La subtile disparition du J/Psi dans les collisions d'ions lourds

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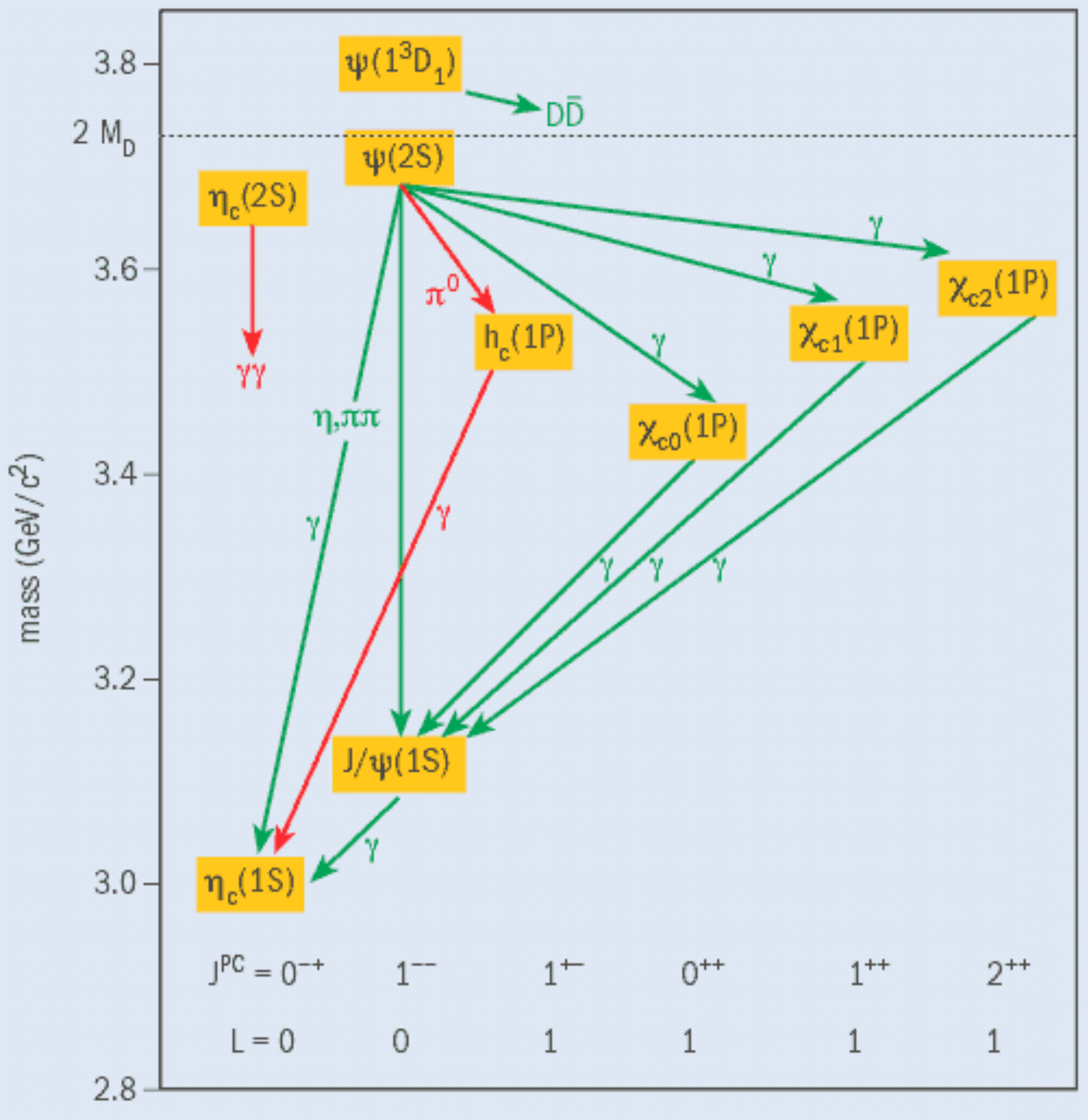
Outline

- Brief historical perspective
- Present experimental situation
- Open theoretical questions
- Outlook

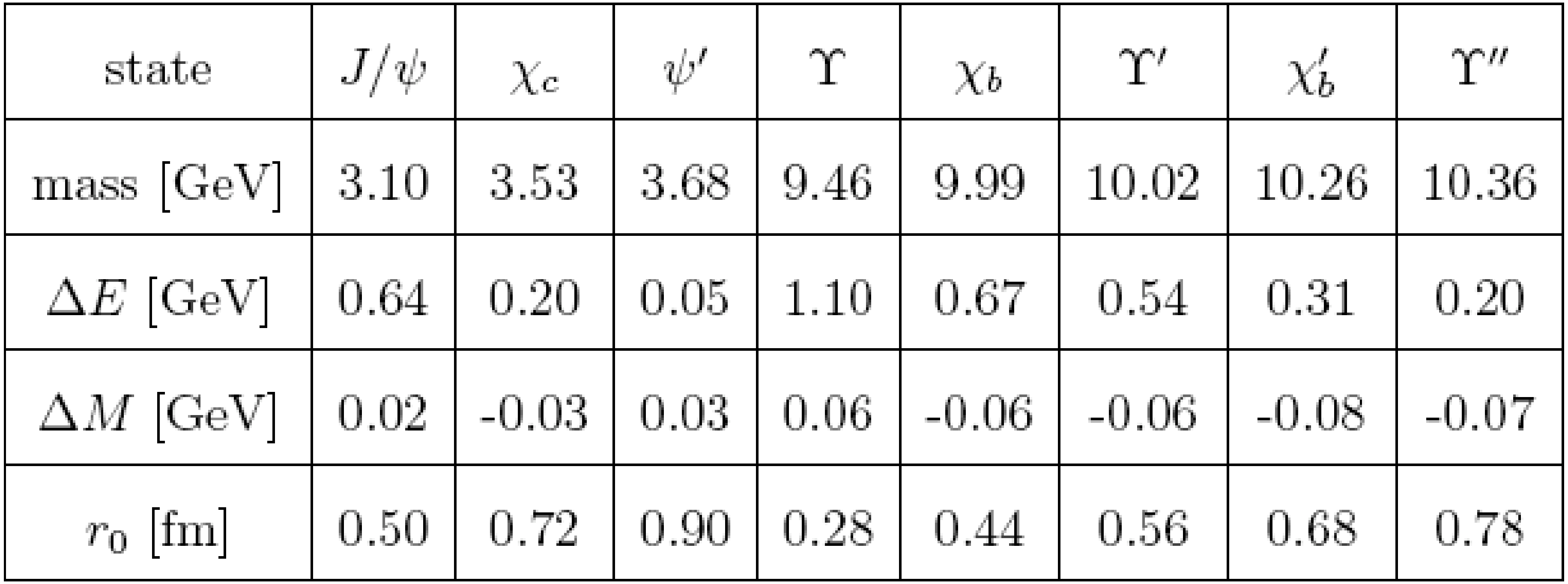
The charmonium is a « non relativistic » system

$$H = 2m_c + \frac{p_1^2}{2m_c} + \frac{p_2^2}{2m_c} + V(r)$$

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


mass (GeV/c²)
3.8
2 M_D
3.6
3.4
3.2
3.0
2.8
ψ(1³D₁)
DD̄
ψ(2S)
η_c(2S)
γγ
π⁰
h_c(1P)
γ
γ
γ
γ
χ_c2(1P)
χ_c1(1P)
χ_c0(1P)
η,ππ
γ
γ
γ
γ
γ
J/ψ(1S)
γ
η_c(1S)
J^PC = 0⁻⁺
1⁻⁻
1⁺⁻
0⁺⁺
1⁺⁺
2⁺⁺
L = 0
0
1
1
1
1

Some charmonium properties



state	J/ψ	χ_c	ψ'	Υ	χ_b	Υ'	χ_b'	Υ''
mass [GeV]	3.10	3.53	3.68	9.46	9.99	10.02	10.26	10.36
ΔE [GeV]	0.64	0.20	0.05	1.10	0.67	0.54	0.31	0.20
ΔM [GeV]	0.02	-0.03	0.03	0.06	-0.06	-0.06	-0.08	-0.07
r_0 [fm]	0.50	0.72	0.90	0.28	0.44	0.56	0.68	0.78

ΔE is binding energy

(from H. Satz, hep-ph/0602245)

Screening of binding forces in a quark-gluon plasma

Screened potential

$$V(r) = -\frac{\alpha}{r} e^{-r/r_D(T)}$$

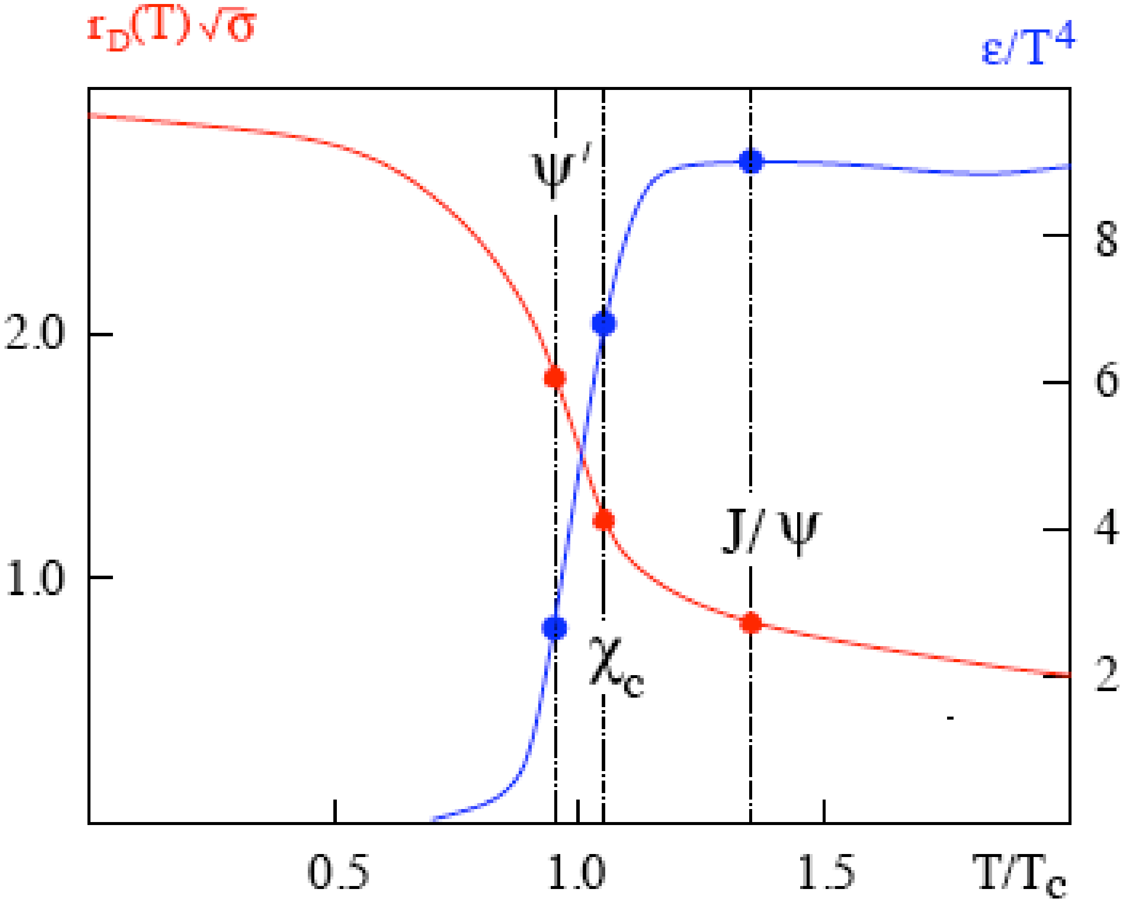
Bound state exists for

$$r_D(T) > r_D^{min}$$

that is, for

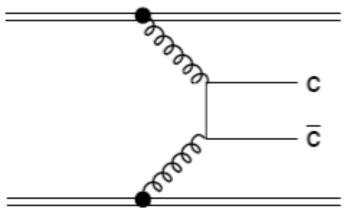
$$T < T_D$$

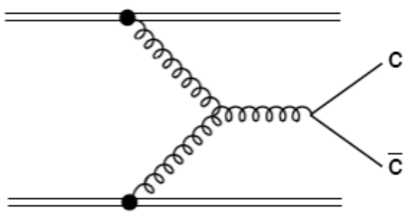
Melting temperature depends on size of bound state

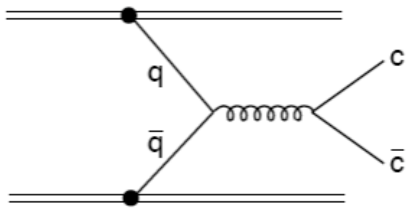


(from H. Satz, hep-ph/0602245)

Production of J/Psi in hadronic collisions (mechanism not fully understood)



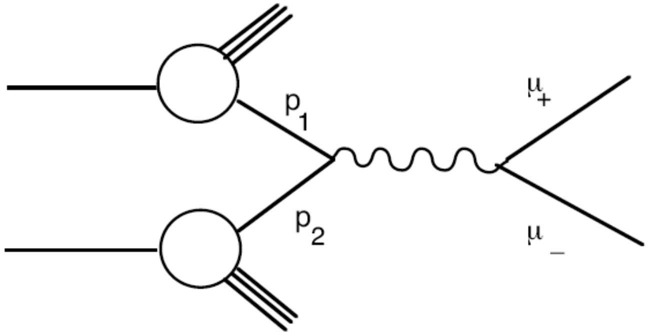


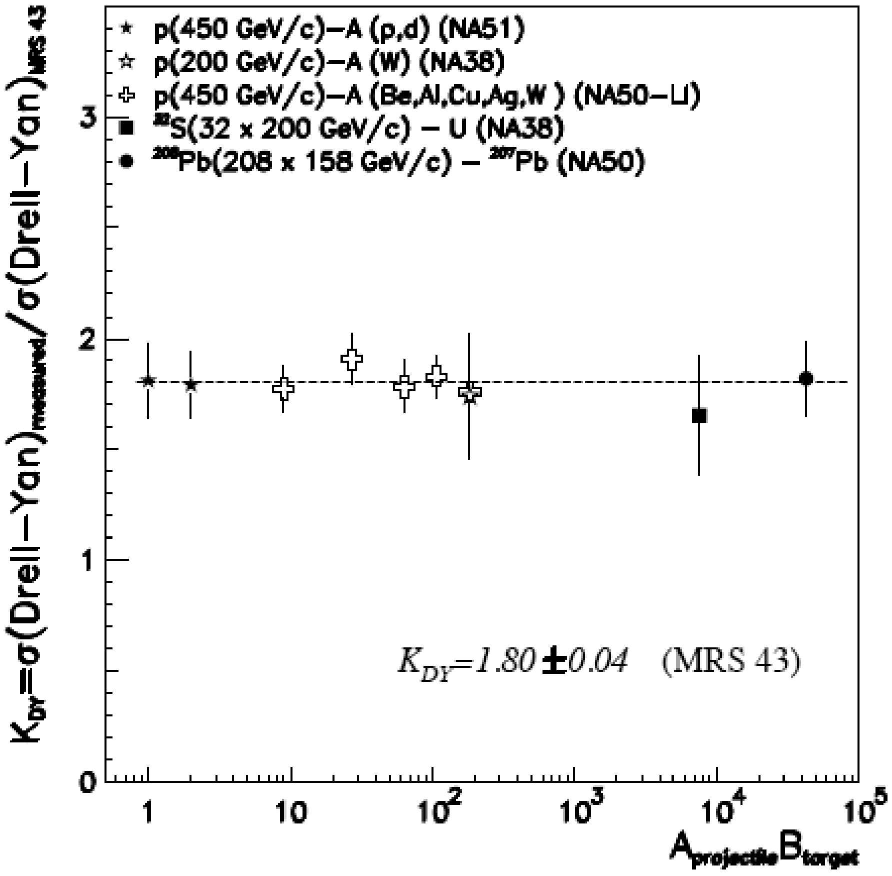


$$\frac{d^2\sigma_{NN\to C}}{dp_T^2} = \int dx_1 dx_2\, \delta(x_1 x_2 s - M_C^2)\, G(x_1) G(x_2) \frac{d^2\sigma_{gg\to C}}{dp_T^2}$$

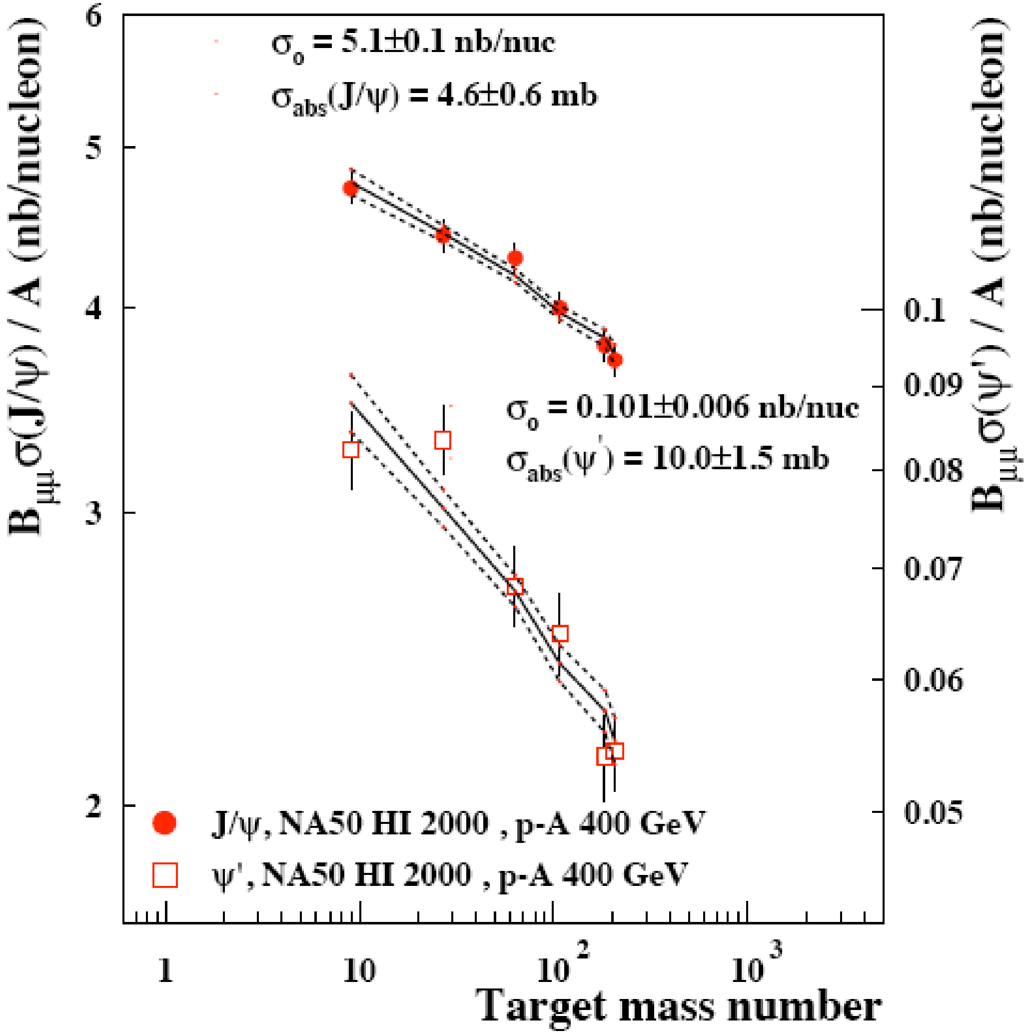
To detect « anomaly », normalize to Drelll-Yan

(yield is proportional to the number of nucleon-nucleon collisions)





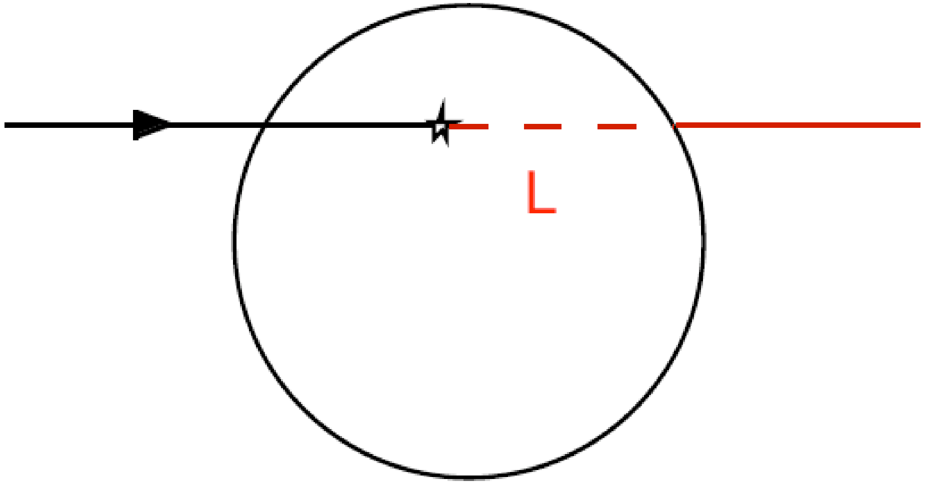
J/Psi production depends on size of nuclei



(from L. Kluberg and H. Satz, arXiv:0901.3831)

« Normal » nuclear absorption

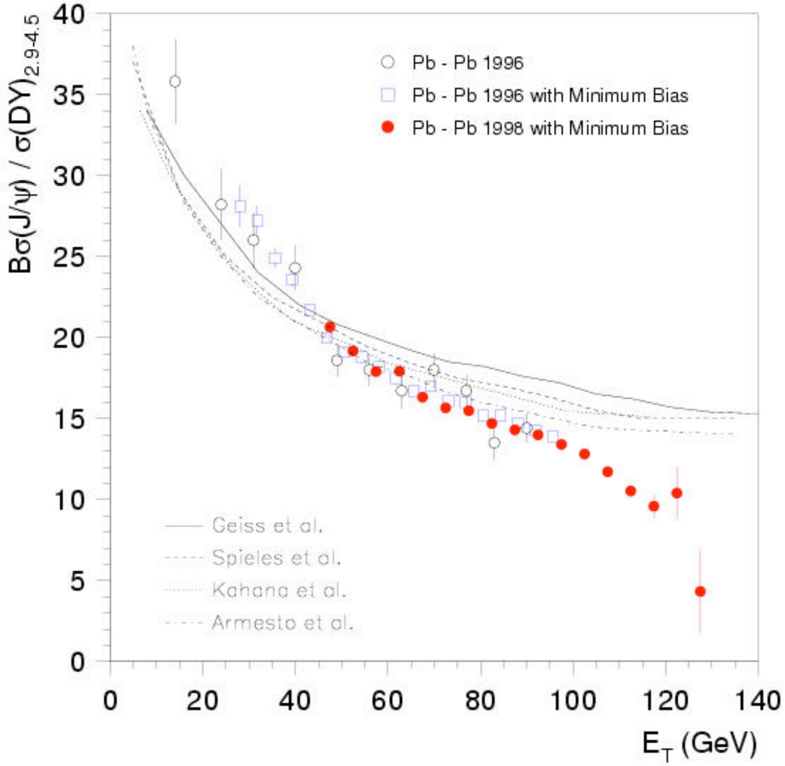
$$\sigma_{hA\to\Psi} = \sigma_{hN\to\Psi}\int \mathrm{d}^2\mathbf{b}\,\mathrm{d}z\,\rho(\mathbf{b},z)\exp\left\{-\sigma_a\int_z^{\infty}\mathrm{d}z'\rho(\mathbf{b},z')\right\}$$

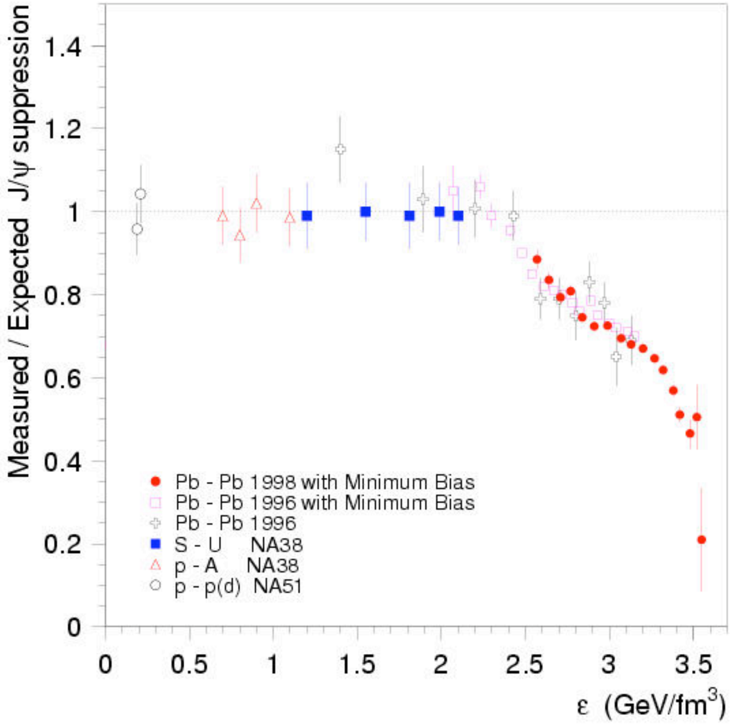


$$\mathcal{N}_A = \frac{1}{A}\frac{\sigma_{pA}}{\sigma_{pp}} = \frac{1}{A\sigma_a}\int \mathrm{d}^2b\,(1-\exp\left(-\sigma_a T_A(\mathbf{b})\right))$$

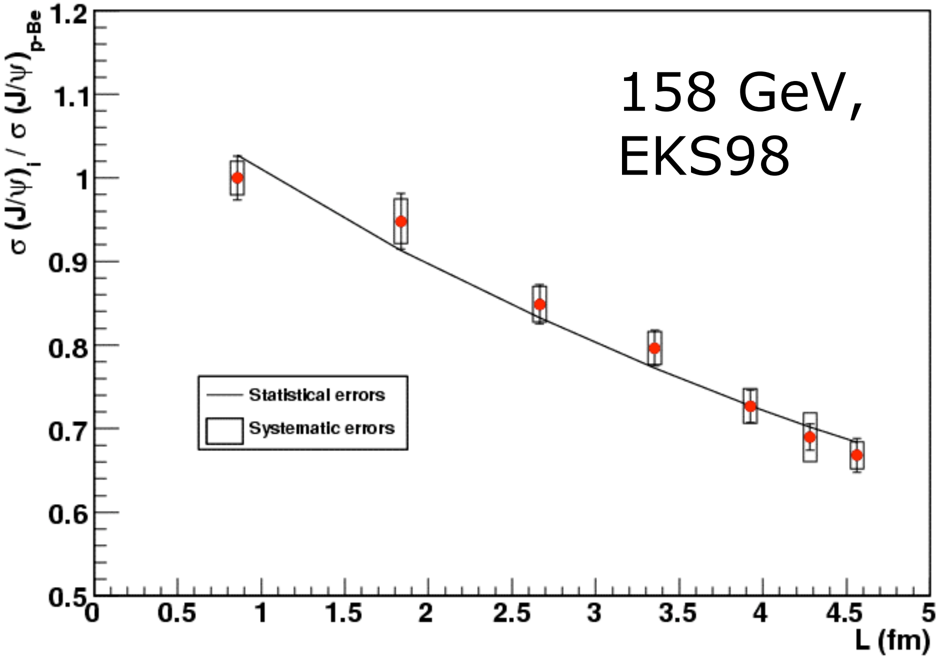
Summary of early measurements (NA38,NA50)

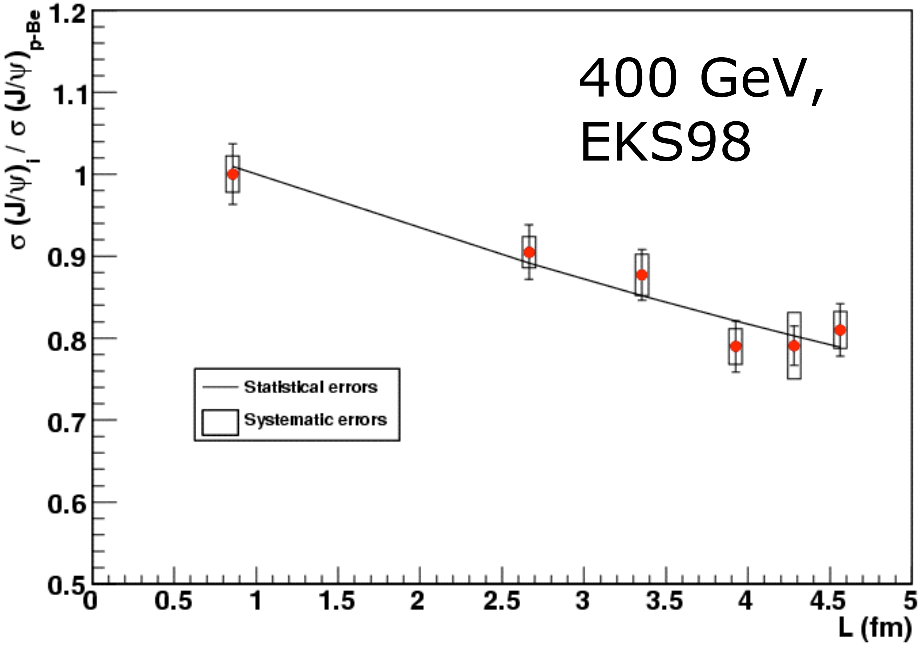
(CERN, 2000)





Recent NA60 measurements indicate that the absoprtion cross section depends on energy

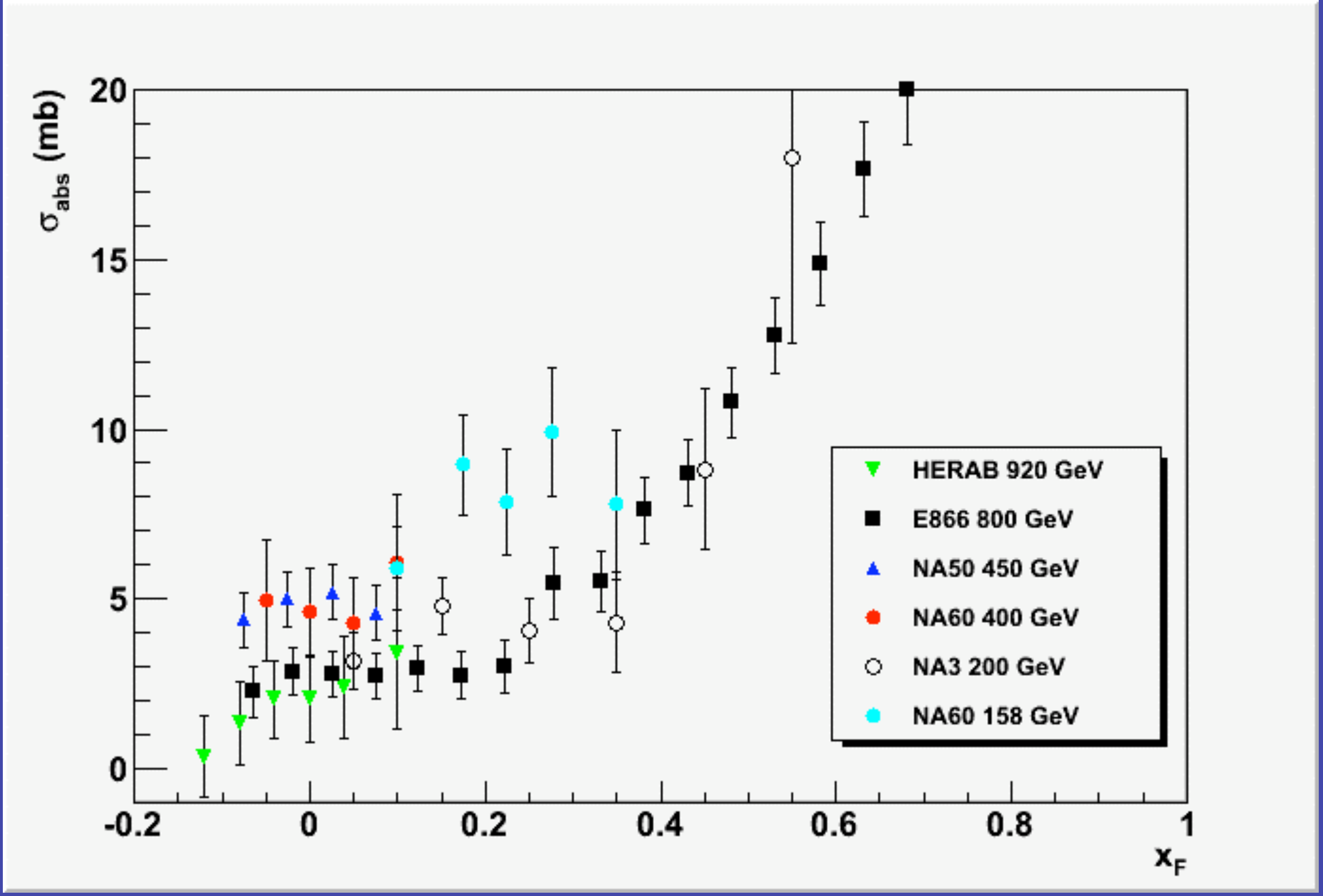




$\sigma_{abs}^{J/\psi}$ (158 GeV) = 7.6 ± 0.7 ± 0.6 mb
$\sigma_{abs}^{J/\psi}$ (400 GeV) = 4.3 ± 0.8 ± 0.6 mb

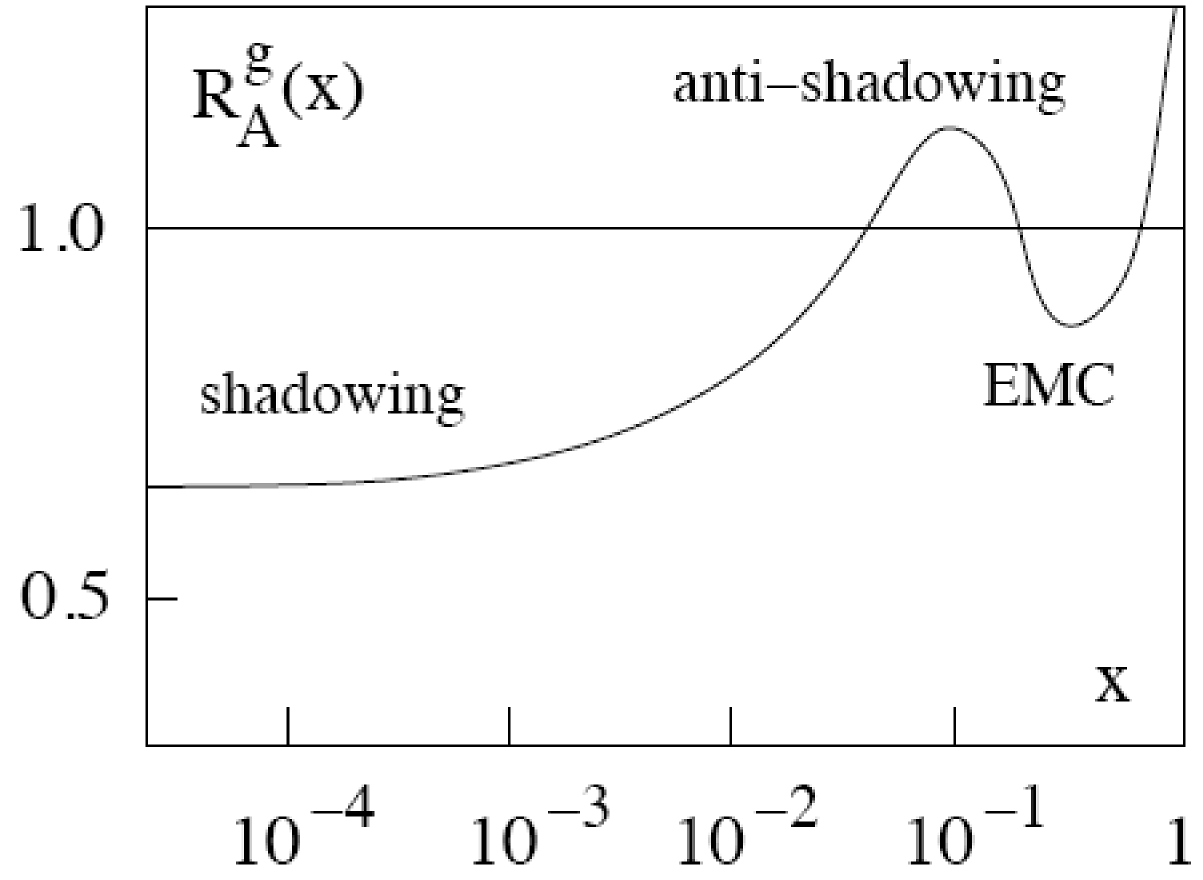
Comparison between experiments

(from R. Arnaldi, Quark Matter 09)



Nuclear absorption is a complex phenomenon

Initial state effects
(nuclear modification of structure functions)



Including shadowing correction leads to significantly higher values of σ_{abs}

$\sigma_{abs}^{J/\psi,EKS}$ (158 GeV)=9.3±0.7±0.7 mb

$\sigma_{abs}^{J/\psi,EPS}$ (158 GeV)=9.8±0.8±0.7 mb

$\sigma_{abs}^{J/\psi,EKS}$ (400 GeV)=6.0±0.9±0.7 mb

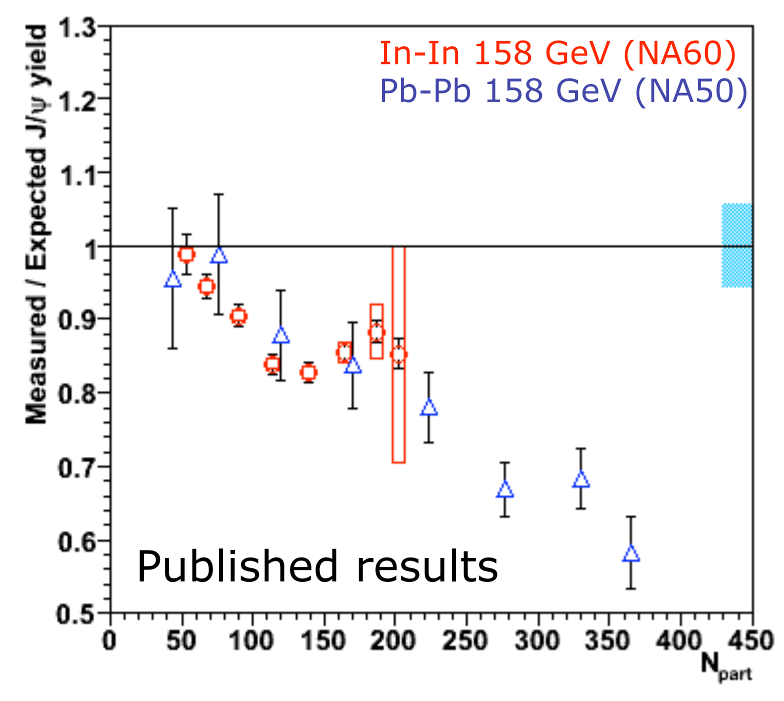
$\sigma_{abs}^{J/\psi,EPS}$ (400 GeV)=6.6±1.0±0.7 mb

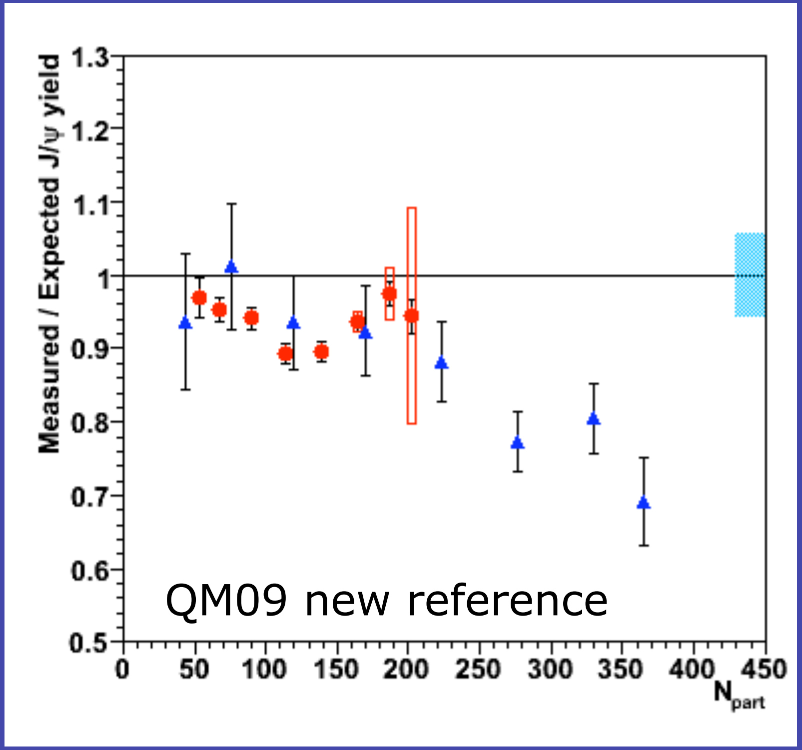
Comparison with AA results

(from R. Arnaldi, Quark Matter 09)

- $\sigma_{abs}^{J/\psi}$ (158 GeV) > $\sigma_{abs}^{J/\psi}$ (400 GeV)

→ smaller anomalous suppression with respect to previous estimates

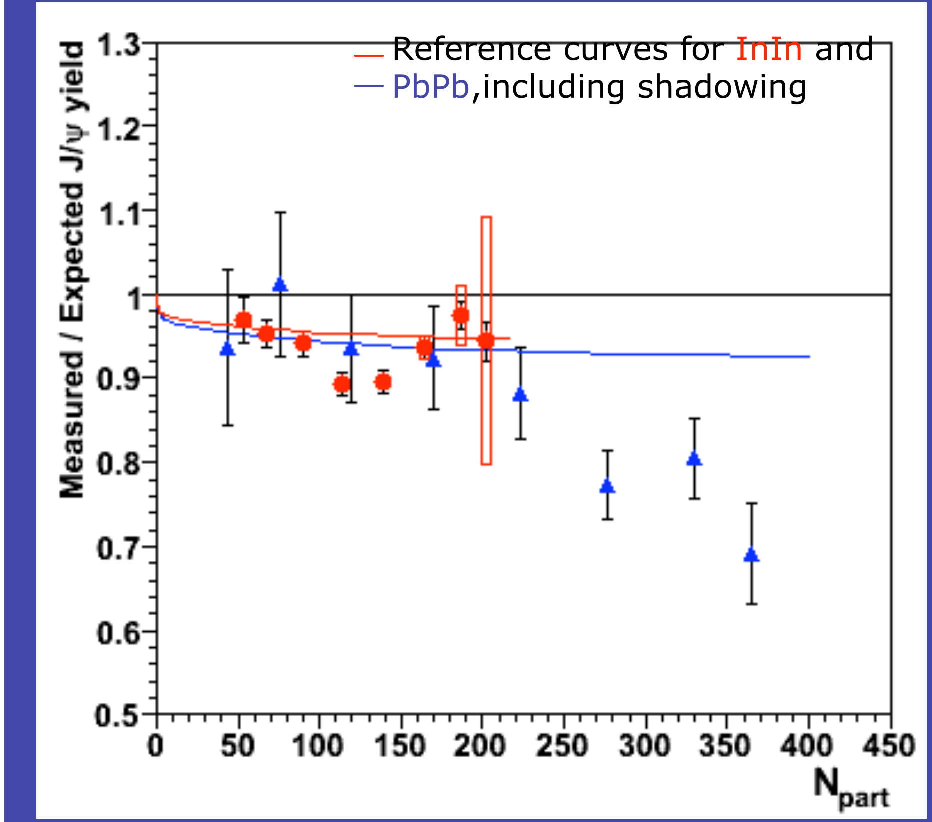


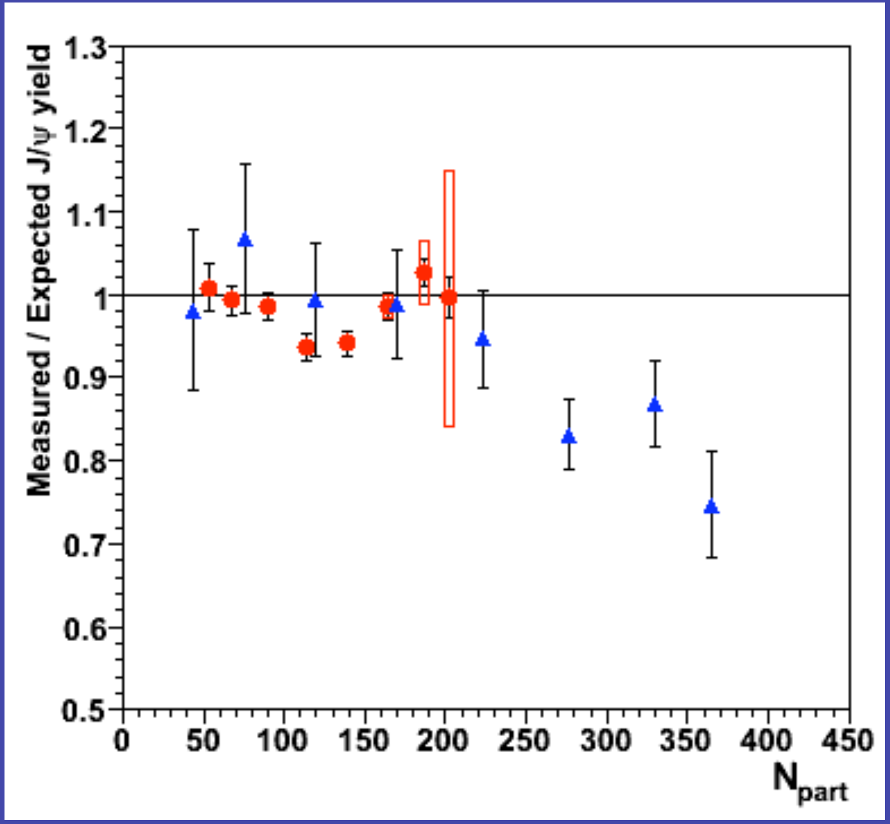


B. Alessandro et al., EPJC39 (2005) 335
R. Arnaldi et al., PRL99 (2007) 132302

- Anomalous suppression in In-In ≤ 10%
- Anomalous suppression in Pb-Pb up to 30%

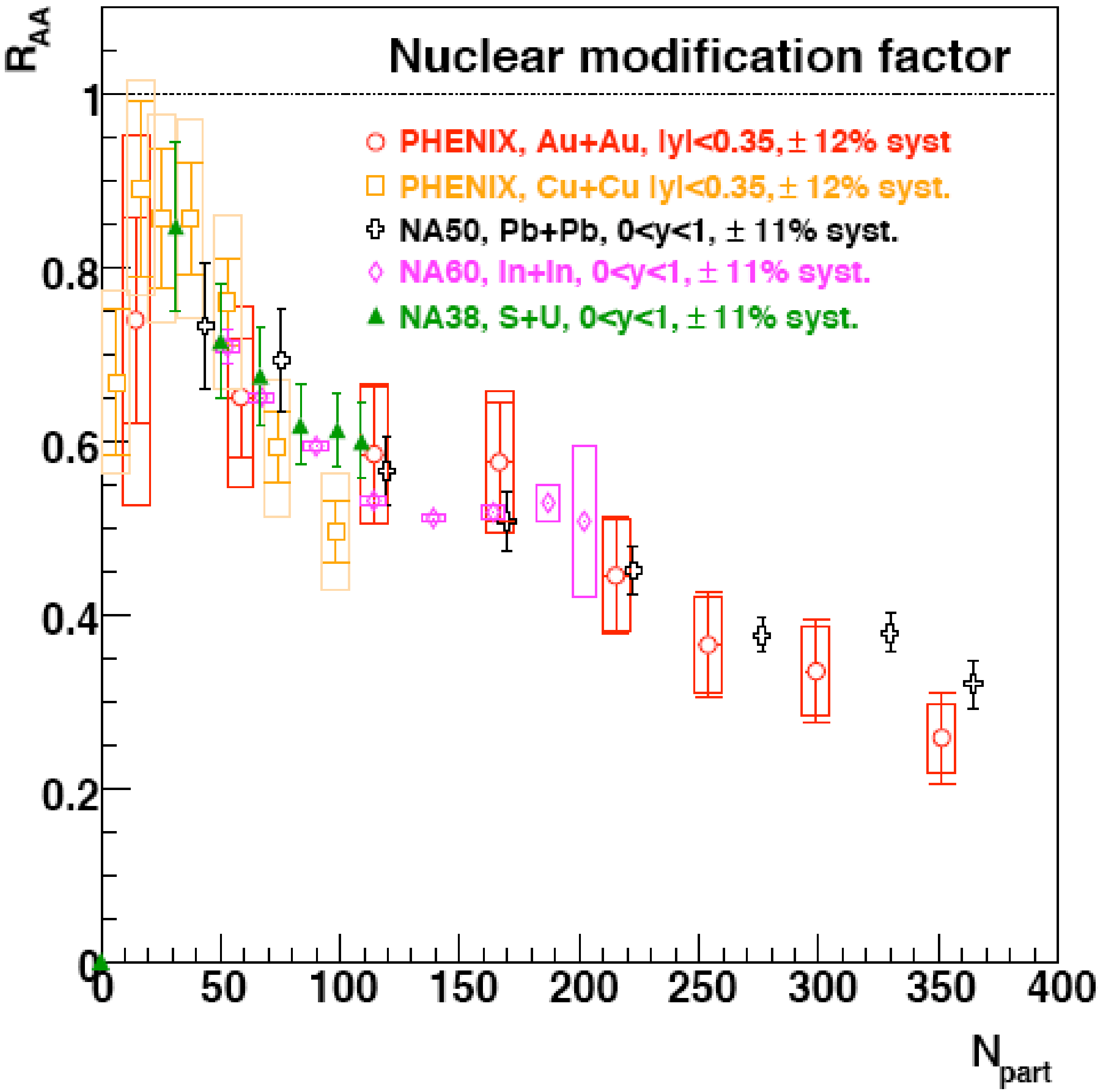
The present situation, as reported at Quark Matter 09





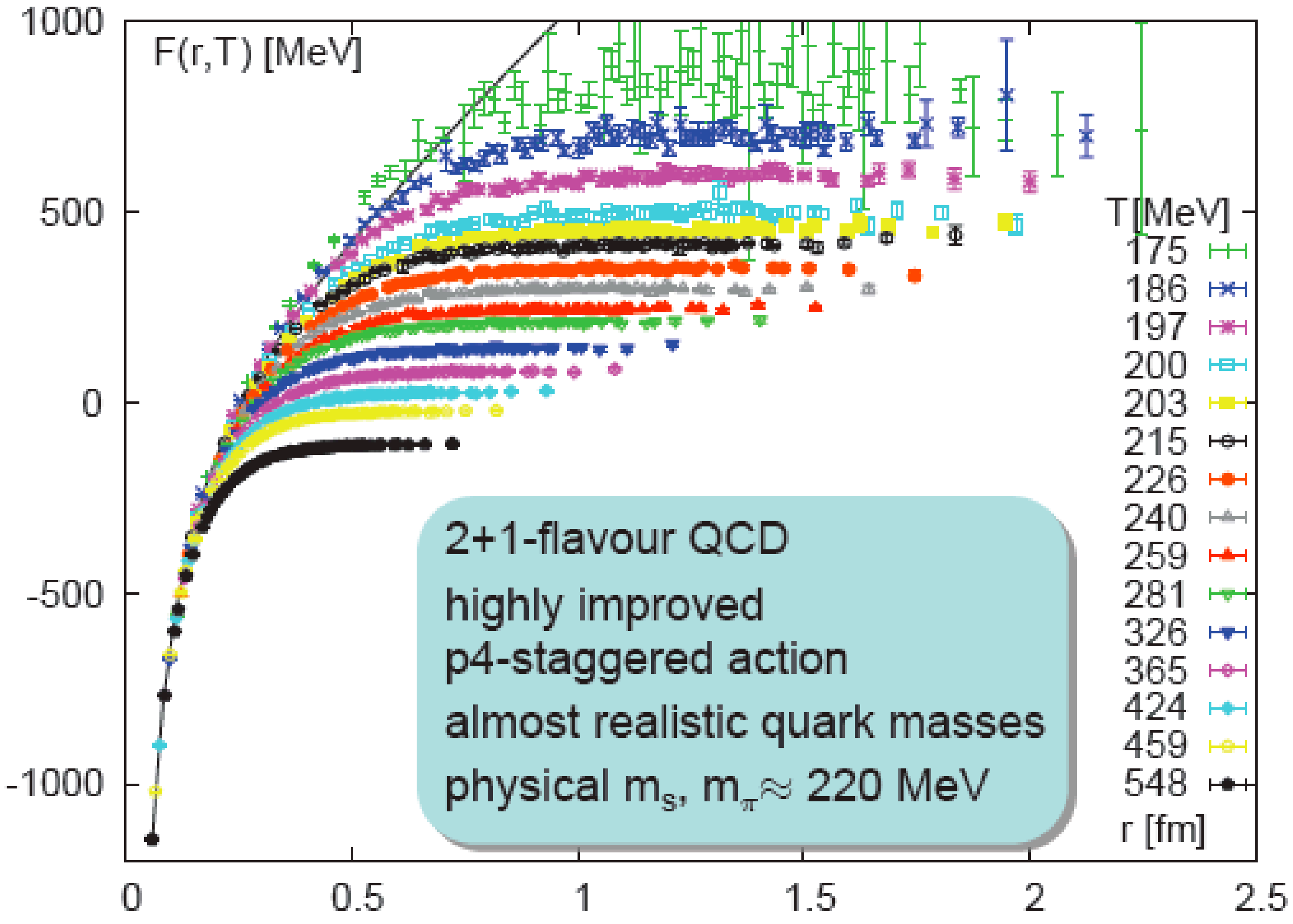
(from R. Arnaldi, Quark Matter 09)

What about RHIC ?



Turning now to theory

Heavy quarks free energy from lattice calculations



2+1-flavour QCD

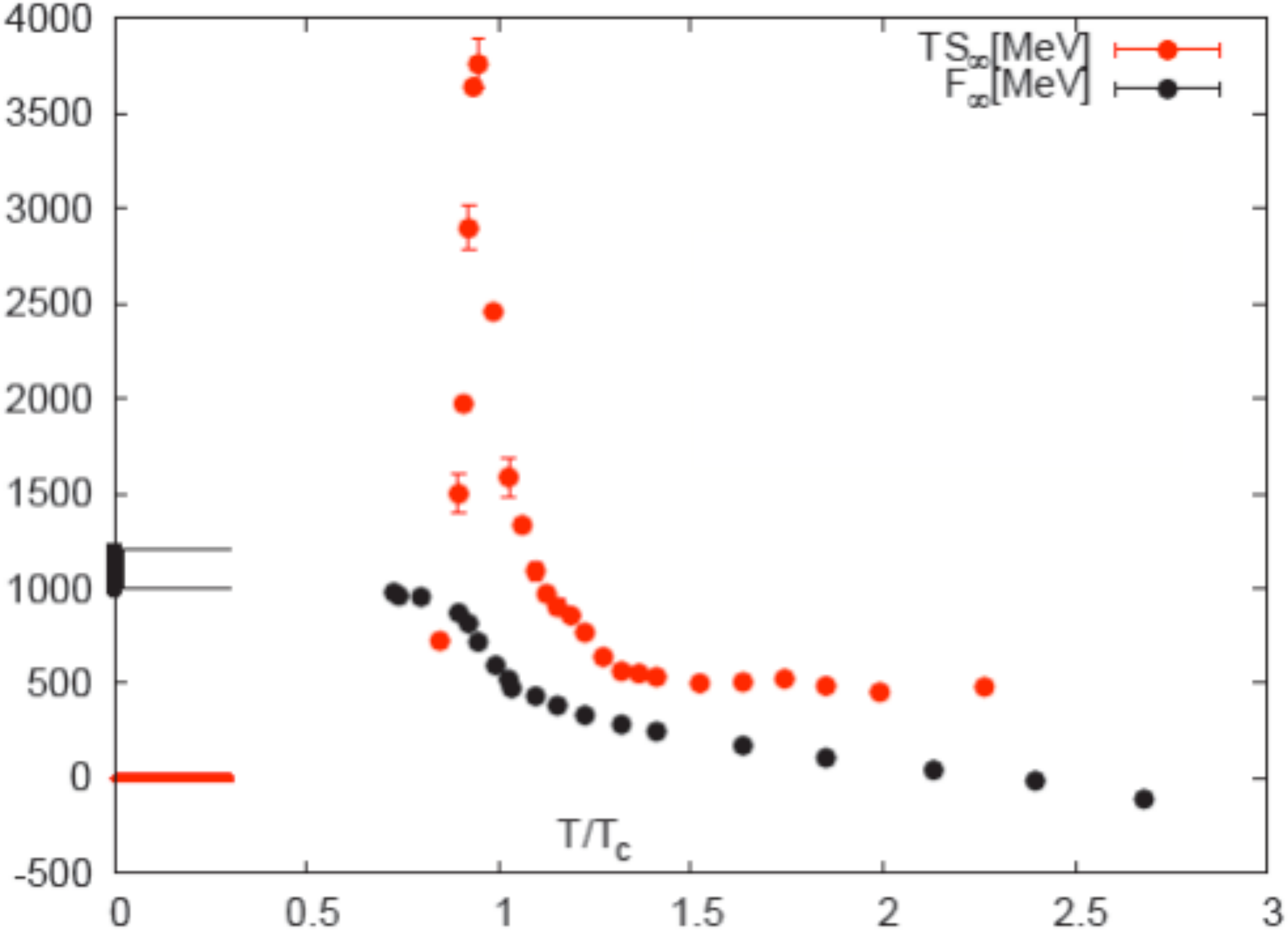
highly improved
p4-staggered action

almost realistic quark masses

physical m_s, $m_\pi \approx 220$ MeV

(O. Kaczmarek et al., PLB543(2002)41,
S. Gupta et al., Phys.Rev.D77(2008)034503)

Free energy contains entropy



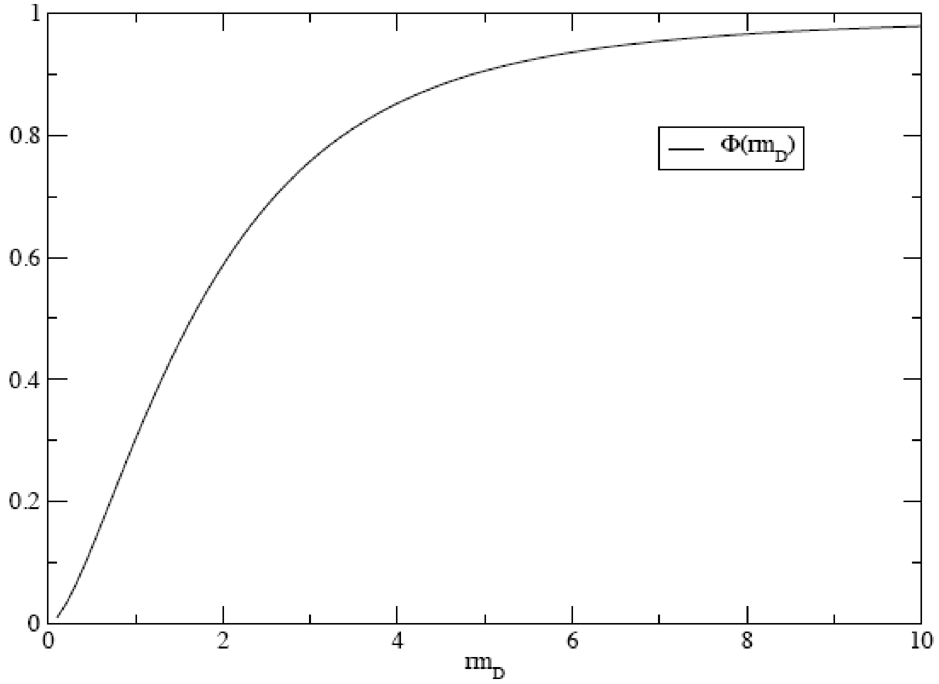
In weak coupling at high T: $$\Delta F_{Q\bar{Q}} = -\frac{g^2 m_D}{4\pi}\left[1 + \frac{e^{-m_D r}}{m_D r}\right]$$

Effective potential has imaginary part

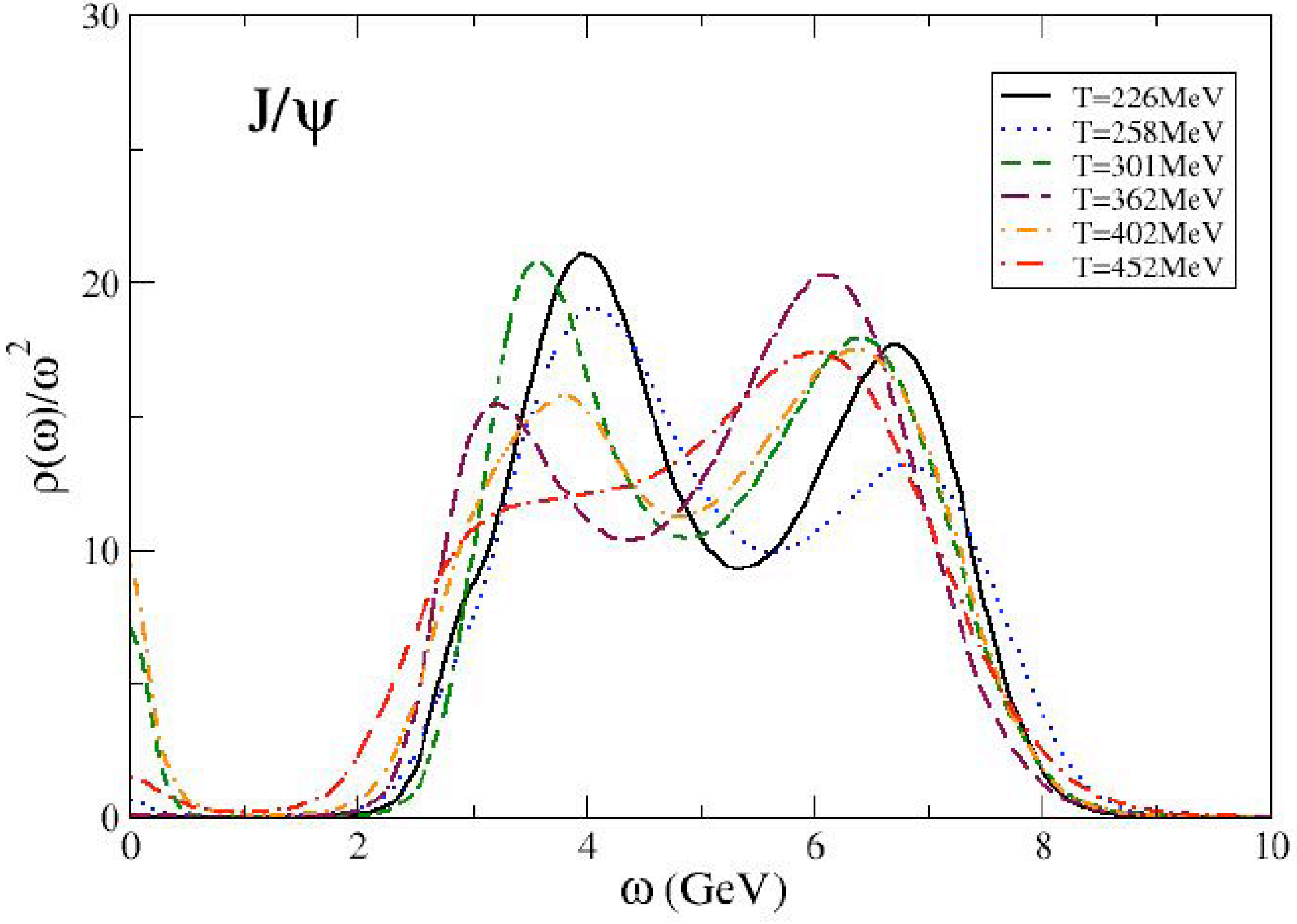
(there is more than screening)

(M.Laine - A. Beraudo, JPB, C. Ratti)

$$V(r) = -\frac{g^2 m_D}{4\pi}\left[1 + \frac{e^{-m_D r}}{m_D r}\right] - i\frac{g^2 T}{4\pi}\phi(m_D r)$$



Lattice : spectral function



(Skullerud, ECT* May 2009)

Outlook

-The subject continues to inspire a lot of works

-Theory of quarkonia is being developed (first principle finite temperature calculations, effective field theory, lattice spectral functions, etc.)

-The experimental situation is still complicated: one needs a better understanding of cold nuclear matter effects.

-At LHC, time scales will be well separated, and things could be cleaner