J/ψ R_{AA} in Au + Au collisions at $\sqrt{s_{NN}}$ = 14.6, 17.3, 19.6 and 27GeV

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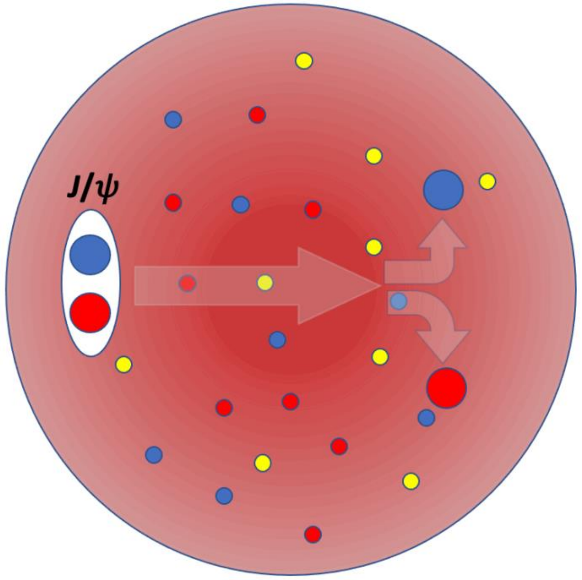
Outline

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

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

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

Introduction

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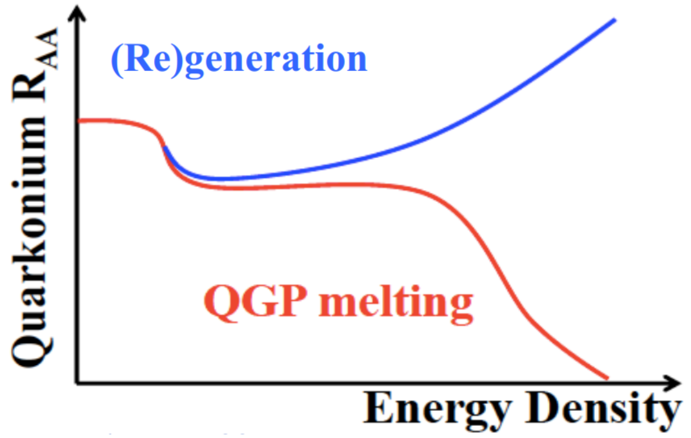
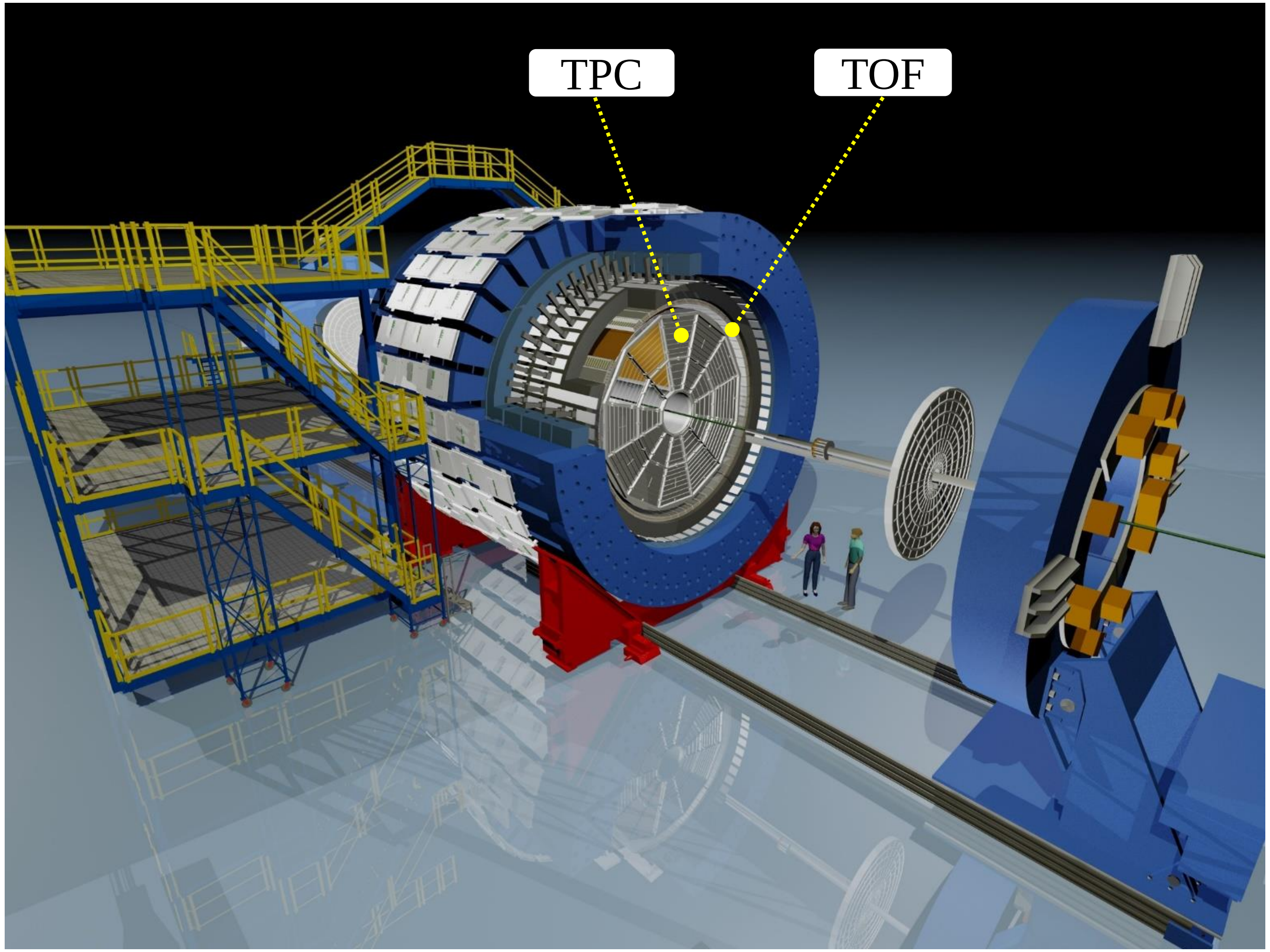


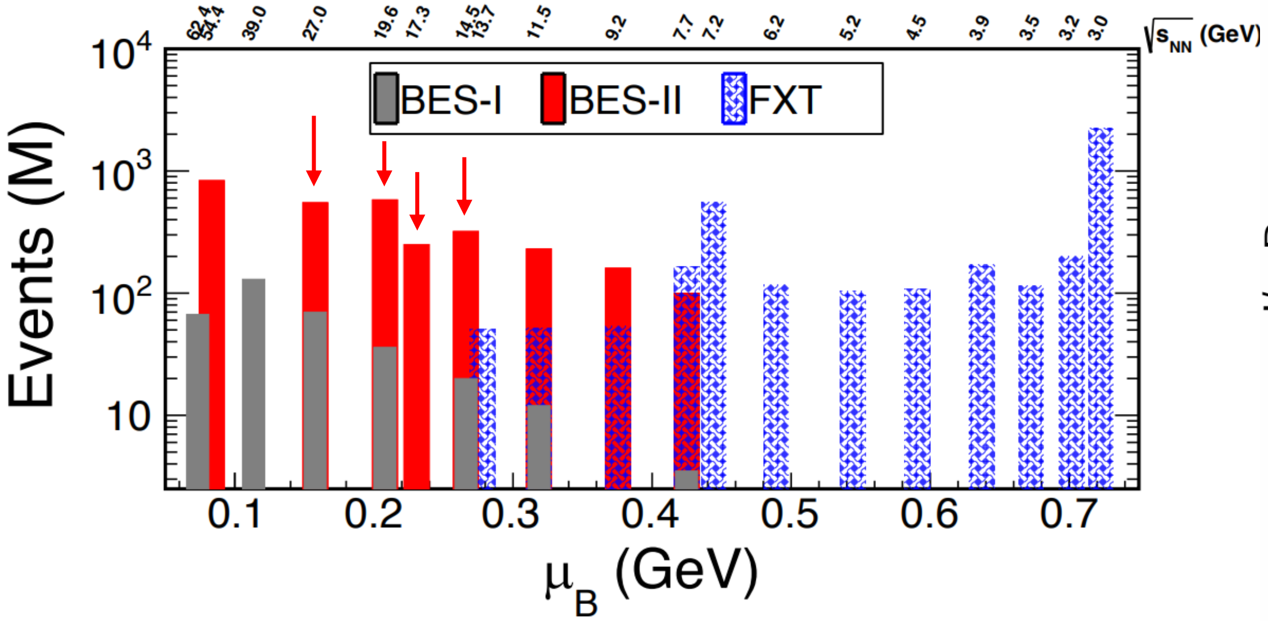
$$R_{AA} = \frac{\sigma_{\text{inel}}}{\langle N_{coll} \rangle} \frac{d^2 N_{AA}/dydp_T}{d^2\sigma_{pp}/dydp_T}$$

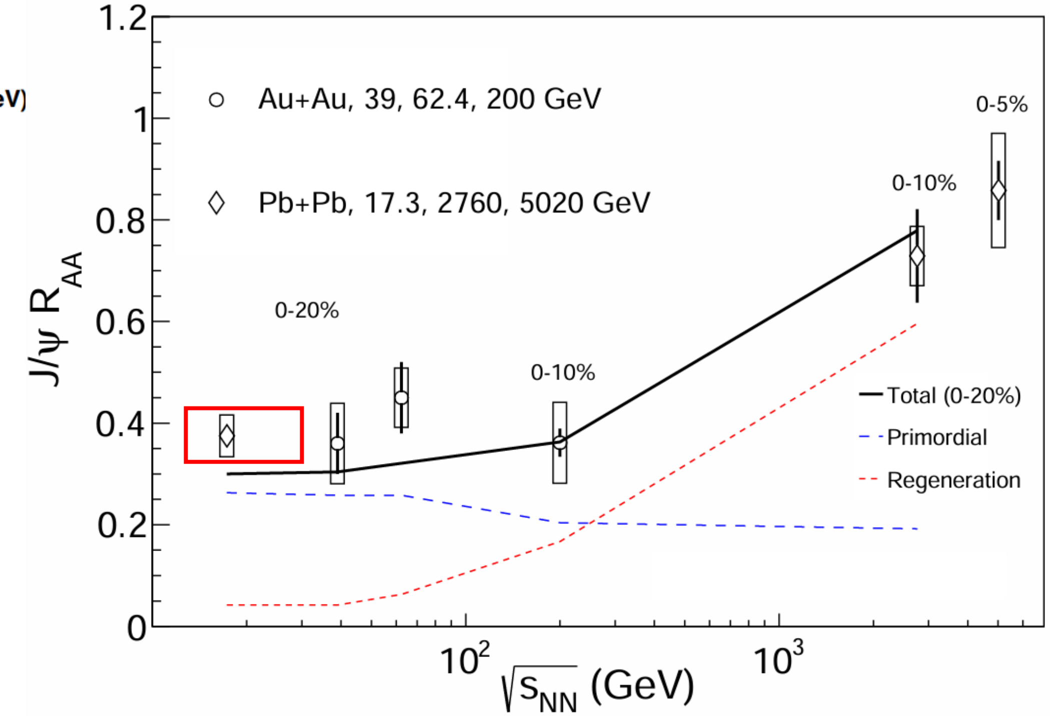
STAR Detector



- **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





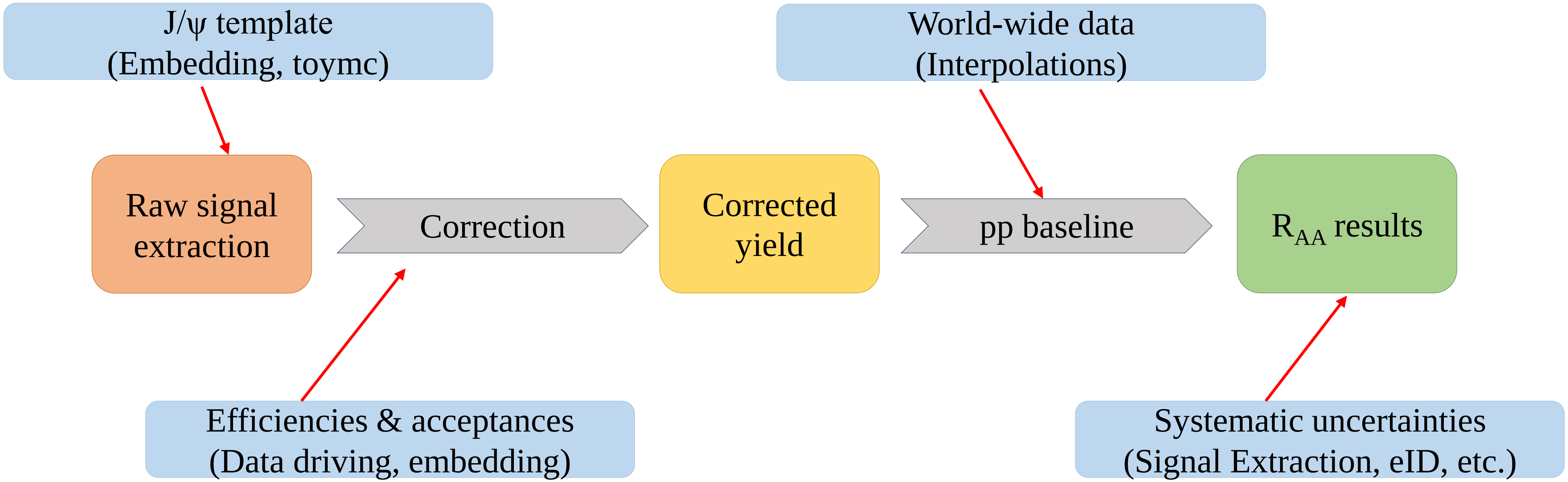
STAR Collaboration Phys. Lett. B 771 (2017) 13–20

- 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

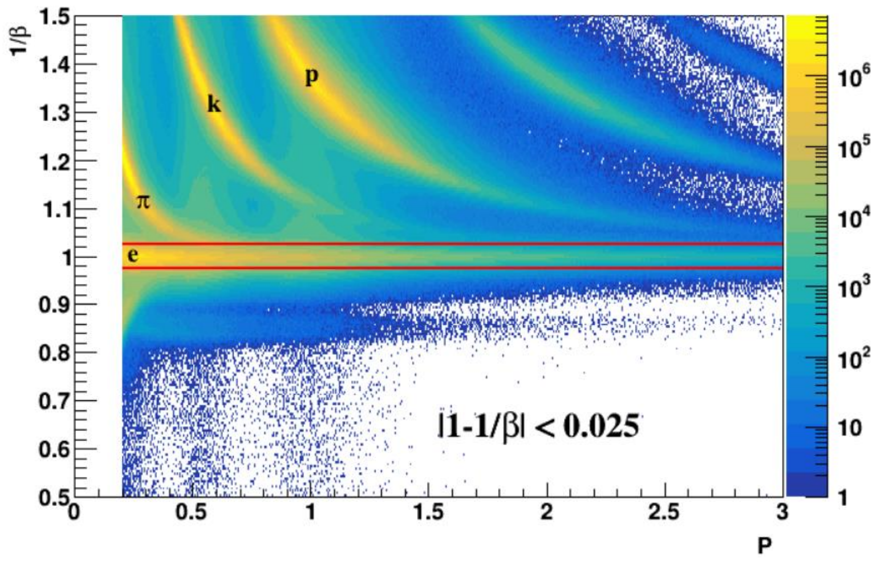
Analysis Procedure

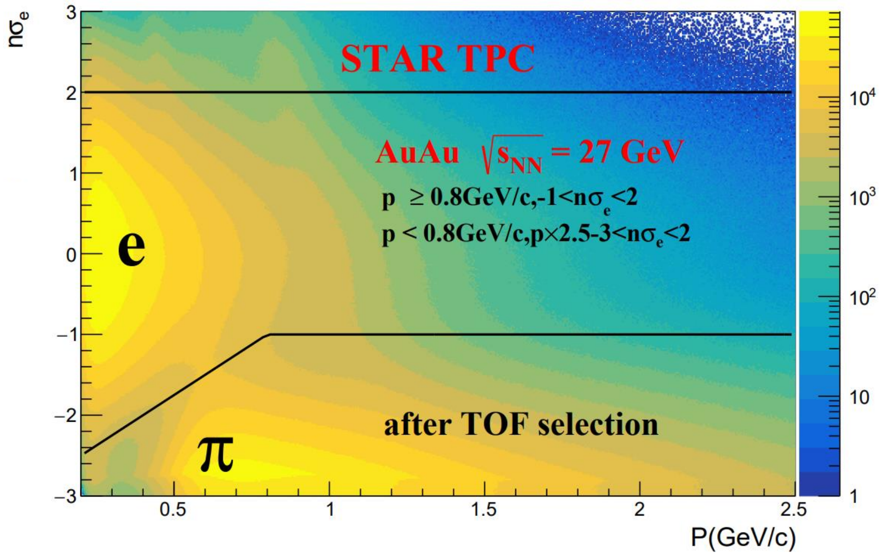
Observable: $$R_{AA} = \frac{\sigma_{\text{inel}}}{\langle N_{coll} \rangle} \frac{d^2 N_{AA}/dydp_T}{d^2\sigma_{pp}/dydp_T} \begin{cases} < 1 & \text{suppression} \\ = 1 & \text{no net medium effects} \\ > 1 & \text{enhancement} \end{cases}$$



Electron Identification

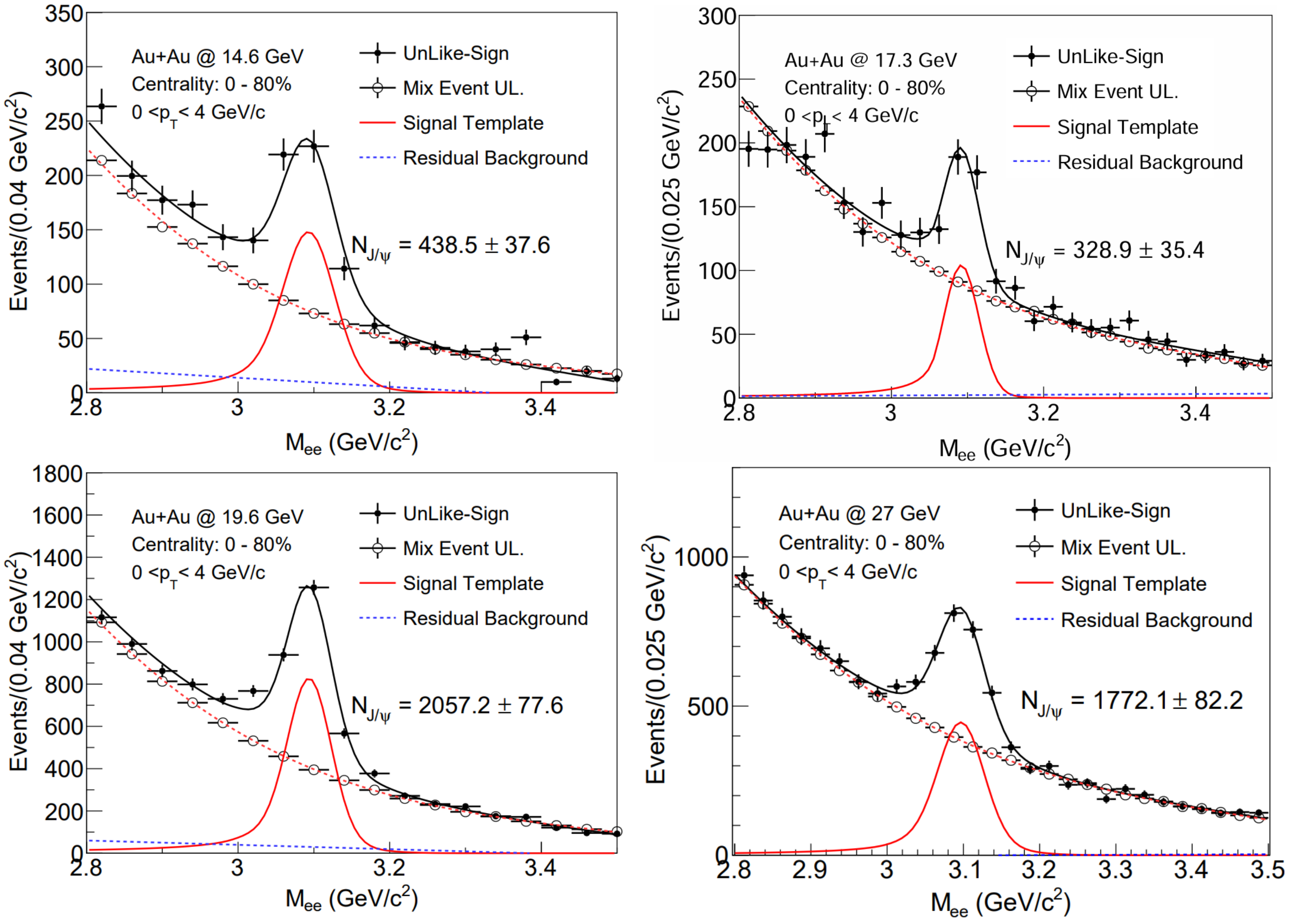
- System : Au+Au collisions in RHIC-STAR
- Collision Energy: 14.6, 17.3, 19.6, 27 GeV
- Decay Channel: $J/\psi \rightarrow e^- + e^+$





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

Raw J/ψ Signal



➢ Fitting components include：
- J/ψ template(simulation)
- combinatorial background(mixed event)
- residual background(straight line)

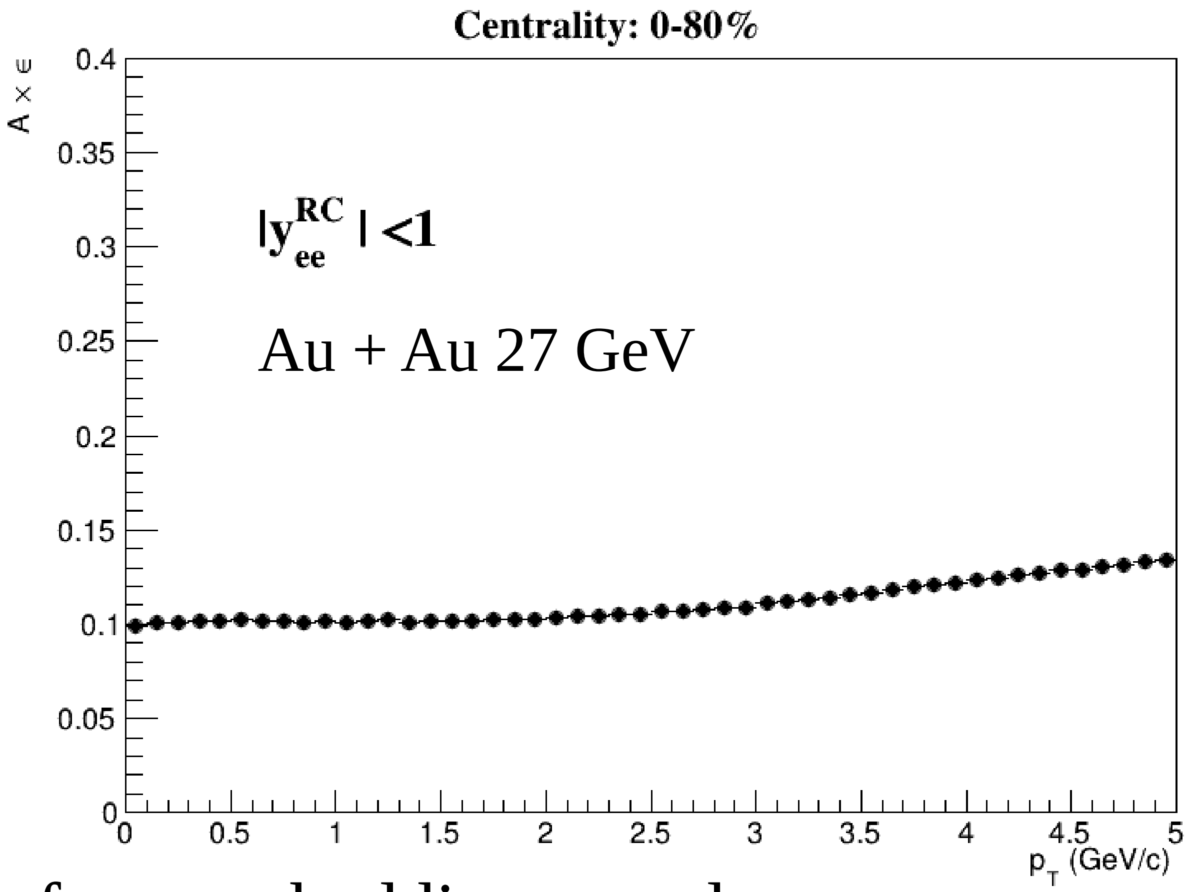
Efficiency and Acceptance Corrections

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

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

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

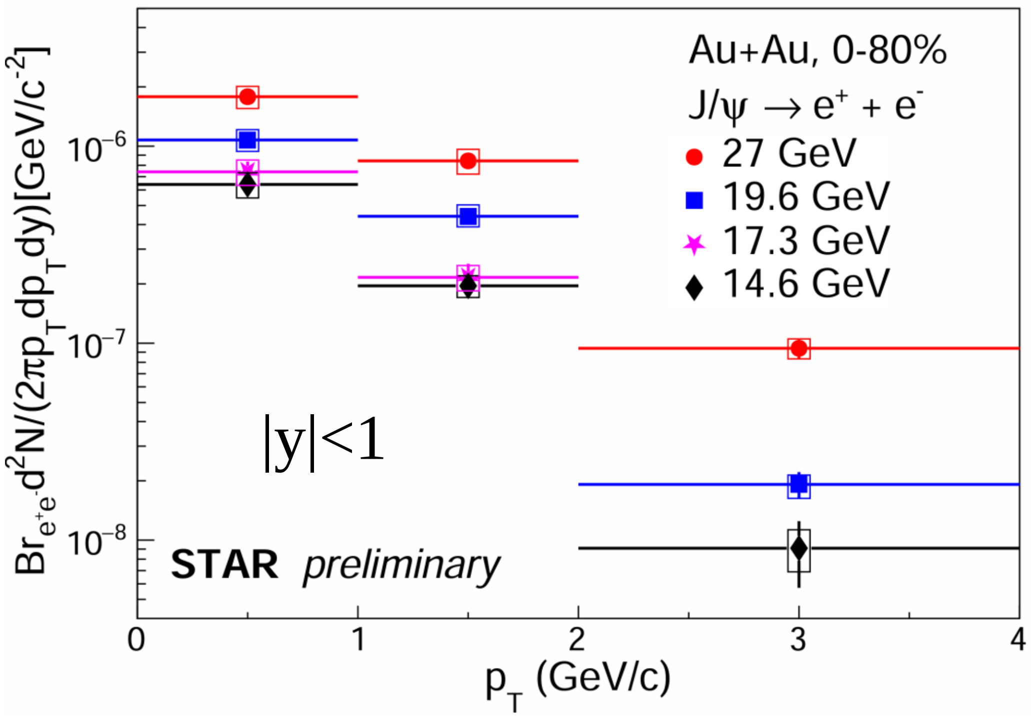
$$\varepsilon_{electron} = \varepsilon_{positron} = \varepsilon_{TPC} \times \varepsilon_{eID} \times \varepsilon_{TOF}$$



Acceptance correction and ε_{TPC} are getting from embedding sample

Inclusive J/ψ Invariant Yields

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

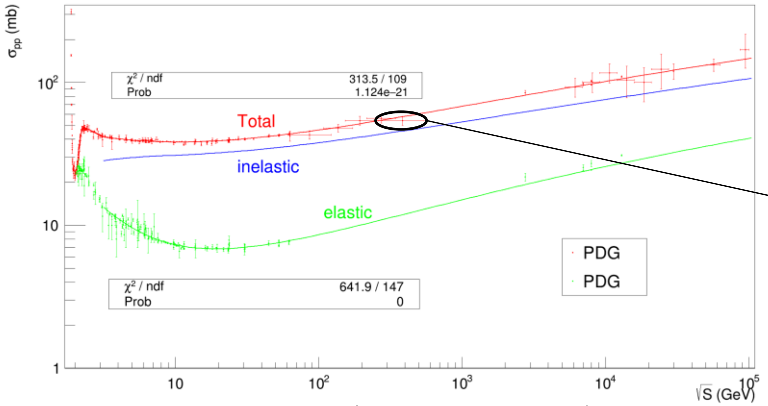


Inclusive J/ψ invariant yields as a function of p_T at mid-rapidity ($|y| < 1$) in Au+Au collisions at $\sqrt{s_{NN}}$ = 14.6, 17.3, 19.6, 27 GeV

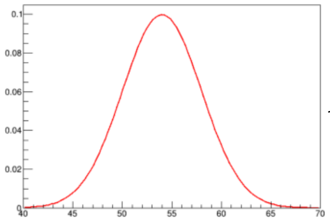
pp Inelastic Cross Section

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

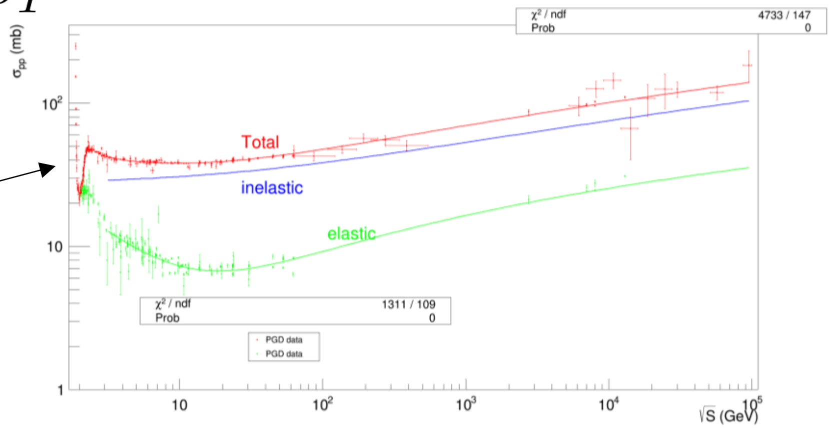
$$\sigma_{\text{inelastic}} = \sigma_{\text{total}} - \sigma_{\text{elastic}}$$

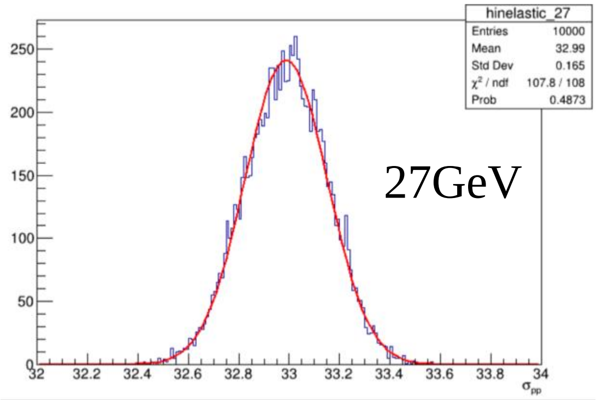


Data from PDG（Particle Data Group）：
https://pdg.lbl.gov/2022/hadronic-xsections/



Smearing each point





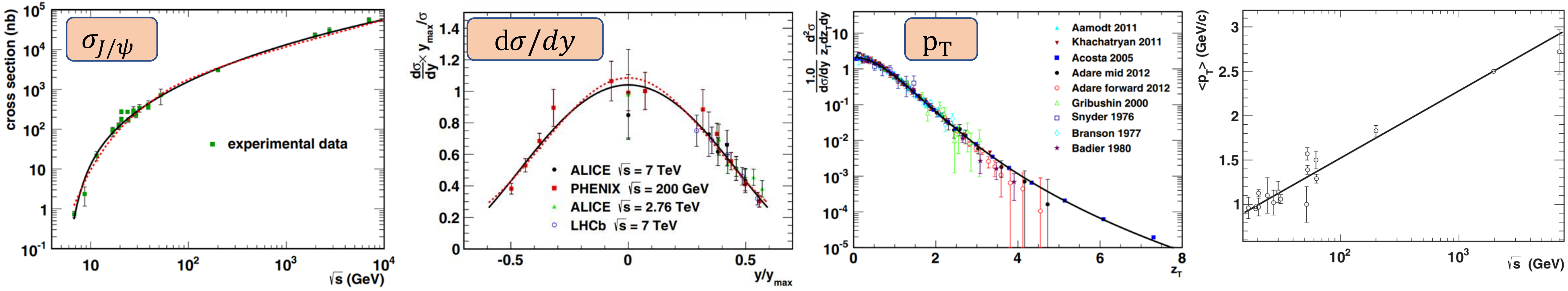
$\sqrt{S_{NN}}$ (GeV)	$\sigma_{\text{inelastic}}$ (mb)	Error(mb)
200	43.40	0.77
27	32.99	0.16
19.6	32.08	0.14
17.3	31.78	0.13
14.6	31.42	0.13
11.5	30.99	0.12
9.2	30.65	0.13

p+p Baseline

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

- **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

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

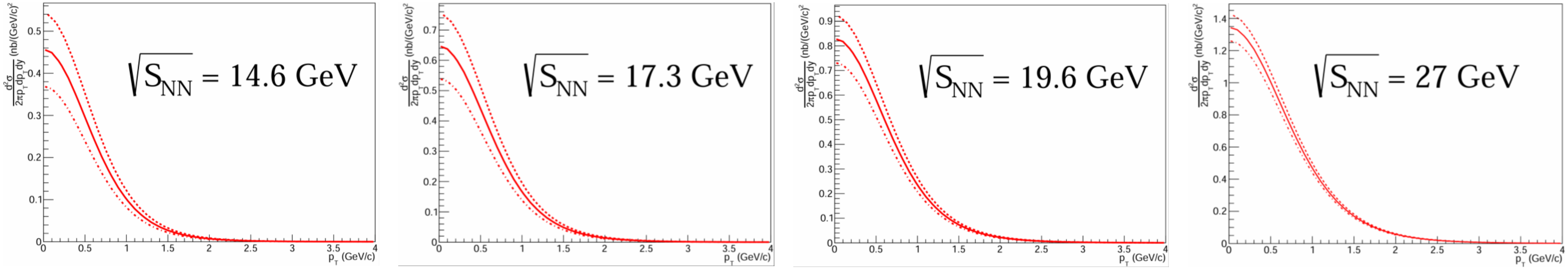
where $y_{max} = ln(\frac{\sqrt{s}}{m_{J/\psi}})$

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

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, 17.3, 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 %

Systematic Uncertainty

➢ Systematic uncertainty from J/ψ yield measurements

Source：

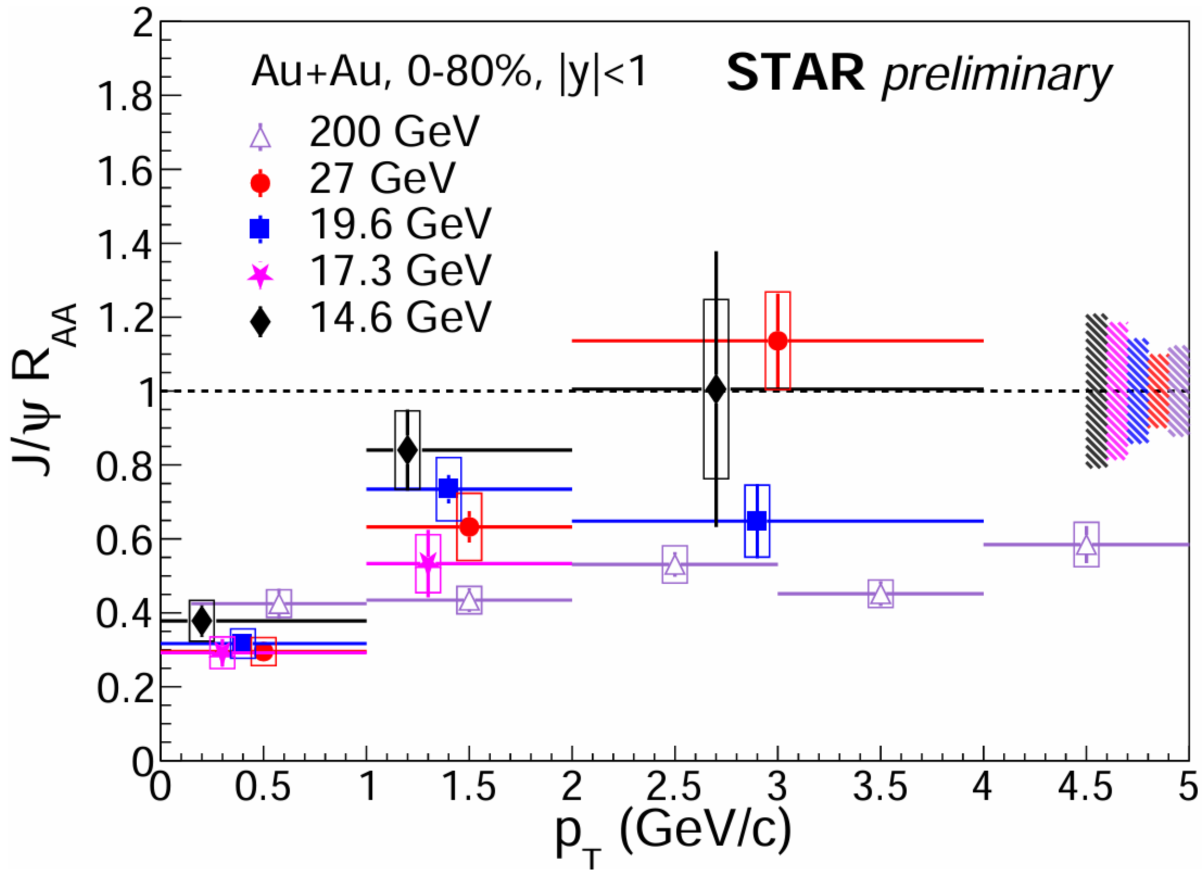
Track Quality Cuts
- nHitsFit
- nHitsDedx
- Dca (cm)

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

Electron Identification Cuts
- $n\sigma_e$ efficiency
- $1/\beta$ efficiency
- TOF Matching efficiency

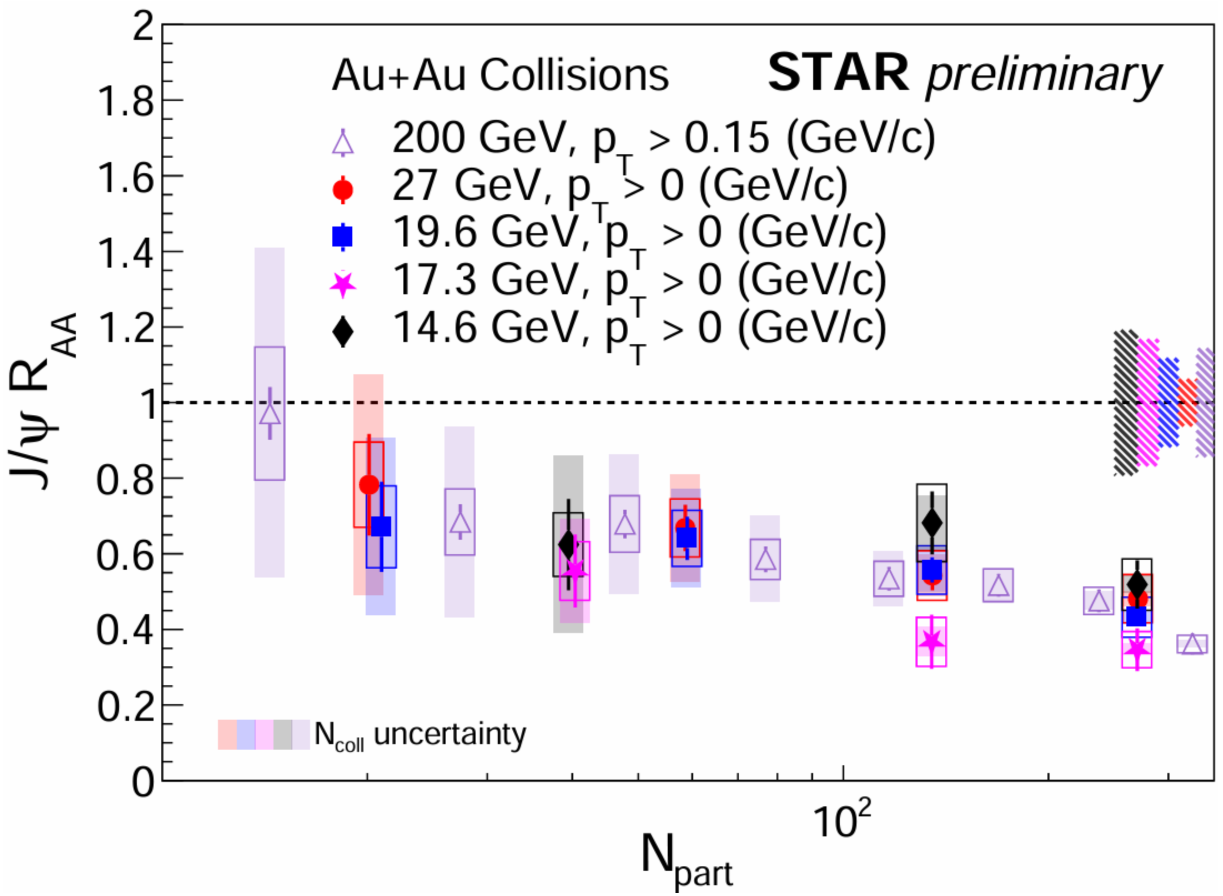
Analyzed bin	27 GeV	19.6 GeV	17.3 GeV	14.6 GeV
0-80 %	12.4 %	11.2 %	12.8 %	13.2 %
0-20 %	13.2 %	12.3 %	13.8 %	13.1 %
20-40 %	12.1 %	11.5 %	17.7 %	15.0 %
40-60 %	11.5 %	11.6 %	13.9%	13.5 %
60-80 %	14.4 %	16.1 %		
0-1 GeV/c	12.8 %	12.5 %	14.7 %	14.6 %
1-2 GeV/c	14.4 %	11.6 %	14.7 %	12.7 %
2-4 GeV/c	11.6 %	15.0 %	-	24.1 %

p_T Dependence of Inclusive J/ψ R_{AA}



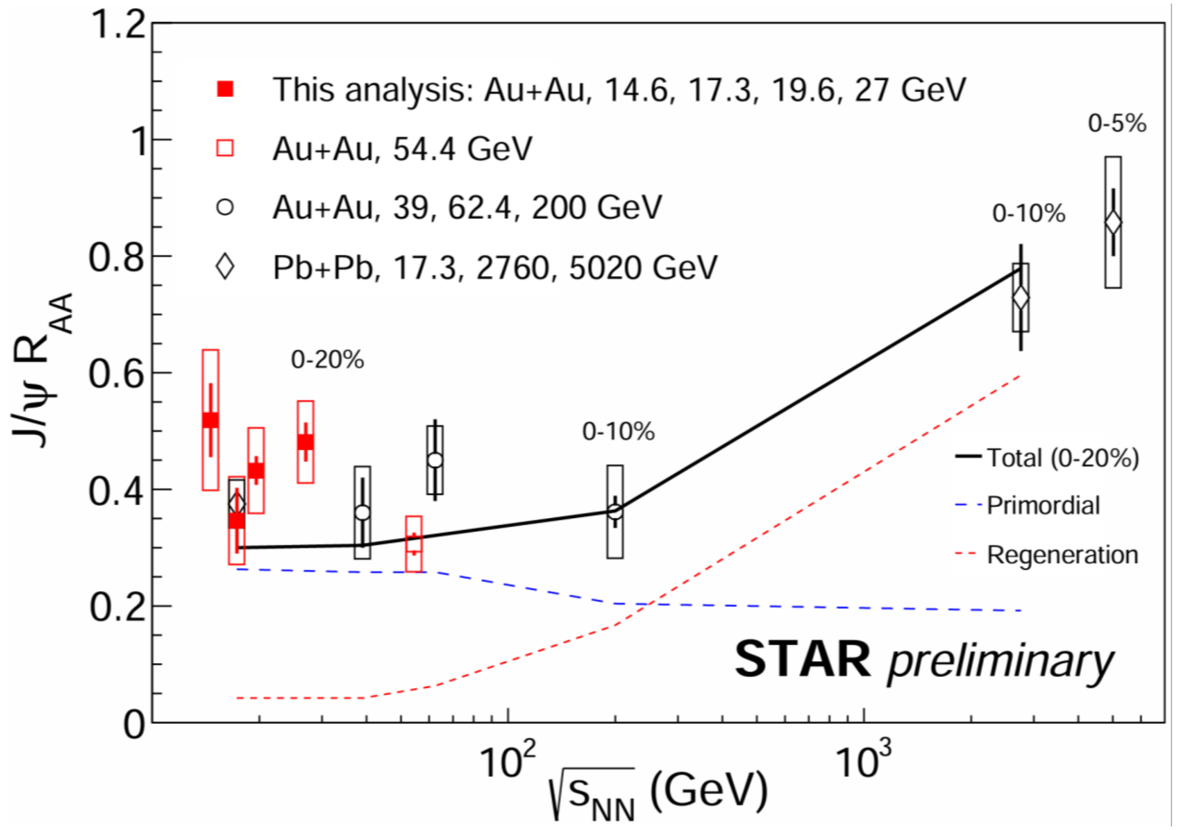
- Low p_T suppression, R_{AA} increases with p_T for $\sqrt{s_{NN}}$ = 14.6, 17.3, 19.6 and 27 GeV
- No significance p_T dependence at 200 GeV

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 <N_{part}>

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 J/ψ productions in RHIC BES-II are observed
- Hint of decreasing with centrality and increasing with p_T for J/ψ R_{AA} at low energies
- No significant collision energy dependence of J/ψ R_{AA} at RHIC
- Stronger suppression at RHIC than LHC, indicate smaller regeneration effect at RHIC

→ Interplay of dissociation, regeneration and cold nuclear matter effects

Thank you

Back up

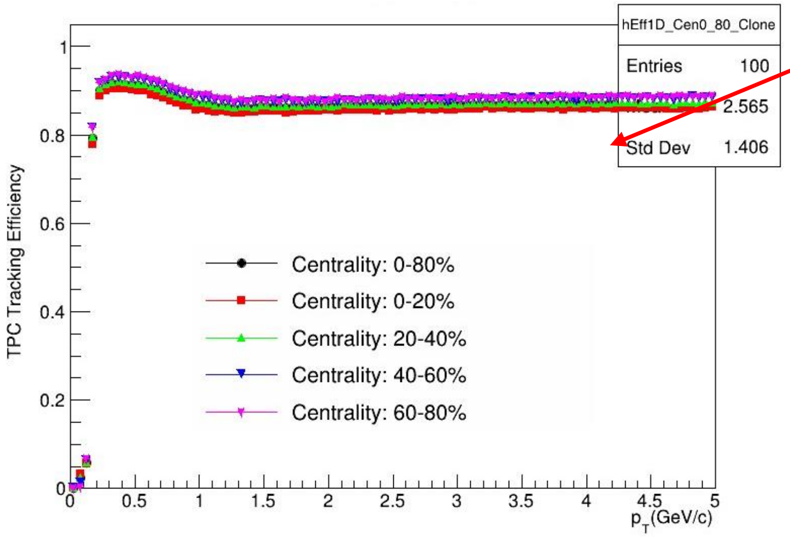
Efficiency and Acceptance Corrections

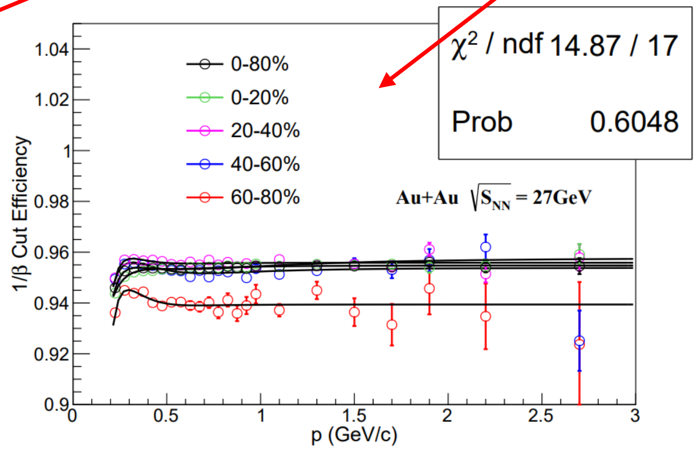
$$R_{AA} = \frac{\sigma_{\text{inel}}}{\langle N_{coll} \rangle} \frac{d^2 N_{AA} / dy dp_T}{d^2 \sigma_{pp} / dy dp_T}$$

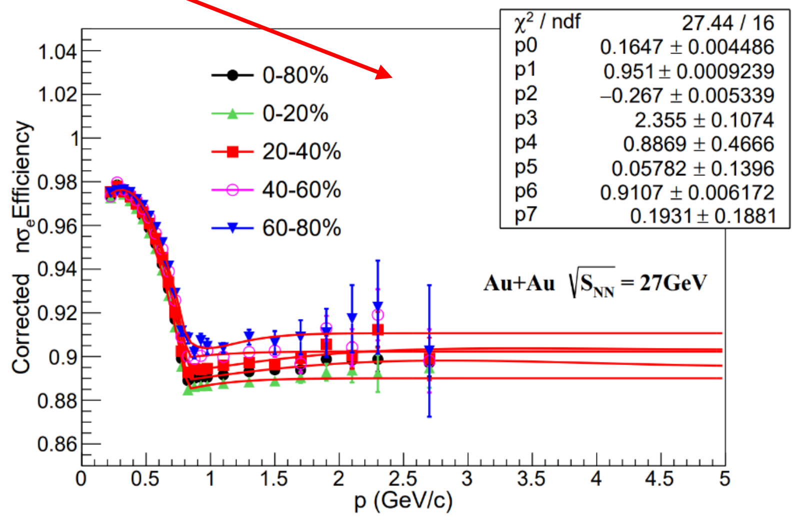
$$N_{AA} = \frac{N_{J/\psi \to e+e-}}{A \times \varepsilon \times Nevent}$$

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

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



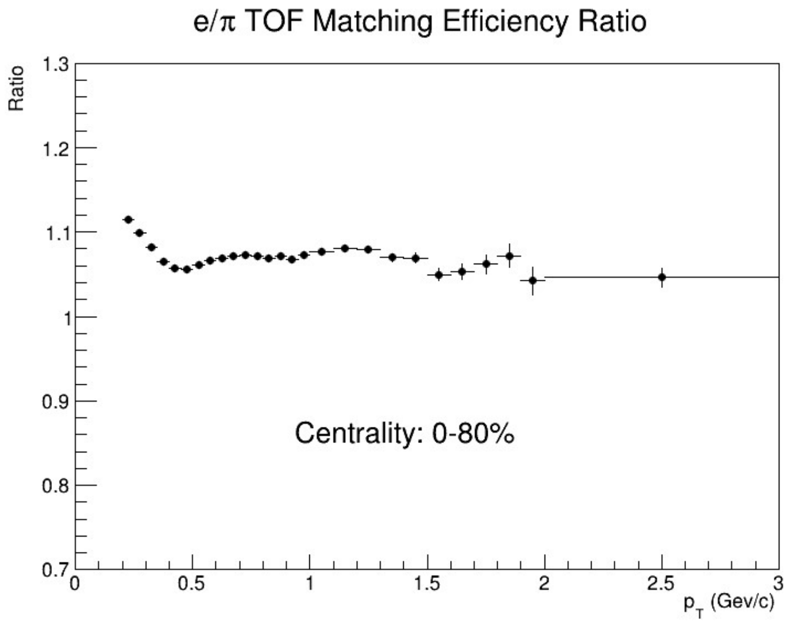


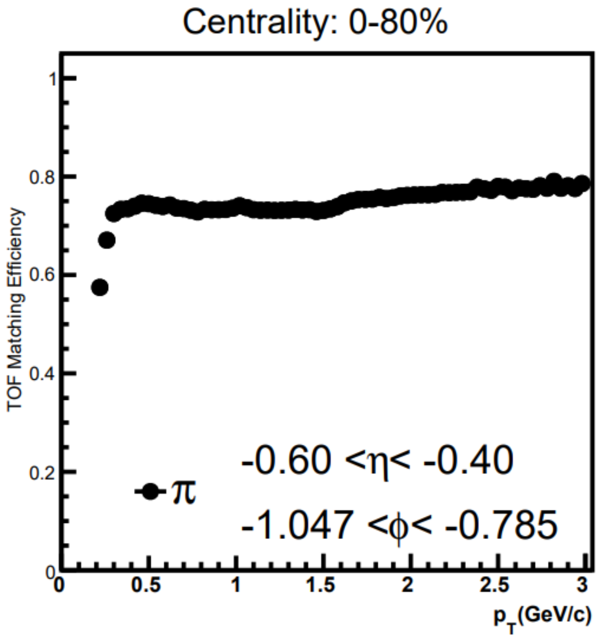


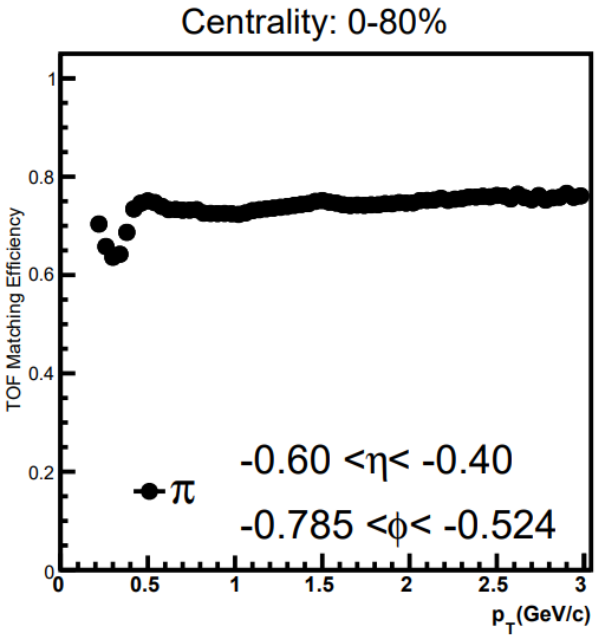
Efficiency and Acceptance Corrections

- TOF Matching efficiency has pt η Φ dependence

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





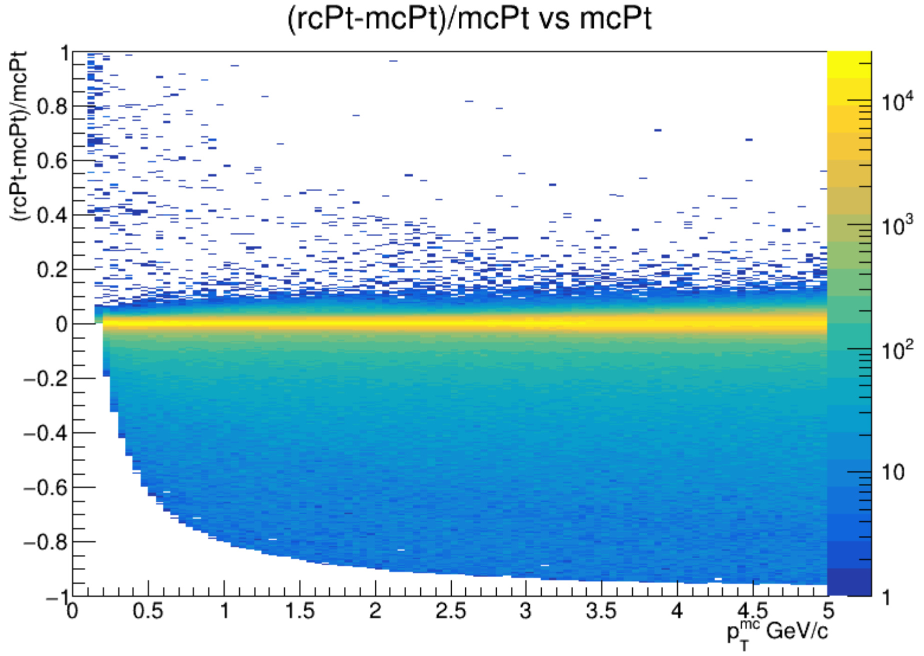


$$\frac{\text{Electron TOF Matching Efficiency (3D)}}{\text{Pion TOF Matching Efficiency (3D)}} = \frac{\text{Electron TOF matching efficiency (1D)}}{\text{Pion TOF matching efficiency (1D)}}$$

Additional Momentum Smearing (27GeV example)

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

→ additional momentum smearing factor



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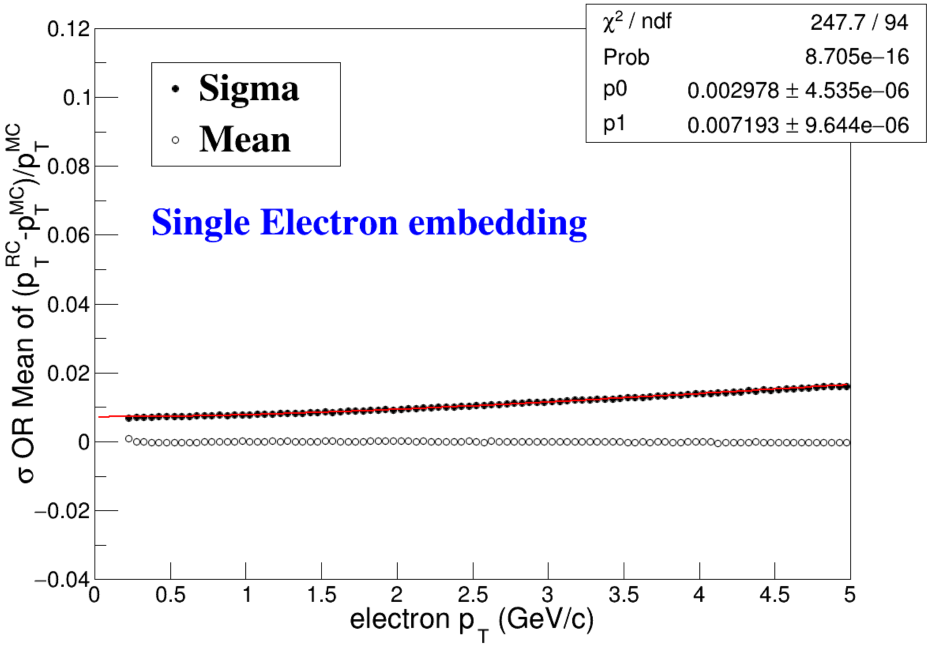
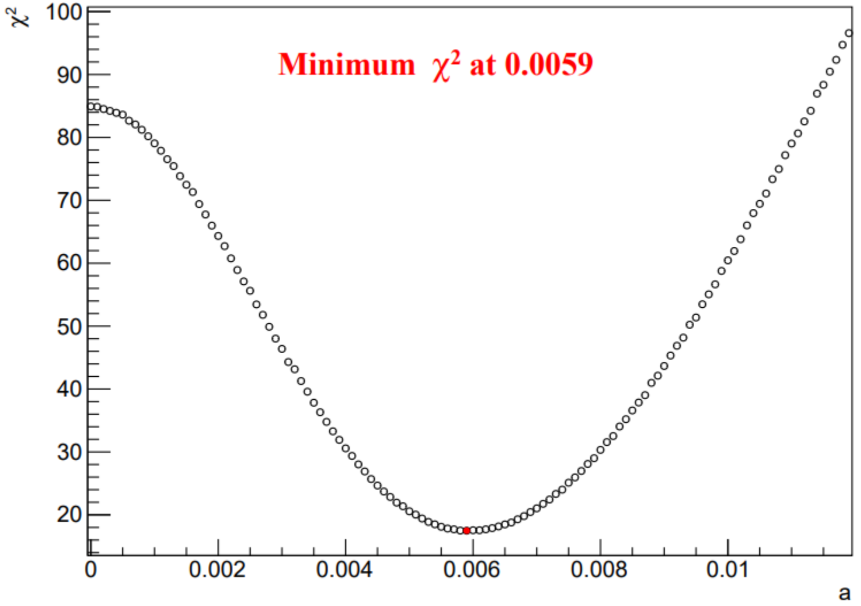
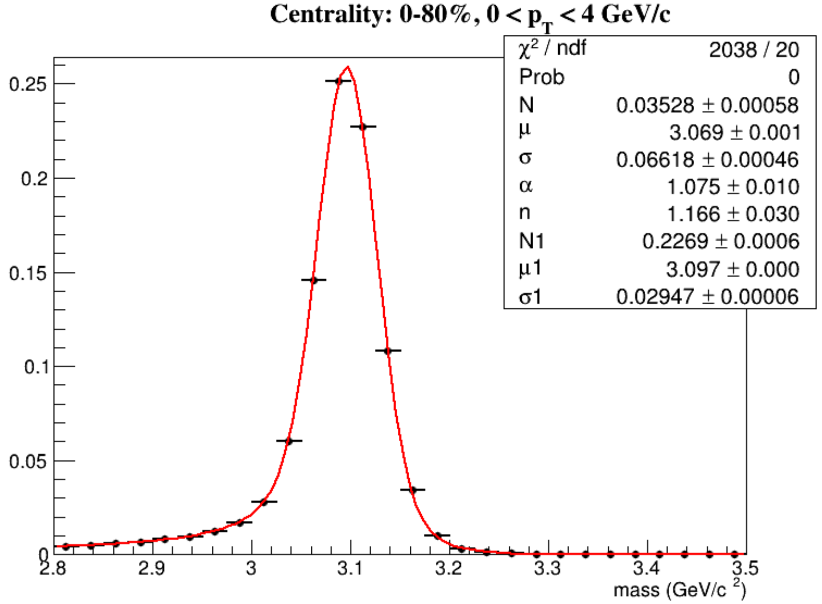


$$\sigma^{\ embed} = \sqrt{a^2 P_T^{\ 2} + b^2}$$

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 at Au + Au 27 GeV

Analyzed bin	Signal Extraction	Track	$N\sigma_e$	$1/\beta$	TOF Matching	Total
0-80%	2.1 %	10.3 %	5.5 %	3.3 %	0.8 %	12.4 %
0-20%	2.7 %	10.3 %	7.6 %	2.1 %	0.5 %	13.2 %
20-40%	1.8 %	10.6 %	4.6 %	3.1 %	0.2 %	12.1 %
40-60%	1.8 %	10.2 %	3.7 %	2.8 %	1.9 %	11.5 %
60-80%	3.8 %	10.5 %	8.4 %	3.7 %	0.06 %	14.4 %
0-1GeV/c	2.8 %	10.8 %	5.2 %	3.3%	1.1 %	12.8 %
1-2GeV/c	2.1 %	10.6 %	8.9 %	3.3%	0.8 %	14.4 %
2-4GeV/c	2.5 %	10.4 %	3.2%	3.2%	0.06 %	11.6 %

Consistency Checks

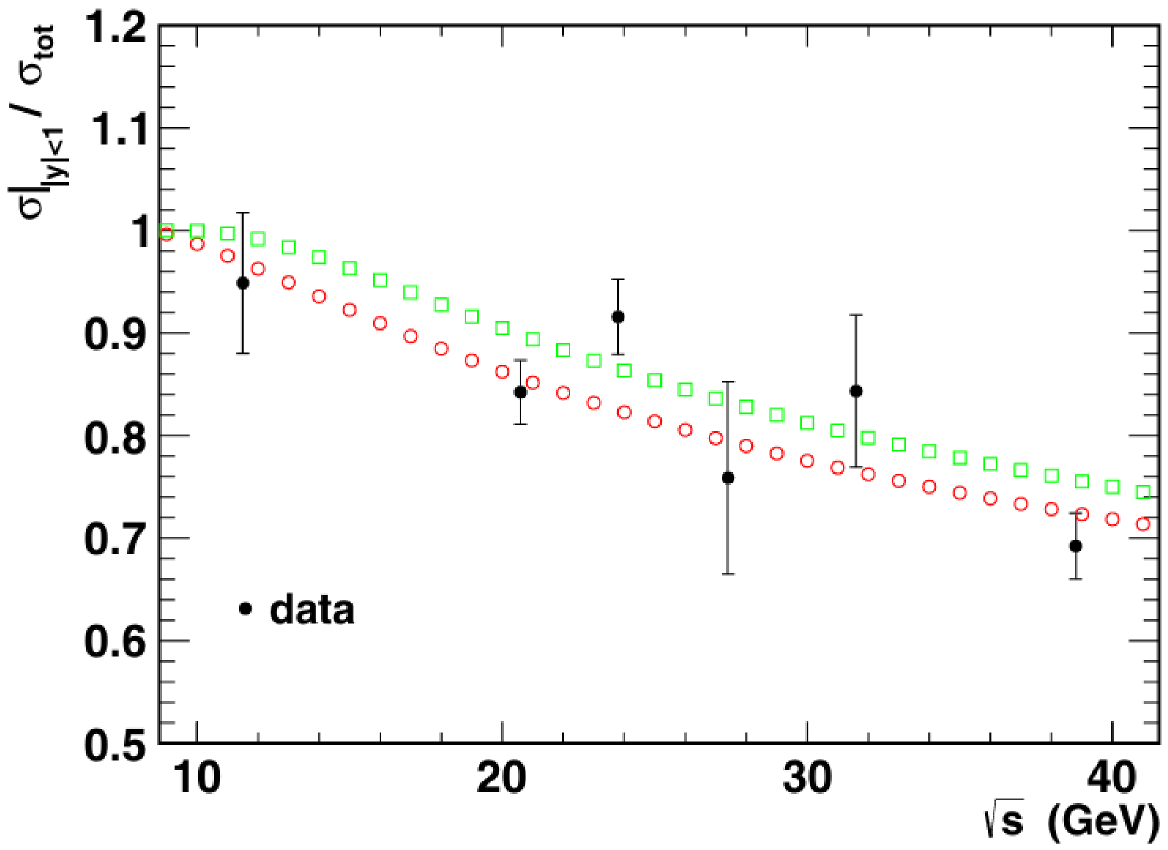


FIG. 7. The ratios of J/ψ $\sigma|_{|y|<1.0}$ to σ_{tot} as a function of cms energy [16–18,30,32–34,37,50]. The open circle and the open square are the estimations using the function fit of Eqs. (6) and (7) in Fig. 4, respectively.

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

<table>
<tr><th>Analyzed bin</th><th>27 GeV</th><th>19.6 GeV</th><th>17.3 GeV</th><th>14.6 GeV</th></tr>
<tr><td>0-80%</td><td>12.4 %</td><td>11.2 %</td><td>12.8 %</td><td>13.2 %</td></tr>
<tr><td>0-20%</td><td>13.2 %</td><td>12.3 %</td><td>13.8 %</td><td>13.1 %</td></tr>
<tr><td>20-40%</td><td>12.1 %</td><td>11.5 %</td><td>17.7 %</td><td>15.0 %</td></tr>
<tr><td>40-60%</td><td>11.5 %</td><td>11.6 %</td><td rowspan="2">13.9%</td><td rowspan="2">13.5 %</td></tr>
<tr><td>60-80%</td><td>14.4 %</td><td>16.1 %</td></tr>
<tr><td>0-1GeV/c</td><td>12.8 %</td><td>12.5 %</td><td>14.7 %</td><td>14.6 %</td></tr>
<tr><td>1-2GeV/c</td><td>14.4 %</td><td>11.6 %</td><td>14.7 %</td><td>12.7 %</td></tr>
<tr><td>2-4GeV/c</td><td>11.6 %</td><td>15.0 %</td><td>-</td><td>24.1 %</td></tr>
</table>

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