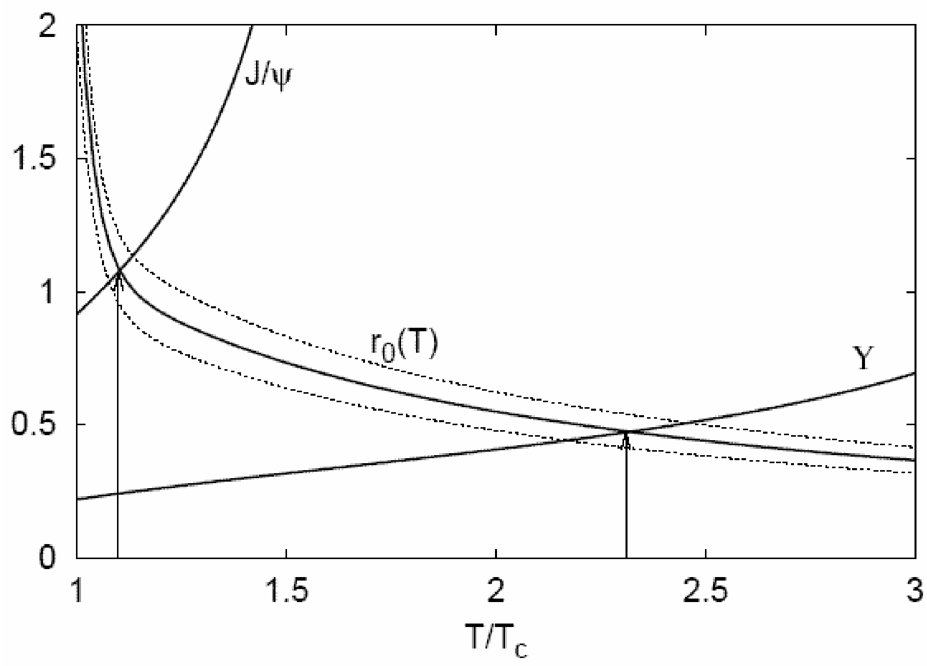
Above T_c

$$[2m + \frac{1}{m}\nabla^2 + V_1(T,r)]\psi_i = M_i\psi_i$$

results: $M_i(T)$, $r_i(T)$

No bound state if

$r_i(T) > r_0(T)$



J/ψ dissolves at T ~ 1.1 T_c

thermal dissociation

$$V(T,r) = -T \;\ln\left\{\frac{1}{9}\exp[-V_1(T,r)/T] + \frac{8}{9}\exp[-V_8(T,r)/T]\right\}$$

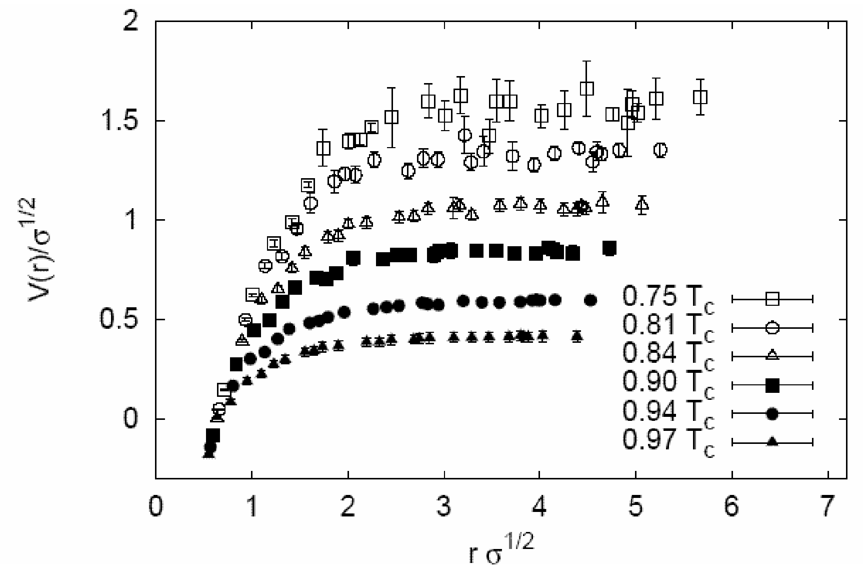
$$V_1(T,r) = -\frac{4}{3}\frac{\alpha(T)}{r}, \quad V_8(T,r) = +\frac{1}{6}\frac{\alpha(T)}{r}$$

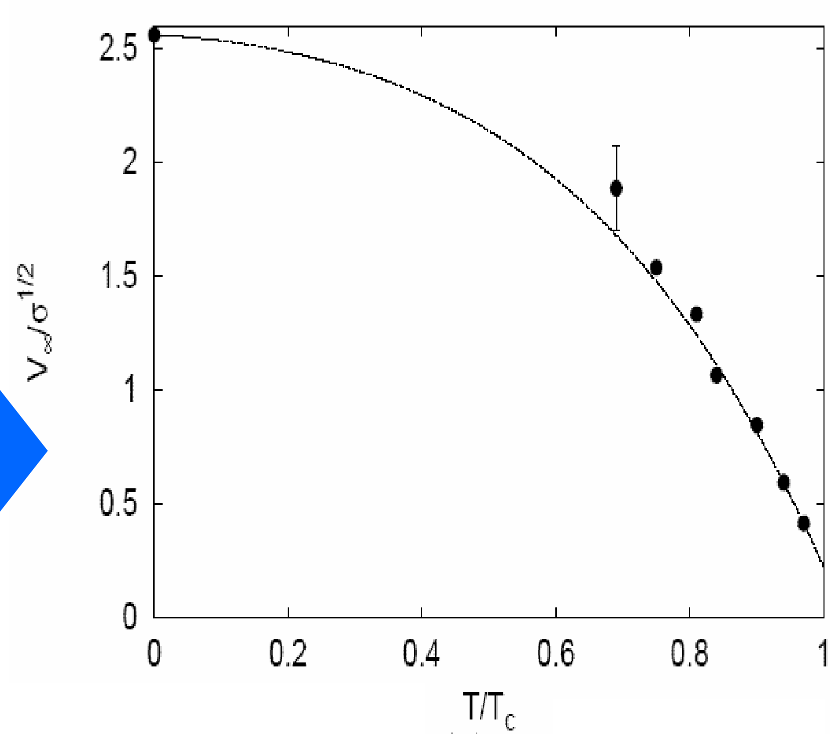
$$-\frac{3}{4}V_1(T,r) = 6\; V_8(T,r) = \frac{\alpha(T)}{r}\exp\{-\mu(T)r\}$$

$$V_8(T,r) = \frac{c(T)}{6}\frac{\alpha(T)}{r}\exp\{-\mu r\}$$

thermal dissociation

Below T_c :

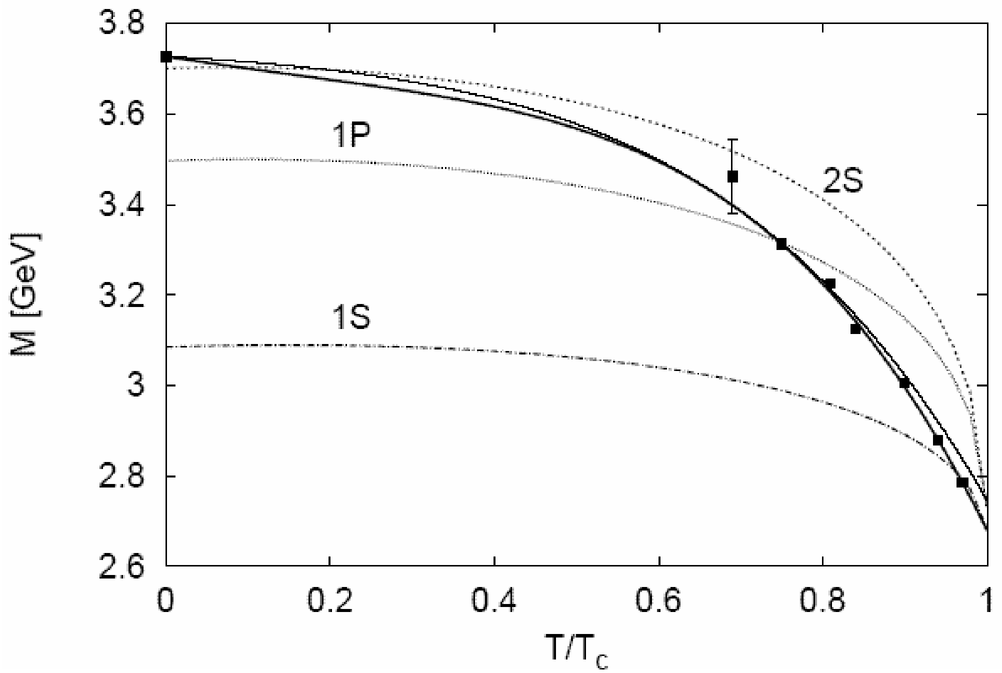




The bound state exists only for

$$M_i(T) < V_\infty(T)$$

thermal dissociation

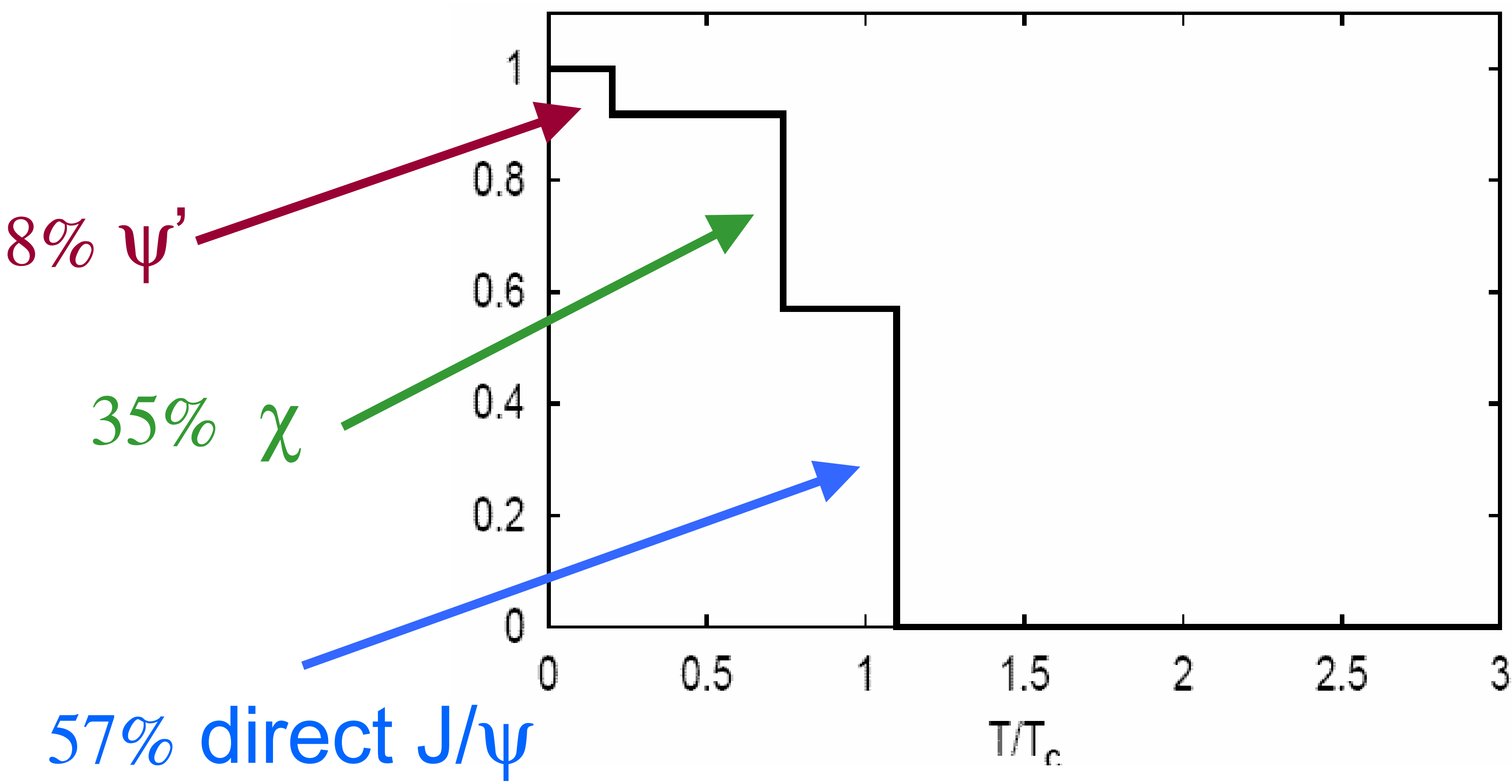


ψ' dissociate at T ~ 0.2 T_c

χ dissociate at T ~ 0.75 T_c

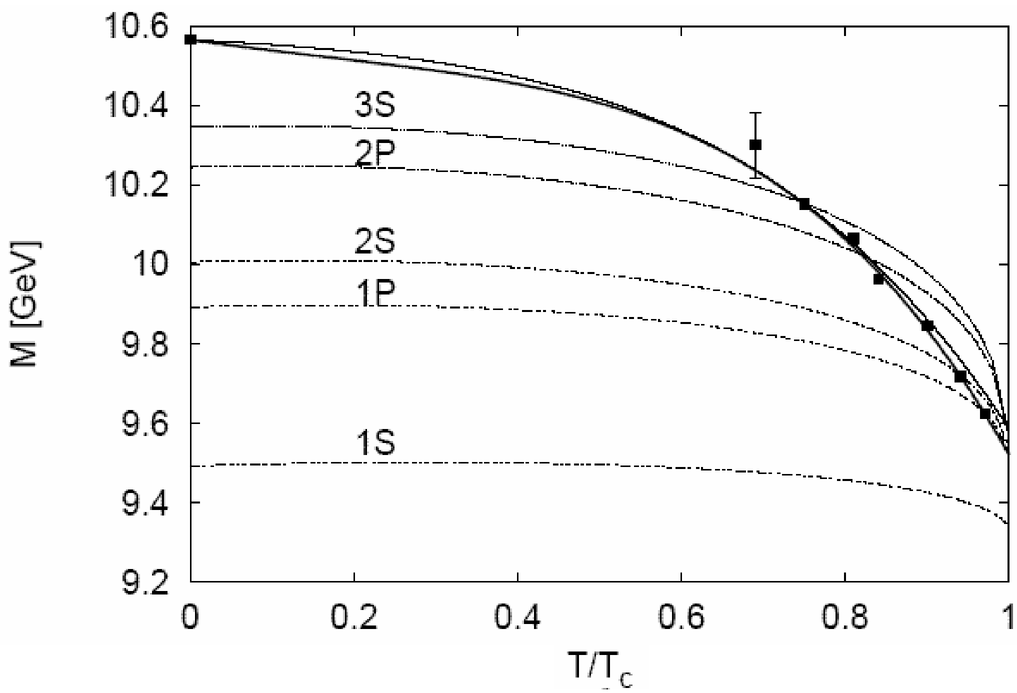
thermal dissociation

J/ψ suppression pattern



thermal dissociation

Results for bottomonium :



thermal dissociation

Υ suppression pattern

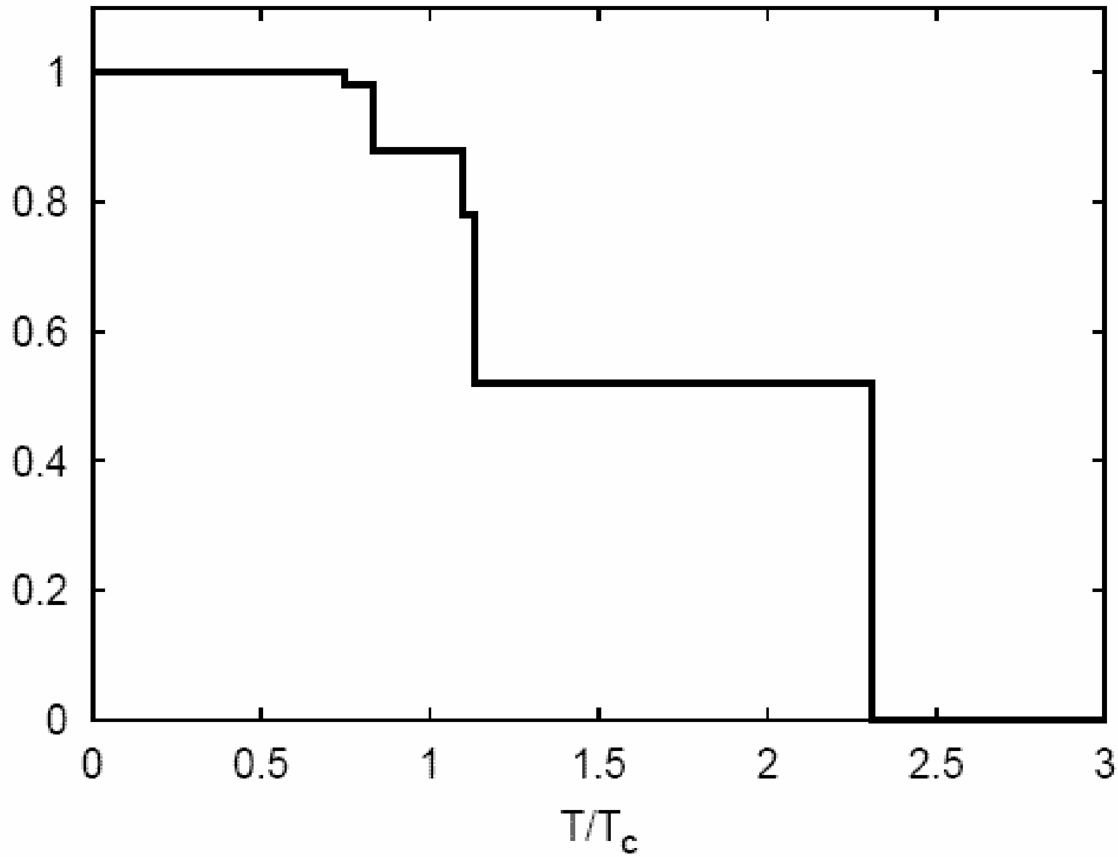
2 % Υ(3s)

10 % χ(2P)

10 % Υ(2s)

26 % χ(1P)

52 % Υ(1s) dir.



thermal dissociation

Warning :

Recent lattice calculations ‡ found:

$$T_{\psi'}^{diss} \approx T_{\chi}^{diss} \approx 1.1 T_c$$

$$T_{J/\psi}^{diss} \approx (1.5 - 2) T_c$$

- The threshold is lowered if the relative momentum is taken into account ¶.
- T dependence of the width ?

‡ Datta et al., hep-lat/0312037 ; hep-lat/0403017; Asakawa et al. hep-lat/0308034

¶ Datta et al., hep-lat/0409147

percolation

percolation

- critical phenomenon
- pre-equilibrium deconfinement
- prerequisite for QGP
- finite system, continuum

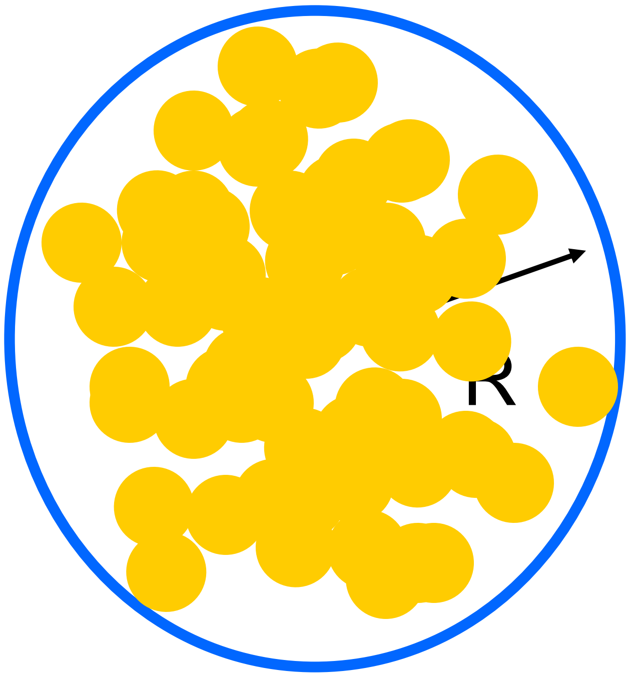
First works:

Baym , Physica (Amsterdam) 96A, 131 (1979)

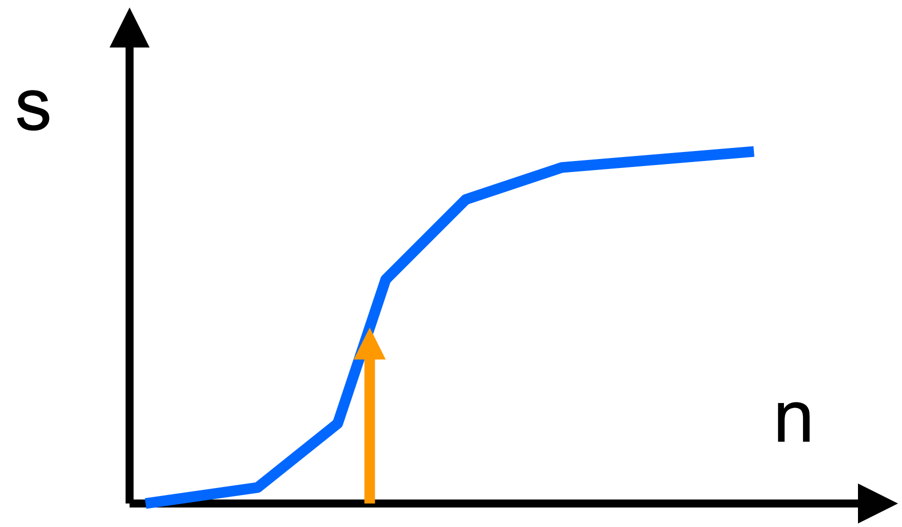
Celik et al., Phys. Lett. 97B (1980) 128

percolation

Circular surface of radius R and N small discs of radius r<<R randomly distributed.



The cluster size increase with increasing $n=N/\pi R^2$



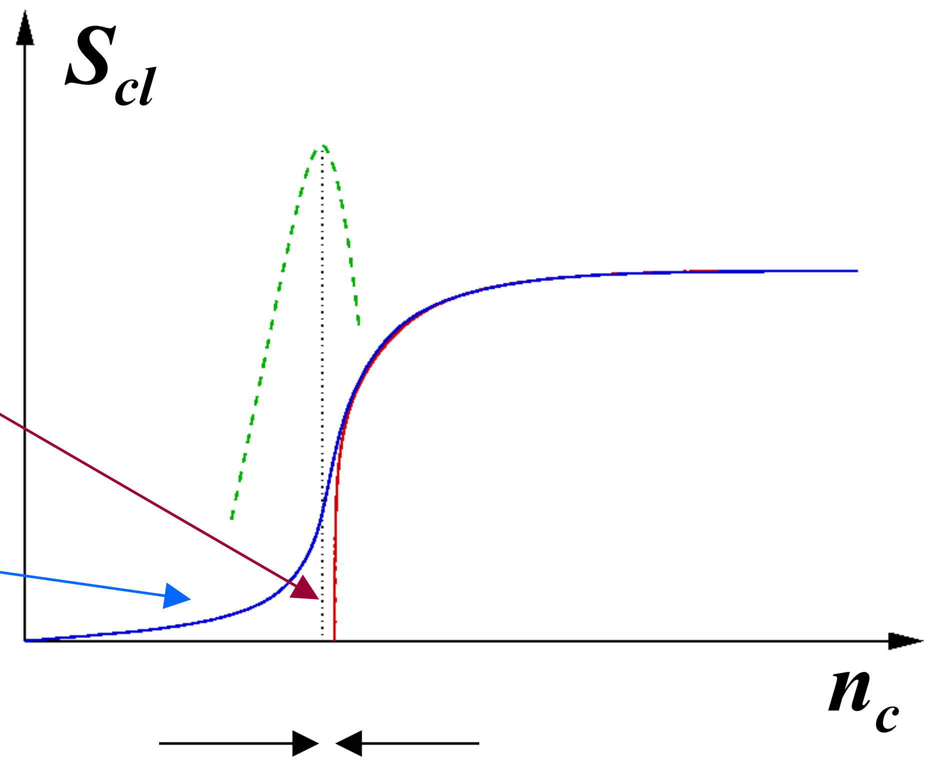
percolation

Continuum percolation

$S_{cl} \sim (n_c - n)^{-\gamma}$

infinite system

finite system



percolation

Cluster formation shows critical behaviour:

in the limit of infinite R and N with constant n

the cluster size diverges at a critical density n_c.

Onset of percolation :

$$n_c = \nu_c / \pi r^2$$

$$S_{cl} \approx (n_c - n)^{-\gamma}$$

with $\gamma = 43/18$; $\nu_c \sim 1.12-1.13$

percolation

J/ψ suppression in percolation models:

- Santiago Model: **Armesto et al., Phys.Rev.Lett. 77 (1996) 3736; Ferreiro et at. Hep-ph/0107319.**
- Bielefeld Model: **Nardi et al. Phys. Lett. B442 (1998) 14; Digal et al., Phys.Lett. B549 (2002) 101; Digal et al., EPJ C32 (2004) 547.**
- Lisbon Model: **Dias de Deus et al., EPJ C16 (2000) 537; Ugoccioni et al. Nucl.Phys. B92 (2001) 83.**

percolation

Santiago Model

• Color strings are exchanged between interacting hadrons.

• The number of strings grows with energy and with the number of partecipating nucleons in nuclear collisions.

•When the density of strings becomes high, some of them fuse.

percolation

- The regions where several strings fuse is a droplet of non-thermalized QGP.
- At the percolation onset the QGP domain becomes comparable to the nuclear size.
- The parameters of the model (transverse size of a string, number of fusing strings) are determined by fitting the anti-Λ rapidity distribution in S-S, S-Ag, Pb-Pb.
  - $r = 0.2$ fm = transverse radius of a string
  - $n_c = 9$ strings/fm^2

percolation

$n_c = 9\ fm^{-2}$

$\sqrt{s}$ (AGeV)	Collision			
	$p-p$	$S-S$	$S-U$	$Pb-Pb$
19.4	4.2	123	268	1145
	1.3	3.5	7.6	9.5
200	7.2	215	382	1703
	1.6	6.1	10.9	14.4
5500	13.1	380	645	3071
	2.0	10.9	18.3	25.6

Table 1. Number of strings (upper numbers) and their densities (fm^{-2}) (lower numbers) in central p–p, S–S, S–U and Pb–Pb collisions at SPS, RHIC and LHC energies.

At SPS energies the percolation threshold is between central S-U and central Pb-Pb

percolation

Bielefeld model:

The transverse size r_c of the percolating partons is determined by the condition ($Q_c=1/r_c$) :

$$n_s(A)\left(\frac{dN_q(x,Q_c^2)}{dy}\right)_{x=Q_c/\sqrt{s}} = \frac{\nu_c}{(\pi/Q_c^2)}$$

the density of the largest cluster at the percolation point is :

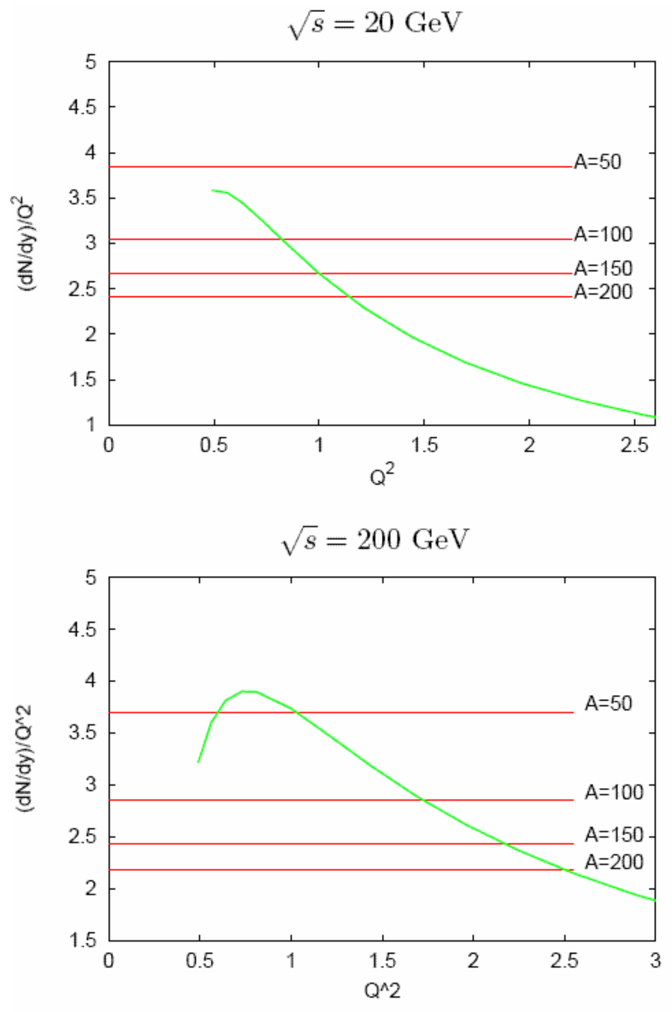
$$m_c(A,Q_c,\sqrt{s}) = \frac{\eta_c}{(\pi/Q_c^2)}$$

with $\eta_c=1.72$ (local percolation condition)

percolation

$$n_s(A)\left(\frac{dN_q}{dy}\right)=\frac{\nu_c}{\pi/Q_c^2}$$

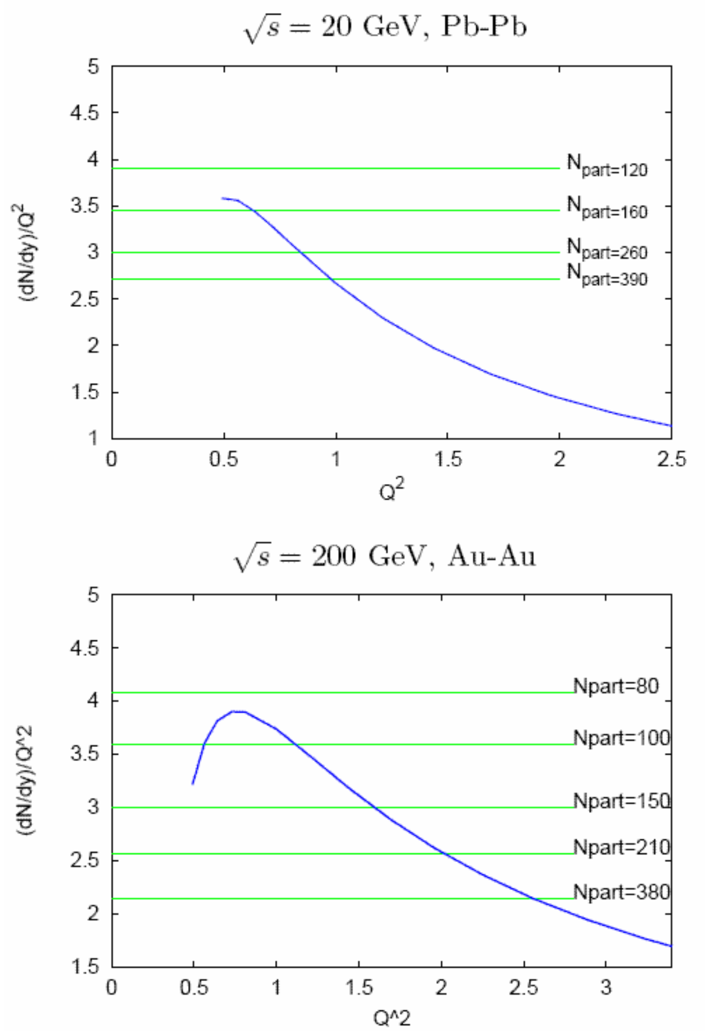
$$\frac{\pi}{Q_c^2}\left(\frac{dN_q}{dy}\right)=\frac{\nu_c}{n_s(A)}$$



percolation

$$n_s(A,b)\left(\frac{dN_q}{dy}\right)=\frac{\nu_c}{\pi/Q_c^2}$$

$$\frac{\pi}{Q_c^2}\left(\frac{dN_q}{dy}\right)=\frac{\nu_c}{n_s(A,b)}$$



percolation

For realistic nuclei the initial parton distribution is given by nuclear density profile (Fermi distrib.).

ν_c, η_c : same as for uniform distribution.

Q_c~ 0.7 GeV, N_{part} = 125 (b ~ 8fm)

Q(χ)~0.6 GeV

Q(ψ')~ 0.5 GeV

χ and ψ' are dissociated at the percolation (onset of deconfinement).

Directly produced J/ψ's survive because

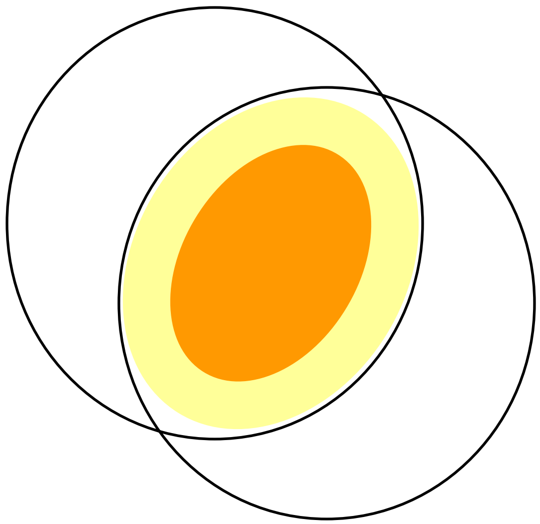
Q(J/ψ)~1GeV; second threshold at N_{part}=200-300

fluctuations

- N_{part} – b : gaussian distribution of N_{part} around its mean value
- non-uniform initial distribution:

internal region is hot : deconf.

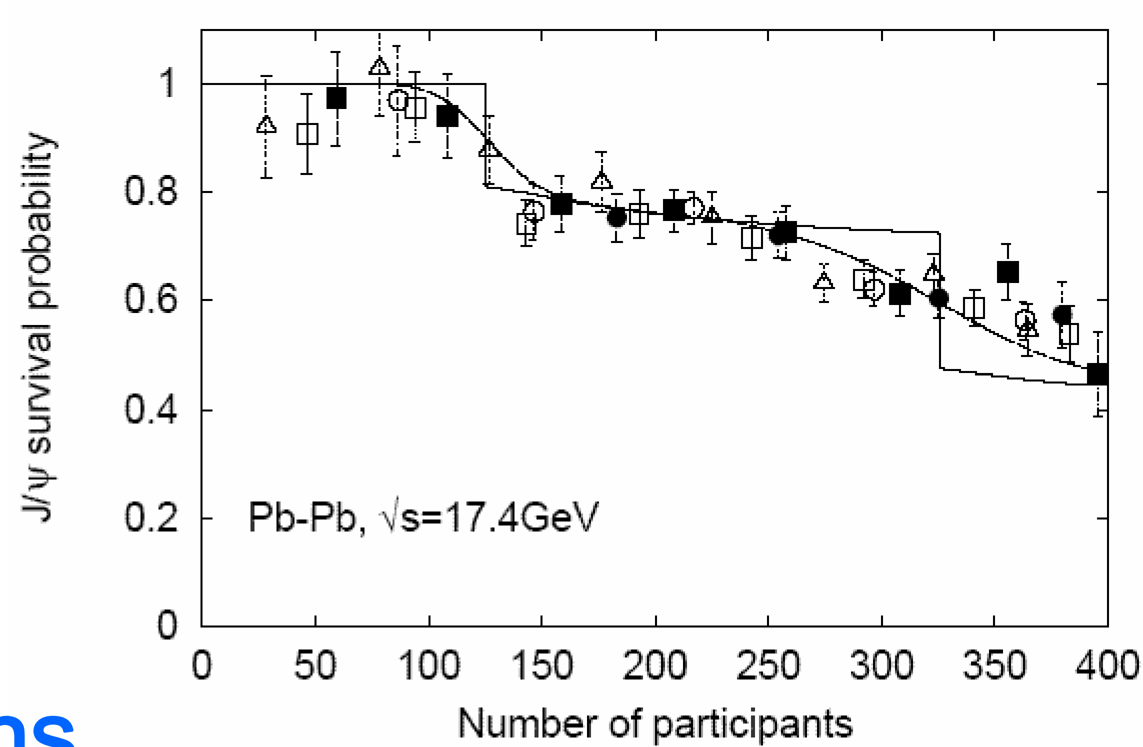
external surface is cold



percolation

Results :

(including N_{part}-b fuctuations)



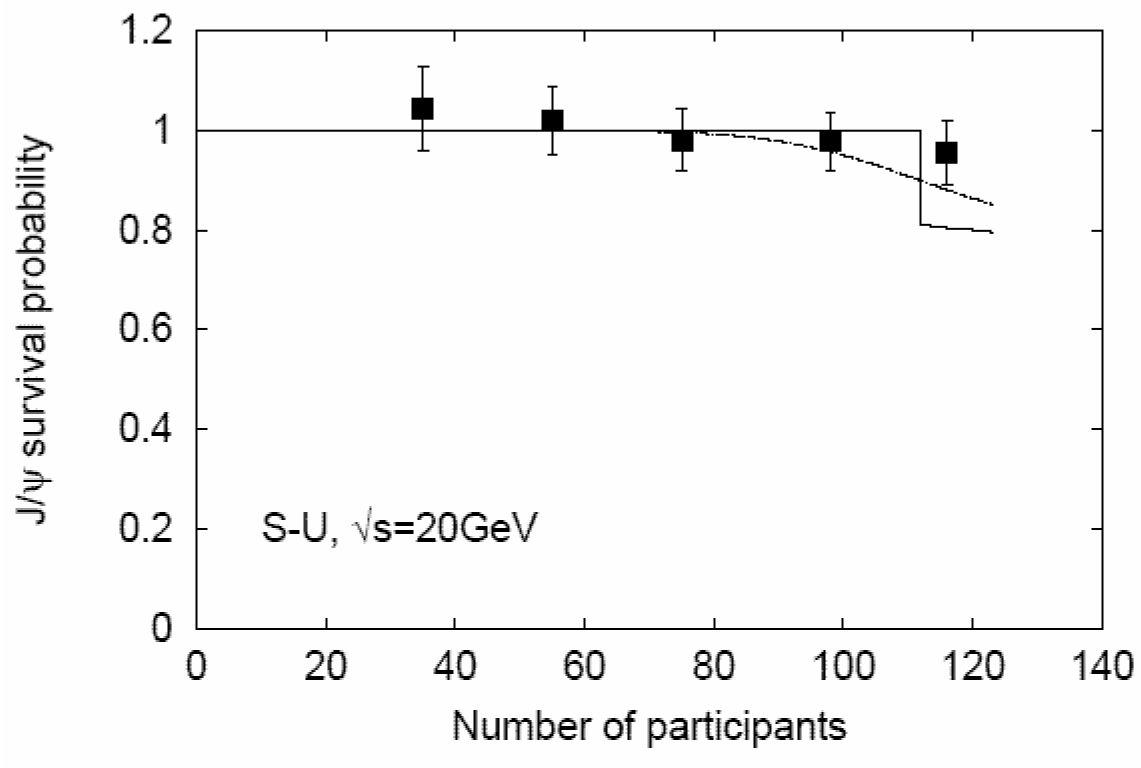
Pb-Pb collisions at SPS

Data: NA50 Coll.

percolation

Results :

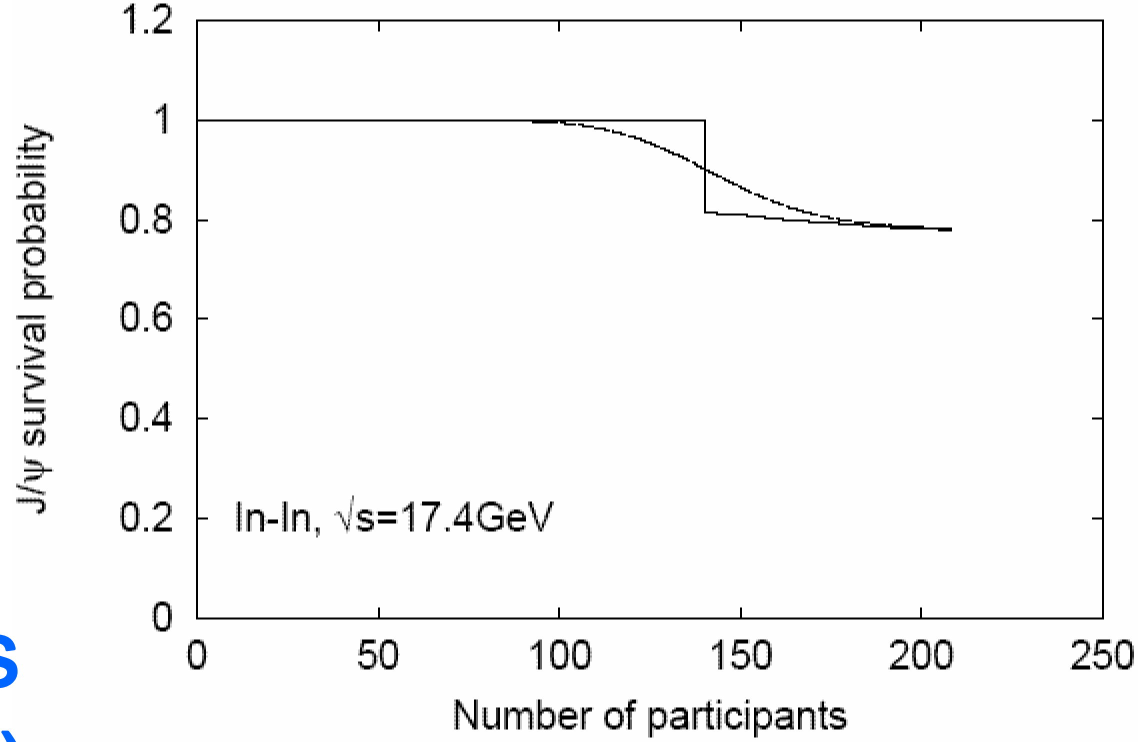
(including N_{part}-b fuctuations)



S-U collisions at SPS

percolation

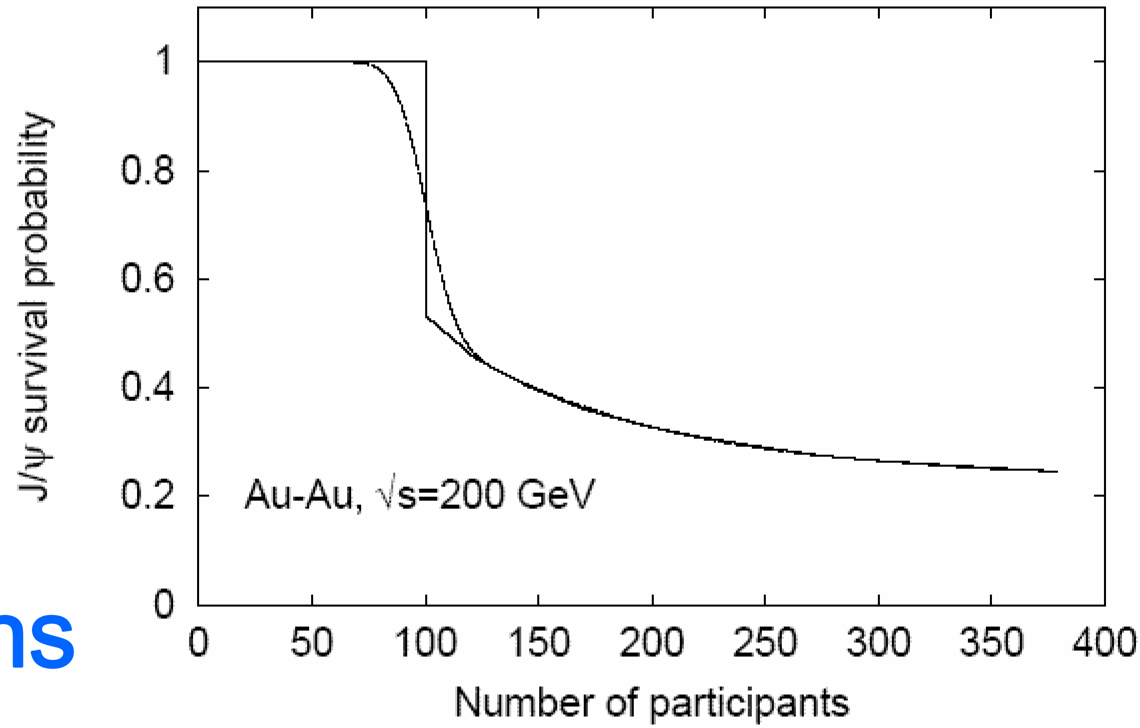
Predictions:



In-In collisions at SPS (NA60)

percolation

Predictions:



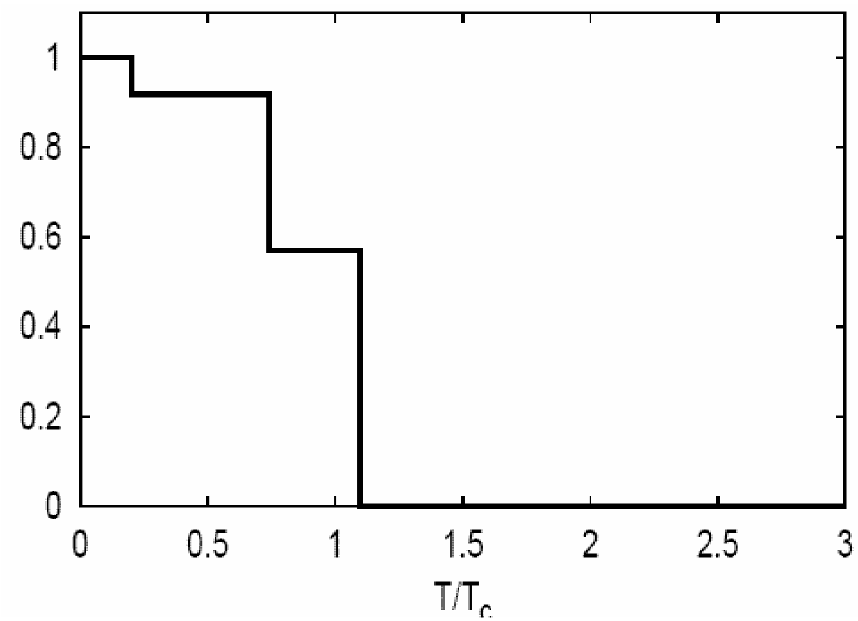
Au-Au collisions at RHIC

Common onset for all charmonium states !

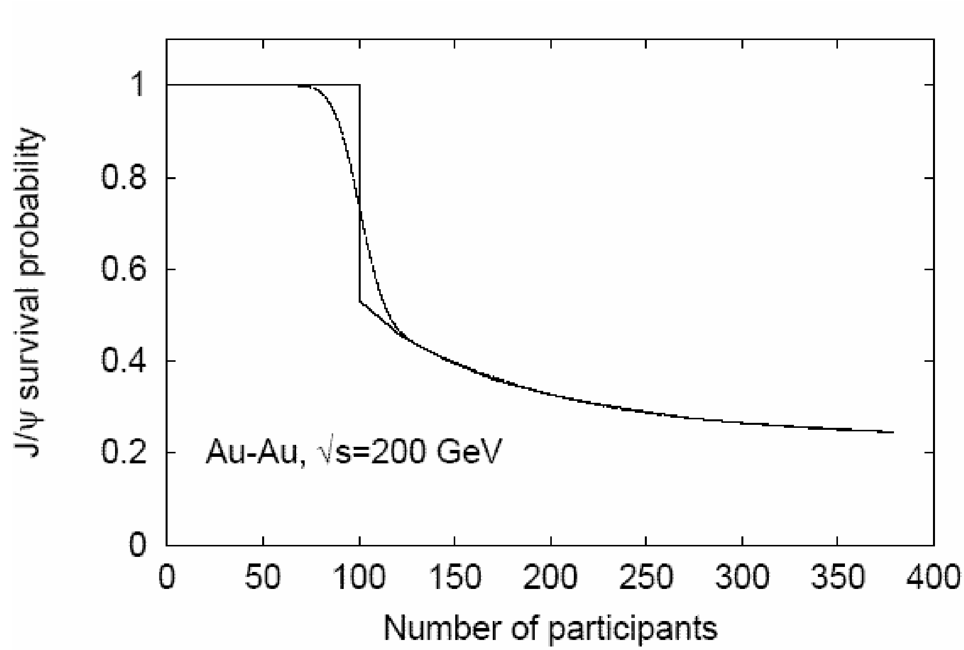
Percolation or thermal dissociation ?

Au-Au collisions at RHIC

Thermal dissociation



Percolation



hadronic interactions : gradual suppression

percolation

Lisbon Model:

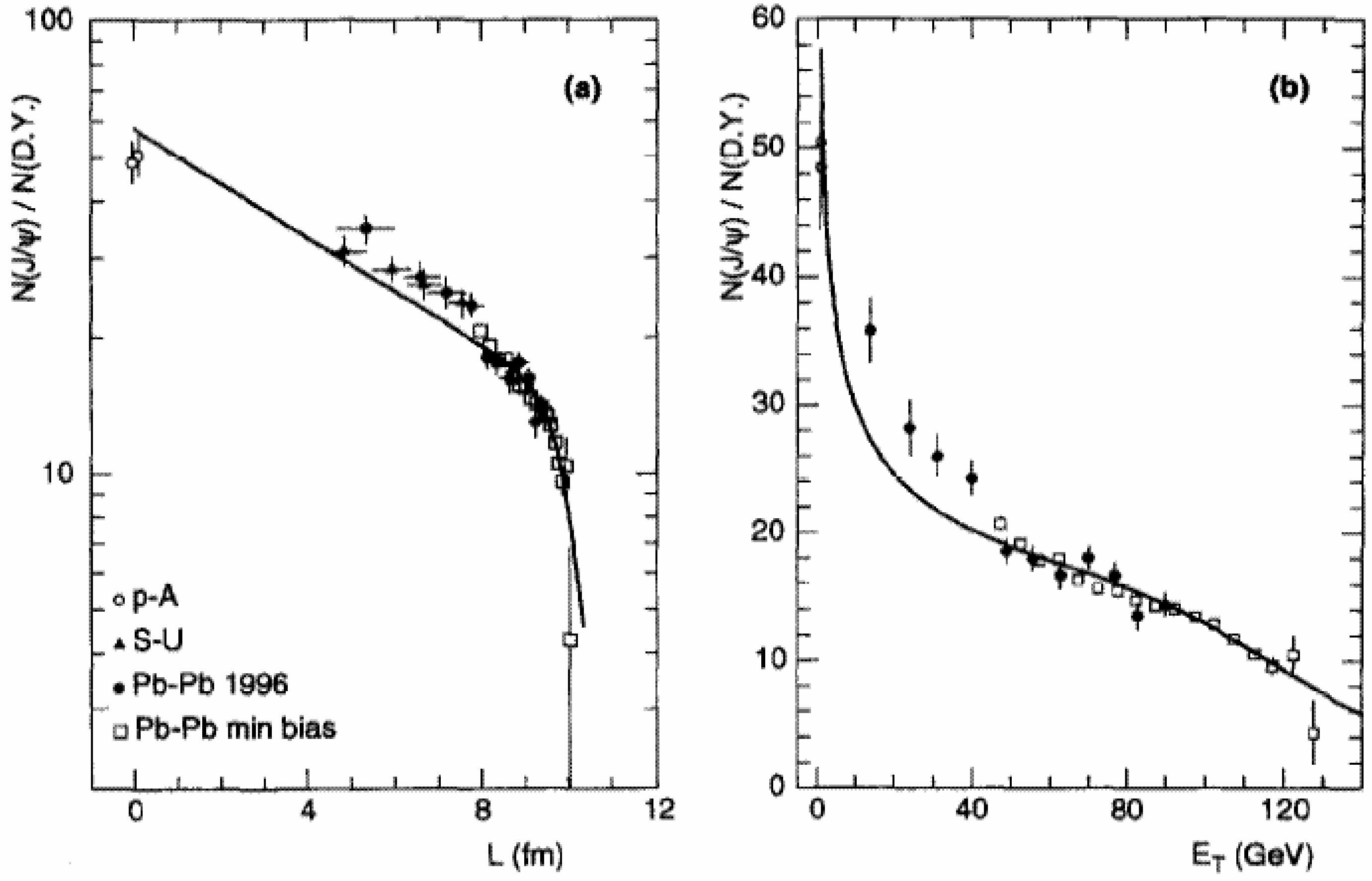
•**Framework of a multicollisional model.**

•**String absorption and fusion: J/ψ** suppression, multiplicity distribution, E_T distribution

•Number of string ∝ number of collisions; r=0.2fm

$$\left.\frac{\sigma^{J/\psi}}{\sigma^{DY}}\right|_{AA} = \left.\frac{\sigma^{J/\psi}}{\sigma^{DY}}\right|_{pp} \exp\{-L\rho_s\sigma\}\left[\exp\left\{\frac{\eta(\nu)-\eta_c}{a}\right\}+1\right]^{-1}$$

$$\eta(\nu) = \pi_s^2 \frac{2\nu}{S(\nu)}$$



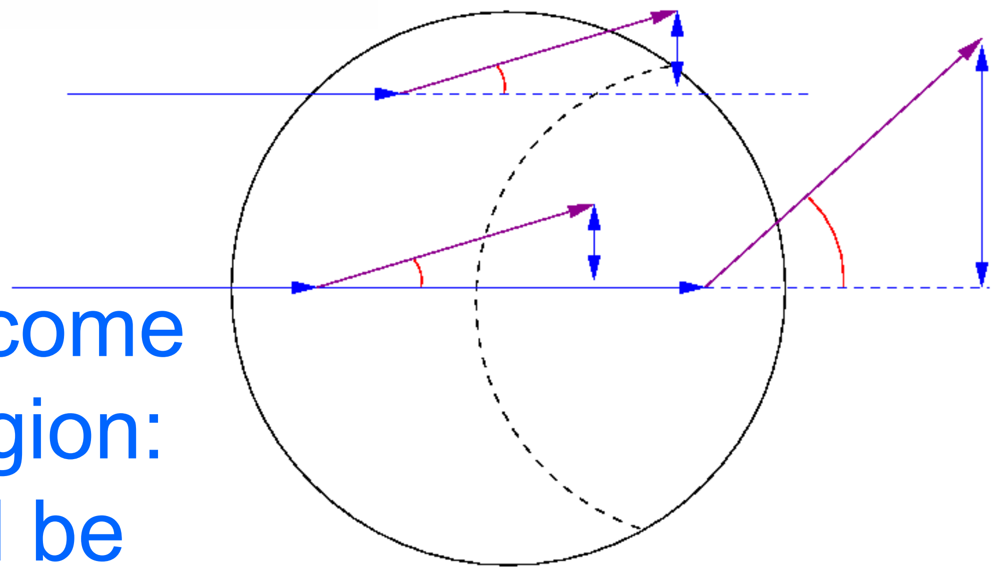
(a)
N(J/ψ) / N(D.Y.)
100
10
0
4
8
12
L (fm)
p-A
S-U
Pb-Pb 1996
Pb-Pb min bias
(b)
60
50
40
30
20
10
0
40
80
120
E_T (GeV)

Can we see the step(s) ?

$$\delta_{pA} \equiv \langle P_T^2 \rangle_{pA} - \langle P_T^2 \rangle_{pp} = \langle q_T^2 \rangle_A - \langle q_T^2 \rangle_p$$

$$\delta_{pA} = N_c^A \delta_0$$

J/ψ's with larger p_T come from the internal region: the step(s) should be more evident



percolation and deconfinement

- Deconfinement in SU(2) gauge theory can be described by the percolation of clusters of like-sign Polyakov loops in 2 space dimensions.
- Analogy with critical behaviour of the Ising model ~ percolation of clusters of parallel spins.
- L(T) in presence of dynamical q is not an order parameter.
- P(T) can be defined also for dynamical q

[hep-lat/9908033 ; hep-lat/0012006]

conclusions

conclusions

- Present experimental data do not allow to distinguish between the two scenarios. Future experiments will help.
- Progress to extend the percolation approach to different observables.

Thank you !

percolation

Continuum percolation

$S_{cl} \sim (n_c - n)^{-\gamma}$

infinite system

finite system