CFRJS

Heavy flavor at RHIC

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NPI AS CR

Prague

STAR

Excited QCD 2010, Stará Lesná, Slovensko

Outline

- Heavy ion program at RHIC in BNL
- Motivation for heavy flavor physics
- Open heavy flavor
  - Charm mesons: D^0
  - Non-photonic electrons
- Quarkonia
  - J/ψ and Υ measurements

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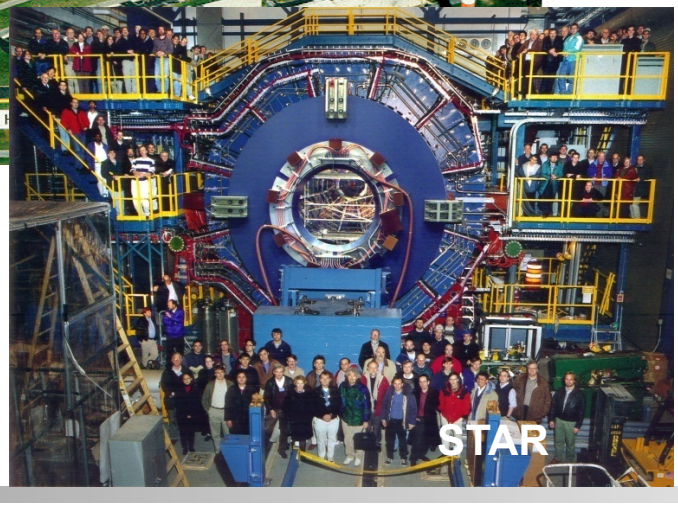
Relativistic Heavy Ion Collider

RHIC site in BNL on Long Island, USA

RHIC has been exploring nuclear matter at extreme conditions over the last few years

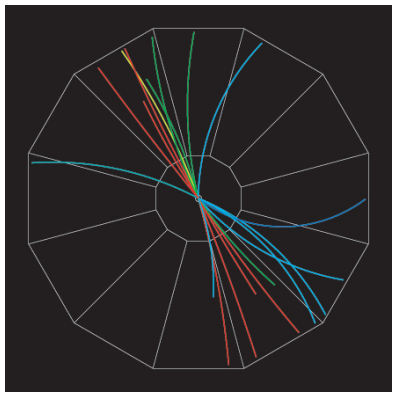
Lattice QCD predicts a phase transition from hadronic matter to a deconfined state, the **Quark-Gluon Plasma**

Colliding systems:
p↑+p↑, d+Au, Cu+Cu, Au+Au
Energies
$\sqrt{s_{NN}}$ = 20, 62, 130, 200GeV

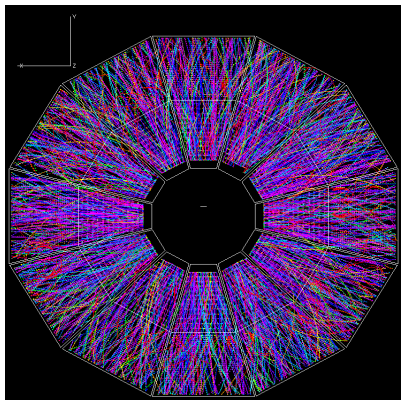


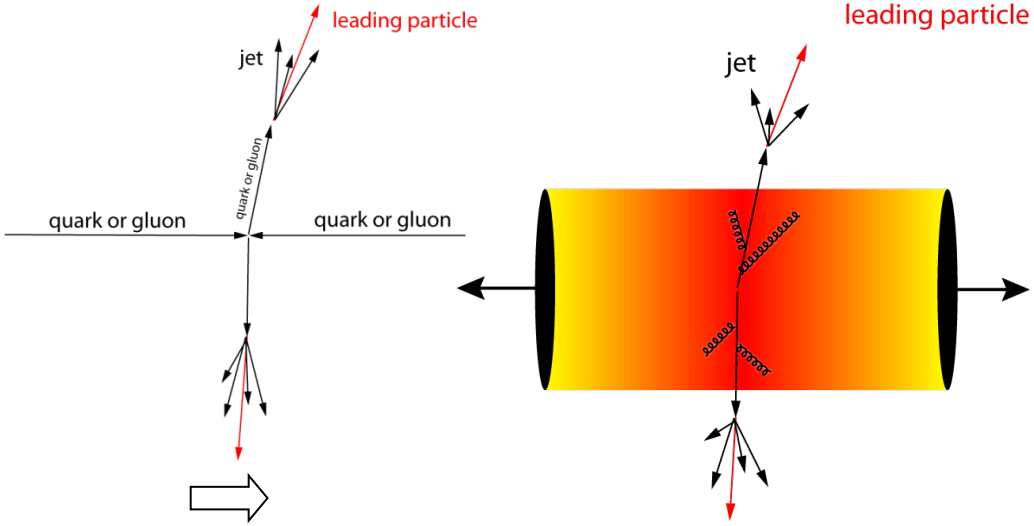
Probing of Dense Matter with jets

p+p Collision



Au+Au Collision





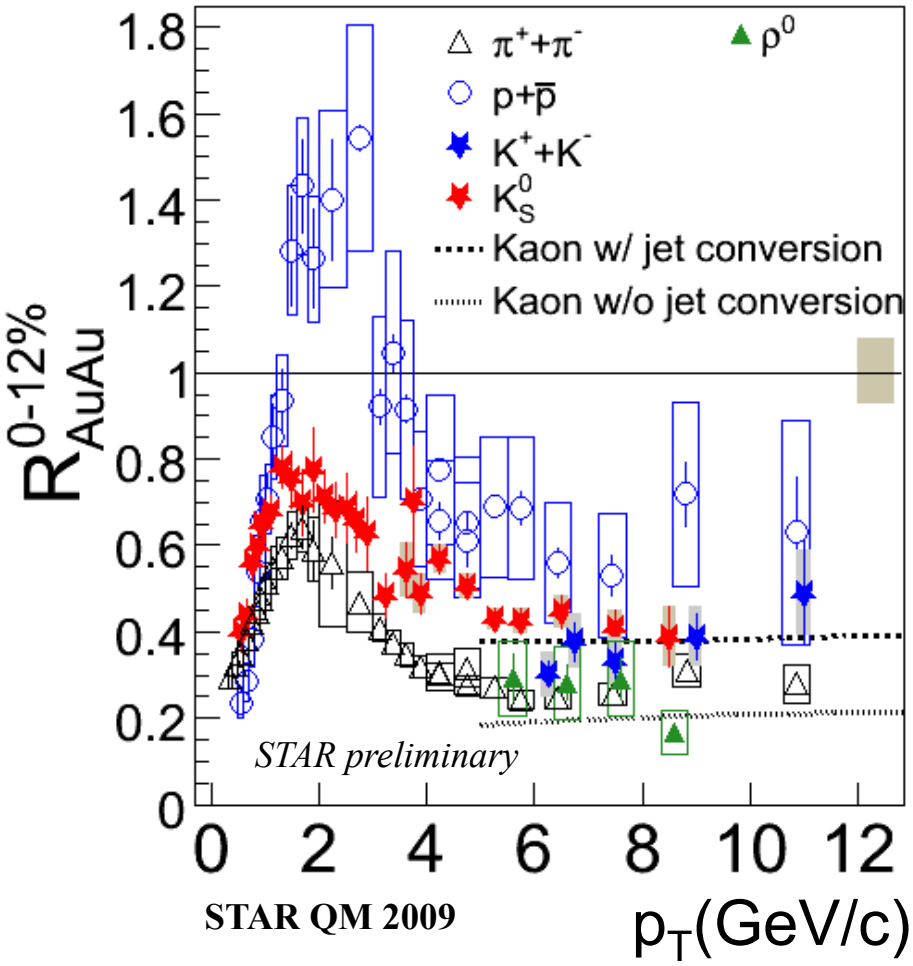
- nuclear modification factor R_{AA} :

$$R_{AA}(p_T) = \frac{Yield(A+A)}{Yield(p+p) \times \langle N_{coll} \rangle}$$

Average number of NN collisions in AA collision

- No "Effect" of nuclear matter: $R_{AA} = 1$ at higher momenta where hard processes dominate
- Suppression: $R_{AA} < 1$
- Partons interact with medium gluon radiation/energy loss
- measuring high-p_T particles in Au+Au vs. p+p to extract the properties of medium

Hadron suppression in central Au+Au

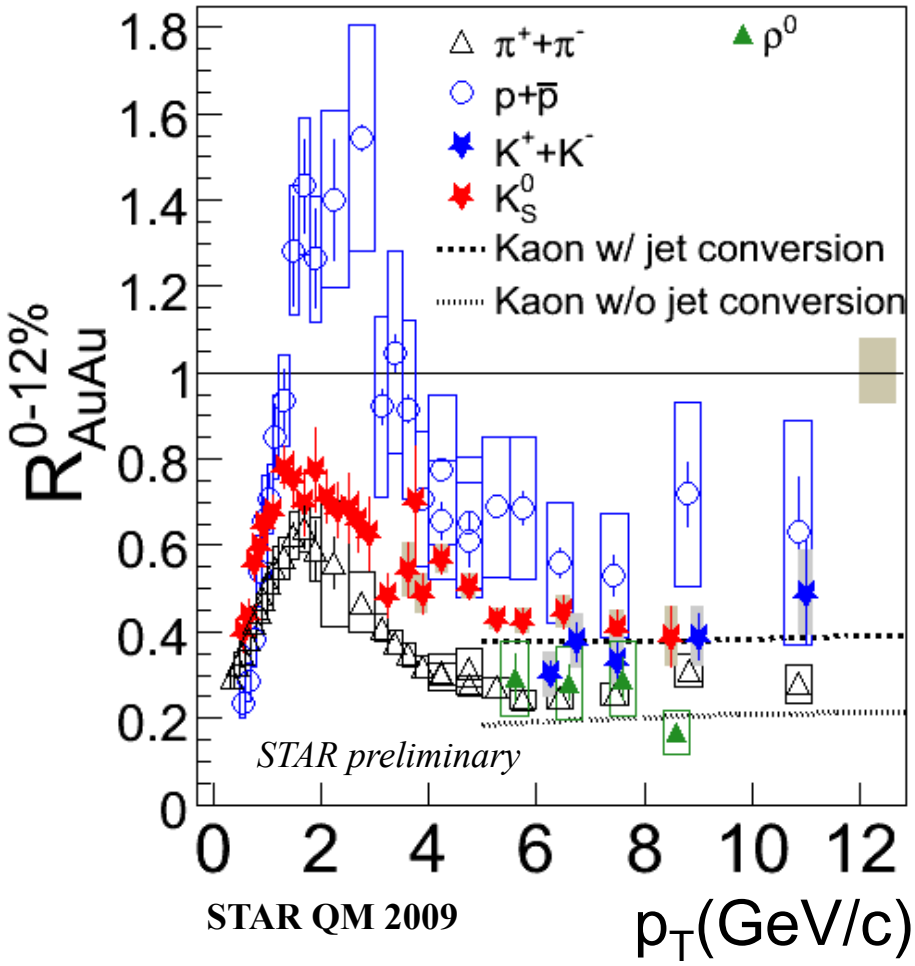


- **Hadron yields:**
  strongly suppressed
  in central Au+Au at 200 GeV

- **Large energy loss of light partons in the formed nuclear matter**

Energy loss depends on
properties of medium
(gluon densities, size)
properties of "probe"
(color charge, mass)

Hadron suppression in central Au+Au



$$\langle \Delta E \rangle \sim \alpha_s \, C \, \langle \hat{q} \rangle L^2$$

- Color charge dependence: g /q (C_A/ C_F=9/4)
- Gluons loose more energy than quarks
- At high-p_T protons are produced mainly from gluon jets
- At high-p_T pions are produced mainly from quark jets

=> Expected $R_{AA}(g \to p) < R_{AA}(q \to \pi)$

protons versus pions

Heavy quarks as a probe

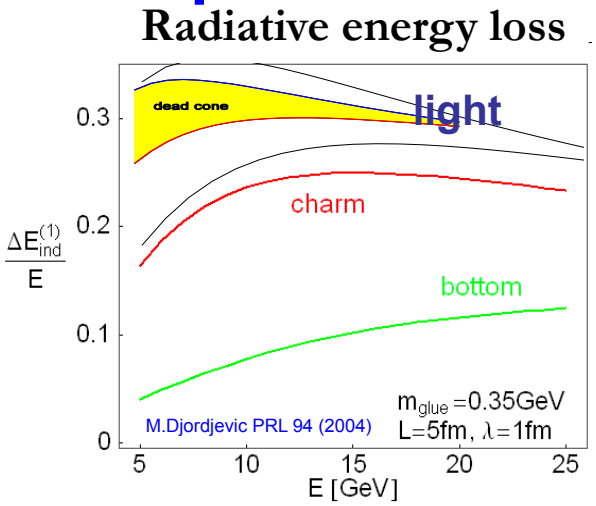
- p+p data:

→ baseline of heavy ion measurements
→ test of pQCD calculations

- Due to their large mass heavy quarks are primarily produced by gluon fusion in early stage of collision

→ production rates calculable by pQCD

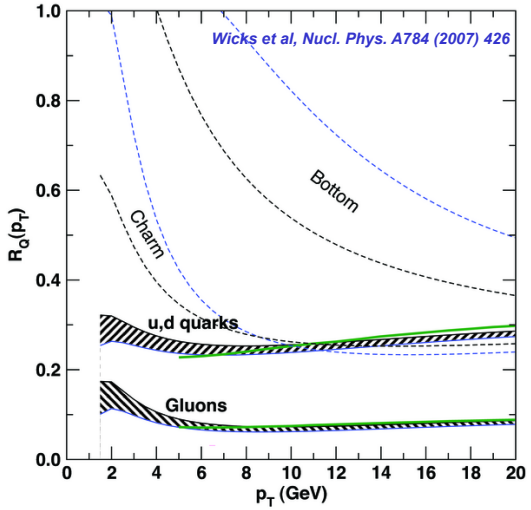
M. Gyulassy and Z. Lin, PRC 51, 2177 (1995)



•heavy ion data:

- Studying energy loss of heavy quarks

→ independent way to extract properties of the medium



Open heavy flavor

Direct: reconstruction of all decay products

$$D^0 \to K^-\pi^+, \overline{D}^0 \to K^+\pi^-,$$

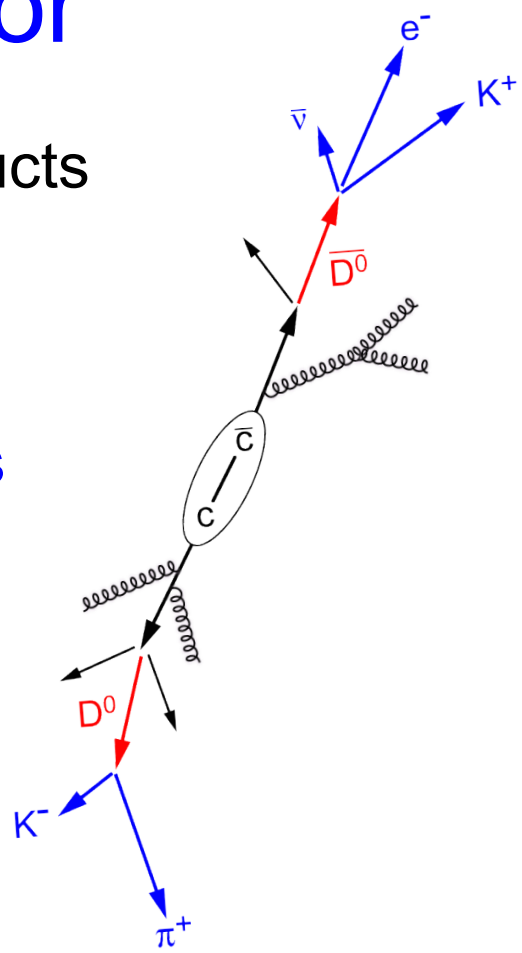
$$B.R. = 3.80 \pm 0.07\%$$

Indirect: charm and beauty via electrons

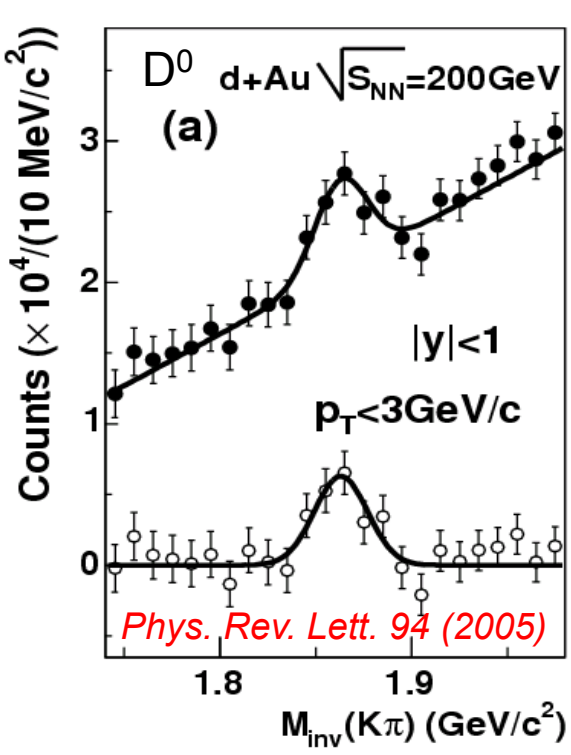
c → e^+ + anything (B.R.: 9.6%)
b → e^+ + anything (B.R.: 10.9%)
issue of photonic background

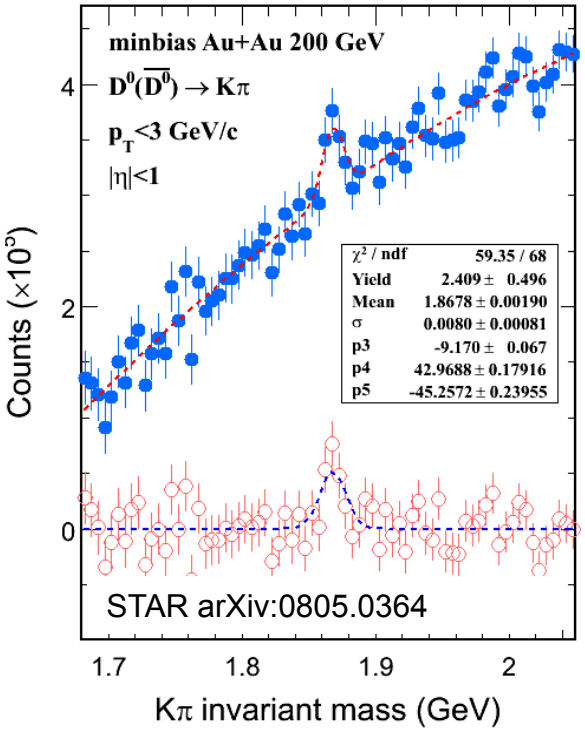
charm (and beauty) via muons

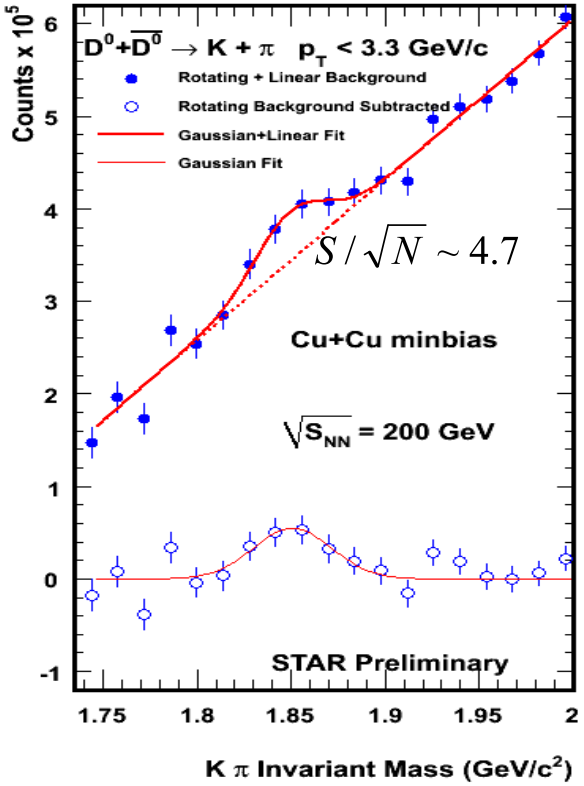
c → μ+ + anything (B.R.: 9.5%)



Direct D-meson reconstruction at STAR

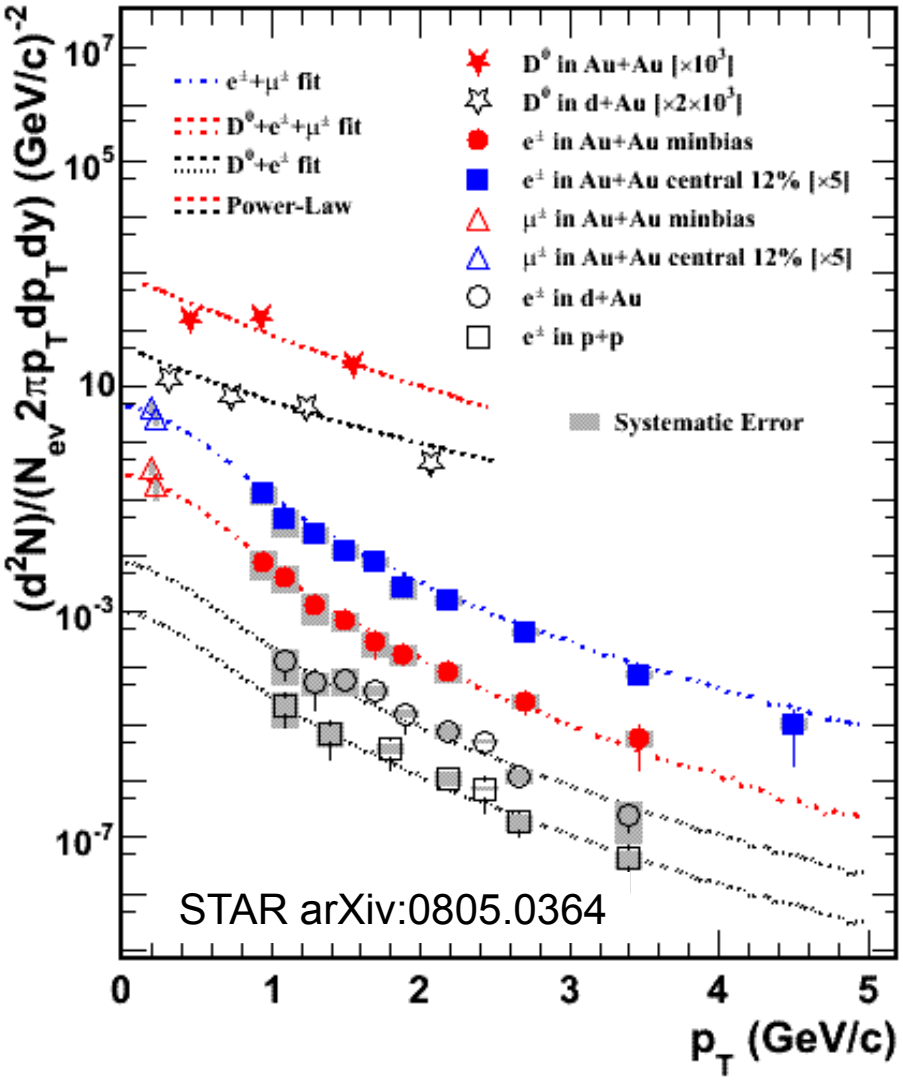






- Kπ invariant mass distribution in d+Au, Au+Au minbias, Cu+Cu minbias at 200 GeV collisions
- No displaced vertex used for open heavy flavor

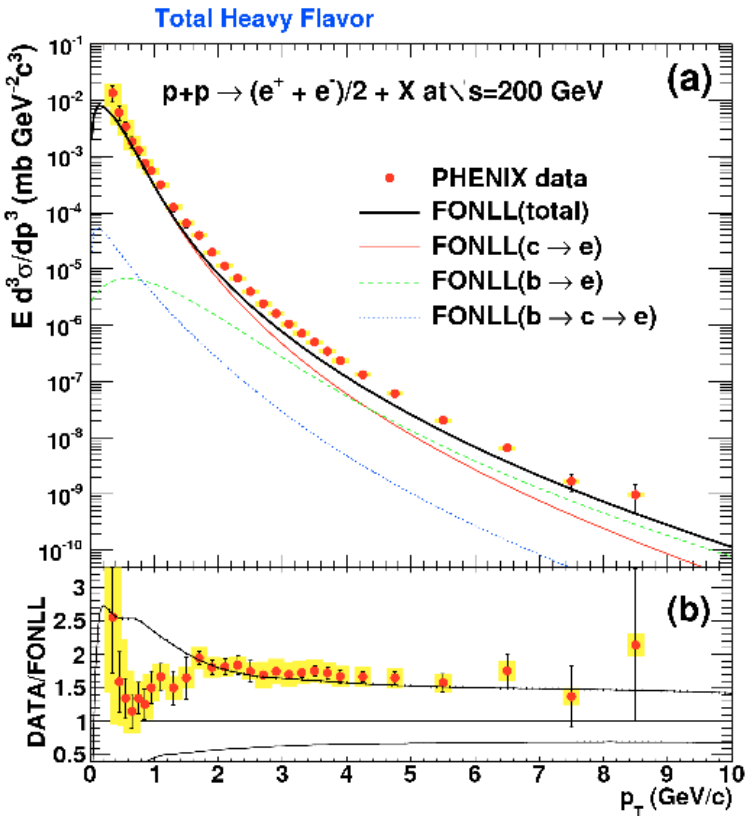
Measurement of charm STAR

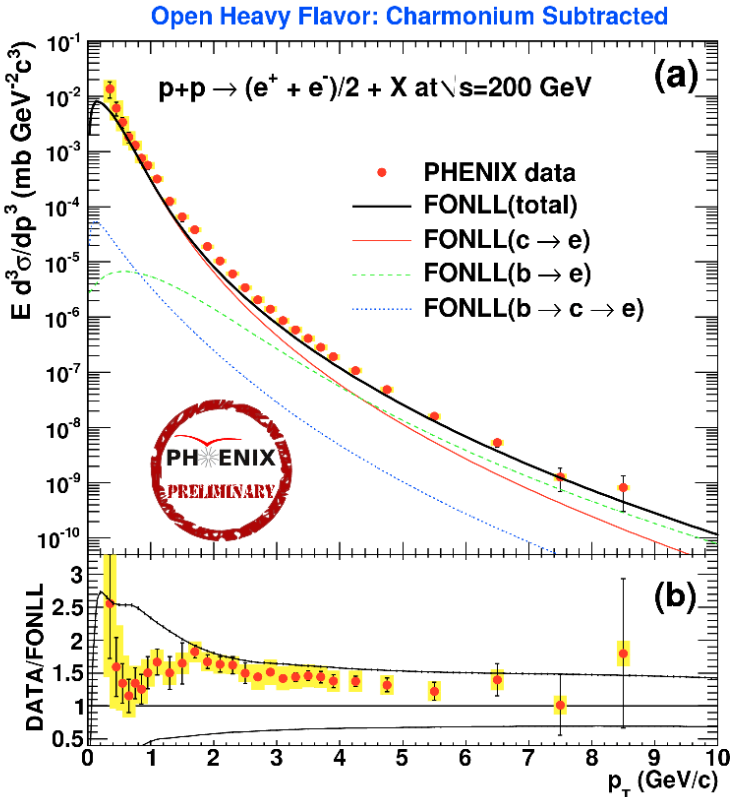


STAR charm measurement:

- D^0 in d+Au, Au+Au, Cu+Cu 200GeV
- low p_T muon in Au+Au 200GeV
- non-photonic electrons in p+p, d+Au, Cu+Cu, Au+Au 200GeV
- 90% of charm total kinematic range covered

Measurement of charm PHENIX

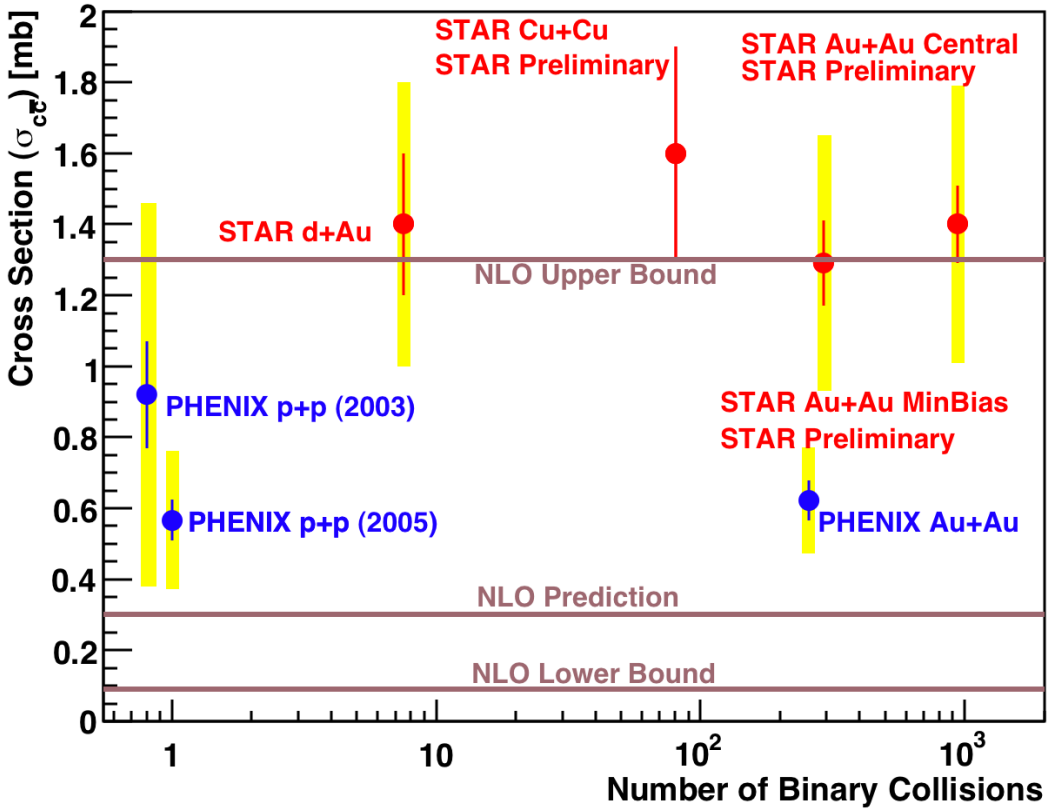




Phys. Rev. Lett. 97, 252002 (2006)

•New study takes J/y→ e± contribution into account

Open Charm Cross-section



STAR:

D^0, electrons

PRL 94(2005) 062301

D^0, muons

arXiv:0805.0364

PHENIX:

Single electrons

PRL 97(2006) 252002

Electron pairs

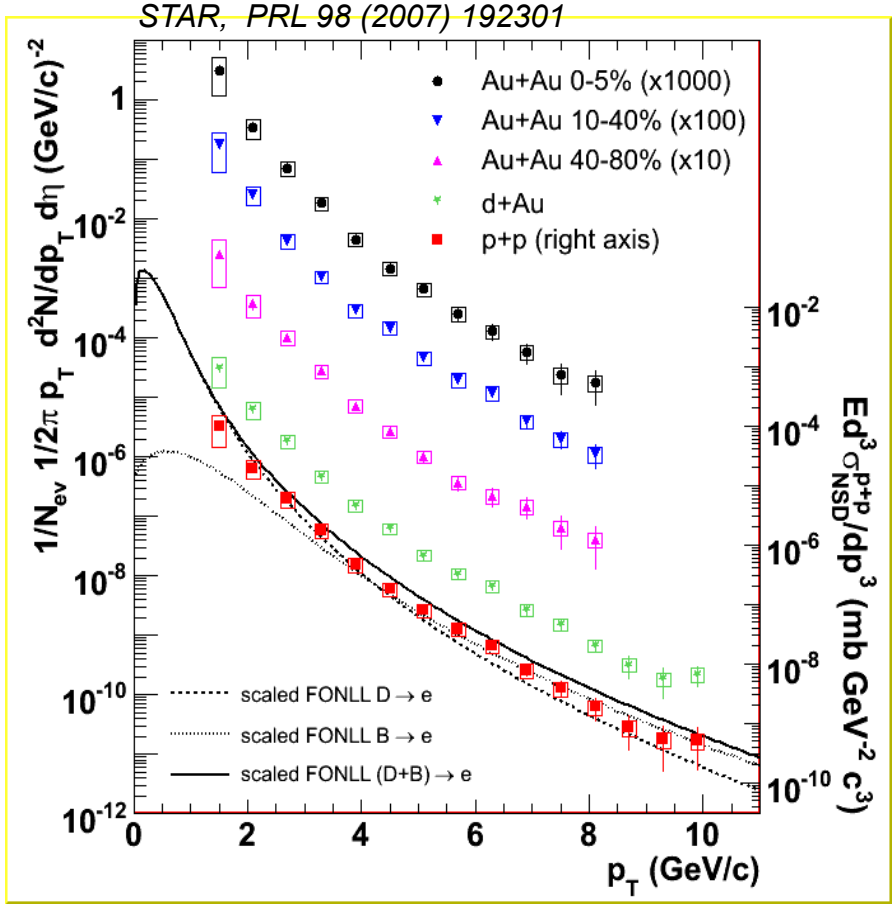
544 ± 39(stat) ± 142 (syst) ± 200 (model)

PLB 670 (2009) 313

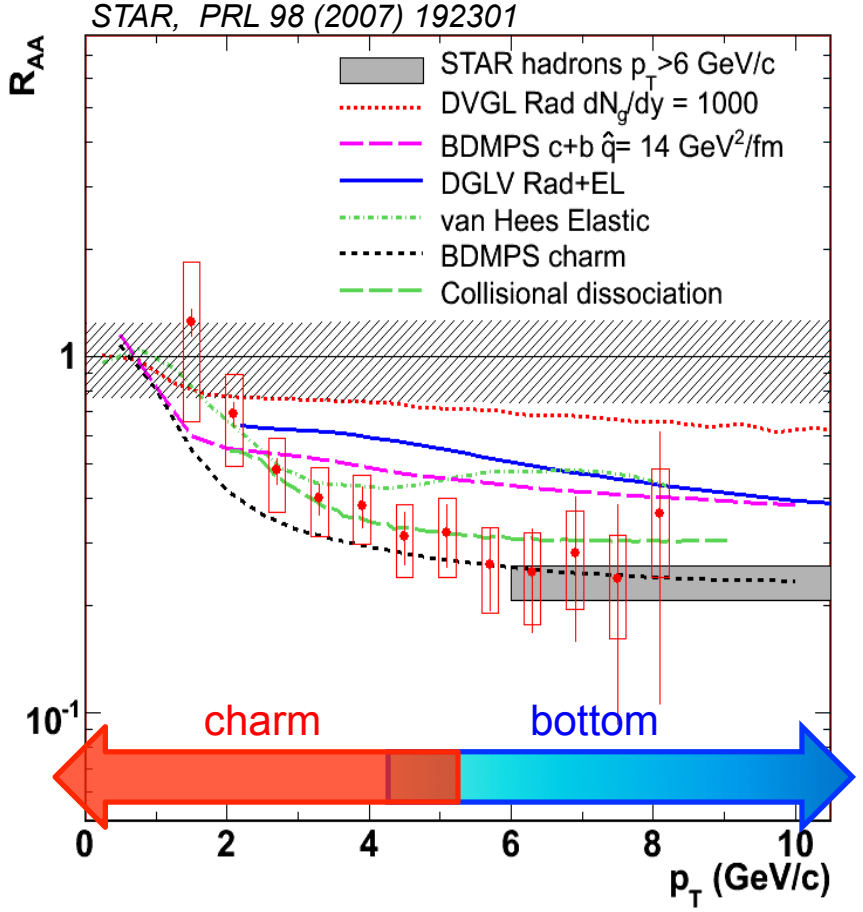
- Large discrepancy between extracted total cross-section from STAR and PHENIX
- Large theoretical uncertainties

Suppression of non-photonic electrons

STAR, PRL 98 (2007) 192301



STAR, PRL 98 (2007) 192301



- Large suppression of non-photonics electrons similar to hadrons
- No satisfactory theoretical description yet

$$R_{AA}(p_t) = \frac{1}{N_{coll}} \times \frac{dN_{AA}/dp_t}{dN_{pp}/dp_t}$$

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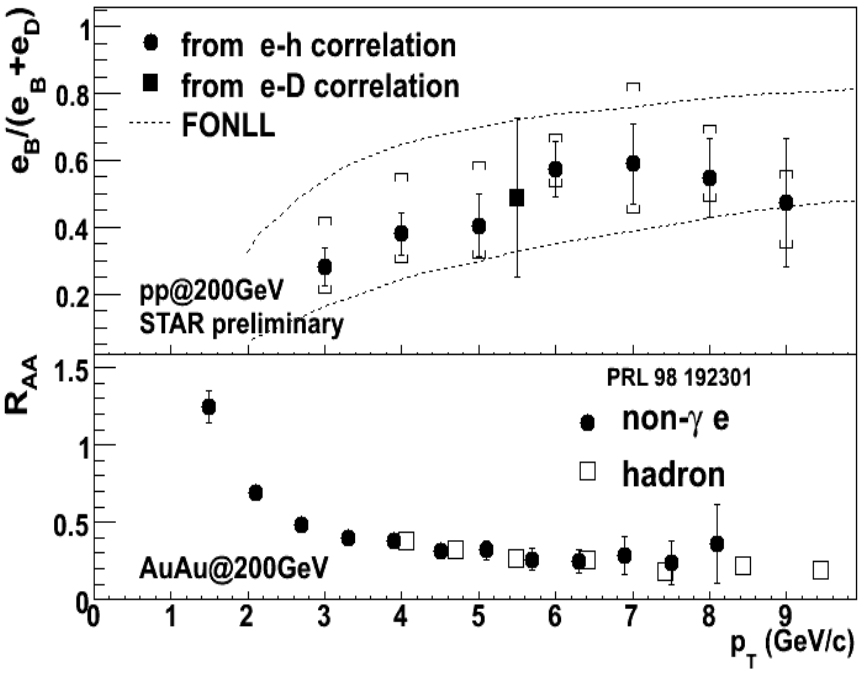
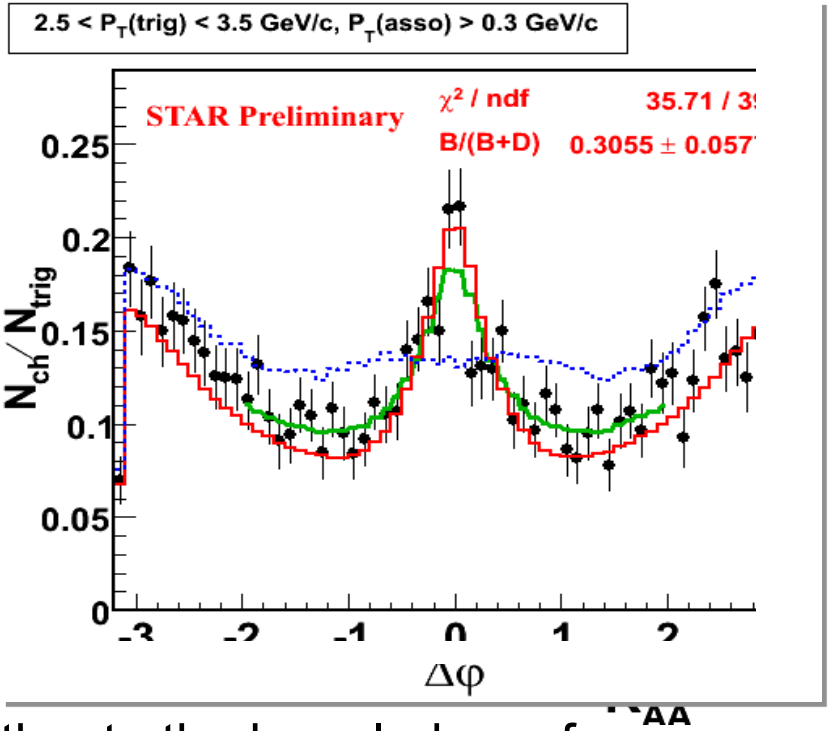
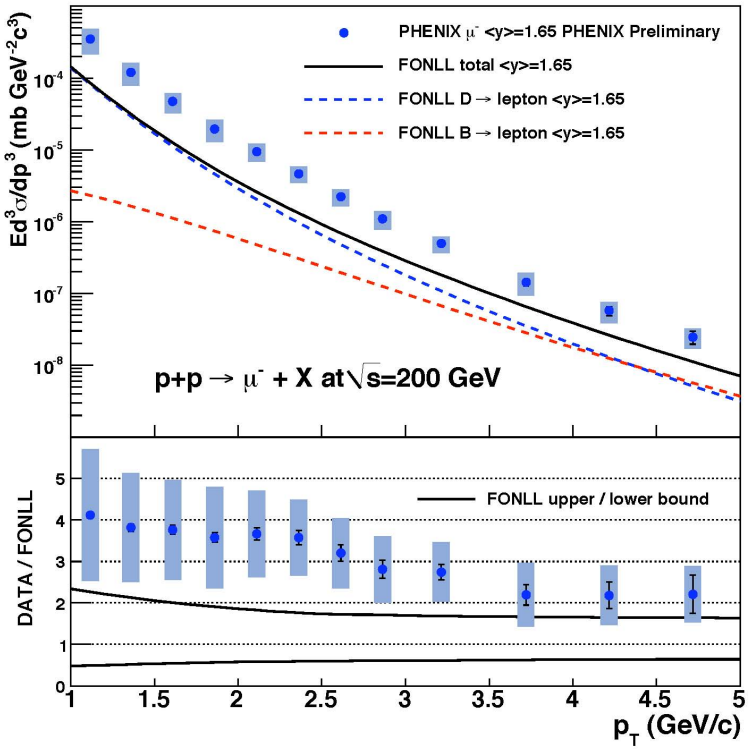
Bottom contribution to electron spectrum

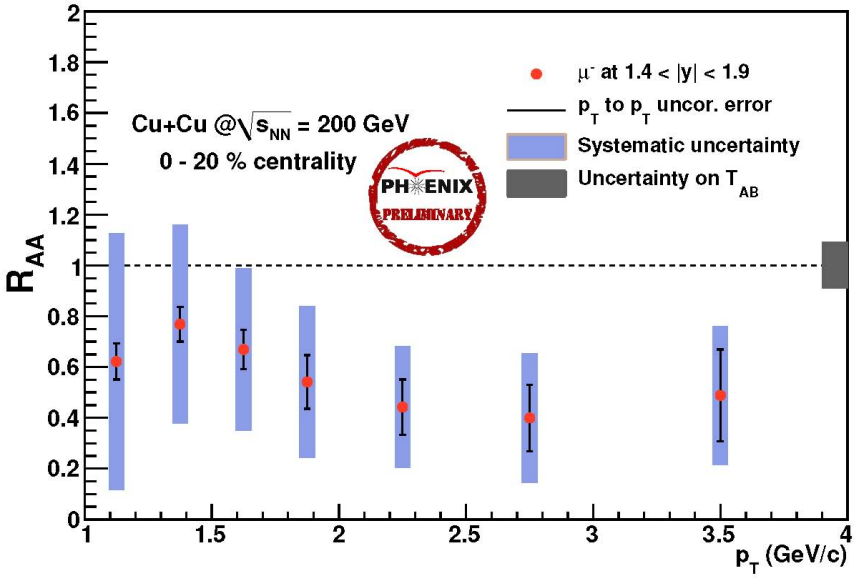




- Difficult to interpret suppression without the knowledge of charm/bottom
- **Data** show non-zero **B contribution** consistent with FONLL
- Charm and bottom contribution comparable at p_T of 5 GeV
- B meson is also suppressed

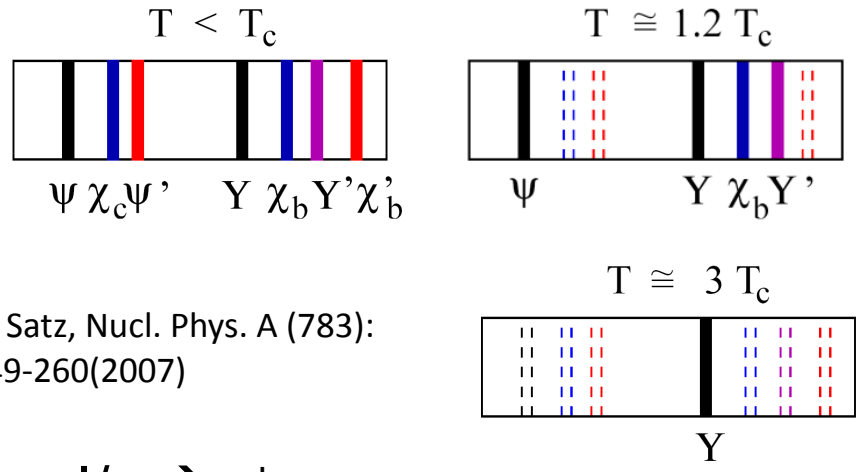
PHENIX forward muons



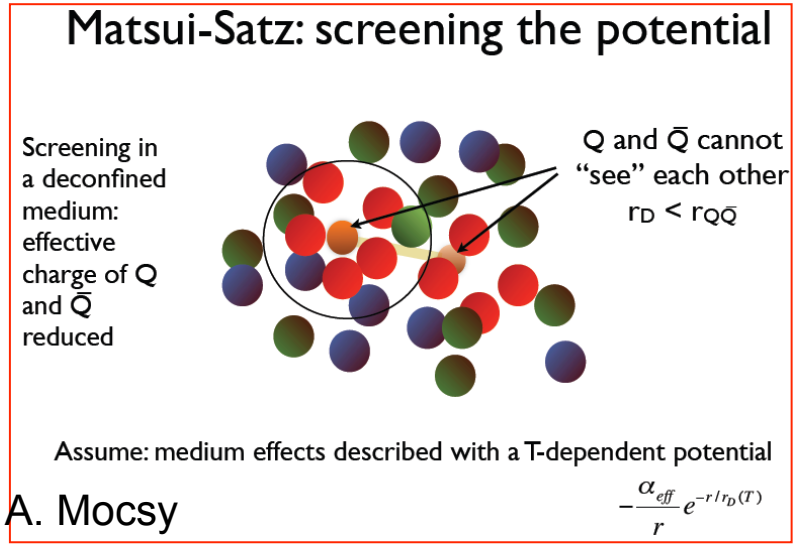


- Factor 4 larger yield than FONLL at low p_T
- Significant forward heavy flavor suppression
- Smaller than at midrapidity

Quarkonia



H. Satz, Nucl. Phys. A (783): 249-260(2007)

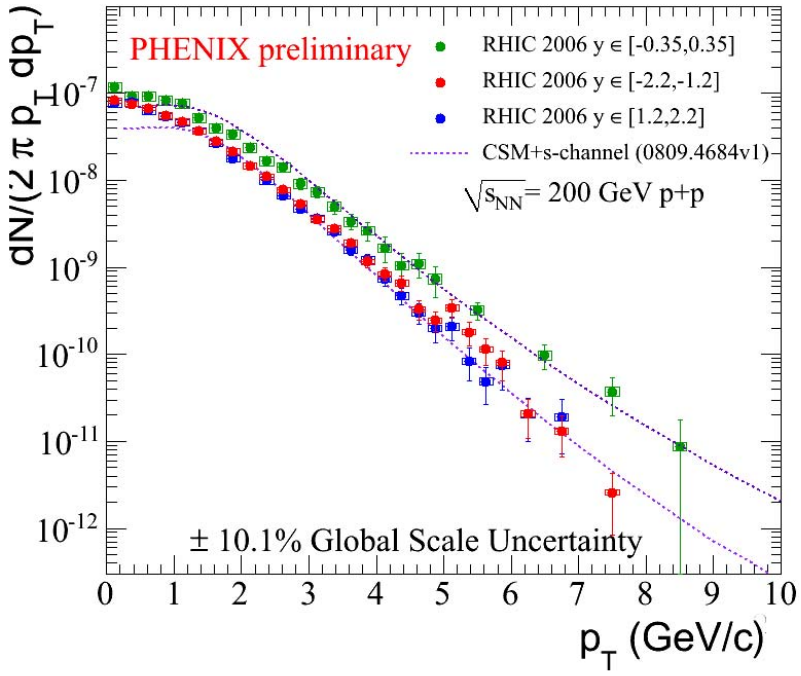


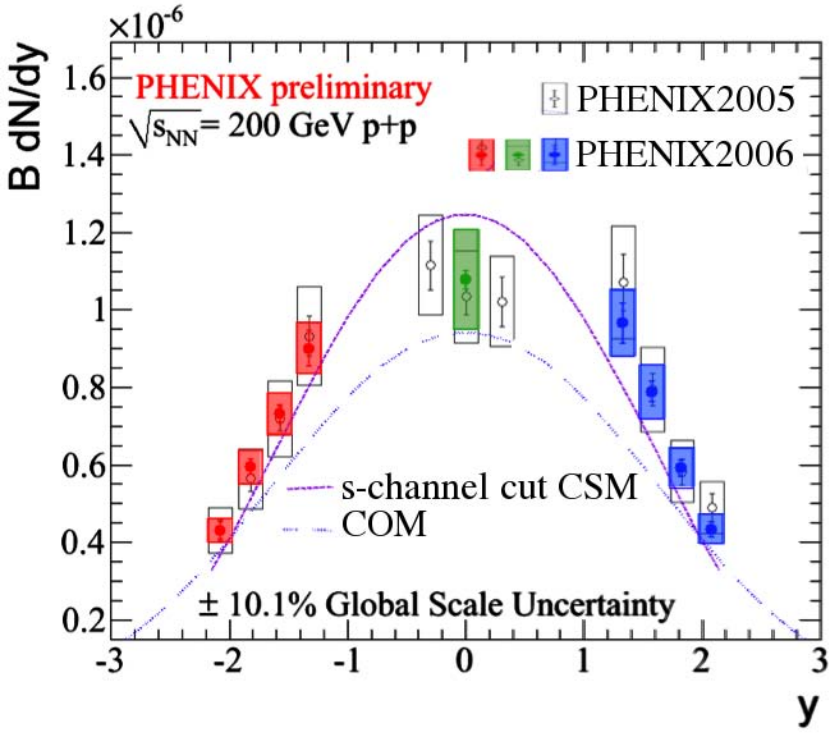
$J/\psi \rightarrow e^+e^-$

$\Upsilon \rightarrow e^+e^-$

- How they melt in hot/dense nuclear matter?
- What is production mechanism at RHIC?

PHENIX J/ψ in p+p 200 GeV

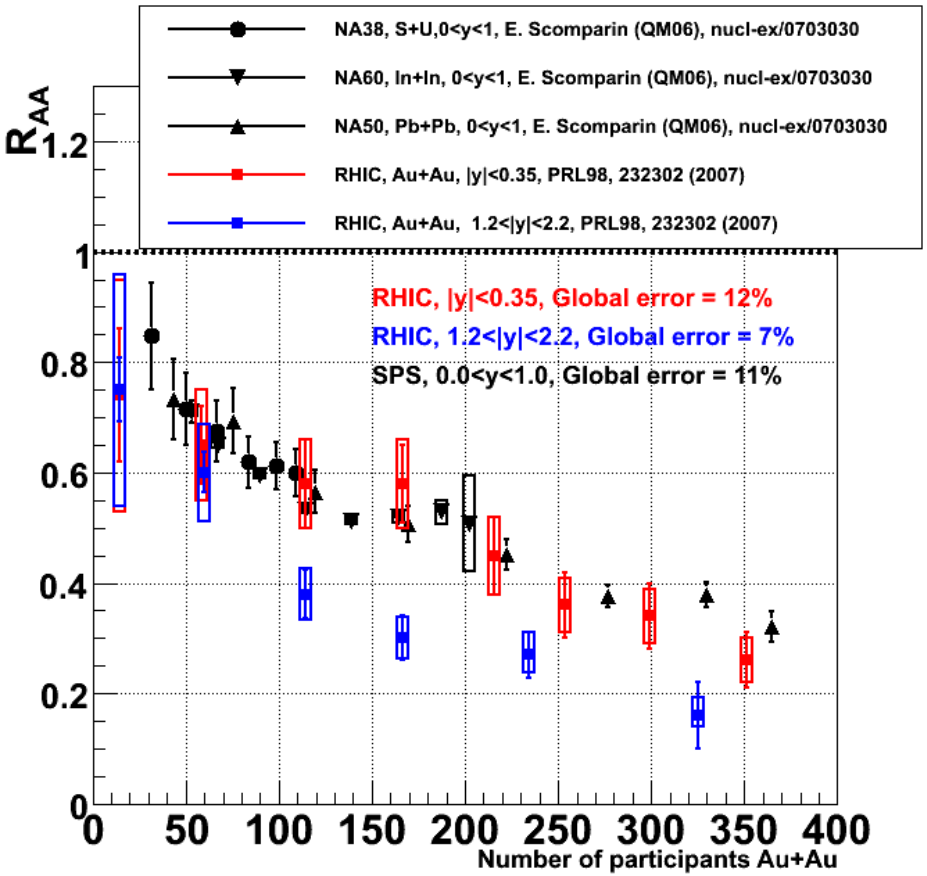




PHENIX QM09 arXiv:0907.4696

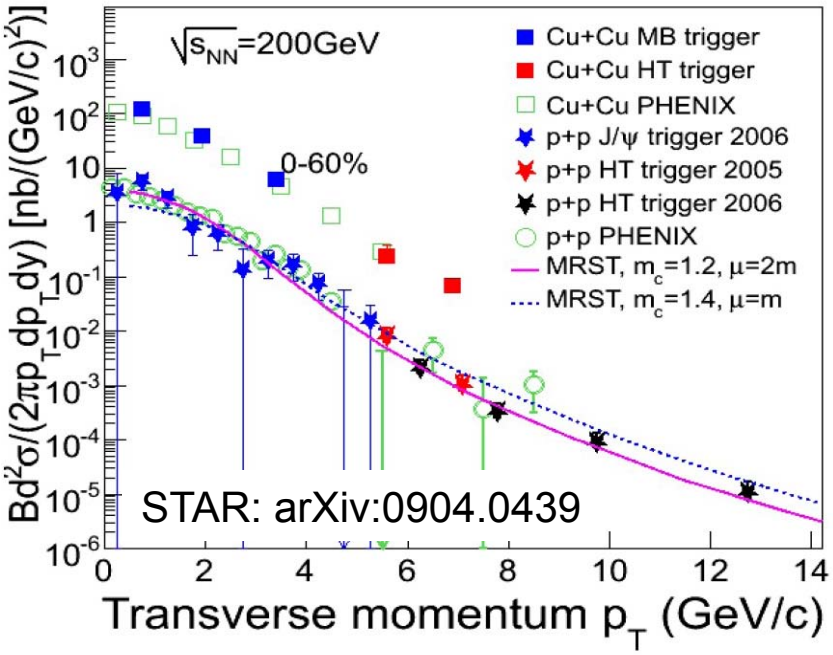
- both mid and forward results well described by the s-channel cut Color Singlet Model (CSM)

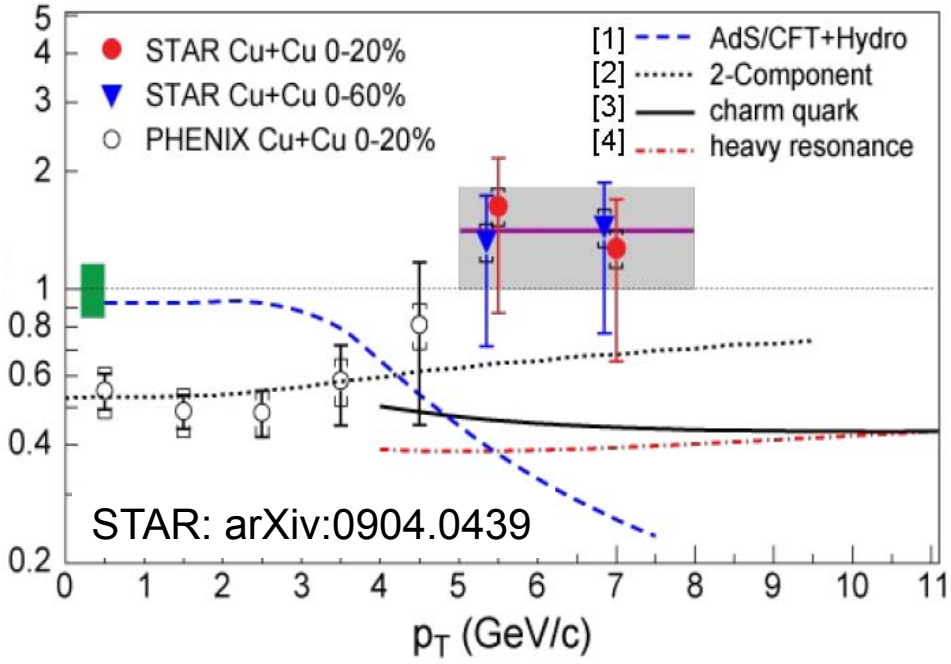
The "RHIC J/ψ puzzle"



- Suppression doesn't increase with local density
  - R_{AA} (|y|<0.35) > R_{AA} (1.2<|y|<2.2)
  - R_{AA} (RHIC, |y|<0.35) ≈ R_{AA} (SPS)
- Possible candidates
  - Suppression (gluon diss.)
  - Sequential melting
  - Regeneration
  - Gluon saturation
  - Some combination of all

J/ψ in p+p and Cu+Cu 200 GeV





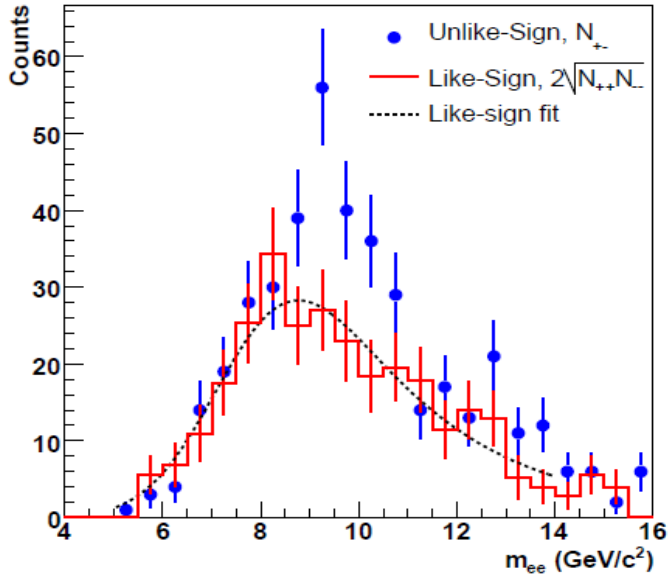
- **$R_{AA}(p_T>5$ GeV/c) = 1.4± 0.4±0.2**
- Consistent with no suppression at high p_T
- Expectation of J/ψ suppression at high p_T from strong open charm suppression from color octet model

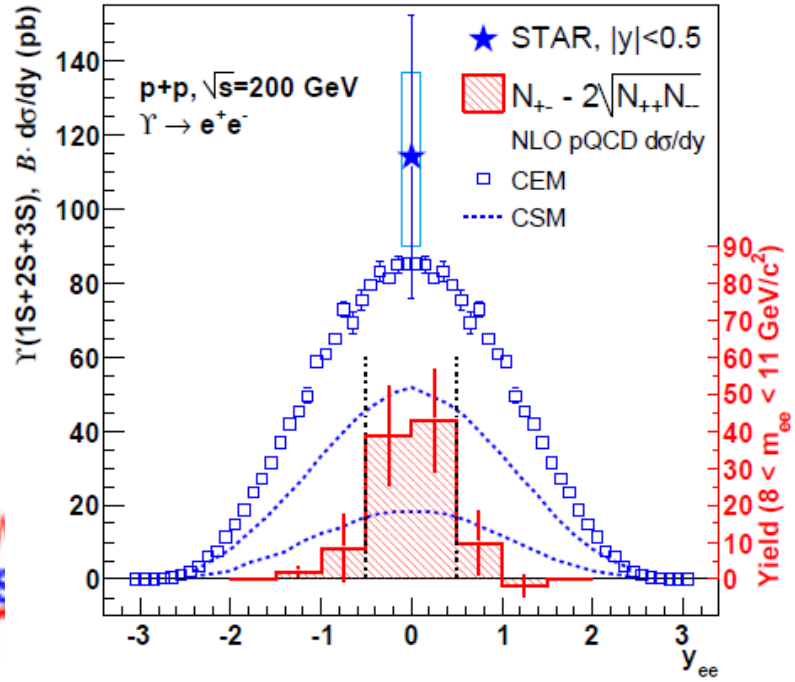
A. Adil and I. Vitev, Phys.Lett. B649, 139 (2007), private c. S. Wicks et al., Nucl. Phys. A784, 426 (2007), and W. A. Horowitz private communication.

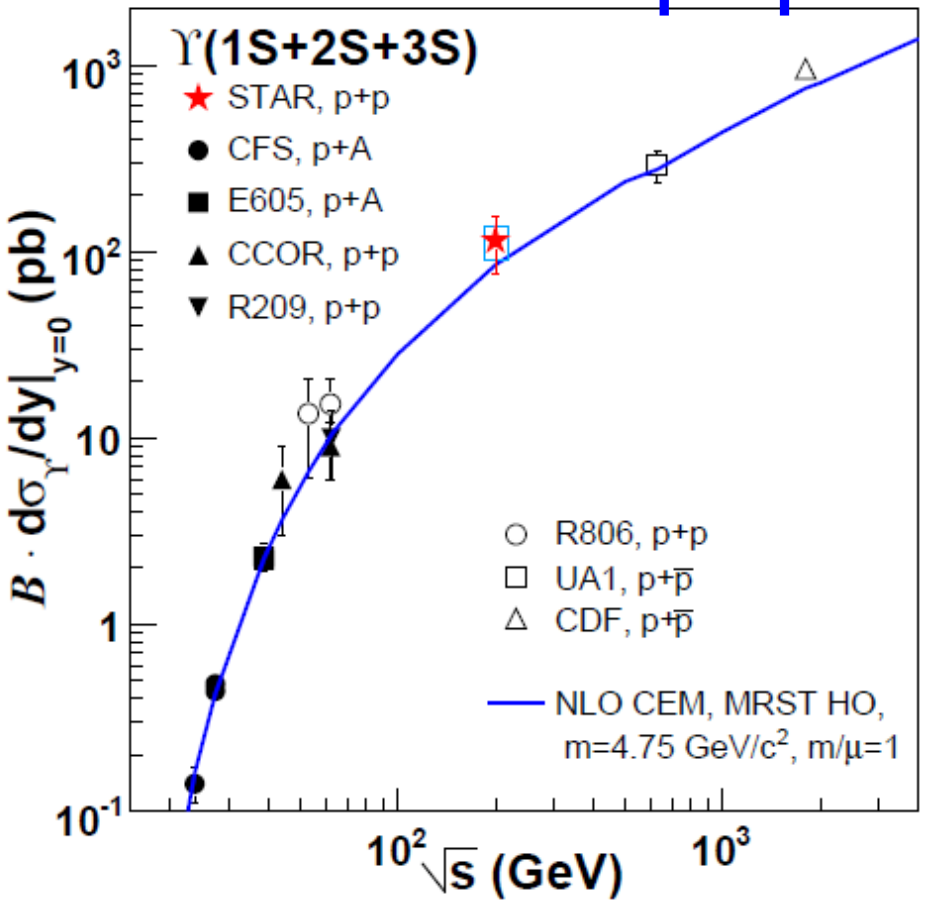
- Two component model+J/ψ form. time+ B feeddown describes the trend well

R. Rapp, X. Zhao, nucl-th/0806.1239

STAR Υ measurements in p+p



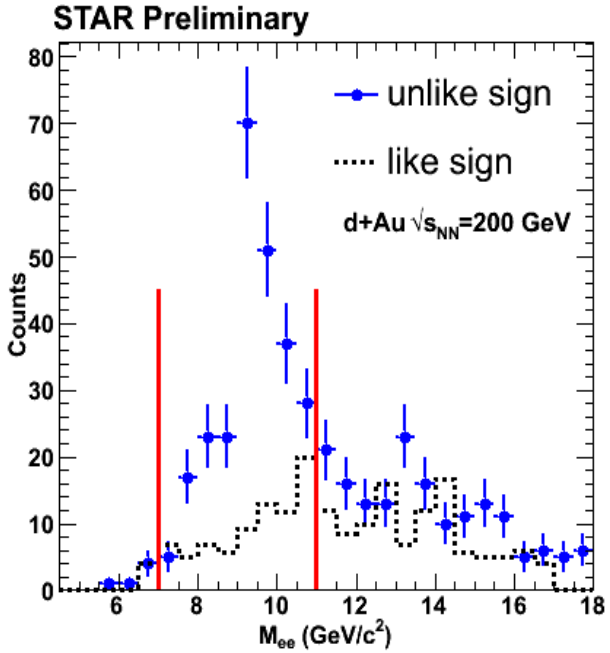


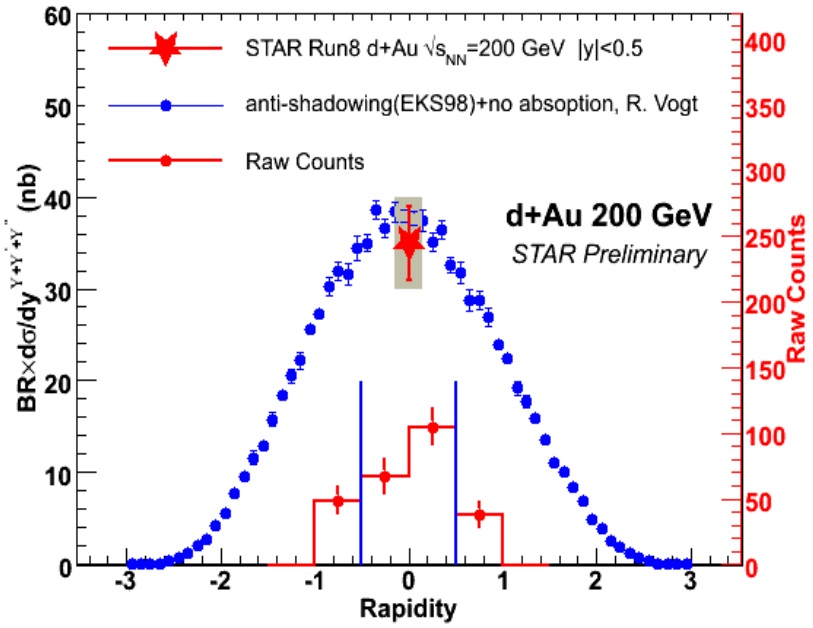


$$B_{ee}\left.\frac{d\sigma}{dy}\right|_{y=0} = 114 \pm 38(stat)^{+23}_{-24}(sys) \quad \text{pb}$$

STAR: arXiv:1001.2745

Υ signal in d+Au 200 GeV collisions





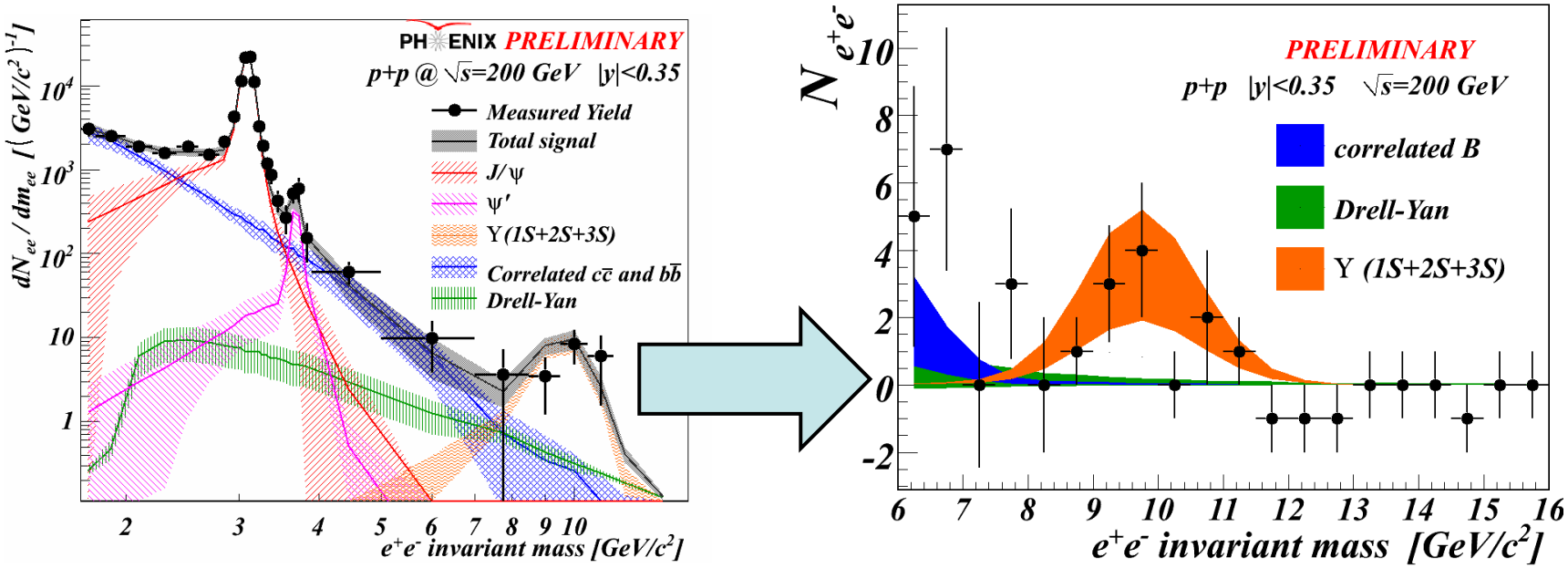
- Strong signal (8σ significance) extracted

$$B_{ee} \times \left(\frac{d\sigma}{dy}\right)_{y=0}^{\Upsilon+\Upsilon'+\Upsilon''} = 35 \pm 4(stat.) \pm 5(syst.)\, pb$$

$$R_{dAu} = 0.98 \pm 0.32\ (stat.) \pm 0.28\ (sys.)$$

- Consistent with N_{bin} scaling of cross-section p+p ⟶ d+Au 200GeV

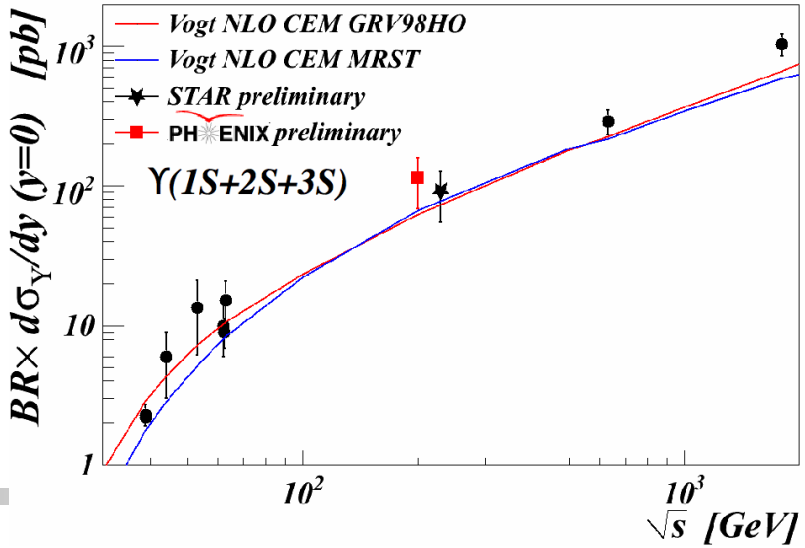
Quarkonia Production & Suppression – Upsilons in p+p



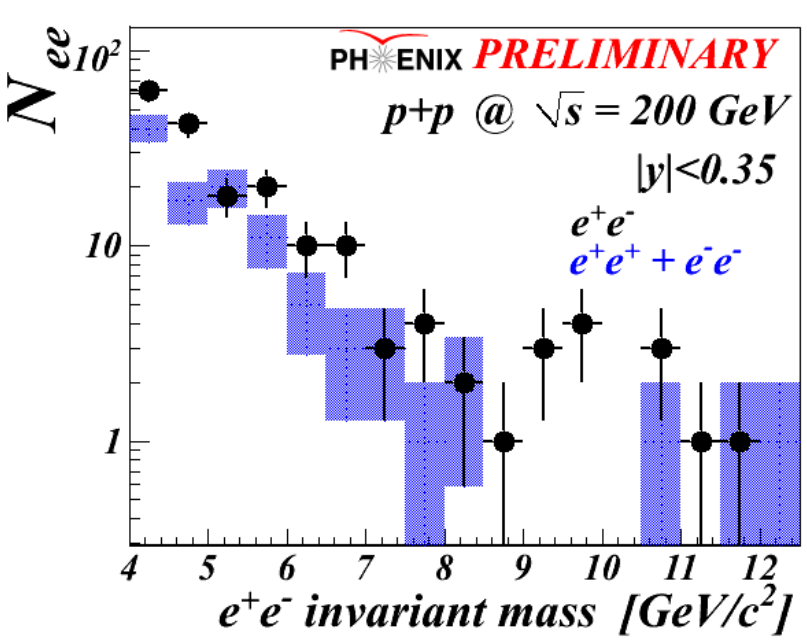
Nucl.Phys.A830:331C-334C,2009.

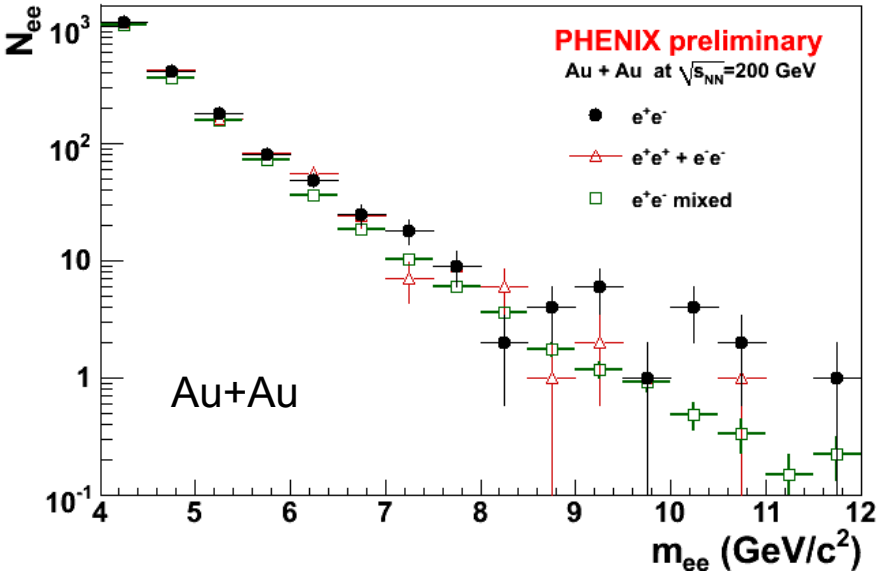
- Cross section follows world trend
- Baseline for Au+Au

$$BR * \frac{d\sigma}{dy}\Big|_{|y|<0.35} = 114^{+46}_{-45}\, pb$$

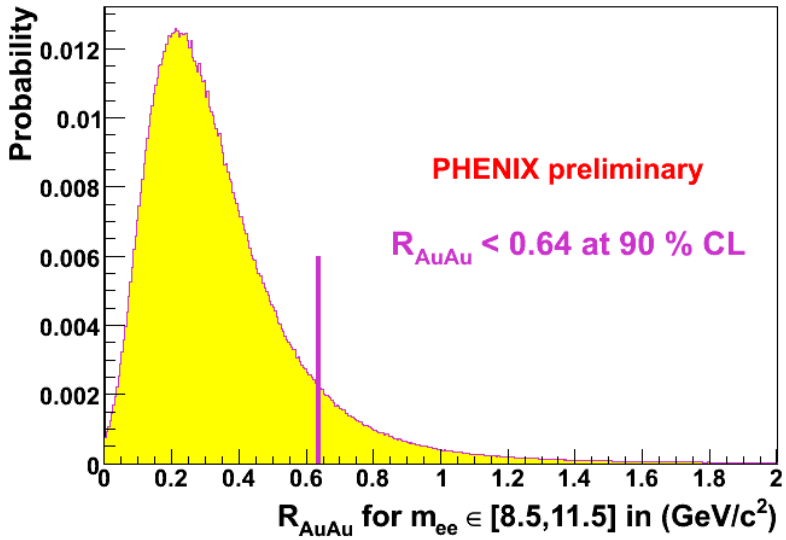


Upsilons Suppressed in Au+Au





R_{AuAu} [8.5,11.5] < 0.64 at 90% C.L.



Nucl.Phys.A830:331C-334C,2009.

Conclusions

- Heavy flavor is an important tool to understand medium properties
- **RHIC** results are interesting and challenging

charm measurement

- Three different channels: D^0 ,μ, electrons

non-photonic electrons

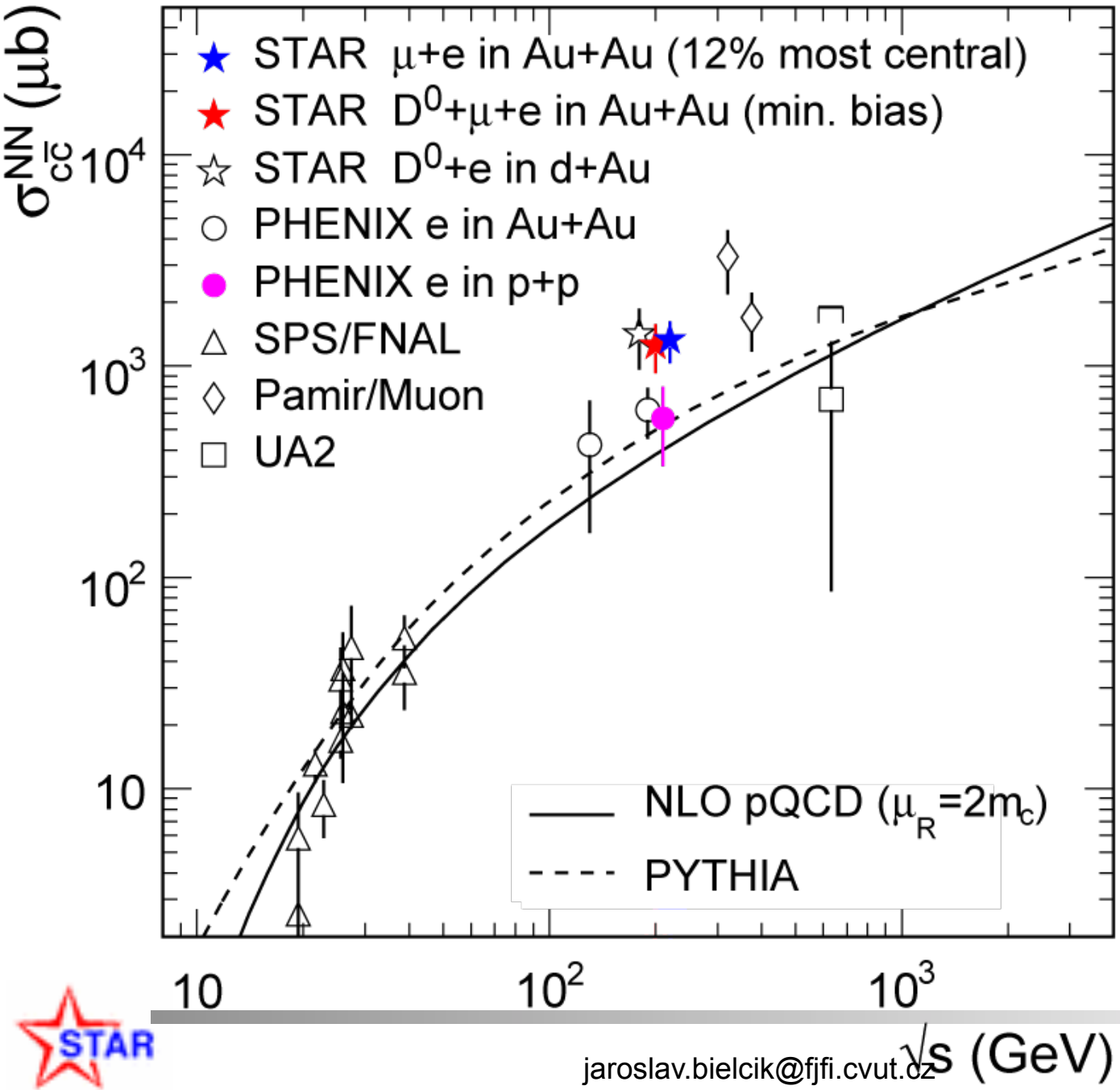
- Bottom relative contribution consistent with FONLL
- Strong high-p_T suppression in Au+Au
- Heavy quark energy loss not fully understood

J/Psi

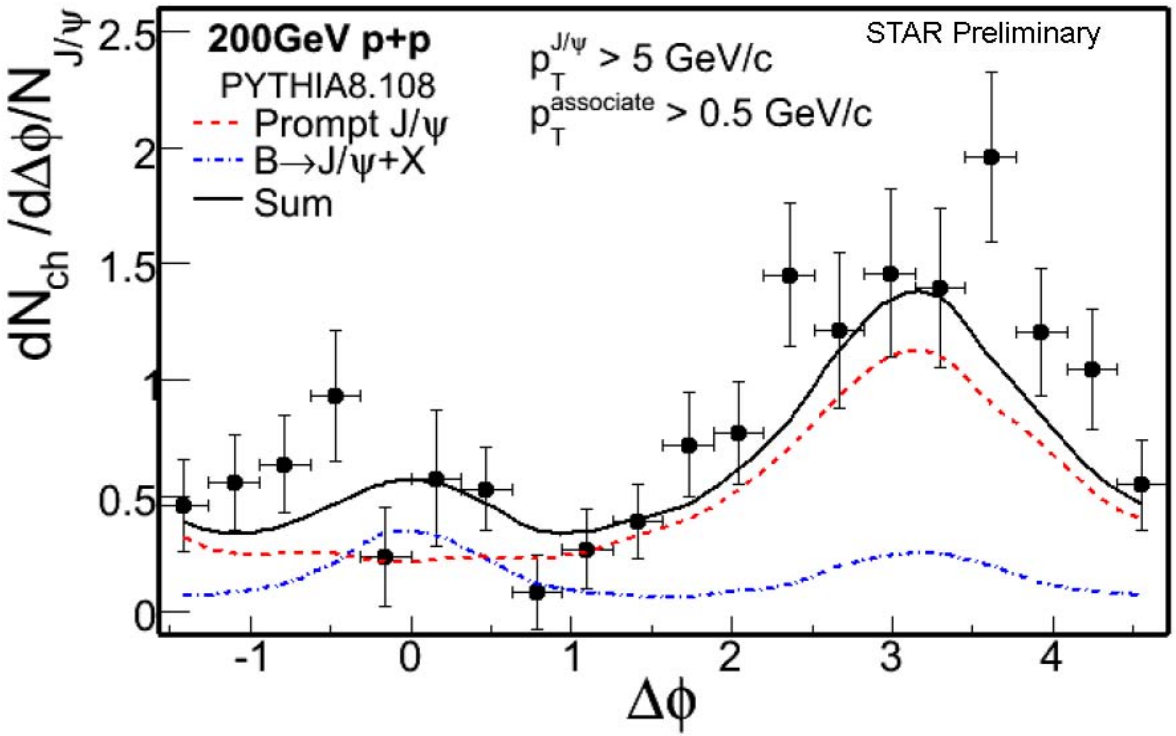
- Consistent with no suppression at high-p_T

Upsilon

- Cross section measurement in p+p and dAu
- Follows N_{bin} scaling

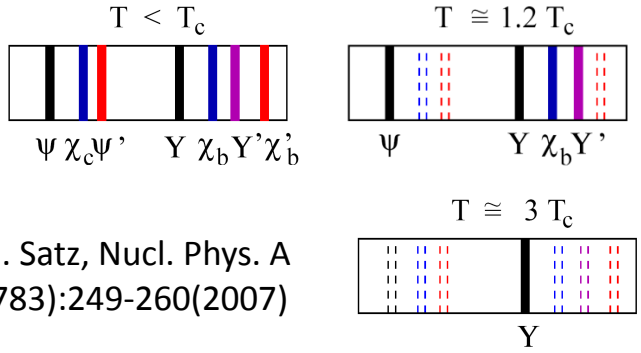

STAR μ+e in Au+Au (12% most central)
STAR D0+μ+e in Au+Au (min. bias)
STAR D0+e in d+Au
PHENIX e in Au+Au
PHENIX e in p+p
SPS/FNAL
Pamir/Muon
UA2
NLO pQCD (μR=2mc)
PYTHIA
σccNN (μb)
10
10^2
10^3
10^4
√s (GeV)

High-p_T J/ψ - hadron correlations



- Near-side correlation due dominantly to **B → J/ψ+X**
- B-meson feeddown to inclusive J/ψ production of **13%± 5%** at p_T > 5 GeV/c.

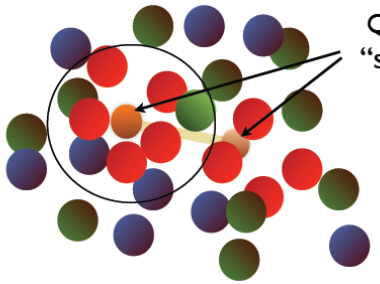
Color screening and sequential suppression of quarkonia



H. Satz, Nucl. Phys. A (783):249-260(2007)

Matsui-Satz: screening the potential

Screening in a deconfined medium: effective charge of Q and $\bar{Q}$ reduced



Q and $\bar{Q}$ cannot "see" each other $r_D < r_{Q\bar{Q}}$

Assume: medium effects described with a T-dependent potential

A. Mocsy

$$-\frac{\alpha_{eff}}{r}e^{-r/r_D(T)}$$

J/ψ suppression at low p_T maybe from excited stats (ψ', χ_c) F. Karsch, D. Kharzeev and H. Satz, PLB 637, 75 (2006); B. Alessandro et al. (NA50), Eur. Phys. J. C 39 (2005) 335; R. Arnaldi et al. (NA60), Quark Matter 2005; PHENIX: Phys.Rev.Lett.98, 232301,2007.

60% from direct J/ψ: not suppressed
30% χ_c and 10% ψ': dissociated