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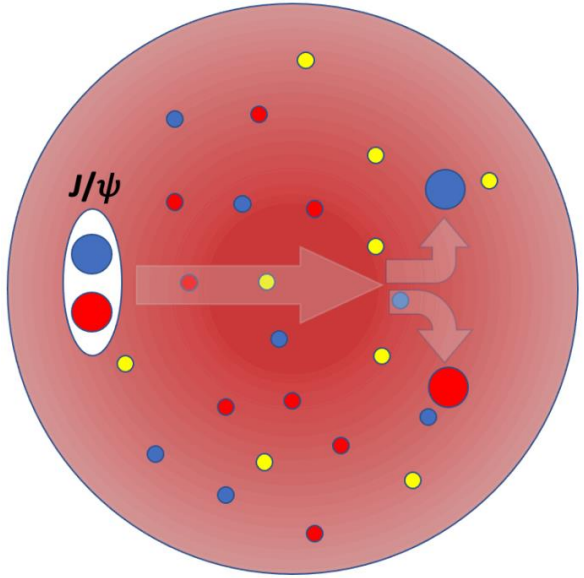
J/ψ R_{AA} in Au+Au collisions at 14.6, 17.3, 19.6 and 27GeV

Wei Zhang

Introduction

- Quarkonia suppression was proposed as a sensitive probe to QGP properties
  - Dominantly produced before QGP formation
- Hot medium effects
  - Dissociation(color screening and dynamic interaction)
  - Regeneration
- Cold nuclear matter effects
  - nPDF
  - Nuclear absorption
- Other effects
  - Comover interactions
  - Feed-down contribution



Credit: Q. Yang

$$R_{AA} = \frac{\sigma_{\text{inel}}}{\langle N_{coll} \rangle} \frac{d^2 N_{AA}/dydp_T}{d^2\sigma_{pp}/dydp_T}$$

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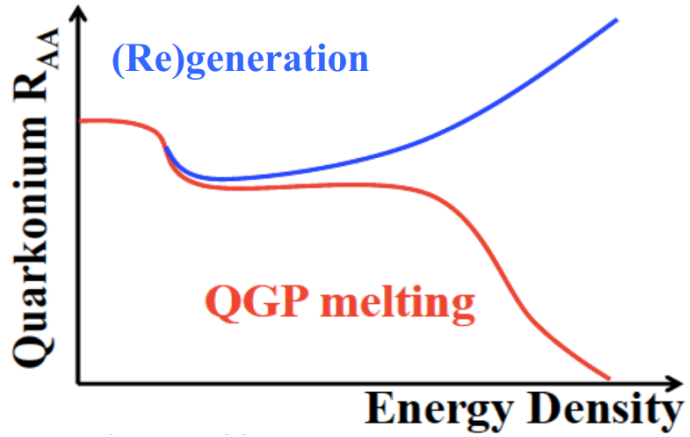

Credit: Q. Yang

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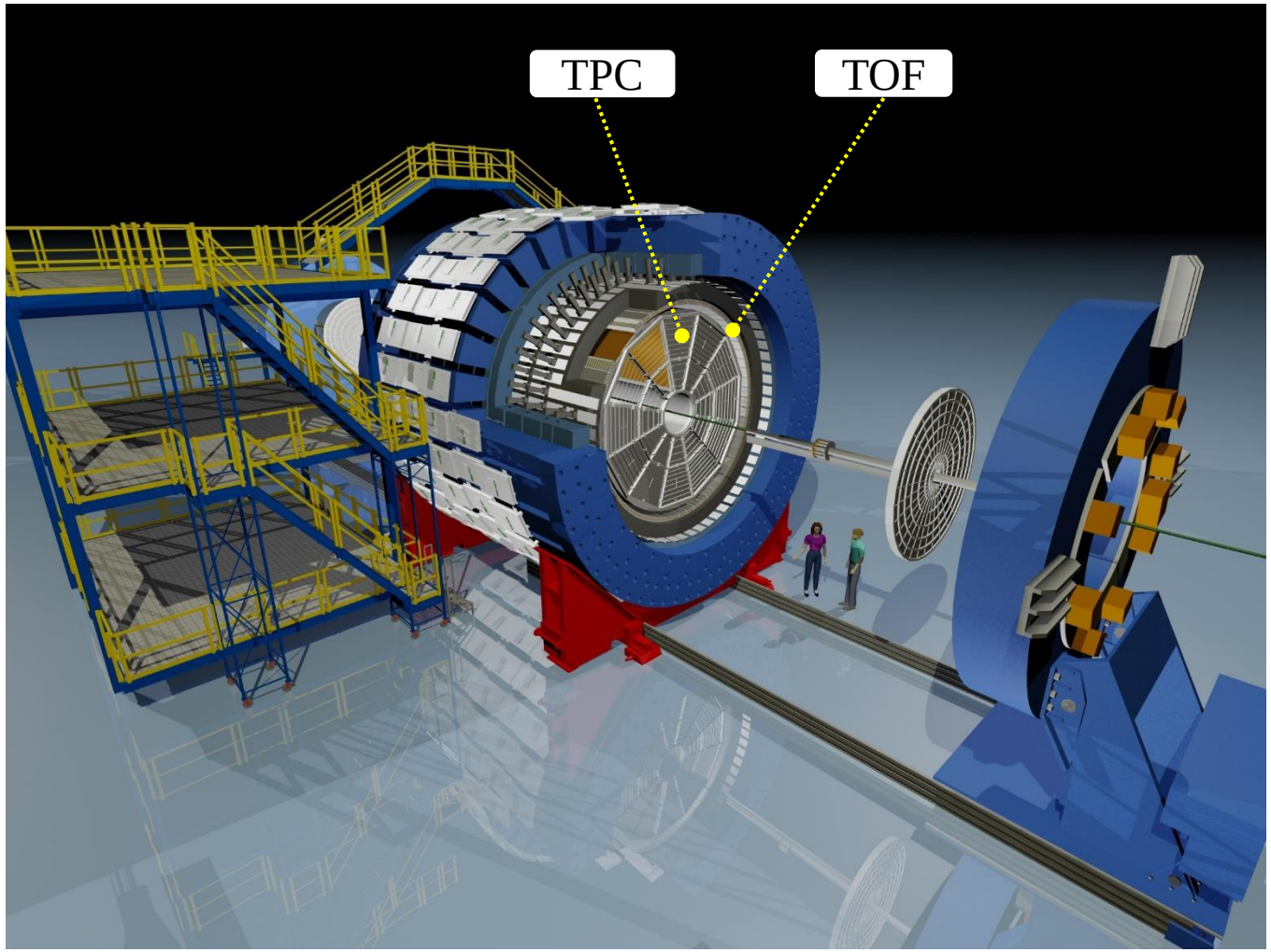
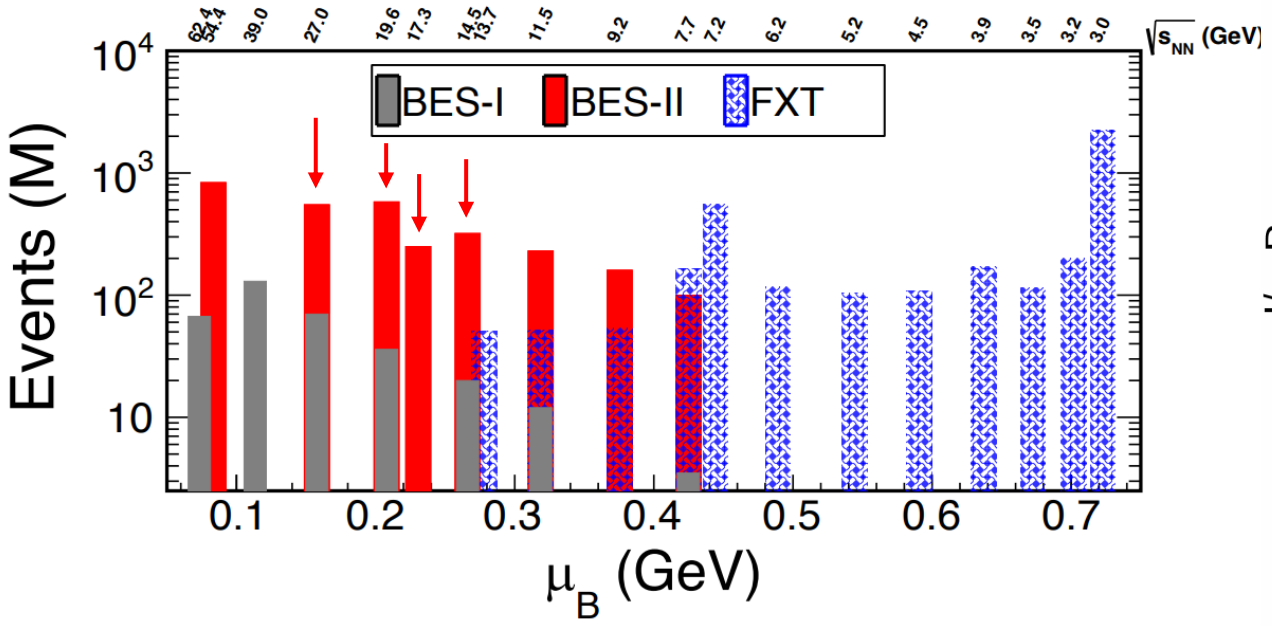
STAR Detector

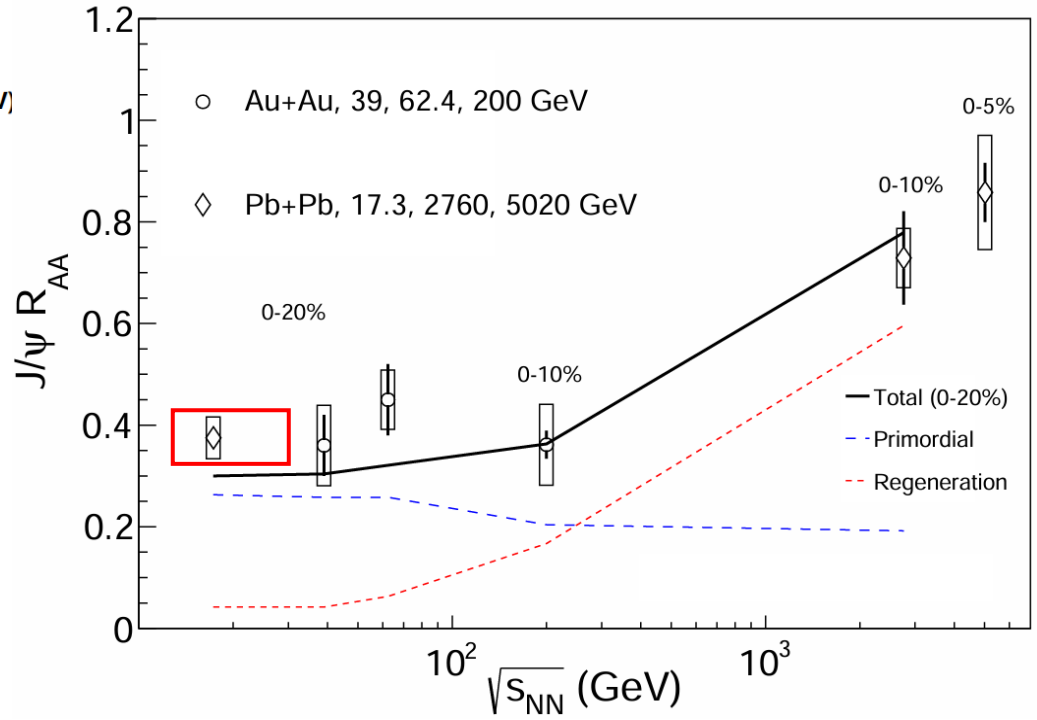


- **Time Projection Chamber**
  - Tracking
  - Momentum and energy loss
  - Acceptance: $|\eta| < 1.5$; $0 \leq \varphi < 2\pi$

- **Time Of Flight Detector**
  - Time of flight
  - Particle identification
  - Acceptance: $|\eta| < 1$; $0 \leq \varphi < 2\pi$

Au+Au Collisions at STAR





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

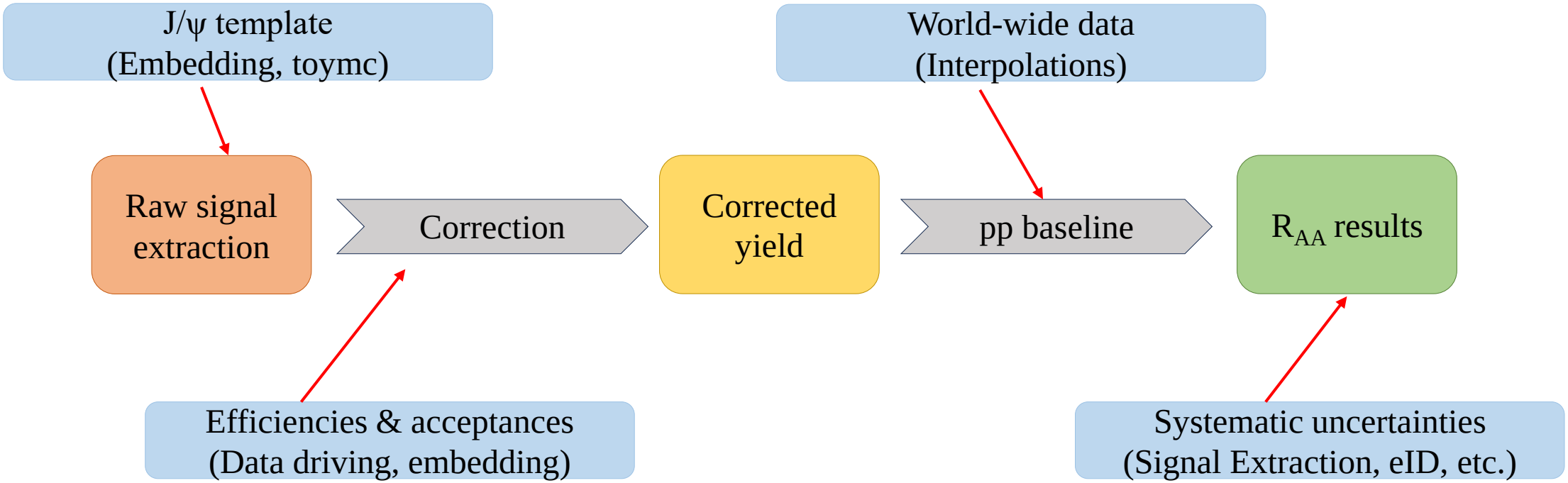
- BES-I → BES-II
  - 10-20 times higher statistics than BES-I
  - Enables differential measurements at low collision energies

- Collision energy dependence of J/ψ production
  - Au+Au collisions at $\sqrt{s_{NN}}$ = 14.6, 17.3, 19.6, 27 GeV
  - Smaller regeneration effect

Analysis Procedure

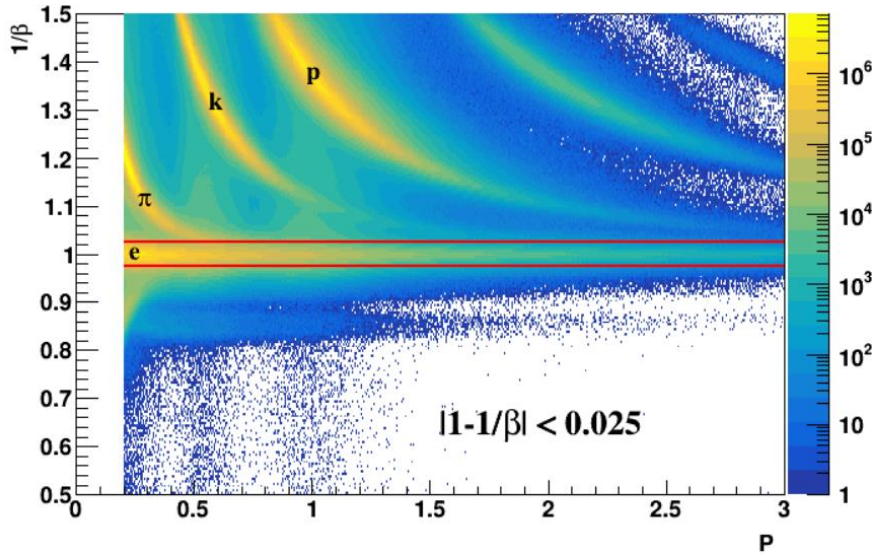
Observable: $R_{AA} = \frac{\sigma_{\text{inel}}}{\langle N_{coll} \rangle} \frac{d^2 N_{AA}/dydp_T}{d^2\sigma_{pp}/dydp_T}$

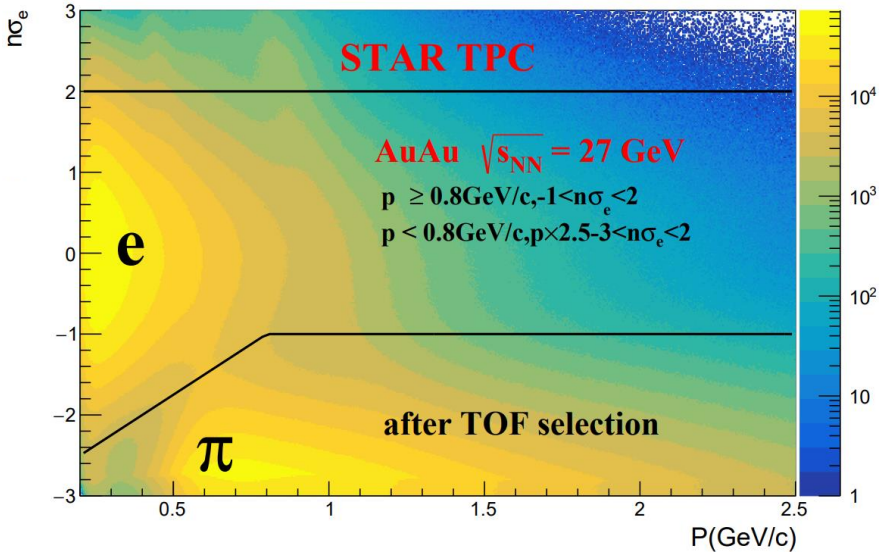
- < 1 suppression
- = 1 no net medium effects
- > 1 enhancement



Electron Identification

- System : Au+Au collisions in RHIC-STAR.
- Particle and decay channel: $J/\psi \rightarrow e^- + e^+$

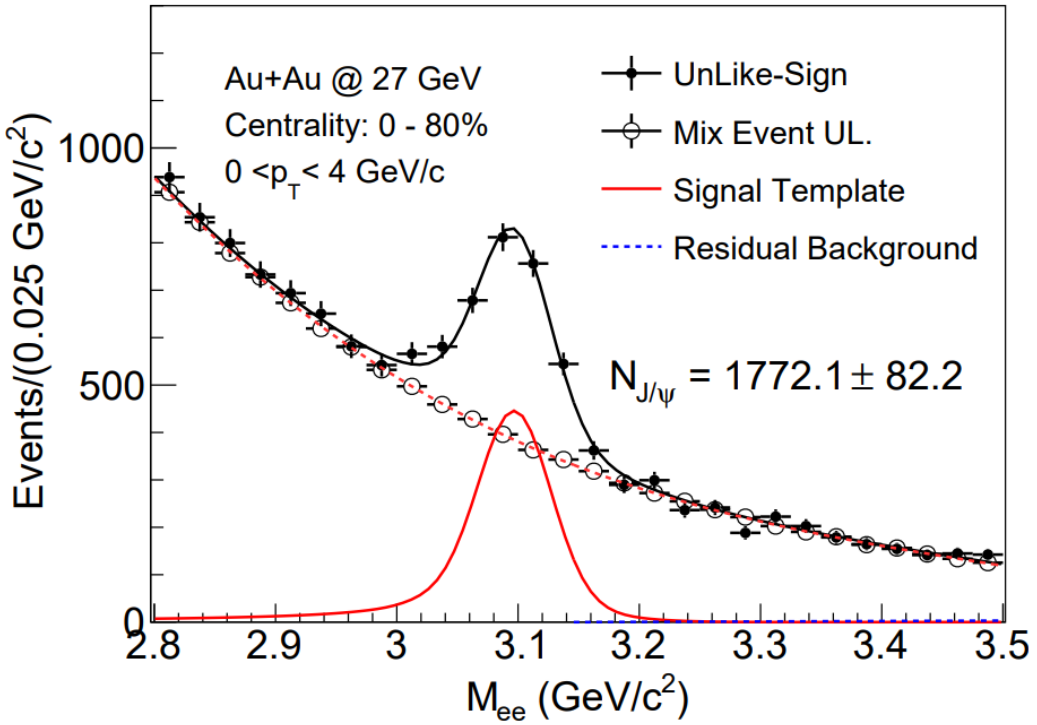




$$n\sigma_e = \frac{1}{R} log \frac{(dE/dx)_{measured}}{(dE/dx)_{electron}}$$

Raw J/ψ Signal

$$R_{AA} = \frac{\sigma_{\text{inel}}}{\langle N_{coll} \rangle} \frac{d^2 N_{AA}/dydp_T}{d^2\sigma_{pp}/dydp_T}$$



$\sqrt{s_{NN}} = 27$ GeV

- The function used to fit UL-Sign (UL) consists of
  - J/ψ template
  - combinatorial background
  - residual background
- Extracted combinatorial background shape from mixed-event UL-Sign.
- Residual background parameterized using a first-order polynomial.

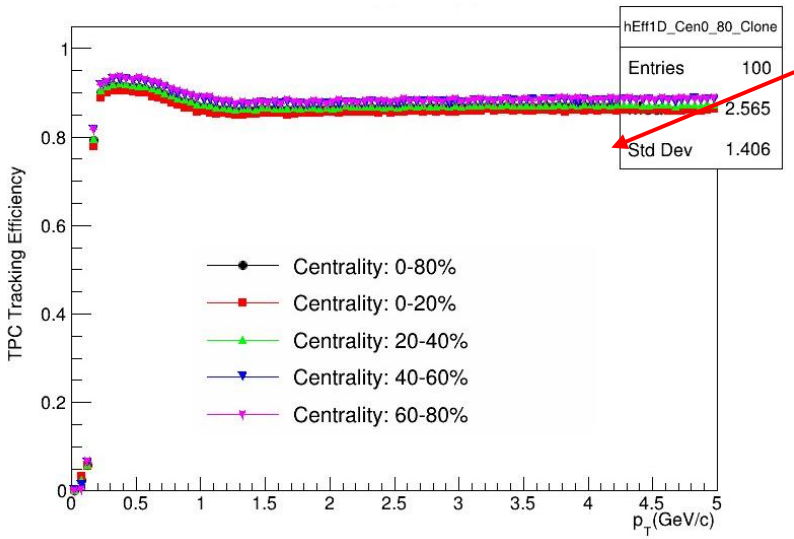
Efficiency and Acceptance Corrections

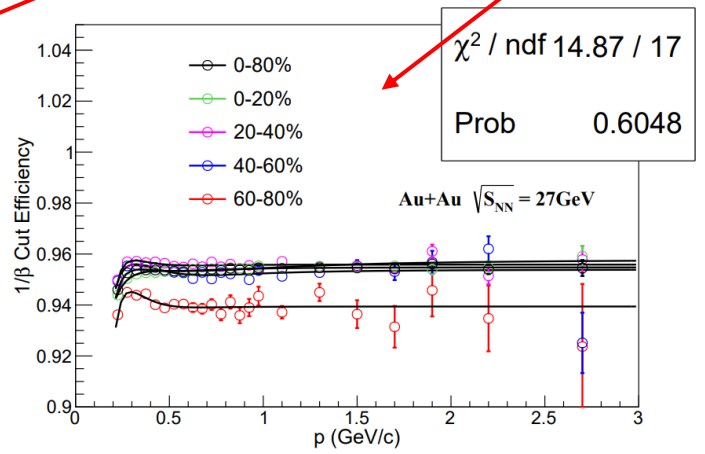
$$R_{AA} = \frac{\sigma_{\text{inel}}}{\langle N_{coll} \rangle} \frac{d^2 N_{AA}/dydp_T}{d^2\sigma_{pp}/dydp_T}$$

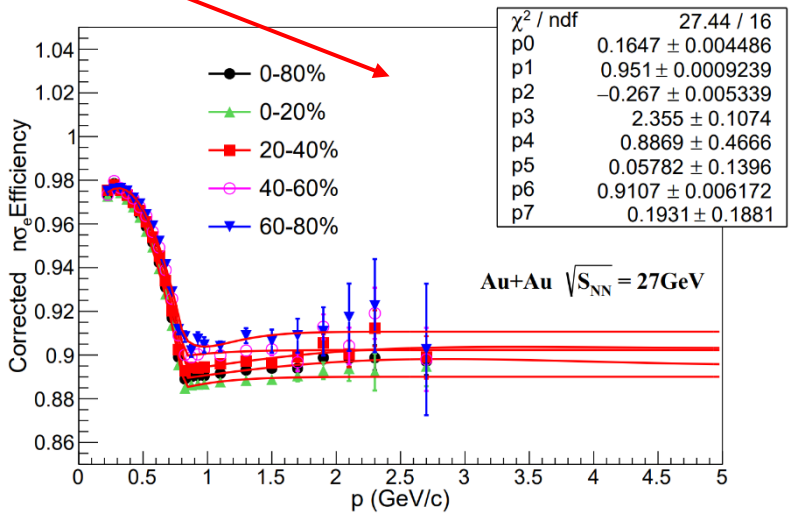
$$N_{AA} = \frac{N_{J/\psi \to e^+e^-}}{A \times \varepsilon \times N_{event}}$$

$$\varepsilon = \varepsilon_{electron} \times \varepsilon_{positron}$$

$$\varepsilon_{electron} = \varepsilon_{positron} = \varepsilon_{TPC} \times \varepsilon_{eID} \times \varepsilon_{TOF}$$



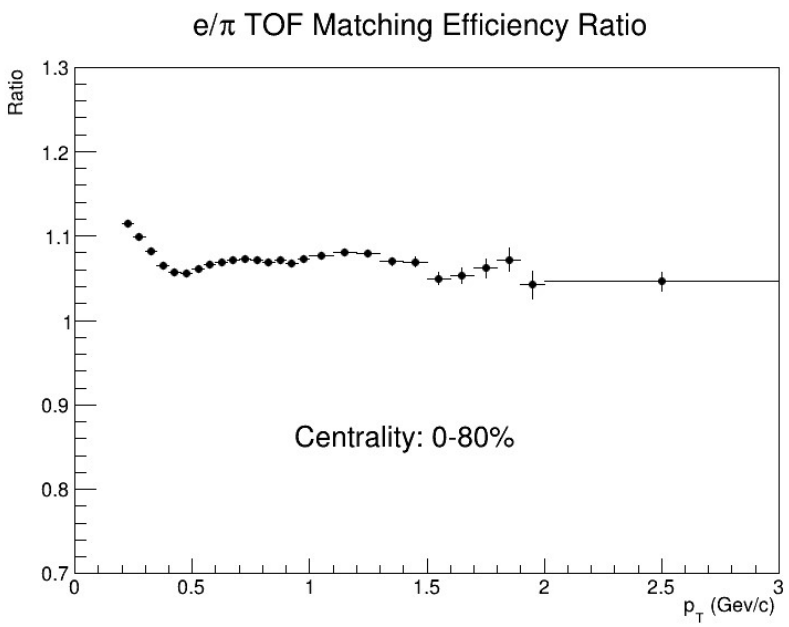


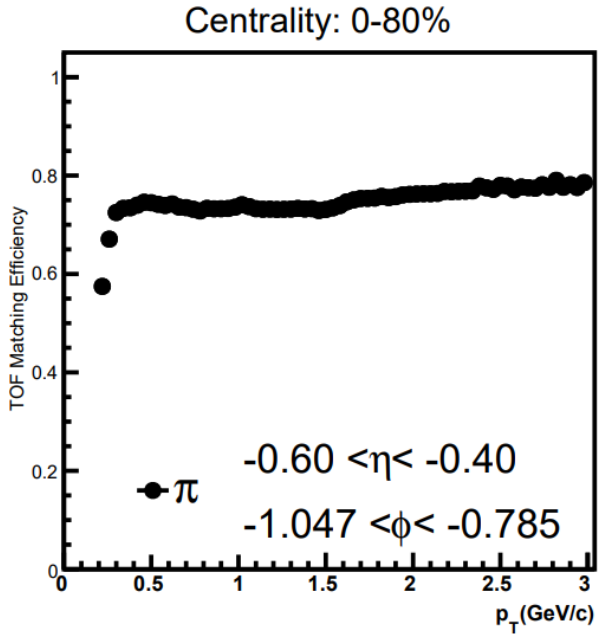


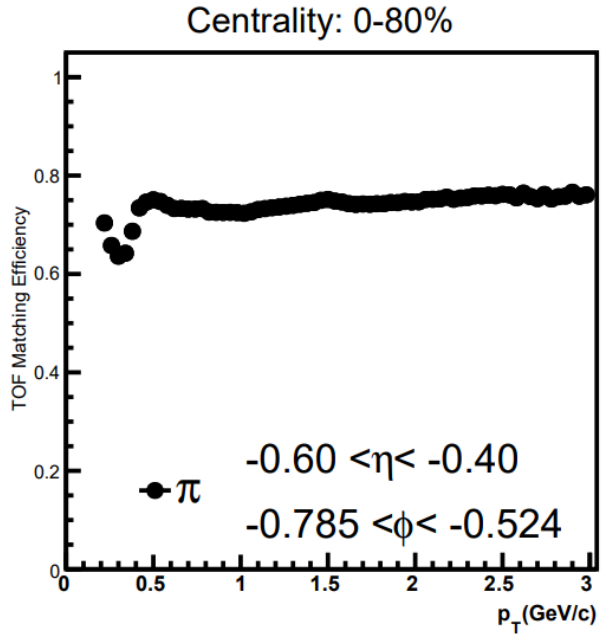
Efficiency and Acceptance Corrections

- TOF Matching efficiency has pt η Φ dependence

$$\varepsilon_{electron} = \varepsilon_{positron} = \varepsilon_{TPC} \times \varepsilon_{eID} \times \varepsilon_{TOF}(3D)$$



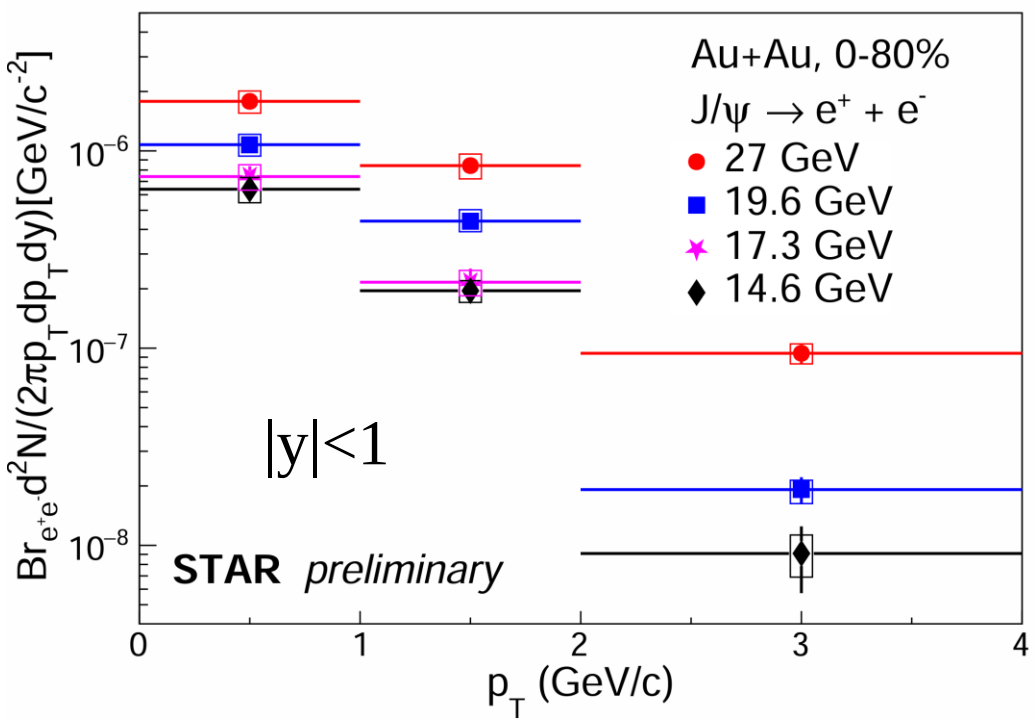




$$\frac{\text{Electron TOF Matching Efficiency(3D)}}{\text{Pion TOF Matching Efficiency}(3D)} = \frac{\text{Electron TOF matching efficiency (1D)}}{\text{Pion TOF matching efficiency (1D)}}$$

Inclusive J/ψ Invariant Yields

$$R_{AA} = \frac{\sigma_{\mathrm{inel}}}{\langle N_{coll} \rangle} \frac{d^2 N_{AA}/dydp_T}{d^2\sigma_{pp}/dydp_T}$$

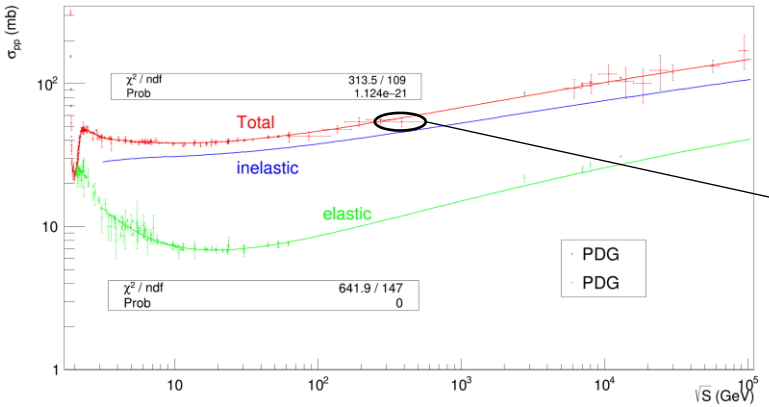


Inclusive J/ψ invariant yields as a function of p_T at mid-rapidity (|y| < 1) in Au+Au collisions at $\sqrt{s_{NN}}$ = 14.6, 17.3, 19.6, 27 GeV.

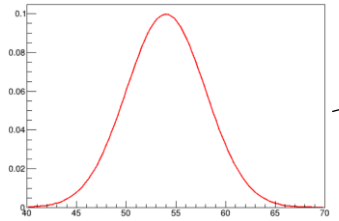
pp Inelastic Cross Section

$$R_{AA} = \frac{\sigma_{\mathrm{inel}}}{\langle N_{coll} \rangle} \frac{d^2 N_{AA}/dydp_T}{d^2\sigma_{pp}/dydp_T}$$

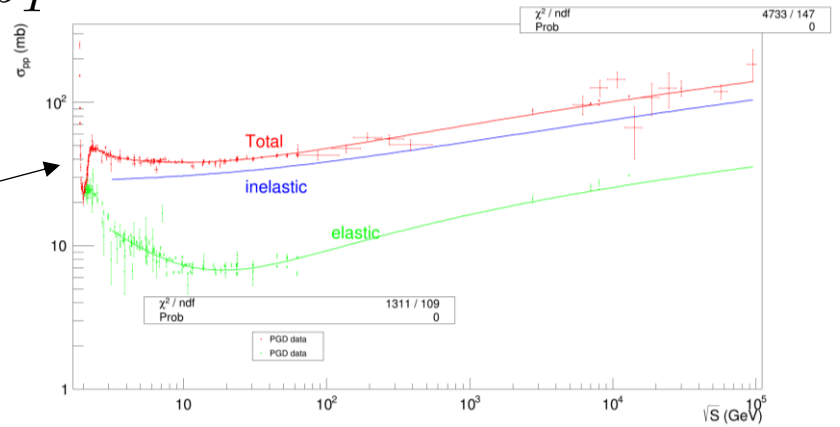
$\sigma_{inelastic} = \sigma_{total} - \sigma_{elastic}$

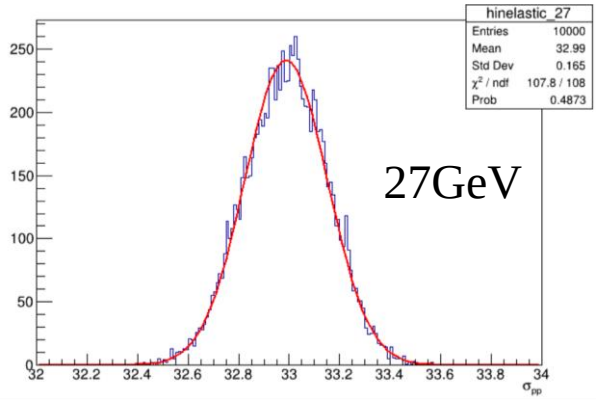


Data from PDG（Particle Data Group）：
https://pdg.lbl.gov/2022/hadronic-xsections/



Smearing each point





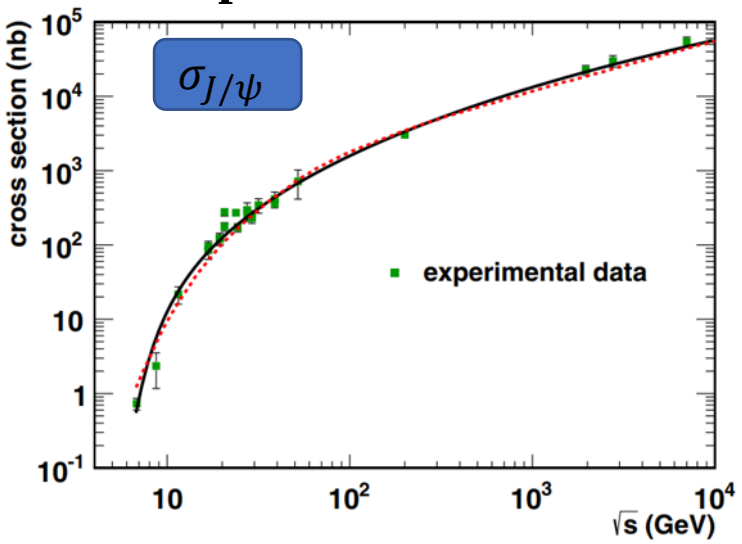
$\sqrt{S_{NN}}$ (GeV)	$\sigma_{inelastic}$ (mb)	Error(mb)
200	43.40	0.77
27	32.99	0.16
19.6	32.08	0.14
17.3	31.78	0.13
14.6	31.42	0.13
11.5	30.99	0.12
9.2	30.65	0.13

p+p Baseline

$$R_{AA} = \frac{\sigma_{\text{inel}}}{\langle N_{coll} \rangle} \frac{d^2 N_{AA}/dydp_T}{d^2\sigma_{pp}/dydp_T}$$

- **For p+p baselines at $\sqrt{s_{NN}}$ = 14.6, 17.3, 19.6, and 27 GeV are extracted from phenomenological interpolations**

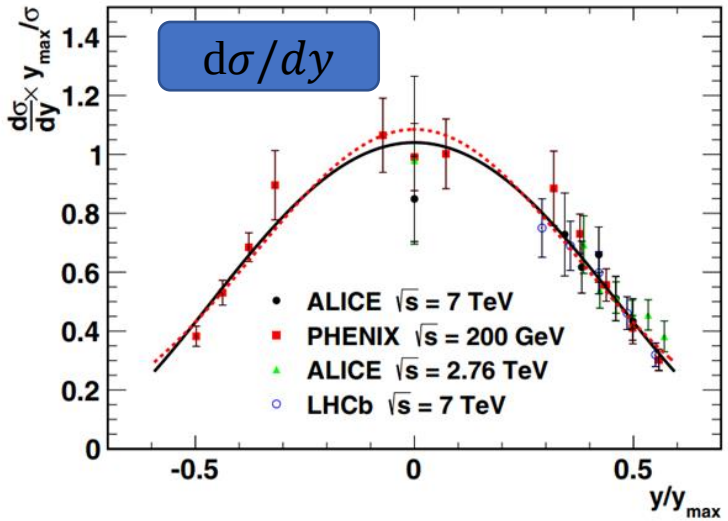
W. Zha, et al., Phys. Rev. C 93 (2016) 024919.



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

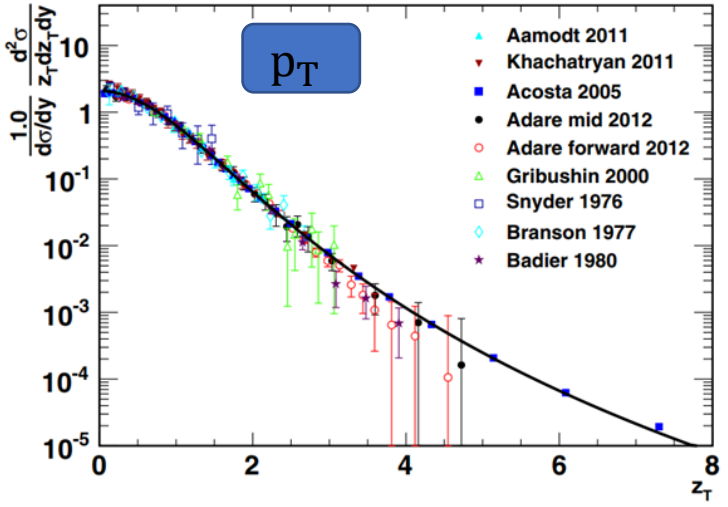
α: scale factor

σ_{CEM}: σ from color evaporation model



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

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

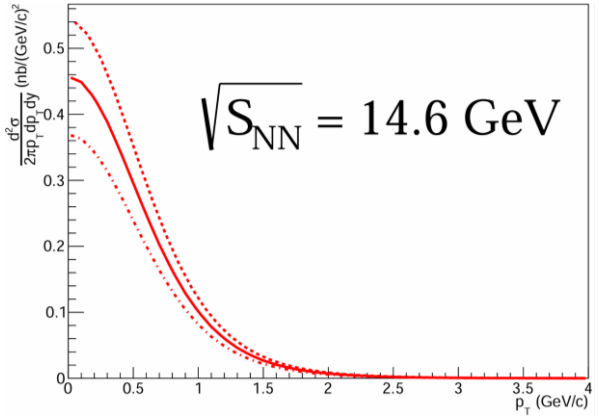


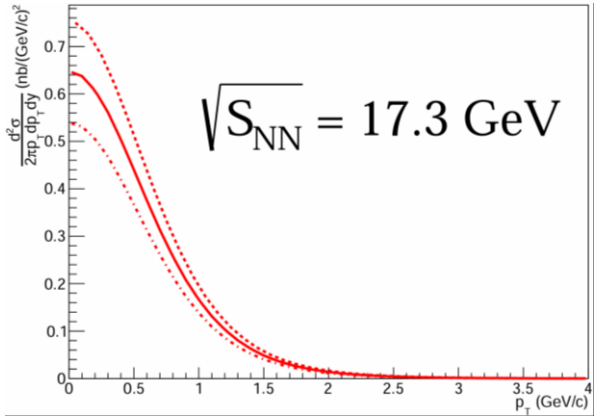
$$\frac{1}{d\sigma/dy}\frac{d^2\sigma}{z_T dz_T dy} = a \times \frac{1}{(1+b^2 z_T^2)^n}$$

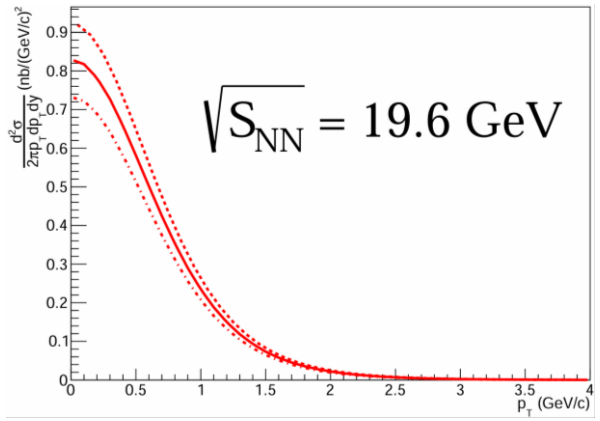
where $z_T = p_T/\langle p_T \rangle$

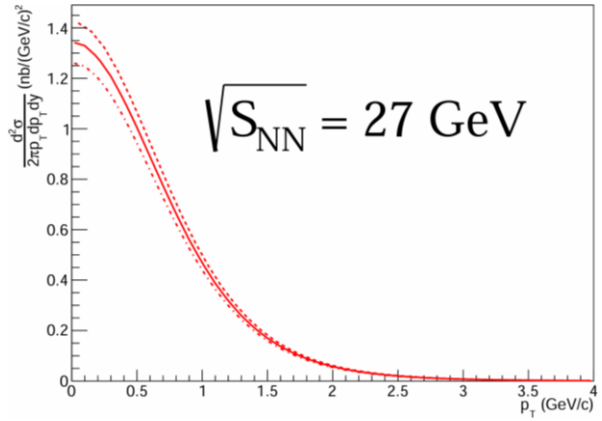
p+p Baseline

$$R_{AA} = \frac{\sigma_{\text{inel}}}{\langle N_{coll} \rangle} \frac{d^2 N_{AA}/dydp_T}{d^2\sigma_{pp}/dydp_T}$$





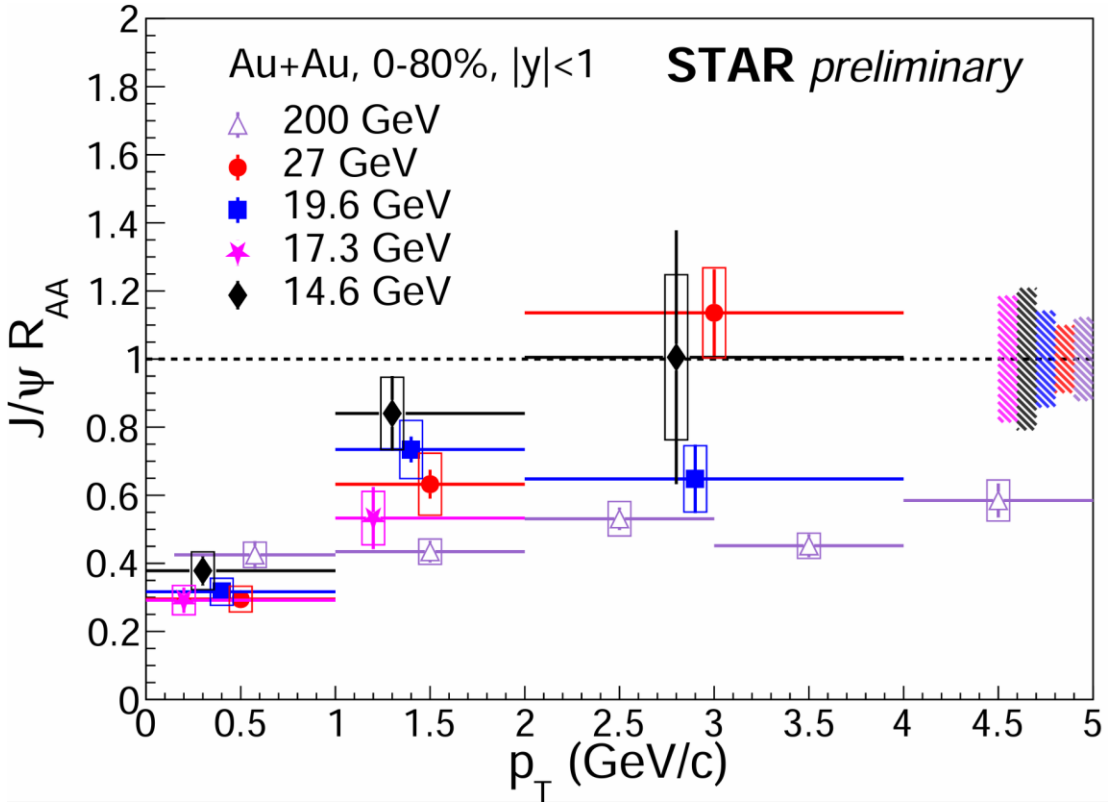




- The p_T dependence of deduced J/ψ differential cross section at midrapidity in p+p collisions at $\sqrt{s_{NN}}$ = 14.6, 19.6, 27 GeV
- The systematic uncertainty arises from fitting world-wide data:

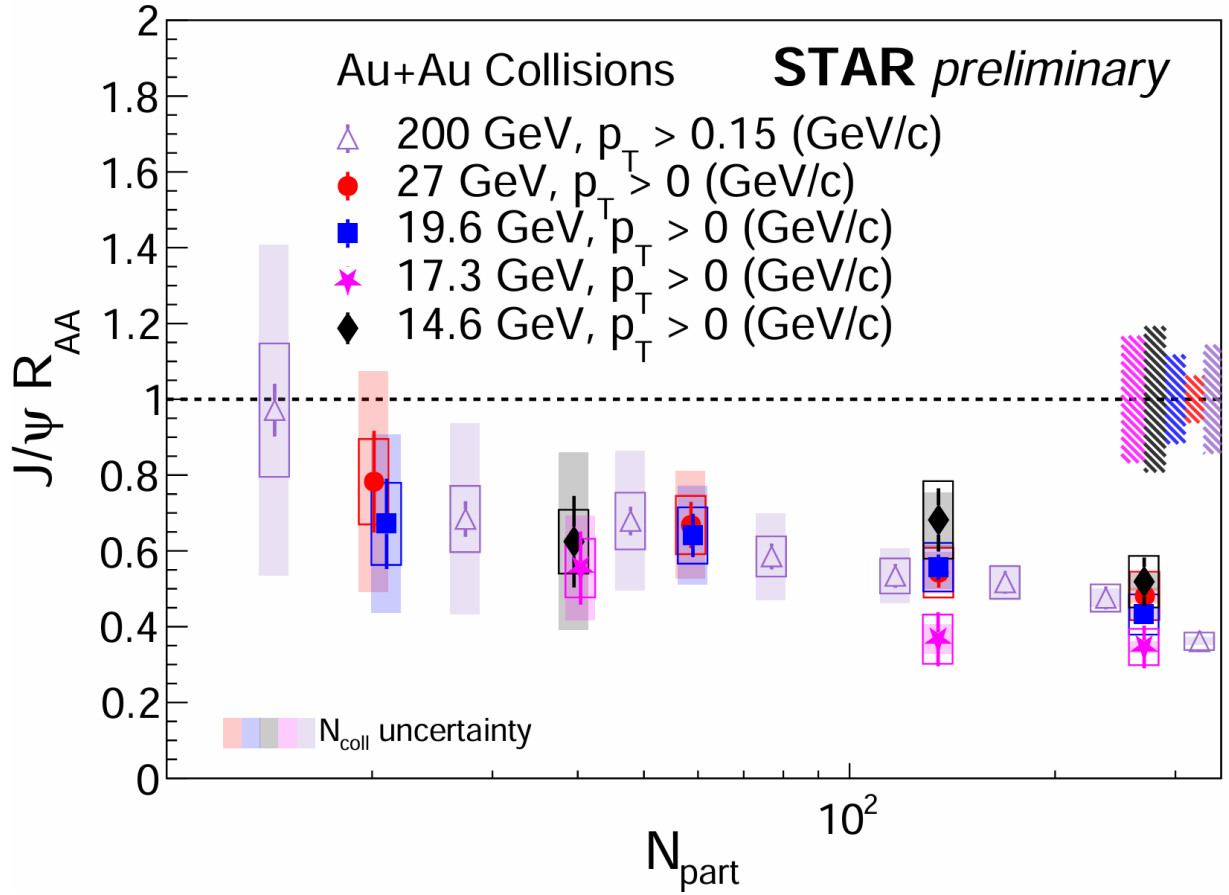
$\sqrt{s_{NN}}$ = 14.6 GeV	19.2 %
$\sqrt{s_{NN}}$ = 17.3 GeV	16.7%
$\sqrt{s_{NN}}$ = 19.6 GeV	11.7 %
$\sqrt{s_{NN}}$ = 27 GeV	6.1 %

p_T Dependence of Inclusive J/ψ R_{AA}



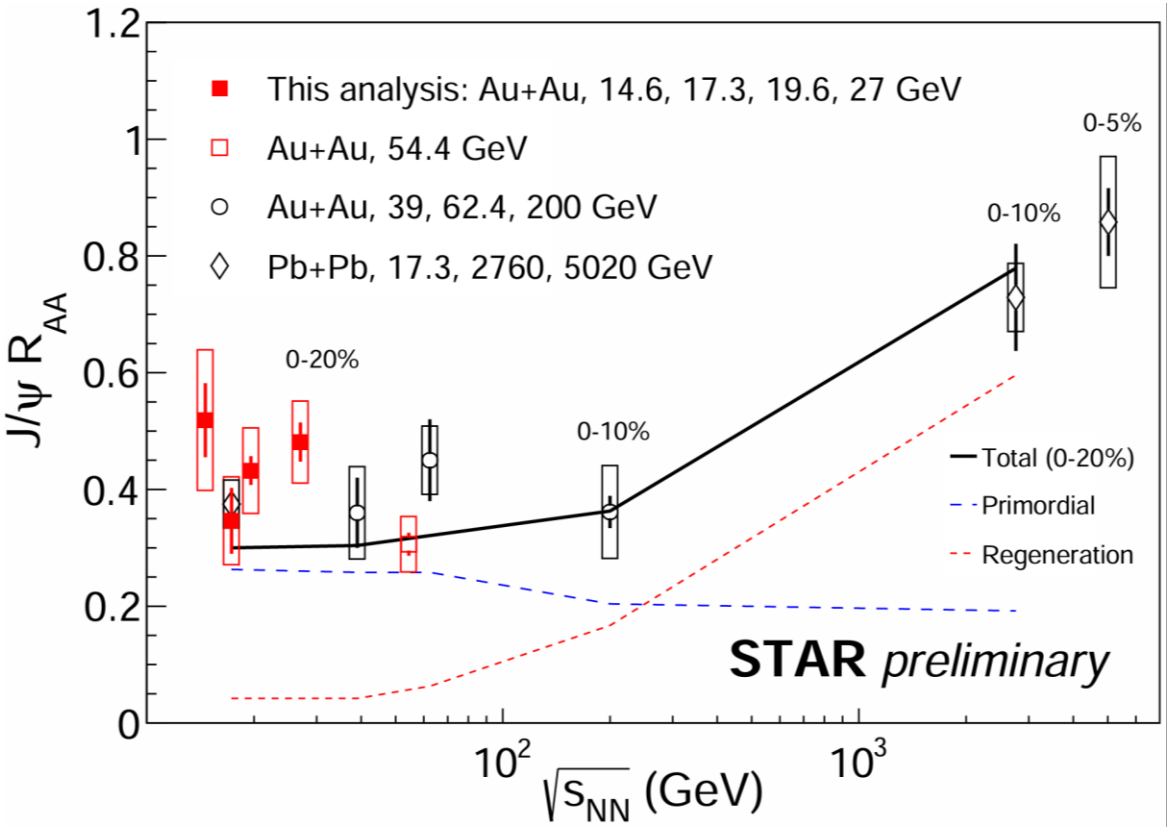
- Low p_T suppression, R_{AA} increases with p_T for $\sqrt{s_{NN}}$ = 14.6, 19.6 and 27 GeV
- No significance p_T dependence at 200 GeV

Centrality Dependence of Inclusive J/ψ R_{AA}



- Hint of decreasing trend as a function of centrality
- R_{AA} shows no significant energy dependence at RHIC for similar $\langle N_{part} \rangle$.

Energy Dependence of Inclusive J/ψ R_{AA}



- Data at $\sqrt{s_{NN}}$ = 14.6, 19.6 and 27 GeV follow the trend
- No significant energy dependence of J/ψ R_{AA} in central collisions is observed within uncertainties up to 200 GeV
- The J/ψ suppression in the LHC energy region is weaker
  - Regeneration dominates at LHC energies
- The transport model qualitatively describes the observed energy dependence

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

Summary

- Significant suppression of charmonium in central heavy-ion collisions at RHIC
- No significant collision energy dependence of J/ψ R_{AA} at RHIC
- Hint of decreasing with centrality and increasing with p_T for J/ψ R_{AA} at low energies

→ Interplay of dissociation, regeneration and cold nuclear matter effects

→ Can be used to constrain QGP properties

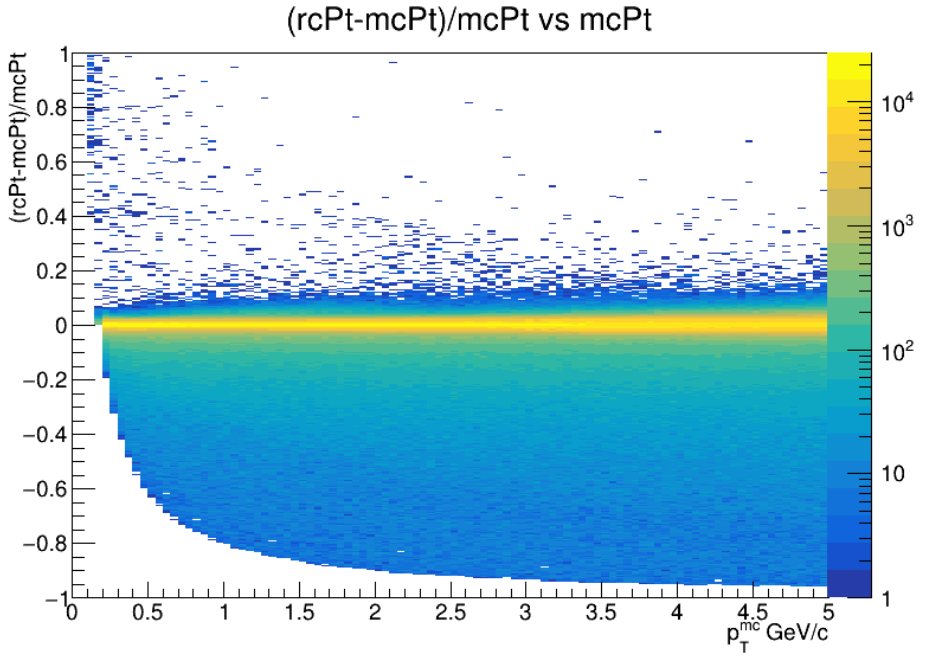
Thank you

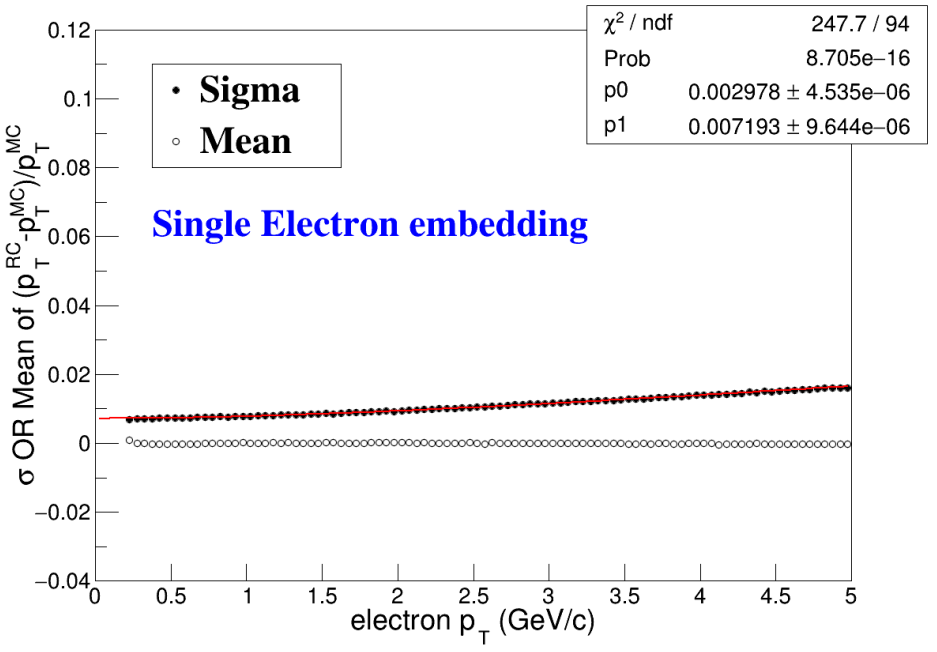
Back up

Additional Momentum Smearing (27GeV example)

$$p_T^{\text{smear}} = p_{T,\ \text{True}} + \Delta p_T \times \frac{\sqrt{(a')^2 P_T^{\ 2} + b^2}}{\sigma^{embed}(p_{T,\ \text{Ture}})}$$

→ additional momentum smearing factor





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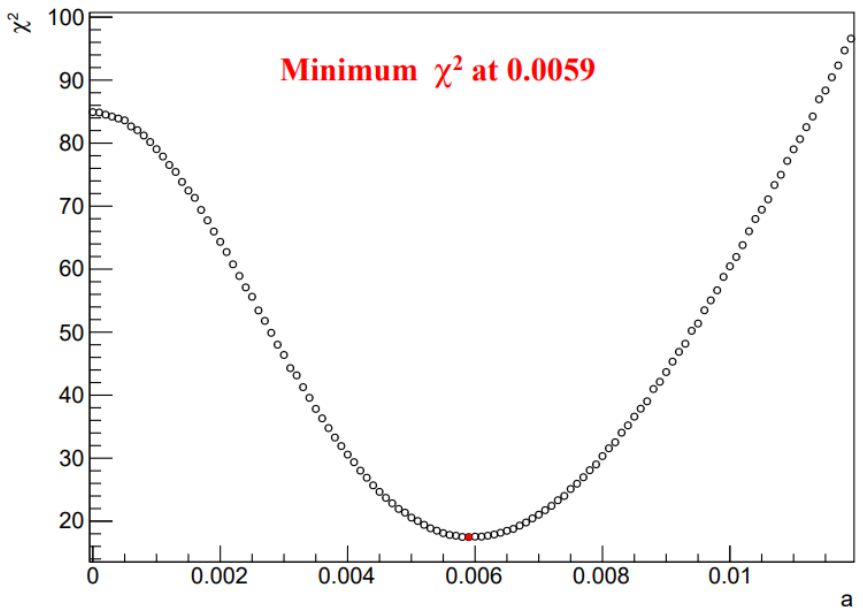
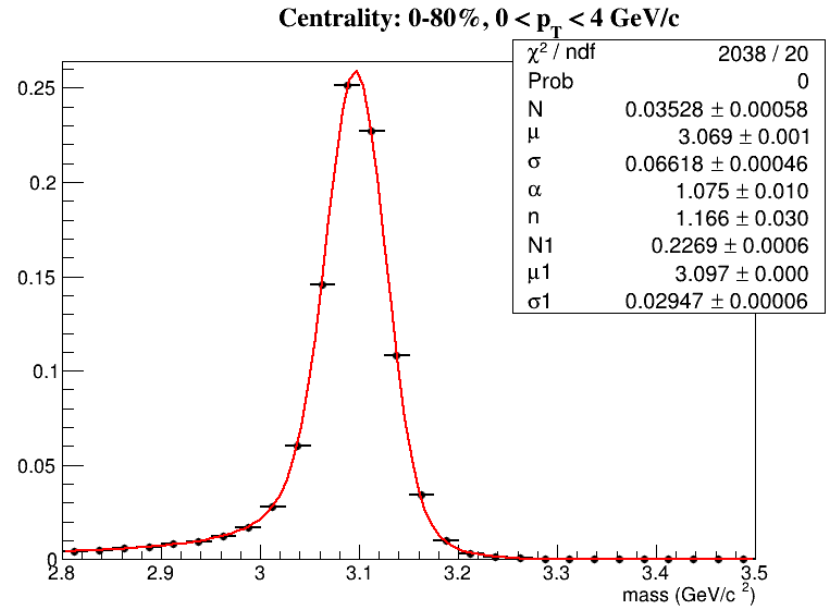
$$\sigma^{\text{embed}} = \sqrt{a^2 P_T^{\ 2} + b^2}$$

Addiction Momentum Smearing (27GeV example)



The J/ψ templates from ToyMC with additional momentum smearing based on best a.



scan a' → get J/ψ σ from ToyMC → compare with data, a' value with minimum χ 2 is the best a' value

Systematic Uncertainty

➢Systematic uncertainty from J/ψ yield measurements

Source：

Track quality cuts

- nHitsFit
- nHitsDedx
- Dca (cm)

Signal extraction

- J/ψ templates
- Fitting range
- Residual background function form
- Combinatorial background function form
- Bin Width

Electron Identification cuts

- $n\sigma_e$ efficiency
- 1/β efficiency
- TOF Matching efficiency

Analyzed bin	27 GeV	19.6 GeV	14.6 GeV
0-80%	12.4 %	11.2 %	13.2 %
0-20%	13.2 %	12.3 %	13.1 %
20-40%	12.1 %	11.5 %	15.0 %
40-60%	11.5 %	11.6 %	13.5 %
60-80%	14.4 %	16.1 %	
0-1GeV/c	12.8 %	12.5 %	14.6 %
1-2GeV/c	14.4 %	11.6 %	12.7 %
2-4GeV/c	11.6 %	15.0 %	24.1 %

pp Inelastic Cross Section

- The parameters:
  - Glauber model inputs:
    - Collision system: Au+Au
    - Energy: 27 GeV
    - Radius of Au: R = 6.38 fm
    - Skin depth: d = 0.535 fm
    - Sigma(NN) = 33 mb
    - Separation of two nucleons: ds = 0.9 fm

$\sqrt{S_{NN}}$ (GeV)	$\sigma_{inelastic}$ (mb)	Error(mb)
200	43.40	0.77
27	32.99	0.16
19.6	32.08	0.14
17.3	31.78	0.13
14.6	31.42	0.13
11.5	30.99	0.12
9.2	30.65	0.13

The input sets in Glauber model	
Mode	Au + Au
Energy	17.3 GeV
Events	10^6
Radius of Au	R = 6.38 fm
Skin Depth	d = 0.535 fm
Inelastic NN cross section	σ_{NN} = 31.8 mb

The parameters (Glauber model inputs)	
Collision system	Au + Au
Energy	14.6 GeV
Radius of Au	R = 6.38 fm
Skin depth	d = 0.535 fm
Sigma(NN)	32 mb