J/Ψ PRODUCTION IN A+A COLLISIONS AT STAR

Ota Kukral

for the STAR Collaboration

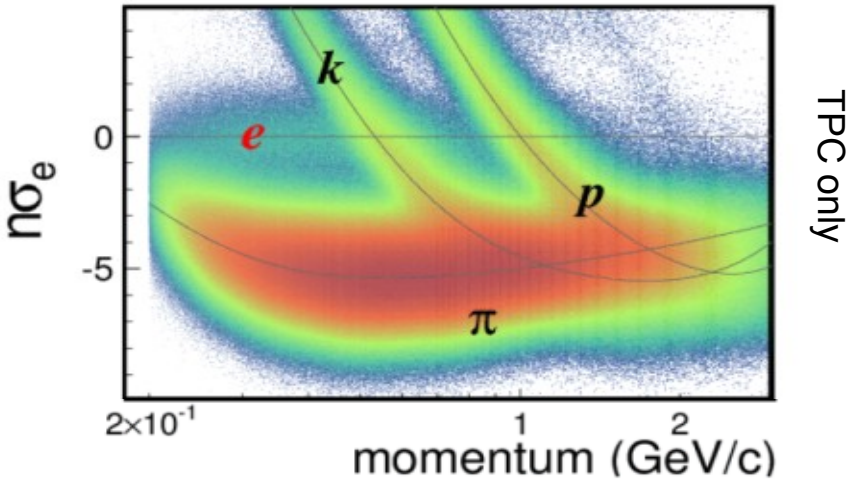
Czech Technical University in Prague

Outline

- J/ψ reconstruction
- Au+Au results
- J/ψ in U+U
- Future prospects: MTD and HFT
- Summary and outlook

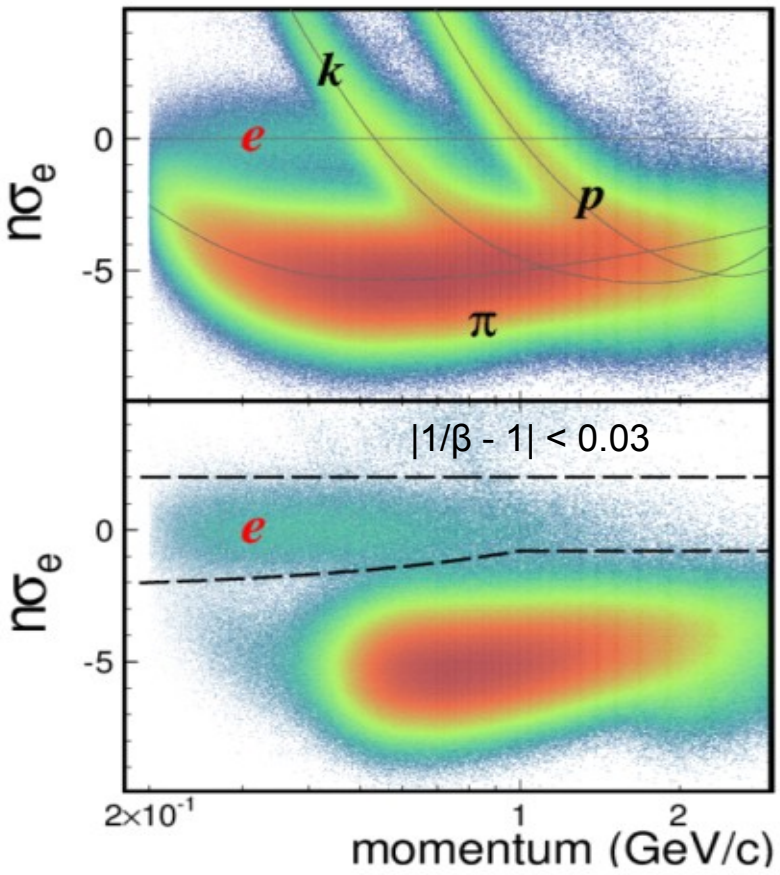
Electron ID

- $J/\psi \rightarrow e^+e^-$ (B.R. 5.9%)
- TPC:
  - nσ – distance from the expected mean value of dE/dx expressed as number of standard deviations
  - Often $-1.5 < n\sigma_{electron} < 2.0$



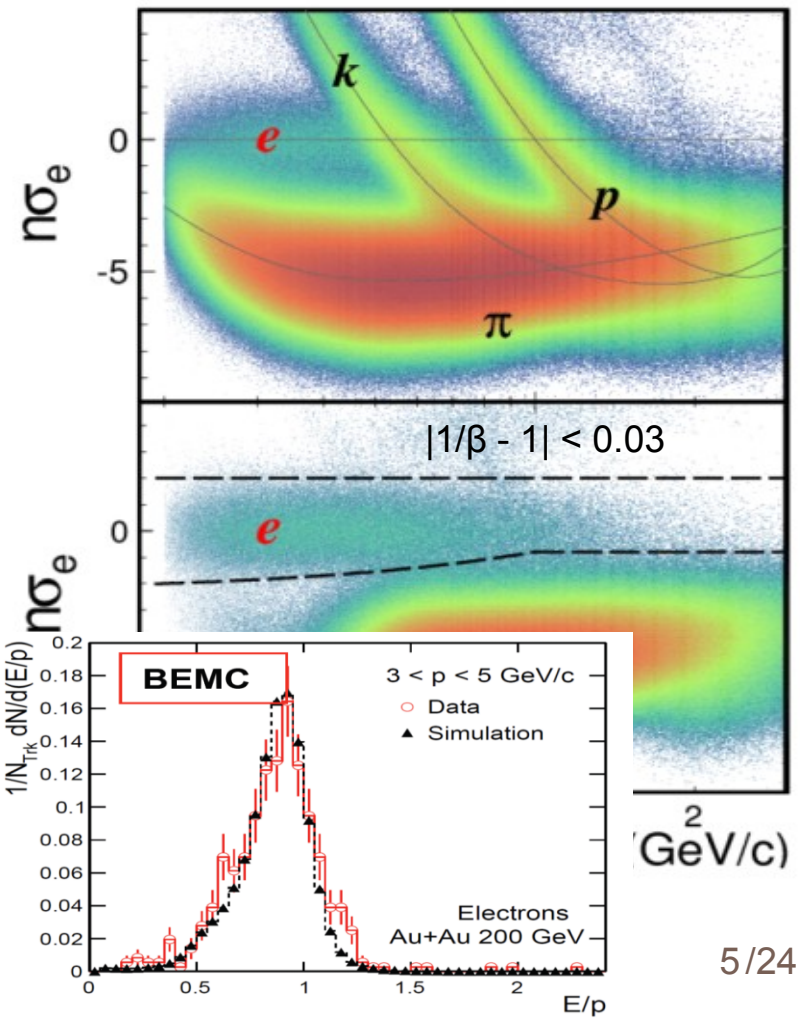
Electron ID

- $J/\psi \rightarrow e^+e^-$ (B.R. 5.9%)
- TPC:
  - nσ – distance from the expected mean value of dE/dx expressed as number of standard deviations
  - Often $-1.5 < n\sigma_{electron} < 2.0$
- TOF:
  - Used mainly for p < ~1.4 GeV/c
  - $0.97 < 1/\beta < 1.03$ (as $\beta_{electron} \approx 1$)



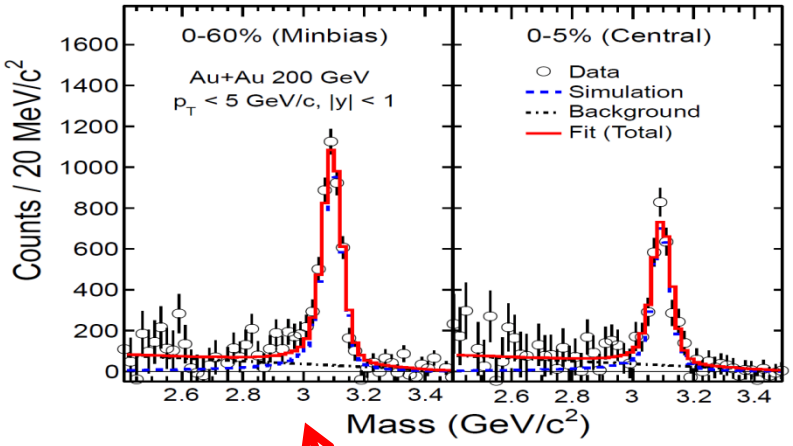
Electron ID

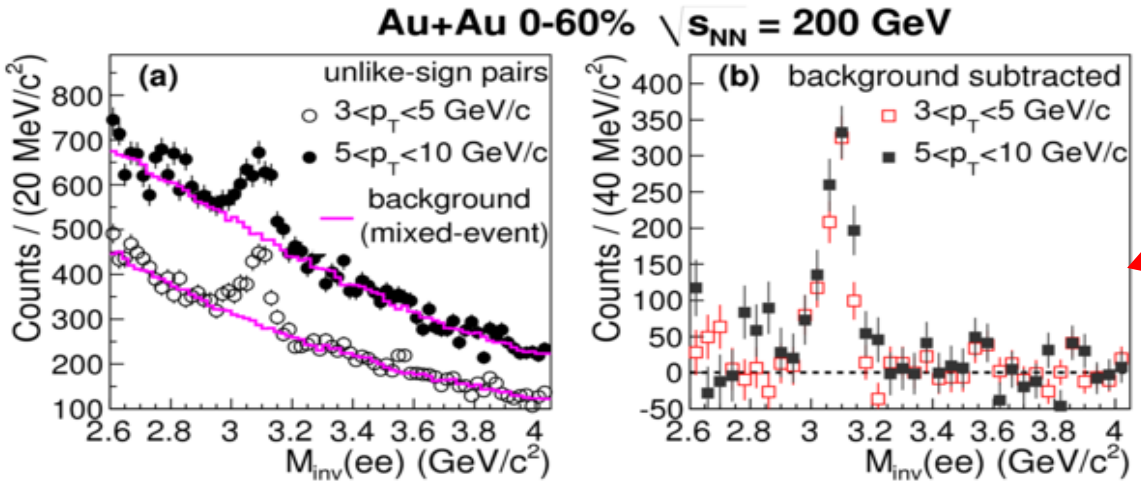
- $J/\psi \rightarrow e^+e^-$ (B.R. 5.9%)
- TPC:
  - $n\sigma$ – distance from the expected mean value of dE/dx expressed as number of standard deviations
  - Often $-1.5 < n\sigma_{electron} < 2.0$
- TOF:
  - Used mainly for p < ~1.4 GeV/c
  - $0.97 < 1/\beta < 1.03$ (as $\beta_{electron} \approx 1$)
- BEMC:
  - Used for p > ~ 1.4 GeV/c
  - Electrons deposit most of their energy: E/p should be around 1



J/ψ → e^+e^- signals

- Combinatorial background estimated by like-sign and mixed events techniques
- Clear signals for both low and high p_T Au+Au collisions

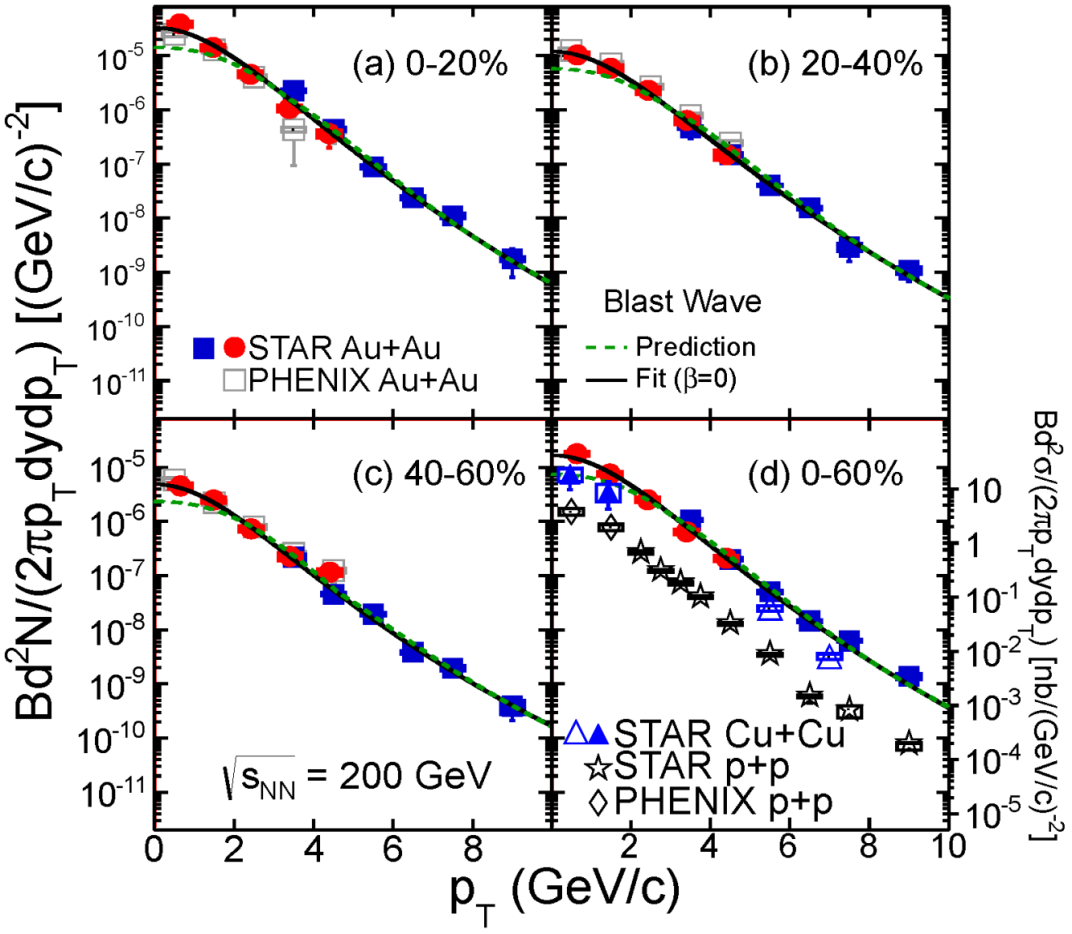




STAR low-p_T : arXiv:1310.3563
high-p_T : Phys.Lett. B722, 55 (2013)

J/ψ spectra in Au+Au at 200 GeV

- Large p_T range
  - Covers 0-10 GeV/c
- J/ψ spectra softer at low p_T than the Tsallis Blast-Wave model prediction with the same freeze-out parameters as for light hadrons
  - Recombination at low p_T?
  - Small radial flow?

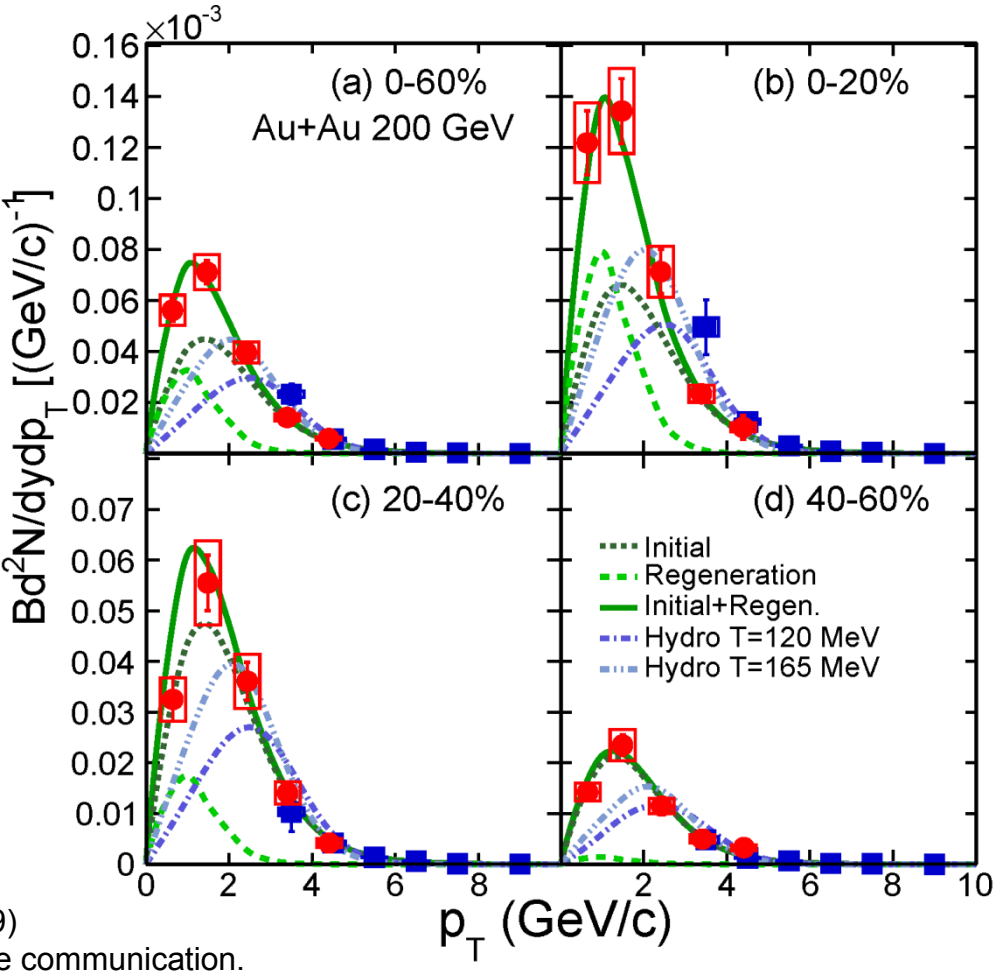


STAR low-p_T : arXiv:1310.3563
high-p_T : Phys.Lett. B722, 55 (2013)

Tsallis Blast-Wave model: Z.Tang et al., Chin.Phys.Lett. 30, 031201 (2013)

J/ψ spectra in Au+Au at 200 GeV

- Viscous hydrodynamics
  - J/ψ decoupling temperature of 120 and 165 MeV fails to describe the low p_T data
- Y. Liu et al.
  - model includes J/ψ suppression due to color screening and the statistical regeneration
  - describes the data well
  - peripheral: initial production dominates.
    central: regeneration becoming more significant at low p_T.



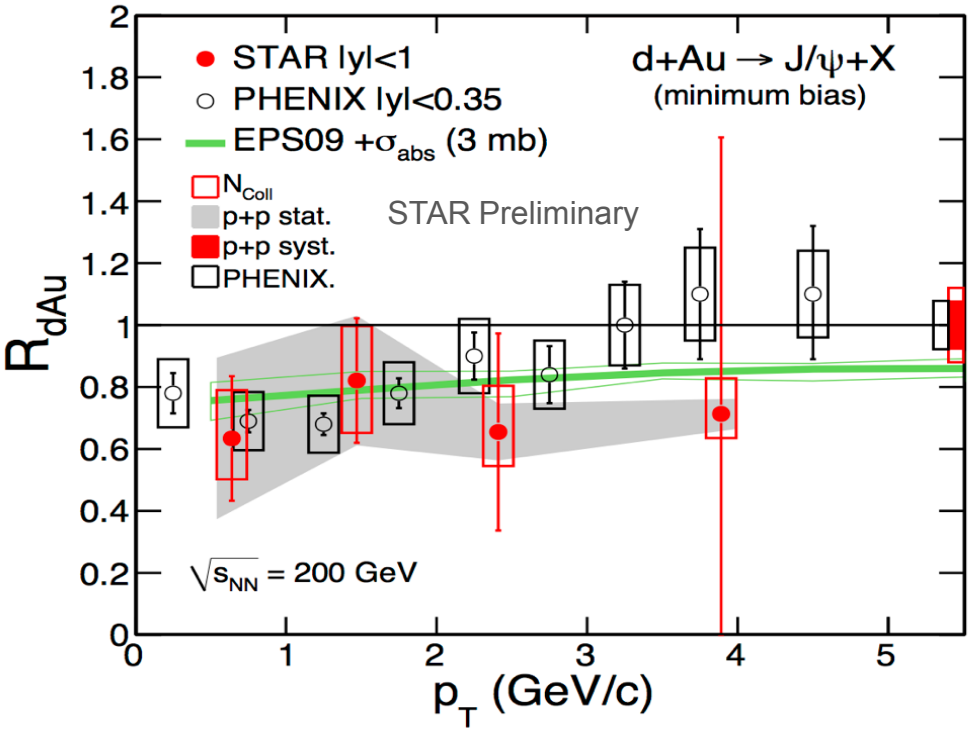
Y. Liu et al., Phys. Lett. B 678, 72 (2009)
U. W. Heinz and C. Shen (2011), private communication.

J/ψ cold nuclear matter effects

- Nuclear modification factor

$$R_{dAu} = \frac{dN^2_{dAu}/dP_T dy}{\langle N_{coll} \rangle \, dN^2_{pp}/dP_T dy}$$

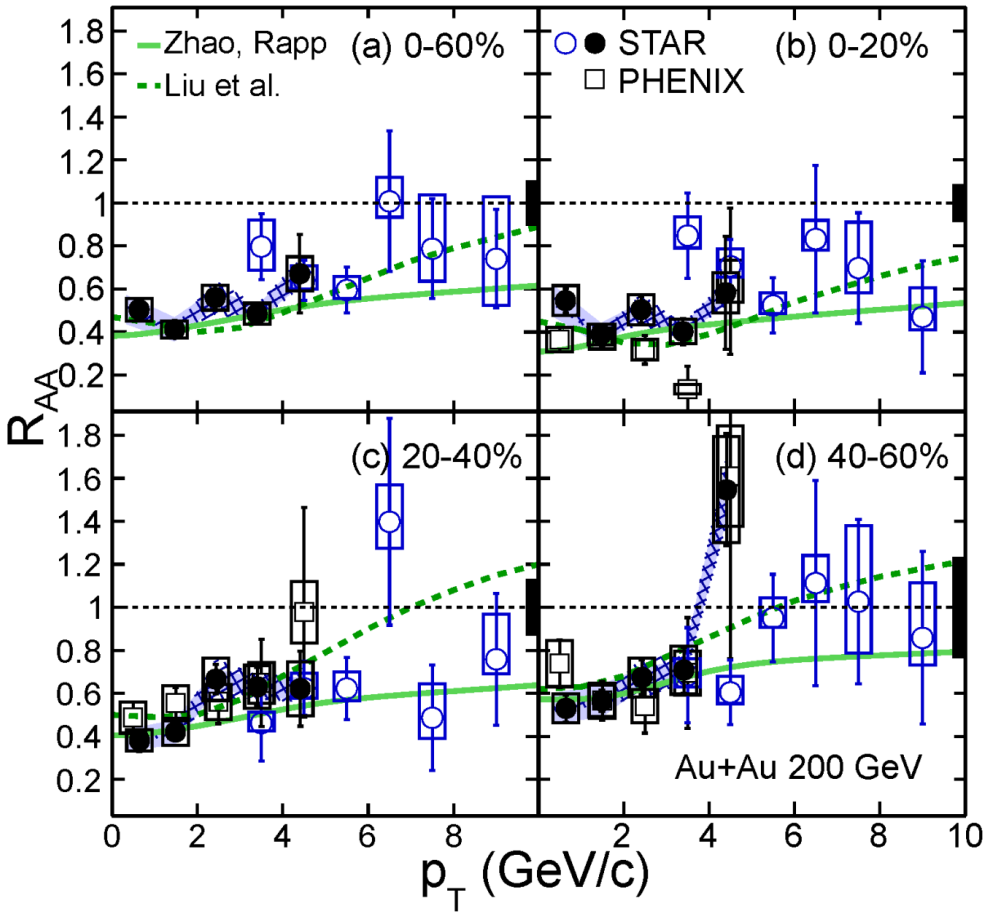
- $R_{dAu} \approx 1$ for high p_T
  - Cold nuclear effects are small at high p_T
  - High p_T results in A+A collisions provide a cleaner probe of the J/ψ interaction with the hot nuclear matter



PHENIX data: Phys. Rev. C 87, 034904 (2013)
Model: E.Eskola, H.Paukkunenea and C.Salgo, Nucl. Phys. A 830, 599 (2009)

J/ψ suppression in Au+Au at 200 GeV

- Nuclear modification factor
  - Increase from low p_T to high p_T
  - Consistent with unity at high p_T peripheral collisions
  - More suppression in central than in peripheral collisions even at high p_T

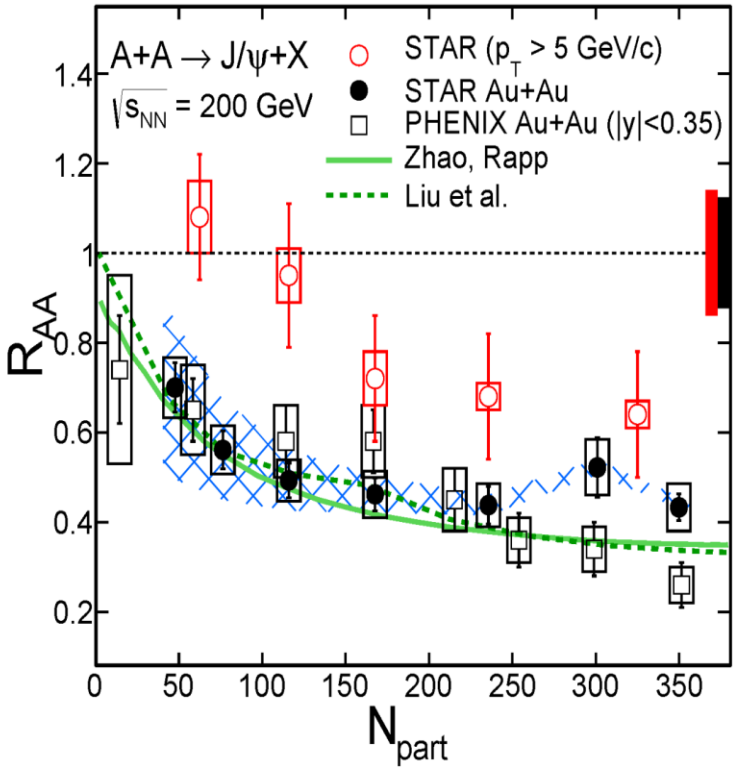


STAR low-p_T : arXiv:1310.3563
high-p_T : Phys.Lett. B722, 55 (2013)

Liu et al., PLB 678, 72 (2009)
Zhao and Rapp, PRC 82, 064905(2010)
PLB 664, 253 (2008)

J/ψ suppression in Au+Au at 200 GeV

- System size (N_{part}) dependence
  - R_{AA} decreases with the size of the system
  - Models including initial production and recombination reasonably describe the J/ψ in our measured p_T region
  - J/ψ in central collisions suppressed even at high p_T
  - High p_T data less suppressed than low p_T



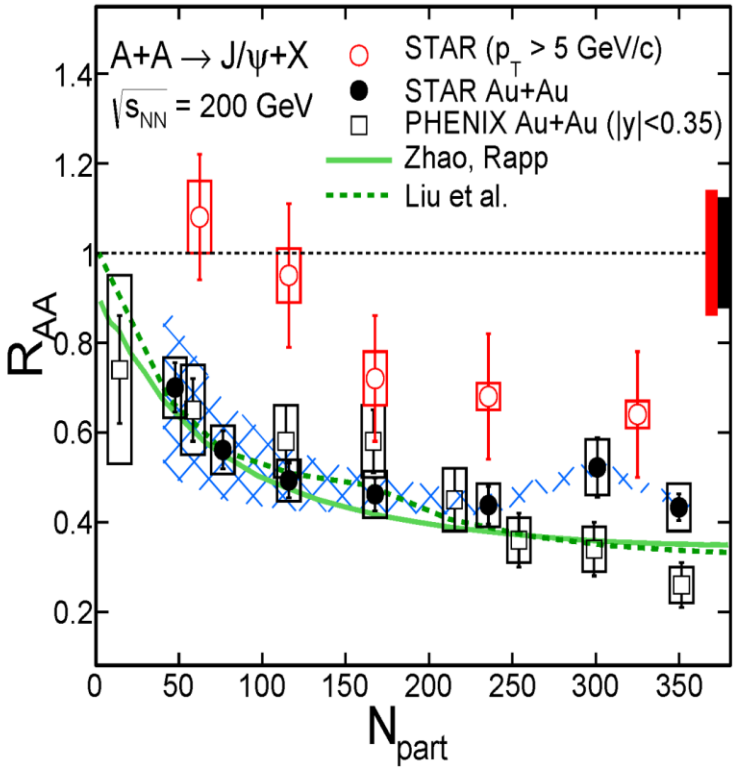
STAR low-p_T : arXiv:1310.3563
high-p_T : Phys.Lett. B722, 55 (2013)

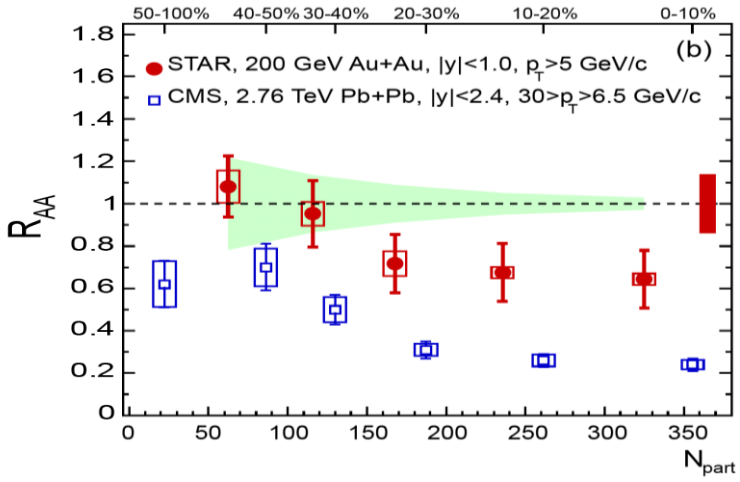
Liu et al., PLB 678, 72 (2009)
Zhao and Rapp, PRC 82, 064905(2010)
PLB 664, 253 (2008)

PHENIX Phys. Rev. Lett. 98, 232301 (2007)

J/ψ suppression in Au+Au at 200 GeV

- System size (N_{part}) dependence
  - R_{AA} decreases with the size of the system
  - Models including initial production and recombination reasonably describe the J/ψ in our measured p_T region
  - J/ψ in central collisions suppressed even at high p_T
  - High p_T data less suppressed than low p_T



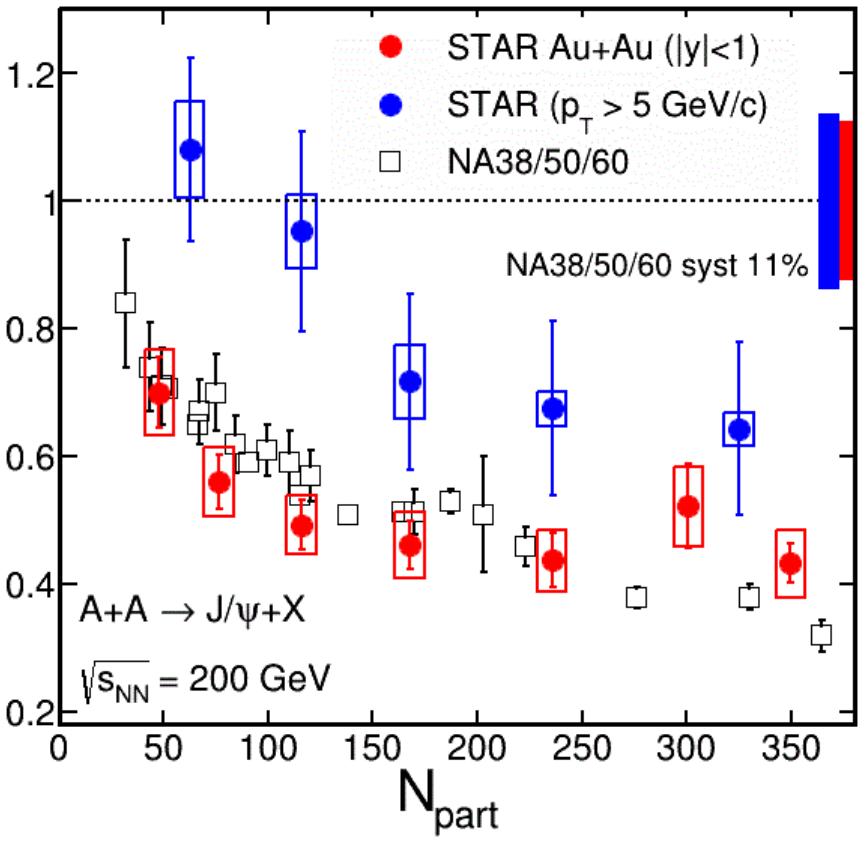


High p_T J/ψ at LHC (prompt) is more suppressed than at RHIC (inclusive)

STAR: Phys.Lett. B722, 55 (2013)
CMS: JHEP 05 (2012) 063

J/ψ at Beam Energy Scan (BES)

- Similar suppression at RHIC and SPS
- RHIC BES program: unique tool to study the interplay of CNM, screening and regeneration effects
- Quarkonia sequential melting: thermometer of QGP



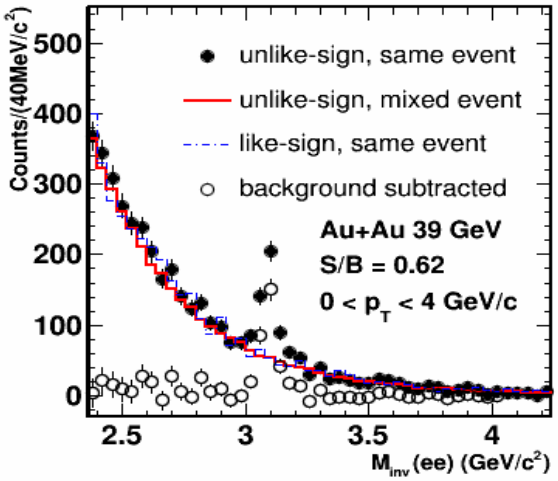
STAR low-p_T : arXiv:1310.3563
high-p_T : Phys.Lett. B722, 55 (2013)

SPS: Scomparin, QM2006

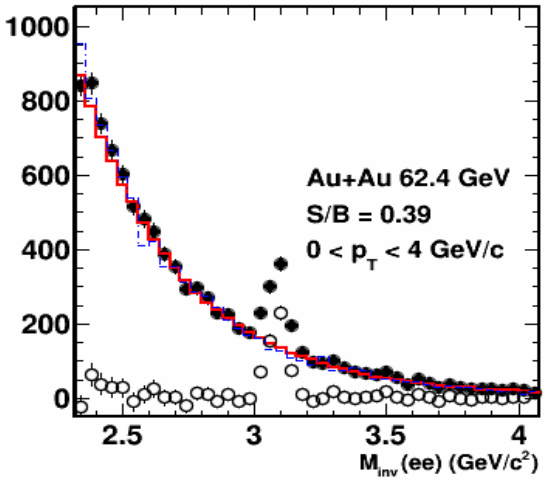
J/ψ at Beam Energy Scan (BES)

- J/ψ observed at 200, 62.4 and 39 GeV
- Data from Run 10
- Signal up to p_T 4 GeV/c for 39 and 62.4 GeV

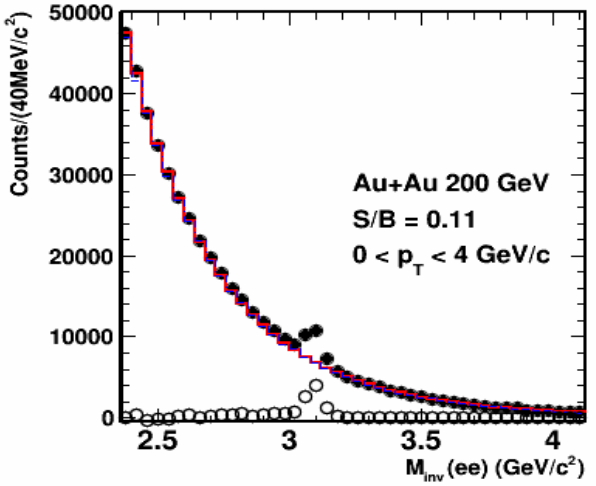
39 GeV



62.4 GeV

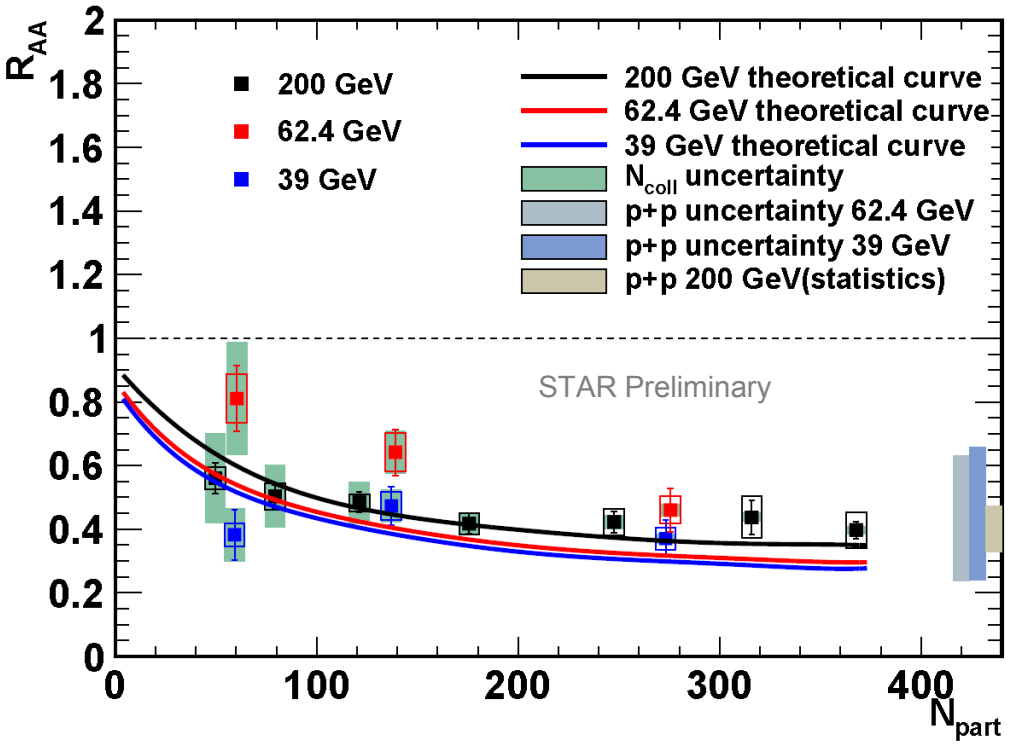


200 GeV



J/ψ suppression at RHIC BES

- R_{AA} for J/ψ in Au+Au at 200, 62.4 and 39 GeV
- Similar suppression for measured energies
  - pp reference is based on CEM calculations
  - Large theoretical uncertainty
- Consistent with theoretical calculations



p+p references for 39 and 62 GeV:
Nelson, Vogt et al., PRC87, 014908 (2013)

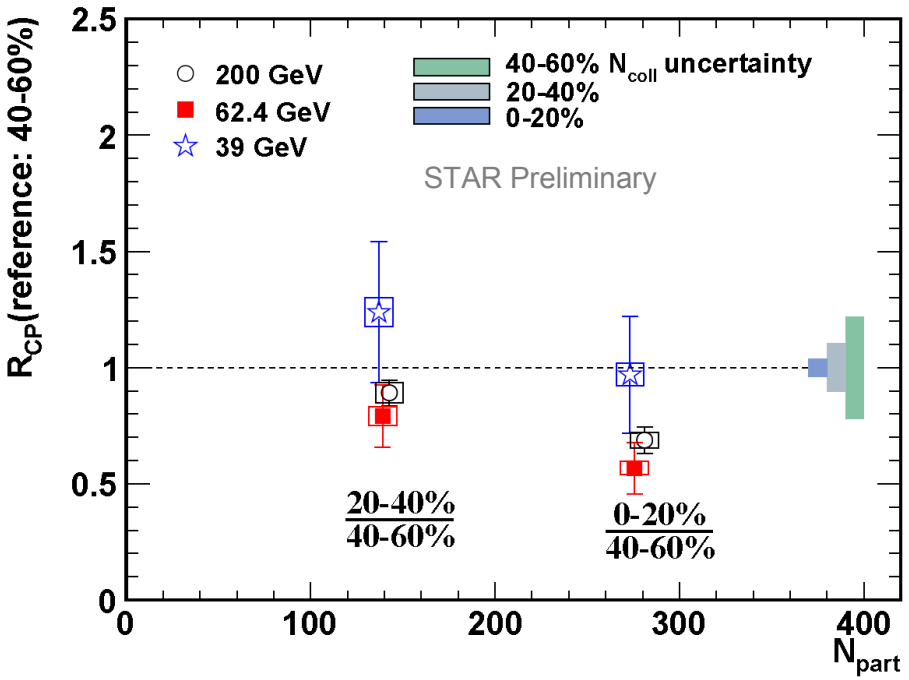
Theoretical curves:
Zhao, Rapp PRC82, 064905 (2010)

J/ψ suppression at RHIC BES

- Central vs. peripheral collisions:

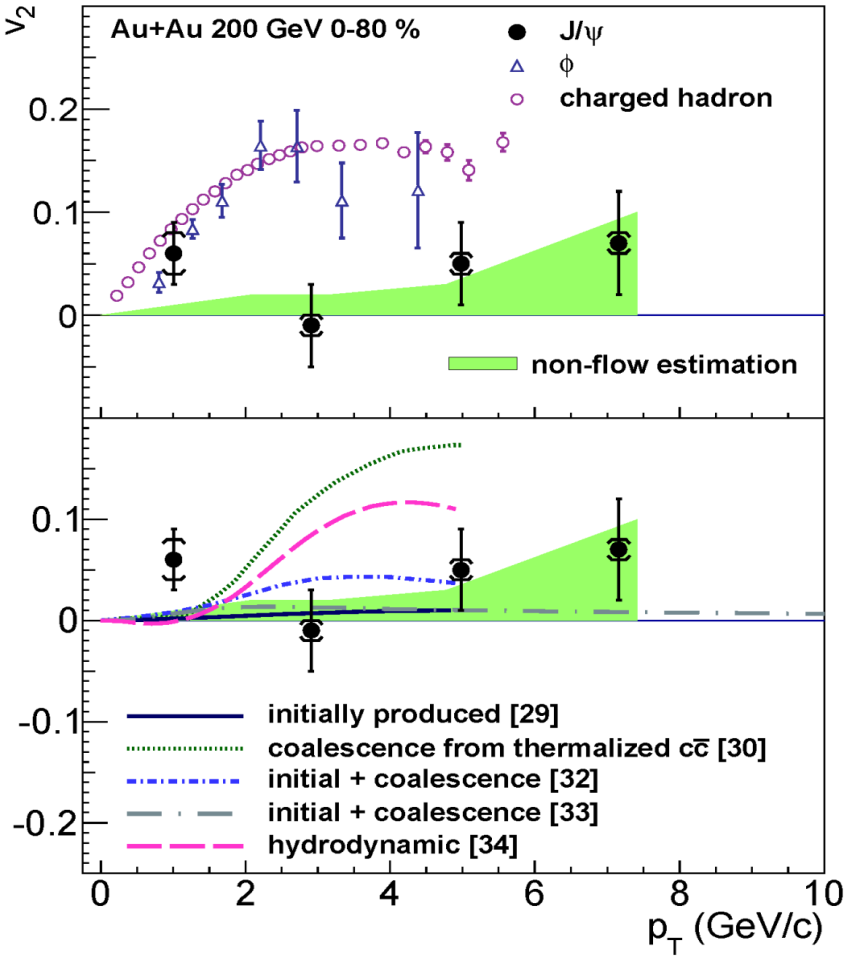
$$R_{CP} = \frac{\frac{dN/dy}{\langle N_{coll} \rangle}\ \text{(central)}}{\frac{dN/dy}{\langle N_{coll} \rangle}\ \text{(peripheral)}}$$

- Significant suppression at 62.4 GeV, similar to 200 GeV



J/ψ elliptic flow v_2

- Consistent with zero (p_T > 2 GeV/c)
- The only hadron so far that does not flow.
- Disfavors coalescence from thermalized charm quarks at high p_T

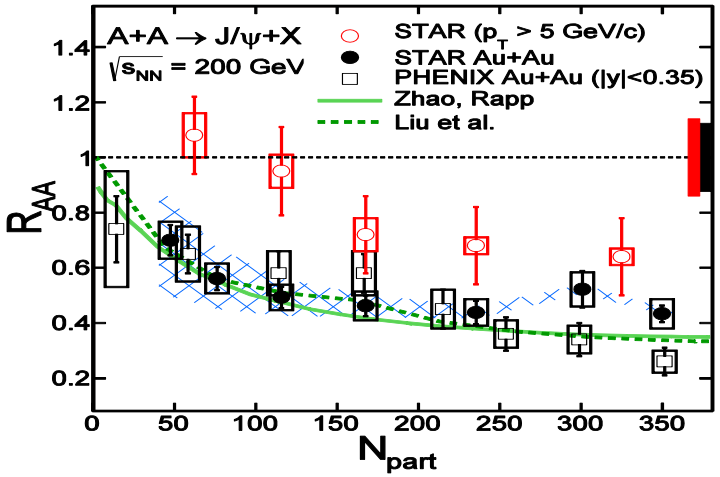


Phys. Rev. Lett. 111 (2013) 52301

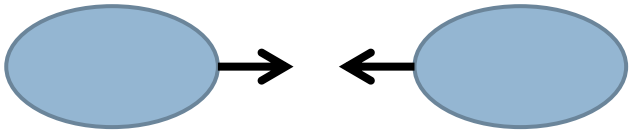
[29] L. Yan, P. Zhuang, N. Xu, PRL 97 (2006), 232301.
[30] V. Greco, C.M. Ko, R. Rapp, PLB 595, 202.
[32] X. Zhao, R. Rapp, arXiv:0806.1239 (2008)
[33] Y. Liu, N. Xu, P. Zhuang, Nucl. Phy. A, 834, 317.
[34] U. Heinz, C. Shen, private communication.

Motivation for U+U collisions

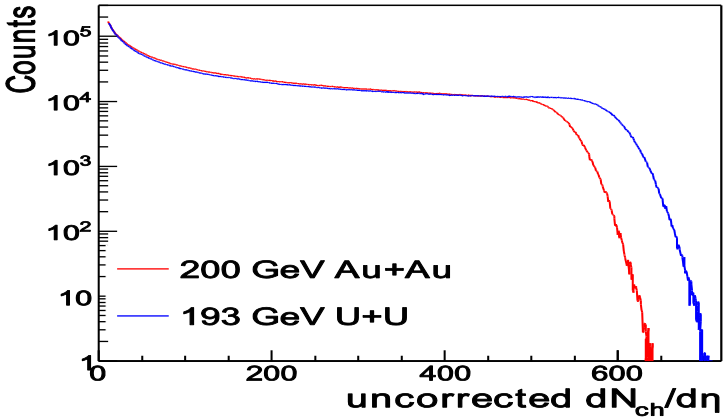
- U+U collisions at 193 GeV per nucleon pair (2012)
- Uranium nucleus is larger than Au and non-spherical
  - U+U collisions (orientation averaged) provide higher energy density
  - Tip-to-tip collisions provide the highest energy density



STAR Collaboration: arXiv 1310.3563 (2013)

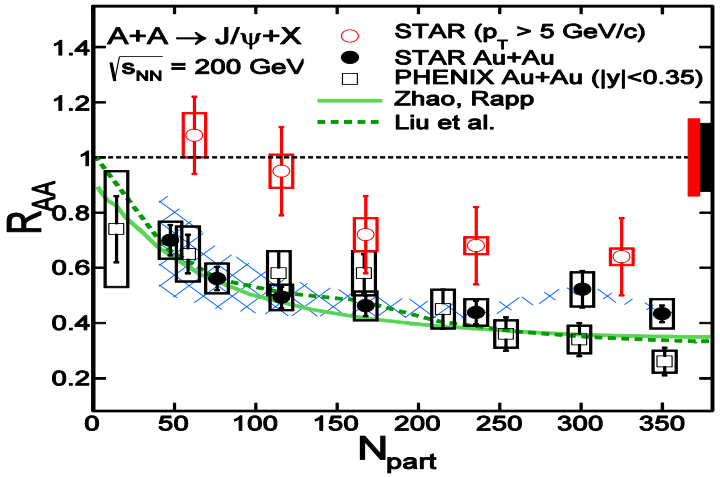


Tip-to-tip collision

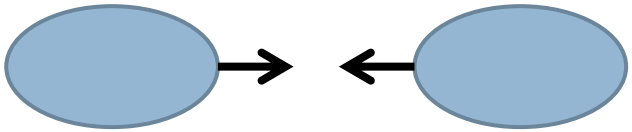


Motivation for U+U collisions

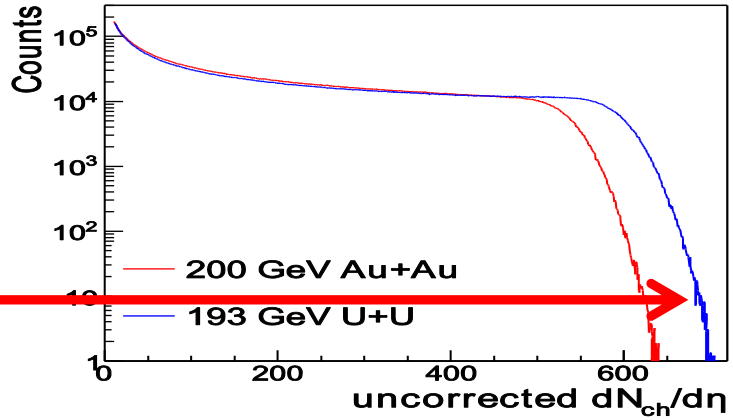
- U+U collisions at 193 GeV per nucleon pair (2012)
- Uranium nucleus is larger than Au and non-spherical
  - U+U collisions (orientation averaged) provide higher energy density
  - Tip-to-tip collisions provide the highest energy density



STAR Collaboration: arXiv 1310.3563 (2013)

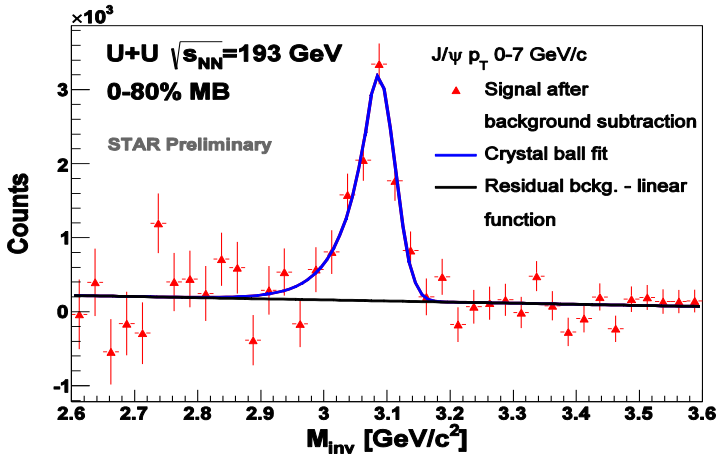


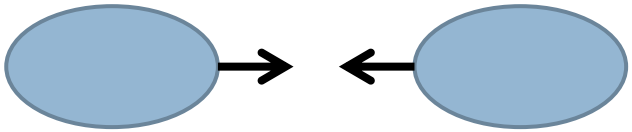
Tip-to-tip collision



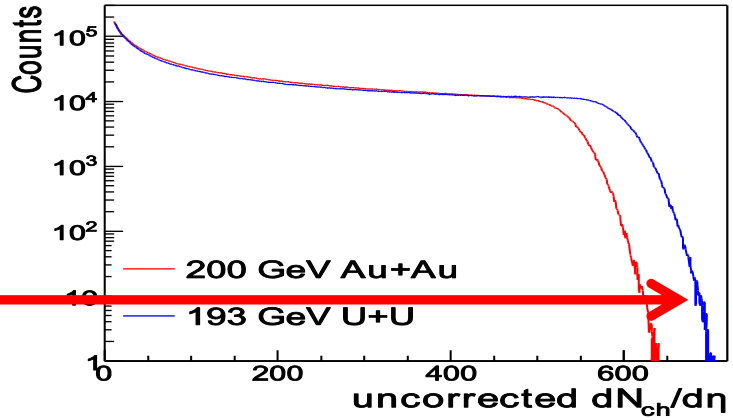
Motivation for U+U collisions

- U+U collisions at 193 GeV per nucleon pair (2012)
- Uranium nucleus is larger than Au and non-spherical
  - U+U collisions (orientation averaged) provide higher energy density
  - Tip-to-tip collisions provide the highest energy density



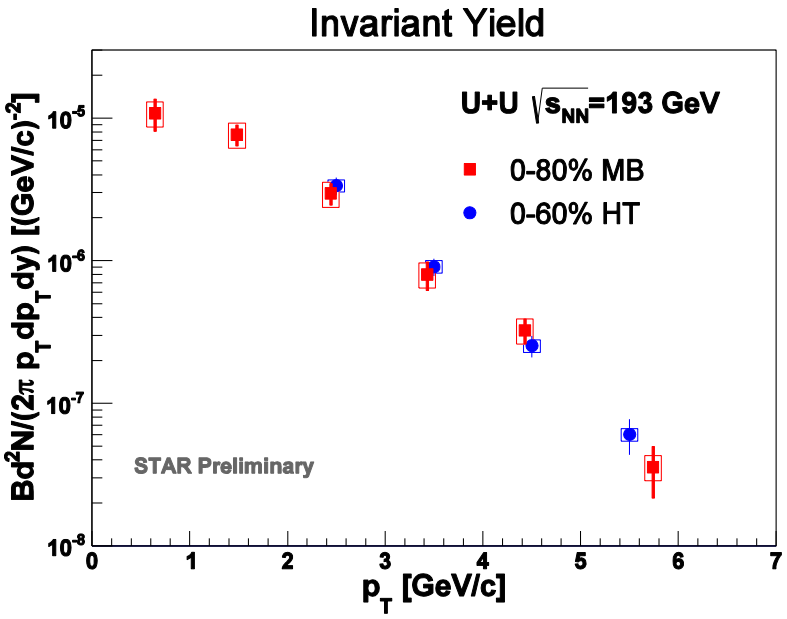


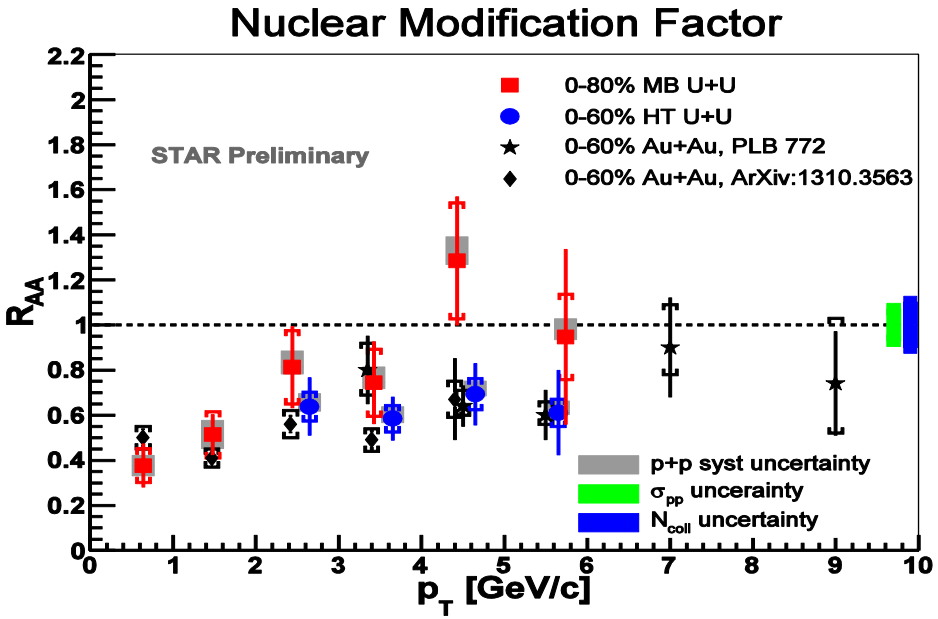
Tip-to-tip collision



J/ψ invariant yield and R_{AA} in U+U

- Nuclear modification factor as a function of p_T similar to Au+Au
- Study of centrality dependence of R_{AA} ongoing
  - central trigger data available

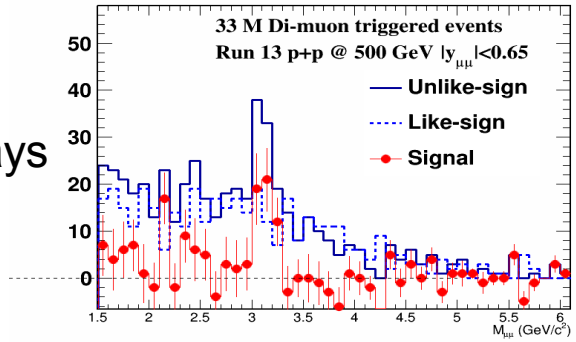


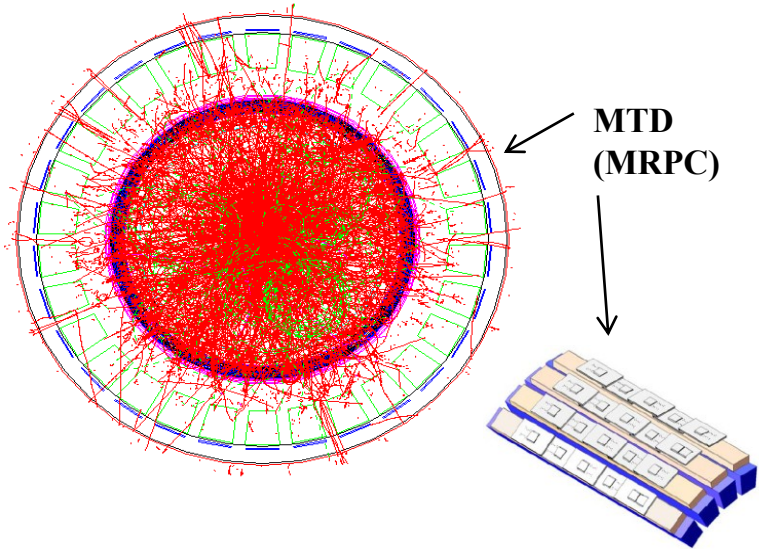


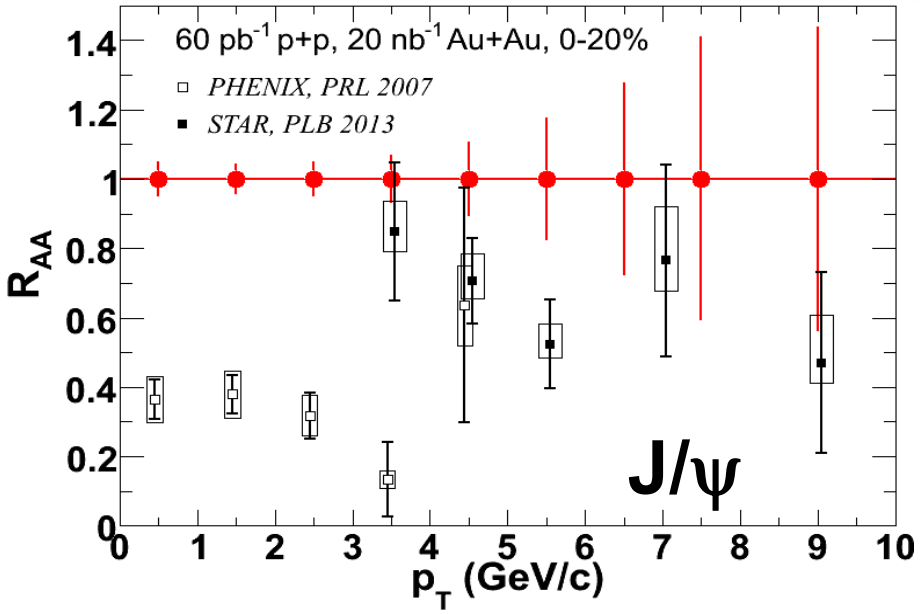
p+p reference from 200 GeV used

Muon Telescope Detector (MTD)

- J/ψ → $\mu^+\mu^-$ (B.R. 5.9%)
  - No γ conversion, less contribution from Dalitz decays
  - Trigger capability for J/ψ in central A+A collisions
- Full MTD installed for year 2014

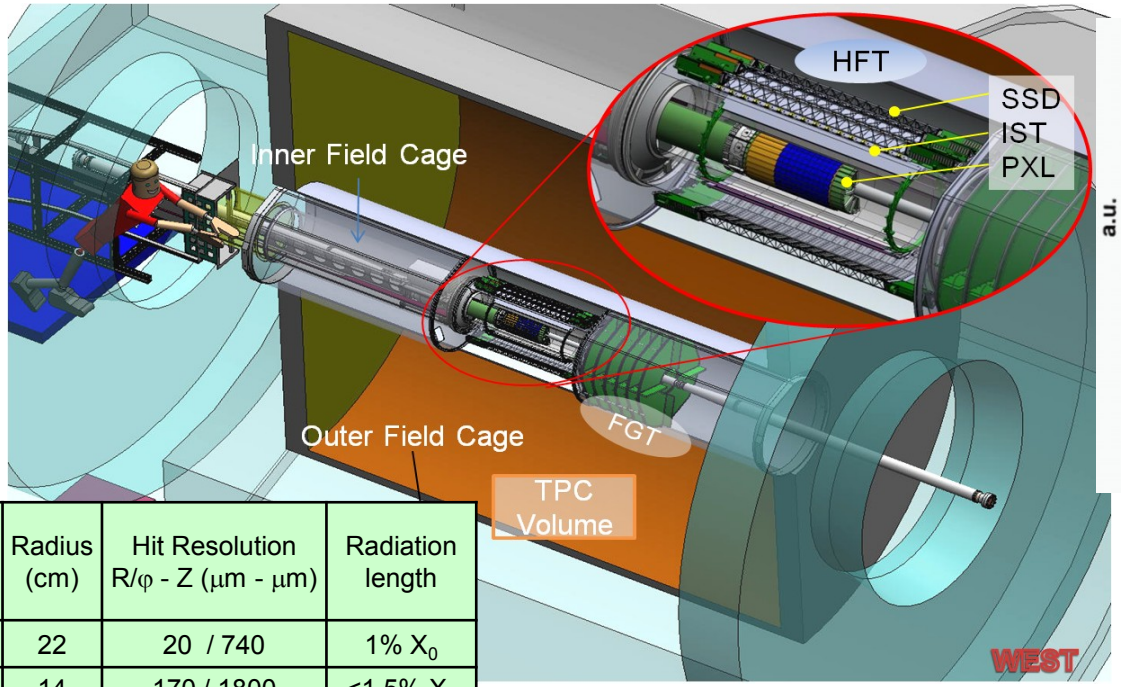


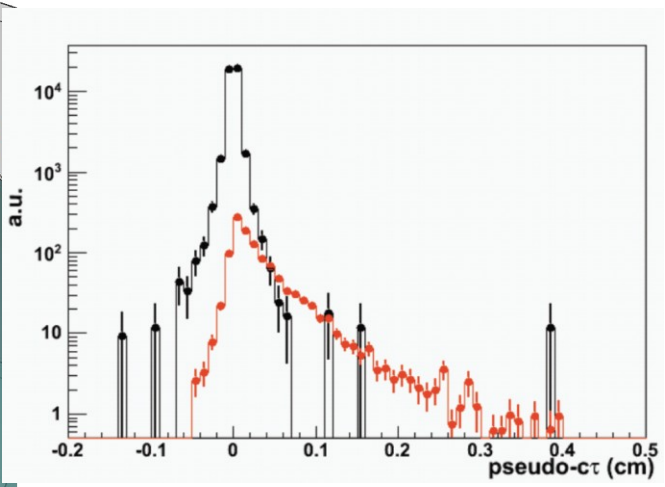




Heavy Flavor Tracker (HFT)

- Inner tracking system - precise pointing resolution
- Study of non-prompt J/ψ ($B \rightarrow J/\psi + X$; $c\tau \approx 500\ \mu m$)
- Installed for year 2014





Simulation of separation of prompt and non-prompt J/ψ using HFT

Detector	Radius (cm)	Hit Resolution R/φ - Z (μm - μm)	Radiation length
SSD	22	20 / 740	1% X_0
IST	14	170 / 1800	<1.5% X_0
PIXEL	8	12 / 12	~0.4% X_0
	2.5	12 / 12	~0.4% X_0

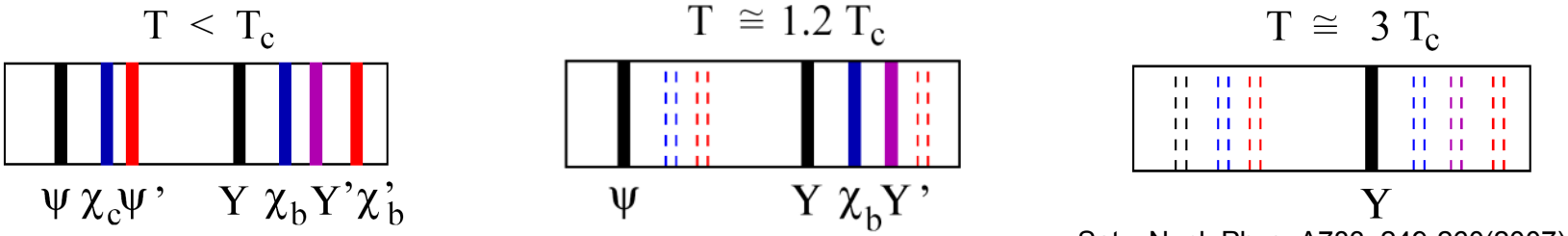
Summary and outlook

- J/ψ in Au+Au at 200 GeV
  - Suppression observed – increases with centrality and decreases with p_T
  - Eliptic flow consistent with zero (p_T>2 GeV/c)
- J/ψ in Au+Au at 39 GeV and 62.4 GeV
  - Similar suppression as in 200 GeV within uncertainties
- J/ψ in U+U collisions at 193 GeV
  - Suppresion pattern similar to Au+Au
- Outlook
  - 2014: Large statistics Au+Au at 200 GeV
  - Muon Telescope Detector: $J/\psi \rightarrow \mu^+\mu^-$
  - Heavy Flavor Tracker: separation of prompt and non-prompt J/ψ

Additional slides

Motivation

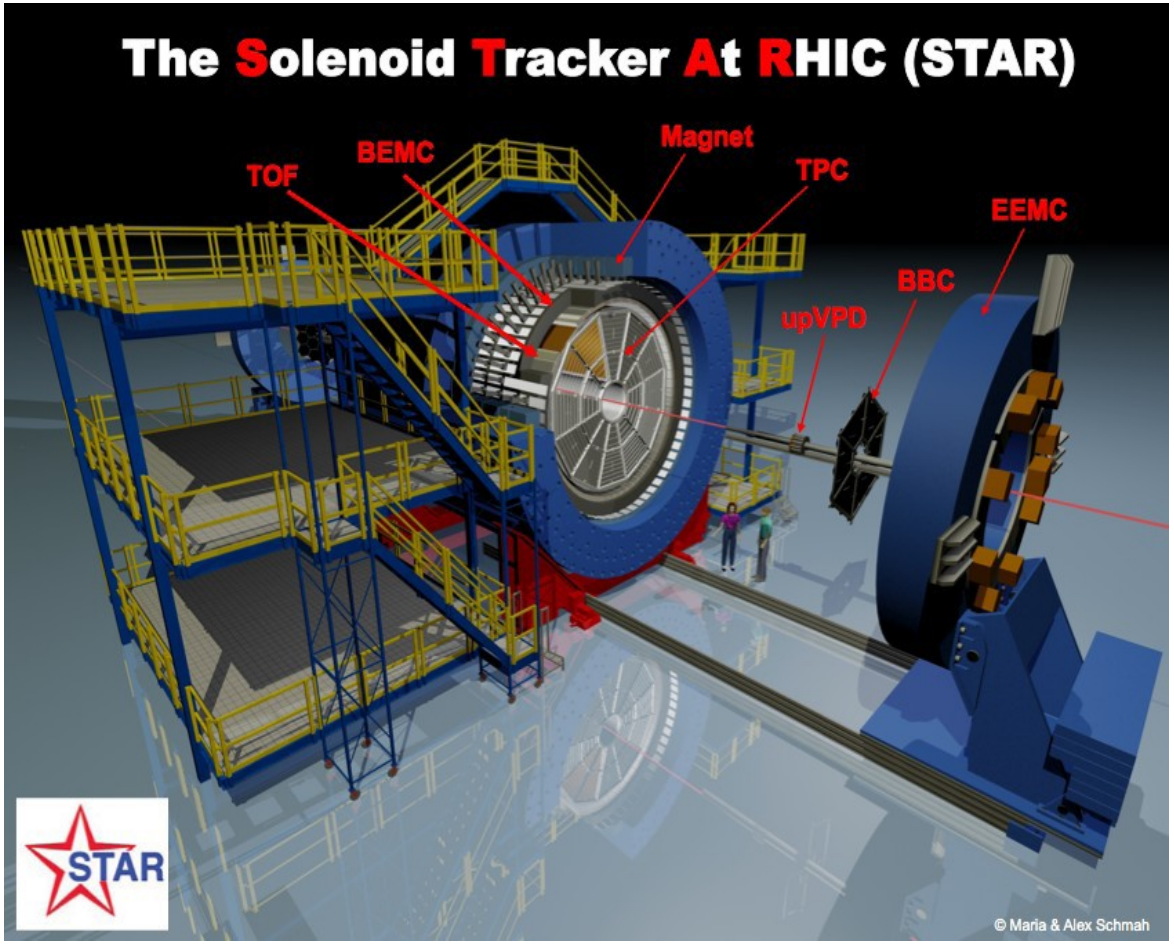
- Mass of charm quark is high (~1.3 GeV/c^2)
  - Production can be described by pQCD
  - Produced early in hard processes
- Quarkonia (J/ψ, Υ) are expected to be suppressed in QGP
  - In-medium screening of color charge – temperature dependent



Satz, Nucl. Phys. A783: 249-260(2007)

- Other important effects:
  - Recombination from uncorrelated charm pairs
  - Observed yields are a mixture of direct production + feeddown (also from B meson)
  - Cold nuclear effects (such as modification to PDFs or nuclear absorption)

STAR experiment



- Brookhaven National Laboratory, USA
- Time Projection Chamber (TPC)
  - Particle momentum, dE/dx
- Time Of Flight (TOF)
  - Particle velocity (1/β)
- Barrel Electromagnetic Calorimeter (BEMC)
  - Electron/photon energy