Statistical hadronization of charm: From FAIR to LHC

A.Andronic – GSI Darmstadt

- The statistical hadronization model
  - assumptions, method and inputs
- Results
  - model vs. data: centrality and rapidity dependence (SPS, RHIC)
  - predictions for LHC and for FAIR energies

AA, P. Braun-Munzinger, K. Redlich, J. Stachel:

NPA 789 (2007) 334, PLB 652 (2007) 259, PLB 659 (2008) 149

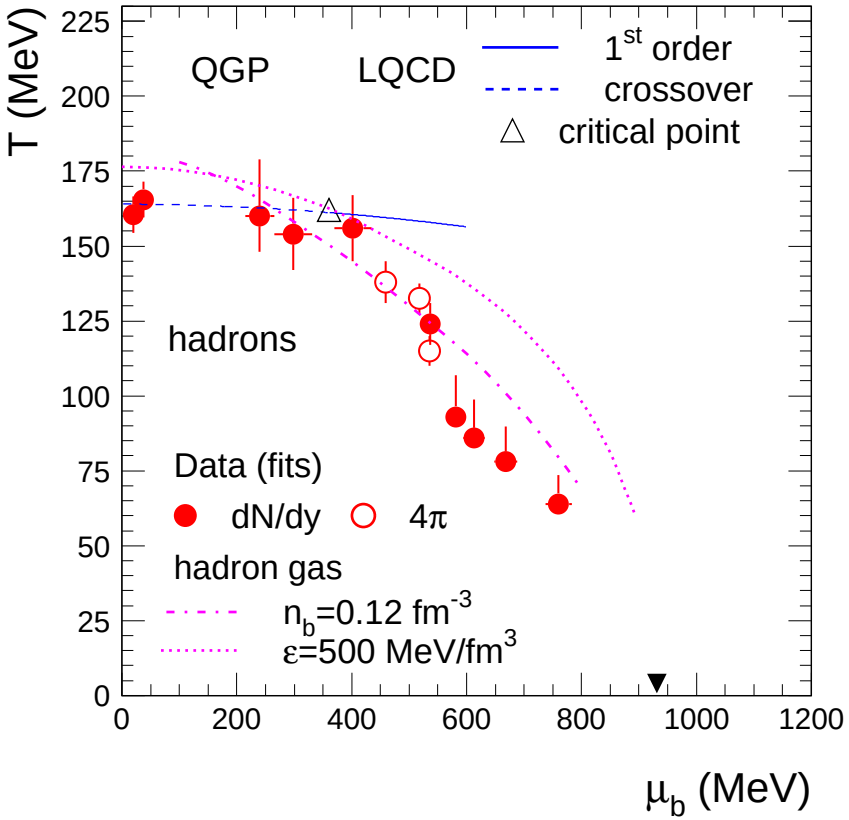
Quark Matter, Jaipur, February 2008

Statistical hadronization: assumptions

P.Braun-Munzinger, J.Stachel, PLB 490 (2000) 196

- all charm quarks are produced in primary hard collisions
- survive and thermalize **in QGP** (thermal, but not chemical equilibrium)
- charmed hadrons are formed at chemical freeze-out together with all hadrons
  statistical laws (quantum nr. conservation)

  freeze-out appears to be at phase boundary
- no J/ψ survival in QGP (full screening)



Statistical hadronization: method and inputs

- Thermal model calculation (grand canonical) T,μ_B: $\rightarrow n_i^{th}$
- Charm balance equation:

$$N_{c\bar{c}}^{dir} = \frac{1}{2} g_c V (\sum_i n_{D_i}^{th} + n_{\Lambda_i}^{th}) + g_c^2 V (\sum_i n_{\psi_i}^{th} + n_{\chi_i}^{th})$$

Canonical (if $N_{c\bar{c}} << 1$)

Cleymans et al., Z. Phys. C51 (1991) 137; Gorenstein et al., Phys. Lett. B 509 (2001) 277

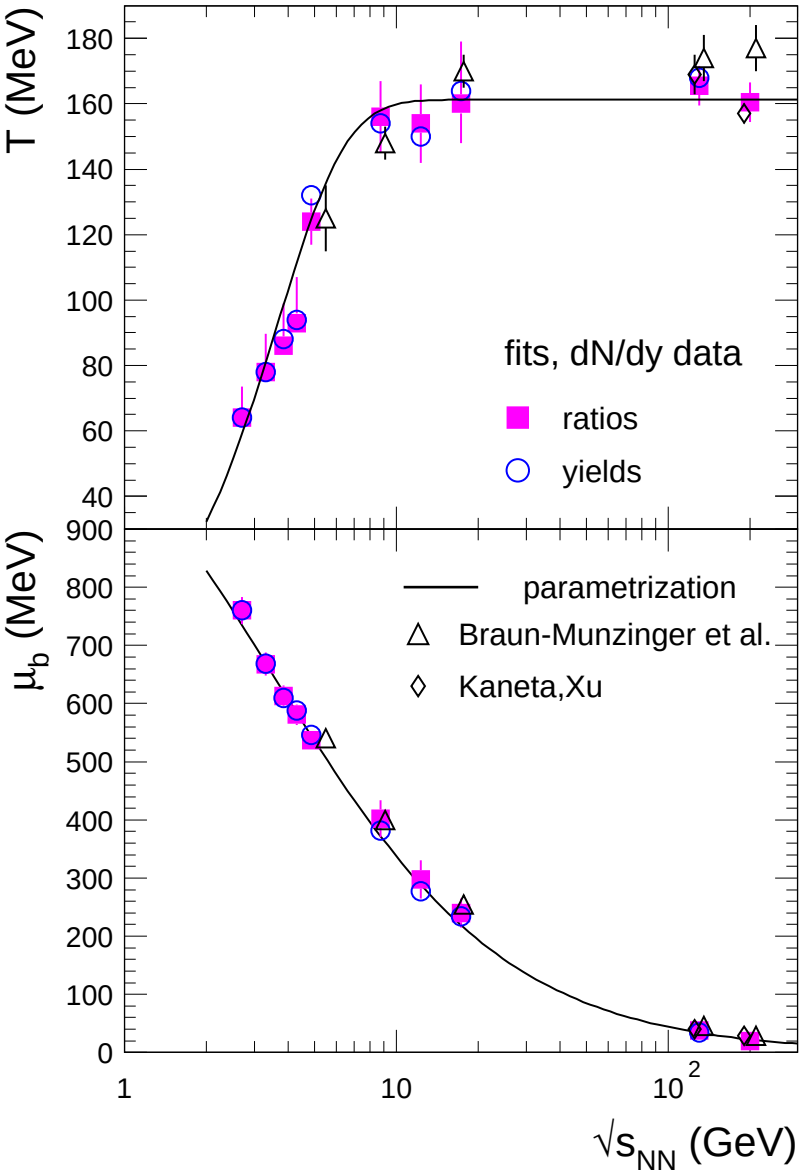
$$N_{c\bar{c}}^{dir} = \frac{1}{2} g_c N_{oc}^{th} \frac{I_1(g_c N_{oc}^{th})}{I_0(g_c N_{oc}^{th})} + g_c^2 N_{c\bar{c}}^{th} \quad \rightarrow g_c \text{ (charm fugacity)}$$

Outcome: $N_D = g_c V n_D^{th} I_1/I_0 \quad N_{J/\psi} = g_c^2 V n_{J/\psi}^{th}$

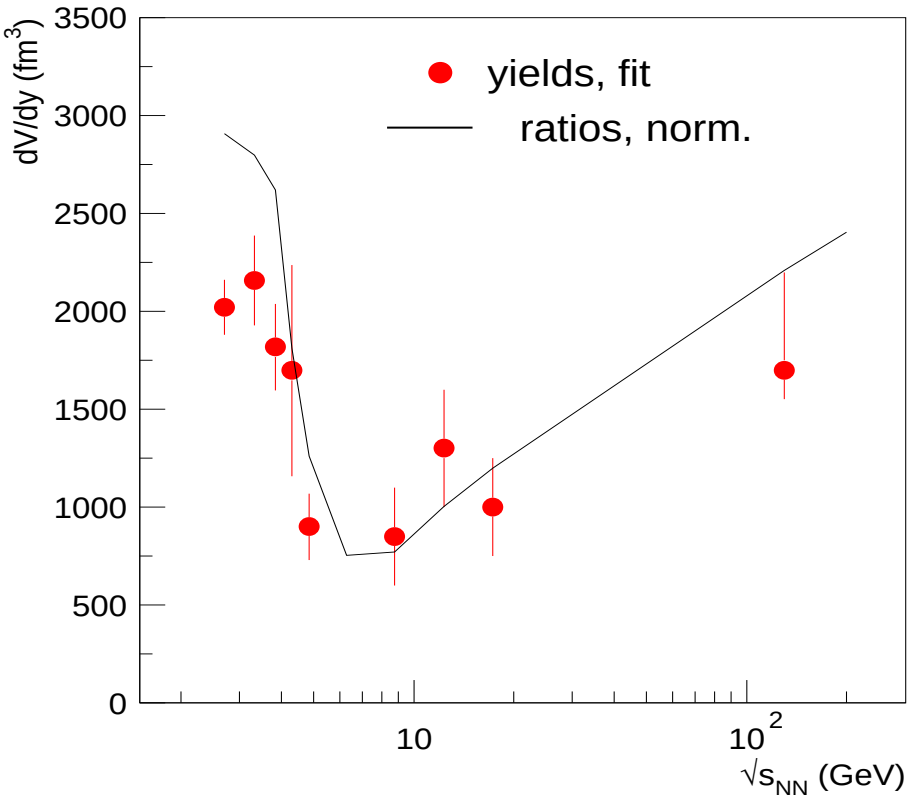
Minimal volume for QGP: V_{QGP}^{min}=400 fm^3

Thermal parameters: from fits to data

...well constrained

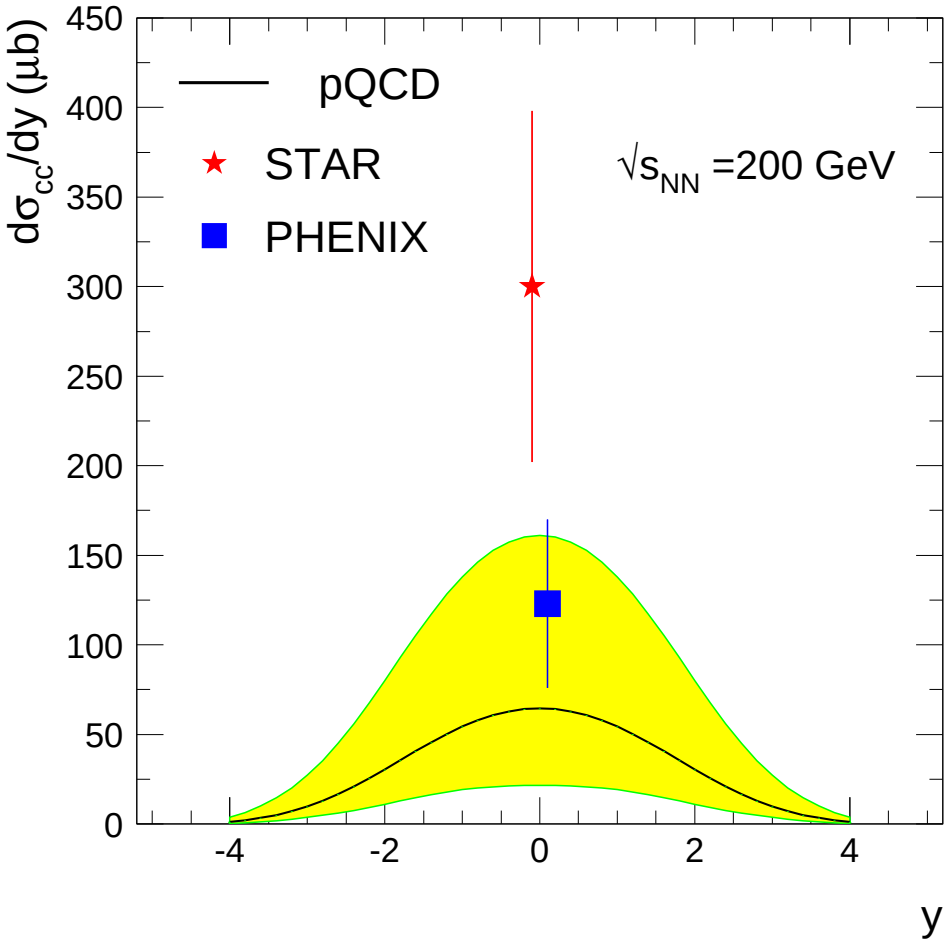


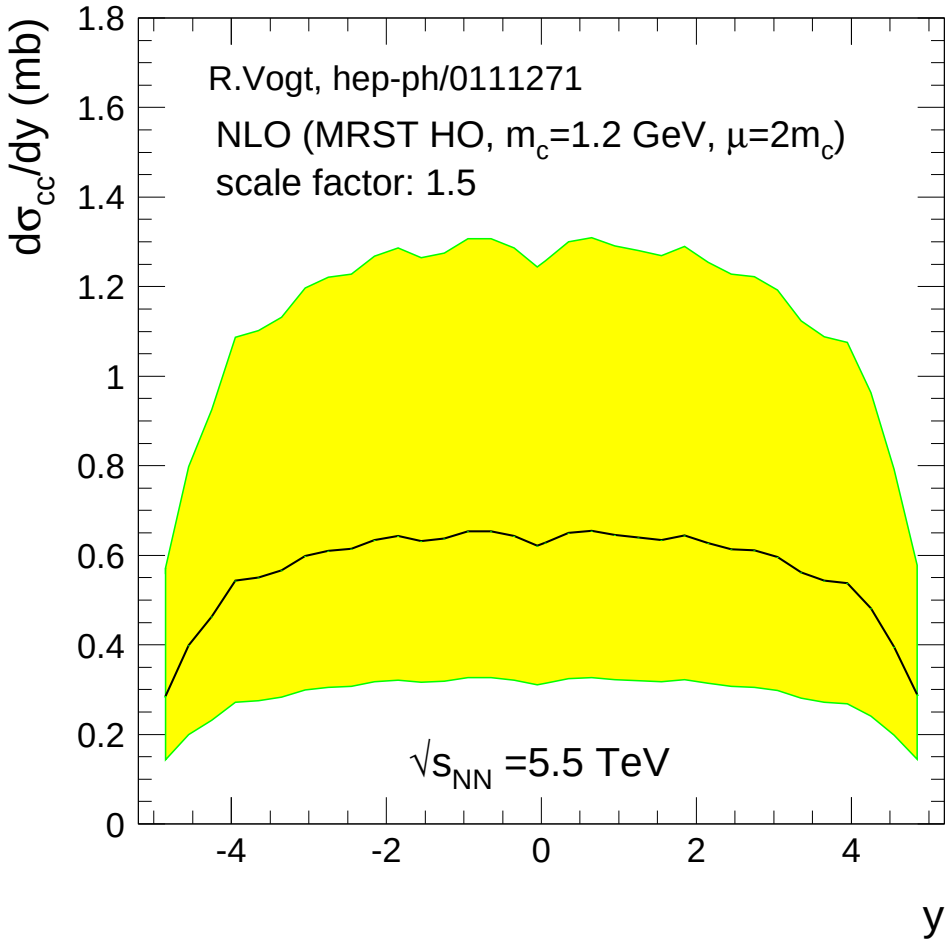
NPA 772 (2006) 167 [nucl-th/0511071]



LHC extrapolations: (T,μ_b)=(161,0.8) MeV

$N_{c\bar{c}}^{dir}$ from pQCD calculations (pp)

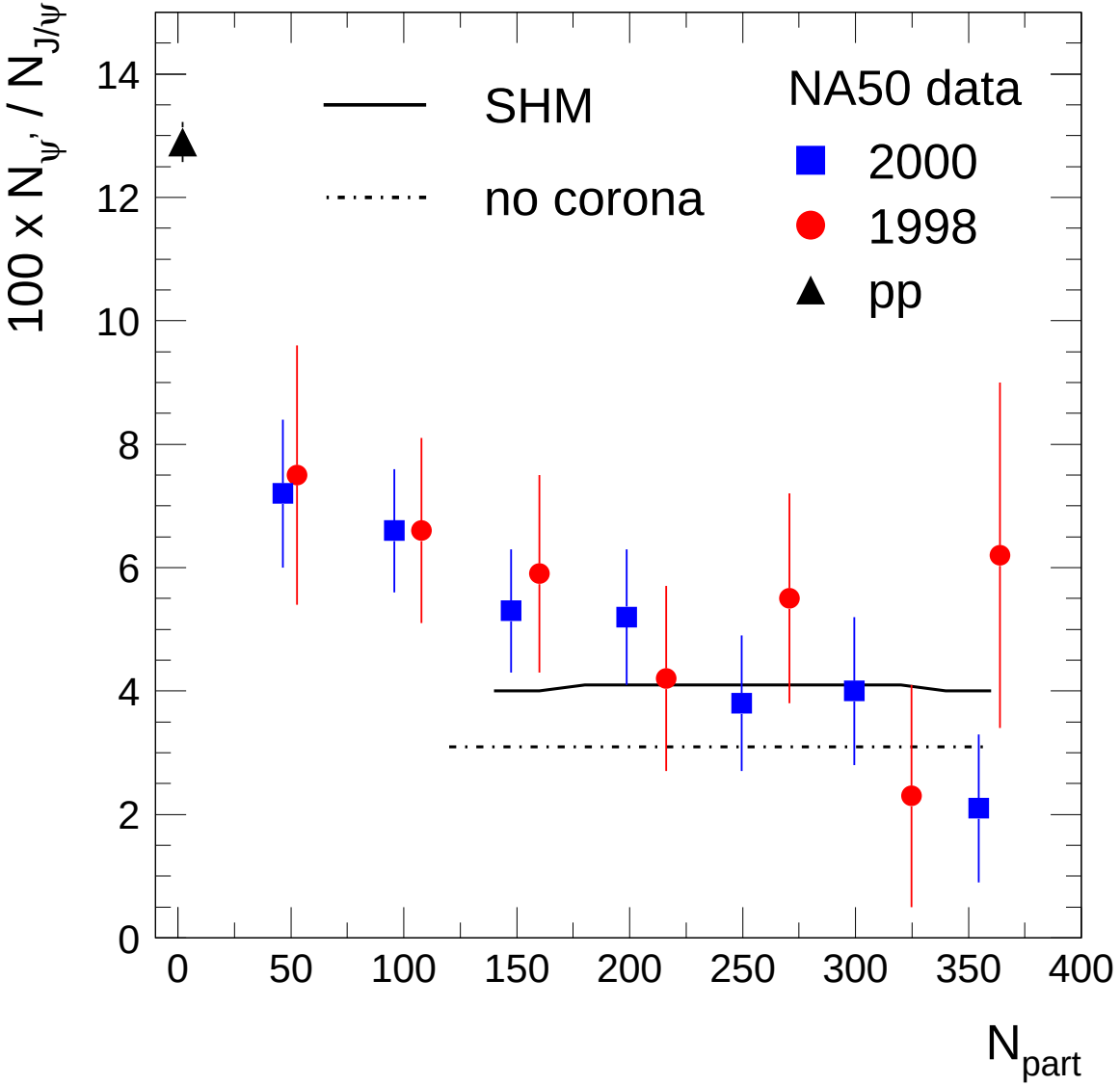




pQCD is not parameter-free! (PDF, m_c, μ_R, μ_F) $\longrightarrow$ large errors

see M. Cacciari, P. Nason, R. Vogt, Phys. Rev. Lett. 95 (2005) 122001

Model vs. data: ψ' at SPS



NA50 Data:
PbPb: EPJ C49 (2007) 559
pp: PLB 466 (1999) 408

good agreement

(good agreement also for J/ψ)

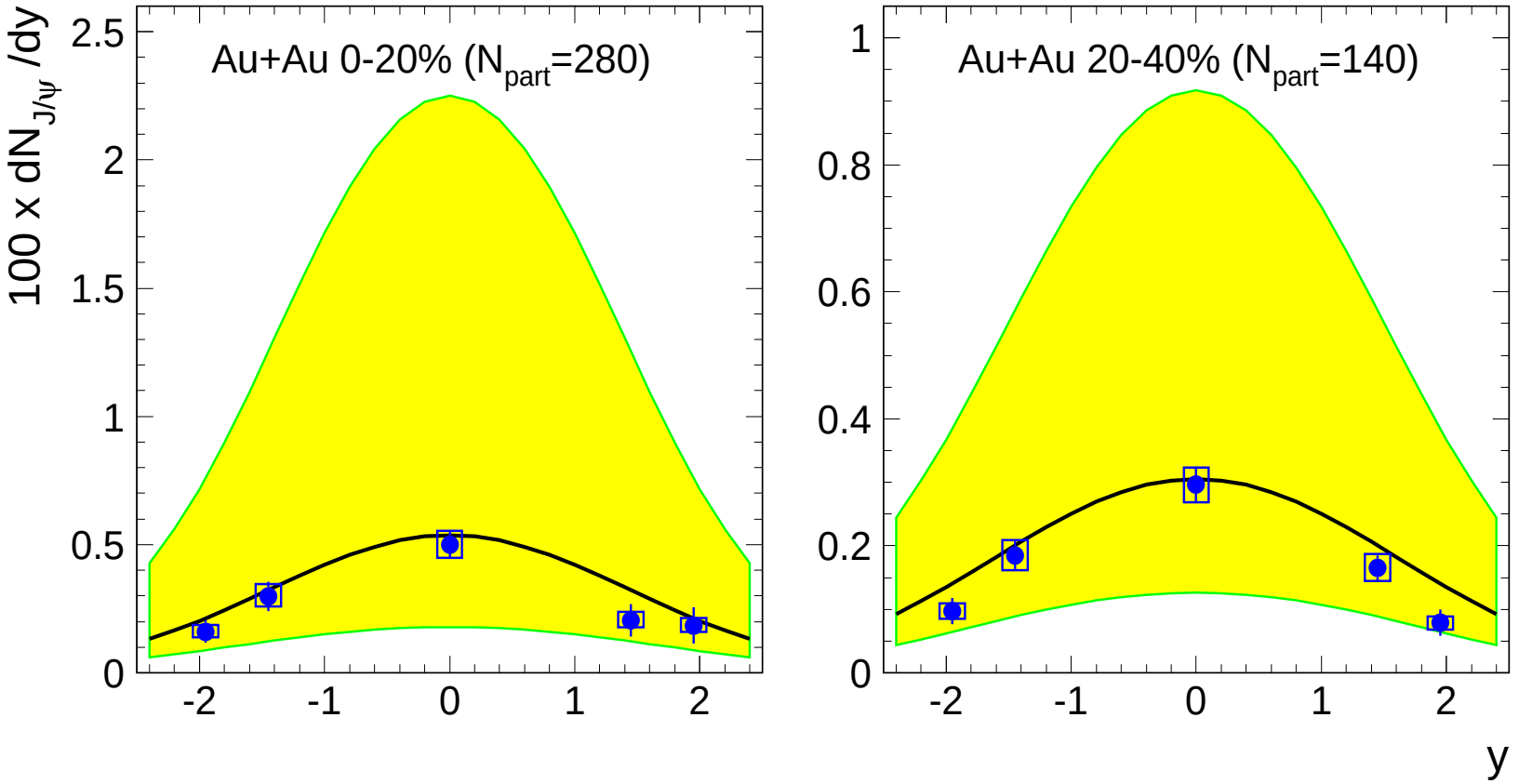
$N_{\psi'}/N_{\psi} \neq 0$!

contradicts screening model

(LQCD: ψ' melted at T_c)

strong indication of ψ' prod. via statistical hadronization

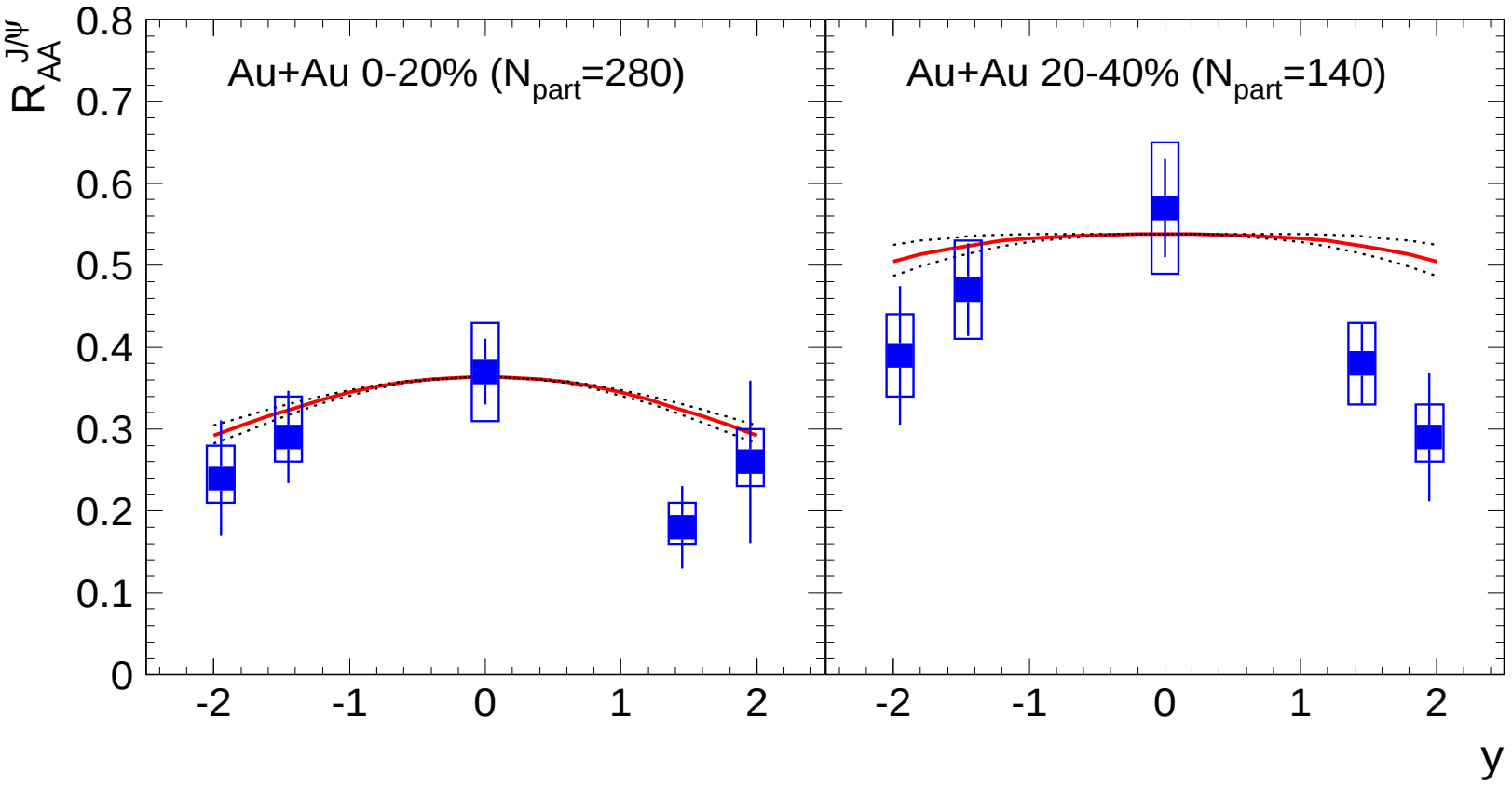
J/ψ at RHIC: rapidity dependence



PHENIX data, PRL 98 (2007) 232301

model reproduces data very well (pQCD cross section)

J/ψ at RHIC: rapidity dependence, R_{AA}

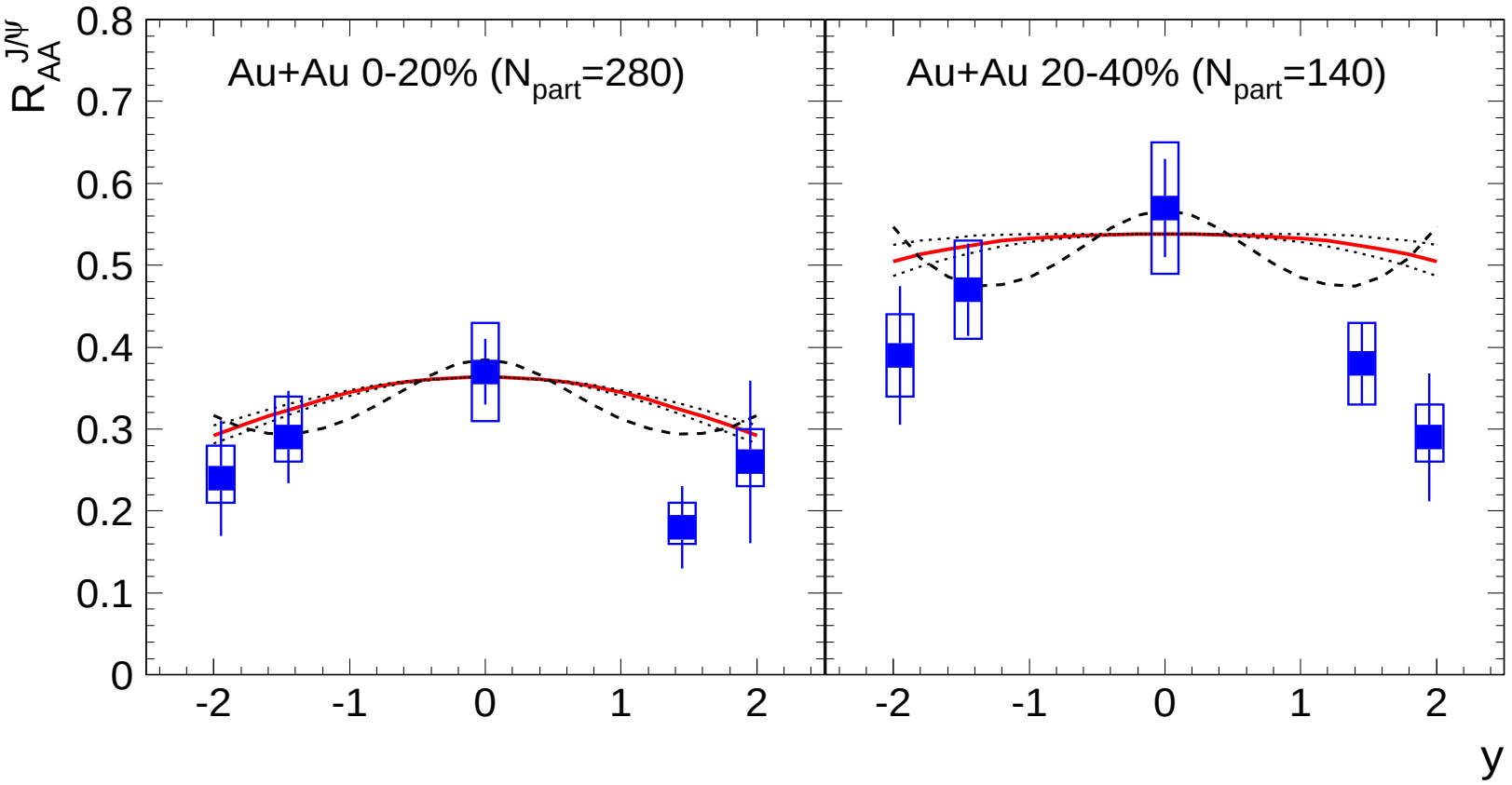


Model: red: J/ψ pp ref. fit 1-gaussian (dotted: error on σ);

model reproduces data (PHENIX) very well (pQCD $\sigma_{c\bar{c}}$)

data show opposite trend than expected within other models (Debye, comover)

J/ψ at RHIC: rapidity dependence, R_{AA}

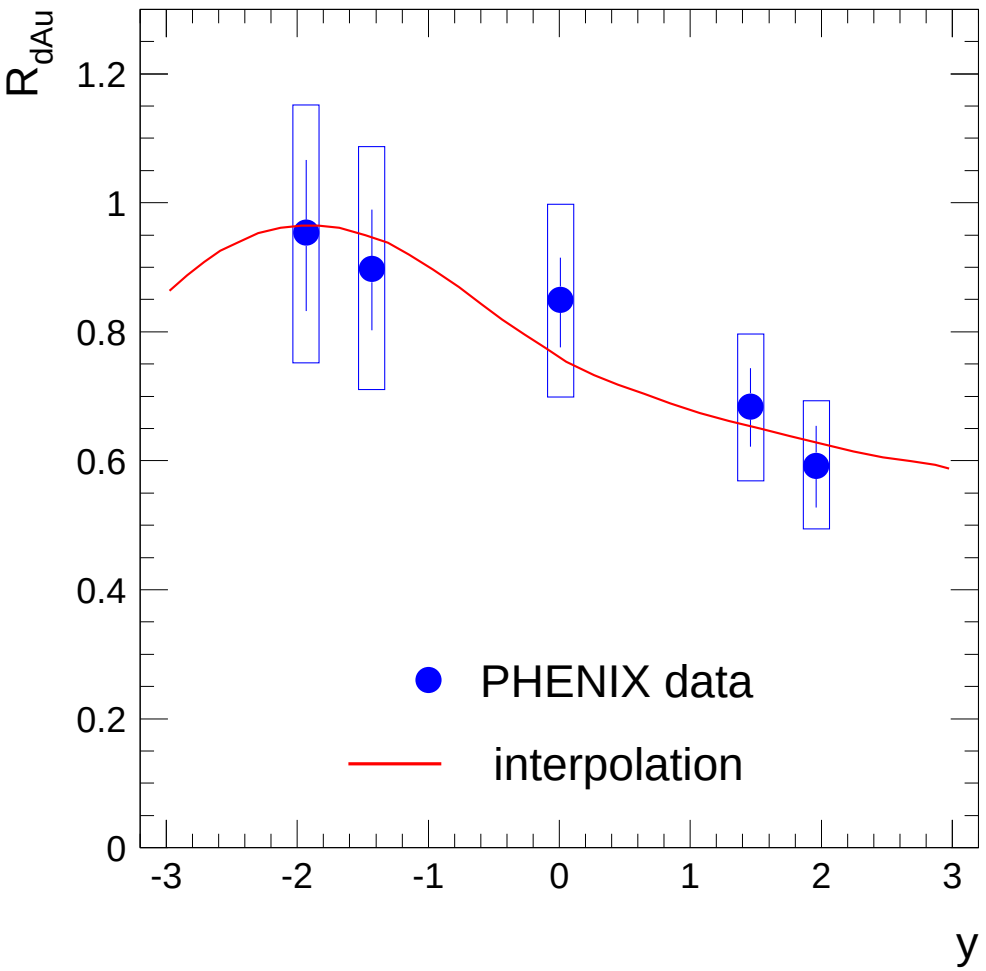


Model: red: J/ψ pp ref. fit 1-gaussian (dotted: error on σ); dashed: 2-g fit

evidence for statistical hadronization of charmonium (enhanced at y=0)

J/ψ in dAu (RHIC)

PHENIX, arXiv:0711.3917



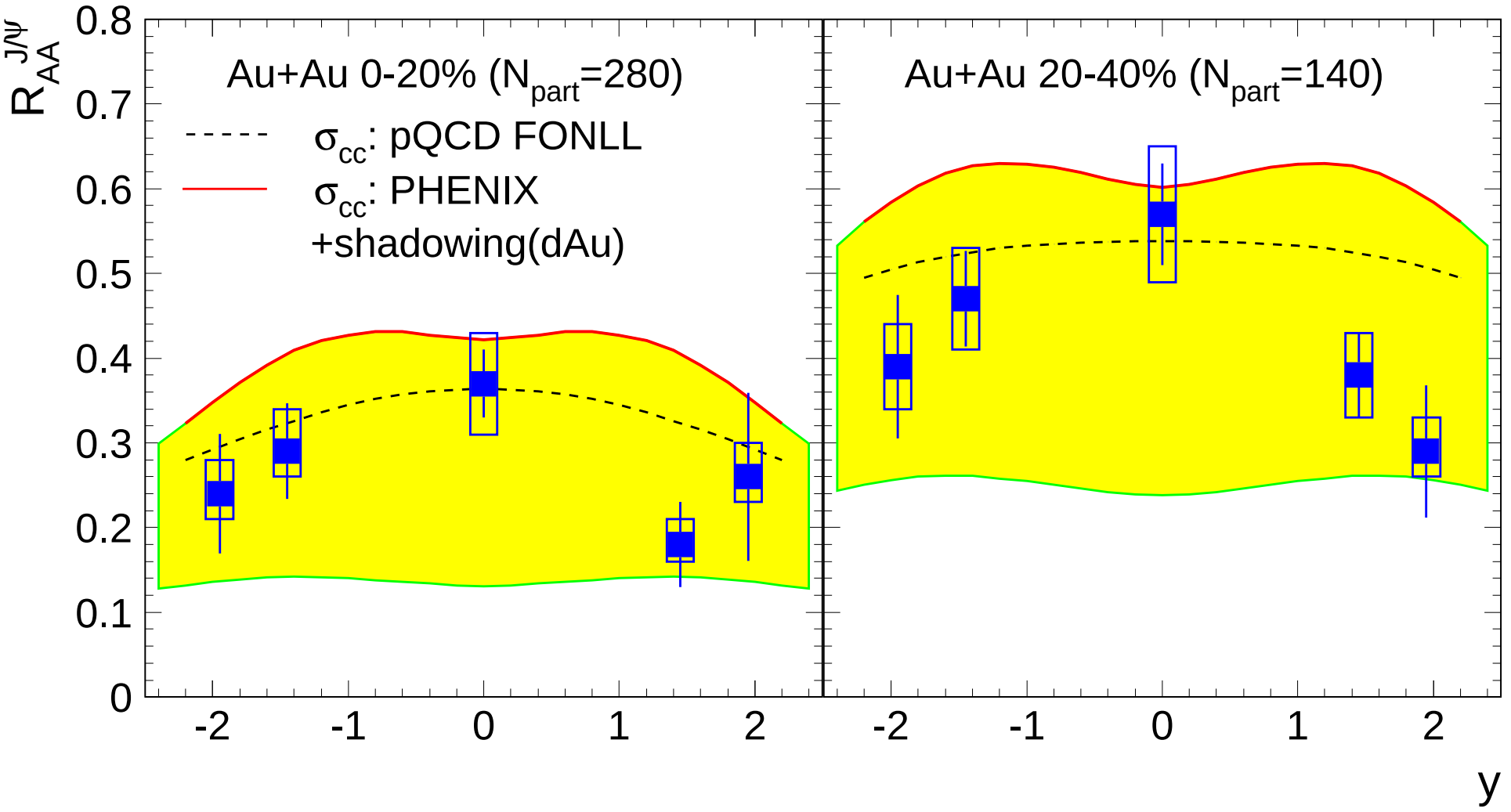
assume R_{dAu} of J/ψ as due only to shadowing of initial charm production cross section:

$$\sigma^{c\bar{c}}_{AuAu} = R^{J/\psi-shad}_{AuAu} \cdot \sigma^{c\bar{c}}_{pp}$$

where $R^{J/\psi-shad}_{AuAu}$ (nuclear modification due to shadowing) is:

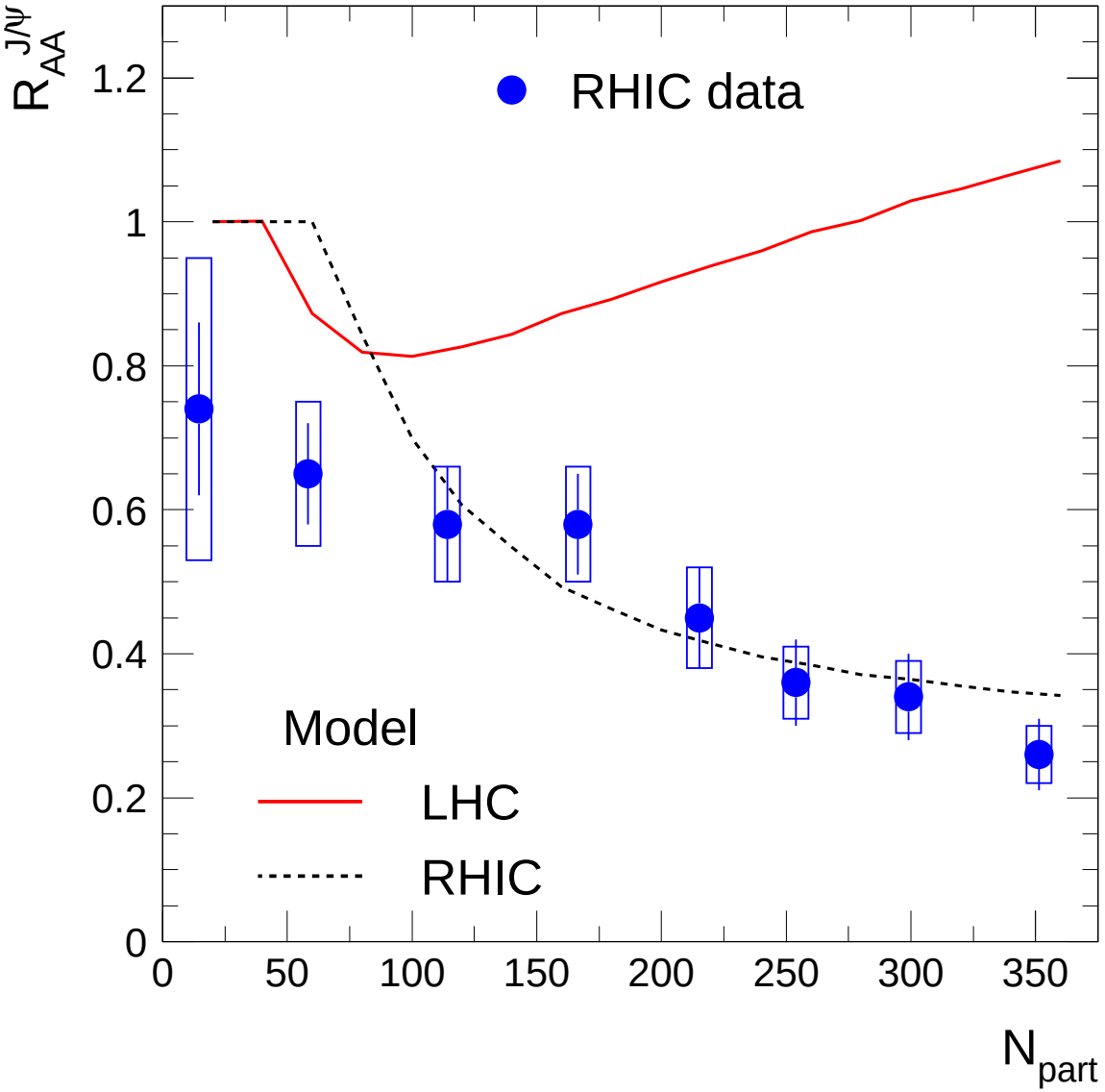
$$R^{J/\psi-shad}_{AuAu}(|y|) = R^{J/\psi}_{dAu}(y) * R^{J/\psi}_{dAu}(-y)$$

J/ψ at RHIC: effect of shadowing



model describes data with PHENIX $\sigma_{c\bar{c}}$ (lower error plotted)

J/ψ R_{AA}: from RHIC to LHC

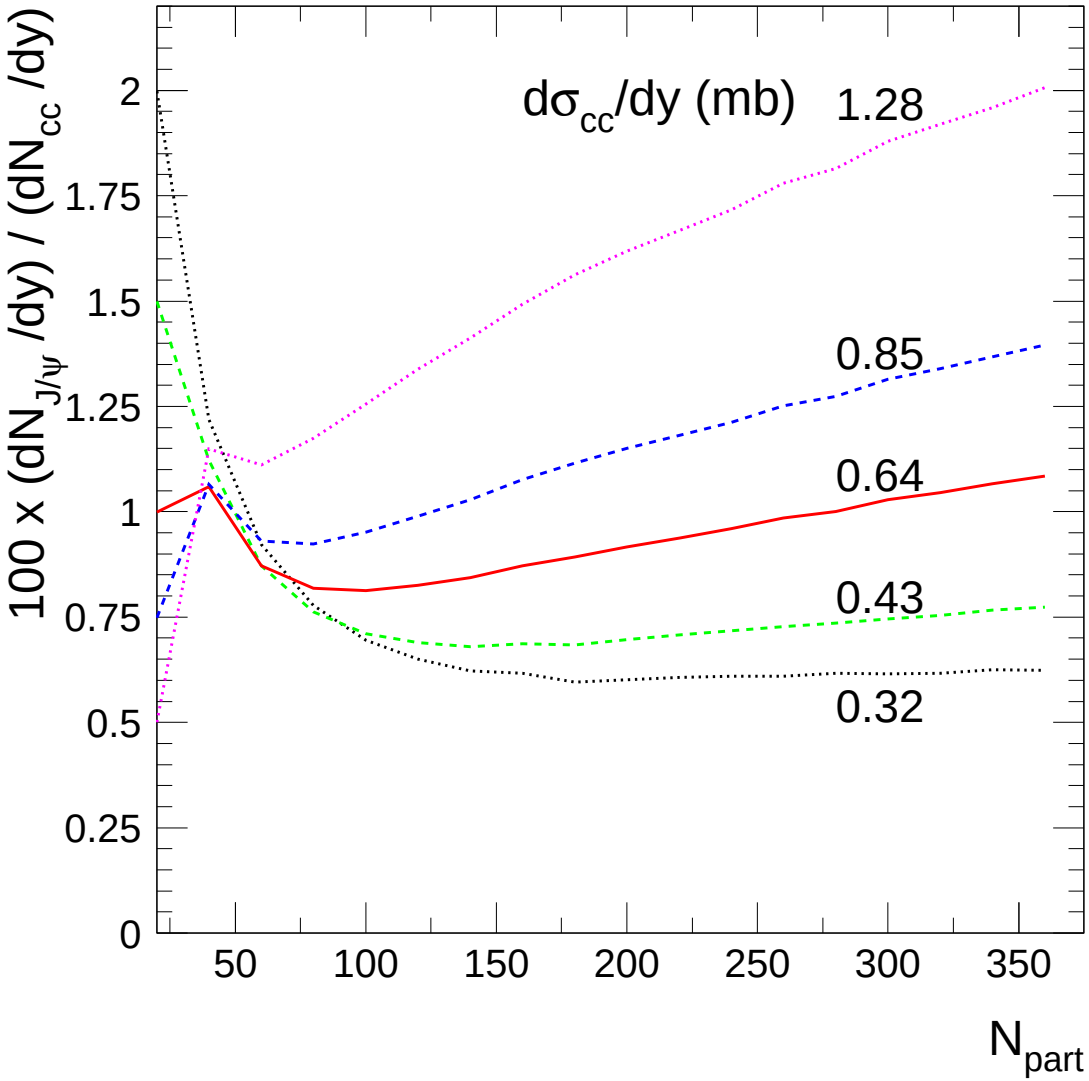


- very different centrality dep.
  - "suppression" at RHIC
  - "enhancement" at LHC

  determined by canonical suppression

  (of open charm hadrons)

J/ψ at LHC



...as RHIC (and SPS) verified...

...solid expectations for LHC

Charm at lower energies

in-medium masses (and/or widths?) of charmed hadrons?

Tsushima et al.,PRC 59 (1999) 2824
Sibirtsev et al., EPJA 6 (1999) 351PLB 484 (2000) 23
Hayashigaki, PLB 487 (2000) 96
Cassing et al., NPA 691 (2001) 753
Friman et al., PLB 548 (2002) 153
Grandchamp et al., PRL 92 (2004) 212301
Tolos et al, PLB 635 (2006) 85
Lutz, Korpa, PLB 633 (2006) 43
Morita, Lee, arXiv:0704.2021.

Timescales for charm(onium) production

- charm could only be produced in initial hard collisions (pQCD)
  $t_{c\bar{c}} \sim 1/2m_c \simeq$ 0.1 fm/c ($m_c \simeq$1.3 GeV $>> \Lambda_{QCD}$)
- charmed hadrons produced in $t_{J/\psi} \simeq$1 fm/c
- $\sigma_{c\bar{c}}$ is not affected by medium

$$= \frac{1}{2}(\sigma_D + \sigma_{\Lambda_c} + \sigma_{\Xi_c} + ...) + (\sigma_{\eta_c} + \sigma_{J/\psi} + \sigma_{\chi c} + ...)$$

Consequence: the only freedom is in redistribution of the charm quarks

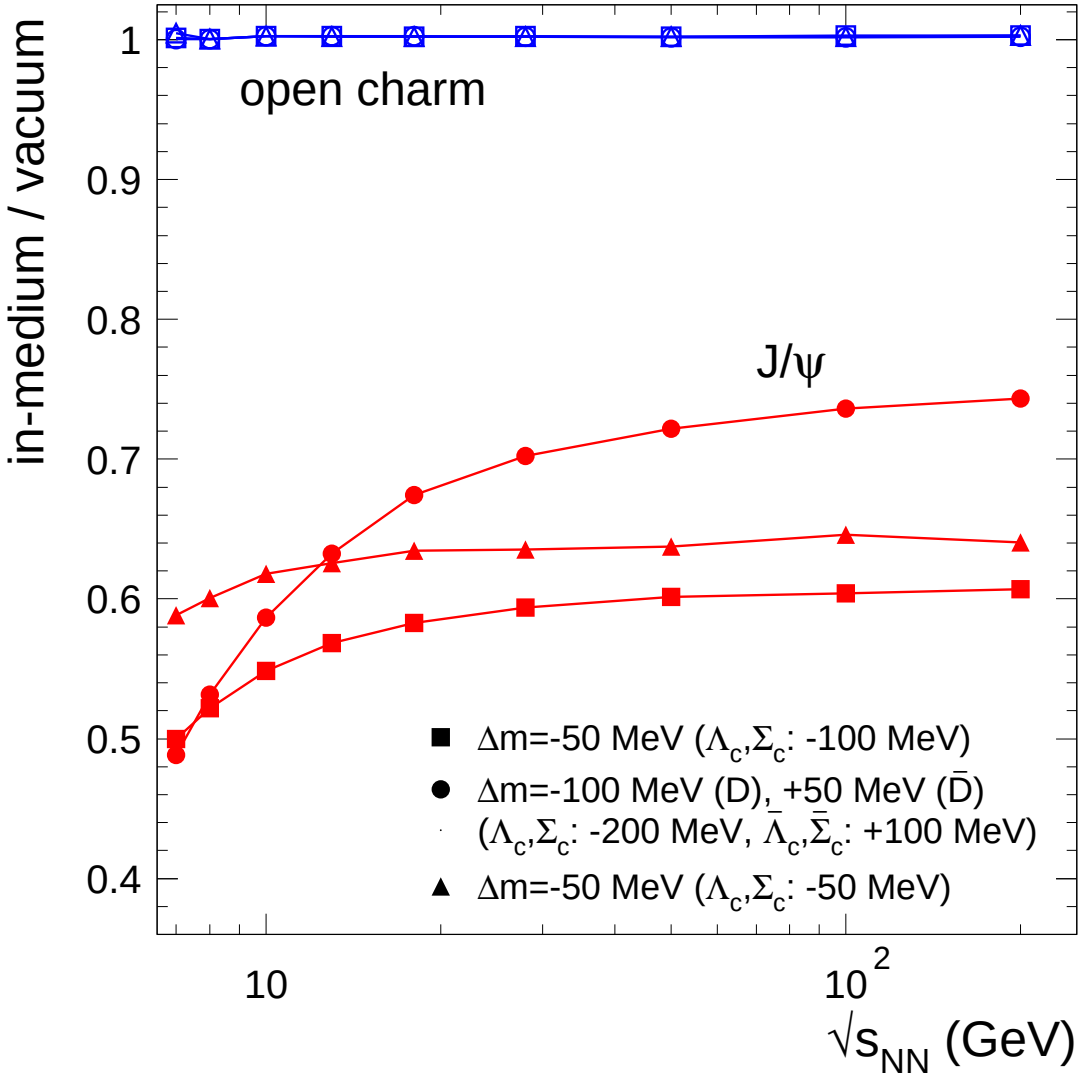
(in our model the effect of mass change is compensated by the constraint to initial charm)

Charm @ FAIR $\neq$ strangeness @ SIS ($m_s \simeq \Lambda_{QCD}$)

Effect of modified masses

yield with in-medium mases relative to vacuum masses

- open charm: very small increase
- ...with large effect on charmonia



Summary and outlook

statistical hadronization of heavy quarks
(produced exclusively in hard collisions, survive and thermalize in QGP)

most input parameters are well constrained by experimental observables

main uncertainty from charm cross section

- Good agreement with J/ψ data at SPS and RHIC
  evidence of statistical hadronization from ψ' at SIS and y-dependence at RHIC

Looking ahead

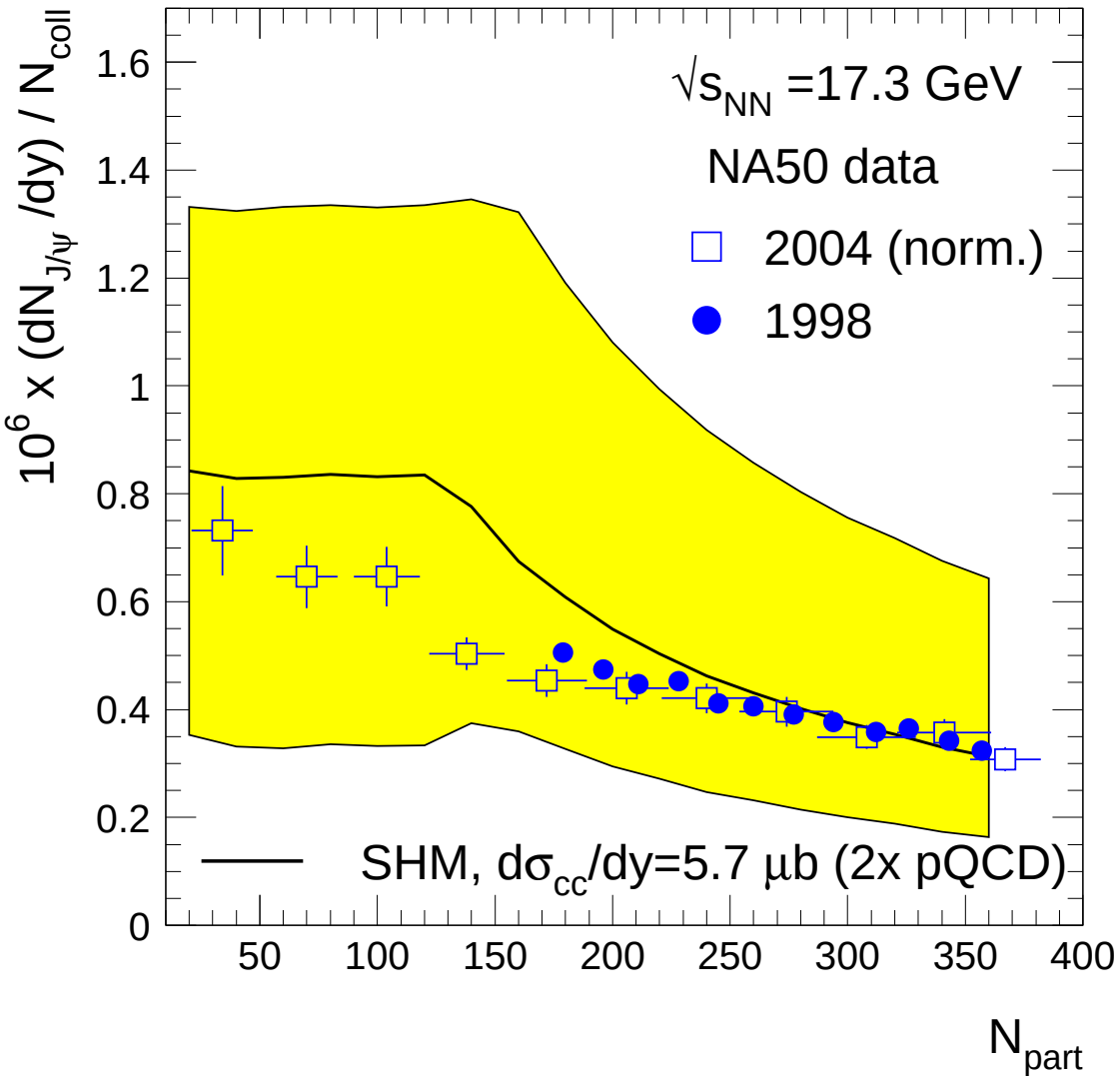
---

the picture will be put under a dramatic test at LHC ...and further at FAIR

.

Backup slides

J/ψ at SPS

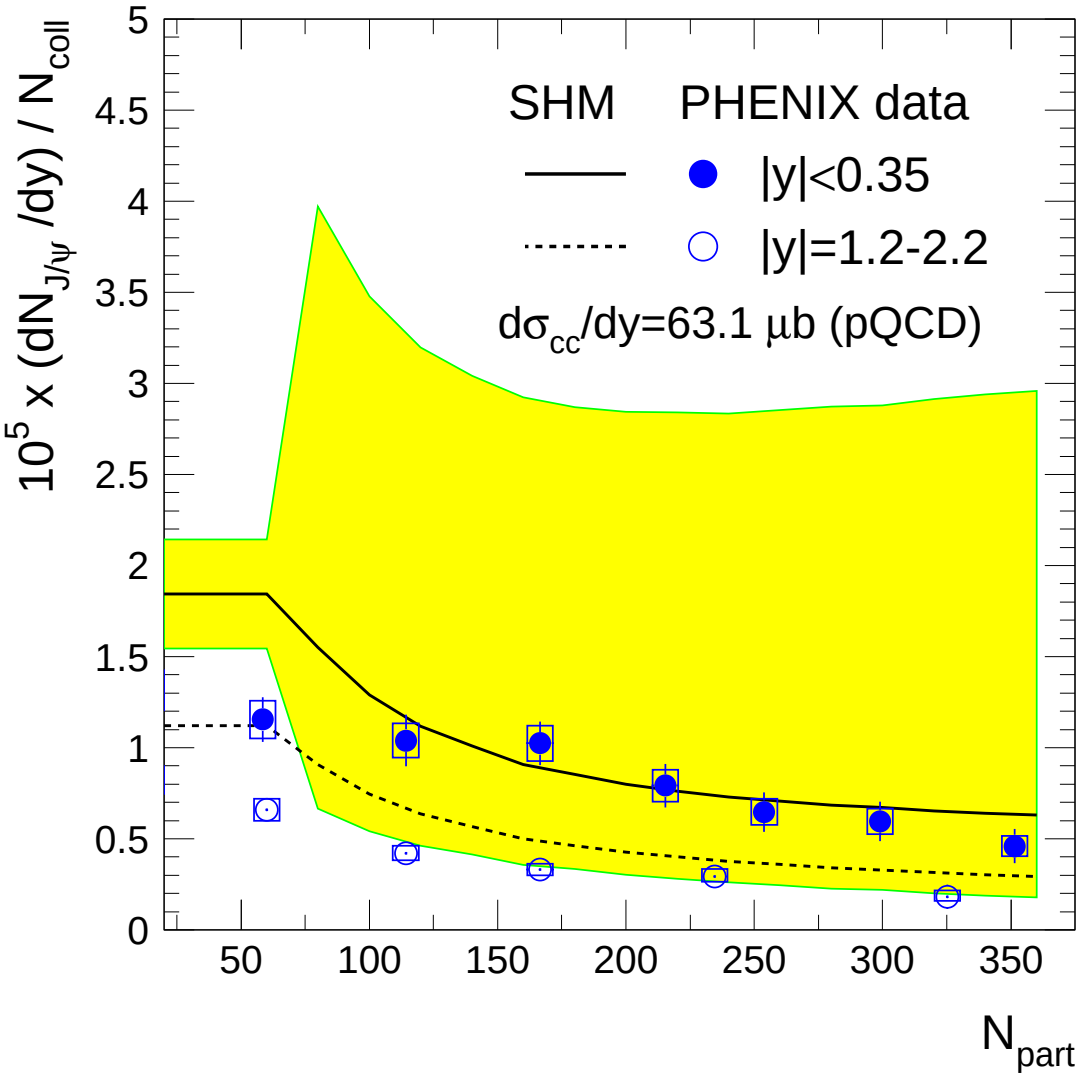


data explained with charm enhancement (2×pQCD)

see also: NPA 690 (2001) 119c, PLB 571 (2003)36
Grandchamp, Rapp, PLB 523 (2001) 60, NPA 709 (2002) 415
Gorenstein et al., PLB 509 (2001) 277, PLB 524 (2002) 265

NA50 data:
1998 ("unofficial"):
J. Gosset et al., EPJ C 13 (2000) 63
2004 (J/ψ/DY, normalized):
EPJ C 39 (2005) 335

J/ψ at RHIC: centrality dependence



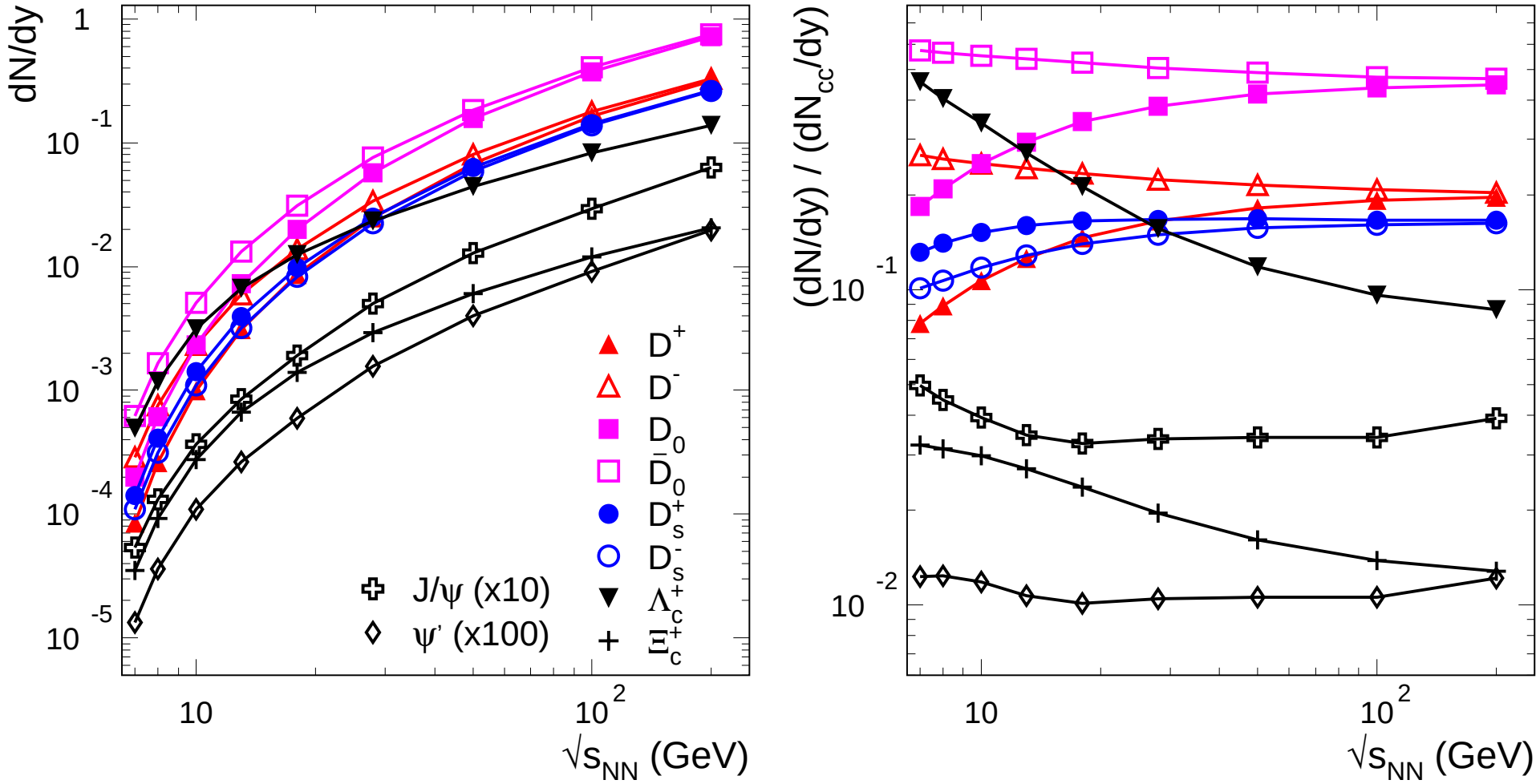
pQCD charm cross section

M. Cacciari, P. Nason, R. Vogt,
Phys. Rev. Lett. 95 (2005) 122001

the model explains data

(PHENIX, PRL 98 (2007) 232301)

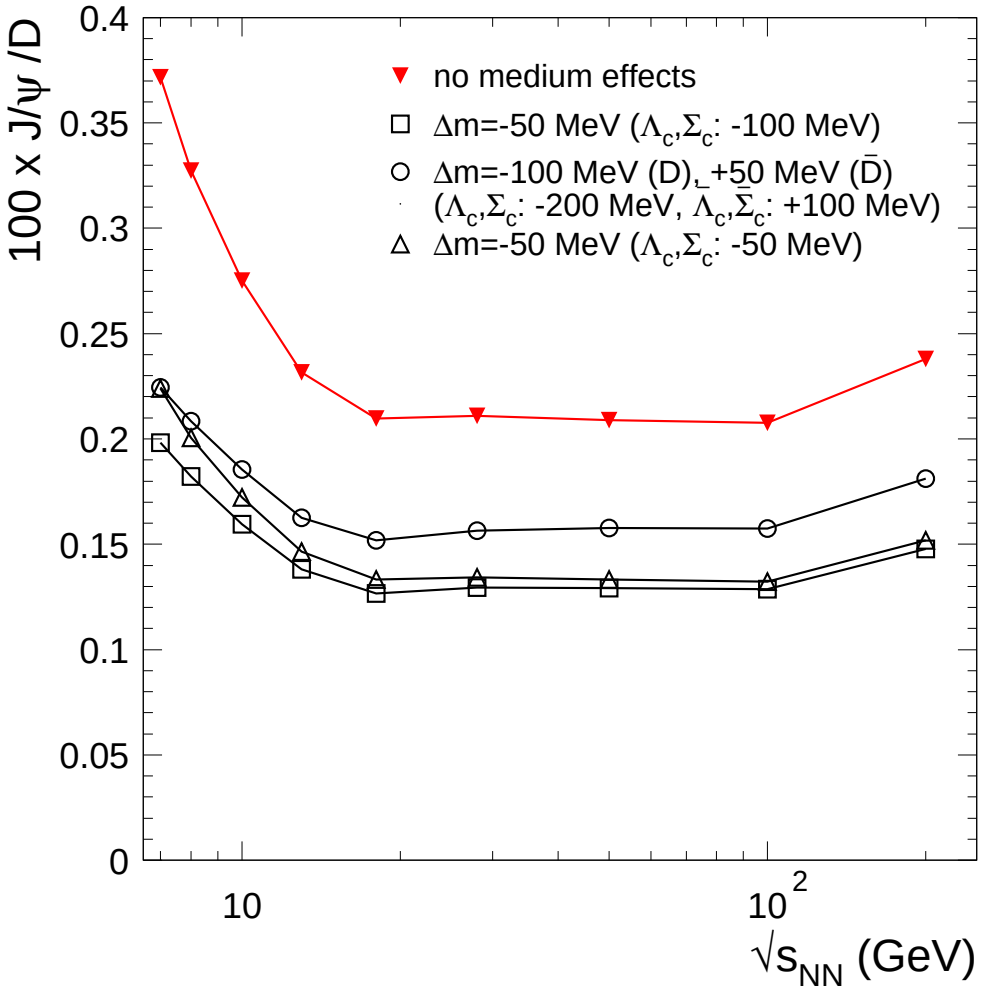
J/ψ within the larger charm picture

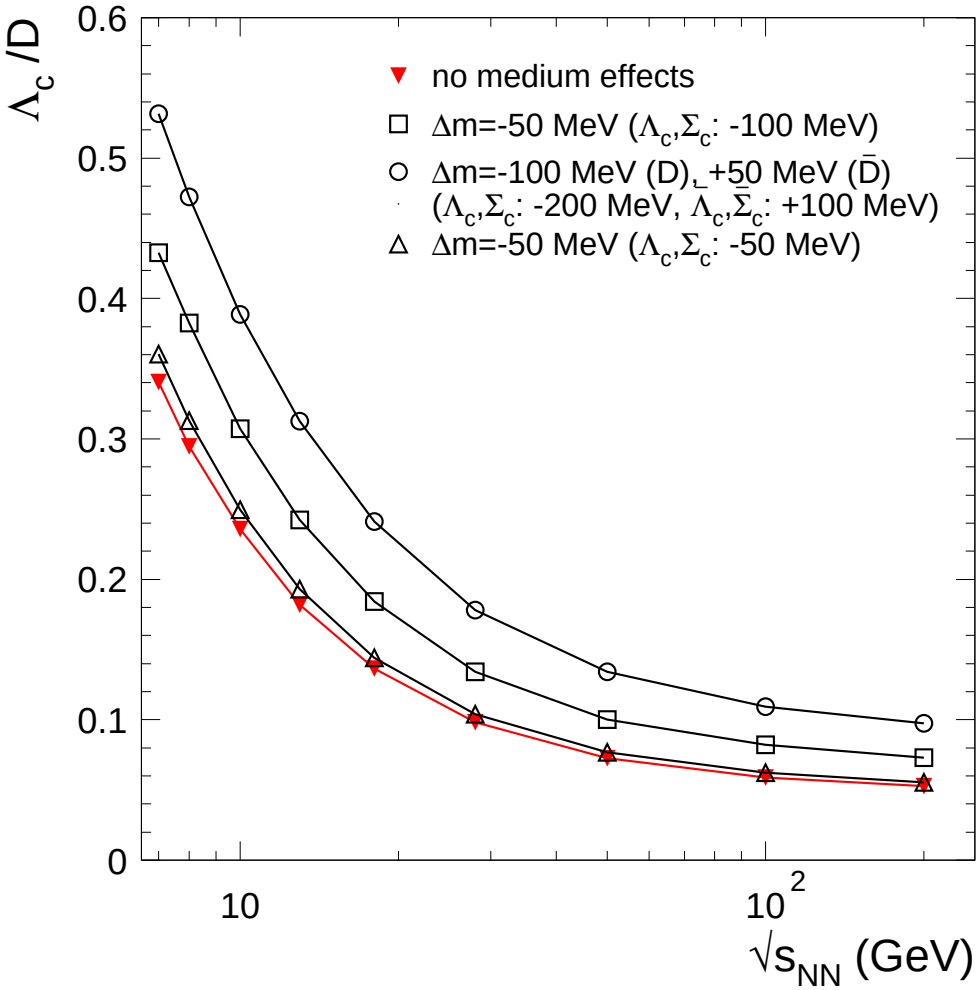


charmonium is a small part of the charm family

importance of charmed baryons (Λ_c) at low energies (role of valence quarks)

J/ψ and in-medium masses





J/ψ suppressed ($\simeq$40%) if in-medium mass reduction of open charm hadrons