J/ψ absorption in heavy-ion collisions

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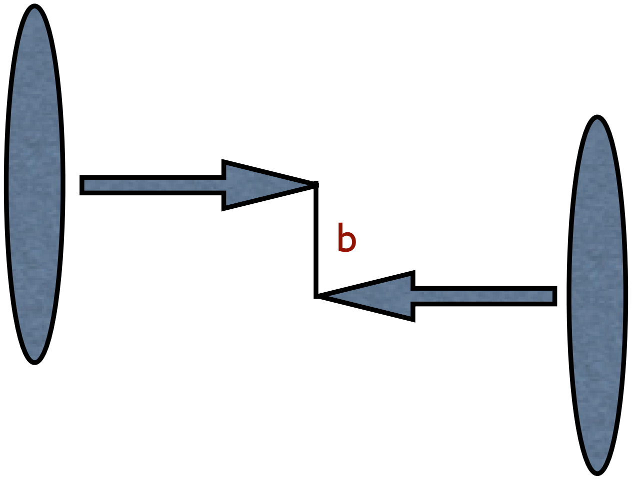


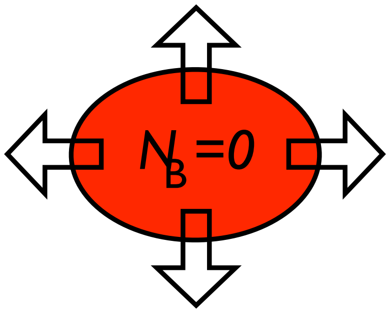
158 GeV/A

SPS energies

$\epsilon \approx 1$ GeV/fm^3

T≈O(100) MeV

P≈10^{30} bar



Hadronization time scale

$\tau \approx 10^{-23}$ (sec) Micro-Bang

$\tau \approx 10^{-5}$ Big-Bang

The role of the impact parameter

Bjorken's picture: for peripheral collisions the energy density of the fireball is such that a gas of pions rapidly evolving to equilibrium with temperature T is formed.

What happens in more central collisions?

As the centrality increases the energy density rises and the system could experience the transition to the deconfined phase predicted by QCD: the quark-gluon plasma.

Observables as a function of centrality:

J/ψ production

Strange particles production

J/ψ suppression

$$\boxed{\phi(\vec{k}) = \frac{4\pi Q}{\vec{k}^2 + \chi^2}}$$

(In a plasma)

$$\chi^2 = 4\pi e^2 \sum_a Z_a \left(\frac{\partial n_a}{\partial \mu_a}\right)_{T,V}$$

The quarkonium potential:

$$V(r) = \sigma r - \frac{\alpha_c}{r}$$

is screened by the plasma (Matsui-Satz)

$$V(r) = \boxed{\frac{\sigma}{\chi(T)}}\left(1 - e^{-\chi(T)r}\right) - \frac{\alpha_c}{r} e^{-\chi(T)r}$$

At large r

For large enough T the screening can prevent the formation of J/ψ

In hadron collisions J/ψ is produced by:

1-perturbative and non-perturbative interactions of gluons and quarks

2-cascade decays of higher excited states

In QGP 2≈1. For example 1-production is $\propto \alpha_s^3(m_c)$ while 2-production via χ_c is $O(\alpha_s^2)$

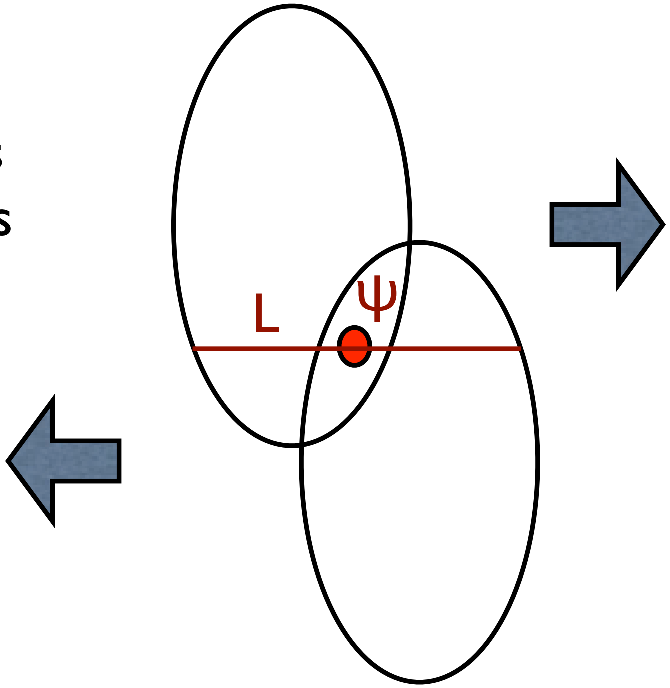
...but the branching ratio of χ in J/ψ +photon is about 20%

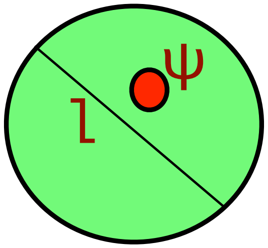
Debye temperature from lattice (MeV)

T_D	nf=4	nf=0
ψ	366	541
ψ’	170	260
χ_c	170	260

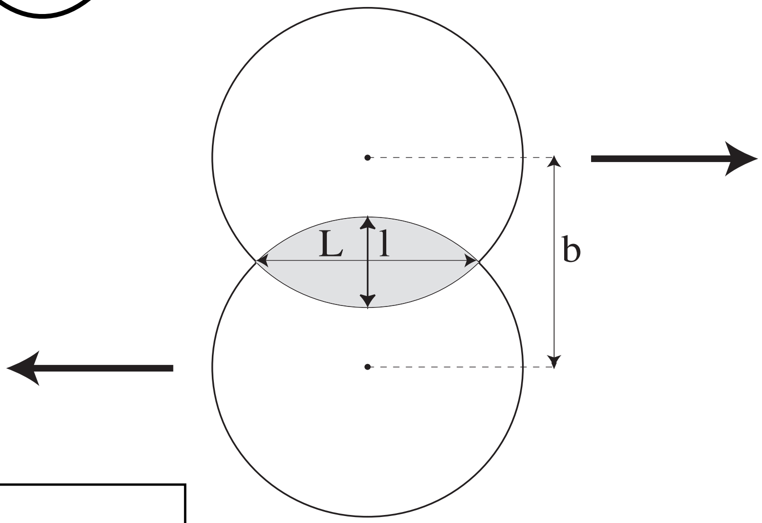
The J/ψ must survive
to nucleon-interactions
<u>and</u> to pion-interactions

$$\pi J/\psi \rightarrow D^{(*)}D^{(*)}$$





Hyp: spherical pion gas



$$\boxed{\ell = 2R - b}$$

Nuclear interactions

The mean free path is defined by:

$$\lambda \approx \frac{1}{\rho\sigma}$$

$$\rho_{nucl} = 0.17\ fm^{-3}$$

$$\sigma_{nucl} = 4.3 \pm 0.6\ mb$$

Measured by NA50
in pA collisions

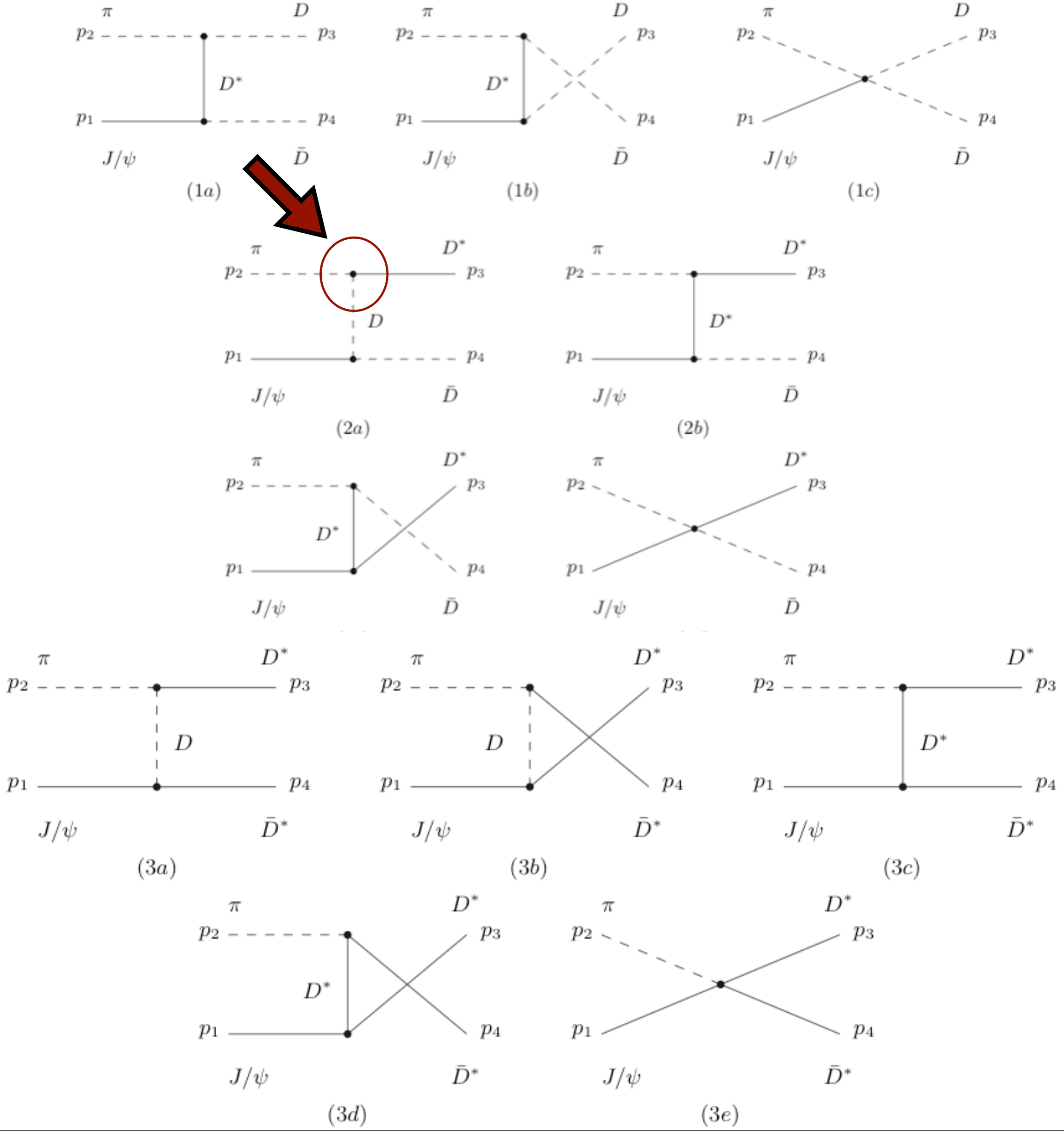
Then we can define the attenuation function:

$$A(x) = N exp\left[-\frac{x}{\lambda_{nucl}}\right]$$

where x=L=f(b) as given by the Glauber theory.

See papers by the NA50 collab.

Pions (comovers) interactions

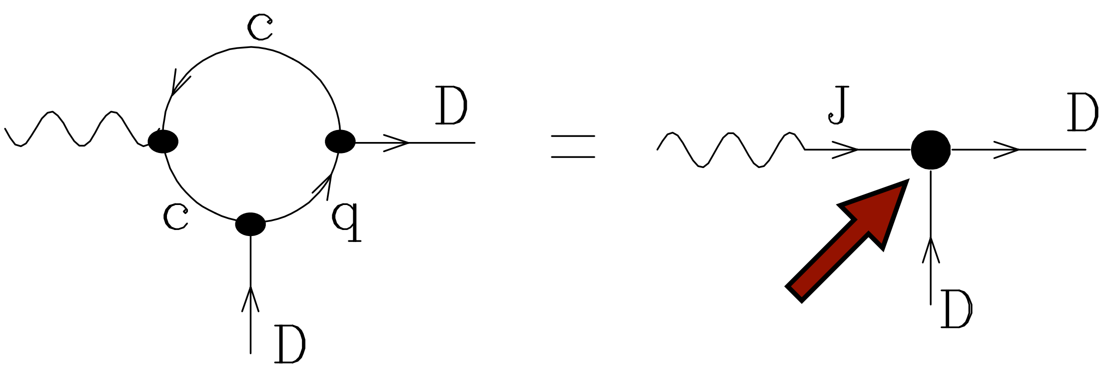


How can we compute such (effective) couplings?

‘First principles’ calculations are not possible here!

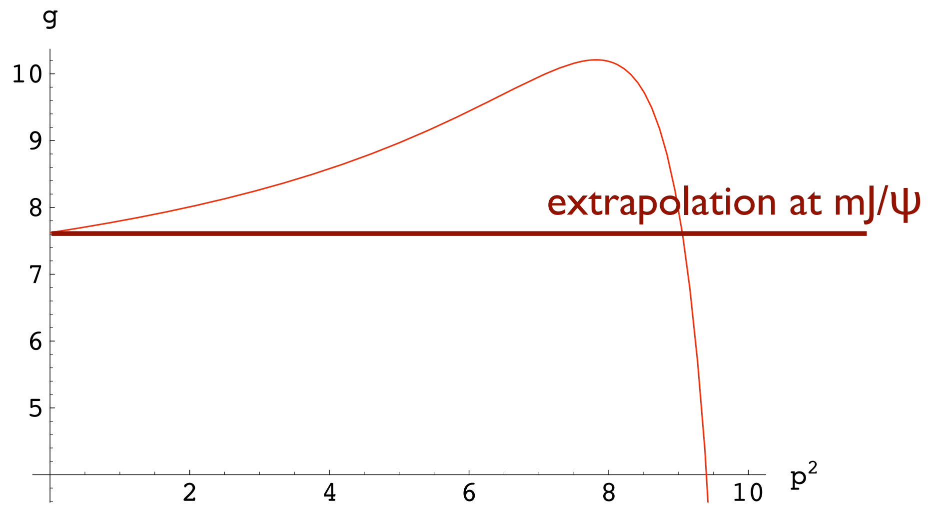
One possibility is to use a Constituent-Quark-Meson model based on HQET and Chiral Symmetry

Ebert, Feldmann, Reinhardt
Bardeen, Hill
Deandrea, Gatto, Nardulli, ADP



$$g_{JDD}(p_1^2, p_2^2, p^2) = \frac{m_{J/\psi}^2 - p^2}{f_{J/\psi} m_{J/\psi}} \xi_{IW}(\omega)$$

After the computation of the effective loop (computation of ξ(ω))

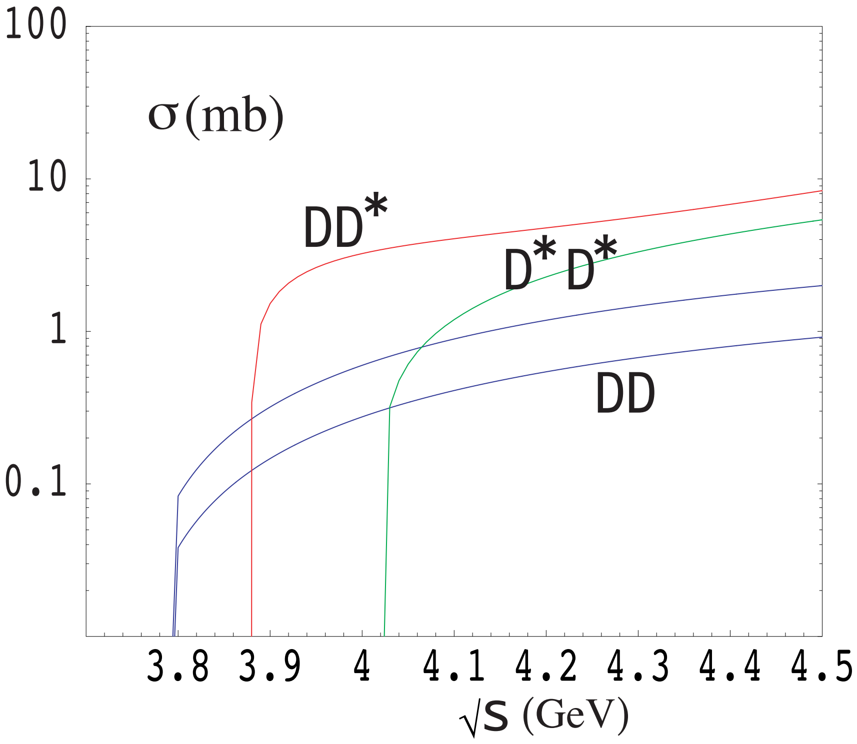


Take the value at zero virtuality and estimate the error
in a stability window: 8.0±0.5

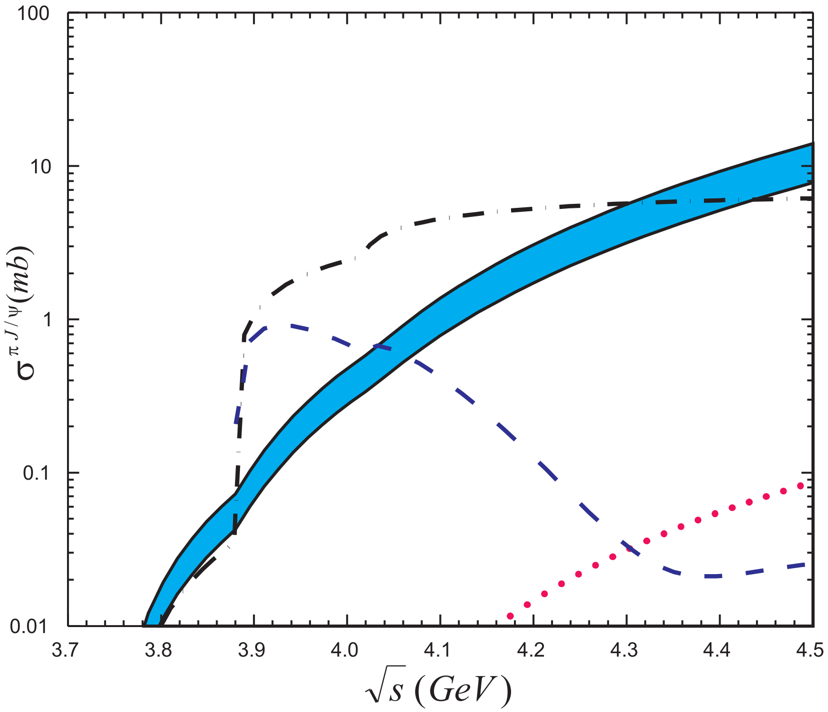
Clearly there is an incomplete cancellation between the kinetic zero and the pole (since g has no zeroes, ξ must have a pole)

Probably because of O(1/mc) corrections the location of the singularity
is not exactly at the mass of the J/ψ

The calculation of the Born



(Our model)



SVZ (blue band)
other Q-models

Pion interactions

We can introduce a second attenuation function,
related to pions:

$$A(x) = N exp\left[-\frac{x}{\lambda_\pi(T)}\right]$$

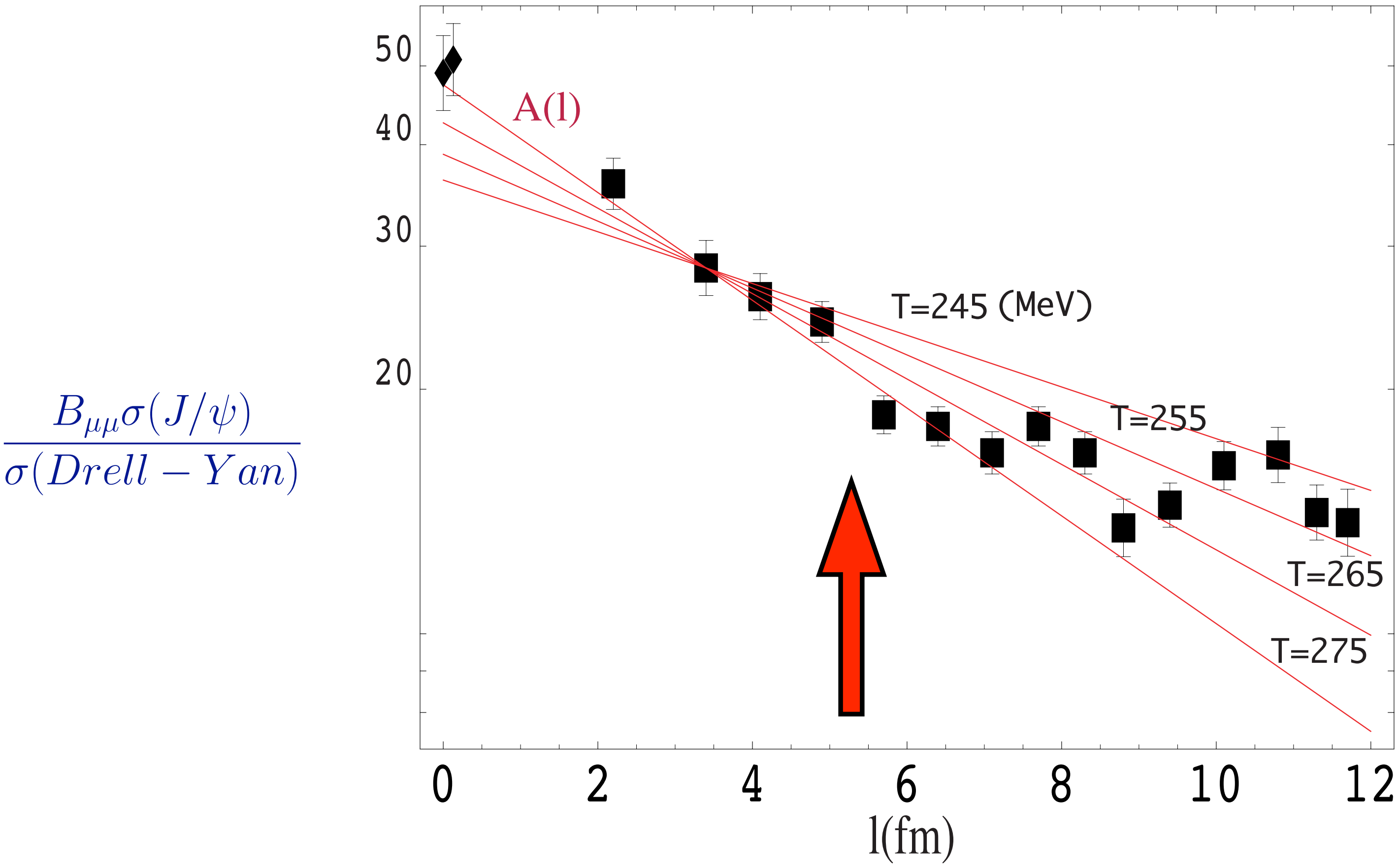
where the mean free path is a complicated function:

$$\lambda_\pi^{-1} = \langle \rho_\pi \sigma_{\pi J/\psi \to D^{(*)} D^{(*)}} \rangle_T = \frac{3}{2\pi^2} \int_{E_\pi^{thr.}}^{\infty} dE_\pi \frac{E_\pi^2 \sigma(E_\pi)}{e^{E_\pi/T} - 1}$$

and x=6/10 l in a spheric fireball.

- ideal gas of pions at temperature T
- zero chemical potential
- no other hadrons (ρ,ω,K,...)

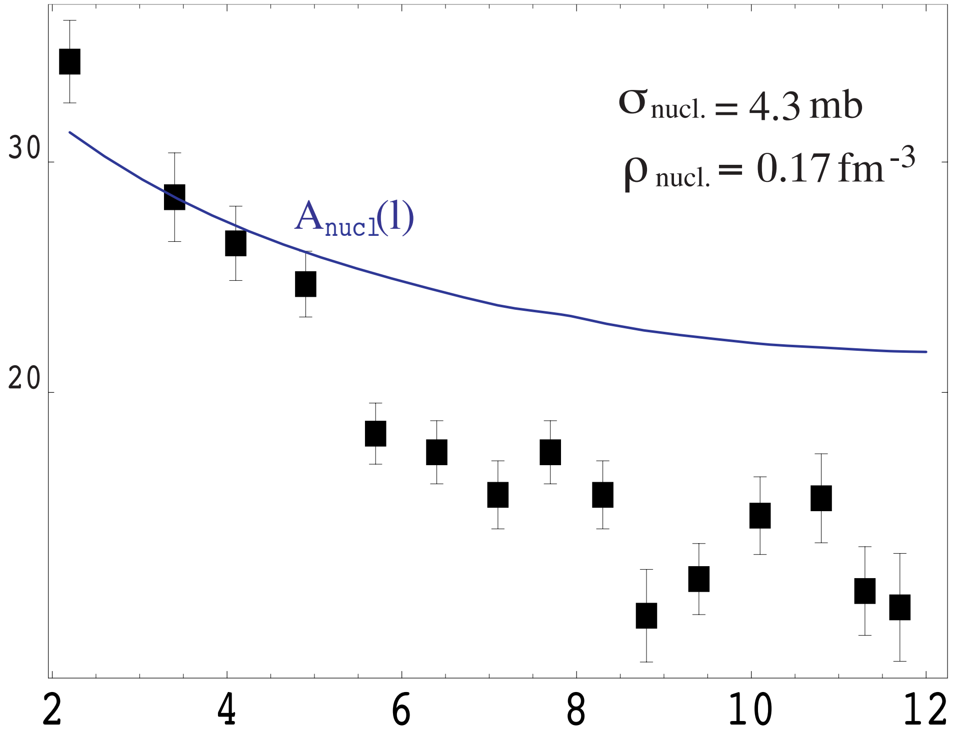
Pion attenuation function: isotherms



Data from NA50 Pb-Pb reactions at SPS (1997)

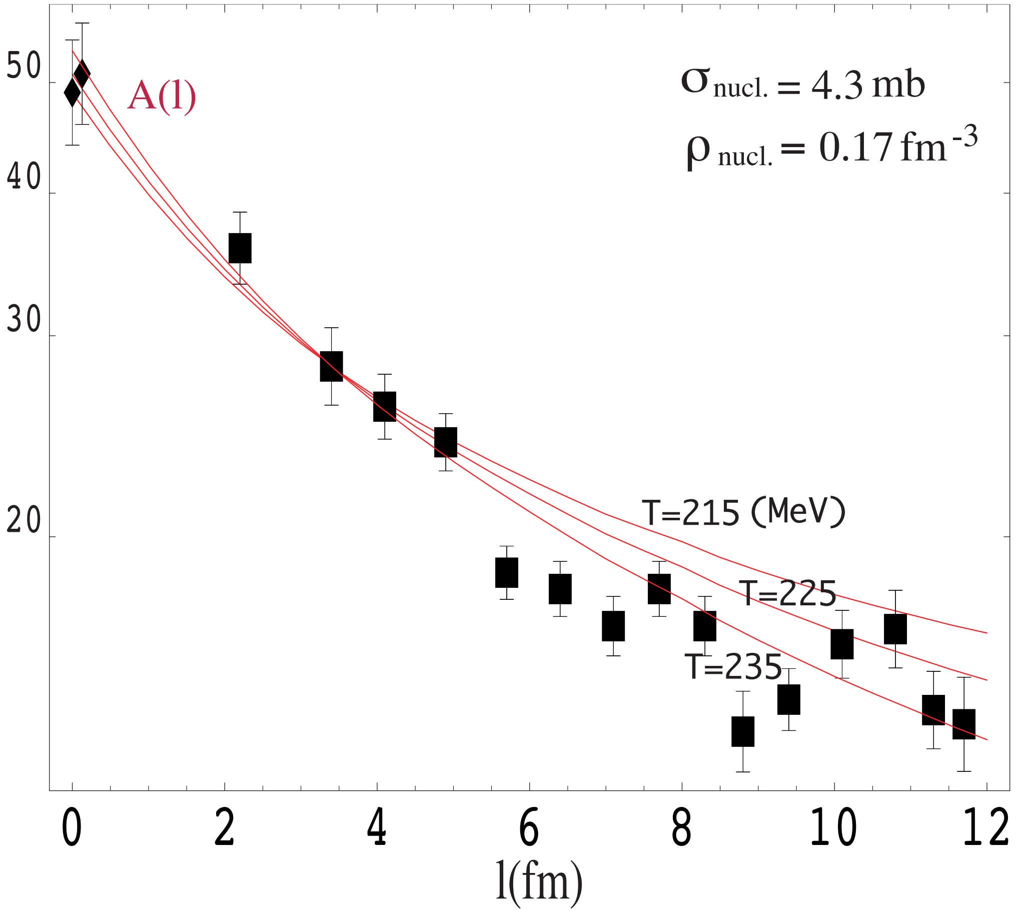
The abrupt formation of the qg-plasma provides the break

Nuclear attenuation function



Insufficient to reproduce the break.
One of the argument used in favor of anomalous J/ψ suppression.

Pions+Nuclear



Better but still insufficient to reproduce the break...

Actually there is something missing here:

the temperature is itself a function of the impact parameter

Bjorken's formula:

$$\epsilon^{Bj} = \frac{A(b)}{S(b)}\left(\frac{dE}{dy}\right)\frac{1}{ct}$$

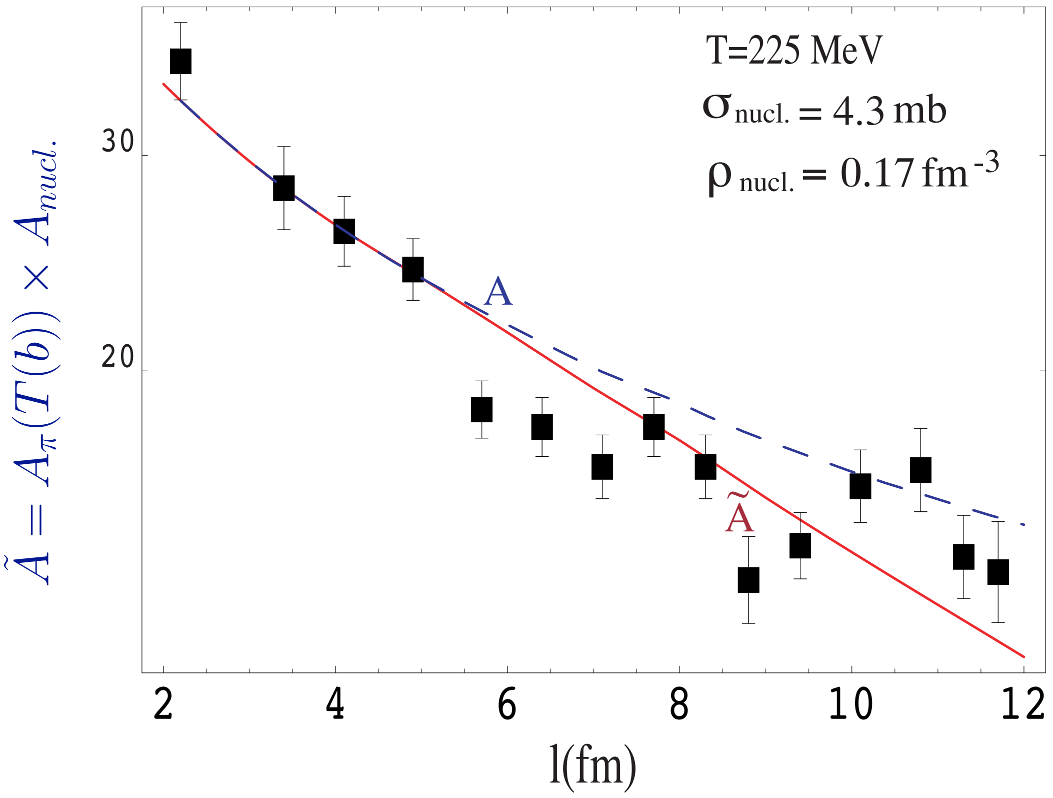
spherical colliding nuclei:

$$T(l) = T_0\left(\frac{g(2-\ell/R)}{g(2-\ell_0/R)}\right)^{\frac{1}{4}}$$

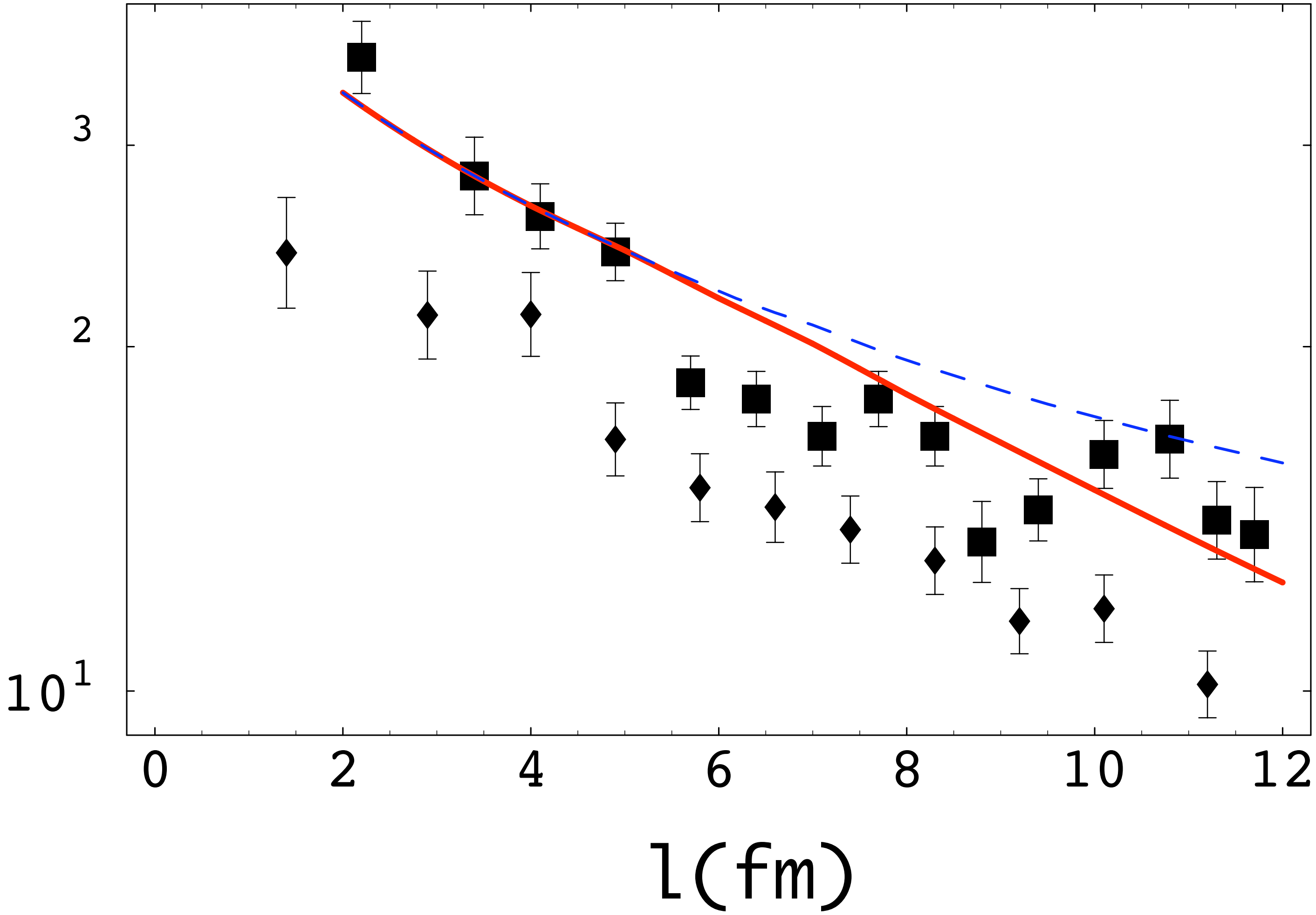
where:

$$\frac{V(b)}{S(b)} = \frac{2}{3}\pi\frac{(R-b/2)^2(R+b/4)}{R^2 arcos(b/2R) - Rb/2\sqrt{1-b^2/(4R^2)}}$$

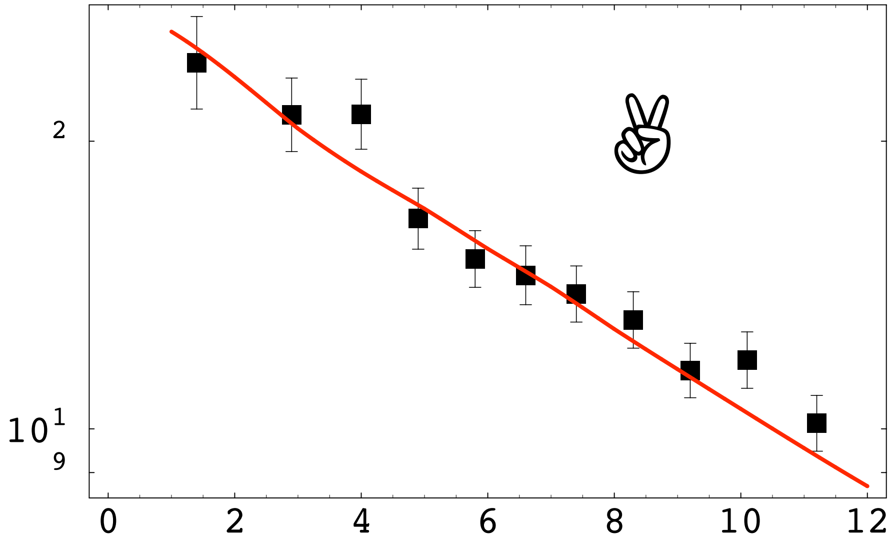
Pion+Nucl.+T(b)



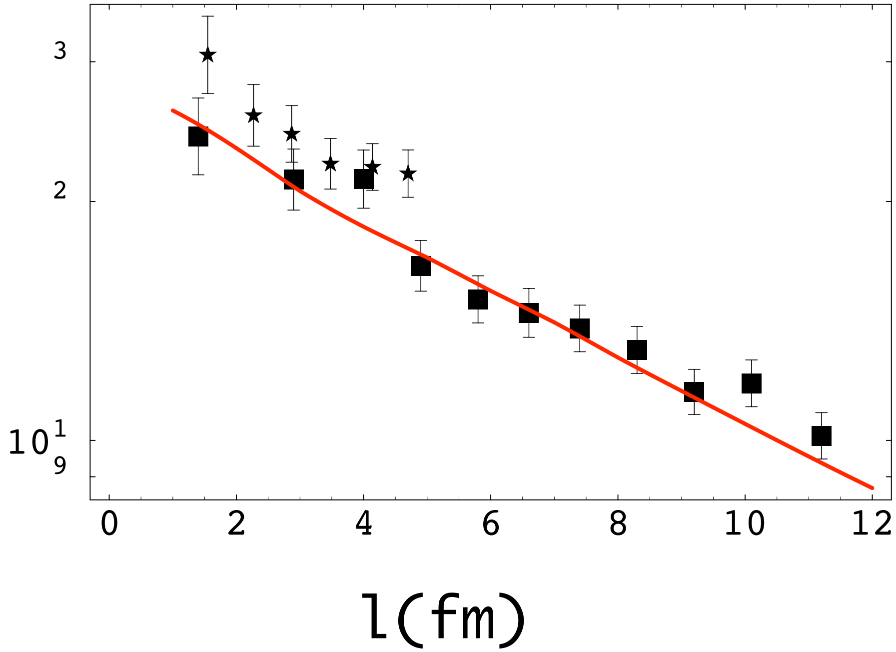
The break is still there...but is it indeed a break?



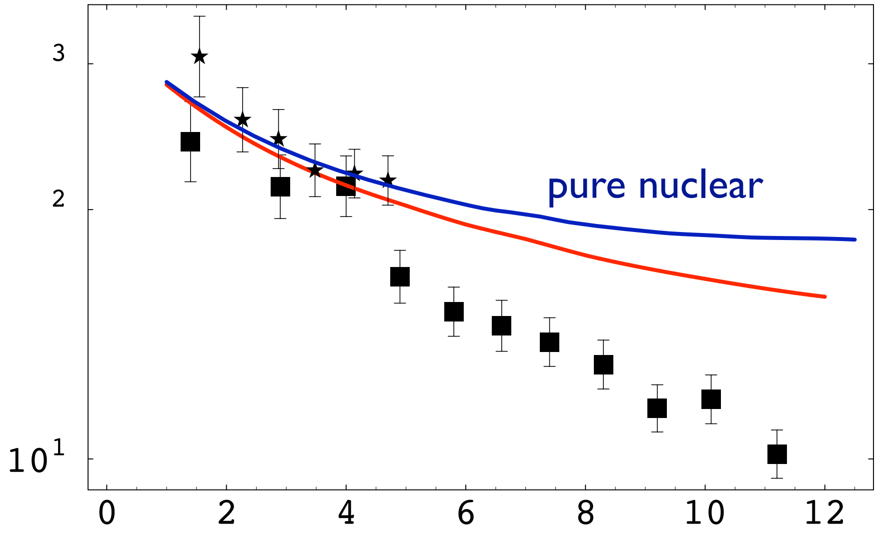
Pb-Pb 1997 vs. Pb-Pb 2000 (diamonds)



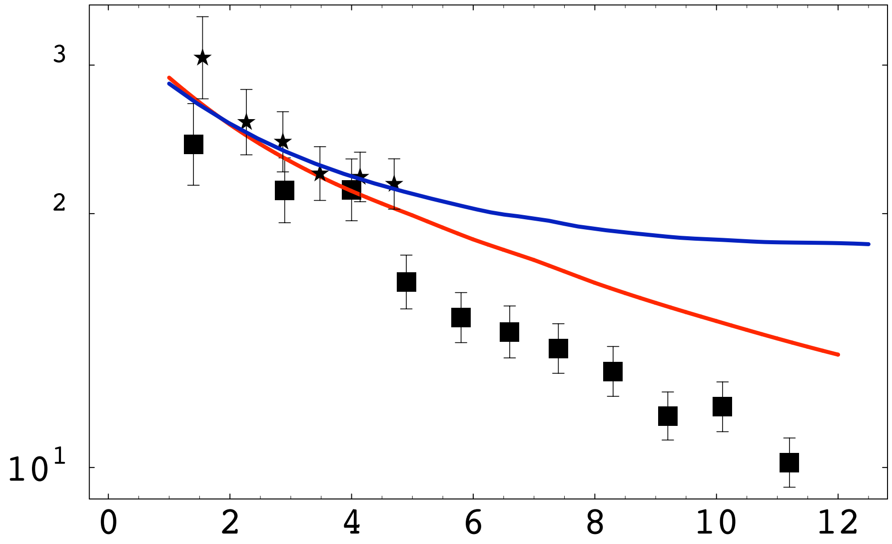
Pb-Pb data



Pb-Pb + S-U



T=180 MeV



T=200 MeV

One has to believe the relative normalization of
Pb-Pb points versus S-U points to asses the break

The opacity of the pion gas to the J/ψ is, in our approach, a thermometer of the fireball

Our limits:

- We ‘measure’ a T ≅ 225 ± 15 MeV that is too high with respect to lattice predictions for the deconfinement critical temperature T ≅ 170 MeV
- The energy density of our Bose gas is ϵ ≅ 0.32 GeV/fm3 versus a value of 0.95 GeV/fm3 predicted by the Bjorken’s formula at l=5 fm, and 1.35 GeV/fm3 at l=13 fm (2R for Pb).

Why?

Hadron gas made only of pions, ideal gas approx., the uncertainties in the model, ...

A naive argument:

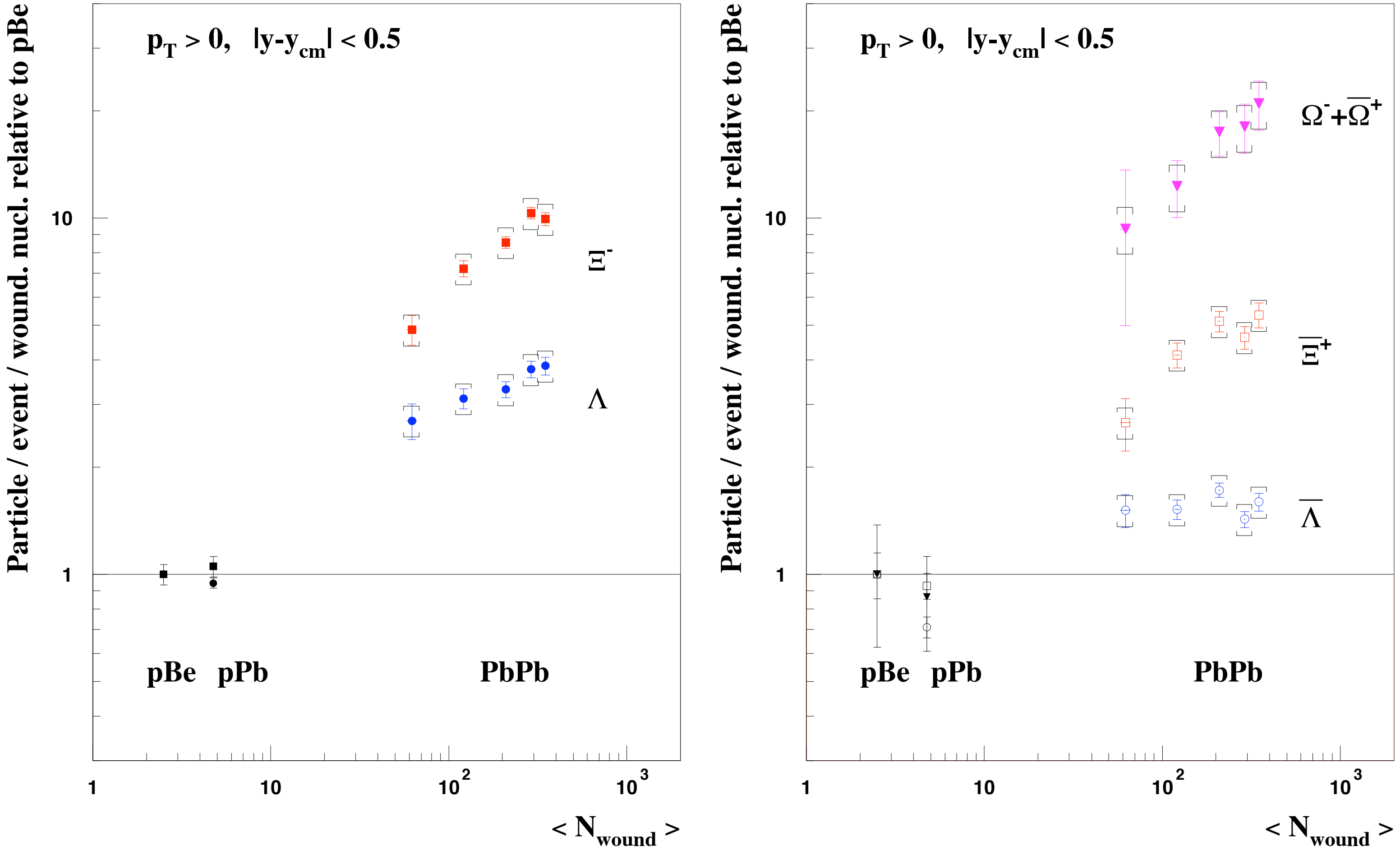
If it exists a phase transition to deconfined qg (as predicted by QCD!) and IF the anomalous suppression of the J/ψ at a certain centrality threshold (NA50) provides evidence of plasma formation, are there other observables exhibiting similar behavior?

Strangeness enhancement?

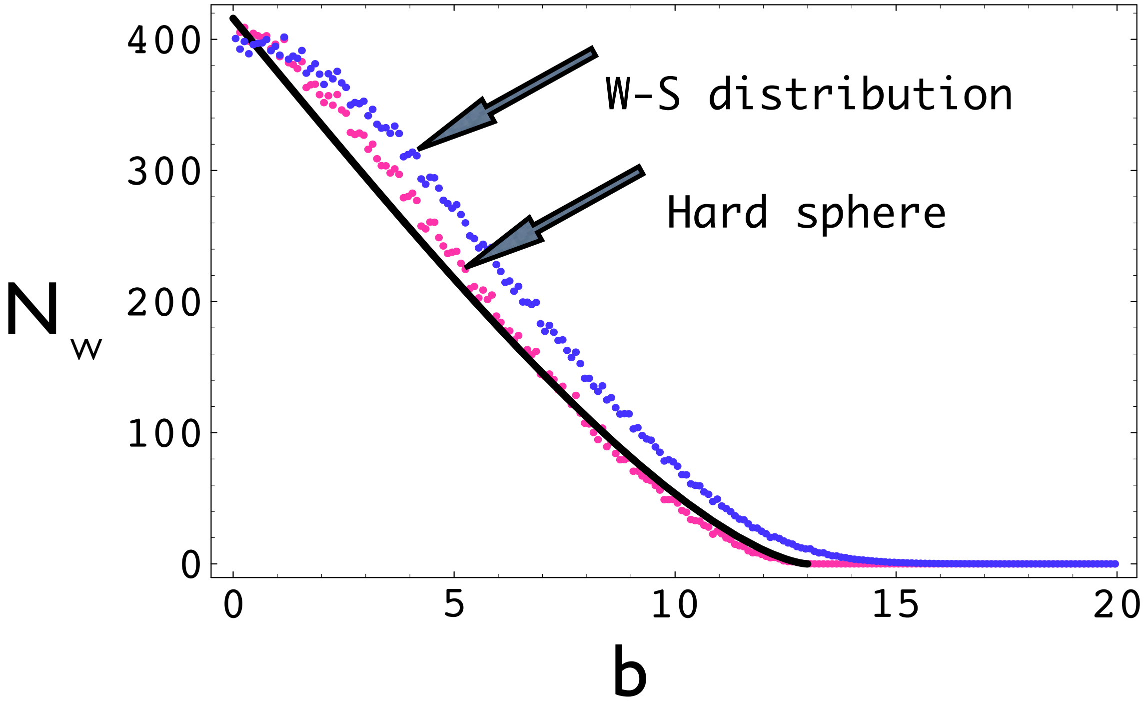
The initial state contains predominantly u,d quarks. If a plasma is formed, deconfined hard gluons have enough energy to produce strange quark pairs which eventually hadronize in stange and multistrange baryons. Moreover:

$$m_s \approx T$$

...the strangeness production is very sensitive to the thermodynamics of the system

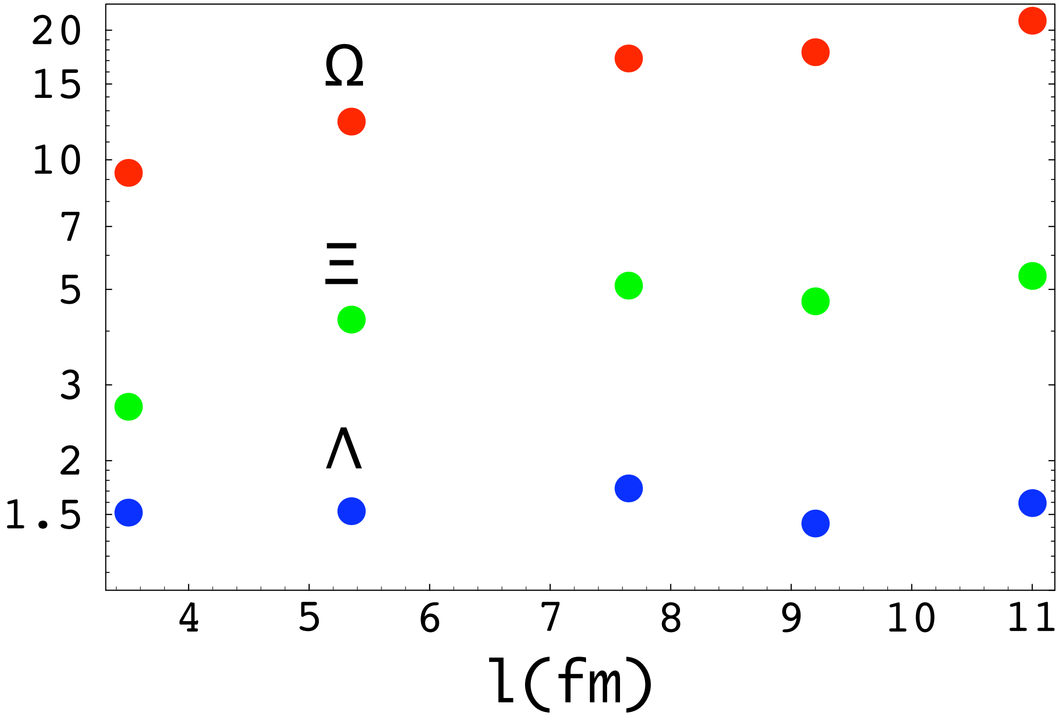


Strangeness enhancements measured by the NA57 experiment. The enhancements are defined as the particle yields normalised by the number of participating nucleons in the collision, and divided by the observed yield in proton-beryllium collisions. The yields expected from a simple superposition of nucleon-nucleon collisions would then lie on a straight line positioned at unity.



black curve = $4\left[\left(\int_0^{\sqrt{R^2-b^2/4}} dx\sqrt{R^2-x^2}\right)-\frac{b}{2}\sqrt{R^2-b^2/4}\right]\frac{2N}{\pi R^2}$

Strangeness as a function of centrality



There are few experimental points but 'looks plausible' that there is no break in correspondence of the NA50 centrality point.

Summary

- Heavy-ion physics is an *experimentally driven field.* Are there different observables neatly pointing at similar patterns?? (Here we focused on quarkonium and strangeness but there are many other experimental facts being discussed at RHICH)

- A *consistent theoretical picture* is missing; we only have a huge jungle of models. Will Alice have some chance to find the phase transition to QGP?

- We have a more modest target here: we plan to *include higher resonances* in our hadron gas. This will certainly lower our 'measure' of T and improve our determination of ϵ.

- What do we learn from that? A solid experimental evidence should resist to all 'naive' theoretical attacks....