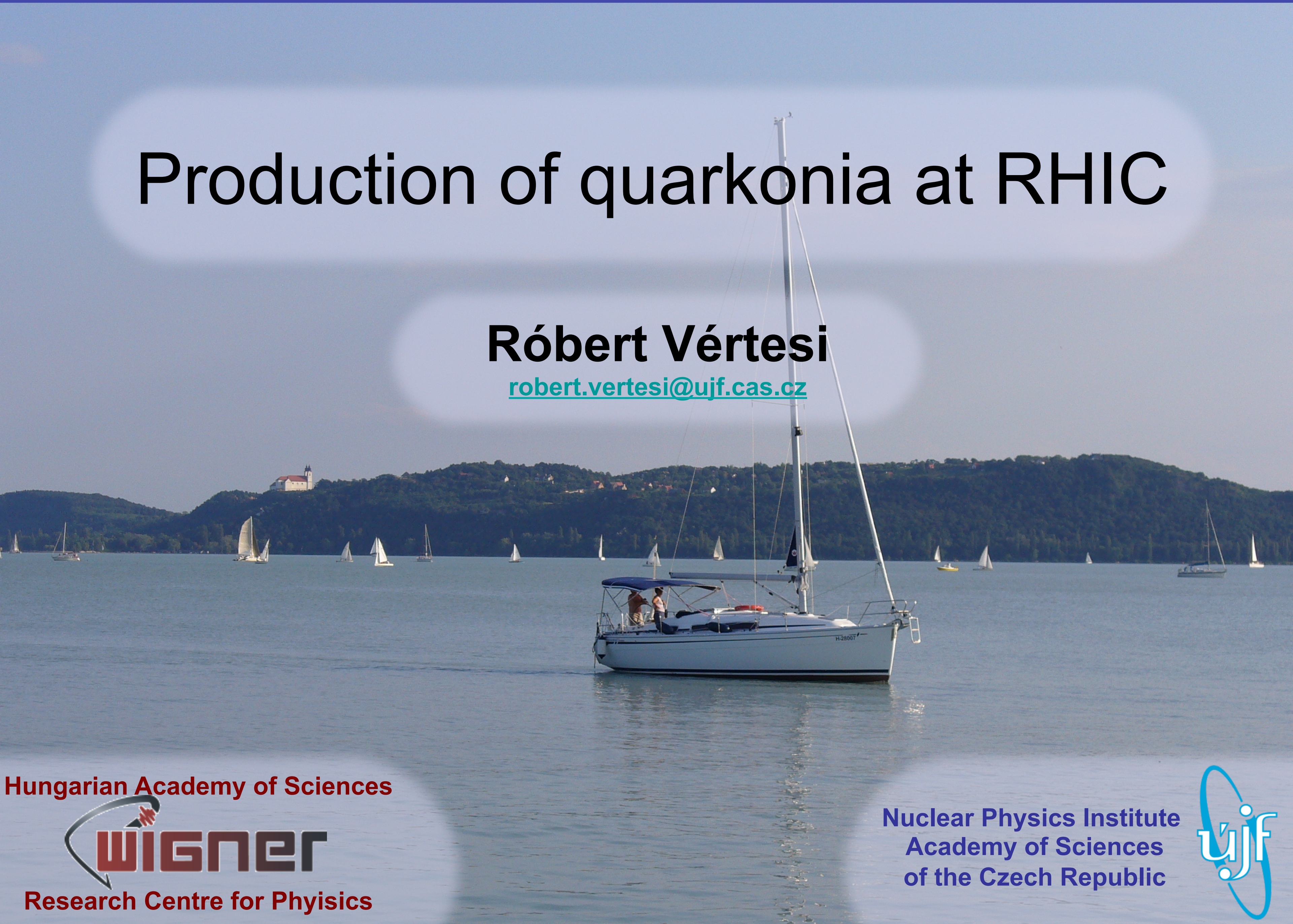


Production of quarkonia at RHIC

Róbert Vértesi
robert.vertesi@ujf.cas.cz

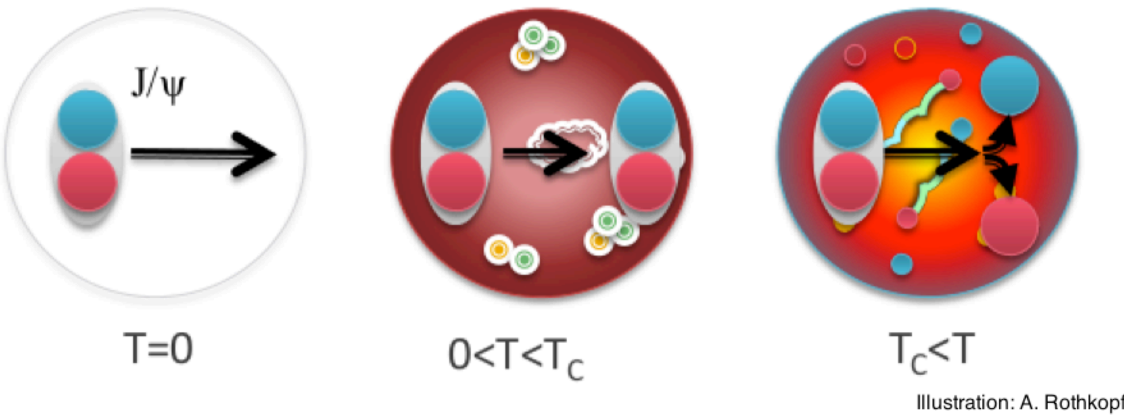
Hungarian Academy of Sciences
Wigner
Research Centre for Phyisics

Nuclear Physics Institute
Academy of Sciences
of the Czech Republic
újf

Probing the sQGP with quarkonia

- Debye screening of heavy quark potential
  → Quarkonia are expected to dissociate

T. Matsui, H. Satz, Phys.Lett. B178, 416 (1986)



Charmonia ($c\bar{c}$):
J/Ψ, Ψ', χ_c

Bottomonia ($b\bar{b}$):
$\Upsilon(1S)$, $\Upsilon(2S)$, $\Upsilon(3S)$, χ_B

Probing the sQGP with quarkonia

- Debye screening of heavy quark potential
  → Quarkonia are expected to dissociate

  T. Matsui, H. Satz, Phys.Lett. B178, 416 (1986)

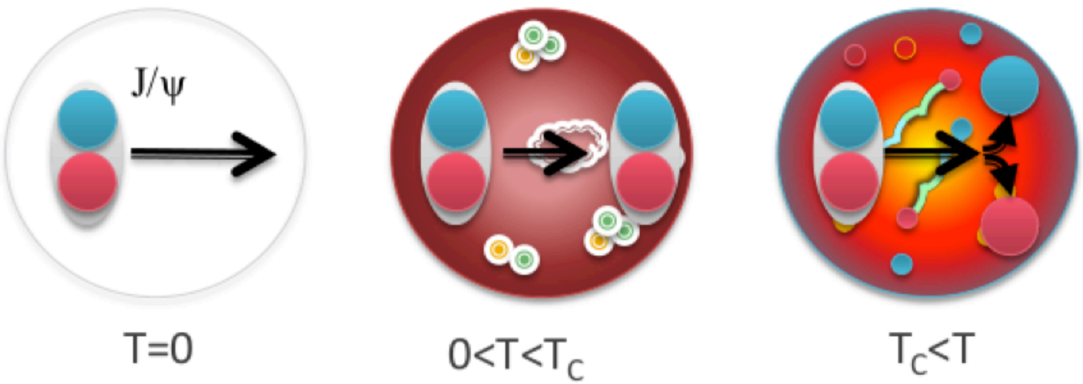
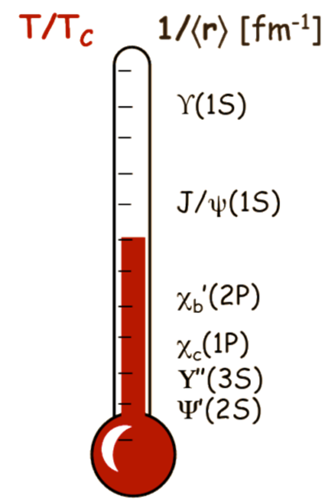


Illustration: A. Rothkopf

Charmonia ($c\bar{c}$):
J/Ψ, Ψ', χ_c

Bottomonia ($b\bar{b}$):
$\Upsilon(1S)$, $\Upsilon(2S)$, $\Upsilon(3S)$, χ_B



- Sequential melting: Different states dissociate at different temperatures

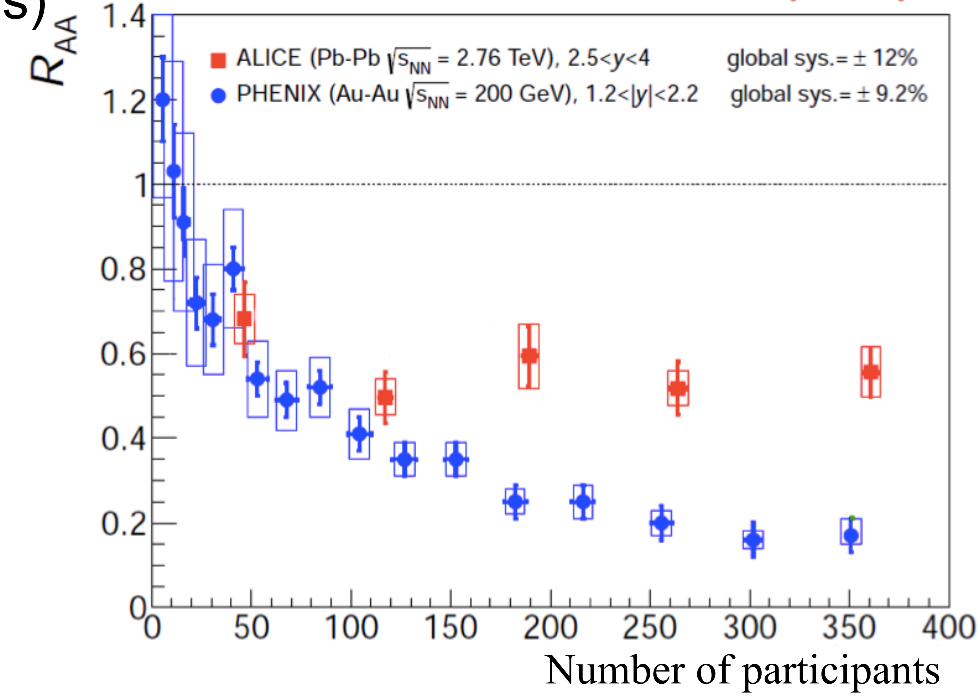
  Á. Mócsy, P. Petreczky, Phys. Rev. D77, 014501 (2008)

Quarkonia may serve as sQGP thermometer

Complications…

- Cold nuclear matter effects
  - Nuclear shadowing (PDF modification in the nucleus)
  - Initial state energy loss
  - Co-mover absorption
- Hot/dense medium effects
  - Coalescence of uncorrelated charm and bottom pairs
- Feed-down
  - χ_c, ψ', B-meson decay to J/ψ
  - χ_b, ϒ(2S), ϒ(2S) to ϒ(1S) …

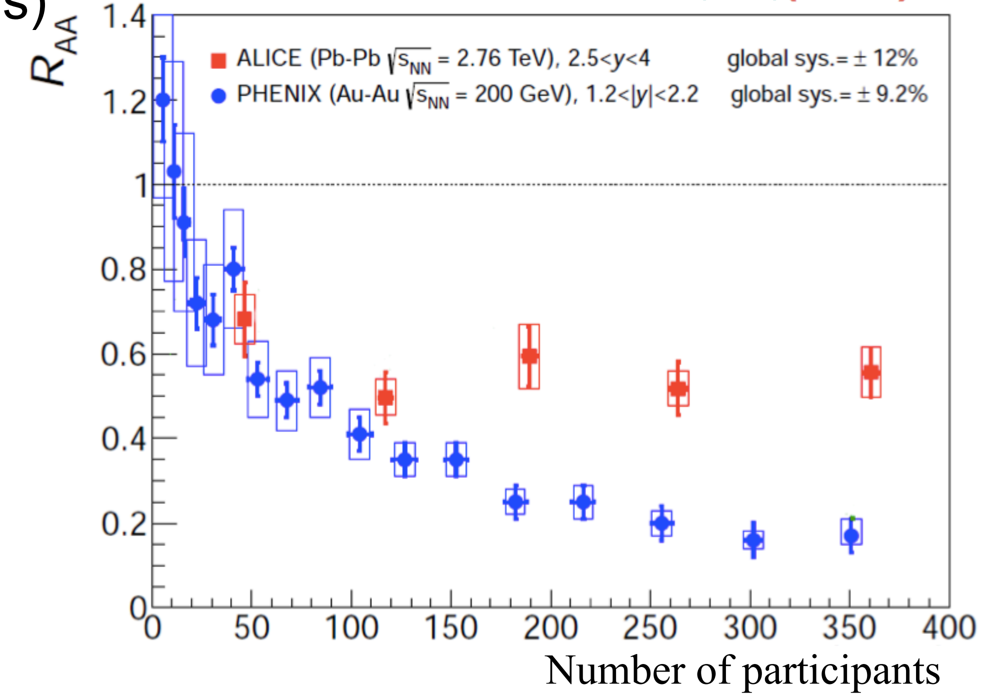
PHENIX: PRC 84 (2011) 054912
ALICE: PRL 109,072301 (2012)



Complications…

- Cold nuclear matter effects
  - Nuclear shadowing (PDF modification in the nucleus)
  - Initial state energy loss
  - Co-mover absorption
- Hot/dense medium effects
  - Coalescence of uncorrelated charm and bottom pairs
- Feed-down
  - χ_c, ψ', B-meson decay to J/ψ
  - χ_b, Υ(2S), Υ(2S) to Υ(1S) …

PHENIX: PRC 84 (2011) 054912
ALICE: PRL 109,072301 (2012)



Contribution of different effects is not well understood

Experimental approach: R_{AA}

- p+p collisions: Reference system and pQCD benchmark
- d+A, p+A: Understand cold nuclear matter effects
- A+A: Hot medium effects on top of those

Experimental approach: R_{AA}

- p+p collisions: Reference system and pQCD benchmark
- d+A, p+A: Understand cold nuclear matter effects
- A+A: Hot medium effects on top of those

Measuring the nuclear modification factor

$$R_{AA} = \frac{1}{\langle N_{coll} \rangle} \frac{dN_{AA} / dy}{dN_{pp} / dy}$$

Some other measurements and observables (not covered)

- Collectivity (azimuthal anisothropy v_2, radial flow)
- Polarization measurements
- Production in ultraperipheral collisions

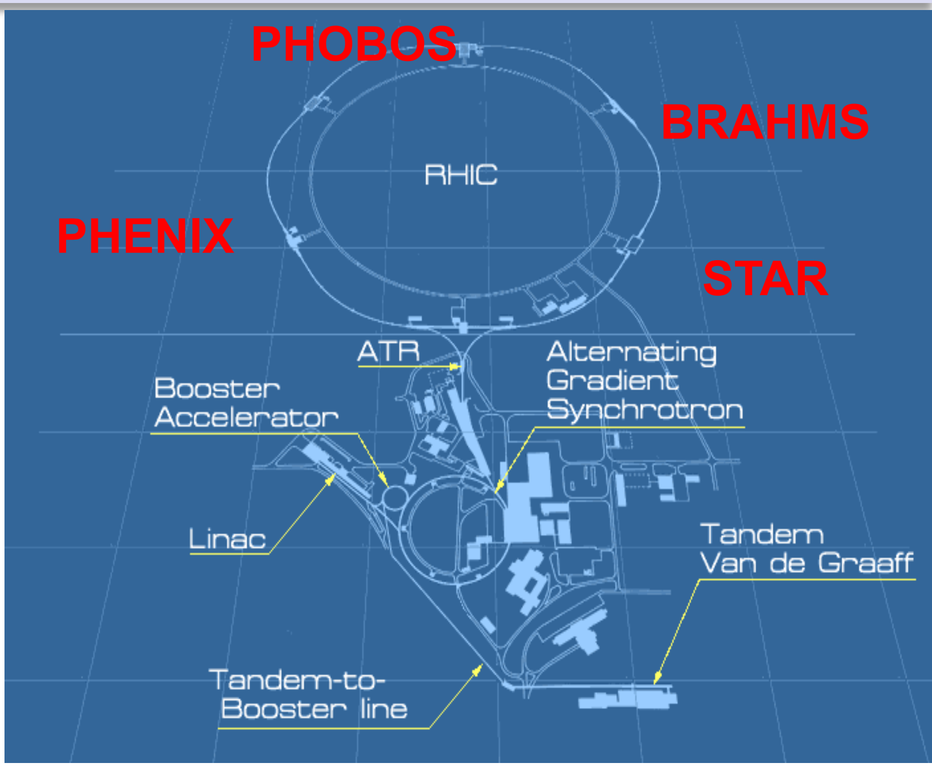
Turning the knobs

- Collision energy: **39, 62.4, 200 GeV**
  → Change relative contributions of dissociation and recombination
- System size/asymmetry: **Au+Au**, **U+U**; **d+Au**, **Cu+Au** …
  → Change relative contributions of hot/cold effects
  → Test sequential melting at different energy densities
- Centrality
  → Tune hot matter effects via path length
- Rapidity and momentum
  → Tune CNM and regeneration effects
- Charmonium vs. Bottomonium states
  → Test sequential melting
  - J/ψ is abundant but prone to various "disturbing" effects
  - Υ is much less affected by regeneration and co-mover absorption

RHIC

RHIC: Broad physics program

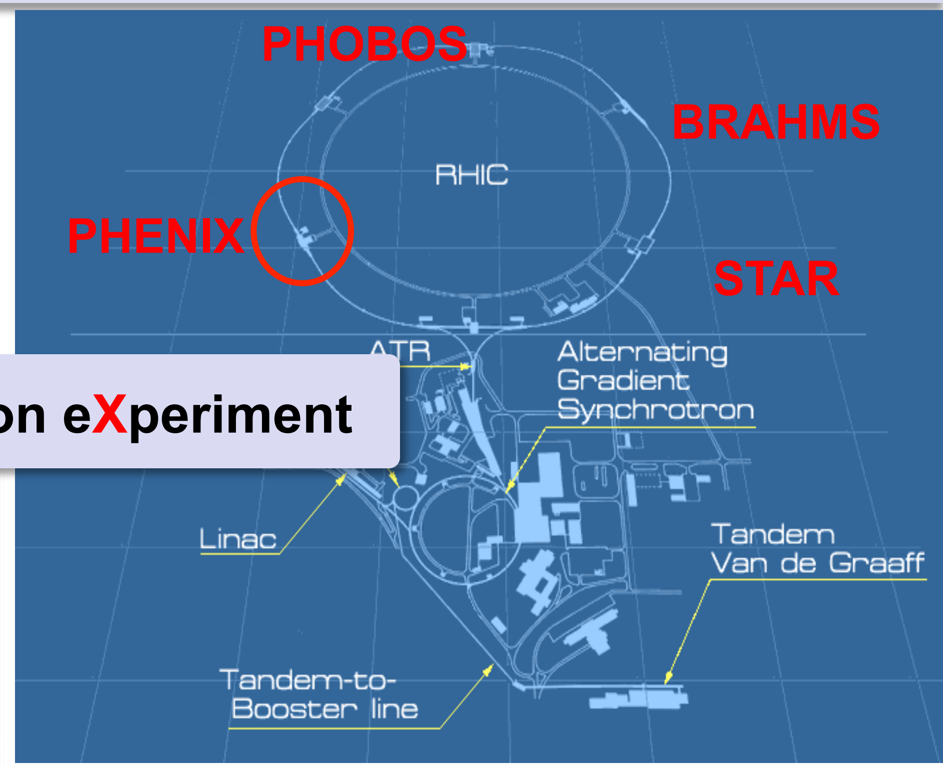
- Heavy ions: Au+Au, Cu+Cu, U+U, $\sqrt{s_{NN}}$=7.7–200 GeV
- Polarized protons up to $\sqrt{s}$ = 510 GeV
- Asymmetric systems (d+Au, Cu+Au)



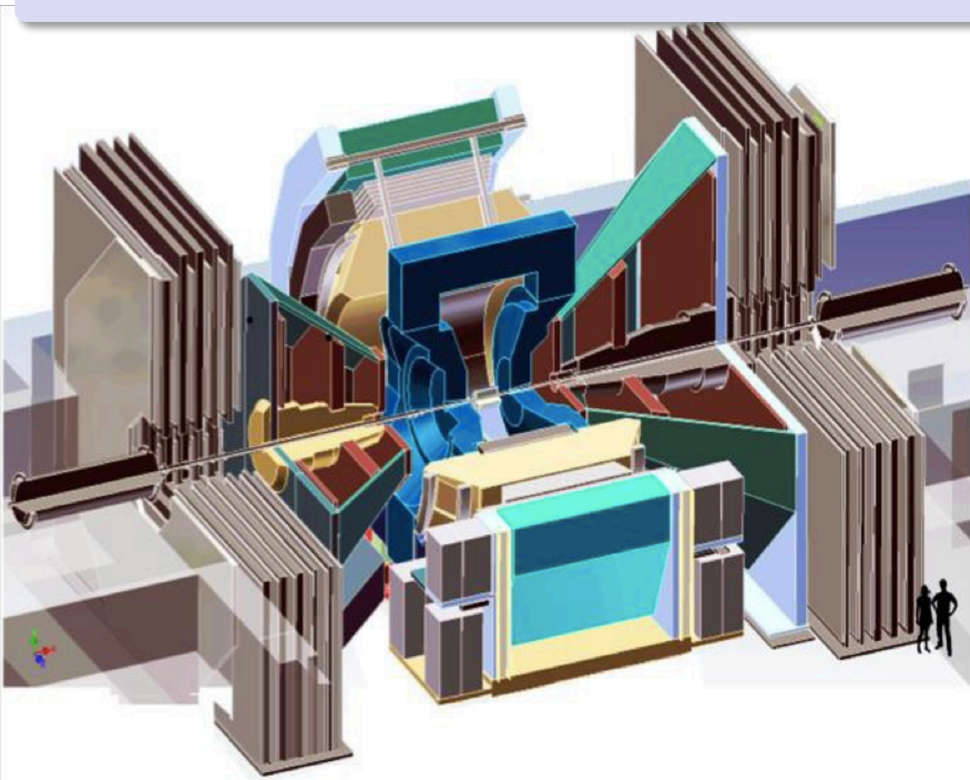
RHIC/PHENIX

RHIC: Broad physics program

- Heavy ions: Au+Au, Cu+Cu, U+U, $\sqrt{s_{NN}}$=7.7–200 GeV
- Polarized protons up to $\sqrt{s}$ = 510 GeV
- Asymmetric systems (p+Au, d+Au, Cu+Au)



A Pioneering High Energy Nuclear Ion eXperiment



Central arms: |y|<0.25, Δφ = (2 x π/2)

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

- DC, PC: dE/dx identification
- RICH, EMCal: Electron ID

Forward arms: 1.2<|y|<2.2, Δφ = 2π

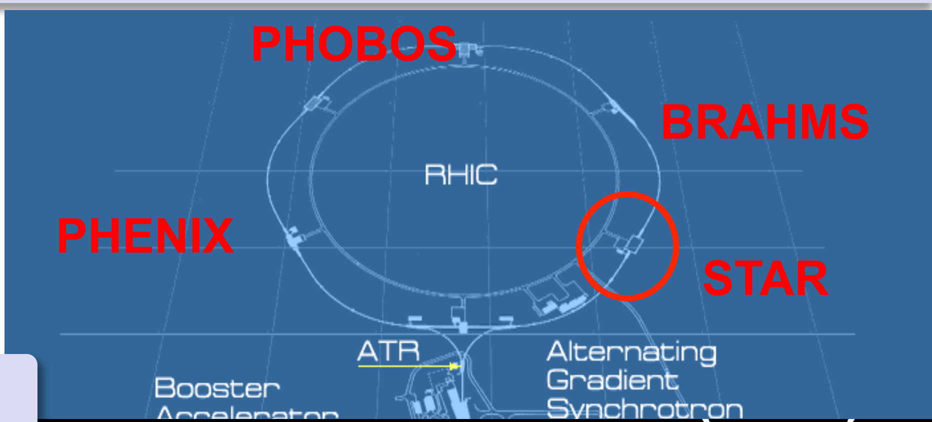
$J/\psi, \Upsilon \rightarrow \mu^+\mu^-$

- Muon tracker and Muon ID

RHIC/STAR

RHIC: Broad physics program

- Heavy ions: Au+Au, Cu+Cu, U+U, $\sqrt{s_{NN}}$=7.7–200 GeV
- Polarized protons up to $\sqrt{s}$ = 510 GeV
- Asymmetric systems (d+Au, Cu+Au)



The Solenoidal Tracker at RHIC

Time **P**rojection **C**hamber

- ID via energy loss (dE/dx)
- Momentum (p)

Barrel **E**lectro**m**agnetic **C**alorimeter

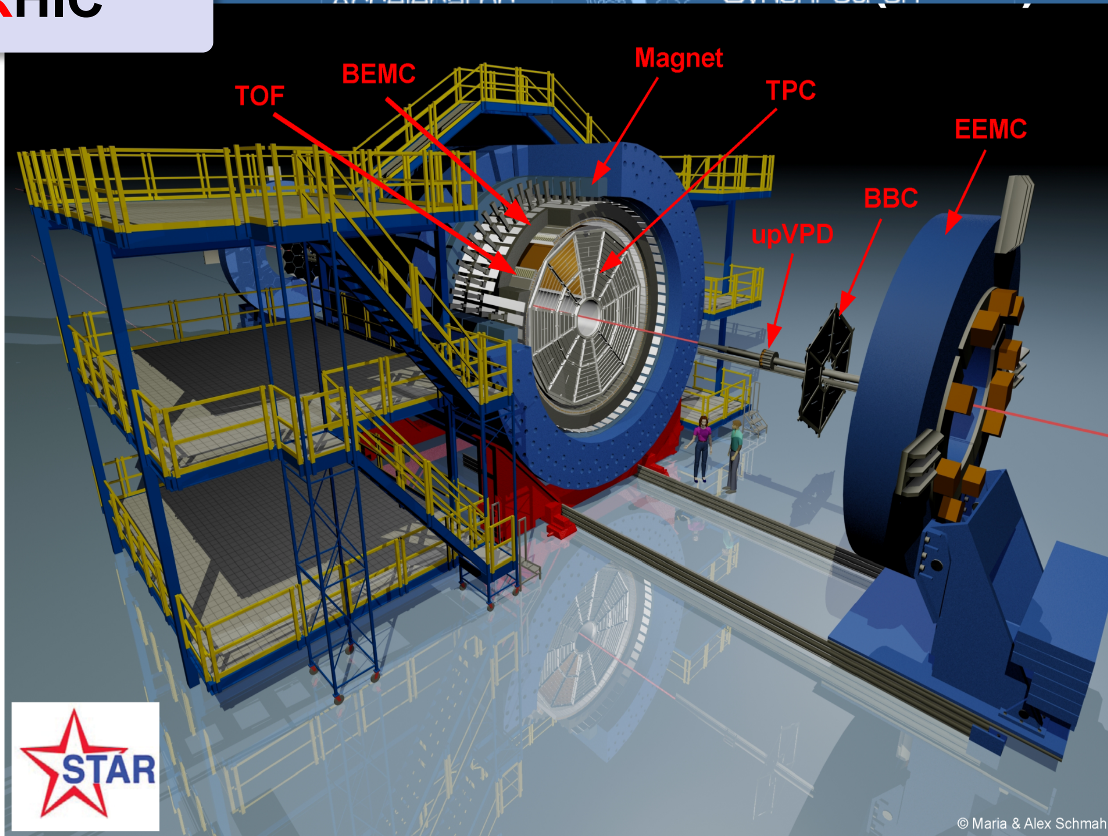
- Electron ID and energy

→ Full azimuth coverage

→ Uniform acceptance

$|y|<1$

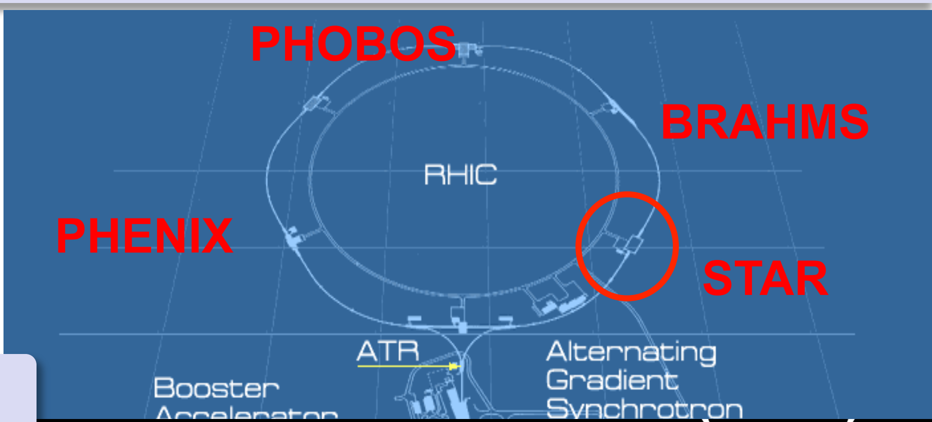
$J/\psi, \Upsilon \rightarrow e^+e^-$



RHIC

RHIC: Broad physics program

- Heavy ions: Au+Au, Cu+Cu, U+U, $\sqrt{s_{NN}}$=7.7–200 GeV
- Polarized protons up to $\sqrt{s}$ = 510 GeV
- Asymmetric systems (d+Au, Cu+Au)



The Solenoidal Tracker at RHIC

Time Projection Chamber

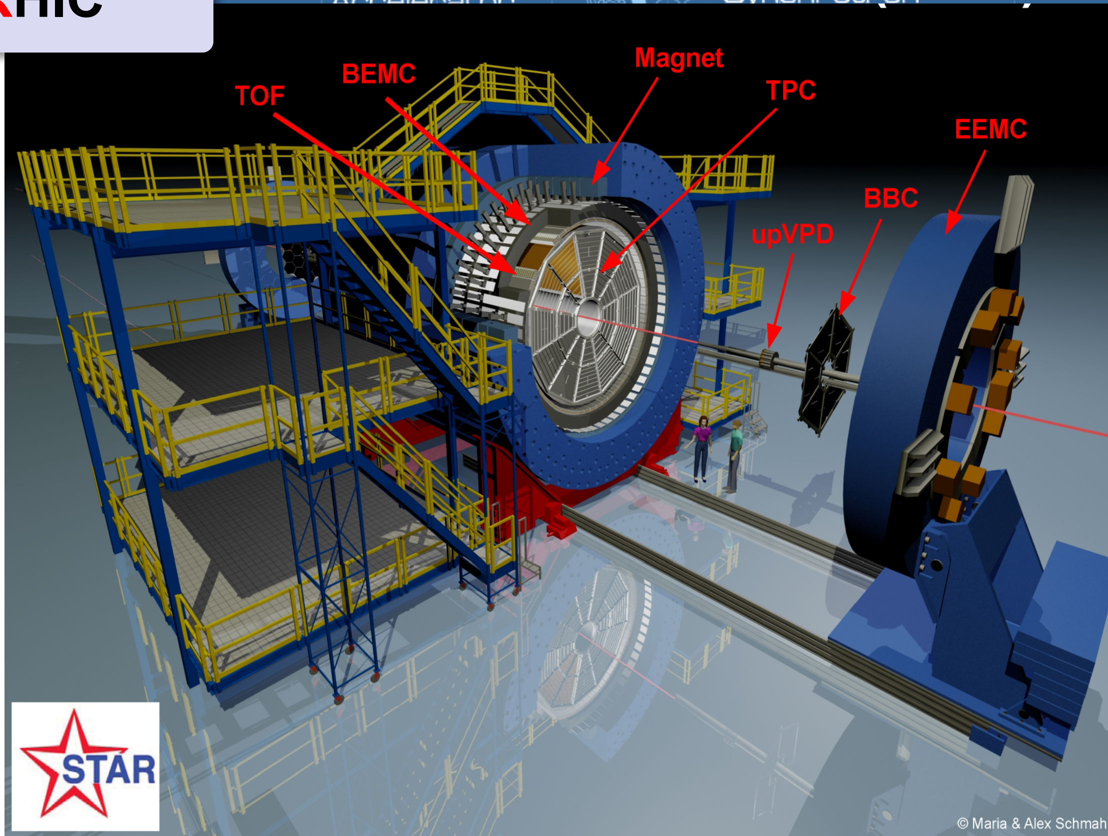
- ID via energy loss (dE/dx)
- Momentum (p)

Barrel Electromagnetic Calorimeter

- Electron ID and energy

→ Full azimuth coverage

→ Uniform acceptance



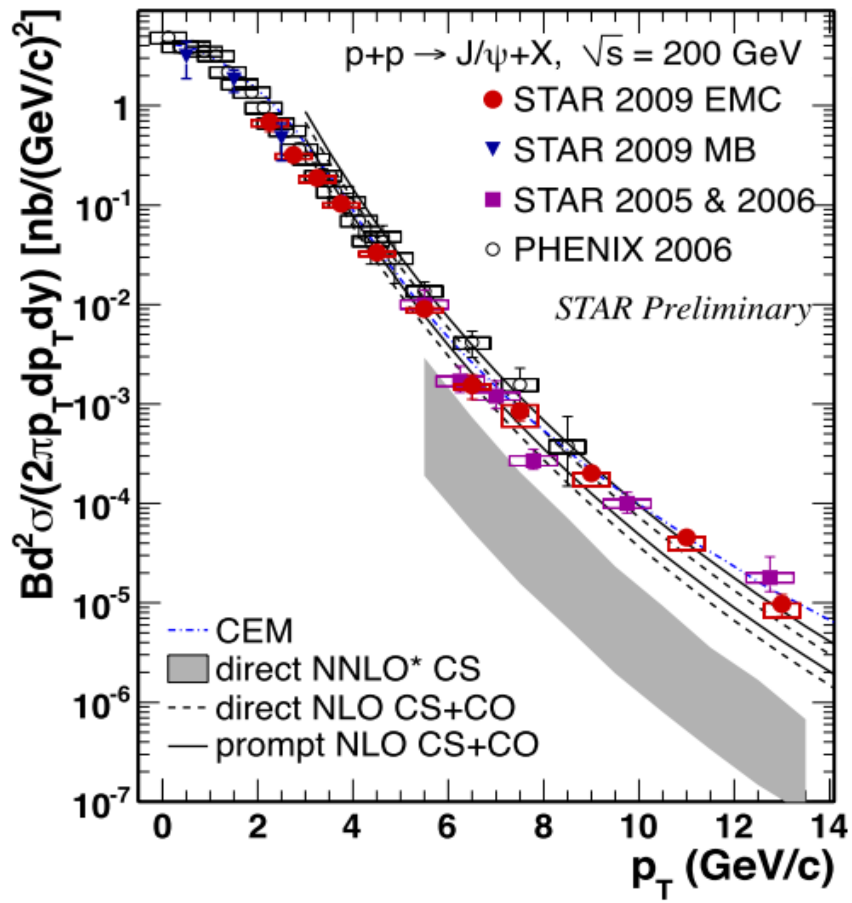
Both experiments:
continuous improvements
to meet evolving physics goals
New subsystems for enhanced PID, rates, coverage…

Do we understand J/ψ in p+p?

- RHIC Data at 200 GeV:
  - $0<p_T<14$ GeV/c in year 2009
  - Good agreement with PHENIX

STAR 2009 EMC : Phys. Lett. B 722 (2013) 55
STAR 2009 MB: Acta Phys. Polonica B Vol.5, No 2 (2012), 543
STAR 2005 & 2006: Phys. Rev. C80, 041902(R) (2009)
PHENIX 2006: Phys. Rev. D 85, 092004 (2012)

Inclusive J/ψ spectra



Do we understand J/ψ in p+p?

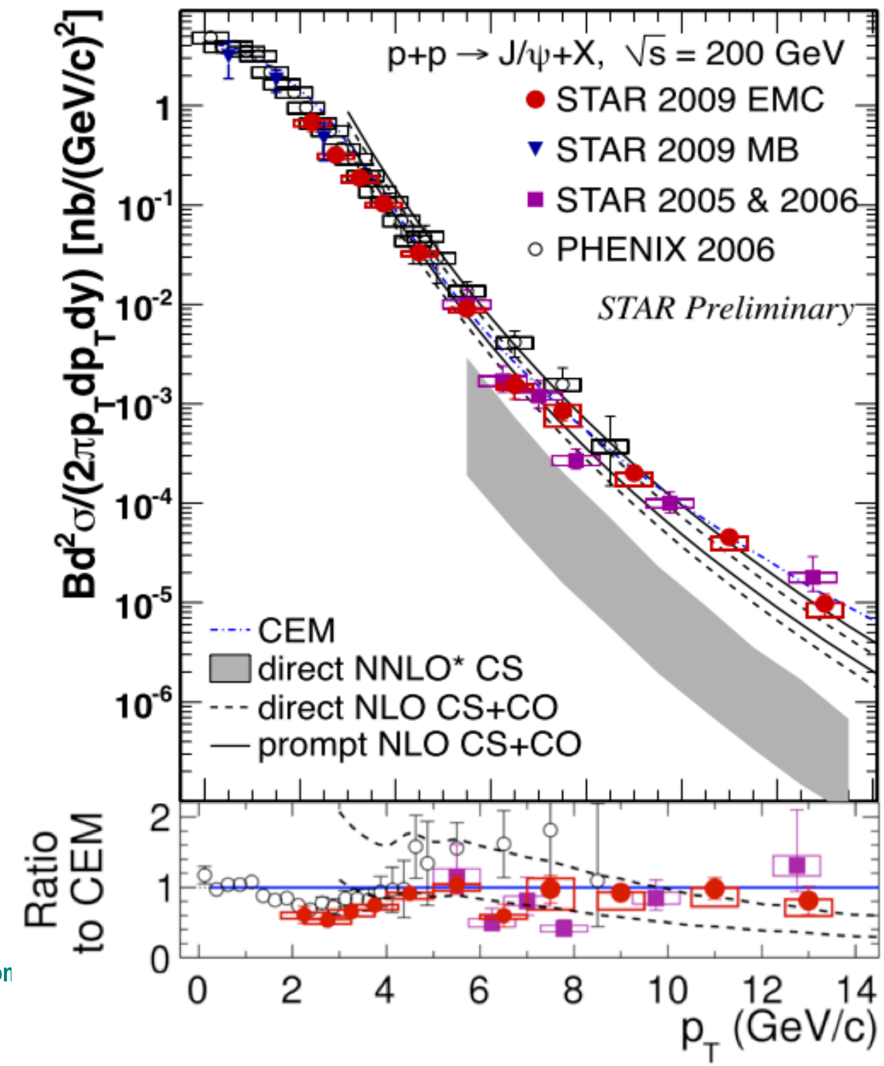
- RHIC Data at 200 GeV:
  - $0<p_T<14$ GeV/c in year 2009
  - Good agreement with PHENIX

STAR 2009 EMC : Phys. Lett. B 722 (2013) 55
STAR 2009 MB: Acta Phys. Polonica B Vol.5, No 2 (2012), 543
STAR 2005 & 2006: Phys. Rev. C80, 041902(R) (2009)
PHENIX 2006: Phys. Rev. D 85, 092004 (2012)

- Model comparison:
  - prompt NLO CS+CO: describes the data for p_T > 4 GeV/c
  - direct NNLO*CS: misses high- p_T part
  - Prompt CEM: reasonable description of spectra, but overpredicts the data at p_T~3 GeV/c

direct NNLO CS: P.Artoisenet et al., Phys. Rev. Lett. 101, 152001 (2008) and J.P.Lansberg private communication
NLO CS+CO: Y.-Q.Ma, K.Wang, and K.T.Chao, Phys. Rev. D 84, 51 114001 (2011) and priv. cor
CEM: A.D. Frawley, T Ullrich, R. Vogt, Pys. Rept. 462 (2008) 125, and R.Vogt priv. comm.

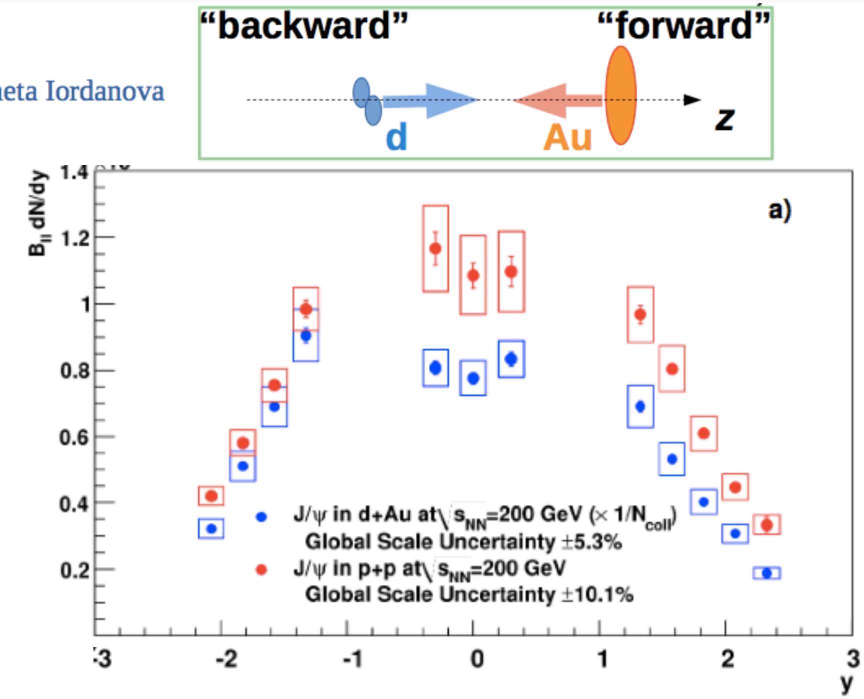
Inclusive J/ψ spectra



d+Au: J/ψ yields vs. rapidity

- d+Au: Cold Nuclear Matter effects
  PHENIX: PRL 107, 142301 (2011)
- Forward-backward asymmetry

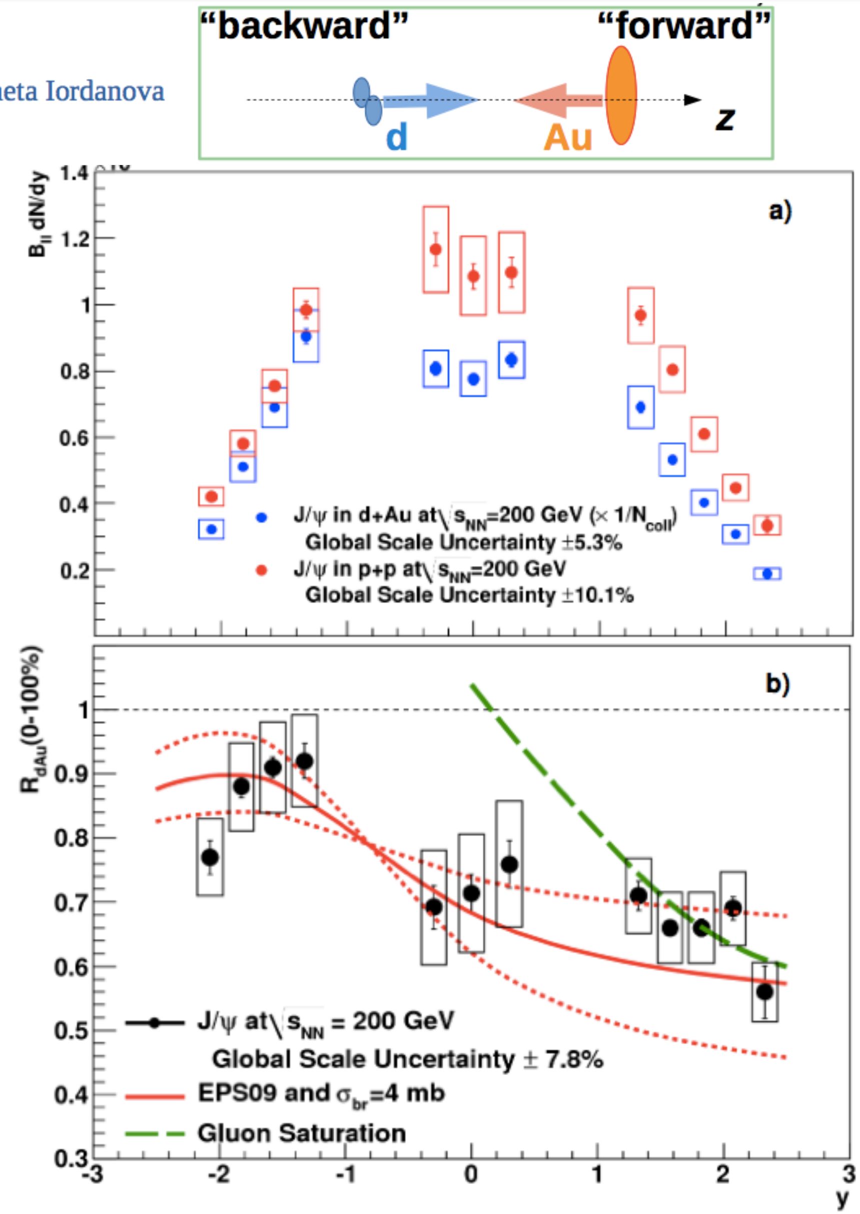
Aneta Iordanova



d+Au: J/ψ R_{dAu} vs. rapidity

- d+Au: Cold Nuclear Matter effects
  PHENIX: PRL 107, 142301 (2011)
- Forward-backward asymmetry
  - More suppression in "forward" (d-going) than in "backward" (Au-going) direction
- CNM Model: Nuclear shadowing + final state ccbar break-up:
  Eskola, Paukkunen, Salgado, JHEP 04065 (2009)
  - Reasonably describes minimum bias R_{AA} vs. y
  - *Note: does not model centrality dependence very well*

Aneta Iordanova

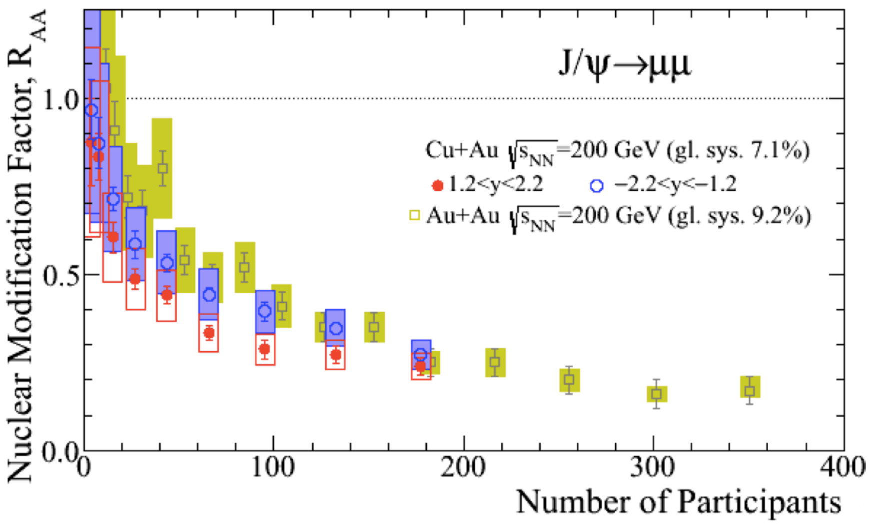


Cu+Au: hot and cold matter effects

- Asymmetric suppression

  PHENIX: PRC 90, 064908 (2014)

  - Suppression in "backward" (Au-going) direction comparable to Au+Au
  - Even stronger suppression in "forward" (Cu-going) direction

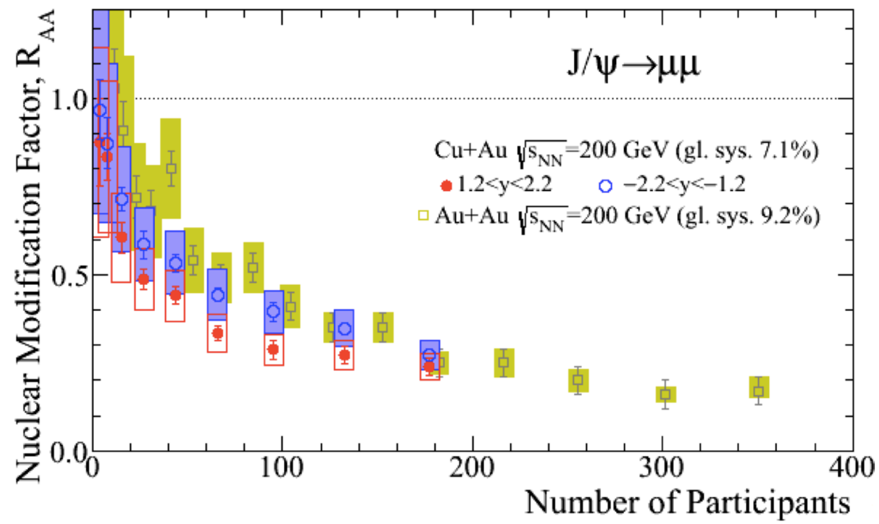


Cu+Au: hot and cold matter effects

- Asymmetric suppression

  PHENIX: PRC 90, 064908 (2014)

  - Suppression in "backward" (Au-going) direction comparable to Au+Au
  - Even stronger suppression in "forward" (Cu-going) direction

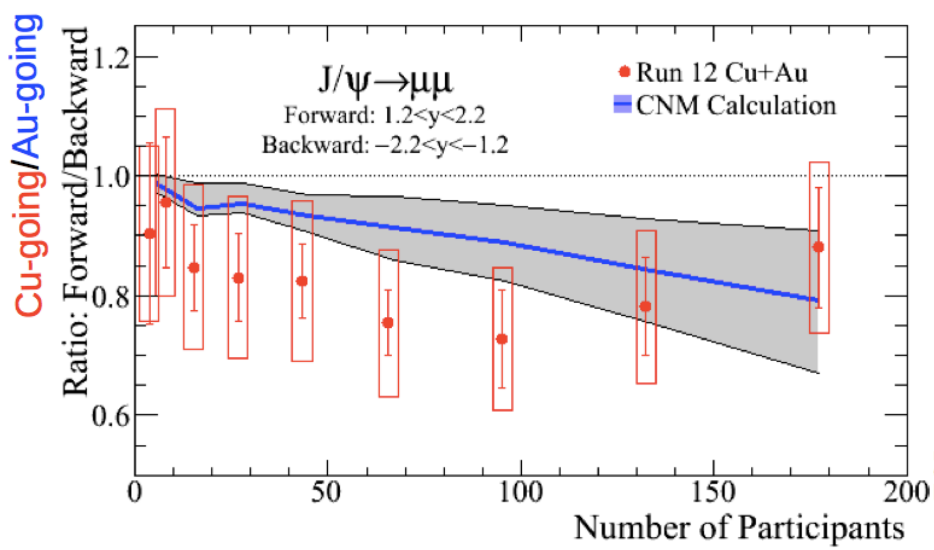


- CNM model: Nuclear shadowing + final state ccbar break-up

  Nagle, Frawley, Levy, Wysocki, PRC 84, 044911 (2011)

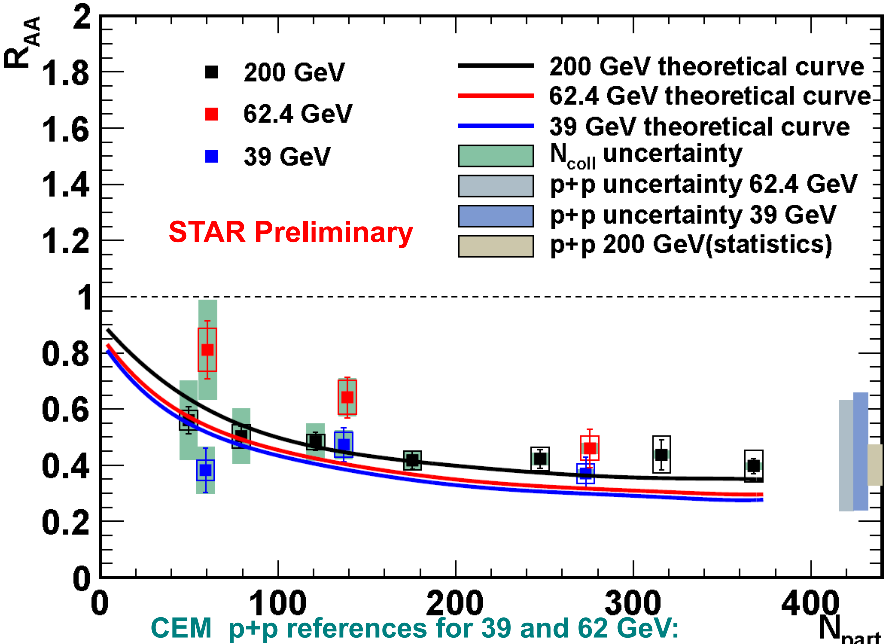
  - Qualitatively describes data
  - No hot effects included

Consistent with stronger low-x gluon suppression in Au than Cu



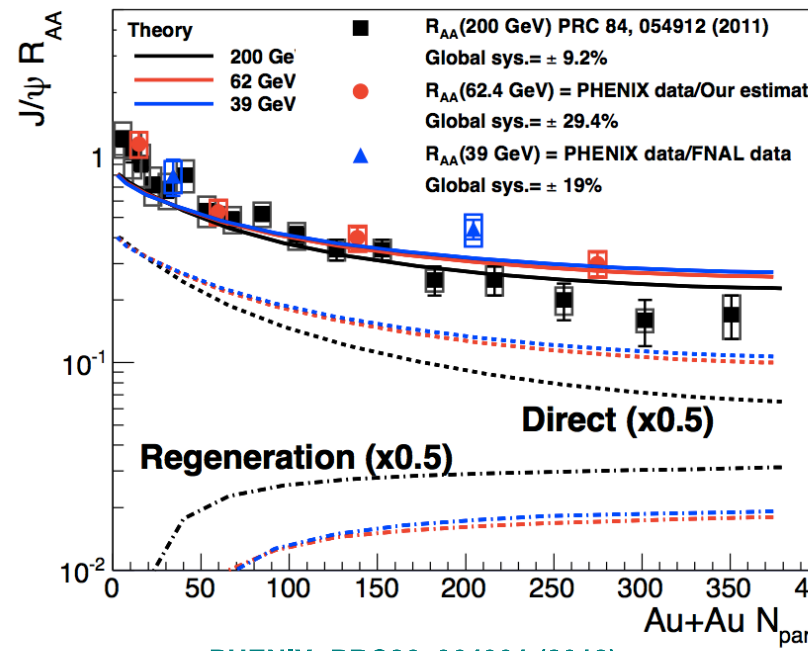
Au+Au J/ψ R_{AA} vs. beam energy

STAR mid-rapidity



CEM p+p references for 39 and 62 GeV:
Nelson, Vogt et al., PRC87, 014908 (2013)
Theory: Zhao, Rapp, PRC82, 064905 (2010)

PHENIX forward rapidity

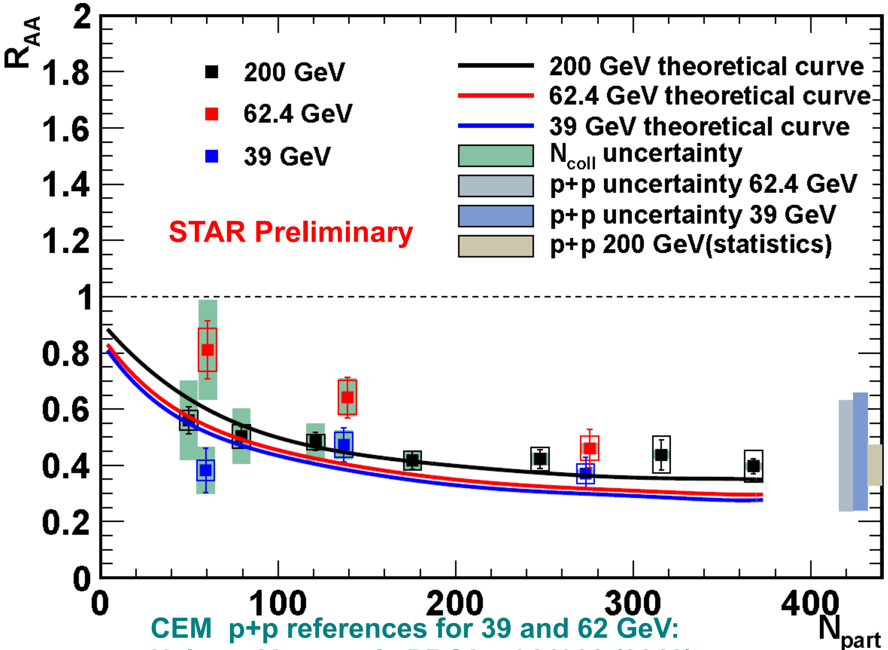


PHENIX: PRC86, 064901 (2012)

- Similar suppression in Au+Au at **200**, **62.4** and **39** GeV
  - Both at mid- and forward rapidity
  - p+p reference is based on CEM calculations → Large uncertainty
  - Consistent with theoretical calculations

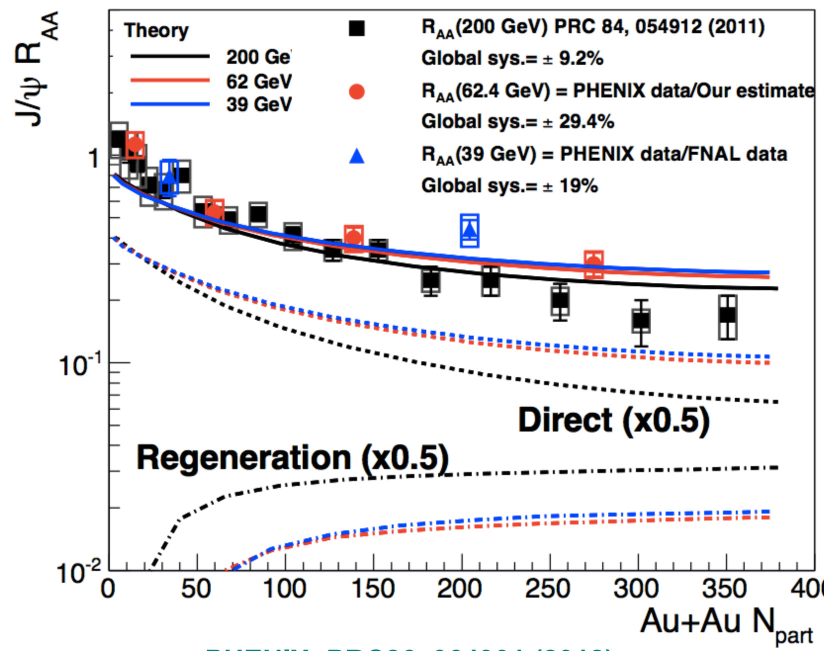
Au+Au J/ψ R_{AA} vs. beam energy

STAR mid-rapidity



CEM p+p references for 39 and 62 GeV:
Nelson, Vogt et al., PRC87, 014908 (2013)
Theory: Zhao, Rapp, PRC82, 064905 (2010)

PHENIX forward rapidity



PHENIX: PRC86, 064901 (2012)

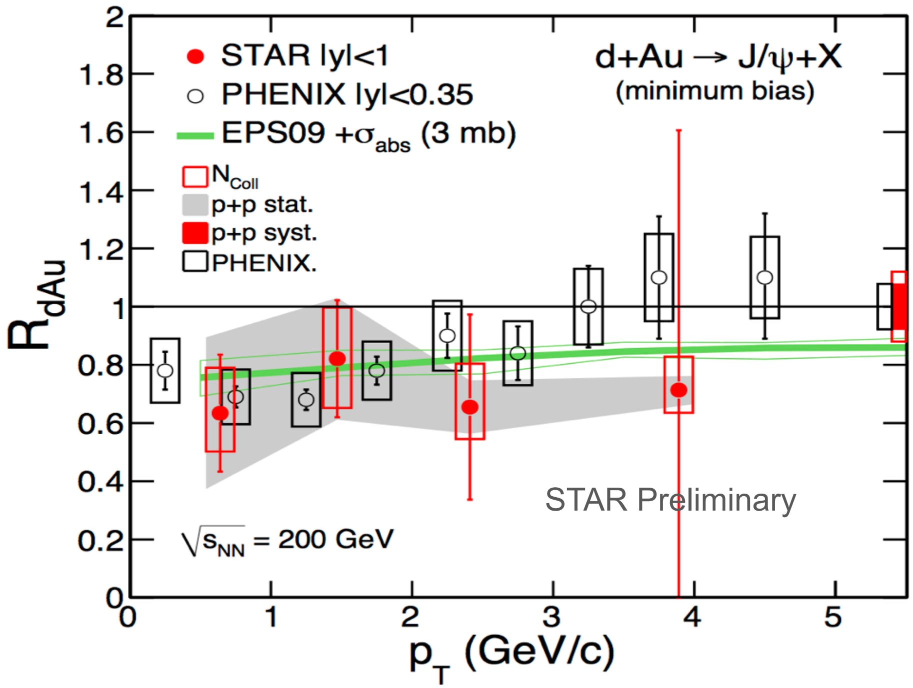
- Similar suppression in Au+Au at **200**, **62.4** and **39** GeV
  - Both at mid- and forward rapidity
  - p+p reference is based on CEM calculations → Large uncertainty
  - Consistent with theoretical calculations

Does coalescence compensate for melting?

Motivation for high-p_T J/ψ

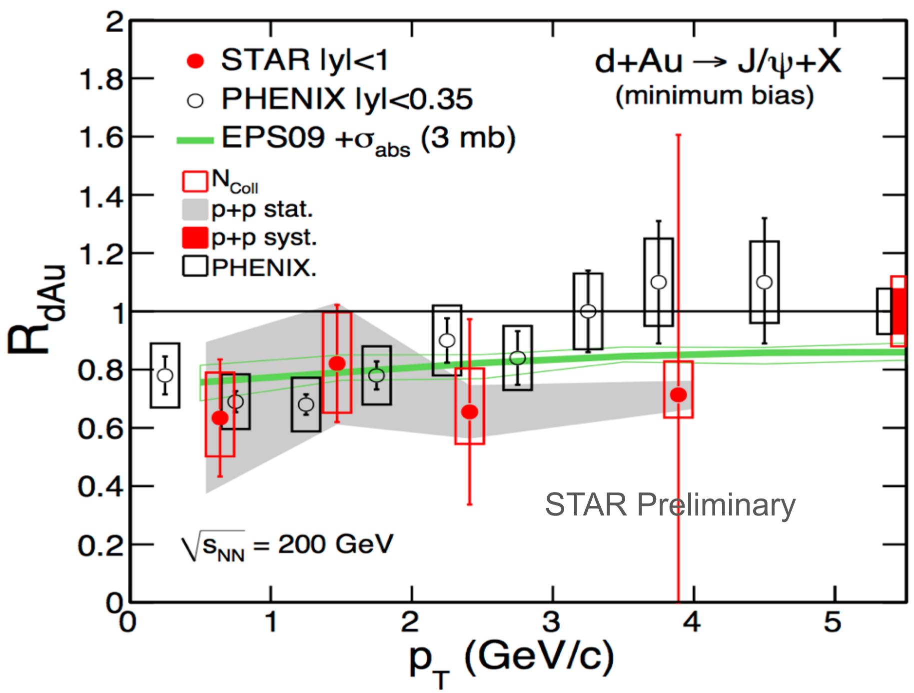
- d+Au → study of cold nuclear matter effects
- $R_{dAu} \approx 1$ for high p_T

  → CNM effects are small at high-p_T



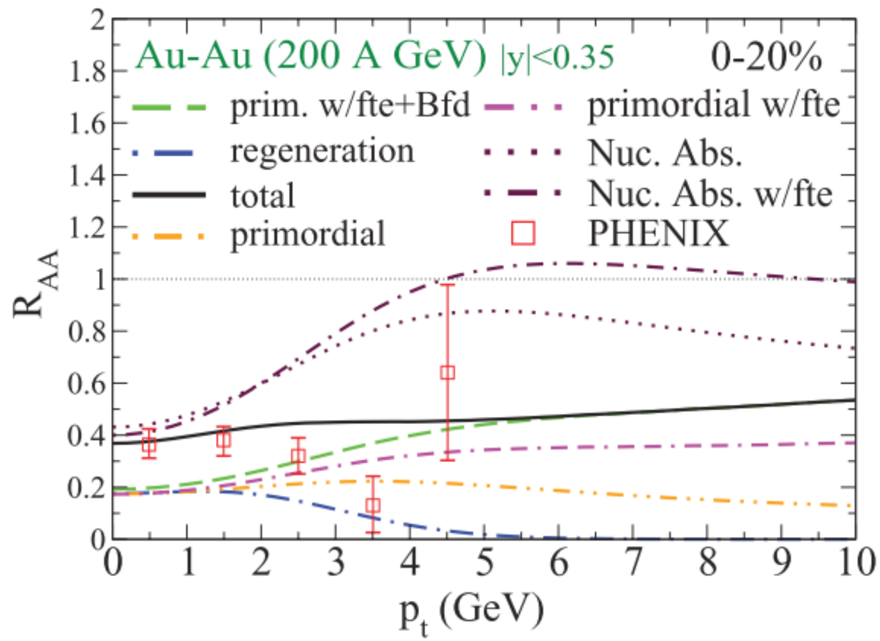
Motivation for high-p_T J/ψ

- d+Au → study of cold nuclear matter effects
- $R_{dAu} \approx 1$ for high p_T
  - → CNM effects are small at high-p_T



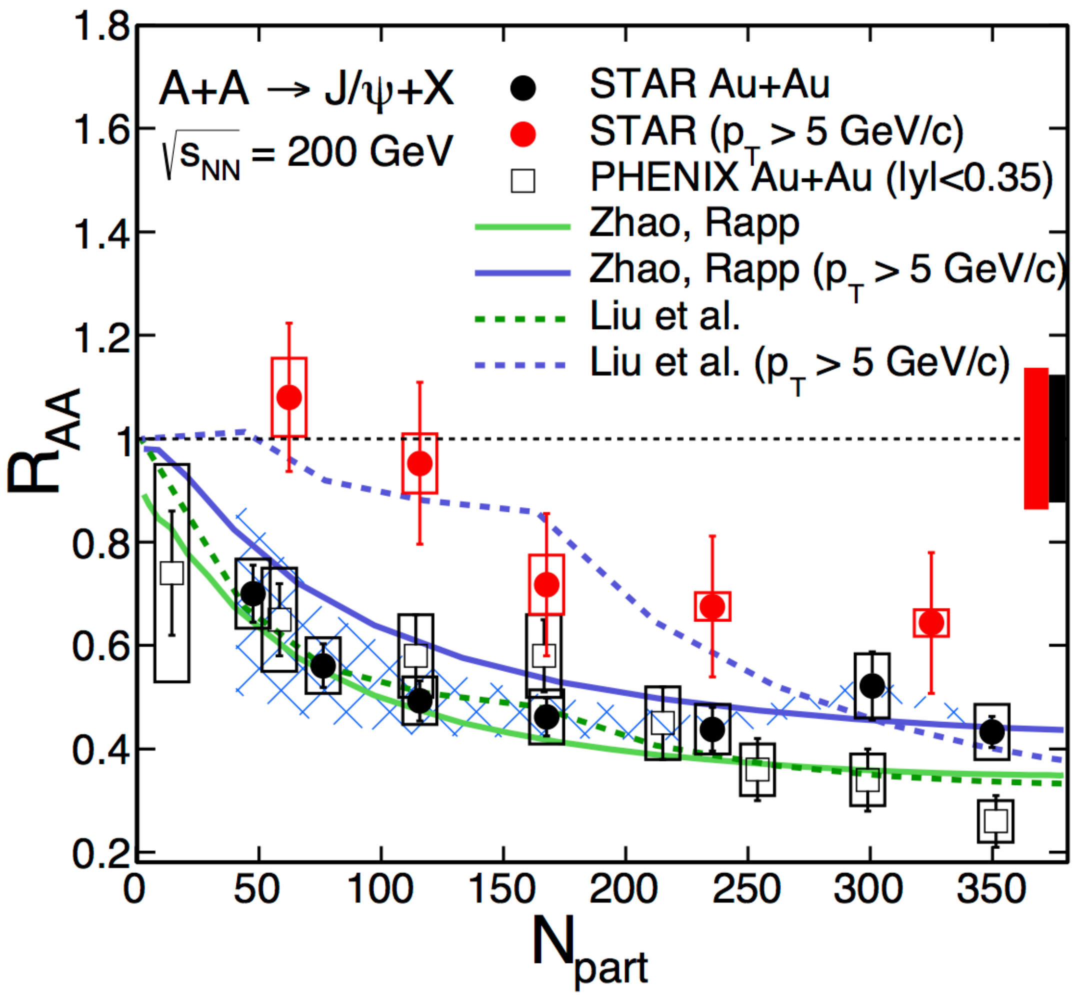
Model:
X. Zhao, R.Rapp, PRC82, 064905 (2010)

Data:
PHENIX, Nucl.Phys. A 774 (2006) 747



- Much less regeneration

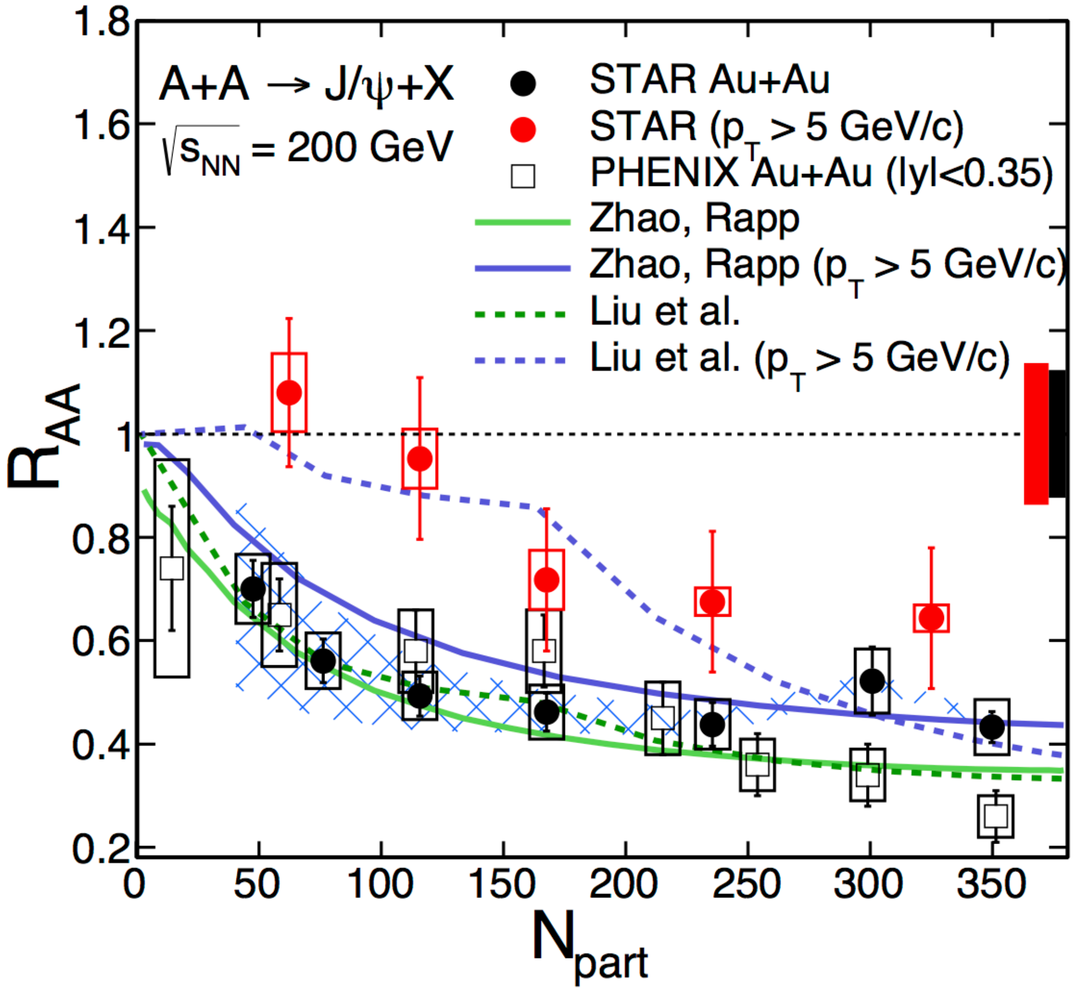
High-p_T J/ψ in Au+Au



- CNM effects are small
- Less regeneration
- Suppression of high-p_T J/ψ in central collisions

STAR low-p_T : arXiv:1310.3563
STAR high-p_T : PLB722, 55 (2013)
Liu et al., PLB 678, 72 (2009)
Zhao and Rapp, PRC 82, 064905(2010), PLB 664, 253 (2008)
PHENIX Phys. Rev. Lett. 98, 232301 (2007)

High-p_T J/ψ in Au+Au



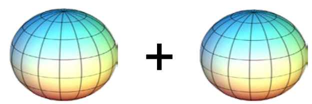
- CNM effects are small
- Less regeneration
- Suppression of high-p_T J/ψ in central collisions

STAR low-p_T : arXiv:1310.3563
STAR high-p_T : PLB722, 55 (2013)
Liu et al., PLB 678, 72 (2009)
Zhao and Rapp, PRC 82, 064905(2010), PLB 664, 253 (2008)
PHENIX Phys. Rev. Lett. 98, 232301 (2007)

High-p_T J/ψ suppression is clearly an sQGP effect

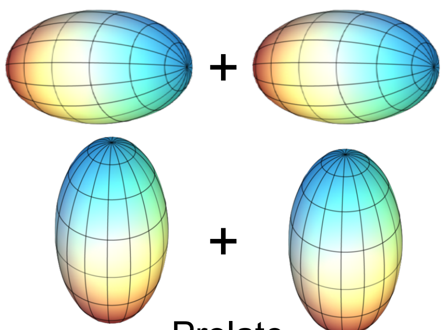
U+U: Higher energy densities

Au+Au Collisions

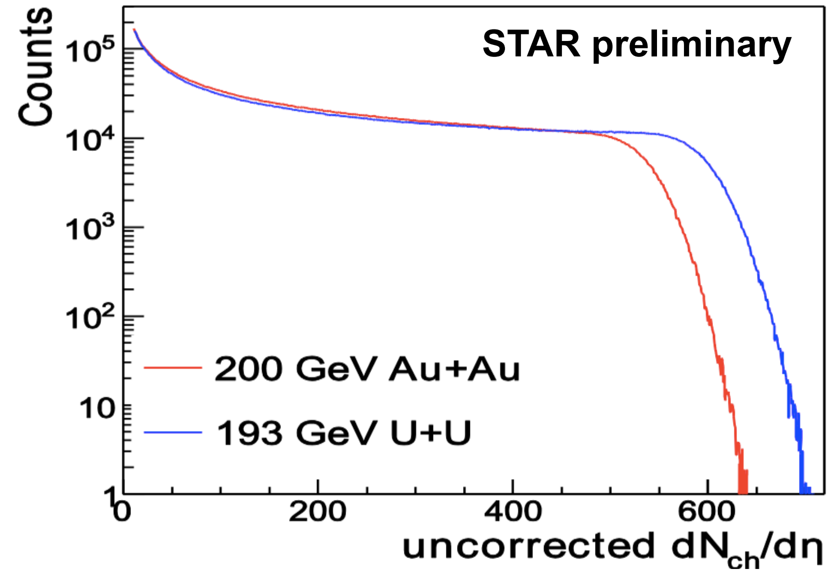


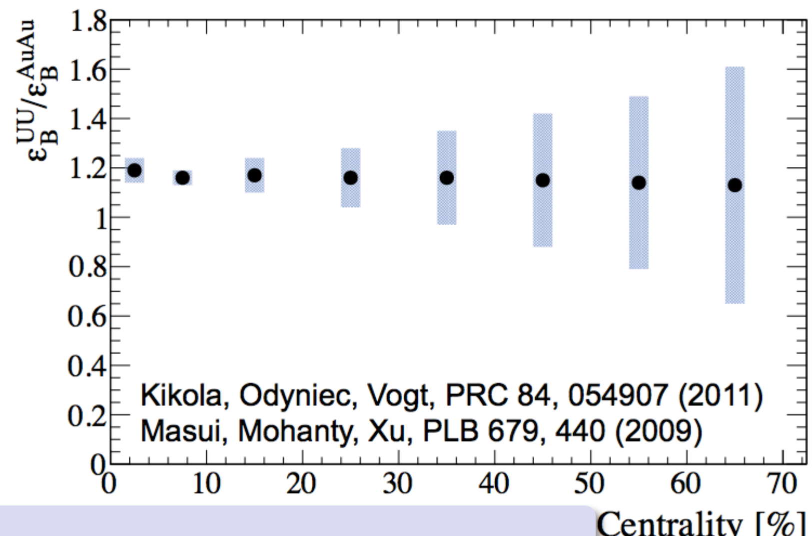
Oblate

U+U Collisions



Prolate



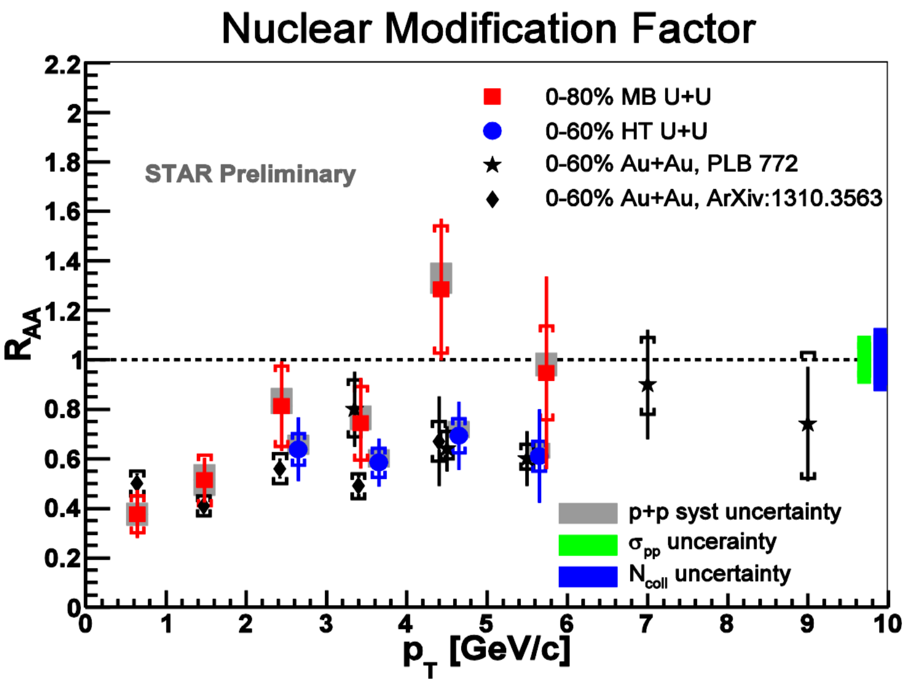


RHIC $\sqrt{s_{NN}}$=193 GeV U+U data (2012)

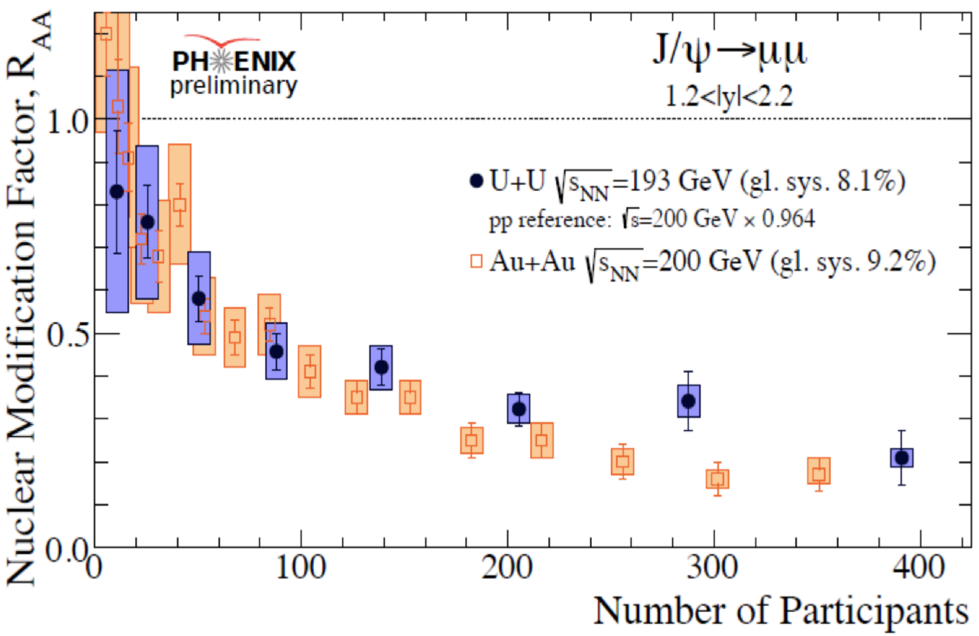
- Reach higher N_{part} than in Au+Au
- Reach higher N_{coll} than in Au+Au
- Provide ~20% higher energy density

Further test of dissociation-coalescence interplay

J/ψ R_{AA} in 193 GeV U+U

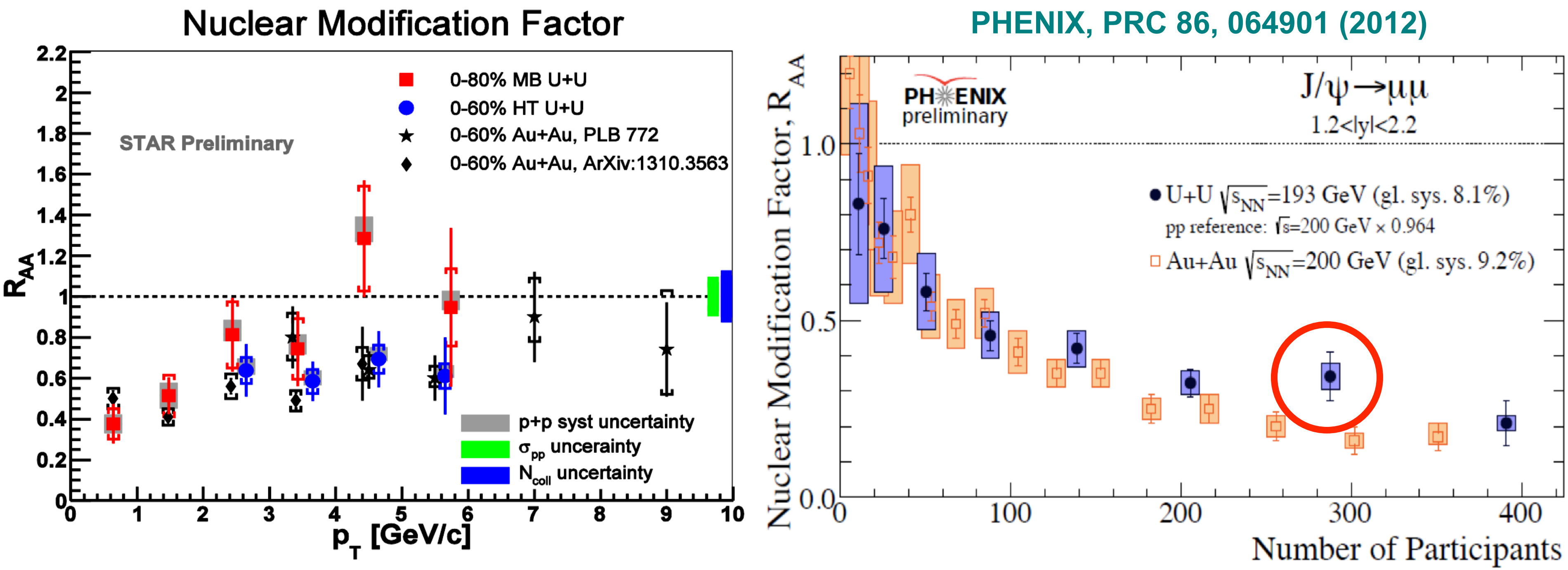


PHENIX, PRC 86, 064901 (2012)



- U+U trend generally similar to Au+Au

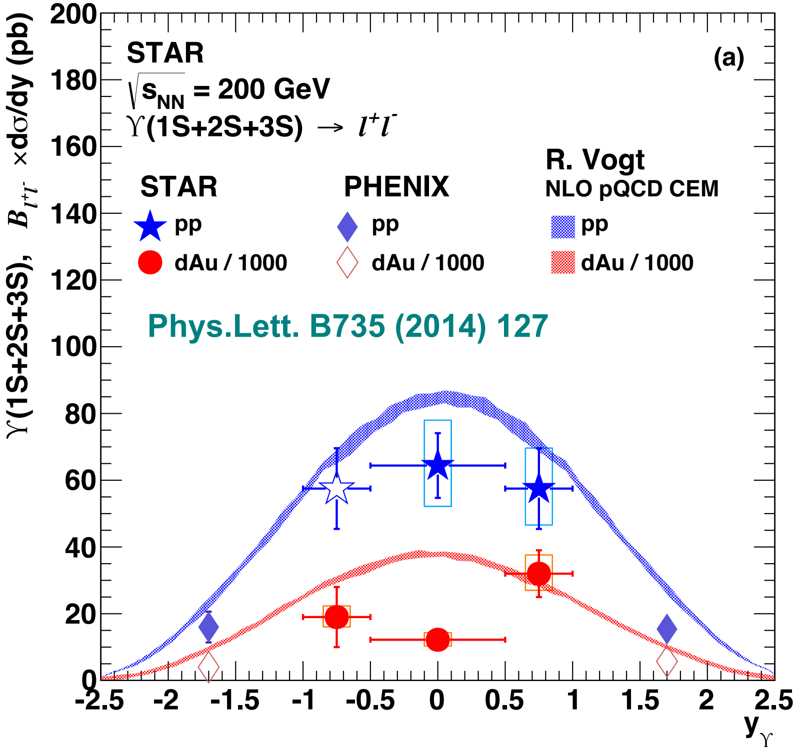
J/ψ R_{AA} in 193 GeV U+U



- U+U trend generally similar to Au+Au
- Indication of weaker suppression in central U+U

More coalescence in U+U than in Au+Au?

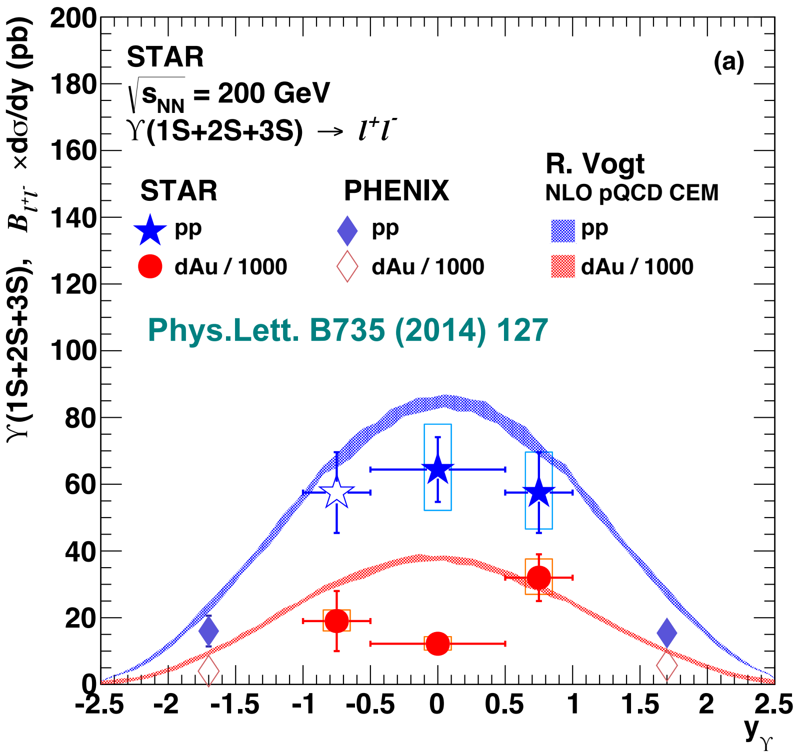
ϒ in p+p – baseline



- p+p ϒ cross section vs. y, compared to pQCD predictions

R. Vogt, Phys. Rep. 462125, 2008

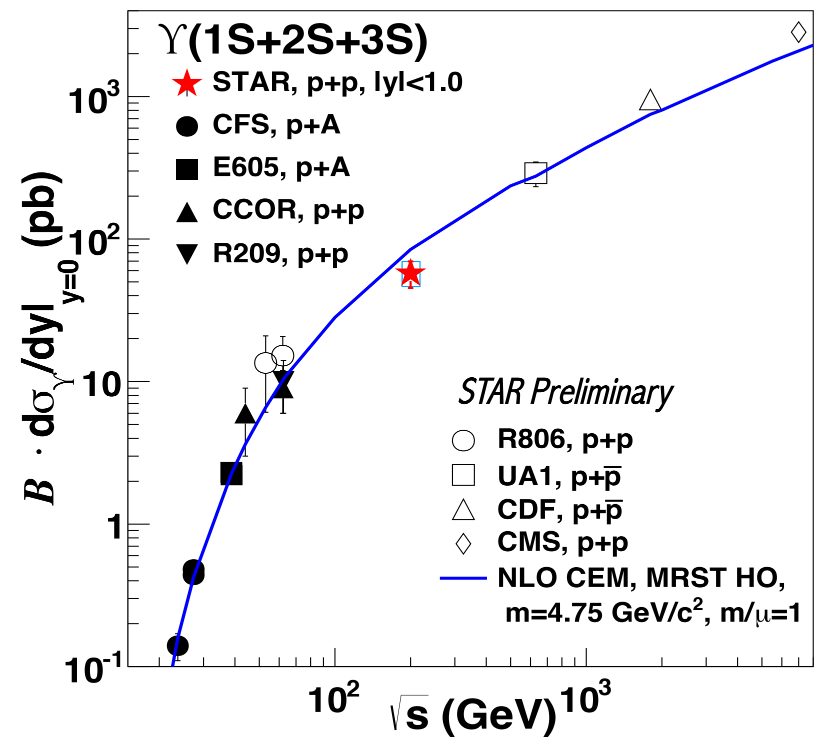
Υ in p+p – baseline and pQCD test



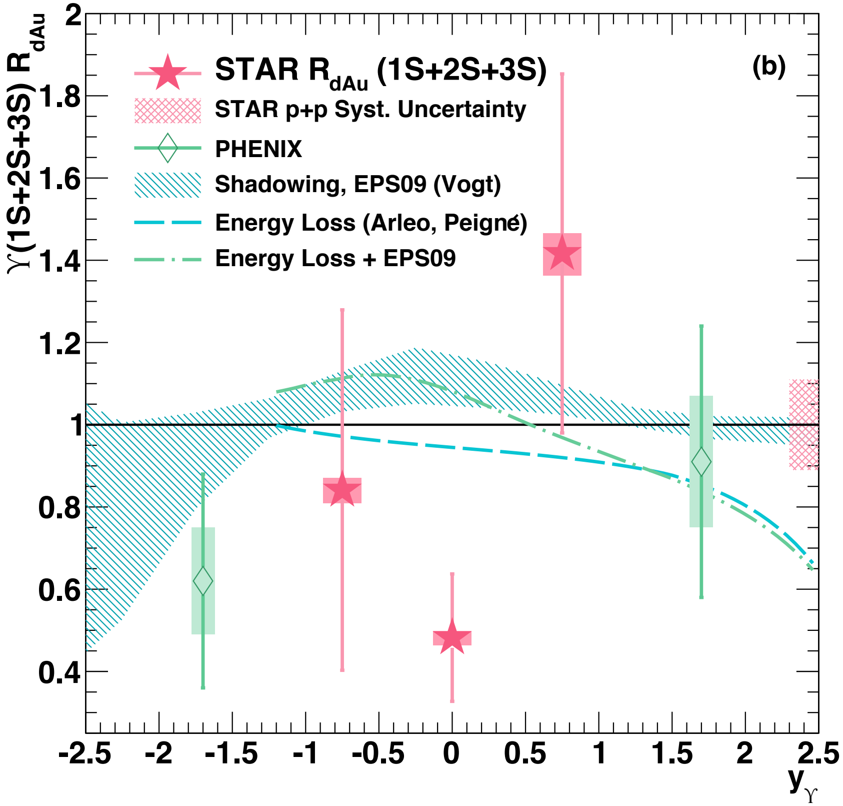
- p+p Υ cross section vs. y, compared to pQCD predictions

R. Vogt, Phys. Rep. 462125, 2008

- p+p Υ cross section, compared to world data trend



Υ R_{dAu} – CNM effects



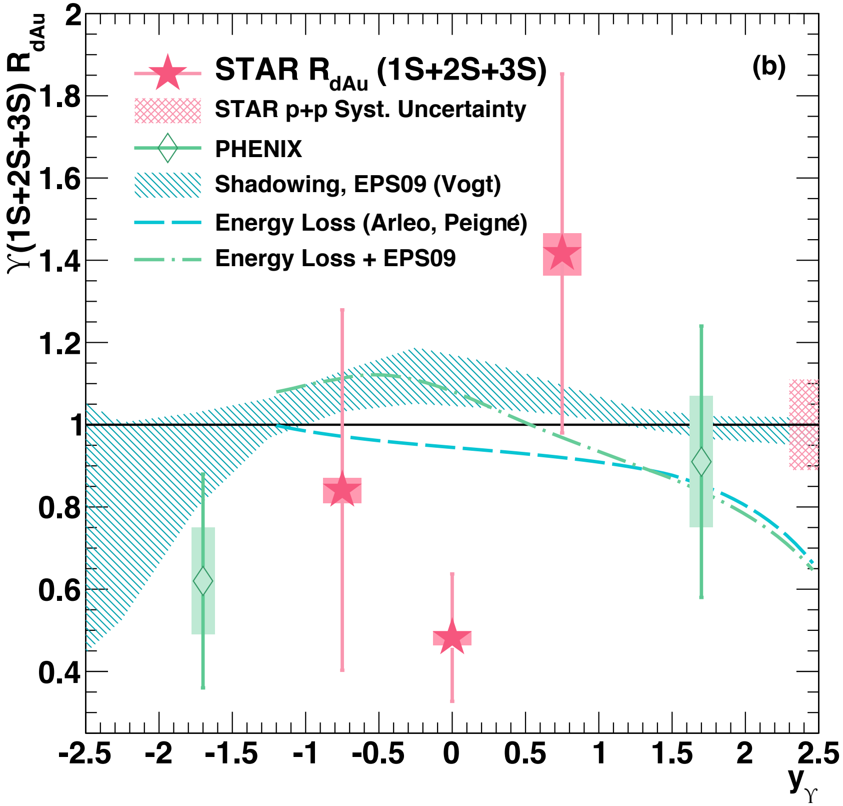
STAR: Phys.Lett. B735 (2014) 127

- Models include
  - Gluon nPDF (Anti)shadowing
  - Initial parton energy loss
- Indication of suppression at mid-rapidity beyond models

R_{dAu} = 0.48 ± 0.14*(stat)* ± 0.07*(syst)* ± 0.02*(pp stat)* ± 0.06*(pp syst)*

|y|<0.5

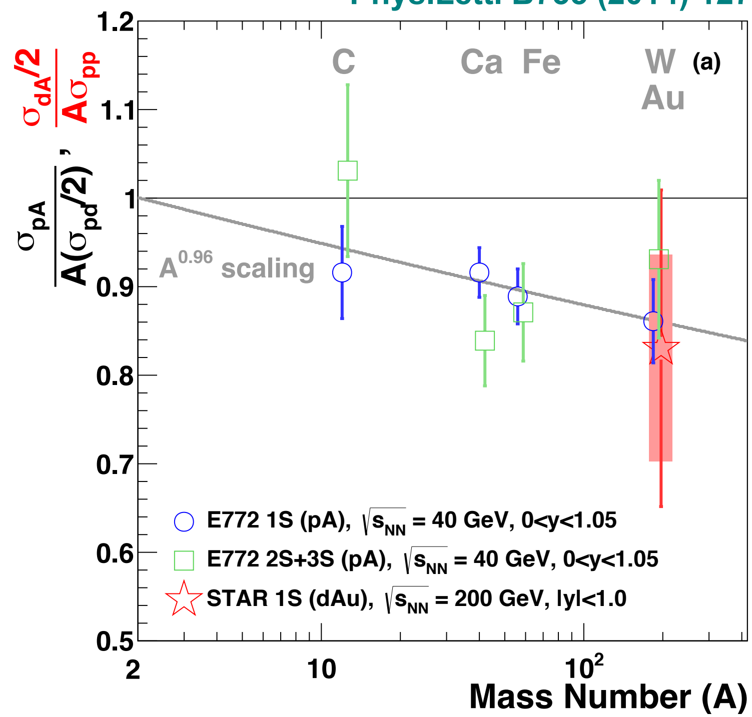
Υ R_{dAu} – CNM effects



STAR: Phys.Lett. B735 (2014) 127

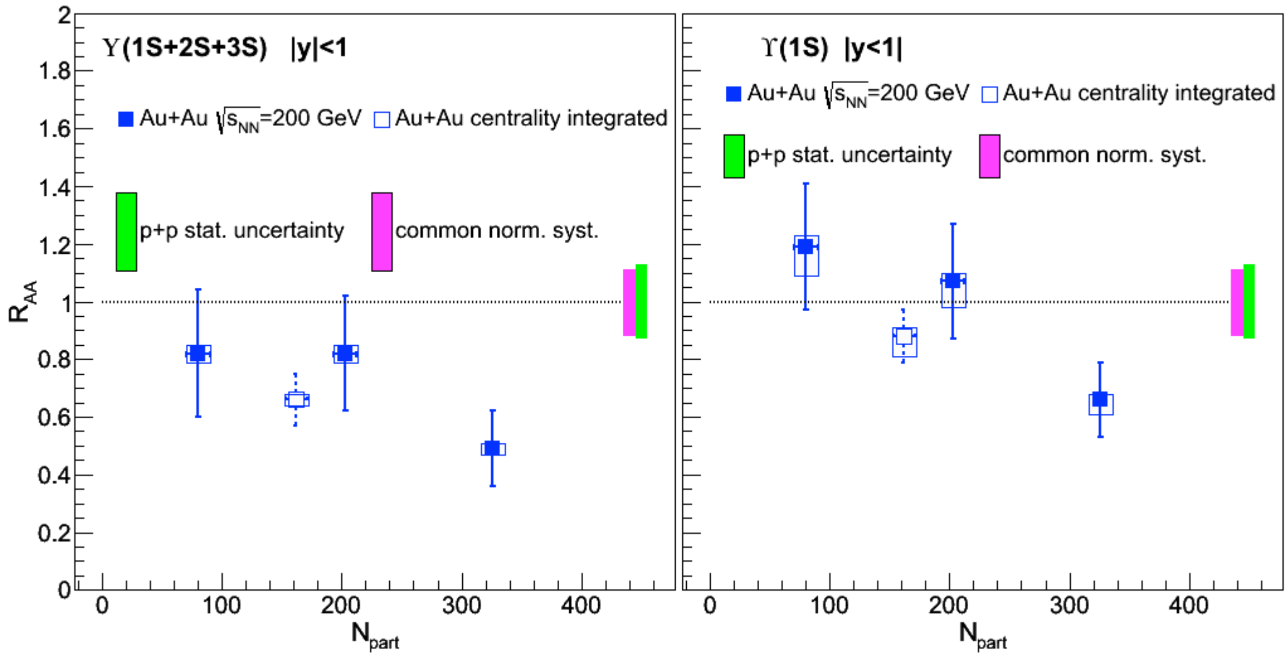
- Models include
  - Gluon nPDF (Anti)shadowing
  - Initial parton energy loss
- Indication of suppression at mid-rapidity beyond models

Phys.Lett. B735 (2014) 127

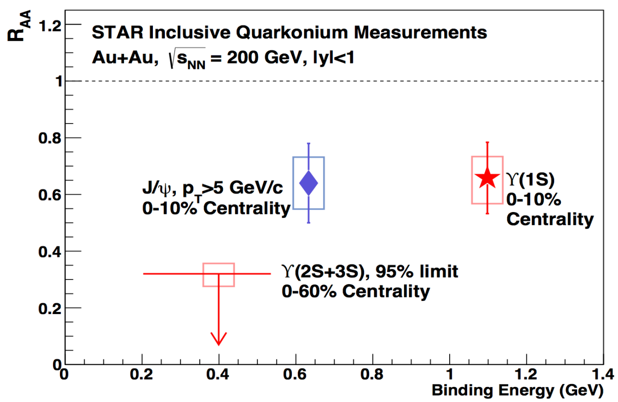


- STAR data consistent with E772 despite difference in energy

R_{AA} of ϒ states in Au+Au



STAR:
Phys.Lett. B735 (2014) 127



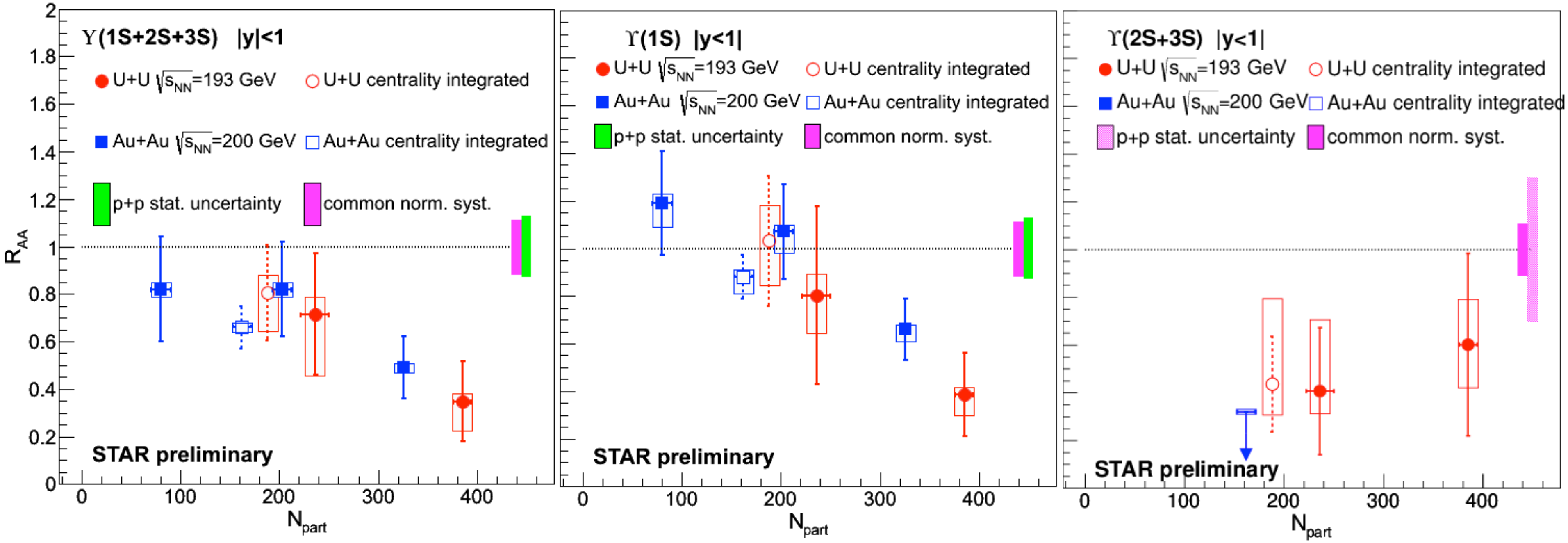
- Peripheral ϒ consistent with no suppression
- Central ϒ shows significant suppression

- Central ϒ(1S): indication of a suppression

- Excited states ϒ(2S) and ϒ(3S) consistent with complete melting

ϒ suppression pattern supports sequential melting

R_{AA} of Υ states: Au+Au vs. U+U



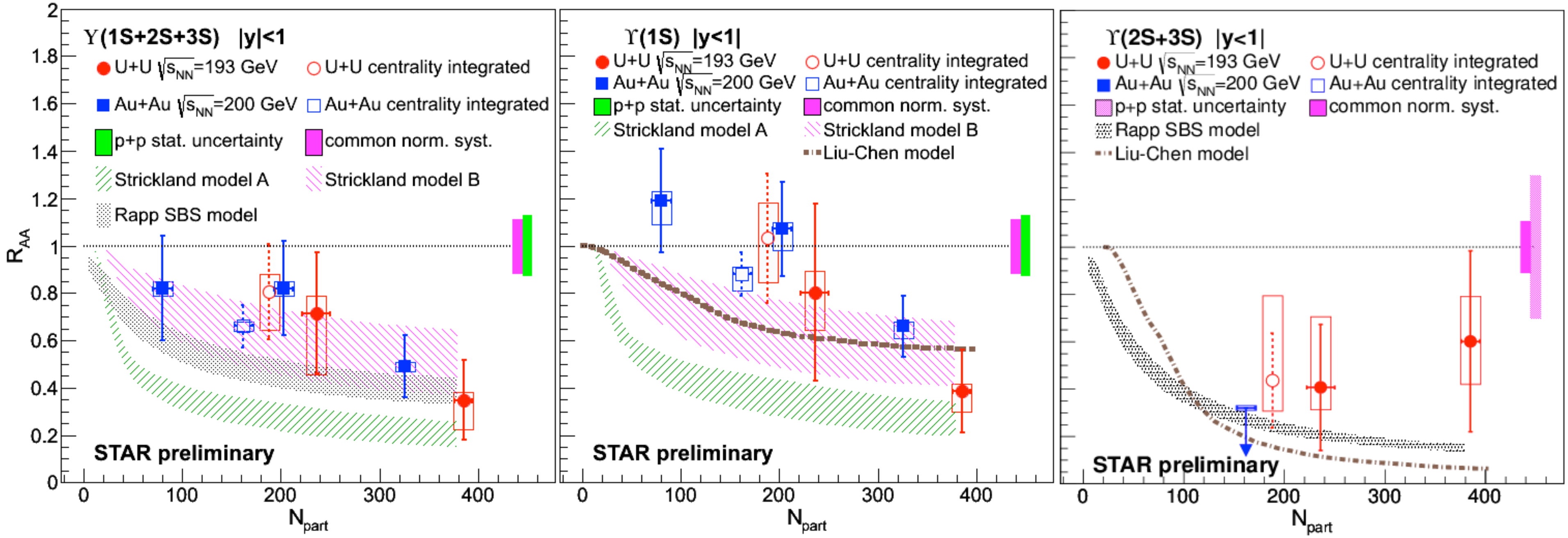
- Peripheral Υ consistent with no suppression
- Central Υ shows significant suppression

- Central Υ(1S): *significant suppression*

- Excited states Υ(2S) and Υ(3S) consistent with complete melting
- *Hint of their presence in U+U collisions*

New U+U data extends Au+Au trend – is U+U different?

R_{AA} of ϒ states: data vs. models



Strickland, Bazov, Nucl.Phys.A 879, 25 (2012)

- No CNM effects, 428<T<443 MeV
- Potential model 'B' based on **heavy quark internal energy**
- Potential model 'A' based on heavy quark free energy (disfavored)

Liu, Chen, Xu, Zhuang, Phys.Lett.B 697, 32 (2011)

- Potential model, no CNM effects
- T=340 MeV, only excited states dissociate

Emerick, Zhao, Rapp, Eur.Phys.J A48, 72 (2012)

- **CNM effects** included
- Strong binding scenario

Suppression indicates ϒ melting in a deconfined medium

However: CNM effects to be understood → **RHIC 2015 p+Au run**

Summary

Hot medium effects: Significant suppression of high-p_T J/ψ, and similar ϒ(1S) suppression in central A+A collisions

- ϒ(2S) and ϒ(3S) suppression is stronger than ϒ(1S)
  → *clear signal of melting in a deconfined medium*
- ϒ suppression in most central collisions similar to LHC

J/ψ regeneration:

- Larger suppression at RHIC than LHC
- Similar suppression in central 39, 62.4 and 200 GeV data

CNM effects:

- **Important role played for** J/ψ and may be important for ϒ
- Forward-Backward difference in asymmetric systems: nuclear shadowing

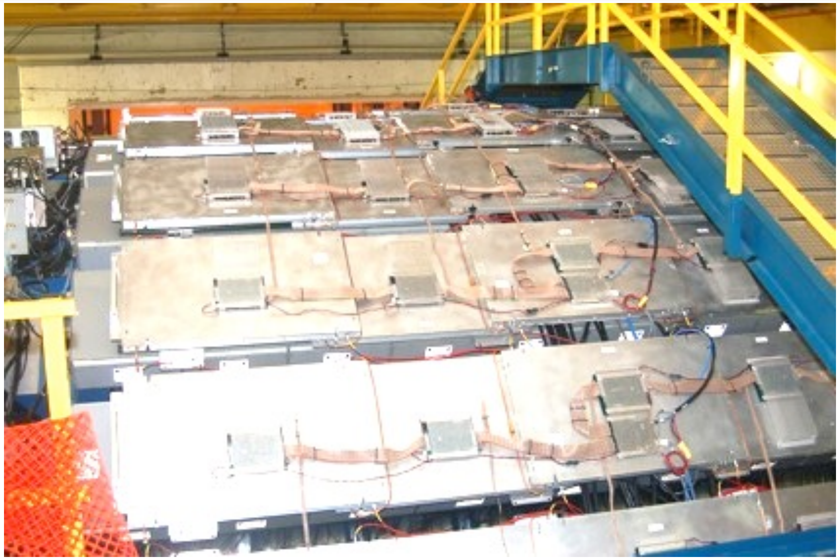
U+U measurements: similar suppression patterns to Au+Au

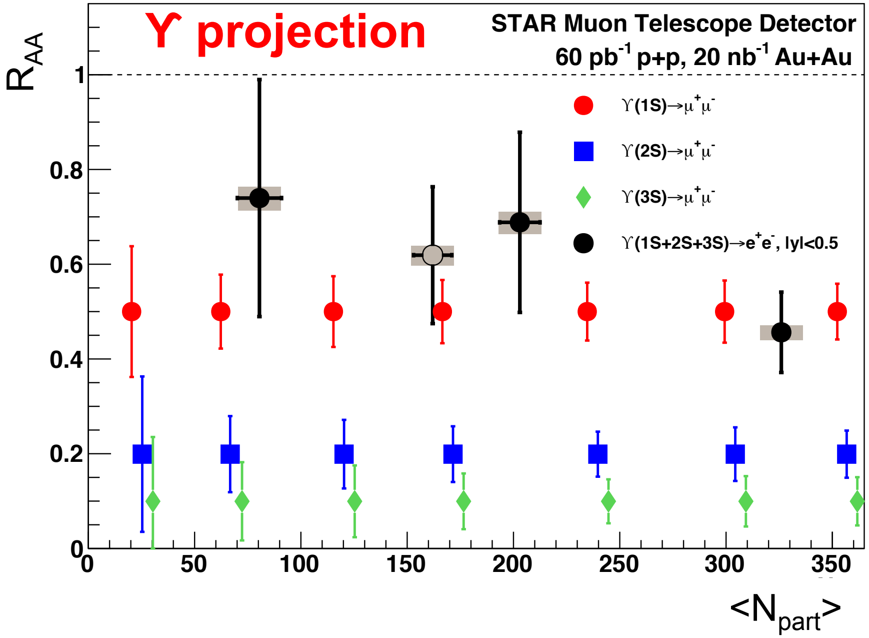
- May be more J/ψ coalescence in central collisions
- Indication of ϒ(2S+3S). Confirmed central ϒ(1S) suppression

Outlook: STAR MTD

Muon Telescope Detector

- Outermost, gas detector
- **Precision measurement of heavy quarkonia through the muon channel**
- Acceptance: 45% in azimuth, |y|<0.5

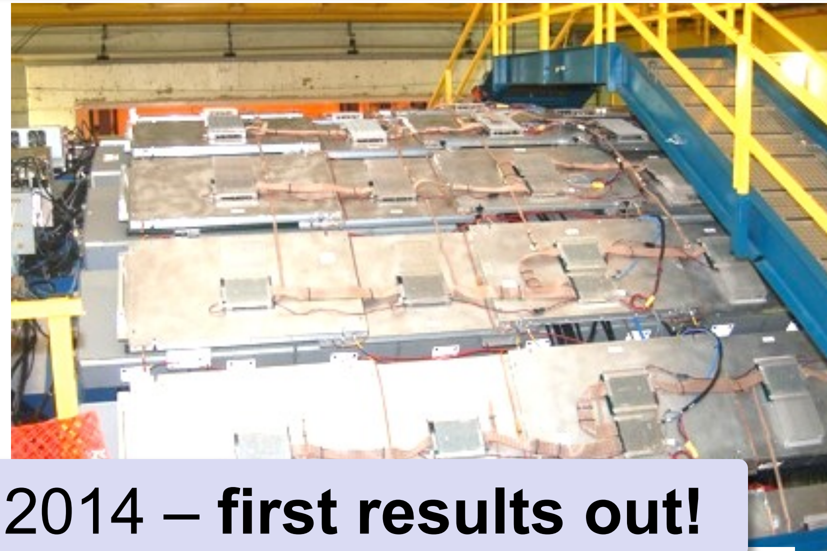




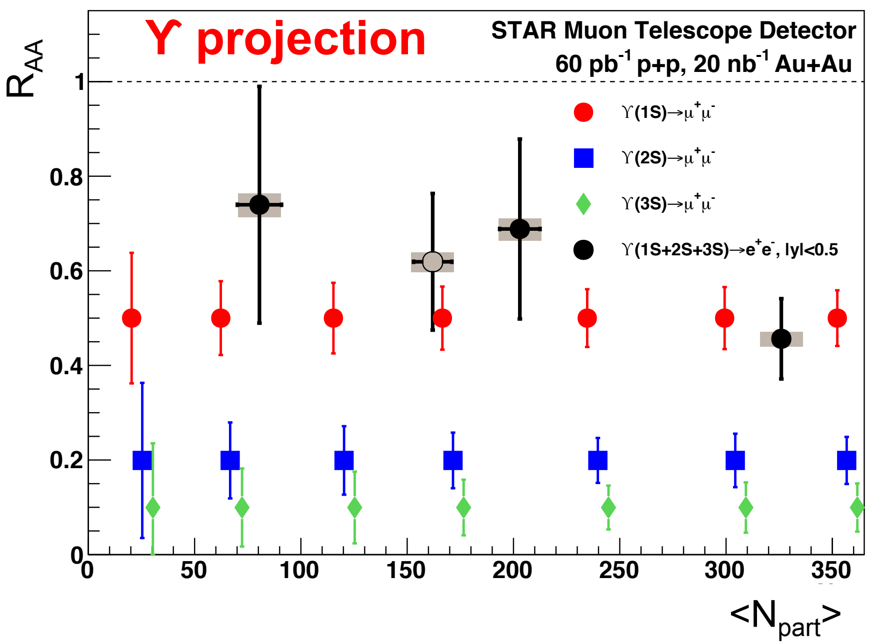
Outlook: STAR MTD

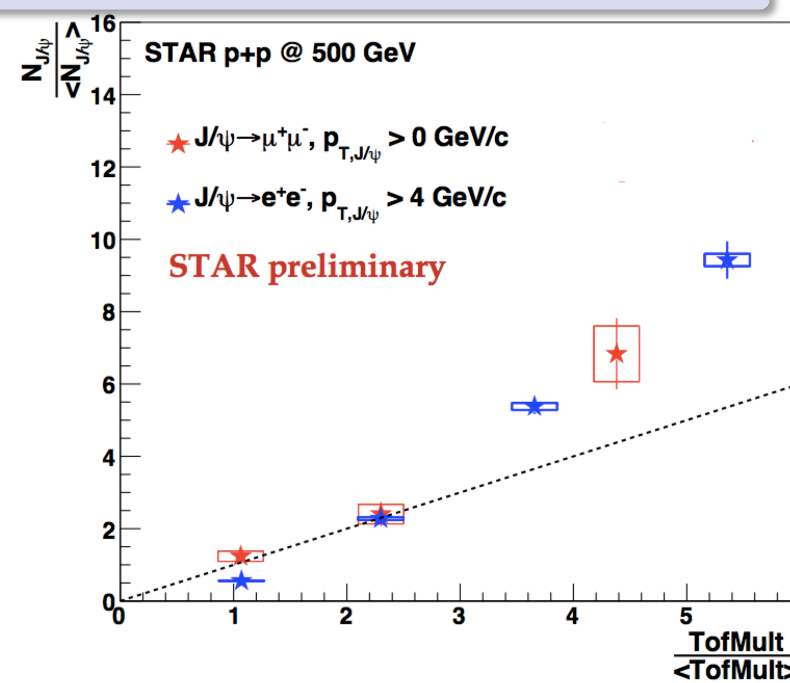
Muon Telescope Detector

- Outermost, gas detector
- **Precision measurement of heavy quarkonia through the muon channel**
- Acceptance: 45% in azimuth, |y|<0.5



~13.8 nb^{-1} Au+Au data from 2014 – **first results out!**



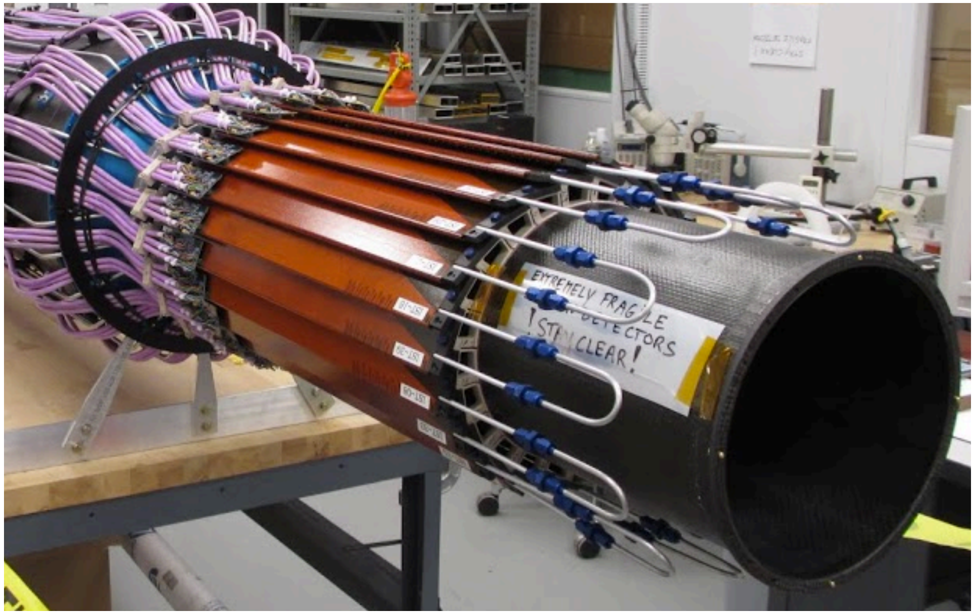


Outlook: STAR HFT, PHENIX FVTX

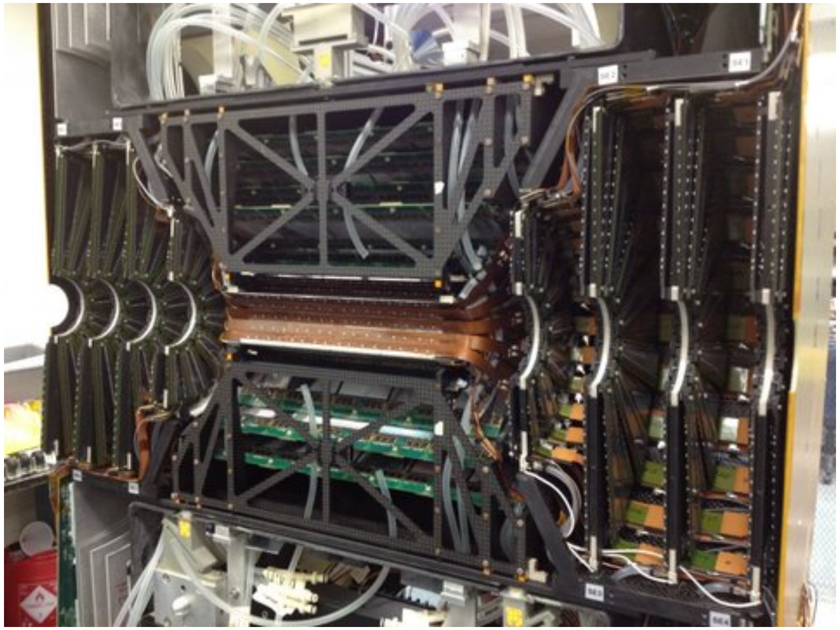
- Innermost, silicon detector subsystems
- STAR HFT (2014) and PHENIX VTX (2011) at midrapidity
- PHENIX FVTX (2012) at forward rapidity
- Highly improved tracking with secondary vertex reconstruction

→ **Separation of prompt J/ψ production and B→J/ψ**

STAR Heavy Flavor Tracker



PHENIX VTX and FVTX



Thank you!

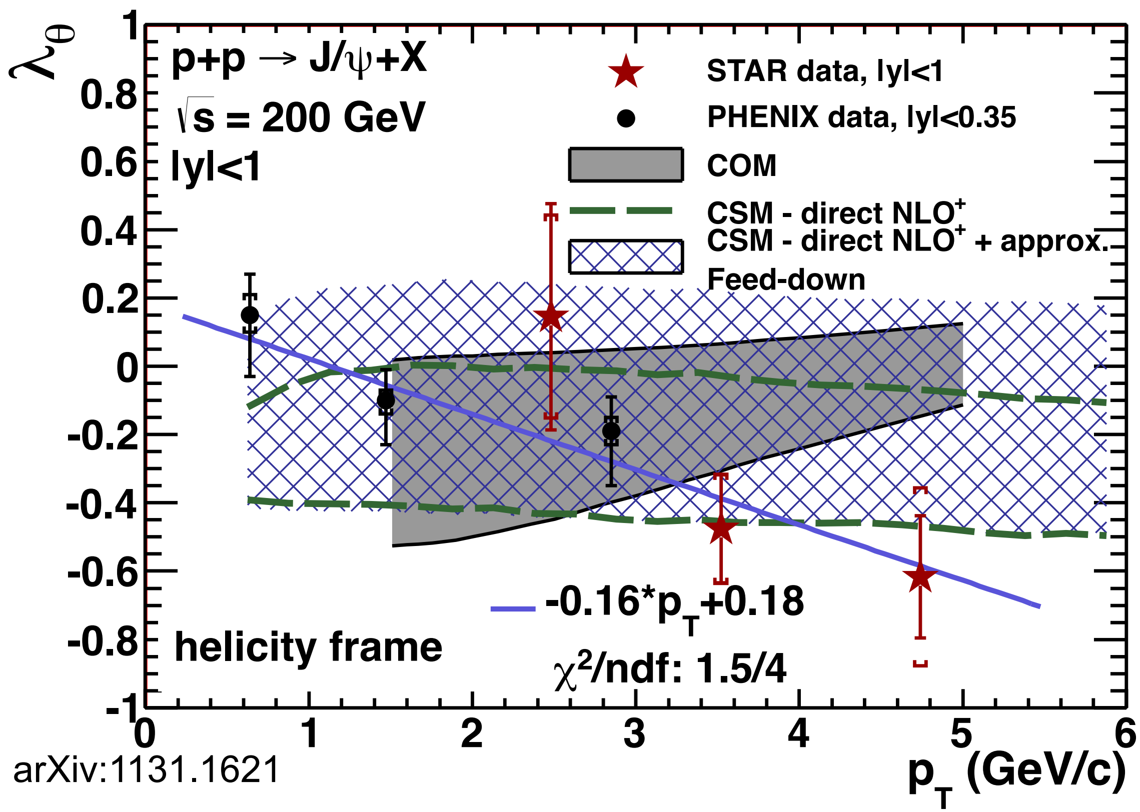
Special acknowledgements to
Aneta Iordanova
Barbara Trzeciak
Petr Chaloupka

<<< Talk

^^^
Sunrise over the Keszthely bay

Backup >>>

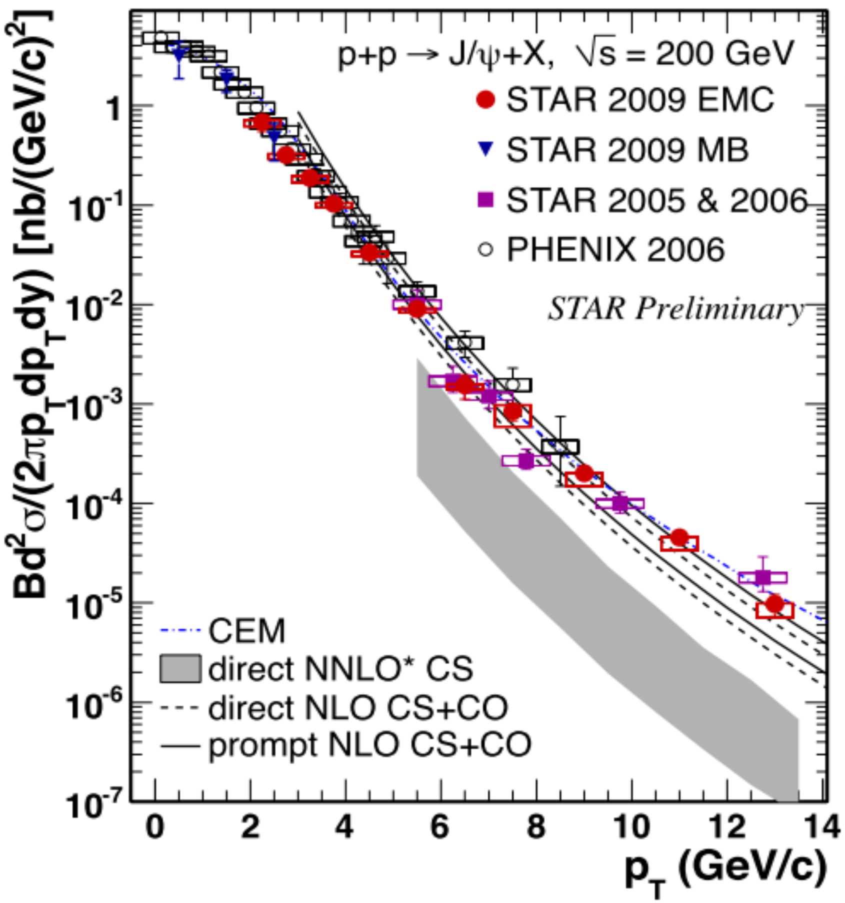
J/ψ in p+p – polarization

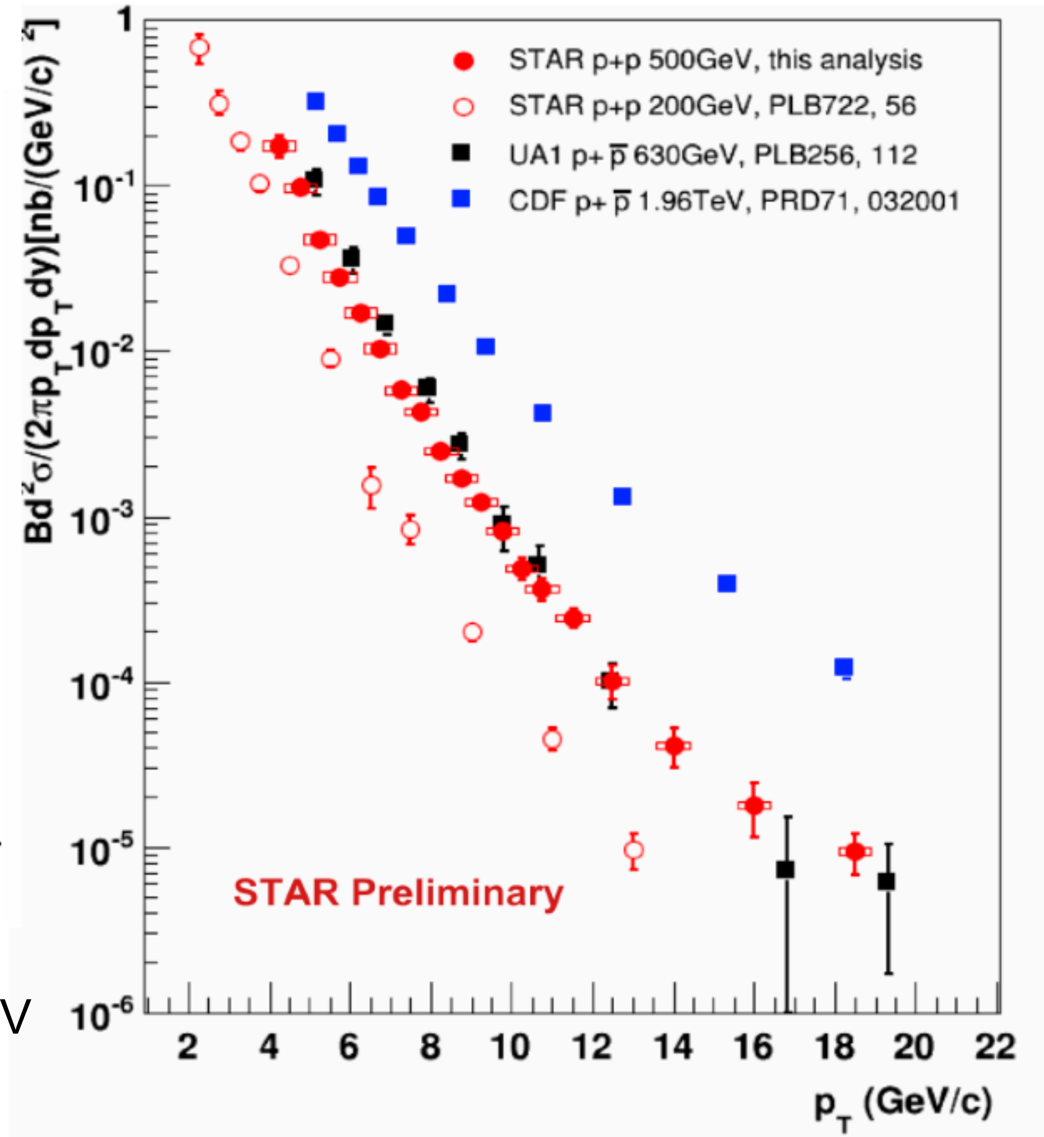


arXiv:1131.1621

- 2<pT<6 GeV/c
- STAR+PHENIX consistent with NLO +CSM
  - Higher statistics needed to discriminate
- p+p 500 GeV results will improve precision for future CNM calculations

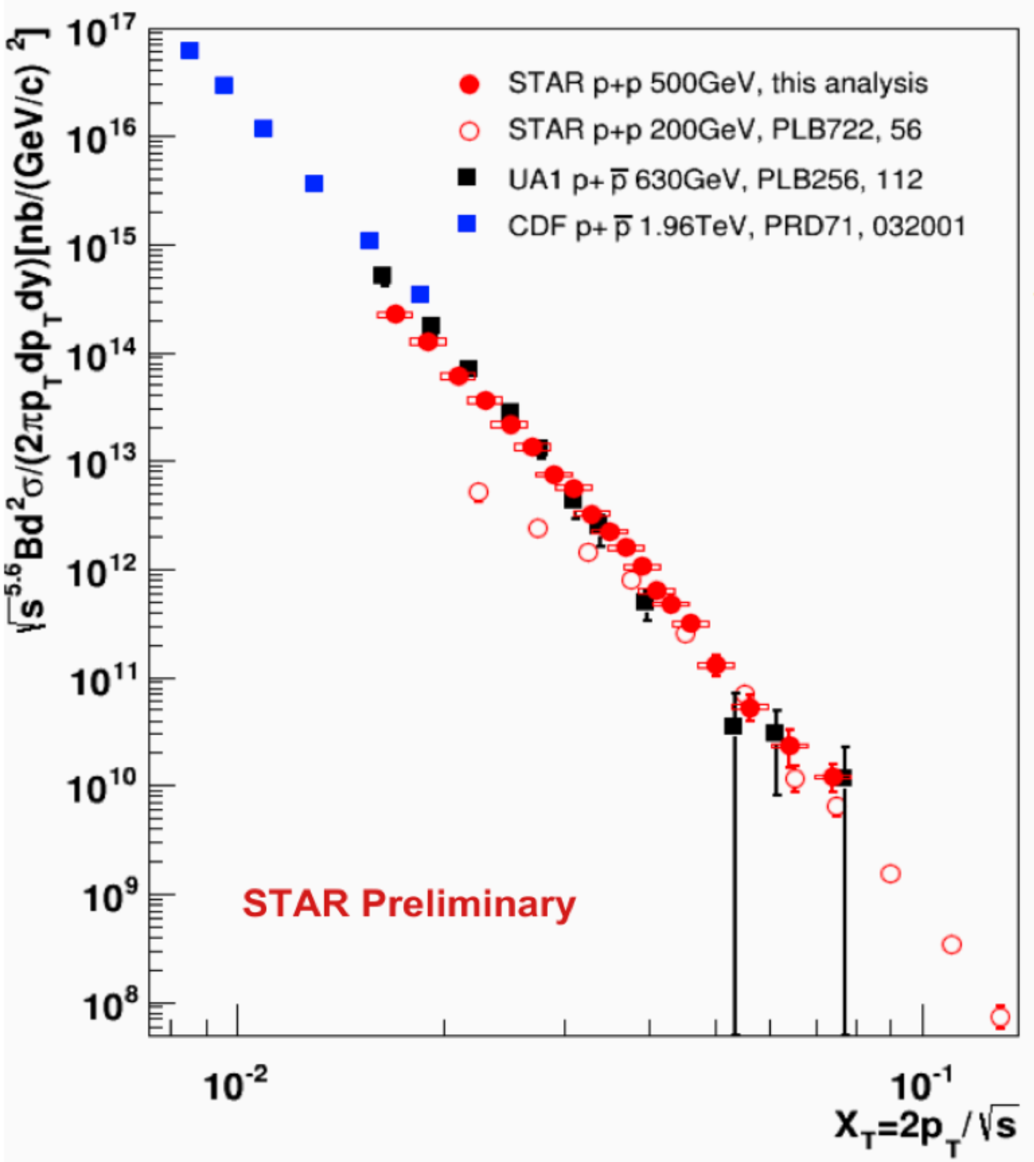
J/ψ spectra, p+p at 500 GeV





- Precise measurements at 500 GeV
- up to p_T=20 GeV

J/ψ x_T-scaling



$$\frac{d^2\sigma}{2\pi p_T\, dp_T\, dy} = g(x_T)/(\sqrt{s})^n$$

200 GeV:

- high-p_T x_T-scaling with
  n = 5.6 ± 0.2

Phys. Rev. C 80, 041902 (2009)

- Breaking of scaling: transition to soft processes

500 GeV:

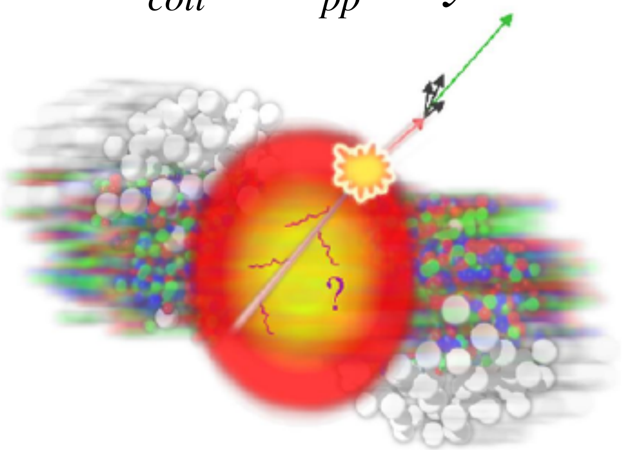
- x_T-scaling present down to lower p_T

Experimental approaches

- p+p collisions: Reference system and pQCD benchmark
- d+A, p+A: Understand cold nuclear matter effects
- A+A: Hot medium effects

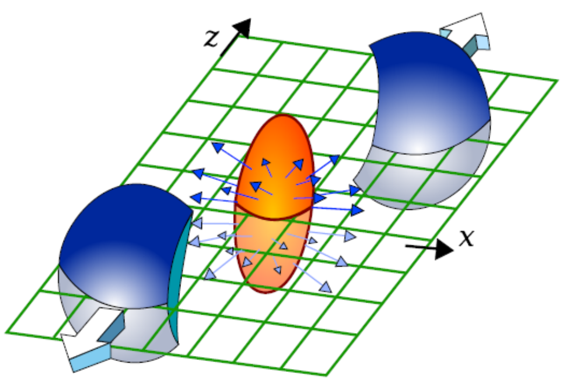
Nuclear modification

$$R_{AA} = \frac{1}{N_{coll}} \frac{dN_{AA}/dy}{dN_{pp}/dy}$$



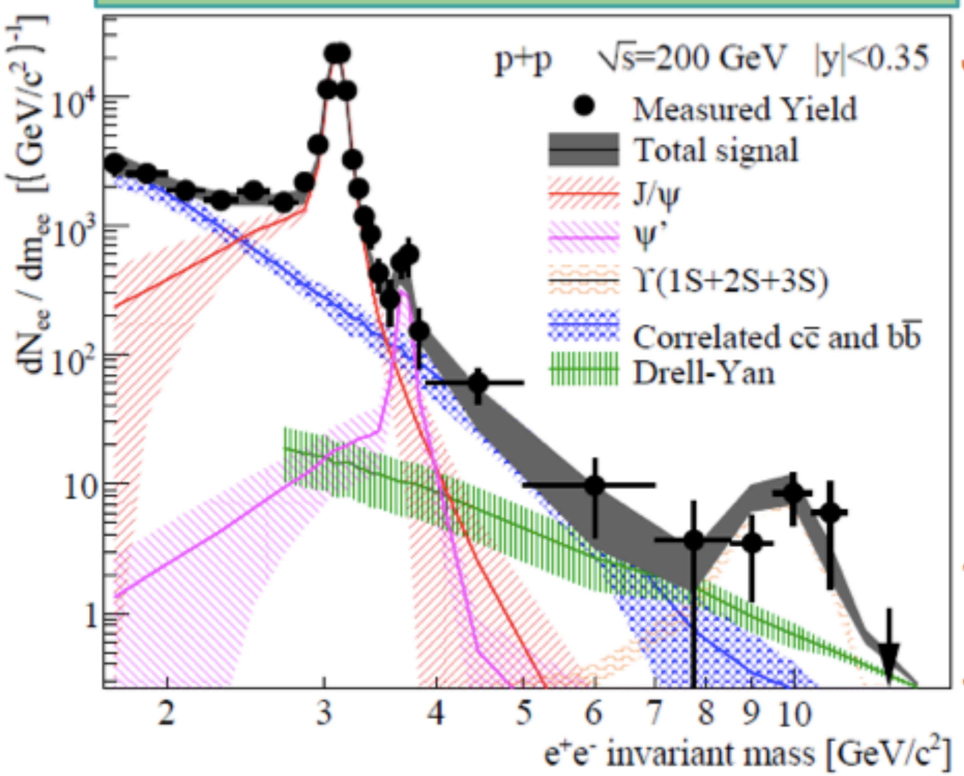
Participation in collectivity

$$\frac{dN}{d\phi} \sim 1 + \sum_n 2v_n \cos\left(n\left(\phi - \phi_{RP}\right)\right)$$



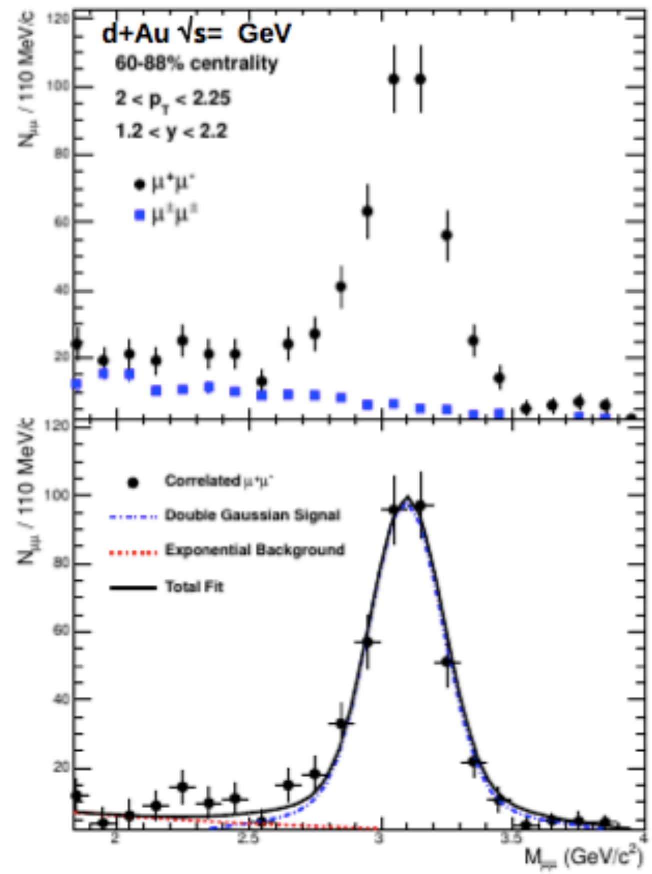
PHENIX dilepton invariant mass

Central arms



Phys. Rev. C. 91 024913 (2015)

Forward arms



Phys. Rev. C 87, 034904

30/June/2015 Aneta Iordanova

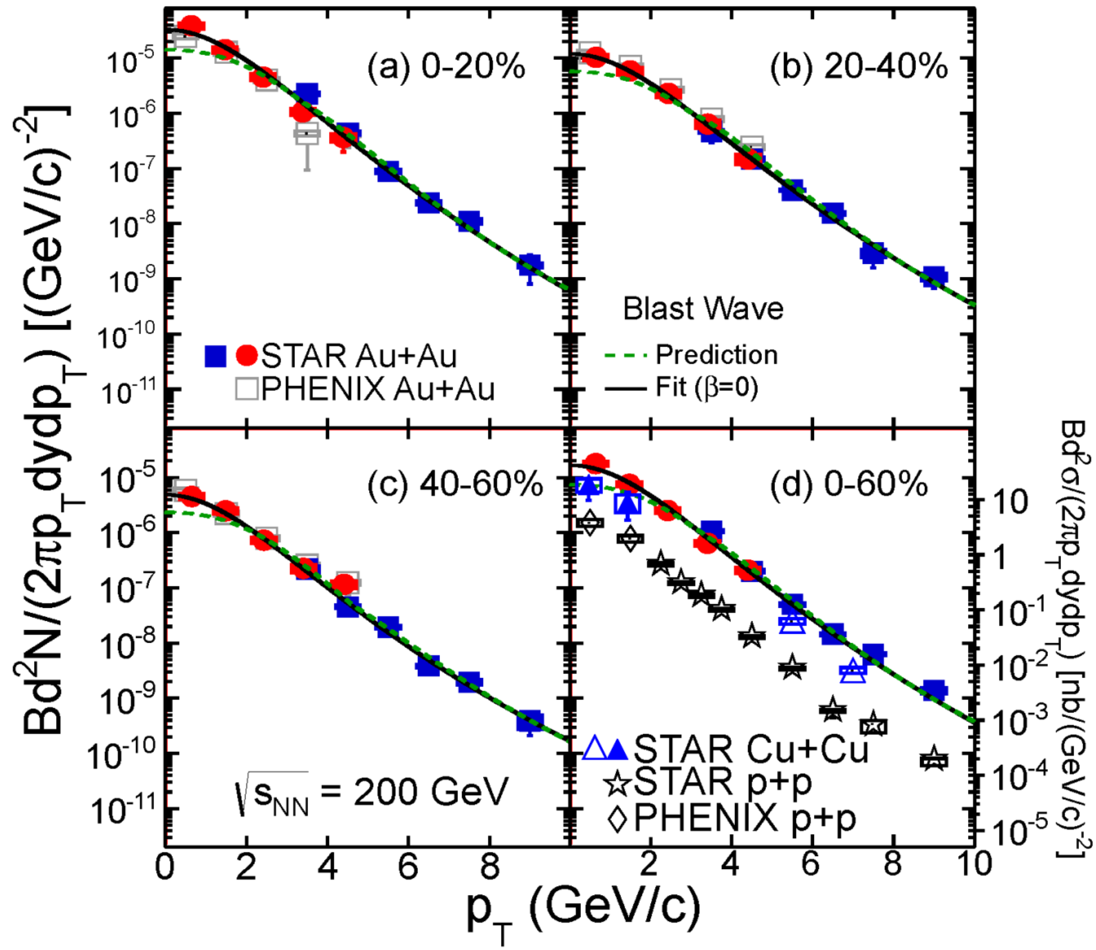
J/ψ spectra in Au+Au at 200 GeV

- J/ψ spectrum softer than Tsallis Blast-Wave prediction
  - Small radial flow?
  - Recombination at low p_T?

Tsallis Blast-Wave:

Hydro-inspired freezeout

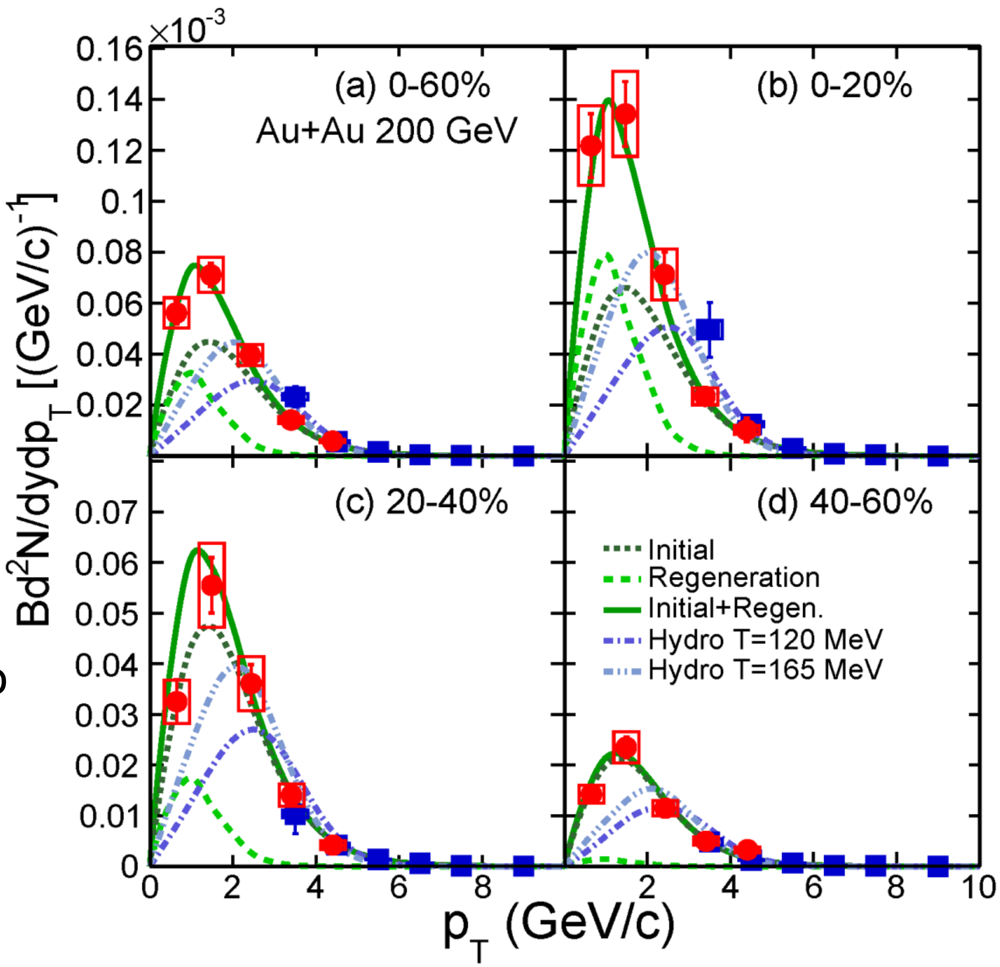
Particles produced according to a Lévy-distribution



STAR low-p_T Au+Au, CuCu : arXiv:1310.3563
high-p_T Au+Au: Phys.Lett. B722, 55 (2013)
high-p_T Cu+Cu : Phys. Rev. C 80 (2009) 041902
PHENIX: Phys. Rev. Lett. 98 (2007) 232301
Tsallis B-W: Z.Tang et al., Chin.Phys.Lett. 30, 031201 (2013)

J/ψ spectra, Au+Au at 200 GeV

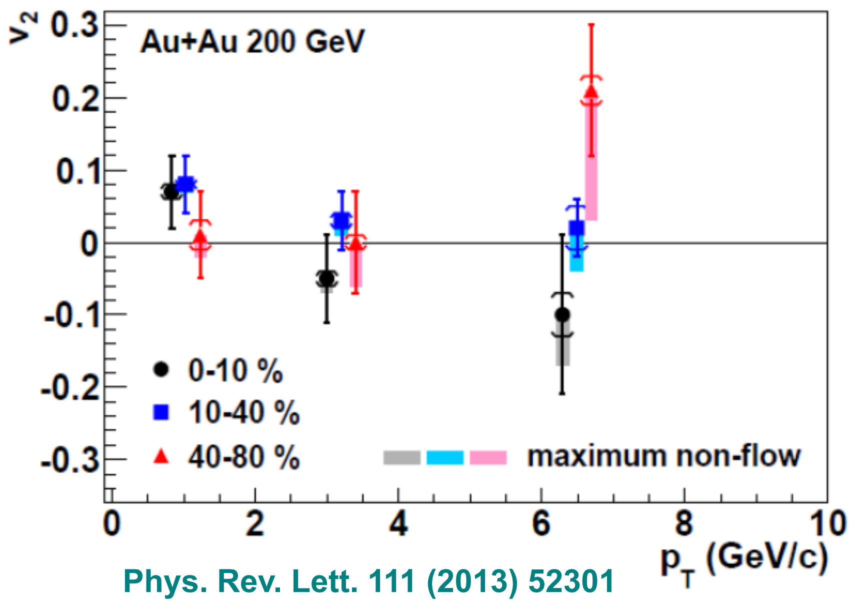
- J/ψ spectrum softer than Tsallis Blast-Wave prediction
  - Small radial flow?
  - Recombination at low p_T?
- **Viscous hydrodynamics**
  - J/ψ decouples at 120..165 MeV
  - fails at low-p_T
- **Y. Liu et al.**
  - Includes J/ψ suppression due to color screening
  - Includes statistical regeneration
  - peripheral: initial production dominates.
    central: regeneration becomes more significant at low p_T.



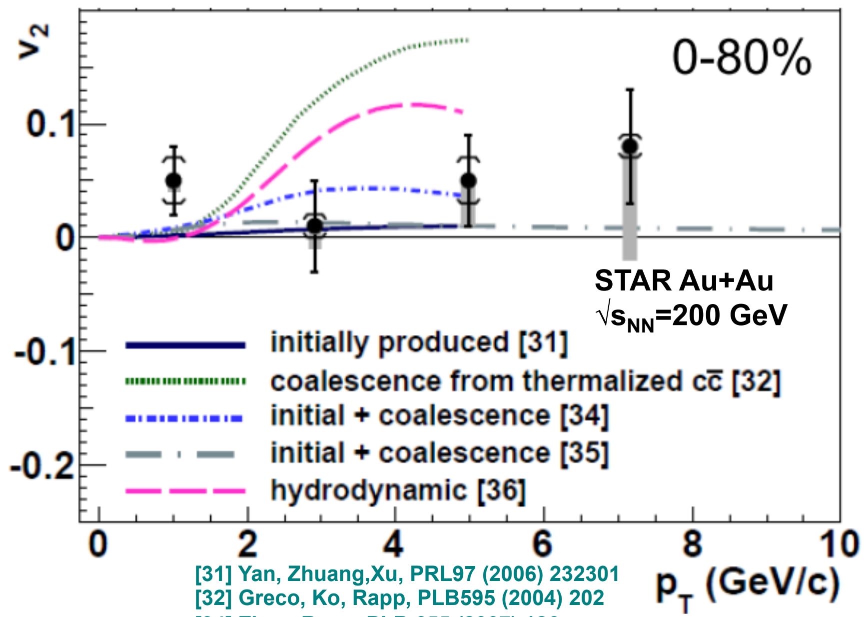
Y. Liu et al., Phys. Lett. B 678, 72 (2009)
U. W. Heinz and C. Shen (2011), private communication.

Coalescence of charm quarks is needed

J/ψ azimuthal anisotropy (v_2)



Phys. Rev. Lett. 111 (2013) 52301

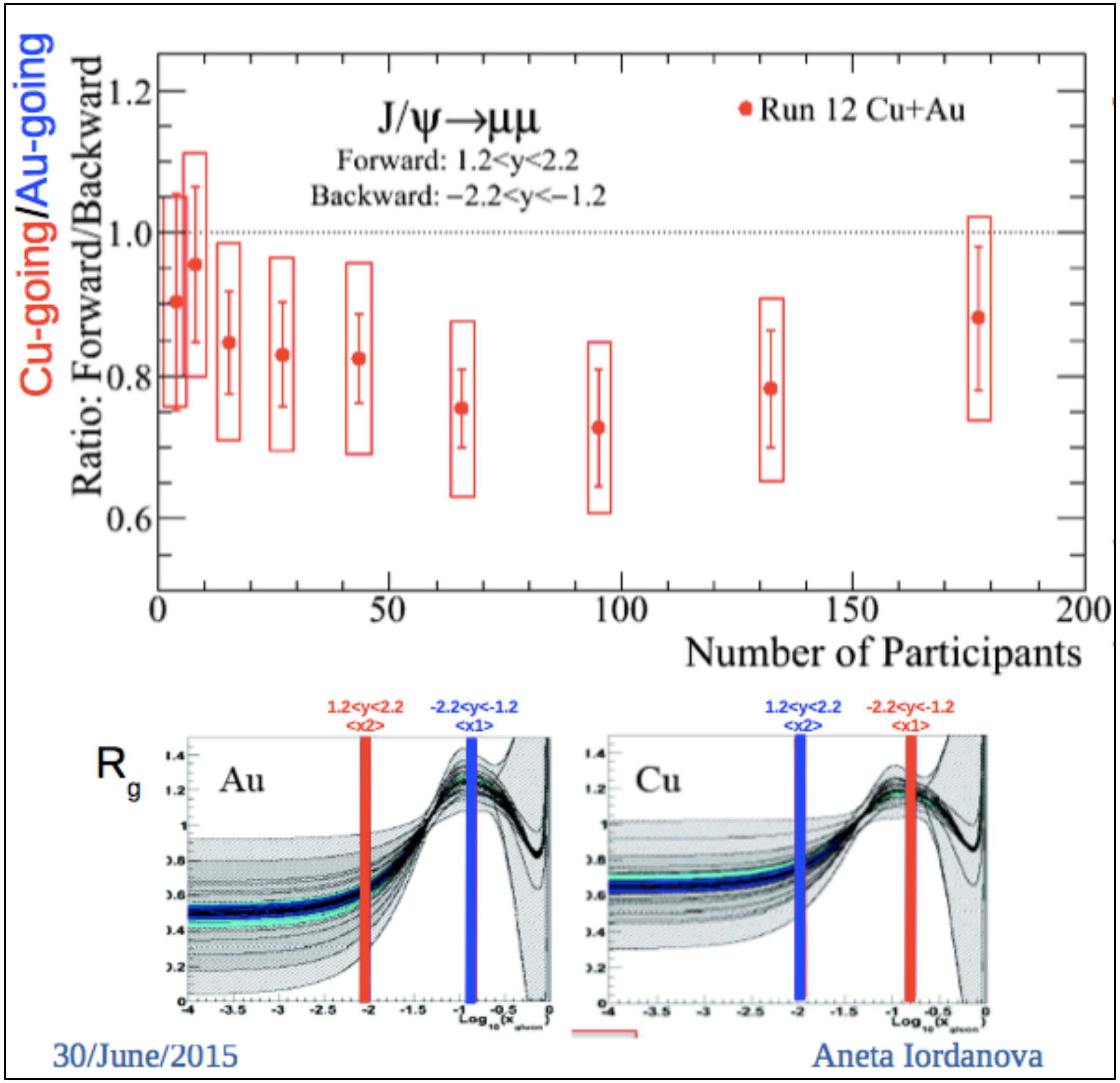


[31] Yan, Zhuang,Xu, PRL97 (2006) 232301
[32] Greco, Ko, Rapp, PLB595 (2004) 202
[34] Zhao, Rapp, PLB 655 (2007) 126
[35] Liu,Xu,Zhuang, NPA834 (2010) 317c
[36] Heinz, Chen (2012)

J/ψ v_2 consistent with non-flow at p_T>2 GeV/c

- Unique among hadrons!
- Regardless of centrality
- Thermalized charm quark coalescence does not dominate production

Cu+Au CNM effects



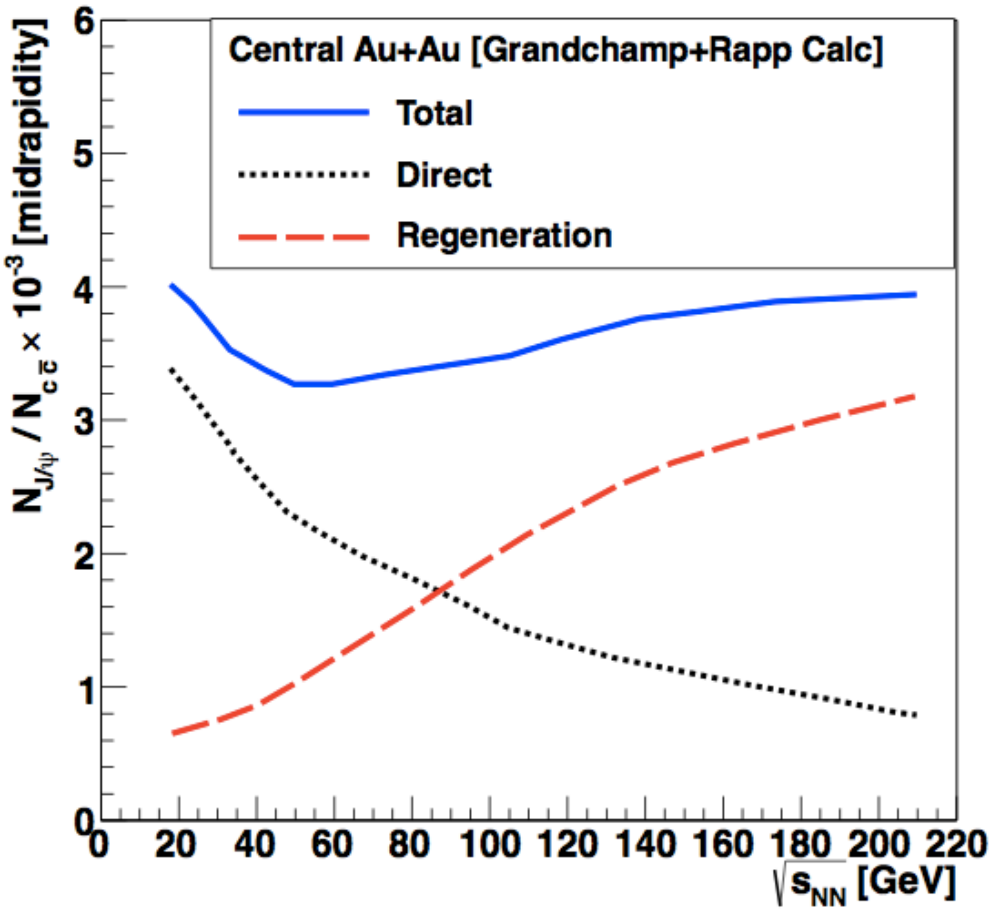
Forward (Cu-going):

- J/psi probes Cu gluons at high-x, Au gluons at low-x
- Short proper crossing time in Au probes Eloss
- Long crossing proper time in Cu → ccbar breakup

Backward (Au-going)

The other way round

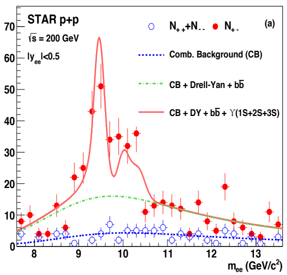
Direct vs. regenerated J/psi vs. $\sqrt{s_{NN}}$

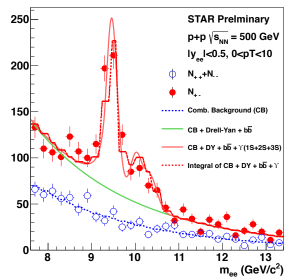


L. Grandchamp and R. Rapp, Nucl. Phys. A709, 415 (2002)

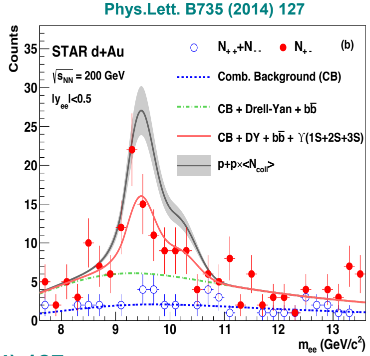
STAR ϒ measurements – summary

Phys.Lett. B735 (2014) 127

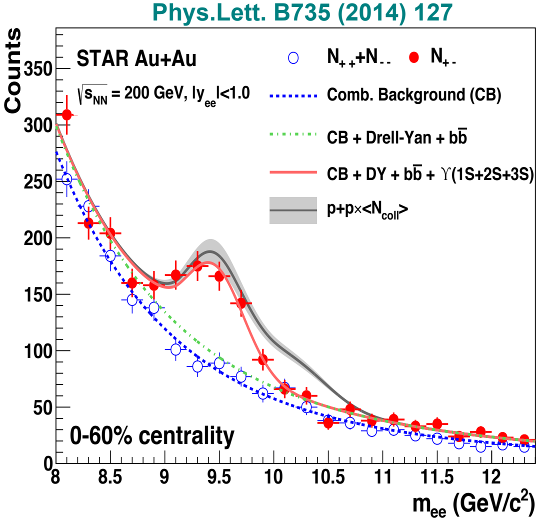


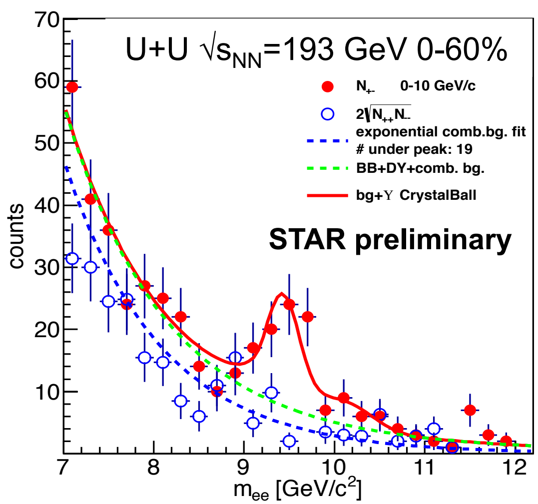


Phys.Lett. B735 (2014) 127



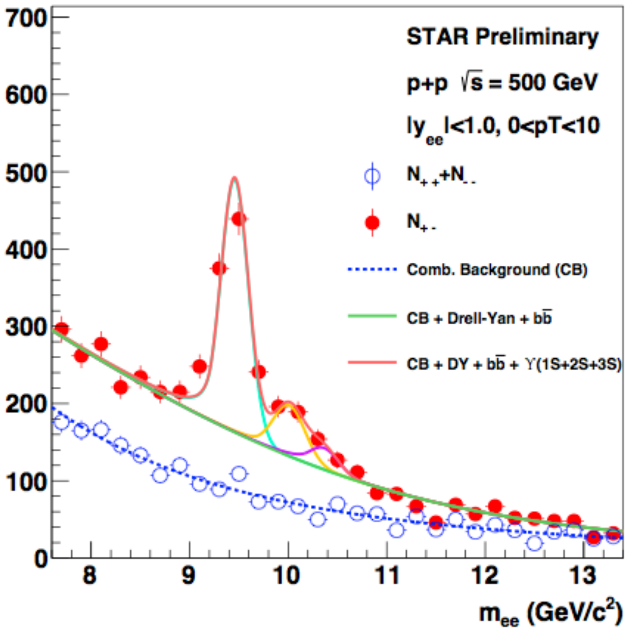
Phys.Lett. B735 (2014) 127

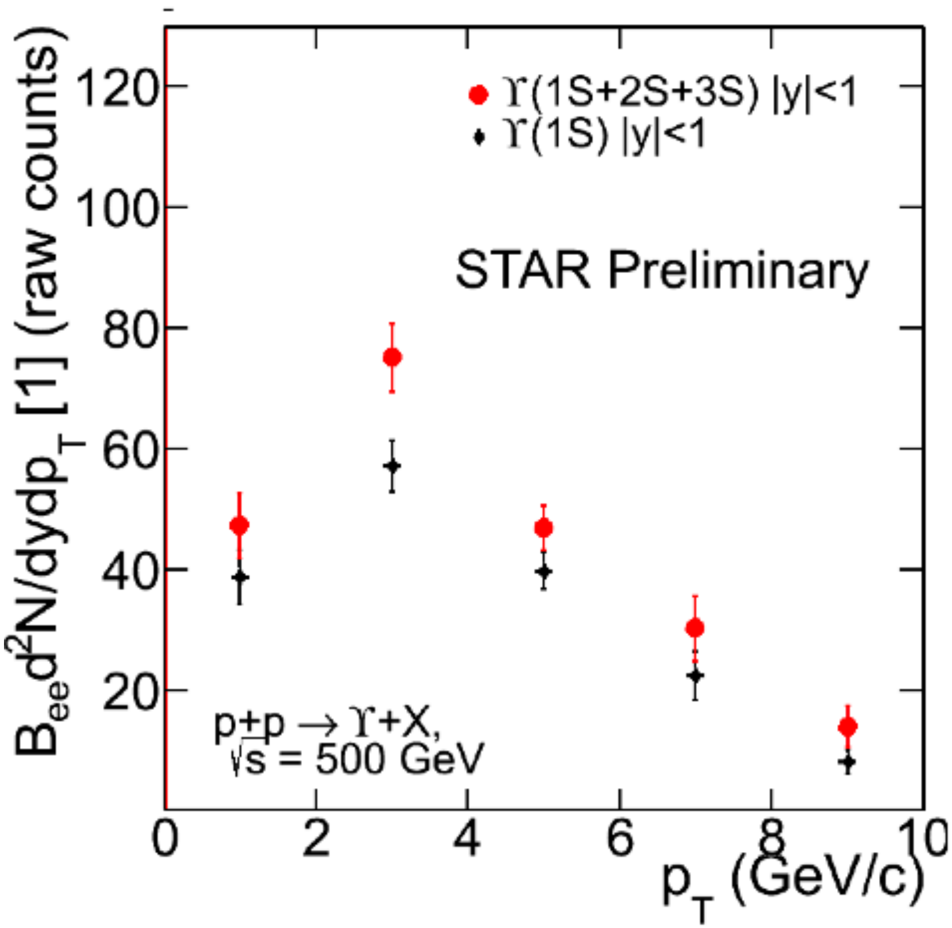




- **p+p @ 200 GeV**
- p+p @ 500 GeV
  - pQCD benchmark
  - Reference for A+A
- **d+Au @ 200 GeV**
  - CNM effects
- **Au+Au**
  - Hot nuclear matter effects
  - Sequential suppression
- **U+U**
  - Further tests of sequential melting
  - N_{part} dependence

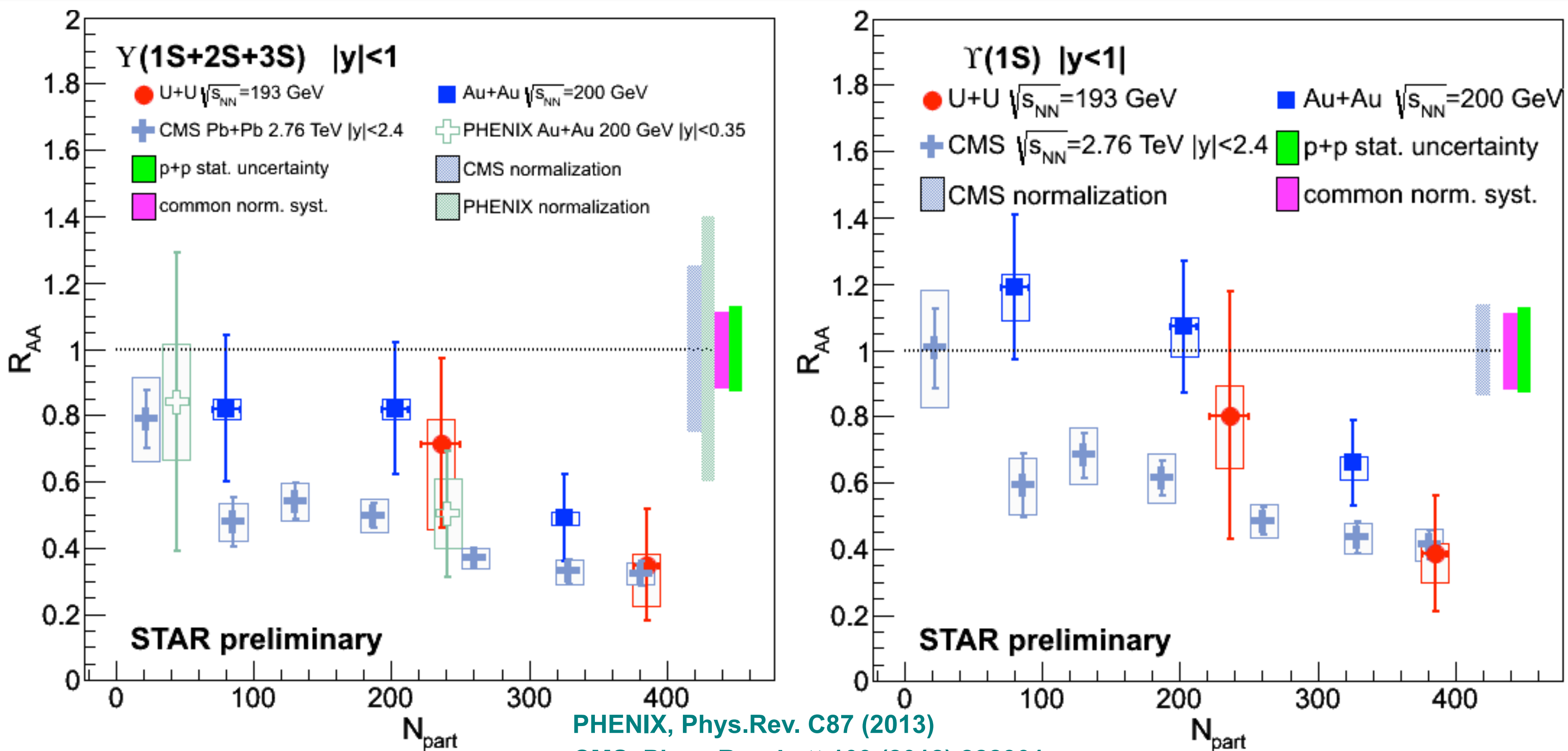
Upsilons in p+p 500 GeV





- Precise measurements
- Uncorrected spectra so far

Υ R_{AA} : RHIC & LHC comparison



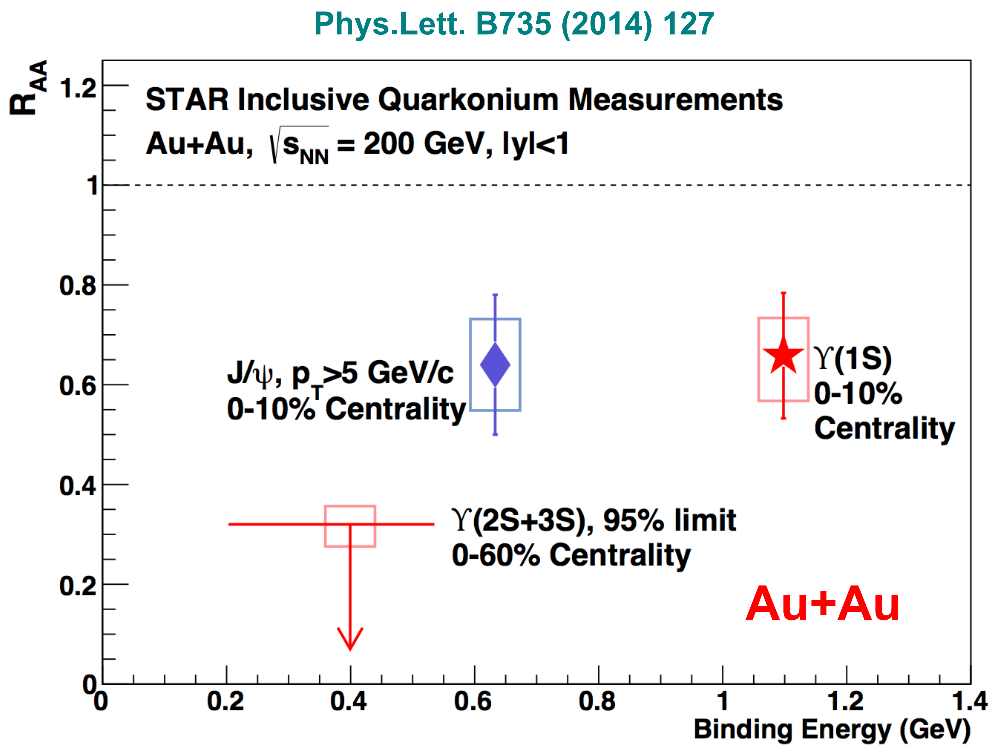
PHENIX, Phys.Rev. C87 (2013)
CMS, Phys. Rev. Lett 109 (2012) 222301

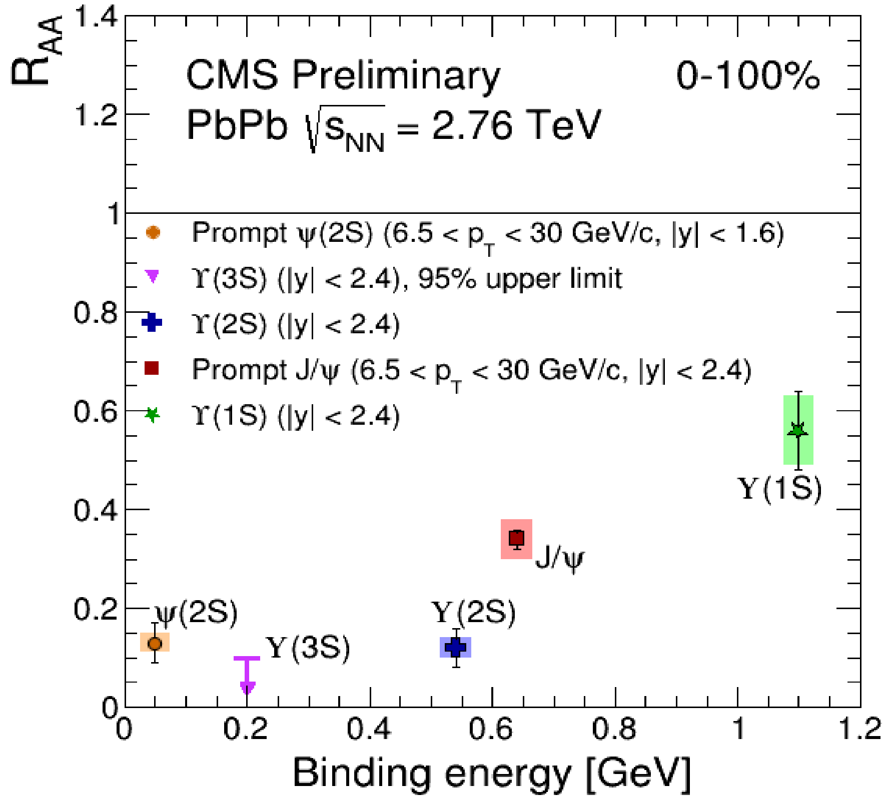
- LHC and RHIC suppressions are comparable at high N_{part}
- N_{part} dependence of Υ suppression appears weaker at the LHC

Is suppression driven by energy density?

→*Note the uncertainties, however*

Excited ϒ states – LHC comparison





- RHIC $\sqrt{s_{NN}}$=200 GeV Au+Au and LHC $\sqrt{s_{NN}}$=2.76 TeV Pb+Pb collisions: Similar suppression of central ϒ(1S)

RHIC/STAR

- Reconstruction:
  $J/\psi \rightarrow e^+e^-$ (B_{ee} ~ 6%)
  $\Upsilon \rightarrow e^+e^-$ (B_{ee} ~ 2.4%)
- TPC
  - dE/dx PID
  - Large acceptance, uniform in a wide energy range
- TOF
  - PID using flight time
- BEMC
  - High-p_T trigger
  - PID using E/p and shower shape
- VPD
  - Minimum bias events

Solenoidal Tracker At RHIC : $-1 < \eta < 1, 0 < \phi < 2\pi$