Heavy-Flavor Production at RHIC

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Outline

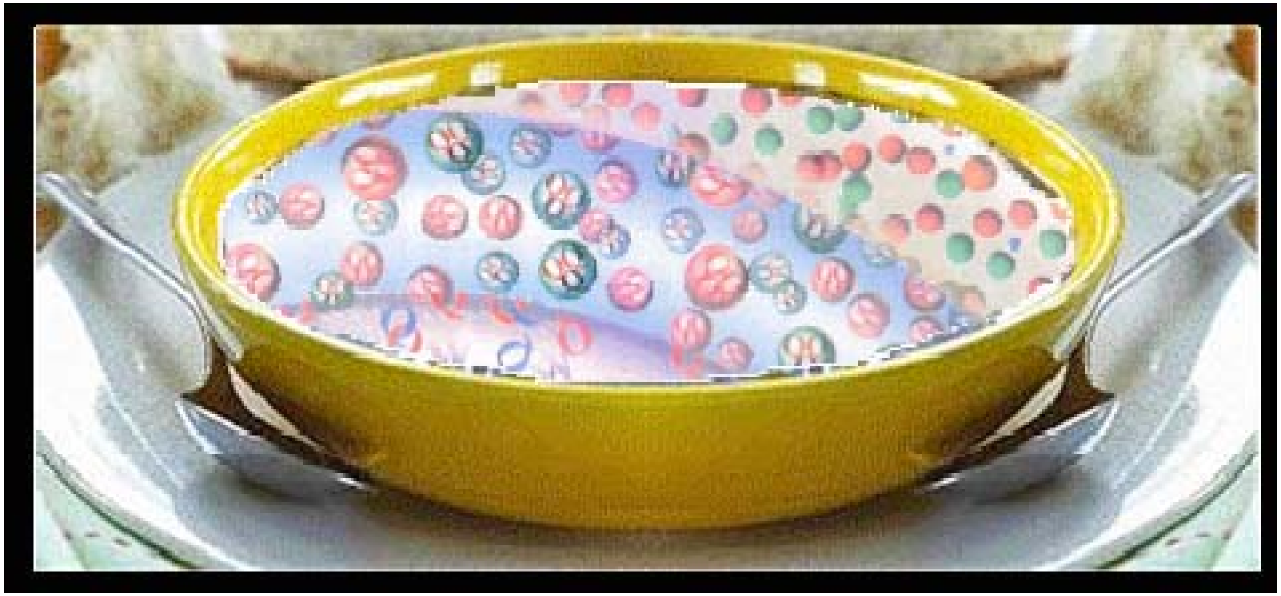
1) Introduction

2) Open charm production at RHIC

3) Heavy – quarkonia (J/ψ, Υ)

4) Summary

Quark Gluon Plasma



Source: Michael Turner, *National Geographic (1996)*

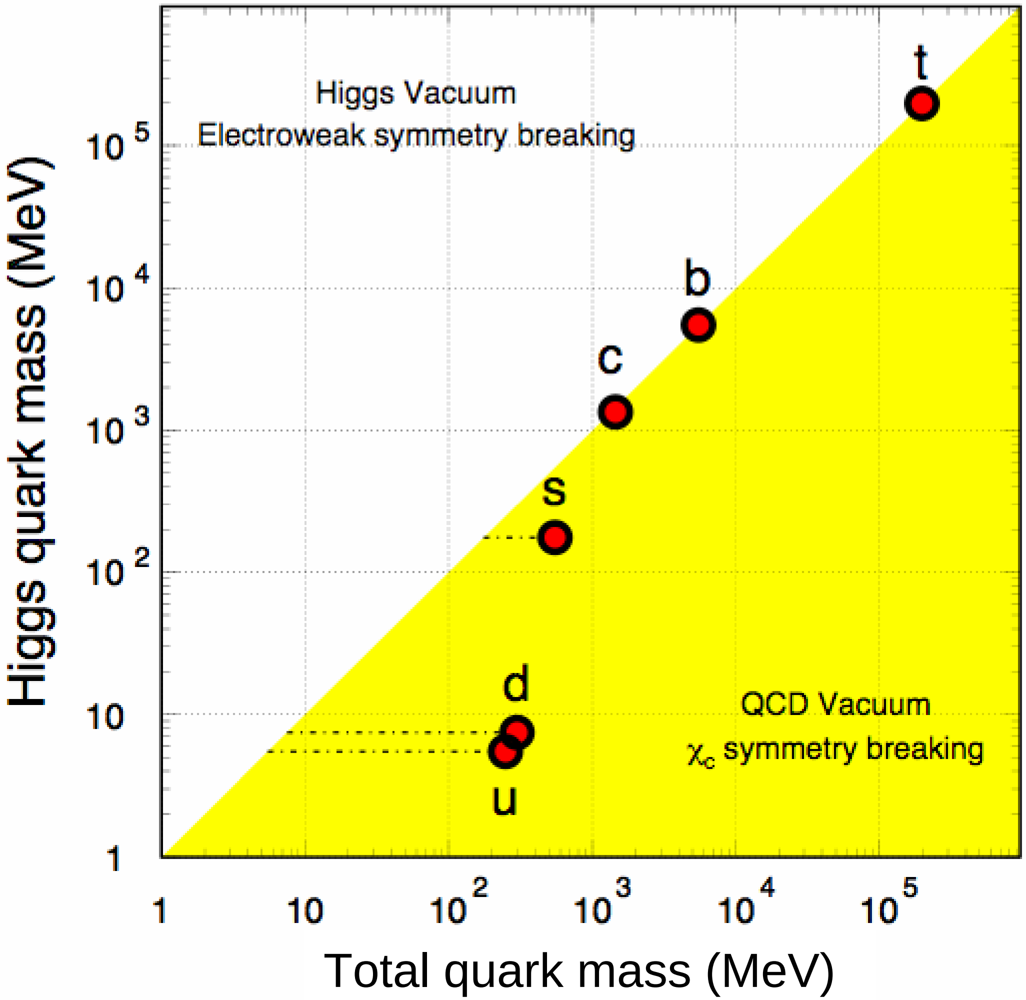
Quark Gluon Plasma:

(a) Deconfined and

(b) thermalized state of quarks and gluons

→ ***Study partonic EOS at RHIC and LHC***
Study effects of chiral symmetry restoration

Quark Masses



1) Higgs mass: electro-weak symmetry breaking. (current quark mass)
2) QCD mass: Chiral symmetry breaking. (constituent quark mass)

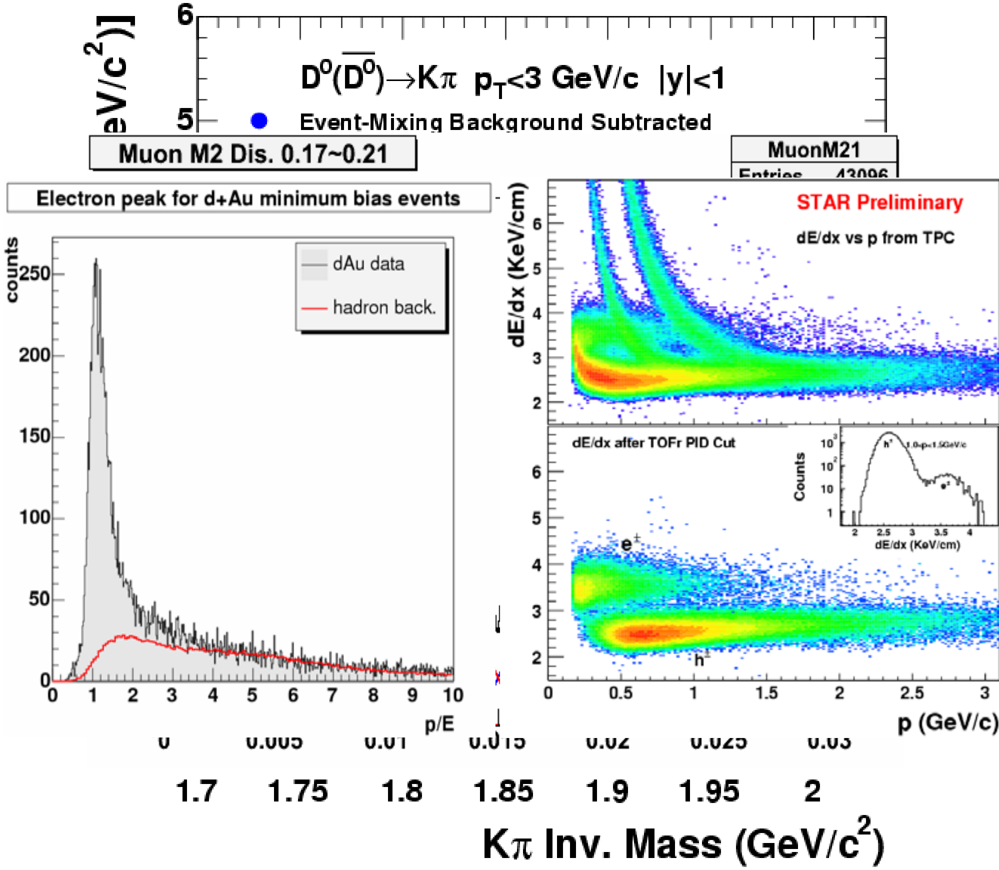
- Strong interactions do not affect heavy-quark masses.
- Important tool for studying properties of the hot/dense medium at RHIC.
- Test pQCD predictions at RHIC and LHC.

X. Zhu et al., hep-ph/0604178, PLB, in print.

Identify Heavy – Flavor at RHIC

- Phenix
  - Electrons
    - EMC and RHIC, mid-rapidity
  - Muons
    - Muon arms, forward rapidity

- STAR (all mid-rapidity)
  - D-mesons by inv. mass
  - Muons by TPC + ToF
  - Electrons
    - TPC + ToF (p_T<4 GeV/c)
    - EMC + TPC (p_T>1.5 GeV/c)

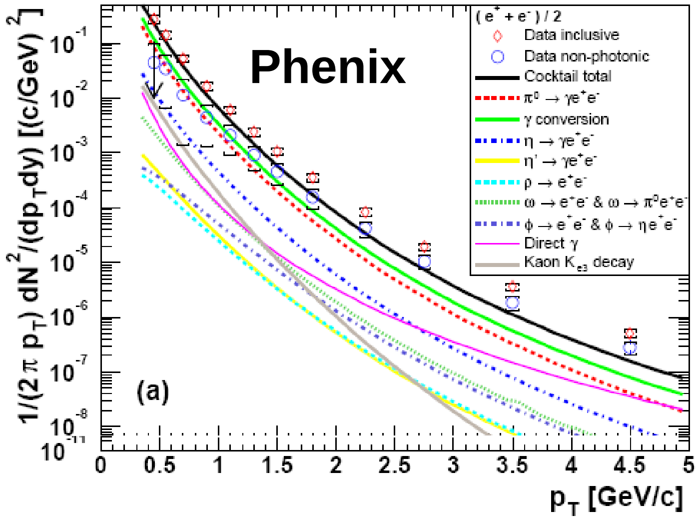


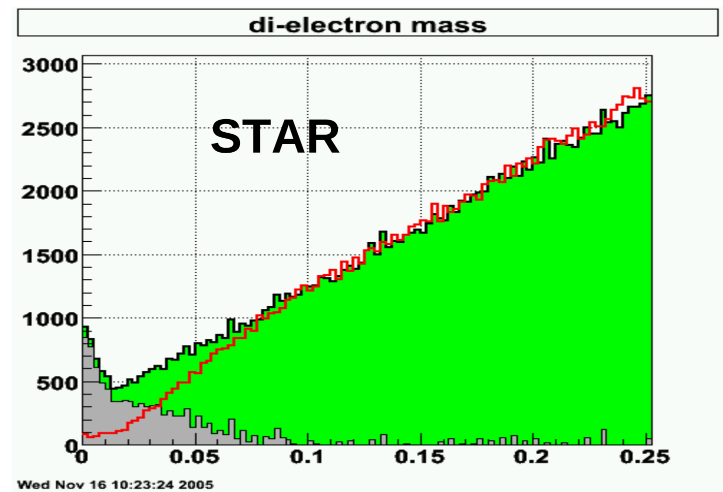
Single – Electron Background

- Experimental background
  - $\gamma \rightarrow e^+ + e^-$ (small for Phenix)
  - $\pi^0 \rightarrow \gamma + e^+ + e^-$
  - η, ω, ϕ, etc.

- Phenix
  almost material free
  background largely reduced
  two different methods
  - Converter method
  - Cocktail method

- STAR
  large material budget
  precise background subtraction



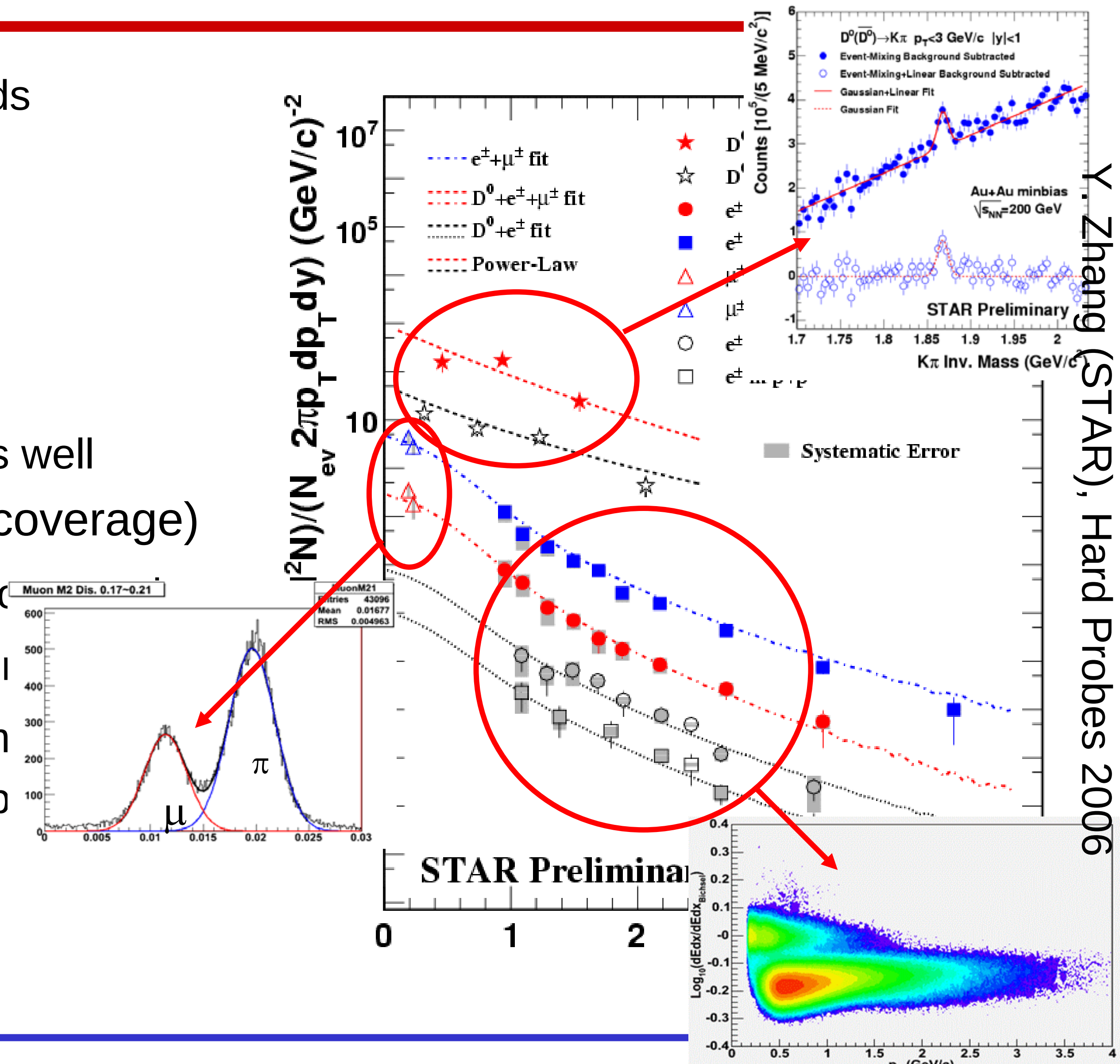


Inv. Mass (GeV/c^2)

Heavy – Flavor from STAR

- Three different methods
  - D – mesons
  - Electrons
  - Muons

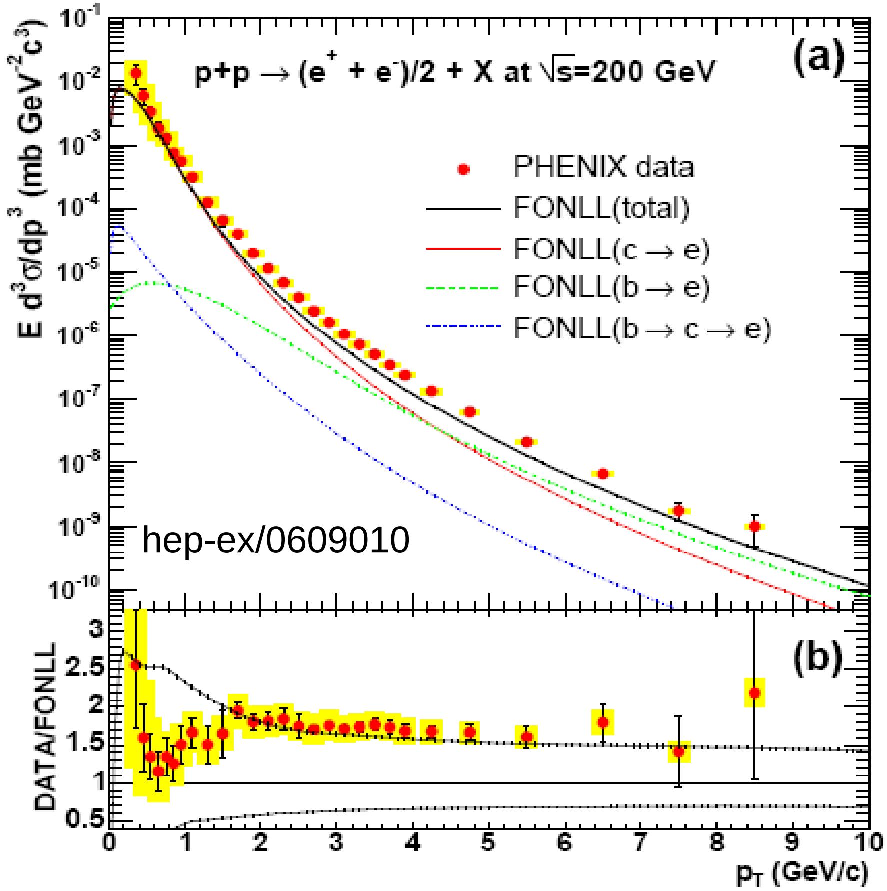
- Charm cross section is well constrained (large p_T coverage)
  - 95% of the total cro
  - Direct measureme
  - D – mesons and m constrain the low-p



Y. Zhang (STAR), Hard Probes 2006

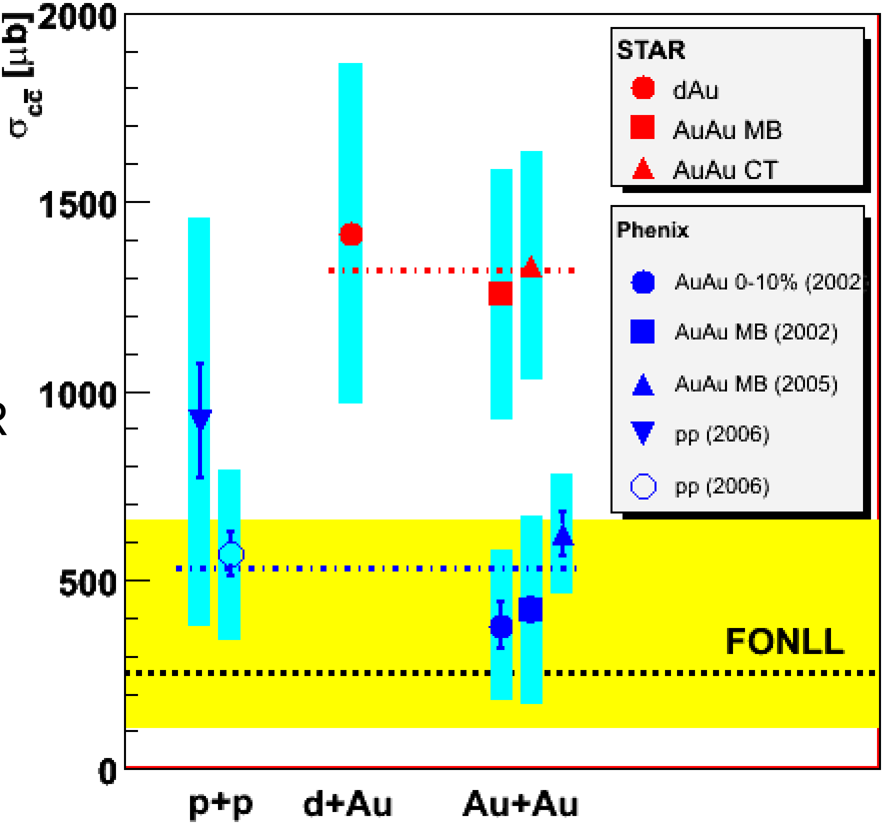
Heavy – Flavor from PHENIX

- Many different datasets
  - Non-photonic electron spectra
  - Improving statistics over time
  - Lowering p_T cut
    - Reduces extrapolation uncertainties



Total Charm Production at RHIC(i)

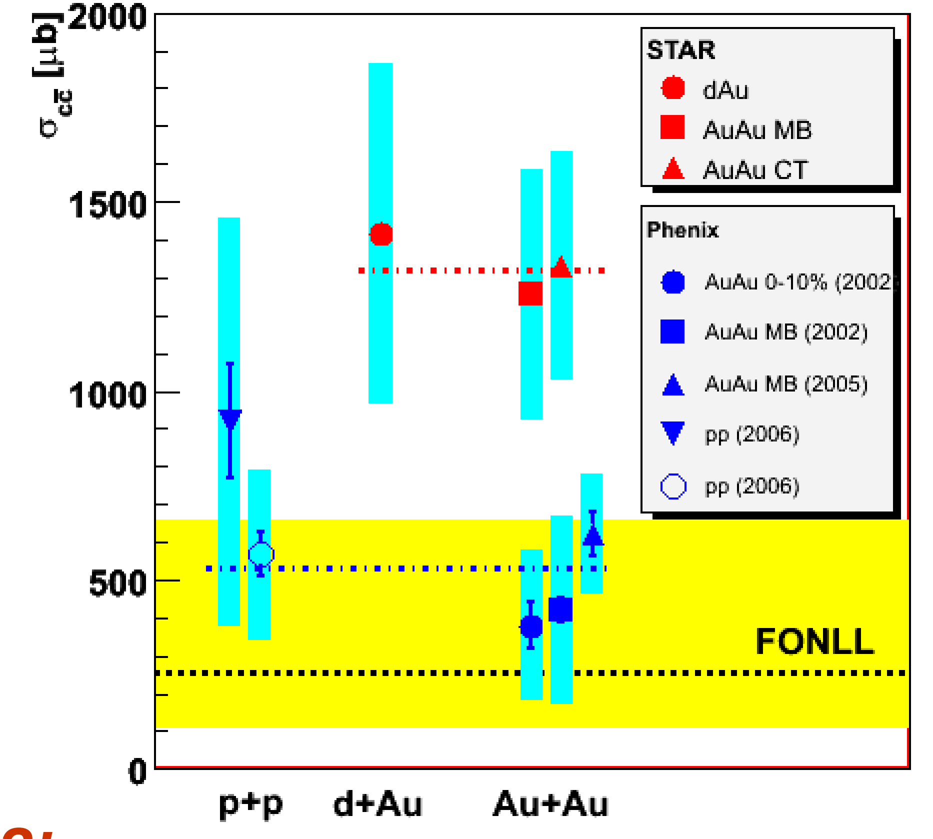
- FONLL as baseline
  - Large uncertainties due to m_c, factorization/renormalization scale
- Phenix
  - factor 2 higher, still consistent within errors
  - Only electrons but less background
- STAR
  - Large discrepancies between STAR and FONLL
  - more detector material
  - the only direct D-mesons measurement
  - 95% of the total cross section is measured
- Energy dependence, CBM, RHIC(200,500) and LHC will help constraining parameters



A. Suaide, nucl-ex/0702035.

Total Charm Production at RHIC (ii)

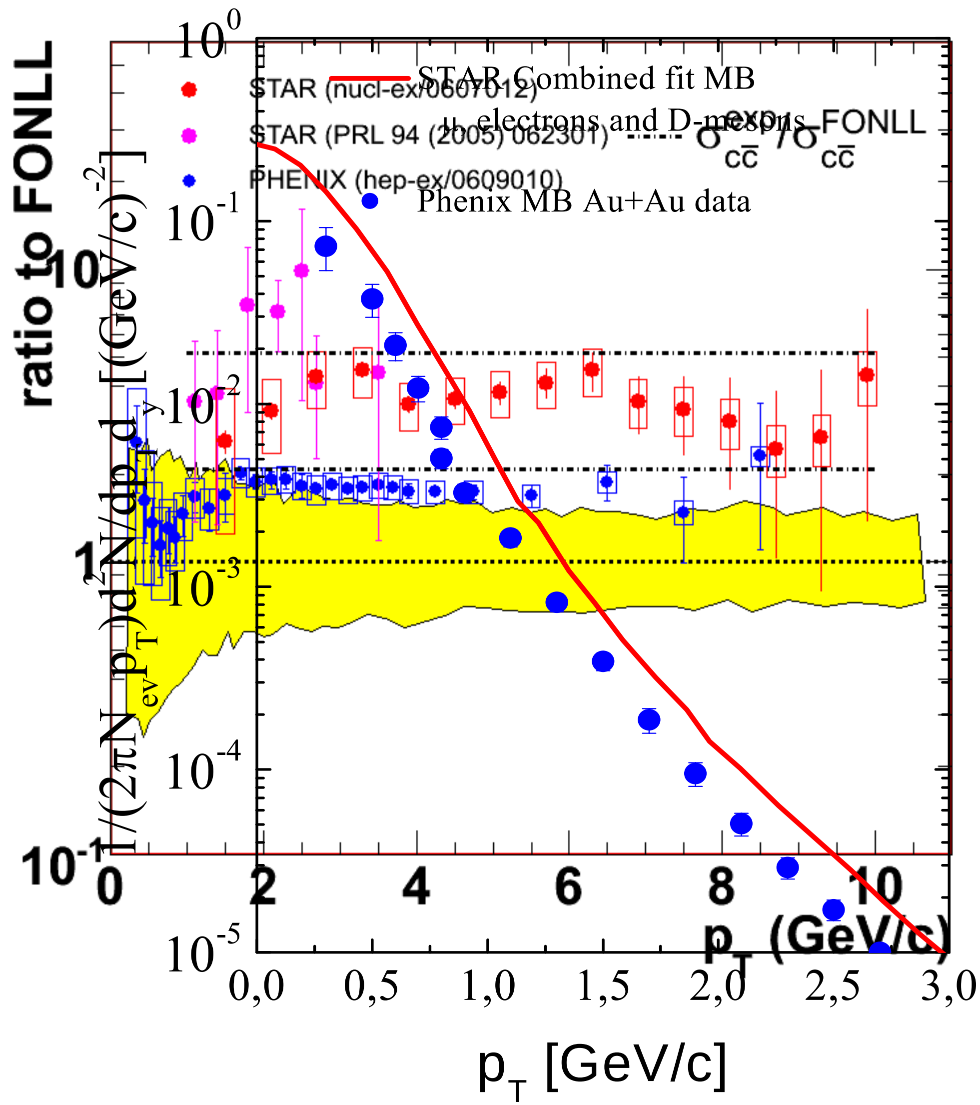
- STAR and PHENIX data suggest N_{bin} scaling
  - Charm is produced by initial collisions
  - No room for thermal production of charm
  - ***Both experiments disagree by factor 2- 3!***



A. Suaide, nucl-ex/0702035.

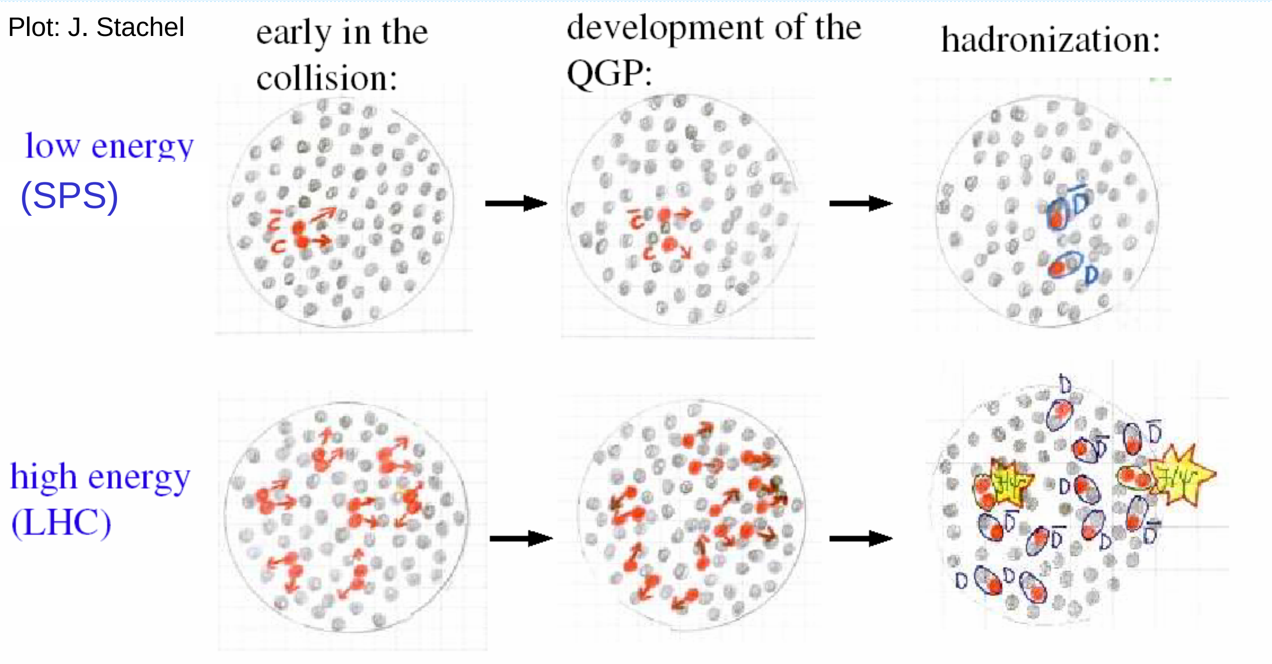
Non-photonic Electron Spectra

- Factor 2 – 3 discrepancy
- Independent on p_T
- Background strongly depends on p_T !
- Normalization Problem ?
- Displaced vertex will give precision data
  $\Rightarrow$ STAR and PHENIX upgrades



J/ψ Production

Plot: J. Stachel



⇒ suppression, compared to scaled p+p

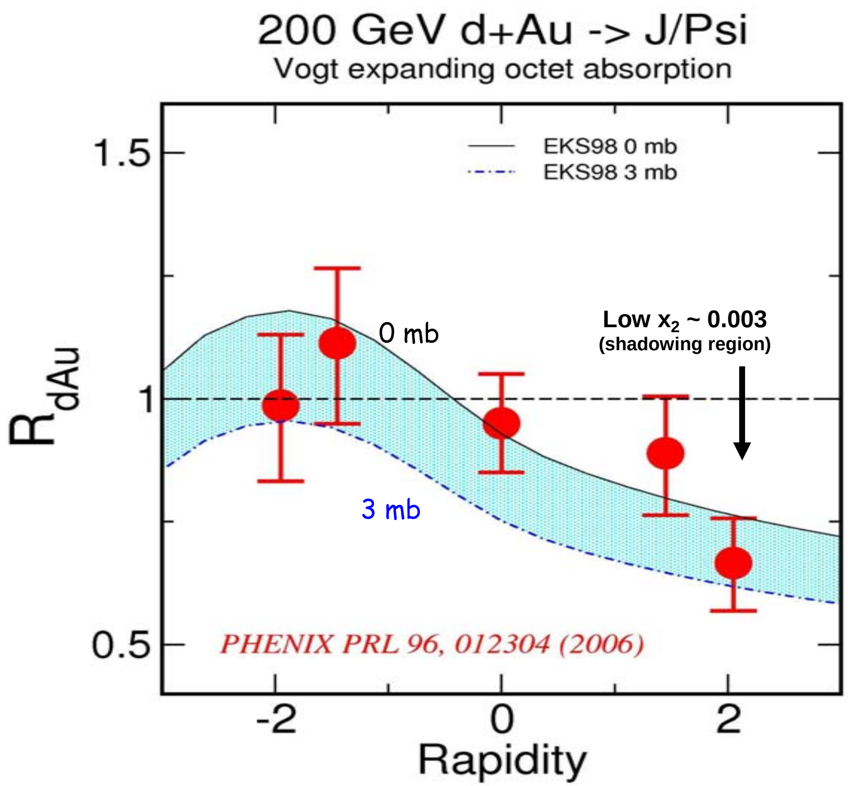
⇒ regeneration, enhancement

Low energy (SPS): few ccbar quarks in the system → suppression of J/ψ

High energy (LHC): many ccbar pairs in the system → enhancement of J/ψ

→ Signal of de-confinement + thermalization of light quarks !

Cold Nuclear Matter Effects



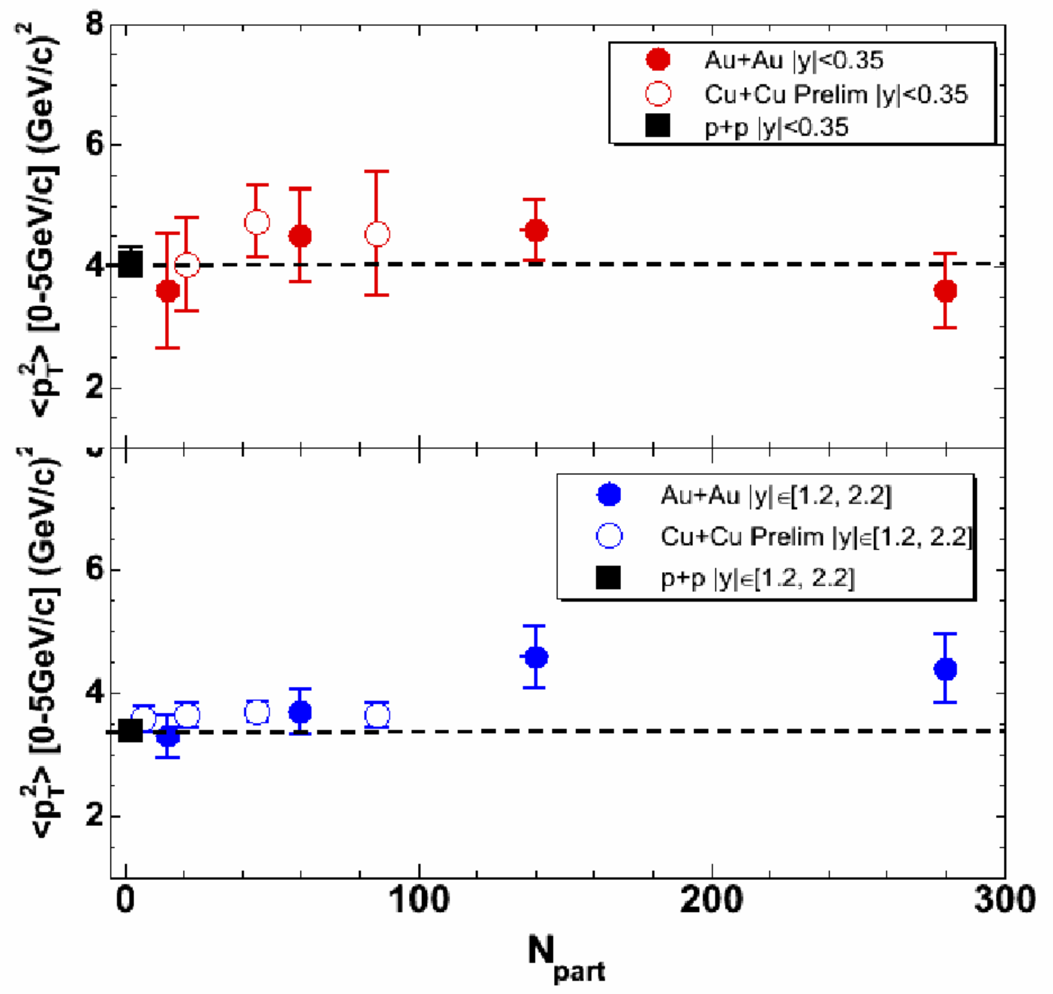
- EKS shadowing + nuclear absorption
- σ_{abs} < 3mb

⇒ *CNM effects are small at mid-rapidity at RHIC*

⇒ *negligible at LHC*

PHENIX: PRL 96, 012304 (2006);
Calcs: S. Klein and R. Vogt, PRL 91 (2003) 142301.

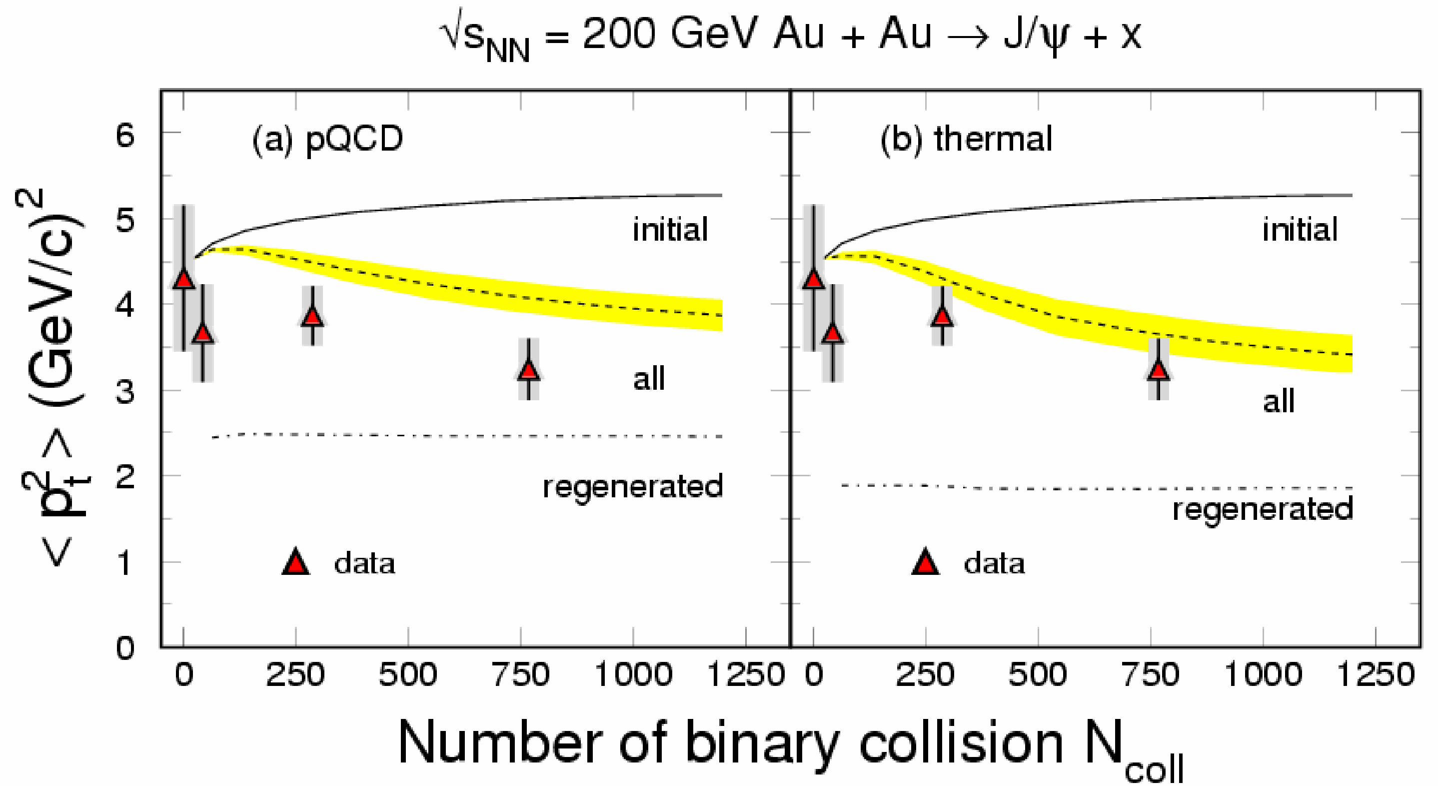
J/ψ Momentum vs Centrality



- almost no centrality dependence
- much different from SPS data (NA50)

⇒ No strong evidence for initial state scattering !

J/ψ Momentum Distribution



Initial: flat

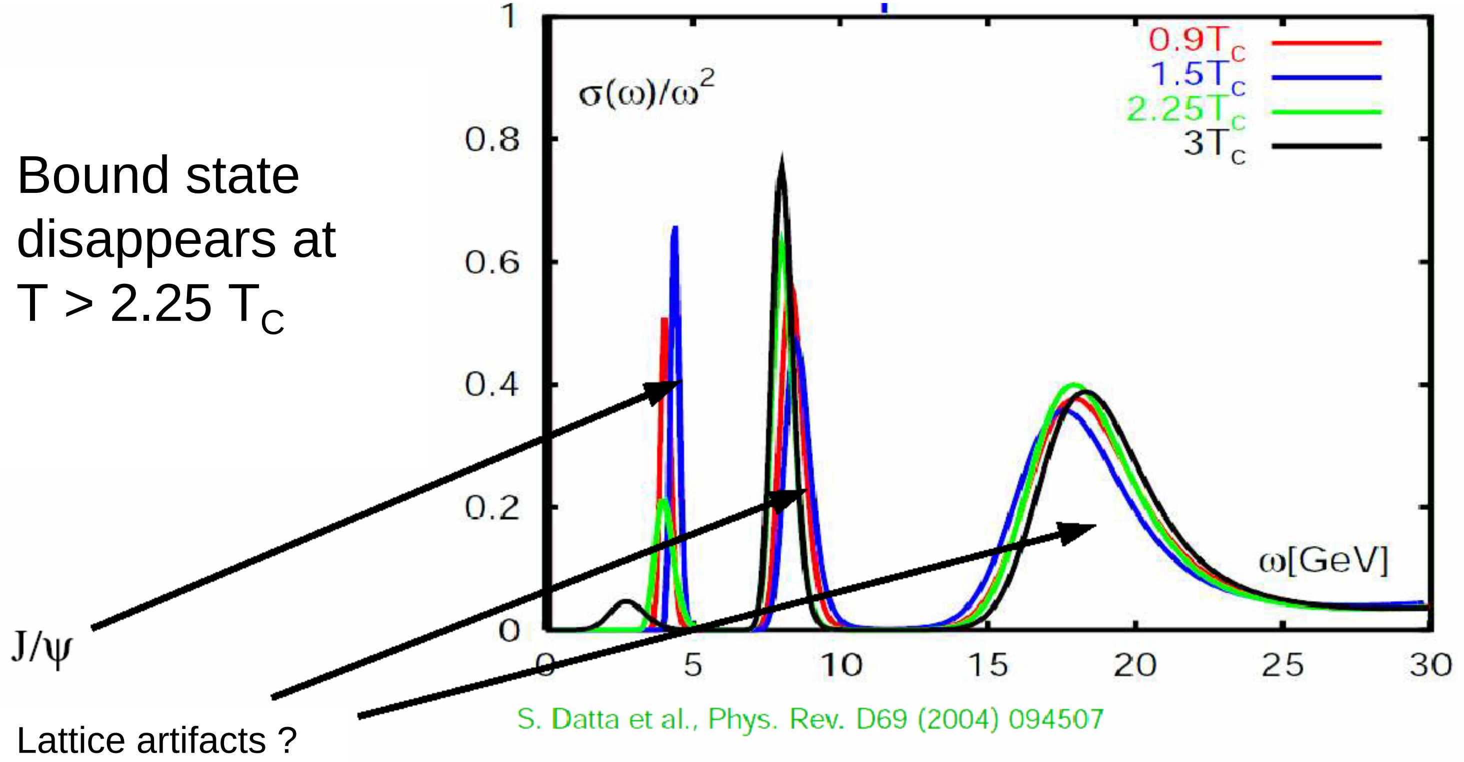
Regeneration: dropping w/ centrality

⇒ Regeneration of J/ψ important at RHIC !

L. Yan. P. Zhuang and N.Xu, PRL 97 (2006) 232301.

Vector Spectral Functions

Bound state disappears at T > 2.25 T_C



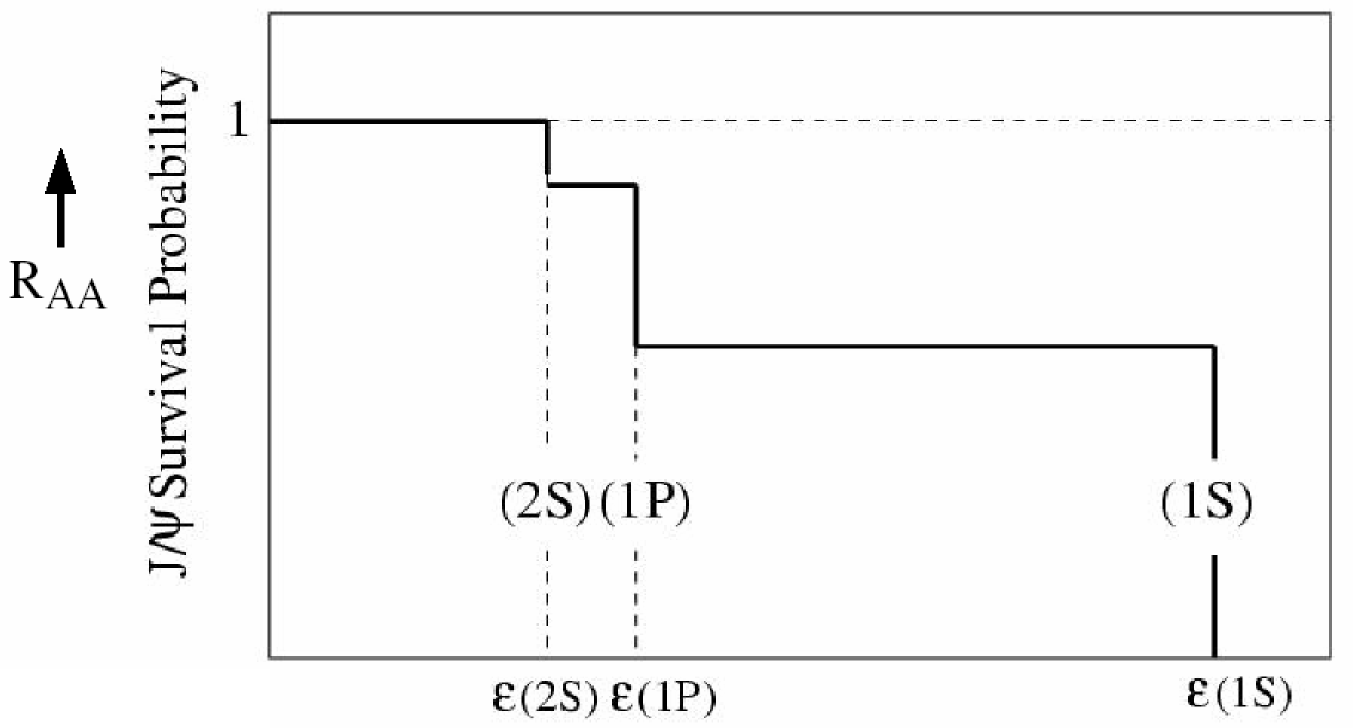
S. Datta et al., Phys. Rev. D69 (2004) 094507

Recent results from Lattice (F. Karsch, HF workshop, Beijing):

χ_C states disappear $T \approx T_C$

J/ψ and η_C gone at $T \approx 3\ T_C$

Schematical Picture

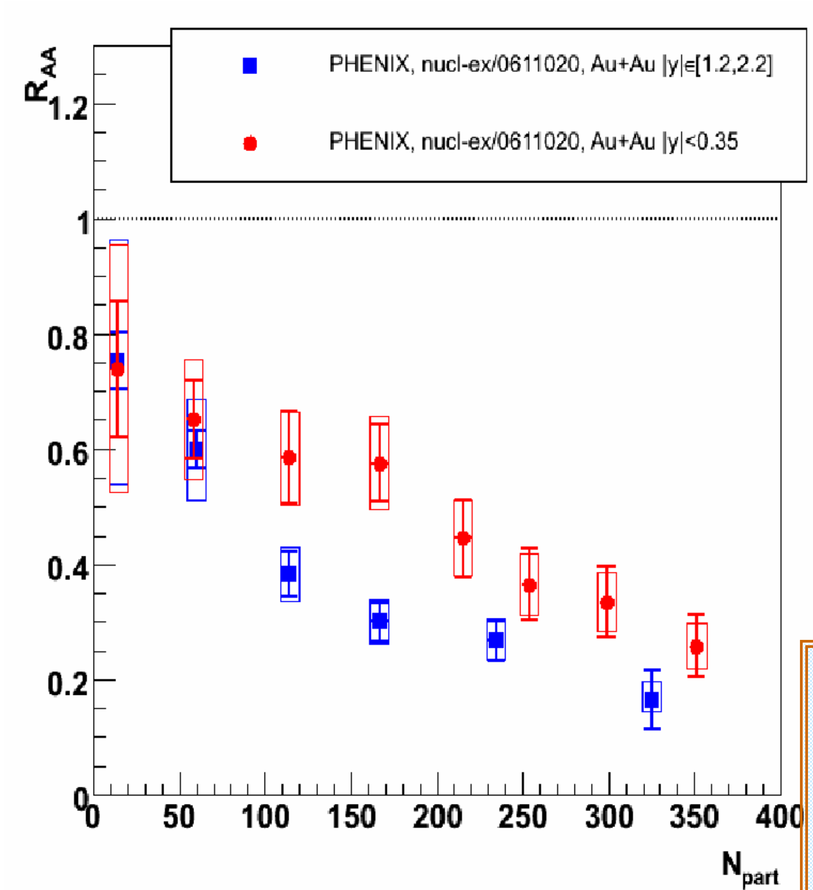


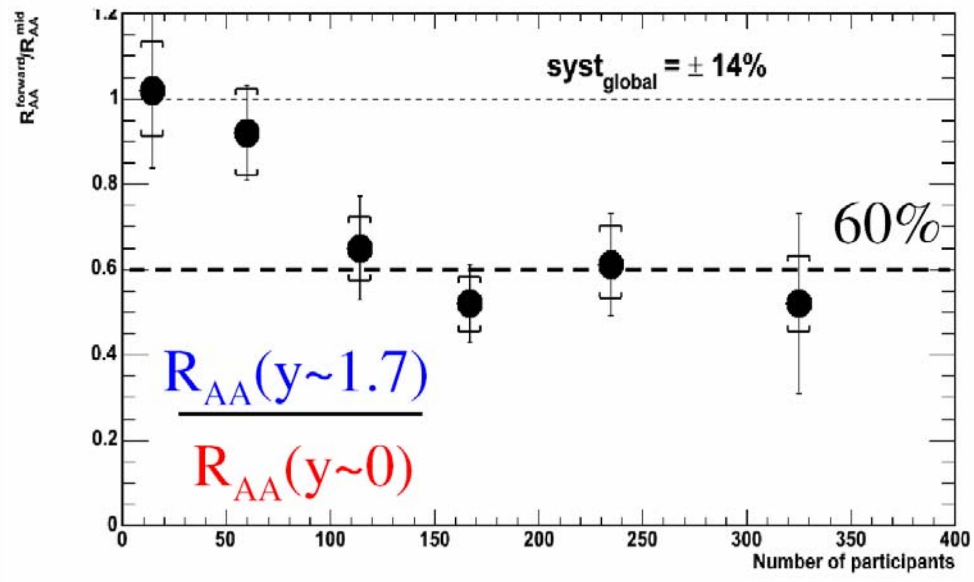
Suppose J/ψ does not melt

→ R_AA should saturate > 0.6

→ no more feeding from χ_C and ψ' → J/ψ + X

J/ψ Suppression (R_AA)





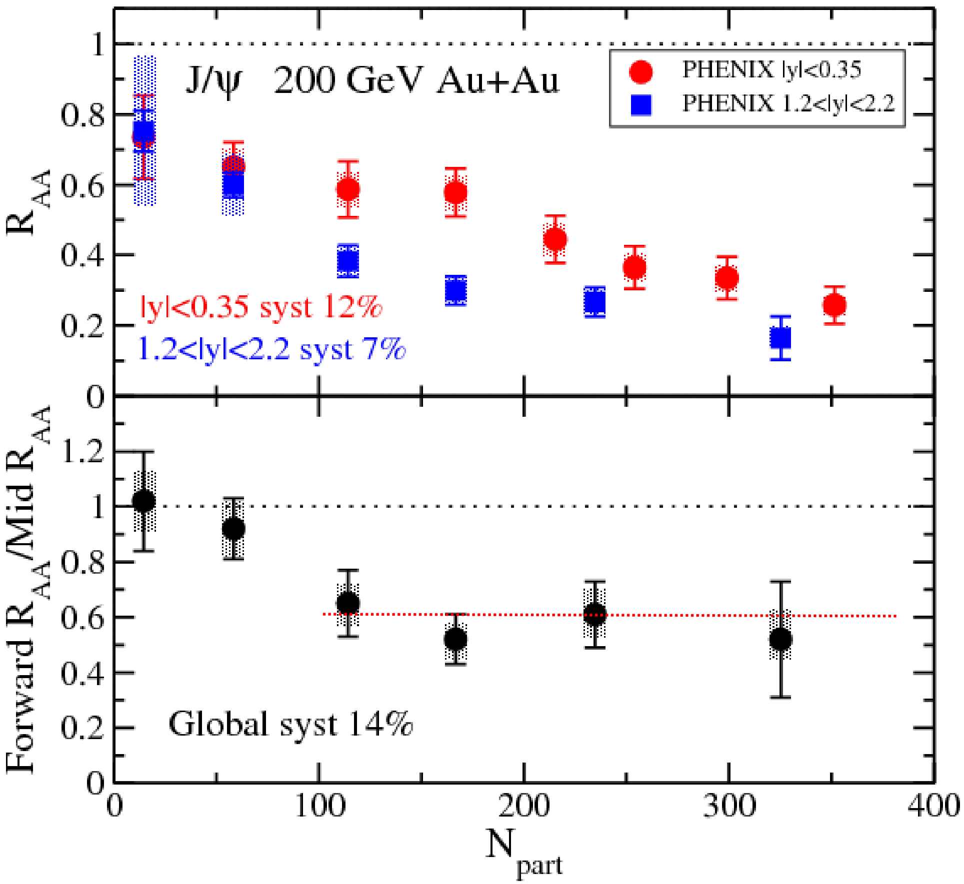
- Supression is weakest at mid-rapidity

⇒ contradicts original Matsui/Satz picture

⇒ contradicts comover picture

PHENIX data: nucl-ex/0611020.

J/ψ R_AA Rapidity Dependence



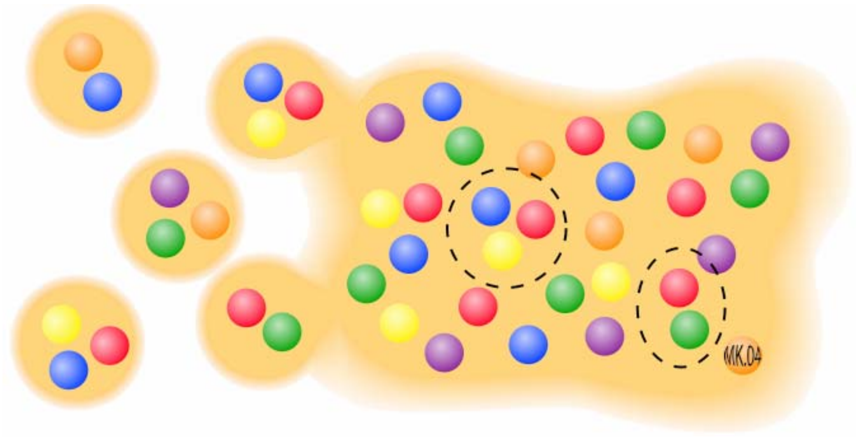
- Sequential screening of χ_C and ψ'
- additional suppression from gluon saturation at forward rapidity
- expect different centrality dependence

⇒ PHENIX data is flat !

⇒ sequential screening ruled out at RHIC !

PHENIX data: nucl-ex/0611020.

Statisitcal Hadronization of Charm



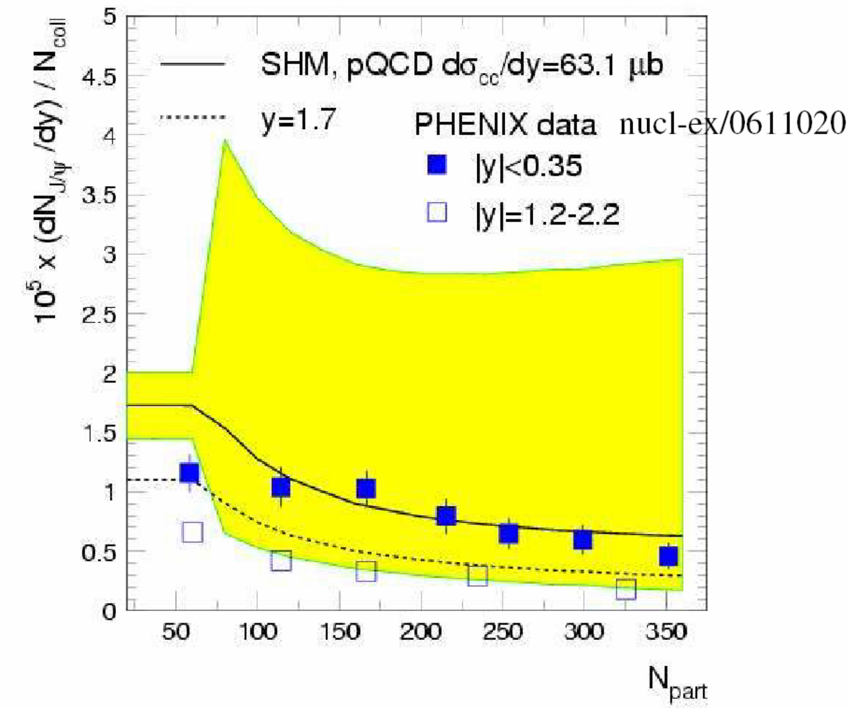
Assumptions:

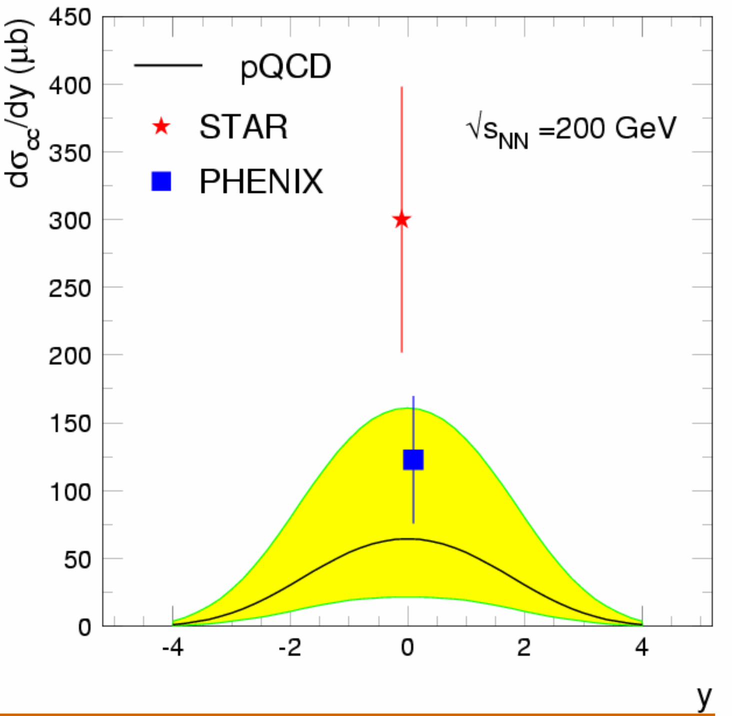
- All charm-quarks produced in initial scattering
- charm in thermal equilibrium (not chemical equilibrium)
- All J/ψ produced at freeze-out
- Include nuclear corona effects
- Input: open charm yield

→ ***Probe deconfinement and thermalization***

*P. Braun-Munzinger, K. Redlich,and J. Stachel, nucl-th/0304013.

Comparison to Data(i)

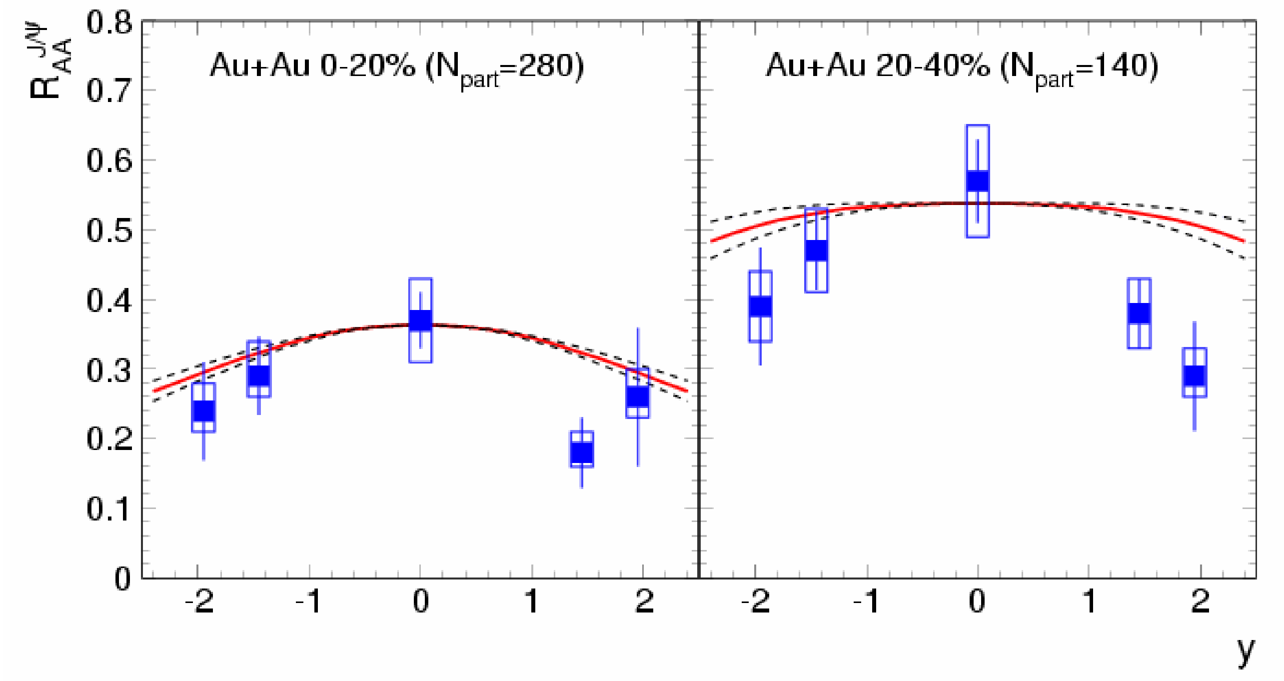




- Assume pQCD initial cross section
- centrality and rapidity distribution well reproduced for PHENIX data
- large uncertainty in experimental charm cross section

A. Andonic et al., nucl-th/06011023; nucl-th/0701079.

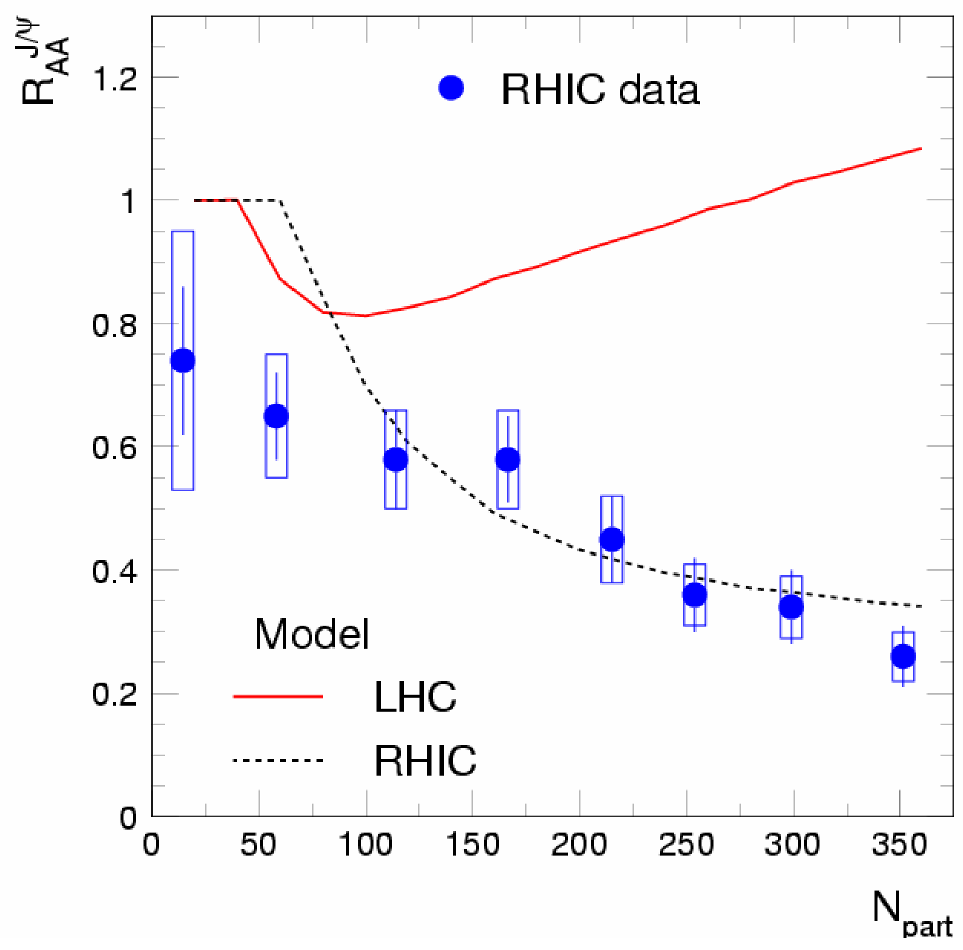
Comparison to Data (ii)



- Use $R_{AA}(p_T) = \dfrac{d^2N^{AA}/dp_T d\eta}{T_{AA} d^2\sigma^{NN}/dp_T d\eta}$
- large exp. uncertainties cancel
- quantitative description of exp. data

A. Andonic et al., nucl-th/0701079.

Predictions for LHC



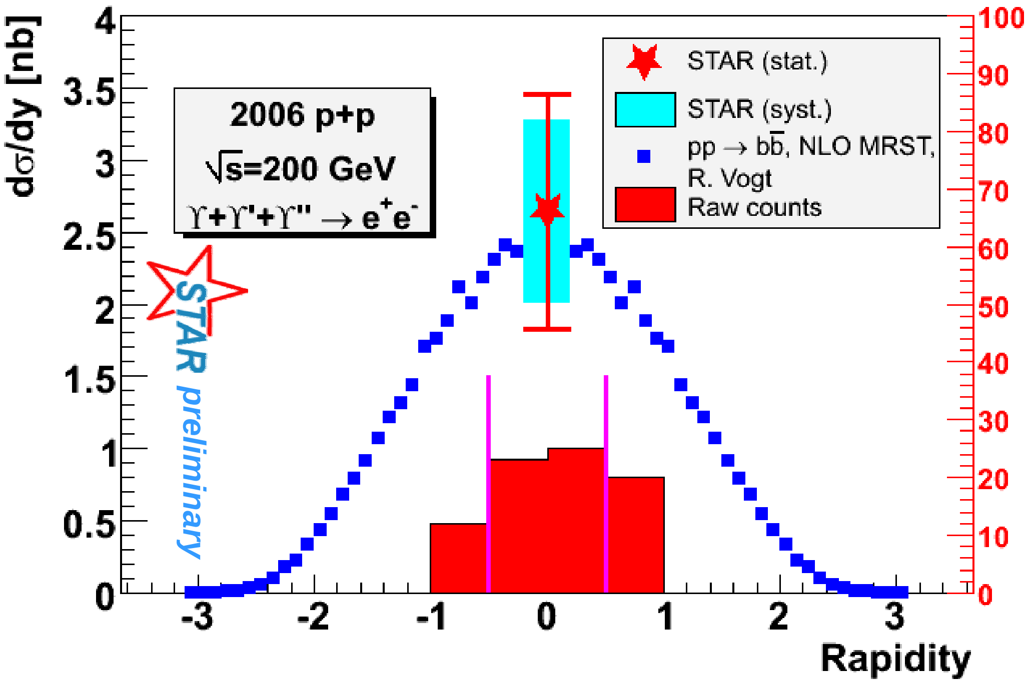
- large ccbar production at LHC
- corona effects negligible
- regeneration of J/ψ dominates
- striking centrality dependence

Signature for QGP formation !

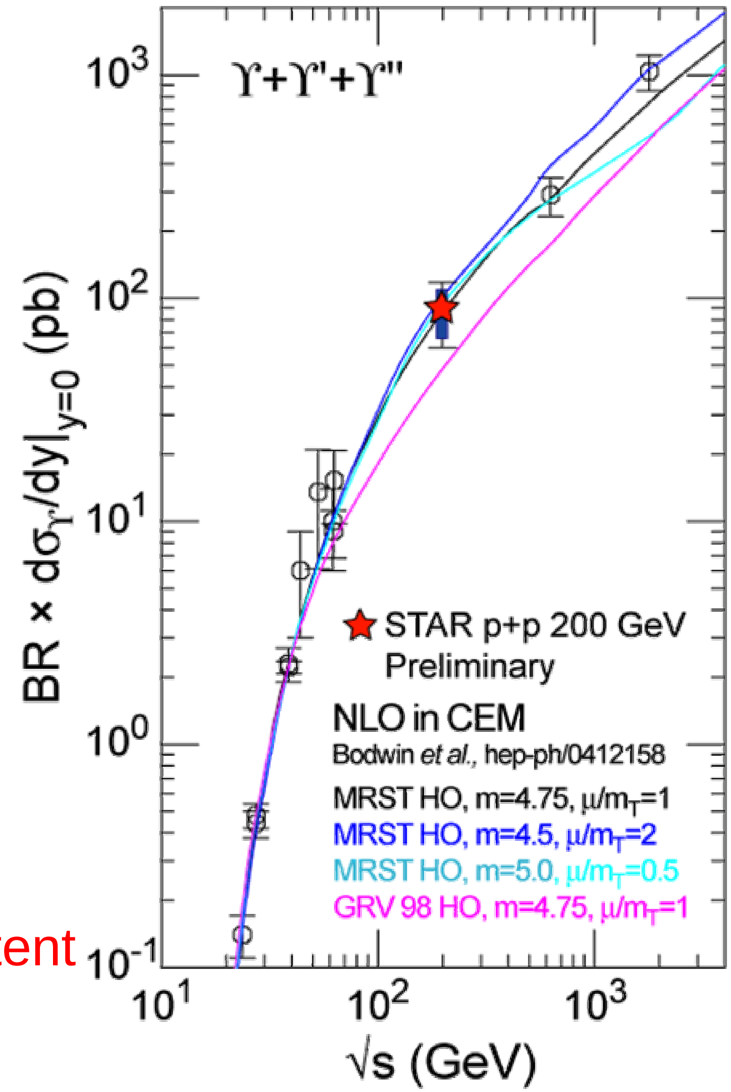
- Initial conditions at LHC ?

A. Andonic et al., nucl-th/0701079.

ϒ Production at RHIC



$$B_{ee} \times \left(\frac{d\sigma}{dy}\right)_{y=0}^{\Upsilon+\Upsilon'+\Upsilon''} = 91 \pm 28(\text{stat.}) \pm 22(\text{syst.})\ \text{pb}$$



STAR 2006 √s=200 GeV

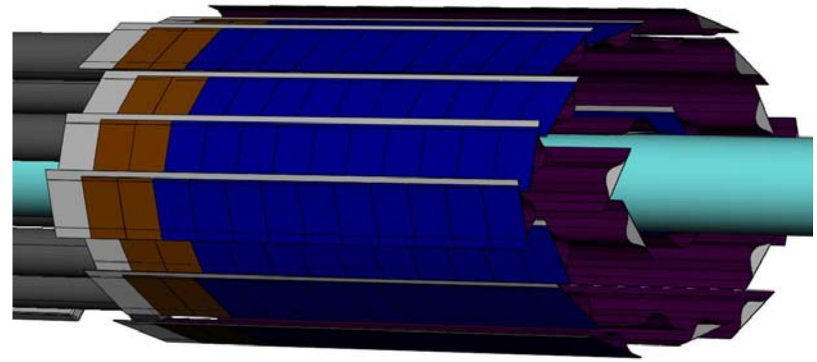
p+p $\Upsilon+\Upsilon'+\Upsilon'' \to e^+e^-$ cross section consistent with pQCD and world data

P. Djawotho, nucl-ex/0701075.

STAR Detector Upgrade

Full Barrel MRPC - TOF

Heavy Flavor Tracker

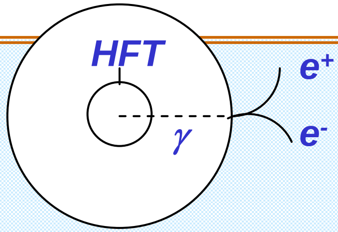


- $D^0 \rightarrow K + \pi$, $c\tau$ = 123μm
- Measure decay vertex, $\sigma \leq$ 50μm
- enhance S/B by factor 100

→ ***precise heavy-flavor measurements !***

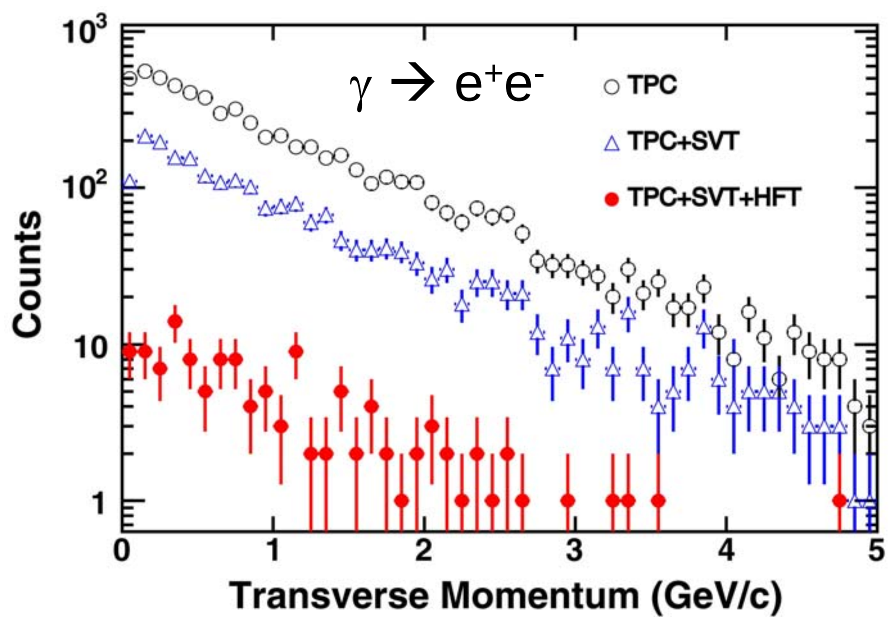
http://rnc.lbl.gov/~jhthomas/public/HFT/hft-proposal.pdf

Measure Vector Mesons



- Dileptons: e.g. $\phi \rightarrow e^+e^-$
- Huge Background:
  $\gamma \rightarrow e^+e^-$
- HFT discriminates background !
- HFT enhances dilepton measurements in STAR

Detectors	ω	ϕ
TPC+TOF	8 M	2 M
TPC+TOF+SVT+HFT	200K	100K



Summary

- At RHIC σ_{CC} = 300 – 1200μb
- Regeneration of J/ψ important at RHIC
- Regeneration will dominate at LHC

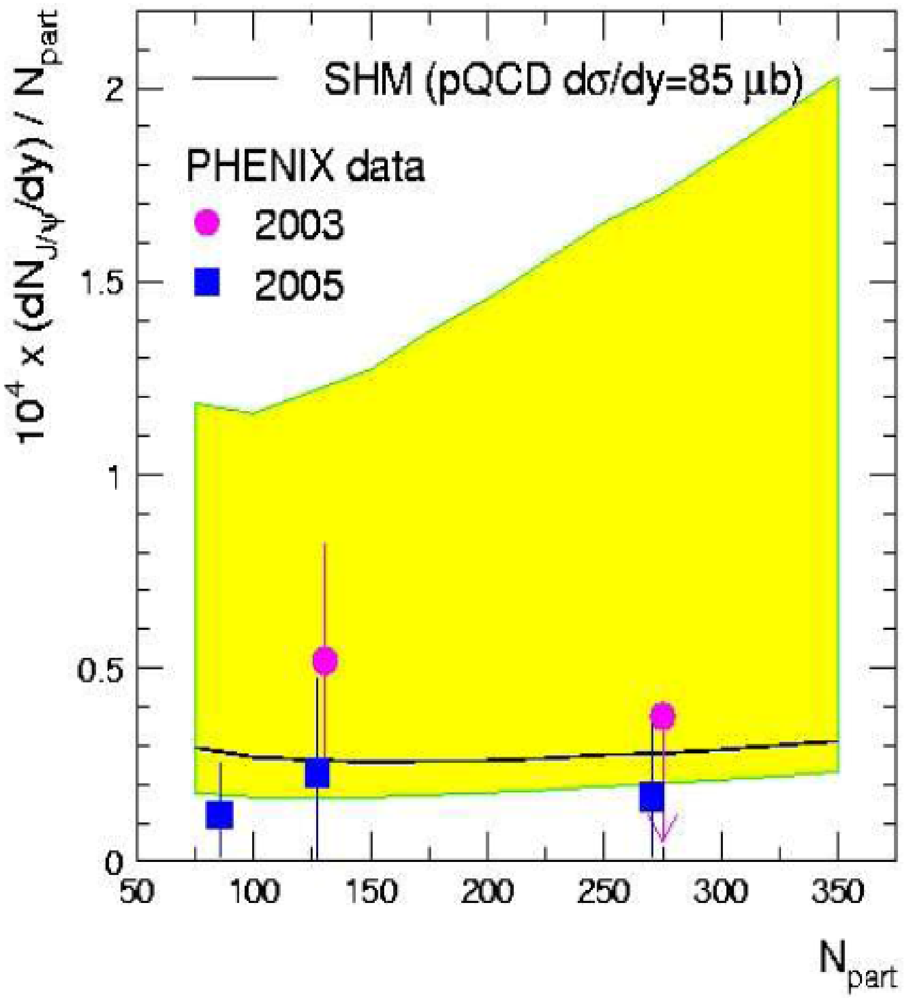
⇒ *Clear QGP signature*

- Angular correlations of D-Dbar mesons

⇒ *Sensitive to medium properties*

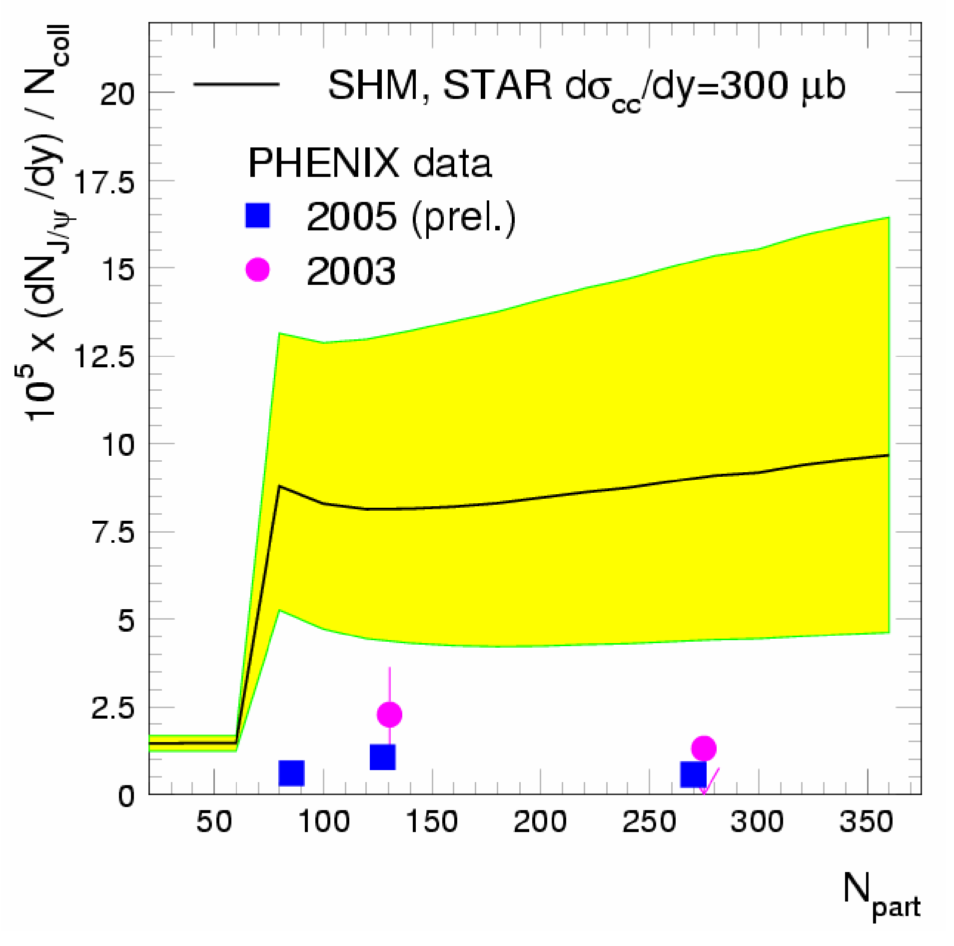
- Displaced vertex for precise measurements
- STAR and PHENIX upgrades
- ALICE: ITS + TPC + TRD + ToF

Early Model-predictions and RHIC Data

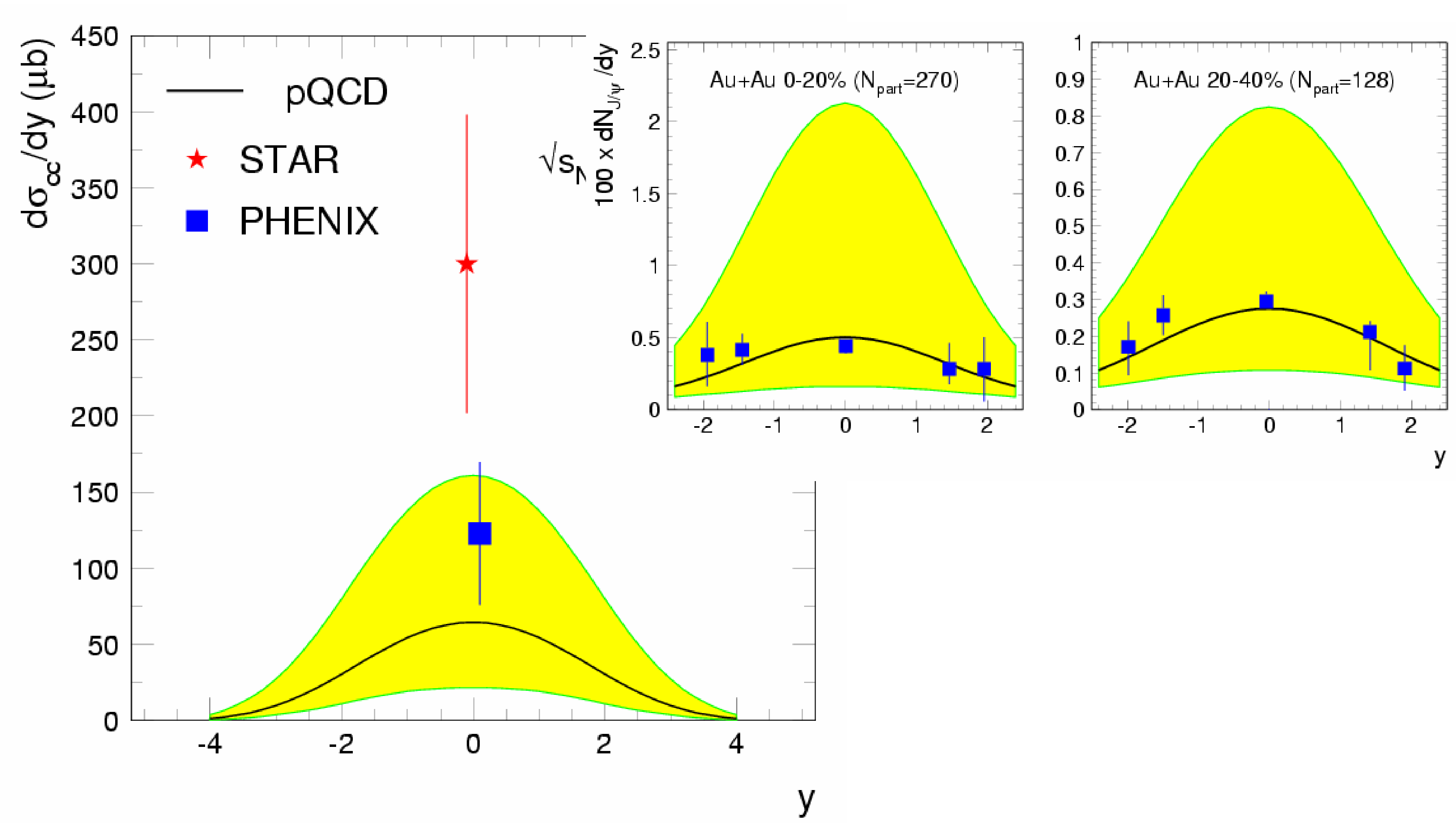


P. Braun-Munzinger et al.

- Yellow band: allowed range by open charm from STAR and PHENIX
- Large uncertainty from open charm cross section !
- ***Statistical Charm-Hadronization might not dominate at RHIC***
- ***Check at LHC…***
- ***Need precise open charm reference !***

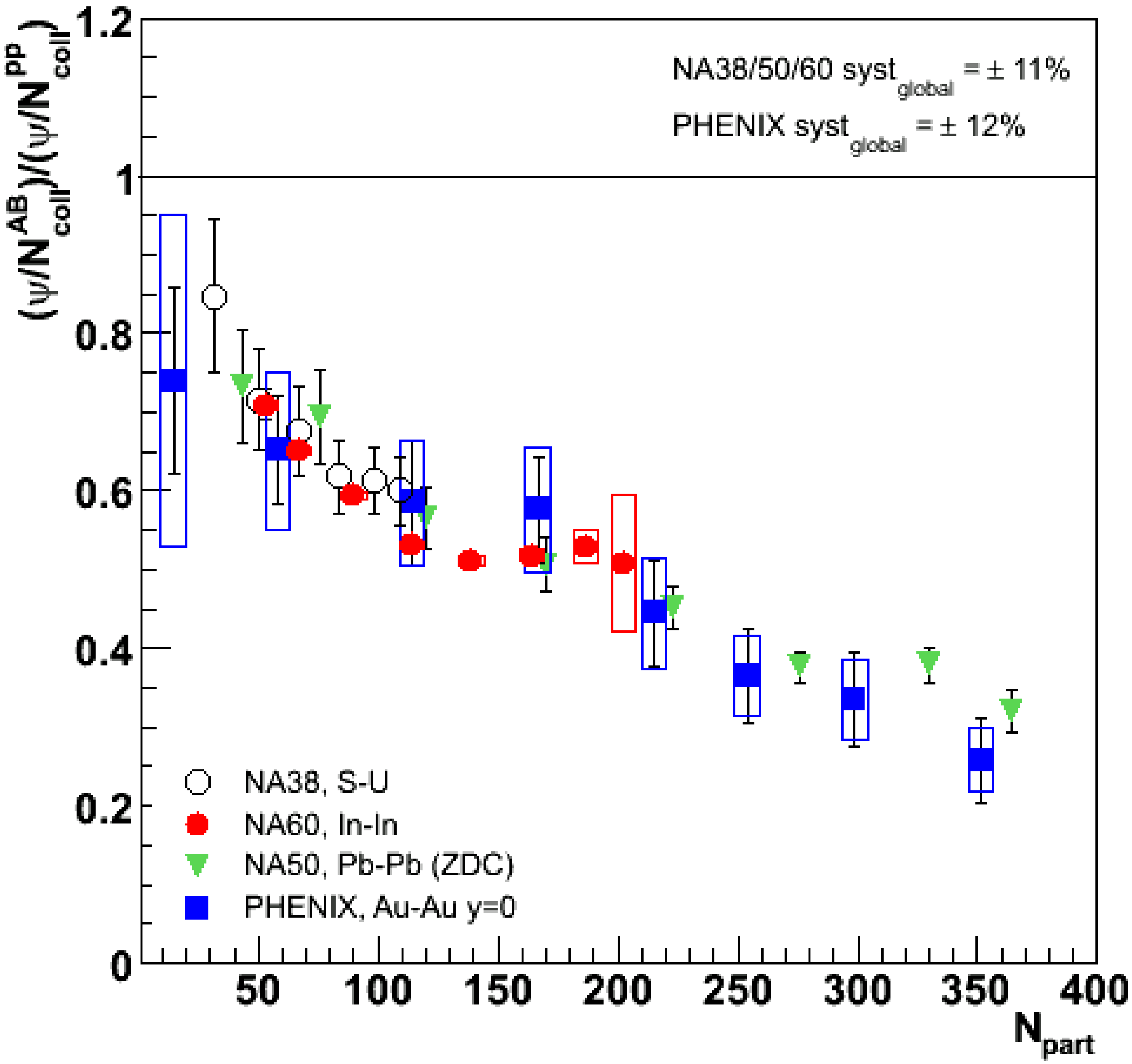


SHM, STAR dσcc/dy=300 μb
PHENIX data
2005 (prel.)
2003
10^5 x (dN_J/ψ /dy) / N_coll
N_part
0
2.5
5
7.5
10
12.5
15
17.5
20
50
100
150
200
250
300
350



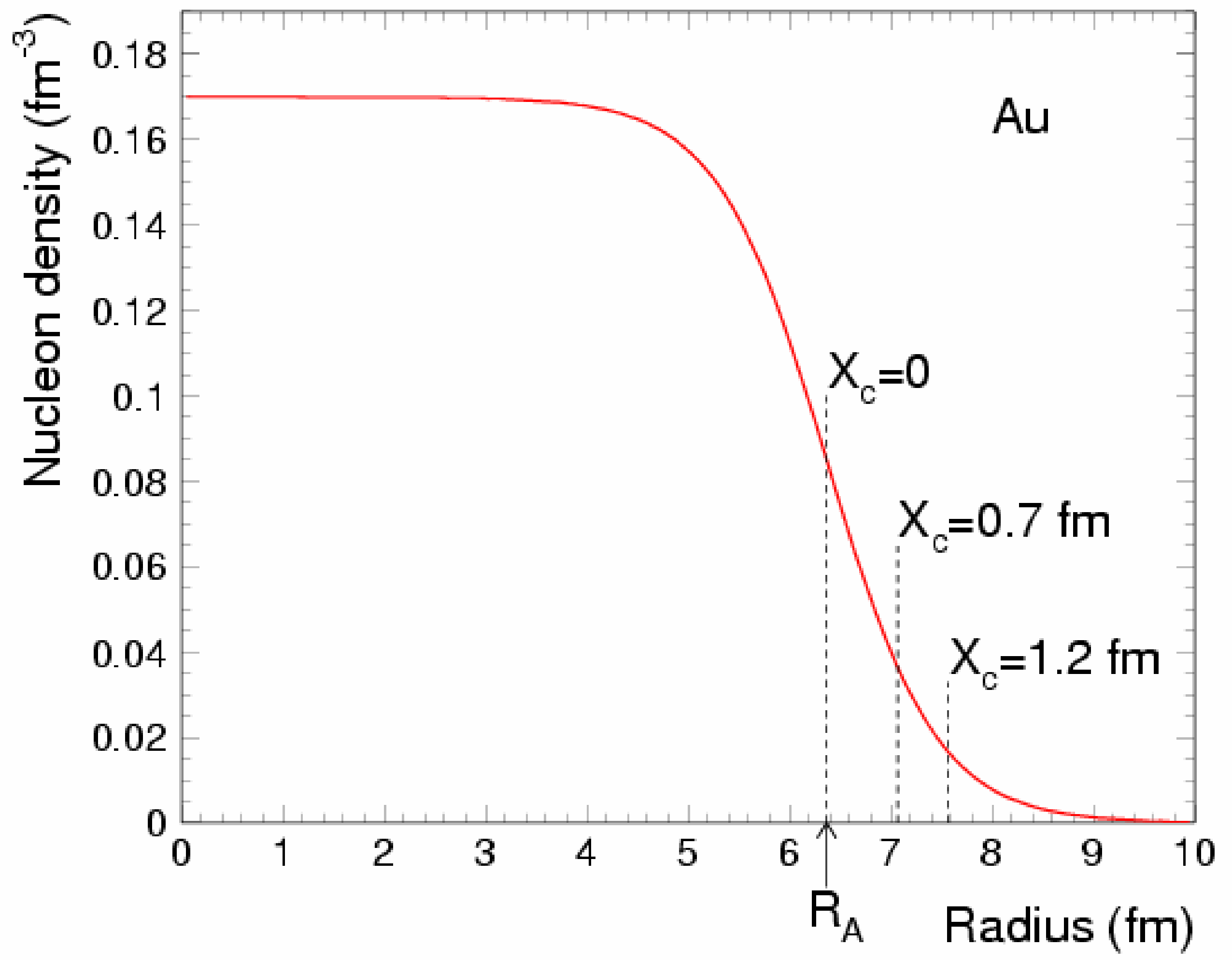
$d\sigma_{c\bar{c}}/dy$ (μb)
450
400
350
300
250
200
150
100
50
0
-4
-2
0
2
4
y
pQCD
STAR
PHENIX
$\sqrt{s_N}$
$100 \times dN_{J/\psi}/dy$
Au+Au 0-20% (N_{part}=270)
Au+Au 20-40% (N_{part}=128)
y

J/ψ at SPS and RHIC



- Puzzle: No energy dependence
- Accident ?

Corona Effect



J/ψ from STAR and PHENIX