



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

Wei Zhang

South China Normal University



Outline

- Motivation
- J/ψ Suppression Measurements
 - Raw Signal Extraction
 - pp Baseline
 - R_{AA} Results
- Summary and Outlook

Introduction

➤ Quarkonia suppression was proposed as a sensitive probe to QGP properties

- Dominantly produced before QGP formation

➤ **Hot medium effects**

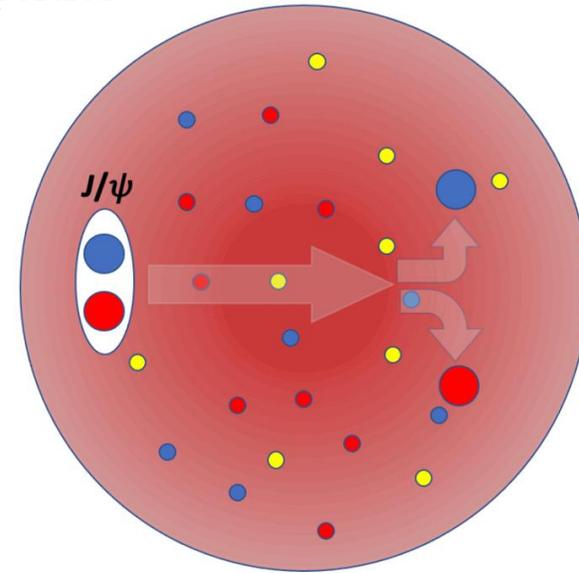
- Dissociation (color screening and dynamic interaction)
- Regeneration

➤ **Cold nuclear matter effects**

- nPDF
- Nuclear absorption

➤ **Other effects**

- Comover interactions
- Feed-down contribution



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

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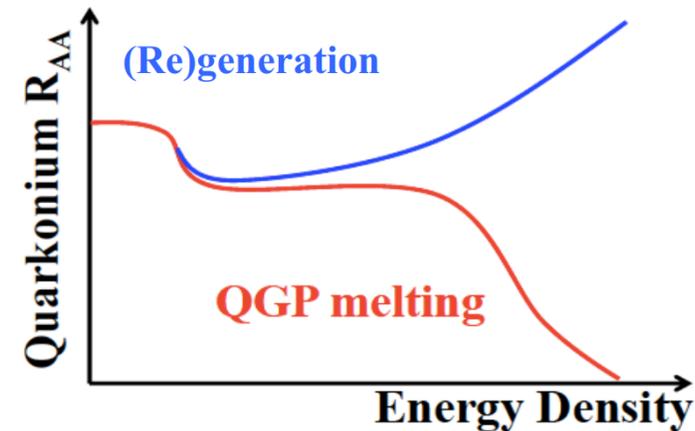
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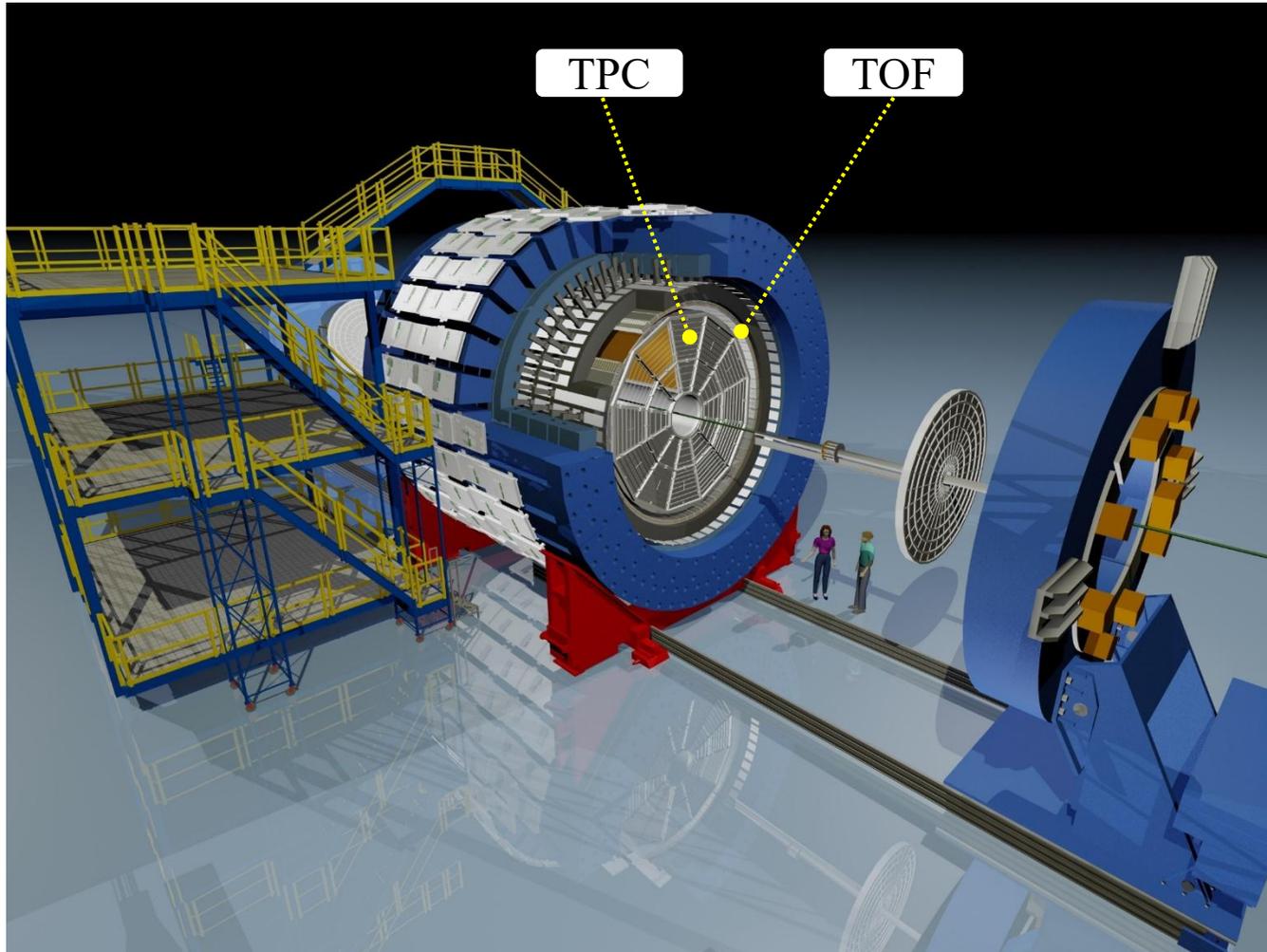
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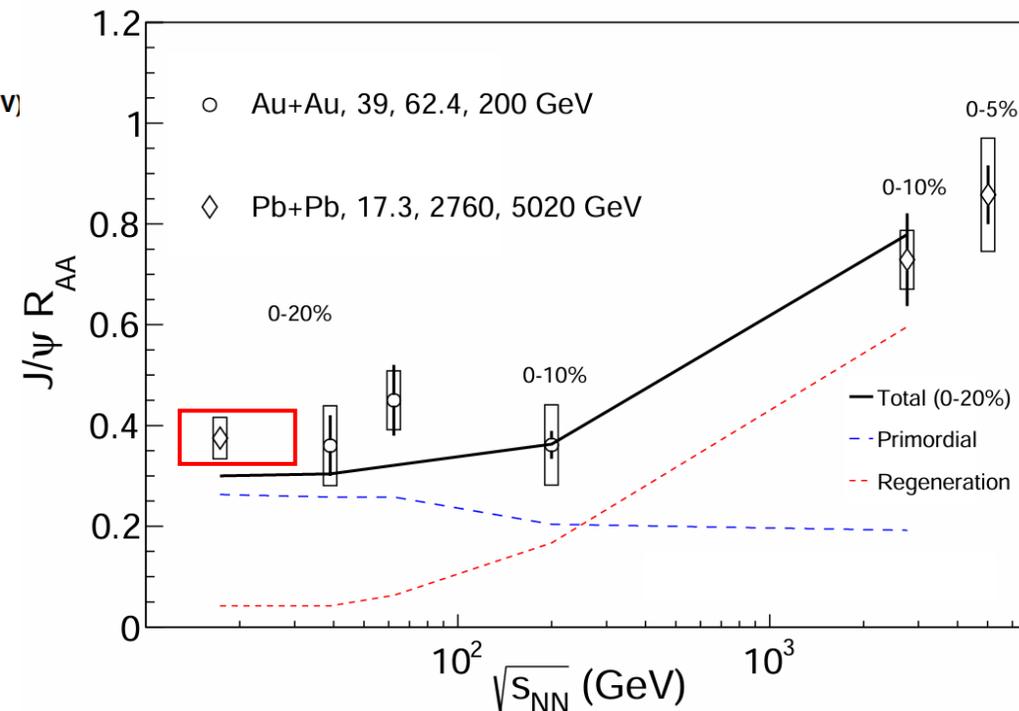
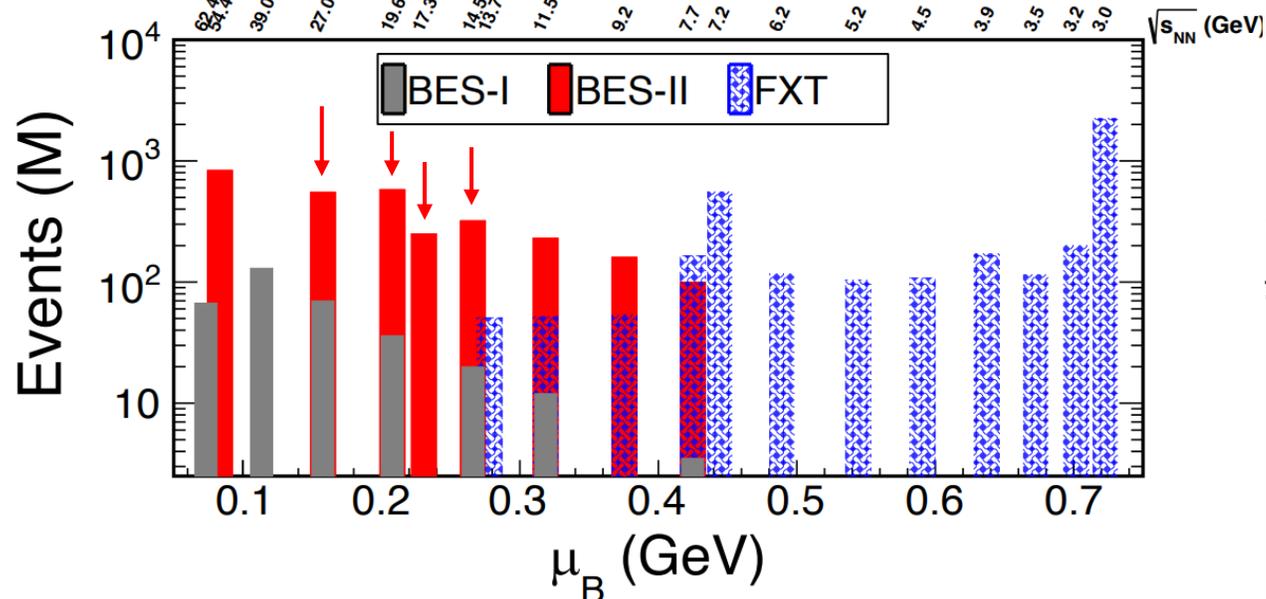
$$R_{AA} = \frac{\sigma_{\text{inel}}}{\langle N_{\text{coll}} \rangle} \frac{d^2 N_{AA} / dy dp_T}{d^2 \sigma_{pp} / dy dp_T}$$

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

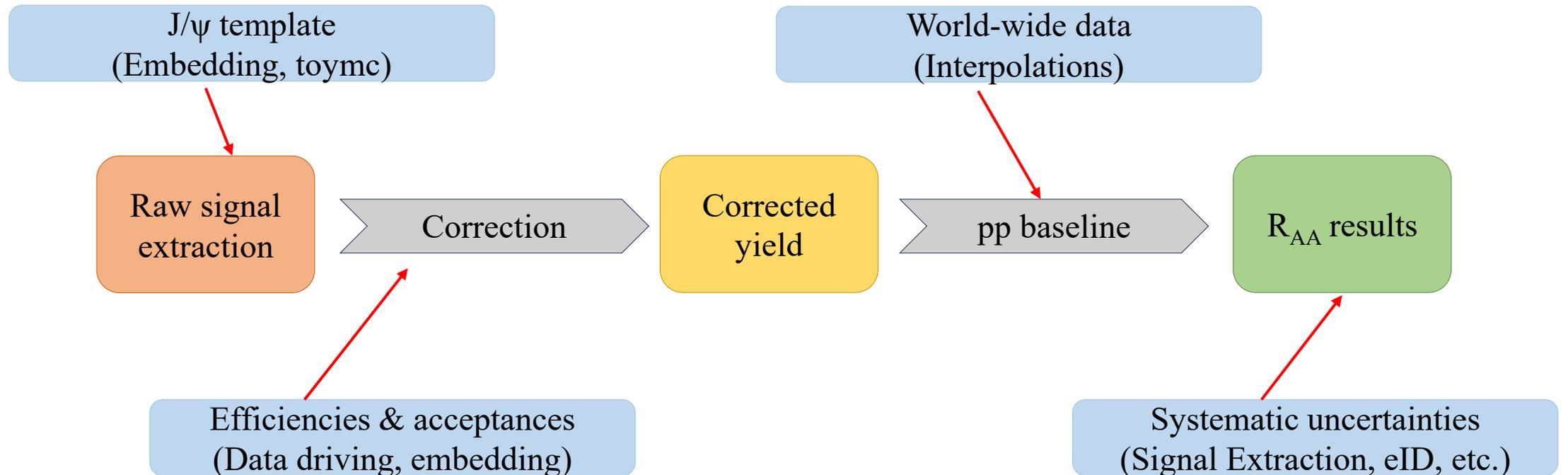
➤ Collision energy dependence of J/ψ production

- Au+Au collisions at $\sqrt{s_{NN}} = 14.6, 17.3, 19.6, 27$ GeV
- Smaller regeneration effect

Analysis Procedure

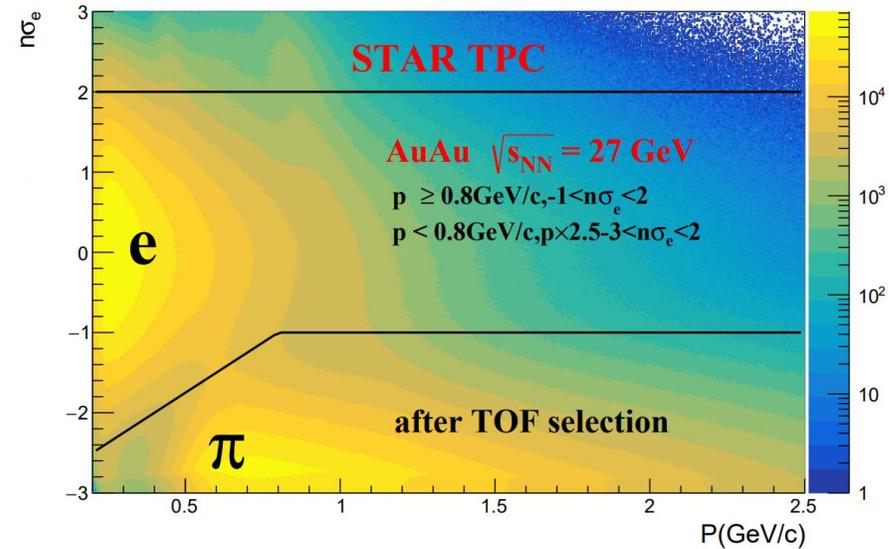
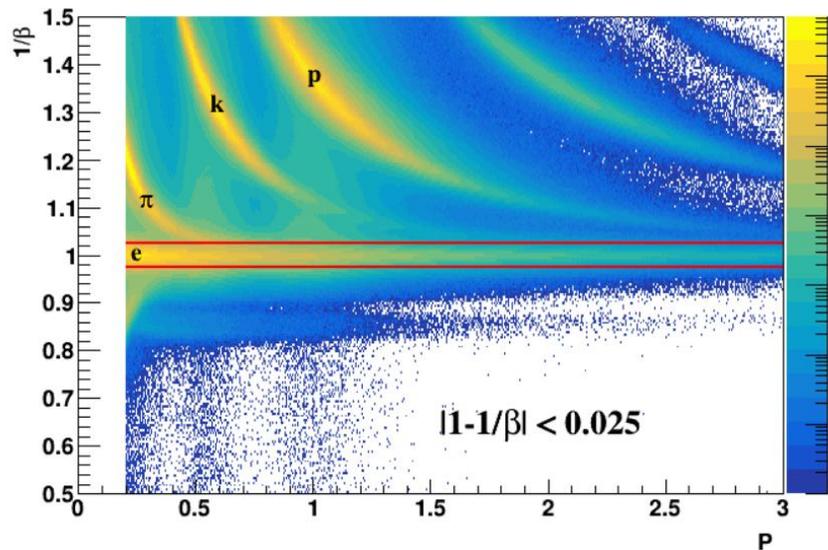
Observable: $R_{AA} = \frac{\sigma_{\text{inel}}}{\langle N_{\text{coll}} \rangle} \frac{d^2 N_{AA}/dydp_T}{d^2 \sigma_{pp}/dydp_T}$

$\left\{ \begin{array}{l} < 1 \text{ suppression} \\ = 1 \text{ no net medium effects} \\ > 1 \text{ enhancement} \end{array} \right.$



Electron Identification

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

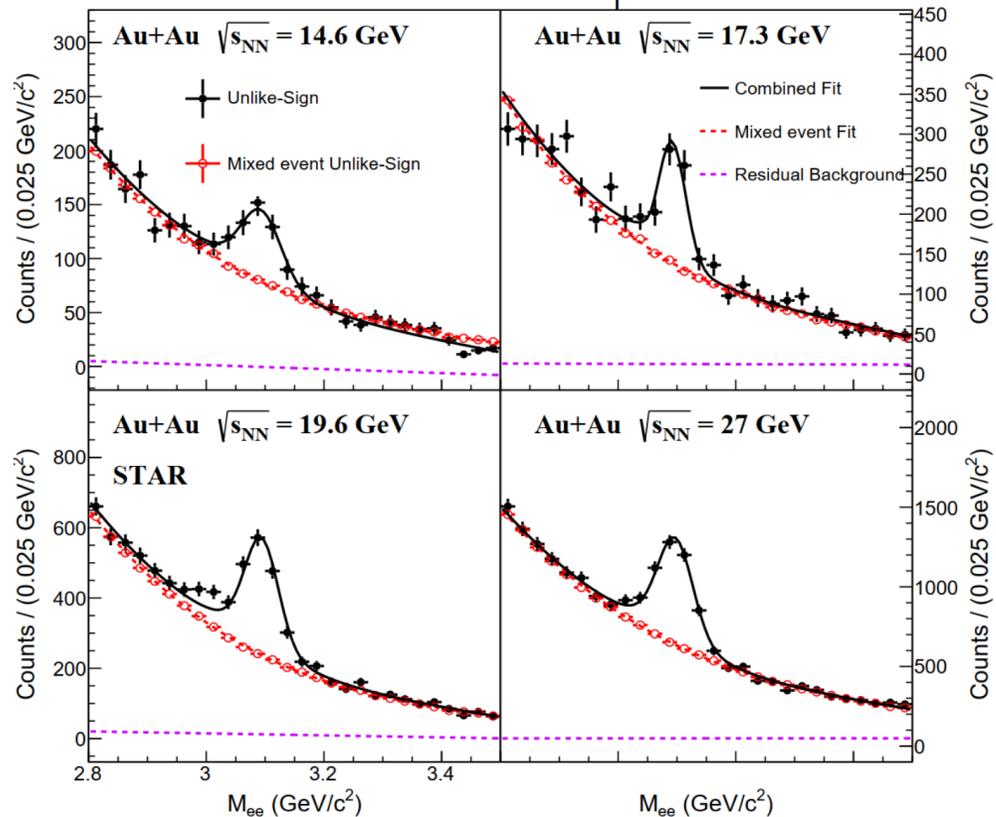


$$n\sigma_e = \frac{1}{R} \log \frac{(dE/dx)_{measured}}{(dE/dx)_{electron}}$$

Raw J/ψ Signal

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

Centrality: 0-80%, $0 < p_T < 4 \text{ GeV}/c$



➤ 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

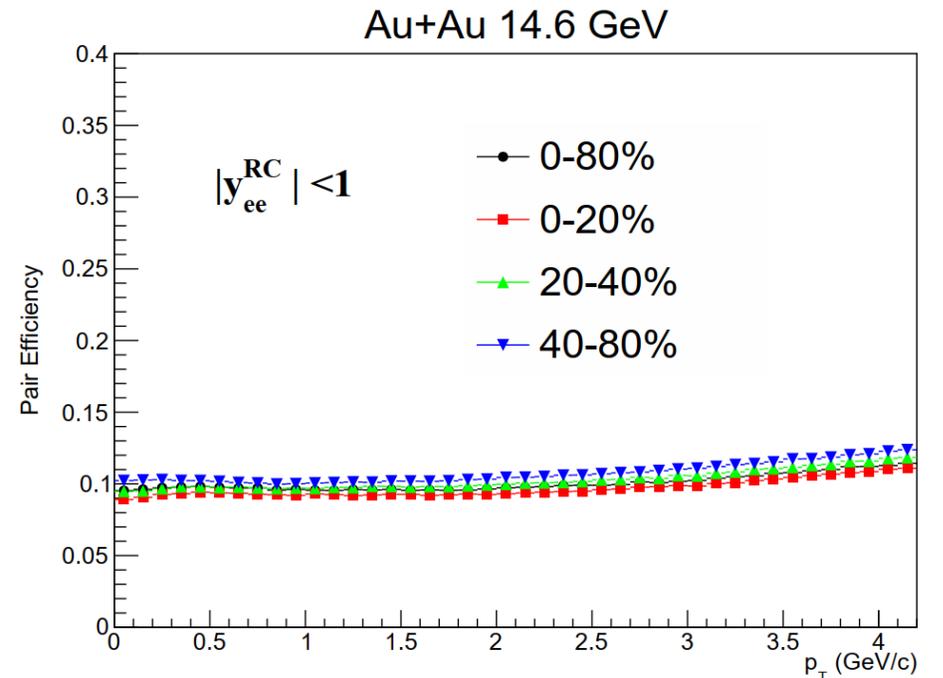
$$R_{AA} = \frac{\sigma_{\text{inel}}}{\langle N_{\text{coll}} \rangle} \frac{d^2 N_{AA}/dydp_T}{d^2 \sigma_{pp}/dydp_T} \quad N_{AA} = \frac{N_{J/\psi \rightarrow e+e-}}{A \times \epsilon \times N_{\text{ev}_{\text{ent}}}}$$

- Estimate the single-electron efficiency using the embedding and data-driven method:

$$\epsilon_{\text{electron}} = \epsilon_{\text{positron}} = \epsilon_{\text{TPC}} \times \epsilon_{\text{eID}} \times \epsilon_{\text{TOF}}$$

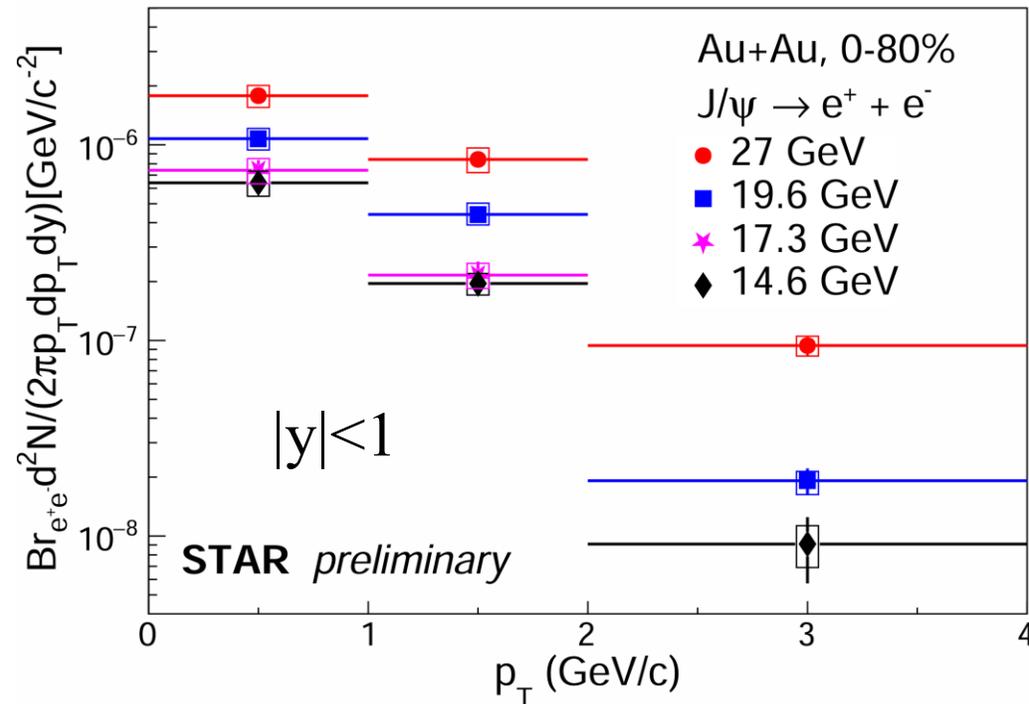
- The pair efficiency is obtained by folding the single-electron efficiencies and applying the acceptance cut

using a toy MC: $A \times \epsilon = A \times \epsilon_{\text{electron}} \times \epsilon_{\text{positron}}$



Inclusive J/ψ Invariant Yields

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



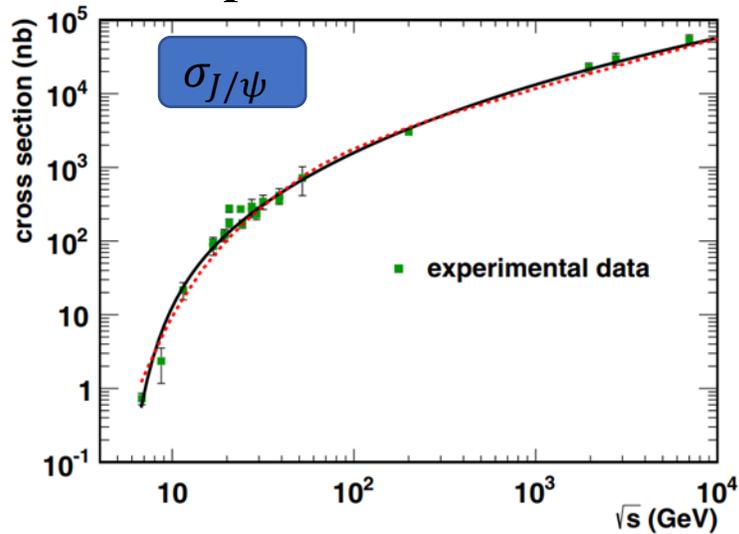
Inclusive J/ψ invariant yields as a function of p_T at mid-rapidity ($|y| < 1$) in Au+Au collisions at $\sqrt{s_{NN}} = 14.6, 17.3, 19.6, 27$ GeV.

p+p Baseline

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

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

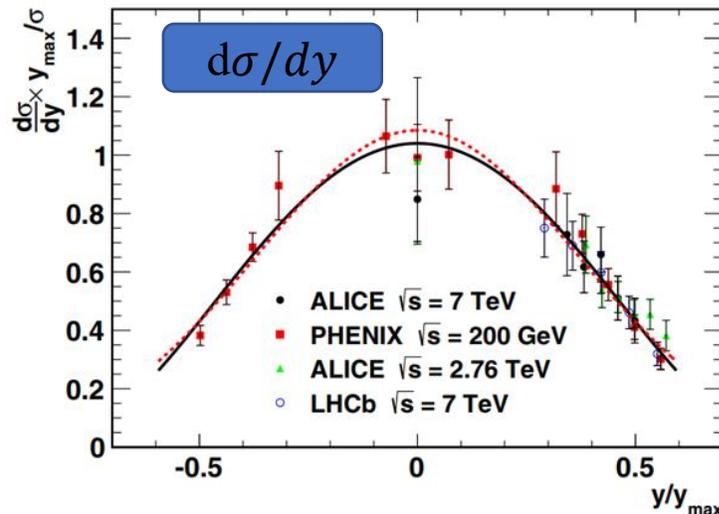
W. Zha, et al., Phys. Rev. C 93 (2016) 024919.



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

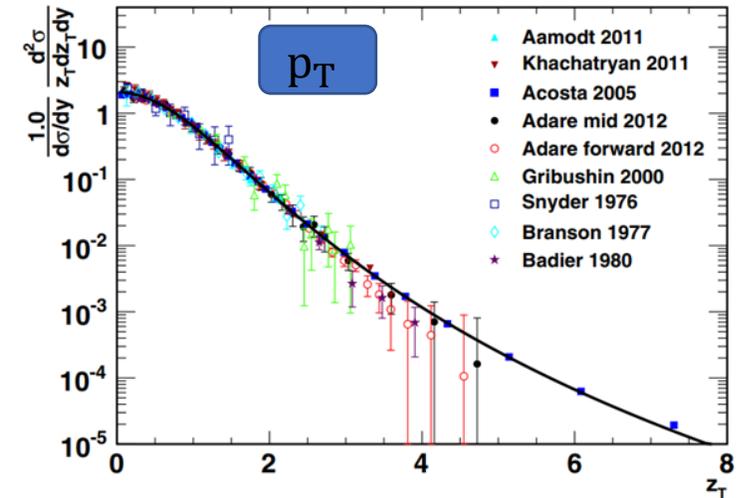
α : scale factor

σ_{CEM} : σ from color evaporation model



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

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

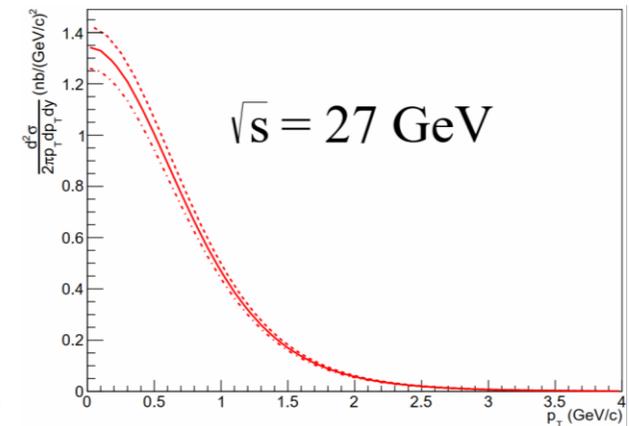
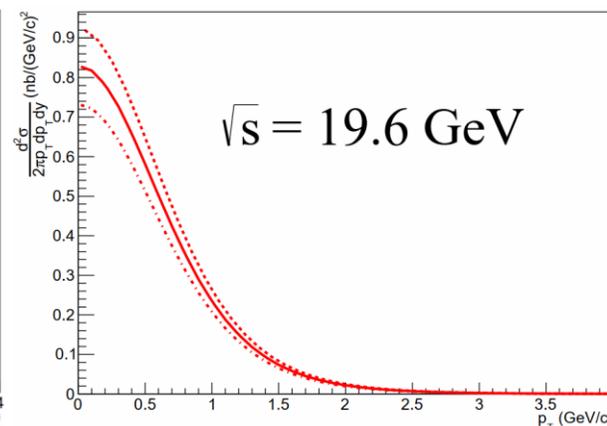
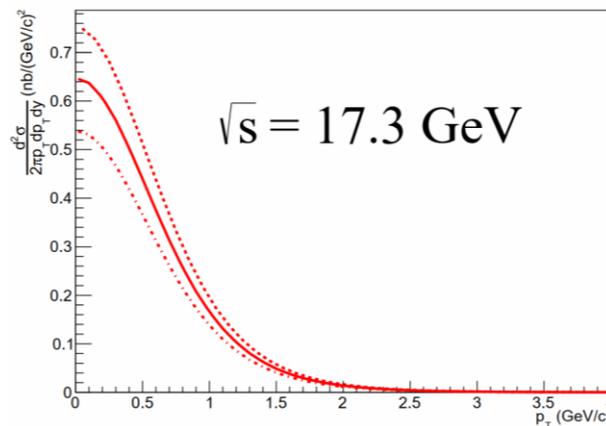
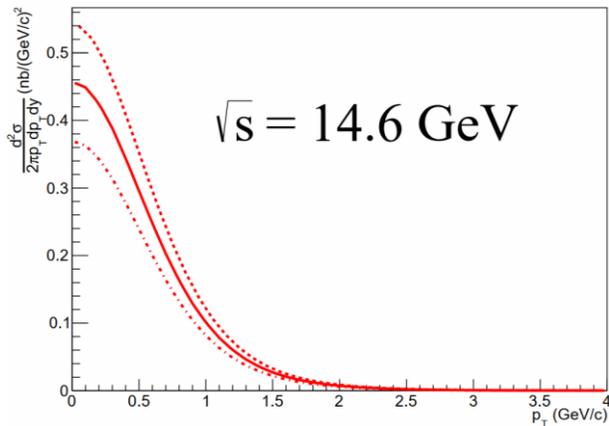


$$\frac{1}{d\sigma/dy} \frac{d^2\sigma}{dz_T dy} = a \times \frac{1}{(1+b^2 z_T^2)^n}$$

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

p+p Baseline

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



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

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

Systematic Uncertainties

Source:

➤ **Track quality cuts**

- n HitsFit
- n HitsDedx
- Dca (cm)

➤ **Electron Identification cuts**

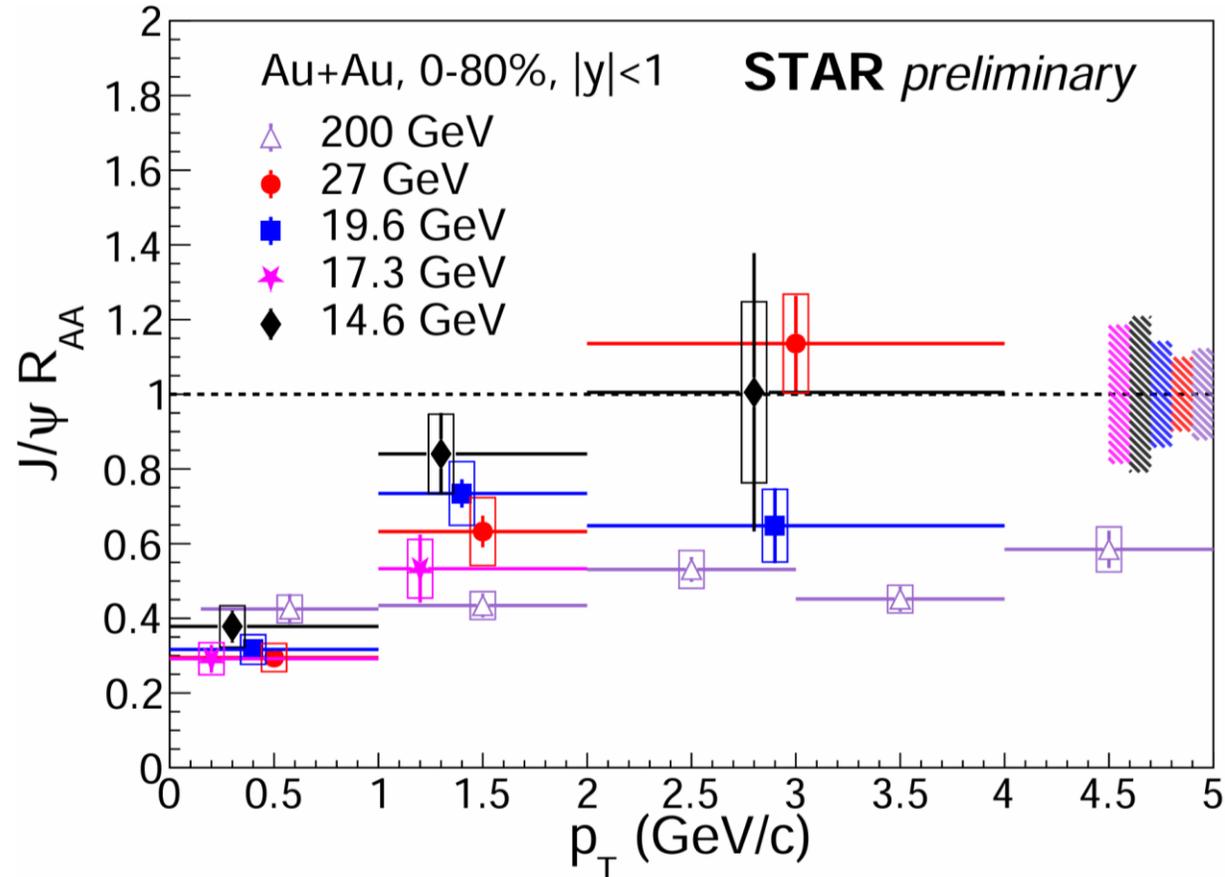
- $n\sigma_e$ efficiency
- $1/\beta$ efficiency
- TOF Matching efficiency

➤ **Signal extraction**

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

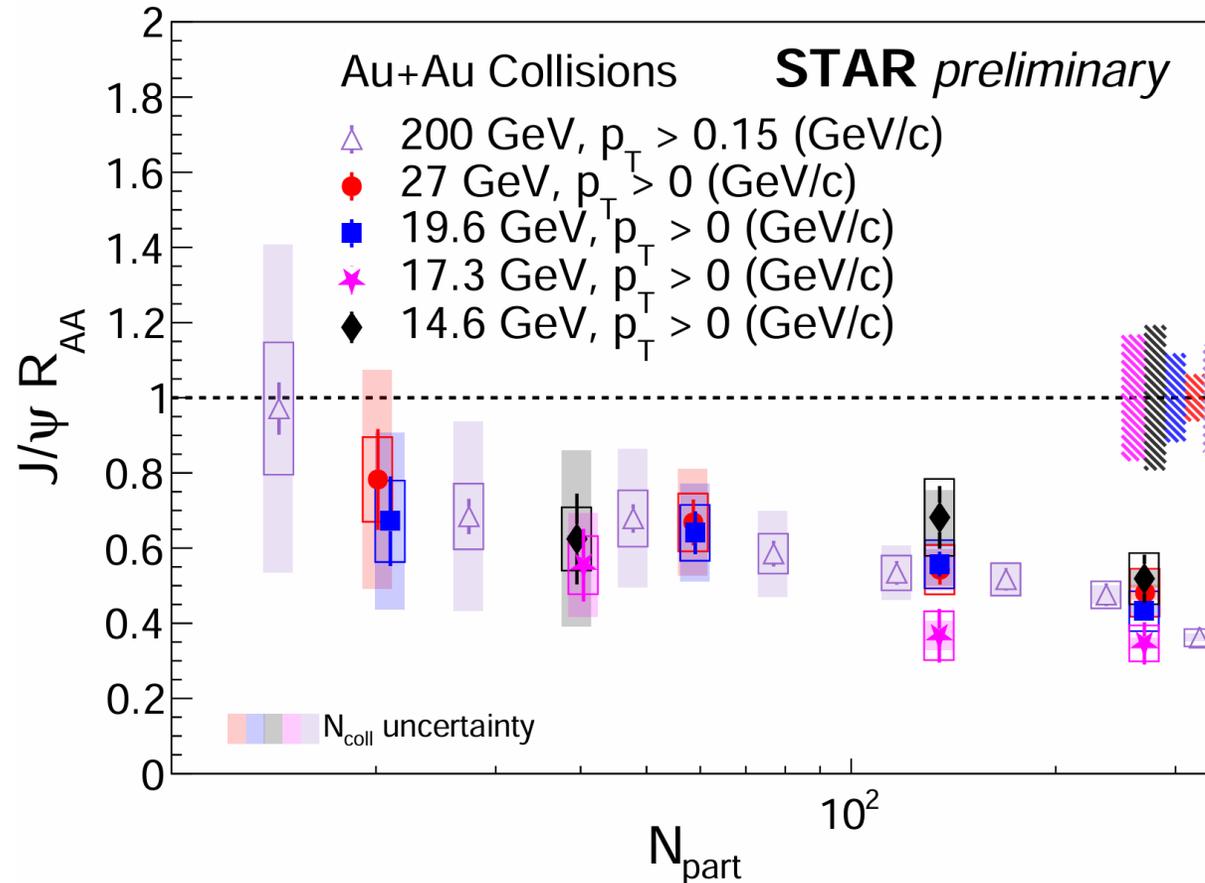
Au+Au	14.6 GeV	17.3 GeV	19.6 GeV	27 GeV
signal extraction	4.5 – 6.0%	4.1 – 8.8%	3.2 – 7.5%	1.8 – 3.8%
TPC tracking	1.7 – 6.8%	4.9 – 8.2%	4.4 – 7.8%	10.2 – 10.8%
TOF matching	0.15 – 2.9%	0.3 – 1%	0.7 – 2.1%	0.06 – 1.9%
$1/\beta$ cut	1.3 – 2.2%	2.3 – 2.6%	0.8 – 2.0%	2.1 – 3.7%
$n\sigma_e$ cut	1.7 – 6.7%	3.2 – 10.7%	1.4 – 6.5%	3.2 – 8.9%
Total	12.7 – 14.7%	8.9 – 15.2%	11.3 – 14.5%	11.5 – 14.4%

p_T Dependence of Inclusive J/ψ R_{AA}



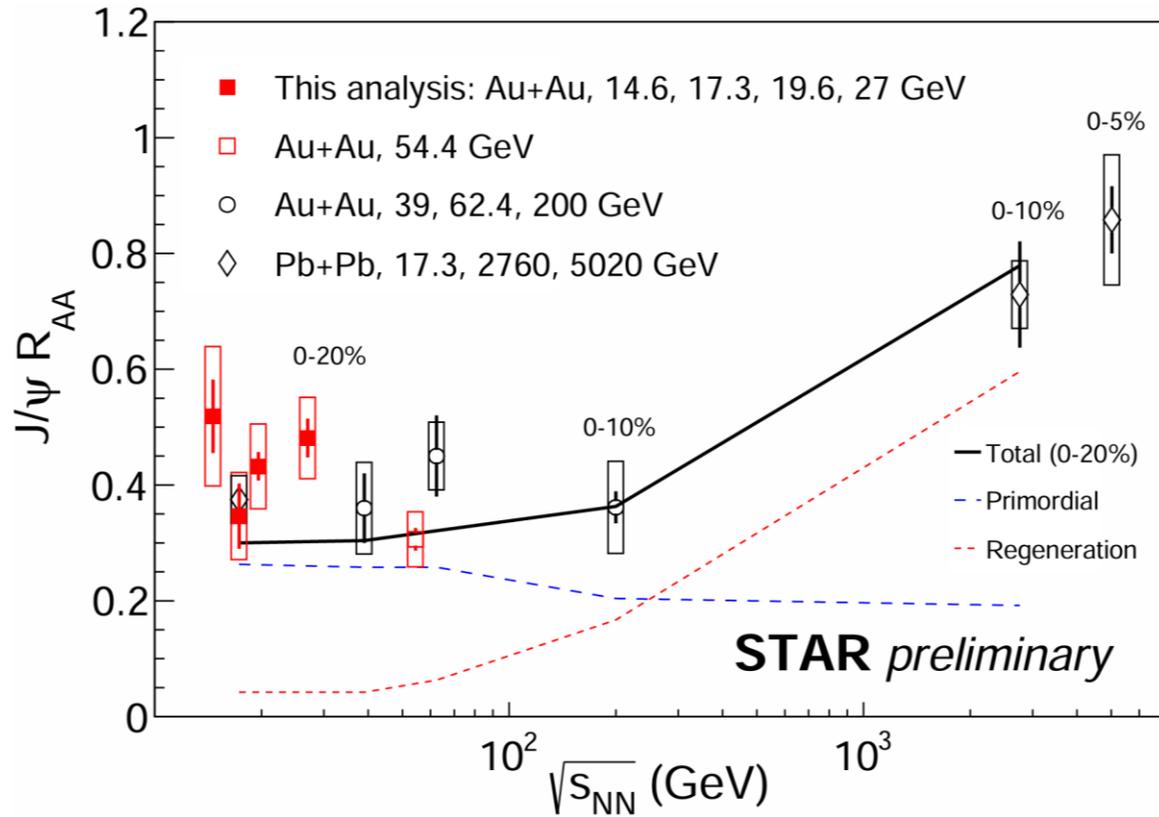
- Low p_T suppression, R_{AA} increases with p_T for $\sqrt{s_{NN}} = 14.6, 17.3, 19.6$ and 27 GeV
- No significant p_T dependence at 200 GeV

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 $\langle N_{\text{part}} \rangle$

Energy Dependence of Inclusive J/ψ R_{AA}



- Data at $\sqrt{s_{NN}} = 14.6, 17.3, 19.6$ 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.

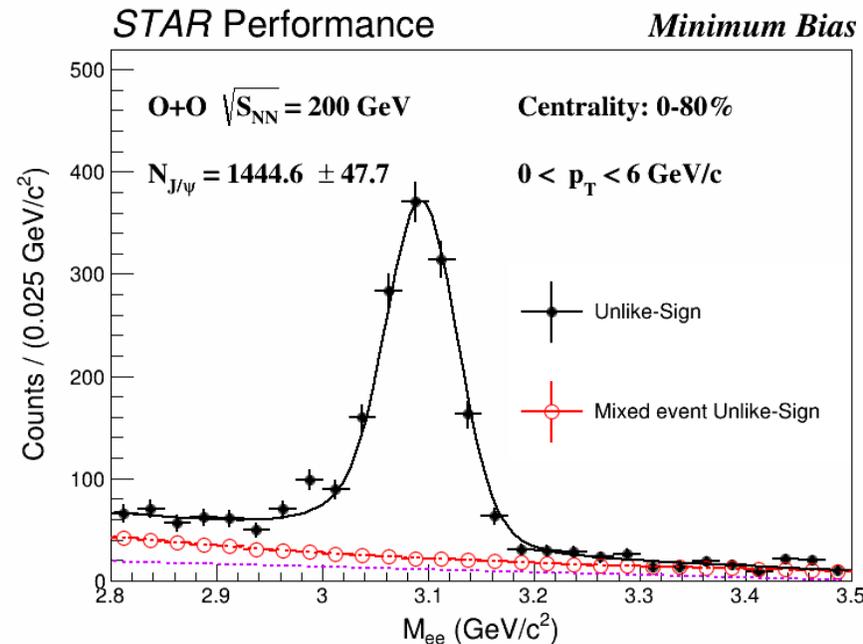
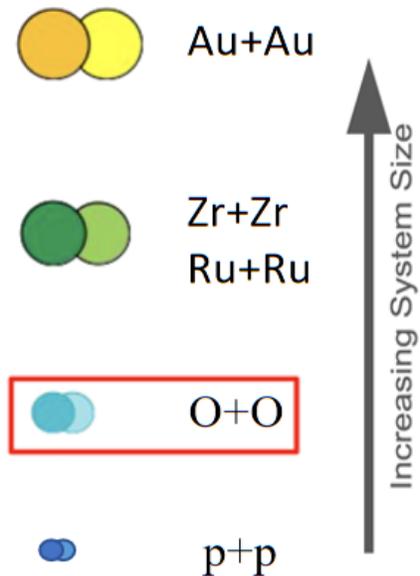
ALICE Collaboration, *Phys. Lett. B* 734 (2014) 314
 STAR Collaboration, *Phys. Lett. B* 771 (2017) 13-20
 STAR Collaboration, *Phys. Lett. B* 797 (2019) 134917
 ALICE Collaboration, *Nucl. Phys. A* 1005 (2021) 121769

Summary

- Significant suppression of charmonium in central heavy-ion collisions
 - J/ψ R_{AA} increases with p_T , hint of decreasing with centrality
 - No significant collision energy dependence of J/ψ R_{AA} at RHIC
-
- ➔ Interplay of dissociation, regeneration and cold nuclear matter effects
 - ➔ Constrain QGP properties

Outlook

- Clear J/ψ signal observed in O+O collisions
- The ongoing R_{AA} analysis will provide new insights into the collision system-size dependence of J/ψ suppression at RHIC



The new results will be presented at SQM 2026

Thank you

Back up

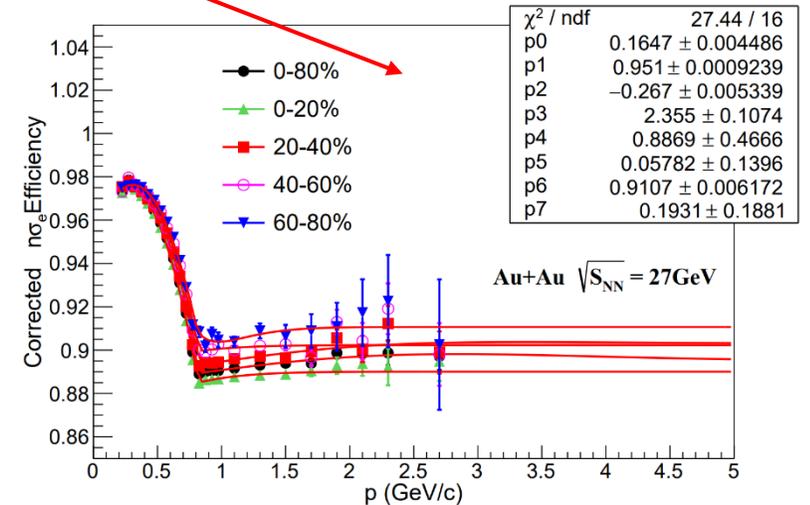
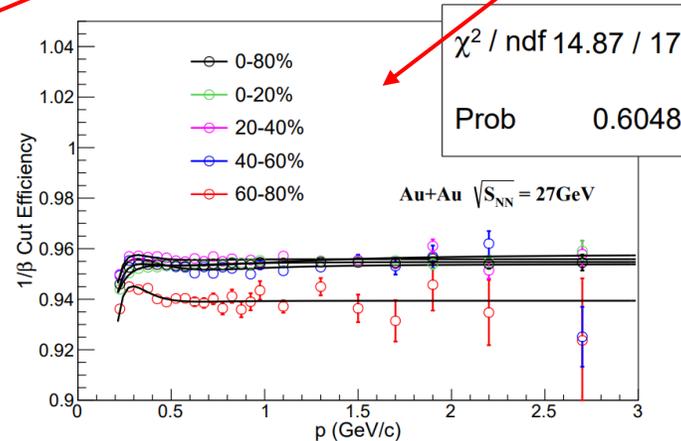
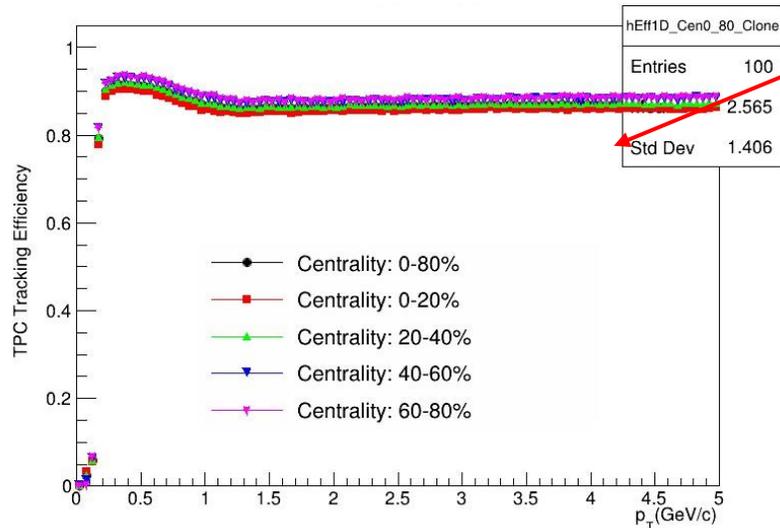
Efficiency and Acceptance Corrections

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

$$N_{AA} = \frac{N_{J/\psi \rightarrow e^+e^-}}{A \times \epsilon \times N_{\text{event}}}$$

$$\epsilon = \epsilon_{\text{electron}} \times \epsilon_{\text{positron}}$$

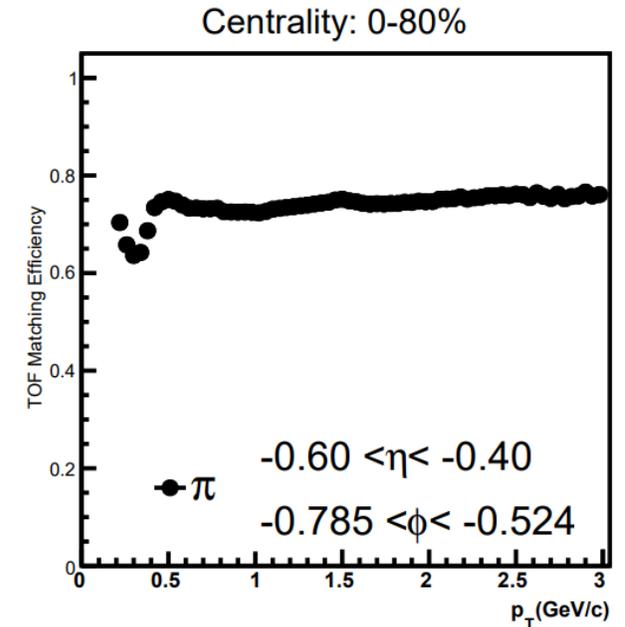
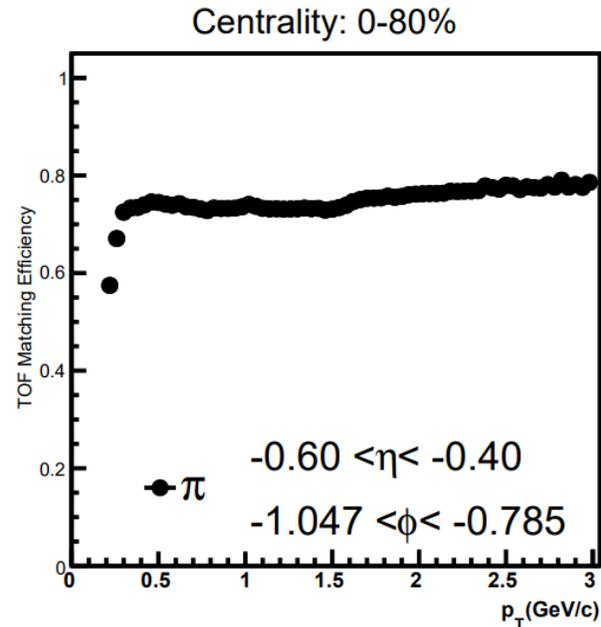
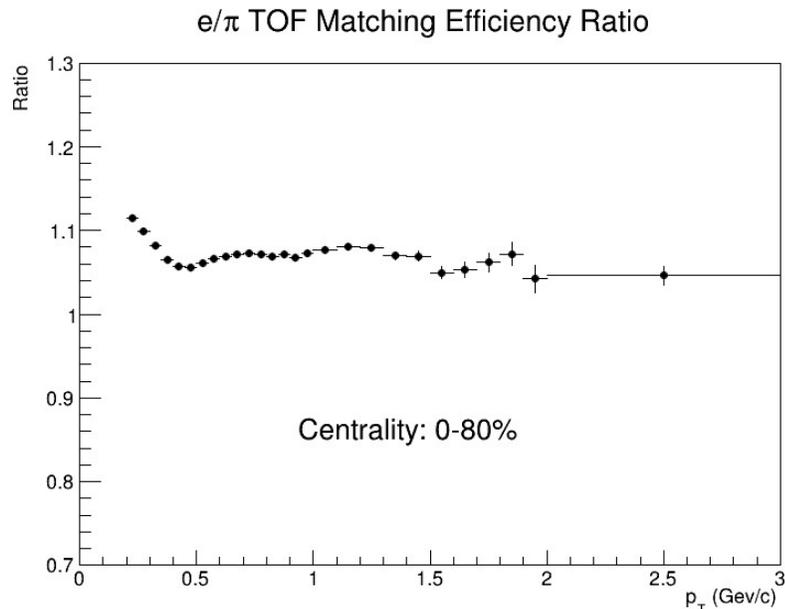
$$\epsilon_{\text{electron}} = \epsilon_{\text{positron}} = \epsilon_{\text{TPC}} \times \epsilon_{\text{eID}} \times \epsilon_{\text{TOF}}$$



Efficiency and Acceptance Corrections

- TOF Matching efficiency has p_T η Φ dependence

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

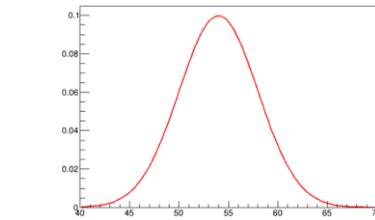
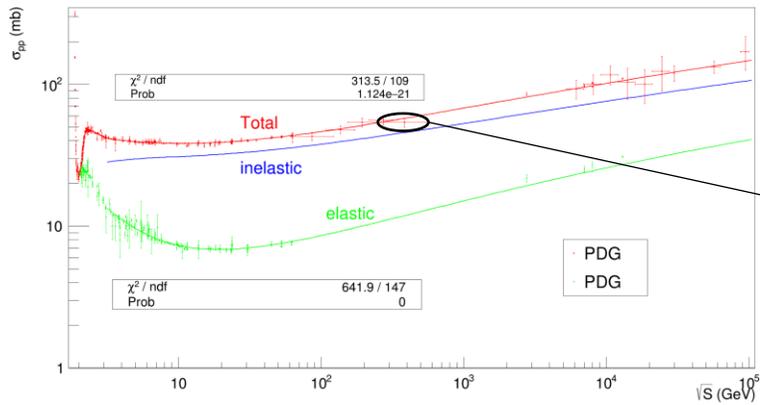


$$\frac{\text{Electron TOF Matching Efficiency}(3D)}{\text{Pion TOF Matching Efficiency}(3D)} = \frac{\text{Electron TOF matching efficiency (1D)}}{\text{Pion TOF matching efficiency (1D)}}$$

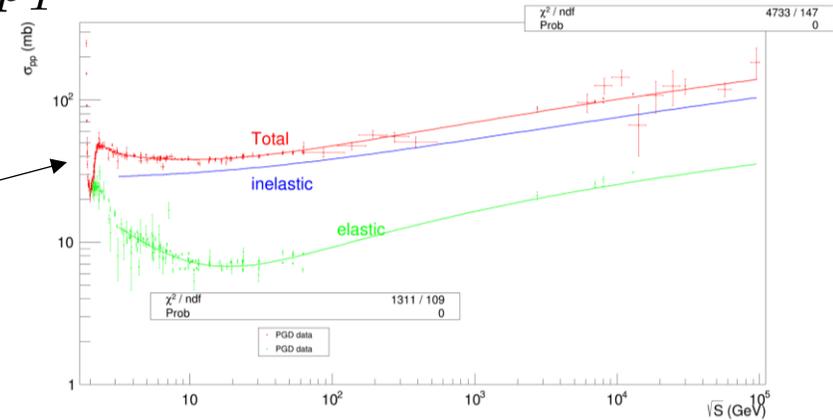
pp Inelastic Cross Section

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

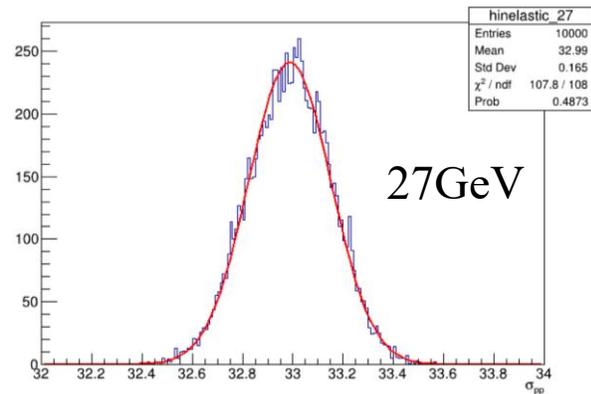
$$\sigma_{\text{inelastic}} = \sigma_{\text{total}} - \sigma_{\text{elastic}}$$



Smearing each point



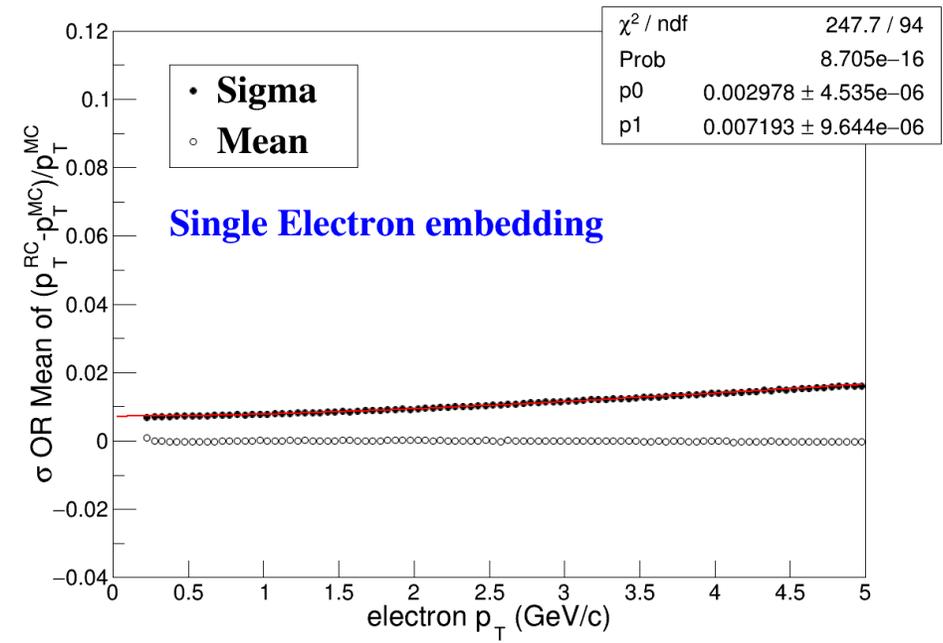
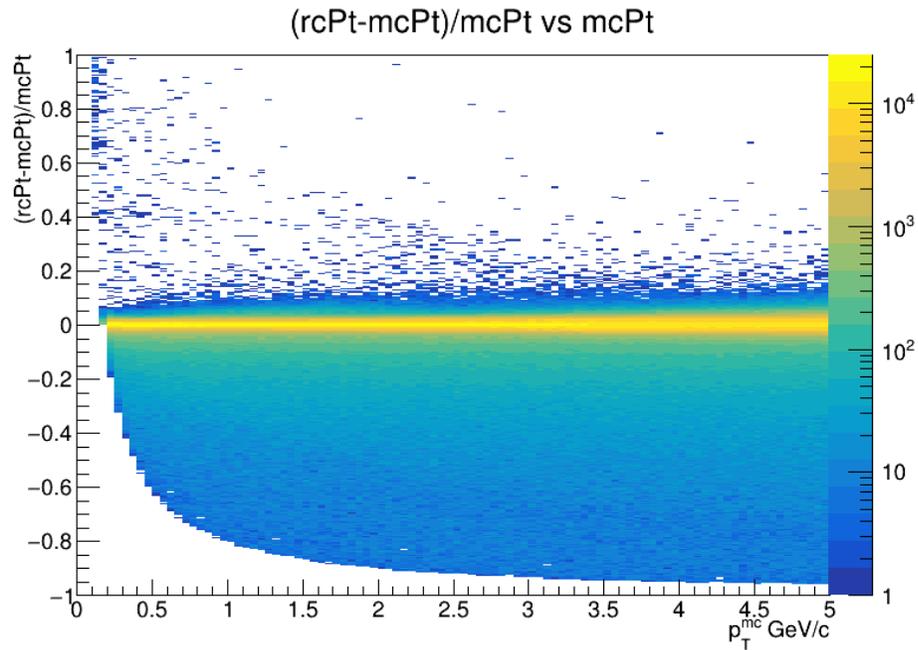
Data from PDG (Particle Data Group) :
<https://pdg.lbl.gov/2022/hadronic-xsections/>



$\sqrt{s_{NN}}$ (GeV)	$\sigma_{\text{inelastic}}$ (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

Additional Momentum Smearing (27GeV example)

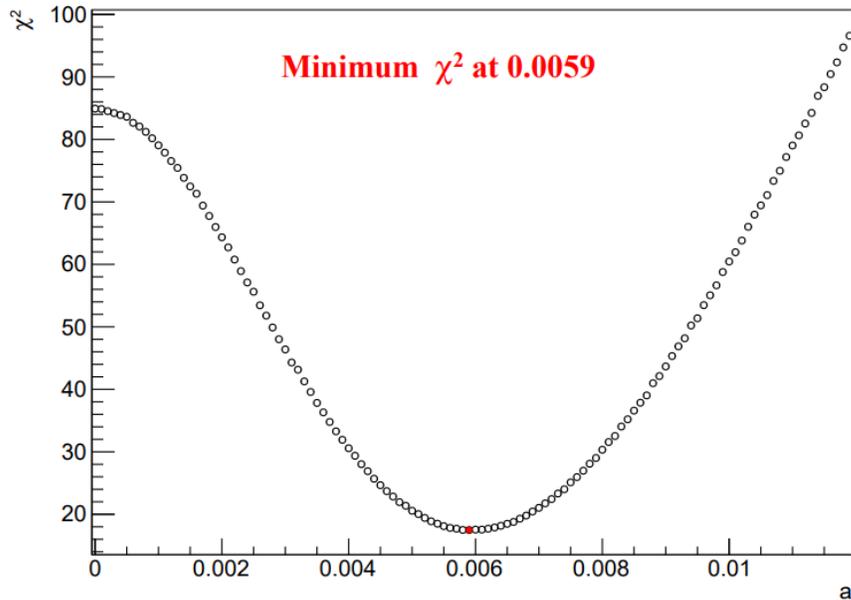
$$p_T^{\text{smear}} = p_{T, \text{ True}} + \Delta p_T \times \frac{\sqrt{(a')^2 p_{T, \text{ True}}^2 + b^2}}{\sigma^{\text{embed}}(p_{T, \text{ True}})} \longrightarrow \text{additional momentum smearing factor}$$



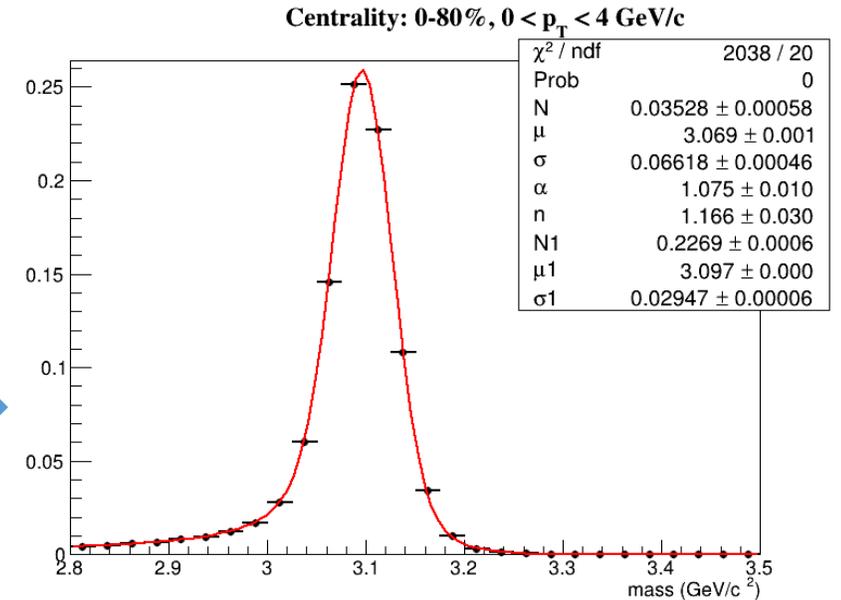
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$$\sigma^{\text{embed}} = \sqrt{a^2 p_T^2 + b^2}$$

Addiction Momentum Smearing (27GeV example)



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



scan a' \longrightarrow get J/ψ σ from ToyMC

\longrightarrow compare with data, a' value with minimum χ^2 is the best a' value

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)	$\sigma_{\text{inelastic}}$ (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	$\sigma_{NN} = 31.8$ 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