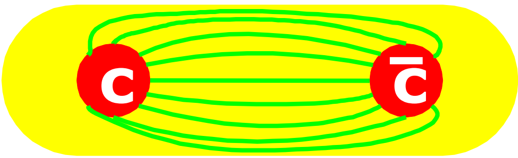
8th International Workshop on High p_T Physics at LHC
Oct. 21-24 , Wuhan, China

Quarkonium Production from STAR at RHIC

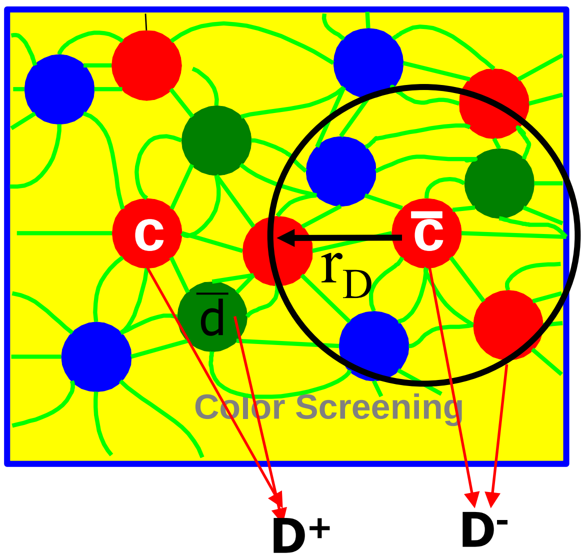
Zebo Tang (for the STAR Collaboration)
University of Science and Technology of China (USTC)

Quarkonium melting in QGP



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

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




Physics Letters B

Volume 178, Issue 4, 9 October 1986, Pages 416–422

J/ψ suppression by quark-gluon plasma formation

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http://dx.doi.org/10.1016/0370-2693(86)91404-8, How to Cite or Link Using DOI Cited by in Scopus (1123)

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If high energy heavy ion collisions lead to the formation of a hot quark-gluon plasma, then colour screening prevents cc binding in the deconfined interior of the interaction region. To study this effect, the temperature dependence of the screening radius, as obtained from lattice QCD, is compared with the J/ψ radius calculated in charmonium models. The feasibility to detect this effect clearly in the dilepton mass spectrum is examined. It is concluded that J/ψ suppression in nuclear collisions should provide an unambiguous signature of quark-gluon plasma formation.

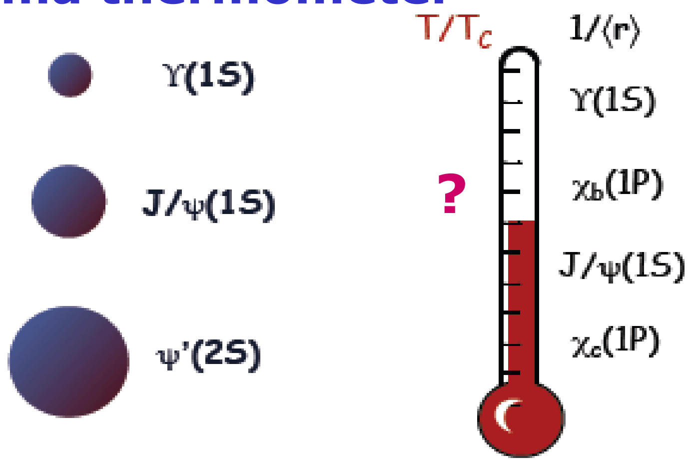
QGP Thermometer

$\lambda_D \propto 1/T$ Quarkonium dissociation temperatures – H. Satz, JPG (2006)

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
T_d/T_c	2.10	1.16	1.12	>4.0	1.76	1.60	1.19	1.17
r_0 (fm)	0.50	0.72	0.90	0.28	0.44	0.56	0.68	0.78

Model dependent

Plasma thermometer

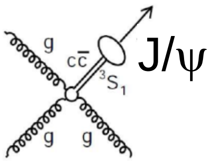


Dissociation temperature depends on binding energy → QGP temperature

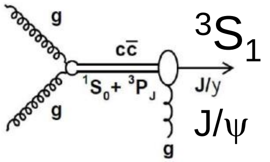
Complications

Reference (production in p+p) is not well understood:

- Production mechanism: Color-singlet vs. Color-octet?
- Feeddown: direct (~60%), ψ’ (~10%), χ_c (~30%) and from B mesons (small for integrated, but strong p_T dependent)



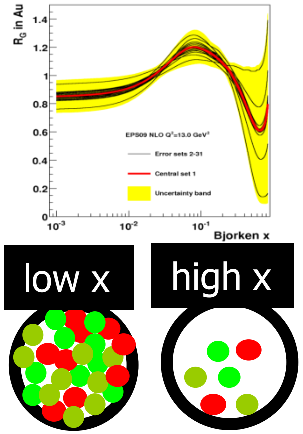
LO CSM

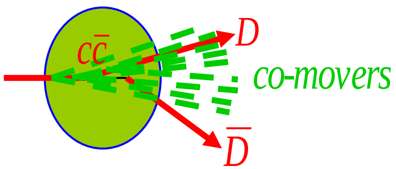


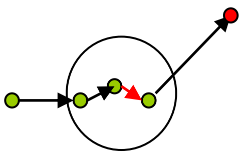
LO COM

Cold Nuclear Matter (CNM) effects:

- Nuclear absorption
- PDF modification in nucleus
- Cronin effect
- Gluon saturation
- …



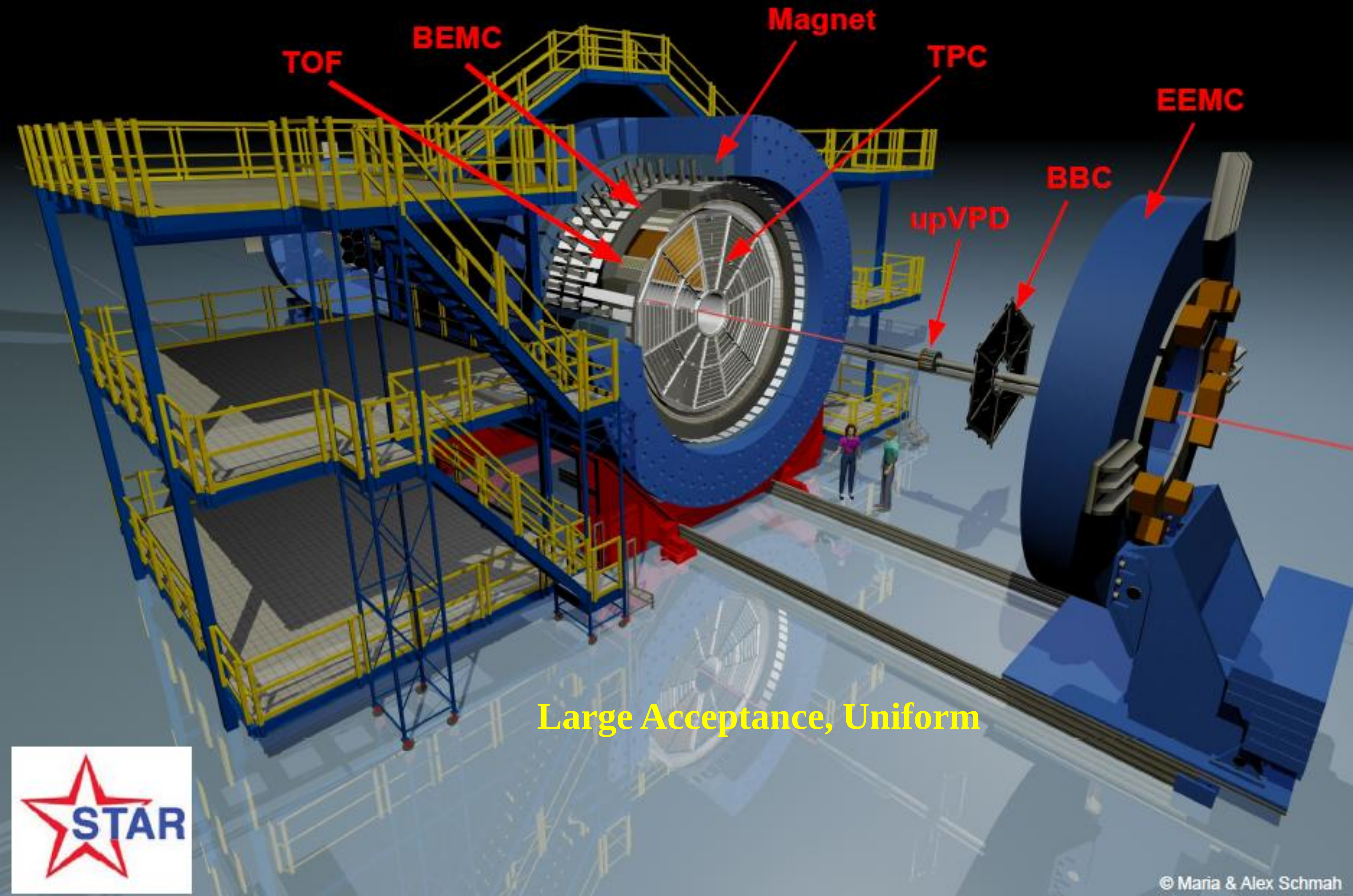




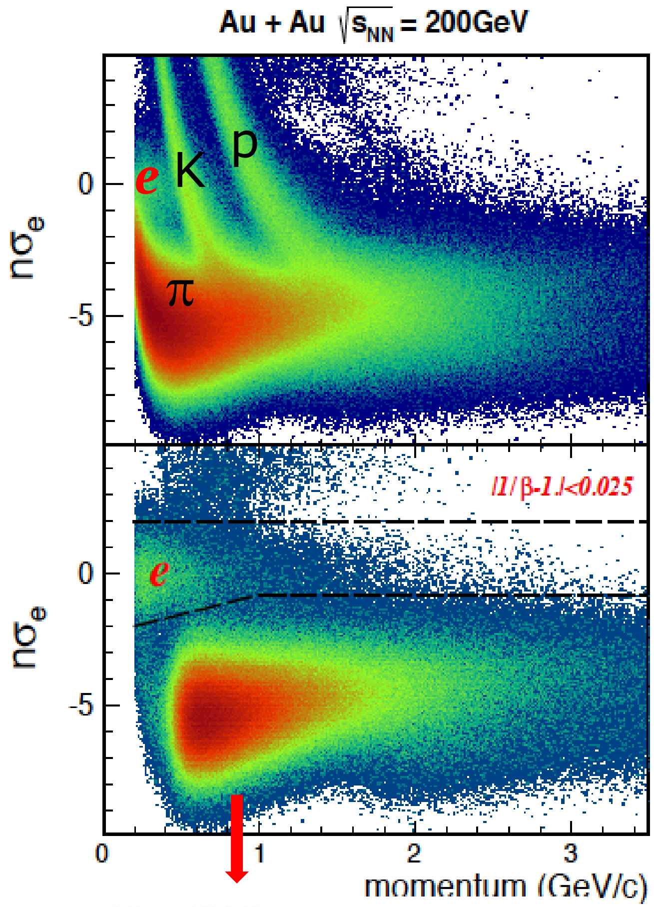
Hot Nuclear Matter effects:

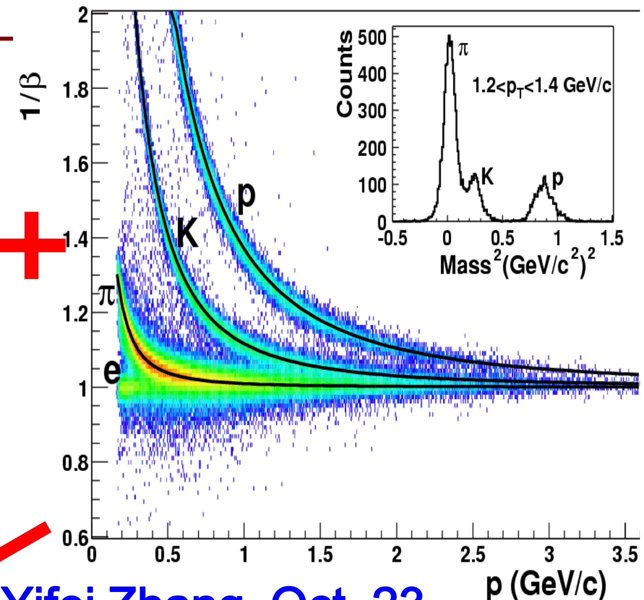
- Color screening — **J/ψ yield↘**
- Recombination of uncorrelated c and cbar — **J/ψ yield ↗**
- …

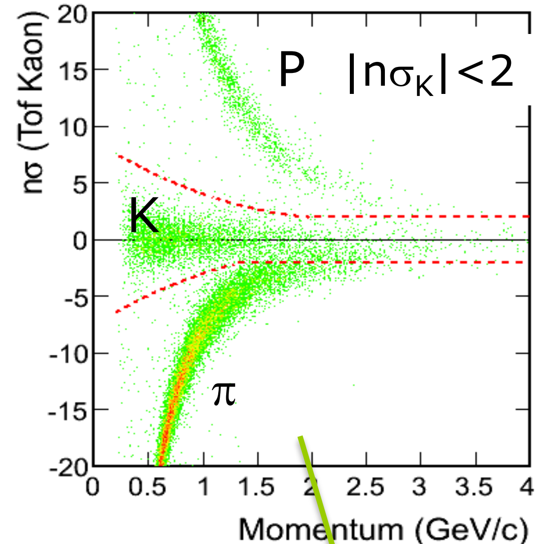
The Solenoid Tracker At RHIC (STAR)



Particle Identification

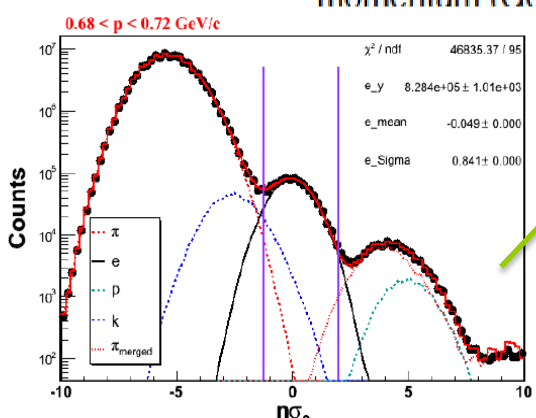




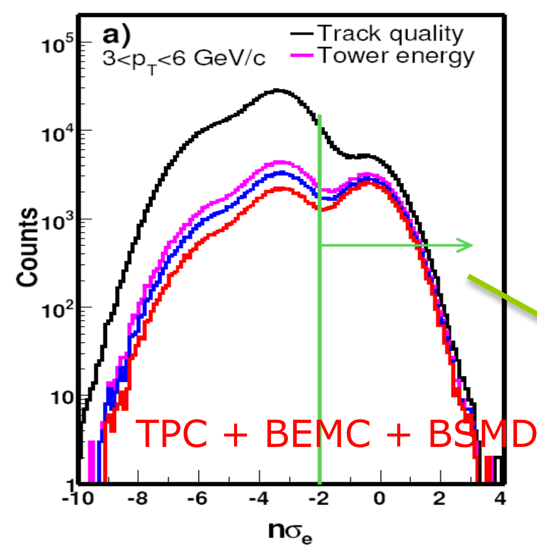


Yifei Zhang, Oct. 23

D meson hadronic daughter ID.

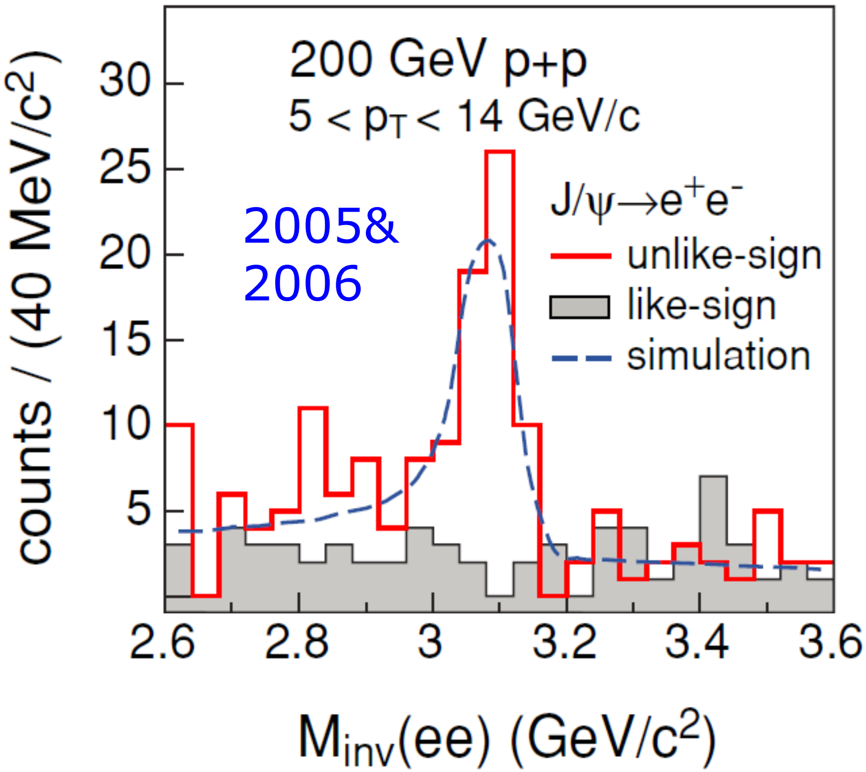


Low p_T e

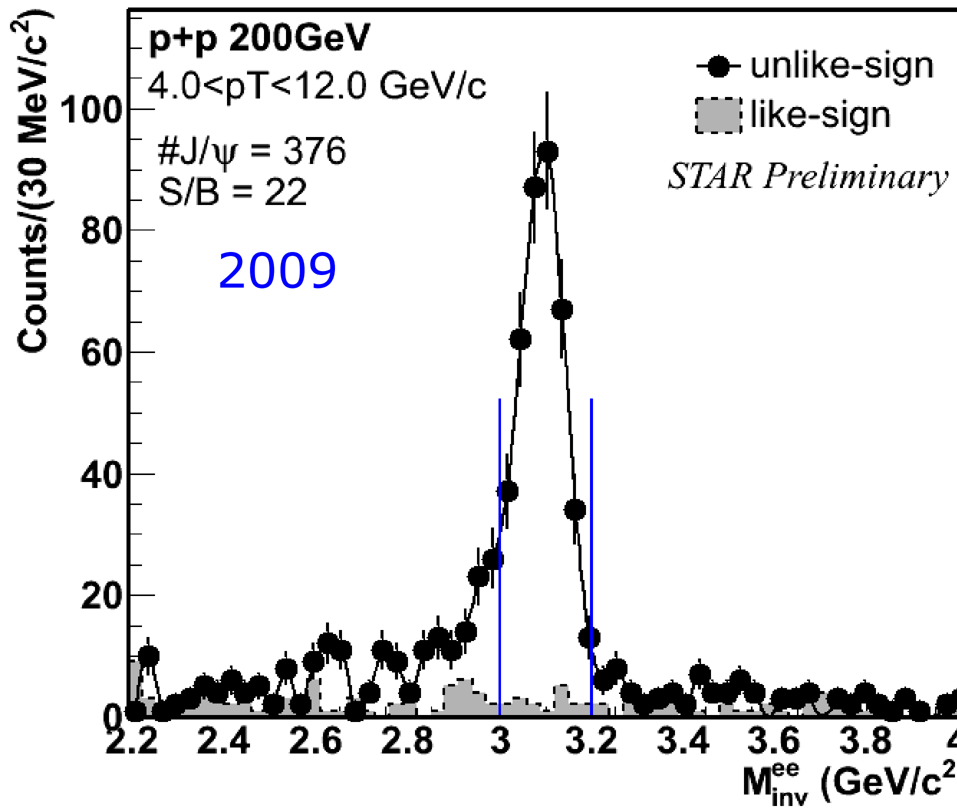


High p_T e

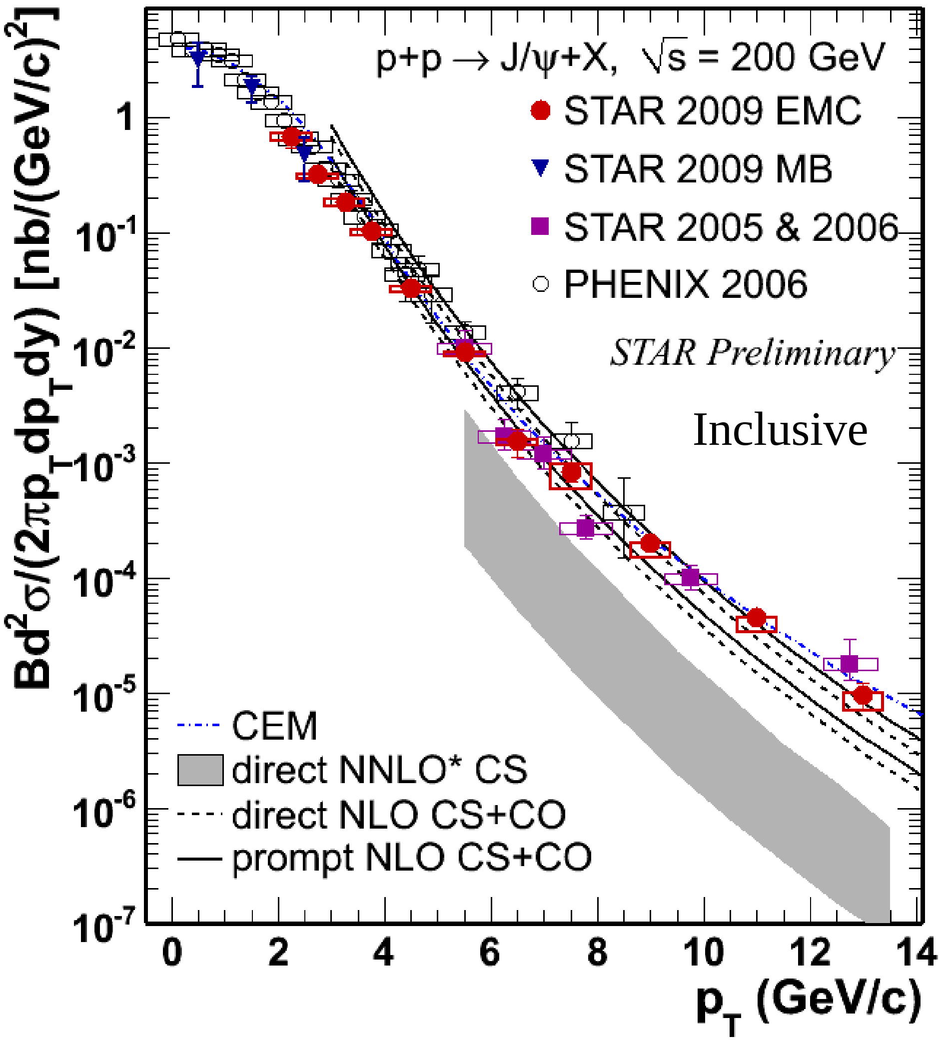
High-p_T J/ψ signals in p+p collisions



STAR, PRC80, 041902(R), 2009



J/ψ p_T spectra in p+p collisions



Consistent between datasets/experiments

Color singlet model: direct NNLO still misses the high-p_T part

P. Artoisenet et al., Phys. Rev. Lett. 101, 152001 (2008), and J.P. Lansberg private communication.

NLO CS+CO describes the data

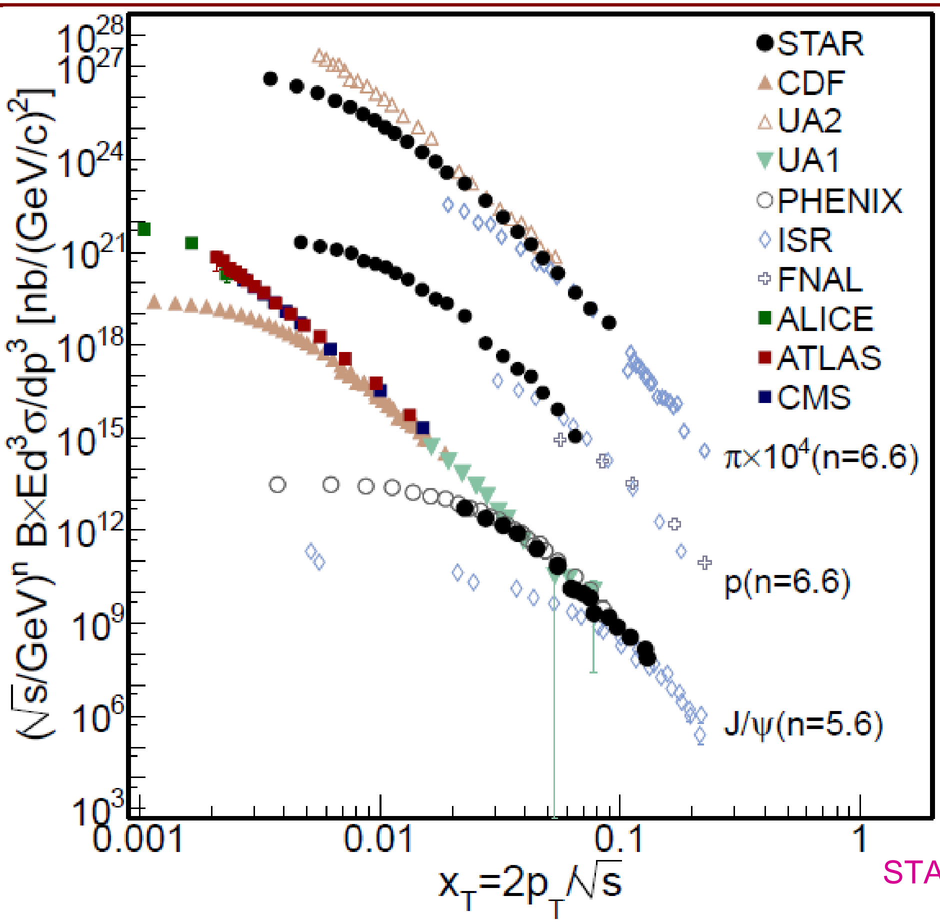
Y.-Q. Ma, K. Wang, and K.-T. Chao, Phys. Rev. D84, 51 114001 (2011), and private communication

CEM can also reasonably explain the spectra down to ~1 GeV/c

M. Bedjidian et al., hep-ph/0311048, and R. Vogt private communication

PHENIX: Phys. Rev. D 82, 012001 (2010)
STAR: Phys. Rev. C80, 041902(R) (2009), arXiv: 1208.2736

x_T scaling

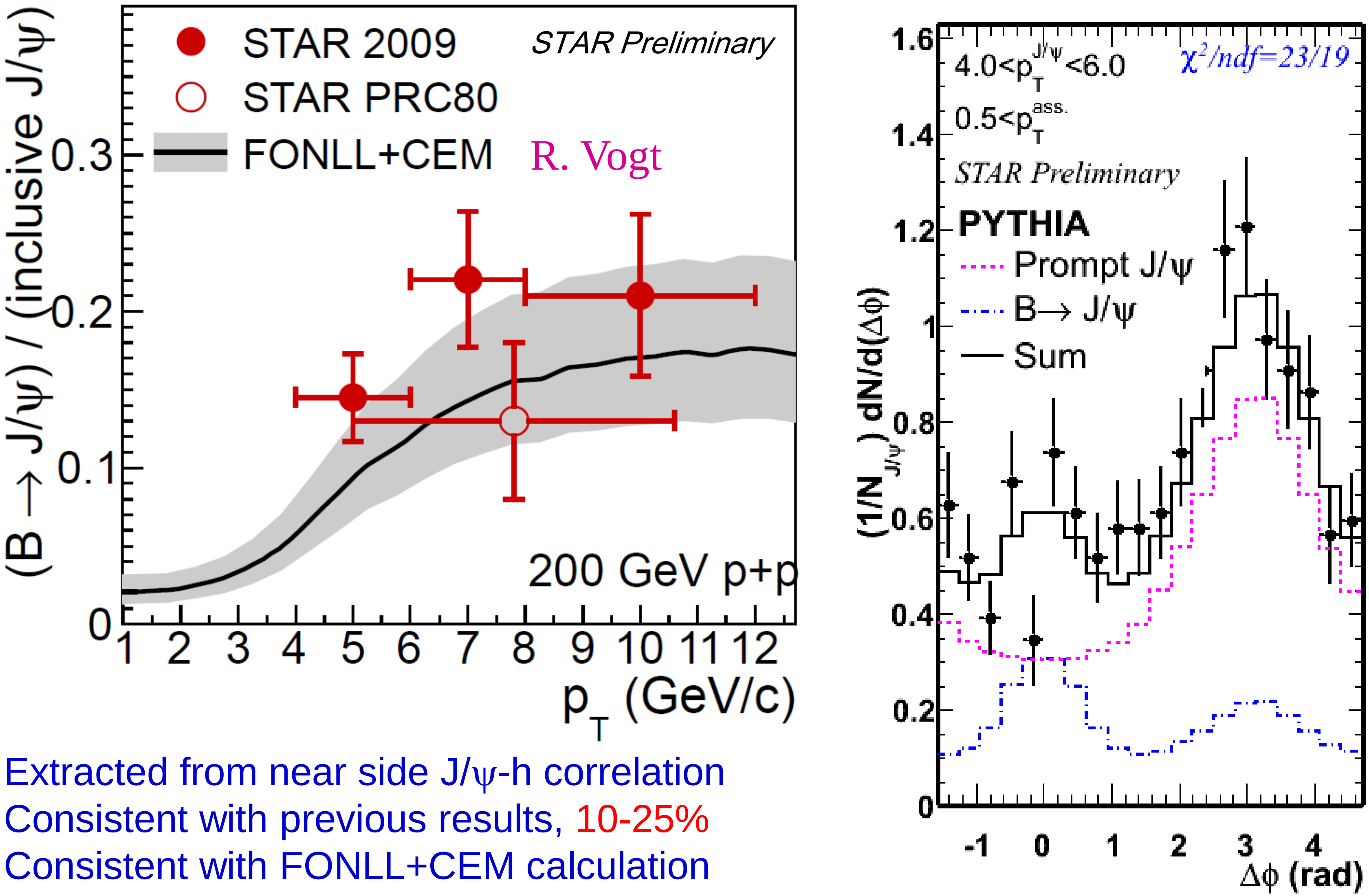


STAR, PRC80,041902 (2009)
arXiv: 1208.2736 (2012)

J/ψ follows x_T scalling at p_T>3 GeV/c

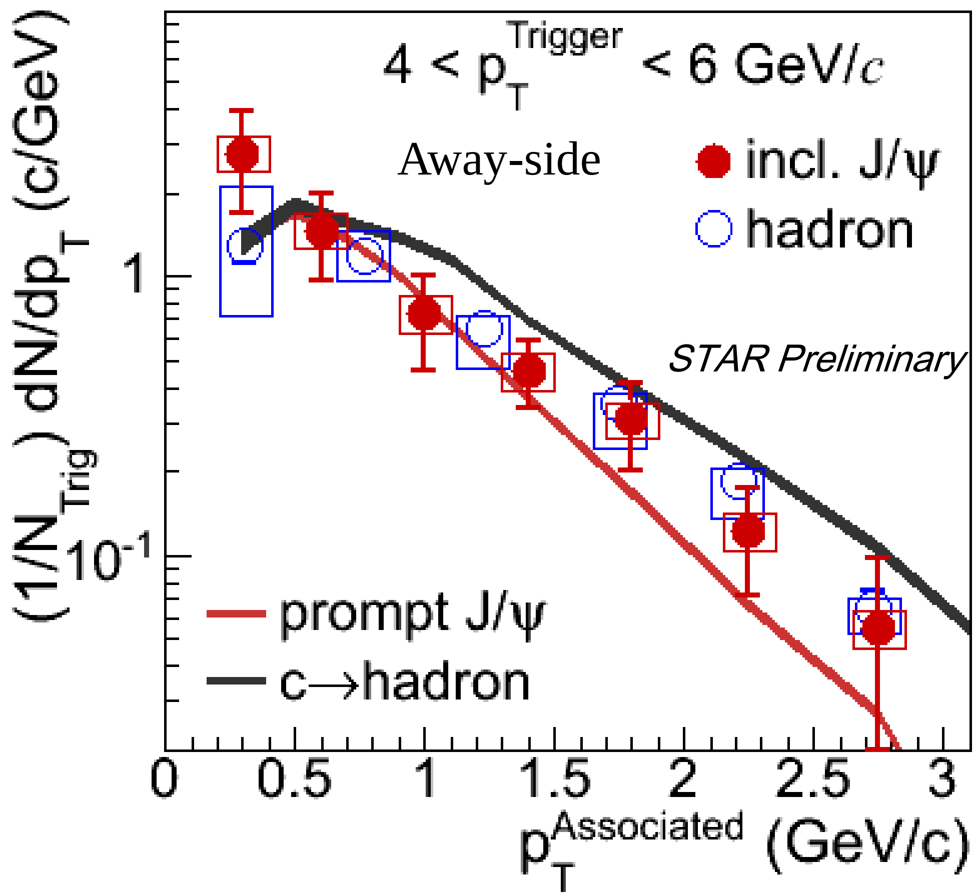
Soft processes affect low p_T J/ψ production

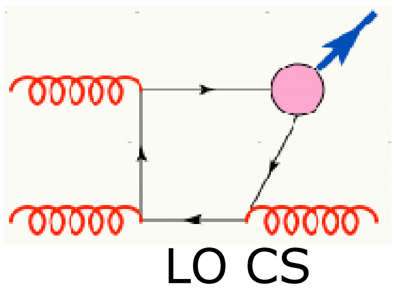
J/ψ–hadron correlation in p+p collisions



- Extracted from near side J/ψ-h correlation
- Consistent with previous results, 10-25%
- Consistent with FONLL+CEM calculation

J/ψ–hadron correlation in p+p collisions





Zhangbu Xu, BNL summer program, Quarkonium production in elementary and heavy ion collisions, BNL, June 4-18, 2011

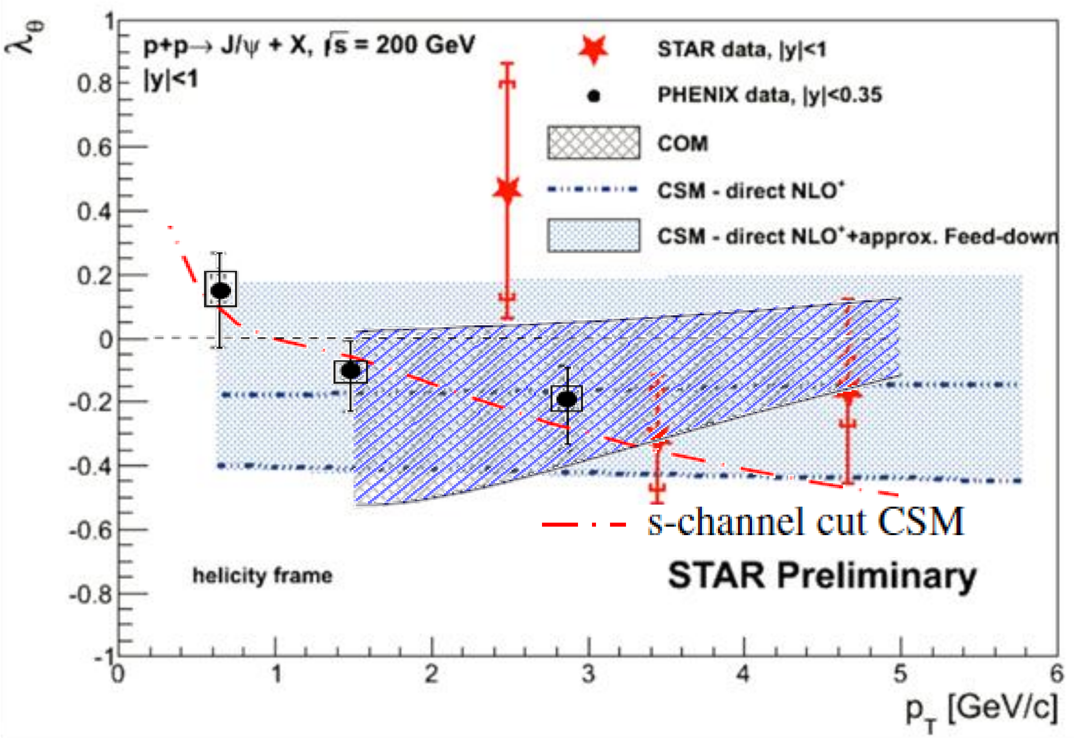
Gluon jet tag?

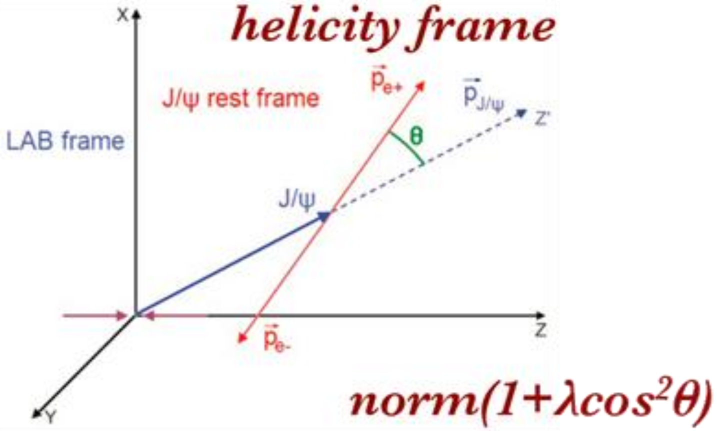
Consistent with hadron-hadron correlation

➔away-side seems to come from gluon/light quark fragmentation

J/ψ polarization in p+p collisions

Discrimination power between different J/ψ production models at high-p_T

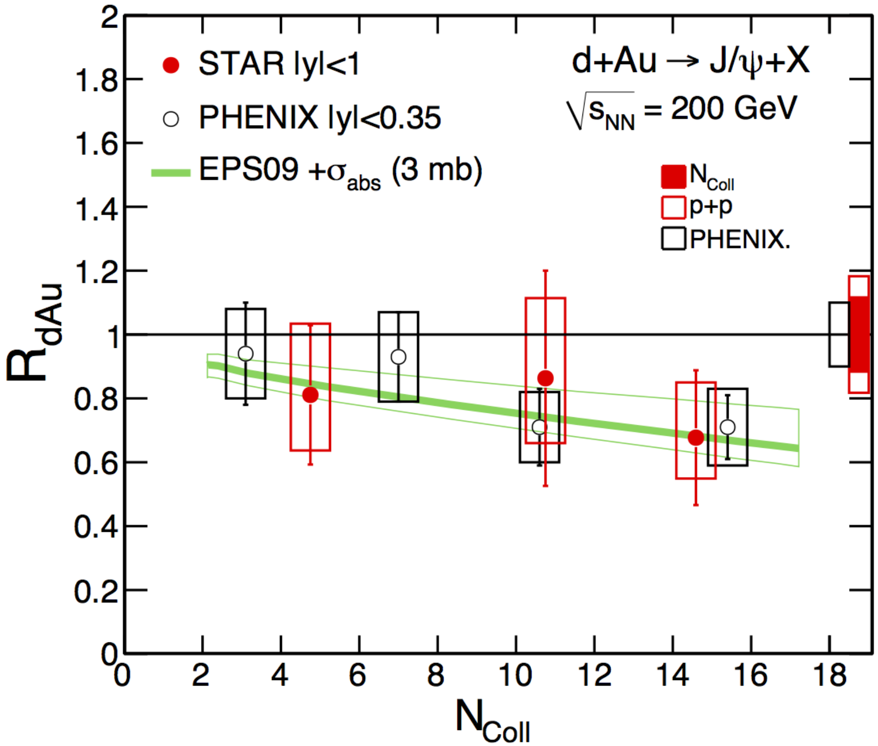


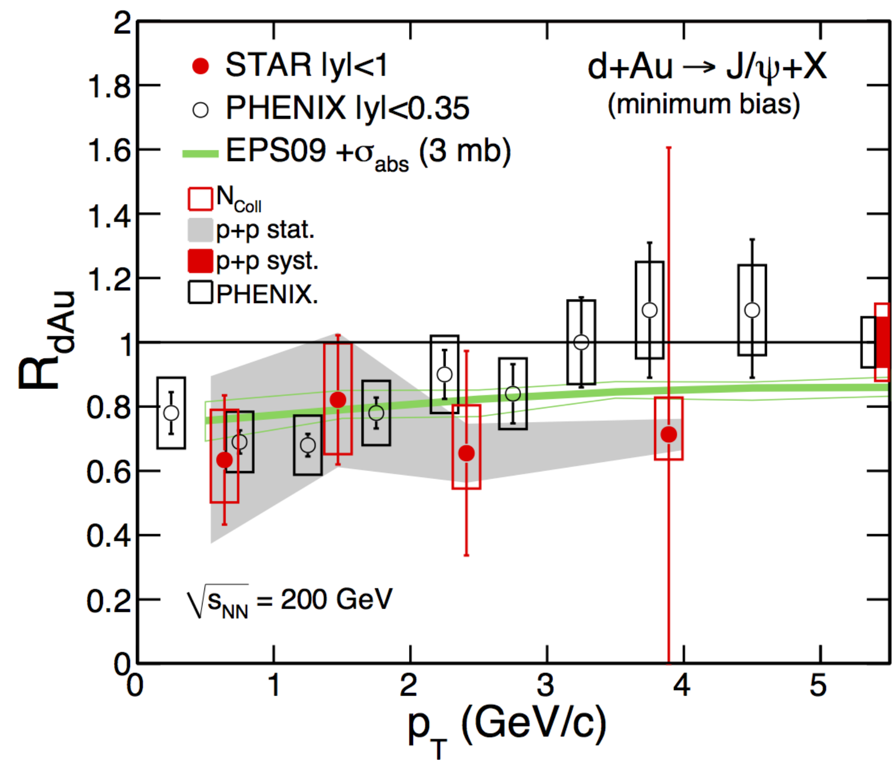


- ✓ Polarization parameter λ_θ is measured in helicity frame at $|y| < 1$ and $2 < p_T < 6$ GeV/c
- ✓ No significant polarization

PHENIX: Phys. Rev. D 82, 012001 (2010)
COM: Phys. Rev. D 81, 014020 (2010)
CSM NLO⁺: Phys. Lett. B, 695, 149 (2011)
CSM s-cut, Phys. Rev. Lett. 100, 032006 (2008).

J/ψ in d+Au collisions





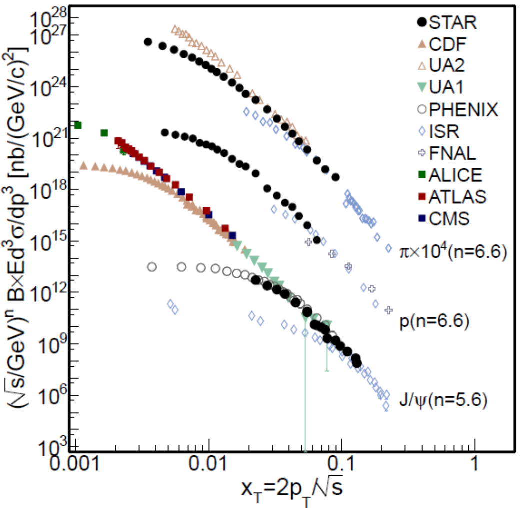
Measurement of J/ψ in d+Au collisions provides information on CNM effects

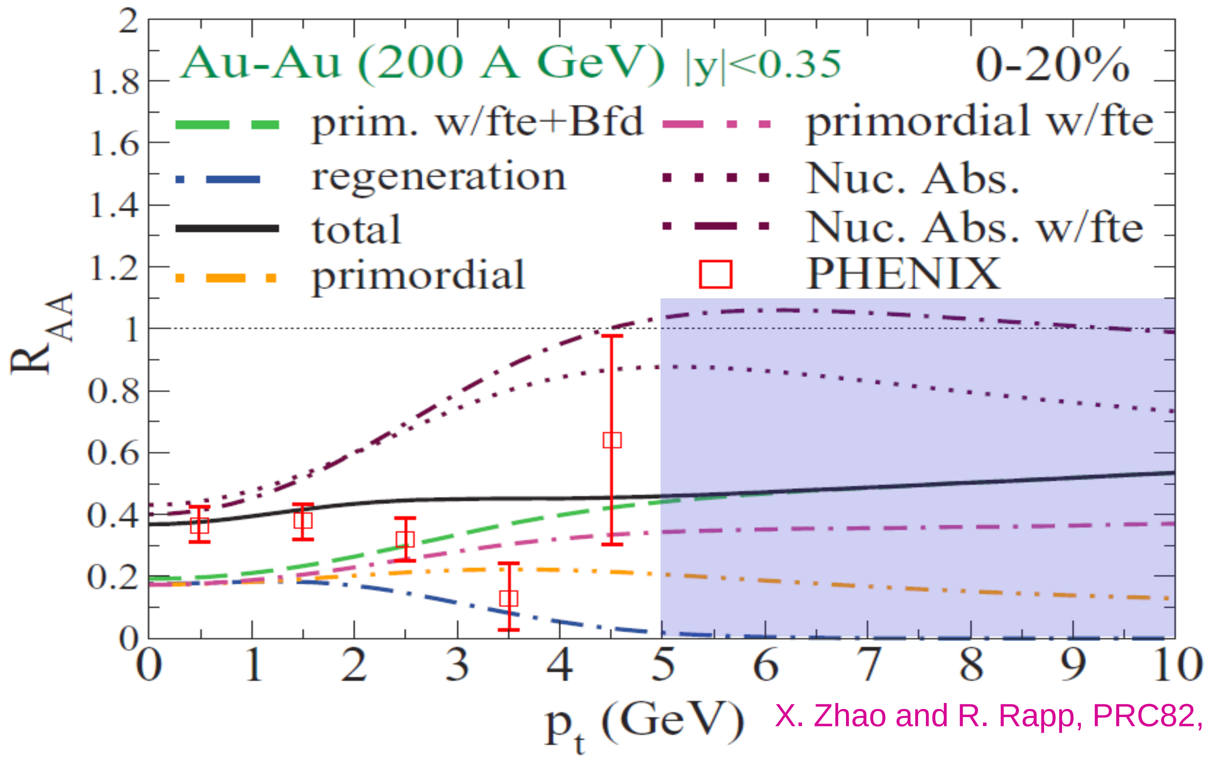
Good agreement with model predictions using EPS09 nPDF parametrization for the shadowing, and a J/ψ nuclear absorption cross section

$\sigma_{abs}^{J/\psi} = 2.8^{+3.5}_{-2.6}\,(stat.)^{+4.0}_{-2.8}\,(syst.)^{+1.8}_{-1.1}\,(EPS09)$ mb

STAR results consistent with PHENIX measurements **CNM not well understood yet!**

High-p_T J/ψ provides a cleaner probe

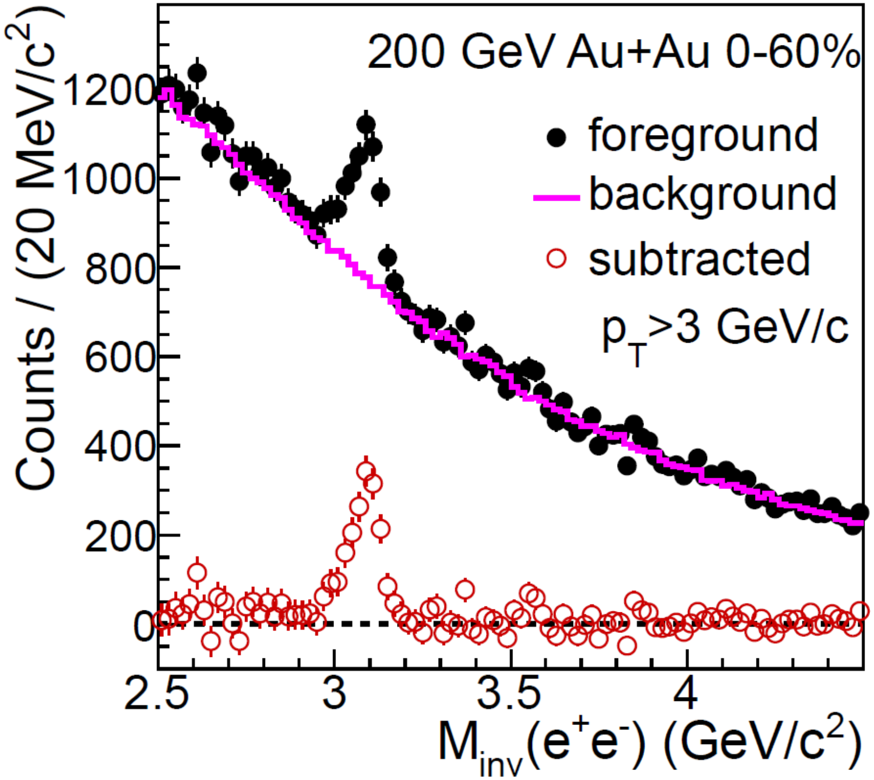




X. Zhao and R. Rapp, PRC82, 064905

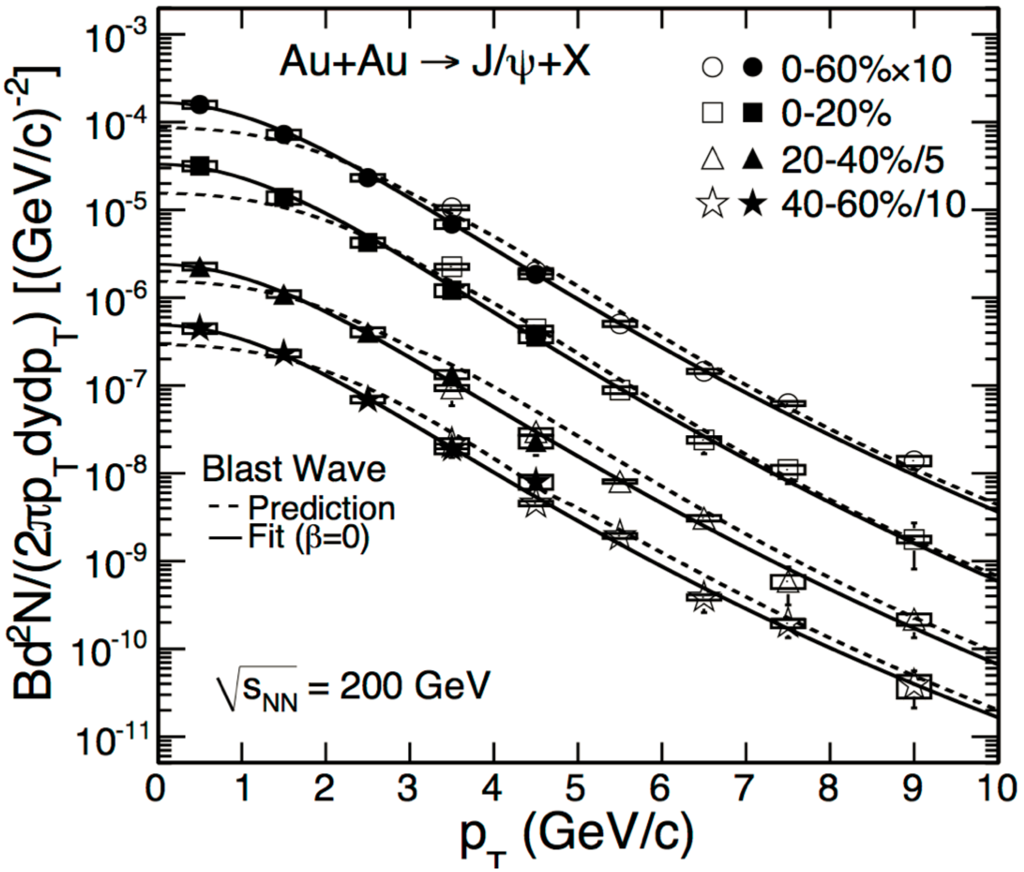
- Nuclear absorption and life time (Cold Nuclear Matter effects) R_{AA}~0.5 at low p_T, increase to unity at 5 GeV/c
- Regeneration and possible radial flow only affect low p_T
- Low-p_T J/ψ deviates from x_T-scaling, soft process affects

High-p_T J/ψ signals in Au+Au collisions



TPC+TOF+BEMC (+BSMD)
0-20%: 1000 signals with S/B ~= 1/7
40-60%: 300 signals with S/B ~=1/2

J/ψ spectra in Au+Au collisions



Significantly extend the p_T range to 10 GeV/c

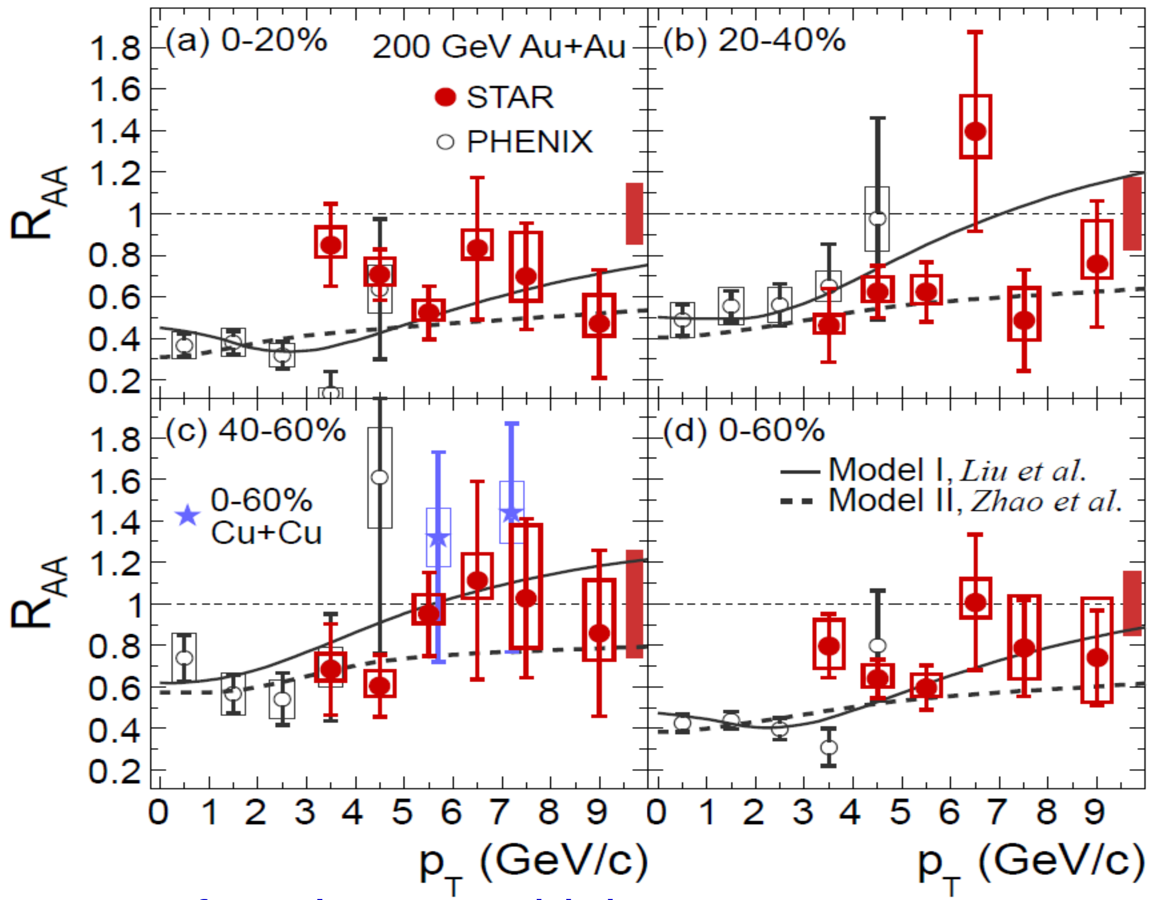
J/ψ spectra significantly softer than the prediction from light hadrons

→ Much smaller radial flow?

→ Regeneration at low p_T?

Tsallis Blast-Wave model: ZBT *et al*., arXiv:1101.1912; JPG 37, 085104 (2010)

R_{AA} vs. p_T



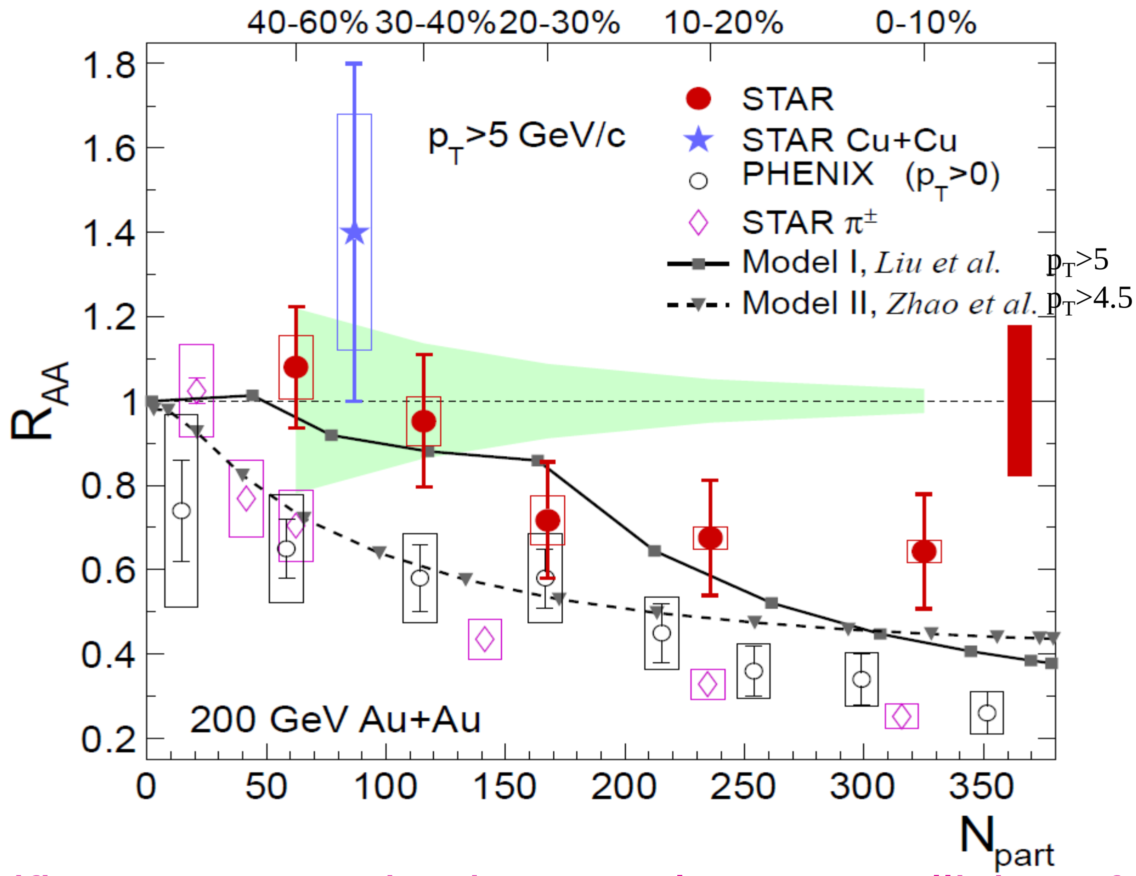
STAR CuCu: PRC80, 014922(R)
PHENIX: PRL98, 232301

Yunpeng Liu, Zhen Qu, Nu Xu and Pengfei Zhuang, PLB 678:72 (2009) and private comminication

Xingbo Zhao and Ralf Rapp, PRC 82,064905(2010) and private communication

Increase from low p_T to high p_T
Consistent with unity at high p_T in (semi-) peripheral collisions
More suppression in central than in peripheral even at high p_T

R_{AA} vs. Centrality



Yunpeng Liu, Zhen Qu, Nu Xu and Pengfei Zhuang, PLB 678:72 (2009) and private comminication

Xingbo Zhao and Ralf Rapp, PRC 82,064905(2010) and private communication

STAR Pion: PRL 108:072302 (2012)

Significant suppression in central Au+Au collisions for high-p_T J/ψ

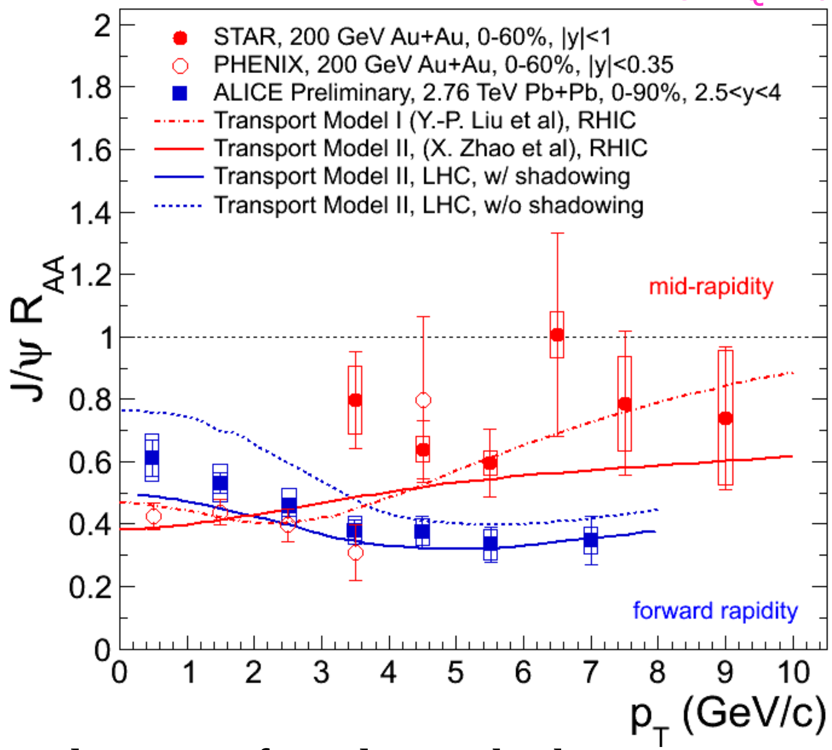
Systematically higher at high p_T in all centralities

Consistent with model I (including color screening effects)

Trend is different from high-p_T pion, not dominantly from color-octet?

Compare to LHC

STAR: arXiv: 1208.2736   ALICE: QM2012   PHENIX: PRL98(2007)



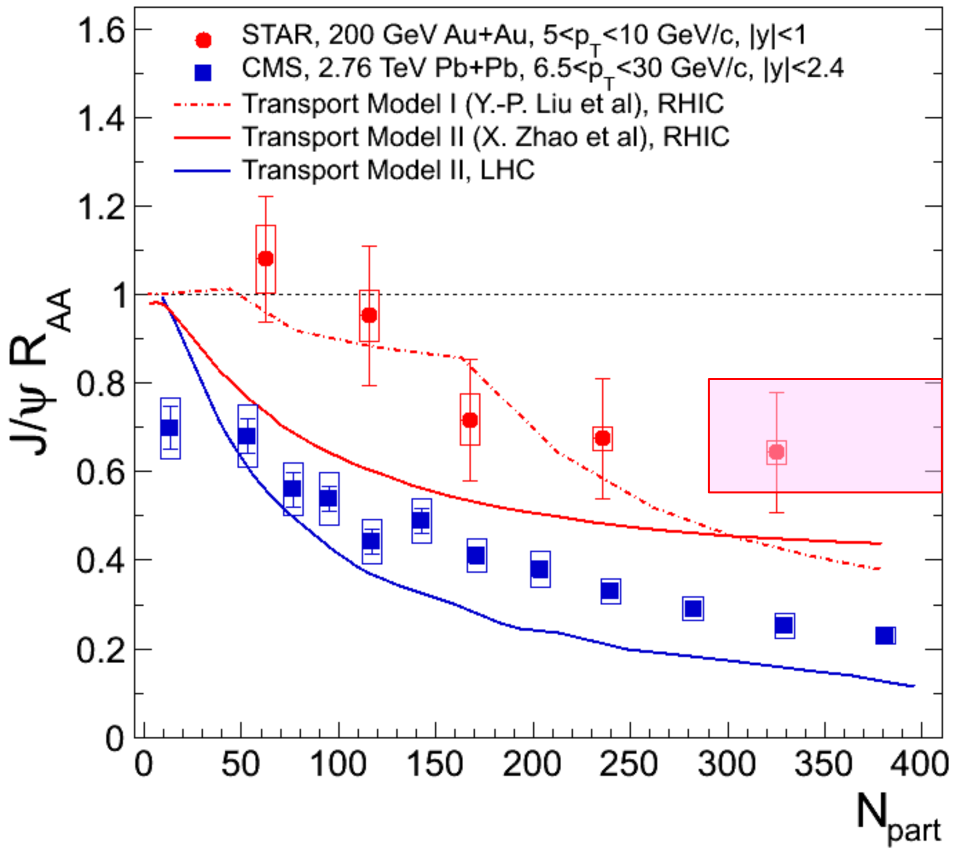
J/ψ R_{AA} decreases from low to high p_T at LHC.

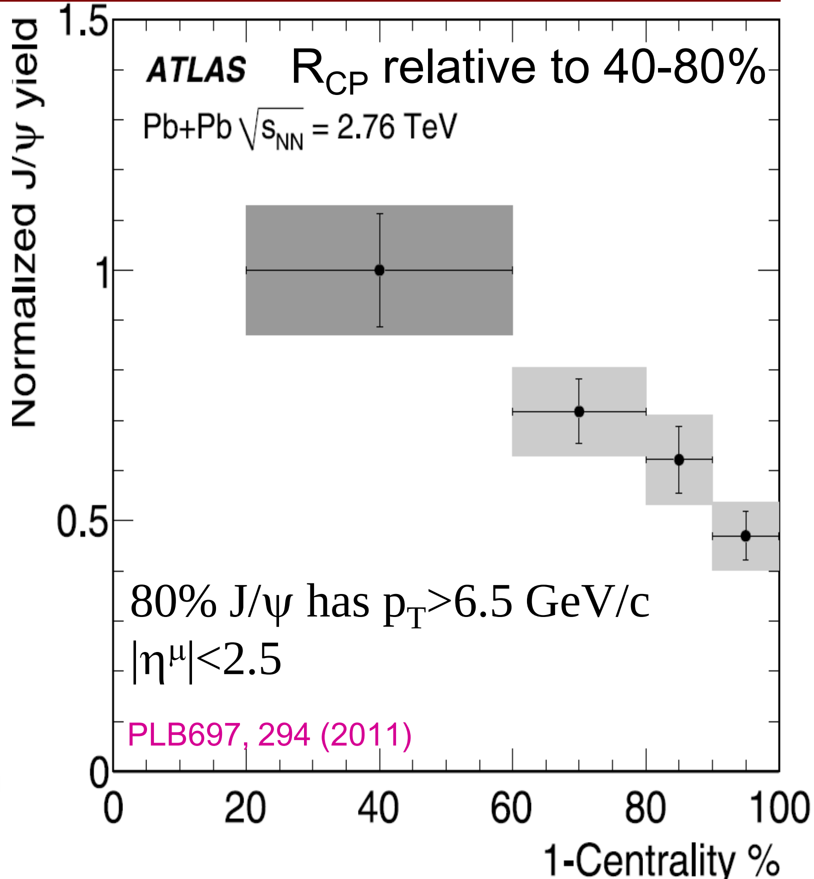
J/ψ R_{AA} increases from low to high p_T at RHIC.

At high p_T, J/ψ more suppressed at LHC.

Models incorporating color screening and recombination can consistently describe the J/ψ suppression pattern.

Compare to LHC





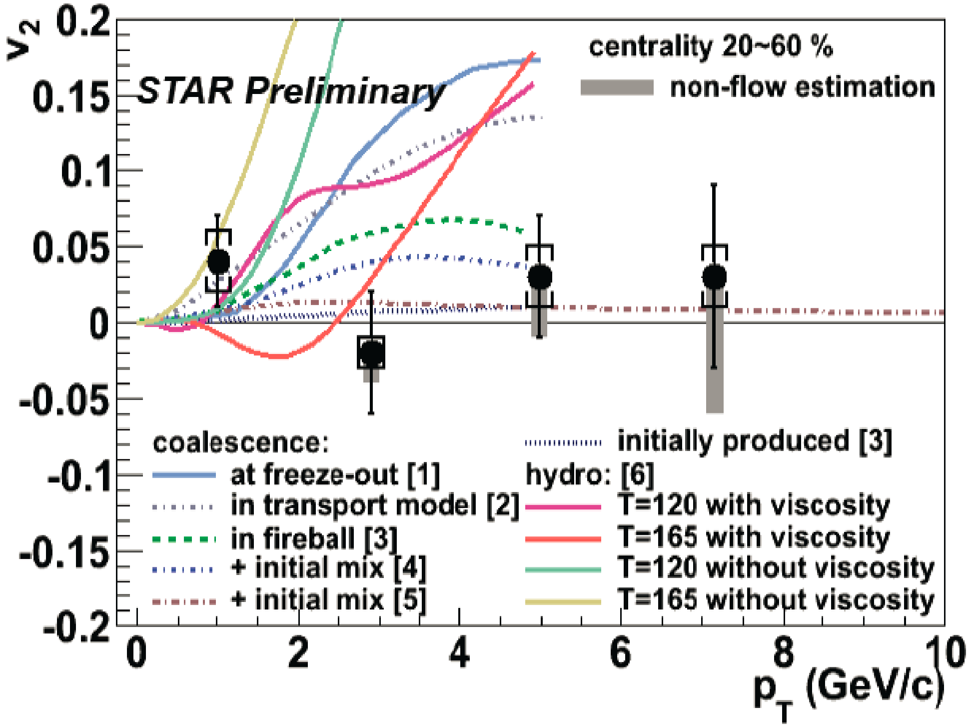
Stronger suppression at CMS than STAR, even in peripheral collisions

R_{CP}~1/3 for CMS, 0.45 for ATLAS and 0.6 for STAR,

Similar at RHIC and LHC if take the uncertainty into account

CNM and regeneration is less important at high p_T at RHIC. ➔ Is it true for LHC?

J/ψ v_2 in semi-central Au+Au collisions



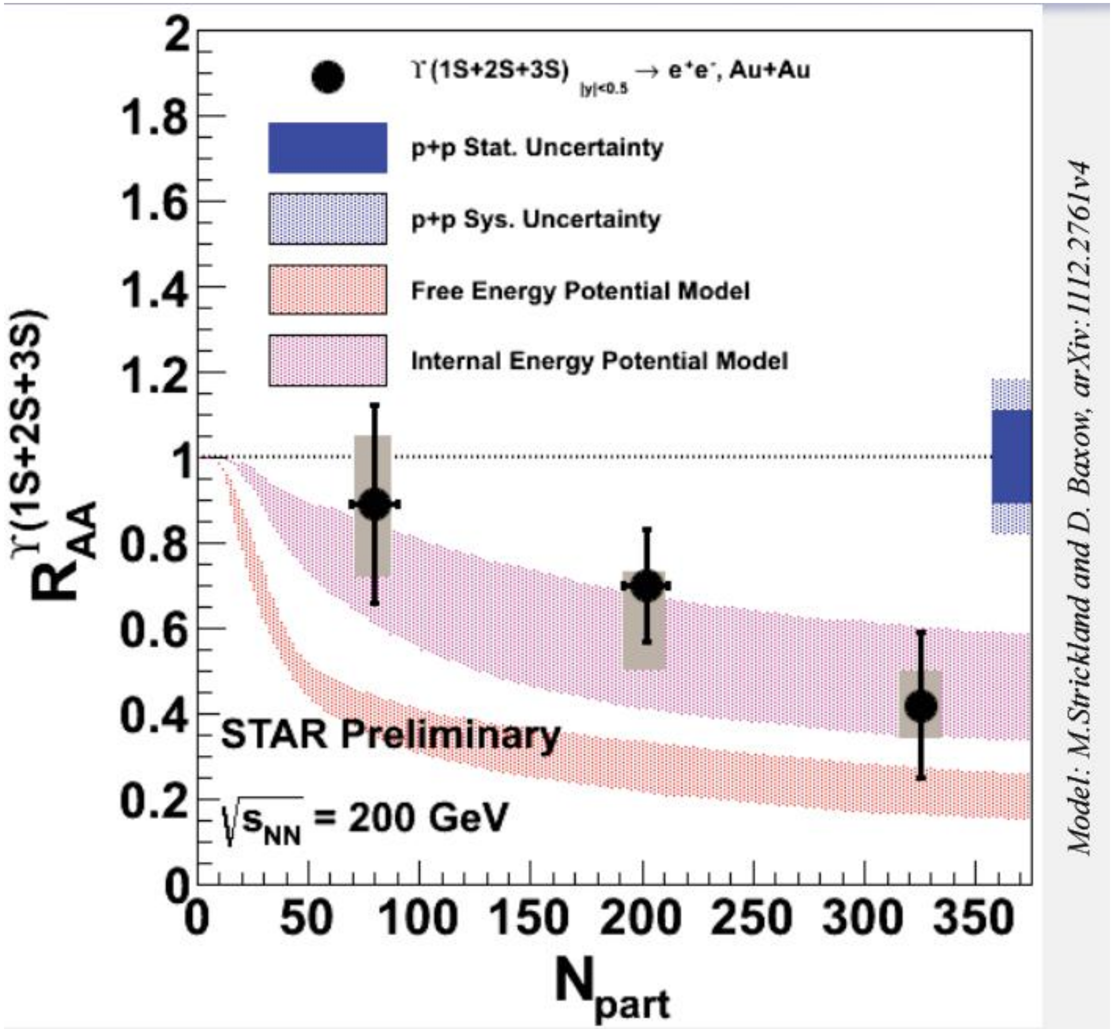
Models		P-value
Initially produced	1.8/3	6.2e-1
Coalescence at freezeout	22.6/3	4.9e-5
Coalescence In transport	13.9/3	3.0e-3
Coalescence In transport	4.8/3	1.8e-1
Coalescence +initial mix	2.9/3	4.0e-1
Coalescence +initial mix	1.8/4	7.7e-1
Hydro T=120 w/viscosity	16.5/3	9.2e-4
Hydro T=165w/ viscosity	14.9/3	1.9e-03
Hydro T=120 w/o viscosity	191.6/3	2.7e-41
Hydro T=165w/o viscosity	237.3/3	0.0

Acta Physica Polonica B
, Proceedings Supplement Vol. 5, No. 2, 2012, page 323

[1] V. Greco, C.M. Ko, R. Rapp, PLB 595, 202. (MB)
[2] L. Ravagli, R. Rapp, PLB 655, 126. (MB)
[3] L. Yan, P. Zhuang, N. Xu, PRL 97, 232301. (b=7.8fm)
[4] X. Zhao, R. Rapp, 24th WWND, 2008. (20-40%)
[5] Y. Liu, N. Xu, P. Zhuang, Nucl. Phy. A, 834, 317. (b=7.8)
[6] U. Heinz, C. Shen, priviate communication. (20-60%)

Disfavors the case that J/ψ with p_T > 2 GeV/c is produced dominantly by coalescence from thermalized charm quarks.

Upsilon measurement in STAR



- recombination can be neglected at RHIC
- Final state co-mover absorption is small.
- More suppression in more central collisions
- Consistent with prediction from a model requiring strong 2S and complete 3S suppression.

Summary

J/ψ :

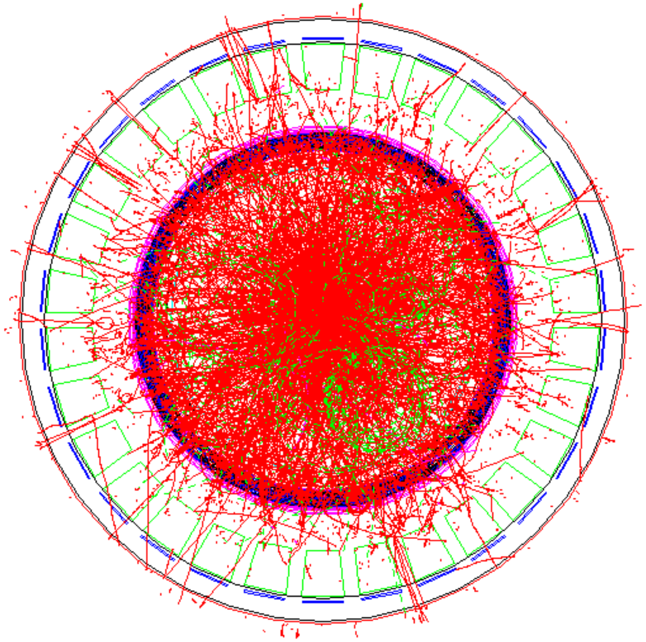
- CEM and NLO CS+CO describe p_T spectra in p+p
- 10-25% B-hadron feeddown contribution at $4<p_T<12$ GeV/c in p+p
- First measurement of high-p_T J/ψ suppression in Au+Au collisions at RHIC
  - Less complication of CNM and Recombination effects
  - Significant suppression at $p_T>5$ GeV/c, color-screening?
- J/ψ v_2 measurements disfavor the case that coalescence dominate the

production at $p_T > 2$ GeV/c.

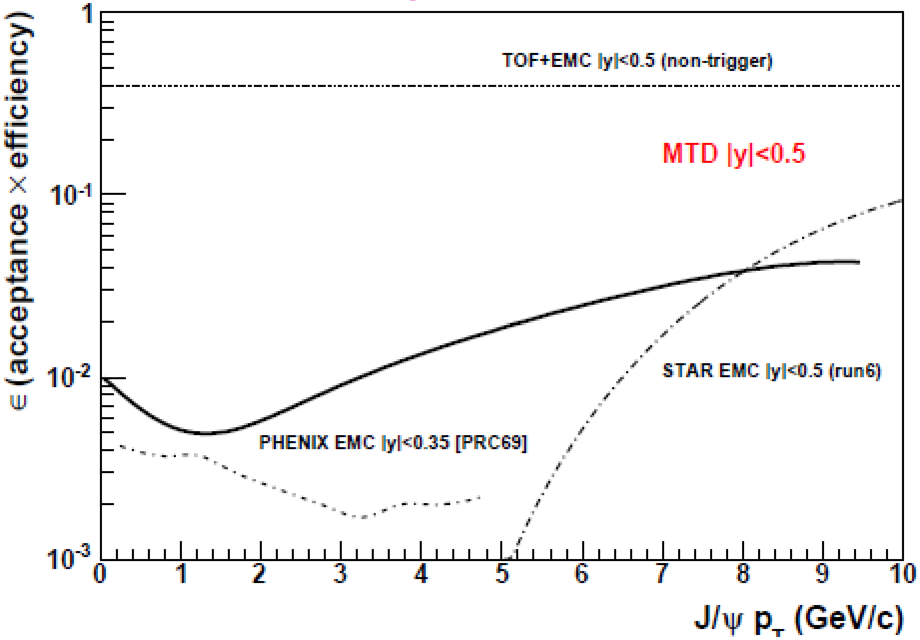
Upsilon:

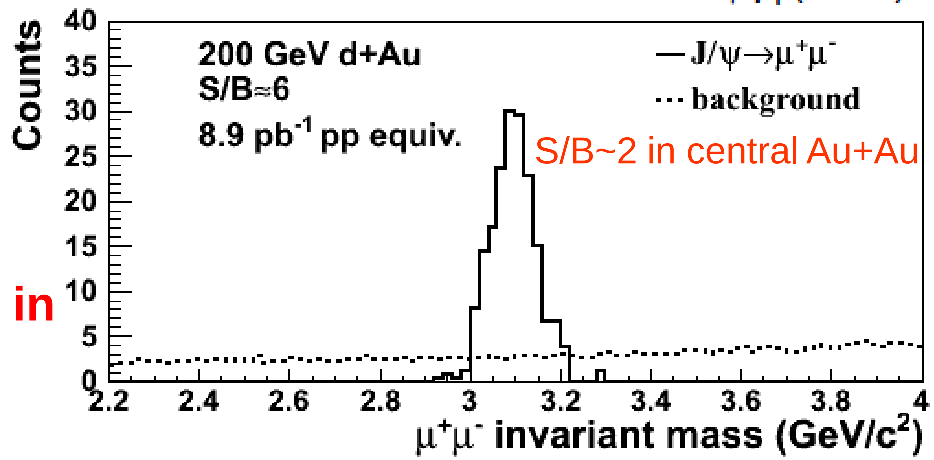
- Significant suppression in central heavy-ion collisions
- Consistent with melting of excited states

Muon Telescope Detector (MTD)



Lijuan Ruan, QM2011





Advantages over electrons

no γ conversion

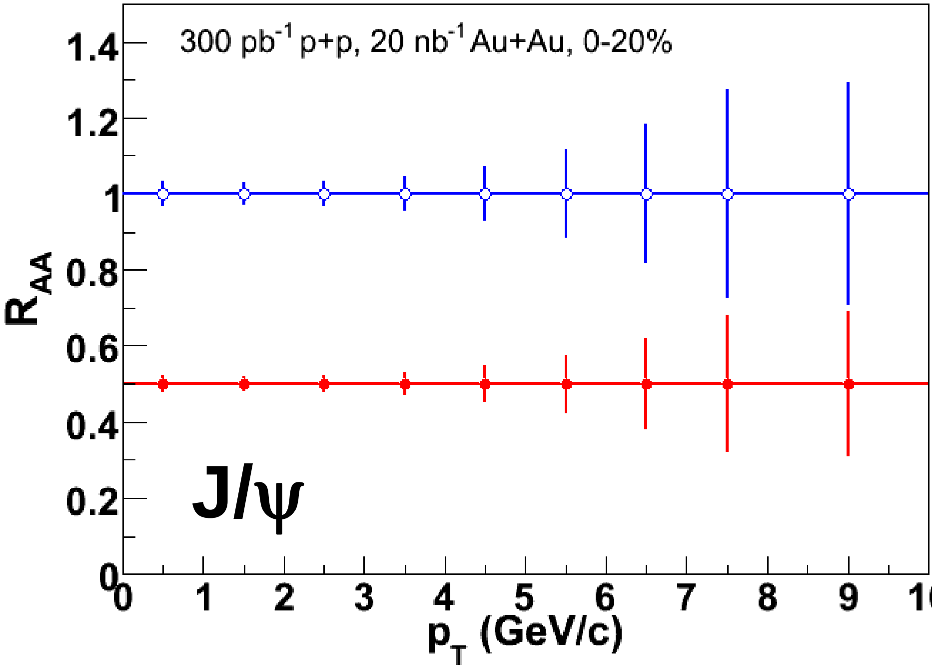
much less Dalitz decay contribution

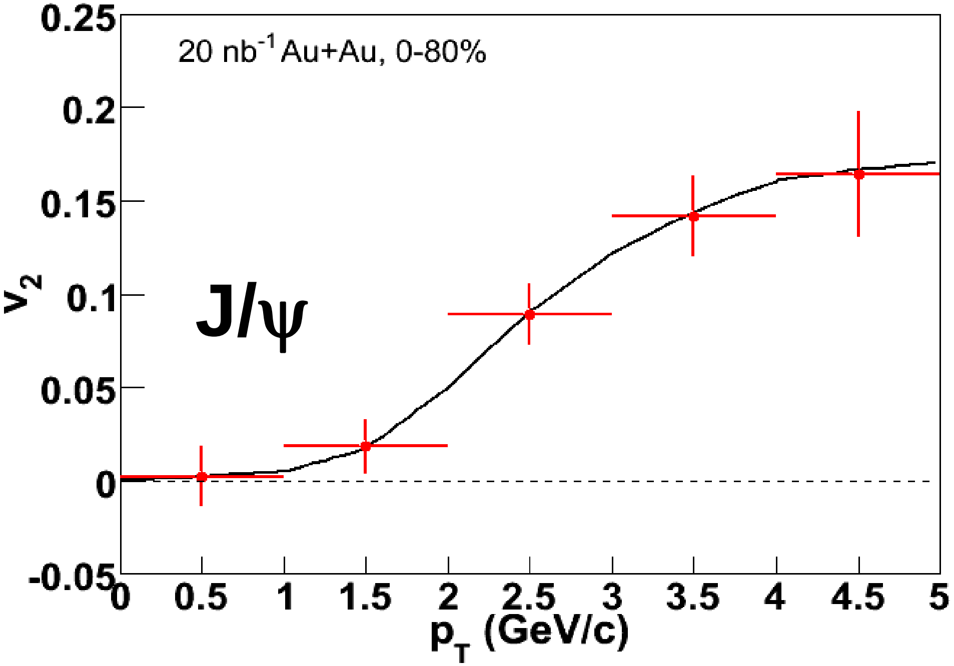
less affected by radiative losses in the materials

Trigger capability for low to high p_T J/ψ in central Au+Au collisions

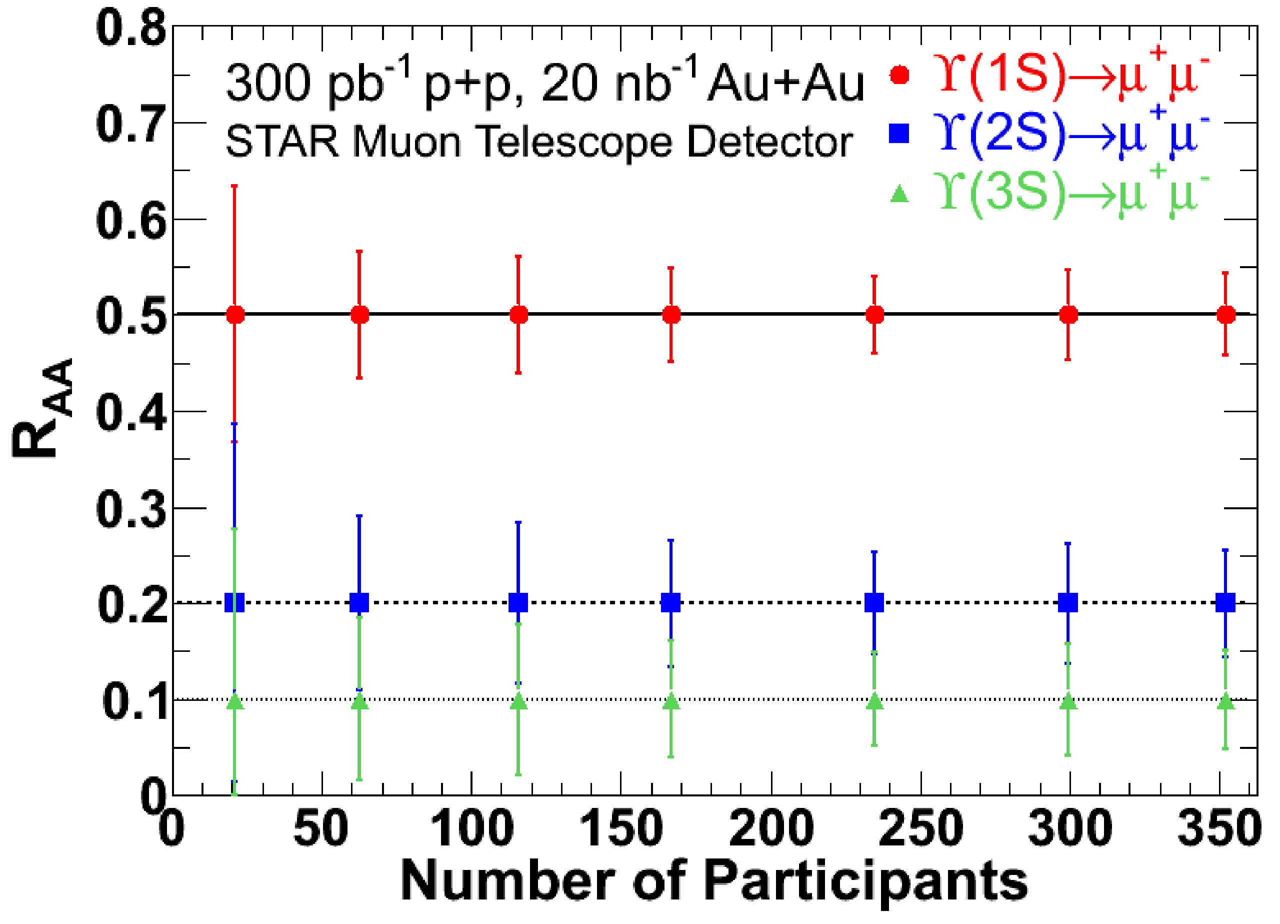
High μ/hadron enhancement

J/ψ with MTD projection





Upsilon with MTD projection



Separate different Upsilon states