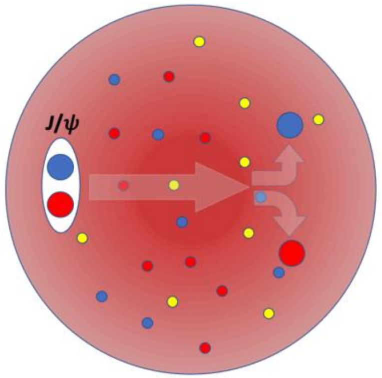
J/ψ R_{AA} in Au+Au collisions at 14.6, 19.6 and 27GeV

Wei Zhang

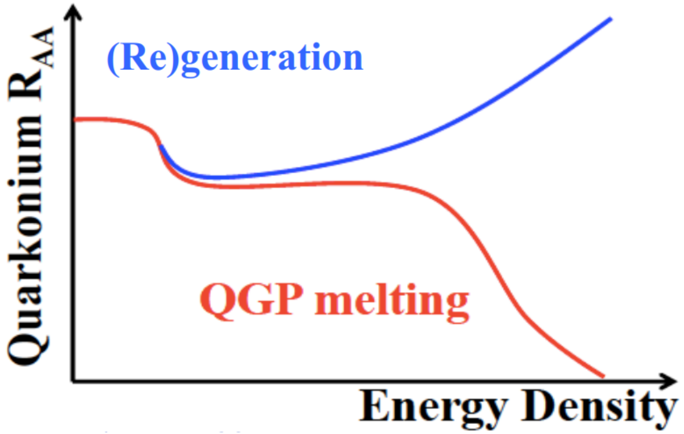
Introduction

➢ Quarkonia provide good probes of the Quark-Gluon Plasma (QGP)

Dissociation



Credit: Q. Yang



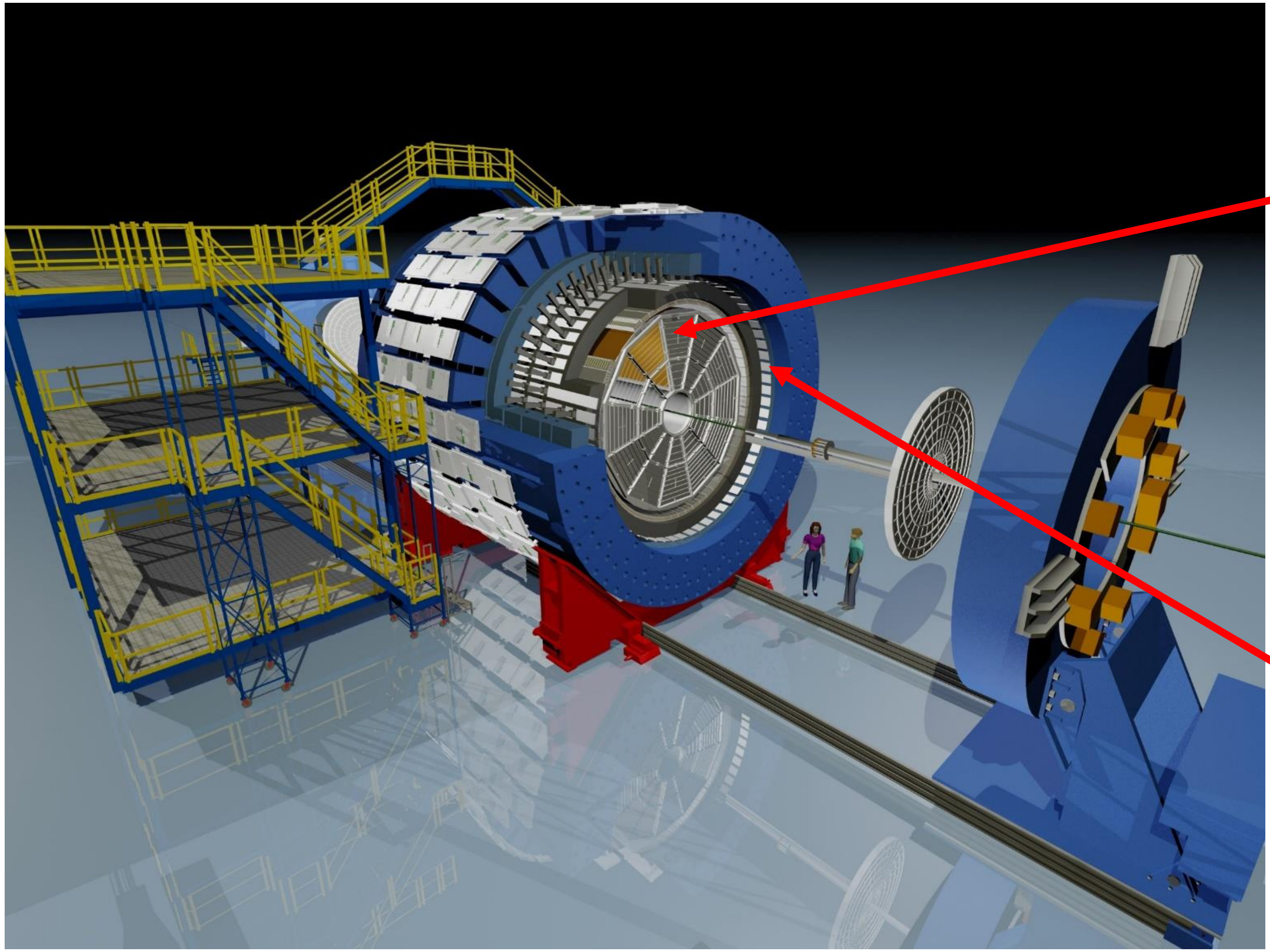
➢ Other effects:

- Regeneration
- Cold nuclear matter effects
- Feed down

➢ Systematically analyze the J/ψ R_{AA}

- p_T, centrality dependence
- Collision energy dependence

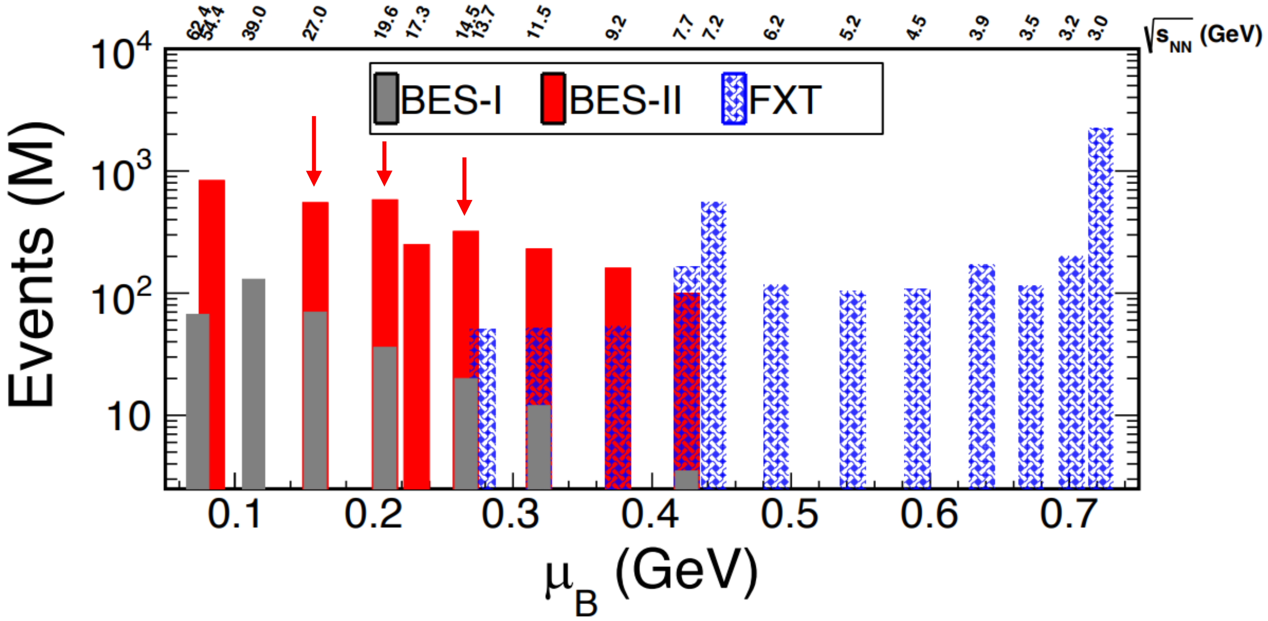
The Solenoidal Tracker at RHIC

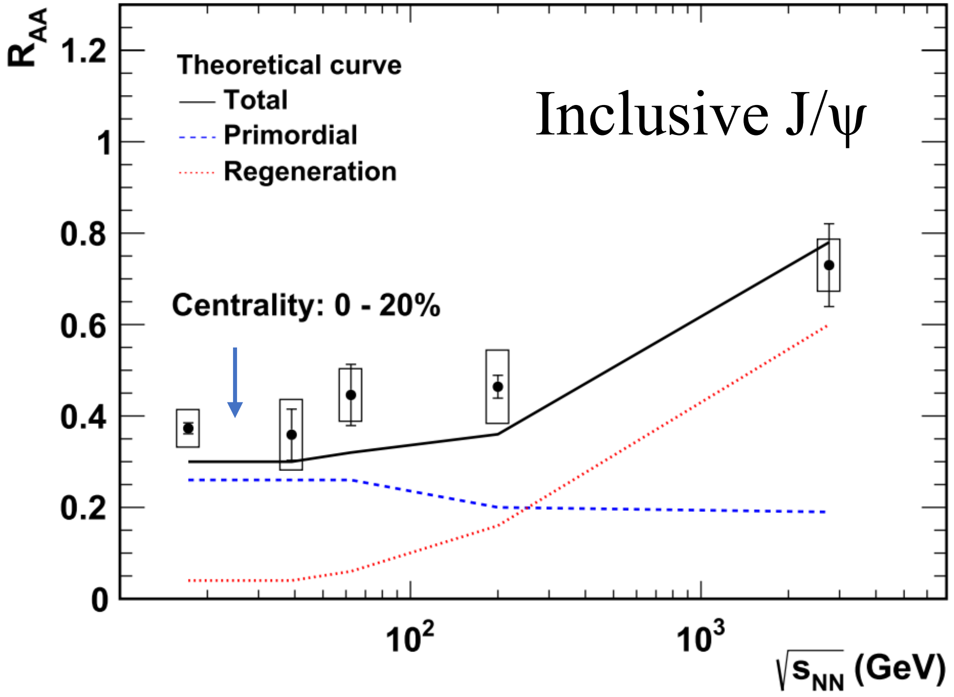


Time Projection Chamber
Tracking, momentum, particle identification with dE/dx
Acceptance: $|\eta| < 1$; $0 \leq \varphi < 2\pi$

Time Of Flight Detector
particle identification with velocity
Acceptance: $|\eta| < 1$; $0 \leq \varphi < 2\pi$

Au+Au Collisions at STAR





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

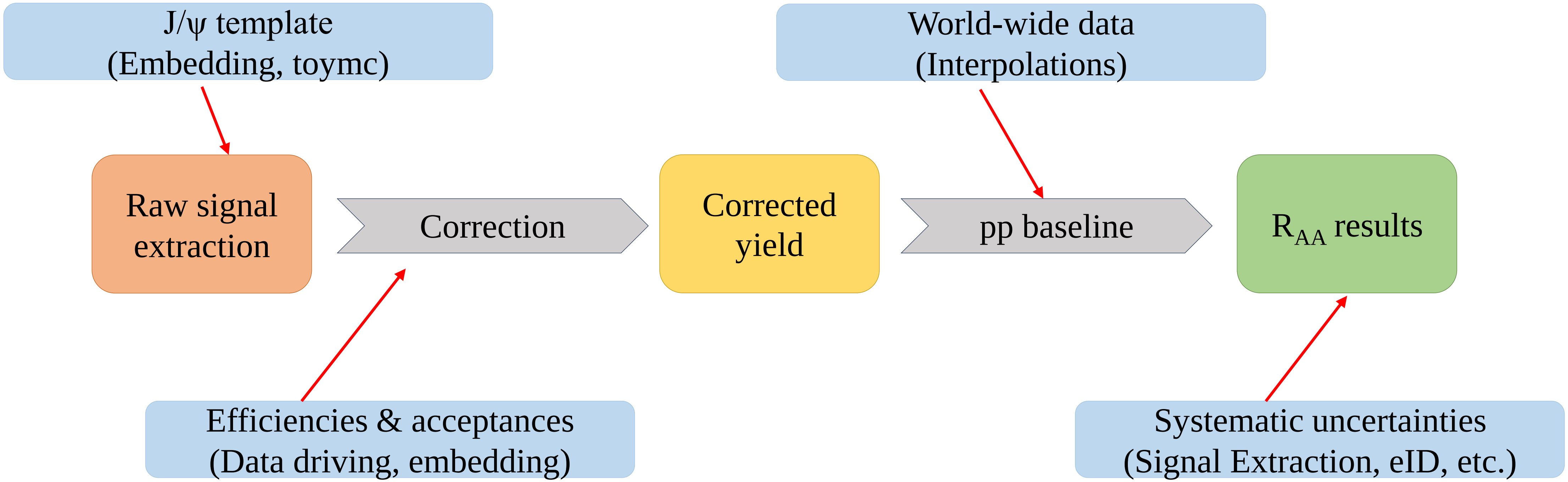
- Beam Energy Scan II
  - 10-20 times higher statistics than BES-I
  - Unique opportunity to study the collision energy dependence

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

Analysis Procedure

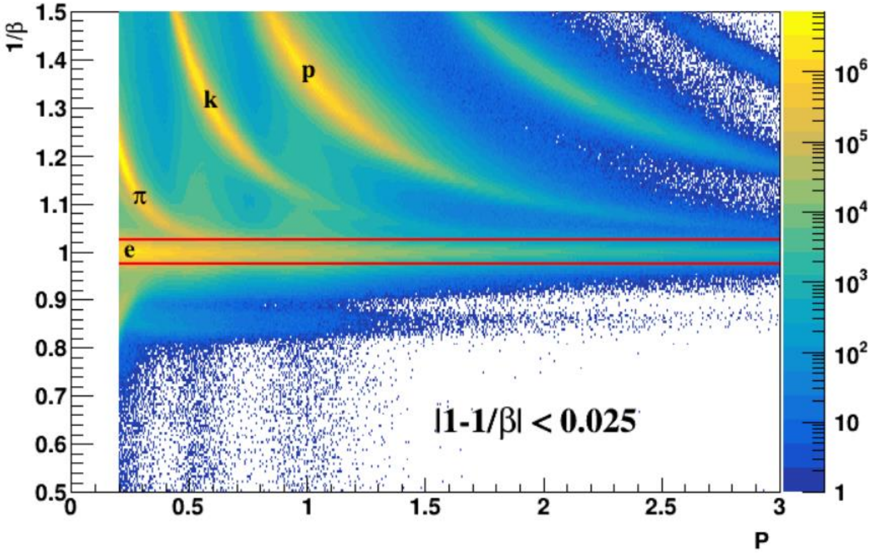
Observable: $$R_{AA} = \frac{\sigma_{\text{inel}}}{\langle N_{coll} \rangle} \frac{d^2N_{AA}/dydp_T}{d^2\sigma_{pp}/dydp_T}$$

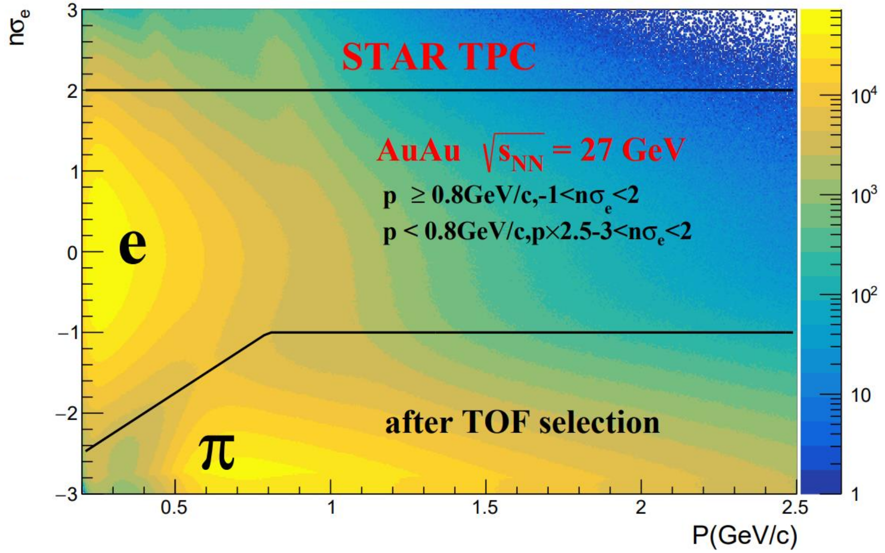
- < 1 suppression
- $= 1$ no net medium effects
- > 1 enhancement



Electron Identification

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

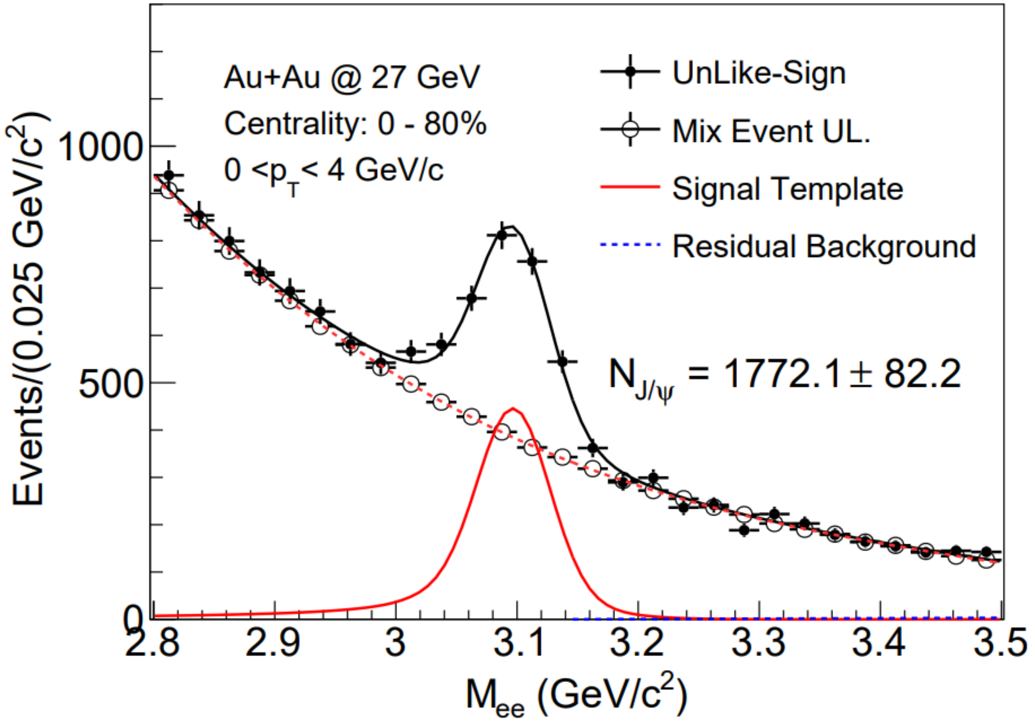




$$n\sigma_e = \frac{1}{R} log \frac{(dE/dx)_{measured}}{(dE/dx)_{electron}}$$

Raw J/ψ Signal

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

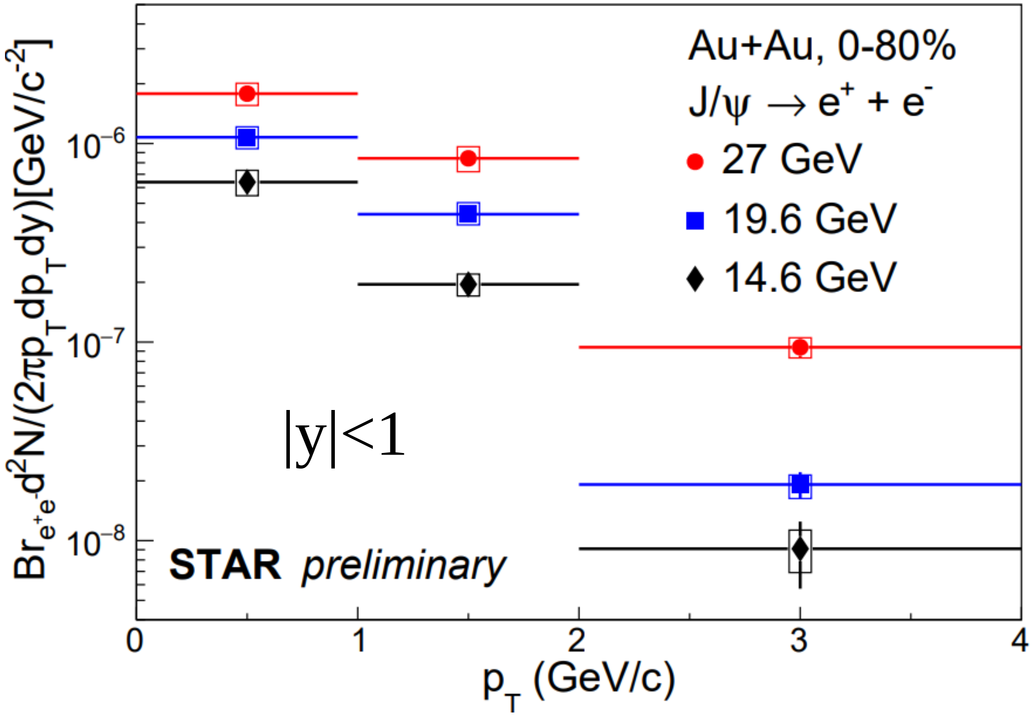


$\sqrt{s_{NN}} = 27$ GeV

- 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.

Inclusive J/ψ Invariant Yields

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

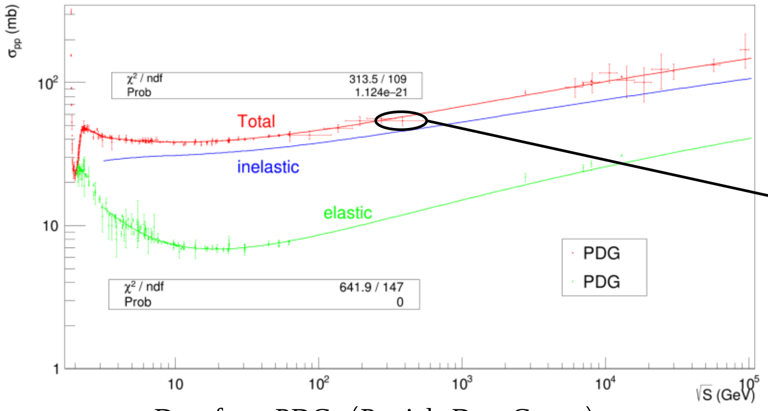


Inclusive J/ψ invariant yields as a function of p_T at mid-rapidity (|y| < 1) in Au+Au collisions at $\sqrt{s_{NN}}$ = 14.6, 19.6, 27 GeV.

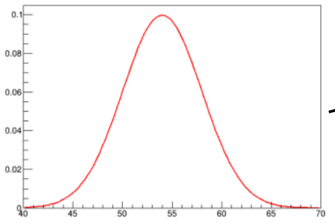
pp Inelastic Cross Section

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

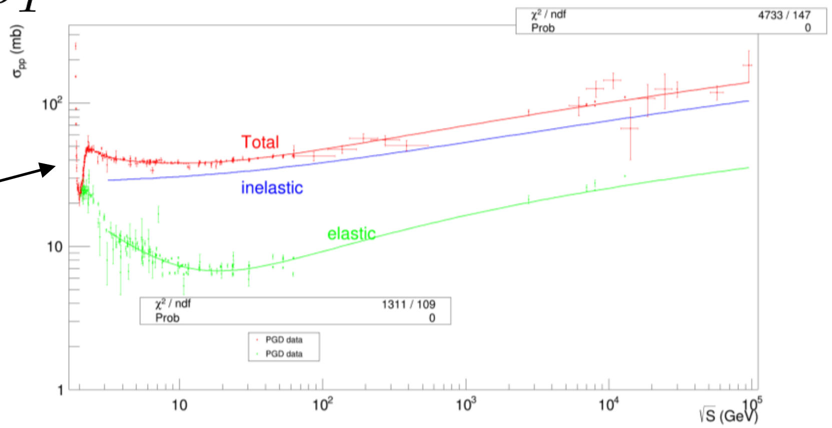
$$\sigma_{\text{inelastic}} = \sigma_{\text{total}} - \sigma_{\text{elastic}}$$

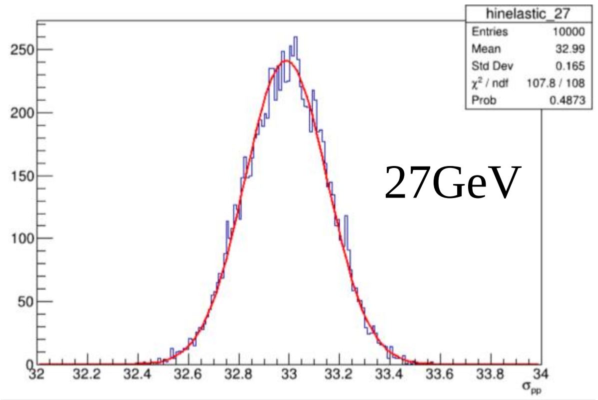


Data from PDG（Particle Data Group）:
https://pdg.lbl.gov/2022/hadronic-xsections/



Smearing each point





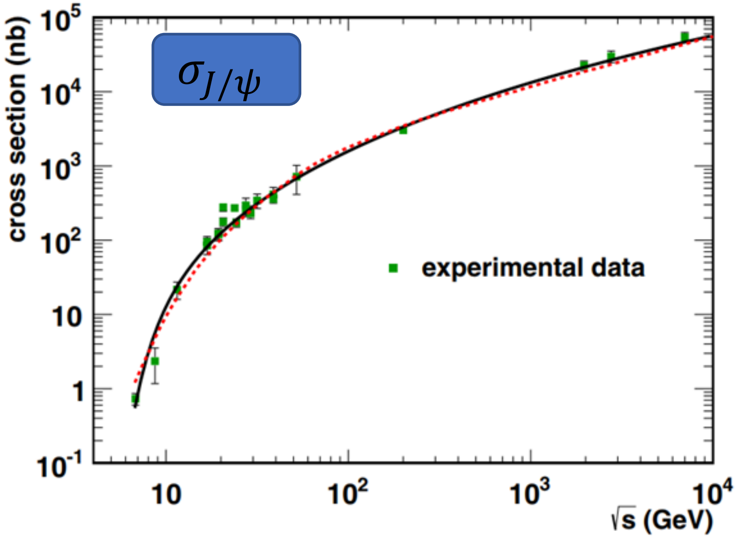
$\sqrt{S_{NN}}$ (GeV)	$\sigma_{\text{inelastic}}$ (mb)	Error(mb)
200	43.40	0.77
27	32.99	0.16
19.6	32.08	0.14
17.3	31.78	0.13
14.6	31.42	0.13
11.5	30.99	0.12
9.2	30.65	0.13

p+p Baseline

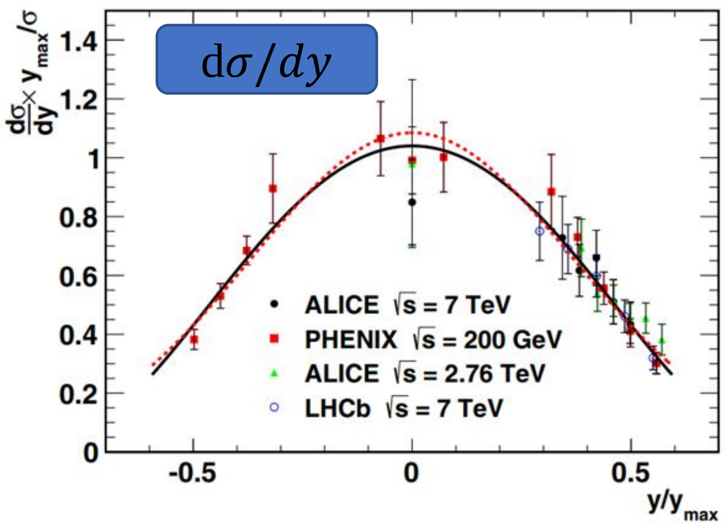
$$R_{AA} = \frac{\sigma_{\text{inel}}}{\langle N_{coll} \rangle} \frac{d^2 N_{AA}/dydp_T}{d^2\sigma_{pp}/dydp_T}$$

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

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

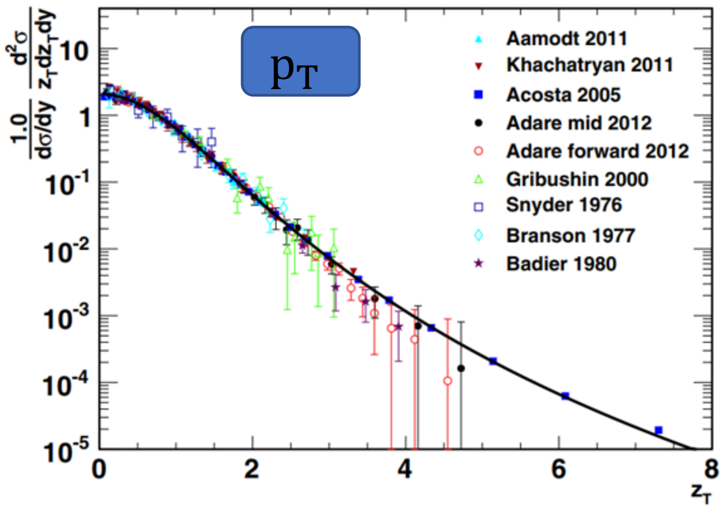


$\sigma = \alpha \times \sigma_{CEM}$
α: scale factor
σ_{CEM}: σ from color evaporation model



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

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

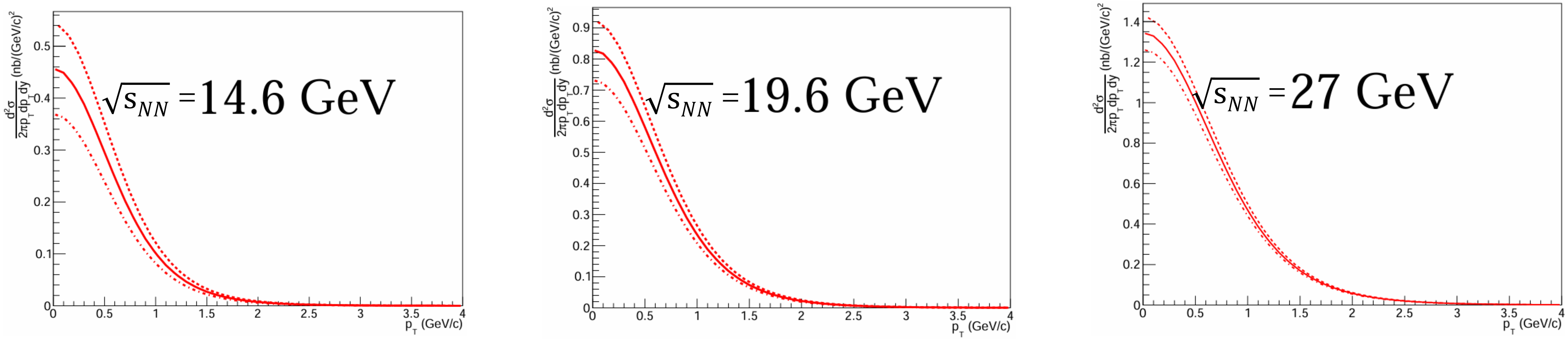


$$\frac{1}{d\sigma/dy}\frac{d^2\sigma}{z_T dz_T dy} = a \times \frac{1}{(1+b^2 z_T^2)^n}$$

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

p+p Baseline

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

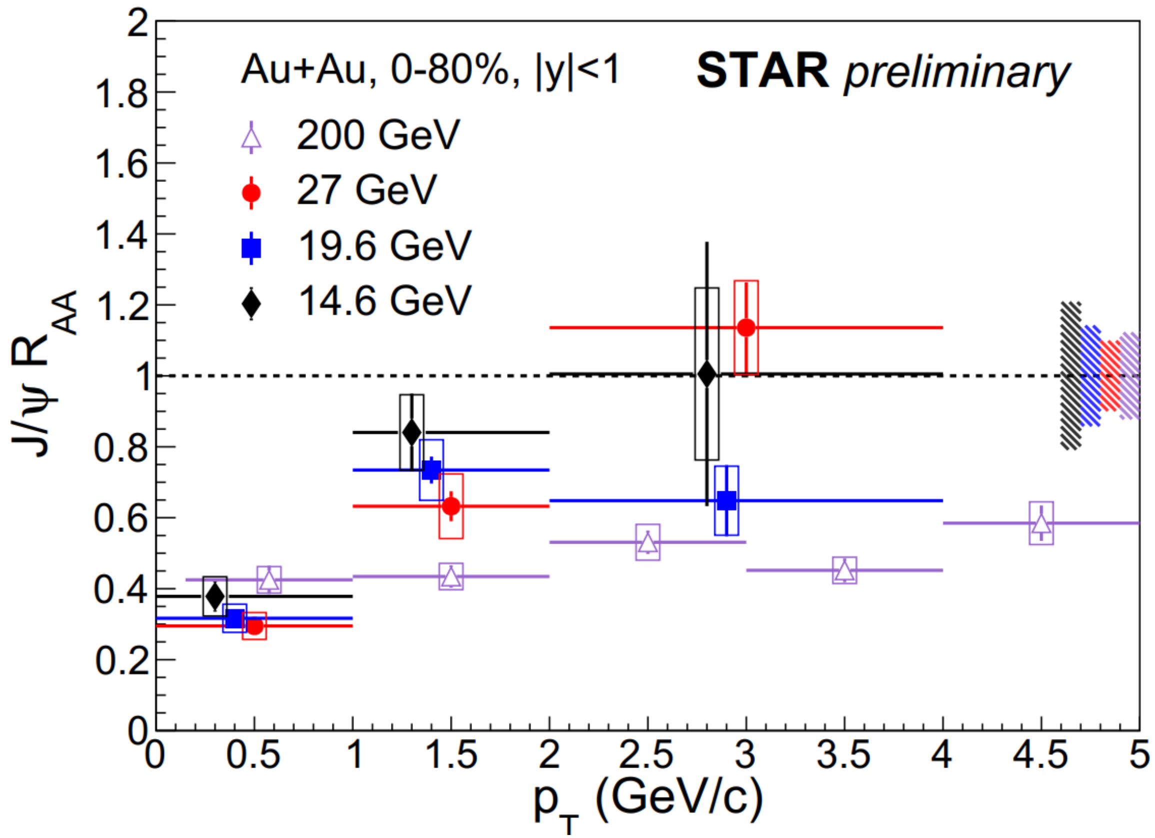


- The p_T dependence of deduced J/ψ differential cross section at midrapidity in p+p collisions at $\sqrt{s_{NN}}$ = 14.6, 19.6, 27 GeV

- The systematic uncertainty arises from fitting world-wide data:

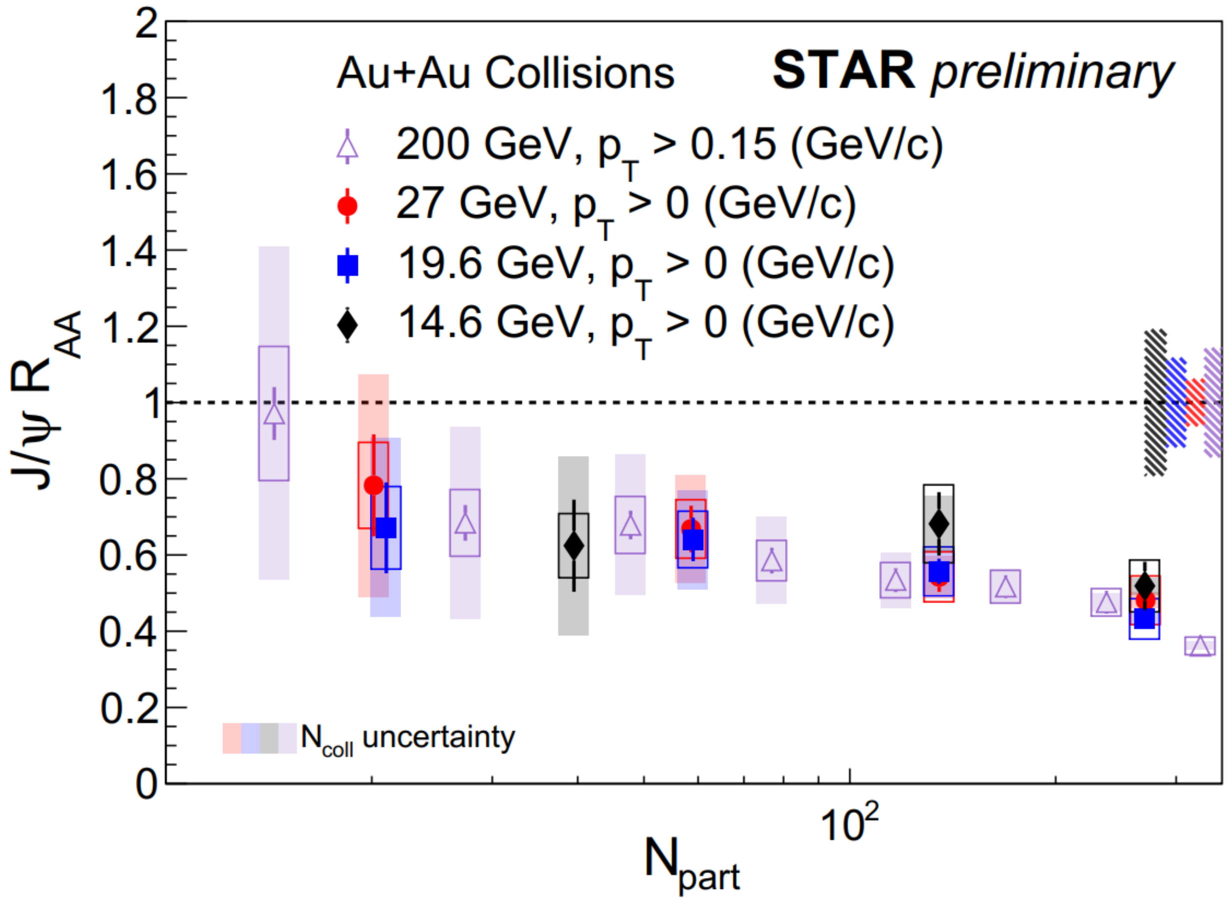
$\sqrt{s_{NN}}$ = 14.6 GeV	19.2 %
$\sqrt{s_{NN}}$ = 19.6 GeV	11.7 %
$\sqrt{s_{NN}}$ = 27 GeV	6.1 %

J/ψ R_{AA} vs. p_T



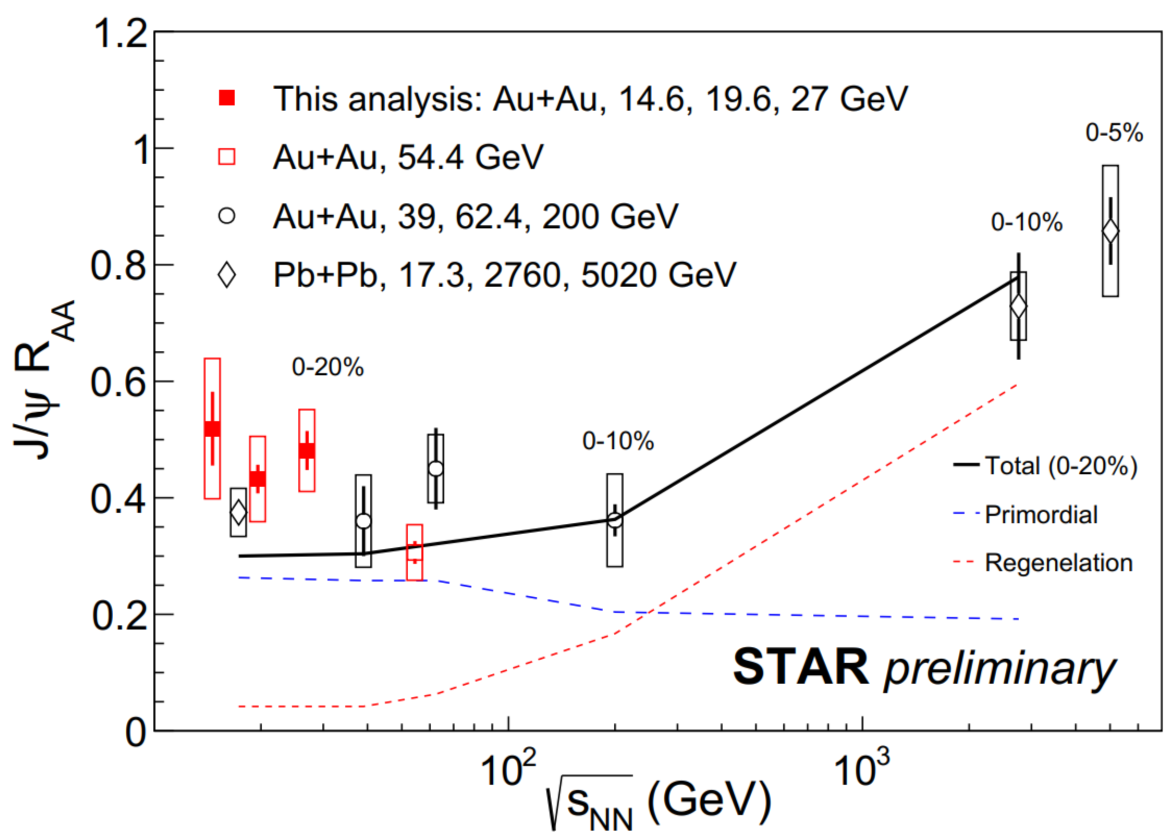
- ➢ Low p_T suppression, R_{AA} increases with p_T for $\sqrt{s_{NN}}$ = 14.6, 19.6 and 27 GeV
- ➢ No significance p_T dependence at 200 GeV

J/ψ R_{AA} vs. $<N_{part}>$



- ➢ 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 J/ψ R_{AA}



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.

- 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
- A transport model qualitatively describes the observed energy dependence

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
- No significant collision energy dependence of J/ψ R_{AA}
- J/ψ R_{AA} increases with p_T, hint of decreasing with centrality

→ Interplay of dissociation, regeneration and cold nuclear matter effects

→ Infer QGP properties

- Ongoing measurement of J/ψ R_{AA} at Au+Au 17.3 GeV.

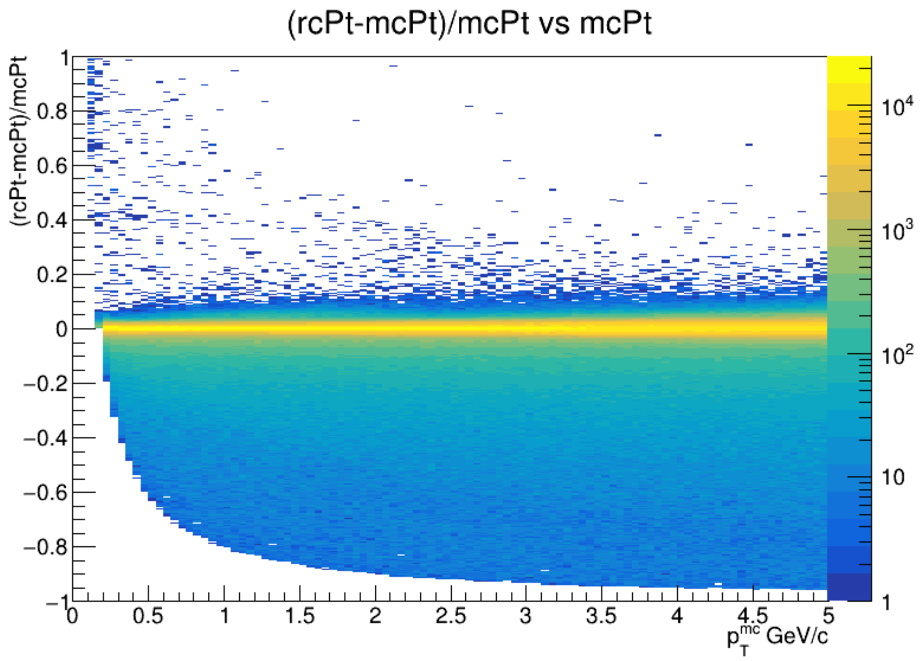
Thank you

Back up

Additional Momentum Smearing (27GeV example)

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

→ additional momentum smearing factor



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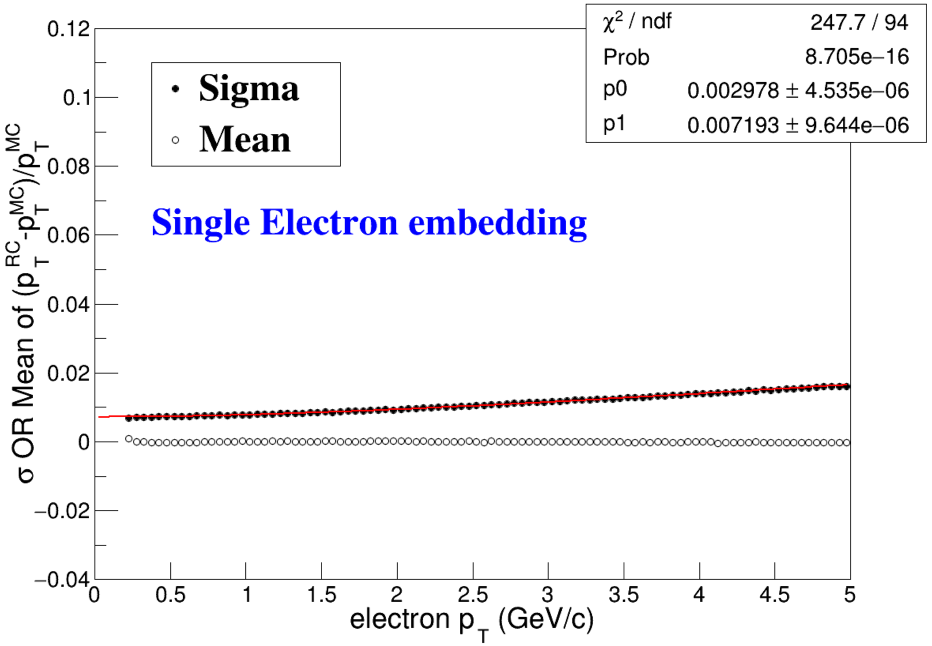
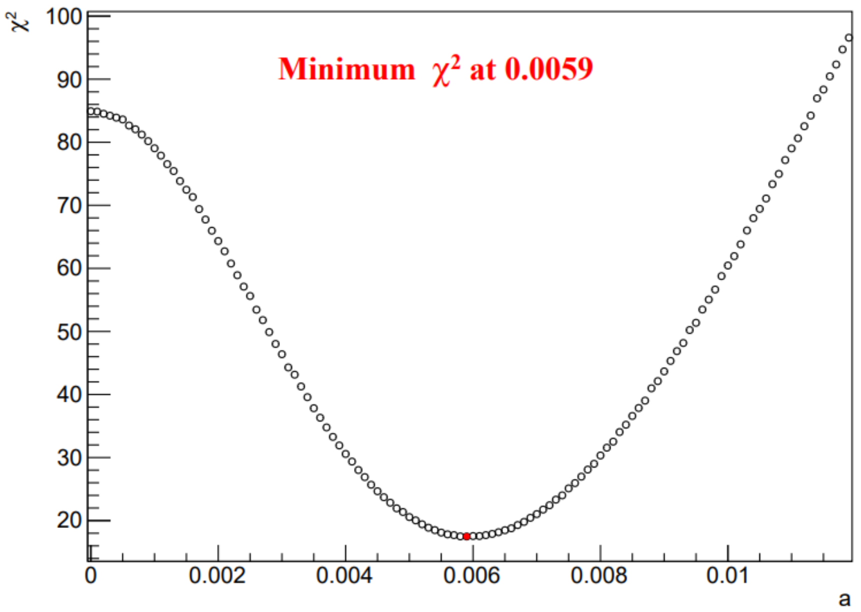
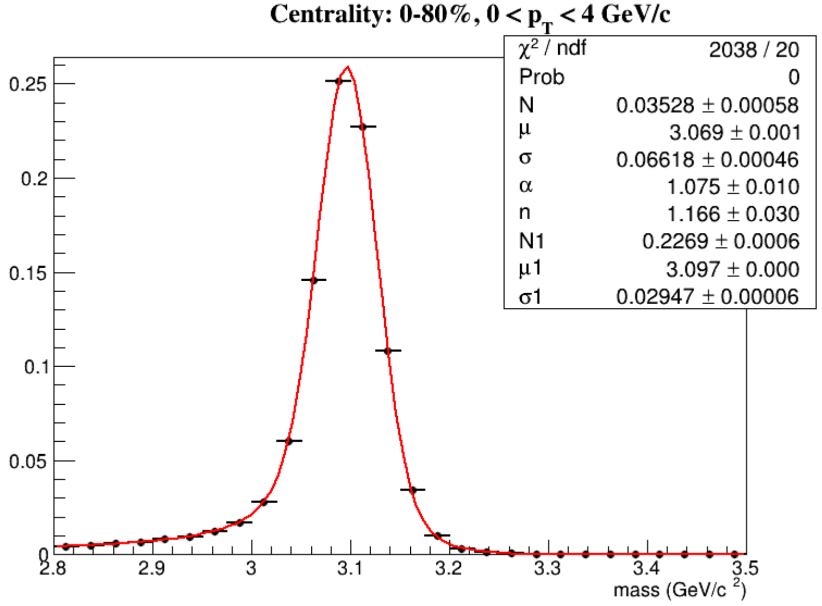


$$\sigma^{\ embed} = \sqrt{a^2 P_T^{\ 2} + b^2}$$

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

Efficiency and Acceptance Corrections

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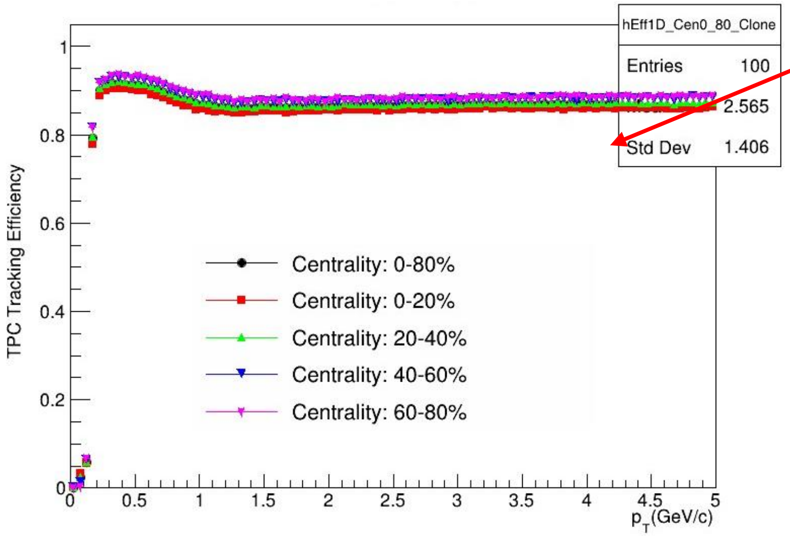
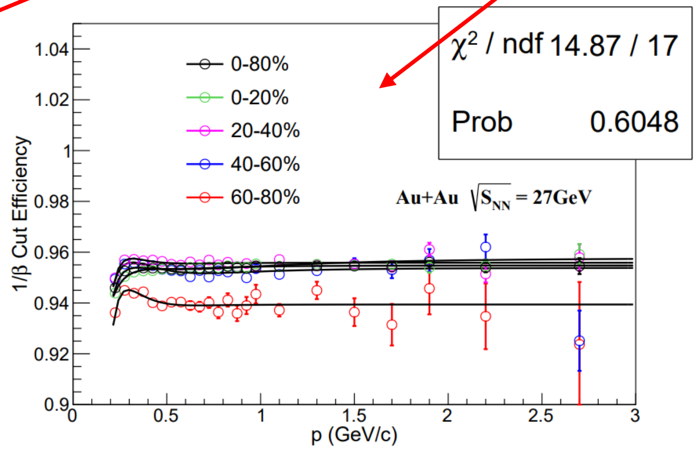
$$R_{AA} = \frac{\sigma_{\text{inel}}}{\langle N_{coll} \rangle} \frac{d^2 N_{AA}/dydp_T}{d^2\sigma_{pp}/dydp_T}$$

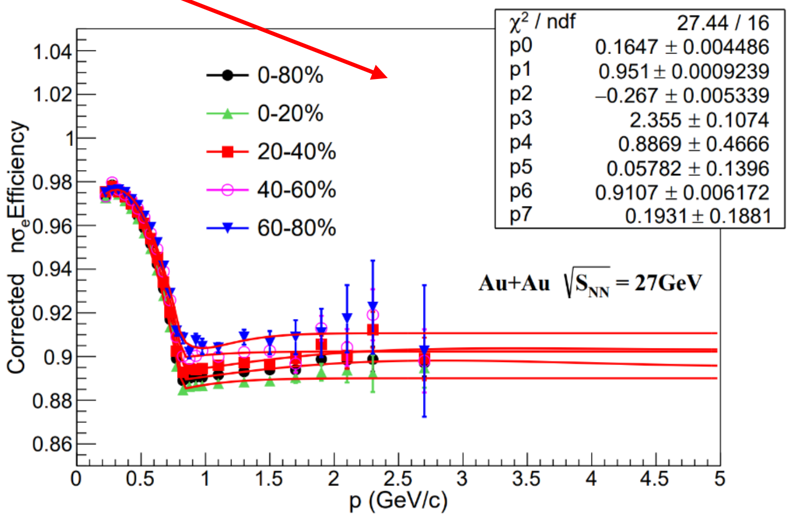
$$N_{AA} = \frac{N_{J/\psi \to e+e-}}{A \times \varepsilon \times Nevent}$$

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

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







Efficiency and Acceptance Corrections

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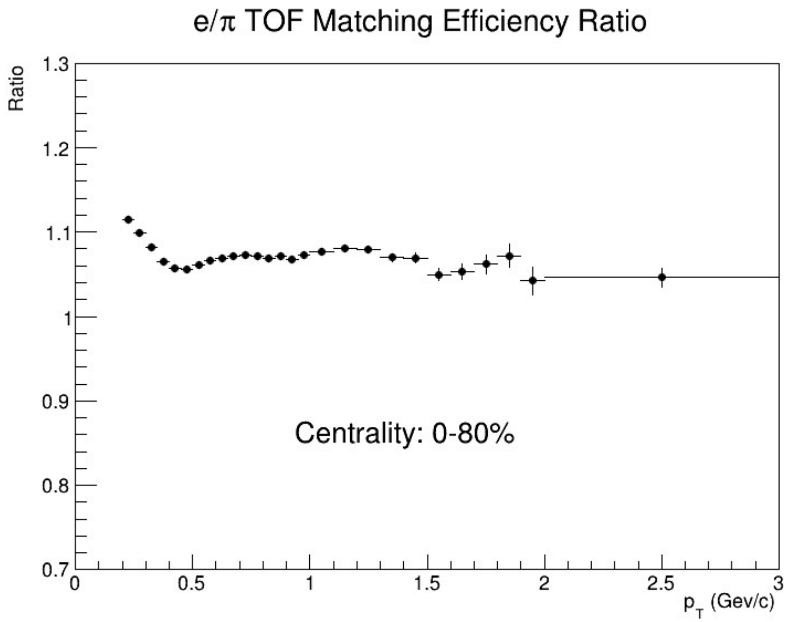
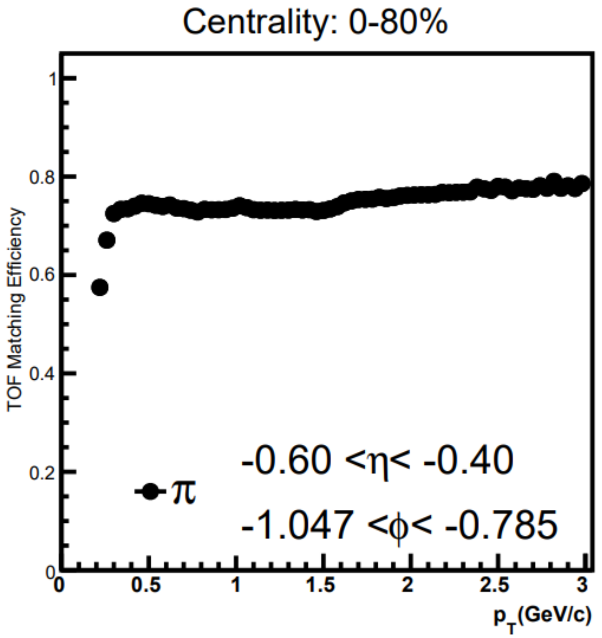
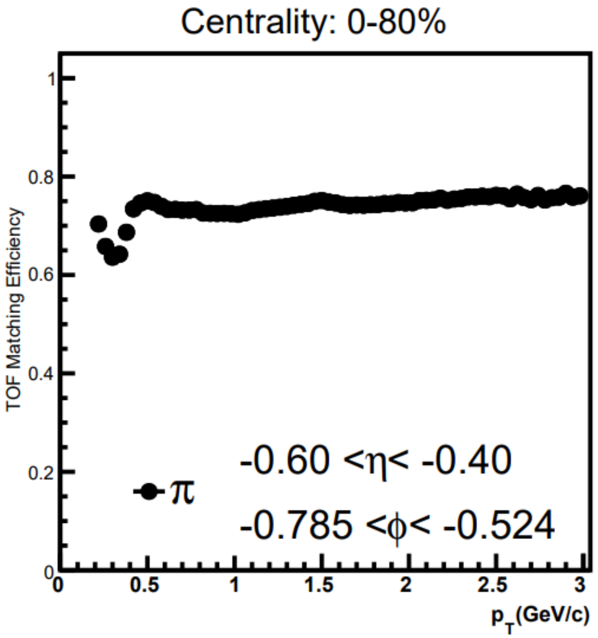
- TOF Matching efficiency has pt η Φ dependence

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







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

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

<table>
<tr><th>Analyzed bin</th><th>27 GeV</th><th>19.6 GeV</th><th>14.6 GeV</th></tr>
<tr><td>0-80%</td><td>12.4 %</td><td>11.2 %</td><td>13.2 %</td></tr>
<tr><td>0-20%</td><td>13.2 %</td><td>12.3 %</td><td>13.1 %</td></tr>
<tr><td>20-40%</td><td>12.1 %</td><td>11.5 %</td><td>15.0 %</td></tr>
<tr><td>40-60%</td><td>11.5 %</td><td>11.6 %</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>14.6 %</td></tr>
<tr><td>1-2GeV/c</td><td>14.4 %</td><td>11.6 %</td><td>12.7 %</td></tr>
<tr><td>2-4GeV/c</td><td>11.6 %</td><td>15.0 %</td><td>24.1 %</td></tr>
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