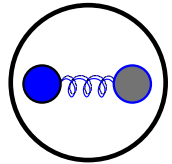# Lecture III:
Quarkonia and Jets in QGP

Johanna Stachel, Universität Heidelberg, Germany
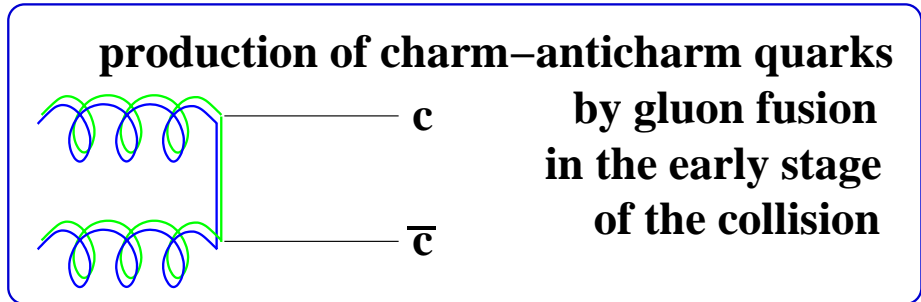
- Motivation

- J/ψ Production at SPS energy

- Statistical Coalescence Model and Data

- Jets in Nuclear Collisions

Charm production and J/$\psi-$ suppression

Hadrons with charm−anticharm valence quarks

J/ψ	ψ'
r=0.45 fm	r=0.9 fm
mass=3097 MeV	3686 MeV

production of charm−anticharm quarks

c

$\bar{c}$
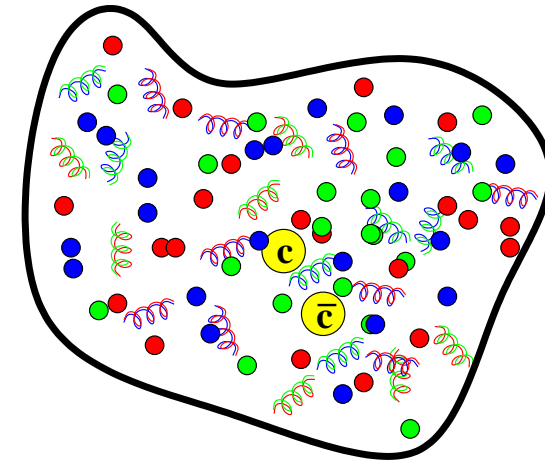
by gluon fusion
in the early stage
of the collision

typically 1 $c\bar{c}$−pair per 6 Pb+Pb collisions
about 1 in 118 would evolve into a J/ψ
about 1 in 7200 into a ψ'

but in Quark−Gluon−Plasma c and $\bar{c}$ do not find each other
"attractive interaction is screened"

expect significantly less J/ψ
and ψ' than without Quark−Gluon−Plasma

c

$\bar{c}$

Detection: 7% of all J/ψ −> $\mu^+\mu^-$

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

color screening in QGP prevents $c\bar{c}$ binding

screening radius temperature dependent

heavy quark potential

$$V(r) = \sigma \cdot r - \alpha/r$$

becomes screened at finite T:

$$V(r, T) = \frac{\sigma}{\mu(T)}(1 - exp(-\mu(T)r)) - \frac{\alpha}{r}exp(-\mu(T)r)$$

and at some $\mu(T)_D$ and T_D bound state dissolves

F. Karsch and H. Satz, Z. Physik **C51 (1991) 209**

	J/ψ	ψ'	χ_c	Υ	Υ'
state	1s	2s	1p	1s	2s
mass(GeV)	3.1	3.7	3.5	9.4	10.0
r (fm)	0.45	0.88	0.70	0.23	0.51
T_D/T_c	1.17	1.0	1.0	2.62	1.12
ϵ_D (GeV/fm^3)	1.92	1.12	1.12	43.3	1.65

small states melt at very high temperature only!

screening of heavy quark potential in lattice QCD

➤ $T = 0$: heavy quark bound states well described by a confining potential

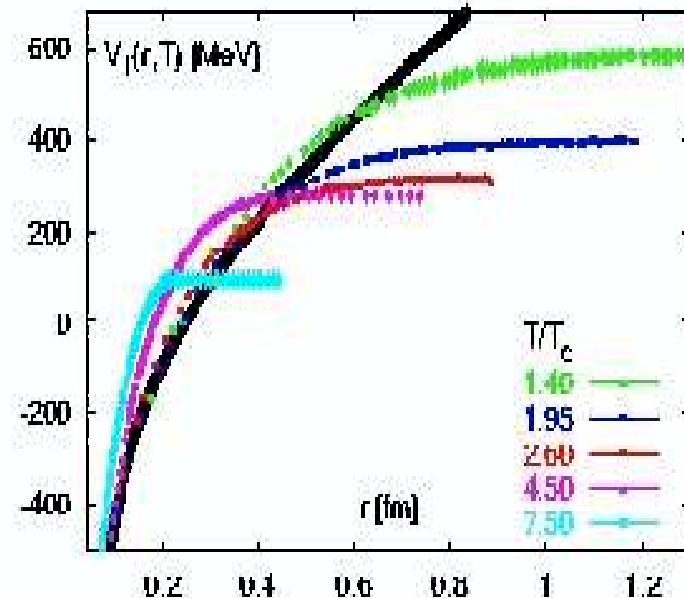$$V_{\bar{q}q}(r) = -\frac{4\alpha}{3r} + \sigma r, \quad \alpha \equiv g^2(r)/4\pi$$

➤ $T > T_c$: no bound state in a Debye screened potential: $V_{\bar{q}q}(r,T) \sim -\frac{\alpha}{r} e^{-\mu r}$

$V_{\bar{q}q}(r,T) \rightarrow \infty$ confinement
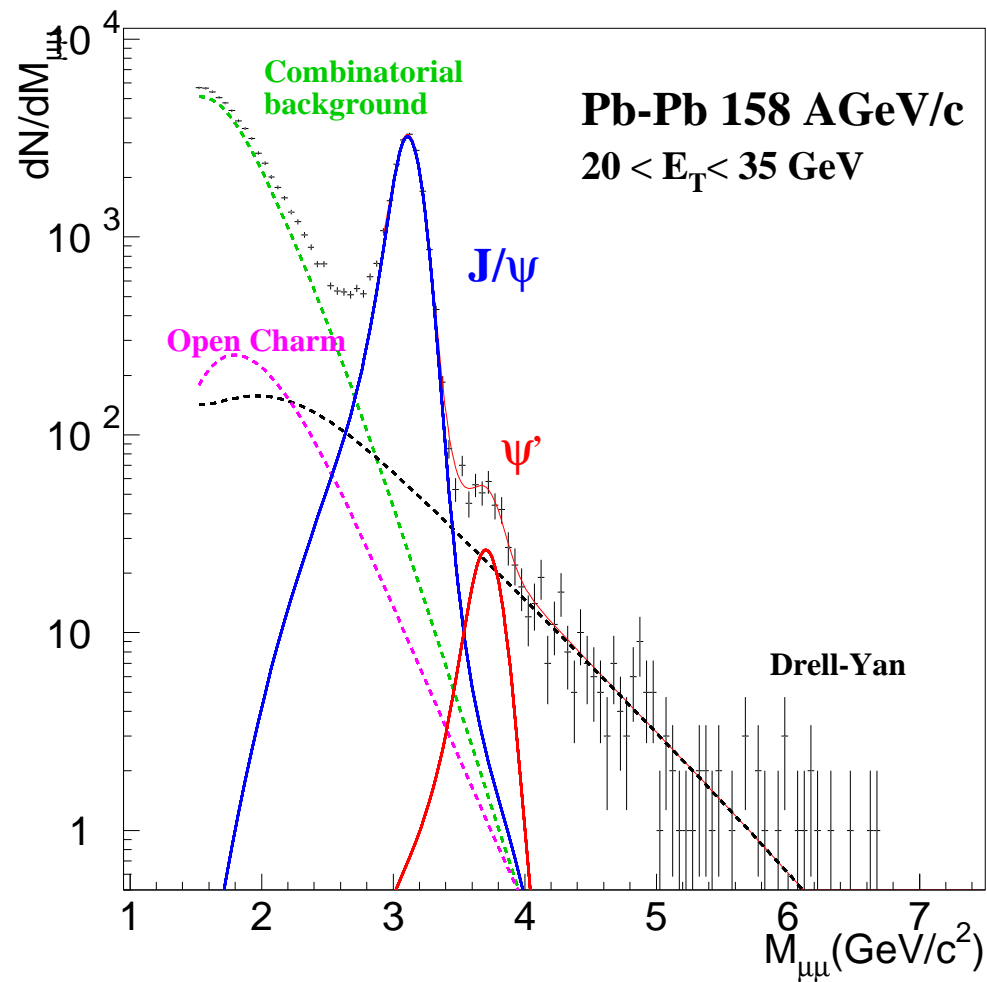
$V_{\bar{q}q}(r,T) < \infty$ deconfinement

J/ψ suppressio

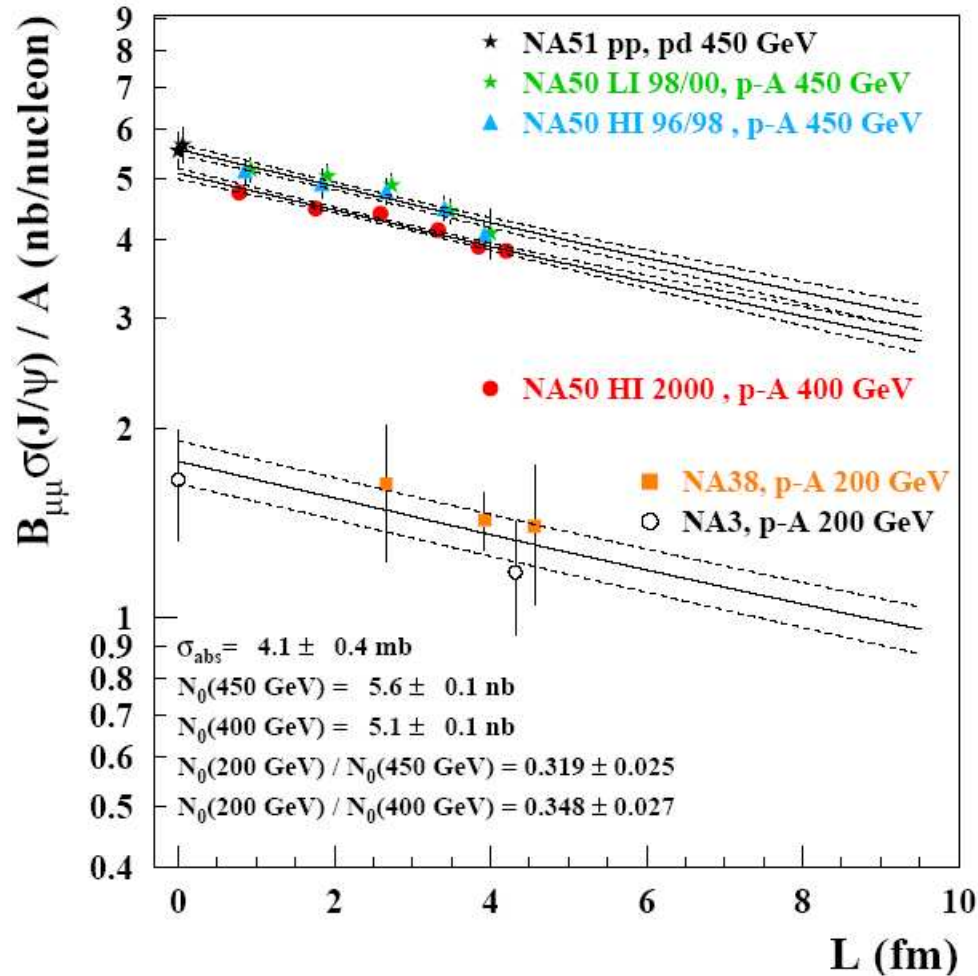F. Karsch, QM2004
J/ψ screened at about 2 T_c

J/ψ Production in Heavy Ion Collisions

NA50 Experiment at SPS: 158 GeV/c Pb + Pb $\rightarrow \mu^+\mu^-$
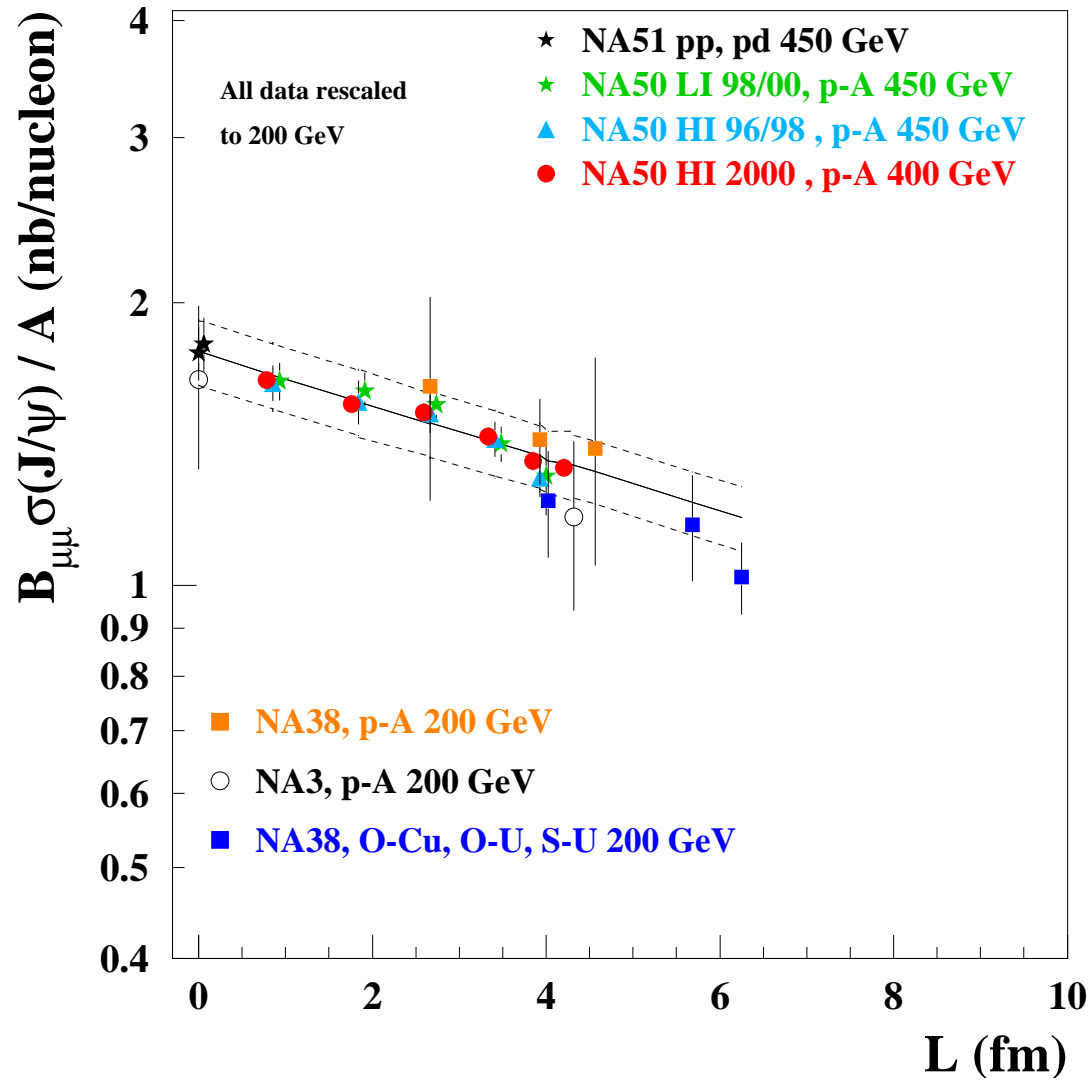
J/ψ Suppression in pA Collisions

NA50,Phys.Lett.B553(2003)167

Universal absorption of
prehadronic state on nucleons:

$$\sigma(J/\psi) \propto exp(-\rho\sigma_{abs}L)$$

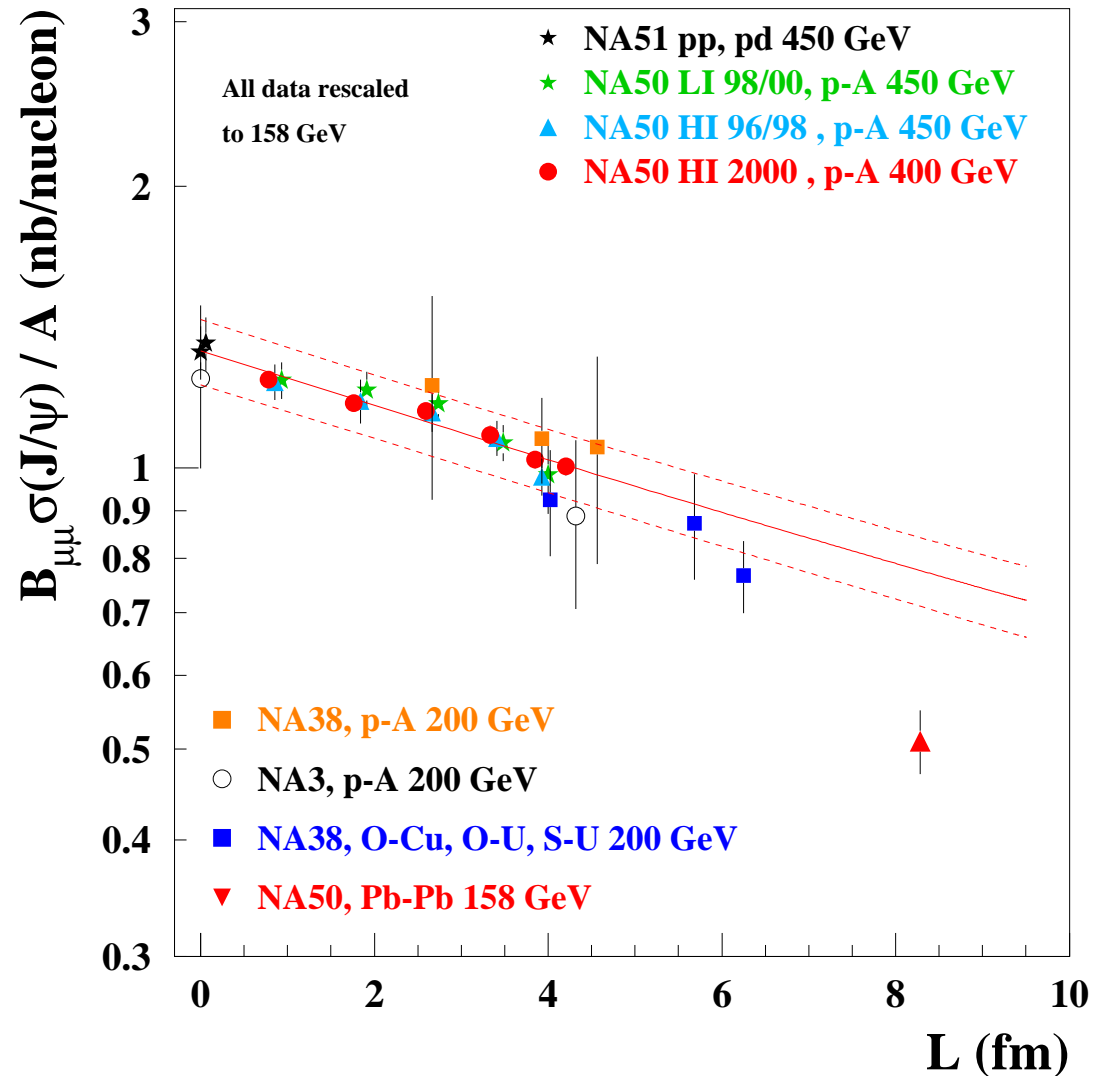with $\rho = 0.17/\text{fm}^3$ and $\sigma_{abs} = 4.1 \pm 0.4$ mb
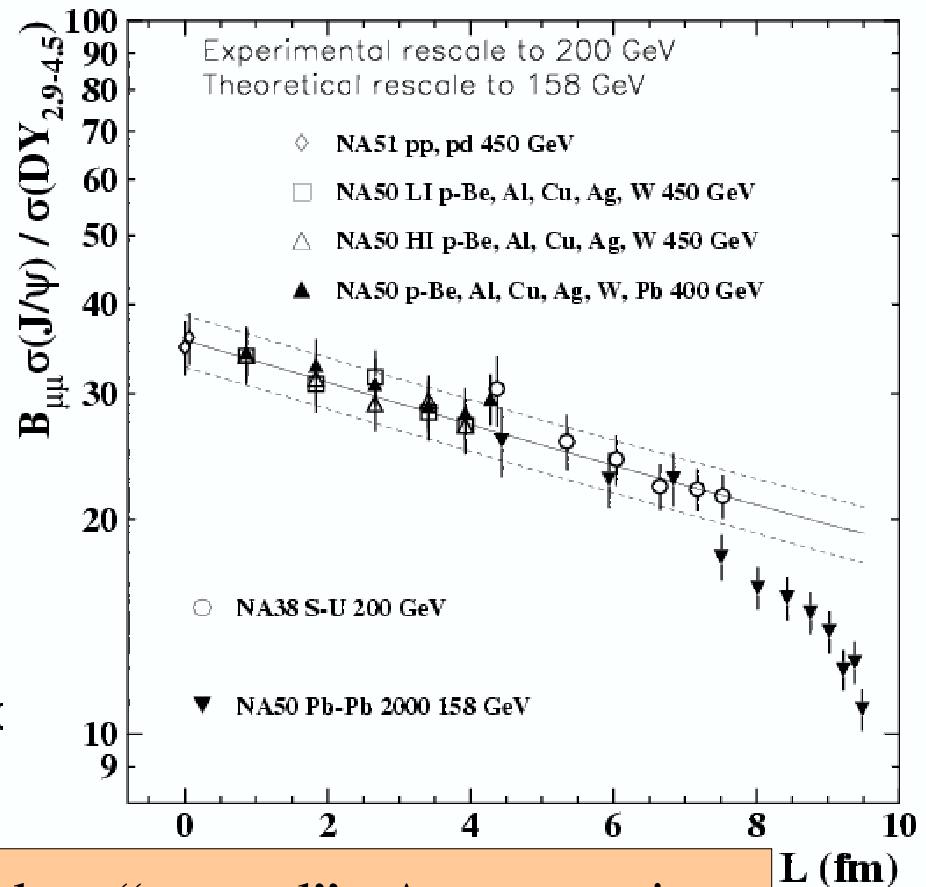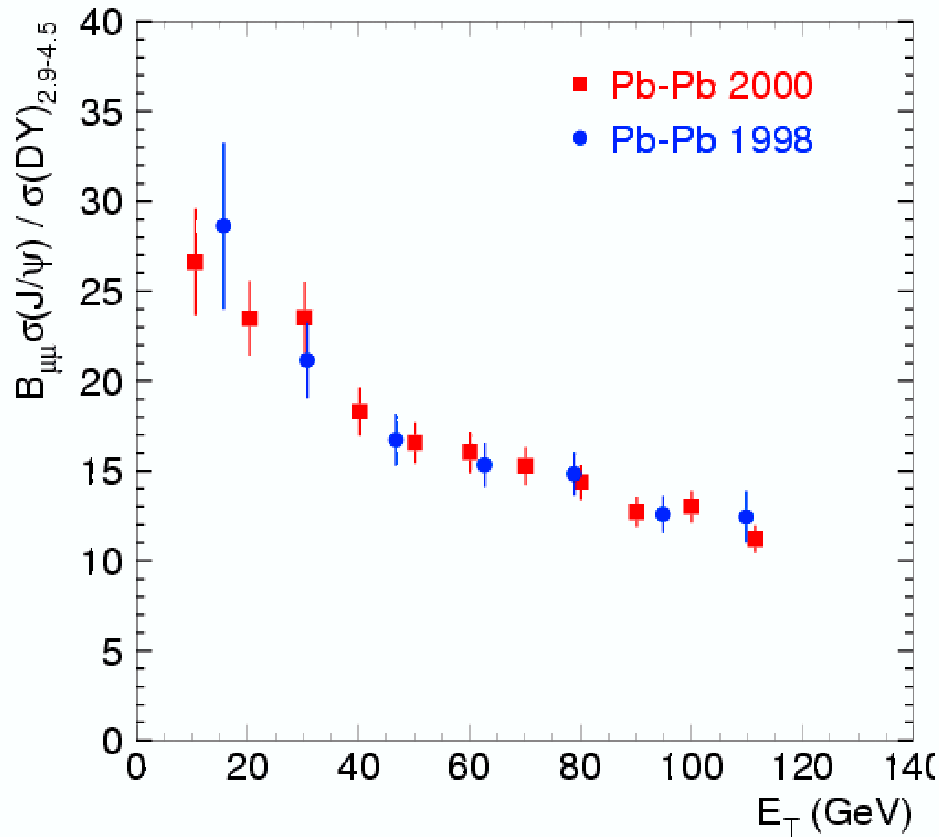
Light Nuclear Collisions fit into the same Picture

NA50,Phys.Lett.B553(2003)167

$\sigma(J/\psi) \propto exp(-\rho\sigma_{abs}L)$ with $\rho = 0.17/\text{fm}^3$ and $\sigma_{abs} = 4.1 \pm 0.4$ mb

but Pb + Pb Collisions are significantly more suppressed

Suppression of J/ψ production in Pb + Pb as function of centrality

systematically central collision below "normal" pA suppression
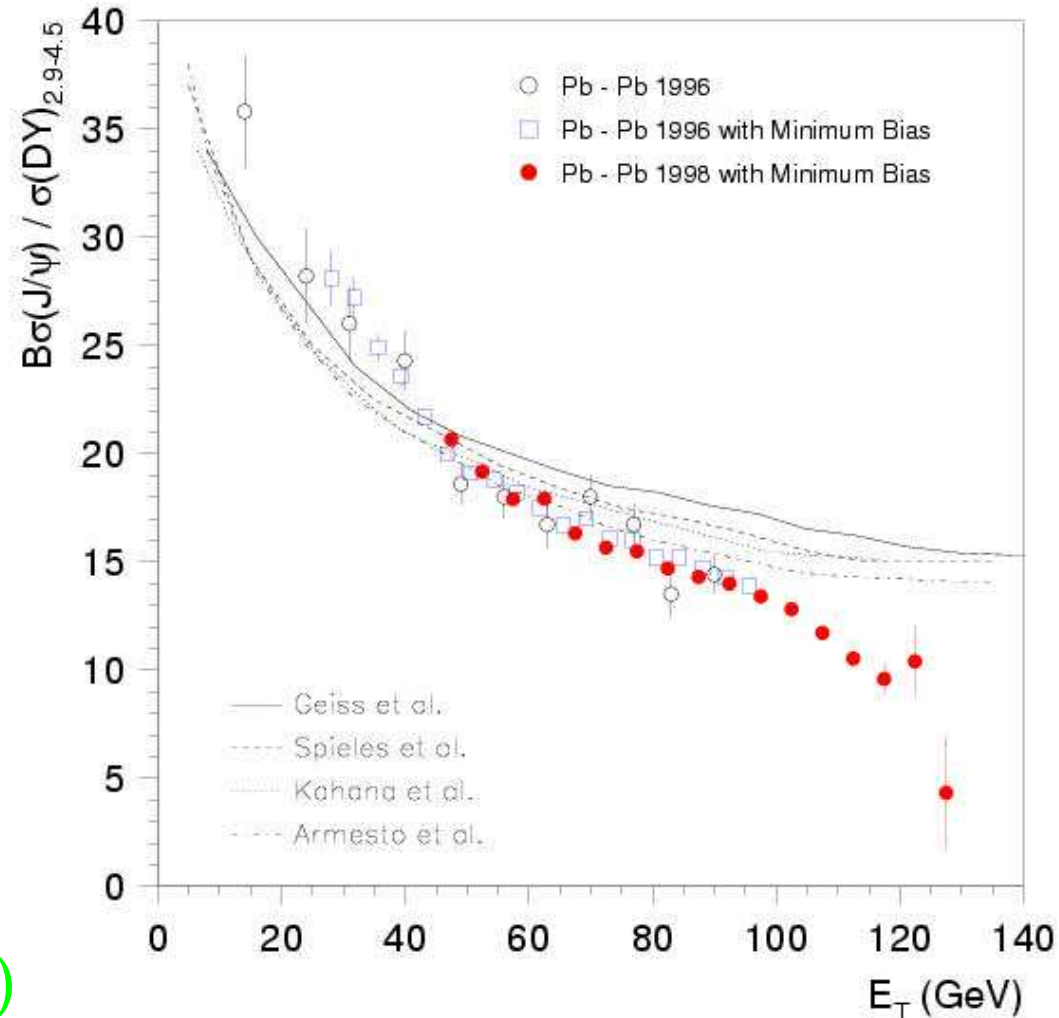**consistent with QGP expectations**

Suppression by Co-Moving Hadrons?

nuclear suppression:

$\propto \exp(-L\sigma\rho_0)$

pp, pA and S-Pb data
consistent with
nuclear suppression only

Co-Mover Models
moderately successful
very large density
(more than 1 hadron/fm^3)

Anomalous suppression in Pb-Pb

J/ψ Suppression in QGP

J.P. Blaizot, P.M. Dinh, J.Y. Ollitrault, Phys.Rev.Lett.85(2000)4012

Dissolution in QGP at critical density n_c (dashes)
and with energy density fluctuations (solid)

n_c=3.7/fm^2 n_{c1}=3.3 and n_{c2}=4.2/fm^2