Supported in part by U.S. DEPARTMENT OF ENERGY Office of Science

J/ψ production in Au+Au collisions at $\sqrt{s_{\mathrm{NN}}} = 54.4$ GeV

Kaifeng Shen
(for the STAR collaboration)
State Key Laboratory of Particle Detection and Electronics,
Department of Modern Physics,
University of Science and Technology of China

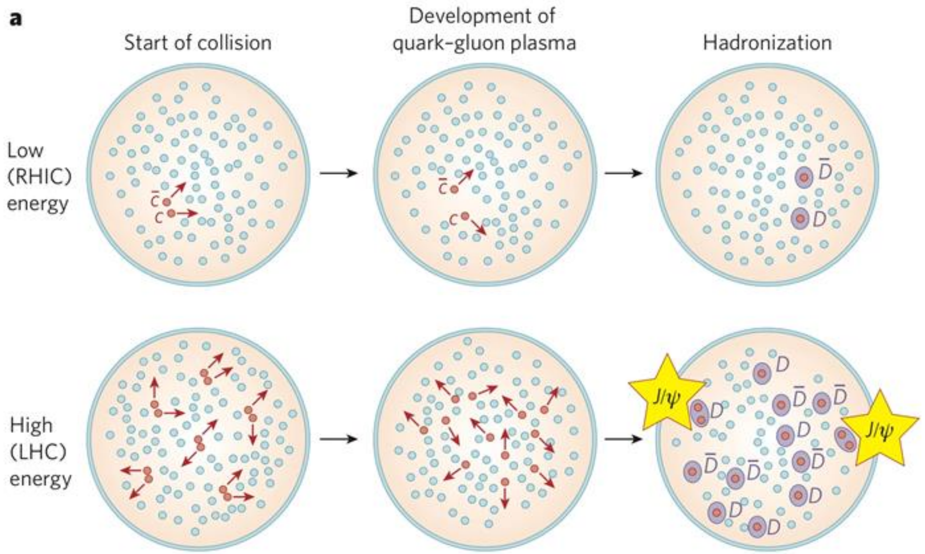
Outline

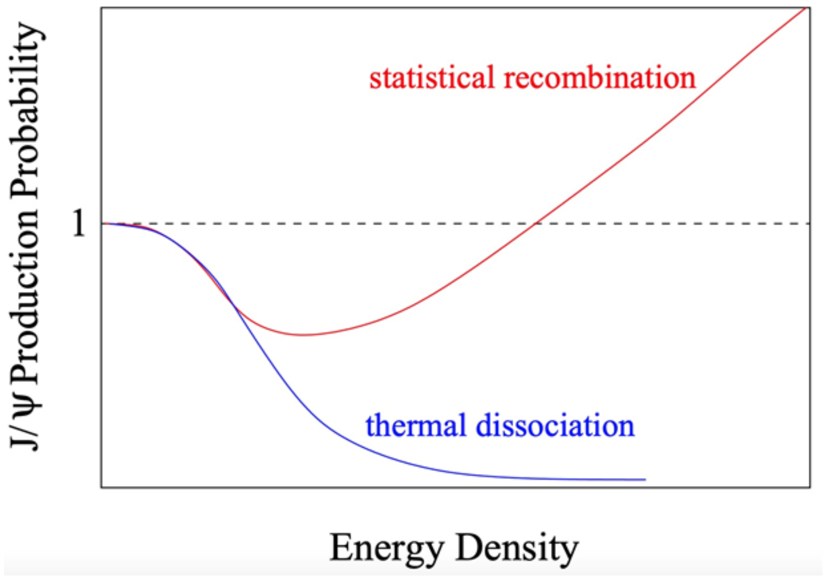
- Motivation
- J/ψ production in Au+Au collisions at $\sqrt{s_{\mathrm{NN}}} = 54.4$ GeV
  - Electron identification
  - J/ψ signal reconstruction
  - p+p baseline
  - Nuclear modification factors
- Summary

J/ψ production in heavy ion collisions

Heavy quarkonia are ideal probes of the Quark-Gluon Plasma (QGP)

- **Dissociation in QGP (static color screening and dynamic dissociation)**





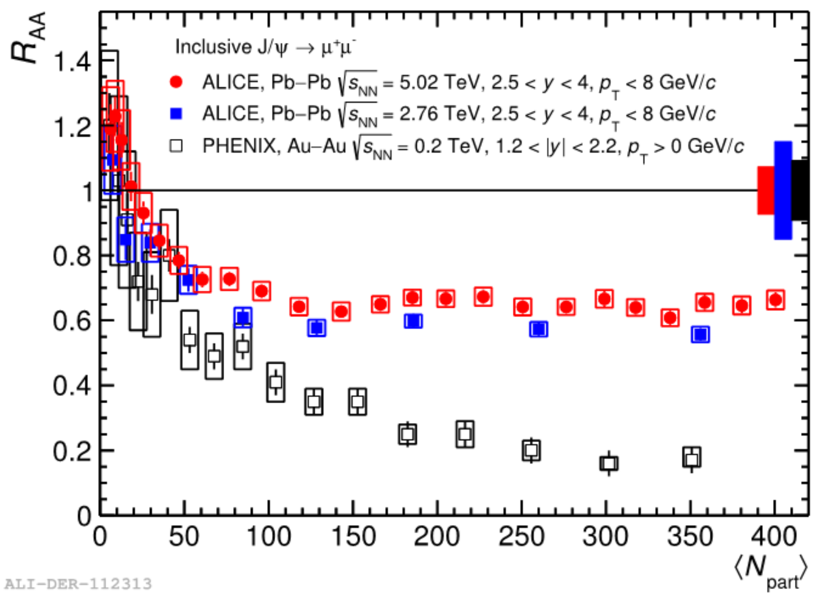
P. Braun-Munzinger, J. Stachel, Nature 448 (2007) 302
P. Braun Muzinger, J.Stachel, PLB 490 (2000) 196
R. Thews et al, Phys.Rev.C 63:054905 (2001)
Kluberg, Satz, arXiv:0901.3831

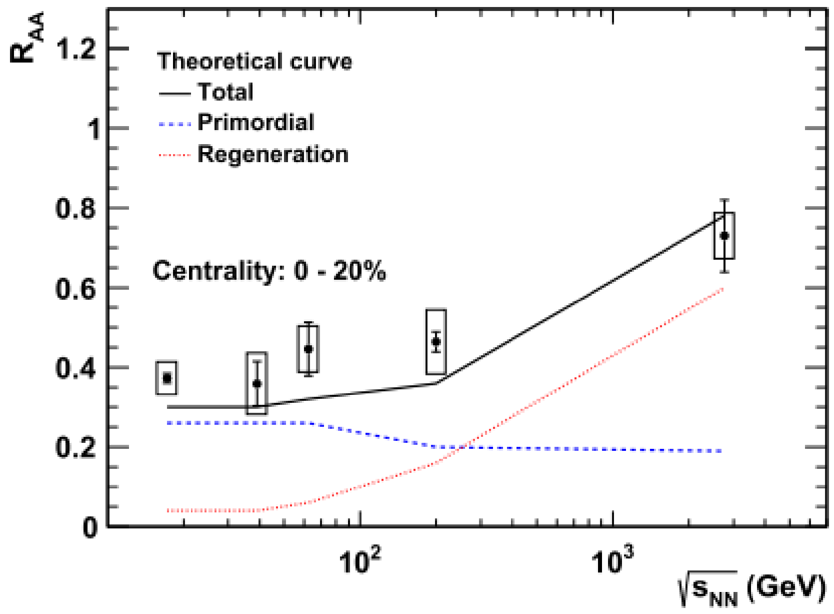
Other effects:

- **Regeneration**
- Cold nuclear matter effects (e.g. nPDF, coherent energy loss, nuclear absorption)
- Other final state effects (e.g. comovers)

J/ψ production in heavy ion collisions

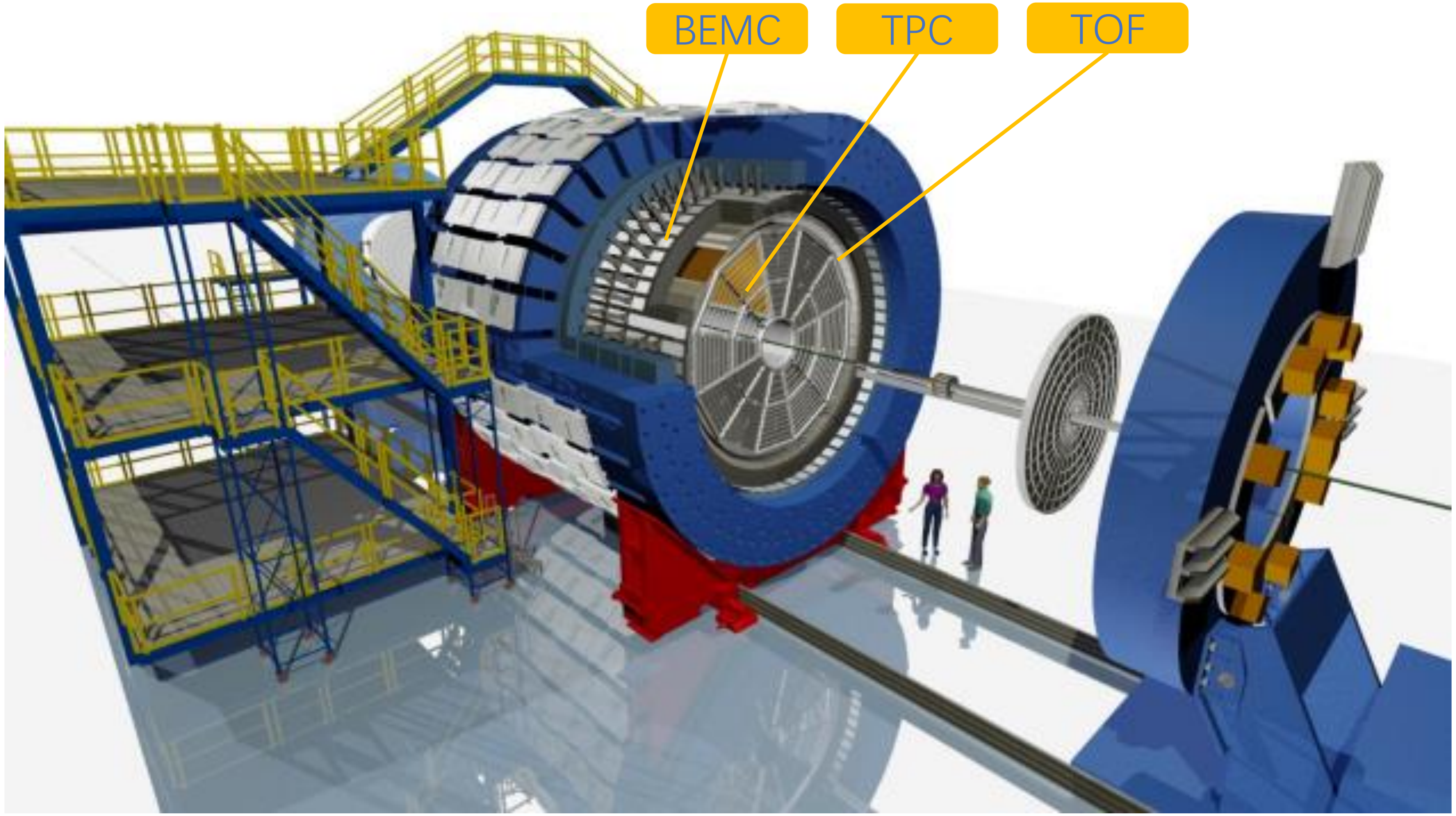
- The J/ψ production has been measured in Au+Au collisions at 39, 62.4 and 200 GeV and in Pb+Pb collisions at 17.2 GeV, 2.76 and 5.02 TeV
- The suppression is reduced at LHC w.r.t RHIC energy
- The nuclear modification factor shows no significant energy dependence within uncertainties at $\sqrt{s_{NN}} \leq 200\ GeV$





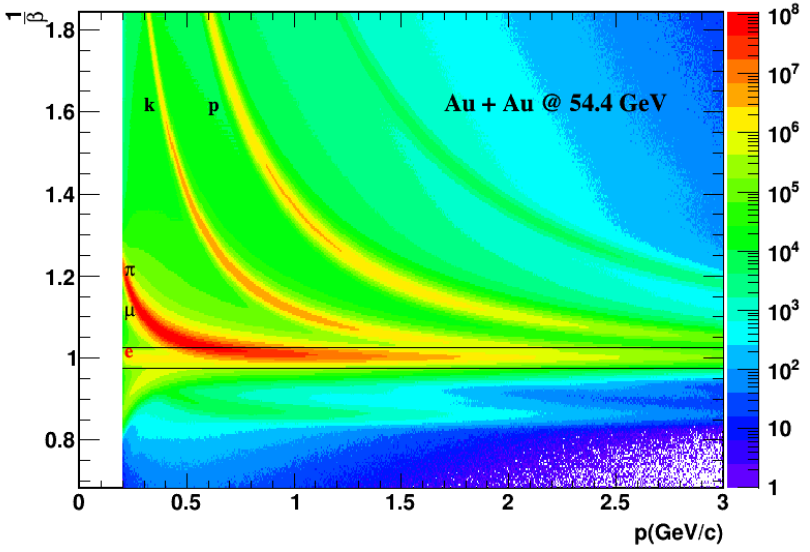
Matsui & Satz PLB 178 (1986) 416
Phys. Lett. B 771 (2017) 13-20 (STAR)
PLB 766 (2017) 212 (ALICE)
PRL 98 (2007) 232301 (PHENIX)
PRL 119 (2017) 242301(ALICE)

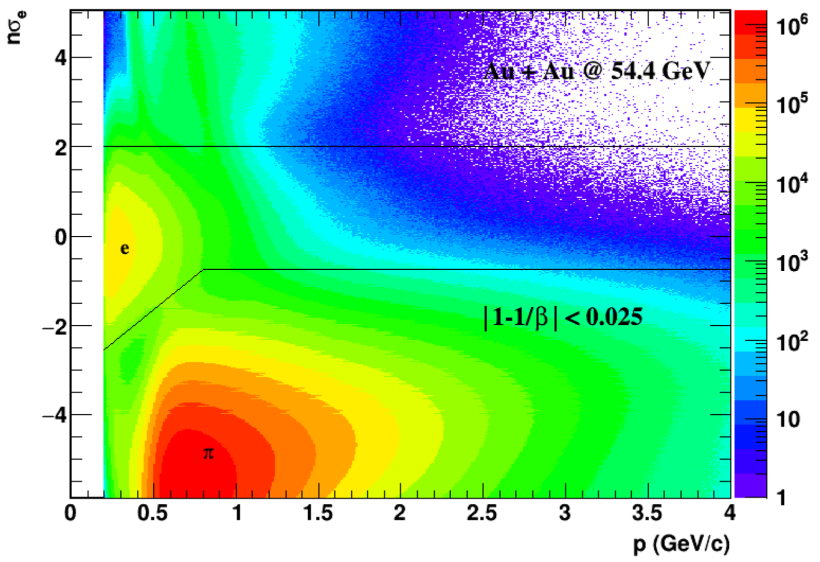
The Solenoidal Tracker At RHIC

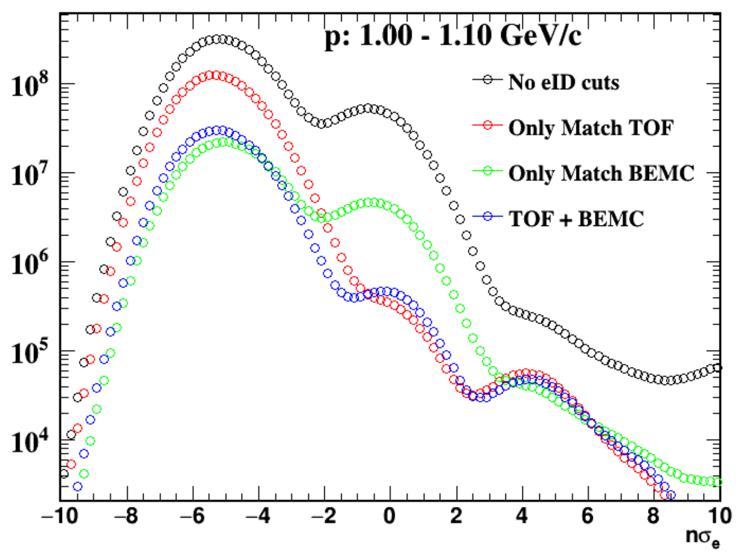


- ✓ TPC: Tracking, momentum and energy loss
- ✓ TOF: Time of flight, particle identification
- ✓ BEMC: Identification of high-p_T electrons
- ● Minimum-bias trigger: VPD and ZDC

Electron identification







$|\vec{P}| \leq 0.8$

- $3\times|\vec{P}|$-3.15< $n\sigma_e$ < 2
- $\left|\frac{1}{\beta} - 1.0\right| < 0.025$

$|\vec{P}| > 0.8$

- -0.75< $n\sigma_e$ < 2
- $\left|\frac{1}{\beta} - 1.0\right| < 0.025$

$p_T \leq 1$ GeV/c

$p_T > 1$ GeV/c

TOF&BEMC

- -1.5 < $n\sigma_e$ < 2
- $\left|\frac{1}{\beta} - 1.0\right| < 0.025$
- 0.5 < E_0/p < 1.5

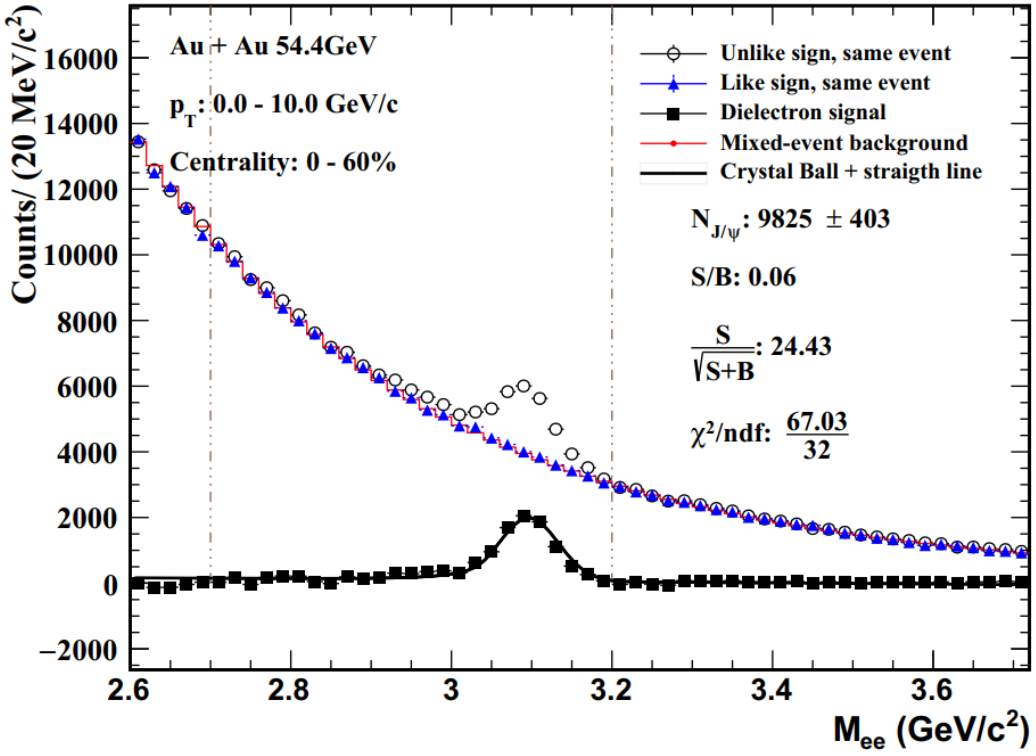
Only match TOF

- -0.75< $n\sigma_e$ < 2
- $\left|\frac{1}{\beta} - 1.0\right| < 0.025$

Only match BEMC

- -1 < $n\sigma_e$ < 2
- 0.5 < E_0/p < 1.5

J/ψ raw signal in 54.4 GeV Au+Au collisions



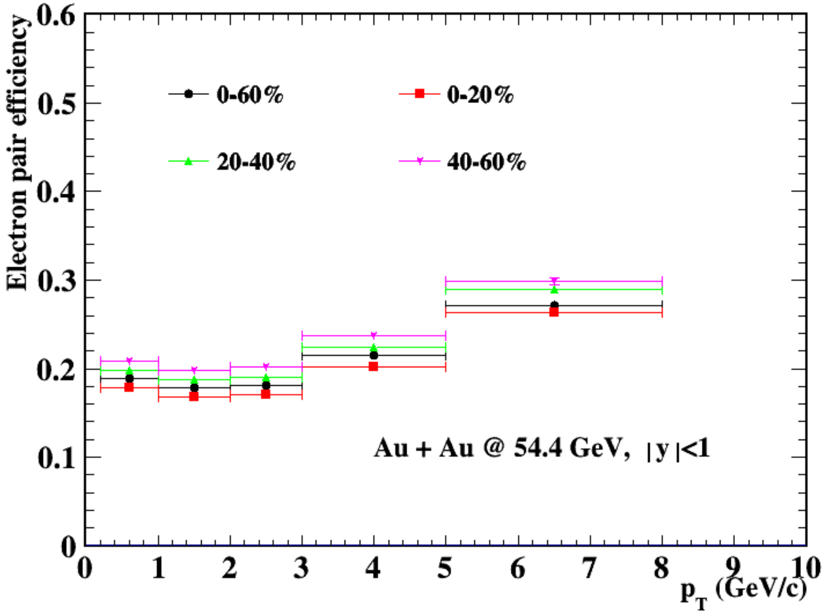
- J/ψ raw signal is reconstructed through dielectron channel
- J/ψ signal shape from embedding with additional momentum smearing
- The combinatorial background is subtracted through mixed-event technique
- Residual background is described by a straight line
- Raw counts extracted by bin counting in $2.7 < \mathrm{M_{ee}} < 3.2\ \mathrm{GeV}/c^2$

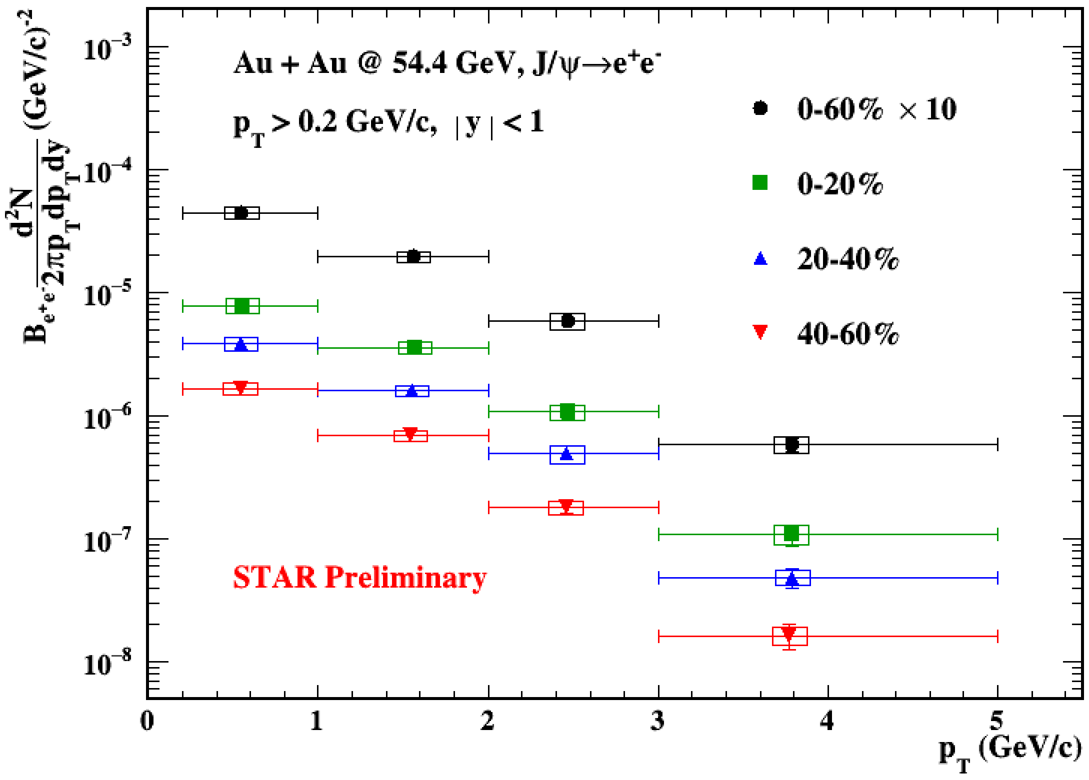
$\sqrt{s_{NN}}$	39 GeV	54.4 GeV	62.4 GeV	200 GeV
S/B	0.34	0.06	0.19	0.03
Significance	10	24	9	22

(STAR Collaboration)
Phys. Lett. B 771 (2017) 13-20

Efficiency and invariant yield

- The pair efficiency is evaluated by folding the single track efficiency
- Acceptance: $p_T^e \geq 0.2$ GeV/c, $|\eta_e| \leq 1$, $|y_{ee}| \leq 1$





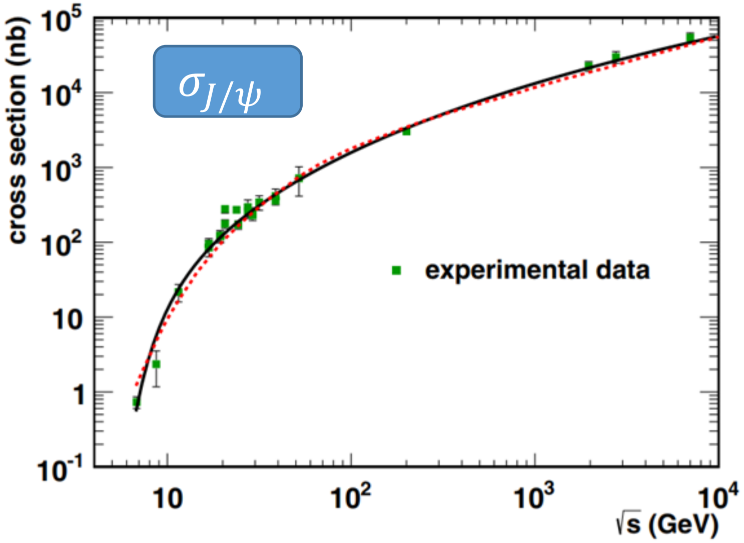
$p_T > 0.2$ GeV/c to exclude coherent photon induced production

p+p baseline

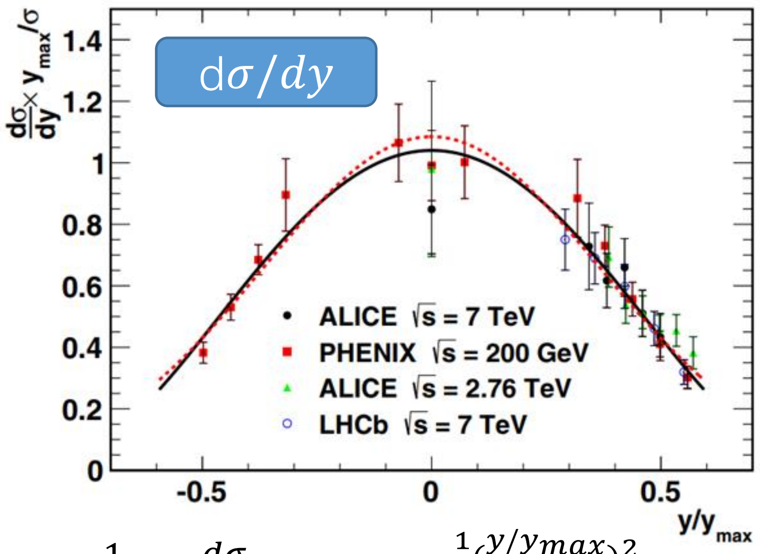
- **For p+p baselines at 39, 54.4, and 62.4 GeV, they are extracted from phenomenological interpolations**

- Energy interpolation from the existing total J/ψ cross section measurements
- Energy evolution of the rapidity distribution
- Energy evolution of J/ψ transverse momentum distribution

W. Zha, et al., Phys. Rev. C 93 (2016) 024919.

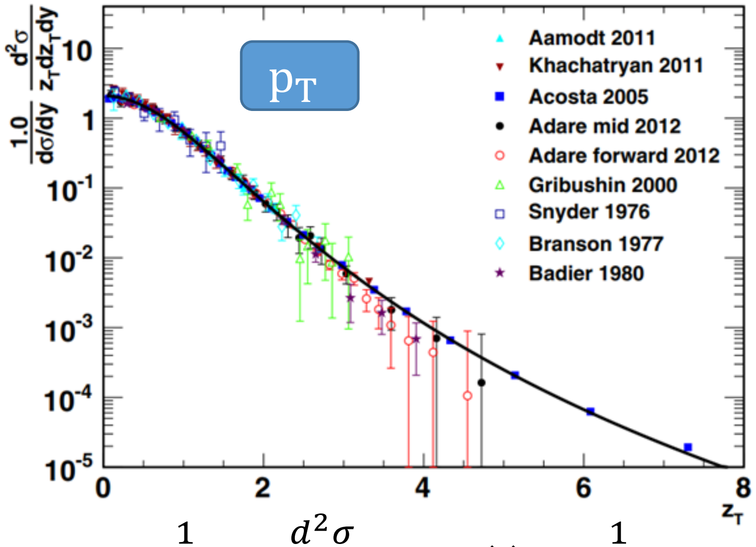


$$\sigma = \alpha \times \sigma_{CEM}$$



$$\frac{1}{\sigma}\frac{d\sigma}{d(y/y_{max})} = ae^{-\frac{1}{2}(\frac{y/y_{max}}{b})^2}$$

where $y_{max} = \ln(\frac{\sqrt{s}}{m_{J/\psi}})$

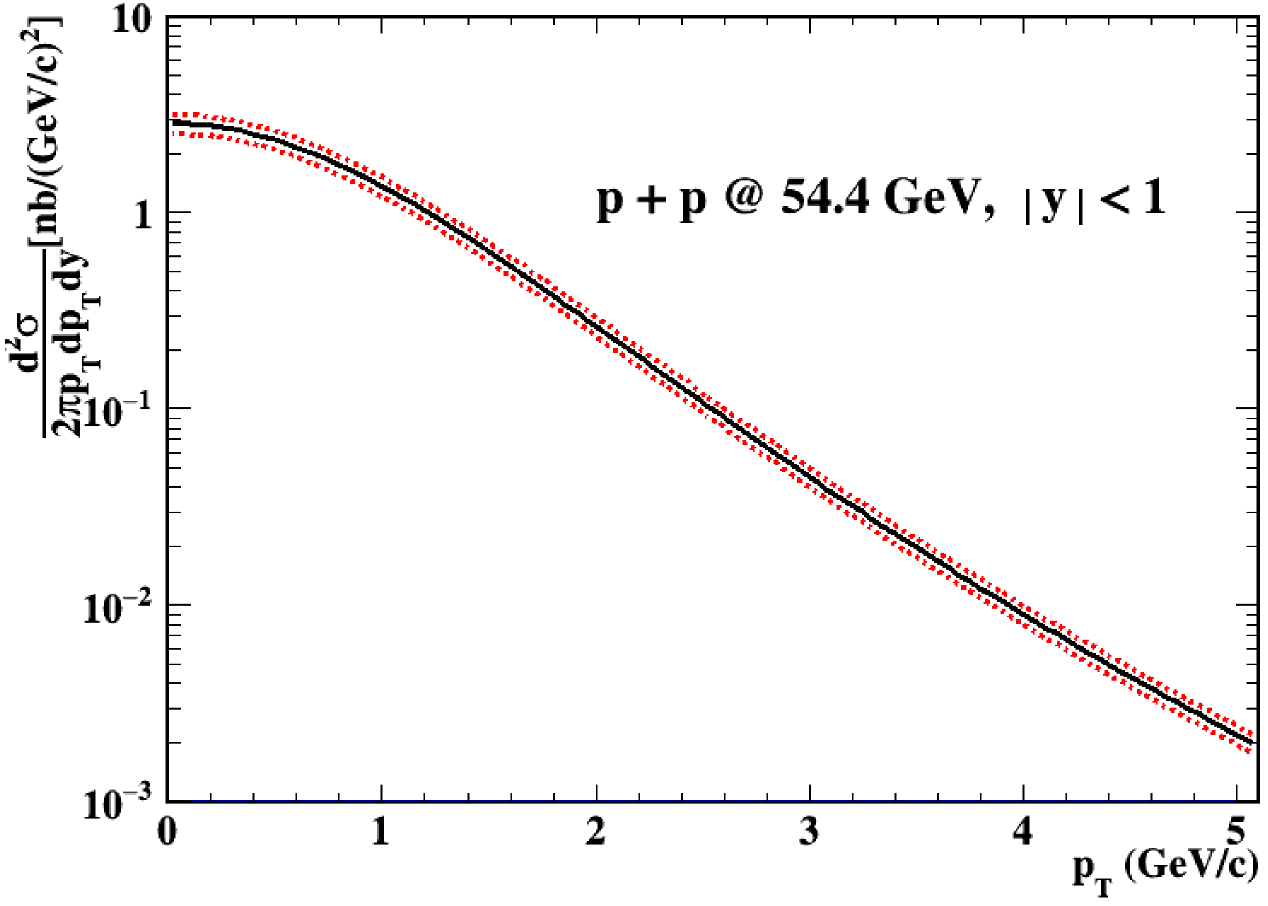


$$\frac{1}{d\sigma/dy}\frac{d^2\sigma}{z_T dz_T dy} = a \times \frac{1}{(1+b^2 z_T^2)^n}$$

where $z_T = p_T/\langle p_T \rangle$

p+p baseline at $\sqrt{s} = 54.4$ GeV

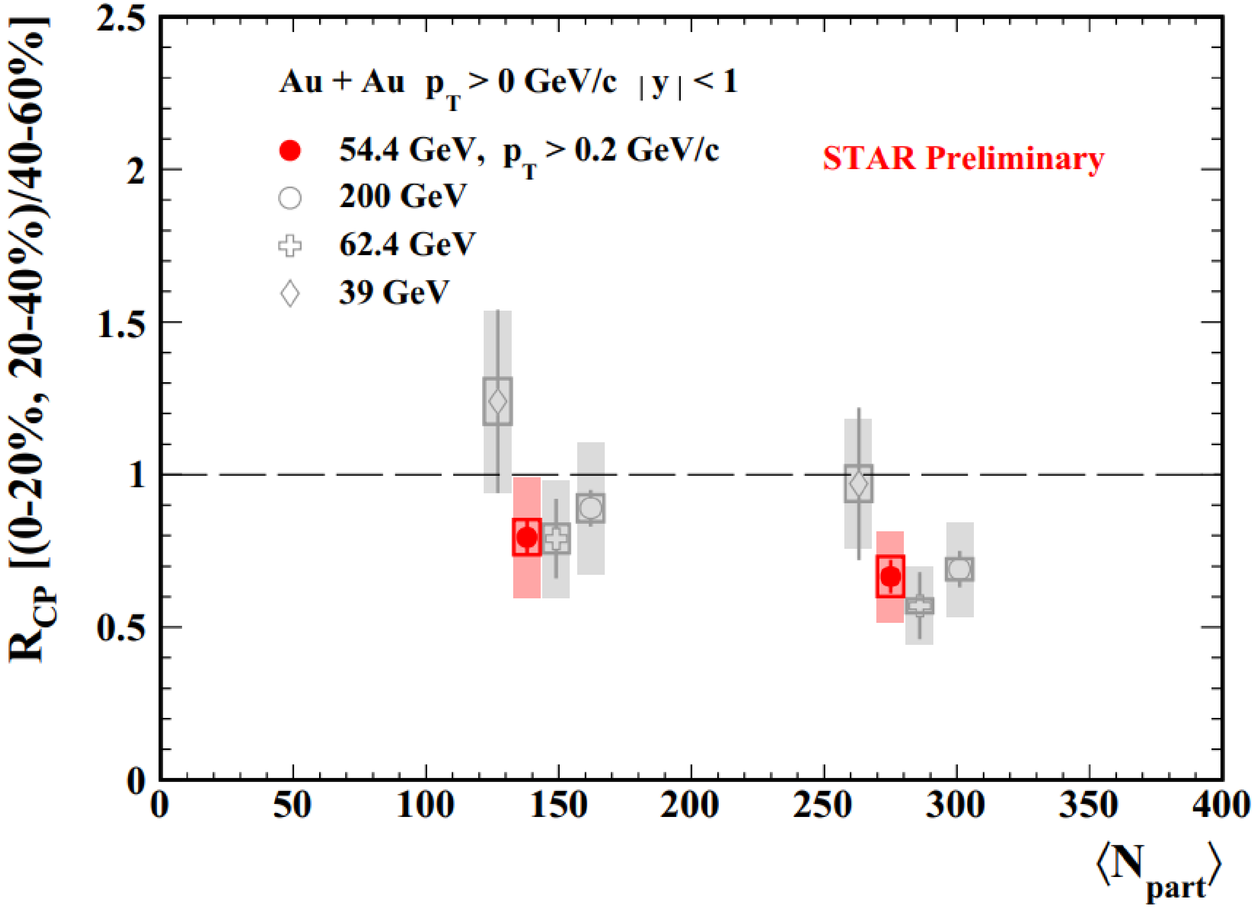
- **For p+p baselines at 39, 54.4, and 62.4 GeV, they are extracted from phenomenological calculations**



- The p_T dependence of deduced J/ψ differential cross section at midrapidity in p+p collisions at $\sqrt{s} = 54.4$ GeV
- The uncertainty from interpolation: ~ 11 %

W. Zha, et al., Phys. Rev. C 93 (2016) 024919.

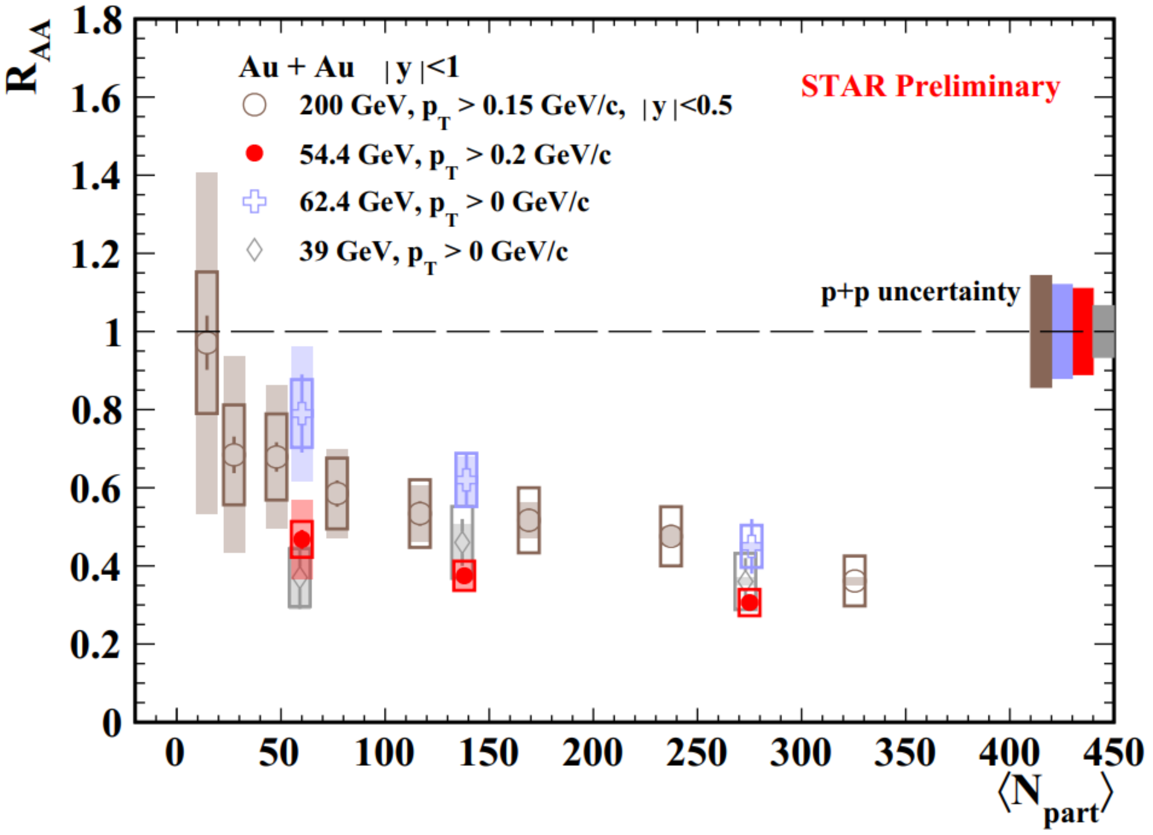
R_{CP} vs $\langle N_{part} \rangle$

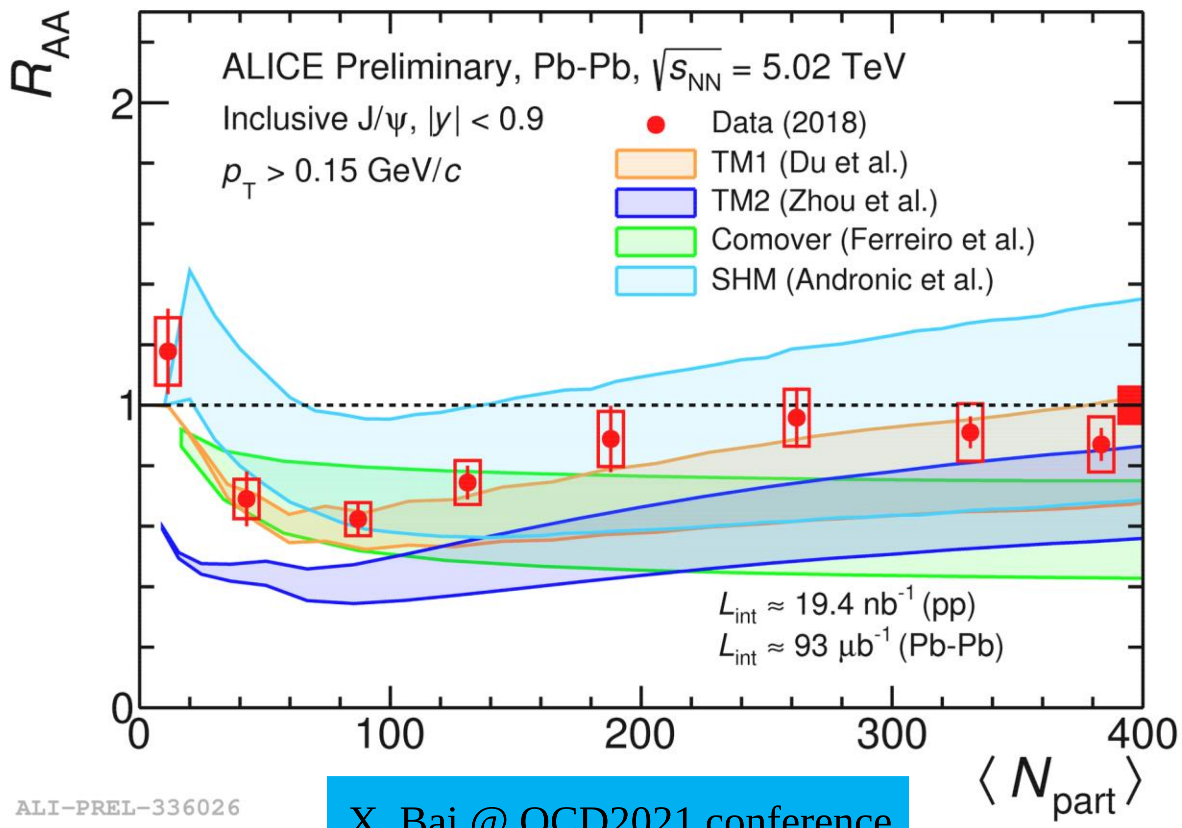


$$R_{CP} = \frac{\frac{dN/dy}{\langle N_{coll} \rangle}(\text{central})}{\frac{dN/dy}{\langle N_{coll} \rangle}(\text{peripheral})}$$

- Peripheral 40 – 60 % centrality is used as reference
- A suppression is observed in central Au+Au collisions at 54.4 GeV, similar to that at 62.4 and 200 GeV

R_{AA} vs $\langle N_{part} \rangle$

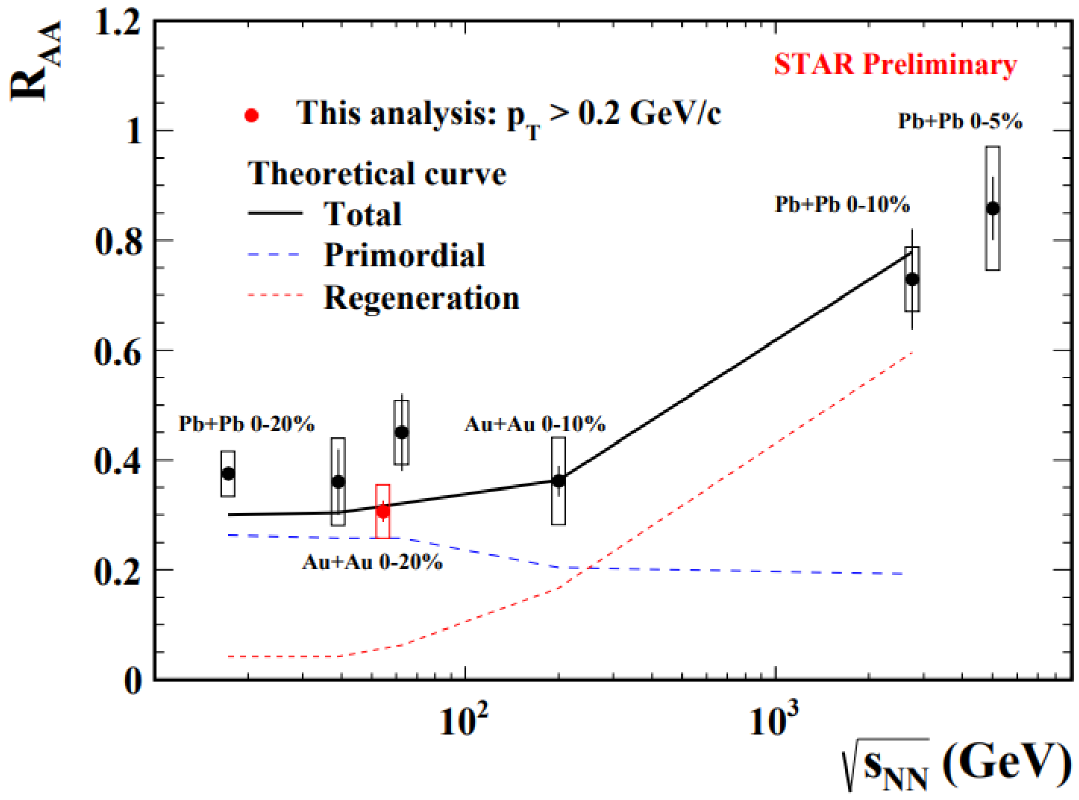




X. Bai @ QCD2021 conference

- Suppression of J/ψ production is observed in Au+Au collisions at 54.4 GeV with better precision compared to 39 and 62.4 GeV
- In central collisions, the R_{AA} is decreasing at RHIC energies while increasing at LHC energy

R_{AA} vs $\sqrt{s_{NN}}$



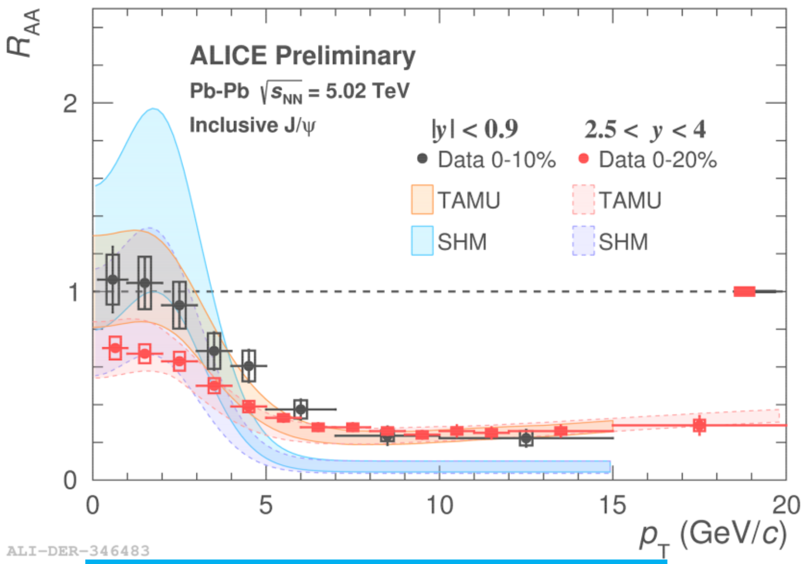
- R_{AA} as a function of $\sqrt{s_{NN}}$, in central A+A collisions
- 54.4 GeV data follow the trend with improved precision
- No significant energy dependence is observed within uncertainties up to 200 GeV
  - ➢ Interplay of dissociation, regeneration and cold nuclear matter effects
- Model calculations are consistent with the observed energy dependence

Calculations are for the same system as data points and in 0-20% centrality

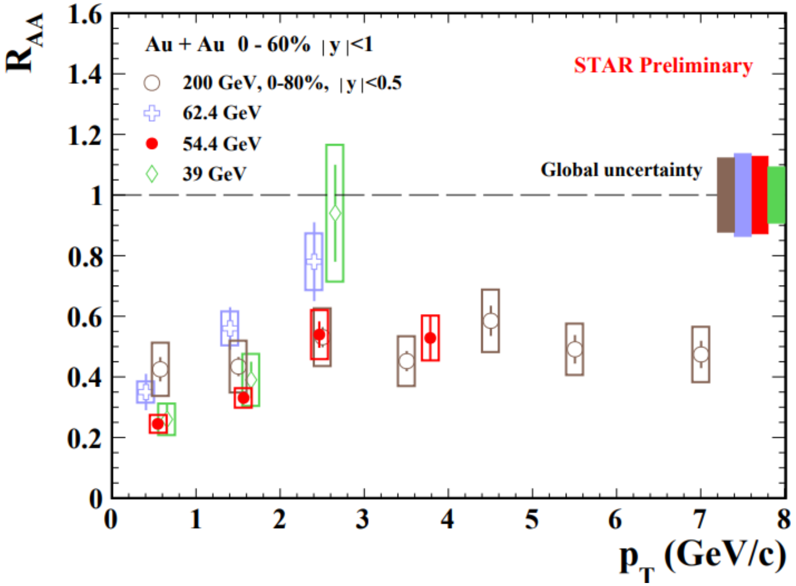
X. Zhao, R. Rapp, Phys. Rev. C 82 (2010) 064905 (private communication).
L. Kluberg, Eur. Phys. J. C 43 (2005) 145.
NA50 Collaboration, Phys. Lett. B 477 (2000) 28.

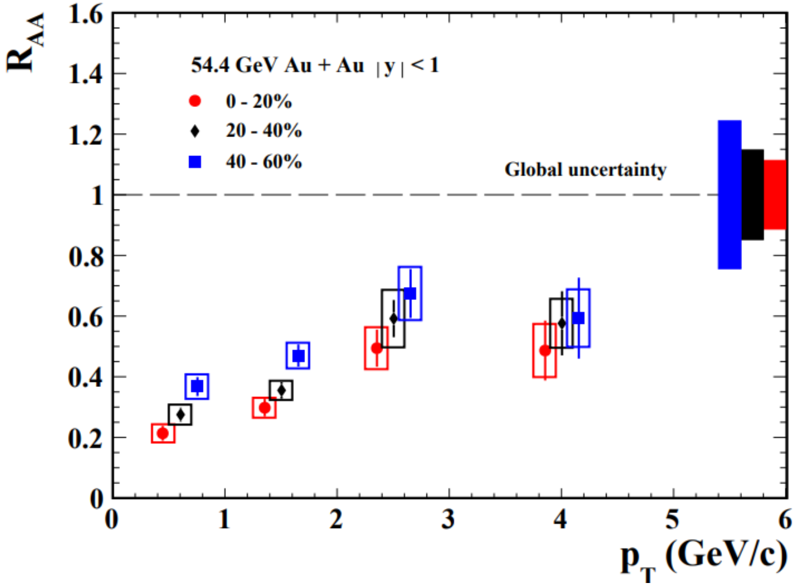
ALICE Collaboration, Phys. Lett. B 734 (2014) 314
STAR Collaboration, Phys. Lett. B 771 (2017) 13-20
STAR Collaboration, Phys. Lett. B 797 (2019) 134917
ALICE Collaboration, Nucl. Phys. A 1005 (2021) 121769

R_{AA} vs p_T



X. Bai @ QCD2021 conference





- The enhancement and rapidity dependence of R_{AA} at low p_T at LHC energy can be explained by regeneration contribution
- R_{AA} increases with increasing p_T for 39, 54.4 and 62.4 GeV
- More suppression towards central collisions for 54.4 GeV

Summary

- In central collisions, the R_{AA} is decreasing at RHIC energies while increasing at LHC energy
- No significant energy dependence of R_{AA} has been observed in central collisions from 17.2 to 200 GeV
  - Interplay of dissociation, regeneration and cold nuclear matter effects
- The enhancement and rapidity dependence of R_{AA} at low p_T at LHC energy can be explained by regeneration contribution
- The suppression is more significant at lower p_T and central collisions at $\sqrt{s_{NN}}$ = 54.4 GeV

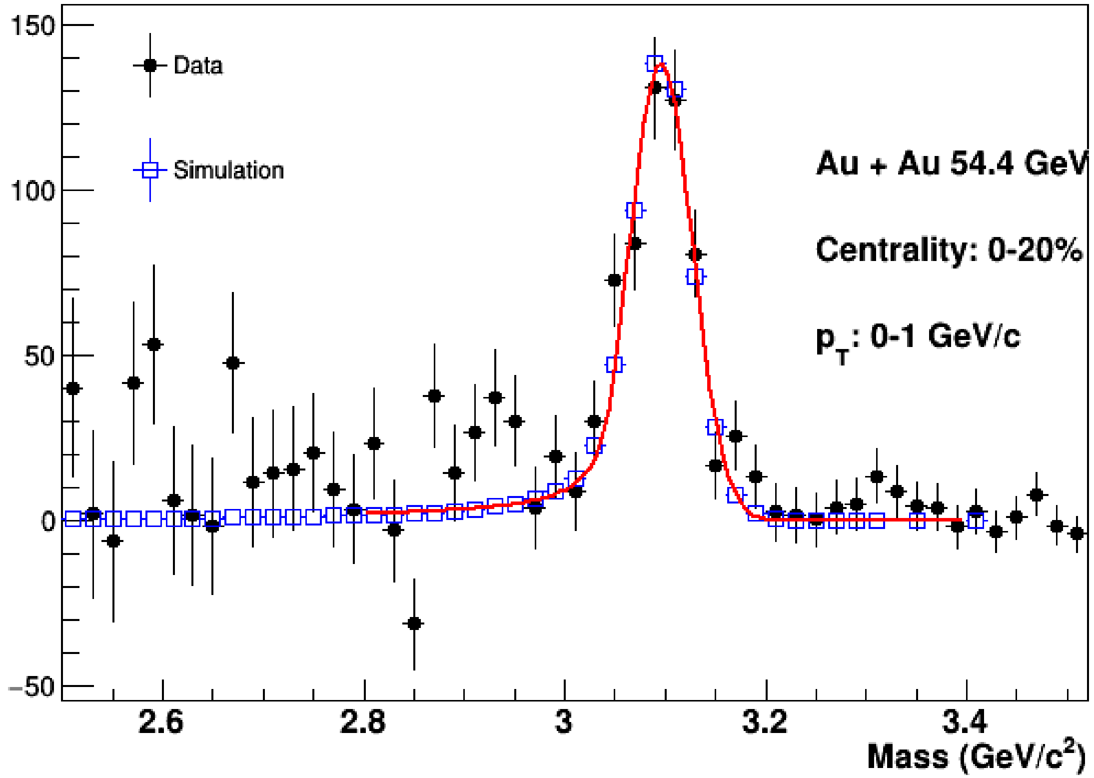
Summary

- In central collisions, the R_{AA} is decreasing at RHIC energies while increasing at LHC energy
- No significant energy dependence of R_{AA} has been observed in central collisions from 17.2 to 200 GeV
  - Interplay of dissociation, regeneration and cold nuclear matter effects
- The enhancement and rapidity dependence of R_{AA} at low p_T at LHC energy can be explained by regeneration contribution
- The suppression is more significant at lower p_T and central collisions at $\sqrt{s_{NN}} = 54.4$ GeV

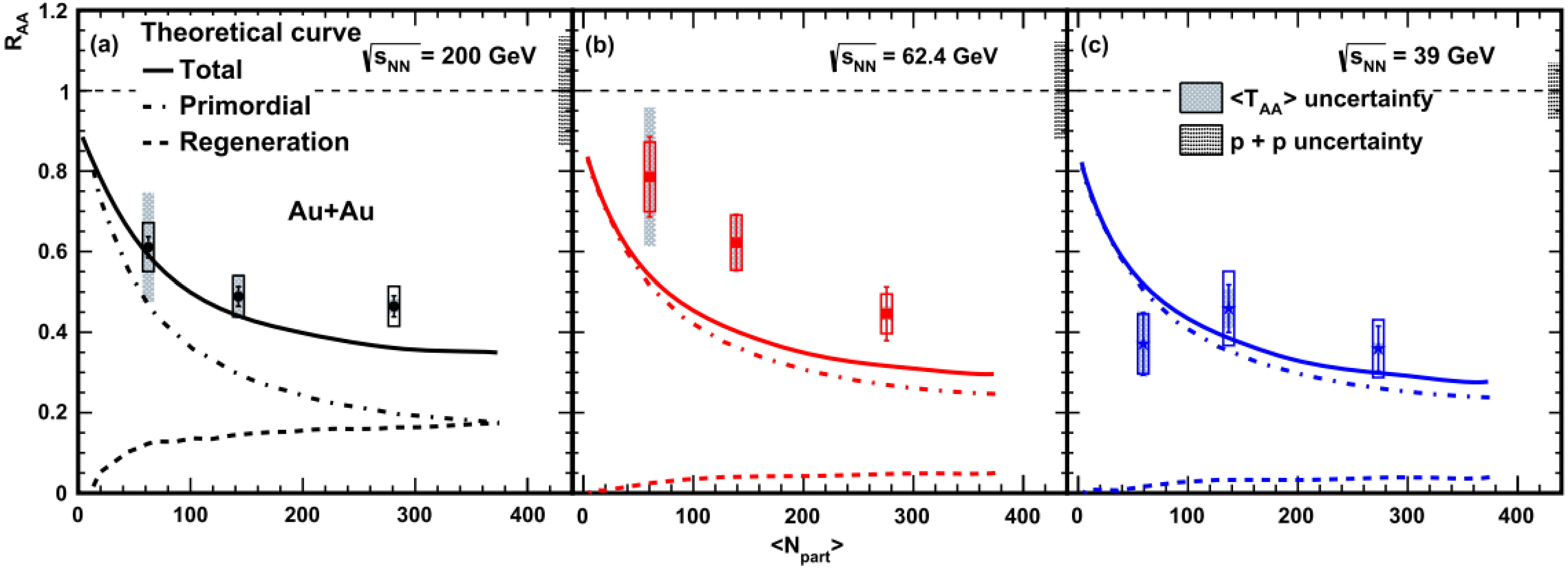
Thank you !

Back up

J/ψ signal templates



- The J/ψ line-shape from embedding with additional momentum smearing matches data well
- The distribution is fitted by a Crystal-ball function
- Fix the shape of the Crystal-ball function according to simulation when fitting the J/ψ raw signal in real data



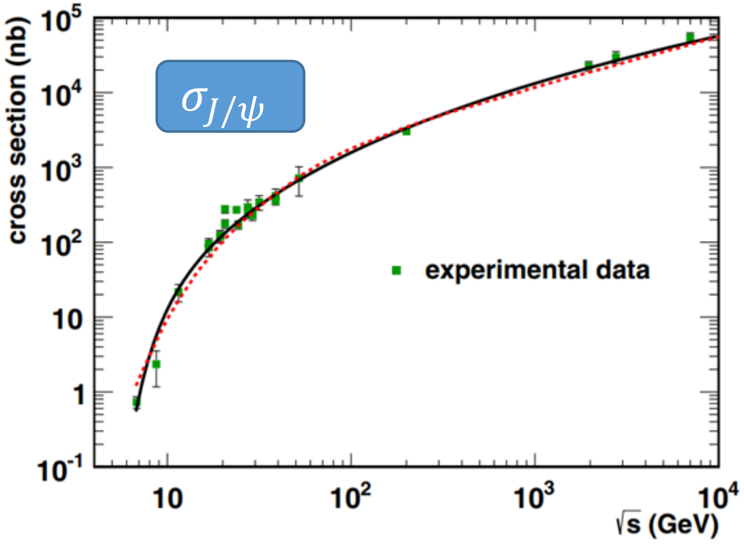
(STAR Collaboration)
Phys. Lett. B 771 (2017) 13-20

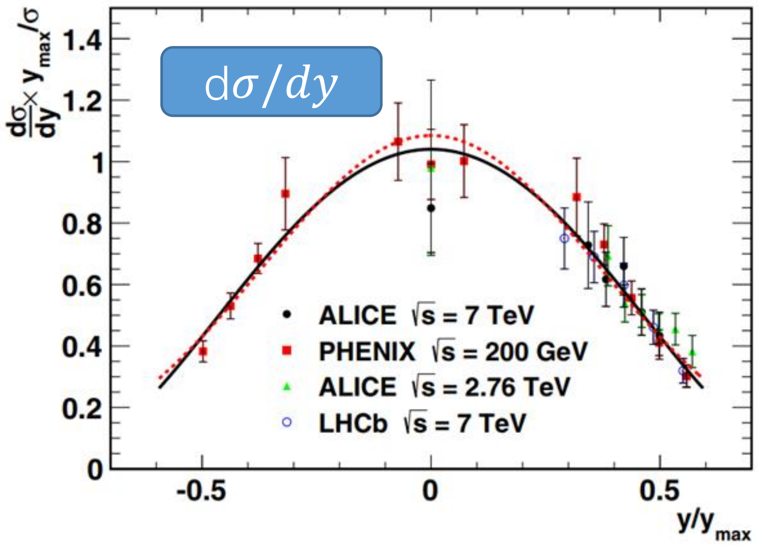
p+p baseline

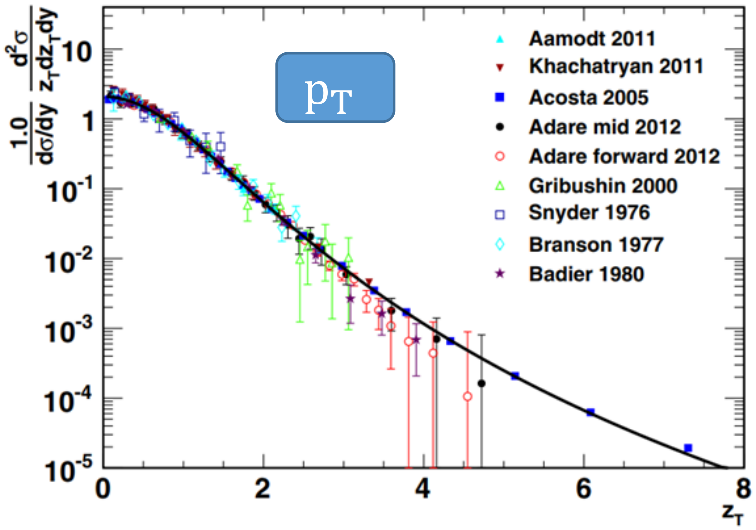
STAR

- For p+p baseline at 39, 54.4, and 62.4 GeV, they are extracted from phenomenological calculations

W. Zha, et al., Phys. Rev. C 93 (2016) 024919.







$\sigma = \alpha \times \sigma_{CEM}$ (default)

$$\sigma(\sqrt{s}) = a \times y_{max}^{d} \times e^{\frac{-b}{y_{max}^{c}}}$$

where $y_{max} = \ln(\frac{\sqrt{s}}{m_{J/\psi}})$

$$\frac{1}{\sigma}\frac{d\sigma}{d(y/y_{max})} = a e^{-\frac{1}{2}\left(\frac{y/y_{max}}{b}\right)^2} \text{(default)}$$

$$\frac{1}{\sigma}\frac{d\sigma}{d(y/y_{max})} = \frac{c}{1-(y/y_{max})^2}\, e^{-d\left(\ln\left(\frac{1+y/y_{max}}{1-y/y_{max}}\right)\right)^2}$$

$$\frac{1}{d\sigma/dy}\frac{d^2\sigma}{z_T dz_T dy} = a \times \frac{1}{(1+b^2 z_T^2)^n}$$

where $z_T = p_T/\langle p_T\rangle$

Dataset and cuts

- Trigger sets: AuAu54_production_2017
- Production Tag: P18ic (SL20c)
- Stream name: st_physics
- Minimum bias trigger: 580001; 580011; 580021
- Bad run list: from Yuanjing's QA: https://drupal.star.bnl.gov/STAR/system/files/npe0324_0.pdf

Event Level:

- V_z < 60 cm
- $|V_z - V_z(VPD)|$ < 3 cm
- $\sqrt{V_x{}^2 + V_y{}^2}$ < 2 cm

Electron identification:

- TPC: $n\sigma_e$
- TOF: $\frac{1}{\beta}$
- BEMC: $\frac{E_0}{p}$

Track quality:

- p_T > 0.2 GeV/c
- $|\eta|$ < 1
- nHitsFit > 20
- nHitsDedx > 15
- nHitsFitRatio > 0.52
- Dca < 1cm