Statistical J/ψ production in A+A collisions

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1. $\langle J/\psi \rangle$
2. $\dfrac{dN}{m_T\, dm_T}$
3. SPS, Pb+Pb, $\sqrt{s} = 17$ GeV
4. RHIC, $\sqrt{s} = 130, 200$ GeV

(1974) J/ψ $\quad j = 1 \quad m_{J/\psi} \simeq 3.1$ GeV

$J/\psi \rightarrow$

- { c quark, $m_c \simeq 1.3$ GeV
- { $(c\bar{q})\ (\bar{c}q)$ $\quad q = u, d, s$
  $\mathcal{D}$-mesons $\quad$ open charm
- { $(c\bar{c})$ $\quad \eta_c, \chi_c, \ldots, \psi', \ldots$ charmonia
- { (cqq) $\quad q = u, d, s$
  charmed baryons
- { (ccq) - ? $\quad (ccc)$ - ??
- { b quark, $m_b \simeq 4.2$ GeV
  B-mesons, $\Upsilon, \chi_b, \ldots \Upsilon', \ldots$
  Bottom baryons
  . . .

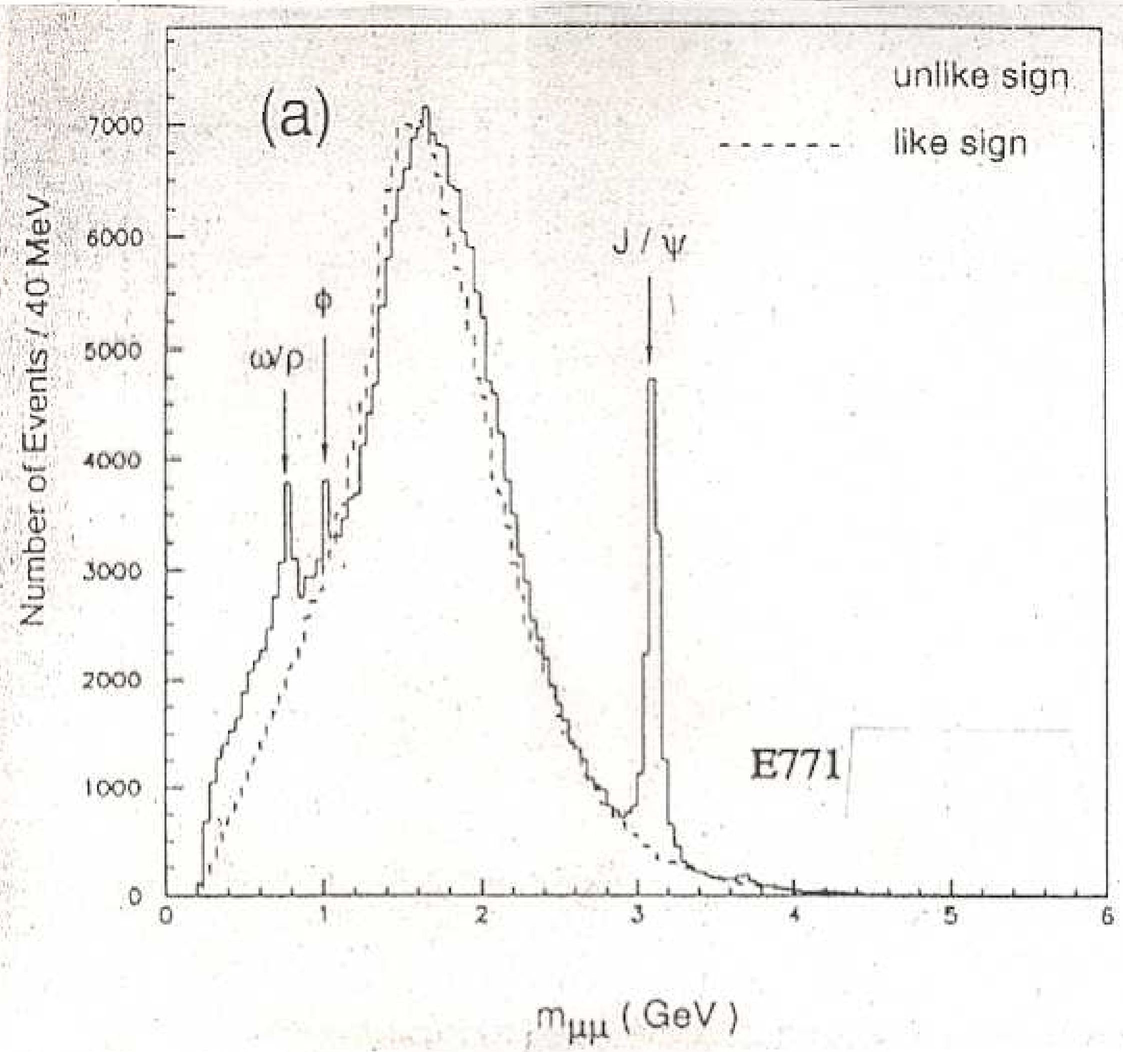
$\downarrow$

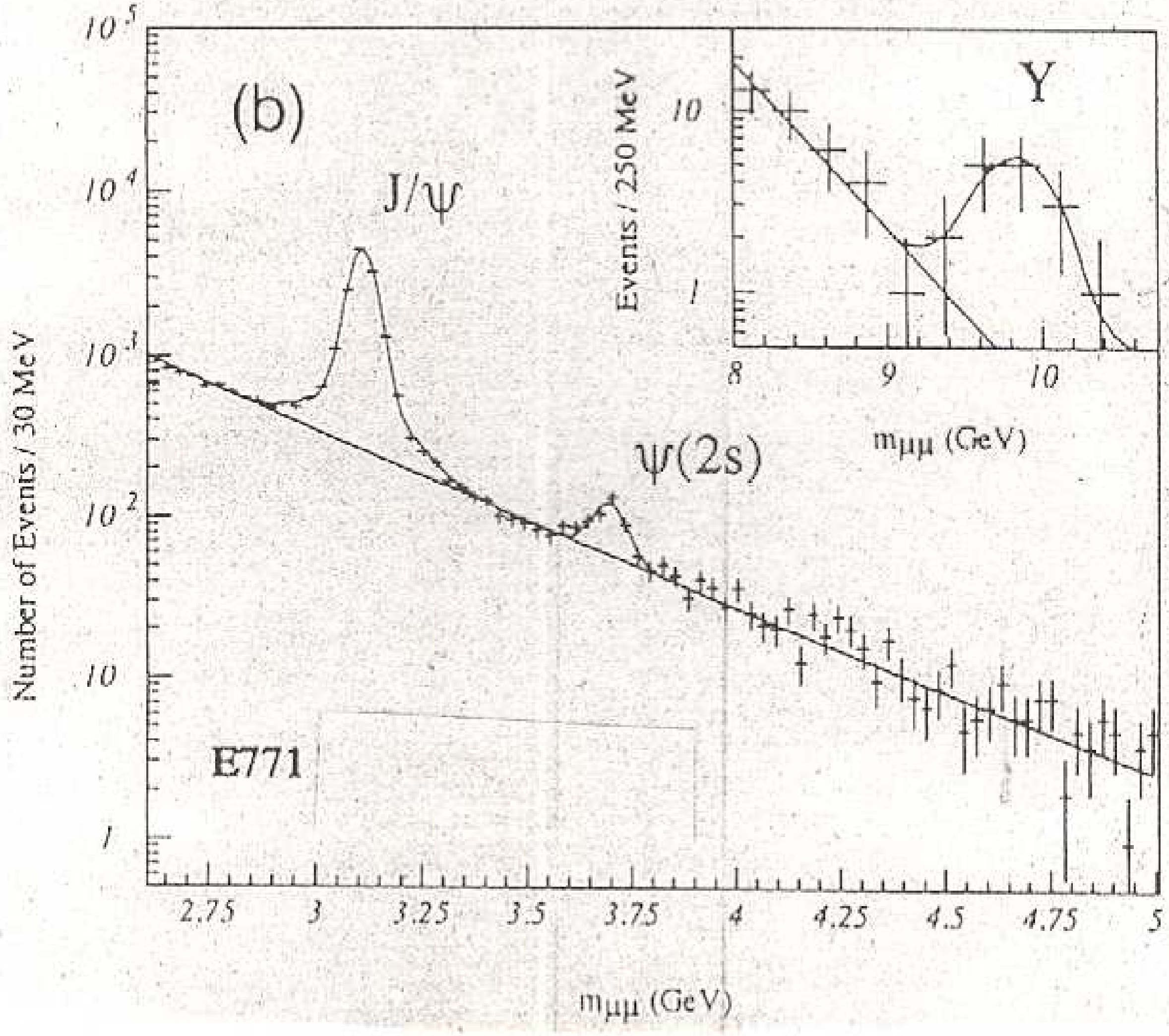
Matsui, Satz (1986)

J/ψ suppression in QGP

$J/\psi \to \mu^+ \mu^-$ $\quad$ 6% $\qquad \psi' \to \mu^+ \mu^-$ $\quad$ 1%

$(\rho, \omega, \varphi) \to \mu^+ \mu^-$ $\quad 10^{-4} \div 10^{-5}$


(a)
unlike sign
like sign
J / ψ
ϕ
ω/ρ
E771
Number of Events / 40 MeV
0
1000
2000
3000
4000
5000
6000
7000
0
1
2
3
4
5
6
m_μμ (GeV)


(b)
J/ψ
ψ(2s)
E771
Υ
Events / 250 MeV
10
1
8
9
10
m_μμ (GeV)
Number of Events / 30 MeV
10^5
10^4
10^3
10^2
10
1
2.75
3
3.25
3.5
3.75
4
4.25
4.5
4.75
5
m_μμ (GeV)

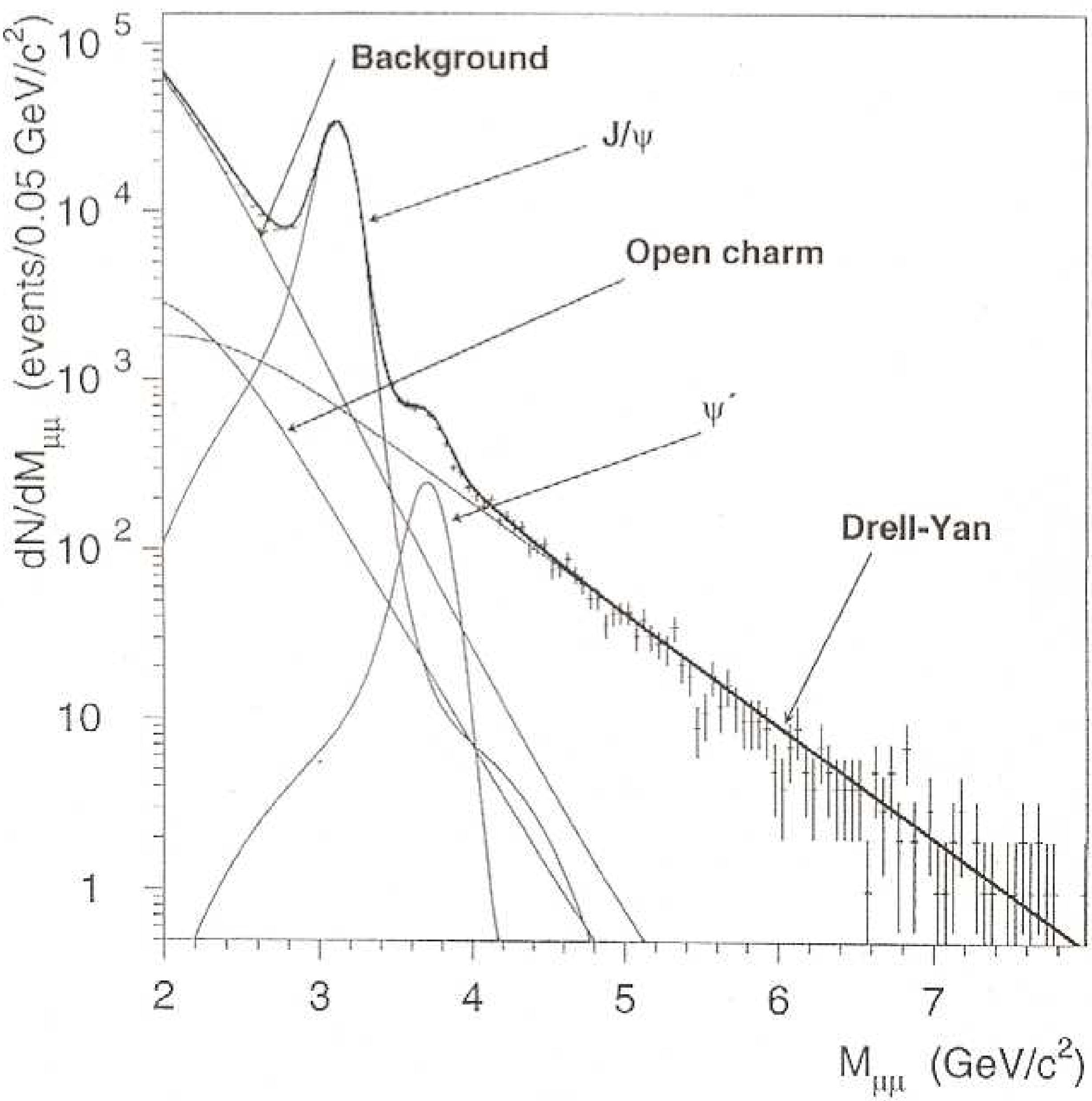
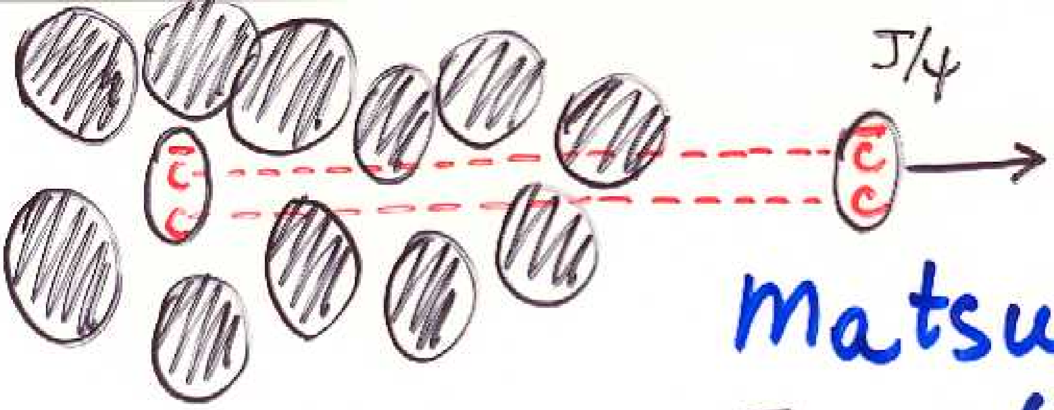
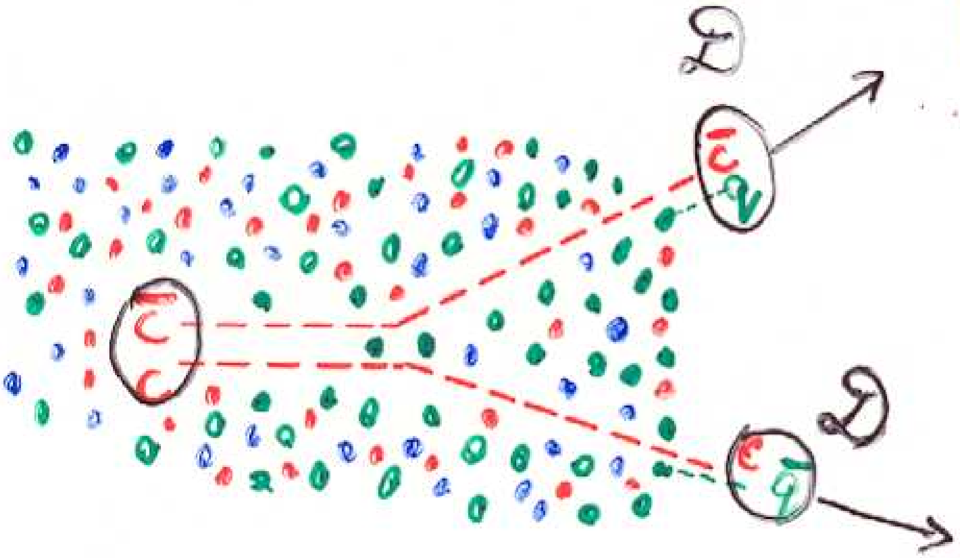


Figure 1: Opposite-sign muon pair invariant mass spectrum for Pb-Pb collisions a
158 GeV/c incident momentum. Data collected in 1996.

Hadron Gas



Matsui, Satz (1986)



QGP

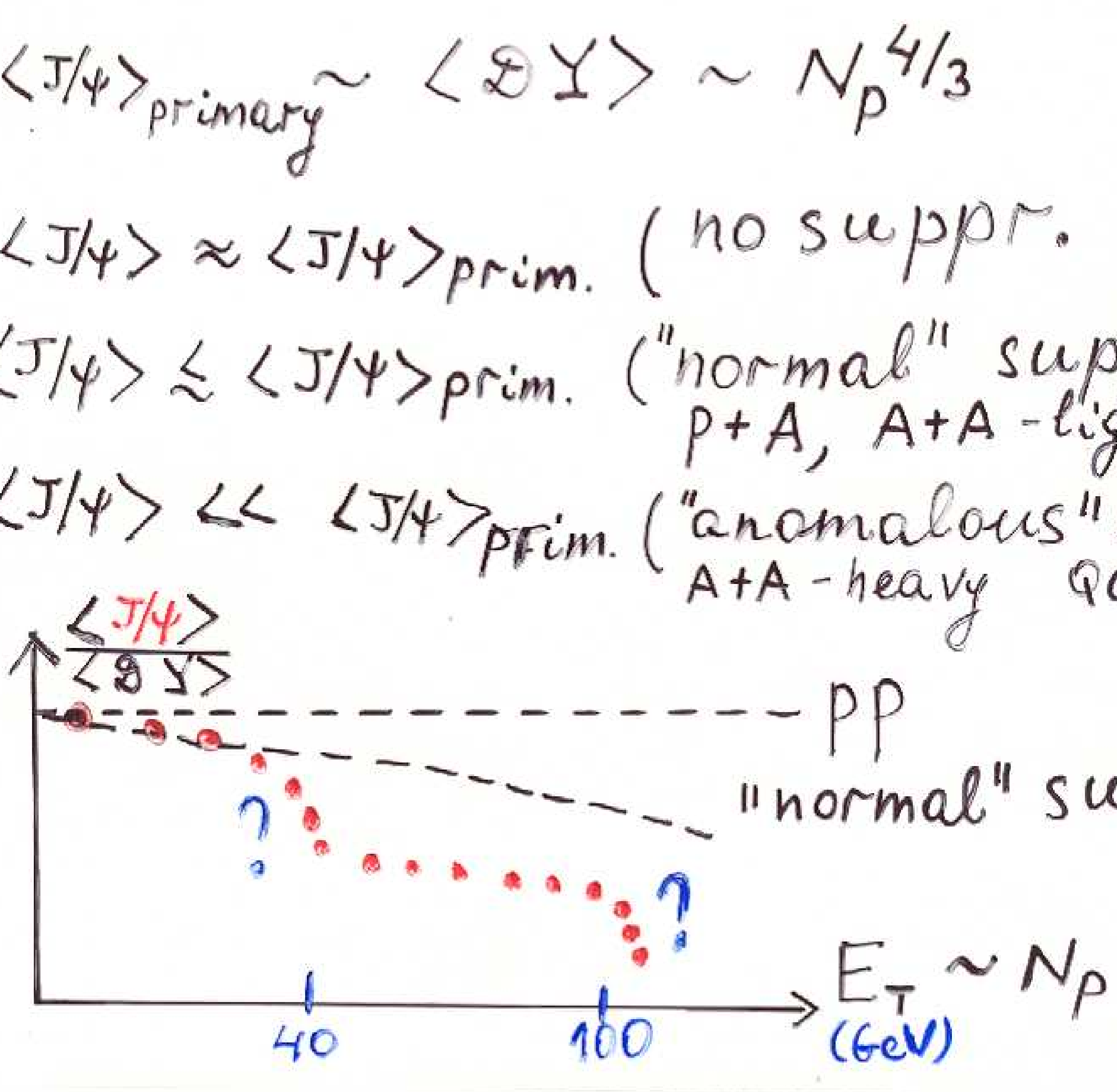
$J/\psi \to \mu^+ \mu^-$ 6%

$$\langle J/\psi \rangle_{primary} \sim \langle DY \rangle \sim N_p^{4/3}$$

$\langle J/\psi \rangle \approx \langle J/\psi \rangle_{prim.}$ (no suppr. p+p)

$\langle J/\psi \rangle \lesssim \langle J/\psi \rangle_{prim.}$ ("normal" suppr.) p+A, A+A - light

$\langle J/\psi \rangle \ll \langle J/\psi \rangle_{prim.}$ ("anomalous" suppr.) A+A - heavy QGP!?



② $$\langle J/\psi \rangle = \frac{(2j+1)}{2\pi^2} V \int_0^\infty \frac{k^2 dk}{\exp\left[\frac{(k^2+m_\psi^2)^{1/2}}{T}\right]-1}$$

$$\cong (2j+1) V \left(\frac{m_\psi T}{2\pi}\right)^{3/2} \exp\left(-\frac{m_\psi}{T}\right)$$

$j = 1, \quad m_\psi = 3097$ MeV

$$\frac{\langle J/\psi \rangle}{\langle h^- \rangle} \cong const(A, \sqrt{s})$$

M. Gaździcki, M. Gorenstein

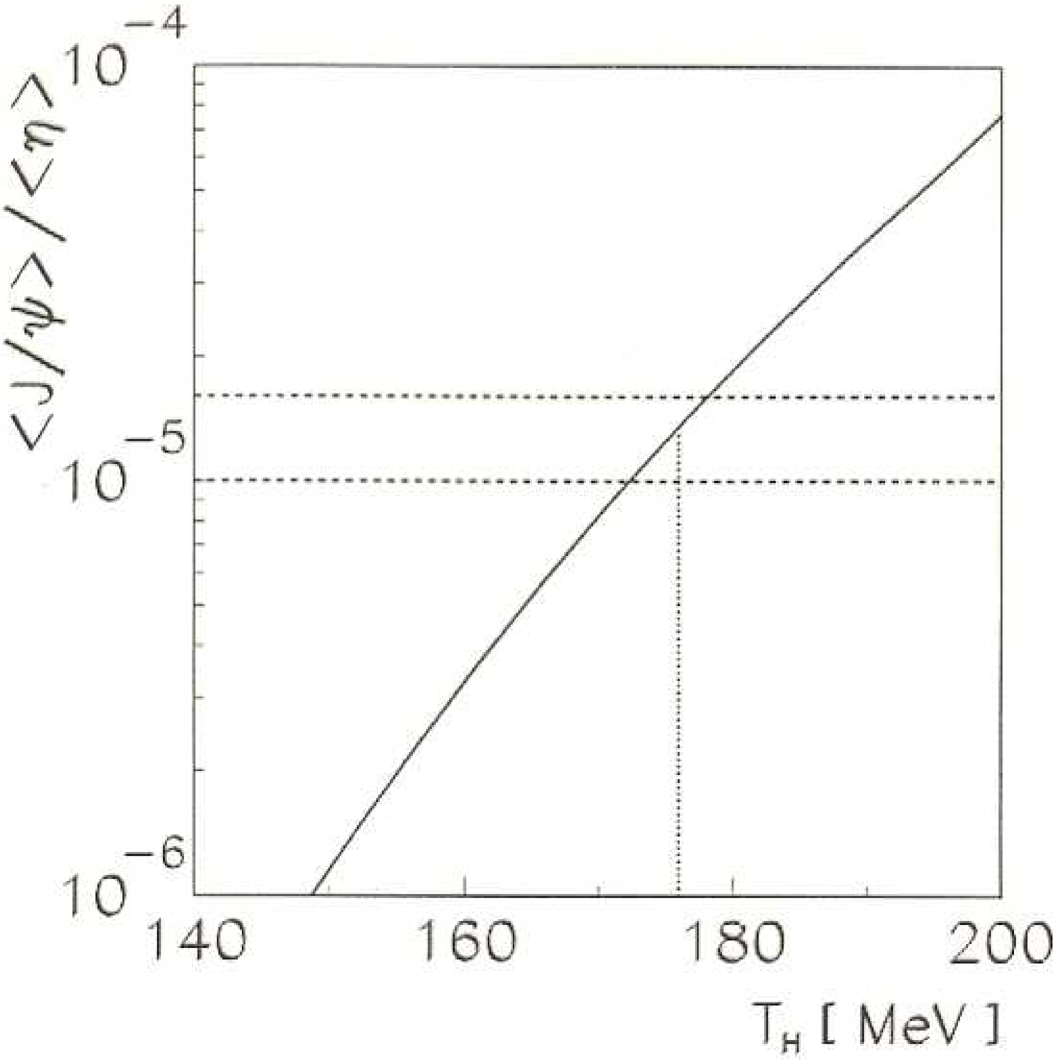
Phys. Rev. Lett. 83 (1999) 4009

$T \approx 176$ MeV

$$\frac{\langle J/\psi \rangle}{\langle h \rangle}$$

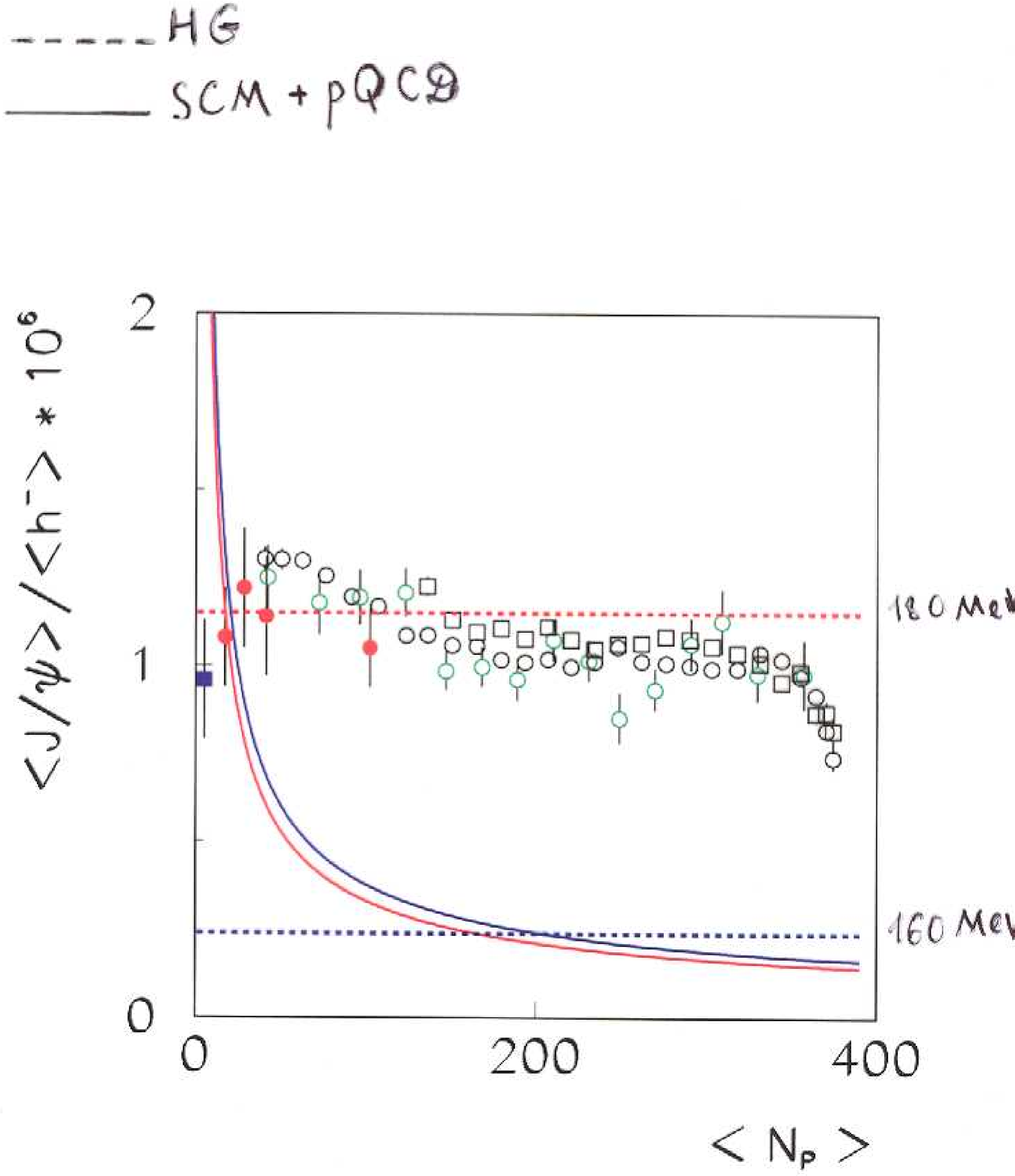
T_H - ? J/ψ "thermometer"

4



$$T_H \simeq 176 \text{ MeV}$$

$$\frac{\langle J/\psi \rangle}{\langle \eta \rangle} = \frac{3\, m_\psi^2\, K_2(m_\psi/T)}{m_\eta^2\, K_2(m_\eta/T)}$$



HG
SCM + pQCD
180 MeV
160 MeV
$\langle J/\psi \rangle / \langle h^- \rangle * 10^6$
$\langle N_p \rangle$
0
1
2
0
200
400

Braun-Munzinger, Stachel (2000)

$\mathcal{D}, \bar{\mathcal{D}}, \mathcal{D}^*, \bar{\mathcal{D}}^*, \ldots$
$\Lambda_c, \ldots$

open charm
hadrons N_O

$N_{c\bar{c}}^{dir}$

calculated
in pQCD

Hadronization

$\eta_c, J/\psi, \chi_c, \ldots \psi', \ldots$

hidden charm
hadrons N_H

γ_c

V, T, μ_B
Found from
fitting N_j/N_k

$$N_{c\bar{c}}^{dir} = \gamma_c N_O + \gamma_c^2 N_H$$

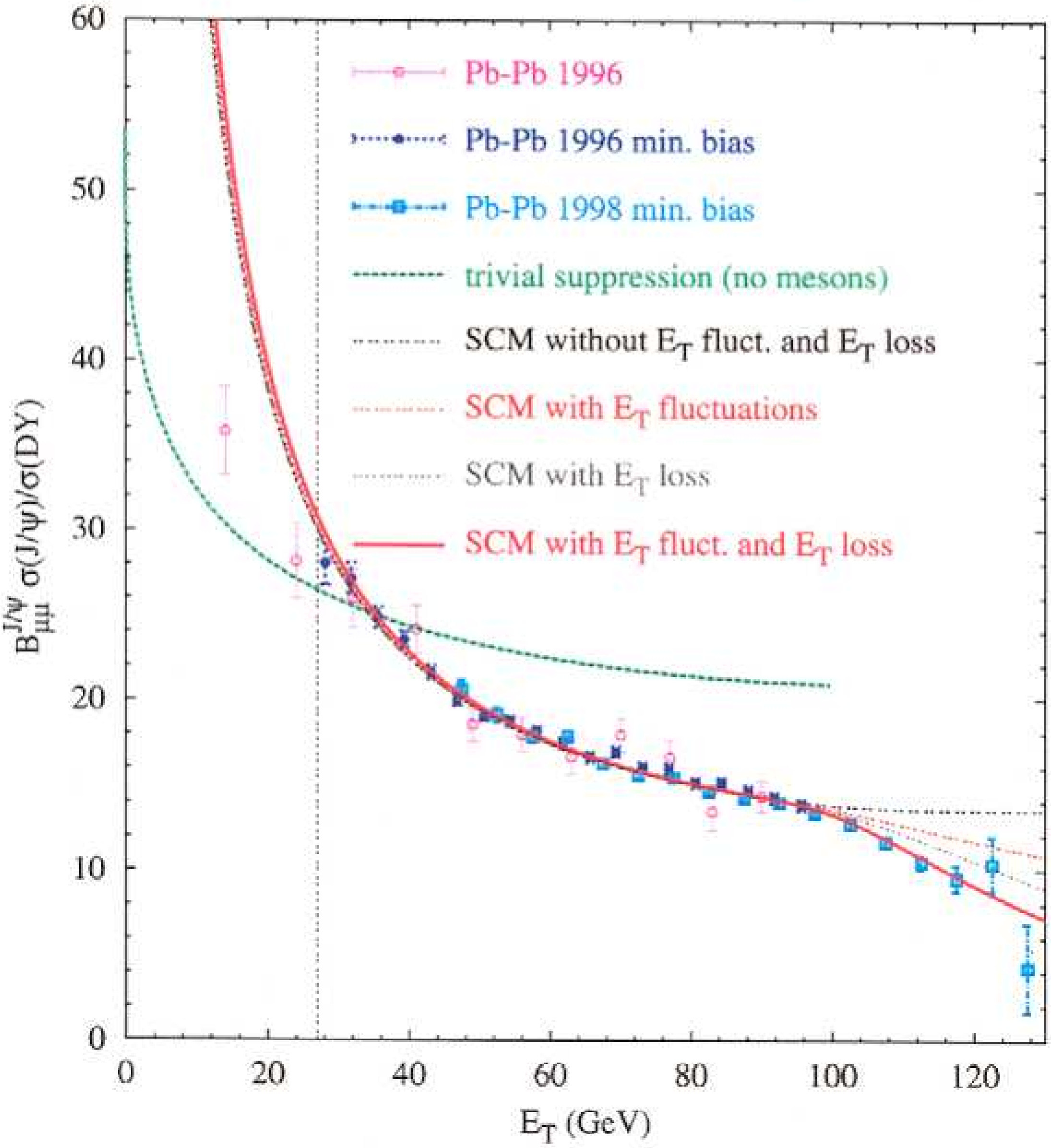
$N_O(V, T, \mu_B)$ g.c.e.

1). N_O c.e.   2). $P(N_{c\bar{c}}^{dir})$ – Poisson distr.

$$\langle J/\psi \rangle \cong \bar{N}_{c\bar{c}} \left(1 + \bar{N}_{c\bar{c}}\right) \frac{N_{J/\psi}^{tot}}{N_O^2}$$

M.G., Kostyuk, Stöcker, Greiner (2001)
Phys. Lett. B (2001, 2002)

SCM result at large E_T



$$\chi^2/\mathrm{dof} = 1.07$$

The fit result

$\sigma_{c\bar{c}}^{NN}$ the effective cross section of charm production by nucleon pair;

η the fraction of J/ψ satisfying the kinematical conditions of NA50 spectrometer

	N+N collisions	Our fit for Pb+Pb collisions
$\sigma_{c\bar{c}}^{NN}$	~ 5.5 μb	(34 ± 9) μb
η	~ 0.24	~ 0.14

The predicted enhancement of the open charm is by the factor of about 4.5–7.5.

The enhancement within the rapidity window of NA50 spectrometer is by the factor of about 2.5–4.5.

$$\langle J/\psi \rangle = N_{c\bar{c}} \left(N_{c\bar{c}} + 1 \right) \underbrace{\frac{N_{J/\psi}^{tot}}{N_0^2}}_{\frac{1}{V} \sim \frac{1}{N_p}}$$

$$N_{c\bar{c}} \propto N_p^{4/3}$$

$$N_{DY} \propto N_p^{4/3}$$

$$\frac{\langle J/\psi \rangle}{\langle DY \rangle} \equiv R \quad ? \qquad \frac{\langle J/\psi \rangle}{\langle \pi \rangle} \equiv R^*$$

$$\langle \pi \rangle \sim N_p$$

1). $N_{c\bar{c}} << 1$ SPS

$$R \propto \frac{N_{c\bar{c}}}{N_{DY}} \cdot \frac{1}{N_p} \propto \frac{1}{N_p}$$

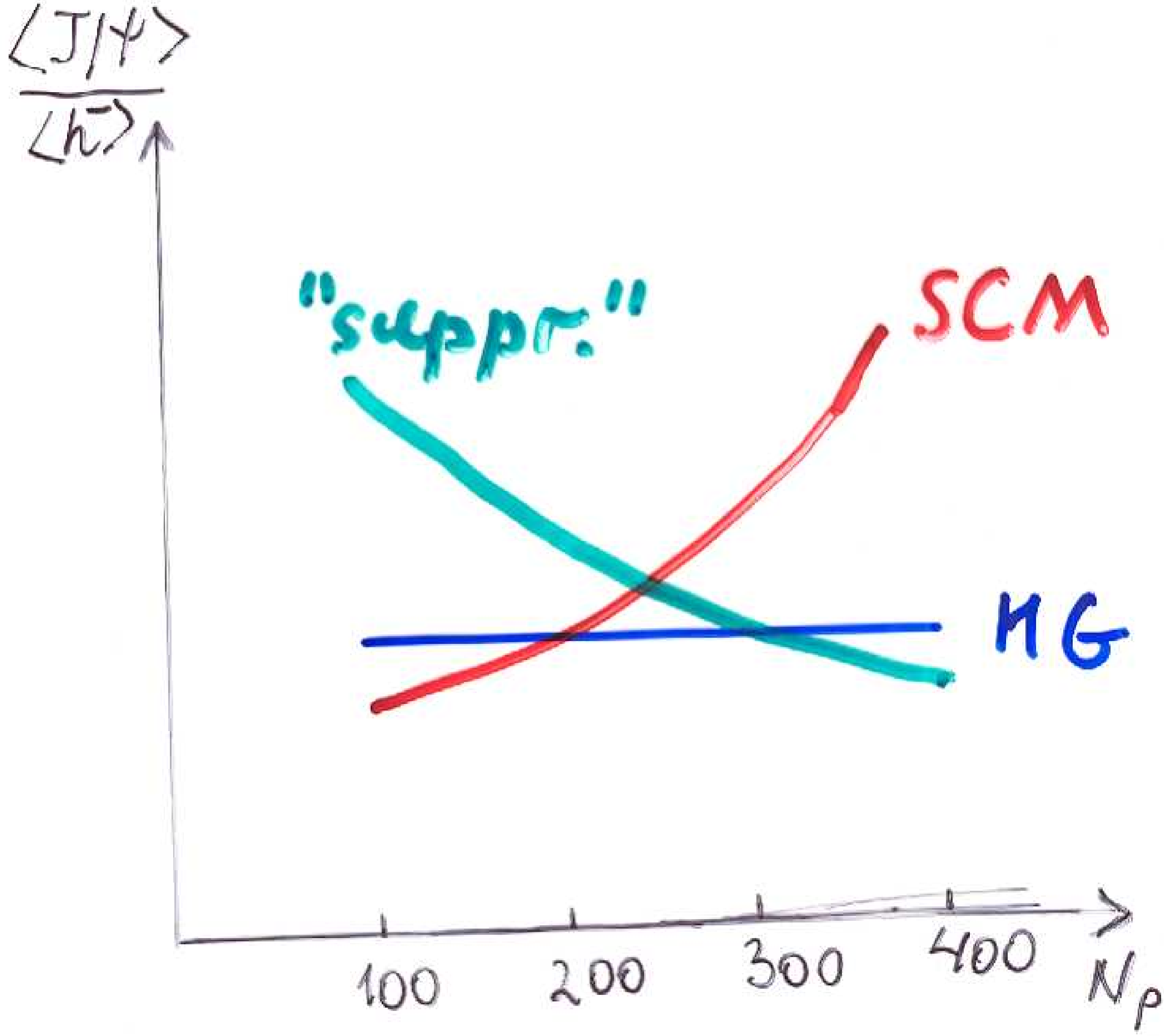
$$R^* \propto \frac{N_{c\bar{c}}}{\langle \pi \rangle} \frac{1}{N_p} \propto N_p^{-2/3}$$

2). $N_{c\bar{c}} >> 1$ RHIC

$$R \propto \frac{N_{c\bar{c}}^2}{N_{DY}} \cdot \frac{1}{N_p} \propto \frac{N_p^{4/3}}{N_p} \propto N_p^{1/3}$$

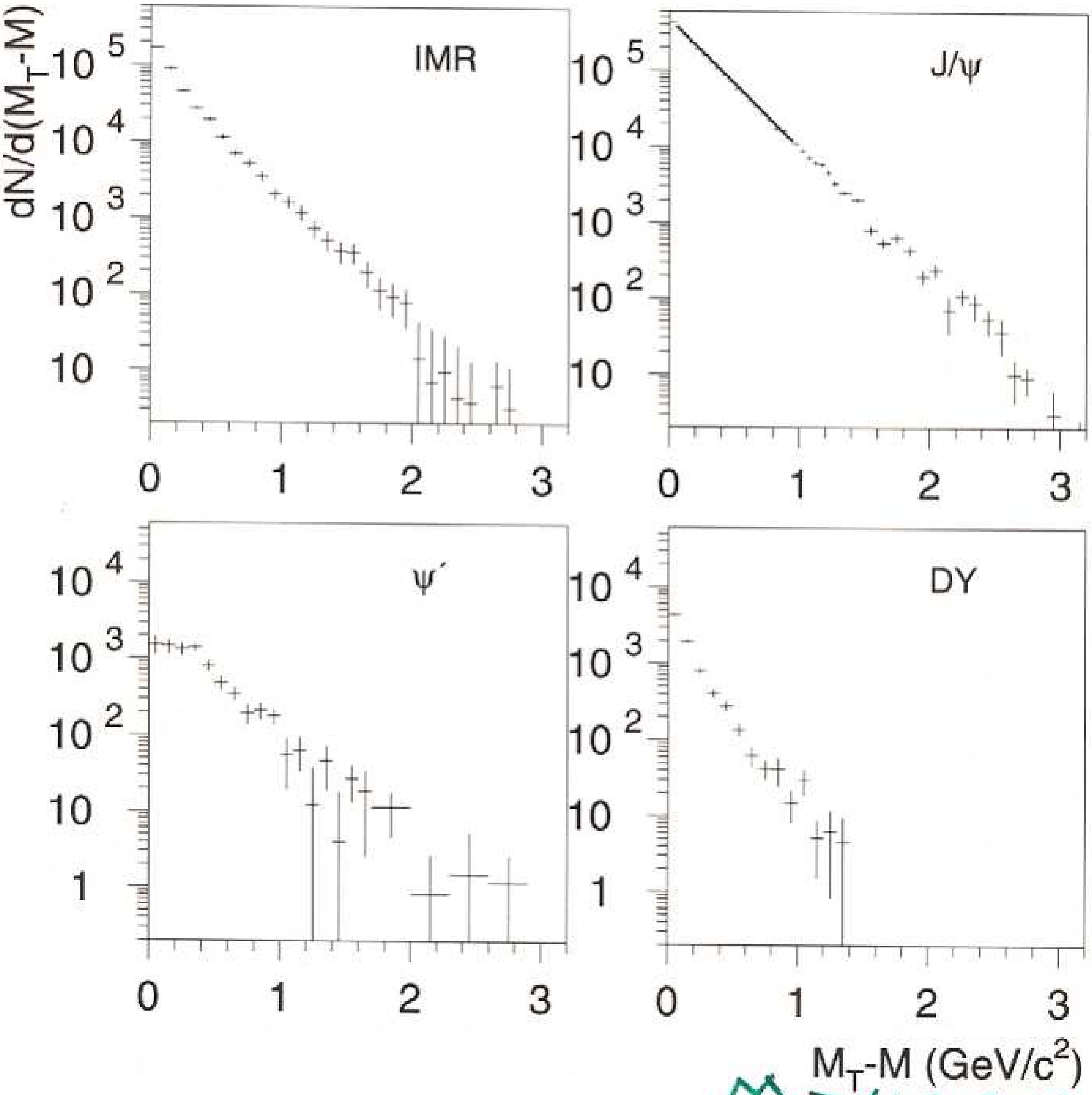
$$R^* \propto \frac{N_{c\bar{c}}^2}{\langle \pi \rangle} \cdot \frac{1}{N_p} \propto N_p^{+2/3}$$

RHIC


$\frac{\langle J/\psi \rangle}{\langle h^- \rangle}$
"suppr."
SCM
MG
100
200
300
400
N_p

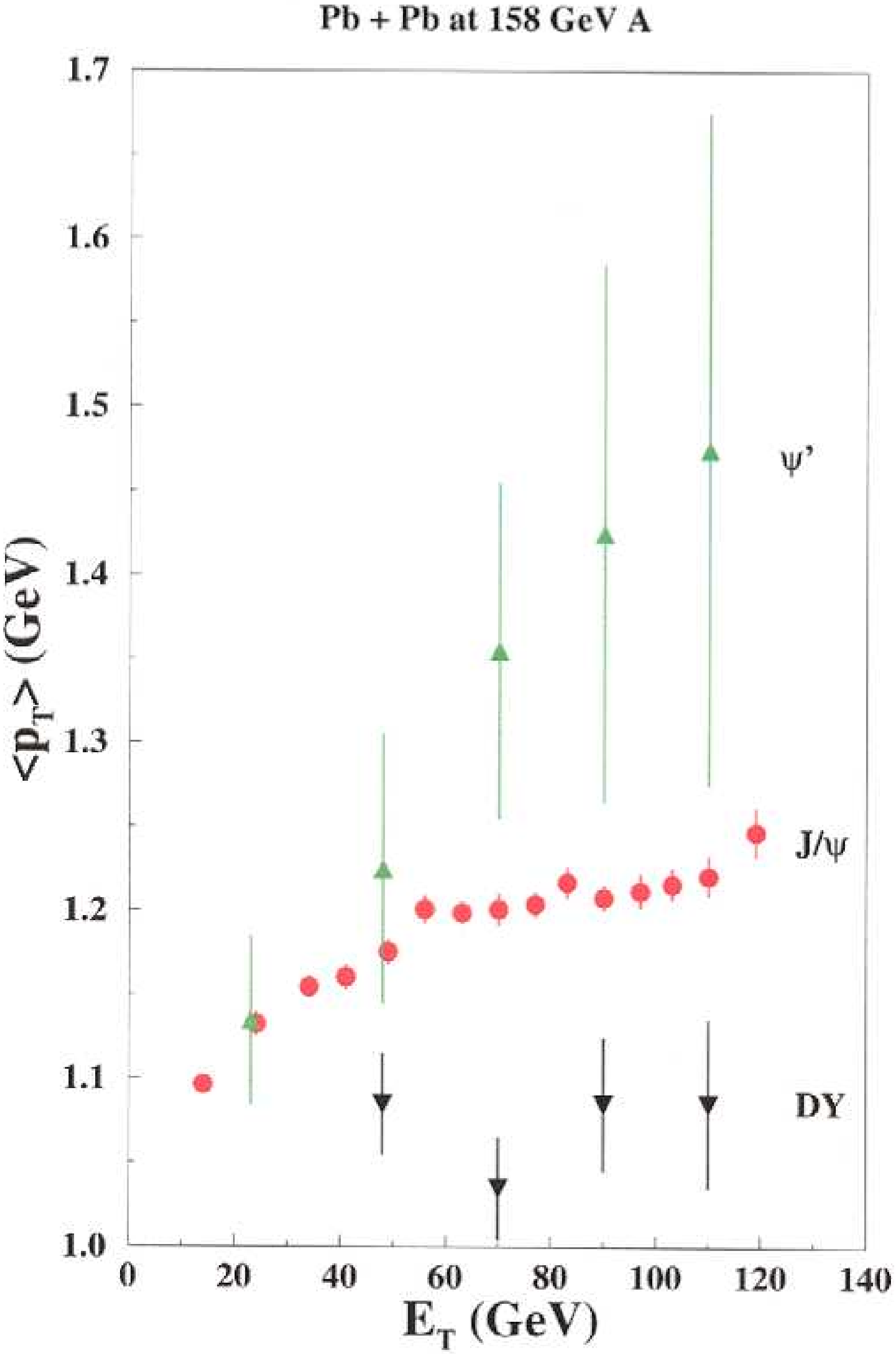
NA50 Phys. Lett. B (2001)

2.1<M<2.7 GeV

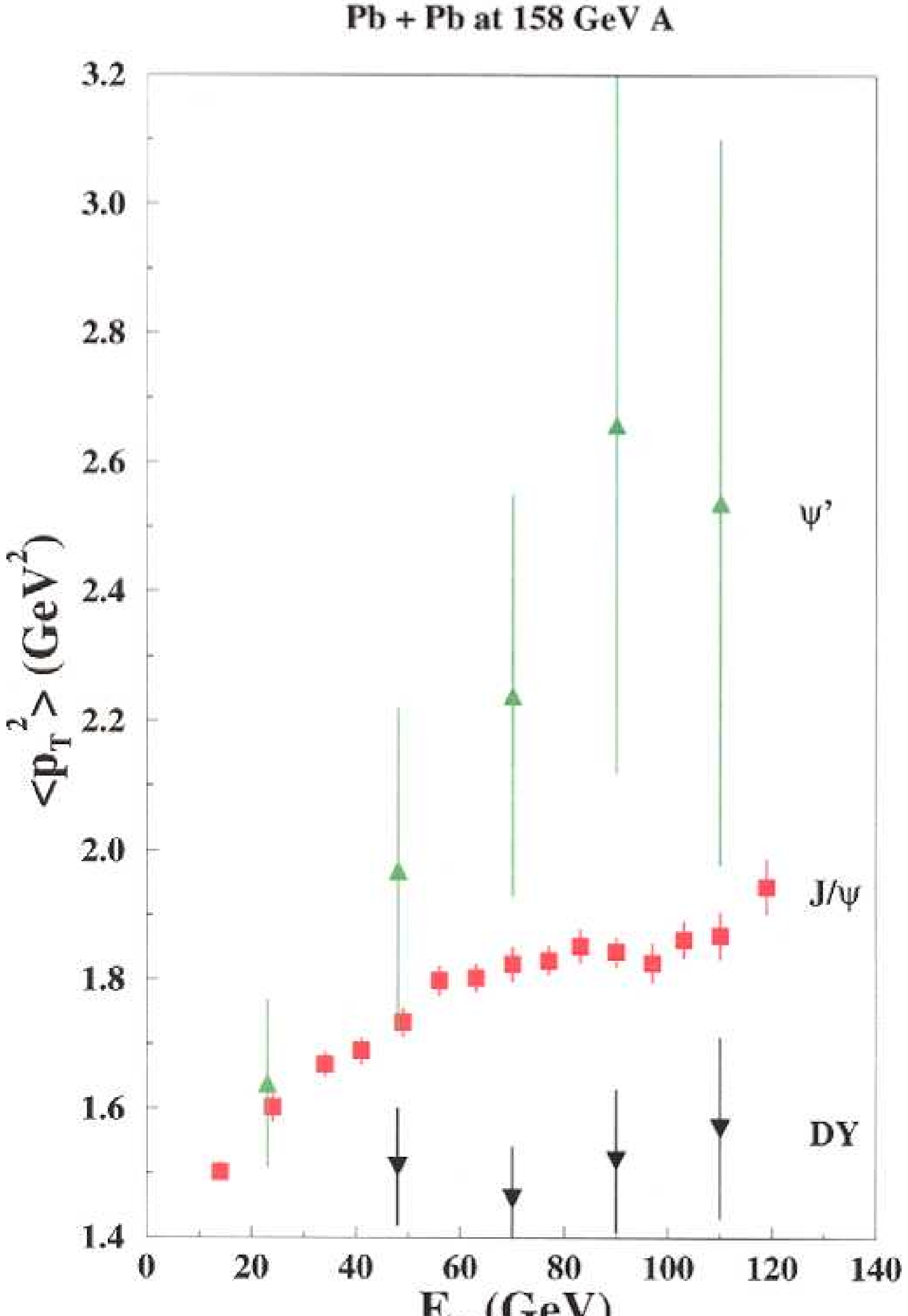


M > 4.2 GeV

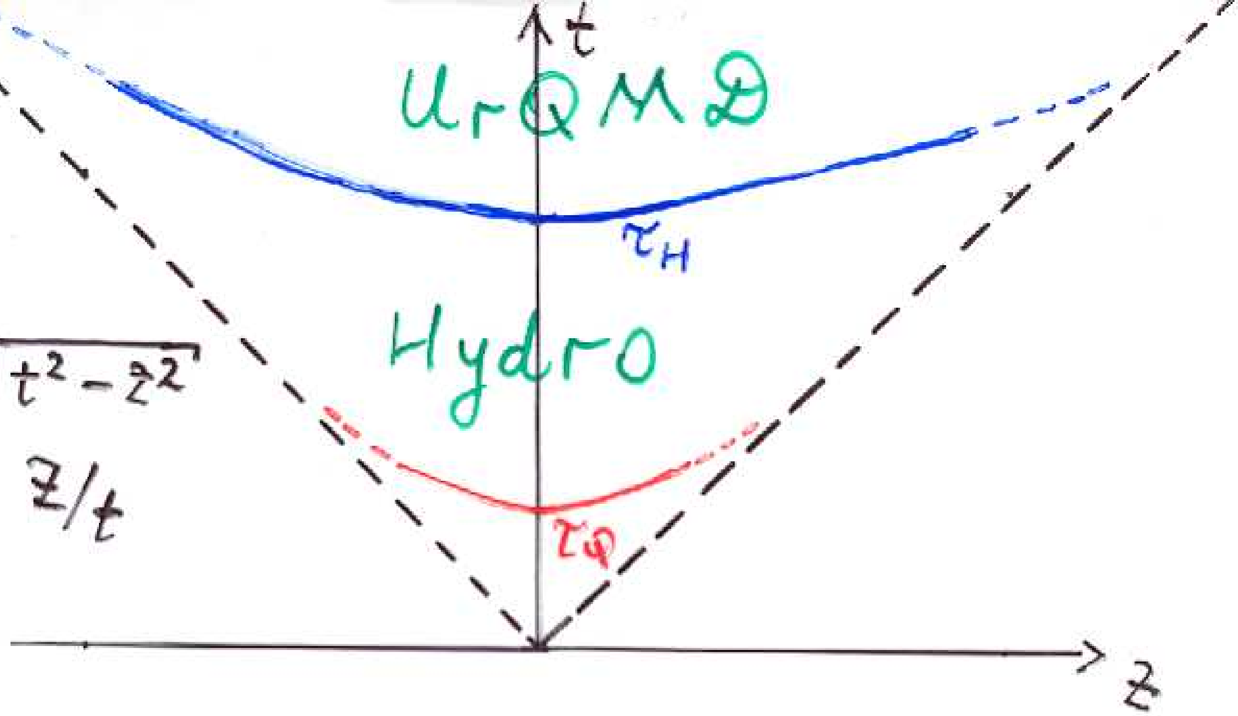
re 7: $M_{\mathrm{T}} - M$ distributions integrated over impact parameter for several muon mass intervals.



Pb + Pb at 158 GeV A
1.7
1.6
1.5
1.4
1.3
1.2
1.1
1.0
<p_T> (GeV)
0
20
40
60
80
100
120
140
E_T (GeV)
ψ'
J/ψ
DY



Pb + Pb at 158 GeV A
ψ'
J/ψ
DY
$<p_T^2>$ (GeV^2)
E_T (GeV)



$\tau = \sqrt{t^2 - z^2}$

$v_L = z/t$

$z = 0, \quad y_T = y_T(r, \tau) \qquad v_T \equiv th\, y_T$

If $\varepsilon(r, \tau = \tau_H) = const(r)$

$$\frac{dN}{m_T\, dm_T} \propto \int_0^{R_T} r\, dr\, K_1\left(\frac{m_T ch\, y_T}{T}\right) I_0\left(\frac{p_T sh\, y_T}{T}\right)$$

Schnederman, Sollfrank, Heinz (1993)
Rischke, Gyulassy (1996)

$y_T = y_T(r) - ?$

$y = \frac{y_T^{max}}{R_T} \cdot r$

QGP Hydr. + (u)RQMD

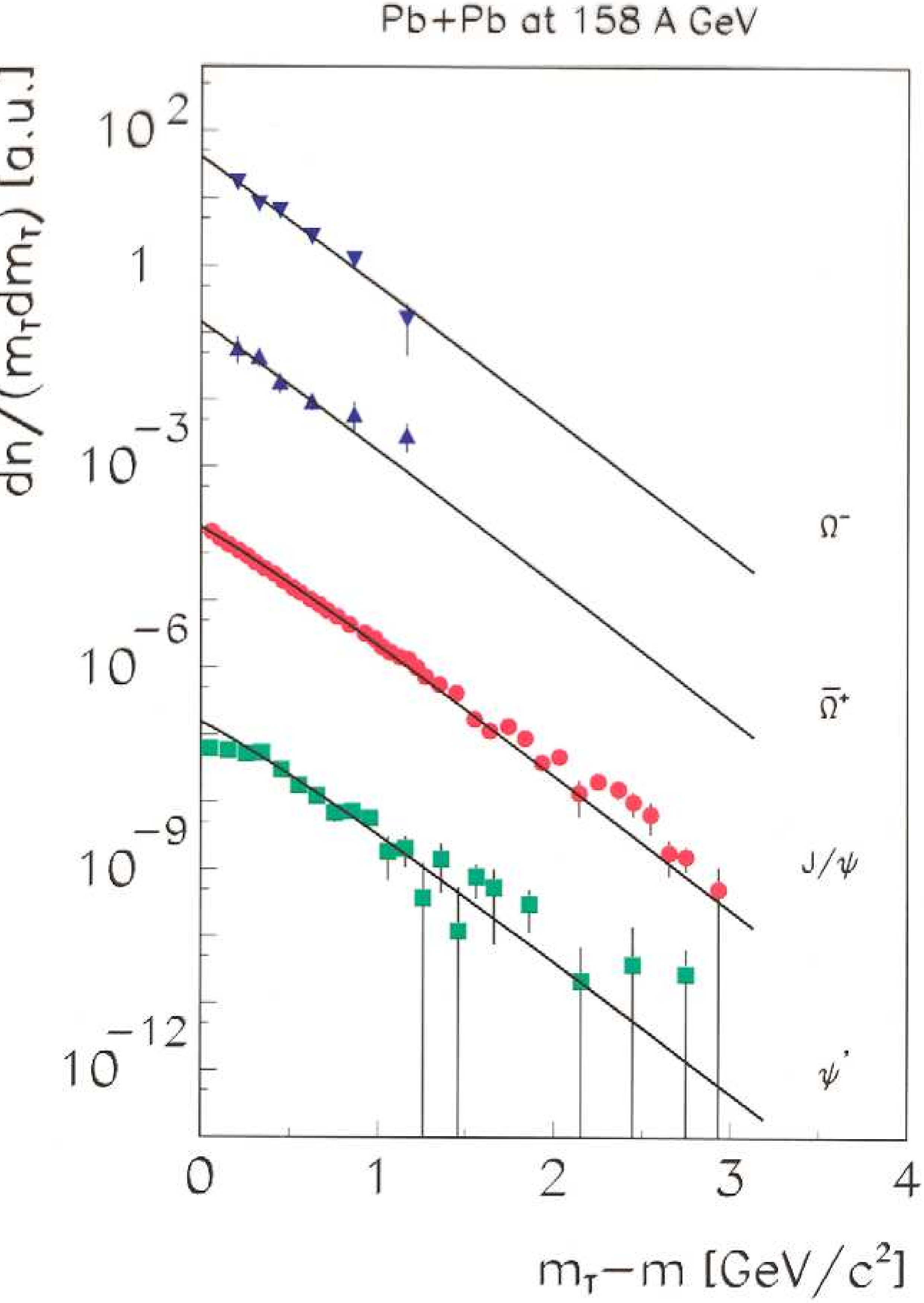
Hadrd. cascade

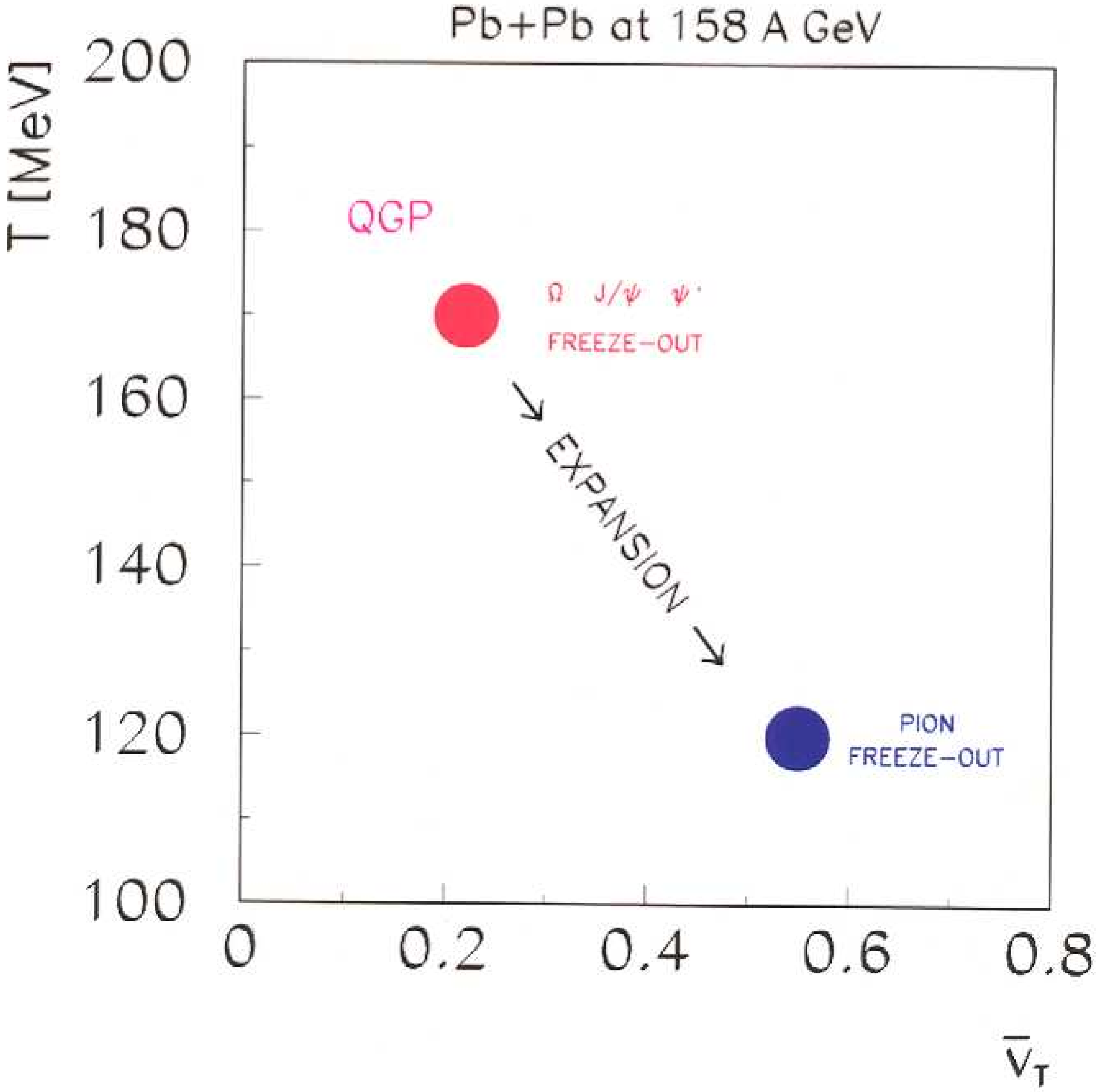
RQMD

Bass, Dumitru (2000)
Teaney, Lauret, Shuryak (2001)

M.G., Bugaev, Gaździcki hep-ph 0112197
14 Dec 2001 Phys. Rev. Lett (2002)

$T = 170$ MeV
$v_T \simeq 0.2$

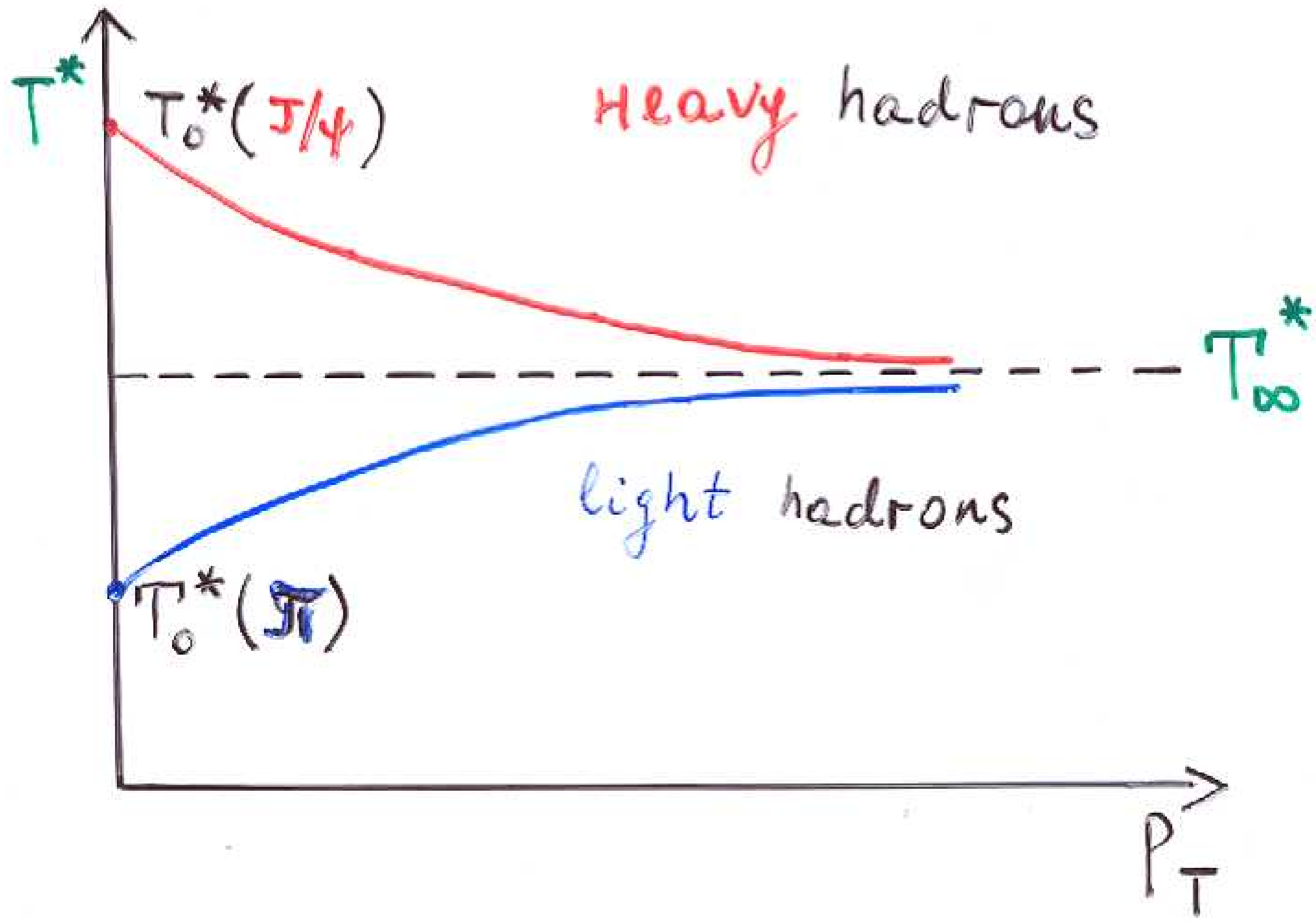


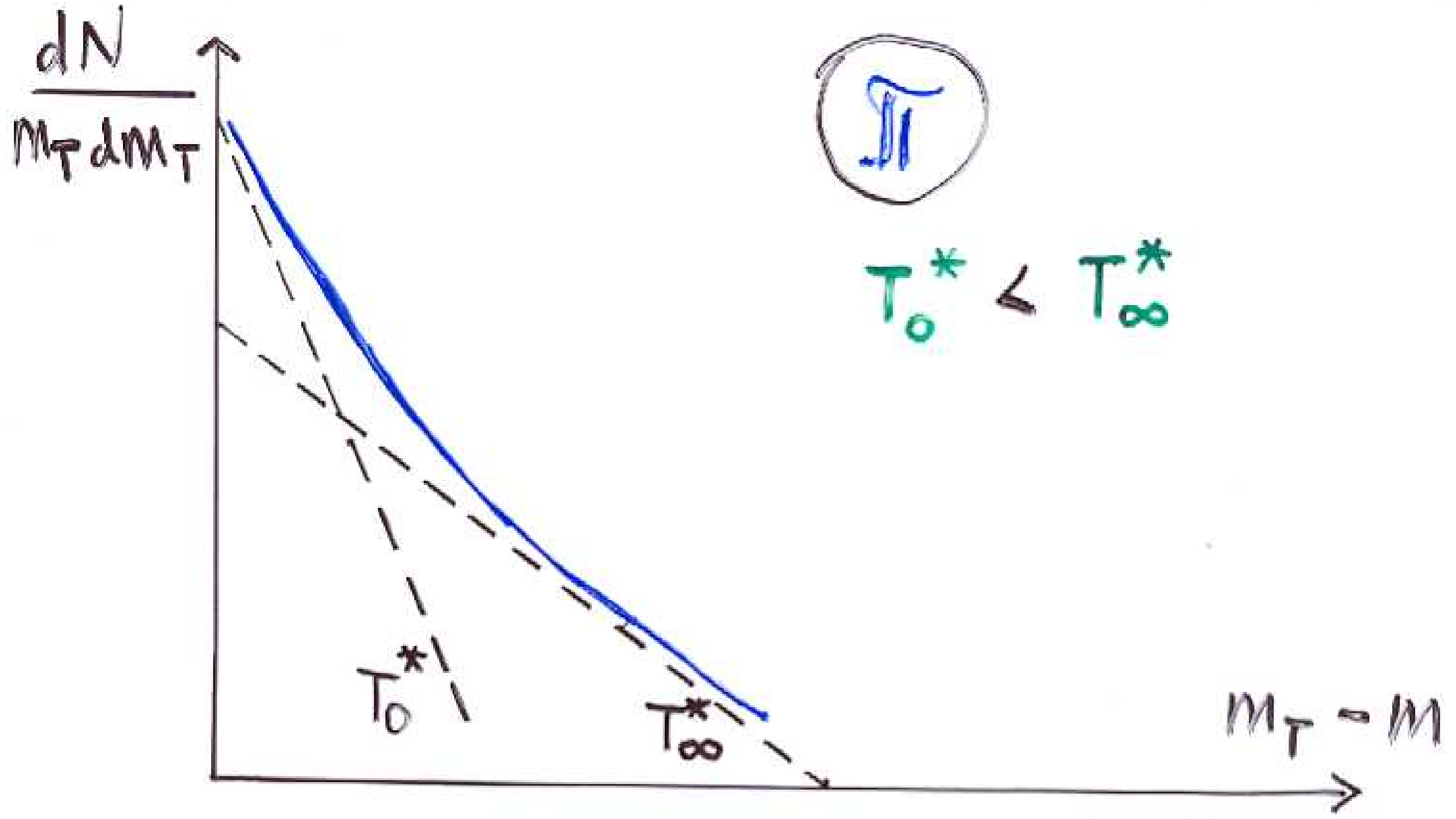

Pb+Pb at 158 A GeV
T [MeV]
200
180
160
140
120
100
QGP
Ω J/ψ ψ'
FREEZE-OUT
EXPANSION
PION
FREEZE-OUT
0
0.2
0.4
0.6
0.8
$\bar{v}_T$

$$\frac{dN}{m_T\, dm_T} \propto m_T\, e^{-m_T/T^*}$$

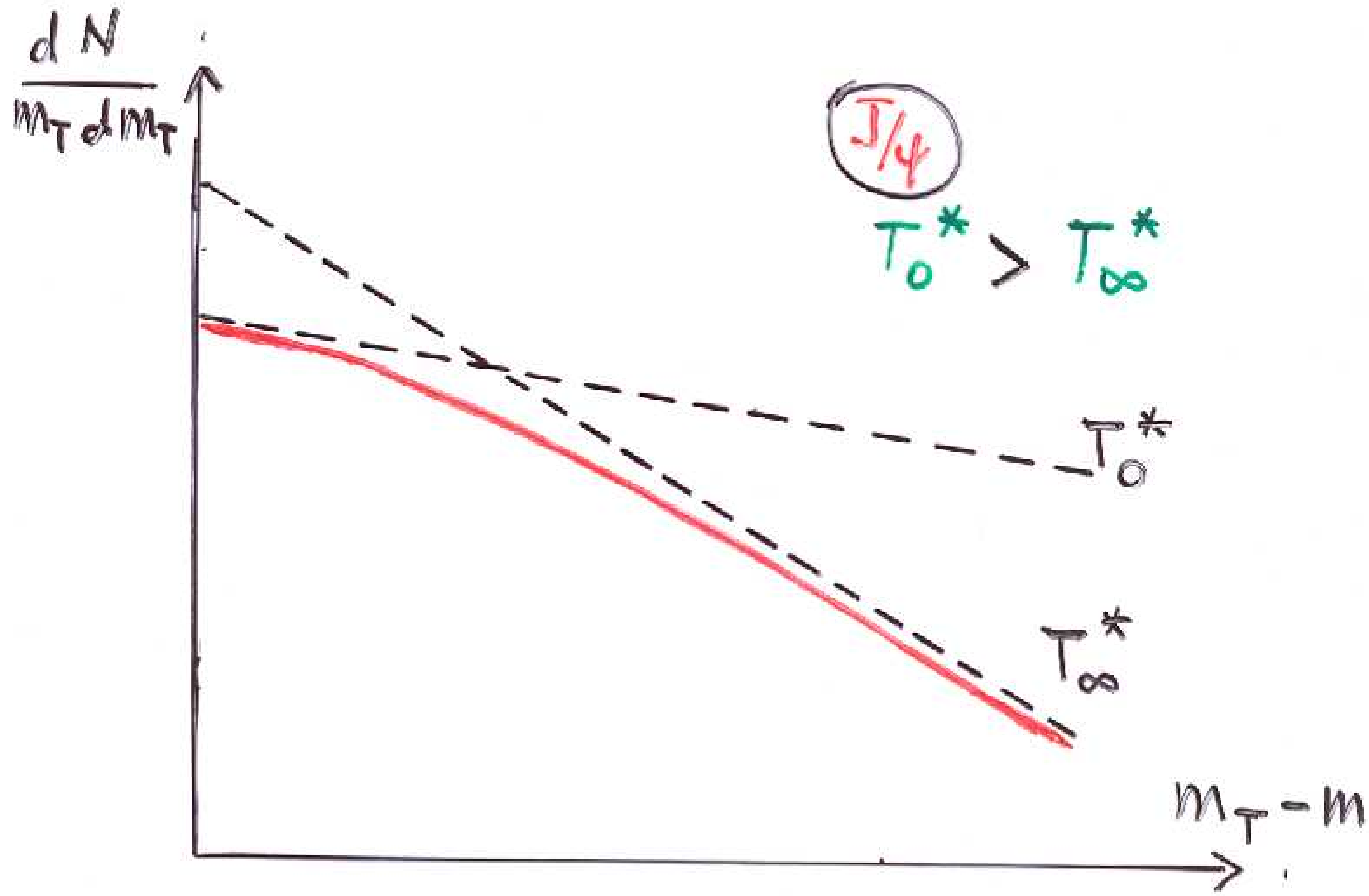
$$T_0^* \equiv T^*(p_T \mapsto 0) = T + \frac{1}{2} m\, \overline{v_T^2}$$

$$T_\infty^* \equiv T^*(p_T \mapsto \infty) = T \sqrt{\frac{1 + v_T^{max}}{1 - v_T^{max}}}$$

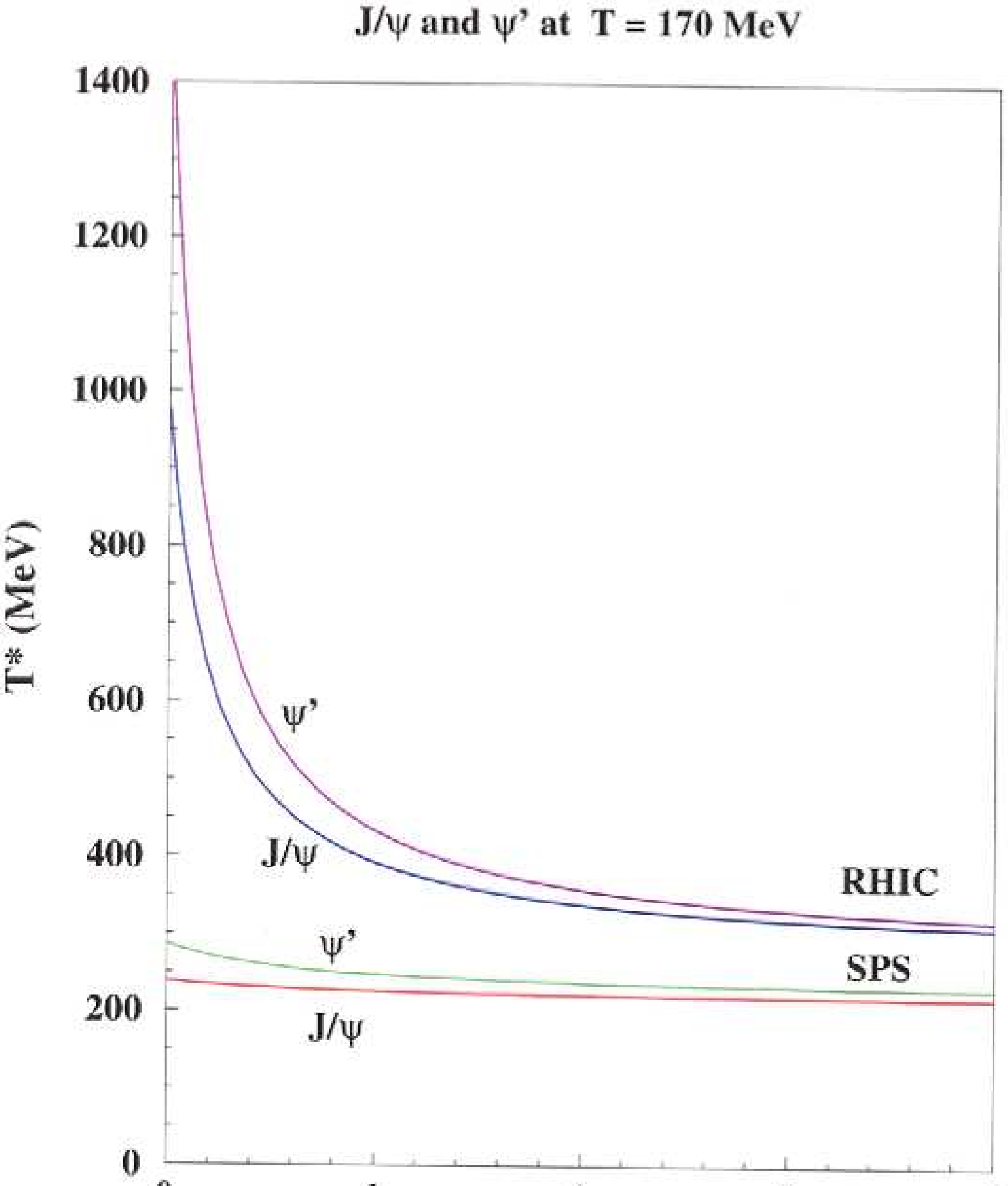




$$\boxed{T_0^*(\pi) < T_\infty^* < T_0^*(J/\psi)}$$



Bugaev, Gorenstein, Gaździcki
Phys. Lett. B (2002)



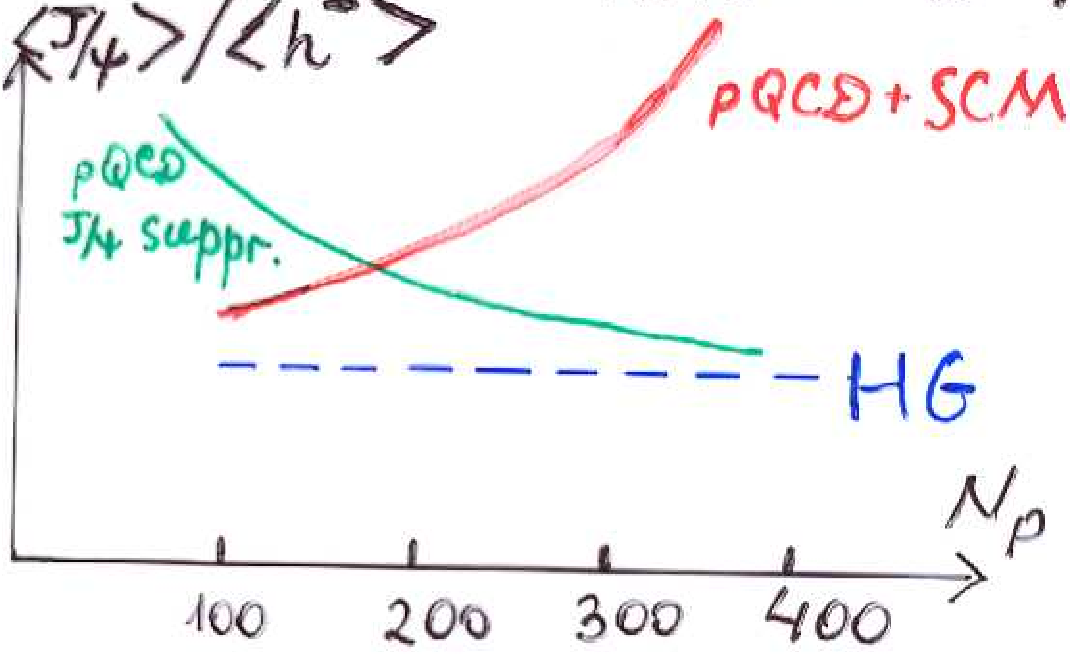
Conclusions

$\sim \underline{6}$

① $\langle J/\psi \rangle$ SPS $\longmapsto$ SCM $\mapsto$ o.c. enh.

NA60 $\mapsto$ D-??

RHIC $\longmapsto$



② $$\frac{dN_{J/\psi}}{m_T\, dm_T} \propto m_T \exp\left[-\frac{m_T}{T^*}\right]$$

a). $T^*(RHIC) > T^*(SPS)$

b). RHIC $T^*(p_T \ll m_{J/\psi}) \gg T^*(p_T \simeq m_{J/\psi})$